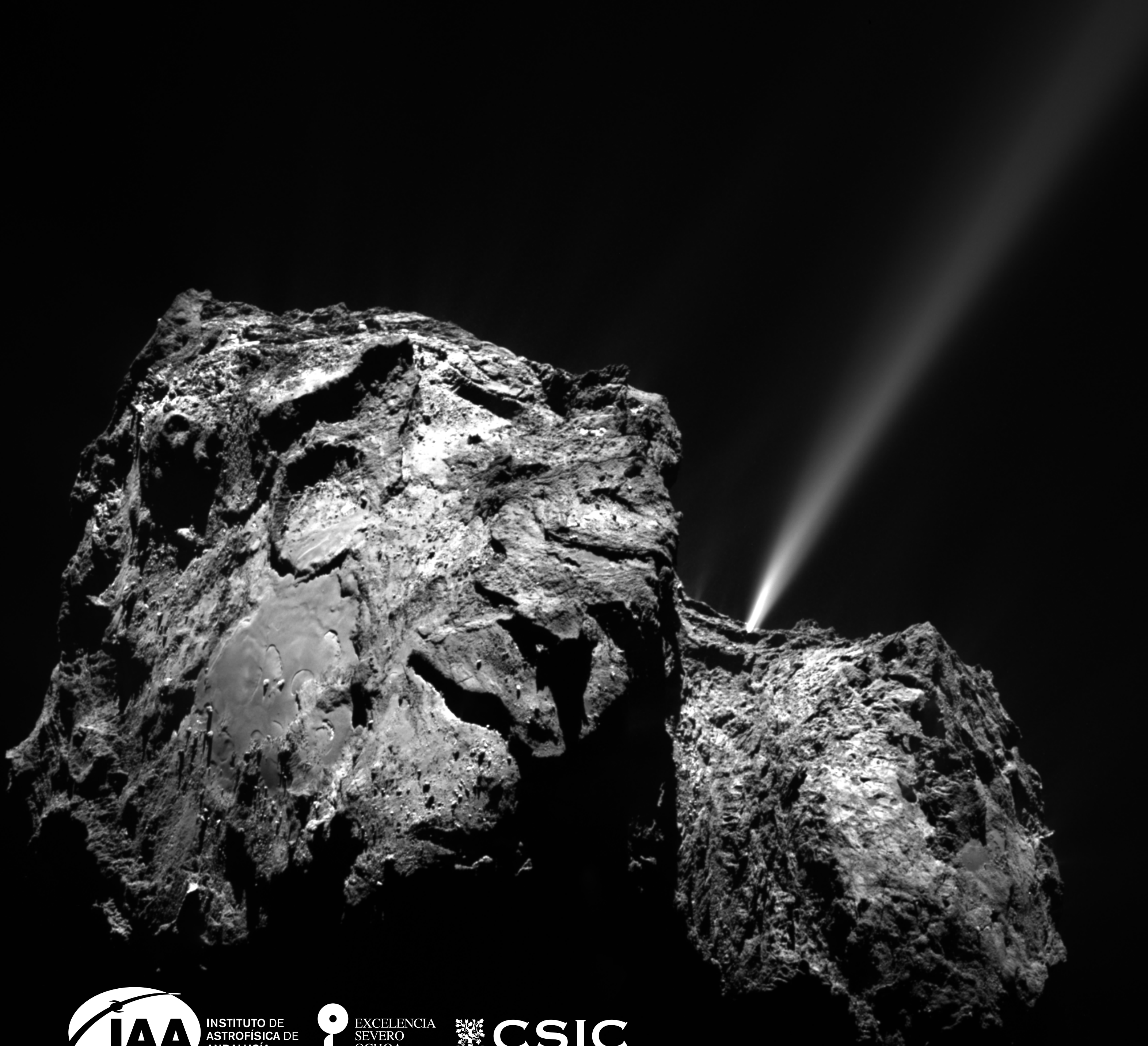
20th Electromagnetic and Light Scattering Conference

Almuñécar. 15th-19th May 2023

Program and abstracts book



IAA INSTITUTO DE ASTROFÍSICA DE ANDALUCÍA
EXCELENCIA SEVERO OCHOA
CSIC

Credits: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA

Conveners

- Olga Muñoz Instituto de Astrofísica de Andalucía, Granada, Spain
- Karri Muinonen, University of Helsinki & National Land Survey, Finland
- Gorden Videen, Army Research Laboratory, Adelphi, MD, USA

Scientific Committee

- Baptiste Auguie, Victoria University of Wellington, Wellington, New Zealand
- Mathew Berg, Kansas State University, USA
- Lei Bi, Zhejiang University, China
- Oleg Dubovik, CNRS/Universite de Lille, France
- Gérard Gouesbet, National Institute of Applied Sciences, Rouen, France
- Maria Antonia Iati, Istituto per i Processi Chimico-Fisici Consiglio Nazionale delle Ricerche, Messina, Italy
- Michael Kahnert, Swedish Meteorological Institute and Hydrological Institute, Sweden
- Ludmilla Kolokolova, University of Maryland, College Park, Maryland, USA
- Andreas Macke, Leibniz-Institut für Troposphärenforschung, Leipzig, Germany
- Onofrio M. Maragò, Istituto per i Processi Chimico-Fisici Consiglio Nazionale delle Ricerche, Messina, Italy
- Hal Maring, NASA HQ, Washington, DC, USA
- M. Pinar Mengüç, Ozyegin University, Istanbul, Turkey
- Fernando Moreno, Instituto de Astrofísica de Andalucía, Granada, Spain
- Karri Muinonen, University of Helsinki & National Land Survey, Finland
- Olga Muñoz, Instituto de Astrofísica de Andalucía, Granada, Spain
- Yurij Shkuratov, V. N. Karazin Kharkiv National University, Kharkov, Ukraine
- Ann Carine Vandaele, Royal Belgian Institute for Spac Aeronomie, Brussels, Belgium
- Gorden Videen, Army Research Laboratory, Adelphi, MD, USA
- Anne Virkki, University of Helsinki, Finland
- Thomas Wriedt, University of Bremen, Germany
- Ping Yang, Texas A&M University, USA
- Maxim Yurkin, Ozyegin University, Istanbul, Turkey
- Evgenij Zubko, Kyung Hee University, Yongin-shi, Republic of Korea

Local Organizing Committee

- Elisa Frattin, IAA-CSIC
- Juan Carlos Gómez-Martín, IAA-CSIC
- Daniel Guirado, IAA-CSIC
- François Malaval, IAA-CSIC
- Julia Martikainen, IAA-CSIC
- Fernando Moreno, IAA-CSIC
- Olga Muñoz, IAA-CSIC
- Alicia Pelegrina, IAA-CSIC

PROGRAM

Sunday, May 14

Time	Title
20:00	**Registration desk opening and Welcome Cocktail (the Solarium terrace (4th floor) of the Bahía Tropical Hotel)**

Monday, May 15

Time	Title	Speaker	
08:30-09:00	**Registration**		
009:00-09:15	**Opening ceremony**		
09:15-10:30	**Session 1: THEORETICAL STUDIES I**	**Chair: Fernando Moreno**	
09:15-09:45	(Plenary van de Hulst Award 2022 Lecture) Light scattering by nonspherical dielectric particles	Ping Yang	O01
09:45-10:00	Modelling of scattering and absorption by multiple cylinders	Lucas Paulien	O02
10:00-10:15	Optimal Truncation of Vector Spherical Harmonic Expansions In Single Homogeneous Particle IITM Scattering Calculations: Going Beyond Dependence On Size Parameter Alone.	R. Lee Panetta	O03
10:15-10:30	Robust DDA simulations for exciting sources inside a particle	Maxim Yurkin (Mustafa Pinar Mengüç)	O04
10:30-11:15	**Coffee break**		
11:15-13:00	**Session 2: THEORETICAL STUDIES II**	**Chair: Hannakaisa Lindqvist**	
11:15-11:45	(Invited) Current features and uses of the MSTM code	Daniel Mackowski	O05
11:45-12:00	A numerically stable T-matrix algorithm	Stuart Hawkins	O06
12:00-12:15	Yet Another Scattering Framework (YASF)	Mirza Arnaut	O07
12:15-12:30	Light scattering by nonspherical particles close to rough surfaces	Karri Muinonen	O08
12:30-12:45	A hybrid physical-geometric optics method for light scattering from large particles with surface roughness	Harry Ballington	O09
12:45-13:00	Quantifying the coherent backscatter enhancement in single scattering with discrete dipole approximation	Chen Zhou	O10

13:00-14:30	**Lunch**		
14:30-15:45	**Session 3: THEORETICAL STUDIES III**	**Chair: Lei Bi**	
14:30-15:00	(Invited) Light backscattering from large particles and dense particulate media: solving a multi-scale electromagnetic problem	Yevgen Grynko	O11
15:00-15:15	Coherent backscattering by large faceted particles calculated within the physical-optics approximation	Aalexander Konoshonkin	O12
15:15-15:30	Analytical Linearization and Preliminary Application of Light Scattering Properties of a Single Particle	Bingqiang Sun	O13
15:30-15:45	Improvements and applications of the finite series method in the generalized Lorenz-Mie theory	Luiz Felipe Votto	O14
15:45-16:30	**Coffee break**		
16:30-17:00	(Michael Mischenko Medal 2021 Award lecture) On light scattering and collaboration, History of Light Scattering in Bremen	Thomas Wriedt	O15
17:00	**Wine and Cheese Poster Session**		

Tuesday, May 16

Time	Title	Speaker	
09:00-10:30	**Session 4: ATMOSPHERIC PARTICLES I**	**Chair: Michael Kahnert**	
09:00-09:30	(Invited) Assessing the effect of atmospheric aerosols on satellite observations of carbon dioxide	Hannakaisa Lindqvist	O16
09:30-09:45	Retrieving Spectral Aerosol Absorption and Speciation from DSCOVR EPIC	Alexei Lyapustin	O17
09:45-10:00	EPIC onboard DSCOVR for cloud and aerosol measurements	Alexander Marshak	O18
10:00-10:15	Classification of Aggregates Using Multispectral Two-Dimensional Angular Light Scattering Simulations	Stephen Holler	O19
10:15-10:30	Constraining the vertical profile and angular scattering effect of aerosols in the Los Angeles megacity using hyperspectral measurements of Oxygen absorption	Zhao-Cheng Zeng	O20
10:30-11:15	**Coffee break**		
11:15-13:00	**Session 5: ATMOSPHERIC PARTICLES II**	**Chair: Patrick Stegman**	
11:15-11:45	(Invited) Citizen scientists monitoring air quality	Hester Volten	O21
11:45-12:00	Reference model for optical properties of marine aerosols	Michael Kahnert	O22
12:00-12:15	Light scattering by nonspherical and inhomogeneous aerosols: T-matrix and Machine learning	Lei Bi	O23
12:15-12:30	Revisiting particle size distributions of nonspherical particles	Masanori Saito	O24
12:30-12:45	Exploring the boundary between spherical and nonspherical atmospheric aerosol particles using angularly-resolved light scattering	Kevin Aptowicz	O25
12:45-13:00	Impacts of Aerosol Radiation Effect (ARE) on the PBL via Altering Entrainment Process in the Upper PBL	Zhanqing Li	O26
13:00-14:30	**Lunch**		
14:30-15:45	**Session 6: LIGHT SCATTERING EXPERIMENTS I**	**Chair: Emma Järvinen**	
14:30-15:00	(Invited) Light-scattering measurements and models for lidar applications	Romain Ceolato	O27
15:00-15:15	The spectral depolarization ratio of mineral dust at 180° backscatter – from lidar field observations to the laboratory	Moritz Haarig	O28

15:15-15:30	Color Digital Holography of Aerosol Particles	Matthew Berg	O29
15:30-15:45	Spectro-polarimetric two-dimensional backscattering measurements by irregularly shaped particles	Killian Aleau	O30
15:45-16:30	**Coffee break**		
16:30-17:30	**Session 7: RADIATIVE TRANSFER**	**Chair: Hester Volten**	
16:30-16:45	Advances in the JCSDA Community Radiative Transfer Model prior to its 20 Year Anniversary	Patrick Stegmann	O31
16:45-17:00	Practical solution of radiative transfer in the plane-parallel atmospheric-surface system	Masahiro Momoi	O32
17:00-17:15	A Markov chain approach for modeling polarized radiative transfer from ultraviolet to far-infrared	Feng Xu	O33
17:15-17:30	The 2Stream-Exact Single Scattering (2S-ESS) Radiative Transfer Model	Vijay Natraj	O34

Wednesday, May 17

Time	Title	Speaker	
09:00-10:30	**Session 8: LASER BEAMS/OPTICAL FORCES**	**Chair: Maria Gritsevich**	
09:00-09:30	(Invited) Manipulation and characterization of cosmic dust and sea microplastics by Optical and Raman tweezers	Alessandro Magazzù (Maria G. Donato)	O35
09:30-09:45	Faster and More Accurate Geometrical-Optics Optical Force Calculation Using Neural Networks	David Bronte Ciriza	O36
09:45-10:00	Ideal two-dimensional discrete superpositions of Bessel beams in stratified media	Jhonas Olivati de Sarro (Leonardo André Ambrosio)	O37
10:00-10:15	Multichromatic nondiffracting surface beams at the millimeter scale	Leonardo André Ambrosio	O38
10:15-10:30	Forces exerted on particles by laser radiation	Gérard Gouesbet	O39
10:30-11:30	**Coffee break**		
11:30-13:00	**Session 9: LIGHT SCATTERING EXPERIMENTS II**	**Chair: Mathew Berg**	
11:30-11:45	Propagation of Laguerre-Gaussian beam with orbital angular momentum in turbid tissue-like medium	Ivan Lopushenko	O40
11:45-12:00	Full-dynamic mixing formulas for the effective refractive index of dense colloids and dependent scattering effects	Augusto Garcia-Valenzuela	O41
12:00-12:15	Imaging and Analysis of Light Scattered by Single Particles and Cells in a Flow Cytometer	Jonas Gienger	O42
12:15-12:30	Optical trapping and manipulation in front of epsilon-near-zero metamaterials	Maria G. Donato	O43
12:30-12:45	Advancing Our Understanding of Solar Radiation in Clouds: PHIPS Probe Reveals New Insights on Light Scattering Behavior of Atmospheric Ice Particles	Martin Schnaiter	O44
12:45-13:00	Radiative Cooling by Sand	Mustafa Pinar Mengüç	O45
13:00-14:30	**Lunch**		
14:30-15:45	**Session 10: ICE CRYSTALS AND CLOUDS**	**Chair: Masanori Saito**	
14:30-14:45	An observational based parameterization of the light scattering properties of natural ice crystals in the visible region	Guanglang Xu	O46
14:45-15:00	Generalized rainbow patterns of ellipsoidal droplets simulated by the vectorial complex ray model	Qingwei Duan	O47

15:00-15:15	Physical Retrieval Algorithm of Cloud Microphysical Parameters and Preliminary Application	Chenxu Gao	O48
15:15-15:30	A New Optical Property Database for Improved Ice Cloud Retrievals in Lidar-based Remote Sensing Applications	James Coy	O49
15:30-15:45	Observational Perspective on Ice Cloud Asymmetry Parameter in Short-wave	Emma Järvinen	O50
20:00	**Conference dinner @La Última Ola**		

Thursday, May 18

Time	Title	Speaker	
09:30-10:00	(Plenary van de Hulst Award 2020 Lecture) Wow stories in the GLMT landscape	Gérard Gouesbet	O51
10:00-10:30	**Session 11:LIGHT SCATTERING IN THE SOLAR SYSTEM: OBSERVATIONS, MODELING AND EXPERIMENTS I**	**Chair: Anne Virkki**	
10:00-10:15	Measurements of microwave analogs for EM and light scattering studies	Jean-Michel Geffrin	O52
10:15-10:30	Design of an active light scattering system for interstellar dust characteristics in future Comet exploration mission	Jiajie Wang	O53
10:30-11:15	**Coffee break**		
11:15-12:30	**Session 12: LIGHT SCATTERING IN THE SOLAR SYSTEM: OBSERVATIONS, MODELING AND EXPERIMENTS II**	**Chair: Yevgen Grynko**	
11:15-11:45	(Invited) Modeling the asteroid polarization of the DART mission impact ejecta	Antti Penttilä	O54
11:45-12:00	The scattering properties of centaur 174P/Echeclus	Oleksandra Ivanova	O55
12:00--12:15	Analysis of Cryovolcano Plumes on Enceladus by Light Scattering and Polarimetry	Claudia Morello	O56
12:15-12:30	Ice crystal halos and comets	Jarmo Moilanen	O57
12:30-14:00	**Lunch break**		
14.00-19:00	**Guided visit to "Cuevas de Nerja" and Frigiliana**		

Friday, May 19

Time	Title	Speaker	
09:30-10:30	**Session 13: LIGHT SCATTERING IN THE SOLAR SYSTEM: OBSERVATIONS, MODELING AND EXPERIMENTS III**	**Chair: Oleksandra Ivanova**	
09:30-10:00	(Invited) Observational Strategy for Danuri/PolCam Measurements of the Lunar Surface from Orbit	Sungsoo S. Kim	O58
10:00-10:15	Fast Variations of Color in Comet C/2016 M1 (PanSTARRS)	Anhelina Voitko	O59
10:15-10:30	Dust properties and their variations in comet C/2013 X1 (PanSTARRS))	Olena Shubina	O60
10:30-11:15	**Coffee break**		
11:15-13:00	**Session 14: LIGHT SCATTERING IN THE SOLAR SYSTEM: OBSERVATIONS, MODELING AND EXPERIMENTS IV**	**Chair: Antti Penttilä**	
11:15-11:45	(Invited) The role of dust in the Martian atmosphere	Ann C. Vandaele	O61
11:45-12:00	Retrieving optical properties of dust particles from laboratory data: refractive indices and scattering matrix elements	Julia Martikainen	O62
12:00-12:15	Deriving the complex refractive index of a mm-sized acoustically levitated single particle using laboratory measurements	Mikko Vuori	O63
12:15-12:30	The 2007 dust trail of the comet 17P/Holmes — open call for light scattering modelling and observations	Maria Gritsevich	O64
12:30-13:00	(Invited) Planetary surface characterization by modeling radar scattering	Anne Virkki	O65
13:00-14:30	**Lunch**		
14:30-16:00	**Session 15: LIGHT SCATTERING IN CIRCUMSTELLAR DISKS: OBSERVATIONS, MODELING AND EXPERIMENTS**	**Chair: Jean-Michel Geffrin**	
14:30-15:00	(Invited) Light scattering by circumstellar dust disks	Francois Menard	O66
15:00-15:15	Scattering properties of microwave analogs of protoplanetary dust aggregates	Amelie Litman	O67
15:15-15:30	Experimental phase function and degree of linear polarization of light scattered by amorphous carbon circumstellar dust analogues	Juan Carlos Gómez Martín	O68

15:30-15:45	Phase function and degree of linear polarization measurements for KCl particles as an exoplanet cloud analog	Colin Hamill	O69
15:45-16:00	Self-scattering by non-spherical particles in protoplanetary disks	Daniel Guirado	O70
16:00	**Closing ceremony**		
16:30	**Farewel party**		

POSTERS

Title	Author	
Coherent extinction enhancement in a thin layer of dielectric nanospheres with an effective medium behaviour	Anays Acevedo-Barrera et al.	P01
Hyperspectral Reflectance of Pre- and Post-Fire Soils: Toward Remote Sensing of Fire-Induced Soil Hydrophobicity	Yasaman Raeofy et al.	P02
Single-scattering properties of ellipsoidal dust aerosols constrained by measured dust shape distributions	Masanori Saito et al.	P03
Retrieval of aerosol and surface properties with synthetic signals from a multi-angle, multi-spectral polarimeter	Anna Gialitaki et al.	P04
Scattering matrices decomposed into pure Mueller matrices with radiative-transfer coherent-backscattering applications	Karri Muinonen et al.	P05
First-order correlation function of the light from quantum scatterers	Pablo Gabriel Santos Dias et al.	P06
Computer algebra solution to Mie scattering problem for the stratified sphere with nonlocal plasmonic layers	Ivan Lopushenko et al.	P07
Advancements on the Hyper-Angular Rainbow Polarimeter (HARP) polarization characterization during NASA Plankton Aerosol and Ocean Ecosystem (PACE) pre-launch calibration	Noah Sienkiewicz et al.	P08
Retrieving Liquid Cloud Droplet Size Distribution from the Geometric Parameters of Polarized Cloudbow: A demonstration with HARP CubeSat Observations	Rachel Smith et al.	P09
Towards a joint retrieval of aerosols and CO2 from space-based hyperspectral imager data	Antti Mikkonen et al.	P10
Origin of vertically elliptical halos – the missing link	Jarmo Moilanen et al.	P11
EMSCOP : a new scattering database	François Malaval et al.	P12
Revisiting basic sphere algorithms for Lorent-Mie scattering under non-absorbing and absorbing media	Victoria Eugenia Cachorro et al.	P13
Optical calibration of acoustic tweezers	Sonia Marrara et al.	P14
Polarization of Jupiter's Large Moons: New Results	Nikolai Kiselev et al.	P15
Parameters of differential equations in two-flux models approximated for multilayers samples showing scattering and absorption	David Barrios et al.	P16
Microwave imaging from truncated measurements: polarization effects	Christelle Eyraud et al.	P17

ORAL COMMUNICATIONS

-O01-

Light scattering by nonspherical dielectric particles

Ping Yang, Texas A&M University
pyang@tamu.edu

Knowledge of light scattering by particles is inevitably necessary for numerous disciplines, including astrophysics, planetary sciences, bio-optics, radiative transfer, remote sensing, and climate science. In the case of spherical particles, the rigorous Lorenz-Mie theory has been well established. With robust computational programs based on the Lorenz-Mie theory, it is now regarded as a trivial effort to compute the optical properties of a sphere with essentially any practical particle size ranging from the Rayleigh regime (the particle size is much smaller than the wavelength of the incident light) to the geometric optics regime (the particle size is much larger than the wavelength of the incident light).

Despite the success in dealing with the scattering of light by a sphere, computing the optical properties of a nonspherical particle poses significant challenges, particularly from the perspective of numerical computation. Exact methods include the method of separation of variables, which in practice is applied only to regular geometries, such as spheroidal particles, the T-matrix method implemented via the extended boundary condition approach, and the invariant imbedding T-matrix method. Numerically feasible and robust methods such as the finite-difference time domain method and the discrete dipole approximation are usually applied to small-size to moderate-size particles in comparison with the wavelength of the incident electromagnetic wave. Many nonspherical particles in nature, such as ice crystals and coarse-mode dust particles in the atmosphere and phytoplankton in the ocean, are much larger than the visible wavelengths. To compute the optical properties of these particles at the wavelengths mentioned above, the only viable option is to employ the principles of geometric optics as an approximate method with increasing accuracy as the particle size increases; in other words, the geometric optics method represents a case where there is “no alternative” for computing the optical properties of nonspherical particles that are much larger than the wavelength of the incident electromagnetic wave.

This presentation will review the development of the physical-geometric optics method and the applications of a combination of the invariant imbedding T-matrix method and the physical-geometric optics method to various problems involved in radiative transfer simulations and remote sensing implementations.

-O02-

Modelling of scattering and absorption by multiple cylinders

Lucas Paulien, Kansas State University
Sergio Carjaval, Instituto Nacional de Metrología de Colombia
Kamran Daryabeigi, NASA Langley research center, Hampton, Virginia
Steve Miller, Heetshield
Matthew Berg, Kansas State University
paulien.lucas@gmail.com

We present an analytical model allowing the computation of the scattered field by a medium composed of polydisperse cylinders, based on the methods presented by Lee [1]. The cylinders are parallel, infinite and can present different refractive indices. We also present an application to a medium composed of aluminum oxide fibers. In this application, we consider a volume fraction and a size distribution retrieved after the analysis of data from X-Ray Computer Tomography scan [2], that have been acquired on a fiber insulation sample. Finally, we discuss the implementation of thermal emission in the model.

[1] Lee, S. C. (1990). Dependent scattering of an obliquely incident plane wave by a collection of parallel cylinders. Journal of Applied Physics, 68(10), 4952-4957.
[2] Ketcham, R.A. and Carlson, W.D., 2001. Acquisition, optimization and interpretation of X-ray computed tomographic imagery: Applications to the geosciences. Computers and Geosciences, 27, 381-400.

-O03-

Optimal Truncation of Vector Spherical Harmonic Expansions In Single Homogeneous Particle IITM Scattering Calculations: Going Beyond Dependence On Size Parameter Alone.

R. Lee Panetta, Texas A&M University
Yuheng Zhang, Texas A&M University
Jiachen Ding, Texas A&M University
Ping Yang, Texas A&M University
panetta@tamu.edu

The Invariant Imbedding T-Matrix (IITM) has been successfully used in numerical simulation of single scattering optical properties for a range of applications in the remote sensing of atmospheric aerosols. As in all numerical T-Matrix methods, IITM implementation requires a choice of truncation number NT in the vector spherical harmonic expansion of the T-Matrix. In this talk we discuss the problem of "optimally" choosing NT, one that achieves acceptable accuracy in calculating chosen scattering properties while minimizing computational cost: in general accuracy and cost each increase with NT.

The rate at which a calculation approaches a desired level of accuracy as NT increases, the "rate of convergence," depends on the scattering property or properties whose accuracy is desired. On physical grounds, we expect that this rate for a homogeneous particle should depend on the size parameter x, index of refraction m, and shape of the particle. The seminal work of Wiscombe (1980) on homogeneous spherical particles measured accuracy by considering the magnitude of terms in the Lorenz-Mie series, and presented an empirical formula relating the optimal truncation number to the size parameter alone: the index of refraction was found to be of only minor importance. In the case of a spherical particle, the T-Matrix expansion can be seen as a generalization of the Lorenz-Mie series, and empirical formulas relating a chosen NT to size parameter alone has formed the basis for many T-Matrix studies since then involving non-spherical particles, each study making some modest variation to the Wiscombe (1980) formula.

Using a new criterion for convergence that is formulated in terms of the scattering phase function instead of cross-sections, we demonstrate the clear sensitivity of optimal NT to m as well as x for several non-spherical particle shapes commonly used in atmospheric aerosol scattering studies. For the case of a hexagonal crystal, we discuss the success of a simple Wiscombe-like relation between optimal NT, x and m in capturing the behavior of optimal NT over an atmospherically relevant range of x and m. We also report some results on the variation of optimal NT with aspect ratio and shape of particle.

-O04-

Robust DDA simulations for exciting sources inside a particle

Maxim A. Yurkin, Özyeğin University, Istanbul, Turkey
Danil V. Shershnev, Novosibirsk State University, Novosibirsk, Russia
yurkin@gmail.com

The discrete dipole approximation (DDA) is a general method to simulate interaction of electromagnetic waves with particles of arbitrary shape and internal structure. Historically, the DDA is applied to scattering of plane waves or shaped beams, but can also be used with point dipole sources. Placing such source near a nanoparticle allows one to simulate emission (or decay rate) enhancement, relevant to fluorescent enhancement and surface-enhanced Raman scattering (SERS) of molecules.

Internal sources are a natural next step, relevant for encapsulated emitters and fluctuational phenomena, such as near-field radiative heat transfer and Casimir forces. However, such extension is confusing in several aspects. Theoretically, it incurs application of strongly singular integral operator to a non-square-integrable incident field, making it unclear whether the source is placed inside a particle or inside a cavity. Practically, the standard DDA based on interaction of point dipoles is known to be highly sensitive to the position of the source with respect to the voxel lattice. While certain empirical corrections are known to produce reasonable results, they are in stark contrast to the numerically-exact aura of the DDA established for other excitation scenarios.

To fill this comprehension gap, we have extended the rigorous derivation of the DDA from the volume-integral equation to the singular incident fields and derived the relation between several terms in the DDA numerical scheme. While this relation is not generally satisfied for point-dipole formulation of the DDA (explaining the abovementioned confusion), it is surprisingly valid for both modern DDA formulations, namely filtered coupled dipoles (FCD) and integration of Green's tensor (IGT). For the FCD, one only need to modify the incident field at the closest voxel, which we implemented in the open-source ADDA code. The IGT formulation works out of the box, benefiting from the semi-analytical evaluation of the integrals that has been recently implemented in ADDA. We used ADDA to simulate the emission enhancement of a point source moved inside a sphere. Both FCD and IGT results are almost constant at the voxel scale and agree with the prediction of the Lorenz-Mie theory, while the point-dipole formulation suffers from superfluous oscillations.

-O05-

Current features and uses of the MSTM code

Daniel Mackowski, Auburn University
mackodw@auburn.edu

The talk will discuss the current features and uses of the multiple sphere T matrix (MSTM) code. Extensions of the superposition formulation to the code now enable 1) the presence of multiple x-y plane boundaries separating layers of different complex refractive index, with the spheres allowed in any of the layers, and 2) the spheres forming infinitely periodic structures in the x-y plane. These two features can be combined to allow modeling of, for example, scattering and absorption by periodic lattices of spheres resting on or embedded within a substrate. In addition, a fast algorithm for computing the exciting field at each sphere, based upon an FFT-enabled discrete Fourier convolution, has been added to the code package. This algorithm significantly accelerates the computation of scattering by large-scale, densely packed clusters of spheres. The talk will conclude by discussing the use of the code in the development and testing of dense--media radiative transport models. Specifically, a direct-simulation procedure to compute the effective radiative transport properties (extinction coefficient, albedo, and scattering matrix) of polydisperse, multicomponent spherical particle media, for a set particle volume fraction, is described. It is shown that vector radiative transport calculations of polarized scattering from spherical volumes, using the MSTM-calculated effective transport properties, can closely match the scattering properties calculated by configuration-averaged large-scale MSTM calculations for particle volume fractions up to 25 percent.

-O06-

A numerically stable T-matrix algorithm

Stuart Hawkins, Macquarie University
stuart.hawkins@mq.edu.au

The T-matrix is an important tool for scattering simulations and is widely used in many applications. In its original form, the T-matrix was computed using the null field method or extended boundary condition method (EBCM). It is well known that the EBCM is numerically unstable for particles that deviate significantly from a sphere. However, the EBCM is not intrinsic to the T-matrix and in this talk we describe a completely different approach that is numerically stable for all scatterers. The key to our method is calculating the T-matrix in the far field instead of on the scatterer surface. We present new numerical results demonstrating the enhanced numerical stability of our method for light scattering by geometries with large aspect ratios and large size parameters.

-O07-

Yet Another Scattering Framework (YASF)

Mirza Arnaut, Image Analysis Group, TU Dortmund University, 44227 Dortmund, Germany
mirza.arnaut@tu-dortmund.de

Numerical simulations help to derive the optical properties of complex particle systems. The larger the systems, the longer the computation time. We present a computationally optimized Python framework that simulates light scattering of clusters of spherical particles. The framework re-implements the Matlab CELES project (https://github.com/disordered-photonics/celes) and provides similar output quantities to MSTM (https://github.com/dmckwski/MSTM). Our model also computes the Stokes parameters necessary for polarization studies of (dense) particle clusters for studying comets, space weathering, and lunar/planetary regolith. Our framework utilizes the Numba library for high parallelization on CPUs and GPUs. The Dask library allows upscaling across multiple machines and HPC clusters. This strategy allows for handling large particle clusters in a reasonable amount of time. After further unit testing, we will deploy YASF on GitHub with user-friendly documentation to foster community interaction.

-O08-

Light scattering by nonspherical particles close to rough surfaces

Karri Muinonen, Department of Physics, University of Helsinki, Finland
Antti Penttilä, Department of Physics, University of Helsinki, Finland
karri.muinonen@helsinki.fi

Scattering by nonspherical particles close to rough surfaces is studied by placing a particle above a finite, thin surface-roughness element on an infinite, planar vacuum-material boundary. A solution for the problem is computed with the help of the surface version of the discrete-dipole approximation code ADDA (Yurkin et al., J. Phys. Chem. C 119: 29088, 2015). The Gaussian-random-sphere geometry (GRS) is incorporated for the description of particle shapes, whereas the surface-roughness element is described using fractional-Brownian motion statistics (fBm; Riskilä et al., JQSRT 267, 107561, 2021). The GRS geometry is described by the autocovariance function of the logarithmic radial distance, parameterized by the standard deviation of the radial distance and spectral index of the Legendre coefficients of the autocovariance function. As to the fBm elements, the horizontal roughness scale is described by the Hurst exponent and the vertical roughness scale with a root-mean-square roughness parameter. First results are shown for four cases: a spherical particle close to a smooth element, a spherical particle close an fBm element, a Gaussian particle close to a smooth element, and a Gaussian particle close to an fBm element. The present study is a natural extension of exact electromagnetic treatments of coherent backscattering in systems of small particles close to interfaces (Muinonen et al., JOSA A 8, 477, 1991; Lindell et al., JOSA A 8, 472, 1991).

-O09-

A hybrid physical-geometric optics method for light scattering from large particles with surface roughness

Harry Ballington, University of Hertfordshire
Evelyn Hesse, University of Hertfordshire
h.ballington@herts.ac.uk

Many techniques exist for the quantitative modelling of the interaction of light with atmospheric particles. Of these, T-matrix and the discrete dipole approximation (DDA) are two of the most accurate methods available. Unfortunately, they are computationally expensive as particle size and refractive index increase [1,2]. For such particles, hybrid physical-geometric optics methods have been developed [3,4] which can provide approximate solutions to the light scattering problem with good accuracy. Using these methods, the scattering, absorption, and polarisation properties of a wide range of smooth ice crystal habits have been well studied. Scattering from rough surfaces has been studied using DDA [4] and a physical-geometric optics model for strongly absorbing faceted particles has been developed [6].

In this work, a physical-geometric optics method for modelling light scattering from large, faceted particles is presented. The model uses a novel approach for tracing beams of light through particles with meshed surfaces. The interaction of light with the mesh is computed by back-tracing rays of light from the mesh elements to the incoming wavefront. Facets are grouped into substructures that define the overall particle shape, and these govern how the incoming beam is split as it refracts into the particle. This approach reduces subdivision of the incoming beams whilst attempting to maintain the underlying physics governing the propagation of light inside the particle, which has been investigated using DDA internal field computations. In this work, single-orientation scattering properties of smooth particles are presented with comparisons to DDA.

[1] M.A. Yurkin, A.G. Hoekstra, JQSRT 2007;106:558–89.

[2] M. Mishchenko, N.T. Zakharova, N.G. Khlebtsov, T. Wriedt, G. Videen, JQSRT 2014;146, 349-354

[3] P. Yang, J. Ding J, R.L. Panetta, K.N. Liou, G.W. Kattawar, M. Mishchenko, Electromagn Waves (Camb). 2019

[4] A. V. Konoshonkin, N. V. Kustova, A. G. Borovoi, D. N. Timofeev, V. A. Shishko, Proc. SPIE. 10466, 104662C (2017)

[5] E. Riskilä, H. Lindqvist, K. Muinonen, JQSRT, Volume 267, 2021, 107561

[6] E. Hesse, L. Taylor, C.T. Collier, A. Penttilä, T. Nousiainen, Z. Ulanowski, JQSRT, Volume 218, 2018, Pages 54-67

-O10-

Quantifying the coherent backscatter enhancement in single scattering with discrete dipole approximation

Chen Zhou, Nanjing University
Xue Han, Nanjing University
Lei Bi, Zhejiang University
czhou17@nju.edu.cn

The prevailing backscattering peak associated with the scattering phase function of large non-absorptive particles can be analytically explained using the coherent backscatter enhancement (CBE) theory, but has not been quantified with numerical simulations based on solving Maxwell's equations. In this paper, a set of numerical simulations performed with the discrete-dipole-approximation (ADDA) model are used to quantify the effect of CBE on the single-scattering phase function. For each scattering case, the volume of a particle is divided into multiple thin slices parallel to the incident beam. The dipole polarizations in the j'th slice in response to the incident field in the i'th slice are computed, and the corresponding contribution to the scattering phase function are calculated. Interference between conjugate terms representing reversible wave paths is constructive at the backscattering direction, which corresponds to CBE. Subsequently, the contribution of CBE on the scattering phase function can be quantified by comparing the electric field calculated with and without the interference between conjugate terms. Results from these numerical simulations are consistent with analytical conclusions of the CBE theory, and extend the CBE theory to particles with maximum dimension comparable to the wavelength. The simulations also quantitatively explain why the effect of CBE is negligible for small and absorptive particles.

-O11-

Light backscattering from large particles and dense particulate media: solving a multi-scale electromagnetic problem

Yuriy Shkuratov, Institute of Astronomy of Kharkiv National University, Sumska Str. 35, 61022 Kharkiv, Ukraine
Samer Alhaddad, Department of Theoretical Electrical Engineering, Paderborn University, Warburger Str. 100, 33102 Paderborn, Germany
Jens Förstner, Department of Theoretical Electrical Engineering, Paderborn University, Warburger Str. 100, 33102 Paderborn, Germany
yevgen.grynko@uni-paderborn.de

The problem of light backscattering from dense particulate media is challenging for numerical simulations because of their multi-scale structure. One has to consider model samples much larger than the wavelength with spatial discretization high enough to resolve the sub-wavelength distances between particles at high packing densities. Here we review our results of numerical simulations of light backscattering from such structures. We consider spherical clusters, thick layers and monolayers with realistic topologies and thousands of particles packed with maximum packing density of 0.5. A numerically exact solution of the electromagnetic problem is obtained using the Discontinuous Galerkin Time Domain method and with application of high-performance computing. We show that high packing density causes light localization which makes an impact on the opposition phenomena: backscattering intensity surge and negative linear polarization feature. Generally, diffuse multiple scattering is significantly reduced even in the non-absorbing case and near-field interaction results in a percolation-like light transport determined by the topology of the medium. With this the negative polarization branch caused by single scattering gets enhanced if compared to lower density samples. We also confirm the coherent backscattering mechanism of negative polarization for light scattered from dense absorbing layers and demonstrate a possibility of this effect at backscattering from by single absorbing grains if they are much larger than the wavelength and have wavelength-scale surface roughness.

-O12-

Coherent backscattering by large faceted particles calculated within the physical-optics approximation

Alexander Konoshonkin, V.E. Zuev Institute of Atmospheric Optics SB RAS, Tomsk State University
Anatoli Borovoi, V.E. Zuev Institute of Atmospheric Optics SB RAS
Natalia Kustova, V.E. Zuev Institute of Atmospheric Optics SB RAS
Victor Shishko, V.E. Zuev Institute of Atmospheric Optics SB RAS
Dmitry Timofeev, V.E. Zuev Institute of Atmospheric Optics SB RAS
sasha_tvo@iao.ru

The problem of light scattering by nonspherical particles of irregular shape is of great interest in physics. For example, the aerosol and dust particles in the atmosphere mostly have irregular shapes. Even in cirrus clouds consisting of ice crystals the irregular shape crystals like aggregates are often predominant. In astrophysics, surfaces of space objects are covered by regolith particles of irregular shapes. However if the particles are large, i.e. if their size parameter is larger than 150, the scattering problem is poorly solved by the conventional exact numerical methods.

In this talk, this scattering problem for large particles of irregular faceted shape is solved by use of the physical-optics approximation (POA). As compared with the rigorous numerical methods, the POA has two advantages. First, the POA solutions demand fewer amounts of computer resources. Second, the numerical solutions obtained with the POA have a evident physical interpretation. Namely, here the scattered wave inside a particle is a superposition of plane-parallel optical beams produced by multiple reflections/refractions of light from plane facets. Then, outside the particle, any refracted beam undergoes the Fraunhofer diffraction on its way from the particle to a receiver. Finally, the outgoing waves interfere with each other at the receiver.

The intensity of light scattered by a large faceted particle was considered by us earlier (Opt. Express 27, 32984, 2019). We showed that the intensity creates a sharp peak around the backward scattering direction. This peak is equivalent to the coherent backscattering peak that is well known for multiple scattering of waves in random media. The physical reason explaining appearance of the peak is the interference of the waves propagating in the reciprocal directions. Generalizing this fact, we concluded that the coherent backscattering effects would appear for all elements of the scattering matrix as well. Namely, they are formed by the interference of the conjugate waves.

We demonstrate that the coherent backscattering effects for all elements of the scattering matrix look as the surges on the scattering direction sphere. The angular widths of the surges are approximately equal to the angular width of the intensity backscattering peak.

-O13-

Analytical Linearization and Preliminary Application of Light Scattering Properties of a Single Particle

Bingqiang Sun, Department of Atmospheric and Oceanic Sciences, Fudan University, China
Chenxu Gao, Department of Atmospheric and Oceanic Sciences, Fudan University, China
Dongbin Liang, Department of Atmospheric and Oceanic Sciences, Fudan University, China
bingqsun@fudan.edu.cn

Physical retrieval algorithm is iteratively proceeded along the gradient of a defined cost function. Linearization of light scattering properties of a single particle is a significant part of the physical retrievals of particle microphysical parameters. Light scattering properties of a single particle include its differential scattering properties represented by a scattering phase matrix and its integrated scattering properties such as extinction, absorption, and scattering cross-sections, and asymmetry factor. The scattering properties can be efficiently obtained using the invariant im-bedding T-matrix method (IITM) for small particles and the physical-geometric optics method (PGOM) for large particles. In this study, the linearization with respect to the refractive indices, size parameters, and shape factors is obtained using the IITM and the PGOM. The linearization is verified using the extended-boundary condition method for the IITM linearization and the finite-difference method for both linearization. The capability and convergence for the two algorithms are discussed based on the linearized scattering properties. The sensitivities associated with linearized parameters are shown and discussed. A linearized scattering demonstration for the regular hexagonal prisms from 0.4 to 15 microns is also established and discussed for further application.

-O14-

Improvements and applications of the finite series method in the generalized Lorenz-Mie theory

Luiz Felipe Votto, Universidade de São Paulo
Leonardo André Ambrosio, Universidade de São Paulo
Gérard Gouesbet, Université de Normandie et INSA de Rouen
luizvotto@gmail.com

Among the methods for obtaining beam shape coefficients (BSCs) in the generalized Lorenz-Mie theory (GLMT), the finite series (FS) method was historically seen as an outlier. While it delivers rigorously exact expressions for the BSCs of any given field that solves Maxwell's equations, it demanded a significant amount of algebraic effort each time it was applied to a new kind of wave. In short, it lacked flexibility as it was first formulated, explaining the hiatus of decades of its application in the context of the GLMT since the late 1980s. Recently, there has been a revival of interest in the method due to its remarkable performance for obtaining exact BSCs of several families of beams without resorting to numerical integration. We have been able to successfully apply the FS method to, for instance, Laguerre-Gaussian, Bessel-Gaussian, Hermite-Gaussian, and Ince-Gaussian beams. Recently, through the FS method, we have obtained BSCs efficiently in the form of recursive relations, iterative algorithms, closed-form expressions, or even as special functions. In face of these significant results, recognizing that the FS method deserves more attention in the literature, we have modified and adapted in a more systematic, more accessible, framework. Such reformulation inspired a more general straightforward implementation of the FS procedure, for instance, in the open source glmtech Python package.
Furthermore, these developments of the FS method have given the opportunity of analyzing the properties of the mathematical models behind these fields. Historically, it has been observed that the BSCs of Gaussian beams tend to "explode" at higher orders depending on the degree of paraxiality of the beam parameters. New advances in the application of the FS method to Gaussian beams have delivered closed-form expressions for their BSCs making it possible to represent them in terms of special functions known as generalized Bessel polynomials. Resorting to the knowledge available on such functions, we were able to mathematically show that the magnitude of Gaussian BSCs must indefinitely increase at high-enough orders.
This work intends to showcase these newer developments in more detail to encourage its broader use for light scattering applications.

-O15-

On light scattering and collaboration, History of Light Scattering in Bremen

Thomas Wriedt, Universität Bremen
thw@iwt.uni-bremen.de

Interaction of light with small plasmonic metal nanoparticles is of increasing interest in different research applications.
As plasmonic nanoparticles become smaller, below about 10 – 20 nm, the classical light scattering approaches based on Maxwell's equations start to fail to predict the measured experimental results. Time-dependent density functional theory (TDDFT) can in principle be used to simulate the quantum plasmonic effects with nanoparticles, but its practical application is restricted to nanoparticles of some low number of atoms because of the high computational demand.
For that reason various approaches have been developed over the years to incorporate the non-local effect into classical Maxwell approaches. One such semi-classical approach is the hydrodynamic Drude model (HDD). In this research we use a generalization of HDD, the Generalized Nonlocal Optical Response theory (GNOR) and incorporated it into the Discrete Sources Method (DSM) as well as into the T-Matrix method.
The key point in our analysis is the separation of the internal field into a transverse and a longitudinal component. In the DSM scheme the discrete sources for expansion of the transverse field and expansion of the longitudinal field are constructed based on the system of lowest order distributed multipoles.
The method for T-matrix calculation relies on the null-field equation for the total field inside the particle, the null-field equation for the longitudinal field outside the particle, and the integral representation of the scattered field. When the nonlocal effects are neglected, the transition matrix becomes the transition matrix in the local optical response theory, while for spherical particles, the transition matrix is analytically equivalent to the transition matrix derived by the extended Mie scattering theory that considers non-local optical response.
One problem is that the longitudinal wavenumber is far larger then the transverse wavenumber. We found that the number of matching points should be at least ten times that used in the local-response approximation.
In the presentation of review of the DSM and T-matrix method development to consider the nonlocal effect for nonspherical particles, dimers of such particles and coated nonspherical particles will be presented.

-O16-

Assessing the effect of atmospheric aerosols on satellite observations of carbon dioxide

Hannakaisa Lindqvist, Finnish Meteorological Institute
Antti Mikkonen, Finnish Meteorological Institute
Timo H. Virtanen, Finnish Meteorological Institute
Anu-Maija Sundström, Finnish Meteorological Institute
Elli Suhonen, Finnish Meteorological Institute
Juan Carlos Gomez Martin, Instituto de Astrofísica de Andalucía
Julia Martikainen, Instituto de Astrofísica de Andalucía
Olga Muñoz, Instituto de Astrofísica de Andalucía
Johanna Tamminen, Finnish Meteorological Institute
hannakaisa.lindqvist@fmi.fi

Satellite observations of carbon dioxide (CO2) have recently matured to the level where they can be used to estimate anthropogenic CO2 emissions of large power plants and other point sources. The true added value of these observations is gained specifically over regions that are otherwise not measured or where the reported emission inventories may be defective. However, satellite observations of CO2 are sensitive to other atmospheric pollutants, specifically aerosol particles that affect the path length of radiation through scattering and absorption. For further complication, these particles are often co-emitted with anthropogenic CO2 emissions. The impact of aerosols on CO2 retrievals can be considered to some extent in the retrieval process and post-processing bias correction. Still, little attention has been dedicated to the evaluation of CO2 retrievals in high aerosol loadings that are characteristic to megacity environments and other regions with persistently poor air quality and high aerosol optical depth (AOD).
In this work, we first quantify the effect of aerosols on current operational satellite retrievals from the Nasa Orbiting Carbon Observatory -2 globally but also locally in the vicinity of ground-based validation sites. Aerosol optical depth is obtained from MODIS Aqua; also, ground-based observations from the AERONET are used to support the analysis. Based on our results, aerosols can introduce either an over- or underestimation of CO2 up to about 2 ppm in magnitude, depending largely on the ability of the CO2 retrieval to correctly account for the ambient AOD. We will further complement the analysis with a case study on the effect of Saharan mineral dust on CO2 satellite observations, using laboratory-measured optical properties of dust particles and a backward Monte Carlo radiative transfer model Siro.
This research lays important ground work to the planned Copernicus Anthropogenic CO2 Monitoring Mission (CO2M) where the ultimate purpose is to support the goals of the Paris Agreement with independent emission estimates derived from satellite observations. For this purpose, it is crucial to investigate the aerosol effect on CO2 observations in high AOD environments and establish the current state of the art and gaps in both retrievals and validation.

-O17-

Retrieving Spectral Aerosol Absorption and Speciation from DSCOVR EPIC

Alexei Lyapustin, NASA GSFC
Sujung Go, UMBC
Myungje Choi, UMBC
alexei.i.lyapustin@nasa.gov

The Earth Polychromatic Imaging Camera (EPIC) onboard the Deep Space Climate Observatory (DSCOVR) makes near-hourly observations of the entire sunlit surface of the Earth in 10 narrow spectral channels from the first Lagrange point about 1.5 million km from Earth. As part of MAIAC processing, EPIC features an optimal simultaneous retrieval of AOD and spectral aerosol absorption based on two UV and three visible bands. The level of aerosol absorption and its spectral dependence carry information about major absorbing species in biomass burning smoke and mineral dust. Specifically, using the effective media approximation, we invert AOD and spectral absorption to provide concentrations of hematite and goethite in the airborne dust, and of black and brown carbon in smoke. Such speciation information serves as an important constraint for the climate models and is also used in the air quality research and applications. We will describe both aerosol retrieval and speciation algorithms, validation analysis, and EPIC-based speciation climatologies for both smoke and dust.

-O18-

EPIC onboard DSCOVR for cloud and aerosol measurements

Alexander Marshak, NASA/GSFC
alexander.marshak@nasa.gov

EPIC (Earth Polychromatic Imaging Camera) is a 10-channel spectroradiometer (317-780 nm) onboard the DSCOVR (Deep Space Climate Observatory) spacecraft. DSCOVR is located near the L1 Lagrange point about 1.5 million km from Earth. EPIC provides 10 narrow band spectral images of the entire sunlit face of Earth at 10 km resolution. The unique near backscatter angular perspective of DSCOVR is used to measure ozone, sulfur dioxide, aerosols, clouds, oceans, vegetation, and solar glints. In the presentation I will focus on clouds and aerosol products: cloud mask, height, and optical thickness, aerosol optical depth and single scattering albedo, their correlation and daytime variability.

-O19-

Classification of Aggregates Using Multispectral Two-Dimensional Angular Light Scattering Simulations

Stephen Holler, Fordham University
Jaeda Mendoza, Fordham University
Kenzie Chen, Fordham University
Sequoyah Walters, West Chester University
Emily Shipley, Fordham University
Kevin Aptowicz, West Chester University
sholler@fordham.edu

Airborne particulate matter plays an important role in climate change and health impacts and is generally irregularly shaped and/or forms agglomerates. By understanding the optical characteristics of such aerosols one can gain a greater understanding their influence in, for example, climate models, or for use in the detection and characterization of unknown respirable particulates such as biological threats. Their morphology makes classification, especially using a single angular dimension, difficult and therefore necessitates an approach that garners as much information as possible about the complex speckle pattern that results. The speckle pattern that results from complex aggregates are sensitive to morphological characteristics of the cluster, such as the size of the constituent particles, their three-dimensional arrangement, and material composition. Through interference and multiple scattering events, these characteristics imprint themselves on the scattering signal and can be used to discriminate among classes of clusters. Analysis of multiple wavelength two-dimensional angular light scattering signatures from such particles have been used to classify aggregate samples into one of several different classes. Various characteristics of the speckle pattern (e.g., mean spectral signal and image entropy) have been used as metrics in the past. This talk will focus on our recent work that revisits the use of certain morphological descriptors (and introduces others) obtained from multi-wavelength light scattering patterns from aggregates of spherical particles computed using Multiple Sphere T-Matrix calculations. These descriptors are used as inputs to a multivariate statistical algorithm and then classified via supervised machine learning algorithms. The classification results show improved accuracy over previous efforts and demonstrates the utility of the proposed morphological descriptors.

-O20-

Constraining the vertical profile and angular scattering effect of aerosols in the Los Angeles megacity using hyperspectral measurements of Oxygen absorption

Zhao-Cheng Zeng, School of Earth and Space Sciences, Peking University
Yuk L. Yung, California Institute of Technology
zczeng@pku.edu.cn

Atmospheric Oxygen is uniformly distributed in the atmosphere with a constant mixing ratio and well-known absorption feature. As aerosols scatter light back to space, they leave distinctive signatures in different parts of the observed Oxygen spectra, which are associated with aerosol's optical depth, vertical structure, and angular scattering effect. In the first half of this study, we introduce a spectral sorting technique that is developed to retrieve total aerosol optical depth and effective aerosol layer height from hyperspectral measurements of Oxygen absorption bands. The effectiveness of the technique is evaluated by applying it to (a) infer the vertical profile of air pollutants in the Los Angeles (LA) basin using measurements in the 1.27-µm oxygen absorption band made by a mountaintop instrument (CLARS-FTS) overlooking the basin, and (b) constraining the vertical distribution of coastal dust aerosol over the western Sahara coast using the Oxygen A-band (0.76 µm) measurements by OCO-2 satellite. In the second half of this study, we investigate the angle-dependent scattering effect of aerosols in the LA basin using multi-year measurements of the 1.27-µm oxygen absorption band from CLARS-FTS. The observational geometries of CLARS- FTS provide a wide range of scattering angles, from about 20° (forward) to about 140° (backward), which is larger than the range provided by any existing aerosol remote sensing instrument. Moreover, CLARS-FTS measurements are highly sensitive to the angular scattering effect of aerosols in the LA urban atmosphere, due to the long light path going through the boundary layer and the wide range of observational angles. Our results show that the differences in aerosol scattering between different surface reflection points targeted by CLARS-FTS can be explained by the differences in their angular scattering geometries. Overall, this study provides a practical observing strategy for quantifying the vertical distribution of aerosols and the angular dependence of aerosol scattering in urban atmospheres that could potentially contribute towards improved aerosol remote sensing in megacities.

-O21-

Citizen scientists monitoring air quality

Hester Volten, RIVM
hester.volten@rivm.nl

Air pollution, in particular PM2.5 (particles smaller than 2.5 micrometer) is estimated to cause hundreds of thousands of premature deaths across the EU. Public awareness of this problem has increased in recent years, notably through many citizen science initiatives building on low-cost sensors.

Low-cost sensors cost roughly between 15 and 50 euros and they work surprisingly well. They typically contain a tiny red laser as a light source. A small ventilator produces an air current flowing through the laser beam. Light scattered by the particles in the ambient airflow are detected by a photodiode. A microcontroller in the sensor calculates PM2.5 values from this light scattering signal.

The number of citizen scientist that measure PM2.5 with such sensors is booming (see e.g. Sensor.Community). This is part of a larger societal change where science and information are more and more democratized. The Dutch National Institute for Public Health and the Environment (RIVM), responsible for the official air quality monitoring network in the Netherlands, decided that the citizen science data represent an opportunity to complement official air quality measurements, while facilitating a societal dialog about air pollution at the same time. They launched the Measure Together program, consisting of a knowledge portal (see samemeten.nl) where citizens can find information on air quality, sensors or citizen science initiatives to team up with, as well as an open data portal (see sensors.rivm.nl). The added benefit of the Measure Together platform lies in the possibility to combine all available sensor data and to compare with nearby official data. Thus people can assess the quality of their measurements. The number of Measure Together users is currently about 3000, and still growing fast.

The citizen science data present a valuable addition to traditional air-quality monitoring, providing much more spatial granularity than the official networks. The Measure Together approach may also be suitable to employ in other countries, and will be developed further in the coming years e.g. in the EU project CitiObs.

-O22-

Reference model for optical properties of marine aerosols

Michael Kahnert, Swedish Meteorological and Hydrological Institute
Franz Kanngießer, University of Cologne
Manu Anna Thomas, Swedish Meteorological and Hydrological Institute
Abhay Devasthale, Swedish Meteorological and Hydrological Institute
michael.kahnert@smhi.se

Marine aerosols are the most abundant type of aerosol in the atmosphere. They play an important role in cloud-formation processes over the oceans, thus influencing the global radiative budget. Here we introduce an optical reference model for marine aerosols that accounts for the irregular, yet often cube-like shape of dry crystals, as well as for the effect of water adsorption in humid air. By use of a surface-potential model, the model particles are constructed in such a way that water vapour first condenses onto minimum-potential points, while solid-phase salt ions dissolve in water starting from maximum-potential points. As a result, the particles make a transition from nonspherical, dry crystals to spherical droplets with a dissolving salt core as more liquid water is condensed onto the particles (Kahnert and Kanngießer, 2023).

The optical properties were computed with ADDA for 74 distinct sizes and stochastic shapes, and for varying amounts of liquid-water. For a wavelength of 532 nm, ensemble-averaged results yield linear backscatter depolarisation ratios (LDR) up to 0.15 for large, dry crystals. As more liquid water is being added, LDR decreases to zero. The simulated lidar ratio (LR) varies between 15-35, where increasing effective radii generally result in a drop in LR. These results are consistent with the majority of field observations from ground-based lidars (see Kanngießer and Kahnert, 2021, and references therein). We also analysed night-time, winter-months CALIPSO observations over the Southern Ocean during 2007-2016 (Thomas et al., 2022). The relative humidity (RH) of the ambient air anti-correlates to LDR, with maximum LDR values up to 0.14 at RH below 50 %. This range of observed LDR values is consistent with those obtained with the reference model.

M. Kahnert and F. Kanngießer, Optical properties of marine aerosol: modelling the transition from dry, irregularly shaped crystals to brine-coated, dissolving salt particles, JQSRT 295, 108408 (2023).
F. Kanngießer and M. Kahnert, Optical properties of water-coated sea salt model particles, Opt. Express 29, 34926-34950, (2021).
M. A. Thomas, A. Devasthale, and M. Kahnert, marine aerosol properties over the Southern Ocean in relation to the wintertime meteorological conditions, Atmos. Chem. Phys. 22, 119-137 (2022).

-O23-

Light scattering by nonspherical and inhomogeneous aerosols: T-matrix and Machine learning

Lei Bi, Zhejiang University
Zheng Wang, Zhejiang University
Xuan Wang, Zhejiang University
bilei@zju.edu.cn

Aerosols including soil dust, organic carbon, black carbon, sea salt, aerosol water, sulfate, and nitrate are essential atmospheric components. In the atmosphere, they could mix and form as nonspherical and inhomogeneous aerosols. Even for a single dust particle, microphysical observations show that the particle is inhomogeneous with different mineral compositions (e.g., quartz, hematite and others). Being hygroscopic aerosols, sea salt particles could be also nonpsherical and inhomogeneous when the relative humidity is low. In this talk, we will report our recent implementation of the invariant imbedding T-matrix method, which can efficiently compute the optical properties of arbitrary nonspherical and inhomogeneous aerosols. In addition, we will present a new aerosol-optics model, followed with comprehensive assessments in radiative transfer and atmospheric models. The new aerosol-optics model has incorporated the particle nonsphericity and inhomogeneity as well as the aerosol mixing variations, which have significant impact on light scattering and absorption. We will also highlight a machine-learning approach for parameterizing the aerosol optical properties, which can be efficiently implemented in the radiative transfer and atmospheric models. Finally, representative results will be given to illustrate the performance of this new aerosol model in remote sensing, weather and climate studies.

-O24-

Revisiting particle size distributions of nonspherical particles

Masanori Saito, Texas A&M University
masa.saito@tamu.edu

Particle size distributions (PSD) are often expressed analytically, such as log-normal and gamma distributions in radiative transfer simulations, numerical cloud-resolving simulations, and analyses of in-situ derived PSDs. Hansen and Travis (1974) summarized these analytical expressions for spherical particle cases, which have been used in atmospheric sciences research. However, atmospheric particles such as ice crystals and dust aerosol particles are typically nonspherical. Unlike spherical particles, the "size" of these nonspherical particles can be defined in many ways, such as a volume-equivalent spherical diameter or geometric diameter, which complicates the interpretations of observational PSDs of atmospheric nonspherical particles. The differing measures of particle sizes cause ambiguity that could bring uncertainty to PSD interconversions of atmospheric nonspherical particles, which are often required in Earth-system models and remote sensing applications. This study derives generalized formulas for the interconversions of PSDs of arbitrary nonspherical particles. With these formulas, converting in-situ measured PSDs and particle shape information into a comparable form is feasible. In the presentation, we will show an application of this PSD interconversion formula to develop an observationally constrained ice crystal optical property model based on in-situ measurements of ice crystals in clouds.

-O25-

Exploring the boundary between spherical and nonspherical atmospheric aerosol particles using angularly-resolved light scattering

Gabriel Seymour, West Chester University
Sequoyah Walters, West Chester University
Daniel Landgraf, West Chester University
Yong-Le Pan, U.S. Army Research Laboratory
Gorden Videen, U.S. Army Research Laboratory
Ronald G. Pinnick, U.S. Army Research Laboratory
Kevin Aptowicz, West Chester University
kaptowicz@wcupa.edu

In fields such as climate science, the accurate characterization and modeling of aerosol particles is critical. Often, the diverse range of particle shapes and compositions is simplified to mix of spherical and nonspherical particles. This simple binary classification for shape works surprisingly well and far better than models that only consider homogeneous spherical particles. However, the morphology of atmospheric particles is a continuous spectrum of shapes from homogeneous sphere to highly inhomogeneous and non-spherical. From a light scattering perspective, there is no clear boundary between particles that behave as spheres and particles that behave as nonspherical. In this paper, we explore this transition from sphere to nonsphere using both experimental and simulated scattering patterns. Our approach is to quantify the extent of rings in the scattering pattern from individual particles and analyze how this ring structure changes with particle shape and composition. Using both experimental data and simulated patterns, we find backward scattering is more sensitive to shape and composition. In addition, based on this analysis, the atmospheric particles analyzed appear to separate into a bimodal distribution of spheres and non-spheres. Using T-matrix simulations, we explore and quantify the boundary between these two classes of particles by varying particle shape, surface roughness, and composition. In summary, our results support the current modeling practice of representing a diverse mixture of particles as a combination of homogeneous spheres and representative nonspherical particles. Furthermore, we quantify the the microphysical properties of the particles that lie at the boundary between these two regimes.

-O26-

Impacts of Aerosol Radiation Effect (ARE) on the PBL via Altering Entrainment Process in the Upper PBL

Zhanqing Li, University of Maryland
Tianning Su, University of Maryland
zhanqing@umd.edu

Aerosol-boundary layer interactions play an important role in affecting atmospheric thermodynamics, convection, and air pollution. Aerosol radiation interaction (ARI) has widely been known to affect the development of PBL, and their interaction may dictate the dispersion of air pollutants, especially for absorbing aerosols. To a large extent, such an effect has been attributed to the reduction of solar radiation near surface. As a key factor in dictating the development of the boundary layer, the entrainment process in the context of aerosol-boundary layer interactions is still poorly understood. Using comprehensive field observations, we have gained a deeper insight into the response of the entrainment process in the upper PBL to aerosols. It is found that high aerosol loading can significantly suppress the entrainment rate, breaking the conventional linear relationship between sensible heat fluxes and entrainment fluxes. Related to aerosol vertical distributions, aerosol heating effects can alter vertical heat fluxes, leading to a strong interaction between aerosols and the entrainment process in the upper boundary layer. Such aerosol-entrainment coupling can inhibit boundary layer development and explains the great sensitivity of observed entrainment rates to aerosols than can traditional calculations. The notable impact of aerosols on the entrainment process raises holistic thinking about the dynamic framework of the boundary layer in a polluted atmosphere, which may have a significant bearing on the dispersion of air pollutants and the land-atmosphere coupling.

-O27-

Light-scattering measurements and models for lidar applications

Romain Ceolato, ONERA
Killian Aleau, ONERA
Andres Bedoya, ONERA
Lucas Paulien, ONERA
Jerome Yon, CORIA
Matthew J. Berg, Kansas State University
Romain.Ceolato@onera.fr

Elastic backscatter lidar, or aerosol lidar, is an established remote-sensing technique based on the measurement of backscattering properties of atmospheric constituents, including aerosols and molecules. Fundamental to lidar measurements are the extinction and backscattering properties of the aerosol particles in the lidar beam. We aim to give an understanding for how light-scattering measurements and models are needed for lidar measurements. Specific emphasis is placed on extinction, which manifests attenuation of the lidar beam by the aerosol, and the backscattering that ultimately constitutes the measured signal. Our approach is based both on laboratory and field measurements. In the lab, two-dimensional small-angle light-scattering patterns are measured for a variety of single microparticles (i.e. spheres, salt, sand, and volcanic dust) using a spectro-polarimetric laser-based scatterometer. In the field, a recently developed picosecond short-range elastic backscatter lidar (PSR-EBL) instrument, Colibri, is presented for measuring extinction and backscattering properties of aerosols at different wavelengths, ranging from ultrafine particles (e.g. soot) to coarse particles (e.g. dust, volcanic ashes) close to their emission sources. Dedicated models for backscattering by irregularly shaped particles, including soot fractal aggregates, will be presented. Accurate spectro-polarimetric light scattering models and measurements are believed to be a potential route to improve lidar retrieval algorithms.

-O28-

The spectral depolarization ratio of mineral dust at 180° backscatter – from lidar field observations to the laboratory

Moritz Haarig, Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, Germany
Ronny Engelmann, Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, Germany
Holger Baars, Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, Germany
Dietrich Althausen, Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, Germany
Albert Ansmann, Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, Germany
Ulla Wandinger, Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, Germany
Andreas Macke, Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, Germany
haarig@tropos.de

The number of triple-wavelength polarization lidars for the observation of mineral dust is growing (Burton et al., 2015, Haarig et al., 2017, 2022, Hu et al., 2020). TROPOS recently installed another lidar system at Cabo Verde providing continuous profiles of the depolarization ratio at 355, 532 and 1064 nm with frequent occurrence of mineral dust. First results will be presented.

The observation geometry of a lidar system requires a scattering angle of 180° to observe the whole atmospheric profile. In order to convert the optical properties measured with lidar into microphysical properties such as number size distribution or mass concentration, scattering models are required. However, the irregular shape of mineral dust particles challenges their representation in optical models. Especially, at 180° backscattering direction, there are only very view experimental data to test and constrain the models (e.g., Sakai et al., 2010, Miffre et al., 2016).

The Leibniz Junior Research Group OLALA (Optical Lab for Lidar Applications) proposes to fill this gap by constructing a new scattering laboratory specialized at measurements of the depolarization ratio at 355, 532 and 1064 nm in the exact backscattering direction. Based on our experiences from field observations (Barbados, Tajikistan, Cyprus), the construction of multiwavelength lidar systems (PollyXT), and the particle preparation for lab studies (ice-nucleating-particle studies), the new laboratory "OLALA" will be set up at TROPOS. The novel approach of using size-segregated dust samples will allow us to study the influence of the particle size on the spectral depolarization ratio. Additional information about the particles like shape and refractive index will be provided from auxiliary measurements (electron-microscopy, chemical analysis). A comprehensive data set will be created to serve as constraint for optical models of irregularly shaped particles in the exact backscattering direction. Currently, we plan to match our observations with light scattering models of Dubovik et al., 2006, Gasteiger et al., 2011, and Saito et al., 2021. However, we are open to apply further particle shape compositions that might fit better both the optical and physical parameter of real dust particles.

-O29-

Color Digital Holography of Aerosol Particles

Matthew Berg, Kansas State University
Ramesh Giri, Corning Inc.
matt.berg@phys.ksu.edu

Digital in-line holography (DIH) is an established method to image small particles in a manner where image reconstruction is performed computationally post-measurement. This ability renders it ideal for aerosol characterization, particularly atmospheric dust, where particle collection or confinement is often difficult, if not impossible. Conventional DIH provides a gray-scale image akin to a particle's silhouette, and while it gives the particle size and shape, there is little information about the particle material. Based on the recognition that the spectral reflectance of a surface is partly determined by the material, we demonstrate a method to image free-flowing particles with DIH in color with the eventual aim to differentiate materials based on the observed color. Holograms formed by the weak backscattered light from individual particles illuminated by red, green, and blue lasers are recorded by a color sensor. Images are reconstructed from the holograms and then layered to form a color image, the color content of which is quantified by chromaticity analysis to establish a representative signature. A variety of mineral dust aerosols are studied where the different signatures suggest the possibility to differentiate particle material. The ability of the method to resolve the inhomogeneous composition within a single particle in some cases is shown as well.

-O30-

Spectro-polarimetric two-dimensional backscattering measurements by irregularly shaped particles

Killian ALEAU, Leukos LASER
Guillaume HUSS, Leukos LASER
Romain CEOLATO, ONERA
killian.aleau@onera.fr

This study presents a new instrument that represents a significant advancement in particles characterization by enabling the measurement of the scattering patterns at multiple wavelengths and polarizations. The instrument utilizes a supercontinuum laser source, achromatic optics, and linear polarizer/analyzer to measure the two-dimensional backscattering pattern of aerosols. The supercontinuum laser is capable of emitting on a large spectrum by utilizing a monochromatic wave that passes through a nonlinear fiber to widen the initial spectra. A filter system is used to select the desired wavelength over the entire visible spectrum (450 to 850 nm). The scattering patterns are captured using a CMOS sensor and are dependent on the microphysical properties of the particles, such as size, shape, and optical index. Each pattern is wavelength and polarization dependent and can be used to obtain morphological quantities such as backscattering phase function and lidar typical measurements like depolarization ratio in terms of two scattering angles and in terms of wavelength. The instrument is also capable of retrieving direct images of the scattering object using digital holography. The technique presented in this study to provide a novel and efficient way of obtaining spectro-polarimetric radiative properties of irregularly shaped particles, including volcanic ash, to demonstrate the potential of the instrument.

-O31-

Advances in the JCSDA Community Radiative Transfer Model prior to its 20 Year Anniversary

Patrick Stegmann, JCSDA/NOAA
Cheng Dang, JCSDA
Benjamin Johnson, JCSDA/NOAA
Isaac Moradi, NASA GMAO
Bryan Karpowicz, NASA GMAO
Will McCarty, NASA Headquarters
Hui Shao, JCSDA/NOAA
Tom Greenwald, University of Madison, Wisconsin
Emily Liu, NOAA EMC
Haixia Liu, NOAA EMC
Shih-Wei Wei, University at Albany, New York
Sarah Lu, University at Albany, New York
patrick.stegmann@noaa.gov

The JCSDA Community Radiative Transfer Model (CRTM) has a long and varied development history as an all-sky radiative transfer model for satellite data assimilation applications in numerical weather prediction that can be traced back long before its official start 19 years ago. In recent years, the CRTM has successfully managed its transition to an open-source project and has seen a number of rapid developments in various areas, both in scientific and engineering terms. On the scientific side, cloud and aerosol scattering properties have been extended with new options and new forward operator options have been added, such as a radar and lidar operator. Aerosol scattering properties for the scattering radiative transfer solvers available in the CRTM have been extended with the CMAQ and the most recent GOCART aerosol optical property schemes. Hydrometeor scattering properties in the microwave and infrared have been extended with databases based on a broad selection of ice particle morphologies. The gaseous transmittance training process for new instrument coefficients has been shaped into a coherent package. On the software engineering side, the code itself was parallelized for shared-memory scenarios and is maintained in a modern version control environment with a cloud-based continuous development pipeline. Furthermore, in light of its primary application towards assimilation of satellite radiance data in numerical weather prediction, the CRTM is now also supported as a unified forward operator in the Joint Effort for Data Assimilation Integration, together with its European counterpart, the RTTOV model.
This integration allows a direct comparison of both models on the same footing.

-O32-

Practical solution of radiative transfer in the plane-parallel atmospheric-surface system

Pavel Litvinov, GRASP SAS
Anton Lopatin, GRASP SAS
Cheng Chen, GRASP SAS
Christian Matar, GRASP SAS
Teruyuki Nakajima, Tokyo University of Marine Science and Technology
Tatyana Lapyonok, Université Lille
Oleg Dubovik, Université Lille
masahiro.momoi@grasp-sas.com

The computational efficiency of solving the radiative transfer equation is a crucial issue for ground- and satellite-based remote sensing and monitoring of aerosols, clouds, and radiation, all of which involve the analysis of large volumes of data. In order to adequately model scattering by atmospheric aerosol and cloud particles, a large number of Fourier decomposition is required due to anisotropic phase function. Since the 1970s, the delta-scaling technique, which cuts off the forward lobe, has been developed to reduce the number of terms in Fourier decomposition. This technique adequately reconstructs the radiance field, except for solar aureole, glory, and sun-glint regions. In the recent decade, two types of correction methods, Waquet-Herman method (Waquet and Herman, 2019) and a series of IMS methods (Improved Multiple and Single scattering; Nakajima and Tanaka, 1988, Momoi et al., 2022ab) have been developed for correcting a forward lobe contribution in I, Q, and U components of Stokes radiance vector in solar aureole and sun-glint regions. In this study, we theoretically investigated the difference among the methods and, then attempted to compare the performance of both methods (Waquet-Herman and Pn-IMS) in the frame of the same radiative transfer implementation: (1) The Pn-IMS method was implemented into the GRASP (Generalized Retrieval of Atmosphere and Surface Properties) program, which uses a successive order of scattering method for the numerical solution of the Fourier decomposed radiative transfer equation. (2) Two methods realizing efficient computational treatment of scattering in aureole and sun-glint regions were compared and discussed in terms of computational speed and accuracy. The results suggest that the P3-IMS method provides better results for total radiance calculations than the truncation approach based on the Waquet-Herman method. In contrast, for polarized components (i.e., Q and U), the calculation efficiency is similar for both methods. (3) We preliminary applied them to retrieve actual observations (e.g., AERONET and POLDER). The aerosol optical depth at the open ocean site obtained with POLDER observation was slightly improved by Pn-IMS with sun-glint correction.

-O33-

A Markov chain approach for modeling polarized radiative transfer from ultraviolet to far-infrared

Feng Xu
Reed Espinosa
Olga Kalashnikova
Anthony Davis
David Diner
Michael Garay
Jie Gong
Benting Chen
Lan Gao
Jens Redemann
Zhao-cheng Zeng
fengxu@ou.edu

The polarization state of atmospheric radiation contains abundant information about aerosol and cloud particle properties. To assist in the combined use of reflected and emitted radiation for dust and cloud remote sensing, we have developed a Markov chain (MarCh) approach for computing polarized radiative transfer (RT) in the spectral range from ultraviolet to far-infrared. Our model has the following main features: a) it accounts for atmospheric emission, scattering, and absorption and resolves the angular radiance distribution; b) it considers non-spherical particles with random and preferred orientations (the latter causing optical anisotropy of a medium); c) it accounts for vertical profiles of particles, gas absorption and temperature, as well as surface reflection and emission; and d) it has high computational efficiency due to its basis on matrix multiplication, making it suitable for implementation using graphics processing units (GPUs). Our approach is a generalization of Esposito and House's unpolarized (radiance-only) version of the MarCh algorithm [Astrophys. J. 219, 1058-, 1978]. The Markov RT uses the gas absorption output from the Line-By-Line Radiative Transfer Model (LBLRTM) [Clough et al., JQSRT 91, 233-, 2005] and the HITRAN database. We have performed calculations for two reference atmospheres (Mid-Latitude Summer and Sub-Arctic Winter) with the presence of dust and cloud particles of random or preferred orientations, as well as the underlying ocean and land surfaces. These surfaces exhibit directional emissivity in the infrared. On such a basis, the impact of particle orientations, non-sphericities, and cross-polarization of extinction on the view-angle resolved radiometric and polarimetric signals will be demonstrated. Additionally, we will analyze the information contained in the difference between the vertically (Iv) and horizontally (Ih) polarized components of infrared radiation, which provides insight into particle properties. Finally, we will discuss the benefits of combining shortwave and infrared polarimetric measurements to better constrain dust and cloud particle retrieval.

-O34-

The 2Stream-Exact Single Scattering (2S-ESS) Radiative Transfer Model

Vijay Natraj, Jet Propulsion Laboratory, California Institute of Technology
Robert J. D. Spurr, RT Solutions, Inc.
Andrew Gao, Peking University
Tianhao Le, California Institute of Technology
Zhao-Cheng Zeng, Peking University
Siteng Fan, LMD/IPSL
Yuk L. Yung, California Institute of Technology
vijay.natraj@jpl.nasa.gov

Radiative transfer (RT) calculations are required for many remote sensing applications, but are often computationally expensive. Plane-parallel two-stream (2S) approximations are a popular alternative to numerically more precise models, especially for calculating fluxes and heating rates relevant to climate modeling. 2S methods avoid the complexity of numerical solutions to the RT equation, instead yielding closed-form analytical results. However, this approach is typically not accurate enough for applications involving the analysis of spectral radiances. We present the 2 stream-exact single scattering (2S-ESS) RT model, which performs an exact calculation of single scattering in a spherically curved medium using an accurate treatment of the phase function and curved ray-tracing of the solar and line-of-sight paths, while approximating multiple scattering with the plane-parallel 2S approach.

The 2S-ESS model has three important features. First, it can be deployed for calculations in vertically inhomogeneous atmospheres. Second, the sphericity capability makes it applicable to large solar and/or viewing zenith angle scenarios such as those encountered close to sunrise or sunset. Third, it is fully linearized: in addition to generating radiances, the model can also compute Jacobians analytically with respect to any atmospheric or surface property (e.g., trace gases, aerosols, surface reflectance). These features of the model are especially useful for remote sensing retrieval applications.

We examine the accuracy of this model, with respect to the numerically precise LIDORT model, for homogeneous slab and inhomogeneous multi-layer scenarios. These simulations cover a large phase space of geometrical and optical parameters. We describe the computational shortcuts used in the formulation and assess speed-ups relevant to remote sensing applications in the shortwave and thermal infrared spectral regions. The results show that this methodology introduces less than a few percent error in most situations, with the exception of heavy aerosol or cloud loading events, while providing three orders of magnitude improvement in computational efficiency. Comparisons with a conventional 2S model further demonstrate the advantages of the 2S-ESS approach. Finally, we perform benchmark comparisons against the DISORT code. The code is publicly available along with documentation and test cases to assist the user.

-O35-

Manipulation and characterization of cosmic dust and sea microplastics by Optical and Raman tweezers

A. Magazzù, CNR-IPCF, Istituto per i Processi Chimico-Fisici, Messina, Italy
R. Gillibert, CNR-IPCF, Istituto per i Processi Chimico-Fisici, Messina, Italy
D. Bronte Ciriza, CNR-IPCF, Istituto per i Processi Chimico-Fisici, Messina, Italy; Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra, Università di Messina, Italy
A. Musolino, CEREGE Aix-Marseille Université, Aix-en-Provence, France
M. G. Donato, CNR-IPCF, Istituto per i Processi Chimico-Fisici, Messina, Italy
A. Foti, CNR-IPCF, Istituto per i Processi Chimico-Fisici, Messina, Italy
M. L. de La Chapelle, Institut des Molécules et Matériaux du Mans, UMR 6283 CNRS, Le Mans Université, 72085 Le Mans, France
F. Lagarde, nstitut des Molécules et Matériaux du Mans, UMR 6283 CNRS, Le Mans Université, 72085 Le Mans, France
A. Rotundi, Dipartimento di Scienze e Tecnologie, Università degli studi di Napoli Parthenope, Italy
L. Folco, Dipartimento di Scienze della Terra, Università di Pisa, Pisa, Italy; CISUP, Center for Instrument Sharing of the University of Pisa, Università di Pisa, Italy
mago.alex@gmail.com

We use optical and Raman tweezers to manipulate micro and nano-plastics and individual cosmic dust particles.

By optical and Raman tweezers, we characterize the mineral composition and optical response of single grains of cosmic dust. In particular, we investigate terrestrial and extraterrestrial samples dispersed in water.

The scattered light by the trapped dust particle is analysed by a photo-detector providing information about optical forces on the trapped particle. Furthermore, by Raman tweezers we identify minerals composition of micron-sized individual meteorites fragments, having a better sight on the bench work where hydrogen molecules and simple organic compounds, carbon monoxide and ammonia are produced. On the other hand, we also use optical tweezers and Raman tweezers to detect, trap and chemically identify microplastics made of different materials and shapes, both in distilled and in seawater showing unambiguous discrimination between different plastics and microparticles coming from marine sediments and organic matter. Similarly, we investigated microplastics released applying mechanical shock and stress to aged brittle plastics due to weathering-induced crystallization, where the degree and scale of fragmentation depend on aging time, weathering conditions and polymer nature. In doing this, Raman Tweezers is a suitable tool to study the fate of micro and nanoplastics in the aquatic environment and the effect of aging and fragmentation of plastic material in marine environments.

-O36-

Faster and More Accurate Geometrical-Optics Optical Force Calculation Using Neural Networks

David Bronte Ciriza, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158Messina, Italy
Alessandro Magazzù, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158Messina, Italy
Agnese Callegari, Department of Physics, University of Gothenburg, SE-41296Gothenburg, Sweden
Gunther Barbosa, Universidade Federal do ABC, Av. dos Estados 5001, CEP 09210-580, Santo André, SP, Brazil
Antonio A. R. Neves, Universidade Federal do ABC, Av. dos Estados 5001, CEP 09210-580, Santo André, SP, Brazil
Maria Antonia Iatì, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158Messina, Italy
Giovanni Volpe, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158Messina, Italy
Onofrio M. Maragò, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158Messina, Italy
brontecir@gmail.com

Optical forces are often calculated by discretizing the trapping light beam into a set of rays and using geometrical optics to compute the exchange of momentum. However, the number of rays sets a trade-off between calculation speed and accuracy. Here, we show that using neural networks permits overcoming this limitation, obtaining not only faster but also more accurate simulations. We demonstrate this using an optically trapped spherical particle for which we obtain an analytical solution to use as ground truth. Then, we take advantage of the acceleration provided by neural networks to study the dynamics of ellipsoidal particles in a double trap, which would be computationally impossible otherwise. We introduce present and future perspectives of this technique.

-O37-

Ideal two-dimensional discrete superpositions of Bessel beams in stratified media

Jhonas Olivati de Sarro, Department of Electrical and Computer Engineering, Sao Carlos School of Engineering,
Leonardo André Ambrosio, Department of Electrical and Computer Engineering, Sao Carlos School of Engineering
jodesarro@gmail.com

Bessel beams (BBs) play an important role in light scattering, optical trapping, manipulation and guidance of atoms and particles. Their self-healing properties are in charge of overcoming limitations imposed by diffraction phenomena. Despite being invariant under propagation, it is not possible to model the shape of the longitudinal field intensity of an ideal BB. However, compositions of several BBs emerged as an excellent solution to overcome this limitation.

A truncated series made of a discrete summation of co-propagating ideal zeroth-order BBs, all sharing the same angular frequency but having distinct longitudinal (transverse) wavenumbers and weighting complex coefficients, initially named frozen waves (FWs), came as a powerful technique to model the shape of the resulting beam according to any desired longitudinal intensity profile (IP) chosen a priori. The complex coefficients of these pencil-like beams are easily extracted through Fourier series techniques, and the longitudinal wavenumbers are constrained so as to ensure that each BB in the FW is a non-evanescent solution to the scalar wave equation.

The FW technique, already demonstrated experimentally, can be extended to incorporate higher-order BBs with infinite or finite energy and different polarizations and/or wavenumbers, heterogenous and also lossy media. Recently, extended versions of FWs called “surface FWs” (SFWs) were proposed based on discrete superpositions of co-propagating FWs, all parallel to each other and to the propagation axis, allowing one to recreate virtually any two-dimensional IP along a homogeneous simple medium. SFWs have been experimentally shown to provide a new and promising holographic technique for projecting 2D and 3D target scenes.

The main goal of our work is to theoretically demonstrate the propagation of ideal two-dimensional discrete zeroth-order SFWs through a stratified lossless media. After passing through several parallel layers of distinct thickness, we show that it is possible to control the resulting beam in order to recover the superficial IP inside the last medium where the SFW is supposed to be constructed. We envision important applications for our results such as in medical and military purposes, propagation through biological tissues, optical and data storage, optical trapping and manipulation, volumetric displays, and so on.

-O38-

Multichromatic nondiffracting surface beams at the millimeter scale

Vinicius S. de Angelis, Department of Electrical and Computer Engineering, São Carlos School of Engineering, University of São Paulo, São Carlos, SP, Brazil
Jhonas O. de Sarro, Department of Electrical and Computer Engineering, São Carlos School of Engineering, University of São Paulo, São Carlos, SP, Brazil
Ahmed H. Dorrah, Harvard John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, Massachusetts, USA
Federico Capasso, Harvard John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, Massachusetts, USA
Leonardo A. Ambrosio, Department of Electrical and Computer Engineering, São Carlos School of Engineering, University of São Paulo, São Carlos, SP, Brazil
vinicius.angelis@usp.br

A suitable superposition of forward propagating ordinary Bessel beams (BBs), all with the same operating angular frequency but with distinct longitudinal wave numbers, was proposed as a new laser beam shaping technique to model the intensity along the optical axis over a finite range. Being known in the literature as a Frozen Wave (FW), this non-diffracting structured light beam was first described by means of a truncated Fourier series whose complex coefficients weight the amplitude and phase of the BBs. As a result, the BBs interfere with each other along the optical axis to shape the total field intensity and generate any arbitrary longitudinal profile. Computer-generated holograms implemented in a programmable spatial light modulator have been used to experimentally generate FWs in free space and also in absorbing media. Multichromatic FWs have also been generated by incorporating BBs with different wavelengths in the superposition, allowing locally and independently longitudinal management of the wavelength along the beam's direction of propagation.

An extended version of a FW known as Surface Frozen Wave (SFW) was recently proposed. It consists of an array of FWs, all of them disposed parallel to each other. Since each FW in this new array acts as a thread of light, a surface intensity pattern of arbitrary shape can be modeled. SFWs constitute a new holographic technique in which a two-dimensional (2D) scene is projected into a plane containing the optical axis and is oriented perpendicular to the hologram plane. Experimental demonstrations of single-wavelength SFWs have shown the effectiveness of this technique in projecting 2D and 3D scenes with high fidelity.

In this work, we explore numerical simulations of multichromatic SFWs. By superposing three SFWs, operating in red, green and blue wavelengths, respectively, and representing the RGB channels of a target color image, we obtain a multichromatic waveform that reproduces the target image at the millimeter scale. Multichromatic SFWs open new routes to holographic displays and can also find applications in optical trapping and manipulation of microparticles, 2D and 3D imaging and printing, volumetric displays based on photophoretic traps and so on.

-O39-

Forces exerted on particles by laser radiation

G. Gouesbet, Normandie University
V. de Angelis, Sao Paulo University
L.A. Ambrosio, Sao Paulo University
J. Wang, Xidian University
gouesbet@coria.fr

General expressions of optical forces in the case of homogeneous spheres illuminated by laser beams are known since decades in the framework of the generalized Lorenz-Mie theory (GLMT stricto sensu) in which the structure of the laser beam is encoded in beam shape coefficients (BSCs) [1]-[2].

Strange as it may be, however, a systematic search for the categorization of optical forces in the framework of GLMT is only recent, and revealed the existence of unexpected non-standard forces. The results obtained in the framework of the GLMT stricto sensu may be extended to the cases of multilayered particles when the expressions of the BSCs are unchanged, requiring only to modify the expressions of the Mie coefficients, and to other kinds of particles leading to expressions which are formally identical to the ones of the GLMT stricto sensu, namely assemblies of spheres and aggregates, and spheres with an eccentrically located spherical inclusion [3]-[4].

Applications of optical forces to the manipulation of optical particles, in particular in optical tweezers, may require to take into account photophoretic forces which, as a matter of fact, may be larger than optical forces by orders of magnitude. The study of photophoretic forces may be carried out as well by using GLMT which allows one to calculate internal fields [5].

[1] G. Gouesbet, B. Maheu, G. Gréhan. Light scattering from a sphere arbitrarily located in a Gaussian beam, using a Bromwich formulation. J. O.S.A. A, 5, 9, 1427-1443, 1988

[2] G. Gouesbet, G. Gréhan. Generalized Lorenz-Mie theories. Springer. 2nd edition, 2017

[3] G. Gouesbet, V.S. de Angelis and L.A. Ambrosio. Optical forces and optical force categorization exerted on quadrupoles in the framework of generalized Lorenz-Mie theory. J. Q. S. R. T. 298, 108487, 2023.

[4] G. Gouesbet, V.S. de Angelis and L.A. Ambrosio. Optical forces and optical force partitions exerted on arbitrary sized spherical homogeneous particles in the framework of generalized Lorenz-Mie theory. Submitted to Journal of Quantitative Spectroscopy and Radiative Transfer.

[5] L.A. Ambrosio, J. Wang and G. Gouesbet. Towards photophoresis with the generalized Lorenz-Mie theory. J.Q.R.S.T. 288, 108266, 2022.

-O40-

Propagation of Laguerre-Gaussian beam with orbital angular momentum in turbid tissue-like medium

Ivan Lopushenko, University of Oulu
Anton Sdobnov, University of Oulu
Alexander Bykov, University of Oulu
Igor Meglinski, University of Oulu, Aston University
ivan.lopushenko@oulu.fi

Monte Carlo (MC) method is employed to investigate the potential of using Laguerre-Gaussian (LG) beams carrying orbital angular momentum (OAM) for biomedical diagnosis. While the spin angular momentum has been extensively employed in diagnostic studies, the OAM is currently expected to be added to the practical toolkit further pushing our tissue characterization capabilities. In this work we consider LG beam propagation through both transparent and turbid tissue-like medium. Computational MC model developed in-house is based on the tracing of individual MC-photon trajectories determined by the Poynting vector direction. Account for polarization is implemented within the framework of iterative solution to Bethe-Salpeter equation. We show that when LG beam propagates through the medium imitating normal and abnormal biological tissues the OAM is preserved with the noticeably different phase shift – twist of light. We demonstrate that the twist of light is highly sensitive to the refractive index variations within the medium. The results of our computational studies are well agreed with experiment. We conclude that LG beam with OAM offers promising opportunities for non-invasive diagnosis of biological tissues in terms of analytes, glucose and structural malformations associated with various diseases.

-O41-

Full-dynamic mixing formulas for the effective refractive index of dense colloids and dependent scattering effects

Augusto García-Valenzuela, Universidad Nacional Autónoma de México
Anays Acevedo-Barrera, Universidad Nacional Autónoma de México
Omar Vázquez-Estrada, Instituto Tecnológico Nacional (Mexico)
Alexander Nahmad-Rohen, Universidad Nacional Autónoma de México
Verónica Solis-Tinoco, Universidad Nacional Autónoma de México
Rubén G. Barrera, Rubén G. Barrera
augusto.garcia@icat.unam.mx

We present a complete dynamic extension of Maxwell Garnett's mixing formula that fully accounts for scattering losses in dense colloids. The new mixing formula is obtained considering the full-dynamic electromagnetic interaction between the particles and a dynamic dipolar response of the particles. It takes proper account of multiple scattering among the particles and predicts a complex refractive index, even in the absence of absorption. Furthermore, it reproduces dependent-scattering effects which are strongest, in relative terms, for dense colloids of particles of dimensions very small compared to the wavelength. Then, we derive an extended formula that considers the multipolar response of larger particles. The resulting formula can also be seen as an extension of the Foldy-Lax approximation through dynamic local-field corrections. This formula reduces to all previously established approximations in the appropriate limits. Predictions by this formula reproduce very well experimental data of the attenuation coefficient versus the volume fraction of the particles in non-absorbing colloids of particles of different sizes, ranging from small to large compared to the wavelength.

By means of the fully dynamic extended Maxwell Garnett mixing formula we provide physical insight into the origin of dependent scattering in non-absorbing colloids of very small particles. In these cases, the colloid is less turbid than the what the independent-scattering approximation predicts. Then we address the case of colloids of larger particles which show the opposite behavior than smaller particles, that is, they are more turbid than what the independent scattering predicts. Next, we analyze the dependence of the refractive index (its real part) of colloidal systems of small and large non-absorbing particles with the density of particles. A non-linear dependence with the particle volume density is predicted in the case of large particles. Interesting and useful applications of colloidal refractometry are briefly discussed. We present experimental measurements showing the viability of measuring the refractive index of highly turbid, non-absorbing colloids made of particles comparable and larger than the wavelength. We study two methods of measurement relying on the determination of a critical angle. One by transmission to, and the other one by reflection from, a medium of higher refractive.

-O42-

Imaging and Analysis of Light Scattered by Single Particles and Cells in a Flow Cytometer

Jonas Gienger, Physikalisch-Technische Bundesanstalt (PTB), Abbestr. 2-12, 10587 Berlin, Germany
Christian Goerke, Physikalisch-Technische Bundesanstalt (PTB), Abbestr. 2-12, 10587 Berlin, Germany
Nirina Beilfuß, Physikalisch-Technische Bundesanstalt (PTB), Abbestr. 2-12, 10587 Berlin, Germany
Dirk Grosenick, Physikalisch-Technische Bundesanstalt (PTB), Abbestr. 2-12, 10587 Berlin, Germany
Martin Hussels, Physikalisch-Technische Bundesanstalt (PTB), Abbestr. 2-12, 10587 Berlin, Germany
jonas.gienger@ptb.de

In a flow cytometer, microscopic objects of interest (e. g., biological cells or artificial microparticles) pass through a laser focus one by one in a fluid flow. In most standard devices the scattered light is collected with detectors in the forward and sideward directions, without any angular resolution. Fluorescent labelling is often used for the differentiation of cells on a biomolecular basis. Imaging flow cytometry combines the high information content of microscopic images with the high throughput of flow cytometry.

Here we present results from a home-built flow cytometer equipped with cameras to image the angular intensity distributions of the scattered light of single microparticles and cells at throughputs in the 1,000 events/s range and interaction times with the laser in the microsecond range. We use two lasers: the scattering from and/or fluorescence excited by a continuous wave laser at 488 nm recorded by photomultiplier tubes trigger the camera and illumination with a gated laser at 406 nm, focused a few micrometers downstream. The images are compared to the far-field scattered intensity angular distributions computed with various computational methods, which yields information about particle size, shape, and orientation in the fluid flow. For spherical particles, we analyze the annular intensity patterns ("fringes") around the forward direction by azimuthally averaging and fitting with a model based on Lorenz-Mie-Theory to quantitatively determine particle diameter and refractive index. We furthermore present measurement data for synthetic dumbbell particles. Here, a comparison with DDA simulations with a bi-sphere shape model provides information about particle size, particularly the inter-sphere distance as well as the orientation in and out of the image plane. We furthermore present data for biological cells that exhibit strong signs of internal structure in the scattering patterns.

In conclusion, our home-built flow cytometer records angular intensity distributions of the light scattered by microparticles and cells that, when combined with simulations, allow for a quantitative analysis with respect to size, shape, refractive index, and possible internal structures of the scatterers.

-O43-

Optical trapping and manipulation in front of epsilon-near-zero metamaterials

Maria G. Donato, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158 Messina, Italy
Yasaman Kiasat, Department of Electrical and Systems Engineering, University of Pennsylvania, Philadelphia, PA 19104, USA
Michael Hinczewski, Department of Physics, Case Western Reserve University, 10600 Euclid Avenue, 44106, Cleveland, Ohio, USA
Mohamed ElKabbash, Department of Physics, Case Western Reserve University, 10600 Euclid Avenue, 44106, Cleveland, Ohio, USA
Theodore Letsou, Department of Physics, Case Western Reserve University, 10600 Euclid Avenue, 44106, Cleveland, Ohio, USA
Pietro G. Gucciardi, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158 Messina, Italy
Rosalba Saija, Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra,Università di Messina, I-98166 Messina, Italy
Onofrio M. Maragò, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158 Messina, Italy
Giuseppe Strangi, Department of Physics, Case Western Reserve University, 10600 Euclid Avenue, 44106, Cleveland, Ohio, USA; CNR-NANOTEC Istituto di Nanotecnologia and Department of Physics, University of Calabria, Via Pietro Bucci 87036, Rende, Italy
Nader Engheta, Department of Electrical and Systems Engineering, University of Pennsylvania, Philadelphia, PA 19104, USA
maria.donato@cnr.it

Optical tweezers are an extremely sensitive tool for the study of force fields in front of surfaces. This technique allows force sensing in the femtonewton range, with a spatial resolution controlled by the size of the trapped probe. In this work, we use optical tweezers to study light-induced forces on nano- and micro-sized particles in front of dielectric, metallic and epsilon-near-zero (ENZ) metamaterials. Optical forces on nano-and micro-sized particles have been calculated by using Dipole Approximation, finite elements and T-matrix modelling, in order to clarify the role of the surface properties on the particle optomechanics. Complex particles such as ENZ particles, core-shell structures and ellipsoid have been considered. Optical trapping and manipulation experiments have been carried out by using micrometric dielectric particles, allowing the observation of a peculiar dynamics in front of ENZ surfaces, likely due to a thermophoretic force induced by illumination close to the ENZ wavelength. The results suggest a strong light-to-heat conversion efficiency of the ENZ structure, which may be exploited for the tailoring of light-induced forces in optomechanics.

-O44-

Advancing Our Understanding of Solar Radiation in Clouds: PHIPS Probe Reveals New Insights on Light Scattering Behavior of Atmospheric Ice Particles

Martin Schnaiter, Karlsruhe Institute of Technology
Emma Järvinen, Karlsruhe Institute of Technology
Guanglang Xu, Karlsruhe Institute of Technology
martin.schnaiter@kit.edu

The interaction of solar radiation with ice particles in clouds plays a crucial role in redistributing solar light before it reaches the ground. Understanding this process is essential for accurate calculations of the shortwave radiative transfer in climate models and for retrieving cloud bulk properties from satellite observations. However, current knowledge of the light scattering behavior of atmospheric ice particles is limited using simplified ice particle morphologies in optical models.

To address this limitation, the Particle Habit Imaging and Polar Scattering (PHIPS) airborne probe was developed to obtain in-situ measurements of single atmospheric ice particles. The PHIPS probe is a combination of a stereo microscopic bright field imager and a polar nephelometer that works on single atmospheric cloud particles. By using PHIPS, a unique and comprehensive dataset of microphysical properties and correlated angular light scattering functions of real atmospheric ice particles has been acquired from several aircraft campaigns. A catalogue of individual ice crystals is currently being compiled and is accessible at https://www.realicecrystals.de.

The acquired dataset is of high value for scientists developing and applying single particle light scattering models. By simulating the light scattering behavior of real ice crystals with the optical engineering software FRED, the study shows that even solid hexagonal crystals require surface roughness assumptions to accurately explain their light scattering function. The study tests two surface roughness models: the tilted-facet angle distribution method and the "smooth surface roughness" approach, which assumes scalar diffraction on wavelength-scale roughness features. The performance of these two models for the example crystals is discussed. Overall, this study demonstrates the importance of in-situ measurements for improving our understanding of the light scattering behavior of atmospheric ice particles.

-O45-

Radiative Cooling by Sand

Ahmet Hocaoglu, Ozyegin University, Istanbul, Türkiye
Çağla Girişken, Sabancı University, Istanbul, Türkiye
Yusuf Mengeloglu, Sabancı University, Istanbul, Türkiye
M. Pinar Mengüç, Ozyegin University, Istanbul, Türkiye
mpmenguc@gmail.com

Understanding the fundamentals of passive radiative cooling is important for thermal management related to buildings and industrial applications. The principle of radiative cooling in buildings involves selectively reflecting incident radiating heat from the surroundings and selectively emitting energy from a surface to the surrounding to achieve minimum heat load on the system. For the case of buildings, solar radiation incident on roofs can be reflected or absorbed. The absorbed heat is either transferred to the surrounding air by convection or it will be emitted back to the sky. If a surface is desired to be radiatively cooled it must have the large reflection of solar energy at the visible wavelength range and the highest radiation emission at the atmospheric window range (8-13 μm wavelength range). This technique can significantly help reducing the greenhouse gas emission as it will help decreasing the air-conditioner use in warm climates during the summer months.

Recently, the use of nanoparticles and different structures have been considered for passive radiative cooling applications. In this study, we investigate the radiative cooling properties of sand particles experimentally, and compare their performance with other materials. Fourier transform infrared spectroscopy (FT-IR) experiments were conducted in order to measure the spectral absorbance and find the effective absorptivity and emissivity, and then calculating the corresponding power of cooling values of the samples. In FT-IR spectroscopy, key components allow for precise measurements of the reflectivity of materials on a submicron scale. The optical path of the instrument consists of a beam splitter, which separates the incoming light into two paths: a reference beam used as a reference in the measurement, and a sample beam which passes through a probe tip and interacts with the sample and then reflects back by a movable mirror allowing the measurement of the reflectivity of the material as a function of wavelength. After measuring the intensity of the reflected light, the information is processed by a computer to generate the spectrum. The results demonstrate that the some special sand particles can be used for this purpose due to their abundance, low cost, and excellent thermal properties.

-O46-

An observational based parameterization of the light scattering properties of natural ice crystals in the visible region

Guanglang Xu, Karlsruhe Institute of Technology
Martin Schnaiter, Karlsruhe Institute of Technology
Shawn Wagner, Karlsruhe Institute of Technology
Emma Järvinen, Karlsruhe Institute of Technology
guanglang.xu@kit.edu

In this work, we report some new developments on the analysis and parameterization of the angular light scattering properties of real atmospheric ice crystals. First, we deduce a parameter from the Legendre analysis of the scattering phase function of ice crystals. We then theoretically demonstrate the connection of this optical parameter with the morphological complexity of the crystals. The validity of this relation is tested using correlated light scattering and microphysical data measured for atmospheric ice crystals. We then introduce a new surface roughness parameterization based on the so-called Harvey-Shack model. The new parameterization will be tested against measurements and its performance is compared with the commonly used tilted facet roughness model. Some implications on ice cloud remote sensing and radiative effects will be discussed.

References:

Xu, G., Schnaiter, M., & Järvinen,
E. (2022). Accurate retrieval of asymmetry parameter for large and complex ice crystals from in-situ polar nephelometer measurements. Journal of Geophysical Research: Atmospheres, 127, e2021JD036071. https://doi. org/10.1029/2021JD036071

Xu, G., Waitz, F., Wagner, S., Nehlert, F., Schnaiter, M., & Järvinen, E. (2023). Toward better constrained scattering models for natural ice crystals in the visible region. Journal of Geophysical Research: Atmospheres, 128, e2022JD037604. https://doi. org/10.1029/2022JD037604

Xu, G., Waitz, F., Wagner, S., Nehlert, F., Schnaiter, M. and Järvinen, E., 2022. Ice Crystal Morphological Complexity and Asymmetry Parameter: Implications for Light Scattering Measurement. Proceedings of International Radiation Symposium.

Harvey, J.E., 1990, January. Surface scatter phenomena: a linear, shift-invariant process. In Scatter from Optical Components (Vol. 1165, pp. 87-99). SPIE

-O47-

Generalized rainbow patterns of ellipsoidal droplets simulated by the vectorial complex ray model

Qingwei DUAN, Xidian University
Fabrice R.A. Onofri, Aix-Marseille Université, CNRS, IUSTI, UMR 7343
Xiang'e Han, Xidian University
Kuan Fang Ren, Normandie Université, CNRS, CORIA-UMR 6614
qwduan@xidian.edu.cn

Originating from the exploration of natural rainbows, the rainbow refractometry can measure the diameter, refractive index, evaporation rate and other parameters of liquid-gas and liquid-liquid droplets in real time and with high precision. It has been widely applied in many areas covered by fluid mechanics and chemical engineering. However, limited by the existing light scattering models, this technology is generally only applicable to spherical droplets. By experiments it has been found that when a droplet is deformed due to gravity, interfacial stress effects or other forces except the surface force, its rainbow pattern evolves from concentric circular fringes to a series of complex structures, producing what is called the generalized rainbow pattern (GRP). Since the size parameter of such a deformed droplet can greatly exceed 1000, the simulation and inversion of the GRPs can hardly be achieved by analytical models or numerical methods. In this communication, we present for the first time our recent work on the simulation for the GRPs of triaxial ellipsoidal droplets, based on a high-frequency approximation method called the Vectorial Complex Ray Model (VCRM). Furthermore, the relationship between the intensity distribution as well as the polarization characteristics of GRPs with the deformation of droplets is analyzed and discussed. These results are expected to provide a theoretical basis for high-precision measurement of the shape and other parameters of non-spherical droplets.

-O48-

Physical Retrieval Algorithm of Cloud Microphysical Parameters and Preliminary Application

Chenxu Gao, Fudan University
Bingqiang Sun, Fudan University
21113020005@m.fudan.edu.cn

A physical retrieval algorithm is established based on an optimal estimation algorithm and the linearized forward model to iteratively retrieve cloud microphysical parameters such as optical thickness, effective radius, and effective variance by means of the multi-spectral reflectance. Linearized particle scattering algorithms and linearized radiative transfer model are combined as the linearized forward model, which can generate radiative properties as well as their Jacobians. Optimal estimation algorithm uses Bayes' theorem to iteratively obtain the maximum likelihood estimation based on a priori and measurement error covariances. The sensitivities of the retrieval algorithm associated with the error covariances of the priori knowledge, the forward model, and measurements are evaluated and discussed in terms of their information content. Different iterative algorithms are also employed to test the convergent efficiency. After several sensitivity evaluations, the algorithm is applied to retrieve the abovementioned cloud microphysical parameters associated with one layer or two layers. A series of preliminary retrievals are presented altogether with the corresponding retrieval errors.

-O49-

A New Optical Property Database for Improved Ice Cloud Retrievals in Lidar-based Remote Sensing Applications

James Coy, Texas A&M University
Masanori Saito, Texas A&M University
Ping Yang, Texas A&M University
jcoy93@tamu.edu

New ice particle optical property databases are being developed or improved upon to better represent the radiative properties of realistic ice clouds for downstream radiative transfer modeling applications. Various ice particle geometries, either randomly- or horizontally-oriented, and optical property computational methods have been considered for the development of these databases for numerous purposes. There are, however, currently no randomly-oriented ice particle optical property databases that are applicable for lidar-based remote sensing without assumptions having to be made. One of these assumptions is an appropriate range of lidar ratios for ice clouds, as there are no physically rational backscattering models. The commonly-used Improved Geometric Optics Method (IGOM) does not provide accurate scattering phase matrix backscattering calculations for large size parameters which significantly affects the corresponding lidar ratios.

For this study, a new ice particle optical property database has been developed for lidar-based remote sensing applications known as the Lidar Ice Model (LIM). The LIM is comprised of a size-dependent mixture of distorted hexagonal columns (small sizes) and distorted 20-column aggregate ensembles (large sizes). Two versions of the LIM database are available with one version also containing optical properties of a smooth hexagonal column with a mixing ratio of up to 8% (LIM-0%; LIM-8%). Optical property calculations from IGOM are combined with calculations from a physics-based computational method known as the Physical Geometric Optics Method (PGOM) that provides accurate backscattering calculations while maintaining computational efficiency. The lidar ratio, depolarization ratio, and integrated attenuated backscatter (IAB) are calculated using the LIM database and are compared with collocated 532nm Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) lidar and depolarization ratios and IAB observations, and Moderate Resolution Imaging Spectroradiometer (MODIS) ice cloud optical thickness (ICOT) observations. The lidar and depolarization ratios and IAB values computed from LIM are significantly more consistent with the observational data due to the better treatment of backscattering by the PGOM. LIM-8% offers slightly more consistent lidar ratio and IAB calculations but significantly more consistent depolarization ratio calculations than LIM-0%. These results show that utilizing the LIM database will lead to more accurate lidar-based retrievals of ice cloud optical properties.

-O50-

Observational Perspective on Ice Cloud Asymmetry Parameter in Short-wave

Emma Järvinen, Karlsruhe Institute of Technology
Martin Schnaiter, Karlsruhe Institute of Technology, schnaiTEC GmbH
Shawn Wagner, Karlsruhe Institute of Technology
Guanglang Xu, Karlsruhe Institute of Technology
emma.jaervinen@kit.edu

Atmospheric ice crystals exhibit a wide range of crystal geometries, posing a challenge for the mathematical description of their interaction with electromagnetic radiation. Despite the lack of an analytical solution, precise knowledge of the radiative properties of ice crystals is crucial for accurate modeling of climate and weather, as well as remote sensing applications. Simplified ice crystal morphologies, such as pristine hexagonal columns or plates, are often used to numerically estimate the radiative properties of ice clouds.

In this context, we present a new study that aims to deepen our understanding of atmospheric ice crystals by investigating their microphysical and angular light scattering properties. Our observations were conducted using the airborne single-particle polar nephelometer PHIPS, which provided us with a direct link between the ice crystal microphysical properties and their angular light scattering function. Our research is based on observations from four airborne campaigns that spanned mixed-phase and cirrus clouds across various locations from the Arctic to the Southern Ocean.

Our study highlights the magnitude and variation of the ice cloud asymmetry parameter with respect to different locations and environmental conditions. Furthermore, we used the single-particle light scattering data to investigate the angular scattering properties of ice crystal ensembles categorized by their habit, aspect ratio, and surface distortions. We also discussed the sensitivity of the short-wave asymmetry parameter to these microphysical features.

Overall, our research provides valuable insights into the microphysical and radiative properties of atmospheric ice crystals. Our findings may contribute to development of new optical particle models and refinement of the magnitude of cloud asymmetry parameter assumed in radiative transfer simulations.

-O51-

Wow stories in the GLMT landscape

Gérard Gouesbet, Université de Normandie et INSA de Rouen
gouesbet@coria.fr

As the 2020 winner of the van de Hulst Award, I have been committed to the presentation of an Award lecture. The Award has been essentially motivated by my work on laser light scattering by particles, which spreads over 40 years. During this time, I may have obtained several results of interest, but some of them made me feeling this kind of extraordinary shocks, both emotional and psychological, to which it is only possible to react by a booming "Wow !". Therefore, my presentation will deal with such wows, more speciÖcally with four wow stories related to the development of generalized Lorenz-Mie theories. They concern (i) the validity of the optical theorem (ii) the speed of laser light, slower than c even in vacuum (iii) the speed of light spots, faster than c and (iv) the "nature" of photons. This last issue required to extend the discussion from pure scientiÖc issues to an epistemological discussion pertaining to the philosophy of sciences.

-O52-

Measurements of microwave analogs for EM and light scattering studies

Geffrin, Aix Marseille Univ, CNRS, Centrale Marseille, Institut Fresnel, Marseille, France
Tobon Valencia, Aix Marseille Univ, CNRS, Centrale Marseille, Institut Fresnel, Marseille, France
Tortel, Aix Marseille Univ, CNRS, Centrale Marseille, Institut Fresnel, Marseille, France
Litman, Aix Marseille Univ, CNRS, Centrale Marseille, Institut Fresnel, Marseille, France
Ménard, Univ. Grenoble Alpes, CNRS, IPAG, 38000 Grenoble, France
jean-michel.geffrin@fresnel.fr

Based on the Scale Invariance Rule, the microwave analogy is well known since the sixties and the work made by Greensberg's group. Nowadays, technical advances in microwave measurements devices, combined with the progress in 3D printing allow in-lab characterizations of the scattering properties of a large range of objects whose geometry and refractive index characteristics can be monitored. From measurements of the complex scattered field of a given particle carried out in controlled conditions at several orientations, we derive its Jones and Mueller matrix parameters under a weak coupling assumption. The number of relevant views is determined by controlling the convergence of our results [1]. As our measurements vary in frequency between 3 and 18 GHz, we use the scaling capability to combine the particles response at different scales, thus mimicking a population of particles with a chosen distribution law [2]. Furthermore, thanks to the capacity of our equipment to deliver calibrated complex measured fields, other combinations may be made, like, for example with a privileged orientation of the particles.

As we made such measurements with an increasing variety of particles, we decided to share our measurements and simulations results through a database named EMSCOP: (cf. fresnel.fr/EMSCOP). This database will regularly be enriched (thanks to ERC project DUST2PLANETS, GA No. 101053020). We will show here some examples of results obtained with aggregates and rough particles and comparisons with computations obtained with our with our FEM code. The next evolution of our experimental setup is already in progress (thanks to France 2030 project IDEC, ANR-21-ESRE-0002), and we will show how, with a dual gantry arm setup, we will be able to measure the scattered field almost all around the object under test.

[1] Renard, J. B. et al (2021). Number of independent measurements required to obtain reliable mean scattering properties of irregular particles having a small size parameter, using microwave analogy measurements. Journal of Quantitative Spectroscopy and Radiative Transfer, 272, 107718.

[2] Vanesa Tobon Valencia. Exploring the formation of planets with microwave measurements of protoplanetary dust analogs. Physics [physics]. Université d'Aix-Marseille, 2022. English. ⟨NNT : ⟩. ⟨tel-03962660⟩

-O53-

Design of an active light scattering system for interstellar dust characteristics in future Comet exploration mission

Jiajie Wang, School of Physics, Xidian University, China
Cunhui Li, Lanzhou Institute of Physics, China Academy of Space Technology, Lanzhou, China
Zecheng Cui, School of Physics, Xidian University, China
Chengxuan Zhao, Lanzhou Institute of Physics, China Academy of Space Technology, Lanzhou, China
wangjiajie@xidian.edu.cn

The characterization of the interstellar dust can provide significant information on the origin and evolution of planets and comets. Remote sensing of cometary dust environment based on optical/microwave spectroscopy probes gave us lot of information on the distribution of dust particles among the deep space. Nevertheless, this kind of detection is of limited capability due to its low resolution. Starting from the 1960s, developments of various types of in-situ dust payloads to characterize cometary, planetary and interplanetary dust environments becoming one of the focuses in deep space exploration. Among those payloads, the Grain Impact Analyzer and Dust Accumulator (GIADA), part of the ROSETTA scientific payload, implemented a long period in situ dust measurements. In GIADA, a Grain Detection System (GDS) was used to detect the speed and size of a dust particle by optical detection, and an Impact Sensor (IS) measured the momentum released during the particle impact on an aluminum plate. In this way, momentum, velocity and mass of single particles can be measured.

Recently, a mission to perform rendezvous with comet within the main asteroid belt was proposed, in which payload to detect the properties of interstellar dust will be included. Due to the advantages of high-accuracy, non-contact, and no perturbation to particle dynamics properties, the measurement methods based on light scattering is one of the most attractive candidates. In this talk, we report a laser-based optical measurement system, which was designed to detect the properties of a single slow (less than 1 km/s) dust particle. In this system, a detection area of 50mm*50mm laser curtain was generated by transforming the laser beam in Gaussian profile to a laser sheet with a rectangular uniform profile. When a dust particle passes through the laser curtain, scattered light will be generated and collected by a compound parabolic concentrator (CPC) and then be converted into an electrical signal by a PIN photodiode. The amplitude and duration of electrical signals, are used to extract the particle scattering cross-sections and the speed of the dust, respectively.

-O54-

Modeling the asteroid polarization of the DART mission impact ejecta

Antti Penttilä, Department of Physics, University of Helsinki, Finland
antti.i.penttila@helsinki.fi

The DART spacecraft by NASA did a successful kinetic impact experiment to Dimorphos, the smaller body of the binary asteroid system Didymos, on September 26th, 2022. As a result, a large amount of dust was ejected from the body. This ejecta cloud was extensively studied by a world-wide observing campaign, including also in-situ imaging by the Italian LICIACube satellite during its flyby about 3 minutes after the DART impact.

While the ejecta cloud is well observed in photometry, polarization measurements are more rare. We will report the linear polarization observations of the Didymos system taken with the FORS2 instrument on VLT (PI Stefano Bagnulo) and with the ALFOSC instrument on NOT (PI Mikael Granvik). These observations cover the timeline from pre-impact to post-impact, from 18.8.2022 to 18.1.2023.

The observations suggest a change in the system's polarization behavior due to the impact. This can clearly be credited to the dust ejecta cloud covering the system. The change in the polarization can be used to study the properties of the dust, and the derived dust models will be reported in the presentation.

-O55-

The scattering properties of centaur 174P/Echeclus

Oleksandra Ivanova (1,2,3); Johannes Markkanen (4,5); Igor Luk'yanyk (3), (1) Astronomical Institute of the Slovak Academy of Sciences, Slovak Republic; (2) Main Astronomical Observatory of the National Academy of Sciences of Ukraine, Ukraine; (3) Astronomical Observatory of Taras Shevchenko National University of Kyiv, Ukraine; (4) Institute für Geophysik und Extraterrestrische Physik, Germany; (5) Max Planck Institute for Solar System Research, Germany
oivanova@ta3.sk

Among the different small bodies belonging to the Solar system, centaurs are representative of the transitional objects that come from the population of Kuiper belt objects. Many of them are scattered inward on unstable orbits with dynamical lifetimes around 10^6–10^7 years, and some become Jupiter family comets. More than 13 percent of these objects show comet-like activity. Therefore, studying active Centaurs is important for a better understanding of the origin of Jupiter family comets. They are often unpredictable outbursts and are not necessarily correlated with the Centaur's perihelion distance. One well-known active Centaur is 174P/Echeclus, which had four major outbursts in 2005, 2011, 2016, and 2017, and one found in Spacewatch images taken in January 2000. It has a period of 35.06 years and its heliocentric distance varies from 5.81 to 15.61 au. 174P/Echeclus is a small Centaur with a diameter of 64.6±1.6 km and an albedo of 5.2 (Duffard et al. 2014). Apparently, it has no ice absorption features (Guilbert et al. 2009; Seccull et al. 2019) and is more steeply red at visible wavelengths than near-infrared ones. We present new results of linear polarization measurements for 174P/Echeclus in the non-active period. Linear polarization of this object was obtained at phase angles near 3 degrees. Using our photometric and polarimetric observations of this Centaur, we attempted to model the physical characteristics of its dust environment.

-O56-

Analysis of Cryovolcano Plumes on Enceladus by Light Scattering and Polarimetry

Claudia Morello, Kansas State University
Matthew Berg, Kansas State University
morelloc@phys.ksu.edu

Enceladus, the sixth largest moon of Saturn, was investigated by NASA's Cassini spacecraft from 2004-2017 and was found to have cryovolcanoes, or geysers, on its south pole. As one of the most geologically active bodies in the solar system, Enceladus quickly became a hot topic in planetary science. Enceladus was also found to have a subsurface global liquid ocean hidden under a thick layer of ice, which makes it a possible location for extra-terrestrial life. Cassini completed several flybys of Enceladus where it photographed its surface and the cryocolcano plumes with the Imaging Science Subsystem (ISS). Images were taken in several filters as well as with linear polarizers at various scattering angles and orbital positions. It is known that larger particles ejected from the cryovolcanoes land back on the surface, while smaller particles escape into Saturn's E-Ring, so studying the surface offers more information about the particles in the plumes. Using this knowledge, the particles are constrained to several possible size distributions and shapes. This work presents the polarization data of Enceladus' surface, which has never before been analyzed, and the possible particle distributions as simulated in ADDA, the Amsterdam Discrete Dipole Approximation code, and compared to the Cassini ISS data.

-O57-

Ice crystal halos and comets

Jarmo Moilanen, 1) Finnish Geospatial Research Institute (FGI), 2) Faculty of Science, Helsinki University, Finland
jarmo.moilanen@nls.fi

Atmospheric halos are light scattering phenomena caused by airborne crystals of water ice in the atmosphere. Halos provide information on what kind of ice crystals are present in the sky. Atmospheric halos are known to exist on Earth and on Mars.

Presence of water ice in comets is known for a long time and water has been detected in interstellar space as molecular clouds. Observations of halos could be an additional identifier of the water and serve as an information source on ice crystal types.

Phase diagrams of ice suggest three crystalline and stabile water ice phases in space. The hexagonal ice, the cubic ice and the orthorhombic ice XI. The fourth phase expected to exist in space is the amorphous ice, but without crystalline structure it does not produce halos. If spherical droplets of amorphous ice exist in space a rainbow like phenomena, the Bouguer's halo, could be possible.

It is possible that ice crystal halos cannot be observed in spaceborne ice. That would indicate that ice crystals do not grow large or transparent enough to produce observable halos. If they do grow large enough, mainly circular halos from randomly oriented ice crystals can exist, although ice crystals may orient due to electromagnetic fields. Randomly oriented ice crystals should be located on a so-called Minnaert's Cigar, an elliptical or vesical piscis like 3D revolution surface to light up a halo. One end of the cigar is the light source and the other end is an observer. Since the angular size of a comet viewed from Earth is usually smaller than the apparent size of a halo, a possible halo probably causes anomalous brightening of a comet.

An ice crystal halo of a comet may not be easy to observe with existing techniques. The comet has to be in a vicinity of the Sun from the observer's point of view and in interplanetary space between the Sun and Earth. When the comet is close to the Sun, the sky is too bright to get a good observability from the ground. Such observations may be feasible using space-based facility.

-O58-

Observational Strategy for Danuri/PolCam Measurements of the Lunar Surface from Orbit

Chae Kyung Sim, Korea Astronomy and Space Science Institute
Minsup Jeong, Korea Astronomy and Space Science Institute
Young-Jun Choi, Korea Astronomy and Space Science Institute
Yuriy Shkuratov, V.N. Karazin Kharkiv National University
sungsoo.kim@khu.ac.kr

PolCam, a wide-angle polarimetric camera, is onboard the Korea Pathfinder Lunar Orbiter (Danuri) to investigate the lunar surface based on polarimetry. PolCam will construct a global lunar map of polarimetric parameters, such as maximal polarization (P_max) and titanium distribution using three color bands centered at 320, 430, and 750 nm. PolCam's twin cameras are mounted at 45° tilt angles from the nadir across the orbital track in opposite directions. PolCam will obtain polarimetric measurements of sunlight scattered by the lunar surface at various phase angles up to ~140° to achieve the scientific goals during the one-year mission. Since degree of linear polarization is a function of phase angle, it is essential to perform several measurements at various phase angles to properly retrieve, e.g., P max, P min, and the inversion angle, α_inv. In this work, we show PolCam's phase-angle coverage as a function of selenographic longitudes from the equator to latitudes up to 70°. Decreasing tilt angle to 25° and 0° limits the high end of phase-angle coverage, as well as the observational chances at high latitudes.

-O59-

Fast Variations of Color in Comet C/2016 M1 (PanSTARRS)

Anhelina Voitko, Astronomical Institute of the Slovak Academy of Sciences, SK 05960 Tatranská Lomnica, Slovak Republic
Evgenij Zubko, Humanitas College, Kyung Hee University, 1732, Deogyeong-daero, Giheung-gu, Yongin-si, Gyeonggi-do 17104, South Korea
Oleksandra Ivanova, Astronomical Institute of the Slovak Academy of Sciences, SK 05960 Tatranská Lomnica, Slovak Republic; Main Astronomical Observatory of National Academy of Sciences, 27 Akademika Zabolotnoho St., 03143, Kyiv, Ukraine; Astronomical Observatory, Taras Shevchenko National University of Kyiv, 3 Observatorna St., 04053, Kyiv, Ukraine
avoitko@ta3.sk

We analyze the results of photometric observations of Comet C/2016 M1 (PanSTARRS) performed at the Skalnate Pleso Observatory (AI SAS) on August 23 – 30, 2017. Heliocentric distance and phase angle changed from 4.346 au to 4.289 au and from 13.4° to 13.6°, respectively. Gaseous emissions are rarely observed at such long distances from the Sun and, hence, the measured flux of radiation predominantly arises from elastic light scattering by dust particles populating coma.

The observations were conducted on 6 nights using the 0.61-m Newtonian telescope equipped with the broadband filters B, V, and R of the Johnson-Cousins photometric system. Over the course of our observations, the comet appeared to have nearly the same brightness. However, we have detected noticeable variations of its color within the aperture radius of ~28,000 km. For instance, the color slope computed using the photometric measurements in the B and R filters was as high as S’ = 11.49 ± 0.91 % per 0.1 µm on August 23. Two days later, on August 25, the color of C/2016 M1 (PanSTARRS) appeared to be noticeably more neutral, S’ = 3.69 ± 0.92 % per 0.1 µm, whereas on the next day, August 26, it was found to be formally negative, S’ = –0.46 ± 0.92 % per 0.1 µm. Note, the positive values of the color slope imply the red photometric color of dust, and the negative values are the blue photometric color. Thus, in only three days, Comet C/2016 M1 (PanSTARRS) turned out to change its color from red to blue. It is worth noting that similar dramatic variations of color were observed previously in the long-period comets and the short-period comets. We analyze the spatial variations of the color in Comet C/2016 M1 (PanSTARRS) using the model of the agglomerated debris particles.

-O60-

Dust properties and their variations in comet C/2013 X1 (PanSTARRS))

Olena Shubina, 1. Astronomical Institute of the Slovak Academy of Sciences, Slovak Republic; 2. Main astronomical observatory of National academy of sciences of Ukraine, Ukraine
Evgenij Zubko, 3. Humanitas College, Kyung Hee University, Gyeonggi-do, 17104, South Korea
Valery Kleshchonok, 4. Astronomical Observatory of Taras Shevchenko National University of Kyiv, Ukraine; 5. Max Planck Institute for Solar System Research, , Gottingen, Germany
Marek Husárik, 1. Astronomical Institute of the Slovak Academy of Sciences, Slovak Republic
Oleksandra Ivanova, 1. Astronomical Institute of the Slovak Academy of Sciences, Slovak Republic; 2. Main astronomical observatory of National academy of sciences of Ukraine, Ukraine; 4. Astronomical Observatory of Taras Shevchenko National University of Kyiv, Ukraine
oshubina@ta3.sk

We present the results of monitoring photometric observations of comet C/2013 X1 (PanSTARRS) during December 2015 and January 2016 obtained within B, V, and R Johnson-Cousins filters. The analysis revealed a sharp increase in comet brightness on January 1, 2016. Calculation of B-V and V-R colors within an aperture size of ~5000 km demonstrate typical red values except for the date of the outburst. Dust productivities (Afρ proxy) and normalized spectral gradient S'(B-R) showed dramatic changes on January 1. Applying the geometrical model to observed data, we studied the evolution of morphological structures over the cometary coma. The model of agglomerated debris particles was used to determine the optical parameters of dust and interpret the observed color variations.

-O61-

The role of dust in the Martian atmosphere

A.C. Vandaele, IASB-BIRA, Brussels, Belgium
L. Neary, IASB-BIRA, Brussels, Belgium
Y. Willame, IASB-BIRA, Brussels, Belgium
O. Munoz, IAA-CSIC, Granada, Spain
T. Jardiel, CSV-CSIC, Madrid, Spain
G. Wurm, UDE, Duisburg, Germany
J. Merrison, AU, Aarhus, Denmark
a-c.vandaele@aeronomie.be

Dust is present everywhere on Mars, yet its abundance, physical properties, size distribution as well as its impact on the composition, structure and dynamics of the atmosphere has today only barely been addressed and understood. The amount of dust in the atmosphere of Mars has a seasonal cycle with large inter-annual variability, with some years having smaller regional scale dust storms and some years developing into a global, planet-encircling dust storm. The nature of this variability is still unknown and is an open question in Mars research. The understanding of the mechanisms involved in getting dust from the surface into the atmosphere is of major importance. The dust and water cycles are coupled through cloud condensation processes, but dust also modifies the thermal structure of the atmosphere. Dust also highly impacts the radiative interaction of radiation with the atmosphere as dust absorbs and scatters light. This also affects remote sensing observations.

We will give an overview of the different properties of dust on Mars and show how these impact the Martian atmosphere and its exploration.

-O62-

Retrieving optical properties of dust particles from laboratory data: refractive indices and scattering matrix elements

Julia Martikainen, Instituto de Astrofísica de Andalucía (CSIC), Granada, Spain
Olga Muñoz, Instituto de Astrofísica de Andalucía (CSIC), Granada, Spain
Teresa Jardiel, Instituto de Cerámica y Vidrio (CSIC), Madrid, Spain
Marco Peiteado, Instituto de Cerámica y Vidrio (CSIC), Madrid, Spain
Juan Carlos Gómez Martín, Instituto de Astrofísica de Andalucía (CSIC), Granada, Spain
Yannick Willame, Belgian Institute for Space Aeronomy (IASB-BIRA), Brussels, Belgium
Antti Penttilä, University of Helsinki, Finland
Karri Muinonen, University of Helsinki, Finland
Gerhard Wurm, University of Duisburg-Essen, Duisburg, Germany
Tim Becker, University of Duisburg-Essen, Duisburg, Germany
juliamar@iaa.es

We present an advanced light-scattering model to retrieve scattering properties of martian dust analogues from laboratory measurements. The retrieval was carried out in two parts: first, we computed the optical constants of the samples. Then, the derived values were used together with a single-scattering database to model the measured scattering matrices of the analogues and to retrieve their scattering properties.

Optical constants, the complex refractive indices, are needed from modelling single-particle scattering by the atmospheric dust to simulating the martian climate in a global scale. However, reliable complex refractive indices of martian dust are difficult to find in the literature. We performed laboratory measurements to obtain narrow particle size distributions in the geometric optics domain, shapes, and diffuse reflectance spectra of the martian dust analogues deposited on a surface. The model framework contains a ray-optics code to compute scattering properties for individual particles, and a radiative transfer treatment to simulate the surface. The irregular shapes of the dust particles are taken into account in the model.
The scattering properties of the analogues were retrieved by using the computed refractive indices, measured scattering matrices, and a database of single-scattering properties of hexahedral shapes (Saito et al. 2021, J. Atmos. Sci. 78) The database was developed by using a combination of three computational methods: the T-matrix method, the discrete-dipole approximation (DDA), and an improved geometric optics method. The database consists of pre-calculated scattering properties over a broad range of complex refractive indices, particle sizes, particle shapes, and wavelengths. The modelled scattering matrices were then compared with those obtained using spherical shapes. Finally, the best-fit model gives us physical properties of the particles such as cross sections, single-scattering albedos, extinction efficiencies, asymmetry factors, and Legendre polynomials used to mathematically calculate the phase functions.

-O63-

Deriving the complex refractive index of a mm-sized acoustically levitated single particle using laboratory measurements

Mikko Vuori, University of Helsinki
Antti Penttilä, University of Helsinki
Karri Muinonen, University of Helsinki
mikko.vuori@helsinki.fi

A method for deriving the complex refractive index of a mm-sized single-particle in a specific wavelength using laboratory measurements is presented. Laboratory measurements were done using the 4π scatterometer, which measures Mueller matrix elements of a particle suspended in air using acoustic levitation as a function of scattering angle. To obtain the complex refractive index of the particle, measurements were compared to simulations from a newly modified SIRIS4 Fixed Orientation (SIRIS4 FO) geometric optics simulation.

The 4π scatterometer is a unique instrument which measures Mueller matrix elements from a particle using linear polarizers and a detector rotating around the particle on a rotational stage. The scatterometer uses an acoustic levitator as a sample holder, which provides nondestructive measurements and full orientation control of the sample.

To compare the measurement results to simulations, SIRIS4 single-particle geometric optics code was modified to handle particles in a fixed orientation. The original code is able to calculate the Mueller matrix elements for a given 3D model, but averages the results over the orientation of the particle. The modified SIRIS4 FO calculates the Mueller matrix elements over the full solid angle around the particle as functions of the two scattering angles defined by the scattering plane. A 3D model of the shape of the measured particle was constructed using X-ray microtomography and was translated to SIRIS4 FO.

The complex refractive index was obtained with the least-squares method by minimizing the sum of squared residuals between the measurements and simulations with varying refractive index values.
Finally confidence regions were constrained for the results, by estimating the random errors in the method to be in the size of the computed residuals.

-O64-

The 2007 dust trail of the comet 17P/Holmes — open call for light scattering modelling and observations

Maria Gritsevich, Finnish Geospatial Research Institute
Markku Nissinen, Ursa Astronomical Association
Jorma Ryske, Ursa Astronomical Association
Jari Suomela, Clayhole observatory
Arto Oksanen, Hankasalmi observatory
Alberto Javier Castro-Tirado, Institute of Astrophysics of Andalucía (IAA-CSIC)
Ioana Boaca, Astronomical Institute of the Romanian Academy
Veikko Mäkelä, Ursa Astronomical Association
Elizabeth Silber, Department of Earth Sciences, Western University
Josep Maria Trigo-Rodríguez, Institute of Space Sciences (IEEC-CSIC)
maria.gritsevich@helsinki.fi

During its recede from the Sun in 2007, comet 17P/Holmes underwent an enormous and sudden increase in brightness. The magnitude of the comet altered from a pre-outburst value of ~17 on 2007 October 23.1 to 2.0 by 2007 October 25.1, which is equivalent to an increase in brightness by a factor of one million. This unique event is relatively well documented and is the largest outburst by a comet thus far recorded in the history of astronomical observations. To study this phenomenon we use a recently introduced model [1] capable of describing the evolution of a cometary dust trail coupled with novel particle-releasing algorithms. The resulting Dust Trail kit model accounts for solar radiation pressure effects and gravitational disturbances. We simulate several particle populations with sizes ranging from 0.001 to 1 mm by varying assumptions about ejection speed distribution of the particles at the start of the outburst. The model is validated against our earlier observations of the trail obtained in common nodes for 0.5 and 1 revolutions. Using these data, we made predictions for the two-revolution dust trail behavior near the outburst point and the observability from Earth of the cometary material released in the event [1]. We have further developed a set of Python scripts to calculate position of the dust trail for observatory topographical location coordinates [2]. Using these predictions, a set of new observations of the 2007 outburst dust trail was obtained in February, March, October, December 2022, and in February 2023. The trail is still observable by using ground-based telescopes. The existence of an observable dust trail implies a vast amount of micron-sized particles scattering sunlight. Both the surface brightness and the position of the dust trail are within the limits of the published predictions provided by the Dust Trail kit model [1, 2].

1. Gritsevich M., Nissinen M., Oksanen A., Suomela J., Silber E.A. (2022). Evolution of the dust trail of comet 17P/Holmes, Monthly Notices of the Royal Astronomical Society, 513(2), 2201–2214, https://doi.org/10.1093/mnras/stac822

2. Nissinen M., Gritsevich M. (2022). Instructions on where and how to observe the comet 7P/Holmes dust trail. Zenodo. https://doi.org/10.5281/zenodo.6977358

-O65-

Planetary surface characterization by modeling radar scattering

Anne Virkki, University of Helsinki
anne.virkki@helsinki.fi

Radar observations provide a remote-sensing method to geologic and physical characterization of the terrestrial planets, moons, and small Solar System bodies. They can provide clues of the near-surface density and surface roughness in the centimeter-to-decimeter scale, and improve the size estimates of asteroids, which is fundamental to both planetary science and planetary defense. However, the physical interpretation of the radar-scattering laws is often presented vaguely or not at all. I conducted numerical modeling to investigate microwave scattering laws developed since 1960s with a fresh look and to improve the physical interpretation for empirical laws that are used widely but often interpreted vaguely. Here, I compared the scattering signatures of different types of surfaces from stationary (non-fractal) to self-affine (fractal) surfaces and introduce a radar scattering law that combines some of the laws introduced in the past, including a clear guide on interpretation.

In microwave scattering, scattering laws based on the ray-optics regime alone are applicable to backscattering by surfaces composed of micrometer-scale particles due to the modest height undulations and illumination using long wavelengths with respect to the particle sizes. Nevertheless, using numerical methods also allows us to add wavelength-scale particle scatterers, which is necessary especially for asteroids that are visibly composed of centimeter-to-meter scale regolith and boulders, such as (101944) Bennu. While the ray-optics scattering is sufficient for the quasi-specular component, including the resonance-regime scattering by the wavelength-scale particles is necessary if a significant diffuse component is observed. The radar-polarimetric signatures of asteroids cannot be explained only by the quasi-specular scattering, if part of the signature arises dominantly from wavelength-scale particles, in which case the polarimetric signature describes rather the physical properties (the shape, size, and electric permittivity) of the particles than the asteroid in a holistic sense. I present numerically computed radar-polarimetric signatures of particles with shapes comparable to boulders on asteroids and a few different refractive indices to demonstrate the role that the physical properties of the particles play.

-O66-

light scattering by circumstellar dust disks

Francois MENARD, IPAG, Grenoble, France
francois.menard@univ-grenoble-alpes.fr

In this review I will present several of the latest observational attempts to reveal dust properties in protoplanetary and debris disks. Dust sizes and chemical composition of dust in disks have been studied abundantly in the past via, e.g., spectral energy distributions and near- and mid-spectroscopy. In this review I will place a special emphasis on recent attempts to highlight the particle shapes instead. This can be done via the measurements of scattering properties, i.e., intensity and linear polarisation phase functions, from the optical to the millimetric wavelength range. These recent advances are particularly interesting to connect the dust properties in disks to the dust evolution and growth mechanisms, a better understanding of which is needed to advance our knowledge of the first stages of planet formation.

To reveal the meaning of these observations, it is necessary to compare them with the "measured" or "calculated" scattering properties of complex dust particles, be them irregular, with rough surfaces, or of fractal nature. I will therefore also present the recent efforts of a few groups to measure the scattering properties of complex dust particles relevant for young disks. To wrap up I will briefly discuss my personal view of future avenues to better understand the evolution of dust in disks.

-O67-

Scattering properties of microwave analogs of protoplanetary dust aggregates

Vanesa TOBON-VALENCIA, Aix-Marseille Univ, CNRS, ECM, Institut Fresnel, Marseille, France
Jean-Michel GEFFRIN, Aix-Marseille Univ, CNRS, ECM, Institut Fresnel, Marseille, France
Amelie LITMAN, Aix-Marseille Univ, CNRS, ECM, Institut Fresnel, Marseille, France
Herve TORTEL, Aix-Marseille Univ, CNRS, ECM, Institut Fresnel, Marseille, France
Francois MENARD, Univ. Grenoble Alpes, CNRS, IPAG, Grenoble, France
amelie.litman@fresnel.fr

Scientists have still some unanswered questions regarding the formation of protoplanets, such as how to overcome the physical barriers in the standard accretion scenario models. To improve the correlation between the telescopic observations of protoplanetary disks (where planets form) and the proposed models, analogs of protoplanetary dust have been 3D-printed with a fractal aggregate morphology. Their scattering properties have been measured and simulated in the microwave range, thanks to the scale invariance properties of Maxwell's equations. Multi-angle measurements are acquired in an anechoic chamber on a large frequency range, while the simulations are performed with a finite element solver based on a scattered field formalism.

In this presentation, we will discuss the results obtained on 7 different aggregate structures with aggregate size parameter ranging from 1 to 20, and with fractal dimension ranging from 1.5 to 2.8 [1]. Indeed, the aggregate characteristics will directly influence their scattering properties such as their scattering cross-sections, phase function, asymmetry parameter, degree of polarization. The comparisons between the resulting measured and simulated scattering properties will be detailed for a single-orientation aggregate and for an orientation-averaged aggregate. We will go into more details on how the different scattering properties were retrieved and how to correlate phase function, size parameter and fractal dimension.

[1] "Scattering properties of protoplanetary dust analogs with microwave analogy: Aggregates of fractal dimensions from 1.5 to 2.8", V. Tobon-Valencia et al, Astronomy & Astrophysics, 666, A68 (2022)

-O68-

Experimental phase function and degree of linear polarization of light scattered by amorphous carbon circumstellar dust analogues

J.C. Gómez Martín, Instituto de Astrofísica de Andalucía, CSIC
O. Muñoz, Instituto de Astrofísica de Andalucía, CSIC
I. Tanarro, Instituto de Estructura de la Materia, CSIC
R. J. Peláez, Instituto de Estructura de la Materia, CSIC
B. Maté, Instituto de Estructura de la Materia, CSIC
M. J. Redondo, Instituto de Estructura de la Materia, CSIC
V. Herrero, Instituto de Estructura de la Materia, CSIC
M. Peiteado, Instituto de Cerámica y Vidrio, CSIC
T. Jardiel, Instituto de Cerámica y Vidrio, CSIC
jcgomez@iaa.es

Astronomical observations of polarized intensity of scattered visible light have revealed the presence of dust envelopes around different types of evolved stars. These observations have helped to determine the diameter and width of dust shells around stars with unprecedented accuracy. Simple geometric particle models have been used in the past in order to retrieve dust properties from these observations. In this work we have synthesized and characterized a particulate sample of hydrogenated amorphous carbon (HAC), which is considered to be a realistic carbonaceous interstellar dust analogue based on infrared absorption spectroscopy, and we have measured its phase function and degree of linear polarization at 514 nm using the CODULAB apparatus at IAA-CSIC. The experimental light scattering data has been examined in order to explore possible improvements in the interpretation of astronomical observations from the point of view of the retrieval of dust properties, including size, porosity and optical constants. In addition, an internal 50% wt mixture of HAC and an ultrafine crystalline silicate powder has been generated to study the effect of the mixing of these two components on the light scattering behavior of dust in circumstellar environments and protoplanetary disks.

-O69-

Phase function and degree of linear polarization measurements for KCl particles as an exoplanet cloud analog

Colin D. Hamill, Purdue Universiy
Alexandria V. Johnson, Purdue University
hamillc@purdue.edu

Clouds and hazes appear to be ubiquitous features of exoplanetary atmospheres, and their presence has stark consequences on the light scattering and radiative balance of these atmospheres. Exoplanet clouds are typically inferred from muted transmission spectra, as optically thick clouds keep photons from penetrating the atmosphere. This means that the exact cloud composition and structure for exoplanets remains unknown with current spectral observations. A laboratory-based understanding of how these cloud particles scatter light across particle size distributions, chemical compositions, and shapes is needed to make the most of current and future observations. Here we present the Exoplanet Cloud Ensemble Scattering System (ExCESS), an apparatus designed to measure the scattering intensity and degree of linear polarization (DOLP) for an ensemble of particles at cloud-relevant sizes and number densities. ExCESS illuminates particles with a polarized laser beam (405 or 532 nm) passed through an electro-optic modulator, and uses a high temperature photomultiplier tube to sweep the plane of illumination from viewing angles of 20° - 169°. I will discuss the scattering phase functions and DOLP measurements for potassium chloride (KCl) particles at three distinct size distributions ($\bar{r}$ ~ 0.6-1.2 um) representative of modeled clouds for the warm (T ~ 500 K) exoplanet GJ 1214b. KCl particles are aerosolized with either a wet or dry generation method to produce cubic and cuboid/irregular shaped particles, respectively. I will also discuss the comparison of our laboratory findings to Lorenz-Mie calculations, which were found to poorly represent the scattering and polarizing properties of cubic and irregularly shaped KCl particles. While we conclude that Mie scattering offers an inaccurate depiction of irregular particle scattering and that more work is needed to accurately simulate the scattering properties of irregular cloud particles, our measurements indicate that low backscattering and preferentially vertically polarized observations may be signs of non-spherical KCl cloud particles in warm exoplanets. Finally, I will briefly discuss the extension of our measuring capabilities to the red and near infrared to provide data comparable to current and upcoming space telescopes. This data will be used to help characterize exoplanet observations and synthetic spectra models.

-O70-

Self-scattering by non-spherical particles in protoplanetary disks

D. Guirado, Instituto de Astrofísica de Andalucía – CSIC
C. Carrasco-González, Instituto de Radioastronomía y Astrofísica – UNAM
P. Aguadero, Instituto de Astrofísica de Andalucía – CSIC
J. Martikainen, Instituto de Astrofísica de Andalucía – CSIC
O. Muñoz, Instituto de Astrofísica de Andalucía – CSIC
J. C. Gómez Martín, Instituto de Astrofísica de Andalucía – CSIC
F. Moreno, Instituto de Astrofísica de Andalucía – CSIC
E. Macías, European Southern Observatory (ESO-Garching)
A. Sierra, Universidad de Chile
dani@iaa.es

Knowing the exact physical properties of dust in protoplanetary disks is essential in order to understand dust growth mechanisms and, eventually, the process of planet formation. Multiwavelength observations in the millimeter range has been proven to be a powerful strategy, especially for very large wavelengths, because of two reasons: (i) disks are optically thinner for larger wavelengths in this regime and (ii) larger wavelengths trace larger particles, as the scattering resonance occurs when the wavelength is of the order of the size of the particle. Light scattering in this resonance regime is highly sensitive to size, composition and, in particular, the structure of the grains: overall shape, compact/fluffy, fractal aggregate/solid, etc. Historically, only homogeneous compact spherical particles have been considered for radiative transfer modeling of disks. Both calculations and experiments have revealed the radical improvement that is achieved by using-non spherical particles in modeling of radiative transfer in cometary comae, planetary atmospheres and other astrophysical scenarios, even if only flux is considered, but much more when the focus is on polarization.

In the mm-wavelength regime, observed radiation it is not the star radiation scattered by dust in the disk, but mainly it is due to the thermal emission by all particles, that is scattered by each other. This is called self-scattering, and a linear polarization effect is associated to it when observed disks are not face-on.

In this work we present some results on self-scattering by non-spherical (irregular hexahedrals) compact particles in protoplanetary disks based on the TAMU Dust 2020 light scattering database, and compare with the case for spheres. In addition, a preliminary study on the effect of porosity of the particles in the disks is presented as well. The sensitivity of the observable magnitudes to these shape effects is discussed, in order to prepare for the investigation of protoplanetary disks by observation through new large facilities as SKA and ngVLA.

POSTERS

-P01-

Coherent extinction enhancement in a thin layer of dielectric nanospheres with an effective medium behaviour

Anays Acevedo-Barrera, Departamento de Física, Facultad de Ciencias, Universidad Nacional Autónoma de México
Ricardo Méndez-Fragoso, Departamento de Física, Facultad de Ciencias, Universidad Nacional Autónoma de México
Augusto García-Valenzuela, Instituto de Ciencias Aplicadas y Tecnología, Universidad Nacional Autónoma de México
anays.acevedo@ciencias.unam.mx

We discuss the effective medium behaviour observed for a thin layer of dielectric nanospheres, sized about 200 nm, deposited randomly on a cover slip. The effective medium behaviour was verified by comparing with the Fresnel's internal reflectance of a homogeneous film with a complex refractive index. In the mentioned comparison, the interfaces are considered as flat; but actually, there is some roughness because the nanoparticles are exposed to air. Another interesting point for analysis is that the size and concentration values managed in this work are out of the range of applicability of the effective medium theory.

On the other hand, for this kind of systems, where the losses are only due to scattering it is possible to obtain an extinction enhancement, observed as a minimum in reflectance after the critical angle. This phenomenon is equivalent to the coherent absorption enhancement, reported in literature for highly absorptive films, and it is basically an interference phenomenon. We can optimize the extinction minimum by tailoring the incident wavelength and the film thickness. Particularly, in the case of a 250 nm thick layer of polystyrene nanoparticles with 5% concentration, we have measured a minimum in reflectance after the critical angle, at an incident wavelength of 515 nm. In this work we explain the physics behind this behaviour and analyse its usefulness for optical sensors applications.

-P02-

Hyperspectral Reflectance of Pre- and Post-Fire Soils: Toward Remote Sensing of Fire-Induced Soil Hydrophobicity

Yasaman Raeofy, University of Nevada, Reno (UNR) and Desert Research Institute (DRI
Vera Samburova, University of Nevada, Reno (UNR) and Desert Research Institute (DRI)
Markus Berli, University of Nevada, Reno (UNR) and Desert Research Institute (DRI)
Eric Schneider, Universität Rostock
Christopher Rüger, Universität Rostock
Hans Moosmüller, University of Nevada, Reno (UNR) and Desert Research Institute (DRI)
yasi.raeofy@dri.edu

Recently, wildfire activity and intensity in the western U.S. has greatly increased, mainly due to a warming climate, population growth, land use changes, and fuel accumulation. Disastrous effects during fires include loss of human lives and infrastructure, ecosystem disturbances, and emissions of carbon dioxide and air pollution. In addition, wildfires modify physical and chemical soil properties and generally cause Fire-Induced Soil Hydrophobicity (FISH), which reduces water infiltration into the soil and accelerates runoff after precipitation events. This may induce cascading disasters including flooding, landslides, and deterioration of water quality. To predict and mitigate such disasters, FISH is generally quantified at a few fire-affected locations using a manual infiltration test. However, this limited spatial coverage poorly represents FISH on a watershed scale as needed for prediction and mitigation purposes.

Watershed-wide monitoring of FISH is only practical using airborne or satellite-based remote sensing, for example utilizing solar reflectance spectra to characterize and monitor physical and chemical properties of fire-affected soils. These spectra depend on light scattering and absorption at the soils surface. Here, we have sampled surface soils from four recent California (US) megafires: the Dixie (2021, 3,890 km2), Caldor (2021, 897 km2), Beckwourth Complex (2021, 428 km2) and Mosquito (2022, 311 km2) fires. We studied the optical, chemical, and hydrological properties of fire-affected and unaffected (i.e., control) soil samples. Optical hyperspectral reflectance spectra (350–2,500 nm) were obtained using natural solar (blue sky) illumination and a spectroradiometer (ASD FieldSpec3), operated in reflectance mode. Comprehensive chemical soil analysis focused on soil organic matter, key for water repellency, and used thermogravimetry (TG) atmospheric pressure ionization (API) Fourier transform ion cyclotron resonance (FT-ICR) mass spectrometry (MS) (or TG API FT-ICR MS). To assess soil water repellency, hydrological soil properties were characterized using water drop penetration time and apparent contact angle tests.

Currently, we are analyzing the results of our optical, chemical, and hydrological measurements to elucidate correlations and causal relationships between them, as needed for using hyperspectral remote sensing to understand, predict, and mitigate postfire, watershed-wide hydrological responses including flooding, landslides, and deterioration of water quality. Results and plans for future work will be discussed.

-P03-

Single-scattering properties of ellipsoidal dust aerosols constrained by measured dust shape distributions

Yue Huang, Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles
Japser F. Kok, Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles
Masanori Saito, Department of Atmospheric Sciences, Texas A&M University
Olga Munoz, Instituto de Astrofísica de Andalucía (IAA-CSIC)
masa.saito@tamu.edu

Most global aerosol models approximate dust as spherical particles, whereas most remote sensing retrieval algorithms approximate dust as spheroidal particles with a shape distribution that conflicts with measurements. These inconsistent and inaccurate shape assumptions generate biases in dust single-scattering properties. Here, we obtain dust single-scattering properties by approximating dust as triaxial ellipsoidal particles with observationally constrained shape distributions. We find that, relative to the ellipsoidal dust optics obtained here, the spherical dust optics used in most aerosol models underestimate dust single-scattering albedo, mass extinction efficiency, and asymmetry parameter for almost all dust sizes in both the shortwave and longwave spectra. We further find that the ellipsoidal dust optics are in substantially better agreement with observations of the scattering matrix and linear depolarization ratio than the spheroidal dust optics used in most retrieval algorithms. However, relative to observations, the ellipsoidal dust optics overestimate the lidar ratio by underestimating the backscattering intensity by a factor of ~2. This occurs largely because the computational method used to simulate ellipsoidal dust optics (i.e., the improved geometric optics method) underestimates the backscattering intensity by a factor of ~2 relative to other computational methods (e.g., the physical geometric optics method). We conclude that the ellipsoidal dust optics with observationally constrained shape distributions can help improve global aerosol models and possibly remote sensing retrieval algorithms that do not use the backscattering signal.

-P04-

Retrieval of aerosol and surface properties with synthetic signals from a multi-angle, multi-spectral polarimeter

Anna Gialitaki, Aristotle University of Thessaloniki & University of Leicester
Marios Panayi, University of Leicester
Alexandra Tsekeri, National Observatory of Athens
Steven D. Lloyd, University of Leicester
Jose Busquets, University of Leicester
Neil Humpage, University of Leicester
Joshua Vande Hey, University of Leicester
ag623@leicester.ac.uk

Atmospheric aerosols either of natural or anthropogenic origin, directly interact with short wave and long wave radiation though scattering and absorption, while the resulting net radiative forcing can be positive or negative depending on the particle properties, vertical distribution in the atmosphere, and the underlying surface albedo. Aerosols also act as cloud and ice condensation nuclei and thus indirectly affect cloud and precipitation processes through modification of the cloud lifetime and radiative properties. Finally, when found near the surface, aerosols can modify the prevailing air quality conditions, cause respiratory or cardiovascular diseases, irritations of the eyes, throat and skin. Aerosol remote sensing enable us to derive aerosol properties from ground-, air- or space-borne measurements with the high temporal and spatial resolution needed to better understand their impact and quantify their effect in the aforementioned processes. A multi-angle, multi-spectral polarimeter measures the intensity and polarization of light scattered by the atmospheric constituents and the underlying surface (in case of air- or space-borne observations). It does so in a number of spectral bands and viewing angles, and thus can provide a dataset of high information content to enable aerosol characterization with high accuracy. Here we present the capabilities of a novel compact MAP (cMAP) currently being developed by Thales Alenia Space UK in collaboration with the University of Leicester. cMAP will operate at 6 spectral bands, and more than 40 observation zenith angles spanning a range from -60 to +60 degrees. For the purposes of the study, we use an ensemble of synthetic scenes assuming different aerosol content and surface parameters. To generate the cMAP synthetic signals and perform simultaneous retrievals of aerosol and surface properties, we employ the Generalized Retrieval of Aerosols and Surface Properties (GRASP) algorithm, aerosol information derived from AERONET long-term measurements at different sites and surface reflectance and polarization information from GRASP/POLDER dataset. We particularly examine the sensitivity of the retrievals to aerosol optical depth and characteristics (shape, size, composition), random and systematic noise, solar zenith angle and surface albedo. cMAP will be employed on a demonstrator flight in the UK scheduled for summer 2023.

-P05-

Scattering matrices decomposed into pure Mueller matrices with radiative-transfer coherent-backscattering applications

Karri Muinonen, Department of Physics, University of Helsinki, Finland
karri.muinonen@helsinki.fi

Scattering matrices of particle ensembles are analytically decomposed into sums of pure Mueller matrices. The ensembles are assumed to have equal numbers of nonspherical particles and their mirror particles, both in random orientation. In the general case, there are four pure Mueller matrices in the decomposition. Of these four matrices, there is a single matrix that qualifies as a pure scattering matrix, whereas the remaining three matrices represent other classes of Mueller matrices. For ensembles of spherical particles, there are two pure Mueller matrices in the decomposition. Again, there is a single matrix qualifying as a pure scattering matrix, whereas the remaining matrix represents another class of pure matrices. The decomposition of ensemble-averaged scattering matrices into pure Mueller matrices allows for radiative-transfer coherent-backscattering (RT-CB) computations for discrete random media of nonspherical particles. In particular, RT-CB computations for media composed of a size distribution of spherical particles can be treated in two ways. First, the computations can be run by incorporating the speficic set of spherical particles composing the media. Second, the computations can be run by incorporating the decomposition of the ensemble-averaged scattering matrix into two pure Mueller matrices. Comparisons of the two approaches are provided for example ensembles of spherical particles. Finally, first results are shown for RT-CB computations for discrete random media of nonspherical particles.

-P06-

First-order correlation function of the light from quantum scatterers

Pablo Dias, Federal University of São Carlos
Marcia Frometa , University of São Paulo
Pedro Magnani, Federal University of São Carlos
Klara Theophilo , University of São Paulo
Mathilde Hugbart , Universite Cote d'Azur
Philippe Courteille , University of São Paulo
Raul Teixeira, Federal University of São Carlos
pablo.dias@df.ufscar.br

In this work [1], we present a new method to obtain the first-order temporal correlation function, also known as g(1)(τ), for the light scattered by an assembly of point like quantum scatters, for example, quantum dots or a cold cloud of atoms. In this method, instead of the usual configuration using photon-sensible photodetectors (APDs and electron-tubes), we measure the g(1)(τ) in an interferometric setup called mirror-assisted backscattering, and the information about the correlation function is encoded in the contrast of the fringes produced by the light scattered in a cone of directions. We theoretically explore how the contrast of the fringes evolves with the physical parameters of the interferometer like the distance between the scatters and the mirror, but also how controlling the polarization of the incident and reflected light can produce effects that don't vanish after an average of the position of emitters. This polarization control allows the measurement of g(1)(τ) for an assemble of randomly distributed point like scatters. This method has direct application to obtaining the saturated spectrum of quantum systems, with the advantage to be possible assembly the detection scheme around a pre-existent vacuum system since the optics can be positioned far away from the sample (an important condition for samples that needs to be cooled and/or where the optics access is limited). In the end, we discuss some nontrivial aspects of this interferometric setup and propose an analogy with a double Mach-Zehnder interferometer.

[1] Dias, Pablo Gabriel Santos, et al. "Mirror-assisted backscattering interferometry to measure the first-order correlation function of the light emitted by quantum scatterers." Physical Review A 104.5 (2021): 053716.

-P07-

Computer algebra solution to Mie scattering problem for the stratified sphere with nonlocal plasmonic layers

Ivan Lopushenko, University of Oulu
ivan.lopushenko@oulu.fi

Plasmonic particles with scale less than 10 nm are known to exhibit unique scattering properties related to the nonlocal spatial dispersion effects. These are not accounted for in the majority of electromagnetic solvers that are conventionally used to simulate scattering by nanostructures. Several nonlocal-corrected Maxwell-based models were recently proposed in attempt to interpret dispersive phenomena in terms of classic constitutive equations and boundary conditions (BC). Among these models Generalized Nonlocal Optical Response (GNOR) theory with hard wall BC and an approach based on mesoscopic BC are being actively studied. For the specific cases they both provide results close to experimental measurements.

Each of the Maxwell-based approaches (traditional Mie theory, GNOR, or mesoscopic) implies its own scattering problem statement involving possibly modified Maxwell equations, BC, and radiation conditions. For spherical particles these problems have analytic solutions. However, corresponding analytic expressions usually must be coded independently because expansion coefficients have to be obtained from scratch for each problem. For a sphere with present nonlocal layers, it is a straightforward but practically cumbersome task due to the lengthy expansions and presence of highly oscillating longitudinal fields.

In this work, outlined problems are solved with a universal computer algebra algorithm (symMie) implemented in the MATLAB/Octave symbolic package framework. The algorithm allows user to construct a set of BC (which could be either classic Mie, GNOR hard wall or mesoscopic) for a stratified sphere optionally involving nonlocal layers. The code comes with symbolically pre-defined full basis set of SVWFs (spherical vector wave functions, including longitudinal ones) and field expansions. Moreover, it is not limited to them, enabling one to flexibly adjust functional basis for the specific problem. Eventually, constructed BC set forms a system of linear equations with unknown Mie expansion coefficients, which can be solved either fully symbolically or with variable precision arithmetic allowing to constrain rounding errors. This approach proves useful when it is necessary to obtain an analytic solution to a scattering problem with spherical geometry given the lack of resources for an implementation of problem-specific code.

-P08-

Advancements on the Hyper-Angular Rainbow Polarimeter (HARP) polarization characterization during NASA Plankton Aerosol and Ocean Ecosystem (PACE) pre-launch calibration

Noah Sienkiewicz, University of Maryland Baltimore County
noahs3@umbc.edu

So far three iterations of the Hyper-Angular Rainbow Polarimeter (HARP) have been constructed at the University of Maryland Baltimore County: AirHARP, HARP CubeSat, and HARP2. HARP represents a technical achievement on making advanced remote sensing measurements in a compact package for low cost. The wide field-of-view polarized images taken by HARP fill a niche only previously filled by the POLDER instruments (active between 2000 and 2011). Multiangular polarimetric measurements are important for the advancement of cloud and aerosol studies by providing increased sensitivity to aerosol shape and type information, and the retrieval of cloud microphysical properties with a high spatial resolution. On PACE, HARP2 will assist in atmospheric correction for studies of ocean color by providing a full global polarimetric coverage in four spectral wavelengths: 440 (\pm10), 550 (\pm10), 670 (\pm10), 870 (\pm20) nm and up to 60 viewing angles. But being an entirely custom instrument, the characterization of HARP in the lab is an ongoing process. Both AirHARP and HARP CubeSat underwent a "static" calibration technique using the normalization of their wide-FOV views to characteristic pixels at the CCD center. HARP2 advanced on this by using a dynamic calibration rig, allowing for tip/tilt scanning of the full CCD view space. In doing so a unique polarization phenomena, not previously recorded, was identified. A change in the polarization plane toward the far corners of the instrument FOV was unexpectedly observed and identified as a strong culprit in polarization measurement error at far view angles. To fully model and correct for this new phenomena, optical models were tuned to the HARP lens distortion effect and multiple polarization plane rotations performed across the field of view. Further, we examine the ranges of error contribution due to binning the plane changes across the FOV with varying levels of granularity. Finally, we present the resulting error expectations of the HARP2 polarimetric calibration using comparison to a known reference "Pol-Box".

-P09-

Retrieving Liquid Cloud Droplet Size Distribution from the Geometric Parameters of Polarized Cloudbow: A demonstration with HARP CubeSat Observations

Rachel Smith, University of Maryland, Baltimore County
Xiaoguang Xu, University of Maryland, Baltimore County
Vanderlei Martins, University of Maryland, Baltimore County
rsmith12@umbc.edu

The spatial and temporal variation of liquid water clouds and their interactions in the atmosphere are key to quantifying the impact they have on global radiative forcing. The cloud droplet size distribution (DSD) offers key insight on how cloud microphysical properties affect radiative forcing. Traditional radiometric observations provide some insight into the cloud droplet effective radius (CDR) but are unable to give any information on the cloud droplet effective variance (CDV) (i.e., the width of the DSD) which significantly impacts radiometric retrievals of CDR and optical thickness. Previous works on polarimetric DSD retrievals have shown that CDR modulates the scattering angle of the primary and supernumerary cloudbow peaks and CDV varies the amplitude of the supernumerary bows. The geometric parameters of the polarized cloudbow, i.e., the angular span of the primary and secondary bows and the amplitude of the secondary bow, are believed to contain the first-order cloud DSD information. In this work, we propose a polarized lookup table (LUT) retrieval method based on the geometric parameters of simulated cloudbow signals which will allow for the simultaneous retrieval of CDR and CDV. We will show a theoretical validation of this method and its application to data from the Hyper-Angular Rainbow Polarimeter (HARP) CubeSat. HARP is a wide field-of-view (FOV) polarimeter designed by the University of Maryland, Baltimore County (UMBC), which is capable of measuring polarized radiance over a 900-km swath at ~ 4km resolution and up to 60 viewing angles in the 670nm spectral band. The proposed approach can be also applied to the HARP2 instrument onboard NASA's upcoming Plankton, Aerosol, Cloud ocean Ecosystem (PACE) satellite that will collect polarimetric data of the entire globe every two days.

-P10-

Towards a joint retrieval of aerosols and CO2 from space-based hyperspectral imager data

Antti Mikkonen, Finnish Meteorological Institute
Hannakaisa Lindqvist, Finnish Meteorological Institute
Janne Nurmela, Finnish Meteorological Institute
Johanna Tamminen, Finnish Meteorological Institute
antti.mikkonen@fmi.fi

Greenhouse gas emissions from anthropogenic activities are the main driver of current global climate change. Emission monitoring is essential the verification of emission reduction efforts and a feasible way for attaining global coverage are satellite observations. Recent developments in space-based hyperspectral cameras open up new possibilities for greenhouse gas emission monitoring also on a smaller scale.

Most of the anthropogenic greenhouse gas emissions originate from urban areas. Urban areas are also sources of co-emitted atmospheric aerosols, which decrease the local air quality and complicate the atmospheric radiative transfer. Even slight concentrations of atmospheric aerosols can cause considerable inaccuracies in space-based remote sensing observations of carbon dioxide (CO2).

In this work, we present a novel retrieval method for a co-emitted CO2 and aerosol emission plume content originating from a point source. We plan to test the method for a joint CO2 and aerosol retrieval and emission rate estimation from satellite-based hyperspectral imaging data, such as imagery obtained using PRISMA or EMIT. The solar and viewing angle dependent radiative coupling of adjacent camera pixels and co-emission of aerosols are investigated as means to improve the CO2 retrieval process.

As part of this work, a hyperspectral imaging simulator is developed. The GPU-based simulator outputs top-of-the-atmosphere radiances in near- to shortwave-infrared wavelengths and thus enables a rapid retrieval of atmospheric constituents in a 3D atmosphere.

-P11-

Origin of vertically elliptical halos – the missing link

Jarmo Moilanen, 1Finnish Geospatial Research Institute (FGI), Faculty of Science of Helsinki University
Maria Gritsevich, Finnish Geospatial Research Institute (FGI), Faculty of Science of Helsinki University
jarmo.moilanen@nls.fi

Atmospheric halos are a light scattering phenomenon caused by airborne ice crystals and they can be seen by the naked eye. They provide the information about ice crystals present in the sky during the halo display. Ice crystals' shape, their orientation, and light ray paths through the crystals dictates what halos can be seen. All well-known halos are produced by crystals of hexagonal water ice obeying the crystallographic structure of water ice. To the contrary, the elliptical halos are small vertically elliptical halos seen sometimes around the Sun, the Moon or around other bright light sources. If they appear around the subsun or the submoon they are called Bottlinger's rings.

The first known observation of any elliptical halos was made already in 1901. First known photos of Bottlinger's and ellipses are from 1970's and 1980's respectively. One or more different sized elliptical halos or Bottlinger's rings have been observed at the same time. Ice crystals causing elliptical halos were sampled in 1990's in two occasions and since then it became apparent that their origin is associated with obtuse pyramidal ice crystals.

However, it has been unclear how these obtuse pyramidal ice crystals form. Pyramidal faces needed to explain these halos seem not to be crystallographically plausible. Because of that, it remained unsolved if elliptical halos come with fixed sizes and why some are centered while some are non-centered ellipses.

We suggest that obtuse pyramidal ice crystals are formed due to nucleation of supercooled water when the temperature is below the water's freezing point. The double-pyramid structure of dendritic ice growing from supercooled water has been observed to grow non-crystallographic faces. The angle between these faces and the basal plane of the ice crystals depends on the supercooling temperature of ice crystal nucleation. The lower the temperature the greater the angle and the size of the elliptical halo.

We conclude that the elliptical halos and the Bottlinger's rings do not have fixed sizes. Our simulations show that at least two different orientations of pyramidal faces explain shapes of ellipses in most of the observations.

-P12-

EMSCOP : a new scattering database

Hervé Tortel, Aix Marseille Univ, CNRS, Centrale Marseille, Institut Fresnel, Marseille, France
Jean-Michel Geffrin, Aix Marseille Univ, CNRS, Centrale Marseille, Institut Fresnel, Marseille, France
Vanesa Tobon-Valencia, Aix Marseille Univ, CNRS, Centrale Marseille, Institut Fresnel, Marseille, France
Malaval François, Aix Marseille Univ, CNRS, Centrale Marseille, Institut Fresnel, Marseille, France
François Ménard, Univ. Grenoble Alpes, CNRS, IPAG, 38000 Grenoble, France
francois.malaval@centrale-marseille.fr

EMSCOP is a freely accessible database, developed and managed by Institut Fresnel (cf fresnel.fr/EMSCOP). It contains measurements and simulations of the scattering properties of various geometries of particles. For now, information on two types of particle is presented in this database : rough spheres and aggregates of 74 monomers. For each type, different samples with various pre-defined characteristics (fractal dimension varying from 1.5 to 2.8 for aggregates, and roughness percentage from 2 to 13 for rough spheres) were measured and simulated. The measurements were performed in the anechoic chamber of the CCRM (Centre Commun de Ressource en Micro-Onde) in Marseille, between frequencies of 3 to 18 GHz, i.e. that the size parameter of the particles varies from 1 to 20. The computations were performed with a homemade finite element code, for the same samples within the same frequency range, in order to cross validate the measurements. The data are given following the Jones and Mueller formalism.

-P13-

Revisiting basic sphere algorithms for Lorent-Mie scattering under non-absorbing and absorbing media

Victoria E. Cachorro , Grupo de Optica Atmosférica. Universidad de Valladolid, Spain
chiqui@goa.uva.es

It might seem outdated in year 2023 to ask how to calculate the Mie scattering coefficients (an, bn) for the basic scattering Lorent-Mie problem in a non-absorbing and absorbing media. Certainly, many algorithms work properly and therefore it seems that there are no essential problems, with the final publications closing the topic in the late 1980´s or early 1990´s. It should be noted that at that time there was some confusion in the "scattering community" about how to calculate the Bessel functions, their derivatives and the associated downward/upward recurrences, giving rise to very different algorithms. Nowadays, after an extended and detailed review of the most known algorithms it becomes clear that not substantial improvements were incorporated in the last 30 years, leaving aside the new potential of personal computers and programming languages. However, some improvements in the algorithms appears as necessary. This is corroborated by the recent article of Mischenko et al. (2018) where the modification of the algorithm is not due to a major requirement for the application to absorbing media but in the limitations of the algorithm itself that could have been improved a long time ago. The idea of this study is to review the most used/known algorithms in order to analyze and compare their drawbacks and advantages and consequently select the most appropriate computational structure. The structure of the basic Mie algorithm is determined by the choice of the explicit formulation for an and bn. The introduction of the complex function of complex argument Dn as the logarithmic derivative was a big progress when the Miller method and its downward recurrence was applied. At the same time the method of "continued fractions" of Lentz, although more complicated, appear as a more efficient option in order to decrease the number of iterations of Miller downward recurrence. Only an alternative method to that of Lentz has been found in the literature, not well known in the scattering community. This review shows the current coexistence of various structures in the Mie algorithms where their different efficacy have been evaluated. The obtained results also affect the algorithms for coated particles.

-P14-

Optical calibration of acoustic tweezers

Sonia Marrara, Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra, Università di Messina, I-98166 Messina, Italy; CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158 Messina, Italy
David Bronte Ciriza, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158 Messina, Italy
Alessandro Magazzù, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158 Messina, Italy
Roberto Caruso, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158 Messina, Italy
Giuseppe Lupò, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158 Messina, Italy
Rosalba Saija, Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra, Università di Messina, I-98166 Messina, Italy
Antonino Foti, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158 Messina, Italy
Pietro G. Gucciardi, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158 Messina, Italy
Andrea Mandanici, Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra, Università di Messina, I-98166 Messina, Italy
Onofrio M. Maragò, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158 Messina, Italy
Maria G. Donato, CNR-IPCF, Istituto per i Processi Chimico-Fisici, I-98158 Messina, Italy
soniamarrara@gmail.com

Acoustic tweezers trap particles with sound waves designed so that matter is confined to specific regions of pressure and velocity fields. Acoustic trapping devices can have applications in many fields, including medicine, nanotechnology and biology, such as optical tweezers. We make use of two different acoustic trapping set-ups in air, based on low-cost sound transducer arrays, and we develope a calibration method for acoustic tweezers based on prior knowledge of optical trapping techniques. In fact, we adopt two optical detection methods to study the dynamics in the acoustic trap: (i) we aim a laser beam on the trapped particle and detect the fluctuations of its shadow on a quarter photodiode (QPD), (ii) we acquire the shadow of the trapped particle using a CCD camera and a telescope, then we extract data on the position of the particle using video tracking software. We collect data on the displacement of the particles in the x, y and z directions with both aforementioned methods. We analyze these data by calculating their power spectra, since periodic oscillations of the particle give rise to a peak in the power spectrum at the corresponding frequency. Spectra obtained with both CCD and QPD signals have peaks at the same frequency. This allows us to evaluate the force constant of the acoustic trap on the basis of the simple harmonic oscillator model f=1/2(k/m)^1/2. Here, we illustrate calibration test measurements in the case of (i) the acoustic trapping instrumental apparatus consisting of a single planar array of ultrasonic transducers and (iI) the TinyLev model consisting of two opposing transducer arrays allowing to obtain a single-axis non-resonant levitator.

-P15-

Polarization of Jupiter's Large Moons: New Results

Nikolai Kiselev, Crimean Astrophysical Observatory, Nauchny, Crimea
Vera Rosenbush, Taras Shevchenko National University of Kyiv, Kyiv, Ukraine
Karri Muinonen , University of Helsinki, Helsinki, Finland
Ludmilla Kolokolova , University of Maryland, College Park, MD, USA
Alexander Savushkin, Crimean Astrophysical Observatory, Nauchny, Crimea
Nikolai Karpov, ICAMER, Peak Terskol Observatory of the Ukrainian Academy of Science
kiselevnn42@gmail.com

We present the results of polarimetric observations of Jupiter's moons Europa, Ganymede and Io in the UBVRI bands, obtained with the 2.6-m ZTSh telescope of the Crimean Astrophysical Observatory and the 2-m telescope of the Peak Terskol Observatory in 2018 – 2023. The purpose of the work is to establish the accurate shapes of the negative branch of polarization (NPB) and their parameters (P_min, alfa_min, alfa_inv), as well as the spectral and longitudinal dependences of satellite's polarization. Comparison of NPB for Europa, Ganymede, and Io will be presented in the figures. We show that: the NPB for the each satellite is represented as a sharp asymmetric curve with a single minimum P_min = (from -0.2 to -0.4) % at phase angles less than 1 deg. Such behavior of polarization is typical for coherent backscattering. Then polarization gradually, but specifically for each satellite, increases to positive values with the inversion angle of ~ 6 deg for Europa, ~ 11 deg for Ganymede, and > 20 deg for Io. Most likely, these differences reflect the differences in the surface composition, particle sizes and structure of the regolithic surfaces. Results of modeling of surface properties using the radiative transfer and coherent-backscattering (RT-CB) technique will be presented.

-P16-

Parameters of differential equations in two-flux models approximated for multilayers samples showing scattering and absorption

David Barrios, Universidad Politécnica Salesiana, Guayaquil, Ecuador
dbarriosp76@gmail.com

New expressions of extrinsic scattering and absorption coefficients (S & K) of three multilayer samples were determined, by means of total differential equations of two-flux model (2FM), which were equalized to the sum of the collimated and the diffuse differential equations of four-flux model (4FM), solved by the author in a previous recent work, and computed knowing the values of the collimated and diffuse light intensities at the inner of the samples. This procedure was tested for a monolayer case approximation, neglecting outer layers and considering only the single inner substrate layer of the three samples: the GEG sample, with two outer glass (G) substrate layers and an inner substrate electrolyte (E) layer, and two chromogenic multilayered smart windows, based on suspended particle device (SPD) and polymer dispersed liquid crystals (PDLC), at their off and on optical states, showing mainly absorption and scattering respectively. Both monolayer and multilayer cases were studied for the GEG sample, but only the monolayer case was studied for SPD and PDLC, due to the unknown of some inner layers in the chromogenic devices characterized, including substrates and thin layers. S and K expressions were obtained using recent expressions on intrinsic scattering and absorption coefficients (α & β), retrieved from collimated and diffuse differential equations of 4FM, using two proposed forward scattering ratios (FSR=σ) for diffuse forward (i) and backward (j) light intensities (σdi & σdj), and two proposed average crossing parameters (ACP=ξ), for each sense of light (ξi & ξj), and solving for scattering α and for forward collimated FSR=σci, with σcj=1-σci and absorption β known from extinction coefficients (ε). Finally, the multilayer case of the GEG sample showed to obtain the same results by using both previous and new methods. Hence, using the 4FM solutions, for the collimated-diffuse transmittance (T) and reflectance (R), with the fifth equation for ACP parameter, in order to obtain α & β of the electrolyte inner substrate layer by the previous method, and compared with the parameters retrieved with the new method, based on the diffuse differential equations, used for retrieving the extrinsic values for scattering and absorption coefficients.

-P17-

Microwave imaging from truncated measurements: polarization effects

Christelle Eyraud, Institut Fresnel
Jean-Michel Geffrin, Institut Fresnel
Hassan Saleh, Institut Fresnel
christelle.eyraud@fresnel.fr

Electromagnetic wave probing is an interesting tool to characterize an unknown target (position, shape, size, complex permittivity) in a non-destructive way. Indeed, the physical characteristics can be recovered from the measurements of the scattered field by the target thanks to the resolution of an inverse problem.
In practice, there are some difficulties because the measurement of the scattered field is truncated: the measurement is performed only on a part of the surface surrounding the target and the different cases of polarization of the scattered field are rarely measured, due to lack of time or other constraints.

In this contribution, we will focus on the effects of these choices and more particularly on the effect of polarization selection in quantitative 3D imaging. The reconstructions have been made from experimental scattered fields, measured in our laboratory. We worked with the Jones matrix formulation, considering the different elements of the Jones matrix, in the case of circular or linear polarization.
We have shown that the choice of the polarization basis (linear or circular) and of the element of the scattering matrix has an important consequence on the imaging results.

-P18-

OAM spectrum analysis of vortex beams after scattering from a spherical particle

Guo Lixin, Xidian University
Shi Chenge, Xidian University
lxguo@xidian.edu.cn

With the increasing maturity of laser polarization imaging technology, a series of difficult imaging problems for traditional methods such as “Imaging through clouds and fog” and “Imaging around the wall” can be well solved by adding the polarization information of light. Compared with the polarization (Spin Angular Momentum), Orbital Angular Momentum (OAM) is an important and underutilized physical attribute of light beams. The utilization of OAM provides an ideal development direction for further improving the efficiency and capability of the existing laser technologies. The measurement and analysis of OAM spectrum is one of the key bases for the application of optical OAM in Lidar detection system. Based on the generalized Lorenz-Mie theory and angular spectrum expansion method, the intensity and phase distributions of the scattering field in the far-field region and total field of a vortex beam scattered by typical spherical particles are simulated. The intensity and phase distributions of vortex beam scattered by a spherical particle are obviously complicated. The calculation results obtained by the early circumferential phase sampling method will change with the changing sampling radius. Therefore, the circumferential phase sampling method cannot fully reflect the phase information of the scattered field. In this paper, the whole area phase sampling method and the spiral spectrum expansion method are combined to analyze the OAM spectrum distribution characteristics of the scattered field and total field of a vortex scattering from a spherical particle. The simulation results show that the influence of the location of the detection plane on the OAM spectrum distribution of the scattered field and total field can be almost ignored. The particle scattering induced OAM spectrum distribution of vortex beam is very sensitive to the variation of the characteristic parameters of spherical particles (such as negative refractive index and particle size). Based on the OAM spectrum distribution data, the characteristic parameters of particles can be quickly deduced. This research results provide a theoretical basis for laser detection technology based on optical OAM spectrum.

A plasma electron density inversion method based on support vector machine

Li Jiangting, Xidian University
Liang Hanwen, Xidian University
jtli@xidian.edu.cn

Electron density is an important physical quantity in plasma. Studying electron density plays an important role in analyzing plasma and understanding the propagation of electromagnetic wave in plasma. Support Vector Machine (SVM) is a general learning method developed on the basis of statistical learning theory in recent years. Based on support vector machine (SVM), a regression model for inhomogeneous plasma cylindrical electron density inversion is proposed. First, the FDTD method is used to calculate the training samples. After setting the initial conditions, the scattering cross sections of the plasma cylinders at each frequency are calculated. Take each radius as a target value and its corresponding scattering cross section as the eigenvalue. Then, plasma cylinders under different electron density distribution curves were used to establish test samples. Plasma cylinder RCS with the same incident frequency as the training samples were taken as the characteristic values. The cylindrical radius corresponding to the critical electron density was calculated and compared with the predicted results. Finally, the eigenvalues of the test samples are put into SVM to obtain the inversion results. The real electron density curves of test samples are compared with the inversion results.
The calculation results show that the error is relatively large where the electron density varies widely. When comparing TE wave with TM wave, it can be seen that the inversion effect of TE wave is better than that of TM wave. Compared with TM wave and TE wave, the scattering cross section of the cylinder varies gently with the radius, and the training is relatively more accurate. Therefore, the inversion effect is the best when the TE wave is incident. The proposed inversion method can accurately invert the electron density distribution curve of cylindrical plasma, and the relative error of the inversion results can be controlled within 1.8%. It provides a powerful theoretical tool for the diagnosis of plasma parameters.

-P20-

Scattering of vector high-order Bessel vortex beams by dust particles in the sandstorm medium

Cheng Mingjian, Xidian University
Cao Yuanchong, Xidian University
mjcheng@xidian.edu.cn

In this paper, a uniform charged sphere is employed to model the dust particles in a sandstorm environment. Based on the generalized Lorentz Mie theory and angular spectrum expansion method, the interaction mechanism between a vector high-order Bessel Gaussian beam and a charged spherical particle is studied in detail. The influence of the incident beam parameters and the eigen parameters of the charged particles on the intensity extinction are analyzed, with a vector high-order Bessel Gaussian beam scattered by a dust spherical particle. The scattering results of uncharged particles are used for comparison, and results show that the extinction effect of the vortex light transmitted in the dust medium depends on the light intensity of the incident vortex beam, and the amplitude and distribution of the light intensity will affect the extinction ratio of charged and uncharged particle spheres in the dust medium. In the small size range of dust spherical particle, the difference of extinction effect between charged particles and uncharged particles is obvious, which is basically consistent with the situation with plane wave incident. In different dust media, such as floating and sinking, blowing sand and sandstorm, the particles will obey different lognormal distribution spectrum. Therefore, based on the scattering model of vector high-order Bessel Gaussian beams by a single dust particle, the transmission characteristics of Bessel Gaussian beams under three classical dust meteorological conditions are studied further. The simulation results show that the transmission performance of the vortex beam is significantly affected by the parameters such as particle charge, temperature, beam wavelength, polarization mode and beam width. Under the same conditions, the larger the topological charge, vortex beam has the smaller signal attenuation rate and can transmit longer distance in sandstorm medium. By adjusting the polarization characteristics of vortex beams, the angular and radial polarized Bessel Gaussian beams have the better transmission performance than classical linear polarized one. The results can provide reference value for the performance evaluation of orbital angular momentum communication system under dust weather conditions.

-P21-

Light Scattering and Microphysical Properties of Atmospheric Bullet Rosette Ice Crystals

Shawn Wagner, Karlsruhe Institute of Technology
Martin Schnaiter, Karlsruhe Institute of Technology
Guanglang Xu, Karlsruhe Institute of Technology
Franziska Nehlert, Karlsruhe Institute of Technology
Emma Järvinen, Karlsruhe Institute of Technology
shawn.wagner@kit.edu

Cirrus clouds provide a substantial amount of coverage in the earth's atmosphere, resulting in a major impact on the global radiative budget. The extent of the radiative impact is determined by the aspherical ice crystal composition within the cirrus. Thus, a proper understanding of ice crystal single scattering properties is necessary for accurate climatological modeling and forecasting. One of the most relevant cirrus ice crystal habits is a polycrystalline bullet rosette where individual bullets are radiating from the same nucleation point. Comprehensive studies on the dependencies of ice crystal habit formation have shown that bullet rosettes grow at a range of ice supersaturations with temperatures below -40 °C; environmental conditions frequently found within high altitude cirrus clouds. Here, single scattering properties of atmospheric bullet rosettes were investigated using correlated high resolution in-situ stereo-images of individual bullet rosettes and their angular scattering functions measured by the airborne Particle Habit Imaging Polar Scattering (PHIPS-HALO) cloud probe during the CIRRUS-HL campaign were analyzed for their maximum dimensions as well as for crystal complexity and visually inspected for number of bullets per rosette, individual bullet aspect ratios and bullet hollowness. These bullet rosette microphysical properties were then associated with environmental conditions and with the simultaneously measured angular light scattering function and resulting asymmetry parameter. Angular scattering functions and asymmetry parameters are discussed for bullet rosettes grouped into subsets by temperature, relative humidity with respect to ice, condensable water, and complexity parameter. Further comparisons are made between solid bullet rosettes and hollow bullet rosettes. Results indicate that much lower asymmetry parameters represent real atmospheric bullet rosette crystals than what is expected by theoretical studies assuming smooth surfaces on solid and hollow bullet rosettes.

-P22-

Research on Electromagnetic Wave Propagation in Inductively Coupled Heterogeneous Plasmas

Yue Dong, Xidian University
Shi Xiaomin, Xidian University
18192218901@163.com

Blackout problem of spacecraft near space is caused by the fact that the plasma formed by ionizing the surrounding air during high-speed flight has a great influence on the propagation of electromagnetic wave, thus hindering the detection and communication capabilities of spacecraft. Its essence is the influence of plasma on the propagation of electromagnetic wave. In this paper, the research is based on the inductively coupled plasma ground simulation device. Firstly, the Langmuir probe method is used to diagnose the plasma parameters of the ground simulation device under different power and pressure. Then the plasma stratification model in the cavity of the experimental device is established by using the measured data and the electromagnetic wave transmission coefficients of different plasma density distributions are calculated by using the propagation matrix method. Two patch antennas were set up respectively in front of quartz observation Windows at both ends of the inductively coupled plasma cavity to carry out electromagnetic wave propagation measurement experiments in the plasma, and to study the absorption and transmission characteristics of electromagnetic wave in the plasma.

Finally, the data calculated by the transmission matrix method show that electromagnetic wave propagation in the plasma will produce absorption and scattering effects, plasma parameters (electron density, collision frequency, etc.) will have a great influence on the results. With the increase of plasma density, the reflection coefficient increases and the transmission coefficient decreases. The law of absorption coefficient is opposite to that of transmission coefficient, which increases with the increase of plasma density. Under the same electron density, with the increase of incident wave frequency, the reflection coefficient and absorption coefficient gradually decrease, while the transmission coefficient gradually increases. The transmission measurement experiment of electromagnetic wave in plasma can show that, under the same electron density, the transmittance of electromagnetic wave is relatively poor when the frequency is low, and reaches the peak value at the plasma frequency. However, after the frequency gradually increases, the transmittance of electromagnetic wave gradually increases to achieve the effect of full transmittance. The law obtained by experiment and the theoretical calculation can be mutually verified.

-P23-

Analyses of Electromagnetic Scattering Properties and Dynamic RCS of RAM C-II Vehicle Covered with Plasma Sheath

Bian Zheng, Xidian University
Zhang Haifeng, Xidian University
Ma Qian, Xidian University
18700917808@163.com

Based on the equivalence principle and the continuous boundary conditions of the tangential components of the electric field and magnetic field in the plasma medium, the incident electromagnetic (EM) wave is reasonably decomposed into TE wave and TM wave, and the correct continued fraction expressions of the reflection coefficients R⊥ and R// in the PO integral equation are systematically derived and given. Based on this, using Huygens principle, the EM scattering characteristics of the RAM C-II vehicle covered with plasma sheath in the L-X band are calculated and analyzed in detail through the measured electron density data of hypersonic targets at different reentry altitudes published by NASA, and the law of the periodic oscillation of the backward RCS with frequency variation is deeply studied. Numerical results show that When the incident EM wave frequency is near the plasma frequency corresponding to the maximum electron density of the plasma sheath, the plasma produces large collision absorption to the incident EM wave and presents sharp absorption peak. In addition, with the decrease of the reentry height, the bistatic radar cross section and the backscattering radar cross section (BRCS) of the vehicle will reduction significantly, which is mainly caused by the increase of electron density in the flow field of the plasma sheath, which leads to the absorption of EM wave energy by collision and the bending of EM wave propagation trajectory. In addition, this paper also calculates the dynamic radar cross section (DRCS) time series of RAM C-II vehicle in different flying states, and the fluctuation trend is closely related to the two factors of the target spacecraft's reentry altitude and reentry velocity. This study provides theoretical basis and data support for space exploration and target recognition of hypersonic vehicle covered with plasma sheath.

-P24-

Characterization of aerosol phase matrix elements for different Saharan dust events with the Polarized Imaging Nephelometer (PI-Neph)

Elena Bazo, Department of Applied Physics, University of Granada; Andalusian Institute for Earth System Research
Daniel Pérez-Ramírez, Department of Applied Physics, University of Granada; Andalusian Institute for Earth System Research
Antonio Valenzuela, Department of Applied Physics, University of Granada; Andalusian Institute for Earth System Research
Francisco José García-Izquierdo, Department of Applied Physics, University of Granada; Andalusian Institute for Earth System Research
Gloria Titos, Department of Applied Physics, University of Granada; Andalusian Institute for Earth System Research
Chong Li, GRASP-SAS, Remote sensing developments, LOA/Université de Lille
J. Vanderlei Martins, JCET and Physics Department, University of Maryland Baltimore County
David Fuertes, GRASP-SAS, Remote sensing developments, LOA/Université de Lille
Lucas Alados-Arboledas, Department of Applied Physics, University of Granada; Andalusian Institute for Earth System Research
Francisco José Olmo, Department of Applied Physics, University of Granada; Andalusian Institute for Earth System Research
ebazo@ugr.es

Atmospheric aerosol particles interact with solar radiation by means of absorption and scattering processes. Inversion algorithms used to retrieve aerosol properties need information on how aerosols interact with incoming light, particularly how they scatter it at different angles. Additionally, the use of polarization in inversion algorithms improves the accuracy of the retrieval. The Polarized Imaging Nephelometer (PI-Neph; Dolgos and Martins, 2014) was developed at the University of Maryland Baltimore County (UMBC) to study scattering by aerosols with the use of polarized light. Recently, the PI-Neph has been optimized, with an automatization of the measurement technique, for continuous monitoring of the scattering by aerosol samples. The PI-Neph measures the phase function (P11) and the polarized phase function (-P12/P11) at three wavelengths: 405, 515 and 660 nm. The instrument counts with a polarizer and two liquid crystal retarders for the obtention of the polarization states. The scattered irradiance is detected with a CCD lens, providing measurements for an angular range of 5-175°.

The PI-Neph is located at the urban background station (UGR) of the Andalusian Global Observatory of the Atmosphere (AGORA), in the city of Granada (Spain). The instrument has been continuously sampling ambient air from the station main inlet since early 2022. During the sampling period, several Saharan dust events affected the Granada area. During March 15th and 25th 2022 two extreme events reached the city, with hourly maximum PM10 concentrations of 1800 and 800 μgm-3, respectively. We present results of P11 and -P12/P11 of these events along with a comparison of the phase matrix elements for moderate dust events (PM10 ~ 50-100 µgm-3) reaching the UGR station. The comparison reveals large differences between the extreme and moderate events in P11 and more particularly in -P12/P11 for the 405 nm channel. Our results for the extreme events agree with laboratory measurements of Saharan dust (Gómez-Martín et al., 2021), while the results for the moderate dust events indicate the presence of urban background aerosol particles mixed with dust particles.

Dolgos, G., and Martins, J. V. (2014). Opt. Express, 22(18), 21972.
Gómez-Martín, J.C. et al (2021). J. Quant. Spectrosc. Radiat. Transf, 271, 107761

-P25-

A method to characterize the distribution of optical paths for remote spectroscopic sensing of atmospheric gases

Santiago Arellano, Chalmers University of Technology - Department of Space, Earth and Environment
santiago.arellano@chalmers.se

Passive remote sensing based on the absorption of diffuse solar radiation is widely used for quantification of localized clouds of gases in the atmosphere. Examples include the measurement of gas fluxes from industrial or natural sources, such as hazardous industrial pollutants or volcanic eruption plumes using differential absorption spectroscopy in the near UV. From the inversion of spectroscopic measurements, the gas column density along an "effective" extinction path is usually derived. Radiative transfer effects can lead to ambiguous results because the effective path becomes dependent on atmospheric conditions and wavelength.
We present a method that characterizes radiative transport by inverting spectral measurements not along one effective path but through a distribution of discernible paths of absorption in the cloud. We validate the method against both a 3-D Monte Carlo radiative transfer model and controlled measurements of sulphur dioxide in volcanic plumes using a drone. We use the algorithm for inversions of different field observations. This approach leads to a consistent characterization of extinction paths inside and outside the target, resulting in more accurate quantification of gas emission and in better representation of the physics of the measurement.

-P26-

Dust orientation measurements

Alexandra Tsekeri, IAASARS, National Observatory of Athens, Athens, Greece
Vassilis Amiridis, IAASARS, National Observatory of Athens, Athens, Greece
Spiros Metallinos, IAASARS, National Observatory of Athens, Athens, Greece
Sotirios Mallios, IAASARS, National Observatory of Athens, Athens, Greece
Peristera Paschou, IAASARS, National Observatory of Athens, Athens, Greece, and Laboratory of Atmospheric Physics, Physics Department, Aristotle University of Thessaloniki, Greece
Nikolaos Siomos, FakultätfürPhysik, MeteorologischesInstitut, Ludwig-Maximilians-Universität, Munich, Germany
Ioanna Tsikoudi, IAASARS, National Observatory of Athens, Athens, Greece, and Department of Physics, Section of Environmental Physics-Meteorology, National and Kapodistrian University of Athens, Athens, Greece
Dimitra Kouklaki, National and Kapodistrian University of Athens, Department of Geology and Geoenvironment, Athens, Greece
Eleni Marinou, IAASARS, National Observatory of Athens, Athens, Greece
atsekeri@noa.gr

Dust orientation is an ongoing investigation in recent years (Ulanowski et al., 2007, Mallios et al., 2021). Its potential proof will be a paradigm shift for dust remote sensing, invalidating the currently used simplifications of randomly-oriented particles. Vertically-resolved measurements of dust orientation can be acquired with the new polarization lidar “WALL-E”, designed to target the off-diagonal elements of the backscatter matrix which are non-zero only when the particles are oriented (Tsekeri et al., 2021). Herein, we present first measurements of dust particles acquired during the ESA Aeolus Cal/Val Campaign “ASKOS” at Cabo Verde (June and September 2022). The dust particles in the Sahara Air Layer, for the specific cases, show small orientation signals that are within the measurement uncertainty, thus they are considered randomly-oriented.

Key Words: dust, orientation, lidar, polarization
Acknowledgments: This research was supported by D-TECT (Grant Agreement 725698) funded by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program, and by PANGEA4CalVal (Grant Agreement 101079201) funded by the European Union .

References:

Tsekeri, A., et al.: Polarization lidar for detecting dust orientation: system design and calibration, Atmos. Meas. Tech., 14, 7453–7474, 2021.
Mallios, S., et al.: Orientation of non spherical prolate dust particles moving vertically in the Earth's atmosphere, J. Aerosol Sci., 151, 2021.
Ulanowski, Z., et al.: Alignment of atmospheric mineral dust due to electric field, Atmos. Chem. Phys., 7, 6161–6173, 2007.

-P27-

Experimental evidence of hygroscopic behavior of a levitated single dust particle

Antonio Valenzuela Gutiérrez, University of Granada
Elena Bazo, University of Granada
Francisco José García Izquierdo, University of Granada
Daniel Pérez, University of Granada
Sonia Castillo, University of Granada
Lucas Alados Arboledas, University of Granada
Francisco José Olmo Reyes, University of Granada
avalenzuela@ugr.es

Mineral dust aerosols influence the Earth's energy balance through direct interactions with radiation and by modifying cloud microphysics. The total effect of dust interactions on the Earth's global energy balance is -0.2 ± 0.5 W/m2, suggesting that dust cools the climate (Kok et al., 2023). In general, pure dust particles injected directly from the desert do not exhibit hygroscopic behavior. However, during long-range transport there is evidence that atmospheric compounds such as sulfate, which absorb water, can deposit on the surface of dust particles (Párraga et al., 2021). In this analysis, we demonstrate, for the first time, the remarkable hygroscopic behavior of a single dust particle collected in a strong dust event in March 2022 over the Iberian Peninsula. A single particle was exposed to changes in relative humidity and elastic scattering and extinction cross sections were measured during a complete hygroscopic cycle. The surprising results show how the potential presence of hygroscopic compounds on its surface affects the adsorption and desorption of water from the background gas. Our findings suggest that a precise rationalization of the water contained in the dust particles will provide a better parameterization of the optical properties.

Kok, J.F., Storelvmo, T., Karydis, V.A. et al. Mineral dust aerosol impacts on global climate and climate change. Nat Rev Earth Environ 4, 71–86 (2023). https://doi.org/10.1038/s43017-022-00379-5.

Párraga, J., Martín-García, J.M., Delgado, G., Molinero-García, A., Cervera-Mata, A., Guerra, I., Fern´andez-Gonz´alez, M.V., Martín-Rodríguez, F.J., Lyamani, H., Casquero-Vera, J.A., Valenzuela, A., Olmo, F.J., Delgado, R., 2021. Intrusions of dust and iberulites in Granada basin (Southern Iberian Peninsula). Genesis and formation of atmospheric iberulites. Atmos. Res. 248, 105260. https://doi.org/10.1016/

-P28-

FETI method applied to the scattering studies of complex shaped agregates

Tortel Hervé, Institut Fresnel UMR7249
herve.tortel@fresnel.fr

The growth of dust grains in protoplanetary disks is not understood in details. In order to understand the scattering properties of these aggregates it is important to have at hand a software able to compute these quantities for complex shaped object (necking of small particles, roughness of the surface, overlap …)

Among the different existing methods with their respective pros and cons one can cite for example TMatrix, DDSCATT, Volume integral formalism …In this paper we are interested to the application of the finite element method to the weak form of the Helmholtz equation. In this method, the unknown of interest (the electric or magnetic field) is expanded onto a set of basis functions. A linear system is then calculated by projecting the Helmholtz equation onto the same set of test functions, as advocated by the Galerkin method. Thus, the efficiency of the method is mainly dependent upon one's own ability to solve the resulting sparse linear system, which can be time and memory consuming, especially in three-dimensional (3D) configurations.

Among the different schemes proposed to solve large scale models and preserve the versatility of the FEM method, the Domain Decomposition Method (DDM) and its different evolutions are especially appealing. The closely related Finite Element Tearing and Interconnecting (FETI) method seems also very robust when one is dealing with arbitrarily mesh partitions. The general principle of FETI methods is first to divide the entire computational domain into smaller non-overlapping subdomains. In each of these subdomains, local linear systems can now more easily be inverted. Simultaneously, the different adjacent subdomains are glued at their common interfaces thanks to appropriate boundary conditions, leading to a so-called global interface problem.

Once this interface problem is solved, the solution inside each subdomain can be evaluated independently by using the known mixed boundary conditions at the internal interfaces between subdomains. In this paper we propose to study the performances of this method when we apply it to the modelling of this kind of structure.

-P29-

Meteoroid properties based on the luminous part of its atmospheric trajectory

Ioana Boaca, Astronomical Institute of Romanian Academy
Maria Gritsevich, Finnish Geospatial Research Institute (FGI)
Alin Nedelcu, Astronomical Institute of Romanian Academy
Tudor Boaca, Department of Computer Science, Information Technology, Mathematics and Physics, Petroleum-Gas University of Ploiesti
François Colas, IMCCE, Observatoire de Paris
Adrien Malgoyre, Service Informatique Pythéas (SIP) CNRS – OSU Institut Pythéas – UMS 3470,
Brigitte Zanda, IMCCE, Observatoire de Paris
Pierre Vernazza, Aix Marseille Univ, CNRS, CNES, LAM, Marseille, France
ioana.boaca@astro.ro

In this work we focus on the topic of determining the physical properties of meteoroids that derive from the luminous trajectory of the meteors. We are working with a dataset of meteor detections made by the FRIPON (Fireball Recovery and Inter Planetary Observation Network) (Colas et al. 2020) network in Romania with the use of MOROI (Meteorite Orbits Reconstruction by Optical Imaging) cameras (Nedelcu et al. 2018). The interpretation of the luminous trajectory of meteors splits in two parts. First, following preceding works (Gritsevich 2008, 2009, Lyytinen and Gritsevich 2016, Sansom et al. 2019, Peña-Asensio et al. 2021, Boaca et al. 2022) by analysing the rate of deceleration in the atmosphere we derive ballistic coefficient and mass loss parameter. This provides sufficient basis to robustly analyse light curves of the meteors using the methods proposed by (Gritsevich and Koschny 2011, Bouquet et al. 2014) and deduce other important properties such as the shape change and the luminous efficiency coefficients. We make a graphic representation comparing the observed and simulated light curves of the MOROI meteors.

Boaca I., et al. (2022), ApJ, 936, 150.
Bouquet A., et al. (2014), PSS, 103, 238-249.
Colas, F., et al. (2020), A&A, 644, A53.
Gritsevich, M. I. (2008), DokPh, 53, 97.
Gritsevich, M. I. 2009, AdSpR, 44, 323.
Gritsevich, M. & Koschny, D., (2011), Icar, 212, 877.
Lyytinen, E., & Gritsevich, M. 2016, P&SS, 120, 35.
Nedelcu, D. A., et al. (2018), RoAJ, 28, 57.
Peña-Asensio, E., et al. (2021), MNRAS, 504, 4829.
Sansom, E. K., et al. 2019, ApJ, 885, 115.

Acknowledgement.
The work of IB and AN was partially supported by a grant of the Ministry of National Education and Scientific Research, PNIII-P2-1214/25.10.2021, program no. 36SOL/2021. MG acknowledges the Academy of Finland project no. 325806 (PlanetS).

-P30-

Parameters of differential equations in four-flux models approximated for multilayers samples showing scattering and absorption

David Barrios, Universidad Politecnica Salesiana, Guayaquil, Ecuador
dbarriosp76@gmail.com

New expressions of differential equations parameters in four-flux model (4FM) recently determined by the author in a previous work, for a three substrate layers glass-electrolyte-glass (GEG) sample, were approximated for two different multilayers samples of smart windows in monolayer case, i.e., neglecting outer glass substrates and transparent conductors' thin layers and considering only the inner chromogenic active layer. The new expressions for these parameters were recently used for determining, in multilayer case for the GEG sample, the new intrinsic scattering and absorption coefficients, two average crossing parameters (ACP) for both light senses, and four forward scattering ratios (FSR) for collimated and diffuse and also for both light senses. Then, in the monolayer case approximation, which is less precise than the multilayer case approximation when the sample characterized is multilayer, the retrieved scattering and absorption coefficients, retrieved using diffuse differential equations, were adjusted by using a simple rule of three, relating extinction coefficients retrieved from collimated-collimated 4FM and from collimated differential equations. This procedure was carried out in order to approximate the monolayer values of two chromogenic smart windows multilayer samples, i.e., a suspended particle device (SPD) and of a polymer dispersed liquid crystal (PDLC), at their off and on optical states, showing mainly absorption and scattering of light respectively. The approximation of monolayer case for the GEG sample was carried out in this work in order to compare the results with the multilayer approximation, and in both cases the same results for both methods were retrieved, i.e., from recent method of 2023, using diffuse differential equations, and from previous method using collimated-diffuse 4FM equations of 1984 together with a fifth equations for ACP parameter, based on the collimated and diffuse forward and backward light intensities at the top and bottom interfaces, proposed in 2019 by the author for the SPD sample and used successfully in 2022 for the PDLC sample, both in monolayer cases. For multilayer case studied with GEG sample, the same intrinsic scattering and absorption coefficients were retrieved from both methods.

-P31-

Effect of particle size on the scattering pattern of a set of absorbing samples

J.C. Gómez Martín, Instituto de Astrofísica de Andalucía, CSIC
J. Martikainen, Instituto de Astrofísica de Andalucía, CSIC
T. Jardiel, Instituto de Cerámica y Vidrio, CSIC
M. Peiteado, Instituto de Cerámica y Vidrio, CSIC
O. Muñoz, Instituto de Astrofísica de Andalucía, CSIC
jcgomez@iaa.es

This work is part of an ongoing experimental effort at the IAA Cosmic Dust Laboratory [1], which aims at disentangling the effect of particle size, composition and shape on the properties of light scattered by clouds of randomly oriented irregular particles. Previously, we have reported the effect of particle size on the experimental curves of $F_{11}(\theta)$, $-F_{12}(\theta)/F_{11}(\theta)$ and $F_{22}(\theta)/F_{11}(\theta)$ for a set of low-absorbing particulate forsterite samples (k(500 nm) ~1E-5). These samples were prepared at the facilities of the Instituto de Cerámica y Vidrio (ICV-CSIC) using state-of-the-art size-segregating techniques to obtain five narrow size distributions spanning a broad range of the scattering size parameter domain [2].

For low-absorbing particles, it was found that: (i) the phase function $F_{11}(\theta)$ at side- and back-scattering provides information on the size regime, (ii) the position and magnitude of the maximum of the degree of linear polarization curve (DLP = $-F_{12}(\theta)/F_{11}(\theta)$) are strongly dependent on particle size, and (iii) the negative polarization branch is mainly produced by particles with size parameters in the ~6 to ~20 range. A comparison of these results with Mie computations shows that the use of the spherical model in the retrieval of particle properties from remote observations results in overestimation of the absorption coefficient and/or underestimation of particle size.

In this contribution we present results of a follow-up study using a set of size-segregated samples consisting of particles with higher absorption coefficient, in order to disentangle the effect of both size and absorption on the measured scattering pattern. From bulk samples of three Martian dust analogues (JSC Mars 1, MMS-2 and MGS-1) with k(500 nm) ~ 2E-4 - 7E-4 [3], a set of samples with well-defined narrow size distributions have been prepared using the same processing routines borrowed from the field of functional, nano- and microceramics. The light scattering measurements have been performed at 488 nm and 640 nm.

References:

[1] Muñoz et al., Icarus, 211, 894-900, 2011, DOI: 10.1016/j.icarus.2010.10.027.
[2] Muñoz et al., ApJS, 256(17), 2021, DOI 10.3847/1538-4365/ac0efa
[3] Martikainen et al., under review at ApJS, 2023.