2026 Workshop: Meteoroids and Space Debris

Long title
Meteoroids and Space Debris
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Description

As meteoroids enter Earth's atmosphere, their kinetic energy is rapidly converted into heat and ionization, generating transient plasmas that form meteor trails. Despite more than a century of study, fundamental questions remain regarding meteoroid ablation, plasma instabilities, fragmentation processes, metal layer formation, and ionospheric coupling.

In parallel, the rapid growth of anthropogenic orbital debris has introduced a new population of artificial meteoroids re-entering the atmosphere. These objects pose increasing risks to satellite infrastructure and contribute additional material and plasma processes to the upper atmosphere. Understanding the physical, chemical, and electrodynamic interactions of both natural and artificial particles is essential for space sustainability and atmospheric science.

This session invites contributions addressing the physics and engineering of meteoroids, meteor plasmas, and space debris, including their impact on the neutral atmosphere, ionosphere, and space-based systems. Topics of interest include, but are not limited to:

• Meteoroid ablation, ionization, and fragmentation dynamics
• Plasma instabilities and trail evolution (underdense, overdense, and non-specular echoes)
• Coupling to sporadic E layers and metal chemistry
• Space debris re-entry physics and atmospheric interactions
• Implications for satellite operations and space situational awareness
• Multi-instrument observations: radar (monostatic/multistatic), lidar, optical, infrasound, and satellite-based measurements
• Development of low-cost radar systems and distributed sensor networks
• Data assimilation and modeling approaches

- Applications of artificial intelligence and machine learning for detection, classification, and physical inference

Recent investments in multistatic radar networks, regional meteor systems, and optical monitoring arrays are enabling unprecedented coordinated observations. Emerging AI-driven analysis methods are further transforming the field, allowing automated classification of meteor echoes, fragmentation detection, debris characterization, and large-scale statistical studies.

We particularly encourage interdisciplinary contributions bridging atmospheric physics, plasma science, radar engineering, space situational awareness, and computational data science.

Justification

Viewing the Earth–atmosphere–geospace system as an interconnected and dynamically coupled environment, meteoroids and re-entering orbital debris represent a continuous source of mass, momentum, energy, and ionization to the upper atmosphere. These particles influence atmospheric chemistry, metal layer formation, ionospheric structure, plasma instabilities, and electrodynamic coupling processes across a wide range of spatial and temporal scales. Natural meteors and artificial debris alike now play a measurable role in space sustainability, satellite risk assessment, and the long-term evolution of near-Earth space.

Despite more than a century of investigation, fundamental questions remain unresolved. These include the physical scattering mechanisms responsible for radar head echoes, the role of fragmentation in trail evolution, the formation and structuring of sporadic E layers, the accurate quantification of meteoric mass input into the atmosphere, and the plasma processes governing underdense, overdense, and non-specular echoes. For anthropogenic debris, uncertainties remain regarding re-entry plasma dynamics, ablation chemistry, and their cumulative impact on the upper atmosphere.

Addressing these challenges requires coordinated and modernized approaches. Emerging multistatic radar networks, distributed low-cost sensor arrays, optical systems, lidar, infrasound observations, and satellite-based platforms are enabling multi-instrument, multi-scale investigations. Advances in computational plasma modeling, data assimilation frameworks, and artificial intelligence and machine learning techniques now permit automated echo classification, fragmentation detection, debris characterization, and large-scale statistical inference across massive datasets. Interdisciplinary collaboration between plasma physicists, atmospheric scientists, radar engineers, and space situational awareness experts is essential.

Progress in this field should be measured by (1) improved physical consistency between observations and first-principles models, (2) reduction in uncertainty in meteoric and debris mass flux estimates, (3) successful integration of multi-instrument datasets, (4) operational advances in detection and classification using AI-driven methodologies, and (5) demonstrable contributions to satellite risk mitigation and space sustainability frameworks. Training of students and early-career researchers through the development of accessible radar systems and open data methodologies should also be considered a key metric of long-term impact.

Related to CEDAR Science Thrusts:

Explore processes related to geospace evolution

Develop observational and instrumentation strategies for geospace system studies

Workshop format

Short Presentations

Keywords

meteor radar, optical, satellite, modelling, space debris

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