National Aeronautics and Space Administration

NASAfacts

Milli-Arcsecond (MAS) Imaging with SmallSat Enabled Super-resolution

Beyond Diffraction-limited Imaging with Photon Sieves

The objective of this project is to demonstrate a new imaging technology with unprecedented capabilities for scientific exploration. This technology innovation will enable extremely high-resolution imaging capability, otherwise unattainable with conventional approaches. It is based on a unique combination of novel diffractive optical sensing (photon sieve), advanced image processing, and small satellite formation flying. The spatial resolution of current solar instruments are more than 100 times coarser than the size of energy dissipation features in coronal heating (<100 km) since conventional optics cannot be figured to near diffraction-limited accuracy at extreme ultraviolet (EUV) wavelengths. This project will demonstrate the feasibility of imaging of a few milli-arcseconds (MAS) to study the structure and development of these dissipation regions.

The project will develop optimal strategies for the solution of the inherent inverse problem of photon sieve image deconvolution, and apply them to a laboratory simulator that will characterize the performance of the deconvolution process and demonstrate (beyond) diffraction-limited imaging capability. A multi-wavelength source simulating the EUV line emission from the solar corona will be developed. This source will be imaged by a 160 mm diameter photon sieve onto a charge coupled device (CCD) detector. Images will be taken at various axial focal positions, and the data from this simulation will be used to validate the deconvolution, and to quantify and demonstrate the MAS imaging system's performance in a realistic experimental setting.

The advent of such imaging technology has potential for broad impact in many areas of scientific exploration within NASA's Science Mission Directorate. Energy dissipation in narrow current sheets is a universal process in heliophysics and astrophysics and likely source of coronal heating in the Sun and other stars. The solar corona represents the best chance to observe such manifestations of reconnection in an astrophysical setting. Dissipation in the solar corona is believed to occur in extremely thin current sheets of order 1-100 km. Emission from these hot but thin current sheets should be visible in coronal EUV emission lines. However, this spatial scale is far below the resolution of existing imaging instruments, so these dissipation sites have never been observed individually. Conventional optics cannot be manufactured with sufficient surface figure accuracy to obtain the required spatial resolution in the EUV where these hot plasmas radiate. A photon sieve, a diffractive imaging element similar to a Fresnel zone plate, has been manufactured and tested in the laboratory to provide a few MAS resolution, with much more readily achievable tolerances than with conventional imaging technology.

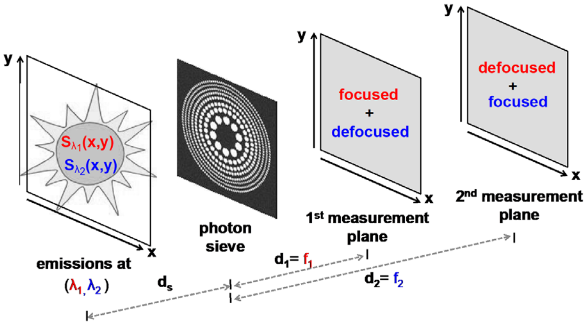

Illustration of a photon sieve imager with a moving detector. Switching between different wavelengths is accomplished by changing the sieve to detector distance. When two wavelengths are imaged with the instrument, each measurement consists of superimposed images of the two wavelengths, with each image being either in focus or out of focus depending on whether the observation plane is at the focal distance of the photon sieve for that particular wavelength.

Through this project, we will demonstrate an imaging system initially conceived for a sounding rocket demonstration payload, which would be enhanced by baselines attainable through formation flying of small satellites. The imaging system obtains 50 MAS (0.050 arcsec) imaging with a 160 mm diameter photon sieve to image Fe XIV 33.4 nm and Fe XVI 33.5 nm. Images from these instruments will have the potential to reveal the structure of the corona at a resolution never before obtained, and unravel the temperature structure in the dissipation region.

The project is led by the University of Illinois at Urbana-Champaign in collaboration with partners at NASA Goddard Space Flight Center.

This project is managed and funded by the Small Spacecraft Technology Program (SSTP) within the Space Technology Mission Directorate. The SSTP expands U.S. capability to execute unique missions through rapid development and in space demonstration of capabilities for small spacecraft applicable to exploration, science, and the commercial space sector. The SSTP will enable new mission architectures through the use of small space- craft with goals to expand their reach to new destinations, and challenging new environments.

For more information about the SSTP, visit:
www.nasa.gov/directorates/spacetech/small_spacecraft

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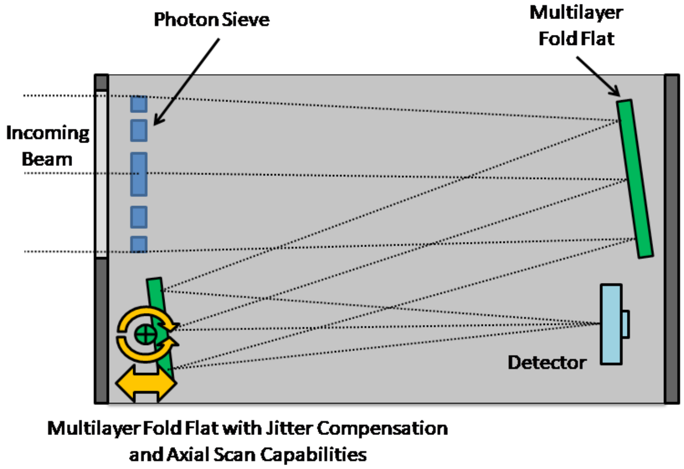
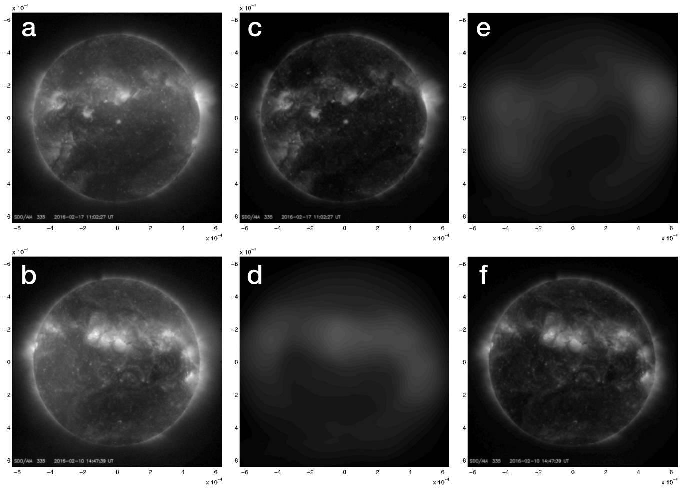

Photon Sieve
Multilayer Fold Flat
Incoming Beam
Detector
Multilayer Fold Flat with Jitter Compensation and Axial Scan Capabilities

Schematic of a sounding rocket instrument payload incorporating an ultra-high resolution photon sieve imager, which could also be implemented as a small satellite flight demonstration. Fold mirrors provide wavelength filtering, image motion compensation, and axial motion for scanning through a limited wavelength band pass of the multilayer mirrors region.



Simulated observations at the first and second focal planes (a)-(b), the contribution from the first emission at the first and second focal planes (c)-(d), the contribution from the second emission at the first and second focal planes (e)-(f). Note that the observation in (a) is obtained through the superposition of the images in (c) and (e) with added simulated photon noise. Similarly, the observation in (b) is obtained from images in (d) and (f).

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