The *Gamma-Ray Imager/Polarimeter for Solar Flares* (*GRIPS*)

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The new balloon-borne *Gamma-Ray Imager/Polarimeter for Solar flares* (*GRIPS*) instrument will provide a near-optimal combination of high-resolution imaging, spectroscopy, and polarimetry of solar-flare gamma-ray/hard X-ray emissions from ~20 keV to >~10 MeV. *GRIPS* will address questions relevant to particle acceleration and energy release that have been raised by recent solar flare observations, such as: What causes the spatial separation between energetic electrons producing hard X-rays and energetic ions producing gamma-ray lines? How anisotropic are the accelerated electrons, and why do relativistic electrons dominate in the corona? How does the composition of accelerated and ambient material vary with space and time, and why?

GRIPS science objectives

Solar flares can accelerate electrons to hundreds of MeV and ions to tens of GeV through the efficient release of magnetic energy, releasing up to 10^{32}–10^{33} ergs in 100–1,000 seconds (Figure 1). Flare-accelerated particles interact with the ambient solar atmosphere to produce observable signatures that reveal information about the abundances and energy spectra of the interacting particles. Ions produce gamma-ray lines through a variety of nuclear interactions, while electrons produce continuum emission through bremsstrahlung. For both populations, the angular distribution of the particles modifies the emission by resulting in, for example, redshifted gamma-ray lines or polarized bremsstrahlung photons.

The *Reuven Ramaty High-Energy Solar Spectroscopic Imager* (*RHESSI*) (a NASA SMEX mission led by SSL) has provided a wealth of information on flare acceleration through imaging and spectroscopy of hard X-rays and gamma-rays. These observations have raised such questions as:

- **What causes the spatial separation between energetic electrons producing hard X-rays and energetic ions producing gamma-ray lines?** *RHESSI* gamma-ray line images, such as for the 2003 Oct 28 flare (Figure 2), indicate differences in the acceleration and/or transport of ions compared to electrons.
- **How anisotropic are the accelerated electrons, and why do relativistic electrons dominate in the corona?** Gamma-ray images probe trapping of relativistic electrons (Figure 3), and polarization measurements probe the electron angular distribution and the magnetic field.
- **How does the composition of accelerated and ambient material vary with space and time, and why?** Imaging spectroscopy techniques can compare different resolved gamma-ray sources and their evolution in time.

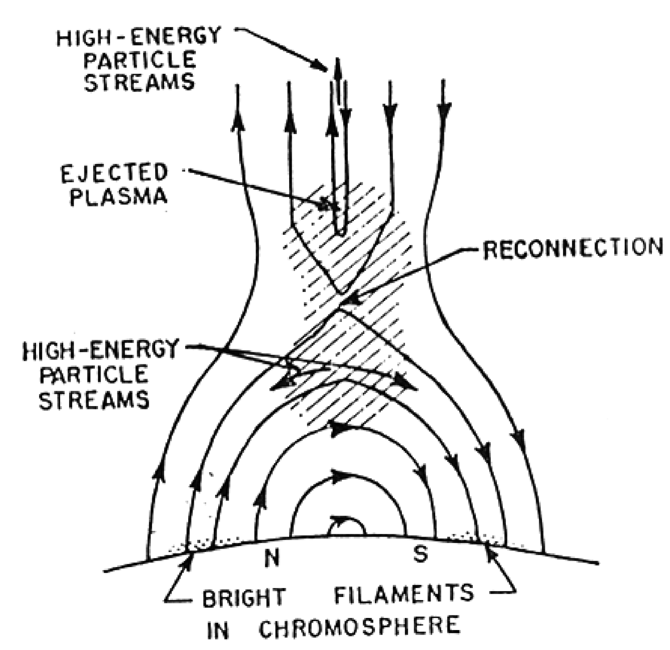


Figure 1 — A classic cartoon of the "standard" flare model (Sturrock 1966). Particles accelerated above the photospheric surface in the magnetic loop can stream down along field lines to produce gamma-ray emission at the footpoints. For most flares, the footpoints are not resolvable by *RHESSI*'s 35-arcsec gamma-ray resolution (1 arcsec = 726 km).

To address these science questions, **the *Gamma-Ray Imager/Polarimeter for Solar flares* (*GRIPS*) is a new balloon-borne instrument (a NASA LCAS mission) that will provide a near-optimal combination of high-resolution imaging, spectroscopy, and polarimetry of solar-flare gamma-ray/hard X-ray emissions from ~20 keV to >~10 MeV.** At gamma-ray energies, *GRIPS* will retain the spectroscopic performance of *RHESSI* while dramatically increasing the imaging effective area and angular resolution (from 35 arcseconds to 12.5 arcseconds, enough to resolve most footpoint sources) by combining a new detector design with a new imaging technique that is made possible by the detector. The balloon platform is advantageous for this instrument due to its size and weight and to minimize atmospheric attenuation. In addition to the primary solar science, *GRIPS* will also be able to observe electron precipitation from the Earth's radiation belts.

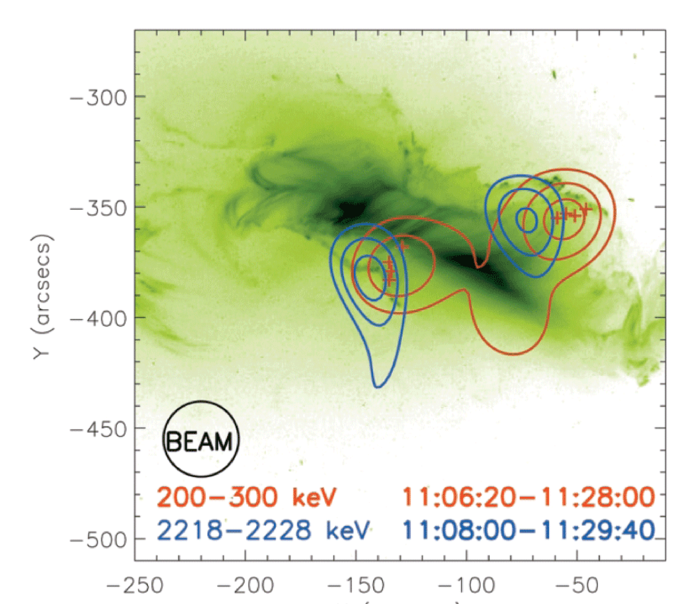


Figure 2 — *RHESSI* contours overlaid on the *TRACE* 195 Å image for the 2003 Oct 28 flare (Hurford et al. 2006). The flare footpoints are separated enough for the ion-produced gamma-ray line footpoints (blue) to be separately resolved and shown to be surprisingly displaced relative to the electron-produced bremsstrahlung footpoints (red).

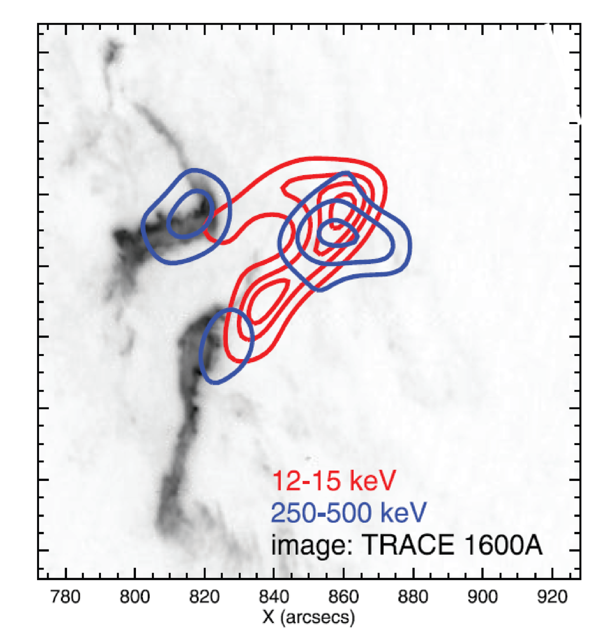


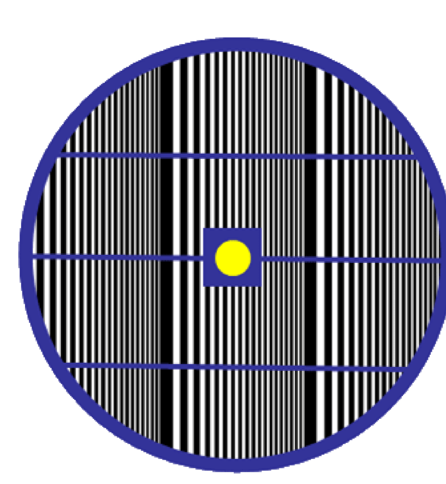
Figure 3 — *RHESSI* image of the gamma-ray coronal source (blue) in the 2005 Jan 20 flare (Krucker et al. 2008). The strength of this source, despite the low densities in the flare loop, and comparisons between the spectra at the loop-top and the footpoints, suggest that relativistic electrons are trapped for a significant time near the loop-top.

GRIPS instrument overview

Gamma-ray imaging cannot be accomplished by conventional optics, so instead *GRIPS* will use a novel imaging technique similar to the rotating-modulation-collimator (RMC) imaging used in *RHESSI*. **Solar photons are modulated by a multi-pitch rotating modulator (MPRM) that is placed 8 meters in front of a position-sensitive detector, which functions as both a spectrometer and a polarimeter.** The changing modulation pattern as the MPRM rotates allows one to reconstruct gamma-ray images.

Specifications for the MPRM and the spectrometer/polarimeter are provided to the right. The MPRM is made of tungsten slats and is rotated at ~15 rpm. **The detector uses 3D position-sensitive germanium detectors (3D-GeDs), a new technology already developed by LBNL for astrophysics, that combine the high spectral resolution of germanium with orthogonal strip contacts that locate each energy deposition in 3D space.** The position sensitivity of the *GRIPS* detector means that there does not need to be a grid immediately in front of the detector unlike in *RHESSI*, which dramatically improves throughput, in addition to benefiting from event selection techniques (see next box below).

Additional components not detailed here include the cryostat/cryocooler, detector electronics that include ASICs, an active BGO shield that covers the sides and rear of the 3D-GeDs, and an aspect system that provides precise knowledge of the orientation of the MPRM without imposing tight constraints on the pointing or boom stiffness.

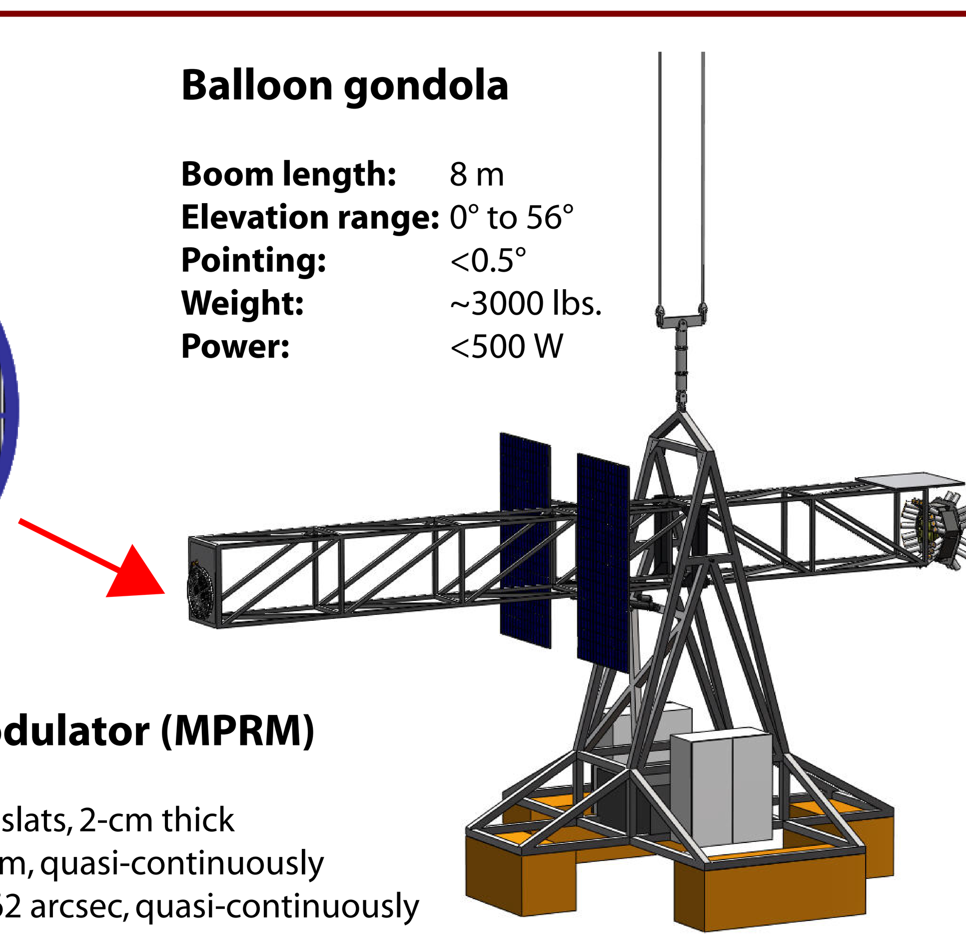


Multi-pitch rotating modulator (MPRM)

Grid material: tungsten slats, 2-cm thick
Slat pitch: 1 to 13 mm, quasi-continuously
Angular resolution: 12.5 to 162 arcsec, quasi-continuously
Rotation rate: ~15 rpm

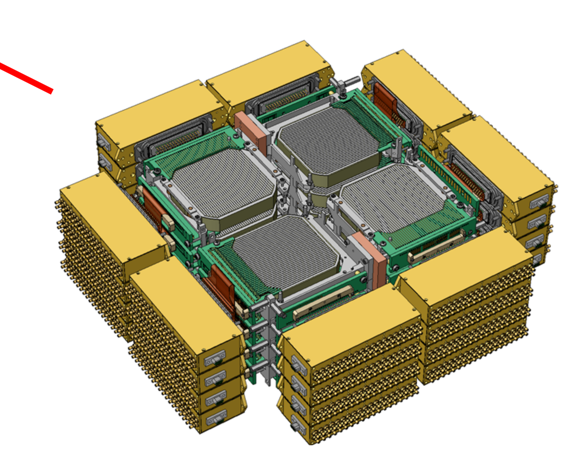
Balloon gondola

Boom length: 8 m
Elevation range: 0° to 56°
Pointing: <0.5°
Weight: ~3000 lbs.
Power: <500 W



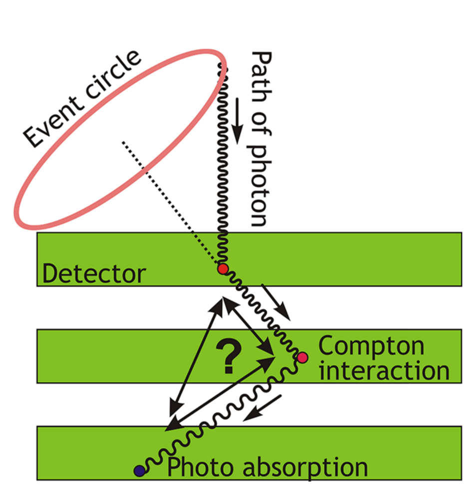
Spectrometer/polarimeter

Detector type: 16 3D-GeDs, orthogonal 0.5-mm strip contacts
Energy range: ~20 keV to >~10 MeV
Spectral resolution: ~2 keV FWHM at 662 keV
Spatial resolution: within ~0.1 mm³
Time resolution: ~1 microsecond
Effective areas: ~23 cm² at 2.2 MeV; ~76 cm² at 300 keV



Event reconstruction/selection

Every interaction in the detector is recorded individually, with energy, time, and spatial information. A gamma ray will typically Compton scatter one or more times in the detector before being completely absorbed (or escaping). **With the information of the individual interactions, one can reconstruct the Compton scatter sequence since the scatter direction uniquely determines the energy deposited.**



One can thus determine the source of a photon to within a ~degree-wide annulus in the sky. A photon with an event circle that does not include the Sun can be excluded as a background photon. Furthermore, one can choose to analyze only those photons that have deposited their entire energies in the detector.

Note that the Compton imaging capability of this detector is not sufficient to spatially resolve flare gamma-ray sources (< tens of arcsec). **The *GRIPS* detector is used to identify solar photons, and then this event list is combined with knowledge about the MPRM orientation to produce the high-resolution images** (see next box to right).

The detector will also function as the polarimeter. Polarized photons Compton scatter anisotropically in the azimuthal direction, and therefore the polarization of a source can be measured by observing the distribution of scatter angles. Simulations indicate that the detector will be capable of measuring polarization down to a few percent at energies of 150–650 keV for a gamma-ray flare comparable to the 2002 Jul 23 flare.

Image reconstruction

Images of sources can be reconstructed after solar photons are identified by the detector. The location where a photon first interacts with the detector can be traced back to a series of stripes on the Sun corresponding to areas not blocked by the MPRM at that time (panel a, below). As more photons are observed at various orientations of the MPRM (panels b–f), ***GRIPS* can produce high-quality gamma-ray images with an angular resolution that ranges quasi-continuously from 12.5 to 162 arcsec and a point-response function that is virtually free from sidelobes.**

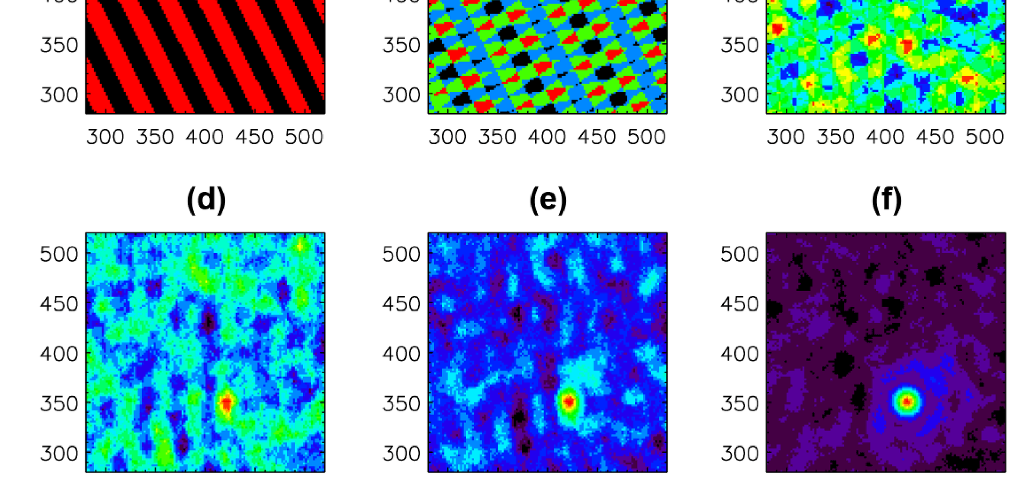


Figure 4 — A sequence of simulated reconstructed images (axes in arcsec) as successively more photons from a source are observed over many MPRM rotations. Note that the Sun is ~1900 arcsec in diameter.

Mission details

The combined instrument will be flown on a balloon, and this platform minimizes atmospheric attenuation and accommodates the instrument's size and weight. The 8-meter boom is launched in the horizontal orientation, and stowed in a near-vertical orientation for landing. A continental-US test flight is slated for June 2012 that will test the subsystems, will likely observe a hard X-ray flare, and may include off-pointing to observe the Crab Nebula (which will be at closest approach to the Sun). The payload will be powered by batteries for the ~2-day flight.

The test flight will be followed by long-duration balloon flights (LDBFs) from Antarctica. Since the Sun remains at an elevation of 20° to 30° during the Antarctic summer, LDBFs allow for month-long uninterrupted observations of the Sun to continuously observe active regions and to maximize the chance of capturing a gamma-ray flare. The payload will be powered by solar panels that are mounted on the boom (as depicted above), which is nominally Sun-pointed.

The science data is recorded on multiple solid-state flash drives (~200 GB capacity) for recovery after each flight, with each energy deposition in the detector stored separately. The analysis described earlier (event reconstruction/selection and image reconstruction) will be performed on the ground, which allows for maximum flexibility.

In addition to the direct science return from these flights, *GRIPS* will prove these technologies for a future space mission. A spacecraft could accommodate a larger detector (e.g., 64 3D-GeDs) and a significantly longer boom (e.g., 20 m), providing gamma-ray images of solar flares at unparalleled sensitivity and angular resolution (~5 arcsec) over many years of observation.