ASTROPHYSICS WITH HESSI

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ABSTRACT In the summer of the year 2000, a NASA Small Explorer satellite, the High Energy Solar Spectroscopic Imager (HESSI), will be launched. It will consist of nine large, coaxial germanium detectors viewing the Sun through a set of Rotation Modulation Collimators and will accomplish high-resolution imaging and spectroscopy of solar flares in the x-ray and gamma-ray bands. Here we describe some of the astrophysical observations HESSI will also perform in addition to its solar mission.

KEYWORDS: Instrumentation, Nuclear Spectroscopy

1. What is HESSI?

The High Energy Solar Spectroscopic Imager (HESSI) is a NASA Small Explorer mission being built at the University of California at Berkeley (Prof. Robert P. Lin, Principal Investigator), the NASA Goddard Space Flight Center, the Paul Scherrer Institut in Switzerland, and Spectrum Astro, Inc., with participation by a number of other institutions. It is scheduled for launch into low-Earth orbit in July 2000.

HESSI’s primary science goals are imaging spectroscopy (3 keV to several MeV), and high-resolution nuclear spectroscopy of solar flares during the next solar maximum. The instrument consists of 9 large germanium detectors (cooled to 75 K by a mechanical cooler) which cover the full energy range. The detectors sit below a Rotation Modulation Collimator (RMC) system for high resolution imaging capability (2 arcsec at hard x-ray energies). The rotation is provided by spinning the whole spacecraft at about 15 rpm.

Each germanium detector is a closed-end coaxial cylinder with a volume of over 300 cm³, electronically segmented into a thin front segment and thick rear segment. The rear segments view nearly half the sky through side walls of only 4mm of aluminum, giving them an effective energy range of 20 keV to 15 MeV. The front segments shield the rear segments from solar photons below 100 keV and view the Sun through beryllium windows and a small amount of insulating blankets, giving them a useful energy range down to about 3 keV.

2. HESSI Astrophysics

Although HESSI is primarily a solar mission, the HESSI team is committed to making sure its capabilities for extra-solar astrophysical observations are fully exploited. All HESSI data and analysis software will be public, with no proprietary period.
The astrophysics program the HESSI team is planning to pursue combines aspects of what has been done with the CGRO/BATSE and Wind/TGRS instruments, as well as techniques unique to HESSI. In addition to the topics discussed below, high-resolution spectroscopy of gamma-ray bursts and soft gamma repeater (SGR) events will be accomplished without the need for a burst trigger: every photon is always telemetered with its arrival time.

3. RMC Imaging of the Crab Nebula

The Crab nebula and pulsar (ecliptic latitude -1.3°), will drift into HESSI’s imaged field of view once per year, so we will automatically produce images from about 3 keV to 100 keV. Only one image above a few keV has ever been produced (Pelling et al. 1997), with a resolution of about 15 arcsec, as compared to HESSI’s 2 arcsec. The ROSAT soft x-ray image of the nebula (Hester et al. 1995) shows features at this scale, as do the radio wisps, so the hard x-ray image should be very informative. Our simulations indicate the statistics will be good enough to see the relevant details. In addition, the radio wisps evolve on the scale of a year, so we may be able to observe annual changes in the hard x-ray image.

4. Galactic Gamma-Ray Lines

By using the Earth as an occulter, we can produce background-subtracted spectra of the Galactic Center region. In this analysis, the whole HESSI array will be treated as a single detector. Spectra will be summed over a time on the order of a minute (several revolutions), and background will be constructed from data taken during other orbits when the Galactic Center was blocked by the Earth. A similar technique has been used to measure the Galactic 511 keV line with BATSE to the highest precision of any experiment. (Smith et al. 1998; see also the other poster by D. M. Smith et al. at this meeting).

Figure 1 shows HESSI’s 3σ sensitivity to narrow lines in one year of observations. The sensitivity is not as good as the INTEGRAL SPI, since HESSI is unshielded, but HESSI also observes a much larger portion of the sky at once, and will therefore receive a larger (albeit unimaged) signal in the diffuse Galactic lines. This will make HESSI a good complement to INTEGRAL; subtracting the fluxes in INTEGRAL line maps from HESSI fluxes will allow us to find large scale, low-surface-brightness components in the 511 keV and 1809 keV lines.

Important results awaiting confirmation include:

- The small (or zero) amount of Galactic 511 keV flux which is in the relatively broad, 6.4 keV FWHM component expected from annihilation in flight after charge exchange with neutral hydrogen. This result, from Harris et al. 1998, implies that Galactic positrons are mostly magnetically excluded from cold cloud cores.
- The large width (5.4 (+1.4,-1.3) keV FWHM) measured for the integrated
Galactic 1809 keV line by the GRIS balloon instrument (Naya et al. 1996). This unexpectedly high width means that $^{26}$Al ejected in supernovae maintains high velocities long after it would be expected to slow down in the ISM.

- The low upper limit on $^{60}$Fe, also from GRIS, constraining models of supernova nucleosynthesis when compared to $^{26}$Al (and assuming most of the $^{26}$Al is produced in supernovae).

5. Pulsar Period Folding

By folding the rear-segment data on the period of known accreting pulsars, we will produce some of the best high-resolution spectra of the pulsed emission from these objects. Figure 2 shows our expected spectrum from the pulsed emission of Her X-1 in one month of observation. The upper curve was generated under the assumption that the cyclotron absorption line is of the same width as the resolution of the scintillators which have generally observed it. The lower curve, divided by 10 for clarity, shows the spectrum we would observe if the absorption line were narrower than the resolution of HESSI’s germanium detectors.

In addition, pulsar period folding will allow us to follow the period evolution of the sources, a project which has been extremely fruitful for BATSE (Bildsten et al. 1997). Although HESSI will have less than 10% of BATSE’s effective area for these observations, there are still a number of known sources which will be bright enough to follow. Furthermore, since every photon will be recovered with a time tag, HESSI will not have the limitation of BATSE’s normal operating mode, which samples rates every 2 seconds. We will therefore be able to do a long-term survey of the undersampled range of periods < 4 sec.
5. Spin Period Folding

By folding the rear-segment data on the spin period of the spacecraft, we will observe bright Galactic point sources by analyzing the repeated occultation of one detector by another with respect to the source. BATSE’s success with occultation by the Earth is well known (Harmon et al. 1992; Zhang et al. 1993). Although HESSI is much smaller than BATSE, we have the advantage of gaining many more occultations per orbit: about 750 detector/detector occultations due to spin per orbit in addition to the 2 Earth occultations. We expect to monitor transients and persistent sources above a few hundred mCrab.

Although the detectors are not completely opaque at 511 keV, we may be able to obtain some spatial information on the 511 keV line by detector/detector occultation, in a way similar to the analysis done by Harris et al. (1998) for Wind/TGRS, but taking advantage of HESSI’s extra order of magnitude of germanium volume.

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