THE HIGH ENERGY SOLAR PHYSICS MISSION (HESP)

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Abstract

NASA's major solar flare project for the next solar maximum around the turn of the century is the High Energy Solar Physics Mission (**HESP**). The prime objective of **HESP** is to study the flare energy release, particle acceleration, and transport processes through high-resolution spatially-resolved spectroscopy of X-rays and gamma-rays. The strawman instrument for **HESP** to achieve this objective is the High Energy Imaging Spectrometer (**HEISPEC**). It will make imaging spectroscopy observations with an angular resolution of several arcseconds and an energy resolution of ~1 keV from a few keV to ~1 MeV and gamma-ray spectroscopy observations with similar energy resolution to 10 MeV. The plan is to launch **HEISPEC** in the year 2000 with a Pegasus launch vehicle into an equatorial orbit to obtain 2 - 3 years of observations during the next solar maximum. In order to fully interpret the **HEISPEC** observations, it will be necessary to obtain complementary observations of the thermal, dynamic, and magnetic context in which the high energy emissions are produced. Much of the necessary context information will be obtained from closely coordinated ground-based optical and radio observations. In addition, it is hoped that additional instruments will be flown on other US or foreign spacecraft to provide context soft X-ray and UV/EUV observations of the high temperature emissions not accessible from the ground.

1. Introduction

The primary scientific objective of the **H**igh **E**nergy **S**olar **P**hysics Mission (**HESP**) shown in Figure 1 is to understand the processes of impulsive energy release and particle acceleration in the magnetized plasmas of the solar atmosphere through imaging and spectroscopy observation of the associated X-ray and gamma-ray emissions with an unprecedented combination of sensitivity and precision over a wider energy range than ever before possible. The processes of interest include the rapid release of energy stored in unstable magnetic configurations, the equally rapid conversion of this energy into the kinetic energy of hot plasma and accelerated particles (primarily electrons, protons and ions), the transport of these particles,

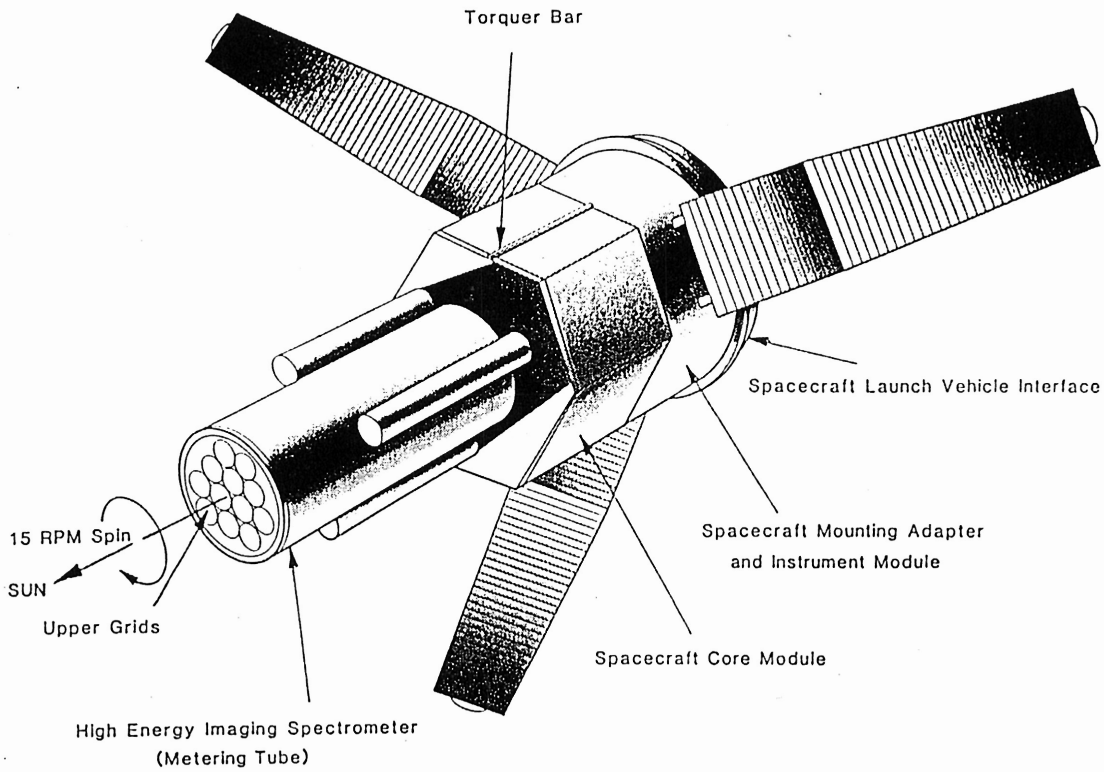

Fig. 1. Artist's concept of the spin-stabilized spacecraft carrying **HEISPEC** in a 600-km equatorial orbit.

and the subsequent heating of the ambient solar atmosphere. The acceleration of electrons is revealed by hard X-ray and gamma-ray bremsstrahlung while the acceleration of protons and ions is revealed by gamma-ray lines and continuum.

2. Scientific Objectives

The fundamental unanswered scientific questions concerning energy release and particle acceleration in solar flares are the following:

- **What role do high energy electrons, protons, and ions play in the energy release process and how much of the released energy do they carry?**
- **What mechanisms accelerate both electrons and ions to high energies so rapidly and efficiently?**
- **What are the energy transport processes and what is the geometry of the acceleration region?**
- **What is the nature of the site in which the ions deposit their energy?**
- **What is the thermal, dynamic, and magnetic environment in which the flare occurs?**
- **What role do electric currents play in the flare processes?**
- **What mechanisms transport the flare energy, the energetic particle component in particular, away from the energy release site?**

• **What are the characteristic radiation signatures of flares that have potentially hazardous effects, and how do these flares occur and evolve?**

3. Observational Approach

HESP will address these scientific questions by making the following key observations:

• **X-ray and gamma-ray imaging spectroscopy with the finest angular and energy resolutions ever achieved and with a higher sensitivity over a broader energy range than ever before possible from a few keV to hundreds of keV.**

• **X-ray and gamma-ray spectroscopy with the finest energy resolution ever achieved and with high sensitivity to energies of at least 10 MeV.**

In order to achieve a full understanding of the acceleration of electrons and ions, and their transport through the solar atmosphere, it is essential to obtain support observations of the plasma and the magnetic fields where the hard X-ray and gamma-ray sources are situated, i.e., the thermal, dynamic, and magnetic context of the high energy flare. The required context observations are as follows:

• **Soft X-ray, EUV, and UV imaging and spectroscopy from space with similar spatial and temporal resolutions to the X-ray and gamma-ray measurements.**

• **Ground-based radio and optical imaging and spectroscopy, and vector magnetic field measurements.**

4. Instrumentation

The strawman **HESP** instrument, the High Energy Imaging Spectrometer (**HEISPEC**), is designed to image flares in energetic photons from soft X-rays (~2 keV) to ~1 MeV gamma-rays. Furthermore, **HEISPEC** has the capability to perform spatially resolved spectroscopy with high spectral resolution, thus allowing the full diagnostic power of hard X-rays and gamma-rays to be applied on a spatial point-by-point basis within solar flares. The coaxial germanium detectors also provide high resolution spectroscopy for gamma-ray lines from 0.4 to 15 MeV.

The imaging capability of **HEISPEC** is based on a Fourier-transform technique using a set of 12 rotational modulation collimators (RMCs). Each RMC consists of two widely-spaced, fine-scale linear grids, which temporally modulate the photon signal from sources in the field of view as the spacecraft rotates about an axis parallel to to the long axis of the RMC. The modulation can be measured with a detector having no spatial resolution placed behind the RMC. The modulation pattern over half a spin for a single RMC provides the amplitude and phase of many spatial Fourier components over a full range of angular orientations but for a small range of spatial source dimensions. Multiple RMCs, each with a different slit width, can provide coverage over a full range of flare source sizes. An image is reconstructed from the set of measured Fourier components in exact mathematical analogy to multi-baseline radio interferometry.

HEISPEC will provide spatial resolution of ~2 arcseconds at X-ray energies below ~300 keV and ~ 8-16 arcseconds for gamma-ray lines and continuum up to ~ 1 MeV. The chosen spacecraft rotation rate of ~15 rpm provides a complete image with the maximum number of Fourier components ($\sim 5 \times 10^3$) in 2 s, but spatial information from fewer Fourier components is still available on timescales down to tens of ms, provided the count rates are sufficiently high.

The detectors baselined for **HEISPEC** behind the RMCs are the largest currently-available hyperpure (n-type) germanium detectors, 7.1-cm in diameter and 8-cm long. They will be cooled to their operating temperature of ~85 K by mechanical coolers. Such detectors can cover the entire X-ray to gamma-ray energy range from ~10 keV to ~20 MeV with the highest spectral resolution of any presently available detector - $<$ 1 keV below 1 MeV to ~5 keV at 20 MeV. The keV spectral resolution of germanium detectors is necessary to resolve all of the solar gamma-ray lines (with the exception of the neutron-capture deuterium line, which has an expected FWHM of about 0.1 keV). It is also required to resolve the detailed features of the X-ray continuum spectrum such as the steep super-hot thermal component and the sharp breaks in the non-thermal component at higher energies. Germanium detectors with two electrically-independent segments will be used so that the front ~2-cm-thick segment will measure hard X-rays up to ~200 keV with low background while the rear 6-cm-thick segment will provide undistorted high-resolution gamma-ray line measurements, even in the presence of very intense hard X-ray fluxes in large flares. The cumulative radiation dose to the germanium detectors in a three-year mission lifetime is low enough in a low-Earth equatorial orbit to avoid noticeable radiation damage to the detectors. Thus, it is not necessary to add a thick and necessarily heavy shield in this orbit making the lightsat approach feasible.

5. Mission Concept

The original **HESP** study (Lin *et al.*, 1991) resulted in a mission design based on a single Delta-launched 2500-kg spacecraft. Subsequently, **HESP** was adapted to fit on several light-weight satellites or lightsats each weighing $\lesssim 350$ kg. More recently, NASA has reduced the budget cap imposed on **HESP** to ~50 million dollars and consequently only the prime X-ray and gamma-ray imaging spectroscopy and the originally-planned ground-based context observations will be possible. Any context observations from space will have to be made by instruments flown as part of another program.

The current plan is to fly the strawman **HEISPEC** instrument on a lightsat designed to fit on a Pegasus XL launch vehicle. In implementing **HEISPEC** on a single lightsat within the new funding cap, some compromises on the original goal have had to be accepted. These include the lack of continuous solar coverage in a polar orbit, the loss of gamma-ray and neutron spectroscopy above 20 MeV, and limitations on the energy range over which the high resolution imaging can be performed.

The strawman **HEISPEC** instrument requires all the weight and volume available to a Pegasus-launched lightsat. In fact, it is necessary to reduce the distance between the grids of a pair from the 5 m that was posssible with a Delta launch vehicle to ~1.7 m to fit inside a Pegasus fairing. In addition, the thickness of the coarser grids had to be reduced from 4 cm to 1 cm to reduce weight. Nevertheless, full high-resolution spectra can still be obtained in the nuclear gamma-ray line range up to 10 MeV. The ability to obtain gamma-ray and neutron images and spectra with coarser resolution to much higher energies (>20 MeV) has also been lost in the lightsat implementation of **HESP** because of the elimination of the 5-cm thick bismuth-germanate shield in the original design to reduce weight.

We have defined a **HESP** mission which we believe can achieve the core scientific objectives within the cost cap of 50 million dollars but with the flexibility to accommodate highly desirable secondary objectives if the constraints change. Examples of changes that may be anticipated are as follows: a more capable launch vehicle may become available for a modest increase in cost, thus allowing a BGO shield to be added back and a polar orbit used for improved solar coverage; some of the instruments may be carried on foreign spacecraft; there may be significant foreign involvement in the instruments, spacecraft and/or launch vehicle; appropriate Long Duration Balloon Flight (LDBF) technology may be developed.

References

Lin, R. P. *et al.*, 1991, *The High Energy Solar Physics Mission (***HESP***), Scientific Objectives and Technical Description*, NASA.