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Solar Flare Gamma-Ray and Hard X-Ray Imaging with the GRID-on-a-Balloon

L. E. Orwig, C. J. Crannell, B. R. Dennis (LASP NASA/GSFC), R. Starr (LASP NASA/GSFC & The Catholic U. of America), G. J. Hurford, T. A. Prince (Caltech), H. S. Hudson (UCSD), F. van Beek (Delft U. of the Netherlands), M. E. Greene (Auburn U.), W. N. Johnson, J. P. Norris, K. S. Wood (NRL), J. M. Davis (NASA/MSFC).

ABSTRACT

A primary scientific objective for solar flare research during the rapidly approaching maximum in solar activity is the imaging of gamma-ray and hard X-ray sources of solar flare emissions. These goals will be pursued by the Gamma Ray Imaging Device (GRID) instrument, one of three instruments recently selected for NASA's Max '91 Solar Balloon Program. GRID is based on the technique of Fourier transform imaging and utilizes scanning modulation grid collimator optics to provide full-Sun imaging with 1.9-arcsecond resolution over the energy range from 20 to 700 keV at time resolutions from 0.1 to 2 s. GRID will employ 32 subcollimators, each composed of a matched pair of high-Z collimator grids separated by 5.2 meters and a phoswich scintillation spectrometer detector having no spatial resolution. The subcollimators and integrally-mounted fine aspect system are contained within a telescope canister which will be pointed to 0.1 degree accuracy and cyclically scanned to produce source modulation. The 32 subcollimators provide a uniform distribution of grid slit orientations and a logarithmic distribution of slit spacings corresponding to angular dimensions of 1.9 arcseconds to several arcminutes. The instrument is several orders of magnitude more sensitive than the HXIS instrument on SMM and nearly 10 times more sensitive than any similar instrument scheduled to fly during the next solar maximum. The payload, designed for **long-duration** high-altitude balloon capabilty, is scheduled for its first science flight (8 to 14 days duration) from the Antarctic in January of 1992.

SCIENTIFIC OBJECTIVES

- Image Dynamic Flare Geometries (where do the hard X-ray and gamma-ray emissions come from?)
- Investigate Energy Release (what processes liberate the energy stored in unstable magnetic fields?)
- Study Particle Acceleration (what mechanisms are at work?)
- Study Energy Transport (what mechanisms transport particles and energy away from the release site?)
- Investigate Magnetic Field Structures (how do simultaneous microwave and hard X-ray/gamma-ray images compare?)
- Provide Definitive Tests for Solar Flare Models
- Study Microflares

OBSERVATIONAL GOALS

- Obtain arc-second imaging of solar flare hard X-rays and gamma-rays with sub-second temporal resolution
- Compare spatially-resolved high energy emissions with simultaneous microwave observations
- Obtain significantly improved spatial resolution over previous measurements
- Extend imaging capability to photon energies not previously attainable (700 keV)
- Develop hard X-ray and gamma-ray imaging technology as a precursor to future instruments such as the Pinhole/Occulter Facility on Space Station

INSTRUMENTAL APPROACH

GRID is based on the concept of Fourier transform imaging using bi-grid collimators - an exact analog to the technique used in the microwave domain at facilities such as the VLA. The measurement of a single Fourier component is performed by a single subcollimator consisting of a pair of widely-spaced identical top and bottom grids. If the slit spacings and orientation of the top and bottom grids are identical, and the subcollimator structure is scanned across a source, rapid modulation in the X-ray transmission of the grid pair is produced. This modulated X-ray flux is measured by a detector which requires no spatial resolution, in this case a phoswich scintillation spectrometer. The amplitude and phase of the fundamental period of this temporally modulated X-ray signal provides a direct measure of the amplitude and phase of the corresponding spatial Fourier component of the source.

The GRID telescope contains 32 such subcollimators, each with grid pairs having different slit spacings and/or orientations. The slit spacings and orientations have been chosen to provide optimal coverage of the (u-v) spatial frequency plane.The modulation of the source is provided by cyclically scanning the telescope over a 3 arcminute radius at a 4 sec period using the main pointing system.

The primary science data consists of the energy and arrival time of each valid photon, along with precise aspect information provided once very 4 ms, all of which is recorded with on-board tape recorders. No significant on-board data processing is performed, greatly simplifying the tasks of the flight data handling electronics. Image reconstruction is then performed in the post-flight data analysis phase where the aspect information is used to "phase bin" each time-tagged photon. Over a chosen time interval the vector summation of the photons (by phase) in any chosen energy interval provides a measured amplitude and phase for that time interval, energy interval and subcollimator. The resulting set of amplitudes and phases can then be processed by standard interferometric image processing software to produce high-resolution images of the X-ray source.

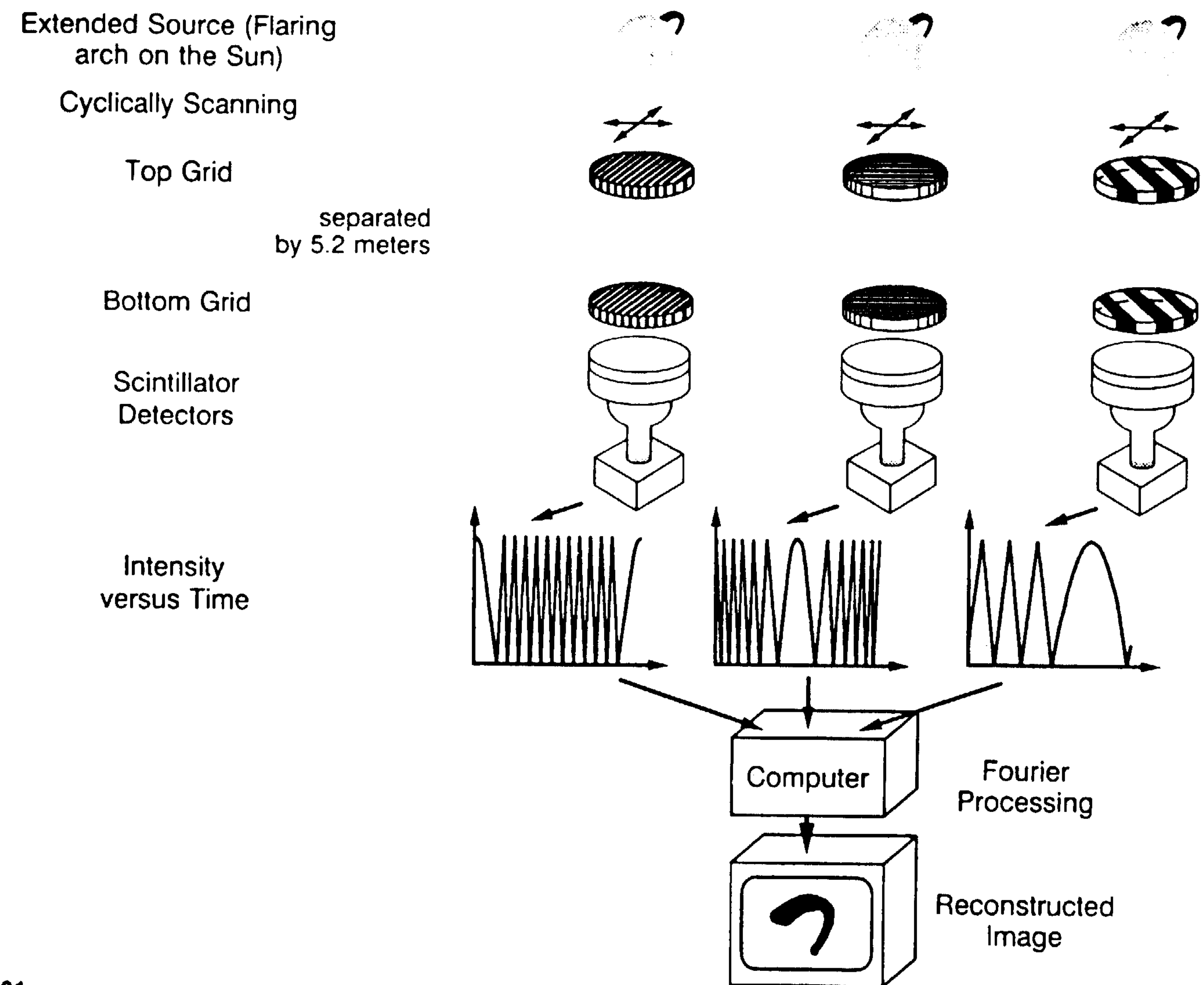
PAYLOAD SUBSYSTEMS

The GRID consists of the following major payload subsystems:

- a set of 32 subcollimator grids each of which has a large number of parallel slits
- a pair of 1-m diameter trays on which the grids are mounted
- a 5.2-m long tube with the grid trays mounted at the ends
- an aspect system which provides a posterior knowledge of the angle between the optical axis of the X-ray grids and the source direction
- a set of phoswich scintillation spectrometers located beneath the lower grid tray
- a digital data system that tags each detected photon with it arrival-time, subcollimator ID, energy, and current aspect information
- an on-board data recording system with sufficient capacity for a 15-day flight and data-rate capability sufficient to handle the largest expected flare
- an on-board power subsystem providing 1000 Watts continuous power through the use of solar cells and rechargeable batteries
- a gondola with pointer used to solar point the telescope to 0.1 deg. accuracy and provide the cyclic scanning motion for the telescope

The first science flight of the GRID is baselined for a long-duration (8-15 day) balloon mission at a float altitude of 130,000 feet in December 1991 in Antarctica where optimum solar observations can be obtained for ~ 12 hours each day at Solar elevation angles between 24° and 36°. Although an Antarctic flight is the baseline the payload can easily be adapted for long-duration flights from mid-latitude launch sites such as Australia.

FOURIER TRANSFORM TELESCOPE



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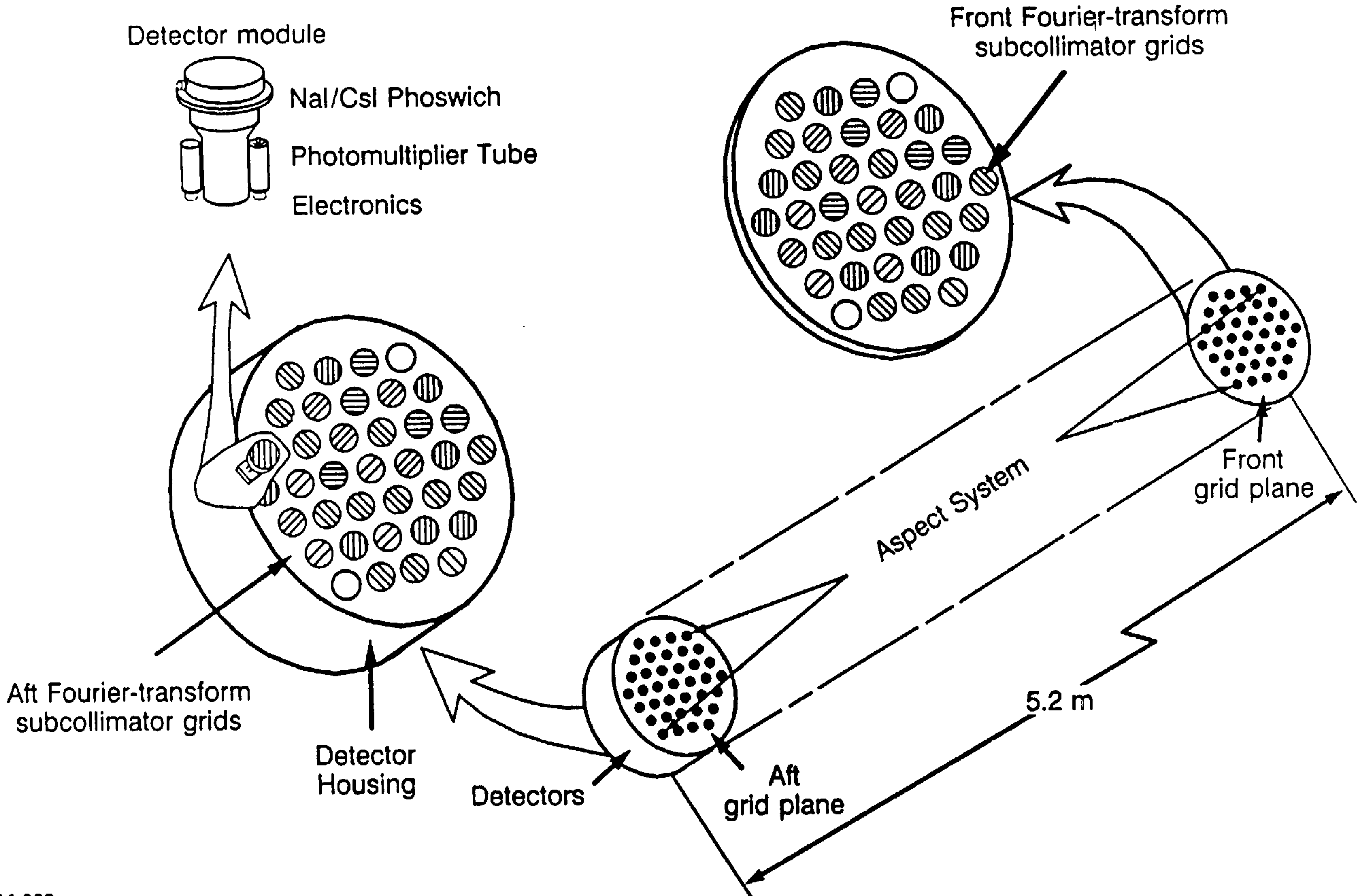
EXPLODED VIEW OF TELESCOPE



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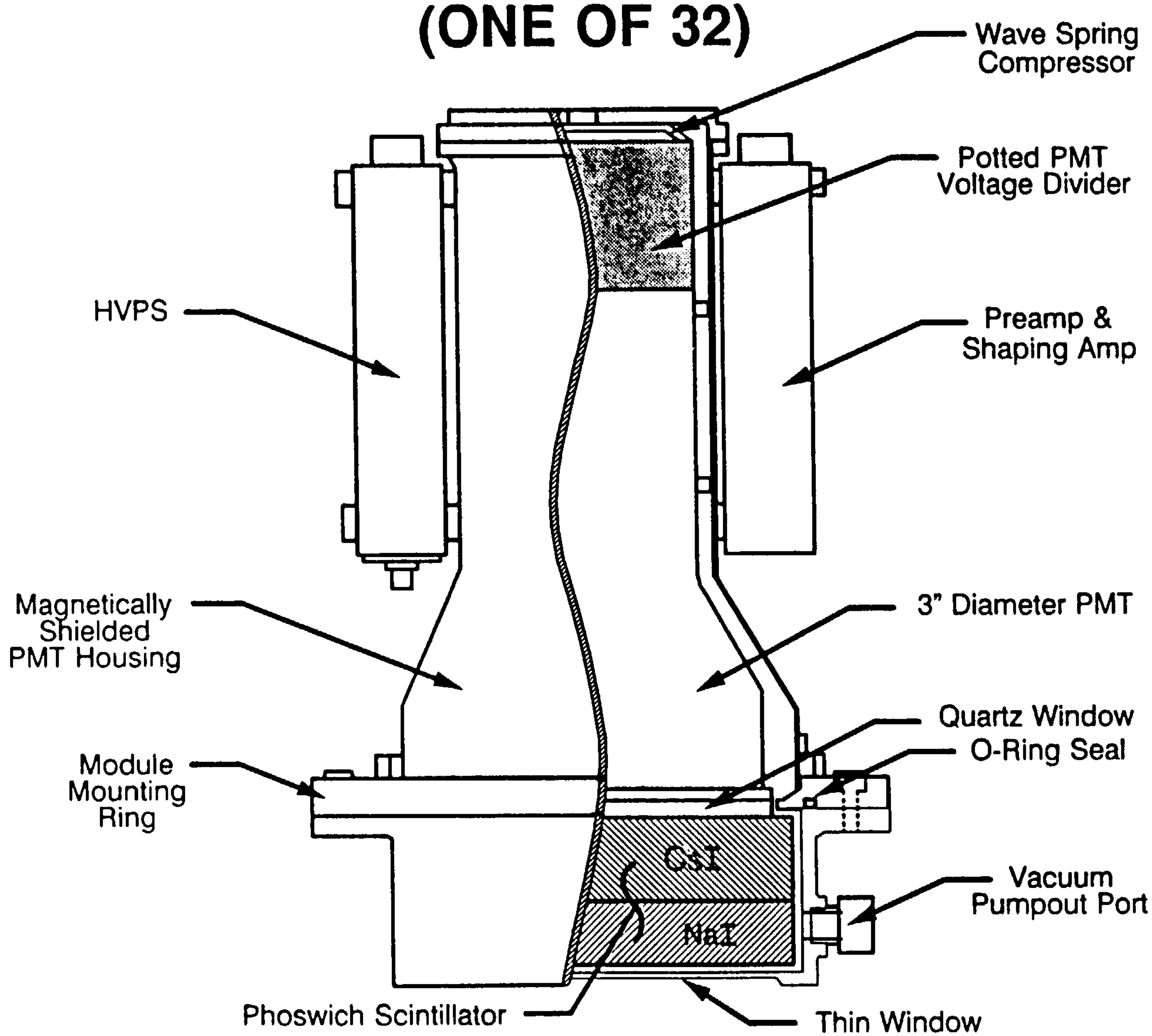
GRID INSTRUMENT CHARACTERISTICS	
Detector type (number)	NaI/CsI phoswich scintillation spectrometers (32)
Detector area	2036 cm**2
Effective area	500 cm**2
Image formation	Fourier imaging using cyclically scanning modulation collimators
Energy range	20 keV - 700 keV
Subcollimator material	Tungsten (3 mm to 10 mm thick)
Number of Fourier components	32
Sensitivity	detect and locate about 140 flares per week
Maximum angular resolution	1.9 arc seconds
Field of view	1 degree FWHM (whole Sun)
Pointing accuracy requirement	0.1 degree (rms)
Pointing stability requirement	0.2 arc second per 4 ms (rms)
Expected flight duration	8 to 15 days

GRID DETECTOR MODULE
(ONE OF 32)



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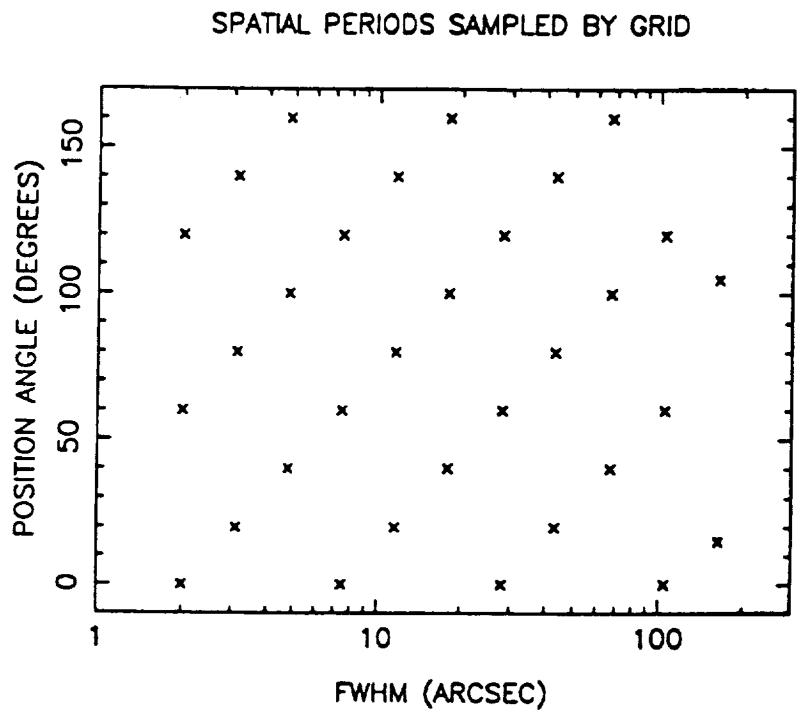
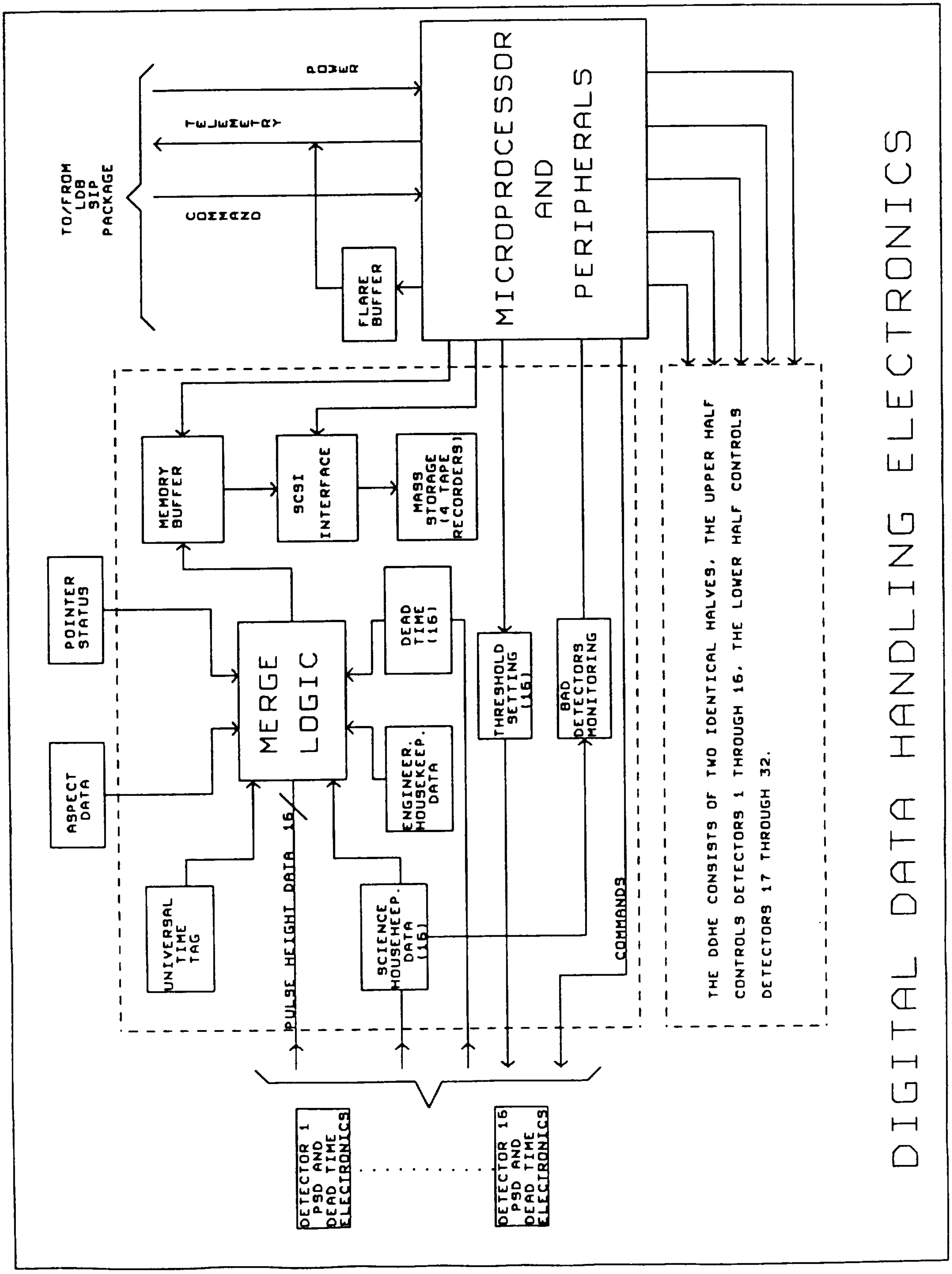
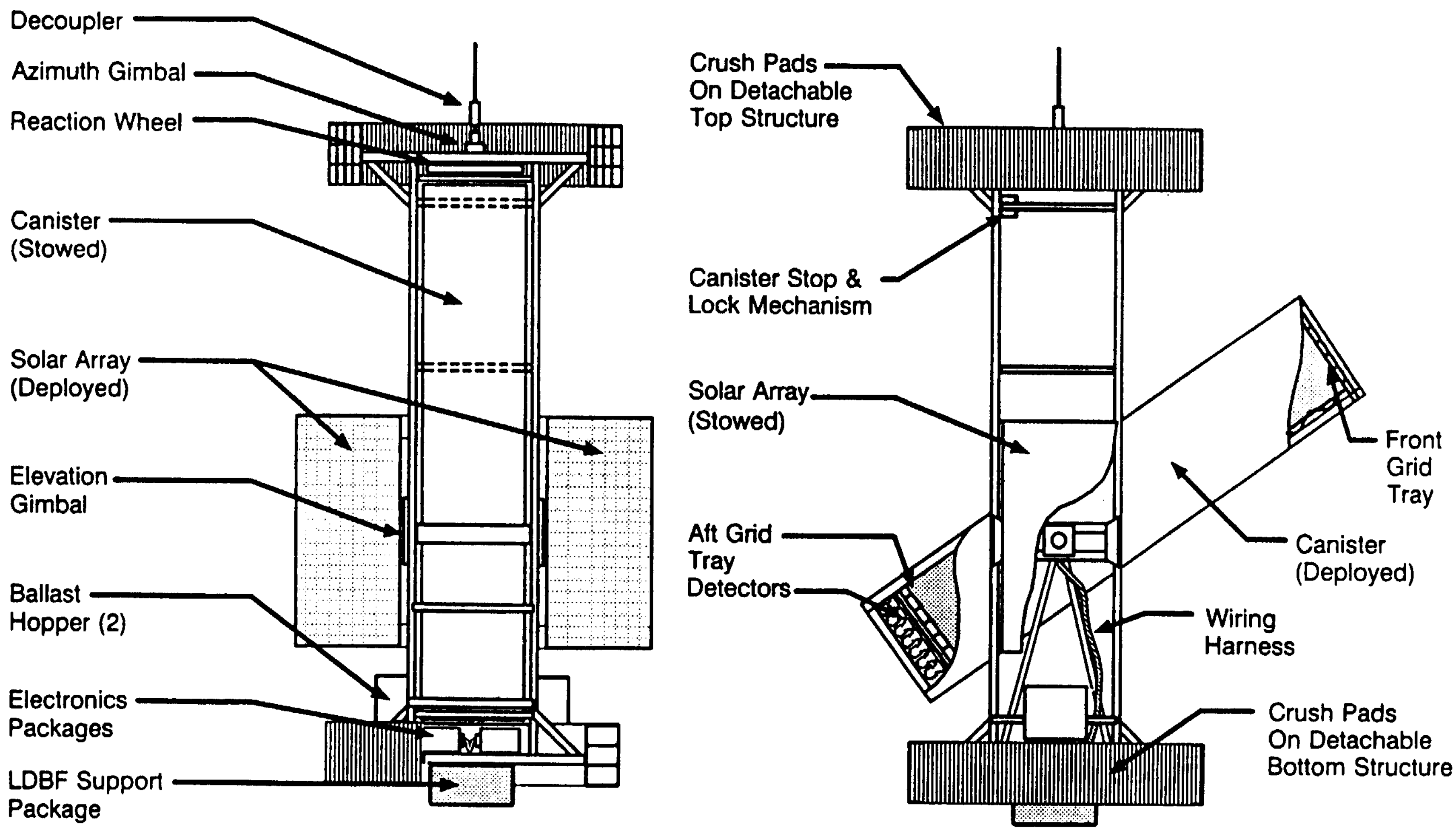

SPATIAL PERIODS SAMPLED BY GRID
POSITION ANGLE (DEGREES)
0
50
100
150
1
10
100
FWHM (ARCSEC)



DIGITAL DATA HANDLING ELECTRONICS
MICROPROCESSOR AND PERIPHERALS
TO/FROM LDB SIP PACKAGE
POWER
TELEMETRY
COMMAND
FLARE BUFFER
MEMORY BUFFER
SCSI INTERFACE
MASS STORAGE (4 TAPE RECORDERS)
POINTER STATUS
ASPECT DATA
MERGE LOGIC
DEAD TIME (16)
ENGINEER. HOUSEKEEP. DATA
THRESHOLD SETTING (16)
BAD DETECTORS MONITORING
UNIVERSAL TIME TAG
SCIENCE HOUSEKEEP. DATA (16)
PULSE HEIGHT DATA 16
COMMANDS
THE DDHE CONSISTS OF TWO IDENTICAL HALVES. THE UPPER HALF CONTROLS DETECTORS 1 THROUGH 16. THE LOWER HALF CONTROLS DETECTORS 17 THROUGH 32.
DETECTOR 1 PSD AND DEAD TIME ELECTRONICS
DETECTOR 16 PSD AND DEAD TIME ELECTRONICS

GRID PAYLOAD



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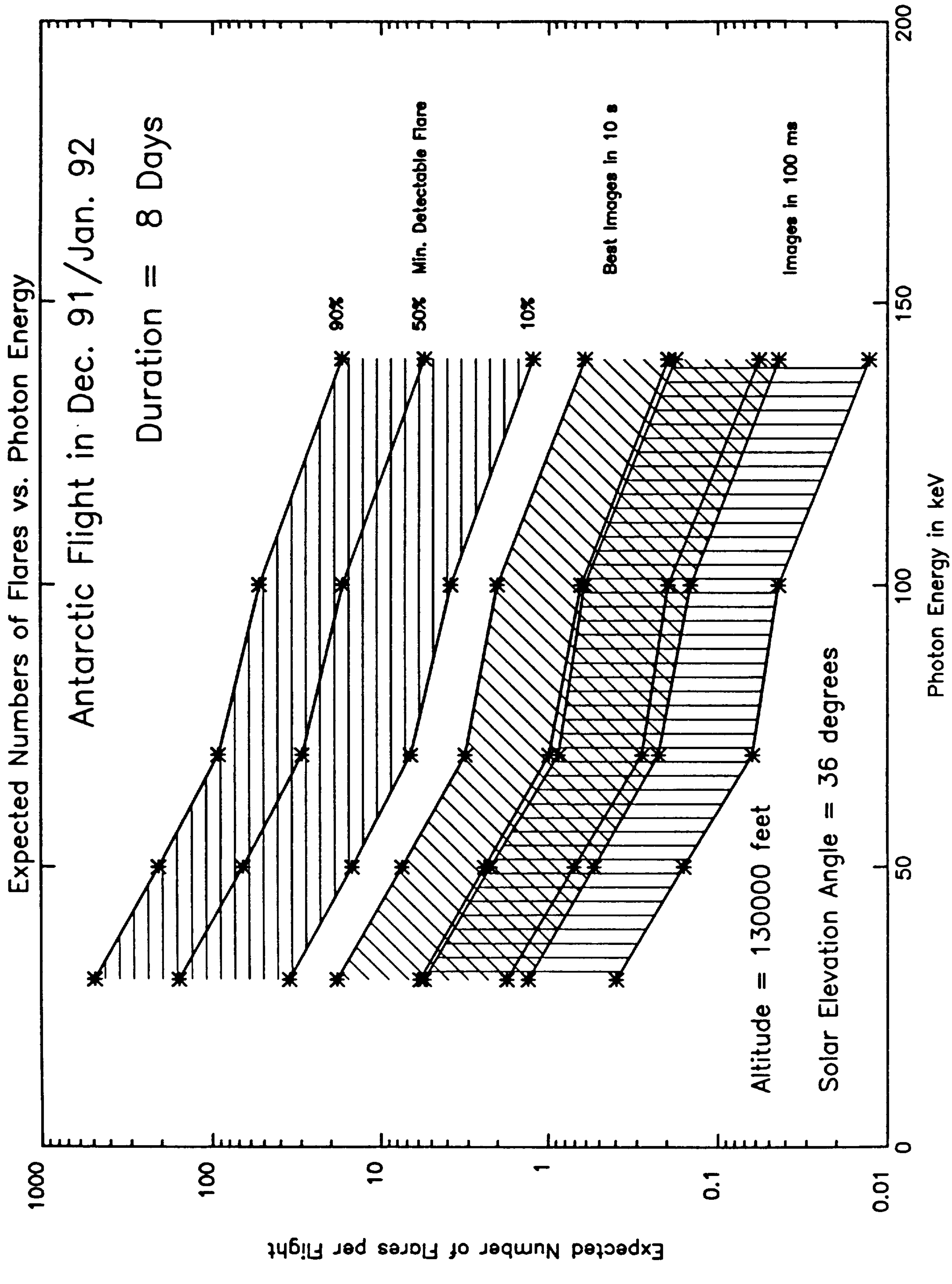
Expected Numbers of Flares vs. Photon Energy
Antarctic Flight in Dec. 91/Jan. 92
Duration = 8 Days
90%
50%
10%
Min. Detectable Flare
Best Images in 10 s
Images in 100 ms
Altitude = 130000 feet
Solar Elevation Angle = 36 degrees
Photon Energy in keV
Expected Number of Flares per Flight
1000
100
10
1
0.1
0.01
0
50
100
150
200