The solar X-Ray/cosmic gamma-ray burst experiment aboard Ulysses

K. Hurley\textsuperscript{1,4}, M. Sommer\textsuperscript{2}, J.-L. Atteia\textsuperscript{4}, M. Boer\textsuperscript{2}, T. Cline\textsuperscript{3}, F. Cotin\textsuperscript{4}, J.-C. Henoux\textsuperscript{6}, S. Kane\textsuperscript{1}, P. Lowes\textsuperscript{5}, M. Niel\textsuperscript{4}, J. Van Rooijen\textsuperscript{5} and G. Vedrenne\textsuperscript{4}

\textsuperscript{1} University of California, Space Sciences Laboratory, Berkeley, CA 94720, USA
\textsuperscript{2} Max-Planck Institut für Extraterrestrische Physik, Giessenbachstrasse, 8046 Garching-bei München, Germany
\textsuperscript{3} NASA-Goddard Space Flight Center, Code 661, Greenbelt, MD 20771, USA
\textsuperscript{4} Centre d’Etude Spatiale des Rayonnements, B.P. 4346, 31029 Toulouse Cedex, France
\textsuperscript{5} SRON–Laboratory for Space Research Utrecht, Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands
\textsuperscript{6} Observatoire de Meudon, DASOP, 5 Place Janssen, 92195 Meudon Principal Cedex, France

Received April 4; accepted August 19, 1991

Abstract. — We describe the scientific objectives of the Ulysses solar X-ray/cosmic gamma-ray burst experiment, and the unique features of the Ulysses mission which will help to achieve them. After a discussion of the special design constraints imposed by the mission, we describe the sensor systems, consisting of two CsI scintillators and two Si surface barrier detectors covering the energy range 5 keV–150 keV. Their operating modes and in-flight performance are also given.

Key words: Gamma rays: Bursts, Sun: X-rays, Instruments.

1. Scientific objectives.

The Ulysses solar X-ray/cosmic gamma-ray burst instrument (acronym: GRB) has three main scientific objectives. The first is the study and monitoring of solar flare X-ray emission. The second is the detection and localization of cosmic gamma-ray bursts. The third is the \textit{in-situ} detection of Jovian auroral X-radiation. We discuss each of these briefly in turn. For a review of experimental data on solar flare X-rays, see Dennis (1985, 1988). Reviews of cosmic gamma-ray burst observations have appeared in Hurley (1988, 1989).

Hard X-ray emission associated with solar flares was first detected in 1959 (Peterson and Winckler, 1959). It is caused by the bremsstrahlung of high energy, flare-produced electrons, on ions in the ambient solar atmosphere. The source of the energy for electron acceleration is generally agreed to be the solar magnetic field, and these electrons may account for half of the total flare energy. The site of X-ray production may vary from low altitudes to altitudes over 40,000 km. The spectral and temporal characteristics of solar flare hard X-rays are diverse, ranging from relatively soft, thermal ($kT \approx 40$ keV) spectra, to hard, power law spectra, and from microflares with durations of seconds (Lin \textit{et al.}, 1981) to events lasting 30 minutes or more. Two examples are shown in Figures 1 and 2. Rapid fluctuations (tens of ms) in hard X-ray intensities have also been observed (Hurley \textit{et al.}, 1983; Kiplinger \textit{et al.}, 1983).

Stereo-photographic observations of solar X-rays by spacecraft widely separated in heliocentric longitude have been carried out (see, e.g., Kane \textit{et al.}, 1988, and references therein). They provide information on the altitude dependence of the X-ray emission, which in turn can be used to constrain electron acceleration models. (The altitude dependence follows from the observations when one or more spacecraft observes the event partially occulted by the solar limb.) These observations also allow a study of the directivity of the X-ray emission, which is related to the electron beaming (Vestrand \textit{et al.}, 1987).

Cosmic gamma-ray bursts were discovered in 1973 by Klebesadel \textit{et al.} They are typically 10-s long events with hard spectra extending to MeV energies. An example is shown in Figure 3. Their energy spectra display evidence of cyclotron features around 20 and 40 keV (Murakami \textit{et al.}, 1988) and redshifted positron-electron annihilation radiation (Golenetskii \textit{et al.}, 1980). These and other lines of evidence suggest that most gamma-ray bursts are associated with strongly magnetized galactic neutron stars. Nevertheless, the energy source of gamma-ray bursts is one of their outstanding mysteries. No unambiguous counterparts to gamma bursters have been identified in any wavelength

Send offprint requests to: K. Hurley.
range, despite deep searches in the radio, infrared, optical, and X-ray ranges. Thus it is not known whether the apparent neutron stars are single objects, or in binary systems. Consequently, it has proven impossible to choose between energy sources associated with lone neutron stars (e.g., starquakes) and sources associated with neutron stars having companions (e.g., accretion).

The only proven method for obtaining precise (arc-minute and less) burster locations is arrival time analysis (or "triangulation") between widely separated spacecraft in an interplanetary network. Interspacecraft distances of several AU are required for good localization, since the characteristic dimension of an error box is inversely proportional to the spacecraft separation. Prior to the launch of Ulysses, interplanetary networks of burst detectors included missions to Venus (see, e.g., Atteia et al., 1987) and Mars.

Jovian X-radiation was first detected by Metzger et al. (1983) using the Einstein satellite. X-rays in the 0.2-3 keV band were imaged with 4" resolution, and provided evidence that the sources of X-radiation were the Jovian north and south auroral zones. The origin of the X-rays could have been either electron bremsstrahlung in the Jovian upper atmosphere, or characteristic line emission from atmospheric atoms excited by heavy ions precipitating from the Io torus. These two models make very different predictions about the hard X-ray flux in the Ulysses GRB energy range.

2. Unique contribution of the Ulysses mission.

The Ulysses mission profile will contribute in a unique way to each of the objectives above. During the Jupiter-bound phase of the mission, the spacecraft explores a wide range of heliographic longitudes, making stereoscopic observations possible. It also monitors solar activity on portions of the solar disk invisible from Earth. In the out-of-ecliptic phase, and particularly during the polar passages, Ulysses will be situated at high solar latitudes, enabling it to view a large part of the Sun's equatorial regions where the majority of flares occur.

Ulysses is also the first spacecraft with a gamma-ray burst detector to travel beyond the orbit of Mars. This results in a triangulation baseline of unprecedented length. Consequently the localization accuracy for cosmic gamma-ray bursts will be the best ever achieved.

Finally, Ulysses will be the first mission to carry an X-ray detector to the Jovian magnetosphere, and thus the first to study Jovian X-radiation in situ.

3. GRB instrument design history and special requirements.

The GRB experiment was proposed in 1977 with a twin experiment aboard the NASA spacecraft. This approach had numerous advantages: a carefully intercalibrated pair of experiments at opposite ecliptic latitudes would survey the solar equatorial regions extensively, and stereoscopic observations would be relatively easy to compare with matched detectors. Triangulation baselines for cosmic gamma-ray bursts would be long, and the fact that two detectors in the network would be out of the ecliptic plane would provide a particularly favorable geometry for localization (non-coplanar detectors are required for arrival time analysis).

With the unique mission opportunities, however, came unique design constraints. A radiation-hardened microprocessor was required to survive the passage through the Jovian radiation belts; few were available during the design phase of the GRB experiment. The limited performance of the unit chosen dictated simplified operating modes for the experiment. Electrical power aboard Ulysses is provided by a radioisotope thermoelectric generator (RTG) containing 10 kg of $^{238}$Pu (about $10^9$ Ci). The GRB instrument would be the first cosmic gamma-ray burst detector to have to operate in this unfavorable background environment. To minimize the interference from the RTG, the sensors had to be mounted on the magnetometer boom, and were required to be essentially amagnetic. (More precisely, the remnant field could not exceed $2 \times 10^{-5}$ G at 25 cm.) Finally, the mass and power allocations for the GRB experiment were small compared to inner planet missions—2 kg and 2.6 W, respectively.

4. The hard X-ray detectors.

The hard X-ray detector was designed to operate in the nominal energy range 15-150 keV. The design approach taken for this unit was to minimize the RTG-induced background
1) by minimizing the interaction cross section in the sensors for the high energy RTG gamma-rays,
2) by mounting the sensors as far as possible from the RTG,
3) by aligning them along the RTG axis to take advantage of the maximum self-absorption in the RTG itself, and
4) by mounting them so that the spacecraft provided passive shielding from the RTG.

Since a boom-mounted instrument far (≈3 m) from the body of the spacecraft can have practically all-sky visibility, the sensor shape was chosen to have a nearly isotropic response. Criterion 1) above dictated the use of thin sensors. Thus hemispherical shell scintillators were chosen. CsI(Tl) was selected to minimize hermeticity problems.
The hard X-ray detection system is shown in Figure 4. It consists of two 3-mm thick by 51-mm diameter CsI(Tl) crystals mounted via a plastic light guide to two photomultiplier tubes. Initially, the photomultiplier tubes were RCA developmental units (C70132D) with convex photocathodes, which minimized the light guide volume. However, in the long waiting period between fabrication and launch, the tubes became noisy, apparently due to absorption of air at the glass-to-metal interfaces. In 1987, it was decided to retrofit new sensor units to the experiment, and as the RCA tube was no longer available, the Hamamatsu R1924 was selected. It is a ten-stage ruggedized tube with a one-inch diameter photocathode; its mass is about 19 g. Tubes with both borosilicate glass and quartz windows were tested, since a potential radiation damage problem was anticipated during the Jupiter flyby. Following a re-evaluation of the radiation damage problem, the borosilicate tubes (which had superior performance) were judged acceptable, and were selected for the flight model. CsI(Tl) cylinders were supplied by Bicron Corporation. Crystal machining, packaging, and mounting to the phototubes was done by MBB. Dornier Systems had overall responsibility for the design and fabrication of the detector assembly, including the analog electronics, under the direction of the Max-Planck Institute.

5. The soft X-ray detectors.

The soft X-ray sensors were designed as solar X-ray monitors for the energy range ~5-20 keV. They consist of two 500-μm-thick, 0.5-cm²-area Si surface barrier detectors manufactured by the Ortec Corporation. A 100 mg/cm² beryllium foil front window rejects low energy X-rays and defines a conical field of view of 75° half-angle. Detectors and front-end electronics are mounted in a cubic housing covered on four sides with an optical solar reflective coating for passive cooling. The detectors operate in the temperature range -35°C to -55°C. The amplified pulses of the two Si detectors are analyzed by a hybrid stack of six-level discriminators which define four differential energy channels and two integral channels. The soft X-ray detector system is shown in Figure 5; it was built by the SRON Laboratory for Space Research at Utrecht.

6. Digital electronics.

The digital electronics package is mounted on the spacecraft platform, and contains the data processing electronics for both sensor systems. It provides:

1) six accumulators for the soft X-ray instrument,
2) four real-time accumulators, two trigger circuits, and a 32 kbit memory managed by an 1802 microprocessor to store background spectra and count rates, calibration spectra, and pretrigger and event data, all for the hard X-ray instrument,
3) one counter for timing,
4) state-of-health monitoring, and
5) command processing.

Count rates from the six channels of one or both of the two Si detectors are accumulated in 19-to-8 bit accumulators/compressors. These data are multiplexed and incorporated into the data stream through one of the five 8-bit telemetry words allocated to the GRB instrument in each spacecraft telemetry frame. Data from the hard X-ray experiment are read out through the remaining four words.

Approximately 50 parameters related to the state of health and mode of operation of the instrument are monitored through three analog lines and one multiplexed 8-bit housekeeping data word. Programs for the microprocessor are stored in two redundant ROMs, selectable by command. When the experiment is turned on, nominal parameters included in the programs are stored in a small RAM. It is therefore possible to modify these parameters through a direct memory access.

The digital electronics were the responsibility of the Centre d’Etude Spatiale des Rayonnements, and were fabricated by Crouzet S.A. A more complete description of this system, including a block diagram, has been published (Cotin et al., 1983).

7. Operating modes.

The Ulysses spacecraft can operate at one of four data rates: 1024, 512, 256, or 128 b/s. The time resolution of some GRB modes varies with the spacecraft data rate. In the following description, these time resolutions are given for the highest data rate, and scale directly in proportion to the actual spacecraft data rate. The telemetry allocation for the GRB instrument is 40 b/s when the spacecraft data rate is 1024 b/s.

Table 1 summarizes the operation of the soft X-ray detectors, which measure X-radiation in the energy range above ~5 keV in six channels. Either one or both of the two Si detector count rates can be read out.

The hard X-ray instrument changes its operating modes depending upon 1) the count rates which it measures, 2) the ground commands which it receives, and 3) the changes in the spacecraft telemetry mode. In the absence of a burst, the instrument operates in one of two waiting modes (operation mode 1 or 2, selectable by command). When a burst is detected, a trigger signal is issued and the instrument switches into a burst mode to record high time resolution data in memory; these data are read out slowly into the telemetry stream. The entry into burst mode may also be selected by command. At the end of the burst readout cycle, the experiment switches automatically into a calibration mode. In addition, the calibration
mode is automatically selected when the spacecraft goes 
from 512 b/s to 1024 b/s (approximately once/day); it
may also be selected by command. The various modes of
the instrument will now be described in more detail. Note
that some solar and cosmic events which do not trigger
the experiment can still be detected in the real-time data
of the waiting modes.

In Operation Mode 1, the outputs of the two hard
X-ray detectors are summed, and integral count rates
are transmitted with 0.25-s time resolution in the 1024
b/s mode. In Operation Mode 2, the outputs of the two
detectors are also summed, but the integral count rates
are transmitted with 0.5-s time resolution in the 1024
b/s mode. In addition, in this mode, four-channel energy
spectra are transmitted from each detector. The four en-
ergy channels are determined by summing channels from
the output of a 64-channel pulse height analyzer, and are
identical for the two detectors. The time resolution of
the energy spectra is 8 s in the 1024 b/s mode.

The instrument may go into the burst mode by com-
mand, or automatically when the count rate exceeds a
certain threshold. In this mode high time resolution count
rates and energy spectra are recorded for a short period of
time, corresponding to a solar flare or a cosmic gamma-ray
burst. In order to determine whether an automatic trig-
ger should be issued, the instrument compares the integral
count rates with backgrounds in two energy ranges simul-
taneously; the energy levels are defined by lower, medium,
and upper level discriminators (adjustable by command).
The range of adjustment starts around 15 keV and ends
around 150 keV. Each of the two comparisons takes place
over a time interval which may be selected from four pos-
sible values; these two intervals may be different for the
two energy levels. The lower level trigger time intervals
are 0.125, 0.25, 0.5, and 1 s; the upper level times are
0.5, 1, 2, and 4 s. Each trigger time interval has an asso-
ciated burst threshold, set by command, in counts; thus
the thresholds do not vary according to the background
counting rates.

Following a burst trigger, high time resolution data are
written into the experiment memories; then the data are
read out. During write mode, the data which appear in
the telemetry stream consist of integral count rates with
0.5-s resolution in the 1024 b/s mode. The burst data,
read out later, consist of:
1) Either 16 s of 8-ms integral count rates, or 64 s of
32-ms integral count rates (selectable by command),
from the sum of the two detectors, and
2) 16-channel energy spectra from the sum of the two
detectors; either
   a) 16 1-s spectra, 16 2-s spectra, and 28 16-s spectra
      (a total of 496 s), or
   b) 16 2-s spectra, 16 4-s spectra, and 28 32-s spectra
      (a total of 992 s).

The choice between the two is made by command. Data
readout requires approximately 35 minutes at 1024 b/s;
during this time the experiment does not accept a second
trigger signal, although burst data can still be acquired in
the real-time mode.

The calibration mode is used to calibrate the gains of
the two detectors. A weak $^{241}$Am source provides a 60-keV
peak which can be detected in the energy spectra. The cal-
bilation mode data consist of 32 spectra, integrated over
64 s, for each detector. As the data are read out, 0.5-s
resolution count rate data from the sum of the two detec-
tors are also output to the telemetry, so the experiment
can detect bursts in real time. In addition, an increase in
the count rate can trigger the burst detection circuit and
override the calibration mode.

8. In-flight performance and initial results.

The experiment was turned on November 9, 1990, and has
been in almost continuous operation since then. The hard
X-ray instrument has detected an average of 2-3 solar flare
X-ray events per day (see Fig. 1 and 2), and numerous
other events, some of which are probably cosmic gamma-
ray bursts, but which have not yet been confirmed by other
spacecraft. (A confirmed event is shown in Fig. 3). A back-
ground spectrum, taken in the calibration mode, is shown
in Figure 6. The background is comparable to that of
other experiments operating in interplanetary space. The
trigger levels are currently set at count rates corresponding
to slightly less than $8\sigma$ above the background. Based
on a cosmic gamma-ray burst which was observed by both
the WATCH experiment aboard the GRANAT spacecraft
(Lund, 1991) and Ulysses on February 19, 1991, we esti-
mate the trigger sensitivity to be about $10^{-6}$ erg/cm², or
in flux units, $10^{-7}$ erg/cm² s. Observations of a partic-
ularly intense solar flare on March 4, 1991 have confirmed
that the hard X-ray detector suffers negligible dead time
losses at count rates up to about $2 \times 10^6$ counts/s.

A key aspect of the Ulysses GRB scientific objectives is
the comparison of Ulysses data with X-ray data taken on other spacecraft, as well as with optical data
from ground-based all-sky monitors searching for optical
flashes coincident with gamma-ray bursts. Figure 7 shows
the experiments which are expected to be in operation over
the nominal Ulysses lifetime. The presence of nu-
merous gamma-ray burst and solar X-ray instruments
in near-Earth orbit and interplanetary space promises to en-
hance the scientific return from Ulysses and advance our
understanding of these two phenomena.

Acknowledgements.

Work on the digital electronics was supported at the
CESR in France by the Centre National d'Etudes Spa-
tiales. At the Max-Planck Institute this effort was sup-

© European Southern Observatory • Provided by the NASA Astrophysics Data System
ported by FRG Contracts 01 ON 088 ZA/WRK 275/4-7.12 and 01 ON 88014. K.H. gratefully acknowledges assistance from JPL Contract 958056.

References

Dennis B. 1985, Solar Phys. 100, 465
Dennis B. 1988, Solar Phys. 1180, 49
Lund N. 1991, IAU Circular 5193, February 21
Peterson L., Winckler J. 1959, J. Geophys. Res. 64, 697
### TABLE 1. Soft X-Ray Data.

<table>
<thead>
<tr>
<th>Energy Range, keV</th>
<th>&gt;3.5&lt;sup&gt;a&lt;/sup&gt;</th>
<th>5-7.1</th>
<th>7.1-10</th>
<th>10-14</th>
<th>14-20</th>
<th>&gt;20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Resolution (s)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Counter Capacity</td>
<td>507904</td>
<td>507904</td>
<td>507904</td>
<td>507904</td>
<td>507904</td>
<td>507904</td>
</tr>
</tbody>
</table>

<sup>a</sup> Noise channel, used to help calibrate the instrument

<sup>b</sup> At 1024 b/s telemetry rate; scales directly with other TM rates

### TABLE 2. Summary of GRB Experiment Operating Modes

<table>
<thead>
<tr>
<th>Detector</th>
<th>Parameter Analyzed</th>
<th>Time Resolution (secs)</th>
<th>Storage Time (secs)</th>
<th>Data Compression</th>
<th>Counter/ Memory Capacity</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operation Mode 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HUS 2A</td>
<td>Count Rates</td>
<td>0.25&lt;sup&gt;a&lt;/sup&gt;</td>
<td>N/A</td>
<td>n(n+1)/2</td>
<td>32640</td>
<td>Σ2 Detectors</td>
</tr>
<tr>
<td><strong>Operation Mode 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HUS 2A</td>
<td>Count Rates</td>
<td>0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>N/A</td>
<td>n(n+1)/2</td>
<td>32640</td>
<td>Σ2 Detectors</td>
</tr>
<tr>
<td>HUS 2A</td>
<td>Energy Spectra</td>
<td>8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>N/A</td>
<td>none</td>
<td>65535</td>
<td></td>
</tr>
<tr>
<td><strong>Burst Data Write Mode</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HUS 2A</td>
<td>Count Rates</td>
<td>0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>N/A</td>
<td>n(n+1)/2</td>
<td>32640</td>
<td>Σ2 Detectors</td>
</tr>
<tr>
<td><strong>Burst Data Readout Mode</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HUS 2A</td>
<td>Count Rates</td>
<td>0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>N/A</td>
<td>n(n+1)/2</td>
<td>32640</td>
<td>Σ2 Detectors</td>
</tr>
<tr>
<td>HUS 2A</td>
<td>Count Rates</td>
<td>0.008</td>
<td>16</td>
<td>none</td>
<td>255</td>
<td>Σ2 Detectors</td>
</tr>
<tr>
<td>HUS 2A</td>
<td>Count Rates</td>
<td>0.032</td>
<td>64</td>
<td>÷1, 2, 4, or 8</td>
<td>959</td>
<td>Σ2 Detectors</td>
</tr>
<tr>
<td>HUS 2A</td>
<td>Energy Spectra</td>
<td>1-32</td>
<td>496-992</td>
<td>none</td>
<td>65535</td>
<td>Σ2 Detectors</td>
</tr>
<tr>
<td><strong>Calibration Mode</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HUS 2A</td>
<td>Count Rates</td>
<td>0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>N/A</td>
<td>n(n+1)/2</td>
<td>32640</td>
<td>Σ2 Detectors</td>
</tr>
<tr>
<td>HUS 2A</td>
<td>Energy Spectra</td>
<td>32</td>
<td>N/A</td>
<td>none</td>
<td>65535</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Time resolution for 1024 b/s; scales with spacecraft telemetry rate
Figure 1. Solar flare X-rays observed by the GRB detector on November 11, 1990. The peak occurs around 04:30 UT. Due to the fact that the detector axis points towards the Earth, and the Earth-Ulysses-Sun angle was large, 10-s spin modulation can be observed in the time history.

Figure 2. Solar flare X-rays observed by the GRB detector on November 16, 1990. The first peak is around 13:12 UT. Spin modulation can be observed on the second peak.
Figure 3. A cosmic gamma ray burst detected by Ulysses on December 4, 1990 around 9:30 UT. The time history in the 20-150 keV range is shown with 64-ms resolution. This event was also detected by Pioneer Venus Orbiter (R. Klebesadel, private communication).

Figure 4. The hard X-ray detectors. The axis points towards Earth. Each unit contains a 10-nCi $^{241}$Am source for in-flight calibration. The energy resolution is about 40% at 60 keV, and the noise threshold around 10 keV, in the laboratory at ambient temperature.
FIGURE 5. The soft X-ray detectors. The two Si surface barrier detectors point towards the Earth. Inflight calibration is provided by two 20-nCi $^{129}$I sources.

FIGURE 6. Background spectrum from one of the hard X-ray detectors, taken in the calibration mode. The 60-keV $^{241}$Am peak is visible.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PVO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GINGA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ETC/RMT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kvant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DMSP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRANAT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ULYSSES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOLAR-A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EURECA-A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MARS OBS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WIND-GGS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HETE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MARS 94</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPECTRUM X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>