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MISSION AND SCIENCE OF MUNIN: THE FIRST SWEDISH NANO-SATELLITE

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Abstract

The Munin satellite and instruments, the scientific results achieved, and the miniaturization effort required to build the 6 kg scientific satellite can eventually lead to future constellation missions. Munin belongs to a new class of very small spacecraft that can provide space plasma measurements at unprecedented low costs. Sweden has during the last decade been dedicated to small and low-cost missions and has carried out a number missions such as the small satellite Freja in 1992 (total cost of $19 million including launch and operation), the micro-satellites Astrid in 1995 ($1 million) and Astrid-2 in 1998 ($2 million), and the nano-satellite Munin in late 2000 ($0.5 million).

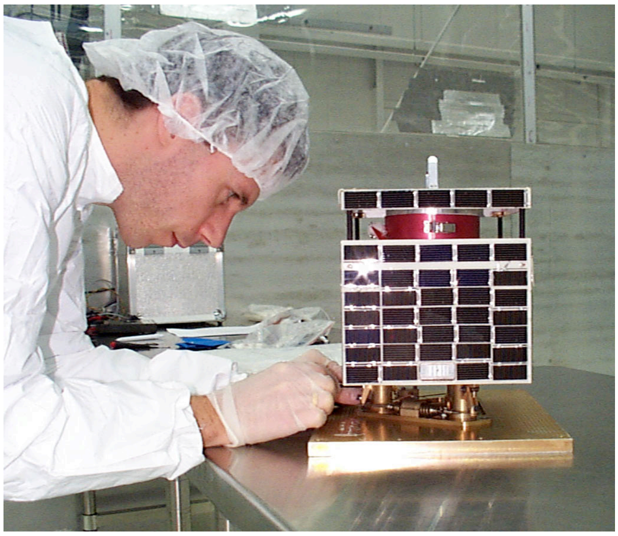

Figure 1. Technical Manager Walter Puccio preparing Munin for launch.

1. Introduction

On 21 November 2000, the Munin "nano-satellite" (Figure 1) was launched as a piggyback payload on a Delta-2 rocket from Vandenberg Air Force Base in California, USA. The launch into an elliptical polar orbit (700 x 1800 km, 95.4° inclination) was provided by NASA. Munin was designed, built and managed by the Swedish Institute of Space Physics in Kiruna. Two of the Munin instruments were also built at IRF. Space Engineering students at Umeå University, Sweden, and students at Luleå University of Technology, Sweden, were involved in all phases of the project, some part of the design of the Munin spacecraft and ground segment was performed as masters and undergraduate theses. The satellite was commissioned during the first weeks of December 2000 and the scientific instruments were functioning as expected.

The purpose of the Munin project was to try out possible technologies and methods to be used in the miniaturization of spacecraft and instrumentation. Within the next decade there will be a need for fleets of small, autonomous spacecraft for various purposes. One objective for such a fleet will be to resolve the spatial-temporal ambiguity in satellite measurements. Another will be to form a fleet of spacecraft for global measurements of plasma parameters, as input for global modelling. Whatever the objective is, it will be necessary to keep the recurrent costs low when producing large number of identical spacecraft. The miniaturization of spacecraft and instruments is necessary to enable deployment of large number of satellites. One issue to address in the future is the possibility to de-orbit satellites after they have ceased to function. Using modern technology, the very small Munin satellite (cube with each side 21 cm long, mass 6 kg) has all the necessary functions needed to support its specific scientific mission: monitoring of the auroral activity on both the northern and southern hemispheres.

Small, simple satellites are also ideal for use in educational environments, in which a Munin-class satellite can be designed, built, launched, and operated during the time of a undergraduate or graduate student career.

2. Spacecraft and ground segment

The satellite is cubic with solar cells on all six sides. The structure is made of aluminum and has a mass of 1.9 kg. The solar cells provides Munin with a power of 6.0 W. The average power consumption is 4.7 W, peak consumption (when the transmitter is on) is 9.1 W. A Li-Ion battery provides the peak power and also keeps the satellite powered during eclipses. A magnet aligning Munin with the local magnetic field controls the attitude. The attitude is measured using a very simple two-axis magnetometer. Soft-magnetic hysteresis rods dissipate oscillation energy. Munin communicates on the UHF band, the up-link frequency is 449.95 MHz and downlink frequency is 400.55 MHz, with a downlink bit rate of 19200 bps. The modem is implemented in software in a digital signal processor (DSP), which also handles command handling and telemetry formatting. Another DSP takes care of instrument operation and data compression. Northern Hemisphere data is transmitted in real time whereas Southern Hemisphere data is stored on-board. The transmitted data are automatically processed in near real-time and open to the public on the Internet. Munin uses an existing ground station located at the Swedish Institute of Space Physics in Kiruna. The satellite and its instruments were fully operational until 12 February 2001, when most probably radiation damage created a bit-flip in the on-board software memory.

3. Payload

Munin has three scientific instruments for monitoring of auroral activity and ring current activity:

- MEDUSA (0.6 kg), a combined electron and ion spectrometer with simultaneous, continuous coverage of all pitch angles in 16 sectors, each 22.5° wide. Covers the energy range 10 eV - 18 keV. MEDUSA was provided by the Southwest Research Institute, San Antonio, Texas. An example of data acquired is shown in Figure 2.

- DINA (0.9 kg), a pair of solid-state detector (SSD) type detectors measures high-energy ions and neutral particles at pitch angles 0° and 90°. Covers the energy range 30 - 1200 keV.

- HiSCC (0.1 kg), a CCD camera for visible and infrared wavelengths. The camera has a field-of-view of 50°, and a resolution of 340 x 240 pixels. The camera is used for attitude determination (star field comparison). The camera used is a commercial “off the shelf” item, the grayscale “QuickCam” from Connectix.

The payload has a total mass of 1.6 kg and a power consumption of 2.6 W. The payload is integrated with the rest of the spacecraft, but it can be tested separately from the platform.

4. The MEDUSA ion and electron spectrometer

The Munin satellite is optimized for particle measurements, and it has much better angular resolution than e.g. Astrid-2 that is equipped with the same MEDUSA particle instrument. In fact MEDUSA has already provided the first ever observations of direct solar-wind penetration deep inside the inner magnetosphere. Figure 2 shows an example. The electron data shows both clear CPS (trapped few keV thermal component) and inverted-V structure at 0850-0851 UT and 0851-0853:30 UT, respectively. In the CPS portion, we see clear signatures of downward ions. One can even recognize overlapping injections (most obvious at 0850:40 UT). This is the first direct evidence at low altitudes that solar-wind type injection can be found deep in the inner magnetosphere.

Excellent cusp (see example shown in Figure 3) and auroral electron data (inverted-V structrures) has also been acquired. Analysis of the MEDUSA data is currently on-going.

5. The DINA particle instrument

The newly developed instrument DINA alternates between measuring 30 - 1200 keV ions and 30 - 400 keV energetic neutral particles (ENAs) using an electrostatic deflection system (cutoff energy 500 keV). Electrons with energies below 400 keV are mostly (86%) swept away by permanent broom magnets. Using two SSD surfaces (to measure $\Delta E/E$), DINA can resolve the mass of the incident particles (hydrogen and oxygen) for energies above 100 keV. DINA consists of two sensors (DINA-0 and DINA-90, each with mass 340 g) with 10° x 38° aperture and 5° x 25° angular resolution each. DINA-0 detects particles with 0° pitch-angle (i.e., precipitating/outflowing particles in the Northern/Southern Polar Regions, respectively), and DINA-90 detects particles with 90° pitch-angle (e.g., ENA flux from the exobase in one local time sector).

6. Conclusions

Advantages of extremely small missions such as Munin are (a) we can cost-effectively build constellations of spacecraft for monitoring of

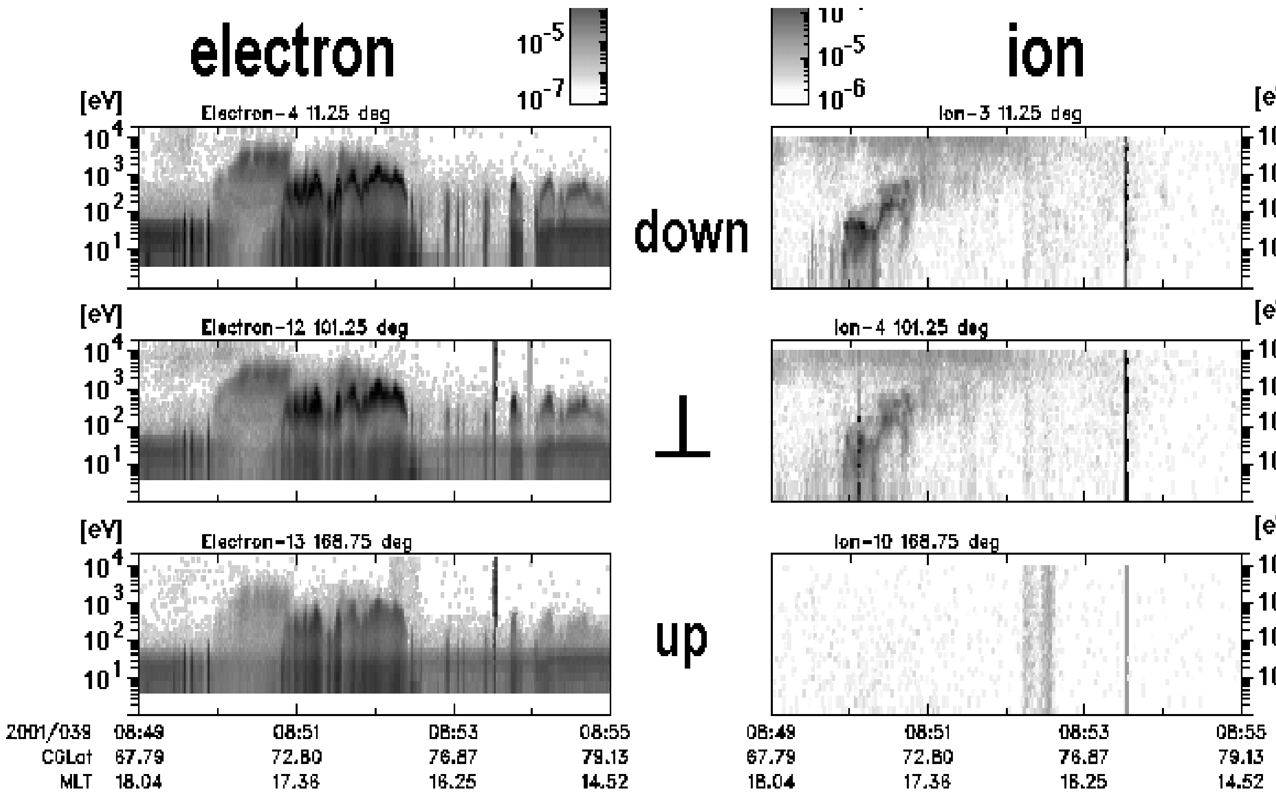

Figure 2. Data from the MEDUSA instrument on Munin, 8 February 2001, 08:49 – 08:55 UT.

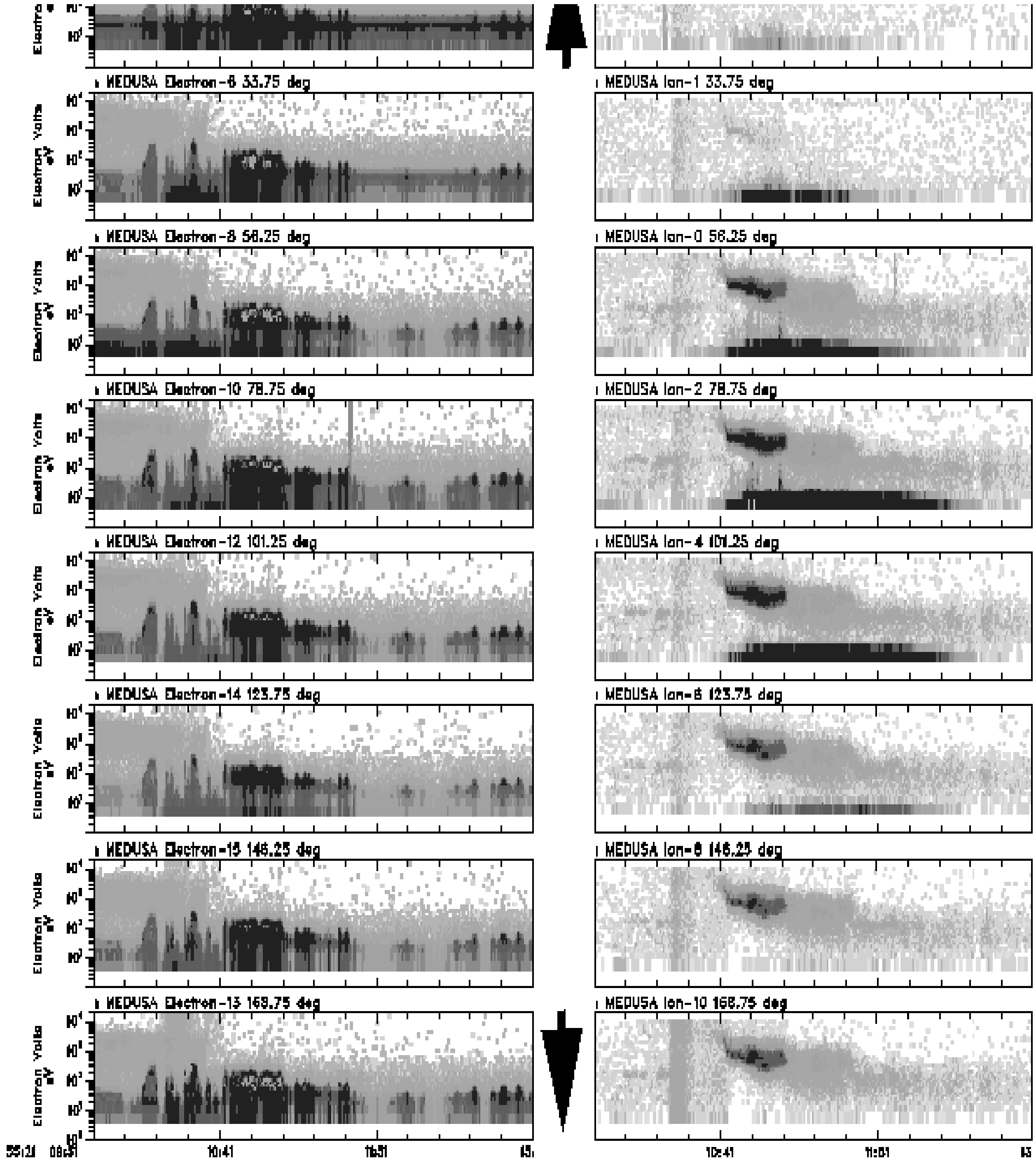

Figure 3. MEDUSA electron and ion data from 20 December 2000, 21:09 – 21:12, a pass through the magnetospheric cusp. 8 different sectors, with pitch angles ranging from 180° (uppermost panels) to 0° (lowermost panels).

the space environment; (b) we can test state-of-the-art instruments because the satellite is manufactured on a short time-scale at low cost; and (c) we can use them as educational tools. The success of Munin opens up the possibility of using nano-satellites as tools for multipoint measurement, both for Earth observation and in particular planetary exploration for which severe spacecraft mass constraints must be considered. There are however several hurdles, such as orbit determination, to be overcome before nano-satellites can be effectively used as sub-satellites for planetary missions. With Munin one more step forward has been taken in the development of space technology.

7. REFERENCES

The Munin web site http://munin.irf.se