MUNIN: A STUDENT NANOSATELLITE FOR SPACE WEATHER INFORMATION

O. Norberg[1], W. Puccio[1], J. Olsen[1], S. Barabash[1], L. Andersson[1], J. D. Winningham[2], U. Jonsson[3], and M. Eriksson[3]

[1]*Swedish Institute of Space Physics, Box 812, SE-981 28 Kiruna, Sweden*
[2]*Southwest Research Institute, Drawer 28510, San Antonio, Texas 78284, USA*
[3]*Luleå University of Technology, SE-971 87 Luleå, Sweden*

ABSTRACT

The Munin satellite (Figure 1) is set to become the first of a new type of monitoring spacecraft. Using modern technology, this very small satellite (mass ≈ 5 kg) will have all the necessary functions needed to support its specific scientific mission: monitoring of the auroral activity on both the northern and southern hemispheres. With Munin we could usher in a fleet of monitor spacecraft to cost-effectively provide global monitoring, and at the same time have a large degree of student involvement on different levels.

Munin has three scientific instruments for monitoring of auroral activity:
- MEDUSA, a combined electron and ion spectrometer with continuos coverage of all pitch angles. Covers the energy range 10 eV - 18 keV.
- DINA, measures high energy ions and neutral particles at pitch angles 0° and 90°. Covers the energy range 30 - 1200 keV.
- HiSCC, a high sensitivity 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 payload has a total mass of 1.0 kg, and consumes 1.8 W, if power permits it will be operated continuously.

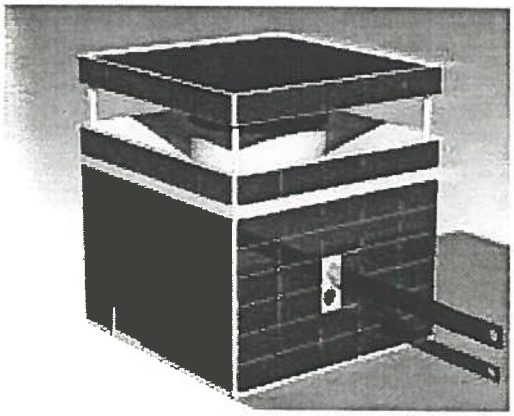

Figure 1. The Munin nanosatellite

The satellite is cubic with solar cells on all six sides. The solar cells provides Munin with a power of 6.0 W. The average power consumption is 4.0 W, peak consumption (when the transmitter is on) is 11.6 W. A Li-Ion battery will provide the peak power and also keep the satellite powered during eclipses. The structure is made from aluminium and has a mass of 1.6 kg. The total mass of the Munin spacecraft, including the separation system, is 4.8 kg. A separation system holding the spacecraft secured to the launcher using three hooks has been designed. Munin communicates on the UHF band, the up-link frequency is 449.95 MHz and down-link frequency is 400.55 MHz. The down-link is designed for a bitrate of either 9600 or 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, The attitude will be controlled by a magnet aligning Munin with the local magnetic field. Soft-magnetic hysterisis rods will dissipate oscillation energy.

Munin will use an existing ground station located at the Swedish Institute of Space Physics, Kiruna, Sweden. The ground station was built in 1994 and has been successfully used for the two Swedish satellites Freja and Astrid.

PROJECT OBJECTIVES

Auroral Research and Forecasting

The Munin satellite is set to become the first of a new type of monitoring spacecraft. Using modern technology, this very small satellite (mass ≈ 5 kg) will have all the necessary functions needed to support a specific scientific mission such as the one we will describe in this document. With Munin we could usher in a fleet of monitor spacecraft to cost-effectively provide global monitoring, and at the same time have a large degree of student involvement on different levels.

Today auroral research is a wide field covering topics such as the acceleration mechanisms of precipitating particles, the physics behind the triggering of substorms, and forecasting of magnetic storms to mitigate the damage that "space weather" can cause in e.g. power distribution lines. These research areas all need data about the conditions in space. Both the solar wind conditions and the resulting disturbances on the Earth such as magnetic and electric field fluctuations, particle populations, and auroral activity are needed in order to deduce the physical mechanisms behind these phenomena.

The northern and southern auroral ovals are always present, day and night. From the Earth they can be seen by the naked eye at latitudes between 60 and 80 degrees north and south. The aurora is the visible manifestation of the particle precipitation along the Earth's magnetic field lines at high latitudes. Since the aurora can be viewed only during relatively cloud-free nights, it is not an optimal source of information about the result of magnetospheric activity. The best tool to gather this information was (very early in the history of spaceflight) found to be satellites in polar orbits. There have been a number of satellites of this type over the years, with new discoveries about auroral physics made by every one.

Up until now, the data from such satellites have first been analysed by the Principal Investigator of the instrument in question, then the results of the investigation have been published in scientific papers. With Munin, we propose to use a new paradigm of data dissemination, which we think will enhance the output from auroral research. We will make the data from the instruments on Munin available in real time to everyone interested, by using the Internet and WWW-based services. Munin will provide measurements of the electron and ion particle distributions above the auroral ovals, the fluxes of energetic particles (ions and neutral particles), as well as images of the aurora taken by a CCD camera in visible wavelengths. As the data comes down to a ground station located in Kiruna, Sweden, the data will be processed such that it can be used by scientists all over the world for auroral research. The satellite will store data from the pass over the southern auroral oval (over Antarctica) in its memory which will then be downloaded when it is over Kiruna, whereas the data from the northern oval will be down-linked in near real time.

The fact that the data is "fresh" will enhance the possibilities of using it for forecasting of auroral activity. The shape of the ovals, and the offset of their centres relative to the geographic poles, means, for example, that it is possible to use measurements over Scandinavia to predict the auroral activity in north America or Siberia at a later time. We intend to use the Munin measurements to present the present status of the auroral ovals, and let users of the data interpolate the position and size of the auroral oval a few hours into the future, in order to forecast auroral activity.

Public and Educational Outreach

The Munin team has strived to implement this project in order to promote the public interest in science, technology, space research, and international co-operation. During the last decades the public interest in these questions has declined, and we are of the opinion that a small, focused, project like Munin can catch the interest of the public. We intend to pursue this objective by visibility in newspapers, magazines, and by the Munin WWW-server, **http://munin.irf.se.**

The complexity of today's space projects makes it extremely difficult for engineering students to grasp how the complete system works, or how it was designed. This results in more and more engineers becoming experts in just a small part of a project, with very limited insight in the overall system functions. With Munin, we intend to give students a possibility to be not only engaged in the mission, but also to gain a genuine knowledge about all parts of a space mission.

The Swedish Institute of Space Physics is engaged in two undergraduate space engineering programmes, a 3-year programme given by Umeå University, and a 4.5 year programme given by Luleå University of Technology. Students from these programmes are already contributing to the project by doing their degree projects on parts of the satellite. The intention is also to have students involved in the operation of the satellite, for example in the form of lab-courses involving hands-on satellite operations.

Orbit Considerations

In order to fulfil the scientific objectives of the Munin project, the satellite will be injected into a polar orbit. The inclination should be at least 63 degrees, and the altitude between 400 and 2000 km. A circular orbit at approximately 1000 km and an orbit plane at around noon-midnight local time is optimal, since this orbit takes Munin both through the active night-side of the auroral ovals, and the polar cusps.

PAYLOAD DESCRIPTION

Miniaturized Electrostatic DUal-tophat Spherical Analyzer (MEDUSA)

The primary instrument on Munin is MEDUSA (Miniaturized Electrostatic DUal-tophat Spherical Analyzer), a combined electron and ion spectrometer. The instrument sensor is provided by the Southwest Research Institute, San Antonio, Texas. Electrons and ions with energies up to 18 keV/q will be measured simultaneously, with a maximum time resolution of 16 energy sweeps per second for electrons, and 8 seconds for ions. Particles are measured in 16 sectors in the plane of acceptance, which is aligned with the Earth's magnetic field.

Electrons are responsible for the major part of the energy input creating the aurora, and therefore the most important species to measure. The precipitating electrons energise (heat) ionospheric ions in the auroral region, these heated ions are then accelerated along the magnetic field lines and leave the heating region. This creates an outflow of atmospheric ions, primarily hydrogen and oxygen. With Munin we intend to measure both the electrons responsible for the aurora and ion heating, and the heated and accelerated ions. During certain circumstances, precipitation of ions also occur in the auroral region.

The MEDUSA sensor will be mounted on Munin in such a way that each of the 16 sectors in the acceptance plane always looks at particles arriving with a certain angle to the magnetic field lines, the "pitch angle". This is possible due to the simple, yet very efficient, attitude control chosen for Munin. A permanent magnet will align one of Munin's axes along the local magnetic field line, this axis will be in the aperture plane.

Particles enter the spectrometer aperture at any angle in the 10° wide plane of incidence (Figure 2), electrons and ions are then deflected into their respective spectrometer unit by a spherical electrostatic analyser (deflection plates). The particles hit a microchannel plate (MCP) after being filtered in energy in the electrostatic analyser, the hits are counted by preamplifiers connected to registers, and the number of hits per sample interval are then further processed by the data processing unit (DPU).

The MEDUSA sensor represents a completely new development in terms of highly compact sensor design. MEDUSA will be flight proven on the Swedish microsatellite Astrid-2, due for launch during the second half of 1997.

Table 1. The MEDUSA Instrument Characteristics

Instrument Characteristics	
Mass	0.60 kg
Power	1.0 W
Energy range (for both electrons and ions)	10 eV/q – 18 keV/q
Energy resolution (ΔE/E)	25%
Acceptance angles	360° x 10°
Geometric factor	7 x 10^{-4} cm^2 sr

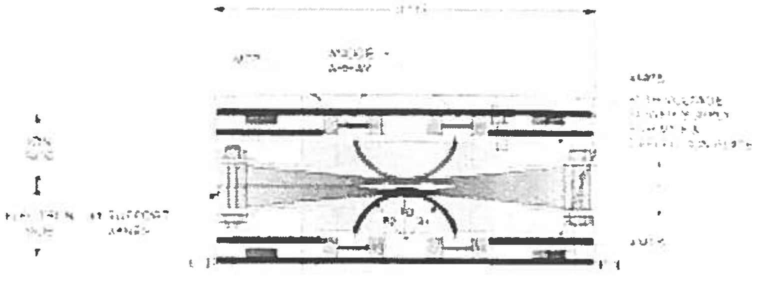

Figure 2. Cross Section of the MEDUSA Sensor Unit.

Detector of Ions and Neutral Atoms (DINA)

The main scientific objective of the instrument is to extend the measurements of the precipitating and mirroring ions to the higher energy range 30 - 1200 keV, complementing the MEDUSA experiment.

Apart from the main scientific objective, the DINA instrument will also be able to measure energetic neutral atoms (ENAs). ENAs are produced via the exchange of charge between singly charged magnetospheric ions and atoms of the upper atmosphere/exosphere. ENAs can be found in almost any space environment and are suitable agents to remotely probe ion populations of plasmas at a distance, so-called ENA imaging. In magnetospheric physics, general attention has so far concentrated on the ENAs generated within the high altitude ring current, because they can be used in global magnetospheric imaging from high altitude (> 20000 km) spacecraft (*Williams et al.*, 1992). However, in the auroral region where the ring current / radiation belt particles plunge into the dense upper atmosphere/exosphere, the charge exchange process is much more effective and ENAs emissions are much more intense. As was shown theoretically by *Roelof* (1997), ENAs from low altitudes are emitted from a very thin area near the exobase and the ENA generation region is, essentially, two-dimensional. The ENA camera PIPPI on-board the microsatellite Astrid has performed ENA measurements from a 1000 km polar orbit and demonstrated the potential of low altitude ENA imaging (*Barabash et al.*, 1997; *C:son Brandt et al.*, 1997). DINA will continue studies of the low-altitude ENAs concentrating on measurements close to the generation region. The results from DINA, looking at the ring current from below at low latitudes and close to the ring current at high latitudes, will undoubtedly help the interpretation of the observations to be performed by IMAGE, the NASA mission to image the ring current from above.

Another interesting topic to be addressed is ENA albedo. The O^+ ions precipitating onto the upper atmosphere during major geomagnetic storms transform their energy and momentum into atmospheric heating and result in escaping fluxes of fast neutral atoms via charge exchange and elastic scattering (*Ishimoto et al.*, 1992). The total neutral flux escaping due to these processes could be significant for the atmospheric evolution during the life-time of the Earth (*Torr et al.*, 1974). However, no direct measurements have been performed to prove the correctness of the developed models. The DINA simultaneous measurements of the precipitating ions and ENA flux would provide the necessary inputs to evaluate the existing models of mass and energy transport in the ring current-atmosphere interaction.

DINA will also investigate the low-altitude equatorial ring current formed by stripped ENAs from the main radiation belt (see *Voss et al.*, 1995, and references therein) by measuring both the trapped ions and parent ENAs. During geomagnetic storms the ENA flux produced in the low-altitude ring current could be sufficient for detection, although for quiet conditions the flux will not be sufficient (*Bishop*, 1996).

In summary, the scientific objectives of DINA are:
1. Measurements of the ion flux in the energy range 30 - 1200 keV.
2. Measurements of the ENA flux from the exobase in the energy range 30 - 400 keV.
3. Measurements of the outflowing ENA flux (ENA albedo) from the precipitation region in the energy range 20 - 280 keV.
5. Mass resolving measurement of particles in the energy range 100 - 1200 keV.
6. Studies of the low-altitude ring current.

The instrument consists of two sensors with an aperture opening of 10° × 38° each. The sensor DINA-0 is detecting particles with 0 degree pitch-angle, and DINA-90 detects particles with 90 degree pitch-angle. Over the northern hemisphere DINA-0 provides measurements of the precipitating ions. While the spacecraft moves over the polar cap, DINA-90 makes measurements of ENA flux from the exobase in one local time sector. Over the southern hemisphere DINA-90 will measure the exobase ENA flux from a different local time sector due to the expected very slow spin of the spacecraft along the magnetically aligned axis. DINA-0 will be pointing toward the Earth over the southern hemisphere, and is aimed to detect outflowing ENA in the precipitation region. Information about the input ion flux can be obtained from the DINA-90 measurements because the energetic ion distributions can be considered approximately isotropic (*Lyons*, 1987). The instrument performs alternative measurements of ions and energetic atoms by turning on and off the high voltage on the electrostatic deflection system. Electrons with energies below 400 keV are always swept away by permanently magnetized broom magnets, the simulated transmittance for 400 keV electrons is 14%. Mass identification is performed by $\Delta E/E$ detectors. For the energy range 30 - 100 keV, the front detector (2μm Si detector) will provide the integral flux of all masses. For energies above 100 keV, coincidence and anti-coincidence logic provide measurements of hydrogen and helium (coincidence between the front and back detectors) and particles with $A > 4$, mainly oxygen (anti-coincidence between the front and back detectors).

Table 2. The DINA Instrument Characteristics

Instrument Characteristics	
Mass	0.34 kg
Power	0.5 W
Energy range (protons or H atoms)	30 - 1200 keV
Masses to resolve	A = 1, 4, A > 4 for E > 100 keV
Particles to measure	ions, neutrals
Aperture per sensor	10°× 38°
Geometric factor (per detector)	3.1×10^{-3} cm^2sr
Deflector cut-off energy	400 keV
Broom magnets transmittance	≈ 2% at for 100 keV electrons ≈ 14% for 400 keV electrons

High Sensitivity CCD Camera (HiSCC)

One of the best global space weather measurement tools is a camera imaging the auroral oval. A camera onboard a satellite supports both onboard instruments and ground facilities. Over the northern hemisphere HiSCC will take images of the night side auroral oval. This will give information about the activity level of the magnetosphere. HiSCC will support MEDUSA with identification of the spacecraft's footprint in the auroral oval, and any intensifications in the oval. Over the southern hemisphere HiSCC will operate as a star imager, enabling attitude determination based on star positions in each image. Attitude knowledge is crucial for interpretation of the measurements made by the MEDUSA and DINA instruments, as well as a major interest for the satellite operation group since the spacecraft behaviour in space can be studied. This means that HiSCC can be used to verify the performance of the spacecraft attitude control system.

The camera will be the main instrument to provide the mission with pictures to the public. HiSCC data will help to educate the public about what space weather is, and the easy access to the data on the Web will increase the public interest in understanding the science of space plasmas in general and specifically the aurora.

The camera field of view is 50° with a highest spatial resolution of 3 x 3 km (nadir looking from an altitude of 1000 km). When the satellite is at 60° latitude the ground coverage ranges from 65° latitude and over the pole. At 75° the camera is almost looking in the nadir direction, covering 10° in both latitude and longitude. In order to avoid blurry pictures the exposure time will be below one second. Approximately 25 pictures will be taken during each pass over the northern auroral oval. The data will be compressed by the DPU before being down-linked to the ground station.

The CCD camera is a modified Quickcam from Connectix Corporation. It is made for connecting to a PC parallel port, for Munin this has been modified to a special interface to the DPU. A new housing and lens system assembly has been designed. We have removed the built-in infrared filter to increase the light sensitivity. The CCD chip used in the camera is a Texas TC-255 with a quantum efficiency of up to 60% in the wavelength range 500-800 nm. It can produce pictures with a resolution of 320 x 240 pixels, in 64 shades of grey. The camera can operate with different exposure times, the shortest time being 1/1000 second.

Table 3. The HiSCC Instrument Characteristics

Instrument Characteristics	
Mass	0.10 kg
Power	0.3 W
Camera Optics	focusing lens, f1.9, field-of-view 50°
Spectral passband	450 - 850 nm
Detector	TC-255 CCD chip, 50,000 e^- full well capacity
Resolution	0.2° x 0.2°, 320 x 240 pixels / 3.2 x 2.4 mm
Quantum Efficiency	20 - 60 %
Exposure time	minimum 10 ms, operationally 0.5 - 1 s

HARDWARE DESCRIPTION

Satellite Structure

The combined electron and ion spectrometer MEDUSA has a requirement of a 360° field-of-view in a plane, the satellite was thus designed as a natural extension of the MEDUSA instrument. The satellite can be considered to be an experiment with its own power and telemetry resources. The use of magnetic attitude stabilisation means that Munin will rotate twice per orbit. All faces of the satellite will thus need to be covered with solar cells to maximise the energy input. To satisfy the power requirement of approximately 6 W it was decided to design Munin as a cube with the sides 210 mm long. The inner structure consists of the bottom platform, four support struts, the battery platform, the MEDUSA platform, and the top platform. The four side panels are screwed together into a shell which can be integrated on Munin after all the units inside the satellite have been assembled and tested. There are aperture openings in some of these panels for the HiSCC and DINA instruments, as well as a mounting hole for the radio antenna. The structure is made of anodised aluminium.

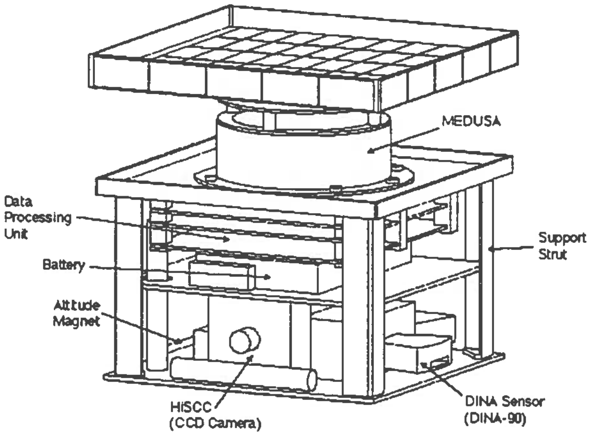

Figure 3. The interior of Munin as seen from the side of the satellite which will face towards the Earth over the northern pole (the camera side).

Separation System

The low mass and the small size of the Munin satellite gives us the opportunity to design a very simple yet reliable separation system. Munin will be clamped down to the launcher interface plate at three points. The satellite is equipped with three steel wires fitted with cylindrical end blocks, these blocks are held down by grappling hooks. Clamping will be provided for by a spring-tensioned Kevlar line. Three helical springs will be used for pushing Munin away from the launcher with a speed of about 0.6 m/s. A small launcher activated pyro-guillotine will be used to initiate the separation by cutting the Kevlar line. The mass of the separation system is 350 grams. The separation mechanism will be attached to the launcher with three bolts. The separation system will include a separation switch, to indicate the separation of Munin in the launcher telemetry. Inside Munin there is also a separation switch which is in the off position when Munin is located on the separation system. At separation this switch will power-on the satellite.

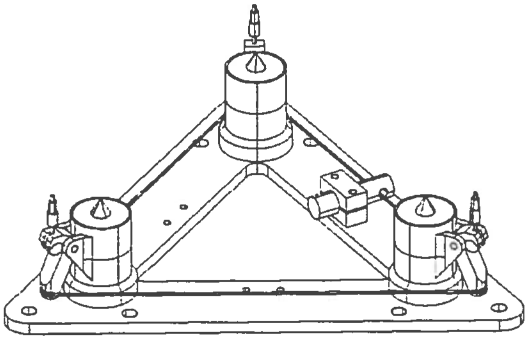

Figure 4. The Munin Separation System. With compressed springs the total height of system is 40 mm.