ISTS 2004-k-01

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24th International Symposium on
Space Technology and Science
Miyazaki, Japan
May 30-June 6, 2004

24th International Symposium on Space Technology and Science
1-18-2, Shinbashi, Minato-ku, Tokyo 105-0004, Japan
Tel : +81-3-3519-4808, Fax : +81-3-3519-9998

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Abstract

As a continuation of the Swedish tradition of designing small and high-quality spacecrafts such as Freja, Astrid, Munin, and SMART-1, Swedish scientists and engineers have proposed aggressive but feasible missions as the next national-level target: (1) an interplanetary plasma module (or sub-satellite) Saga, and (2) a technology mission Prisma. The Saga micro-satellite contains a separation mechanism, technologically-challenging communication package, and plasma payload with an estimated total mass of 37kg to make the mission possible with a piggy-back launch or by attaching to another planetary mission. The Prisma mission consists of a semi-coordinated dual micro- and nano-satellites flying together in Earth orbit with state-of-art instruments to test. Both projects aim to develop and test new key spacecraft technologies.

1. Introduction

Small countries like Sweden must seek low-cost missions in order to keep a cutting-in-edge position in national level space missions. This of course includes miniaturization of scientific instruments. This is how Sweden has performed its in-situ space science and missions. Starting with Viking satellite, the missions have followed two directions, down-sizing and sophistication as summarized in [1][2][3][4]. After performing both ends, Munin nano-satellite and Odin high precision satellite, it is natural to start considering the feasibility of low-cost interplanetary missions. This is why we have proposed Saga sub-satellite module. However, such a mission requires state-of-art technologies which must be tested on Earth-orbiting satellite. Prisma (TechnoSat) is one such mission to make a pathway toward the Saga international sub-satellite module.

2. SAGA

The original Saga mission was proposed as an aggressive Venus exploration with dual satellite (one 150-200kg and the other 10-20 kg) that, however, relies on a dedicated launch and DSN communication availability. By doing this the mission can provide both scientific frontier and technological advance. This low-cost interplanetary mission has, however, turned out to be too expensive for Sweden without its own launcher or DSN. Therefore the mission concept was drastically downsized from mini-satellite level to micro-satellite level, i.e., from its own planetary mission to sub-satellite concept. The dual-satellite technological aspect is now considered in the Prisma mission discussed later.

The redesigned Saga mission (see Figure 1) is an interplanetary plasma sub-satellite which is ready for any piggy-back opportunities on interplanetary missions to study the plasma environment of inner planets such as Venus, Mars, Comets, Asteroids, and Earth (further than lunar orbit). The Saga micro-satellite contains a separation mechanism, communication package, and an Astrid-2 type plasma payload as listed in Table 1 with an estimated total mass of 37 kg (50x50x40cm). Astrid-2 is a Swedish micro-satellite launched in 1998 with a total mass of 30 kg including 10 kg payload [2][5]. The Saga payload would be upgraded from Astrid-2 type to Prisma type (see description of Prisma in the next section). Such a ready-made design allows a quick response to any planetary-magnetotail mission opportunities as an additional sub-satellite. Also, the spinning platform with electromagnetically clear environment makes Saga a good supplement to the majority of planetary missions with a 3-axis stabilized platform for imaging purposes.

The importance of plasma science on different planets is obvious. For example, the atmospheric evolution issue alone is a big scientific mystery: Why the brother planets Venus, Earth and Mars evolved so differently? The difference is particularly large for the atmospheric composition, but no explanation is given because we do not know even the on-going escape processes. This study naturally requires investigation of the solar wind interaction with the non-magnetized planetary upper atmospheric and electromagnetic environment. For all these topics, having multi-point measurements is ideal while the planetary mission itself is expensive and rare. For example, we had no dedicated plasma mission after Pioneer-Venus to Venus or after Phobos-2 to Mars; both missions are more than 15 years ago. Therefore, the low-cost sub-satellite concept makes such a rare planetary mission more fruitful with very little additional cost.

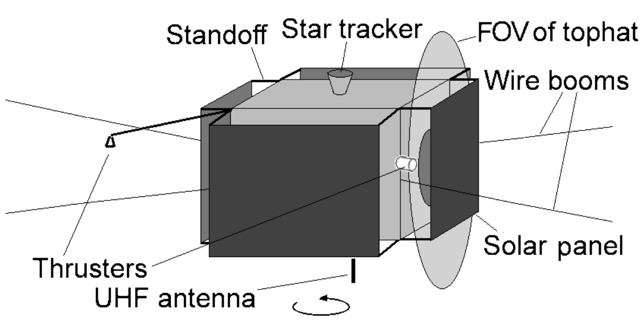

Figure 1: Saga configuration. Solar panels are mounted on standoffs and particle sensors mounted behind panels. Wire boom roots are located at the corners. Star tracker is located on the top or bottom platform. UHF antenna for communication to mothership is located on the top and/or bottom platform. Cold-gas or propane thruster is located on the short boom to make the thrust vector parallel to spin vector.

Table 1: Saga payload compared to Astrid-2

Instrument	**Saga (9kg)**	**Astrid-2 (10kg)**
DC Magnetometer	dB < 0.1nT	same
Wave and E-field	up to 16 MHz	< 2 kHz
2 Langmuir probes (n and T)	$1 \sim 10^6$ cm-3 Vsc: ± 20V	same
Booms	1m x 2 + 10m x 4	3.3m x 4 + 0.8m x 2
Ion mass spectrometer	0.01~40 keV M/dM=5	no mass
Electron spectrometer	0.01~25keV	same
Energetic neutral imager*	0.03-1keV H, O, CO2	no
X-ray detector*	< 1keV	no
Photometer*	HI 1216, OI 1304	same

*optional

An interplanetary micro-satellite also means a technical challenge. The major difference in platform between an Earth orbiting micro-satellite and an interplanetary sub-satellite is the communication, relevant attitude control, and autonomy system to manage the satellite operation without direct link. The most plausible communication method is a relay-communication through the mothership like the one between Mars-Express and Beagle-2 because this method has become more or less an international standard for motherships and launders. Such relay-communication requires Saga to have attitude and orbit control by a small propulsion system (~3kg) in order to keep the sub-satellite within range of the UHF communications link. The other technical details are summarized in Table 2.

Such an interplanetary sub-satellite requires state-of-art technologies in both instruments and satellite body, and it is ideal if we can test them with the Earth-orbiting micro-satellite. The state-of-art instruments are also expected to fly on big missions such as ESA's Bepi-Colombo, and testing these instruments before the big missions is also desired. The Prisma mission described below was proposed and studied (phase-A completed) under such a background. Figure 2 summarizes the strategic location of the Prisma mission in the context of past and future Swedish space activity.

Table 2a: Saga mass budget

Subsystem	mass
Structure including solar panel	6.0 kg
Avionics unit	6.0 kg
UHF communication system (assumed)	3.0 kg
Sun sensor	0.3 kg
Star tracker	1.0 kg
Nutation damper	0.3 kg
Cable harness	1.3 kg
Battery	2.0 kg
Thermal blanket	0.3 kg
Propulsion system	2.5 kg
Propellant	1.5 kg
Payload	9.0 kg
Contingency & balance mass	4.2 kg
Total (Saga)	**37.4 kg**

Table 2b: Saga technical summary

Axis	spin-stabilized, axis perpendicular to ecliptic
Size	50x50x40cm box
Mass	37 kg for sub-satellite + 4 kg for communication package on mothership
Power	70 W from solar array (0.5x0.4m), peak consumption 60 W
Payload	mass 9 kg, power 10 W
Data link (+ranging?)	Beagle-2 (MARESS) type UHF radio, 1-10 kb/sec with 40W power
Separation & spin-up	Mars Express (SUEM) type made by Hunting
Main avionics	simplified from SMART-1 (up to 40 kRad)
Attitude/orbit control	Cold gas (N2) propulsion + nutation damper
Attitude determination	sun sensor, star tracker

3. PRISMA

Prisma is a semi-coordinated dual satellite mission with a micro-satellite (60kg) and a nano-satellite (5~10kg) flying together in Earth orbit. The project aims to develop and test new key spacecraft technology in order to significantly enhance Swedish spacecraft capabilities for the future, as well as to make a flight test of new scientific instrumentation that can be used in the Saga mission or future international large missions (like those within ESA, JAXA, NASA and IKI).

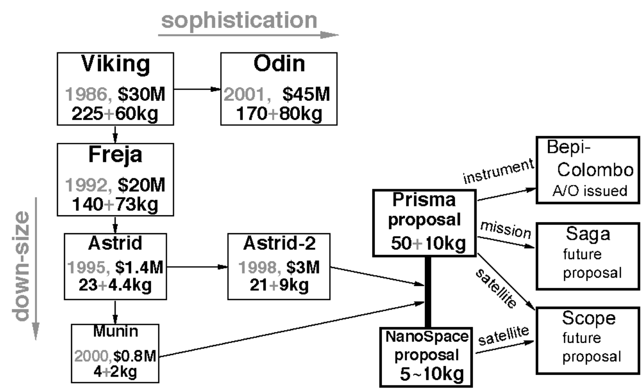

Figure 2: Development of Swedish space missions. Bepi-Colombo is an ESA cornerstone mission to Mercury. Scope is a Japanese multi-satellite project with 1 mini-satellite, 3~4 micro-satellites, and hopefully 3~4 nano-satellites if the single launch is possible.

The micro-satellite (Prisma) and the nano-satellite (NanoSpace-1) will be launched together and separated shortly thereafter to a short distance from each other (a few meters). After some time the nano-satellite will be ejected away from the neighbourhood of Prisma to a distance of a few km. Prisma will then spin up and deploy the PREFIX wire booms (see below). If Prisma has no active orbit control (this is TBD), the formation flying will end after they have separated outside of the intended laser range of the nano-satellite, i.e., after a few orbits.

Both spacecrafts have spinning platforms on the polar orbit to test the performance of the newly developed scientific instruments in relevant parameter regions. Since these scientific instruments produce extremely high data rates, a low-altitude (300-1000km) orbit passing over the Esrange ground station (inclination > 68 deg) is preferable. Meanwhile telemetry rate will be enhanced to at least 512 kbps by use of new improvements of the Esrange downlink facilities. Miniaturization of the payload (Table 3) and spacecraft is another important goal with a high degree of integration. All the payload electronics are harbored in one electronics box except for some particle instruments. All instruments use the same DC/DC converters and power supply, which is situated in this common electronics box.

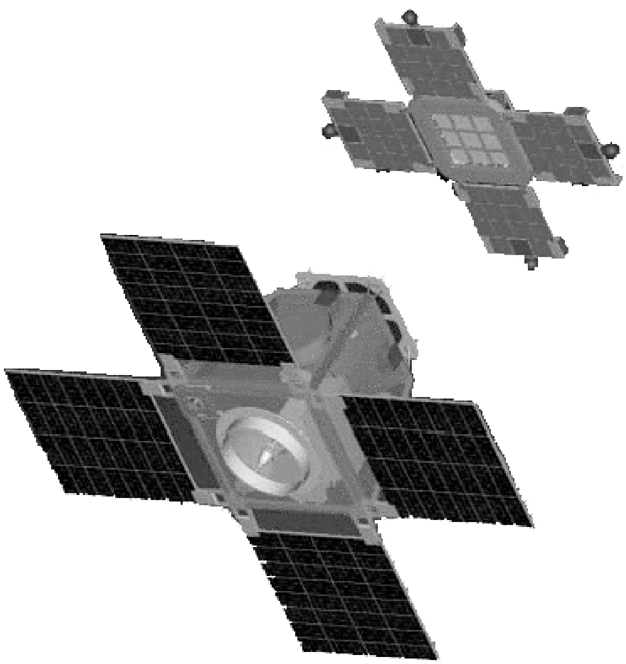

Figure 3: Prisma (lower left) and NanoSpace-1 (upper right).

Although the mission is thus driven by technology development, it is still possible to have a concrete science goal because the mission carries state-of-art miniature instruments with high data generation rates. The polar low-altitude orbit required from the technology side makes Prisma eventually the first ionospheric plasma mission with modern instrumentation during the last 25 years. Possible valuable science by the Prisma mission includes:

1. Ionosphere-Magnetosphere coupling effects at ionospheric altitudes, e.g., electrodynamic interaction through non-linear wave or resonance activity; quasi-static electric fields; and associated small-scale turbulence and particle energization.
2. Plasma turbulence and structure formation and its role in plasma heating and energization.

Table 3: Prisma payload

Instrument	**function**	**mass**	**power**
*MAG *	DC-B, dB<0.1nT	0.6 kg	2.0 W
*PREFIX	DC/AC-E, ~MHz	2.75 kg	4.2 W
*RPW	Wave, 1Hz~16MHz	1.3 kg	7.4 W
LP	n=1~10^6cm-3, T, Vsc<±20V	0.55 kg	1.6 W
MIPA	i+, e-, 0.01~25keV, M/dM=5	1.6 kg	2.3 W
LENA	neutral=0.03~1keV, H, O, CO2	2.0 kg	2.0 W
DIXI	X-ray=5~40keV	0.3 kg	0.8 W
GAMMA	HI 1216, OI 1304	0.5 kg	0.7 W
	common electric box	0.95 kg	0.2 W
Total	**(Prisma)**	**10.5 kg**	**21.2 W**
nano-RPW		0.2 kg	7 W
nano-MAG		0.1 kg	2 W
Total	**(NanoSpace-1)**	**0.3 kg**	**9 W**

(*) wire booms: MAG=1mx2, PREFIX=13mx2, RPW=1mx6

3. Atmosphere-Ionosphere coupling such as physical processes behind certain lightning phenomena (e.g. sprites), gravity waves, and upper atmospheric heating in the auroral region.
4. Solar-Ionosphere coupling (part of space weather), i.e., the response of the ionospheric plasma, its radiation environment and its thermal properties depending on solar variability.
5. Oxygen and other heavy ion circulation out of and into the ionosphere.

4. Instruments on board Saga and Prisma

Below one can find a rough description of the instruments (see Table 3) that we are developing toward the Prisma (and Saga) mission.

DC Magnetometer (MAG)

The magnetometer has three single axis fluxgate magnetometers with ±65 536 nT science range. Built-in digital decimating Bessel filters determine the magnetometer's 3dB frequency to be 13.1 Hz for the internal sampling rate of 50 vectors/second.

Electric Fields (PREFIX)

PREFIX consists of two pairs of wire booms and accompanying electronics of a novel design. At the tip of each boom, a 40 mm diameter spherical probe is located, suspended by a 2 m long naked wire. The instrument has a few options for measurement, using 4 orthogonal wire-booms for electric field measurements, up to 3 MHz for one boom pair and up to 10 MHz for the other sensor pair.

Radio & Plasma Wave Instrument (RPW):

RPW has a three-axis HF magnetic sensor (100 kHz - 5 MHz), three fully digital signal analyzers and Mux-filters operating in the frequency range 100 Hz - 10 MHz. Due to the short distance (a few km apart) between the two spacecraft, the transmitter can act as an in-situ plasma sounder, and the transmitter can be used to measure radio wave propagation along the inter-satellite path between Prisma and NanoSpace-1.

Dual Langmuir Probe System (LP):

The Langmuir probe (LP) system comprises two small spherical sensors, with 18-bit resolution in the frequency range from DC to 10 kHz. Two separate Langmuir probes will allow the determination of the velocity of plasma structures by a "time-of-flight" method. In a similar way the phase velocity of certain plasma waves can be estimated.

Miniaturized Plasma Analyzer (MIPA):

MIPA consists of two identical sensors (ions and electrons) mounted at a distance of 30 cm from front-end-electronics and HV supply. The time-of-flight measurements provide mass identification. For electrons only START signals will be used (TBC). Extensive ray-tracing and feasibility studies have been completed.

Low Energy Neutral Atom (LENA):

The LENA experiment analyzes azimuth (360 deg coverage), energy and mass (10~100 eV for H, N, O, N2, O2, and 500~3300 eV for H, O) of neutral particles entering the instrument.

X-ray detector (DIXI):

The feasible energy range is between 5 and 40 keV with an energy resolution better than 1.5 keV that is dominated by threshold shifts between pixels. The instrument has roughly a 20x20 degree field of view with an angular resolution in the order of a 10 arc-min.

Gamma-Ray Detector System (GAMMA)

GAMMA detector efficiency is highest (99% to 31%) at lower energies of 100-500 keV. The detector efficiencies are highest when the gamma rays enter perpendicular to the largest surface of the crystal (=0°), and smallest when they enter parallel to this surface. By using this effect, we expect to determine the direction of the incoming gamma rays.

NanoSpace-1

The Nano-RPW instrument is a highly advanced miniaturized radio receiver instrument, where the electronics has been integrated into a silicon multi-chip module, with a mass of only ca 42 g. The total mass of the instrument is only a couple of hundred grams. The Nano-MAG on board NanoSpace-1 is the only instrument that is more traditional. It is just a rough magneto-resistive sensor with a resolution of 10 nT noise level on a 30 cm short boom.

Capabilities

The above-listed payload has several novel capabilities which must be tested during the mission. These include:

1. Passive HF thermal noise detection with the PREFIX wire booms (RPW, PREFIX).
2. Determine the three-dimensional plasma wave electric field for k-vector determination from about 100 Hz up to several MHz frequencies (RPW).
3. Accurate instantaneous direction finding of radio waves (RPW).
4. Active radio sounding of the surrounding plasma (RPW, PREFIX).
5. "Mutual impedance" sounding between two sensors (RPW, PREFIX)
6. Plasma temperature monitoring with ms resolution by a dual Langmuir probe system (LP).
7. PREFIX wire boom deployment mechanisms.
8. Full 4pi particle distribution with mass resolution in a miniaturized design (MIPA).

9. Detection of energetic neutral atoms of less than 100 eV with mass-resolving capability (LENA).
10. Detection of the direction, time, and energy of gamma rays and X rays in the range 5-40 keV with energy resolution of 1.5 keV (DIXI)
11. Radio transmission experiments between two spacecraft to study plasma and atmospheric structure (RPW, PREFIX, Nano-RPW).

5. Concluding Remarks

As a continuation of low-cost space projects, Swedish scientists are considering low-cost planetary missions. Such missions are in principle possible as sub-satellite projects on other planetary missions flown by large organizations such as ESA, JAXA, NASA, and IKI. To acquire the technology required for such interplanetary sub-satellites, Swedish scientists have proposed the technology mission Prisma. Through the Prisma mission, they can develop and test key technology for micro-spacecraft body, micro-spacecraft control, subsystem, and payload.

The mission thus makes planetary missions handy and increases the chance of international collaboration. Similarly Sweden should be able to collaborate with other countries in making science missions smaller and easier once the Prisma mission is completed.

References

[1] Lundin, R., O. Norberg, M. Yamauchi, S. Barabash, S. Grahn, G. Marklund, and D. Winningham, Design and achievement of Swedesh micro- and nano-satellite missions, in 22nd ISTS proceedings, 2000.
[2] Marklund G., M. Andre, and R. Lundin, Swedish small satellites investigate the aurora, Eos, 85, 157-165, 2004.
[3] Norberg, O., et al., "Munin: A Student Nanosatellite for Space Weather Information, Microsatellites as Research Tools," in Proc. of COSPAR Colloquium on Microsatellites as Research Tools, p352-364, Pergamon, 1999.
[4] Yamauchi, M., O. Norberg, S. Barabash, R. Lundin, and D. Winningham, Mission and science of Munin: The first Swedish nano-satellite, 23rd ISTS proceedings, 2010-2013, 2002.
[5] Marklund, G., et al., “Astrid-2, A Low-Budget Microsatellite Mission for Auroral Research,” ESA SP-397, 387-394, 1997.