ASPERA-3 Flight Performance Report

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Abstract. The scientific objective of the ASPERA-3 experiment is to study the solar wind - atmosphere interaction and to characterize the plasma and neutral gas environment near Mars space utilizing instruments measuring energetic neutral atoms (ENAs) and the local plasma. The investigations will address the fundamental question:
What is the long-term and short term impact by the solar wind on Mars and its atmosphere?
This question is directly related with the problem of dehydration on Mars. The ASPERA-3 instrument comprises four sensors; two ENA sensors and an electron and ion spectrometer.

This report provides first a brief summary of the ASPERA instrument, subsequently presenting an overview of the performance of the instrument after extensive calibrations and tests .

The ASPERA scientifique instrument is now ready for launch.

1. ASPERA Scientific Objectives

The scientific objectives of the Mars Express Orbiter mission are to study the subsurface, the surface, and the atmosphere of Mars, as well as the interaction of the atmosphere with the interplanetary medium. The experiment ASPERA-3 (Analyzer of Space Plasma and Energetic Atoms) have the following scientific objectives:

1. Remote sensing of energetic neutral atoms (ENA):
   (a) for remote-mapping of the global solar wind interaction with the Martian atmosphere,
   (b) to characterize quantitatively the effects of plasma interacting with the atmosphere,
   (c) to determine the morphology of the global plasma and neutral gas outflow at Mars.
2. Provide *in situ* measurements of ions and electrons in order:
   (a) to better understand the transfer of energy, mass and momentum of solar wind plasma to the martian ionosphere and upper atmosphere,
   (b) to provide adequate measurements of the plasma acceleration/outflow from the martian ionosphere, part of the outflow charge-exchanging to ENAs,
   (c) to provide undisturbed solar wind parameters required for interpretation of ENA images.

The objectives will be met by ASPERA using a set of instruments doing imaging of energetic neutral atoms and direct measurements of the hot plasma (electrons and ions).
The impact of hot plasma (the solar wind) into neutral gas (the atmosphere of Mars), results in a strong interaction between them. One of the fundamental collisional interactions is the charge - exchange process

$$A^{+}(energetic)+M(cold)\text{->}A(energetic)+M^{+}(cold),$$

which produces energetic neutral atoms (ENA). Directional detection of the ENA thereby yields a global image of the interaction. The ASPERA-3 experiment will investigate the effects of the plasma - neutral coupling at Mars via ENA imaging. In addition the energy, mass, and momentum transfer by the solar wind, resulting in a strong ionospheric plasma outflow, will be investigated by measurements of electrons and ions. The plasma instrument will also be capable to study the potential role of dusty plasmas in the martian environment.

Table 1. The ASPERA-3 scientific objectives

Scientific objectives	Associated measurements	Measurements requirements
Determine the instantaneous global distributions of plasma and neutral gas near the planet	ENAs originated from the shocked solar wind	Measure the ENA flux in the energy range tens eV - few keV with 4π coverage. ENA flux > 10^4 $cm^{-2}s^{-1}keV^{-1}$ Measure the upstream solar wind parameters
Study plasma induced atmospheric escape	ENAs from inside the magnetosphere	Mass resolving (H / O) ENAs up to tens keV. ENA flux > 10^3 $cm^{-2}s^{-1}keV^{-1}$
Modification of atmosphere by ion bombardment	ENA albedo	Mass resolving (H / O) ENAs down to tens eV from nadir flux > 10^6 $cm^{-2}s^{-1}keV^{-1}$ (100 eV)
Energy deposition from the solar wind to the ionosphere	Precipitating ENAs	ENA measurements in the energy range tens eV - few keV. flux > 10^4 $cm^{-2}s^{-1}keV^{-1}$
Search for the solar wind - Phobos interactions	ENA originated from Phobos	ENA measurements in the energy range 10-3000 eV - 4π cov. ;flux 10^4 $cm^{-2}s^{-1}keV^{-1}$
Define local characteristics of the main plasma regions	Ions and electrons, hot plasma	Ion and electron measurements in the energy range few eV - tens keV with 4π coverage

2. The ASPERA-3 instrument

The ASPERA-3 instrument comprises four sensors; two ENA sensors, an electron and an ion mass spectrometer. The two ENA sensors are optimized for some of the scientific objectives while at the same time complementing each other. This approach also gives the necessary redundancy as well as independent cross-checking, necessary for such a ”first ever” measurements. The charged particle sensors not only provide characterization of the local plasma environment but also support ENA measurements in terms of charged particles background and inter - calibrations.

The Neutral Particle Imager (NPI) provides measurements of the integral ENA flux with no mass and energy resolution but with 5° × 11° angular resolution. The intrinsic field of view is 9° × 344°. The sensor utilizes a graphite surface to suppress the UV background. ENAs incident on the surface at a grazing angle of 20° are reflected and / or cause ion sputtering. An MCP stack detects the reflected particles and sputtered fragments with a discrete anode. The NPI head is a replica of the NPI - MCP sensor developed for the ASPERA - C experiment on the Mars - 96 mission (launch failure) and successfully flown on the Swedish microsatellite Astrid launched in 1995

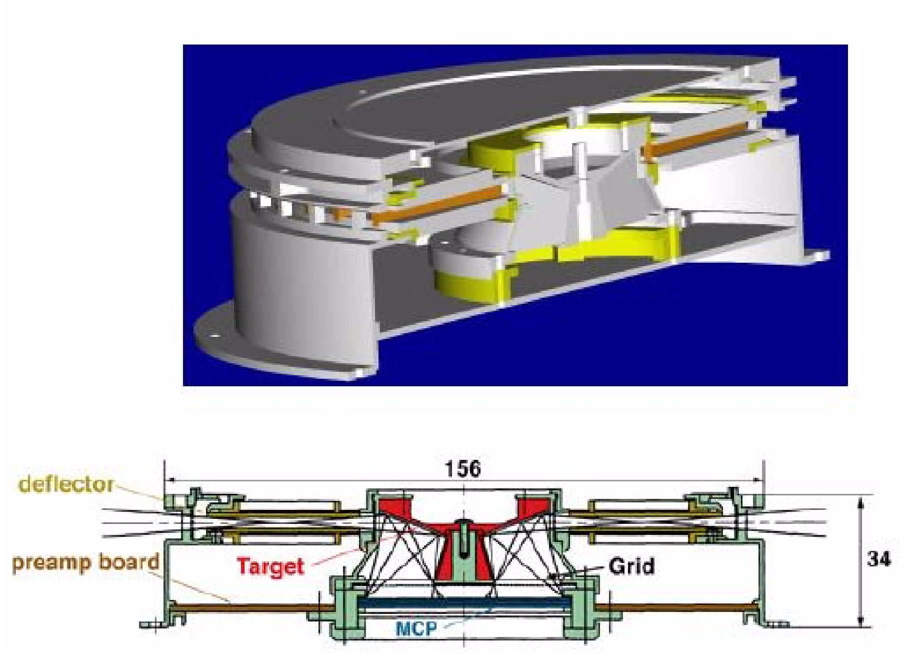


Figure 1. *Cut-away view of the NPI sensor*

The Neutral Particle Detector (NPD) provides measurements of the ENA differential flux over the energy range 100 eV - 10 keV resolving H and O with a coarse 5° × 30° angular resolution. The sensor consists of two identical detectors each with a 9° × 90° intrinsic field of view. The measurement technique is based on a principle similar to NPI. ENAs incident on a surface at a grazing angle of 20° are reflected and cause secondary electron emission. The secondary electrons are transported to an MCP assembly, which gives the START signal. The reflected ENAs hit the second surface and again produce the secondary electrons used to generate the STOP signal. The time-of-flight (TOF) electronics give the ENA velocity. The pulse - height distribution analysis of the STOP signals is used to provide a rough determination of the ENA mass.

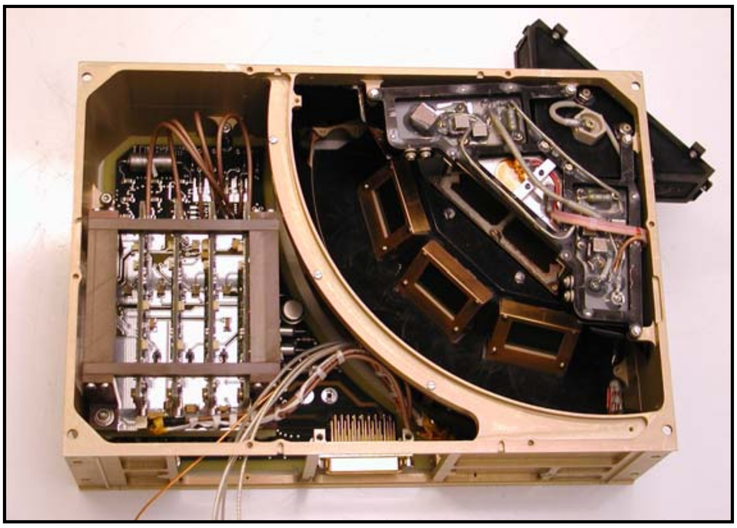


Figure 2. *The NPD flight unit*

The Electron Spectrometer (ELS) provides electron measurements in the energy range 0.01 - 20 keV. The intrinsic field of view is 10° × 360°. There are 16 fields of view each with 22.5° resolution. The sensor is a standard top - hat electrostatic analyzer in a very compact design. ELS is a reduced version of the MEDUSA experiment successfully flown on the Astrid-2 microsatellite and Munin nanosatellite missions launched in 1998 and 2000 respectively.

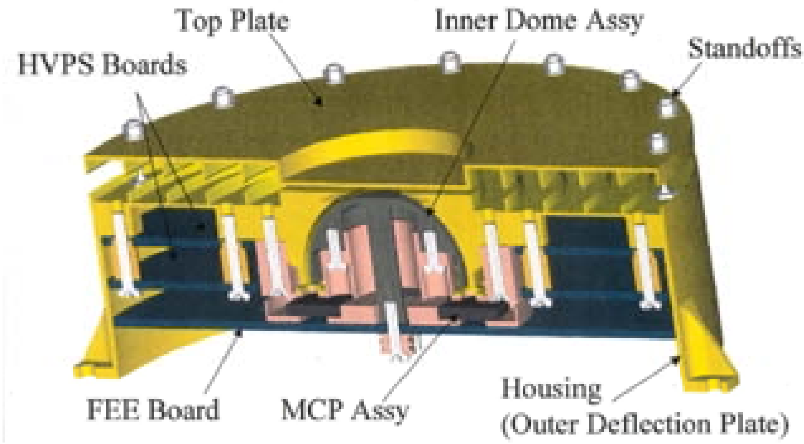


Figure 3. *Cut-away view of the ELS sensor*

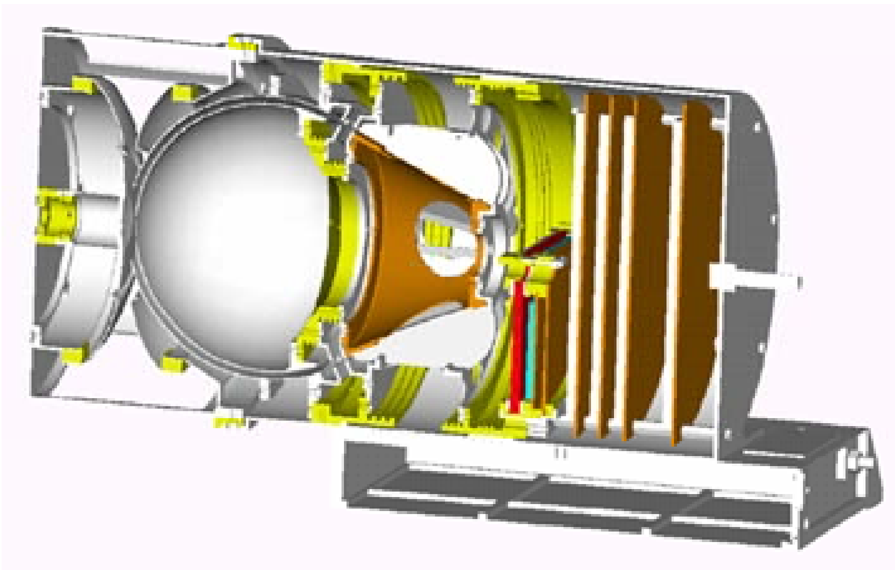


Figure 4. *Cut-away view of the IMA sensor*

The Ion Mass Analyzer (IMA), an improved version of the ion mass spectrographs TICS / Freja, IMIS/Mars-96, IMI/Planet-B, and an exact copy of the ICA instrument to be flown on Rosetta mission. In this design option the IMA sensor is a separate unit connected by a cable to the ASPERA-3 experiment. IMA provides ion measurements in the energy range 0.01 - 30 keV/Q for the main ion components H^+, H_2^+, He^+, O^+, the group of molecular ions ($20 < M/q < \sim 80$), and up to 10^6 amu/q. Mechanically the IMA is a separate unit with a 4.6° × 360° field of view. Electrostatic sweeping performs elevation (±45°) coverage. The IMA sensor is a spherical electrostatic analyzer followed by a circular magnetic separating section. A large diameter MCP with a discrete anode images matrix azimuth × mass. IMA uses an open magnetic separating system and is therefore able to investigate the plasma component with very high *M/q* (up to 10^6 amu/q), i.e. corresponding to a dusty plasma.

The three sensors (NPI, NPD, and ELS) are located on a scanning platform. The combination of the 360° field of view and the scans from 0° to 180° give the required 4π maximum coverage (the real coverage depends on the instrument location on the spacecraft). Mechanically the instrument consists of two units, the Main Unit (MU) with the scanner and IMA. Table 2 summarizes the baseline instrument performance.

Table 2 The baseline performance of the NPI, NPD, ELS, and IMA sensors

Parameter	NPI	NPD	ELS	IMA
Particles to be measured	Neutrals	Neutrals	Electrons	Ions
Energy range, keV per charge	≈0.1 - 60	0.1 - 10 (H) 0.3- < 100 (O)	0.01 - 20	0.01 - 30
Energy resolution, *ΔE/E*	No	0.8	0.07	0.07
Mass resolution,	No	H, O	N/A	m/Δm≈1-4
Intrinsic field of view	9°×344°	9°×180°	10°×360°	90°×360°
Angular resolution (FWHM)	4.6°×11.5°	5°×30°	10°×22.5°	4.5°×22.5°
G-factor / pixel, $cm^2 sr$ (efficiency not included)	2.5×10^{-3}	6.2×10^{-3}	7×10^{-5}	3.5×10^{-4}
Time resolution (full 3D), s	32	32	32	32
Mass, kg	0.7	1.3	0.3	2.2
Power, W	0.8	1.5	0.6	3.5

Manufacturing, integration and tests

Manufacturing of the instrument details has ben a joint effort by the participating investigators. Assembly and integration has taken place at IRF in Kiruna. I major setback in the project occurred when we had to abandon the 32 bit Thor II processor design for a 16 bit processor MA 31750 in January 2001. The Thor II processor had such an astonishing amount of flaws in the chip bondings (Honeywell manufactoring) that it had to be rejected.

Calibration results

Calibration of the ASPERA sensors can be divided up in: 1. Characterization, tests and selection of detectors (MCPs and secondary emitting surfaces). 2. Characterization and final calibration of the integrated sensor units. 3.Functional tests, of the sensors in the fully mounted (flight) configuration. All sensor units were fully calibrated, and some preliminary functional tests were made in the fully mounted, flight, configuration in June 2002. The final functional tests were successfully carried during the retrieval period 18/11 – 9/12 2002. The ASPERA-3 flight unit is now ready for launch. Below follows a brief summary of the individual calibration of the sensors.

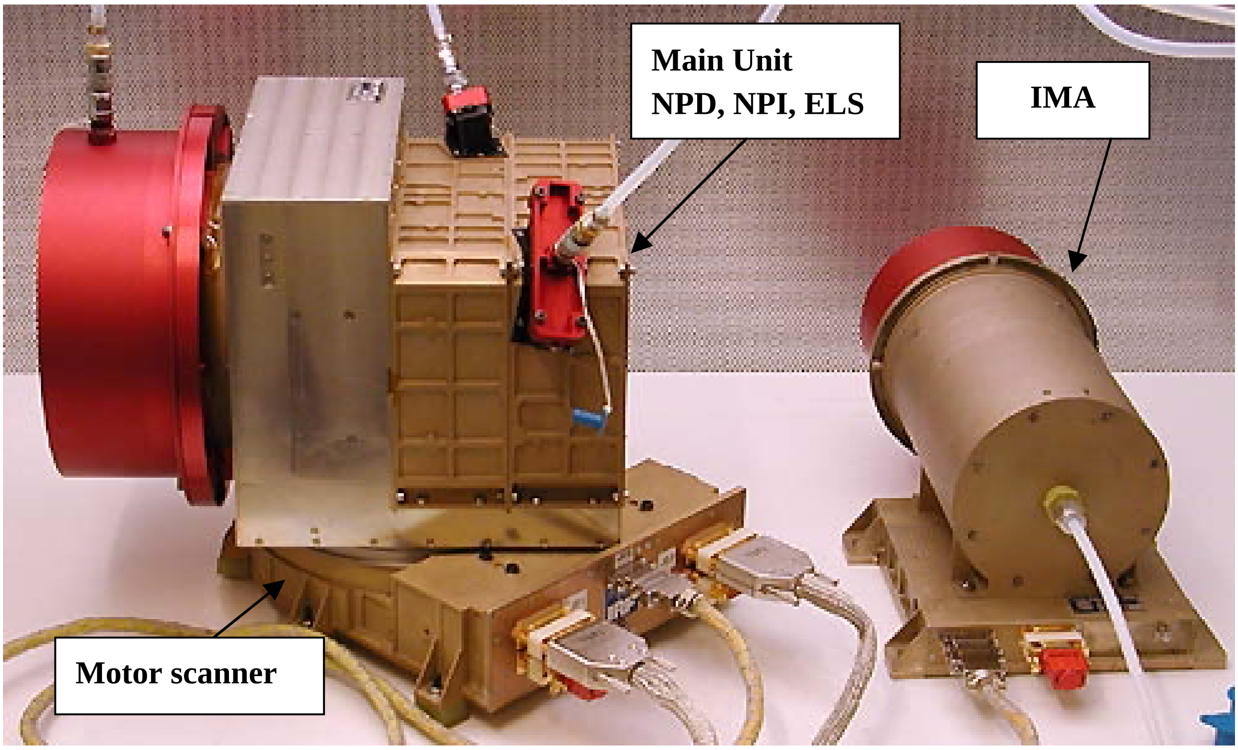


Figure 5. *The full ASPERA-configuration during assemby tests in Kiruna*

The neutral particle imager, NPI, was calibrated in Nov-Dec 2001 at the IRF ion source in Kiruna. The sensitivity of the instrument and the characterization of the acceptance field of view were obtained using ions (e.g. N^+, H_2O^+ and H^+). The ion deflector properties versus energy were calibrated for various deflector voltages. The integral efficiency of the secondary surface were found to range between 2% and 24 % (MCP bias dependent). Azimuthal field-of-view slightly broader than nominal (13.5°). NPI-calibration performance as expectated.
The ideal NPI field of view, 4π, is coeverd in half a scan of the scanninge platform.

The neutral particle detector, NPD, is a completely new design using secondary emitting surfaces and a geomtry that has not been flown before. NPD therefore underwent extensive characterisation tests and calibrations during the spring of 2002. The results of the calibrations at the IRF calibration facility in Kiruna were very successful, the NPD performance surpassing expectations. NPD is even more sensitive than expected (Fig. 6). The mass and energy resolving capability of the instrument were as expected in the energy range ≈1 – 10 keV (Fig. 7).
The NPD field-of-view, 2π, is covered after a scan of the scanning platform.

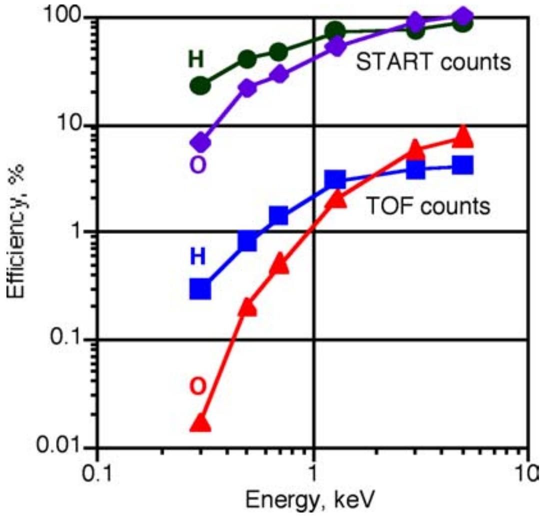
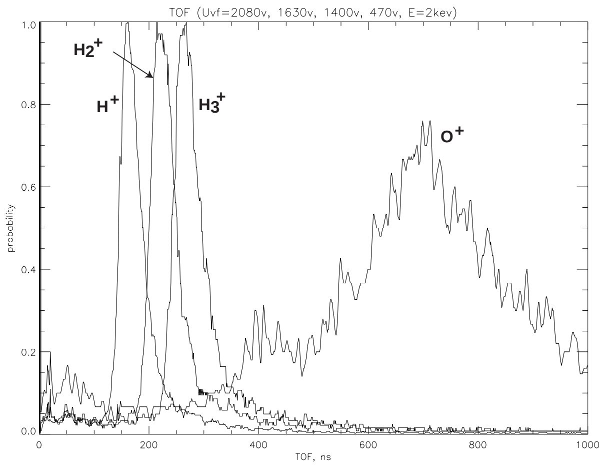


Figure 6. *Efficiency curves for the START and STOP setectors of the NPD instrument.*



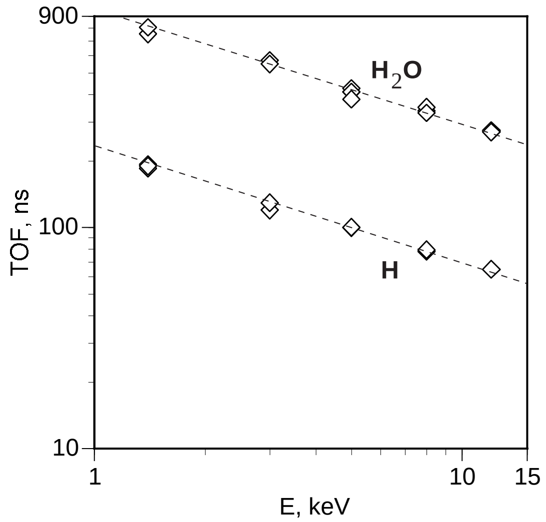


Figure 7. *Mass resolving capability of the NPD sensors using pulse-height analysis of the STOP MCP-detector (left) and time-of-flight analysis (right)*

The electrons spectrometer unit, ELS, was calibrated at MSSL in London, fall 2001. The energy resolution was found to be better than expected, which is an advantage for studying the narrow electron peaks expected as a result of the solar impact on the ionosphere and upper atmosphere. The geometric factor is a factor of five less than nominal, but the loss of sensitivity is for this mission considered to be well compensated by the improved energy resolution of ELS. Calibrations and tests are considered to be successful and the sensor is ready for flight.

The ion mass analyzer, IMA, is a heritage from Freja (1992 launch), Mars-96 (launch failure 1996), Nozomi (launch 1998) and is also used in Rosetta (launch Jan 2003). IMA was successfully calibrated January to March, 2002. Performance largely as expected, except that the upper energy limit has been lovered from 40 keV to 30 keV. Mass resolution as expected (Fig. 8). Energy and angular characteristics also as expected (e.g. Fig. 9)

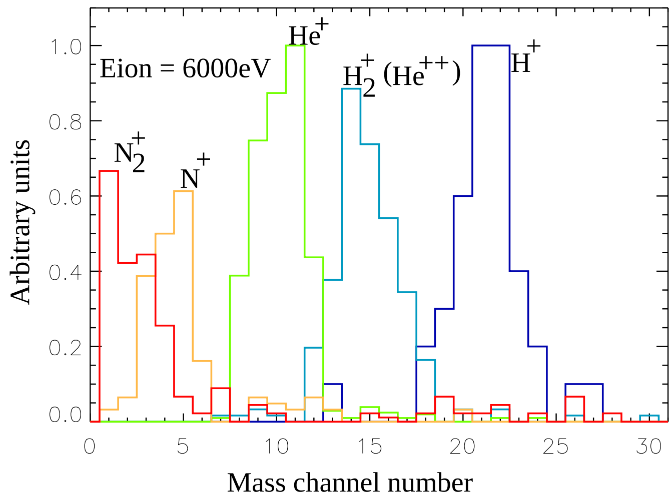


Figure 8. *Calibrated Ion Mass Analyzer mass resolving capability of 6 keV ions*

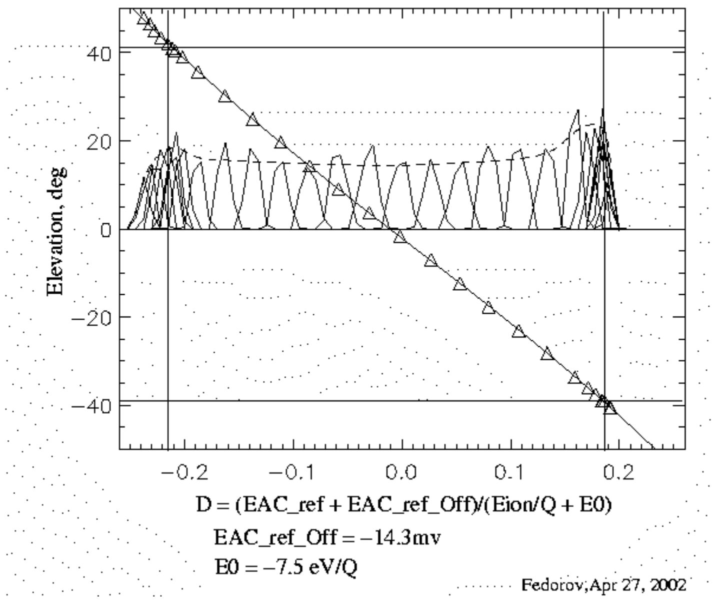


Figure 8. *Calibrated elevation angle response of the Ion Mass Analyzer*

Summary of sensor performance

Table 3 summarizes the results of the calibrated performance of the four ASPERA sensors units.

Table 3: Summary of the ASPERA individual sensor performance.

Sensor	*Parameters to measure*	*Performance as of 2002-06-10*	*Scientific modes*
Neutral Particle Imager (NPI)	**ENA flux ~0.1 - 60 keV**	**Pixel 4.5°x 13.5° ε(int)=2-24% (1%)**	**ENA images of 5° x 11° pixels / 32, 64, 128 sec**
Neutral Particle Detector (NPD)	**ENA flux, energy, mass, 0.1 - 10 keV**	**as proposed**	**ENA images of 5° x 30° pixels for H and O for 8 energy-steps. / 32, 64, 128 sec**
Electron Spectrometer (ELS)*	**3D e- spectra 10 eV - 20 keV**	**ΔE/E = 8% (25%) G-factor=6x10^{-5} (3x10^{-4}) cm^{2}sr**	**3D electron distribution functions / 32, 64, 128 sec**
Ion Mass Analyzer (IMA) **	**3D ion spectra, ion mass 10 eV/q - 40 keV/q**	**E_{max} = 30 keV (40) Slightly worse angular resolution for E < 300eV and E> 23 keV**	**Ion distribution functions within 90° x 360° solid angle / 32, 12 sec energy – mass matrixes / 32 sec**

*** ELS performance was changed to resolve photoelectron peaks**

**** Changes in IMA performance does not affect instrument scientific capabilities**

Motor scanner

Lifetime tests of the motor scanner have been carried out in several stages and modifications have been introduced following non-conformances. The flight model of the scanner has performed up to 100 000 turns in thermal vacuum and is now space qualified. The performances degrades at temperatures below – 30° C,. but this is still considered acceptable from the measurements point of view.

Data processing unit

The data processing unit and the flight software have been a matter of concern following the very unfortunate discovery of a sever non-conformance of the Thor II processor in Nov- Dec- 2000. The recovery plan involving a switch to MA 31750 processors and a complete rewriting of all flight software that was almost ready, started Jan. 2001 and commenced basically up to October 2002. The DPU is now performing as expected. Extensive tests in thermal vacuum with the full ASPERA configuration has been done to verify the experiment performance.

Overall status

The flight sensors were calibrated and tested during the spring 2002. After integration in Kiruna and tests the ASPERA flight unit was delivered to Alenia in the end of June 2002. However, missing some major parts of the software, including proper softaware in the E-PROMs, the

instrument was still not ready for for flight. Work on the on-board software were completed in October 2002. The ASPERA flight model was retrieved from Astrium November 18 to IRF-Kiruna for replacement of the DPU-board and final tests of the on-board flight software in thermal vacuum. These tests were completed on December 6 and the instrument is now ready for launch after final mating with the MEX spacecraft.
Table 4 summarises the mass, power and telemetry budget of the ASPERA instrument. Notice for instance that the final mass budget is even below the mass in the proposal as of Feb. 1998.

Table 4: ASPERA mass, power and telemetry budget.

	Budget as for 2002-06-11	Budget as proposed
Mass	8125 g	8200 g
Power	16.8 W *	15 W
TM	0.6, 2.2, 6.2, 18.2 kbits/s	2, 7, 20 Mbyte/orbit,

* max, depends on the scanner operations

Conclusions

ASPERA-4 for Mars Express have been extensively tested and calibrated and is now ready for launch.