भारतीय अन्तरिक्ष अनुसंधान संगठन
HEX • MIP • RADOM • SIR-2 • MiniSAR
इसरो ISRO
चन्द्रयान-1
CHANDRAYAAN-1
TMC • HySI • CIXS • SARA • LLRI • M3
INDIAN SPACE RESEARCH ORGANISATION

SARA Experiment on the Chandrayaan-1 Mission

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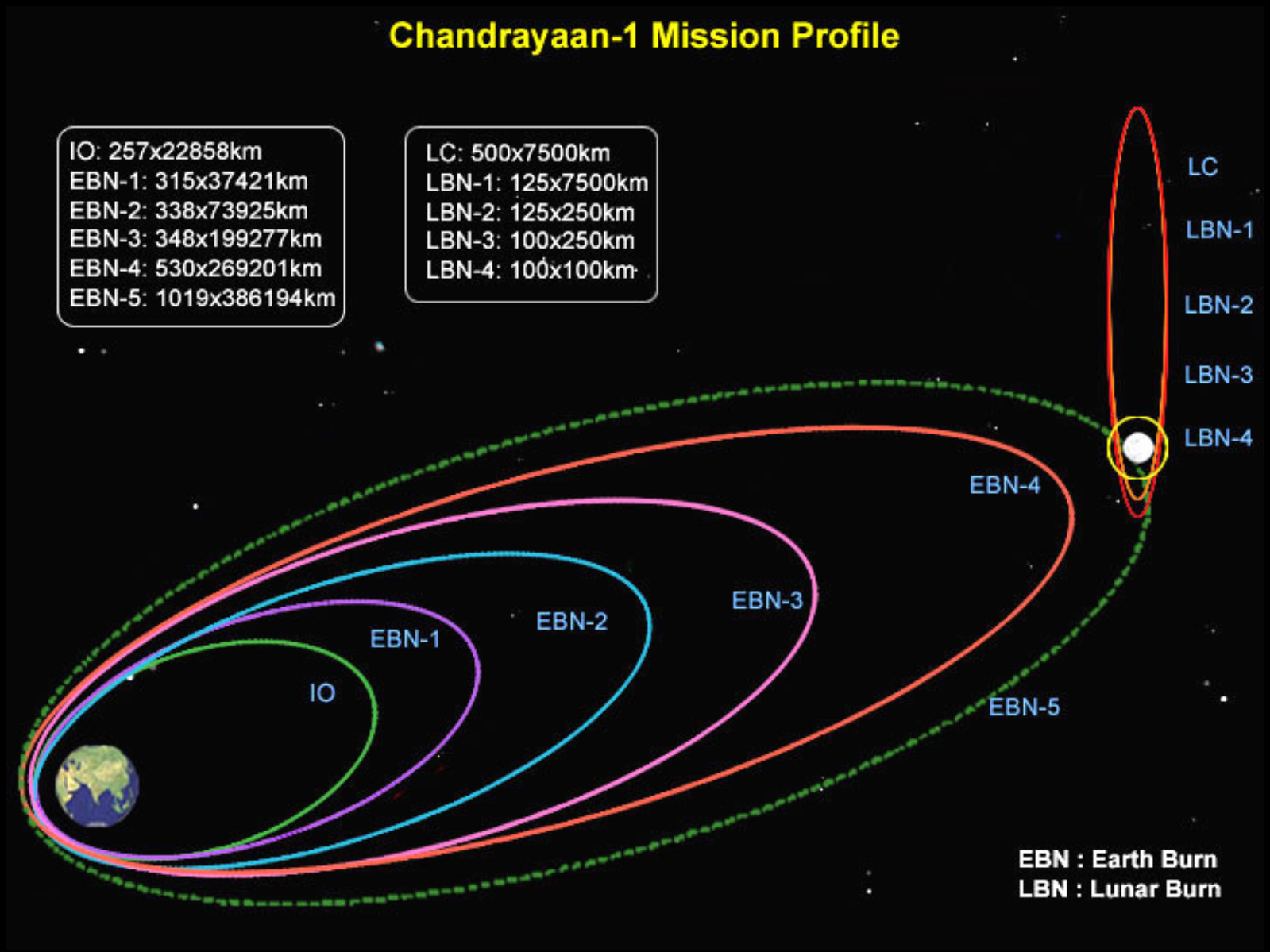
PSLV-XL Launch Vehicle with Chandrayaan-1 at the Launch Pad in Sriharikota

October 22, 2008; 06:22 am
Indian Time



Launched: Oct. 22, 06:22 IST

Arrived on Moon: Nov. 08; 16:51 IST (after 16 days of travel)

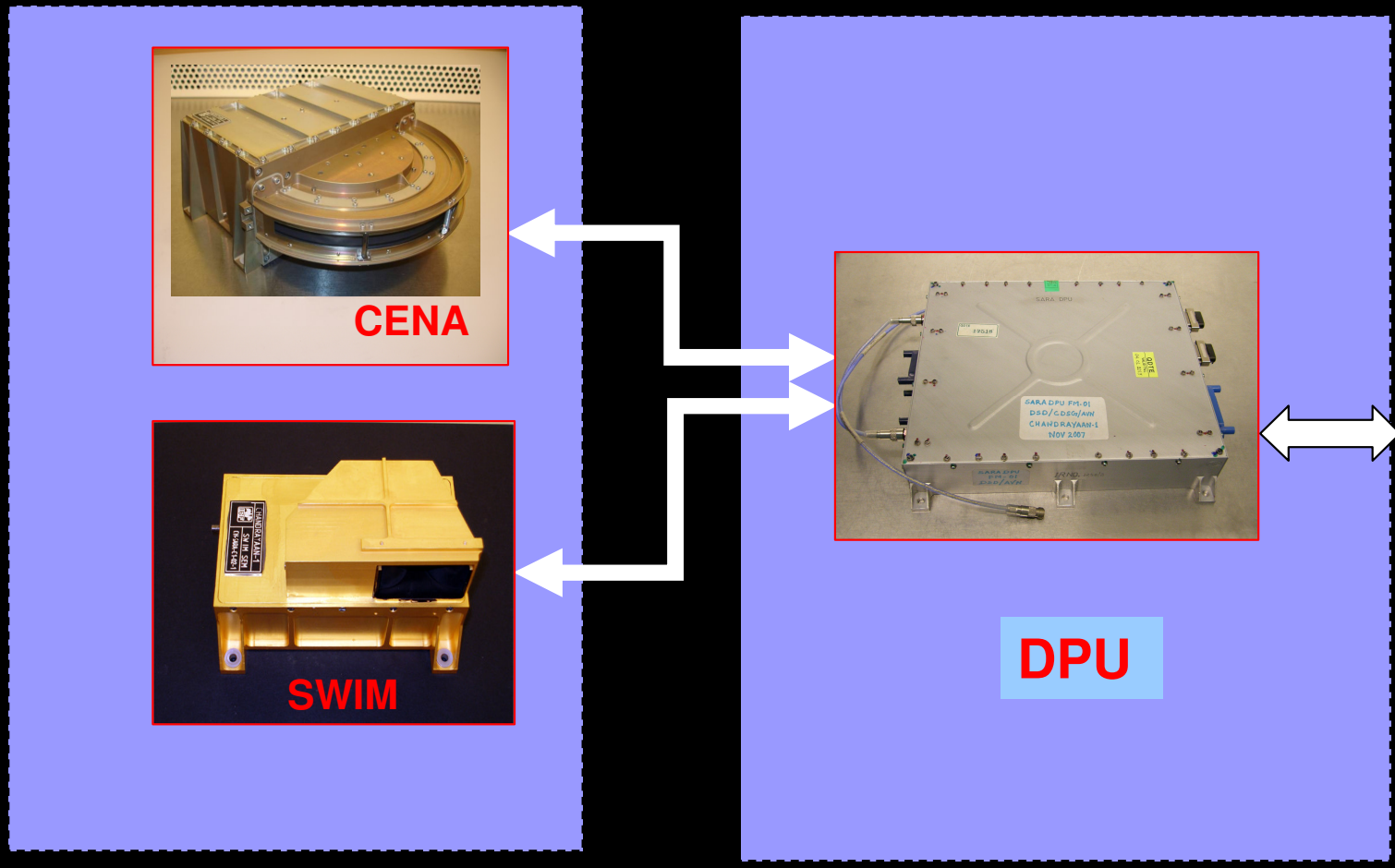
In 100 km orbit around Moon: Nov. 12

Release of MIP: Nov. 14, 20:06 IST – landed on Moon: 20:36 IST

Anil Bhardwaj

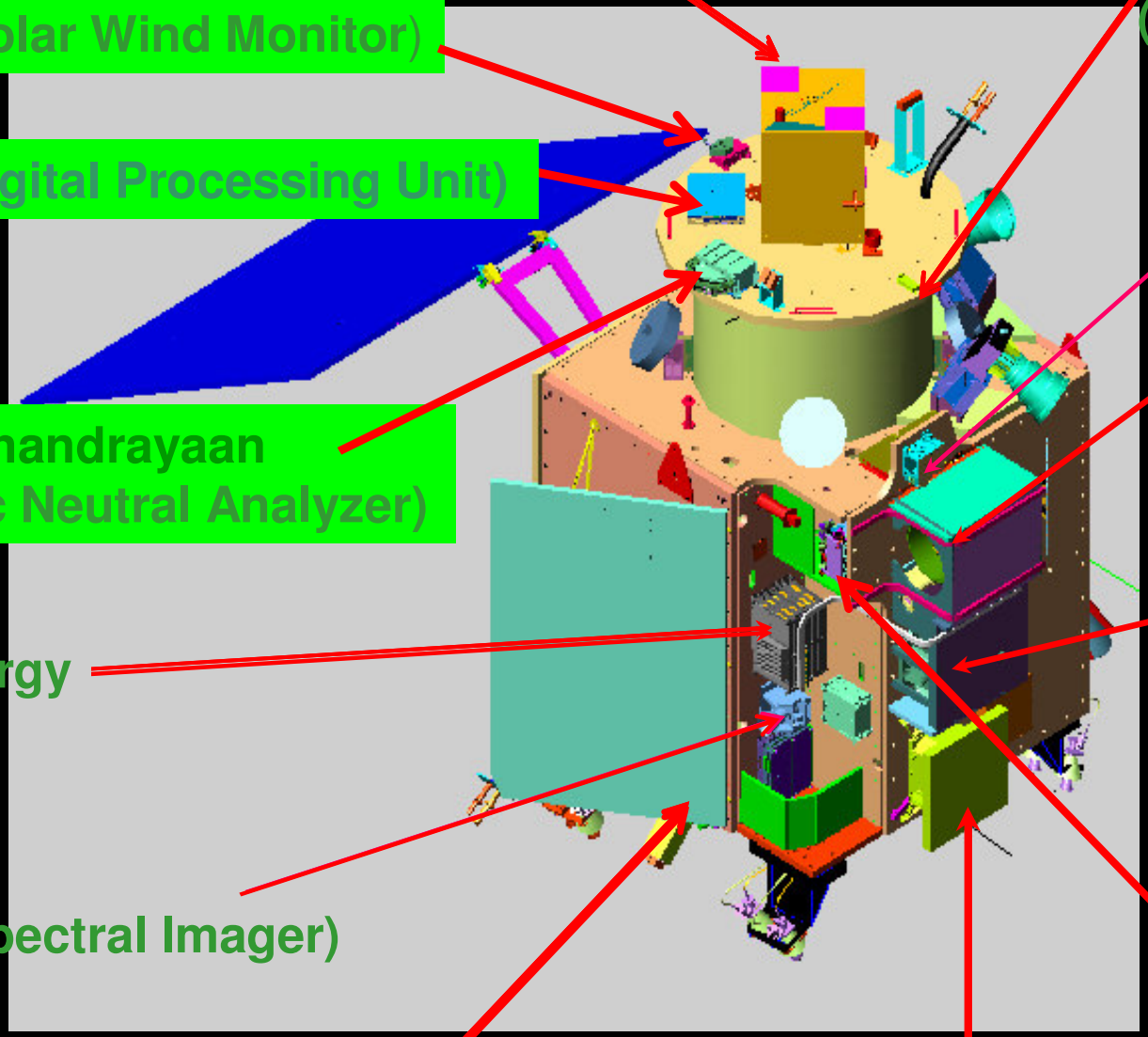
Space Physics Laboratory,
Vikram Sarabhai Space Centre, Trivandrum,
INDIA

SARA Design



- **CENA**: Chandrayaan Energetic Neutrals Analyzer
- **SWIM**: Solar WInd Monitor
- **DPU**: Digital Processing Unit

Chandrayaan-1 Payloads Accommodation



MIP (Moon Impact Probe)

RADOM (Radiation dose monitor)

SWIM (Solar Wind Monitor)

DPU (Digital Processing Unit)

SIR-2 (Infrared Spectrometer O-box)

LLRI (Lunar Laser Ranging Instrument)

CENA (Chandrayaan Energetic Neutral Analyzer)

HEX (High Energy X-ray)

TMC (Terrain Mapping Camera)

HySI (Hyper Spectral Imager)

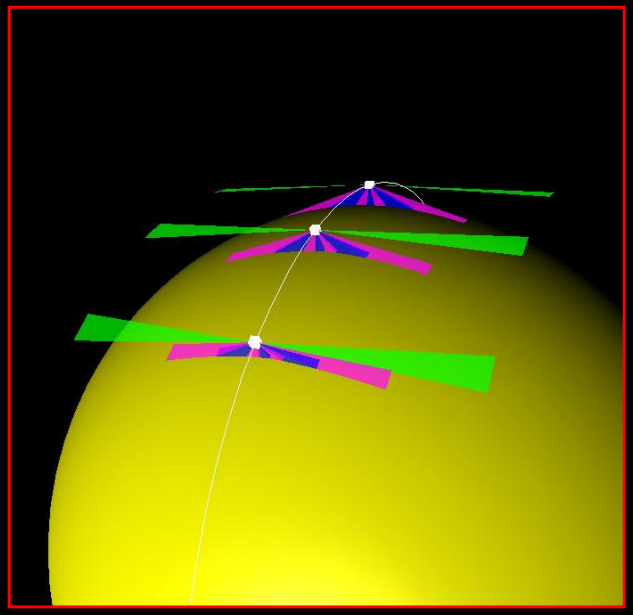
CIXS (Compact Imaging X-ray Spectrometer)

MINI-SAR (Miniature Synthetic Aperture Radar)

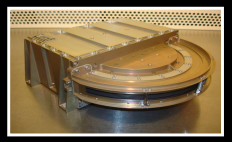
M^3 (Moon Mineralogy Mapper)

SARA: Introduction

- **SARA**
  - to measure flux, mass, arrival direction, and energy of energetic neutral atoms (ENA) sputtered from the Moon surface by the solar wind in the ~10 eV-3 keV (**CENA**)
  - to monitor solar wind (**SWIM**)
- SARA is the first ever ENA imaging mass spectrometer.
- Replica of CENA was selected to fly to Mercury onboard BepiColombo MMO and MPO.



CENA Sensor



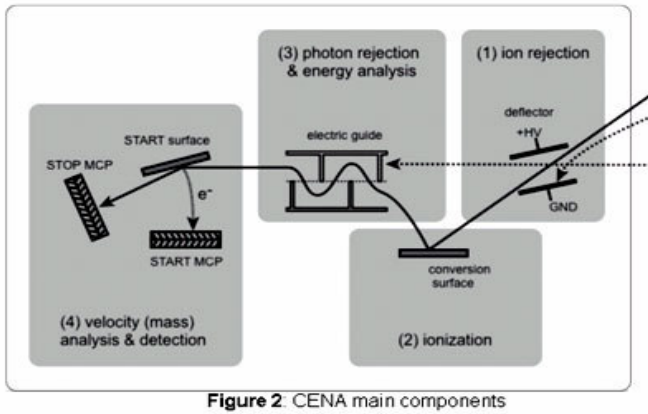


Figure 2: CENA main components

Prime objective :
To detect low energy neutral atoms (LENAs) produced by sputtering from lunar surface.

Specifications of the SARA CENA sensor

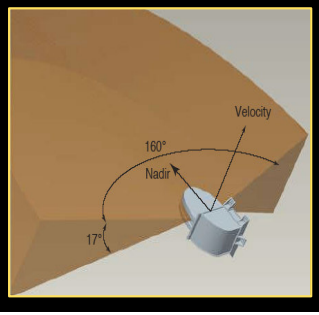
Parameter	Value
Energy range	10 eV- 3.3 keV
Energy resolution, ΔE/E	50 %
Mass resolution	H, O, Na-Mg-group, K-Ca group, Fe-group
Pure geometrical factor	10^{-2} cm^2 sr eV /eV sector
Total efficiency	~0.01-1 %
Angular resolution, FWHM	9° (elevation) × 25° (azimuth)
Field of view	17° × 160°
Mass	1.98 Kg

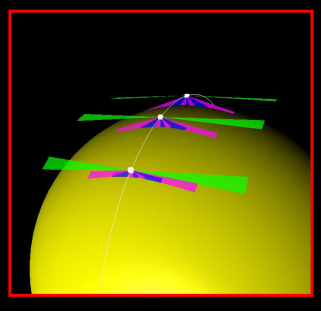
Consists of :

- charged-particle removal system
- A conversion surface
- Energy analysis system
- Time of flight analysis system.

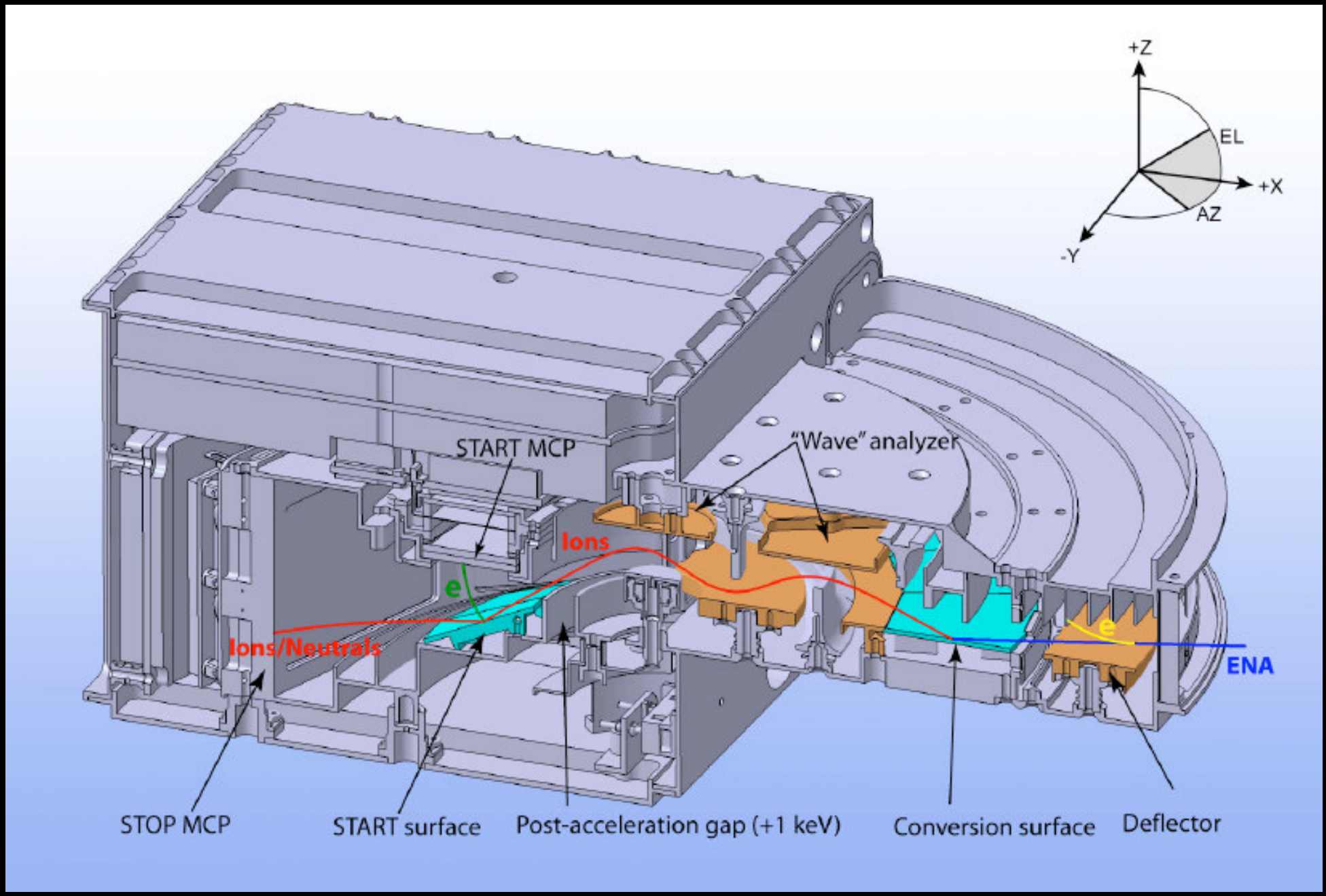
Data output:
Flux of neutral atoms in various energy bins, Mass bins and direction bins.

CENA Field of View



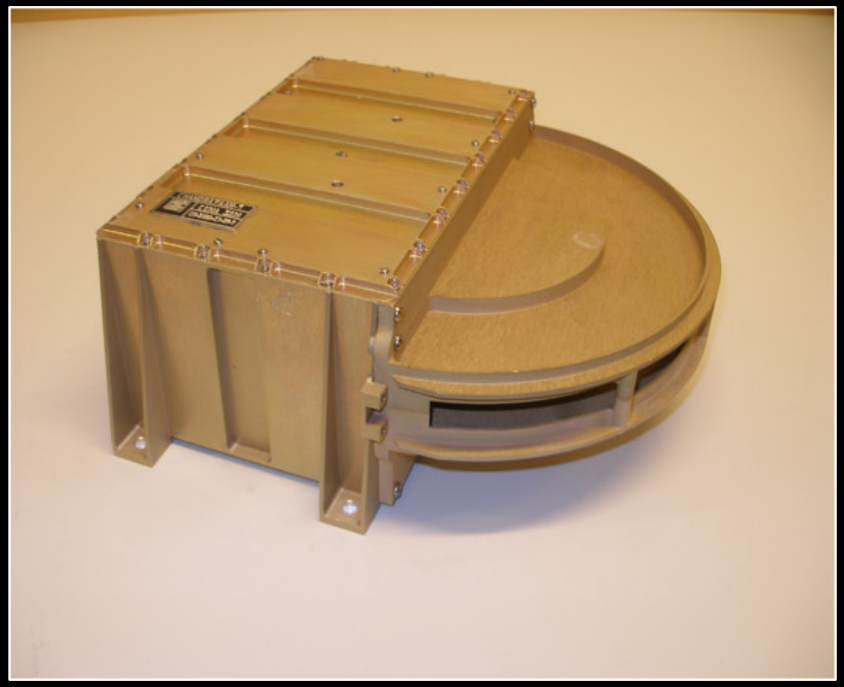


CENA principle

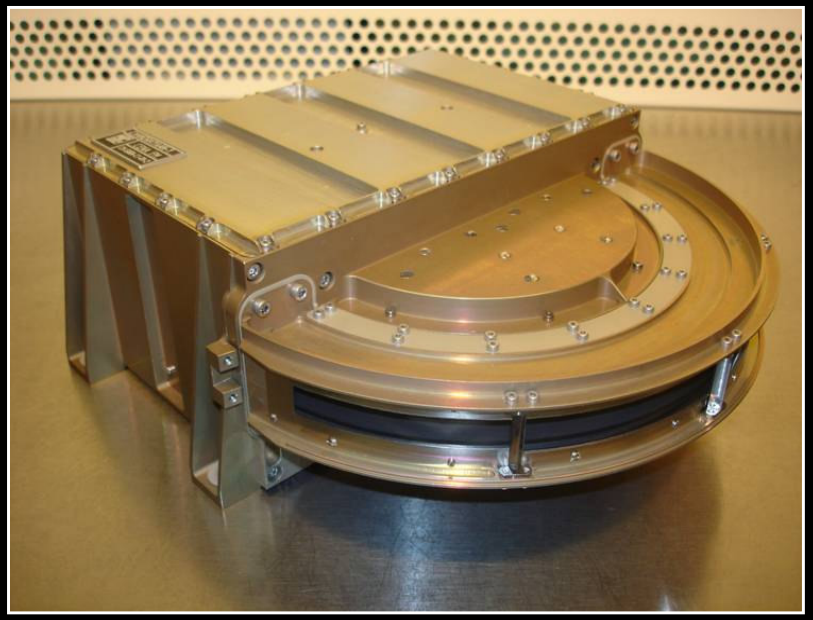


CENA models

CENA SEM

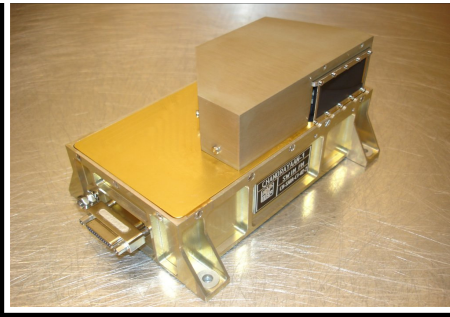


CENA TM

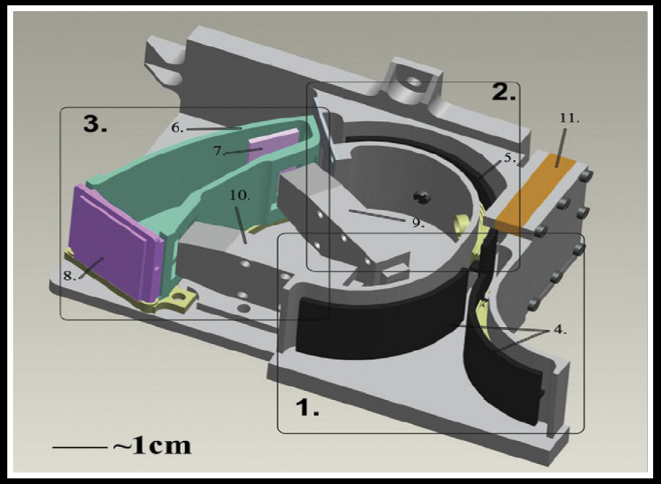


CENA FM

SWIM Sensor



Prime objective:To measure solar wind flux



~ Size of a Credit card !

3D view of the SWIM

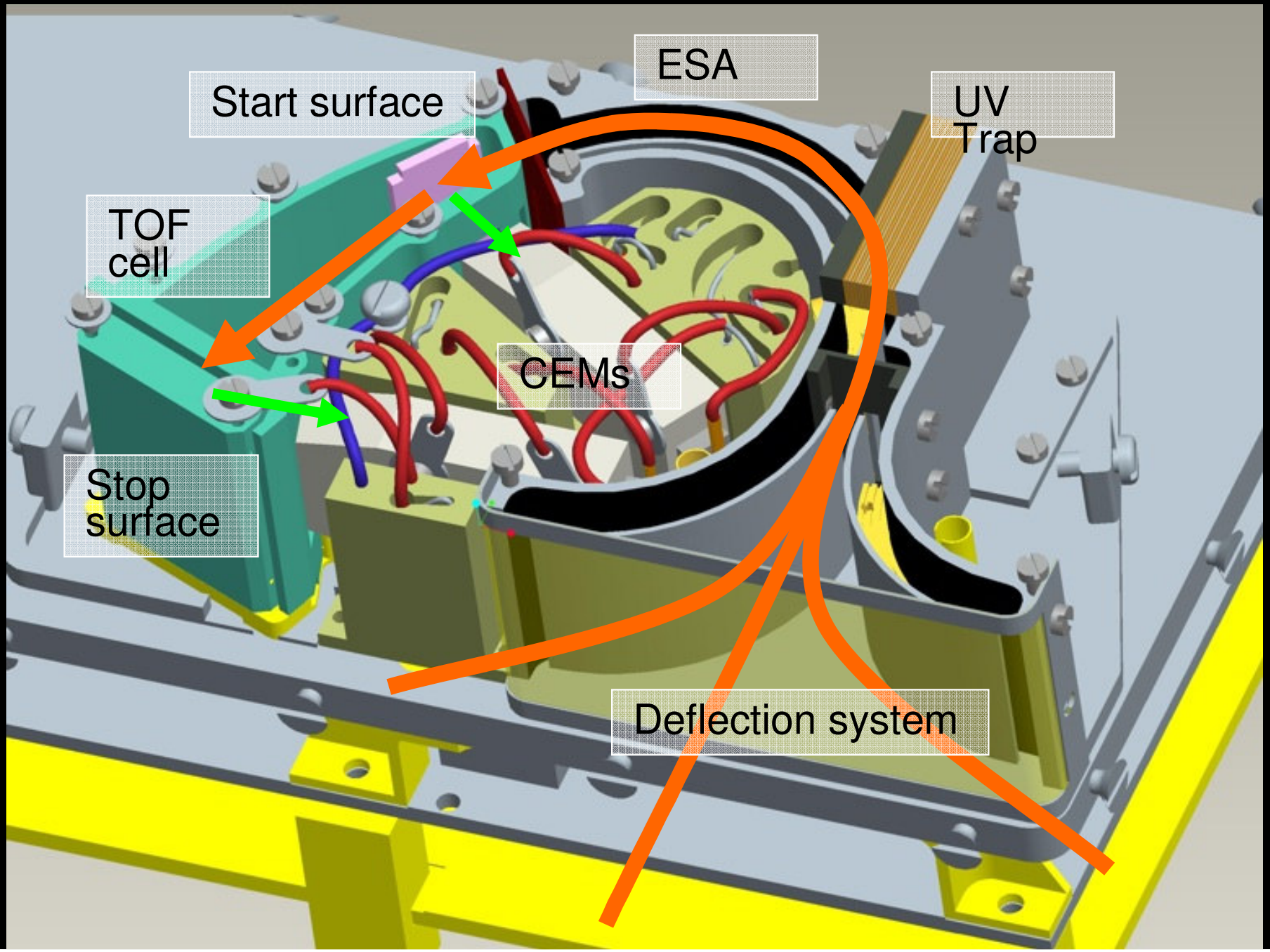
(1) The electrostatic deflector,
(2) The electrostatic analyzer and
(3) The time-of-flight system.

Specifications of the SARA SWIM sensor:

Parameter	Value
Energy range	10 eV- 15 keV
Energy resolution, ΔE/E	7 %
Viewing angle	9° × 180°
Angular resolution	9° × 22.5°
Mass resolution	6 mass groups;H+, He++, (He+, O++, O+, >20 amu)
Mass	0.452 gm

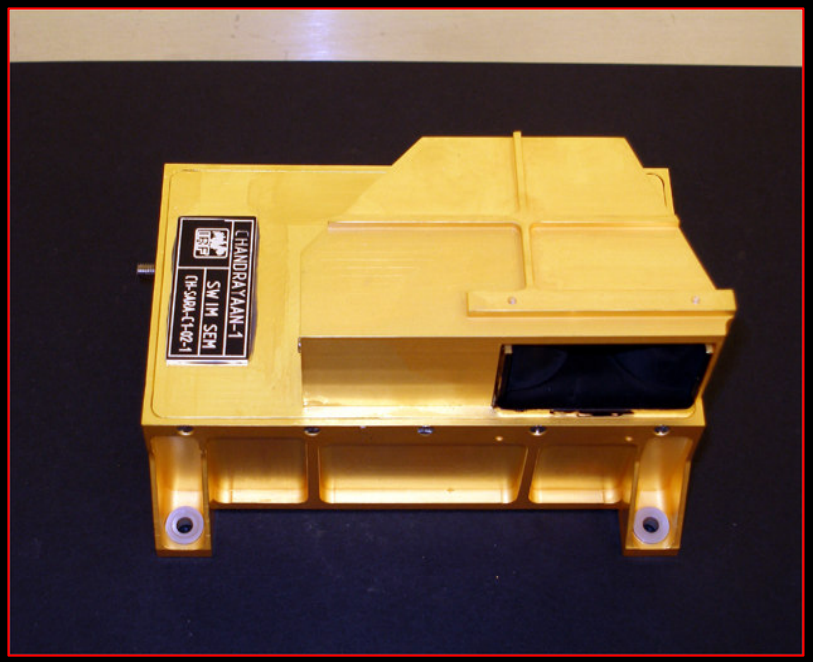
Data output:
Ion flux in various energy bins, Mass bins and deflection bins.

SWIM principle

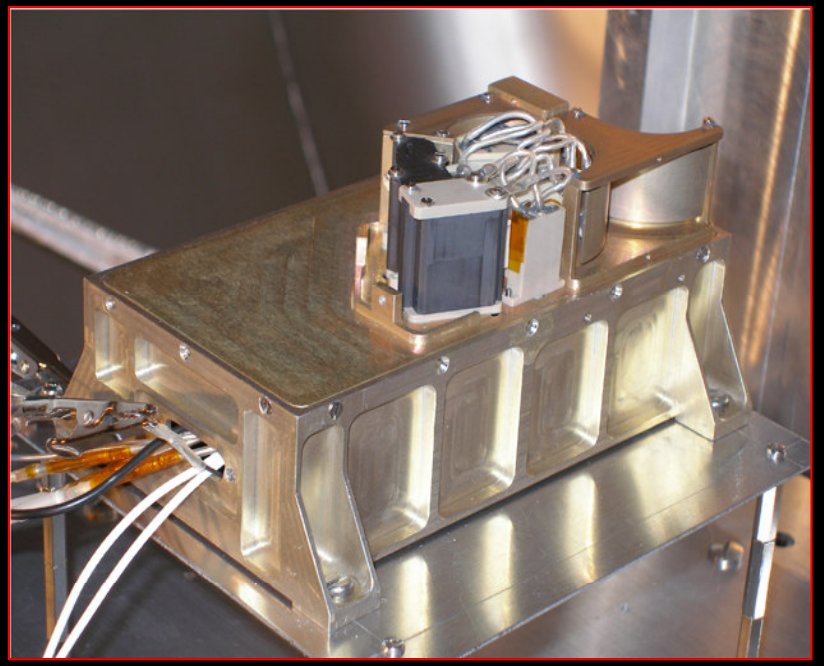


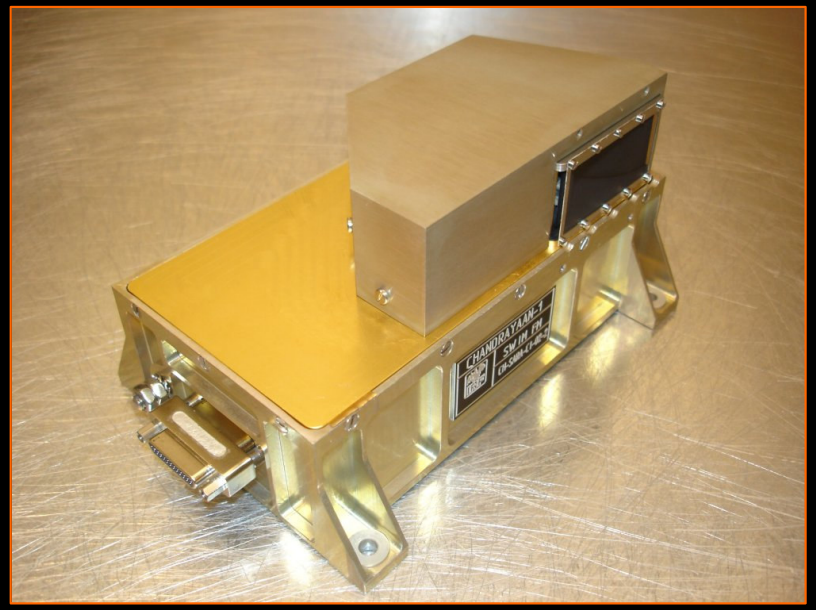
SWIM models

SWIM EM



SWIM TM





SWIM FM

Digital Processing Unit (DPU)

DPU FM

Contains :

Processing unit

Sensor interface unit

Power distribution unit

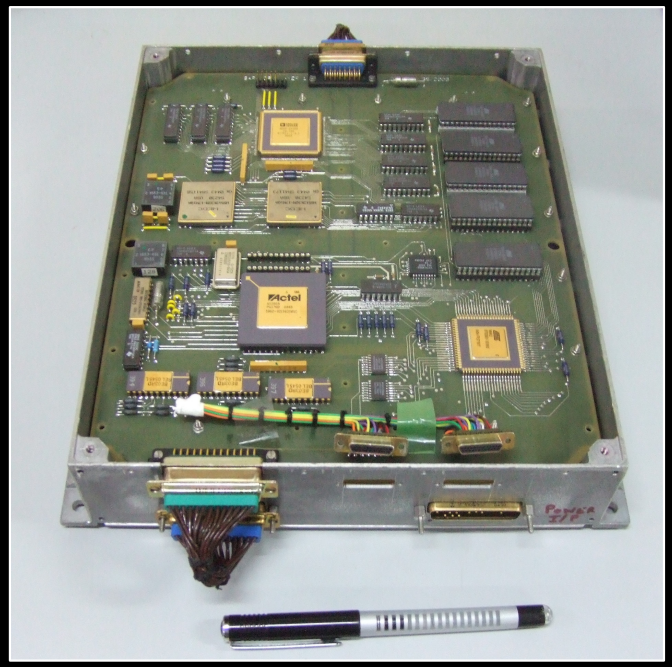
Spacecraft interface unit.

Data processing in the DPU

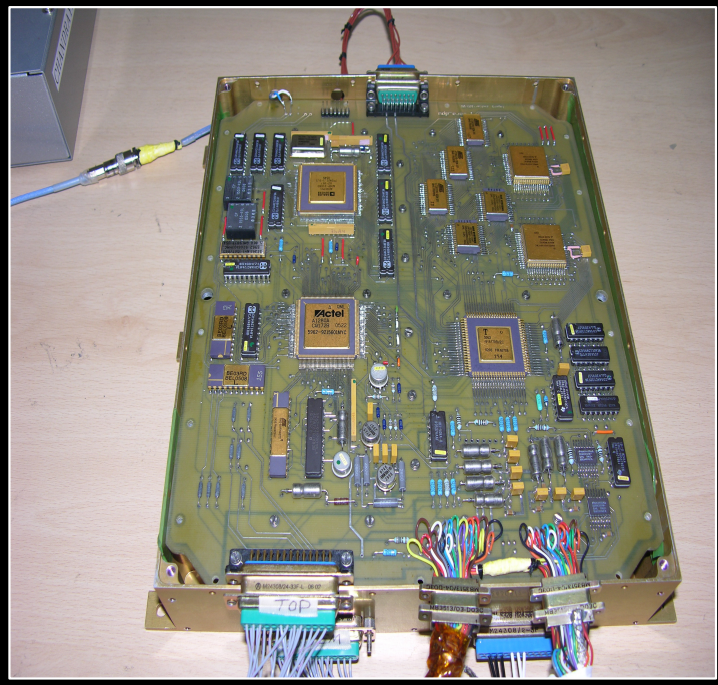
1. Acquire data from the two sensors simultaneously
2. Does the raw data processing including:
   time integration, binning, lossless compression, data formatting, storage, and transfer to telemetry as per TM requirements.

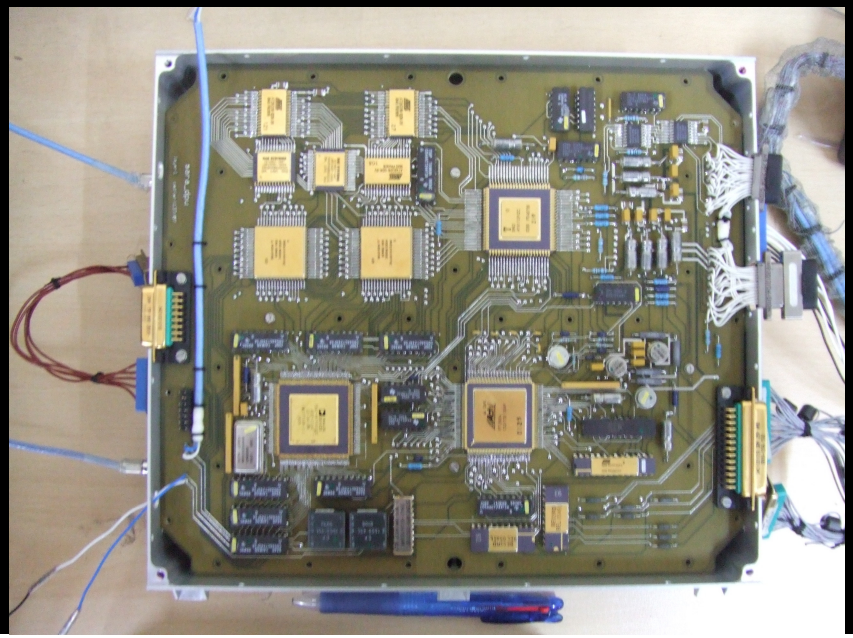
DPU Models

DPU EM



DPU QM



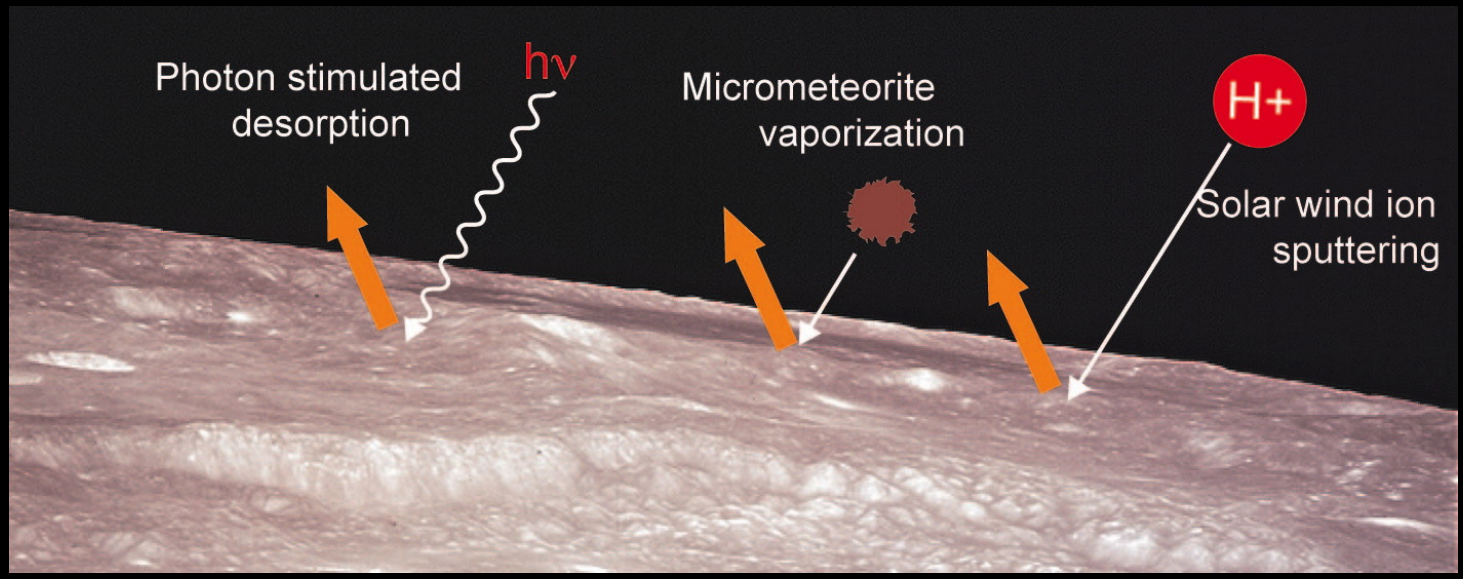


DPU FM

The Moon <u>does not</u> possess

- **Atmosphere (only a tenuous exosphere!)**
- **Magnetosphere (no global magnetic field)**

Therefore, ENA in the Moon environment can be produced by three main processes :



- **Micrometeorite impact vaporization**
- **Solar photon stimulated desorption (PSD) or "photon sputtering"**
- **Sputtering by precipitating solar wind ions**

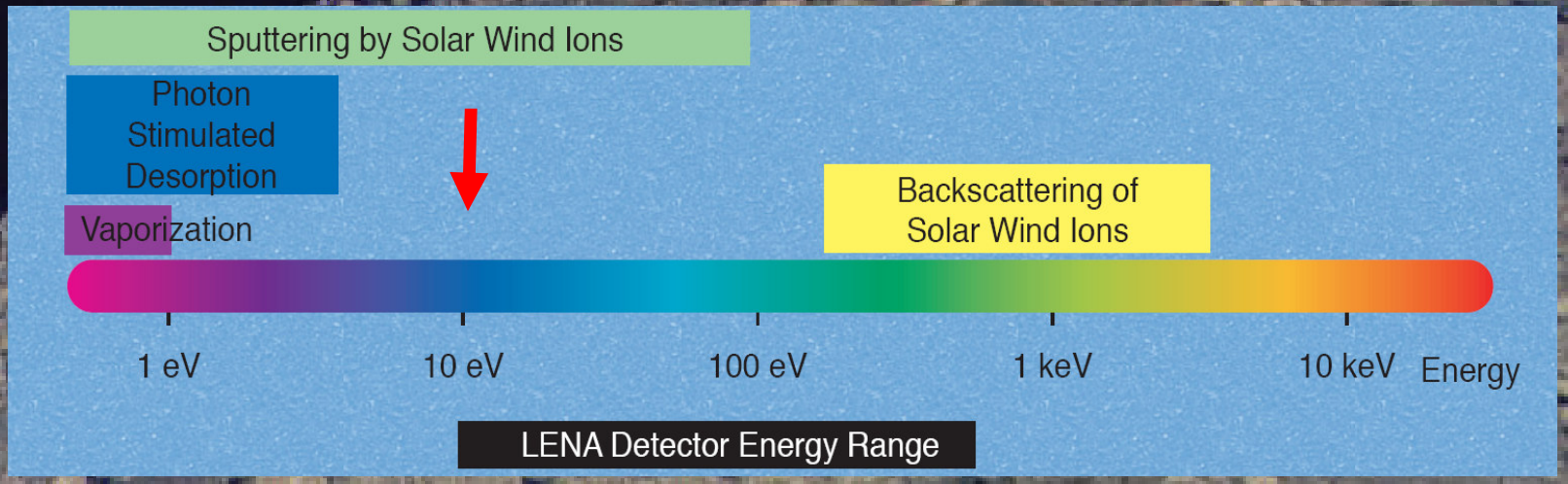
(1) The micrometeorite impact vaporization produces atoms with gas temperature of 2500-5000 K.

The LENAs produced thus will have energy too low [4000 K = 0.34 eV] to be detected by LENA instrument.

(2) The PSD produced atoms have an energy spectrum:

$f(E) \sim E^{-(b+1)}$, with b = 0.25 or 0.7

This process is important only around binding energy (2–4 eV) and up to ~10 eV.



Therefore, it is only the solar wind sputtering which can produce atoms with energies substantially higher than 10 eV.

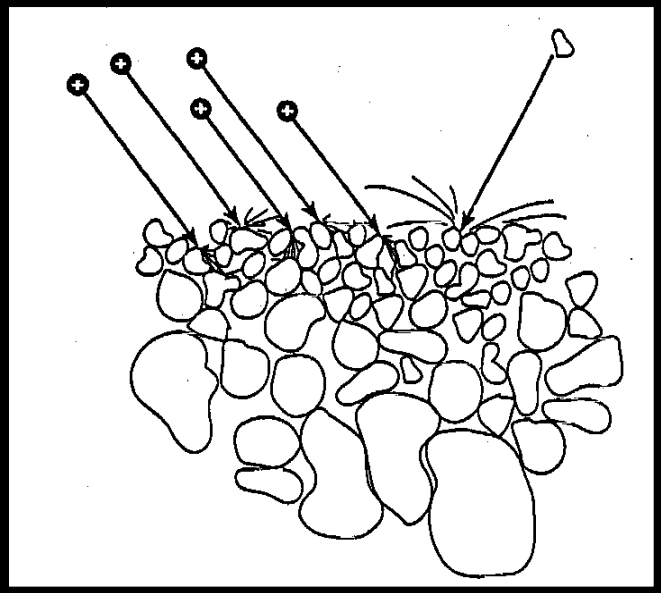
Sputtered atoms

- Angular distribution does not depend on the impinging ion flux angular distribution (statistically).
- Atoms are not affected by electromagnetic forces and gravitation ($E >> E_{escape}$ = 1.7 eV for Fe).
- Sputtered atoms: O, Na, Al, Si, K, Ca, Ti, Mn, Fe
- Atom sputtering conserves stoichiometry - an analytical tool in the lab.
- Thomson - Sigmund spectrum:

$$f \sim \frac{E}{(E+E_{bind})^3}\left(1-\sqrt{\frac{E+E_{bind}}{E_{cut-off}}}\right),$$

$$E_{cut-off} = 4\frac{E_{ion}(M_1+M_2)}{(M_1M_2)^2}$$

$$f \sim 1/E^2 \; for \; E >> E_{bind} \; and \; E << E_{cut-off}$$



(*Johnson and Baragiola, 1991*)

Precipitating particles

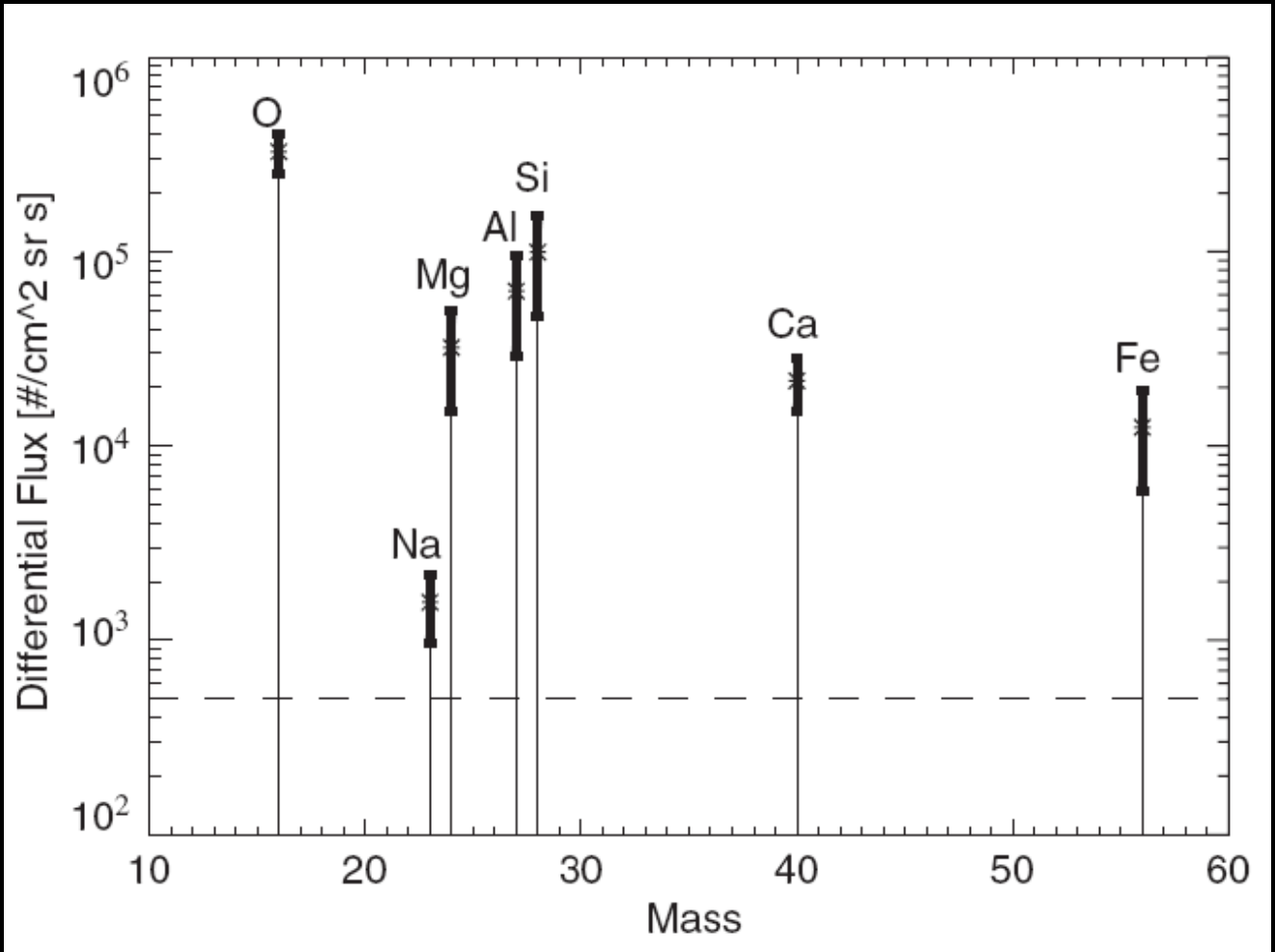
The Moon can be located either in the undisturbed solar wind or in Earth's magnetotail (lunar phase angles <30°). The parameters of plasma precipitating onto the lunar surface were measured by plasma detectors placed on the Moon surface during Apollo mission.

Plasma populations which can reach the Moon surface.

Population	Flux, cm^{-2} s^{-1}	Density, cm^{-3}	Energy, keV
Solar wind	2.8×10^8	8.7	1
Plasma sheet	10^6	0.5 – 0.8	0.25 – 3.5
Lobe-plasma (mantle)	10^5 – 4×10^7	0.2 – 2	0.02 – 0.25

The sputtered flux is proportional to the precipitating particle flux and the yield. The higher the precipitating particle energy, the higher is the yield in the energy range (a few keV) in question. Yet, the function is weaker than linear. The efficiency of the solar wind sputtering is obviously higher that then the lobe plasma. It is also higher than the efficiency of the plasma sheet population because of a much higher (300 times) flux.

Therefore, we conclude that the dominant sputtering population is the solar wind.



Expected differential flux for each elements with energies larger than 10 eV.

The dashed line at 500 per [cm2 sr s] corresponds to the one-count level of the LENA imager.

[Futaana et al. 2006, PSS]

Fluxes given in Figure above can be summarized as:

The fluxes of the sputtered LENAs in the energy range 10 – 100 eV

O:	**2-4 x 10^5 cm^{-2} sr^{-1} s^{-1}**
Ca, Si, Al, Mg:	**0.1-1 x 10^5 cm^{-2} sr^{-1} s^{-1}**
Fe, Na:	**0.1-2 x 10^4 cm^{-2} sr^{-1} s^{-1}**

The LENAs to be detected have energies $E_{min} \geq 10$ eV

E_{min} >> escape E for elements on the Moon (1.7 eV for Fe)
LENAs thus propagate straight unaffected by gravity.

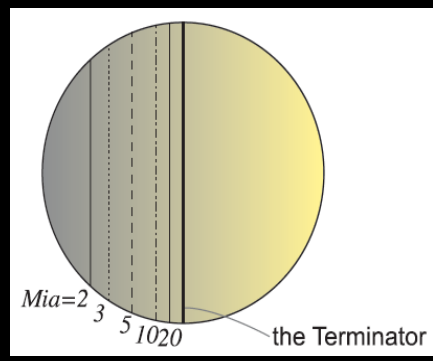
Potassium has the shortest photoionization time (7.5×10^4 s) of the elements in question.

The corresponding length for 10 eV will be 5×10^5 km, which is much longer than the typical Lunar orbiter's height of 100-200 km.

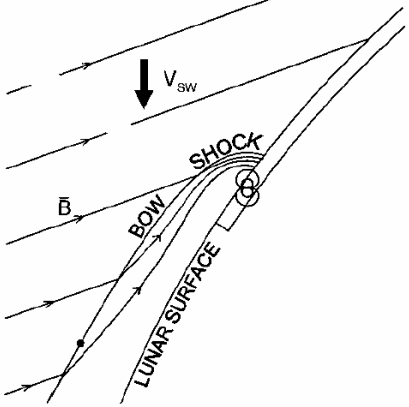
Therefore, LENA can be used for imaging the Moon environment.

Scientific Objectives of SARA

- Imaging of the Moon's surface composition including imaging of temporarily and permanently shadowed areas and search for volatile rich areas



- Imaging of the surface magnetic anomalies: "mini-magnetospheres"
- Studies of space weathering
- Imaging of the sputtered sources of the exospheric gases and comparative studies of the exospheric gas production at the Moon and Mercury



Schematic of the solar wind interaction with a crustal magnetic field near the edge of the Imbrium antipodal zone.

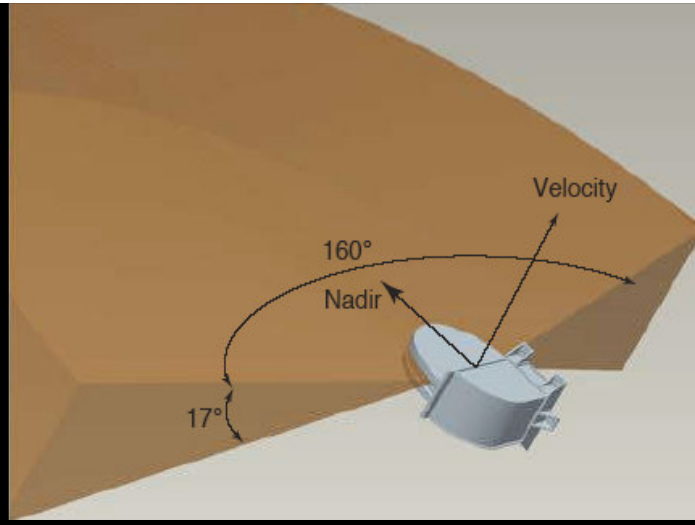
How will SARA help study Sun: SWIM

SWIM will provide the solar wind composition, energy distribution, and flux around the Earth at 60 RE.

The moon's orbit provides a unique location to observe solar wind continuously over 27 days period around the Earth, over a 2 year period of the Chandrayaan-1 nominal mission life time.

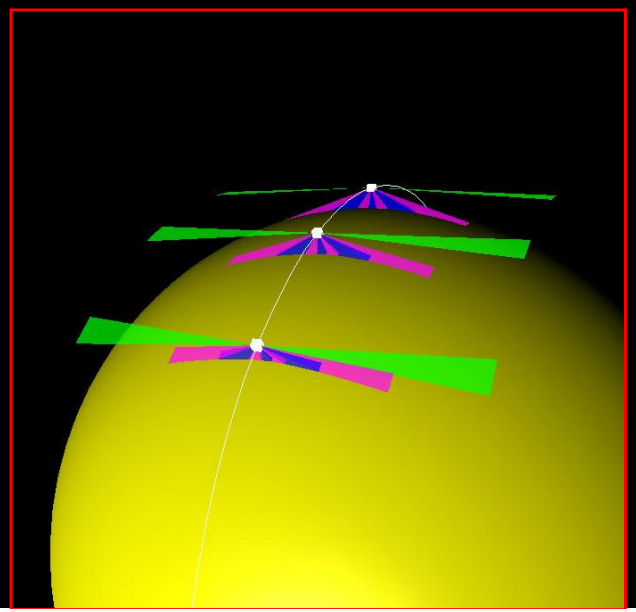
With solar wind measurements being made at L1 point (240 Re; Re = Earth's radius) and at distance close to the Earth (6-10 RE) by Space Weather satellites, the SWIM will not only help to study lunar-solar wind interactions, but will also be of great importance to study changes in solar wind as it propagate from L1 point to Moon's orbit (60 Re) to Geostationary orbits.

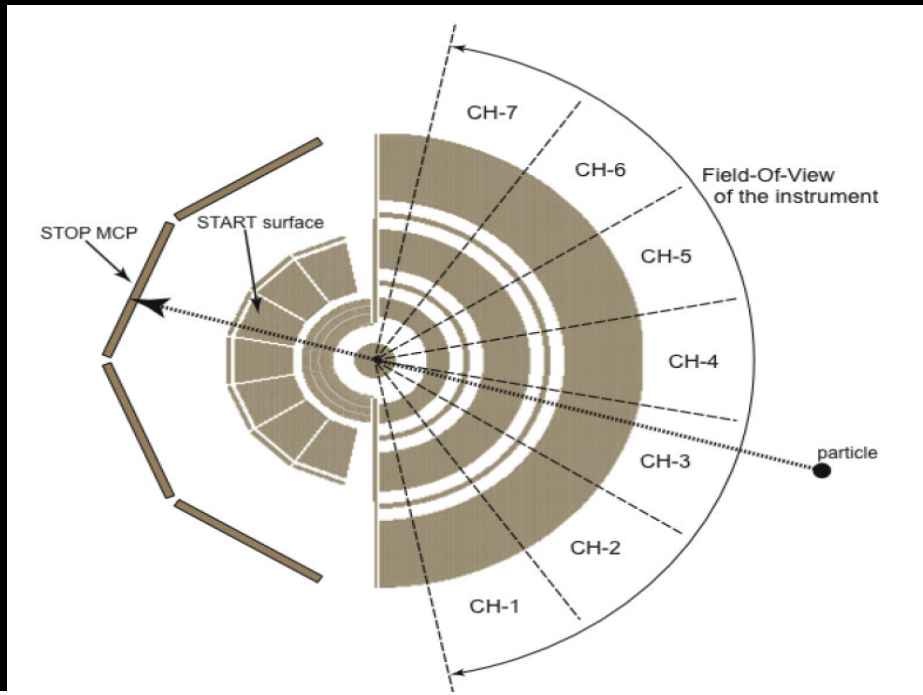
How will SARA help study Sun: CENA



CENA field of view is 160 deg, which is beyond the 141 deg for projection at 100 km from lunar surface.

So, CENA the will be able to observe heliospheric ENA's through Ch-1 and Ch-7.





Because of monthly variations (Moon orbital period 27.3d) and seasonal variations (Earth orbital period, 365 days) there will be certain configurations that would provide very important observations configurations. These are summed up in Table 2.4.2. During these periods SARA would operate continuously over all orbits .

Table 2.4.2 Specific orbital configurations

Configuration	Time period	Objectives
Moon in the Earth magnetosphere	Every Moon month for 5 days	Search for non-solar wind sputtering
Near - terminator orbits (±20°) (short / no eclise)	41d per one year	SWIM provides the best temporal coverage of the solar wind.
Solar eclipses	30 min during eclipses 21 Feb. 2008 03:26 UT (100%) 16 Aug.2008 21:00 UT (80%) 31 De. 2009 19:23 UT (54%) 26 Jan. 2010 08:17 UT (26 %)	Studies of the sputtering by magnetospheric ions Join CH-1 ground-based observations of the exopshere.

For more info Google ⇒

"Anil Bhardwaj + SARA"

THANKS !!

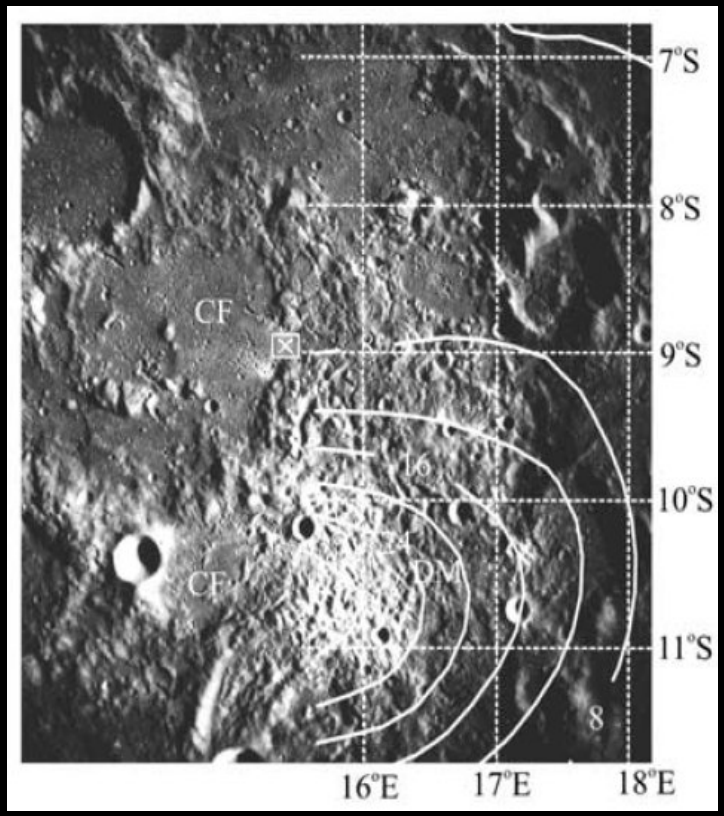
Contact

Anil_Bhardwaj@vssc.gov.in

Inform inspire innovate

Space Weathering

- **Space weathering: changing albedo (visible, IR) under space environment effects, e.g., particle and photon flux, micrometer bombardment**

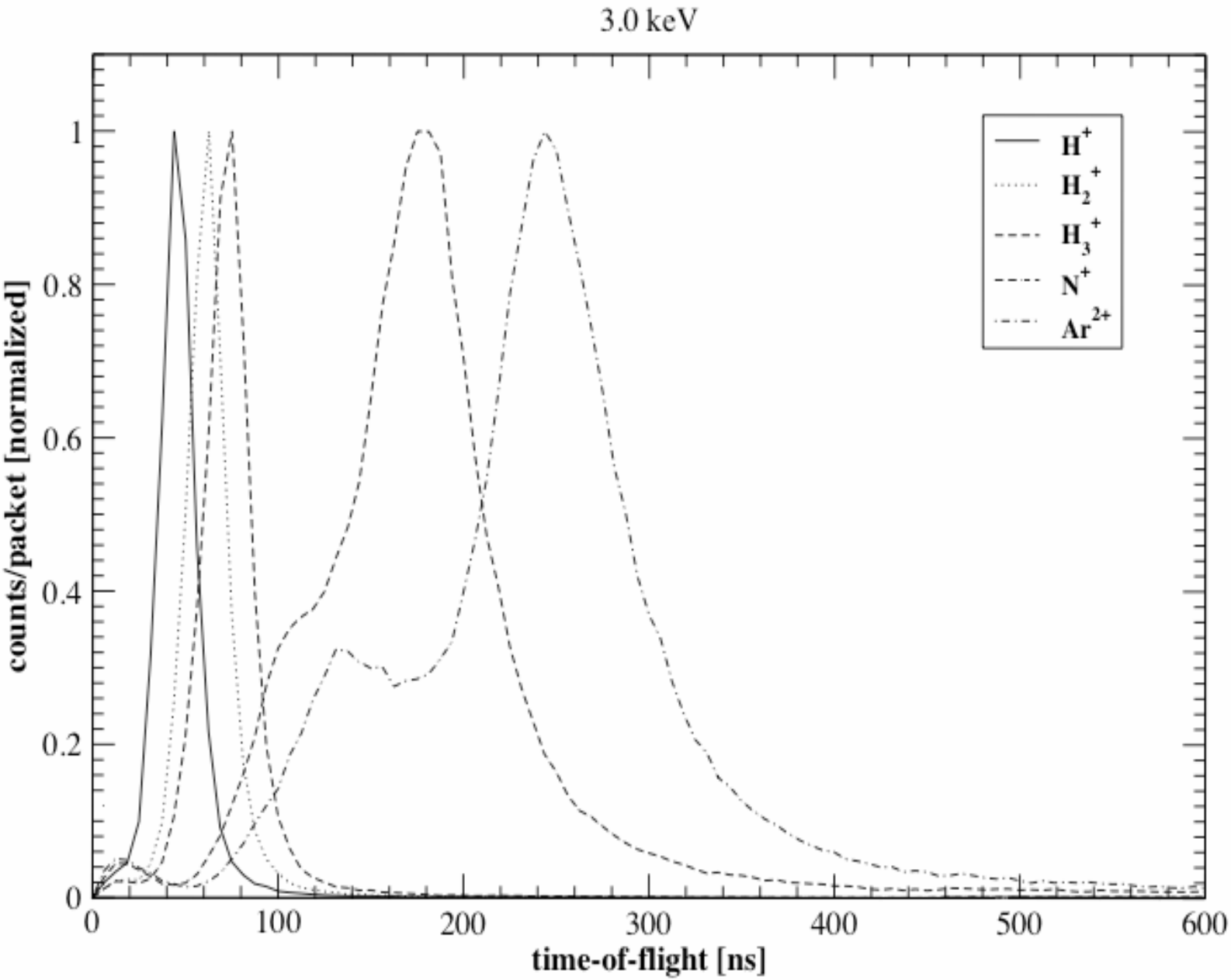


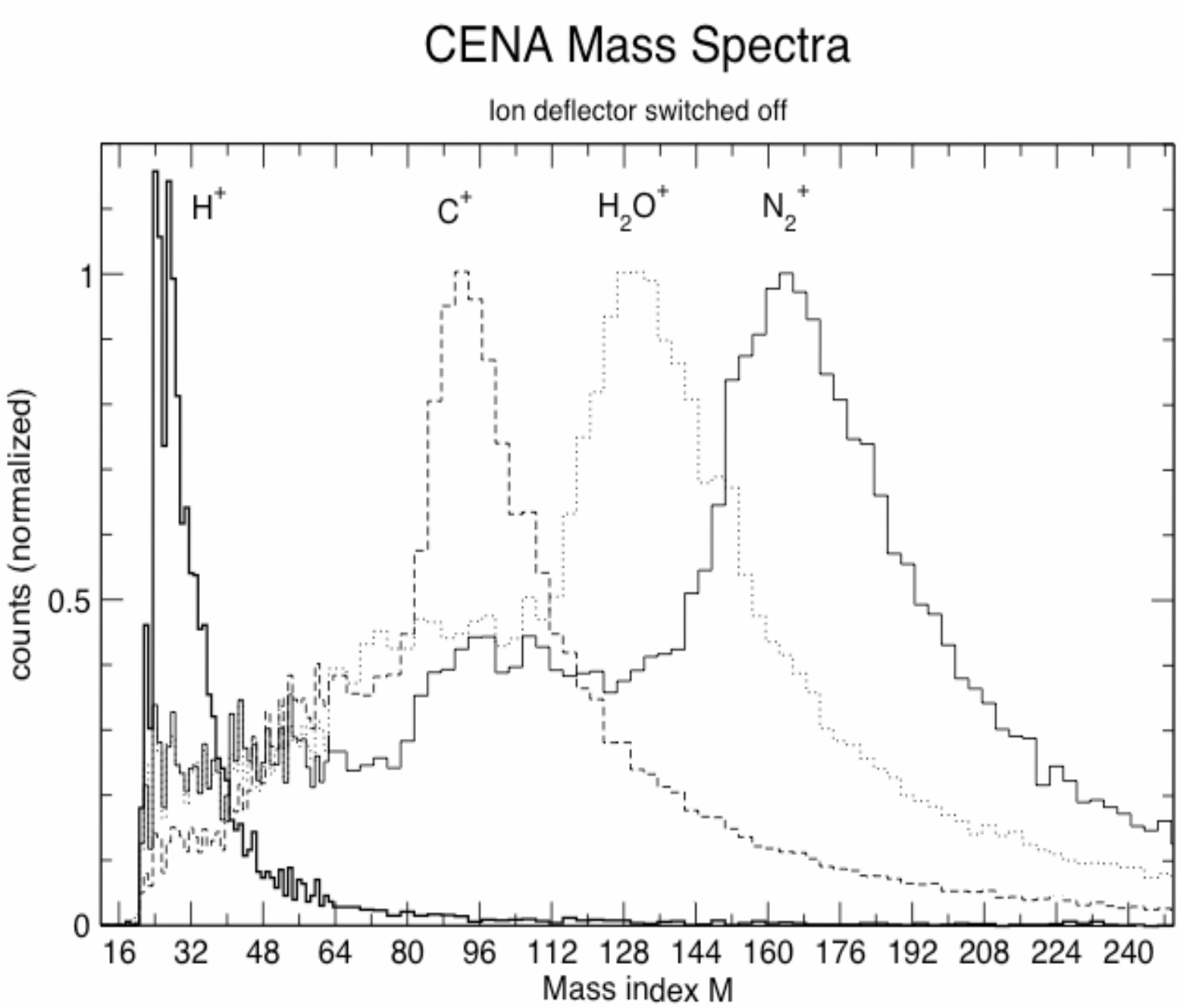
Richmond et al. 2003, GRL

Magnetic field contour map of the Imbrium antipode overlaying a geologic map of the area. The contour interval is 2 nT, starting at 4 nT. The high-albedo regions of Mare Ingenii are outlined in red.

[Richmond et al. 2005, JGR]

SWIM FM time-of-flight data

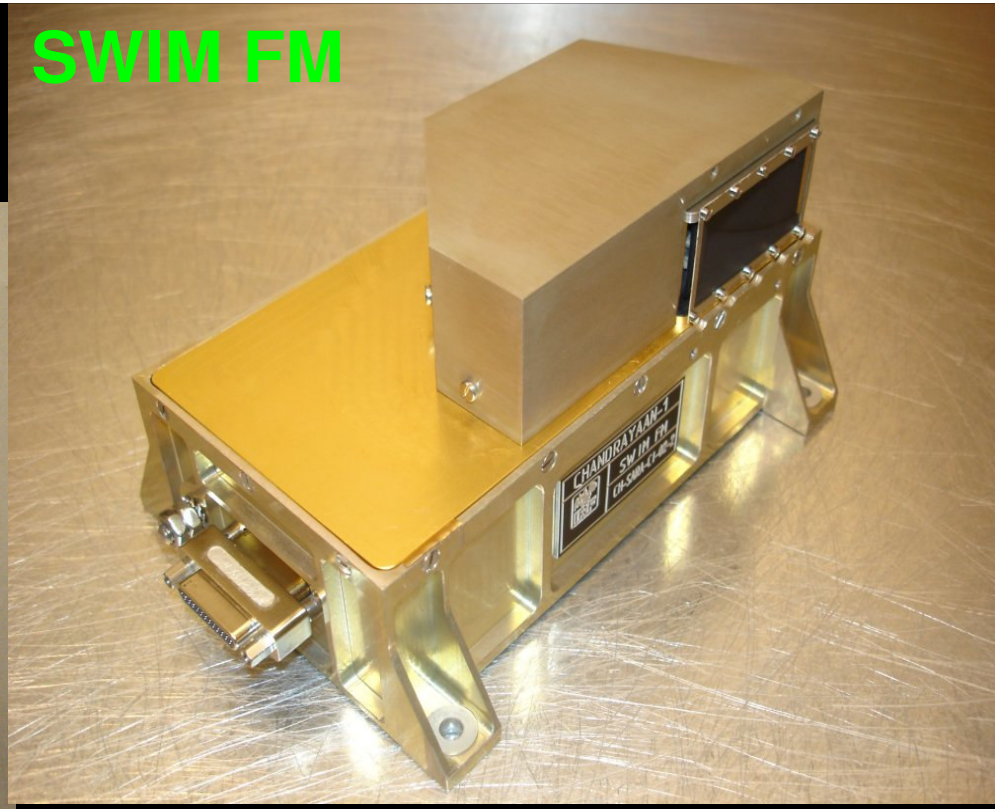


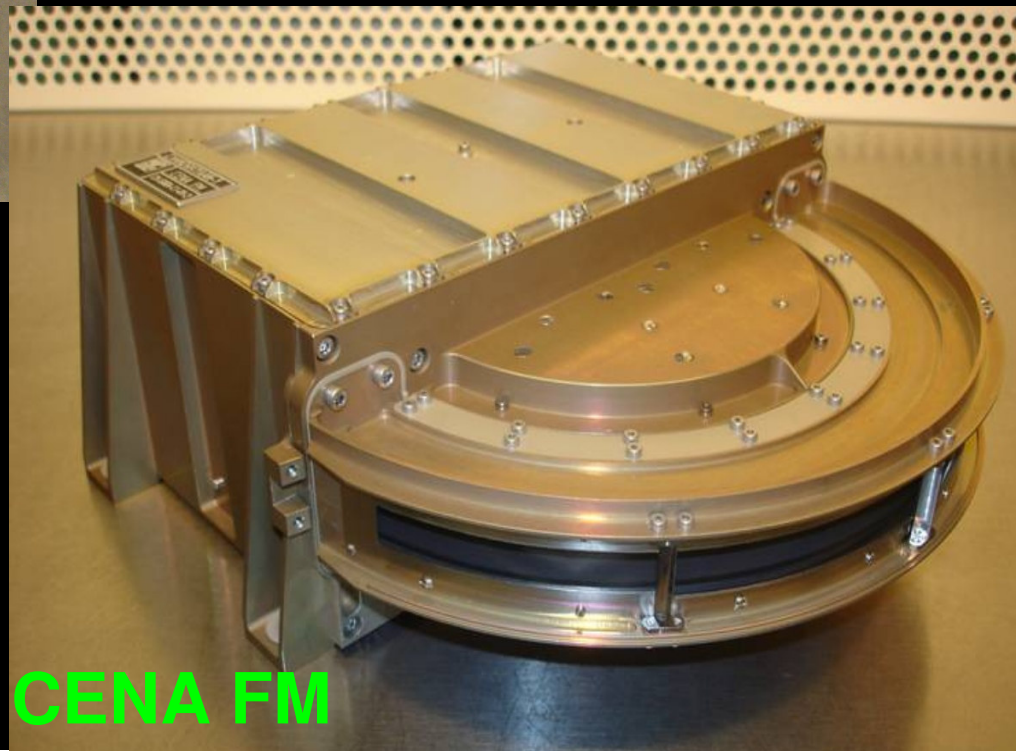


Fri Feb 15 14:00:14 2008

DPU FM

SWIM FM





CENA FM