# *Venus Express Legacy Session*
# ASPERA-4

***Sensors, science, operation, analysis, tools, and archive***

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# ASPERA-4 team

- Principal Investigator (Swedish Institute of Space Physics, Kiruna)
  - Yoshifumi Futaana (2014–)
  - Stas Barabash (–2013)
- Co-Investigators from 17 groups in 12 countries

| | |
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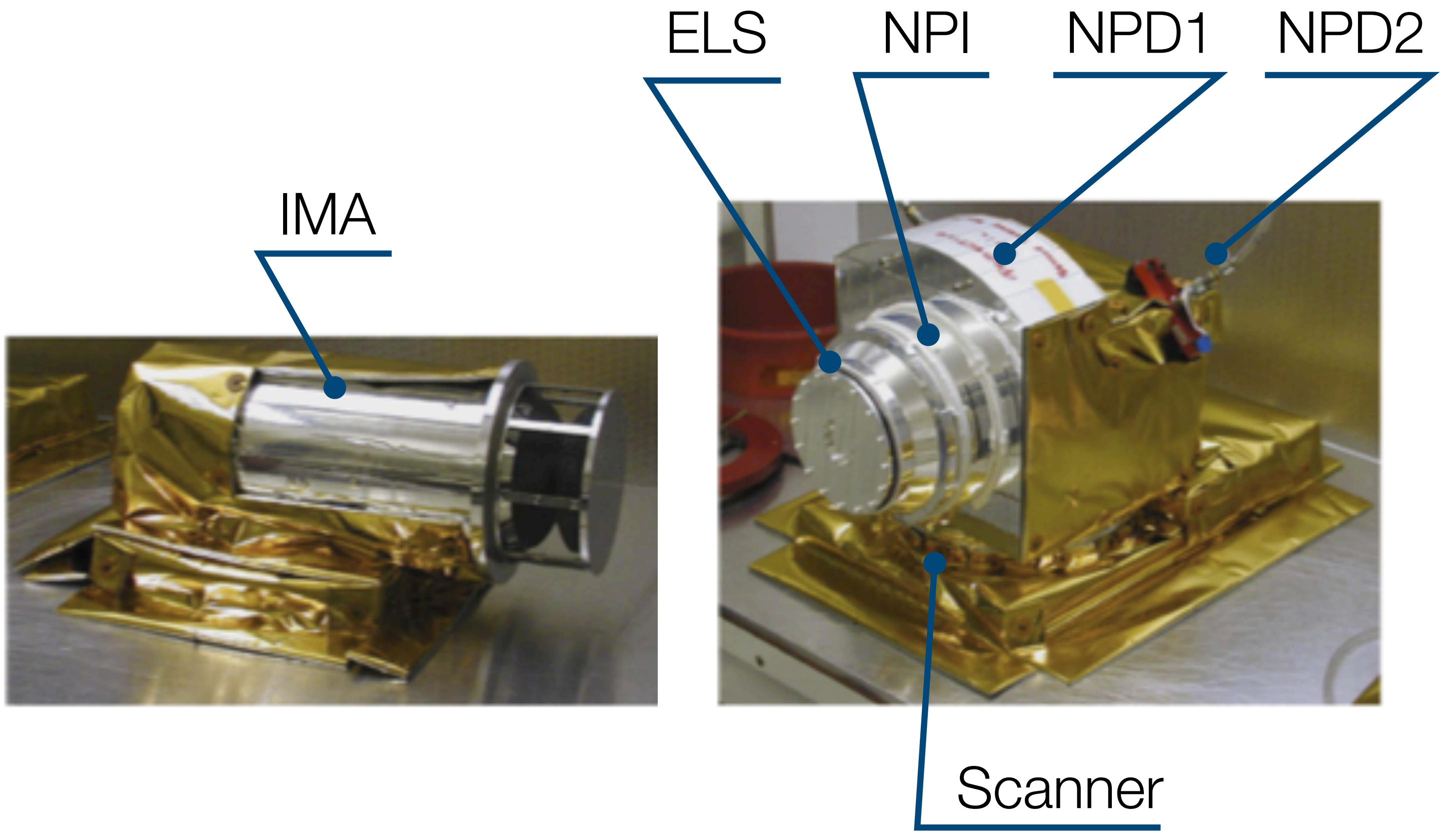
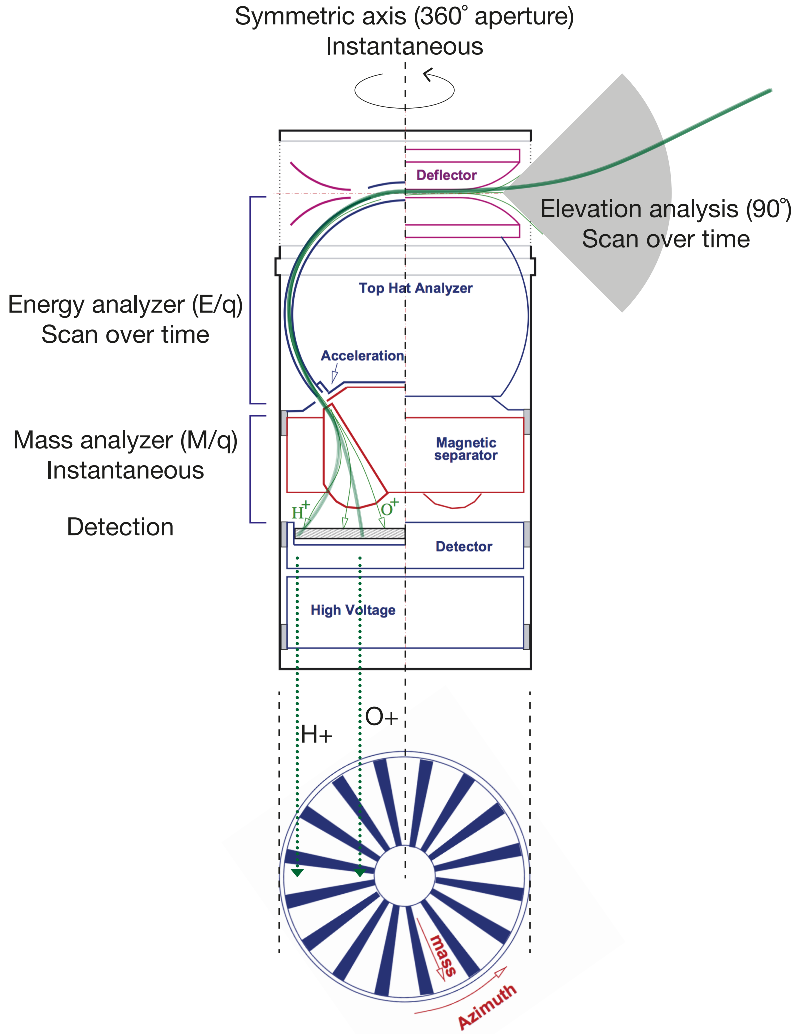
# ASPERA-4 instrument

$$\text{ASPERA-4} = \text{IMA} + \frac{\text{ELS} + \text{NPI} + \text{NPD} \times 2}{\text{Scanner}}$$



# IMA: Ion Mass Analyzer

$$\text{ASPERA-4} = \boxed{\text{IMA}} + \frac{\text{ELS} + \text{NPI} + \text{NPD} \times 2}{\text{Scanner}}$$



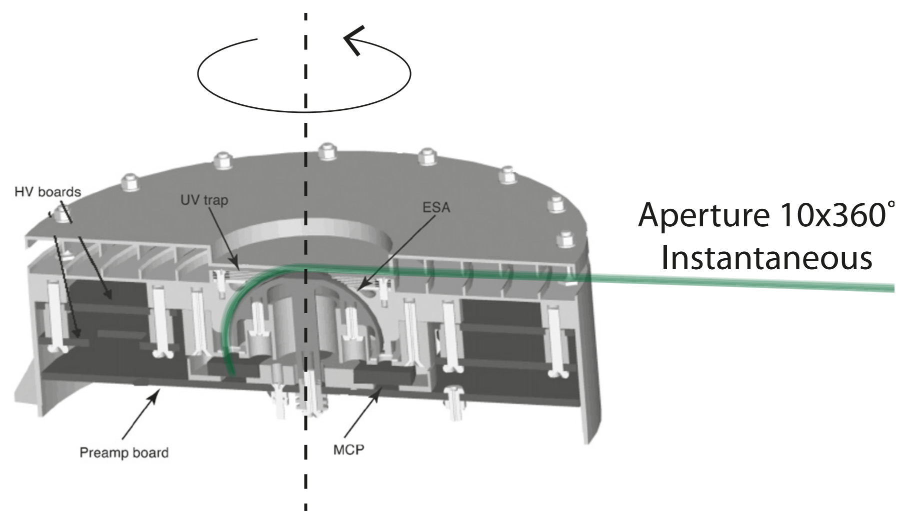

| Parameter | IMA |
|---|---|
| Particles to be measured | Ions |
| Energy, keV per charge | 0.01–36 |
| Energy resolution, $\Delta E/E$ | 0.07 |
| Mass resolution | $m/q = 1, 2, 4, 8, 16, 32, >40$ |
| Intrinsic field of view | $90^\circ \times 360^\circ$ |
| Angular resolution, FWHM | $4.5^\circ \times 22.5^\circ$ |
| G-factor/pixel, cm$^2$ sr | $3.5 \times 10^{-4}$ |
| Efficiency, % | Incl. in G-factor |
| Time resolution (full 3D), s | 196 |
| Mass, kg | 2.4 |

# ELS: Electron Spectrometer

$$\text{ASPERA-4} = \text{IMA} + \frac{\boxed{\text{ELS}} + \text{NPI} + \text{NPD} \times 2}{\text{Scanner}}$$

| Parameter | ELS |
|---|---|
| Particles to be measured | Electrons |
| Energy, keV per charge | 0.01–15 |
| Energy resolution, $\Delta E/E$ | 0.07 |
| Mass resolution | – |
| Intrinsic field of view | $10^\circ \times 360^\circ$ |
| Angular resolution, FWHM | $10^\circ \times 22.5^\circ$ |
| G-factor/pixel, $cm^2$ sr | $7 \times 10^{-5}$ |
| Efficiency, % | Incl. in G-factor |
| Time resolution (full 3D), s | 32 |
| Mass, kg | 0.3 |

Symmetric axis (360° aperture)
Instantaneous



# NPI: Neutral Particle Imager

$$\text{ASPERA-4} = \text{IMA} + \frac{\text{ELS} + \boxed{\text{NPI}} + \text{NPD} \times 2}{\text{Scanner}}$$

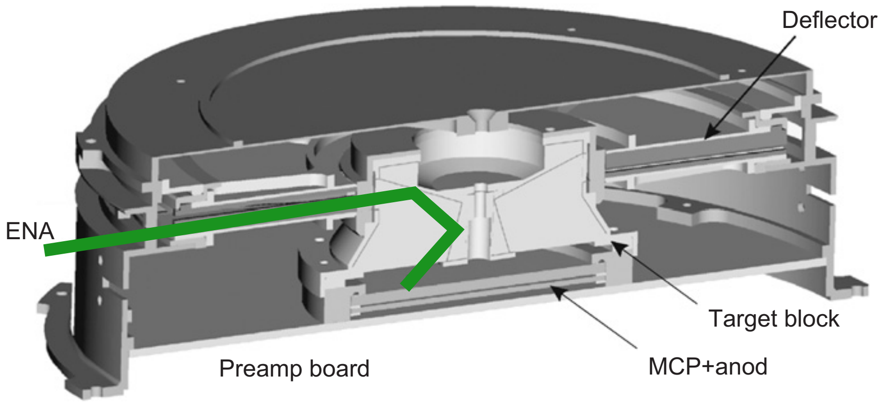


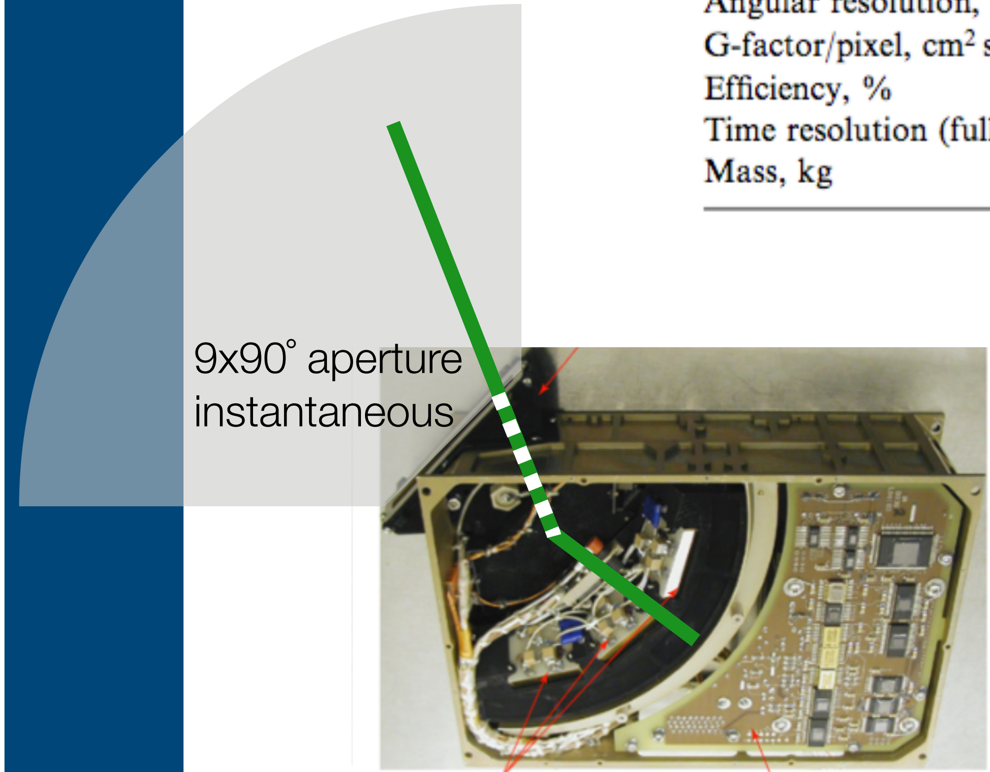

Fig. 2. Cut-away view of the NPI sensor.

| Parameter | NPI |
|---|---|
| Particles to be measured | ENA |
| Energy, keV per charge | ≈ 0.1–60 |
| Energy resolution, $\Delta E/E$ | – |
| Mass resolution | – |
| Intrinsic field of view | $9^\circ \times 344^\circ$ |
| Angular resolution, FWHM | $4.6^\circ \times 11.5^\circ$ |
| G-factor/pixel, $cm^2$ sr | $2.7 \times 10^{-3}$ |
| Efficiency, % | ≈ 1 |
| Time resolution (full 3D), s | 32 |
| Mass, kg | 0.7 |

# NPD: Neutral Particle Detector

$$\text{ASPERA-4} = \text{IMA} + \frac{\text{ELS} + \text{NPI} + \boxed{\text{NPD}} \times 2}{\text{Scanner}}$$

| Parameter | NPD |
|---|---|
| Particles to be measured | ENA |
| Energy, keV per charge | 0.1–10 |
| Energy resolution, $\Delta E/E$ | 0.8 |
| Mass resolution | H, O |
| Intrinsic field of view | 9° × 180° |
| Angular resolution, FWHM | 5° × 30° |
| G-factor/pixel, cm$^2$ sr | $6.2 \times 10^{-3}$ |
| Efficiency, % | 0.5–15 |
| Time resolution (full 3D), s | 32 |
| Mass, kg | 0.65 each |



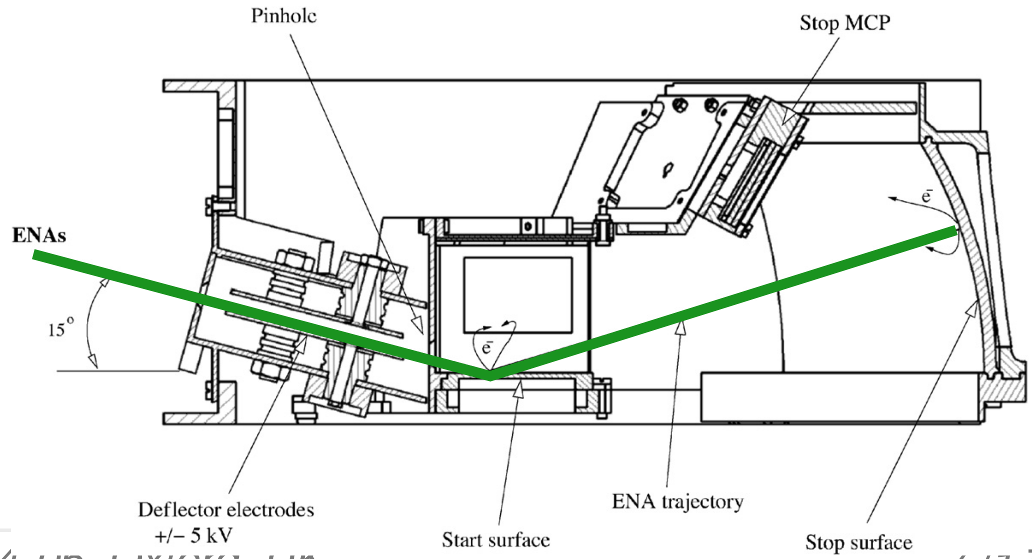
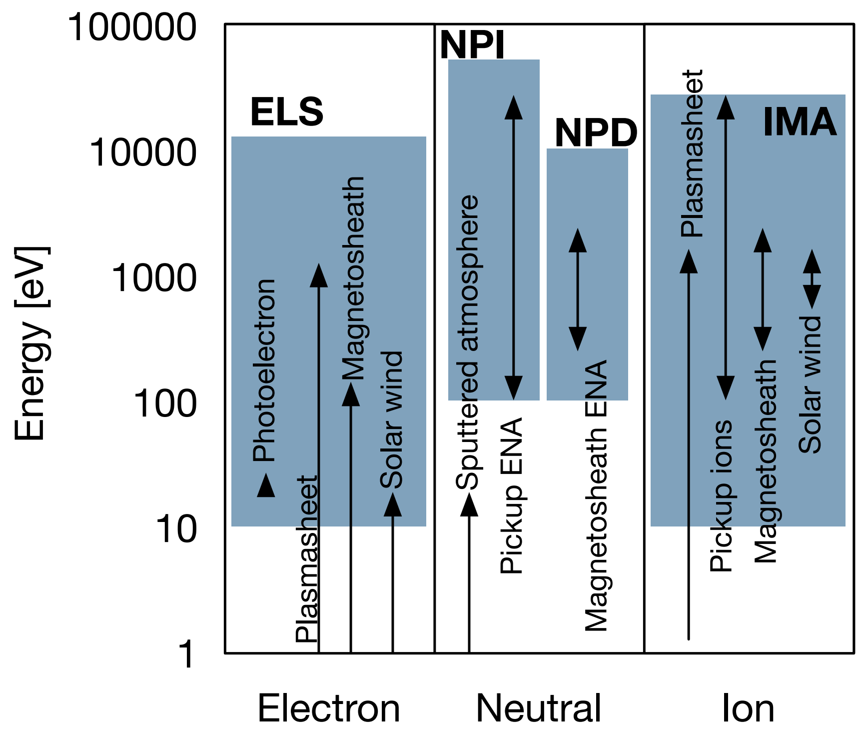




Fig. 11. Cross-view of the NPD sensor.

# Energy & charge state

$$\text{ASPERA-4} = \text{IMA} + \frac{\text{ELS} + \text{NPI} + \text{NPD} \times 2}{\text{Scanner}}$$

Using four sensors, ASPERA-4 measures Venus plasma environment and plasma-atmosphere interaction near Venus



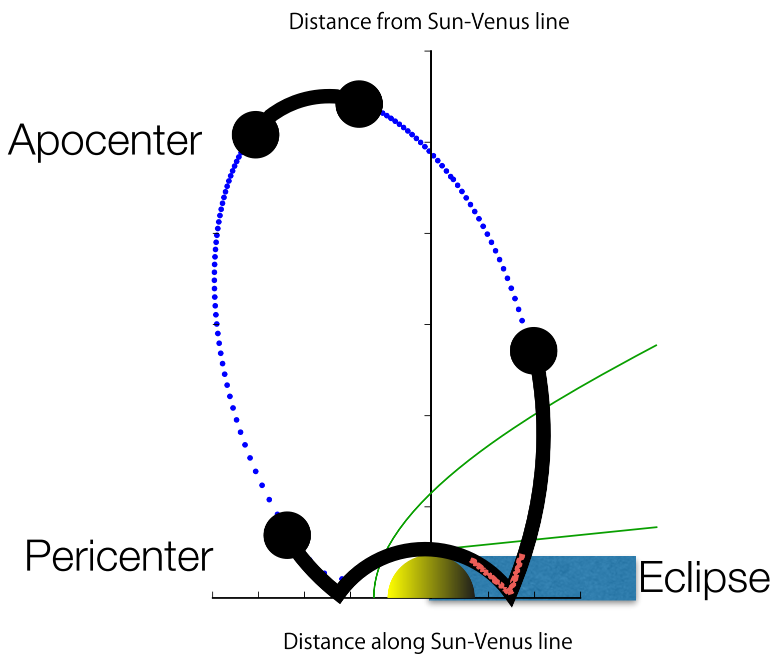
# Scientific objectives

- Venus has **no intrinsic magnetic field**. Atmosphere interacts with solar wind directly.
  - Different from Earth. Rather similar to Mars.
- Scientific goals
  - Atmosphere coupling with the solar wind
  - Mass addition/removal from the atmosphere
  - Structure of the induced magnetosphere
  - Mass composition of the escaping plasma
  - Loss of water
  - Neutral–plasma interaction
  - Comparative planetology (Earth, Mars)
  - Long-term variabilities (solar-cycle dependence)
  - **Lower ionosphere characterization & dynamics (aerobraking)**
- Most of the above had been / are going to be addressed.
- New ideas of data analysis is welcome.

# Operations

| | | IMA | ELS | NPI | NPD | scan | Observation time | Notes |
|---|---|---|---|---|---|---|---|---|
| Regular | **Pericenter** | ✓ | ✓ | ✓ 1) | ✓ 2),3) | Fix | 3–6 hr near pericenter | ±1-2 hr outside BS |
| | **Eclipse** | ✓ | ✓ | ✓ | ✓ | Fix or Scan | In shadow | Limited scanner operation |
| | **Apocenter** | ✓ | ✓ | ✓ 1) | ✓ 2) | Fix | 1–2 hr near apocenter | Avoid WOL |
| Special | **Calibration** | | | | | | On demand | - ELS degradation check<br>- Functionality improvement |
| | **Special ops** | | | | | | On demand | - Solar wind continuous<br>- Aerobraking |

1) NPI OFF: Sun–FOV angle < 30˚
2) NPD OFF: Sun-FOV angle < 60˚
3) NPD OFF: Venus-FOV angle < 5˚



# Data products (General)

- Most valuable data is "counts".
  - Number of particles (ion, electron & ENAs) arriving at the detector
- Counts is proportional to the differential flux (*j*)
  - Number of particles with specific mass, energy and direction ranges

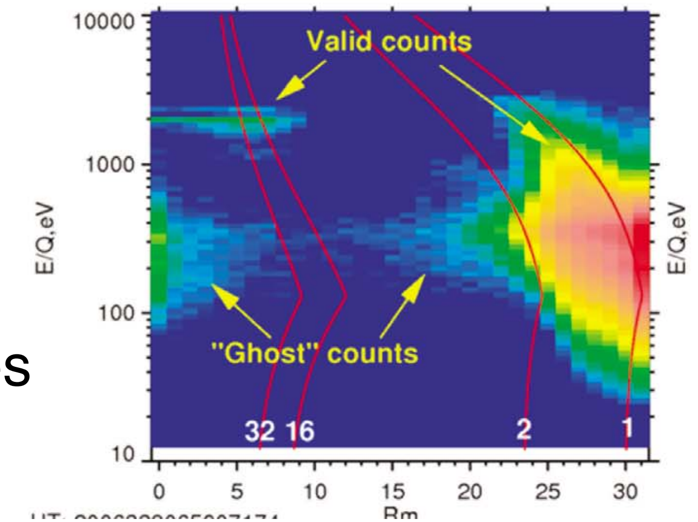
$$C(M, \phi, E, \theta) \propto j(M, \phi, E, \theta) \cdot \Delta M \cdot \Delta\phi \cdot \Delta E \cdot \Delta\theta$$

| | IMA | ELS | NPI | NPD |
|---|---|---|---|---|
| Mass | 32 | – | ∑ | Yes |
| $\phi$ | 16 | 16 | 32 | 6 |
| Energy | 96 | 128 | ∑ | Yes |
| $\theta$ | 8 or 16 | (scanner) | (scanner) | (scanner) |

# IMA data product

$$C(M, \phi, E, \theta) \propto j(M, \phi, E, \theta) \cdot \Delta M \cdot \Delta\phi \cdot \Delta E \cdot \Delta\theta$$

- Data product is time series of 4-D matrix
  - C[32, 16, 96, 16] (2010–) over 192s
  - C[32, 16, 96, 8] (–2010) over 192s
- Indeed, it is time series of 2-D matrix
  - C[32, 16, $E_i$, $\theta_j$] at specific time
  - E scan over 12s at fixed θ
  - 16-θ scan, taking 192s
- Representation depends on the objectives
  - Slice or collapse in certain dimensions
- Issues
  - Non-4π FOV
  - Spacecraft blockage of FOV
  - Interference during high-count rate
  - Proton is edge of mass capabilities

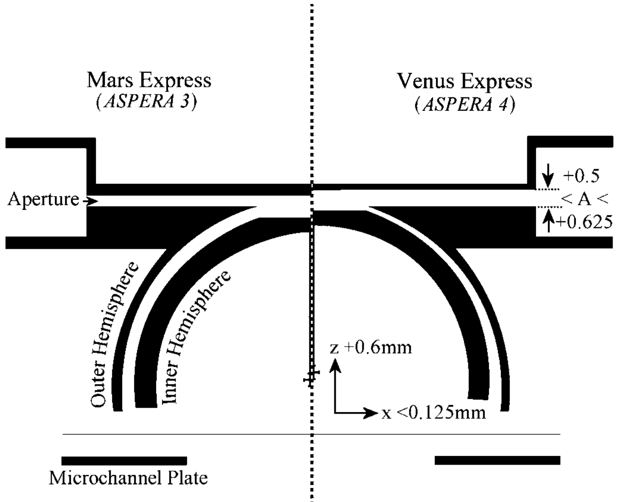



Fedorov et al., 2011

# ELS data product

$$C(\phi, E) \propto j(\phi, E) \cdot \Delta\phi \cdot \Delta E$$

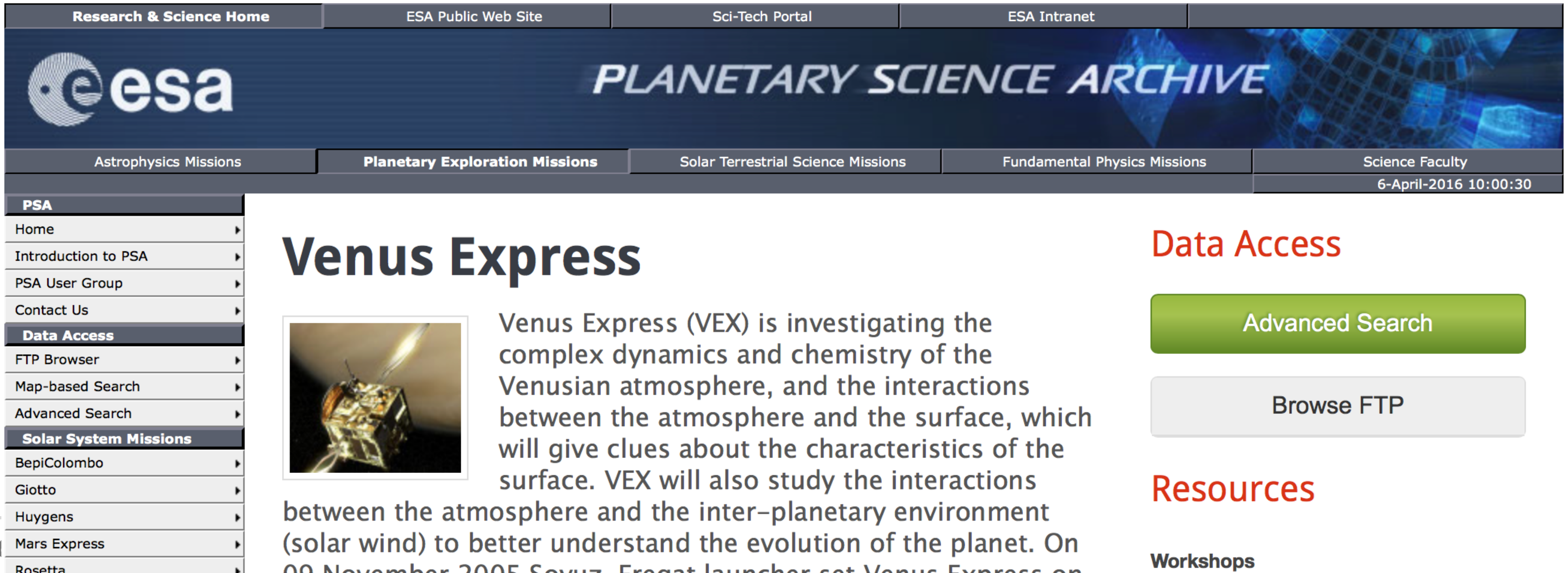
- Data is time series of 2-D counts:
  - C[16, 128] every 4s
- Or indeed, it's time series of 1-D counts
  - C[16, Ei] at specific time
  - E scan over 4s
- Sometimes fast-scan campaign was conducted
  - C[16, 32] with 1s resolution
- Issues
  - Limited FOV (plane-shaped)
  - Not much scanner operation covering 4π
  - Unsettled performance due to miss-alignment of the sensor




Collinson et al., 2009

# Planetary Science Archive

- Status
  - All ASPERA-4 data product is archived under PSA
- Available product in PSA
  - Spectra (matrix) of ions, electrons, and ENAs. Raw counts.
  - Ongoing higher-level product: Moment (density, speed, and temperature) in the solar wind – to be archived in PSA (est ~1 year)
- Tools to read PSA tables
  - No tools exist
  - No plans to implement



# Data analysis: Recommended way

- Contact to the PI, **futaana@irf.se**

- Unofficial tools for data analysis
  - Quick look web services
    - AMDA (IRAP)
    - SDDAS (SwRI)
  - Plotting software
    - SDDAS (SwRI)
    - CL (IRAP)
  - Analysis package/library
    - Ccati (MPS)
    - **irfpy (IRF)** – newly developing analysis environment powered by python3
      - Raw count access.
      - High-level product access / conversion
      - SPICE-integrated

# Data workshop & support

- ASPERA-4 data workshop in Beijing (jointly with ASPERA-3)
  - 8–10 August 2016 (TBD)
  - NAOC, Beijing
  - Invitation only
  - Organized by D Titov & J Cui
- Similar workshop can be supported upon request
- Individual support is always best
  - Best way is stay at IRF, Kiruna
    - ZJ Rong (China)
    - K Masunaga (Japan)
    - G Collinson (US)

# Summary

$$\text{ASPERA-4} = \text{IMA} + \frac{\text{ELS} + \text{NPI} + \text{NPD} \times 2}{\text{Scanner}}$$

**IMA:** $C(M, \phi, E, \theta) \propto j(M, \phi, E, \theta) \cdot \Delta M \cdot \Delta\phi \cdot \Delta E \cdot \Delta\theta$

**ELS:** $C(\phi, E) \propto j(\phi, E) \cdot \Delta\phi \cdot \Delta E$

*C: counts*
*j: differential flux*
*M: mass*
*E: energy*
*θ,ϕ: angles*

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