# Martian Ionized Carbon Dioxide and Atomic Oxygen Electrons Escaping the Atmosphere

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December 14, 2011

# Introduction to Southwest Research Institute



- Founded in 1947 as an Independent, Not for Profit, Applied Engineering and Physical Sciences Research and Development Institution
- Occupies a 1200 Acre Campus in Northwest San Antonio, Texas, USA
- Employs 3 000

# Space Science & Engineering Division

- We conduct scientific research in space - magnetospheric and heliospheric physics as well as planetary and solar astronomy.

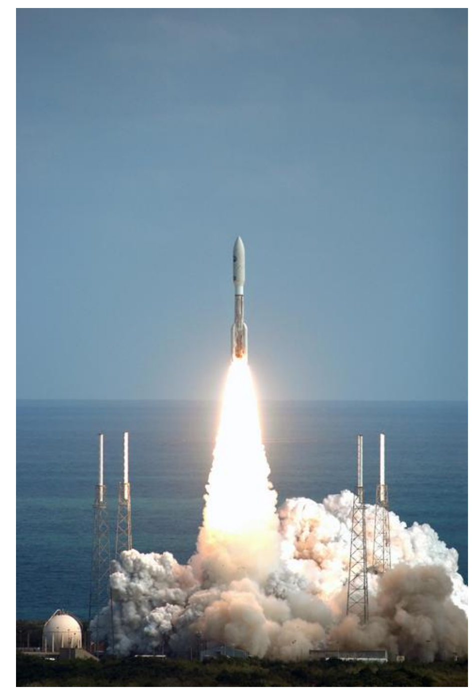
  We design and build instruments for space research.

  We sometimes build the entire payload.

  We have numerous instruments on Earth-orbiting satellites and probes to other planets.

  We also build rocket payloads.

  We analyze the data.

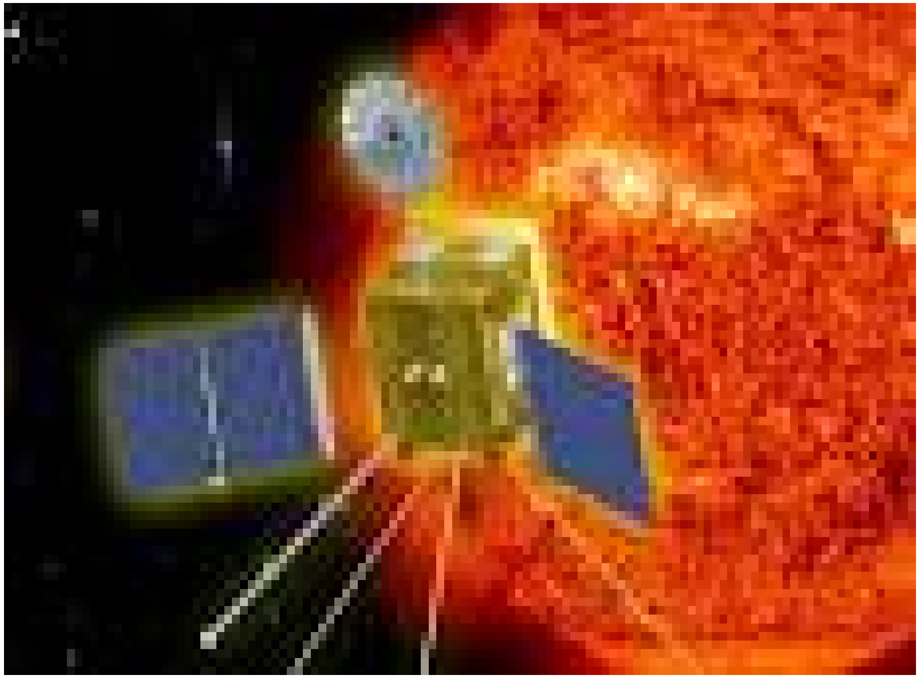


*New Horizons departs for Pluto, 19 January 2006.*

# Missions to the Sun

<u>**ESA - Solar Orbiter**</u>
**High Altitude (48 Solar Radii), Close-up Solar Observation**

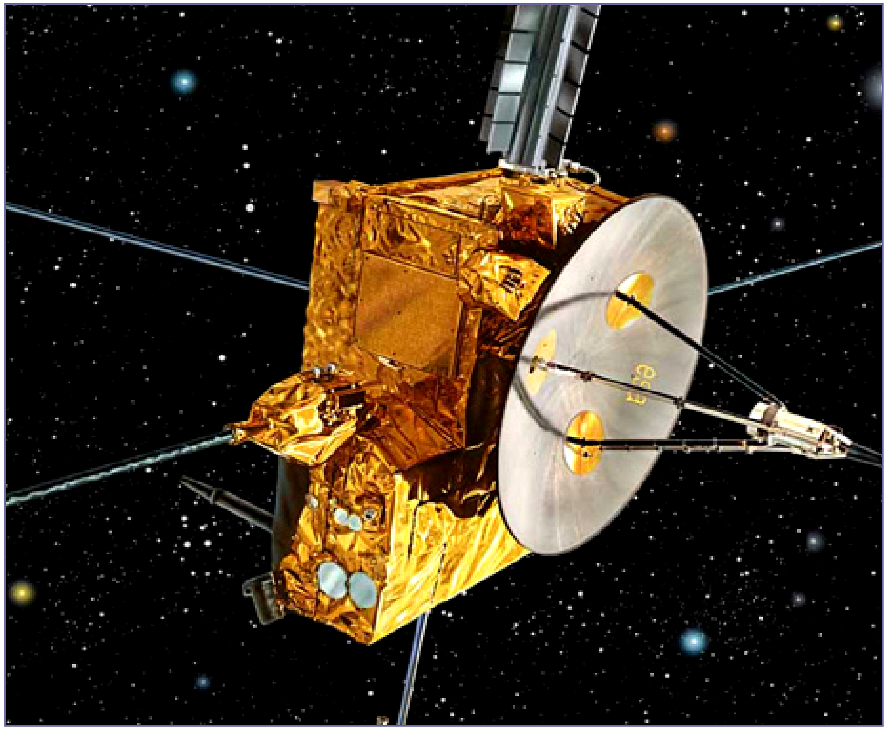
**EUV Spectrometer**
**PI: Don Hassler**
**Launch in 2017 from Cape Canaveral, FL**
**Launch Vehicle: Atlas V**
**Mission Duration: 7 years**



# Solar Wind Missions

<u>**NASA - Solar Wind Plasma: Ulysses/ACE**</u>
**First observations of 3-D solar wind (Ulysses) and real-time advanced warning (ACE)**

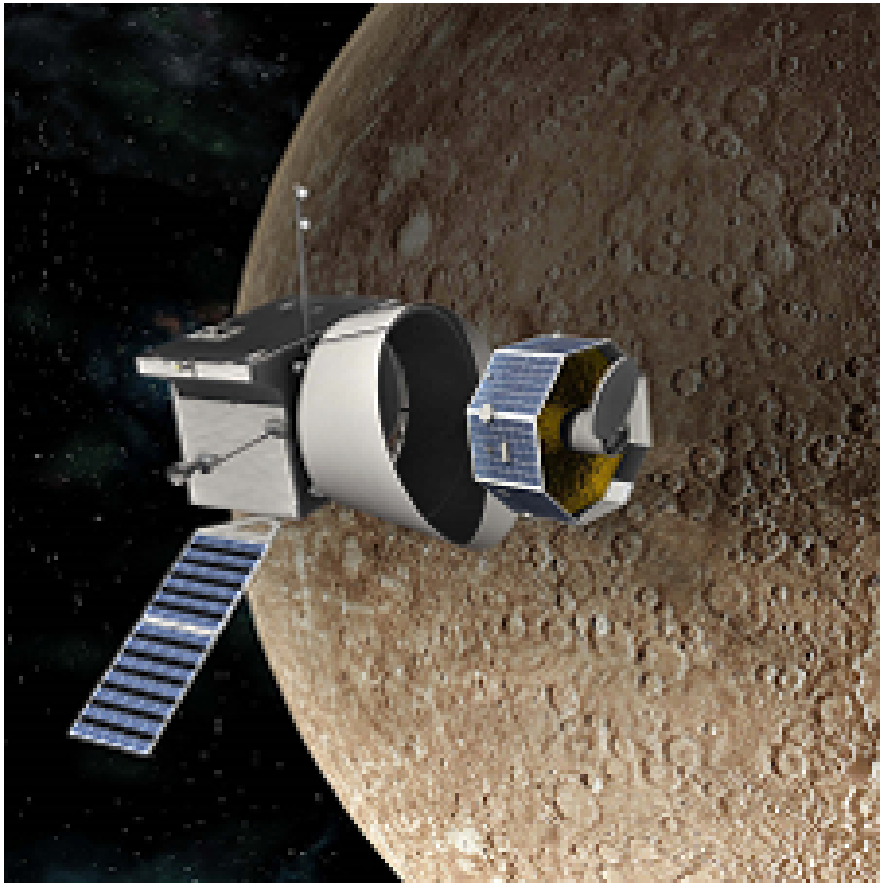
**PI: Dave McComas**
**Launched in 1990 and 1997**
**Are both still producing data.**



# Missions to Mercury

**<u>ESA - Bepe Columbo: Mercury Polar Orbiter</u>**
Determine the origin and evolution of Mercury
Launch: 2014 (6 year curse)
Launch Vehicle: Soyuz-2B/Fregat M from French Guiana

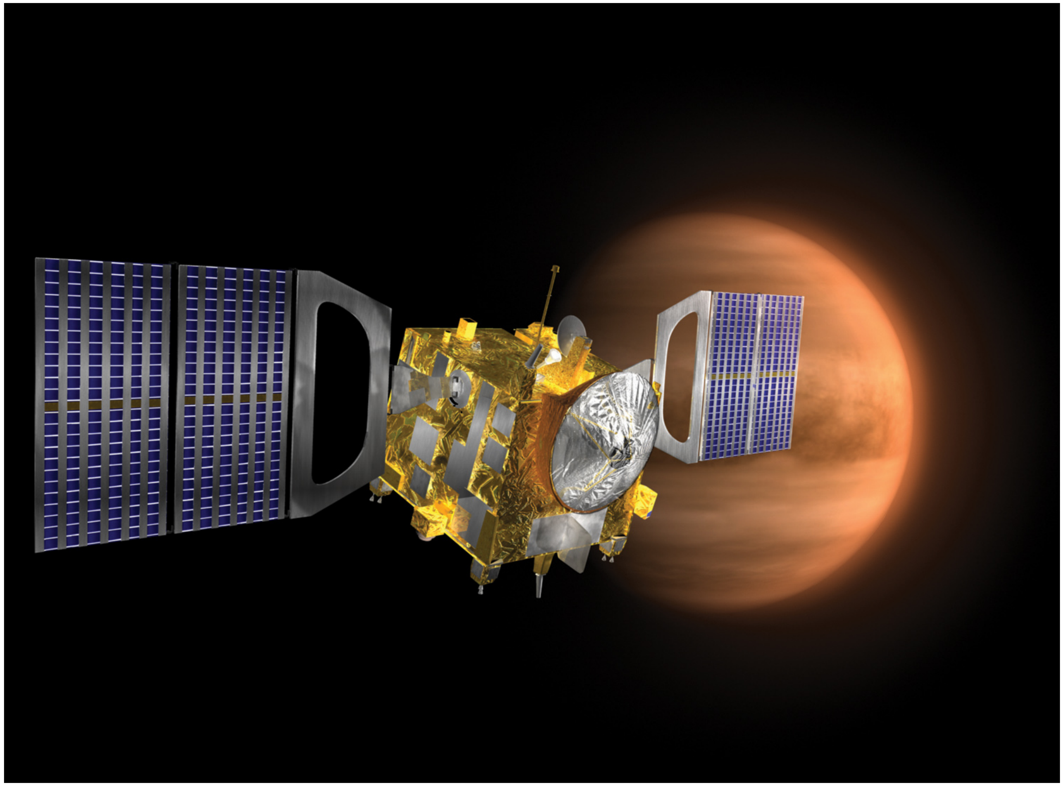
STROFIO
PI: Stefano Livi
Neutral Particle Analyzer to determine remaining 70 % of observed atmospheric pressure



# Missions to Venus

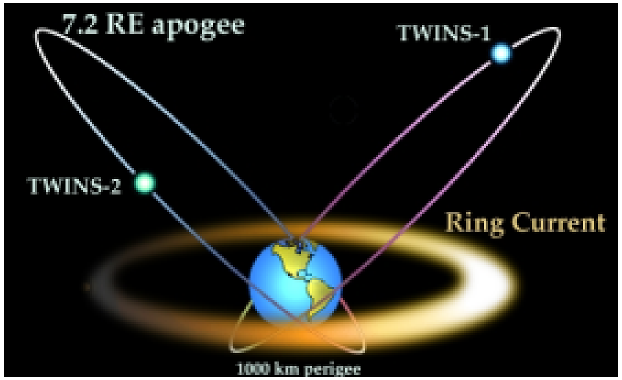
**ESA – Venus Express**
Venus complex dynamics and chemistry, interactions between the atmosphere and surface, and interactions between atmosphere and solar wind

ELS/ASPERA-4
PI: J. David Winningham
Launch: November 9, 2005
Launch Vehicle: Soyuz-Fregat
Baikonur, Kazakhstan



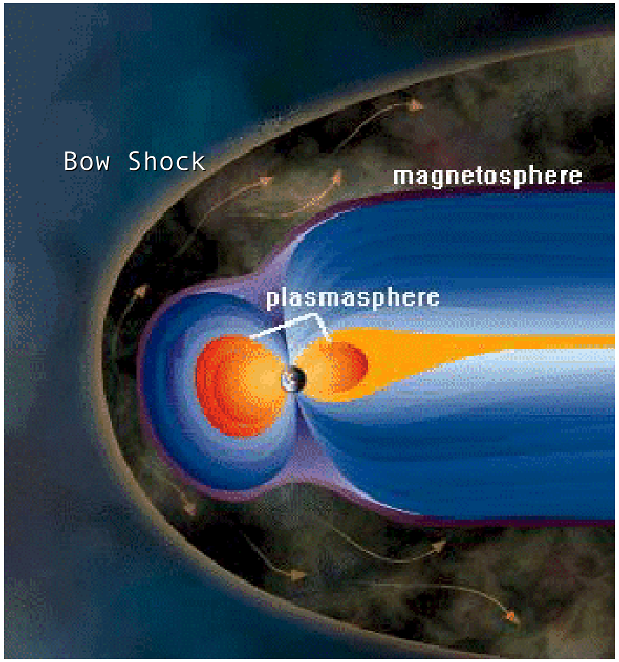
# Missions to Earth

**<u>DOE - TWINS</u>**
**First stereo imaging of the Earth's magnetosphere**
**PI: Dave McComas**
**Launches in 2008**
**(Mission of Opportunity on 2 DOE spacecraft)**



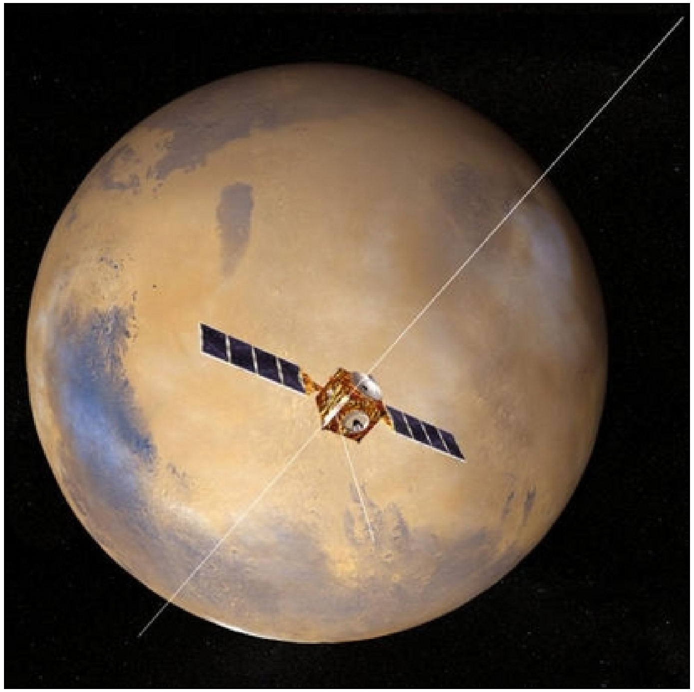
TWINS Orbits

**<u>NASA - Magnetospheric Multiscale</u>**
**PI: Jim Burch**
**4-spacecraft mission. Objective is to understand how particles are accelerated in the Magnetosphere. Launch in 2013.**



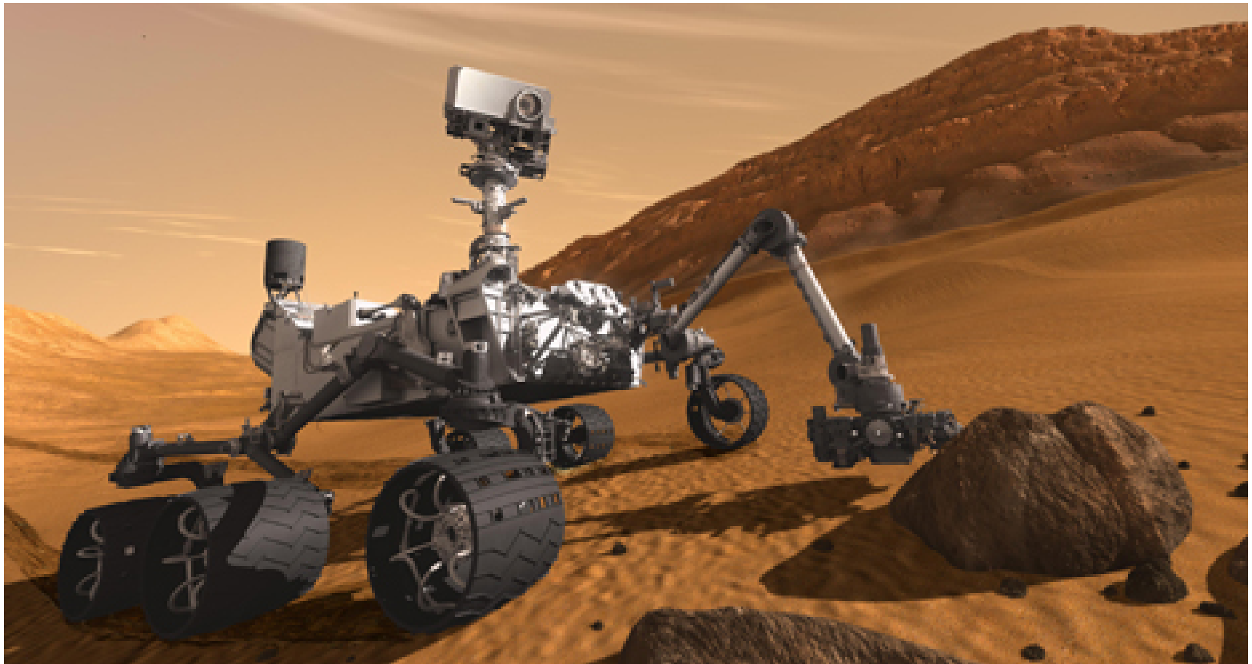
Earth's Magnetosphere

# Missions to Mars



**ESA – Mars Express**
Search for Mars Water Escape

ELS/ASPERA-3
PI: J. David Winningham
Launch: June 2, 2003
Launch Vehicle: Soyuz-Fregat
Baikonur, Kazakhstan



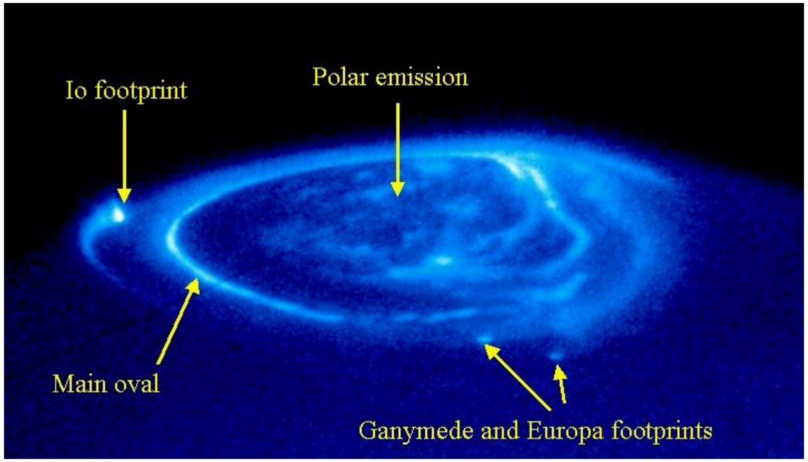
**NASA – Mars Science Laboratory**
Search for organic life

RAD – radiation detector
PI: Don Hassler
Launch: November 26, 2011
Launch Vehicle: Atlas V
Cape Canaveral, FL

# Missions to Jupiter

## NASA - JUNO

**Jupiter Polar Orbiter Mission**
**PI: Scott Bolton**
**Launch: August 5, 2011**

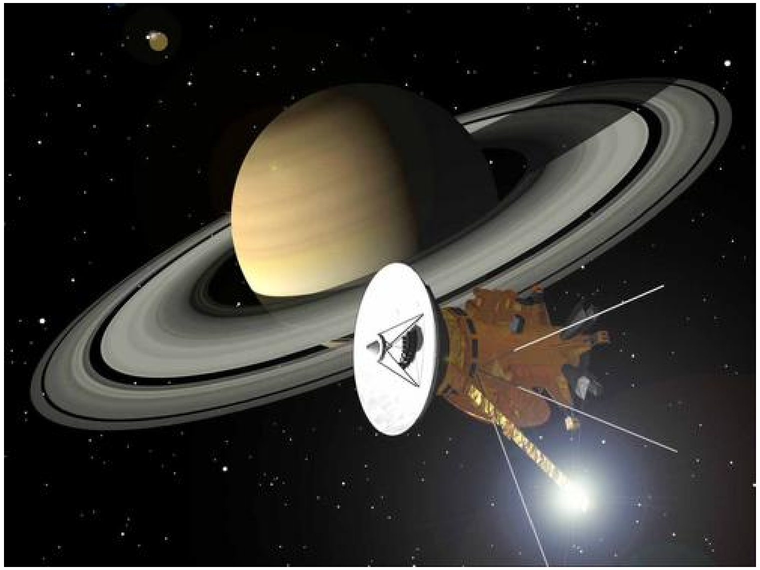



**Juno investigates: the possible existence of an ice-rock core; the water abundance and deep wind profiles in the atmosphere; the origin of the magnetic field, and the dynamics of the polar magnetosphere and aurora.**

# Missions to Saturn

<u>**NASA - Cassini Plasma Spectrometer**</u>
**PI: Dave Young**
<u>**Ion-Neutral Mass Spectrometer**</u>
**Team Leader: Hunter Waite**

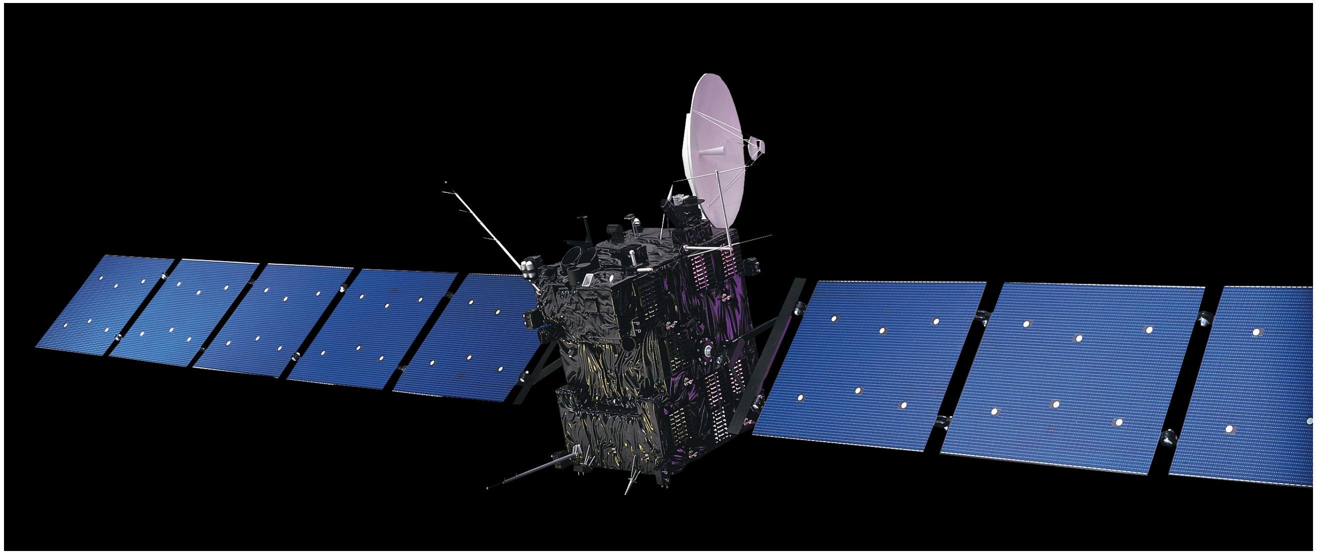
**Launched in 1997**
**In Saturn orbit since 2004**
**Prime mission through 2008.**



# Missions to Comets

**<u>ESA - Rosetta Comet Orbiter/Lander</u>**
**PI: ALICE (Alan Stern); IES (Jim Burch)**

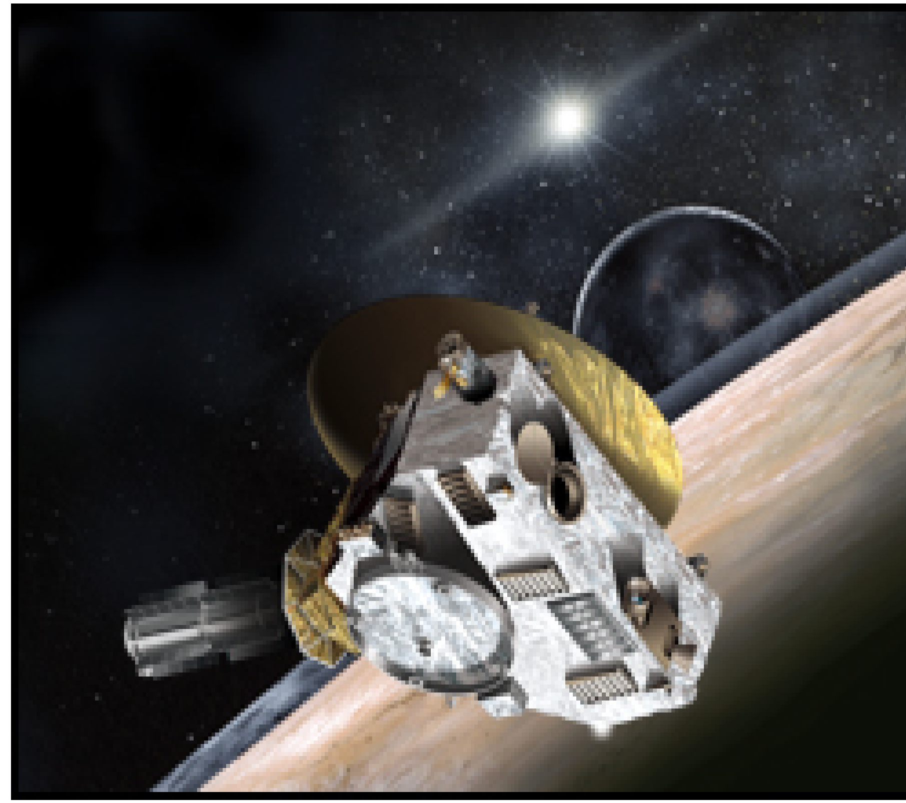
**Launched in 2004, Arrives 2014**
Comet: 67P Churyumov-Gerasimenko
**End of mission 2017**



# Missions to Pluto and Kuiper Belt

**<u>NASA - New Horizons</u>**
**First mission to Pluto**
**PI: Alan Stern**
**Launched January 2006**
**Arrival at Pluto in July 2015**

New Horizons is the first mission to the last planet—the initial reconnaissance of Pluto-Charon and the Kuiper Belt, exploring the mysterious worlds at the edge of our solar system.

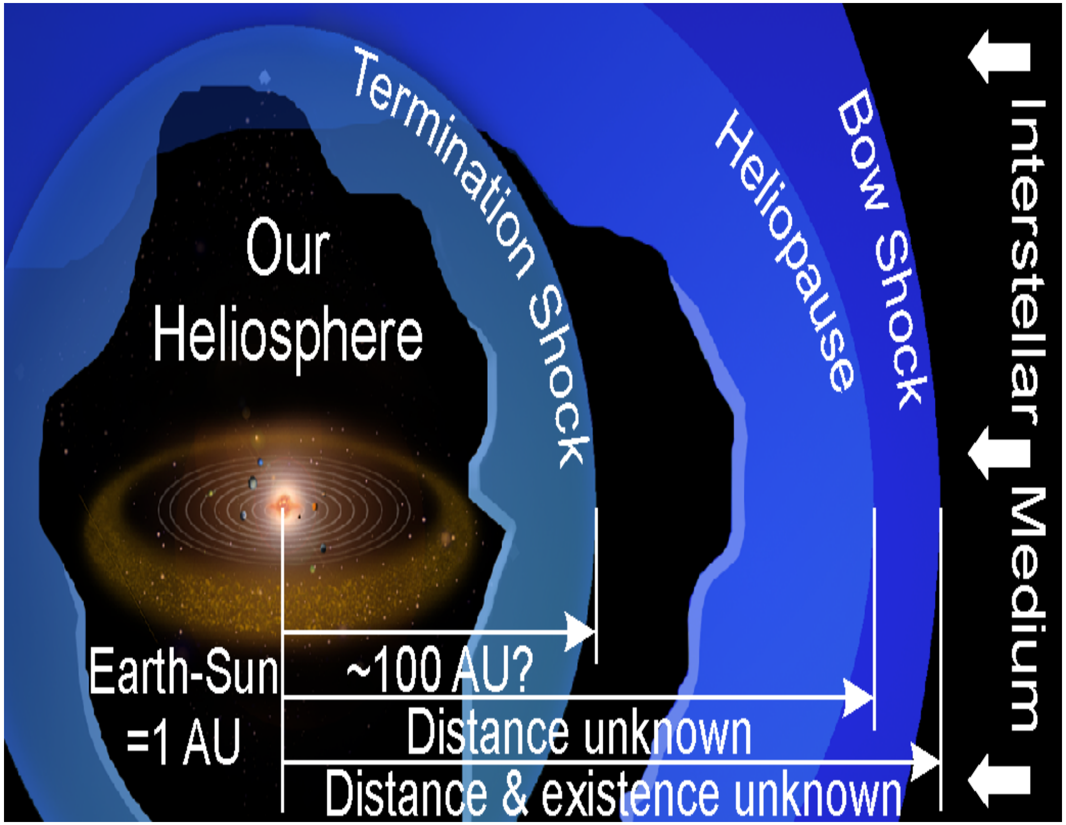


# Intersteller Boundary Missions

**<u>NASA - Interstellar Boundary Explorer</u>**
**- IBEX**

**PI: Dave McComas**
**Launch in 2008**

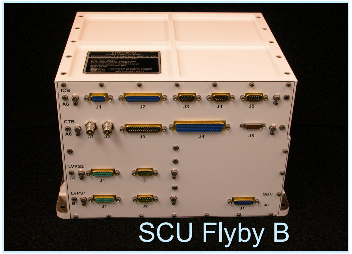
**IBEX globally images particles from the termination shock to determine the solar system's interaction with the galaxy.**

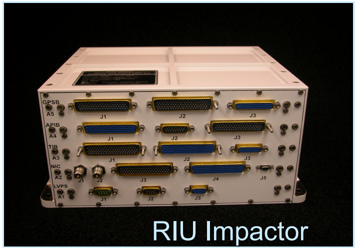


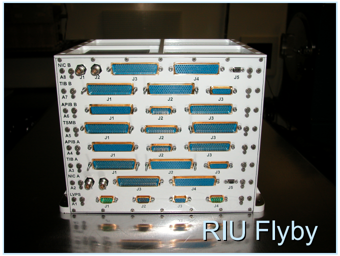
# Avionics Projects

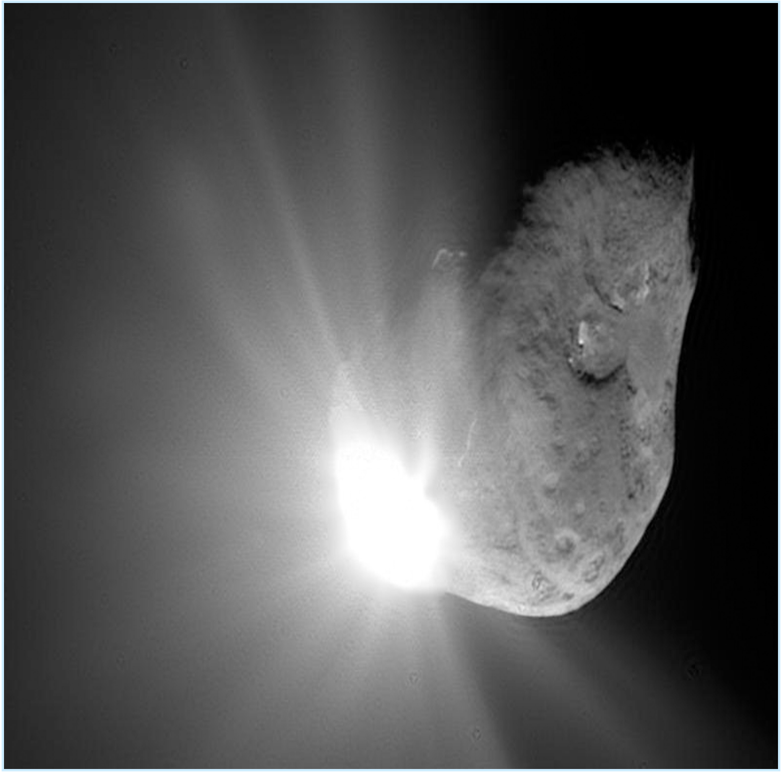
## Avionics for numerous science & defense missions

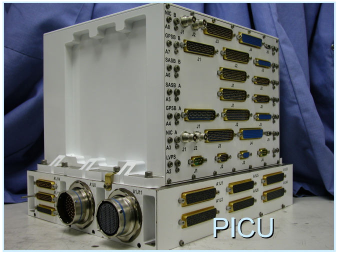
***"Deep Impact" Mission to Comet Tembel***



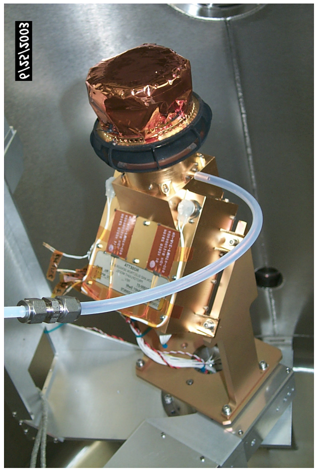





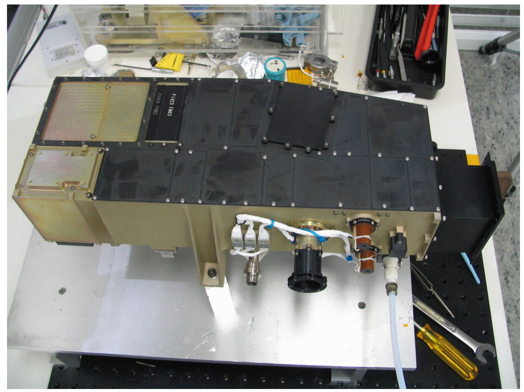

*SwRI provided all of the Control and Data Handling electronics.*

*RIU = Remote Interface Unit* *PICU = Primary Interface Computer Unit*

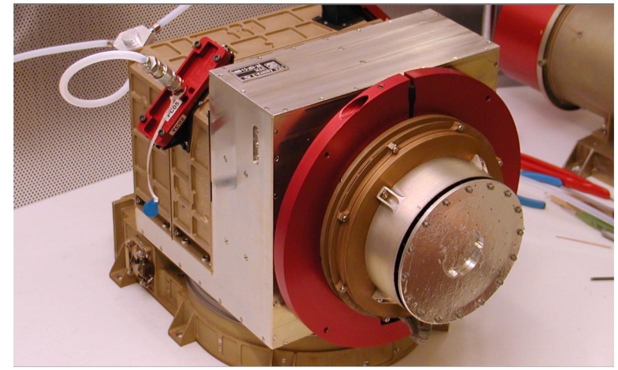
# Recently Developed Instruments



Rosetta/IES



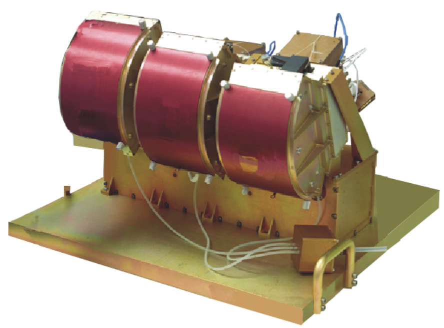
New Horizons/Alice



Mars Express/ELS

New Horizons/Ralph

(joint w/Ball Aerospace)

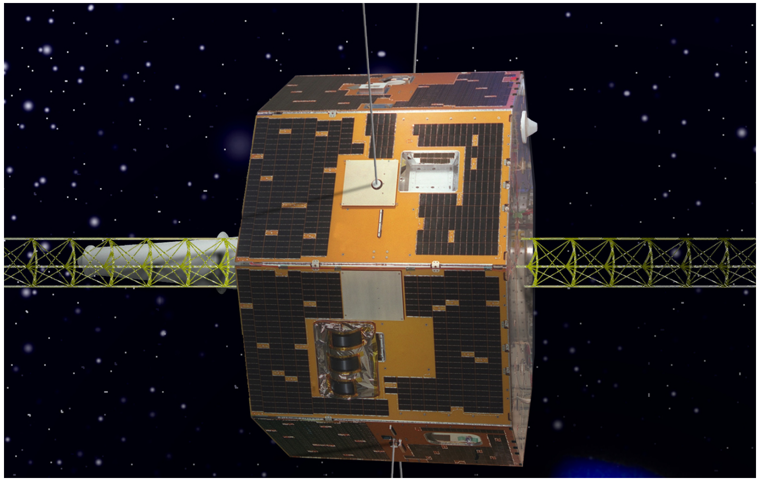


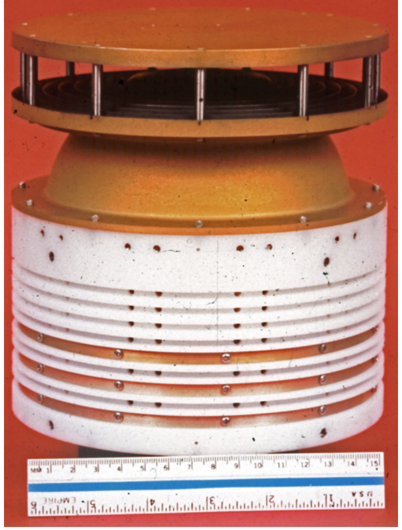
IMAGE/MENA

New Horizons/SWAP

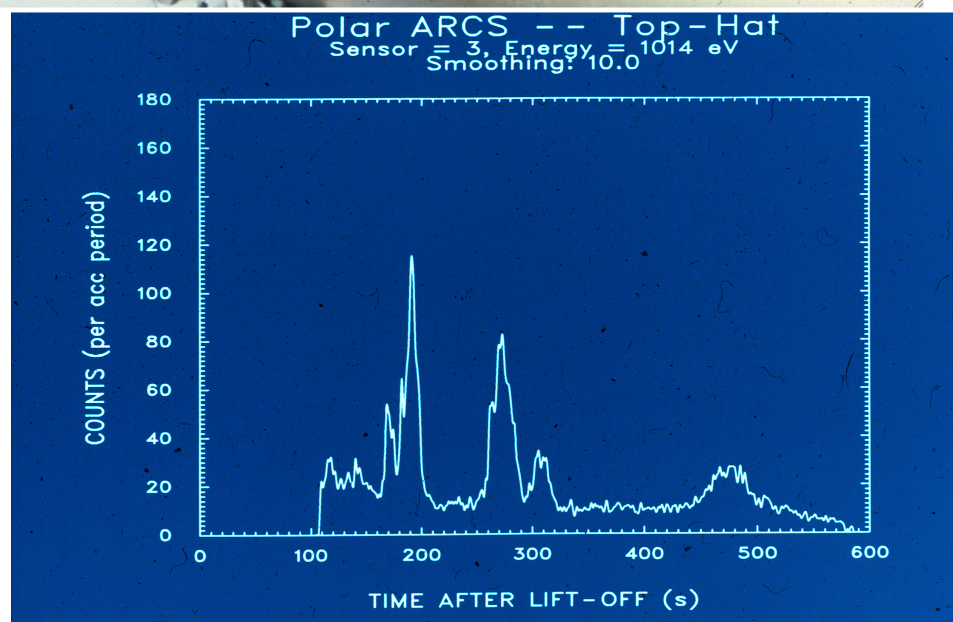
# SwRI Constructed Science Deck

**<u>NASA - IMAGE</u>**
**First mission to image the Earth's magnetosphere. PI: Jim Burch**
**Launched in 2000.**
**In extended mission until 2010.**
**Operation interrupted in Dec. 05.**





# Rocketry



Polar ARCS -- Top-Hat
Sensor = 3, Energy = 1014 eV
Smoothing: 10.0
COUNTS (per acc period)
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
TIME AFTER LIFT-OFF (s)

## *Young Engineers and Scientists - YES*

Reaches high school age students and teachers in the San Antonio area.

It is a 3-week summer workshop here at SwRI.

Consists of research/engineering projects, electronics, basic computer skills, Power Point presentations, etc.

In some cases students pursue independent study with SwRI mentors during the school year.

The goals of YES are to increase the number of students -- especially minorities and women -- seeking Science or Engineering careers, assist their choice of college and college major, and involve high school teachers in science and engineering research and technology that can be used in their classrooms.

Check out the web site: http://yesserver.space.swri.edu/

# *UTSA - SwRI Graduate Program*

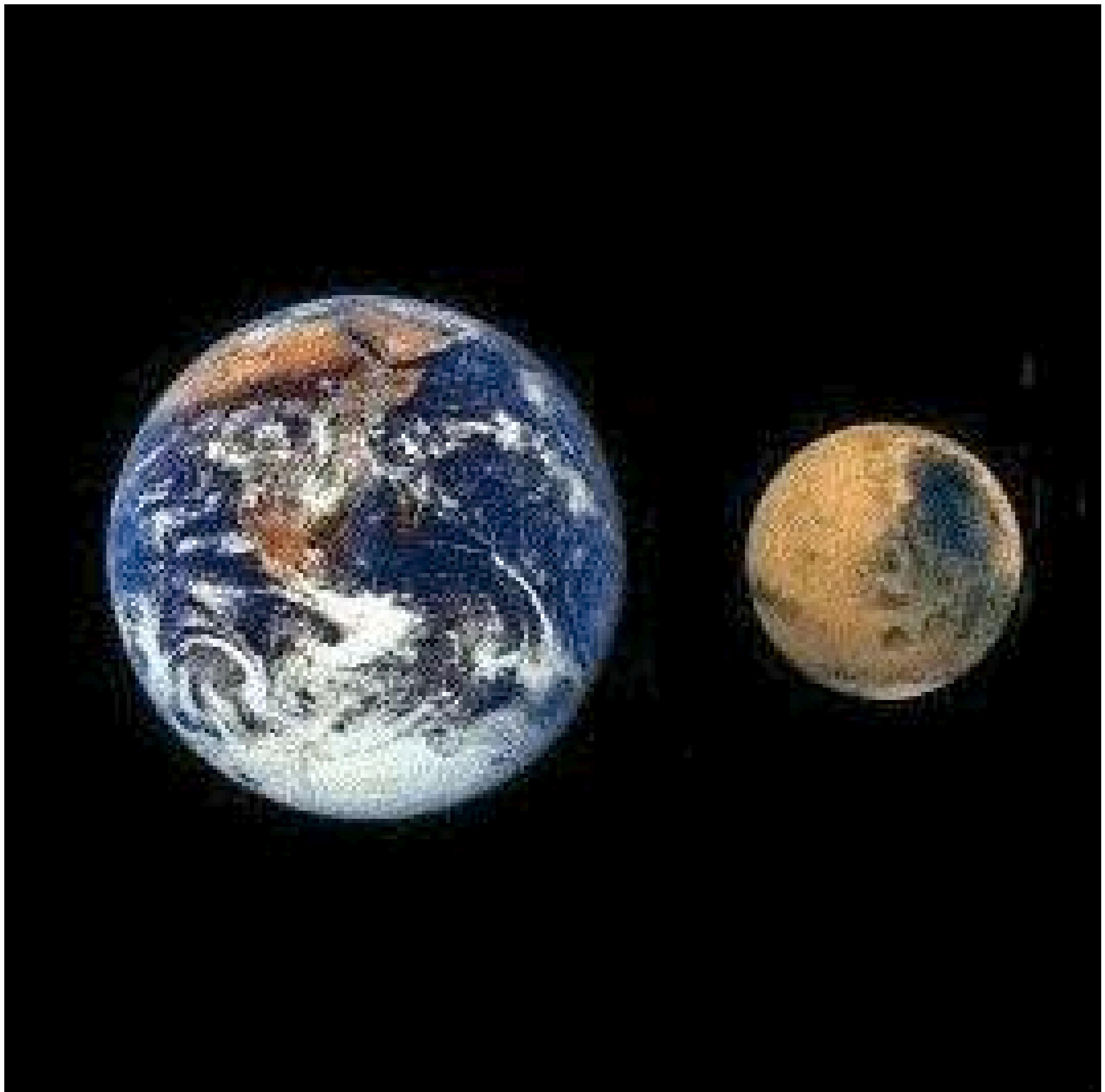
# *Physics and Astronomy*

*Ten members of the science staff at SwRI are joint faculty members in the Department of Physics and Astronomy of the University of Texas at San Antonio.*

# Mars - The Red Planet

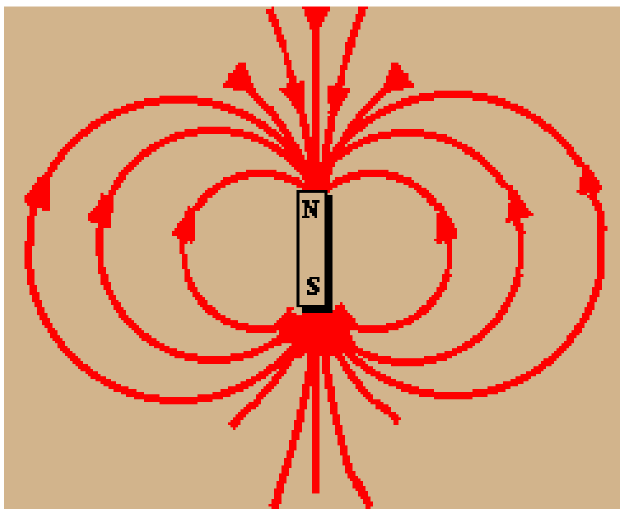
# The Size of Mars Versus Earth

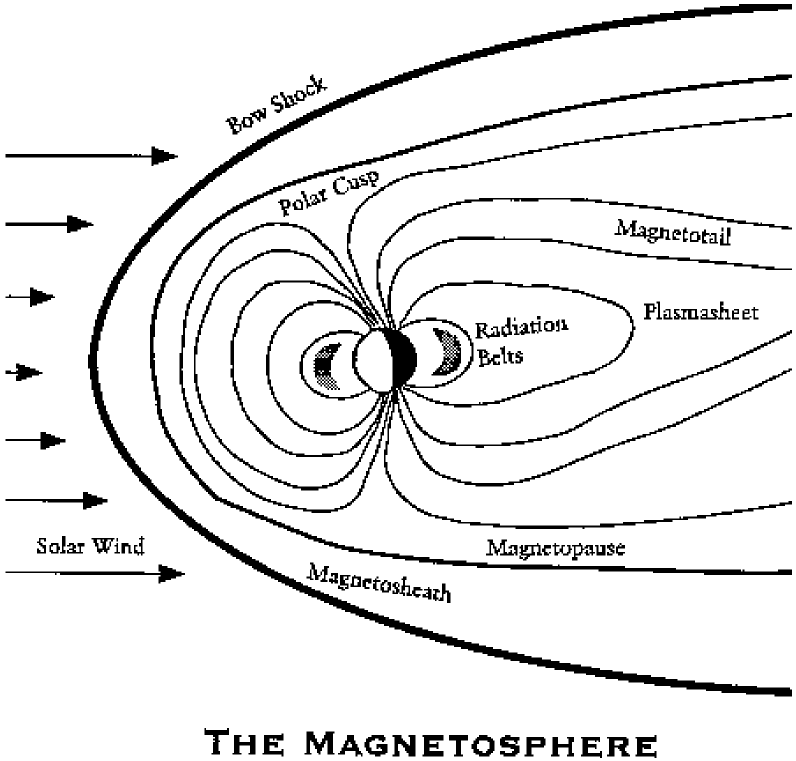
Earth



Mars

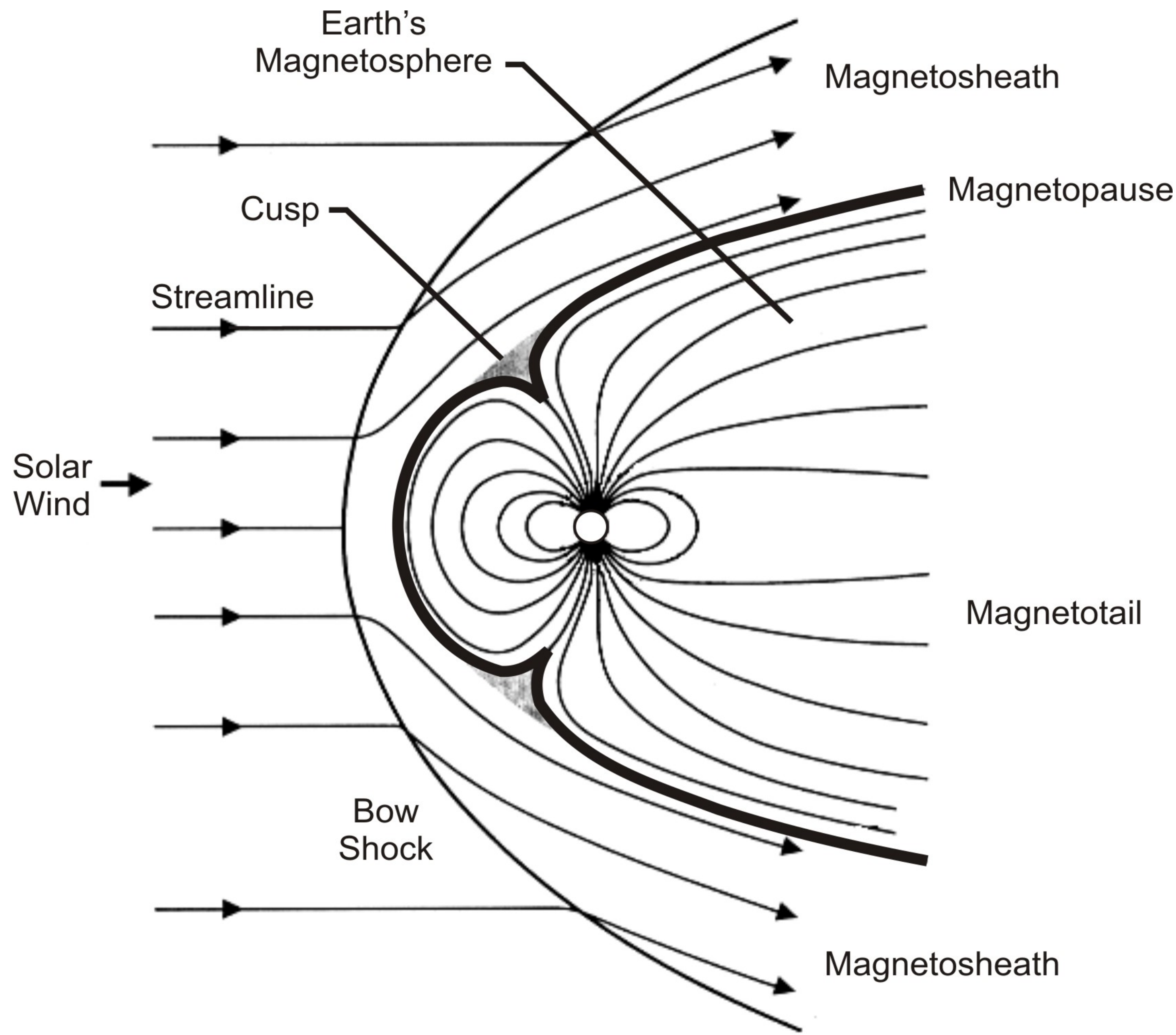
# *What is the Magnetosphere?*




The presence of the solar wind re-shapes the magnetic field lines.

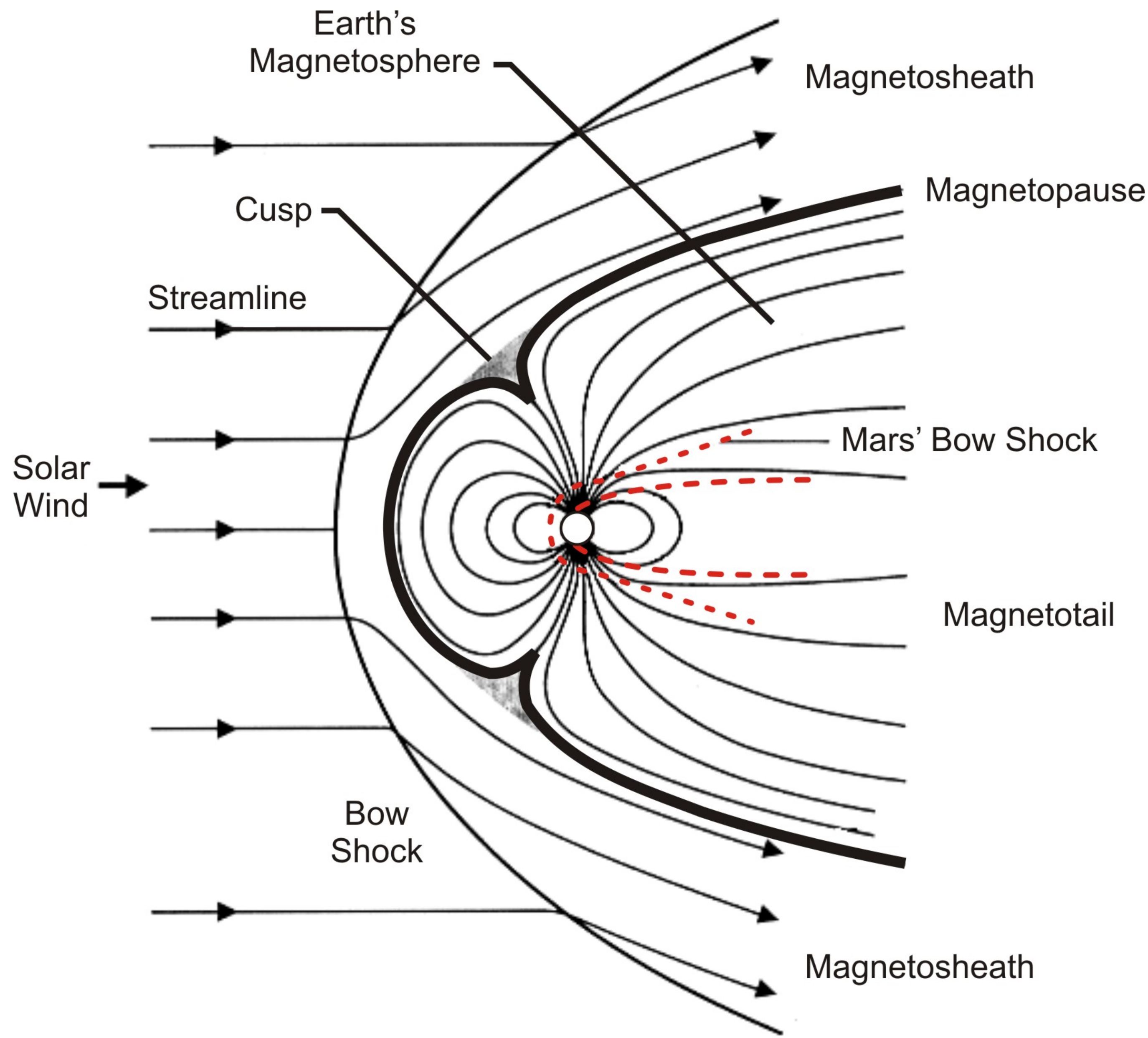
# Magetosphere of the Earth




Comparison of the spatial extent of the Martian solar wind interaction to that of the Earth [adapted *Luhmann and Brace* 1991].

TA004550B

# Magnetosphere of Mars (red dashed magnetic field lines)




Comparison of the spatial extent of the Martian solar wind interaction to that of the Earth [adapted *Luhmann and Brace* 1991].

TA004550

# Background on the Solar Wind

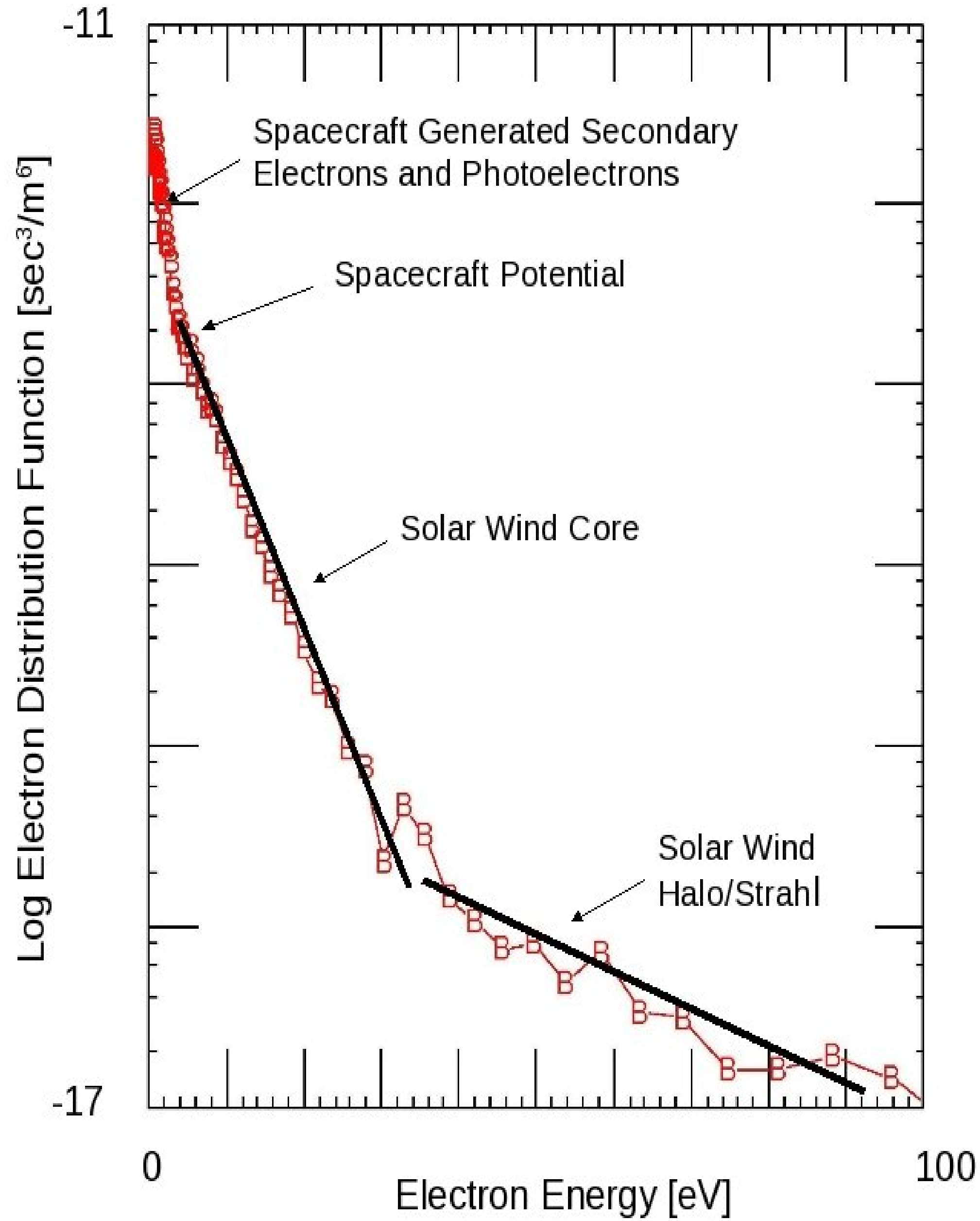
Solar Wind Core Electrons
- Generally, <50 eV
- Isotropic

Solar Wind Halo Electrons
- Generally, >50 eV
- Isotropic

Solar Wind Strahl Electrons
- Generally, >50 eV
- Aligned with the Magnetic Field

Electron Distribution Accelerated by the Spacecraft Potential

Spacecraft Generated Secondary Electrons and Photoelectrons are Observed Below the Spacecraft Potential



# Penetration of Obstacle by the Solar Wind

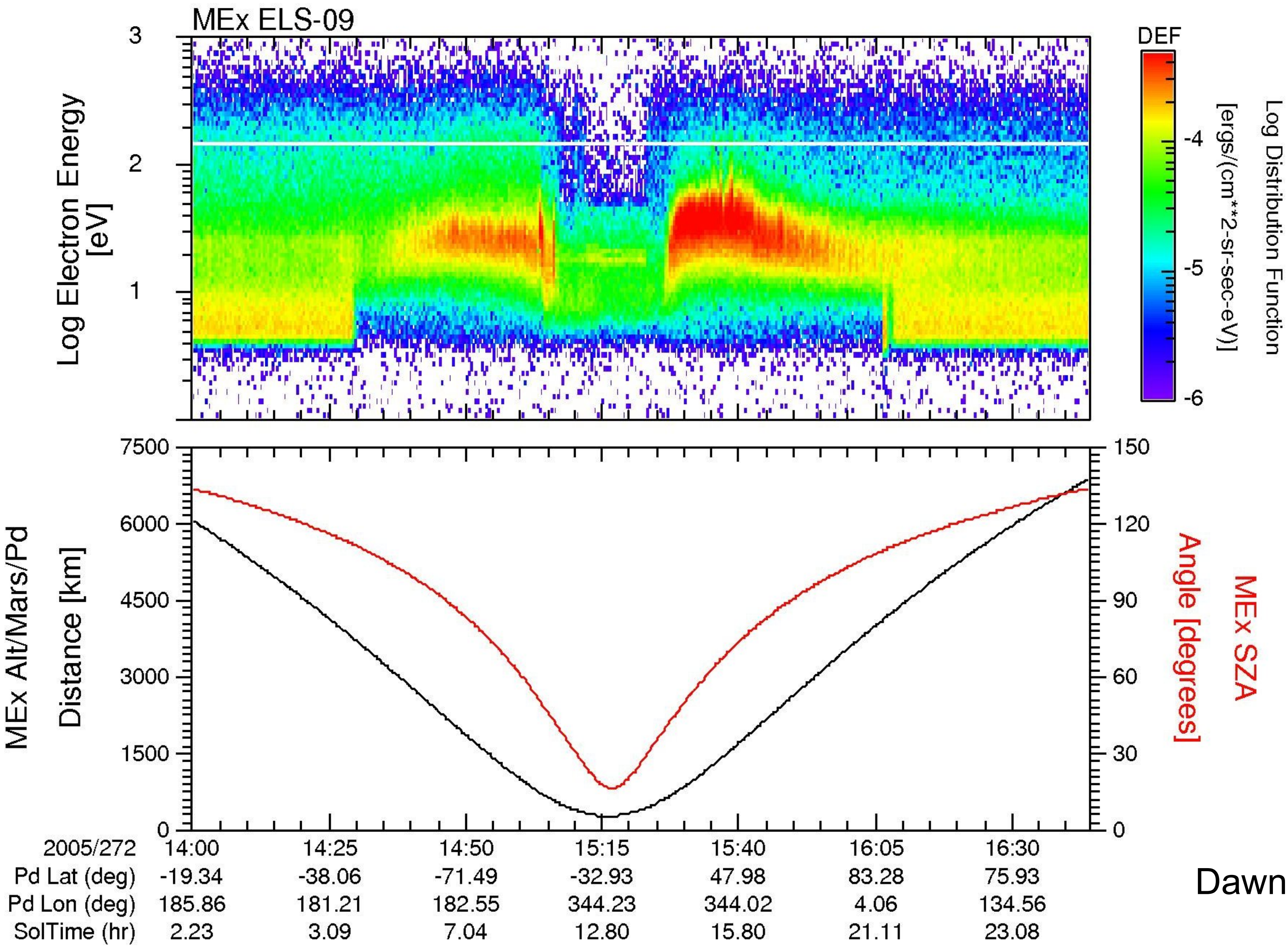
Solar Wind Penetrates to the Ionosphere of the Obstacle (Mars and Venus)

Solar Magnetic Field Distorts and is Draped Around the Obstacle

Solar Wind Core Influenced by the Shock Potential

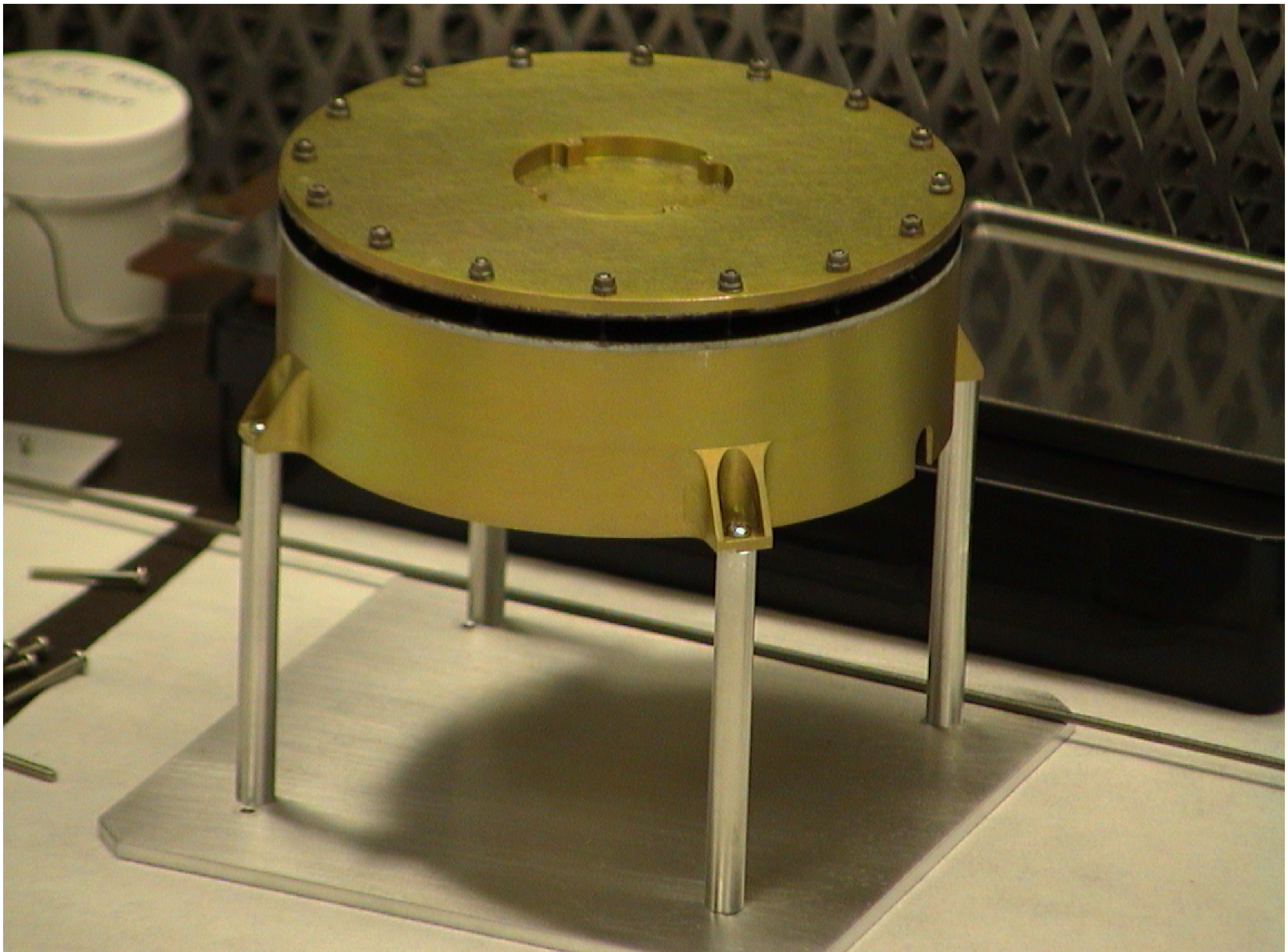
Since the Bulk of the Solar Wind Halo/Strahl Population has Energies Above the Shock Potential, the Solar Wind Halo/Strahl is Observed to Penetrate (Mostly Undisturbed) Through the Shock, to the Ionosphere of the Planet

# Mars Express View

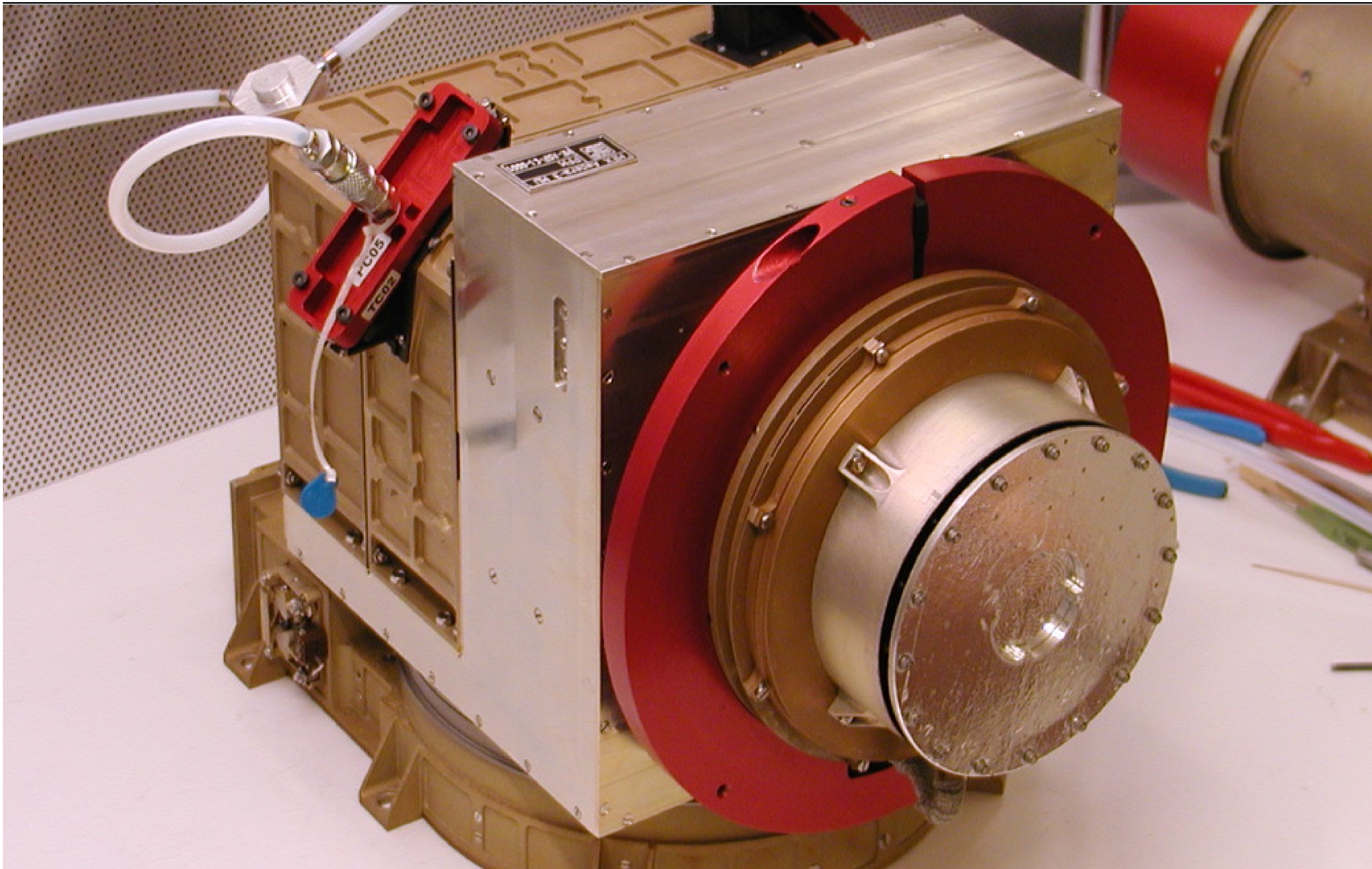



Dawn - Dusk

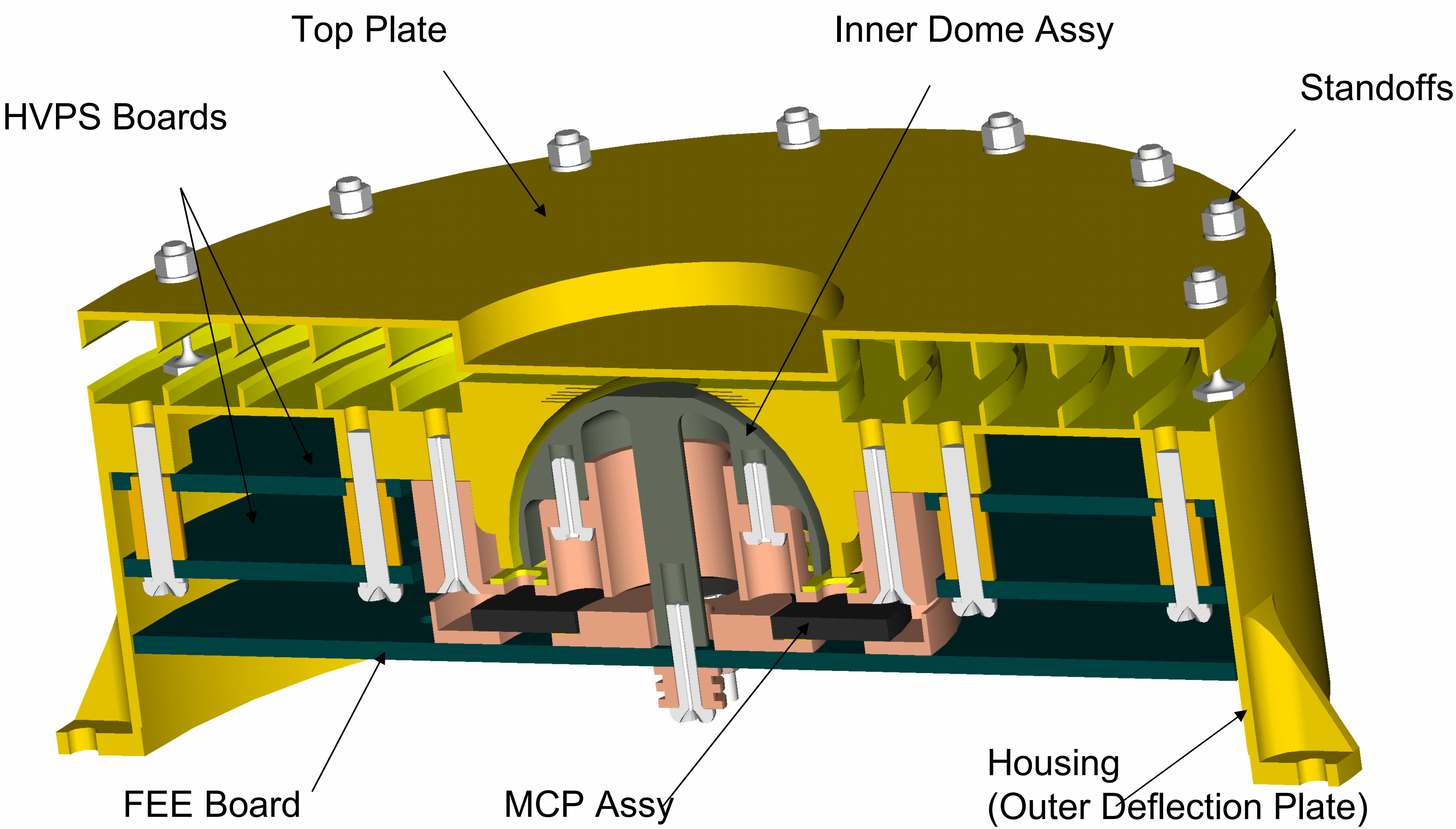
# The Mars Express Electron Spectrometer

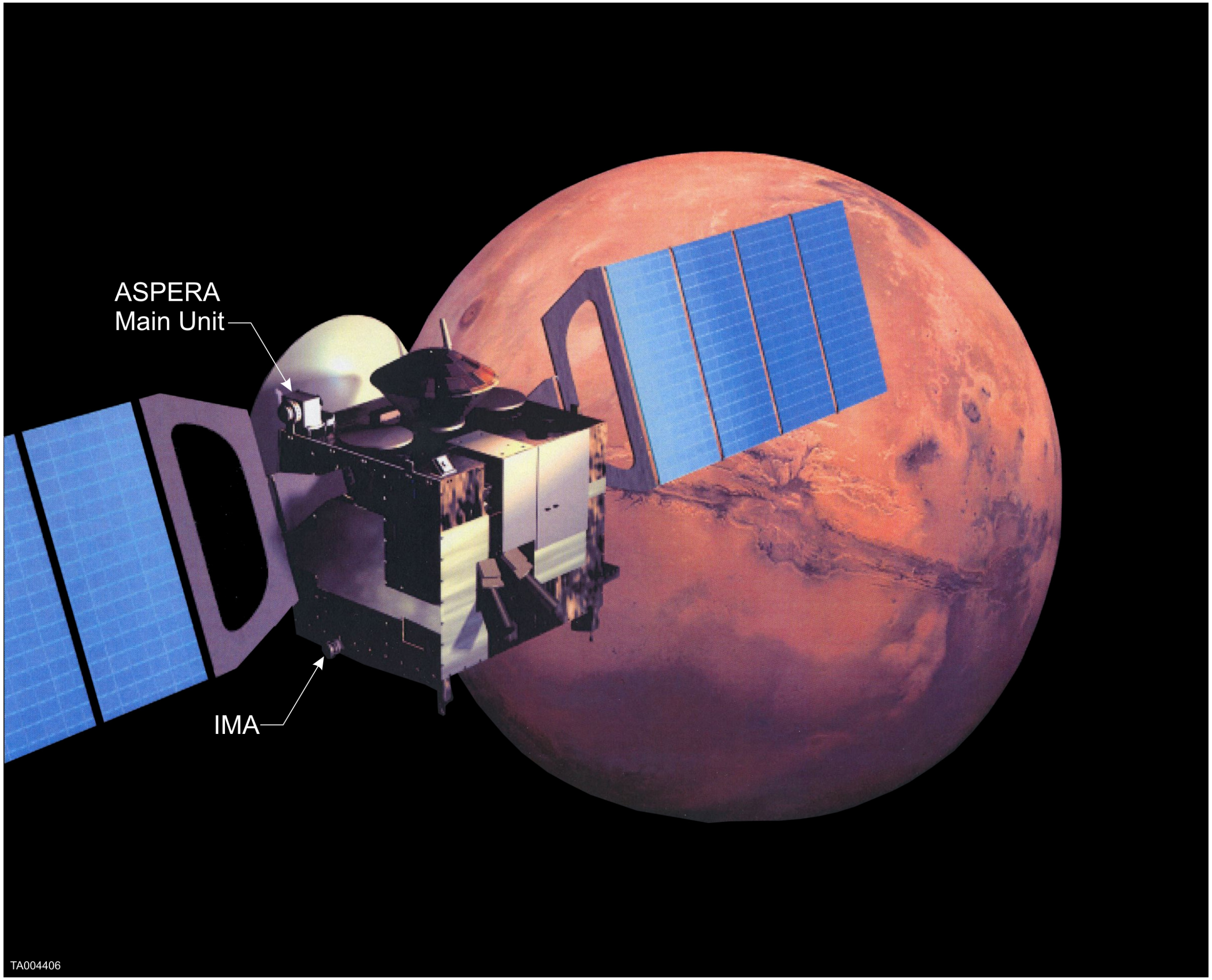


# The Mars Express Analyzer of Space Plasmas and Energetic Atoms Experiment Main Unit



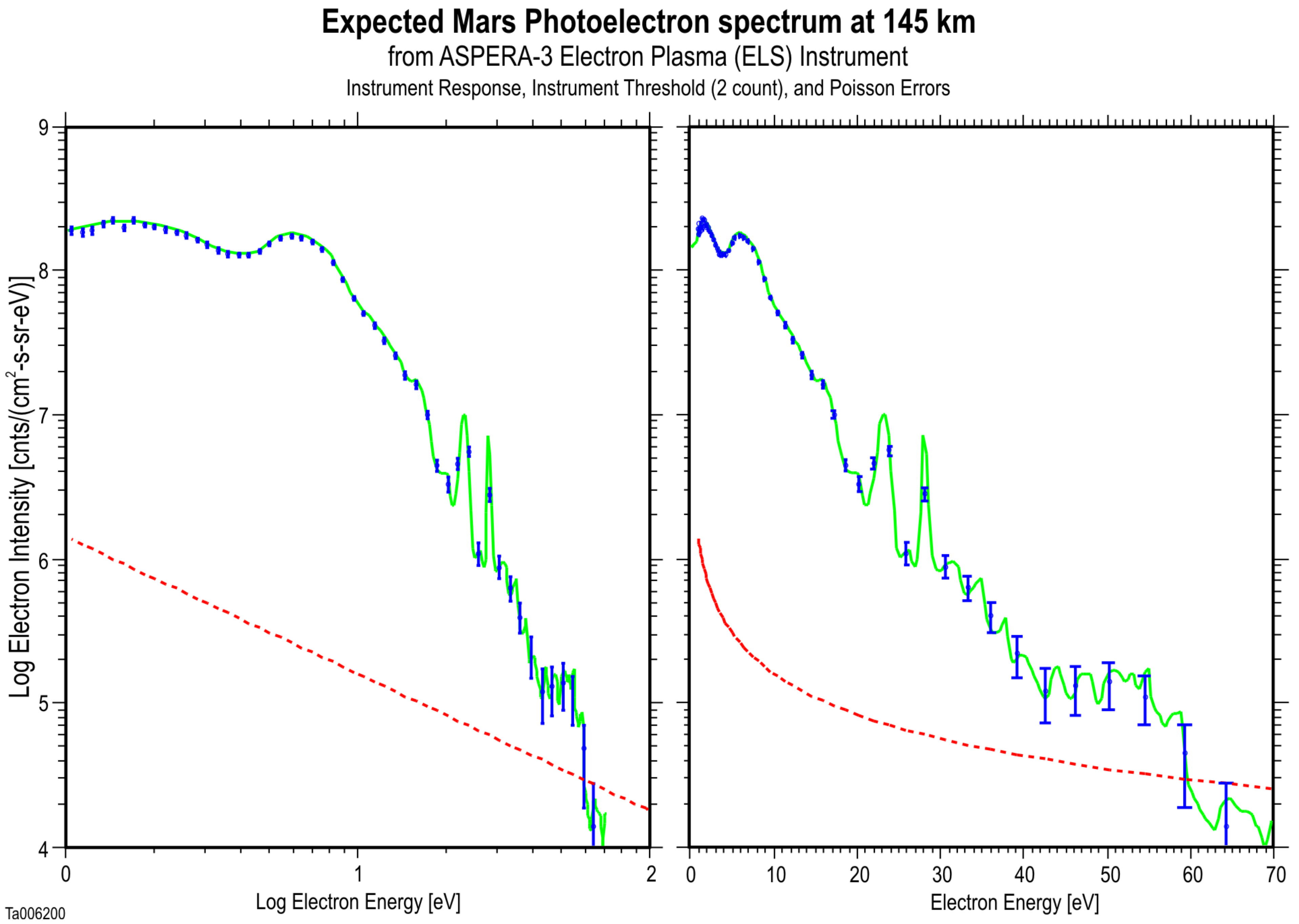
# Cross-Section of the Mars Express Electron Spectrometer






Mars Express was launched on June 2, 2003 and executed its orbital insertion burn on December 25, 2003.

# Expected Electron Spectrum at Mars



# 30.4 nm Photoionization of Carbon Dioxide

$$CO_2 + h\nu \longrightarrow CO_2^{+} + e^{-} \begin{cases} X\,^2\Pi_g \text{ ionization potential } 13.8 \text{ eV} \longrightarrow 27.0 \text{ eV electron} \\ A\,^2\Pi_u \text{ ionization potential } 17.7 \text{ eV} \longrightarrow 23.1 \text{ eV electron} \\ B\,^2\Sigma_u^{+} \text{ ionization potential } 18.1 \text{ eV} \longrightarrow 22.7 \text{ eV electron} \\ C\,^2\Sigma_g^{+} \text{ ionization potential } 19.4 \text{ eV} \longrightarrow 21.4 \text{ eV electron} \end{cases}$$

TA006195_AGU

[Padial et al., 1981]

# 30.4 nm Photoionization of Atomic Oxygen

$$O + h\nu \longrightarrow O^{+} + e^{-} \begin{cases} {}^{4}S \ \text{ionization potential 13.62 eV} \longrightarrow \text{27.16 eV electron} \\ {}^{2}D \ \text{ionization potential 17.10 eV} \longrightarrow \text{23.68 eV electron} \\ {}^{2}P \ \text{ionization potential 18.50 eV} \longrightarrow \text{22.28 eV electron} \end{cases}$$

TA006169_AGU

[Mantas and Hanson, 1979]

# Solar Spectrum Between 30 and 50 nm

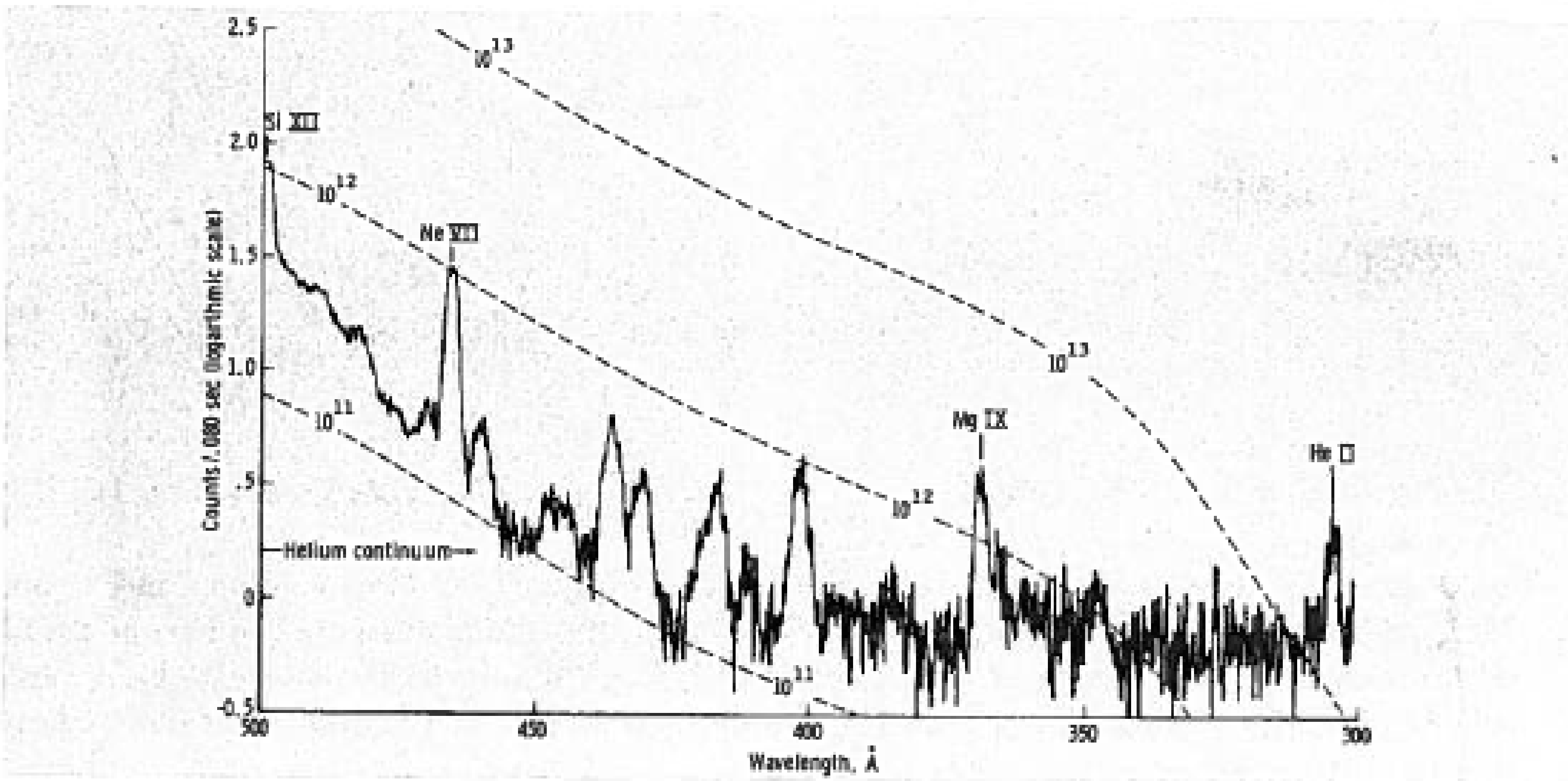
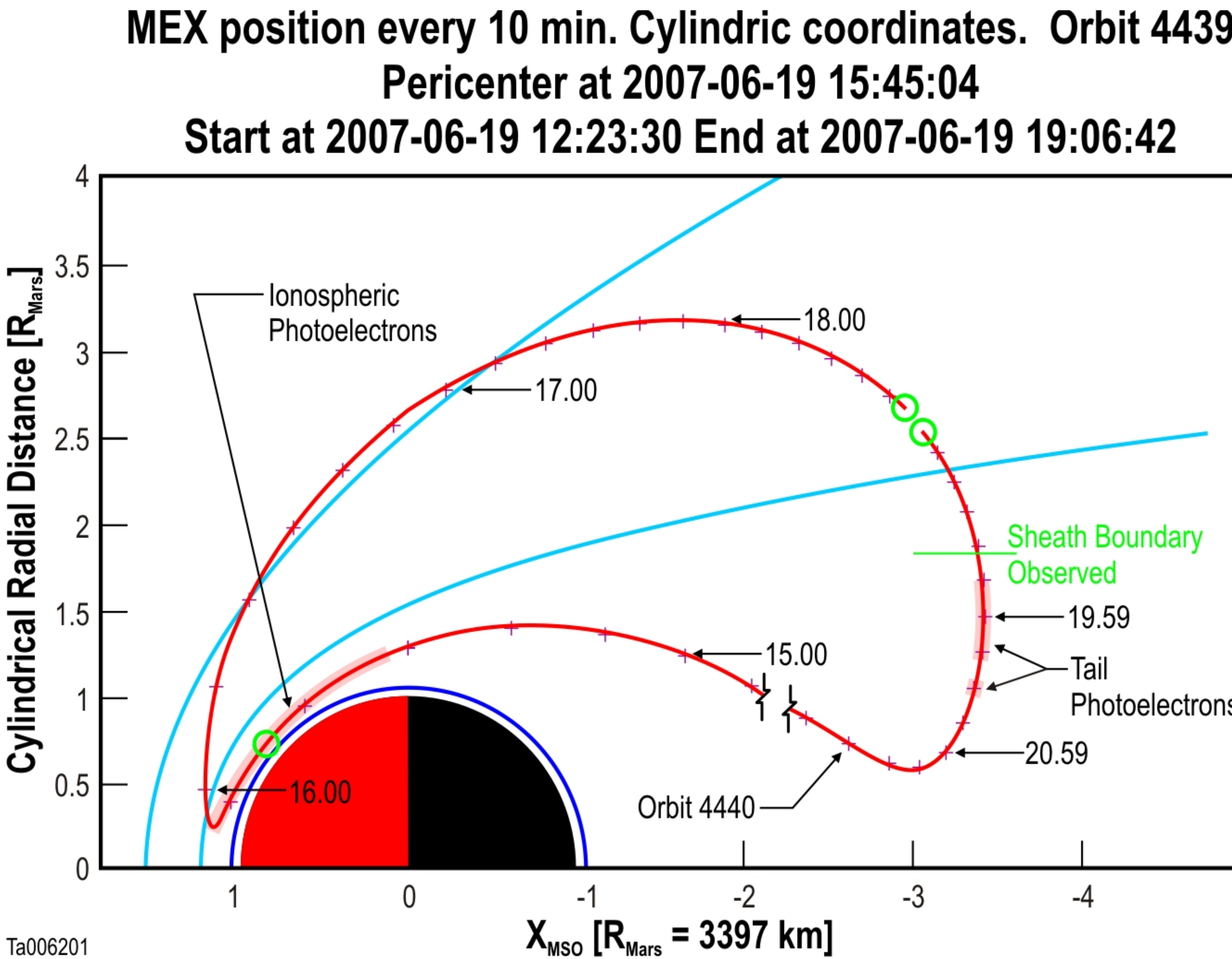


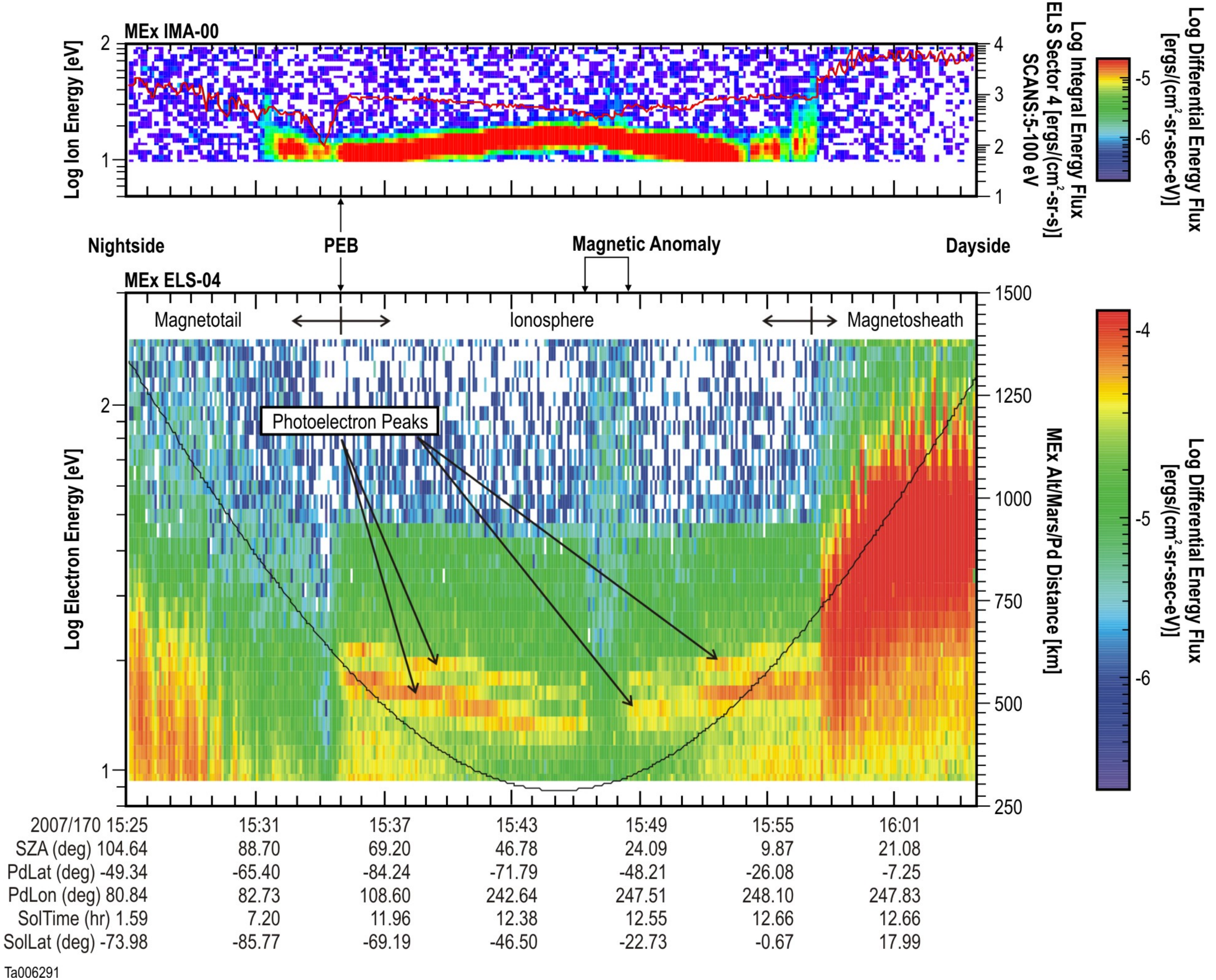

FIGURE 6-30 (concluded).—A detailed view of the spectrum from 1400 to 300 Å recorded by OSO 4.

Gibson E. G., The Quiet Sun, NASA SP-303, 1973

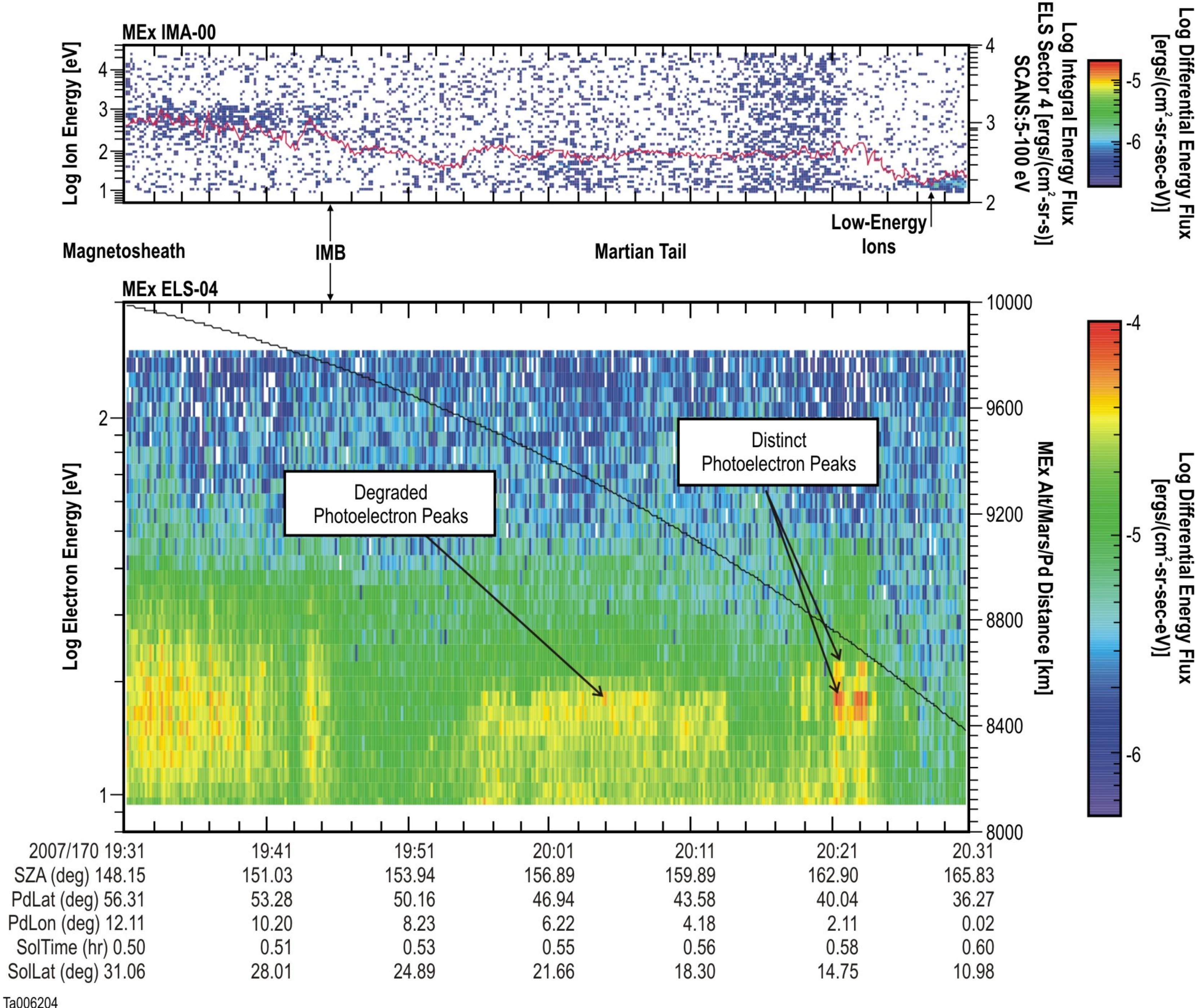
# Mars Express Sample Orbit



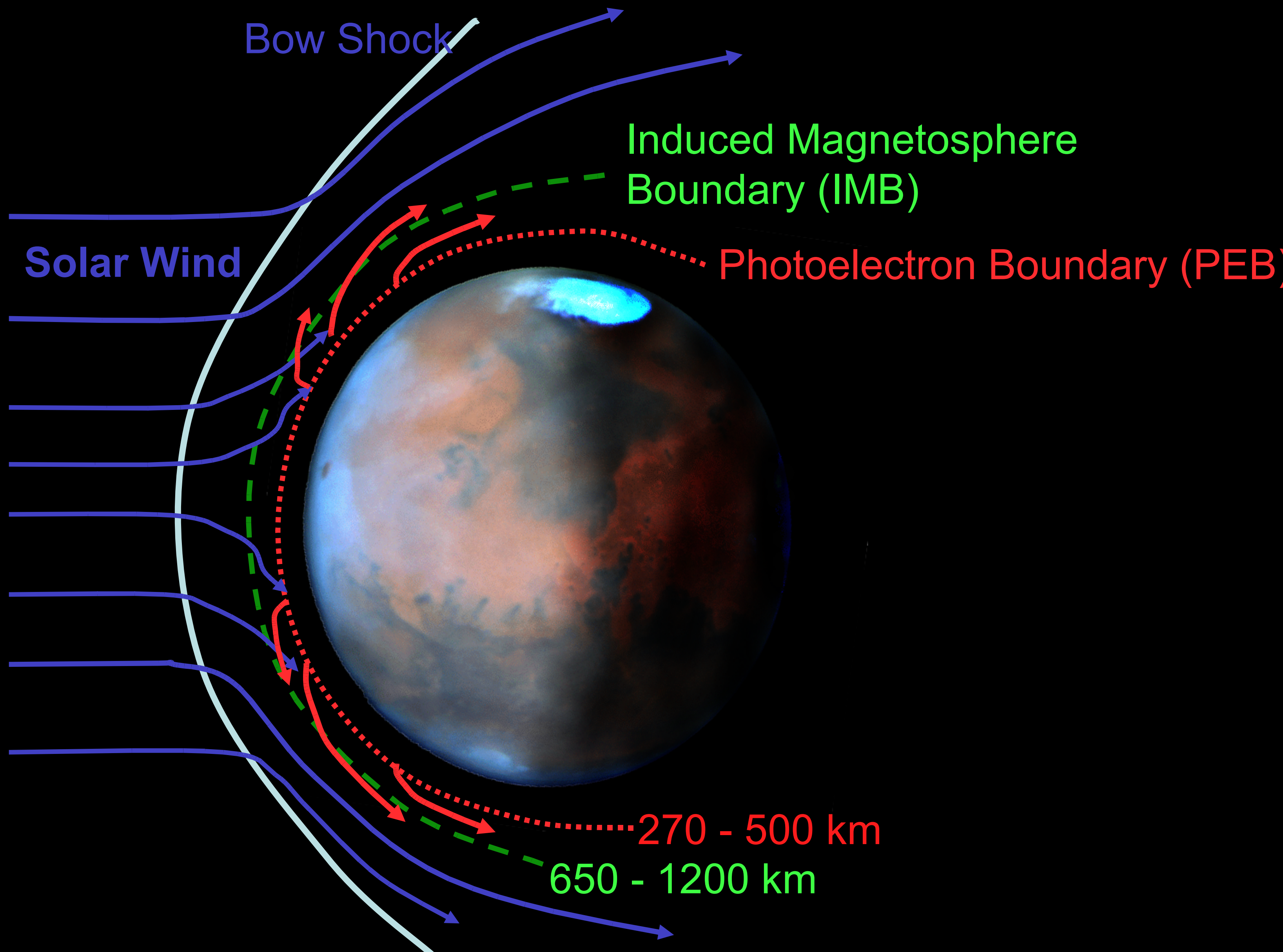
# 19 June 2007 Ionosphere Plasma



# 19 June 2007 Tail Plasma

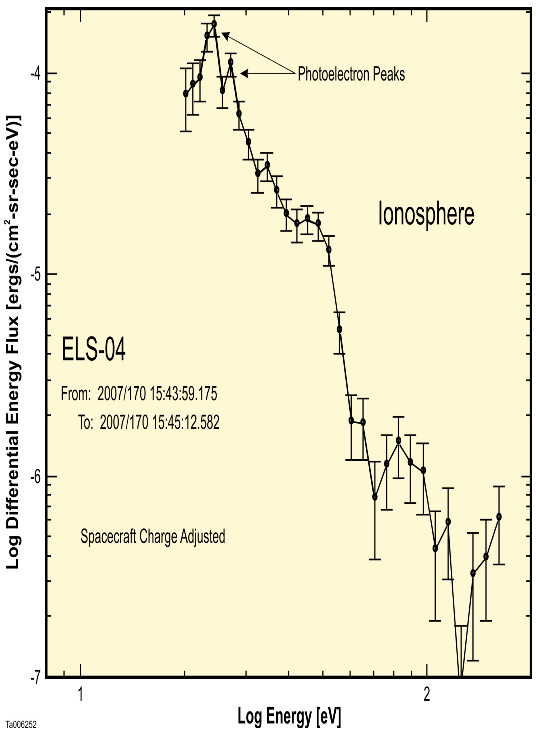


# Atmospheric Outflow from Mars

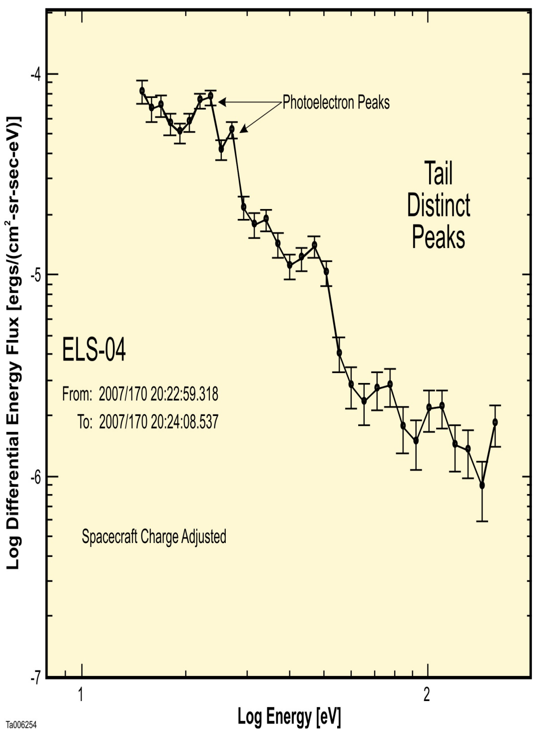


# Ionosphere and Tail Electron Spectra

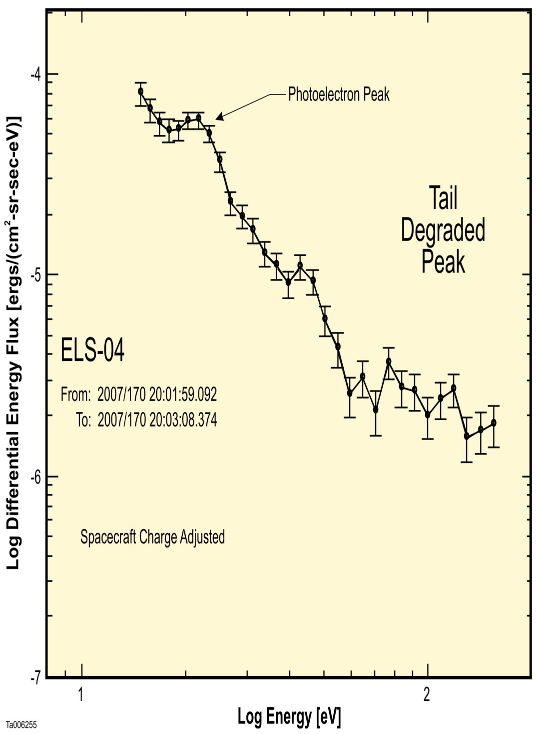
A




B

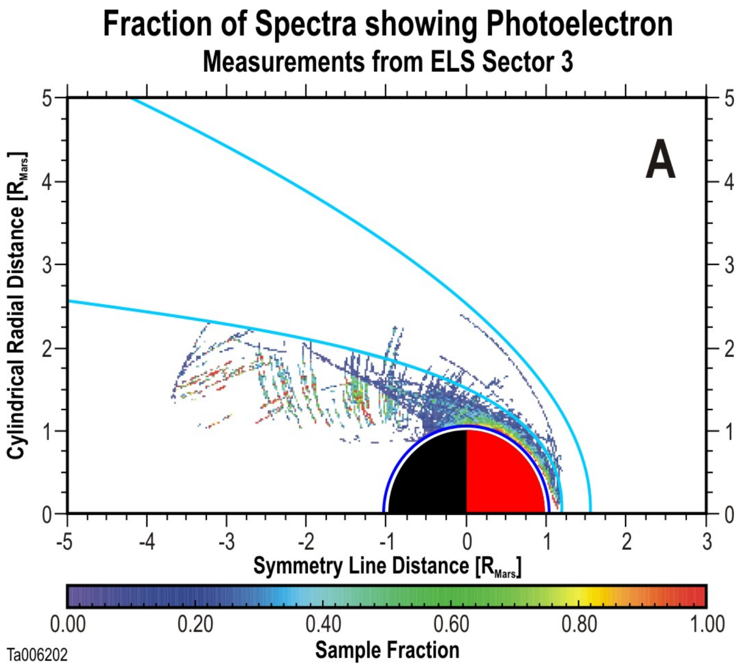


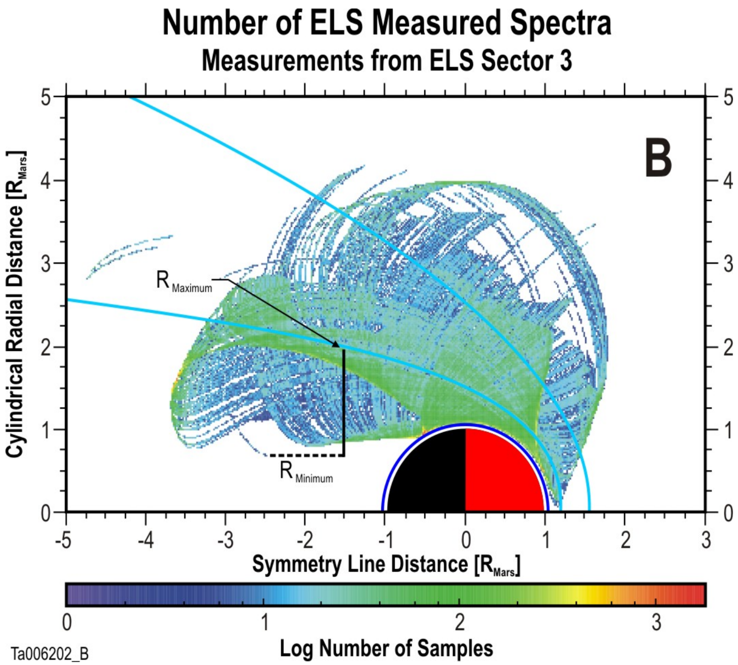

C



# 2004 Distinct Photoelectron Statistics

Jan 05, 2004 – Jan 25, 2005



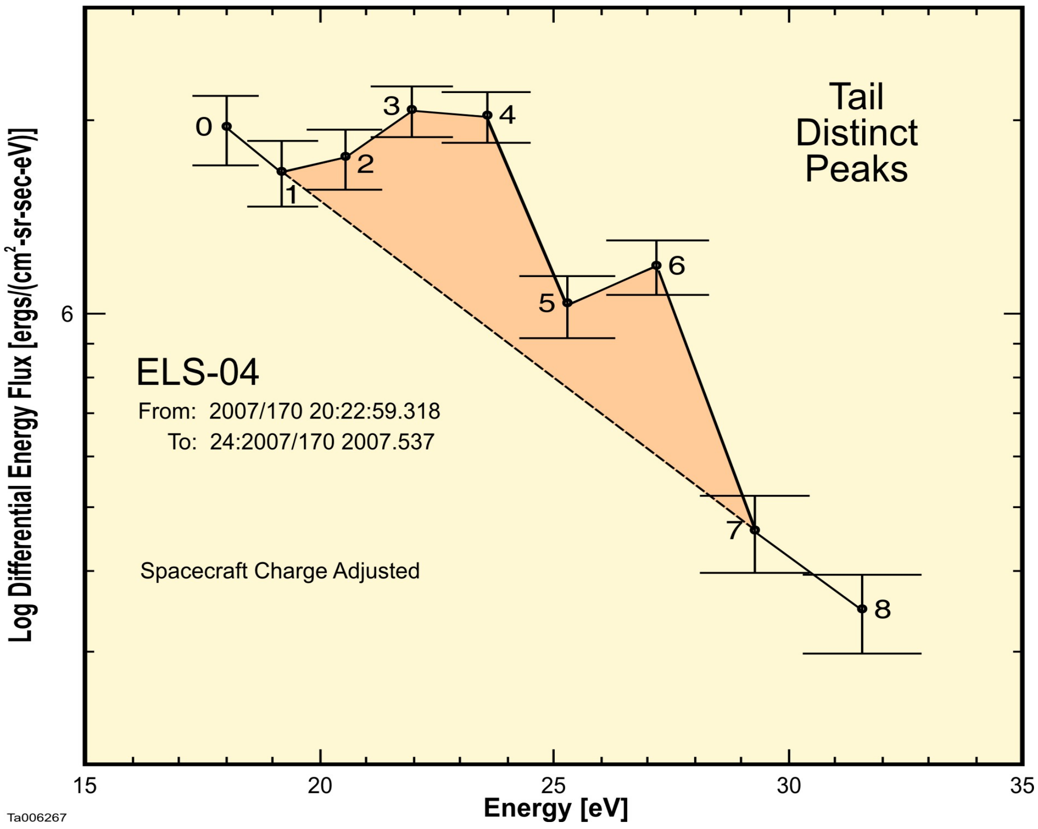




- 81,575 measured spectra less than 1.5 $R_{Mars}$ and below average MPB position
- 7,331 Photoelectron spectra less than 1.5 $R_{Mars}$ and below average MPB position
- ELS measured distinct photoelectron spectra 9% of the time

# Tail Area at 1.5 $R_{Mars}$

- $R_{max}$ = 6700 km (average MPB position)
- $R_{min}$ = 2850 km (min measured position)
- Annular Area = $1.16 \times 10^{18}$ $cm^2$

# Electron Flux Integration Details




Escaping Electron: 5,74 x $10^6$ electrons/(cm$^2$ s sr)

Uncertainty: 1.26 x $10^{26}$ electrons/(cm$^2$ s sr)

# Angular Measurement Range

Measurements typically between 1 and 3 ELS sectors.

Average angular area (2 ELS sectors): $0.478 \pm 0.235$ sr

# Estimation of Electron Outflow from Mars in 2004

Electron Outflow

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| = | Electron Flux | * | Angular Flow | * | Escape Area | * | Yearly Measured Fraction |
| = | $5.74 \times 10^{6}$ | * | 0.478 | * | $1.16 \times 10^{18}$ | * | 0.09 |

= $2.85 \pm 1.53 \times 10^{23}$ electrons/s

2004 Electron loss = 15 ± 8 Mmole

Acknowledgement: NASA Contract NASW-00003

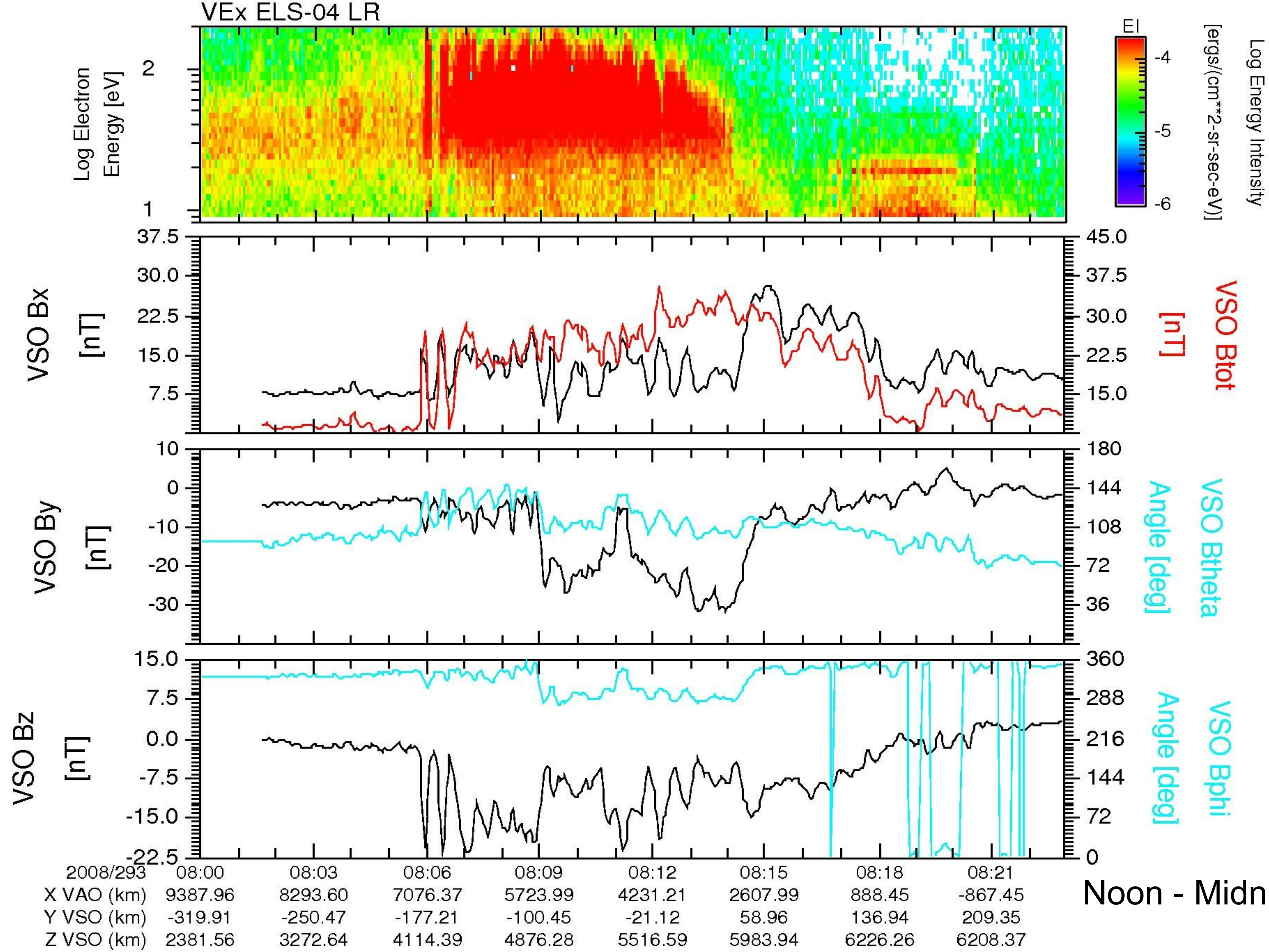
# How much is 15 Mmole?

We assume that all the escaping electrons from Mars are due to carbon dioxide and that the escape rate is the same for all time.

Mars is approximately 5 billion years old.

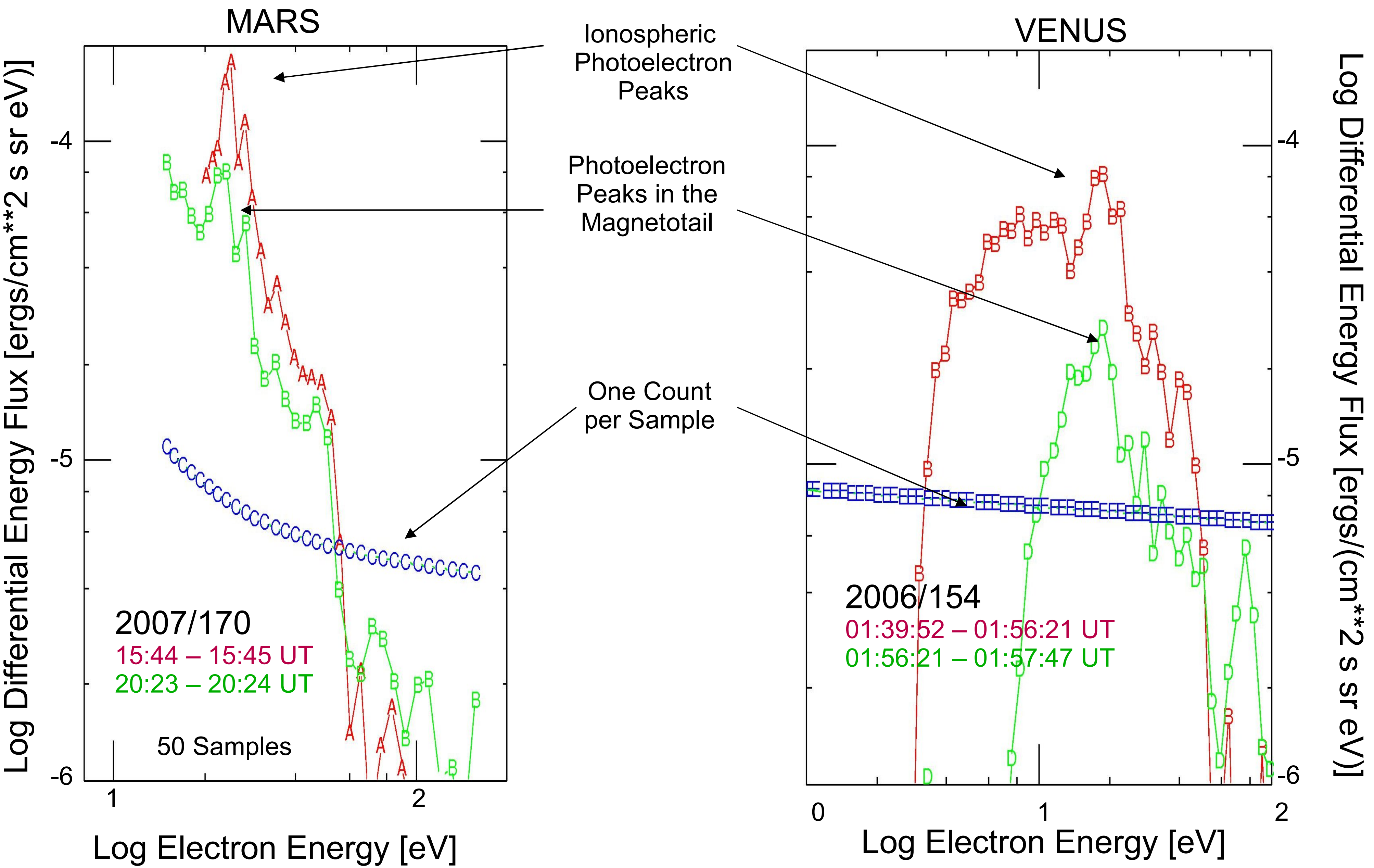
In 5 billion years, if all of the escaping carbon dioxide formed a frozen polar cap 1 mm thick above 80° latitude, this is the quantity which would have been lost from the planet since it was formed.

# Venus Express View




Noon - Midnight

# Electron Escape Down the Obstacle Tail



# Summary

During 2004, the average electron escape rate from Mars due to Solar Helium 30.4 nm radiation was $2.85 \pm 1.53 \times 10^{23}$ electrons/s.

For all of 2004, this electron outflow amounted to $15 \pm 8$ Mmole of electrons.

In 5 billion years, an equivalent amount of carbon dioxide amounting to a polar cap 1 mm thick above 80° latitude would have been lost under current escape rates.

# Acknowledgments

This presentation acknowledges the generous support from the NASA under contract NASW-00003 at Southwest Research Institute in the United States of America, as well as the individual national agencies and institutions which support the Mars Express program in Sweden and the United Kingdom.

# BACK-UP SLIDES

# Comparison to Ion Outflow

Object – Determine the number of electrons created by ionization of solar 30.4 nm HeII which escape Mars.

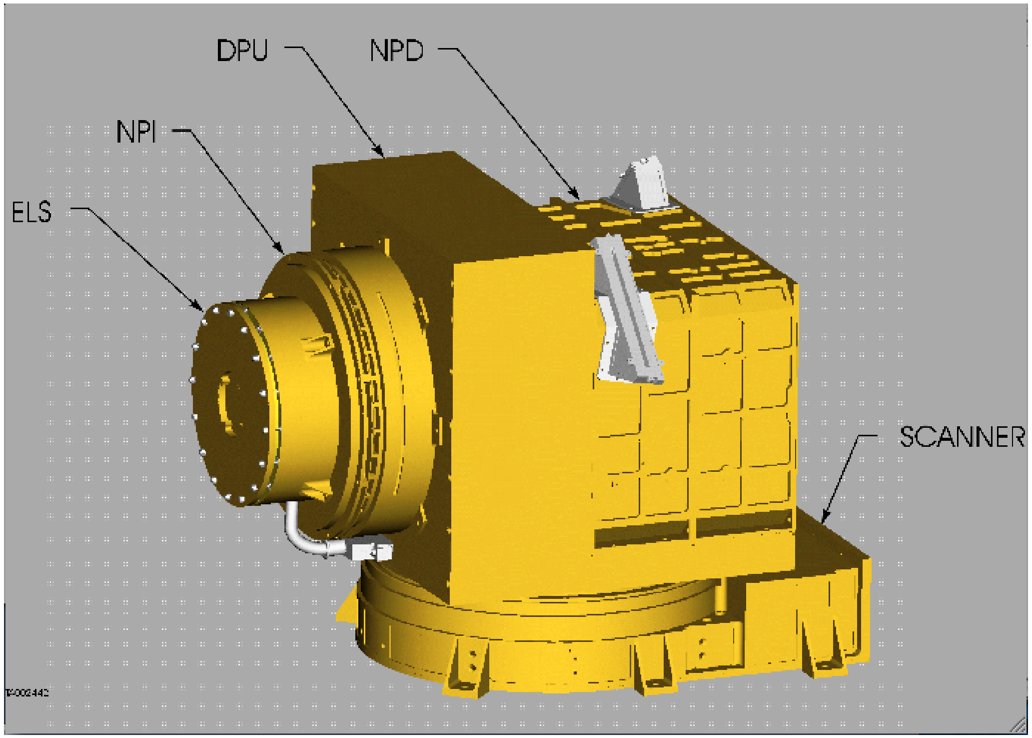
Ion Escape

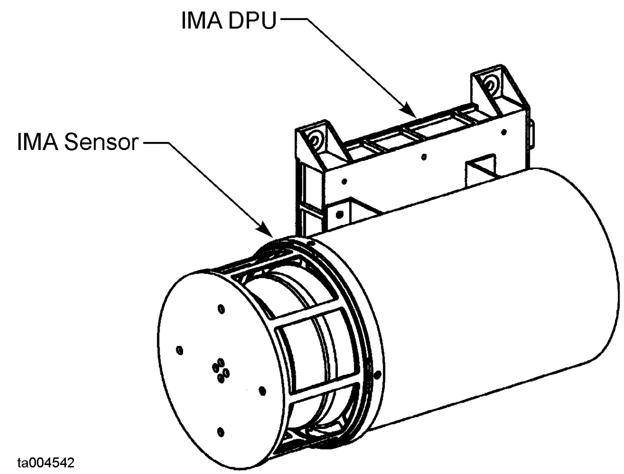
- Total Phobos-2 at Solar Max: $3 \times 10^{25}\ s^{-1}$ [Lundin et al., 1989,1990]
- Total MEX at Solar Min: $6\text{-}60 \times 10^{23}\ s^{-1}$ [Dubinin et al., 2006]
- $CO_2^+$ scaled from Phobos-2: $4 \times 10^{24}\ s^{-1}$ [Carlsson et al., 2006]
- $O^+$ from MEX: $1.6 \times 10^{23}\ s^{-1}$

  $O_2^+$ from MEX: $1.5 \times 10^{23}\ s^{-1}$

  $CO_2^+$ from MEX: $8 \times 10^{22}\ s^{-1}$ [Barabash et al., 2007]

# *ASPERA Instrumentation*



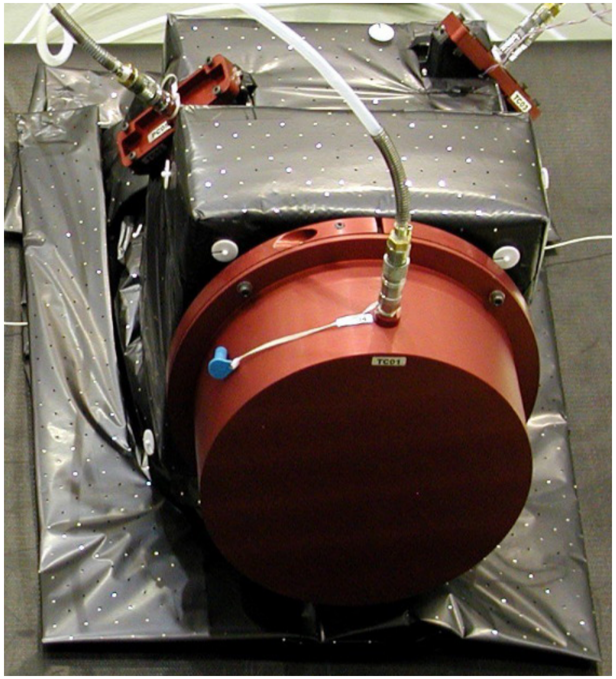




**<u>Main Unit:</u>**

- Neutral particle imagers (NPI, NPD)
- Electron spectrometer (ELS)
- Data processing unit (DPU)
- Mechanical scanner

Ion Mass Analyzer (IMA)

# *Packaged for Pre-launch Testing*



**Main Unit:**

- Neutral particle imagers (NPI, NPD)
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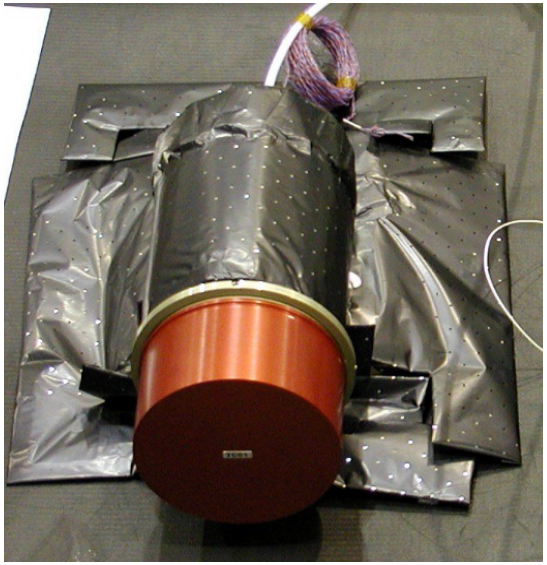
- Mechanical scanner



- Ion Mass Analyzer

# *Electron Spectrometer (ELS)*

The Electron Spectrometer (ELS) sensor is a light-weight, low-power, spherical top-hat electrostatic analyzer with collimation, detection, and readout system.

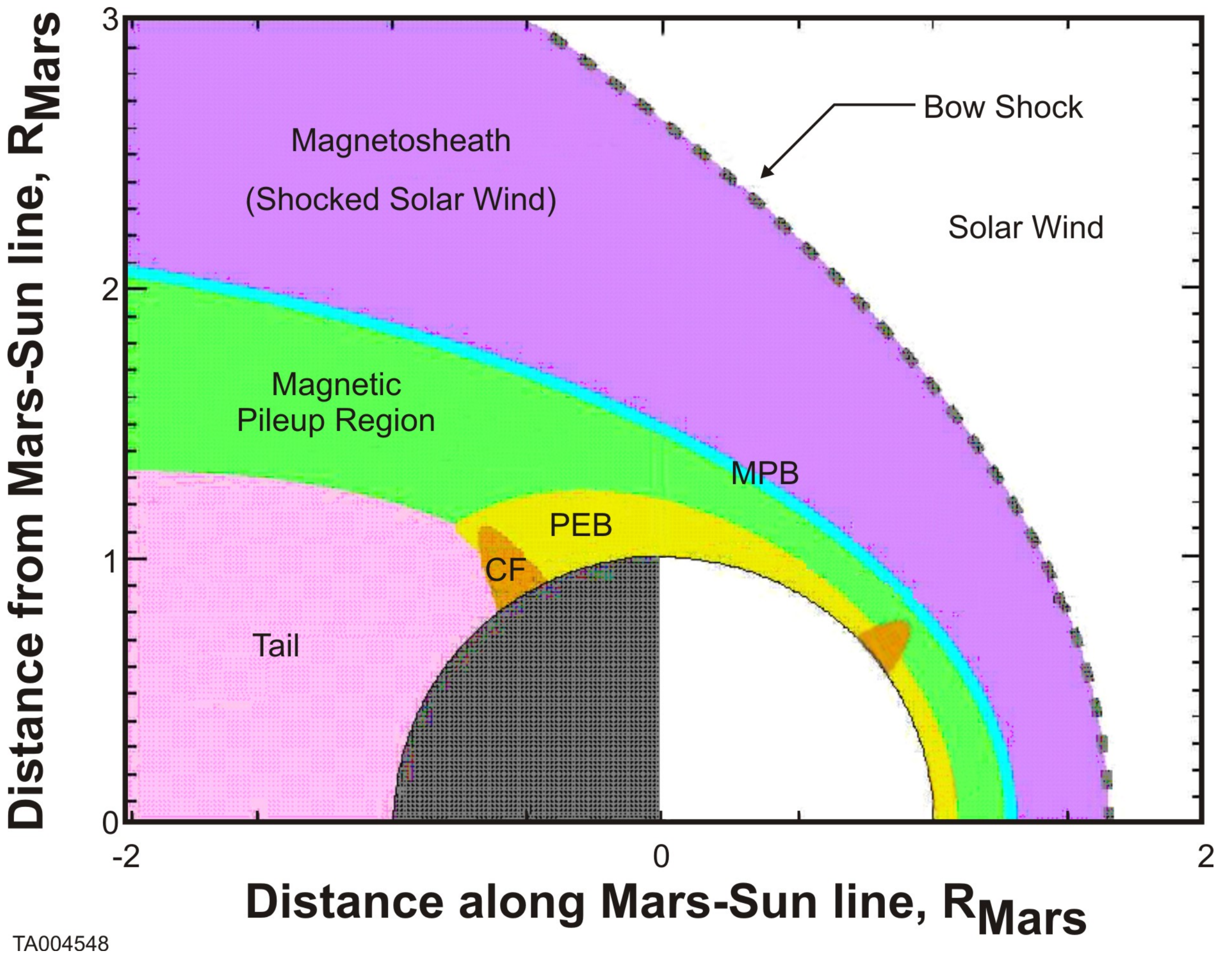
*It measures the electron spectrum:*
*electrons/cm$^2$ s sr eV vs. energy*

*Energy range: 1 eV/q to 20 keV/q, one energy sweep (128 energy levels) per four seconds.*

*Energy resolution is 7%.*

*There are 16 anodes around a 360° fov, each defining a 22.5 º sector.*

*Geometric factor (per sector) is 7.5 x 10 -5 cm$^2$ sr.*



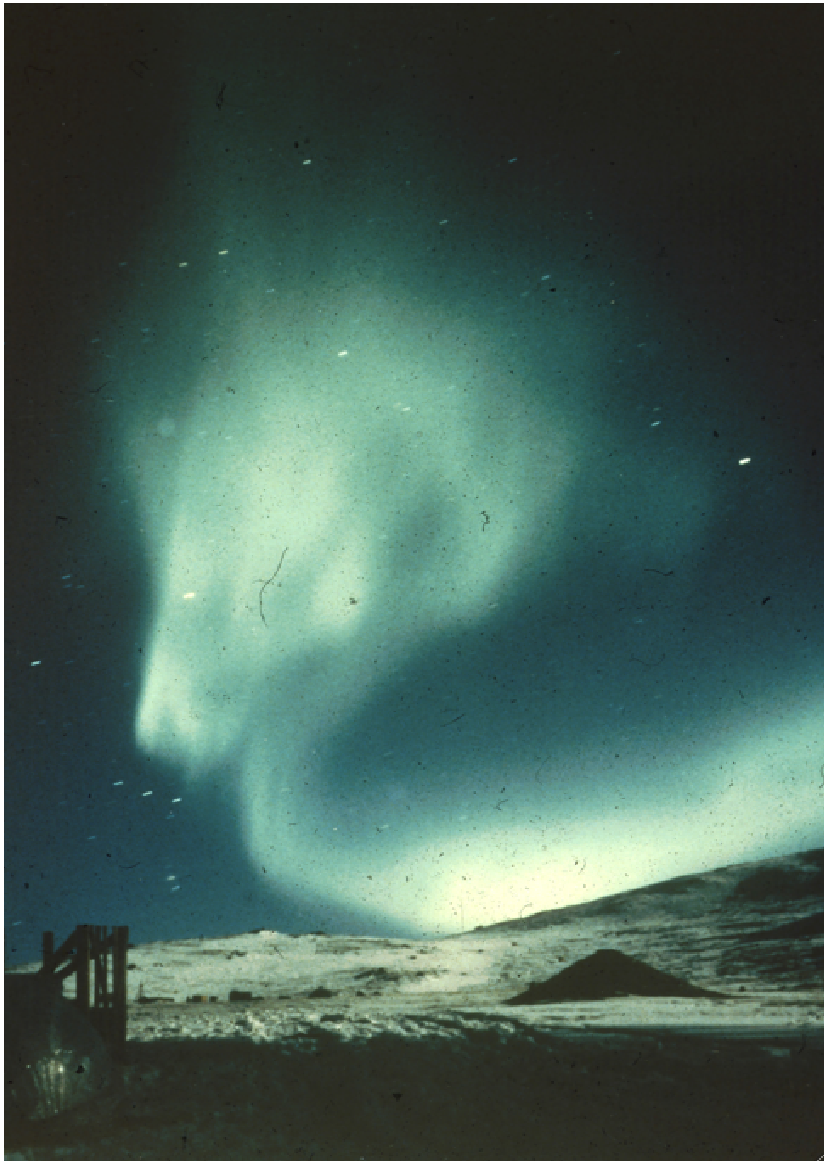
Bow Shock
Magnetosheath
(Shocked Solar Wind)
Solar Wind
Magnetic
Pileup Region
MPB
PEB
CF
Tail
Distance from Mars-Sun line, $R_{Mars}$
Distance along Mars-Sun line, $R_{Mars}$
3
2
1
0
-2
0
2
TA004548

*One of the topics of study here on the Earth is the* *<u>aurora borealis (northern lights)</u>.*

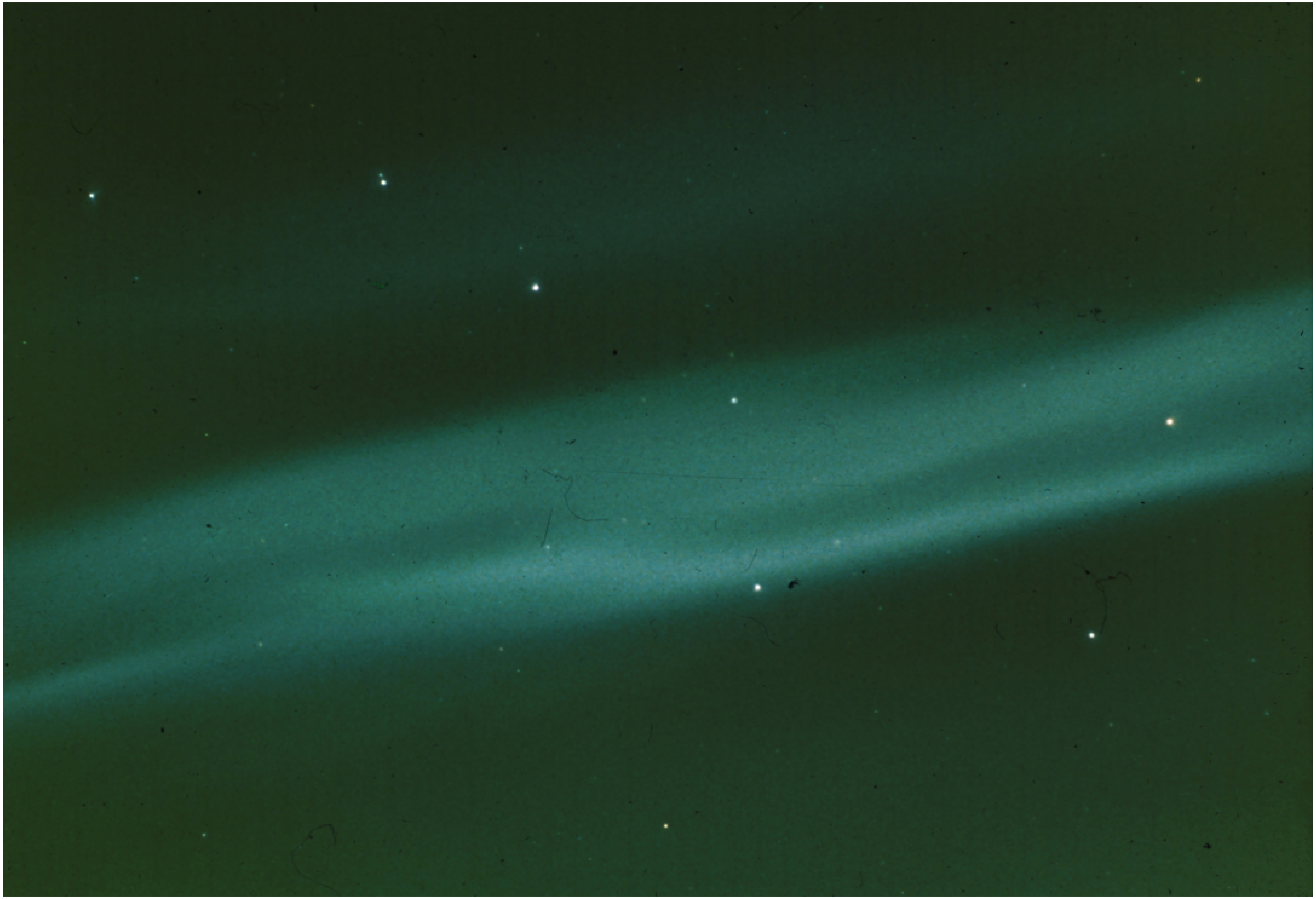
# AURORAL SHEETS

PICTURE TAKEN IN SAN ANTONIO IN 1989

# A BRIGHT AURORAL DISPLAY



# A STABLE ARC



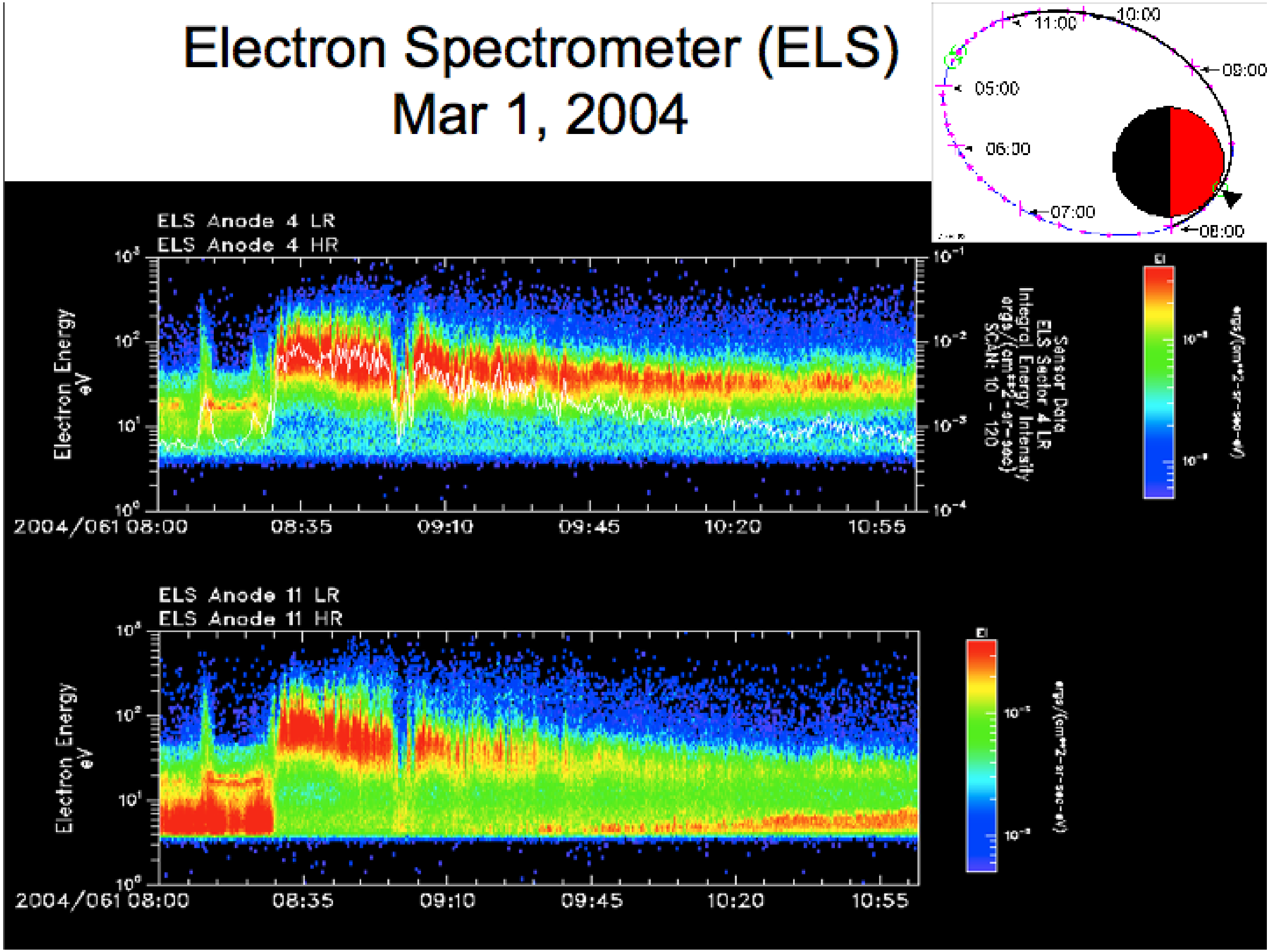
# Getting Ready for Launch in Kazakhstan

Soyuz - Fregot Launch Vehicle

Launch Day
June 2, 2003

# *Arrival on December 25, 2003*

# *Real Data from Mars*



# Calibration

*One of the most important things we do.*