SwRI's Contribution to the Analyzer of Space Plasmas and Energetic Atoms (ASPERA-3) Experiment on ESA's Mars Express

Presented By: Rudy A. Frahm
Present Status of Mars Express

All systems and experiments operational.
In orbit around Mars since December 2003.
Launch was June 2003.
The Mission Objectives

Mars Express is a mission of comparative planetology. It makes observations of the surface, atmosphere, surface - atmosphere and atmosphere - interplanetary medium interactions.

Mars Express is an imaging mission and performs:

- global high resolution imaging (photogeology)
- global high resolution IR imaging (mineralogical mapping)
- atmosphere composition monitoring (IR spectroscopy)
- global atmospheric UV imaging (mapping of atmospheric composition and circulation)
- subsurface remote sensing (radar)
- Global energetic and neutral atom imaging (plasma and neutral gas distributions)
MEX Management Implementation

- ESA
  - Science Performance and Operations
  - Spacecraft Design and Operations
  - Experiment Interfaces and Procurement

- PI's

- Matra Marconi Space
# The MEX Payload

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Name</th>
<th>Principal Investigators</th>
<th>Institute</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPERA</td>
<td>Energetic Neutral Atoms Analyser</td>
<td>R. Lundin</td>
<td>Swedish Institute of Space Physics, Kiruna, Sweden</td>
</tr>
<tr>
<td>HRSC</td>
<td>High Resolution Stereo Colour Imager</td>
<td>G. Neukum</td>
<td>Institut für Planetenforschung, Berlin, Germany</td>
</tr>
<tr>
<td>OMEGA</td>
<td>IR Mapping Spectrometer</td>
<td>J. P. Bibring</td>
<td>Institut d’Astrophysique Spatiale, Orsay, France</td>
</tr>
<tr>
<td>PFS</td>
<td>Atmospheric Fourier Spectrometer</td>
<td>V. Formisano</td>
<td>Istituto Fisica Spazio Interplanetario, Rome, Italy</td>
</tr>
<tr>
<td>RSE</td>
<td>Radio Science Experiment</td>
<td>M. Paetzold</td>
<td>University of Cologne, Cologne, Germany</td>
</tr>
<tr>
<td>SPICAM</td>
<td>UV Atmospheric Spectrometer</td>
<td>J. L. Bertaux</td>
<td>Serviced’Aeronomy, Verrieres-le-Buisson, France</td>
</tr>
<tr>
<td>SSRA</td>
<td>Sub-surface Sounding Radar / Altimeter</td>
<td>G. Picardi</td>
<td>University of Rome, Rome, Italy</td>
</tr>
<tr>
<td>Beagle 2</td>
<td>Lander</td>
<td>C. Pillinger</td>
<td>Open University, Milton Keynes, UK</td>
</tr>
</tbody>
</table>
ASPERA Team

R. Lundin, S. Barabash, H. Andersson, A. Grigoriev, M. Holmström, M. Yamauchi
K. Asamura JAXA / ISAS,
P. Bochsler, P. Wurz
A. Coates, D.R.Linder, D.O.Kataria
C. C. Curtis, K. C. Hsieh, B. R. Sandel
R. Frahm, J. Sharber, D. Winningham
M. Grande, M. Carter, D. H. Reading
H. Koskinen, E. Kallio, P. Riihela, T. Säles
J. Kozyra
N. Krupp, S. Livi, J. Woch
J. Luhmann
S. McKenna-Lawlor
S. Orsini, R. Cerulli-Irelli, A. Mura, A. Milillo
E. Roelof, D. Williams
J.-A. Sauvaud, A. Fedorov, J.-J. Thocaven

IRF, Kiruna, Sweden
Sagamichara, Japan
UBe, Switzerland
MSSL, UK
UA, Tucson, USA
SwRI, San Antonio, USA
RAL, Oxfordshire, UK
FMI, Helsinki, Finland
SPRL /U. of Michigan, Ann Arbor, USA
MPAe, Katlenburg-Lindau, Germany
SSL /U. of California in Berkeley, USA
STIL, Ireland
IFSI, Rome, Italy
APL /JHU, Laurel, USA
CESR, Toulouse, France
ASPERA-3 Components

IMA Unit:
- Ion Mass Analyzer (IMA)
- Data Processing Unit (DPU)

Main Unit:
- Neutral Particle Detector (NPD)
- Neutral Particle Imager (NPI)
- NPI Solar Sensors (SS)
- Electron Spectrometer (ELS)
- Main Unit DPU (MU)
- Scanner
Mars Express in orbit around MARS

ASPERA-3 Main Unit

ASPERA-3 IMA

Credits: ESA – Illustration by Medialabi, ID number: SEMBHY0P4HD
ASPERA-3 Ready for Flight
SwRI Areas of Involvement in ASPERA-3

SwRI was and is Involved in three areas which include: Hardware, Software, and Science.

All three areas of SwRI involvement began at the proposal stage and participated in the project simultaneously.
Hardware
John Scherrer - PM pre-launch

Tom Adamietz\textsuperscript{3}, Jack Alexander\textsuperscript{3}, Tony Alonzo\textsuperscript{1}, Albert Anaglia\textsuperscript{1}, Irene Arevalos, Willie Barth, Kim Barclay, Tom Booker\textsuperscript{4}, John Brune\textsuperscript{3}, Pat Casey\textsuperscript{3}, Jason Castillo\textsuperscript{1}, Carolin Chadwell\textsuperscript{1}, Pat Chenault, Greg Dirks, Joe Esquivel, Connie Garza\textsuperscript{1}, Robert Garza, George Geleta\textsuperscript{1,8}, Pat Gonzales, Chris Grandjean\textsuperscript{1}, Dennis Guerrero, Rita Guerrero, Brian Gupta\textsuperscript{3}, Bob Harbaugh, Marc Johnson, Sisoulith (Lit) Ksor\textsuperscript{1,8}, Joe Langle\textsuperscript{1}, Walter Lockhart\textsuperscript{5}, Larry McCullough\textsuperscript{3}, Walter McGinnis\textsuperscript{3}, Bill McLaren, Tom Mayces, Ernie Mayfield\textsuperscript{1}, Holly Mayfield\textsuperscript{1}, Richard Menchaca, Annette Nordenstam\textsuperscript{1}, Greg Palacios, Norm Pelletier, Kristian Persson, Susan Pope, Adrian Ramirez, Robert Rendon, Jeff Roese, Syrrel Rogillio\textsuperscript{3}, John Rudzki\textsuperscript{1}, James Sanders, Richard Sanders\textsuperscript{1,8}, Kelly Smith, Toby Stecklein\textsuperscript{1}, Norma Swaka, Tony Swaka, Linda (Bjork) Theis\textsuperscript{1}, Carlos Urdiales.

\textsuperscript{1}No longer at SwRI, \textsuperscript{2}Converted to TA, \textsuperscript{3}Retired from SwRI, \textsuperscript{4}Now in Div 18, \textsuperscript{5}Private Contractor, \textsuperscript{6}Div 16, \textsuperscript{7}Now at ITC, \textsuperscript{8}Deceased
SwRI Hardware Involvement

SwRI was involved in two of the four instruments comprising the ASPERA-3 experiment: IMA and ELS. SwRI was charged with improving the IMA anode and providing an ELS instrument.
SwRI IMA Involvement

1) SwRI improved the IMA anode design and functionality,
2) Built the IMA anode and 2 flight spare anodes,
3) tested the IMA anode.

remainder of IMA constructed at IRF and CESR

Note: 1 flight spare anode is in Ion Composition Analyzer instrument on Rosetta
ASPERA-3 IMA
Cross Section of IMA

- Electrostatic acceptance angle filter
- Electrostatic energy filter
- Magnetic mass filter
- Microchannel plates
- Ring (mass) and sector anodes
- Preamplifiers
- High voltage power supplies
- $360^\circ \times 90^\circ$ aperture
- Data Processing Unit
Improved IMA Anode
IMA Vacuum Testing
SwRI ELS Involvement

SwRI designed, built, and tested the ELS instrument and a flight spare ELS. (MSSL participation)

final calibration conducted at MSSL

The ELS flight spare is part of the ASPERA-4 experiment on ESA’s Venus Express.
ELS Electronics
ELS Housing
ELS Power & Deflection Systems
ELS Active/No Source
ELS Active/Source Active
ELS Testing
Software
Sandee Jeffers - PM post launch

Andrew Galus¹, Carrie Gonzalez, Andrew Hudson¹, Kevin Jennings⁵, Anders Johansson¹, Michael Madrigal⁶, William Motley, Joey Mukherjee, Michael Muller, Richard Murphy⁷, Jeran Pardue¹, David Preciado⁵, Louis Vela¹.

¹No longer at SwRI, ²Converted to TA, ³Retired from SwRI, ⁴Now in Div 18, ⁵Private Contractor, ⁶Div 16, ⁷Now at ITC, ⁸Deceased
Continual Software Tasks

1) Process all ASPERA-3 telemetry into IDFS format files: IMA, ELS, NPI, NPD, MU, Scanner, and Sun Sensors within 24 hours.
2) Generate Spacecraft Orbit and Attitude within 24 hours of availability.
3) Maintain EPO web site with quick-look ASPERA-3 Data.
4) Process and support correlative data sets.
5) Submit ASPERA-3 data to ESA and NASA long term data archives.
6) Support Science Activities.
http://www.aspera-3.org

- Where did the Martian water go?
- Is it lost or simply frozen?
- If it’s lost, what enabled it to escape the planet?
- If it’s frozen, where is the tremendous amount of water stored?

These are the questions that the ASPERA-3 experiment is helping to answer through the study of the solar wind/atmosphere interaction in near-Mars space. This device is onboard the Mars Express spacecraft launched in June of 2003. No instrument with similar scientific objectives has flown or is scheduled to be flown to Mars.
ASPERA-3 Data and Plots: http://mexdata.space.swri.edu
Spectrum Example
Spectrogram/Line Plot Example
NPI Strip Image Example
3D Interactive Orbit Plot Example

MARS/Mars_Express/AUXILIARY/Attitude/ATTSNP1R
2004/25 14:00:02.304 - 16:00:32.016
Standard Orbit Plot
NPI Center Look Directions

BLUE = Sector 0, RED = Sector 31
Examples of Contours
gPlot Example
Science
David Winningham\textsuperscript{2} - US PI

Kathy Coers, Rudy Frahm (ASPERA Co-I), Rick Link\textsuperscript{1}, Stefano Livi (ASPERA-3 Co-I), Venissa Preciado, Christina McCarty, Jim Sharber\textsuperscript{2} (ASPERA Co-I), Dave Slater.

\textsuperscript{1}No longer at SwRI, \textsuperscript{2}Converted to TA, \textsuperscript{3}Retired from SwRI, \textsuperscript{4}Now in Div 18, \textsuperscript{5}Private Contractor, \textsuperscript{6}Div 16, \textsuperscript{7}Now at ITC, \textsuperscript{8}Deceased
Contiguous Sampling Achievement

Expected Mars Photoelectron Spectrum at 145 km
from the ASPERA-3 Electron Plasma (ELS) Instrument
Instrument Response, Instrument Threshold (2 count), and Poisson Errors
Electrons in the Mars Ionosphere

- Magnetic Anomaly
- Ionospheric Plasma
- Sheath Plasma
- Transition Region
- Protection Grid
- Cut-Off
- Photoelectrons

Graph showing the distribution of electron energy and altitude over time with specific values for latitude and longitude.
30.4 nm Photoionization of Carbon Dioxide

\[ \text{CO}_2 + h\nu \rightarrow \text{CO}_2^+ + e^- \]

\[
\begin{cases}
X^2 \Pi_g \text{ ionization potential } 13.8 \text{ eV} \rightarrow 27.0 \text{ eV electron} \\
A^2 \Pi_u \text{ ionization potential } 17.7 \text{ eV} \rightarrow 23.1 \text{ eV electron} \\
B^2 \Sigma_u^+ \text{ ionization potential } 18.1 \text{ eV} \rightarrow 22.7 \text{ eV electron} \\
C^2 \Sigma_g^+ \text{ ionization potential } 19.4 \text{ eV} \rightarrow 21.4 \text{ eV electron}
\end{cases}
\]

[Padial et al., 1981]
30.4 nm Photoionization of Atomic Oxygen

\[ O + h\nu \rightarrow O^+ + e^- \]

\[ ^4S \text{ ionization potential } 13.62 \text{ eV} \rightarrow 27.16 \text{ eV electron} \]

\[ ^2D \text{ ionization potential } 17.10 \text{ eV} \rightarrow 23.68 \text{ eV electron} \]

\[ ^2P \text{ ionization potential } 18.50 \text{ eV} \rightarrow 22.28 \text{ eV electron} \]

[Mantas and Hanson, 1979]
Oversampling Spectral Resolution Achievement

Expected Mars Photoelectron Spectrum at 145 km
from the ASPERA-3 Electron Plasma (ELS) Instrument
Instrument Response, Instrument Threshold (2 count), and Poisson Errors
19 June 2007 Ionosphere Plasma

MEx IMA-00

Log Ion Energy [eV]

Log Integral Energy Flux
ELS Sector 4 / ergs/cm²-s-sec-eV
SCANS 5-100 eV

Nightside
PEB
Magnetic Anomaly
Dayside

MEx ELS-04

Magnetotail
Ionosphere
Magnetosheath

Log Electron Energy [eV]

Photoelectron Peaks

Log Differential Energy Flux
ELS/IMARS/PdD Distance [km]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SZA (deg)</td>
<td>104.64</td>
<td>88.70</td>
<td>69.20</td>
<td>46.78</td>
<td>24.09</td>
<td>9.87</td>
</tr>
<tr>
<td>PdLt (deg)</td>
<td>-49.34</td>
<td>-65.40</td>
<td>-84.24</td>
<td>-71.79</td>
<td>-48.21</td>
<td>-26.08</td>
</tr>
<tr>
<td>PdLon (deg)</td>
<td>80.84</td>
<td>82.73</td>
<td>108.60</td>
<td>242.64</td>
<td>247.51</td>
<td>248.10</td>
</tr>
<tr>
<td>SolTime (hr)</td>
<td>1.59</td>
<td>7.20</td>
<td>11.96</td>
<td>12.38</td>
<td>12.55</td>
<td>12.66</td>
</tr>
<tr>
<td>SolLat (deg)</td>
<td>-73.98</td>
<td>-85.77</td>
<td>-69.19</td>
<td>-46.50</td>
<td>-22.73</td>
<td>-0.67</td>
</tr>
</tbody>
</table>
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
Electron Flux Integration Details

Escaping Electron: $5.74 \times 10^6$ electrons/(cm$^2$ s sr)
Uncertainty: $1.26 \times 10^{26}$ electrons/(cm$^2$ s sr)
Photoelectron Escape Rate

Electron Outflow

\[ \text{Electron Outflow} = \text{Electron Flux} \times \text{Angular Flow} \times \text{Escape Area} \times \text{Yearly Measured Fraction} \]

\[ = 5.74 \times 10^6 \times 0.478 \times 1.16 \times 10^{18} \times 0.09 \]

\[ = 2.85 \pm 1.53 \times 10^{23} \text{ electrons/s} \]

2004 Electron loss = 15 ± 8 Mmole

Acknowledgement: NASA Contract NASW-00003
Conclusion

The ASPERA program at SwRI has been highly successful in achieving hardware, software, and science goals.

SwRI has made this FIRST NASA Discovery Program Mission of Opportunity a success.

Thanks to all who have contributed to and continue to contribute to the ASPERA program.

Acknowledgement: NASA Contract NASW-00003