MAVEN

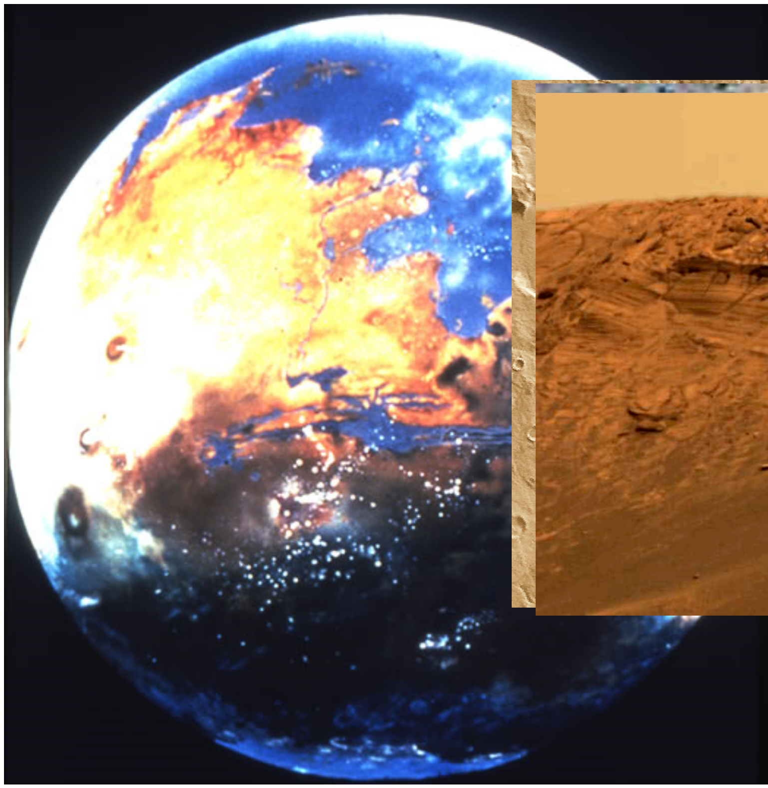
Space weather and Mars: Observations from MAVEN

Jared Espley

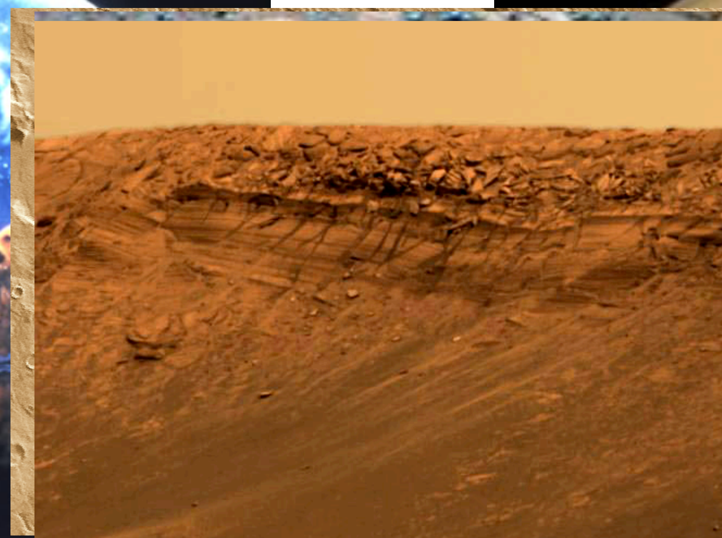
Laboratory for Planetary Magnetospheres

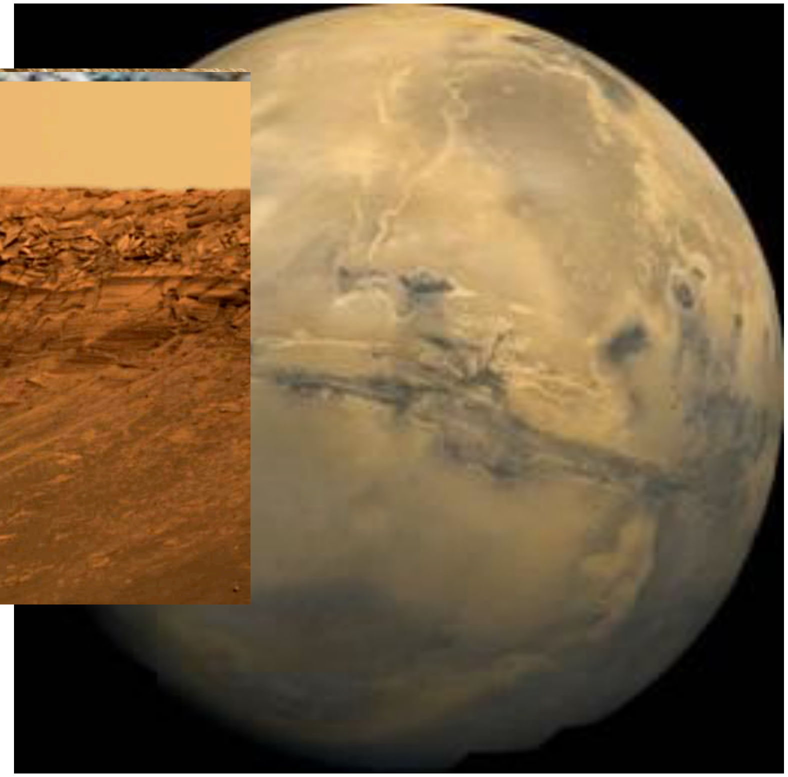
NASA Goddard

Ancient Mars was warm and wet; modern Mars is cold and dry



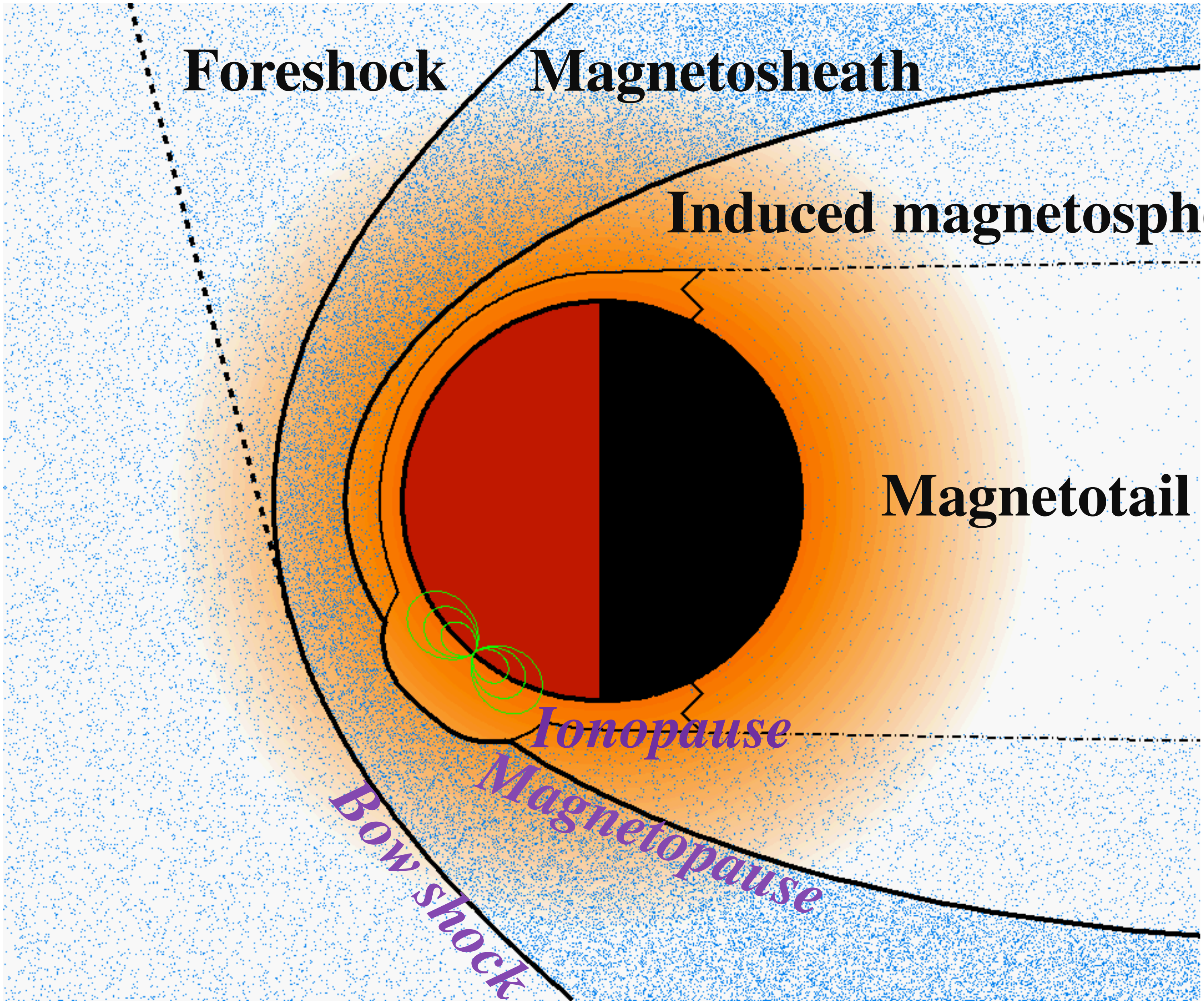
Ancient wet Mars





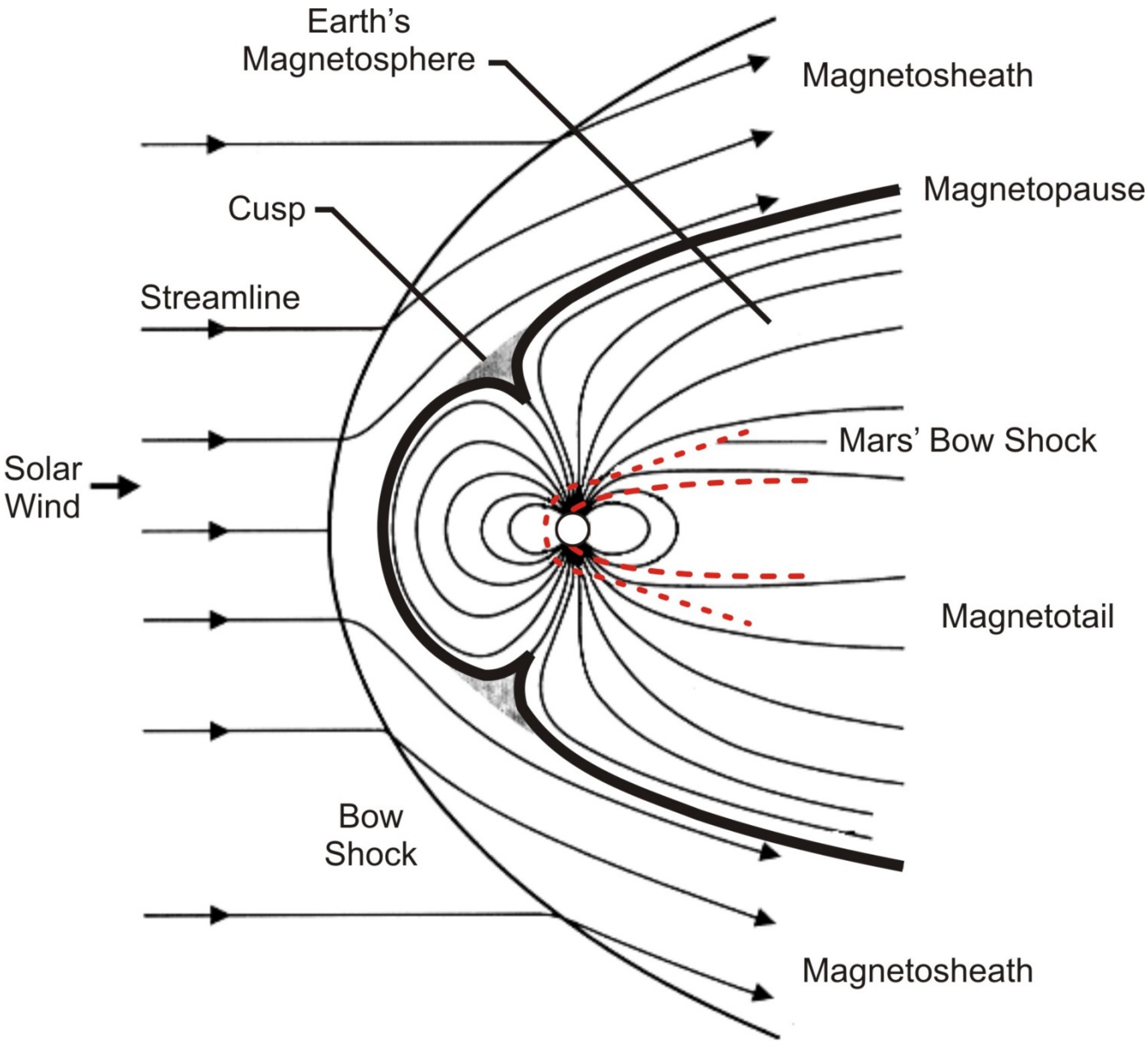
Modern dry Mars

The martian “magnetosphere”



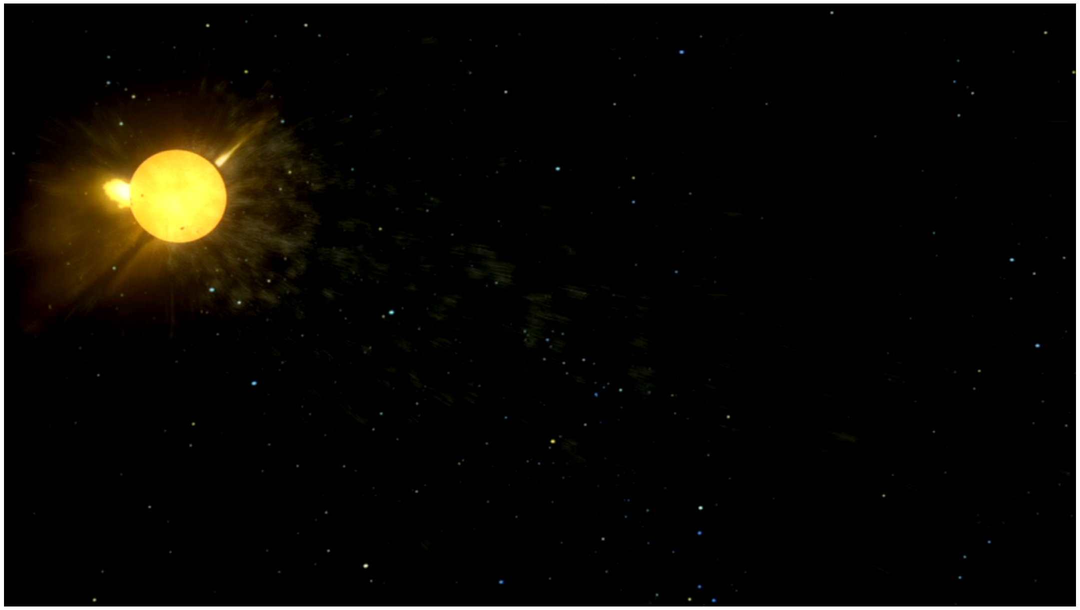
From D. Brain

Terrestrial vs. Martian Magnetospheres

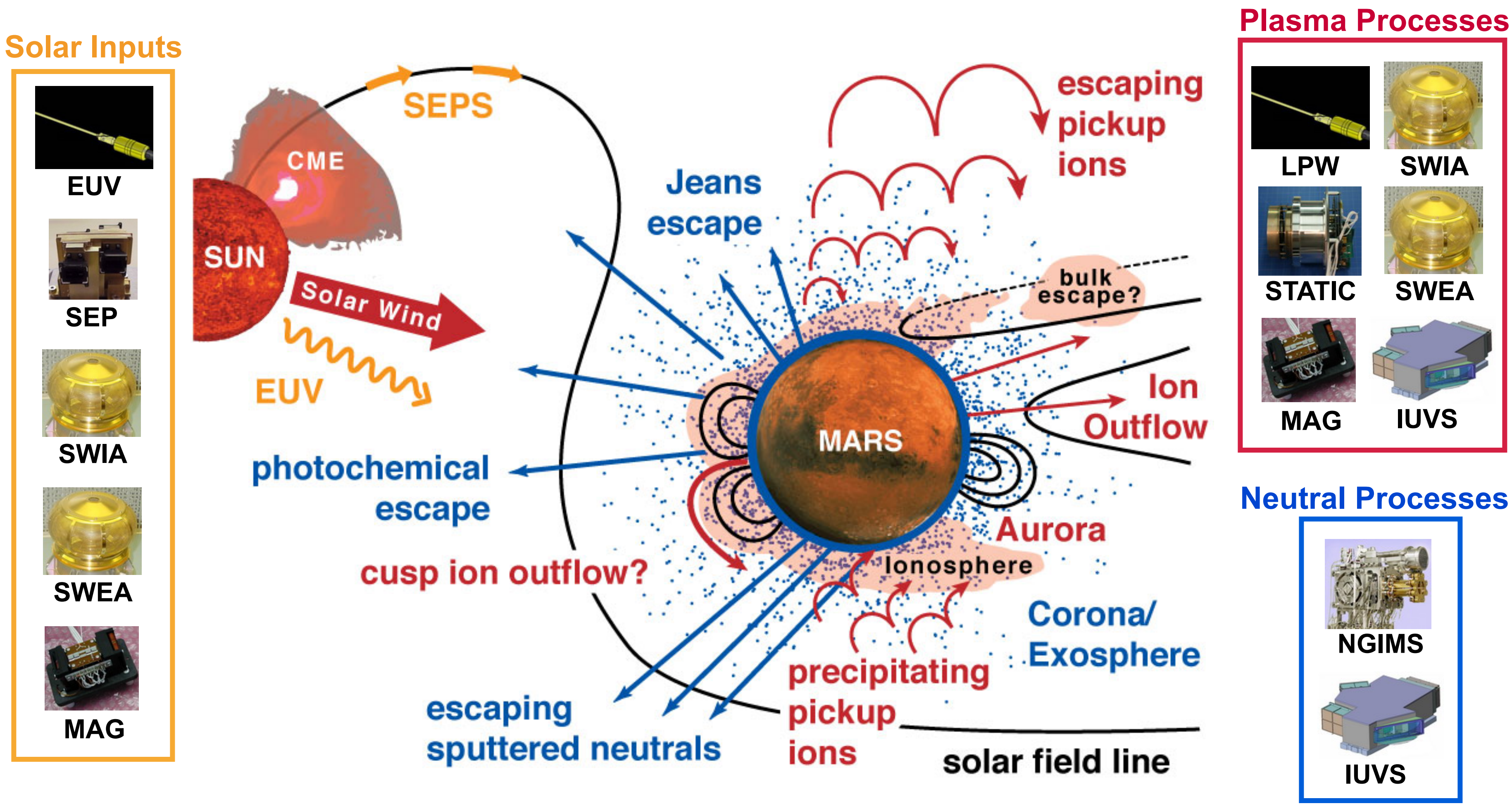


Did the solar wind erode away the martian atmosphere?

1. Liquid metallic core produces planetary magnetosphere
2. Core solidifies and magnetosphere lost
3. With no planetary magnetosphere, the solar wind gradually erodes the martian atmosphere
   – Generally very mild effect but it has had 3.5 billion years to work (plus solar storms).

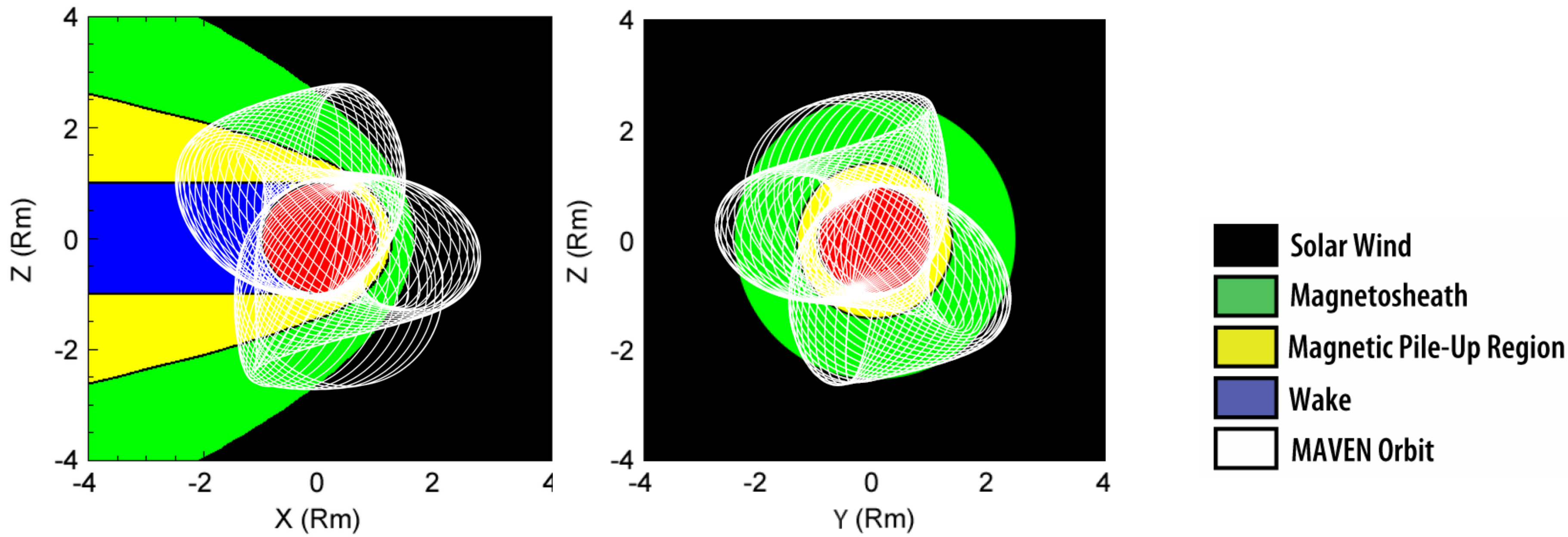


MAVEN science measurements

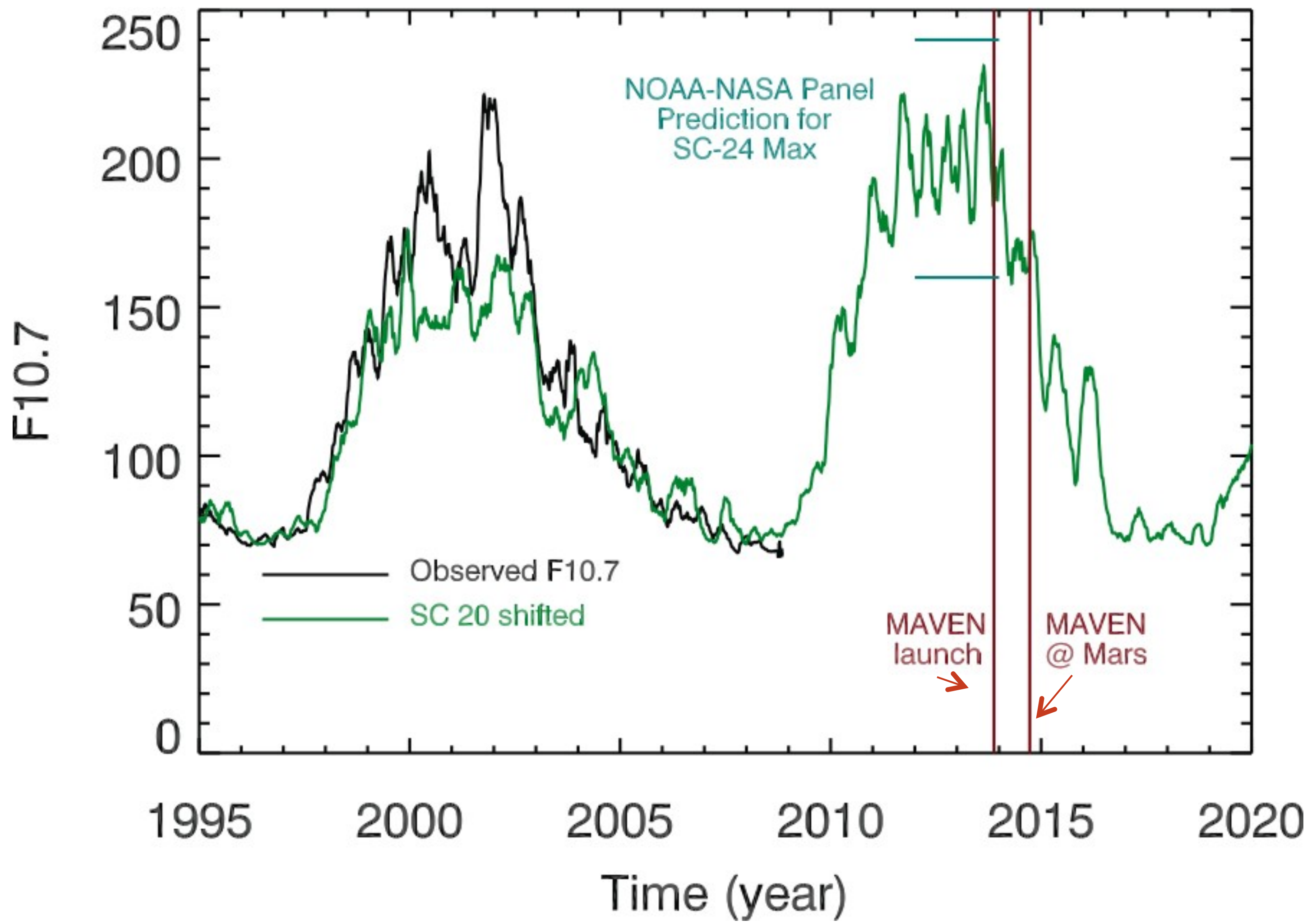


MAVEN Orbit and Primary Mission

- Elliptical orbit to provide coverage of all altitudes
- The orbit precesses in both latitude and local solar time
- One-Earth-year mission allows thorough coverage of near-Mars space



MAVEN's Timing in the Solar Cycle

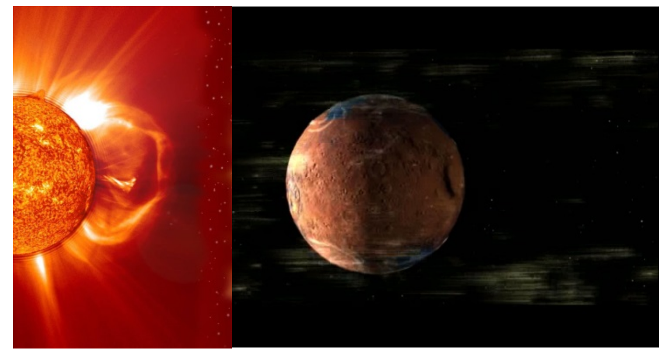


Space weather and MAVEN

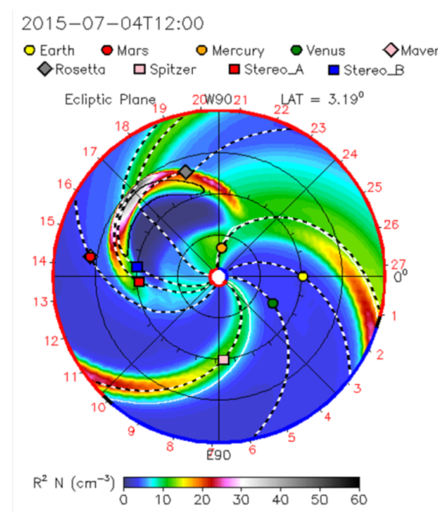
MAVEN
Mars Atmosphere and Volatile Evolution Mission
CU/LASP • GSFC • UCB/SSL • LM • JPL

- Operational responses?
  - Very limited (e.g. Comet Siding Spring)

- Science opportunities
  - Space weather drives atmospheric escape: main MAVEN goal



- Collaborative opportunities
  - Comparisons with heliospheric simulations (e.g. ICME, SEP arrival times)
  - Upstream/downstream monitoring (e.g. ACE, STEREO, DSCVR, Mars Express, Rosetta)



MAVEN contacts

- Bruce Jakosky, PI, U-Colorado
- Janet Luhmann, Deputy PI, UC-Berkley
- Joe Grebowsky, Project Scientist, GSFC 695
- Phil Chamberlin, EUV team, GSFC 670
- Jared Espley, MAG team, GSFC 695
- Jacob Gruesbeck, MAG team, GSFC 695

Jared.Espley@nasa.gov

Extras

Mars Atmosphere and Volatile Evolution Mission

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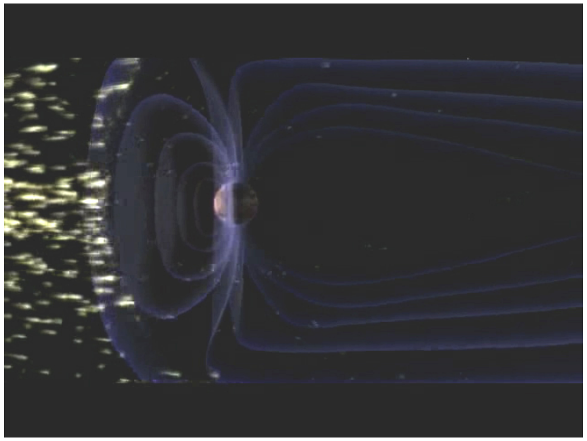
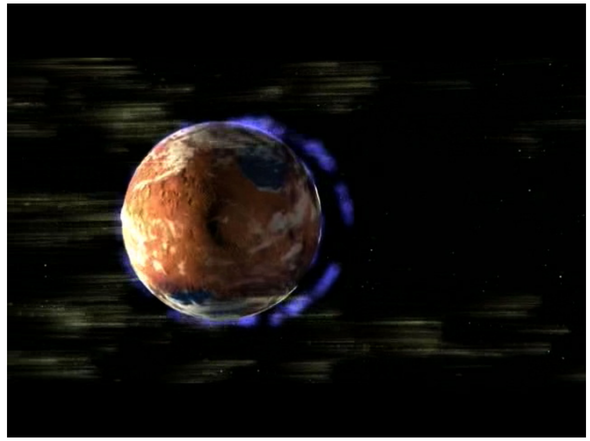
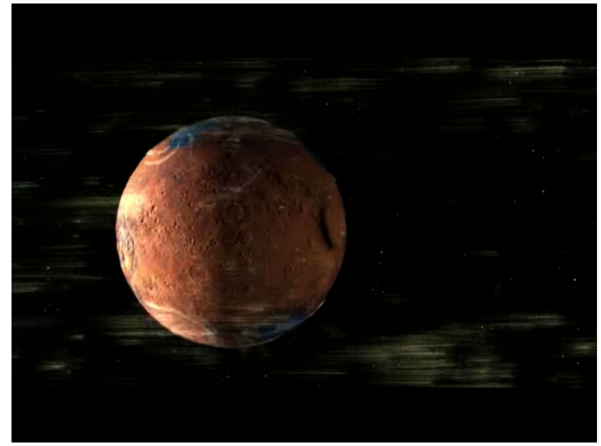
Hypothesis: Mars lost its magnetosphere so the solar wind eroded its atmosphere



Liquid metallic core produces planetary dynamo and magnetosphere

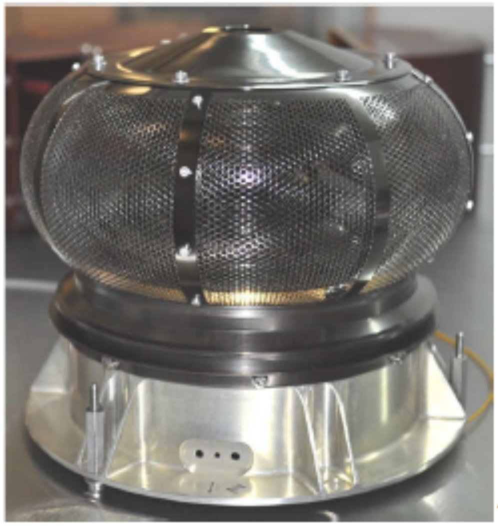


Core solidifies and dynamo ceases



Solar wind interacts directly with the ionosphere and gradually erodes the atmosphere over billions of years

Solar Wind Electron Analyzer (SWEA)
David L. Mitchell, SSL

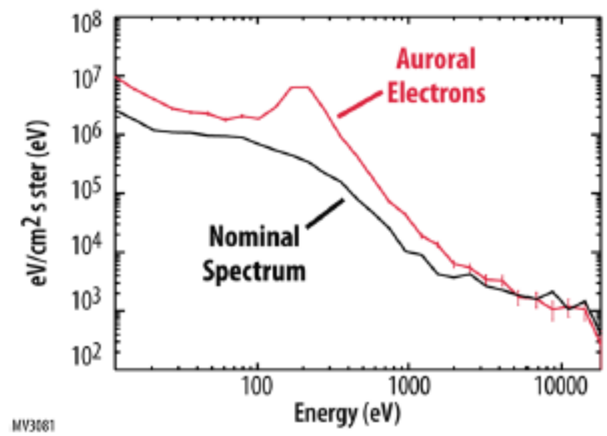


SWEA Flight Analyzer

Measurement objectives:
- Measure energy and angle distributions of electrons in the Mars environment
- Determine electron impact ionization rates
- Measure magnetic topology via loss cone measurements
- Measure primary ionospheric photoelectron spectrum
- Measure auroral electron populations
- Evaluate plasma environment

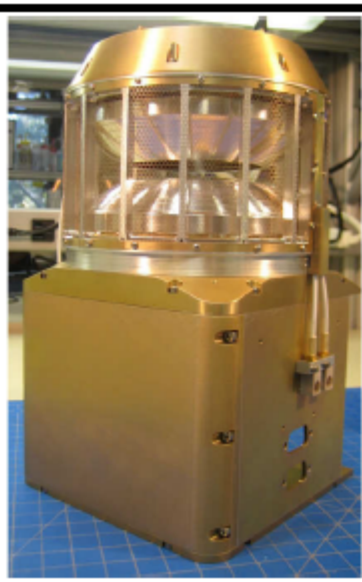
Technical details and heritage:
- Hemispherical Electrostatic Analyzer
- Electrons with energies from 5 eV to 5 keV
- FOV 360º X 130º
- Angular resolution 22.5º in azimuth, better than 14º in elevation
- Energy fluxes 10^3 to 10^9 eV/cm^2-s-ster-eV
- Energy resolution 18% (capability for 9% below 50 eV)
- Based on STEREO SWEA

MGS measurements of auroral electrons:



Solar Wind Ion Analyzer (SWIA)

Jasper Halekas, SSL



SWIA Engineering Model

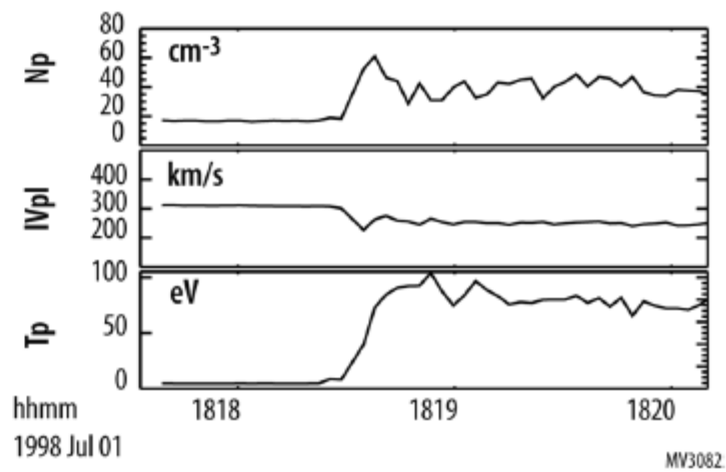
Measurement objectives:

- Density and velocity distributions of solar wind and magnetosheath ions to determine the charge exchange rate and the bulk plasma flow from solar wind speeds (~350 to ~1000 km/s) down to stagnating magnetosheath speeds (tens of km/s).

Technical details and heritage:

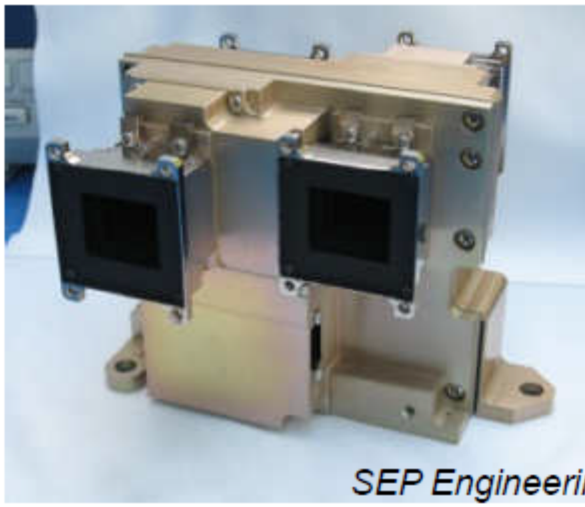
- Proton and alpha velocity distributions from <50 to >2000 km/s, density from 0.1 to >100 cm^{-3}. Energy resolution of ~10% and angular resolution of ~22.5° (4.5° around sun). Intrinsic time resolution of 4 s.
- Heritage from Wind, FAST, and THEMIS.

Similar measurements provided by *Wind*:



Solar Energetic Particle (SEP) Analyzer

Davin Larson, SSL



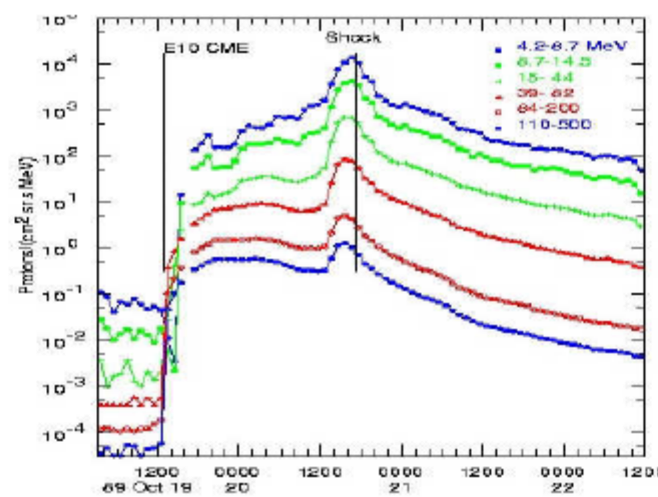
SEP Engineering Model

Measurement objectives:

- Characterize solar particles in an energy range that affects upper atmosphere and ionospheric processes (~120 – 200 km)
- Time resolution adequate to capture major SEP events (<1 hour)

Technical details and heritage:

- Two dual double-ended telescopes
- Four look directions/species, optimized for parallel and perpendicular Parker Spiral viewing
- Protons and heavier ions from ~25 keV to 12 MeV
- Electrons from ~25 keV to 1 MeV
- Energy fluxes 10 to 10^6 eV/cm^2-sec-ster-eV
- Better than 50% energy resolution
- Nearly identical to SST on THEMIS



Prompt Mev proton enhancement after solar disturbance and at arrival of shock (Reams, 1999)

Suprathermal and Thermal Ion Composition (STATIC)

Jim McFadden, SSL

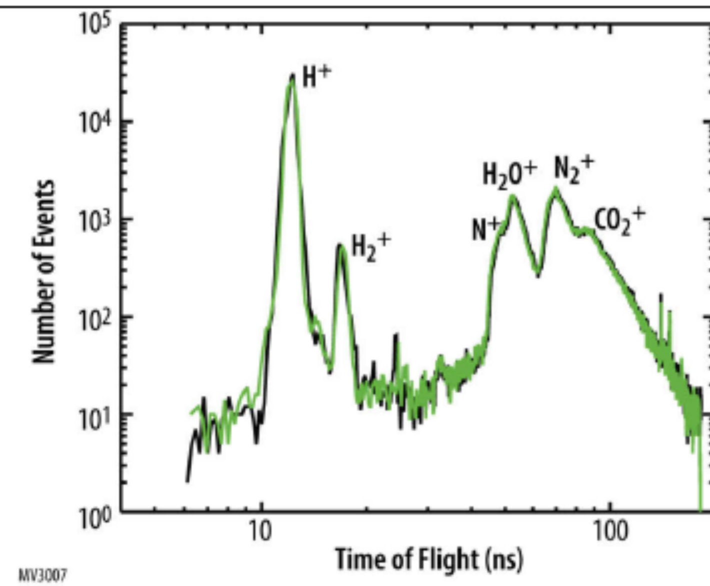
STATIC Engineering Model

Measurement objectives:

- Escaping ions and processes
- Composition of thermal to energetic ions; energy distributions and pitch angle variations
- Ionospheric Ions 0.1-10 eV
- Tail superthermal ions (5-100eV)
- Pick-up Ions (100-20,000 eV)
- Key ions H^+, O^+, O_2^+, CO_2^+

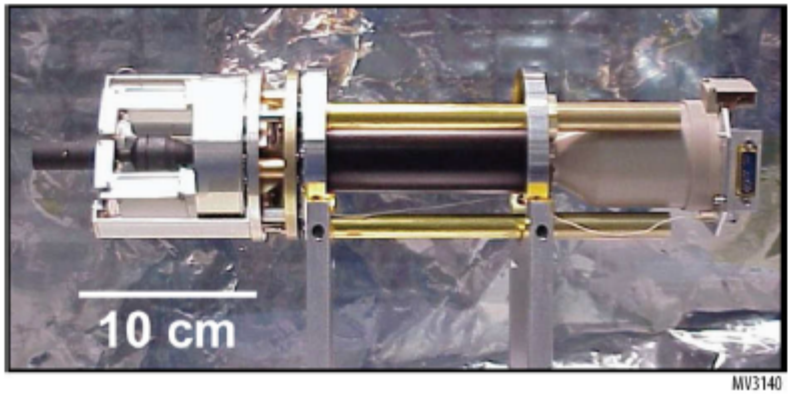
Technical details and heritage:

- Toroidal Electrostatic Analyzer with Time of Flight section
- Mass range 1-70 AMU, $\Delta M/M > 4$
- Energy range ~1 eV to 30 keV, $\Delta E/E$~15%
- FOV 360º X 90º
- Angular resolution 22.5ºX6º
- Energy flux < 10^4 to 10^8 eV/cm^2-s-sr-eV (to 10^{12} w/attenuators for low energy beam)
- Can be oriented to measure either upwelling/ downwelling ions or horizontal flows
- Heritage from Cluster CODIF.



Laboratory spectrum from Engineering Model

Langmuir Probe and Waves (LPW)
Bob Ergun, LASP



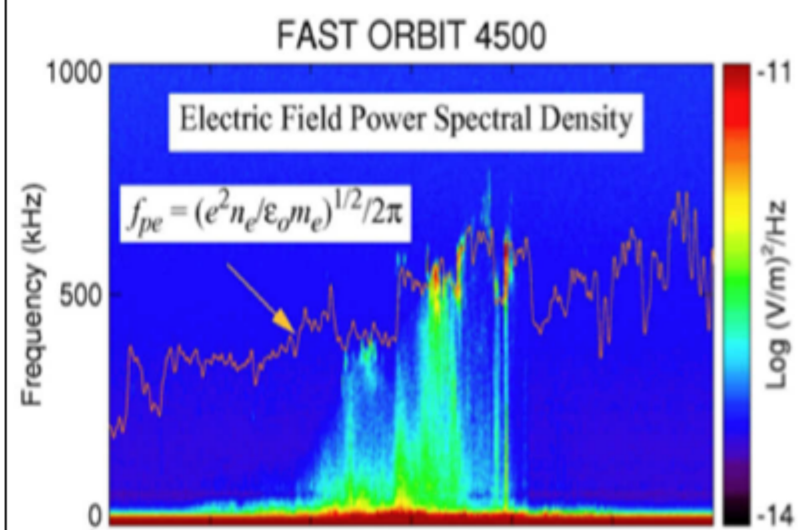
LPW Stacer boom (undeployed)

Measurement Objectives:

- Electron temperature and number density throughout upper atmosphere
- Electric field wave power at low frequencies important for ion heating
- Wave spectra of naturally emitted and actively stimulated Langmuir waves to calibrate density measurements

Technical details and heritage:

- Cylindrical sensors on two 7-meter booms
- I-V sweeps (at least ±50 V range) of sensors
- Low frequency E-field wave power sensing (f: 0.05-10 Hz); sensitivity10^{-8} $(V/m)^2/Hz$ $(f_0/f)^2$ where f_0=10 Hz and 100% bandwidth
- E-Spectra measurements up to 2 Mhz
- White noise (50 kHz-2 MHz) sounding
- Thermal Electron density 100 to 10^6 cm^{-3}
- Electron temperatures 500 to 5000° K
- Heritage from THEMIS and RBSP



Magnetometer (MAG)
Jack Connerney, GSFC

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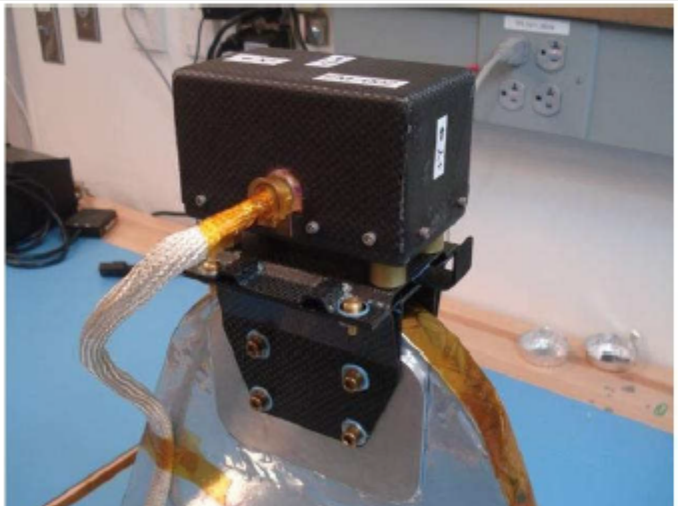


MAG Flight Model

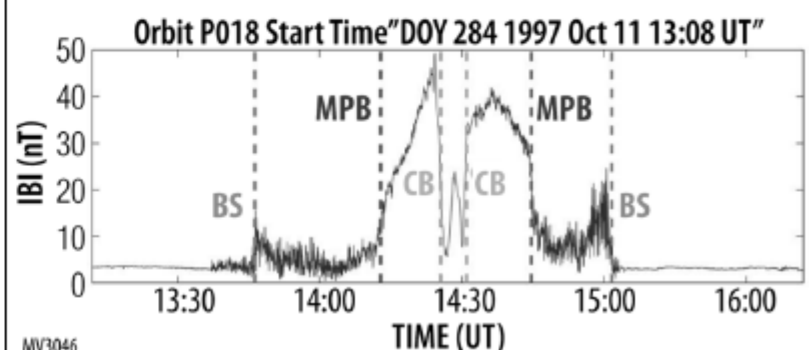
Measurement objectives:

- Vector magnetic field in the unperturbed solar wind (B ~ 3 nT), magnetosheath (B ~ 10-50 nT), and crustal magnetospheres (B < 3000 nT)
- Ability to spatially resolve crustal magnetic cusps (horizontal length scales of ~100 km)

Technical details and heritage:

- Magnetic field over a dynamic range of ~ 0.1 nT to ~ 60,000 nT, with 1 sec time resolution (4 km spatial resolution), 1° angular determination, and 5% precision on scalar value
- Heritage: *MGS, Voyager, AMPTE, GIOTTO, CLUSTER, Lunar Prospector, MESSENGER* and others; identical to MAG on *STEREO*

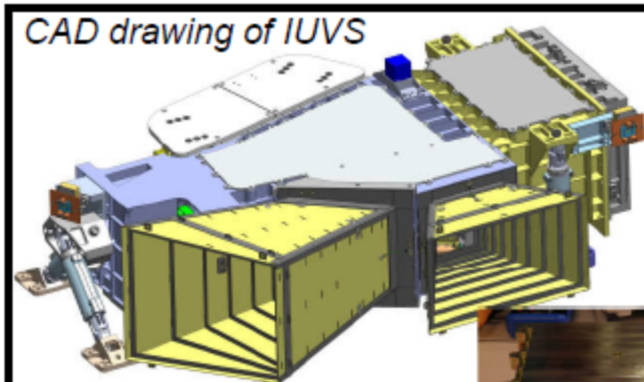
MGS MAG measurements:



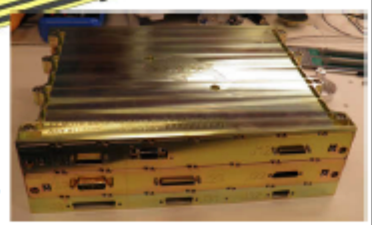
Imaging Ultraviolet Spectrometer (IUVS)

Nick Schneider, LASP

CAD drawing of IUVS



Flight Data Processing Unit

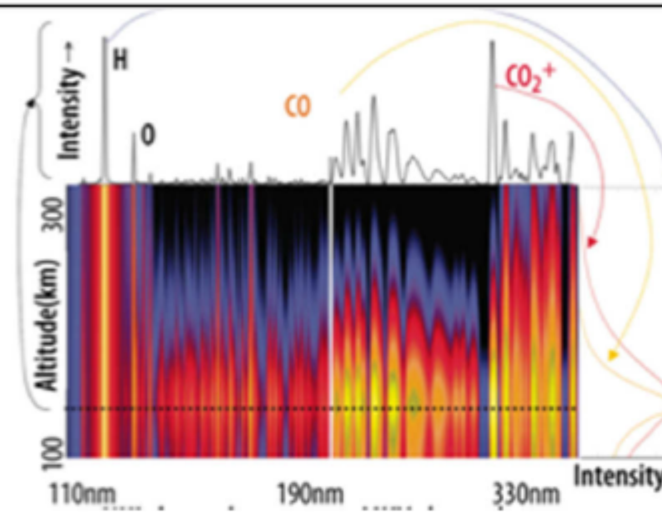


Measurement objectives:

- Vertical profiles of neutrals and ions through limb emissions and lower atmosphere properties from stellar occultations
- Disk maps from near apoapsis.
- D/H and hot oxygen coronal mapping
- Atmospheric properties below homopause

Technical details and heritage:

- Imaging spectroscopy from 110-340 nm, with resolution of 0.5 nm
- Vertical resolution of 6 km on limb, horizontal resolution of 200km in nadir viewing
- Detectors: Image-intensified 2-D active pixel sensors
- Most recent heritage from AIM CIPS

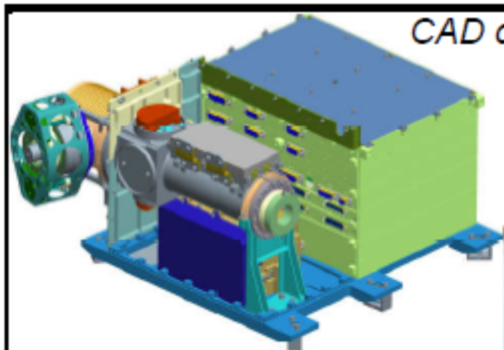


Model spectra and derived profiles

Neutral Gas and Ion Mass Spectrometer (NGIMS)

Paul Mahaffy, GSFC

CAD drawing of NGIMS



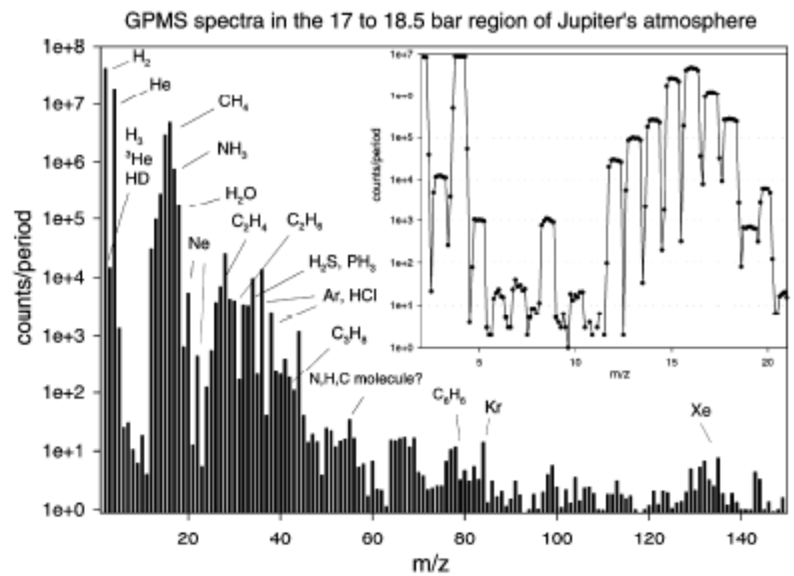
Flight Quadrupole Housing

Measurement Objectives:

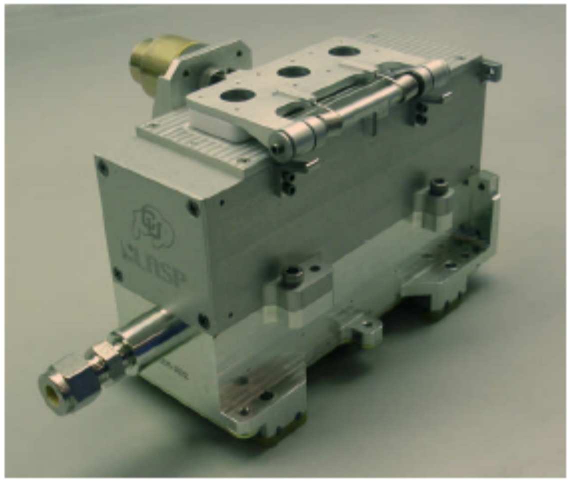
- Basic structure of the upper atmosphere (He, N O, CO, N_2, NO, O_2, Ar and CO_2) and ionosphere from the homopause to above the exobase
- Stable isotope ratios, and variations

Technical Details:

- Quadrupole Mass Spectrometer with open and closed sources
- Closed source measurements: non-reactive neutrals
- Open source species: neutrals and ions
- Mass range: 2 - 150 Da
- Mass resolution: 1 Da over entire mass range
- Modes: scan entire spectra or adapt to fixed masses
- Sensitivity: 10^{-2} (counts/s)/ (particles/cm-3)
- Heritage from Galileo GPMS, Pioneer Venus ONMS, CASSINI INMS, Contour NGIMS



LPW – EUV Monitor
Frank Eparvier, LASP



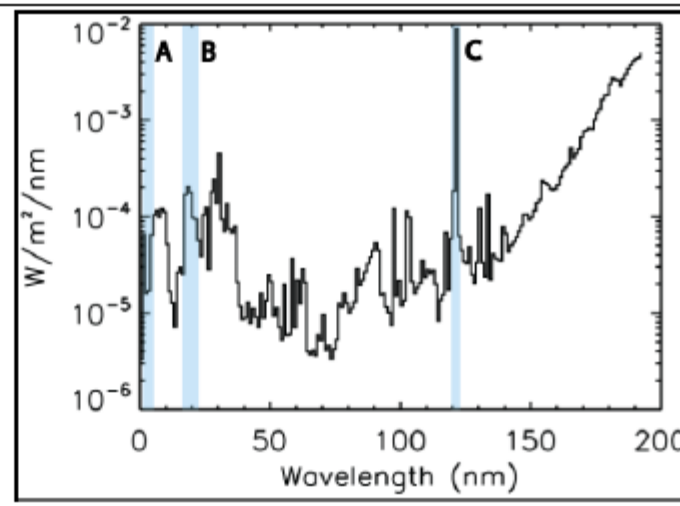
EUV Engineering Model

Measurement Objectives:

- Solar EUV irradiance variability at wavelengths important for ionization, dissociation, and heating of the upper atmosphere (wavelengths shortward of H Ly-α 121.6 nm)

Technical details and heritage:

- Three photometers at key wavelengths representing different temperature solar emissions (0.1-7, 17-22, and 121.6 nm)
- EUV hardware is part of LPW instrument
- Heritage from TIMED, SORCE, SDO and rocket instruments
- Full spectrum (0-200 nm) derived from measurements using Flare Irradiance Spectral Model (FISM).



EUV detector bandpasses

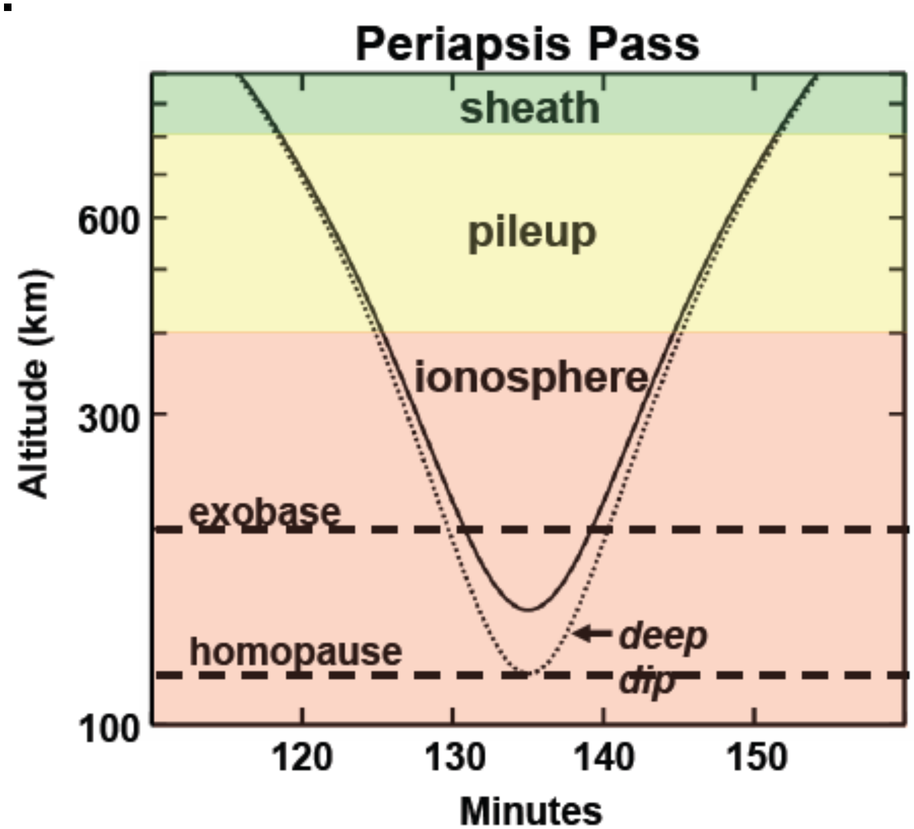
Parameters driving escape

- Extreme UV (EUV) flux
- Solar wind pressure
- Solar Energetic Particle (SEP) flux
- Interplanetary Magnetic Field (IMF) direction
- Subsolar longitude (i.e. crustal field location)
- Season (i.e. convolution of heliocentric distance and subsolar latitude).

6-D parameterization of total escape rate:
Escape Rate (EUV, IMF, SEP, P_{SW}, L_s, $\phi_{subsolar}$)

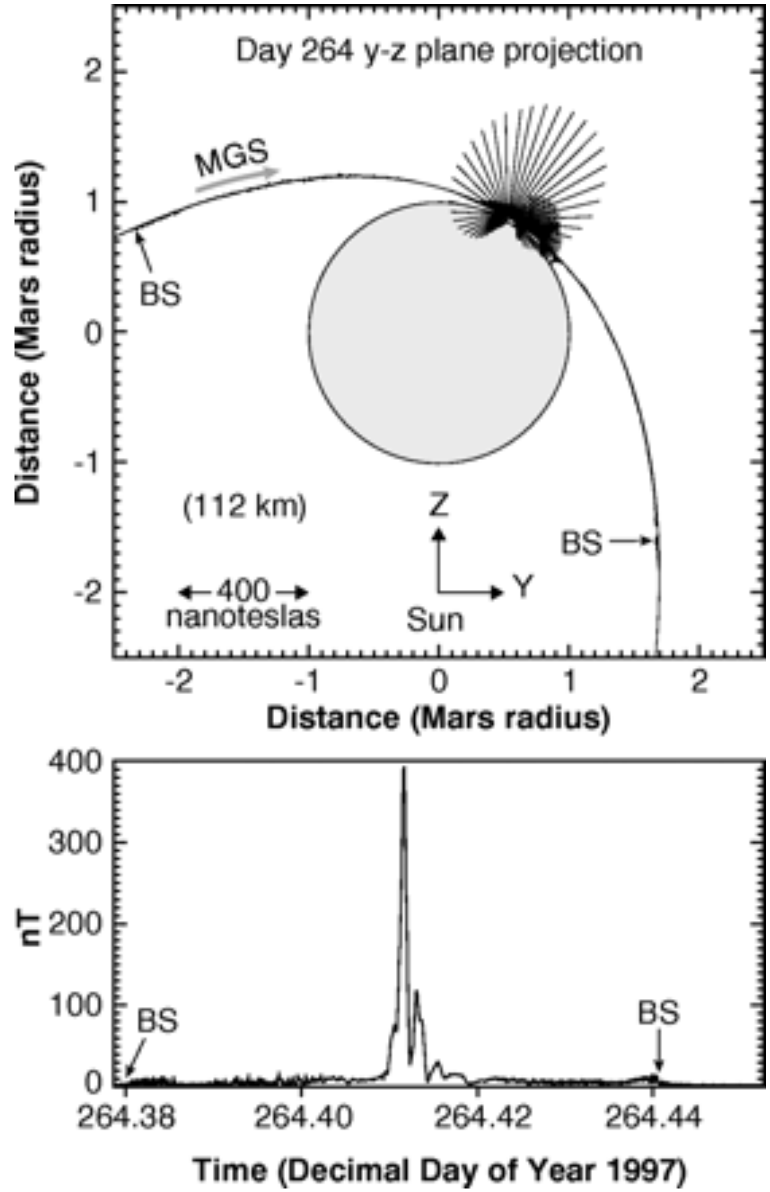
Elliptical Orbit Allows Measurement of All Relevant Regions of Upper Atmosphere

- Nominal periapsis near 150 km.
- Five “deep-dip” campaigns with periapsis near 125 km.

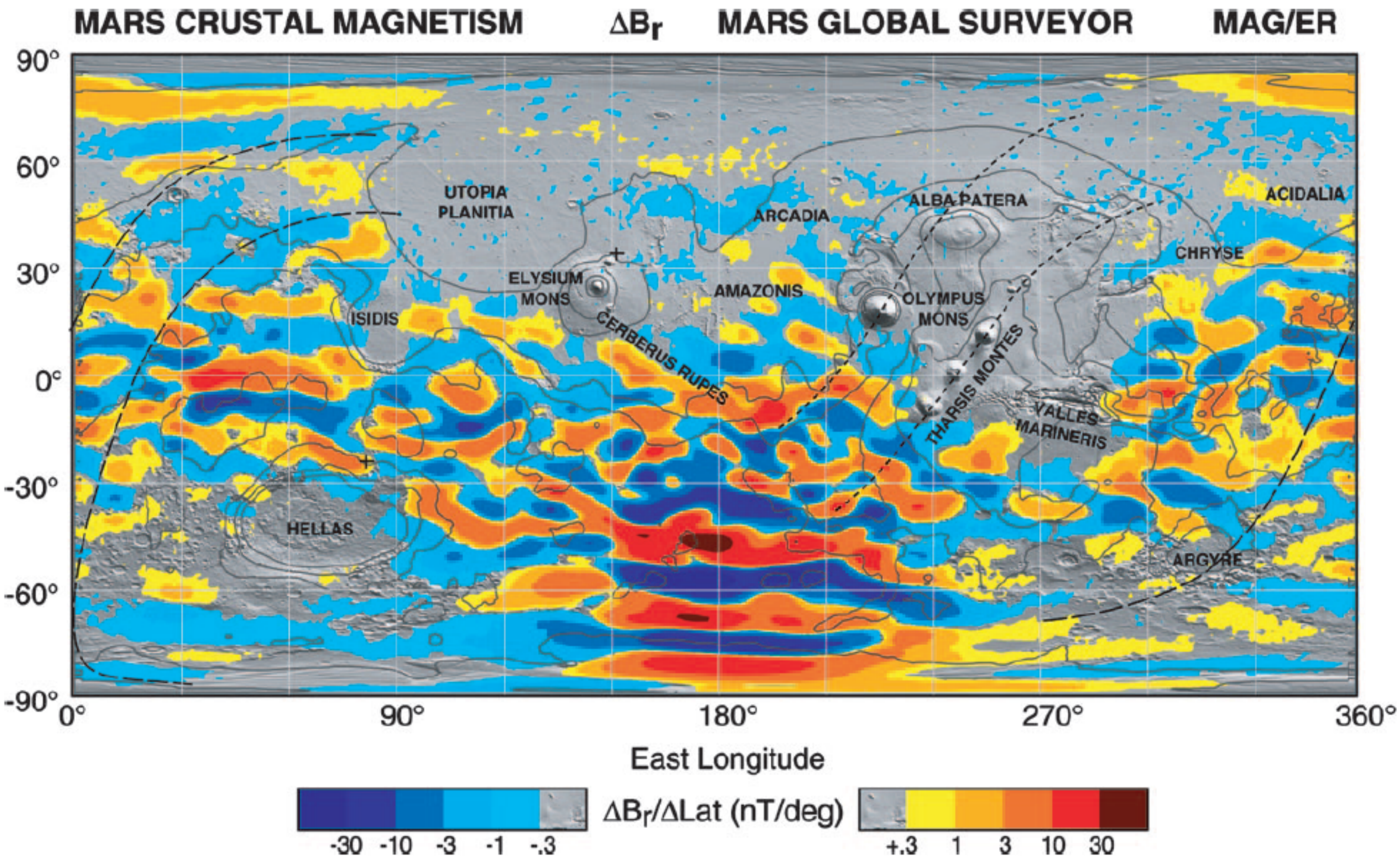


Mars has no planetary magnetic field

- Portions of the Martian crust are highly magnetized
- Definitely not global – very localized



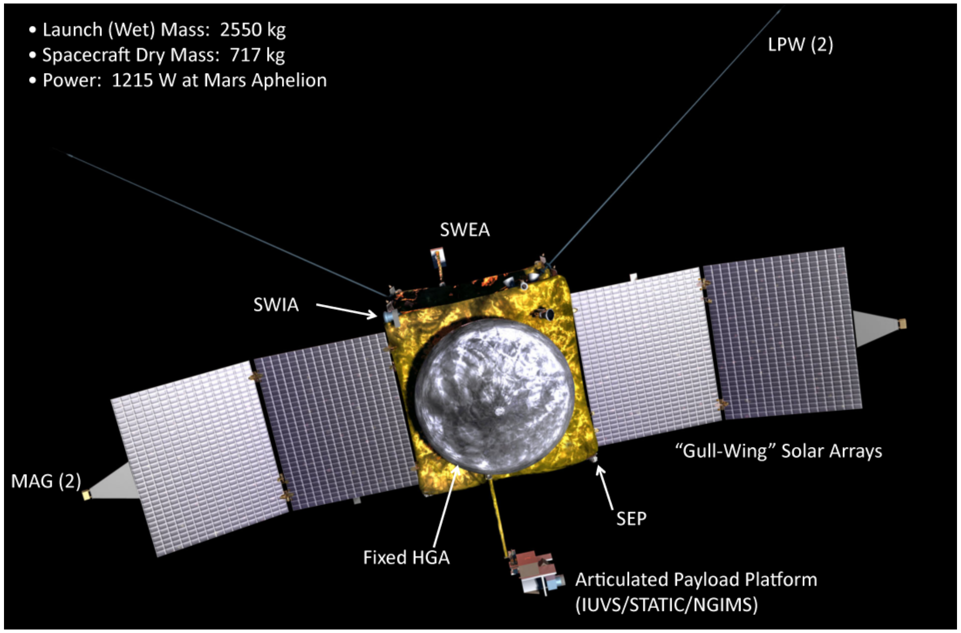
Crustal fields indicate Mars used to have planetary field



- Ancient terrain have fossil fields (frozen locally into rocks)
- Newer terrain is completely unmagnetized

How to test this hypothesis?

The MAVEN mission (Mars Atmosphere and Volatile EvolutioN)



Three main science goals:

- Determine the structure and composition of the Martian upper atmosphere today
- Determine rates of loss of gas to space today
- Measure properties and processes that will allow us to determine the integrated loss to space through time

The MAVEN Science Instruments

Mass Spectrometry Instrument

NGIMS

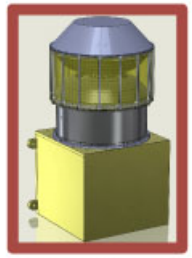
Neutral Gas and Ion Mass Spectrometer; Paul Mahaffy, GSFC

Remote-Sensing Package

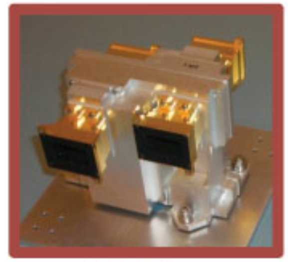
IUVS

Imaging Ultraviolet Spectrometer; Nick Schneider, LASP

Particles and Fields Package



STATIC



SEP

SupraThermal And Thermal Ion Composition; Jim McFadden, SSL

Solar Energetic Particles; Davin Larson, SSL

SWEA

SWIA

Solar Wind Electron Analyzer; David Mitchell, SSL

Solar Wind Ion Analyzer; Jasper Halekas, SSL

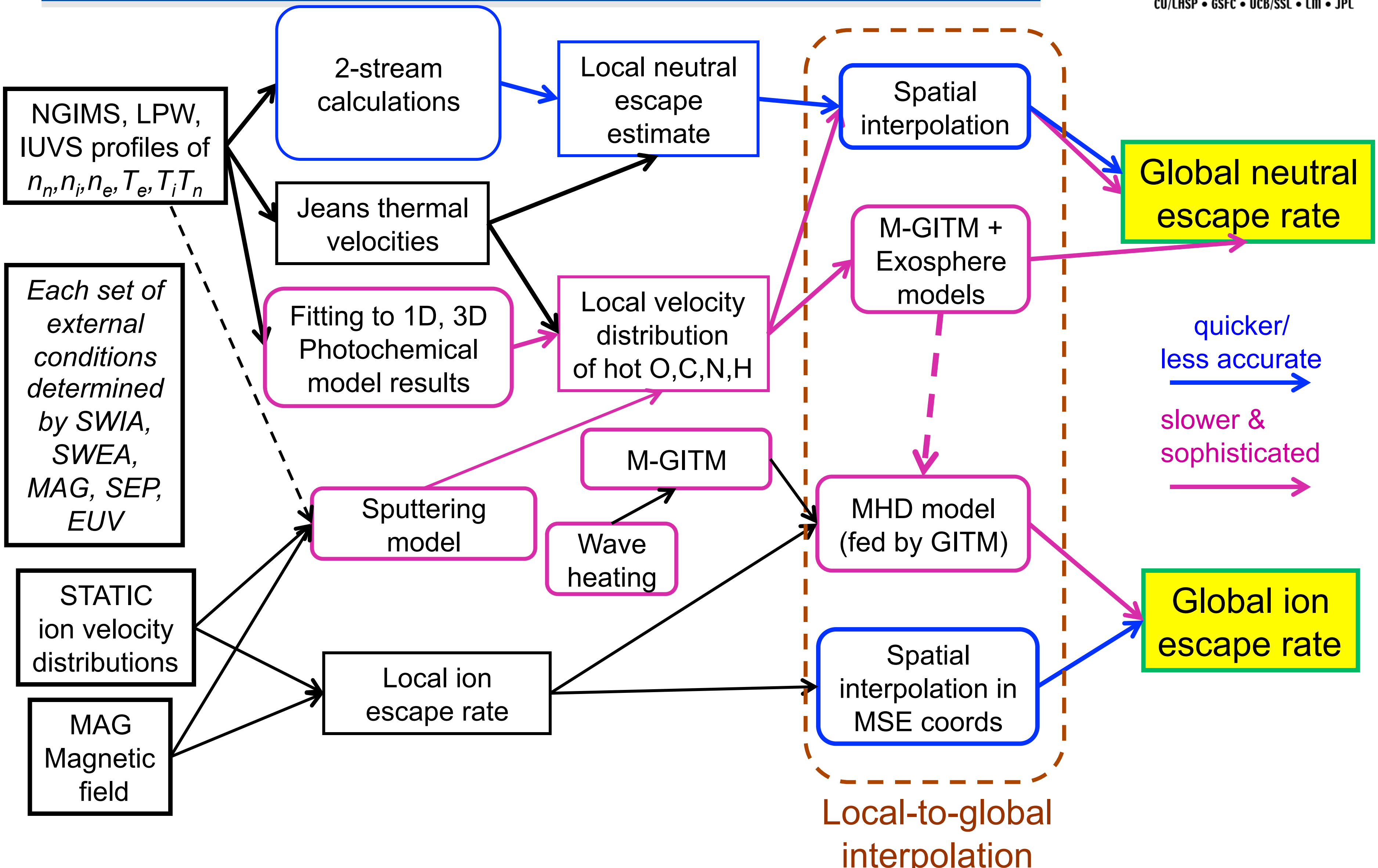
LPW

MAG

Langmuir Probe and Waves; Bob Ergun, LASP

Magnetometer; Jack Connerney, GSFC

Measurements to Escape Rates



Charts by R. Lillis

Escape Rates to Integrated Loss

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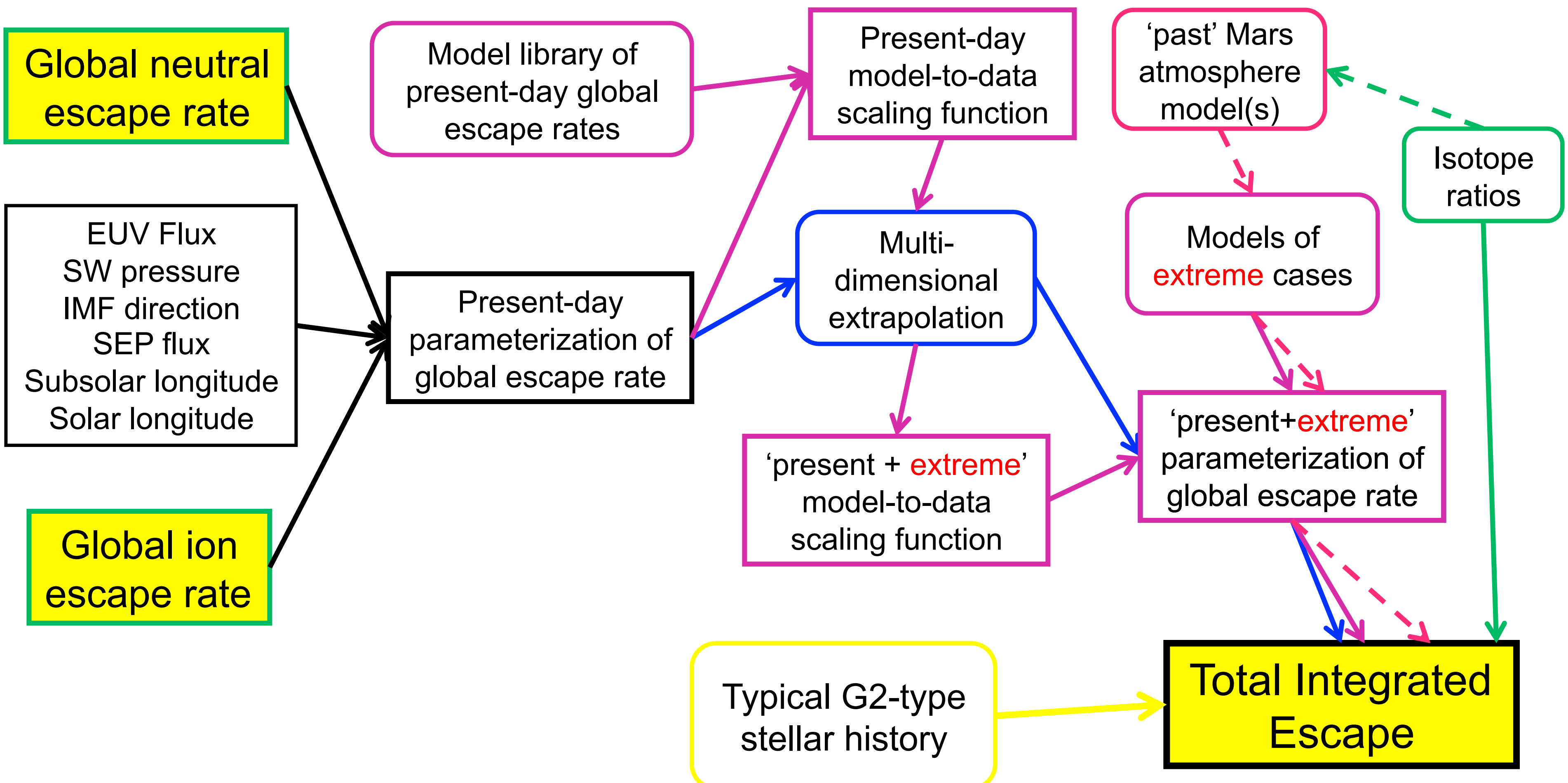
Challenge is to go from present day to extreme conditions

Iteratively 'add atmosphere' back in time?



Charts by R. Lillis