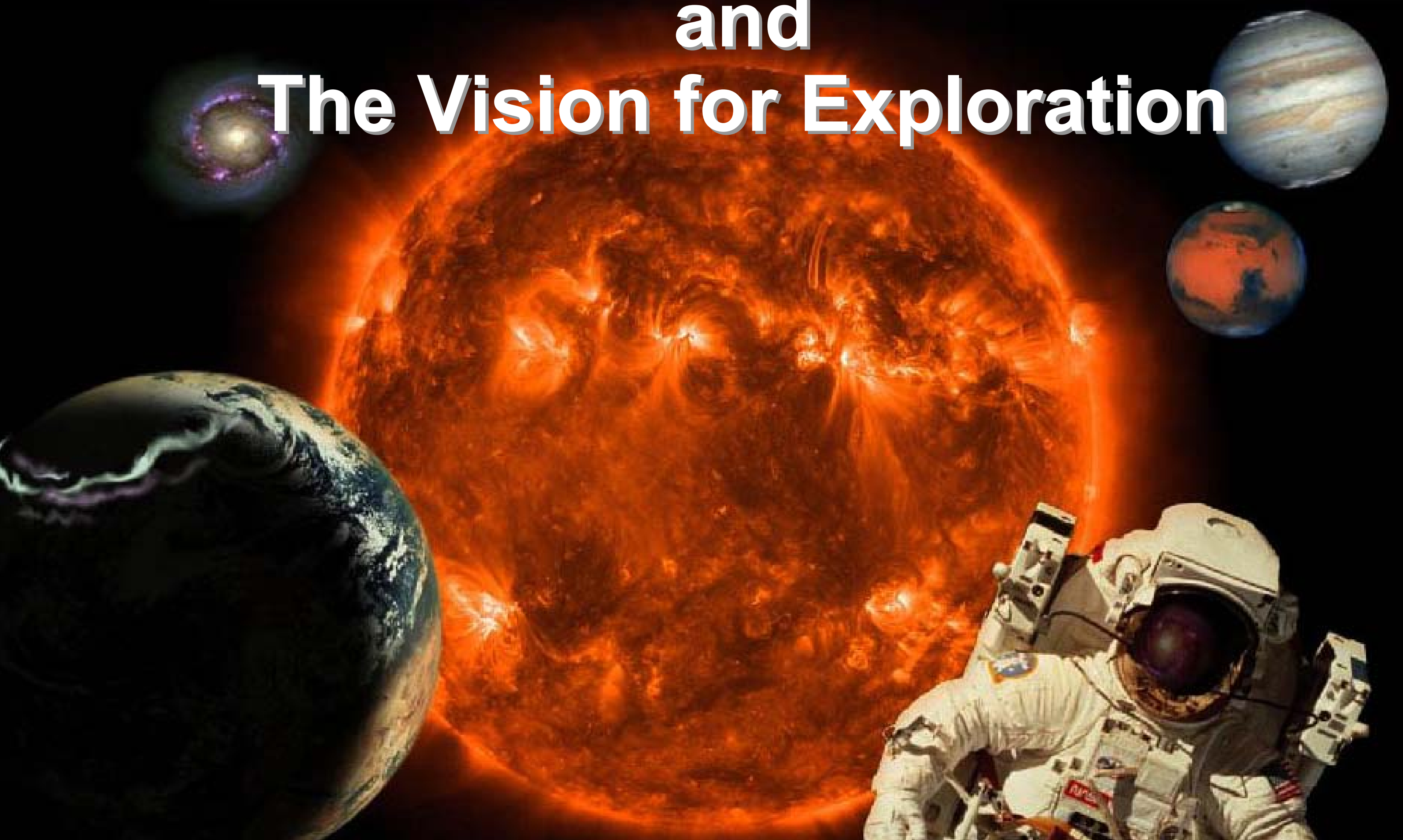
Living With a Star
and
The Vision for Exploration



The Vision for Exploration: Moon, Mars and Beyond…

- Implement a sustained and affordable human and robotic program to explore the solar system and beyond
- Extend human presence across the solar system, starting with human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations
- Develop the innovative technologies, knowledge, and infrastructure both to explore and support decisions about the destinations for human exploration
- Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests

SEC Approach

- Identify areas in which LWS can contribute to the successful implementation of “The Vision for Exploration”
  - Develop a list of the space physics/weather areas that support the design and implementation of manned lunar and Mars missions
  - SEC will use this information to connect existing and future missions and research with the exploration goals
- Specific questions:
  - What is planned for the period of time of interest?
  - What is missing?
  - What is the next thing to be done?

Areas for Discussion

- Radiation Effects on Human Flight
  - Near the Earth - Shuttle and ISS ops:
  - In cislunar and lunar orbits, lunar surface operations
  - Beyond the Moon - L1 and Mars:
    - (EVA scheduling, occasional "sheltering" - Knowledge of current SWx required)
    - (Optimization of flight plans and ops - Predictive capability enables exploration)
- Satellite Systems:
  - Radiation and induced current effects on flight systems
  - Navigation / Communication
  - Aerobraking / Aerocapture
    - (Quiescent ionosphere impacts interplanetary navigation - storm-time much worse)
    - (Mars TIGCM from Earth TIGCM - at core of exploration technologies)

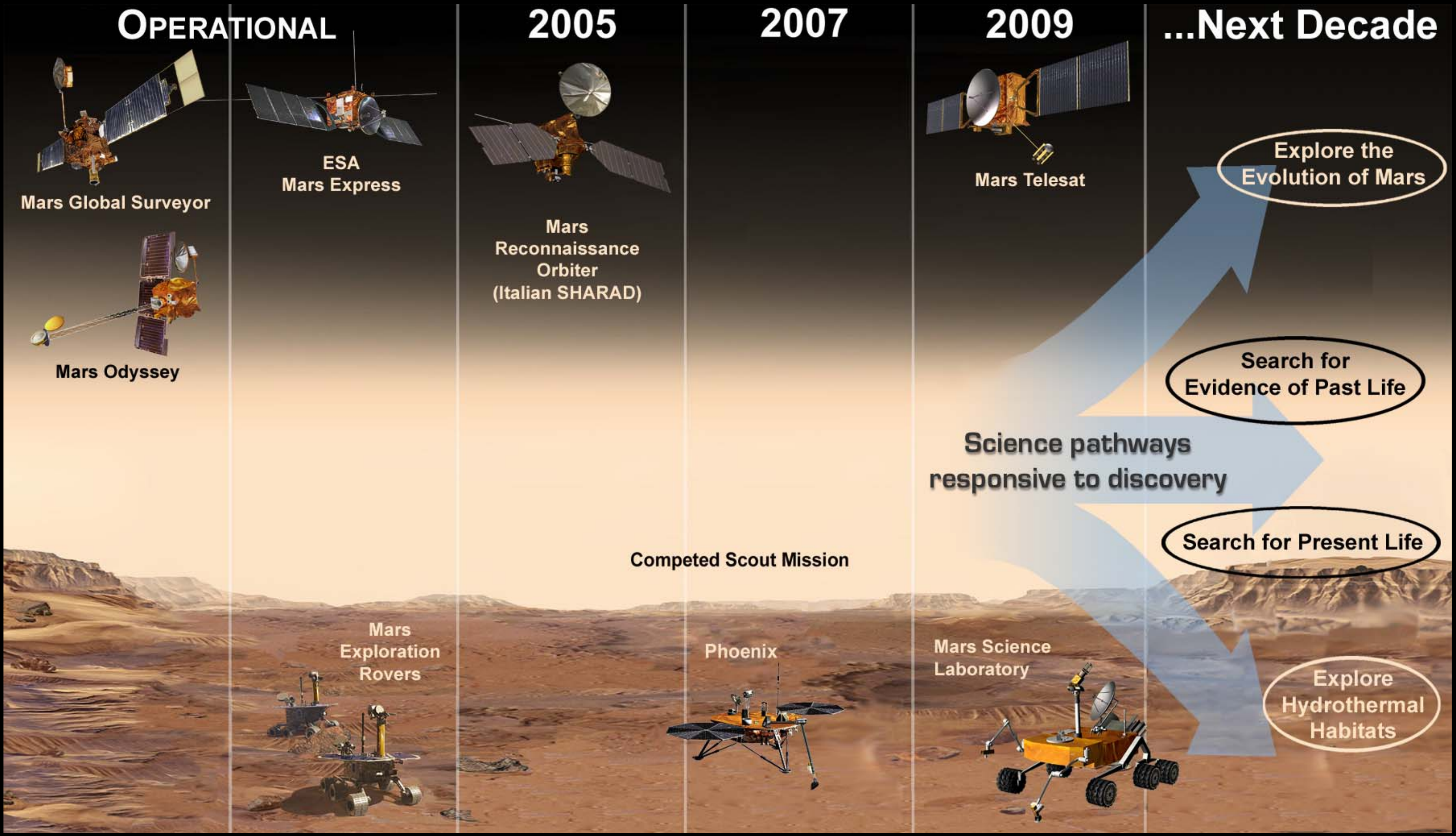
human impacts / engineering solutions   immediate / longer-term

Radiation Effects on Human Flight

Present State of Mars Exploration (Jim Garwin)

- 2004 is a big year for Exploration:
  - MER experience,
  - President's "Vision",
  - lots of planning...
- For Mars, we know **RADIATION** and how living systems "adapt" is an essential issue (MEPAG, NRC, etc.)
- We need **LWS** help filling in the details of what it means to use the Moon as the "proving ground" to get to Mars and beyond (Radiation issues)
- We will charter a LEPAG to analyze lunar measurement needs this Spring
- For NASA to effectively respond to the President's challenge, trans-Enterprise measurements must be enabled and fostered
- We must be CLEVER about using what we are measuring to its maximum or lose the program (i.e, LWS/SEC, MEP, ...)

Mars Exploration Program

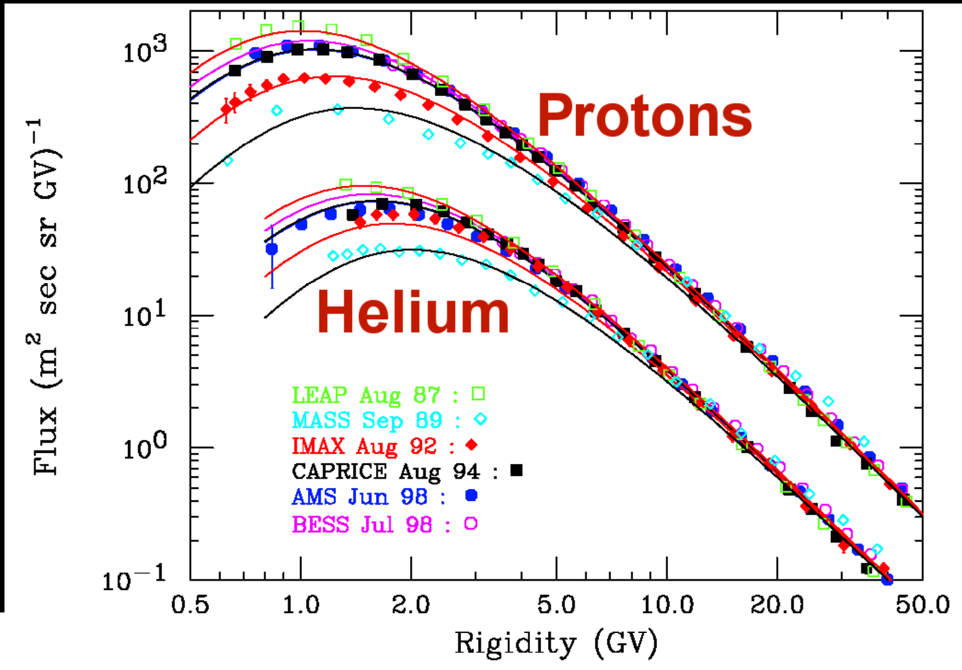


"Follow the Water" to ultimately ***Explore a Habitat****...*

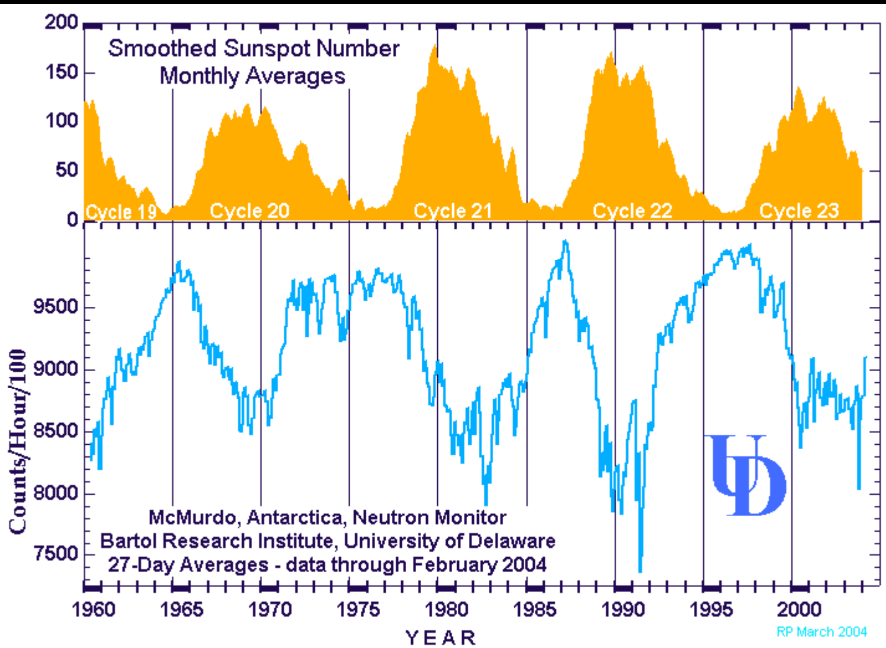
Exploring the "real" Mars

- Dust,
- atmospheric chemistry (CH_4?),
- sulfates instead of carbonates?,
- toxic molecules and elements,
- weather,
- subsurface resources?,
- electrostatics?,
- habitable zones,
- planetary protection,
- rocks as resources…
- RADIATION!

Galactic Cosmic Ray Modulation (Bieber)



Below ~ 2 GeV the GCR flux varies by a factor of 5-10 from solar minimum to solar maxiumum



However, the GCR modulation is fairly well understood and it can be modeled with an accuracy of ~50%

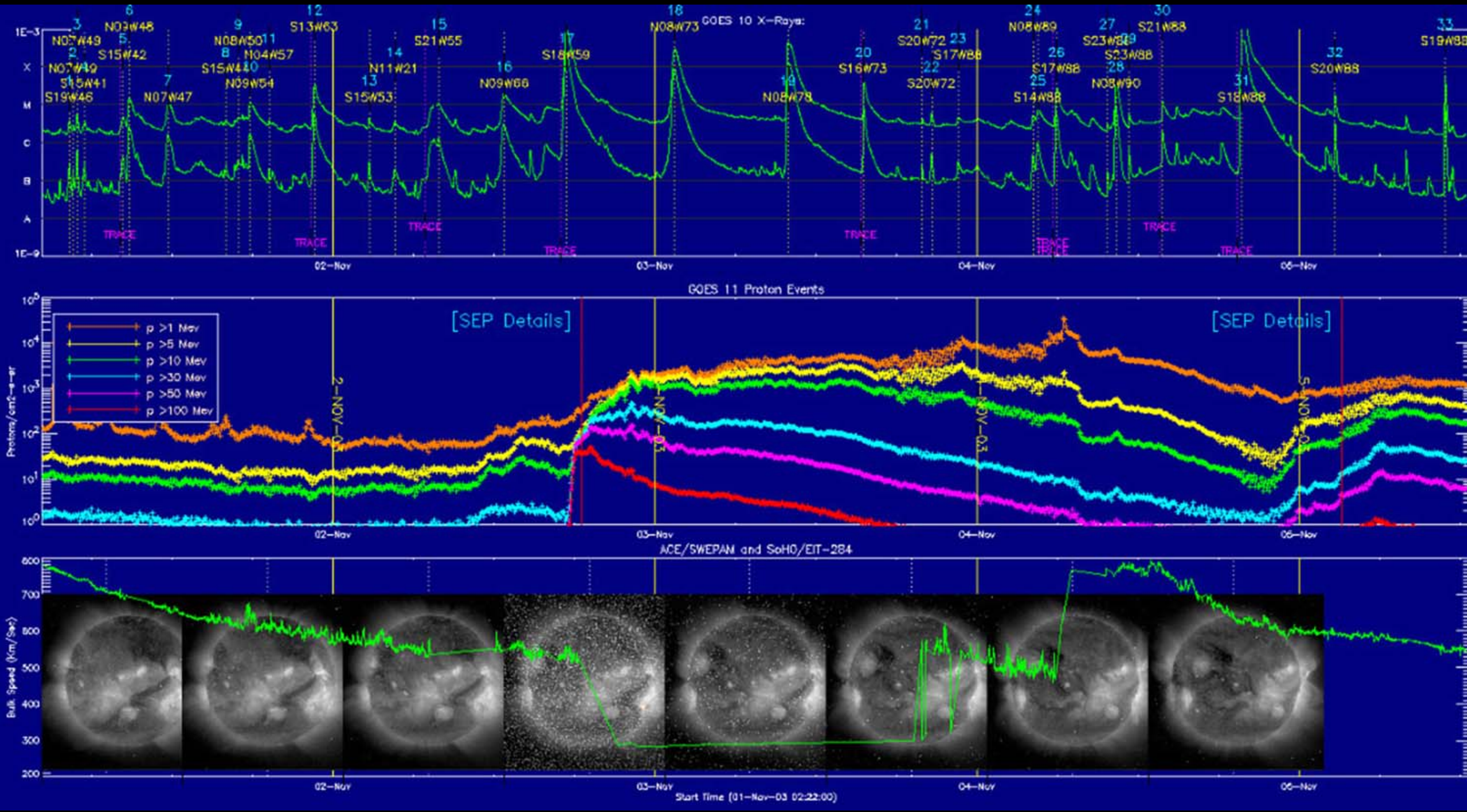
Identified Research Needs--GCR

- GCR environment model for spacecraft/mission
  - Model energy spectra and composition
    - 10 MeV/n to 10 GeV/n
    - 1 ≤ Z ≤ 28, Z > 30
  - Dynamic
    - Physics-based model of solar modulation
      - Can use data on solar variations, CMEs, GMIRs, current sheet tilt, and B-field for future predictions
    - Solar cycle variations over a complete solar cycle
    - Radial gradient
    - long-term temporal variations (beyond present decade)
      - developed from archival records of paleo Be-10 measurements
  - An error for any species at any energy and time of not more than 10%
  - Data assimilation
    - capability to predict GCR intensities 1-2 years into the future
- End-to-end validation
  - Measure and model GCR and secondary neutron spectrum
    - In space (e.g., L1)
    - Above lunar surface
    - On Mars' surface
- Best estimates of solar maximum and minimum conditions
- Worst-case GCR spectrum
  - Maunder minimum
  - Interstellar spectrum
- Continued synoptic measurements
  - ACE: Z > 2
  - Ulysses, IMP-8, and or SAMPEX: protons, He
  - Voyager
  - Balloons: protons and He to high energy
  - Ground-based neutron monitors

The Greatest Single Challenge is the Forecast of Solar Particle Events . . .

- Significantly lower in energy than GCR, SEP proton flux is orders of magnitude greater over hours to days
- ALARA (As Low As Reasonably Achievable) principles require exposure to SEP be minimized
- Potential to be caught away from shelter on the Lunar or Martian surface may impose operational rules that limit flexibility and reduce efficiency … unless we improve our ability to predict SEP events.

October-Nov 2003 Summary Data Plot



Radiation Exposure Primer

Units

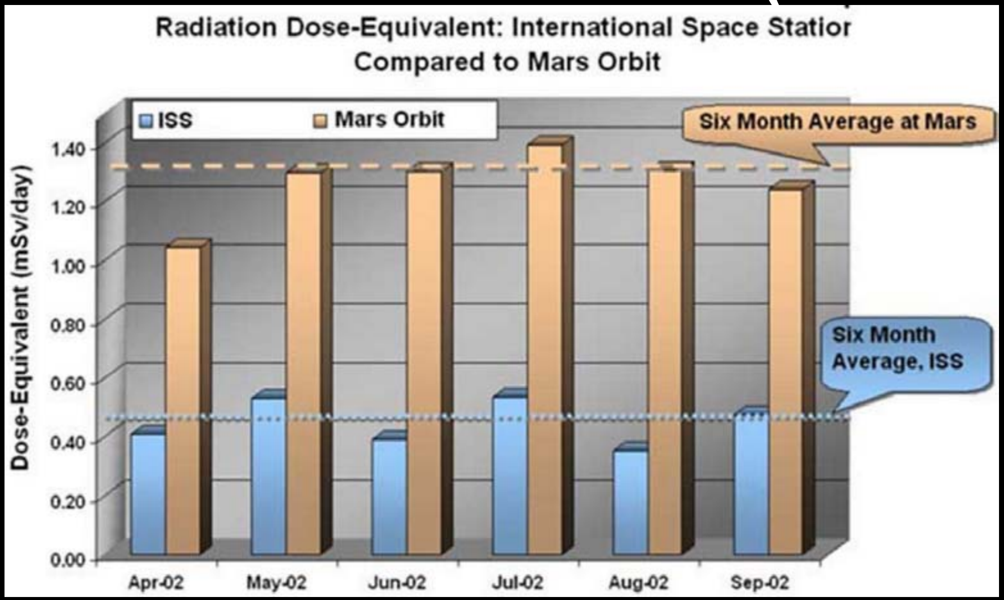
- Dose
  - Rad (Radiation Absorbed Dose)
  - Grey (Gy)
  - 1 Gy = 100 Rad = 1 Joule/kg
- Dose equivalent: incorporates biology into the physics of radiation exposure
  - Rem (Roentgen Equivalent Man)
  - Sievert (Sv)
  - 1 Sv = 100 Rem = 1 Joule/kg

- Because of the complicated nature of human tissues it is very challenging to estimate dose equivalents
  - Needs composition and energy spectrum of penetrating radiation
  - Estimates are for
    - Skin
    - Ocular lens
    - Blood forming organs (BFO)
- Shield definitions
  - Spacesuit (0.3 g/cm^2 of Al)
  - Pressure vessel (1.0 g/cm^2 of Al)
  - Equipment room (5.0 g/cm^2 of Al)
  - Shelter (10.0 g/cm^2 of Al)

Age	25	35	45	55
Male	0.070	0.100	0.150	0.300
Female	0.040	0.060	0.090	0.150

Lifetime exposure limits

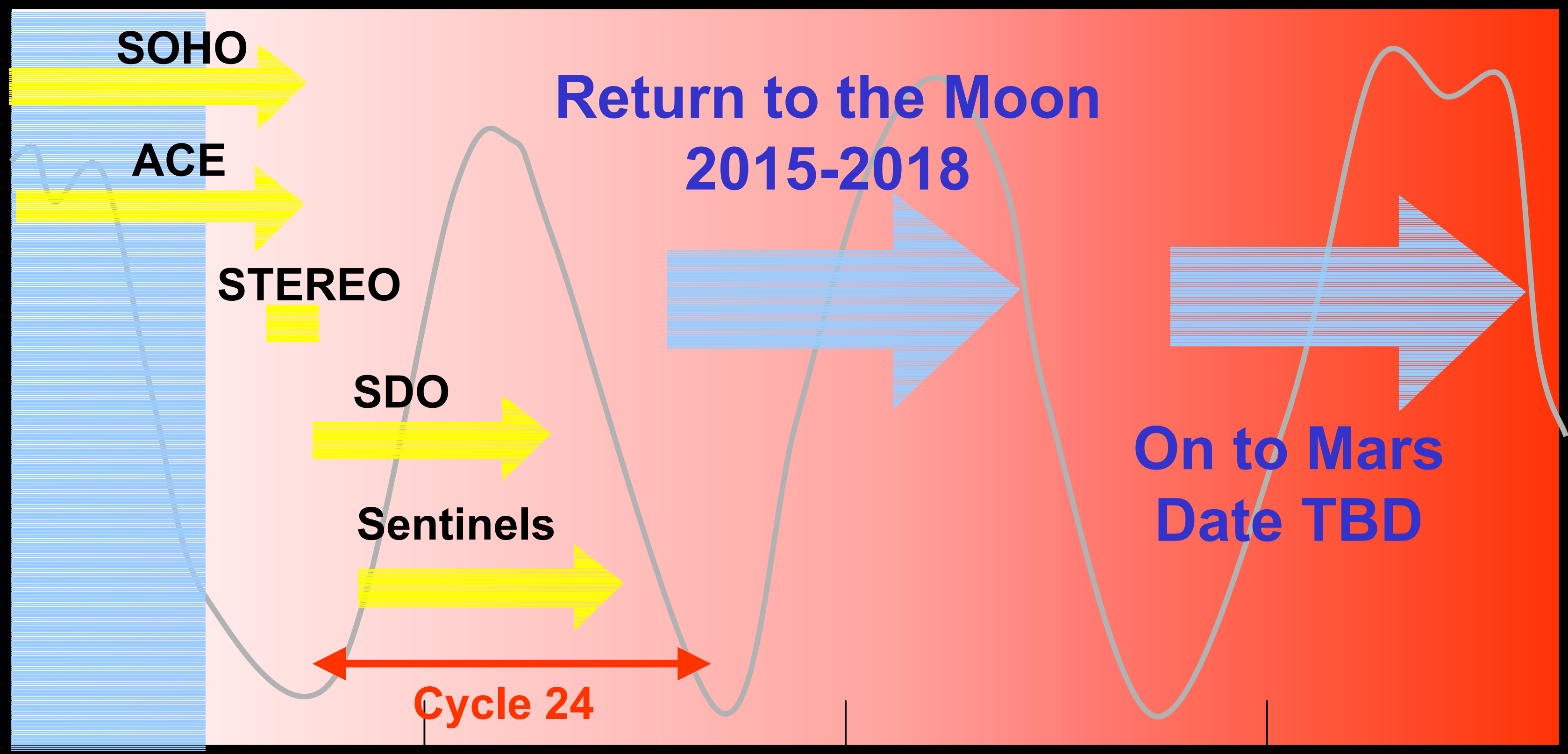
Radiation Environment for 2.5 yr Mars Mission (Wilson & Cucinotta)



- Only >55 males can go
- Halloween storm series could kill the crew

Source	1 yr transit dose eq.		1.5 yr surface dose eq.	
	Skin	BFO	Skin	BFO
GCR SolMax	0.0334	0.0279	0.0201	0.0176
GCR SolMin	0.0938	0.0727	0.0465	0.0407
Aug 72 SEP	0.0638	0.0170	0.0046	0.0024

Significant Events in the Moon, Mars, and Beyond Vision



Only One More Solar Cycle Left to Learn What We Must Learn

Solar Observations

- Routine solar monitoring is the necessary first step to forecast and characterize of SEPs
- Near-real-time observations of solar active regions and emerging Coronal Mass Ejections (CMEs) may provide data useful to forecast the progress of an on-going SEP over a period of hours to days
- Additional progress in understanding the physics of CMEs may lead to a multiday forecast of the probability of an SEP
- LWS Solar Dynamics Observatory and the Sun-Earth Connections STEREO Mission can build on the current suite of research spacecraft and ground-based facilities to select the appropriate operational instruments for solar monitoring

Heliospheric Observations

- Heliospheric observations provide information necessary to model or monitor the propagation of solar energetic particles from the source to the astronauts
- The data that may be necessary for SEP propagation models include
  - State of the ambient solar wind plasma
  - Interplanetary magnetic field
  - Local disturbances moving through the inner heliosphere
- LWS Sentinel Missions will provide experience and proof of concept from which we will be able to learn more about the underlying physics and select the appropriate operational instruments for solar monitoring

What We Must Know About Solar Particle Events to Reduce the Risk to Astronauts (Ron Turner)

- **Priority 1 Critical Question 10.10.**
  - ***What are the risks from SEP's and what is their impact on operations, EVAs and surface exploration?***

- For astronaut radiation safety, the important SEP energy range is from 30 MeV up to 100-200 MeV
  - Spectral slope is very important
- SEP forecast goal according to findings of 1996 SEP risk mitigation workshop is
  - 10 to 12 hour forecast prior to a likely event
  - 6 to 8 hour forecast of magnitude and spectral slope after event on-set
  - 3 to 4 hour rolling forecast as SEP progresses
- Realistic near-term challenge:
  - 8 hour rolling forecast as SEP progresses
  - Predict, at event on-set, the time of arrival and magnitude of shock-enhanced peak
  - Reliably forecast 3 to 7 day “all clear”

How Can LWS Science Support the Moon, Mars, and Beyond Vision (Ron Turner)

- Better understanding of Solar Dynamics
  - Improved Forecasting of Coronal Mass Ejections
  - Improved forecasting of SEPs
- Better understanding of Heliospheric Dynamics
  - Improved Forecasting of Solar Wind profiles
  - Improved forecasting of SEPs
- Better understanding of SEPs
  - Improved design of habitats and shelters
  - Higher confidence in mission planning
- Better forecasts of SEP evolution after onset
  - Higher confidence in exposure forecast
    - Implementation of more flexible flight rules
  - Reduced period of uncertainty
    - Greater EVA scheduling flexibility
    - Less down-time of susceptible electronics
- Prediction of SEPs before onset
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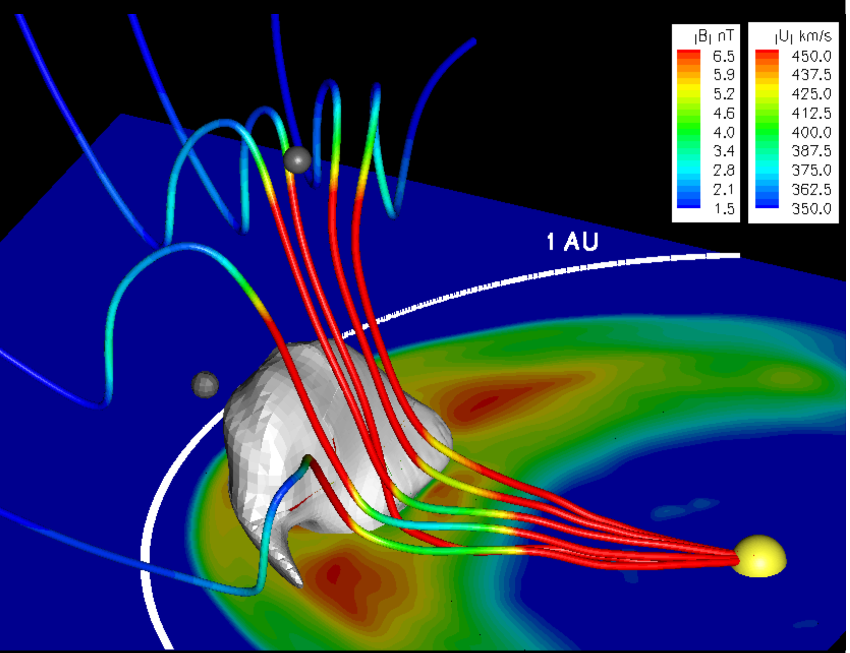
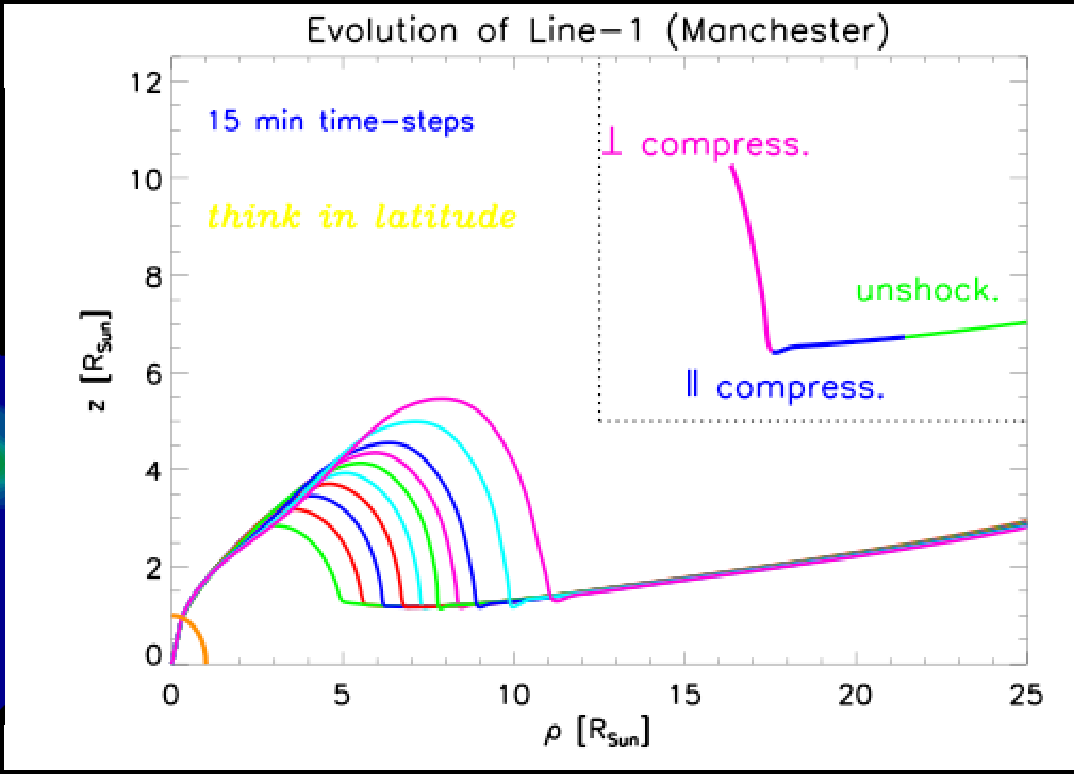
⇒ Improved Safety and Enhanced Mission Assurance

CME at 1 AU

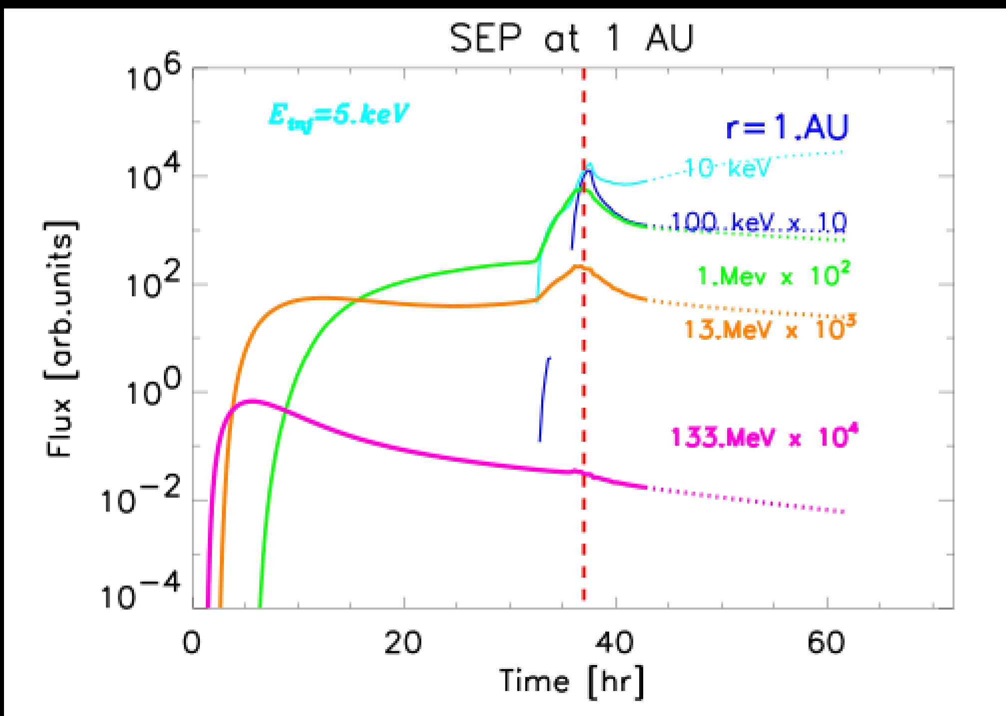


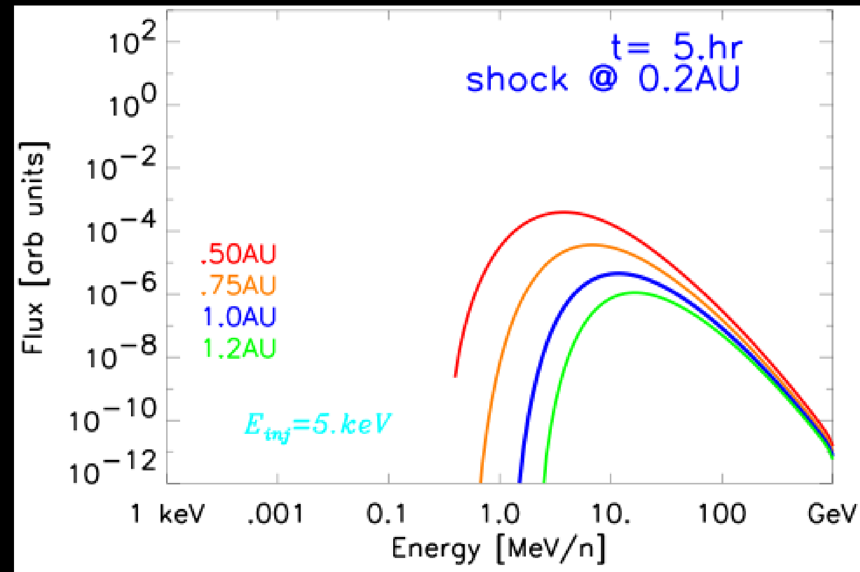


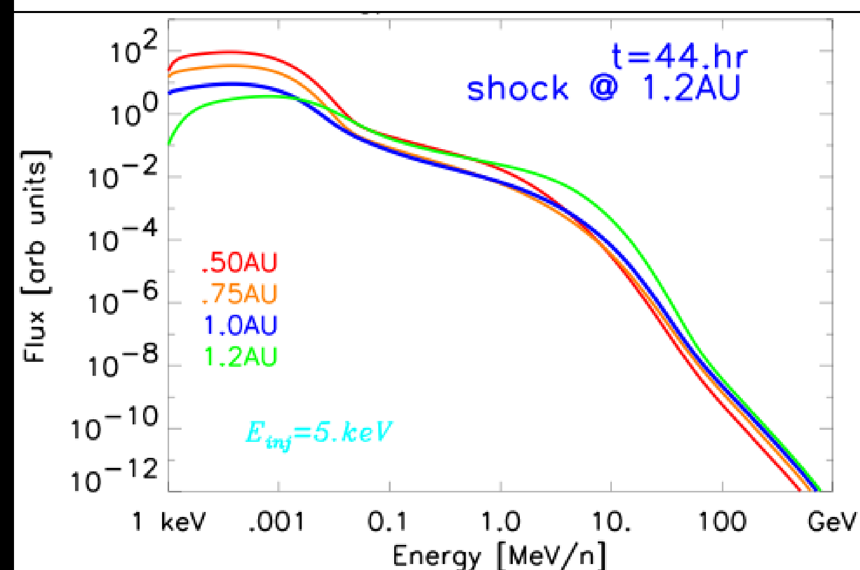
- Note the stronger magnetic field at the deflection.
- More acceleration than with a simple parallel shock.

Time-Profile at 1 AU for Different Energies

For space weather purposes we estimate the penetrating component of the SEP population (~20 MeV/n can penetrate 2 mm Al)







- Particles are injected at about 5 keV.
- The important part of the time profile is the evolution before the arrival of the shock

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OSHA exposure levels

Lifetime exposure limits

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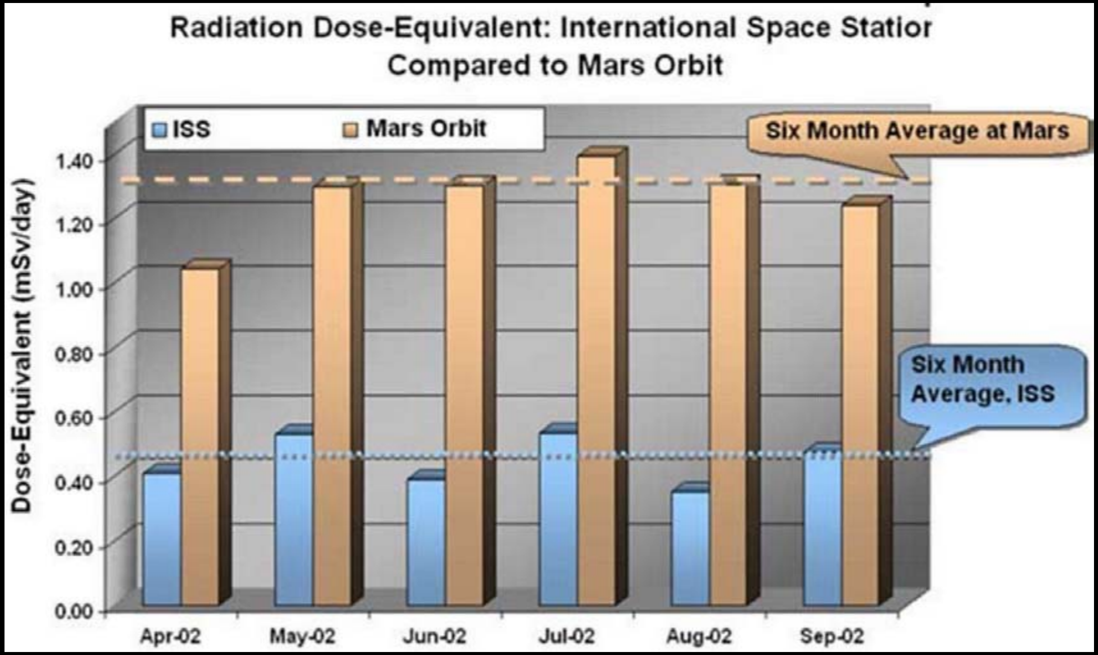

- Only >55 year old males qualify??!
- Mortality potential of Oct-Nov 2003 storm series requires further study

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Improved Safety and Enhanced Mission Assurance

Identified Research Needs--SEPs

- Fully characterize measured SEP spectra, including uncertainties
  - Protons, He, HZE (spatially correlated)
  - Extend spectral measurements to high energies
    - > 100 MeV for protons
    - > 30 MeV/n for HZE
  - Temporal variations and evolution of isotropy
  - Ultra-heavy species energy spectra
    - Z > 26
    - Identify to energy range of the spectral "knee"
- Solar cycle dependence has to be understood on time scales finer that just "solar maximum" and "solar minimum"
- Develop a plausible but physically realistic worst-case event model
  - Statistical and/or deterministic approaches
  - Need to better characterize cumulative event fluences
- Measurements characterizing the azimuthal and radial SEP flux gradients
  - Requires multipoint measurements within 1 AU
- Continued CME and SEP synoptic observations
  - SOHO, SMEI
  - Space-based stereoscopic coronagraph observations are needed to better characterize the 3D evolution and propagation of CMEs (e.g. STEREO)
  - Continue WIND EPACT instrument (provides spectral measurements of ultraheavy ions)
  - Cross-calibrate measurements throughout heliosphere
- Spectrometer development to measure high energy protons and helium ions and HZE particles
  - For use on crew transfer vehicles, on crew surface exploration vehicles, and heliospheric monitoring platforms
- Full exploitation of existing data archives
  - e.g., charged particle measurements from HELIOS and Voyager
- Shock models
  - When will they arrive
  - What particles/spectra are incorporated
  - What is the particle content, if any, of the associated CMEs
  - New heliospheric multipoint measurements to use in validating new 2D/3D CME/shock evolution models

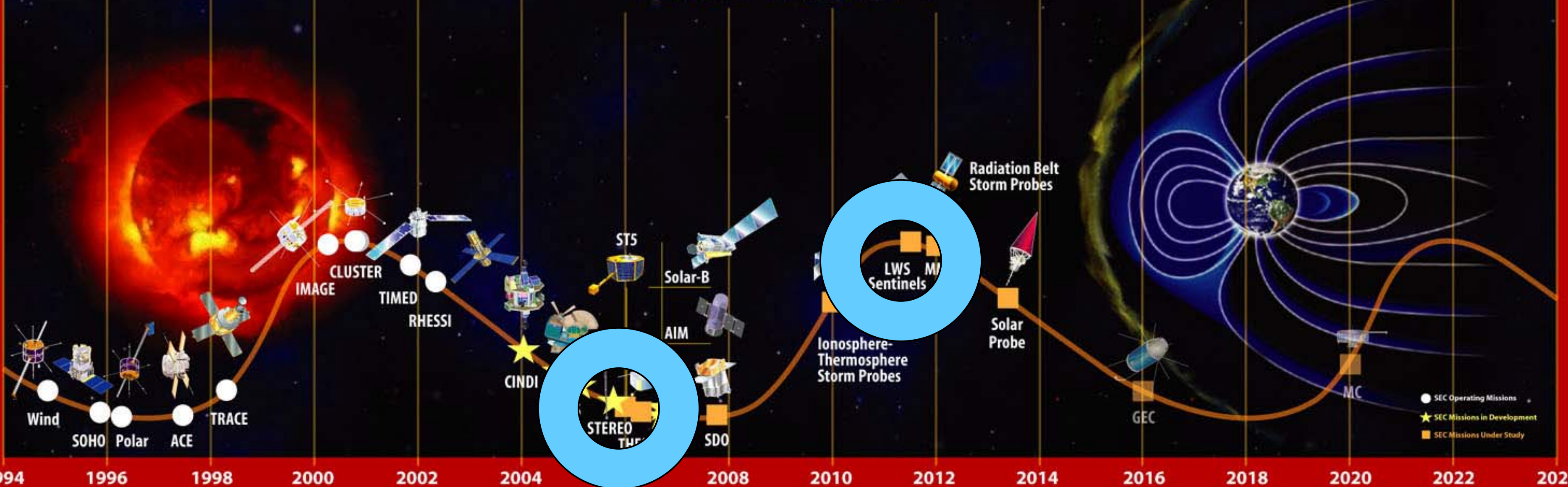
Identified Research Needs: In Situ Measurements

- Radiation environment measurements at Mars orbit
  - SEP primary and secondary radiation
    - Protons
      - 10-1000 MeV
      - designed for accurate measurements at very high count rates
      - designed to operate for long periods (≥ 3 years)
      - measurements need to coincide with surface SEP measurements
- Radiation environment measurements on Mars surface
  - GCR and secondary charged-particles
    - Heavy ion charge and LET
      - Z = 3 to 28
      - LET = 100 – 30000 MeV•g/cm²
    - Proton and He energy spectrum
      - 10-500 MeV/n
    - 1-hour temporal resolution
  - Secondary neutrons from Mars atmosphere and surface albedo
    - Energy spectrum
    - Thermal neutron flux
    - Epithermal neutron flux
    - 1-100 MeV with 20% resolution in energy
    - distinguish forward and backward traveling neutrons
    - 1-hour temporal resolution
- Radiation environment measurements on Mars surface (cont).
  - Multiple measurements to characterize temporal and spatial variability
    - measure radiation environment changes over a solar cycle
    - measure radiation environment changes with locality (variation in surface composition and altitude)
- SEP primary and secondary radiation
  - Protons
    - 10-1000 MeV
    - designed for accurate measurements at very high count rates
    - designed to operate for long periods (≥ 3 years)
  - Neutrons
    - 20-100 MeV (listed in Turner-Cucinotta presentation as “high energy”—does this characterize desired energy range?)
    - designed for accurate measurements at very high count rates
    - designed to operate for long periods (≥ 3 years)

Infrastructure Needs: In Situ Measurements

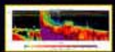
- Mars Surface
  - SEP + GCR/LET + neutron spectrometers
- Lunar Orbit
  - SEP + GCR spectrometers
- Lunar Surface
  - neutron spectrometer
- Earth Orbit
  - SEP + GCR spectrometers
- Inner Heliosphere
  - 2 STEREO/Sentinal/ Solwind spacecraft at 1AU
  - 1 STEREO/Sentinal/ Solwind spacecraft at L1
- Heliospheric State
  - Global view of heliospheric state desirable
  - Will understand requirements better following STEREO

FLIGHT PROGRAM



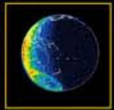
MISSION STATUS

WIND:



SOHO:

POLAR:

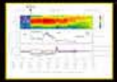


ACE:

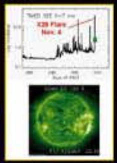
TRACE:

IMAGE:

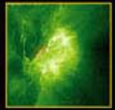
CLUSTER:



TIMED:



RHESSI:



CINDI:

- Part of the payload for the Communication and Navigation Outage Forecast System (C/NOFS)
- Mission of Opportunity

TWINS:

- Mission of Opportunity
- In Development

STEREO:

- Fabrication of Spacecraft and Instruments in Progress
- Launch Vehicle in Procurement

ST5:

Solar-B:

- Solar Terrestrial Probe Mission
- In Development

AIM:

- SMEX
- Design Concepts in Development

THEMIS:

- MIDEX
- Design Concepts in Development

SDO:

- Initial Confirmation Review Complete
- Non-Advocate Review Held December 2003

ITSP:

LWS Sentinels:

- Undergoing Early Formulation and Definition Stage
- Strategy Panel Meeting in Progress

Solar Probe:

- Science Definition Team Formed in December 2003

MMS:

- Two Principal Investigator Groups Selected for Phase A Design Studies
- Phase A Study Period and Funding Increased

RBSP:

GEC:

- Request for Offer Announced January 2003 for Mission Designs
- Spacecraft Design Studies to be Completed in September 2003

MC:

- Currently in the Pre-formulation Phase
- Technologies for Implementation to be Flown on NMP ST5 Mission

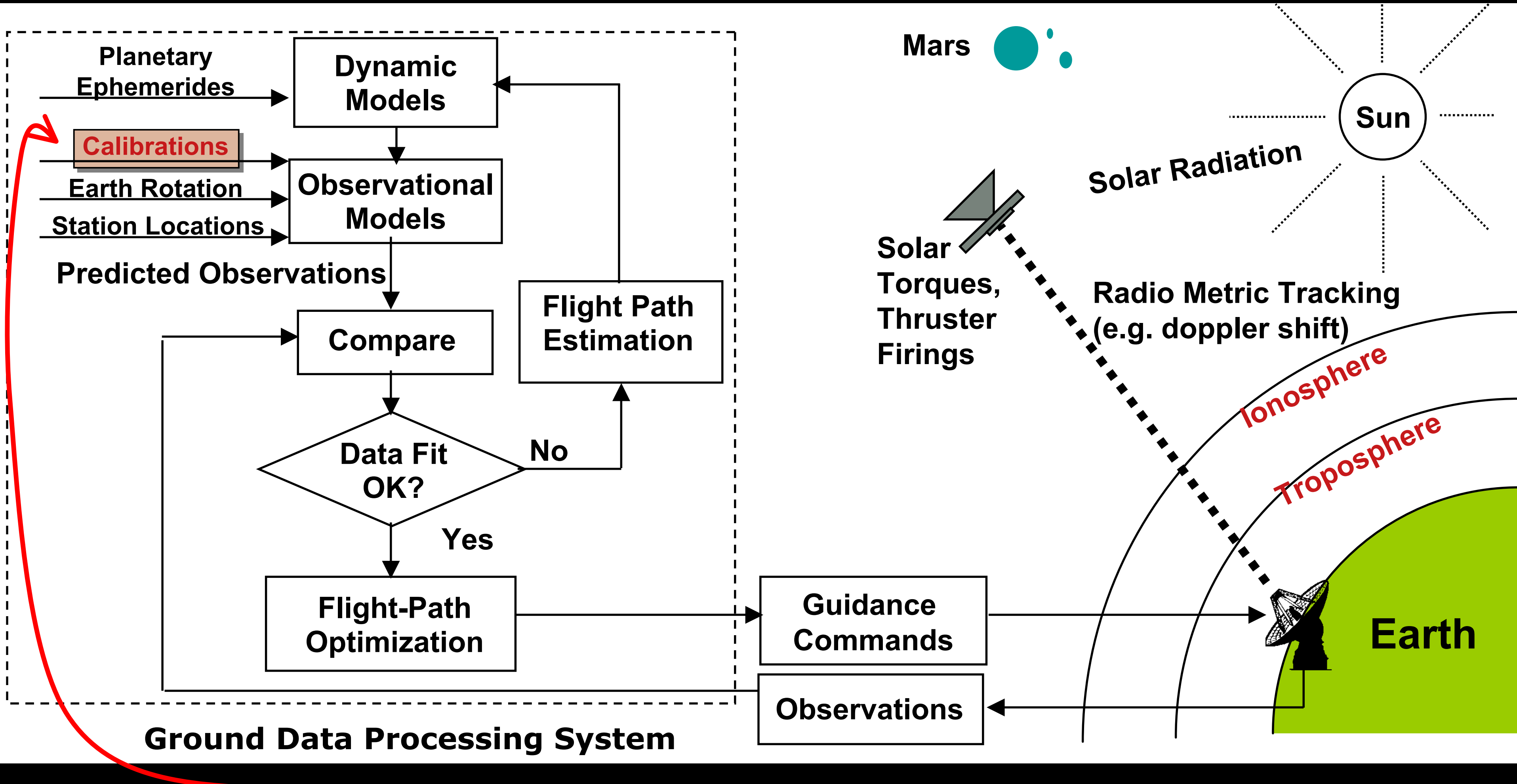
LWS/ISTP Spacecraft: Recommendations?

- Maintain
  - ACE
  - Ulysses
  - WIND
  - Voyager
- Rephase Sentinels
  - operating by next solar maximum
  - Radiation Storm Probes for Radiation Belt Science
  - Ionosphere Storm Probes for Communication/Navigation
- Holes/Gaps
  - ACE follow-on

Satellite Systems

Deep Space Navigation System

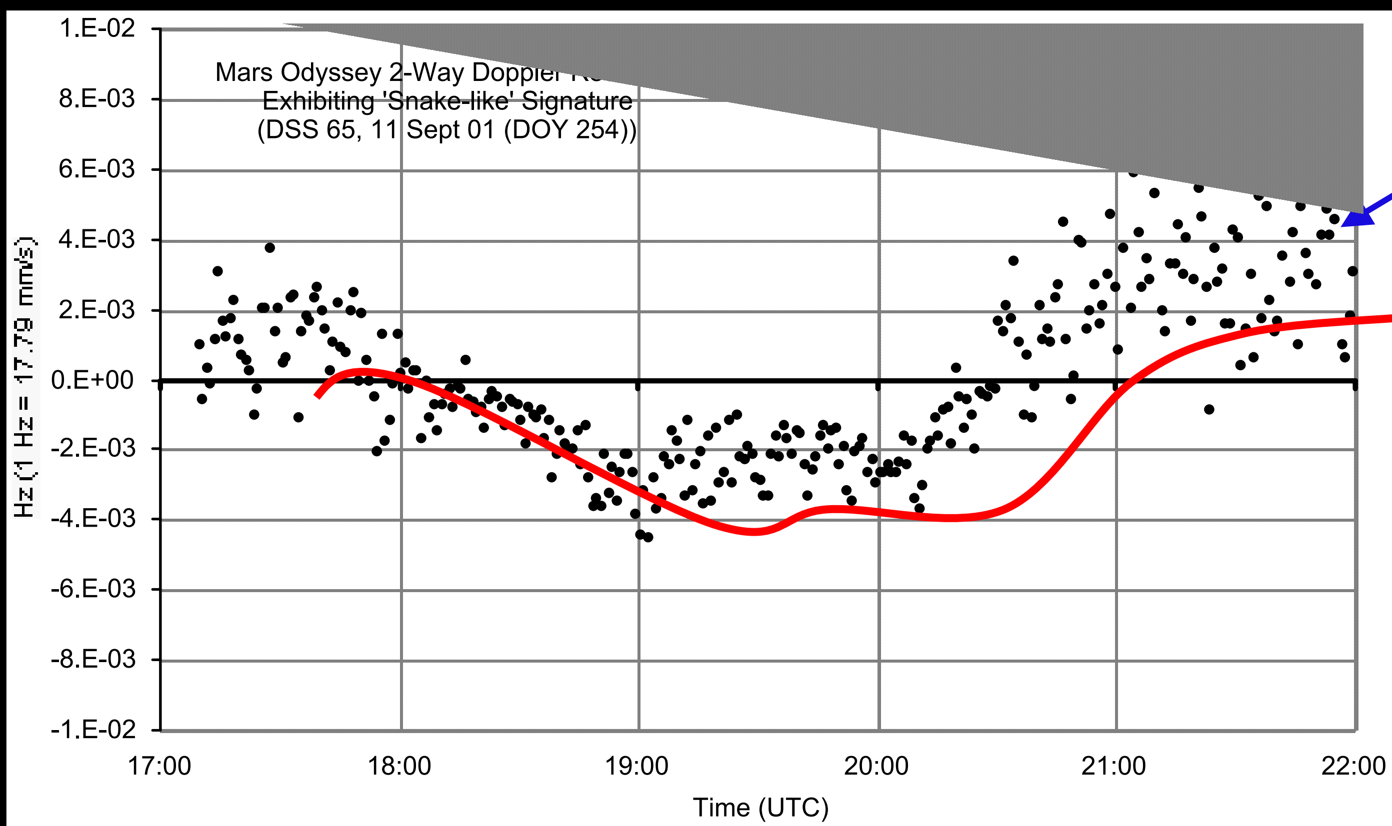
Functions: Acquisition, Flight Path Determination, Maneuver Computation and Command



NOTE: **Calibrations** are critical in accounting for media transmission delays

Ionospheric Effect in Mars Odyssey Tracking Data

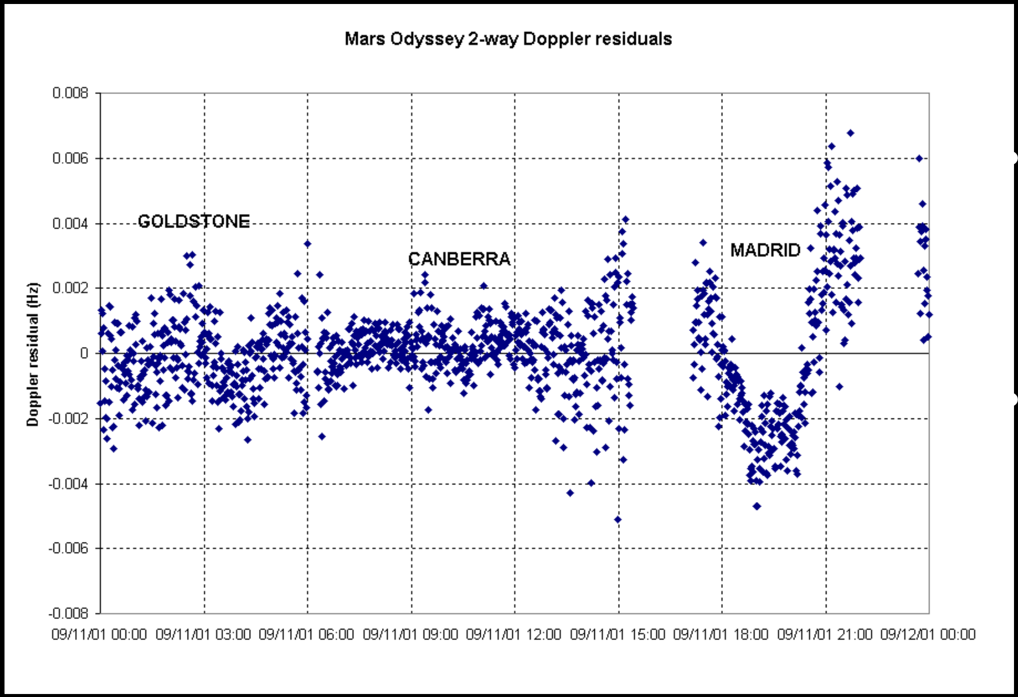
- Unexplained signature appeared in Mars Odyssey tracking data (2001)
- Signature has ~10 mHz peak-to-peak amplitude in Doppler residuals
  - For well-modeled Doppler, residual scatter is 1-2 mHz (1-sigma)
  - DSMS commitment level is 6 mHz 1-sigma
- Undulations can be abrupt or evolve over 1-2 hours
- Signature not obviously in phase with any known ground, spacecraft activity
- 'Snakelike' signature strongest in Madrid passes, smallest in Canberra passes



Ideally, these residuals should be a flat straight line

residuals = unexplained error

Mars Odyssey Residuals Compared

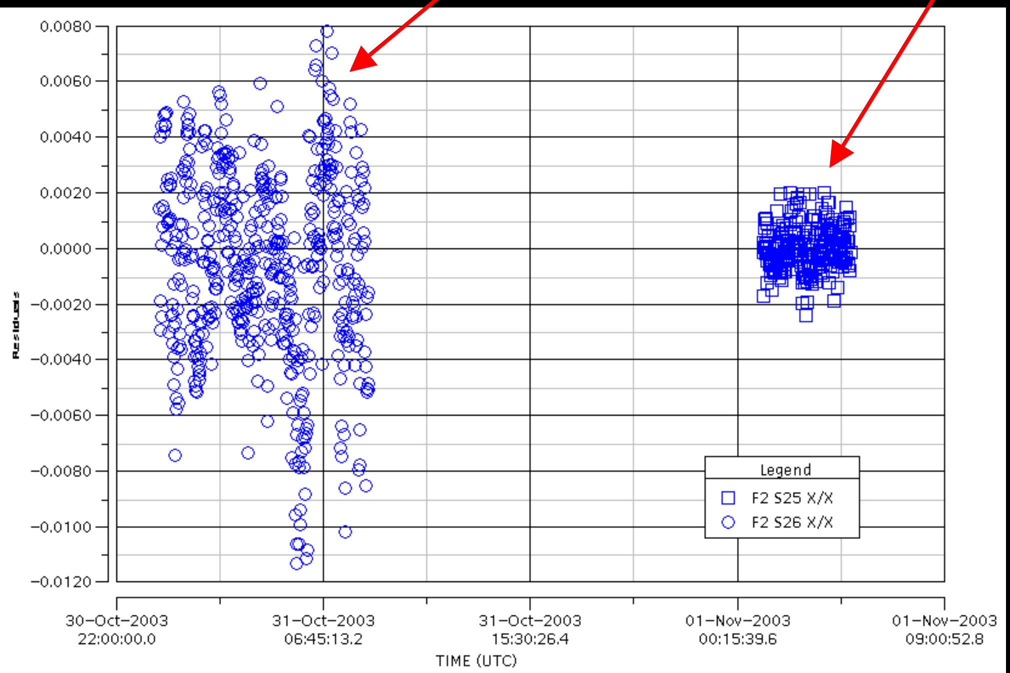


- Doppler residuals much more pronounced at Madrid, affecting entire pass
- Determined later that inadequately modeled ionosphere was the cause
  - Planetary geometry required low-elevation passes from Madrid
- Negligible improvement from state-of-the-art calibrations applied later
  - Tracking through low-latitude equatorial anomaly from Madrid is challenging
- Significant improvement requires sophisticated "data assimilation" approaches
  - Similar to numerical weather prediction models
  - Research has begun with Global Assimilative Ionosphere Model (GAIM)
  - Full understanding of Earth's ionosphere important for mitigation of such effects

Impact of Ionospheric Storms on Spacecraft Tracking

Storm period: increased tracking error

Nominal period



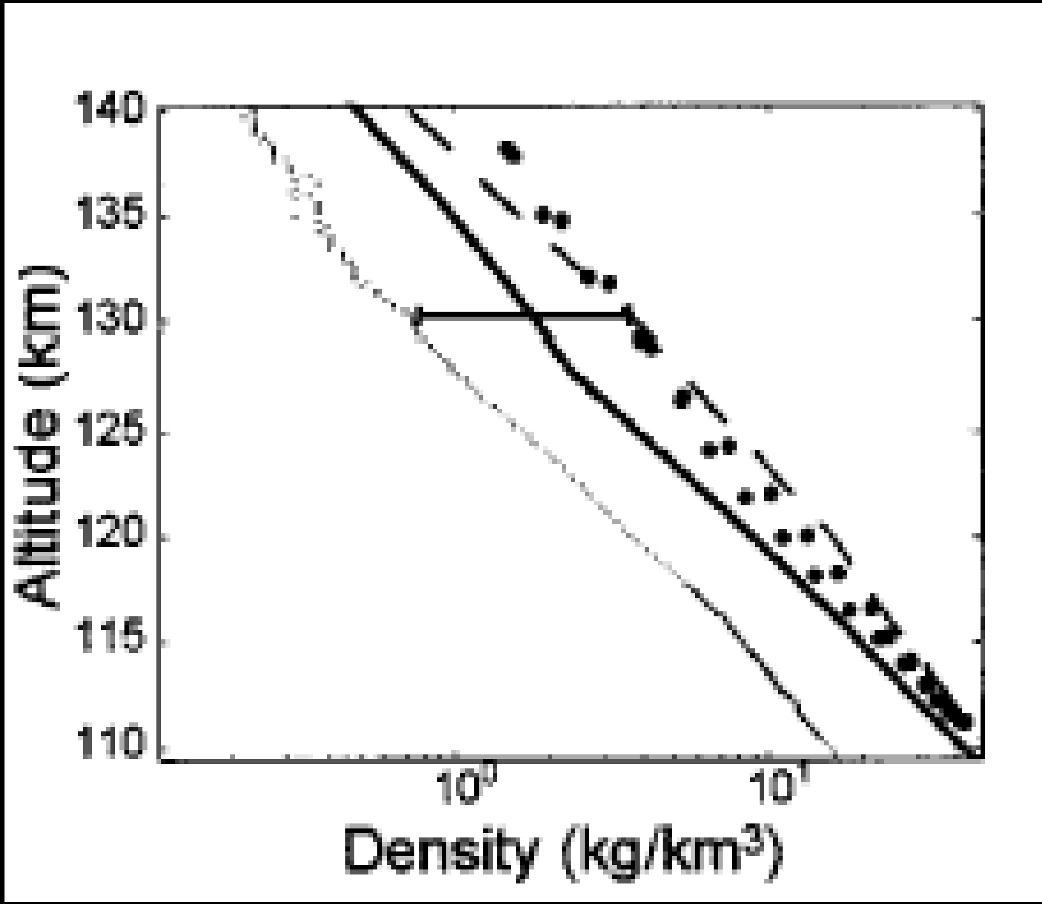
- Radiometric data acquired for Mars Exploration Rover S/C during Halloween 2003 storms
- Using state-of-the-art calibrations, tracking was degraded by at least a factor of 5
  - Degradation affected entire 8-hr tracking pass
  - Several tracking stations were affected -- tracking data from storm period was rejected
- Geomagnetic storm effects could be critical depending on operational

Mars Global Surveyor Observations of Thermospheric Variability

- Accelerometer measurements show upper atmospheric densities (130 km) to vary by 70% on time scales of a day or less,
- Variability increases to 200% during periods of dust storms,
- Thermospheric density bulges (believed to originate from topographically forced planetary wave propagating upward), and due to seasonal structure [*Keating et al, 1998*].
- Similar planetary wave modulation of the dynamics of Earth's upper atmosphere has also been observed.
- Neutral density, temperature, and wind data from ITSP will address the nature of these dynamic features through TIGCM model development
- Model progress and VALIDATION will directly support and predict drag conditions on Mars, and provide estimates for the range of uncertainty and variability of the system.
- **Variability has direct effects on aerodrag and aerocapture systems.**

Magnitude of Variability

Horizontal line shows estimate of change between Mars Pathfinder and MGS values due to seasonal and diurnal differences based on MTGCM calculations



Atmospheric Loss

- Mars Global Circulation Model and Mars Thermospheric Global Circulation Model are also used to infer where and for how long liquid water could exist at the surface [*c.f., Montmessin et al., Sixth International Conference on Mars (2003)*].
- Models provide constraints on the possibility and location of potential near-surface water
- Mars ionosphere is locally inflated over the magnetic fields embedded in the crust,
  - Represent significant barrier to erosion of the atmosphere by the solar wind and an important model component.
  - Accounting for observed neutral altitude profiles, global density variations, and the associated wind systems within the Martian ionosphere represent some of the major challenges in need of study [*Mendillo et al., JGR, 2003*].
  - These are the same processes at the heart of the uncertainties in predicting Earth's space weather effects, and therefore are prime science targets of the ITSP mission.

LWS Science Support for Satellite Systems

- Media calibration is currently largest source of DSN tracking error
  - ionospheric, solar plasma and tropospheric
  - LWS provides storm-time information for improved calibrations
- LWS Geospace missions provides the scientific understanding necessary to incorporate storm-time information into real-time and forecasting models
- Models at the core of engineering solutions are critical to manned exploration objectives

- Mars Ionosphere/Thermosphere relation to Earth's Ionosphere/Thermosphere
  - Striking similarities and key differences
  - Both have ionosphere, thermosphere, mesosphere
  - But Mars has direct interaction with solar wind
- Earth Thermosphere-Ionosphere Global Circulation Model (TIGCM) is foundation for Mars Thermospheric Global Circulation Models (MTGCM)
- Model development benefits from advances made at the two environments

Improved Safety and Enhanced Mission Assurance