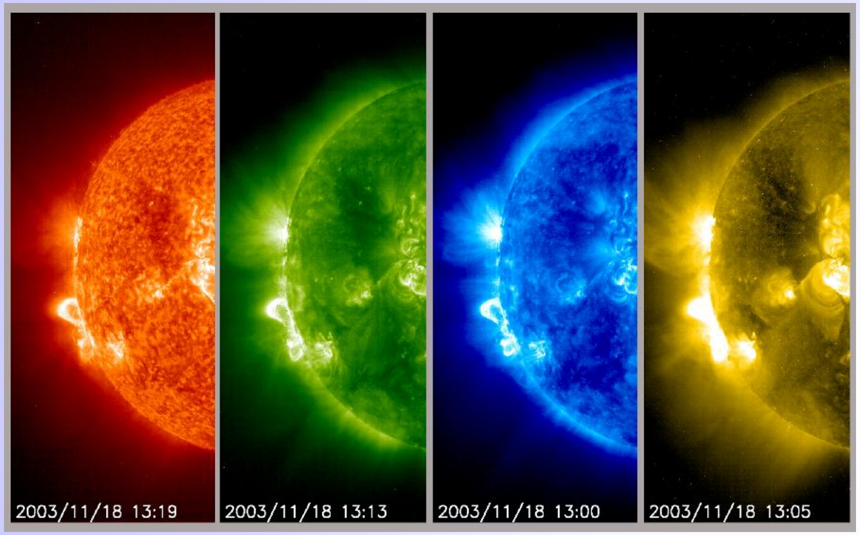
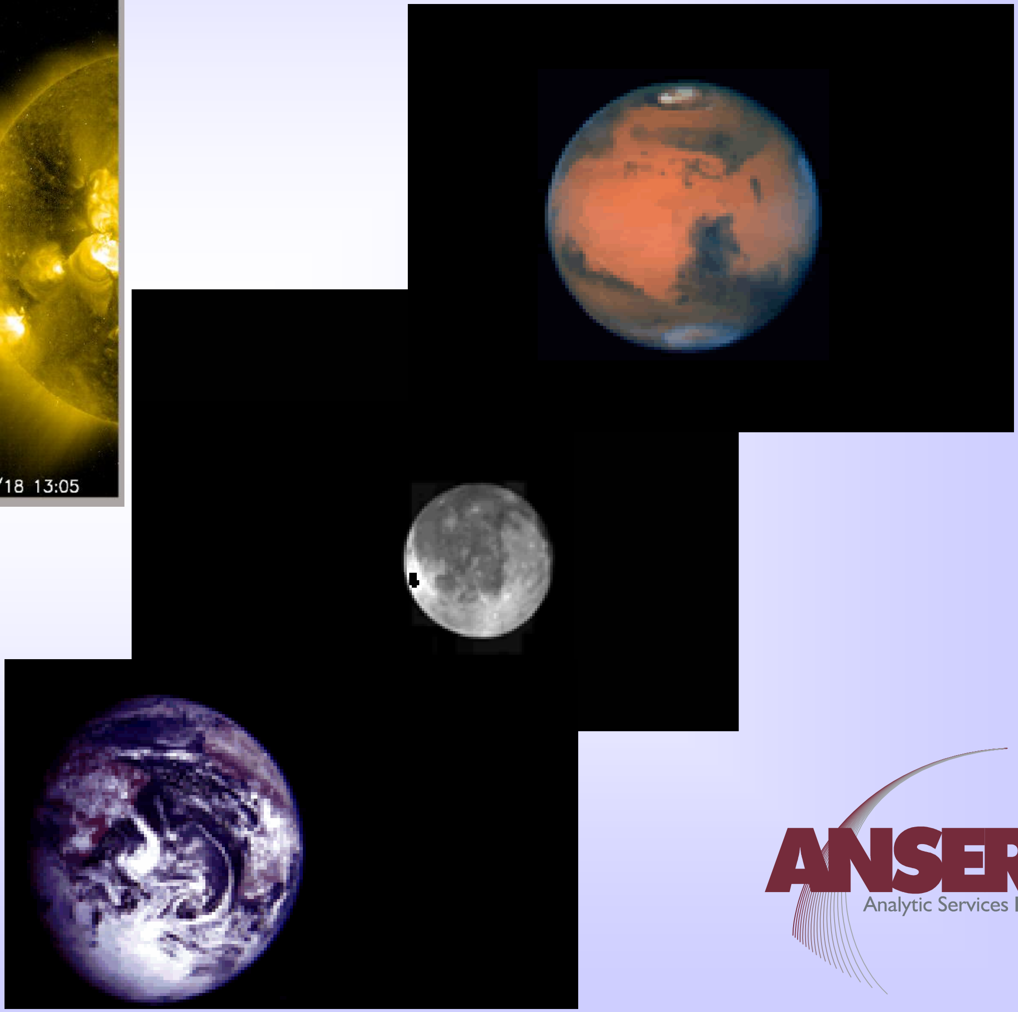
Space Weather Challenges Intrinsic to the Moon, Mars, and Beyond Vision





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Presented at

AGU Chapman Conference

August 6, 2004

ANSER Analytic Services Inc.

Moon, Mars, and Beyond

On January 14, 2004 the U.S. President announced and ambitious change in U.S. Civil Space policy, declaring:

"In preparation for future human exploration, we must advance our ability to live and work safely in space and, at the same time, develop the technologies to extend humanity's reach to the Moon, Mars, and beyond."

The President's Vision for U.S Space Exploration

Presidential Commission

In June 2004, the President's Commission on Implementation of the United States Space Exploration Policy affirmed this vision:

"These goals lay out an astonishingly ambitious vision. Our objectives in space have been radically transformed...a successfully implemented vision will create a sustained capability in space for the nation."

NASA's Response

On June 24, 2004, NASA revealed the first steps in its most ambitious reorganization in years (to be effective August 1, 2004). NASA Programs will now be managed through four Directorates: Exploration Systems, Science, Space Operations, and Aeronautics Research.

"*This transformation will be an evolutionary process, exploring new ways to move forward and implement change. ... Doing so will enable us to take the next bold steps into space and rekindle the innovation and entrepreneurial skills that is our legacy to humankind.*"

-- Sean O'Keefe

Harsh Choices Must Be Made

The new vision must be implemented in a tightly constrained budget environment. This demands that tough decisions be made. Planned cuts and reductions include:

- Retiring the Space Shuttle
- Significant reductions in use of ISS
- Potential end to Hubble Space Telescope

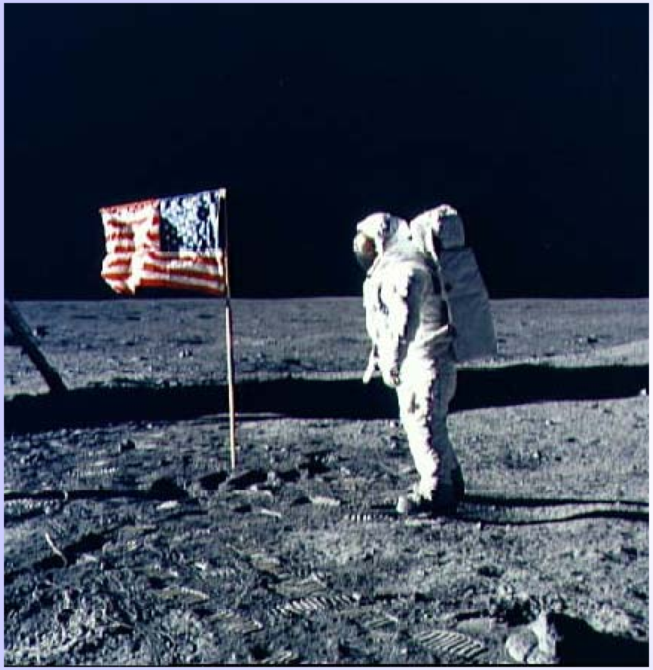
Programs that do not meaningfully contribute to the vision will be increasingly difficult to sustain

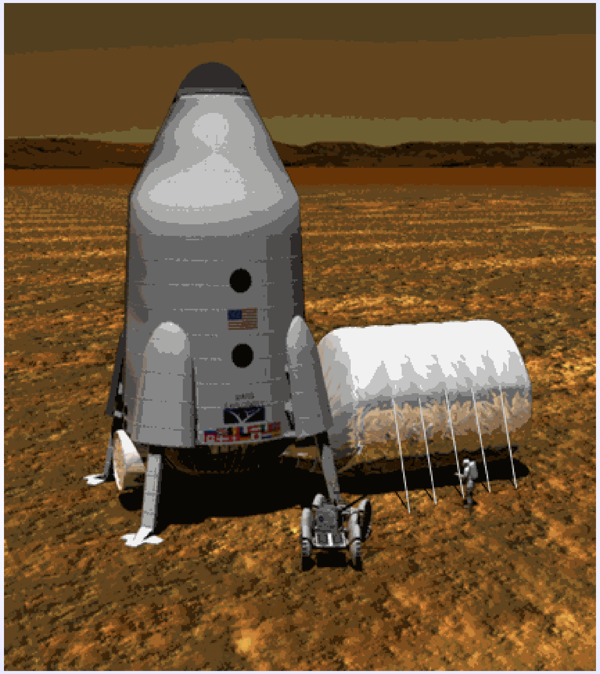
"The journey will need to be managed within available resources using a "go as you can pay" approach..."

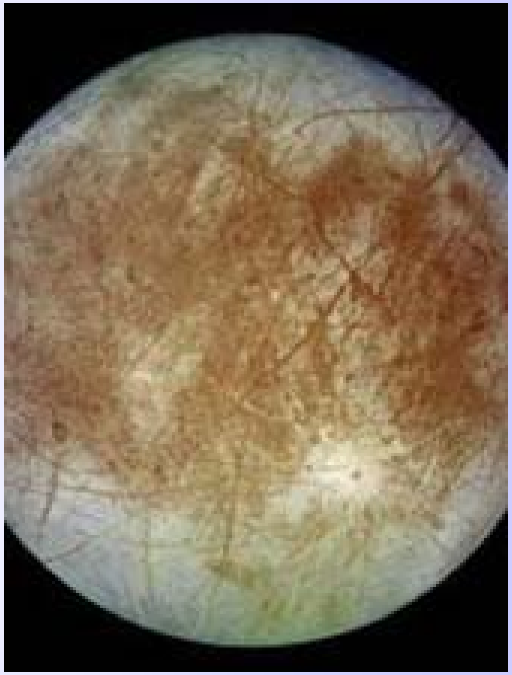
---Presidential Commission

Why Should Exploration Care About Space Weather?

Return to the Moon | **On to Mars** | **Beyond...**

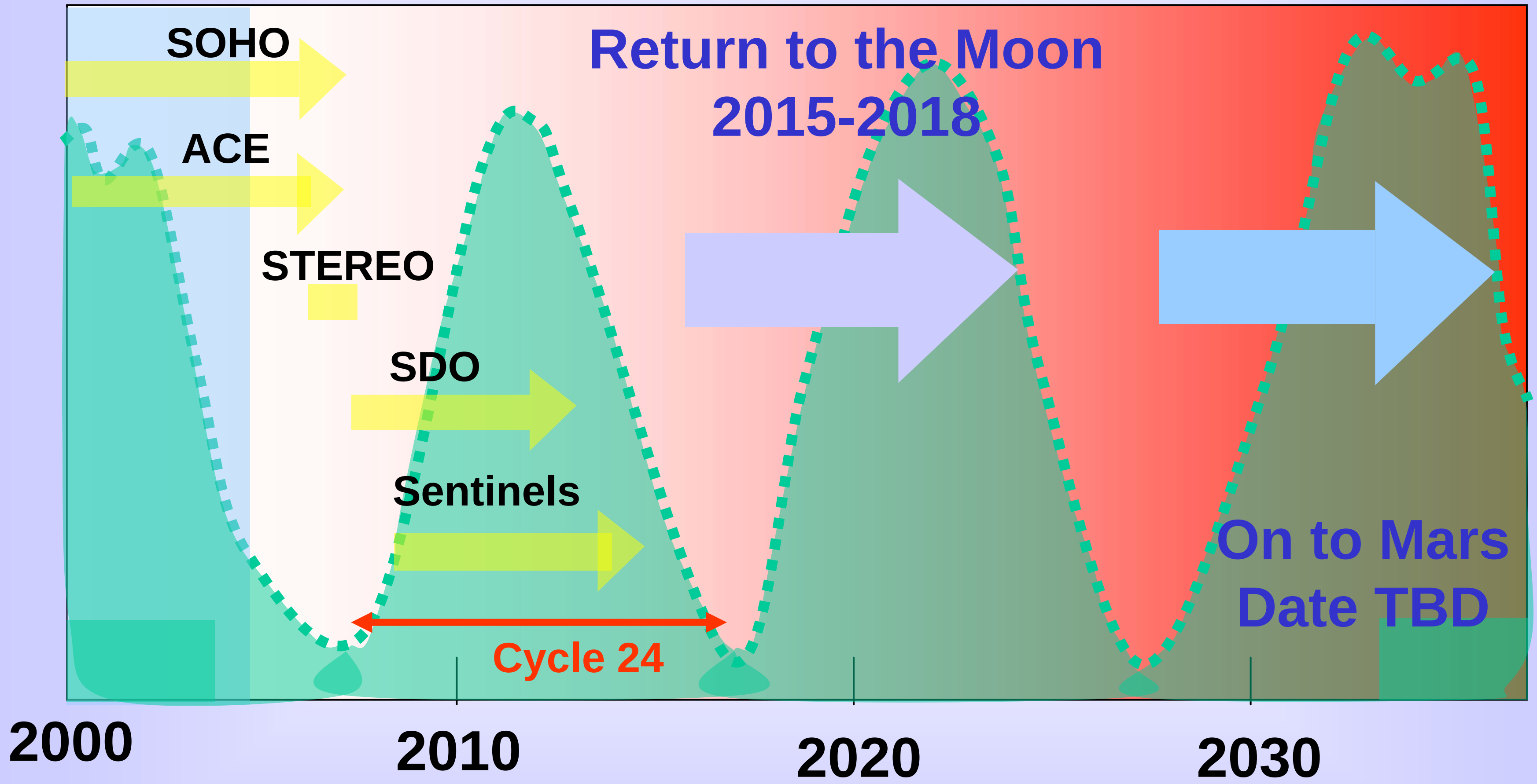






Radiation exposure will be a significant and serious hazard during any human expedition transiting deep space

Significant Space Weather Missions, Mapped into the Moon, Mars, and Beyond Vision



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

The Greatest Single Challenge to the Space Weather Community is to Improve Our Ability to Forecast Solar Particle Events

- **While significantly lower in energy that the GCR, the proton flux of SPEs is orders of magnitude greater for hours to days**
- **Principle of ALARA requires that exposure to SPEs be minimized**
- **Potential to be caught away from shelter on the Lunar or Martian surface will impose operational rules that will limit flexibility and reduce efficiency**

Health Risks to Astronauts

Environment	Impact
Microgravity	Space Sickness
	Cardiovascular Changes
Confined Space	Muscle Atrophy
Small, Isolated Crew	Bone Loss
Closed Life Support System	Human Performance Factors
	Reduced Resistance to Disease
Radiation	Acute Radiation Sickness
	Long-term Radiation Effects
Limited Medical Facilities	

Radiation Effects on Humans

Acute Effects

High dose over a short period can lead to

- ➔ Headaches
- ➔ Dizziness
- ➔ Nausea

In extreme cases, acute effects can be severe

- ➔ Directly through radiation sickness
- ➔ Indirectly, as from vomiting in space suit

Long-term Effects

Lower dose over prolonged period can have long-term impact

- ➔ Increased risk of cancer
- ➔ Damage to Central Nervous System
- ➔ Genetic or fertility impact
- ➔ Development of cataracts

Short-Exposure Radiation Effects

- **0 – 35 cGy**
  - No impact on performance
- **35 – 75 cGy**
  - Nausea; mild headache
- **75 – 125 cGy**
  - 5 to 30 % experience nausea and vomiting within 3 to 5 hrs
- **125 – 300 cGy**
  - 20 to 70 % experience nausea and vomiting within 2 to 3 hrs
  - 5 to 10 % probability of death with no treatment
- **300 – 530 cGy**
  - 50 to 90 % experience nausea and vomiting within 2 hrs
  - 10 to 50 % probability of death with no treatment
- **530 – 800 cGy**
  - 50 to 90 % mild to severe nausea and vomiting within 2 hrs
  - 50 to 90 % probability of death with no treatment

Medical Management of Radiological Casualties Handbook, 2nd Edition AFRRI, April 2003

NASA Philosophy

- **NASA's approach to radiation safety is a three-tier system:**
  - **Lifetime limits**
    - **Designed to reduce the long-term risks, especially risk of developing fatal cancer**
  - **Short-term limits**
    - **To reduce lifetime dose and to minimize risk of acute affects**
      - **Annual**
      - **Monthly**
  - **"As Low As Reasonably Achievable"**

NASA limits apply only to Low Earth Orbit – There are no approved limits for Exploration Missions

NCRP* Recommended LEO Limits

NCRP 98 (1989)

Time Period	Blood-Forming Organs (cSv)	Lens of the Eye (cSv)	Skin (cSv)
Career	*see Table*	400	600
Annual	50	200	300
30 Days	25	100	150

	Career Limits	
Age	Female (cSv)	Male (cSv)
25	100	150
35	175	250
45	250	325
55	300	400

NASA limits apply only to Low Earth Orbit – There are no approved limits for Exploration Missions

NCRP 132 (2000)

Time Period	Bone Marrow (cGy-Eq)	Eye (cGy-Eq)	Skin (cGy-Eq)
Career	-	400	600
Annual	50	200	300
30 Days	25	100	150

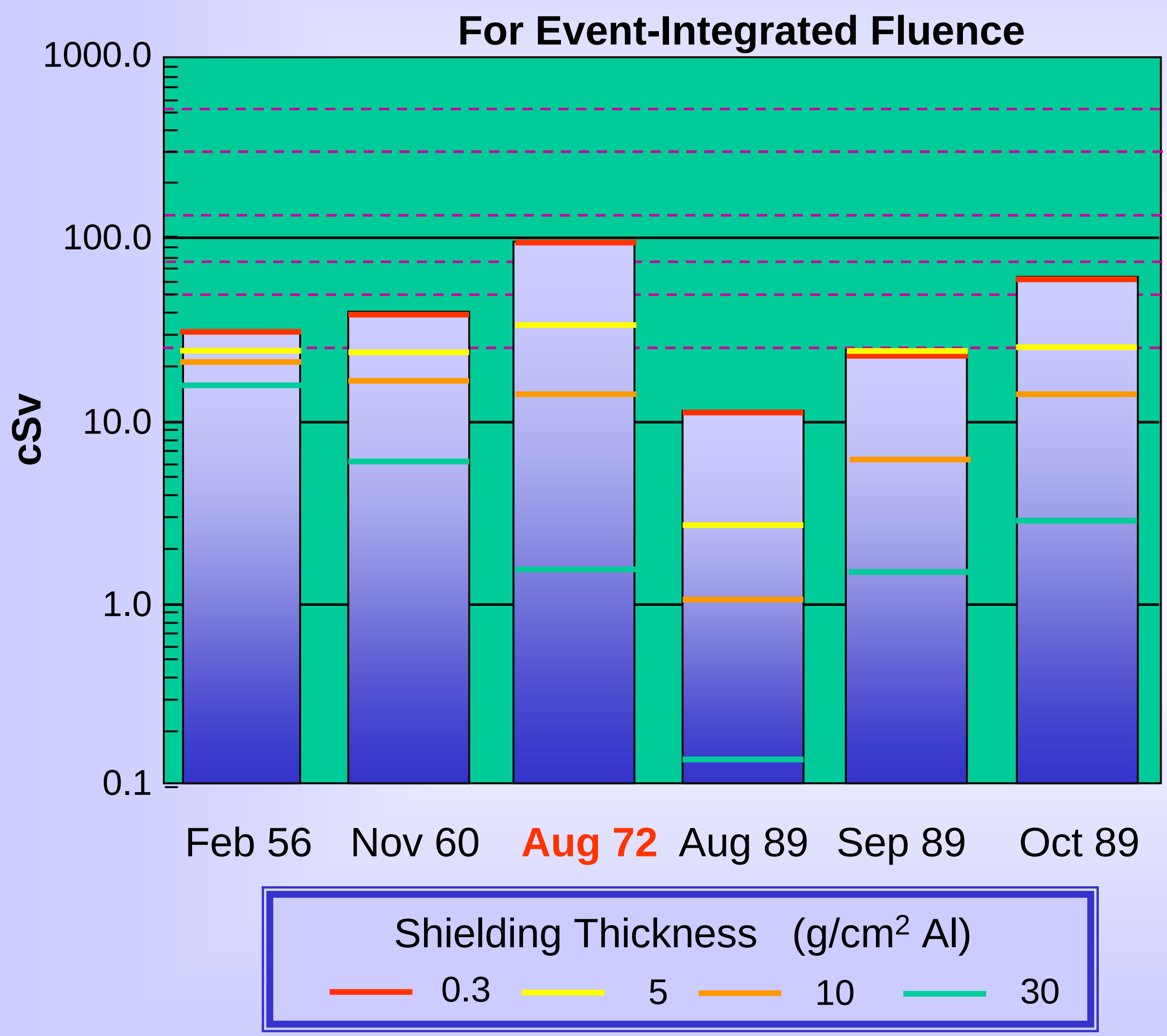
Ten-year Career Limits		
Age	Female (cSv)	Male (cSv)
25	40	70
35	60	100
45	90	150
55	170	300

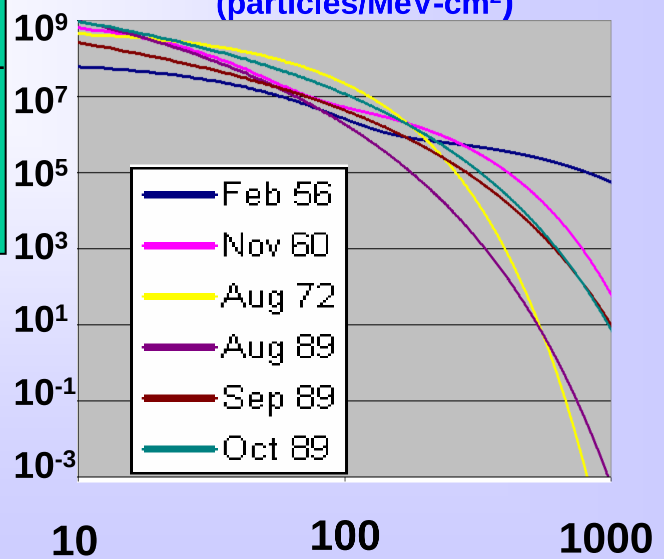
1) Age is age at first exposure
2) Based on three percent excess lifetime risk of fatal cancer
3) In addition, these limits incur 0.6 percent risk of heritable effects and 0.6 percent risk of nonfatal cancer

*National Council on Radiation Protection and Measurements

How Bad Can an SPE Be?
Selected Historical Events

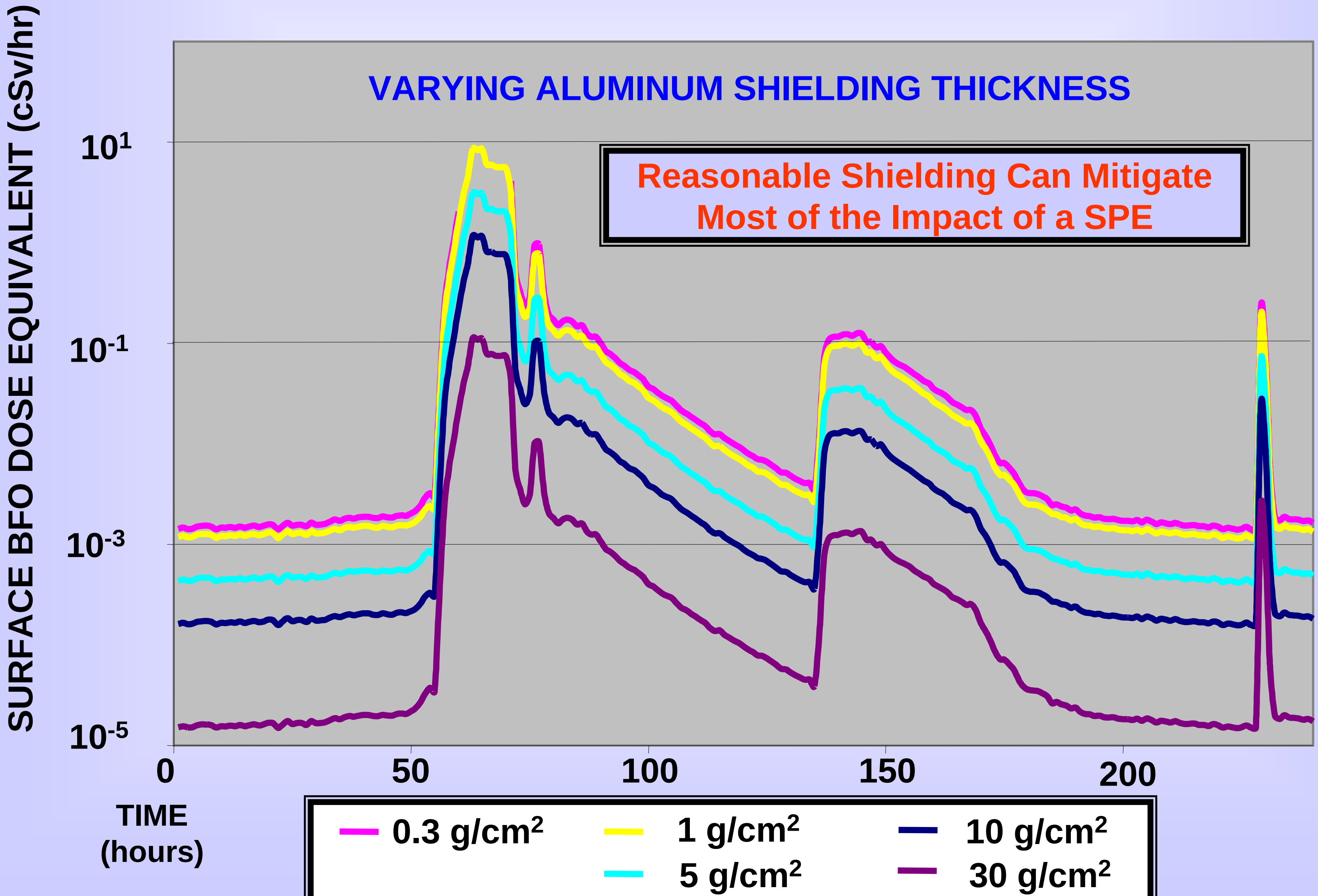
Surface BFO Dose Equivalent (cSv)





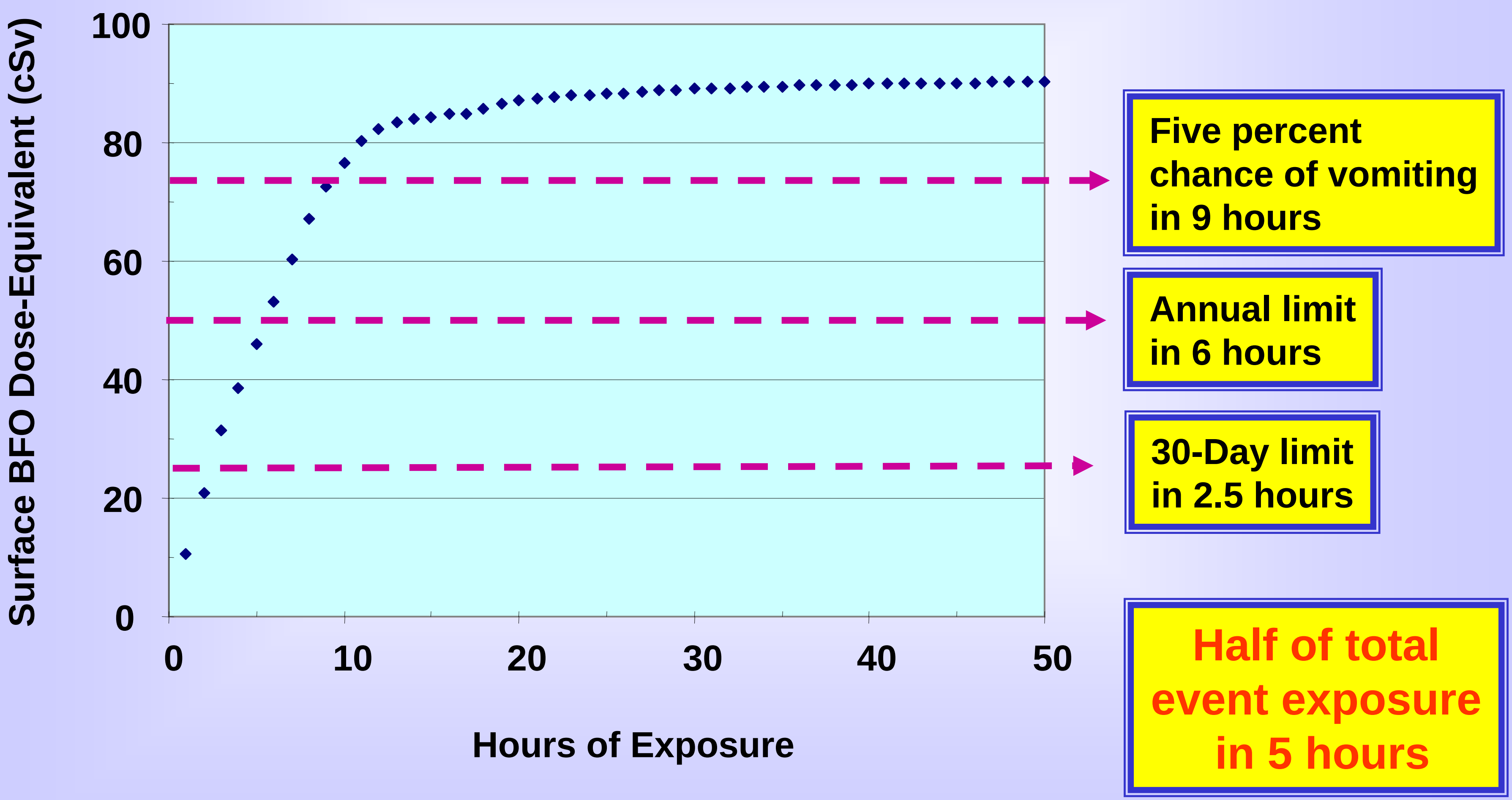
Surface BFO Dose-Equivalent Rate During Aug 72 Event

(cSv per hour)



Peak BFO Dose-Equivalent Exposure Vs Length of Exposure on Surface

Surface EVA During Aug 72 Event (cSv)



Mission Operations are Rule-Driven

- **Astronaut activities are managed against a set of "Flight Rules"**
- **These Rules define the overall Concept of Operations (CONOPS)**
- **CONOPS should reflect the best science available to the mission planners**
- **Translation of research to operations is not trivial and needs thoughtful scientist input**

Converting Science to Operations

Example

- **How far should astronauts be permitted to travel away from a "safe haven"**
  - **Overly-restrictive rules limit the science that can be accomplished**
  - **Too-lenient rules put the astronauts at risk**
- **Under what conditions must they abort an excursion; With how much urgency?**
  - **Based on what observations?**
  - **Based on what forecasts?**

What We Must Know About Solar Particle Events to Reduce the Risk to Astronauts

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

- **For astronaut radiation safety, the important SPE energy range is from 30 MeV up to 100-200 MeV**
  - **Spectral slope is very important**

- **SPE forecast goal according to findings of a 1996 NASA-sponsored SPE 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 SPE progresses**

- **Realistic near-term challenge:**
  - **8 hour rolling forecast as SPE progresses**
  - **Predict, at event on-set, the time of arrival and magnitude of shock-enhanced peak**
  - **Reliably forecast 1 to 3 day “all clear”**

Forecasting SPE is a Multidiscipline Challenge

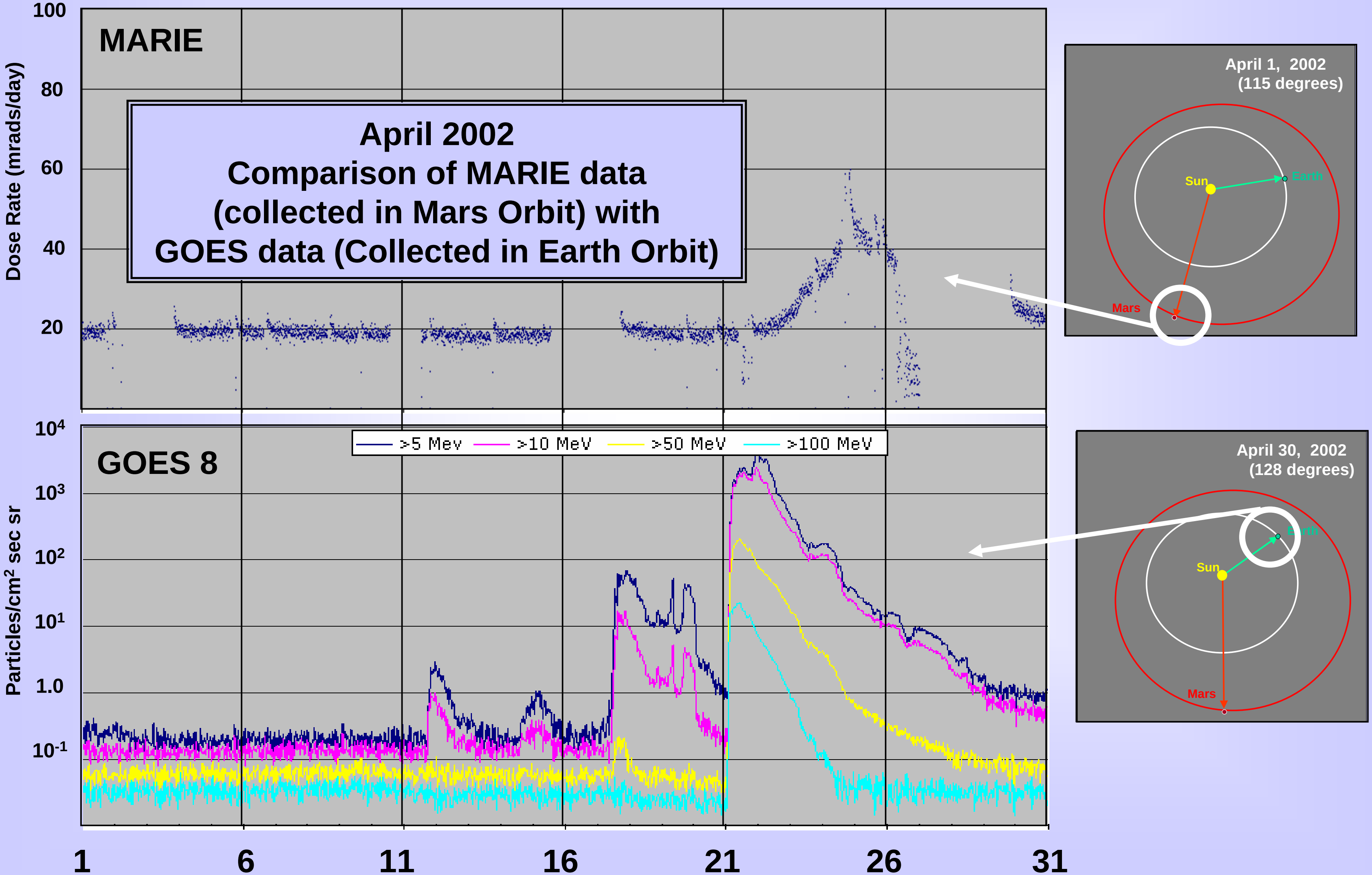
Predict the eruption of a CME

Predict the character of the CME

Predict the efficiency of the CME to accelerate particles

Predict the particle escape from shock and subsequent transport through heliosphere

And to make matters worse, we must eventually be able to forecast throughout the inner heliosphere



Solar Monitoring

Routine solar monitoring is the necessary first step to forecast and characterize of SPEs

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 SPE over a period of hours to days

Additional progress in understanding the physics of CMEs may lead to a multi-day forecast of the probability of an SPE

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 Monitoring

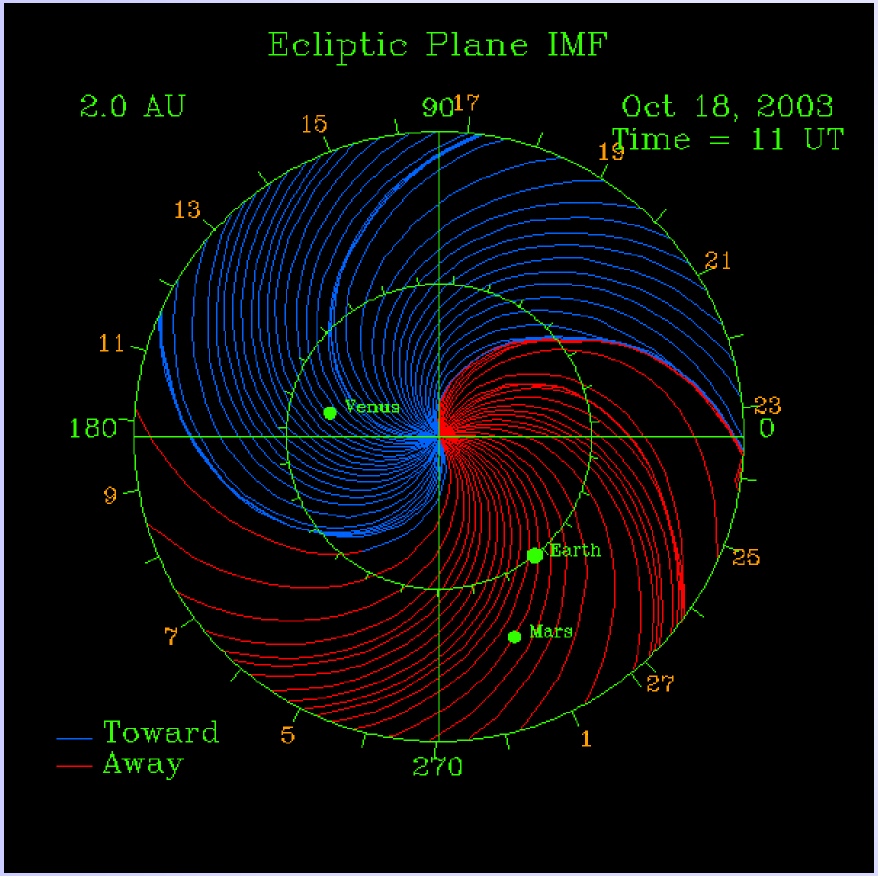
Heliospheric observations provide information necessary to model or monitor the propagation of solar energetic particles from the source to the astronauts

The data that may be necessary for SPE propagation models include

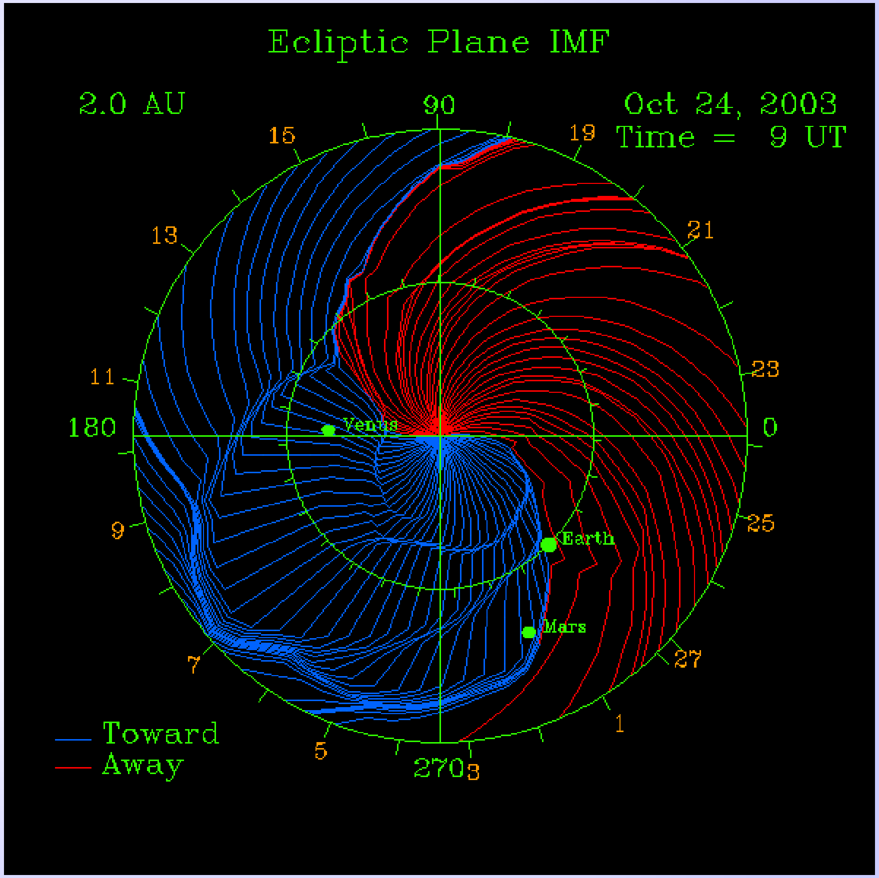
- **State of the ambient solar wind plasma**
- **Interplanetary magnetic field**
- **Local disturbances moving through the inner heliosphere**

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

Solar Wind Forecasting and Specification

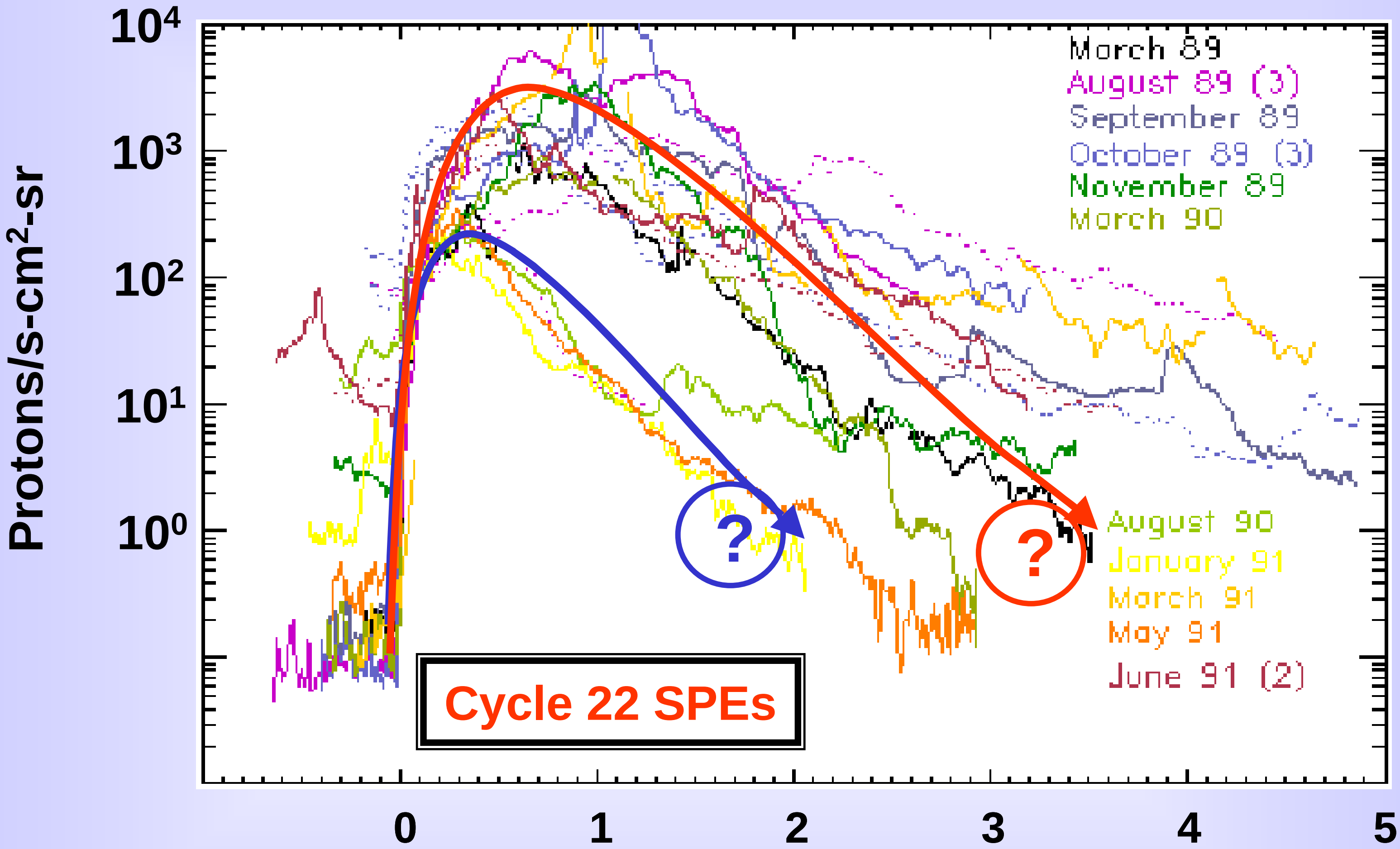


Nominal View
(Archimedian Spiral)



Modeled After Multiple CMEs
(Complex Structure)

SPE Forecasting



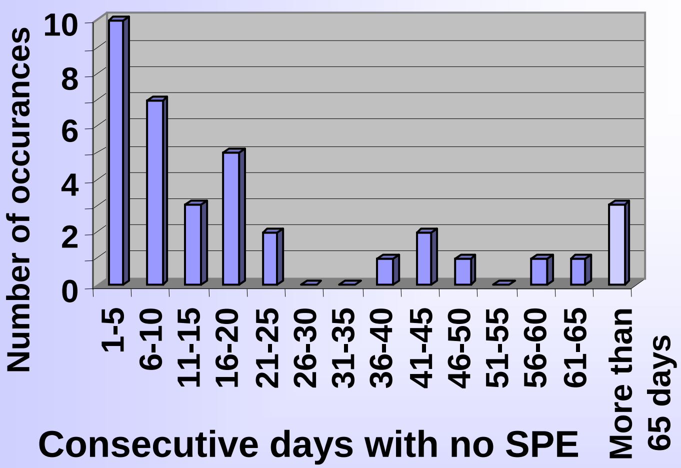
How early in, or prior to, an event can we distinguish between a major and a minor SPE?

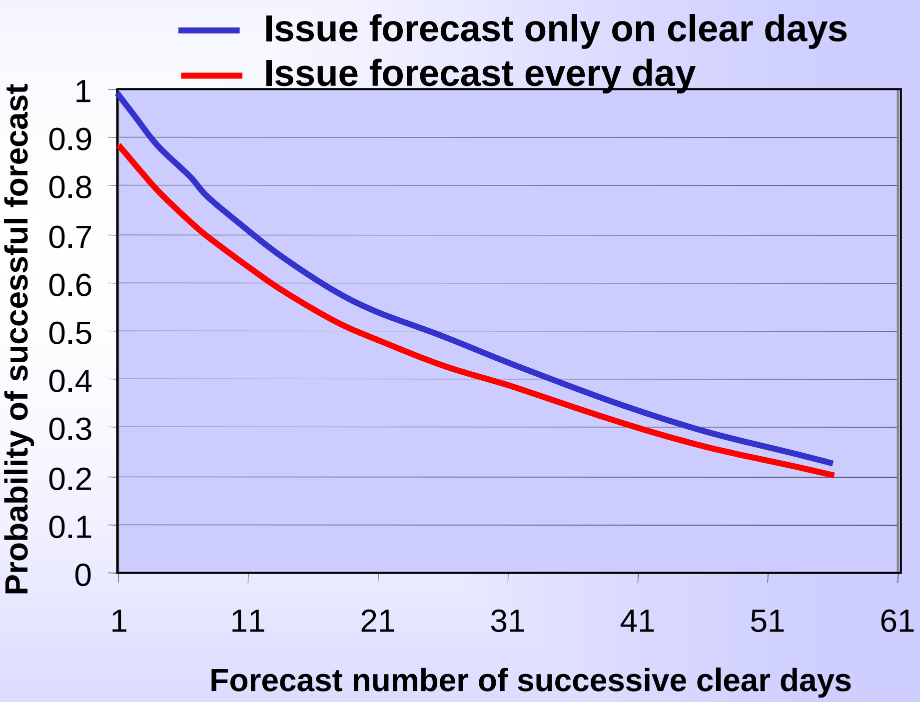
Credibly Forecasting "All Clear" Is a Challenge But Would Provide Tremendous Benefit

Between 1989 and 1991:
974 days no SPE
117 days of SPE*

*GOES Data; an SPE is underway when the 5-minute flux of protons with energy greater than 10 MeV exceeds 10 particles/cm^2-sec-sr for 15 minutes

Histogram of days between SPEs for 1989-1991





To be credible, a 3-day "All Clear" forecast must be right more than 99% of the time and must avoid more than 99% of the SPEs

How Can the Space Weather Community Support the Moon, Mars, and Beyond Vision

Better understanding of Solar Dynamics
- Improved Forecasting of Coronal Mass Ejections
  - Improved forecasting of SPEs

Better understanding of Heliospheric Dynamics
- Improved Forecasting of Solar Wind profiles
  - Improved forecasting of SPEs

Better understanding of SPEs
- Improved design of habitats and shelters
- Higher confidence in mission planning

Better forecasts of SPE evolution after on-set
- 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 SPEs before on-set
- Higher confidence in exposure forecast
  - Greater mission schedule assurance
  - Less down-time of susceptible electronics

Prediction of "all clear" periods
- Higher confidence in exposure forecast
  - Greater EVA scheduling flexibility
  - Greater mission schedule assurance

Improved Safety and Enhanced Mission Assurance