The Ionizing Radiation Environment for Exploration

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Outline

This talk will focus on what is needed for lunar missions. It will address:

- What we need to know?
- When we need to know it?
- The current issues
- What we need to do and why

What do we need to know?

- To predict, manage and assess crew exposures
  - Solar Proton fluxes from 20 MeV to ~1000 MeV
  - GCR fluxes for $0.1 \leq E \leq 10$ GeV/nuc for $1 \leq Z \leq 26$
  - Knowledge of the lunar neutron albedo
- To predict the impact on electronics
  - SEP fluxes for $5 \leq E \leq 200$ MeV/nuc for $1 \leq Z \leq 26$
    - *$0.1 \leq E \leq 1000$ MeV/nuc in special cases*
  - GCR fluxes for $.02 \leq E \leq 10$ GeV/nuc for $1 \leq Z \leq 30$

When do we need to know it?

- <u>To predict, manage and assess crew exposures:</u>
  - Reliable predictions during the largest SPEs of the solar proton spectrum versus time extending least a few hours into the future.
  - The predicted worst-case solar proton spectrum for the mission, years in advance.
  - Measurements of the solar proton spectrum in real-time and the measured proton fluence spectrum for the mission after the flight.
  - The measured mission-integrated elemental fluence spectra for GCRs after the flight as well as predictions of it years in advance.

When do we need to know it?

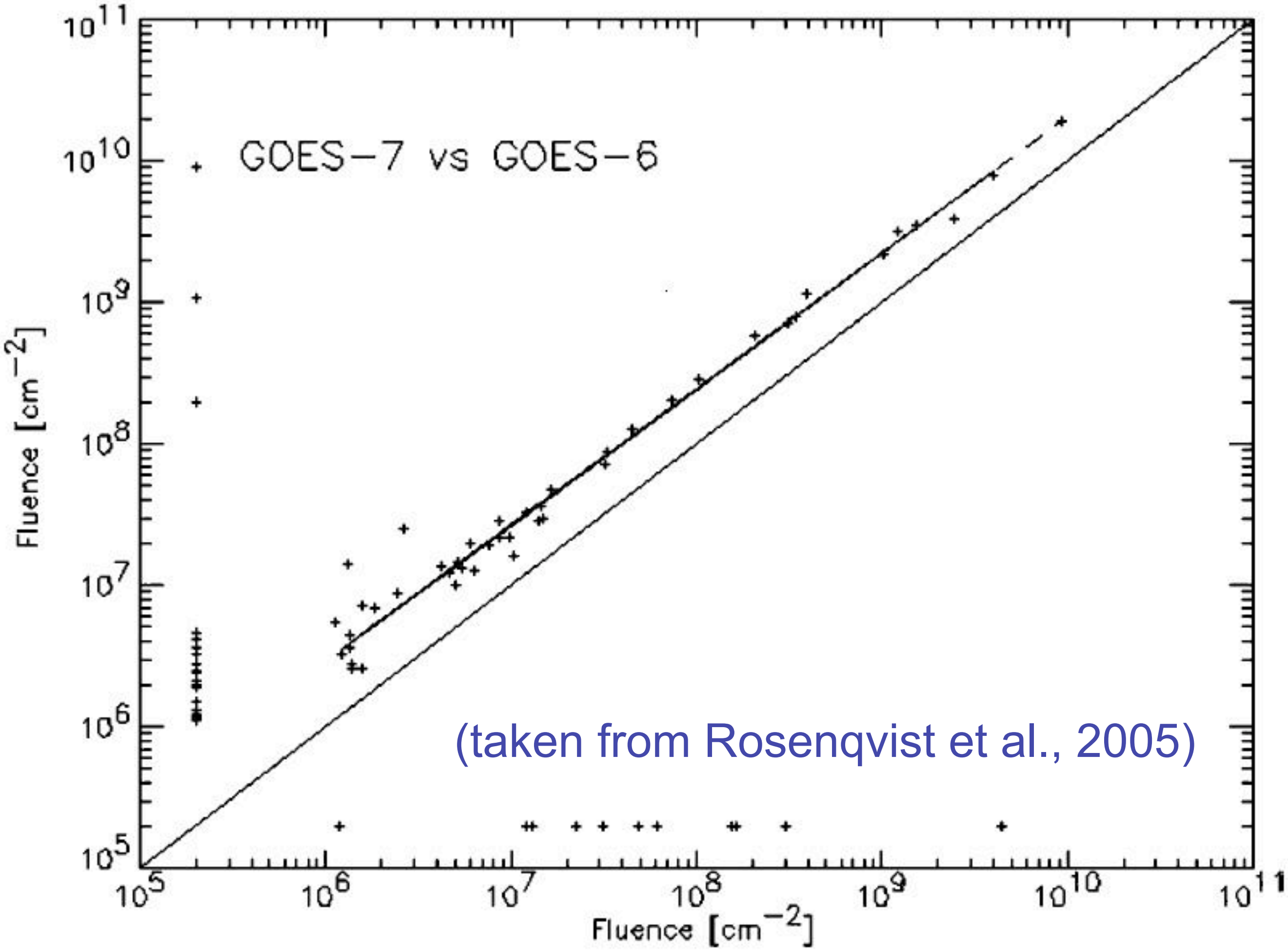
- To predict the impact on electronics in specific missions the following are needed for at design time for each mission:
  - The worst-case solar elemental flux spectra at selected confidence levels.
  - The worst-case solar proton fluence spectra at selected confidence levels.
  - The GCR elemental flux spectra

Current Issues

Unreliable Solar Particle Data

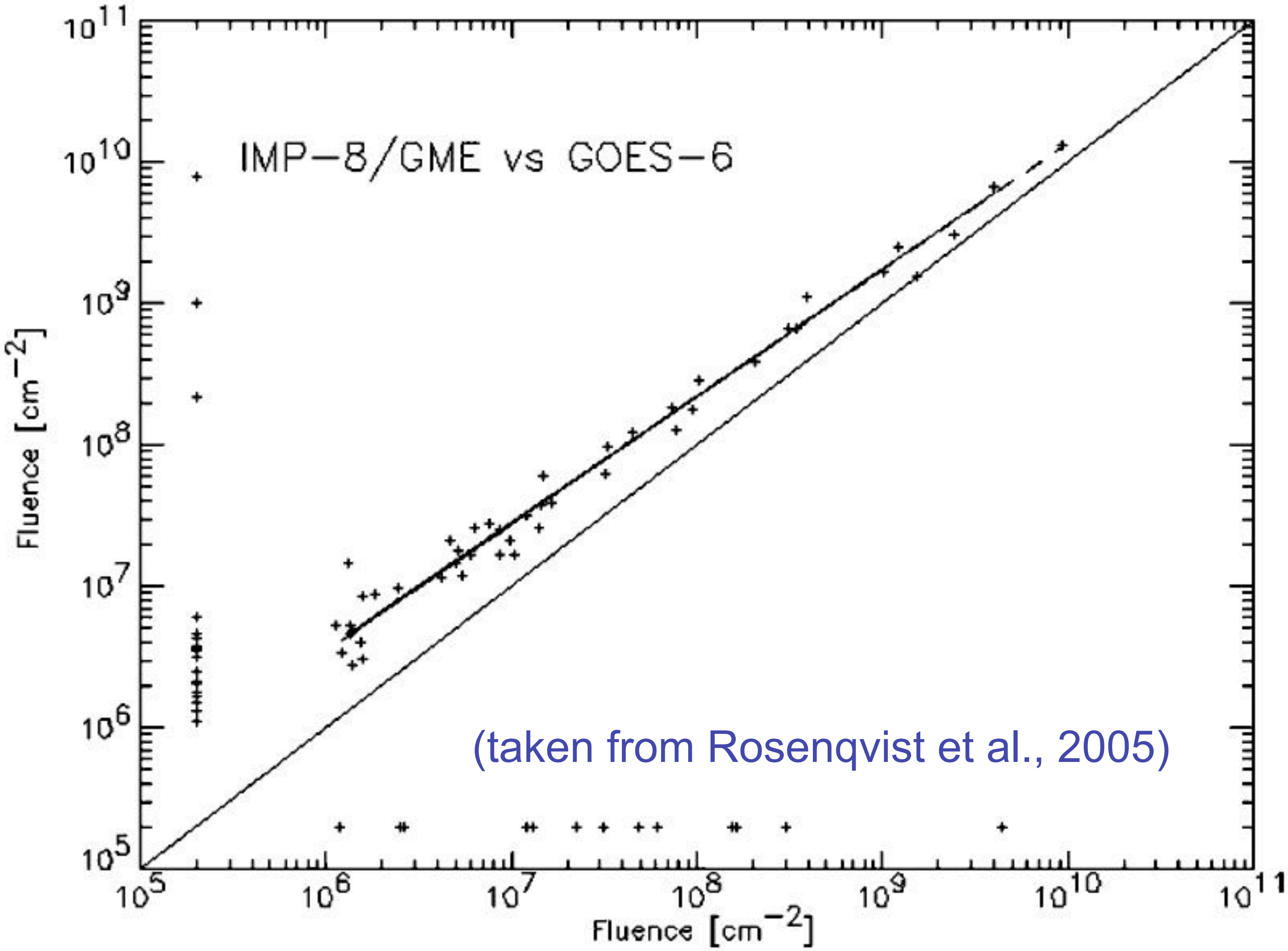
- Solar proton fluences from the IMP-8 and the GOES satellites are inconsistent
  - This has effected the accuracy of such widely used engineering models as the JPL proton fluence model (Feynman et al, 2002) and probably others as well.
- The ERNIE instrument on SOHO is known to saturate in large SPEs (ERNIE WWW site)
- There is known to be an over-correction of the CRNC instrument on IMP-8 for the deadtime in large SPEs (Tylka, 2007)

Examples of event-integrated proton fluences, E>10 MeV



(taken from Rosenqvist et al., 2005)

Another Example



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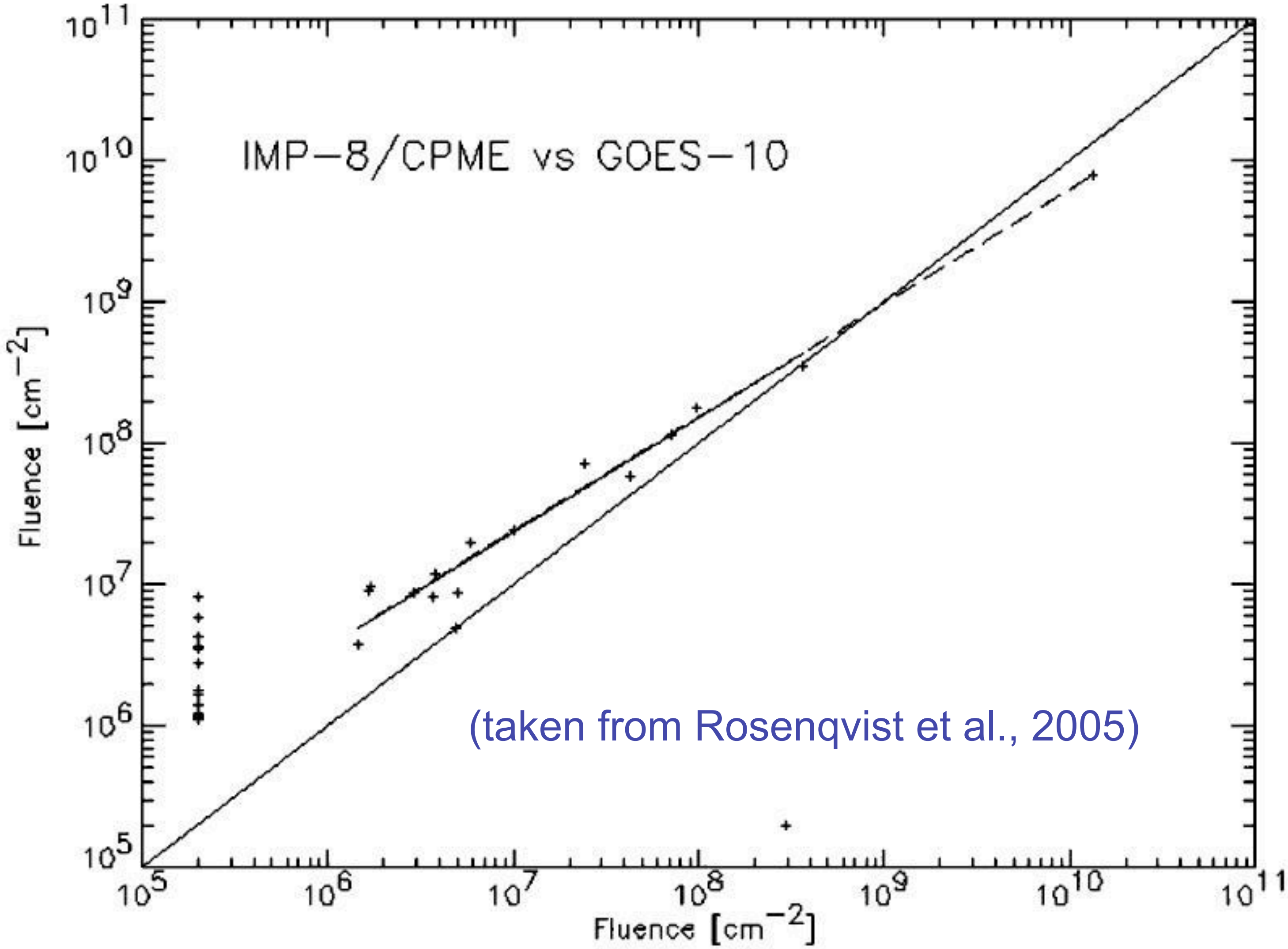
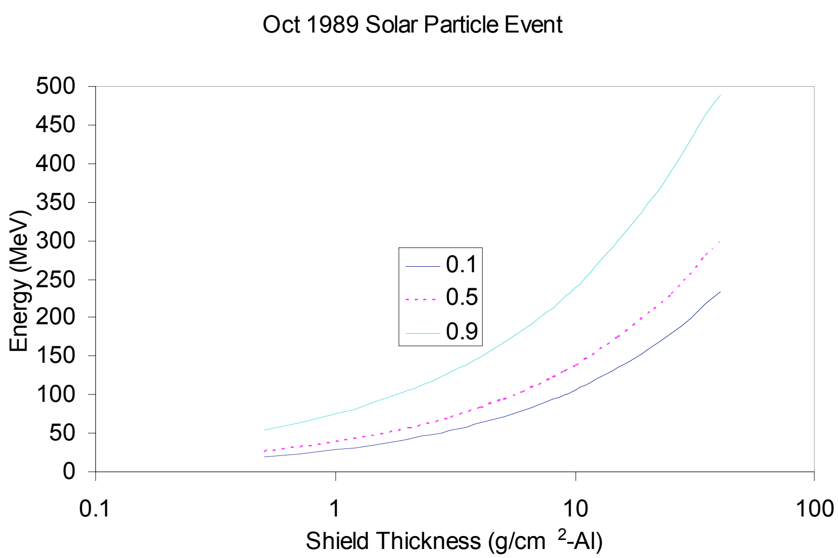


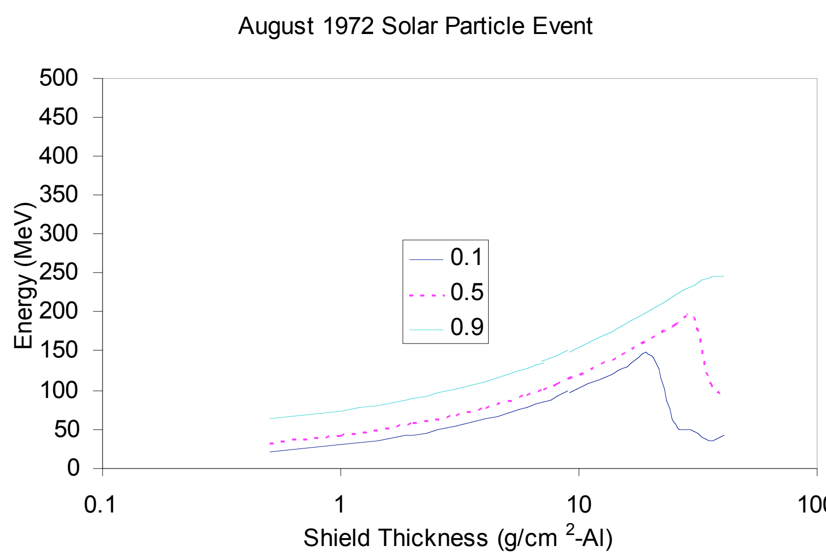
IMP–8/CPME vs GOES–10
Fluence [cm^{-2}]
Fluence [cm^{-2}]
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
(taken from Rosenqvist et al., 2005)

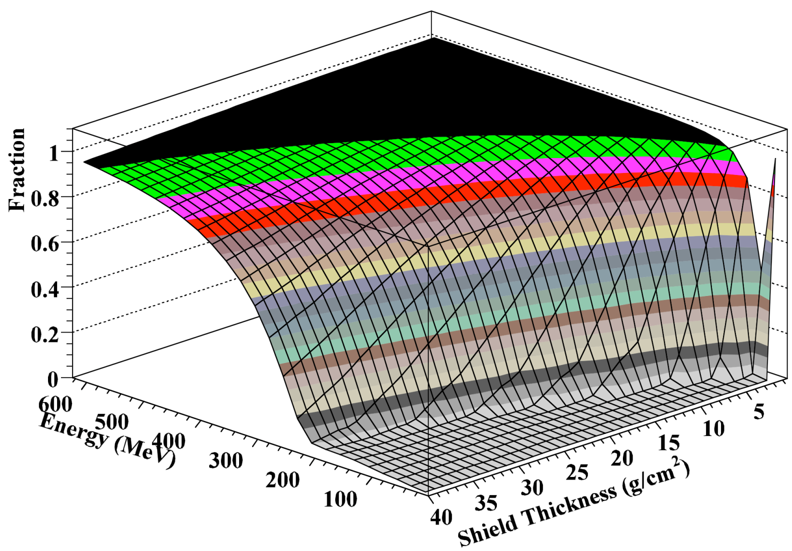
Required Range for Solar Proton Measurements

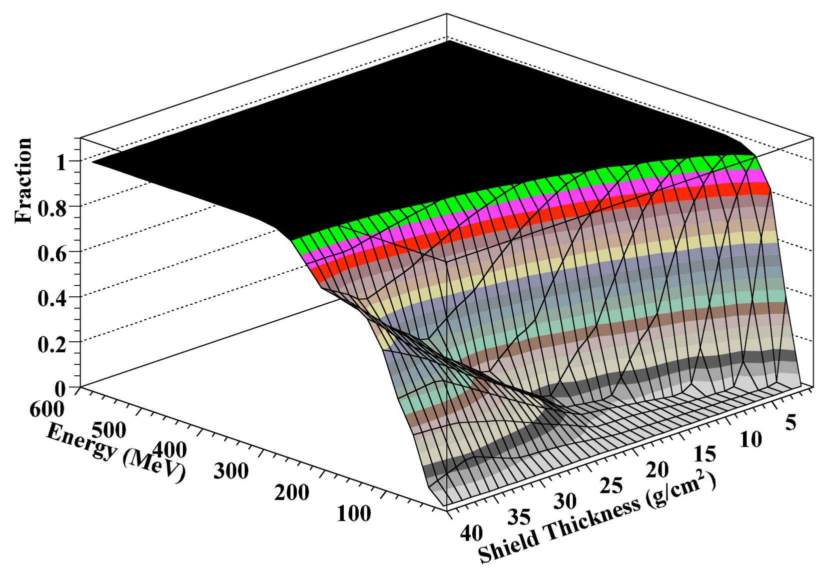
- For Skin Dose
  - Behind 0.5 to 40 g/cm^2 of Al shielding
  - For six large SPEs
  - ≥80% of the dose comes from protons with energies 20 ≤ E ≤ 600 MeV
- For dose to the blood forming organs
  - The dose comes from protons with energies ~50 ≤ E ≤ ~1000 MeV

Proton energy range to account for 80% of the skin dose









Proton Energy Ranges

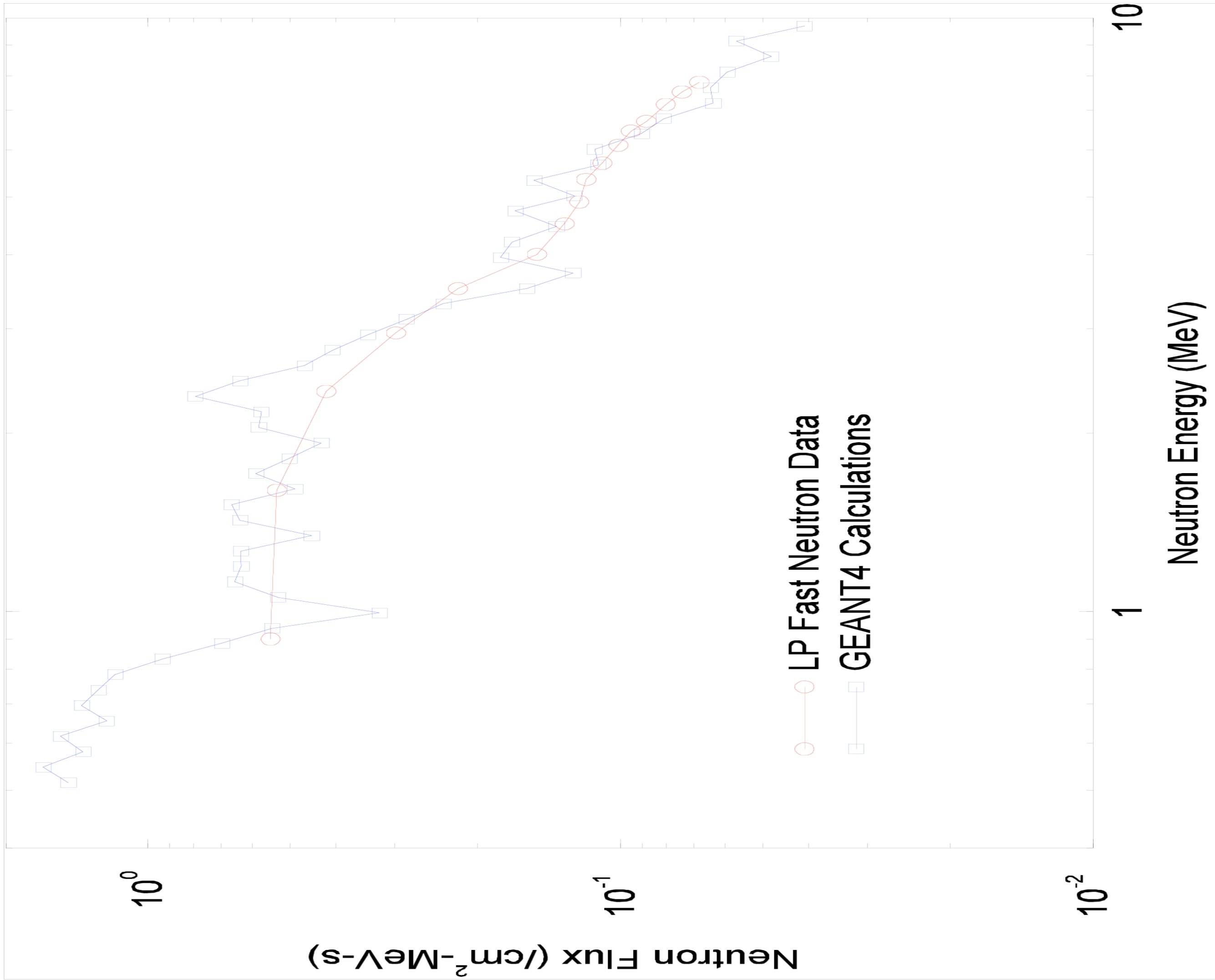
Spacecraft	Instrument	Z range	Proton Energy Range in MeV
SAMPEX	PET	$1 \le Z \le 2$	$20 \le E \le 300$
IMP-8	CPME	$1 \le Z \le 28$	$0.3 \le E \le 440$
IMP-8	CRNC	$1 \le Z \le 28$	$4 \le E \le 95$
IMP-8	GME	$1 \le Z \le 28$	$0.5 \le E \le 500$
Wind	EPACT	$1 \le Z \le 30+$	$0.04 \le E \le 110$
Ulysses	COSPIN	$1 \le Z \le 28$	$5.4 \le E \le 92$
SOHO	ERNIE	$1 \le Z \le 28$	$1 \le E \le 100$
Stereo	HET	$1 \le Z \le 2$	$13 \le E \le 100$
Helios A&B	E7	$1 \le Z \le 2$	$0.6 \le E \le 56$
ACE	SIS	$1 \le Z \le 28$	$\ge 10, \ge 30$
PAMELA	PAMELA	$1 \le Z \le 6$	$40 \le E$
GOES	HEPAD	$1 \le Z \le 2$	$0.8 \le E \le 700$
RBSP	RPS	$Z=1$	$50 \le E \le 2000$

Are Lunar Albedo Neutrons a Hazard?

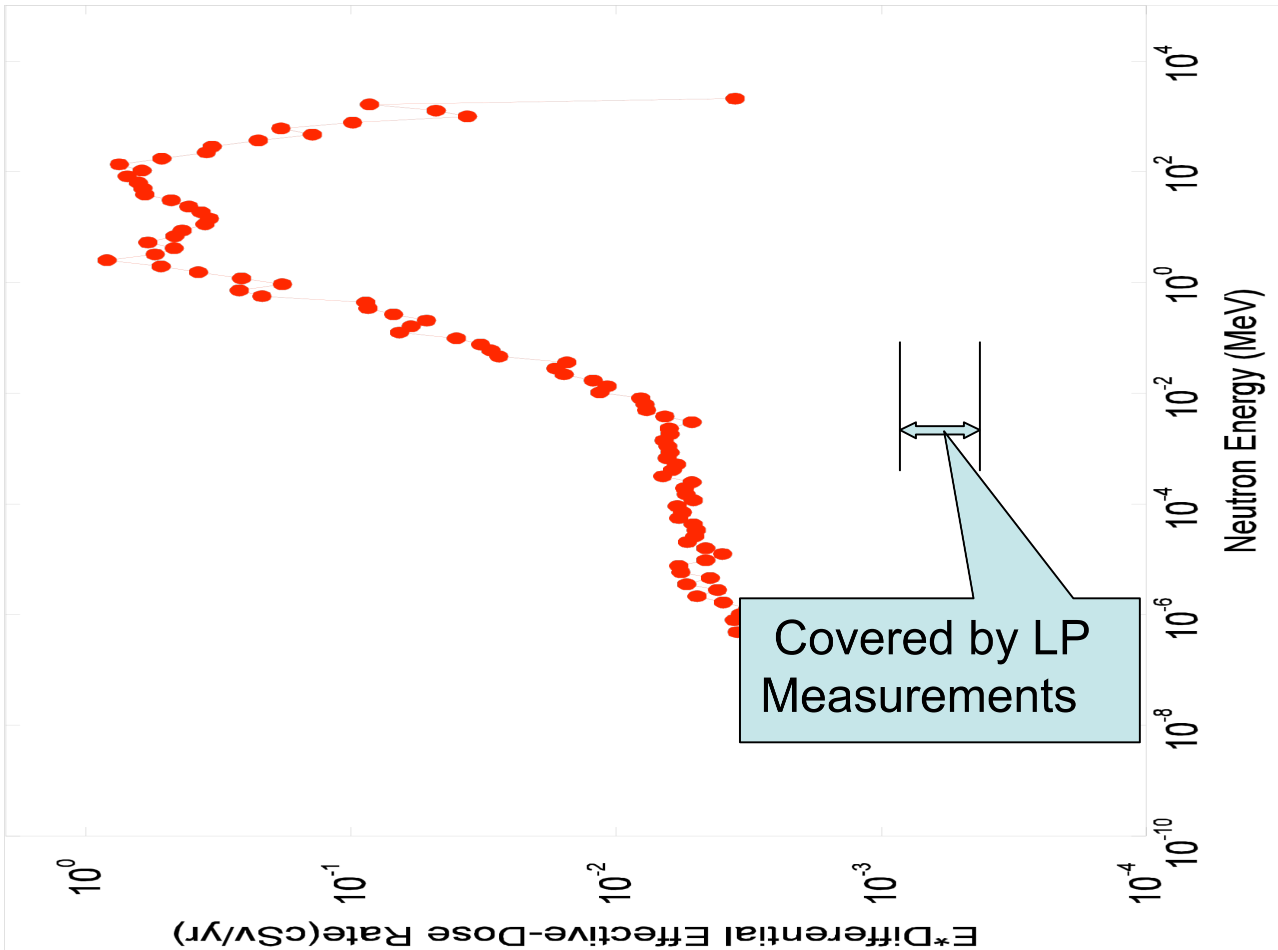
- The effective dose has been estimated from
  - Monte Carlo simulations of lunar neutron albedo
  - Fluence to effective dose conversion (Bozkurt et al, 2000 and 2001)
- The results have been compared to the ionizing particle doses and the results are:

	1970 GCRs in cSv/yr	1977 GCRs in cSv/yr	October 89 SPE in cSv
Neutrons	2.63	3.84	1.43
Charged Particles	8.95	24.40	96.40
% from Neutrons	13.6	23.0	1.5

So how good is the simulation?



But the effective dose comes mostly from higher energies



SPE Prediction

- In Advance
  - This requires a detailed understanding of:
    - The free energy available in active regions
    - The mechanisms for its release
    - When the release will occur
    - How much energy will be released
  - Prediction of "All Clear" periods seems possible.

SPE Prediction

- After the outburst on the Sun
  - This requires knowledge of:
    - The pre-existing state of the IPM
      - To predict the Cobpoint location
    - Detailed diagnostics of the event
      - Will it be a gradual event?
      - What are the characteristics of the IP shock
    - A model for shock acceleration that
      - Is driven by real-time data
      - To produce detailed spectra injected at the Cobpoint
    - A reliable shock propagation model
      - That accurately predicts storm-time
      - And the proton spectra at storm-time

Forecast Models

- Proton Prediction System (Shea and Smart)
- SEC Proton Prediction Model (Balch, 1999)
  - Flux predictions from these codes are uncertain by a factor ~10 $\Rightarrow$ they do not provide actionable info.
- SOLPENCO Model (Aran et al., 2005)
  - This model is in the early stages of development
  - Only 10 events have been modeled so far
- Improved HAF model (Frye and Wu)
  - This model shows promise of accurate shock arrival time predictions

What is Needed and Why?

- An evaluated data base of the SEP event measurements over the space age
  - To accurately plan missions and reduce cost
- Solar proton measurements on future missions for energies up to ~1000 MeV that are reliable in the largest events
  - For the planning and management of crew exposures
- Measurements of lunar neutrons to ≥100 MeV
  - To be sure we understand the radiation hazard
- SPE predictions hours to days in advance
  - To minimize the radiation exposure of the crew

The End

Gyroradii of Solar Energetic Protons

All protons have pitch angles of 90°