Environmental Models and Validation of Engineering Designs

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Workshop on Radiation Measurements on ISS

Oklahoma State University, Stillwater

10-12 September 2007

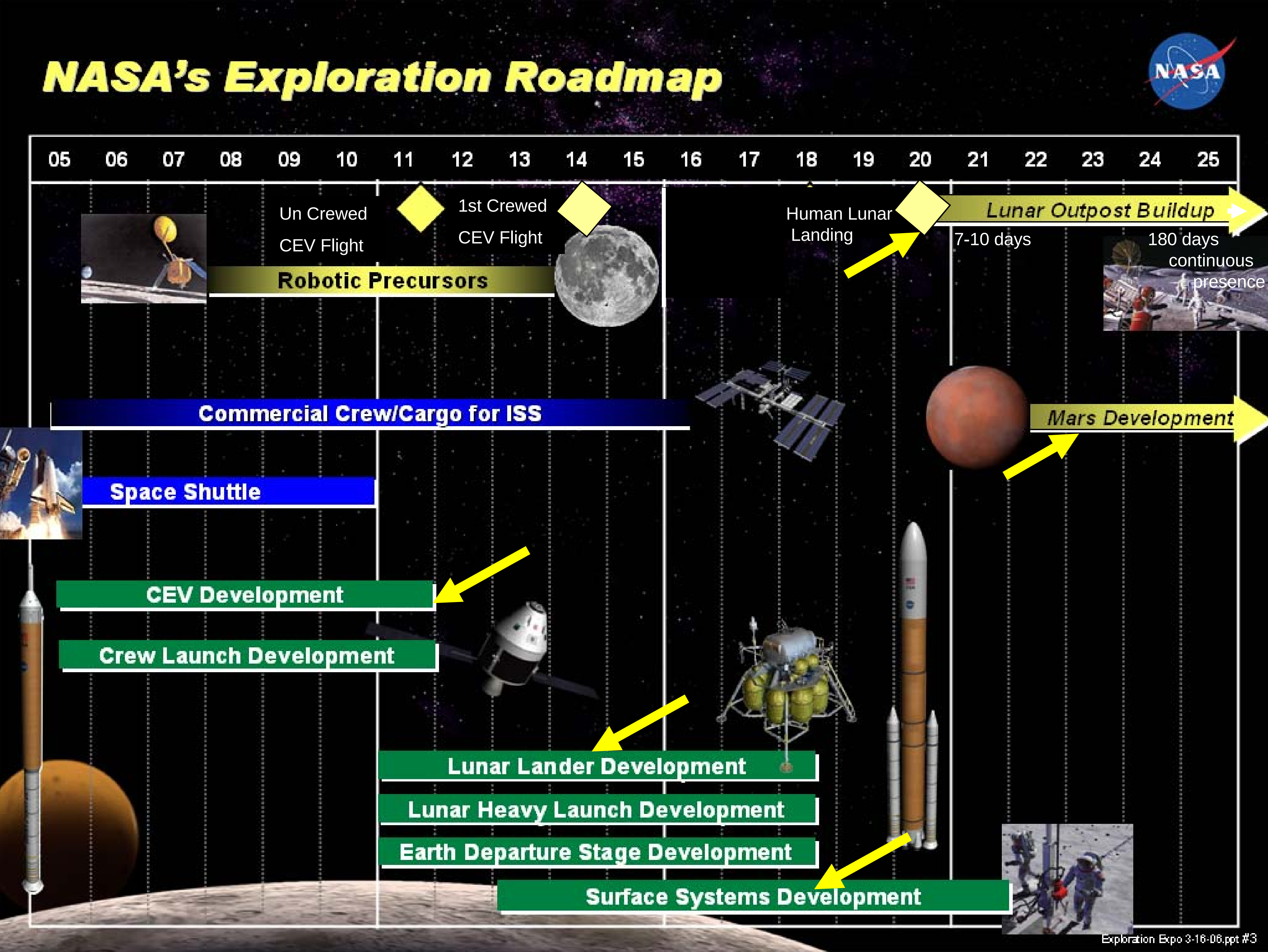
Motivation

- Radiation protection is one of <u>five identified critical enabling technologies</u> for the future space exploration program.
- Requires shield design software development with <u>modern engineering methods and practice</u>:

1) **<u>Verification and validation processes</u>** with established use cases
2) Seamless connection to engineering models:
   a) conceptual design studies through
   b) final engineering designs
3) Integration into multidisciplinary optimization frameworks
4) Reliability based design processes

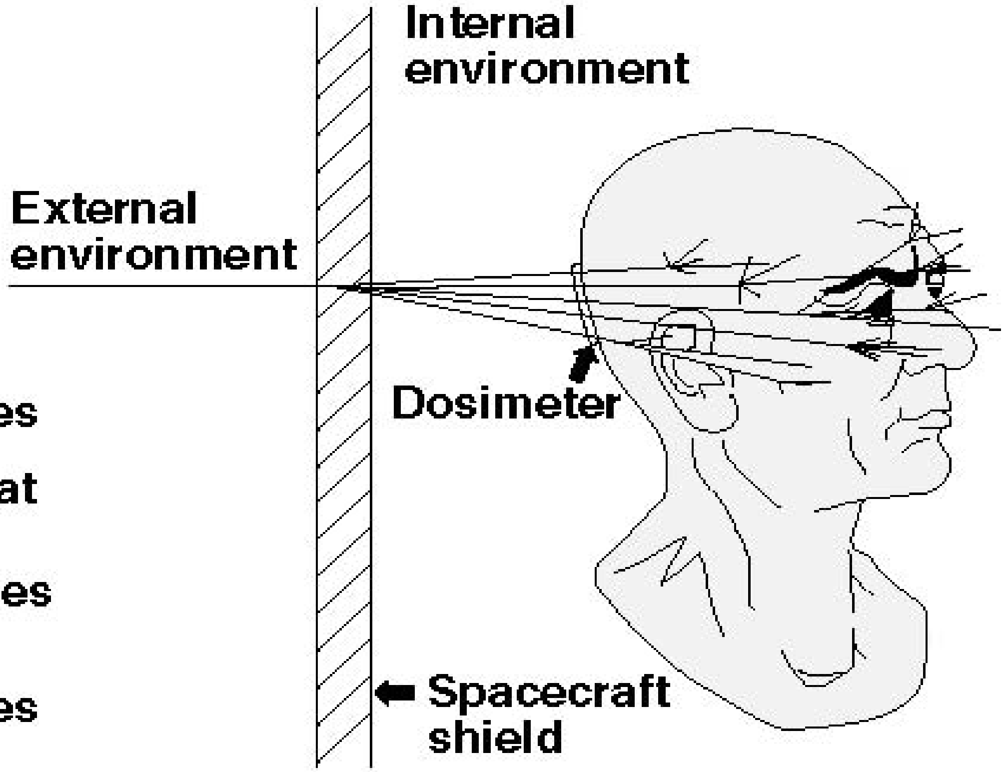
A Bold Vision for Space Exploration, Authorized by Congress

- Complete the International Space Station
- Safely fly the Space Shuttle until 2010
- Develop and fly the Crew Exploration Vehicle no later than 2014 (goal of 2012)
- Return to the Moon no later than 2020
- Extend human presence across the solar system and beyond
- Implement a sustained and affordable human and robotic program
- Develop supporting innovative technologies, knowledge, and infrastructures
- Promote international and commercial participation in exploration


NASA's Exploration Roadmap
NASA
05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Un Crewed
CEV Flight
1st Crewed
CEV Flight
Human Lunar
Landing
Lunar Outpost Buildup
7-10 days
180 days
continuous
presence
Robotic Precursors
Commercial Crew/Cargo for ISS
Mars Development
Space Shuttle
CEV Development
Crew Launch Development
Lunar Lander Development
Lunar Heavy Launch Development
Earth Departure Stage Development
Surface Systems Development
Exploration Expo 3-16-06.ppt #3

ASTRONAUT RISK ASSESSMENT KNOWLEDGE REQUIREMENTS

1. External Environment
   a. Trapped radiations*
   b. Solar flare particles
   c. Galactic cosmic rays
2. Interior Environment
   a. Transport properties
   b. Shield geometry
   c. Computational procedures
3. Energy Absorption Events at Specific Tissue Sites
   a. Tissue transport properties
   b. Human geometry
   c. Computational procedures
4. Astronaut Risk Model
   a. Track structure and high LET effects
   b. Protracted and fractionated components
   c. Extrapolate the low LET, single exposure database in a l-g field

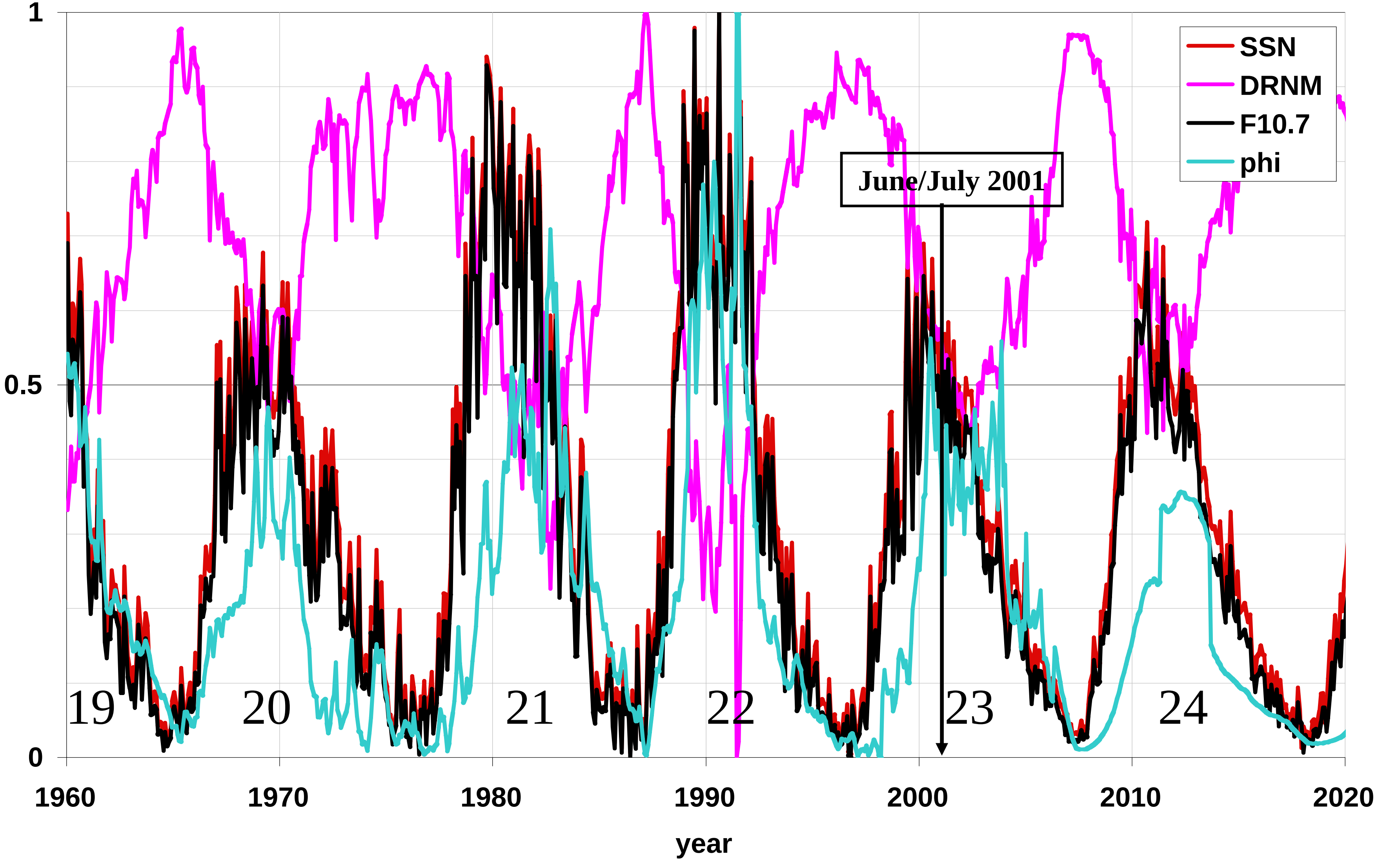


*Currently a large uncertainty

Environmental Description of LEO

- Solar modulated neutron albedo
- Dynamic/directional geomagnetic cutoffs
- Badhwar-O'Neill 1995 GCR model
- AP8MOD-a modulated, scaled, drifting, directional trapped proton model (a work in progress)
- 2006 HZETRN model
- 6A ISS shield model
- Liulin MDU#1 to MDU#4 detectors

Measured and Projected Modulation Parameters



Modulated Albedo Neutrons in LEO

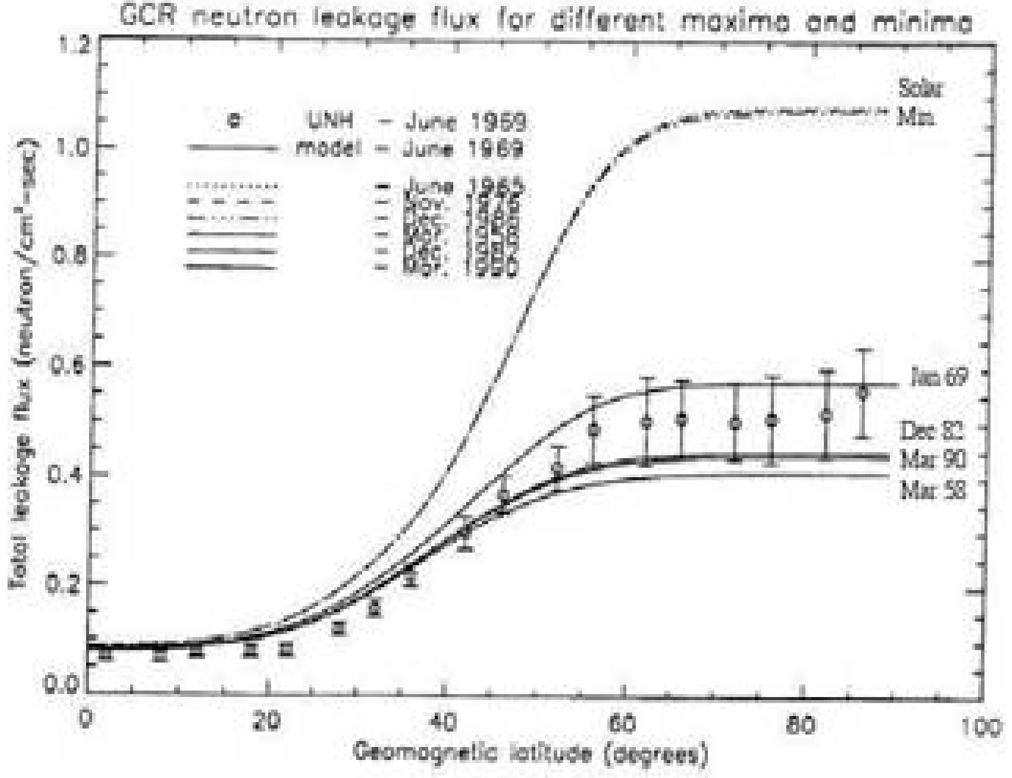
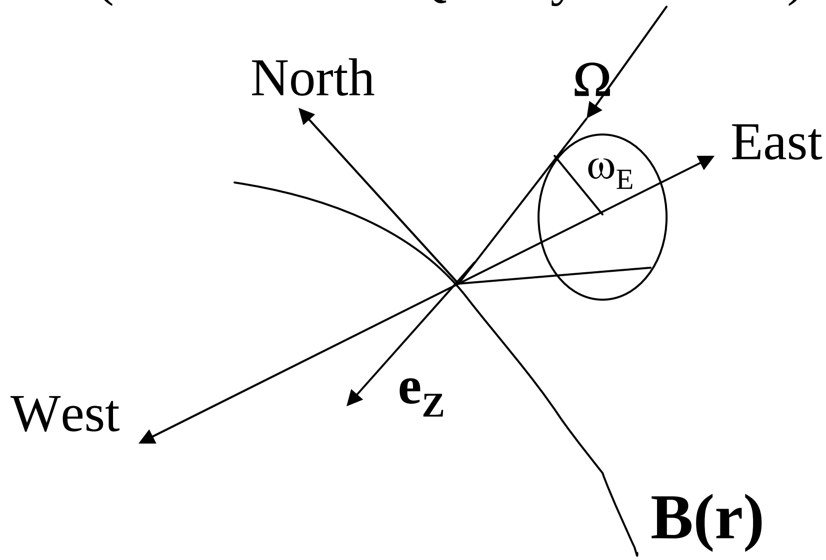


Fig. 3 GCR induced neutron leakage flux for different solar cycle maxima and minima compared to measurements by Univ. New Hampshire (Lockwood et al. 1972)

Geomagnetic Cutoff Model

(renormalized Quenby&Webber)



For a dipole geomagnetic field approximation

$P_c(\lambda, \mathbf{\Omega}) = M \cos^4(\lambda)/\{r^2 [1+(1 - \cos^3(\lambda) \cos(\omega_E)]^2\}$

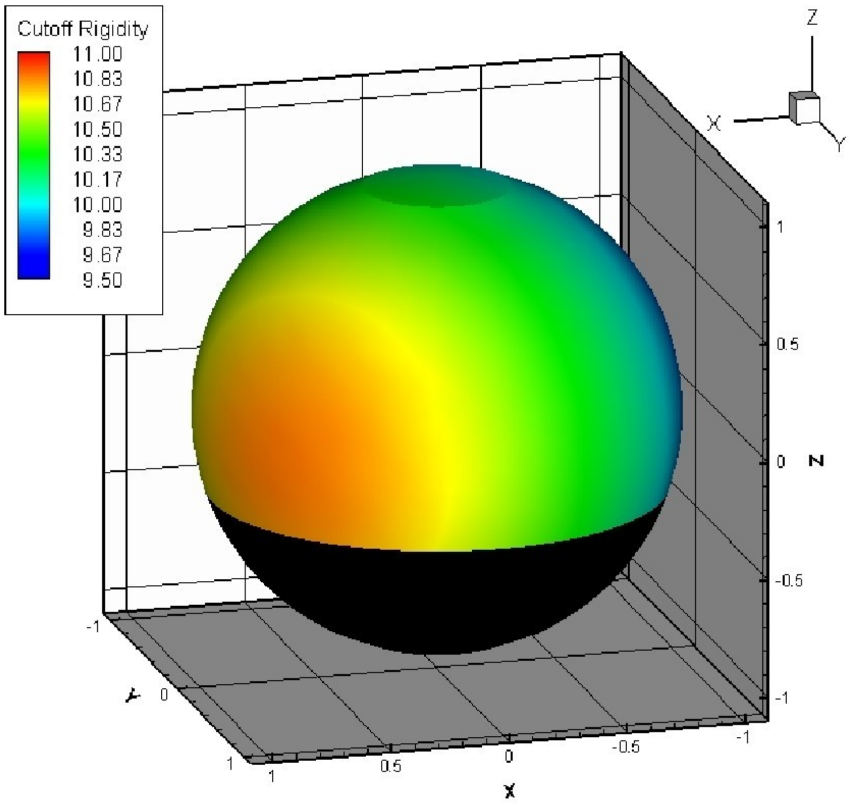
A non-dipole geomagnetic field is approximated by replacing λ by λ' given by
$\lambda' = \tan^{-1}\{[V_c + 0.52\ \delta_V]/[2(H_c + 0.52\ \delta_H)]\}$
where V_c and H_c are the local vertical and horizontal field components and δ_V and δ_H field deviations from dipole values.

Highly accurate values of $P_c(\lambda, \mathbf{\Omega})$ are obtained by replacing M by
$M_R = M\ P_V(\lambda) / P_c(\lambda', \mathbf{\Omega} = -\mathbf{e_Z})$ where $P_V(\lambda)$ is the vertical cutoff of Smart and Shea

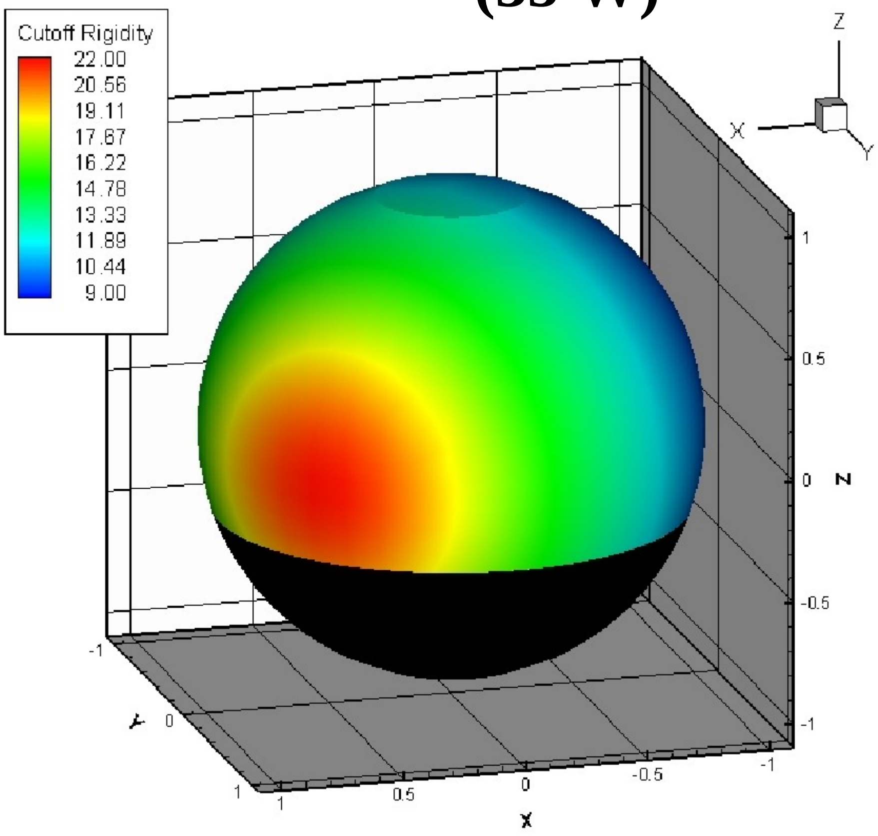
Directional Rigidity Cutoff for ISS Orbit

(Quenby and Webber model normalized to evaluated vertical cutoff maps)

30 N
(35 W)



Equator
(35 W)

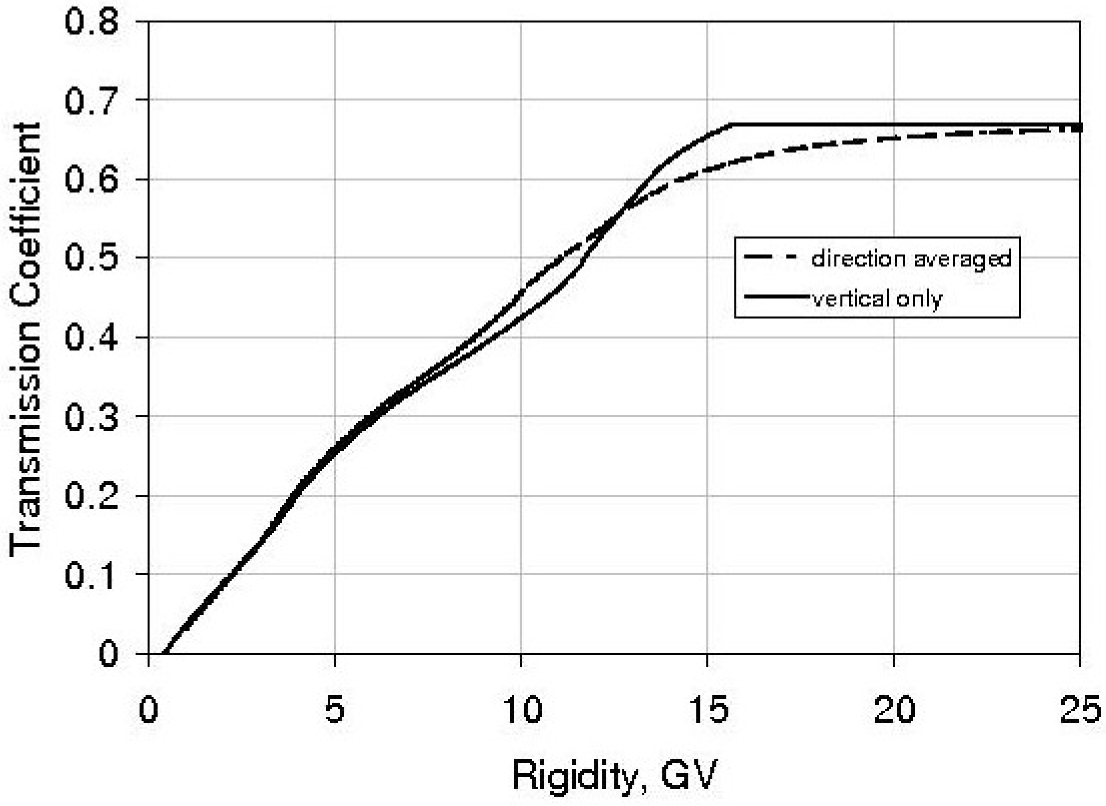


ISS Trans. Coeff. for Vertical Cutoff (VTC)

vs

Direction Averaged Trans Coeff. (DTC)

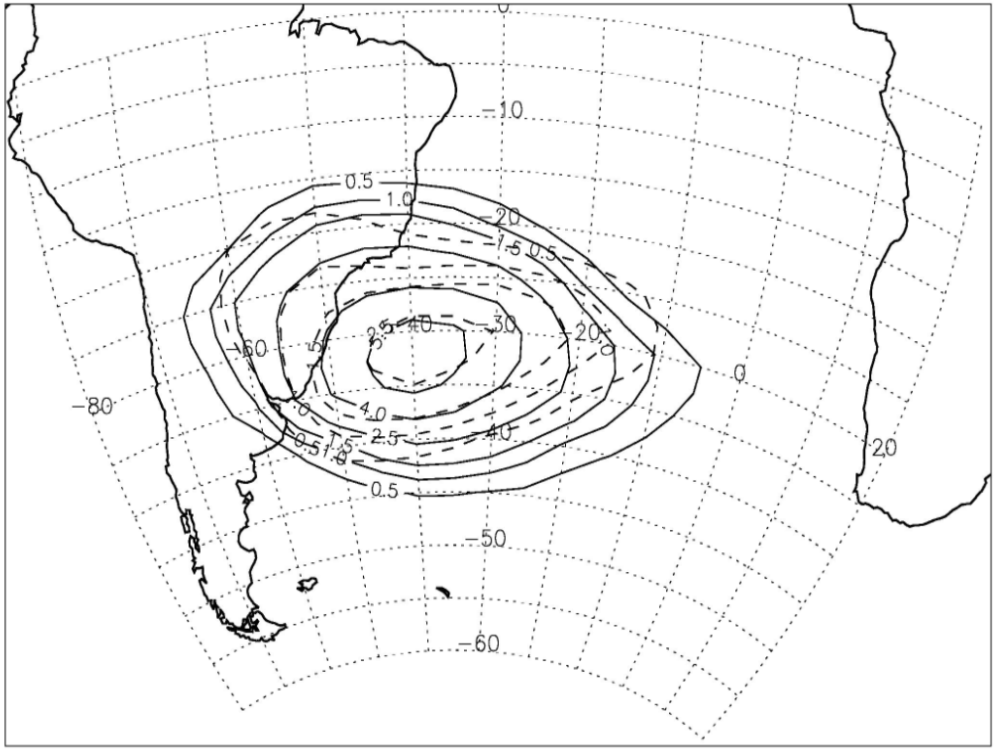
51.6 ° × 400 km in June 2001

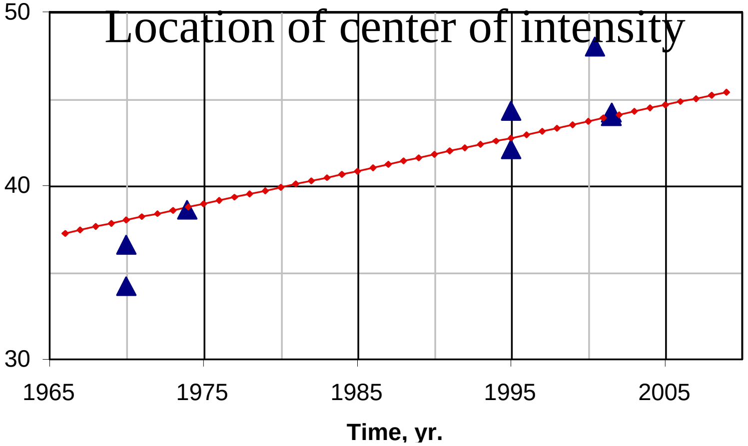


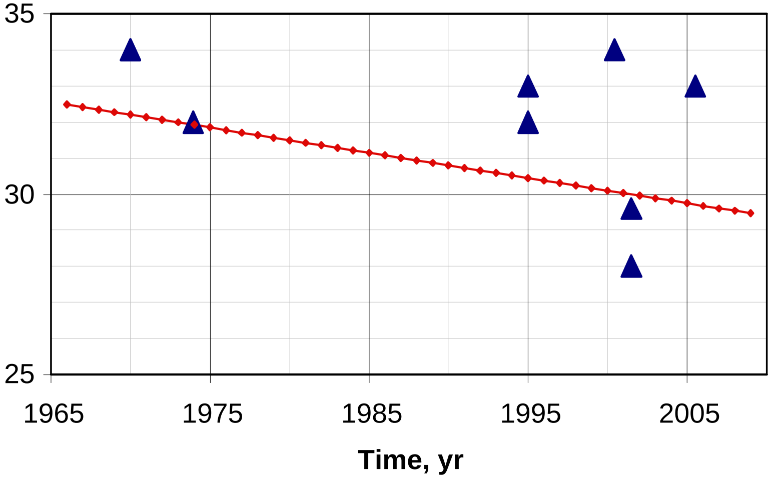
Basic Proton Field Distributions Adjusted to 1970

(with drifting latitude and longitude)

Aligned fields for 1970
Solid: AP8MIN 1965 map
Dashed: AP8MAX 1970 map





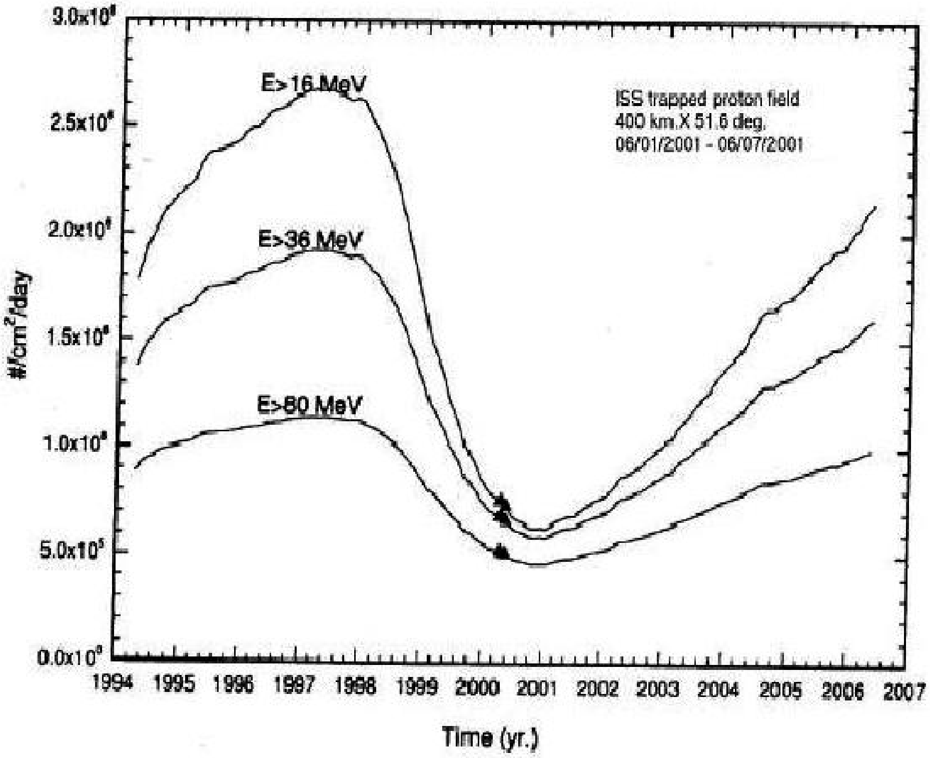


Tentative AP8 Modulation Model

$f_p(E) = f_{p,min}(E)\ exp[-\ \ {}_p\ (DRNM \times F_{10.7})]$

$f_p(E) = f_{p,max}(E)$ *at 1970*

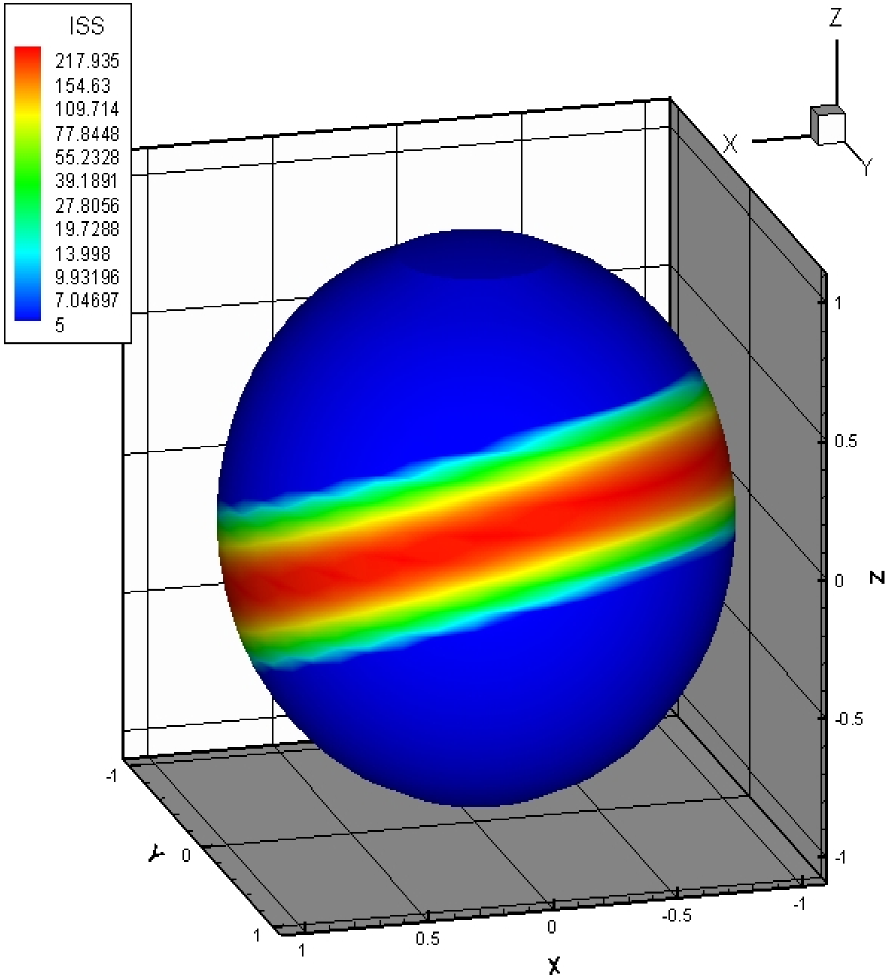
Based on prior three month averages at solar maximum and prior fifteen month averages at solar minimum

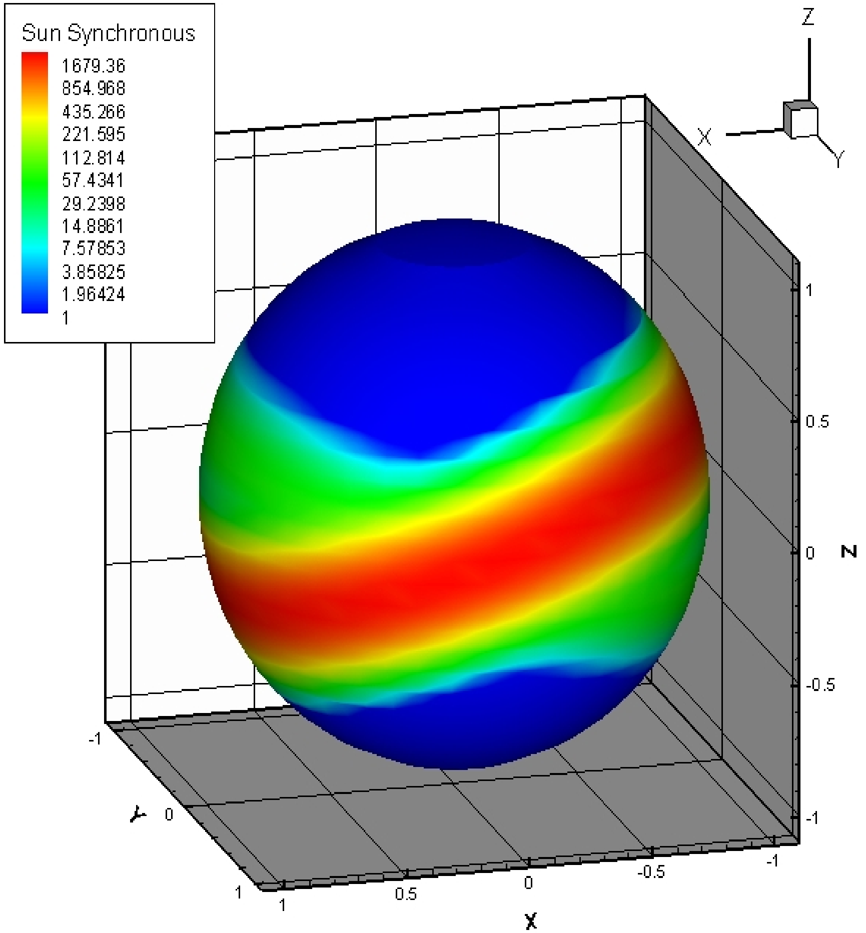


Trapped Proton Directional Flux Distributions

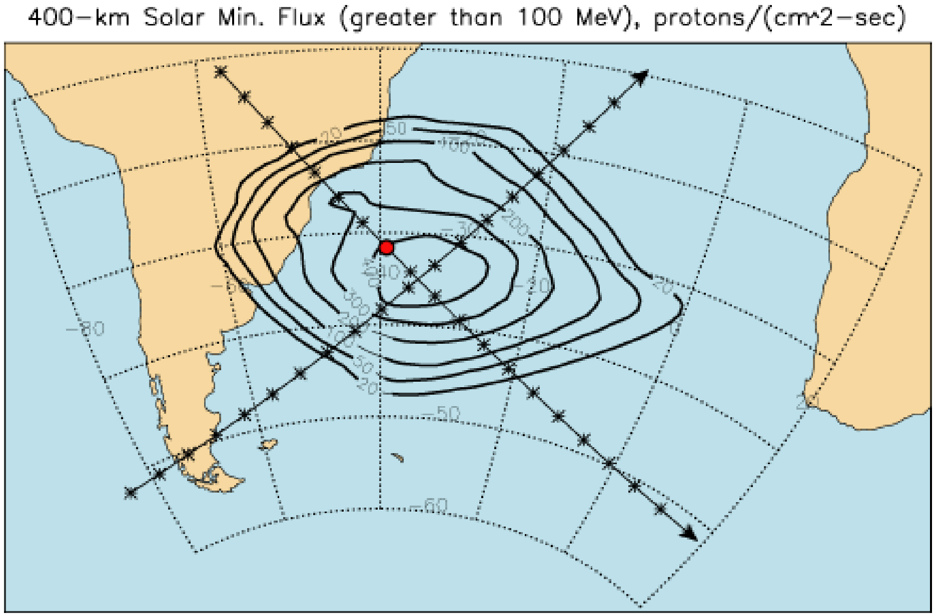
(82 MeV Single SAA pass on ascending node)

ISS Orbit **Sun-synchronous Orbit**

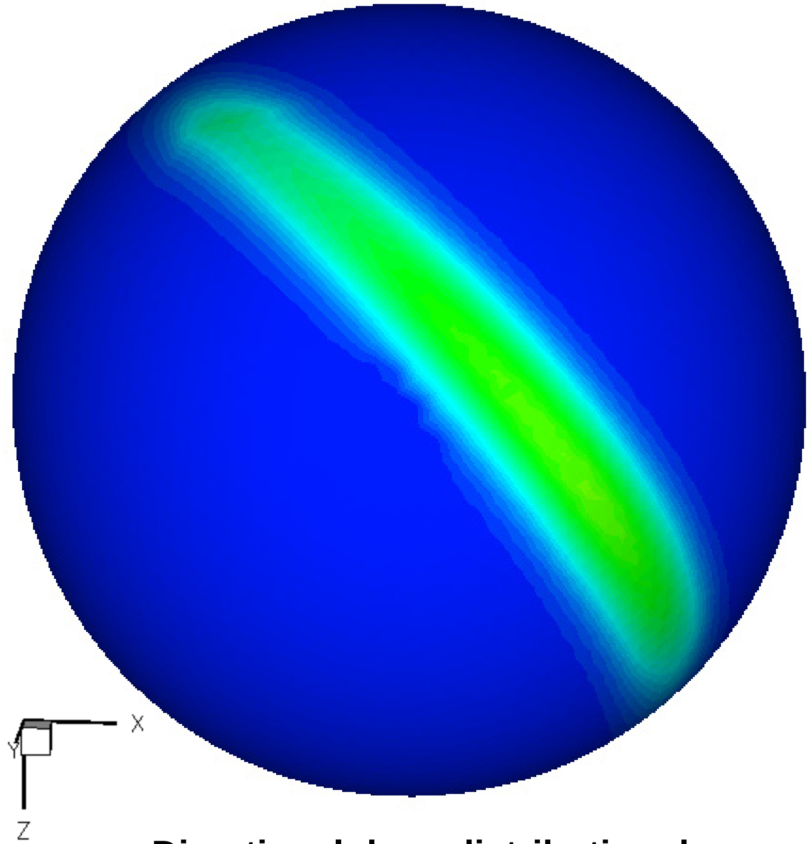




Radiation Environment: South Atlantic Anomaly, Protons

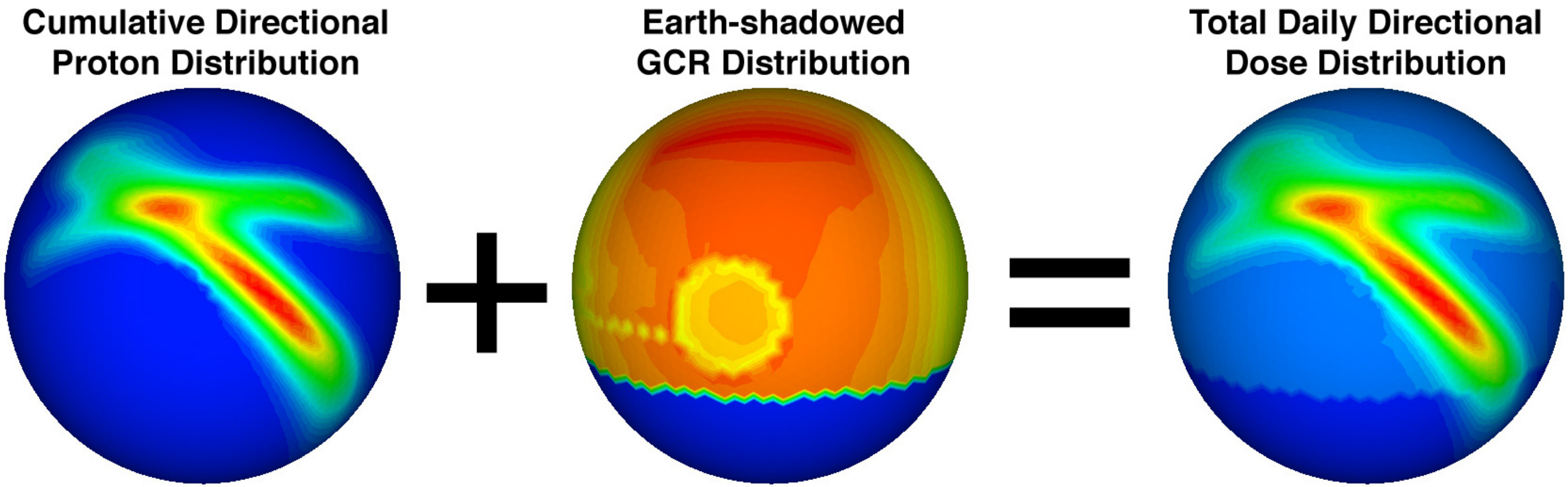


ISS descending pass through center of SAA



Directional dose distribution due to protons within the SM starboard Crew Quarters

Radiation Environment: SAA Protons plus GCR



Calculated directional dose distributions within the ISS SM Starboard Crew Quarters

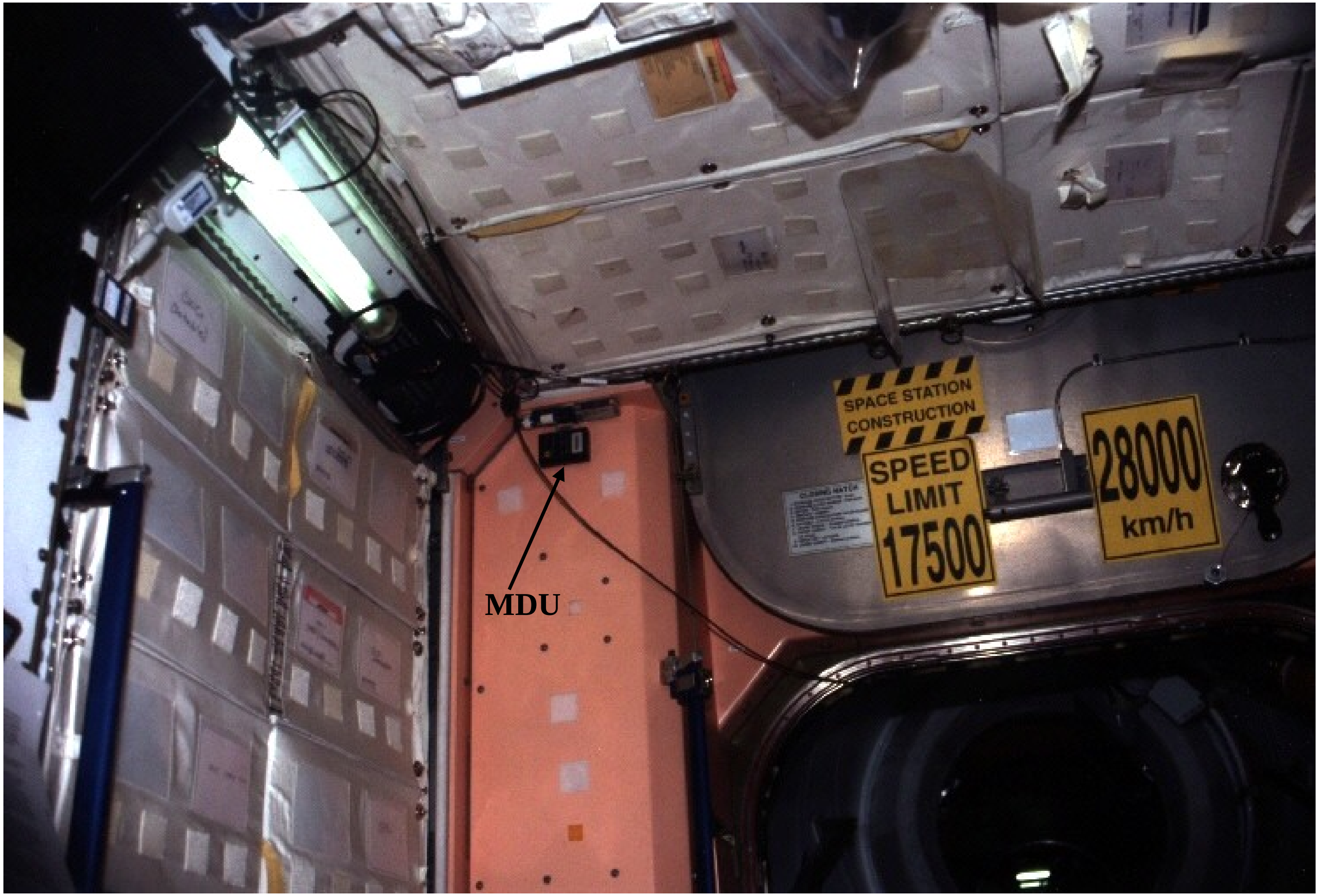
ISS Dosimetric Locations of Interest

- <u>Module identifier description of location</u>
- Node 1 dloc 102 Zenith area of aft hatch, opposite of US Lab
- US lab dloc 103 on BBND
- Node 1 dloc 104 Zenith area of forward hatch
- Node 1 dloc 105 Zenith area of Starboard hatch
- Node 1 dloc 106 Port side close to US Lab
- US Lab dloc 107 Zenith area of aft hatch
- Node 1 dloc 108 Nadir area of forward hatch
- US Lab dloc 109 Seat track, on the starboard side close to forward hatch
- US Lab dloc 110 Seat track, on starboard side close to aft hatch
- US Lab dloc 111 Seat track on port side close to forward hatch
- US Lab dloc 112 Sear track on port side close to aft hatch
- US Lab dloc 113? Overhead seat track near TEPC and DOSTEL
- US Lab dloc 114? Zenith area of forward hatch

Description of Liulin-E094 Locations

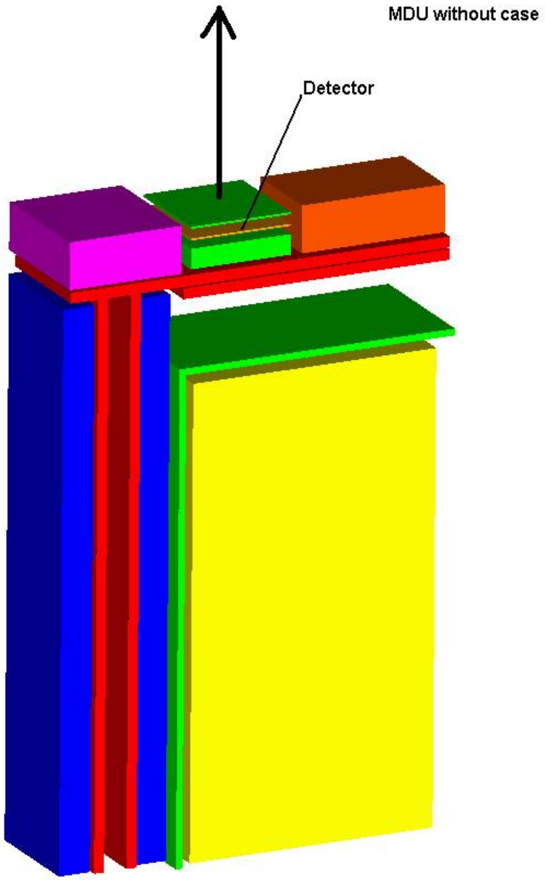
	MDU#1	MDU#2	MDU#3	MDU#4
11-30/5/2001 mix	Dloc 102	Dloc 113	Dloc 114	Dloc 107
31/5/2001-6/6/2001 *mix*	Dloc 105	Dloc 106	Dloc 109	Dloc 110
7-14/6/2001 XPOP	Dloc 103	Dloc 104	Dloc 108	Dloc 109
15-25/6/2001 *mix*	Dloc 105	Dloc 106	Dloc 110	Dloc 111
26/6/2001-5/7/2001 +XVV	Dloc 112	Dloc 113	Dloc 114	Dloc 102
6-13/7/2001 +XVV	Dloc 103	Dloc 104	Dloc 107	Dloc 108
14-25/7/2001 +XVV	Dloc 111	Dloc 112	Dloc 113	Dloc 114

Detector Placement in Node 1



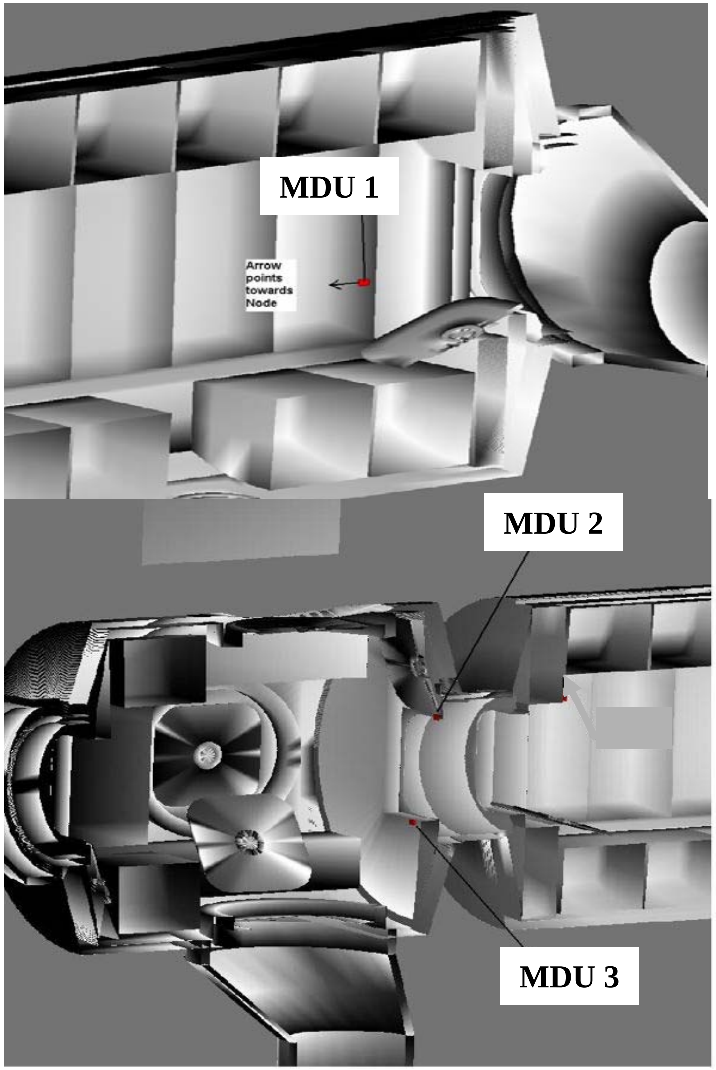
Liulin Experiment on ISS

7-14 June 2001



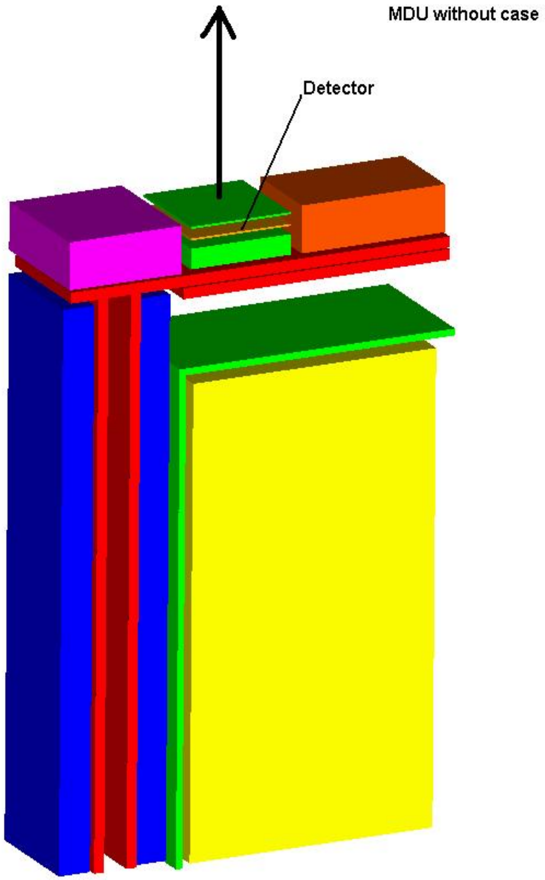
Liulin detector model

Mobile Dosimetry Unit, MDU



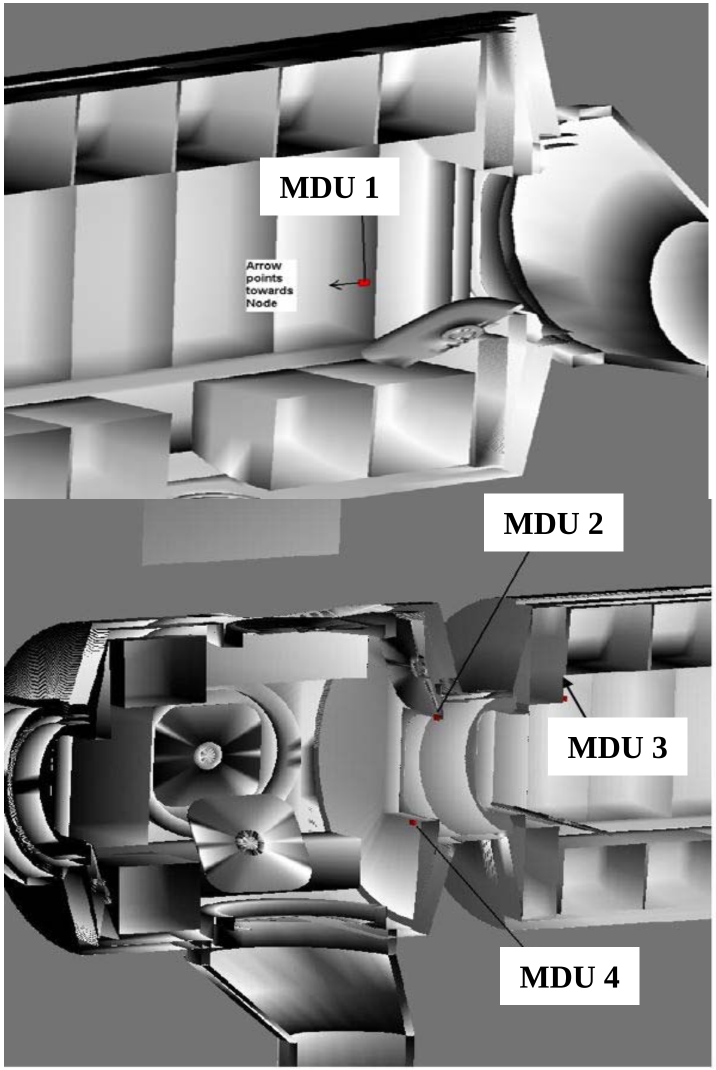
Liulin Experiment on ISS

6-13 July 2001



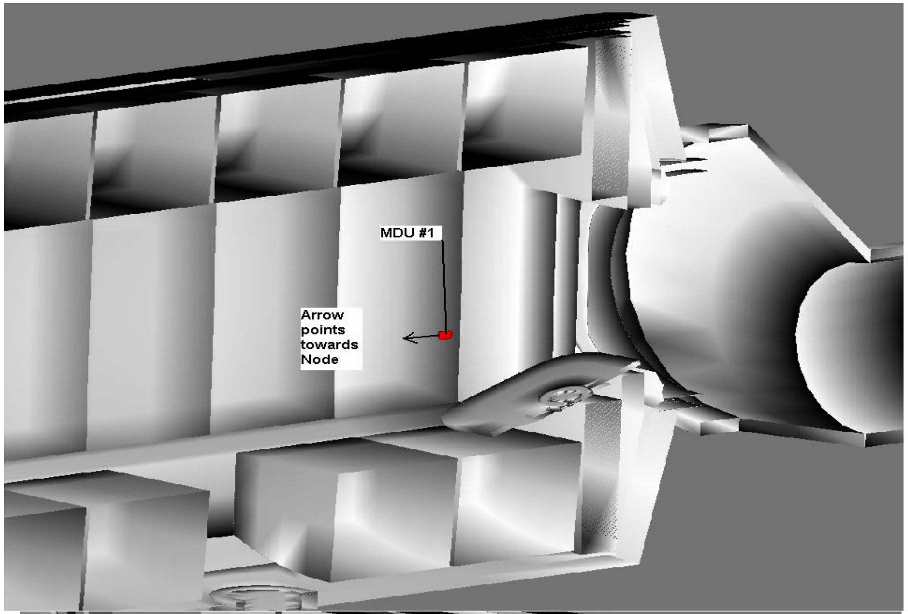
Liulin detector model

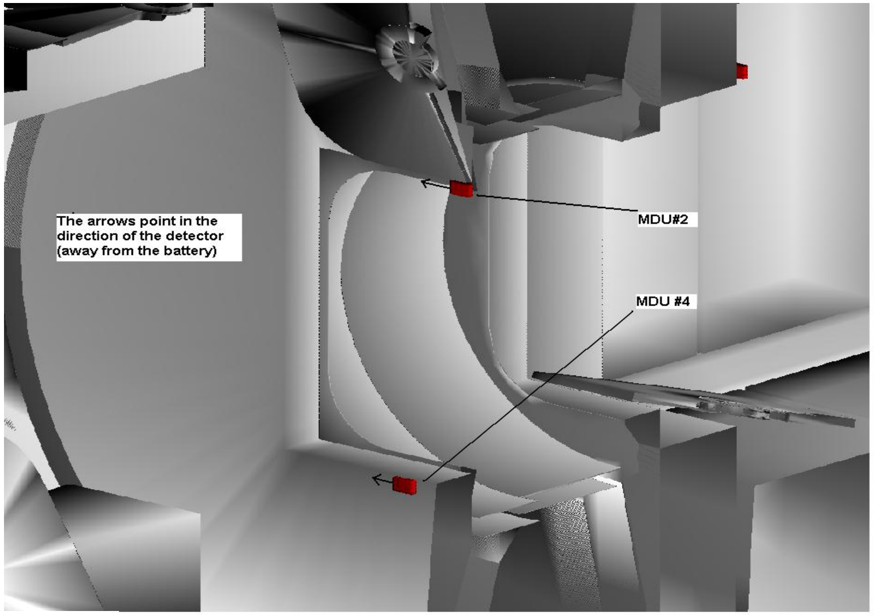
Mobile Dosimetry Unit, MDU

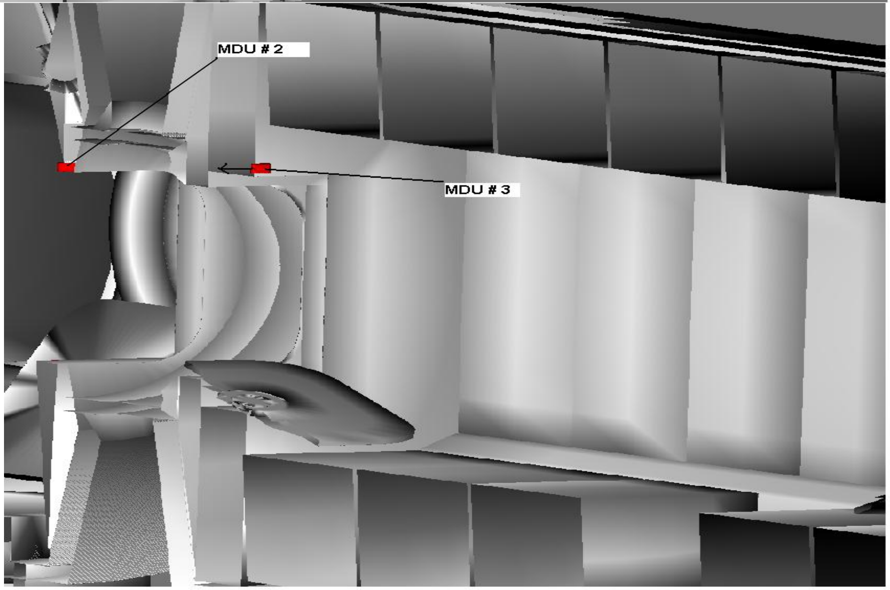


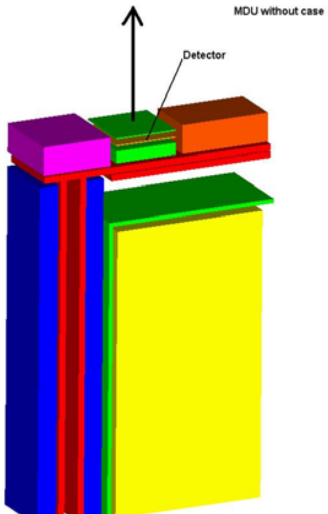
Liulin Location/Orientation

6-13 July 2001



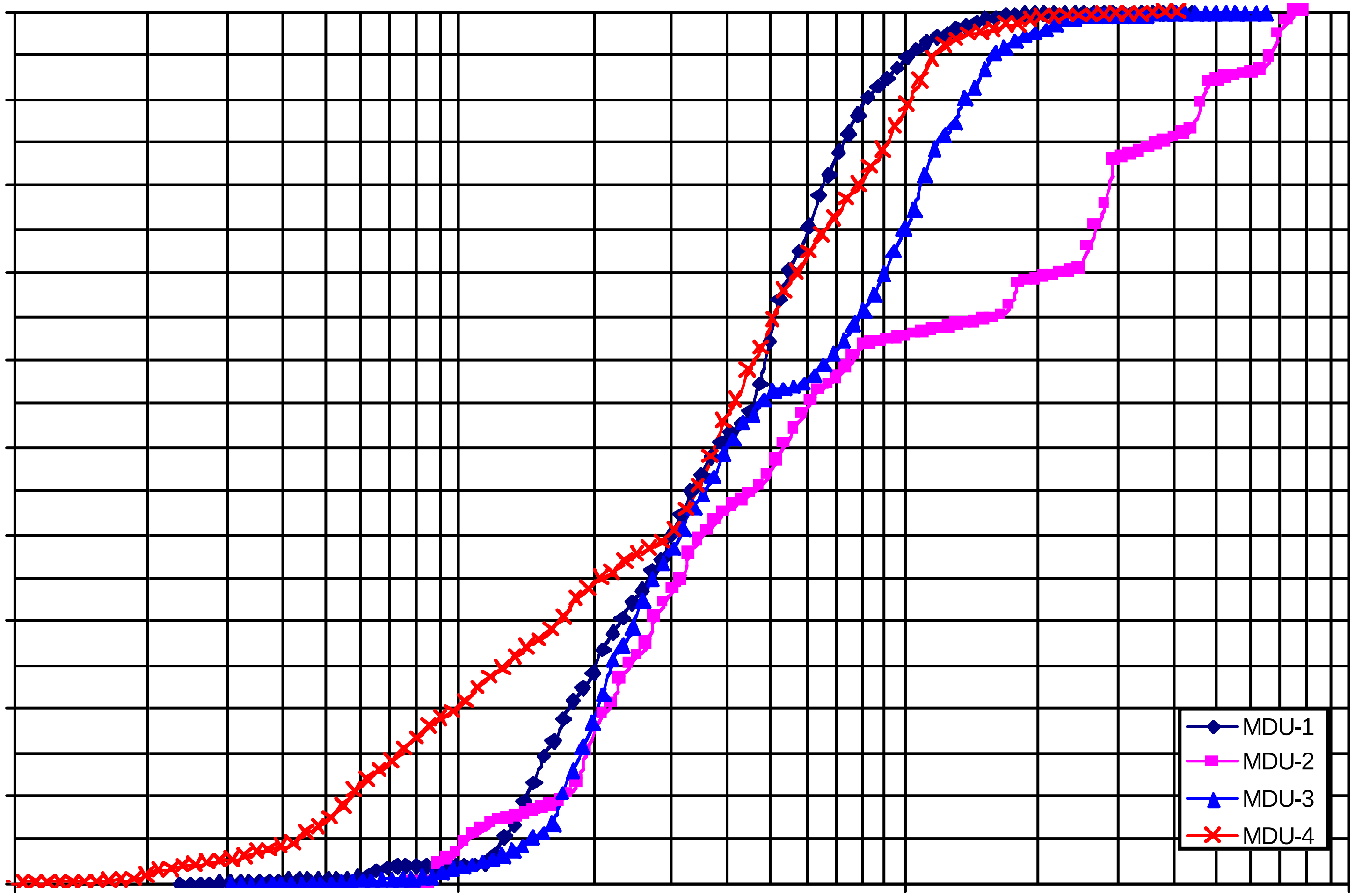




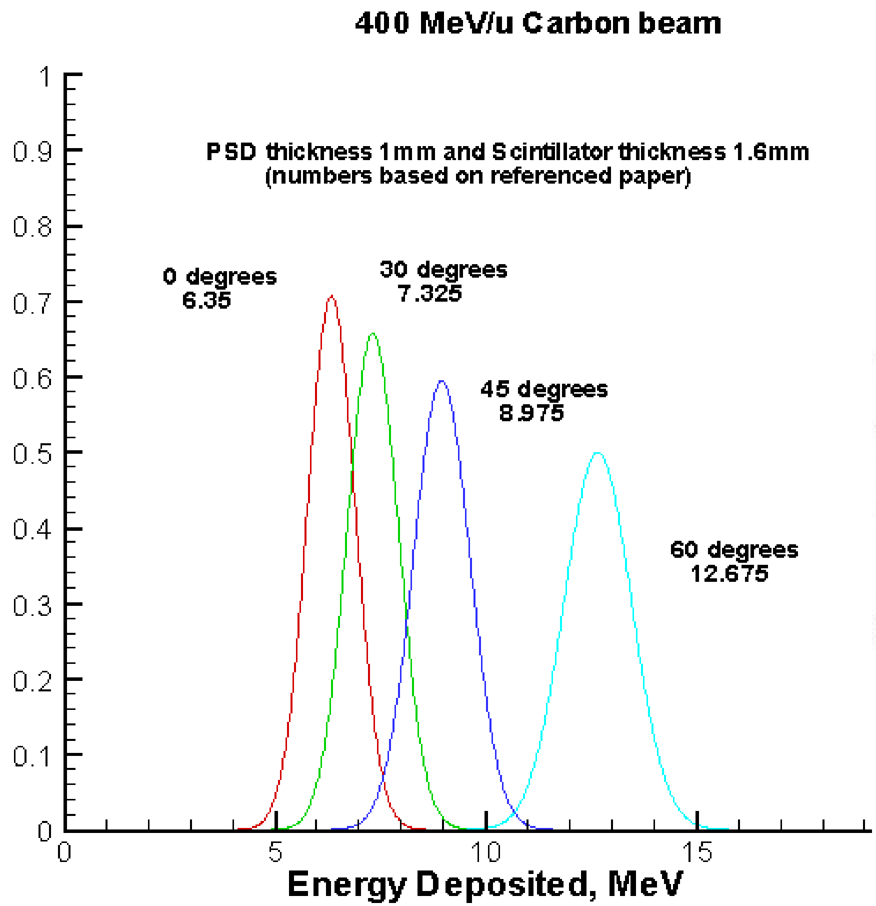


Mass Distributions About Detector

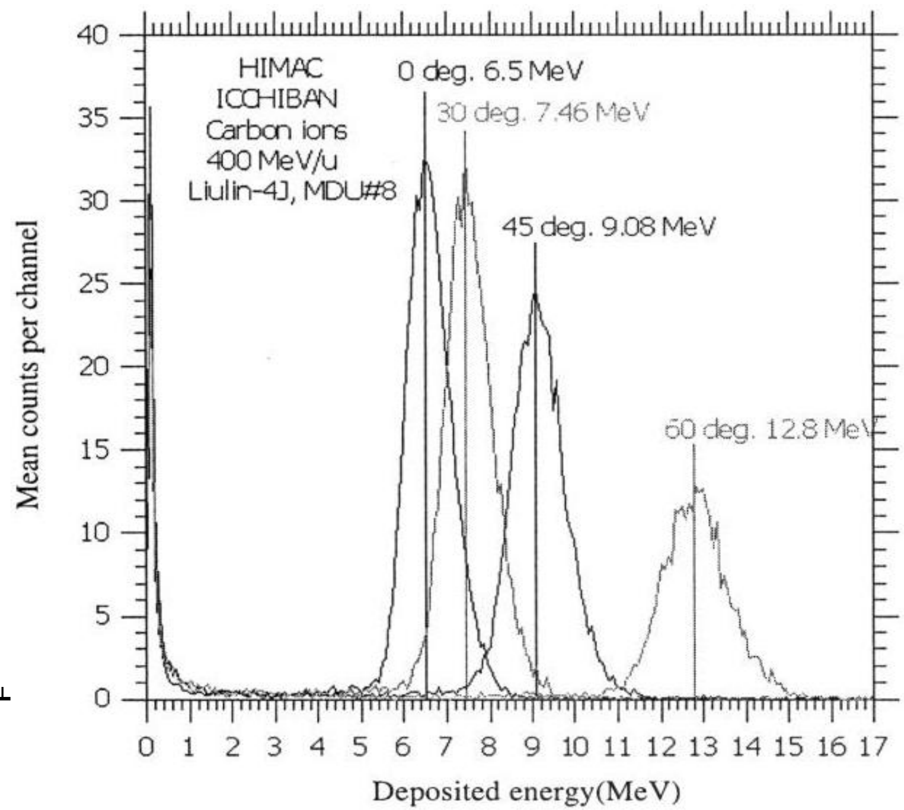
6-13 July 2001



Straggling/Slowing-Down Provides First Approximation to Liulin Detector Response

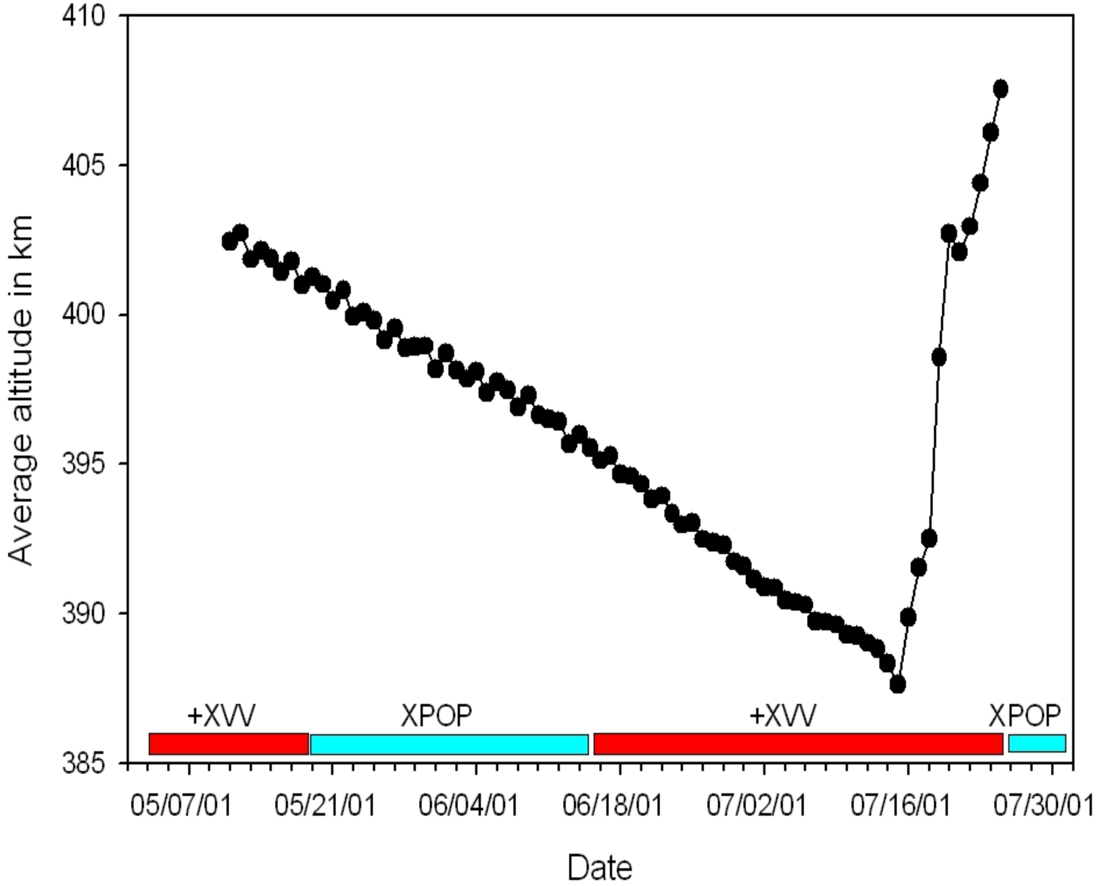


Uchihori et al.



Flight Trajectory Data

- six degrees of freedom -



ISS 6A Configuration

DATASET MEASUREMENT SUMMARY

6/26-28/01

MDU-1

7/6-13/01

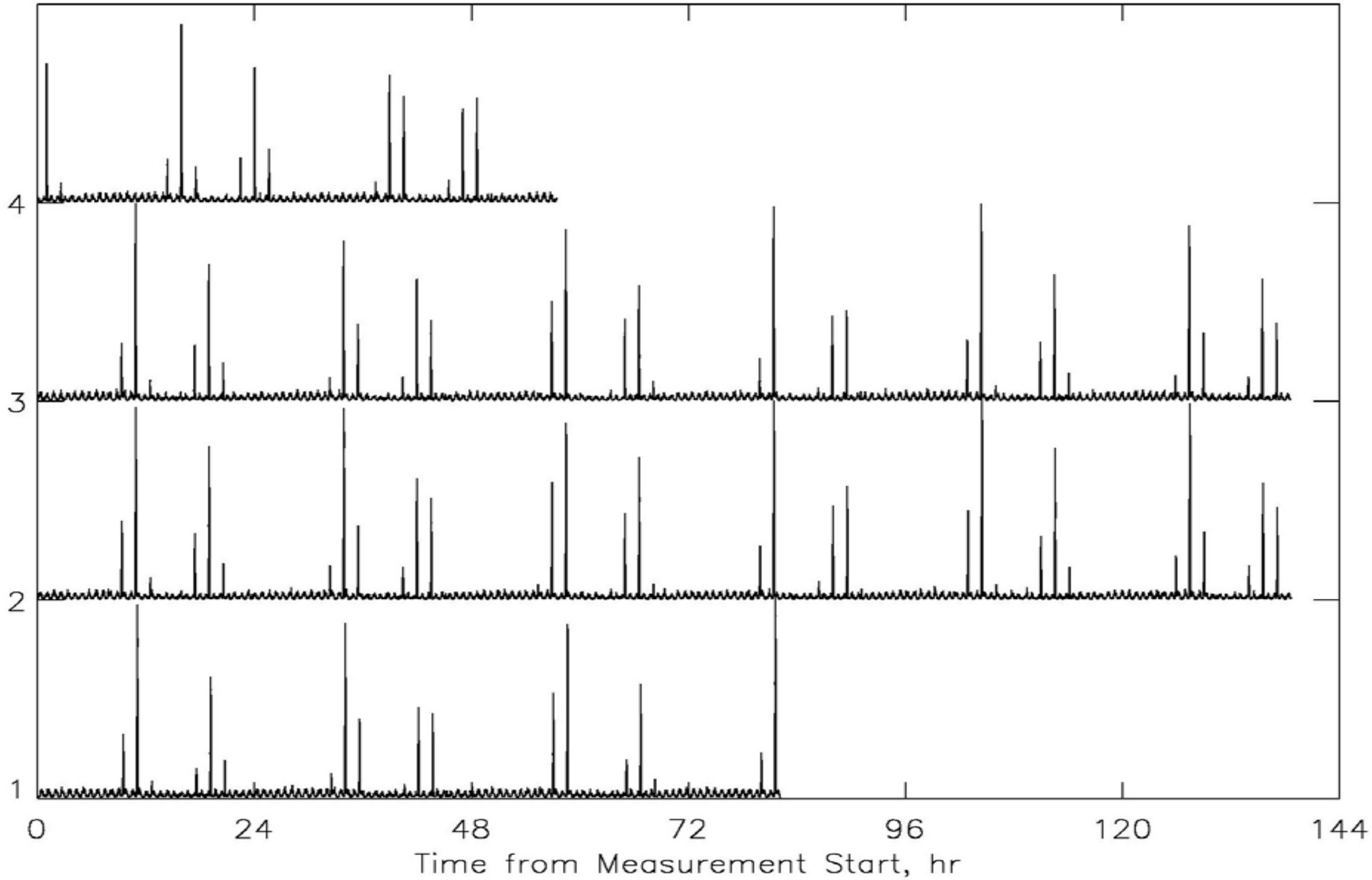
MDU-3

7/6-13/01

MDU-1

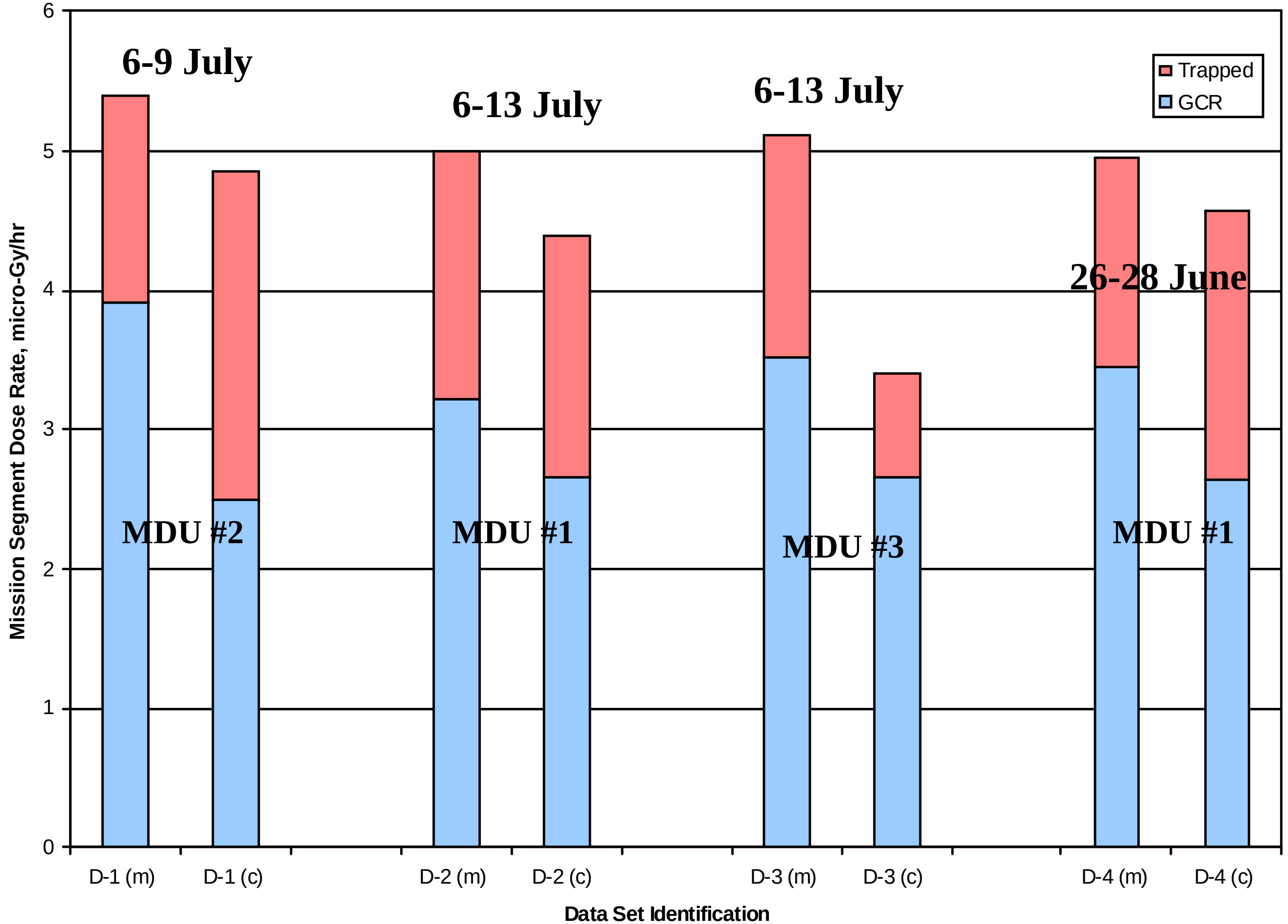
7/6-9/01

MDU-2



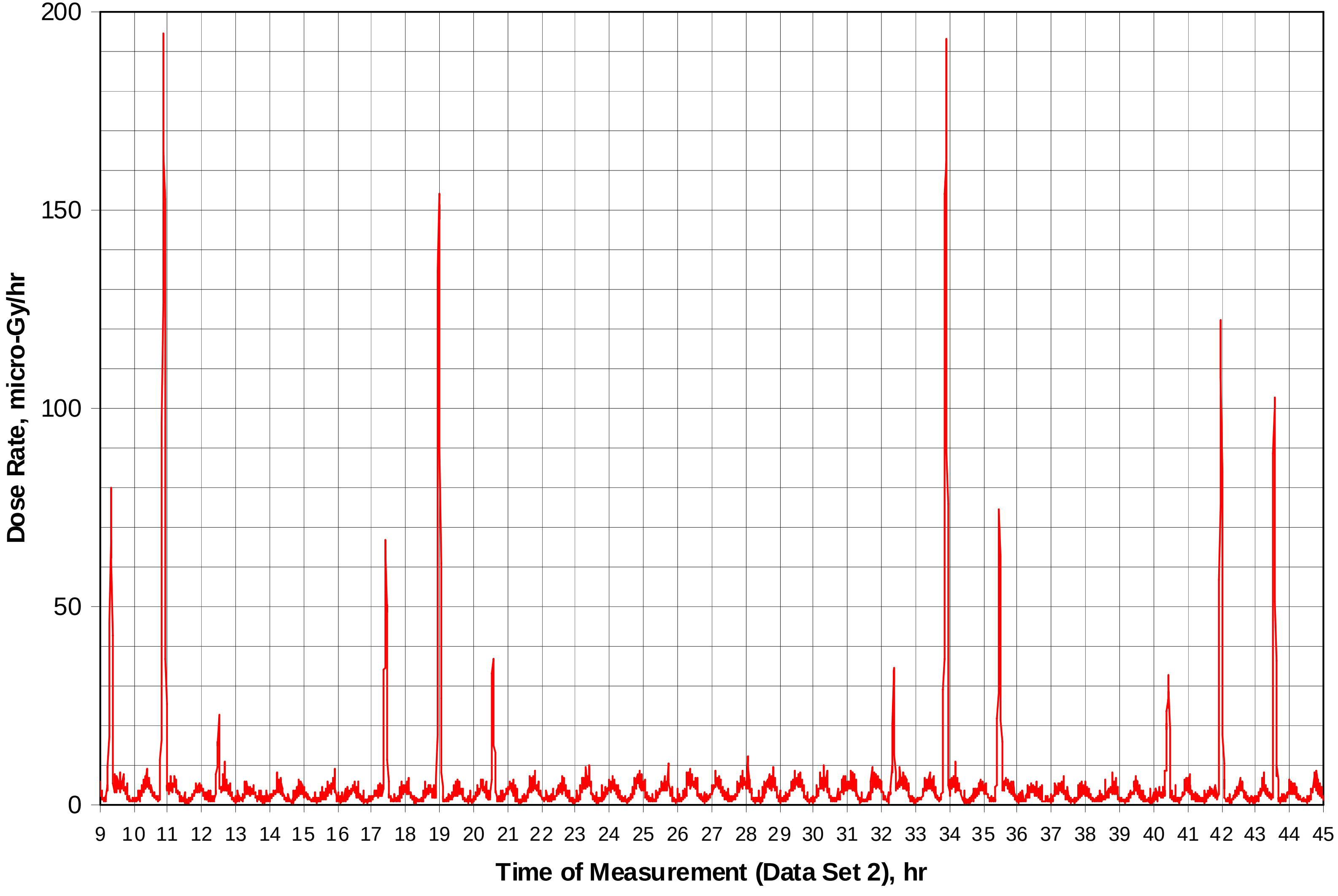
Total Dose Results

6-13 July 2001, 26-28 June 2001



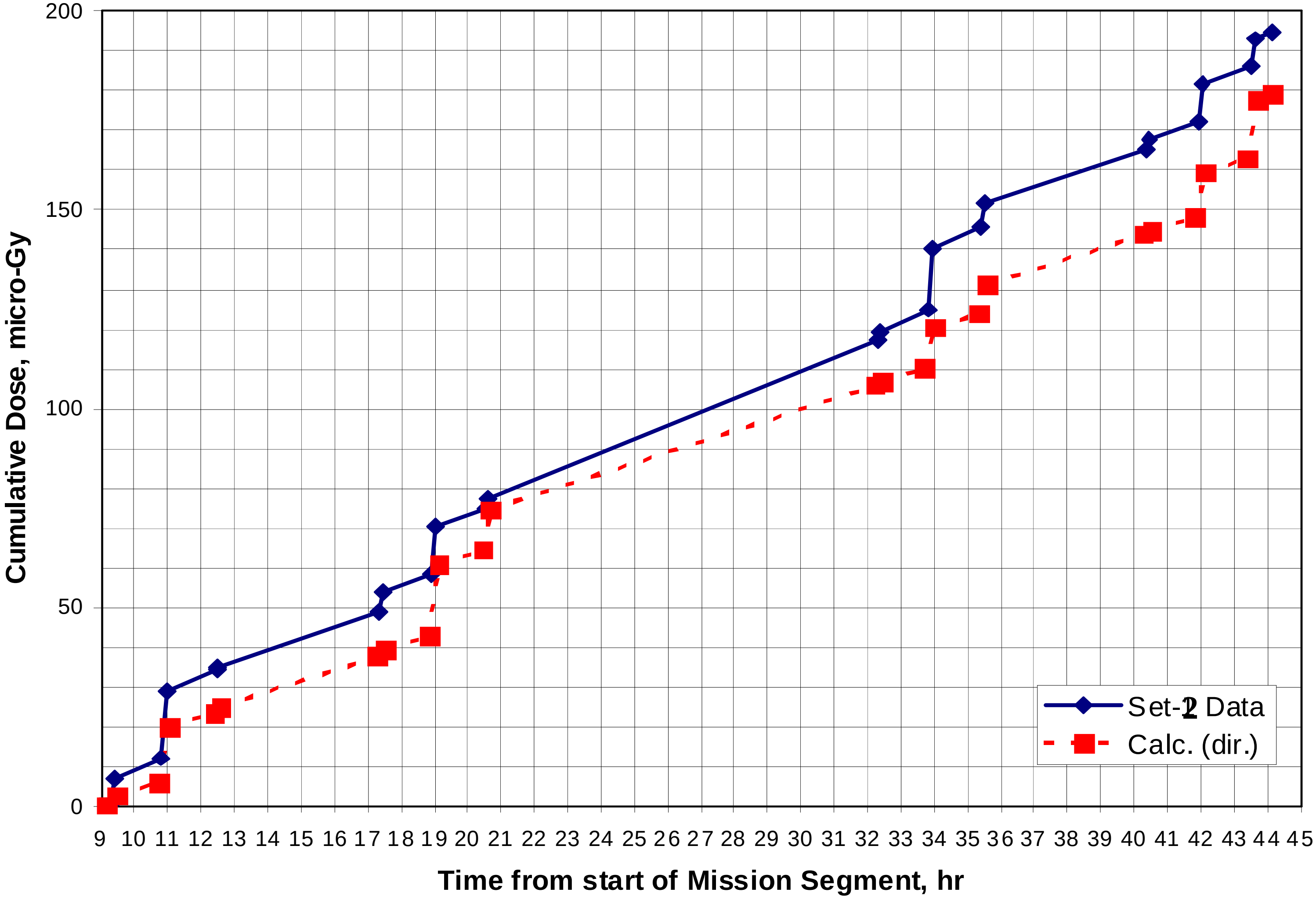
DATA SEGMENT FOR TIME SEQUENTIAL ANALYSIS

MDU #1, 6-7 July

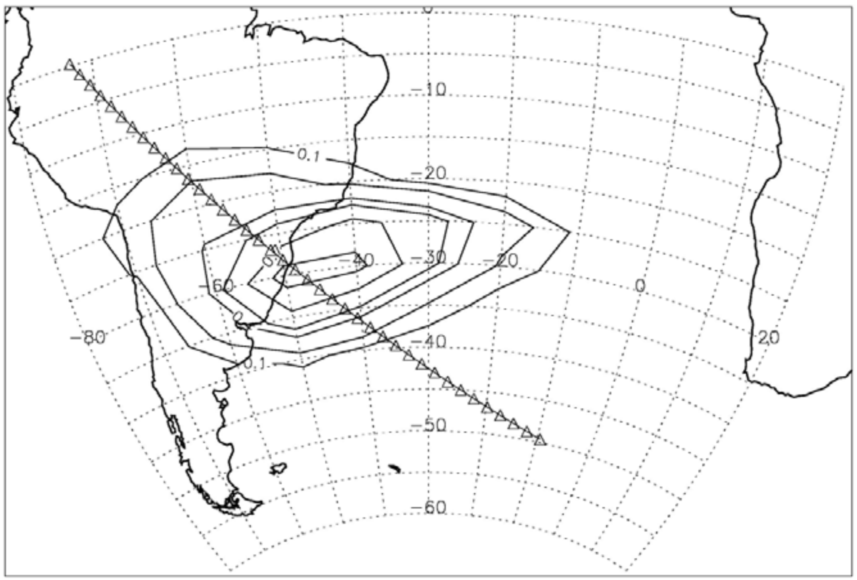


CUMULATIVE DOSE COMPARISON

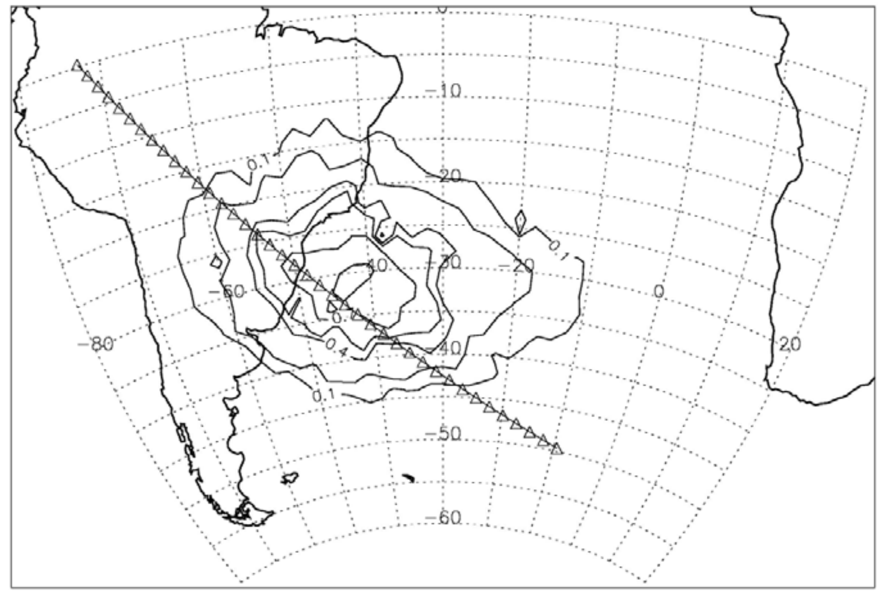
(MDU-1 ; DATA SET 2, 6-7/7/2001)



Modeled and Actual Single Descending Node Passage
6 July 2001



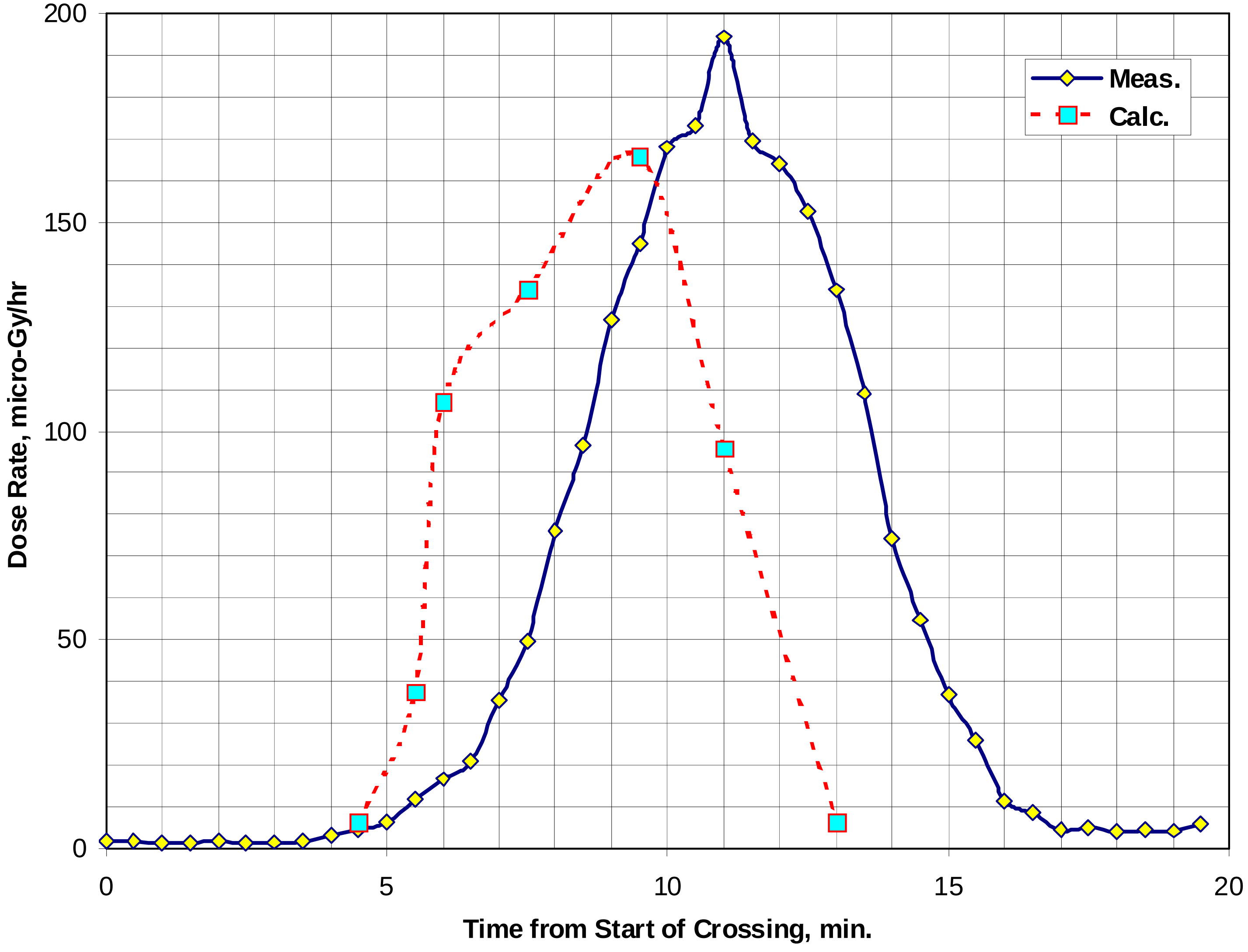
AP8MOD 100 MeV



MDU #1 to #4

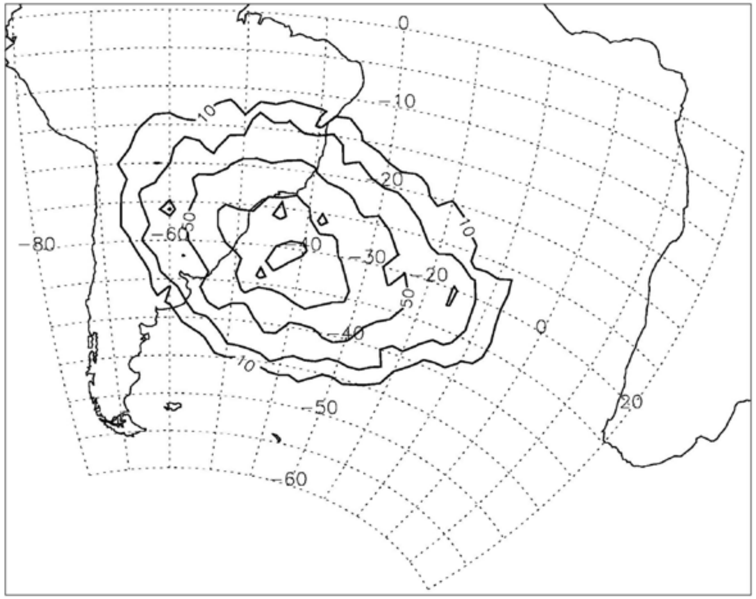
MEASUREMENT/CALCULATION COMPARISON

6 July 2001 SAA CROSSING

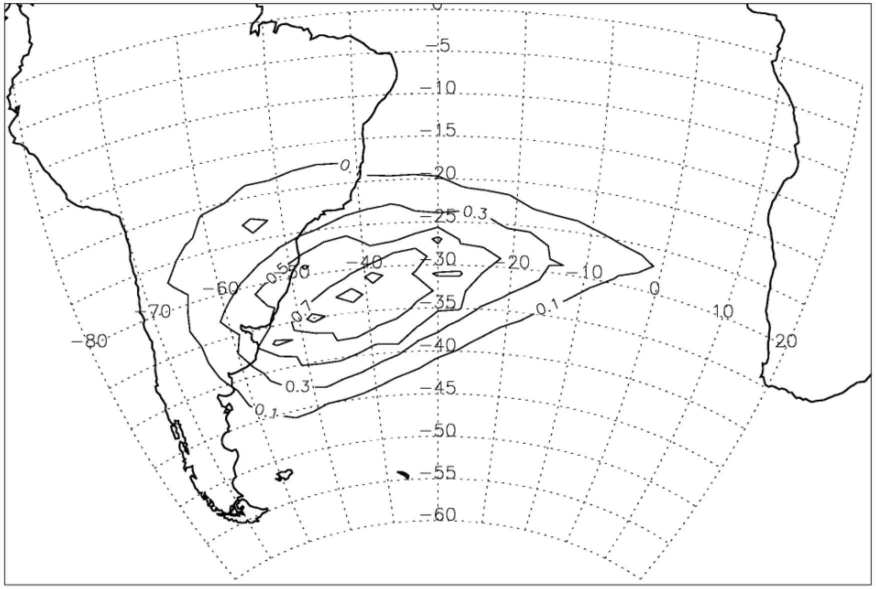


Towards a New Revised Model?

- Measurement Dose Map



- AP8MOD on IGRF 2001



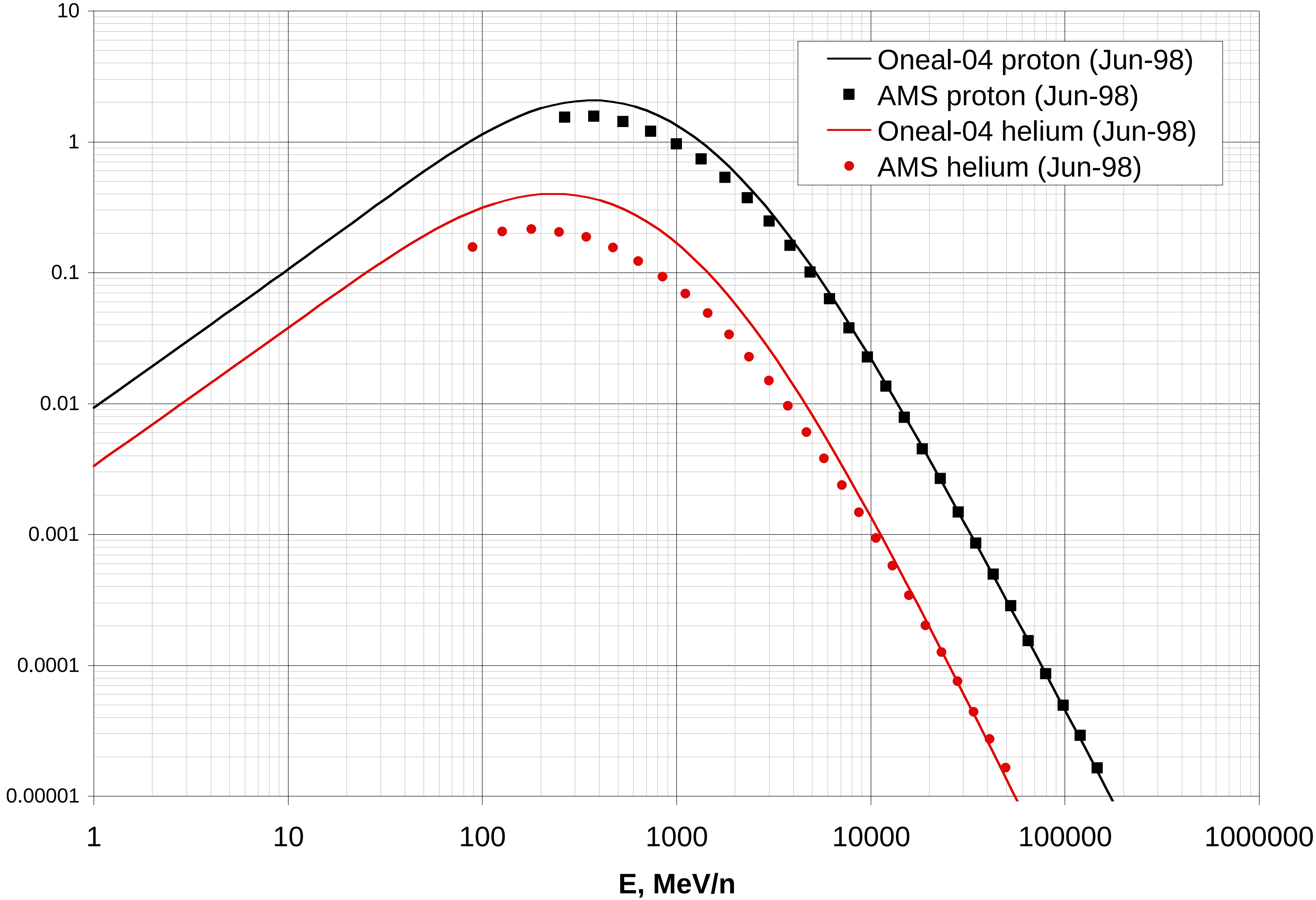
SUMMARY

- **The foregoing studies described represent only the first brief look at the very definitive data provided by the LIULIN instruments**
- **The temporal analysis (despite the brevity) has indicated that currently used GCR model may be deficient near solar maximum intensity**
- **The SAA region is well mapped by LIULIN in the 2001 time frame; the current Langley environment code (GEORAD) has imposed a westward drift of the AP8 models to conform to observations by SKYLAB and MIR … the present temporal analysis suggests that further adjustments are in order**
- **The importance of accurate assessment of long term space radiation exposure is well-recognized … further analysis of the LIULIN data in hand (and to come) is practically a mandate for future work**
- **The hope is to have models which can more reliably predict radiation levels within space structures and able to validate new designs by LEO flight testing**

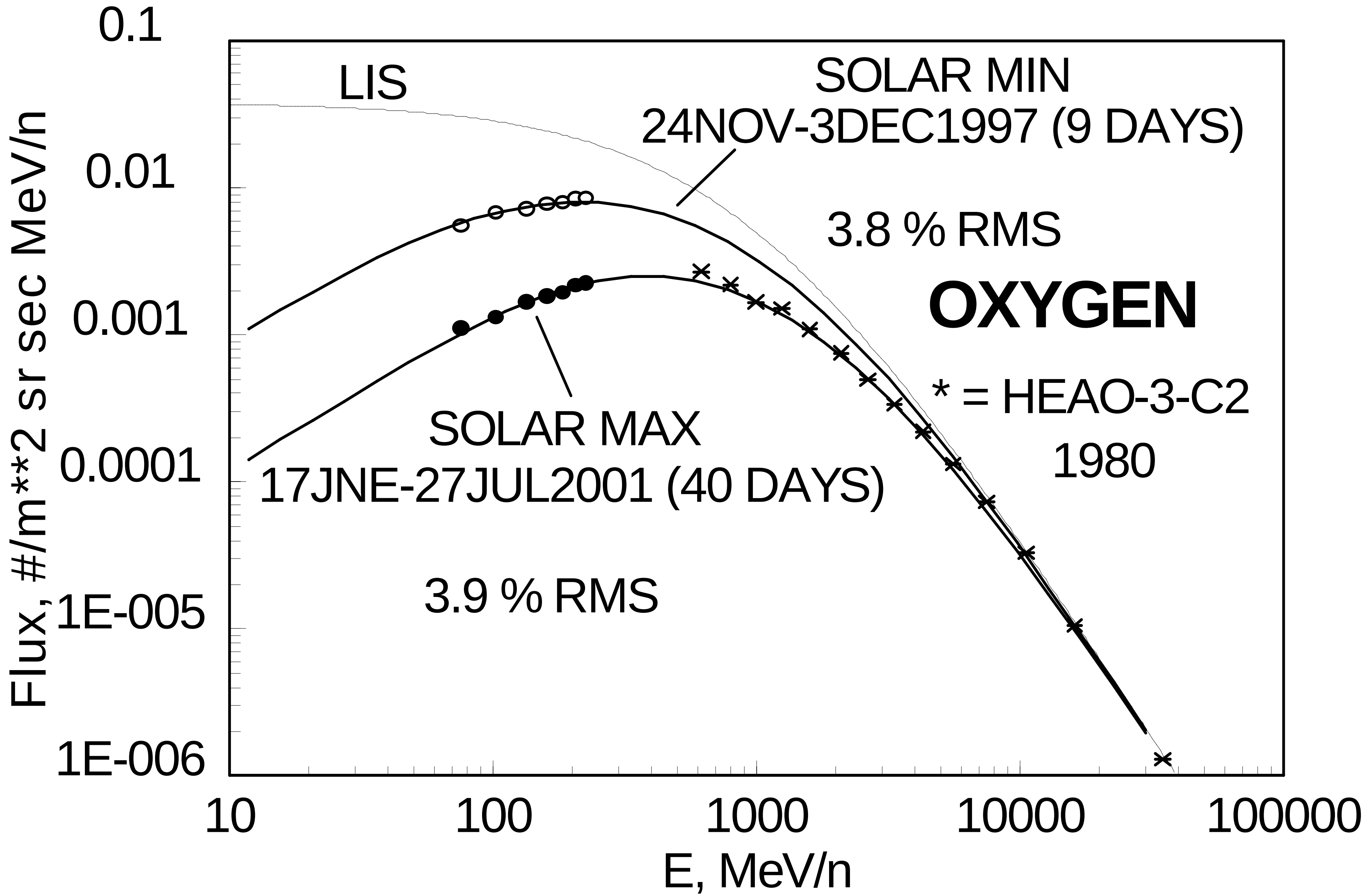
A Need for Further Improvements

- Verify/improve GCR model description
- Verify/improve geomagnetic transmission factor
- Improve AP8MOD
- Verify instrument placement
- Verify ISS shield model (JSC vs LaRC)
- Verify transport (Monte Carlo vs HZETRN)
- Improved Liulin response model
- Analyze additional mission segments
- Analyze additional instruments
- Include AP9 beta version scheduled for 2010

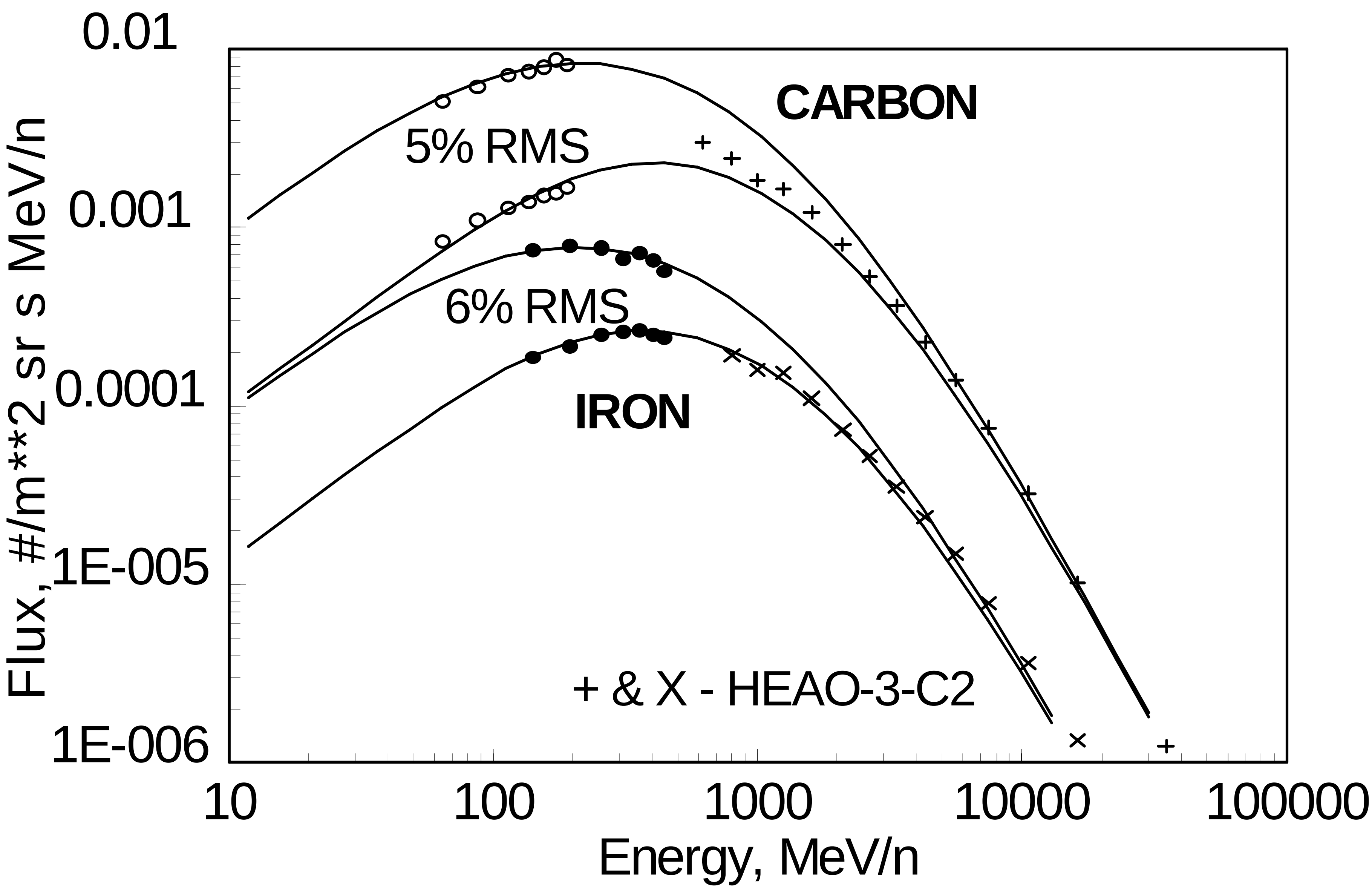
Badhwar/O'Neill vs AMS Data for Light Ions



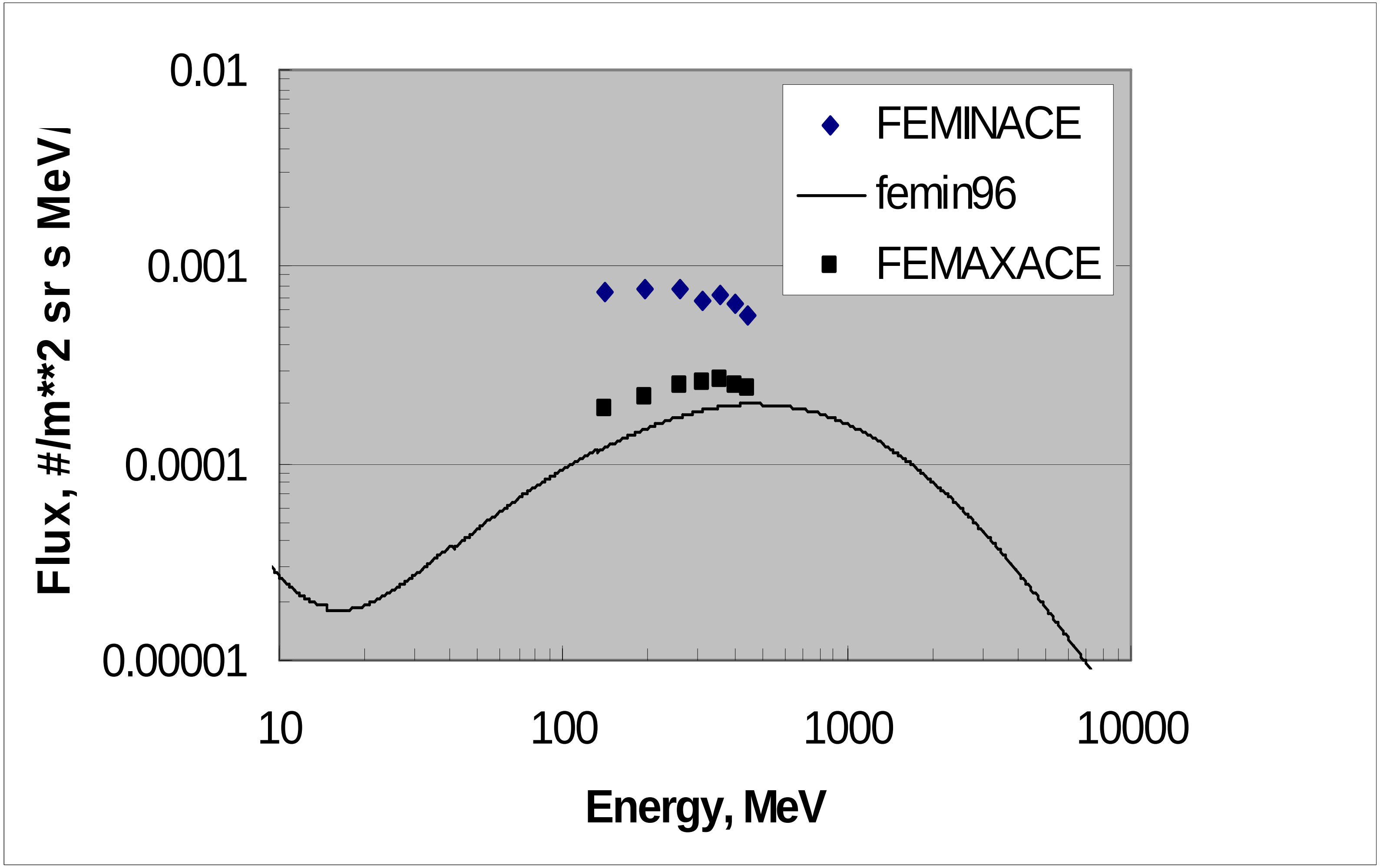
Badhwar/O'Neill MODEL & ACE/CRIS for OXYGEN



Badhwar/O'Neill FIT FOR MORE ABUNDANT ELEMENTS

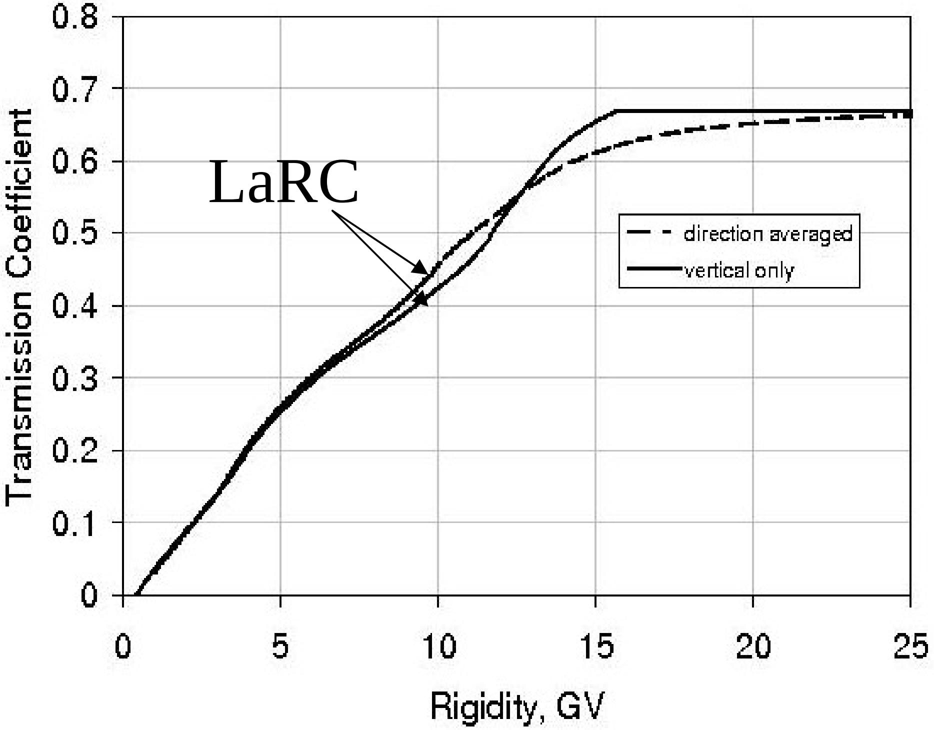


ACE vs CREME96

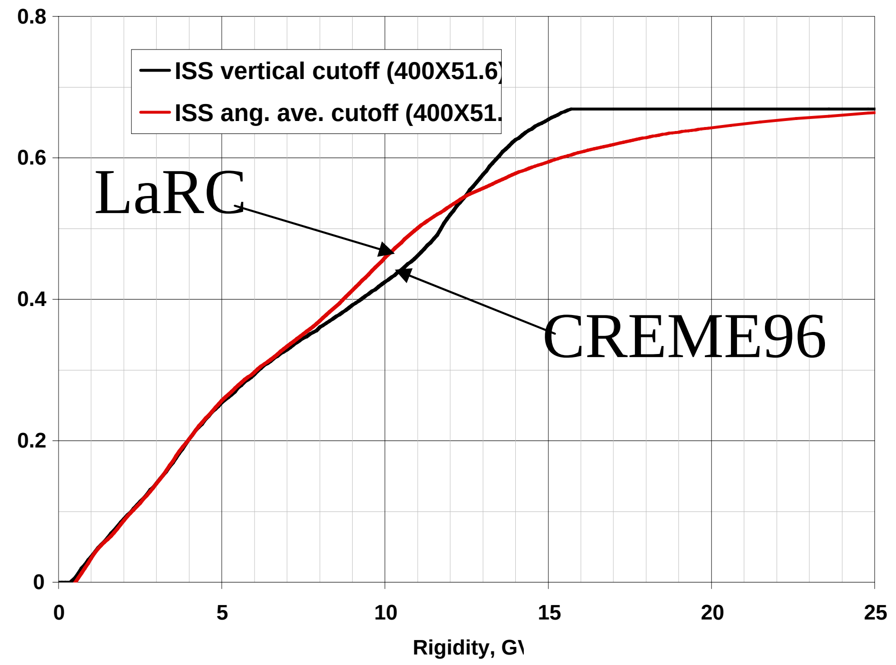


1975 Directional Averaged Transmission
vs
CREME96: 1975 Averaged Vertical Cutoff Transmission

51.6 ° × 400 km in June 2001



51.6 ° × 400 km in 1975



HZETRN vs Monte Carlo