Evaluation of the New Trapped Proton Model (AP9) at ISS Attitudes

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Background

- I – Traditionally, trapped exposure estimates for the tissue/SSD based components are computed using NASA trapped models AP8/AE8. These trapped models were developed in the 1970s and 1980s.
- II – AP8/AE8 are static models. Don't provide probability distribution or error bars. Don't include broad energy range (i.e., hot plasma / energetic protons) and don't include complete spatial coverage for LEO, MEO, GEO, GTO and HEO missions.
- III – Aerospace Corporation, Los Alamos National Laboratory (LANL), National Reconnaissance Office (NRO) and Air Force Research Laboratory (AFRL), embarked on producing AP9/AE9.
- IV – AP9/AE9 offer improvements in spectral and spatial coverage definition, epoch correlated probability distribution, statistical accuracy and uncertainty quantification.

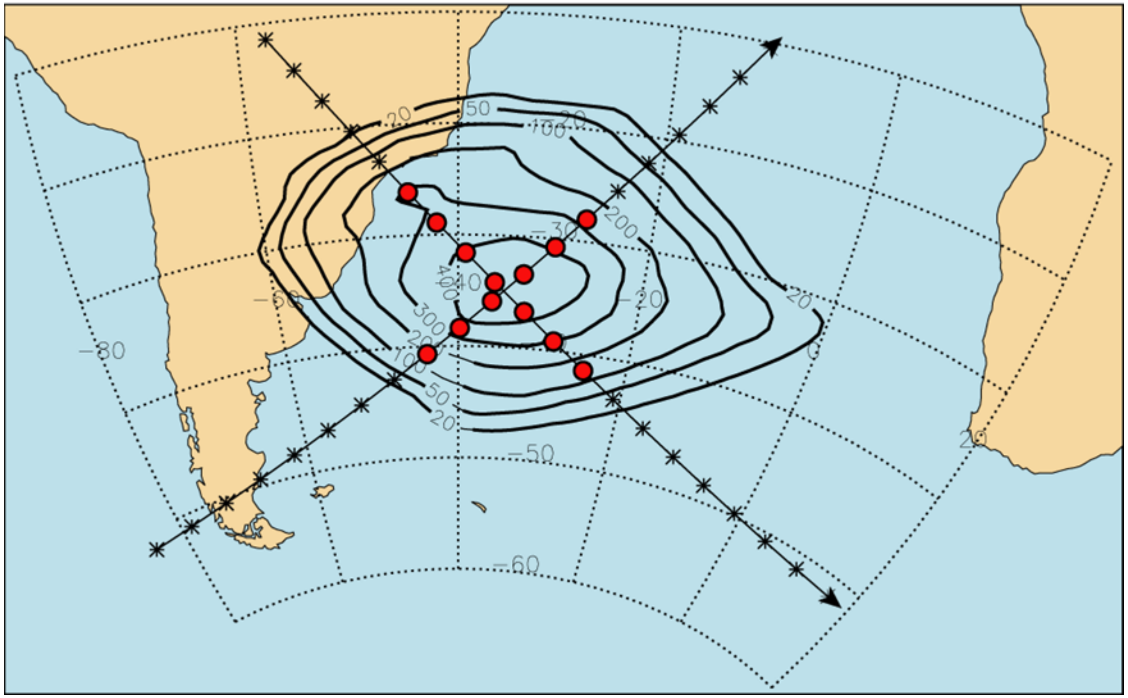
Outline

- I – Solar indices and the particular epoch I chose for analysis.
- II – Show the deficiencies of AP8 and the improvements that AP9 offers.
- III – Talk about the specific Liulin data and AP8/AP9 proton boundary conditions that I am using.
- IV – For one day ISS orbit (1440 minutes), I will shows dosemetric correlation among AP8, AP9 environments and Liulin data for 6 SAA passes.
- V – Summary and future work.

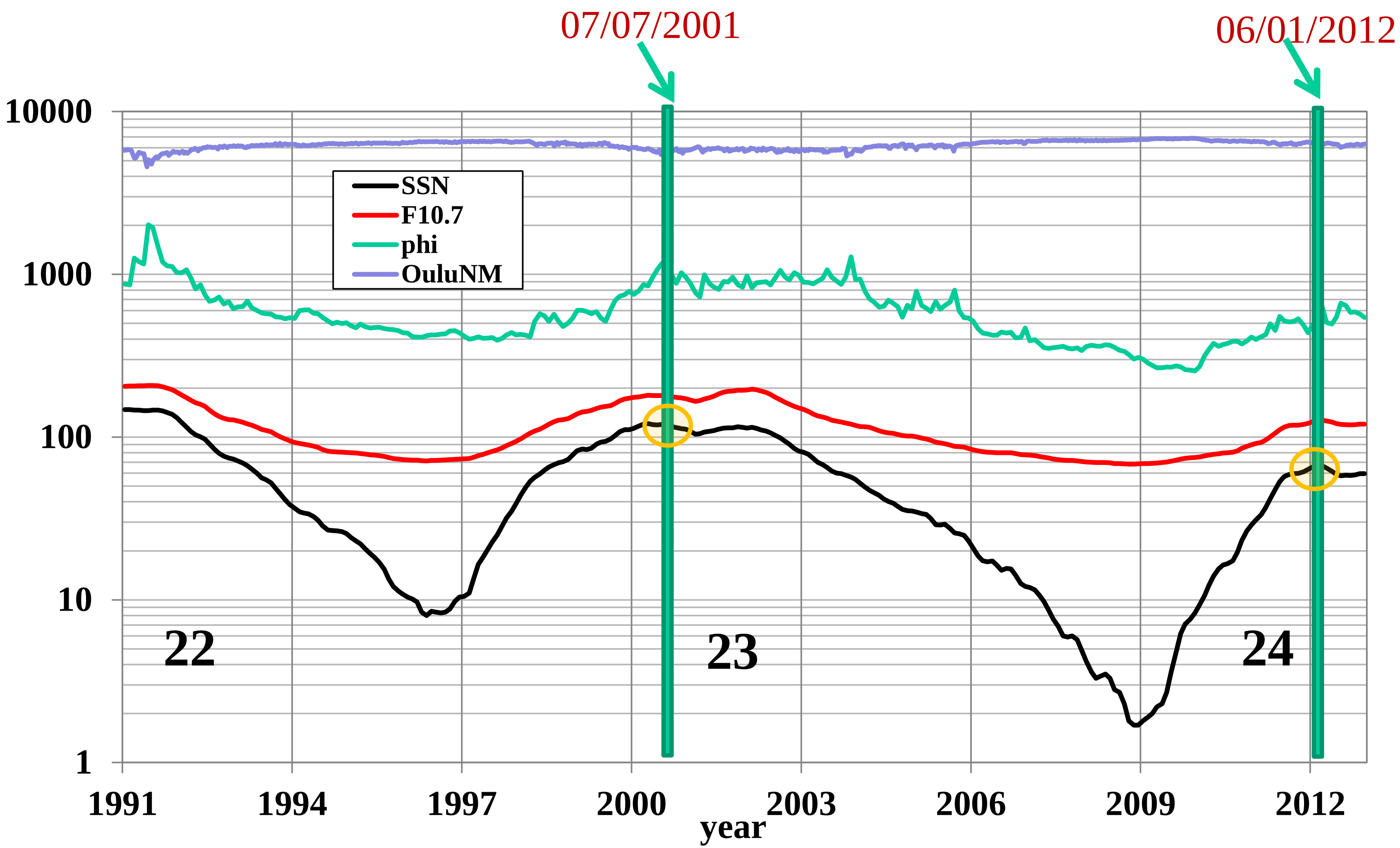
*** No further discussion of AE9***

ISS South Atlantic Anomaly (SAA) Pass

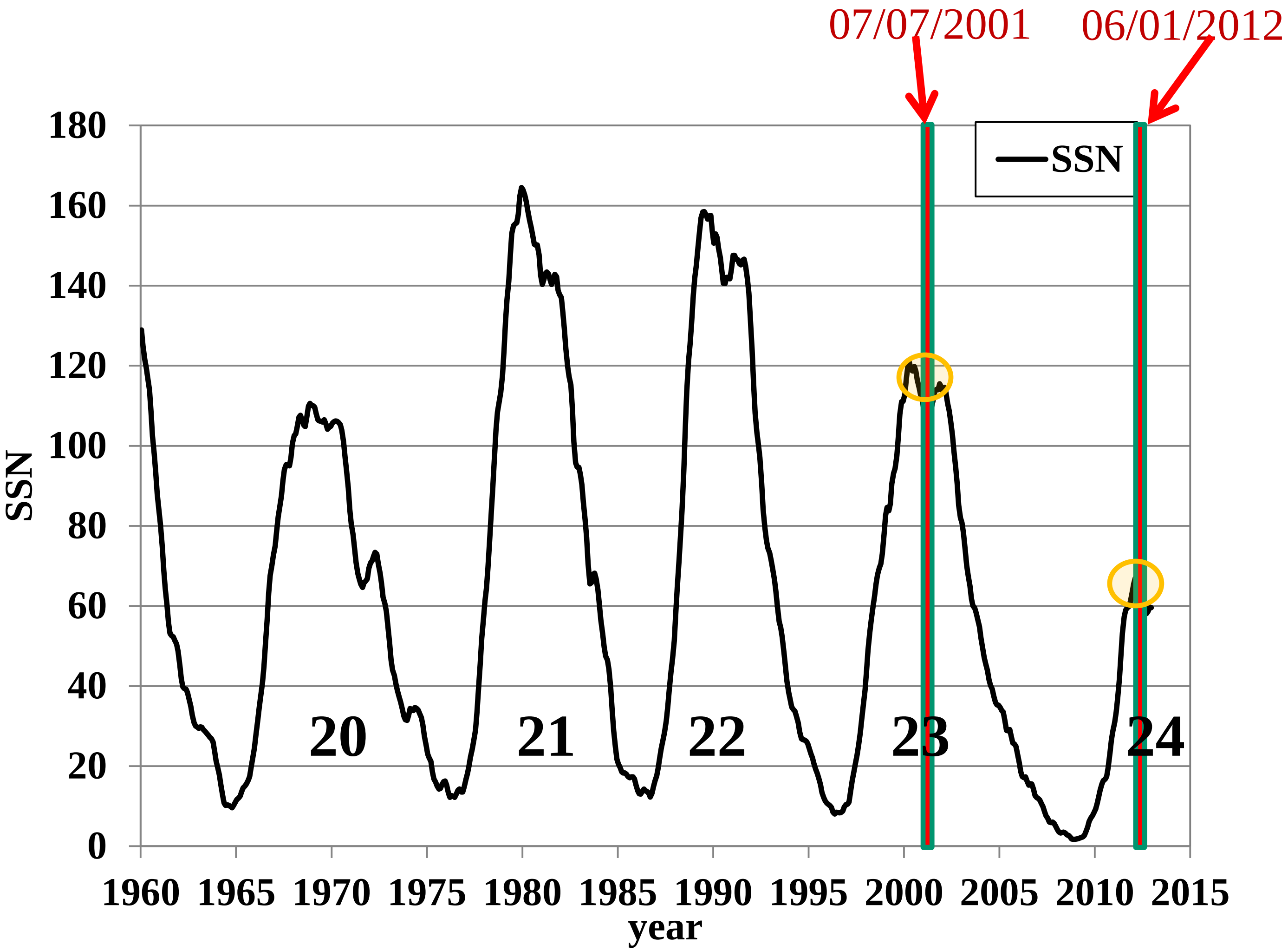
400–km Solar Min. Flux (greater than 100 MeV), protons/(cm^2–sec)



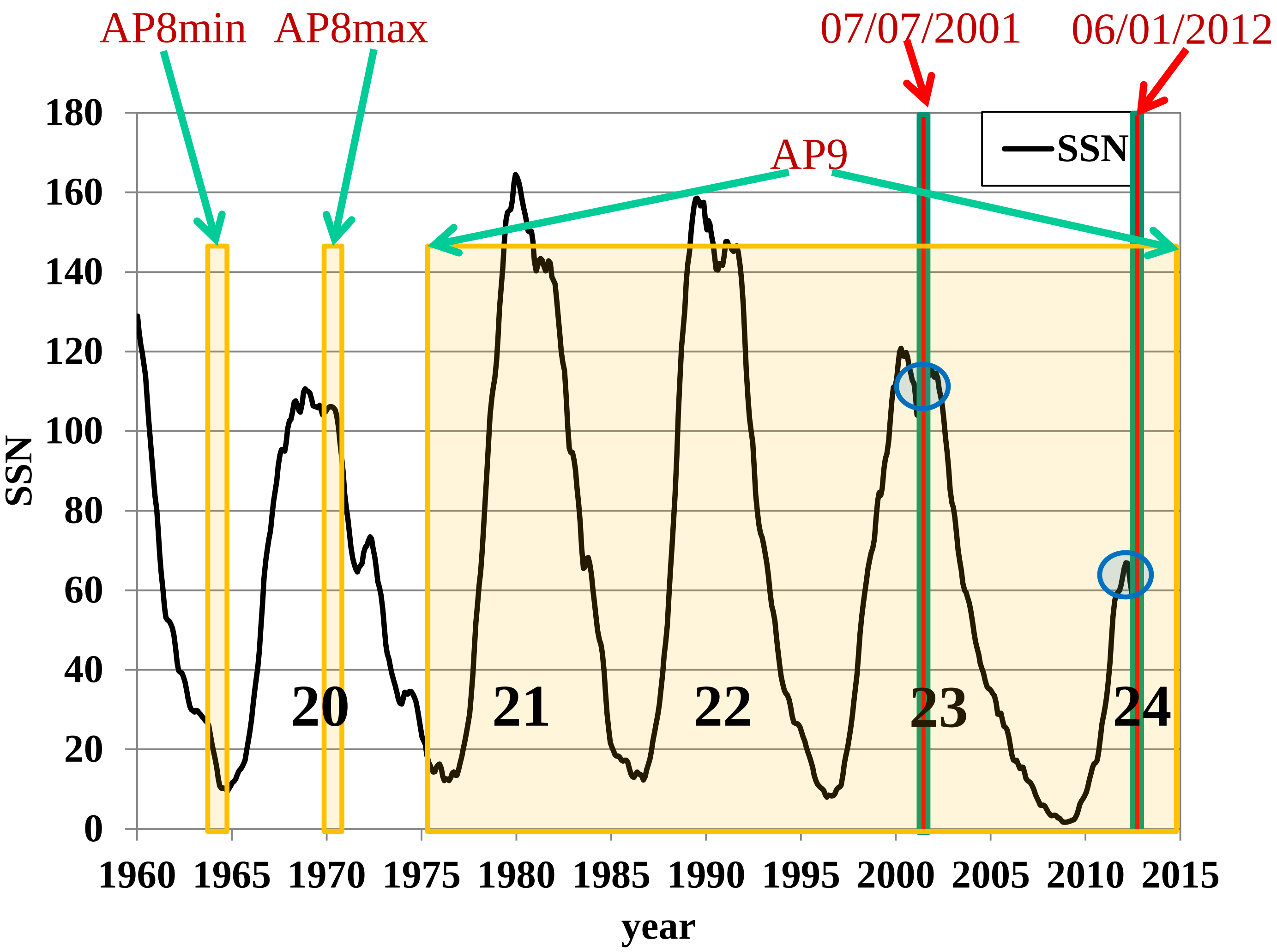
Solar Indices



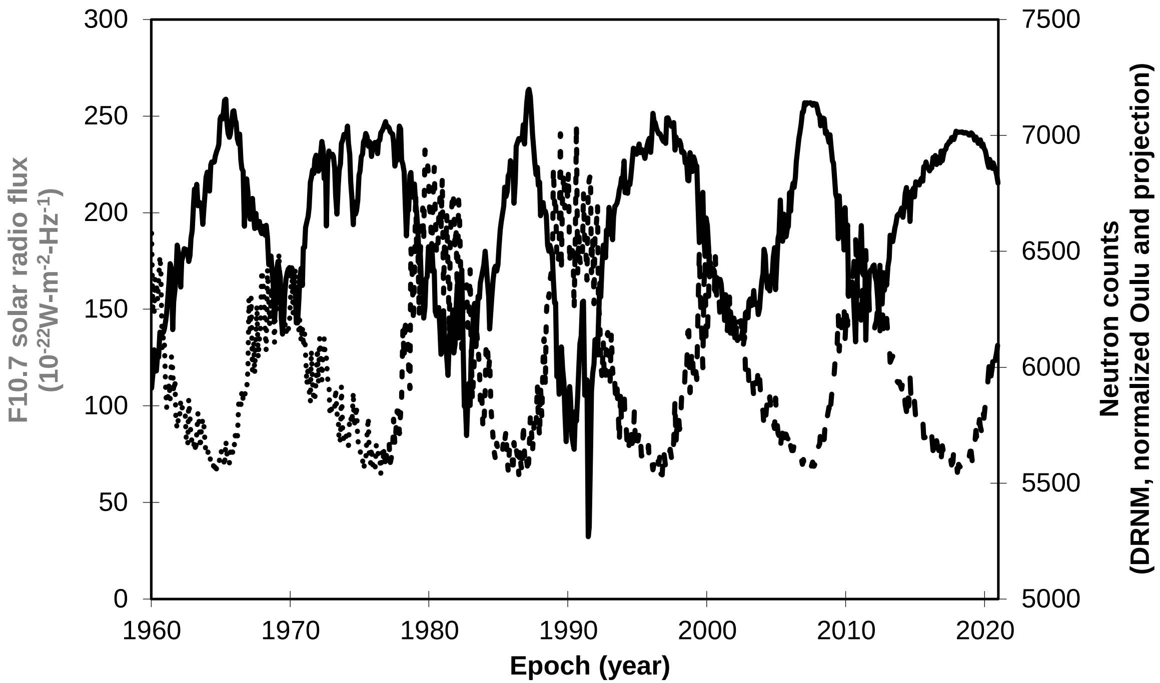
SSN Solar Index



AP8min-AP8max vs. AP9



Modulation of the Trapped Protons in LEO



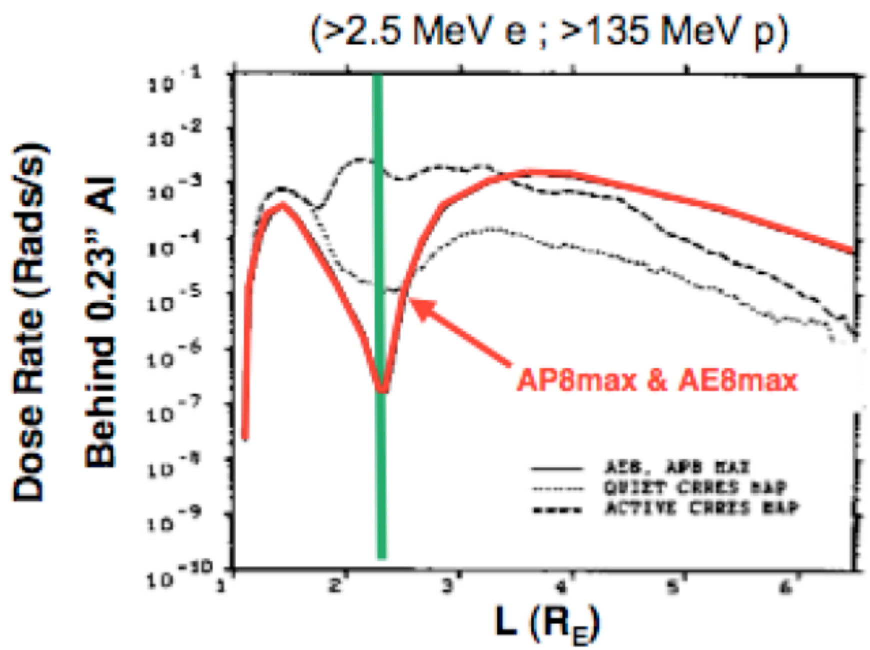
$$f_p(r,\theta,\phi,E,t) = f_{p,min}(r,\theta,\phi,E) \;\; exp\{-\alpha_p[NM\times F_{10.7} - NM\times F_{10.7}|_{MIN}]\}$$

$$\alpha_p = \{log\,[f_{p,min}(r,\theta,\phi,E) / f_{p,max}(r,\theta,\phi,E)\,]/[NM\times F_{10.7}|_{Max} - NM\times F_{10.7}|_{MIN}]$$

Badavi (2006)

Errors in AP8/AE8

Example: Medium-Earth Orbit (MEO)



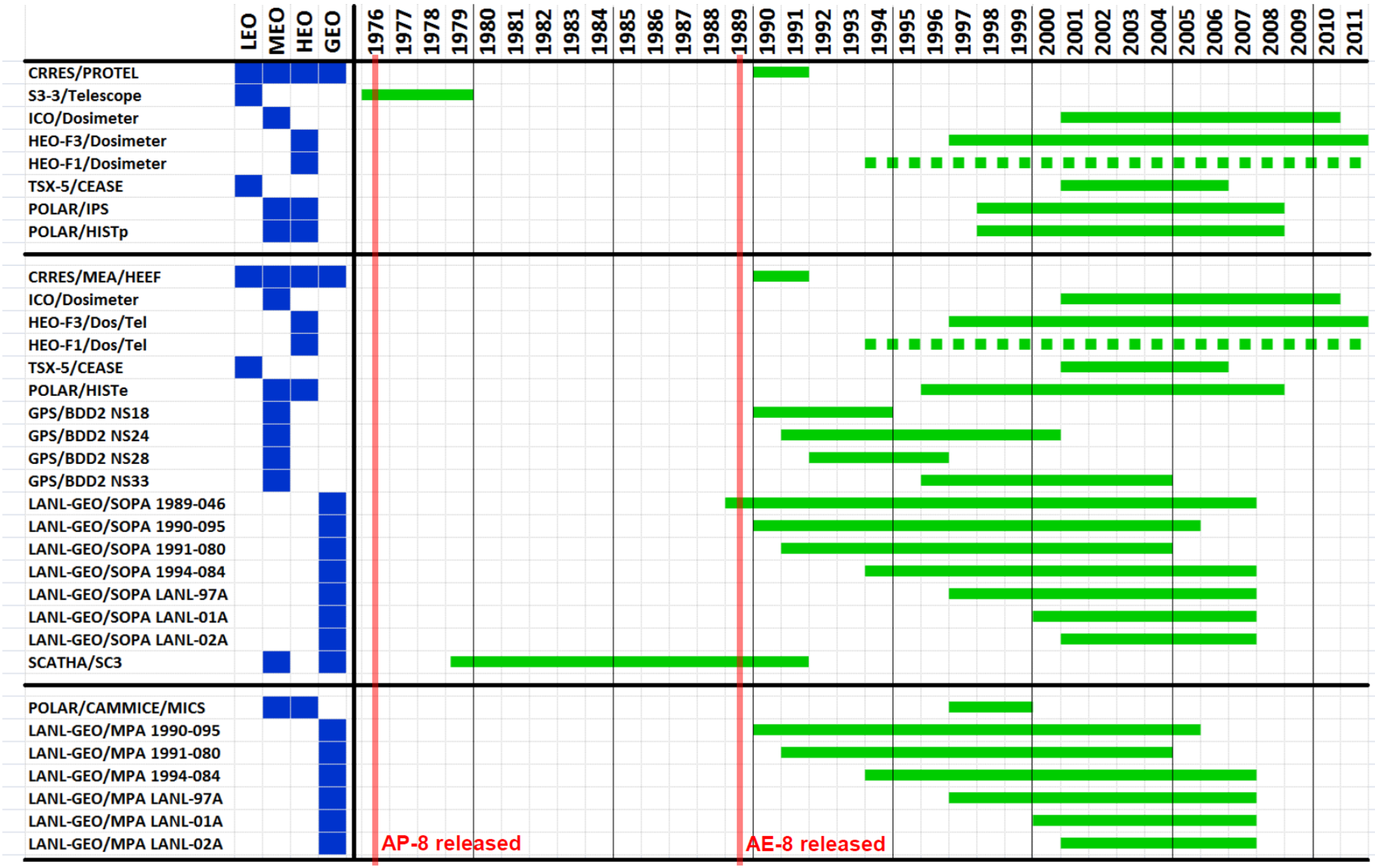
For MEO orbit (L=2.2), #years to reach 100 kRad:

- **Quiet conditions (NASA AP8, AE8) : 88 yrs**
- **Active conditions (CRRES active) : 1.1 yrs**

AE8 & AP8 under estimate the dose for 0.23'' shielding

Courtesy AP9/AE9 documents

AP9/AE9 Data Sets – Temporal Coverage

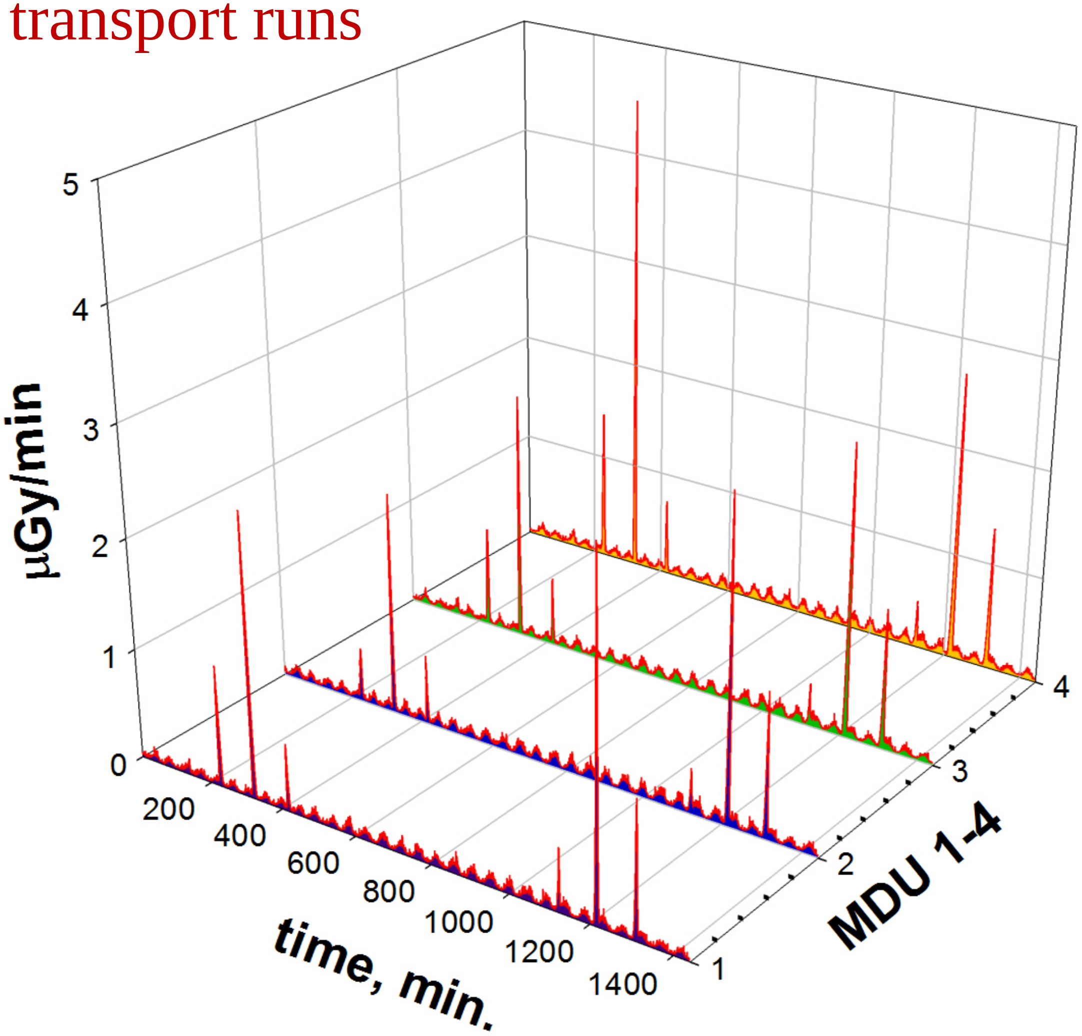


Combined Release and Radiation Effects Satellite (CRRES)
Surface Charging at high altitudes (SCATHA)

Courtesy AP9/AE9 documents

Liulin 1-4 Data Sets (07/07/2001)

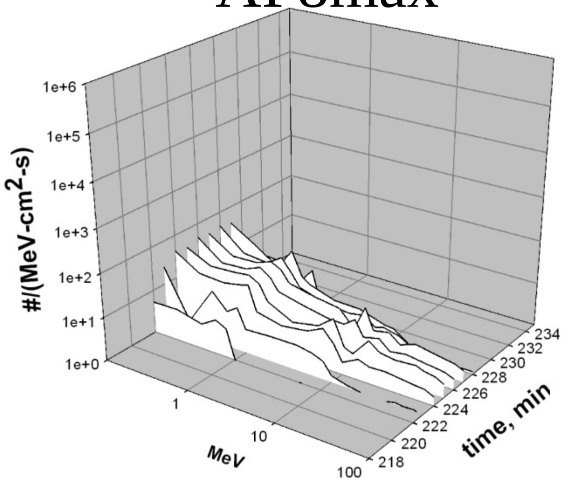
15x6x4=360 transport runs



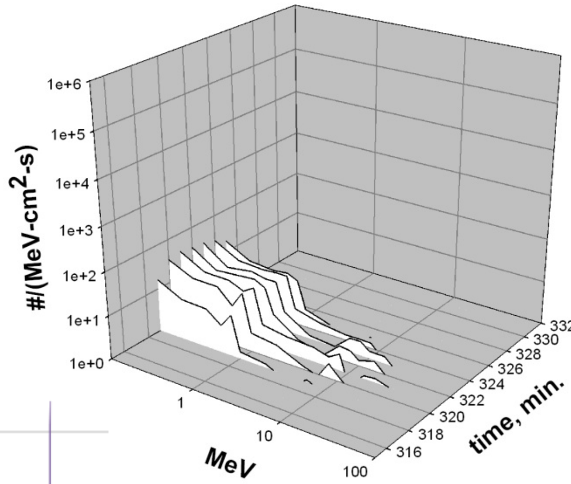
Liulin data courtesy of T. Dachev

AP8/AP9 Comparison (Ascending Nodes, 07/07/2001)

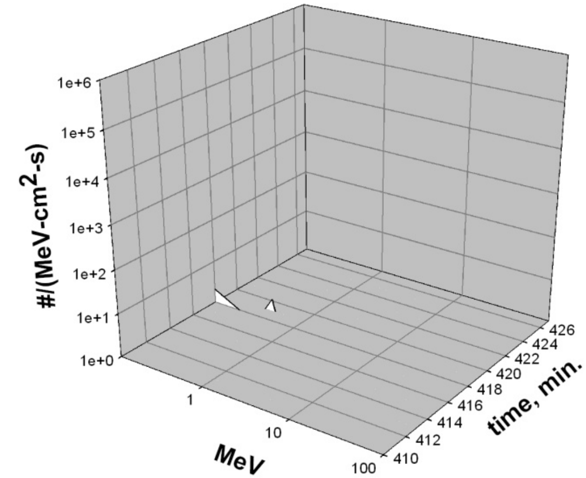
AP8max



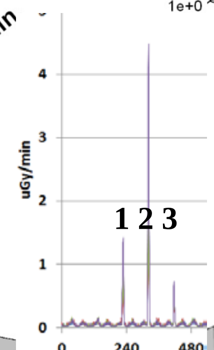
AP8max



AP8max

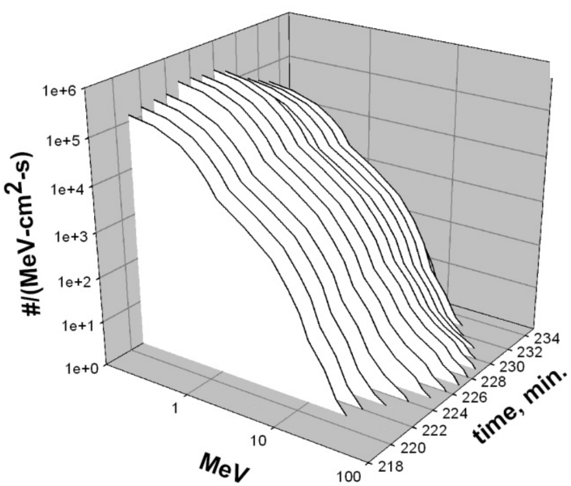


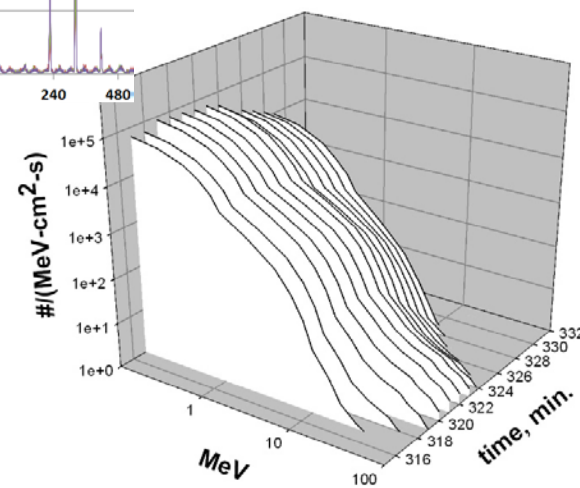
Pass1

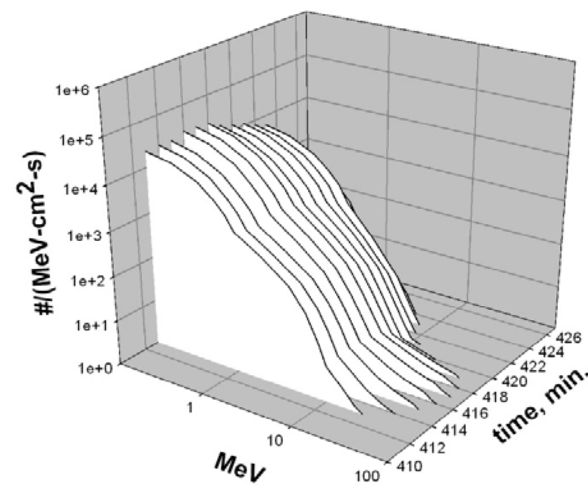


Pass2

Pass3







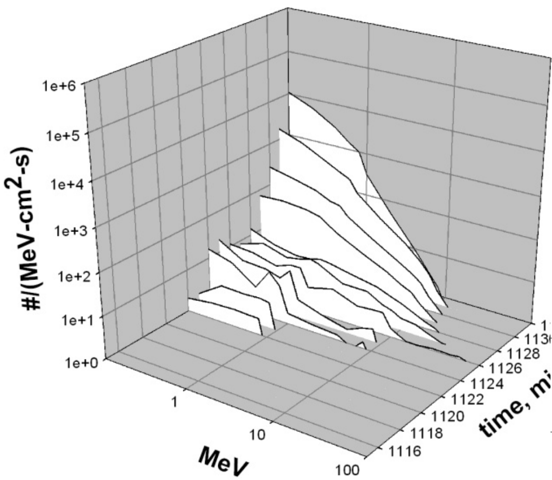
AP9

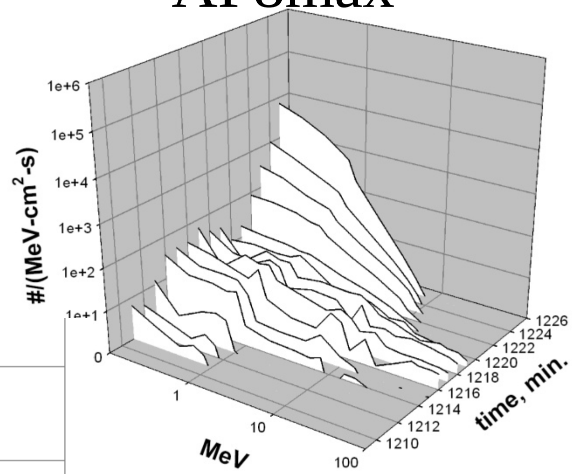
AP9

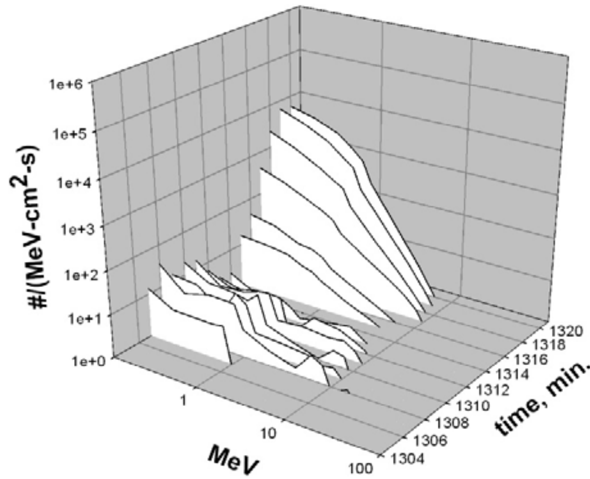
AP9

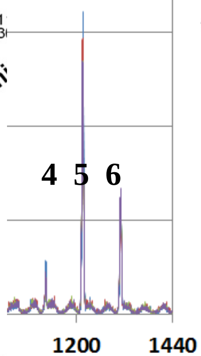
AP8/AP9 Comparison (Descending Nodes, 07/07/2001)

AP8max AP8max AP8max

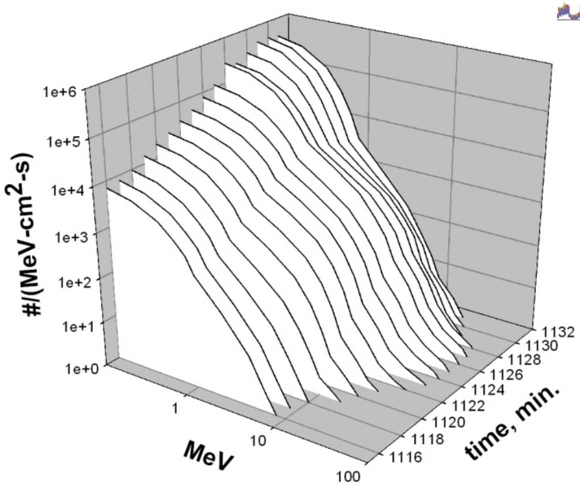


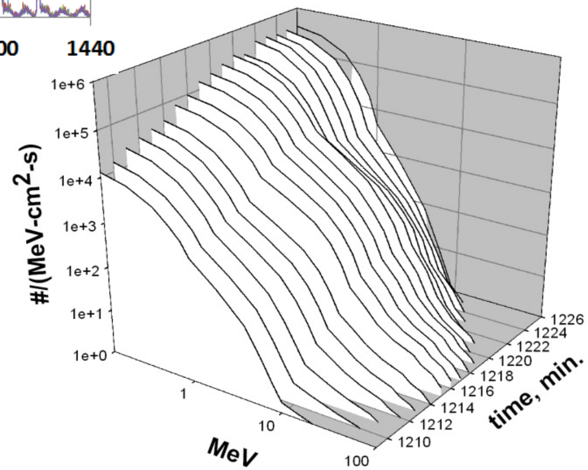


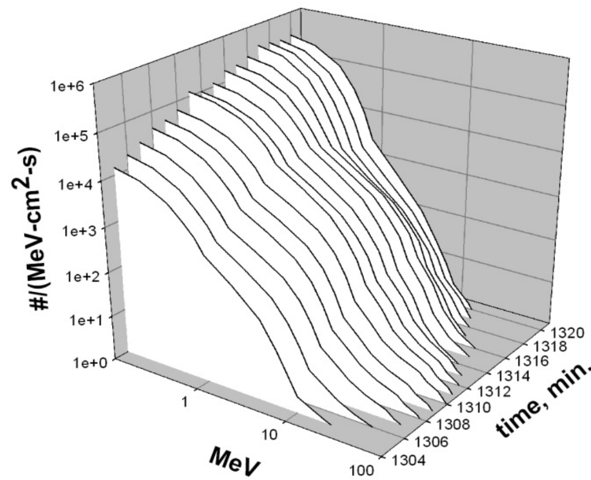




Pass4 Pass5 Pass6

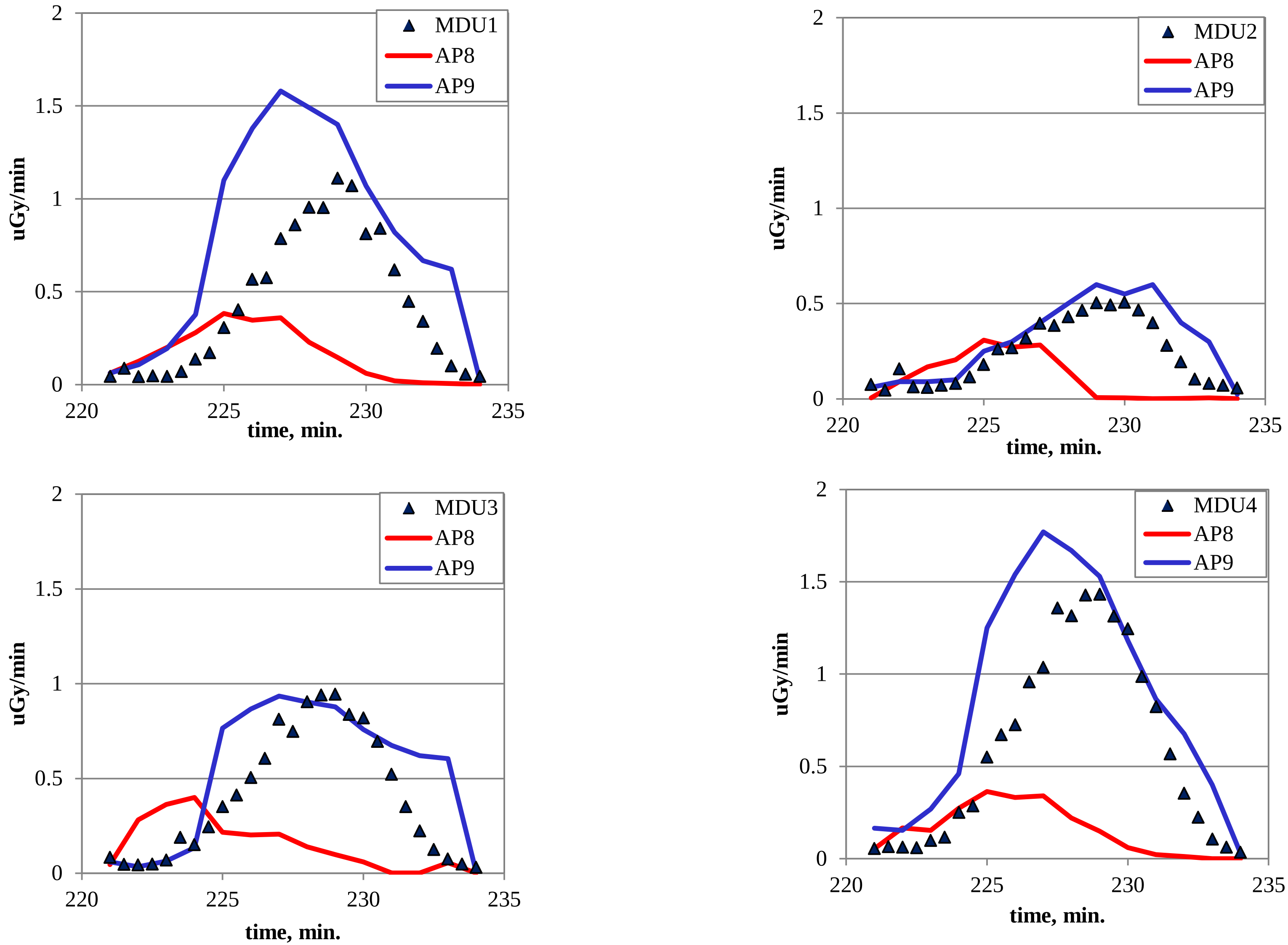






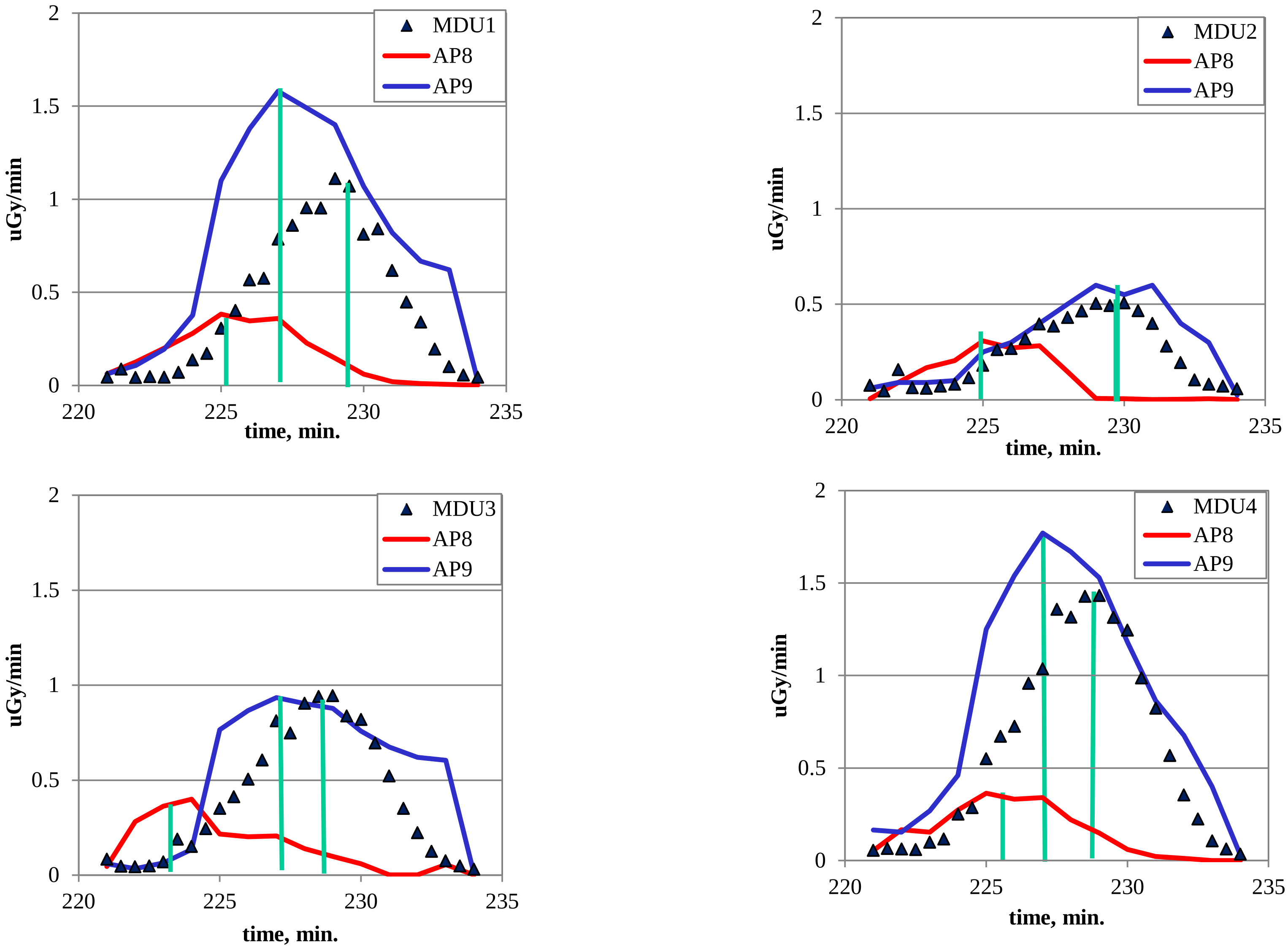
AP9 AP9 AP9

AP8/AP9 Dosemetric Comparison (Ascending Node, Pass1)



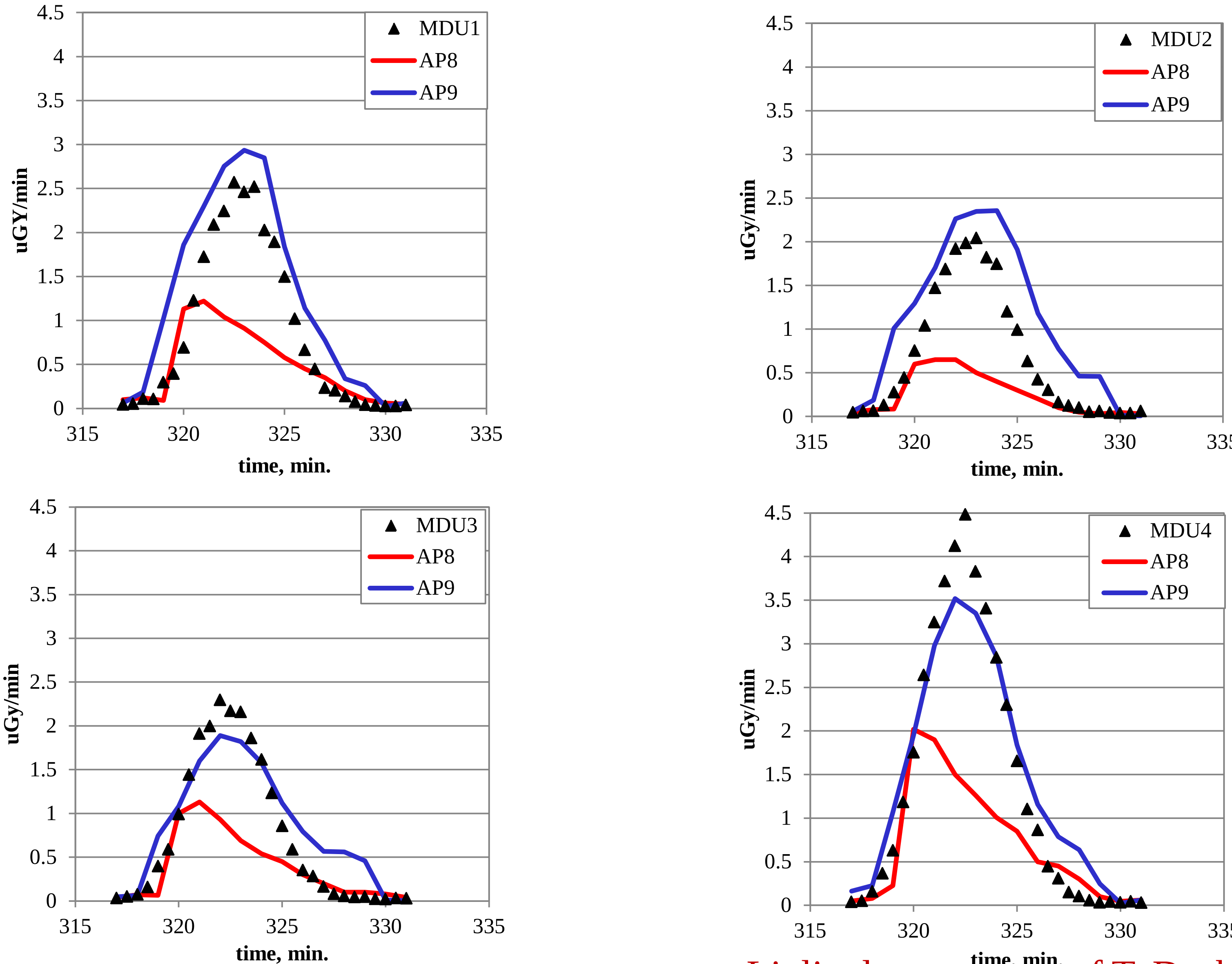
Liulin data courtesy of T. Dachev

AP8/AP9 Dosemetric Comparison (Ascending Node, Pass1)



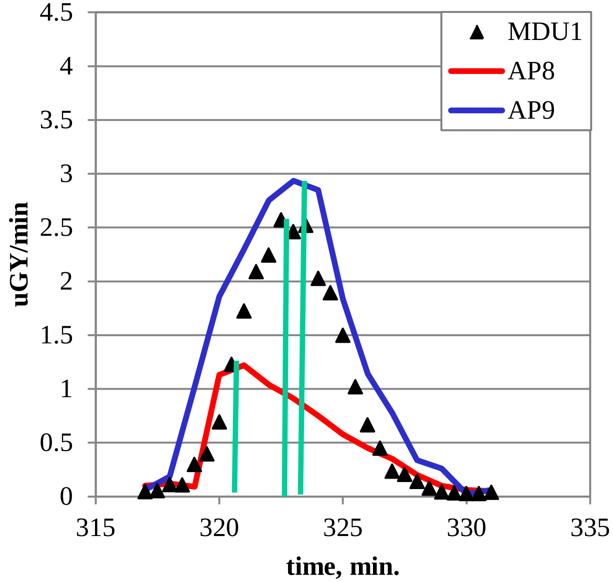
Liulin data courtesy of T. Dachev

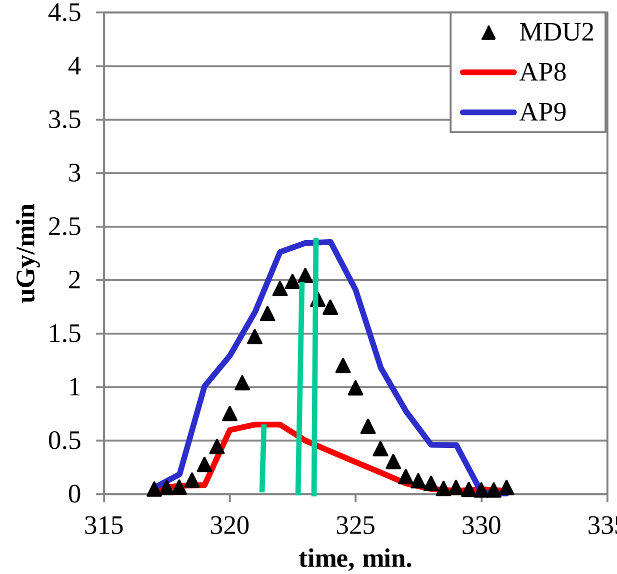
AP8/AP9 Dosemetric Comparison (Ascending Node, Pass2)

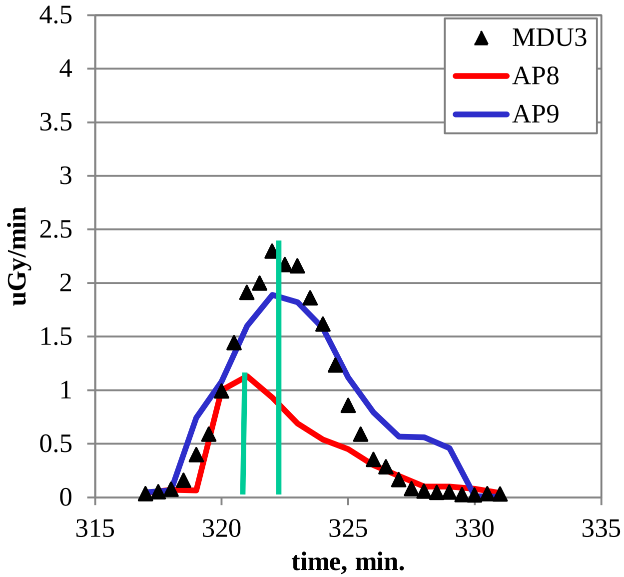


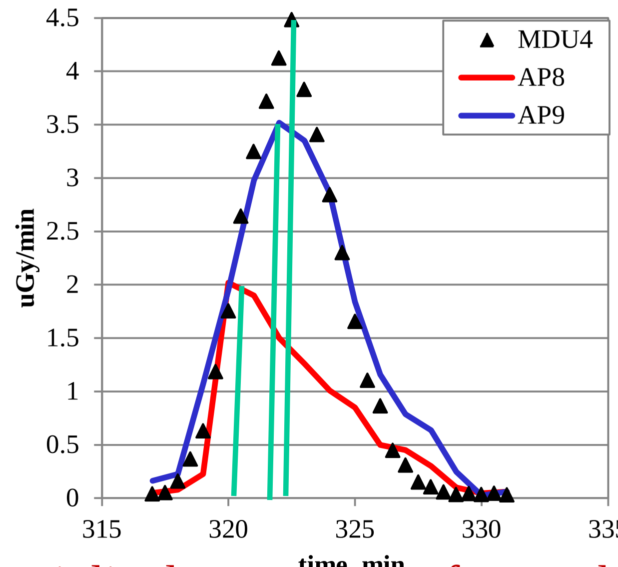
Liulin data courtesy of T. Dachev

AP8/AP9 Dosemetric Comparison (Ascending Node, Pass2)



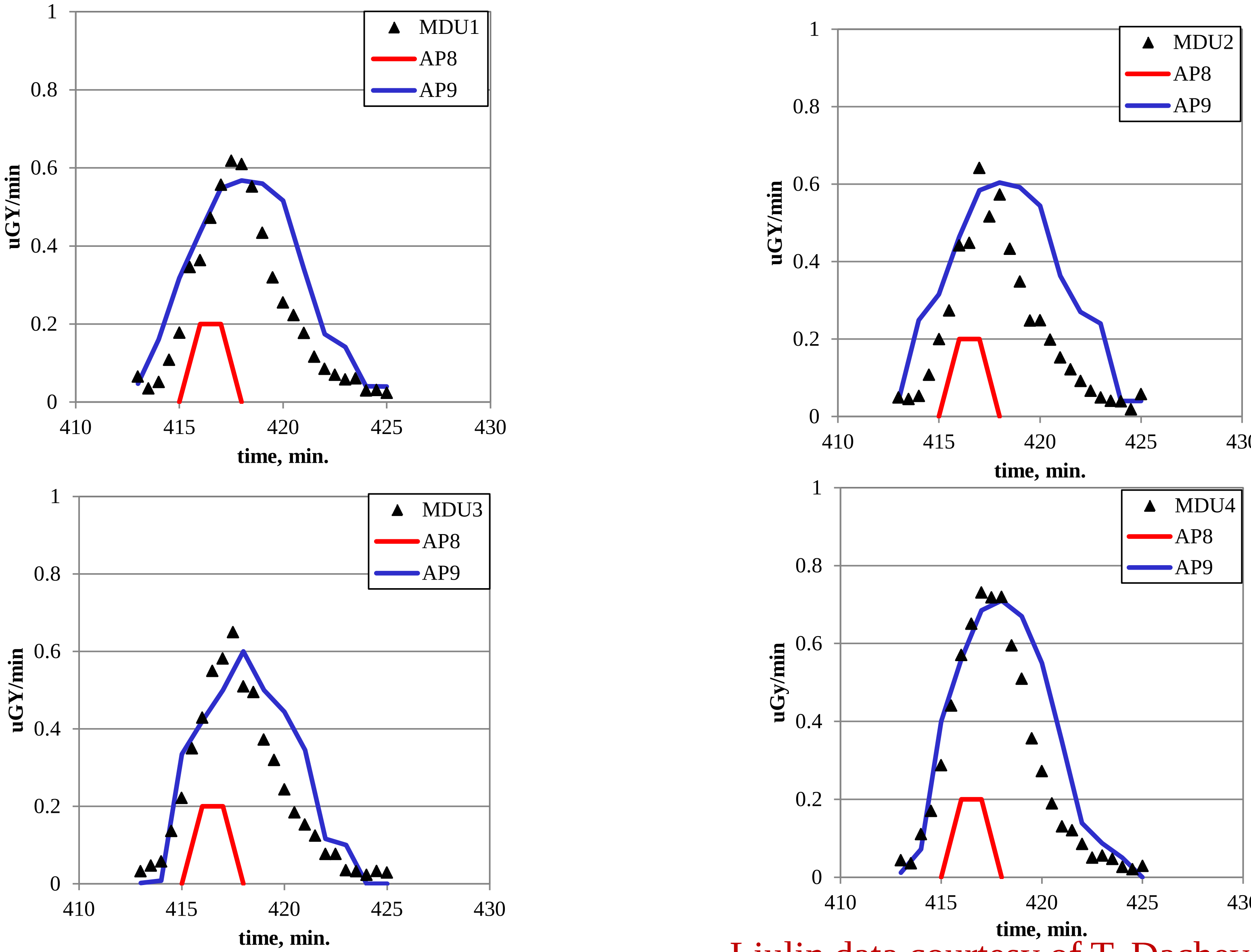






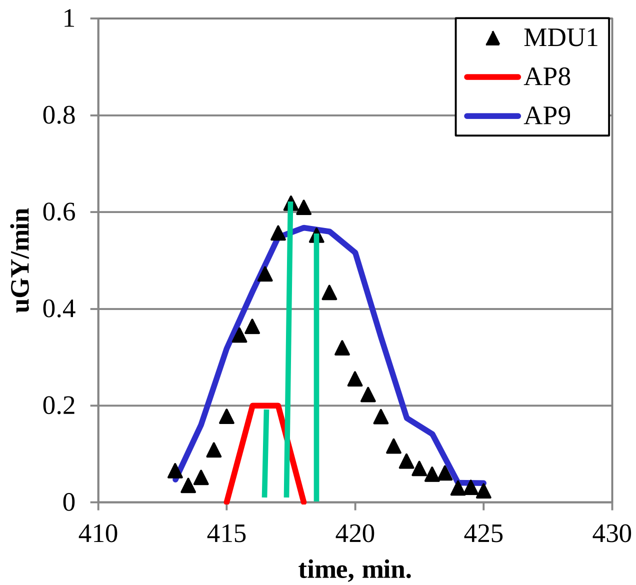
Liulin data courtesy of T. Dachev

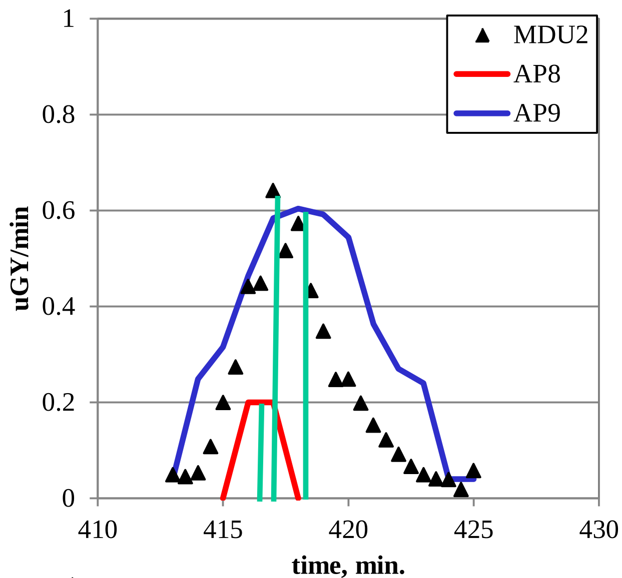
AP8/AP9 Dosemetric Comparison (Ascending Node, Pass3)

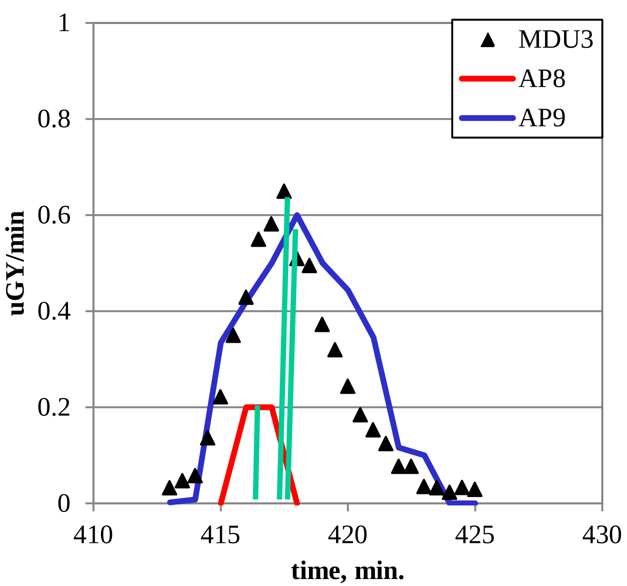


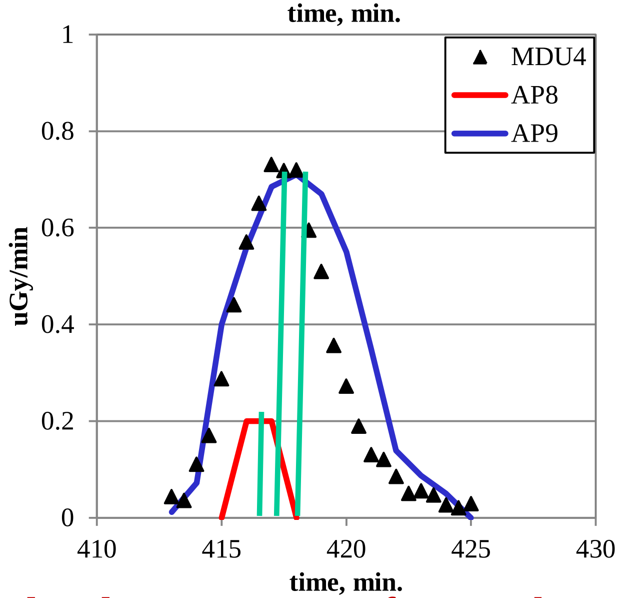
Liulin data courtesy of T. Dachev

AP8/AP9 Dosemetric Comparison (Ascending Node, Pass3)



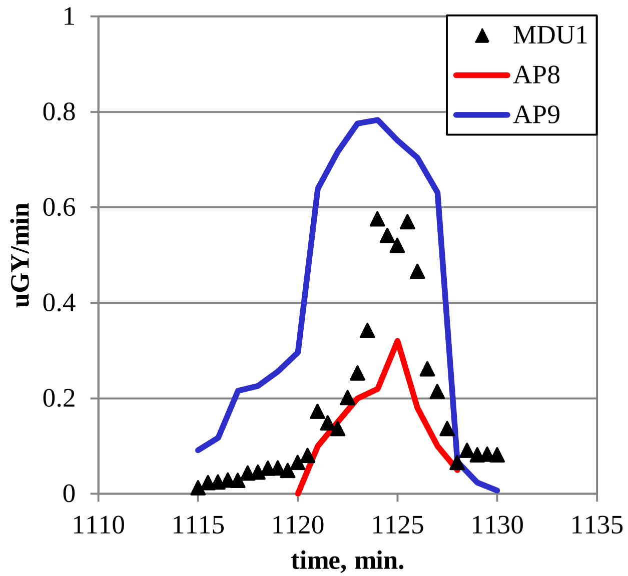


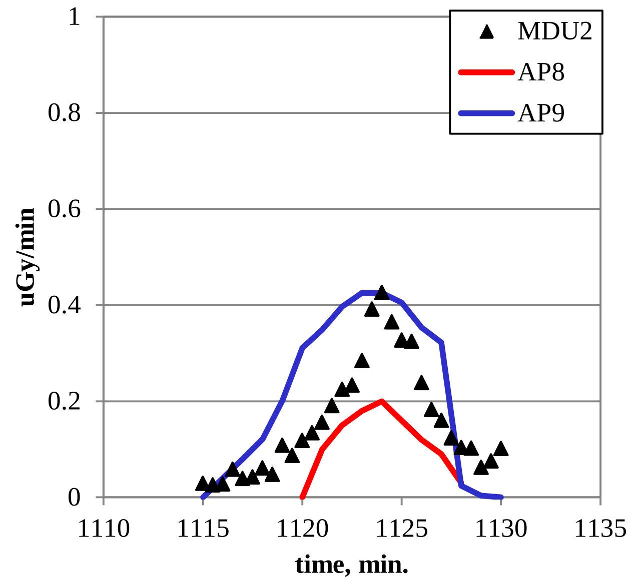


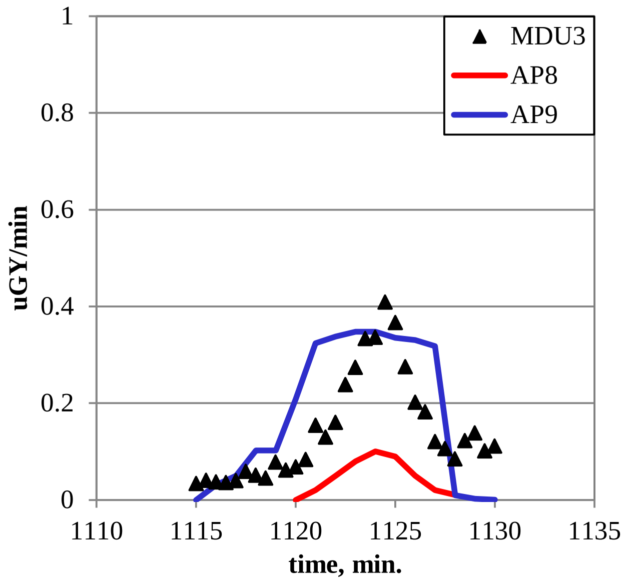


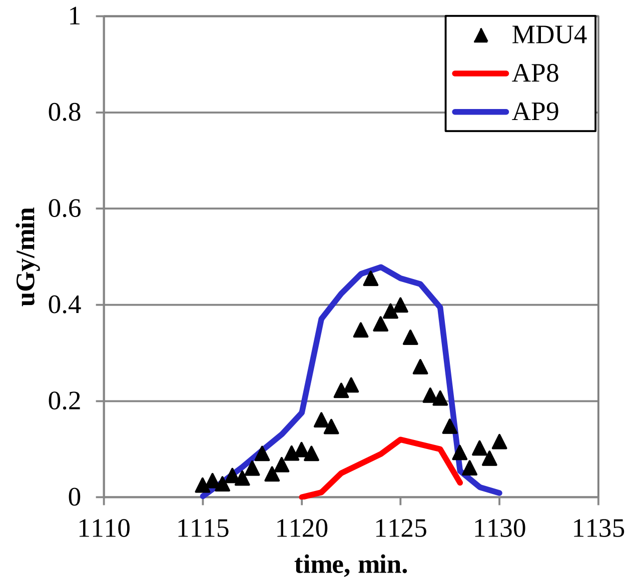
Liulin data courtesy of T. Dachev

AP8/AP9 Dosemetric Comparison (Descending Node, Pass4)



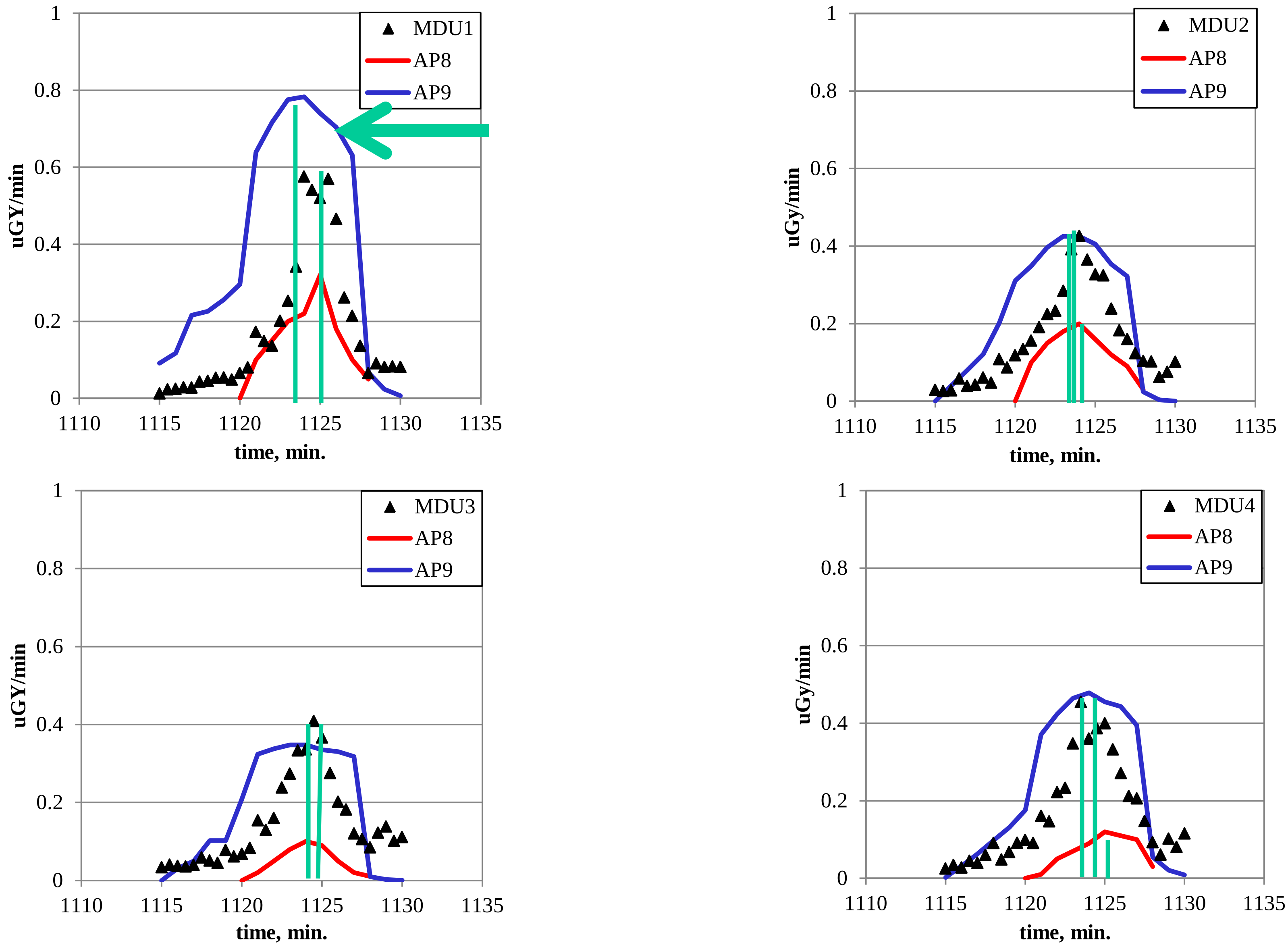






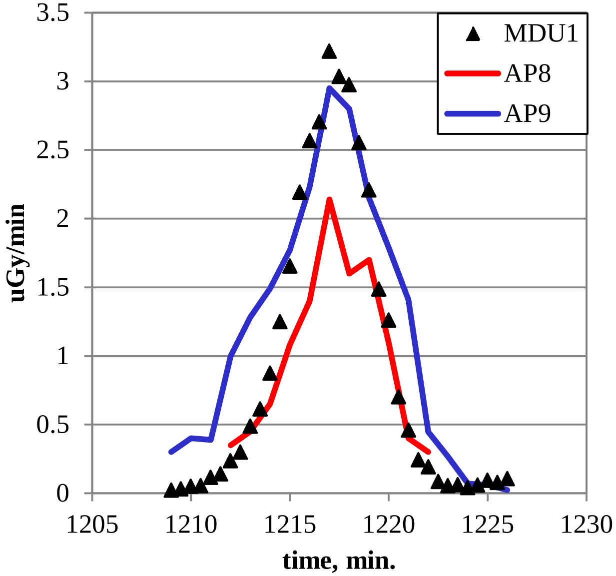
Liulin data courtesy of T. Dachev

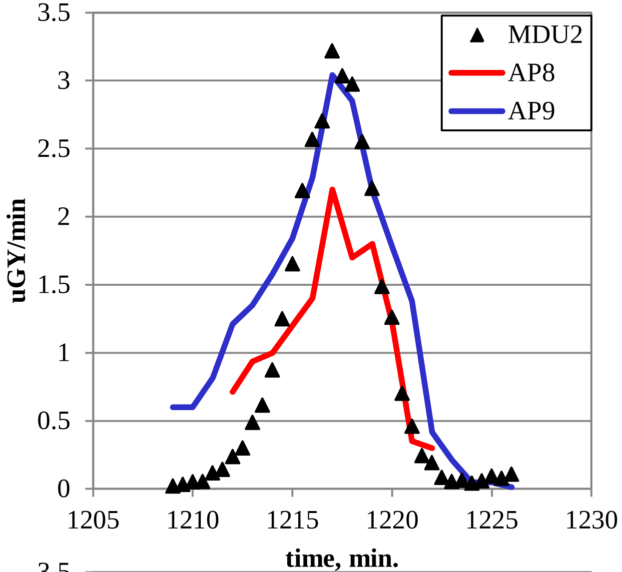
AP8/AP9 Dosemetric Comparison (Descending Node, Pass4)

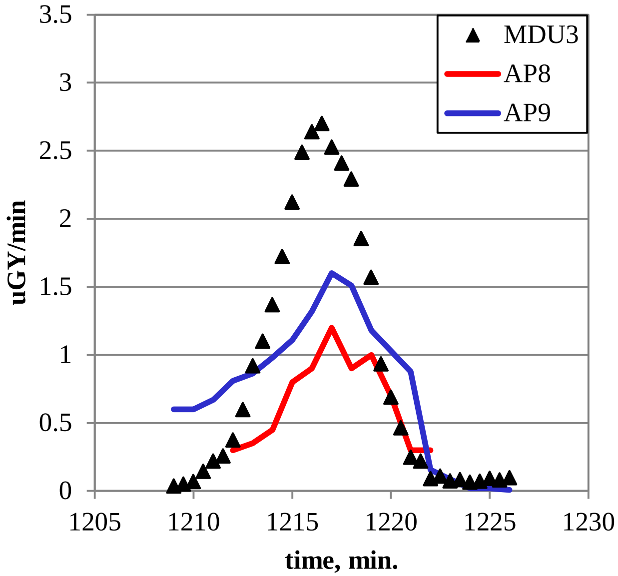


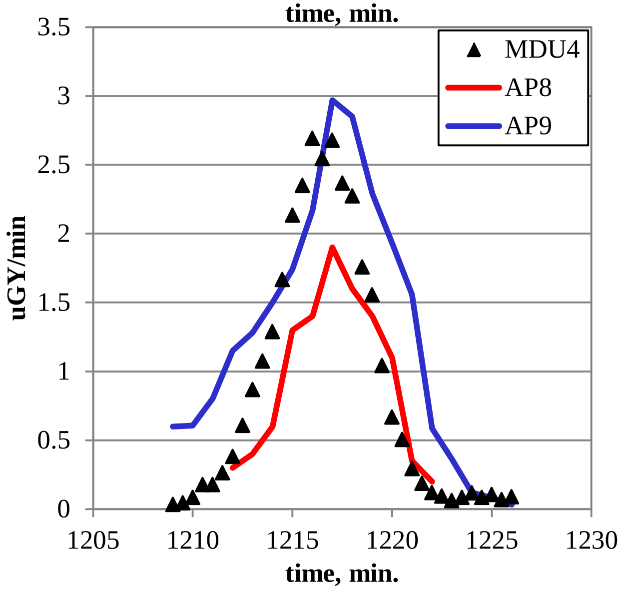
Liulin data courtesy of T. Dachev

AP8/AP9 Dosemetric Comparison (Descending Node, Pass5)



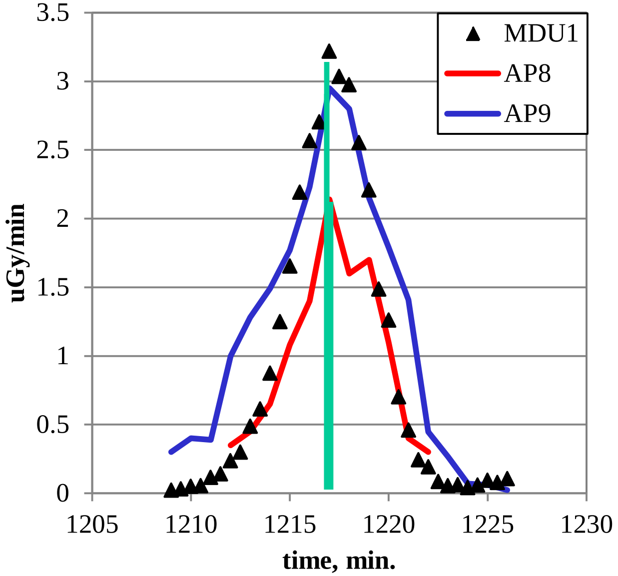


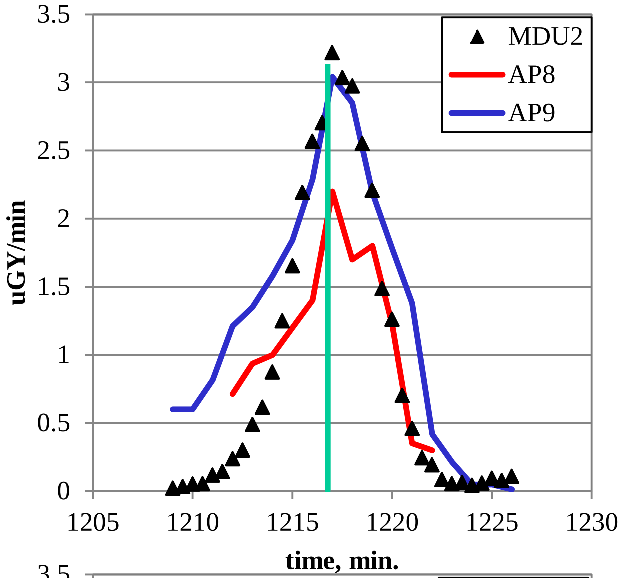


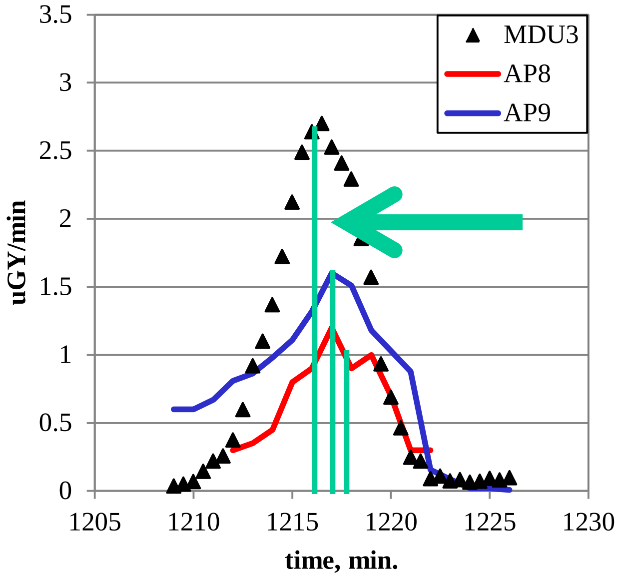


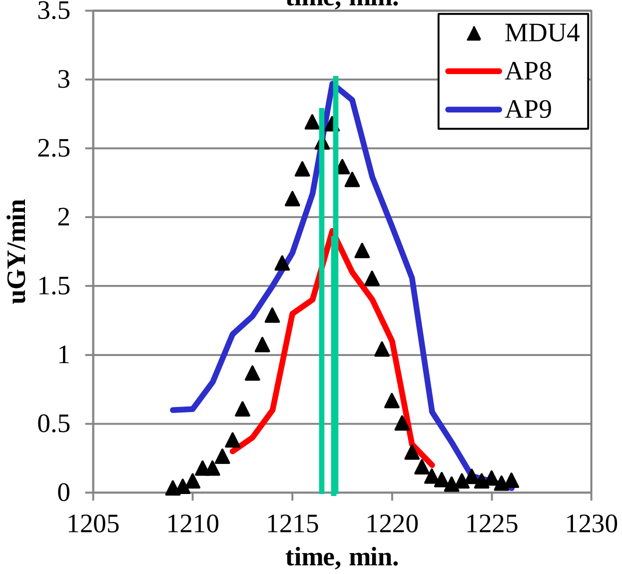
Liulin data courtesy of T. Dachev

AP8/AP9 Dosemetric Comparison (Descending Node, Pass5)



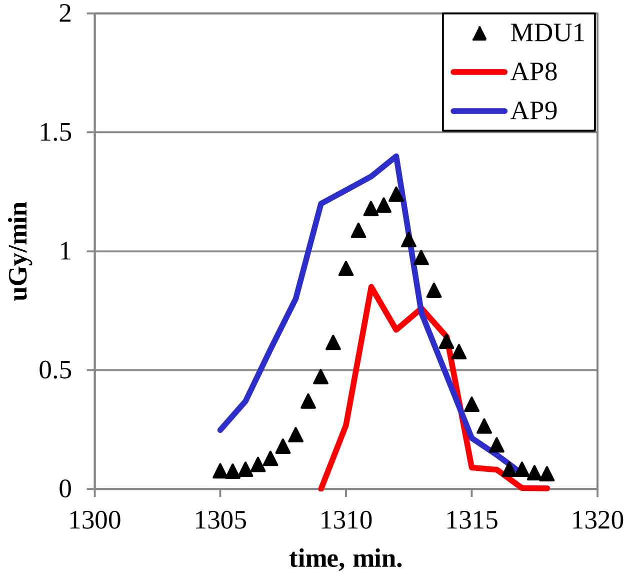


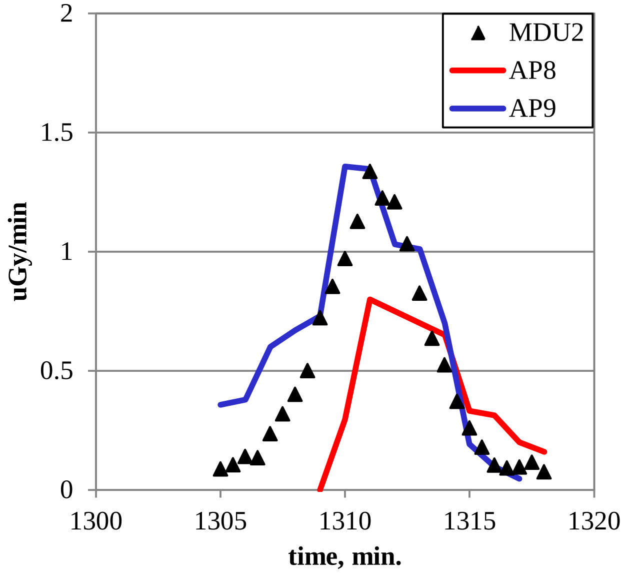


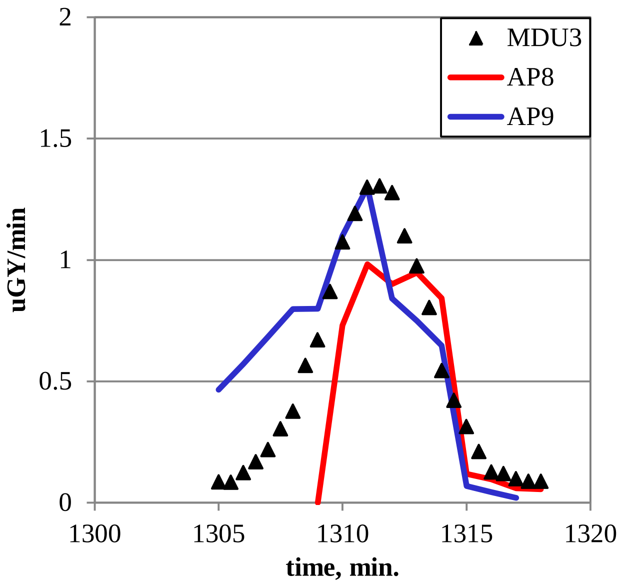


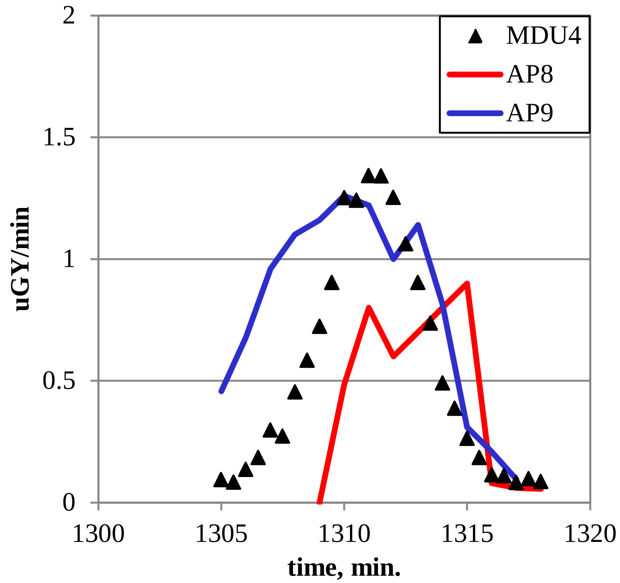
Liulin data courtesy of T. Dachev

AP8/AP9 Dosemetric Comparison (Descending Node, Pass6)



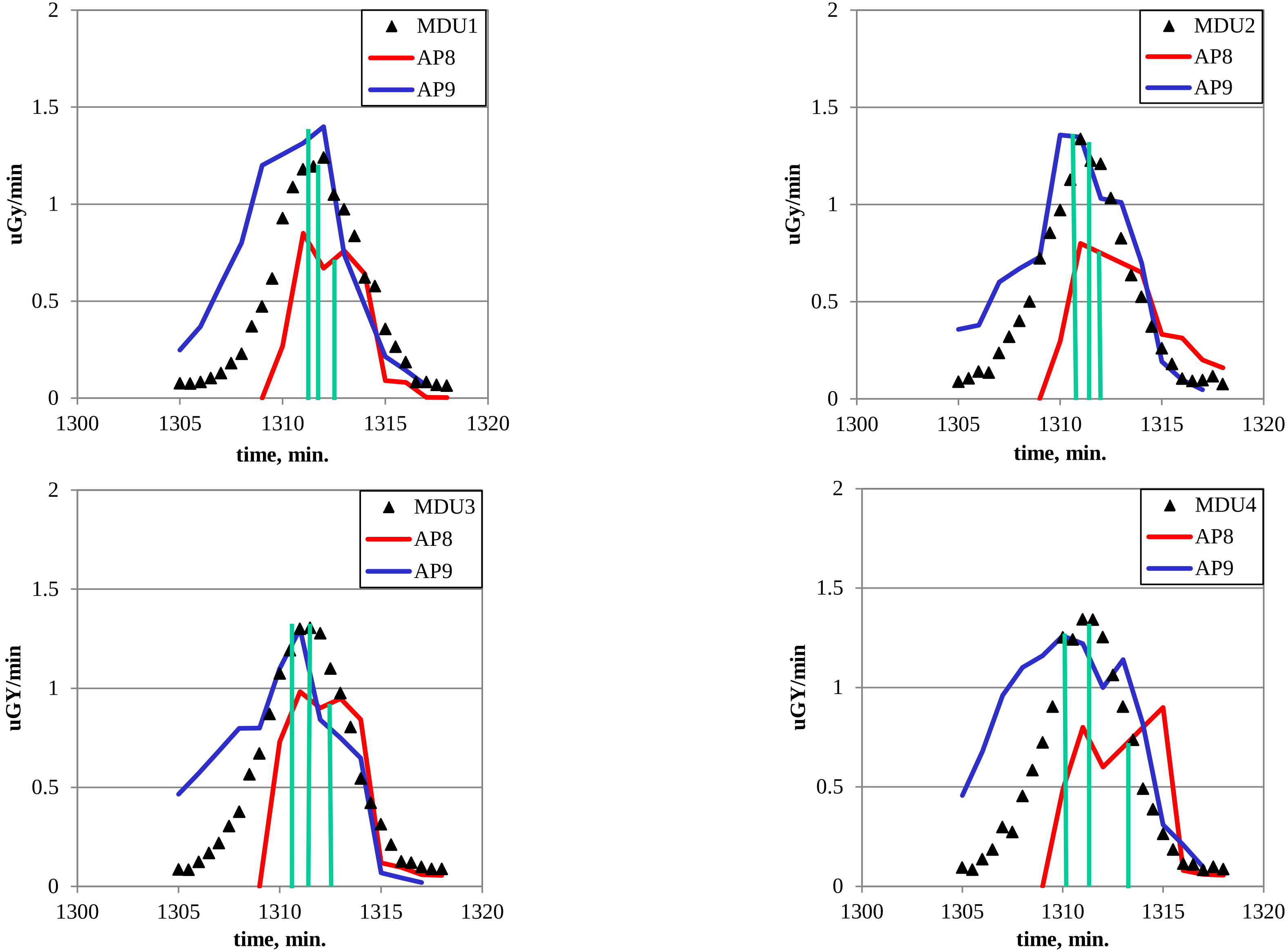






Liulin data courtesy of T. Dachev

AP8/AP9 Dosemetric Comparison (Descending Node, Pass6)



Liulin data courtesy of T. Dachev

Summary and Future Work

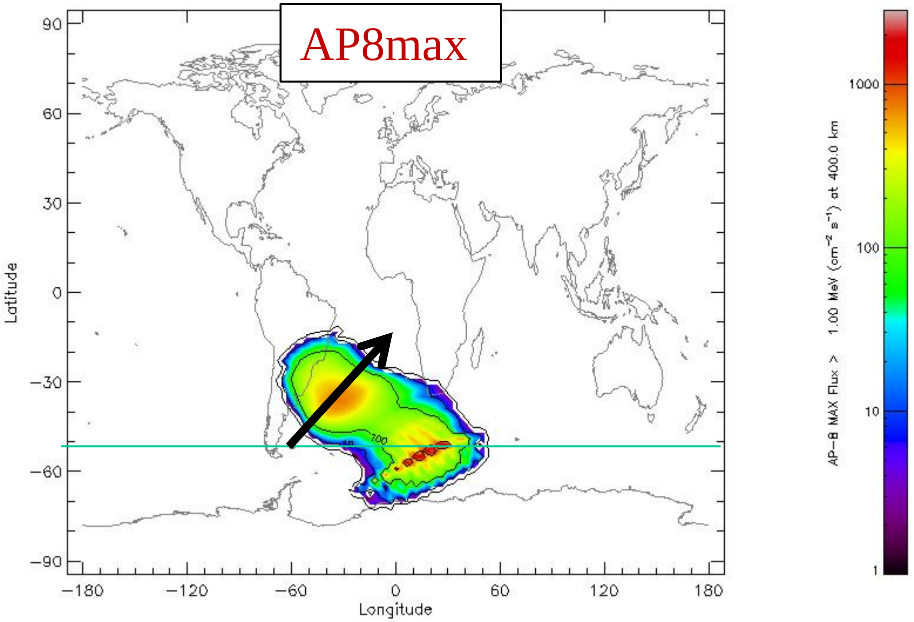
- I – Deficiencies and limitations of AP8 was discussed and AP9 capabilities was introduced.
- II – The differences in proton boundary conditions for 6 SAA was discussed.
- III – Validations results among AP8, AP9 and Liulin data was discussed. In 22/24 validation cases, AP9 correlated fairly well with measurement. In 2/24 cases, AP9 validation was marginal.
- IV – So far, the validation process is strictly manual. Work is underway to automate the validation process.
- V – Next step is to perform validation for the ISS ULF7 configuration. This will depend on the availability of CAD/mass model of ISS for this epoch. (ULF7 → 3R in 2014)
- VI – Limited 3D measurements are currently available. It is very desirable to validate 3D data (TRITEL, etc…) with simulation.

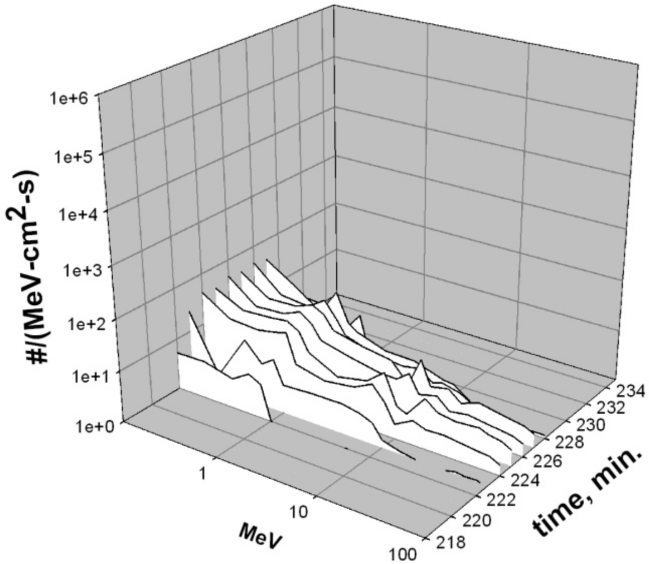
Backups

Satellite/Sensor	Orbit	Temporal range	Energy range
Protons			(MeV)
CRRES/PROTEL	350 km × 33000 km, 18°	07/1990–10/1991	2.0–80
S3-3/Telescope	236 km × 8048 km, 97.5°	07/1976–07/1979	0.1– 2.0
HEO-F1/Dosimeter	500 km × 39000 km, 63°	05/1994–02/2011*	10–400
HEO-F3/Dosimeter	500 km × 39000 km, 63°	11/1997–02/2011	10–400
ICO/Dosimeter	1000 km circular, 45°	06/2001–12/2009	10–400
TSX5/CEASE	410 km × 1710 km, 69°	06/2001–07/2006	10–400
POLAR/IPS	5100 km × 51000 km, 86°	02/1996–04/2008	0.1–1.0
POLAR/HISTp	5100 km × 51000 km, 86°	02/1996–04/2008	6.0–15.0
Electrons			(MeV)
CRRES/MEA/HEEF	350 km × 33000 km, 18°	07/1990–10/1991	0.1–7.0
SCATHA/SC3	28000 km × 43000 km, 7.8°	01/1979–05/1991	0.25–4.5
HEO-F1/Dos/Tel	500 km × 39000 km, 63°	05/1994–02/2011*	1.5–10.0
HEO-F3/Dos/Tel	500 km × 39000 km, 63°	11/1997–02/2011	0.5–5.0
ICO/Dosimeter	1000 km circular, 45°	06/2001–12/2009	1.0–7.0
TSX5/CEASE	410 km × 1710 km, 69°	06/2001–07/2006	0.07–3.0
SAMPEX/PET	550 km × 675 km, 82°	08/1992–07/2004	2.0–3.5
POLAR/HISTe	5100 km × 51000 km, 86°	02/1996–04/2008	1.0–6.0
GPS/BDDII ns18	20200 km circular, 55°	01/1990–05/1994	0.25–1.0
GPS/BDDII ns24	20200 km circular, 55°	08/1991–12/2000	0.25–1.0
GPS/BDDII ns28	20200 km circular, 55°	05/1992–09/1996	0.25–1.0
GPS/BDDII ns33	20200 km circular, 55°	04/1996–05/2004	0.25–1.0
LANL-GEO/SOPA 1989-046	36000 km circular, 0°	09/1989–01/2008	0.05–1.5
LANL-GEO/SOPA 1990-095	36000 km circular, 0°	11/1990–11/2005	0.05–1.5
LANL-GEO/SOPA LANL-97A	36000 km circular, 0°	07/1997–01/2008	0.05–1.5
LANL-GEO/SOPA LANL-02A	36000 km circular, 0°	01/2002–01/2008	0.05–1.5
Plasma			(keV)
POLAR/CAMMICE/MICS	5100 km × 51000 km, 86°	03/1997–09/1999	1.2–1.64
POLAR/HYDRA	5100 km × 51000 km, 86°	03/1997–09/1999	1.0–40.0
LANL-GEO/MPA 1990-095	36000 km circular, 0°	11/1990–11/2005	1.0–63.0
LANL-GEO/MPA 1991-080	36000 km circular, 0°	11/1991–11/2004	1.0–63.0
LANL-GEO/MPA 1994-084	36000 km circular, 0°	12/1994–01/2008	1.0–63.0
LANL-GEO/MPA LANL-97A	36000 km circular, 0°	07/1997–01/2008	1.0–63.0

SAA Ascending Descending Nodes Differences

flux > 1 MeV ($cm^{-2}s^{-1}$) at 400 km

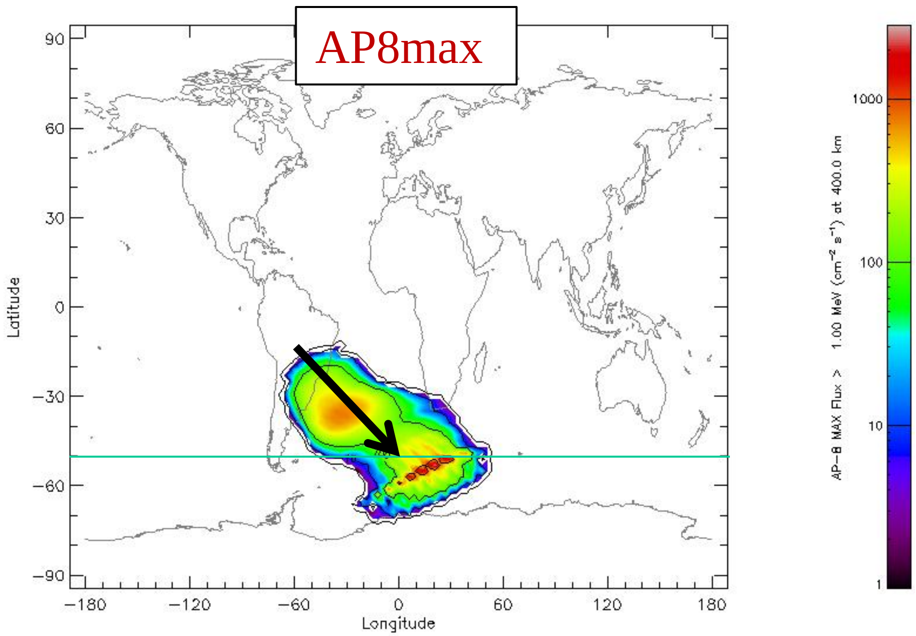


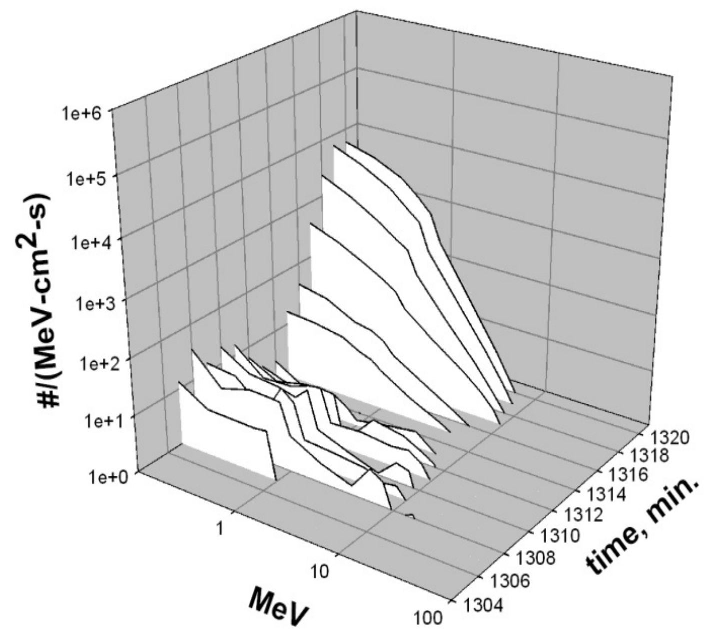


Badavi (2006)

SAA Ascending Descending Nodes Differences

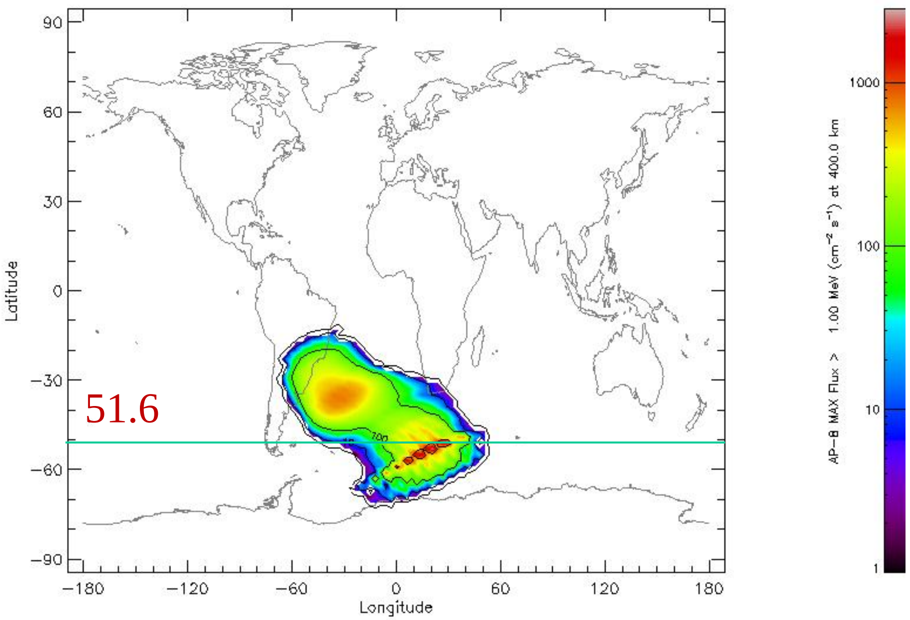
flux > 1 MeV ($cm^{-2}s^{-1}$) at 400 km



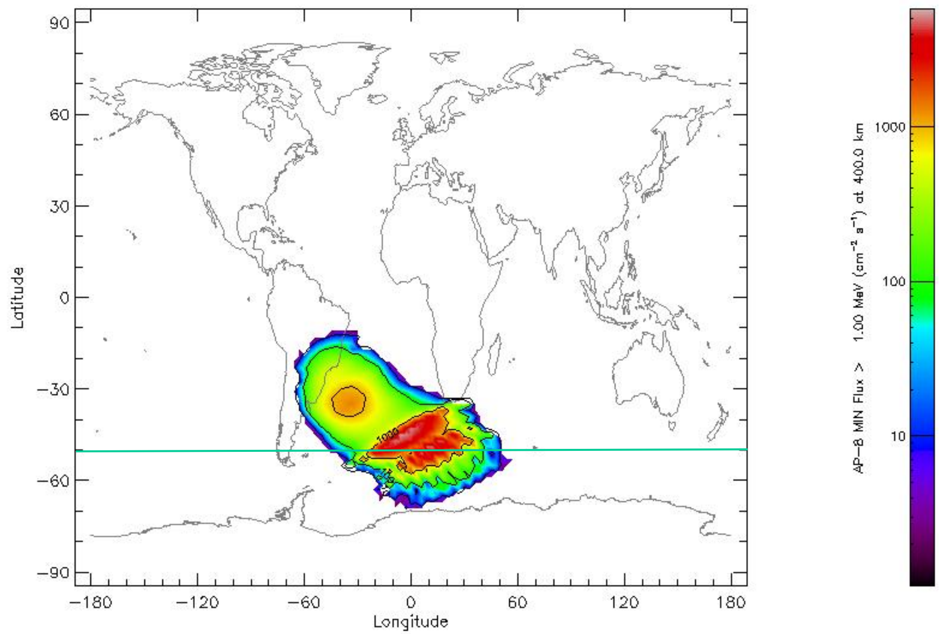


Badavi (2006)

SAA Ascending Descending Nodes Differences



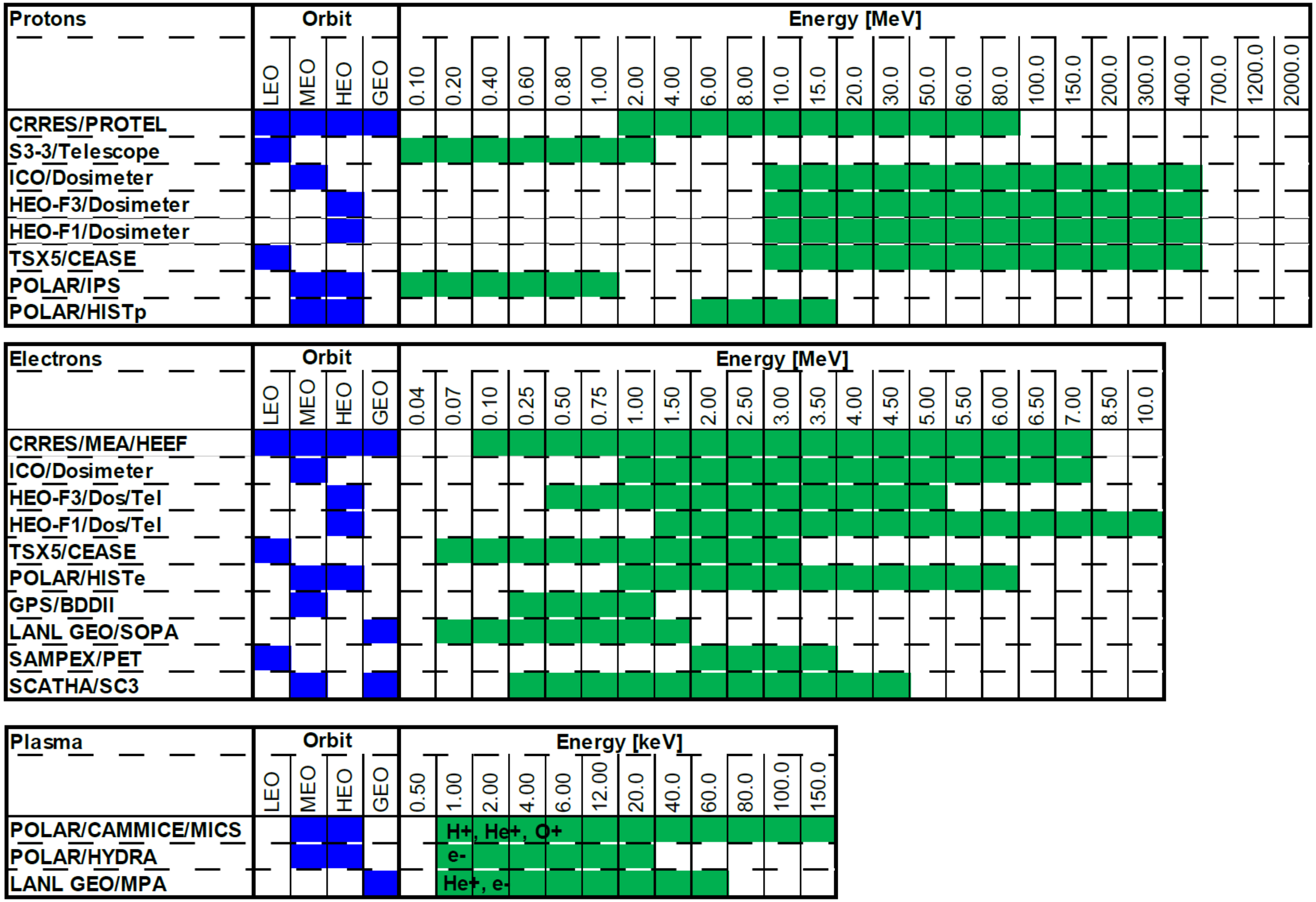
AP8max



AP8min

Badavi (2006)

AP9/AE9 Data Sets – Spectral (Energy) Coverage

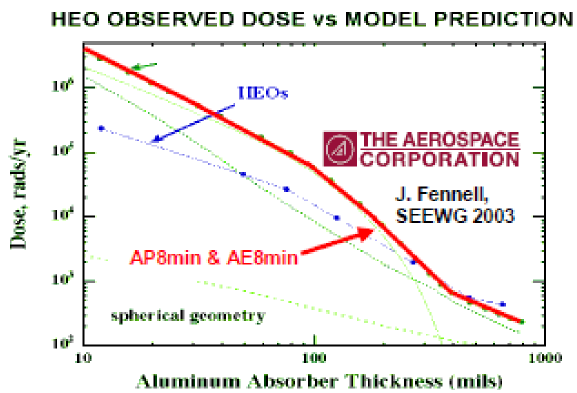


Combined Release and Radiation Effects Satellite (CRRES)
Surface Charging at high altitudes (SCATHA)

Courtesy AP9/AE9 documents

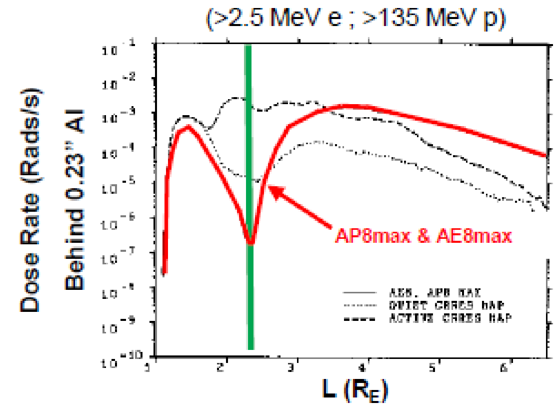
Errors in AP8/AE8

Example: Highly Elliptic Orbit (HEO)



HEO dose measurements show that current radiation models (AE8 & AP8) over estimate the dose for thinner shielding

Example: Medium-Earth Orbit (MEO)

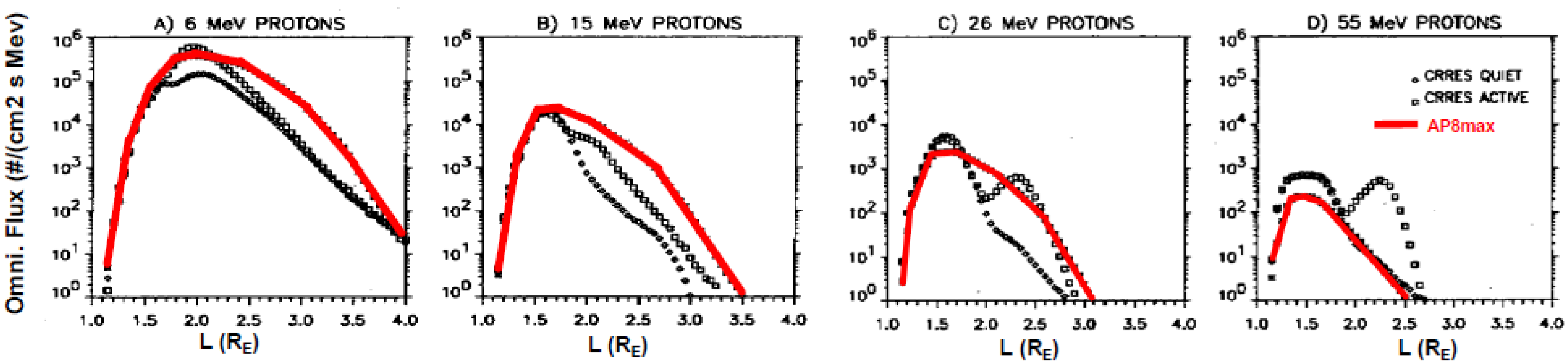


For MEO orbit (L=2.2), #years to reach 100 kRad:

- Quiet conditions (NASA AP8, AE8) : 88 yrs
- Active conditions (CRRES active) : 1.1 yrs

AE8 & AP8 under estimate the dose for 0.23" shielding

Model differences depend on energy:



Courtesy AP9/AE9 documents

ISS-6A Liulin / TEPC Dosimeter Data Format

- Liulin dosimeters at 4 different locations in lab. module. Present data analysis includes all 4 datasets (MDU1 - MDU4).
- Liulin (MDU1- MDU4) data were recorded at 30-s. intervals.
- Data for each of 4 instruments consisted of 166XX records (~140 hrs.) with no gaps.

- TEPC dosimeter at one location in service module.
- TEPC data were recorded at 60-s. intervals.
- Data for TEPC consisted of 8313 records (138.5 hr) with 65 min. of gaps.

- Liulin / TEPC data included orbital parameters as well as dose rates.
- Measurements were for July 7-13, 2001 (near solarmax, GCR ???).

ISS-6A Liulin Dosimeter Data Format

1ch1	1ch2	1ch3		1ch242	1ch243	1ch256	TIME	BMAG	L	LONG180	LAT	ALT	AscDesc	DOSE1	FLUX1
9	9	1	. . .	0	0	0	6-Jul-01	0.37	1.06	95.72	-6.33	380.55	D	1.94568	0.39063
6	7	4	. . .	0	0	0	6-Jul-01	0.37	1.08	96.83	-7.87	380.58	D	0.83999	0.32552
8	12	5	. . .	0	0	0	6-Jul-01	0.38	1.1	97.95	-9.4	380.55	D	1.64568	0.48177
8	12	7	. . .	0	0	0	6-Jul-01	0.39	1.13	99.08	-10.92	380.59	D	1.24283	0.44271
:	:	:	. . .	:	:	:	:	:	:	:	:	:	:	:	:
:	:	:		:	:	:	:	:	:	:	:	:	:	:	:
8	14	7	. . .	0	0	0	13-Jul-01	0.24	1.24	-85.22	-30.9	383.32	A	1.57711	0.48177
12	21	3	. . .	0	0	0	13-Jul-01	0.23	1.22	-83.73	-29.53	383.08	A	1.73997	0.48177
5	12	3	. . .	0	0	0	13-Jul-01	0.23	1.2	-82.27	-28.15	382.76	A	2.02282	0.45573
6	9	6	. . .	0	0	0	13-Jul-01	0.22	1.19	-80.86	-26.74	382.51	A	1.68854	0.58594

$$Dose = 0.008571\sum_{1}^{N}(n+1)C_n$$

$$Flux = 0.01302\sum_{1}^{N}C_n$$

MDU1: 16633 records t_0=-1.5 min.
MDU2: 16686 records t_0=-12.0 min.
MDU3: 16625 records t_0=-0.5 min.
MDU4: 16631 records t_0=-1.5 min.

Time sync: point @ <u>10.92S, 99.08E</u>, correspond to <u>6 Jul 01 10:26:00</u> Z (GMT)

Description of Liulin Locations

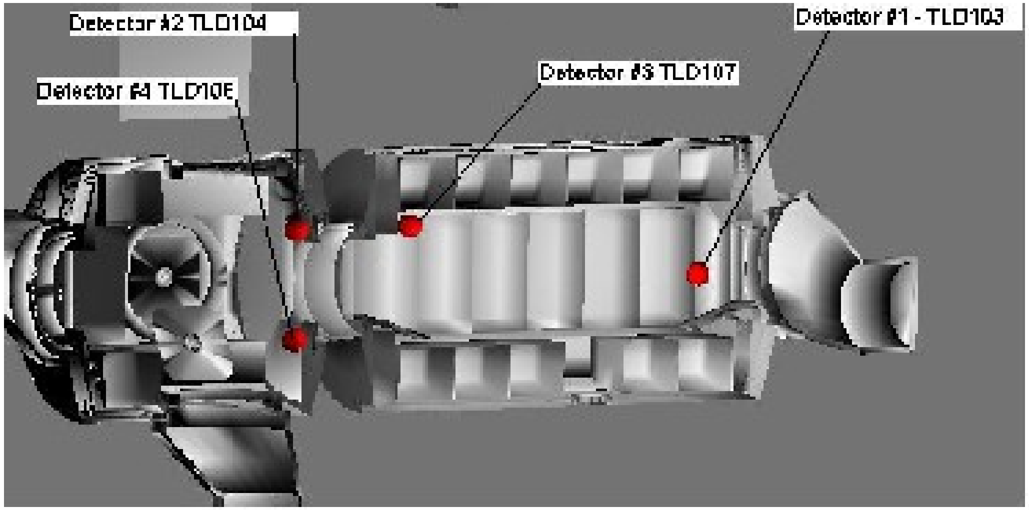
	MDU#1	MDU#2	MDU#3	MDU#4
11-30/5/2001 mix	Dloc 102	Dloc 113	Dloc 114	Dloc 107
31/5/2001-6/6/2001 mix	Dloc 105	Dloc 106	Dloc 109	Dloc 110
7-14/6/2001 XPOP	Dloc 103	Dloc 104	Dloc 108	Dloc 109
15-25/6/2001 mix	Dloc 105	Dloc 106	Dloc 110	Dloc 111
26/6/2001-5/7/2001 +XVV	Dloc 112	Dloc 113	Dloc 114	Dloc 102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

X-Axis Perpendicular to Orbit Plane (*XPOP*)

X-Axis along Velocity Vector (*XVV*)

ISS 6A-Configuration with Liulin Dosimeters

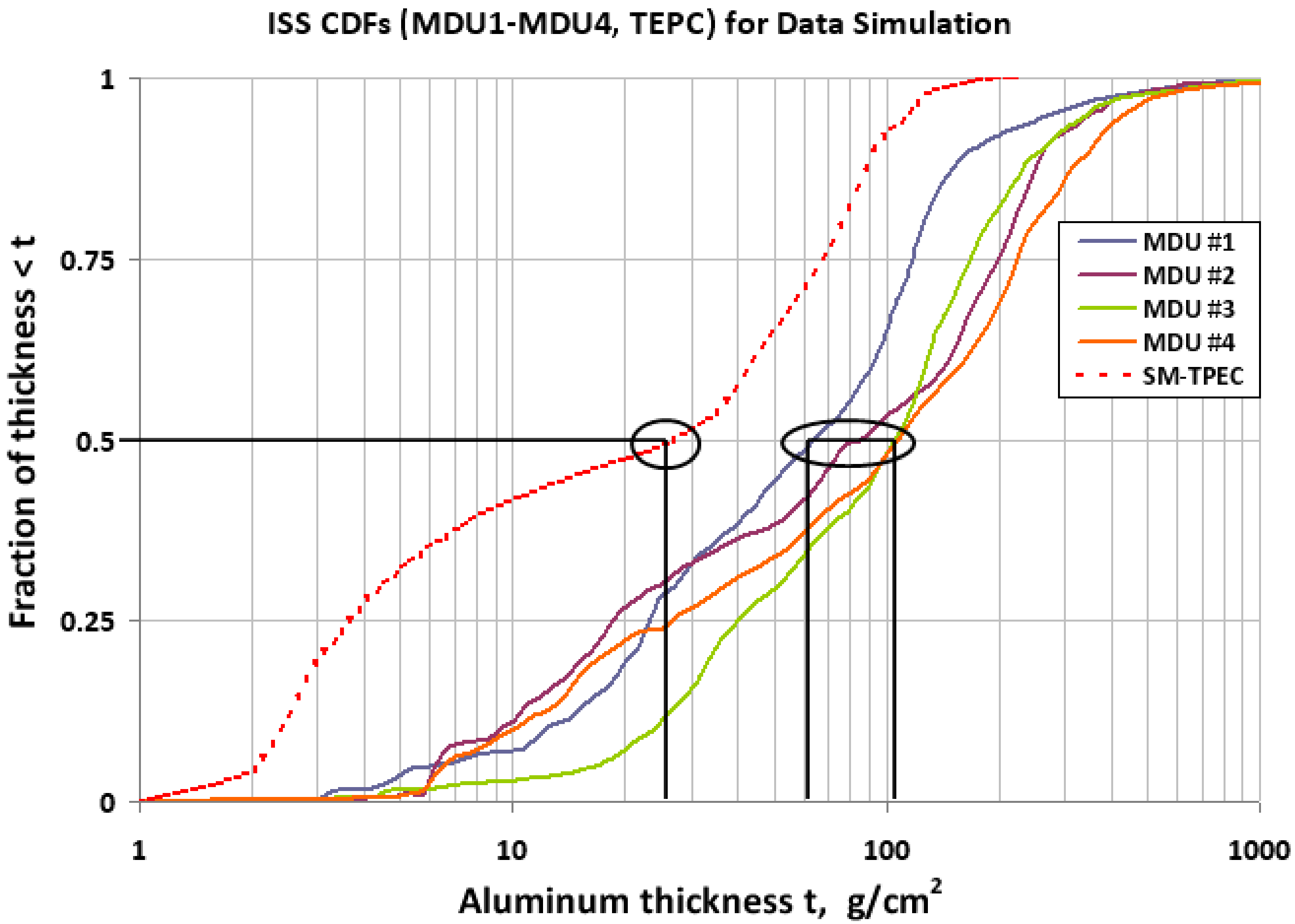
(6-13 July 2001)



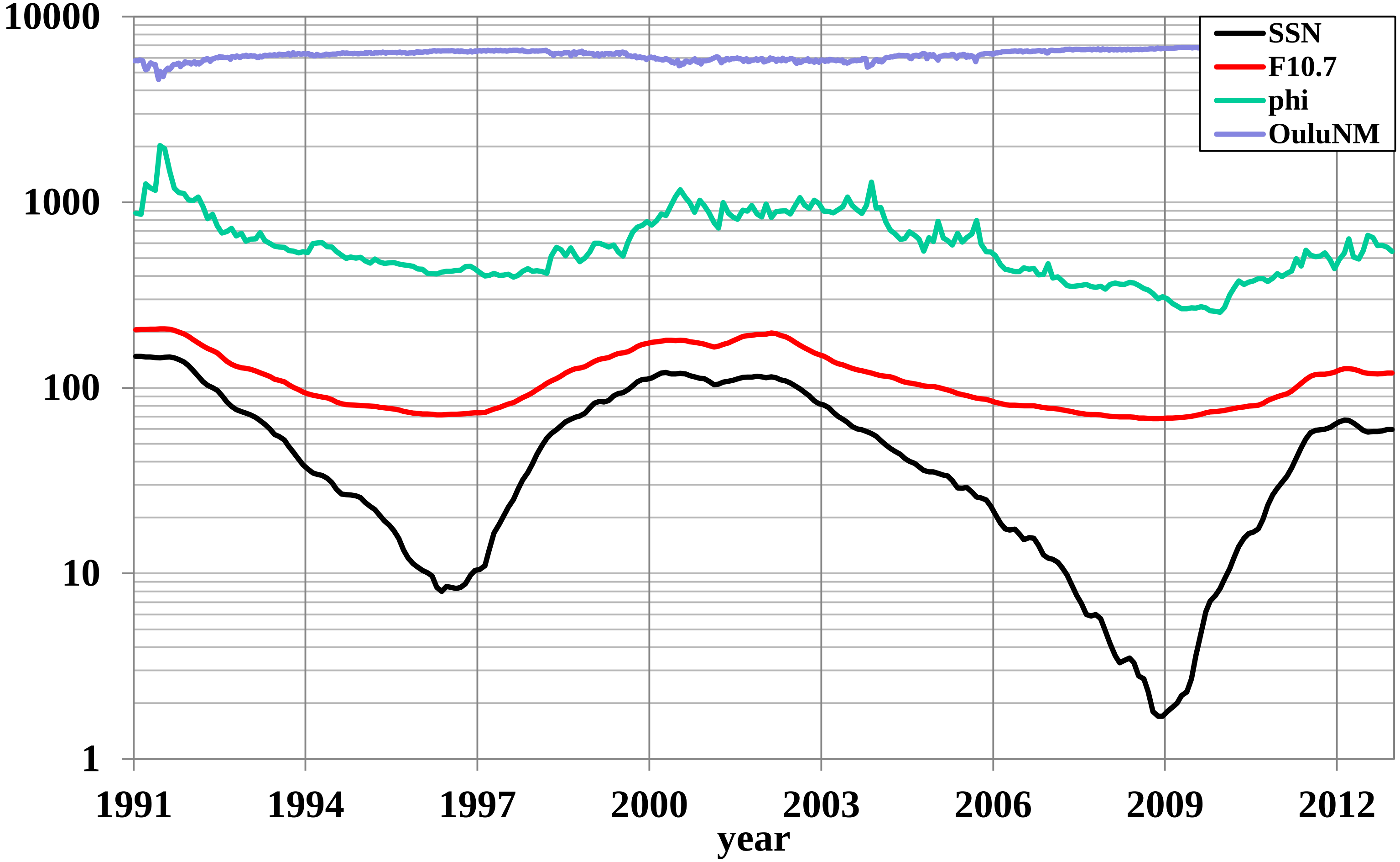
IV

CDF for MDU1 - MDU4 and TEPC

(6-13 July 2001)

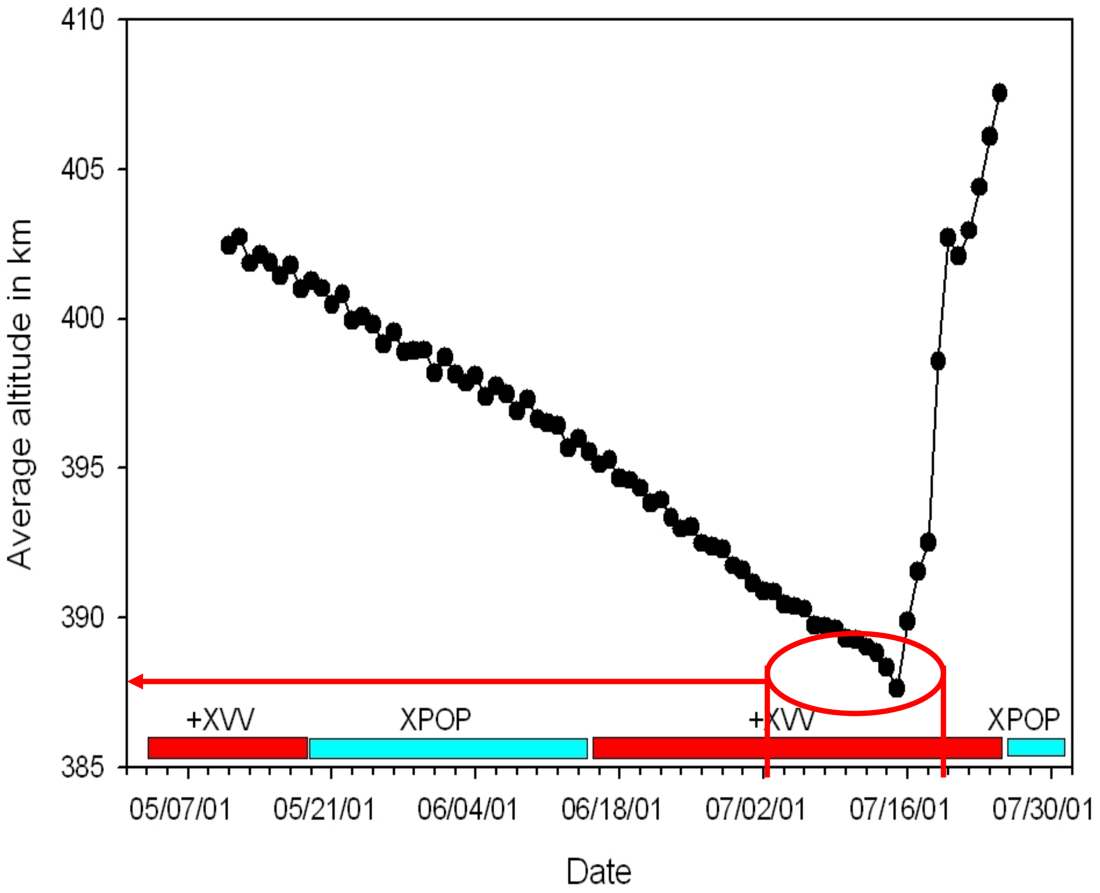


Solar Indices



III

ISS-6A Flight Trajectory Data (six DOF)

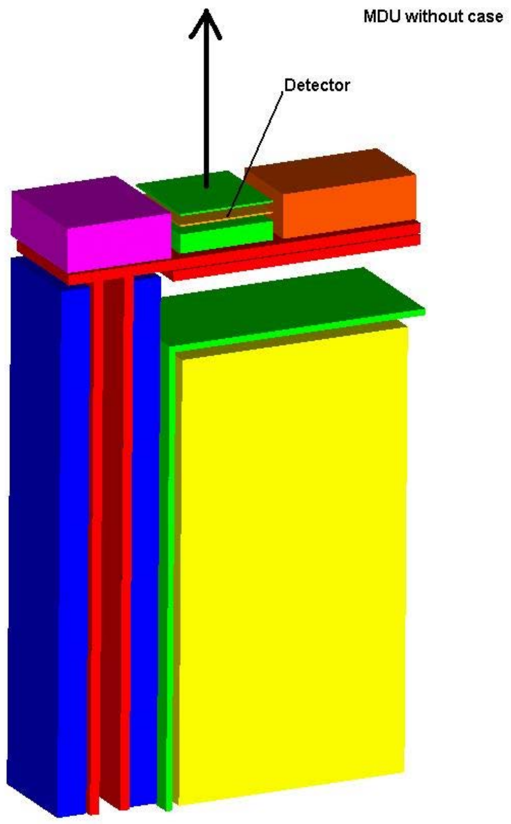


Ref. Borislav T. Tomov (STIL)

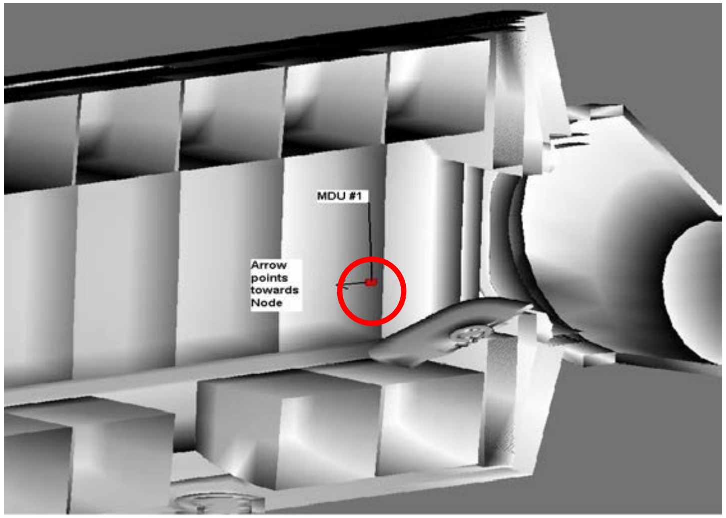
II

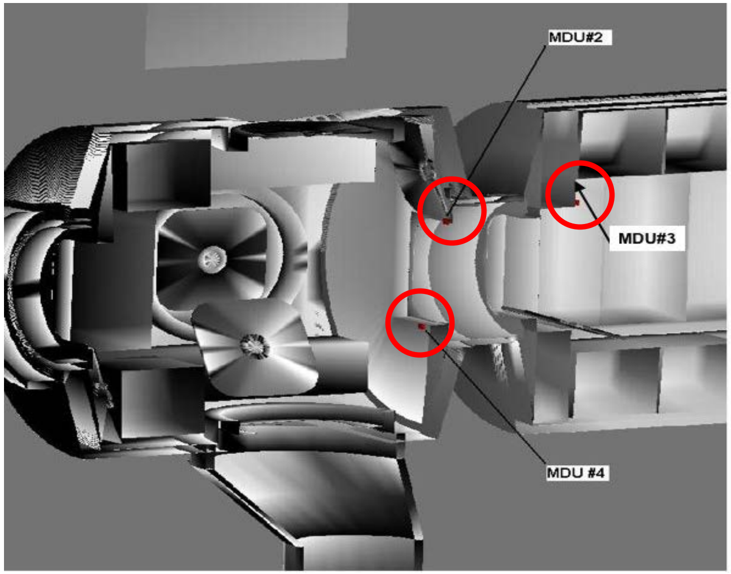
ISS 6A Liulin MDU1-MDU4 Location/Orientation

(6-13 July 2001)



Liulin detector CAD model
(MDU1 – MDU4)



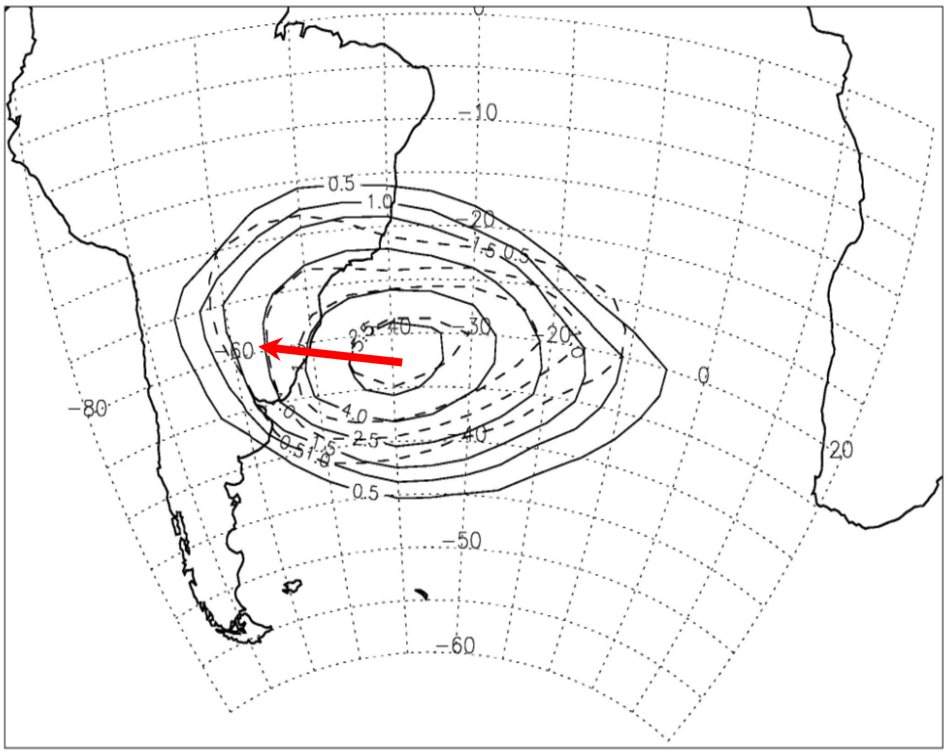


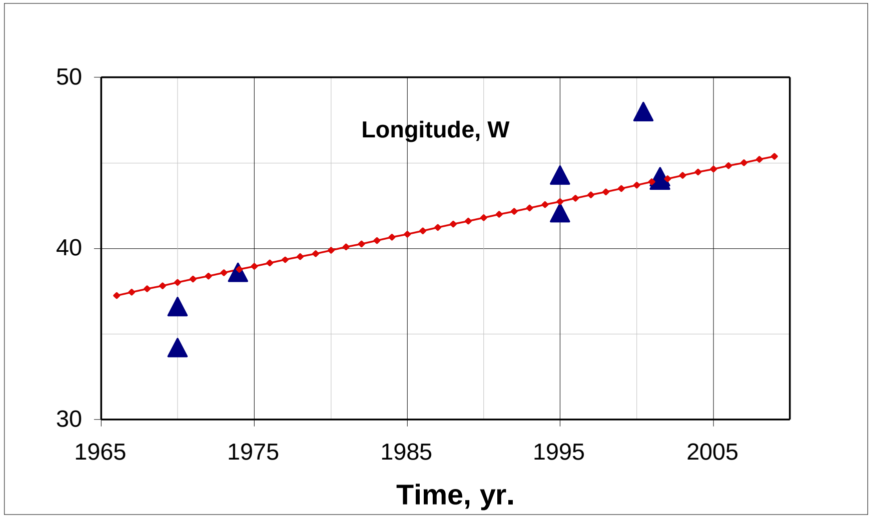
III

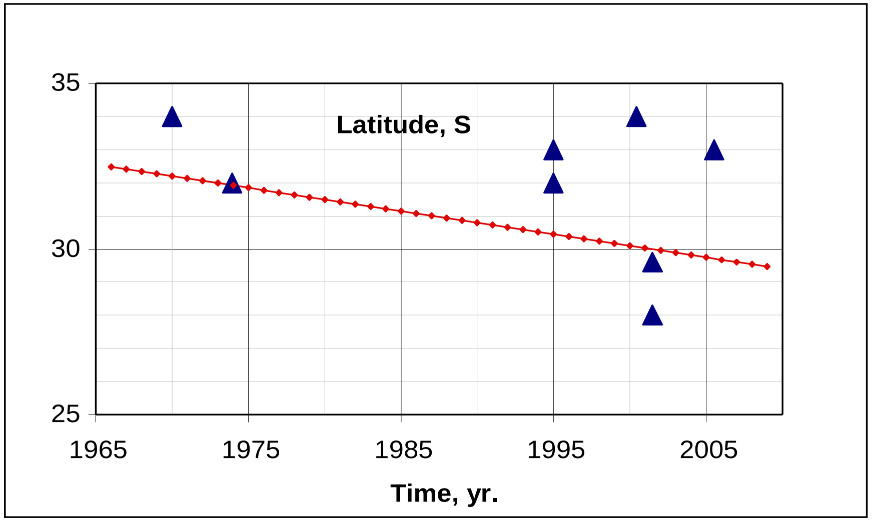
Basic Proton Field Distributions

(with drifting latitude and longitude)

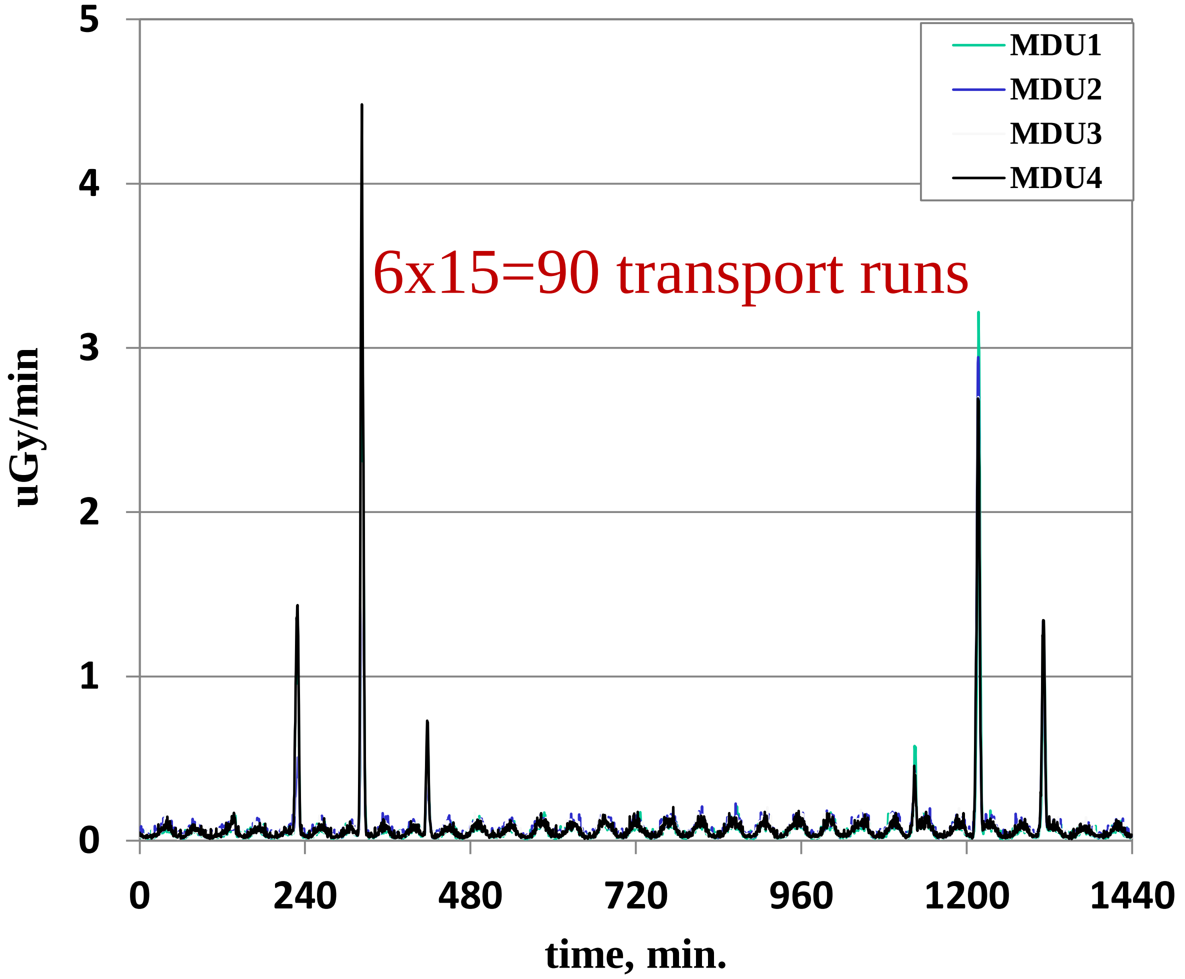
Solid: AP8MIN 1965 map
Dashed: AP8MAX 1970 map







Liulin 1-4 Data Sets (07/07/2001)



Liulin data courtesy of T. Dachev