Review of Analyses of XMM Radiation Problem

E. Daly on behalf of :

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and others

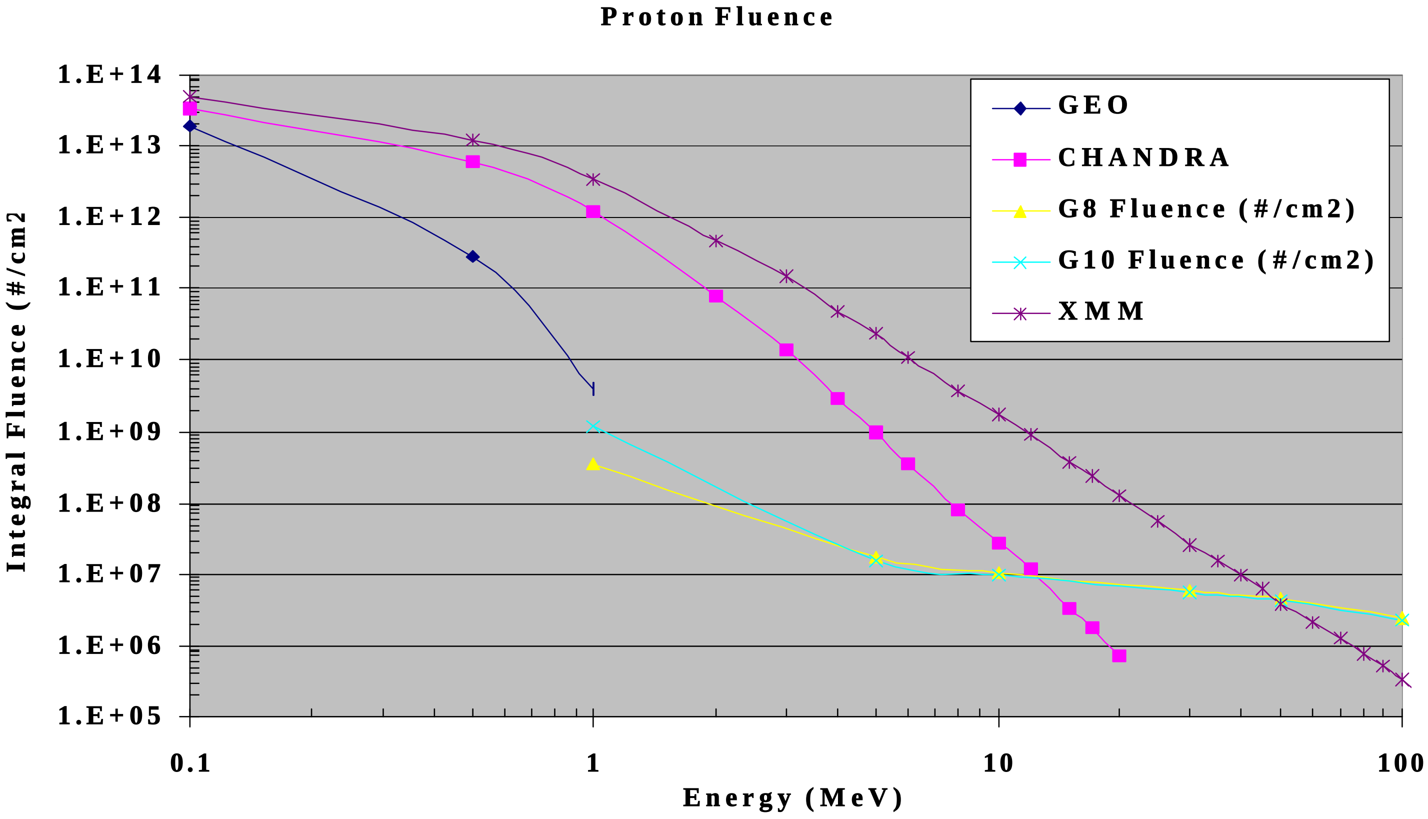
Outline

- Low energy proton problem
- modelling in ESTEC (TRIM, Geant4,…)
- validation attempts
- environment assessment (then)
- environment (recent)

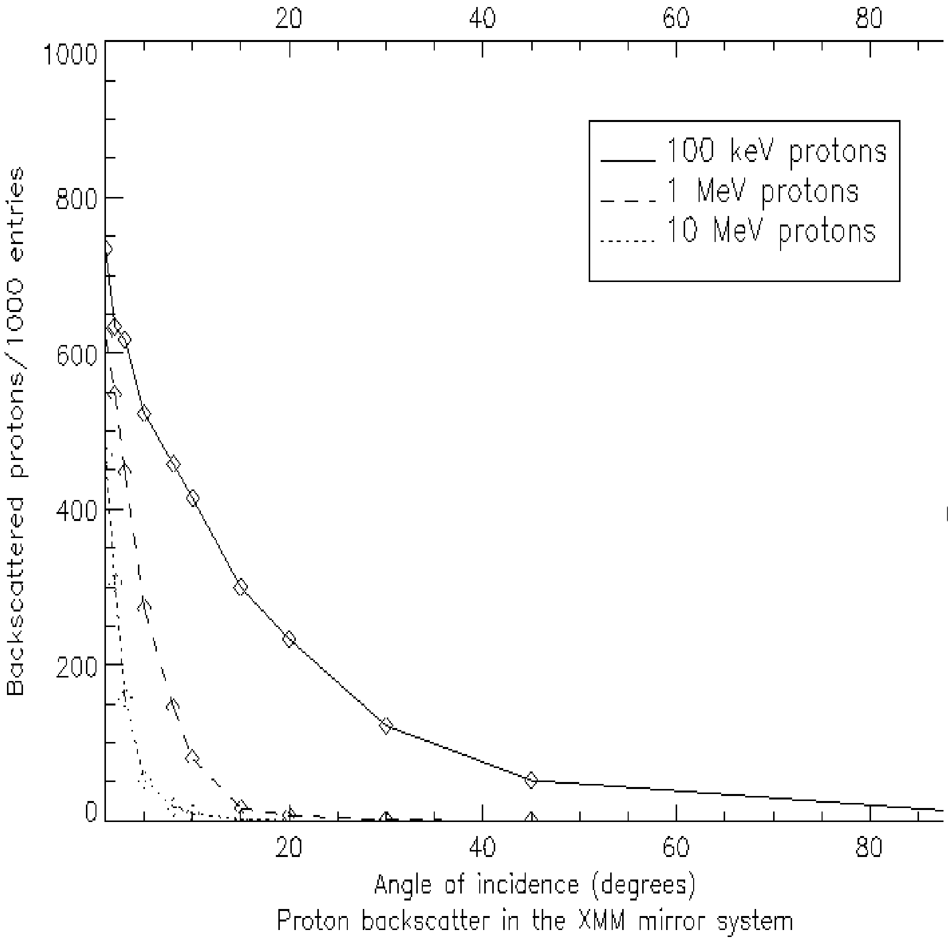
XMM had a potentially more severe environment than Chandra (Rad Belts)

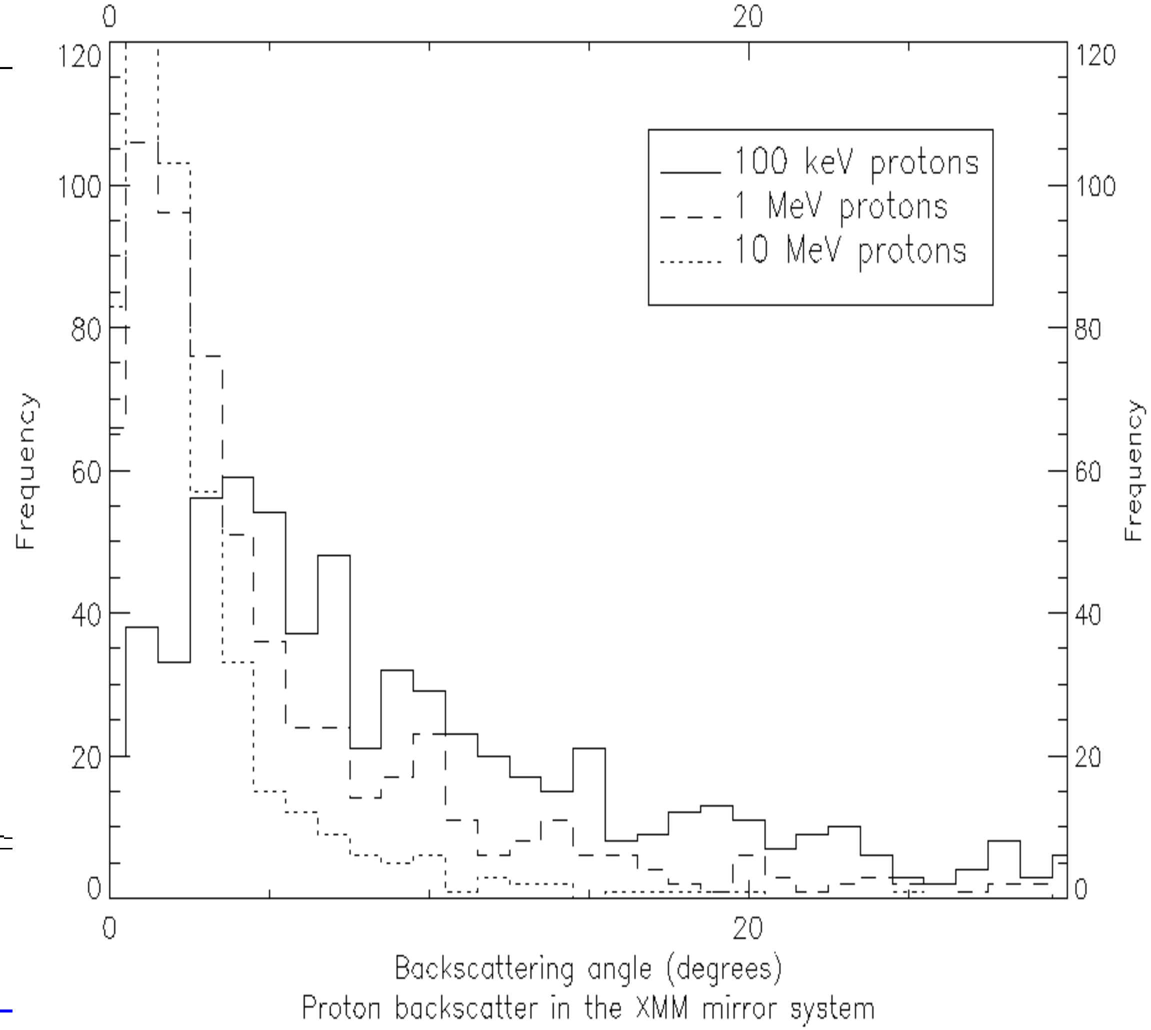
Orbit parameters	Chandra	XMM
Apogee	140000km	114000km
Perigee	10000km	7000km
Inclination	28º	39º
Argument of Perigee	270º	57º

60-day fluence (AP8)
- large numbers at low E, high dE_{NIEL}/dx, if unshielded

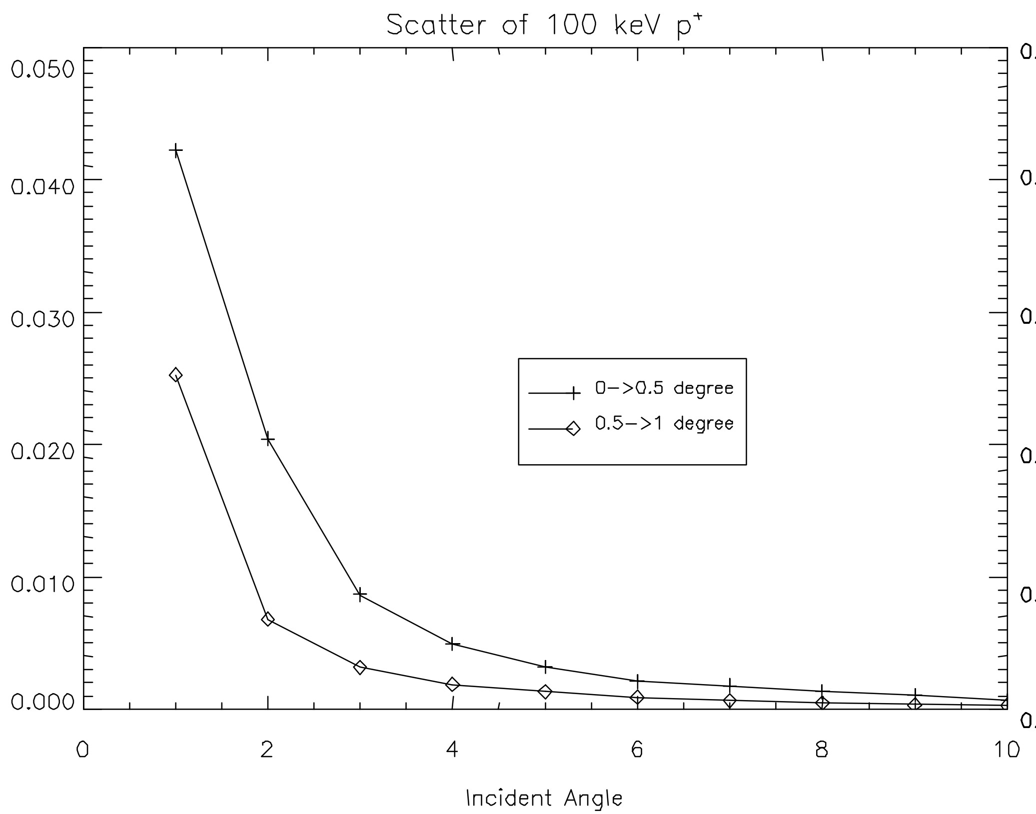


TRIM demonstrated that low-angle scattering was very efficient

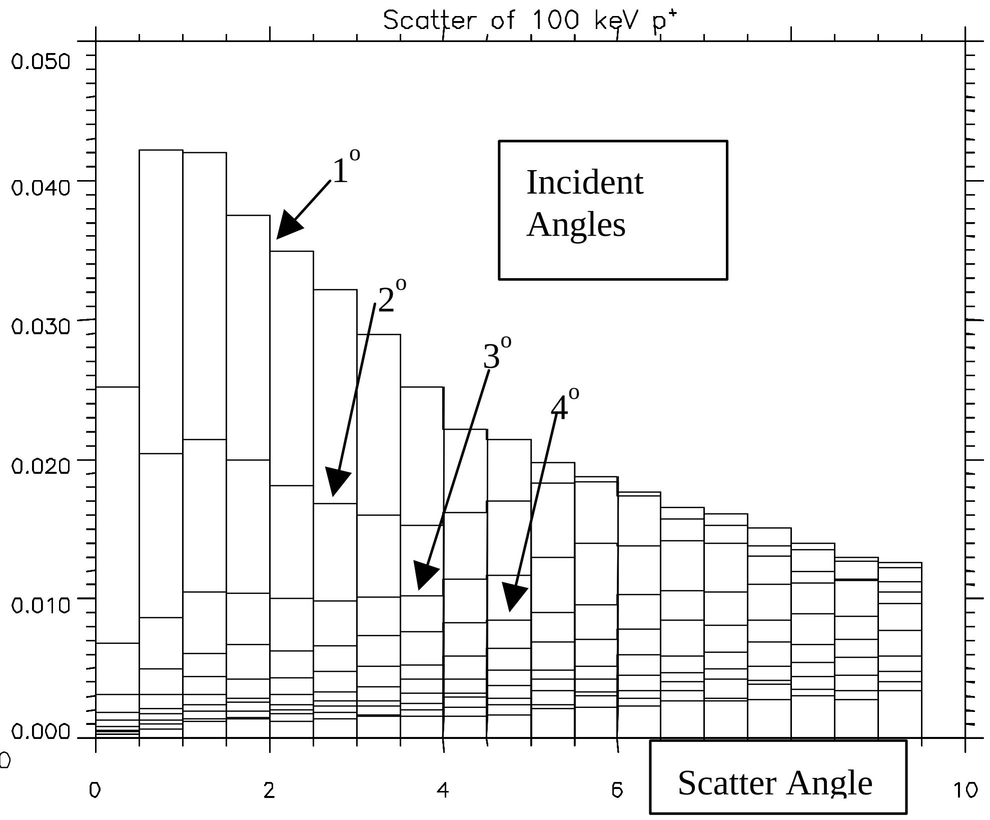




Fraction of particles in each 0.5º scattered angle bin [0,0.5], [0.5,1] as a function of incident angle.



Fraction of particles scattering into each scattered angle bin for various incident angles.



Assuming these protons illuminate an area of the focal plane given by ΩL^2 where Ω is the acceptance solid angle and L the focal length, the fluence of particles of energies between E and dE is:

$$Q(E)^2 \, f(E)dE \; S \, \{\Omega/4\pi\} \, / \, \Omega L^2 = Q(E)^2 \, f(E)dE \; S \, /4\pi L^2$$

Where Q(E) is the scattering from a single encounter with a shell (either a single scatter of a "condensed" multiple scatter) and is a strong function of energy, S is the telescope acceptance area and *f* is the omnidirectional flux of particles, differential in energy.

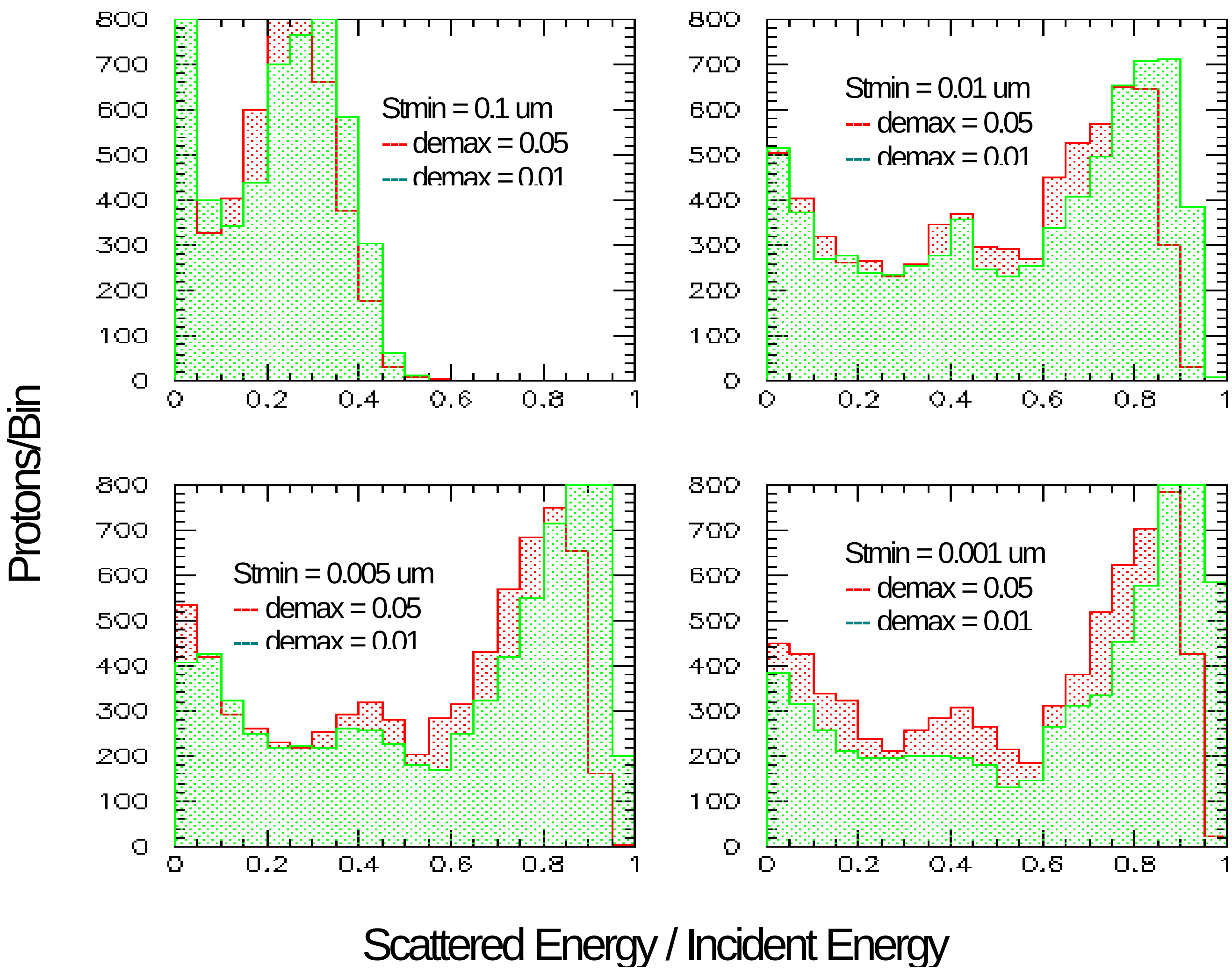
fluence values in Table 1 as being lower bounds. If Q is as high as 0.3, the 10MeV equivalent fluence from 100keV protons will be of the order of 10^{10} cm^{-2} in 60 days at the CCDs.

Acceptance Area S (cm^{2})	Acceptance Angle (Sr)	L (cm)	E (MeV)	Fluence interval (f(E)DE) (cm^{-2})	Q	Fluence (cm^{-2})	10MeV Equivalent Fluence (cm^{-2})
Chandra							
1145	10^{-4}	10^{3}	0.1	$>10^{13}$	0.065	~ 1.3 10^{6}	~1.3 10^{8}
			1	$>10^{12}$	0.065	~4.8 10^{5}	~4.8 10^{6}
XMM							
1700/mirror	6.5 10^{-5}	7 10^{2}	0.1	>2 10^{13}	0.065	~3.5 10^{6}	~3.5 10^{8}
			1	>2 10^{12}	0.065	~1.1 10^{6}	~1.1 10^{7}

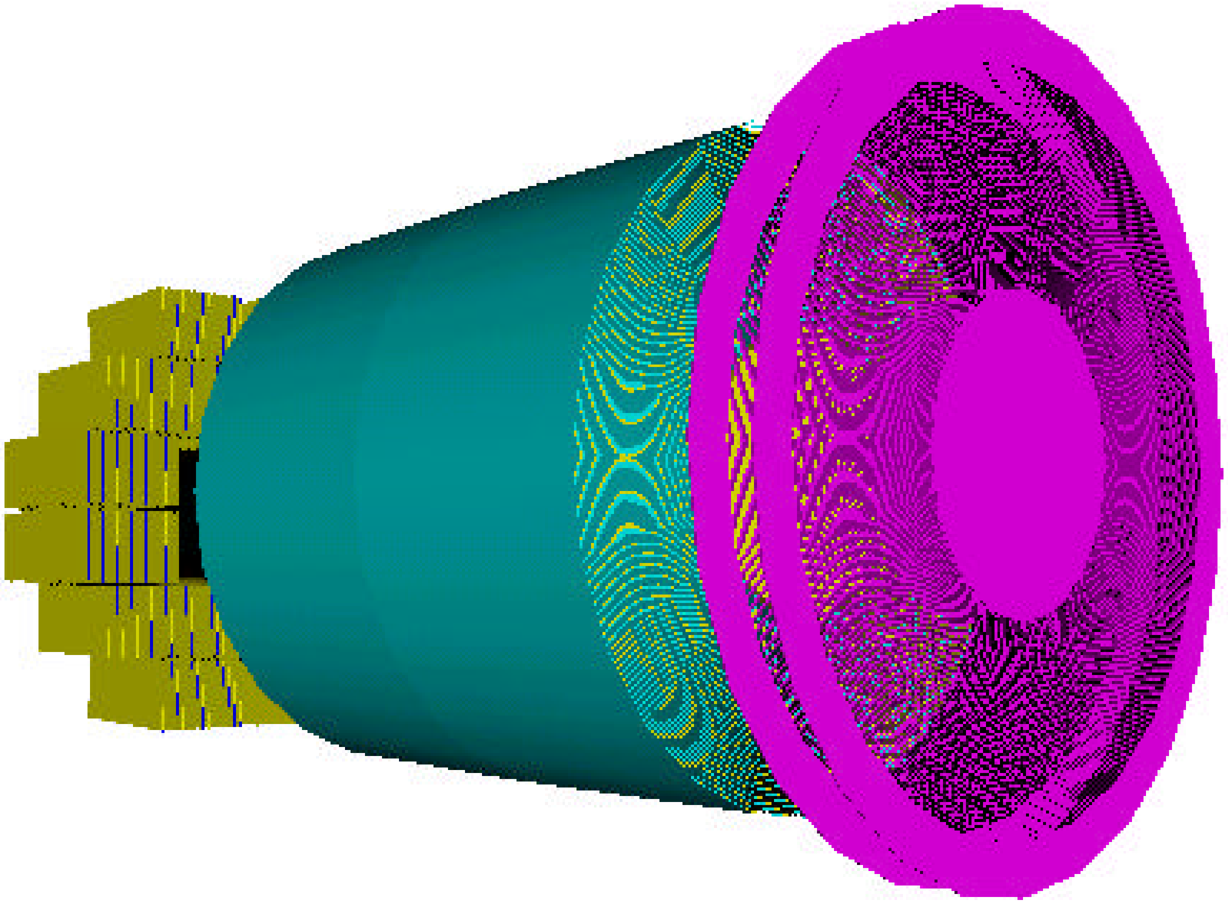
Table 1. Telescope parameters and orbit fluences for Chandra and XMM.

Geant4 simulations

- Geant4 is the next generation of general-purpose Monte-Carlo codes, successor to Geant 3.21
- uses object oriented methodologies and coded in C++ to allow quality control, distributed (modular) development and rapid (modular) updating
- ESA is a formal member of the Geant4 collaboration, initiated by CERN
- complete geometrical capabilities
- complete physics capabilities: only question-mark was small angle scattering - extensive tests and comparison to TRIM



Full 3D simulations



- The number of counts registered at each of the detector volumes is converted to an efficiency measurement ***h*** defined by

$$h = \Omega / 4p \; (A_{source} / A_{\mathrm{detector}})(N_{\mathrm{detected}} / N_{\mathrm{incident}})$$

  - where Ω is the solid angle that corresponds to the selected source half-angle θ and
  - is given by 2π(1 - cosθ)
  - A_{source} is the area over which the isotropic particle distribution is generated
  - $A_{detector}$ is the area of the detector volume on which particles are recorded
  - $N_{incident}$ is the total number of particles generated over A_{source}
  - $N_{detected}$ is the number of particles recorded at a detector location within $A_{detector}$

- **The <u>efficiency</u> is the number that the omnidirectional incident flux must be multiplied by to derive the flux at the "target".**
- In the XMM simulations the areas involved in the efficiency calculations are:
  - A_{source} = 3455.75cm^2
  - $A_{mirror\_detector}$ = 3739.28cm^2
  - $A_{RGS\_detector}$ = 126.88cm^2♣
    - » The size of the RGS collecting area was doubled to ensure detection of particles arriving outside the detector nominal position due to the approximation made by neglecting the "saw-tooth" surface.
  - $A_{EPIC\_detector}$ = 33.18cm^2

θ (°)	N_{inc}	Mirror (scattered) N_{det}	η	±	Mirror (direct) N_{det}	η	±	RGS N_{det}	η	±	EPIC N_{det}	η	±
100keV protons													
0.5	5.0E+06	79272	2.8E-07	9.9E-10	508	1.8E-09	7.9E-11	69	7.2E-09	8.6E-10	410	1.6E-07	8.0E-09
1	5.0E+06	64636	9.1E-07	3.6E-09	3724	5.2E-08	8.6E-10	48	2.0E-08	2.9E-09	381	6.0E-07	3.1E-08
2	5.0E+06	38477	2.2E-06	1.1E-08	4699	2.6E-07	3.9E-09	34	5.6E-08	9.7E-09	200	1.3E-06	9.0E-08
4	8.0E+06	31682	4.5E-06	2.5E-08	2206	3.1E-07	6.6E-09	34	1.4E-07	2.4E-08	126	2.0E-06	1.8E-07
10	1.2E+07	14875	8.7E-06	7.1E-08	547	3.2E-07	1.4E-08	15	2.6E-07	6.7E-08	40	2.6E-06	4.2E-07
300keV protons													
0.5	5.0E+06	163257	5.7E-07	1.4E-09	528	1.9E-09	8.1E-11	181	1.9E-08	1.4E-09	1232	4.9E-07	1.4E-08
1	5.0E+06	121473	1.7E-06	4.9E-09	3724	5.2E-08	8.6E-10	150	6.2E-08	5.1E-09	1087	1.7E-06	5.2E-08
2	5.0E+06	71857	4.0E-06	1.5E-08	4733	2.7E-07	3.9E-09	101	1.7E-07	1.7E-08	572	3.6E-06	1.5E-07
4	8.0E+06	61104	8.6E-06	3.5E-08	2217	3.1E-07	6.6E-09	77	3.2E-07	3.6E-08	344	5.5E-06	2.9E-07
10	1.2E+07	25394	1.5E-05	9.3E-08	564	3.3E-07	1.4E-08	36	6.2E-07	1.0E-07	83	5.5E-06	6.0E-07
600keV protons													
0.5	5.0E+06	202896	7.1E-07	1.6E-09	508	1.8E-09	7.9E-11	272	2.8E-08	1.7E-09	1878	7.4E-07	1.7E-08
1	5.0E+06	145581	2.0E-06	5.4E-09	3607	5.1E-08	8.5E-10	220	9.1E-08	6.2E-09	1446	2.3E-06	6.0E-08
2	5.0E+06	86738	4.9E-06	1.7E-08	4673	2.6E-07	3.8E-09	134	2.2E-07	1.9E-08	688	4.4E-06	1.7E-07
4	8.0E+06	68360	9.6E-06	3.7E-08	2179	3.1E-07	6.6E-09	80	3.3E-07	3.7E-08	376	6.0E-06	3.1E-07
10	1.2E+07	29300	1.7E-05	1.0E-07	504	2.9E-07	1.3E-08	36	6.2E-07	1.0E-07	101	6.7E-06	6.6E-07
30	4.0E+07	13746	2.1E-05	1.8E-07	208	3.2E-07	2.2E-08	15	6.8E-07	1.8E-07	37	6.5E-06	1.1E-06
1MeV protons													
0.5	5.0E+06	209847	7.4E-07	1.6E-09	547	1.9E-09	8.2E-11	286	3.0E-08	1.8E-09	1744	6.9E-07	1.7E-08
1	5.0E+06	153276	2.2E-06	5.5E-09	3725	5.2E-08	8.6E-10	256	1.1E-07	6.6E-09	1391	2.2E-06	5.9E-08
2	5.0E+06	90840	5.1E-06	1.7E-08	4677	2.6E-07	3.9E-09	142	2.4E-07	2.0E-08	708	4.5E-06	1.7E-07
4	8.0E+06	73559	1.0E-05	3.8E-08	2169	3.1E-07	6.6E-09	112	4.6E-07	4.4E-08	431	6.8E-06	3.3E-07
10	1.0E+07	28172	2.0E-05	1.2E-07	419	2.9E-07	1.4E-08	26	5.4E-07	1.1E-07	88	7.0E-06	7.4E-07
30	4.0E+07	15490	2.4E-05	1.9E-07	214	3.3E-07	2.3E-08	10	4.6E-07	1.4E-07	61	1.1E-05	1.4E-06
1.5MeV protons													
0.5	5.0E+06	212232	7.5E-07	1.6E-09	542	1.9E-09	8.2E-11	372	3.9E-08	2.0E-09	1836	7.3E-07	1.7E-08
1	5.0E+06	154651	2.2E-06	5.5E-09	3677	5.2E-08	8.5E-10	292	1.2E-07	7.1E-09	1464	2.3E-06	6.1E-08
2	5.0E+06	92165	5.2E-06	1.7E-08	4669	2.6E-07	3.8E-09	170	2.8E-07	2.2E-08	718	4.6E-06	1.7E-07
4	8.0E+06	76141	1.1E-05	3.9E-08	2153	3.0E-07	6.5E-09	133	5.5E-07	4.8E-08	384	6.1E-06	3.1E-07
10	1.0E+07	35312	2.5E-05	1.3E-07	585	4.1E-07	1.7E-08	38	7.9E-07	1.3E-07	127	1.0E-05	8.9E-07

Table 1. XMM simulation runs for protons in the energy range 0.1 to 1.5MeV for source half-angles θ and N_{inc} number of incident particles. The number of protons recorded at each of the dummy detector volumes N_{det} is used to calculate the efficiency η, its error is estimated assuming Poisson statistics apply.

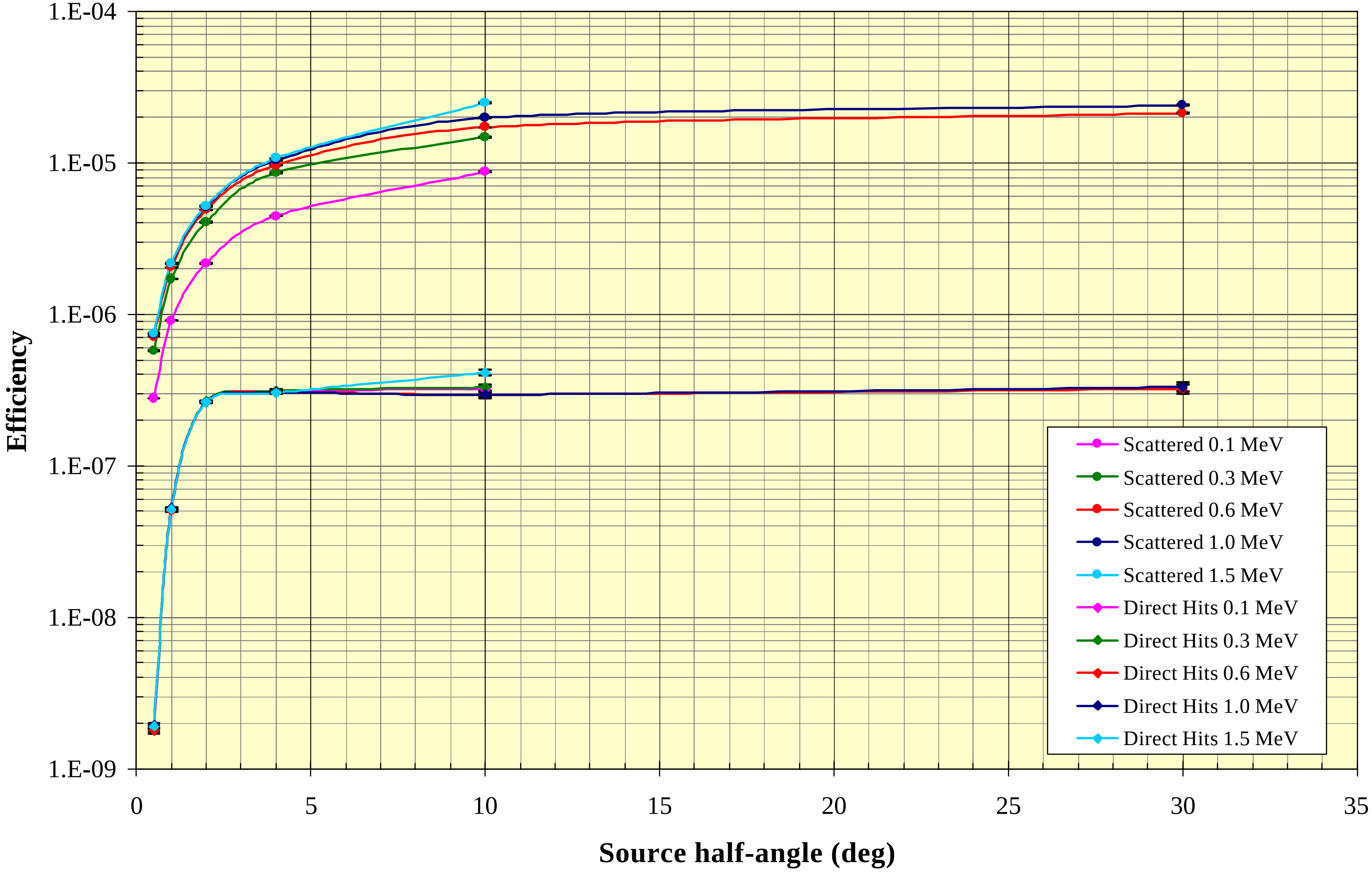


Figure 1. Efficiency of the mirrors is plotted against source half-angle for proton energies in the range 0.1 to 1.5MeV. Scattered protons and direct, unhindered protons are shown.

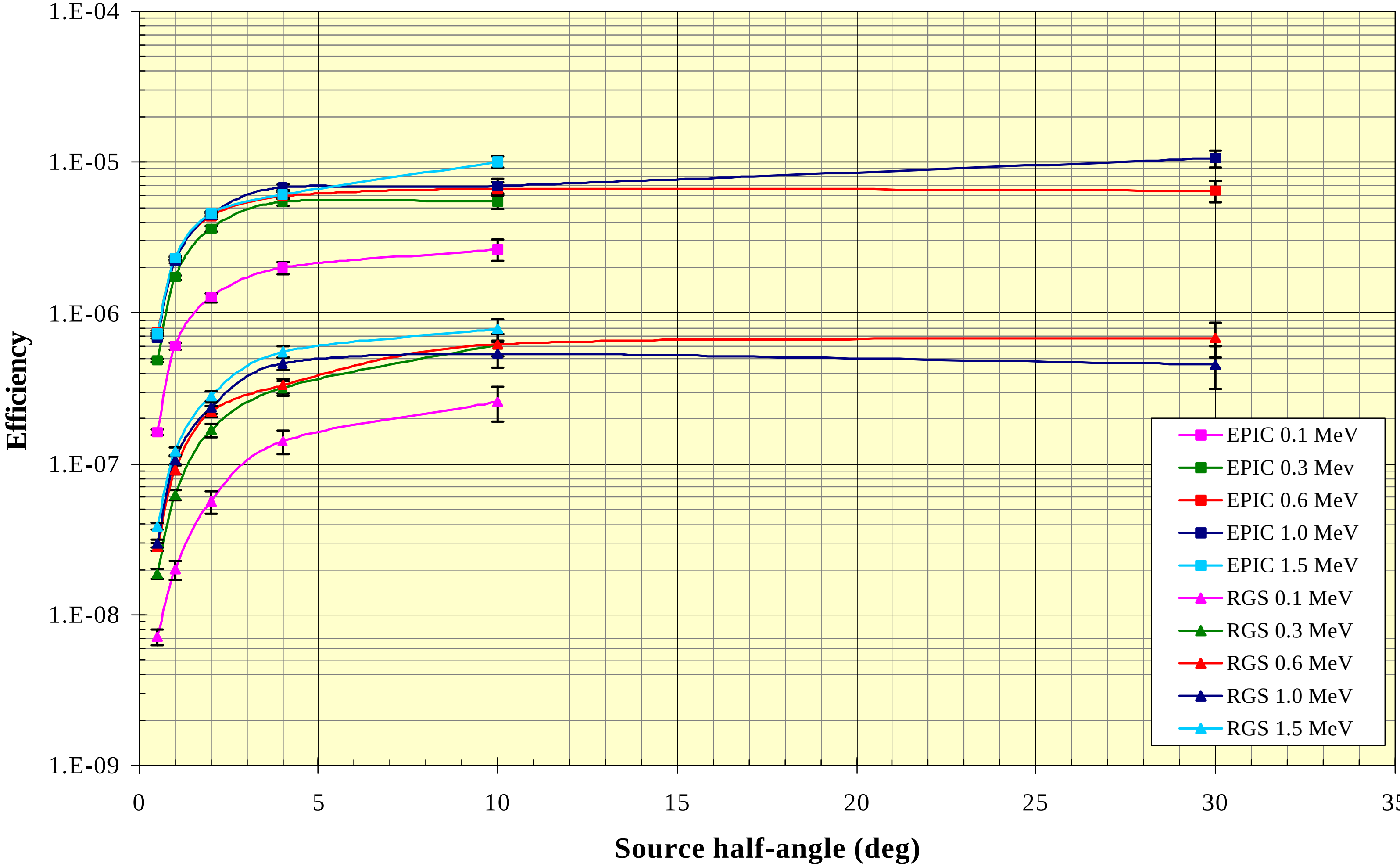


Figure 1. Efficiency of the EPIC and RGS detectors is plotted against source half-angle for proton energies in the range 0.1 to 1.5MeV.

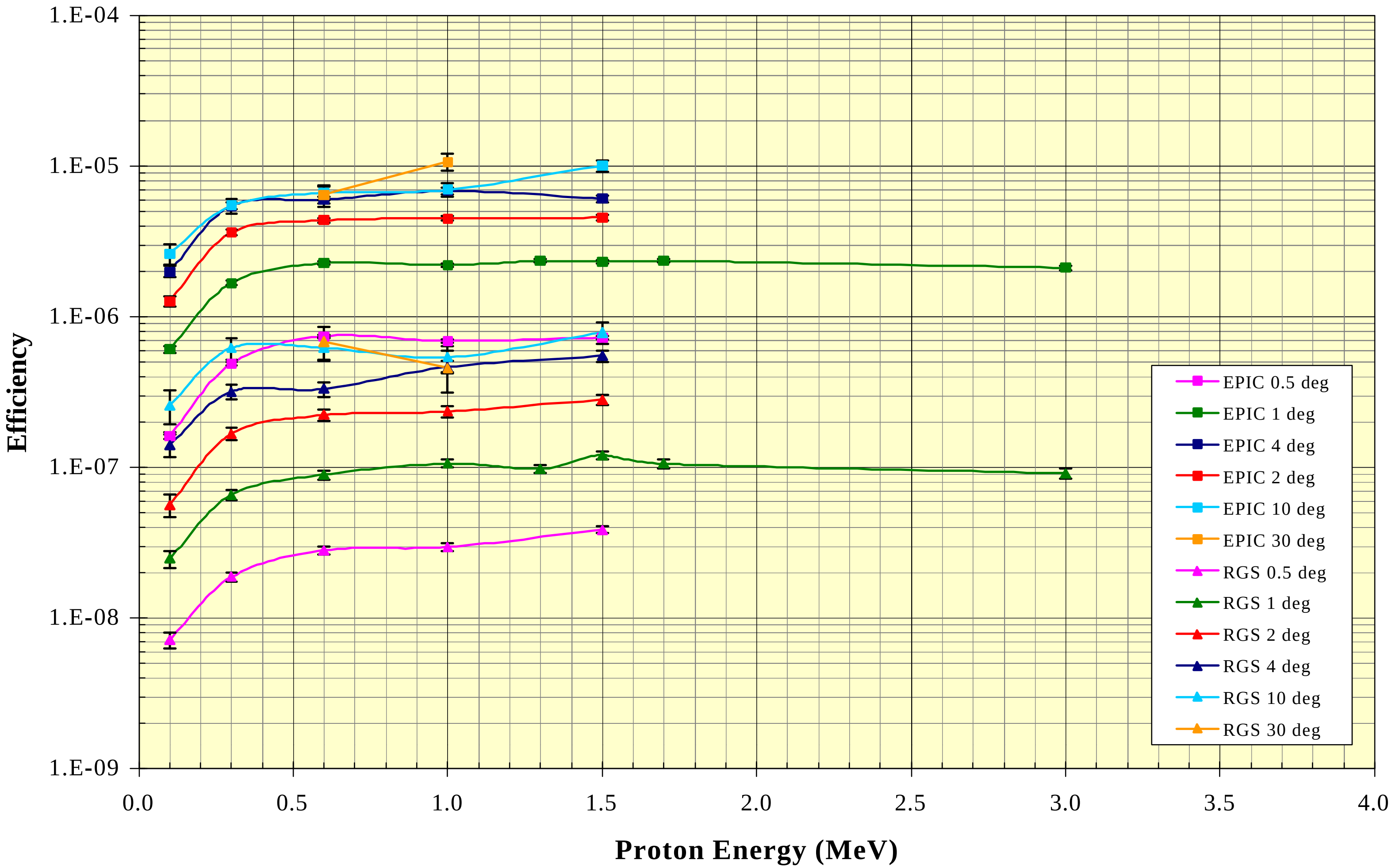
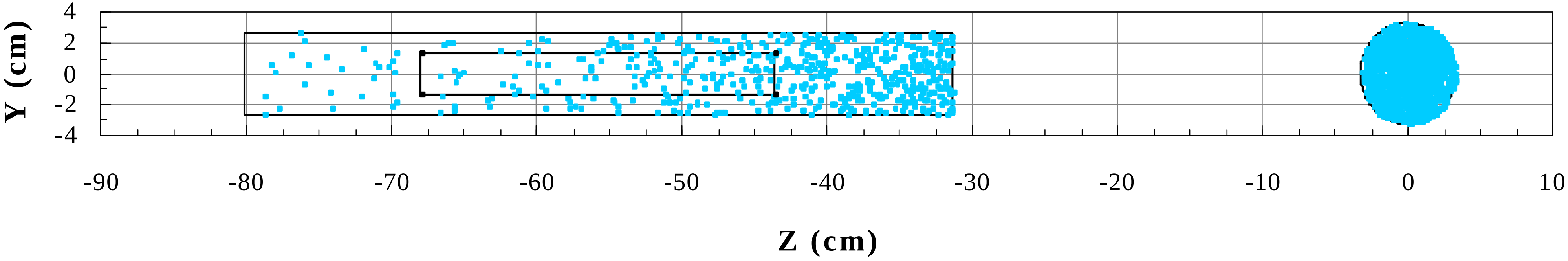
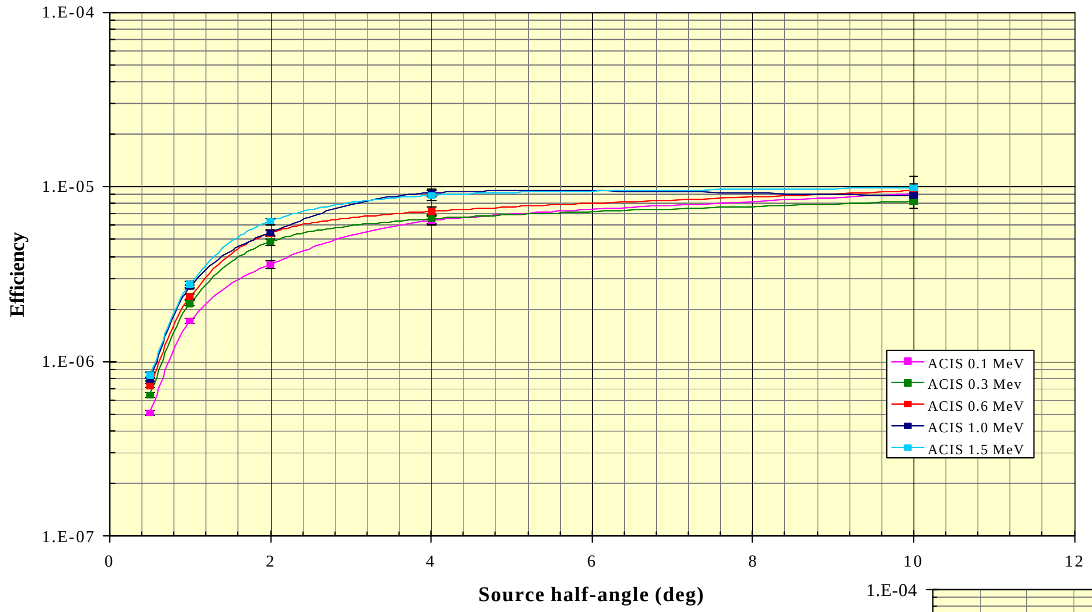


Figure 1. Efficiency of the EPIC and RGS detectors is plotted against proton energy for each source half-angles in the range 0.5 to 30 degrees.

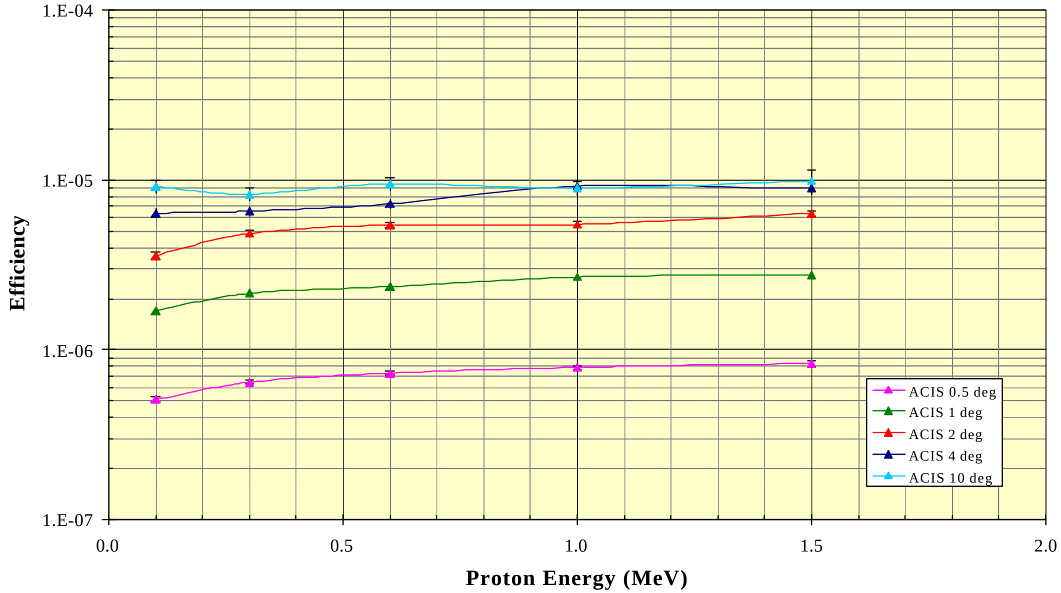

4
2
0
-2
-4
Y (cm)
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
Z (cm)



Efficiency of the ACIS detector plotted against source half-angle for proton energies in the range 0.1 to 1.5MeV.

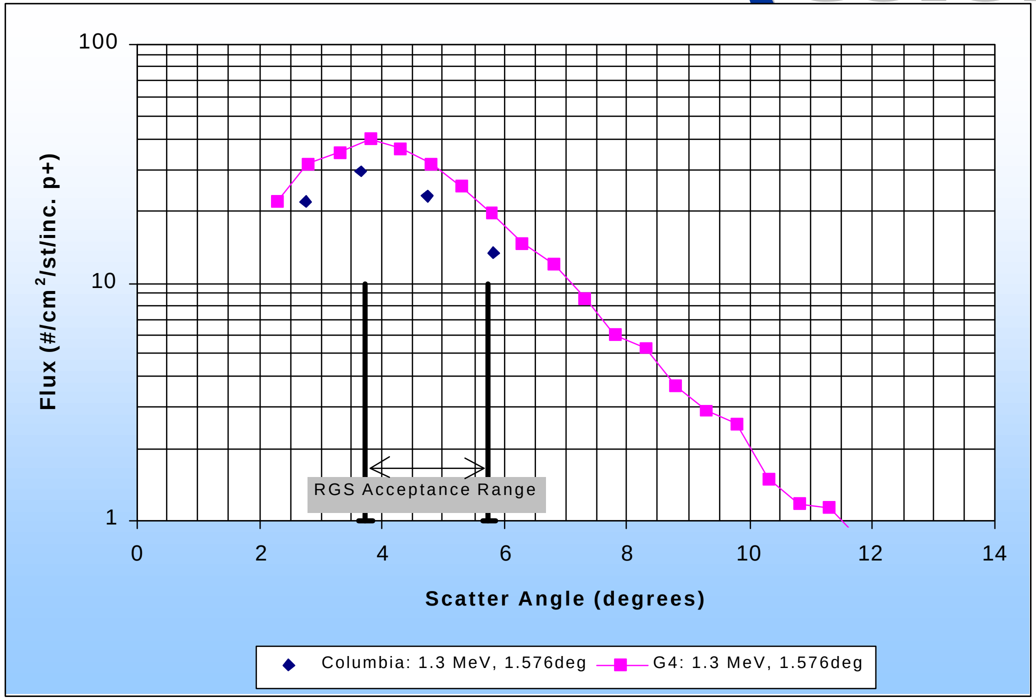
Chandra has similar efficiency to XMM

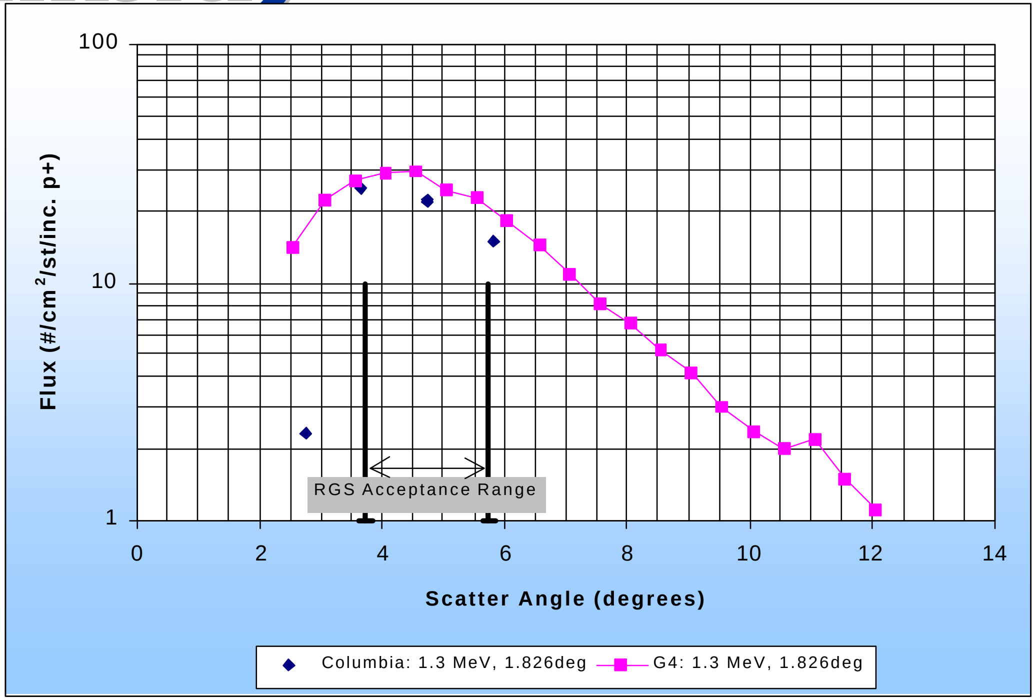
(Qualitative: NOT definitive - Geometry may be incomplete)



Efficiency of the ACIS detector plotted against proton energy for each source half-angles in the range 0.5 to 10 degrees.

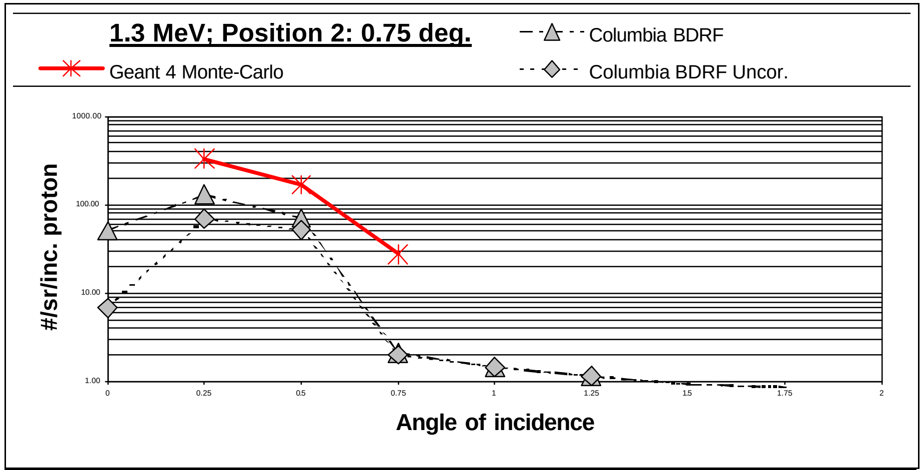
Comparison with experiment (Columbia)

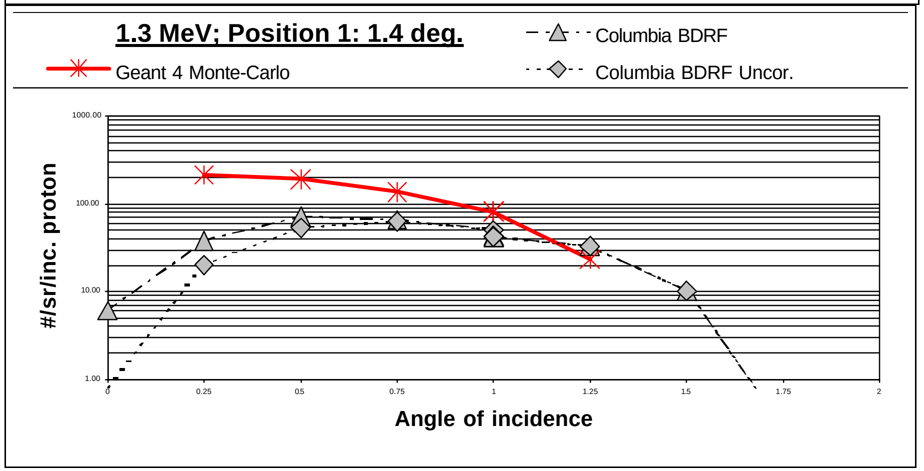


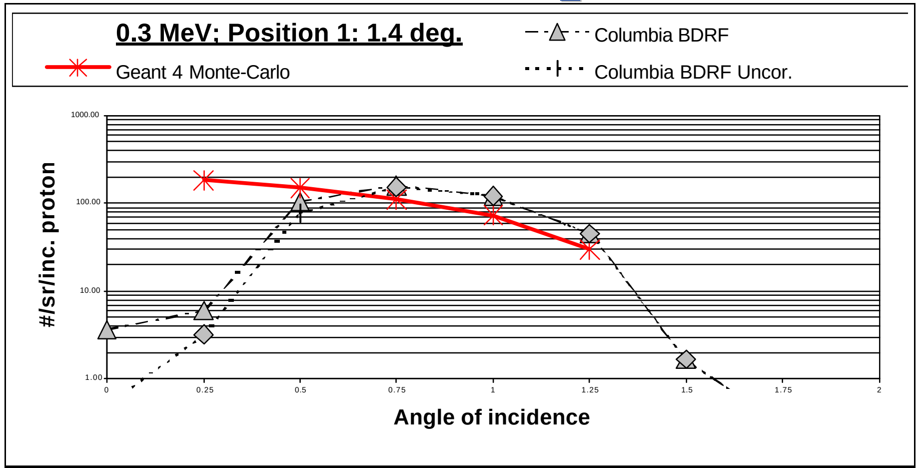


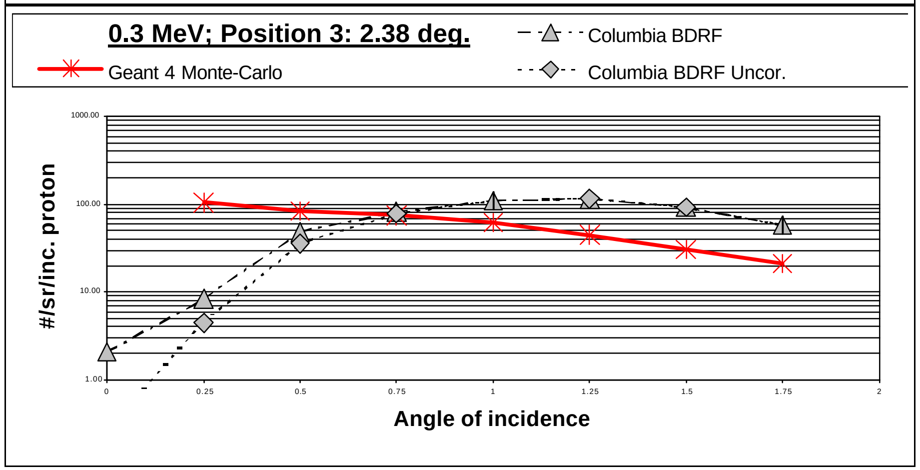
Grating samples

Experiment - mirror shard sample



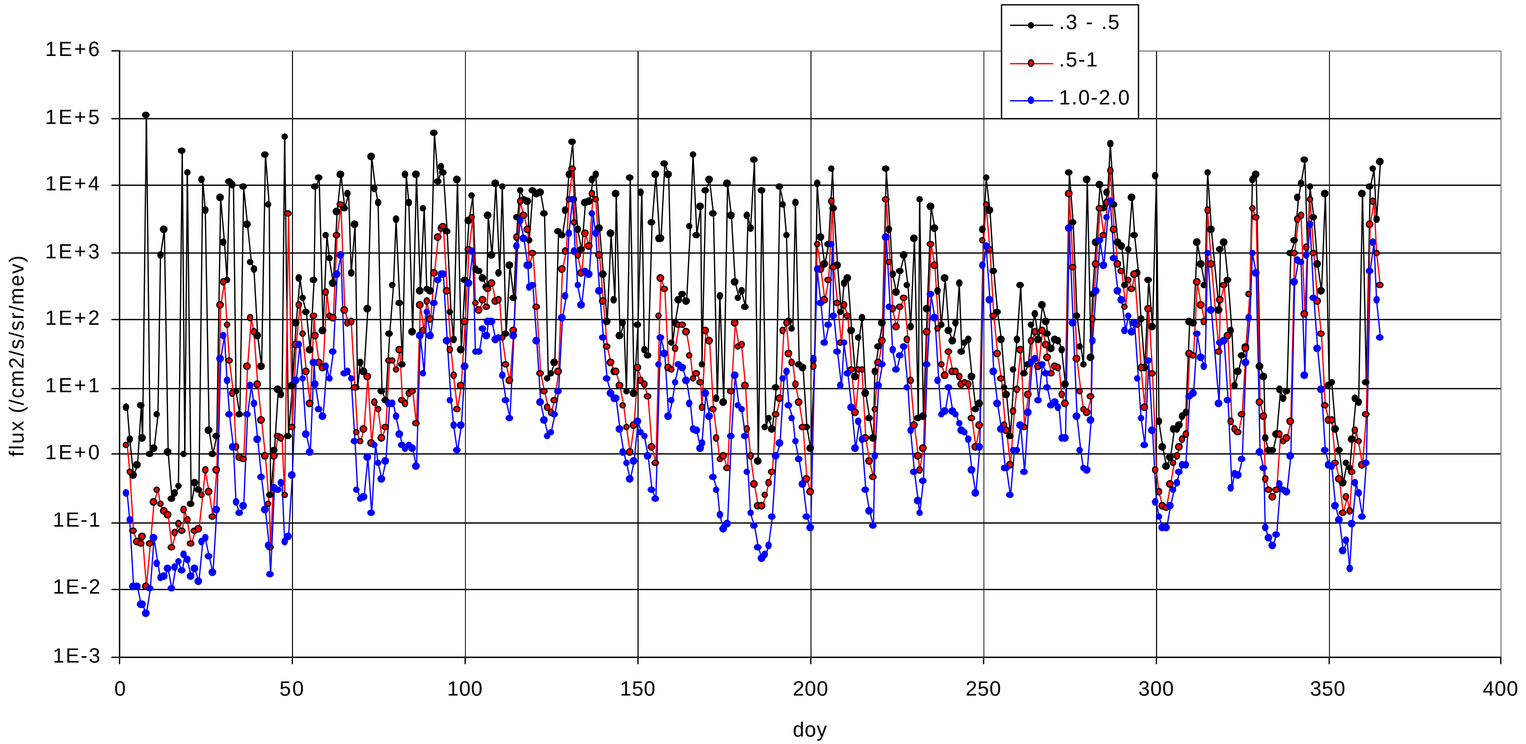






Geant4 results reasonable, but do not fall off towards low angles

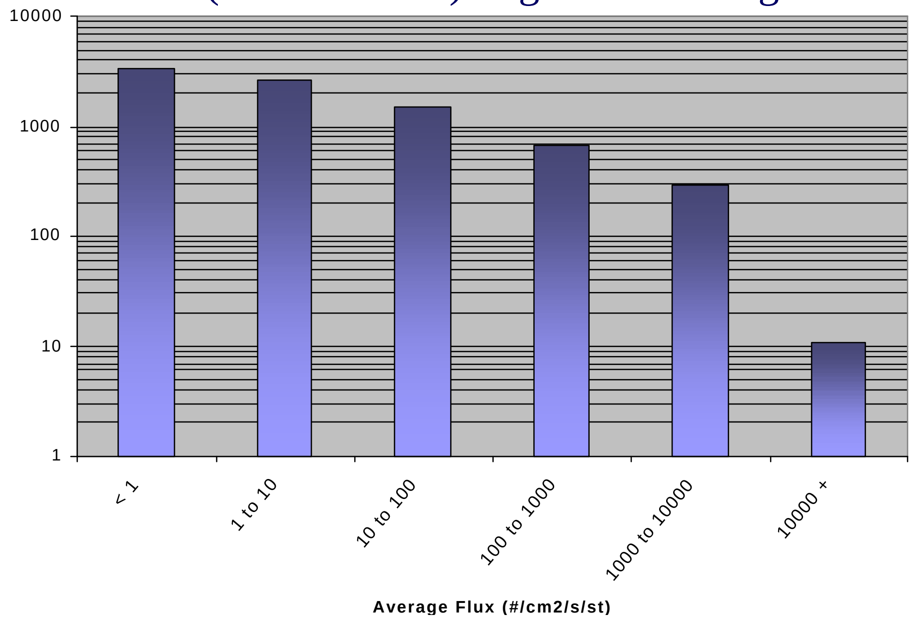
Environment



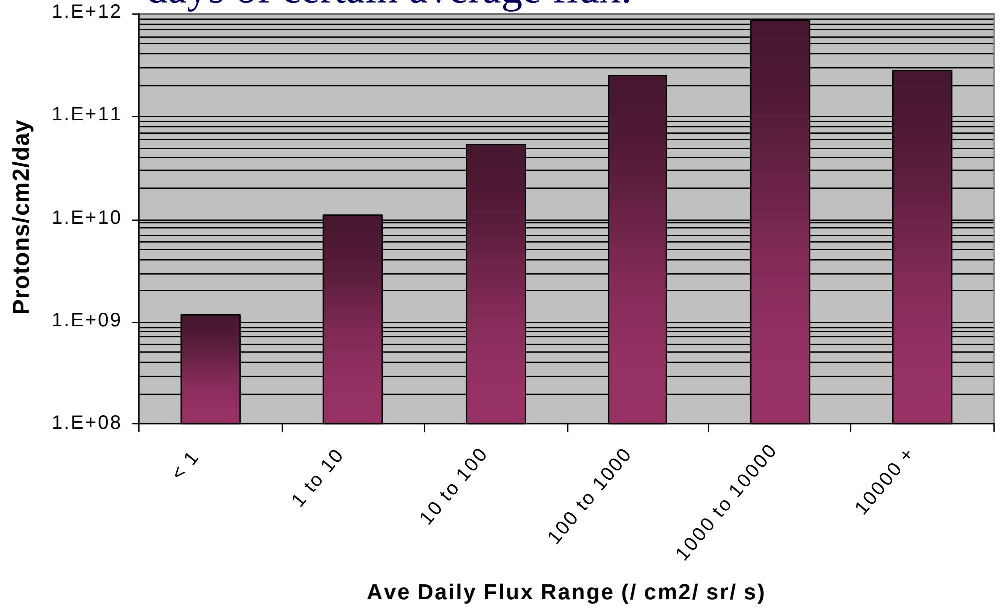
1981 from IMP: a bad year

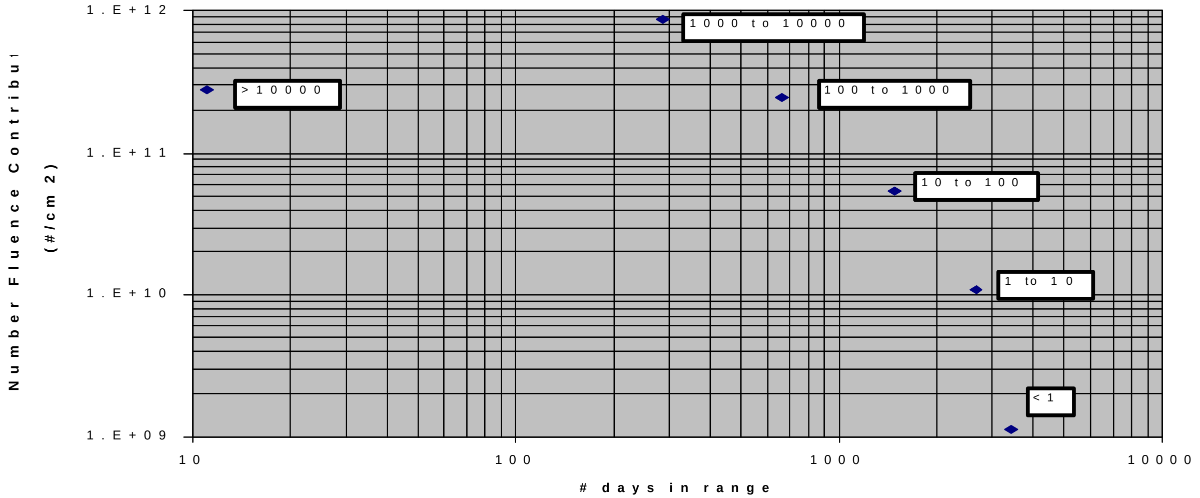
Evaluation of time lost in protection

Number of days in IMP-8 EPAM record (0.3 - 0.5MeV) in given flux ranges.

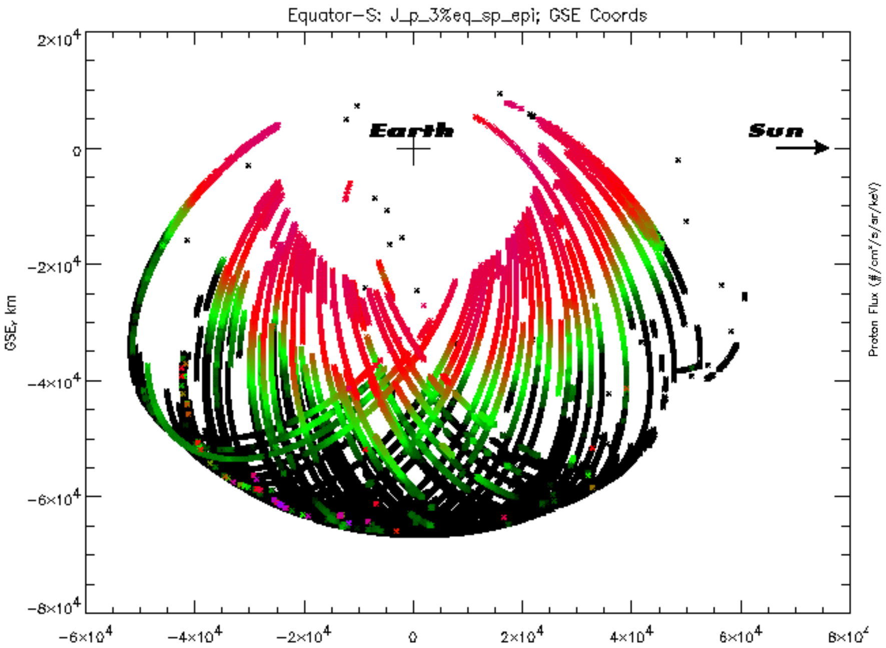


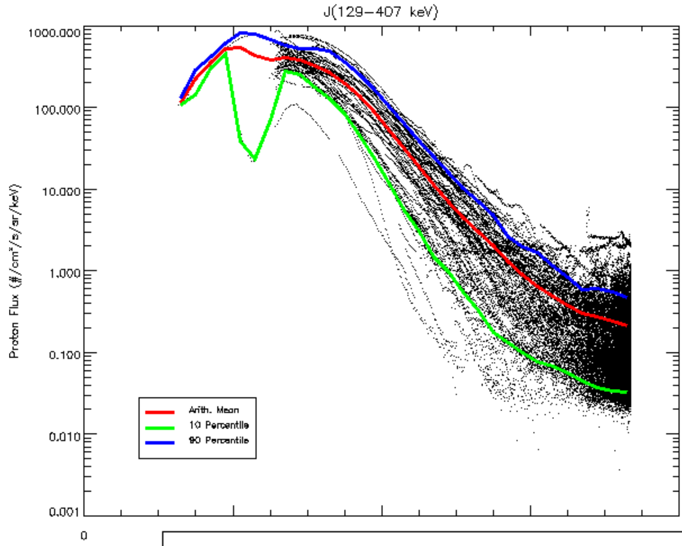
The contribution to the total fluence from days of certain average flux.

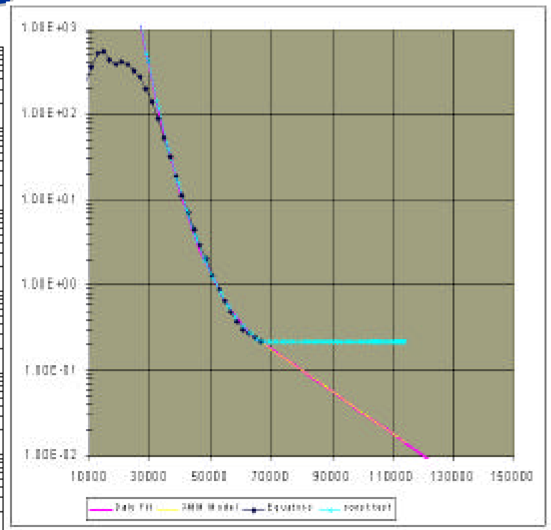


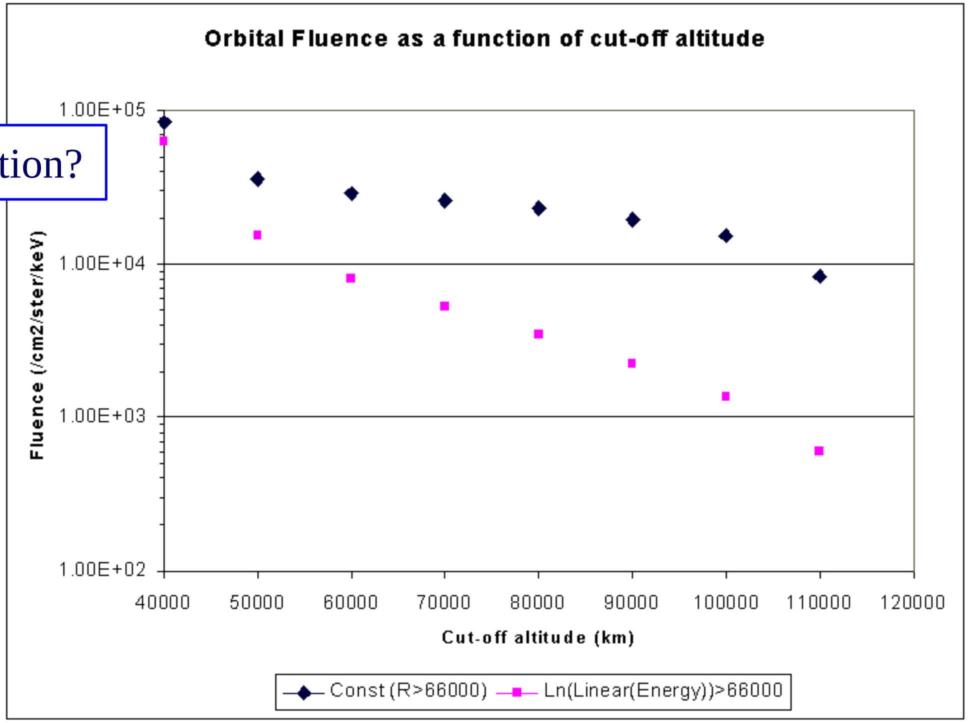


magnetospheric



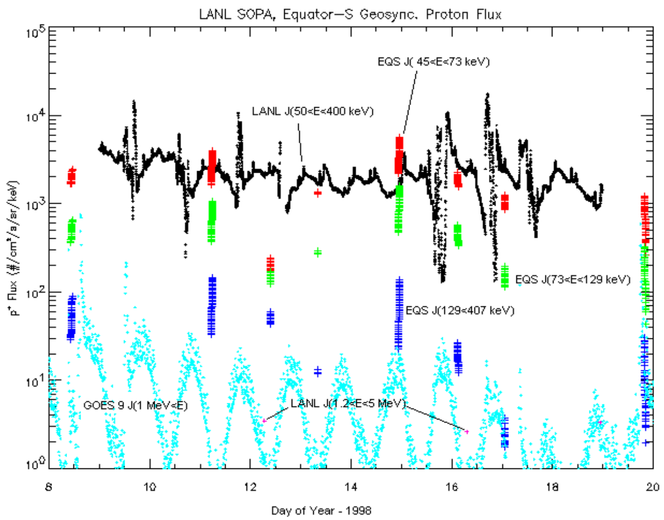


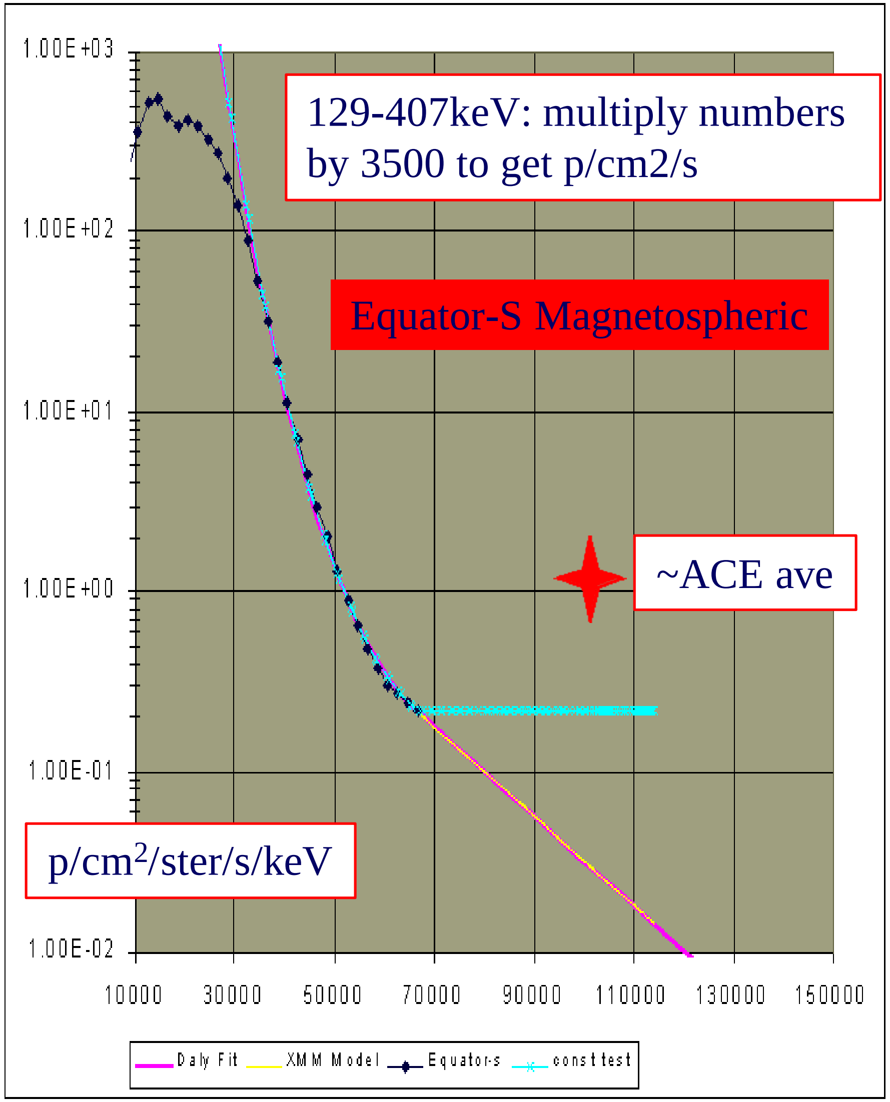


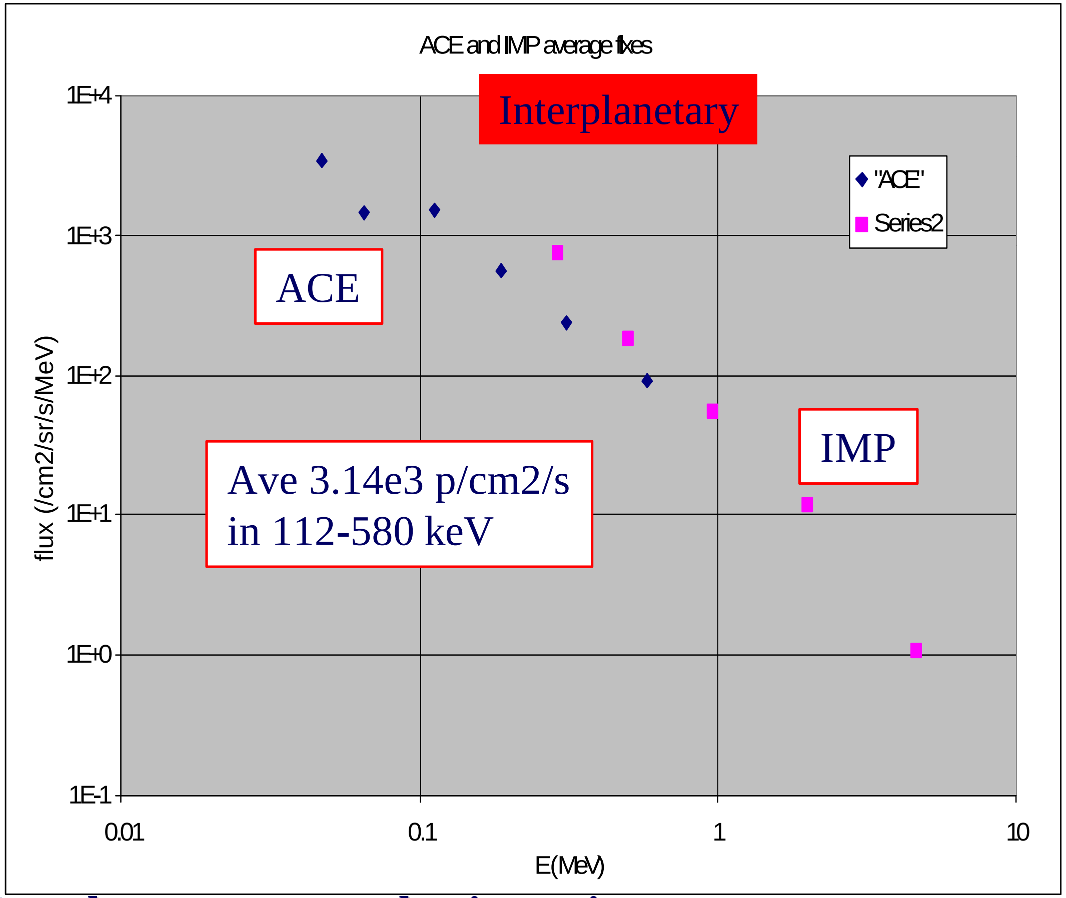


Question: where do you have to stop operation?

Check EQ-S vs. LANL



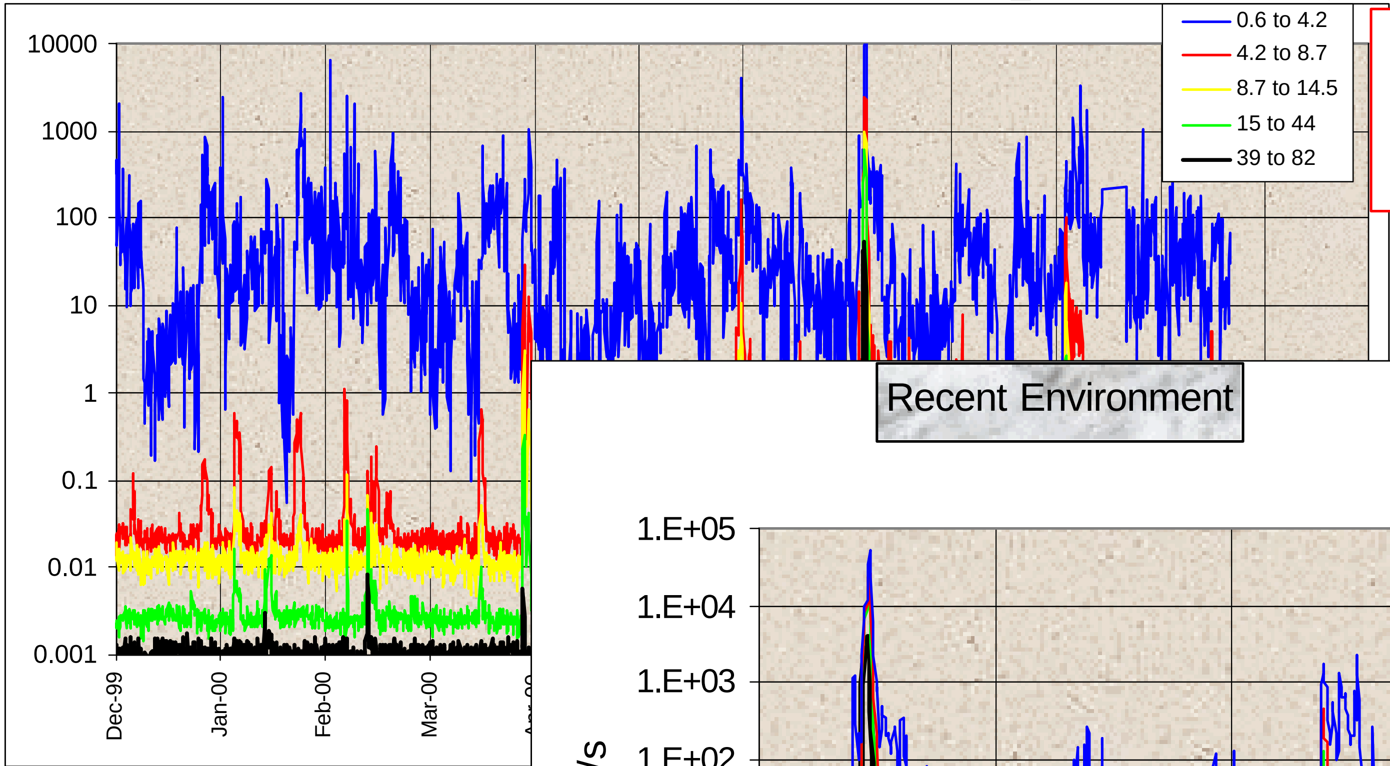




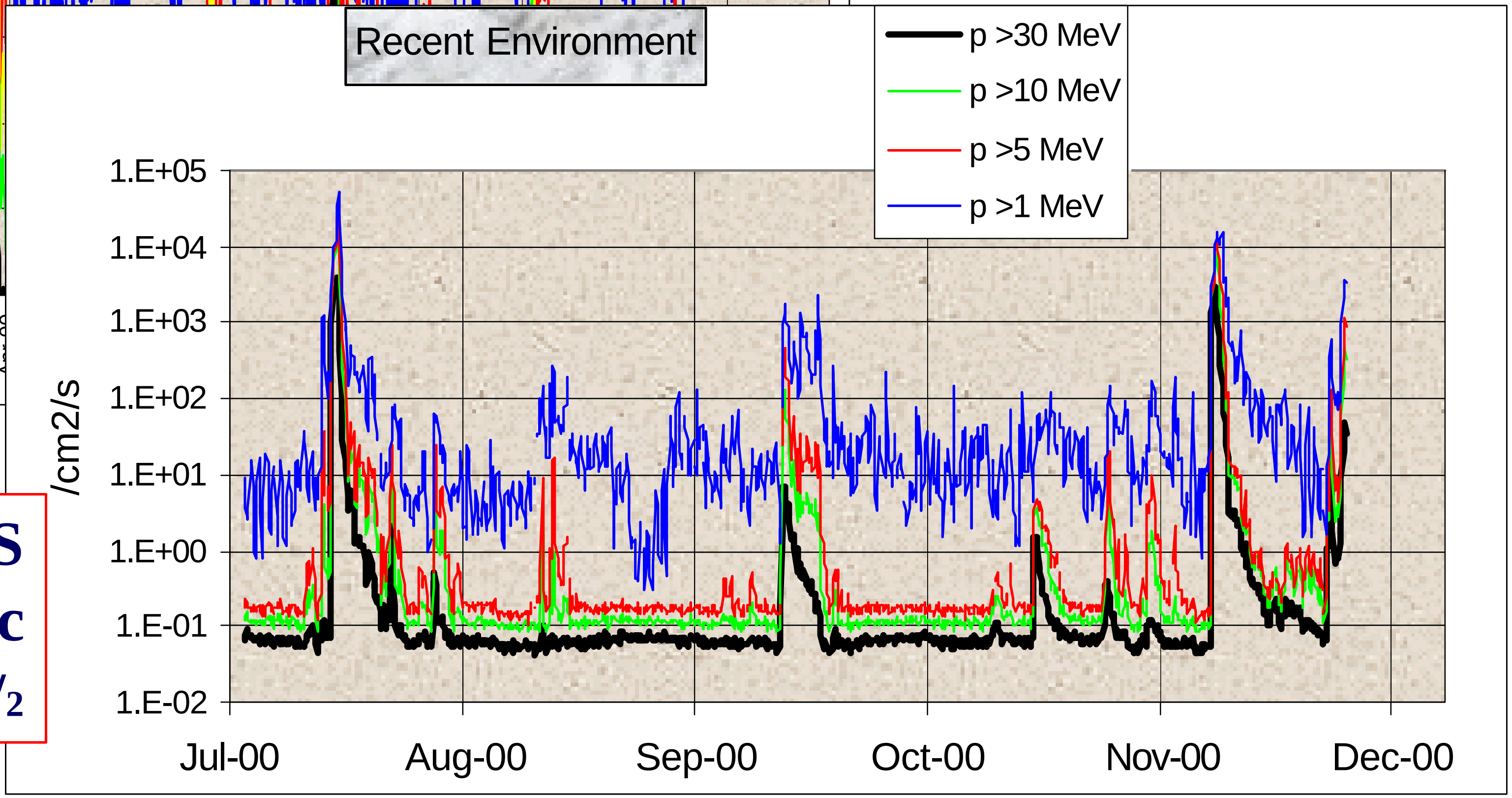
• **<u>How does magnetospheric environment compare with interplanetary?</u>**

• NOTE!!: different periods! - *next slides show that peak periods are similar inside and outside magnetosphere; baseline is higher inside (instrument or magnetospheric particles?)*

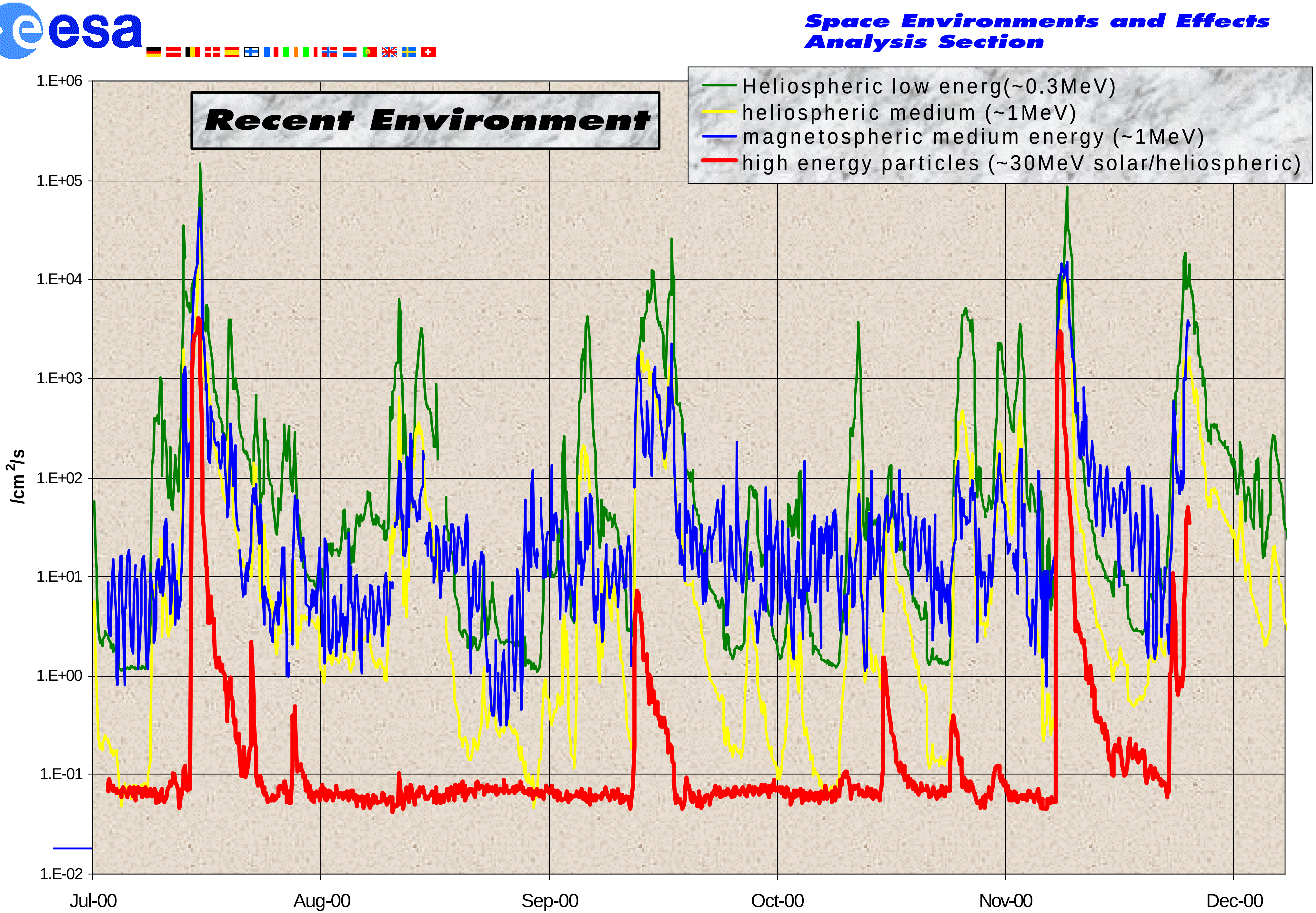
This year's environment has been stormy (as expected)



ACE (Heliospheric)

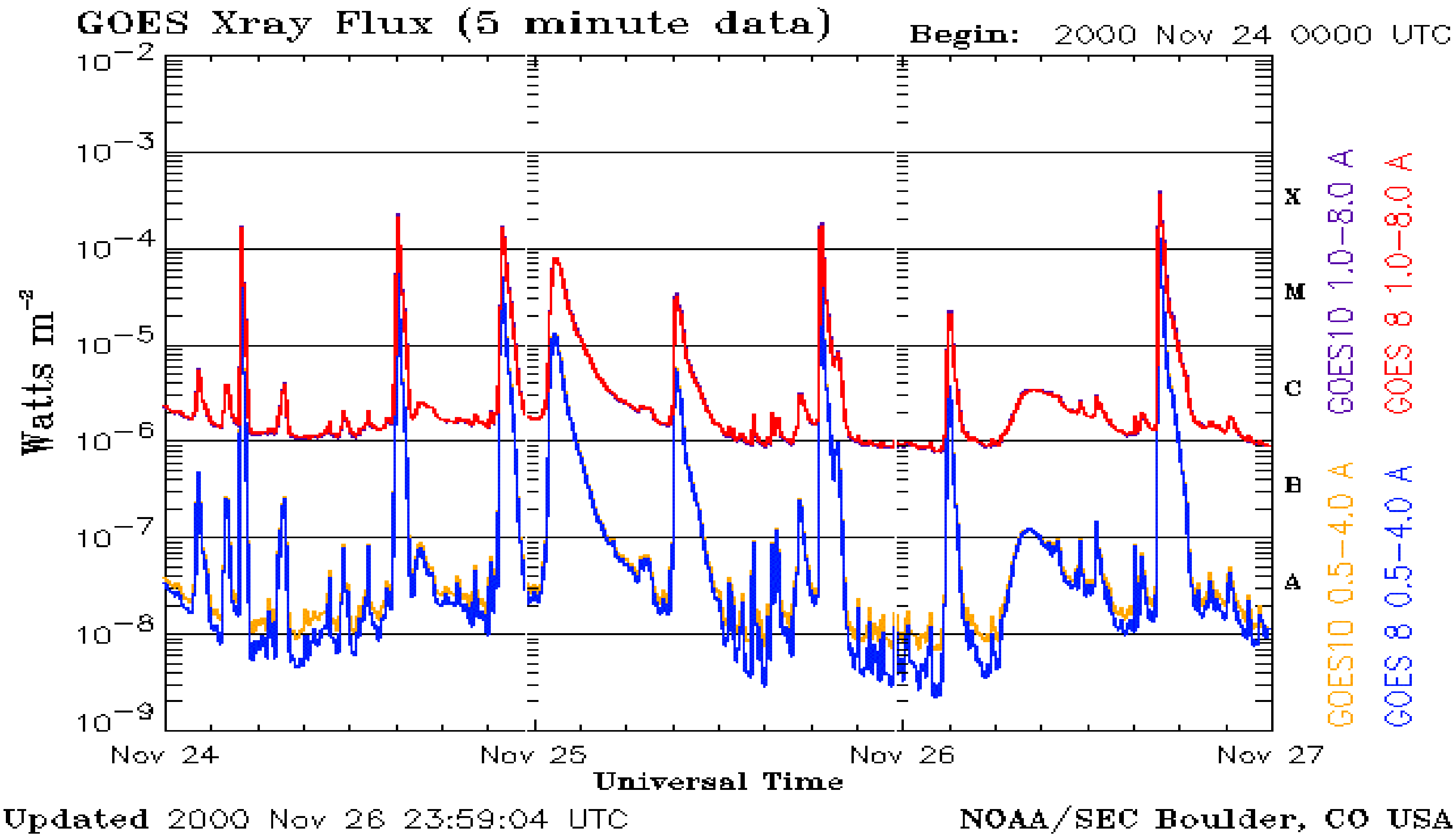


GOES (Magnetospheric L~$6^1/_2$

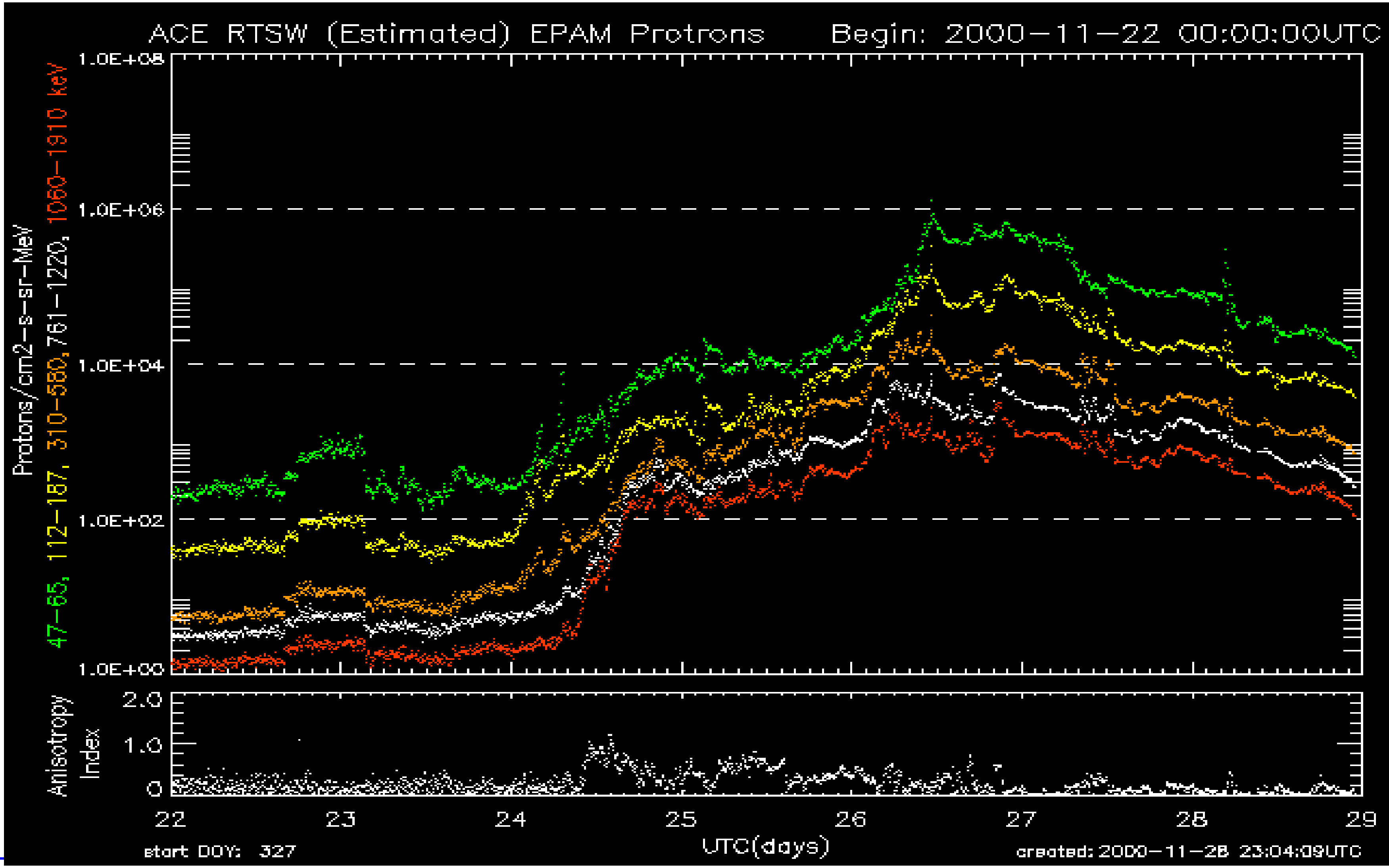


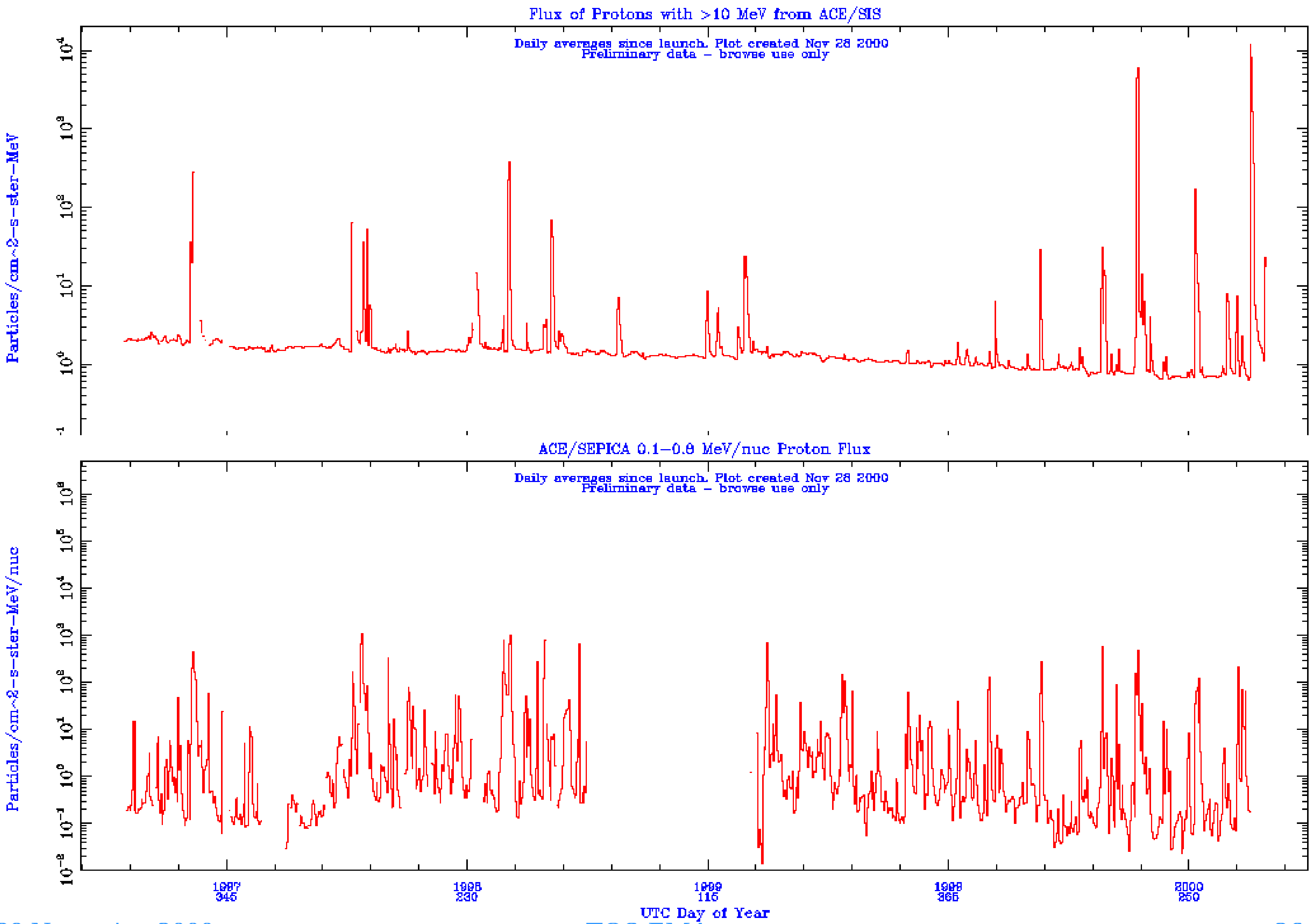
Space Environments and Effects Analysis Section
Recent Environment
Heliospheric low energ(~0.3MeV)
heliospheric medium (~1MeV)
magnetospheric medium energy (~1MeV)
high energy particles (~30MeV solar/heliospheric)
/cm²/s
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Dec-00

Recent series of X-ray flares



ACE


ACE RTSW (Estimated) EPAM Protrons Begin: 2000-11-22 00:00:00UTC
Protons/cm2-s-sr-MeV
47-65, 112-187, 310-580, 761-1220, 1060-1910 keV
1.0E+08
1.0E+06
1.0E+04
1.0E+02
1.0E+00
Anisotropy Index
2.0
1.0
0
22
23
24
25
26
27
28
29
UTC(days)
start DOY: 327
created: 2000-11-28 23:04:09UTC


Flux of Protons with >10 MeV from ACE/SIS
Daily averages since launch. Plot created Nov 28 2000
Preliminary data – browse use only
Particles/cm^2-s-ster-MeV
ACE/SEPICA 0.1–0.8 MeV/nuc Proton Flux
Daily averages since launch. Plot created Nov 28 2000
Preliminary data – browse use only
Particles/cm^2-s-ster-MeV/nuc
1997 345
1998 230
1999 115
1999 365
2000 250
UTC Day of Year

Conclusions

- A lot of work was done to quantify the problem pre-launch
- Tools that have proved useful: Geant4, TRIM, on-line data;
  (***aside***: *many space weather resources are thanks to science missions, with science goals, not a guaranteed service in the future - is more something more needed?*)
- Environment data available for interplanetary space but magnetospheric is largely missing;
- Effort now need to understand what is observed in flight and:
  - *validate modelling methods*
  - *interpret observations*
  - *anticipate evolution of problem(s)*
  - *prepare for other missions*