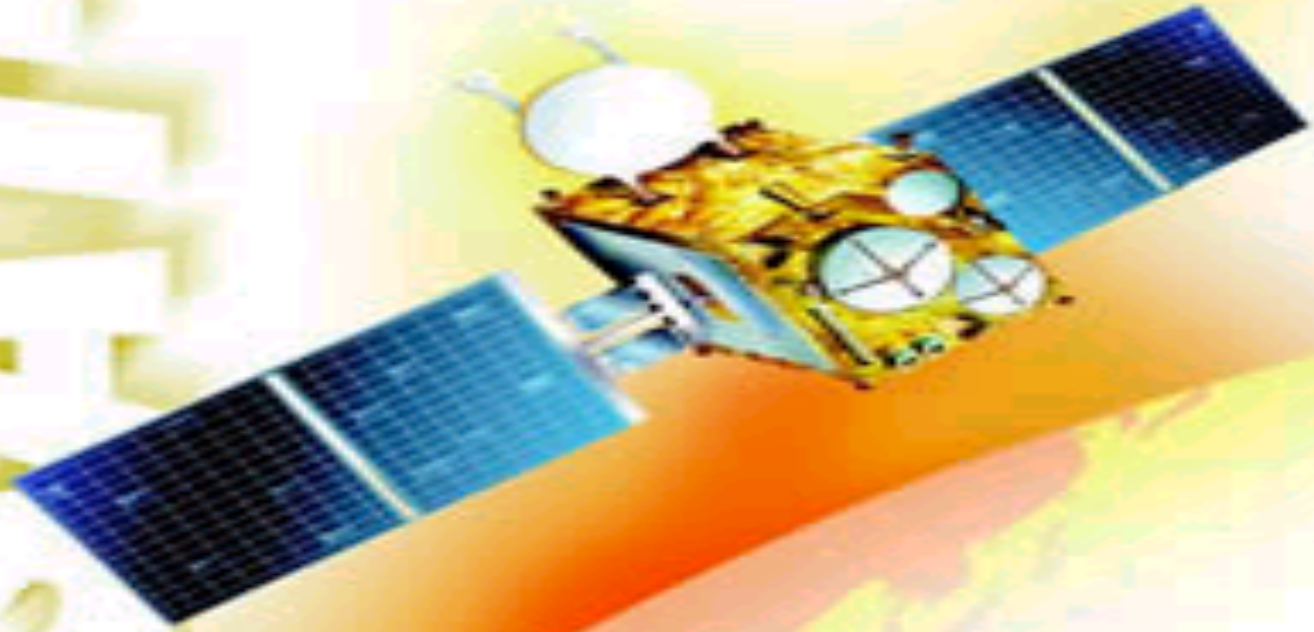
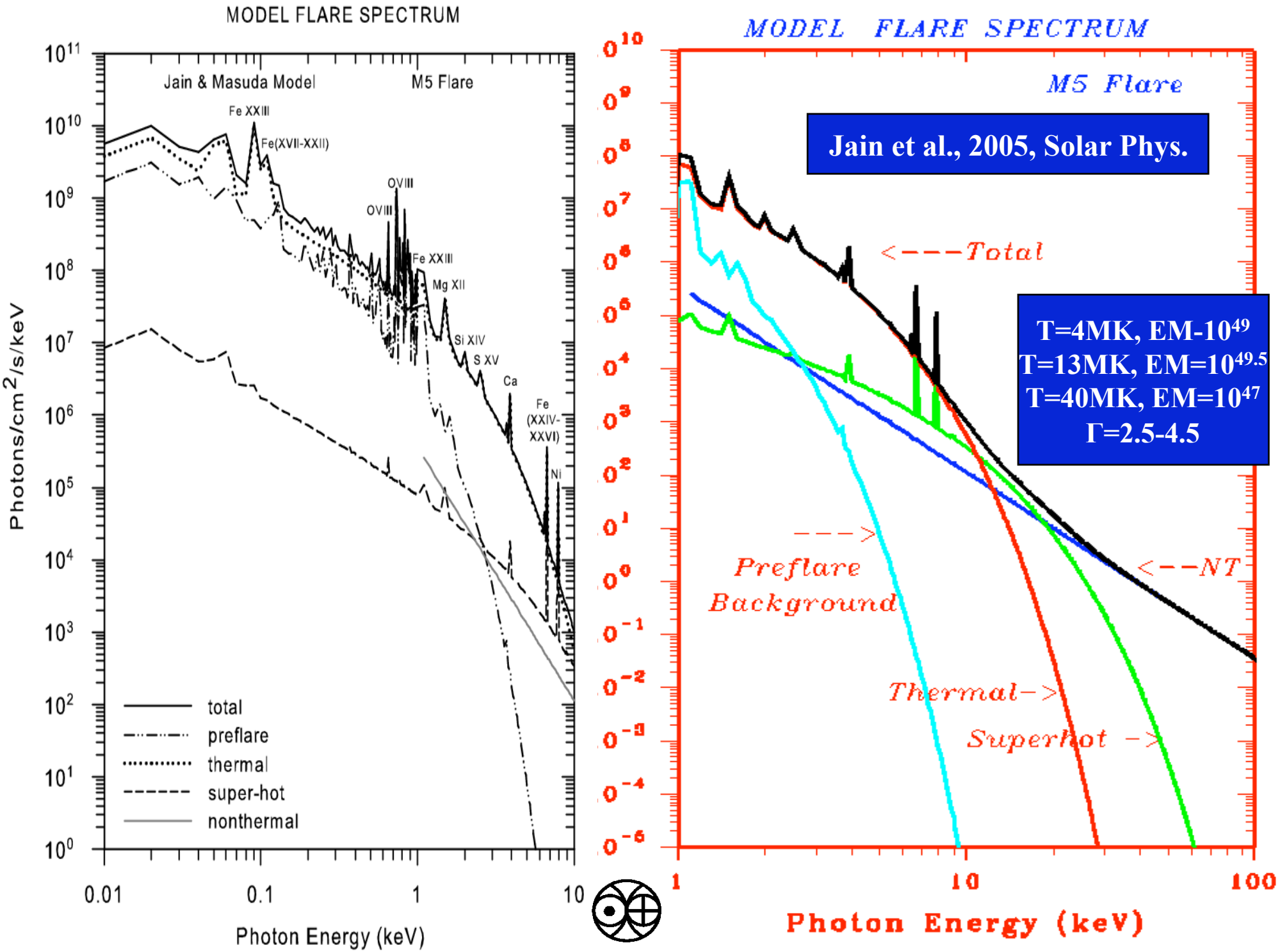
X-ray Diagnostics of Fe and Fe/Ni line Features seen during Solar Flares



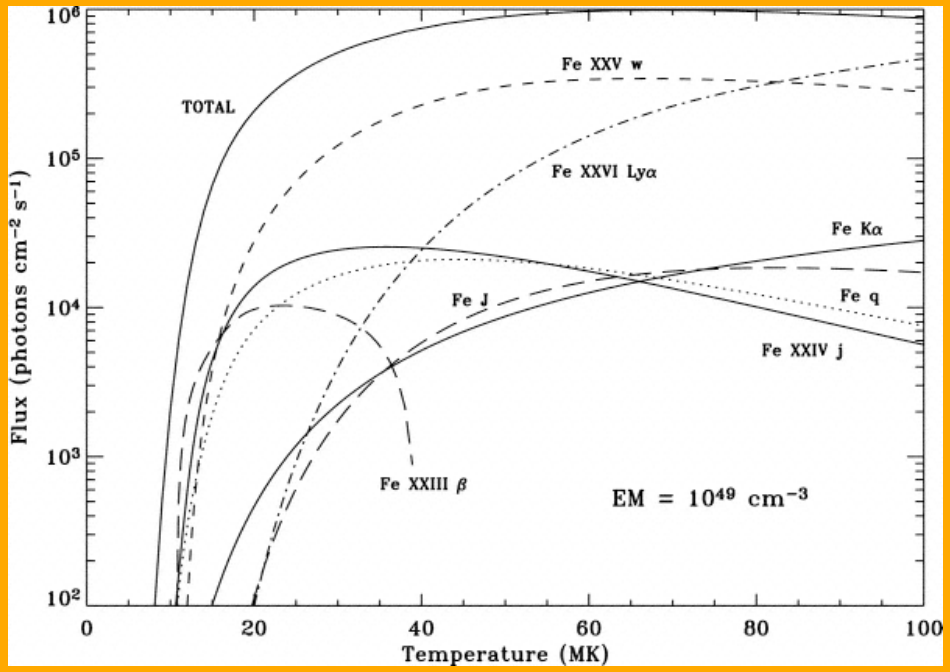
Rajmal Jain

Physical Research Laboratory,

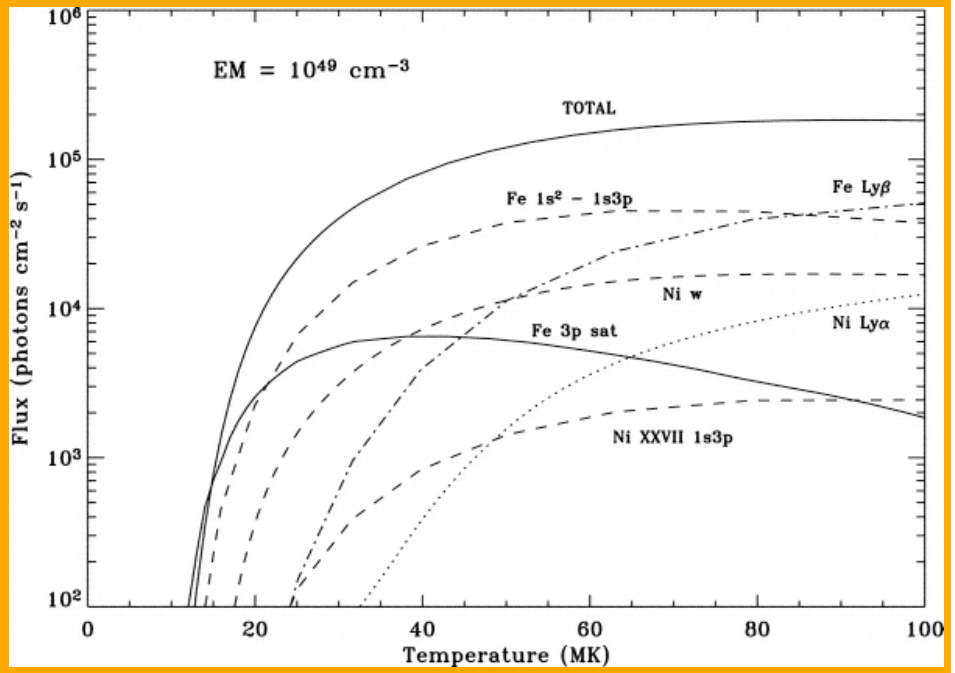
Ahmedabad, India

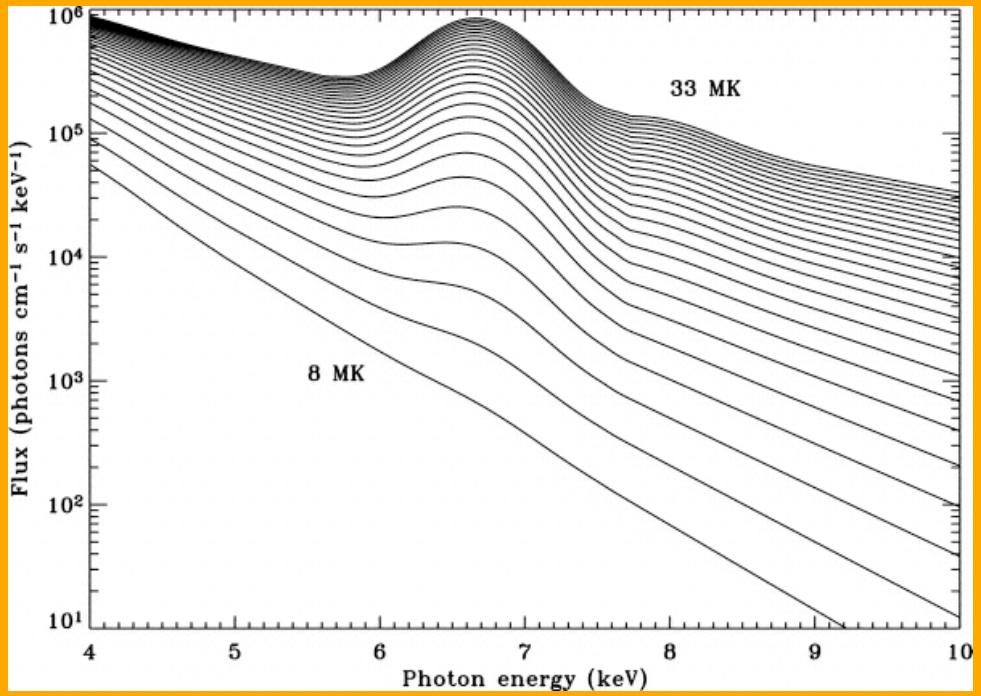

MODEL FLARE SPECTRUM
Jain & Masuda Model
M5 Flare
Fe XXIII
Fe(XVII-XXII)
OVIII
OVIII
Fe XXIII
Mg XII
Si XIV
S XV
Ca
Fe
(XXIV-
XXVI)
Ni
total
preflare
thermal
super-hot
nonthermal
Photons/cm^2/s/keV
Photon Energy (keV)
MODEL FLARE SPECTRUM
M5 Flare
Jain et al., 2005, Solar Phys.
<---Total
T=4MK, EM-10^{49}
T=13MK, EM=10$^{49.5}$
T=40MK, EM=10^{47}
Γ=2.5-4.5
---> Preflare Background
<--NT
Thermal->
Superhot ->
Photon Energy (keV)

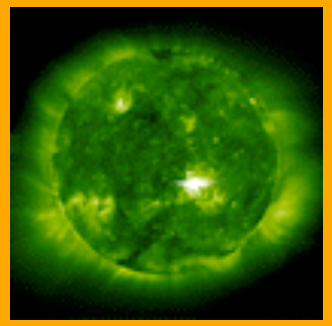
Fe line Feature



Fe/ Ni line Feature







SOXS Science

Emission Characteristics of Fe and Fe/Ni line Features.

Energy Release and particle acceleration in Solar Flares.

Thermal/ non-thermal nature of Solar Flares.

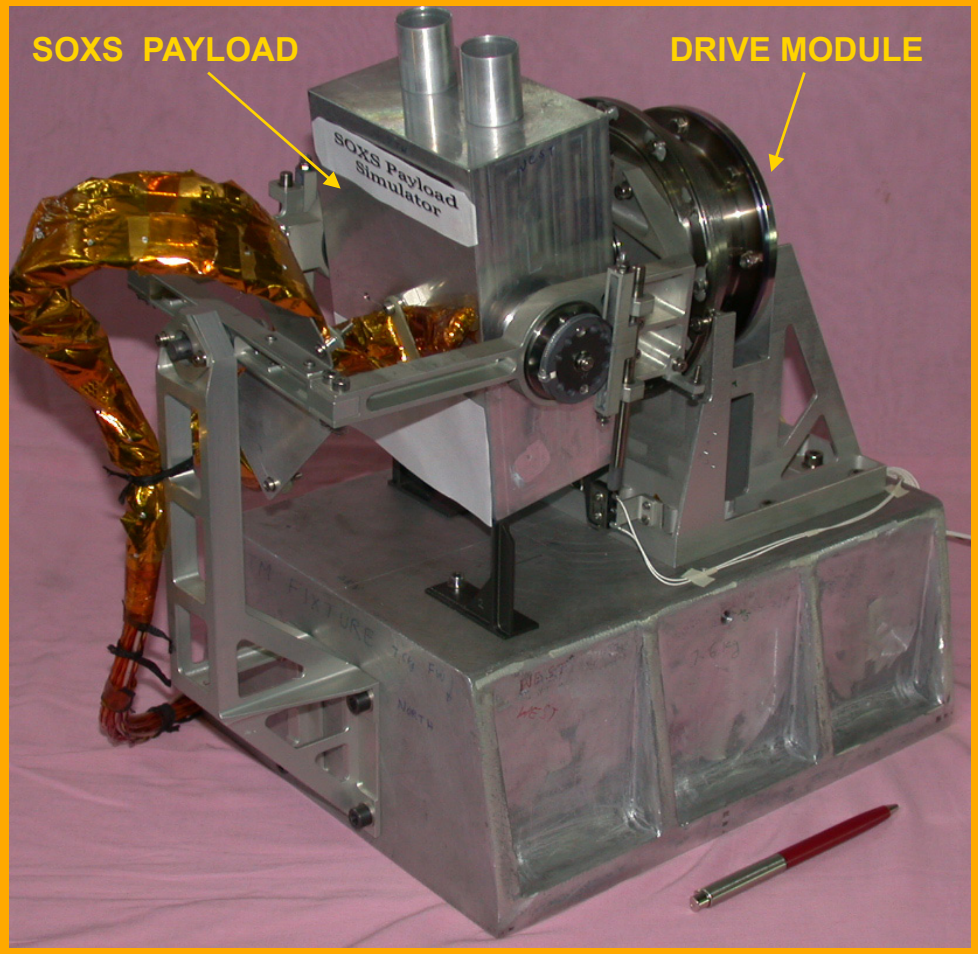
Low Energy cut-off as a function of Flare duration to determine the nature of X-ray photons that varying over time.

Contribution of micro flares in heating the Solar Corona.

Short and long term variation of the Solar Corona: Coronal Seismology

Sun-Earth connection and Space-Weather.

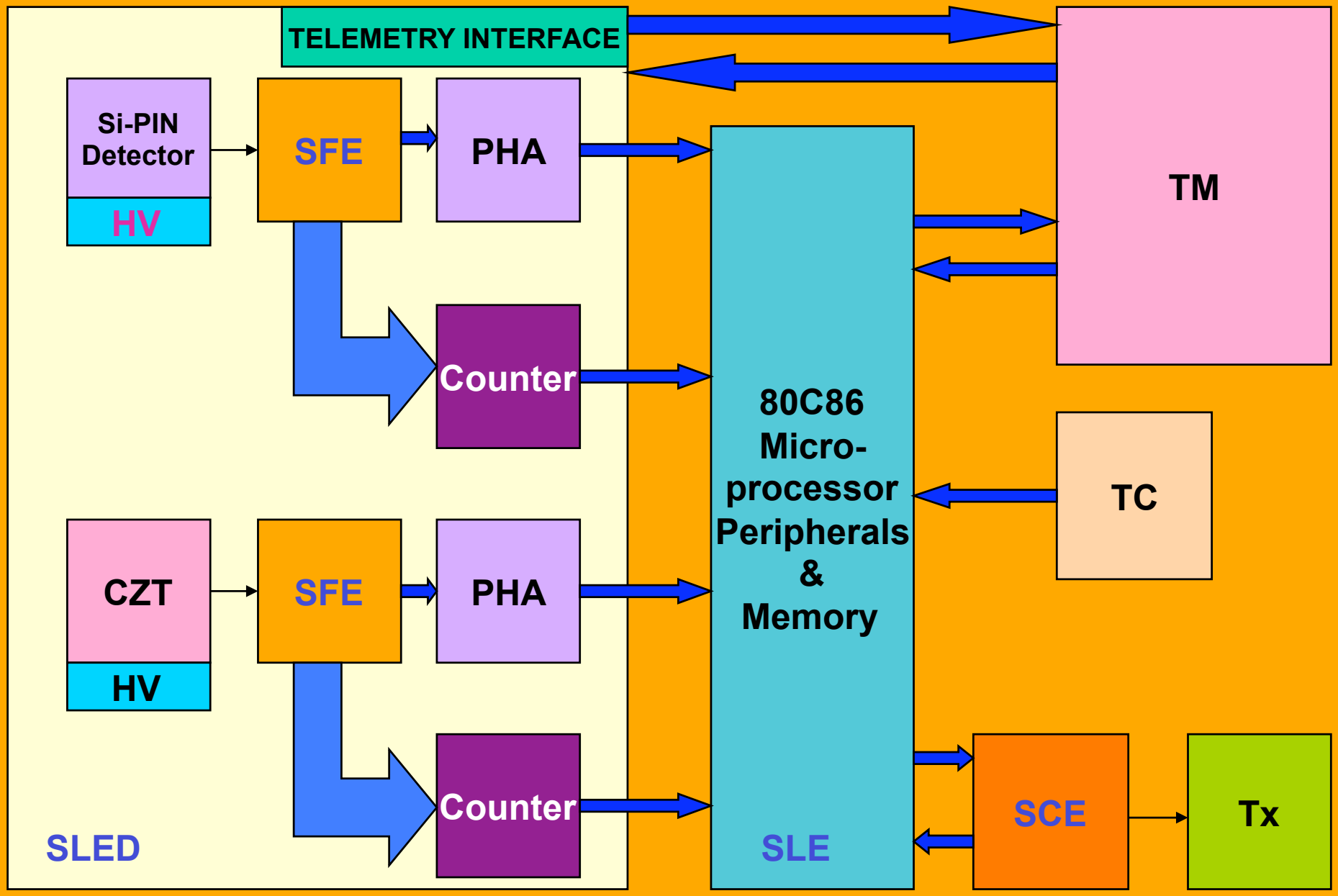
SSTM Daily Tracking [0 TO 180°]



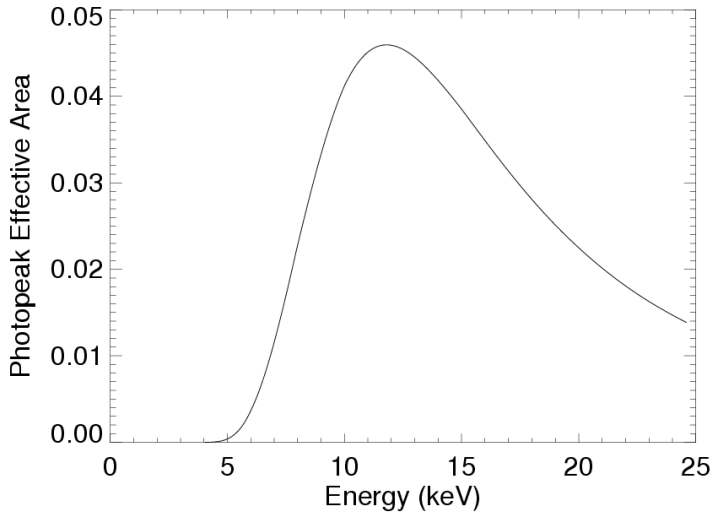
⇦ 12 'O' Clock Position

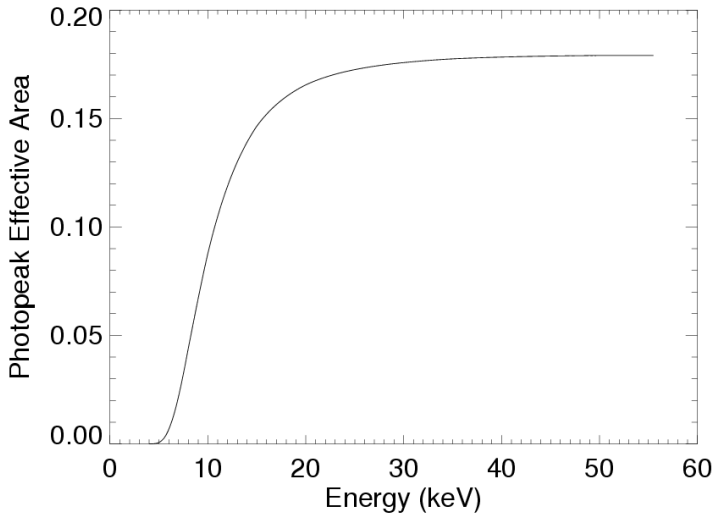
East Position ⇨

Block schematics of SLD Payload (SLED, SFE, SLE & SCE)

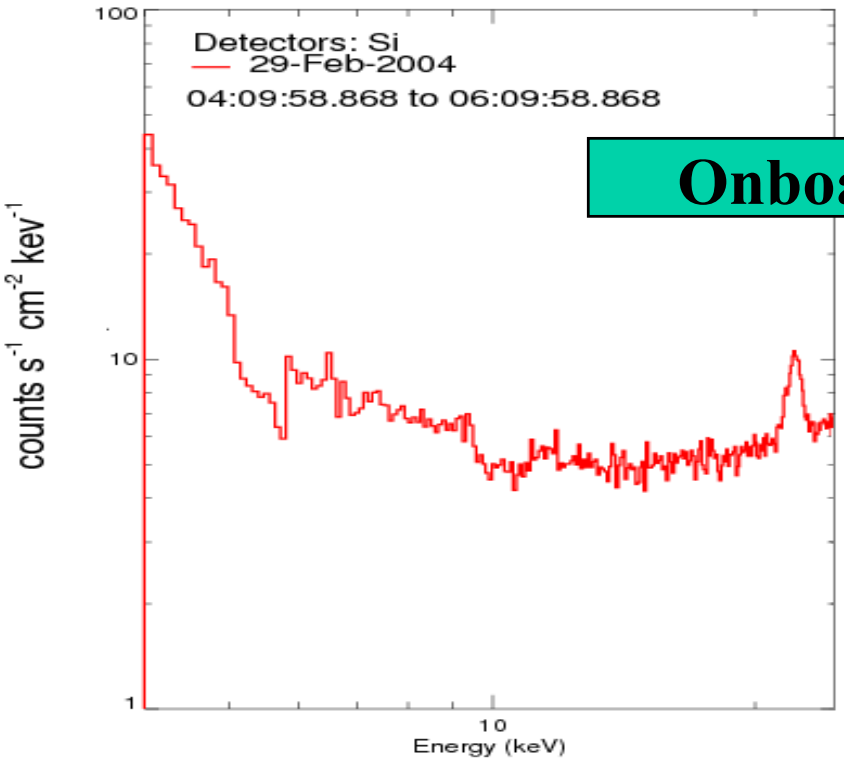


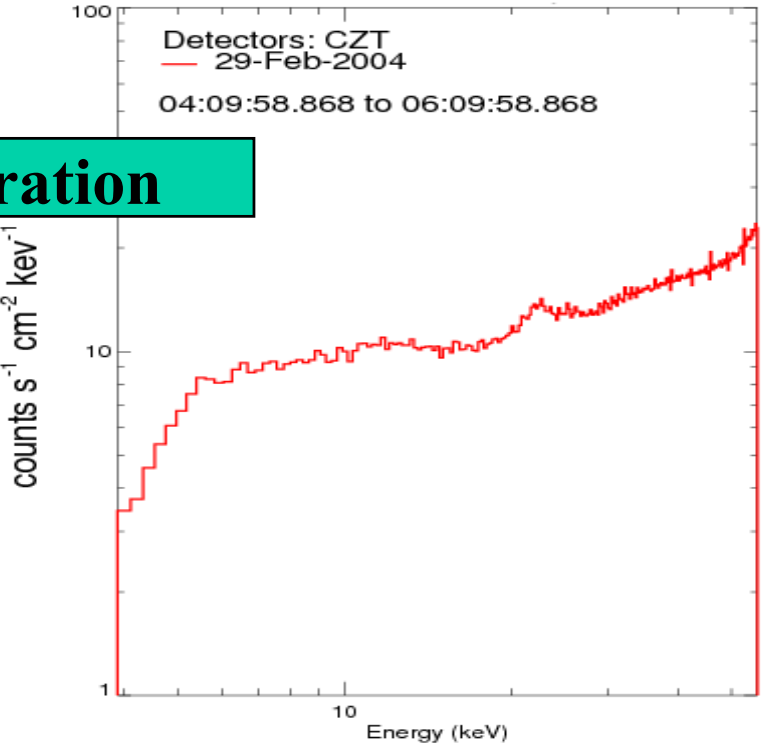
Detector - Response

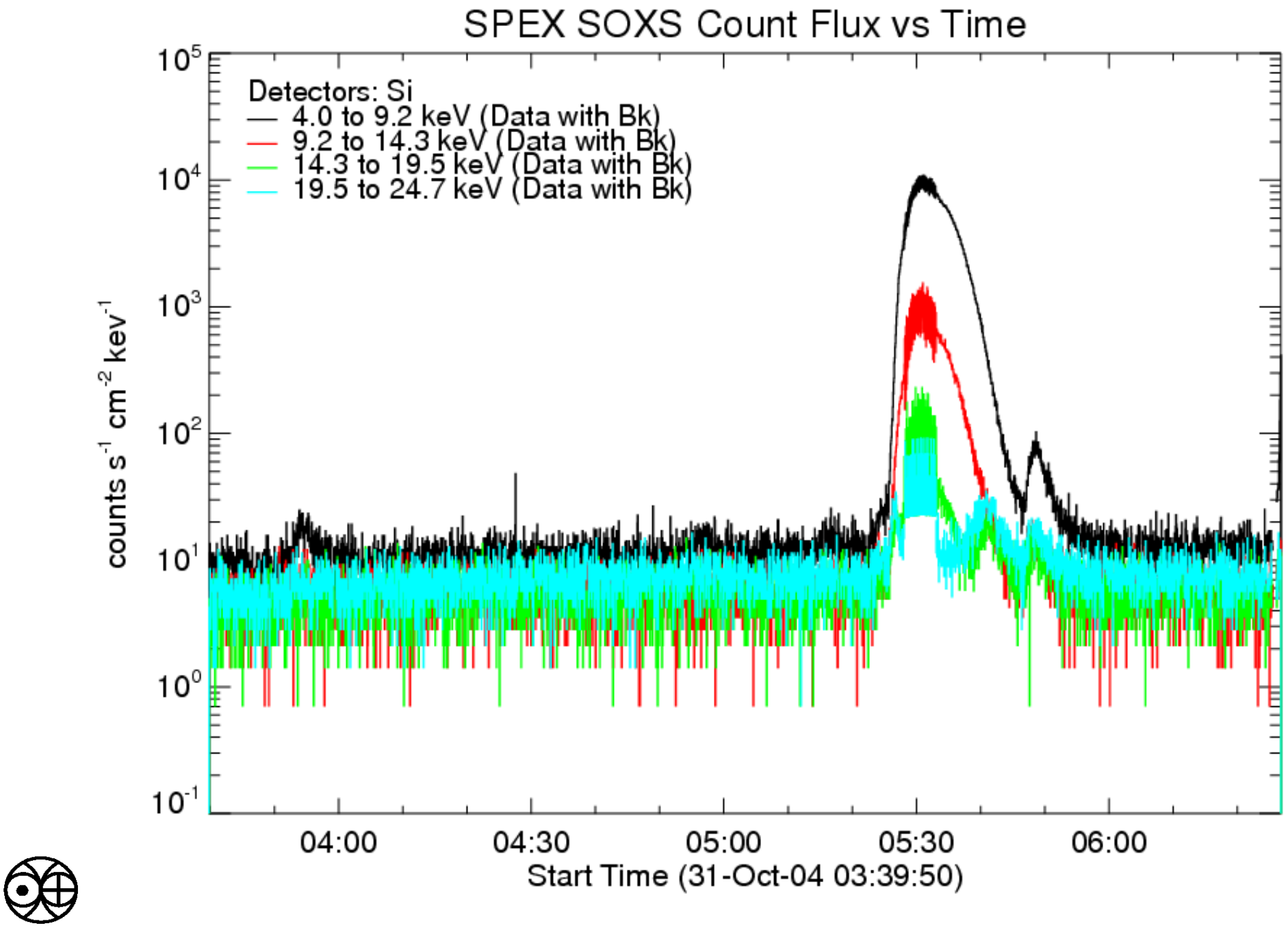


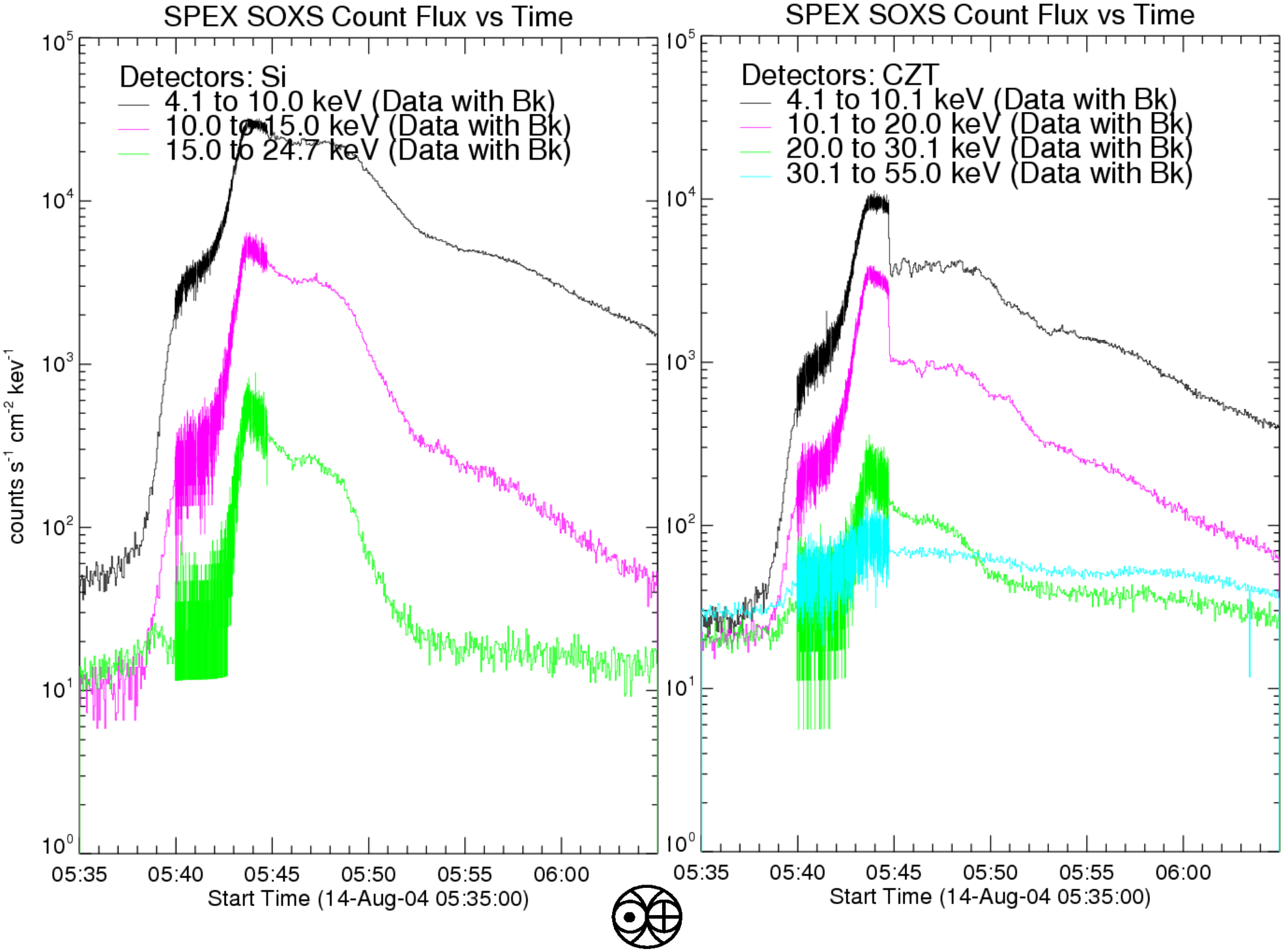


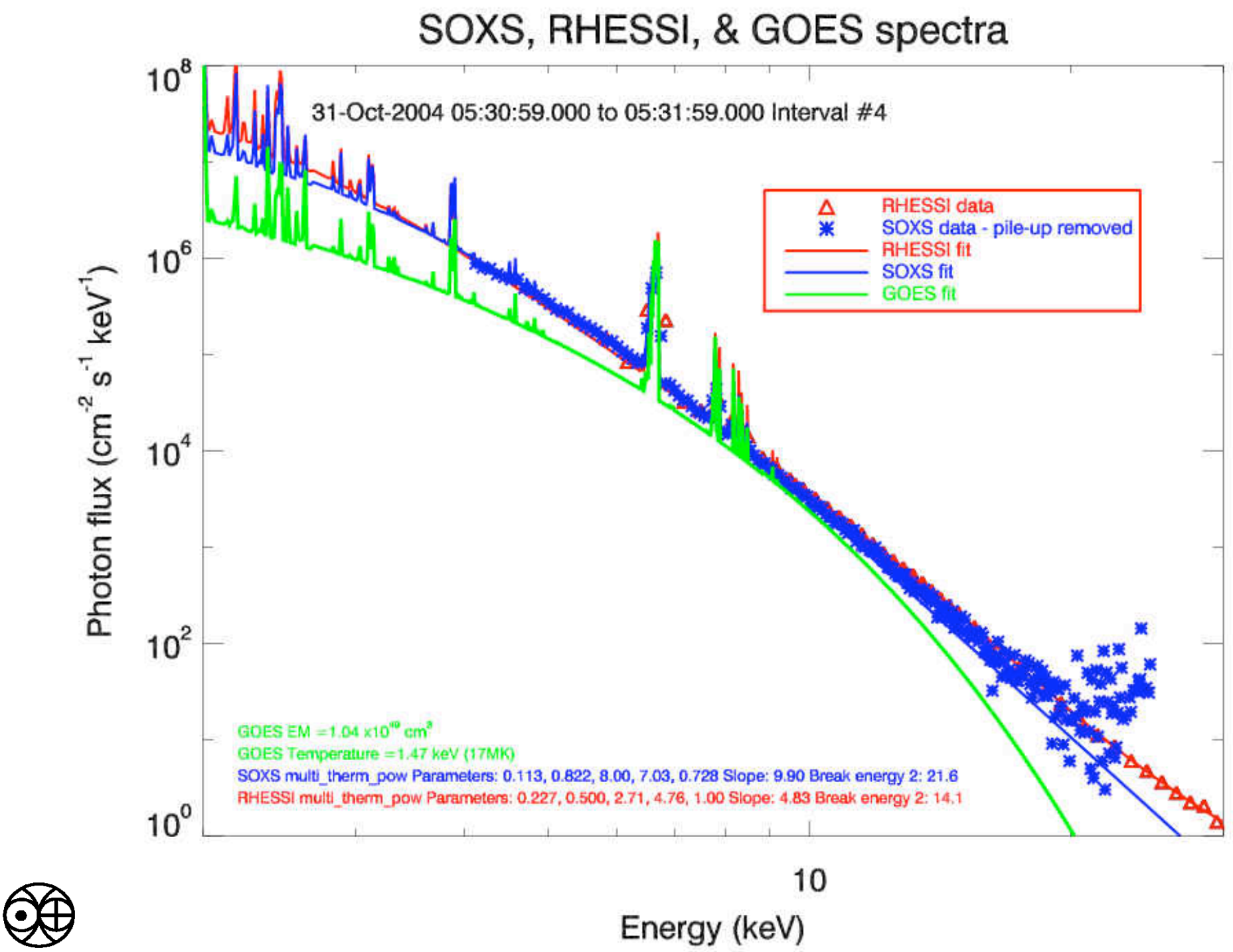
Onboard Calibration

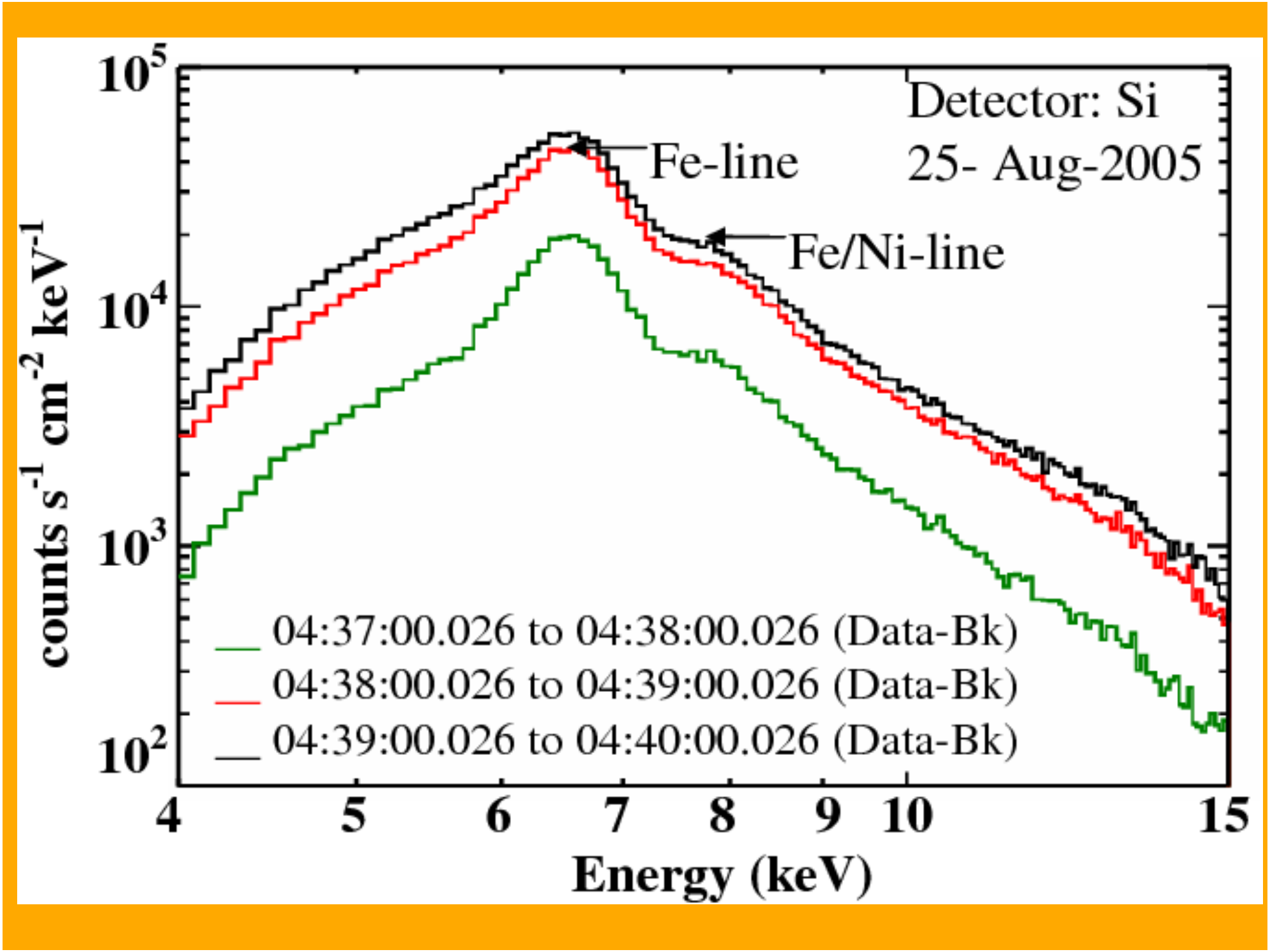





SPEX SOXS Count Flux vs Time
Detectors: Si
4.0 to 9.2 keV (Data with Bk)
9.2 to 14.3 keV (Data with Bk)
14.3 to 19.5 keV (Data with Bk)
19.5 to 24.7 keV (Data with Bk)
counts s-1 cm-2 kev-1
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
04:00
04:30
05:00
05:30
06:00
Start Time (31-Oct-04 03:39:50)


SPEX SOXS Count Flux vs Time
Detectors: Si
4.1 to 10.0 keV (Data with Bk)
10.0 to 15.0 keV (Data with Bk)
15.0 to 24.7 keV (Data with Bk)
counts s-1 cm-2 kev-1
10^5
10^4
10^3
10^2
10^1
10^0
05:35
05:40
05:45
05:50
05:55
06:00
Start Time (14-Aug-04 05:35:00)
SPEX SOXS Count Flux vs Time
Detectors: CZT
4.1 to 10.1 keV (Data with Bk)
10.1 to 20.0 keV (Data with Bk)
20.0 to 30.1 keV (Data with Bk)
30.1 to 55.0 keV (Data with Bk)
10^5
10^4
10^3
10^2
10^1
10^0
05:35
05:40
05:45
05:50
05:55
06:00
Start Time (14-Aug-04 05:35:00)


SOXS, RHESSI, & GOES spectra
31-Oct-2004 05:30:59.000 to 05:31:59.000 Interval #4
RHESSI data
SOXS data - pile-up removed
RHESSI fit
SOXS fit
GOES fit
GOES EM =1.04 x10^49 cm^3
GOES Temperature =1.47 keV (17MK)
SOXS multi_therm_pow Parameters: 0.113, 0.822, 8.00, 7.03, 0.728 Slope: 9.90 Break energy 2: 21.6
RHESSI multi_therm_pow Parameters: 0.227, 0.500, 2.71, 4.76, 1.00 Slope: 4.83 Break energy 2: 14.1
Photon flux (cm^-2 s^-1 keV^-1)
10^8
10^6
10^4
10^2
10^0
10
Energy (keV)


Detector: Si
25- Aug-2005
Fe-line
Fe/Ni-line
04:37:00.026 to 04:38:00.026 (Data-Bk)
04:38:00.026 to 04:39:00.026 (Data-Bk)
04:39:00.026 to 04:40:00.026 (Data-Bk)
counts s-1 cm-2 keV-1
Energy (keV)
10^5
10^4
10^3
10^2
4
5
6
7
8
9
10
15

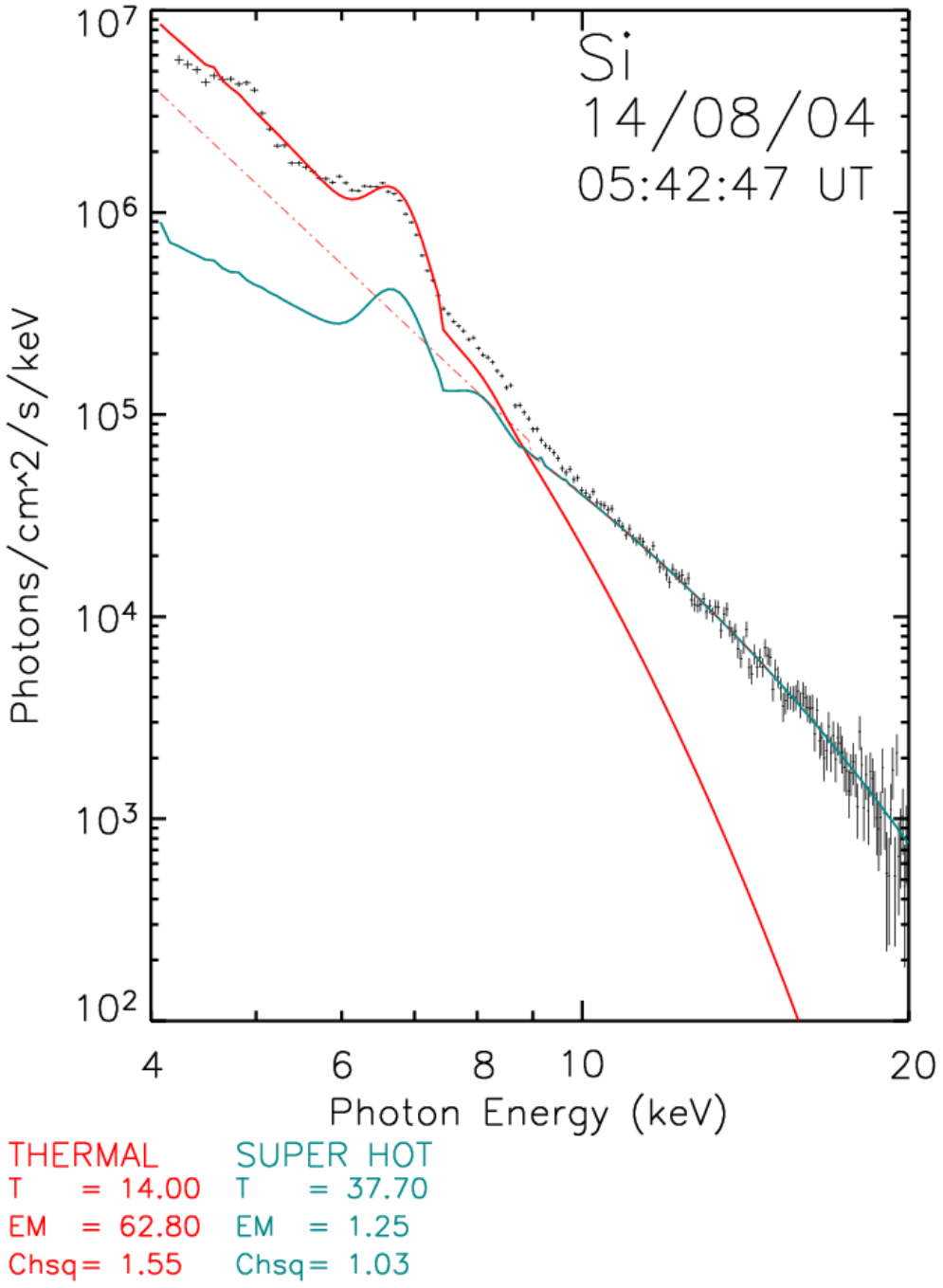
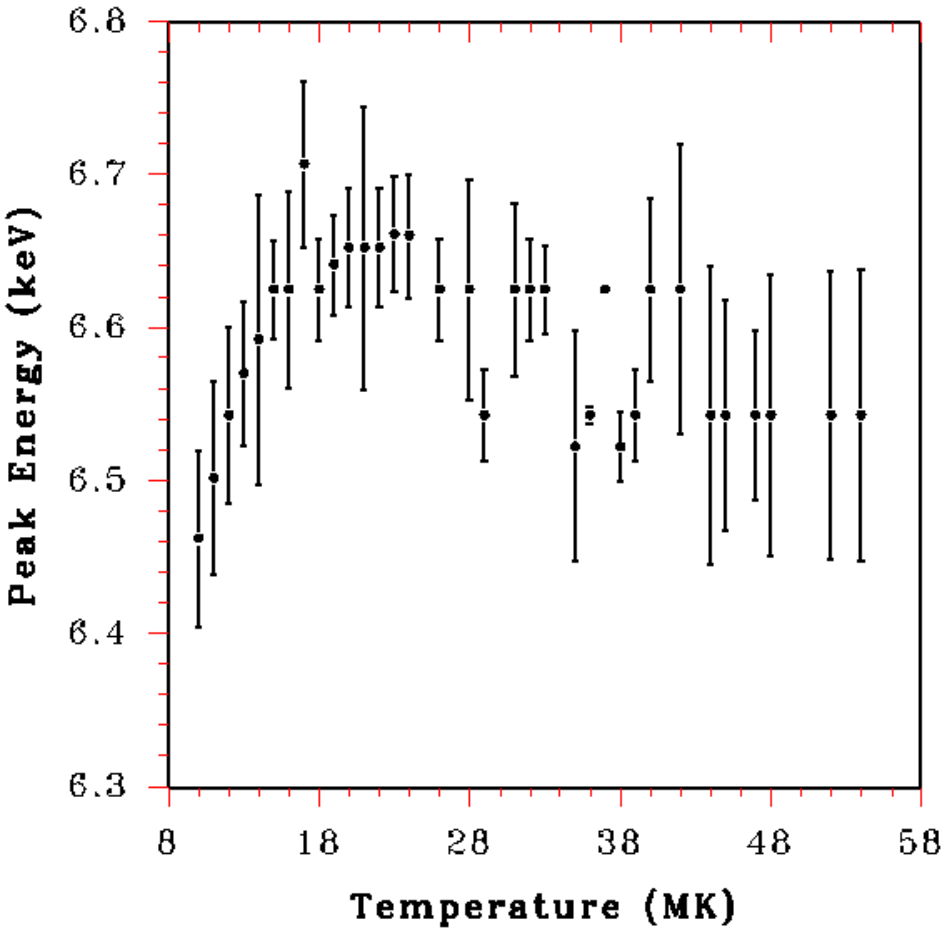

Si
14/08/04
05:42:47 UT
Photons/cm^2/s/keV
Photon Energy (keV)
THERMAL
T = 14.00
EM = 62.80
Chsq= 1.55
SUPER HOT
T = 37.70
EM = 1.25
Chsq= 1.03

Table I

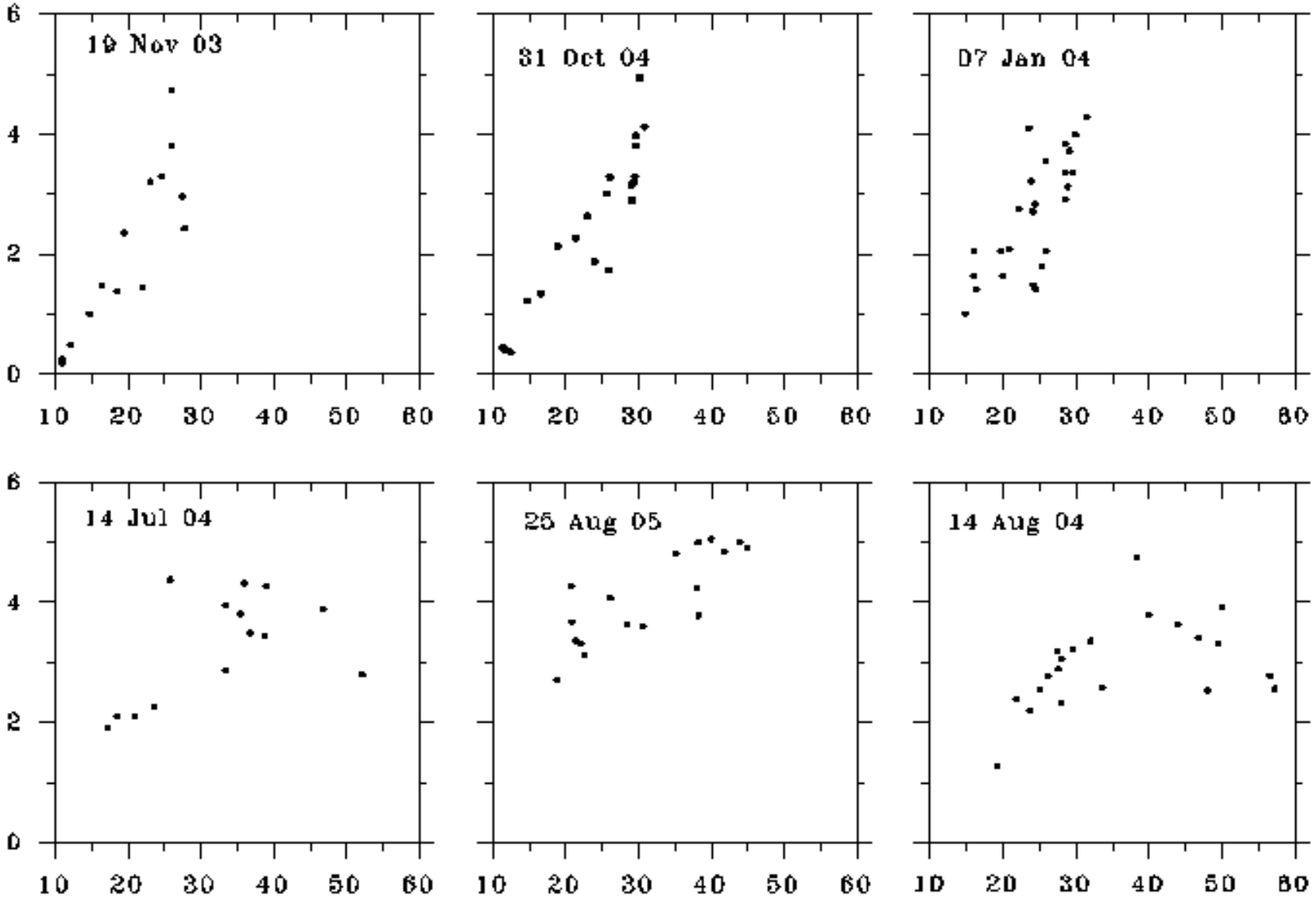
SLD/SOXS Flare events considered for investigation

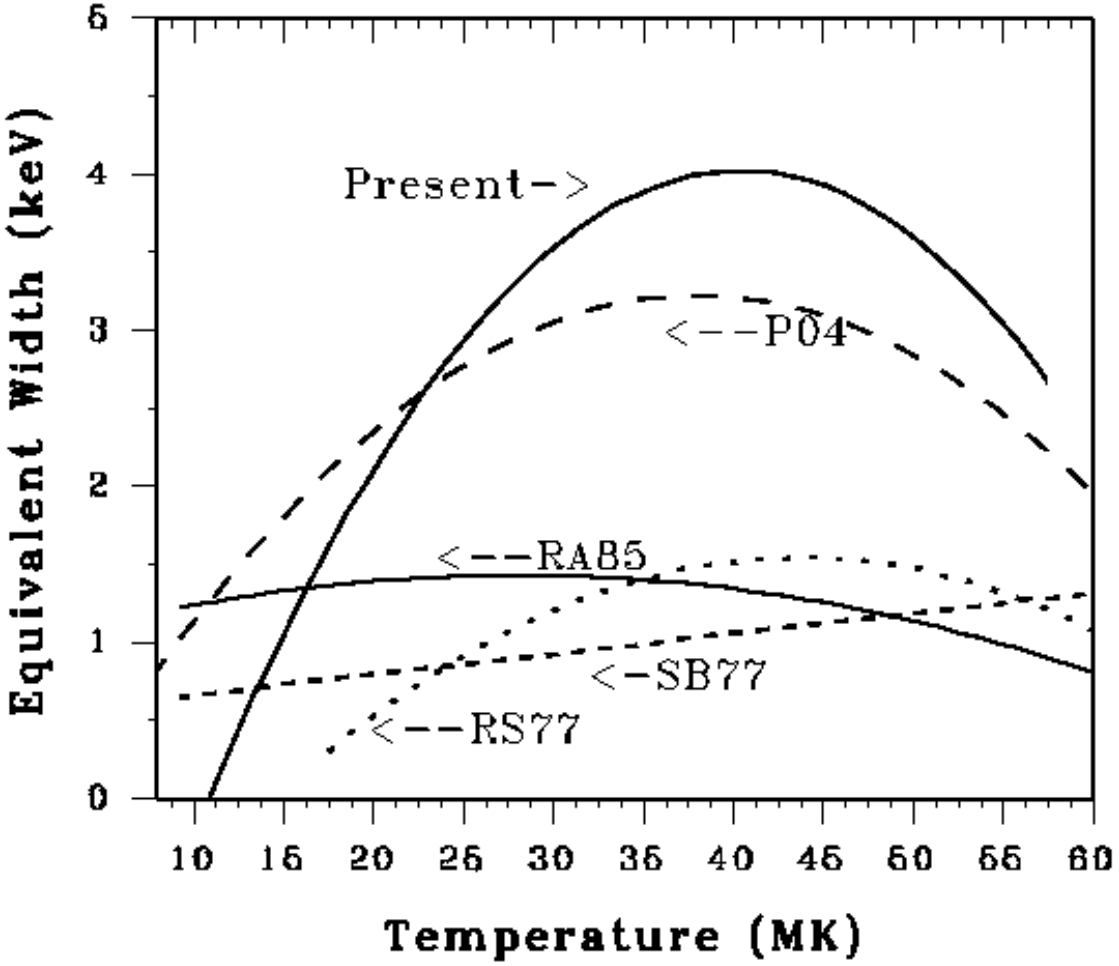
S. No.	Date	Time UT			GOES	Active Region	
		Begin	Peak	End	Class	Location	NOAA
1.	30 Jul 2003	0407	0409	0428	M2.5	N16 W55	10422
2.	13 Nov 2003	0454	0501	0510	M1.6	N04 E85	10501
3.	19 Nov 2003	0358	0402	0419	M1.7	N01 E06	10501
4.	07 Jan 2004	B0355	0400	0433	M4.5	N02 E82	10537
5.	25 Mar 2004	0429	0438	0507	M2.3	N12 E82	10582
6.	25 Apr 2004	0528	0536	0558	M2.2	N13 E38	10599
7.	14 Aug 2004	0413	0414	0432	M2.4	S13 W30	10656
8.	31 Oct 2004	0526	0531	0546	M2.3	N13 W34	10691
9.	14 Jul 2004	0518	0523	A0525	M6.2	N12W62	10646
10.	25 Aug 2005	0436	0439	0452	M6.4	N07E78	10803



Jain et al., 2006, Solar Phys

$$w = \int_{Line} \frac{[I(E_f) - I(E_c]}{I(E_c)} \mathrm{dE}$$





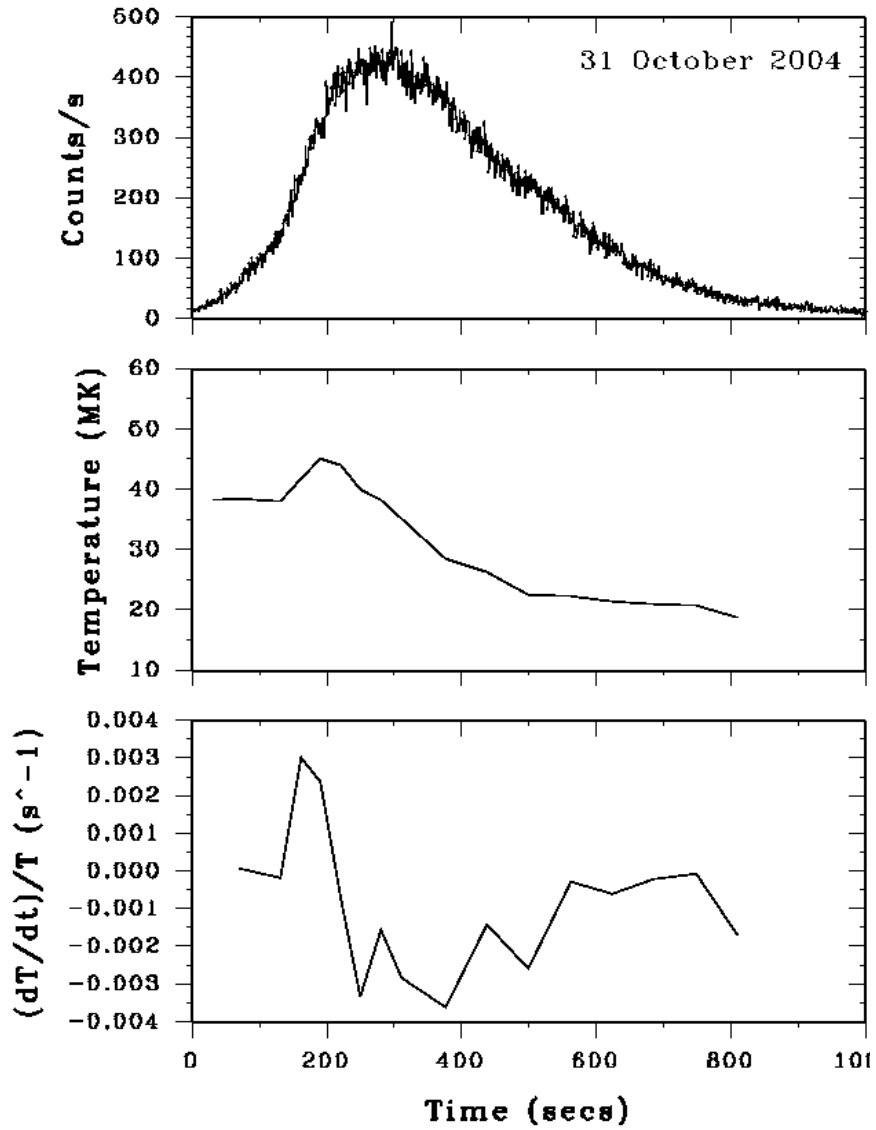
Jain et al., 2006, Solar phys.

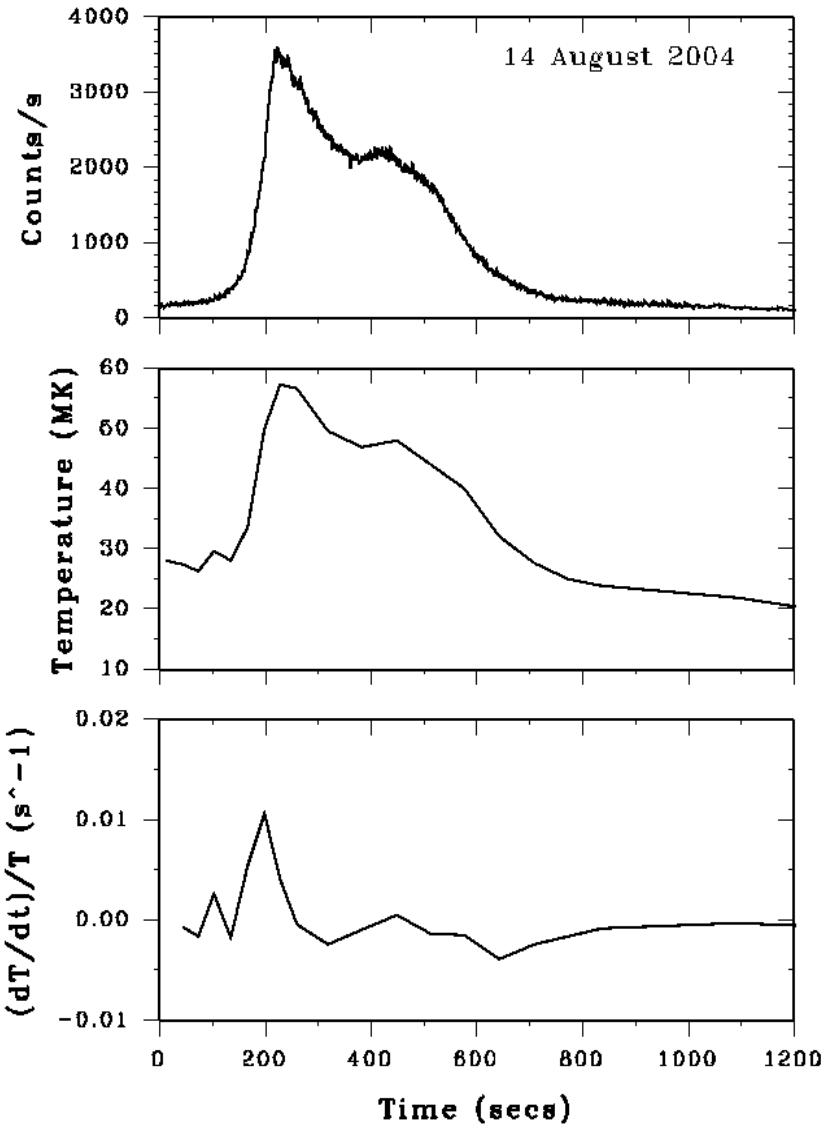
P04: Phiilips, K.J.H., (2004), ApJ, 605, 921-930

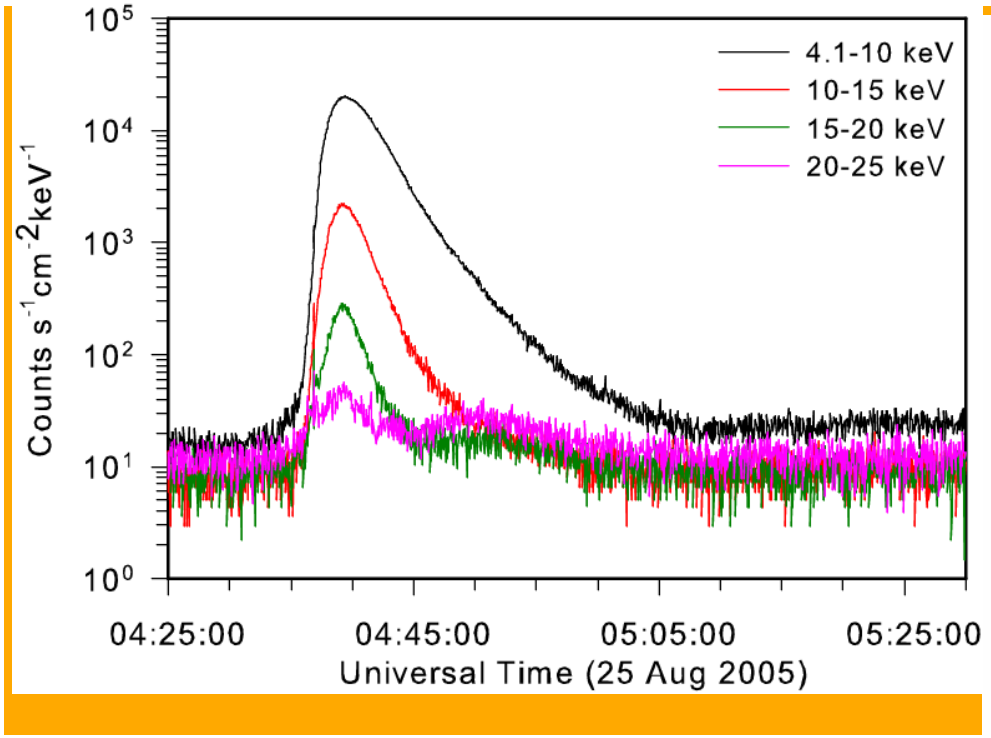
RA85: Rothenflug, R.; Arnaud, M. Astron & Astrophys., 144, 431-442

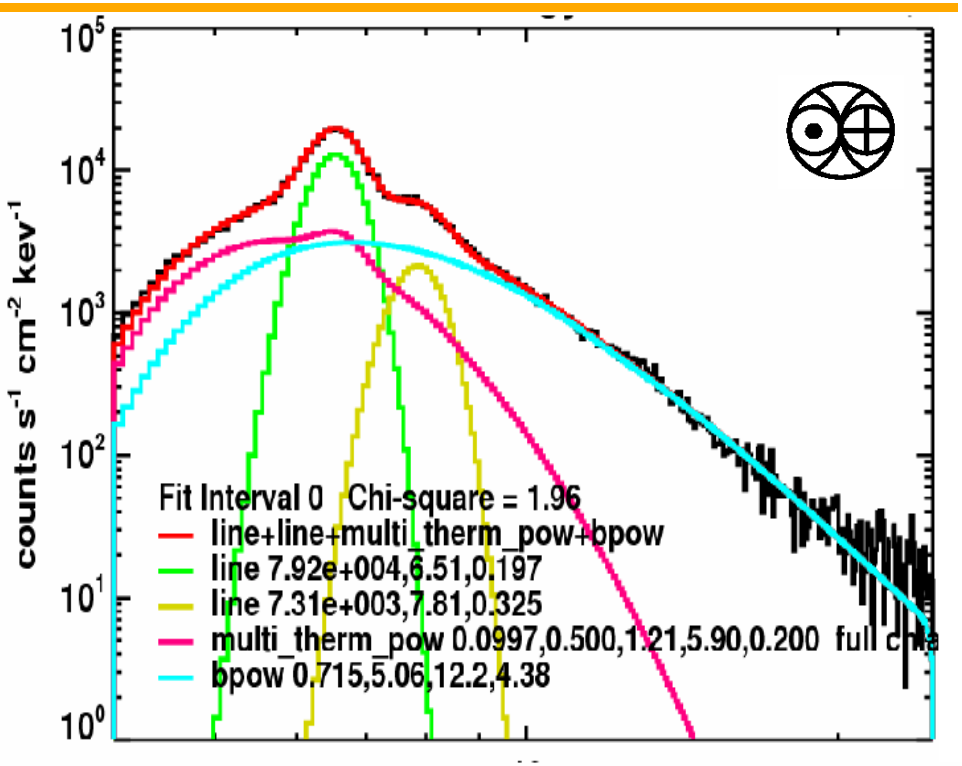
SB77: Sarazin, C. L., and Bahcall, J. N.; 1977, ApJ Suppl., 34, 451-467.

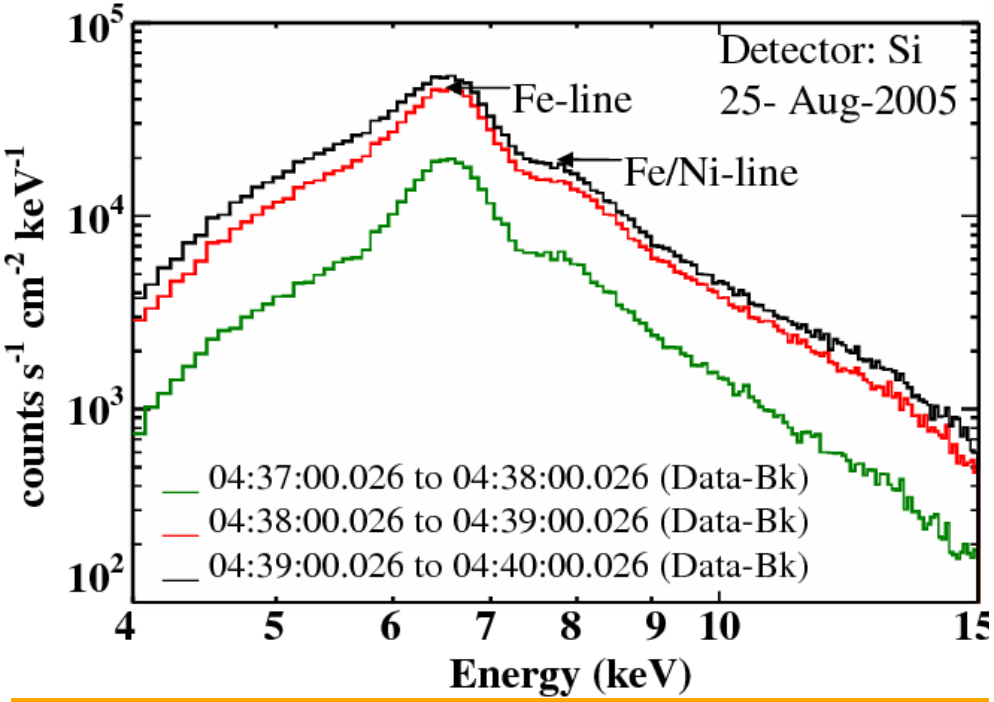
RS77: Raymond, J. C., and Smith, B. W.; 1977, ApJ Suppl., 35, 419-439.

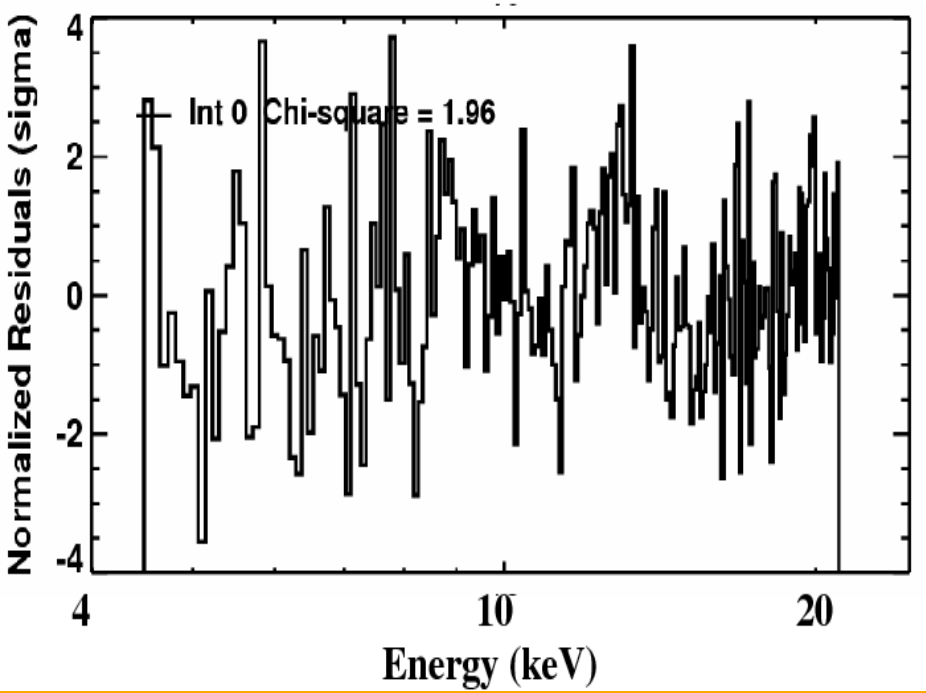

31 October 2004
Counts/s
Temperature (MK)
(dT/dt)/T (s^-1)
Time (secs)

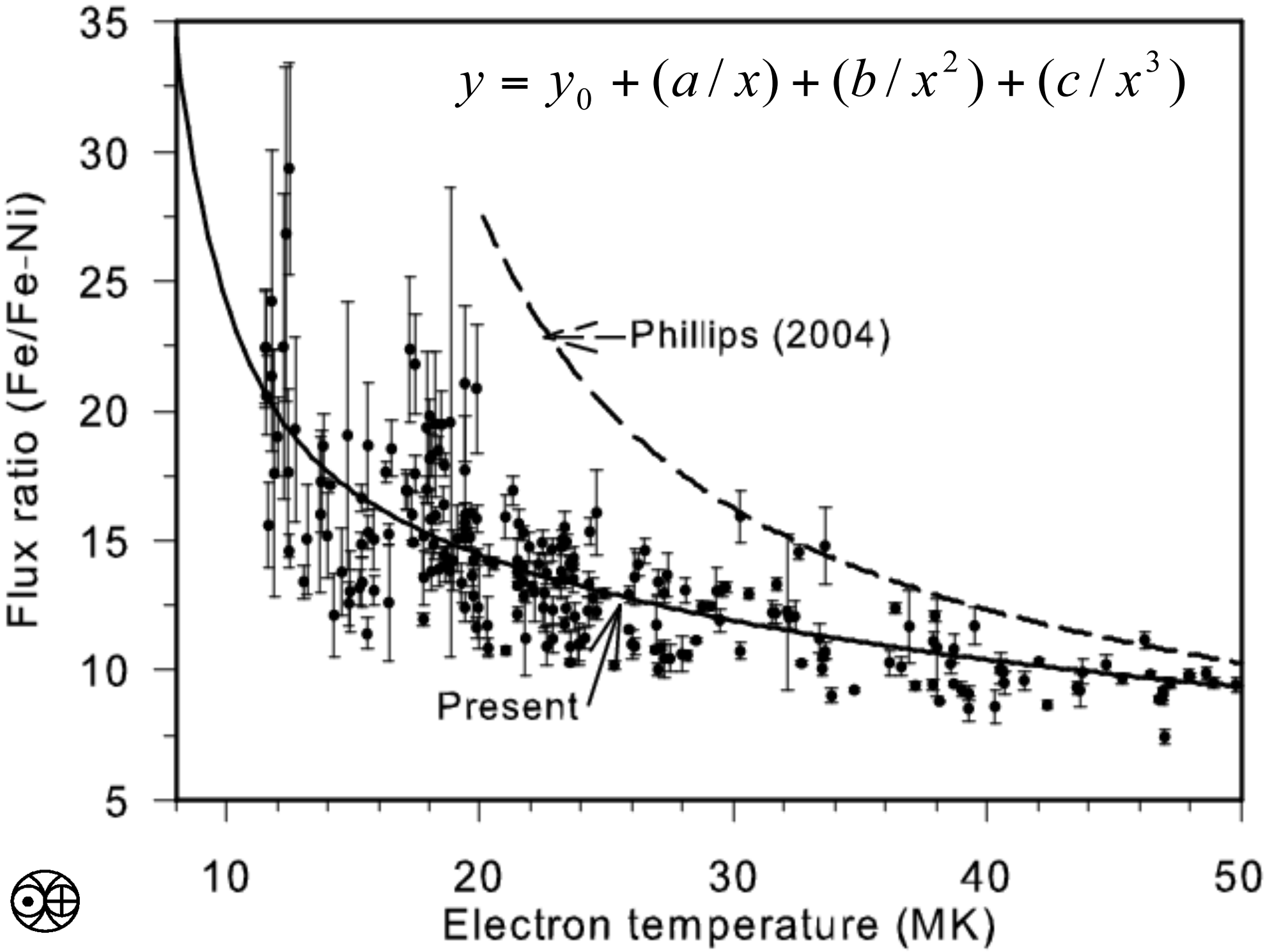

14 August 2004
Counts/s
Temperature (MK)
(dT/dt)/T (s^-1)
Time (secs)


4.1-10 keV
10-15 keV
15-20 keV
20-25 keV
Counts s^{-1}cm^{-2}keV^{-1}
04:25:00
04:45:00
05:05:00
05:25:00
Universal Time (25 Aug 2005)


counts s^{-1} cm^{-2} kev^{-1}
Fit Interval 0 Chi-square = 1.96
line+line+multi_therm_pow+bpow
line 7.92e+004,6.51,0.197
line 7.31e+003,7.81,0.325
multi_therm_pow 0.0997,0.500,1.21,5.90,0.200 full
bpow 0.715,5.06,12.2,4.38


Detector: Si
25- Aug-2005
Fe-line
Fe/Ni-line
counts s^{-1} cm^{-2} keV^{-1}
04:37:00.026 to 04:38:00.026 (Data-Bk)
04:38:00.026 to 04:39:00.026 (Data-Bk)
04:39:00.026 to 04:40:00.026 (Data-Bk)
Energy (keV)


Int 0 Chi-square = 1.96
Normalized Residuals (sigma)
Energy (keV)


$y = y_0 + (a/x) + (b/x^2) + (c/x^3)$
Phillips (2004)
Present
Flux ratio (Fe/Fe-Ni)
Electron temperature (MK)
35
30
25
20
15
10
5
10
20
30
40
50

Future Plans

1. Next Generation SOXS is under discussions.

a) We plan Solar X-ray Spectroscopy covering energy range from 1-100 keV.

b) We propose to use four detectors *viz.*

   1. SDD very small area for 0.3-3 keV – to study line emission.
   2. SDD small area for 1-10 keV – to study line + thermal regime
   2. SDD large area for 4-30 keV – to study thermal regime
   3. CdTe or Ga-As large area for 10-100 keV – to study thermal+ non-thermal regimes.

2. Solar Energetic Particle spectrometer (already in developmental stage)

3. Simultaneous observations in X-ray, optical (H-alpha) and radio waveband is planned next year.

Conclusions

1. SOXS is operating satisfactorily. However, due to high temperature limits on the spacecraft its operation time now is restricted to 2 hrs daily.

2. SOXS so far has observed more than 700 flares of >B2.0 *GOES* class.

3. SOXS Data is available at: http://www.prl.res.in/~soxs-data
Data may be downloaded and analyzed in SolarSoft.
Instrumental functions are incorporated in the SolarSoft

4. SOXS marks detection of Fe and Fe/ Ni line complexes distinctly separate.

5. SOXS observations reveal flare plasma of multi-thermal nature.

6. Peak energy and Equivalent width of Fe line complex vary over temperature.

7. Flux ratio of Fe to Fe/Ni line features decreases exponentially with flare plasma temperature in 12-20 MK.

8. Next generation solar X-ray spectroscopy in the energy range 0.1-100 keV is planned. Energetic particle spectrometer is under development.

Key Issues

- **Diagnostics of line emission between 0.1 and 10 keV;**

  High energy resolution and counts handling capabilities are challenge.
- **Fe and Fe/Ni line features also appear in micro-flares, some of which are non-thermal. Any non-thermal contribution to line formation?**
- **"The >20 keV electrons contain 10 to 50% of the total energy output" Lin and Hudson (1976).**

  Not a single component of the energy budget "is presently known to better than an order of magnitude" (Hudson 1986). Still a challenge.
- **Energy in electrons is uncertain because of lower energy cutoff to spectrum (Lin et al., 2002).**

  Thermal energy in plasma is uncertain because of uncertain volume, density, filling factor.
- **Only plasma in narrow temperature range is generally imaged. It is not uniform all over?**

  Temperature of coronal flare plasma: Time scales of isothermal or multi-thermal is challenge. (Jain et al., 2008).
- **Pre-flare to main flare connection in context to energy release.**

  No detailed study is made so far.
- **Re-acceleration of electrons during the flare?**

  High-time and high-energy resolution X-ray spectroscopy is required, which is a challenge?

Thank you