Non-thermal diagnostics of flares observed by RESIK

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Motivation

The Polish soft X-ray spectrometer RESIK *(REntgenovski Spektrometer s Izognutimi Kristalami)* was operated on Russian Coronas-F spacecraft during the years 2001-2003. RESIK observed X-ray flare spectra in wavelength range of 3.35 - 6.05 Å.

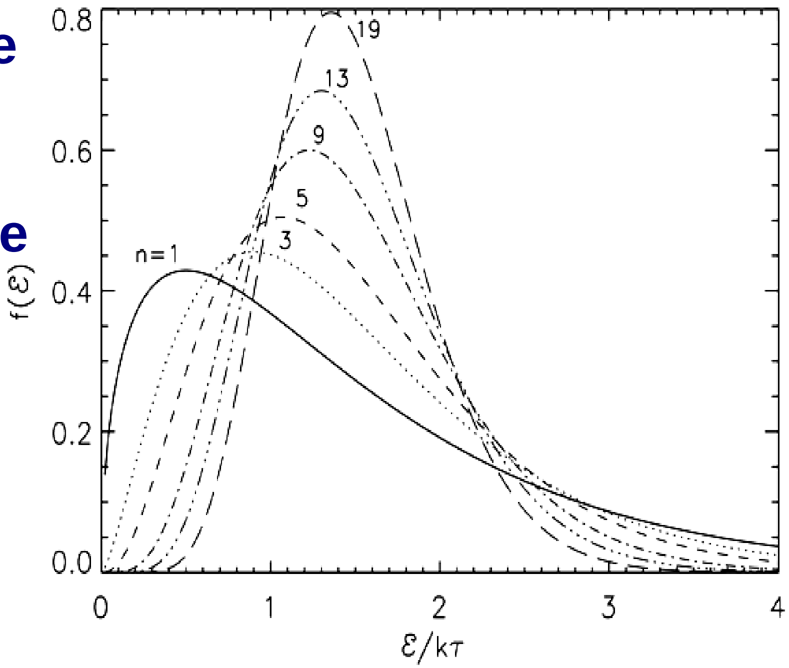
Brief inspection of several flare spectra shows rather high fluxes of dielectronic satellites of Si XII (Si XIId) in comparison with the fluxes of allowed Si XIII or Si XIV lines. Dzifčáková *et al*. (*2008, A&A, 488, 311*) have reported that this kind of spectra could be explained under the assumption of non-thermal electron distribution.

Non-thermal electron distribution:

- can occur in flare plasma when beams of accelerated electrons appear and are neutralized by the so called return current (*Dzifčáková and Karlický, 2008, SP, 250, 329*). Both the electron beam and the return current modify the electron distribution function.

- changes the ionization and excitation equilibrium - changes in the ratios of spectral line intensities and it allows us to diagnose the shape of electron distribution.

As the non-thermal distribution here we consider the so called n-distribution.
It describes the bulk of non-thermal plasma electrons but it does not include the effects of the high-energy tail.



$$f(E)dE = B^n \left(\frac{m}{2\pi kT}\right)^{\frac{3}{2}} \left(\frac{E}{kT}\right)^{\frac{(n-1)}{2}} e^{-\frac{E}{kT}} E^{\frac{1}{2}} dE$$

$$\langle E \rangle = \frac{(n+2)}{2} kT = \frac{3}{2} k\tau \qquad \tau = \frac{n+2}{3} T$$

Diagnostics

- **The best diagnostic are the ratios of satellite and allowed lines of ions of one element in different ionization stages.**

- ***The satellite lines sample the electron distribution function at discrete energies while the intensities of the allowed lines depend on the integral of the product of the collisional cross sections with electron velocity over the distribution function from the excitation energy.***

For the aimed analysis the following lines from RESIK spectra from Channel 4 have been used:

ion	wavelength	transition
Si XIV	5.217, 5.218	$1s\ ^2S_{1/2} – 2p\ ^2P_{1/2,3/2}$
Si XIII	5.681, 5.689	$1s^2\ ^1S_0 – 1s\ 3p\ ^{1,3}P_1$
Si XIId	5.816	$1s^2\ 2p\ ^2P_{1/2,3/2} – 1s\ 2p\ 3p\ ^2D_{3/2,5/2}$
	5.818	$1s^2\ 2p\ ^2P_{3/2} – 1s\ 2p\ 3p\ ^2D_{3/2}$

Synthetic spectra

A grid of synthetic spectra (5 - 6 Å) has been calculated using 'the non-thermal' modification of CHIANTI package (Dzifčáková, 2006):

- Isothermal approximation - log τ = 6.7 – 7.3 with step 0.02
- constant $n_e = 10^{10}$ cm^{-3}
- RESIK abundances (C. Chifor, DAMTP, Cambridge, UK)
- column EM = 10^{22} cm^{-5}, FWHM=20.0 mÅ.
- the ionization equilibrium for n-distributions was calculated by Dzifčáková (2005).

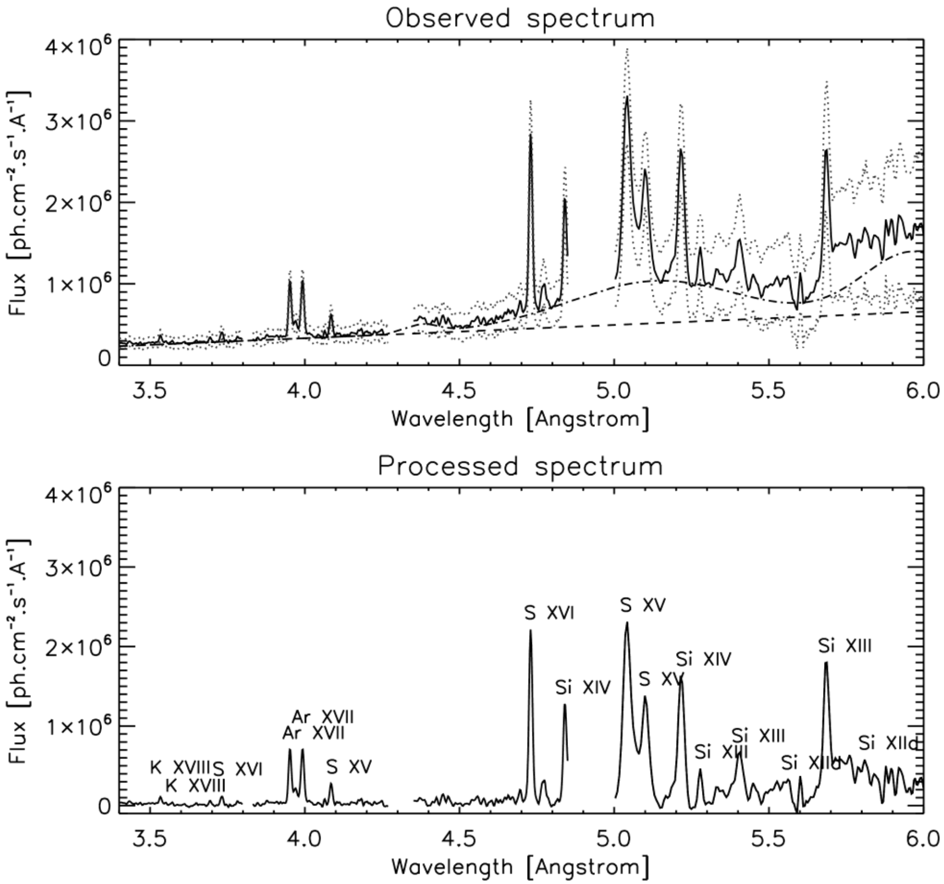
'The non-thermal' modification of CHIANTI package software and extended database allows computation of the excitation equilibrium for non-thermal distributions and involves computation of satellite line intensities. This modification will be included in new version of CHIANTI.

CHIANTI is a collaborative project involving the NRL (USA), RAL (UK), MSSL (UK), the Universities of Florence (Italy) and Cambridge (UK), and George Mason University (USA). The software is distributed as a part of SolarSoft.

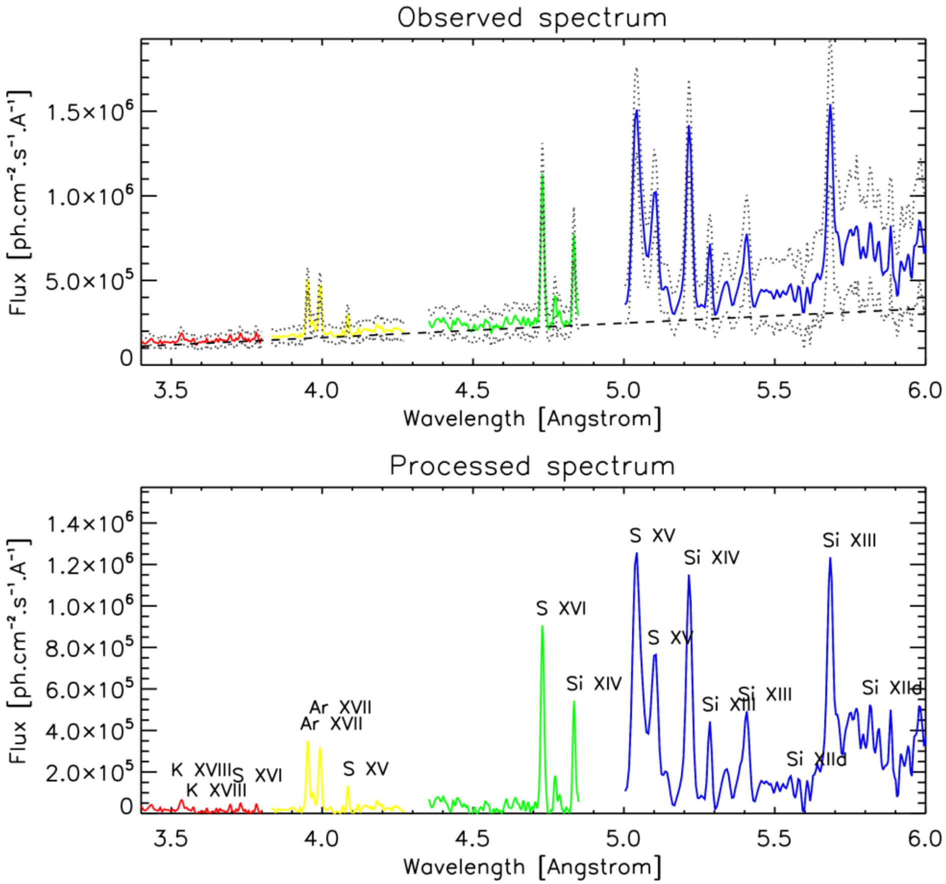
RESIK spectra – all chanels

Before the analysis of the spectra the linear approximation of continuum has been subtracted.

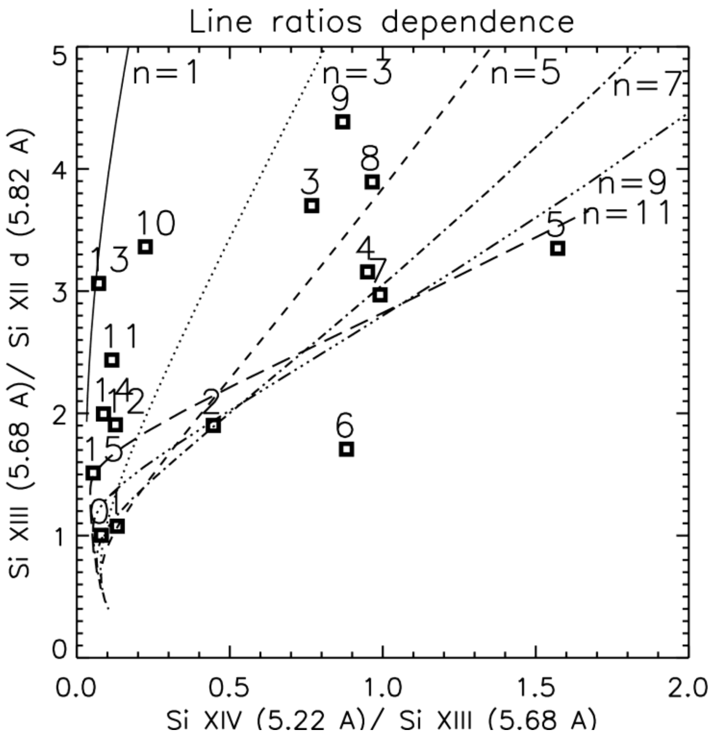
7 - Jan - 2003, class M4.9 – *'mounds'*

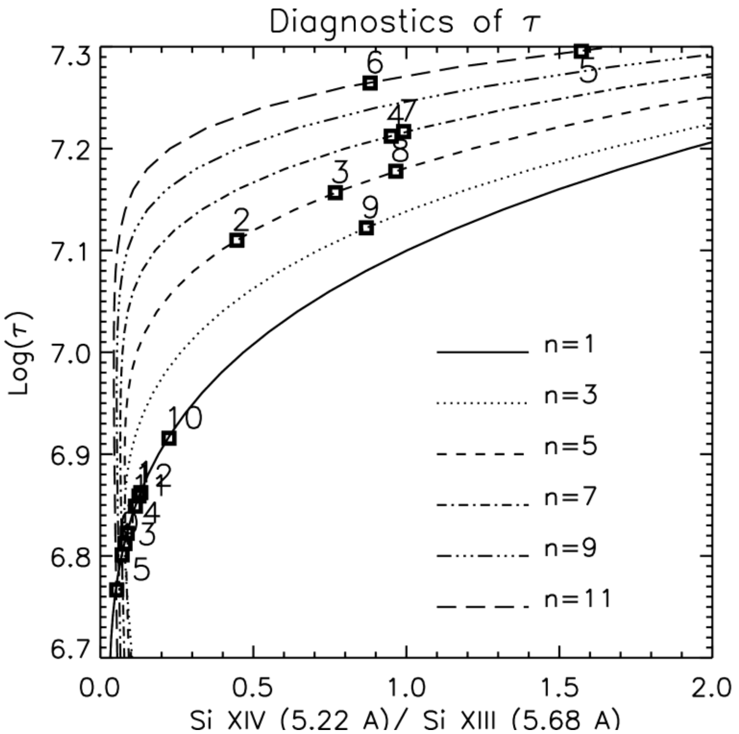


21- Jan - 2003, class C8.1 – Level2 data



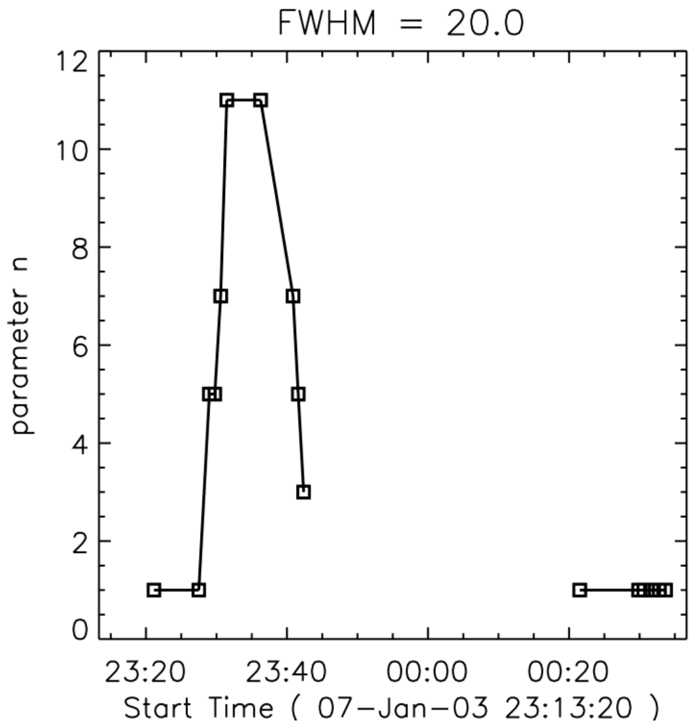
7 – Jan – 2003: 23:25 – 23:33 – 23:40 UT, M4.9, S14E81 – diagnostics of n and τ

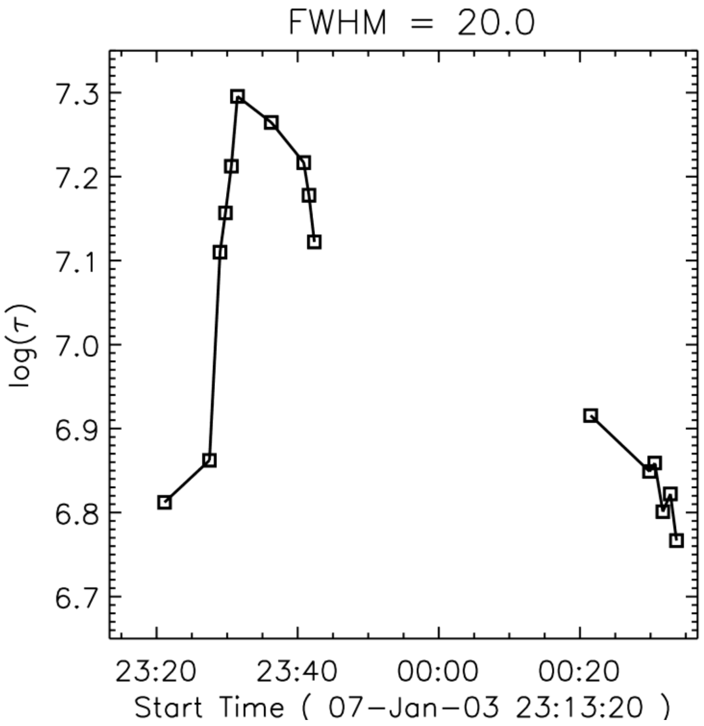




7 – Jan – 2003: 23:25 – 23:33 – 23:40 UT, M4.9, S14E81 – diagnosed parameters

Time evolution of parameter 'n' and log(τ):

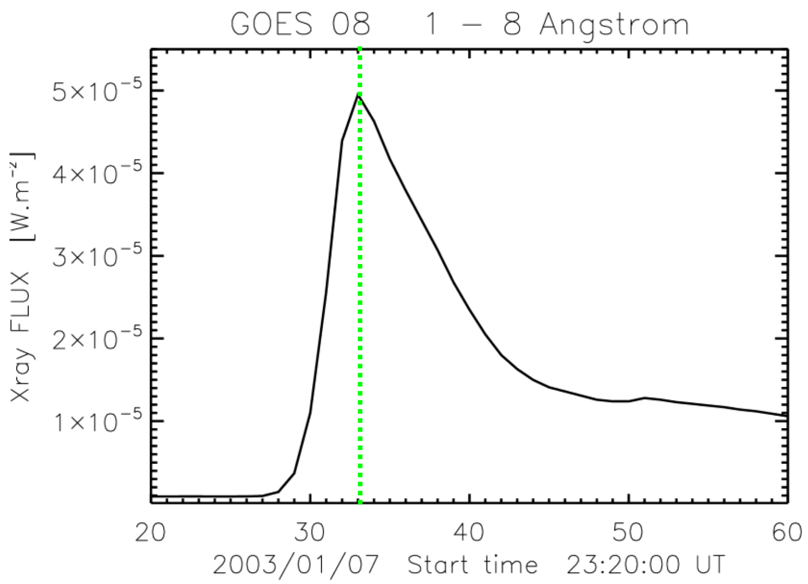


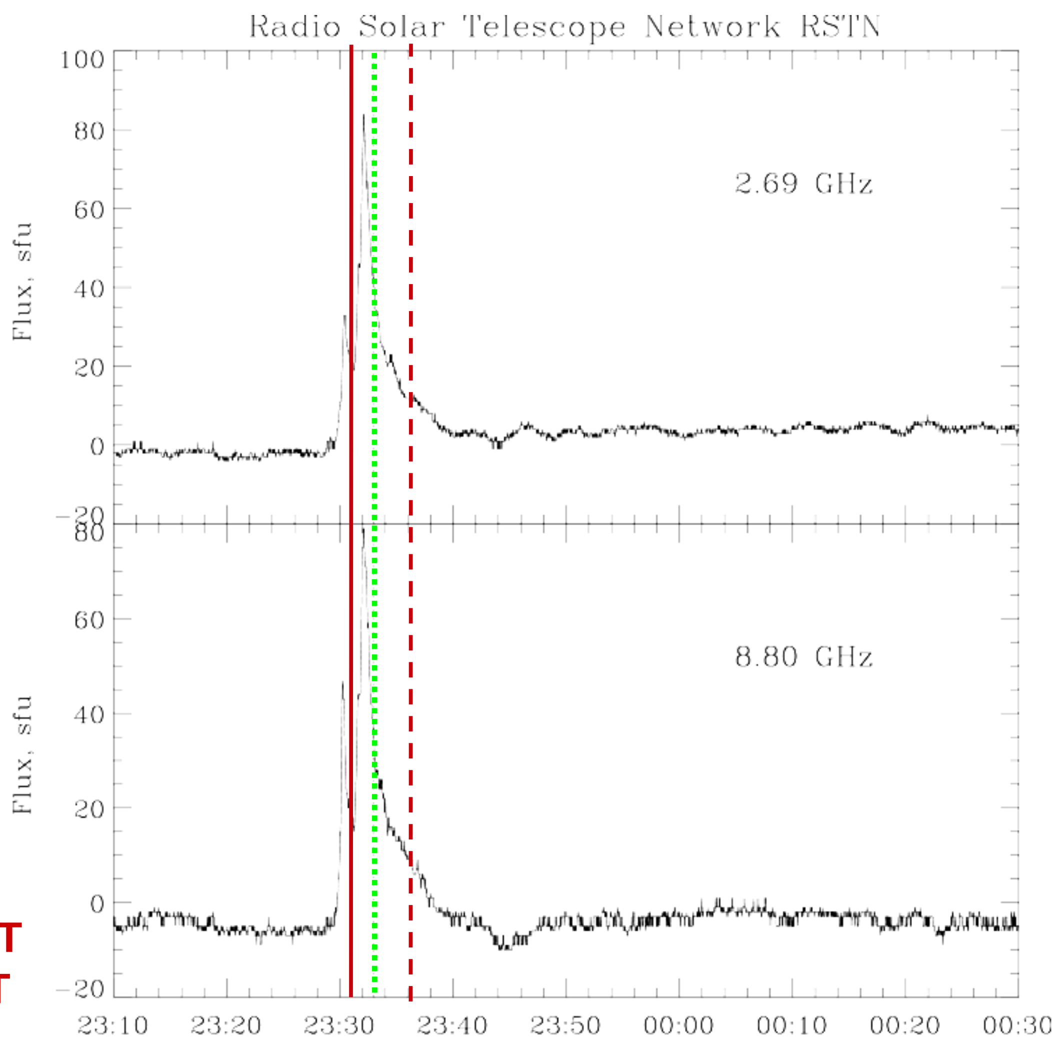


The parameter 'n' of the n-distribution reaches value of 11 about 23:31 UT and 23:36 UT and reaches log(τ)=7.296 K and log(τ)=7.264 K, respectively.

GOES-08 light curve and radio data

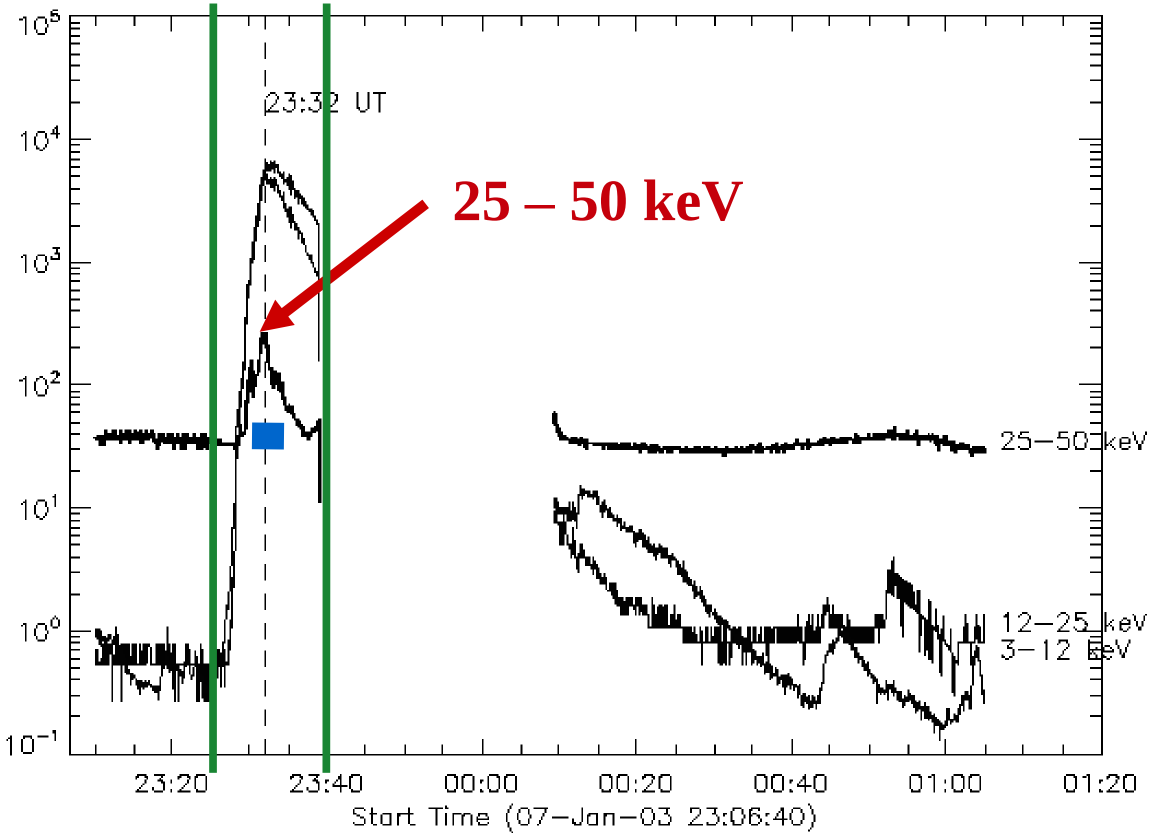
Jan 7th, 2003:
23:25 – 23:33 – 23:40 UT,
M4.9, S14E81





Observed type III: 23:31 – 23:32 UT
n = 11 and log(τ)=7.296 K 23:31 UT
n = 11 and log(τ)=7.264 K 23:36 UT

RHESSI light curves



Green lines indicate flare (GOES):

beginning	**23:25UT**
maximum	**23:33UT**
end	**23:40UT**

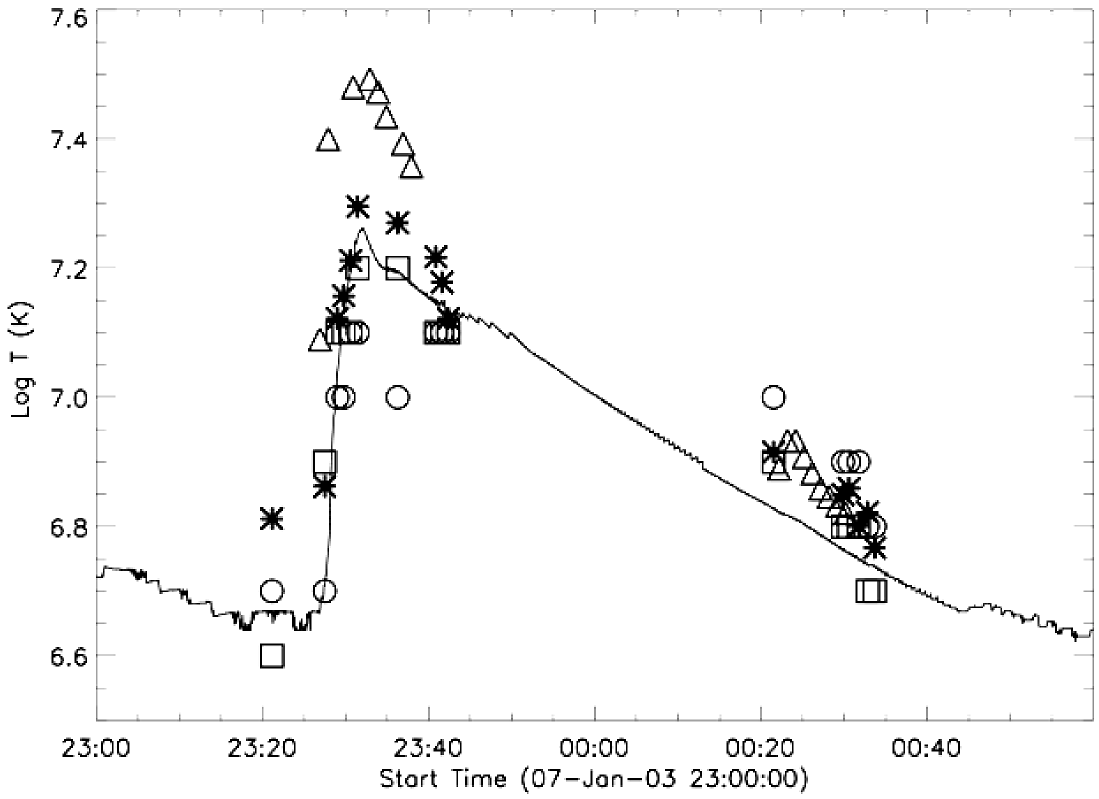
The blue line indicates the time of type III radio pulses: 23:31-23:33 UT

The red arrow shows the peak of high-energy emission at 23:32 UT

Courtesy of C. Chifor, DAMTP, Cambridge, UK

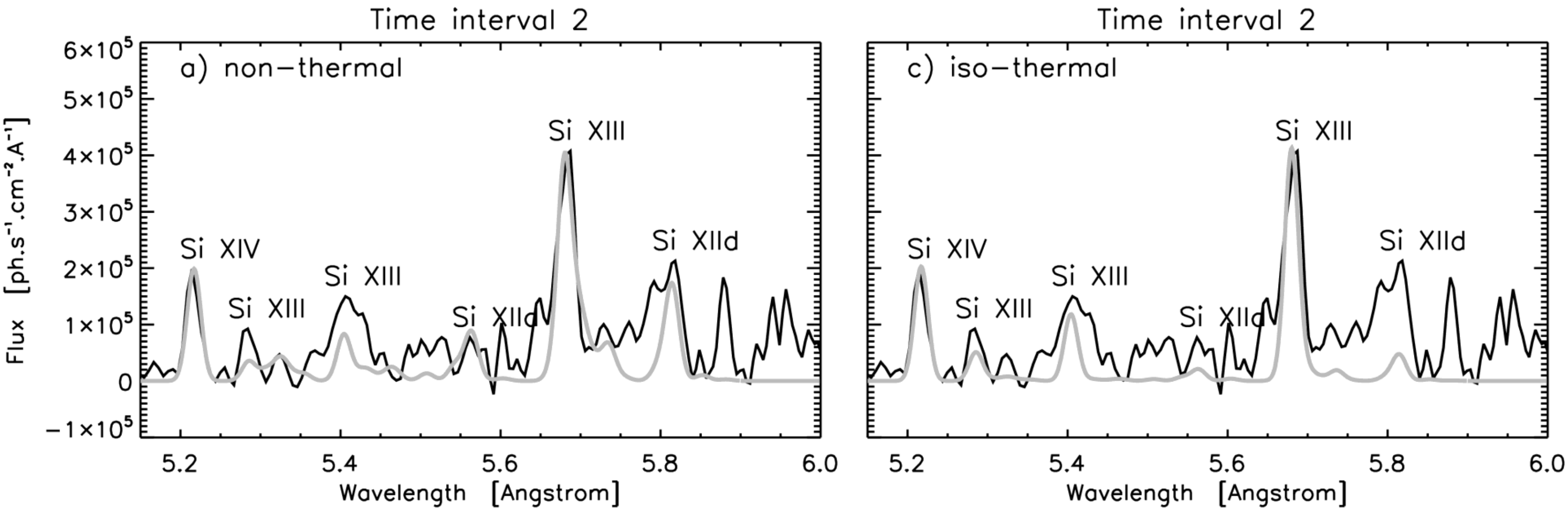
Results - log T and log τ

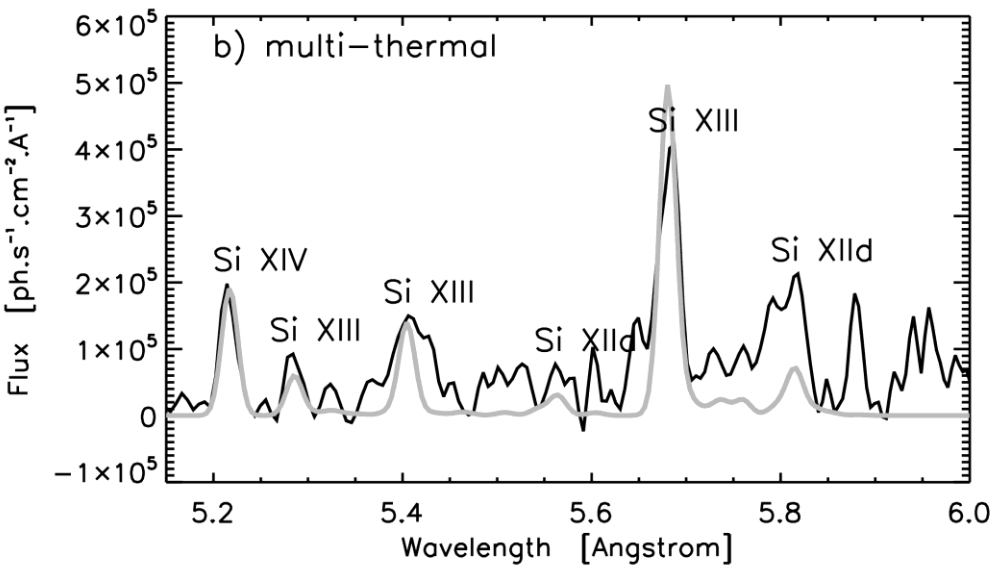
- **Squares** – T derived from the line EM loci analysis
- **Circles** – T_{max} corresponding to the maximum for the DEM curves
- **Solid curve** – T calculated from the ratio of 2 GOES channels assuming isothermal plasma
- **Triangles** – T derived from the slope of RHESS continua
- **Stars** – τ derived from non-thermal analysis



Courtesy of C. Chifor, DAMTP, Cambridge, UK

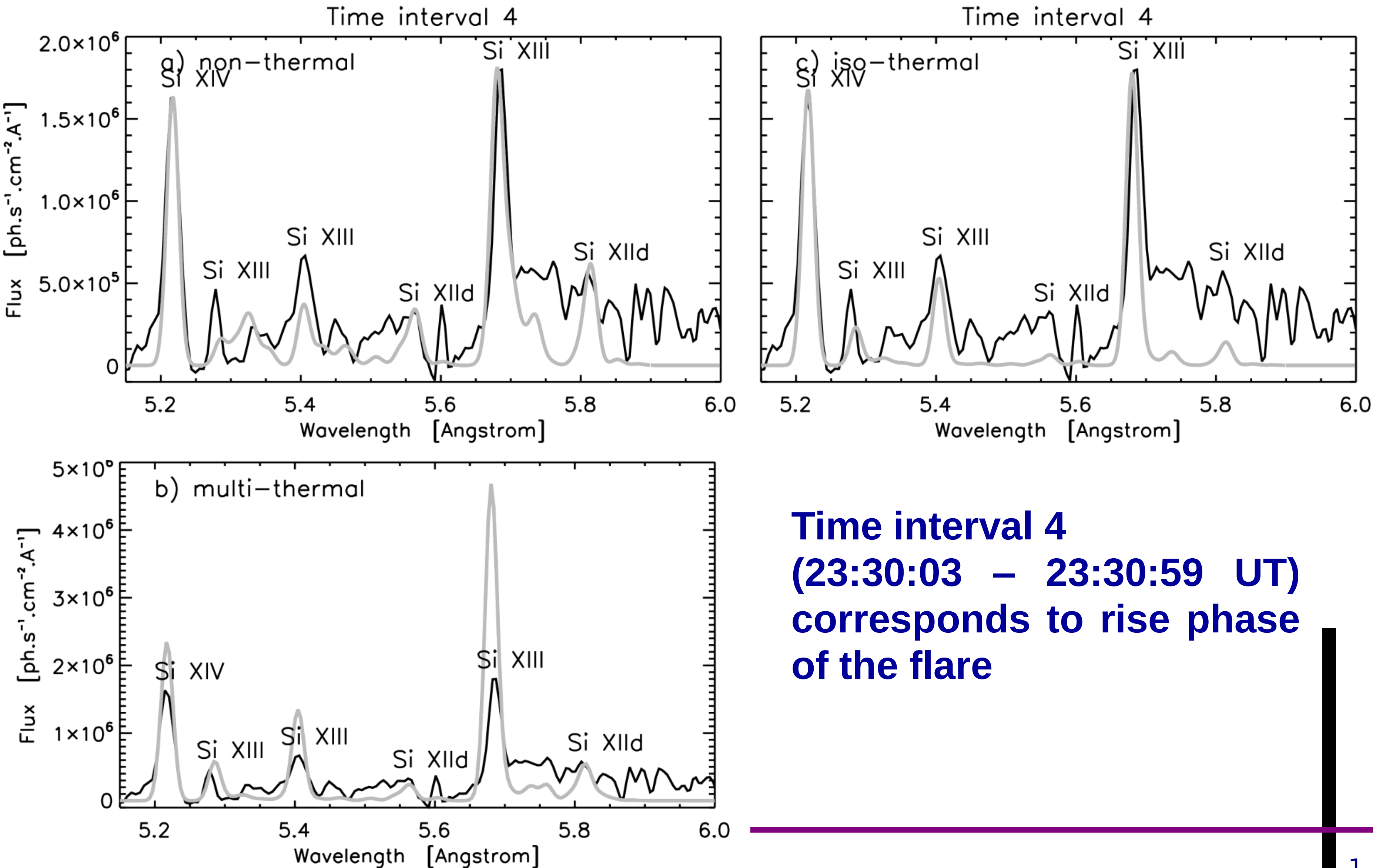
Synthetic vs. observed spectra





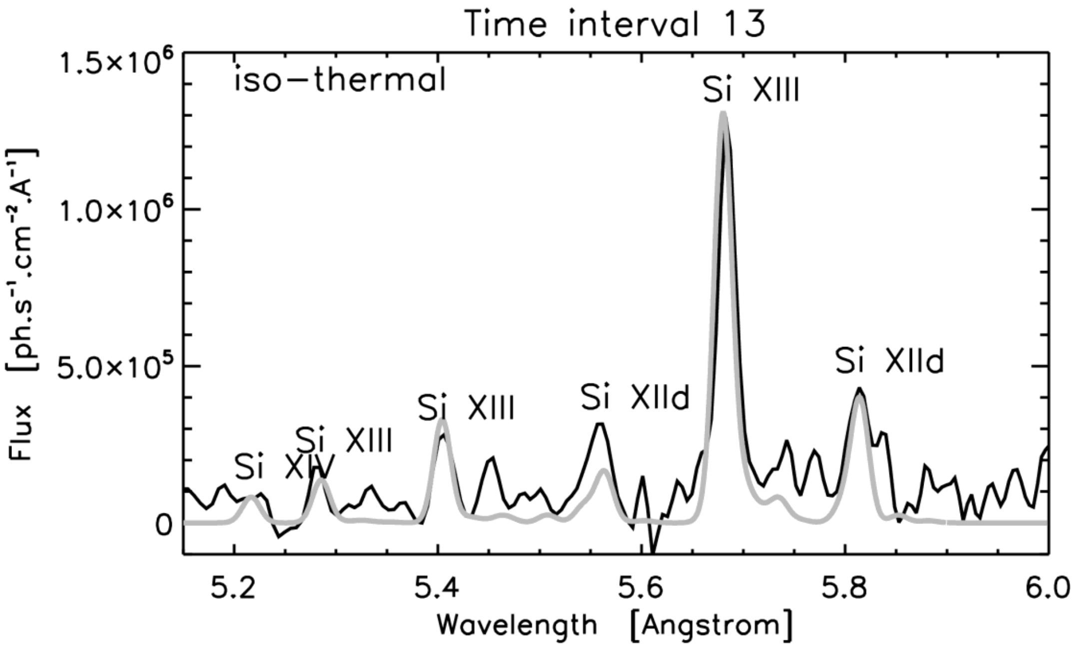
Time interval 2 (23:28:25 – 23:28:59 UT) corresponds to rise phase of the flare

Synthetic vs. observed spectra



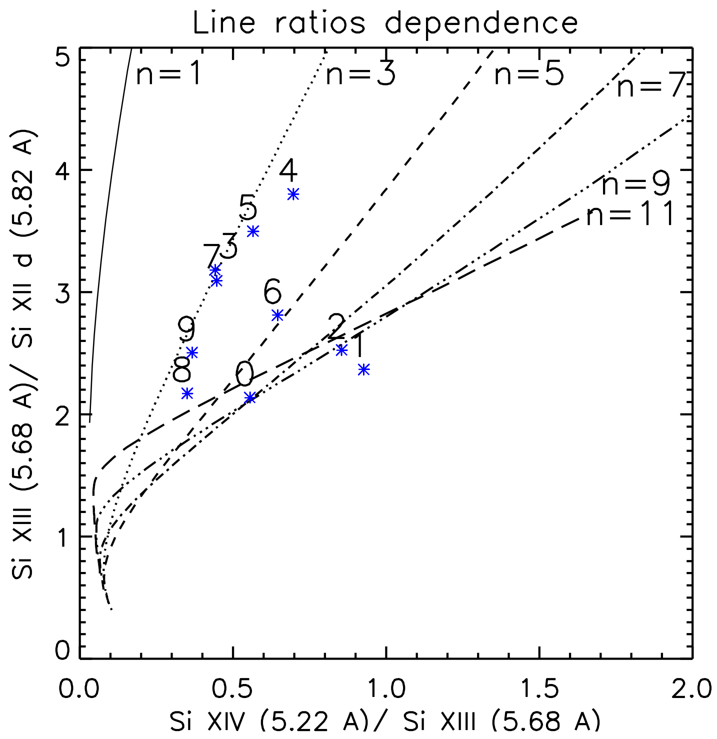
Time interval 4 (23:30:03 – 23:30:59 UT) corresponds to rise phase of the flare

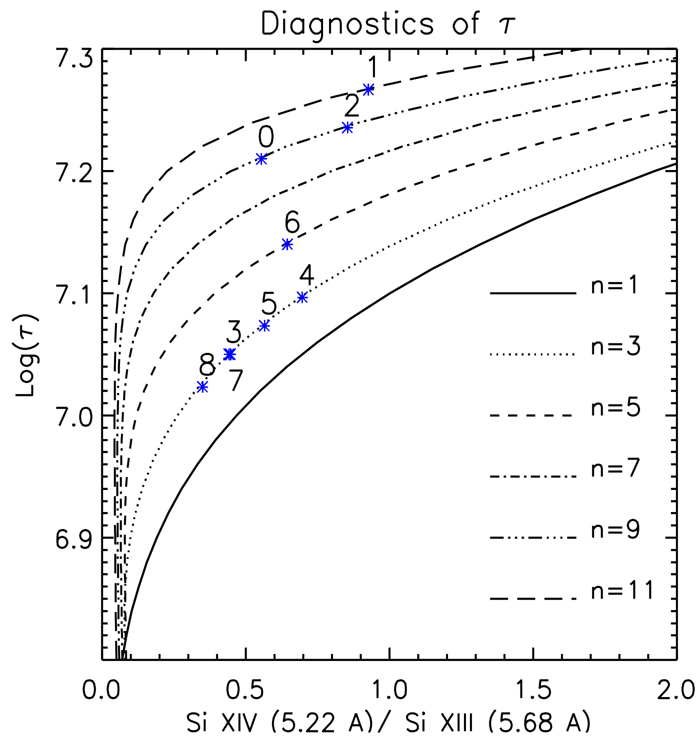
Synthetic vs. observed spectra



Time interval 13
(00:31:09 – 00:31:57 UT) corresponds to post-flare phase

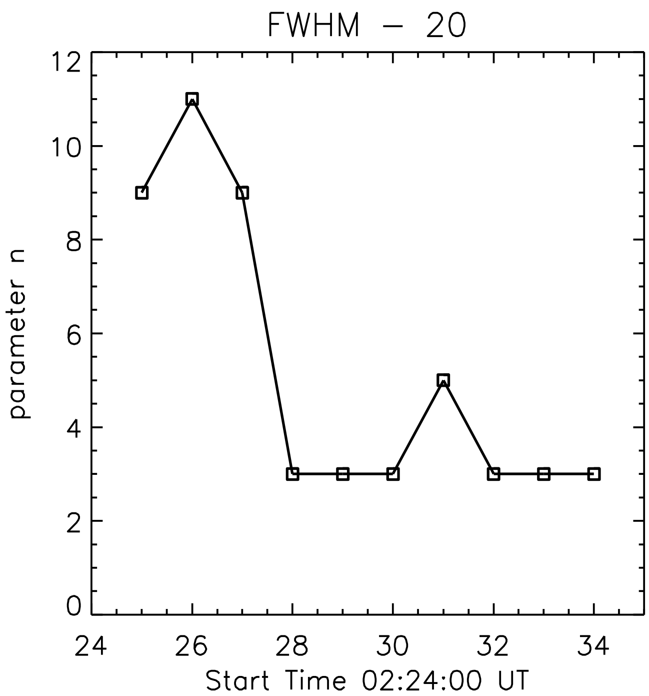
21 – Jan – 2003: 02:23 – 02:28 – 02:33 UT, C8.1, N14E09 - diagnostics of n and τ

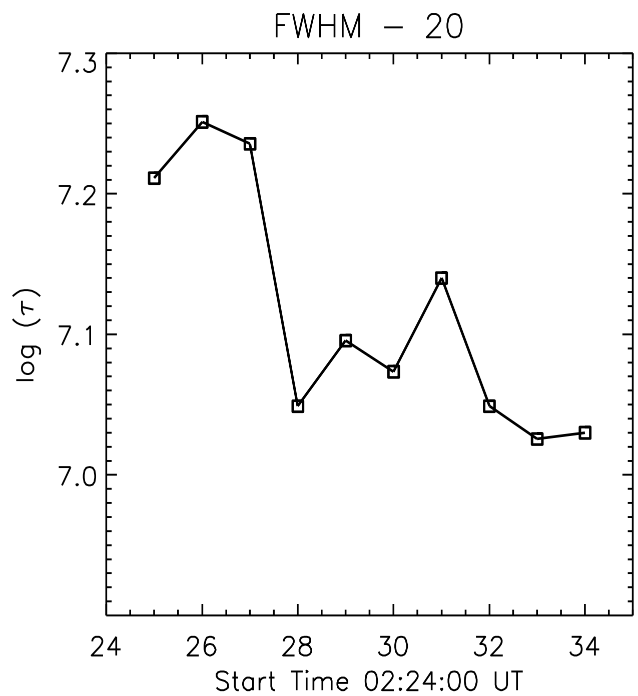




21 – Jan – 2003: 02:23 – 02:28 – 02:33 UT, C8.1, N14E09 – diagnosed parameters

Time evolution of parameter ‘n’ and log(τ):

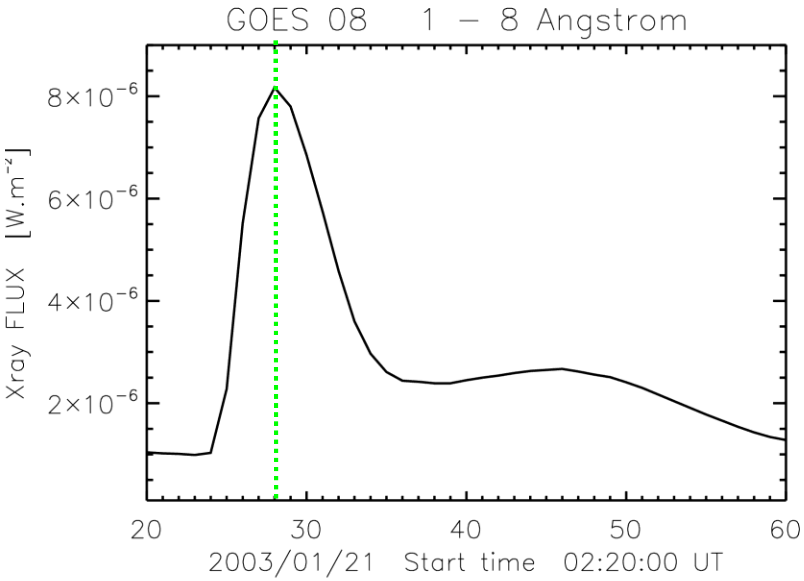


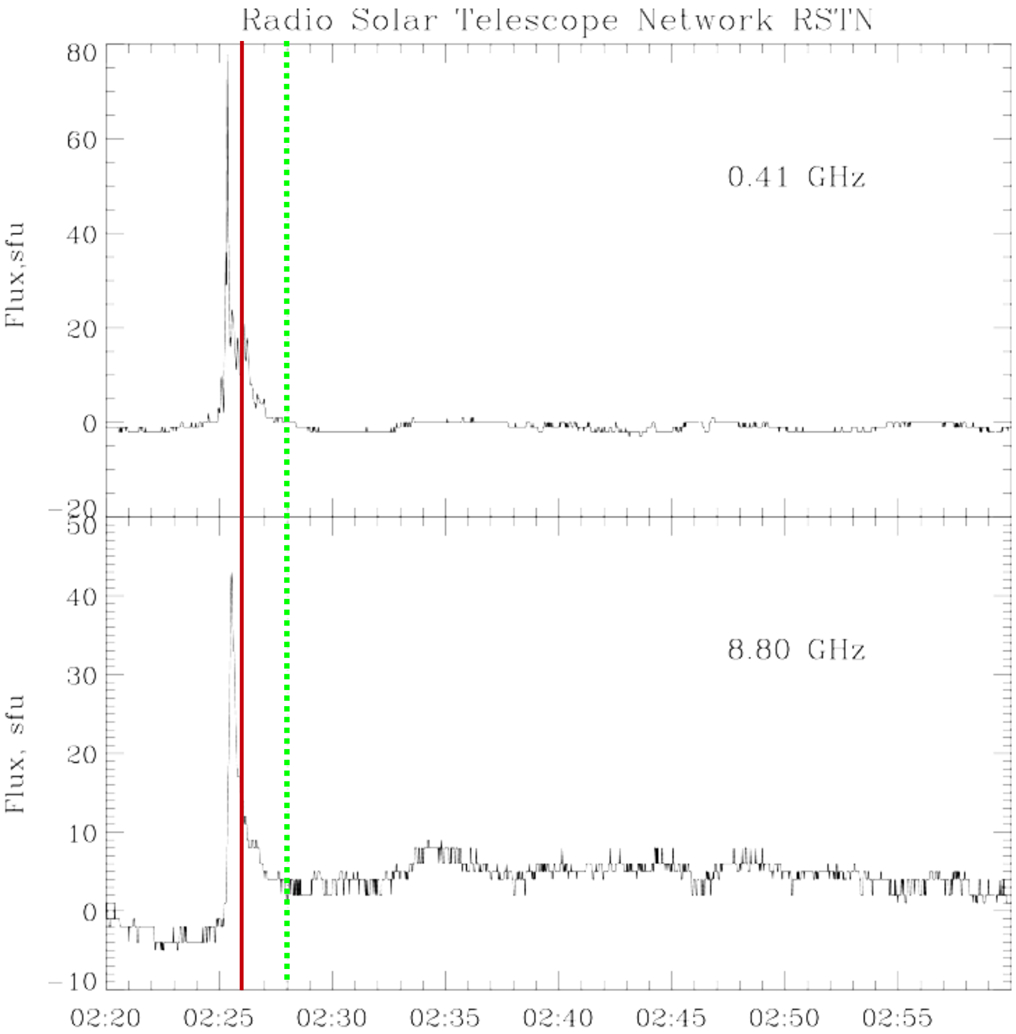


The parameter 'n' of the n-distribution reaches value of 11 and log(τ)=7.267 K about 02:26 UT .

GOES-08 light curve and radio flux

Jan, 21th, 2003:
02:23 – 02:28 – 02:33 UT,
C8.1, N14E09

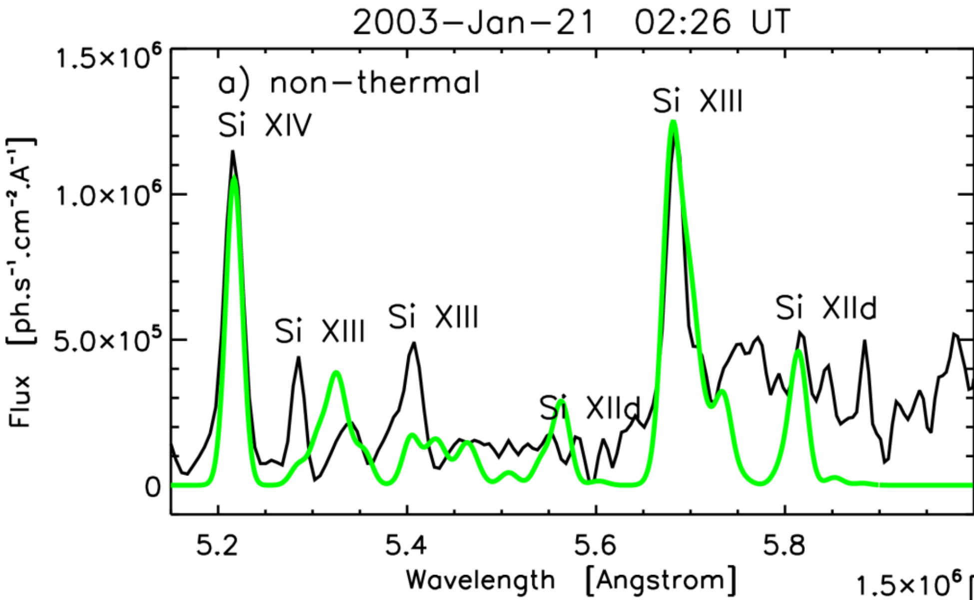




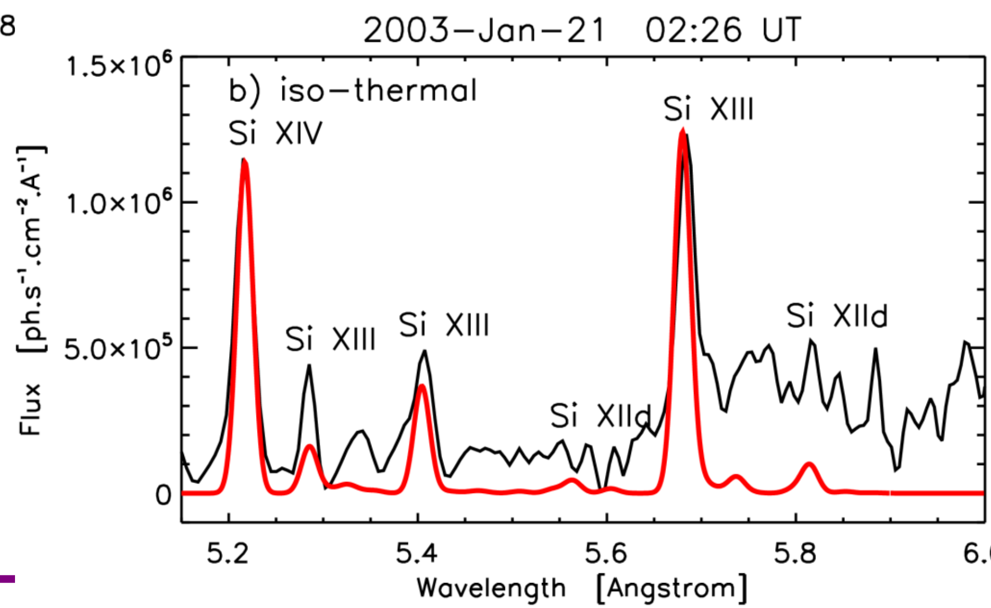
Observed type III: 02:24 – 02:29 UT

n = 11 and log(τ)=7.267 K 02:26 UT

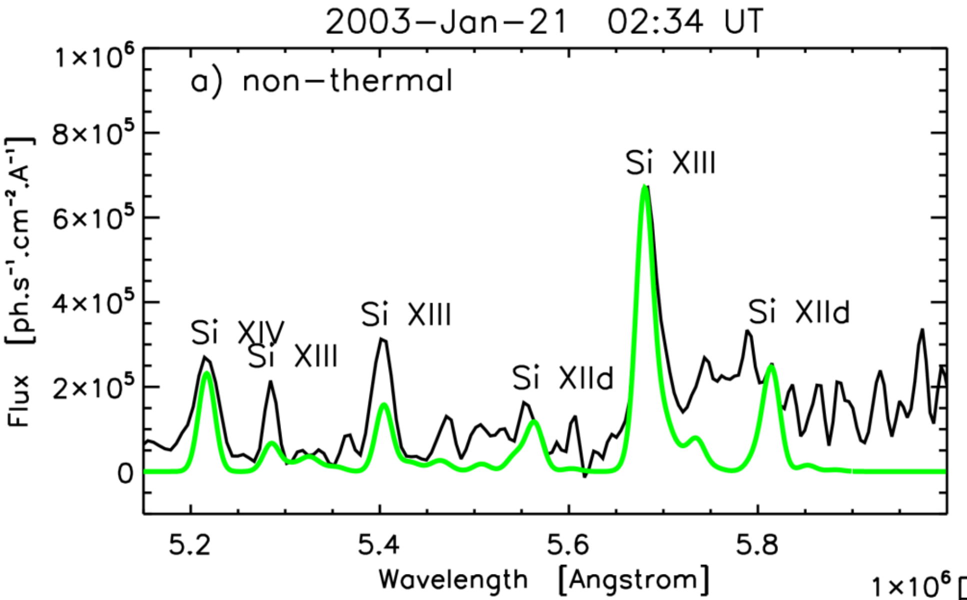
Synthetic vs. observed spectra



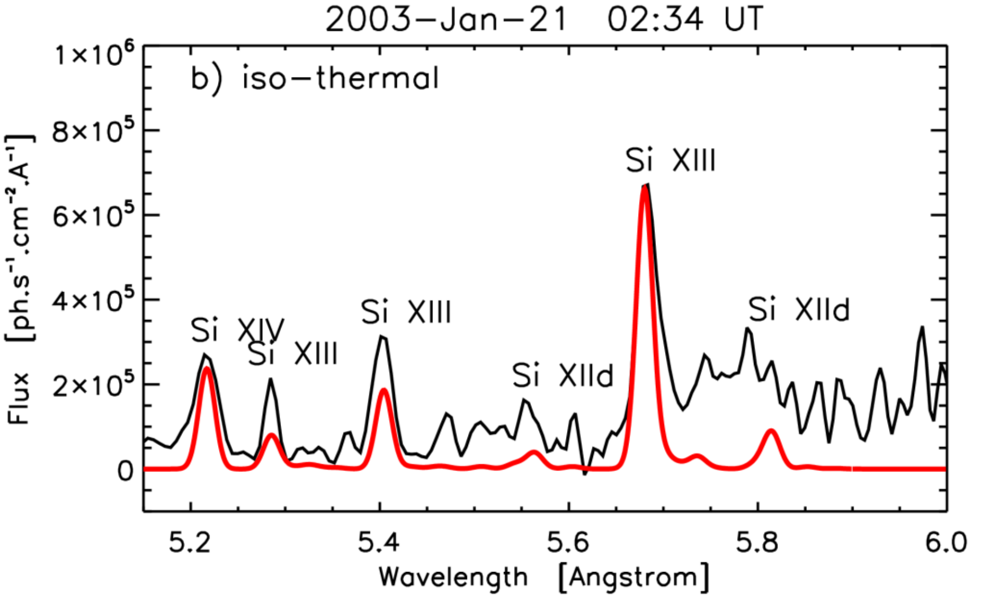
Time interval 1 (02:26:07 – 02:26:55 UT) corresponds to rise phase of the flare



Synthetic vs. observed spectra



Time interval 9 (02:34:15 – 02:34:55 UT) corresponds to (early) decay phase of the flare



Conclusion

It is possible to probe the non-thermality of the free electron distribution in flaring plasma but the estimated errors of measurements are about 30%-50%!

The plasma starts to be non-thermal during the rise phase up to the maximum of flares.

- ***M4.9, Jan 7, 2003 flare* – the maximum deviation from the Maxwellian distribution occurred close to the flare maximum;**
- ***C8.1, Jan 21, 2003 flare* - the maximum deviation from the Maxwellian distribution occurred 2 minutes before the flare maximum.**

In both cases the non-thermality correlates well with radio emission - type III bursts and RHESSI 25 – 50 keV non-thermal emission (M4.9 flare).

The synthetic spectra modelled under the assumption of n-distribution with diagnosed parameters 'n' and log(τ) rather satisfactorily mimic the observed ones. However, they failed to model higher fluxes of Si XIII lines $1s^2\ ^1S_0 – 1s\,np\ ^{1,3}P_1$, where $n \geq 4$. We suppose that this can be due to presence of high energy tail of electron distribution affected by electron beams (*Dzifčáková and Karlický, 2008, SP, 250, 329*).

Thank you for your attention

Acknowledgement

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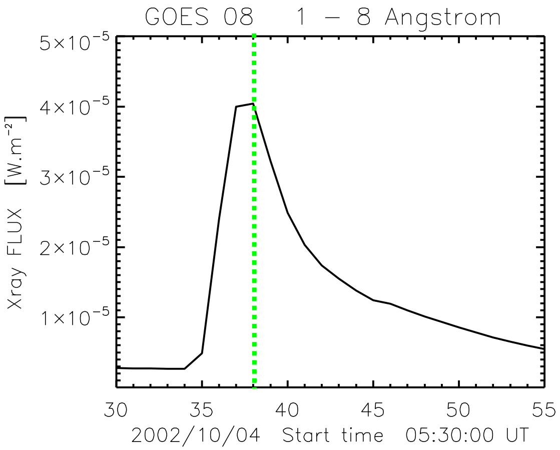
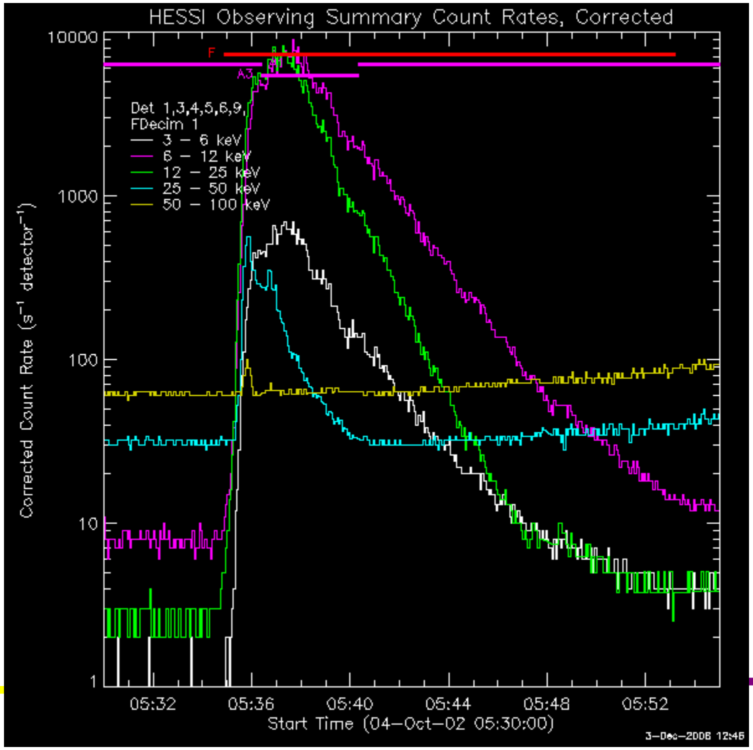
CHIANTI is a collaborative project involving project involving the Naval Research Observatory and George Mason University (U.S.A.), the Rutherford Appleton Laboratory, the Mullard Space Science Laboratory and University of Cambridge (U.K.) and the University of Florence (Italy).

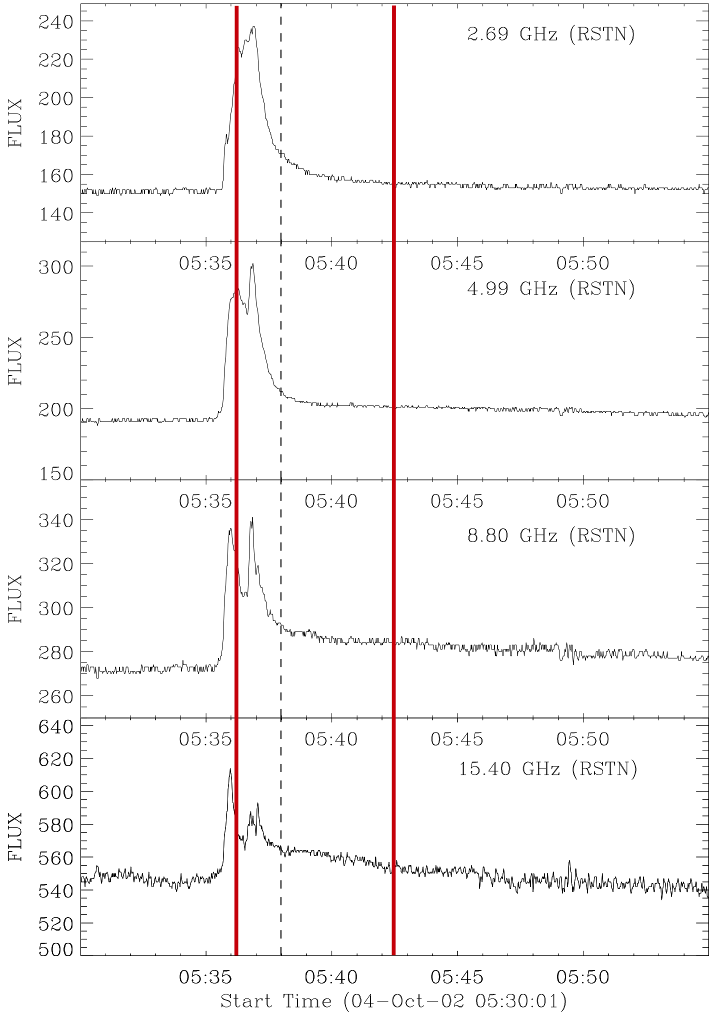
BS and JS acknowledge support from the Polish Ministry of Science grant 1.P03D.017.29.

4 – Oct – 2002: 05:34 – 05:38 – 05:41 UT, M4.0, S19W09

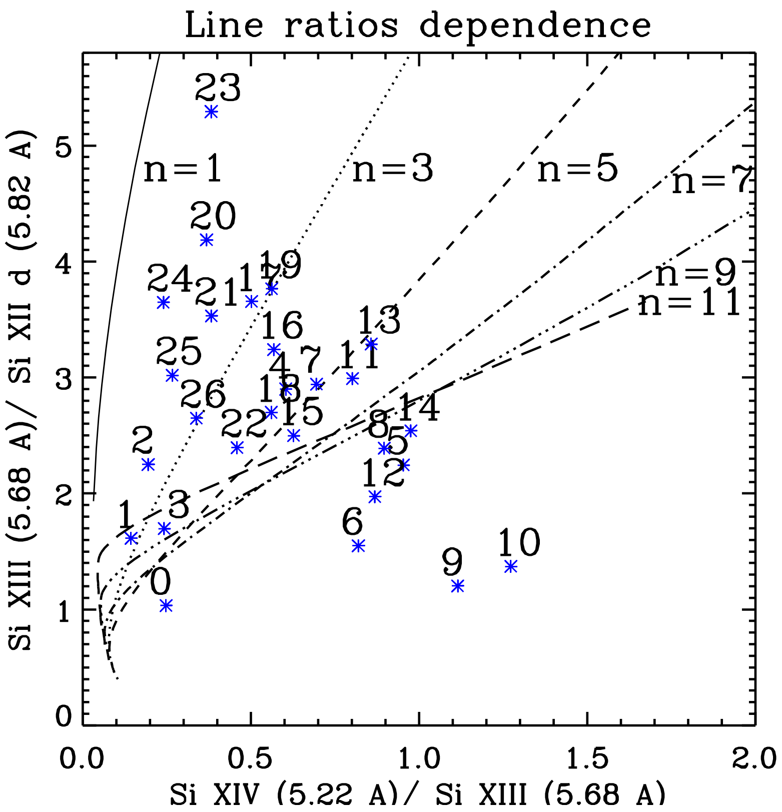


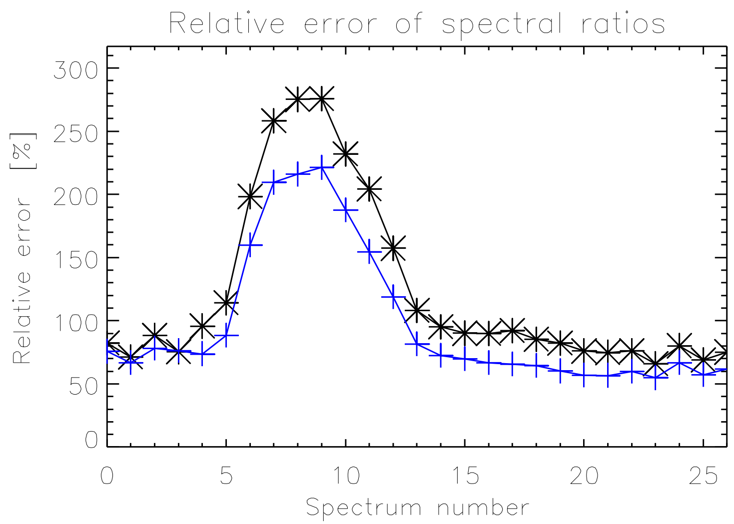
- **GOES 08**
- **RHESSI**
- **Radio Flux**





4 – Oct – 2002: 05:34 – 05:38 – 05:41 UT, M4.0, S19W09 - diagnostics of n





Strong non-thermal component for spectra 5 – 15 corresponding to time interval 05:36:19 UT – 05:42:30 UT

Level2_Flare_2002-Oct_04_0538_UT_M4.0_S19W09.fits

Observed type III: 05:35 – 05:37 UT

n ≥ 11 at about 05:36:19 – 05:42:30 UT