Remarks on determinations of coronal plasma abundances performed within SOTERIA framework at SRC-PAS

Janusz Sylwester

Polish Academy of Sciences

Space Research Centre

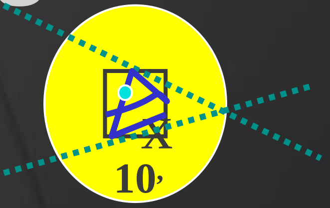
Solar Physics Division - Wrocław

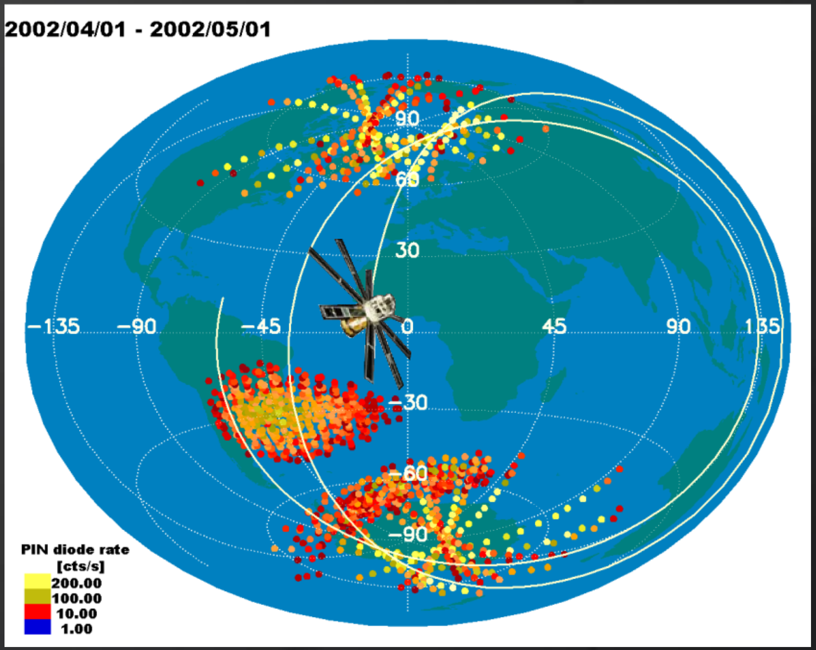
Motivation

- Understanding of X-ray spectra as observed at higher spectral resolution supports the SphinX data interpretation
- Unique RESIK data are available, only partly reformatted and reduced- future extensive research is possible
- X-ray observations of line and continuum intensity pave the way for a new spectrometers design - vide ChemiX aboard the Russian Interhelioprobe mission to the Sun

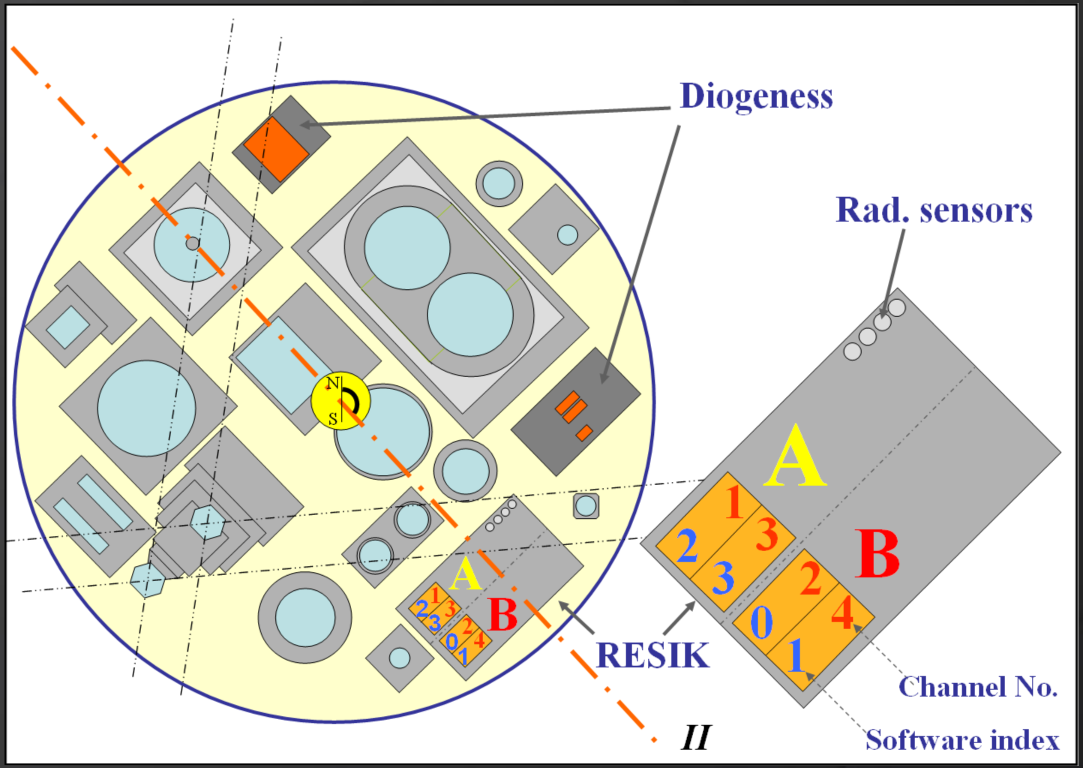
CORONAS-F launch, orbit & pointing – new alley for us

31 July 2001,
polar orbit, 95min,
~500 km
semi-Sun-synchronous





On the payload: two Polish Bragg spectrometers



Diogeness: scanning Flat Crystal Spectrometer like on *P78-1*

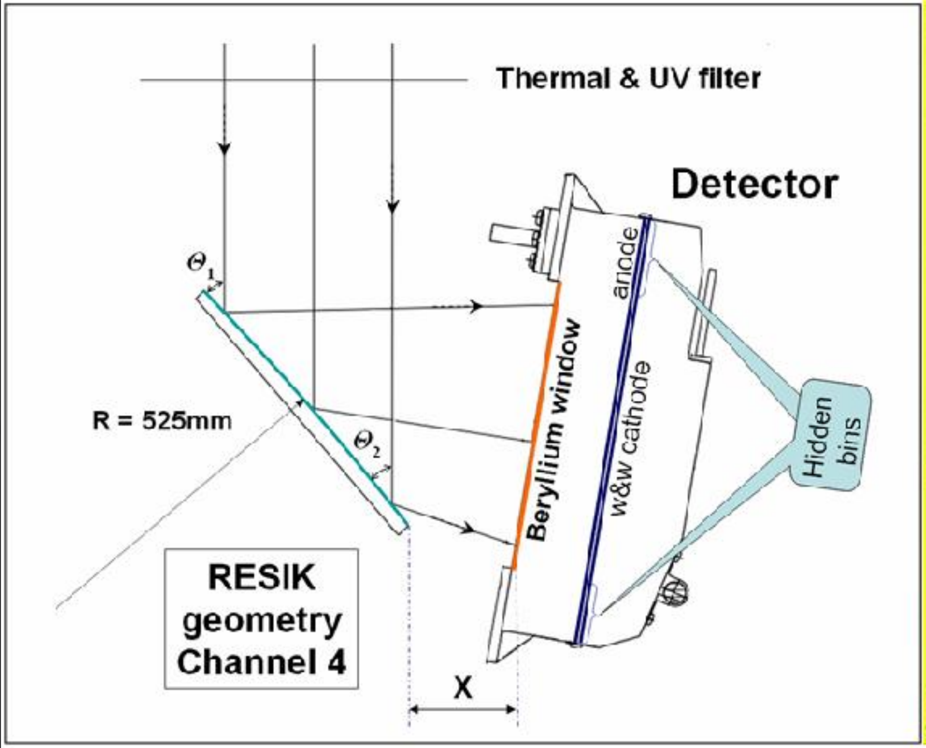
RESIK: Bent Crystal Spectrometer like on *SMM* and *Yohkoh*

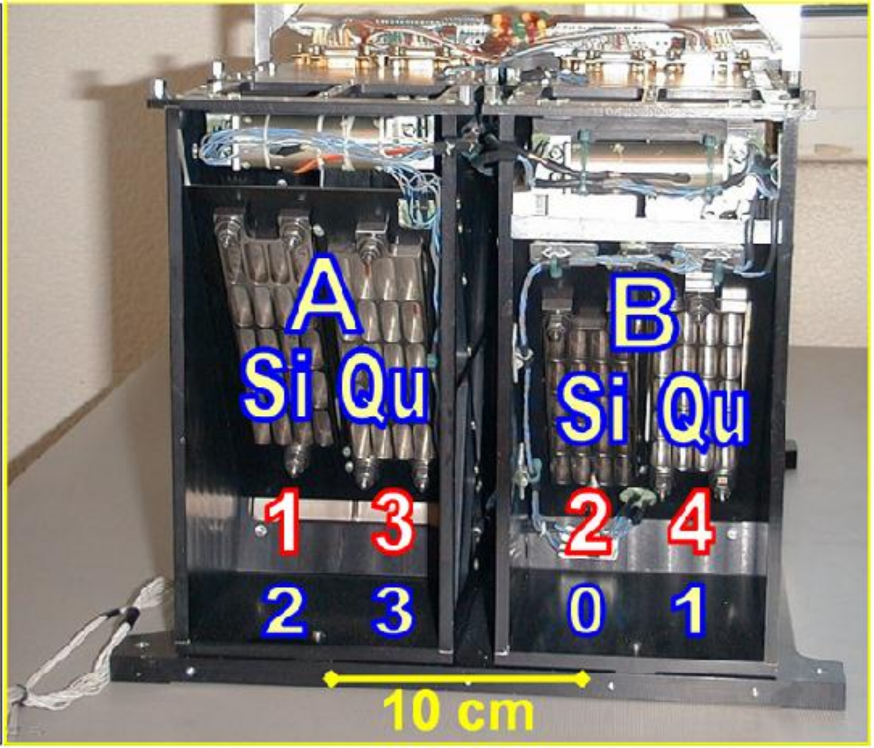
Bragg spectrometer: $k\lambda = 2d\, sin\Theta$

Рентгеновский Спектрометр с Изогнутыми Кристаллами

NRL, USA + RAL, UK + MSSL, UK + IZMIRAN, Russia

Measures spectra in range: 0.335 nm – 0.610 nm, instantly in all λ





What we see - page from RESIK Catalogue (2000 pages)

GOES fluxes

S/C nights

Spectra normalized to maximum in each channel 4.96 - 6.09

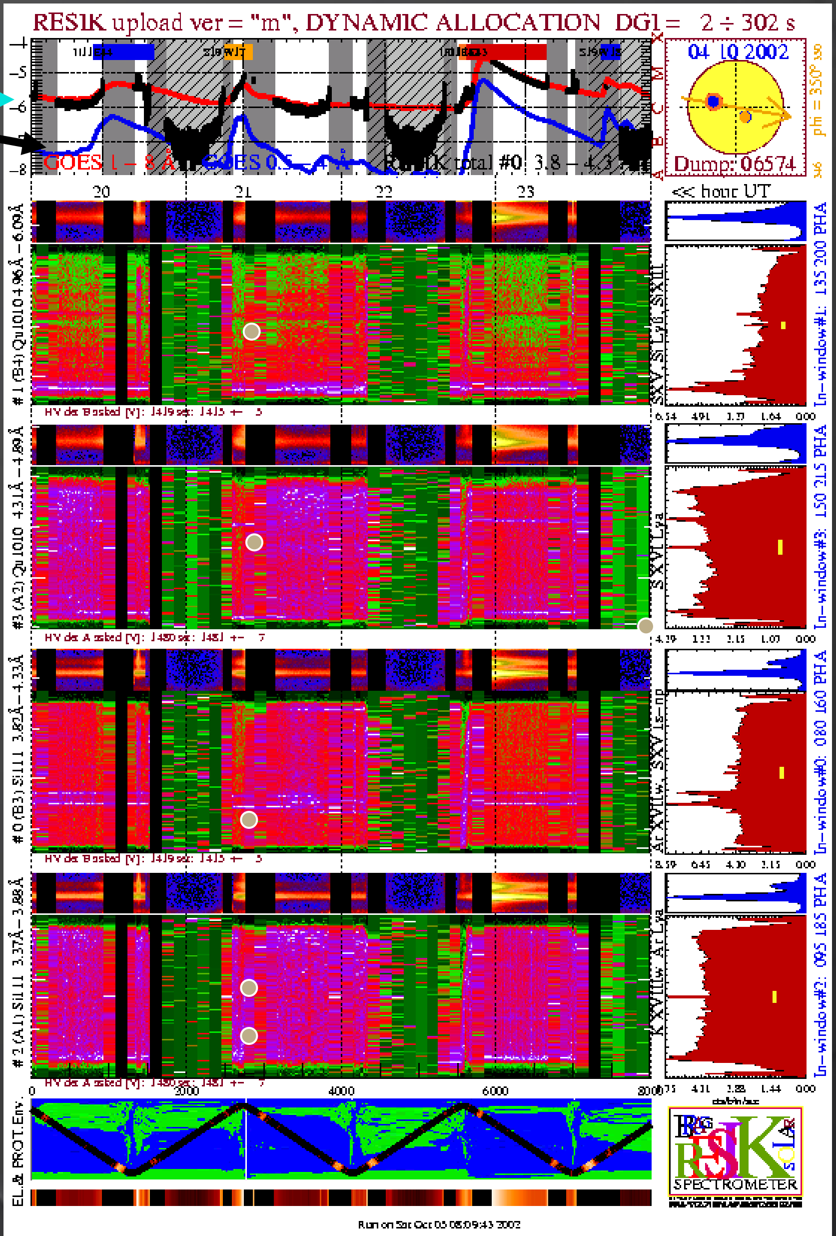
4.31 - 4.89 Å

Black - HV off

3.82 - 4.33 Å

3.37 - 3.88 Å

Orbit & particles 'background'



Flare positions & dispersion plane

PHA

spectrum #4

PHA

spectrum #3

ADS = 112 - 165

PHA

spectrum #2

ADS = 80 - 165

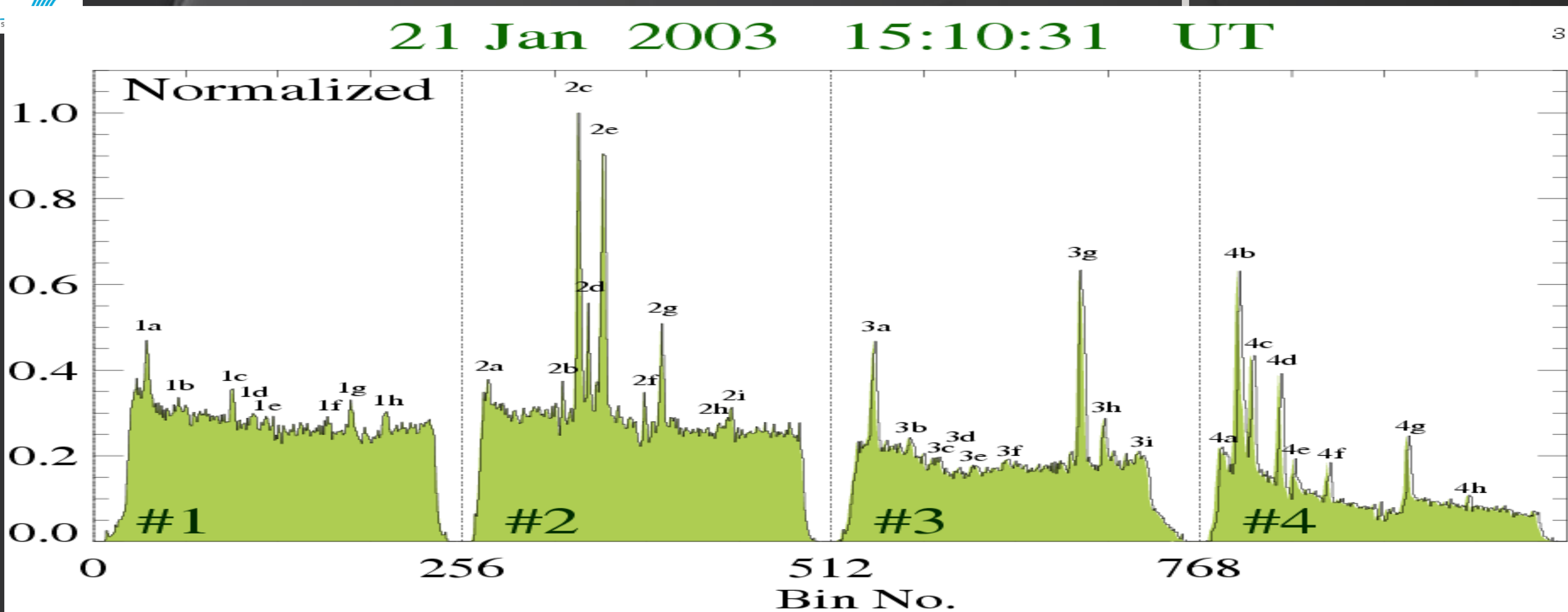
PHA

spectrum #1

ADS = 80 - 165

eHeroes

Lines are seen thanks to high crystal resolution – continuum level present



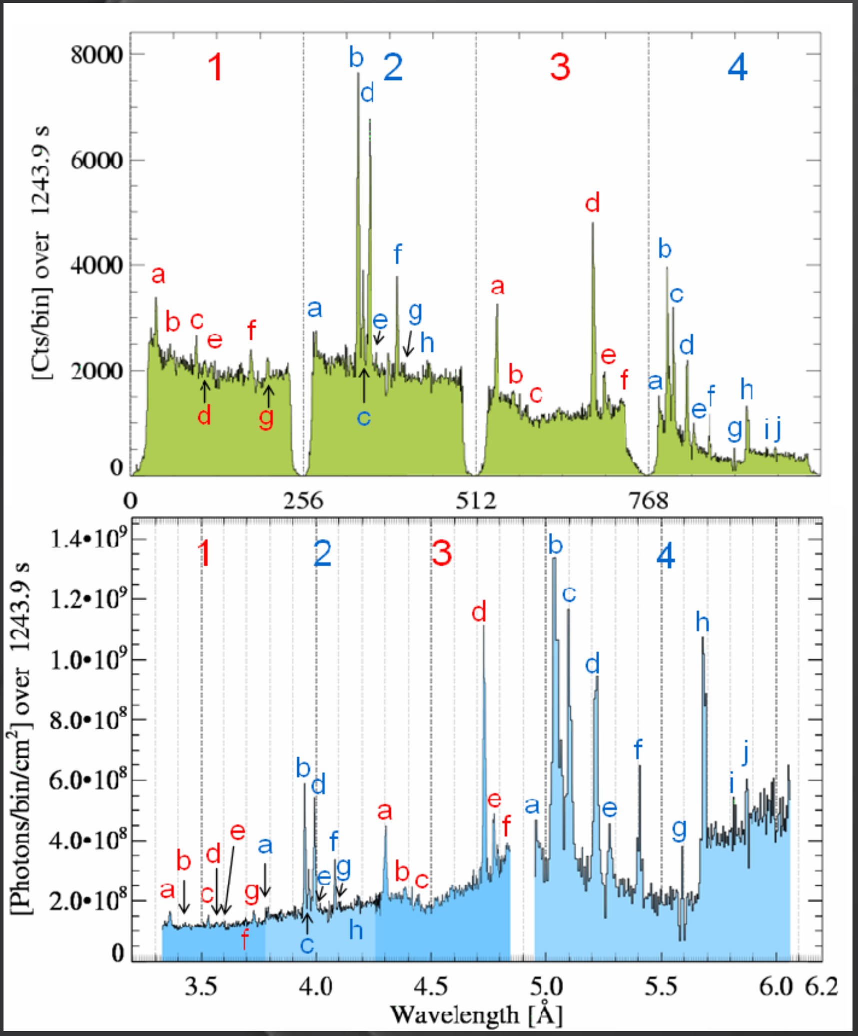
Key	λ [Å]	Ion	Transition
Ch. #1			
1a	3.367	Ar XVII	$1s^2\,{}^1S_0 - 1s3p\,{}^{(1,3)}P_1$
1b	3.422	?	
1c	3.532*	K XVIII	$1s^2\,{}^1S_0 - 1s2p\,{}^1P_1$
1d	3.548	K XVIII	$1s^2\,{}^1S_0 - 1s2p\,{}^3P_{1,2}$
1e	3.571	K XVIII	$1s^2\,{}^1S_0 - 1s2s\,{}^3S_1$
1f	3.689	S XVI (?)	$1s\,{}^2S_{\frac{1}{2}} - 5p\,{}^2P_{\frac{3}{2},\frac{1}{2}}$
1g	3.733*	Ar XVIII	$1s\,{}^2S_{\frac{1}{2}} - 2p\,{}^2P_{\frac{3}{2},\frac{1}{2}}$
1h	3.798	S XVI (?)	$1s\,{}^2S_{\frac{1}{2}} - 4p\,{}^2P_{\frac{3}{2},\frac{1}{2}}$

Key	λ [Å]	Ion	Transition
Ch. #2			
2a	3.805	S XVI (?)	$1s\,{}^2S_{\frac{1}{2}} - 4p\,{}^2P_{\frac{3}{2},\frac{1}{2}}$
2b	3.919	?	
2c	3.949*	Ar XVII	$1s^2\,{}^1S_0 - 1s2p\,{}^1P_1$
2d	3.967	Ar XVII	$1s^2\,{}^1S_0 - 1s2p\,{}^3P_{1,2}$
2e	3.994	Ar XVII	$1s^2\,{}^1S_0 - 1s2s\,{}^3S_1$
2f	4.055	?	
2g	4.088*	S XV	$1s^2\,{}^1S_0 - 1s4p\,{}^1P_1$
2h	4.186	Cl XVII	$1s\,{}^2S_{\frac{1}{2}} - 2p\,{}^2P_{\frac{3}{2},\frac{1}{2}}$
2i	4.197	?	?
2j	4.299*	S XV	$1s^2\,{}^1S_0 - 1s3p\,{}^1P_1$

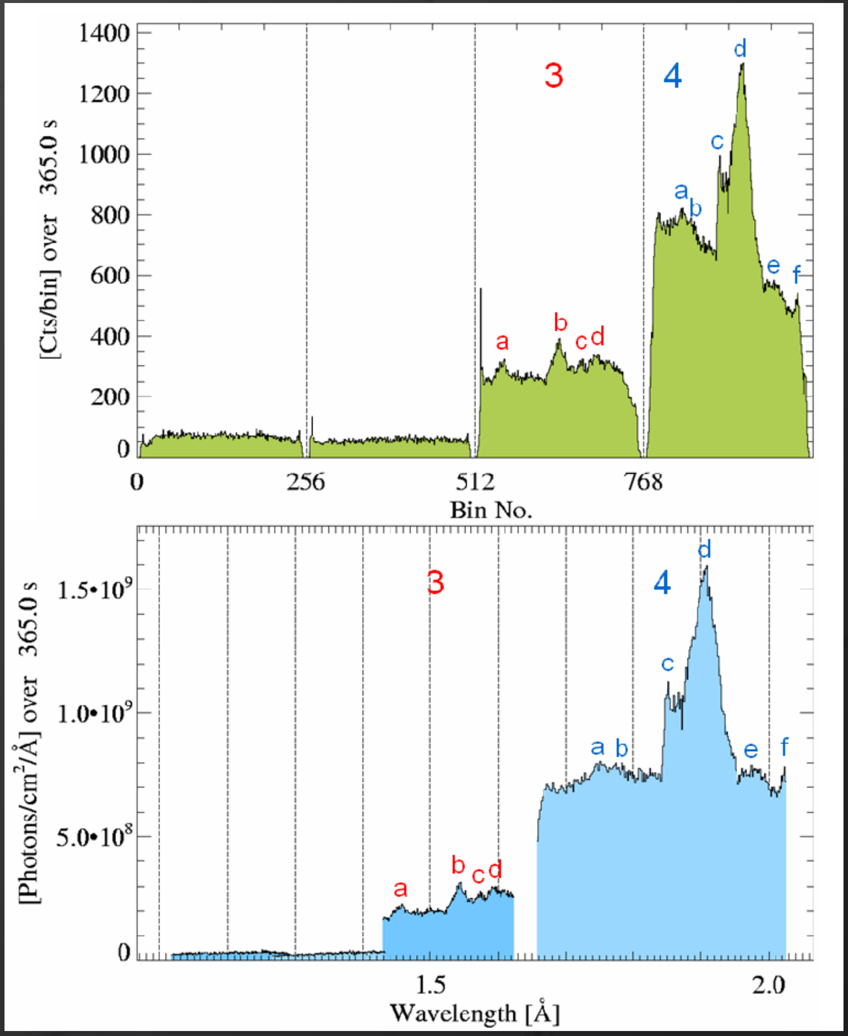
Key	λ [Å]	Ion	Transition
Ch. #3			
3a	4.299*	S XV	$1s^2\,{}^1S_0 - 1s3p\,{}^1P_1$
3b	4.376	?	
3c	4.444	Cl XVI	$1s^2\,{}^1S_0 - 1s2p\,{}^1P_1$
3d	4.466	Cl XVI	$1s^2\,{}^1S_0 - 1s2p\,{}^3P_{1,2}$
3e	4.496	Cl XVI	$1s^2\,{}^1S_0 - 1s2s\,{}^3S_1$
3f	4.578	?	
3g	4.729*	S XVI	$1s\,{}^2S_{\frac{1}{2}} - 2p\,{}^2P_{\frac{3}{2},\frac{1}{2}}$
3h	4.775	?	
3i	4.855	Si XIV	$1s\,{}^2S_{\frac{1}{2}} - 5p\,{}^2P_{\frac{3}{2},\frac{1}{2}}$

Key	λ [Å]	Ion	Transition
Ch. #4			
4a	4.968	Si XIV	$1s\,{}^2S_{\frac{1}{2}} - 4p\,{}^2P_{\frac{3}{2},\frac{1}{2}}$
4b	5.039*	S XV	$1s^2\,{}^1S_0 - 1s2p\,{}^1P_1$
4c	5.102	S XV	$1s^2\,{}^1S_0 - 1s2s\,{}^3S_1$
4d	5.194	Si XIV	$1s\,{}^2S_{\frac{1}{2}} - 3p\,{}^2P_{\frac{3}{2},\frac{1}{2}}$
4e	5.253	Si XIII	$1s^2\,{}^1S_0 - 1s5p\,{}^1P_1$
4f	5.384	Si XIII	$1s^2\,{}^1S_0 - 1s4p\,{}^1P_1$
4g	5.681*	Si XIII	$1s^2\,{}^1S_0 - 1s3p\,{}^1P_1$
4h	5.919	Si XII d	$1s^2 2p\,{}^2P_{\frac{3}{2}} - 1s2p\,({}^3P)3p\,{}^2D_{\frac{5}{2}}$

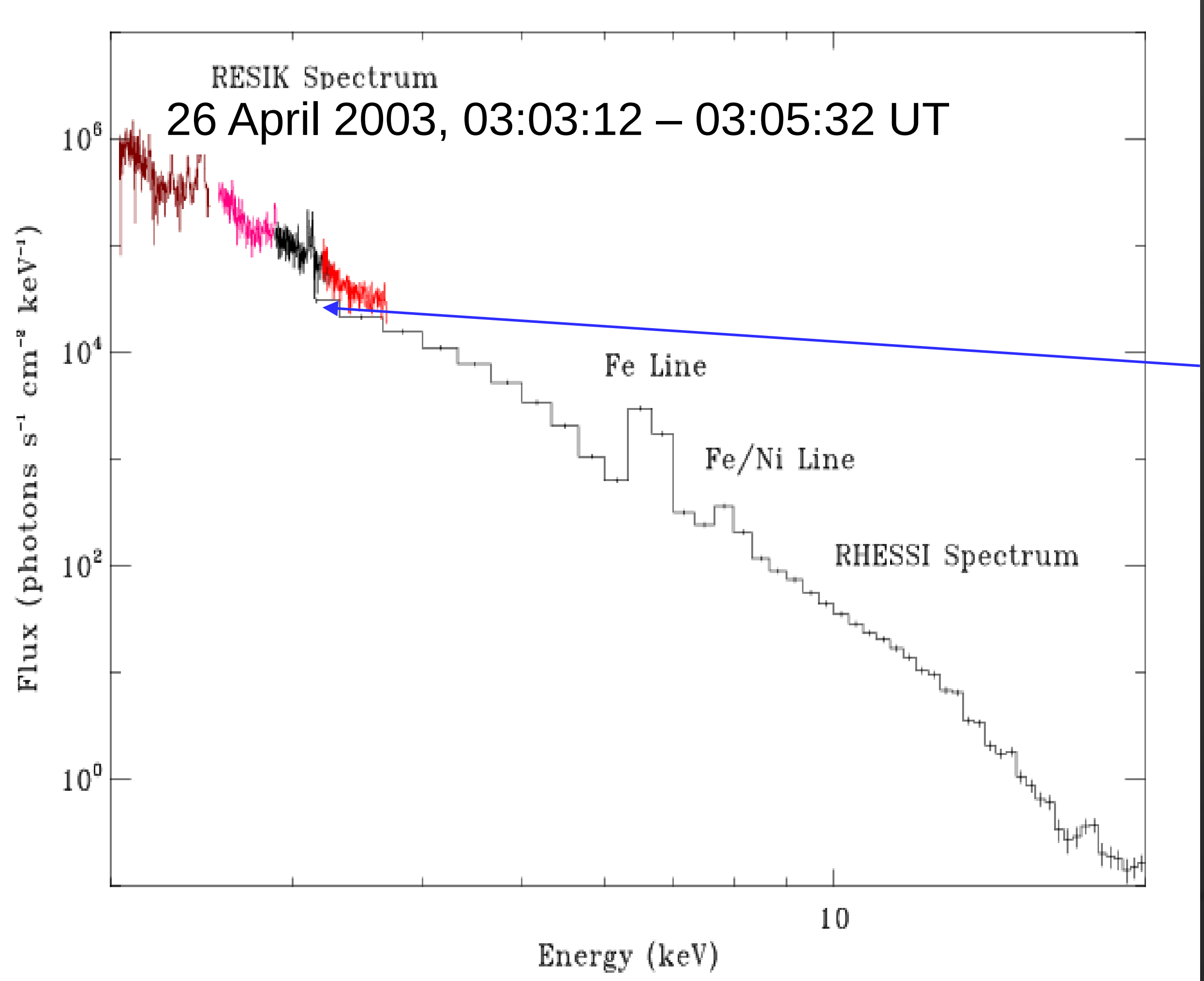
First order reflections



Third order reflections

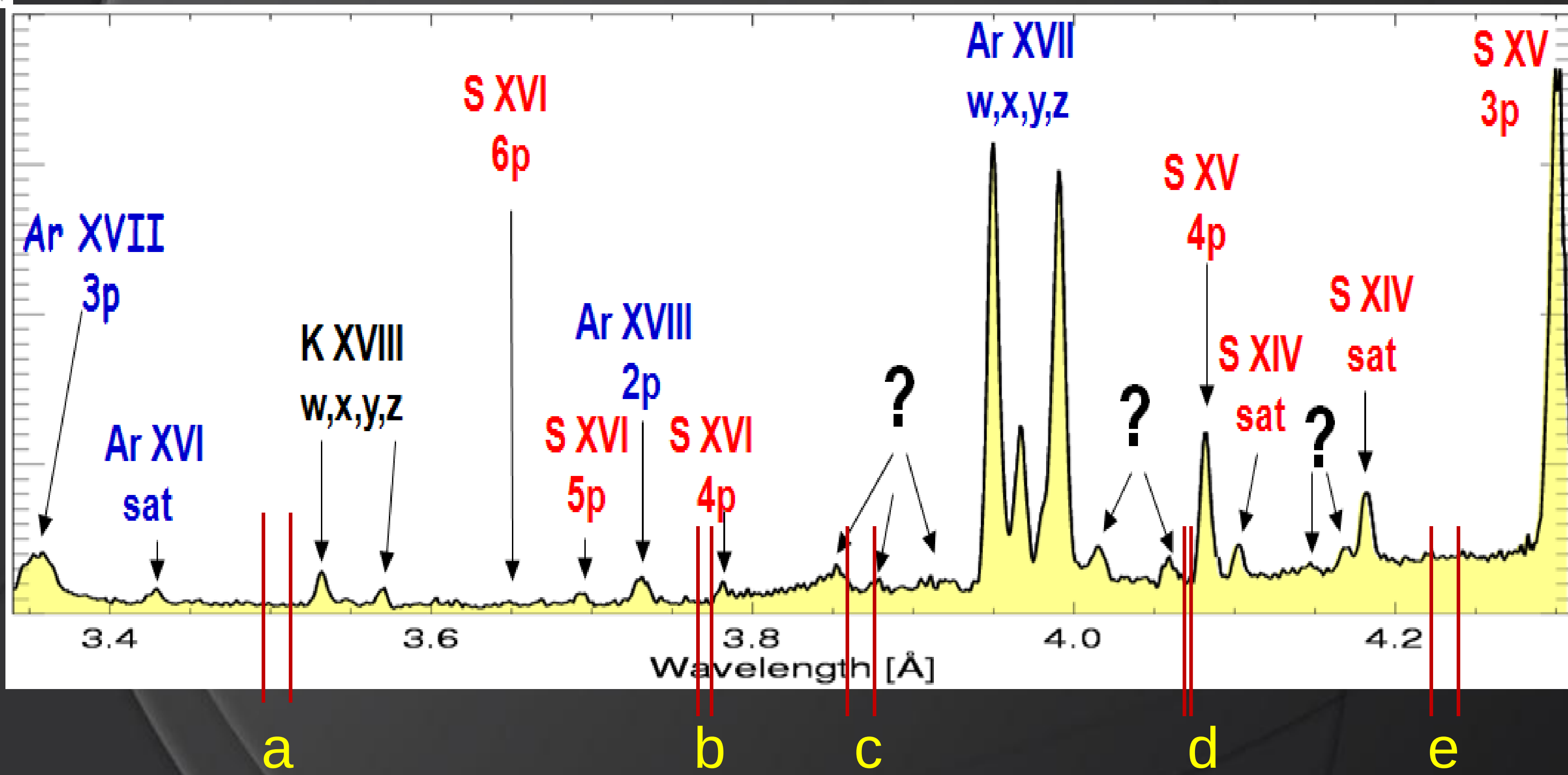


RESIK & NASA RHESSI



Without attenuators ~10% agreement

Continuum band selection



no obvious lines or line groups, no theory-predicted lines

The solar X-ray continuum measured by RESIK

Phillips, K. J. H.; Sylwester, J.; Sylwester, B.; Kuznetsov, V. D.

ApJ, 711, 179-184, 2010

Data: level2 reduced RESIK spectra available on the web:
http://www.cbk.pan.wroc.pl/experiments/resik/resik_level2.php
~3000 flare spectra, 20 flare events, mostly from 2003 measurements

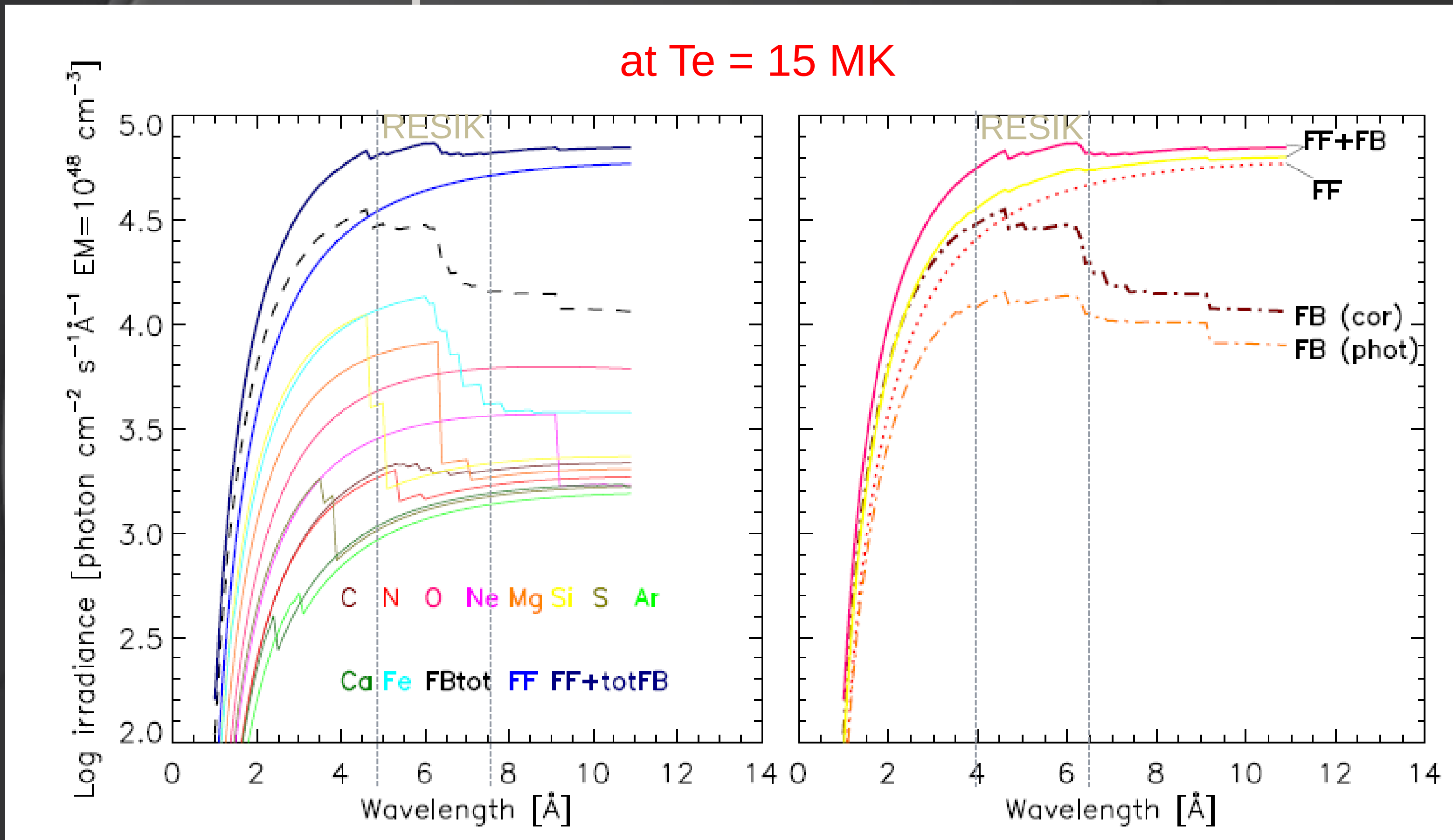
This constitutes ~20 % of the database available

Theory: CHIANTI

http://www.chiantidatabase.org/chianti.html

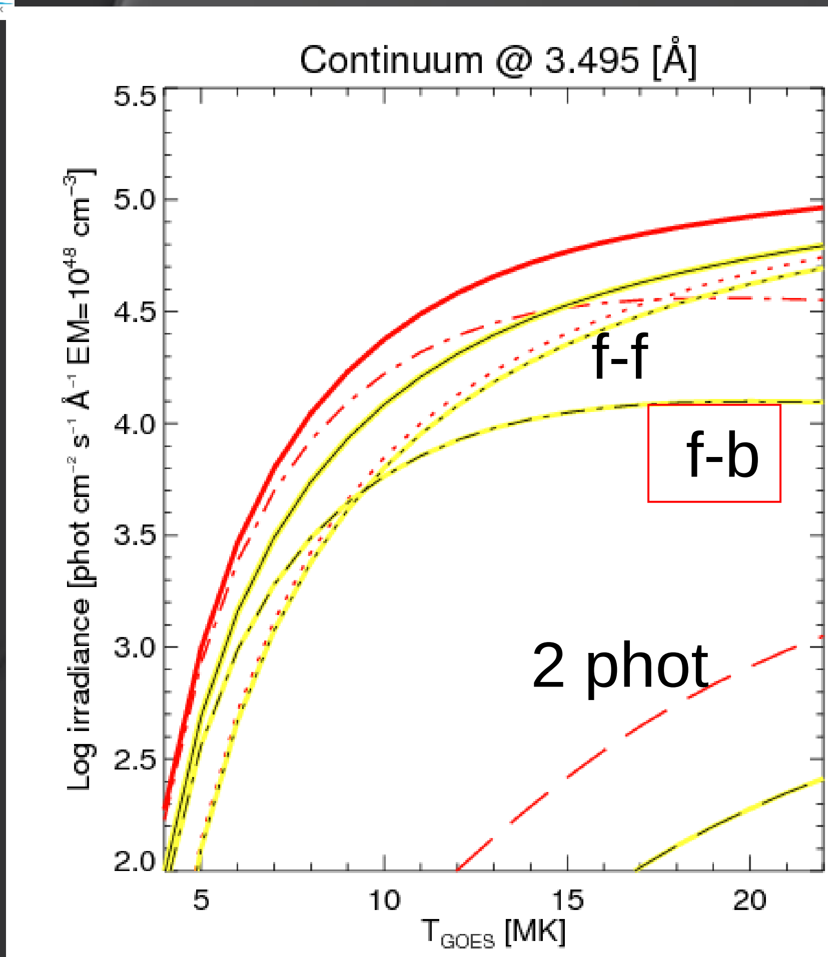
- The CHIANTI free–free continua are based on fitting formulas given by Sutherland (1998) and Itoh et al. (2000).
- Ionization fractions which are needed as input to both free–free and free–bound continua were from the recent work of Bryans et al. (2009)- not Mazzotta. Elemental abundances also affect the free–bound continuum. It is checked that the continua in the RESIK wavelength range are made up of free–free and free–bound continua in comparable weigths.
- two-photon continua (arising from de-excitation of metastable levels in H-like and He-like ions) are a factor 30 less important than either free–bound or free–free continuum emission, and were therefore neglected.

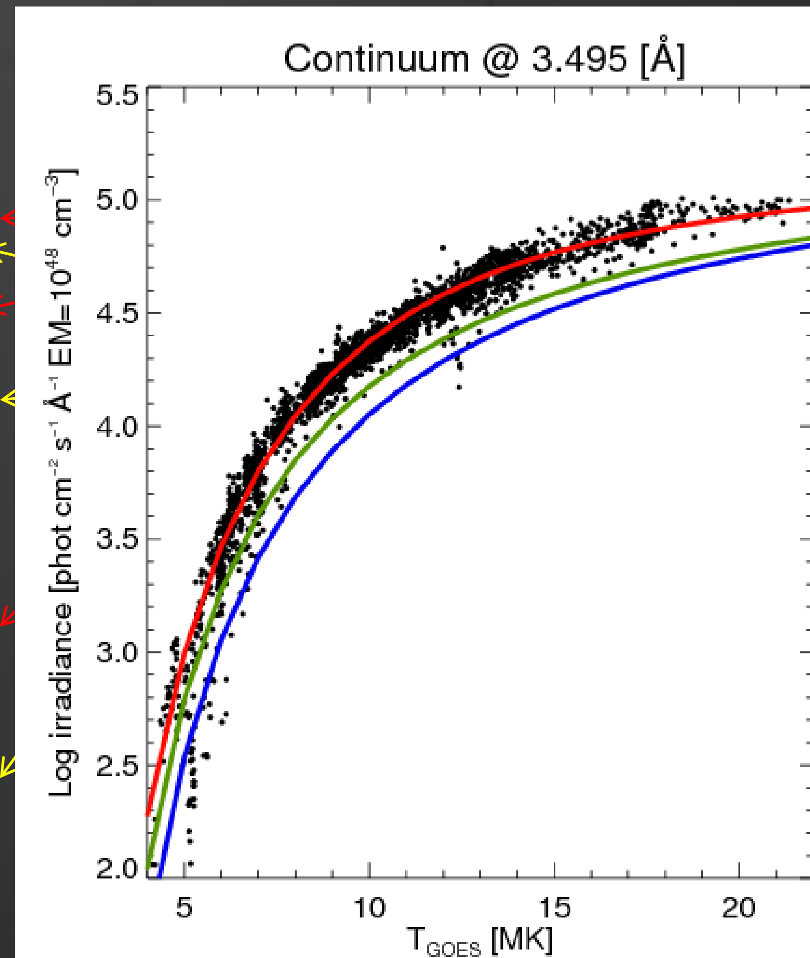
CHIANTI predictions



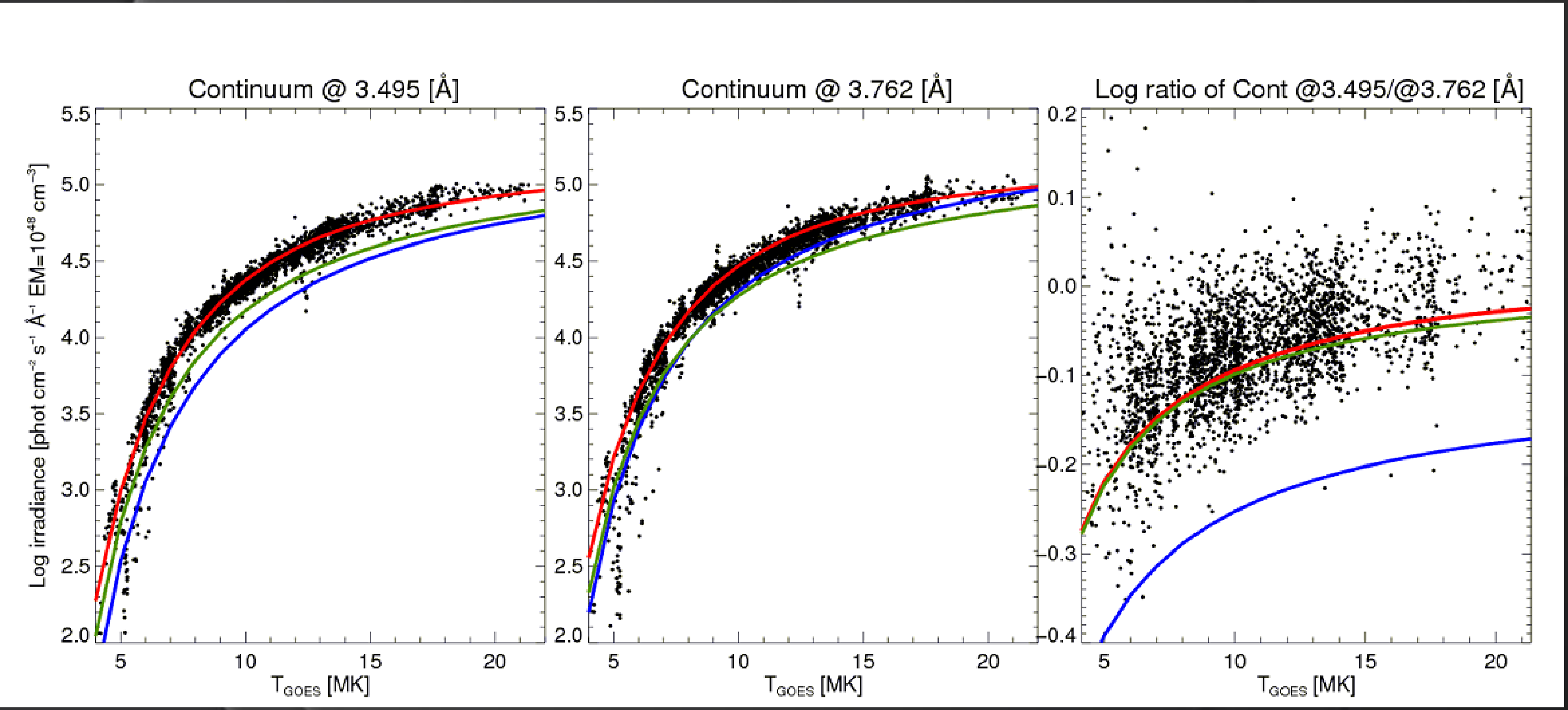
Left panel: Continuum fluxes (irradiances, photon units) calculated from the CHIANTI atomic package at Te = 15 MK and an emission measure 1048 cm−3 plotted against wavelength (1–11 °A). The solid line shows the sum of free–free (FF) and free–bound (FB) continua, the dotted lines the free-free and free–bound continua for all elements. Other curves show the contributions to the free–bound continua made by individual elements (O, Fe, Si, Mg, S) with coronal abundances (Feldman (1992)). Right panel: Continuum fluxes compared for coronal (Feldman (1992)) and photospheric (Grevesse et al. (2007)) abundances for Te = 15 MK. Solid lines are the total of free–free and free-bound, the dot–dash curves are for free–bound (FB), coronal and photospheric abundances indicated. The dotted curve is the free–free continuum for coronal abundances (free-free emission for photospheric abundances is about 10% lower). [A color version of this figure is available in the on-line version of the journal, showing free–bound emission from more elements: color key is C (maroon); N (red); O (pink); Ne (magenta); Mg (orange); Si (yellow); S (olive); Ar (green); Ca (dark green); Fe (cyan); free–free emission (blue); and total emission (dark blue).]

RESIK Continnum Chan. 1 & 2

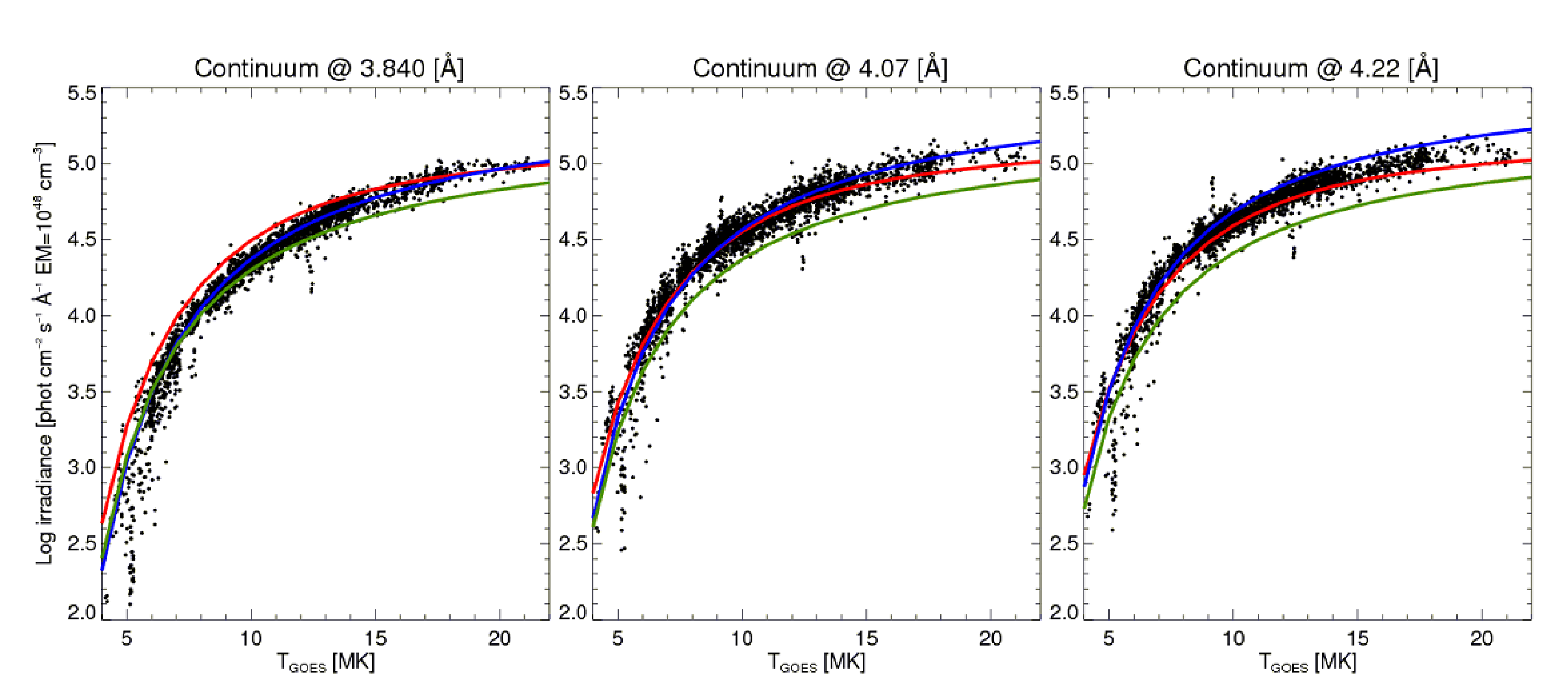




Continuum bands a & b



Continuum bands c, d & e



Note:

Isothermal aprox. All points icluded also from the rise phase

Highly Ionized Potassium Lines in Solar X-ray Spectra and the Abundance of Potassium

Phillips, B & J Sylwester,

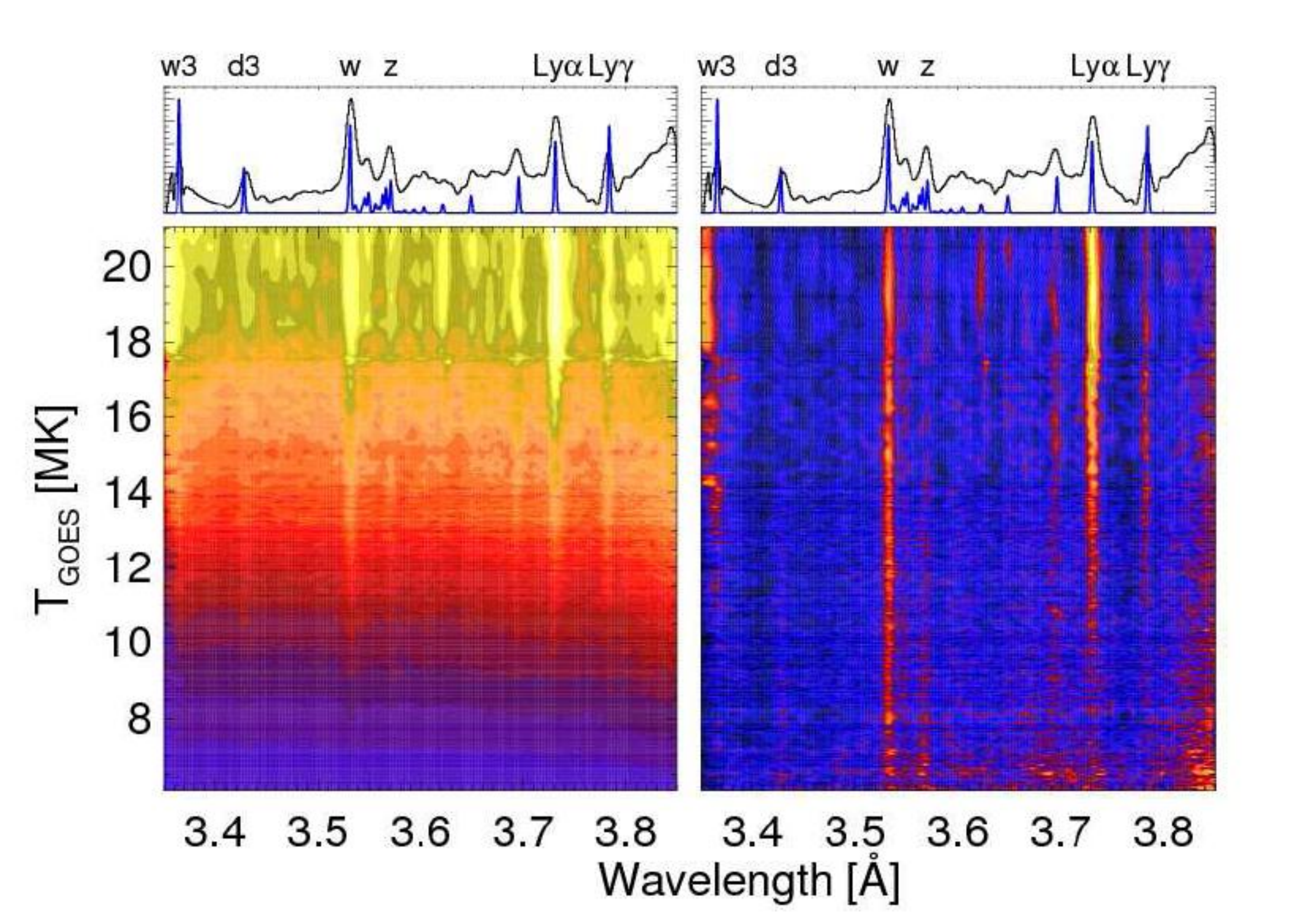
ApJ, 710, 804-809, 2010

Data: level2 reduced RESIK spectra available on the web:

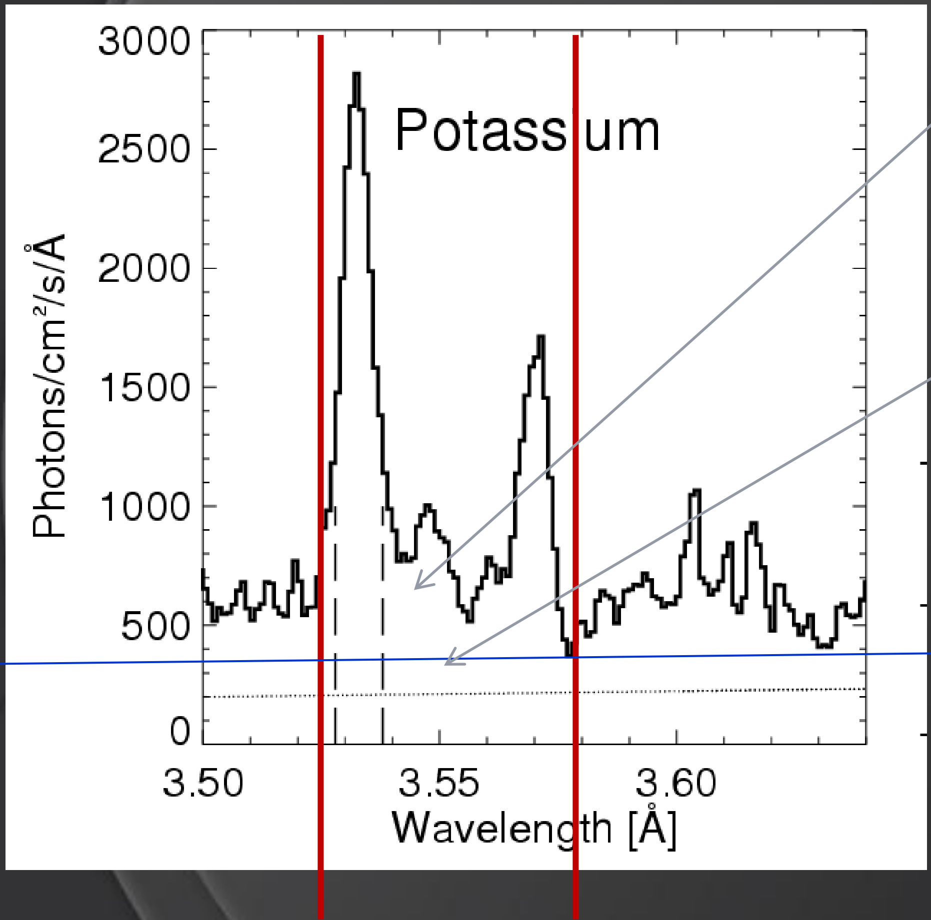
http://www.cbk.pan.wroc.pl/experiments/resik/resik_level2.php

~3000 flare spectra, 20 flare events mostly from times 2003

RESIK channel 1 Dependence on T



K XVIII He-like ione spectrum low FIP (4.341 eV) element



Line Flux (area)

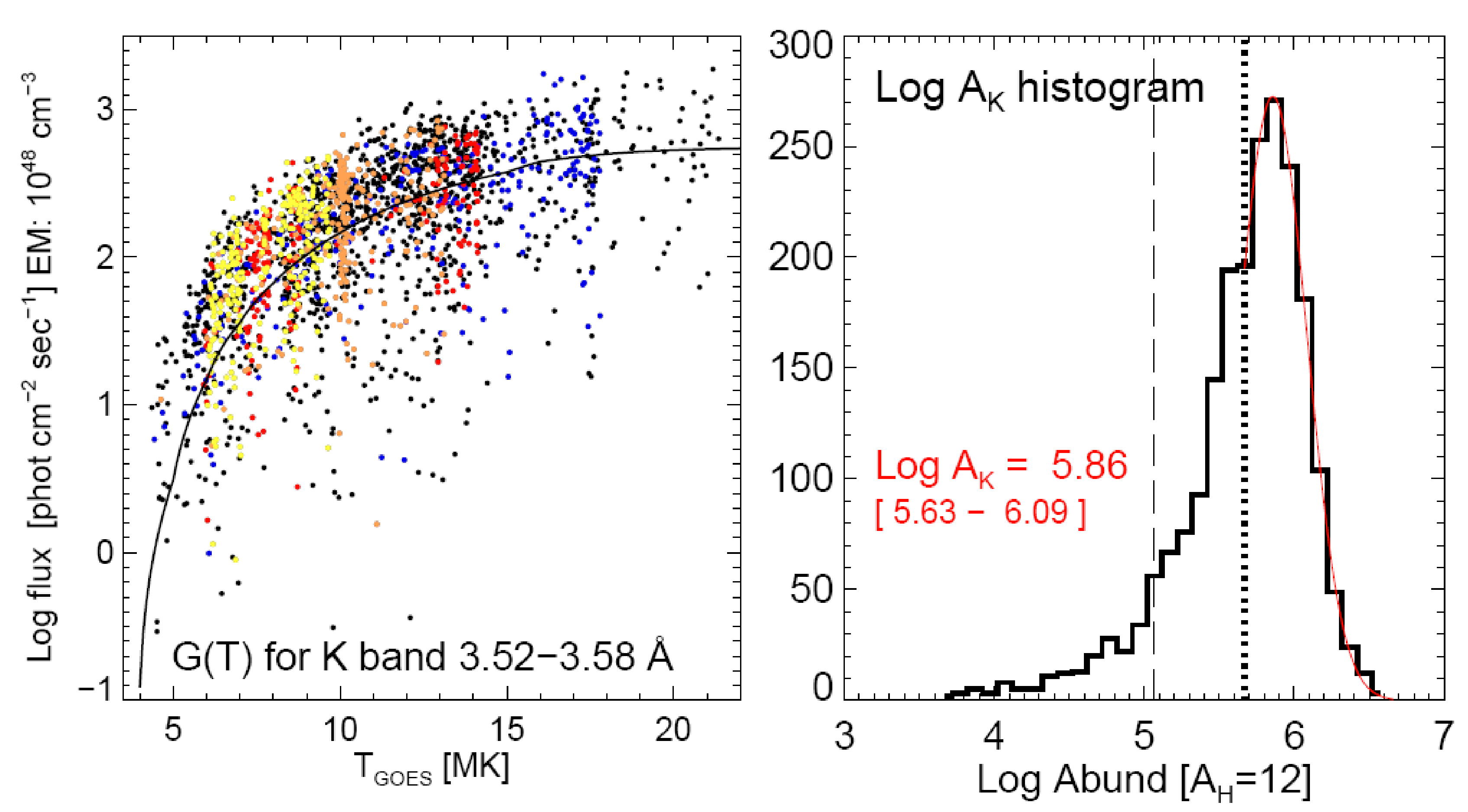
above

the continuum

Is divided by emission measure determined in the isothermal approximation

How potassium line group contribution has been accounted for

Normalized K line group intensities



First Absolute spectroscopic K abundance in the corona has been determined !!!

A Solar Spectroscopic Absolute Abundance of Argon from RESIK

Spectroscopic Ar abundance NEVER beeing determined before directly for the solar plasma

ApJ, 720, 1721-1726, 2010

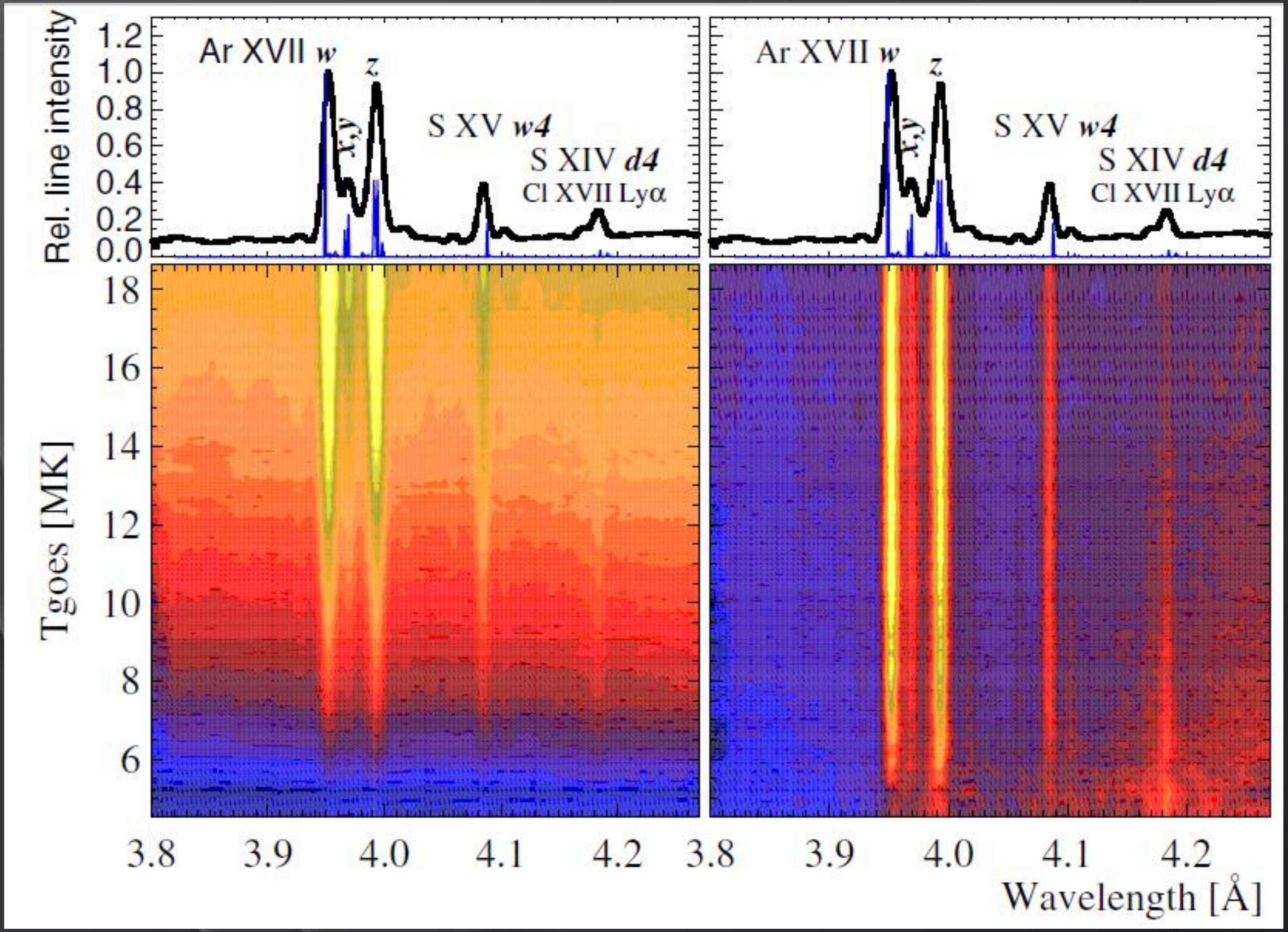
Argon is a high-FIP (15.6 eV) element

Data: level2 reduced RESIK spectra available on the web:

http://www.cbk.pan.wroc.pl/experiments/resik/resik_level2.php

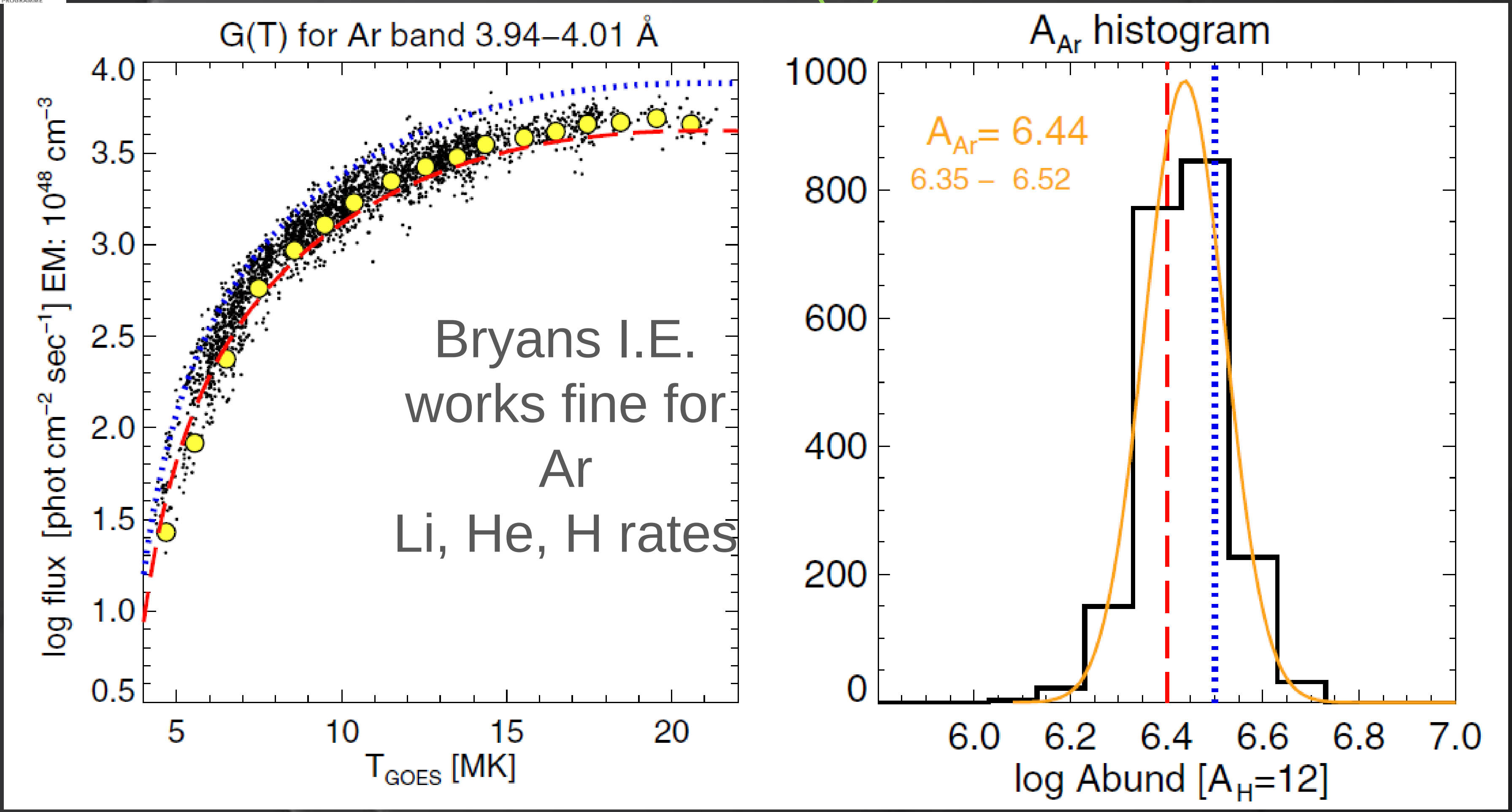
~3000 flare spectra, 20 flare events mostly from times in 2003

The same analysis methodology

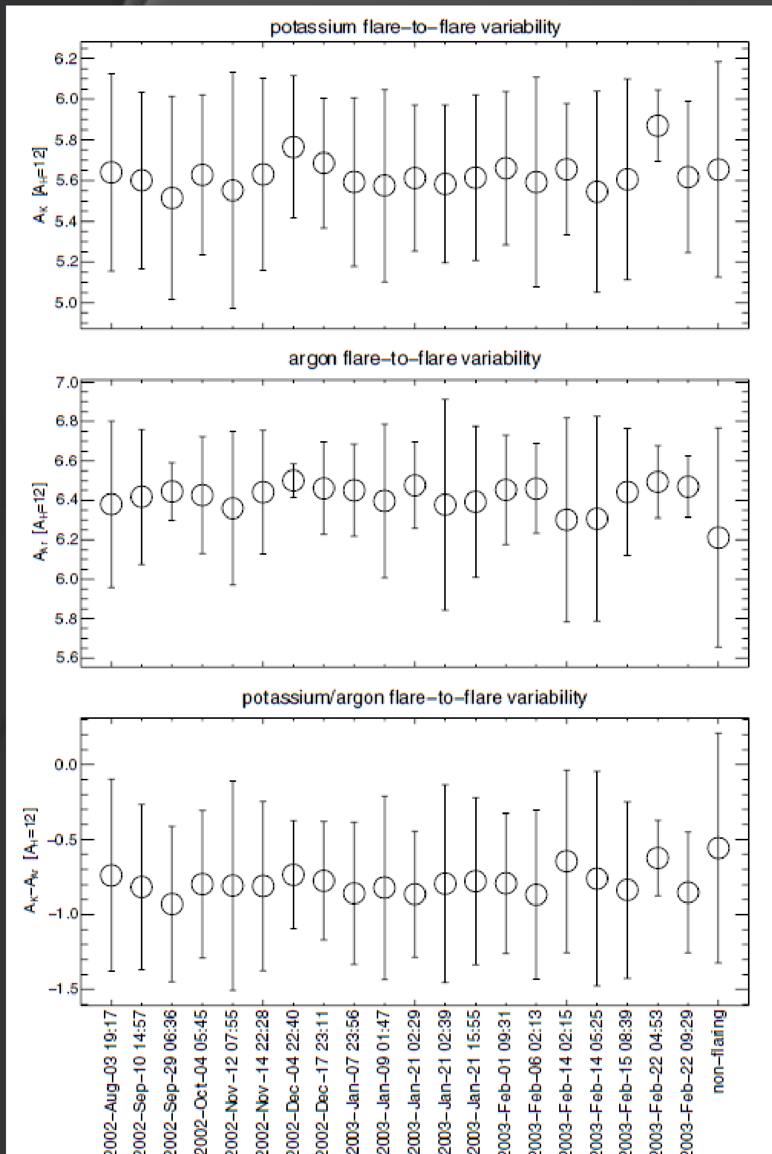


Theory compares v. well with observations

first direct observational test of „atomic theory” for line G(T)’s



Event–to-event changes

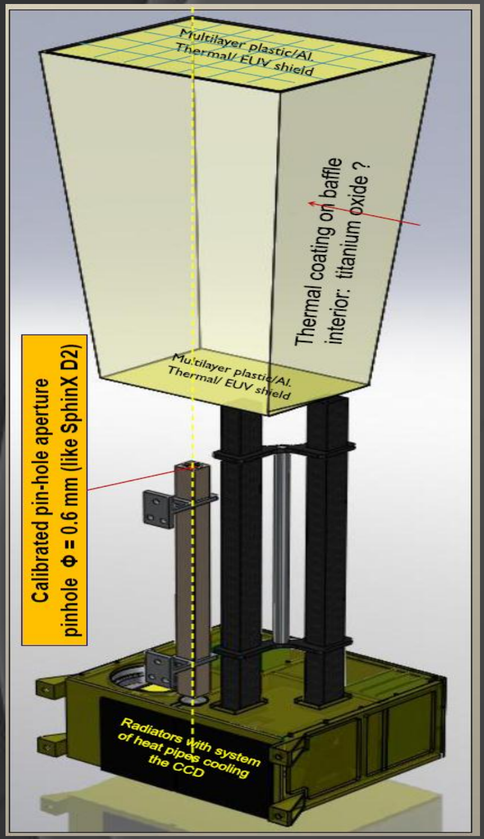


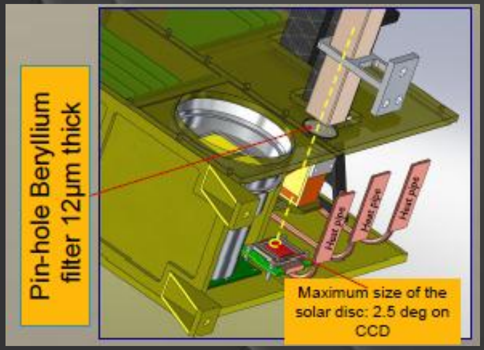
- No K event-to-event variability
- No Ar event-to-event variability
- No K/Ar event-to-event variability

Conclusions

- The first ever spectroscopic determination of solar Ar abundance has been made (no Ar lines are available in the visible)
- Ar abundance is in agreement with the indirect estimates of Lodders, 2009 and close to Greevese Ar/O from in situ…SEP, sol wind
- No flare-to-flare or AR variability of low-to-high FIP aundance ratio unvieled- further events need to be analysed

The future of Bragg spectroscopy: ChemiX aboard the Russian Interhelioprobe





- Solar-Orbiter orbit
- 0.25 a.u. proximity
- Data rates 60 MB/day
- High spectral resolution 10 x RESIK
- Better overall sensitivity and S/N 10x RESIK
- Launch 2017

Thanks to SOTERIA these research work has been possible !!!

End of the talk