Rationale for placing the soft X-ray package at L5 or L4

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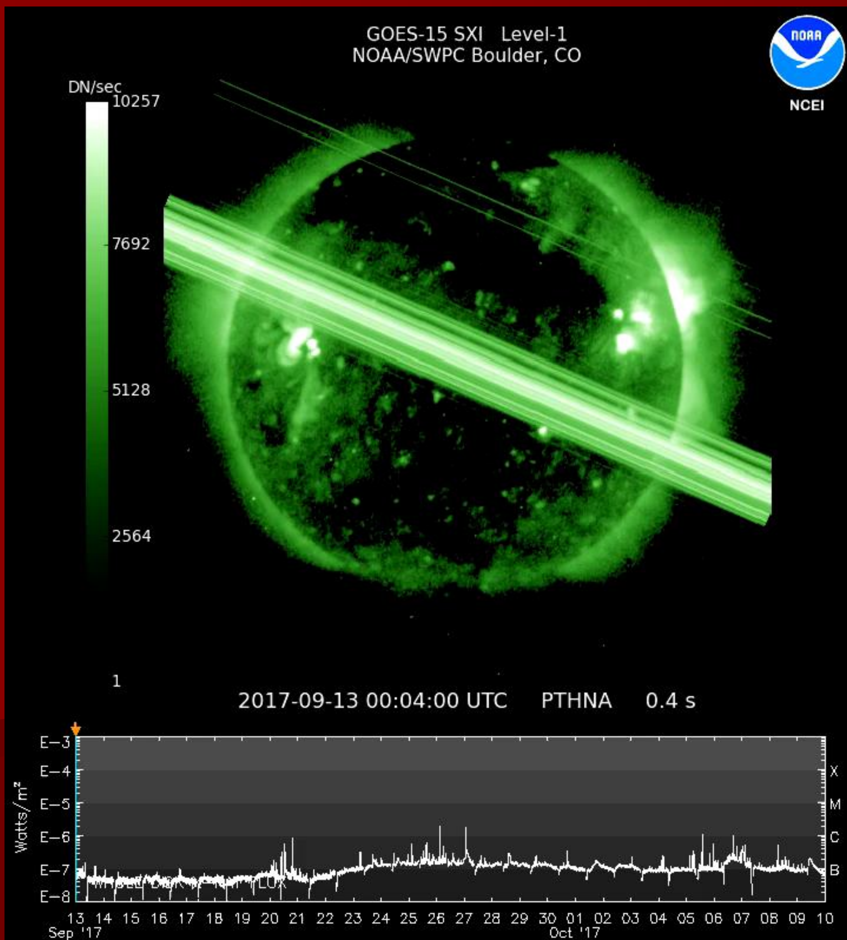
Space Research Centre, Polish Academy of Sciences,
Solar Physics Division Wrocław

The package
<10 kg, <1m, < 10 M$, ~10 MB/day, < 1kB/s)

http://www.cbk.pan.wroc.pl/

The Sun - highly variable star in X-rays



- Flares: dynamic range – up to 7 orders, up to T ~30 MK,
  EM up to 10^{51} cm^{-3}
- AR: dynamic range 3 orders, T: 2 ÷ 6 MK
  EM ~10^{49} cm^{-3}
- „quiet" diffuse corona with bright points T: 1.7 MK
  EM ~10^{48} cm^{-3}
- coronal holes T: ~1 MK

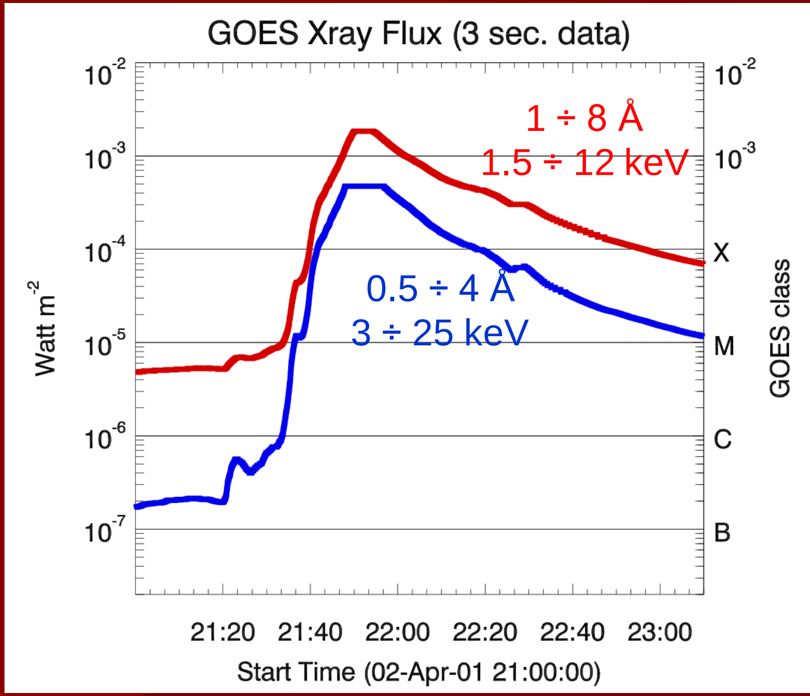
Of interest for SW

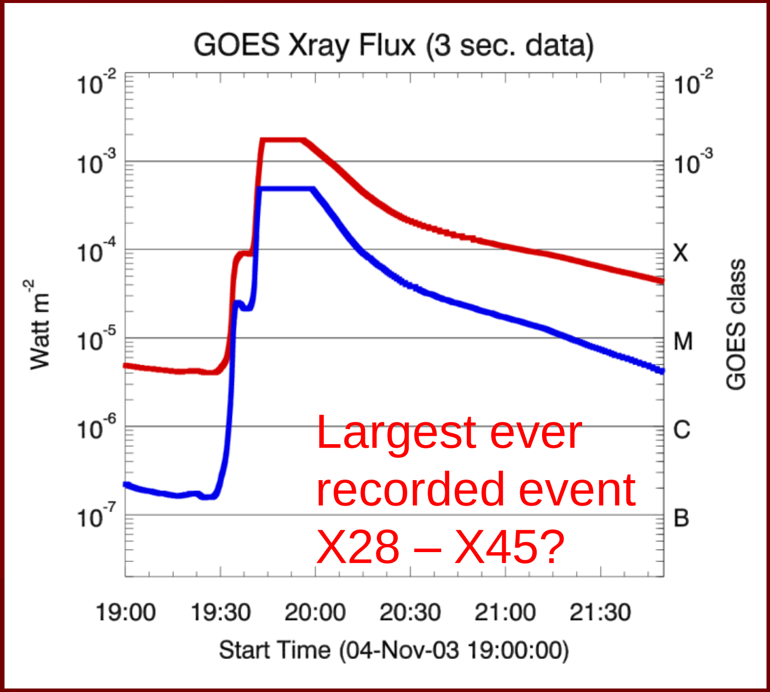
images & spectra

Why investigating/continuous monitoring solar X-rays is important

- Influence on Earth and other System bodies driven by highly variable flux of electromagnetic radiation in the energy range ~0.2 keV and above (wavelengths below ~50 Å)
- Hard X-ray spectra contain information on non-thermal processes in hot coronal plasma
- Better understanding of energy release in AR & flares
- Uninterrupted measurements of crucial importance, continuation of monitoring the 0.5 ÷ 4 Å and 1 ÷ 8 Å fluence

Some examples- GOES X-ray Monitor

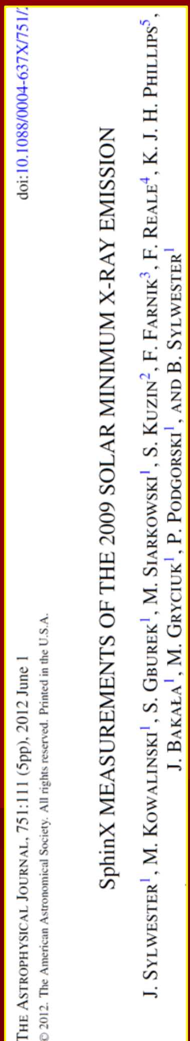




Presence of upper threshold prevents measuring levels of X-ray intensity above X20 ($2\ 10^{-3}\ W/m^2$)

SphinX (Solar photometer in X-rays)

in orbit Feb. - Nov. 2009 aboard CORONAS – Photon offered unprecedented measurements during deep solar minimum



THE ASTROPHYSICAL JOURNAL, 751:111 (5pp), 2012 June 1
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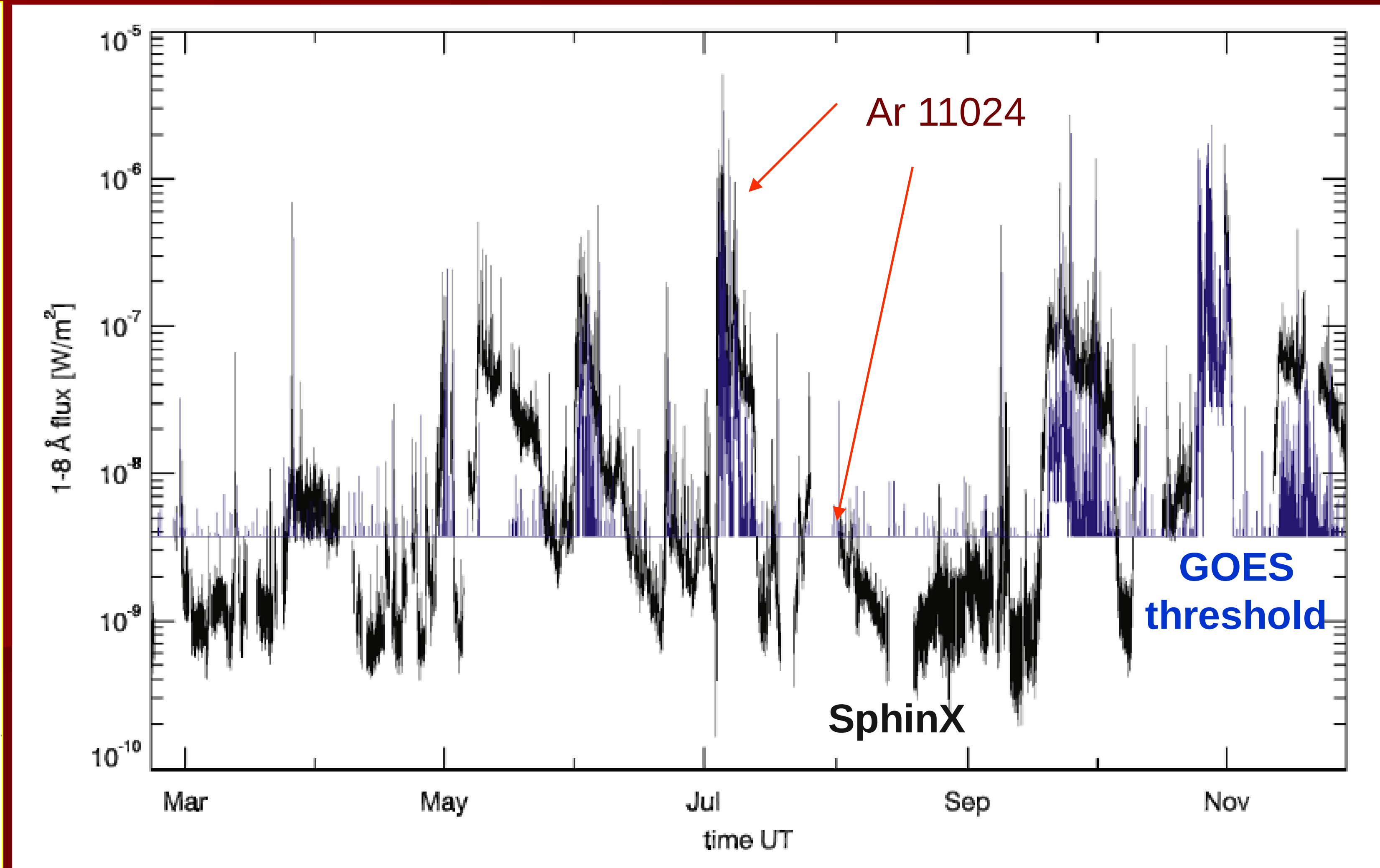
doi:10.1088/0004-637X/751/2

SphinX MEASUREMENTS OF THE 2009 SOLAR MINIMUM X-RAY EMISSION

J. SYLWESTER[1], M. KOWALINSKI[1], S. GBUREK[1], M. SIARKOWSKI[1], S. KUZIN[2], F. FARNIK[3], F. REALE[4], K. J. H. PHILLIPS[5], J. BAKAŁA[1], M. GRYCIUK[1], P. PODGORSKI[1], AND B. SYLWESTER[1]

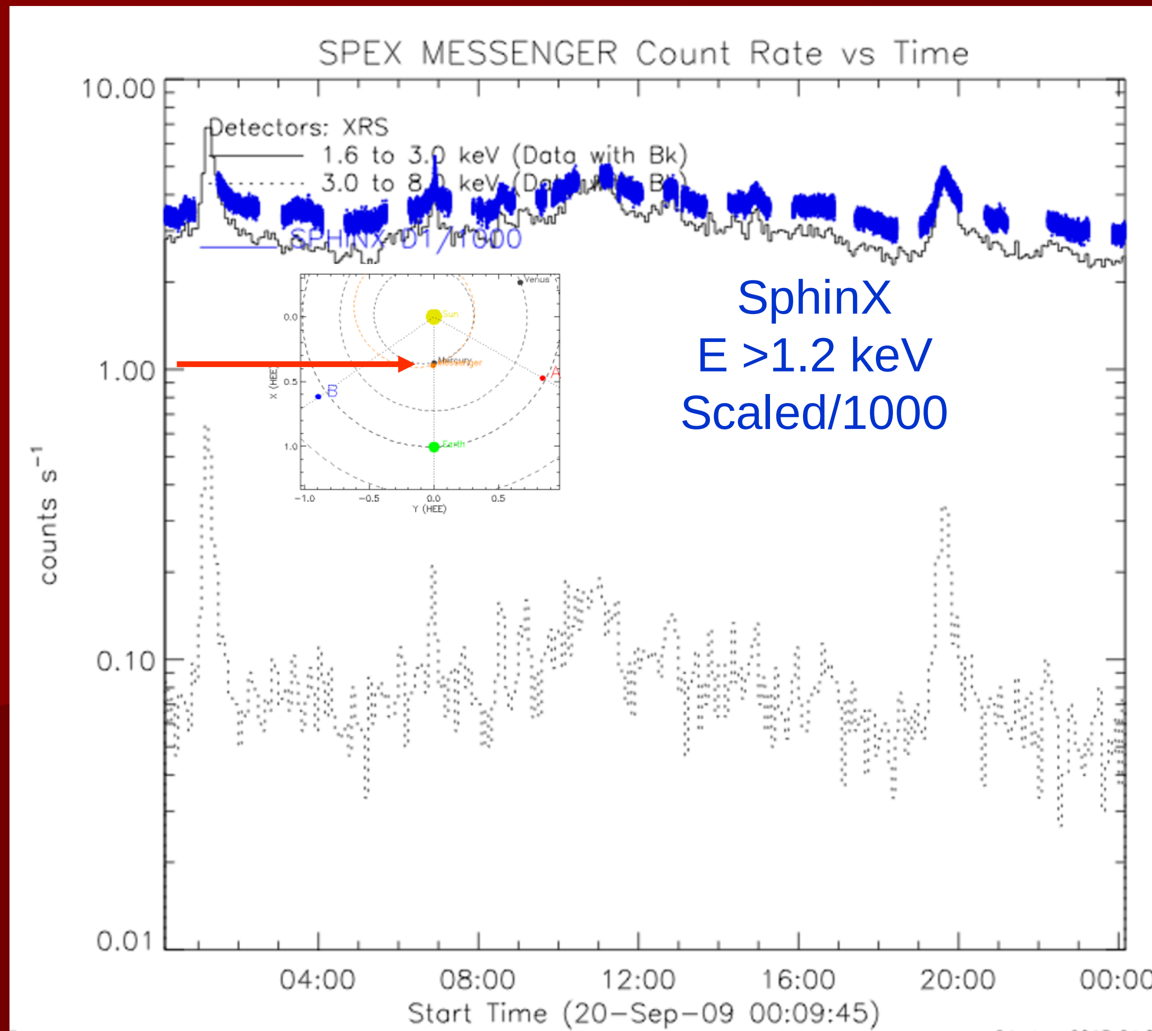


Measurements from Sun-Earth line, L5 & L4
Messenger X-Ray Spectrometer (XRS)

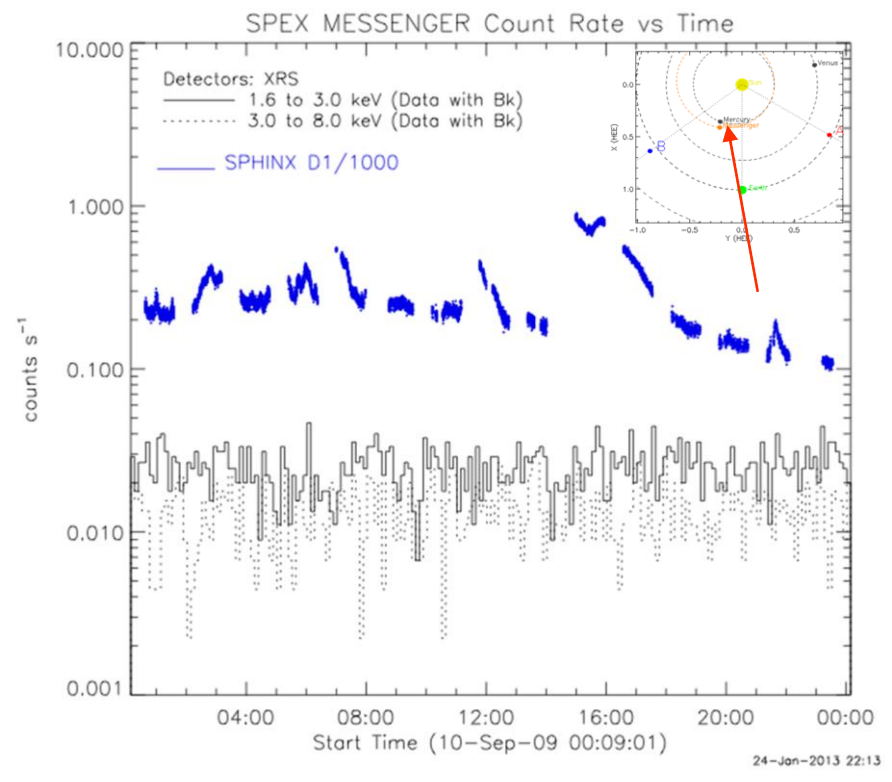
Calibration of the MESSENGER X-Ray Spectrometer

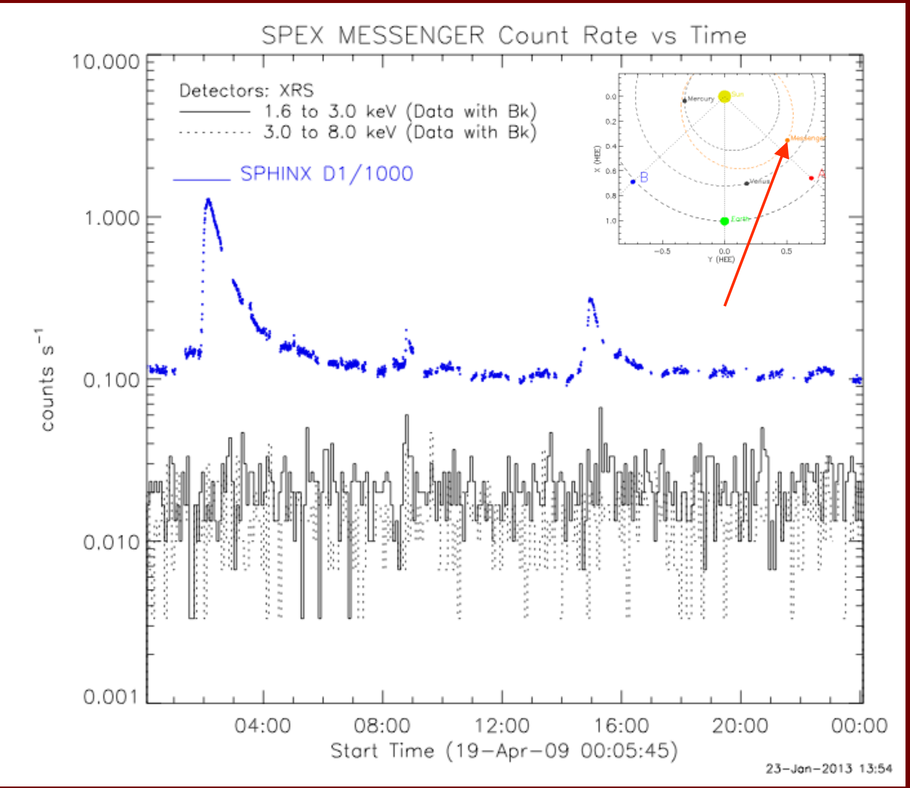
Richard D. Starr[a,*], Charles E. Schlemm II[b], George C. Ho[b], Larry R. Nittler[c], Robert E. Gold[b], Sean C. Solomon[c,d]

Planetary and Space Science 122(2016)13–25



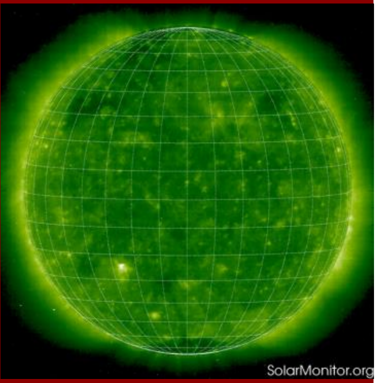
Comparison of X-ray fluence from LEO and L5, L4 SphinX & Messenger



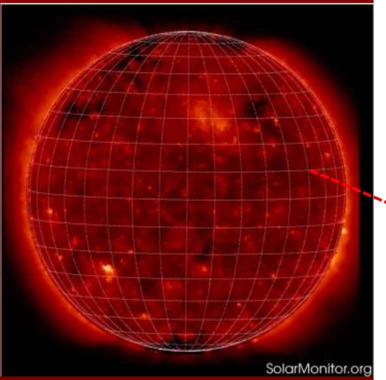


So, X-ray package(s) should be placed along the Sun-Earth line (LEO, GSO, L1) also in order to observe exactly these parts of the solar corona which illuminates Earth
Simple X-ray imagers will help, as it would be possible to trace activity of individual AR

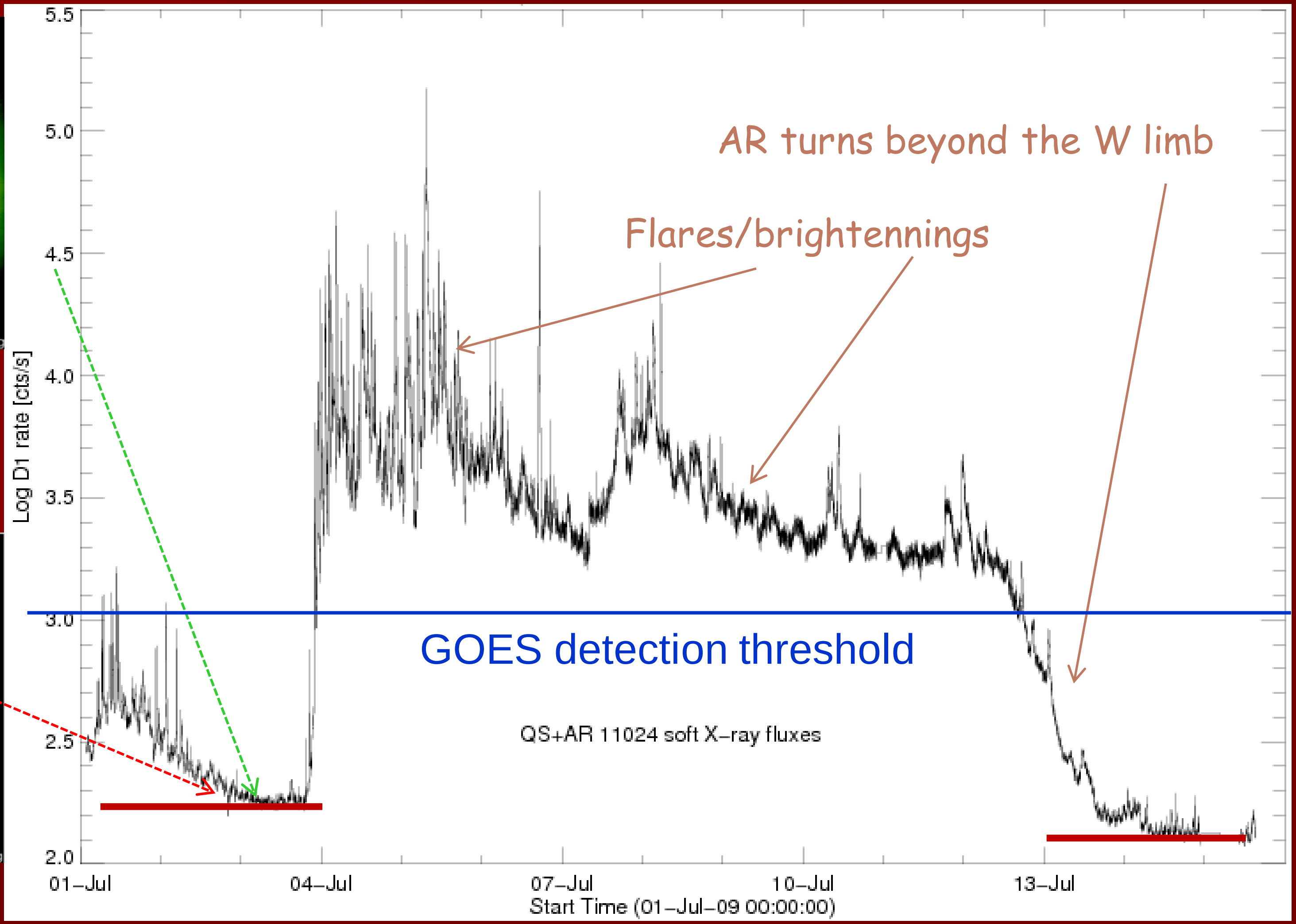
SphinX: SXR flux above 1.19 keV (1-16 July 2009) example history of AR emission



EIT 195
3 Jul. 2009
05:48 UT

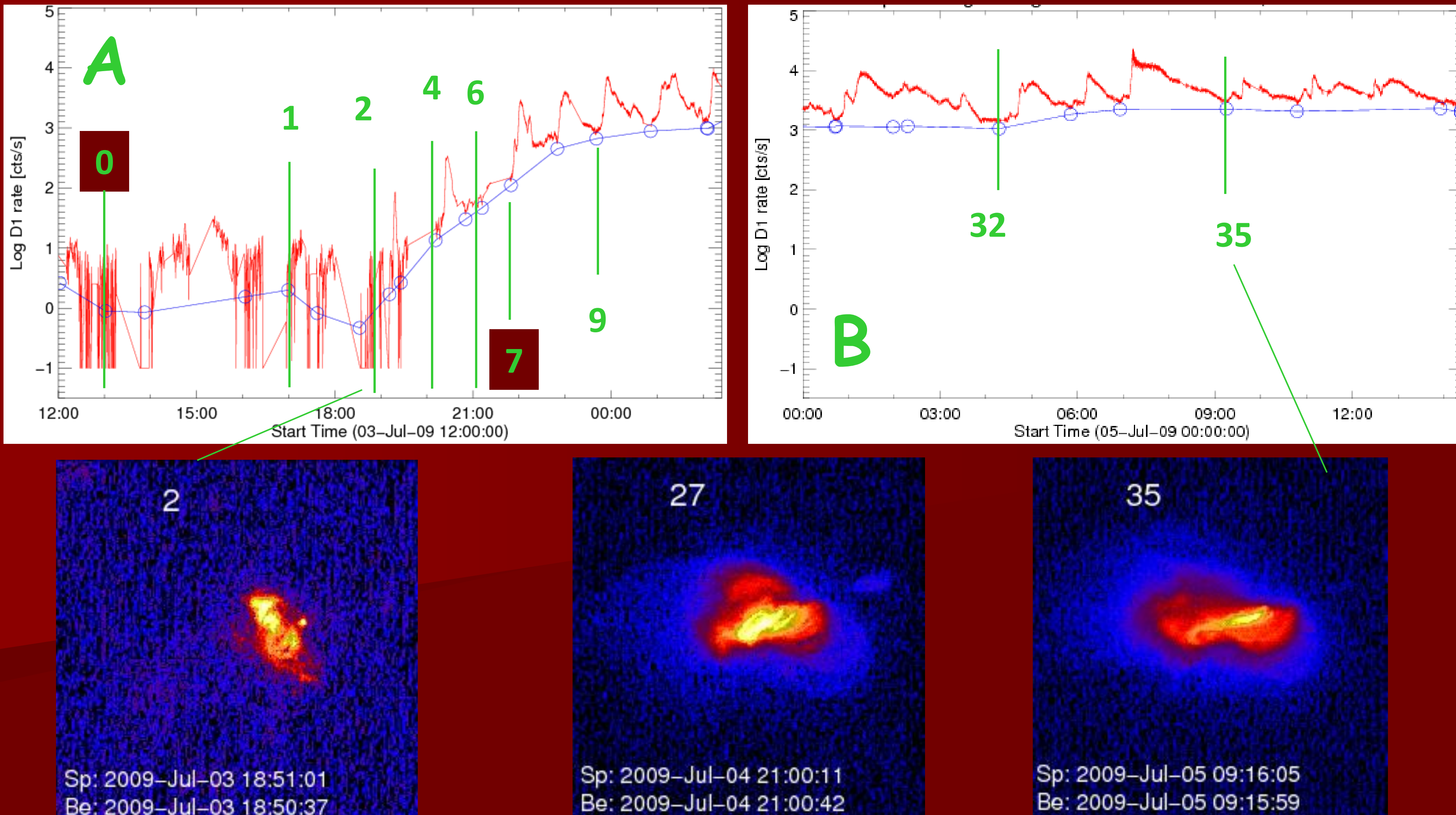


Hinode XRT
2 Jul. 2009
18:03 UT



Total of 175 flaring events
135 before 9th

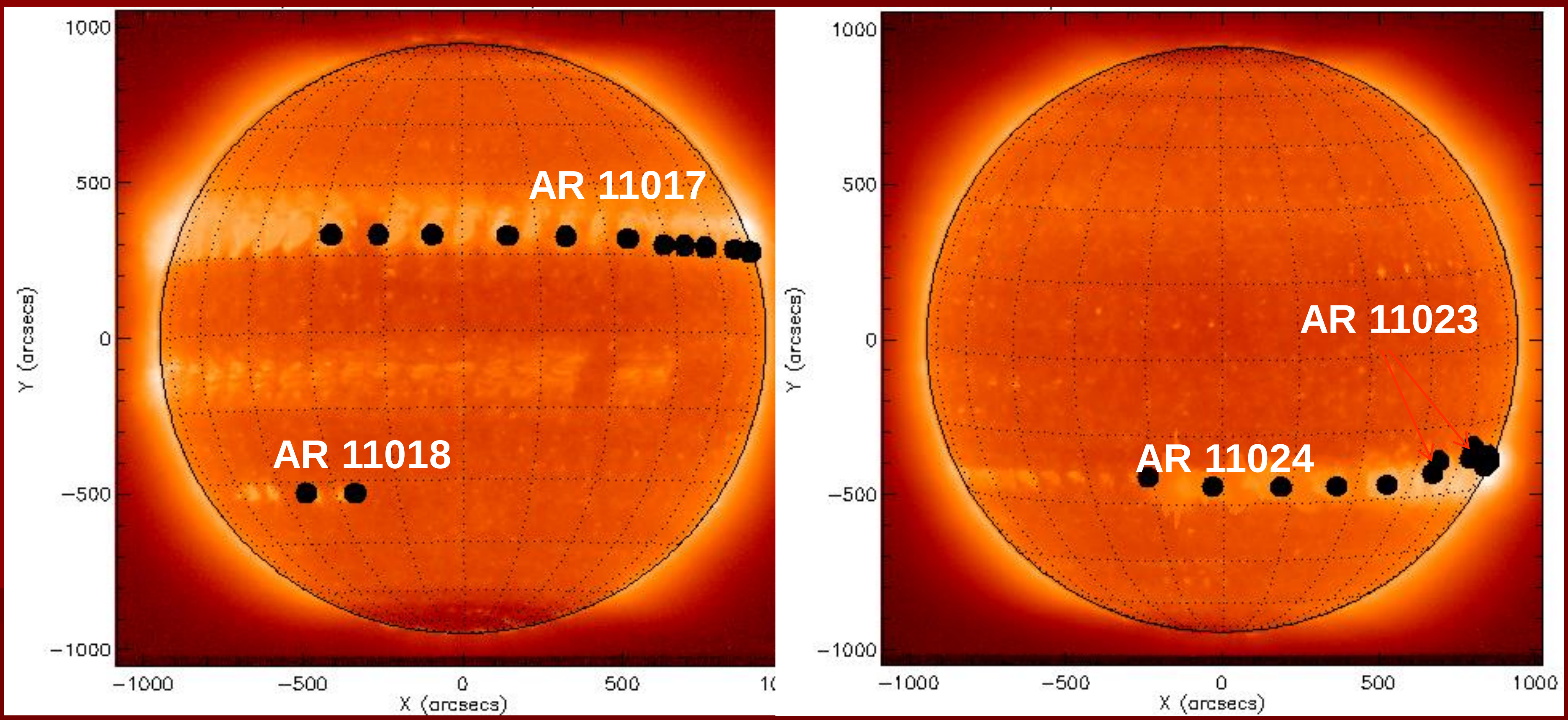
Higher time resolution



On X-ray (XRT) or EUV images AR emission is seen often much earlier than any activity is discerned in visible

Comparison of selected ARs as seen in photosphere and corona

(adapted from Szymon Gburek)



- Some AR seen in X-rays are not accompanied by any activity in visible
- There were small flares observed in 2009 „not connected with any AR”

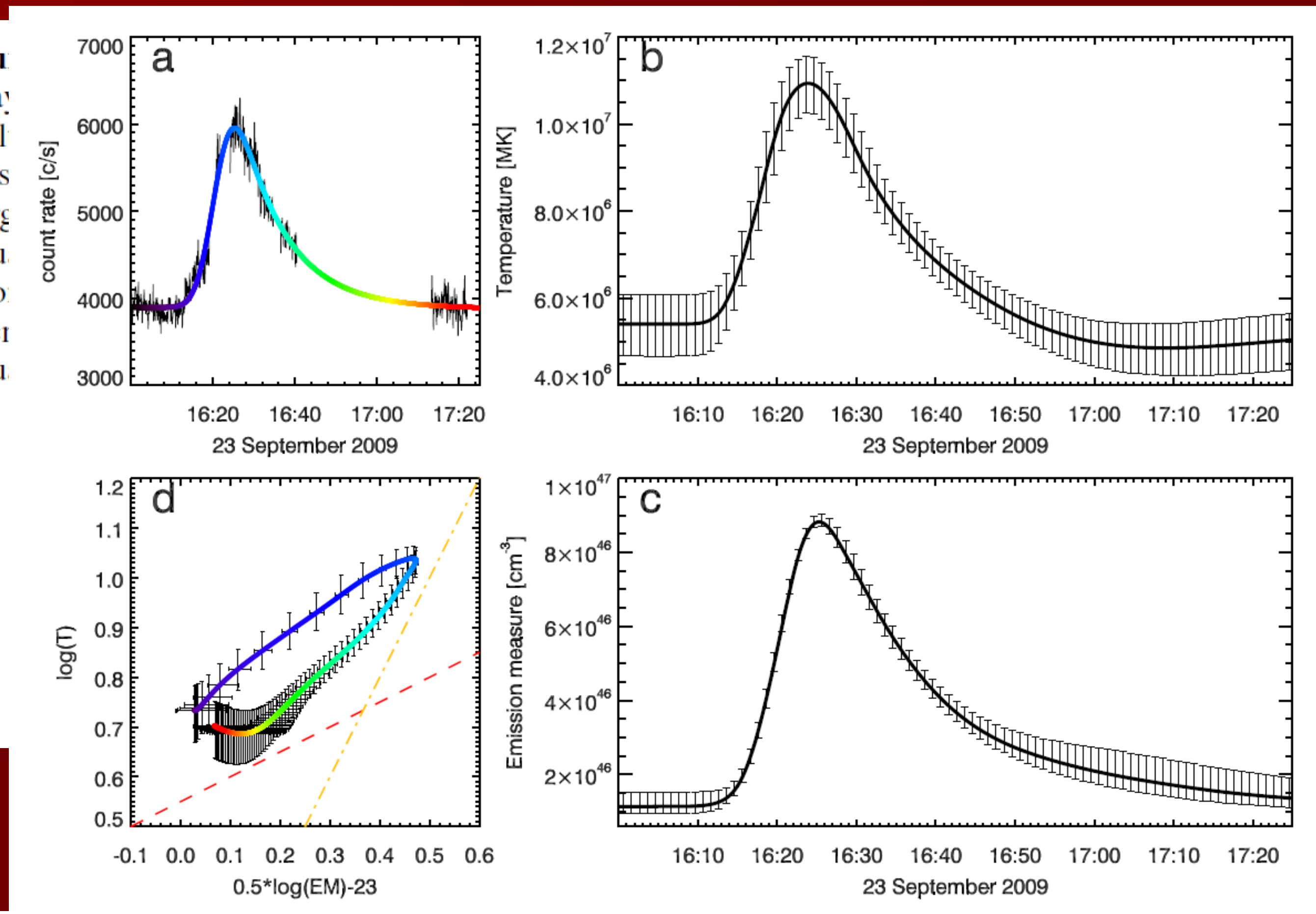
Automatic determinations of flare characteristics – elementary flare profile fits

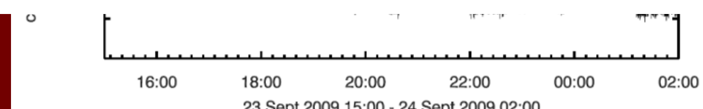
Flare Characteristics from X-ray Light Curves

M. Gryciuk[1,2] · M. Siarkowski[1] · J. Sylwester[1] · S. Gburek[1] · P. Podgorski[1] · A. Kepa[1] · B. Sylwester[1] · T. Mrozek[1,2]

Solar Phys (2017) 292:77
DOI 10.1007/s11207-017-1101-8

Figu… X-ray… resul… Gaus… energ… (Equ… expo… descr… (Equ…





…kind
…e by
the instrument
computer

Solar X-ray spectra @ low activity SphinX

THE ASTROPHYSICAL JOURNAL, 751:111 (5pp), 2012 June 1
doi:10.1088/0004-637X/751/2/111

SphinX MEASUREMENTS OF THE 2009 SOLAR MINIMUM X-RAY EMISSION

J. SYLWESTER[1], M. KOWALINSKI[1], S. GBUREK[1], M. SIARKOWSKI[1], S. KUZIN[2], F. FARNIK[3], F. REALE[4], K. J. H. PHILLIPS[5], J. BAKAŁA[1], M. GRYCIUK[1], P. PODGORSKI[1], AND B. SYLWESTER[1]
[1] Space Research Centre, Polish Academy of Sciences, 51-622, Kopernika 11, Wrocław, Poland; js@cbk.pan.wroc.pl
[2] P. N. Lebedev Physical Institute (FIAN), Russian Academy of Sciences, Leninsky Prospect 53, Moscow 119991, Russia
[3] Astronomical Institute, Ondřejov Observatory, Czech Republic
[4] Dipartimento di Fisica, Universitá di Palermo, Palermo, Italy, and INAF, Osservatorio Astronomico di Palermo, Palermo, Italy
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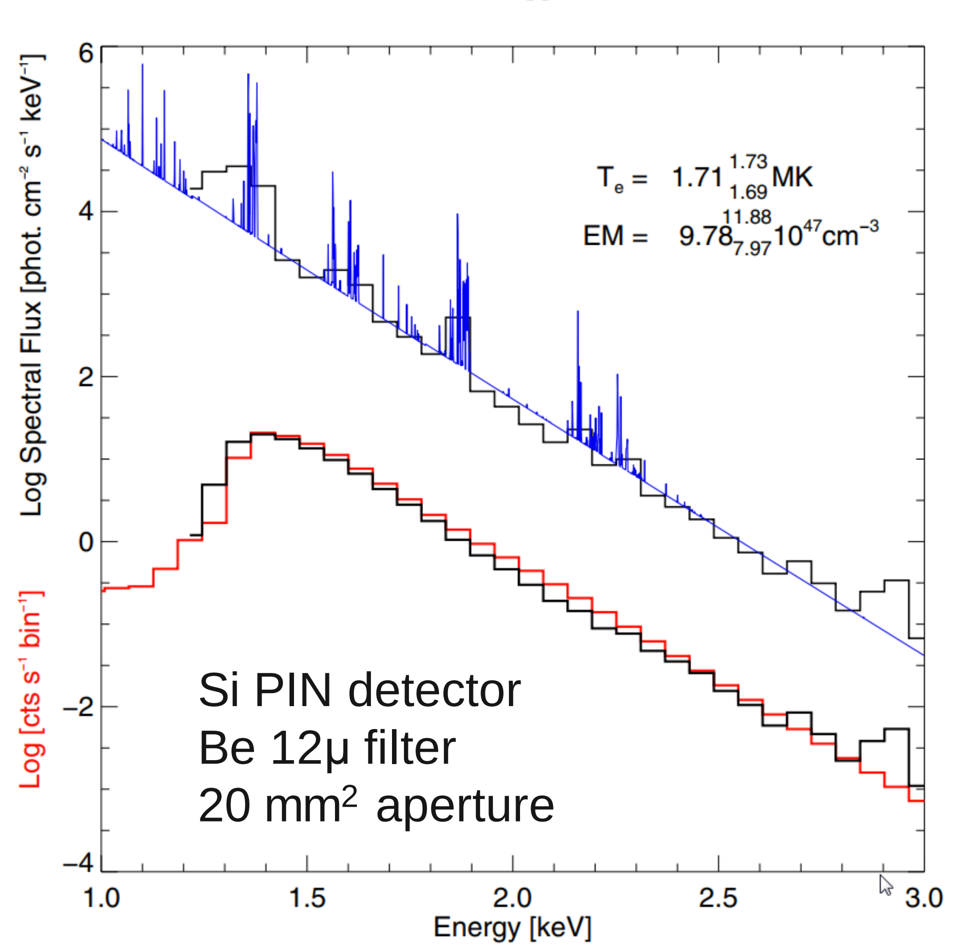
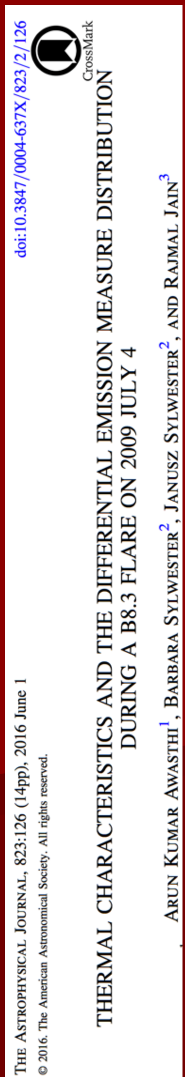
Received 2011 November 13; accepted 2012 March 29; published 2012 May 11

THE ASTROPHYSICAL JOURNAL, 751:111 (5pp), 2012 June 1



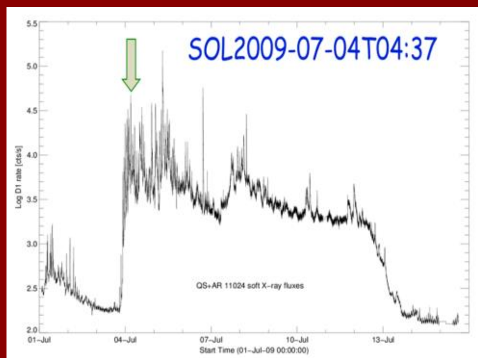
Averaged photon spectrum (upper histogram) over a time period on 2009 September 16 between 01:50 UT and 07:33 UT, made up of intervals when the total SphinX D1 count rate was below 110 counts s−1. The energy bins correspond to those in the count rate spectrum (lower histograms). The blue curve is the chianti photon spectrum at a few eV resolution showing principal line groups. In the count rate spectra, the black histogram is the observed SphinX spectrum, and the red histogram shows the best fit to the count rate spectrum with estimated temperature and emission measure indicated in the legend.

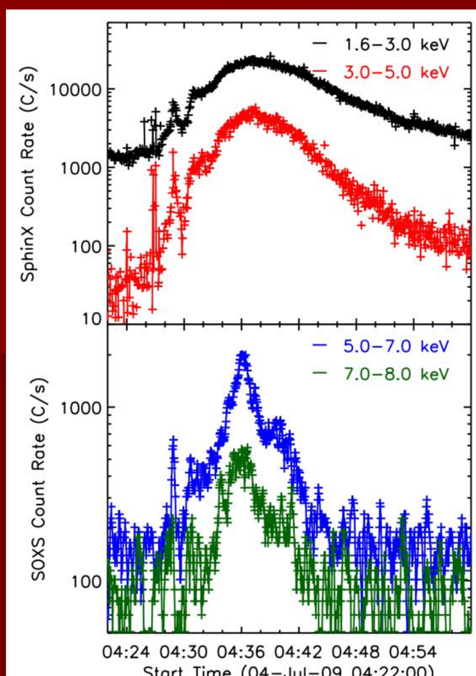
DEM (differential emission measure) for individual AR's and flares in it

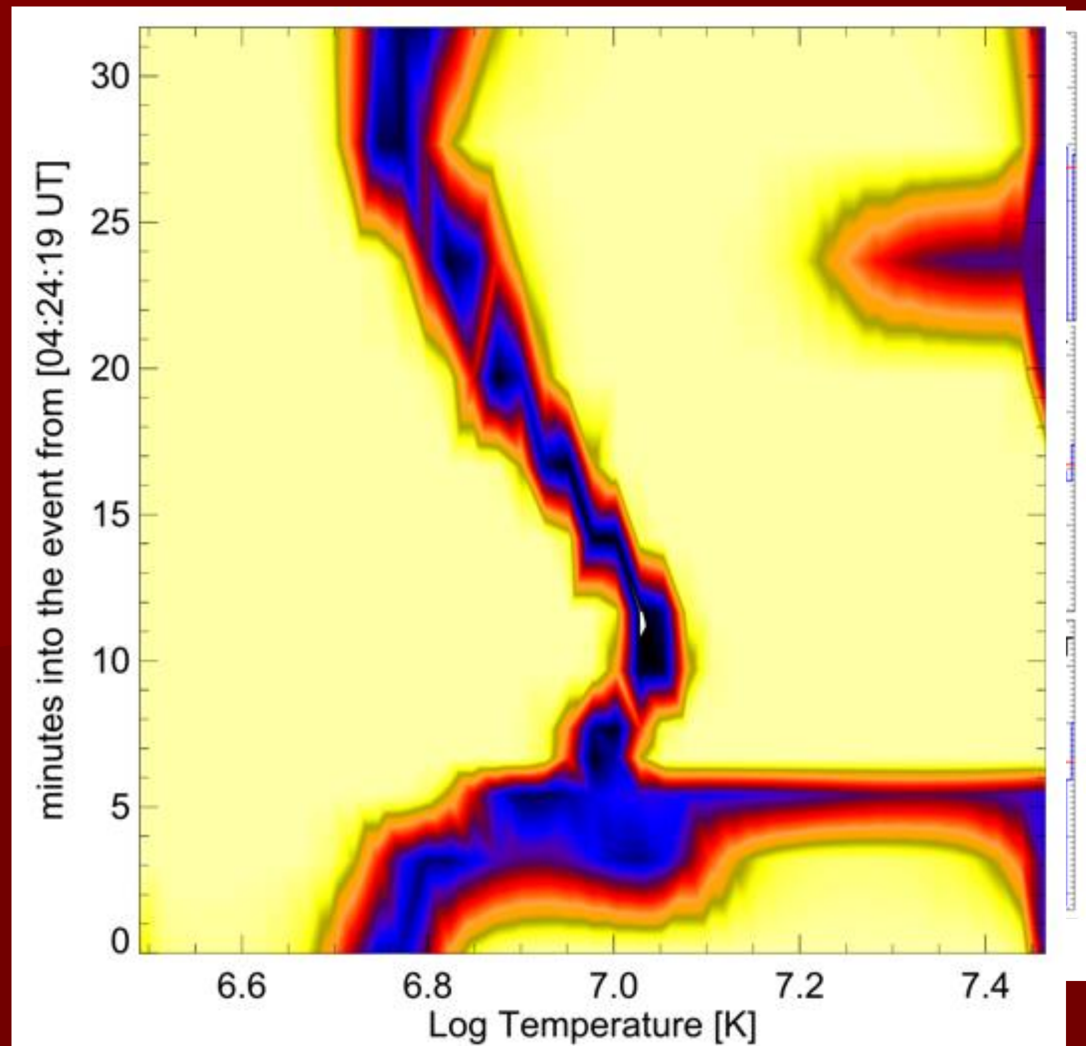

THE ASTROPHYSICAL JOURNAL, 823:126 (14pp), 2016 June 1
doi:10.3847/0004-637X/823/2/126

THERMAL CHARACTERISTICS AND THE DIFFERENTIAL EMISSION MEASURE DISTRIBUTION DURING A B8.3 FLARE ON 2009 JULY 4

ARUN KUMAR AWASTHI[1], BARBARA SYLWESTER[2], JANUSZ SYLWESTER[2], AND RAJMAL JAIN[3]





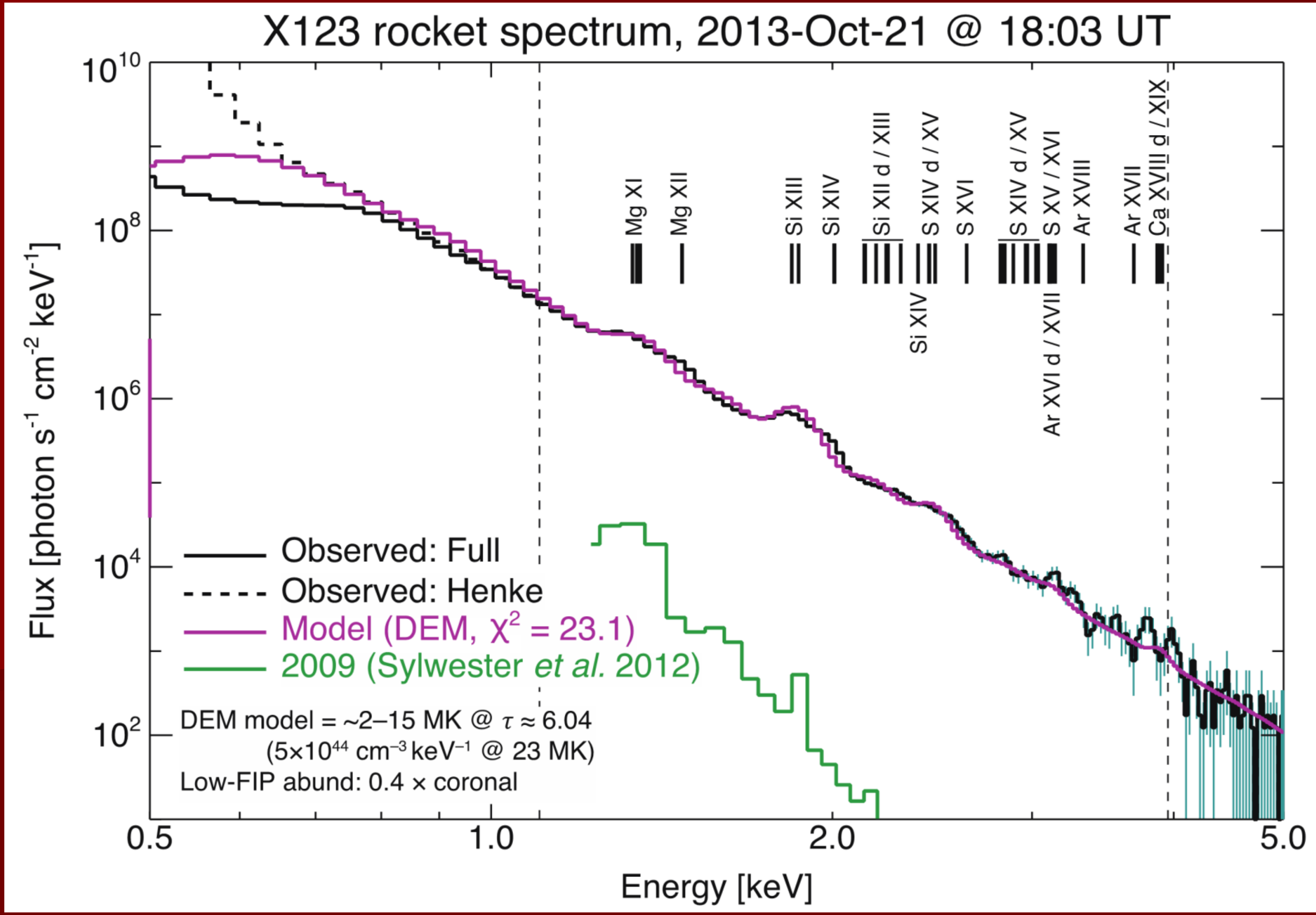


Spectrum of AR CubiXSS heritage

THE ASTROPHYSICAL JOURNAL LETTERS, 802:L2 (6pp), 2015 March 20
doi:10.1088/2041-8205/802/1/L2

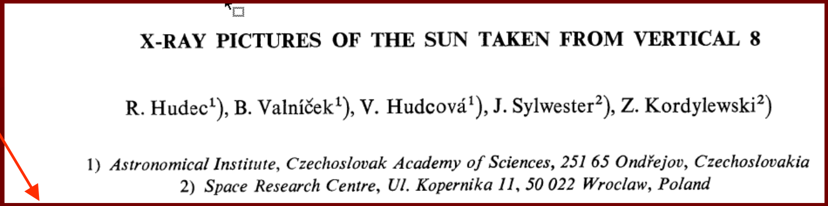
NEW OBSERVATIONS OF THE SOLAR 0.5–5 KEV SOFT X-RAY SPECTRUM

AMIR CASPI[1,3], THOMAS N. WOODS[1], AND HARRY P. WARREN[2]
[1] Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80303, USA
[2] Space Science Division, Naval Research Laboratory, Washington, DC 20375, USA
Received 2014 October 28; accepted 2015 January 23; published 2015 March 18



X-ray (soft) imagers

- Pin-holes !!!
  - Small aperture grazing incidence mirror possible
- X-ray grazing optics (SXT-Yohkoh, XRT-Hinode) bulky
- FOXSI, Fresnel lenses (long focal lengths)


X-RAY PICTURES OF THE SUN TAKEN FROM VERTICAL 8

R. Hudec[1]), B. Valníček[1]), V. Hudcová[1]), J. Sylwester[2]), Z. Kordylewski[2])

1) *Astronomical Institute, Czechoslovak Academy of Sciences, 251 65 Ondřejov, Czechoslovakia*
2) *Space Research Centre, Ul. Kopernika 11, 50 022 Wroclaw, Poland*

Which characteristics of AR & flares can be derived from pin-hole imagers?

- AR locations on the disk
  - positions o COG
  - Ellipsiticy (inclination of main axis)
  - Butterfly diagrams in X-rays
  - Rotation rates
- Physical conditions
  - Temperature from filter ratio (T)
  - Emission Measure (EM, DEM) & abundances
  - Thermodynamic measure $\eta = T\ EM^{1/2}$; $E_{thermal} = \eta\ V^{1/2}$
- Outlines/boundaries of larger coronal holes easily detected

All these parameters can be derived onboard by respective algorithms, their values send to telemetry. Full info stored in large redundant memory buffer. If necessary, interesting parts of memory content send to telemetry

Image detectors: CMOS/sCMOS

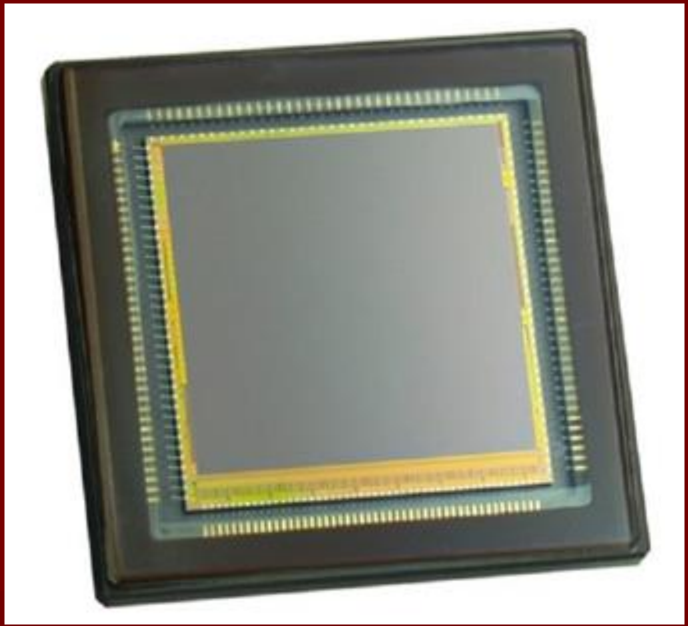
https://www.gophotonics.com/search/cmos-image-sensors

- In HDR (high dynamic range) mode - 24 fps Standard 48 fps.
- Up to ~30 X-ray photons/pixel/frame
- ROI lines can be Selected electronically
- Amplitudes related to photon energy can be measured in low count rate mode


Design and characterisation of the new CIS115 sensor for JANUS, the high resolution camera on JUICE

Matthew Soman[a], Andrew D. Holland[a], Konstantin D. Stefanov[a], Jason P. Gow[a], Mark Leese[a], Jérôme Pratlong[b], Peter Turner[b]

High Energy, Optical, and Infrared Detectors for Astronomy VI, edited by Andrew D. Holland, James Beletic, Proc. of SPIE Vol. 9154, 915407 · © 2014 SPIE · CCC code: 0277-786X/14/$18 · doi: 10.1117/12.2056810

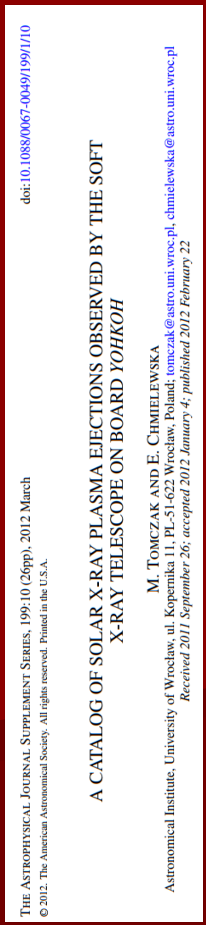


GSENSE4000 4MP Scientific CMOS Image Sensor, now in X-ray tests at our lab.
Energy resolution ~200eV @ 1.5 keV
Larger sCMOS up to 6k x 6k are available from e2v
(https://www.e2v.com , CIS115 for Janus)

Soft X-ray coronograph:
pin-hole image with disk emission blocked

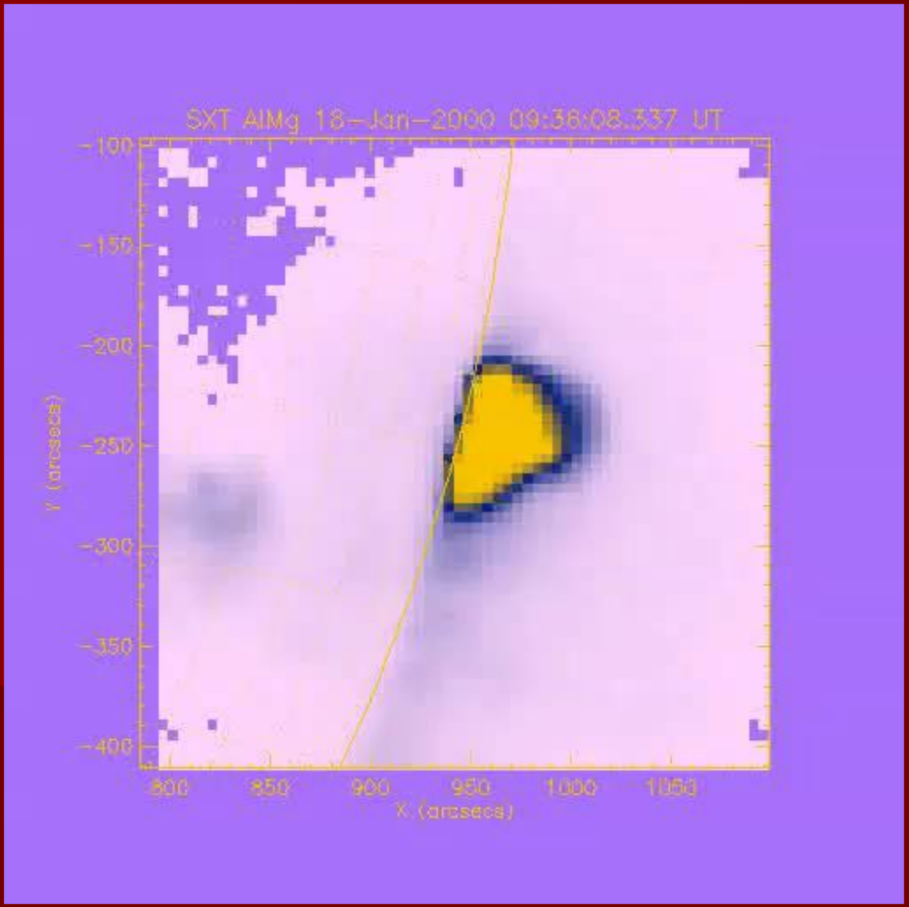
- Good background emission estimates from blocked central portion
- Very thin mylar filter to see „above the limb" radial intensity profile
- Studies of plasmoid ejections possible
  - Direction, speed, spectra with medium resolution (200 eV) available from CMOS for every pixel
- Intensity profiles along the disk circumference
- Photometry of selected areas in the corona
- Data gather interval - every minute

X-ray plasmoids in the corona (http://www.astro.uni.wroc.pl/XPE/catalogue.html)


THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 199:10 (26pp), 2012 March
doi:10.1088/0067-0049/199/1/10

A CATALOG OF SOLAR X-RAY PLASMA EJECTIONS OBSERVED BY THE SOFT X-RAY TELESCOPE ON BOARD *YOHKOH*

M. TOMCZAK AND E. CHMIELEWSKA
Astronomical Institute, University of Wrocław, ul. Kopernika 11, PL-51-622 Wrocław, Poland; tomczak@astro.uni.wroc.pl, chmielewska@astro.uni.wroc.pl
Received 2011 September 26; accepted 2012 January 4; published 2012 February 22



- ~400 erupting plasma ejections found on Yohkoh SXT images

The best instrument to observe such ejections would be X-ray pin-hole coronograph where strong disk emission is blocked. Larger pin-hole – more photons, less resolution 3 ÷ 5 arcmin

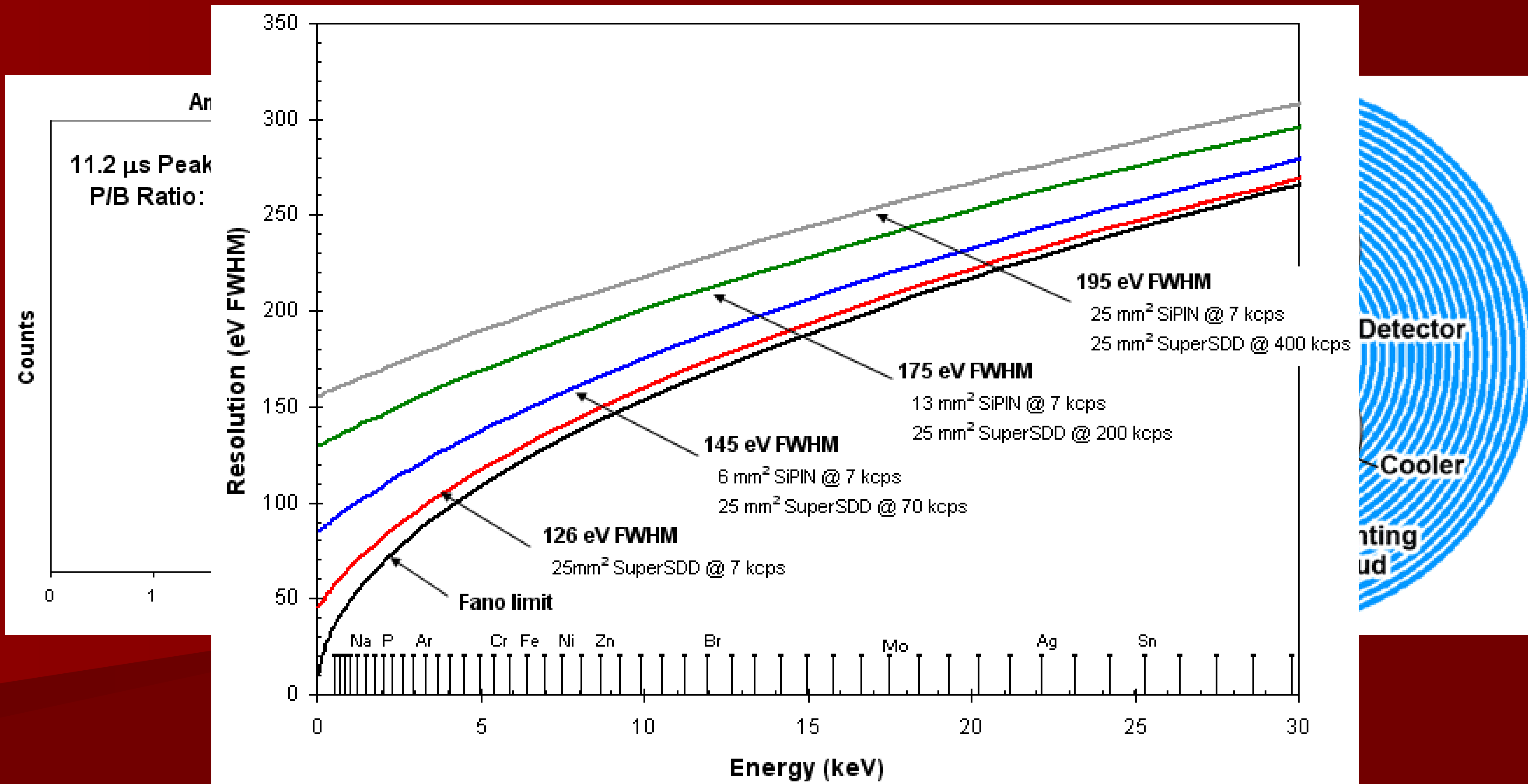
Spectrophotometer block, similar to those proposed for SphinX-NG

- Entire corona in the FOV (~2 degrees)
- Should record X-ray photons from the range 0.5 ÷ 100 keV
- Each photon arrival time (1 microsec) and energy (512 bins) should be stored to memory
- Spectra should be processed on-board and results of parametric fits transmitted to the ground (DEM shape, average T & EM, non-thermal characteristics, elemental abundances)

modern SDD: Si drift detectors (Amptek, Ketel

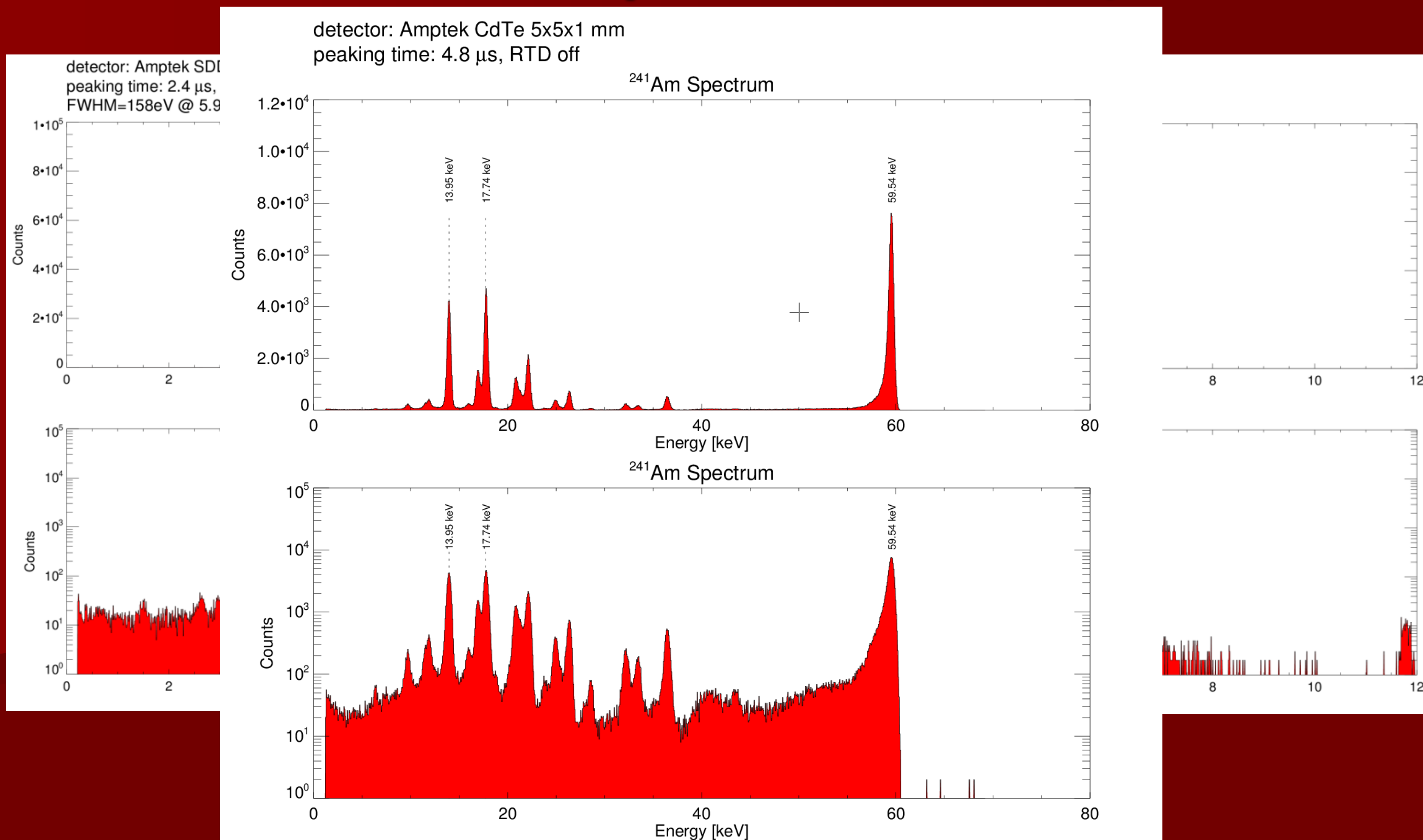
http://www.amptek.com/drift.html US

https://www.ketek.net/sdd/vitus-sdd-modules/ EU

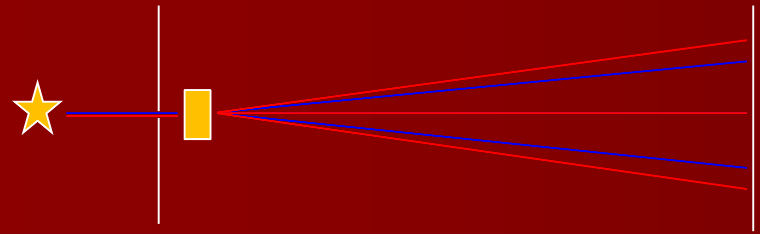


Dynamic range ~20 000, so three such detectors with different apertures will cover 8 orders of magnitude dynamic range with redundant overlap.
Much lower noise, with the same sensitivity to particles.

Test spectra taken at our Laboratory in Wrocław, Poland



Dispersive imagers
CubiXSS 6U (MOXSI) being a good example



If one put fine transmission grating behind the pin-hole an image is formed in zeroth order and spectra of AR are formed in 1st order

PROCEEDINGS PAPER

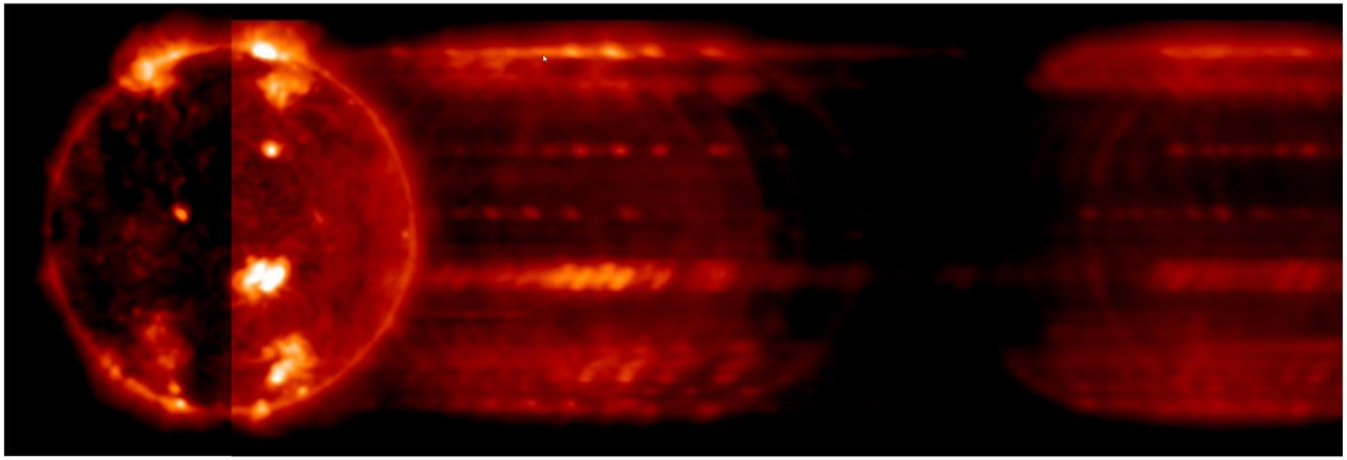
A slitless x-ray imaging spectrograph concept for solar-pointed CubeSats (Conference Presentation)

Author(s): Amir Caspi; Albert Y. Shih; Harry P. Warren; Marek Steslicki; Janusz Sylwester; Craig DeForest; Glenn Laurent

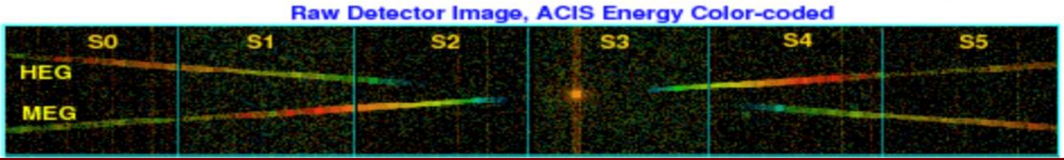
Date Published: 7 December 2016
PDF: 1 pages
Proc. SPIE 9978, CubeSats and NanoSats for Remote Sensing, 99780B (7 December 2016); doi: 10.1117/12.2238478

Multi-Order X-ray Spectral Imager

- Combination of pinhole imaging and transmission grating dispersion yields full-Sun "overlappograph" with 0^{th} order and dispersed orders on same detector



Chandra HTG image for point sources (stars)



X-ray package - not only monitoring; areas of envisaged science progress

- The soft X-ray range 0.8 - 15 keV
  - Bulk of thermal emission is formed in this range
  - Substantial radiative cooling of the plasma takes place
- Ęxtension of existing 40y+ database for X-ray fluence
  - 0.5 ÷ 4 Å & 1 ÷ 8 Å (GOES)
- Studies possible
  - long term, individual AR solar flux variability, average temperatures & emission measure behaviour, DEM studies, coronal energy balance, histories of individual AR flaring
  - coronal plasma abundances for individual AR
- Measurements of interplanetary background due to energetic particles (X-ray coronograph, small aperture SDD & CdTe)

Status of individual blocks is TRL 9 (all parts flight tested) but

- Electronics (FPGA) should be rad-hard in order to span at least 10y operation in interplanetary space
- Detectors should be ground tested to operate long in high doses of radiation
- Filters, especially „thin plastic" should resist long operation under solar EUV
- Advanced autonomous algorithms for on-board data processing should be carefully ground tested, uplink to S/C should be possible
- Few minutes delay will exist for telemetry signal to reach ground station from L5(4) or S/C from the ground
- Large ~1 TB, redundant (at least triple) data memory banks available on-board to store ALL collected info
- Parts of this info to be put to telemetry on request from the ground

Conclusions & Thank you!

- Imaging X-ray Package (similar to CubiXSS, TBD by Marek)
  - Set of pin-hole cameras with different filters
    ~ 1 ÷ 2 arcmin resolution
  - X-ray pin-hole coronograph
    ~ 3 ÷ 5 arcmin resolution
  - Grating dispersive imager, medium spectral resolution
  - Hard X-ray imager Calliste based, energy range
    4 ÷ 100 keV
- Spectrophotometer package (TBD by Szymon)
  - Soft X-ray range – set of SDD, line groups clearly seen
  - Hard X-ray range – set of CdTe PIN detectors