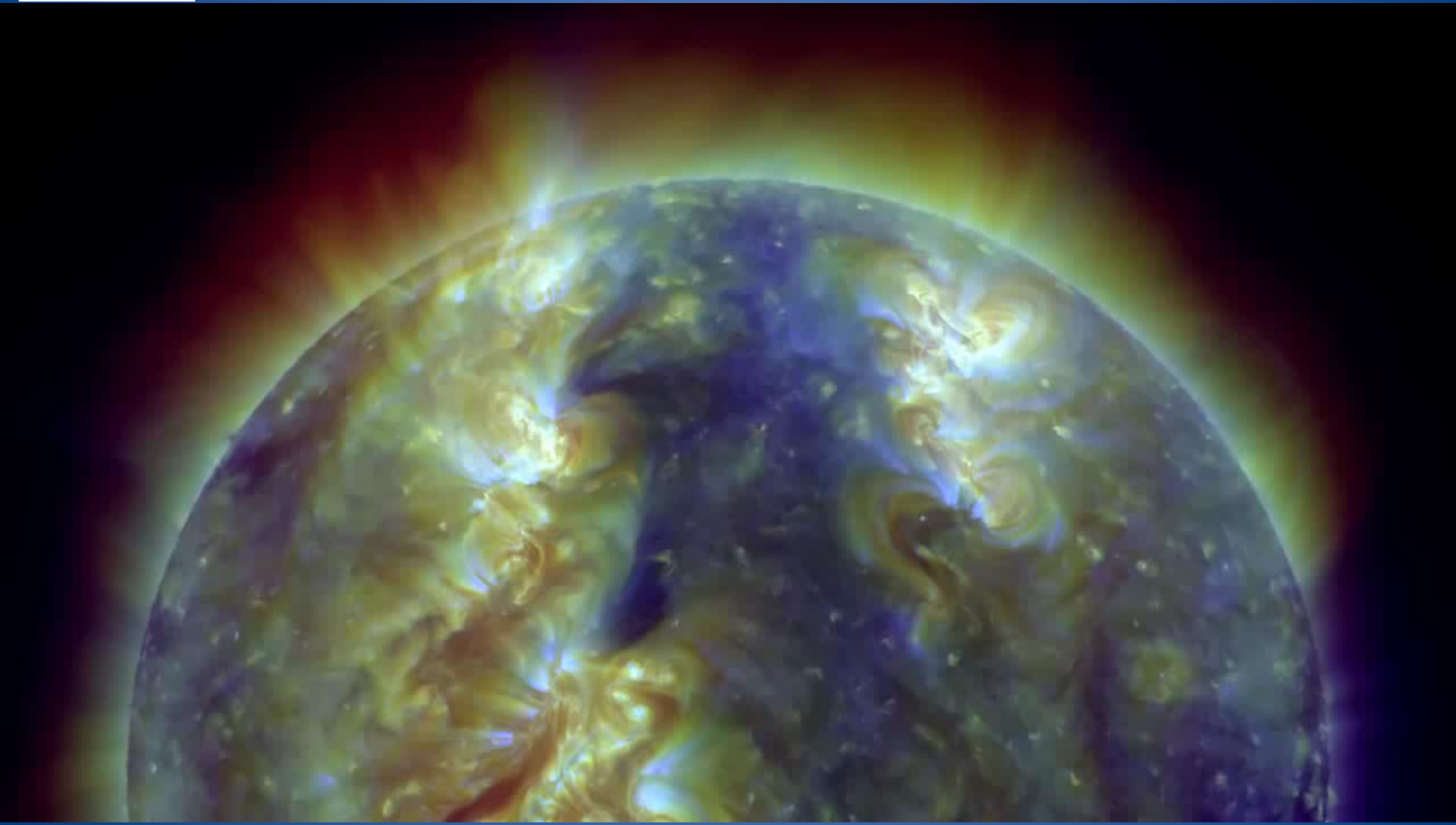
PRESENT STATUS OF RESEARCH AT THE WROCLAW SOLAR PHYSICS DIVISION OF SPACE RESEARCH CENTRE PAS

Janusz Sylwester

Outline

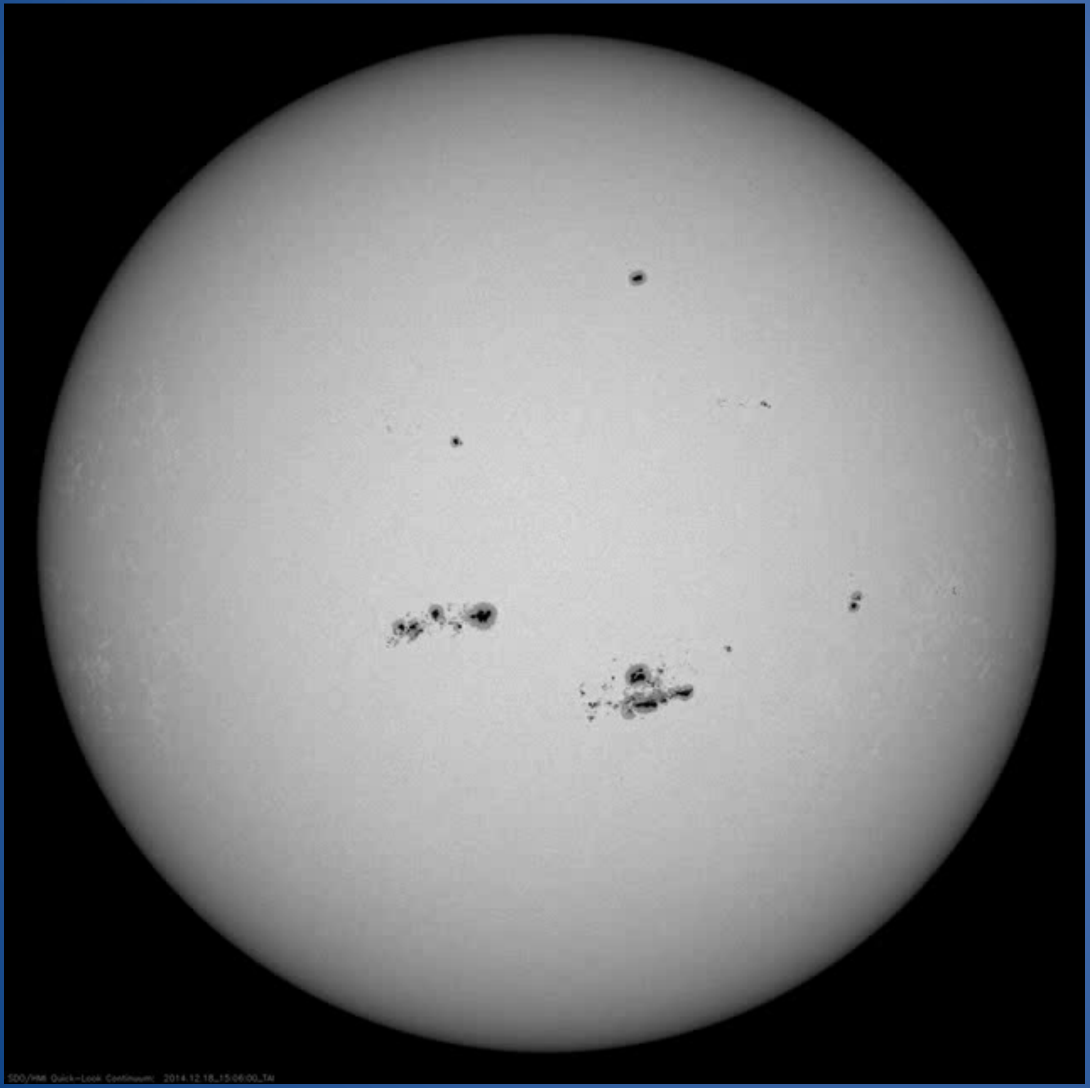
- Rationale of studying solar atmosphere
- History & heritage
- Our contributions to solar physics
- Present team, science interests and collaborations
- Experiments we are working on

Solar flare is the catastrophic energy release process on the Sun (up to 10^{33} ergs; 10^{12} TNT)



NASA SDO multispectral image 1 – 5 MK corona

Surface of the Sun with sunspots



- Size

  10000 km
  -30000 km

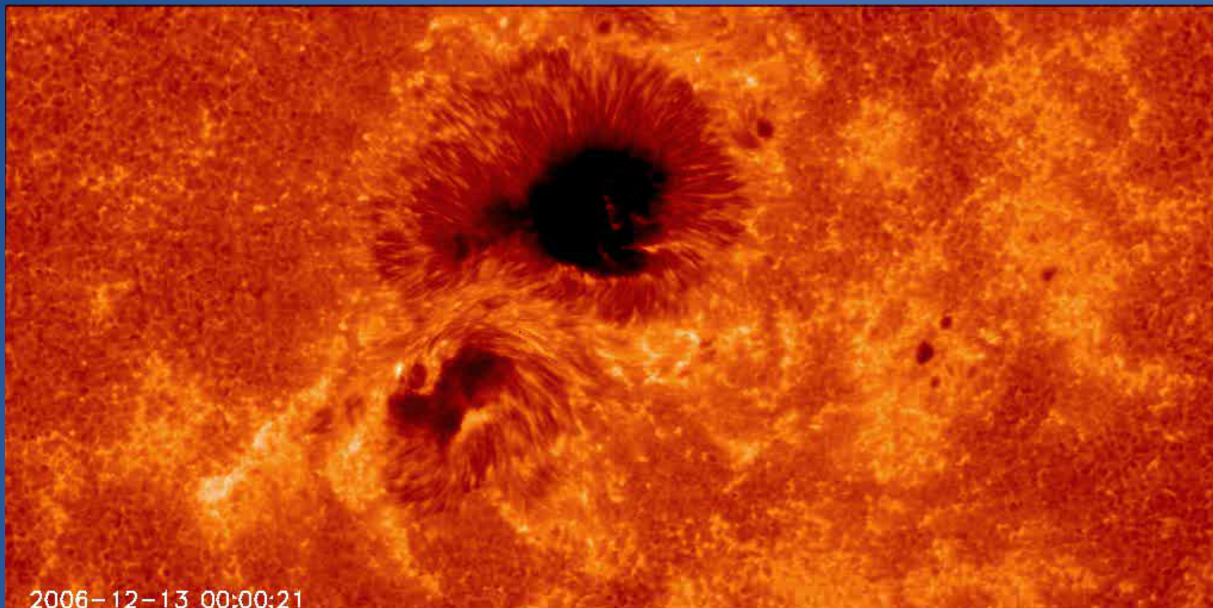
- Magnetic field

0.2-0.3 Tesla

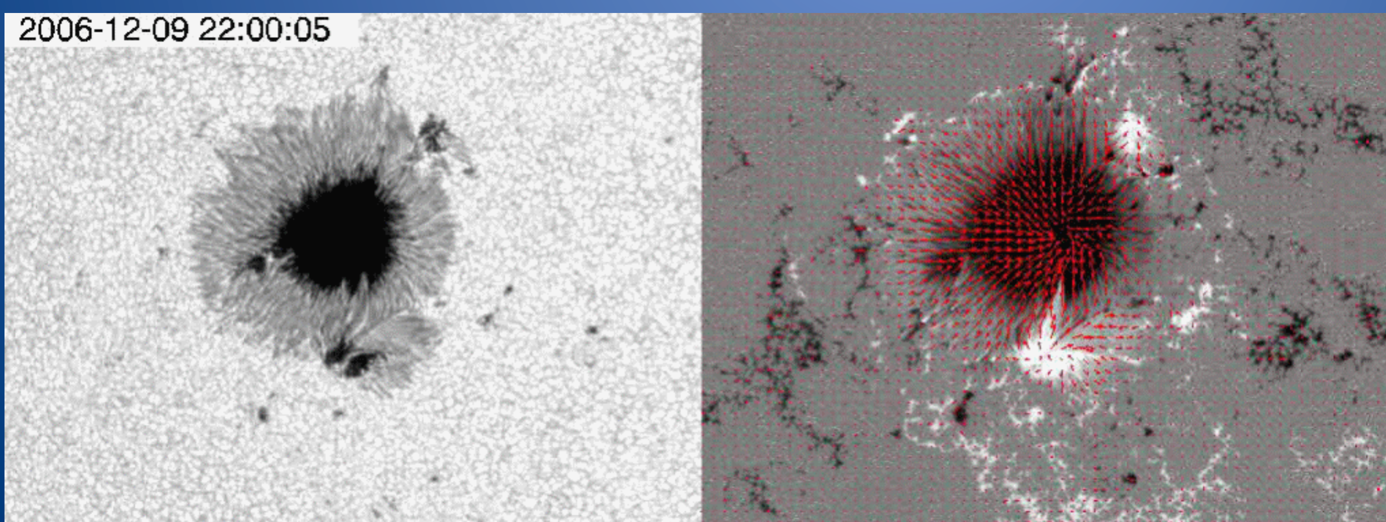
- Up to 3-4 months on the disk

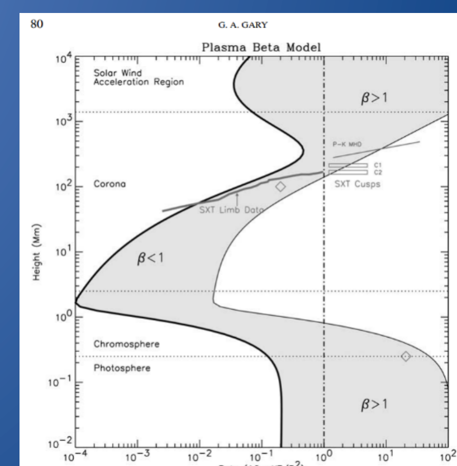
The Active region – part of the solar atmosphere where strong magnetic fields dominate

PLASMA 2015 Solar Flares Janusz Sylwester



- The role of magnetic fields
- $\beta = 8\pi p / B^2$





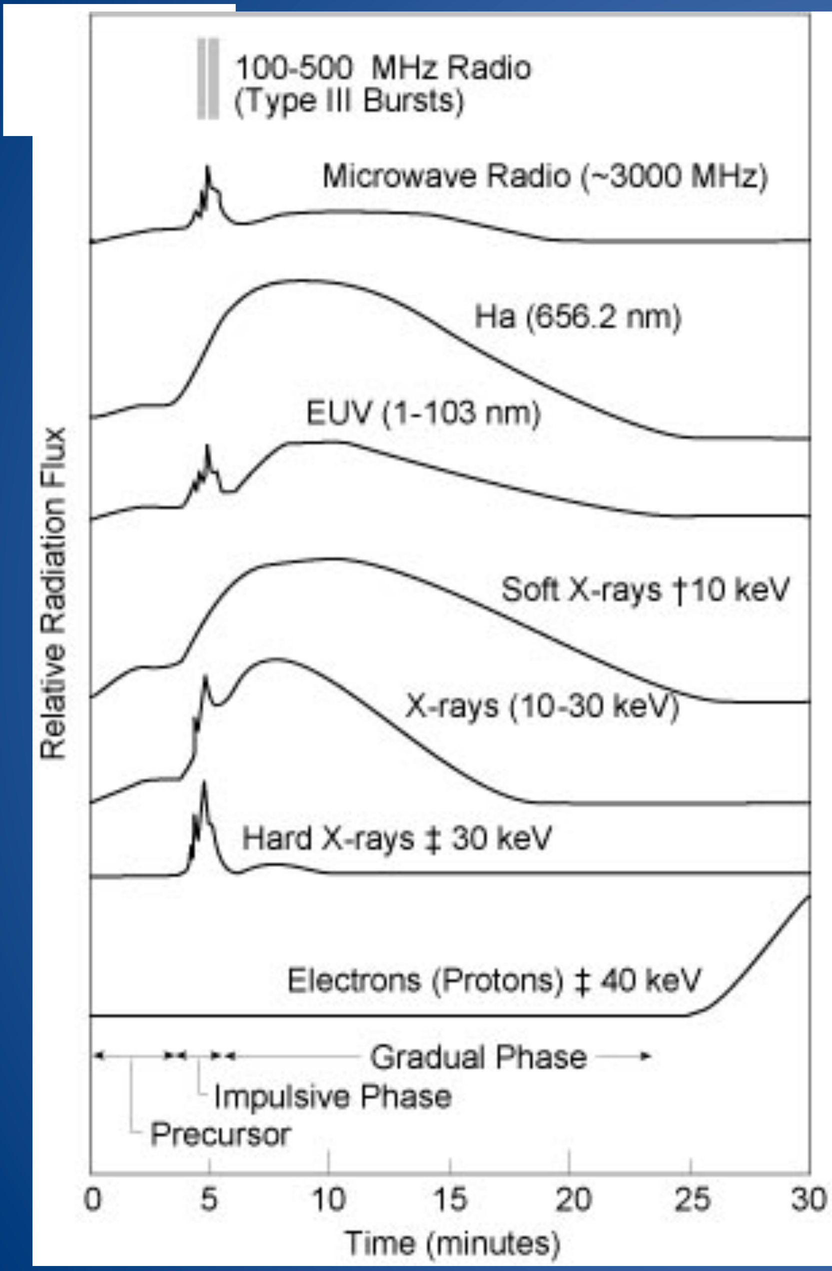
Solar Physics 203: 71–86, 2001.

Solar flare releases non-potential energy stored in magnetized plasma of an active region

Somewhat "mysterious" process of energy release

- We cannot observe the current sheets at the reconnection region as the transversal scale "km"
- We do observe secondary emissions from beams of accelerated particles (electrons & protons) through the hard X-rays, radio type III emission, Ha & sometimes white light
- We do see so-called evaporation (ablation) at the places of contact between the coronal and denser portions of the flaring loops

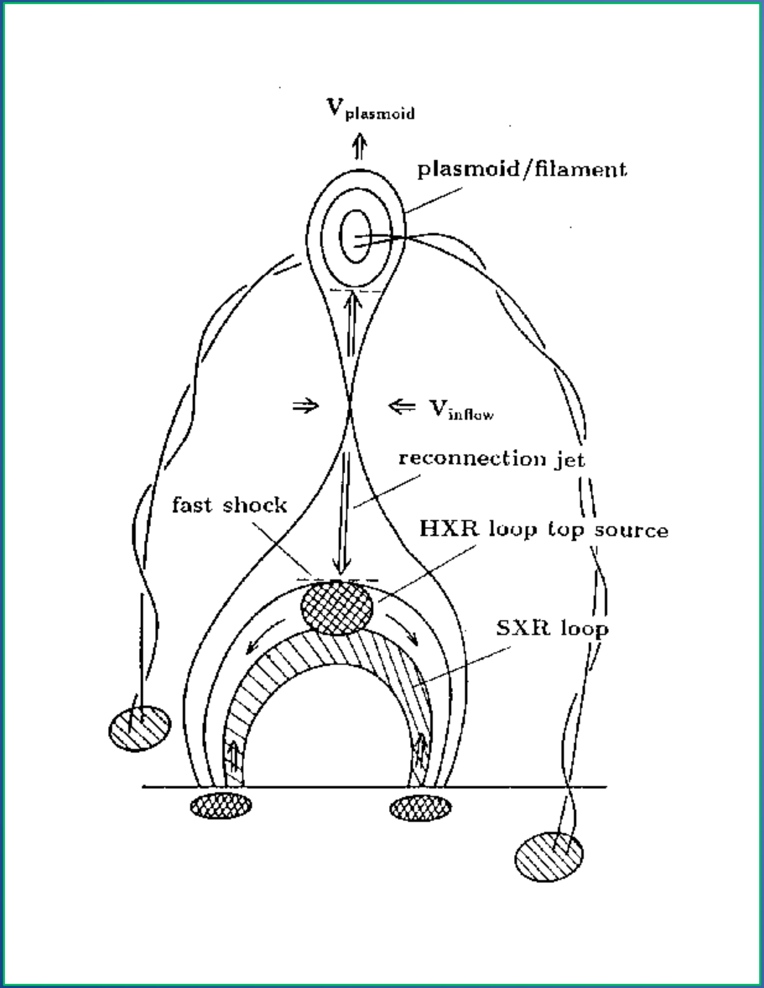
Flare time profiles



During the early impulsive phase of a solar flare, electrons accelerated to high energies and very rapid speeds emit radio bursts and hard X-rays. The radio emission is at frequencies from 100 to 3000 MHz, or at wavelengths between 3 and 0.1 meters; the hard X-rays have photon energies greater than ~20 keV. The subsequent gradual phase is detected with soft X-rays, at energies of about 10 keV or less (GOES X-ray channels), as an aftereffact of the impulsive radiation. The soft X-rays are the thermal radiation, or bremsstrahlung, of a gas heated to temperatures of tens of millions of degrees.

Standard CSHKP flare scenario

(Carmichael 1964; Sturrock 1966; Hirayama 1974; Kopp & Pneuman 1976)



- Reconfiguration of remote footpoints leads to filament rising
- Magnetic field „reconnects” at the X-point causing reconnection jets, shocks, particle acceleration & evaporation off denser plasma

Physical conditions in the flaring loop

- Energy source at or above loop system apex
- Ne~ 10^9 cm^{-3} Te ~2 MK (180 eV)
- Early on, the most of energy is contained in the accelerated beams of particles
- Beams & heated plasma are confined by loop-like magnetic field all along
- Highly non-equilibrium conditions, non-local energy transport is present at the initial phase
- Hydrodynamic response of the atmosphere to heating: plasma pressure jump at the base, condensation propagating down & hot plasma evaporates filling the coronal portion of the loop

Modelling the HD response to energy release: so-called diagnostic diagram

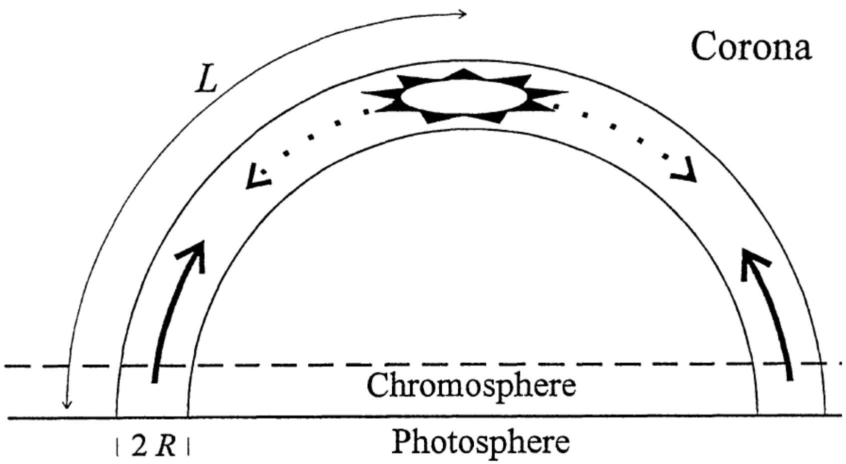


Fig. 1. The schematic drawing of the flaring loop. The asterisk shows the place of release. The dotted arrows denote downward flow of conducted energy. The thick ar the inflow of evaporated chromospheric plasma into the loop. The dashed line represen region – the thin layer between chromosphere and corona.

Space Science Reviews **76:** 319–337,

$$T^{3.5} = 1.2 \times 10^6 E_{\mathrm{H}} L^2.$$

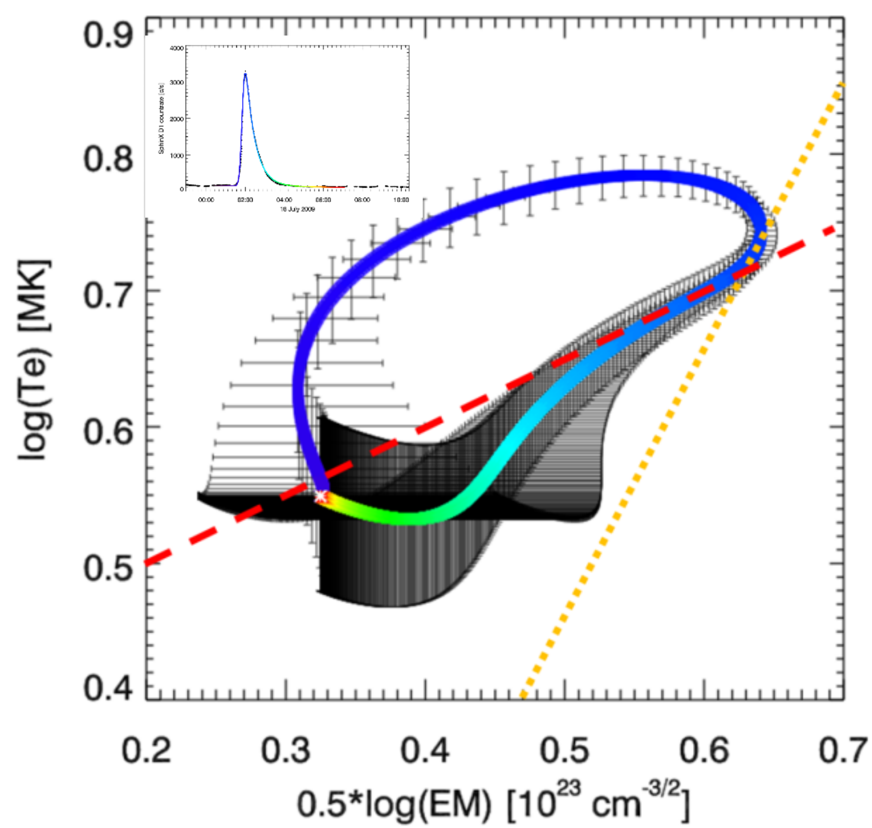


Fig. 2. The density-temperature diagram for the plasma at the loop summit. The diagram corresponds to the model of the flare for which $L = 2 \times 10^9$ cm, the initial temperature $T_0 = 3.2 \times 10^6$ K, the initial base pressure $p_0 = 6$ dyn cm^{-2} and the flare heating lasting for 300 s has been assumed. The maximum value of the heating rate $E_{\mathrm{H}} = 10$ ergs cm^{-3} s^{-1}.

Rosner, R., Tucker, W. H., and Vaiana, G. S.: 1978, *Astrophys. J.* **220**, 643.

Flare threats:

K. Shibata keynote presentation, IAU General Assembly, Honolulu, August 2015

Carrington flare

(1859, Sep 1, am 11:18)

http://en.wikipedia.org/wiki/Solar_storm_of_1859

If the Carrington-class flare occur now, what will happen ?

According to a study by the National Academy of Sciences (2008), http://www.nap.edu/catalog.php?record_id=12507
the total economic impact could exceed
$2 trillion

- Largest magnetic storm (> 1000 nT) in recent 200 yrs.

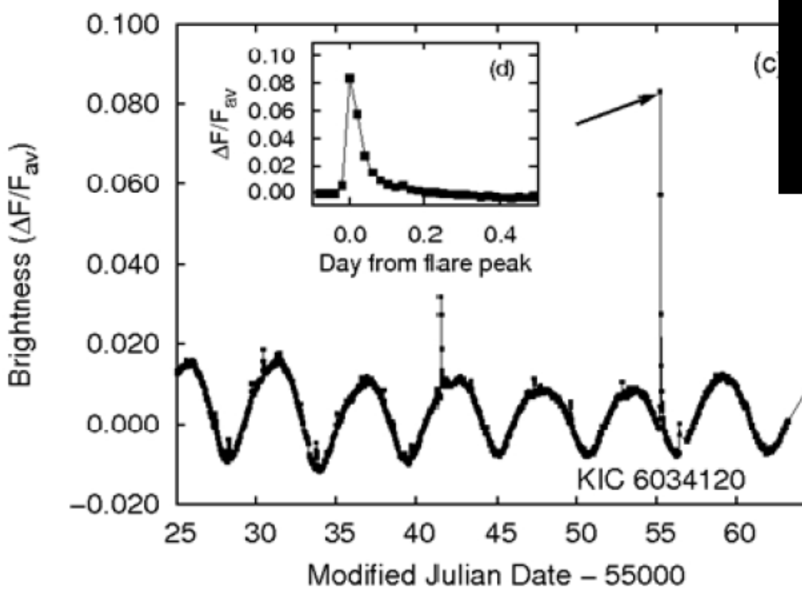
Telegraph pylons threw sparks and telegraph paper spontaneously caught Fire (Loomis 1861)

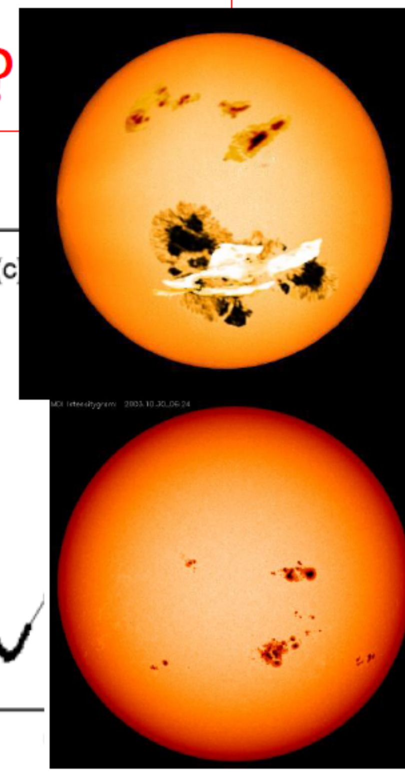
Can we detect flares on Sun-similar stars?

YES! K. Shibata presentation, IAU Honolulu, August 2015

What is the cause of stellar brightness variation ?

Brightness of a star and a flare



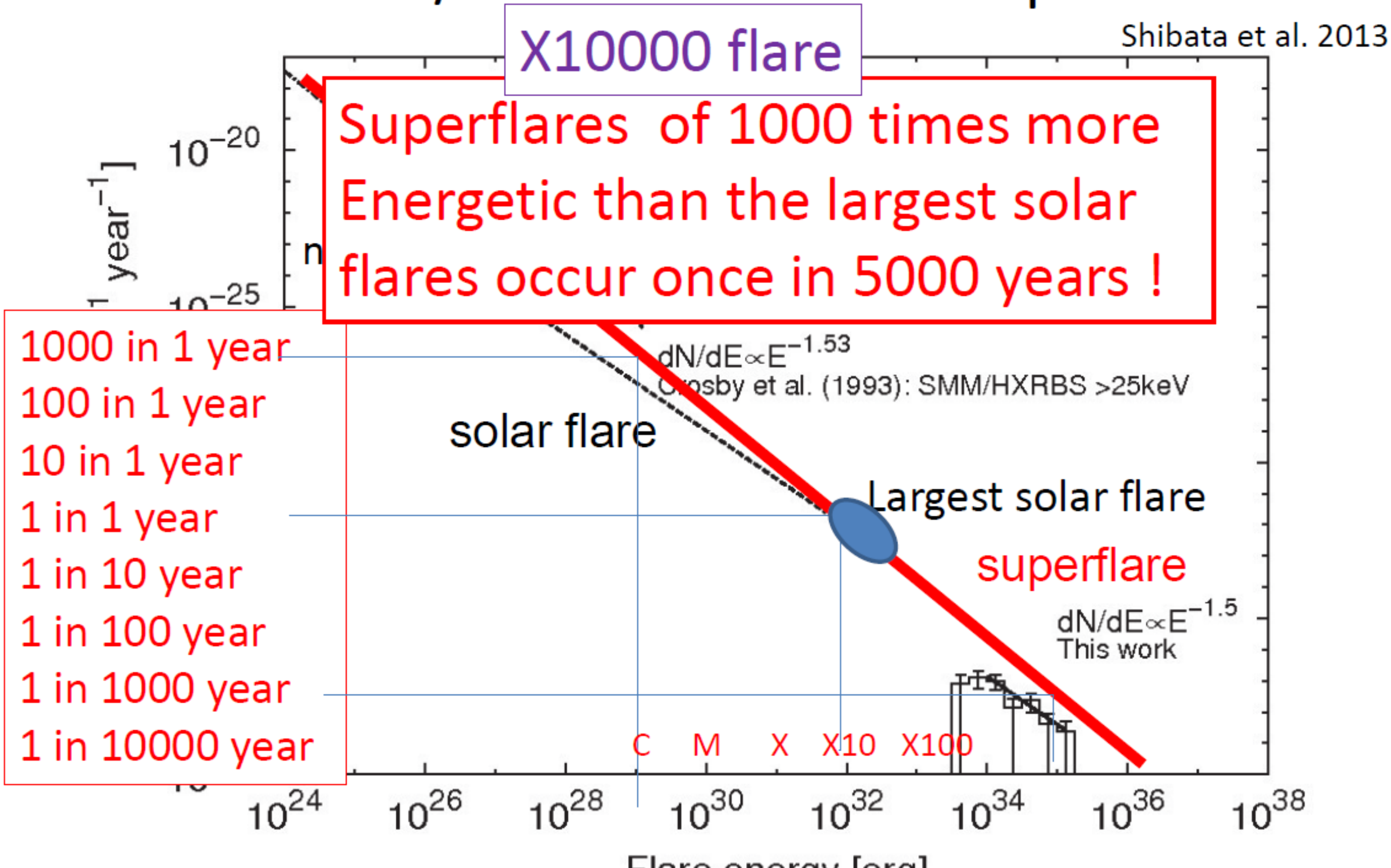


It is likely due to rotation of a star with a big star spot

Can super-flares occur on the Sun?

Comparison of statistics between solar flares/microflares and superflares

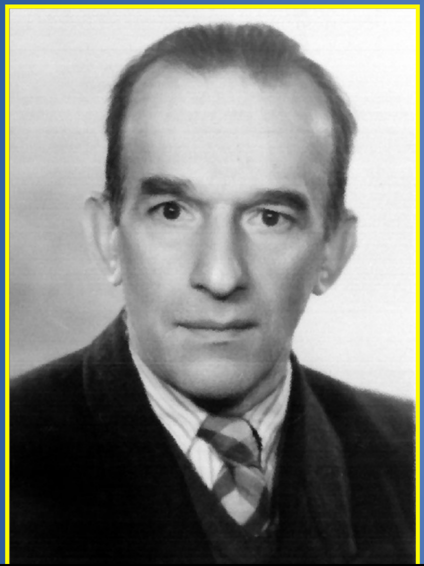
Shibata et al. 2013



PLASMA 2015 Solar Flares Janusz Sylwester IFPiLM

The past: Founders

- The Professors:



Jan Mergentaler
(1901-1995, Lwów-Wroclaw)
in 1951 became interested in Solar Physics – organizer of Wroclaw heliophysical Centre, 1956 – solar monograph

Stefan Piotrowski (1910–85), supported the development of Wroclaw group remotely, as Head of Astronomical Division, PAS, Warsaw, where the group was initially assigned

Prof. Jerzy Jakimiec – overlooked from the beginning (30 years) the scientific aspects of the program

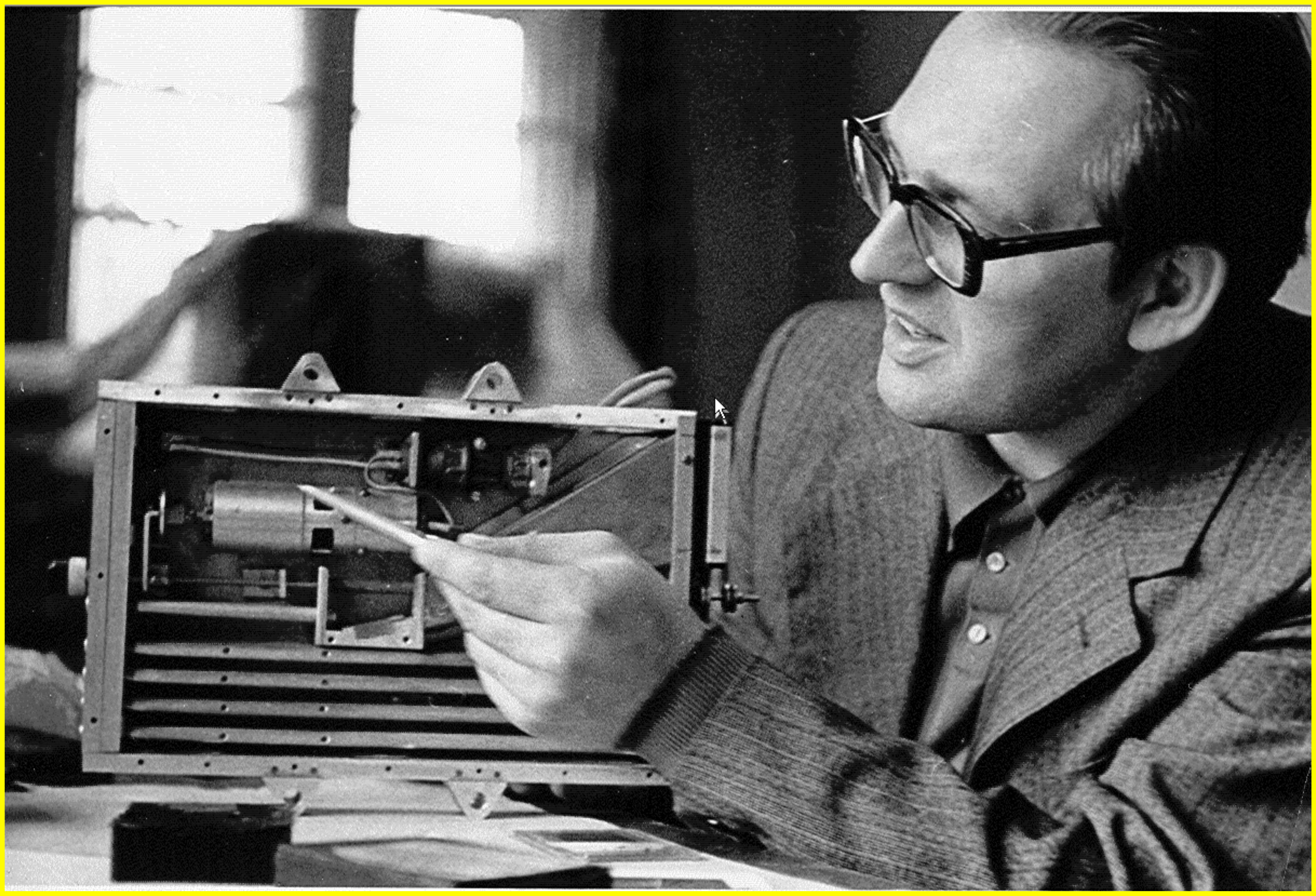
Dr. Zbigniew Kordylewski – was (and is) responsible for the hardware development over more than 35 years

Prof. Antoni Opolski took charge of the developing Laboratory in 70-ties

Prof. Stanislaw Grzedzielski and Prof. Zbigniew Klos, as Directors of Space Research Centre, of which the Solar Physics Division is now a part looked with an interest to the group development

Dr. Zbigniew Kordylewski

in 1971, presenting Polish part of Vertical-1 payload, after recovery



First Polish (and INTERCOSMOS) space experiment 28 November 1970

At Kapustin Yar, early morning h = ~500 km, 10 min in space *(around 05:32 UT)*

The past: political opportunities and Founders

- Intercosmos (1967) – no launch payments

Kapustin Yar
Sounding rockets
7 launches

1970
1971
1977
~~1979~~
1980
1981
1983
1984

Plesetsk
Orbital
missions
launches

1994
Coronas-I

1995
Interball-Tail

2001
Coronas-F

2009
Coronas-Photon

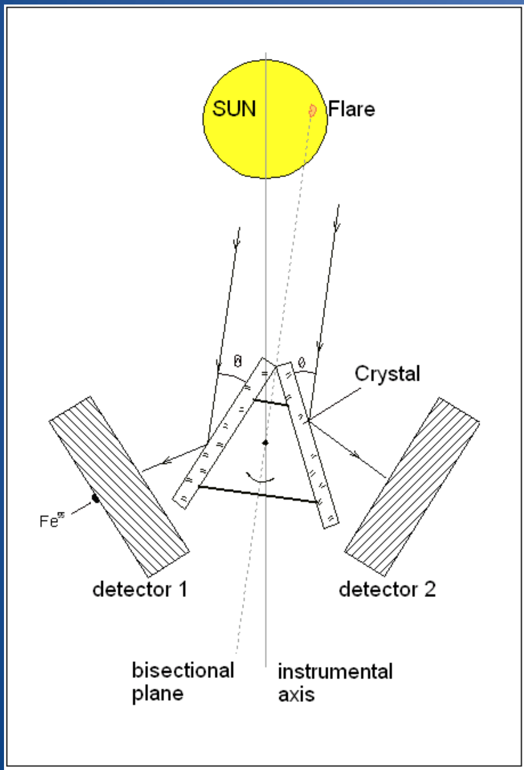
First Polish (and INTERCOSMOS) space experiment 28 November 1970

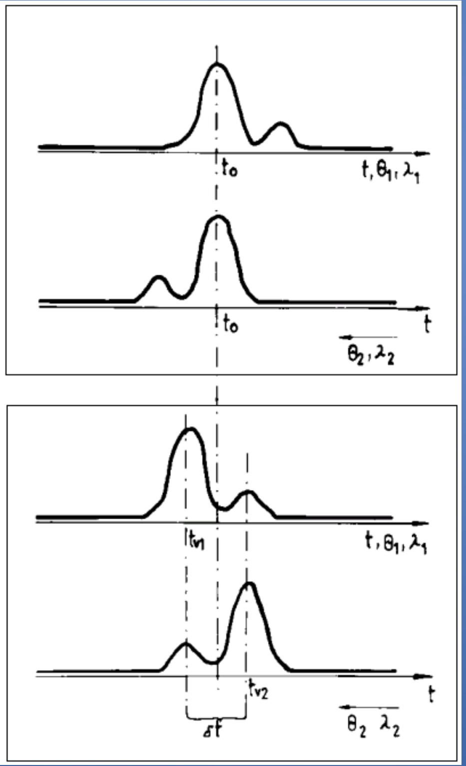
Space Research XIII, Vol. 2, p. 787 – 792, 1973

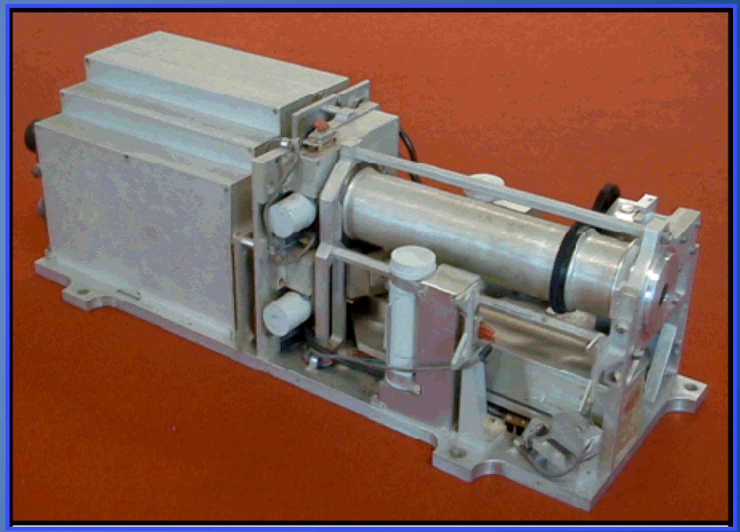
The Be 50 μm and Al 6 μm filter images represent emissions from the hotter and cooler plasma. The ''filetr ratio'' technique allowed to determine the temperature structure within individual active regions. The spatial resolution in the images is rather low (1 arcmin), typical for pin-hole technique

New experience - new designs

- X-ray Dopplerometer (~1980): absolute measurements of line shifts



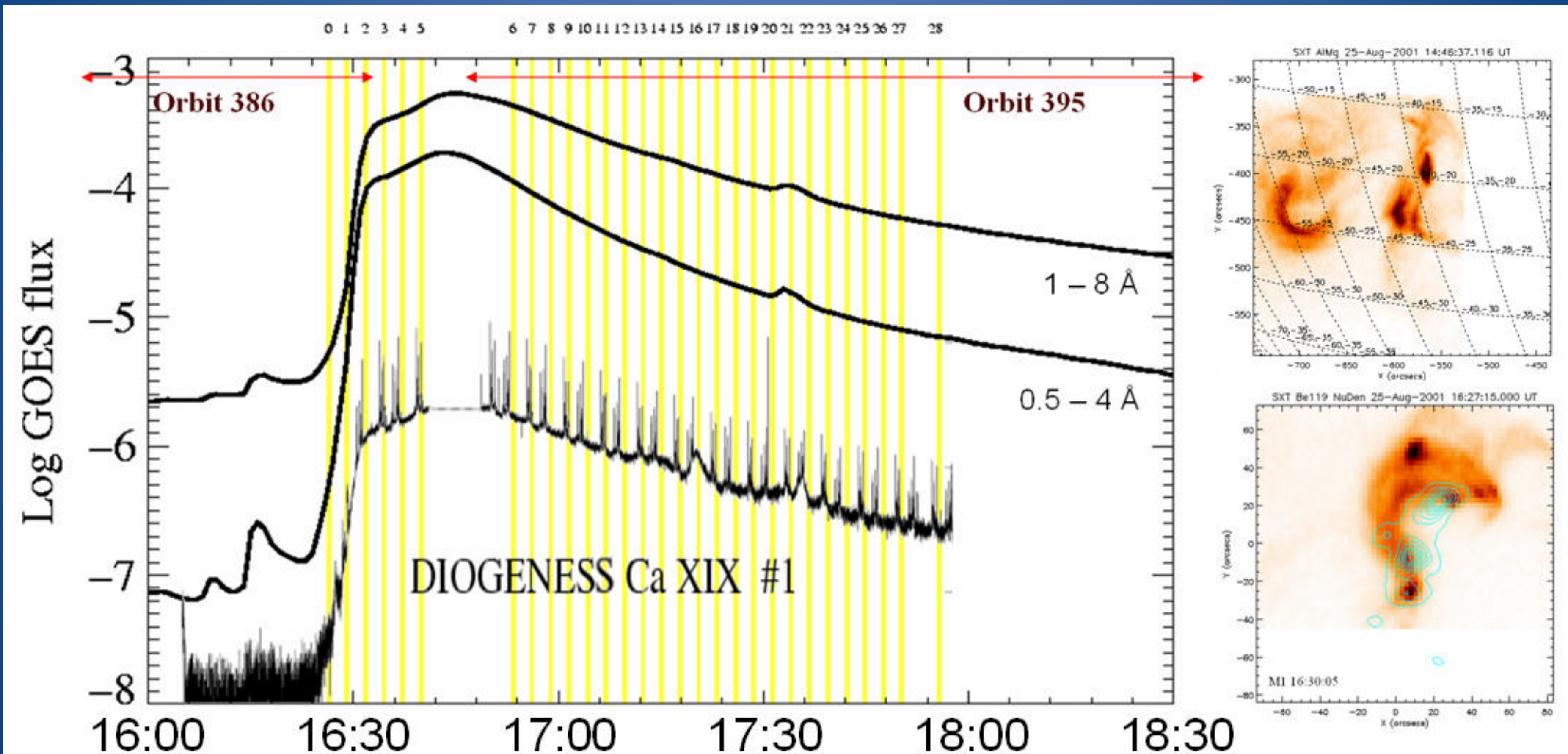




RDR – Rocket Dopplerometer flown aboard Vertical-11 sounding rocket
Made in one year, launched in 1983

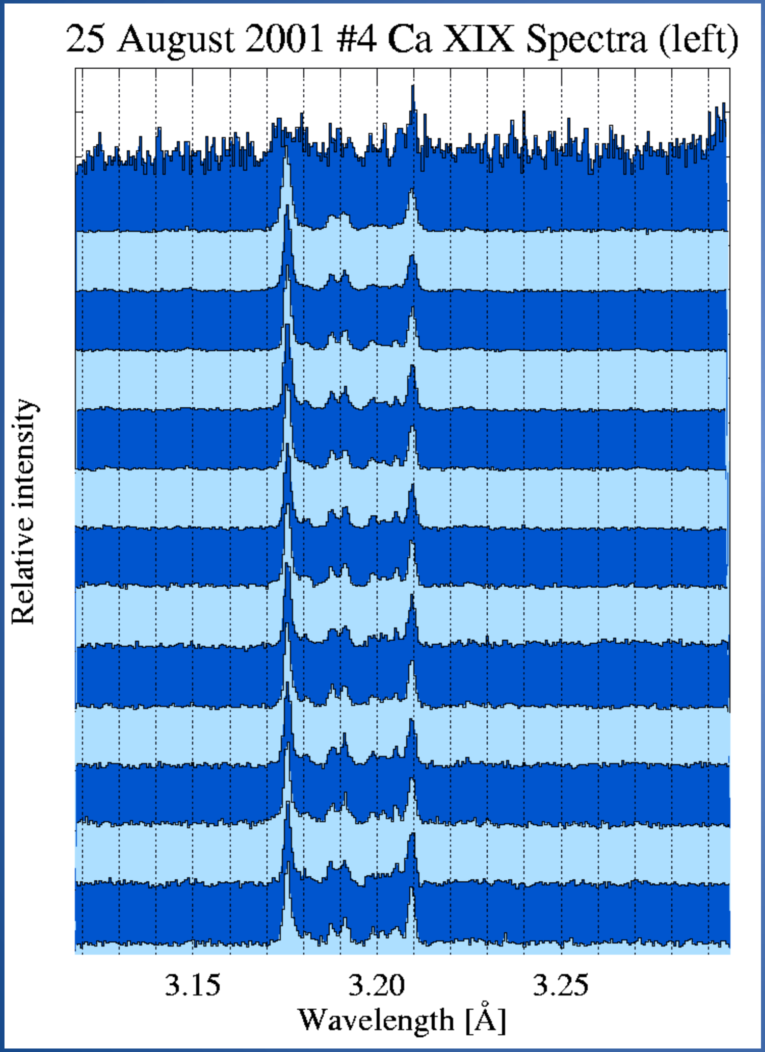
Solar Physics: 644, 2015**DOI:** 10.1007/s11207-014-0644-1

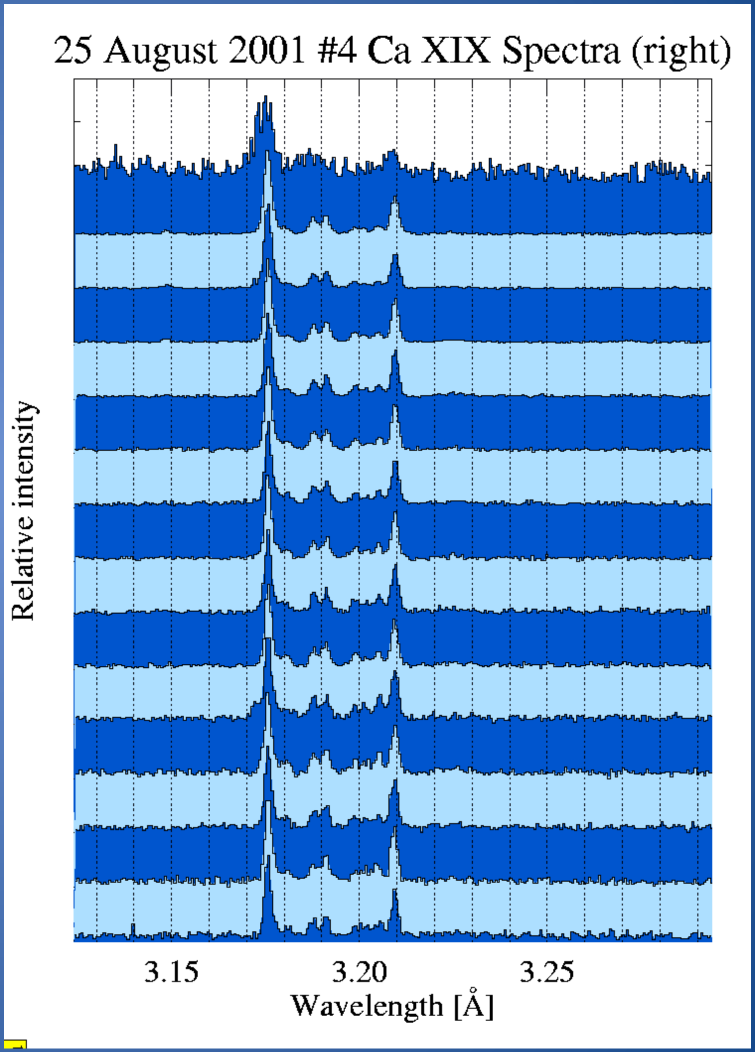
Satellite dopplerometer results
CORONAS-F: 25 Aug 2001 3B/X5.3



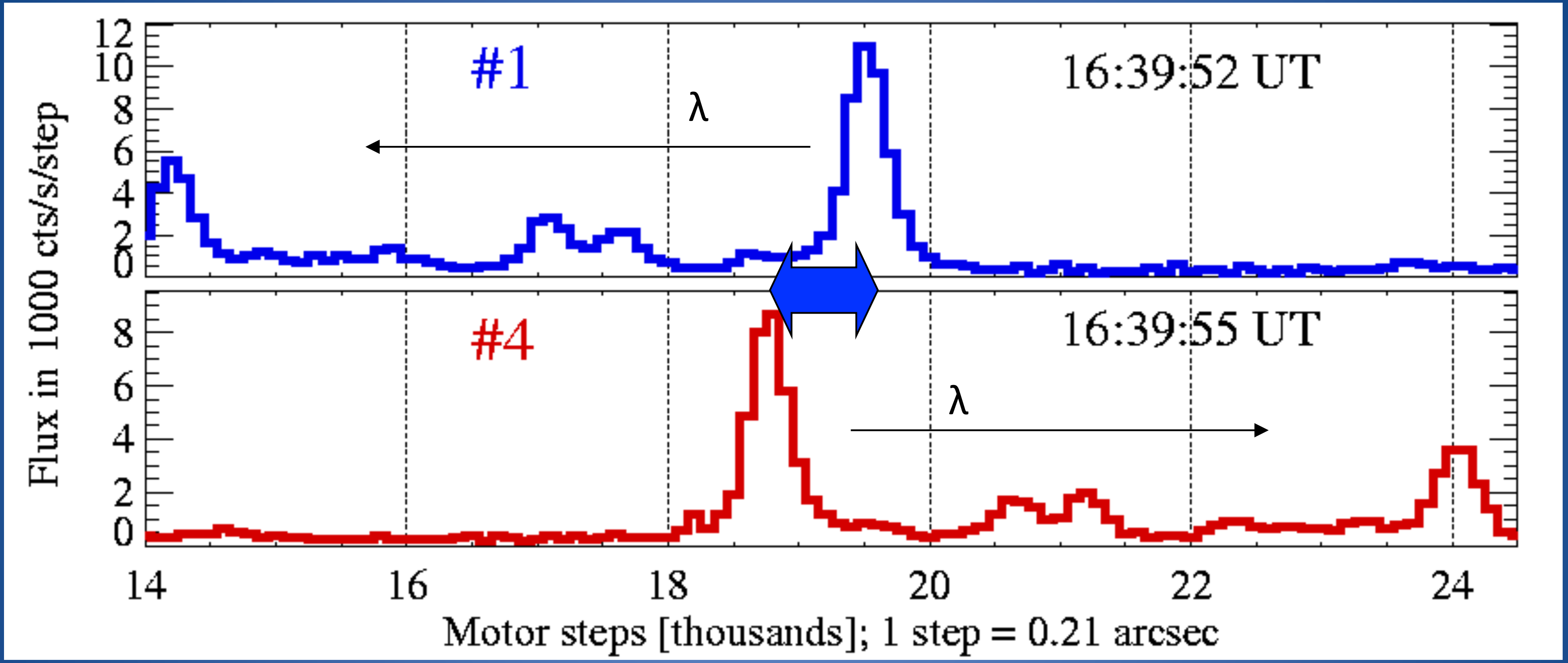
Janusz Sylwester Zakład Fizyki Słońca CBK PAN, Wrocław

Time Sequence of left & right scans



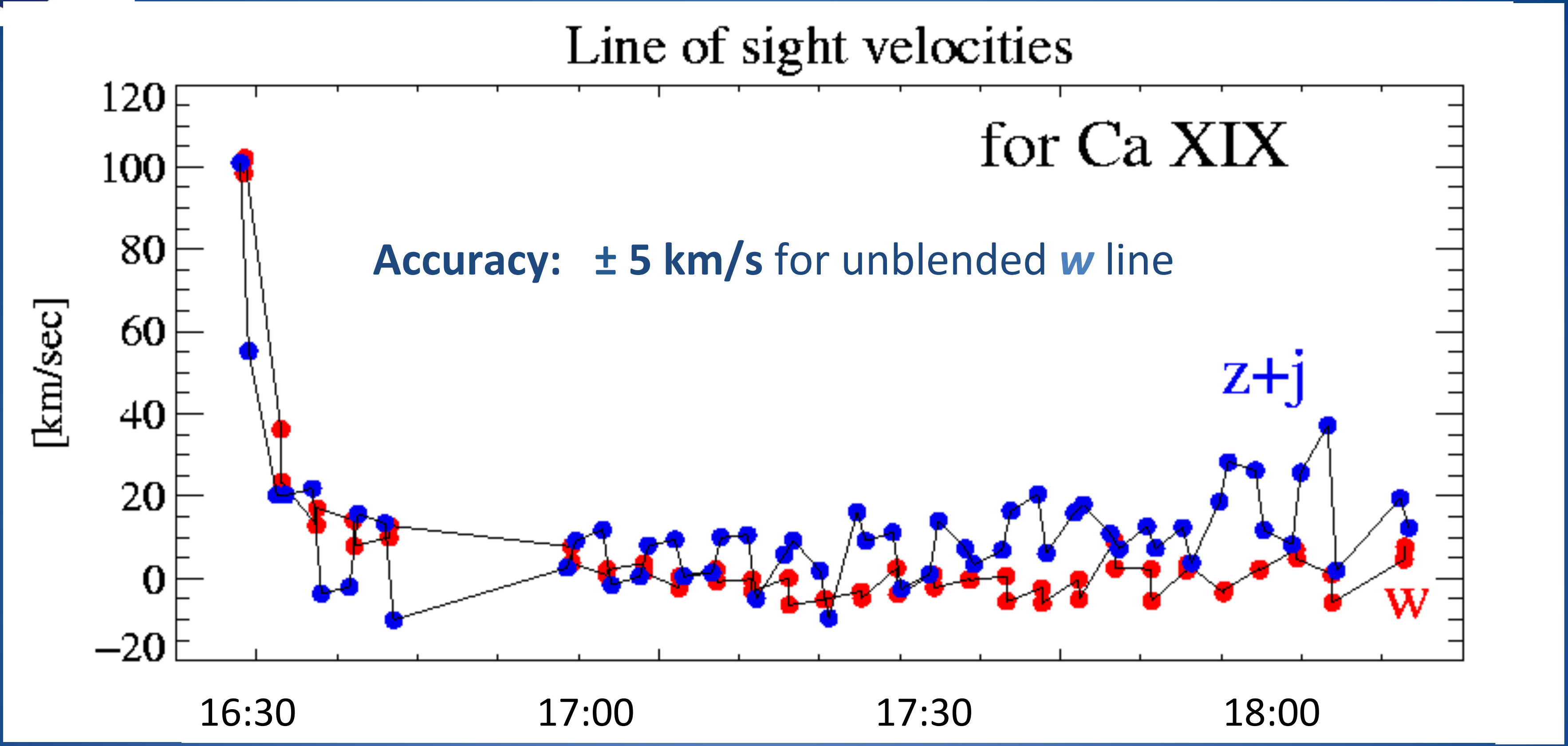


X-ray Dopplerometer results



Spectra recorded nearly simultaneously in Channels #1 and #4 of Diogeness during the maximum phase of X5.3 flare on 25 Aug. 2001. The scanning in both channels is made in the opposite wavelength sense. Thus the intercombination and forbidden lines comprising the Ca XIX triplet are seen on the opposite sides of the presented range (recorded 20 s apart in time).

Velocities: entire spectra shifted

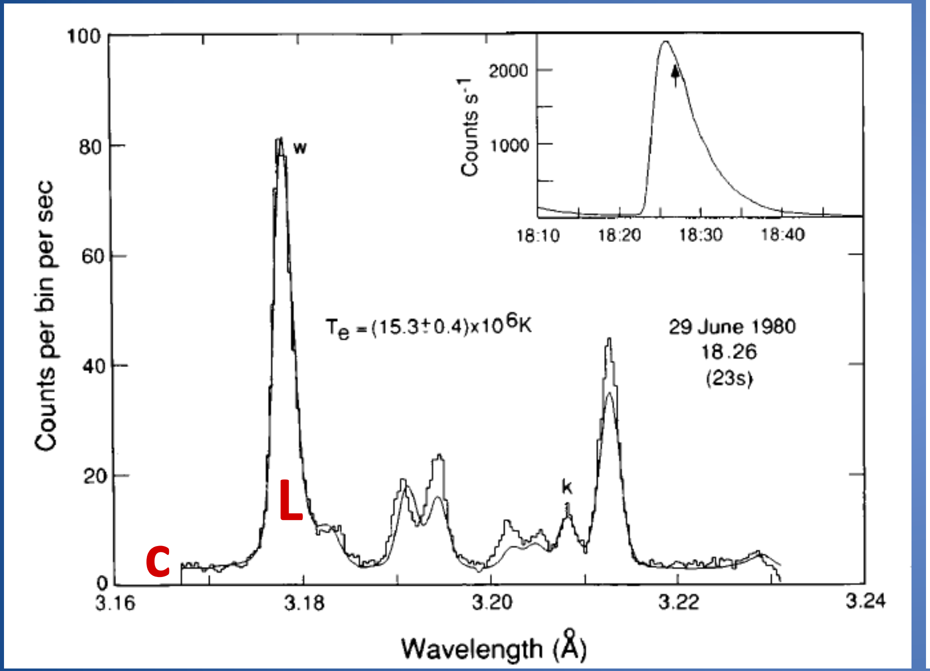


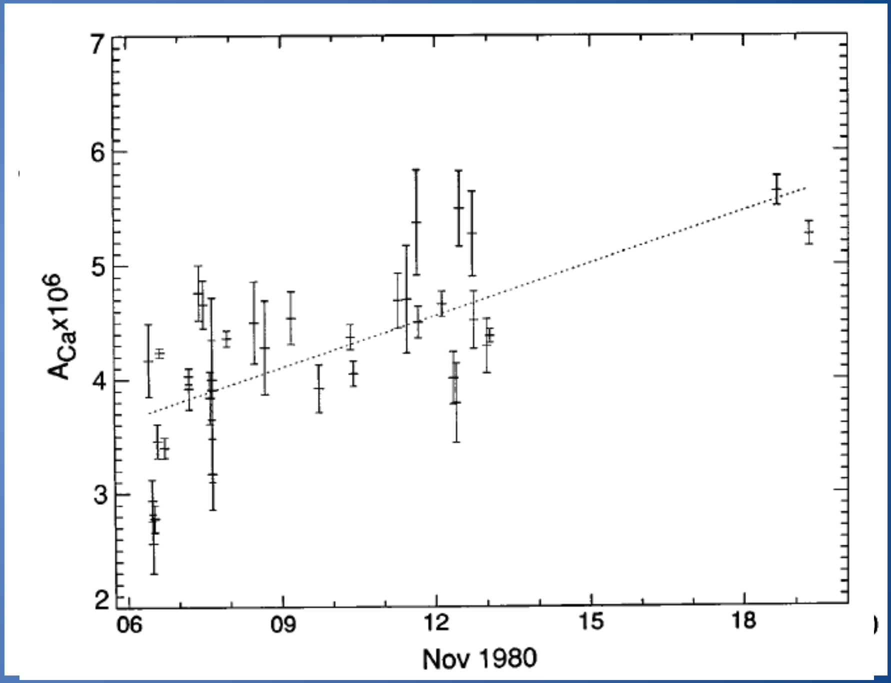
Velocities as determined for the resonance (*w*) and forbidden lines (*z*) of the Ca XIX triplet. The forbidden line is blended with a strong dielectronic satellite line (*j*) which might account for slightly different pattern of behaviour later in the flare decay.

Spectroscopic evidence of changing abundance in flares (since 1984)

Sylwester et al., 1984, Nature, 310, 665

Sylwester et al., 1998, ApJ 501, 397





L/c is sensitive to elemental abundance

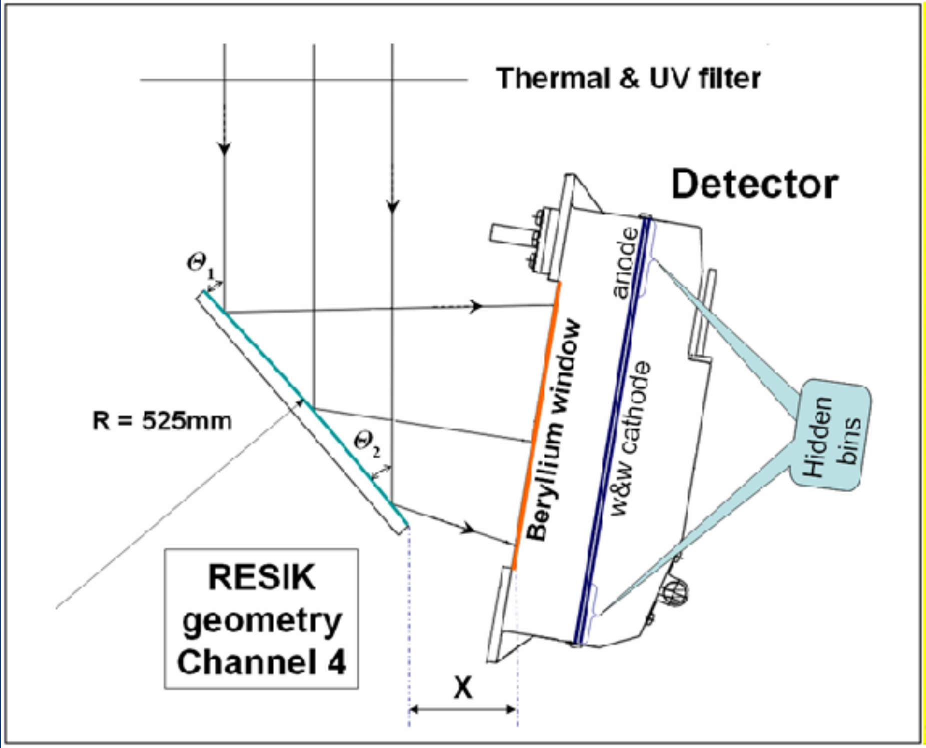
L ~A_{El} ; c ~ hydrogen and helium + small f-b from recombinations

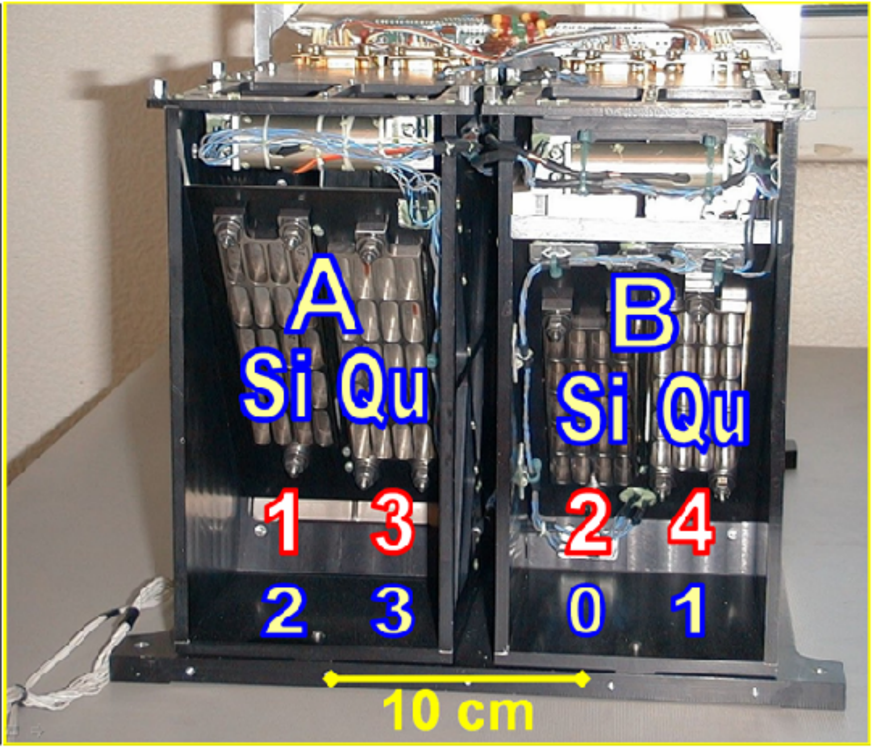
ragg spectrometer: $k\lambda = 2d \sin\Theta$

Рентгеновский Спектрометр с Изогнутыми Кристаллами

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

Solar Physics, Volume 226, Issue 1, pp.45-72, 2005 DOI: 10.1007/s11207-005-6392-5





What we see - page from Catalogue (2000 pages)

fluxes

S/C nights

Spectra normalized to maximum in each channel 4.96 - 6.09

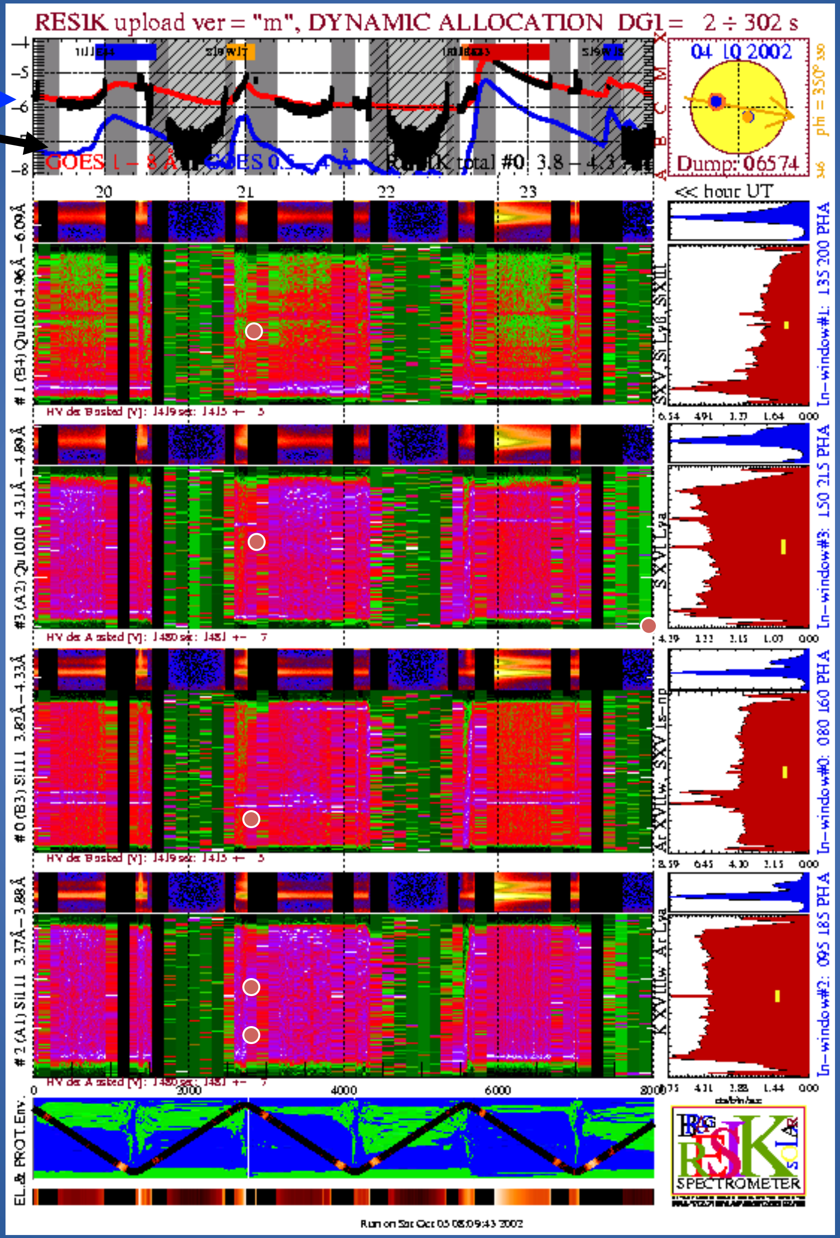
4.31 - 4.89 Å

Black - HV off

3.82 - 4.33 Å

3.37 - 3.88 Å

Orbit & particles ‘electrons PHA’



Flare positions & dispersion plane

PHA spectrum #4 4

PHA spectrum #3 3
ADS = 112 - 165

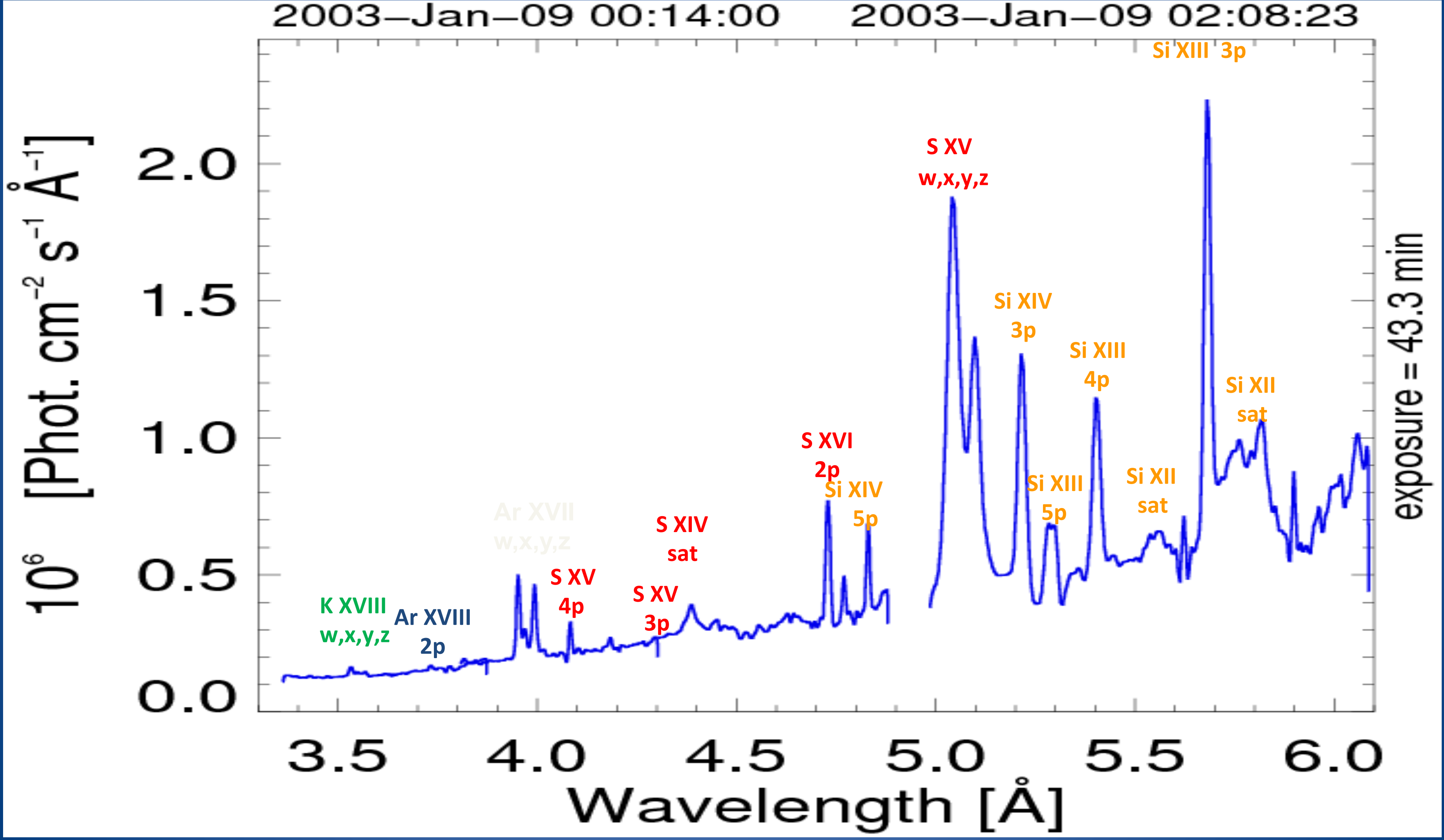
PHA spectrum #2 2
ADS = 80 - 165

PHA spectrum #1 1
ADS = 80 - 165

engineering

for publication

Average RESIK spectrum



http://www.cbk.pan.wroc.pl/RESIK_Level2/

Multithermal character of flaring plasma,

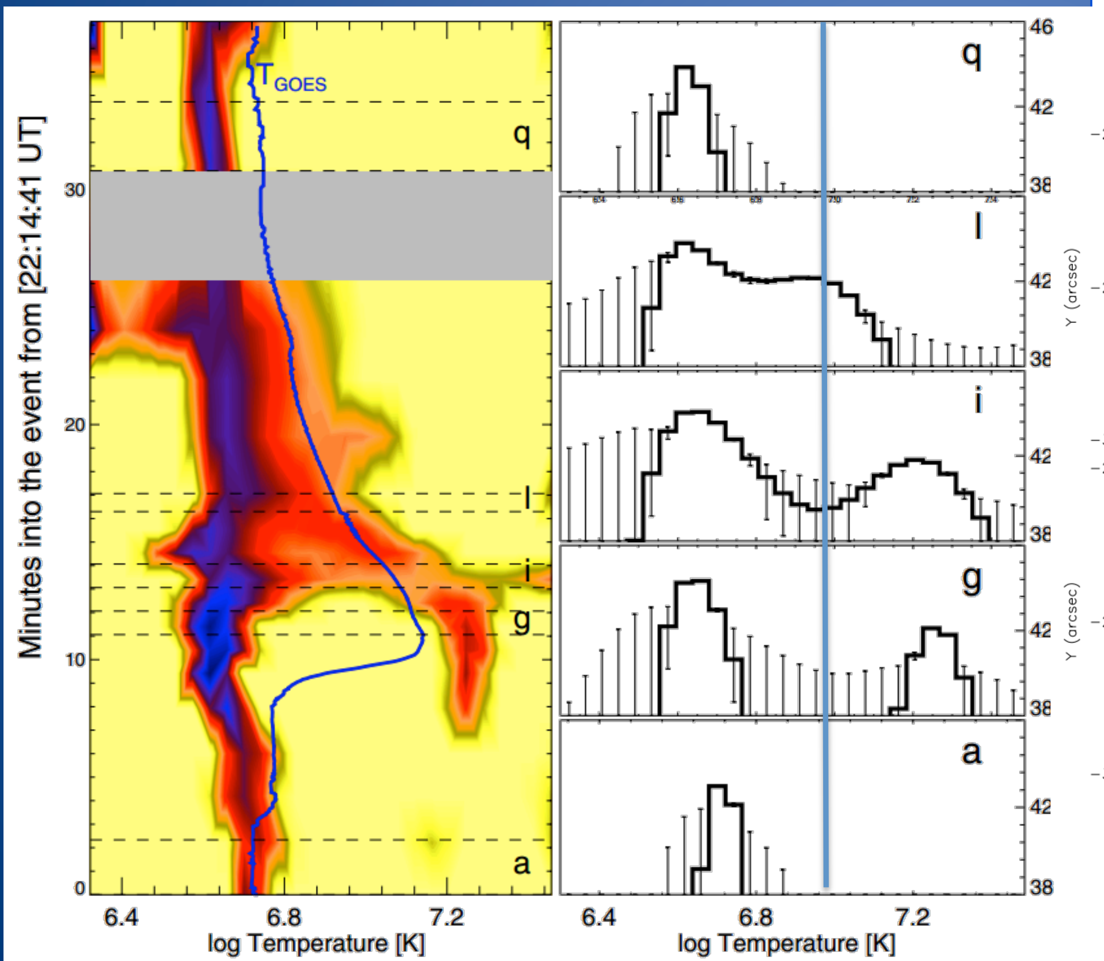
Differential Emission Measure:

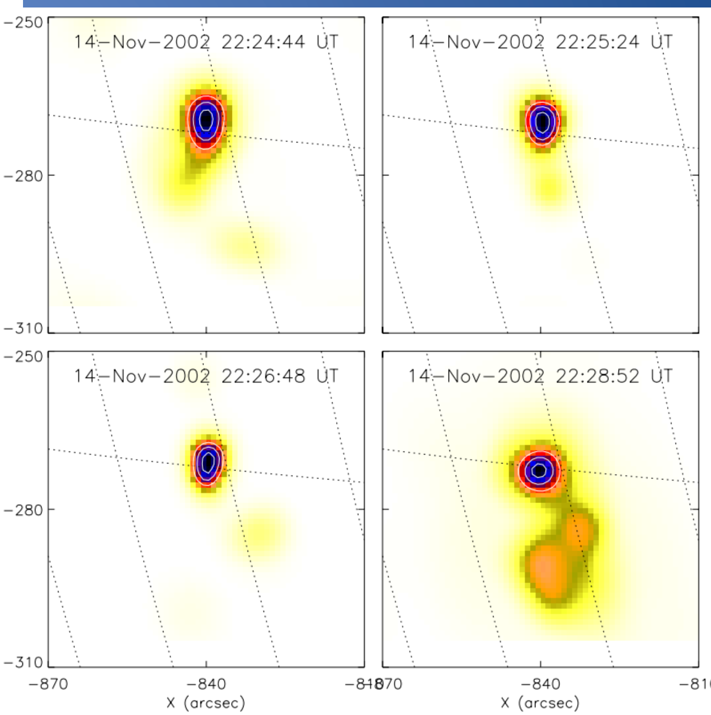
$$\mathrm{DEM} \equiv \varphi(T) \equiv N_e^{\,2}\frac{dV}{dT},$$

The Astrophysical Journal, 787:122 (10pp), 2014

B. Sylwester[1], J. Sylwester[1], K. J. H. Phillips[2,4], A. Kępa[1], and T. Mrozek[1,3]

$$F_i = A_i \int_{T=0}^{\infty} f_i(T)\varphi(T)dT,$$





NASA, *RHESSI*, E=6 keV

PIXON reconstructed images

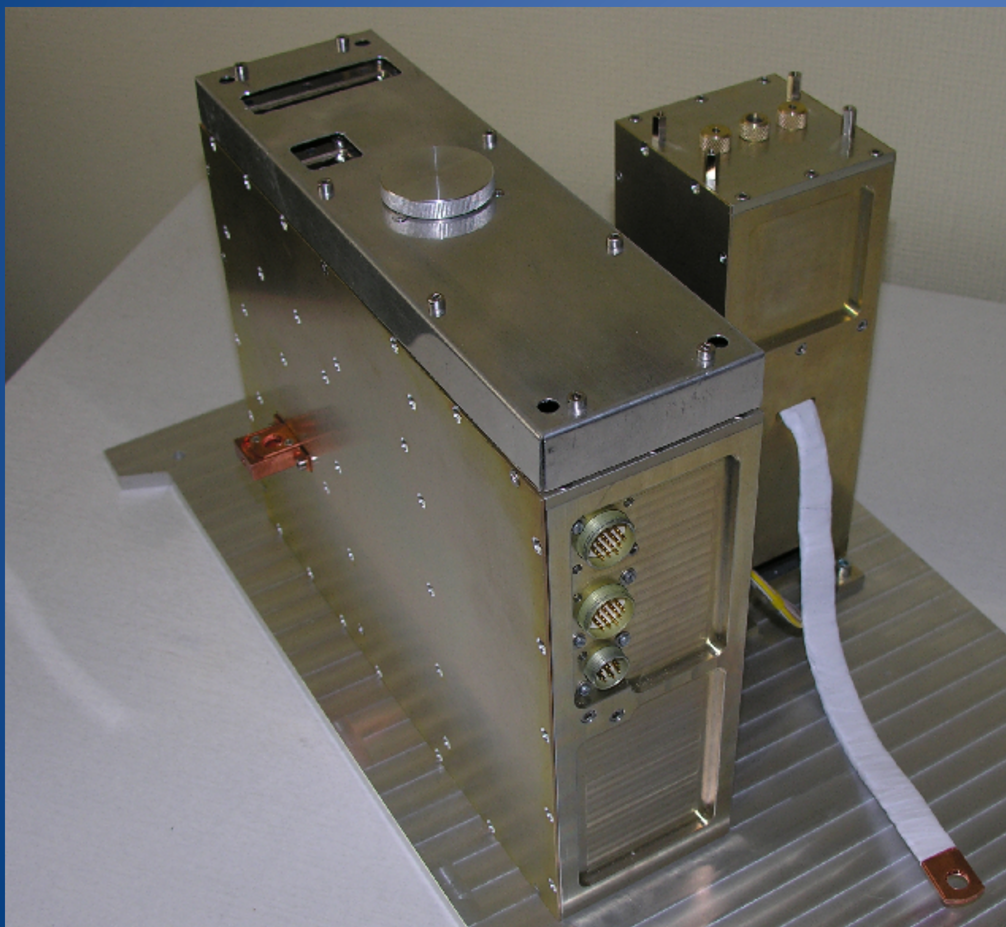
General remarks

- Rotation rate appears to be the main factor defining creation of magnetic field in stars
- Reconnection of magnetic fields give rise to particle acceleration and heating of plasma to multimilion degrees temperature
- Statistics of flares indicate for self-organized state of individual energy release acts for the Sun and stars
- Studying the flares is important, but exact predicting of geo-threatening events is hard.

SphinX

Polish concept, design & manufacture

Solar Physics, 2013, DOI: 10.1007/s11207-012-0201-8



Measures the X-ray emission of the Sun

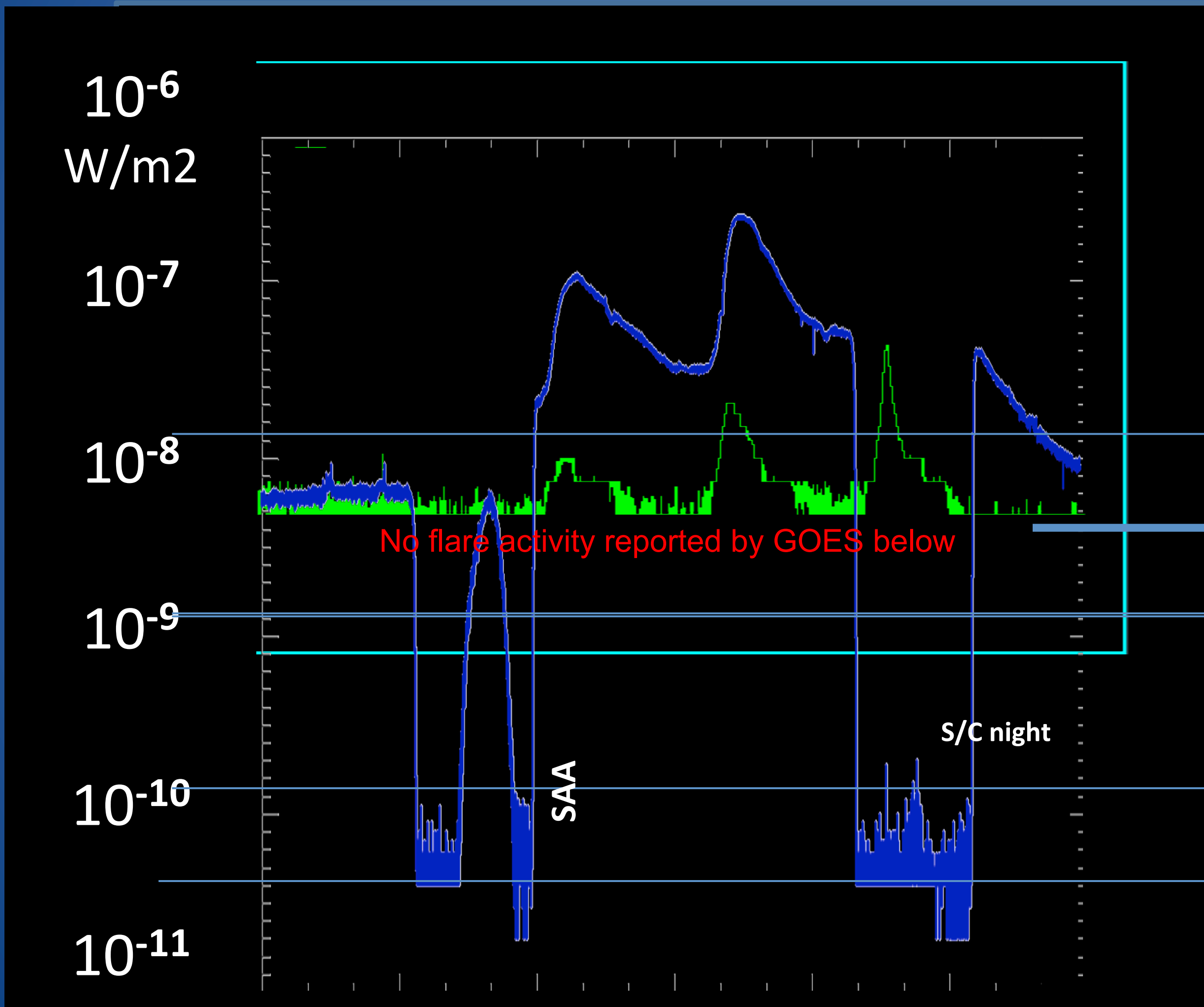
in the 85 – 15 keV band

with *unprecedented*

- Time resolution ~0.00001 s
- Sensitivity 100 x better than *GOES* (NOAA) XRM – the standard for 30+years
- Energy resolution 3x RHESSI (NASA)

Aimed to see Non-AR level of emission

GOES X class range → to be extended down



$C = 10^{-6}\ W/m^2$

$B = 10^{-7}\ W/m^2$

$A = 10^{-8}\ W/m^2$

$S = 10^{-9}\ W/m^2$

$Q = 10^{-10}\ W/m^2$

SphinX detection threshold

Main contributions to solar physics

- Discovery of Ca abundance differences between flares (SMM spectra, Nature, 1984)
- First determination of absolute Ar abundances in the Sun (RESIK, ApJ, 720, pp. 1721-1726 2010)
- Detection of X-ray Doppler-shifted lines from multi-million degree plasmas (Diogeness, 2015)
- Study of Si, S, Ar & K abundances in flares (RESIK, ApJ 787, 122, 10 pp. 2014)
- Determination of non-active –X-ray solar luminosity (SphinX, ApJ 751, 111, 5 pp. 2012)
- Introduction of new X-ray flare classes (SphinX, 2010)
- Recovery of DEM pattern for flares (RESIK, ApJ 805, Issue 1, article id. 49, 8 pp 2015, next talk)

Present team, science interests and collaborations

- The SPD Team now, one of 5 SRC Divisions. In charge Dr. Mirek Kowaliński
  - 8 scientists, 4 PhD students, 7 engineers, physicist
  - Cleanroom, cooled vacuum chambers, X-ray sources & optics, various support equipment
- Data reduction & interpretation in progress
  - RESIK & Diogeness Spectra
  - RESIK particle signal
  - SMM BCS old spectra
  - SphinX and STEP-F particle data
- Science interests
  - AR and flare Plasma diagnostics (T, EM, DEM), spectral synthesis
  - Abundance determinations (next talk)
  - Particle background
  - SXR & HXR imaging
- Main collaborating people
  - Kenneth Phillips (X-ray spectroscopy)
  - Oleksyi Dudnik (Particles in magnetosphere)
  - Elena Dzifcakova (Non-Maxwellian plasmas), ISSI collaboration

Experiments we are working on

- STIX on Solar Orbiter (phases C, D), ESA, 2018
- PROBA-3, ESA (2018)
- Interhelioprobe 1 & 2 (Roskosmos) 2025,2026
- SolpeX for ISS (FIAN), 2018
- CubIXSS with USA, 2018
- SphinX-NG – ?

STIX: The Spectrometer Telescope for Imaging X-rays (fixed)
ESA: Solar Orbiter, 2018

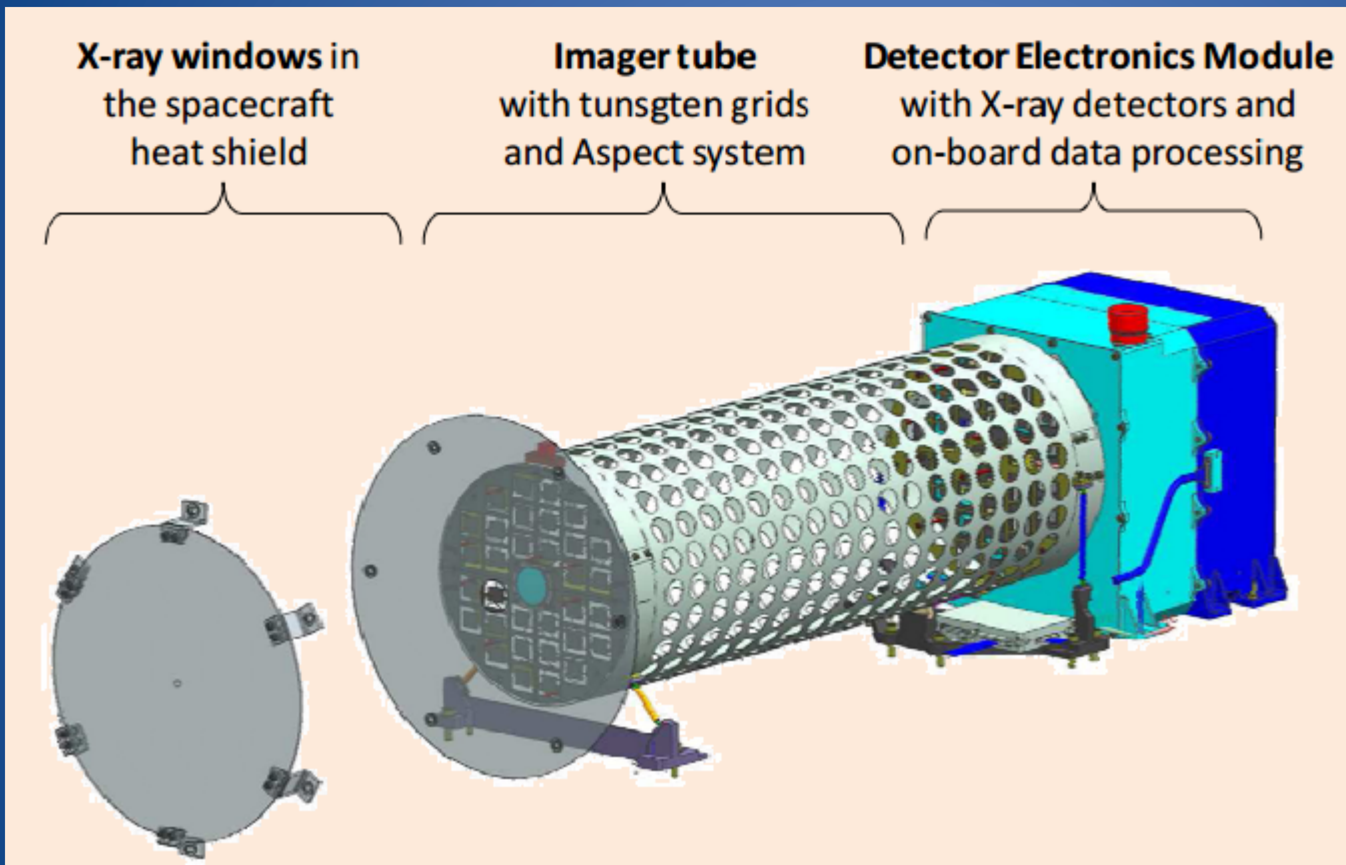
http://sci.esa.int/solar-orbiter/51217-instruments/

- Understanding the acceleration of electrons at the Sun and their transport into interplanetary space
- Determining the magnetic connection of the Solar Orbiter back to the Sun

Polish involvement: **30%,** second after the Switzerland; IDPU, EGSE, Data simulator, interface to spacecraft

STIX - cd

STIX provides imaging spectroscopy of solar X-ray emissions with unprecedented spatial resolution and sensitivity near perihelion.



Energy range: 4-150 keV
Effective area: 6 cm^2
Field of view: 2°
Finest angular resolution: 7 arcsec
Image position accuracy: 4 arcsec
Energy resolution (FWHM):

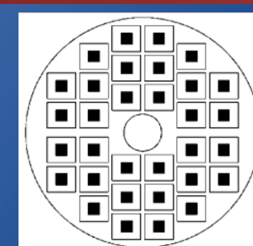
- 1 keV at 6 keV
- 15 keV at 150 keV

Time resolution (stat limited): ≥ 0.1 s

SYSTEM PARAMETERS

Mass: 5 kg
Power: 4 W
Volume: $76 \times 22 \times 22$ cm^3
Temperature:

- Feedthrough: +270°C
- Spacecraft: +50°C
- CdTe Detectors: –20°C

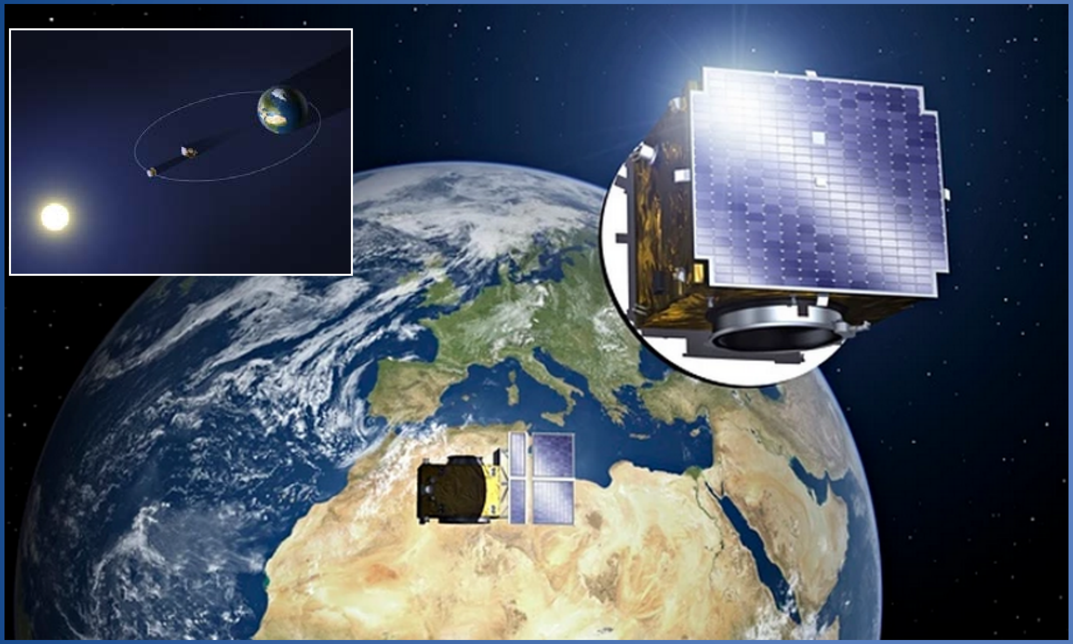


STIX is based on a Fourier-transform imaging technique using:

- An imager with 32 subcollimators,
- An spectrometer with 32 CdTe X-ray detectors, one behind each subcollimator

Proba-3 ESA, 2018 (fixed)

http://www.esa.int/Our_Activities/Space_Engineering_Technology/Proba_Missions/About_Proba-3

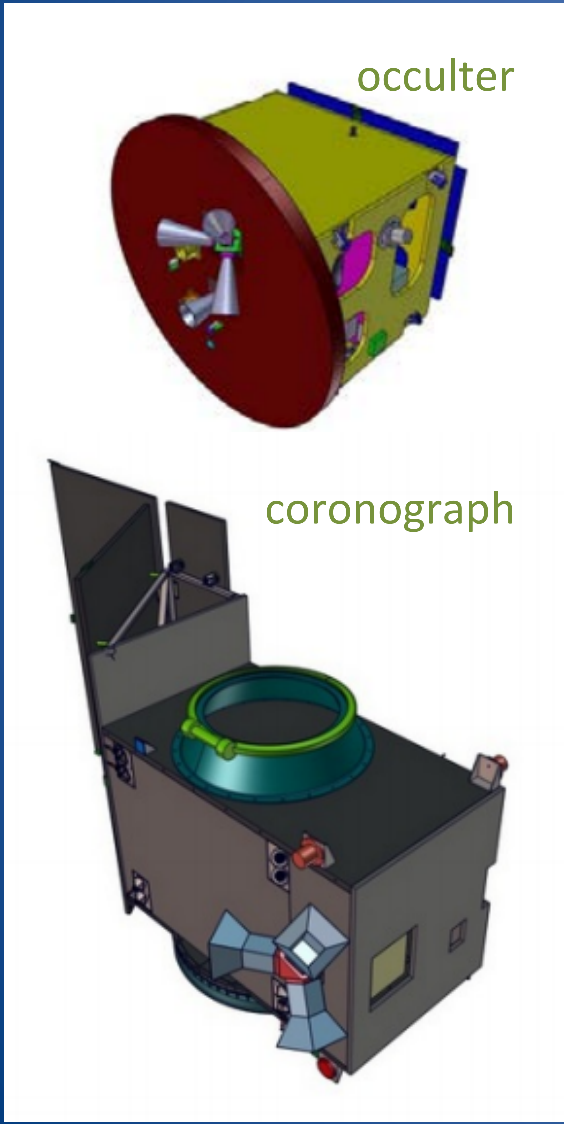


Proba-3 is ESA's – and the world's – first precision formation flying mission. A pair of satellites will fly together maintaining a fixed configuration as a 'large rigid structure' in space to prove formation flying technologies.

The paired satellites will together form a 150-m long solar coronagraph to study the Sun's faint corona closer to the solar rim than has ever before been achieved.

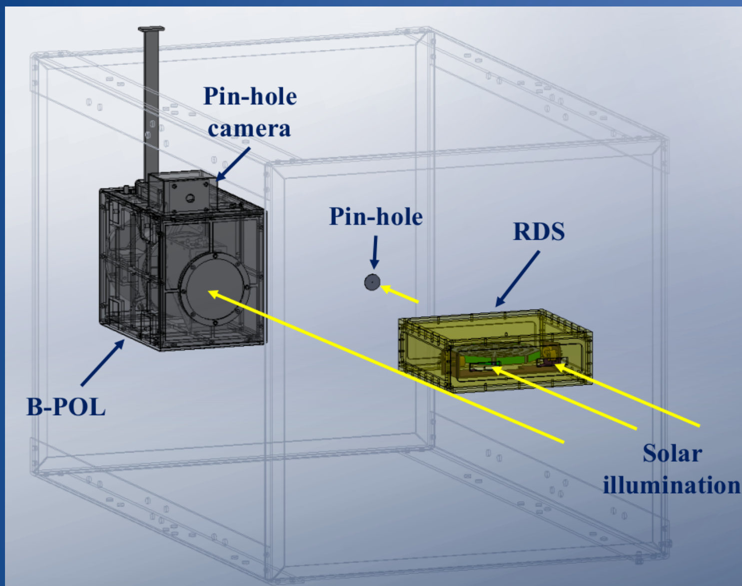
Proba-3 cd

Occulter spacecraft 200 kg
Coronagraph spacecraft 340 kg;
High Earth orbit, 19.7 hours orbital period,
60 530 km apogee, 600 km perigee

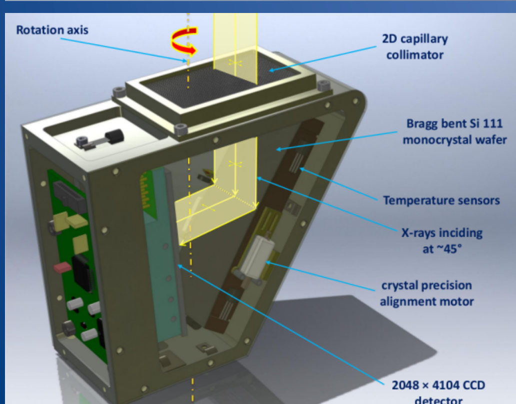


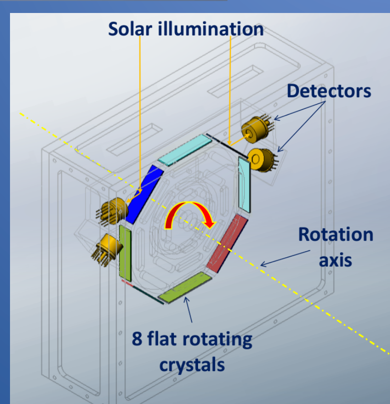
- Poland shares ~30% of the mission cost hardware through contracts with ESA (Warsaw)
  - **PROBA-3 CORONAGRAPH Filter Wheel Assembly**
- Science groups are located in Wroclaw SPD-SRC PAS (3 people) and University Astronomical Institute (3 people)
  - Construction of the instrument numerical simulator
  - On-board memory simulator
  - Construction of the Data Processing Software Tools

SolpeX for ISS, to be placed on new НАУКА Russian module ~2018

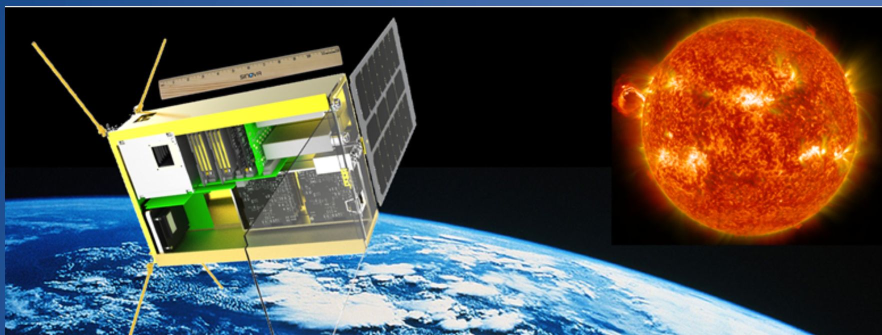


- A part of KORTES under construction at FIAN
- First Bragg solar polarimeter
- New concept of fast-rotating drum flat crystal spectrometer
  - Pin-hole imager- will provide location of the source on the disk
  - ISS offers a chance to test these concepts

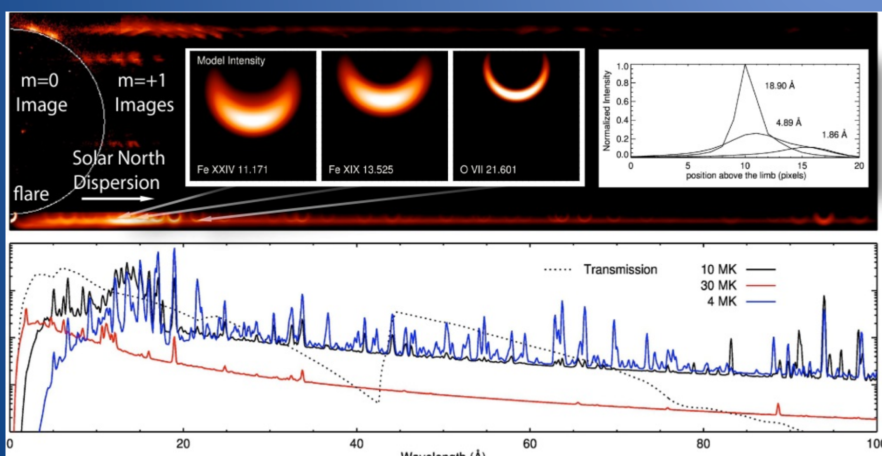




CubIXSS 6U nanosatellite collaboration with SwRI, LASP & GSFC



60 cm x 20 cm x 10 cm, 8 kg, 20 W, -
SASS (0.5-100 keV), MOXSI (0.12-10 keV)

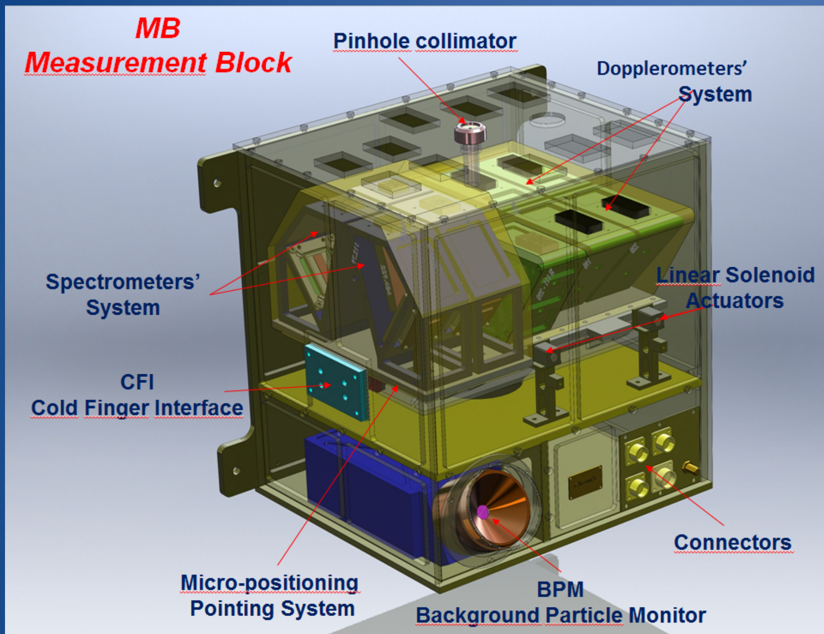


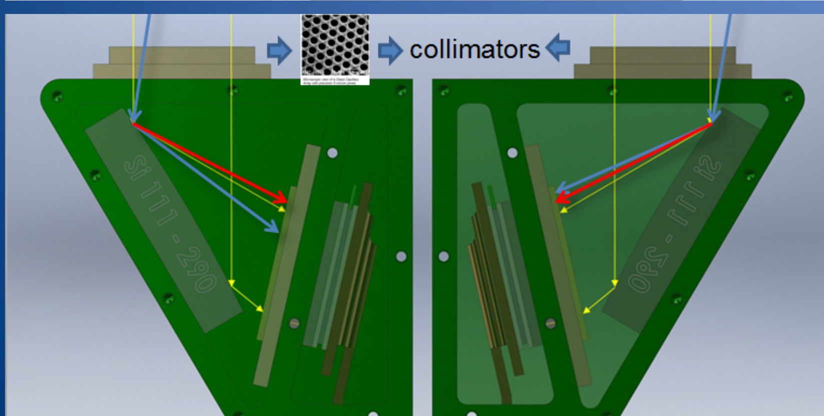
revolutionary X-ray observations of the high temperature corona. These observations will allow us to address fundamental questions related to the physics of magnetic reconnection and particle acceleration, the heating of the solar corona, and the coupling of the Sun's radiative output to the Earth's upper atmosphere. With CubIXSS we will:

- *Quantify the evolution of thermal and non-thermal emission during solar flares;*
- *Constrain theories of coronal heating by measuring the distribution of high temperature plasma in the non-flaring corona;*
- *Understand the flow of mass and energy into the corona by determining the composition of the solar upper atmosphere for both quiescent and impulsively heated loops; and*
- *Measure the solar irradiance and its variability at soft X-ray wavelengths and model its impact on the Earth's ionosphere and thermosphere.*

Janusz Sylwester Zakład Fizyki Słońca CBK PAN, Wrocław

ChemiX on Interhelioprobe 1 & 2
Chemical composition in X-rays





Determination of

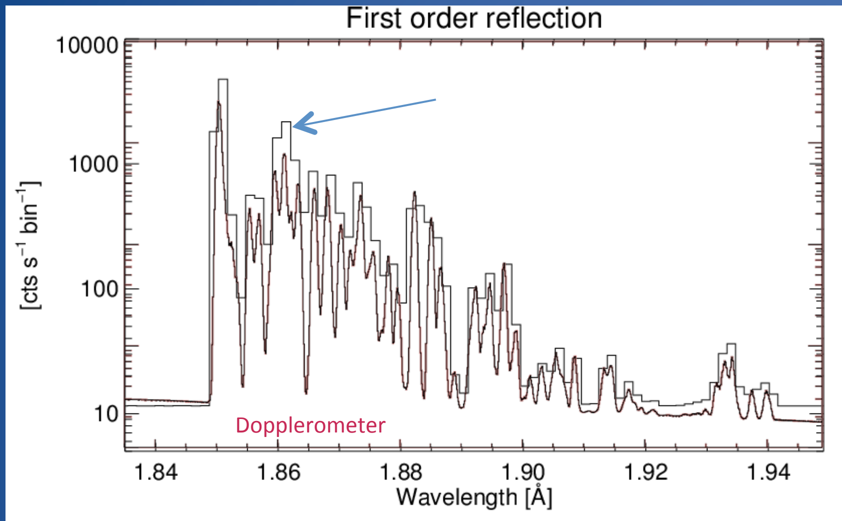
Mg, Al, Si, S, Cl, Ar, K, Ca, Fe & Ni

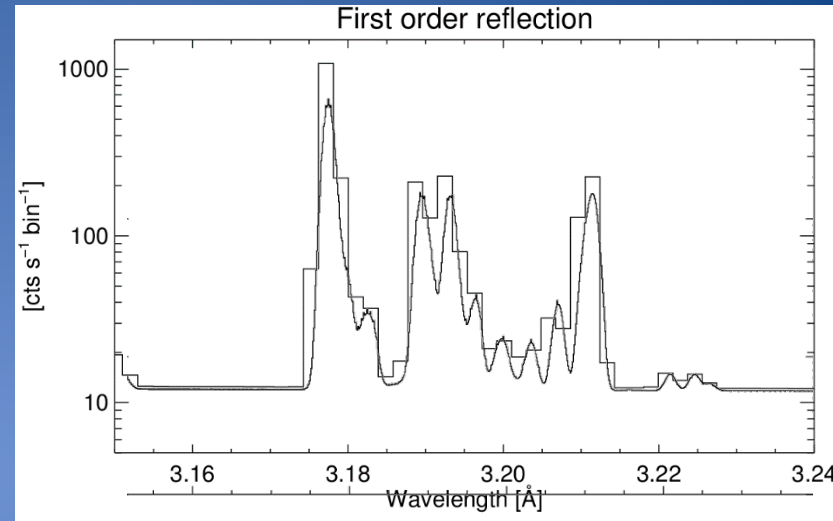
coronal abundances

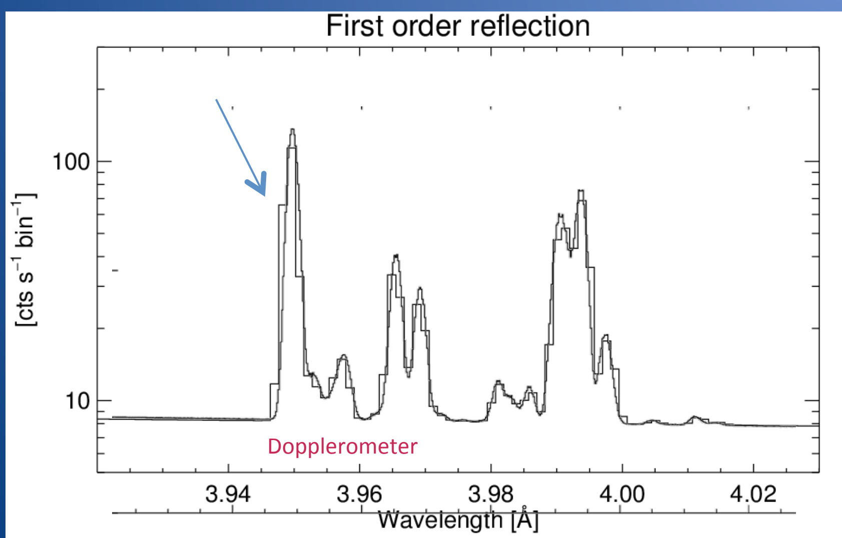
- Studies of DEM plasma distribution in AR & Flares
- Detection of Non-Maxwellian plasmas
- Spectra of particle environment, e, p, He-O

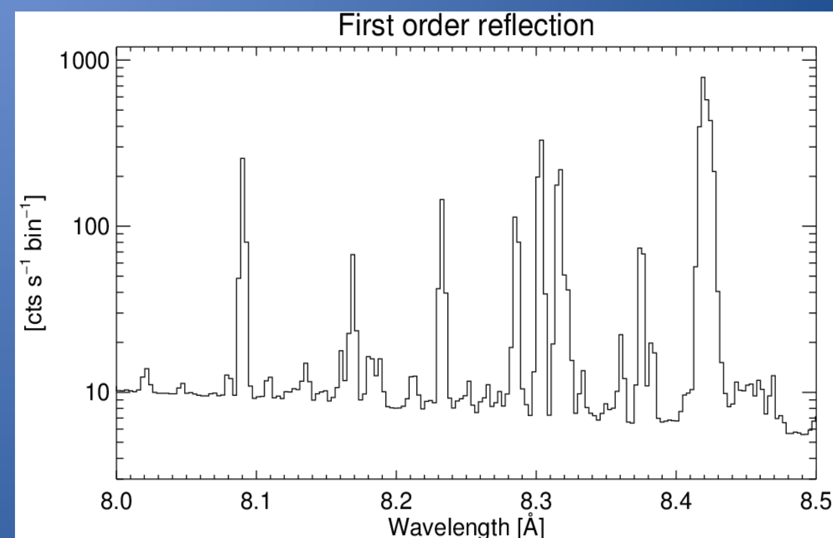
Janusz Sylwester Zakład Fizyki Słońca CBK PAN, Wrocław

ChemiX spectra









We are looking for collaborations

THANK YOU !

SPD SRC Awards

- PAS – RAS International Award 2011
  - IZMIRAN
  - FIAN
  - SRC PAS
- PAS-NANU International Award 2014,

Radioastronomical Institut NANU
DrS. O. W. Dudnik
Mgr. E. W. Kurbatov

SRC PAS

Janusz Sylwester
Dr. Szymon Gburek
Dr. inż. Mirosław Kowaliński
Mgr. inż. Piotr Podgórski

ДИПЛОМ

Премією
Національної академії наук України
і Польської академії наук
нагороджується
кандидат фізико-математичних наук
Дудник
Олексій Володимирович
за цикл спільних наукових досліджень
"Дослідження динамічної структури
високоенергетичних частинок
в навколоземному просторі",
виконаних спільно
Радіоастрономічним інститутом
НАН України
та Центром космічних досліджень ПАН

Київ – Варшава, 2014

Президент
Національної академії наук України
академік НАН України
Б.Є. Патон

DYPLOM

Wspólną nagrodą
Polskiej Akademii Nauk
i Narodowej Akademii Nauk Ukrainy
uhonorowany zostaje
Doktor nauk fizyczno-matematycznych
Ołeksij W. Dudnyk
za serię wspólnych prac badawczych
„Badania dynamicznej struktury
wysokoenergetycznych cząstek
w bezpośrednim otoczeniu Ziemi"
zrealizowanych we współpracy
Centrum Badań Kosmicznych PAN
i Instytutu Radioastronomicznego NANU

Warszawa – Kijów 2014

Prezes
Polskiej Academii Nauk
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Prof. Michał Kleiber