Solar Bragg spectrometry: new opportunities with micro-satellites

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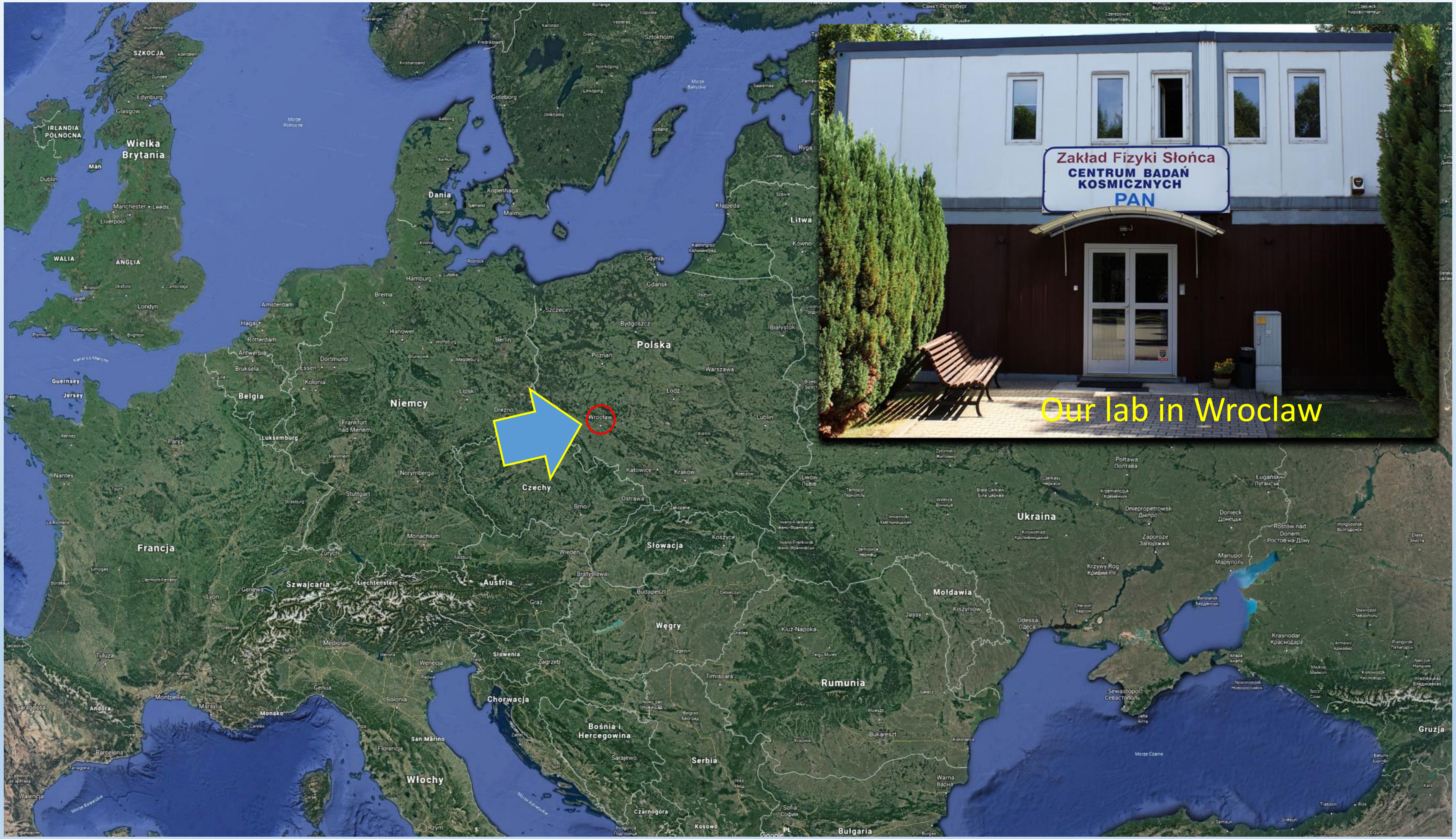
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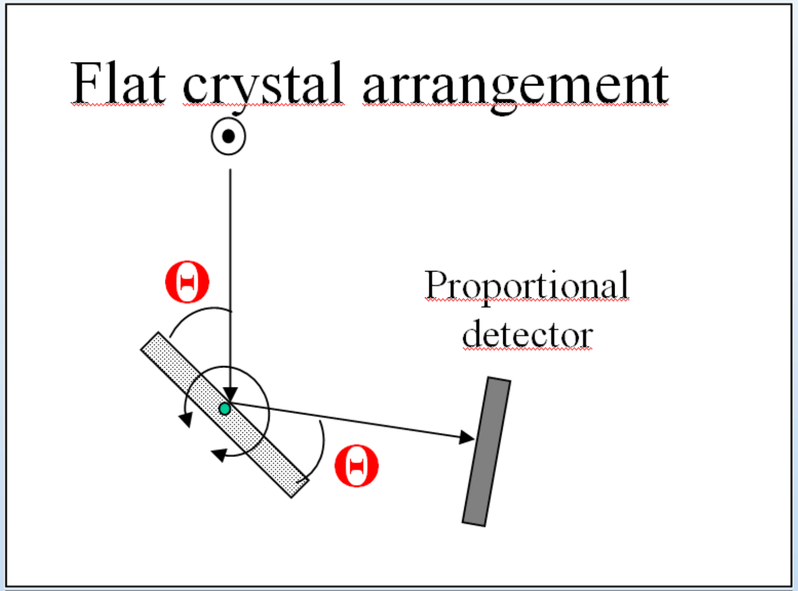
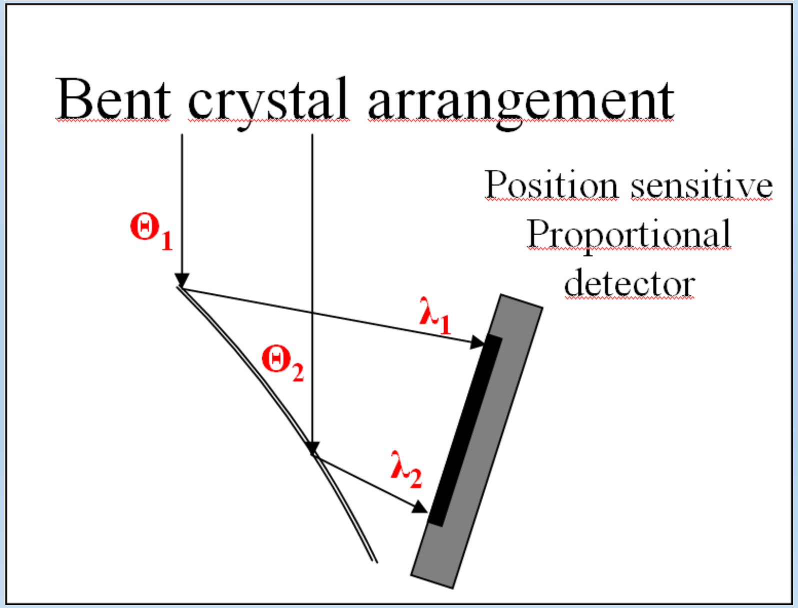
Bragg spectrometers

The principle of crystal spectrometers is based on the Bragg diffraction equation

$$n\lambda = 2d \sin \theta$$

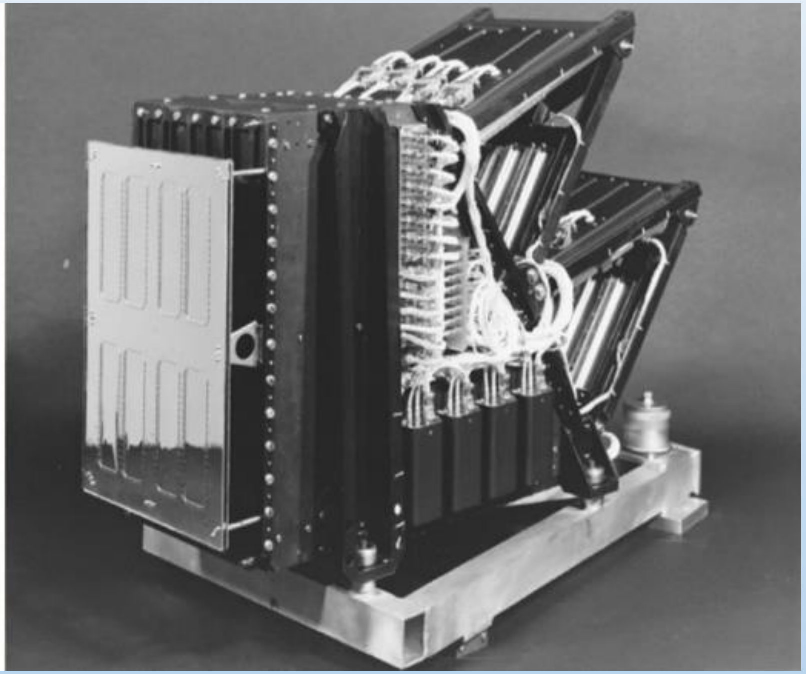
n - the diffraction order,
λ - the wavelength,
d - the crystal lattice spacing,
θ - the glancing angle of incidence





BCS aboard Solar Maximum Mission (1980-1989)

CAD illustration of the SMM Bent Crystal Spectrometer with channel numbers indicated.



The instrument bolted to a calibration stand before installation in the SMM spacecraft.

BCS

Was a part of the *X-ray Polychromator* (XRP)

BCS Dimensions:

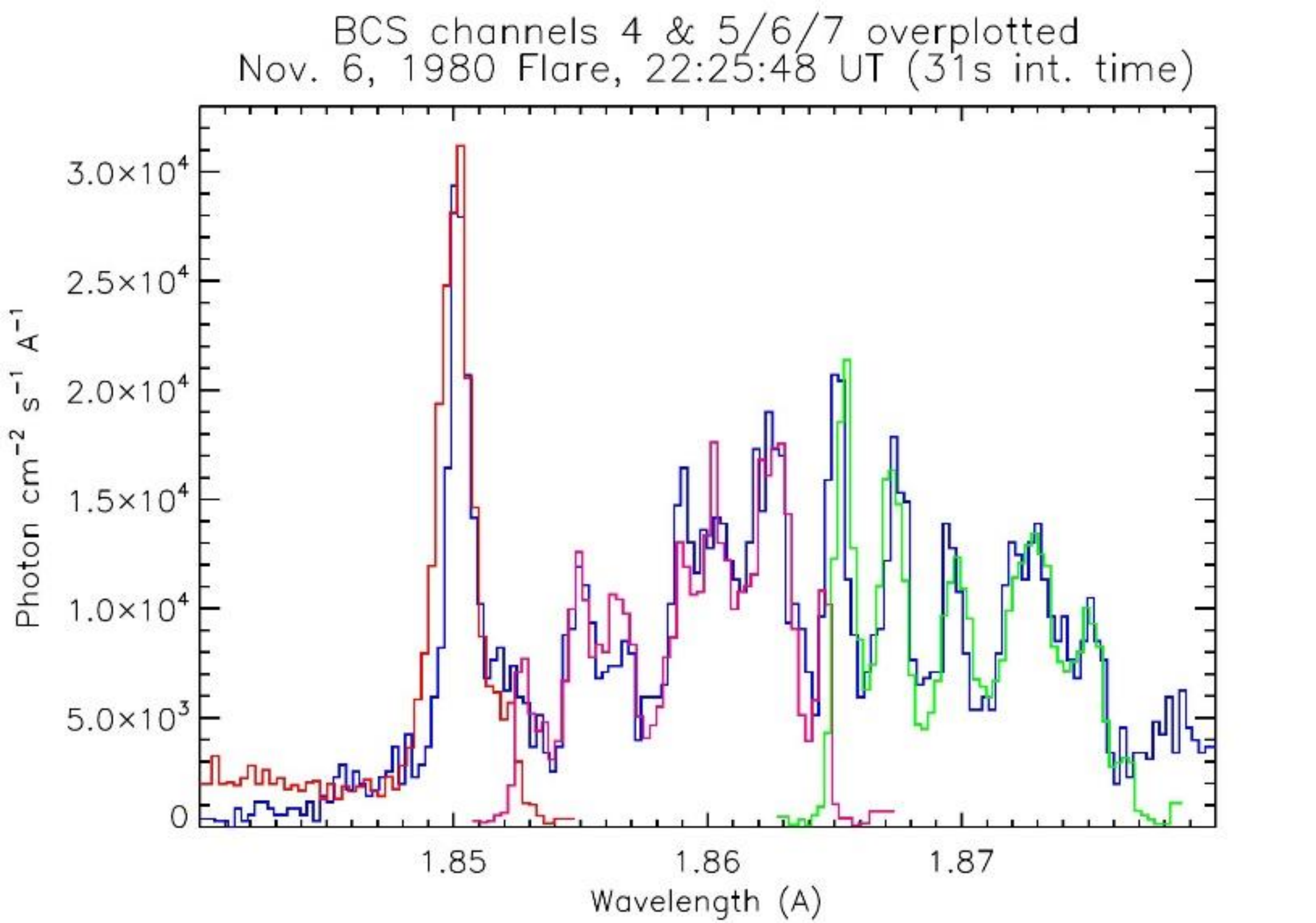
800 x 600 x 350 mm

Approximate Mass: 35 kg

The BCS consisted of the components:

- Heat shield;
- Multi-grid Oda collimator;
- Eight dispersive diffracting X-ray crystals;
- Eight position-sensitive proportional counters with commandable ^{55}Fe calibration sources (two sources per deck of four detectors);
- Analogue electronics and high-voltage units;
- Digital electronics.

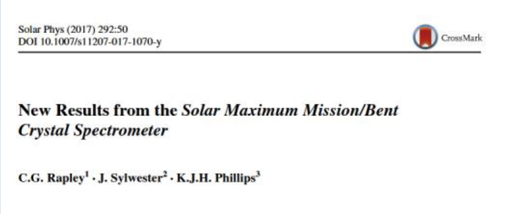
BCS on-board Solar Maximum Mission (1980-1989)



BCS spectra from channel 4 (blue) compared with spectra from channels 5 (green), 6 (red), and 7 (orange) for a 45 second integration time starting at 22:24:07 UT during the 06 November 1980 (SOL1980-11-06T22:27) flare along BCS boresight), with counts/bin converted into absolute fluxes [photon/cm²/s] using effective areas and bin widths from.

https://link.springer.com/article/10.1007/s11207-017-1070-y

The range covered includes the Fe XXV line *w* (1.850 Å) and other Fe XXV lines and dielectronic satellites of Fe XXIV and Fe XXIII.


Solar Phys (2017) 292:50
DOI 10.1007/s11207-017-1070-y

CrossMark

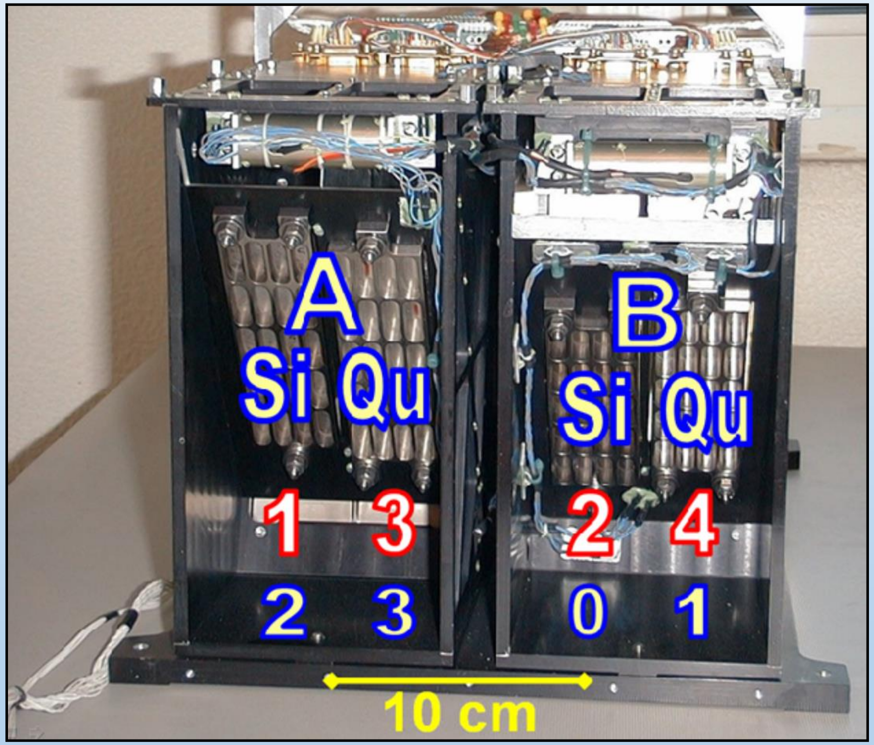
New Results from the *Solar Maximum Mission/Bent Crystal Spectrometer*

C.G. Rapley[1] · J. Sylwester[2] · K.J.H. Phillips[3]

Diogeness and RESIK on-board CORONAS-F (2001-2003)

RESIK Dimensions: 450x315x313mm
Approximate Mass: 15 kg

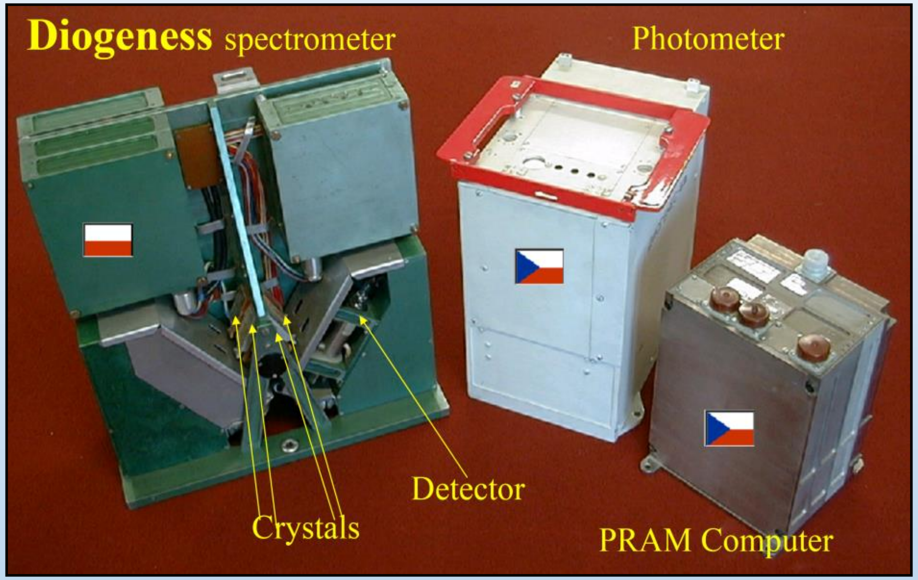
Diogeness Dimensions: 330x336x170mm
Approximate Mass: 7.4 kg



Two million spectra collected & presented as Spectral atlas available online

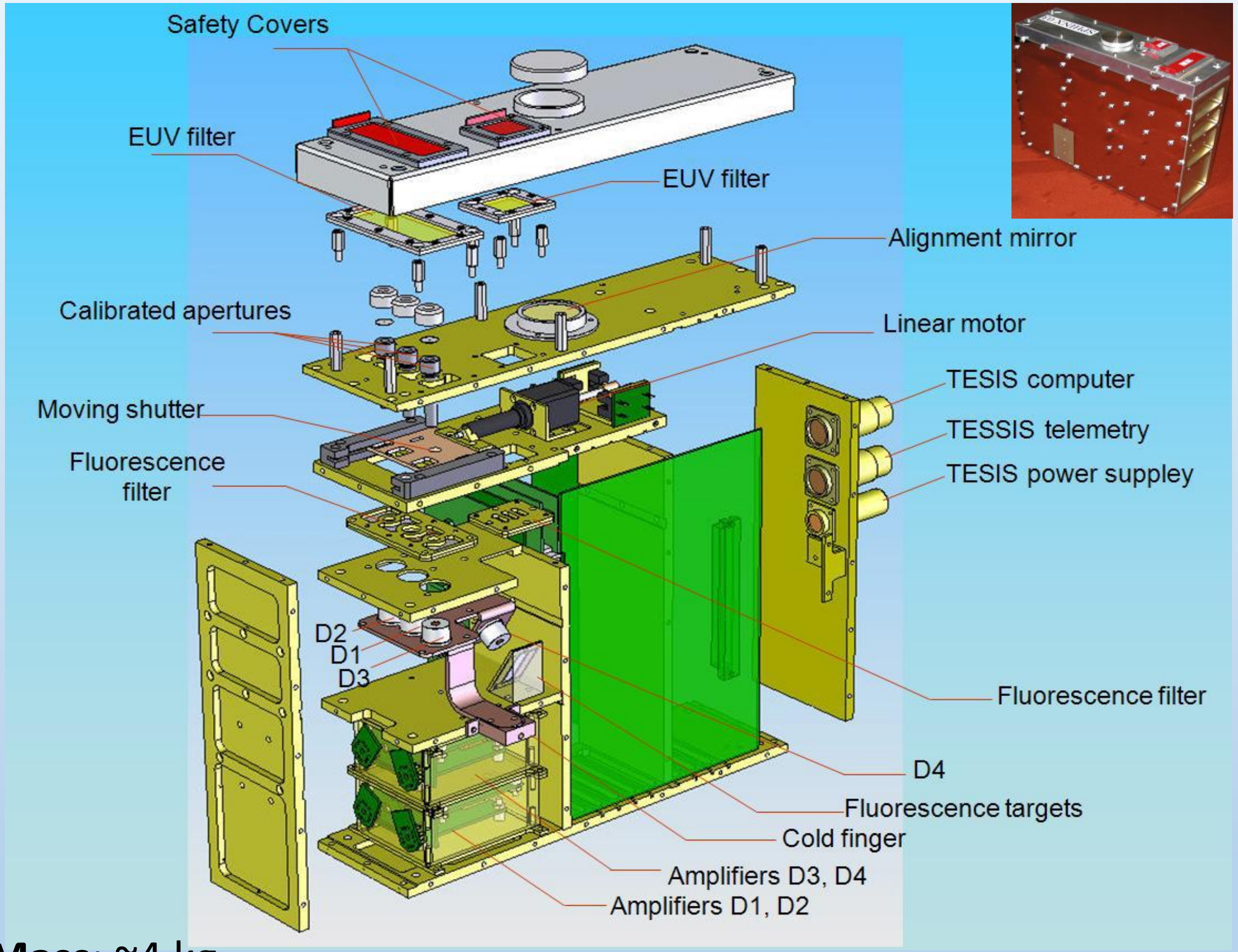
http://www.cbk.pan.wroc.pl/experiments/resik/resik_catalogue.htm

RESIK was an X-ray spectrometer recording X-ray spectra in four channels covering the wavelength range from 3.33 Å to 6.15 Å. Bent quartz and silicon crystals were used as an diffraction elements. The gas detectors were filled with a mixture of xenon, argon and carbon dioxide.



Diogeness was a scanning Bragg flat crystal spectrometer equipped with four mono-crystals used as dispersion elements. Two of them are identical quartz crystals mounted on the common shaft in an unique, so-called Dopplerometer configuration.

SphinX soft X-ray spectrophotometer aboard Coronas-Photon (2009)



Mass: ~4 kg,
Size 270 × 280 × 80 mm
Power consumption: 10W (peak)
Telemetry: ~50 MB/24h

Solar **P**h**o**tometer **in** X-rays (**SphinX**) was a spectrophotometer developed to observe the Sun in soft X-rays. The instrument observed in the energy range 0.5 keV - 15.0 keV with resolution ~0.4 keV. SphinX observed the Sun during extremely low activity and there are many periods in which it dropped ~20 times below the *GOES* detection threshold. Thus SphinX data open new possibilities in investigations of the quiet Sun.

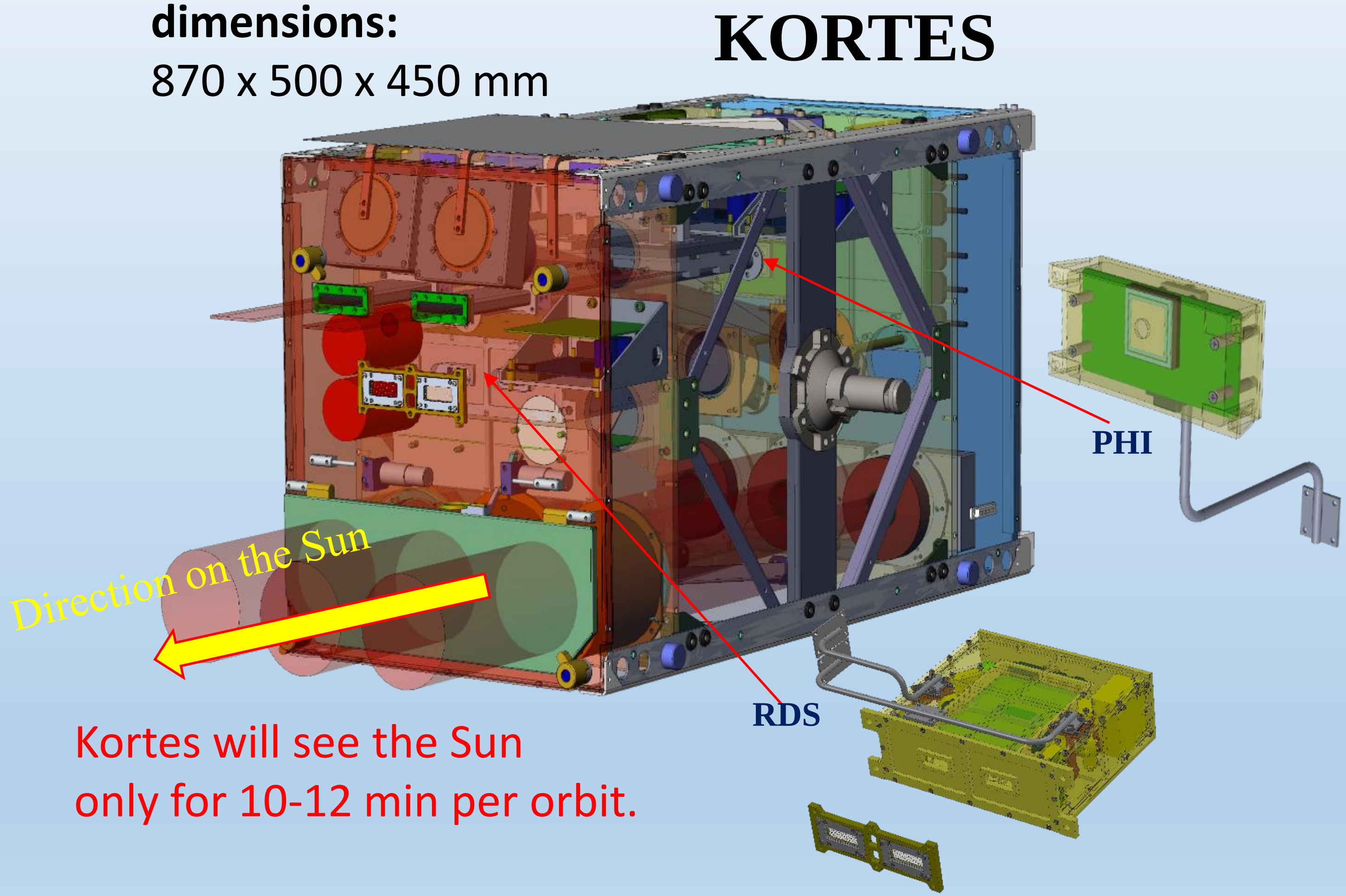
SphinX was flown aboard the Russian *CORONAS-PHOTON* satellite and was placed inside TESIS EUV and X telescope assembly.

All SphinX data are available at Level_1 data:
http://www.cbk.pan.wroc.pl/sphinx_l1/sphinx_l1_catalogue/SphinX_cat_main.html

The SOLPEX instrument

Launch to ISS is expected in 2022

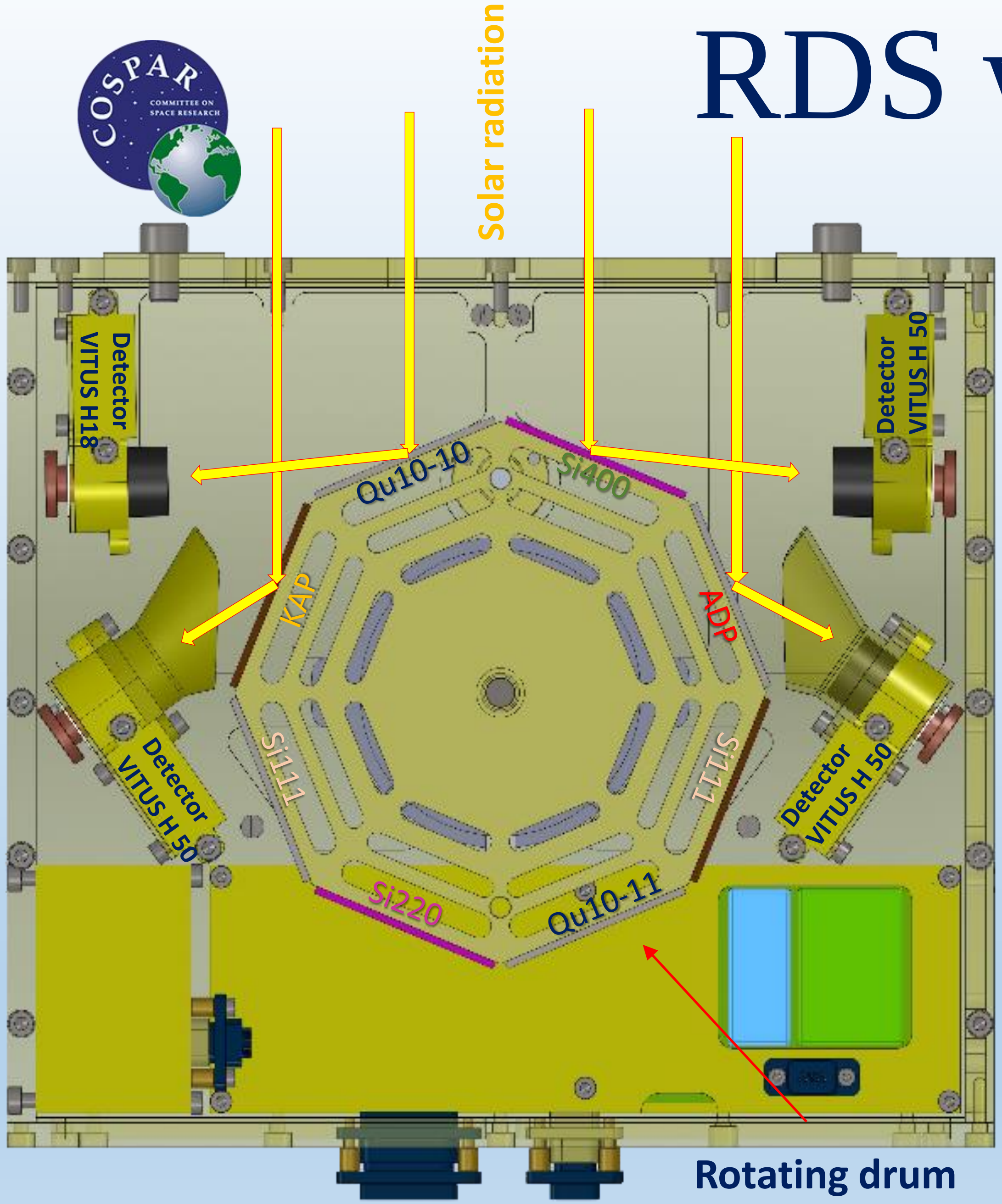
dimensions:
870 x 500 x 450 mm



Kortes will see the Sun
only for 10-12 min per orbit.

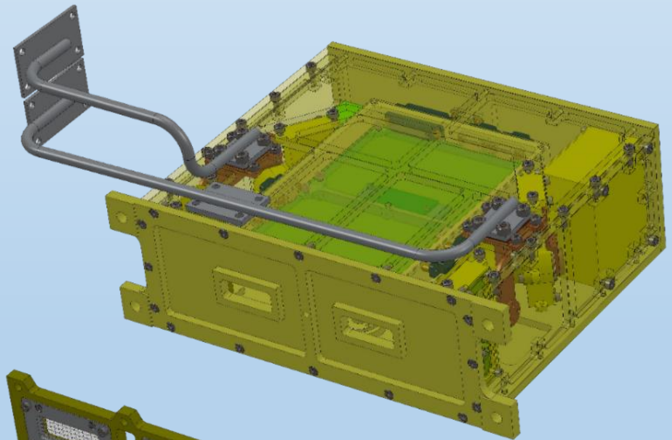
The instrument will be placed within the KORTES package. KORTES is to be placed a top the solar pointing platform attached to the Russian Nauka module on ISS. The pointing platform of Nauka will be guided towards the center of the solar disk.

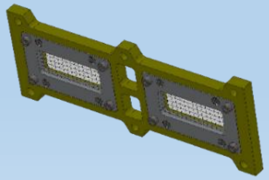
RDS within SOLPEX



Rotating drum
10 rev/s

Rotating Drum Spectrometer contains **Eight crystals** (two of them identical: fixed to the rotating (10 rps) or rocking drum. Bragg reflected spectra are recorded by **four SDD detectors**.





Mass: 2 Kg
RDS Dimensions:
200 x 175 x 76 mm

RDS scanning modes

- **During Entire spectral range 0.5 - 23 Å scanning**

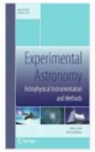
the drum will be rotated with constant speed @ 10 rev/s

During selected spectral line scanning mode

Drum will rock the crystal around position where a strong spectral lines are seen and will periodically change this position in order to observe a numer of pre-selected spectral lines of interest to plasma diagnostic.

SOLPEX- Pin-Hole Imager

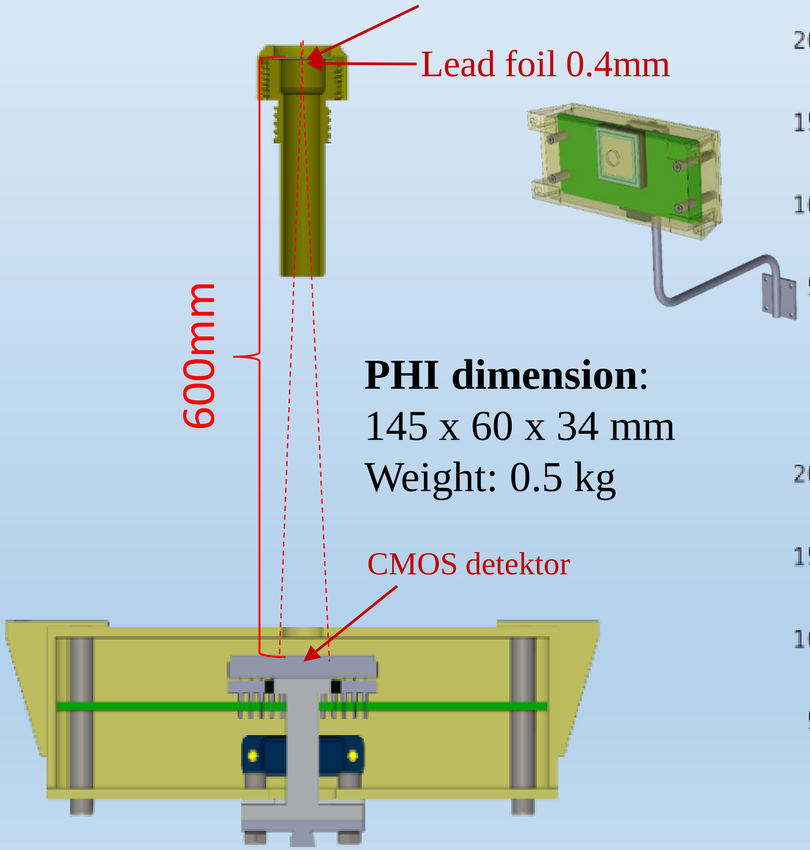
PHI (Pin-hole imager) will provide location of the source on the solar disk. It consists of the CCD, and the pin-hole itself which is mounted on the front-side of the instrument.



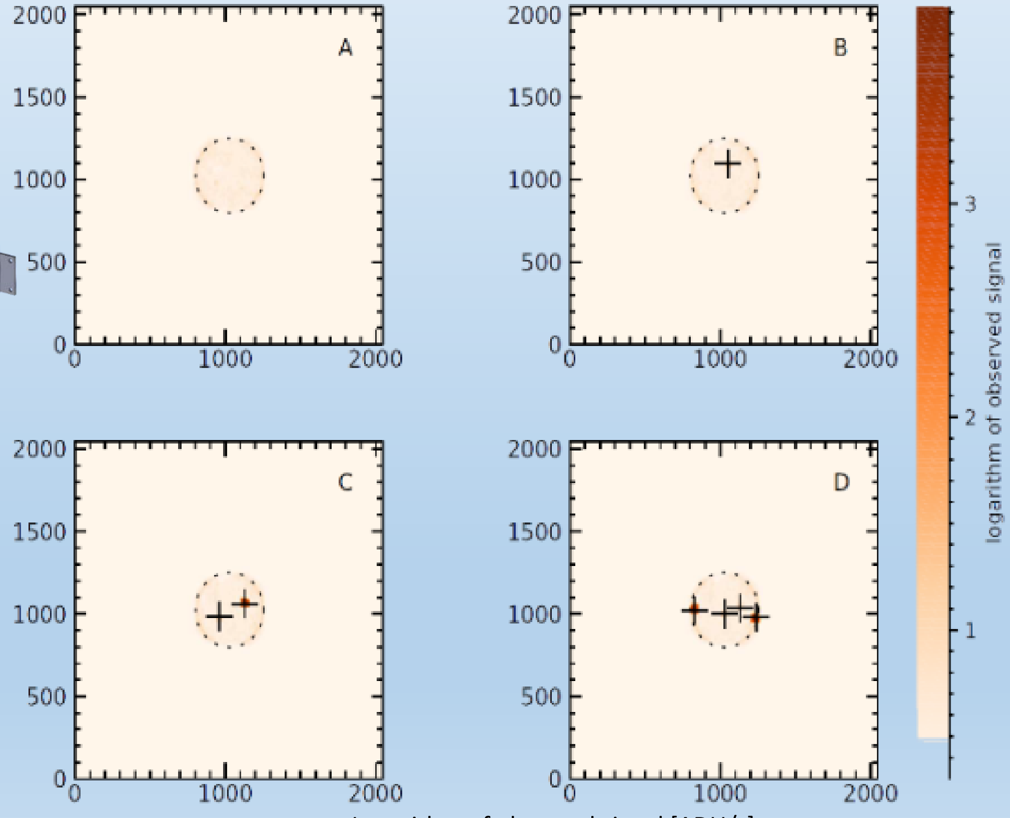
Experimental Astronomy

April 2019, Volume 47, Issue 1–2, pp 199–223 | Cite as

The soft X-ray spectrometer polarimeter SolpeX



PHI dimension:
145 x 60 x 34 mm
Weight: 0.5 kg



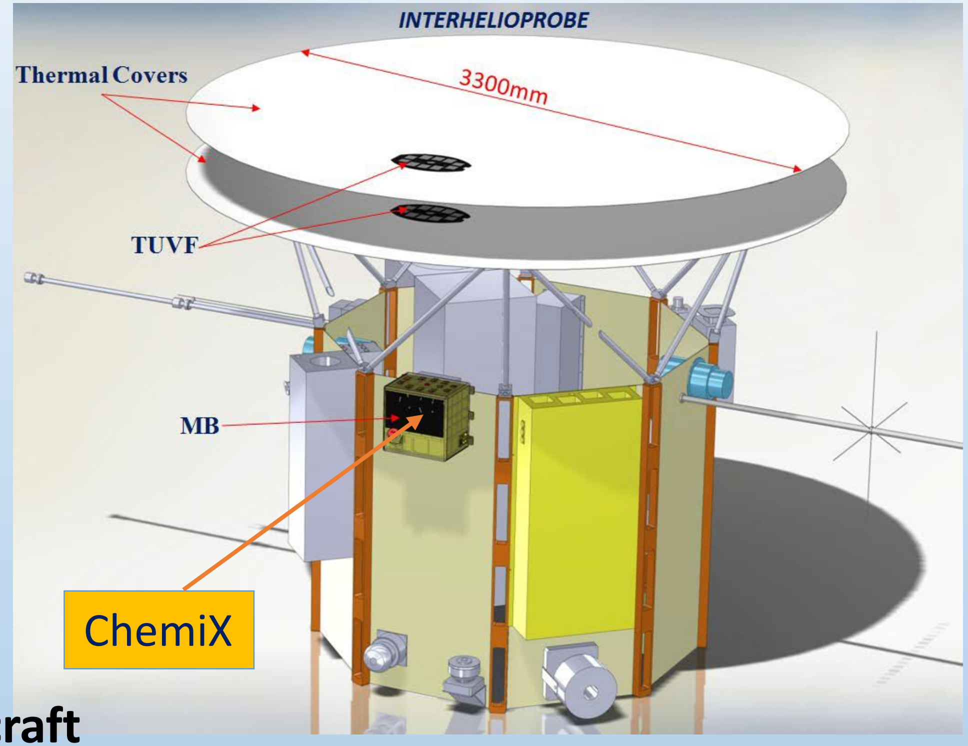
Logarithm of observed signal [ADU/s]

- "Quiet" A - only limb brightening + bright points' contribution are present
- AR1 – B one non-flaring AR detected by the algorithm (AR2, AR3 etc. if more AR detected)
- FL1 – C one flare in progress (or FL2, as sometimes two flares may happen at the same time in different ARs)

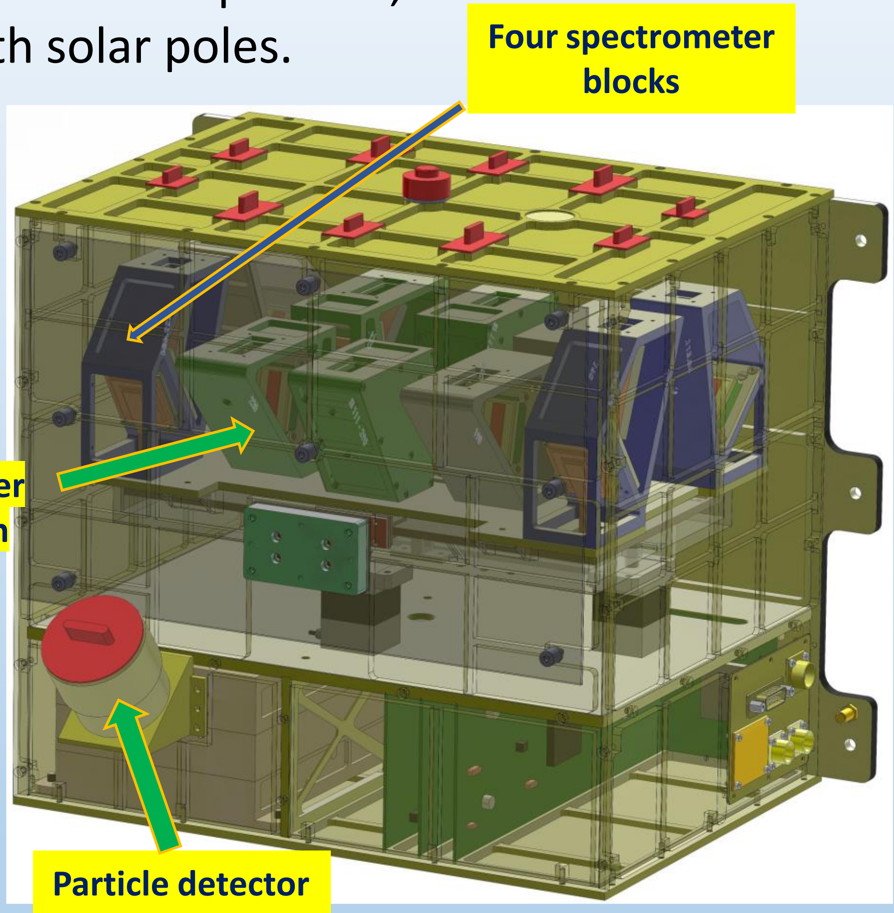
https://link.springer.com/article/10.1007/s10686-018-09618-4#citeas

ChemiX aboard InterHelioProbe 2025-27

ChemiX will be the Bragg crystal spectrometer to fly on the **two** Interhelioprobe spacecraft with perihelion of only 0.3 a.u. and the orbit inclination up to 30°, so instruments will have a close view of solar activity near both solar poles.



ChemiX dimension:
334 x 310 x 243 mm
Weight: 6 kg

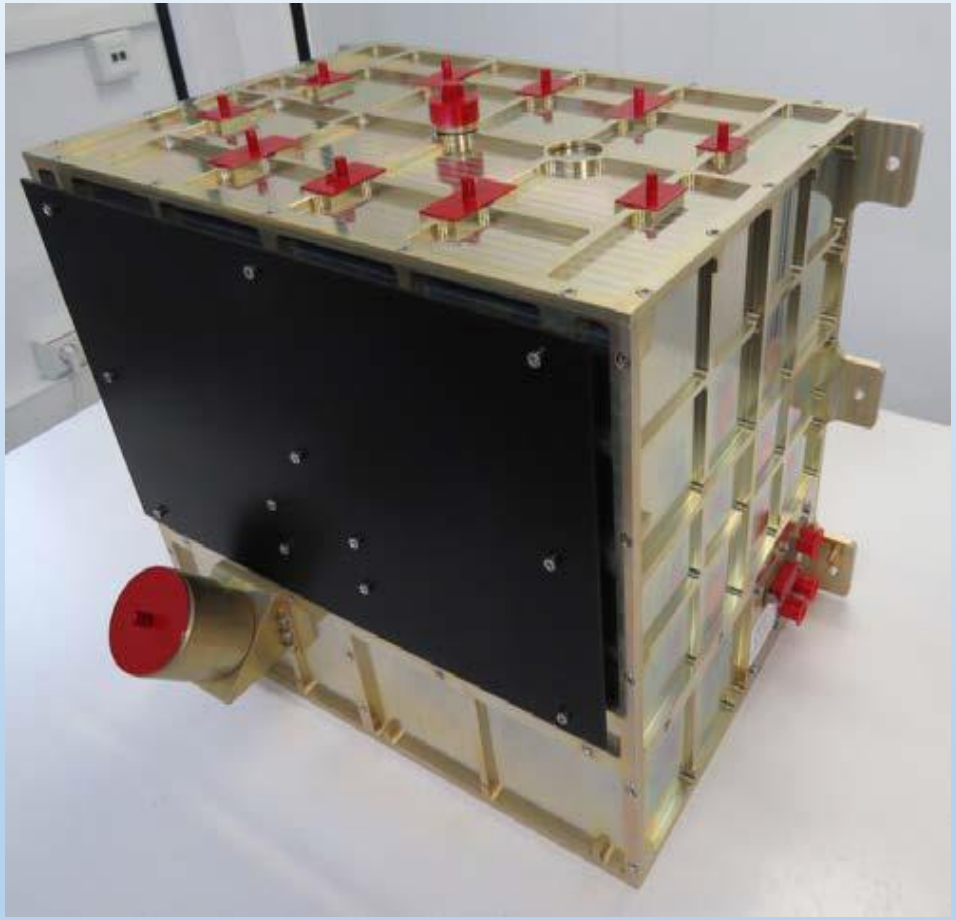


2 **Spacecraft**
3-axis stabilized platform
Sun-pointing
Mission active operation time 5 years
Total mass of scientific payload 160 kg
Number of scientific instruments 19

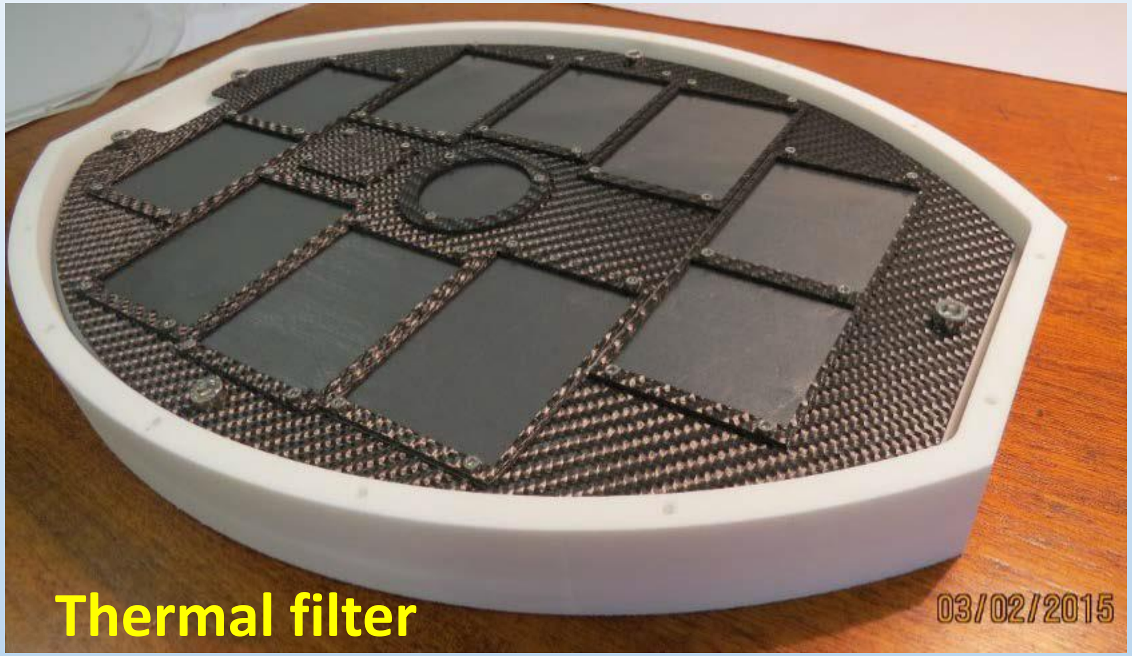
4 crystals to record spectra in the 1.5 – 9 Å range
3 pairs of identical crystals to see Doppler motions of AR and flare plasmas + Background particle detector (Kharkov)

ChemiX aboard InterHelioProbe

https://link.springer.com/article/10.1007/s10686-016-9491-4

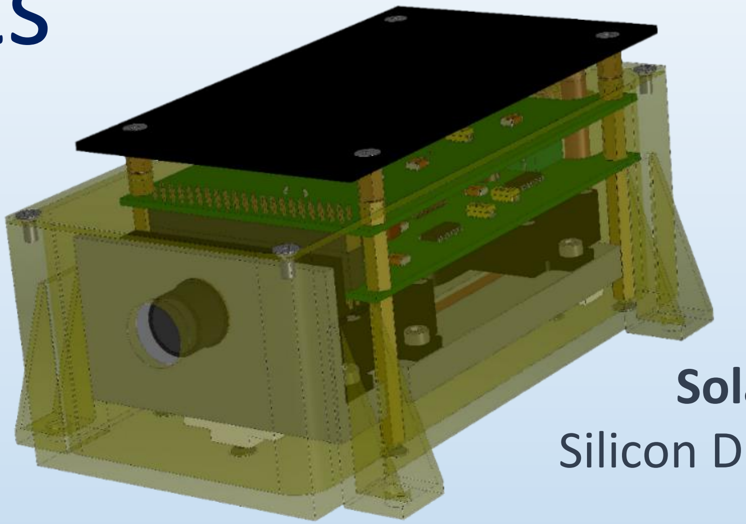


Completion of the ChemiX instrument

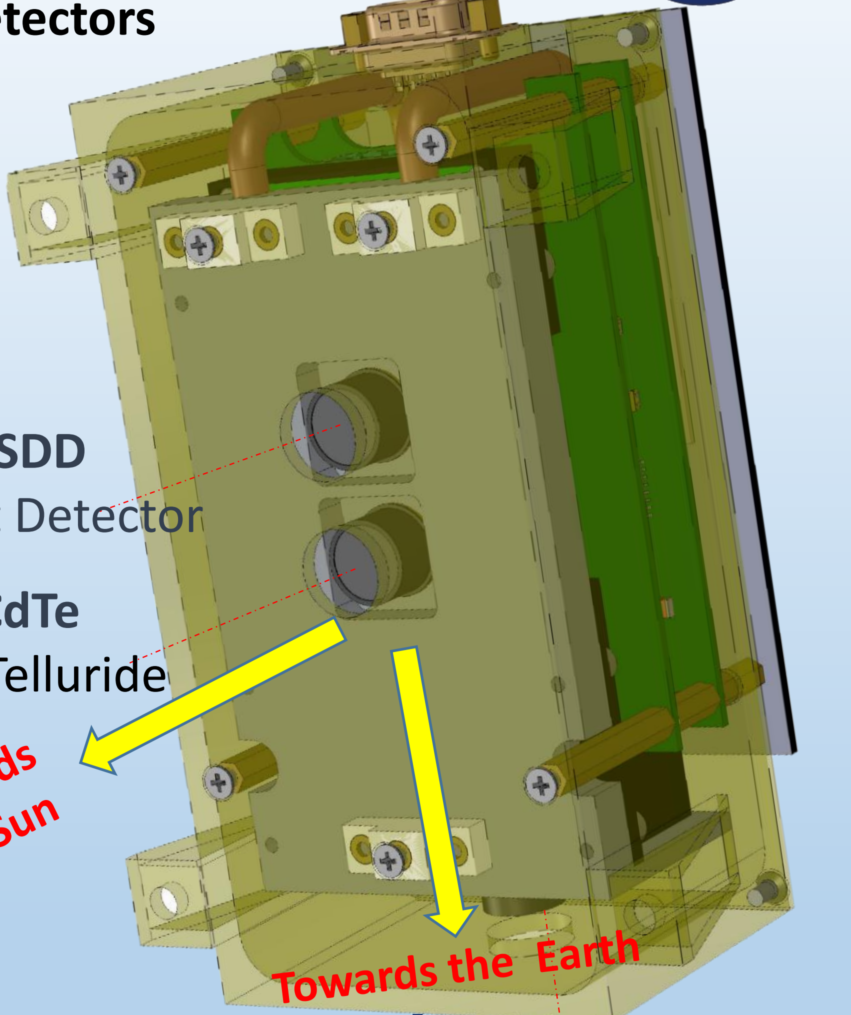


Abstract *Interhelioprobe* (IHP), an analogue to the ESA *Solar Orbiter*, is the prospective Russian space solar observatory intended for in-situ and remote sensing investigations of the Sun and the inner heliosphere from a heliocentric orbit with the perihelion of about 60 solar radii. One of several instruments on board will be the Bragg crystal spectrometer ChemiX which will measure X-ray spectra from solar corona structures. Analysis of the spectra will allow the determination of the elemental composition of plasma in hot coronal sources like flares and active regions. ChemiX is under development at the Wrocław Solar Physics Division of the Polish

SphinX-NG
for cubsats



SphinX-NG3 Box version
with 3 detectors



Solar SDD
Silicon Drift Detector

Solar CdTe
Cadmium Telluride

Towards the Sun

Solar X-ray monitoring:
- Temperature and differential emission measure studies
- Long-term solar flux variability
- Studies of non-active corona
- Active regions' physics
- Solar flares' energy release physics
- Coronal sources plasma abundances

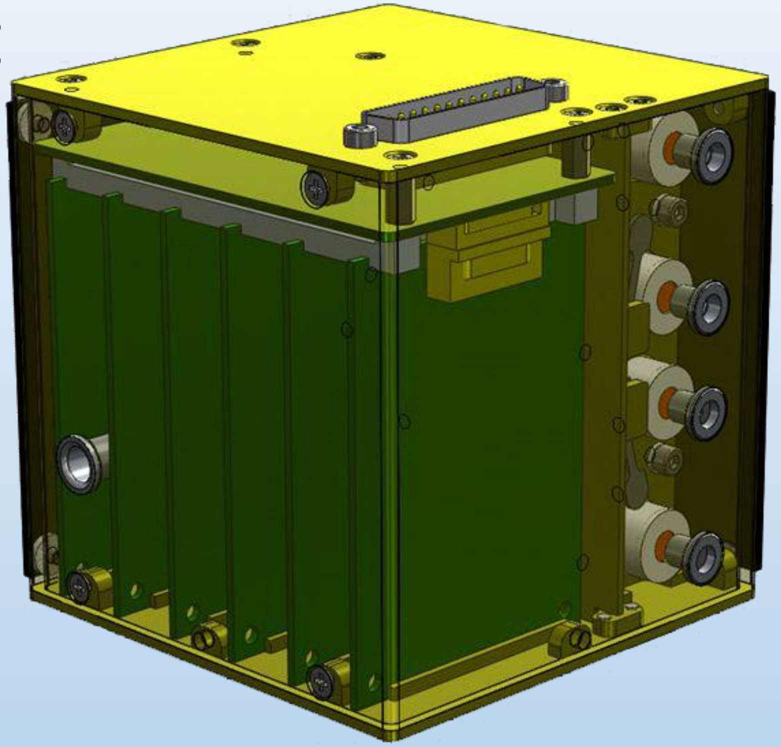
Terrestrial X-ray and particle observations:
- X-ray signatures of Terrestrial Gamma-ray Flashes (TGFs)
- Auroral X-ray spectra while in transit
- Orbital particle environment fluctuations

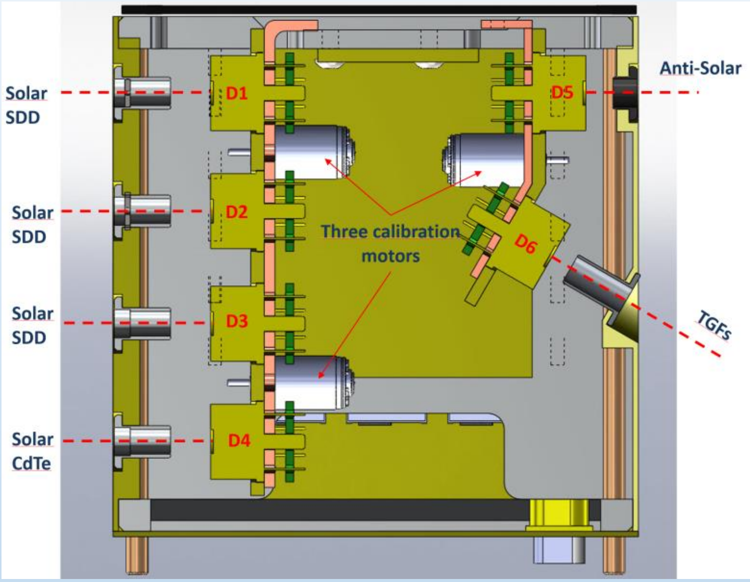
SphinX-NG Dimensions:
150 x 76 x 67 mm
Weight: 0.8 kg

- 0.5 keV – 150 keV
- Resolution: 200 eV

CdTe Detector
TGFs
Terrestrial Gamma-ray Flashes

CubeSat Sphinx_NG6
1U Box with 6 detectors, to be placed within 3U nanosat





Satellite and orbit:

- CubeSat or Firefly type

Orbit:

- Sun synchronous
- One-axis directed towards solar disc
- Pointing within ±1 degree on every axis
- Liftime depends on the orbit

The proposed 1U CubeSat mission consists of soft X-ray spectrophotometer placed into 450-660 km near circular orbit. It will be devoted to better understanding of particle acceleration and plasma heating in the solar atmosphere and detection of terrestrial thunderstorms through X-ray spectroscopy which is important for space weather predictions.

CubeSat 3U

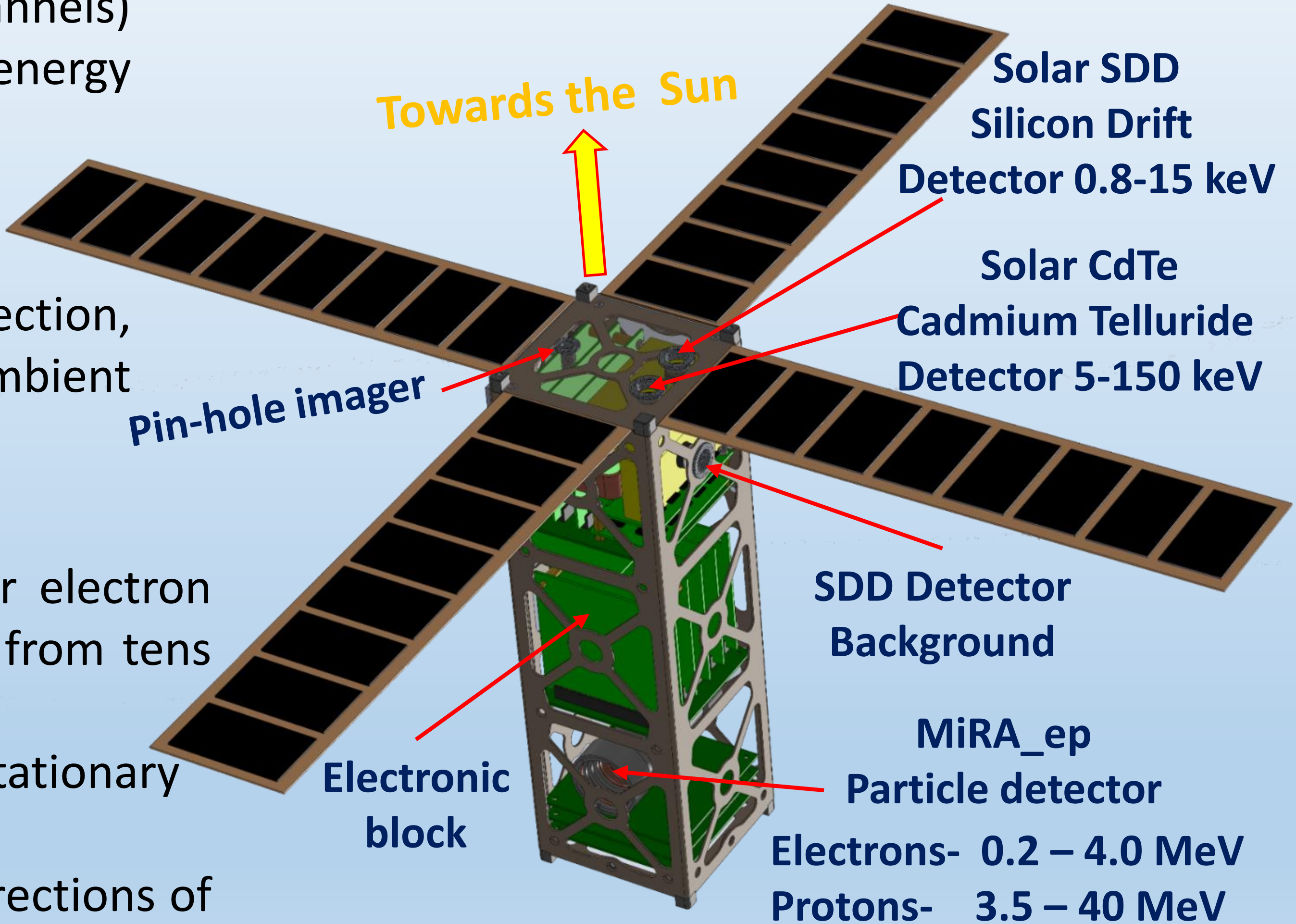
CubeSat SphinX_NG will be equipped with three multi-channel X-ray detectors (each having 256 energy channels) two the soft (0.8-15 keV) and one harder (5-150 keV) energy domains.

Configuration:

- two detectors will look towards the Sun;
- The third detector will look in the anti-solar direction, taking measurements of particle background and ambient soft X-ray emission arising within Earth.

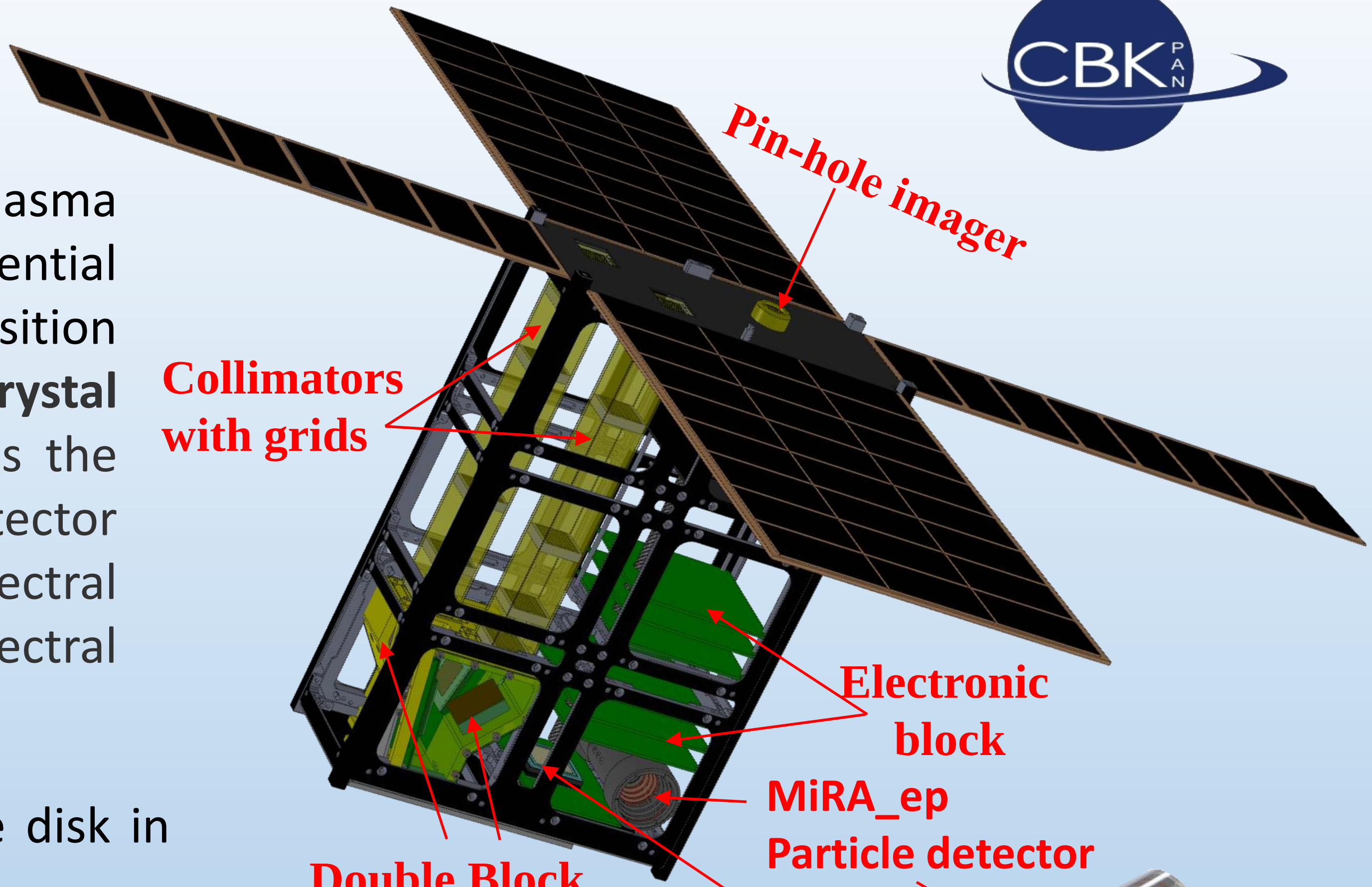
MiRA_ep

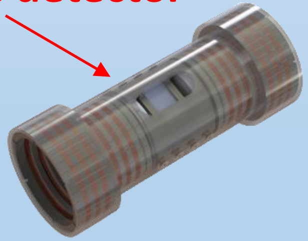
- Verification of the existence of an additional inner electron radiation belt at L ~ 1.6 for particles with energies from tens keV to ~ 0.5 MeV
- Determination of the energy spectra of particles in stationary radiation belts and in microbursts outside the belts.
- Determination of the degree of anisotropy of the directions of the electron velocities in the midpoint of the radiation.



CubeSat 6U

Spectrometer will allow for studies of thermal plasma properties like turbulence, directed motions, dierential emission measure distribution and elemental composition for Ar and S. We selected **Silicon 111 ideal mono-crystal wafer bent cylindrically to a 820.97 mm radius** as the dispersive medium. The adopted crystal-detector geometry allows spectra to be obtained in the spectral range **3.9 Å–4.1 Å** with an exceptionally good spectral resolution of ~ **90 μÅ/bin**





Pin-hole imager

- **Primary**: to localize sources (AR & flares) on the disk in the instrument coordinate system
- Will provide positions [x,y] of more prominent individual sources (resolution ~**1.5 arcmin**)
- **Secondary**: detect active phenomena on the disk, analyse individual lightcurves for separate AR
- Easy concept: pin-hole + CMOS detector (2048 x 2028 pixels 26 μm); image readout: **every ~0.2 s**

Orbit:

- Sun synchronous
- One-axis directed towards solar disc
- Pointing to within 20 arcsec
- Liftime depends on the orbit

Satellites pros and cons

Large satellites

Pros:

- Big, multifunctional instruments can be used
- Good stabilization at the Sun centre
- Easy offsetting

Cons:

- Long development time
- Large costs

Micro-satellites

Pros:

- Cheap (relatively)

Cons:

- Worse stabilization
- Problems with heat dissipation

THANK YOU !