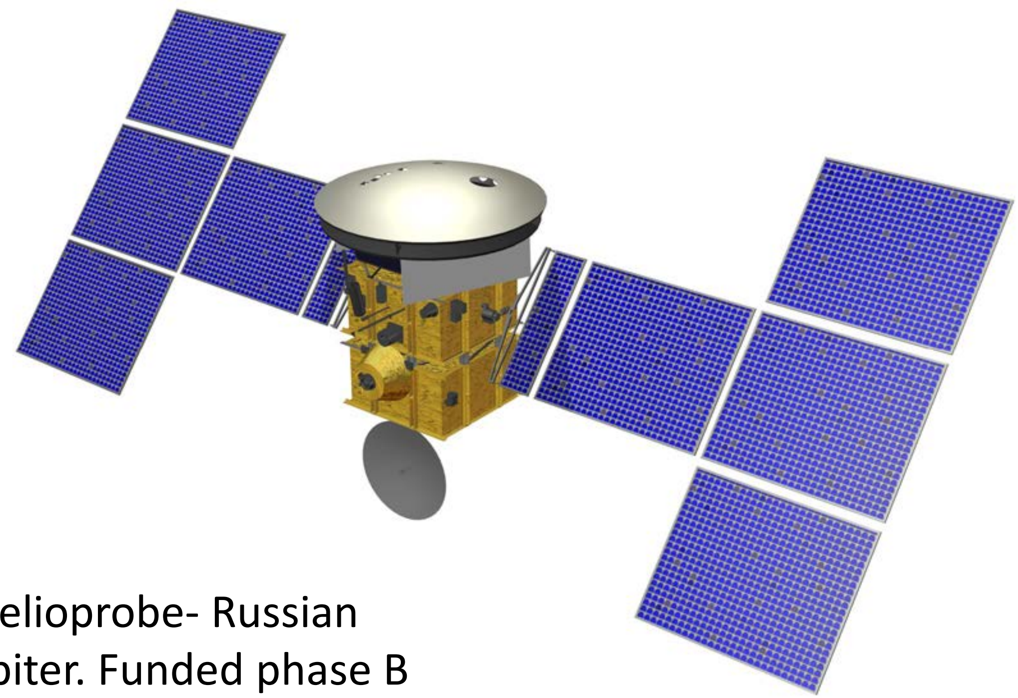
ChemiX- the Bragg crystal spectrometer for the Interhelioprobe mission to the Sun

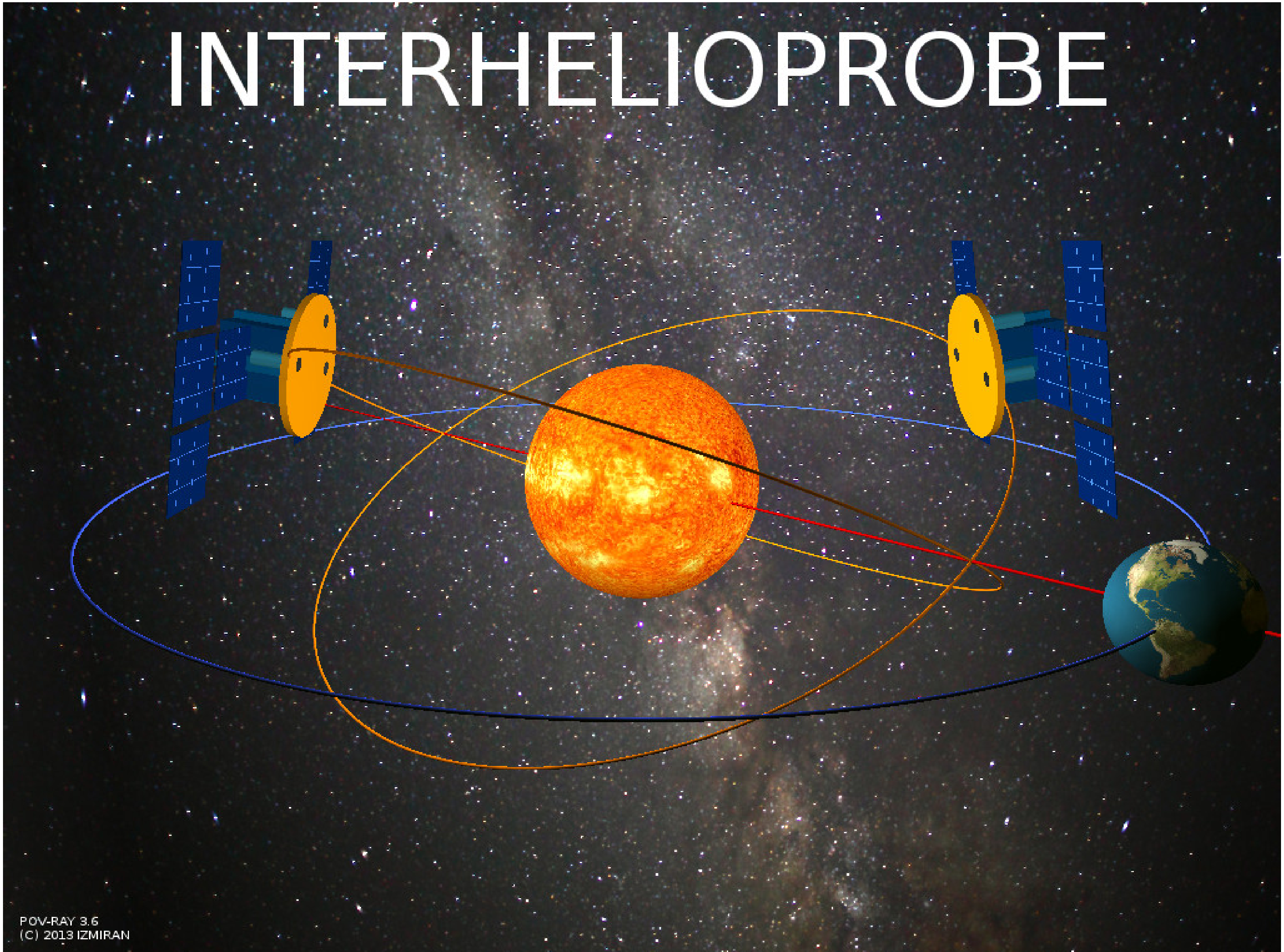
Janusz & Barbara Sylwester
Zaneta Szaforz
SRC PAS, Wroclaw

Next step towards soft X-ray diagnostics of coronal plasmas

- Aim
- Concept
- Present status
- Possible impact



Interhelioprobe- Russian
Solar Orbiter. Funded phase B
Launch windows: 2018 –one S/C
2022- two S/C


INTERHELIOPROBE
POV-RAY 3.6
(C) 2013 IZMIRAN

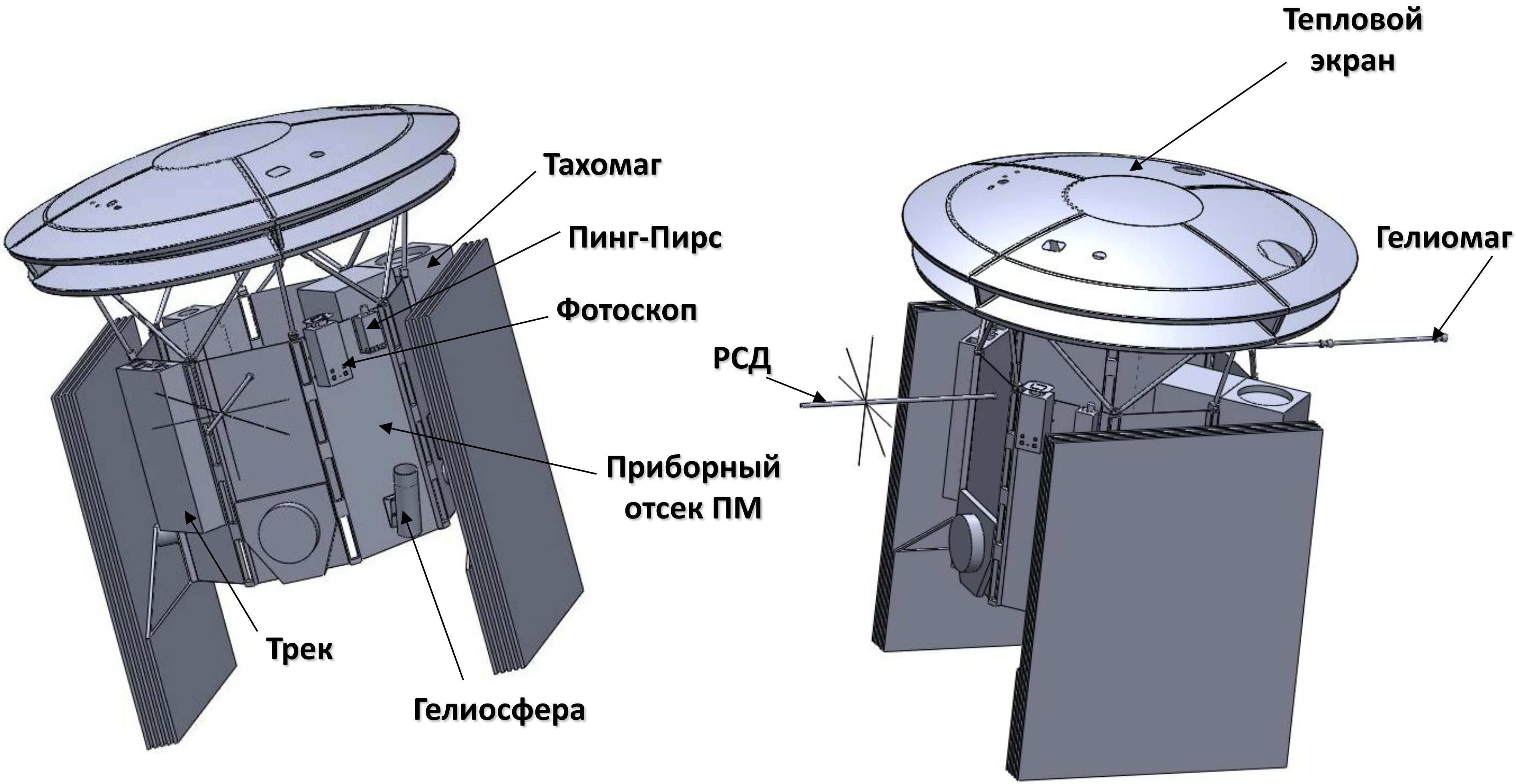
SRC PAS (Wroclaw) the only „foreign” collaborator

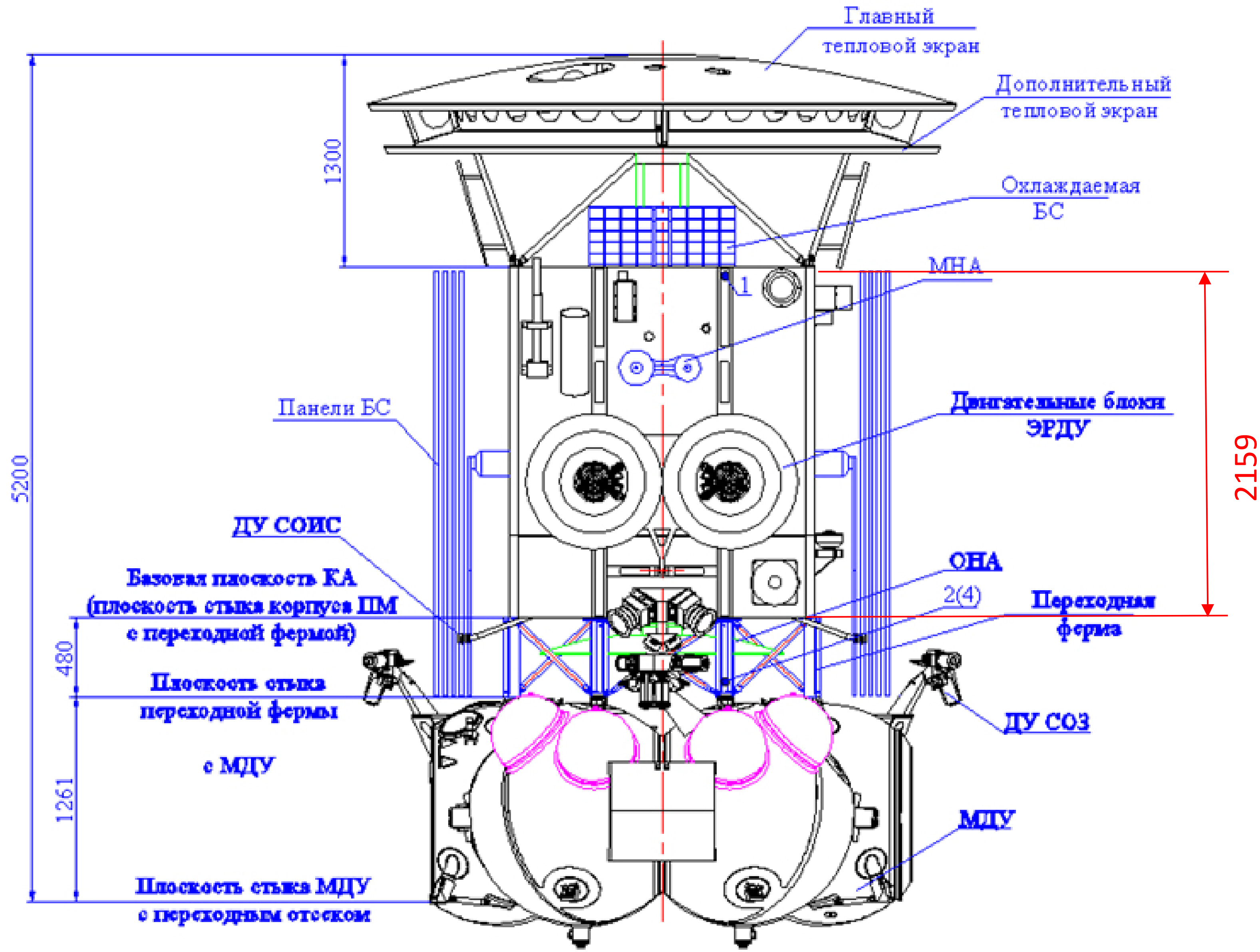
3.1.1 Состав комплекса научной аппаратуры приведен в таблице 3.1

Таблица 3.1

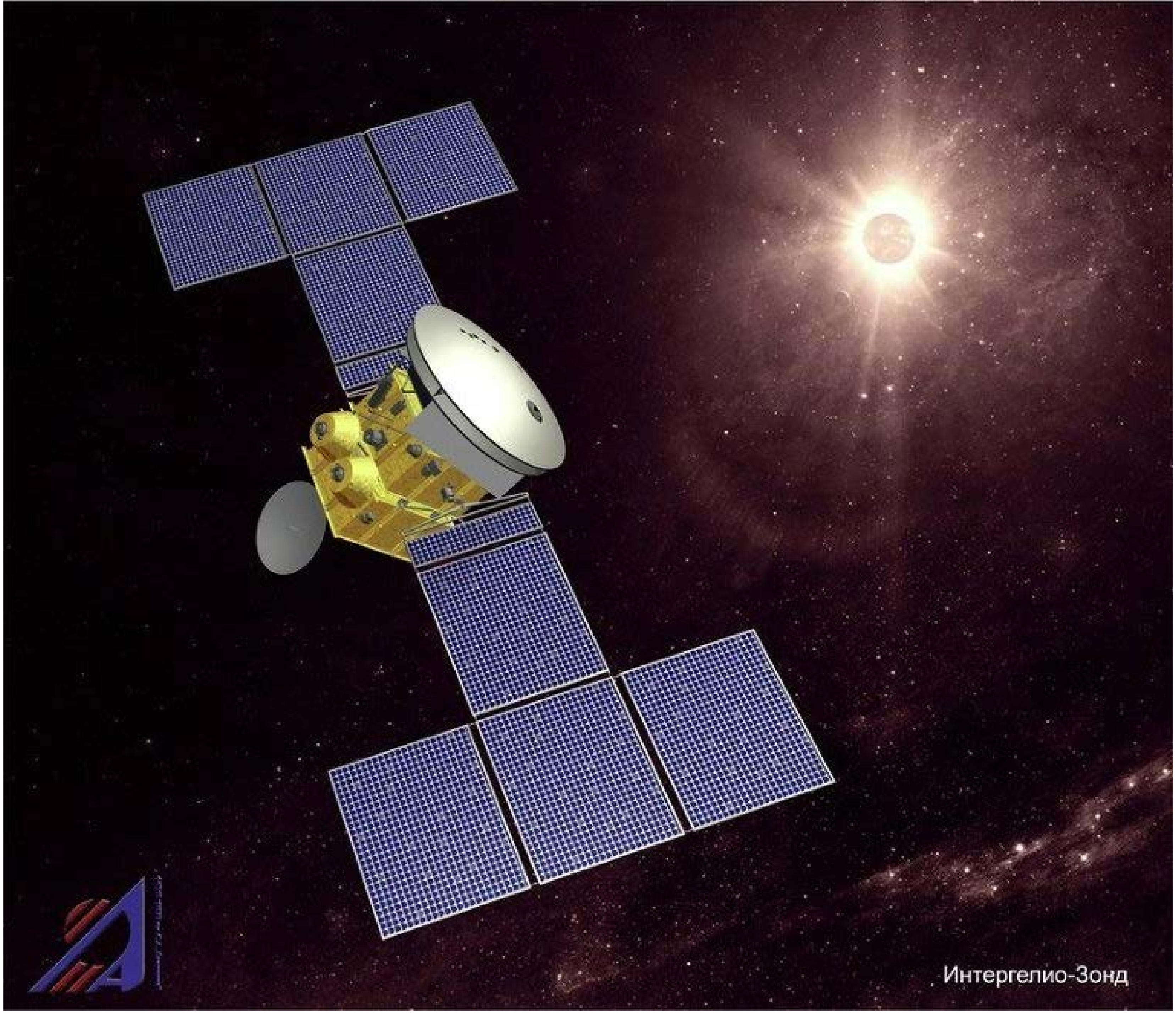
Наименование научного прибора	**Организации-изготовители**
Солнечные приборы	
1 Многоканальный солнечный фотометр «Фотоскоп»	ИЗМИРАН
2 Многофункциональный оптический телескоп «ТАХОМАГ» (см. примечание)	ИЗМИРАН НИРФИ
3 Анализатор химического состава корональной плазмы «ХЕ-МИКС»	ИЗМИРАН / ЦКИ ПАН
4 Рентгеновский спектрометр изображающий «Трек»	ФИАН
5 Внезатменный солнечный коронограф «Ока»	ФИАН
6 Солнечный рентгеновский телескоп изображающий «Соренто»	ФИАН
7 Гелиосферный широкополосный телескоп «Гелиосфера»	ФИАН
8 Бортовой компьютер «БК-ГОСТ»	ФИАН
9 Сцинтилляционный гамма-спектрометр «Геликон-И»	ФТИ им. А.Ф. Иоффе

Перелётный модуль КА «Интергелио-Зонд»

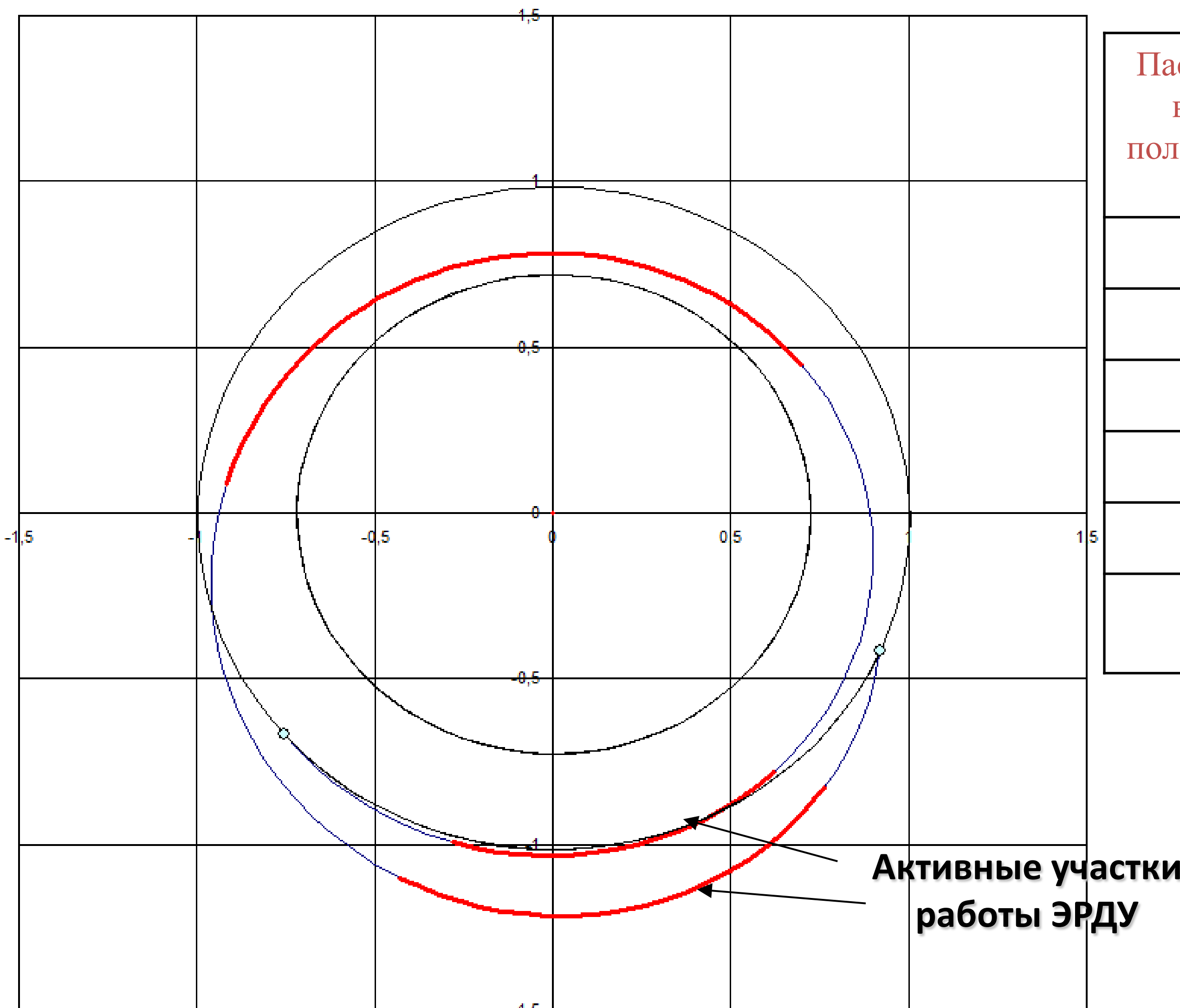




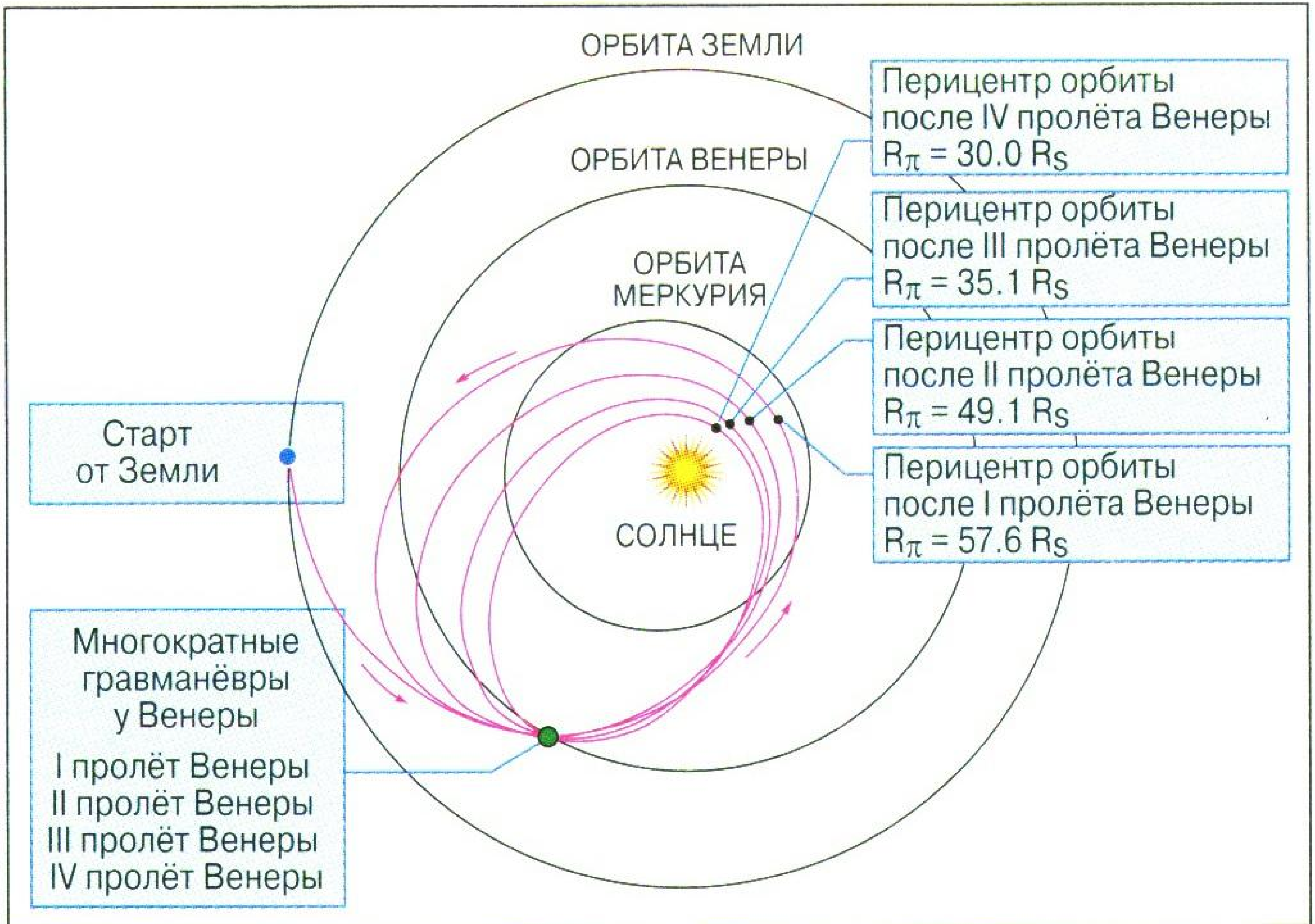
Главный
тепловой экран
Дополнительный
тепловой экран
Охлаждаемая
БС
МНА
1
Панели БС
Двигательные блоки
ЭРДУ
ДУ СОИС
Базовая плоскость КА
(плоскость стыка корпуса ПМ
с переходной фермой)
ОНА
2(4)
Переходная
ферма
Плоскость стыка
переходной фермы
с МДУ
ДУ СОЗ
МДУ
Плоскость стыка МДУ
с переходным отсеком
5200
1300
480
1261
2159

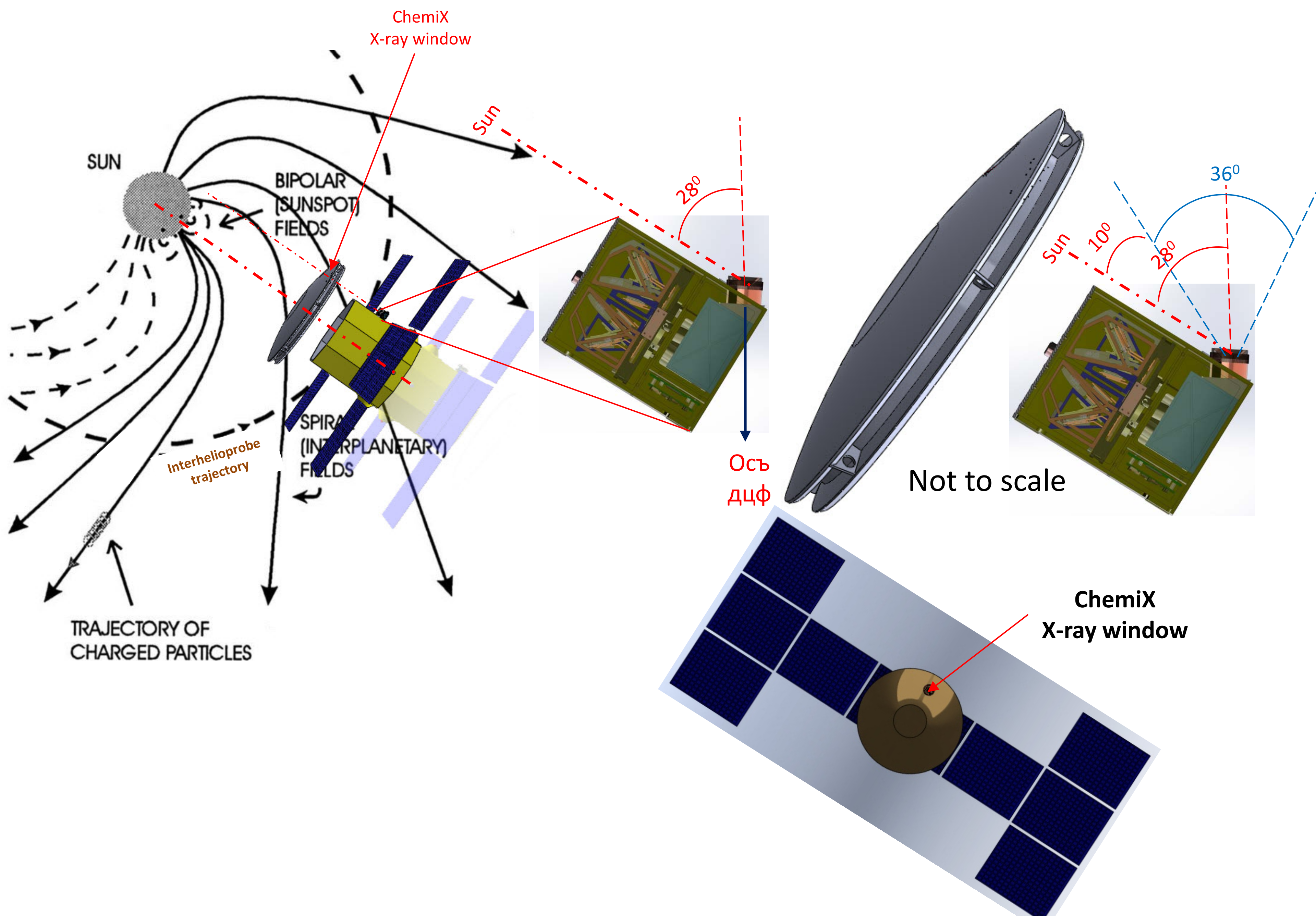

Интергелио-Зонд

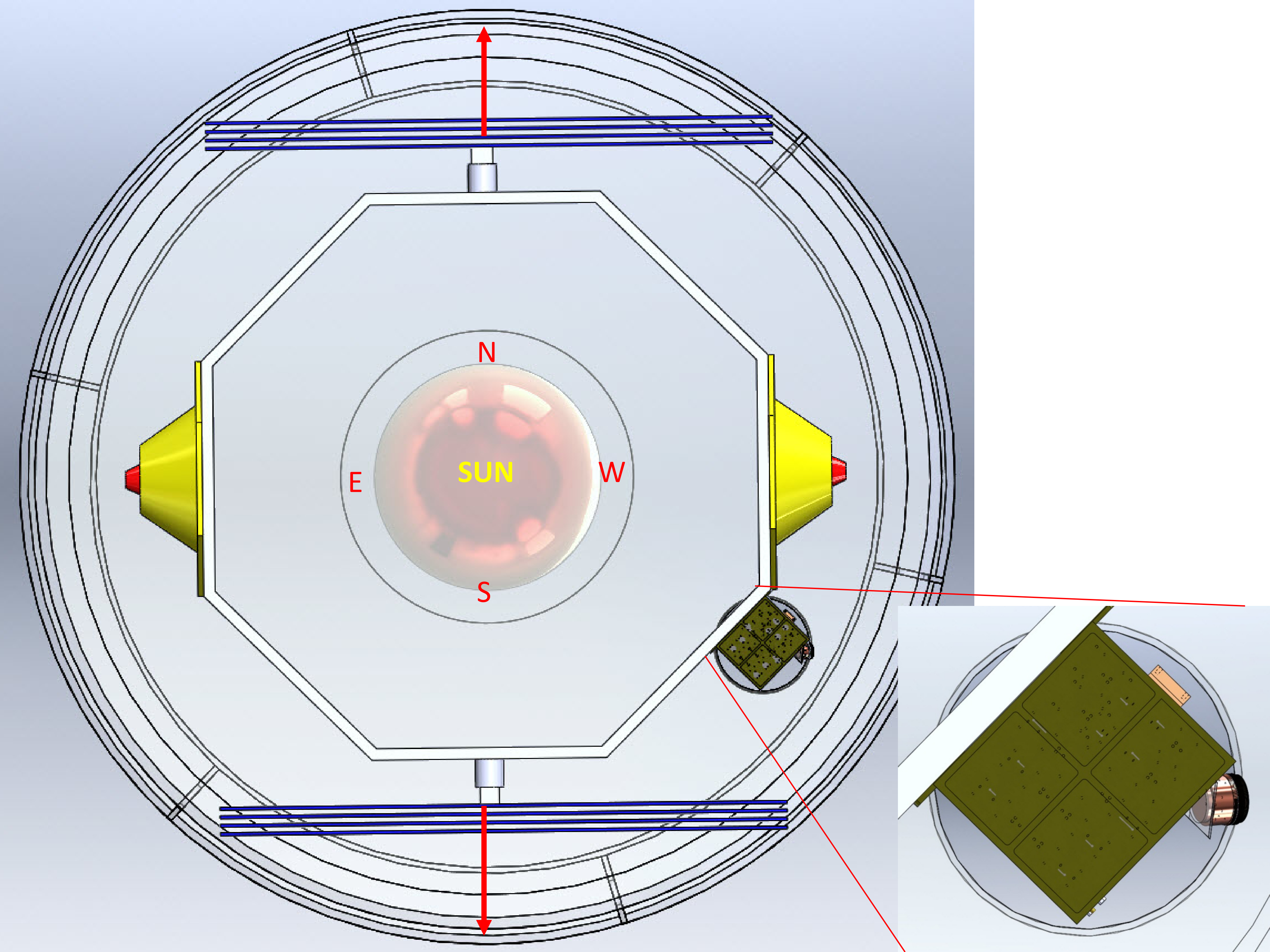
Околоземный баллистический участок полёта КА «Интергелио-Зонд»



Пассивное время полёта (сут)	Активное время полёта (сут)	Гелиоцентрическое удаление (Rs)
35		216-221
	61	221-214
75		214-178
	101	178-197
86		197-253
	97	253-241


ОРБИТА ЗЕМЛИ
ОРБИТА ВЕНЕРЫ
ОРБИТА МЕРКУРИЯ
СОЛНЦЕ
Старт от Земли
Многократные гравманёвры у Венеры
I пролёт Венеры
II пролёт Венеры
III пролёт Венеры
IV пролёт Венеры
Перицентр орбиты после IV пролёта Венеры $R_\pi = 30.0\ R_S$
Перицентр орбиты после III пролёта Венеры $R_\pi = 35.1\ R_S$
Перицентр орбиты после II пролёта Венеры $R_\pi = 49.1\ R_S$
Перицентр орбиты после I пролёта Венеры $R_\pi = 57.6\ R_S$


ChemiX
X-ray window
Sun
SUN
BIPOLAR
(SUNSPOT)
FIELDS
28⁰
Sun
10⁰
28⁰
36⁰
Ось
дцф
Interhelioprobe
trajectory
SPIRA
(INTERPLANETARY)
FIELDS
TRAJECTORY OF
CHARGED PARTICLES
Not to scale
ChemiX
X-ray window



N
E
SUN
W
S

Aim

- Determine coronal abundances of elements and their possible temporal/spatial distributions
- Study multi-T/**non-Maxwellian conditions**
- Detect **non-equilibrium plasmas**
- Measure „absolute” Doppler shifts of lines formed at three selected T's (FeXXV 20 MK, Ca XIX 10 MK, Ar XVII 3-5 MK)
- Measure „physical” profiles of lines (turbulence, assymetries etc)

Why such instrument?

- 10 x larger fluxes at 0.3 a.u. Instead 19 kg spectrometer (like RESIK), 6 kg instrument will do the job having similar sensitivities
- New detectors: CCD e2V 1024 x 256 pixels (2.6 cm x 7 mm) (RESIK 9cm x 3 cm) i.e. 2 x higher spectral resolution (RESIK ~2.5 mA) for spectral atlas, 4 x higher for Dopplerometer
- Instant measurements at all wavelengths 1-9 A
- Much improved signal/noise (as compared with RESIK) less size of detector (20 times)
- Chemix will be a shorter- wavelength XRP

Instrument concept

- First locate interesting source (Pin-hole camera)- constant imaging ~200 x 200 pixel solar disk, 30 arcsec resolution 0.5-10 keV, 200 eV energy resolution, 1s DGI
- Move the spectrometers' mount to target (single AR or flare within the FOV ~50000 km on the disk)
- Measure spectra in Spectral Atlas mode 1.5-9 Å Measure Doppler shifts and profiles
- Avoide measurements within CME or SEP (dedicated particle detector e & p spectra)

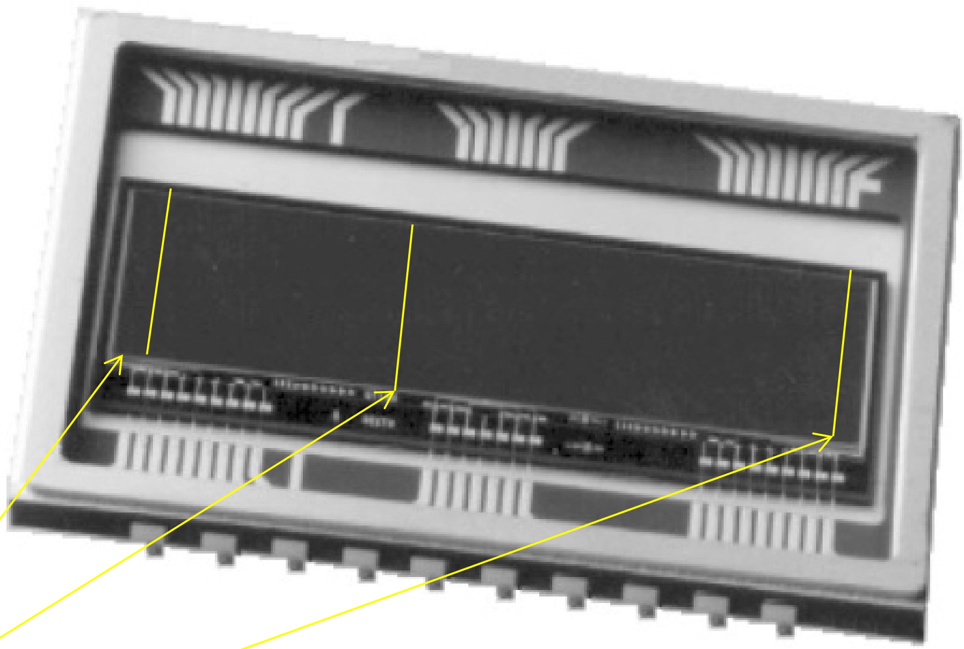
Lessons learnt

- Scanning (flat crystal) takes time
- All spectrometers flown had substantial fluorescence XRP, P78, HINOTORI, Yohkoh BCS, even RESIK in channels 3 & 4 (4.3-6 A)
- Except RESIK (channels 1 & 2) no reliable continuum was measured
- Solution adopted: Crystals must not give fluorescence at ranges where spectra are to be measured.

Detector

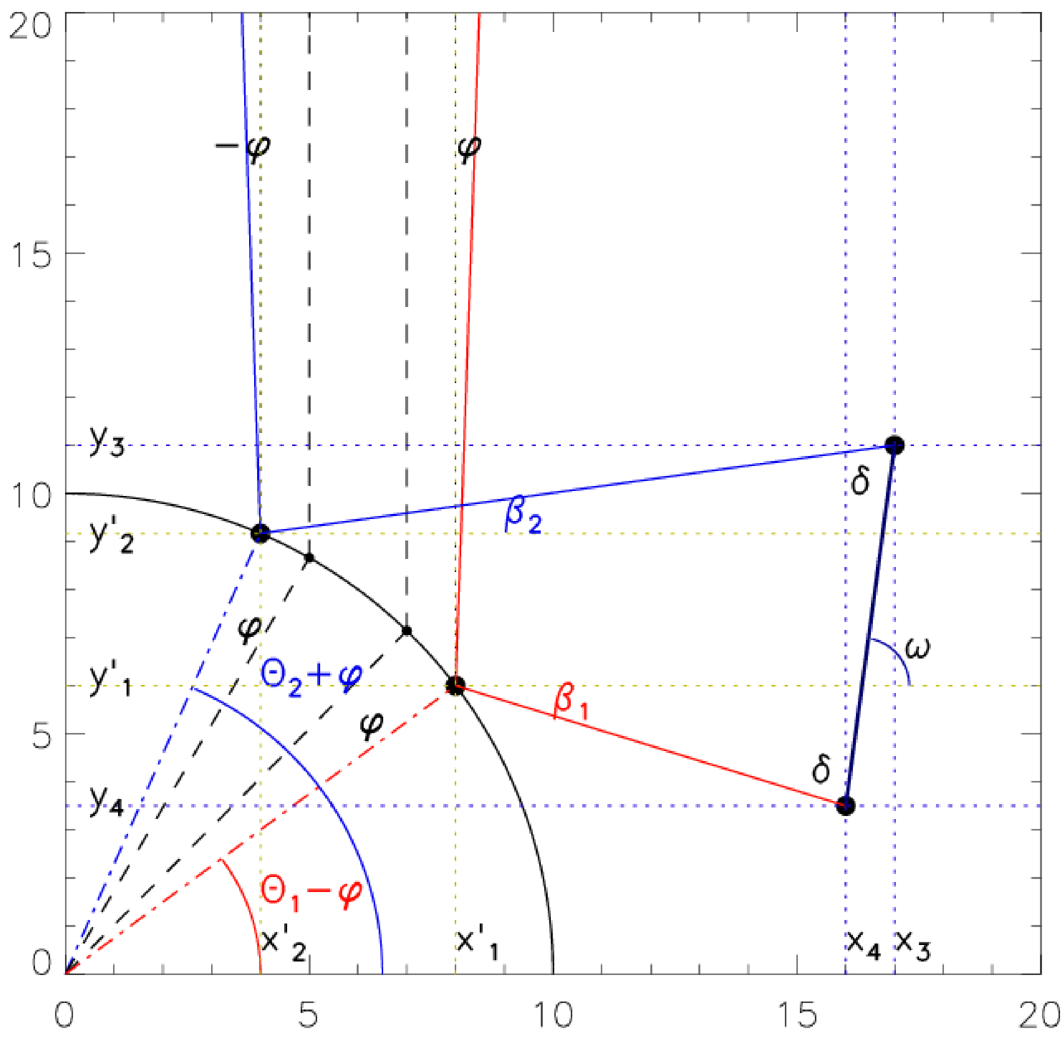
CCD30-11 Back Illuminated Deep Depletion Full Frame Scientific CCD Sensor

- E2V
- 1024 x 256 pixes
- Image area 26.6 x 6.7 mm
- Pixel size 26 x26 µm
- At low count rates selection of diffraction order possible through charge deposition/event controll
- Spectral lines seen as stripes across



Choosing the crystals

compromise on size, weight power



WE SPECIFY:

- ❖Detector dimensionS
- ❖Crystal TYPE (2d)
- ❖ Wavelenght range (avoid FLU)
- ❖ Minimal distance between detector and the crystal

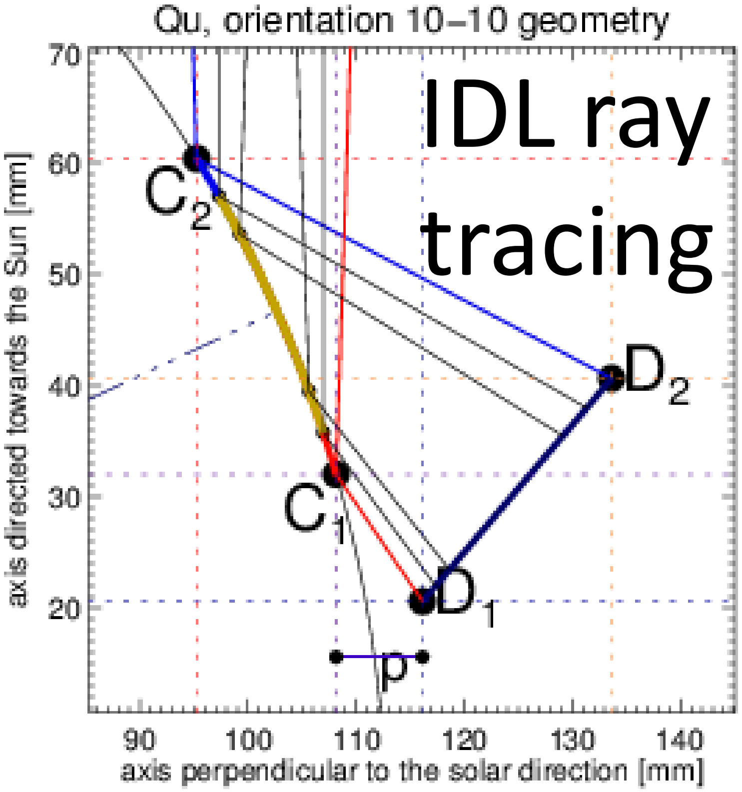
We look for:

- ❖ Radius of curvature of the crystal (avoid breaking)
- ❖ The mutual position of the crystal and the detector

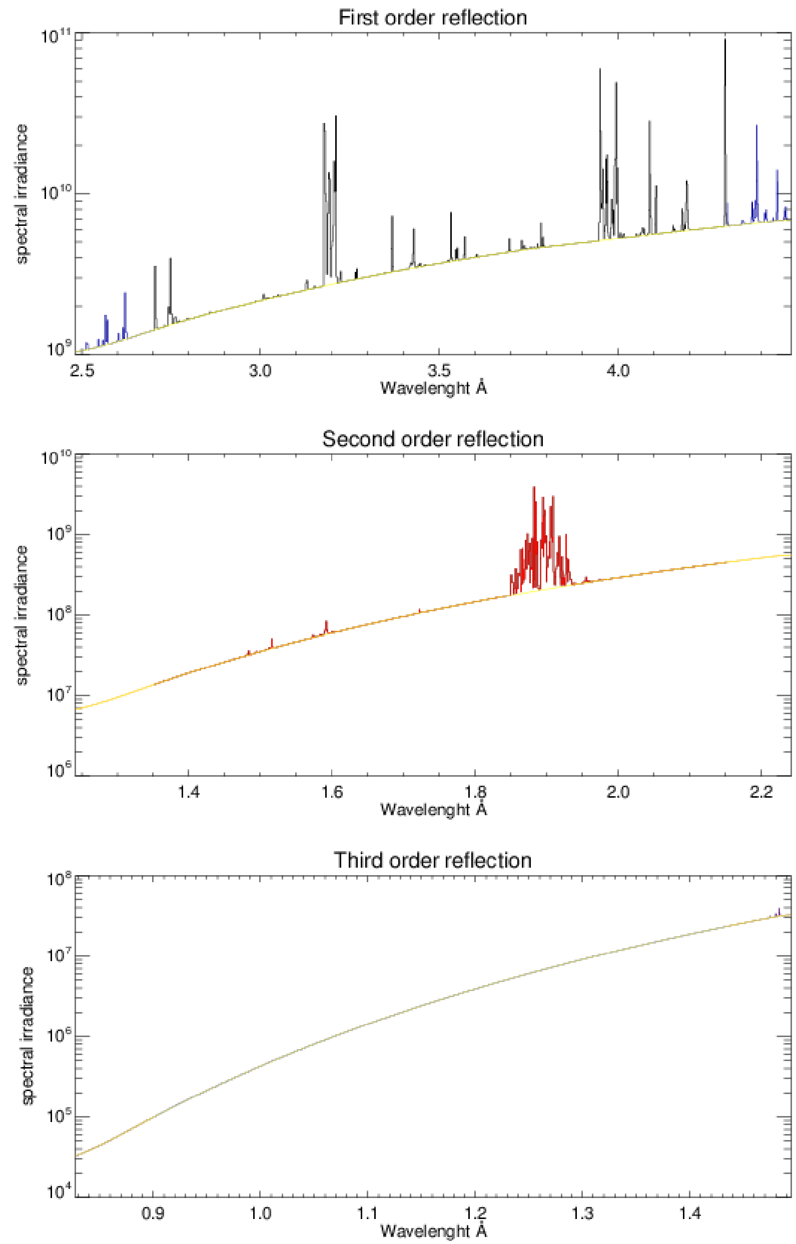
We generate (CHIANTI)

- ❖ Observed spectrum in allowed orders
- ❖ allow source offser +-2 deg (solar disc size)

Quartz 10$\bar{1}$0



Waverange: 2.700 - 4.304 Å
2d: 8.514 Å
Radius of curvature:
112.789 mm
Detector slope: 48.88°

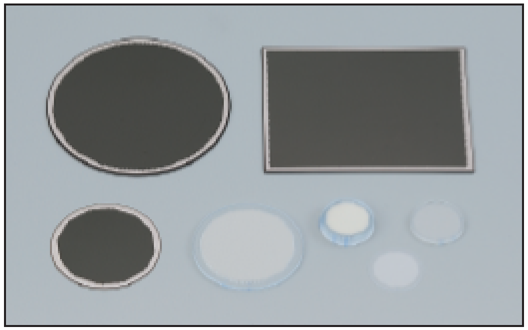


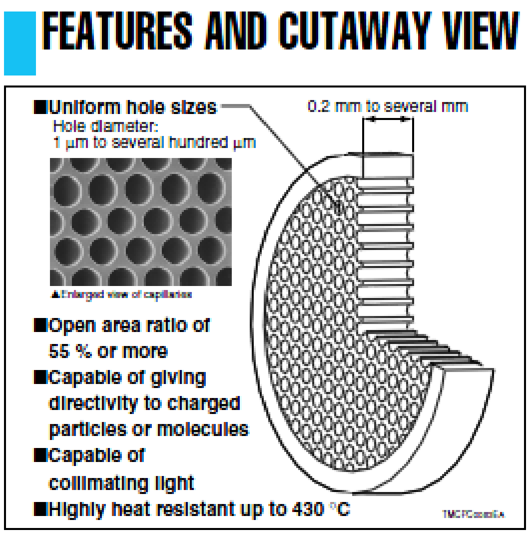
Rules adopted

- No self-crystal fluorescence (under solar X-ray illumination)- possibility to reliably measure the continuum
- Spectral ranges slightly overlapping, with stronger lines near edges (provide good cross-calibration) of effective areas.
- Reasonable widths of spectral channels-spectral resolution 2x better than RESIK
- Full spectral coverage 1.5 - 9 Å (four crystals)
- Doppler shifts in Fe XXVI, Fe XV, Ca XX, Ca XIX
- Line profiles as above

No	crystal	orientation	2d	wavelenght range [Å]	average spectral resolution [mÅ/pix]	curvature radius [mm]	total desired crystal lenght [mm]
Spectrometer							
1	Si	111	6.271	1.500 - 2.713	1.46	113.844	41.3
2	Quartz	10-10	8.514	2.700 - 4.304	1.95	112.789	41.2
3	ADP	101	10.648	4.290 - 5.228	1.46	247.454	51.6
	KDP	011	10.185	4.290 - 5.228	1.43	229.484	49.9
4	KAP	001	26.64	5.200 - 8.800	4.73	204.909	52.95
Dopplerometer							
1	LiF	022	2.848	1.770 - 1.943	0.30	220.000	43.0
2	Si	111	6.271	3.000 - 3.378	0.70	290.000	50.5
3	Si	111	6.271	3.700 - 4.201	0.78	190.000	42.8

Equipped with collimator





- Possibly capillars (unfortunately these we tested have substantial grazing reflections)
- Or multigrid 2D net. Seven grid system allows for 5 arcmin FWHM FOV and 2.5 arcdeg suppresion of sidelobes

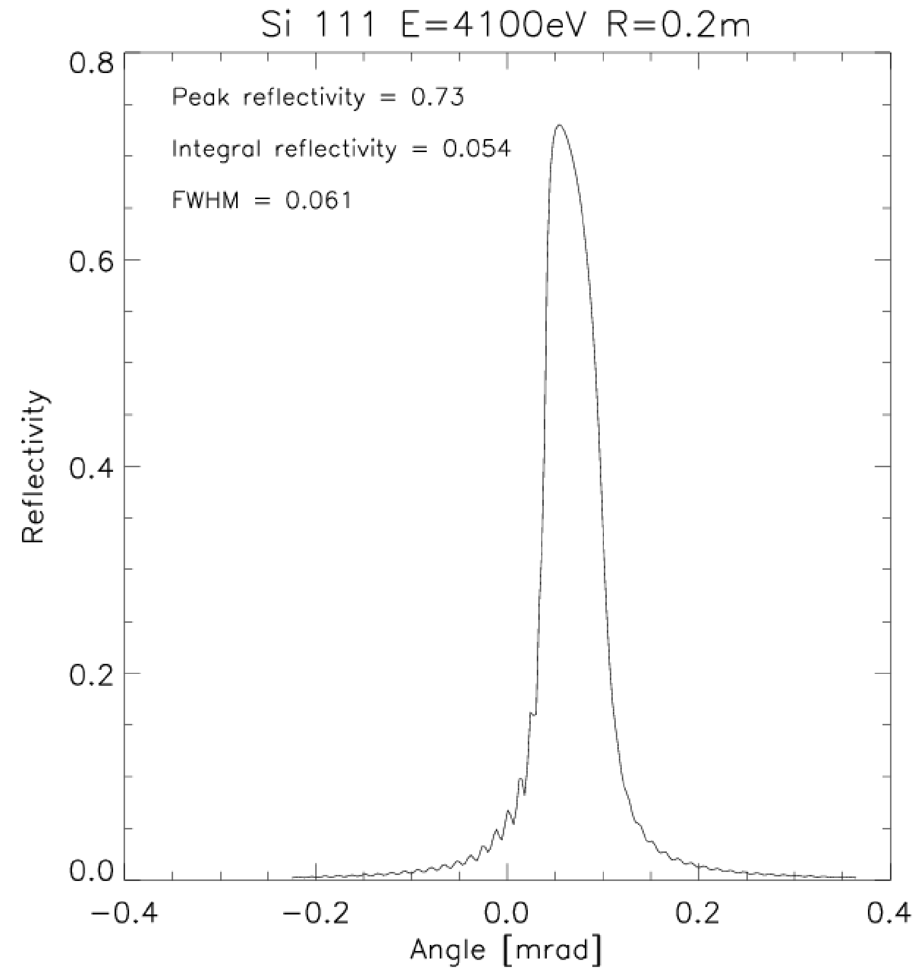
Crystal reflectivities

- XOP: X-ray Oriented Programs

Roger J. Dejus and Manuel Sanchez del Rio, "XOP: A graphical user interface for spectral calculations and x-ray optics utilities", Rev. Sci. Instrum. 67(9) 1996

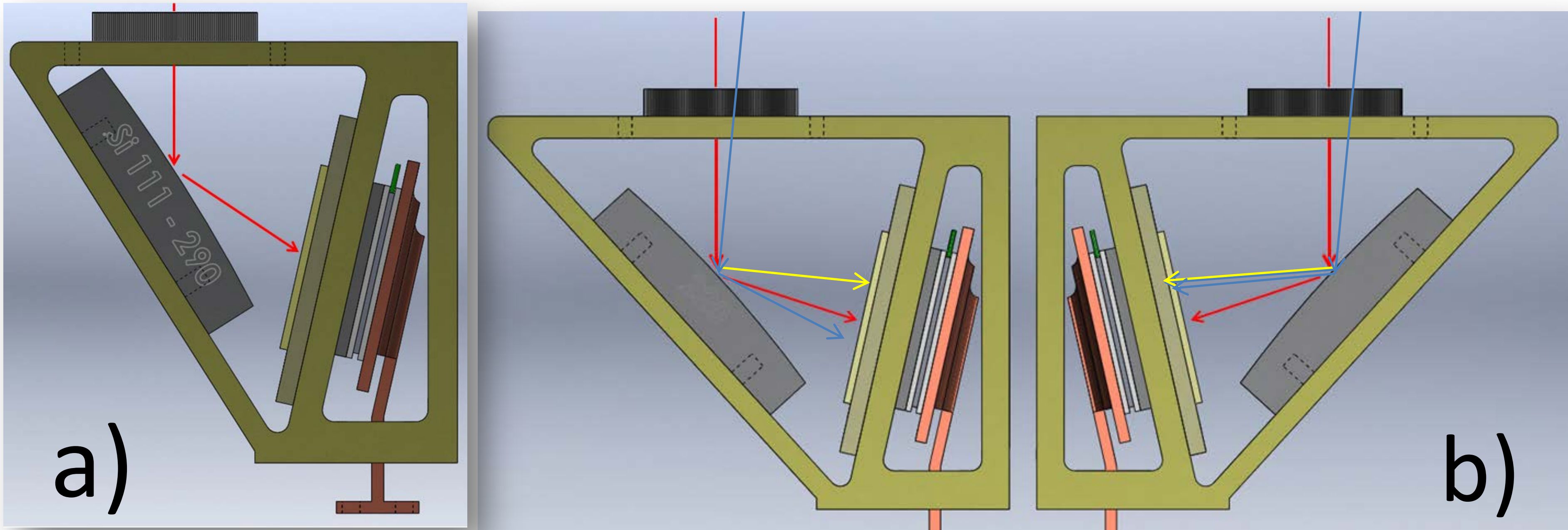
- XCRYSTAL_BENT applicaton:

M. Sánchez del Río, C. Ferrero and V. Mocella " Computer simulations of bent perfect crystal diffraction profiles " SPIE proceedings vol. 3152, 1997.



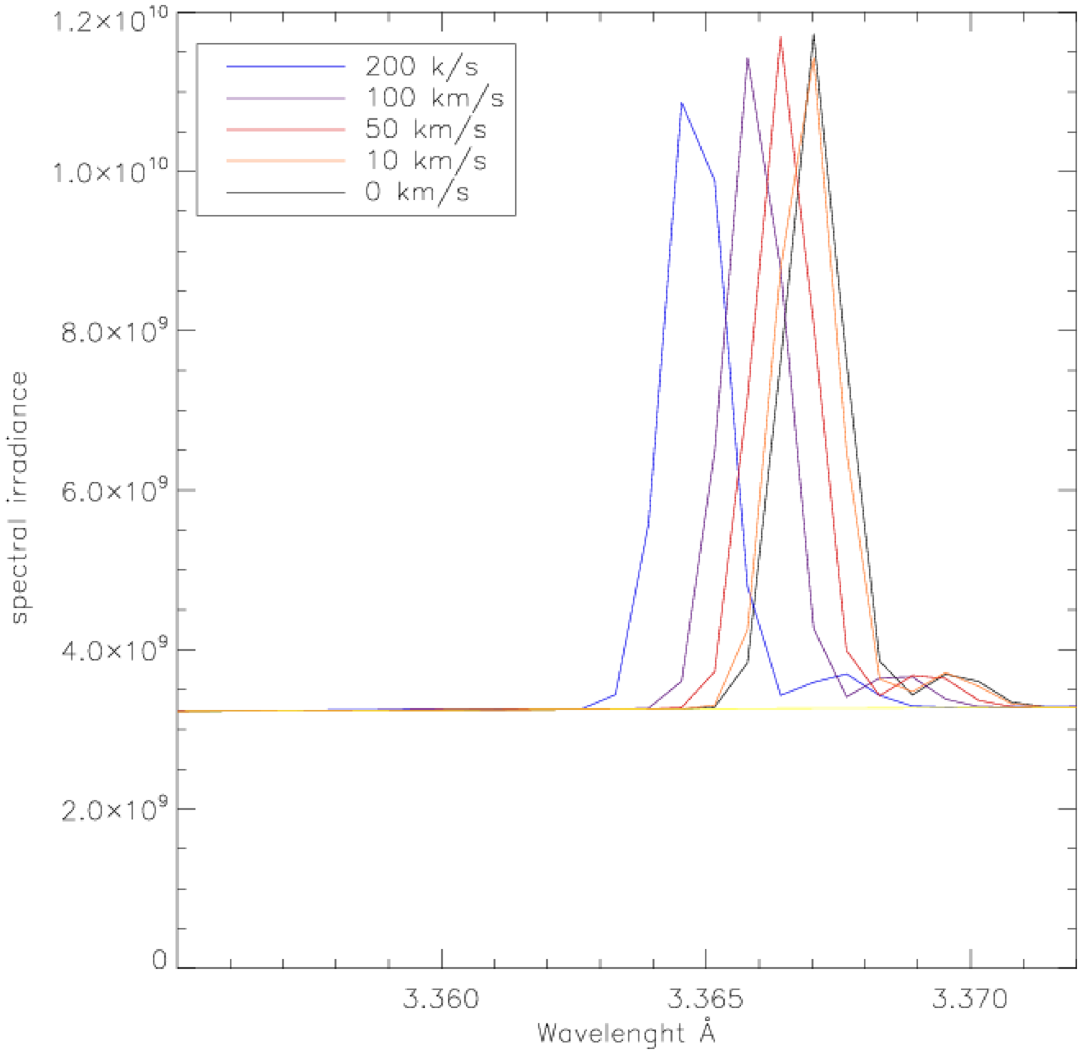
Spectral Atlas
x 4

X-ray dopplerometer
x 3 (independent of FOV position)

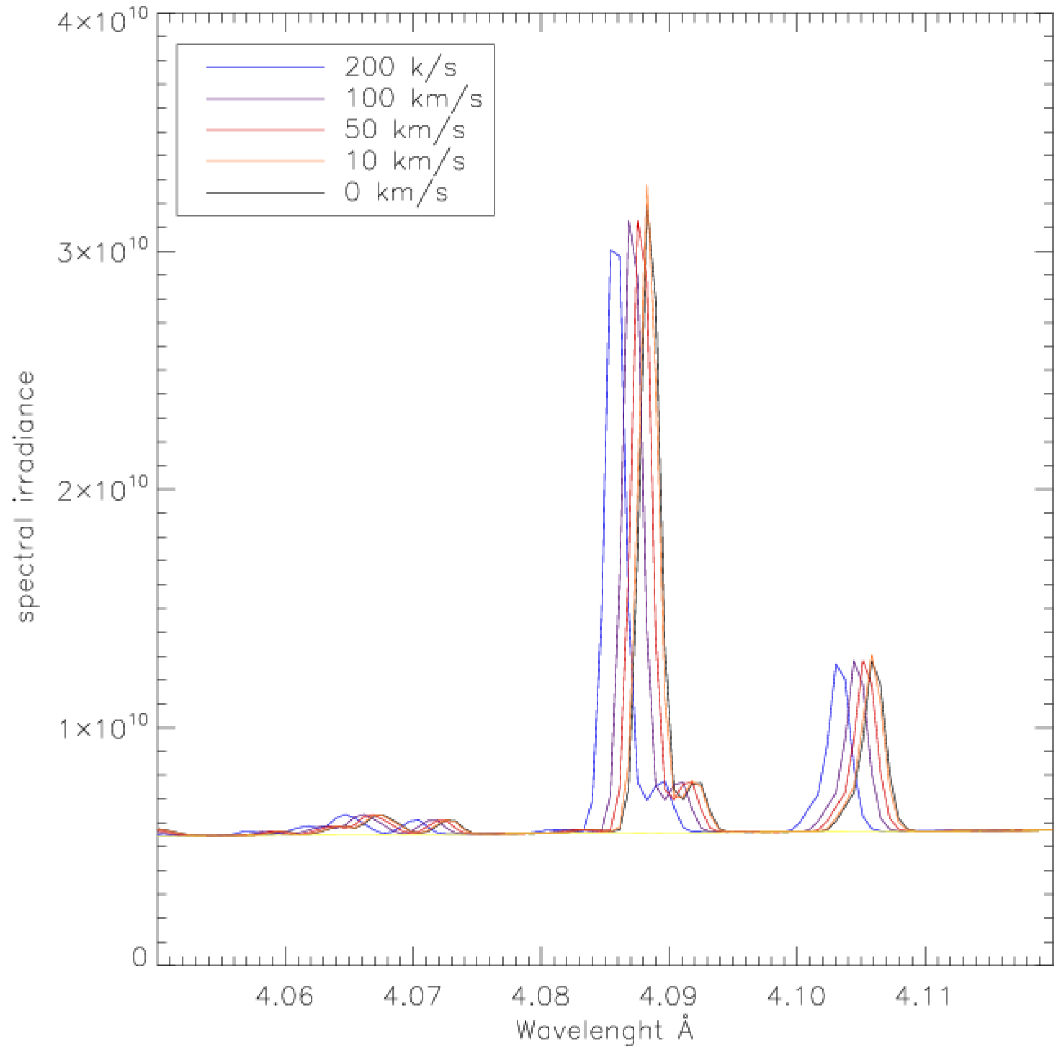


Close view of crystal-detector segments of spectrometer (a) & dopplerometer (b). Red arrows shows the path of X-rays which are collimated, diffracted on crystals and recorded on CCD detectors.

Doppler shift of Ar XVII 1s2-1s3p line

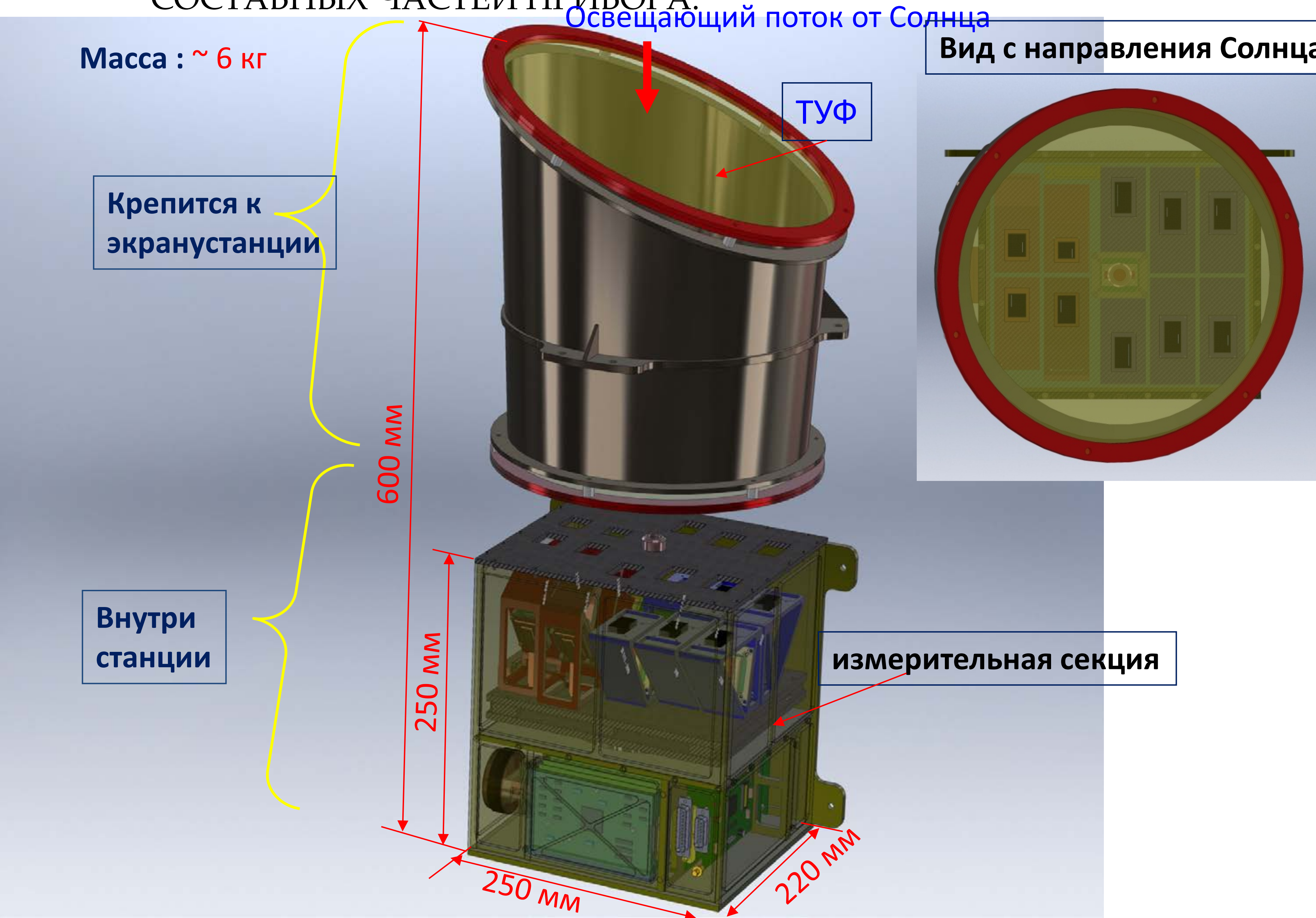


Orbital projected motion will calibrate

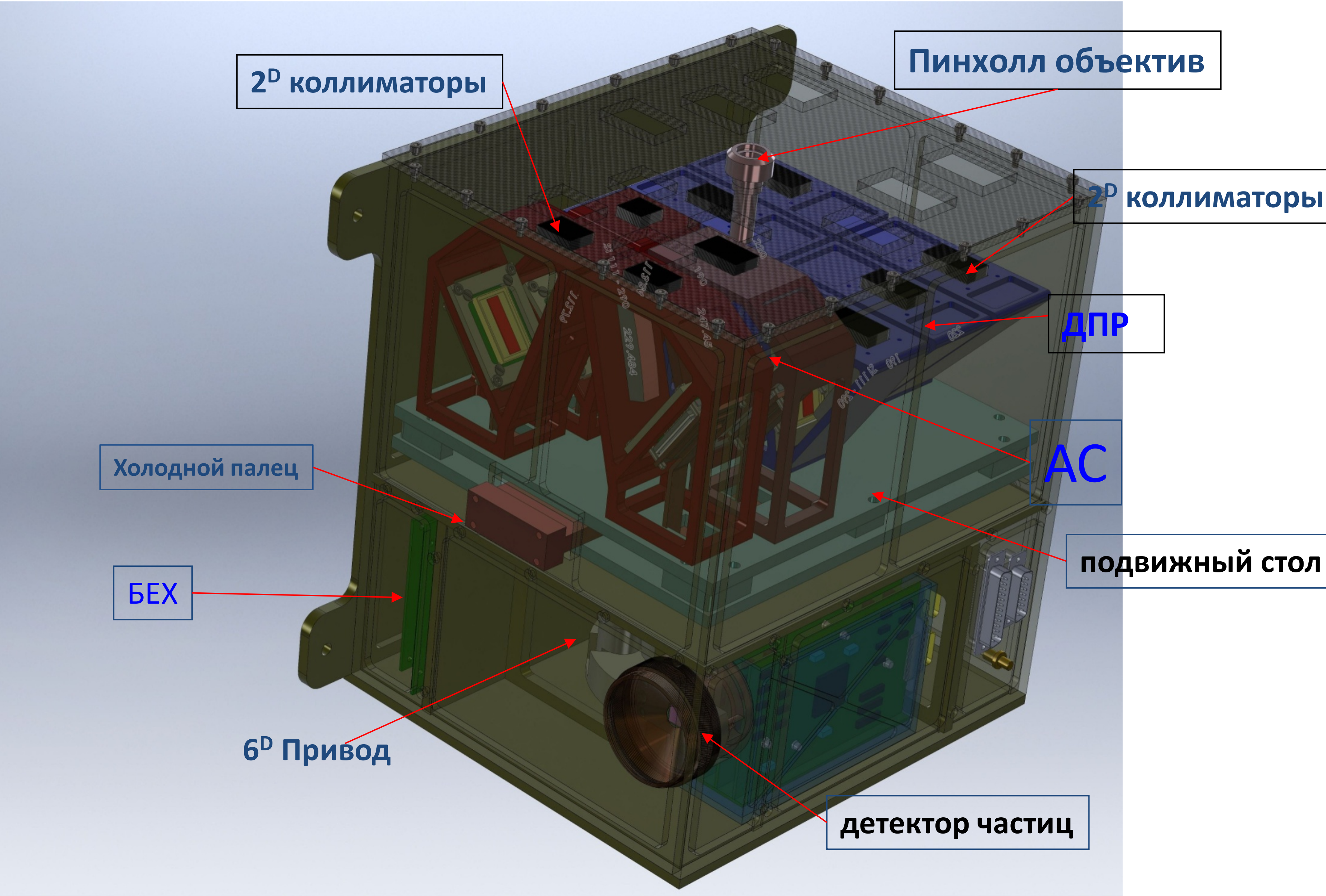


Doppler shifts of S XV and S XIV lines

ПРЕДВАРИТЕЛЬНЫЙ ВНЕШНИЙ ВИД ПРИБОРА/ГУЧ ОПИСАНИЕ СОСТАВНЫХ ЧАСТЕЙ ПРИБОРА.

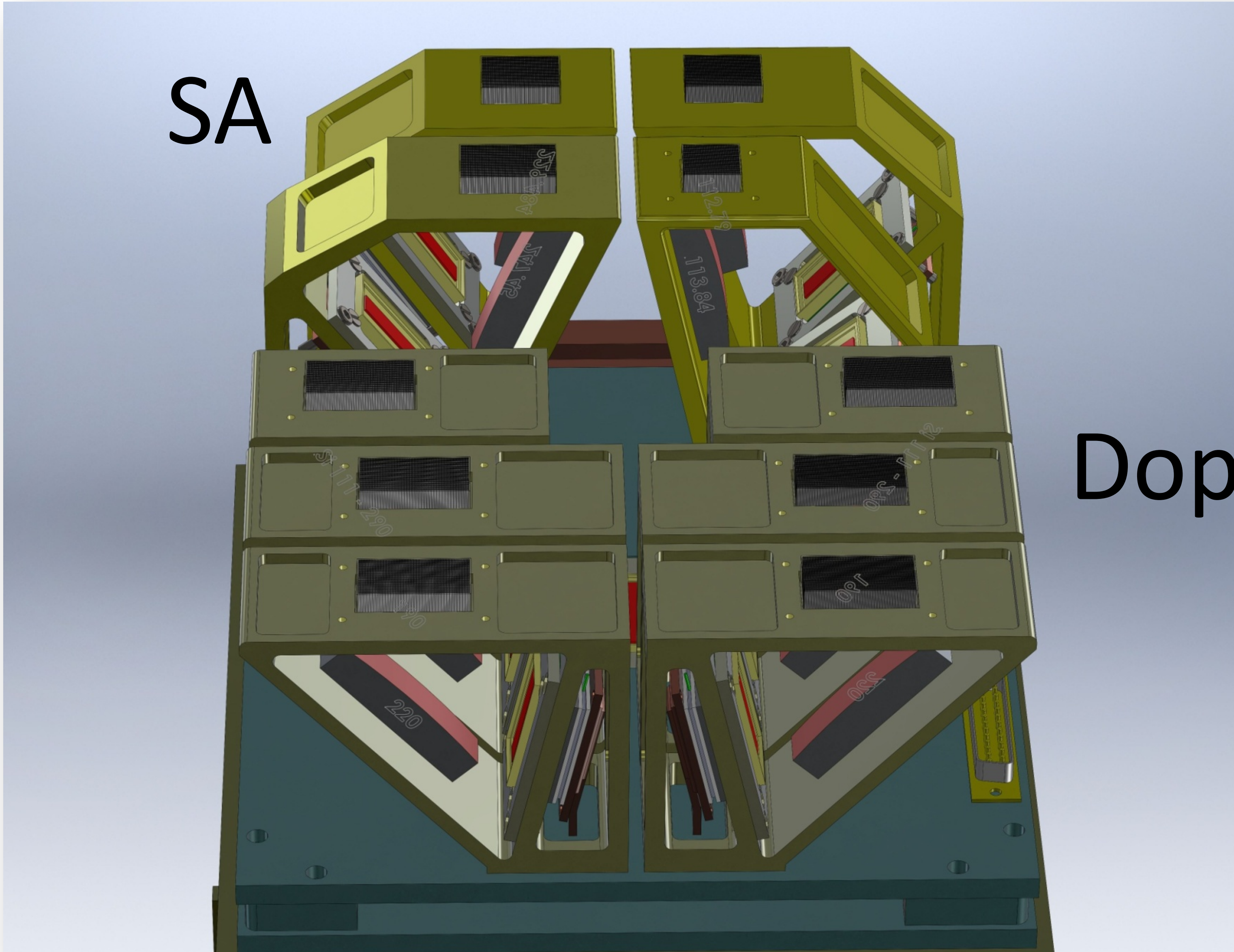


ПРЕДВАРИТЕЛЬНЫЙ ВНЕШНИЙ ВИД ПРИБОРА/ГУЧ ОПИСАНИЕ СОСТАВНЫХ ЧАСТЕЙ ПРИБОРА.



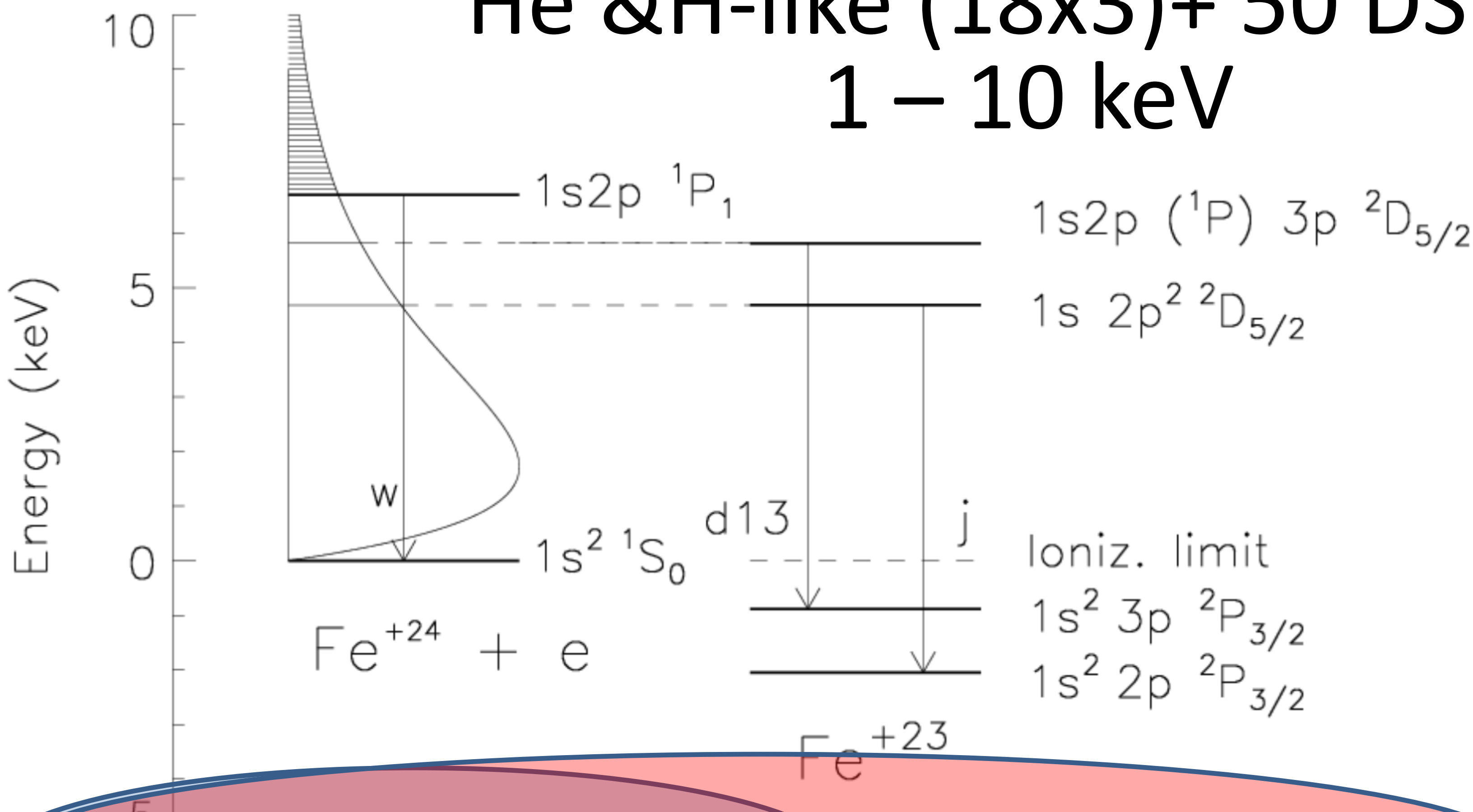
ТЕХНИЧЕСКИЕ ХАРАКТЕРИСТИКИ ПРИБОРА

Параметр	Значение
Масса [кг]	6
Габариты [мм]	250 x 220 x 600
Среднее энергопотребление [В]	15
Максимальное энергопотребление [В]	21,5
Минимальная квота телеметрии [Мбайт/24ч]	20
Максимальная квота телеметрии [Мбайт/24ч]	700
Температура на местах крепления [ºC]	-20 ÷ +30
поле зрения [градусы дуги]	± 5
телесное разрешение колиматора [минуты дуги]	5 x 5


SA
Doppl.

Distribution function Diagnostics

He &H-like (18x3)+ 50 DS.
1 – 10 keV



Mg, Al, Si, S, Ar, K, Ca, Fe Ni?

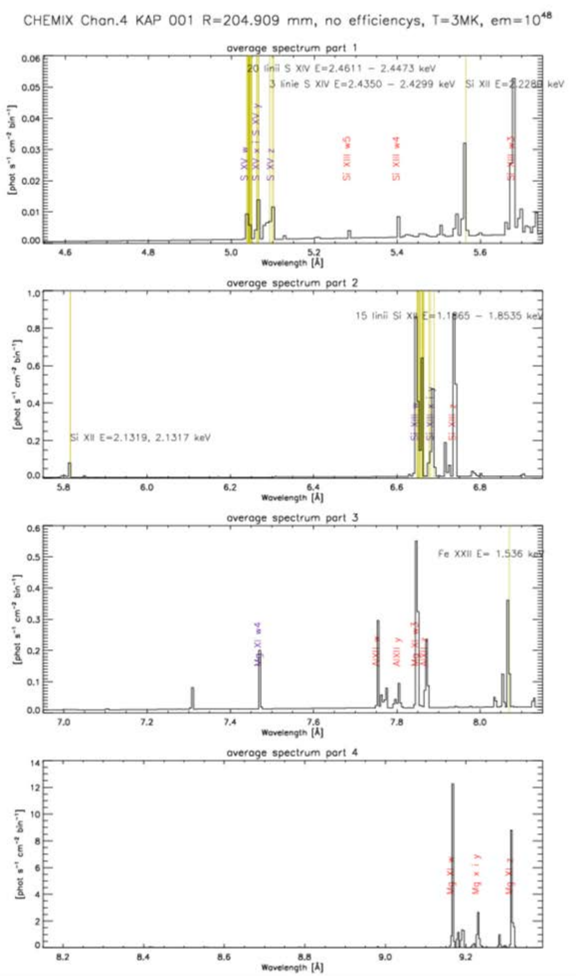
But

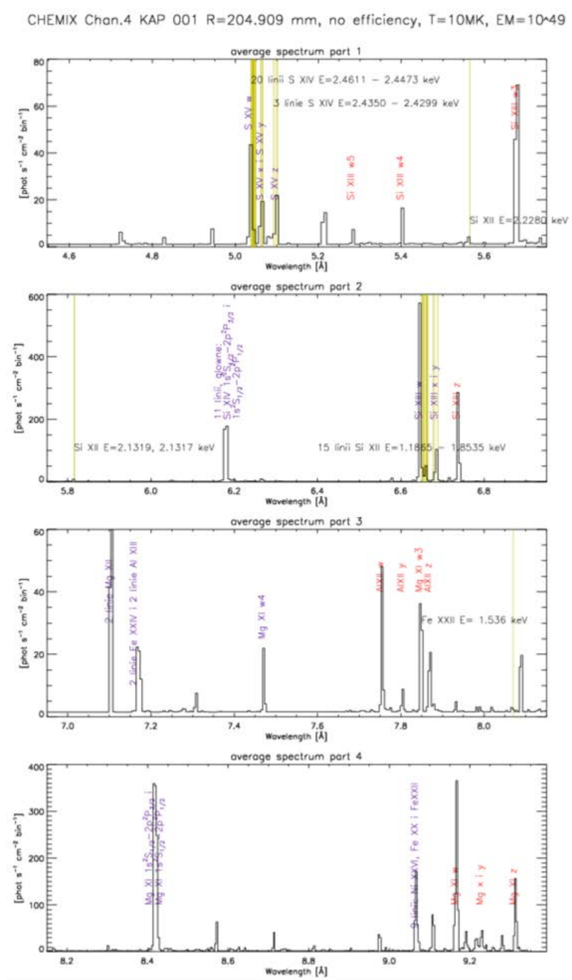
- Elemental abundances must be known (Line and continuum intensities)
- Muli-T must be first checked? Or can it be rejected a priori from DS. intensity analysis (must be checked by modelling – needs testing) say generete for kappa and try fitting multi-T
- Off- limb pointing possible & long exposures

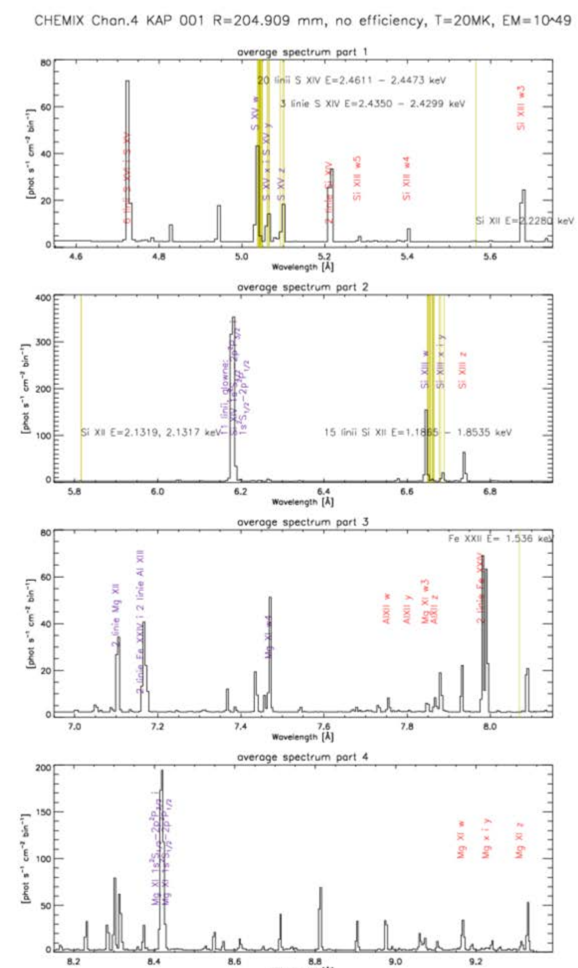
any other ideas?

- Please help in making simulations, we soon can prepare the spectral efficiencies and dispersions necessary to run modelling
- What if dense hot target is moving against exciter populations with bulk relative velocity- how the DS will react?

3 MK 10 MK 20 MK

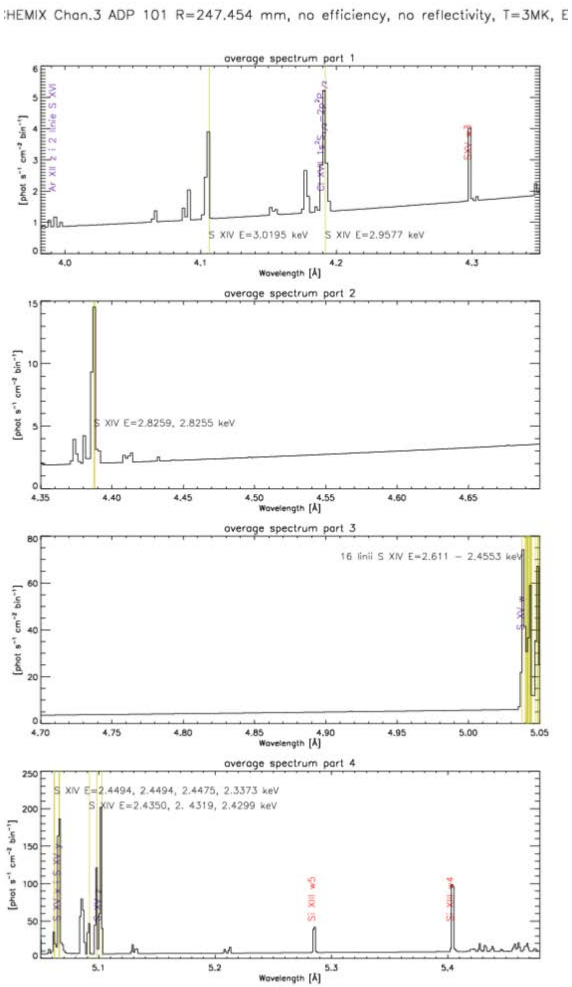


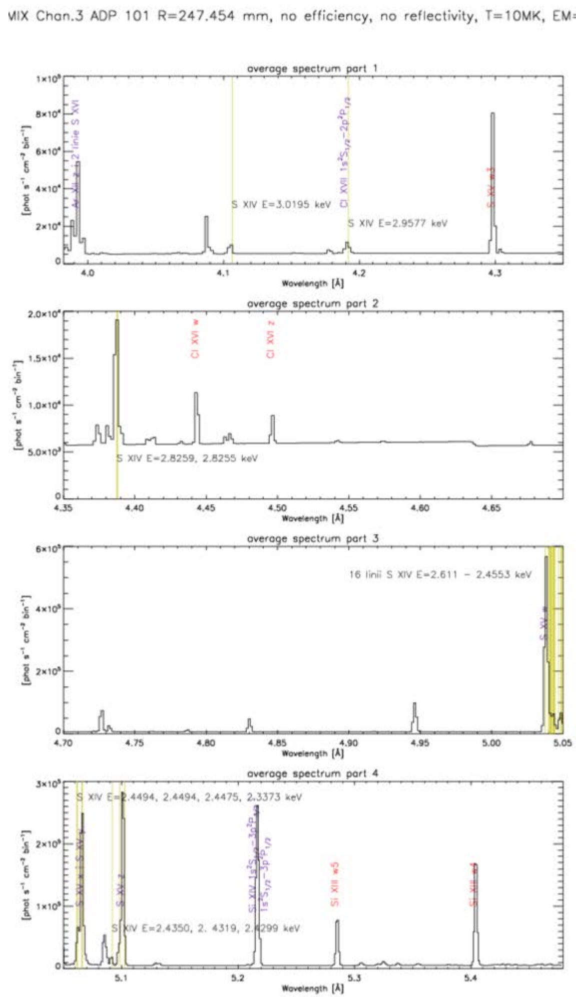


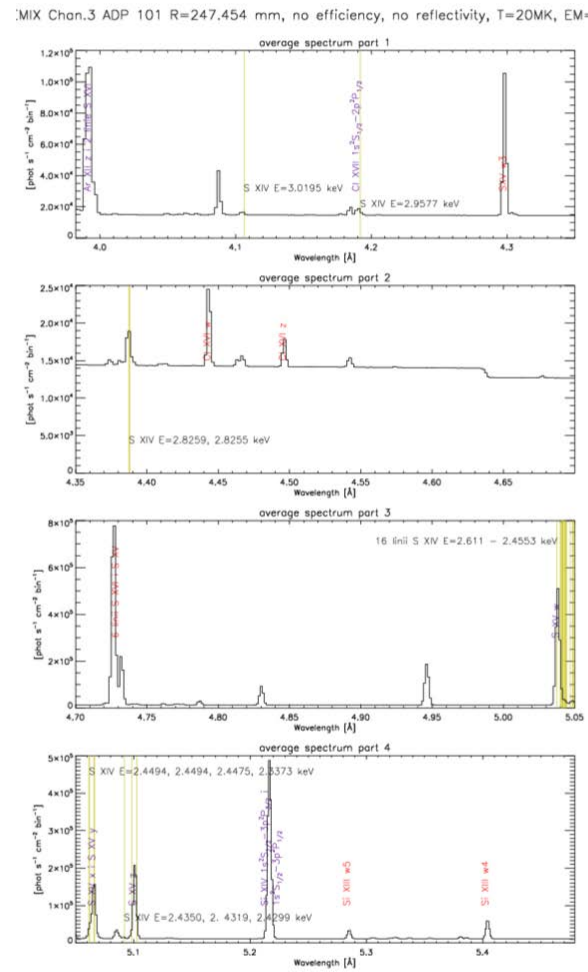


SA channel 4 4.5 Å - 9.4 Å

3 MK   10 MK   20 MK

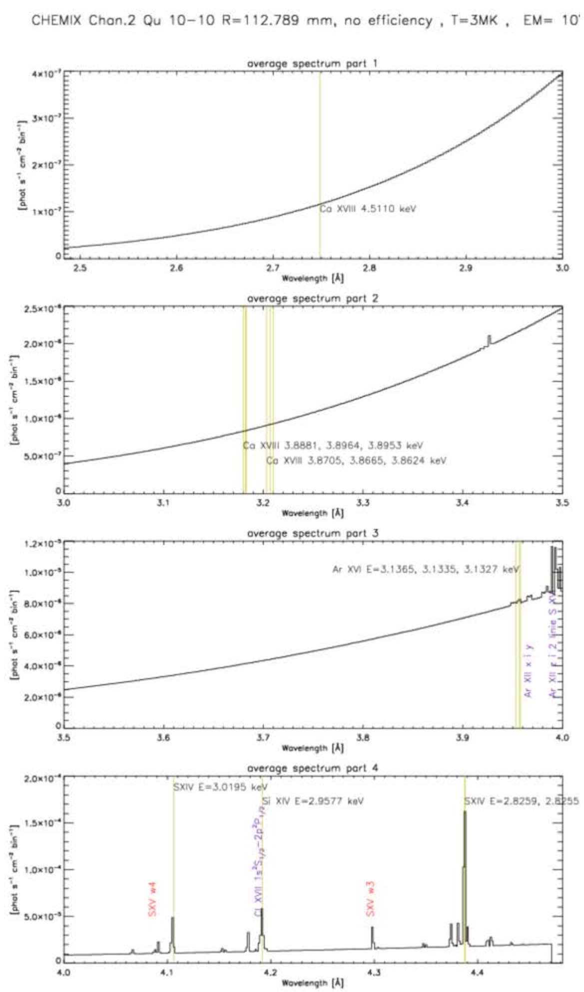


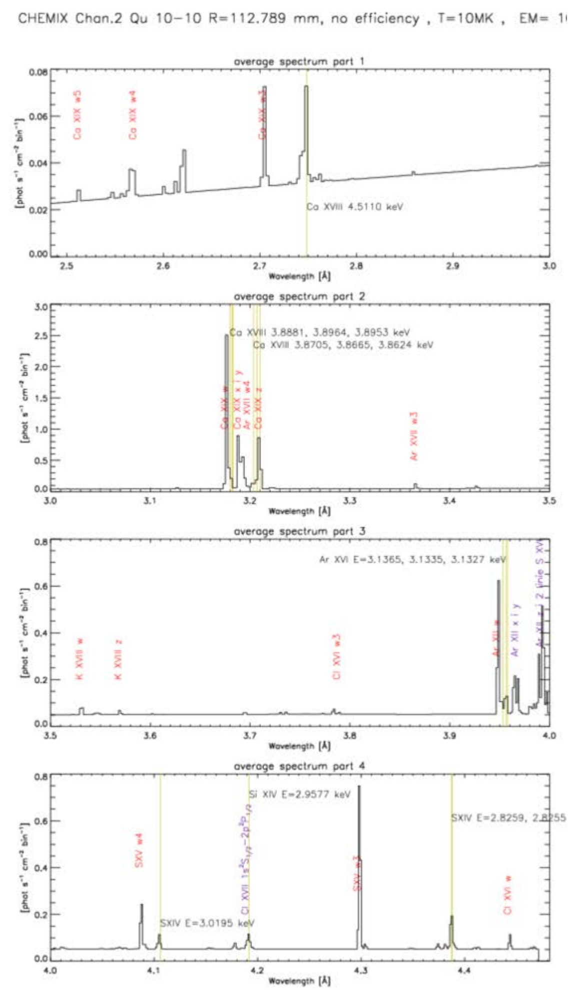


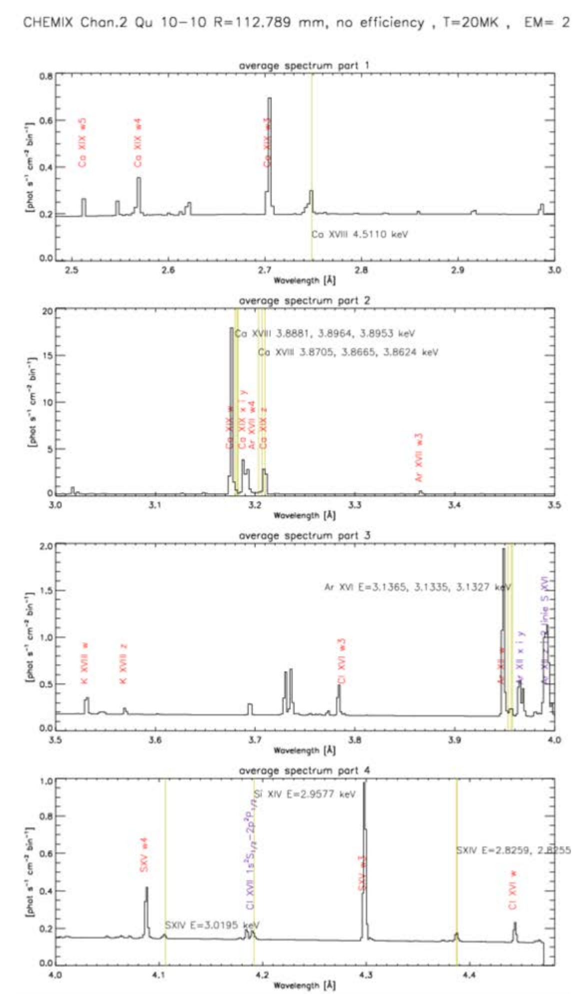


SA channel 3   3.95 Å - 5.5 Å

3 MK　　10 MK　　20 MK

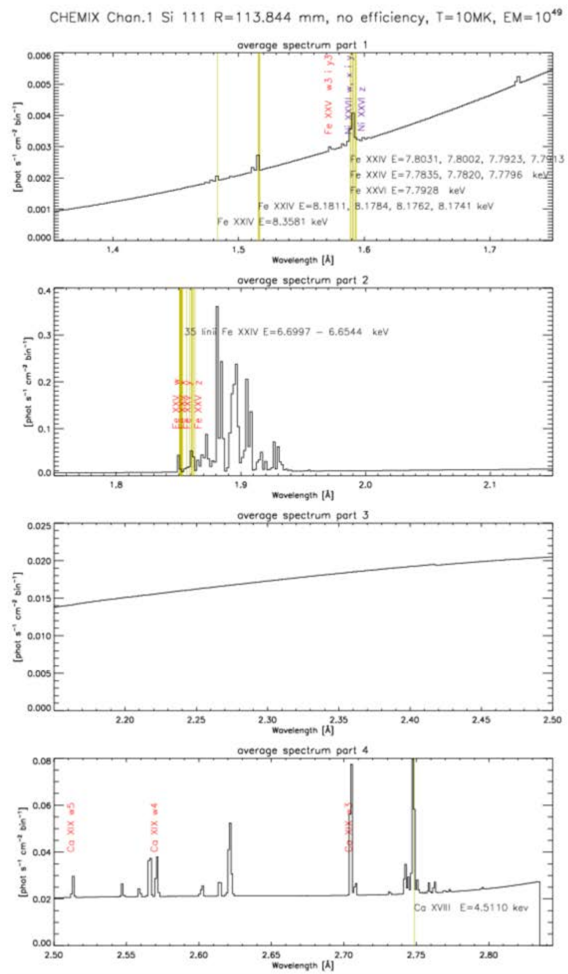


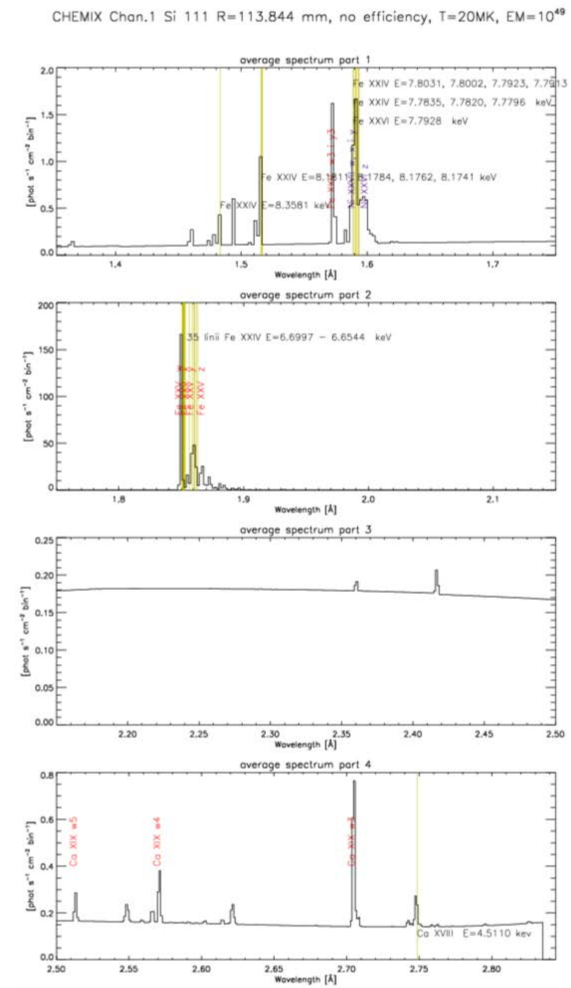




SA channel 2　　2.5 Å - 4.5 Å

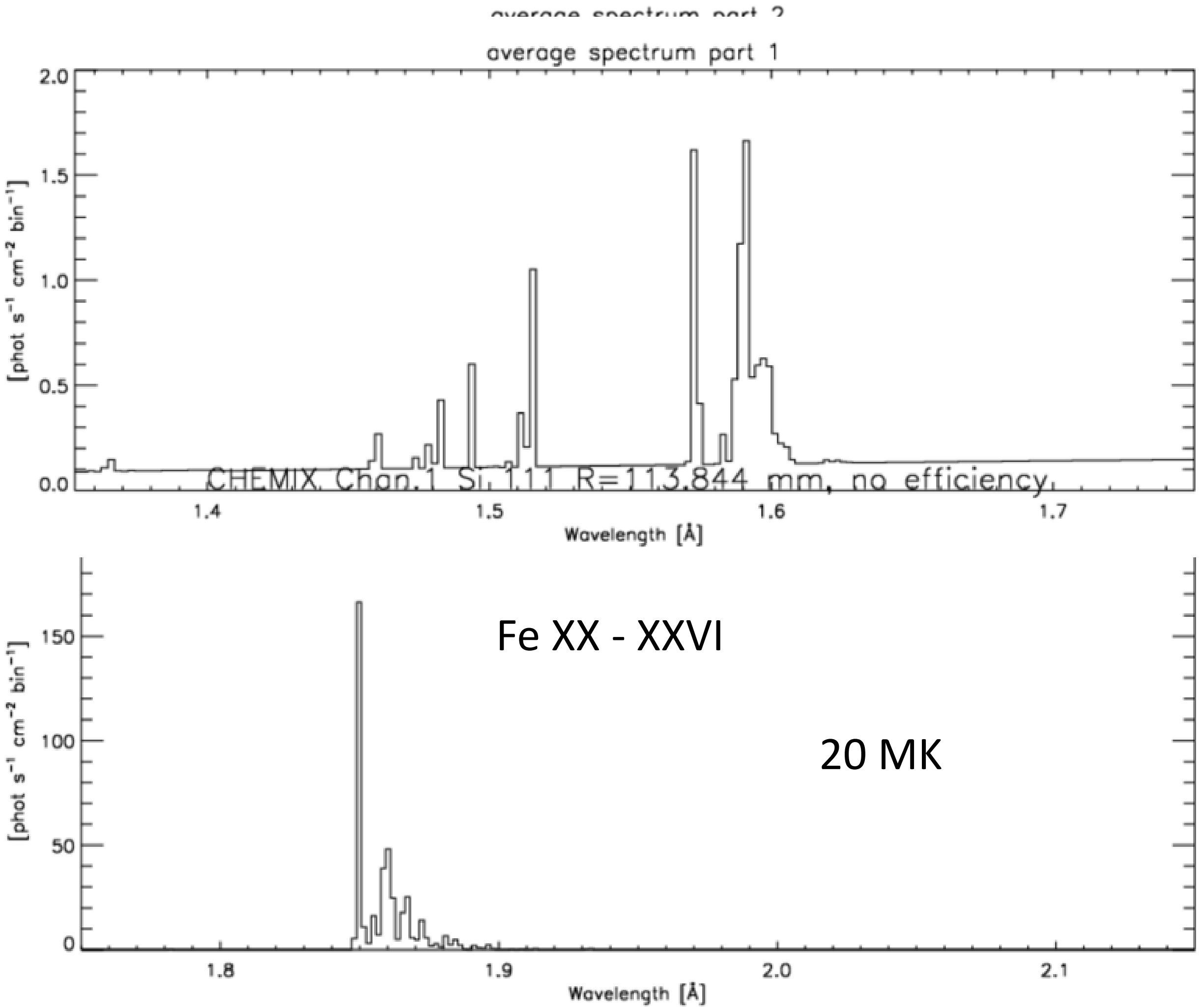
3 MK   10 MK   20 MK

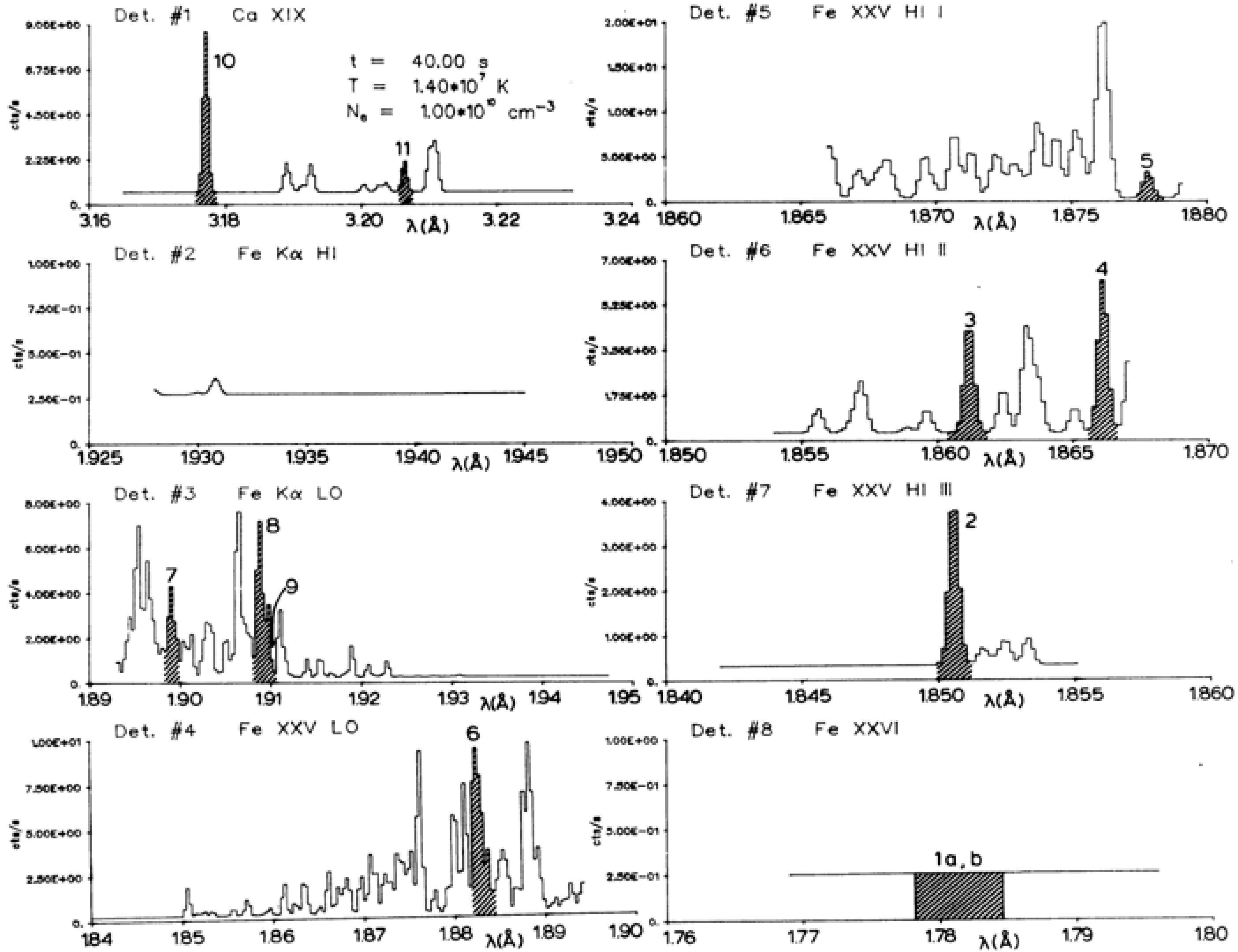




SA channel 1   1.3 Å - 2.8 Å

Diagnostics of transient conditions





J. SYLWESTER (*), R. MEWE and J. SCHRIJVER

J. Syl., Polish Academy of Sciences, Space Research Center, Wrocław, Poland
R. M., J. S., The Astronomical Institute, Space Research Laboratory, Beneluxlaan 21, 3527 HS Utrecht, The Netherlands

Simulated results

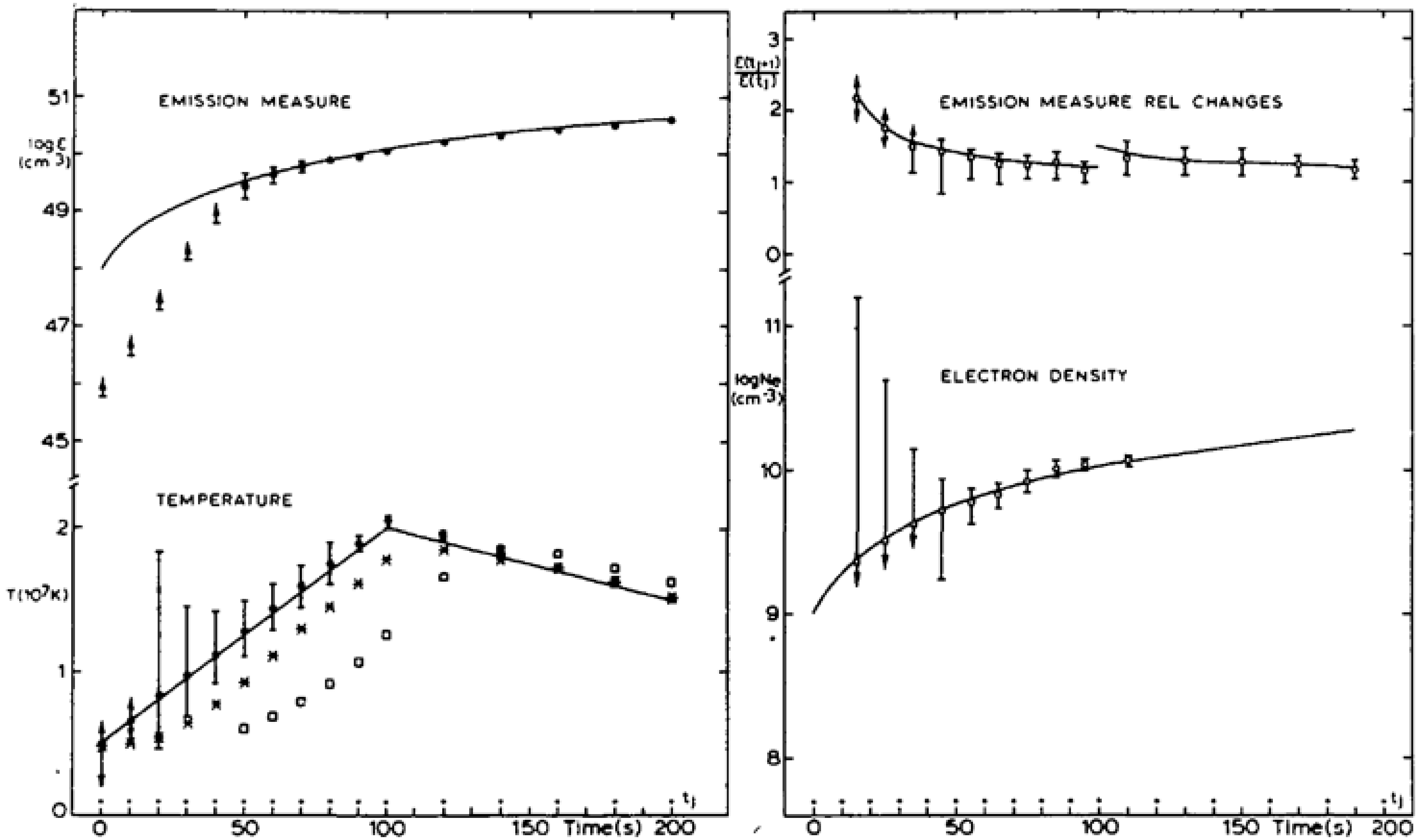


FIGURE 9. — Results of the analysis for a *typical* big flare. The assumed changes of all input parameters are given by full lines, whereas dots represent the calculated values. For other symbols see figures 7 and 8.