SPACE RESEARCH CENTRE, POLISH ACADEMY OF SCIENCES

SOLAR PHYSICS DIVISION

WROCŁAW

REPORT FOR 2014

Janusz Sylwester

February 2014

Based on individual Team members contribution

Our Team consisted of 23 people:

9 scientists, 5 PhD, 7 engineers and 2 support

Data reduction and interpretation

RESIK

RESIK was a unique Bragg crystal spectrometer operating on the Russian CORONAS-F satellite launched 31 July 2001. The instrument operated for two years (2002-2003) during a period close to the maximum of Solar Cycle 23. The instrument recorded many high quality spectra in the spectral range 3.3-6.1 Å, which has never before been studied before systematically. In the spectra, several prominent X-ray emission lines are seen formed in active regions and flares in particular.

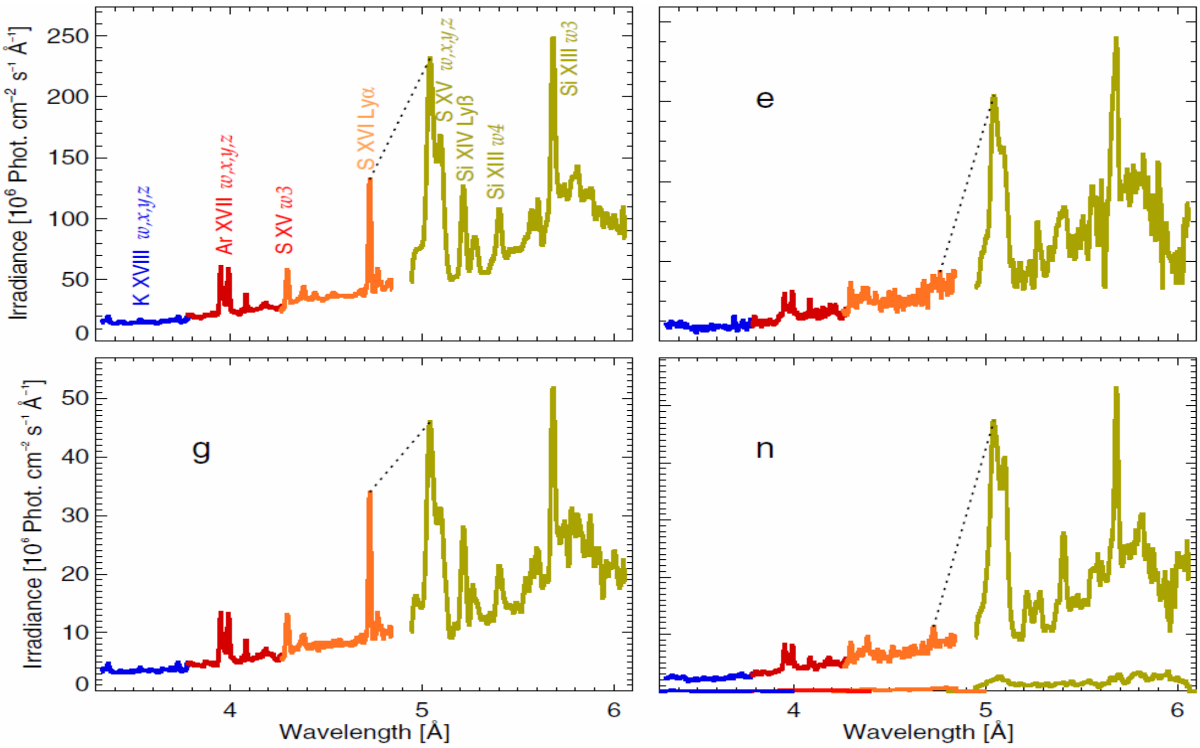


Fig. 1. Example of RESIK spectra for flare SOL2002-11-14T22:26 . On the flare- averaged spectrum (top left panel), identifications of stronger spectral lines are given. Panels e, g and n correspond to the rise, maximum and decay phases of the event. The pre-flare spectrum is shown at the bottom of panel n.

The analysis of emission lines and the continuum allows the study of the physical conditions in the multi-million kelvin plasmas and determination of plasma chemical composition in particular. In 2014, further analysis of flaring plasma spectra have been performed in close collaboration with Prof. Ken Phillips (Natural History Museum, London).

The dependence of abundance determinations on iso- or multi-temperature plasma source models has been investigated. The results obtained indicate that a simplified isothermal approach provides overestimated values for abundances of elements whose ions are formed at relatively low-temperature. Thus, for RESIK X-ray spectra, it is clear from these studies that an isothermal approach is not valid for abundance determinations of silicon and sulfur, and instead, a multi-temperature approach is necessary. A dedicated multi-temperature abundance optimization method *AbuOpt* has been further developed and described in the paper published in ApJ (10.1088/0004-637X/787/1/1). This has been applied for a single flare in 2002 (SOL2002-11-14T22:26), with the result that abundance estimates of Si and S are decreased compared with those from isothermal analyses but Ar and K (ions formed at higher temperatures) are approximately the same. With mean optimized abundances (A_{Si}, A_S, A_{Ar} and A_K) for this flare, the time evolution of the differential emission measure was determined. Fig. 2 illustrates this.

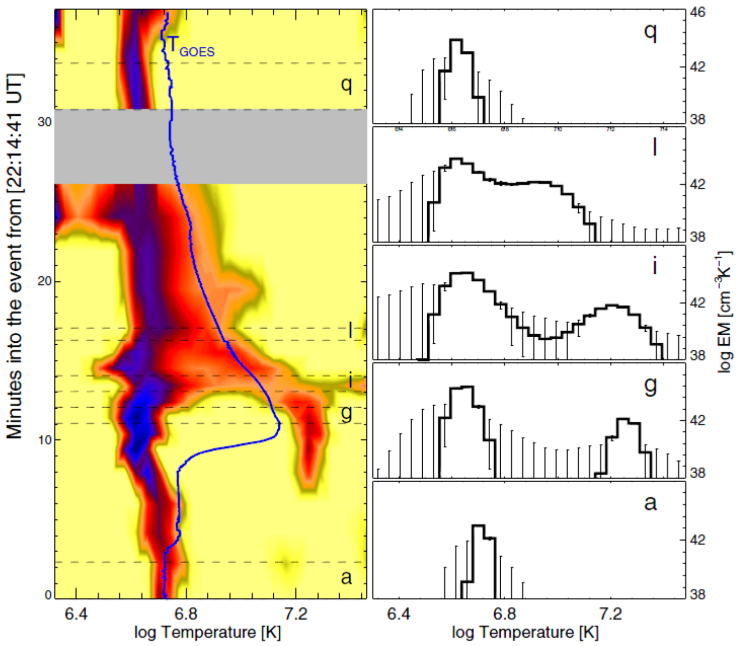


Fig. 2. Left: contour plot of the differential emission measure during the SOL2002-11-14T22:26 flare, darker colors indicating greater emission measure. The horizontal scale is the logarithm of temperature in K, with time increasing upwards, measured from 22:14:41 UT. The horizontal dotted lines define the time intervals a, g, i, l, and q (right panel) and the

smooth curve running from top to bottom is the temperature derived from the ratio of the two GOES channels on an isothermal assumption. Right: emission measure distributions for the intervals indicated in the left plot, derived from the Withbroe–Sylwester routine. Vertical error bars indicate uncertainties. A cooler (temperature ~4–5 MK) component is present over all the time intervals shown, with the hotter component (~18 MK) at the peak of the GOES light curve.

Subsequently, our AbuOpt approach has been used in the analysis of 33 flares observed by RESIK in the period December 2002 – March 2003, after the instrument settings had been optimized. Very precise determinations of abundances (A_{Si}, A_S, A_{Ar} and A_K) were made throughout each event to search for any time dependence but no such variability was detected outside the measurement uncertainties (Fig. 3 shows one of the 33 flares).

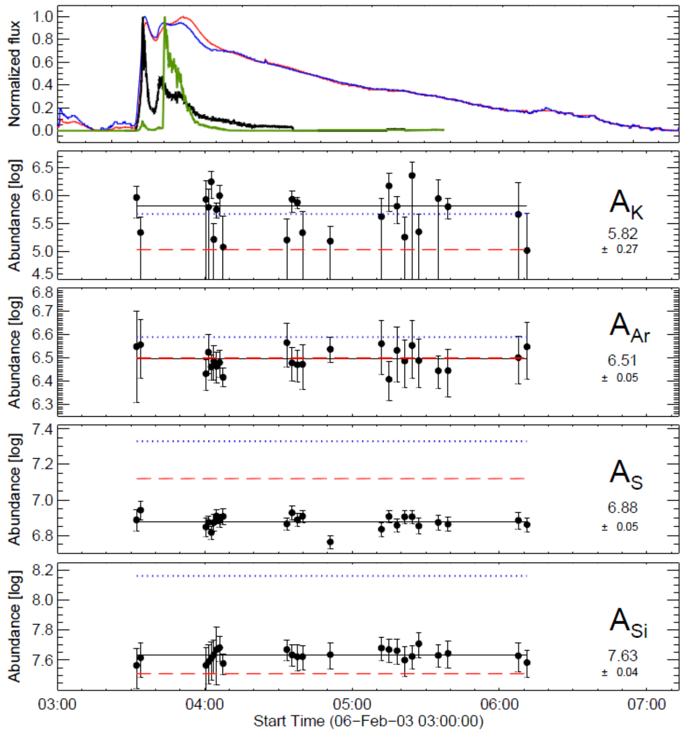


Fig. 3. Time variations of absolute abundance estimates of K, Ar, S, and Si. The abundances were determined using the abundance–optimization (AbuOpt) approach described in the text. The error bars on abundance determination are based on the results in Figure 4 and correspond to the range of values for min(χ^2) + 1.0. The thin black horizontal lines represent time-averaged values of elemental abundances together with their rms error bands (dotted horizontal lines). X-ray light curves from GOES (blue and red) and the RHESSI hard X-ray spacecraft are shown in the top panel. In the lower 4 panels, the horizontal blue dotted lines correspond to "coronal" abundances (Feldman 1992), the dashed red lines to "photospheric" abundances (Asplund et al. 2009).

Also, very little if any difference is present from flare to flare. The paper describing these results has been submitted to ApJ and is at present under review.

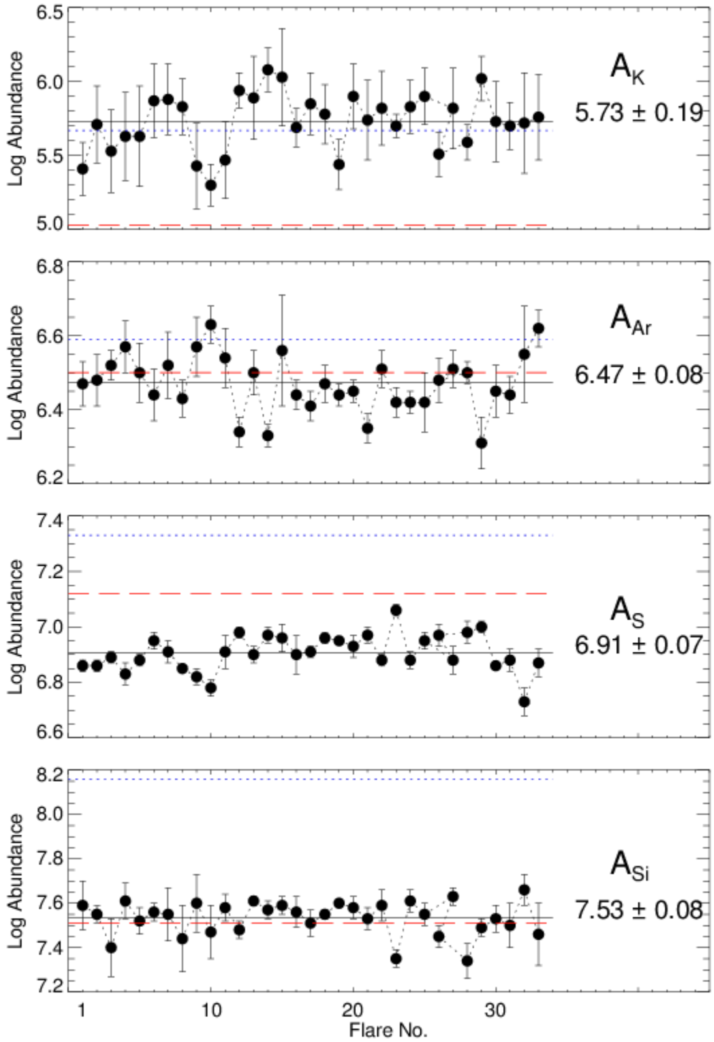
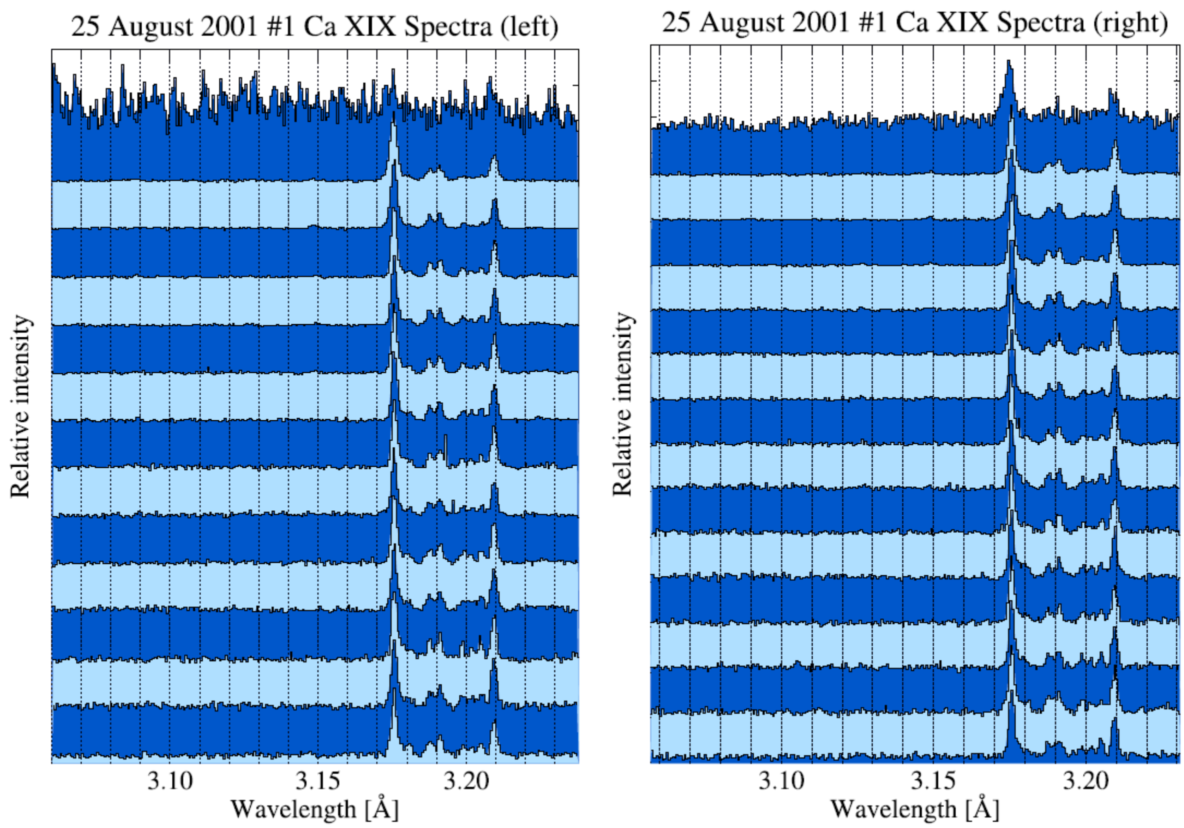


Fig. 4. Mean abundance estimates for each of the 33 flares of K, Ar, S, and Si. The red dashed horizontal lines indicate photospheric abundance estimates from Asplund et al. (2009) (Si, S, K) or solar proxies from Lodders (2008) (Ar). The blue dotted lines are coronal abundance estimates from Feldman et al. (1992), those specified in the CHIANTI database "coronal" abundance set.

DIOGENESS

DIOGENESS was a spectrometer on the CORONAS-F spacecraft consisting of the four flat scanning crystals. The instrument operated a couple of months after the launch in 2001. Two of the crystals were mounted in a so-called dopplerometer configuration. Around 600 spectra were recorded for flares of

M and X classes. Spectra from the four bands have been reduced and show several lines not seen before. Some forty emission lines at least feature in the spectra and nearly all have been identified.



Left: Forward (increasing wavelength) scans for DIOGENESS channel 4 (Ca XIX lines) during the 25 August 2001 flare stacked with increasing times from top to bottom (time range 16:29 – 18:00 UT). Right: Corresponding backward (decreasing wavelength) scans.

Details of the Diogeness construction, operation data reduction and initial analysis are given in the paper published in Solar Physics (DOI 10.1007/s11207-014-0644-1).

SphinX

The SphinX soft X-ray spectrophotometer on board the Russian *CORONAS-Photon* satellite operated successfully between February and December 2009. The instrument collected ~2 million spectra from a period of record low solar activity, the lowest for approximately 100 years. SphinX was developed entirely in Wroclaw Solar Physics Division of SRC PAS under the financial support from the Ministry of Science grants 4 T12E 045 29 and N N203 381736. Over the past year, a detailed analysis of X-ray light curves observed in the energy range above ~1 keV has been performed with the aim of counting weak flares and X-ray brightenings. A new analysis approach allowed us to decompose the light curves into individual flare components (Figure 4 illustrates this).

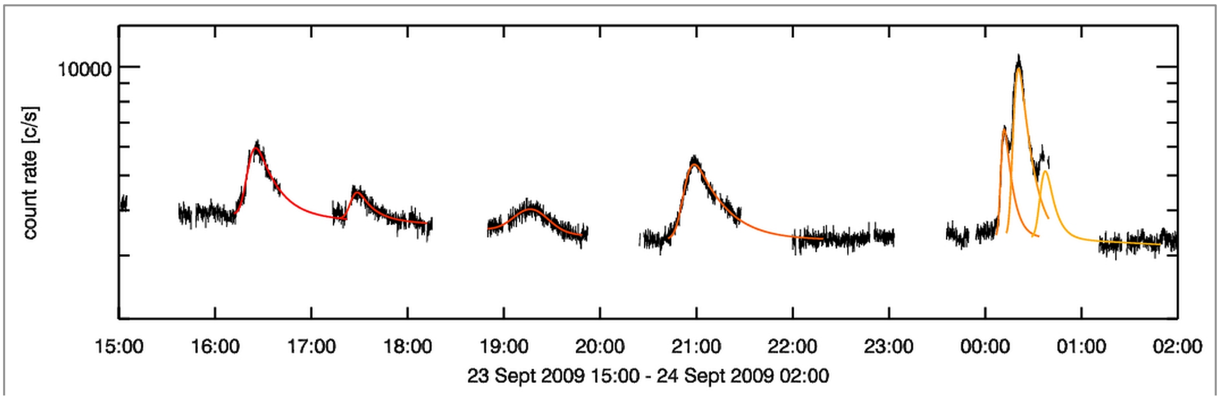


Fig. 4. Example of the fit to the observed lightcurve over a several-hour period of solar X-ray emission (E > 1 keV) with individual elementary flare profiles.

By fitting the elementary flare profiles, it is possible to precisely determine basic flare characteristics: start, maximum and end times and study flare evolution on a so-called diagnostic diagram.

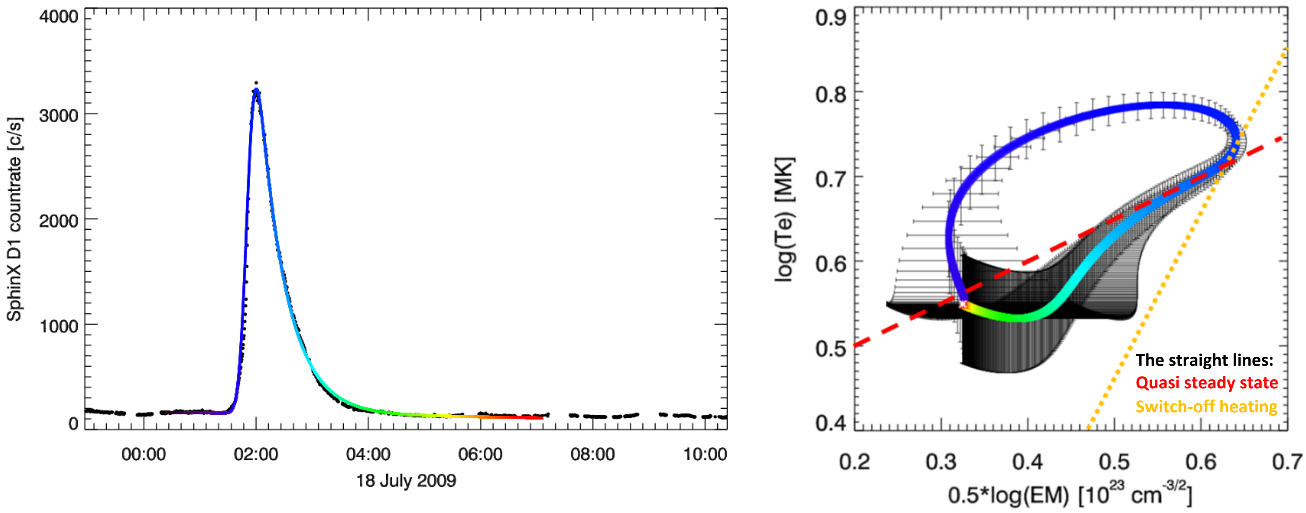


Fig. 5 Example of the elementary flare time profile fit to the SphinX light curve of a small (A9.0) event SOL2009-07-18T0204 (left) and the corresponding diagnostic diagram (right) showing the evolution of plasma emission measure and the temperature. Changing colours reflect progressing times. It is seen that initial decay phase runs along the steady state branch (red dashed). At later times the "heating-OFF" takes place and the inclination steepens, being close to the OFF-case (yellow dot branch). Such a detailed study has been performed for the first time and the results are to be presented in a dedicated paper.

X-ray light curves from SphinX have been compared with measurements of solar X-ray emission from the XRS-SAX instrument on board the *MESSENGER* spacecraft on its way to the planet Mercury. For two intervals during 2009, the location of Messenger was along the Sun-Earth line, so during those times a comparison of SAX and SphinX X-ray emission profiles is possible, as shown in Fig. 6.

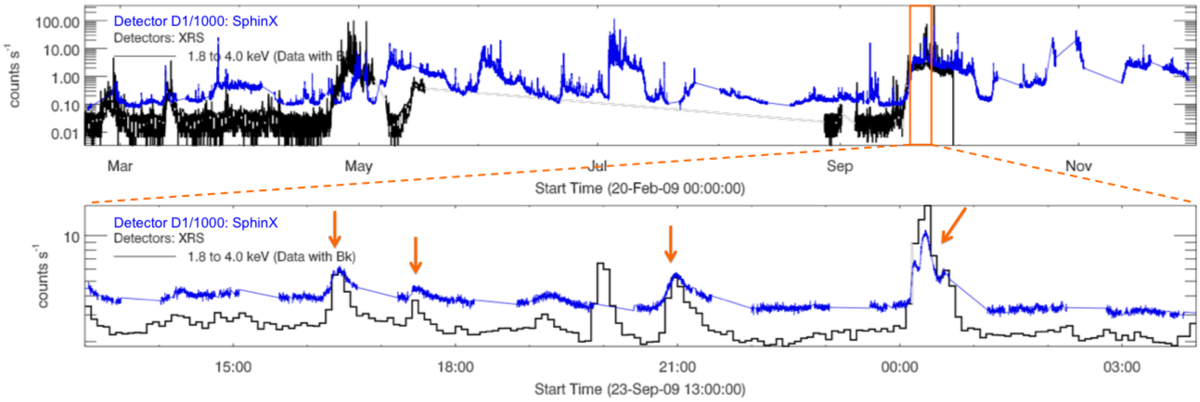


Fig. 6 Upper panel: The comparison of X-ray lightcurves of the Sun as seen from MESSENGER (black) and SphinX (blue). The sensitivity of SphinX was many times higher than XRS. For the period in late September 2009 (lower panel), MESSENGER observed the same part of the solar disk, so a direct comparison is possible.

Analysis of SphinX and XRS-SAX data is in progress, with early results indicating a problem with absolute calibration of one of the instruments, most likely the XRS.

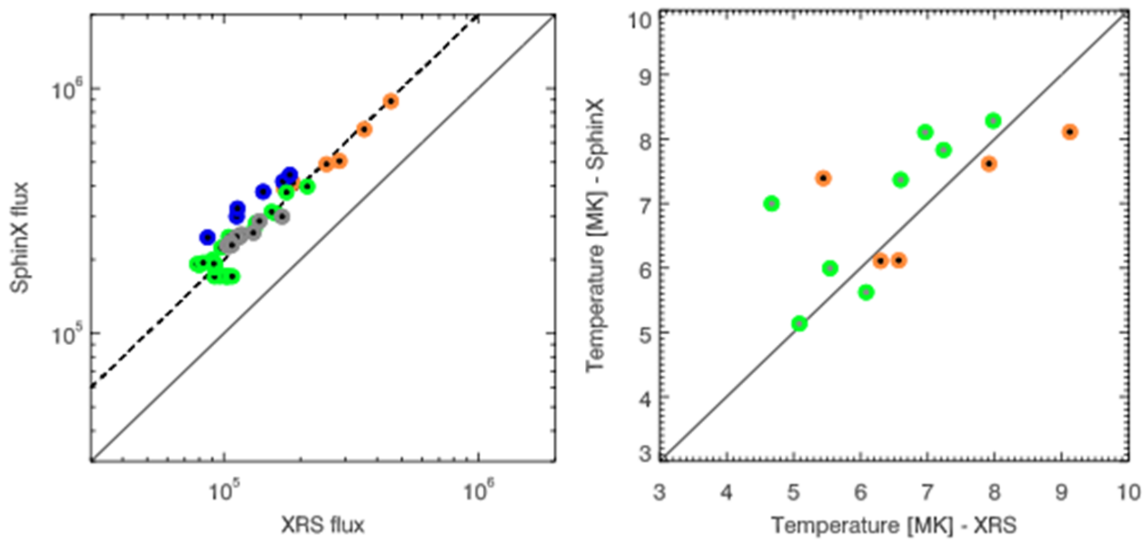


Fig. 7. Comparison of XRS (MESSENGER) and SphinX absolute fluxes of solar X-ray emission above 1 keV (left). SphinX values are about twice those of the XRS, though the derived plasma temperatures (from an isothermal assumption) are in a good agreement. Different colours correspond to particular small flares indicated by arrows in Fig. 6 (lower panel).

SphinX individual detector “events” from D1 (the detector having the largest aperture) were carefully examined “one by one” with the aim of discriminating those due to solar X-ray photons from those due to magnetospheric energetic particles penetrating the instrument.

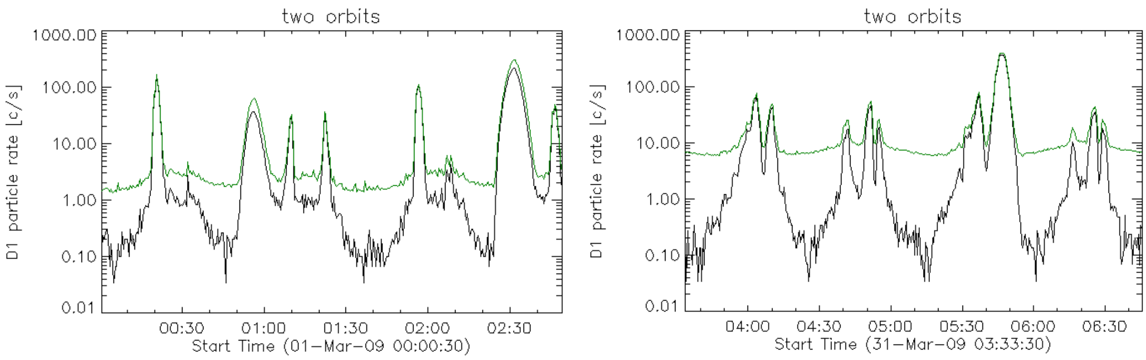
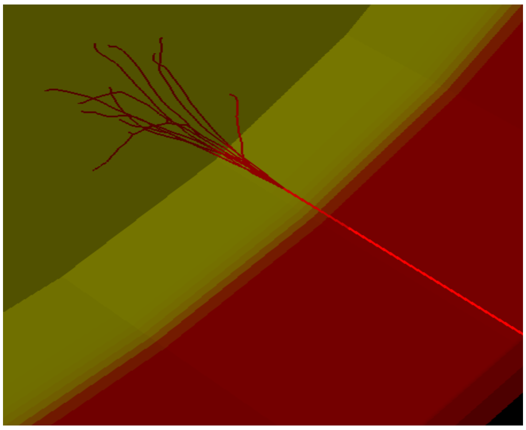


Fig. 7. Two examples of D1 SphinX records from very low activity period. Green lines represent signal before “cleaning” and black after rejection of solar “events”. The dynamic range of the signal due to energetic particles is increased by about a factor of 100.

In Fig. 7, an example of this analysis is shown. Elimination of solar detector events allows for studies of particle events with an accuracy that is ~100 times better than before. The analysis of SphinX records due to particles is progressing in close collaboration with the Kharkiv group (Dr. Dudnik).

Theoretical Modeling

A new approach has been conceived using the CERN Geant4 particle package to model the detailed interaction of electron beams precipitating from the coronal acceleration region to denser chromospheric layers. Geant4 has an advantage of solving the problem in a Monte-Carlo approach, without using simplified assumptions as has been done before.



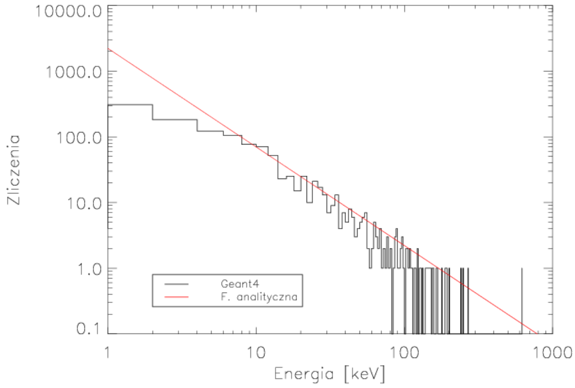


Fig. 8. Left: visualization of the relativistic electron track (red) impeding the solar denser chromosphere. Secondary electron paths are clearly visible leading to emission of bremsstrahlung continuum. Right: Spectrum of X-ray emission, calculated using Geant4 for electron power low beam above 10 keV (histogram). Straight line represents the analytical solution.

New instruments & ideas

STIX

STIX is the imaging Fourier hard X-ray spectrophotometer for the ESA *Solar Orbiter*. The instrument is in the final phase of construction C/D for the launch expected in 2018. Poland is contributing to the hardware and software development as a significant partner in the instrument consortium led by Switzerland. The main task of the SPD SRC Wrocław group is development of the instrument EGSE, development of the hardware/software detector simulator (~300 independent detector channels) and software flare simulator.

All the activities evolved nominally over 2014. Numerous documents have been drawn up and delivered to the consortium and/or ESA. Software and hardware progress were substantial, example of which is the construction of so called 3D detector simulator (cf. Fig. 9). This DSS allows the simulation of “real” responses of the instrument detector pixels (>300 units in 32 detectors) and electronics down to the compressed telemetry stream. The front part of the simulator consists of elaborated block of IDL routines simulating the hard X-ray source with a high time (20 ns) and spatial resolution (1 arcsec) in a Monte-Carlo approach.

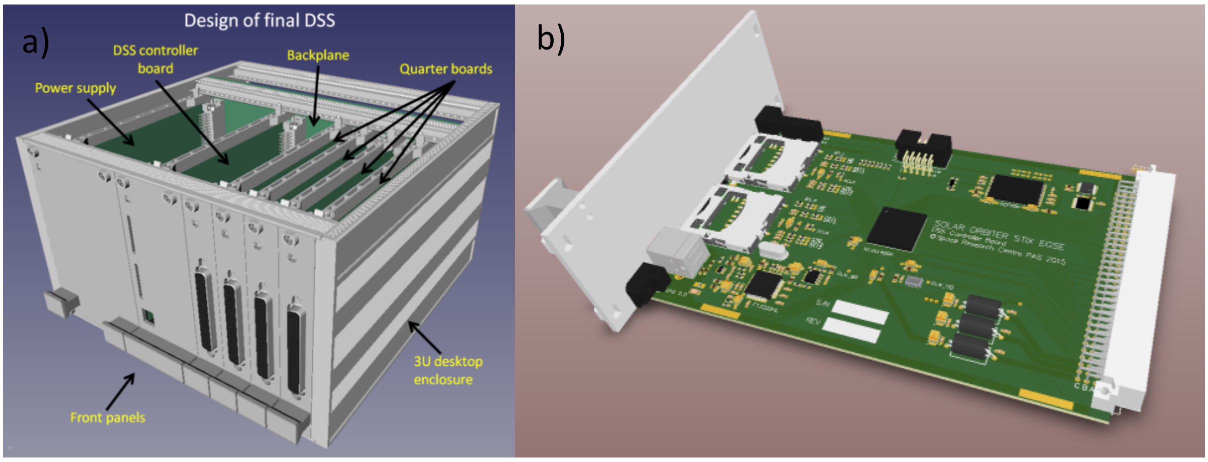


Fig. 9. A view of the detector simulator system (DSS-left) and one of the printed boards to be placed inside.

The back-end of the instrument IDPU, under construction in Warsaw, interfaces with the SIIS Solar orbiter's simulator system delivered to SPD from ESA. The corresponding software (scripts) has been written in Wrocław to allow development of the IDPU software and test procedures.

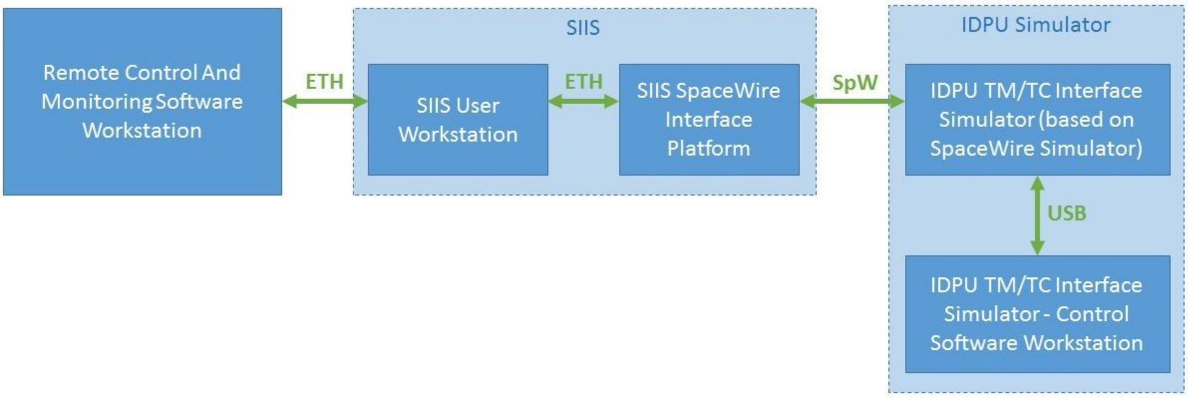


Fig. 10. Block scheme of the STIX test configuration to be used for EM and FM of the instrument.

In Fig. 10, a block-scheme of the test configuration, including SIIS and IDP.

In order that the simulator adequately represents the real instrument with all its detectors, a Geant4 simulation of detector response to illumination by X-rays has been undertaken. These calculations were found to be in a good agreement with the test measurements of the detector response performed in the SACLAY, France - the detector construction laboratory.

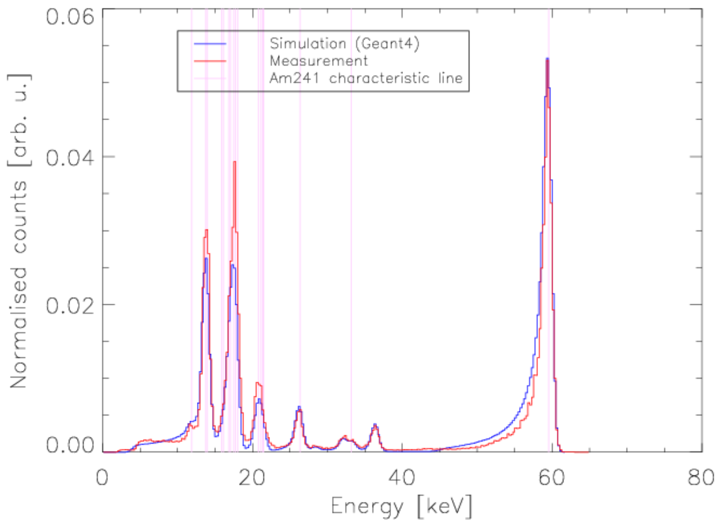


Fig. 11. Comparison of the measured STIX detector response (in red) with the Geant4 calculated response (in blue). Satisfactory agreement is observed. All 32 STIX detectors (flight units) will be measured and fitted in order to properly convert the stream of telemetry data into images of X-ray flares in selected energy ranges.

ChemiX

ChemiX is the Bragg bent crystal spectrometer under development for the two Russian Interhelioprobe interplanetary missions to be launched in 2020 and 2022. Orbits of Interhelioprobe will be similar to Solar Orbiter, reaching distances to the Sun as close as ~0.3 a.u. ChemiX is equipped with pin-hole soft X-ray imager and 10 bent crystals illuminating CCD detectors taking the soft X-ray spectra in the entire range from 1.5 Å to ~9 Å. Three pairs of identical crystals are placed in a so-called dopplerometer configuration allowing for precise determinations of line shifts and physical line profiles. Over 2014, a complete reconfiguration of the instrument construction took place reducing the weight of the detection section.

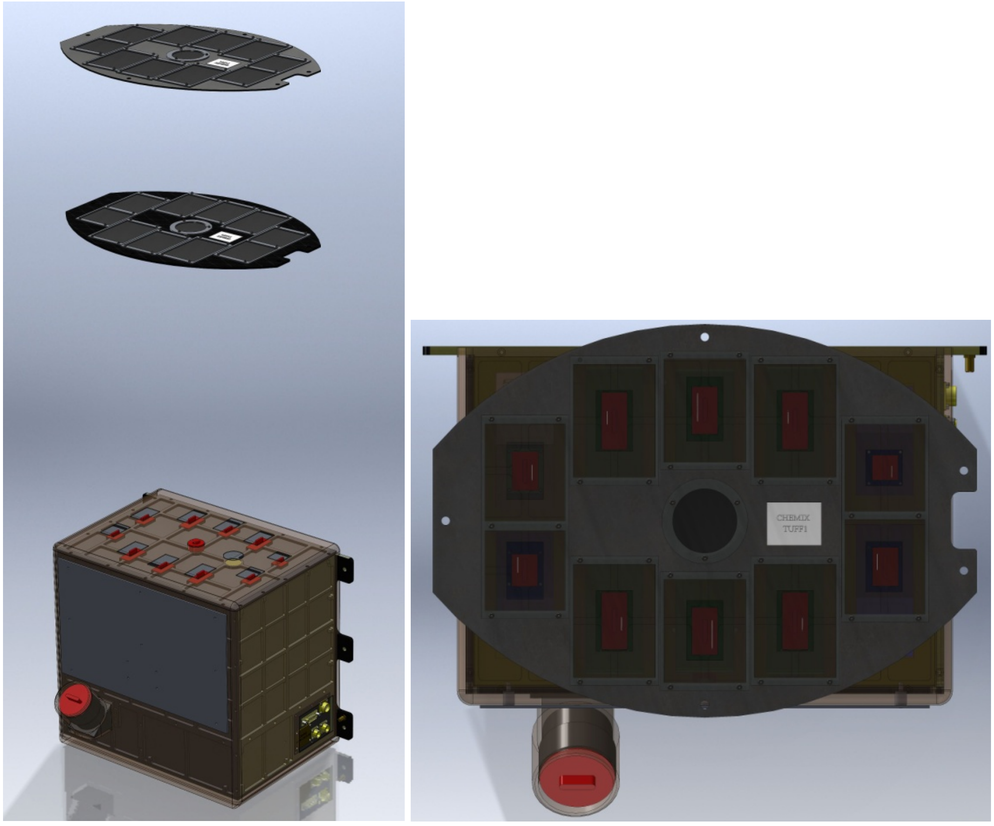


Fig. 12. General view of the ChemiX Bragg spectrometer (left). The upper two panels are the filter boards to be mounted on the mission thermal screen. They have to withstand harsh thermal conditions (~400 C). The crystals and detectors are mounted within the block placed ~1m behind the filters. The red-capped tube is the particle detector system, under development by the Ukrainian Kharkiv group led by Dr. Dudnik. Right: a view of ChemiX from the direction of the Sun.

Reliable thermal modelling is especially important for ChemiX since the mission approaches the Sun so closely and the solar thermal flux is many times larger than in the Earth's neighborhood. An example of the thermal modelling is shown in Fig. 13.

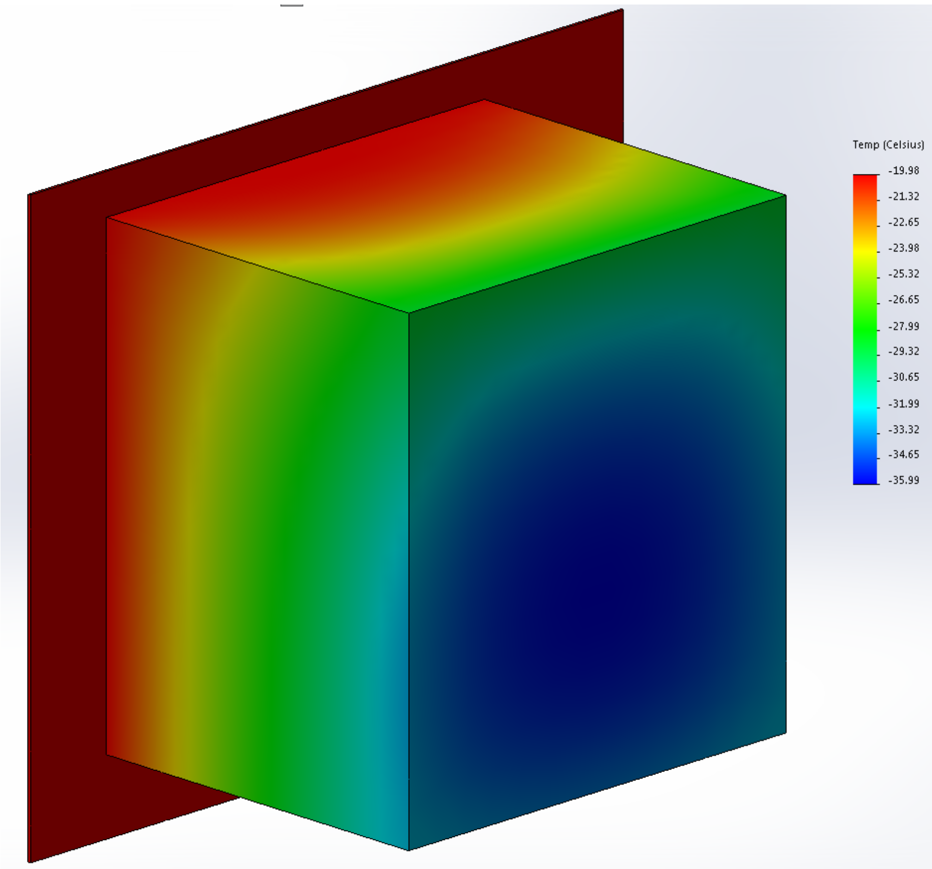


Fig. 13. Distribution of ChemiX instrument temperatures, calculated for the case of the instrument support temperature being at -20 C. This corresponds to the lowest temperature envisaged for the payload support plate.

SolpeX

SolpeX is the soft X-ray polarimeter-spectrometer for the International Space Station. The instrument consists of three functional blocks to be placed inside Russian-build KORTES assembly. Delivery of KORTES to the ISS is planned for 2017/2018. The three SolpeX units are: the rotating bent-crystal polarimeter (B-POL), a fast rotating drum spectrometer RDS, and the pin-hole imager. B-POL will hopefully detect (for the first time) the polarization of the soft X-ray lines and continuum around a photon energy of ~3 keV, which is expected to be present during impulsive phase of flares. RDS will take spectral measurements covering the entire soft X-ray range 1.5 Å – 23 Å up to 10 times per sec and the pin-hole will image the solar disk in a softer X-ray range detecting position and the lightcurves of individual events.

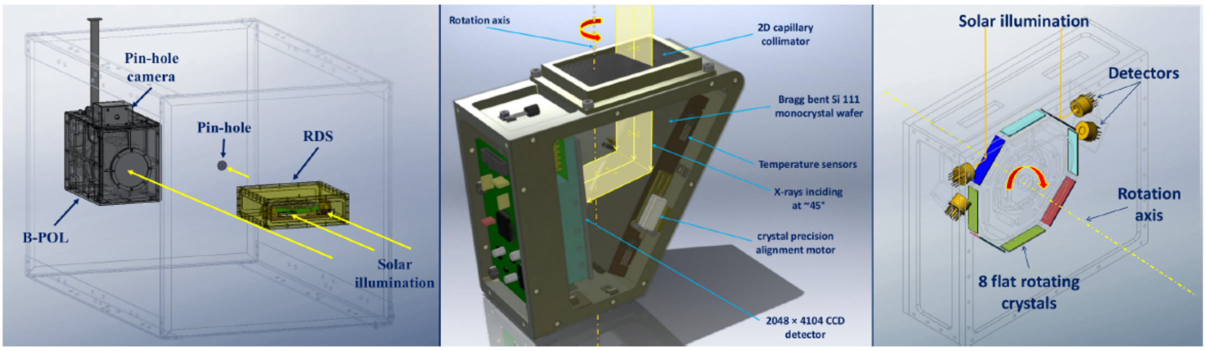
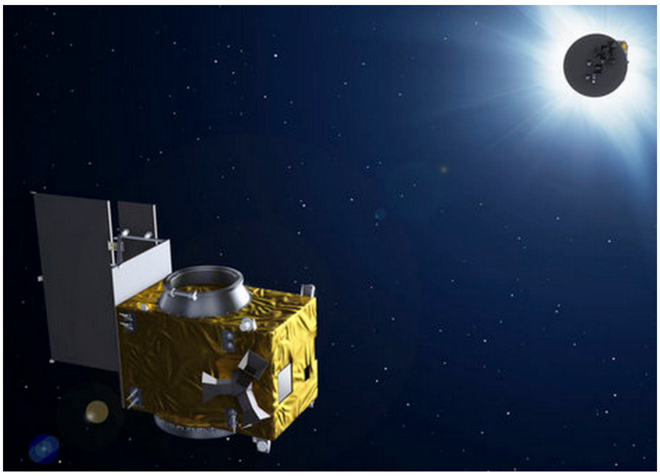


Fig. 14. A view of the three SolpeX units within KORTES shadow. The B-POL rotating polarimeter axis is actively directed towards the flare (being in progress) as seen in the pin-hole image. The RDS consists of 8 flat crystals mounted on the rotating drum revolving 10 times/sec. Bragg-reflected X-rays are collected by four SDD detectors. Appropriate crystal selection assures a full spectral coverage over the soft X-ray spectral range.

Proba-3

Proba-3 is the ESA project aimed to observe details of solar corona in the optical range. Project is in phase C/D.



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

Members of the SPD SRC (Siarkowski, Stęślicki & Sylwester), were engaged in process of selection of the spectral bands where the observations are to be undertaken by this formation flying solar coronograph. We suggested that the mission be equipped with the X-ray spectrometer SphinX-NGP to widen the science output.

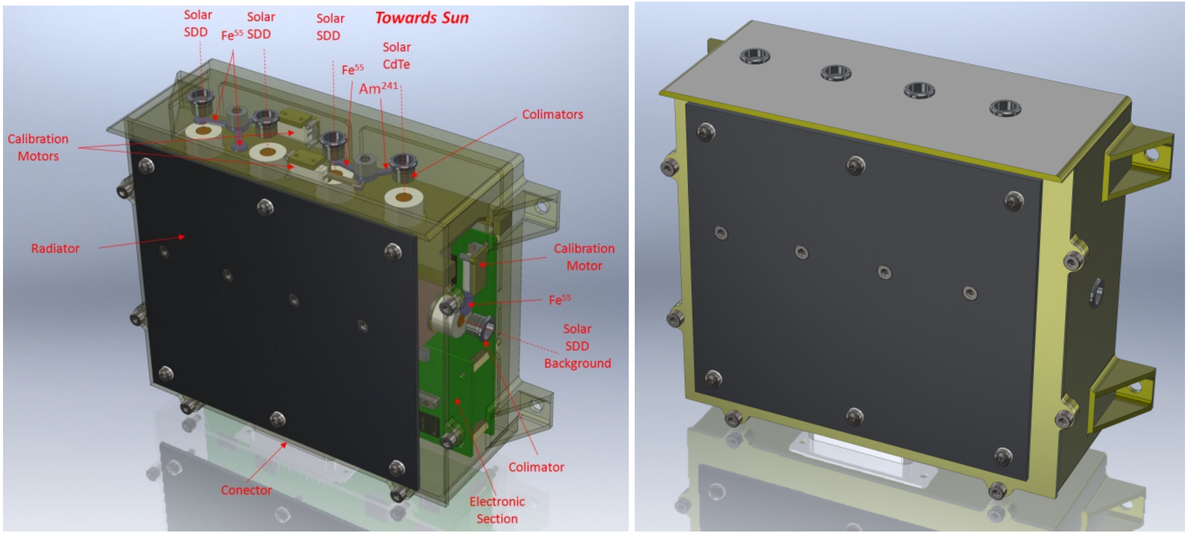


Fig. 15. The construction of SphinX-NGP soft X-ray spectrophotometer intended to be placed on the front satellite (occulter) of the Proba-3 formation flying duo.

Grant applications & grant progress

Eleven grant applications were submitted to various Polish grant agencies. Out of them only one was granted funds (SolpeX), while one other is still under consideration by the peer review commission.

The team of SPD-SRC continued receiving the support through 7FP as a member of the eHEROES consortium of 15 European institutes. eHEROES aims to study problems of "Environment for Human Exploration and RObotic Experimentation" within the scope of THEME [SPA.2011.2.1-01] Exploitation of space science and exploration data. Activities at SPD SRC were led in 2012 by Szymon Gburek. Three quarterly reports of activities have been compiled.

In 2014 the NCN supported works at SRC PAS through the following running grants:

- Prof. Barbara Sylwester, Investigation of physical conditions based on analysis of their X-ray spectra, Badanie warunków fizycznych w strukturach korony słonecznej na podstawie analizy ich promieniowania rentgenowskiego, 2011/01/B/ST9/05861- year three out of three,
- Prof. Marek Siarkowski, Design of a new concept Polish Bragg spectrometer ChemiX. **ChemiX: opracowanie założeń naukowych i konstrukcji (faza B) nowego spektrografu Bragga na misję międzyplanetarną Interhelioprobe (IHPM)")** - year three out of four,
- Prof. J. Sylwester (we spólpracy z Tomaszem Mrozkiem, Piotrem. Orleanskim i Markiem Stęślickim- przyjętym w 2012 na etat adiunkta w ramach tego grantu), Design of STIX hard X-ray imaging telescope for

the ESA Solar Orbiter mission to the Sun **Rentgenowski spektrometr obrazujący STIX: zdefiniowanie szczegółowych celów naukowych i sposobu prowadzenia obserwacji na podstawie modelowania matematycznego przyrządu, oraz jego systemu testującego"**. - year three out of four,

- SPD-SRC participated (J. Sylwester, M. Kowaliński, P. Podgórski) in PECS/PRODEX supporting STIX technical activities (led by SRC Headquarters team).

A new international agreements had been signed between the National Radioastronomical Institute of Ukraine represented by Dr. O. Dudnik and SRC PAS (J. Sylwester). The agreement will support common interpretation of data collected by STEP-F and SphinX instruments on the CORONAS-Photon and the ChemiX construction.

The teams from Radioastronomical Institute of Ukraine (Dr. O. Dudnik, and E. Kurbatov) and SPD SRC PAS (Prof. J. Sylwester, Dr. S. Gburek, Dr. M. Kowalinski, P. Podgórski) were awarded prestigious inter-Academy Award between Polish and Ukrainian Academies of Sciences. For details see http://www.cbk.waw.pl/en/index.php?option=com_content&view=article&id=370:the-solar-physics-division-of-the-space-research-centre-won-pas-nasu-competition&catid=2:aktualnoci&Itemid=91

Visiting scientists

Irina Myaghkova, Skobeltsyn Institute, MGU, Moscow, Russia, 13-21 May

Ken Phillips, National History Museum, London 16-27 August

Oleksiy Dudnik, Kharkiv University and Radioastronomical Institute of Ukraine, 5-25. 10.2012

Kanti Aggarwal, Astrophysics Research Centre, School of Mathematics and Physics, Queen's University Belfast, 1-2. October

Publications from the "Philadelphia" list

tytuł	*autor*	czasopismo
Solar Flare Composition and Thermodynamics from RESIK X-Ray Spectra	Sylwester, B.; Sylwester, J.; Phillips, K. J. H.; Kępa, A.; Mrozek, T.	The Astrophysical Journal, Volume 787, Issue 2, article id. 122, 10 pp
A CCD Search for Variable Stars of Spectral Type B in the Northern Hemisphere Open Clusters. IX. NGC 457	Mozdzierski, D.; Pigulski, A.; Kopacki, G.; Kolaczkowski, Z.; Steslicki, M.	Acta Astronomica, vol 64, no 2, p. 89-114
X-ray Flare Spectra from the DIOGENESS Spectrometer and its concept applied to ChemiX on the Interhelioprobe spacecraft	Sylwester, J.; Kordylewski, Z.; Płocieniak, S.; Siarkowski, M.; Kowaliński, M.; Nowak, S.; Trzebiński, W.; Stęślicki, M.; Sylwester, B.; Stańczyk, E.; Zawerbny, R.; Szaforz, Z.; Phillips, K. J. H.; Farnik, F; Stepanov, A.	Solar Physics, accepted for publication
Izerski Park Ciemnego Nieba i inne inicjatywy	Tomasz Mrozek, Sylwester Kołomański	Prace i Studia Geograficzne Tom: 53, Strony: 171-185
Spectroscopic survey of Kepler stars: high-resolution observations of A- and F-type stars	Niemczura, E.; Smalley, B.; Murphy, S.; Catanzaro, G.; Uytterhoeven, K.; Drobek, D.; Briquet, M.; De Cat, P.; Marcos-Arenal, P.; Pápics, P. I.; Gameiro, J. F. S., Stęślicki M.	MNRAS, Precision Asteroseismology, Proceedings of the International Astronomical Union, IAU Symposium, Volume 301, pp. 467-468
Testing the Model of Oscillating Magetic Traps	Szaforz Z; Tomczak M.;	Solar Physics, Volume 290, Issue 1, pp.115-127
RESIK solar X-ray flare element abundances on non-isothermal assumption	B. Sylwester, K.J.H. Phillips, J. Sylwester, A. Kępa	2014, ApJ, submitted
Multiperiodicity in quasi-periodic pulsations of flare hard X-rays: a case study	Szaforz Ż., Tomczak M.,	Central European Astrophysical Bulletin 2014, accepted

Other publications (12)

Lp	*tytuł*	*autor*	czasopismo
1	Development of small-sized SIDRA device for monitoring of charged particle fluxes in space	Dudnik, O.V.; Kurbatov, E.V.; Sylwester J; Siarkowski,M.; Kowaliński, M; Tarasov, V.O.; Andryushenko, L.A.; Zajtsevsky, I.L.; Valtonen, E.	Space Research in Ukraine, 2012-2014. The Report to the COSPAR". - ISBN 978-966-360-255-4, ed. by O.P. Fedorov. – Kyiv: Publ. House "Akademperiodika". – 2014. – p. 62-67.
2	Разработка малогабаритного спутникового прибора SIDRA для мониторинга потоков заряженных частиц в космическом пространстве	Dudnik, O.V.; Kurbatov, E.V.; Sylwester J; Siarkowski,M.; Kowaliński, M; Tarasov, V.O.; Andryushenko, L.A.; Zajtsevsky, I.L.; Valtonen, E.	Космічні дослідження в Україні, 2012–2014. Звіт до COSPAR». – ISBN 978-966-360-254-7, під ред. О.П. Федорова. – Київ: Видавничий дім «Академперіодика». – 2014. – С. 65-70.
3	Properties of magnetospheric high energy particles based on analysis of data from STEP-F and SphinX instruments aboard the "CORONAS-PHOTON" satellite	Dudnik, O.V.; Sylwester, J.; Podgórski, P.	Space Research in Ukraine, 2012-2014. The Report to the COSPAR, ISBN 978-966-360-255-4, ed. by O.P. Fedorov. – Kyiv: Publ. House "Akademperiodika". – 2014. – P. 53-61
4	Исследования частиц высоких энергий на низкоорбительном спутнике «КОРОНАС-ФОТОН» по данным приборов СТЭП-Ф и SphinX	Dudnik, O.V.; Sylwester, J.; Podgórski, P.	Космічні дослідження в Україні, 2012–2014. Звіт до COSPAR, ISBN 978-966-360-254-7, під ред. О.П. Федорова.– Київ: Видавничий дім "Академперіодика". – 2014. – С. 56-64.
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