Contribution to panel discussion Heliophysics

Janusz Sylwester
Space Research Centre, Polish Academy of Sciences, Wrocław
js@cbk.pan.wroc.pl

Importance of research in heliophysics

- The Sun is the ultimate “ecological” source of energy for the solar system, for Earth is the energy source for (most of) life forms
- The Sun is our nearest star, the only one for which we can observe fine structure in detail (at present down to ~50 km size)
- The Sun defines and influences its immediate stellar neighbourhood→heliosphere, including all solid and gaseous bodies: planets, asteroids, comets
- The Sun has a magnetic field; the plasma ejected from the corona as the solar wind is also magnetized
- Sun’s influence is time-dependent: the solar radiation and particle fluxes vary on time scales from fraction of a second (hard X-rays) to giga-years (increasing radiative output as solar internal nuclear energy source evolves)

Basic present knowledge

- The Sun supplies energy for the Solar system, including the Earth
  - drives the climate, ocean currents, vegetation, habitations
  - It is a variable star → giving rise to changes in all "subordinate" bodies
  - Level of irradiative variability depends on the spectral region; total (TSI) variation is ~0.2%, but reaches x 10^7 for the soft X-ray region (i.e. can be ten million times brighter during solar flares than at minimum activity). This X-ray variability influences state of Earth's ionosphere →radio blackouts & GPS problems. Other planetary atmospheres are also affected.
- The Sun can be in an active or quiet state. Activity changes on time scales of 10y, 90 y, but X-ray emission may change in a fraction of a second
  - Mass ejections (CMEs) become frequent during active state- some of them are Earth-directed
  - Accelerated energetic particle clouds ("satellite killers") are sent in various directions, some hitting Earth infrequently
  - Sometimes this solar cycling activity stops or activity level becomes weak→Sun spends long periods in a quiet state (Maunder Minimum 1645-1715)
- Sun is the source of solar wind, blowing permanently with changing speed; wind can be fast or slow; the magnetic field which is frozen into the plasma may change direction, perturbing the Earth's magnetosphere
  - Presence of Solar Wind determines existence of Earth magnetosphere, our only reliable defence against CMEs and potentially devastating SEP intrusions. CME & SEP collisions cause magnetosphere to react in the form of magnetic substorms and storms
  - Earth magnetosphere state may change from quiet to stormy (sometimes causing failures of large power stations)
- CMEs propagating outwards in the heliosphere divert cosmic rays from outside the solar system. Earth is subject to fewer high-energy particle hits during maximum phase of solar activity .
  - This process causes modulation of ^{14}C isotope content in organisms

Importance of heliophysics for human society

- Solar activity-related “disturbances” may cause problems for all human society: power-outages, misleading GPS indications, radio blackouts
  - Multi-billion $ losses in exceptional circumstances (satellites lost, power stations and pipe-lines devastated)
  - Health risks (ISS astronauts, aircraft pilots on polar routes)
  - Main factor defining safety on missions outside the magnetosphere (Moon, Mars, asteroids)
- The Sun in a quiet state may also be “dangerous”
  - Increased level of galactic cosmic rays (risk of possibly lethal radiation doses for astronauts)
  - decrease of solar wind may cause magnetospheric “anomalies”
- Moon, asteroid or Mars ground bases should be safely located; these bodies have no magnetosperes so are directly exposed to solar radiation also SEPs.

Importance of heliophysics for science

- The Sun is a "prototype star & standard reference in astrophysics"
- Sun's hot (multimillion degree) magnetized corona is a natural laboratory for plasma magnetohydrodynamics (no investments source, except for the cost of observing instruments)
- Basic mechanisms giving rise to coronal heating are still not determined.
  - Waves and/or numerous small magnetic reconnections
- Energy release in flares- the most energetic phenomena in the Solar System still poorly known – many theoretical models still relatively untested.
  - When the flare mechanism is determined, there may be many applications to other astrophysical sources (accretion disks, stellar X-ray flares and activity)
  - Also possibility of a better understanding of the physics of fusion energy devices
- Peculiar present state of solar activity
  - Solar physicists are disturbed by the present pattern of solar activity
  - Has the Sun already reached maximum? Is there another burst of activity expected?
  - Is the Sun going to stay inactive again for tens of years to come?
- Activity level predicions are in confusion - basic dynamo theory has some difficulties

Space solar physics heritage in Europe: **important** SOHO, Yohkoh, Hinode, Coronas, Proba2

how to keep this status in a view of only one specialized dedicated solar mission: **Solar Orbiter**

- Present European science potential is equivalent that of US and Japan, so this would be advantageous to keep making progress in heliophysics in the future.
- Progress in heliophysics is intimately connected to development of space experiments
  - NASA/ESA SOHO mission brought most of the new understanding in heliophysics since its launch in 1995
  - The present NASA SDO is now the major solar mission, and will continue to be so until the ESA Solar Orbiter starts to take first solar measurements in 2019-2020
  - JAXA Yohkoh & Hinode with European instruments aboard were/are highly successful

Solar physics is alive in Europe - how to maintain this

- **EU could promote the following directions:**
  - High-resolution X-ray solar imaging (only US XRT instrument on Hinode and GOES X-ray imager available at present, Russian instruments were placed on Coronas).
  - High-resolution X-ray and EUV imaging spectroscopy (EIS-Hinode, BCS-SMM, Yohkoh, RESIK, Diogeness heritage - US has no planned mission for high-resolution X-ray spectroscopy), no X-ray imaging spectroscopy ever performed yet
  - X-ray polarimetry: flares, dark matter - axions
  - Coronal elemental abundance mapping
- These areas of solar research have been negleted recently apart from instruments made by FIAN (Moscow) and SRC (Poland) in spite of their continued basic importance for solar physics.

Proposal for Solar observatory **SOLMON** as next European solar cornerstone mission (geostationary orbit)

possible modification: two identical observatories at (stereo) L4 & L5 locations

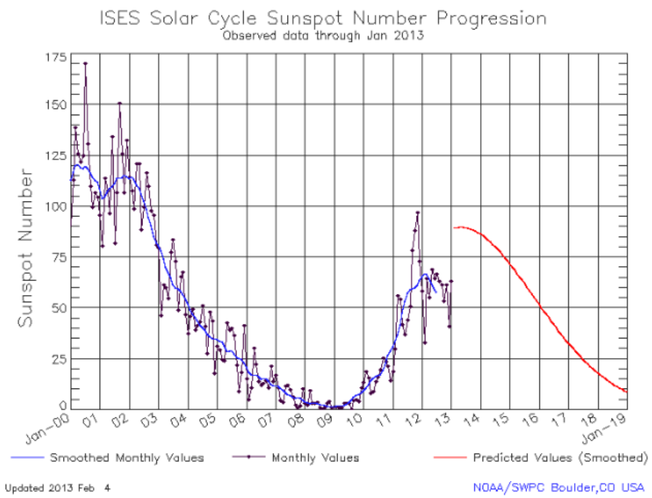
- Monitoring & observing the Sun in X-rays with high sensitivity and time resolution, preparing for possible Maunder Minimum or low solar activity periods. Among the instruments aboard, the Observatory should include:
  - **XMON** which should provide science-grade, absolutely calibrated, multichannel, uninterrupted observations of solar activity in soft X-rays. Simple imaging capability needed to distinguish between individual active regions. This will represent European high-sensitivity equivalent of NOAA GOES X-ray monitoring, with improved (x100) sensitivity and spectral resolution. Such an instrument could be vital for flare prediction and will allow for sufficient time for warning & response of Earth-based infrastructure & services. Geostationary positioning is better than in L1, L4 & L5 as concerns telemetry and operational safety. But L4 & L5 offer stereo view. **No counterpart is presently planned**
  - **XTEL** imaging spectrometer with medium resolution X-ray telescope equipped with microcalorimeter imager 512 x 512 cooled close-loop detectors, spectral resolution ~10000, spectral range 1- 40 Å. **No counterpart mission planned**
  - Independent **XNET** detector packages (<1 kg) to be mounted on every satellite to be launched by ESA (say attached to solar panels to see the Sun most of the time). Operations of each individual XMON unit to be controlled by independent team of students at high-school level selected by competition. Every instrument to be controlled in real time from a ground-station located at the high-school, with students uploading commands. This system may allow for sounding of local plasma conditions between satellites by pinging. The "Net" will grow with increasing number of satellite launches.
  - Common EOF facility to run the XMON & the growing net of XNETs, offering student training, support etc.

Suggested proposals for small specialized missions

Every part of this proposed missions would be a significant step forward in solar physics

- A number of dedicated small science missions ~ 50 kg class on typical Sun-synchronous LEO ~600 km polar orbits
  - Flare X-ray polarimetry (solving still unsettled problem of whether polarisation exists); particle acceleration & energy release; axion dark matter hypothesis verification
  - Extreme high resolution EUV and/or X-ray imaging of solar coronal features (focal lengths >100m with satellite formation flying), resolution down to 1 km on the Sun; vital for the study of primary energy release mechanisms in flares/microflares

Heritage
Need for a new SphinX instrument

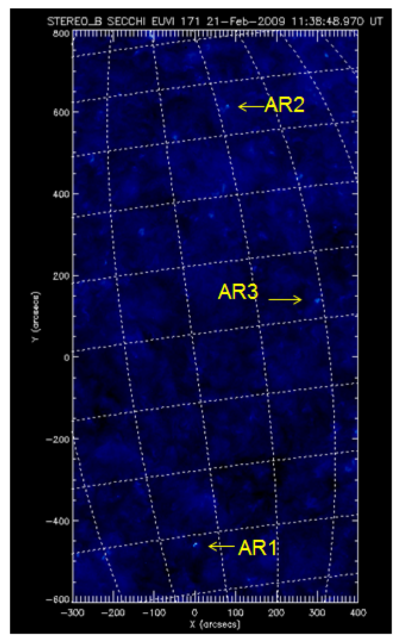


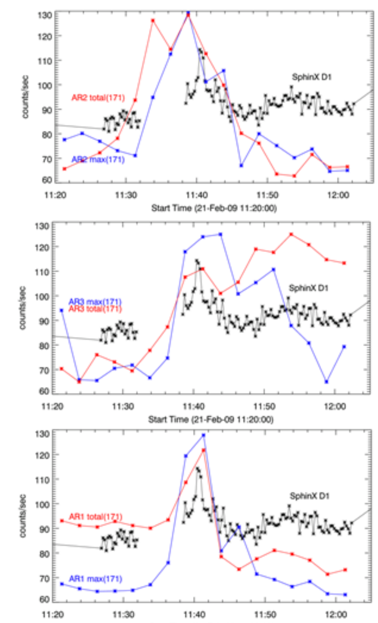
SphinX on CORONAS-PHOTON recorded the deepest solar minimum (2009) since the start of the Space Age (late 1950)s. Its energy range, 1-12 keV, is similar to the GOES long-wavelength channel (1-8 A), but with much greater (x100) sensitivity.

X-ray levels many times less than A1 (GOES limit) were recorded in 27 intervals of several days.

The next solar minimum looks as if it will be even lower.

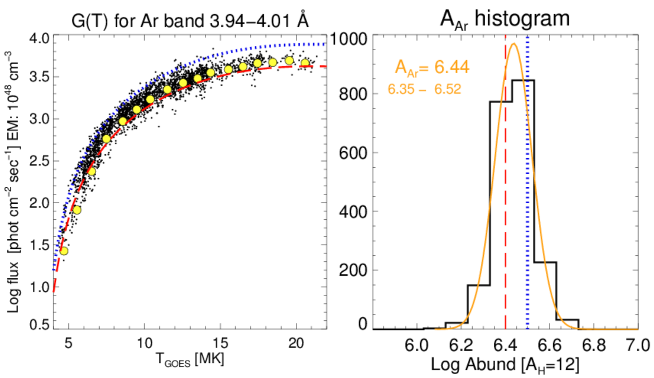
Among the many discoveries that SphinX made in 2009 is that tiny microflares sometimes occur as X-ray brightenings which are revealed as EUV brightenings in widely separated regions over the Sun's disk – the simplified magnetic field during solar minimum may give rise to a greater tendency for transequatorial loops connecting these regions.



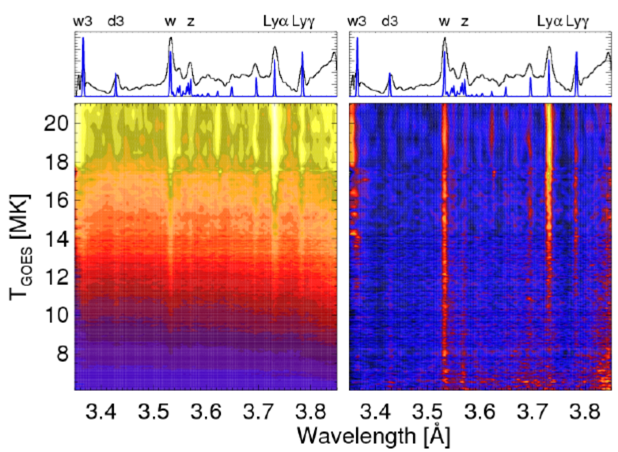


Heritage

RESIK – a key to solar coronal abundances



Determination of Ar abundance in flares: A(Ar) = 6.44 (log scale, H = 12).



RESIK observations of He-like K at 3.55A

RESIK was a high-resolution X-ray crystal spectrometer (range: 3-6 A), the first for several years. Its highly precise intensity calibration has allowed the measurement of absolute abundances for Ar, S, Si, and even for the trace elements K and Cl.

The Ar abundance determination in flares that RESIK observed is the most precise for the Sun – all other determinations rely on proxies such as planetary atmospheres and nearby H II regions.

Element abundances are a hot topic still since the way that coronal abundances differ from photospheric remains controversial – a dependence on the first ionization potential (FIP effect) is very clear.

The mechanism for the FIP effect is still under discussion.

Recent studies with RS CVn stars shows how abundances are quite different so the FIP effect in some stars operates in a very different way.