Long-term study of the solar EUV corona, its dependence on the magnetic field structure and local sources of plasma outflow using the coordinated SWAP and Hinode/EIS observations

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Aim of the Project

The solar inner corona below 2 R_{sun} is an important region of restructuring of the magnetic field and formation of solar wind streams. The SWAP telescope has advantages to study the inner corona in comparison with similar instruments like EIT/SOHO and AIA/SDO, because its spectral band (174 A) is the most sensitive to the coronal EUV emission at temperature ~ 1 MK, it has a wide field of view and low stray light. Imaging of the solar corona with SWAP in the 174 A wavelength band, started in 2010, revealed large-scale coronal ray-like structures which appeared at the limb above some active regions (ARs) and expanded super-radially to distances of 1.5 – 2 $R_{sun.}$ In the first stage of the research it was found that in solar minimum (August 2009) coronal rays observed at the limb above interface regions between ARs and neighboring coronal holes, where Hinode/EIS detected plasma outflows in the Doppler shifted Iron lines. The rays were correlated with open magnetic field lines expanding from those regions to white-light streamers, and accompanied with fan ray structures at the disk originating from regions of outflows. Hereof, coronal rays were assumed to be signatures of local streams of quasi-stationary slow solar wind. This assumption has to be confirmed at rising solar activity by temporarily correlated appearances of coronal rays and outflows in the same time scales and correspondence to similar magnetic field configurations.

The aims of the current project were:

- to study a long-term (solar rotation) and a medium term (days) variability of the coronal structures seen at the limb by SWAP, their correlation with temporal evolution of outflows seen at the disk by EIS and compliance with specific magnetic field configurations;
- to confirm that outflows may be local sources of solar wind propagating in the corona along coronal rays by comparison of positions of outflows at synoptic maps with the positions of solar wind sources derived from the ACE data.

Data preparation

Long-term variability of the EUV corona during several solar rotations has been studied from the images of the Sun obtained by SWAP in the regular synoptic mode as well as in the special off-pointing sessions carried out when appearance of coronal rays may be presumed by the structure of ARs and CHs as well as presence of fan rays at the disk. For selection of extended coronal structures ordinary images of the corona were transformed into polar coordinates as latitude/radial distance. The temporal sequences of polar coronal maps were collected for whole solar rotation. Using these packets of polar maps, the Carrington synoptic maps of the EUV brightness in the corona above E-limb and W-limb were constructed as cross-sections at different heights in the range R=1 - 1.6 $R_{sun.}$ In the case of the off-point mode emission of the corona was studied up to 2.5 $R_{sun.}$ The coronal synoptic maps were compared with the synoptic maps of the extrapolated magnetic field and white-light corona.

To study a probable relationship between extended coronal structures and evolution of local plasma outflows, the presumed targets were examined by Hinode/ EIS for outflows and tracked during a visible part of solar rotation. Local positions of outflows were compared with photospheric magnetograms and PFSS extrapolations. Latitudinal positions and variability of outflows were correlated with that of coronal structures observed by SWAP and with parameters of the solar wind from the ACE data tracked back to the source surface.

Dedicated Instrument Campaign

The data for three solar rotations have been studied: CR 2102 (3 – 30 October 2010), CR 2108 (15 March – 11 April 2011) and CR 2115 (22 September – 19 October 2011). The first two rotations were analyzed using the data from the SWAP database, including synoptic observations and 8 off-pointing sessions 20-21 October 2010, 23 March 2011, 5 and 6 April 2011, 1, 2, 13 and 14 October 2011. The EIS data for periods 15 October 2010, 23 March – 4 April 2011 were taken from the Hinode/EIS database. In the rotation CR 2115 a special coordinated observational program "EIS-SWAP-AR" has been developed and realized on 1 – 14 October 2011. In total, we processed 72 Gb of the SWAP data and the EIS data obtained in 45 sessions.

Preliminary results and discussion

1. Coronal structures detected at the SWAP images evidently evolved with rising solar activity and strength of the magnetic field: from radial or super-radial rays emerging from single ARs in CR 2102 to quasi- radial interacting structures in CR 2108 and a variety of structures of different forms in CR 2115 which merge at the heights above 1.5 Rsun in a single streamer. In all periods the corona contained a plenty of individual radial rays most of which were rooted in ARs. In polar pictures as well as in the synoptic maps those can be easily distinguished from closed arch structures as seen at distances $R>1.5\ R_{sun}$.

2. Outflows were detected by EIS in three ARs: 11112 (CR 2012), 11176 (CR 2108) and 11309 (CR 2115). In the last two cases outflow regions were tracked by EIS from E-limb to W-limb, where appropriate coronal structures were observed at the limb by SWAP. In both cases the outflows were stable in the timescale of days, the ouftlux density measured as a product of density to radial velocity varied no more than in 30%. Very bright radial coronal rays were clearly observed up to $R=2\ R_{sun}$ above AR 11112 on 20-21 October 2010. In two other ARs the rays were not so large due to their non- radial shape, and appeared as parts of helmet-like structures in basements of streamers.

3. In all listed ARs EIS identified several separated outflows with velocities more than 10 km/s. Some of outflows were co-spatial with origins of open magnetic field lines calculated by PFSS, other – not. At the photosphere outflow regions were projected to the regions of magnetic fields no strongest than 200 Gs with tendency of velocity to increase with the strength of the field. The coronal rays were evidently appeared above the AR-CH complex. Though, due to low spatial resolution at the limb it was not possible to identify exactly origins of coronal rays with particular outflows.

4. Comparison of the EIS velocity maps in the Carrington coordinates with synoptic maps of global magnetic field has shown that outflows were located nearby the main heliospheric plasma sheet or local plasma sheets associated with pseudostreamers. The coronal rays from distant outflows were inclined to the HPS.

5. In the WSA map of the derived solar wind sources the positions of outflows coincided with presumed local sources of the slow wind with velocity 300-500 km/s. The ACE solar wind projected to the source surface at $2,5\ R_{sun}$ correlated of the outflow positions within the accuracy of the ballistic approach (10^0). The O^7/O^6 and Fe/O ratios in the solar wind were in agreement with location of the source in AR. At low solar activity (CR 2102 and 2108) the solar wind density showed a temporal fractality, probably, produced by spatially separated outflow streams. At high solar activity (CR 2115) the solar wind density had a smooth distribution which well agreed with observed merging of coronal rays from separated outflow regions in one broad streamer base.

6. Concluding, our results confirm that at rising solar activity extended coronal structures seen in 1 MK Fe-lines are linked with plasma outflows from active regions propagating along open magnetic field lines and parameters of the solar wind.

7. Future Work

In the next stage of research it is planned to study the properties of EUV emission of coronal streamers in order to understand their mechanisms of excitation and dependence on plasma parameters.

Publications

1. Slemzin, V.; Harra, L.; Urnov, A.; Kuzin, S.; Goryaev, F.; Berghmans, D. Signatures of Slow Solar Wind Streams from Active Regions in the Inner Corona. Solar Physics, Online First, June 2012, tmp..144S. DOI: 10.1007/s11207-012-0004-y
2. V. Slemzin , F. Goryaev, L. Harra, A. De Groof . Structure and properties of the inner solar corona in the FeIX-X EUV lines. Abstracts of the 6th Hinode meeting, St. Andrews, UK, August 14-17, 2012.
3. V. Slemzin, A. De Groof. Evolution of coronal structures associated with local plasma outflows at rising solar activity from the SWAP and Hinode/EIS observations. ESWW 9, Brussels, November 5-9, 2012.