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Dynamic 10 MK plasma structures observed in monochromatic full-Sun images by the SPIRIT spectroheliograph on the *CORONAS-F* mission

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ABSTRACT

High-resolution temporal series of monochromatic full-Sun images in the L Mg XII emission line at 8.42 Å have been obtained by the SPectroheliographIc X-Ray Imaging Telescope (SPIRIT) spectroheliograph on the *CORONAS-F* satellite. For a six-month period since the launch on 2001 July 31 more than 10 000 Mg XII images were recorded. The images revealed plasma structures with the temperature in the range 3–20 MK characterized by specific shape and dynamics, different to that of relatively low temperature (1–2 MK) plasma. The main remarkable features of the phenomena first seen in the monochromatic images are as follows: (1) high spatial variability in brightness with the contrast of more than two orders of magnitude, (2) the presence of some compact sources with high altitude locations up to 0.3 solar radius and well-distinguished 'spider'-like forms, (3) substantially different variability in dynamical behaviour characterized by lifetimes from minutes to days. Sporadic condensations of coronal plasma with $\log N_e \approx 10$ and peak temperature of about 10 MK were observed in the vicinity of active region systems.

Key words: Sun: activity – Sun: corona – Sun: UV radiation.

1 INTRODUCTION

XUV full-Sun imaging spectroscopy is the most direct method for study the structure and dynamics of high-temperature plasma in the solar corona. Information on the spatial and temporal distribution of plasma parameters, in particular differential emission measure (DEM) in active region systems, is fairly important for a choice of the precise physical mechanisms of release, dissipation and transformation of energy needed for a quantitative modelling of coronal heating. Plasma structures with relatively low temperatures 3 MK and 'superhot' flare plasma with characteristic temperature of about 20 MK were a subject of numerous complex studies by means of imaging data obtained from the *SOHO* and *Yohkoh* satellites during last decade. However highly dynamical non-flare transient phenomena revealed by *Yohkoh* SXT images in the temperature 'window' 3–20 MK (see, for example, Hudson 1994; Golub & Pasachoff 1997) could not be analysed by *SOHO* CDS owing to long image composition time for the wavelength of their emission. At the same time, plasma temperature and corresponding DEM derived from Solar X-ray Telescope (SXT) data have considerable uncertainties caused by the smooth temperature gradient and the indeterminacy of response functions for broad spectral bandpasses, depending on elemental and ionic abundances (Schmelz et al. 1999) as well as on the excitation mechanism (thermal/non-thermal).

This paper presents a short review of phenomena first observed in monochromatic full-Sun images obtained in the Mg XII resonance line at 8.42 Å with spatial resolution of 4.1 arcsec pixel^{-1} in the framework of the SPectroheliographIc X-Ray Imaging Telescope (SPIRIT) experiment on board the *CORONAS-F* satellite launched on 2001 July 31 (Orayevskii & Sobelman 2002). The experiment SPIRIT is devoted to simultaneous recording of temporal series of *XUV* images for the whole solar disc and off-limb region in spectral lines and narrow wavelength bands with time resolution up to 1 s. The instrumentation complex SPIRIT consists of multichannel spectroheliograph RES (X-Ray & *EUV* Spectroheliograph) and the Soft X-Ray Telescope (SRT). The spectroheliograph RES besides the X-ray (Mg XII) channel includes also two EUV channels providing full-Sun images in the regions 177–207 and 285–335 Å with high spectral resolution of about 0.02 and 0.04 Å, respectively. The telescope SRT provides images in six spectral bandpasses in the range 171–304 Å (for detailed description of the

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SPIRIT instruments see Zhitnik et al. 2002a,b). Joint multi-thermal analysis of the SPIRIT data makes it possible to study the morphology and dynamical properties of plasma in the temperature range 0.05–20 MK and thus to derive observational constraints for coronal heating models.

Monochromatic images in the Mg XII resonance line give direct information on the plasma at temperatures in the vicinity of 10 MK since line emission is substantially in excess of the continuum within the spectral linewidth and because the temperature gradient of the line emissivity function is steep compared with the response function in a wide spectral bandpass. These properties allow us to avoid contamination with emission from plasma with lower temperatures 3 MK. The advantages of Mg XII resonance line emission for high-temperature diagnostics of active regions were appreciated in early measurements of high resolution spectra at 8.42 Å made on board the satellites *Intercosmos 4* (Grineva et al. 1973) and *Intercosmos 7* (Jakimec et al. 1975), and the rocket *Vertical* (Zhitnik, Korneev & Oparin 1989).

These measurements discovered sporadic condensations in the absence of flares with average temperatures estimated as 4–8 MK. The first monochromatic full-Sun images recorded in the Mg XII resonance line on board the *CORONAS-I* satellite (launched on 1994 March 2) revealed such condensations in the vicinity of some active regions with high flux variability and lifetimes of a few hours (Sobelman et al. 1996). Results of more detailed studies of the transient phenomena in the temperature range 3–20 MK by the advanced instrumentation SPIRIT are given in the present paper.

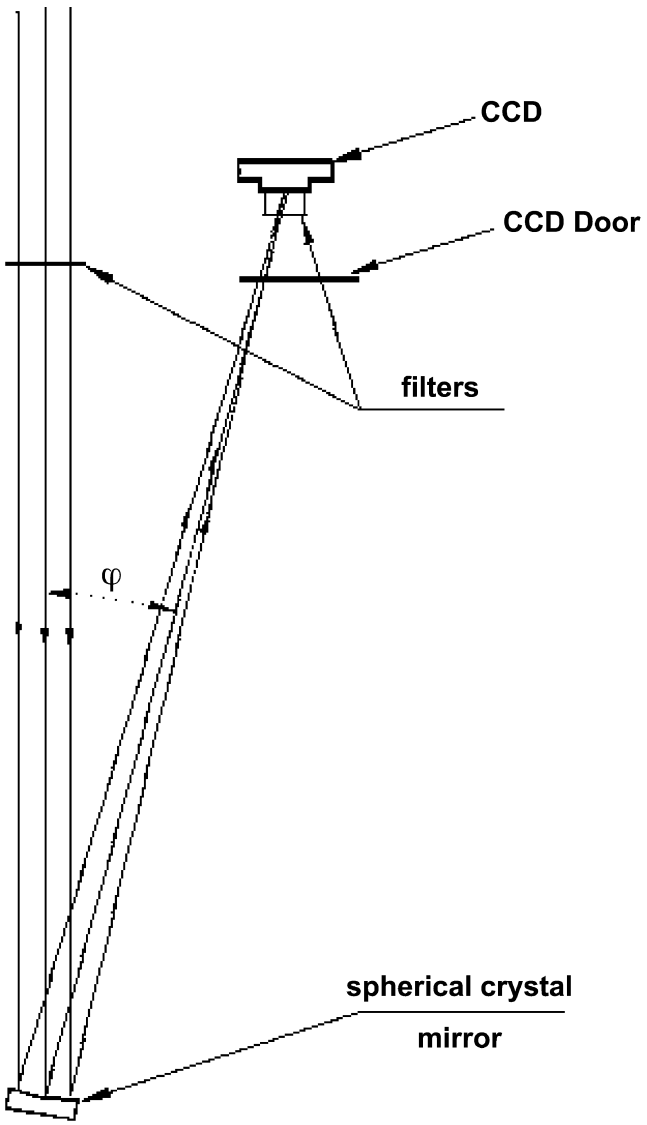

Figure 1. Optical layout of the Mg XII spectroheiograph.

Table 1. The main characteristics of the Mg XII spectroheliograph on board the *CORONAS-F* satellite.

Bragg crystal mirror	
Crystal	quartz [1340]
2d	8.5098 Å
Bragg angle	81°26
Radius of curvature	1286 mm
Dimensions	4060 mm
Filters	
Entrance filter	3.6 μ mylar, both side coated with 0.15 μ Al
CCD stray light filter	2.5 μ mylar, both side coated with 0.15 μ Al
CCD detector	
Architecture	three phase, split full frame (SFF), active cooling, without antiblooming
Array size	10241152
Pixel size	1313 μ
Full well	~300 000 e
Readout rate	500 000 pixel s^{-1}
Full frame readout	~2.5 s
Exposure	0.01600 s
Cooler	2-stage Peltier, ~40 degrees cooling
ADC	14 bit
Data processing	22 summation, losseless compression up to factor of 5, median filter, readout noise ~30 e sqrt, thermal noise 2–8 e pixel s^{-1}
Instrument	
Spectral range	8.418.43 Å
Spatial resolution	4.1 arcsec $pixel^{-1}$
Field of view	1°3 up to 2°5 using pointing mechanism
Dynamic range of the image	600

2 EXPERIMENTAL

The SPIRIT spectroheliograph on the *CORONAS-F* mission is the improved version of that on board the *CORONAS-I* satellite. The Mg XII spectroheliograph is based on the focusing Bragg crystal mirror. The spherically bent quartz crystal with [1340] crystalline plane (2d8.5098 Å) parallel to the optical plane was used to provide close-to-normal incidence reflection in the working range (Fig. 1). The effective focus distance of the mirror is about 650 mm. Reflected radiation is registered by the front-side-illuminated CCD, which is closed with the CCD door between exposure series to decrease radiation damage. Parameters of the main elements of the Mg XII spectroheliograph are shown in Table 1. The device includes two completely independent channels with cross-dispersion planes in order to separate spectral and spatial components in the registered images and to remove particle tracks from Earth radiation belts registered by the CCD. The channels may operate simultaneously or in a sequence depending of operating mode.

3 AN OVERVIEW OF THE OBSERVATIONS

For the first six months of observations by the SPIRIT Mg XII spectroheliograph since the launch of the *CORONAS-F* satellite on 2001

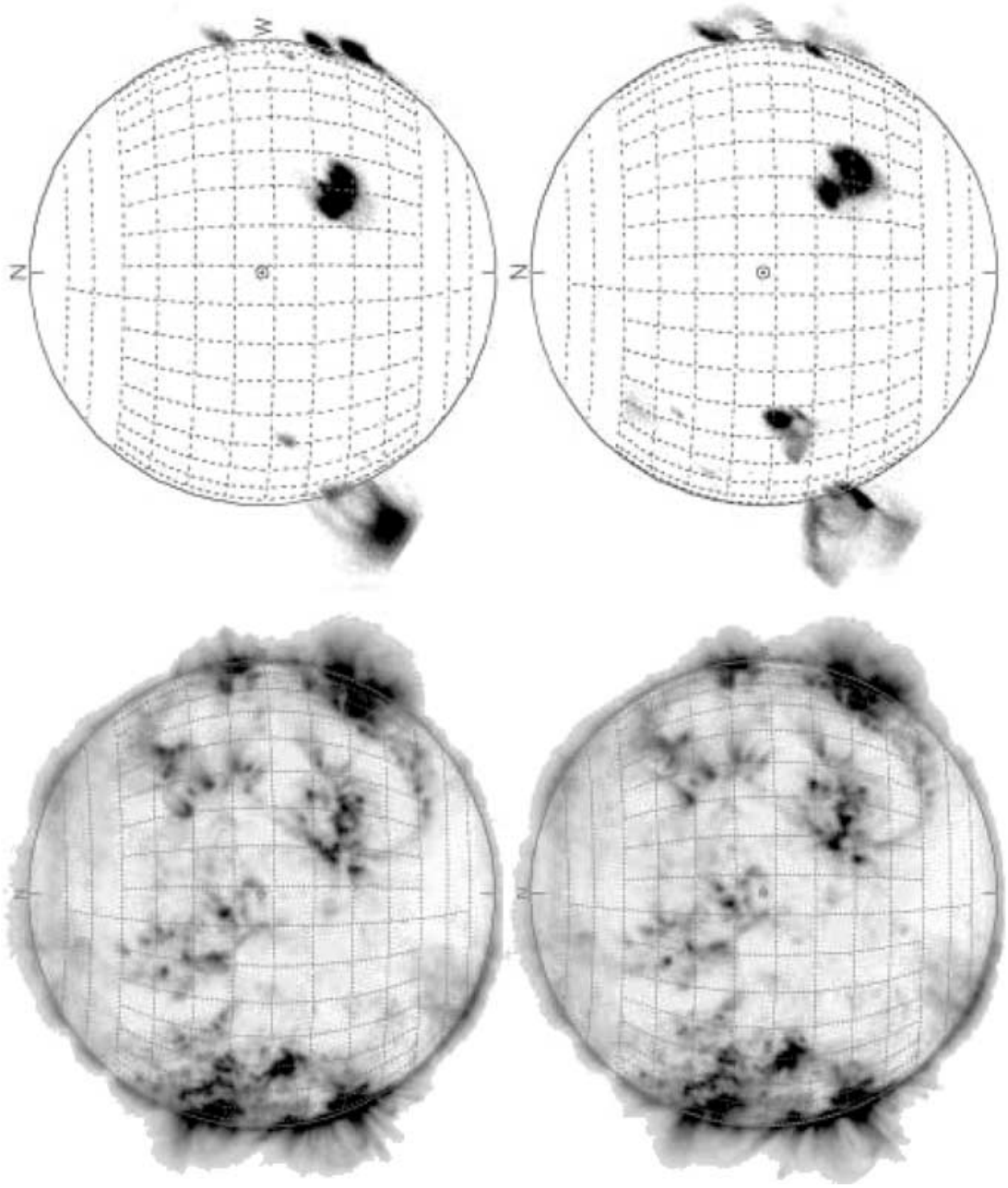

Figure 2. Two images in the Mg XII resonance line of 8.42 Å emission on 2001 November 12 taken, respectively, at 19.14 and 23.53 UT with juxtaposed Fe XI (175 Å) images.

July 31, more than 10 000 full-Sun images revealing on-disc and off-limb distribution of hot plasma at the temperatures in the range 3–20 MK were obtained. Quick look inspection of these images along with that recorded by the SRT Fe XI channel (175 Å) brought out that the plasma heated to such temperatures is constrained within the solar corona sites associated with active regions. Temporal sequences of pictures with short exposure times about 10 s revealed specific features of recently discovered structures in monochromatic emission and their dynamical properties.

Fig. 2 shows two representative pictures of Mg XII emission on 2001 November 12 taken, respectively, at 19.14 and 23.53 UT with juxtaposed Fe XI images. On the south-east off-limb part of the image at 19.14 UT, a typical 'spider'-like source is seen with a characteristic knob 'body' located at a distance of about 0.25 solar radius and accompanied by less bright 'legs', which morphologically appeared as closed magnetic-loop systems. Similar structure is apparently seen as a projection on the disc at the south-west part of this image. There are also a few off-limb brightenings on the western part and one weak knot on the disc on the eastern one. An image taken about four and a half hours later demonstrates substantial restructuring of Mg XII sources: the bright knob in the south-east disappeared, and the off-limb loop systems and two sources on the limb changed their shapes and intensities. At the same time, there are no visible correlations between Mg XII and Fe XI images, neither in shape nor in dynamics. It is also worth noting that at that time the brightest off-limb spots correspond to the bottom of the loops. Another example of such a 'spider'-like structure is given in Fig. 3, where the Mg XII image is combined with that of the Fe XI channel. This

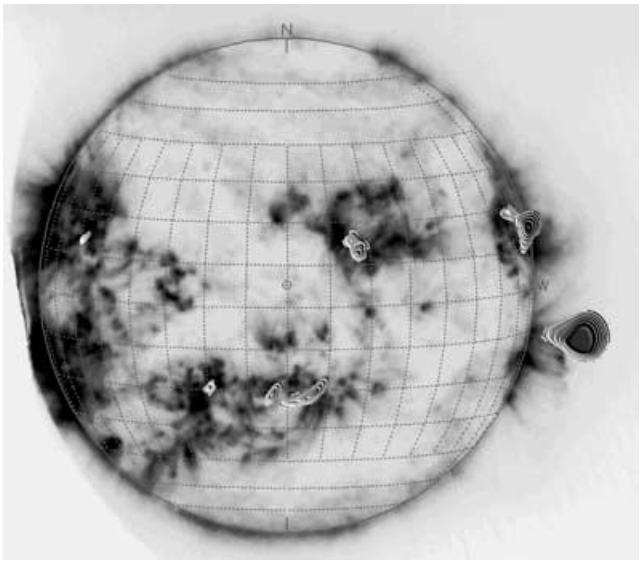

Figure 3. Mg XII image (given in contrasting black and white spots) of 2001 October 10 combined with that of the Fe XI (175 Å) channel.

picture distinctly shows the uncorrelated character of the spatial distributions for relatively cold (1.3 MK) and hot (3–20 MK) plasmas in active regions.

A study of temporal sequences of Mg XII emission showed substantially different variability in the dynamical behaviour of hot plasma structures, characterized by lifetimes from tens of seconds through days. Fig. 4 gives an example of on-limb series of 6 images taken of 2002 February 10 at about 09 UT for a period of about 16 min with exposure time 37 s. The activity in the Mg XII line is associated with the active-region system depicted in the Fe XI image also presented in this figure. A remarkable fact to note is that hot plasma emission does not coincide with 1.3 MK emission brightening. The image showed the complex structure of the emission flux intensity that occupied the area of about 3 × 3 arcmin consisted of clearly developed bright spots with characteristic size 30 arcsec (note that there are raw data not corrected for the instrumental function). The inspection of the whole series lasting about 30 min showed that these spots had variable intensities with lifetime between 1 and 30 min. The dynamical range for intensity changes of spots was about 10–100 times while the total flux integrated over the whole region changed by only a few times.

To provide a quantitative description of the phenomena observed, one has to have the information on the distribution of the DEM in the emitting volume. This information could be derived from the spectra simultaneously obtained with the SPIRIT *EUV* spectroheliograph. Preliminary analysis of the spectra of one 'spider'-like event and bright knot on the limb recorded on 2001 December 29 at 14.29 UT showed that the DEM has a peak at the temperature of about 10 MK. The log N_e estimated from the emission measure (EM) at this temperature is about 10.

The results of modelling and statistical analysis that will allow us to evaluate the energy content of the averaged transient events (sporadic condensations) seen in the Mg XII resonance-line emission will be given elsewhere.

4 CONCLUSIONS

We conclude the following.

(i) Monochromatic full-Sun images in the Mg XII resonance line at 8.42 Å obtained by the RES spectroheliograph on board the *CORONAS* satellites revealed coronal condensations. They are characterized by a temperature distribution in the 'window' 3–20 MK with a typical peak temperature of about 10 MK and log N_e of about 10.

(ii) More than 10 000 full-Sun images obtained by the SPIRIT Mg XII spectroheliograph on the *CORONAS-F* mission showed a constant presence of transient events on the solar disc and off-limb.

(iii) Compact plasma structures seen in the images are associated (but do not coincide) with some active region systems and are characterized by specific shape and dynamics, that are different from those of relatively low (1–2 MK) temperature active region plasma.

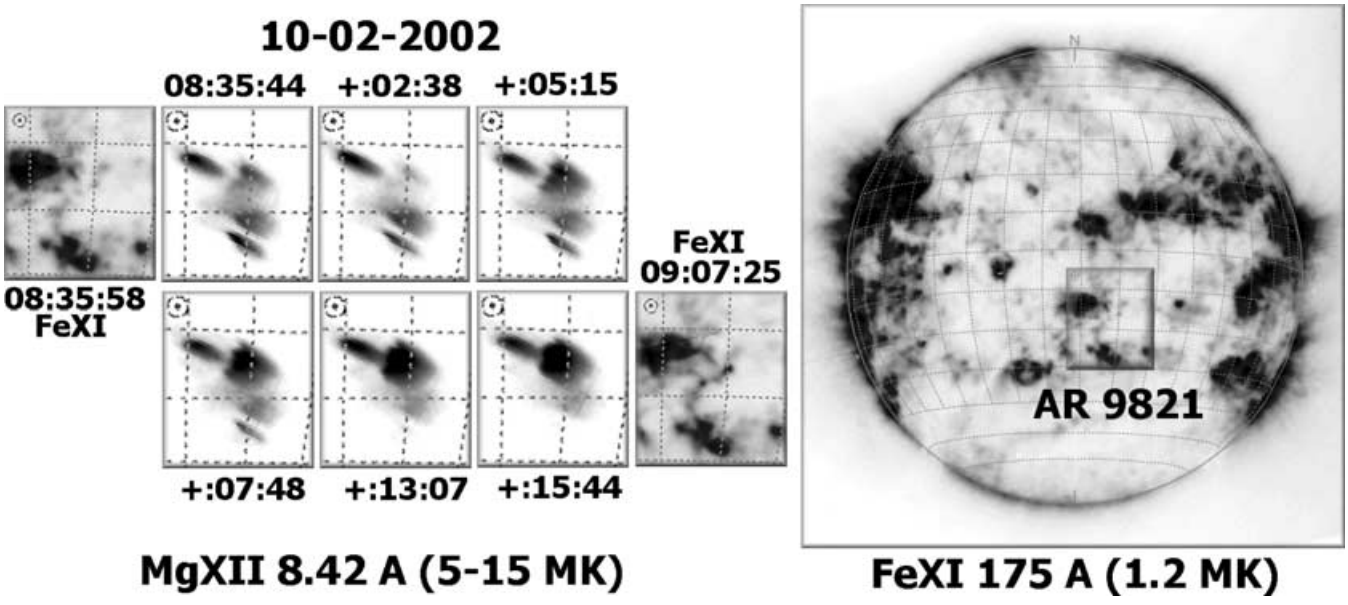

Figure 4. Series of 6 Mg XII images taken on 2002 February 10 at about 09 UT for a period of about 9 min with exposure time 37 s.

(iv) The following features of these structures could be marked:

(a) high spatial variability in brightness with a contrast of more than two orders of magnitude;

(b) presence of some compact 10 MK sources at high altitudes up to 0.3 solar radius with well distinguished 'spider'-like forms;

(c) substantial variability in dynamical behaviour characterized by lifetime from minutes up to days.

Monochromatic (Mg XII) full-Sun images along with simultaneous imaging spectroscopy in the regions 177–207 and 285–335 Å provided by the current experiment SPIRIT on board the *CORONAS-F* mission is a powerful tool for the study of transient coronal phenomena in the temperature range 3–20 MK, which may also considerably complement the SXT/*Yohkoh* data. In future observations with the SPIRIT spectroheliograph, we plan to investigate the dynamics of flare plasma as well as of such other peculiar transient phenomena as CME and others.

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REFERENCES

Golub L., Pasachoff J. M., 1997, The Solar Corona. Cambridge Univ. Press, Cambridge

Grineva Yu. I., Karev V. I., Korneev V. V., Krutov V. V., Mandelstam S. L., Vainstein L. A., Vasilyev B. N., Zhitnik I. A., 1973, Solar Phys., 29, 441

Hudson H., 1994, in Enome S., Hirayama T., eds, Proc. Kofu Symp., NRO Report 360, Japan, p. 1

Jakimec J., Korneev V. V., Krutov V. V., Zhitnik I. A., 1975, Solar Phys., 44, 391

Orayevskii V. N., Sobelman I. I., 2002, Russian: Pis'ma v Astron. Zh., 28, 457

Schmelz J. T., Saba J. L. R., Strong K. T., Winter H. D., Brosius J. W., 1999, ApJ, 523, 432

Sobelman I. I., Zhitnik I. A. et al., 1996, Russian: Pis'ma v Astron. Zh., 22, 604; English translation in Astron. Lett., 22, 539

Zhitnik I. A., Korneev V. V., Oparin S. N., 1989, Trudi FIAN, 195, 73, (in Russian); English translation: 1992, Proc. P. N. Lebedev Physical Institute, Vol. 195

Zhitnik I. A., Bkuzin S., Bugaenko O., 2002a, Adv. Space Res., submitted

Zhitnik I. A., Afanas'ev A., Kusin S., 2002b, Adv. Space Res., submitted