Mem. S.A.It. Vol. 78, 591

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Magnetic activity and the solar corona: first results from the Hinode satellite

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Abstract. The structure, dynamics and evolution of the solar corona are governed by the magnetic field. In spite of significant progresses in our insight of the physics of the solar corona, several problems are still under debate, e.g. the role of impulsive events and waves in coronal heating, and the origin of eruptions, flares and CMEs. The Hinode mission has started on 22 september 2006 and aims at giving new answers to these questions. The satellite contains three main instruments, two high resolution telescopes, one in the optical and one in the X-ray band, and an EUV imaging spectrometer. On the Italian side, INAF/Osservatorio Astronomico di Palermo has contributed with the ground-calibration of the filters of the X-ray telescope. We present some preliminary mission results, with particular attention to the X-ray telescope data.

Key words. Sun: corona – Sun: magnetic field – Sun: X-rays – Sun: UV

1. Introduction

The study of the colar corona has made large steps forwards since the launch of the first telescopes outside the earth atmosphere, which have allowed us to collect the X-ray radiation from the Sun. In the 70s the S054 X-ray telescope on board the Skylab mission (Vaiana etal. 1973) first monitored the corona for significant parts of a solar rotation and led to a first breakthrough in our insight of the structure, dynamics and physics of the corona. The Solar Maximum Mission (SMM, Bohlin et al. 1980) addressed the most dynamic and energetic events on the Sun, the flares, and achieved high resolution X-ray spectroscopy, by means of Bragg crystal spectrometers. The

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Yohkoh mission (1991-2001, Ogawara et al. 1991) monitored and imaged the solar corona during a whole solar cycle The SoHO mission (Domingo et al. 1995), an ESA/NASA cornerstone, has been launched in 1995 and is still active, with more than ten instruments. It is capable of EUV spectroscopy and imaging. The TRACE mission (Handy et al. 1999), launched in 1998 and still operating, images the EUV Sun with very high spatial resolution (0.5").

All these missions have enphasized the crucial role of the solar magnetic field in confining, heating and accelerating the coronal plasma. In typical coronal conditions the plasma moves and transports energy along the magnetic field lines. Since it is optically thin, and the emission scales as the square of the density, the brightest part of the corona consists of regions full of closed magnetic structures, the so-called coronal loops, where the plasma is strongly confined and therefore denser. Coronal loops can be found on several spatial scales, from $\sim 10^8$ cm (bright points) to $\gtrsim 10^{10}$ cm (large scale structures) and typically live on time scales of several hours, longer than the typical cooling time scales (e.g. Vaiana et al. 1973a, Serio et al. 1981). Therefore, coronal heating mechanisms are invoked to act on time scales as long as to maintain the coronal structures steady. On the other hand coronal loops are the site of very dynamic events, from fast brightening, to explosive flares, lasting from several minutes to many hours. Although the space missions have provided a wealth of useful observational data and have contributed to explain many aspects of the link between the dynamic and heated corona and the solar magnetic field, the details of how the magnetic field releases its energy and determines the plasma dynamics is still unclear and under debate (e.g. Reale & Ciaravella 2006, Klimchuk 2006). Further questions have been opened by new dynamic phenomena detected thanks to the higher temporal and spatial resolution achieved by the new missions.

2. The Hinode mission

Hinode is the successor to the orbiting solar observatory Yohkoh and was launched on 23 September 2006 (Fig. 1). The mission consists of a coordinated set of optical, X-ray and EUV telescopes. The satellite had been coordinated and developed by the United Kingdom, the United States and Japan, each with the following main responsibilities: the satellite systems were developed by JAXA and Mitsubishi Electric Corporation. The large solar optical telescope (SOT) was jointly developed by the United States and Japan. JAXA and the National Astronomical Observatory of Japan worked on the telescope optics and the U.S. National Aeronautics and Space Administration (NASA) developed the focal-plane package (FPP). For the X-ray telescope (XRT), NASA provided grazing-incidence mirror optics, and JAXA the CCD camera. Development of the Extreme Ultraviolet (EUV) Imaging Spectrometer is being led by the Particle Physics and Astronomy Research Council (PPARC) of the United Kingdom with the support of NASA and JAXA.

The Hinode spacecraft is built around the optical telescope assembly (OTA). The focal plane package (FPP) of the OTA, the XRT and EIS are strapped to the sides of the OTA. The payload has a dry weight of 875 kg. The solar arrays provide 1000 W of power and the telemetry system has a downlink capability of 4.2 Mbps. ESA is providing 15 contacts per day from Svalbard to supplement the four day passes at Kashima for a total of $\sim$ 7 GB per day.

The optical telescope (SOT) is a diffraction limited, aplanatic Gregorian in the band 388-670 nm, with an aperture of 0.5 m. It provides angular resolution of about 0.2 arcsec at 400 nm over the field of view of about 4 x 4 arcmin^2. The focal plane package of the optical telescope consists of a filter vector magnetograph and a spectro-polarimeter. This combination is able to provide a continuous series of high-precision vector magnetograms, Dopplergrams, and filtergrams with sub-arcsec resolution.

The Extreme Ultraviolet Imaging Spectrometer (EIS) provides spatially resolved high resolution spectra and aims at determining velocity fields and other plasma

Fig. 1. The X-Ray Telescope (XRT) is one of the main instruments on board the Hinode satellite.

parameters in the corona and transition region. It is sensitive in the wavebands 170-210 Åand 250-290 Å, where intense Fe lines are present. The spatial and spectral resolution are about 1 arcsec, and 2.23 mÅ/pixel respectively. The minimum slit is 1×512 arcsec^2.

The grazing-incidence X-ray telescope (XRT, Golub et al. 2007) images the high temperature (1 to 30 MK) corona with high angular resolution, a few times better than the soft X-ray telescope on board Yohkoh, through several filters so to provide temperature and density diagnostics. The telescope is a modified Wolter I with a 35 cm aperture and a 2.71 m focal length. It provides a flare flag to alert the other instruments. The angular resolution is ≈ 1 arcsec, the encircled energy is 68% within a 2 arcsec diameter circle at 0.523 keV. The CCD is 2048×2048 pixels corresponding to a field of view of 35×35 arcmin. It includes a visible light optic. The optics are mounted at one end of the telescope tube. At the other end there are two filter wheels with analysis filter, the main shutter and a camera. XRT enables several algorithms to maximize the quality of the observations.

2.1. XRT calibration at Palermo OAPa/XACT

Several of the ight focal plane lters for the XRT were tested at the X-Ray Astronomy Calibration and Testing (XACT) facility of INAF-Osservatorio Astronomica di Palermo. The goal of these calibrations was to determine

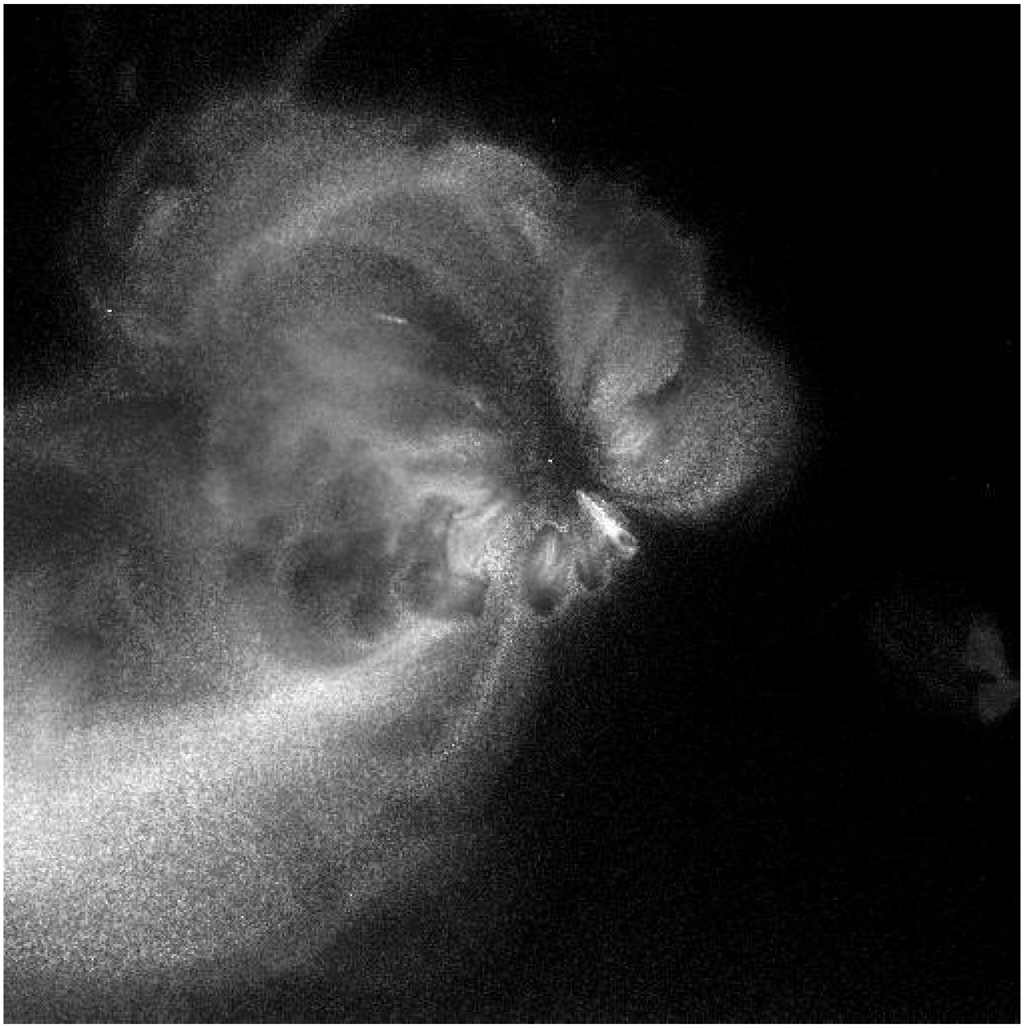

Fig. 2. Map of the ratio of the emission in the Al-medium filter passband and in the Al-poly filter passband of the active region observed with Hinode/XRT on 12 November 2006. This ratio is a proxy of the temperature for isothermal plasma long the line of sight. In this grey scale, bright is hot and dark is cool. The approximate temperature range is $6.1 < \log T < 6.6$.

the spatial uniformity of the lters and the transmission properties (Barbera et al., 2004). Three different set-ups were adopted. The shadowgraphs provided transmission maps for each of the filters. Transmission measurements below and above 2 keV provided average X-ray curves of the filter as a function of energy, and constraints on the areal density of the filter materials. Of the nine lters tested seven are installed in the XRT, since several were damaged in shipping and needed to be replaced. The results show that the spatial uniformity is 2% or better for the metal on polyimide lters and better than 3.3% for the single metal lters. The transmission tests showed that the results were within 5-10% of the predicted values.

3. XRT observations

The X-ray telescope has been designed to achieve several scientific goals. The main ones include the origin and triggering of Coronal Mass Ejections, the heating of coronal structures, the presence of waves and the role of the interaction between the structures, the details of magnetic reconnection, the dynamics and energetics of flares, the coupling of the corona to the photosphere, the energy transfer to the corona. To these purposes several observation modes have been set up; the analysis of the coronal dynamics requires sensitivity to rapid evolution and therefore frequent sampling at high cadence; the study of the plasma energetics requires the capability to recover the thermal structure and evolution and this can be obtained from observations with multiple filters; the analysis of the coronal structure topology requires the monitoring of the magnetic activity on a large scale and therefore the observation with large field of view and with long and short exposures to achieve a large dynamic range of emission.

Here we present a preliminary result which shows the kind of diagnostics expected from the X-ray data of Hinode/XRT. Fig. 2 shows the map of the ratio of the emission in two XRT filter passbands of the active region observed with Hinode on 12 November 2006. This ratio is a proxy of the temperature for a plasma isothermal along the line of sight (Vaiana et al. 1973a, Tsuneta et al. 1992). This kind of maps will be extremely useful to study the temperature distribution of the plasma in coronal regions and therefore for the diagnostics of the coronal heating. For instance, these studies will contribute to clarify the role of fast heating episodes (nanoflare) in the global energy budget of the corona (e.g. Parker 1988, Cargill 1994, Cargill & Klimchuk 2004).

Acknowledgements. Hinode is a Japanese mission developed and launched by ISAS/JAXA, with NAOJ as domestic partner and NASA and STFC (UK) as international partners. It is operated by these agencies in co-operation with ESA and NSC (Norway). FR, GP and MB acknowledge support from Italian Ministero dell'Università e Ricerca and Agenzia Spaziale Italiana (ASI). US members of the XRT team are supported by NASA contract NNM07AA02C to SAO. SP acknowledge the support from the Belgian Federal Science Policy Office through the ESA-PRODEX programme. This work was partially supported by the International Space Science Institute in the framework of an international working team.

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