



IMAGING THE SOLAR CORONA IN THE EUV

J. -P. Delaboudiniere*, R. A. Stern***, A. Maucherat**, F. Portier-Fozzani**,
 W. M. Neupert†, J. B. Gurman†, R. C. Catura***, J. R. Lemen***, L. Shing***,
 G. E. Artzner*, J. Brunaud*, A. H. Gabriel*, D. J. Michels‡, J. D. Moses‡, B. Au‡,
 K. P. Dere‡, R. A. Howard‡, R. Kreplin‡, J. M. Defise⁶, C. Jamar⁶, P. Rochus⁶,
 J. P. Chauvineau⁷, J. P. Marioge⁷, F. Clette⁸, P. Cugnon⁸ and E. L. Van Dessel⁸

*Institut. d' Astrophysique Spatiale, Universite Paris XI, 91405 Orsay Cedex, France

**Laboratoire d' Astronomie Spatiale, BP8, 13376 Marseille 12, France

***Solar and Astrophysics Laboratory, Lockheed Martin, Palo Alto, CA 94304, U.S.A.

†NASA/Goddard Space Flight Center, Greenbelt, MD, U.S.A.

‡Naval Research Laboratory, Washington, DC 20365, U.S.A.

⁶Center Spatial de Liege, Liege, Belgium

⁷Institut d' Optique Theorique et Appliquee, 91403 Orsay, France

⁸Observatoire Royal de Belgique, Brussels, Belgium

ABSTRACT

The SOHO (Solar and Heliospheric Observatory) satellite was launched on December 2nd 1995. After arriving at the Earth-Sun (L1) Lagrangian point on February 14th 1996, it began to continuously observe the Sun. As one of the instruments onboard SOHO, the EIT (Extreme ultraviolet Imaging Telescope) images the Sun's corona in 4 EUV wavelengths. The He II filter at 304 Å images the chromosphere and the base of the transition region at a temperature of $5 - 8 \times 10^4$ K; the Fe IX-X filter at 171 Å images the corona at a temperature of $\sim 1.3 \times 10^6$ K; the Fe XII filter at 195 Å images the quiet corona outside coronal holes at a temperature of $\sim 1.6 \times 10^6$ K; and the Fe XV filter at 284 Å images active regions with a temperature of $\sim 2.0 \times 10^6$ K. About 5000 images have been obtained up to the present. In this paper, we describe also some aspects of the telescope and the detector performance for application in the observations. Images and movies of all the wavelengths allow a look at different phenomena present in the Sun's corona, and in particular, magnetic field reconnection.

© 1997 COSPAR. Published by Elsevier Science Ltd.

INTRODUCTION

The SOHO (Solar and Heliospheric Observatory) satellite, which is completely dedicated to understanding the physics of the Sun, was launched December 2nd 1995. Having arrived at its working orbit on February 14th 1996, it is now able to continuously observe the Sun from the Lagrangian L1 (Earth-Sun) point. The EIT (Extreme ultraviolet Imaging Telescope), one of the instruments onboard SOHO, images the Sun's corona and transition region in 4 EUV wavelengths. EIT's first light occurred on January 2, 1996 and the instrument was declared operational on January 15th, 1996. In this paper we discuss the instrument, the operations and the first results of EIT observations.

THE EIT INSTRUMENT

The EIT telescope uses a modified wide-field Ritchey-Chretien design, (Delaboudinière 1989b, Chauvineau 1991). With a full field of view of 45×45 arcmin, the telescope has an effective focal length of 1.652 m and a primary diameter of 0.12 m.

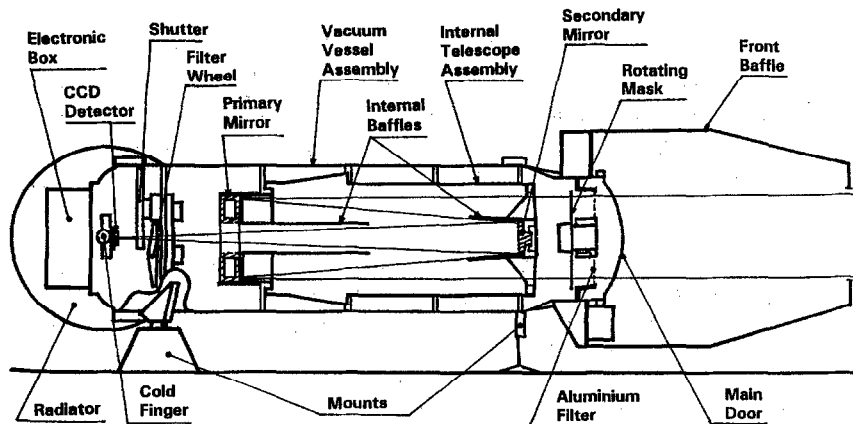


Figure 1: The EIT instrument

The mirror is divided into 4 sectors (geometrical area per quadrant = 0.0013 m^2), to isolate with appropriate filters the emission in narrow wavelength ranges. Four separate multilayers are deposited on the matched quadrants of both the primary and secondary mirrors of the telescope. A rotating mask allows only a single multilayer-coated quadrant of the telescope to be illuminated by the Sun at any time. The image from a selectable single EIT quadrant is focused on a back-illuminated CCD (1024×1024 pixels, 1 pixel = $21 \times 21 \mu\text{m}^2 = 2.6 \times 2.6 \text{ arcsec}^2$) with good efficiency at extreme-ultraviolet (EUV) wavelengths. The CCD is also sensitive to visible light, so 2 aluminium filters were used as visible blockers. These blocking aluminium filters in EIT are mechanically supported by nickel meshes which create a grid pattern in the focal plane. Another Al filter on a filter wheel can also be introduced in the field, if necessary. The telescope is contained in a vacuum enclosure for cleanliness and to reduce acoustical loads on the thin-film filters during launch. The main door at the front of the telescope was opened after spacecraft outgassing and may be re-closed when thrusters are fired for SOHO station keeping. The CCD is cooled to about -65°C by a cold finger attached to a passive radiator facing deep space. The CCD was calibrated at Orsay and Lockheed Martin and the entire instrument was calibrated at IAS, using the Orsay synchrotron (Song 1995). A more detailed description of the EIT instrument and calibration may be found in Delaboudinière *et al.* (1995).

Operations

The baseline observation plan consists of taking full field of view images in all four bandpasses one to three times per day (joint EIT/LASCO synoptic plan). In addition, smaller size images can also be obtained.

LASCO and EIT have the same electronic box. The telemetry of EIT is shared with the 3 coronagraphs of LASCO which observes the corona in visible wavelengths. EIT uses, on average, about 20 percent of the total telemetry capability and computer resources available to the EIT/LASCO experiments. The combined telemetry rate is 5.2 Kbps . For short time periods 26.2 Kbps can be made available using the telemetry allocation of the other instruments.

Data compression routines allow the storage/transmission requirements for an image to be reduced by a factor of 2-4 using a loss-less Rice compression algorithm. It then takes 22 minutes to transmit a full 1024×1024 image. To study smaller regions on the Sun at faster rate, sub-arrays of pixels,

each 32×32 (83×83 arcsec) in size, may be read out while the rest of the CCD field is discarded. Missing pixels due to transmission problems represent less than 1 percent of the total image.

Extraction of the grid from images:

The grid pattern created by the filter support mesh must be removed from the images prior to scientific analysis.

One approach to this problem uses the classical Fourier method with a FFT followed by filtering. Results obtained by adding many images permit removal of the grid pattern (F.Clette & al., 1996).

Response of the CCD with time:

During the first months of EIT operations, it became apparent that the instrument response was decreasing with time. This effect can be seen by plotting counts per unit time in full-field EIT images in each of the four sectors from the start of operations (see Fig. 3). Note that the 304 Å channel shows the greatest change with time, and the greatest recovery after periods of warming up the CCD (bakeouts). Bakeouts were performed on 1996 May 23 - 25 and 1996 June 23 - 24. After the second bakeout, the 304 Å response returned to approximately the same level as after the first bakeout. Given the shorter duration of the second bakeout (24 hours vs. 48), this may be considered supporting evidence that we are seeing the effects of (organic ?) ice condensing on the detector. However, the phenomenology of the response variations is not well understood at present.

EIT SCIENCE TOPICS

The consortium of EIT investigators has developed a list of science topics which will be investigated through EIT observations and analysis. These are not meant to be exclusive or to indicate permanent rights of any sort, but it would benefit any prospective Guest Investigator (official or otherwise) to read the full list of science topics and lead consortium members (available on the World Wide Web at: <http://umbra.nascom.nasa.gov/eit/>) and to contact them prior to requesting use of EIT data. Some of the science areas to be investigated are:

- Morphology and evolution of loops in the corona (quiescent features)
- Signatures of coronal heating, including waves, nanoflares, emerging flux regions, and magnetic shear

INSTRUMENT OPERATIONS AND PERFORMANCE

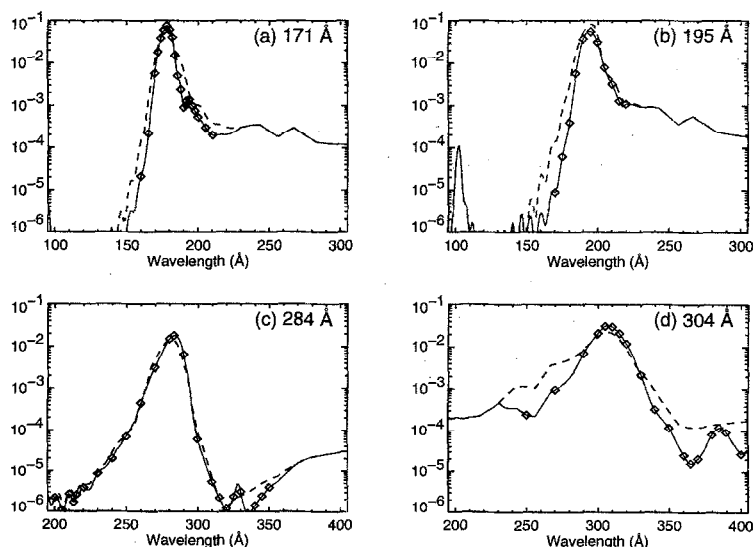


Figure 2: The two-mirror reflection efficiency for each EIT quadrant. Measured values are shown as data points; dashed and solid curves represent the predicted and adopted values respectively.

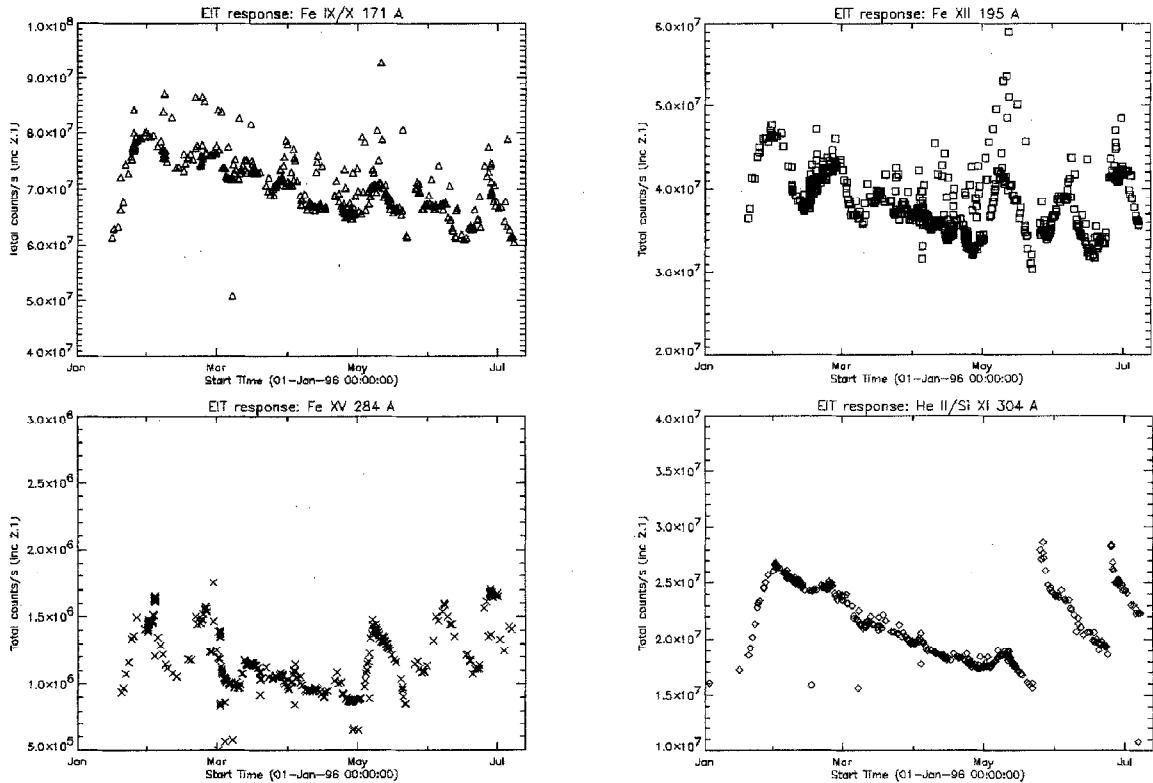


Figure 3: Variation during the Sun's observation in each wavelength (linear scales)

- Sources of the solar wind and interplanetary disturbances, including coronal plumes, transient events
- Properties of He II emission and structures
- Properties and evolution of the large scale corona
- EUV proxies and EUV source modeling; correlations with SEM, LASCO, and ground based images

STEREOVIEWS AND MOVIES

By using coronal rotation, we obtained a pair of stereoviews (1 to 5 hours between right and left views) that give an idea of long lived coronal morphologies (loops, coronal holes, plumes) (Koutchmy 1994).

A special Carrington grid that appears to vanish under bright plasma clouds (providing a visual reference for the solar surface) is superposed on the images. Stereo movies can be also created with help of numerous intermediate images generated by interpolation between two consecutive images.

Stereomodels of polar plumes adapted from Walker and Deforest (1993) are developed and compared with stereoviews to obtain morphology, orientation and evolution of polar plumes.

ACTIVITY IN CORONAL HOLES AND POLAR PLUMES

One of the most exciting results to have come from early EIT observations has been the realization that solar activity continues at all levels, even during Solar Minimum and even in coronal holes. EIT movies made of the south polar coronal hole during the early operational phases of EIT demonstrate

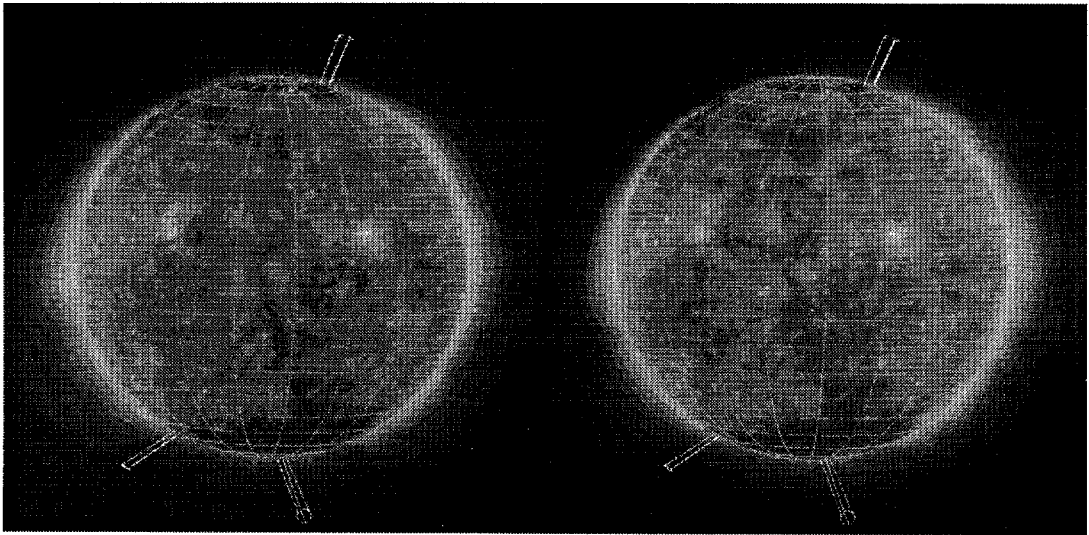


Figure 4: Respectively the left and right pictures for stereovision effect (full images of the Sun at 195 Å (FeXII) taken April 17th, 1996)

transient brightenings in coronal holes on surprisingly short (2 - 10 minutes) time scales. In addition, the EIT movies have revealed the source areas of polar plumes as regions of possible magnetic flux reconnection and at least in some cases, of mass ejections in "microjets."

CONCLUSION

The EIT is a very versatile instrument that provides full-Sun EUV images covering temperatures characteristic of the chromosphere to the corona. EIT's spatial (2.6 arcsec pixels) and diagnostic capabilities allows us to study a wide range of coronal problems (see Fig. 5) and enhances the studies made by other diagnostic instruments on the SOHO spacecraft. The EIT images are an important link between observations of the inner and outer corona and will also play an important role in correlating SOHO data with ground-based observations.

ACKNOWLEDGEMENTS

French laboratories (IAS, IOTA and LAS) were supported by CNRS and CNES. Belgian laboratories were funded by SPPS via PRODEX. NRL received support from the Office of Naval Research and from NASA through contract DPR S-19506-E. LSAL acknowledges NASA support through contract NAS5-32627 and NRL contract N00014-90-C-2346 and from the Lockheed Independent Research Program. We benefited greatly from the work of Dr. Barry Labonte of the Yohkoh SXT team who provided an IDL version of the flat-field algorithm of Kuhn et al. (1991). We thank R. Nakatsuka, E. E. Einfalt and S. L. Freeland for aid in developing the ground data analysis system and software. G. Holland contributed greatly to this project by his extensive innovation in vacuum related technologies. We are indebted to the Scientific Imaging Technologies Inc., Tektronix for fabricating the CCDs used in this investigation. We acknowledge the work of the Physikalisch-Technische Studien G.M.B.H. (Germany) and the Luxel Corporation (USA) in fabricating the thin-film filters for the EIT. We thank the referee for his useful comments.

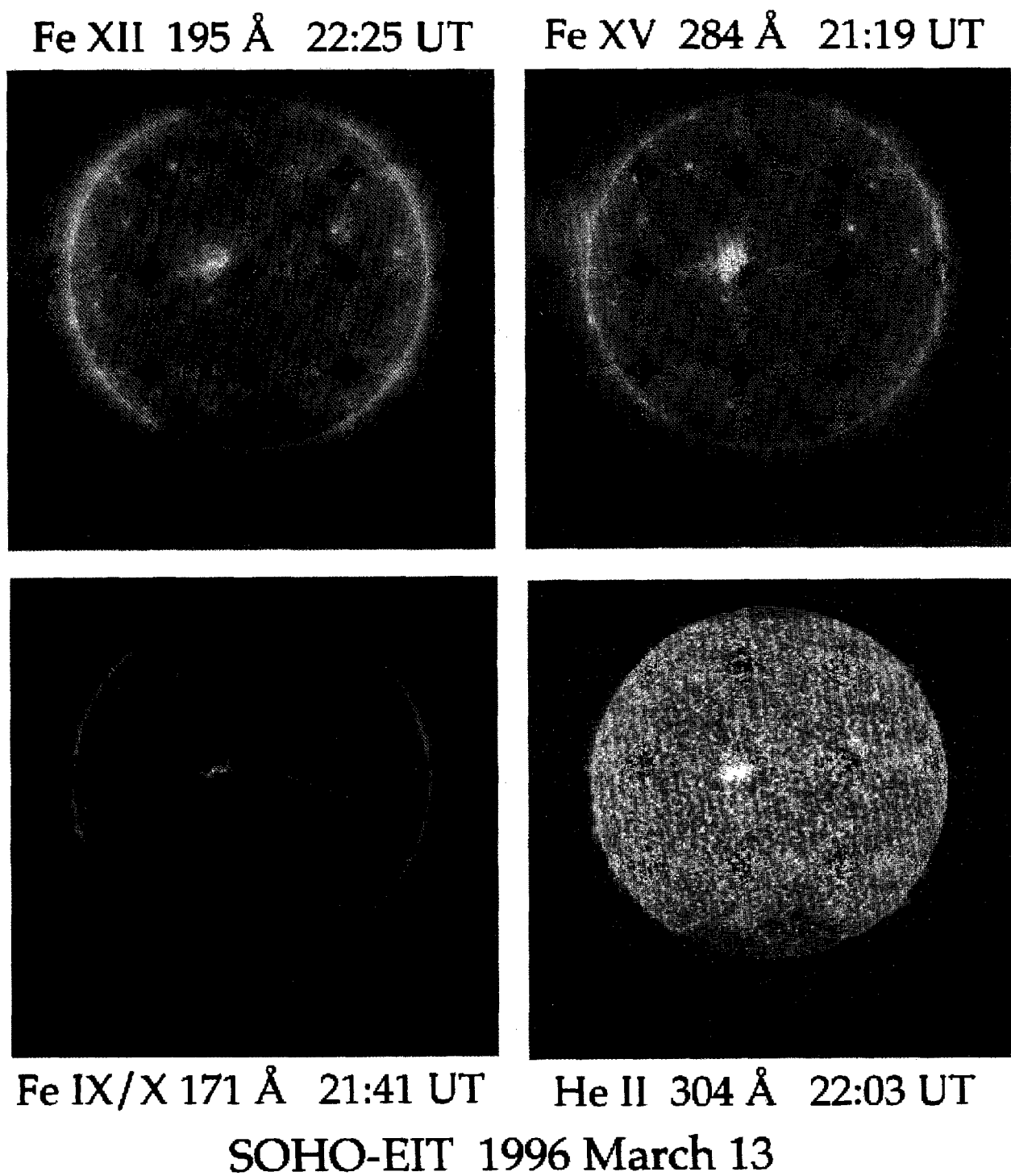


Figure 5: Structures of the corona revealed by full disk images of the 4 different lines of SOHO/EIT

REFERENCES

1. J.-P. Delaboudinière & al . , EIT: Extreme ultraviolet imaging telescope for the SOHO mission, *Solar Physics*, 162, p 291-312, (1995)
2. J.-P. Delaboudinière & al . , Solar corona synoptic observations from SOHO with an Extreme Ultraviolet imaging Telescope, ESA (European Space Agency) & NASA (National Aeronautics and Space Administration), *esa sp-1104*, (1989)
3. Eds by B. Fleck, V. Domingo & A.I. Poland, The SOHO Mission, *Solar Physics*, 162, 1-2, (1995)
4. F. Portier-Fozzani & al . , EIT images of the EUV solar atmosphere : initial data reduction, proceeding of Yohkoh Bath reconnection meeting, March 1996, *PASJ Conf Series*, (1996)
5. A. Maucherat, F. Portier-Fozzani & A. Martial, internal note about stereovision, (June 1996)
6. W. Neupert & al., internal note about science with EIT, (May 1996)
7. Song, X.Y., Thesis, Universite d'Orsay (France), (1995)
8. Walker A.B.C., Jr., DeForest, C., E., Hoover, R.B., Barbee, T.W. , Jr. *Sol. Phys.*, 148, 239 (1993)
9. Koutchmy S., Molodensky M.M., Vial J.C., IAU Colloq.144 "Solar Structures", V. Rusin, P. Heinzel, J.C. Vial, p 585 VEDA Bratislava, (1994)
10. Batchelor D., "Quasi-stereoscopic imaging of the solar X-ray corona", *Solar Physics*, 155, 57B, (1994)