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Electron Density Measurement in an Active Region observed By Extreme Ultraviolet Imaging Spectrometer (EIS) on Hinode

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Abstract

Active regions are the brightest features seen on the Sun's surface when observing in ultra-violet and X-rays. They are the structures of complex magnetic topology and most of the high energy explosions such as flares and coronal mass ejections (CMEs) originate from active regions. The Extreme-ultraviolet Imaging Spectrometer (EIS) on board Hinode provides an excellent opportunity to study the physical plasma parameters in spatially resolved coronal structures. Using spectral observations performed over an active region on February 07, 2007 with the EIS spectrometer on Hinode, we study the density structure at different temperatures. To analyze the density structure we compare density ratios of a series of iron lines Fe XII 186.88 Å , Fe XII 195.12 Å, Fe XIII 202.04 Å, Fe XIII 203.82 Å, Fe XIV 264.79 Å and Fe XIV 274.20 Å observed by the Hinode/EUV Imaging Spectrometer (EIS). We found that the electron density in the observed active region (AR 10940) varies from 10^8 -10^{12} cm^{-3} and is highest in the core of this active region.

Key words: Sun, Corona, Active region, Hinode, EIS, X-rays.

Introduction

Hinode or Solar-B is the follow up to the highly successful Japanese satellite YOHKOH (Solar-A). It is an international collaboration between Japan (ISAS), the USA (NASA), the UK (PPARC), ESA and Norway. The Solar-B payload comprises three instruments: the Solar Optical Telescope (SOT), the X-ray Telescope (XRT) and the EUV Imaging Spectrometer (EIS). The details of the instrument Extreme Ultraviolet Imaging Spectrometer (EIS) on board Hinode have been described in details[1-2]. EIS has an off-axis paraboloid design, with multilayer toroidal gratings and produces spectra and images in two narrow wavelength bands in the EUV; short-wavelength (SW: 163–209Å) and a long-wavelength (LW: 242–289Å). It is a representative of a new generation of instruments, which regard high spatial imaging and high spectral resolution as equally important.

Density is a fundamental plasma parameter and line intensity ratios from various iron lines can be used to obtain electron density in solar active regions and coronal magnetic structures at temperature of the order of MK. The best density diagnostics for solar active regions and coronal structures belong to the set of iron emission lines Fe X-XVI. These emission lines arise due to the complex atomic structures of these iron ions that lead to a number of metastable levels which are the source of the density sensitivity of the emission line ratios[3]. The density diagnostics of these iron ions are mostly found below 300 Å, a wavelength region well covered by EUV Imaging Spectrometer (EIS) on board the Hinode satellite launched during 2006 September. The high sensitivity of the EIS instrument is enabled by a simple optical design that incorporates multilayer coatings. The density diagnostic capability of various iron emission lines has been established by many researchers[4-5]. The six emission lines used in the present work (Fe XII 186.88 Å, Fe XII 195.12 Å, Fe XIII 202.04 Å, Fe XIII 203.82 Å, Fe XIV 264.79 Å, and Fe XIV 274.20 Å) were already discussed by several authors to give good agreement with other line ratios from Fe XII[6-7]. They also pointed out that lines such as Fe XII 186.88 Å, Fe XIII 203.82 Å and Fe XVI 274.20 Å are affected by line blending.

Active regions having most complex magnetic topology are the brightest features seen on the Sun's surface in ultra-violet and X-rays. The high energy explosive events such as flares and coronal mass ejections (CMEs), that directly affects space weather and geo-space climate, originate from active regions[8]. For density diagnostic, the emission lines ratio technique has been used for an active region observed by Coronal Diagnostic Spectrometer on board SoHO[9]. It has been found that the core of the active region was denser and hotter as compared to the outer region. Since comparison of electron densities at different temperatures was not possible due to limited temperature coverage and a limited number of density and temperature sensitive spectral lines. So, in this paper, we are presenting overall intensity and density structures of an active region that demonstrate the plasma diagnostic power of EIS.

Observations and Data Reduction Technique: In this paper we discuss the observations of EIS study 'GAD002_AR_rast' of an active region (AR10940) observed on 2007 February 7 near 00:27:12 UT that comprises 20 spectral lines covering a broad range of temperatures represented by ions formed in the lower transition region (He II) at temperature of about 50,000 K and in corona at temperature of about 5×10^6 K (Ca XVII). The data were obtained with 1″ slit in scanning mode stepping west to east in steps of 1″. The exposure time at each slit position was 60 s. This study includes many different density sensitive iron ions lines, providing an opportunity to measure simultaneously electron densities at different temperatures. The images of the observed active region obtained from Extreme Ultraviolet Imaging Telescope (EIT) on board SOHO reveal that there is a small change in the overall configuration of the active region during the EIS raster time interval. For electron density diagnostic, the ratios of Fe XII lines [(186.89+186.85)Å/195.12Å], Fe XIII lines [(203.8+203.83)Å/202.04Å] and Fe XIV [264.79Å/274.20Å] are used to obtain electron density maps.

The EIS raw data (level-0 FITS) was pre-processed and calibrated by the standard SolarSoft EIS software package routine EIS_PREP. This routine subtracts the background from each spectral line, despikes (cosmic ray hits) the data, and converts data numbers to physical units (erg cm^{-2} s^{-1} sr^{-1} $Å^{-1}$). The central outputs of EIS_PREP are two level-1 FITS files, one containing calibrated intensities at each pixel, and the other containing error bars on these intensities. For Gaussians fit of EIS lines the standard Solarsoft routine EIS_AUTO_FIT have been implemented to automatically fit the calibrated line intensities from the spectral line windows output by the IDL routine EIS_GETWINDATA.

Results and Discussion

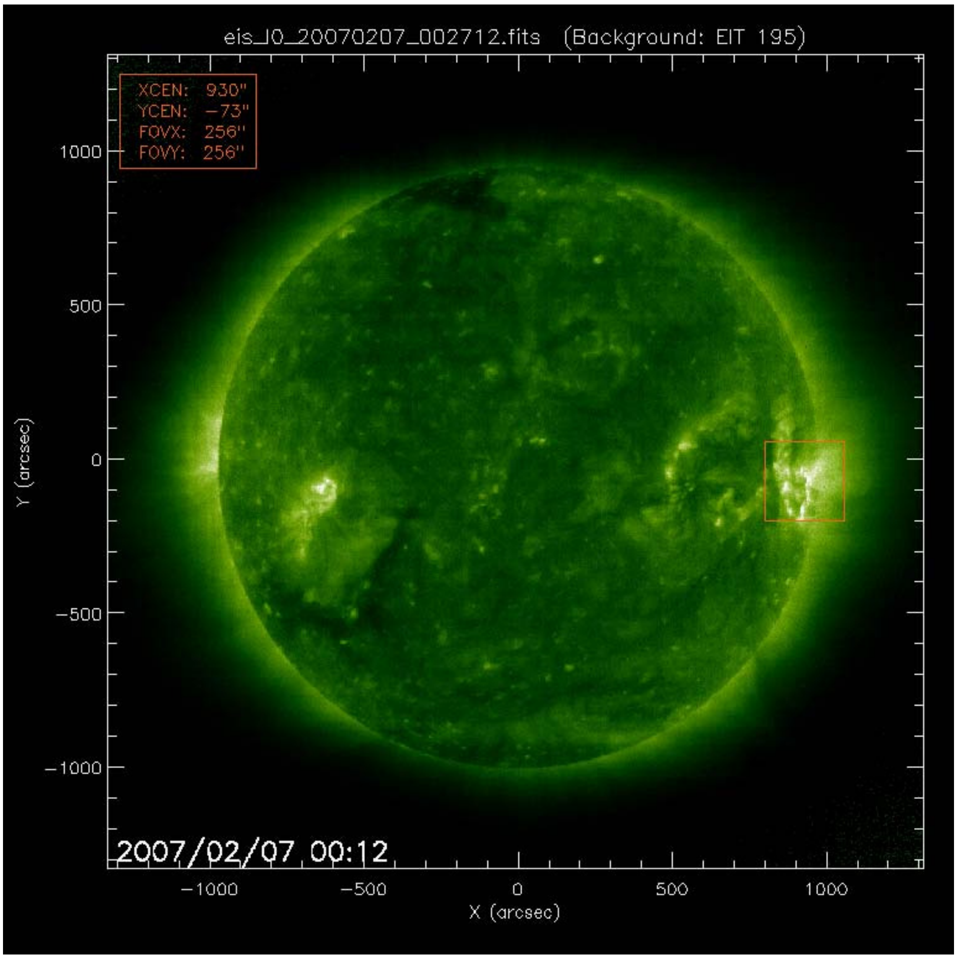

Figure - 1
Full-disk image from 195Å filter of EIT on February 7, 2007 at 00:27:12 UT showing the FOV of the EIS study

Figure 1 displays an image recorded by EIT on board SoHO in its 195Å passband showing the complete active region taken at 00:27:12 UT. The overplotted box on the EIT image represents the field of view (FOV) of the EIS raster.

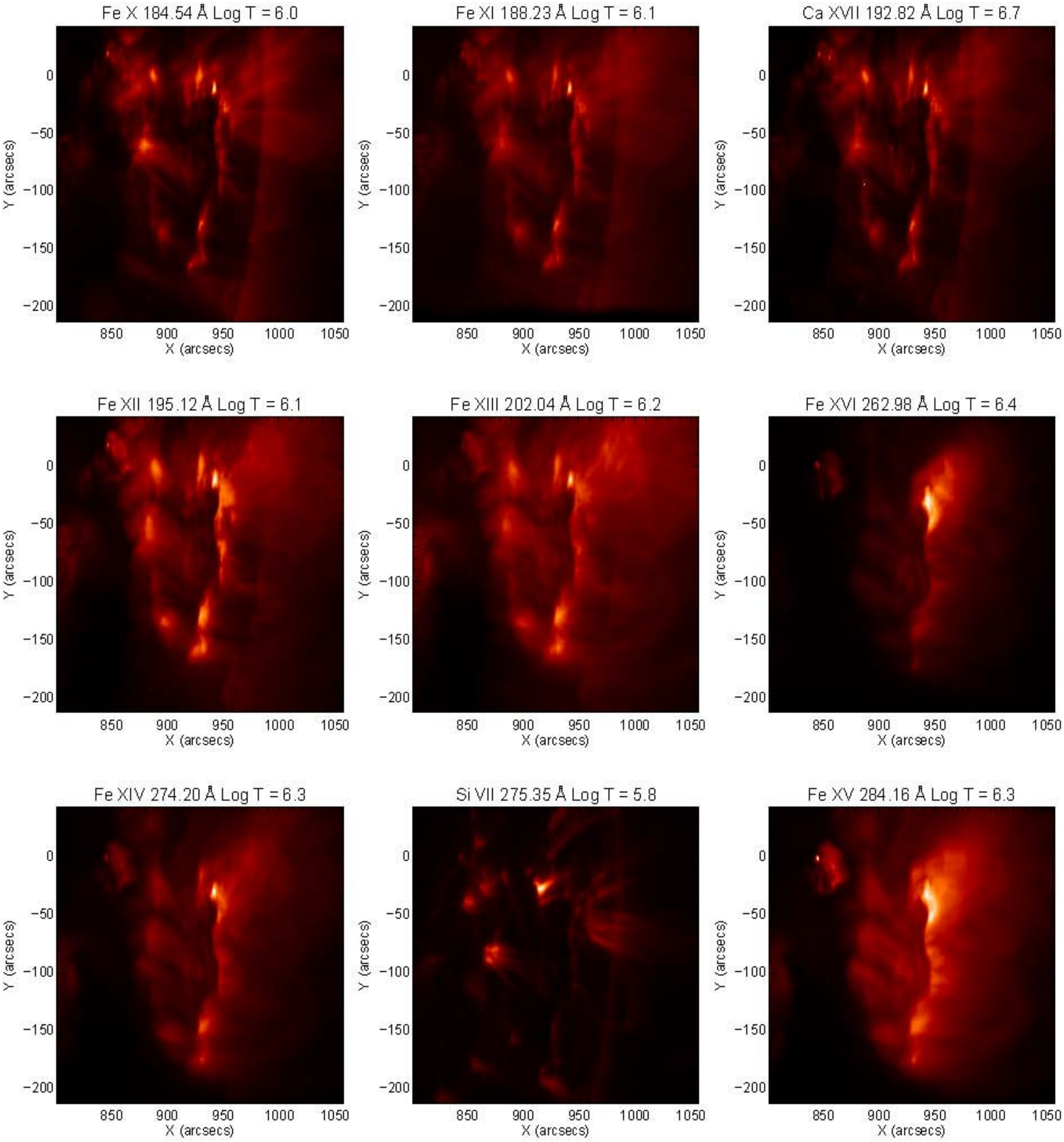

Figure - 2
Monochromatic images of active region in different spectral lines of the indicated ions. the lines are: FE X 184.54 Å, FE XI 188.23 Å, CA XVII 192.82 Å, FE XII 195.12 Å, FE XIII 202.04 Å, FE XVI 262.98 Å, FE XIV 274.20 Å, SI VII 275.34 Å AND FE XV 284.16 Å. Bright is higher temperature than dark

Figure 2 shows nine monochromatic images of elements Fe, Ca and Si of the observed active region in different ionization stages. These images are formed in the temperature range log T = 5.8– 6.7 K. This figure reveals considerable morphological differences between the images in hot lines like Fe XV and the in a cool lines like Si VII line. It is observed that in the cool lines there are open, bright, fan-like structures that are bright at their bases and fade with height. However, in hot lines such as Fe XV, image is amorphous appearing loop like structures. At the typical coronal temperature represented by Fe XII, Fe XIII and Fe XIV lines, bright loop structures as well as more confined bright spot-like regions that are difficult to characterize in shape, are observed. These bright spot-like structures might be small closed loops.

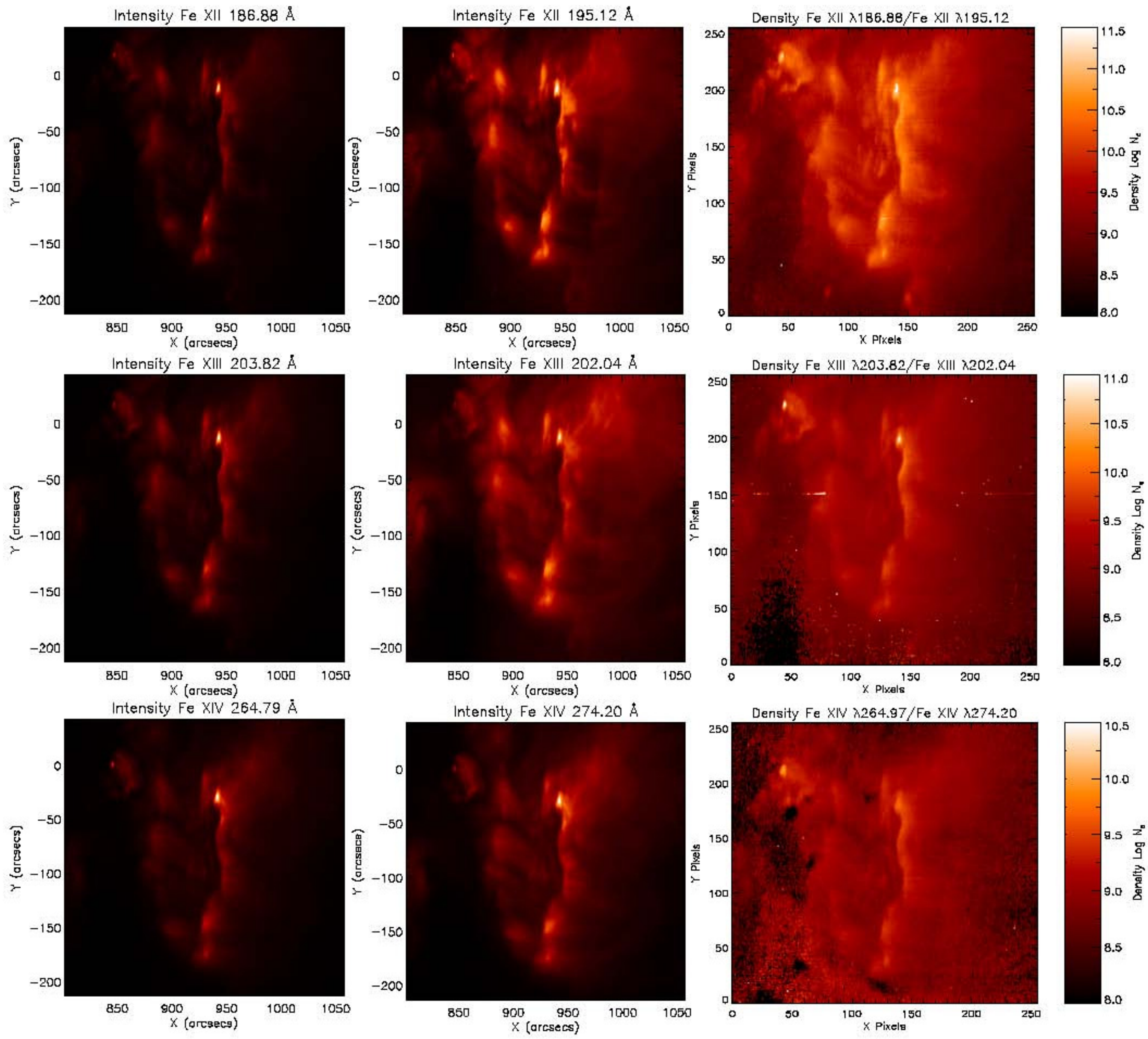

Figure - 3

Left and middle column: intensity in Fe XII (top panel), Fe XIII (middle panel) and Fe XIV (bottom panel). The right column displays the respective density maps derived using the line ratio techniques. Bright is high density; dark is lower density

Figure 3 displays intensity images and density maps obtained by fitting selected spectral lines. EIS has excellent density diagnostic capability at coronal temperatures, with several line ratio diagnostics with strong sensitivity to density. The top panel shows the intensity images and density map of the observed active region in Fe XII (186.88 Å, left; 195.12 Å, middle; density, right), second panel in Fe XIII (203.82 Å, left; 202.04 Å, middle; density, right) and third panel in Fe XIV (264.79 Å, left; 274.20 Å, middle; density, right). The electron density maps were generated using the density sensitive line intensity ratios of Fe XII 186.88 Å to 195.12 Å, Fe XIII 203.82 Å to 202.04 Å and Fe XIV 264.79 Å to 274.20 Å. The method used for electron density diagnostics is described in detail by[10-11]. The theoretical line ratios were calculated using CHIANTI, v7.0[12-14]. The line ratios can be converted to actual electron density ratios using the CHIANTI atomic physics database. The core of the active region was found to be highly dense with peak value $>10^{11}cm^{-3}$. These results are similar to those of[15] who studied Hindoe/EIS observations of an on-disk active region.

The three strongest Fe XII lines are the decays of the $3s^2\,3p^2$ (3P) 3d $^4P_{5/2,\,3/2,\,1/2}$ states to the ground state, giving lines at 195.12 Å, 193.51 Å, 192.39 Å, respectively. The Fe XII line of wavelength 195.12 Å lies at the peak of the EIS sensitivity curve and so it is the strongest emission line observed by EIS in most conditions. It is one of the EIS core lines and therefore included in all EIS studies. Fe XII provides some of the best density diagnostics for EIS. The ratio of the 186.88 Å line to 195.12 Å is sensitive to a wide range of densities (log Ne =8–12). The Fe XII 186.88 Å line has a self blend with two other Fe XII lines and Fe XIII 203.82 Å line is blended with another Fe XII 203.72 Å line. Fe XIV 274.20 Å line is blended with a Si VII line but in most active region conditions this blending of Fe XIV 274.20 Å with Si VII can safely be ignored. The ratio of Fe XIV 264.79 Å to Fe XIV 274.20 Å line yields a good density diagnostic and is recommended for probing hotter parts of active regions.

The line ratios, particularly Fe XII 186.88 Å line to Fe XII 195.12 Å and Fe XIII 203.82 Å line to Fe XIII 202.04 Å, are quite sensitive to electron density over the range of densities in the quiet Sun corona and active regions. The Fe XII (186.88 Å/195.12 Å) ratio gives the best density diagnostic due to its broad range of sensitivity. Using this line ratio, the density inside the active region, as well in the outer region, can be derived simultaneously. Thus the diagnostics are excellent indicators of density variations. From figure 3 it is evident that the core of the active region appears to be denser than the outer regions. This density in the core can be as high as 10^{11} cm^{-3}.

Conclusion

The EIS on broad Hinode provides us an opportunity to study the physical parameters in spatially resolved coronal structures at different temperatures simultaneously. We have shown the capabilities of EIS for investigating electron density variations at coronal temperatures in active regions. We have derived ranges of density for a particular active region. For all temperatures, the core of the active region is denser than the outer regions. The density in the core can be as large as 10^{11} cm^{-3}. The Fe XII (186.88 Å/195.12 Å) is the best ratio for deriving electron densities in the corona due to its broad range of sensitivity. The results in this paper will be refined and clarified further by investigating many more active regions.

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