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EUV line diagnostics for solar plasma

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Abstract. We present the solar EUV wavelength region which is rich in emission lines from the upper chromosphere, transition region and the corona ($10^4 < T_e < 10^6$ K). Spectroscopic diagnostic techniques have been used extensively to determine the physical conditions in the solar atmosphere for such diverse phenomena as coronal holes, active regions, sunspots, flares etc. In view of the Coronal Diagnostic Spectrometer (CDS) and the Solar Ultraviolet Measurements of Emitted Radiation (SUMER) aboard the Solar and Heliospheric Observatory (SOHO), an extensive theoretical investigation of most of the abundant solar ions has been carried out in the spectral range 150 - 1610 Å which is covered by these two major instruments with excellent spectral, spatial and temporal resolutions. A few significant findings of this Ph.D. research form the basis of some important observing sequences by the CDS and the SUMER science teams.

Key words : solar EUV, line diagnostics, diagnostics for solar ions, EUV spectroscopy

Access to images and spectra of the hotter plasma in the UV (ultraviolet), EUV (Extreme-ultraviolet) and X-ray regions has provided a major advance over the few coronal forbidden lines in the visible region. Observation of coronal lines has long been recognized as an important means of investigating the physical properties of coronal plasma and addressing fundamental questions such as coronal heating and solar wind acceleration. EUV spectroscopic diagnostics make use of information contained in the measurement of the intensities and the profiles of spectral lines. The diagnostic methods which depend on the atomic parameters and the emitting plasma properties, are often carried out with some assumptions and limitations that have to be clearly specified. They give very important information on basic physical quantities such as electron density, temperature, elemental abundance, flow characteristics etc. which in turn impose serious constraints on the models proposed. Thus, it is very important to understand the degree of precision expected from these measurements and to improve their accuracy, for instance by making advances in the atomic physics theory and with well-calibrated high resolution EUV observations made from space. This Ph.D. research (Mohan 1996) begins with presenting the spectroscopic diagnostic techniques in the UV and EUV to study solar plasma, the atomic processes involved, the recent observations made with major solar space programs and future high-resolution EUV observations obtainable with the Coronal Diagnostic Spectrometer (CDS) and the Solar Ultraviolet Measurements of Emitted Radiation (SUMER) on board the SOHO mission (cf., Dwivedi and Mohan, 1996).

Spectroscopic diagnostics for the Ne V and Mg V solar ions have been investigated. The theoretical forbidden line ratios from these ions (e.g., Ne V: λ1145.61/λ1574.67, and Ne V/Mg V : λ1145.61/λ1324.45) are shown to be very valuable in diagnosing solar plasma and understanding the Ne/Mg variation in different solar structures. An observing sequence on these lines has been planned for the SUMER. Calculations for density and temperature line diagnostics of these ions are given for the several spectral line ratios and their applications are discussed with the help of available solar observations made from space. We also emphasize the need for atomic data calculations for the Mg V ion (cf., Dwivedi and Mohan, 1995a). Diagnostics of Ne VI, Mg VI, Si VIII and Mg VIII solar ions in an active region observed by SERTS have been presented. Density, temperature and electron pressure in the solar transition region and lower corona have been derived from the theoretical line ratios and its EUV spectrum obtained by SERTS. Density sensitive Si VIII line ratios λ276.85/λ314.34, λ276.85/λ316.22 and λ276.85/λ319.83 observed by SERTS are found to be suitable for active region diagnostics. These line ratios are also studied under an appropriate electron pressure $N_e T_e = 4\times10^{16}$ cm^{-3} K in the emitting source and the density and temperature inferred from these ratios are found to be appropriate and consistent. Also, several Ne VI/Mg VI and Si VIII/Mg VIII line ratios are found to be good candidates for active region density diagnostics. This study also shows density inhomogeneity in the active region. The variation of neon-to-magnesium and silicon-to-magnesium abundances has been investigated in the interpretation of the SERTS EUV spectrum of an active region. We find that Ne/Mg and Si/Mg abundance ratios of 1.15 and 1.05 respectively, satisfactorily explain the SERTS EUV spectrum. We have also investigated the electron density in a coronal hole (Source region of high speed solar wind) from the new calculation for Mg VIII λ436.62/λ430.47 density-sensitive theoretical line ratio and with the help of available observations. It is found that the coronal hole density of $N_e = 2\times10^7$ cm^{-3} adopted in Axford and McKenzie model does not seem to be entirely unrealistic. In addition, some theoretical Ne VI/Mg VI forbidden line ratios λ999.60/λ1191.64, λ999.60/λ1190.07, λ1006.1/λ1191.64 and λ1006.1/λ1190.07 are found to be excellent tools for density diagnostics for $N_e > 10^8$ cm^{-3}, applicable to active regions, sunspots, umbrae and flare plasmas. An observing sequence has already been planned for observation by the SUMER, based on this investigation (cf., Dwivedi and Mohan 1995b,c,d).

Spectral diagnostics of the active region observed by SERTS have been investigated. Active region EUV spectrum in the spectral range 170-450 Å of several ions namely Ne IV, Ne V, Mg V, Ne VI, Mg VI, Si VII, Mg VII, Si VIII, Mg VIII, Si IX, Mg IX, Si X and S X in the temperature range $10^5 < T_e < 10^6$ K has been used to estimate electron density, column emission measure, elemental abundance and inhomogeneity in the emitting source from spectroscopic diagnostics for these ions. Some of the EUV lines which are not observed by SERTS, are discussed to have observable intensities and indicated for observation from future SERTS flights and CDS instrument (cf., Mohan and Dwivedi 1996; Dwivedi, Mohan and Thomas, 1996). Finally, new calculations for the line emissivities as a function of electron density and temperature have been carried out. Several density-sensitive and temperature-sensitive line emissivity ratios are studied and their diagnostic applications to the solar atmosphere are discussed with the help of available observations. Several N III density-sensitive line ratios, hitherto not observed, will be good tools for determining density in the chromosphere-corona transition region from the observations obtainable from the CDS and SUMER instruments. It is also found that the temperature-sensitive line ratio λ991/ λ686 yields a lower temperature of line formation of N III ion ($T_e \sim 4\times10^4$ K) that the temperature of its maximum fractional abundance (Tmax ~ 8×10^4 K) cf., Dwivedi Mohan and Gupta, 1995). Some of the investigations reported in this thesis form the basis for a couple of observing sequences planned by the CDS and the SUMER science teams and have now been successfully carried out. It is hoped that research findings of this thesis should be scientifically rewarding in the analysis and the interpretation of high quality EUV data currently obtainable from the CDS and the SUMER instruments aboard the SOHO spacecraft.

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