DIAGNOSING SOLAR PLASMAS FROM EUV AND X-RAY EMISSION LINES

BHOLA N. DWIVEDI
Department of Applied Physics, Institute of Technology
Banaras Hindu University, Varanasi-221005, India

ABSTRACT. The electron density and temperature measurement of solar plasmas from EUV and X-ray emission lines have been briefly discussed. Diagnostic EUV line ratios from MgVI ion and X-ray line ratios from MgVIII and SiX ions have been presented. A brief account of the general methodology for diagnostics of inhomogeneous structures has also been given.

Introduction

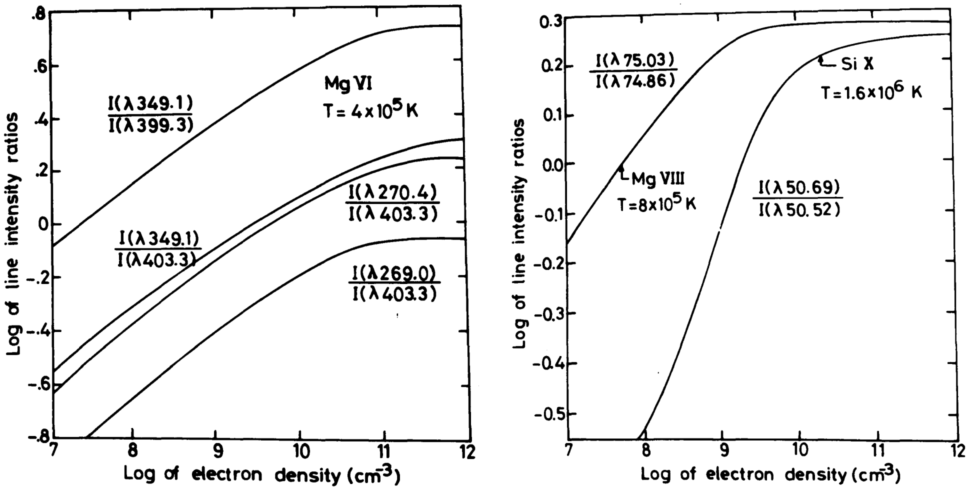
The determination of electron density N and temperature T of astrophysical and laboratory plasmas from diagnostic line ratios is a problem of universal importance. The physical significance of these diagnostics lies in the influence of N and T on plasma process being considered, whether thermonuclear fusion, transport coefficients, energy transport, magnetic reconnection, particle acceleration etc. Diagnostics of solar plasmas from EUV and X-ray emission lines have been extensively studied and several reviews are available (Gabriel and Jordan (1972), Dere and Mason (1981), Doschek (1985), Dwivedi (1988a) and references cited there). Density diagnostics are similar to that used by optical astronomers for deriving densities using the well known OII lines at 3726 and 3729 Å. Diagnostic techniques for an electron density determination usually rely on identifying transitions in which one or both levels are metastables. This causes the relative level population to be density dependent so that the intensity ratio of two collisionally excited lines becomes a function of density. The local electron temperature can be probed by selecting two lines both of which are collisionally excited by electrons from the same level. The excitation rates are dependent on the Boltzmann factor, exp $(-E_{ij}/kT)$, where E_{ij} is the energy of the transition. A ratio of line intensities yields the electron temperature for levels of sufficient energy separation. An elegant method for temperature diagnostics is to use the temperature dependence of the ratio of a line formed by dielectronic recombination to a line formed primarily by electron impact excitation.

E. R. Priest and V. Krishan (eds.), Basic Plasma Processes on the Sun, 403–407.

For a number of years we have been involved in an extensive series of N- and T- diagnostic calculations for solar plasmas. In this paper, some spectral line ratios which have hitherto received little attention are presented. A brief discussion on diagnostics of inhomogeneous structures is also presented.

Diagnostic Line Ratios

EUV emission lines from MgVI (4 x 10^5 K) ion have received little attention for diagnostic studies. Line ratios λ 387.9/λ 403.3 and λ387.9/λ 400.7 from MgVI ion have been used to infer electron density in sunspot plumes [Dwivedi (1989)]. Figure 1 shows some more EUV line ratios from MgVI ion which could be used as density monitors of the emitting region. Line ratios λ 349.1/λ 399.3 and λ 349.1/λ 403.3 are good density indicators in the range 10^7-10^{11} cm^{-3}. MgVIII (8 x 10^5 K) line ratio λ 430.5/λ 436.7 has been suggested to be an excellent candidate to infer density in the range 10^7-10^9 cm^{-3} and probe the quiet Sun and coronal holes [Dwivedi (1988b)]. Theoretical computations by us in the EUV region from ions of boron, nitrogen, oxygen and carbon sequences will be useful for density diagnostics, using observations that SOHO may provide [Dwivedi and Raju (1980, 1988), Raju and Dwivedi (1978, 1979)].



Figs. 1 and 2. Electron density dependence of EUV line ratios from MgVI ion and X-ray line ratios from MgVIII and SiX ions.

Figure 2 shows the variation of X-ray line ratios from MgVIII (8 x 10^5 K) and SiX (1.6 x 10^6 K) ions as a function of electron density. The line intensity ratio of the $(\frac{3}{2} - \frac{5}{2})$ and $(\frac{1}{2} - \frac{3}{2})$ lines of the multiplet ($2s^2\,2p\ {}^2P^o - 2s^2\,3d\ {}^2D$) is an electron density diagnostic. The ($\frac{3}{2} - \frac{5}{2}$) transition is usually blended with the ($\frac{3}{2} - \frac{3}{2}$) transition. X-ray line pair λ 75.03/λ 74.86 from MgVIII and λ 50.69/λ 50.52 from SiX are useful for diagnosing solar plasmas. However, observational data with improved spectral and spatial resolution are needed by future solar missions to probe solar structures.

Diagnostics of Inhomogeneous Structures

Almleaky et al. (1989) have discussed the problem and importance of interpreting density sensitive line ratios from plasmas which are isothermal but of non-uniform density. Brown et al. (1989) then develop the methodology of the diagnostics of inhomogeneous structures by considering arbitrary density and temperature distributions of which a brief discussion is presented here.

For an optically thin plasma of electron density $N(\vec{r})$, temperature $T(\vec{r})$ at position $\vec{r}$ in a volume V, the total power emitted in a spectral line α can be expressed as

$$P_\alpha = \iiint_V N^2(\vec{r})\, F_\alpha(N(\vec{r}), T(\vec{r}))\, dV \qquad (1)$$

where F_α is determined by elemental abundance, ionisation and excitation balance calculations using atomic coefficients. The power emitted in resonance lines where F_α is independent of N and where proper choice of volume element dV is based on constant temperature surfaces S_T is given by Craig and Brown (1976):

$$P_\alpha^R = \int_{T=0}^{\infty} \xi(T)\, F_\alpha^R(T)\, dT \qquad (2)$$

where

$$\xi(T) = \iint_{S_T} \frac{N^2(\vec{r})}{|\vec{\nabla} T(\vec{r})|}\, dS_T \qquad (3)$$

is the emission measure differential in T which can, in principle, be derived from integral equation (2) using measurements of temperature-sensitive line strengths P_α^R. Likewise, the special case of density-sensitive line analysis for an isothermal plasma T_o has a natural formulation:

$$P_\alpha^D = \int_{N=0}^{\infty} \xi(N)\, F_\alpha^D(N, T_o)\, dN \qquad (4)$$

where

$$\xi(N) = \iint_{S_N} \frac{N^2(\vec{r})}{|\vec{\nabla} N(\vec{r})|}\, dS_N \qquad (5)$$

Consideration of these two cases shows that for the general case (1) we must deal with a volume element dV related to elements on which both N and T are constants. In first case, surfaces of constant N and of constant T are coincident. This is in fact the case which proves most tractable in terms of an inversion of the problem and which is probably of the greatest relevance. In second case, S_N and S_T are not coincident but intersect on a line $L_{N,T}$. Then the natural formulation of (1) into an integral expression over the variables N, T on which the line strengths depend, is in terms of the volume element as shown in Figure 3.

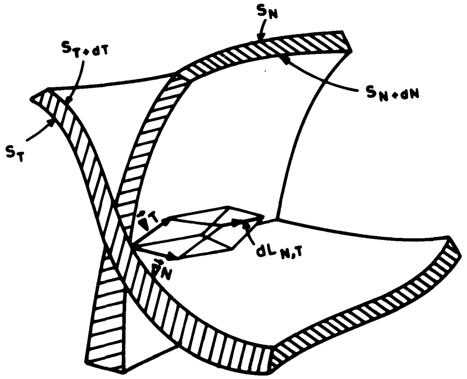


Fig.3 Representation of volume element in terms of surfaces of constant N and of constant T which are not coincident but intersect on a line $dL_{N,T}$ (Brown et al. 1989)

$$dV = dL_{N,T} \frac{dN\, dT}{|\vec{\nabla} N|\,|\vec{\nabla} T|} (\sin \theta_{N,T})^{-1} \tag{6}$$

where $\theta_{N,T}$ is the local angle between the vectors $\vec{\nabla} N$ and $\vec{\nabla} T$ normal to surfaces S_N and S_T, respectively. If we then define an emission measure function differential in both density and temperature by

$$\psi\,(N,T) = \oint_{L_{N,T}} \frac{N^2(\vec{r}\,)\,(\sin \theta_{N,T}(\vec{r}\,))^{-1}}{|\vec{\nabla} N(\vec{r}\,)|\,|\vec{\nabla} T(\vec{r}\,)|}\, dL_{N,T} \tag{7}$$

We have for any line

$$P_\alpha = \int_{N=0}^{\infty} \int_{T=0}^{\infty} \psi\,(N,T)\, F_\alpha(N,T)\; dN\, dT \tag{8}$$

The general diagnostic problem is then seen as that determining $\psi\,(N,T)$ by inversion of double integral equation (8) for a set of measurements P_α of various α .

Concluding Remarks

EUV line ratios discussed here should be valuable to infer electron density using observations that SOHO may provide. X-ray line ratios will be useful for density determination when observational data with improved spectral resolution becomes available. The problem of diagnostics of inhomogeneous plasmas is of fascination and of great mathematical complexity.

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