Bull. Astr. Soc. India (1996) **24**, 333–337

Plasma Diagnostics for SUMER on board the SOHO Mission

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Abstract. We highlight a rich source of high-resolution EUV observations that the Solar Ultraviolet Measurements of Emitted Radiation (SUMER) instrument, on board the SOHO mission, is capable of making in the broad spectral range from less than 500 Å to 1610 Å, and which is further extended to shorter wavelengths by the Coronal Diagnostic Spectrometer (CDS) instrument. This will provide a unique opportunity to study in greater detail than previously done, the diagnostics and dynamics of the solar plasma from the upper chromosphere to the corona. We also briefly present the spectroscopic diagnostics for several ions relevant to the SUMER/CDS spectral range for the inference of the physical parameters and discuss underlying coronal physics.

Key words: Line diagnostics, Density and temperature diagnostics, Spectroscopic diagnostics for solar ions.

1. Introduction

The Solar and Heliospheric Observatory (SOHO) is one of the two elements constituting the first cornerstone of "Space Science : Horizon 2000" and will play a profound role in the pursuit of space science and plasma physics. This mission jointly undertaken by ESA and NASA, carrying a variety of telescopes and scientific instruments, scheduled for launch in November 1995, will be placed in a halo orbit around the Lagrangian point L1 where the gravitational forces of the Earth and the Sun balance one another. The main objectives of SOHO include the study and understanding of solar coronal phenomena and of the solar structures and interior dynamics from its core to the photosphere. The SUMER, a high-resolution normal-incidence EUV spectrometer and the other instruments on board the SOHO mission, will have continuous observation opportunities in a thermally stable environment. With the high-resolution capabilities of SUMER, it is hoped to make detailed studies of the structures of the solar atmosphere and its dynamics - a significant contribution to the achievement of the science goals of SOHO.

The SUMER is a telescope and spectrometer, capable of making high-resolution solar observations in the spectral range from less than 500 Å to 1610 Å. EUV images of the Sun with short exposure times will allow us to study the diagnostics and dynamics of the solar plasma, e.g., plasma density, temperature, abundances of species, velocity fields, topologies of the plasma structures and their time evolution at high temporal resolution of a few seconds. It will address to provide better understanding of some of the outstanding problems in solar physics, namely of coronal heating by detecting line broadenings and Doppler shifts, of solar wind acceleration by estimating the amount of wave energy available in the corona, and of structure of the solar atmosphere, whose small and large inhomogeneities at the base of the corona are in a continuous state of fluctuation on time scales ranging from seconds to days and sometimes weeks. It will also help us in better understanding of stellar physics, plasma physics and solar-terrestrial relationships (see, Wilhelm (1995) and Wilhelm et al. (1995) for more details).

2. SUMER Science

The SUMER capabilites are complementary to those of the other instruments on SOHO, especially the CDS (Harrison et al., 1995). They include (1) a spatial resolution compatible with the spacecraft constraints, (2) an effective, relative spectral resolving power in the full wavelength range of approximately 3×10^5 , in order to determine line-of-sight velocities from Doppler shifts with an accuracy of about 1 kms^{-1} and to estimate wave amplitudes and (3) a temporal resolution down to 1 second or less in some strong lines, to follow dynamically evolving solar features like jets and bright points, and to resolve wave motions at the lower limit of periods expected.

We expect to study solar structures down to the 1-arcsec level and events down to the 1 second time scale in the SUMER wavelength range which will be further extended to shorter wavelengths by the CDS instrument. Some of the lines observable over the full spectral range covered by the SUMER and the CDS are shown in Fig. 1. Also indicated in this figure are the wavelength ranges and lines covered by the UVCS (Ultraviolet Coronograph Spectrometer) and the EIT (Extreme-Ultraviolet Imaging Telescope) instruments (Kohl et al., 1995; Delaboaudiniere et al., 1995) on SOHO.

Existing EUV observations are clearly inadequate to determine physical properties of coronal structures with enough precision to differentiate between different models. Previously flown EUV imaging instruments have generally obtained angular resolution of > 5 arcsec, with many images obtained in the 15–16 arcsec range which is clearly inadequate for studies of the detailed structures and dynamics of the corona and underlying physics. Measurements of the line intensity ratios of certain selected EUV line pairs give direct measurements of electron density and temperature in the emitting source (cf. Dwivedi, 1994). A list of some prominent line ratio diagnostics for the SUMER and the CDS are given in Table 1. Observations from these instruments will allow better maps of the solar wind flow, enabling a more detailed assessment of various theories for solar wind acceleration, for instance, theories involving momentum transfer from Alfven waves (Davila, 1985). Line shift measurements from SUMER will also help to pinpoint mechanisms (e.g., gas flows, waves running from the corona etc.) regarding the origin of the redshift. These mechanisms involve processes that are important for the question of mass and energy balance.

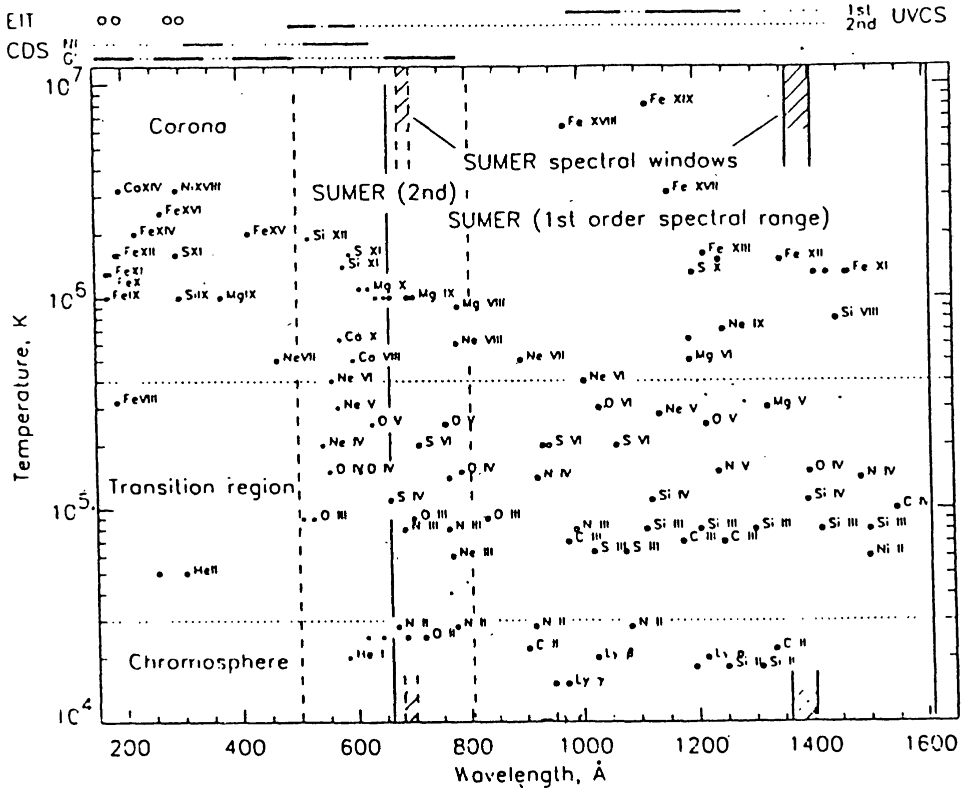

Figure 1. Selection of emission lines in the wavelength range from 150 to 1610 Å together with the corresponding SUMER, CDS, UVCS, and EIT coverages. Observations from 500 to 805 Å can be performed in second order and from 661 to 1610 Å in first order. The instantaneous coverage is approximately 22 Å in second order and 44 Å in first order. This is indicated for a specific wavelength setting. The short-wavelength region will be observed by CDS in NI (normal incidence) and GI (grazing incidence) bands as indicated in the upper margin. The overlap in wavelength bands of all the four instruments is to be noted, in view of their importance for the inter-calibration (Wilhelm et al., 1995).

3. Capabilities of SUMER

As mentioned above, the SUMER spectral range (500–1610 Å) enable us to study the diagnostics and dynamics of solar plasma by observing emission lines of atoms and ions in the temperature range of 10^4 to 2×10^6 K, carrying the radiation signatures of the chromosphere, transition region and the corona. With angular resolution of close to 1 arcsec, a temporal resolution of down to 1 second or even 60 ms for specific observations of intense lines, and the spectral resolving power $\lambda/\Delta\lambda$ in the first order between 1.77×10^4 at $\lambda = 800$ Å and 3.83×10^4 at $\lambda = 1600$ Å where $\Delta\lambda$ corresponds to the pixel size in the spectral dimension, i.e. $\Delta\lambda \approx 43$ mÅ, the SUMER will be capable of making significant contributions to the better understanding of coronal physics from its line-shift and line-broadening measurements. Wavelength ranges for detector A are 390–805 Å (second order), 780–1610 Å (first order) and for detector B 330–750 Å (second order), 660–1500 Å (first order). In the range below 500 Å, the sensitivity is very low, because of the normal-incidence reflections. However, strong lines have been observed in this regime during the calibration. In principle, any line in the SUMER spectral range or any combination of

Table 1. Some prominent line pairs useful for N_e or T_e diagnostics with SUMER/CDS

Ion	Wavelength (Å)	Density N_e (cm^{-3})	Temperature T_e(K)
O IV	1407.39/1404.81	$10^{10} - 10^{12}$	1.7×10^5
Si III	1312.59/1301.15	$10^9 - 10^{10}$	3.5×10^4
S X	1213.62/1196.26	$2 \times 10^8 - 2 \times 10^{10}$	1.2×10^6
C III	1175.70/977.02	$10^9 - 10^{10}$	7.0×10^4
Ne V	416.20/482.99	$10^8 - 10^{10}$	3.2×10^5
Mg VI	349.13/399.20	$10^8 - 10^{11}$	4.0×10^5
Mg VII	319.03/367.66	$10^8 - 10^{11}$	6.3×10^5
Mg VIII	430.47/436.62	$10^7 - 10^9$	8.0×10^5
Si VIII	1445.78/1440.49	$10^7 - 10^{10}$	8.0×10^5
Si IX	345.13/341.95	$10^8 - 10^{10}$	1.0×10^6
Si X	356.04/347.40	$10^7 - 10^{10}$	1.2×10^6
Fe IX	241.74/244.91	$10^{10} - 10^{12}$	9.0×10^5
Fe X	174.53/175.27	$10^8 - 10^{10}$	1.0×10^6
Fe XI	180.41/182.17	$10^9 - 10^{10}$	1.3×10^6
Fe XII	186.88/193.51	$10^8 - 10^{11}$	1.5×10^6
Fe XIV	211.32/219.12	$10^8 - 10^{11}$	1.9×10^6
O IV	554.08/790.20	–	$5 \times 10^4 - 2 \times 10^5$
O V	172.17/629.73	–	$1 \times 10^5 - 4 \times 10^5$
O VI	1032/173	–	$3 \times 10^5 - 10^6$
N III	991.51/685.70	–	$< 7 \times 10^4$

lines can be observed. However, only two bands can be simultaneously observed on one of the detectors. Their widths are approximately 44 Å in first order and 22 Å in second order (cf. Fig. 1). Only one of the detectors either A or B will be activated at a time and this will be detector A under normal operational conditions. Should the SUMER operational team select detector B, the user interface will not change, but the available wavelength range will be different due to the offset in position of detector B with respect to A (for details, see Wilhelm et al., 1995). An added attraction of the SUMER instrument is that it also carries a rear-slit camera (RSC) operating in wavelength range 5770–6520 Å of which the main scientific objectives are : the investigation of the solar limb position, the quality of the image on the entrance slit (6 μm) of the SUMER spectrometer for telescope alignment and calibration, the localization of small solar structures (pores, sunspots) and the measurement of telescope jitter displacements.

Operating the SUMER instrument is similar to operating an observatory. A specific SUMER Command Language (SCL) has been developed for the instrument operation which allows us to compile base functions (sub-modes) on different levels of complexity into observing sequences. Both Predefined Operational Programmes (POPs) and the option of User Defined Programmes (UDPs) will be available to the observer. POPs are complete observing sequences aimed at specific scientific investigations. They are resident in the flight software and can be executed by a single command (a summary list

Table 2. Summary list of Predefined Operational Programmes (POPs)

- High resolution line shifts
- Line shift variation/line ratios
- Line ratios at fixed location
- Off-limb line profiles
- Reference spectra
- Full Sun imaging
- Evolution of structures
- Explosive events
- Lyman-α 'calibration'
- Fine structure of a prominence
- Ephemeral active regions
- Bright point diagnostics
- Active structure dynamics
- Vector velocity fields off limb
- Star spectra and coronal streamers
- Turbulence and flows
- Sunspot velocity fields
- Magnetohydrodynamic waves
- Forbidden/allowed line widths
- Transition region and corona studies
- Transition region and coronal emission relationship using Si III
- N_e diagnostics using O IV, Si IV, Si V
- N_e diagnostics using Ar VIII, Si VIII and Fe XI off limb
- Explosive events at different temperatures
- Coronal mass ejection onset
- Solar wind in a coronal hole
- Sun grazing comet observation
- Chromospheric network
- Prominences and coronal mass ejections
- Sub-second oscillations
- Synoptic sequence
- Transition region line intensities
- Coronal magnetohydrodynamic turbulence
- Temperature gradient in a coronal hole

of POPs is given in Table 2), whereas UDPs have to be uplinked on demand at any time of operation prior to their execution.

4. Concluding Remarks

In conclusion, the instrument SUMER is capable of making observations that will provide a rich source of data, hitherto not available, for better understanding of coronal heating and solar wind acceleration mechanisms, one of the main science goals of the SOHO mission.

Acknowledgments

Author's participation in the science planning of the SUMER instrument is enabled by the generous support from Dr. K. Wilhelm, Principal Investigator of SUMER.

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