EXTREME ULTRAVIOLET SPECTRA OF
SOLAR ACTIVE REGIONS AND THEIR ANALYSIS

KENNETH P. DERE

E. O. Hulburt Center for Space Research, Naval Research Laboratory, Washington, D.C. 20375, U.S.A.

(Received 23 February; in revised form 29 May, 1981)

Abstract. Extreme ultraviolet spectra of several active regions are presented and analyzed. Spectral intensities of 3 active regions observed with the NRL Skylab XUV spectroheliograph (170–630 Å) are derived. From this data density sensitive line ratios of Mg viii, Si xi, S xii, Fe ix, Fe x, Fe xi, Fe xii, Fe xiii, Fe xiv, and Fe xv are examined and typically yield, to within a factor of 2, electron pressures of 1 dyne cm\(^{-2}\) (\(n_e T = 6 \times 10^{15} \text{ cm}^{-3} \text{ K}\)). The differential emission measure of the brightest 35" × 35" portion of an active region is obtained between 1.4 \times 10^4 K and 5 \times 10^6 K from HCO OSO-VI XUV (280–1370 Å) spectra published by Dupree et al. (1973). Stigmatic EUV spectra (170–1710 Å) obtained by the NRL High Resolution Telescope and Spectrograph (HRTS) are also presented. Doppler velocities as a function of position along the slit are derived in an active region plage and sunspot. The velocities are based on an absolute wavelength scale derived from neutral chromospheric lines and are accurate to ±2 km s\(^{-1}\). Downflows at 10^5 K are found throughout the plage with typical velocities of 10 km s\(^{-1}\). In the sunspot, downflows are typically 5 to 20 km s\(^{-1}\) over the umbra and zero over the penumbra. In addition localized 90 and 150 km s\(^{-1}\) downflows are found in the umbra in the same 1" × 1" resolution elements which contain the lower velocity downflows. Spectral intensities and velocities in a typical plage 1" resolution element are derived. The velocities are greatest (−10 km s\(^{-1}\)) at 10^5 K with lower velocities at higher and lower temperatures. The differential emission measure between 1.3 \times 10^5 K and 2 \times 10^6 K is derived and is found to be comparable to that derived from the OSO-VI data. An electron pressure of 1.4 dynes cm\(^{-2}\) (\(n_e T = 1.0 \times 10^{16} \text{ cm}^{-3} \text{ K}\)) is determined from pressure sensitive line ratios of Si iii, O iv, and N iv. From the data presented it is shown that convection plays a major role in determining the structure and dynamics of the active region transition zone and corona.

1. Introduction

In order to study the hydrodynamics of the solar atmosphere, it is necessary to measure quantities such as density, temperature, pressure and velocity as a function of position and time. These parameters can be obtained to a large extent from spectroscopic observations. The accuracy and completeness with which they can be specified depends on the resolution (spatial, spectral, and temporal) of the observing instrument and the number and accuracy of the diagnostics available. In this paper, intensities of extreme ultraviolet lines emitted from solar active regions are presented and analyzed to derive pressures, velocities and differential emission measures as a function of temperature and position. The data has been obtained by three experiments: the NRL Skylab XUV spectroheliograph (170–630 Å), the HCO OSO-VI XUV spectroheliometer (280–1370 Å), (Dupree et al., 1973), and the NRL High Resolution Telescope and Spectrograph (HRTS) (1170–1710 Å). The present analysis is significant because it provides the most complete description of the active region transition zone and corona presently available and should enable a fairly detailed comparison with theoretical hydrodynamical models.

During the Skylab mission a number of observations of solar active regions, as well as other solar phenomena, were made by the NRL slitless XUV spectroheliograph. This instrument operated in the 170–630 Å wavelength range and produced dispersed images of the Sun on photographic film with a spatial resolution of 2" and a spectral resolution of 0.03 Å. A detailed description of the instrument has been provided by Tousey et al. (1977).

Because of the overlapping of images from different lines, spectral intensities of active regions on the disk are hard to accurately determine, aside from those of the strongest lines. The overlapping is considerably reduced for active regions at the limb. In these cases, the observed intensity inside the limb is practically zero, at a maximum just above the limb and decreases exponentially with distance above the limb. Thus the contrast against the disk emission is greatly increased and it is possible to measure intensities for a number of weak lines which would not have been otherwise observable. Spectral line intensities have been reduced for 3 such active regions at the limb: McMath 12390 observed on 1973 June 12 at 22:10 UT, McMath 12375 observed on 1973 June 15 at 14:15 UT and McMath 12686 observed on 1973 January 15 at 22:20 UT. Images of the McMath 12375 spectra have been published by Dere (1978). Observations of McMath 12686 were also obtained 3 hr before the Skylab spectra by a similar spectroheliograph (CALROC) aboard a sounding rocket. This latter instrument was a half-scale version of the Skylab instrument whose purpose was to determine a reference solar spectrum against which the Skylab instrument could be calibrated. In fact, the spectra of McMath 12686 played a large role in the calibration of the Skylab instrument. The intensities were obtained by making raster scans of the active region images with a microdensitometer slit size on the order of the instrumental resolution (2""). Each point was converted to an intensity using the instrumental efficiency, the film characteristic curve appropriate to that wavelength and the exposure time. The intensities were then summed along a line tangent to the solar limb at the center of the active region. Figure 1 shows a sample of these summed intensities plotted as a function of height above the limb. Since there is no absolute standard against which to fix the height, the scale is relative. Multiple active region images are displayed because two-dimensional imaging and dispersion occur simultaneously. Thus, there is an ambiguity between one spatial coordinate and wavelength which results in the overlapping of images produced by lines nearby in wavelength. To find the total power emitted by the active region in a given spectral line the intensities (as in Figure 1) were integrated over height. From the same figure it is clear that the power derived for strong lines such as Fe xiv and Fe xvi should be fairly accurate. The intensities of these lines are considerably above background values and the overlapping of images is not severe. In many cases it is possible to determine only the maximum intensity near the limb because of partial blending with nearby images. It is then assumed that the intensity decreases exponentially with height.