STELLAR FLARES: OBSERVATIONS AND THEORY

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ABSTRACT

Photometric and spectroscopic observations of a very large flare on AD Leo are presented. A self consistent model of a flare corona, transition region and chromosphere is developed; in particular the chromospheric temperature distributions resulting from X-ray and EUV irradiation by coronae of various temperatures are determined. The predicted line fluxes in Hγ are compared to the observed line fluxes to find the coronal temperature as a function of time during the flare. This run of temperature with time is then compared with the predictions of an independent theoretical flare model based on a dynamic scaling law (see paper by Fisher and Hawley, these proceedings).

OBSERVATIONS

- 4.5 magnitude (in U) flare on AD Leo observed on 12 April 1985 UT.

- Optical spectroscopy, McDonald Observatory, 2.1m telescope, cassegrain spectrograph, CCD detector. Observations extended for more than 5 hours and are spectrophotometric to ±10%. Spectral resolution was 3.5 Å; spectra were taken every 1 to 3 minutes.

- Optical photometry, McDonald Observatory, 0.9m telescope, eight filters (U, B, V, R, Hα narrow and wide, Hβ narrow and wide). Observations made by B.R. Pettersen.

- IUE short wavelength (SWP) spectrum includes the first 15 minutes of the flare. IUE long wavelength (LWP) spectra, time resolution of 3 to 8 minutes obtained by moving star to five positions in the aperture during each exposure. Coverage begins 20 minutes after U band flares. Saturated regions marked in red. Observations made by B.N. Andersen.

- Quiescent spectra for comparison. Note greatly magnified flux scales.

- Continuum fluxes per Å are presented in Figure 3. The flux in U and V was obtained using photometric calibration from standard stars. Fluxes at 2800 and 2100 Å were obtained from the IUE spectra. The 2800 Å flux is a lower limit.

- Equivalent width indices for Hα and Hβ were found by dividing the counts in the narrow filter by the counts in the wide filter after sky subtraction. An equivalent Hγ index was computed from the optical spectra and is included for comparison in Figure 4.

- Line fluxes for Hγ, Hδ, Ca II K and Mg II $h+k$ are presented in Figure 5. Note that Ca II K has a broad flat peak compared to the Balmer lines. The first five Mg II points are lower limits. The Hγ flux is used as an example in the modeling ——————————————————————.

THEORY

The goal is to develop a simple but self consistent model of the corona, transition region and chromosphere that includes all the important heating and cooling processes that result after an initial burst of energy is deposited in the corona.

- Coronal scaling law (Fisher and Hawley, this meeting) used to determine coronal pressure, column depth and temperature structure for various values of coronal apex temperature.

- From temperature structure, emergent downward directed X-ray flux can be computed.

- Column depth determines where transition region begins; T.R. structure computed by equating conductive flux with optically thin metal losses.

- Chromospheric structure determined using the Scharmer-Carlsson NLTE radiative transfer method to solve HSE, statistical equilibrium and radiative transfer in hydrogen, Ca II and Mg II. Six bound levels and three continua of hydrogen are included explicitly. The temperature structure is then adjusted until the computed X-ray heating from the X-ray flux is balanced by the radiative cooling at each depth level in the atmosphere. Resultant atmospheres for coronal apex temperatures of 3×10^6 K (the quiescent model), 8×10^6 K, 10×10^6 K, 15×10^6 K, and 20×10^6 K are shown in Figure 6. Significant temperature minimum and photospheric heating occurs as a result of back-warming in the optical and ultraviolet continua. The X-ray heating in these atmospheres is shown in Figure 7.

- Line and continuum fluxes computed fromthe models can be plotted as a function of coronal apex temperature. Hγ is shown in Figure 8. When combined with the observed line fluxes (Figure 5), the observationally predicted apex temperature is obtained as a function of time. This is shown for the AD Leo flare in Figure 9.

- Our flare loop evolution model (Fisher and Hawley, this meeting) predicts the time evolution of the apex temperature for given values of loop length, heating time and volumetric heating rate in the corona. We choose values of 10^{10} cm, 1000 seconds (the observed Balmer line rise time) and 1 erg sec^{-1} cm^{-2}, resulting in a total energy deposition of $10^{13} \times$ (flare area) ergs. Approximately ten percent of the stellar surface must be flaring at this rate to match the observed radiative flare energy.

- The loop model evolution is shown in Figure 10, and is to be compared with Figure 9. It appears that the model is able to reproduce some important features of the observations, such as the shape of the rise phase and initial decay. Continued heating would be necessary to match the long decay phase. The application of this simple but self-consistent model indicates that X-ray heating probably plays an important role in stellar flares, and must be included in any detailed model.

Figure 3

Continuum Fluxes vs. Time

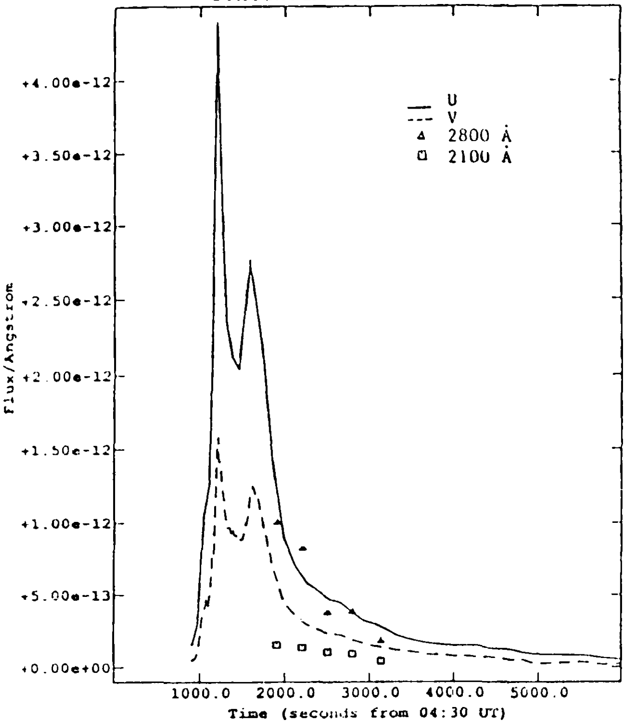

Figure 5

Line Fluxes vs. Time

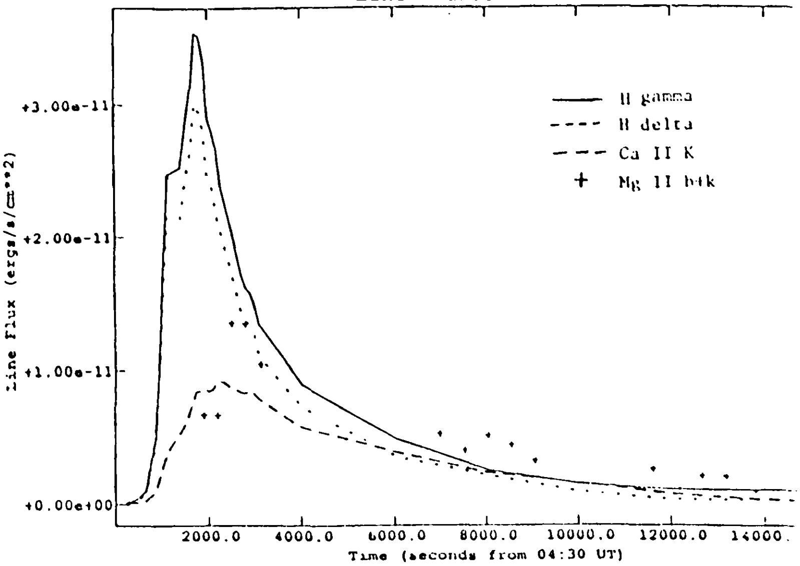

Figure 6

Chromospheric Temperature Distributions for Various Coronal Apex Temperatures

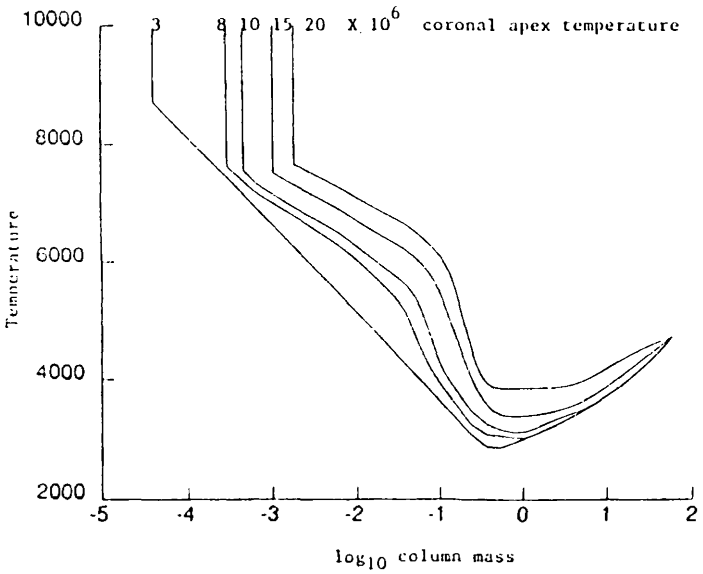

Figure 7

X-ray Heating vs. Column Mass

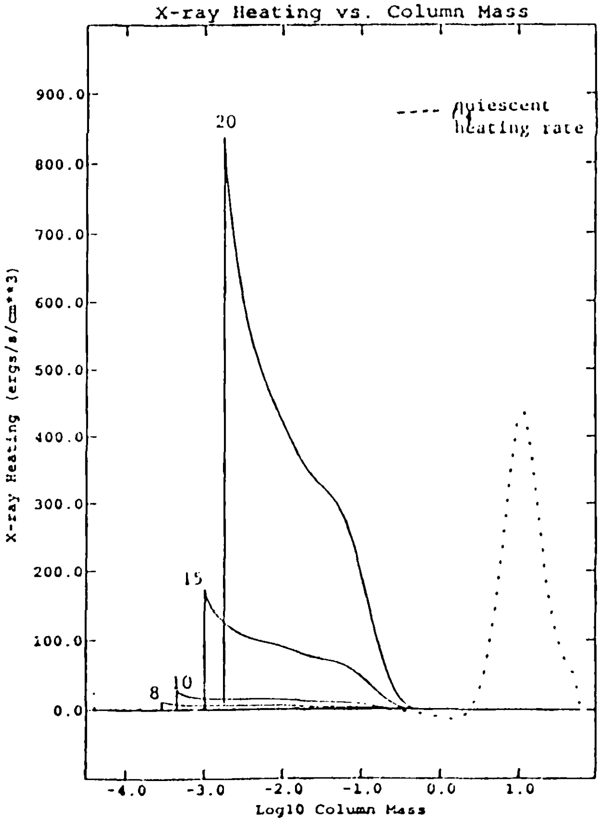

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Figure 8

H-gamma Line Flux vs. Coronal Temperature

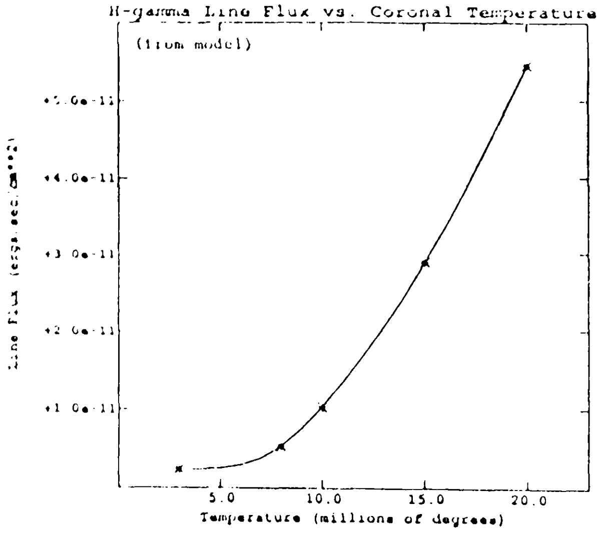


Figure 9

Coronal Apex Temperature vs. Time

(from H gamma Observations)

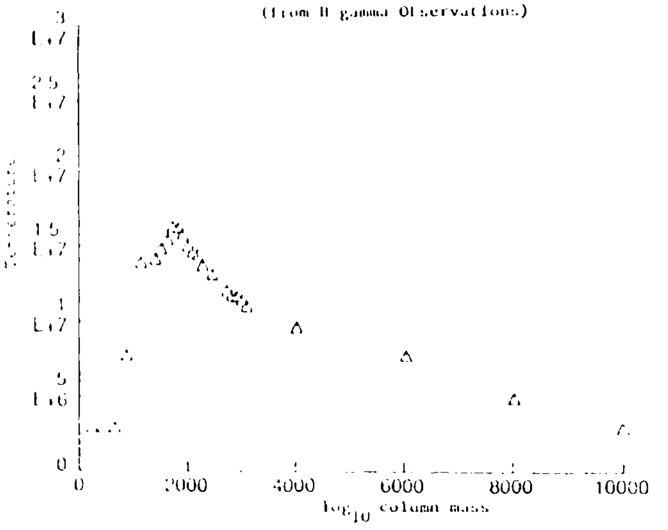
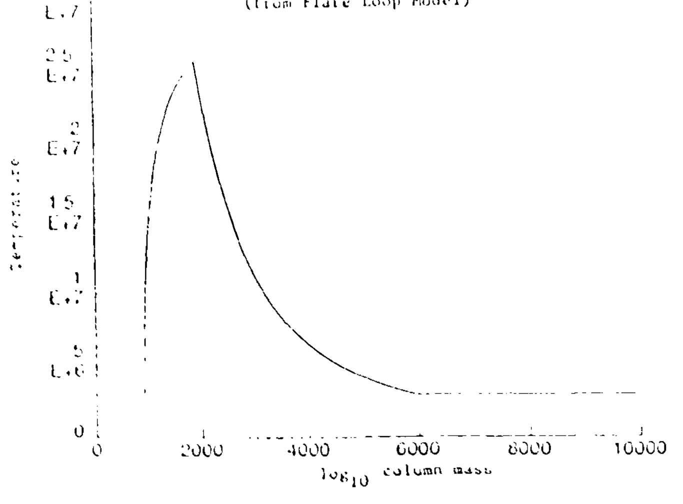


Figure 10

Coronal Apex Temperature vs. Time

(from Flare Loop Model)



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