THE AXAF LOW-ENERGY TRANSMISSION GRATING SPECTROMETER LETGS: DIAGNOSTIC CAPABILITIES FOR THE STUDY OF STELLAR CORONAE

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Abstract. We study the diagnostic capabilities of the high-resolution, Low-Energy Transmission Grating Spectrometer, LETGS, of NASA's planned Advanced X-ray Astrophysics Facility, AXAF, for optically thin stellar coronae. Spectra are simulated on the basis of isothermal and source loop models and are analyzed with particular emphasis on the extraction of the differential emission measure distribution. The AXAF-LETGS is shown to be particularly sensitive for plasma at temperatures between 0.5 and 15 MK. Emission from temperatures in excess of 20 MK can be observed, but the lack of strong spectral lines hampers accurate temperature determinations. We simulate spectra of close binaries to demonstrate the observability of the Doppler effects associated with orbital motions. We present lists of spectral lines that can be used for density diagnostics, and we simulate and compare various spectra at different electron densities.

1. Introduction

The detailed spatial structure of stellar coronae is not yet known, although by analogy with the Sun it is widely assumed that much of the hot, X-ray emitting plasma in the coronae of cool stars with a convective envelope is confined in magnetic loops which connect opposite polarities in the photosphere. The actual three-dimensional temperature and density structure of stellar coronae, with few exceptions, has evaded detailed study because the X-ray instruments of the past had only a limited spectral resolution and sensitivity. NASA's Advanced X-ray Astrophysics Facility (AXAF) (e.g., Weisskopf, 1987) and ESA's X-ray Multi-Mirror Mission (XMM) (e.g., Barr et al., 1988) will change the present situation dramatically. The high spectral resolution of the AXAF-LETGS ($\Delta \lambda \approx \frac{1}{20} \text{Å}$) allows observations of resolved emission lines in soft X-rays between 3 and 140 Å with a high signal-to-noise ratio. Because of the large light-collecting area, exposure times for spectral observations as short as a few hours suffice for many bright sources.

The most detailed spectral observations of stellar coronae to date have been made with the EXOSAT transmission grating spectrometer (TGS). This instrument permits...
the study of individual spectral line features and line complexes over a wavelength range from 10 to 200 Å with approximately 3 Å resolution. An analysis of the TGS spectra of the late-type stars Capella and $\sigma^2$ CrB has confirmed an early working hypothesis - based on the low-resolution EINSTEIN-IPC data - that the emission of the corona of each of these stars is dominated by plasma in two distinct temperature integrals: around 5 and 25 MK (Mewe et al., 1986b; Lemen et al., 1989). In the case of Procyon a cool 0.6 MK component was found, together with a $\sim$3 MK component. The EXOSAT soft X-ray spectra were also used in an attempt to constrain some of the basic properties of the presumed coronal magnetic loops (Schrijver and Mewe, 1986; Mewe et al., 1987; Schrijver et al., 1989): the derived differential emission measure (DEM) distributions for $\sigma^2$ CrB and Capella suggest that the coronae of these stars may comprise at least two distinct ensembles of quasi-static magnetic loops with maximum temperatures $T_m$ at apex around the dominant temperatures given above. A two-component analysis using computed loop spectra shows evidence that at least the 5 MK component has a relatively strong expansion with height: the expansion factors $\Gamma$ (the ratio of the loop cross-sections at the top and at the footpoints near the transition region) appear to lie between 30 and 50. The optimal expansion factor for the 25 MK component is about 2–5.

Although Schrijver et al. (1989) placed constraints on the expansion of the loops with height, it was not possible to derive the loop length $L$, because this parameter has a small effect on the DEM distribution. The combined data about emission measure $\int n_e^2 \, dV$, temperature $T$, and electron density $n_e$ (derived from density-sensitive spectral lines) provides us with the gas pressure and with information about the emitting volume $V$, hence, also about $L$, in combination with the area-filling factor $f$. The large number of resolved spectral lines that can be observed also allows studies of abundances and velocities.

We study the capabilities of the AXAF instrument for the determination of temperatures, densities, and velocities from the theoretically well-understood spectra emitted by hot, optically thin plasmas such as the coronae around late-type stars.

2. Instrument Description

The principle of operation and the basic geometry of the AXAF low-energy transmission grating spectrometer (LETGS) is described by Brinkman et al. (1987). The spectrometer, intended for high-resolution spectroscopy in the 3–140 Å range, is composed of the high-resolution mirror assembly (HRMA) and the low-energy transmission grating (LETG), with the high-resolution camera (HRC) as the detector positioned in the focal plane of the telescope mirror. The incident rays are reflected off the paraboloid and hyperboloid sections of the AXAF telescope and the resulting converging beam falls on the transmission grating to form a central zero-order image on the detector in the focal plane with first-order spectra on both sides. The grating will be attached to the back of the (movable) telescope and can be moved in and out of the X-ray beam.