AD Leonis: Flares observed by XMM-Newton and Chandra

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The M-dwarf AD Leonis has been observed with the Reflection Grating Spectrometers and the European Photon Imaging Camera aboard XMM-Newton and also with the Low Energy Transmission Grating Spectrometer aboard the Chandra X-ray Observatory. In the observation taken with XMM-Newton five large flares produced by AD Leo were identified and only one in the observation taken with Chandra. A quiescent level to the lightcurves is difficult to define, since several smaller flares mutually overlap each other. However, we defined a quasi-steady state outside of obvious flares or flare decays. The spectra from the flare state and the quasi-steady state are analysed separately. From these spectra the temperature structure was derived with a multi-temperature model and with a differential emission measure model. The multi-temperature model was also used to determine the relative abundances of C, N, O, Ne, Mg, Si, S, and Fe. He-like ions, such as Ovii and Neix, produce line triplets which are used to determine or constrain the electron temperature and electron density of the corresponding ion. During the flare state a higher emission measure at the hottest temperature is found for both XMM-Newton and Chandra observations. The derived abundances suggest the presence of an inverse First Ionization Potential effect in the corona of AD Leo.


Introduction

AD Leo is an M-dwarf with spectral type M3.5 V at a distance of 4.7 parsec Many cool stars (F – M) maintain active coronae with temperatures up to 20 MK. Our goal is to determine differences in the physical coronal conditions such as temperatures, emission measures, abundances, and densities between different states of the corona of AD Leo. We note that in the corona of the Sun a First Ionization Potential (FIP) effect is observed which implies that elements with a low FIP (say 10 eV) are enhanced in the corona relative to the photospheric values. But for other active stars an Inverse FIP (IFIP) effect was suggested. The underlying mechanism for these FIP and IFIP effects is not well understood. In this paper, the abundances are measured to see if there are anomalies and whether these are different for the flare state and quasi-steady state.

AD Leo is known to be capable of frequent flaring in the X/EUV/optical regime. Flares on M-dwarfs may play a part in the heating mechanism of the outer atmospheres of stars. The expression ‘quasi-steady’ emission is in fact a superposition of multiple small flares. The expression ‘quasi-steady’ is therefore used in this paper to refer to the state between the distinct flares.

The X-ray spectra taken by rgs 1, rgs 2 and epic-mos 2 aboard XMM-Newton. The dominant lines in the spectrum have been labeled with the corresponding ion. epic-mos 2 has a lower resolution and is used only from ~2 to ~14 Å. rgs 1 and 2 have a higher resolution and are used from 8 to 38 Å. A typical error bar for the continuum is included in the upper right corner.