HYBRID STARS AND CORONAL EVOLUTION

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1 Scientific Activity

This program addresses the evolution of stellar coronas by comparing a solar-like corona in the supergiant β Dra (G2 Ib–IIa) to the corona in the allegedly more evolved state of a hybrid star, α TrA (K2 II–III). Because the hybrid star has a massive wind, it appears likely that the corona will be cooler and less dense as the magnetic loop structures are no longer closed. By analogy with solar coronal holes, when the topology of the magnetic field is configured with open magnetic structures, both the coronal temperature and density are lower than in atmospheres dominated by closed loops. The hybrid stars assume a pivotal role in the definition of coronal evolution, atmospheric heating processes and mechanisms to drive winds of cool stars.

XMM-NEWTON observations were awarded through the Guest Investigator program, and obtained in March 2001 of α TrA with a total exposure time of 95.6 ks, and in Sept./Oct. 2002 of β Dra with a total exposure time of 19.7 ks. The data were delivered in multiple segments, and each RGS segment was reduced separately using the current version of the XMM-NEWTON Standard Analysis System (SAS: *http://xmm.vilspa.esa.es/sas*) and Current Calibration Files (CCF). Individual source light curves were constructed to insure that the stars were not flaring. Model fittings and line identifications were made with *Sherpa*, the modeling and fitting engine of CIAO (Chandra Interactive Analysis of Observations) and APEC (Astrophysical Plasma Emission Code; Smith *et al.* 2001, ApJ, 556, L91).

Analysis of the XMM spectra has been reported at the American Astronomical Society Meeting in January 2003, and also at the 13th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun in 2004. Results are also in press. Our main conclusions are:

1. Both of these single giant and supergiant stars show very high temperature emission (T$\sim10^7$K) in their steady (non-flaring) state extending hot coronas to spectral type K2. These temperatures are much hotter than a typical solar/dwarf corona, and vividly demonstrate that high energies can be achieved in slowly-rotating single stars of low gravity.

2. Multi-temperature fits to the spectra are required to adequately fit all ion species. A 1-T fit however suggests that the corona of β Dra is sightly hotter (kT=0.78$\pm$0.01 keV) than the corona of α TrA (kT=0.75$\pm$0.01 keV) supporting the idea that coronal structure can change, becoming cooler as luminous stars evolve to the hybrid phase.

3. Abundances of O, Ne, and Fe are 'solar' (Anders & Grevesse 1989, Geochim. Cosmochim. Acta, 53, 197) in β Dra, but in the α TrA spectrum, the high First Ionization Potential (FIP) elements Oxygen and Neon are enhanced with respect to solar values by factors of 1.7 and 3.1 respectively in contradiction to the First Ionization Potential (FIP) effect observed in the Sun.

4. The value of the density sensitive ratio of O VII transitions (the *r-ratio*): f/i = [22.1Å/21.8Å] is comparable both stars, and suggests an electron density at T$\sim2\times10^6$K on the order of 10^{11} cm^{-3}. The temperature sensitive *G-ratio* $[(f+i)/r]$ confirms the results of the 1-T fit that the corona of β Dra is hotter than α TrA.

5. Signs of anomalous abundances appear in the cooler corona of α TrA. The energy deposition is unknown for both stars. It may be comparable in each, but allocated differently between coronal heating and momentum and energy deposition to drive a massive wind in the hybrid star α TrA.

In sum, these spectra demonstrate that slowly-rotating giants and supergiants can have coronae hotter than the Sun. These spectra also give the first evidence that stellar coronal structure changes, becoming cooler as luminous stars evolve to the hybrid phase. Our observations are in harmony with coronal evolution that resembles the change between the closed magnetic field regions on the Sun and the open magnetic field regions (coronal holes) that lead to both a cooler corona and a high speed wind.