The Relative Emission from Chromospheres and Coronae: Dependence on Spectral Type and Age

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1. Perspective

- Photochemistry in exoplanet atmospheres is driven by UV emission from the host star's chromosphere.
- X-ray and EUV radiation from a host star's corona drives escape from exoplanet atmospheres.

2. Objectives

- Does the ratio of chromospheric to coronal emission (flux ratios and ratios of luminosity to bolometric luminosity) depend on stellar parameters? If so, which parameters?
- What do these trends tell us about the relative amount of magnetic heating in stellar chromospheres and coronae?

3. Methods

- X-ray fluxes observed by XMM-Newton, Chandra, and ROSAT measure the X-ray emission from stellar coronae.
- Extreme ultraviolet (EUV) radiation (100-912 Å) can be estimated from the X-ray flux or Lyman-α flux.
- The hydrogen Lyman-α line (1216 Å) is the brightest UV emission line in G stars and represents about half of the total UV emission from M stars. It is a good test of the total UV emission from chromospheres (T=4000-20000 K).
- Interstellar absorption has been removed to obtain the intrinsic stellar flux.
- We analyzed spectra from all available (79) dwarf stars of F, G, K, M1–M2, and M3–M6 spectral types. The solid lines with different colors are least square fits to the stars in each spectral type category. The fluxes of cool M dwarfs are plotted with the star names and symbols of F, G, and K dwarf stars. The solid lines are linear fits. The circle symbol is for the Sun at low activity.
- The Lyman-α data are from various HST observing programs including the MUSCLES and MEGUSCLES programs to obtain spectra of M stars. The X-ray fluxes are from the Chandra, XMM-Newton, and ROSAT missions.

4. Results: flux/flux comparisons

- F, G, and K stars follow similar trend lines in plots of L(α)/L(X-ray). See Figure 1. Young active stars lie near the top of the trend lines and old inactive stars like the Sun lie near the bottom. As stars age, their rotation and activity decrease producing decant along the same trend lines.

5. Results: Comparing L(X-ray)/L(bol) with L(Lyman-α)/L(bol)

- For stars younger than 450 Myr, L(Lyman-α)/L(bol) increases to cooler stars reaching saturation (10^-7) near T=3200 K. See Figure 4. This indicates that an increasing fraction of L(bol) is the energy source for chromospheric heating in the cooler stars.
- For stars younger than 450 Myr, L(X-ray)/L(bol) jumps to saturation near T=2000 K. Ages in Myr are indicated. Thus for K and M stars, L(Lyman-α)/L(bol) but the difference decreases to cooler stars.
- For stars older than 4 Gyr, L(X-ray)/L(bol) is larger than L(Lyman-α)/L(bol), but the ratio decreases from a factor of 100 at T=6000 K to a factor of 3 near T=2000 K. See Figure 5. Thus, L(Lyman-α)/L(X-ray) decreases rapidly to cooler old stars.

6. Conclusions

- There are correlations between the high energy emission from coronae that drives escape from exoplanet atmospheres and the UV emission from chromospheres that photo-dissociates molecules in exoplanet atmospheres.

- The correlations depend on both age and Teff.
- For dwarf stars of all ages, chromospheric emission as measured by L(Lyman-α) increases systematically as Teff decreases.
- For young stars (t < 450 Myr), X-ray saturation occurs for stars with Teff > 5,000 K. Thus for young stars cooler than 5,200 K, the (X-ray)/L(Lyman-α) ratio increases rapidly to the cooler stars.
- Older stars (t > 4 Gyr) behave differently. L(X-ray)/L(Lyman-α) increases rapidly to the cooler stars.
- These correlations provide important constraints on theories of magnetic heating on stellar chromospheres and coronae.

7. What does this mean?

Emission from the corona and chromosphere requires magnetic heating in these layers. Our result that for M stars the weakness of chromospheric vs coronal emission implies that the relative amount of heating at chromospheric temperatures is decreasing towards the cooler stars. We can either call the M stars chromospheric weak or coronal strong compared to hotter stars. This result should stimulate theoretical studies of magnetic heating in M dwarf stars. The change in internal structure as stars become fully convective near spectral type M0.5 V and thus do not have a tachocline may be important.

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