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 from exoplanet atmospheres.
- These two topics would be related if there are systematic trends in the relative emission from the chromospheres and coronae of host stars.

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 (T=1–10 MK).
- 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=4,000–20,000 K). Interstellar absorption has been removed to obtain the intrinsic stellar flux.
- We analyzed spectra from all available (79) dwarf stars with both reconstructed Lyman-α fluxes and X-ray fluxes: 6 F stars, 18 G stars, 20 K stars, and 35 M stars many of which have exoplanets.
- The Lyman-α data are from various HST observing programs including the MUSCLES and Mega-MUSCLES programs to obtain spectra of M stars. The X-ray fluxes are from the Chandra, XMM-Newton, and ROSAT missions.

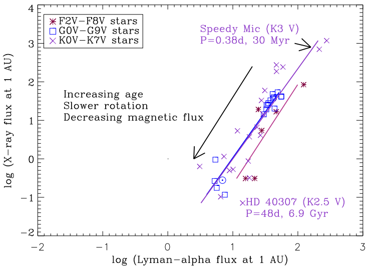

FIGURE 1: A plot of the reconstructed Lyman-α flux vs. X-ray flux at 1 au. Different symbols represent the fluxes of F, G, and K dwarf stars. The solid lines with different colors are least square fits to the stars in each spectral type category. The names, rotational periods, and age of the most X-ray active and least X-ray active K stars are identified. The $\odot$ symbol is for the Sun at low activity.

4 Results: flux/flux comparisons

1. F, G, and K stars follow similar trend lines in plots of f(X-ray) vs f(Lyman-α). **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 decent along the same trend lines.
2. M stars deviate from the FGK trend lines because their Lyman-α flux ratios are smaller. **See Figure 2.**
3. The relative decrease is Lyman-α emission from M stars is also shown by plotting the Lyman-α fluxes divided by what they would be if M stars followed the FGK trend lines. **See Figure 3.**

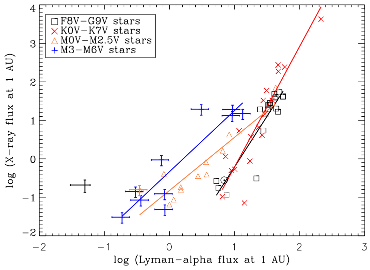

FIGURE 2: A plot of the reconstructed Lyman-α flux vs. X-ray flux at 1 au for a diverse group of dwarf stars. Different symbols represent the fluxes of dwarf stars of F, G, K, M1–M2, and M3–M6 spectral types. The solid lines with different colors are least square fits to the stars in each spectral type category. The fluxes of cool M dwarfs are ploted with the star names and spectral types. The data for the metal-poor subdwarf Kapteyn's star and the very cool M8 V star TRAPPIST-1 (black) are not included in the least squares linear fits. The $\odot$ symbol is for the Sun at low activity.

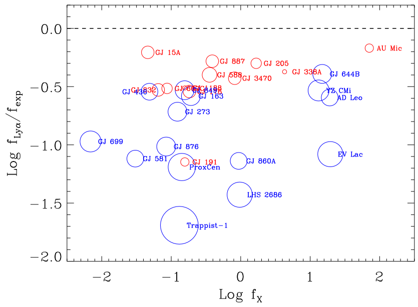

FIGURE 3: Ratios of the reconstructed Lyman-α flux, $f_{\mathrm{Ly}\alpha}$, to the Lyman-α flux predicted if the M stars followed the G star trend line, f_{exp}. The stars are indentified and color coded red for M0 V to M2.5 V stars or blue for M3 V to M8 V stars. The larger circles indicate later spectral type. The horizontal dashed line is where the M stars should lie if their Lyman-α flux followed the G star trend line for their X-ray flux.

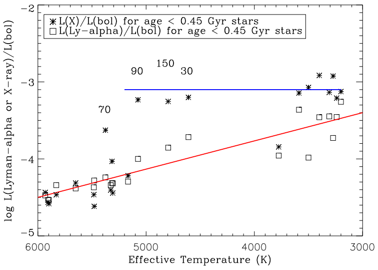

FIGURE 4: Plot of L(X-ray)/L(bol) and L(Lyman-α)/L(bol) vs T_{eff} for stars younger than 450 Myr. The solid red line is a least squares linear fit L(Lyman-α)/L(bol data. The solid blue line is the 10^{-3} saturation level. The ages (in Myr) are given for four stars.

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

1. For stars younger than 450 Myr, L(Lyman-α)/L(bol) increases to cooler stars reaching saturation (10^{-3}) 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.
2. For stars younger than 450 Myr, L(X-ray)/L(bol) jumps to saturation near T=5200 K. Ages in Myr are indicated. Thus for K and M stars, L(X-ray) exceeds L(Lyman-α but the difference decreases to cooler stars.
3. For stars older than 4 Gyr, L(Lyman-α)/L(bol) is larger than L(X-ray)/L(bol), but the ratio decreases from a factor of 100 at T=6,000 K to a factor of 3 near T=2,400 K. **See Figure 5.** Thus, L(Lyman-α)/L(X-ray) decreases rapidly to cooler old stars,

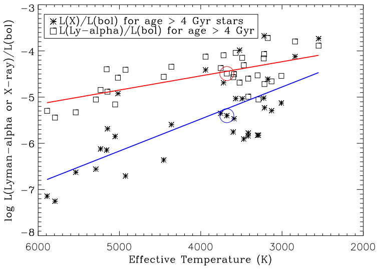

FIGURE 5: Plot of L(X-ray)/L(bol) and L(Lyman-α)/L(bol) vs T_{eff} for stars older than 4 Gyr. The solid lines are least squares linear fits to L(Lyman-α)/L(bol) (red) and L(X-ray)/L(bol) (blue) data. The circled symbols are for the GJ 176.

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 T_{eff}.
- For dwarf stars of all ages, chromospheric emission as measured by L(Lyman-α) increases systematically as T_{eff} decreases.
- For young stars ($t < 450$ Myr), X-ray saturation occurs for stars with $T_{\mathrm{eff}} < 5,200$ K. Thus for young stars cooler than 5,200 K, the L(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 M3.5 V and thus do not have a tachocline may be important.

This poster is a summary of the paper Linsky et al. (ApJ 902, 3 (2020)). Also arXiv 2012.11738. The first author can be contacted at jlinsky@jila.colorado.edu. This work is supported by grants HST-GO-12475, 12596, 13650, 14640, and 15071 from STScI.