Detection of H_2 in AU Mic: An Extremely Cold Star Spot?

Laura Flagg (1); Christopher Johns-Krull (1); Kevin France (2); Gregory Herczeg (3); Joan Najita (4); Allison Youngblood (2); Adolfo Carvalho (1); John Carptenter (5); Scott J. Kenyon (6); Elisabeth R. Newton (7)
(1) Rice University; (2) Laboratory for Atmospheric and Space Physics, University of Colorado; (3) Kavli Institute for Astronomy and Astrophysics, Peking University; (4) NOAO; (5) Joint ALMA Observatory; (6) SAO (7) Dartmouth College

INTRODUCTION

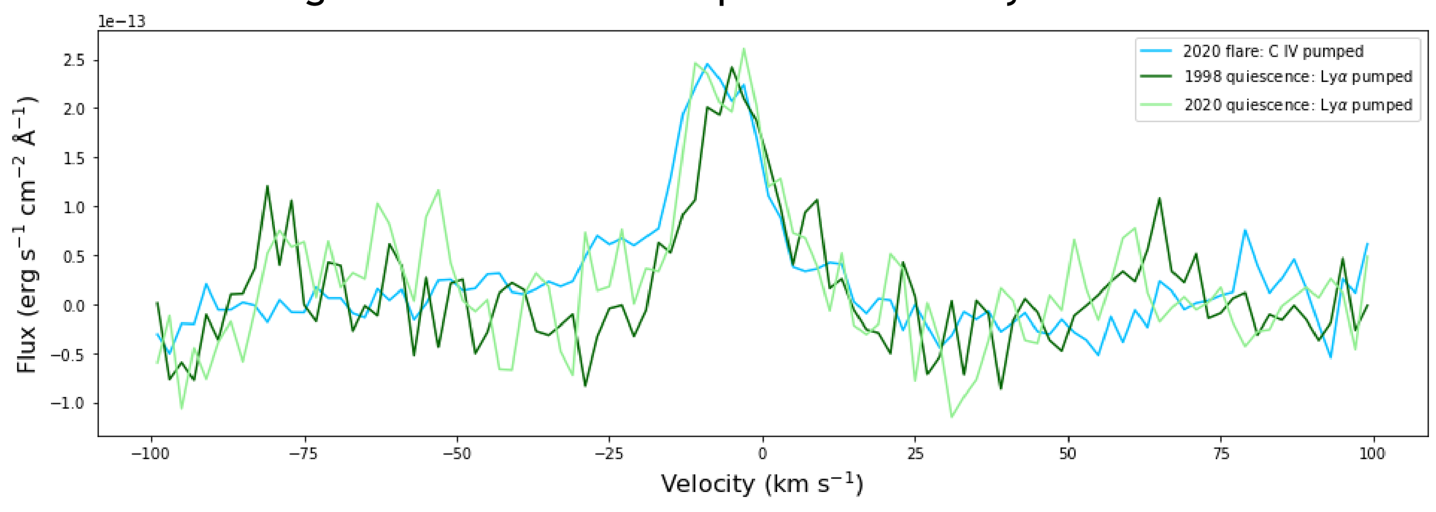
H_2 is the most abundant – and arguably the most important – molecule in the galaxy. It is crucial to many aspects of astronomy, including the earliest stages of planet formation and evolution. It is the largest constituent of any newly-formed gas giant planet. So understanding the timescale of how H_2 goes from the circumstellar disk in which the planet forms to the planet is necessary to understanding the planet itself. However, M dwarfs have H_2 in both their photospheres and star spots. Differentiating between stellar and circumstellar H_2 can be difficult given the low flux levels. At ~20 Myr with a well-studied debris disk, AU Mic is an ideal target to study this.

OBSERVATIONS

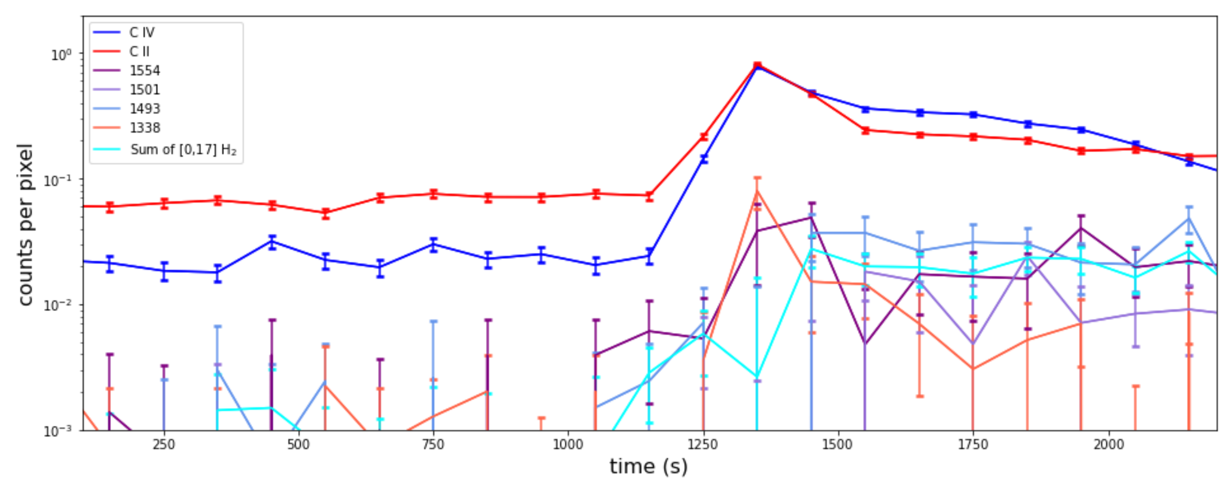
AU Mic was observed in 1998 and 2020 with HST-STIS using the E140M grating, which results in a R~46,000 between 1144 and 1710.

H_2 DETECTION IN AU MIC

We have confirmed the H_2 detection [1] from AU Mic in both epochs. We also detected separate H_2 emission as a result of a stellar flare. Plotted are the line profiles of features pumped by Lyα from both data sets, as well as the CIV pumped features that only emitted detectable flux during the flare. All three profiles are very similar.

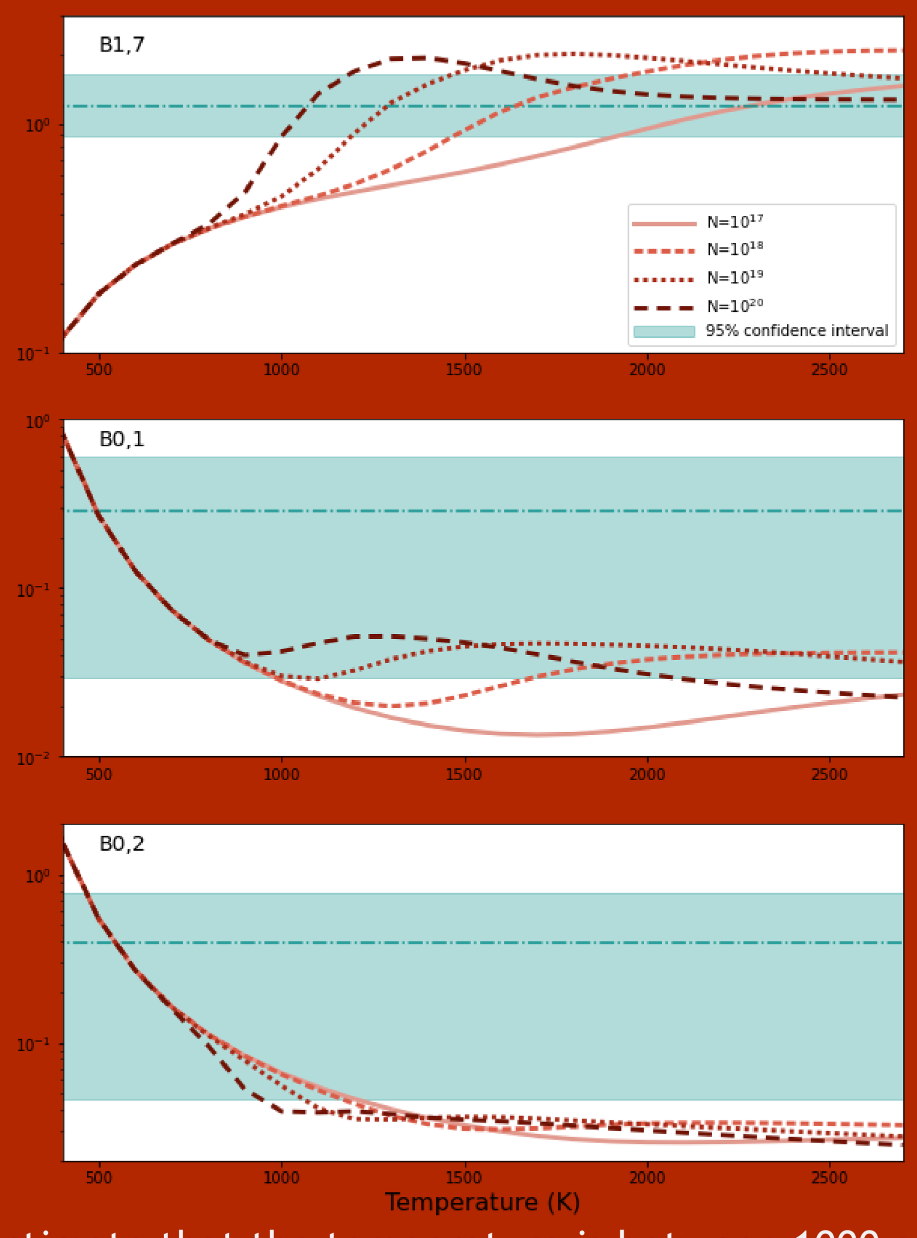


The light curve shows how the H_2 features responded in time to the flare. There appears to be a 50-150 s delay between the C IV flare and the response of the related H_2 features.



TEMPERATURE OF H_2

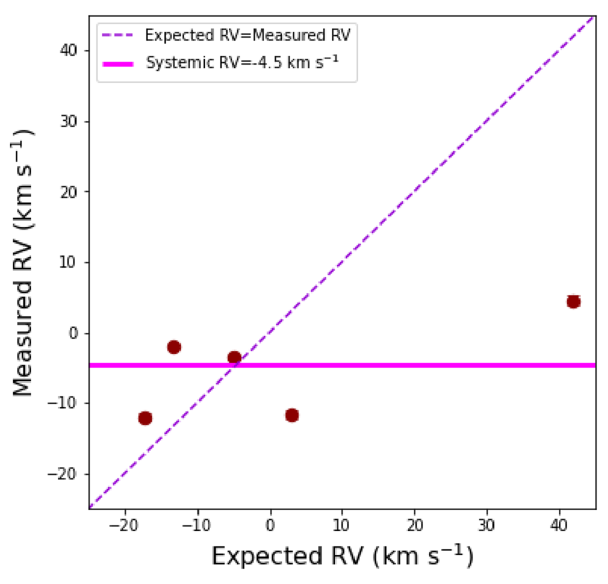
By looking at the line ratios measured from progressions we detect, plotted in teal below, in comparison with ones from model spectra, we can put limits on the temperature of the H_2.



Based on this, we estimate that the temperature is between 1000 and 1500 K. This is consistent with the measurements of the temperature from FUSE data [1].

H_2 ORIGIN

1. If it were in a planet, we would see the location of the peaking moving with the planet's orbit. As plotted below, the peaks are scattered around the systemic velocity of the system, not the planet's orbital velocity. Thus, we can rule a planets out.



2. A foreground source would not have been affected by the flare. We can rule this out.
3. If it were in a disk, then because the flare would only affect part of the disk, the profile from the flare would be significantly offset or more narrow than the normal profile. We see very similar profile shapes during quiescence and from the flare.
4. That leaves the star.

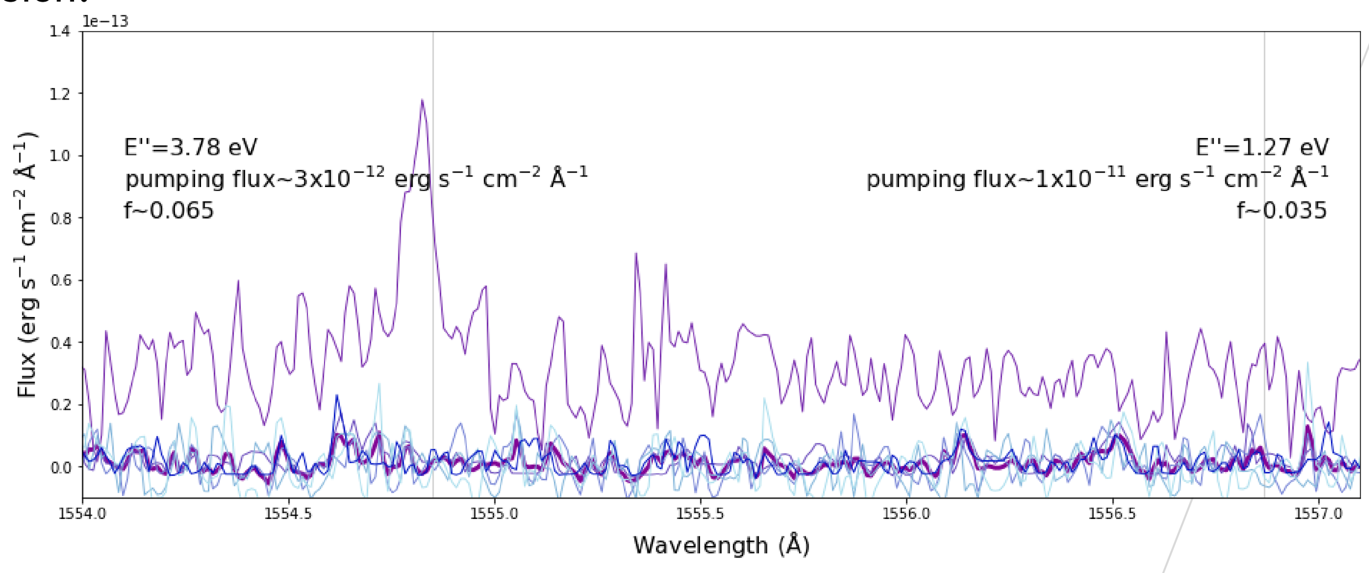
POSSIBLE SOURCES FOR VERY COLD GAS IN A M0.5 STAR

The photosphere is ~3800 K [2]. It cannot be the source of this cold gas. We have two other possible sources:

1) A star spot. The temperatures of star spots typically measured for AU Mic are much warmer than this, at least 2650 K [2,3]. But we cannot rule out star spots at different temperatures.
2) A cold layer of gas between the photosphere and the chromosphere, equivalent to the CO-mosphere [4] in the Sun. While somewhat similar layers have been discovered in giant stars [5], this has not been investigated for red dwarf stars.

NON-THERMAL EXCITATION OF H_2 DURING FLARE

The progression we detect the most flux from during the flare is excited from too high a state – E=3.78 eV – to be populated thermally at these temperatures, especially given that lower energy states do not appear populated. Plotted is the spectrum during the flare showing two such features, and only the line originating from a highly excited state shows visible emission.



We have thought of two possibilities to explain this: heating from the FUV continuum that occurs during the flare or dissociative recombination.

REFERENCES

[1] France et al. (2007) ApJ, 668, 1174. [2] Afram and Berdyugina (2019) A&A, 629, A83.
[3] Rodono et al. (1986) A&A, 165, 135. [4] Wiedemann et al. (1994) ApJ, 423, 806.
[5] Sloan et al. (2015) ApJ, 811, 45.