What can Trappist-1 Tell us about Radiation from M Dwarf Chromospheres and Coronae?

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Radio Exploration of Planetary Habitability
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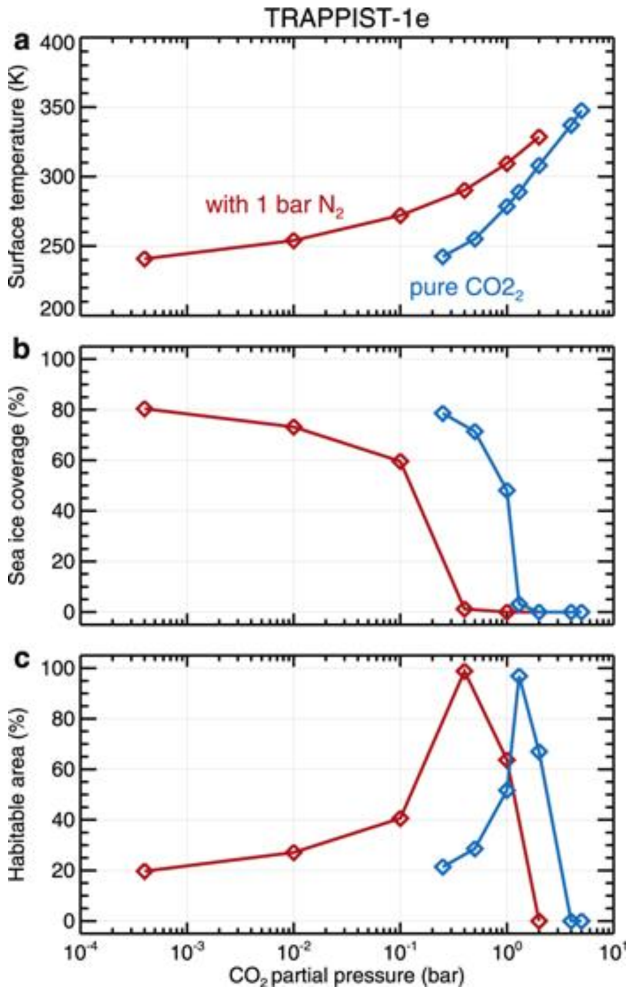
Trappist-1e is likely a habitable exoplanet

- Trappist-1 (Teff~2560) has 7 exoplanets R/R_E=0.755-1.086 (Gillon et al. 2016)
- Global 3D climate models (P>1mbar) assuming ocean covered and N_2, CO_2, H_2O in atmosphere (Wolf ApJL 839, 1 (2017))
- Only Planet e is habitable (T_{mean}~288 K) with 1 bar N_2 and <2 bar CO_2 or <4 bars CO_2 but no photochemistry included (chemical equilibrium models)



UV, EUV and X-ray observations of Trappist-1

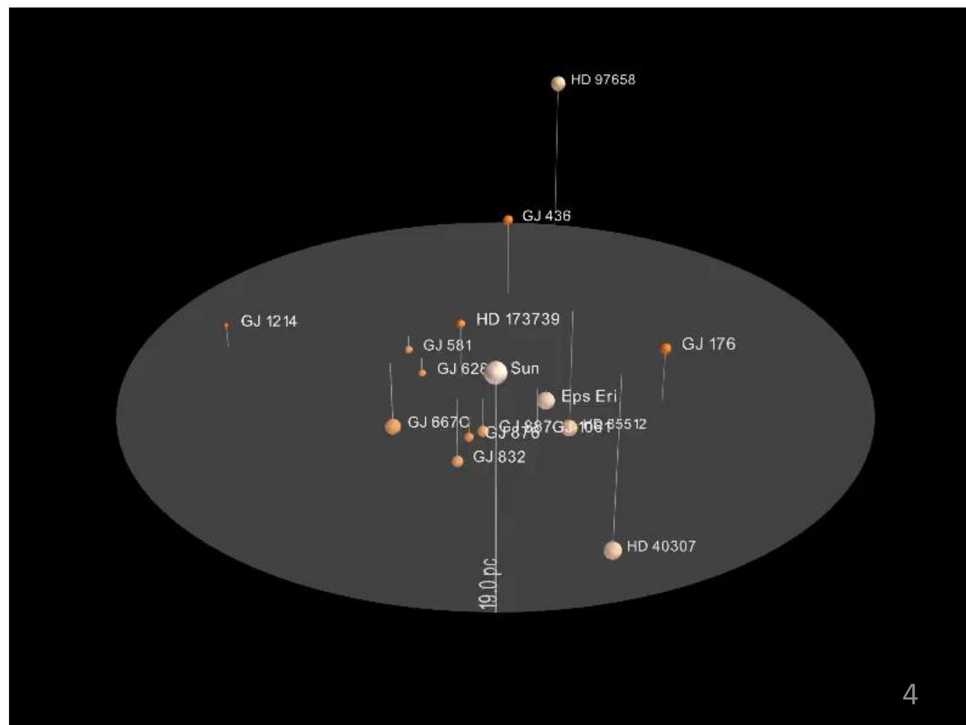
- X-ray flux observed by Wheatley et al. (2017) with L_x similar to quiet Sun and Prox Cen and L_x/L_{bol}=2-4x10^{-4}.
- Reconstructed Ly-α flux 6 times weaker than Prox Cen and 200 times weaker than quiet Sun (Bourrier et al. 2017).
- Ly-α line has narrow wings unlike Sun.
- L(Ly-α)/L(x) is very weak compared to Prox Cen, suggesting that Trappist-1 has a weak chromosphere compared to its corona.
- L(EUV) strong or weak depending on whether scaled from X-rays or Ly-α. Best to compute a model atmosphere.

MUSCLES

MUSCLES Treasury Survey: 11 K and M dwarf exoplanet hosts at d < 20 pc. HST-Cy22, X-ray, Opt

PI – K. France

- Characterize the energetic radiation environment in the habitable zones around low-mass stars
- Measure flare distributions on typical (`inactive') K & M dwarfs host stars
- Constrain impact on atmospheric photo-chemistry and the production of molecular tracers



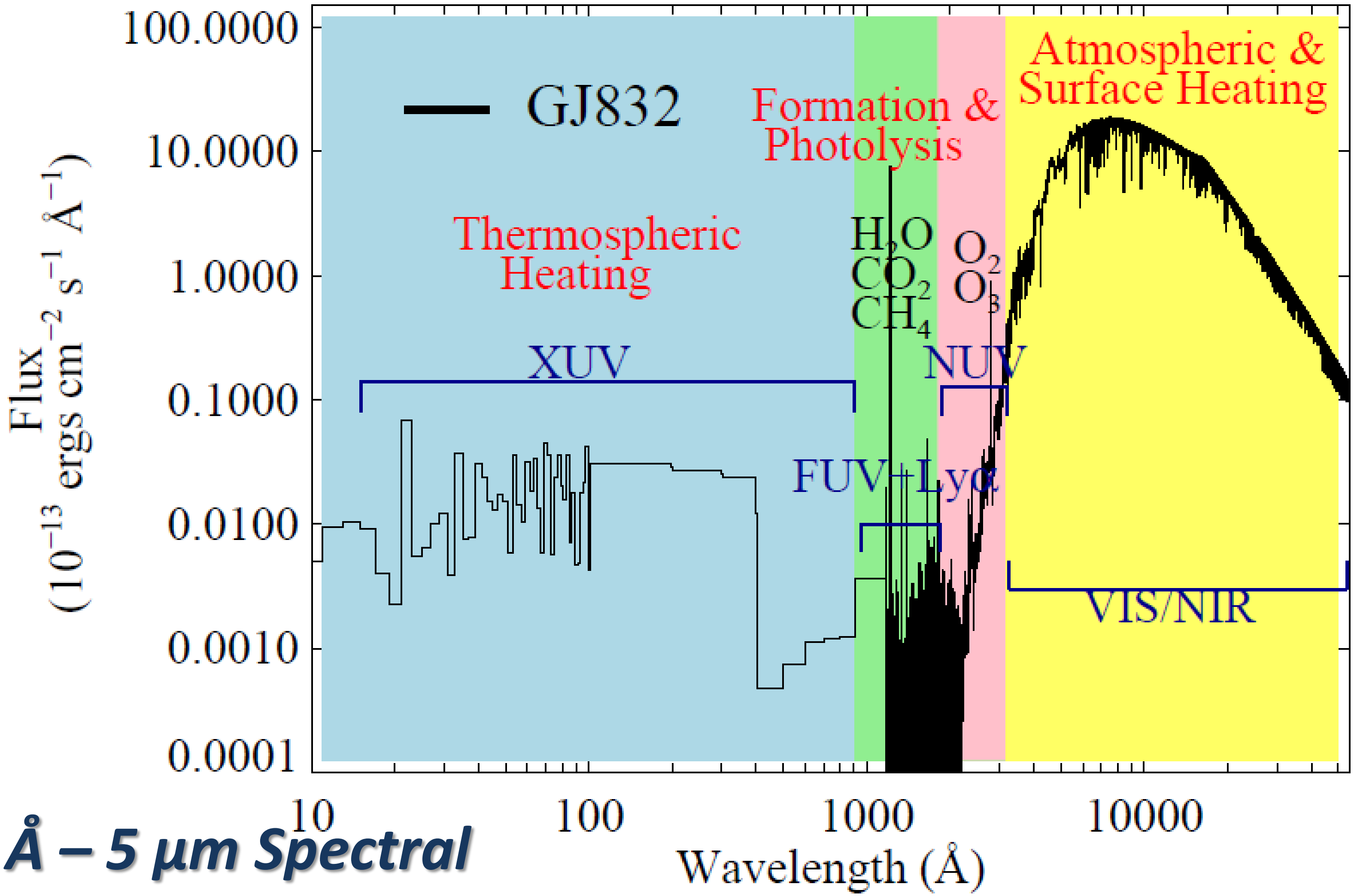
Observational & Modeling Program

- **Optical & NIR** -
  - North: APO, LCOGT, South: El Leoncito, VLT
- **FUV (w/ Lyα) & NUV**
  - *Hubble Space Telescope*, **Cycle 22 Treasury**
- **LUV**
  - *Far-Ultraviolet Spectroscopic Explorer* + models
- **EUV**
  - Calculation based on new solar/stellar models and observed FUV line emission + *EUVE*
- **X-ray**
  - *Chandra, XMM-Newton, Swift*

X-ray = 0.5 - 10 nm
EUV = 10 – 90 nm
LUV = 91 – 116 nm
FUV = 117 – 170 nm
NUV = 171 – 310 nm

PI – France

https://archive.stsci.edu/prepds/muscles/

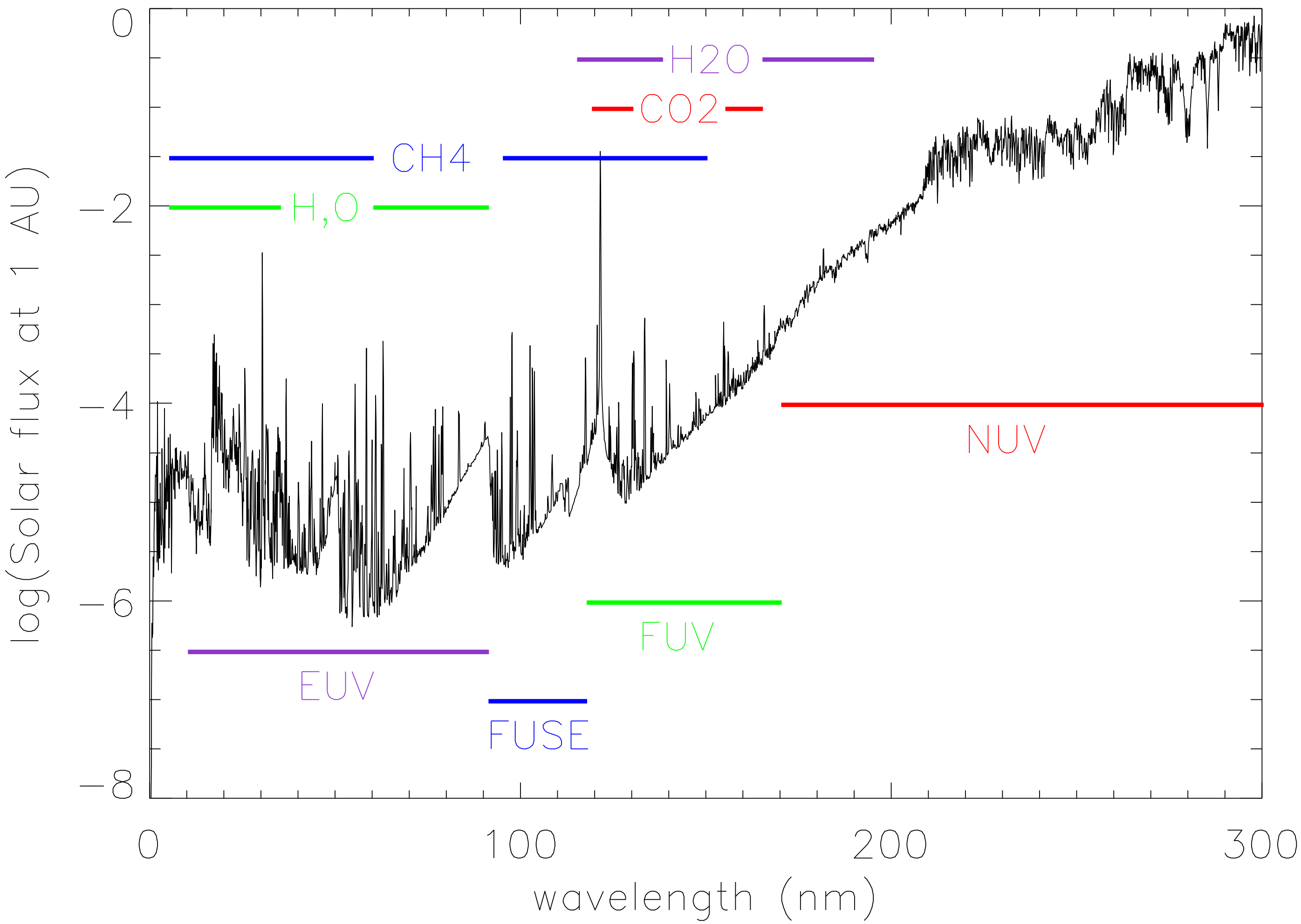


5 Å – 5 µm Spectral Irradiance Database for 11 M and K dwarfs

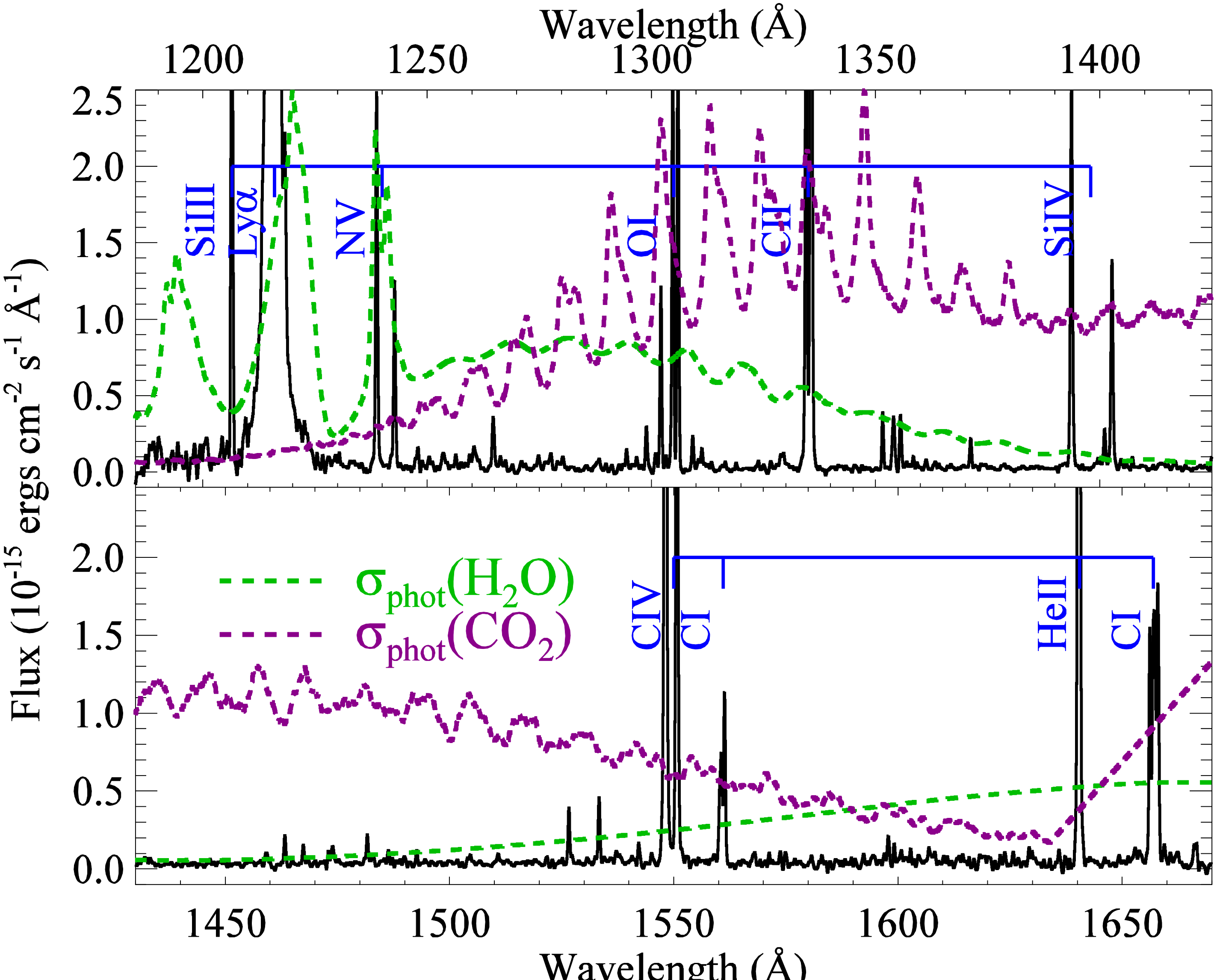
Model atmosphere for GJ832: Fontenla et al. (ApJ-2016)

France et al. (ApJ-2016)
Loyd et al. (ApJ-2016)
Youngblood et al. (ApJ-2016)

Photodissociation and Photoionization Cross Sections of some Important Molecules in Exoplanet Atmospheres

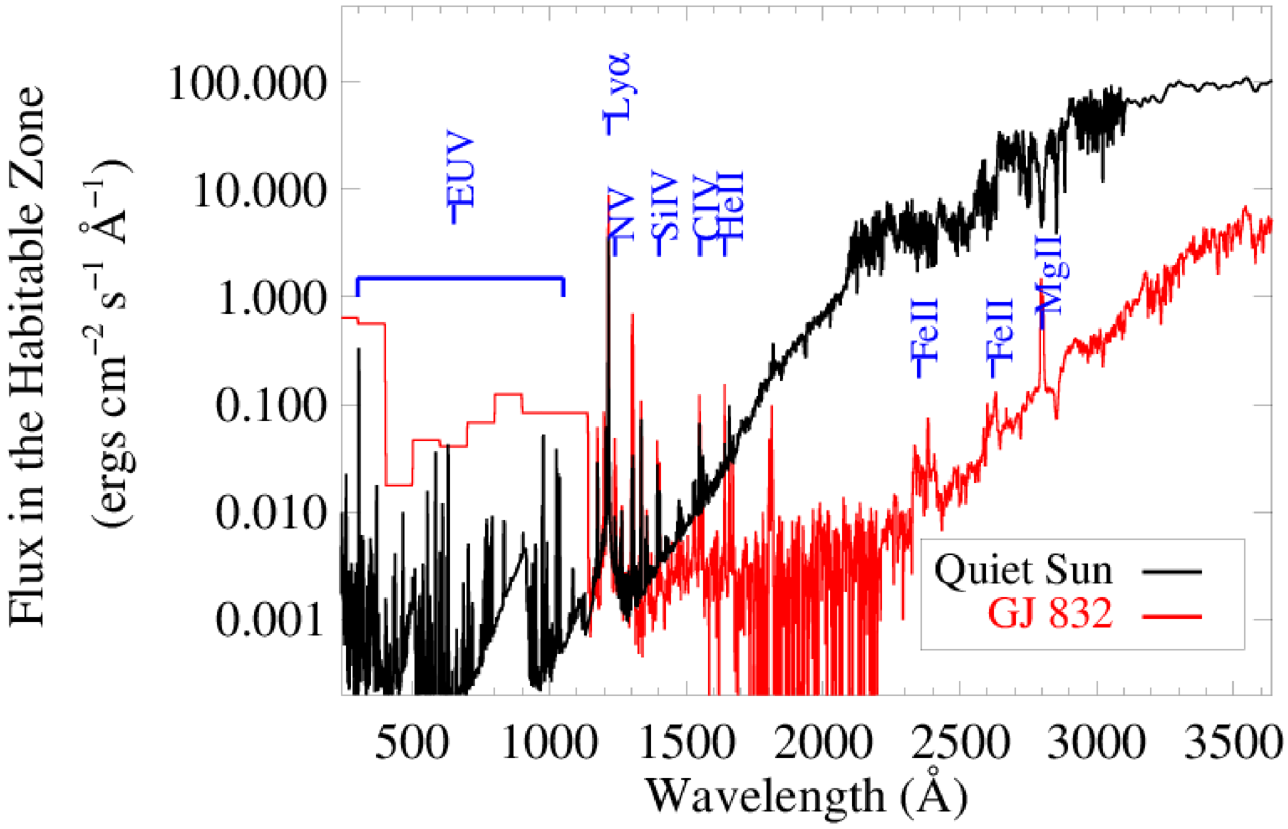


UV spectrum of GJ832 with H_2O and CO_2 cross-sections included



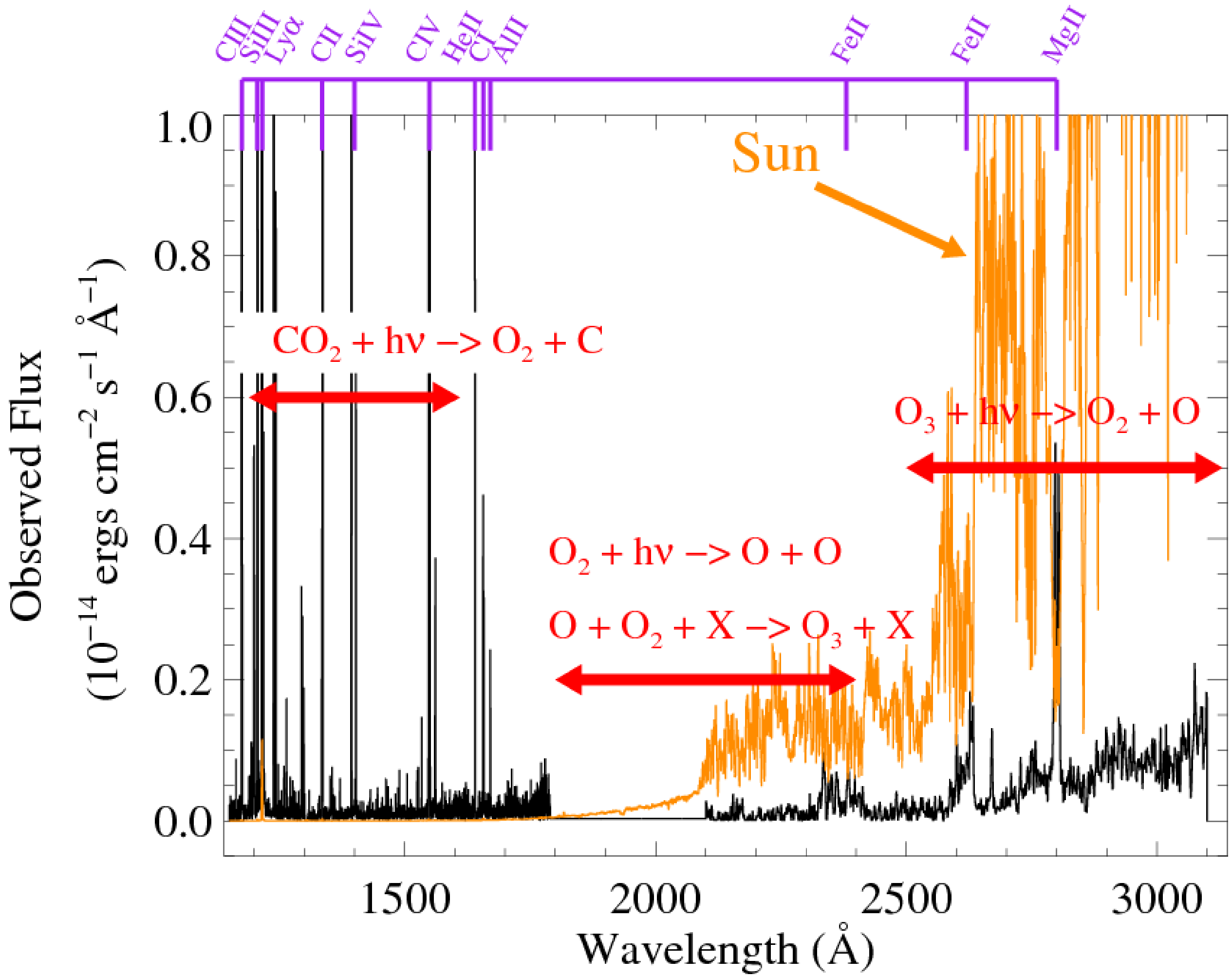
M dwarf XUV, FUV, and NUV vs. Solar

- GJ 832, UV Spectrum

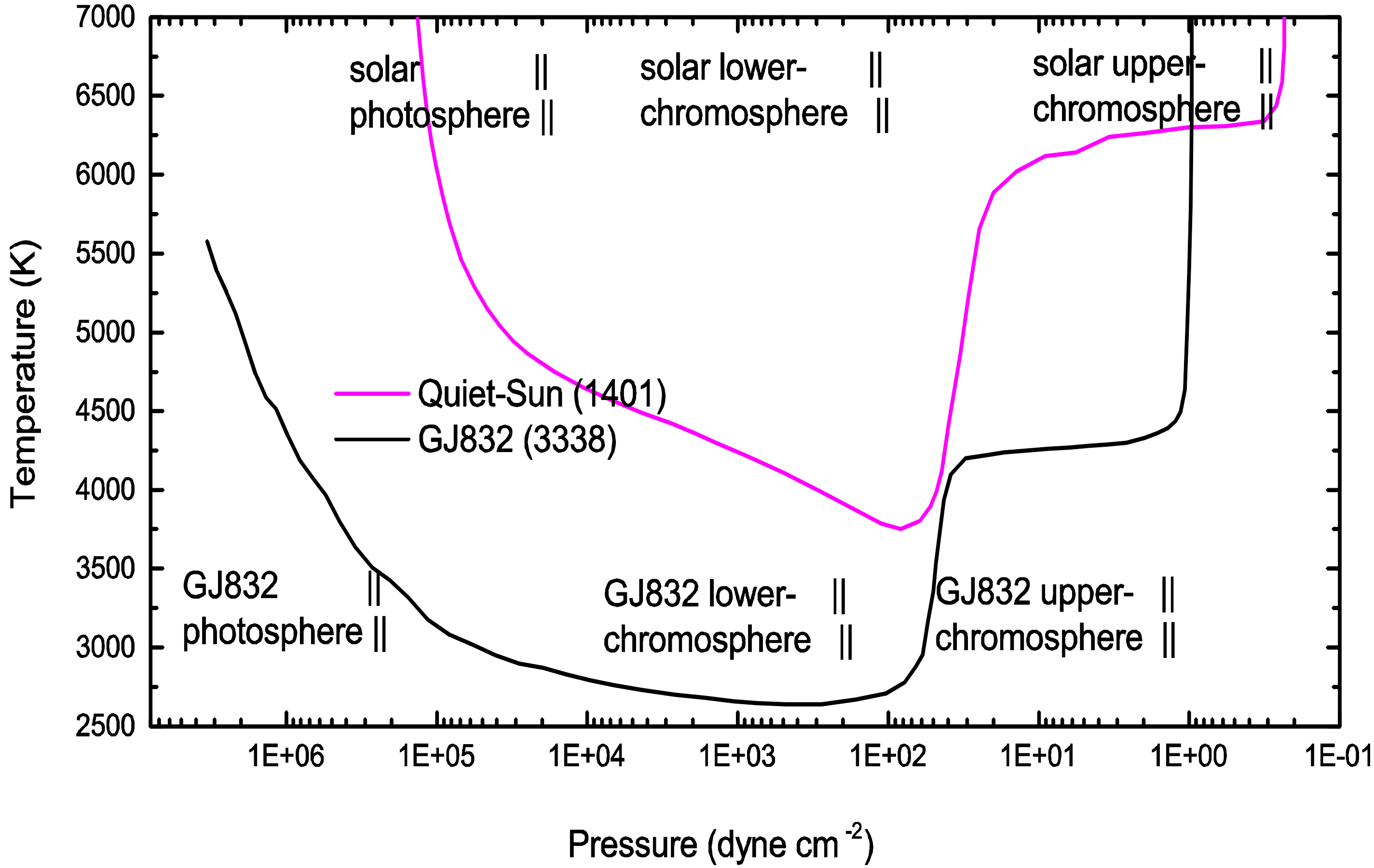


France et al. (ApJL-2012c, ApJ-2016)

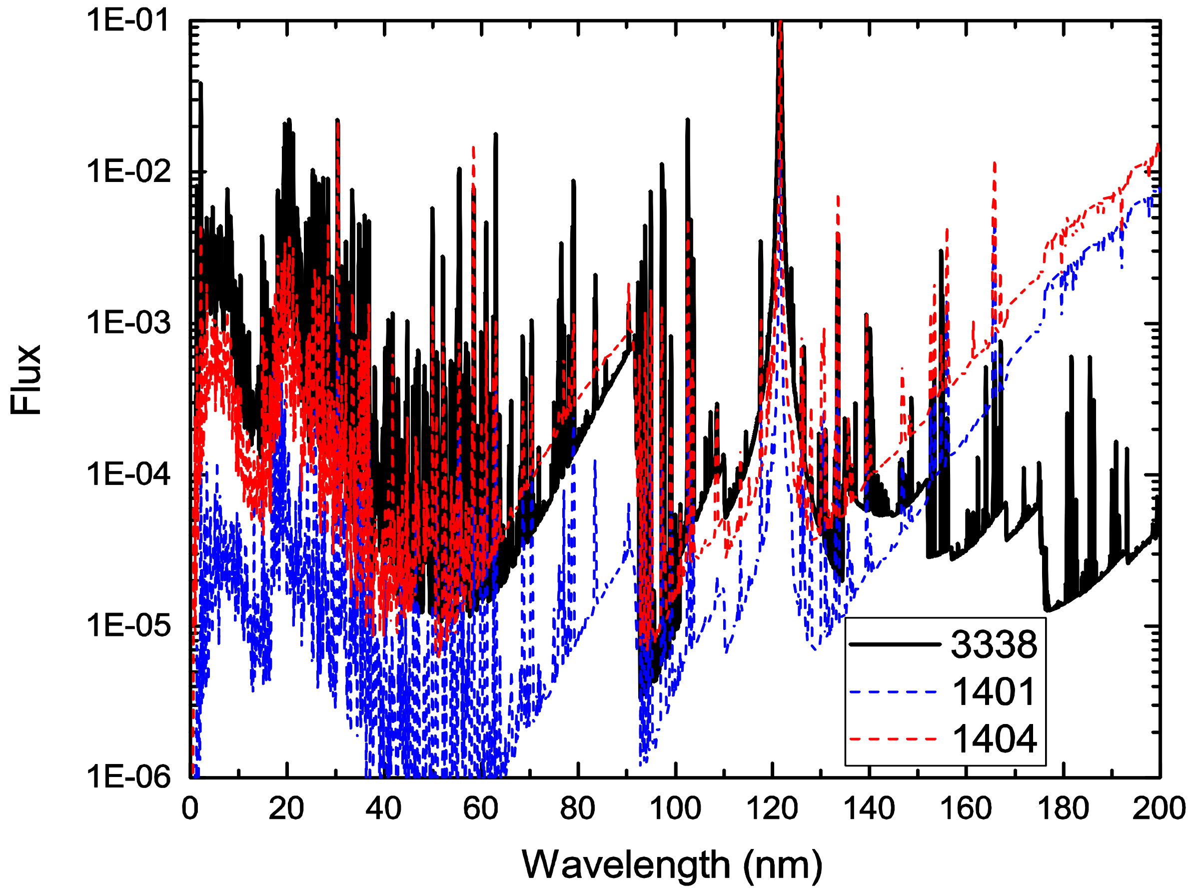
Exoplanet Atmospheres: Exo-Earths



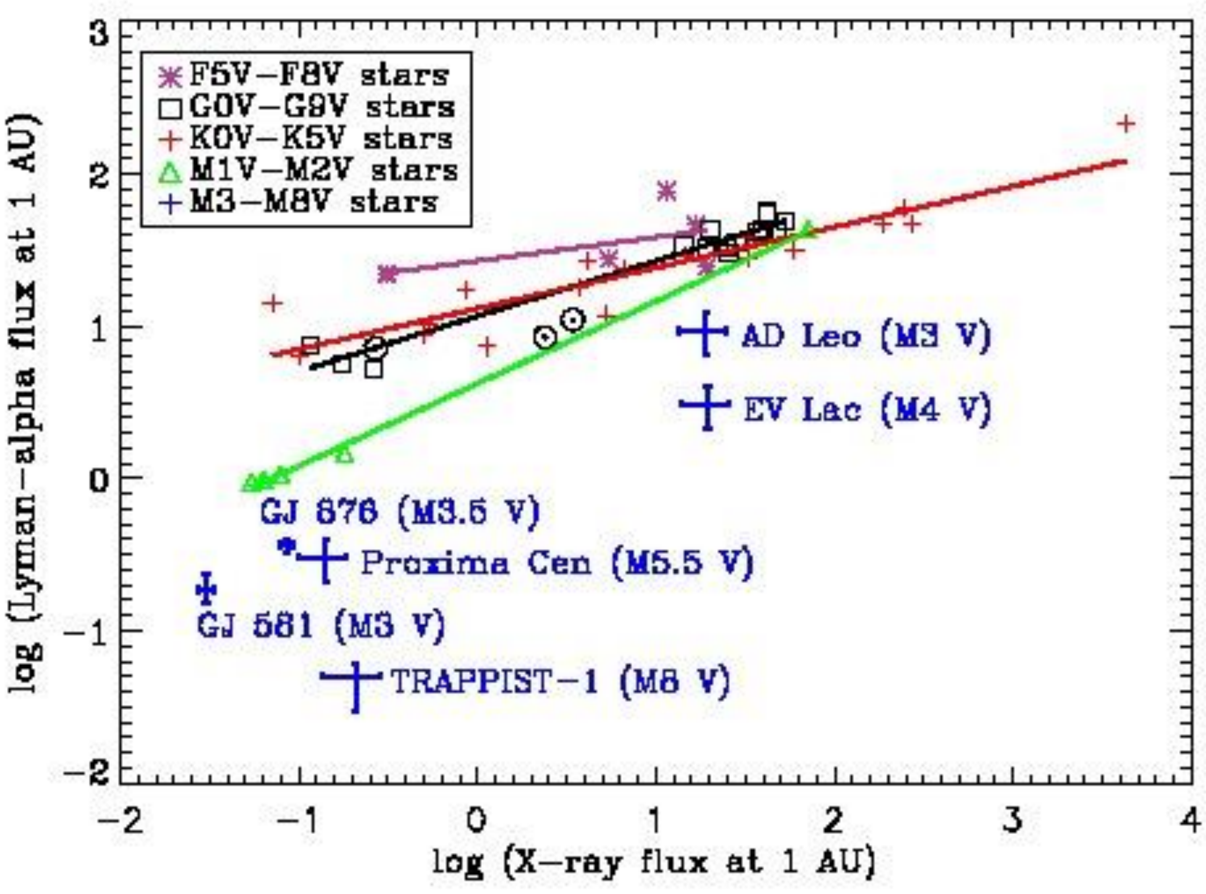
Comparison of semi-empirical non-LTE models of GJ832 (M1 V, black) and the quiet Sun (G2 V, red). Models by Fontenla et al. (2015, 2016). The photosphere and lower chromosphere of Trappist-1 will be much cooler.



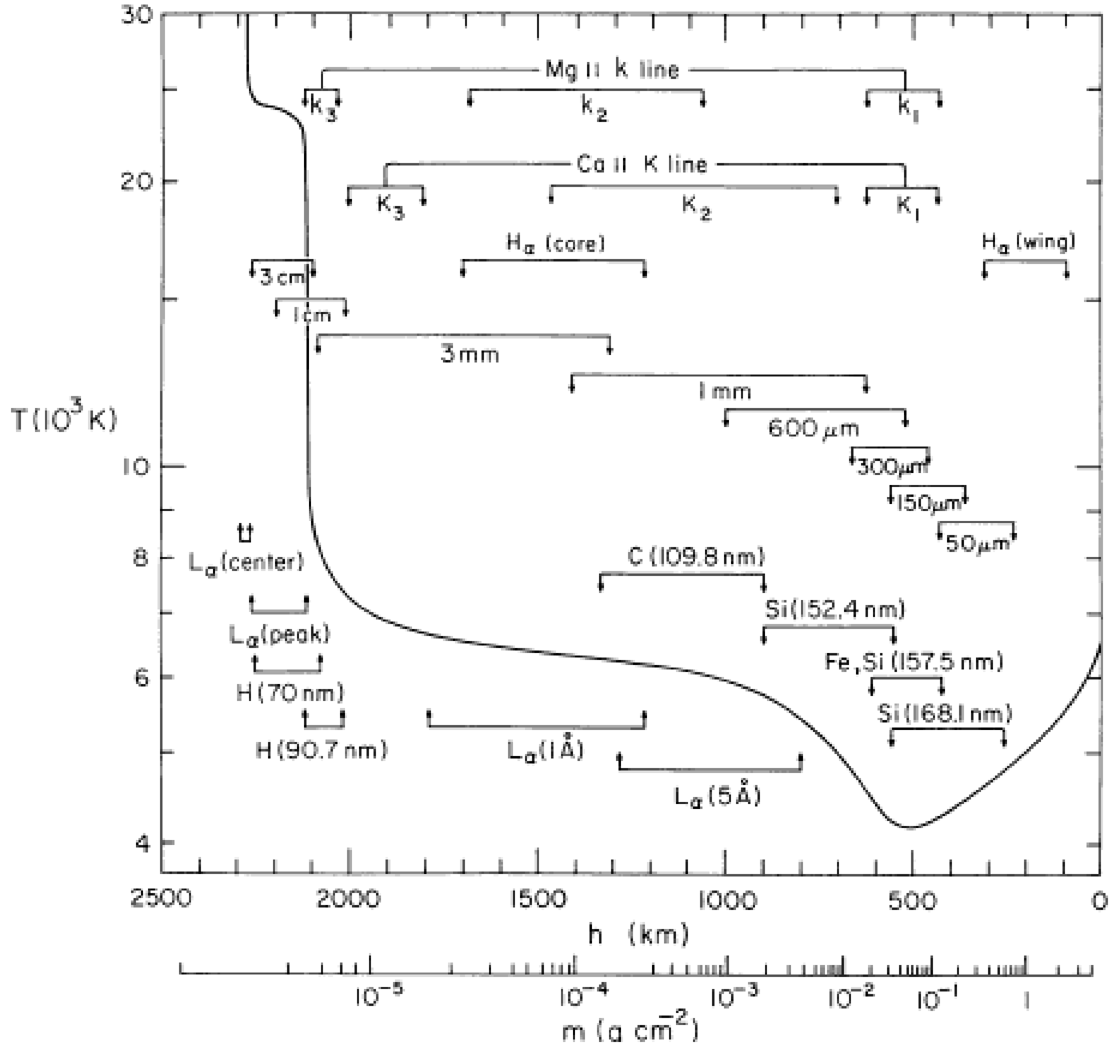
Comparison of the X-ray, EUV, and far-UV spectra of the quiet Sun (blue, model 1401) and active Sun (red, model 1404) seen from 1AU with GJ832 (black, model 3338) seen from 0.23AU (its habitable zone)



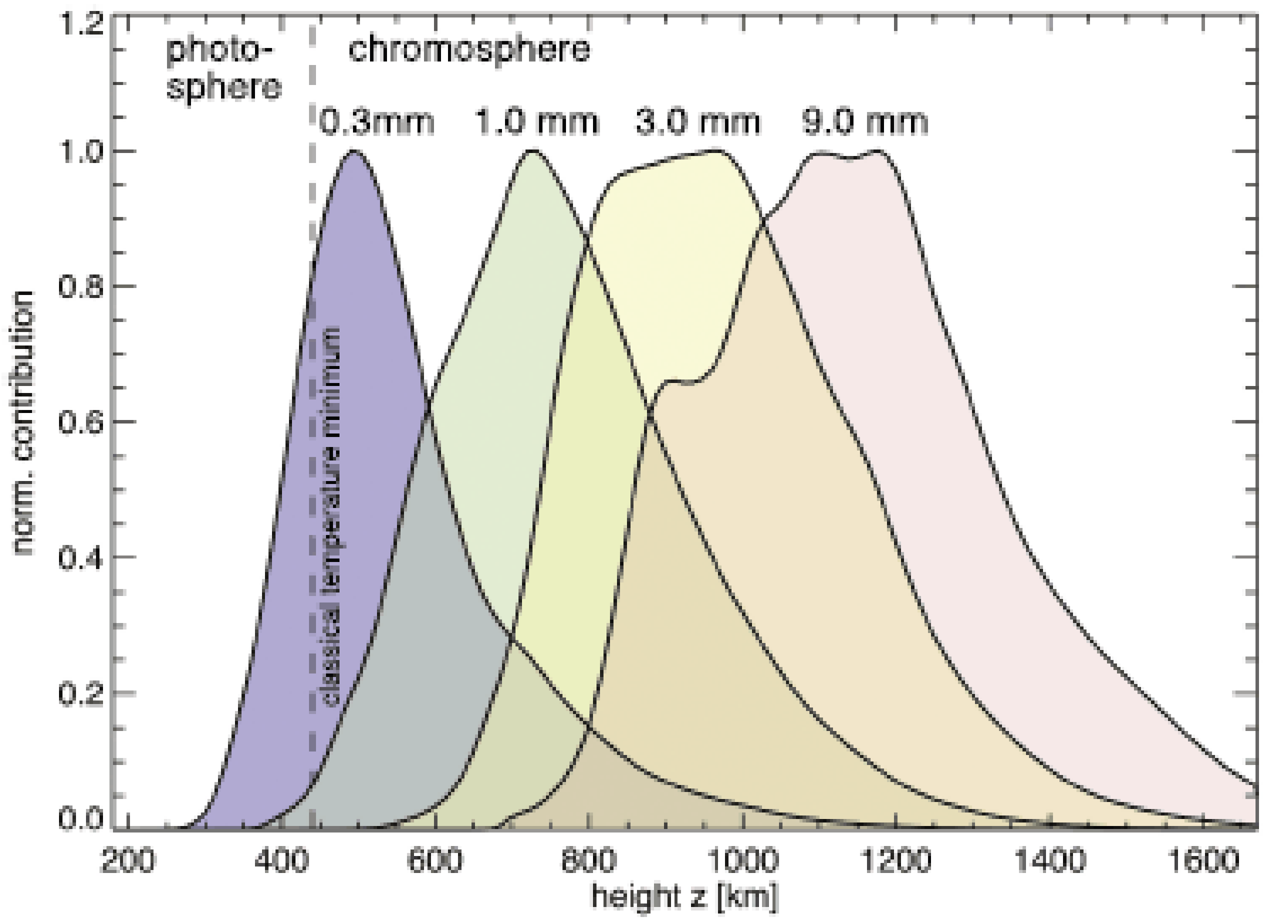
The coolest M dwarfs have low UV fluxes relative to X-rays



Millimeter and far-IR emission regions in the quiet Sun (Model C of Vernazza, Avrett, & Loeser 1981)



Contribution functions for continuum intensity at solar disk center (Wedemeyer et al. 2016)

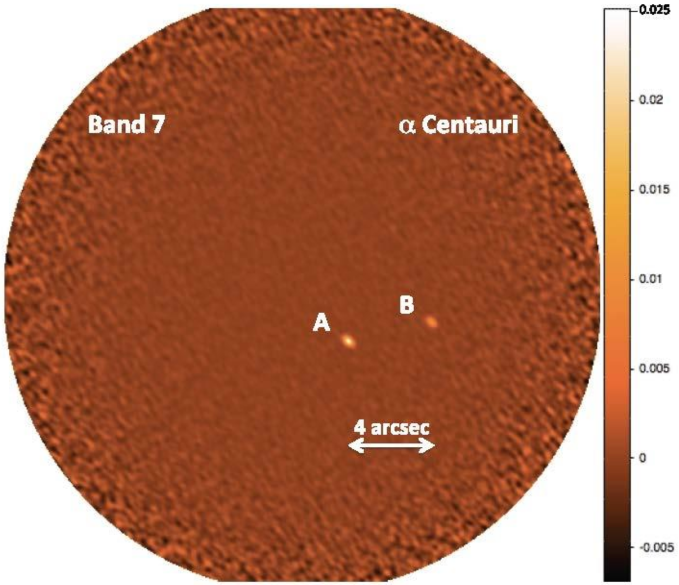


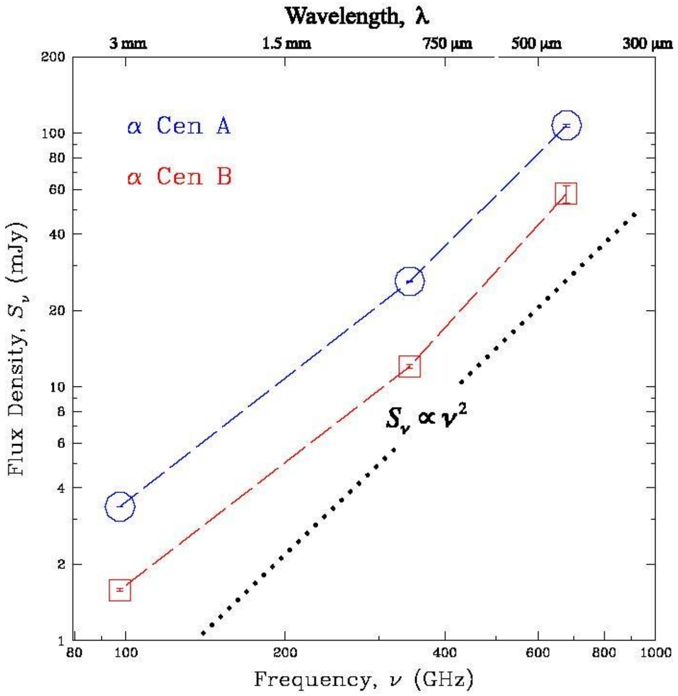
ALMA observations of α Cen A and B

(Liseau et al A&A 573, L4 (2015))

2 minutes exposure at 344 GHz

30 min at 97.5 GHz, 2 min at 344 GHz, 8 min at 679 GHz



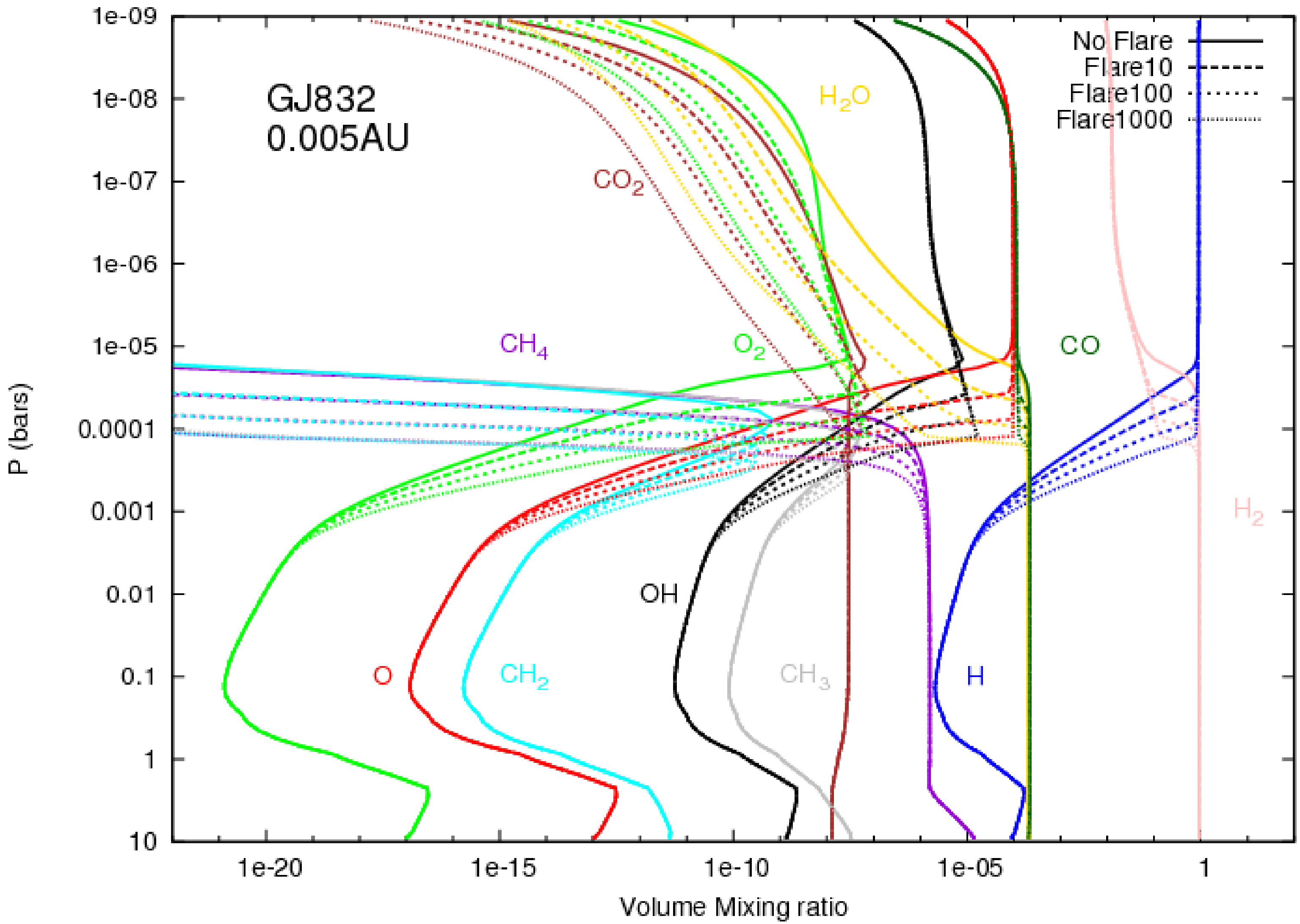


First detection of a dwarf star at 3 mm with only 30 of 40 ALMA antennas.
Dotted line is predicted slope for optically thick free-free emission.

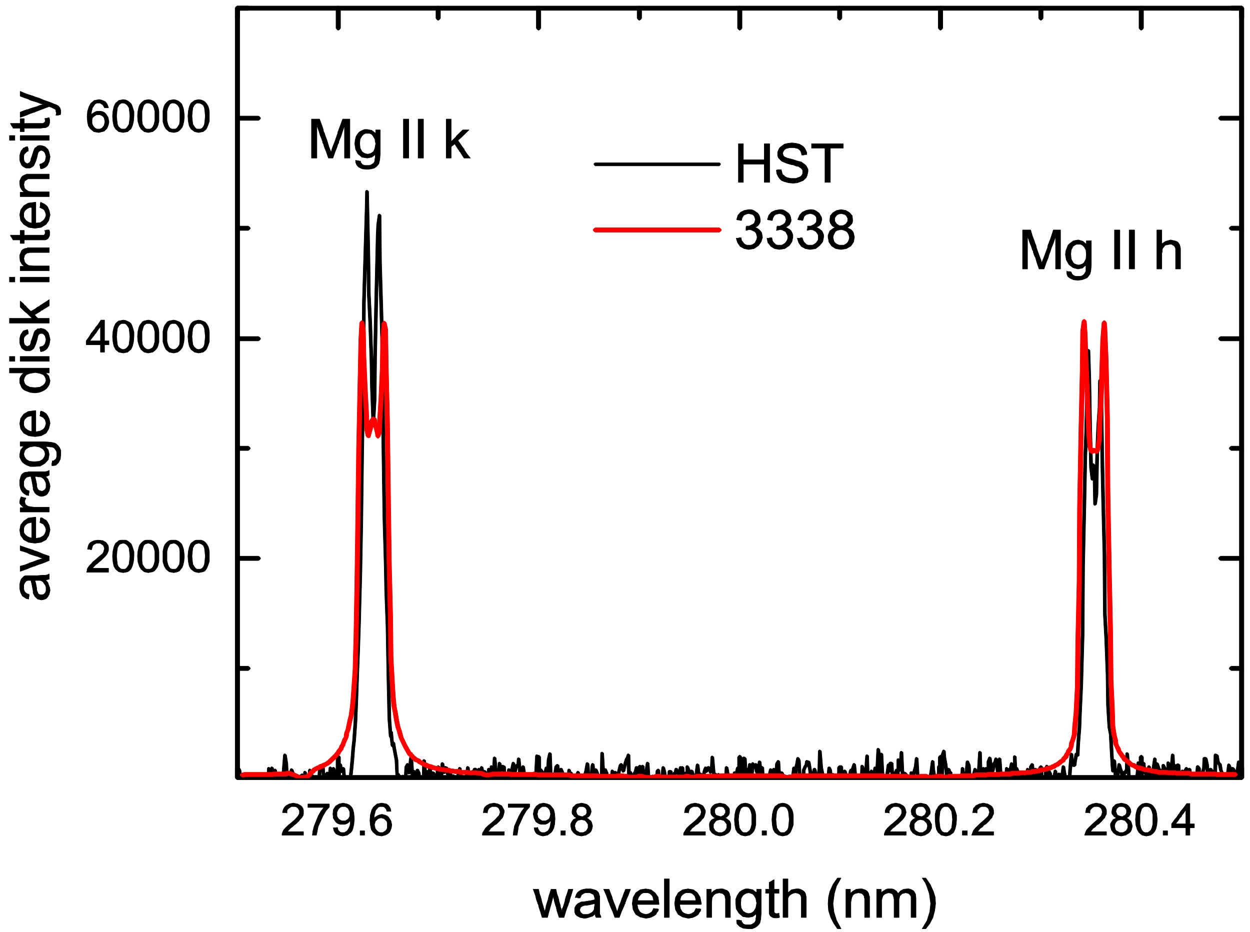
Thank you

Any Questions?

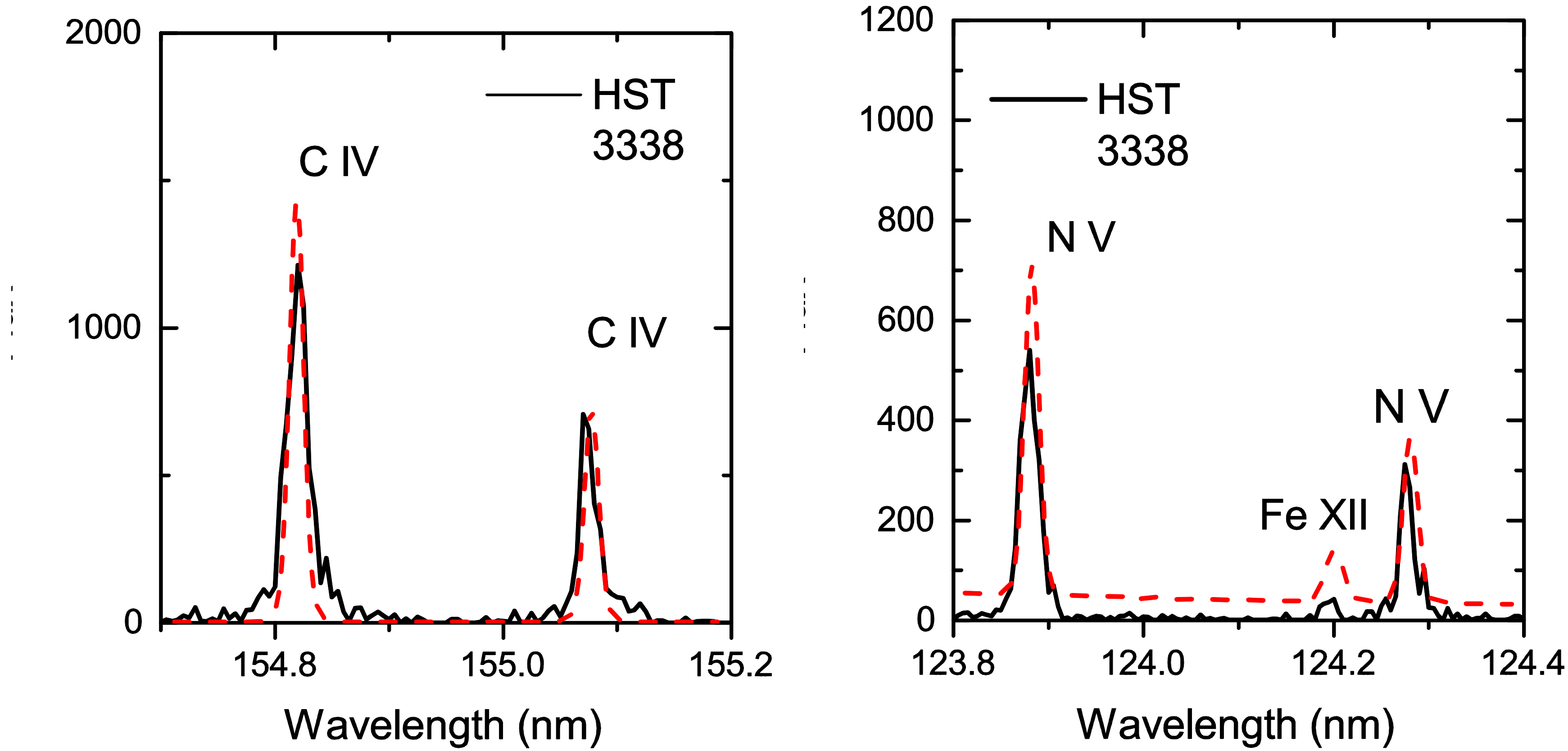
Photochemistry of an M dwarf atmosphere as function of host star UV flux (Miguel et al. MNRAS 446, 345 (2015))



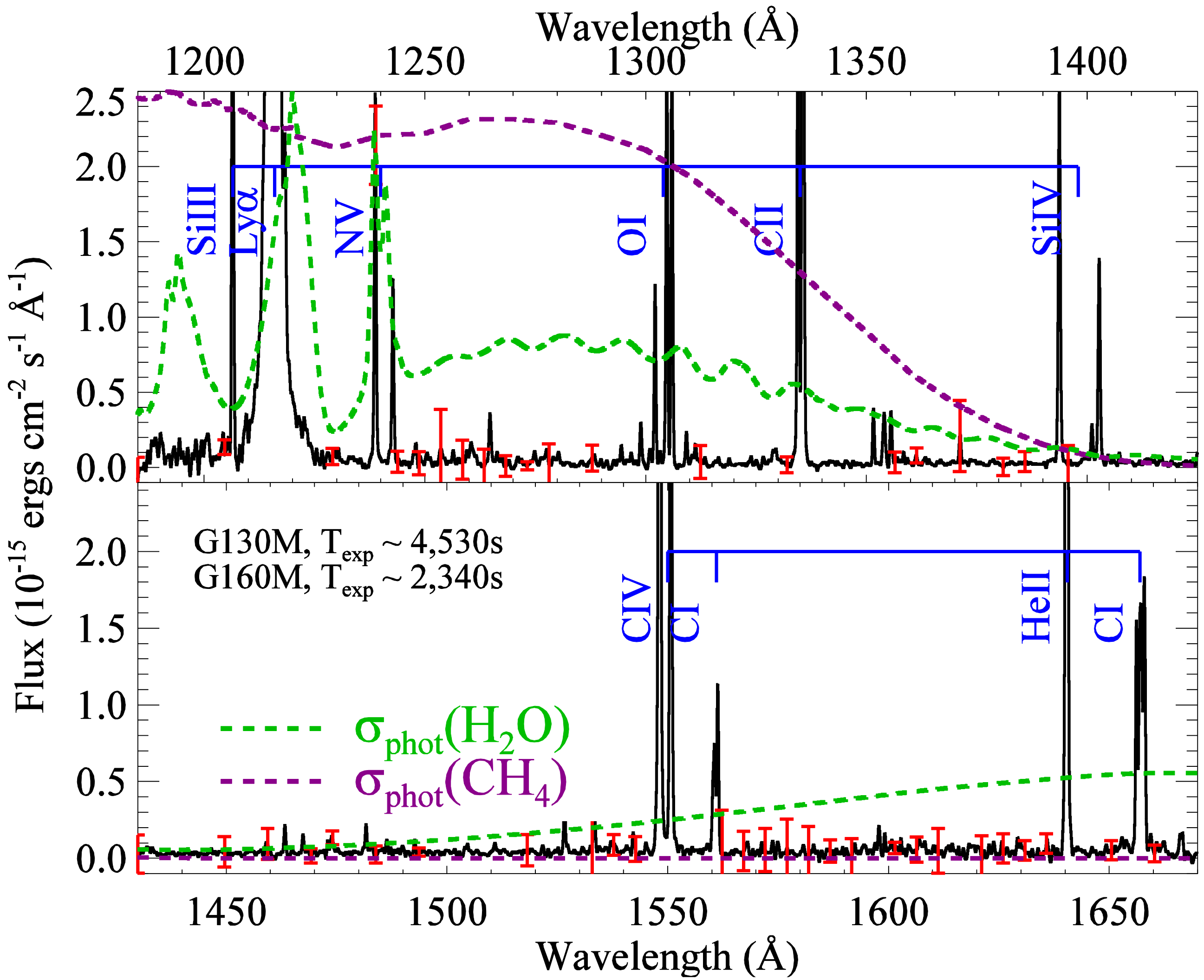
Comparison of high-resolution spectra of GJ832: observed (black) and computed (red)



Observed (black) and computed (red) transition region lines of GJ832 formed at 100,000K and 170,000K



Simulated spectrum of GJ 436 (M2.5 V with a 0.073M_J exoplanet). Note emission lines and photo-absorption cross-sections of H_2O and CH_4



Detecting Rocky HZ Planets

- **Habitable planet candidates exist today; TESS will likely identify ~ 15 potentially habitable planets around M dwarfs**

However, we have few constraints on the high-energy irradiance from "typical" (optically inactive) M and K dwarf planet hosts, neither observational nor theoretical

- **Low-mass stars as laboratories for chromospheric and coronal activity**
- **Modeling and interpretation of biomarkers require realistic inputs**

Can an exoplanet retain its atmosphere?

- Thermal evaporation (upward diffusion followed by Jeans loss) is very slow but often assumed
- Hydrodynamic escape driven by EUV+X-rays (requires estimate of unobservable EUV flux and flare rate for the EUV and X-ray flux)
- Roche lobe overflow and enhanced hydrodynamic escape
- Erosion (sputtering) by the stellar wind (steady and episodic - coronal mass ejections)(Mars water loss)
- Ion pick-up , charge-exchange and dissociative recombination processes with magnetic stellar wind (planetary magnetic field important) (Mars water loss)