Ultraviolet Emission from M Dwarfs during Quiescence and Flares

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NASA Goddard Space Flight Center

NASA

NASA POSTDOCTORAL PROGRAM

Administered by Universities Space Research Association

Know Thy Star, Know Thy Planet

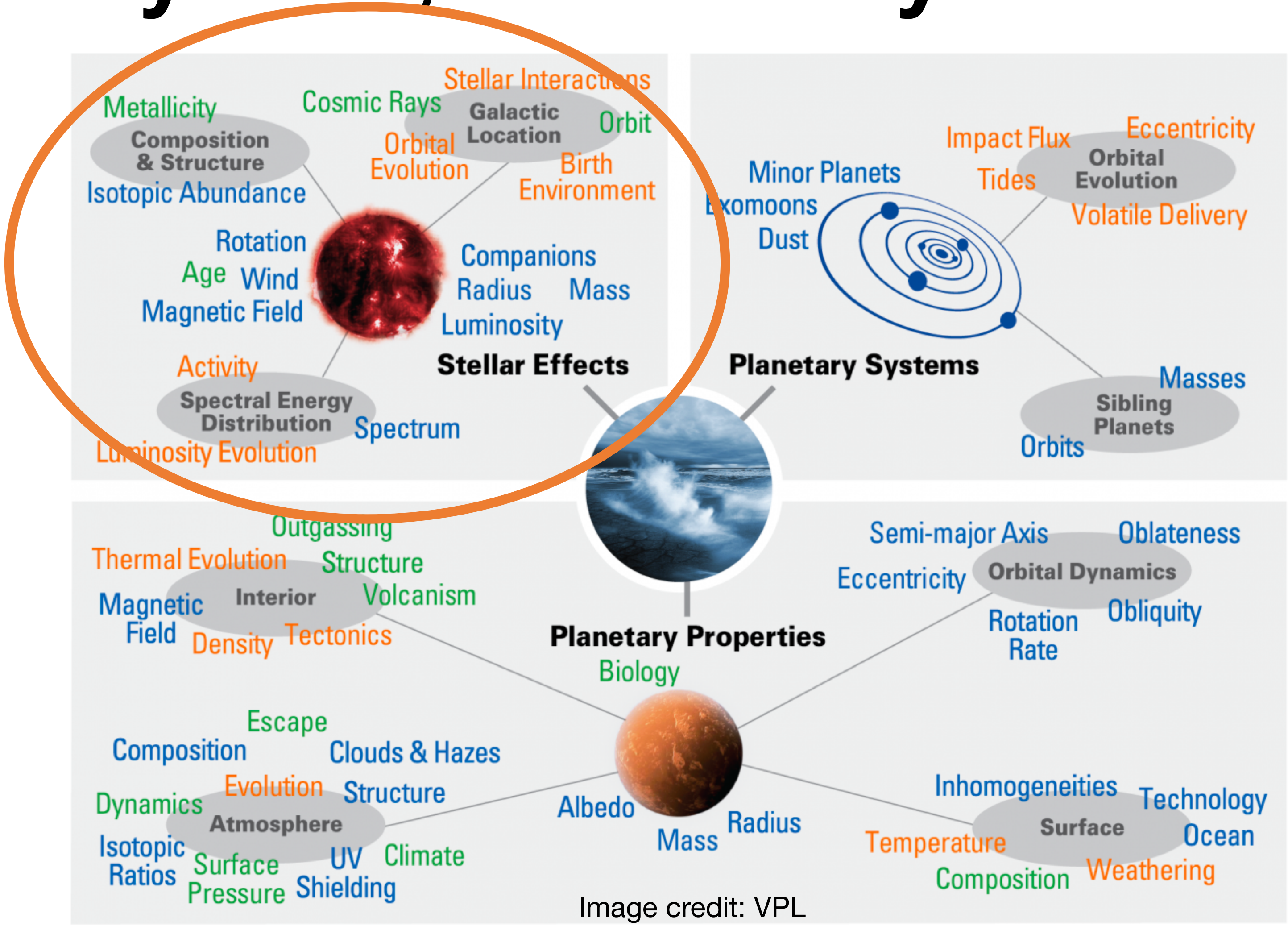
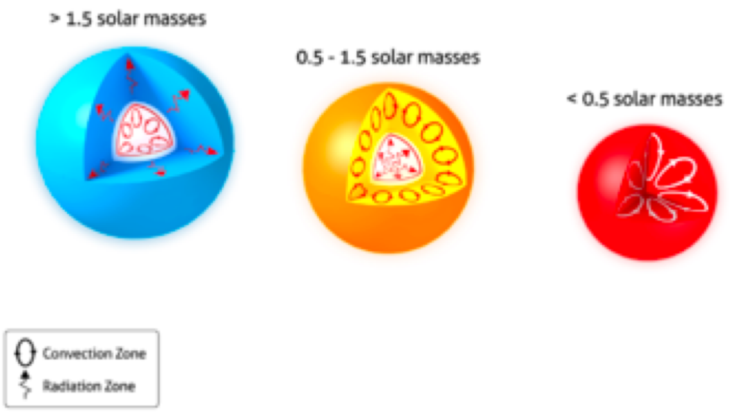
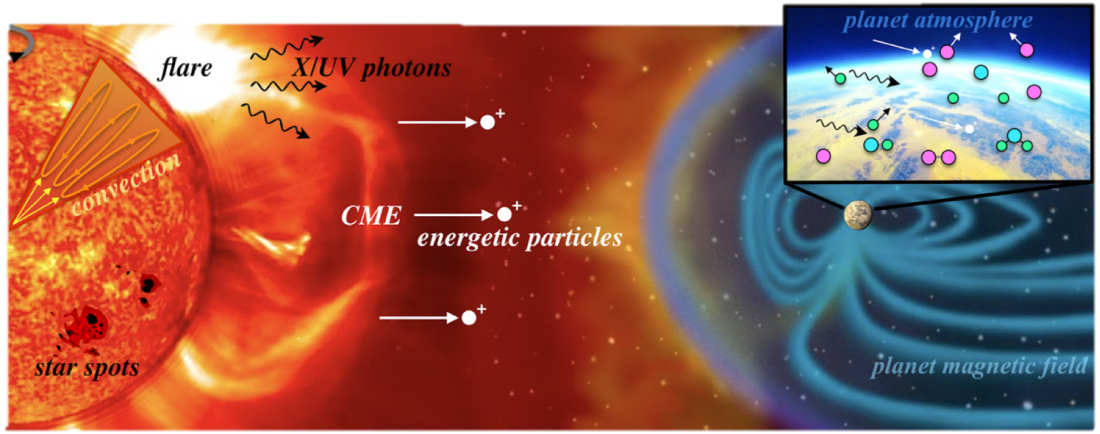


Image credit: VPL

Stellar Activity is due to magnetism

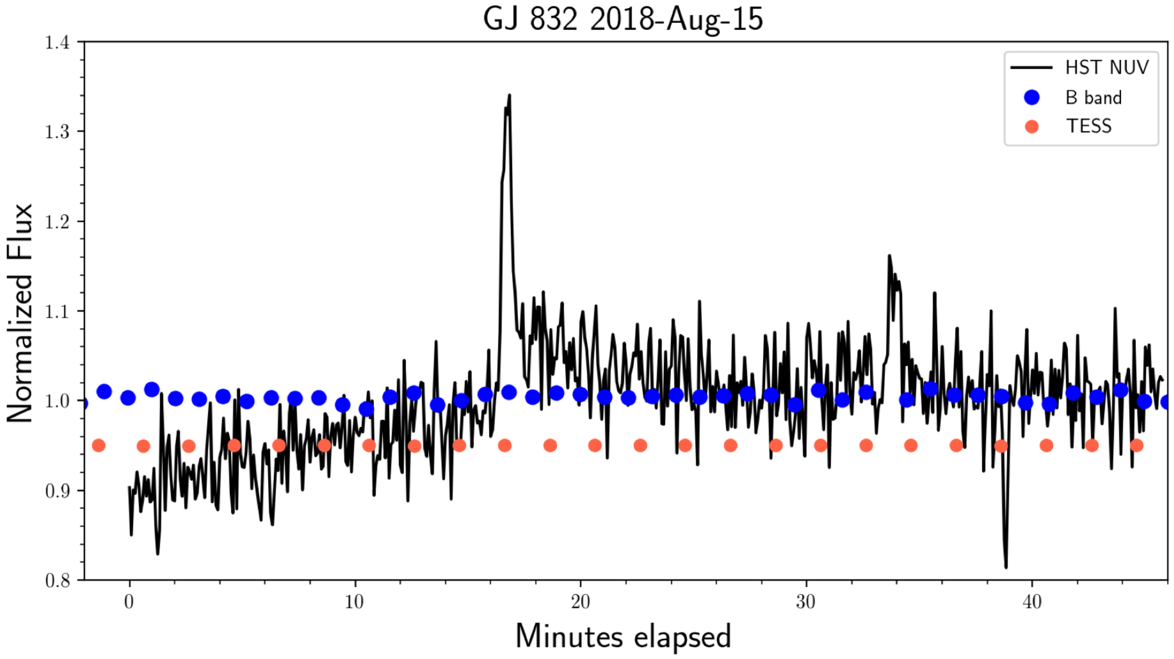
- Manifests as starspots, X-ray and UV emission, flares, coronal mass ejections
  - Directly affects exoplanets as well as our observations of those exoplanets (e.g., Rackham+ 2018)





Activity: most pronounced in UV/X-ray

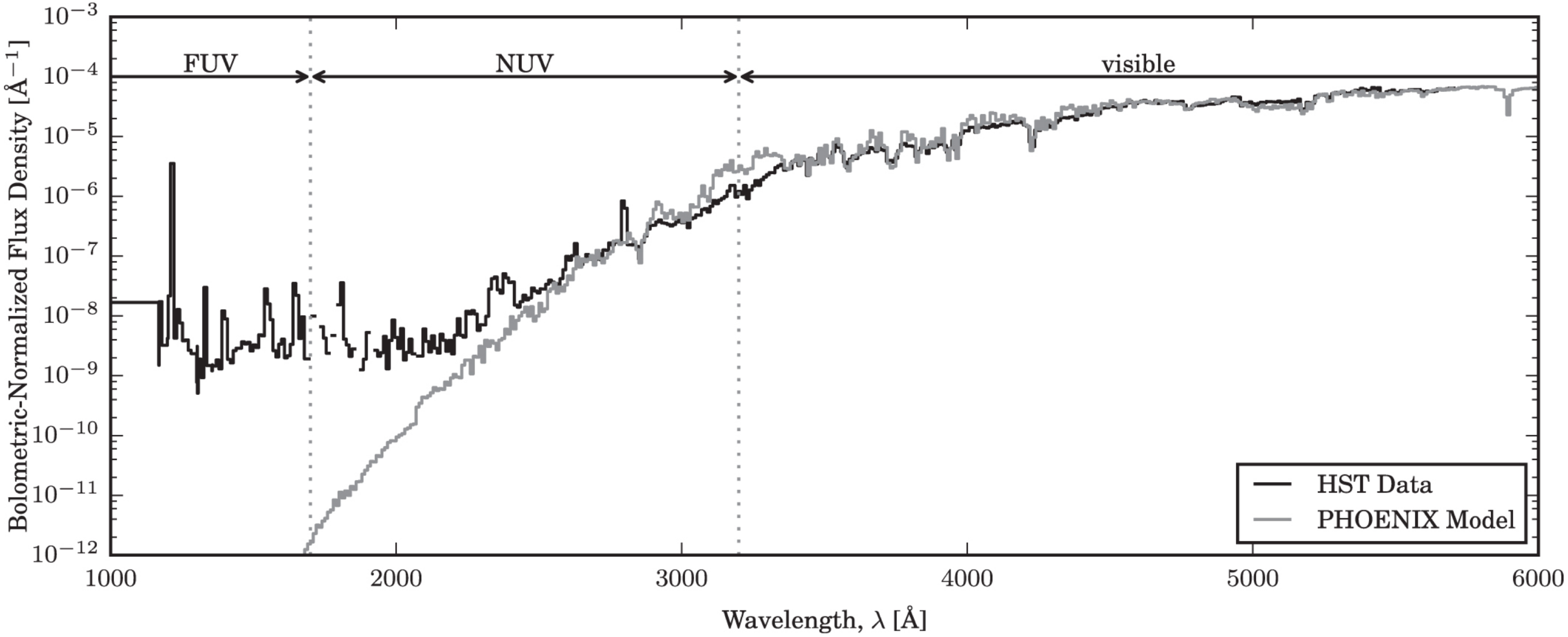
- UV/X-ray emission almost entirely from magnetically heated regions (chromosphere, TR, corona)



Youngblood et al. in prep.

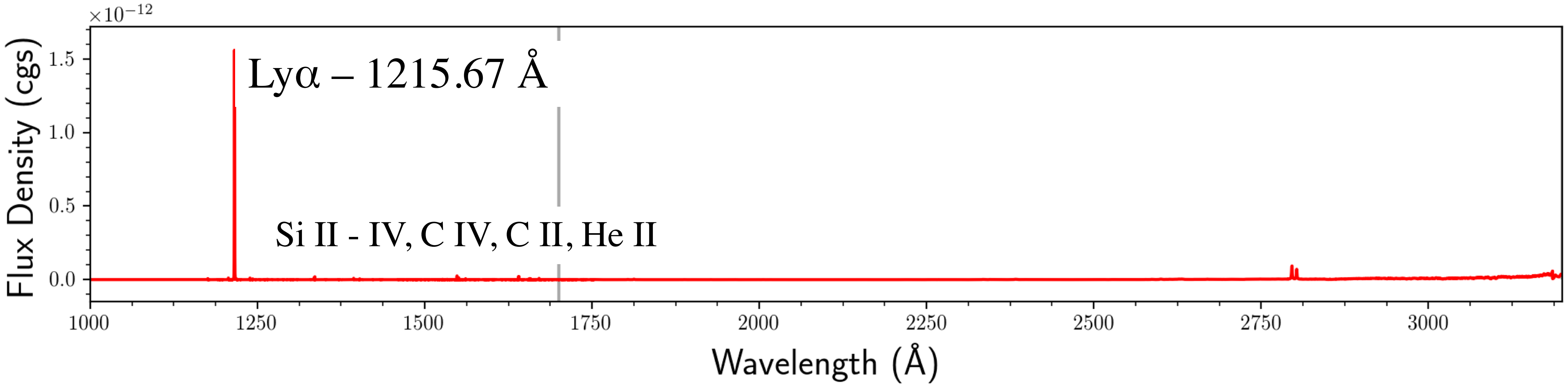
Total solar eclipse
Pink: Hα (chromosphere)
White: scattered white light (corona)

UV spectra of M dwarfs



Husser et al. 2013
Loyd, France, Youngblood et al. 2016

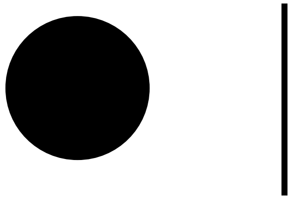
H I Lyman alpha: the brightest UV emission line from M dwarfs



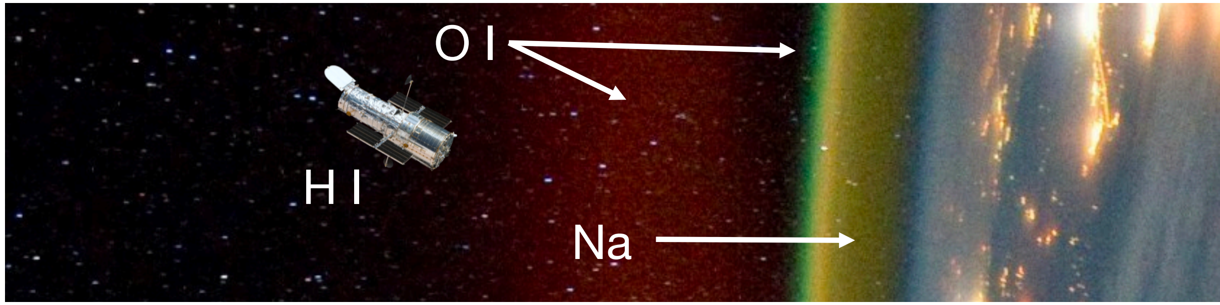
- Important to observe, but:
  - Swamped by airglow
  - Severe ISM attenuation
  - Need competitive Hubble time

Lyman alpha is hard to observe!

- Swamped by airglow
- Severe ISM attenuation
- Need competitive Hubble time

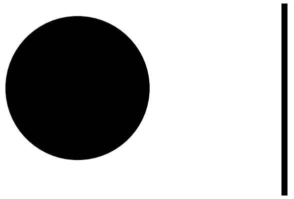


COS vs. STIS apertures



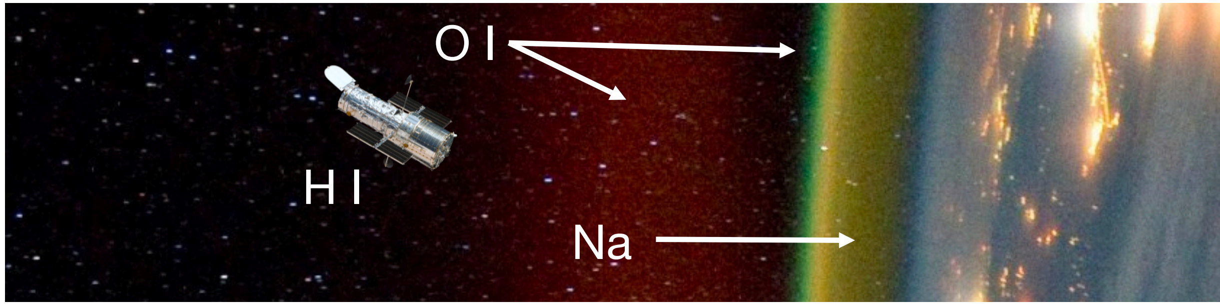
Lyman alpha is hard to observe!

- Swamped by airglow
  - COS airglow subtraction may be possible for most objects! (Bourrier et al. 2018; HST-AR-15635 PI: Youngblood)
- Severe ISM attenuation



COS vs. STIS apertures

- Need competitive Hubble time



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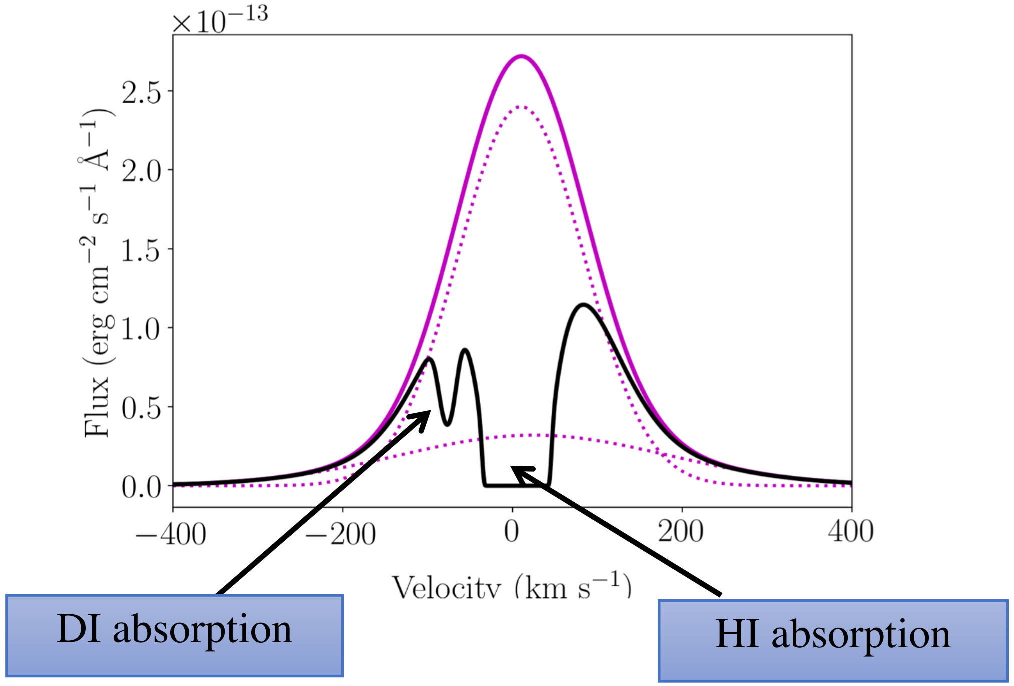

Youngblood et al. 2016

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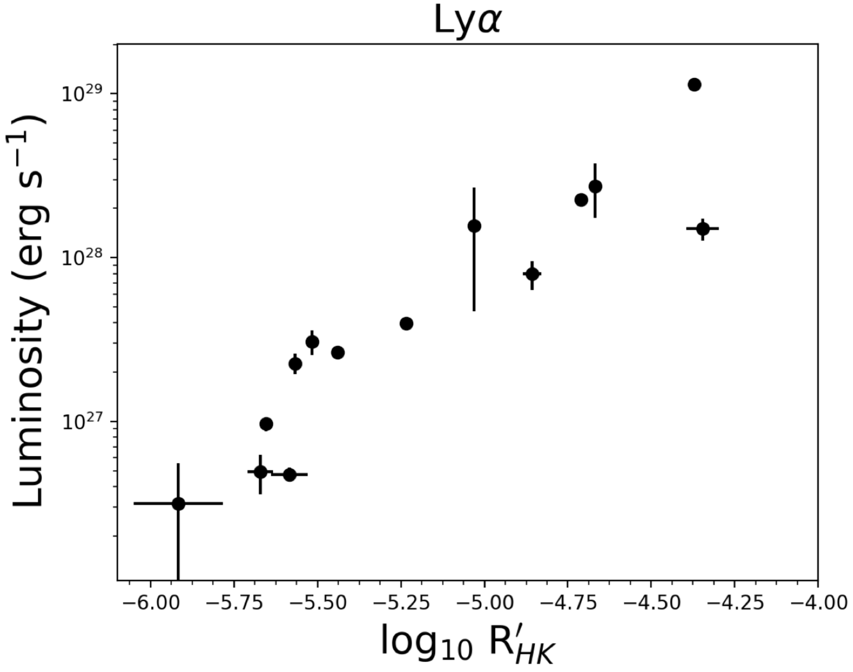
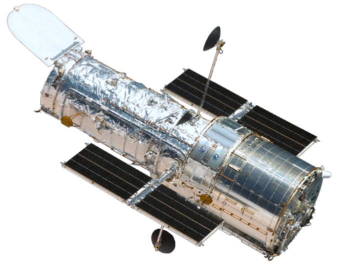
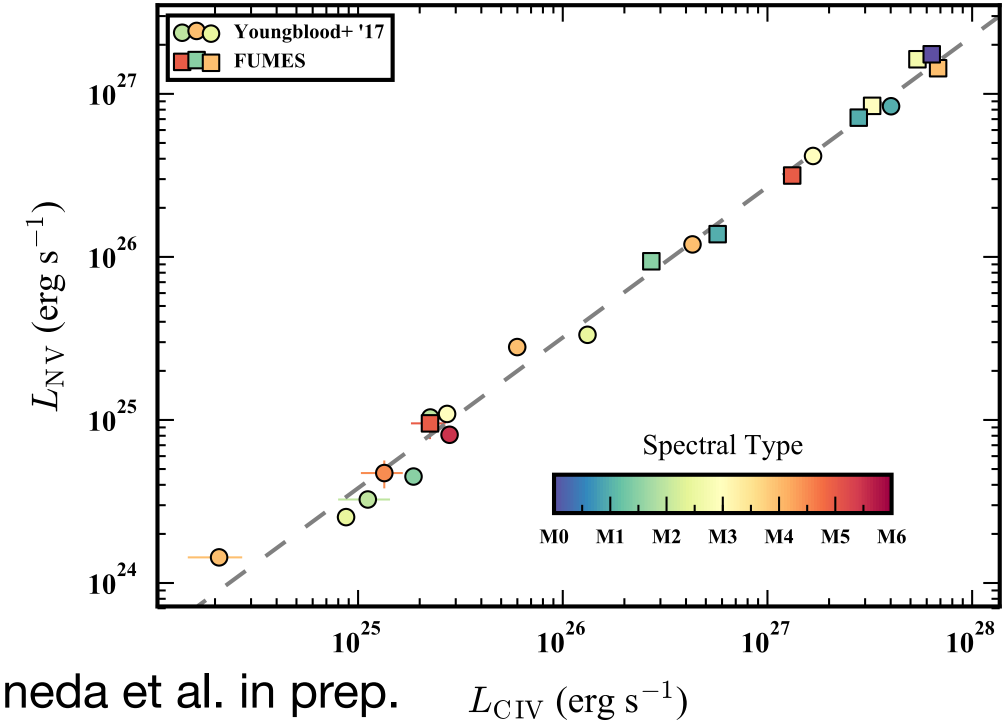
- Severe ISM attenuation
  - Reconstructions from observed wings and D I
- Need competitive Hubble time
  - Can estimate M dwarf Lyα flux from other UV lines or Ca II H&K (Youngblood et al. 2017; Melbourne et al. in prep.)



M dwarf UV surveys

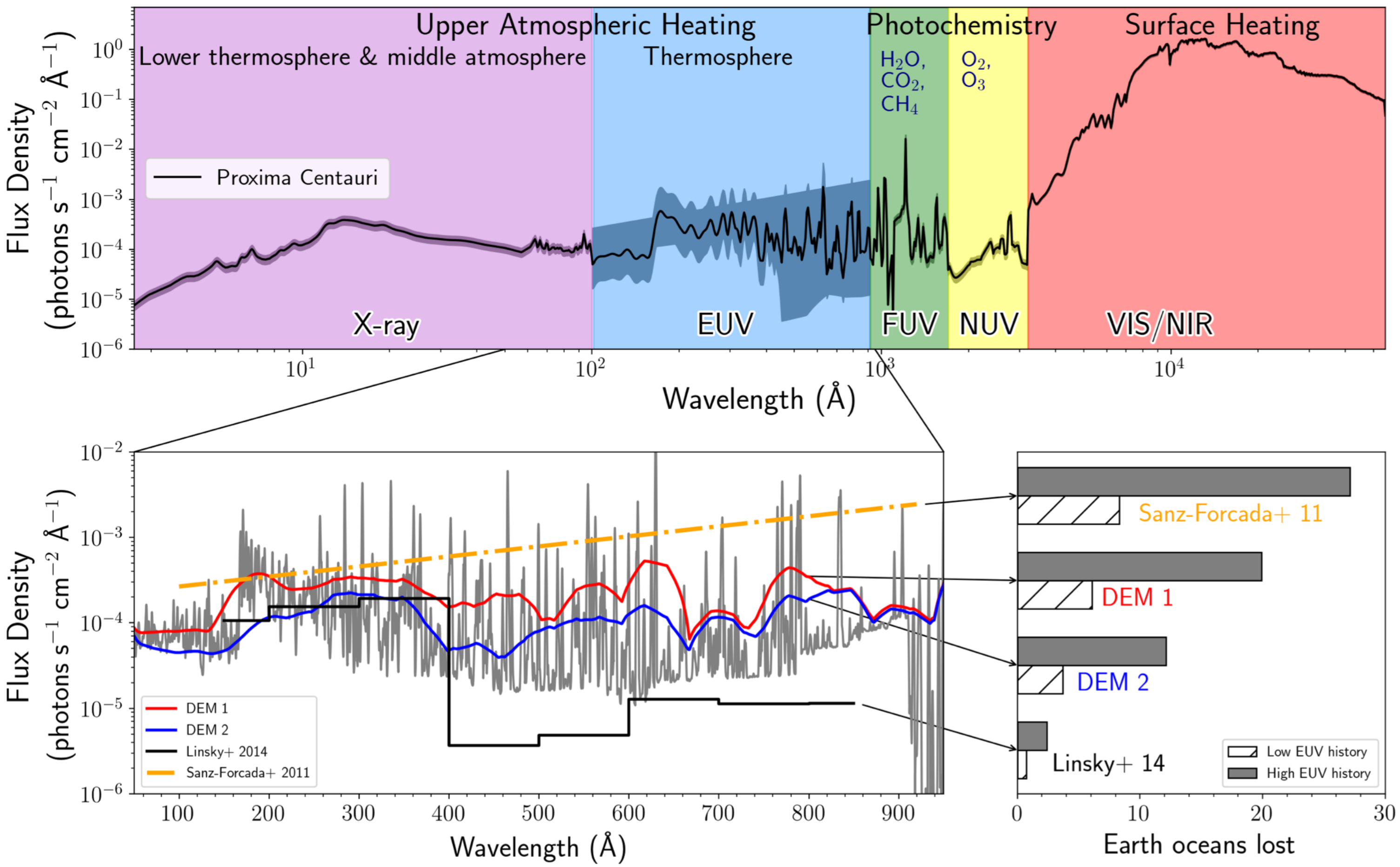


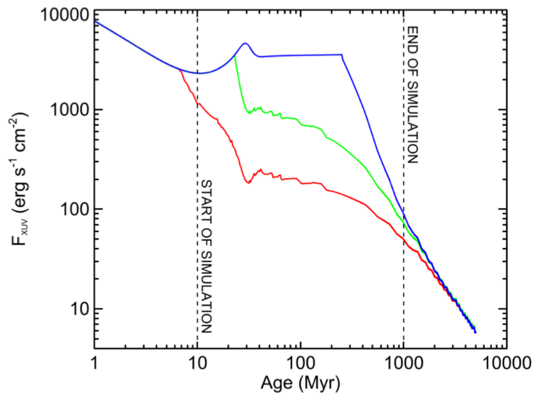
- Mega-MUSCLES focuses on "inactive" M's (Cynthia Froning, Kevin France, David Wilson, Sebastian Pineda, Christian Schneider, Girish Duvvuri, Allison Youngblood, Elisabeth Newton, and many many more)
- FUMES focuses on young M's (Sebastian Pineda, Kevin France, Girish Duvvuri, Allison Youngblood)
- We are studying spectrally-resolved UV emission across a variety of M dwarf masses and ages
  - All M dwarfs appear to be UV-active



Pineda et al. in prep.

The missing EUV (100-912 Å)

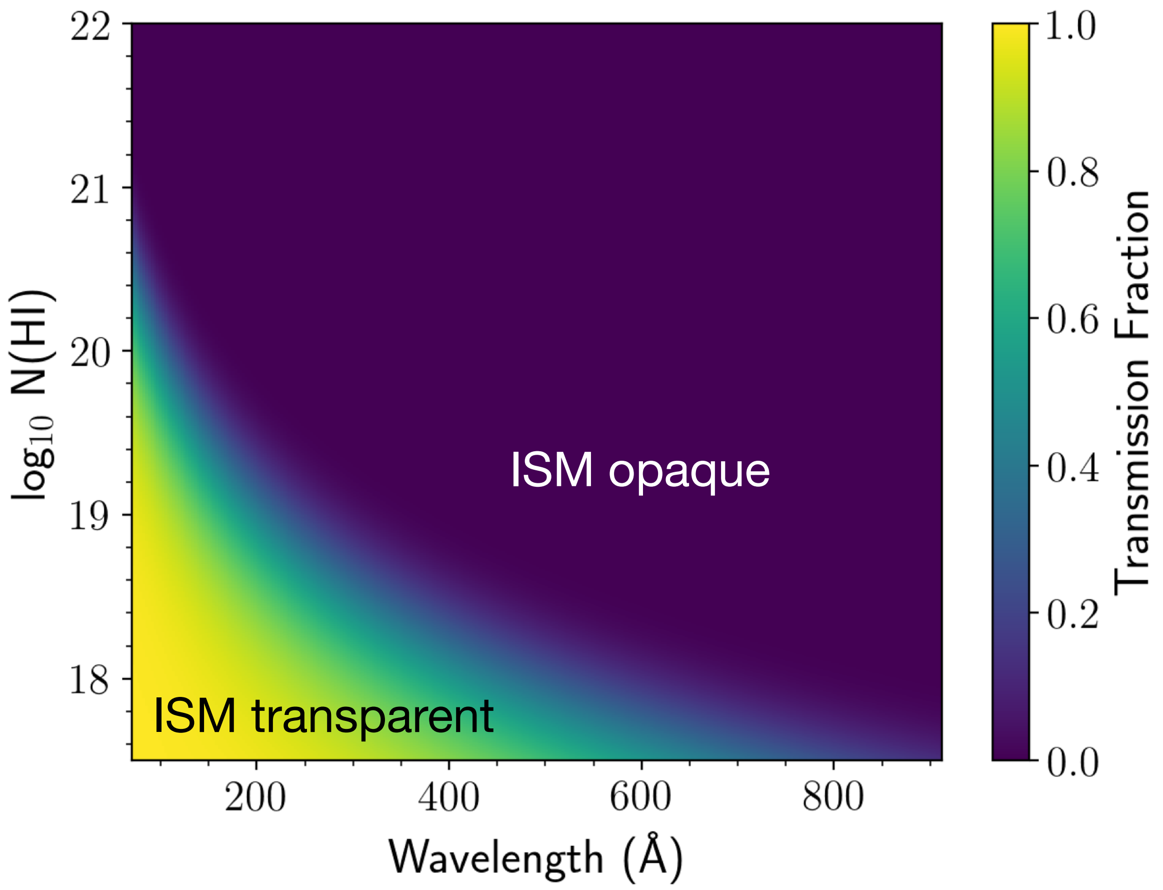




Johnstone+ 2015

with
Jeremy Drake
Tommi Koskinen
Kevin France

The EUV is hard to observe

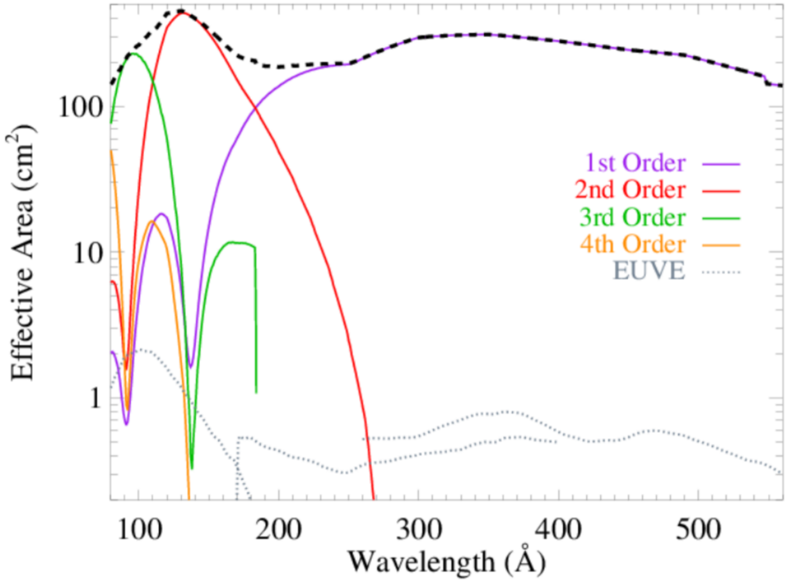


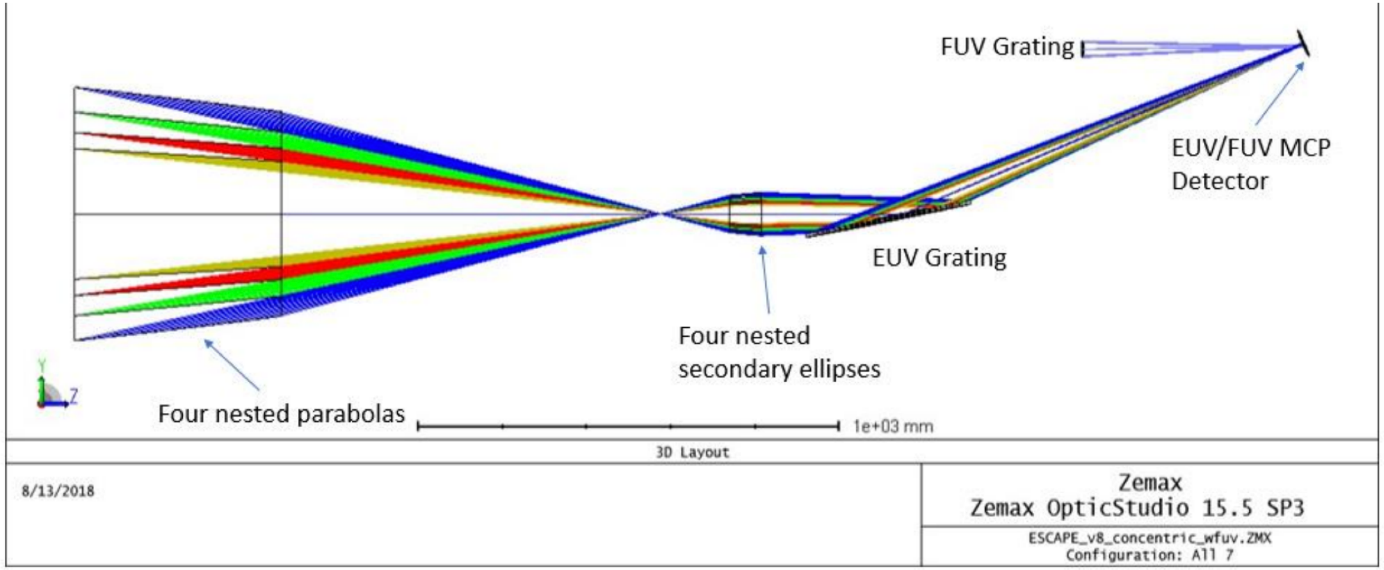
ESCAPE: SMEX 2019 mission concept

Extreme-ultraviolet Stellar Characterization for Atmospheric Physics and Evolution

PI: Kevin France (CU)
NASA Marshall
Harvard SAO
Berkeley SSL
Ball Aerospace
Penn State

- NASA SMEX AO 2019 - $195M cost cap
- 70-570 Å at 1 Å spectral resolution

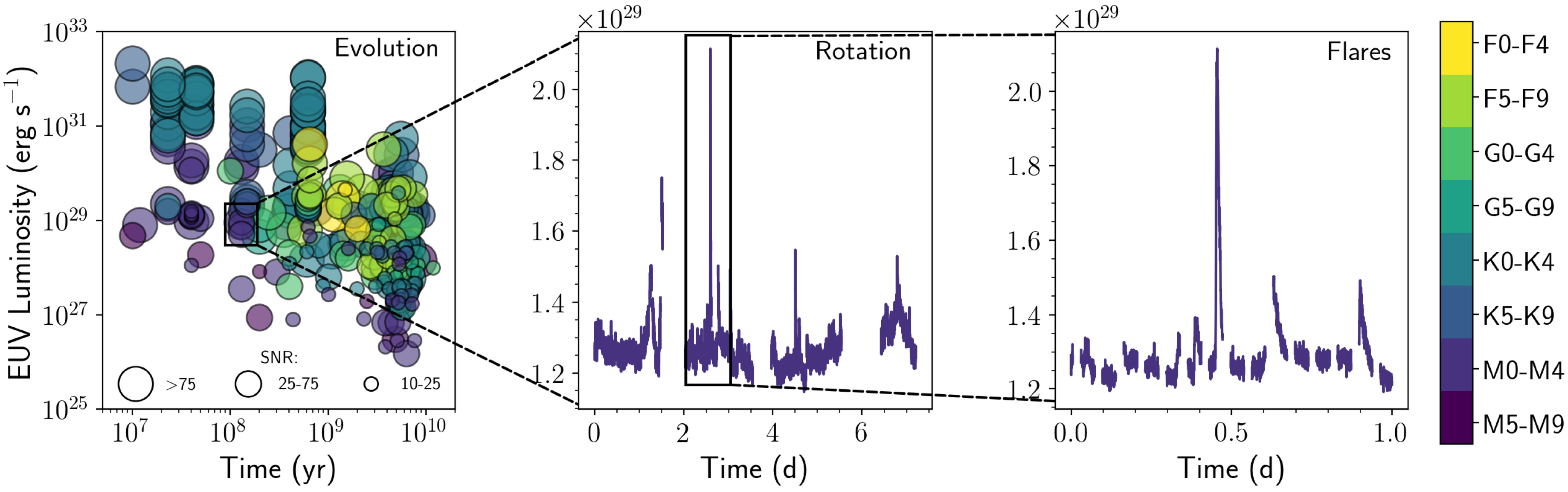




Instrument Scientist: Brian Fleming

ESCAPE: SMEX 2019 mission concept

Extreme-ultraviolet Stellar Characterization for Atmospheric Physics and Evolution



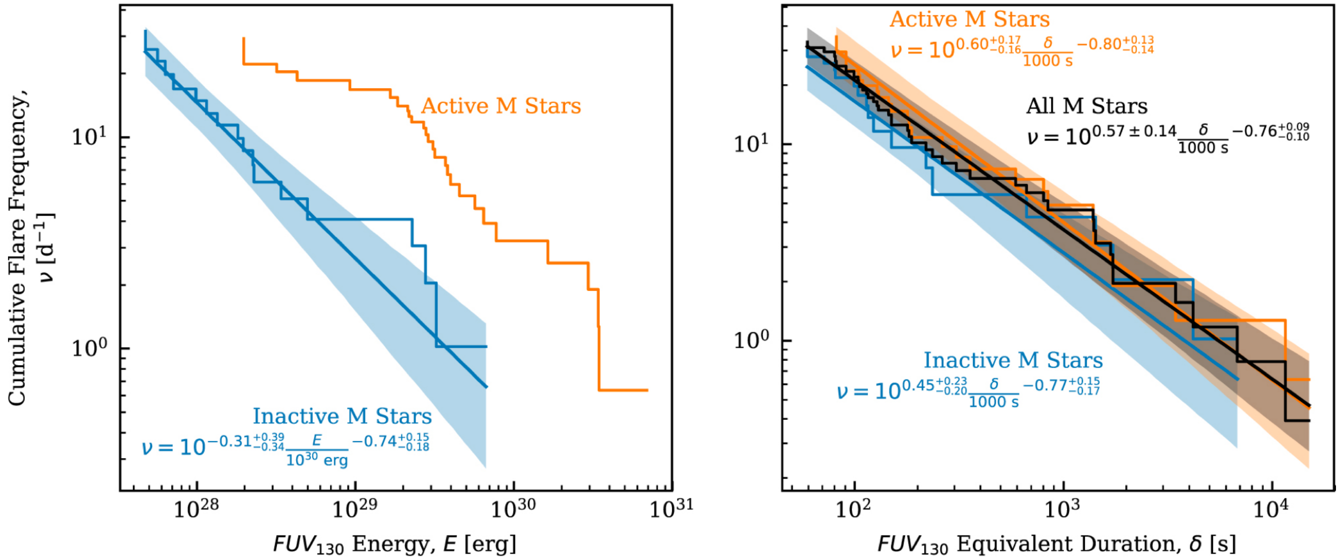
ESCAPE target list with estimated luminosities and synthetic lightcurves

UV flares

- How does the stellar spectrum change during flares?
- What are the flare frequencies and energies?
- What kind of flare data products do exoplanet modelers need?

UV flares with Hubble

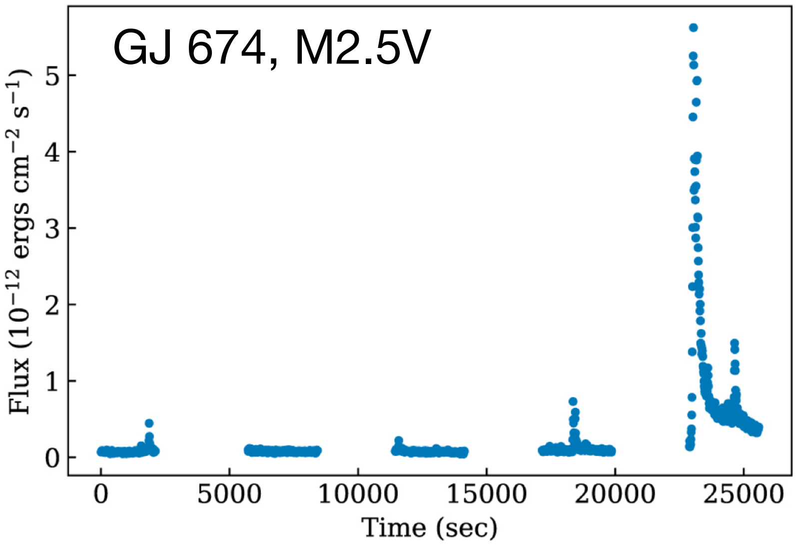
- M dwarfs FUV emission may be dominated by flares (Loyd et al. 2018 a,b)
- Is the same true for NUV emission?
  - The answer could be important for origin of life (Rimmer et al. 2018; Ranjan et al. 2018)

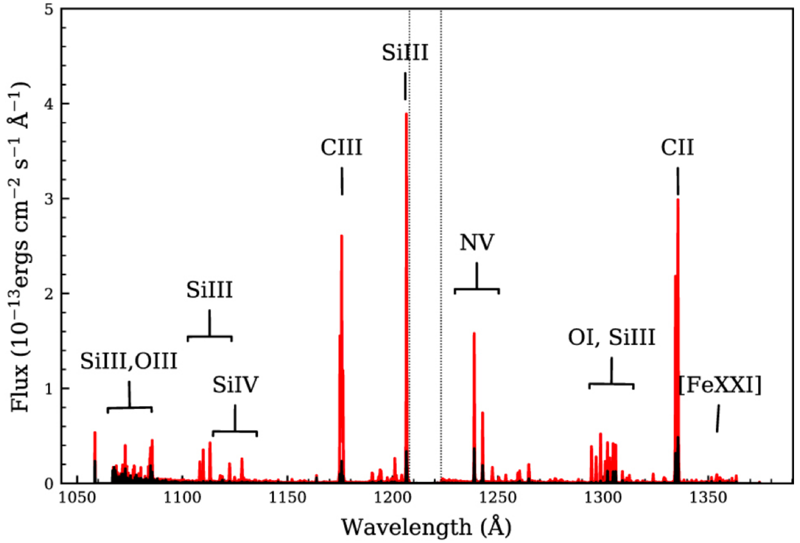


Loyd et al. 2018 (incl. AY)

UV flare spectra

- FUV flares show strong line enhancement and hot blackbody emission
  - T~40,000 K (Froning et al. 2019); T~15,000 (Loyd et al. 2018b)
- NUV flare spectra only exist for a handful of stars (Hawley et al. 2007, Wargelin et al. 2017, Kowalski et al. 2018, Youngblood et al. in prep.)

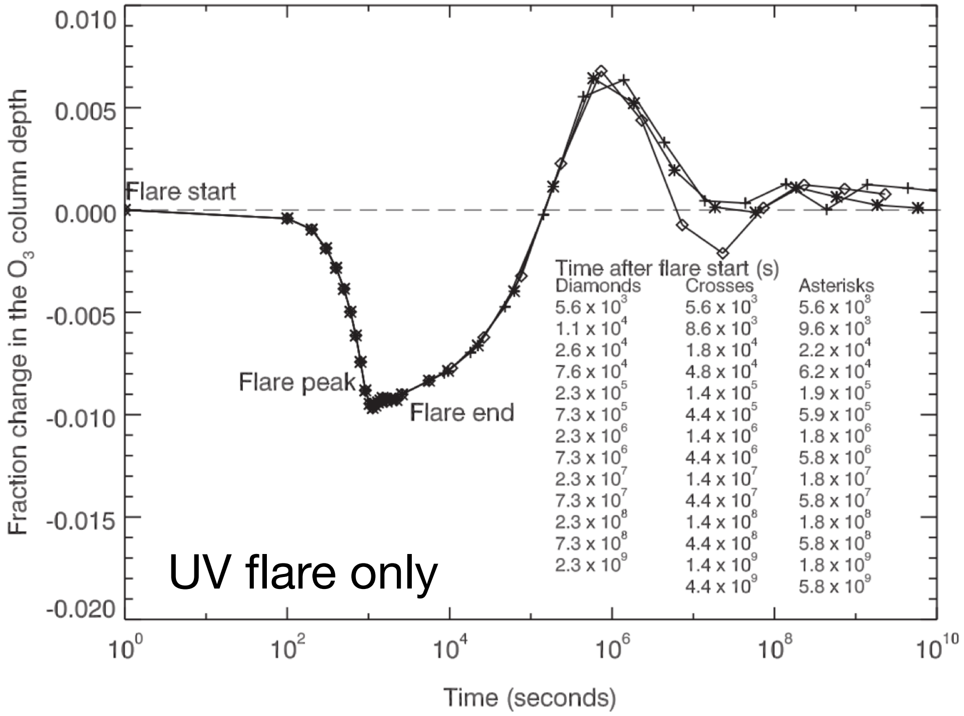


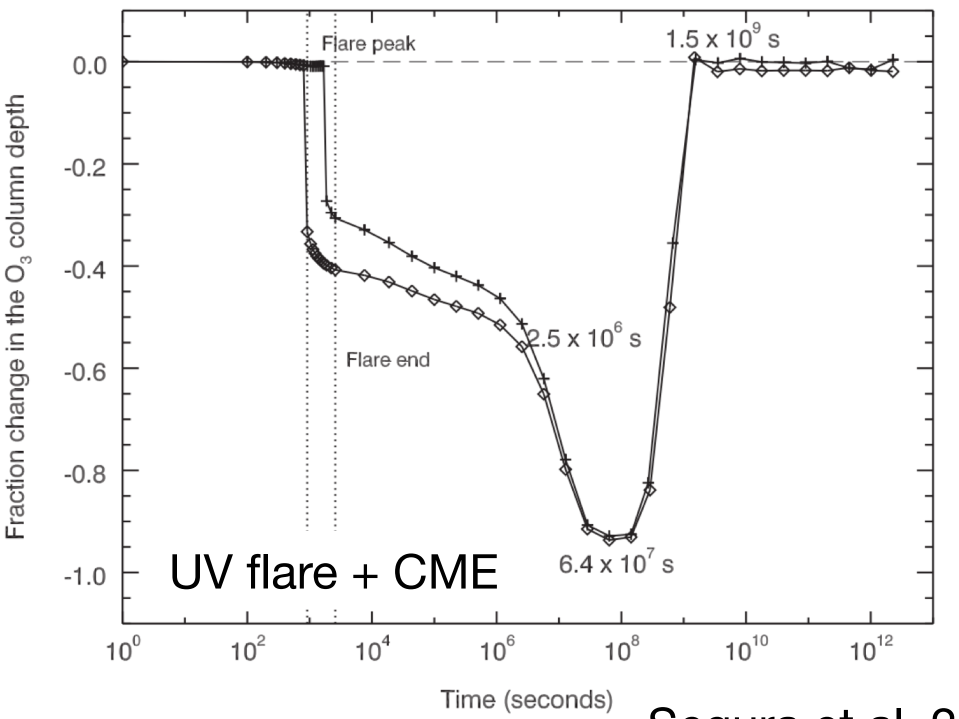


Froning et al. 2019 (incl. AY)

What about CMEs?

- Energetic particles have a greater effect on atmospheric chemistry than flare photons

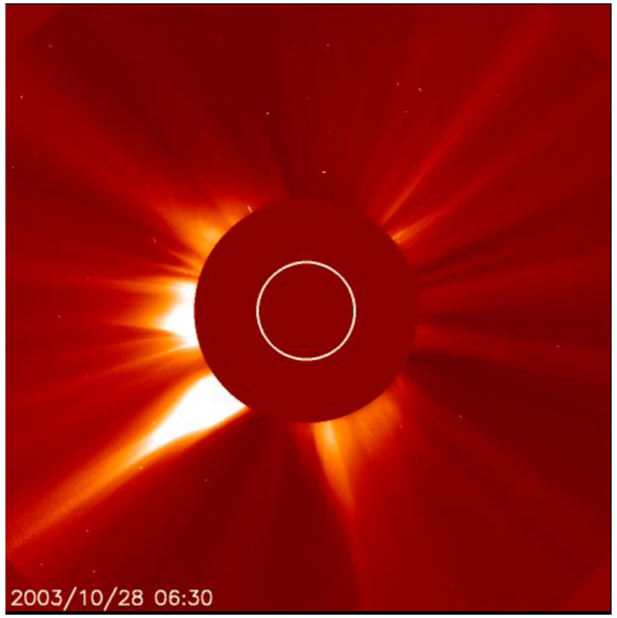




Segura et al. 2010
Tilley et al. 2019

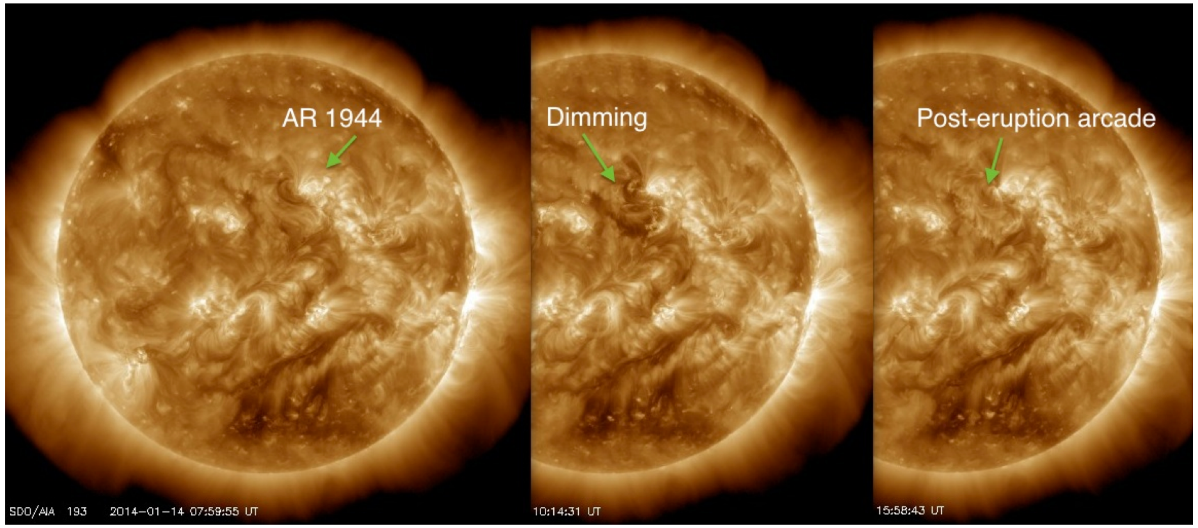
How do we detect stellar CMEs?

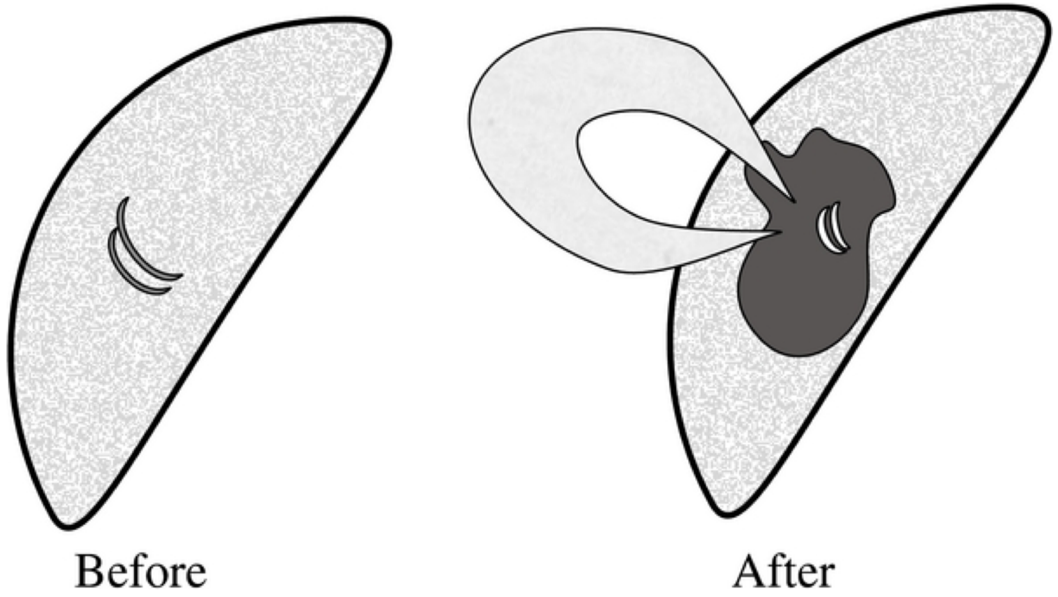
- We don't … yet
  - Flare kinematics (blueshifts) are ambiguous
  - Type II radio bursts not detected (Crosley & Osten 2016, 2018a,b, Villadsen & Hallinan 2019)
  - X-ray absorption works in special cases (Moschou et al. 2018)
  - Coronal dimming has not been applied to stars yet (Mason et al. 2014, 2016; Harra et al. 2016)



SOHO/LASCO

Coronal dimming is the most promising technique





Do M dwarfs even have CMEs?
Alvarado-Gomez et al. 2018

Quiet corona evacuated as CME departs

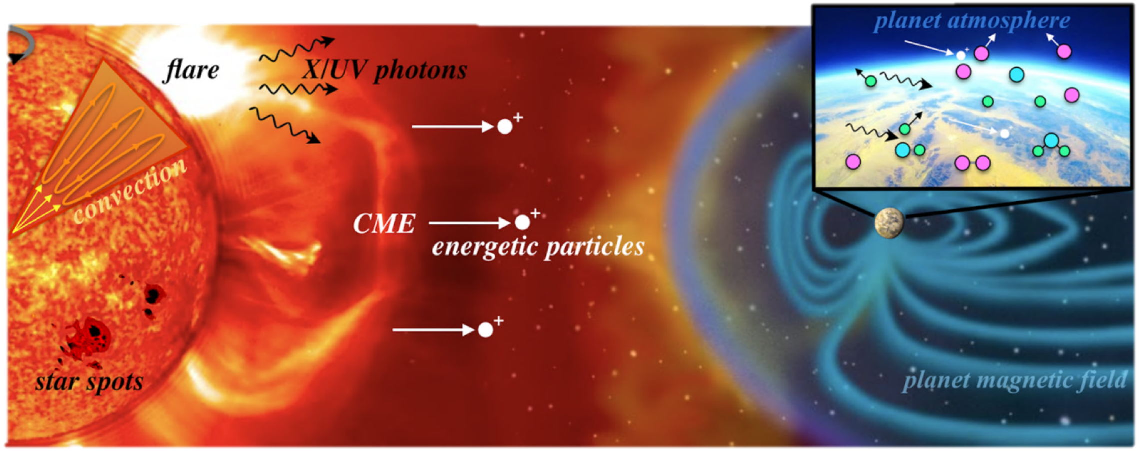
CME mass ∝ dimming depth

CME speed ∝ dimming slope

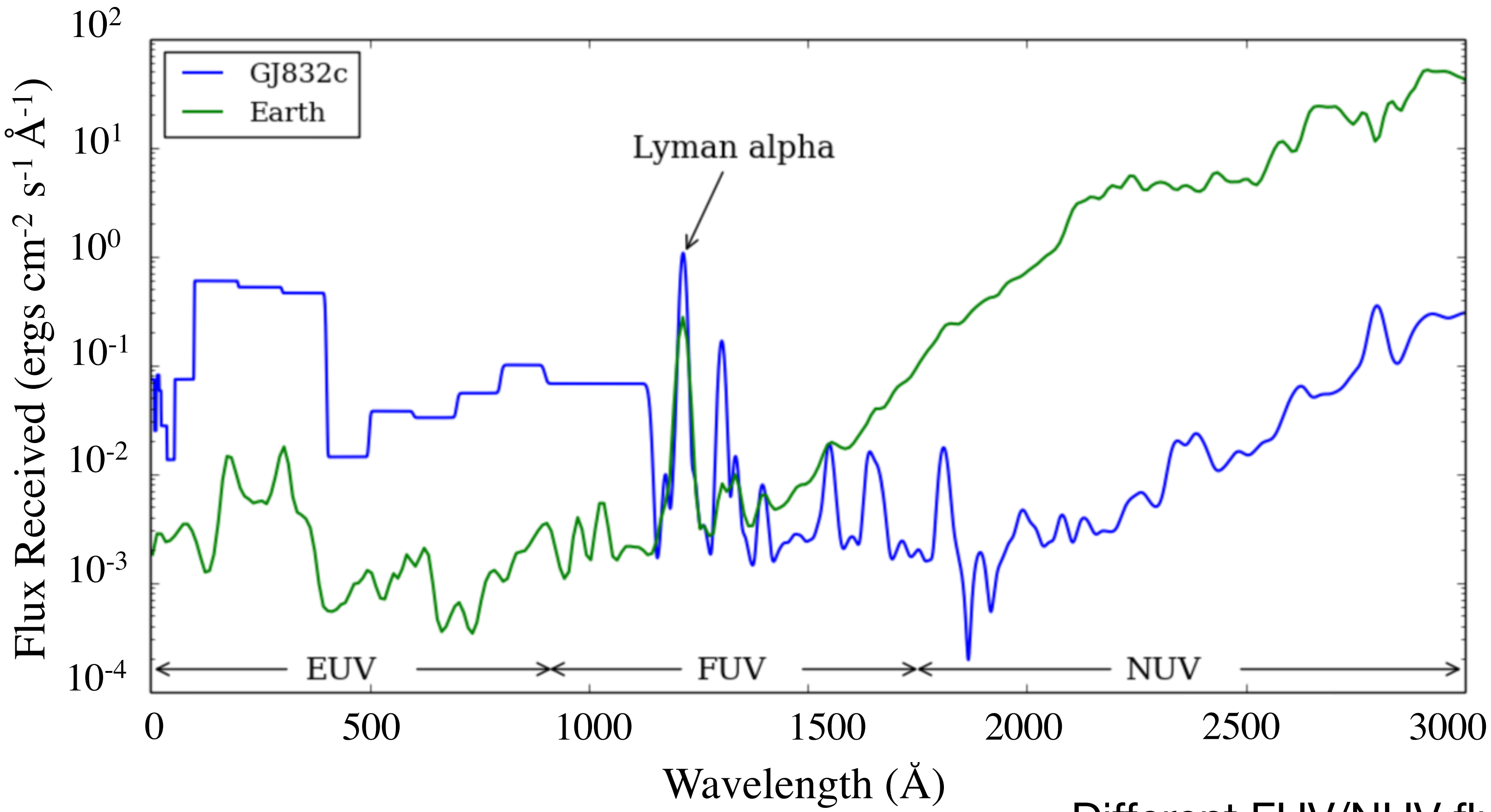
Krista et al. 2017
Mason et al. 2014, 2016
Jin et al. 2018

Summary

- Important to characterize: UV emission from exoplanet hosts
  - Photochemistry/biosignatures, mass loss, prebiotic chemistry
  - Lyman alpha and the EUV are particularly important but are challenging to observe
    - EUV SMEX concept called ESCAPE
  - Flares and CMEs
    - M dwarfs flare often and energetically
    - Do they have CMEs? Theory indicates possibly not, and observations are elusive

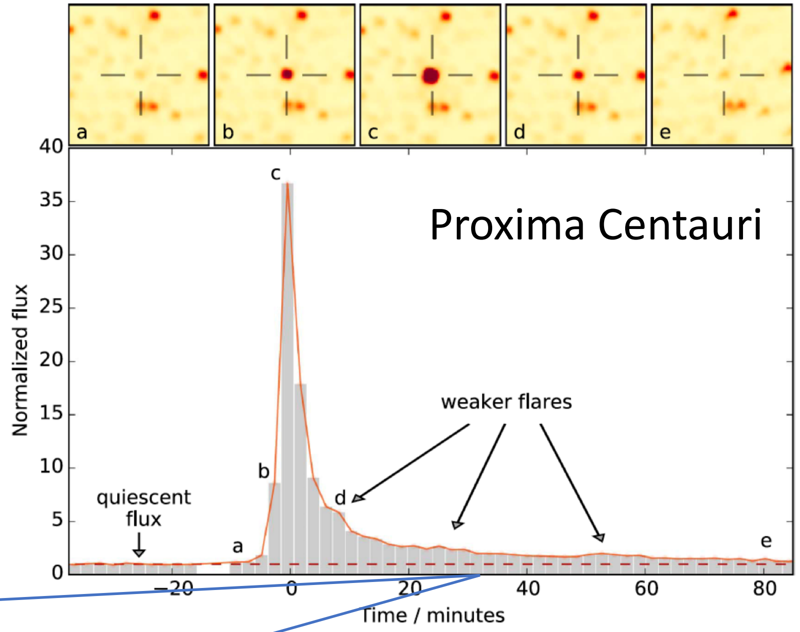


UV spectra of M dwarfs

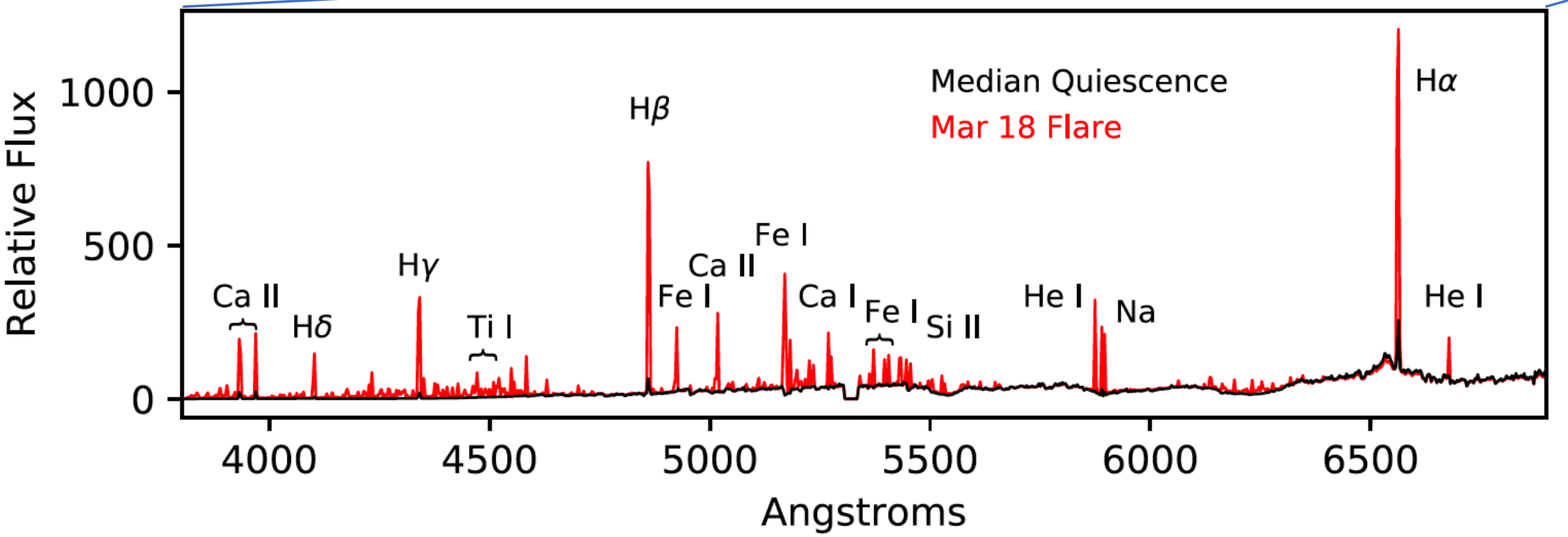


Different FUV/NUV flux ratios drive unique chemistry!

A “typical” flare spectrum

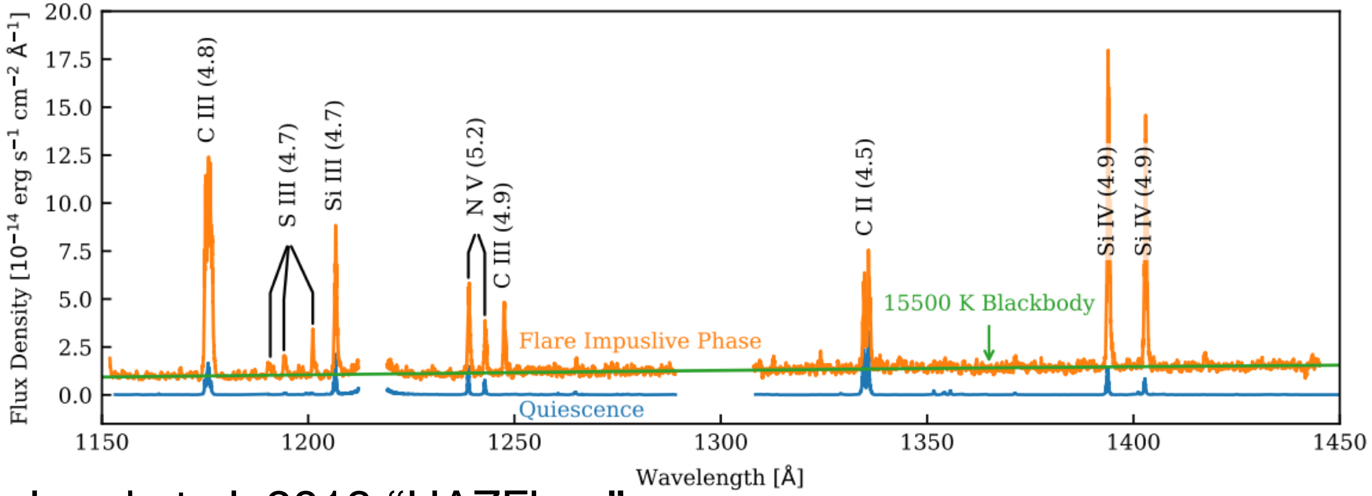


Gradual phase



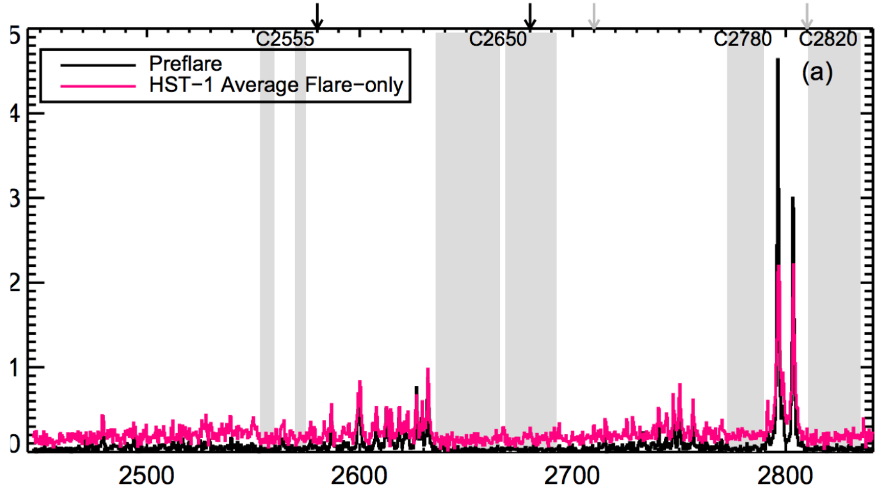
Howard et al. 2018 (incl. AY)

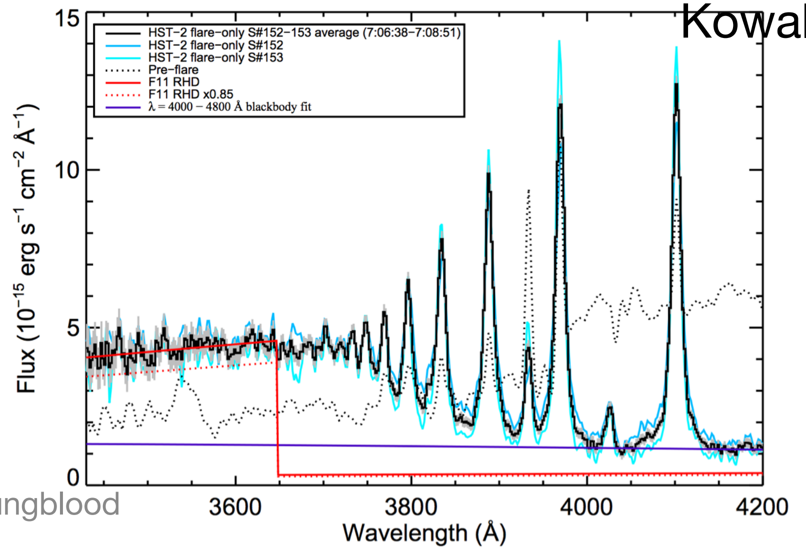
UV Flare spectra



Loyd et al. 2018 “HAZFlare”

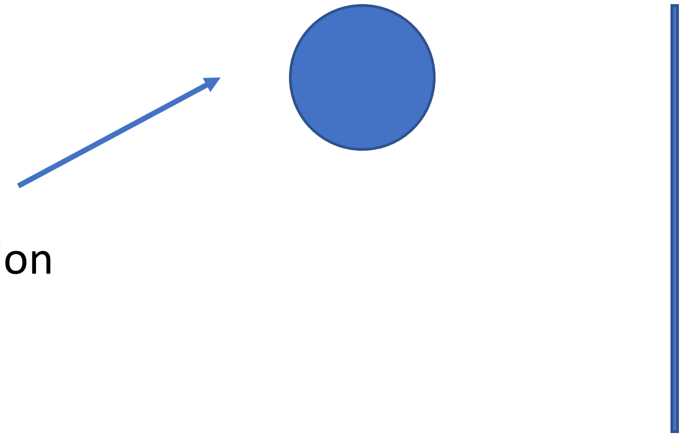
GJ 1243 M4 flare star





Kowalski et al. 2018

Why is airglow subtraction with COS hard?



Limited spatial resolution
Lets lots of airglow in

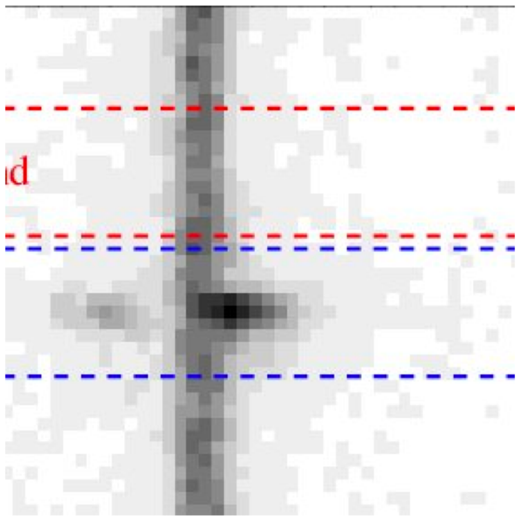
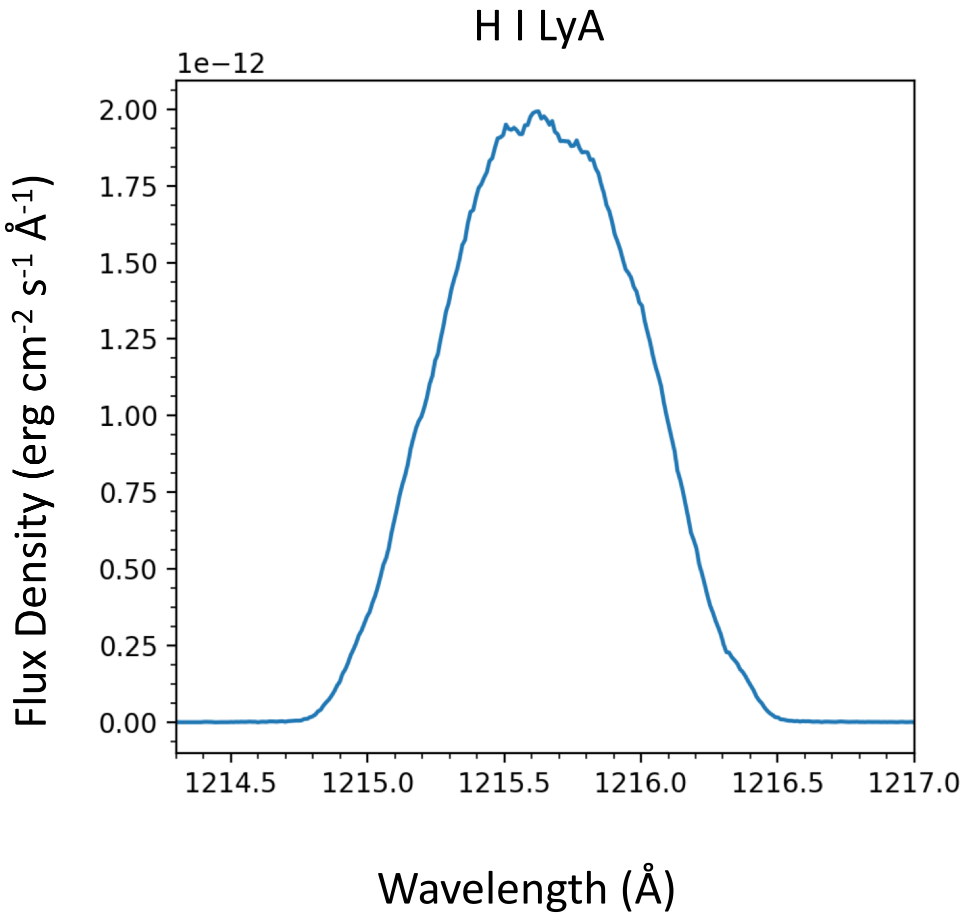
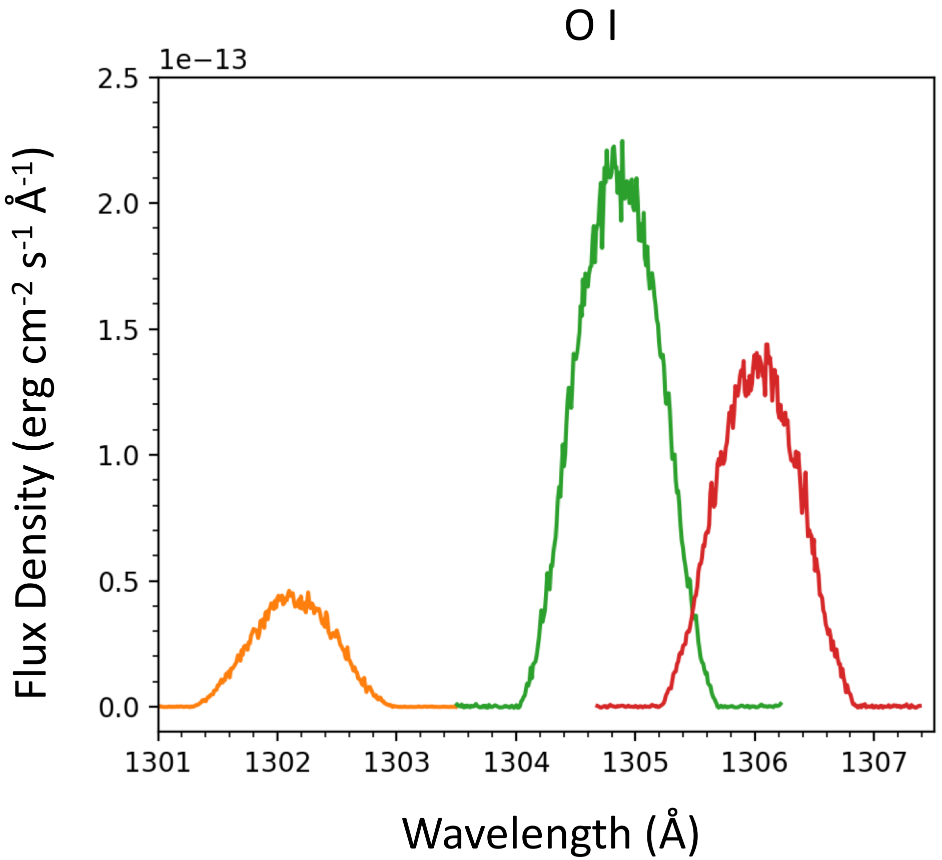


Figure credit:
Vincent Bourrier

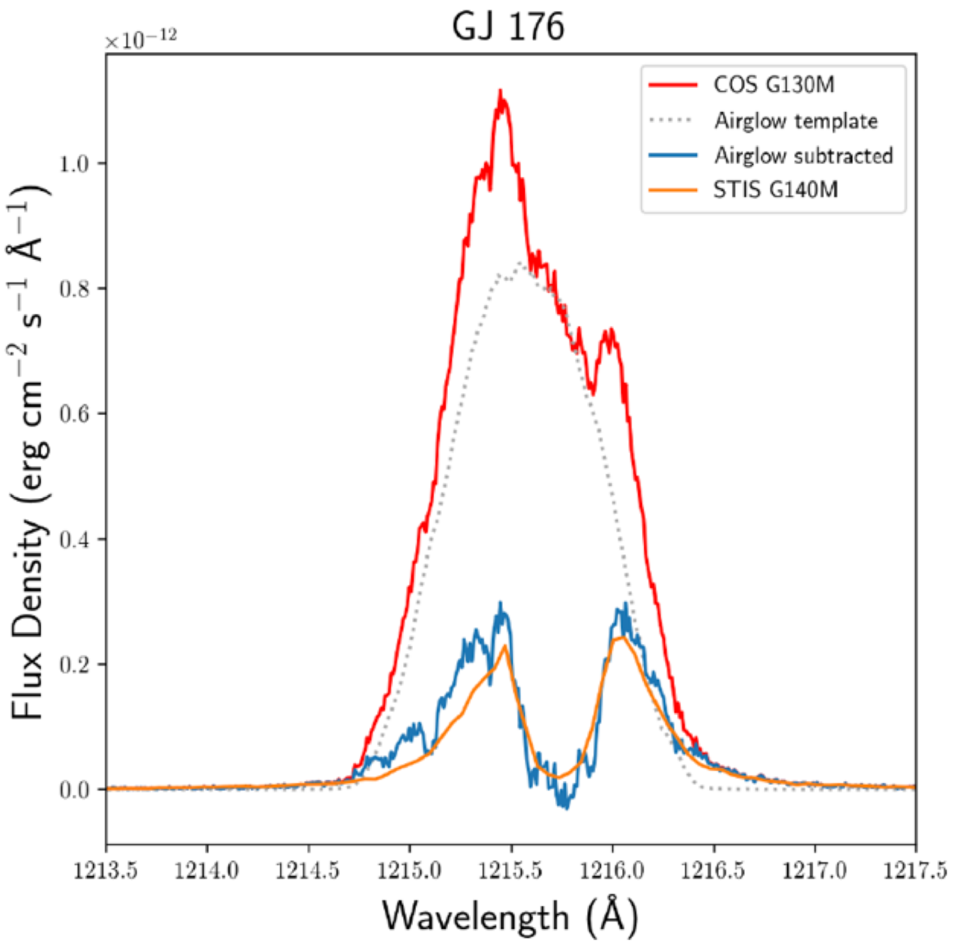
Airglow profiles remarkably stable

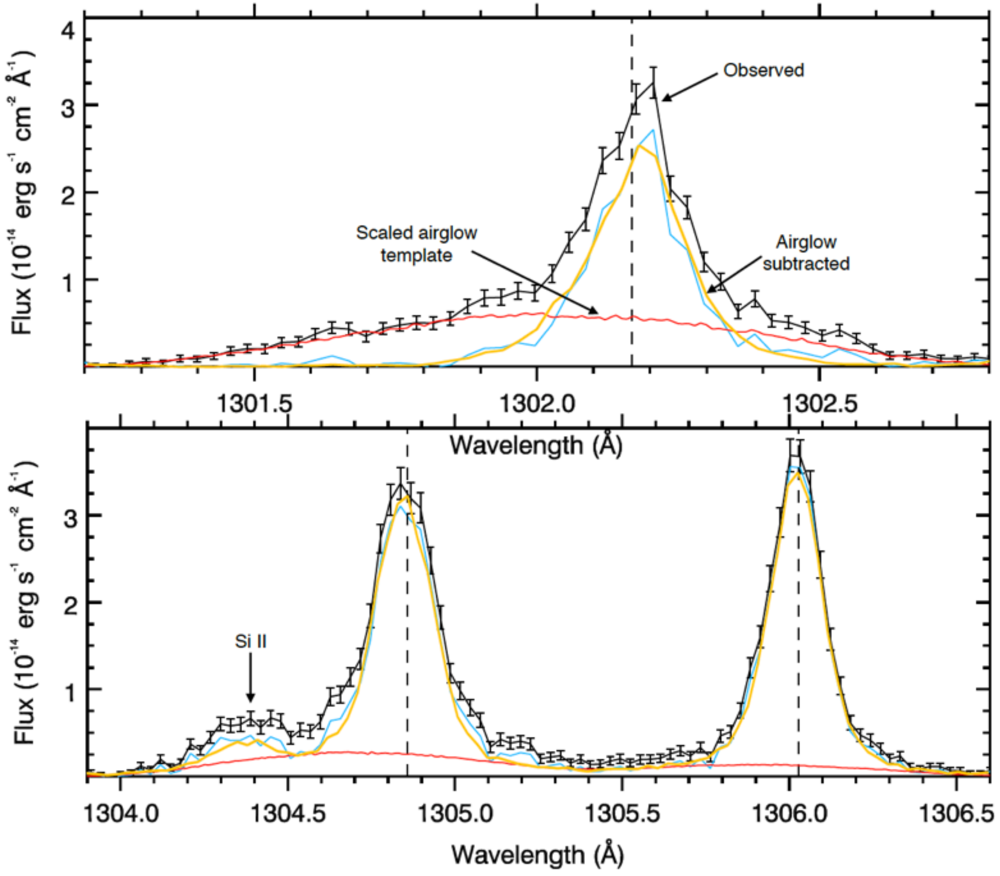




Bourrier et al. 2018b

Shift and scale airglow templates, subtract

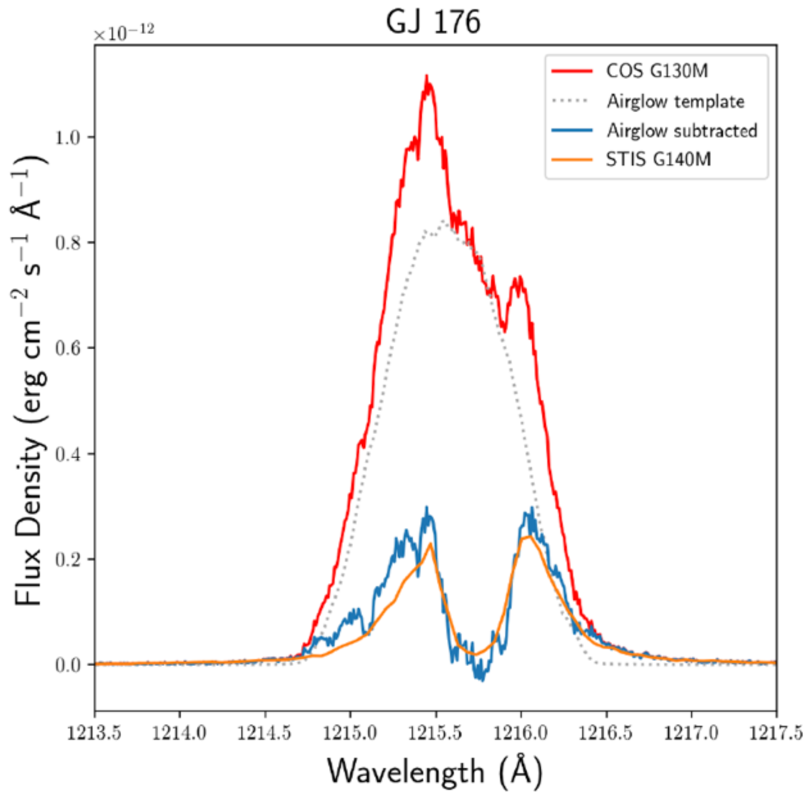




Bourrier et al. 2018b
Ben-Jaffel & Ballester 2013
Wilson et al. 2017

Airglow subtraction in the COS archive

- Cycle 26 Legacy AR proposal
- Recovering LyA and O I from COS archive
  - 125 F, G, K, and M dwarfs
    - Most have exoplanets!
  - User-friendly tool to enable future airglow subtraction



Method based on Bourrier et al. 2018b

Co-I's:

Vincent Bourrier

Kevin France