Modeling the Impact of Flares on Short-Period Brown Dwarfs

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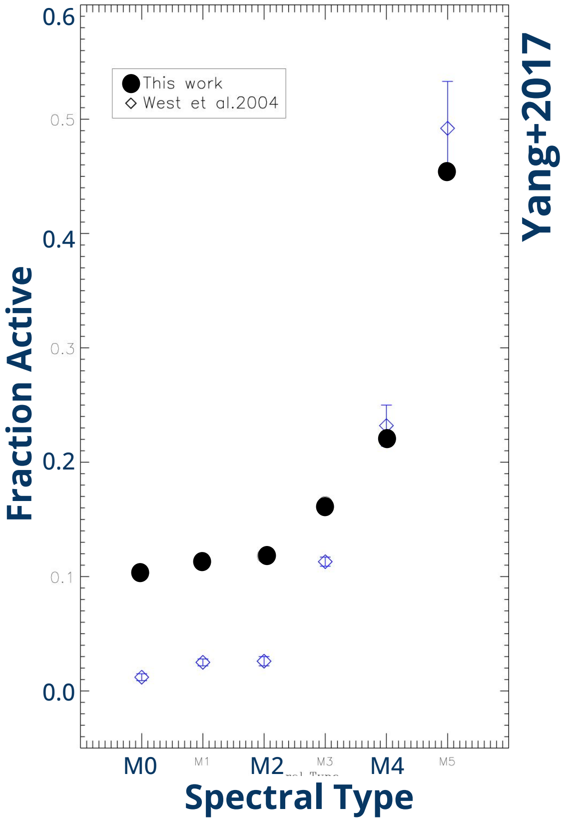
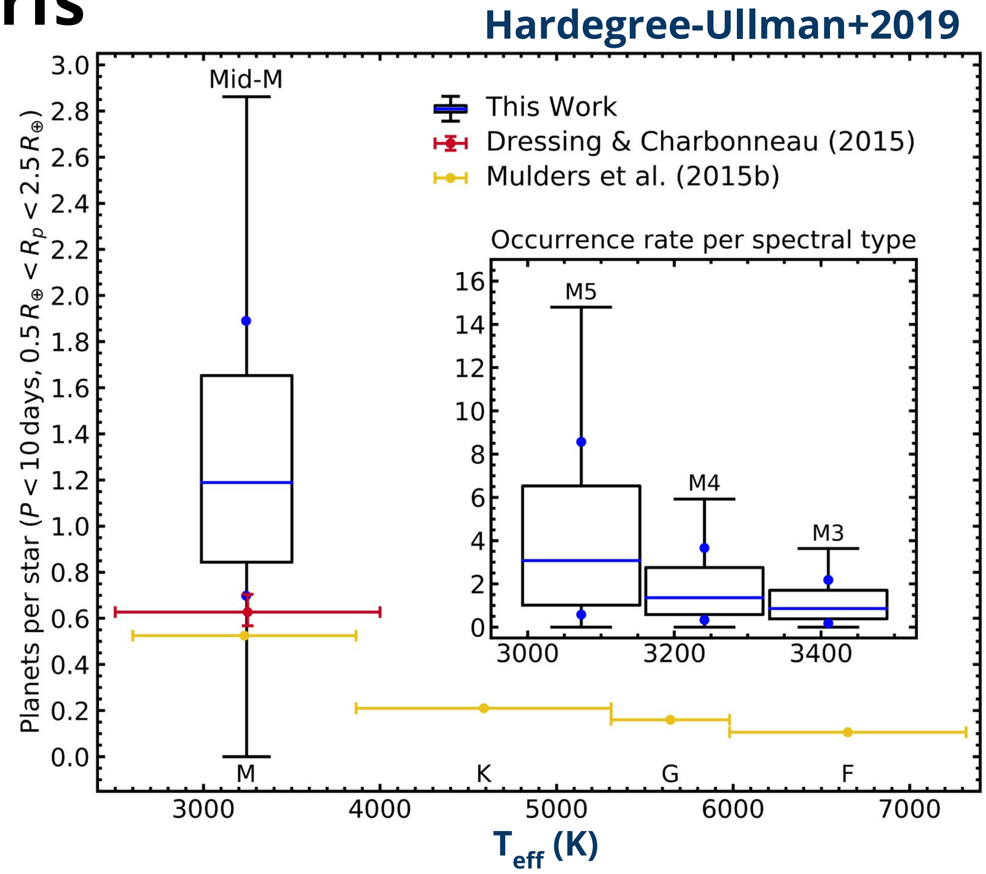
Know Thy Star 2 - February 7th, 2025

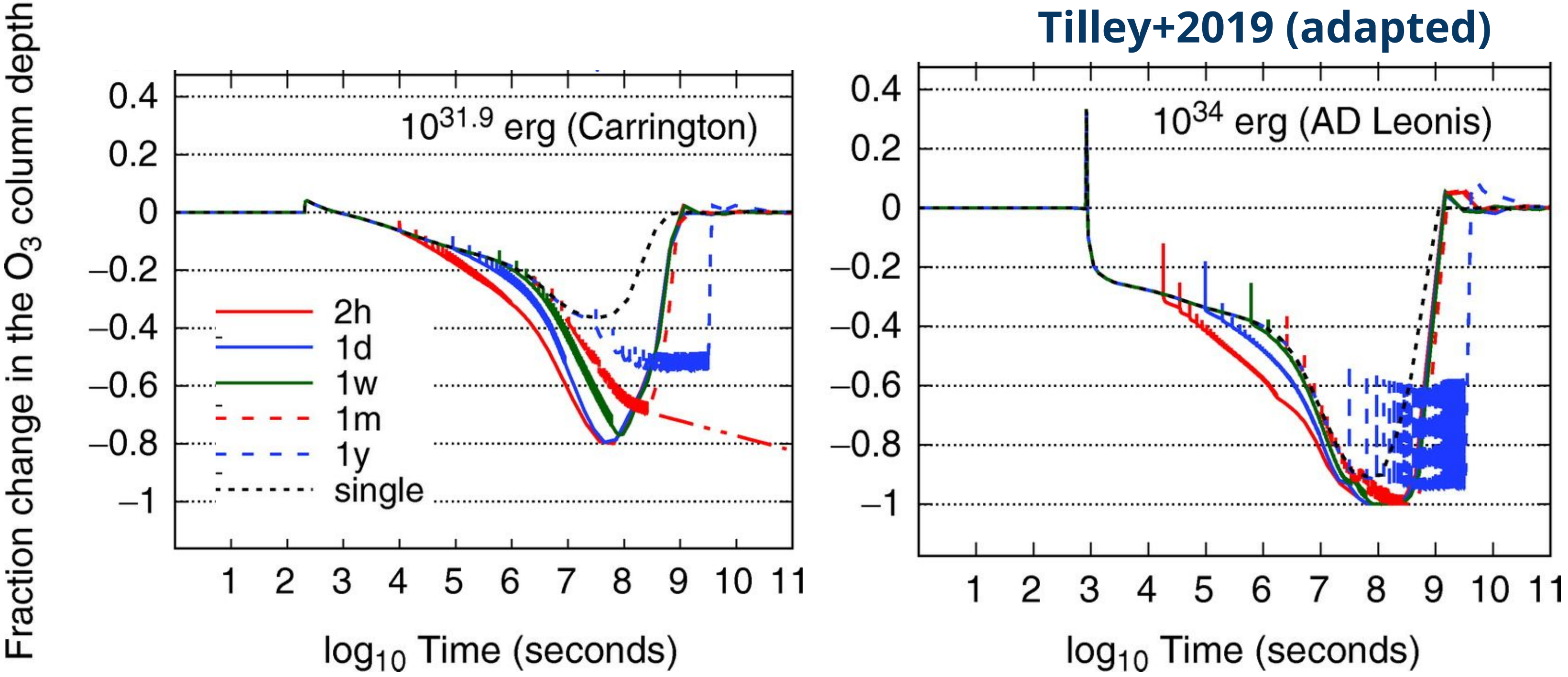
Potentially habitable planets are very common around active M dwarfs





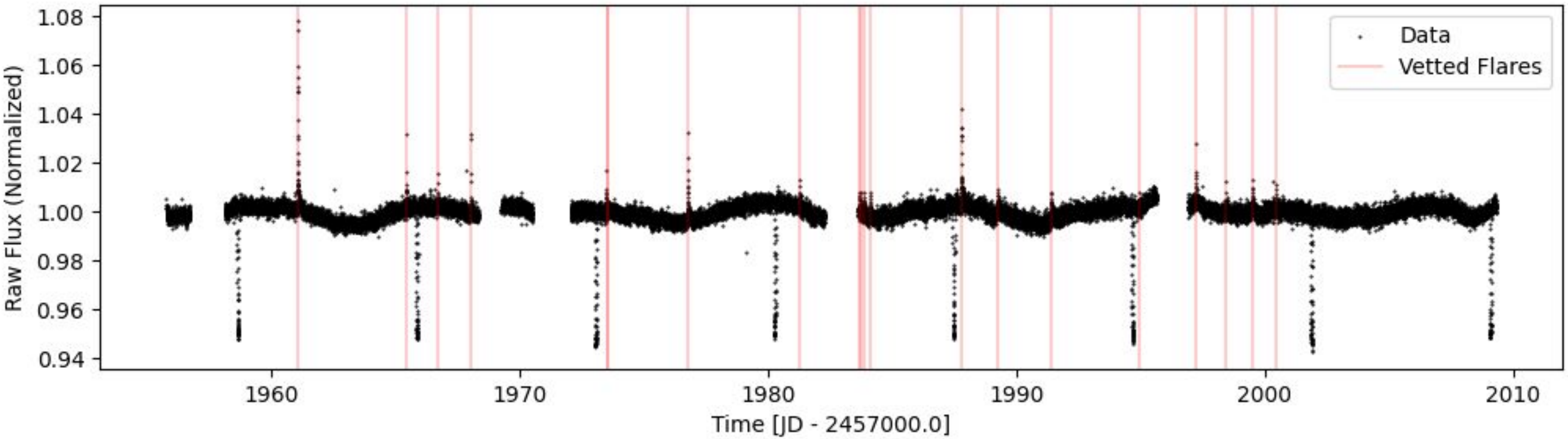
Stellar activity can significantly impact atmospheres

Tilley+2019 (adapted)



In what types of atmospheres will the impacts of stellar activity be most visible?

A growing number of brown dwarfs are known on short-period orbits around active M dwarfs



TESS lightcurve of TOI-2119 b, with visible deep transits of a companion brown dwarf and numerous optical flares

What will be the impact of these flares on the atmosphere of the brown dwarf?

VULCAN - 1D Photochemical Kinetics Code

Shang-Min Tsai+2017,2021

Solves **continuity equation** given thermochemical and photochemical reaction rates and transport by diffusion and vertical mixing

HELIOS - 1D Radiative-Transfer Code

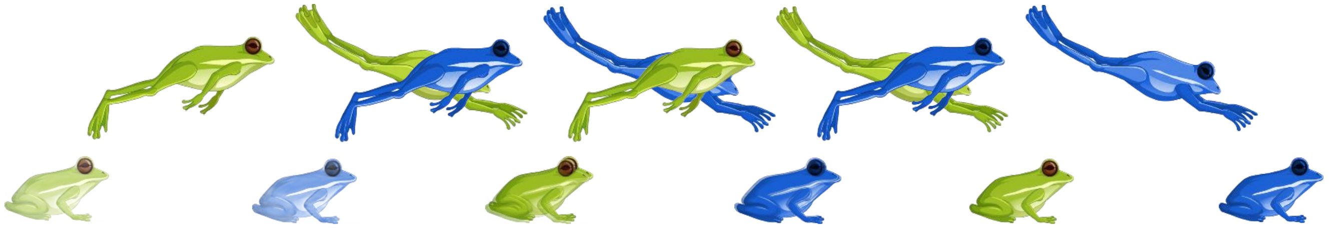
Malik+2017,2019a,b, Whittaker+2022

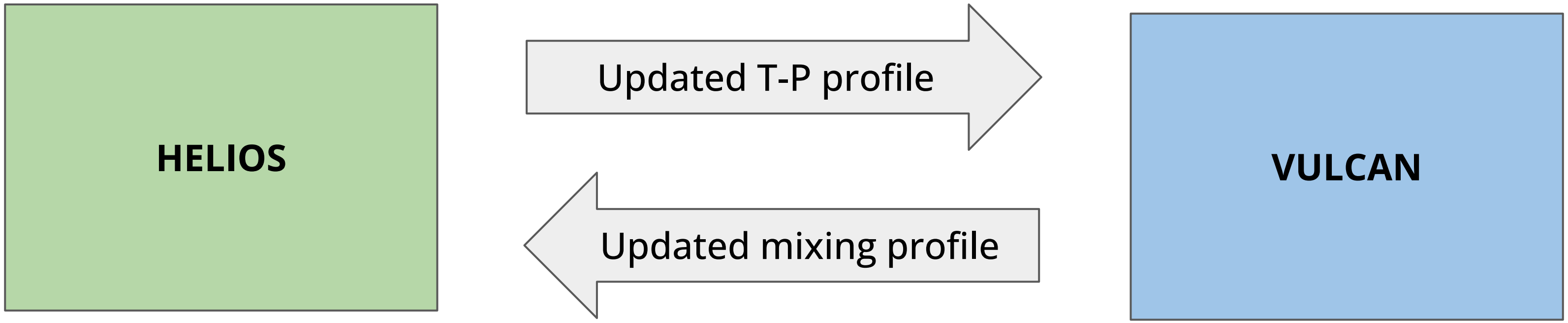
Solves **radiative-transfer equation** in plane-parallel, two-stream approximation
Opacities can be mixed on-the-fly for arbitrary atmospheric composition

Coupling atmospheric temperature and chemistry

In solving the initial atmosphere, codes run to steady state between leaps

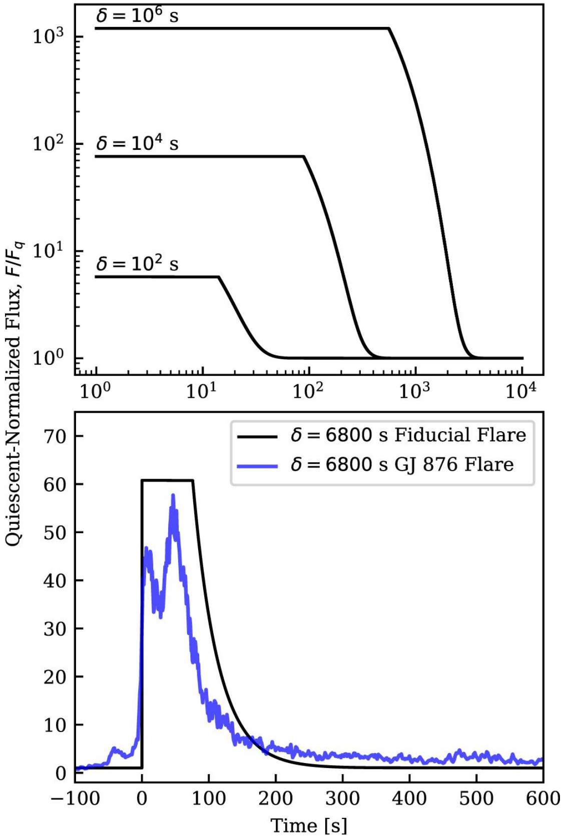
In flare simulation, codes only run for small time step between leaps

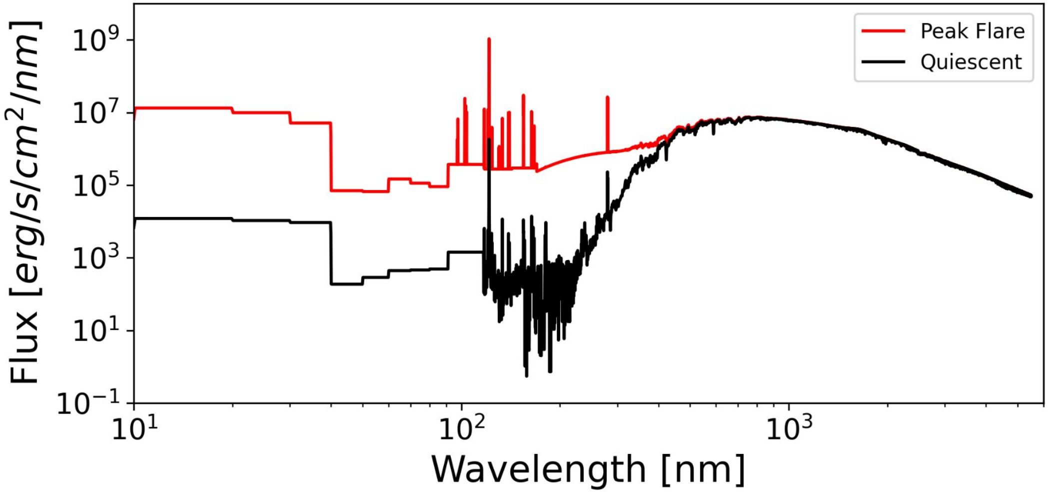




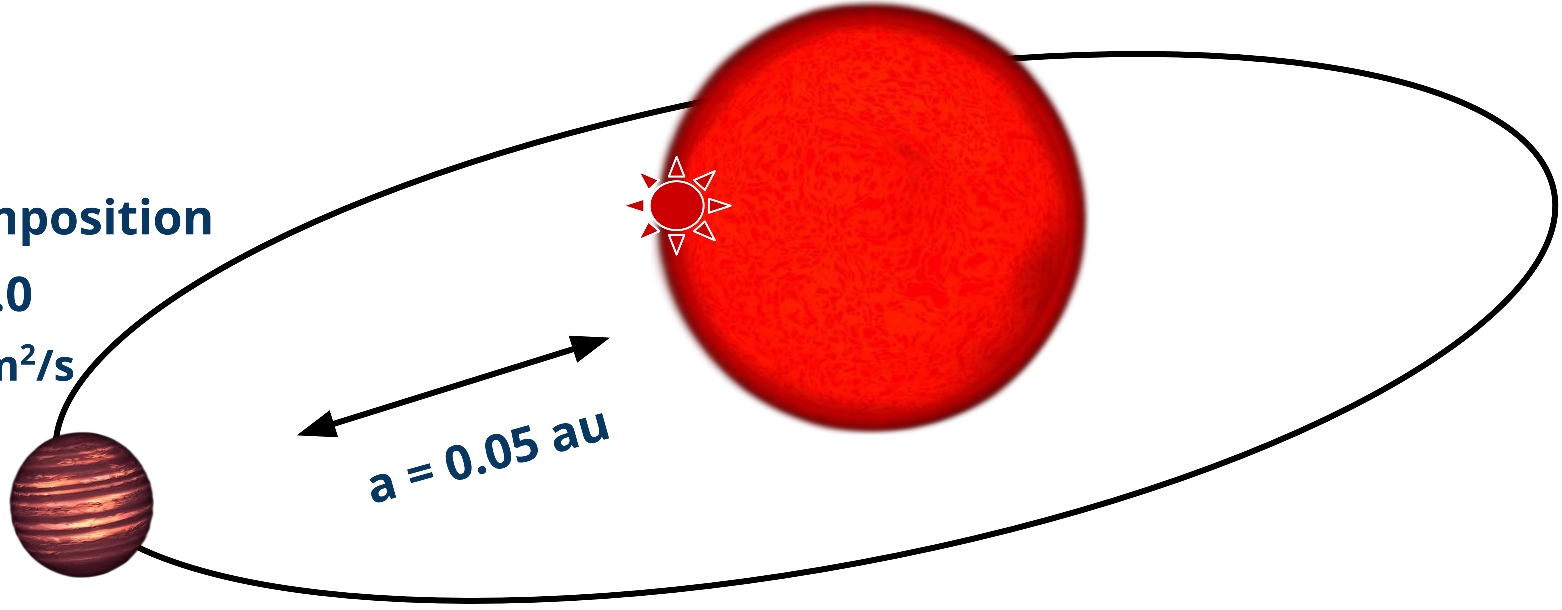
Temporal spectral model of a M dwarf flare

Fiducial Flare - Loyd+2018



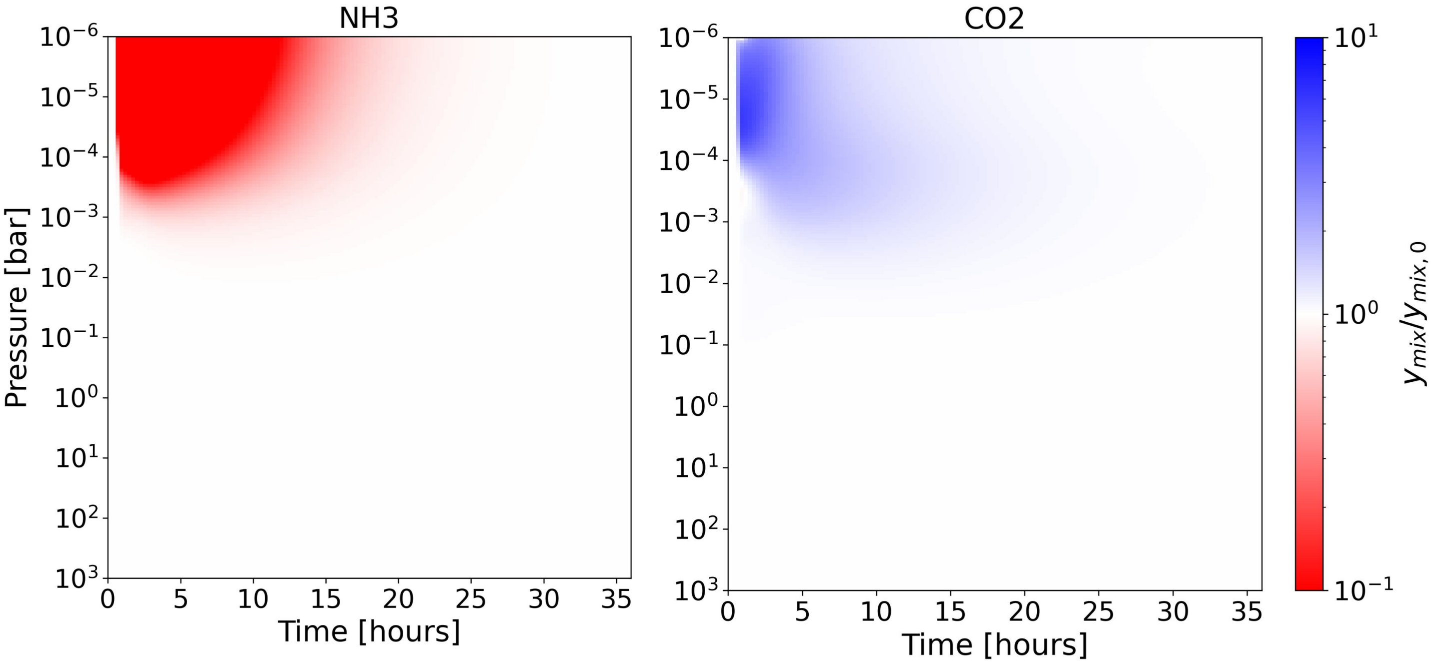


Properties of the simulated system



Some species are significantly enhanced or destroyed, others nearly unchanged

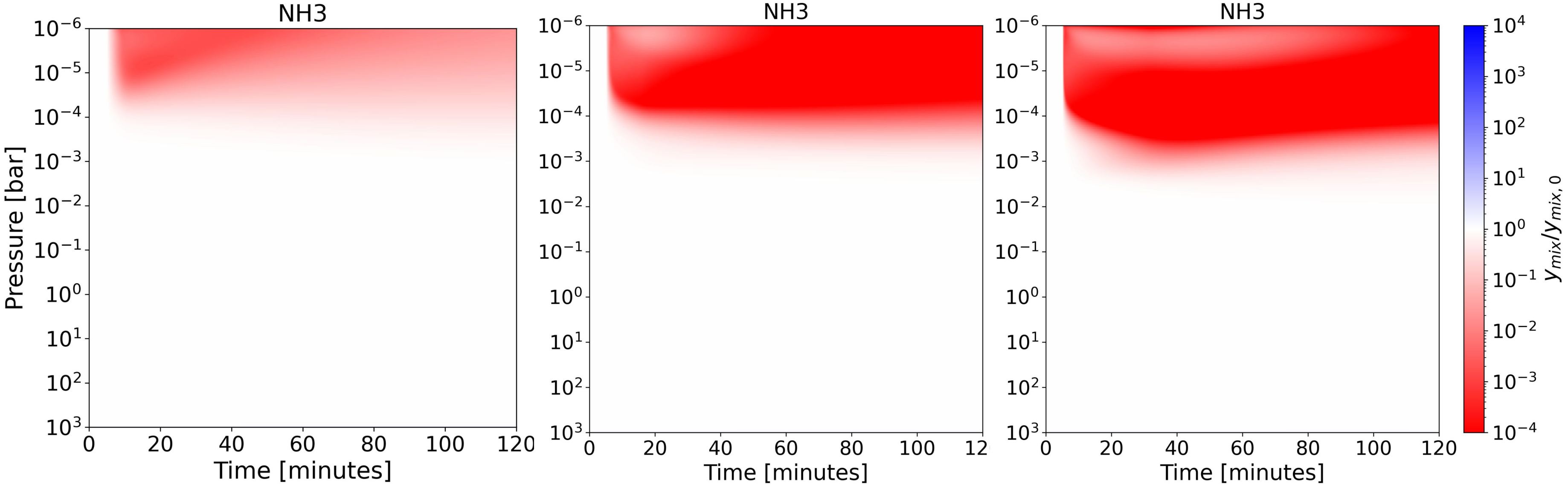
10^{34} erg Flare



Stronger flares, stronger reaction

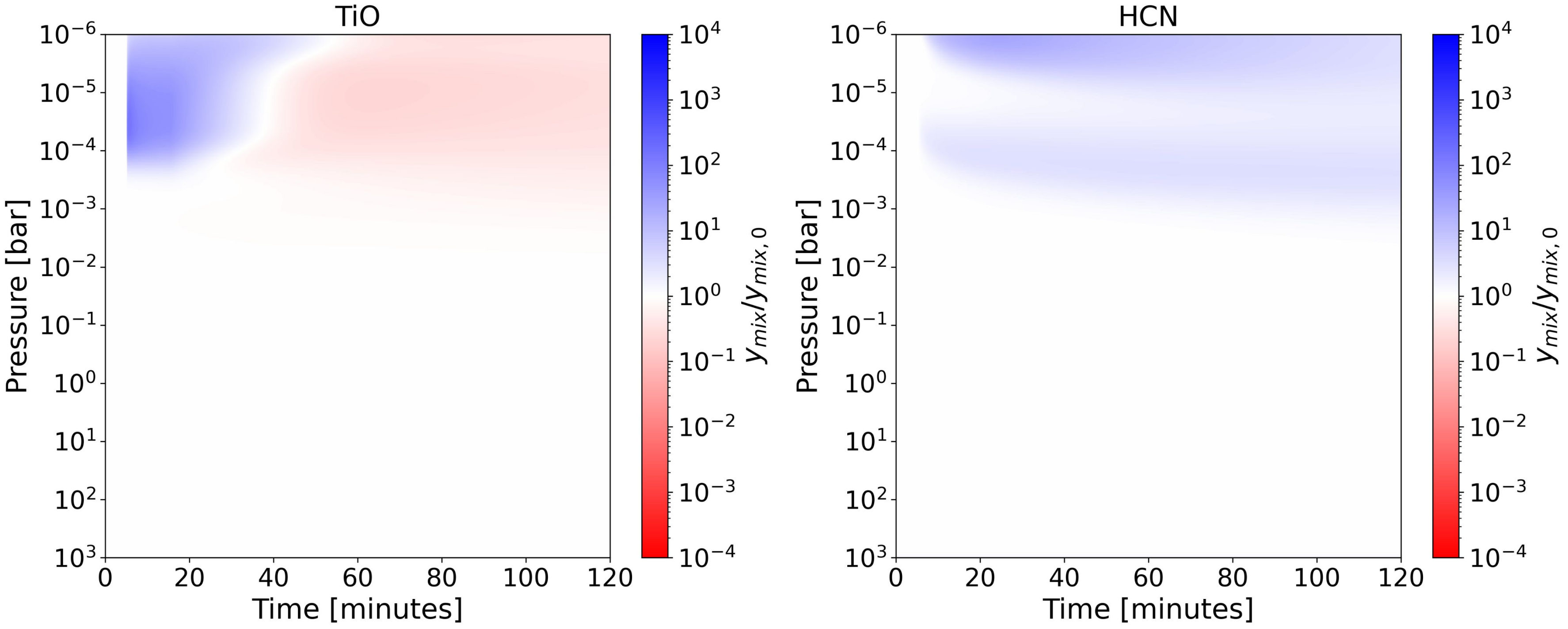
10^{33} erg | **10^{34} erg** | **10^{35} erg**

10x Carrington | **100x Carrington** | **1000x Carrington**



Complex behavior can be driven by dissociation and mixing

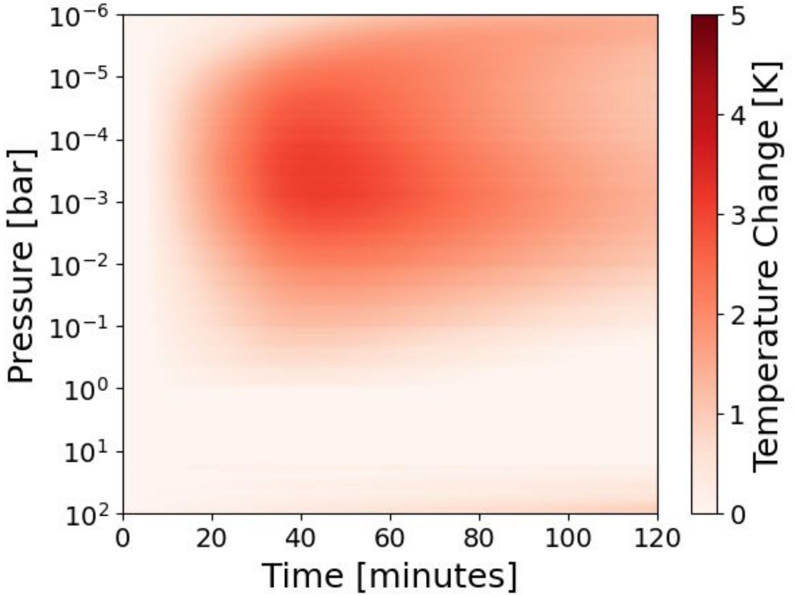
10^{34} erg Flare



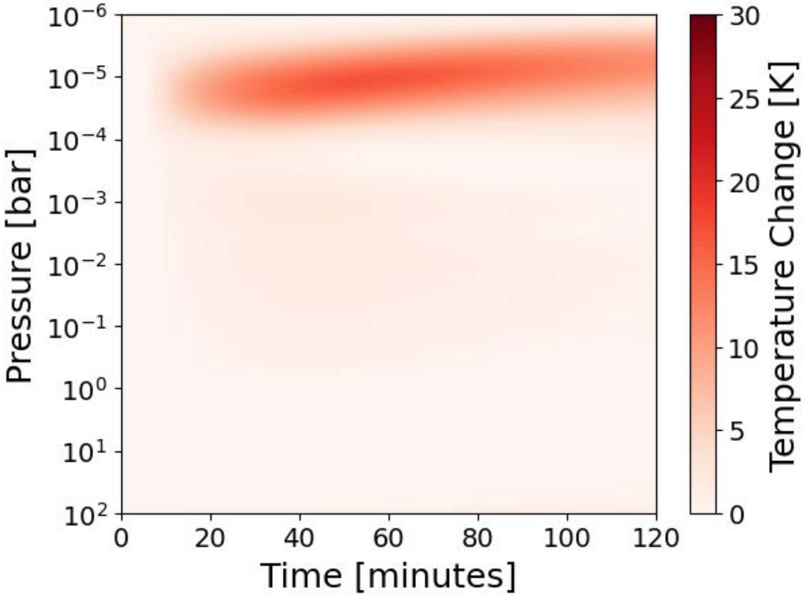
Temperature changes can be driven by changes in mixing and opacity

10^{35} erg Flare

HELIOS only



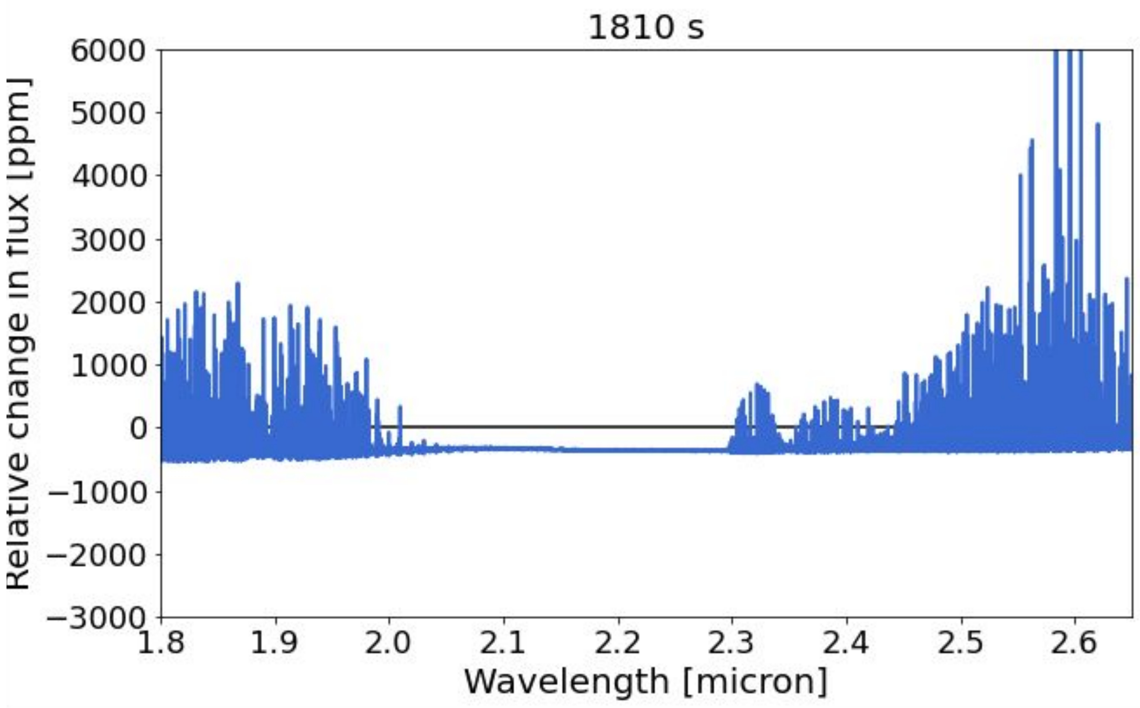
VULCAN-HELIOS



Detection of single flares may be difficult, but long term effects may result in observable disequilibrium

10^{34} erg Flare

R~100k



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Mollière+2019

Summary

- Short-period brown dwarf - M dwarf binaries are a possible context to observe the atmospheric impacts of stellar activity
- Single powerful flares can change the abundance ratios of certain species by orders of magnitude above 1 mbar
- Changes in opacity can drive temperature changes
- Observing impacts of single flares is unlikely, future work should investigate impacts of long term activity and particle events

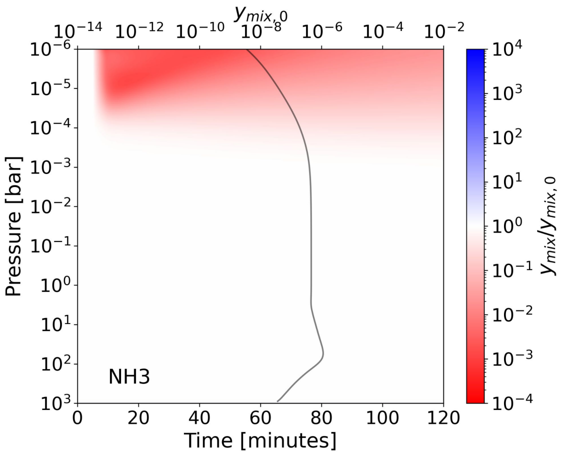
Currently on the job market!

Extra Slides

Stronger flares, stronger reaction

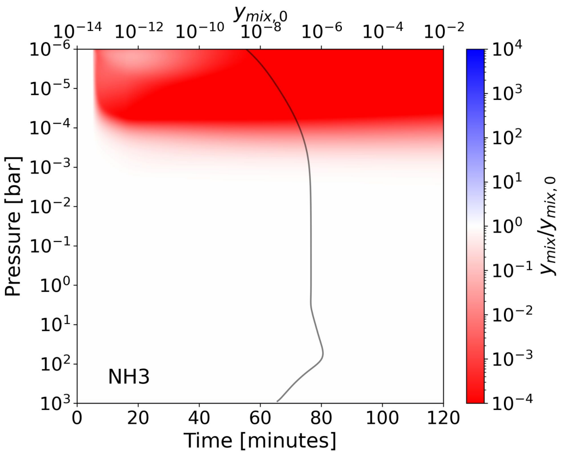
10^{33} erg

10x Carrington



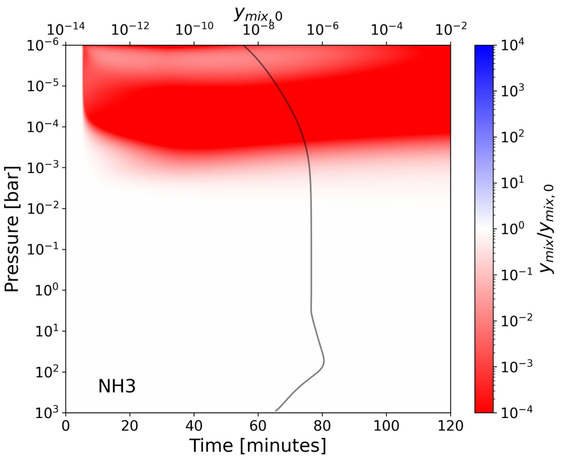
10^{34} erg

100x Carrington



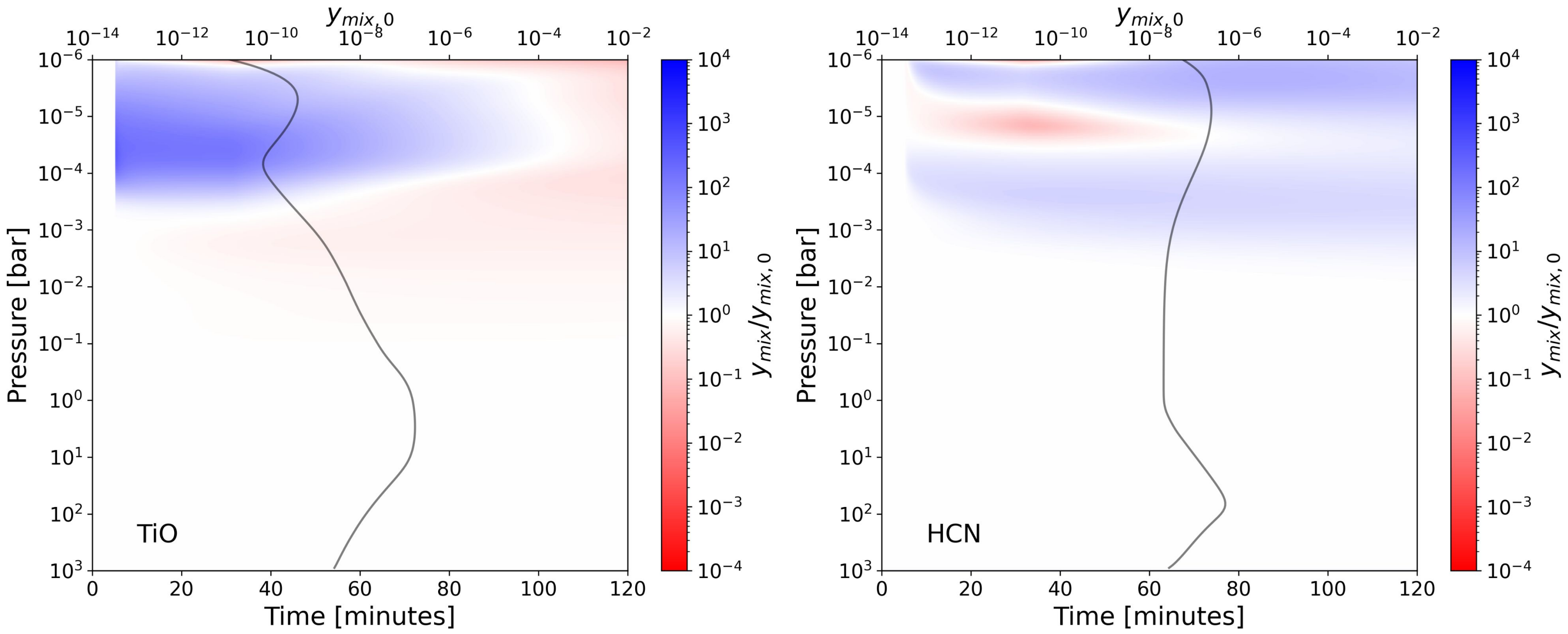
10^{35} erg

1000x Carrington



Complex behavior can be driven by dissociation and mixing

10^{35} erg Flare



VULCAN - 1D Photochemical Kinetics Code

Shang-Min Tsai+2017,2021

Solves continuity equations

$$\frac{\partial n_i}{\partial t} = P_i - L_i - \frac{\partial \phi_i}{\partial z}$$

n_i - number density of chemical species

P_i - production from thermochemical and photochemical reactions

L_i - loss from chemical reactions

ϕ_i - transport flux including advection, eddy diffusion, molecular and thermal diffusion