The Meteorology of Non-global Atmospheres on Lava Planets

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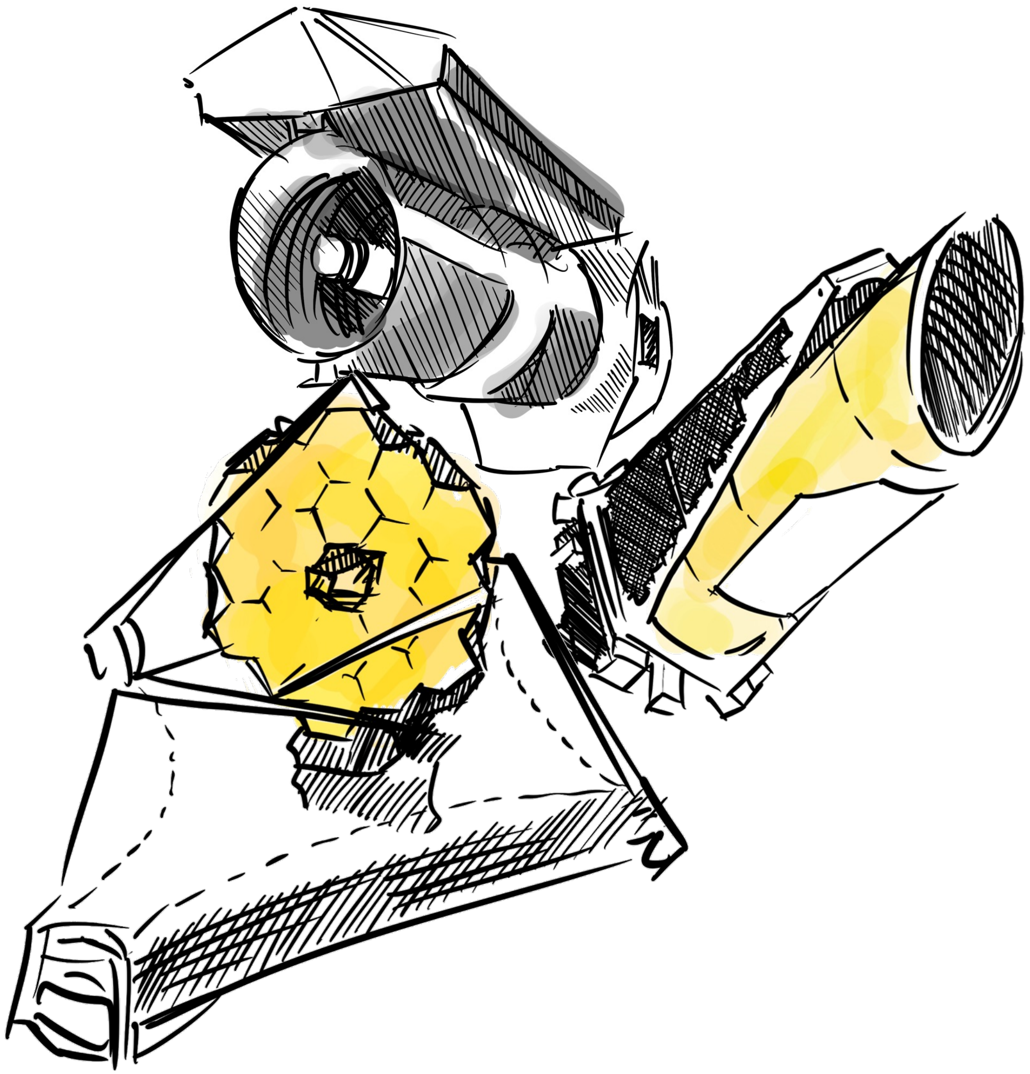
Nicolas Cowan (supervisor)

observing exoplanets in JWST era



recent missions such as Kepler and Spitzer has allowed for better detection and characterization of exoplanets

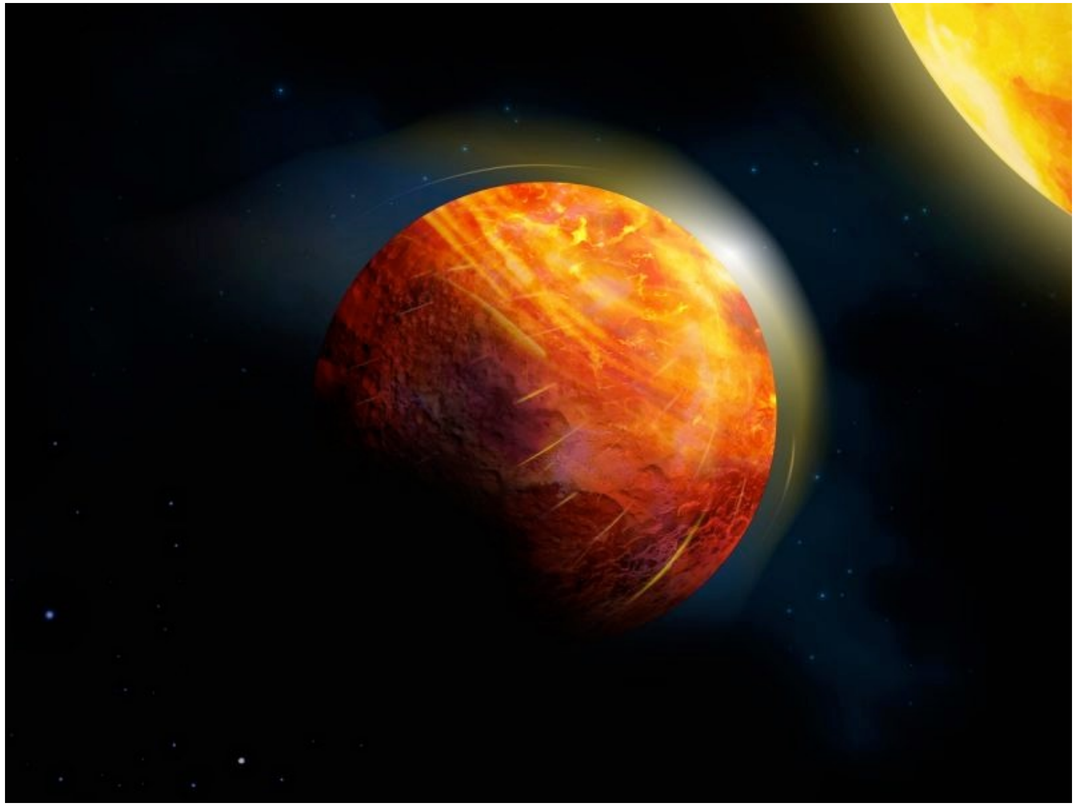
with JWST, we can further characterize Earth-sized planets and their atmospheres

introducing lava planets

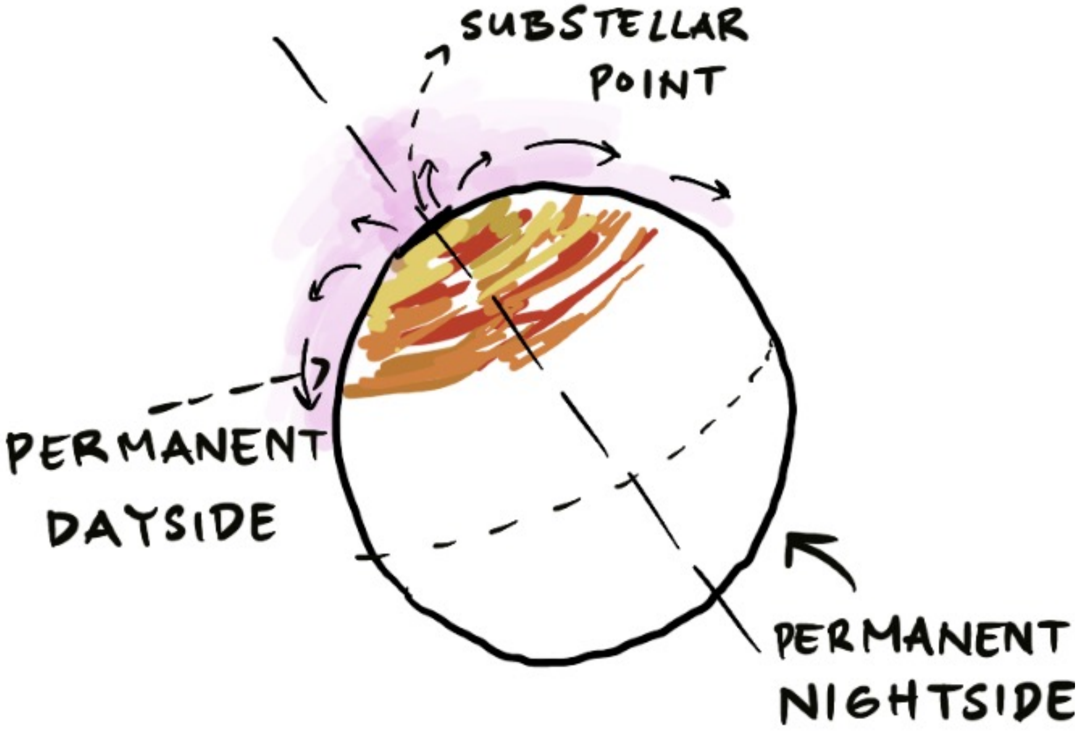
lava planets are a class of rocky planets with extremely short orbital periods

temperatures on these planets not only melt rocks, but vapourize them

their signal-to-noise makes them the best target for atmospheric detection and characterization



atmospheric dynamics on a tidally locked planet



tidally locked planets risk having their atmosphere collapsed on the nightside

non-global and transient atmospheres are observed on Io and Pluto

dynamics are impossible for general circulation model to handle

the turbulent boundary layer model

modelling lava planet atmospheres rely on either 1D radiative transfer model or hydrodynamical model

hydrodynamical models have less complexities in chemical composition but handles mass distribution very well

we use a hydrodynamical model to infer atmospheric properties and simulate observations

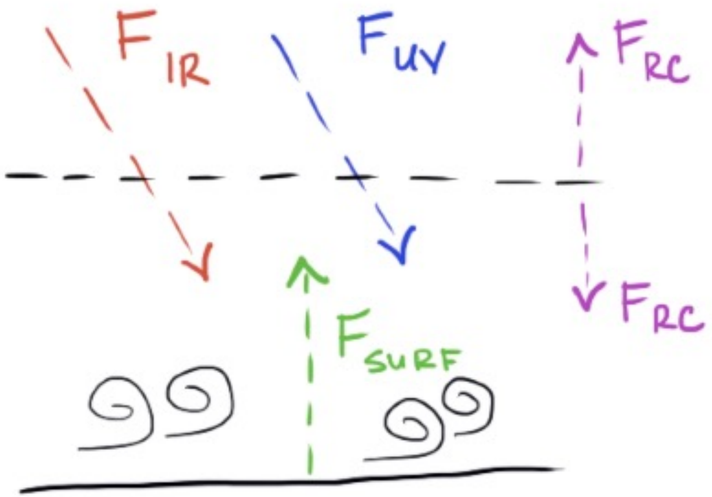
MASS: $\nabla \cdot (\rho h V) = E$

MOMENTUM : $\nabla \cdot (\rho h V^2) = -\nabla \int_z P dz + \tau$

ENERGY : $\nabla \cdot \left(\left(\frac{V^2}{2} + C_p T \right) (\rho h V) \right) = Q$

implementation of radiative transfer

$$Q = Q_{sens} + F_{IR} + F_{UV} + F_{surf} - 2F_{RC}$$



$$\sigma T_s^4 = F_* - F_{IR} - F_{UV} + F_{RC}$$

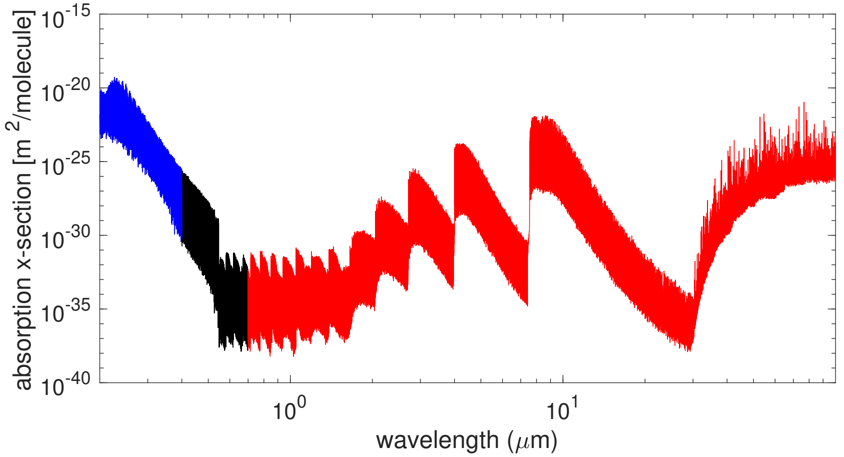
$$F_{RC} = \pi(\,\epsilon_{IR}\int_{\lambda_{IR}} B(\lambda)d\lambda + \epsilon_{UV}\int_{\lambda_{UV}} B(\lambda)d\lambda)$$

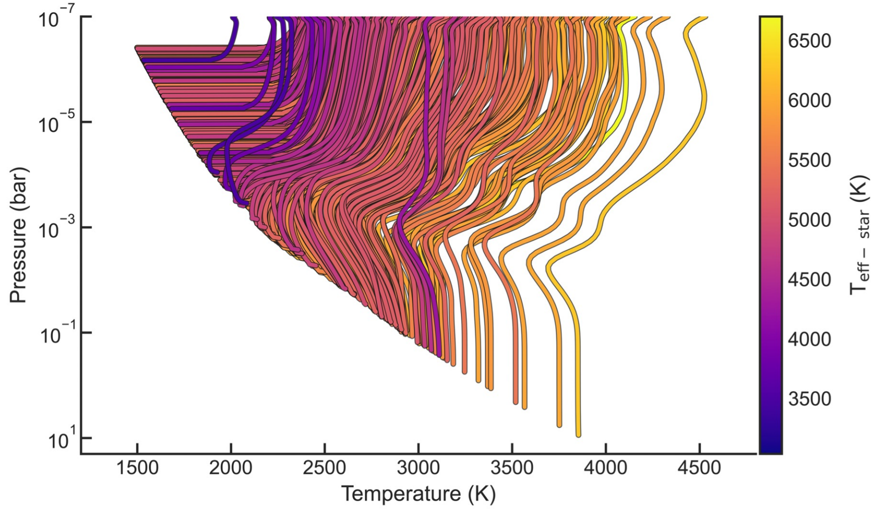
we improve upon previous models by implementing radiative transfer into the energy balance

we also add in the greenhouse effect which couples the energy balance between the surface and atmosphere

because a silicate atmosphere absorbs UV very well, there is likely a substantial temperature inversion

implementation of radiative transfer





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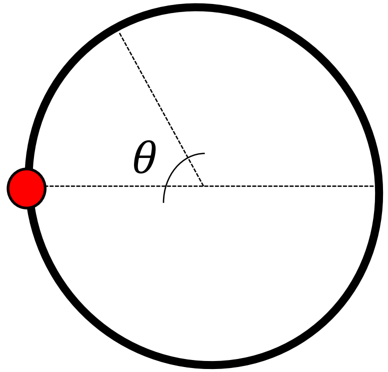
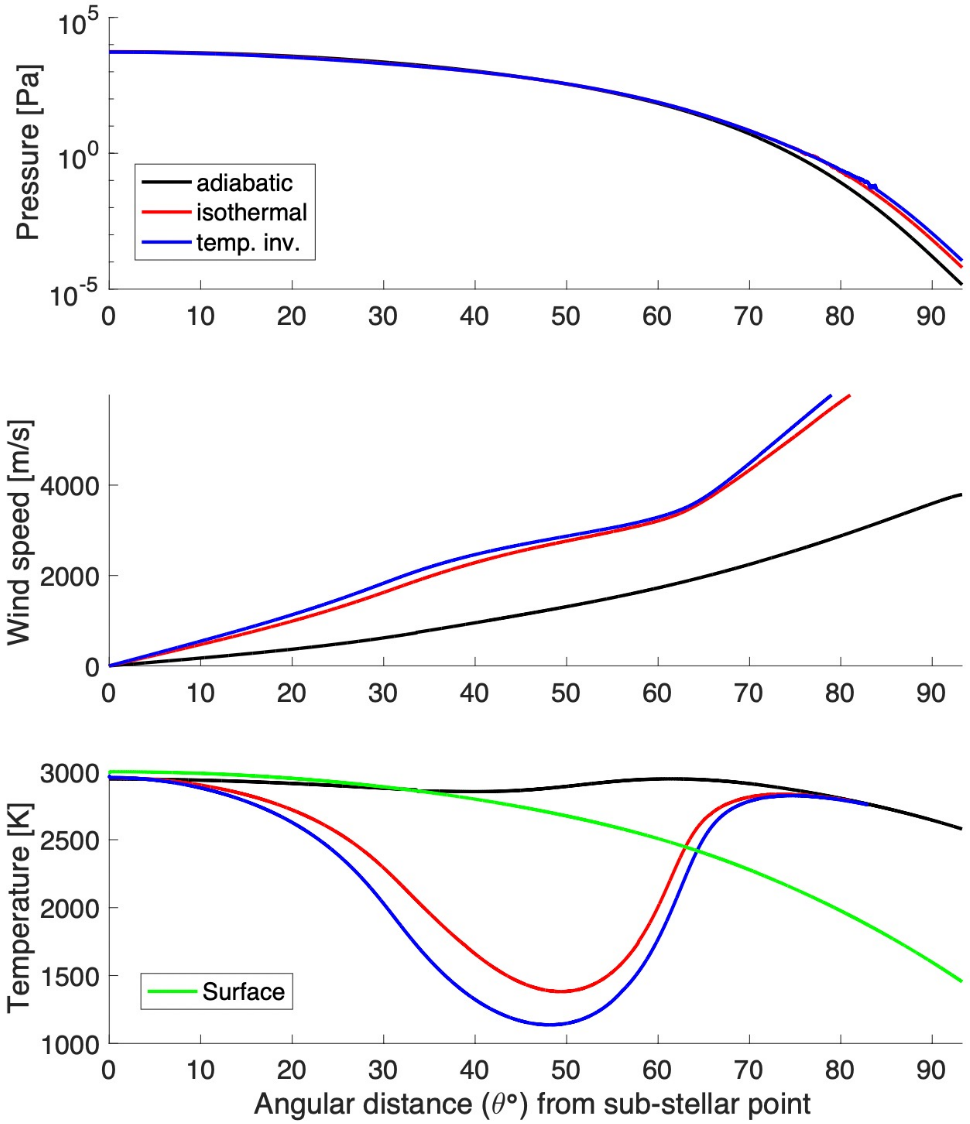
Zilinskas, M., Van Buchem, C. P. A., Miguel, Y., Louca, A., Lupu, R., Zieba, S., & van Westrenen, W. (2022). Observability of evaporating lava worlds. *Astronomy & Astrophysics*, *661*, A126.

model results: K2-141b

we simulate the atmosphere of K2-141b for 3 different atmospheric profiles: adiabatic, isothermal, and inverted temp. profile (Nguyen et al., 2022)

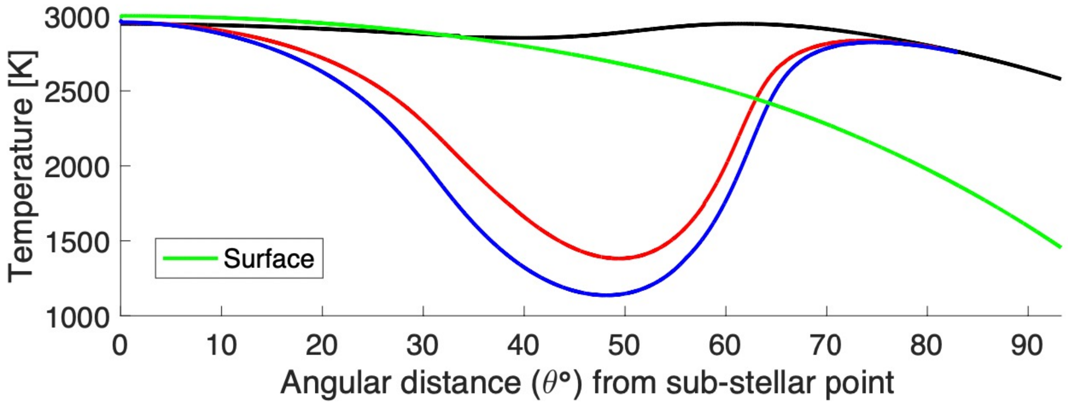
results show the properties at the boundary of the surface turbulent layer (1/2 scale height)

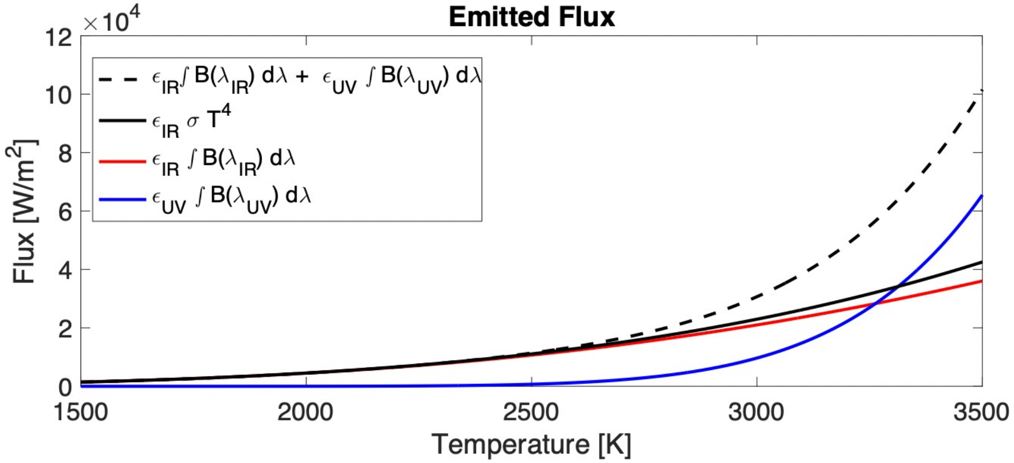




Nguyen, T. G., Cowan, N. B., Pierrehumbert, R. T., Lupu, R. E., & Moores, J. E. (2022). The impact of ultraviolet heating and cooling on the dynamics and observability of lava planet atmospheres. *Monthly Notices of the Royal Astronomical Society*, *513*(4), 6125-6133.

effects of UV radiative cooling





atmospheric temperature tends to become horizontally uniform

UV emissivity is much larger than IR so eventually, the only dominate radiative terms are UV heating and cooling

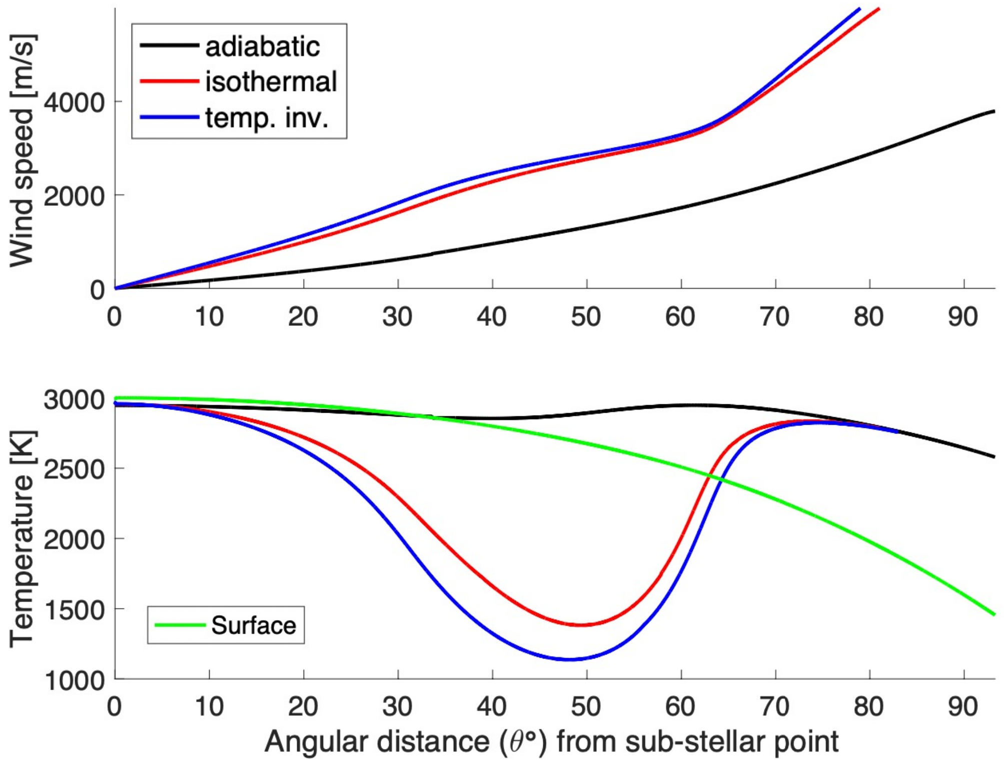
UV cooling is only effective when it's hot enough so temperatures will converge towards a point where UV heating and cooling balances one another

effects of temperature inversions

a negative lapse-rate (temperature increasing with height) increases the pressure gradient force

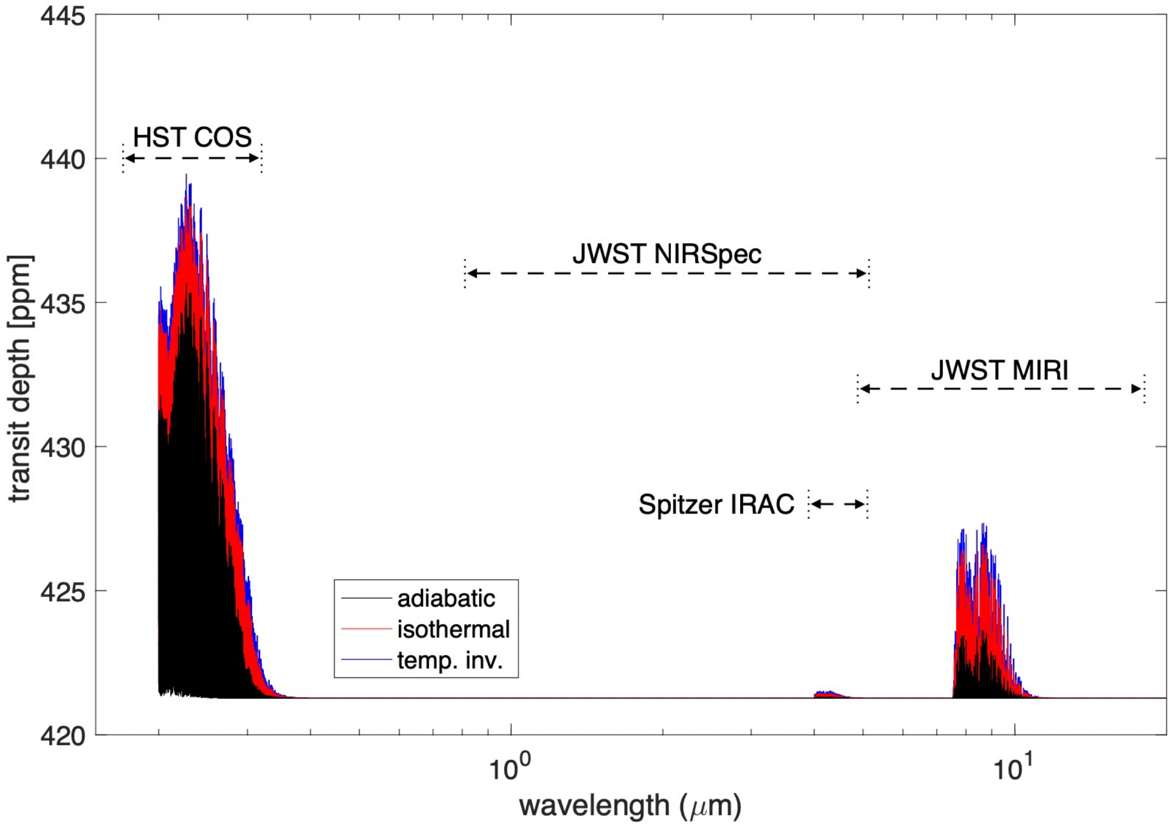
larger pressure gradient leads to stronger winds, but this cools down the atmosphere as heat energy is converted to kinetic energy

physically, cold lower air can't be easily lifted and flow is restricted horizontally



$$\textbf{ENERGY}: \nabla \cdot \left(\left(\frac{V^2}{2} + C_p T \right) (\rho h V) \right) = Q$$

observing with JWST

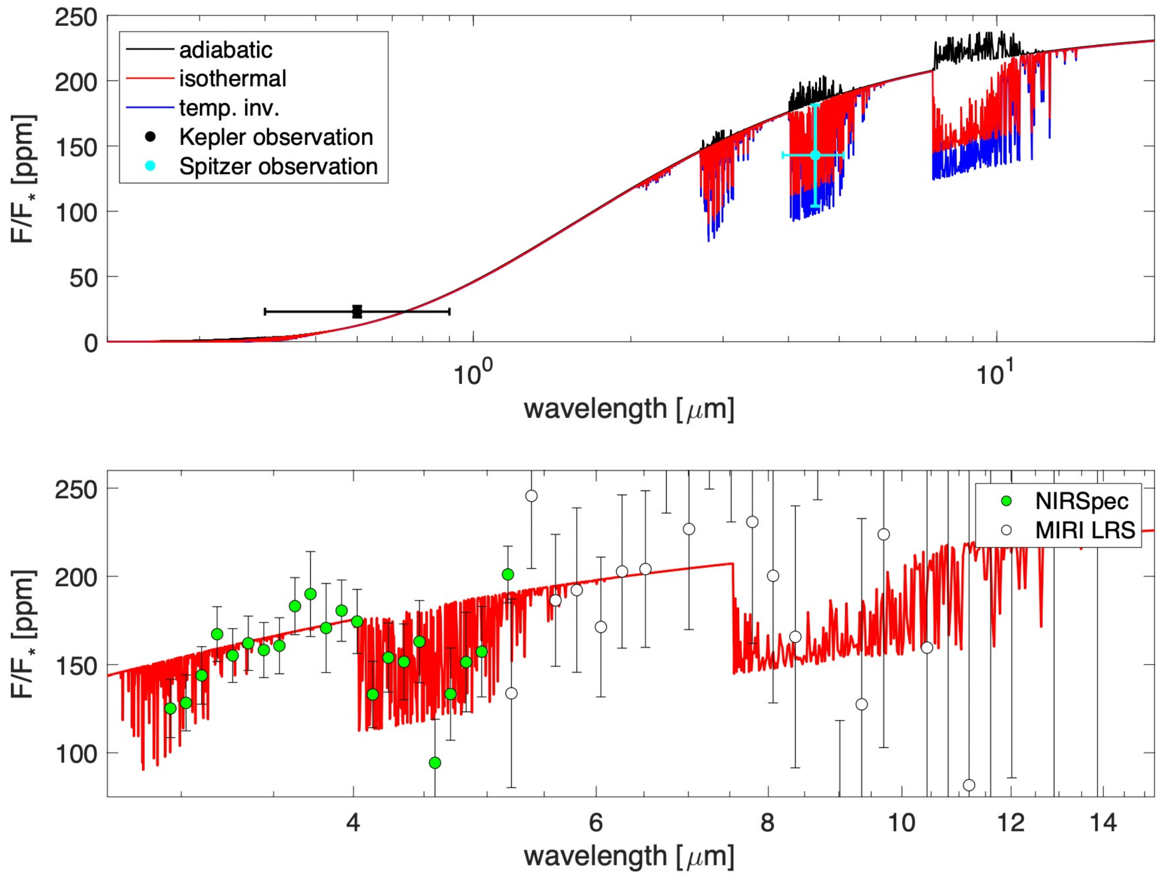


we can simulate observations from the results

since the atmosphere is too thin around the terminator, transit spectroscopy is unlikely to detect an atmospheric signal

eclipse spectroscopy is much more promising where SiO spectral features may be observable with JWST for K2-141b

observing with JWST



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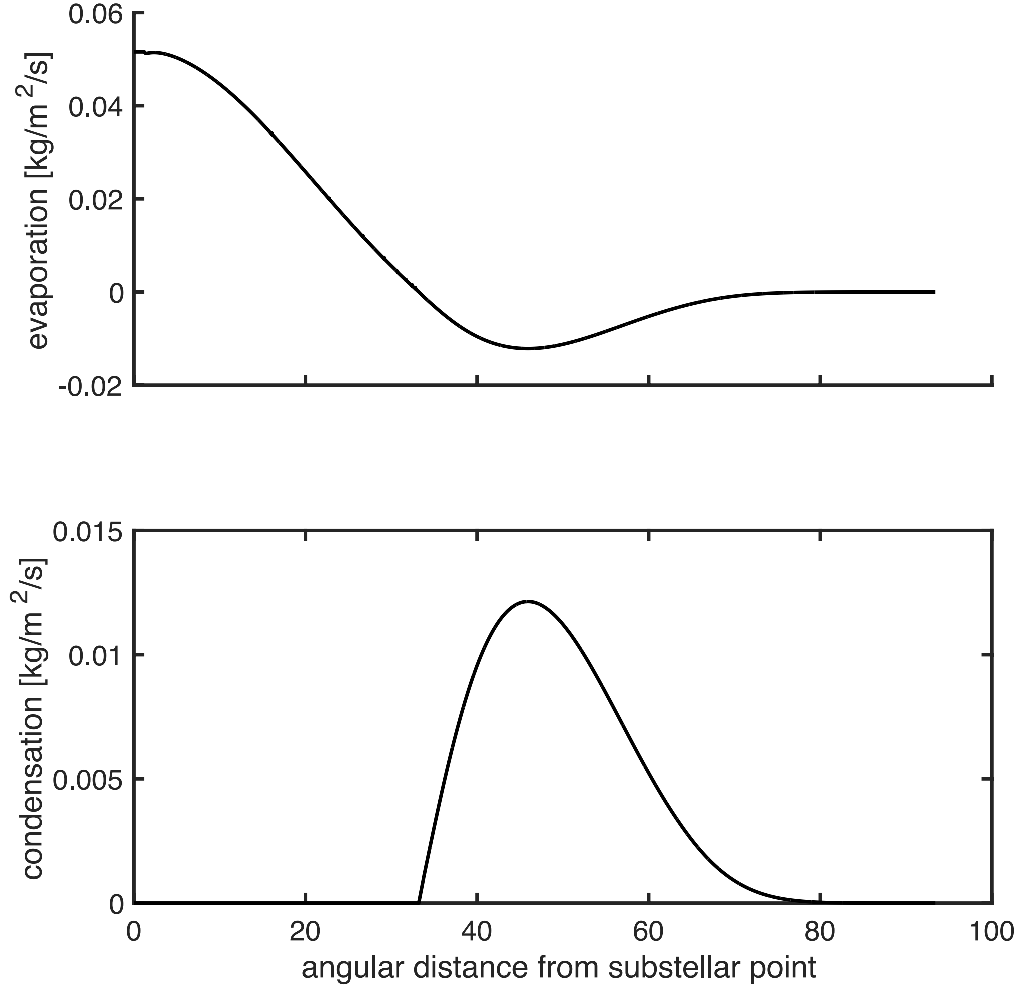
current work: cloud implementation

more work is being done now on cloud implementation

we can use the condensation rate to infer how much clouds can form

although there are many cloud parameters to handle, we can scale the optical depth to the condensation rate to see the varying effects of cloud coverage



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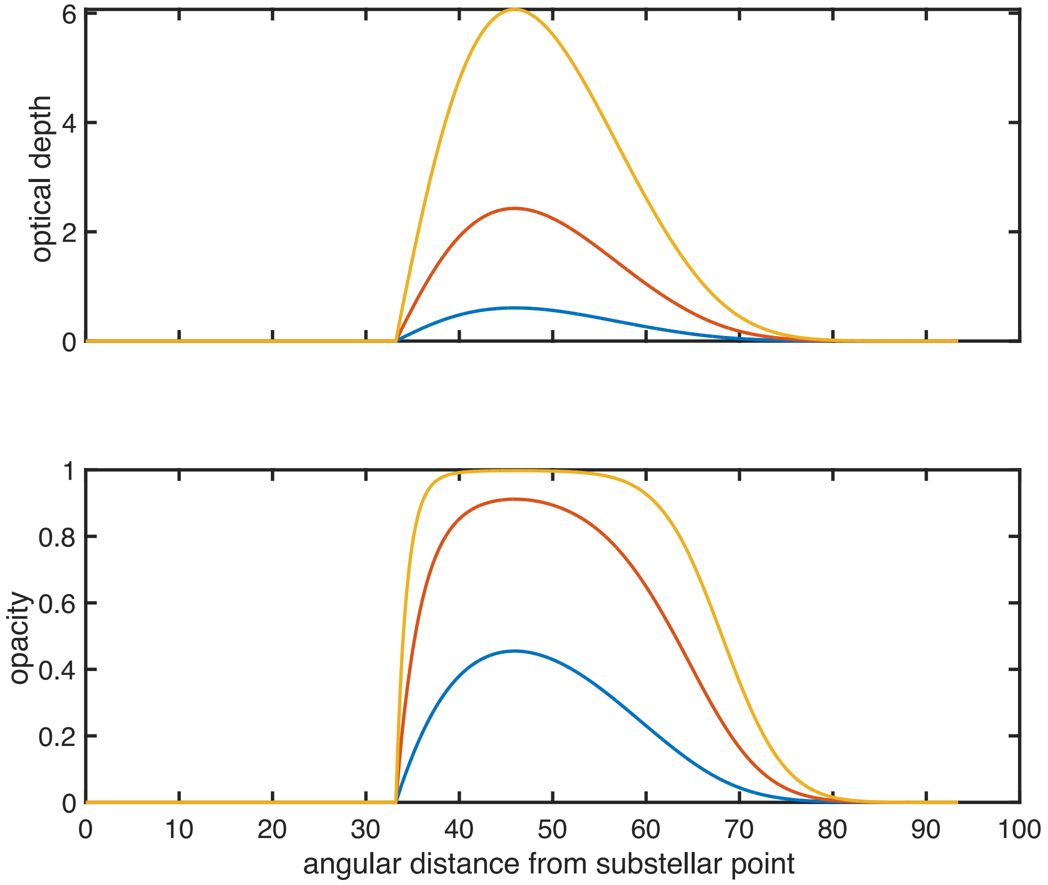
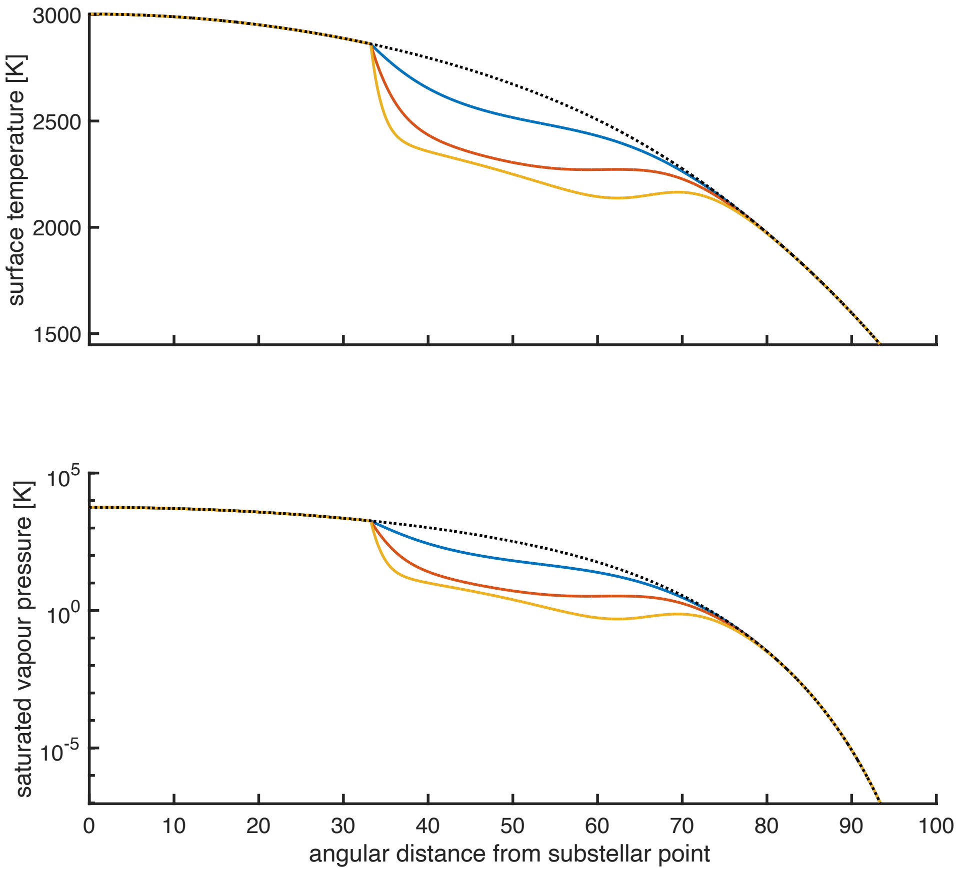


implications of silicate clouds



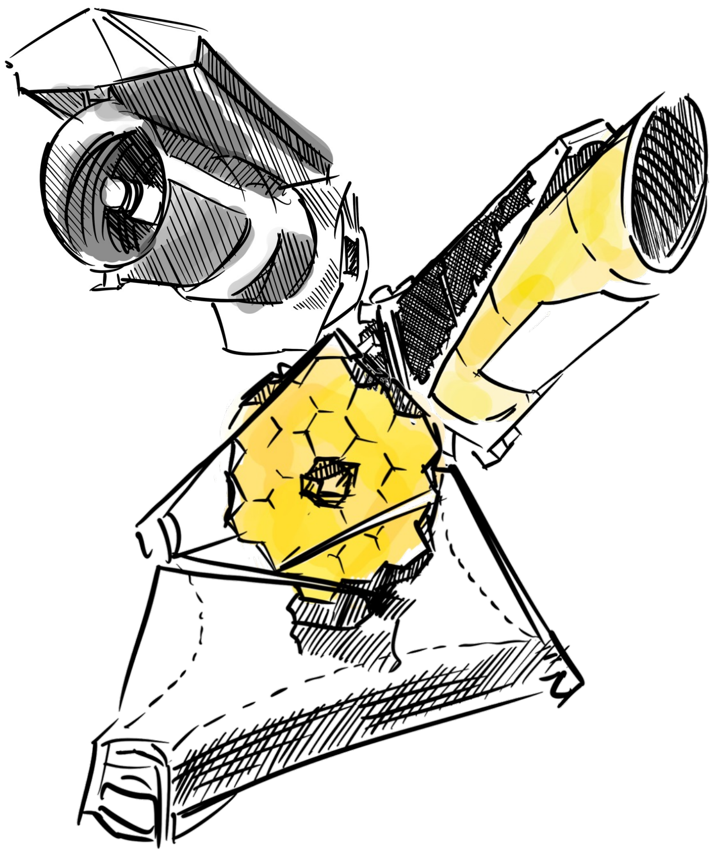
the current goal is to add clouds for the self-consistent model

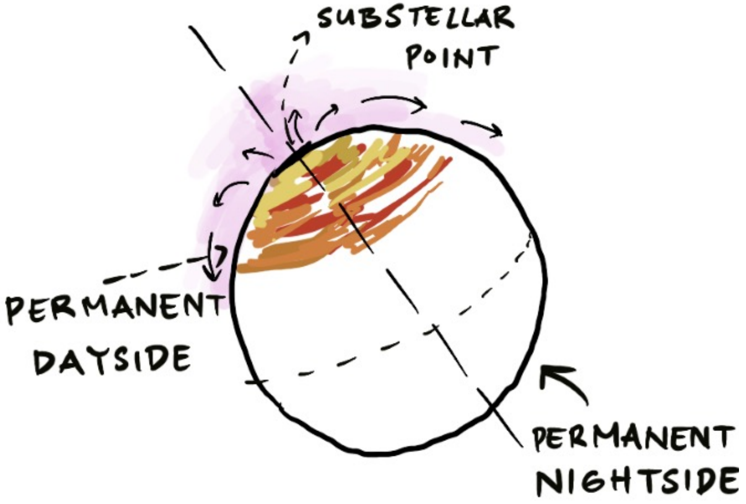
assuming isotropic scattering of visible light from clouds, we project the resultant surface temperature

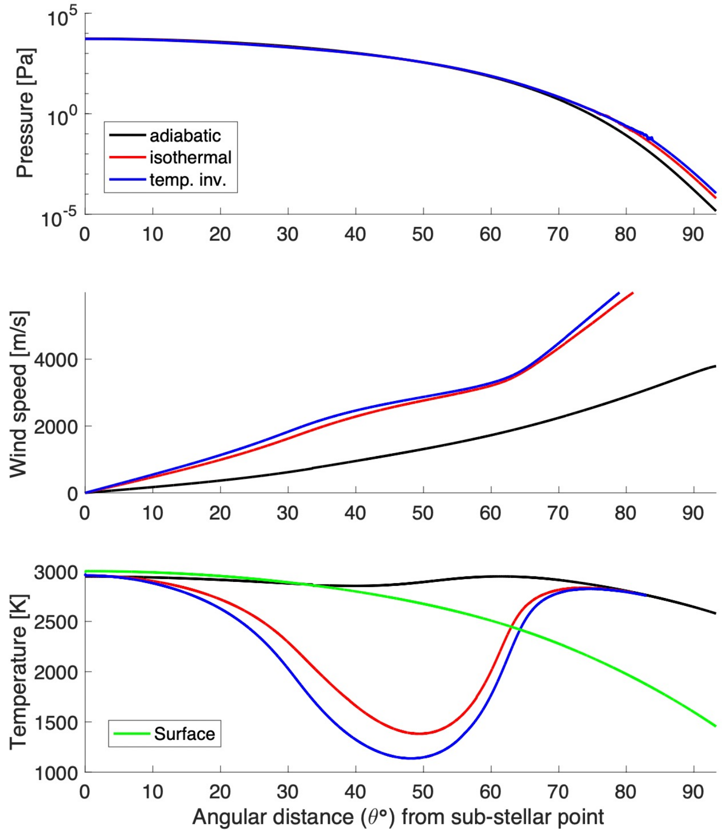
for any levels of cloud formation, this will cool the lower atmospheric level which promotes more condensation and more cloud formation leading to a feedback loop

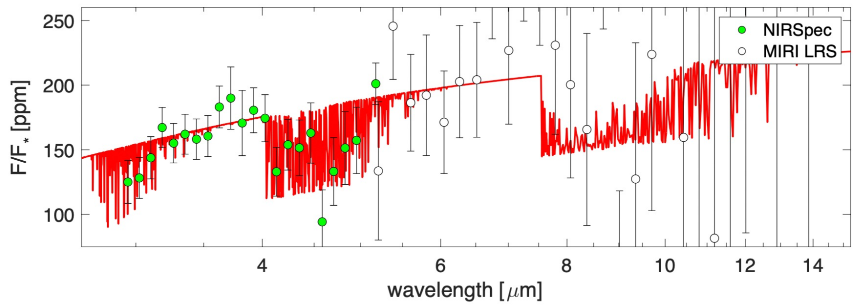
the end

Special thanks to Raymond Pierrehumbert, Roxana Lupu, and John Moores

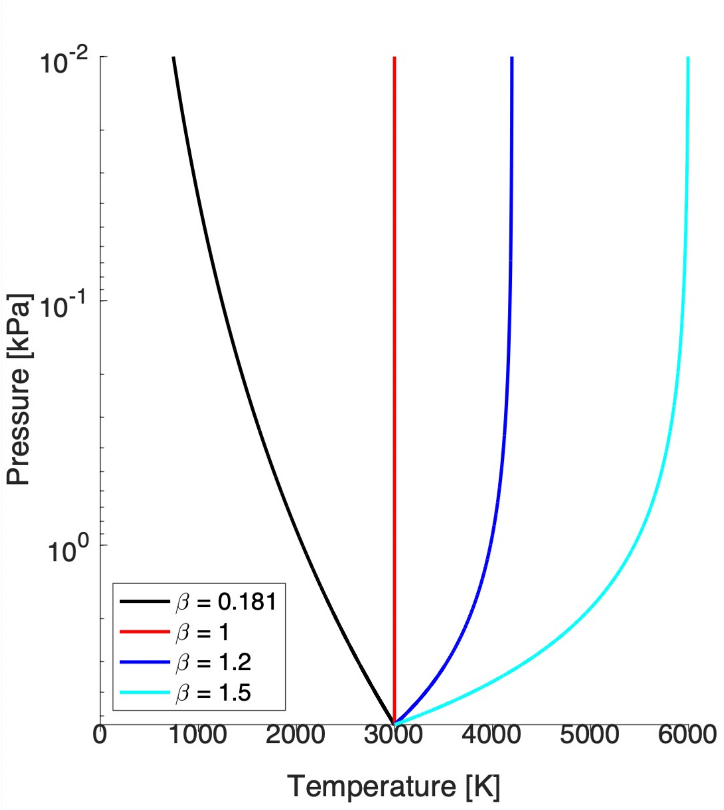








extra



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Temperature [K]
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β = 1
β = 1.2
β = 1.5