Group 3: Effect of limb darkening on the transmission spectrum

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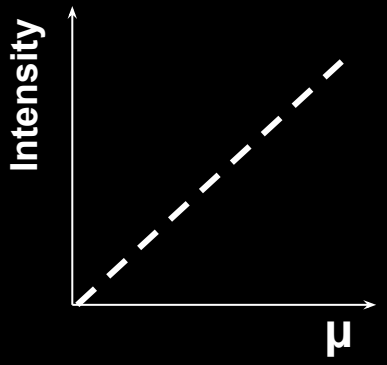
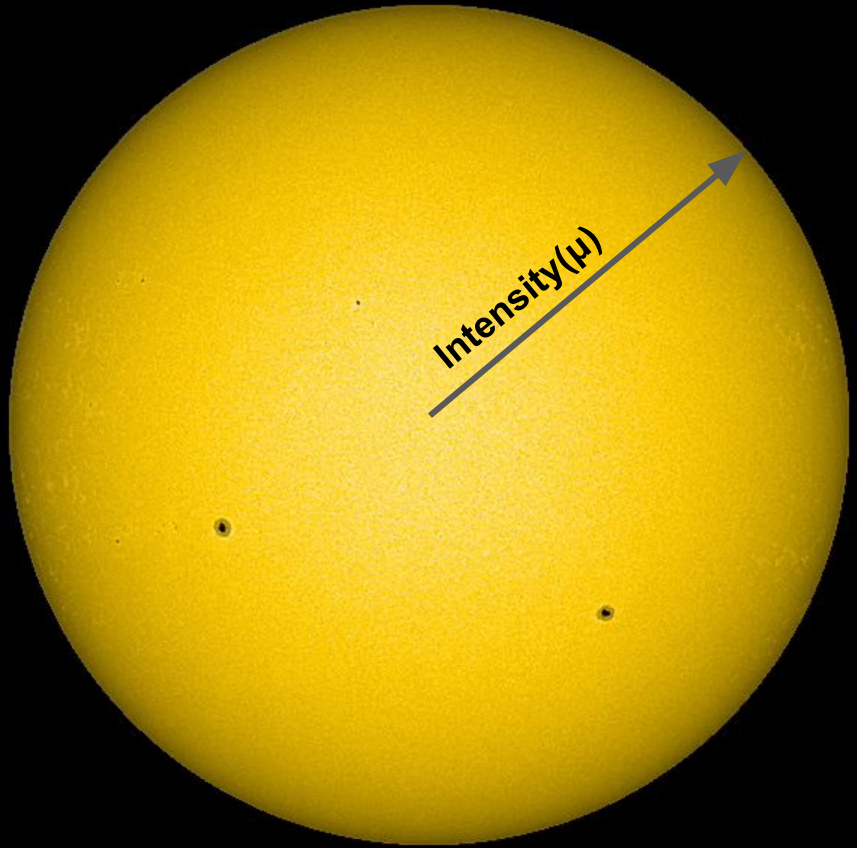
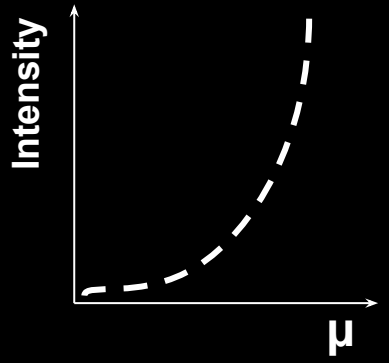
Sagan NExScI Workshop, Friday, July 22, 2016

Linear?

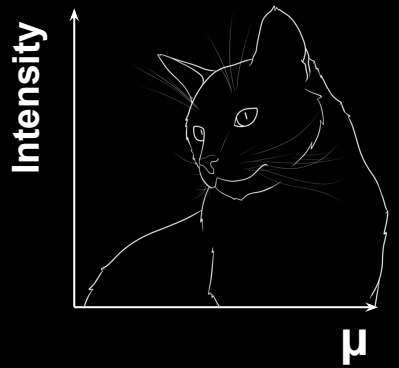




Quadratic?

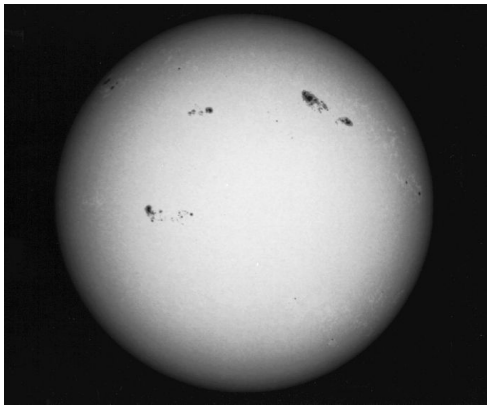


Cats?

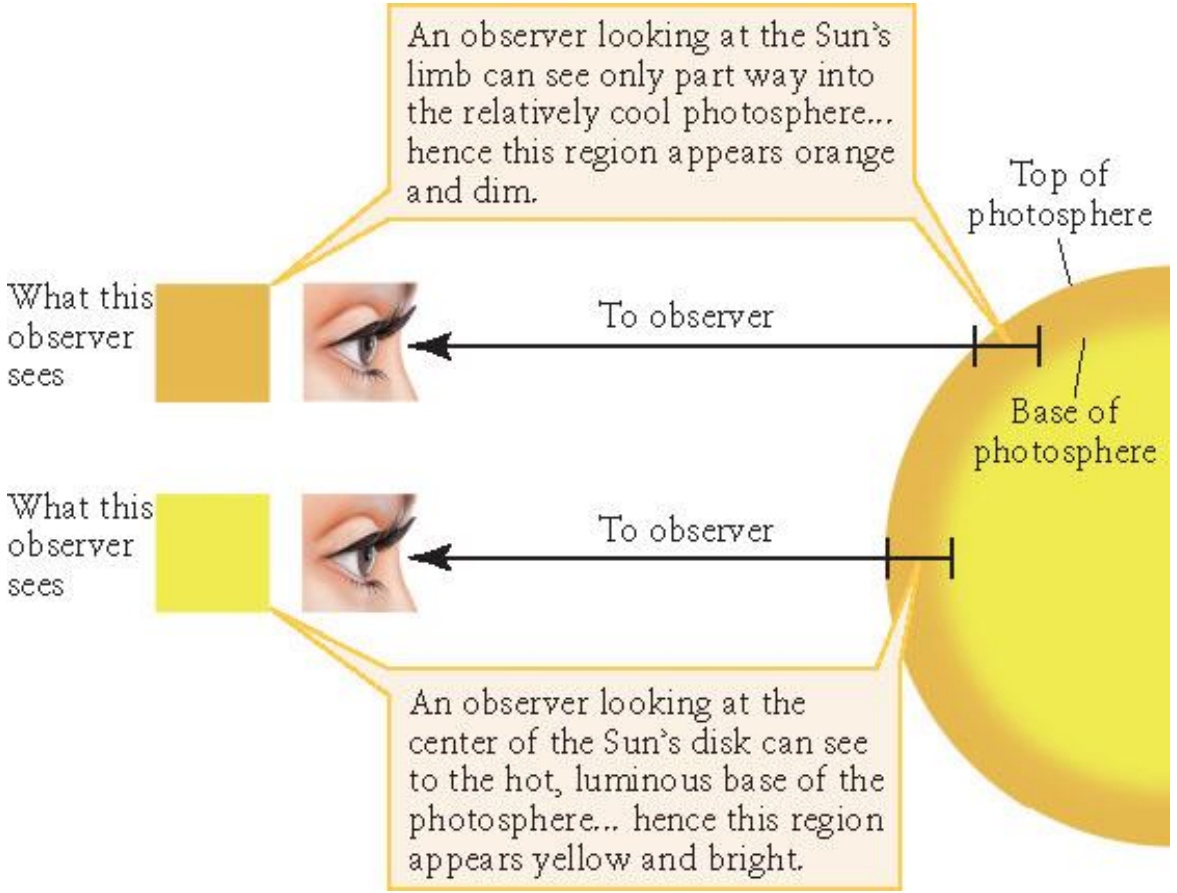


Solar Dynamics Observatory

Introduction to Limb Darkening

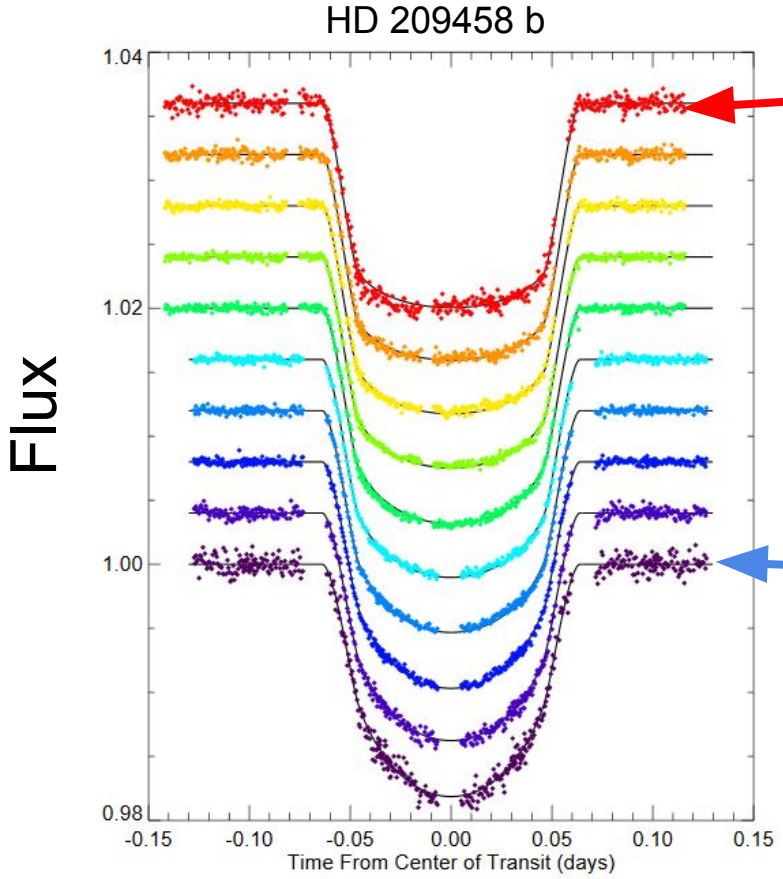


Limb darkening on the Sun
(Michael Richmond)



Dmitri Pogosian (University of Alberta)

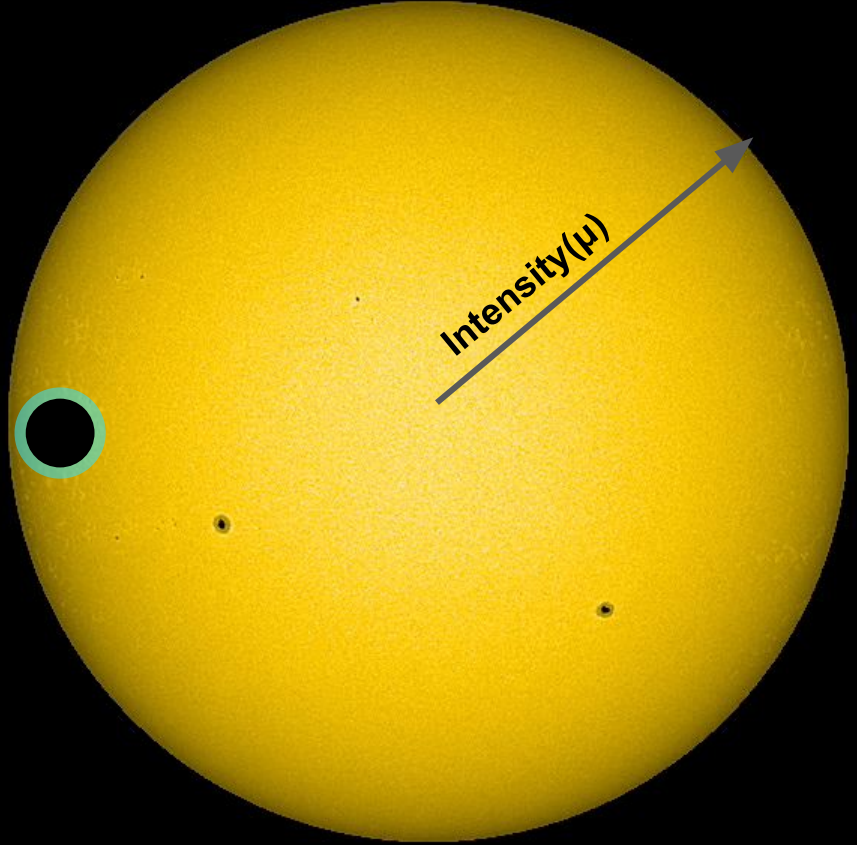
Limb Darkening in Transit Spectroscopy



Redder wavelengths = **less** contrast between center and limb = **sharper** corners

Bluer wavelengths = **more** contrast between center and limb = **rounder** transits

Knutson et al. 2007



Project Goal:

Investigate how limb darkening parametrizations affect derived transmission spectrum

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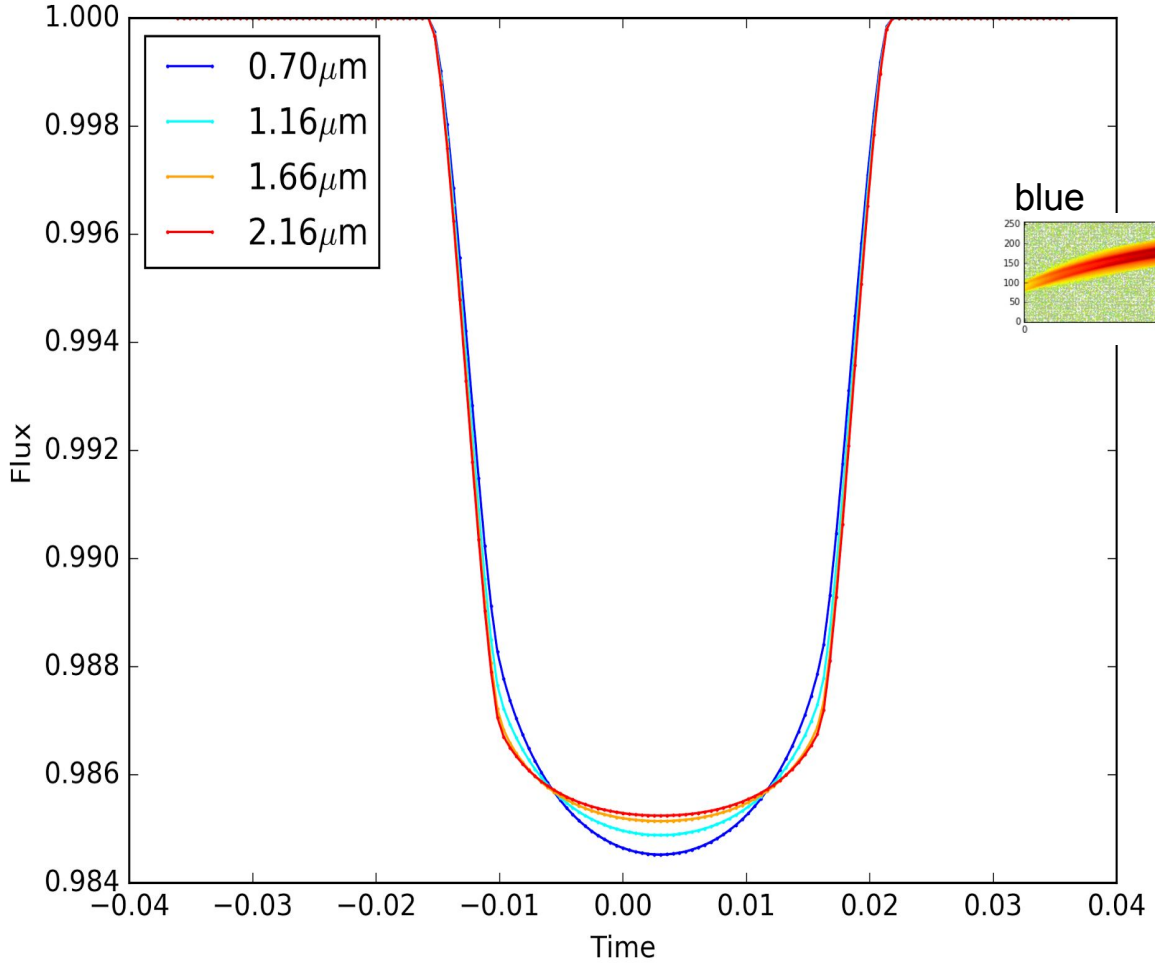
Hypothesis:

We expect that common models -- *e.g.*, linear or 3-parameter (“nonlinear”) should produce spectra in 1-sigma agreement on most points

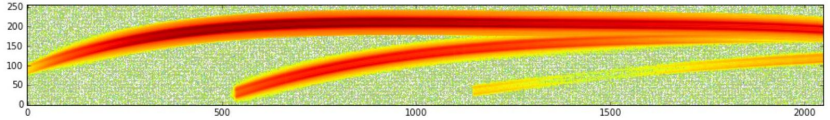
Method: Compute $R_p/R_s(\lambda)$ for different choices of model, given:

Testing the Simulated Dataset



Full dataset:

blue red



- Transit depth as a function of wavelength (16 bins); no model.
- We can see the **reddest** wavelength mimics the box-like observations of the ***Knutson et al. 2007*** data set, while the **bluer** wavelengths produce the observed parabolic shape.

Limb Darkening Models

$$I(\mu) = I_0 (\text{uniform}) \tag{7}$$

$$I(\mu) = I_0 [1 - c_1 (1 - \mu)] (\text{linear}) \tag{8}$$

$$I(\mu) = I_0 [1 - c_1 (1 - \mu) - c_2 (1 - \mu)^2] (\text{quadratic}) \tag{9}$$

$$I(\mu) = I_0 [1 - c_1 (1 - \mu) - c_2 (1 - \sqrt{\mu})] (\text{square-root}) \tag{10}$$

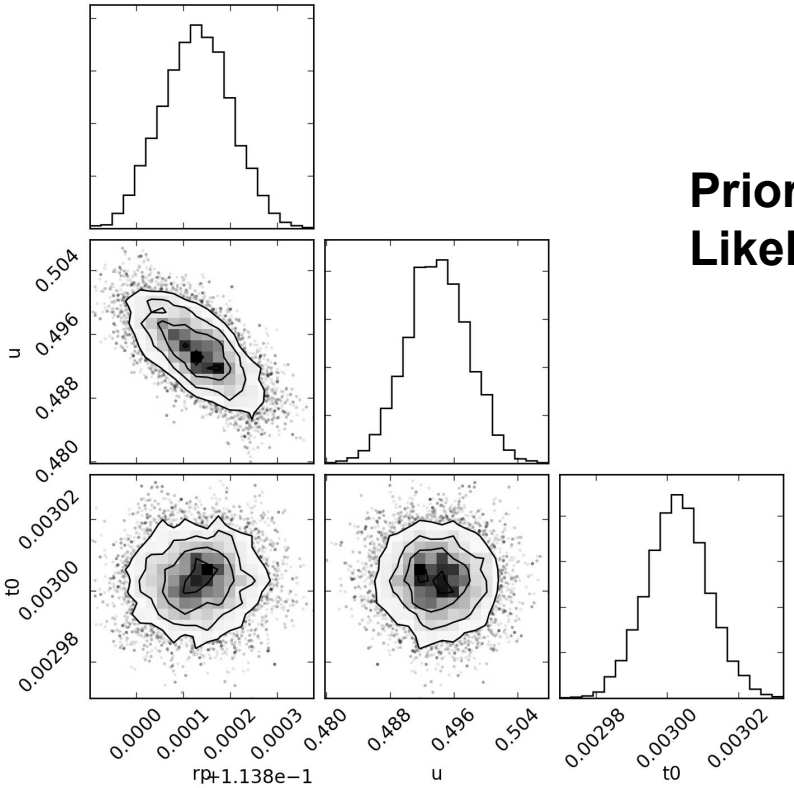
$$I(\mu) = I_0 [1 - c_1 (1 - \mu) - c_2 \mu \ln \mu] (\text{logarithmic}) \tag{11}$$

$$I(\mu) = I_0 [1 - c_1 (1 - \mu) - c_2 / (1 - \exp \mu)] (\text{exponential}) \tag{12}$$

$$I(\mu) = I_0 [1 - c_1 (1 - \mu^{1/2}) - c_2 (1 - \mu) - c_3 (1 - \mu^{3/2}) - c_4 (1 - \mu^2)] (\text{nonlinear}) \tag{13}$$

Kreidberg 2015

Method: We fit our binned light curves for limb darkening coefficients, mid-transit time, and planet radius. Posteriors shown for ~100nm bin centered on λ=700nm.

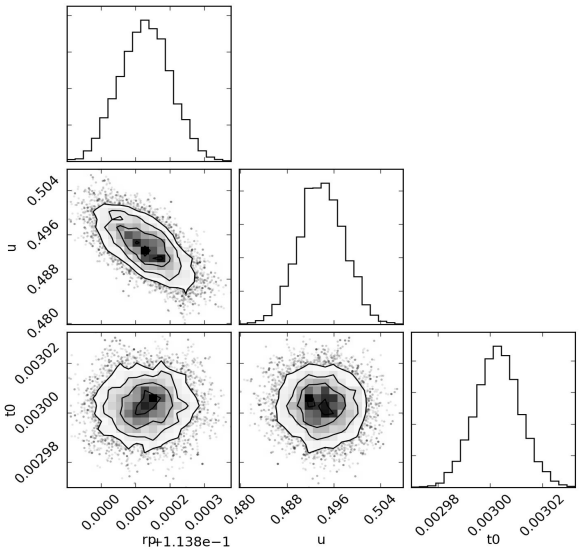


Priors: uniform
Likelihood: Gaussian

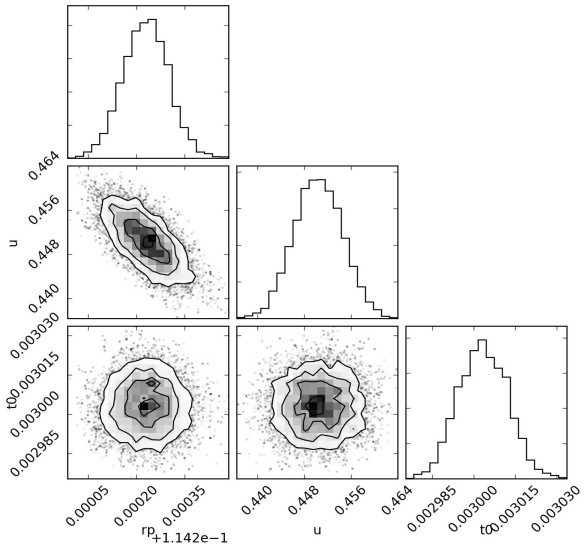
emcee (MCMC)
corner (plots)
(Foreman-Mackey, 2013 & 2014)

Posterior pdfs for (u, t_0, R_p/R_s) over more 16 wavelength bins.

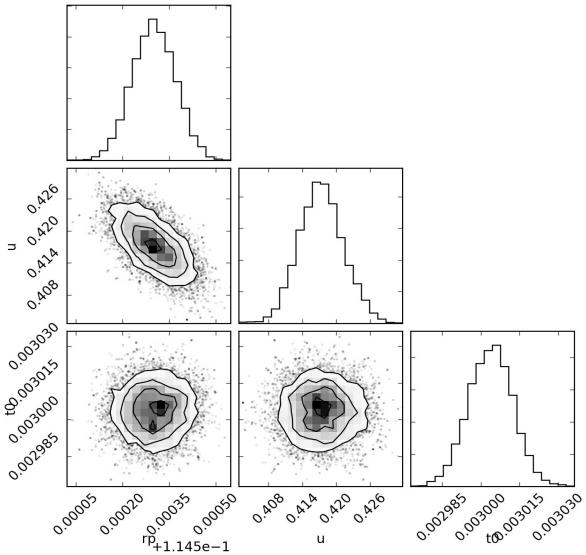
700μm [bin width ~100nm]



810μm

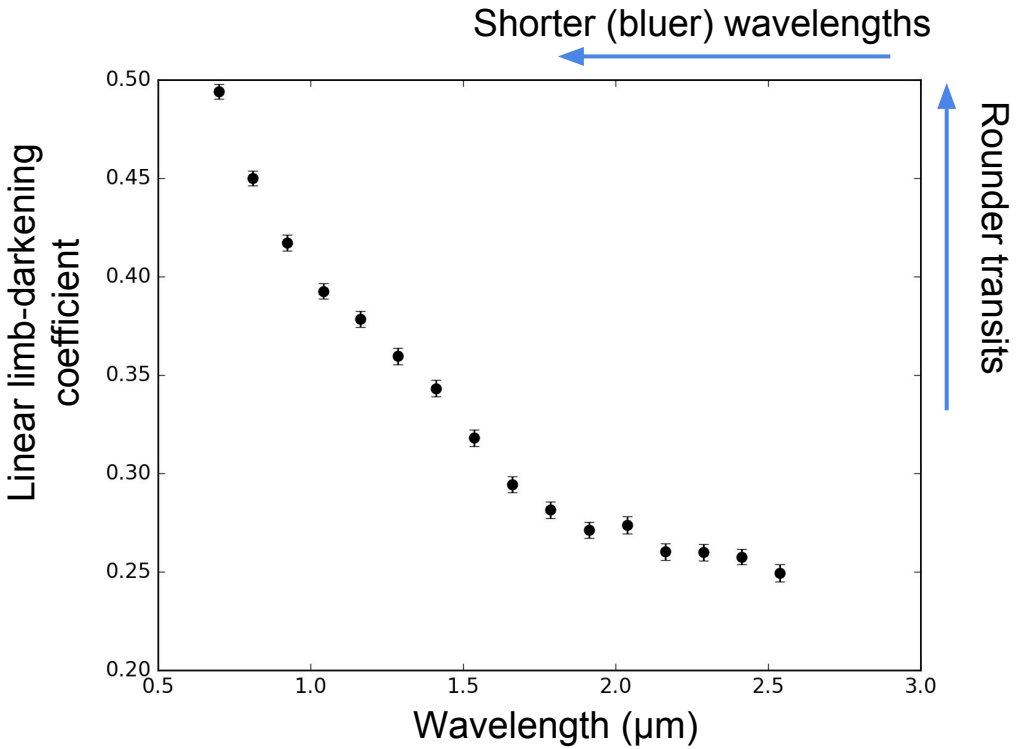


920μm



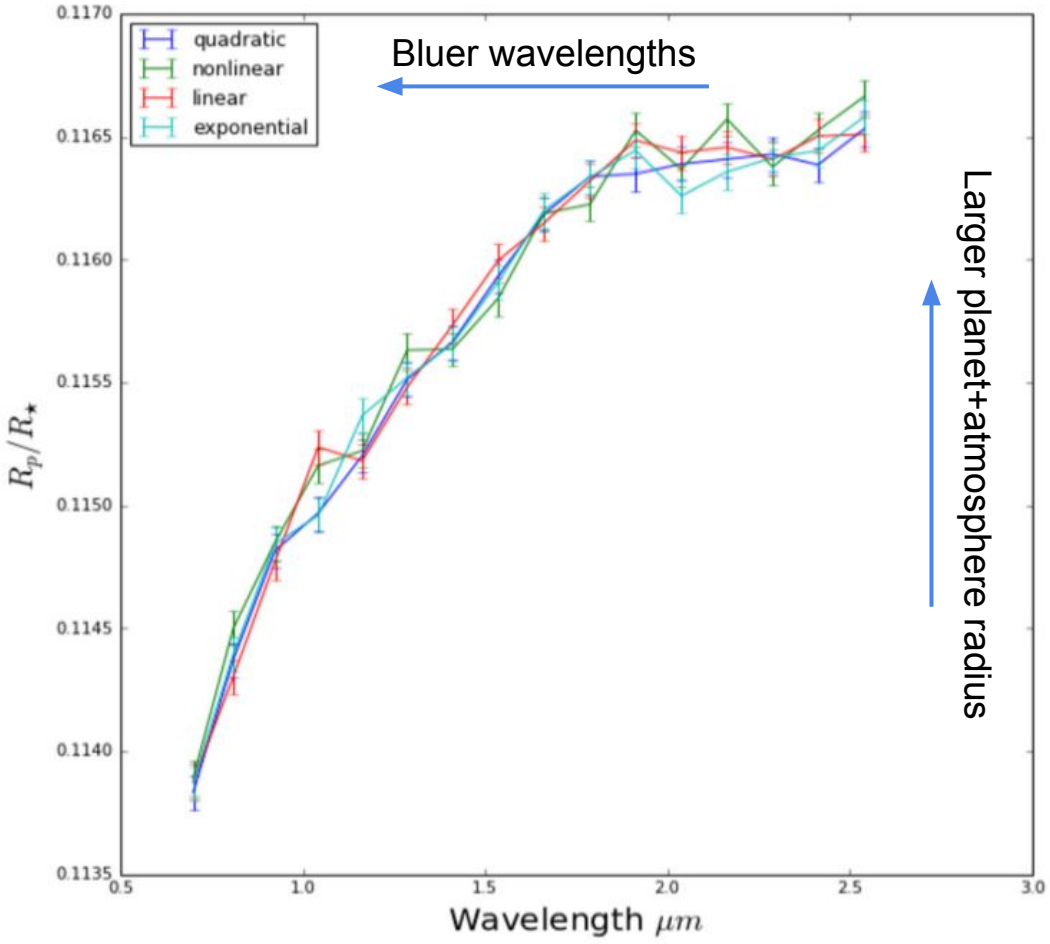
Wavelength

Linear limb darkening coefficients are larger at shorter wavelengths.



- Larger limb-to-center intensity ratio at bluer wavelengths

We repeat this process for quadratic, nonlinear, and exponential limb darkening



All R_p/R^* values are roughly 1-sigma consistent.

Take-away: For OOM constraints on atmospheric & planet parameters, any limb-darkening is fine, and linear is cheapest. For precision (which matters!), we should be more careful.

Warning!

Results from Markov Chain Monte Carlo analyses are only correct if the chains have converged. We had limited time to run our chains so these results are preliminary.

Future Work

- How would stellar activity (starspots, flares, prominences) bias our limb-darkening parameters and transit depths?

PS: don’t forget to sample efficiently!

Efficient, uninformative sampling of limb darkening coefficients for two-parameter laws

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References

Richmond, Michael. Limb Darkening of the Sun. Digital image.

Pogosian, Dmitri. Limb Darkening Cartoon. Digital image.

H. Knutson, et al., Ap. J., 655:564-575, 2007.

Sing, David K. “Limb Darkening.” *Limb Darkening.* Web. 20 July 2016