Steps towards the interpretation of exoplanet phase curves

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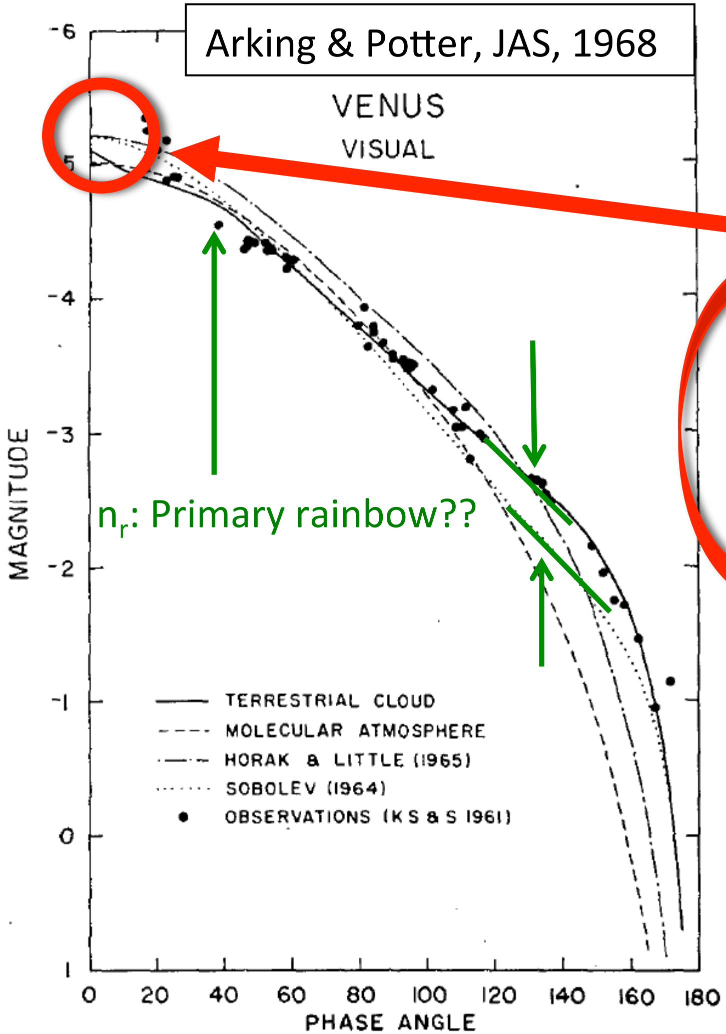
Phase curves
A classical problem in planetary science



What is the information content of the curve?:

1) max brightness ($\alpha \approx 0$), A_g
2) shape: Model-observation comparisons

Model-theory comparisons.

Rule out a few configurations (e.g. gas atmosphere)

Venus phase curves

Arking & Potter, JAS, 1968

ABSTRACT

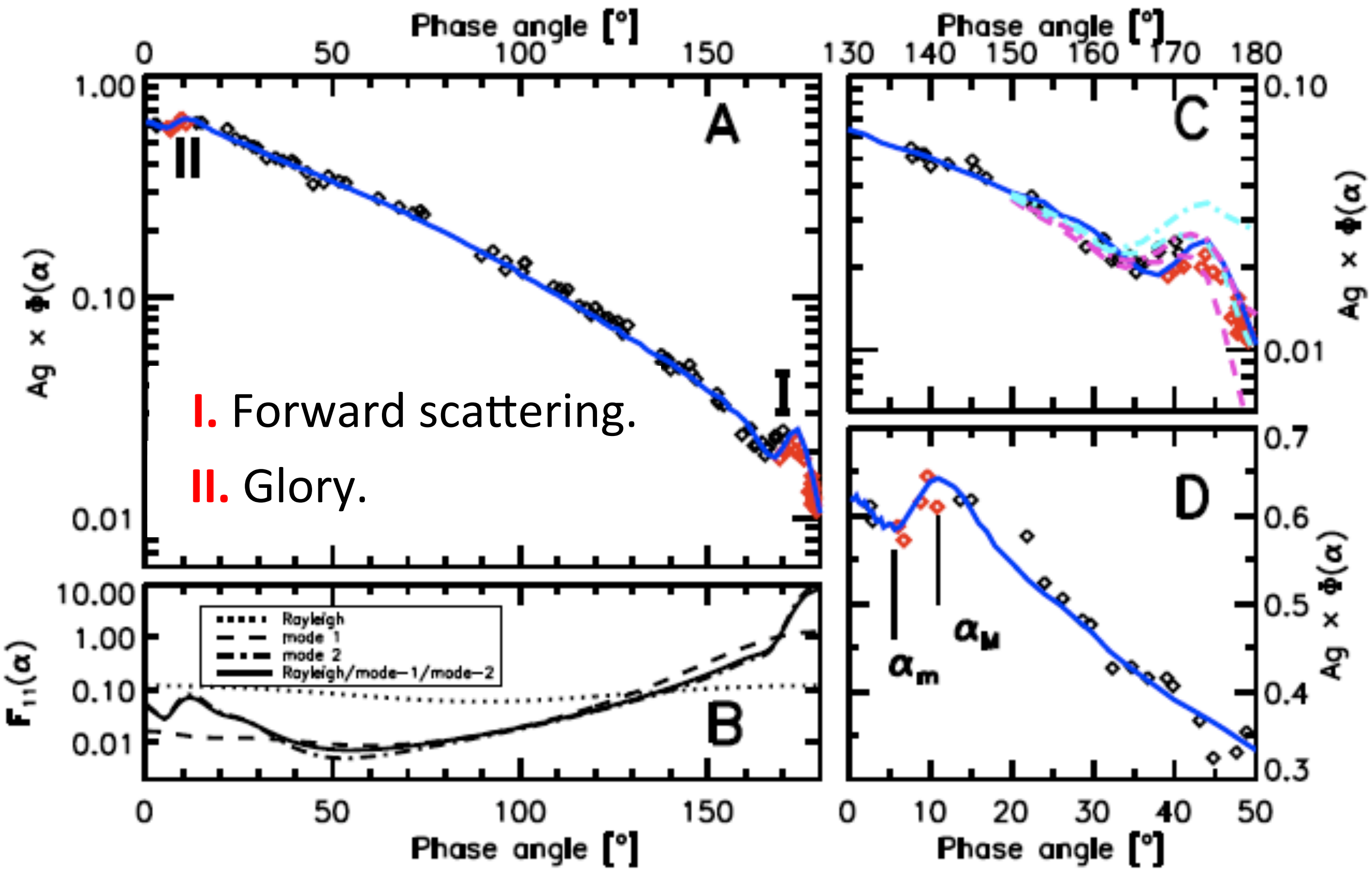
Theoretical models of the Venus cloud layer are compared with observations in the U, B and V spectral regions. It is found that the models are sensitive to the detailed scattering properties of the particles. A model of a terrestrial type cloud containing spherical water droplets or ice particles with radii distributed around 4 μ provides good agreement with the observed phase curve of Venus, superior to that obtained in previously published calculations. There is a small disagreement with the observations at low phase angles, suggesting the particles may have a slightly higher index of refraction than for water. However, observations are sparse and uncertain at these angles and improved data are needed to resolve this point. The comparison with observations leads to the following conclusions: the particles in the cloud layer must be of micron-size or larger, and are highly transparent; highly reflective but opaque particles are excluded; and scattering properties of the cloud particles on Venus resemble those of water droplets, ice particles, or particles of transparent minerals such as quartz.

$r_{eff} \sim 1.05$ µm; $\varpi_0 \sim 1$ ☑

$H_2SO_4 \bullet H2O(l)$ ☒ n_r (Venus; ~1.45) > n_r (H_2O; ~1.33)

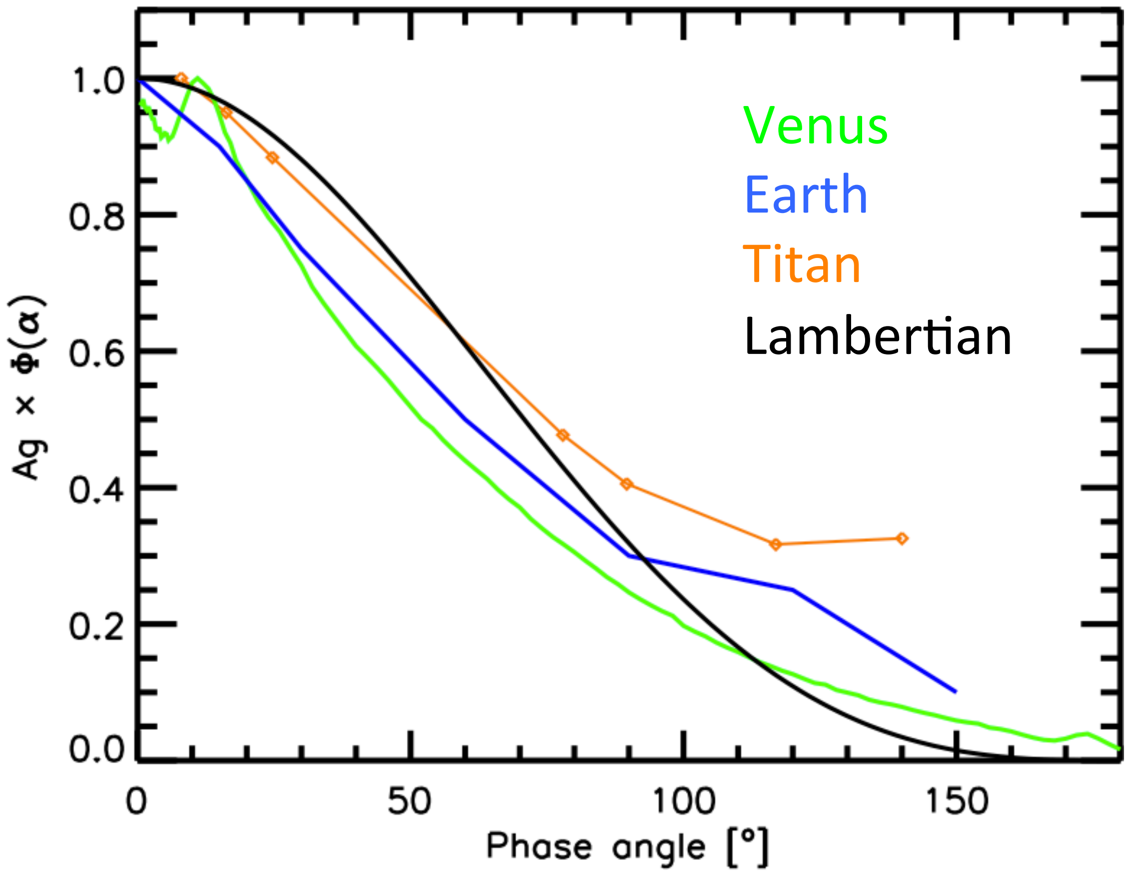
These are key constraints on cloud microphysics and composition!!

Venus phase curves



García Muñoz, Pérez-Hoyos & Sánchez-Lavega, AAL, 2014

Venus… Earth, Titan, …

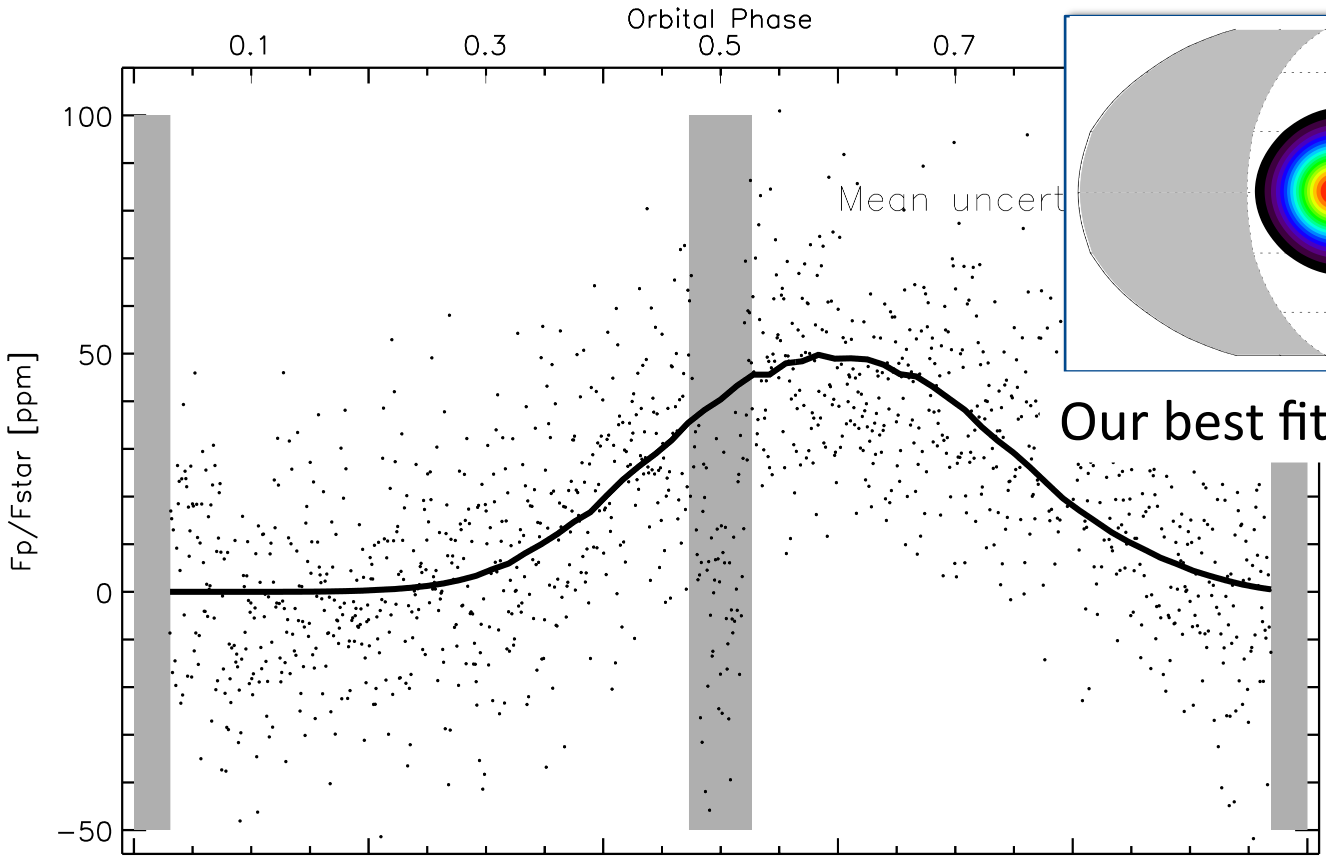


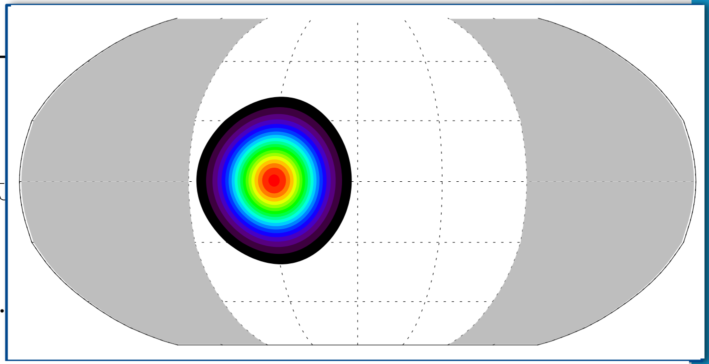
Both A_g & $\Phi(\alpha)$ contain unique unique info on the planet atmosphere

Kepler-7b

A phase curve dominated by reflected starlight

Observations from Demory et al., ApJL, 2013

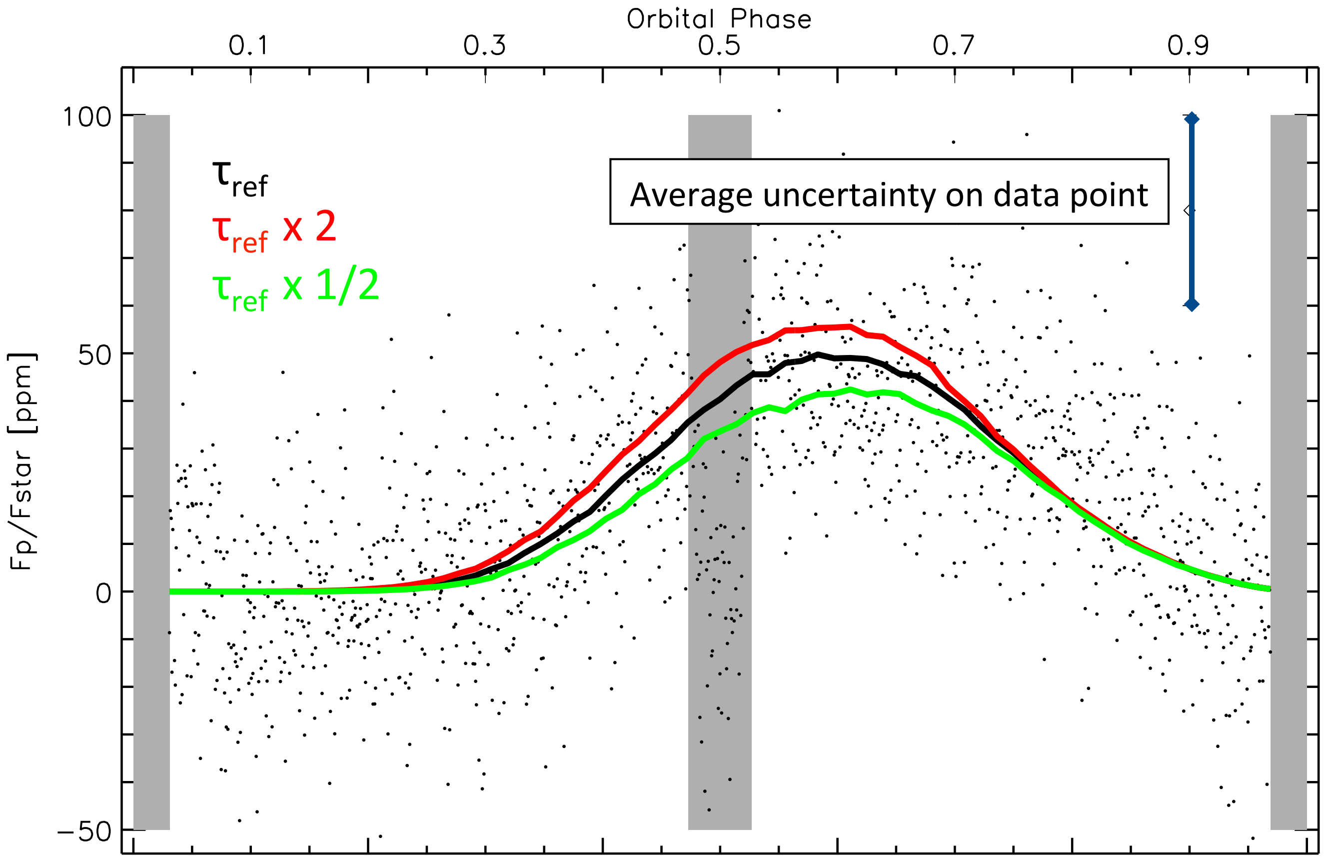




Our best fitting phase curve

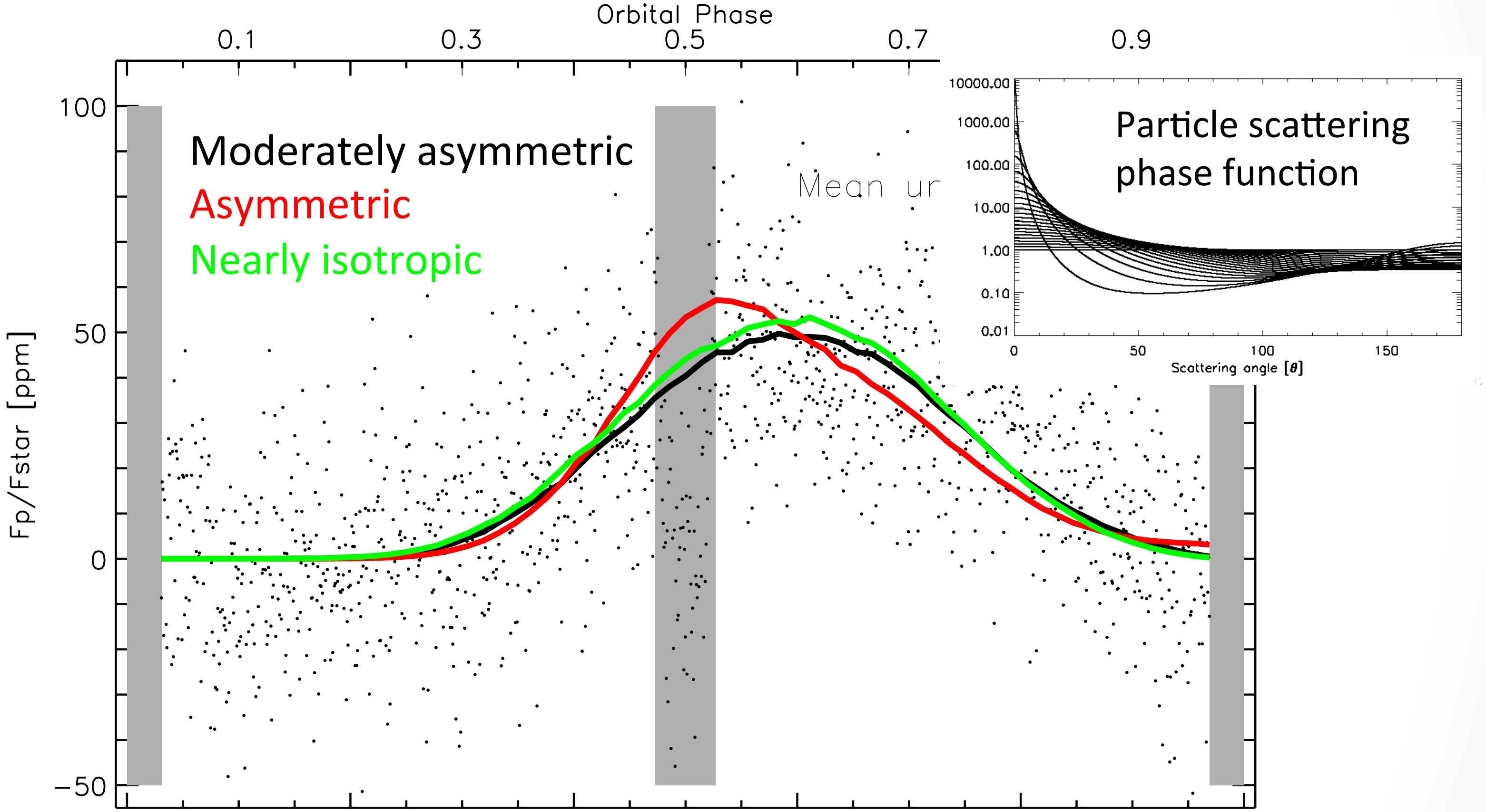
Adapted from García Muñoz & Isaak, *submitted*

Kepler-7b
Perturbation in cloud optical thickness



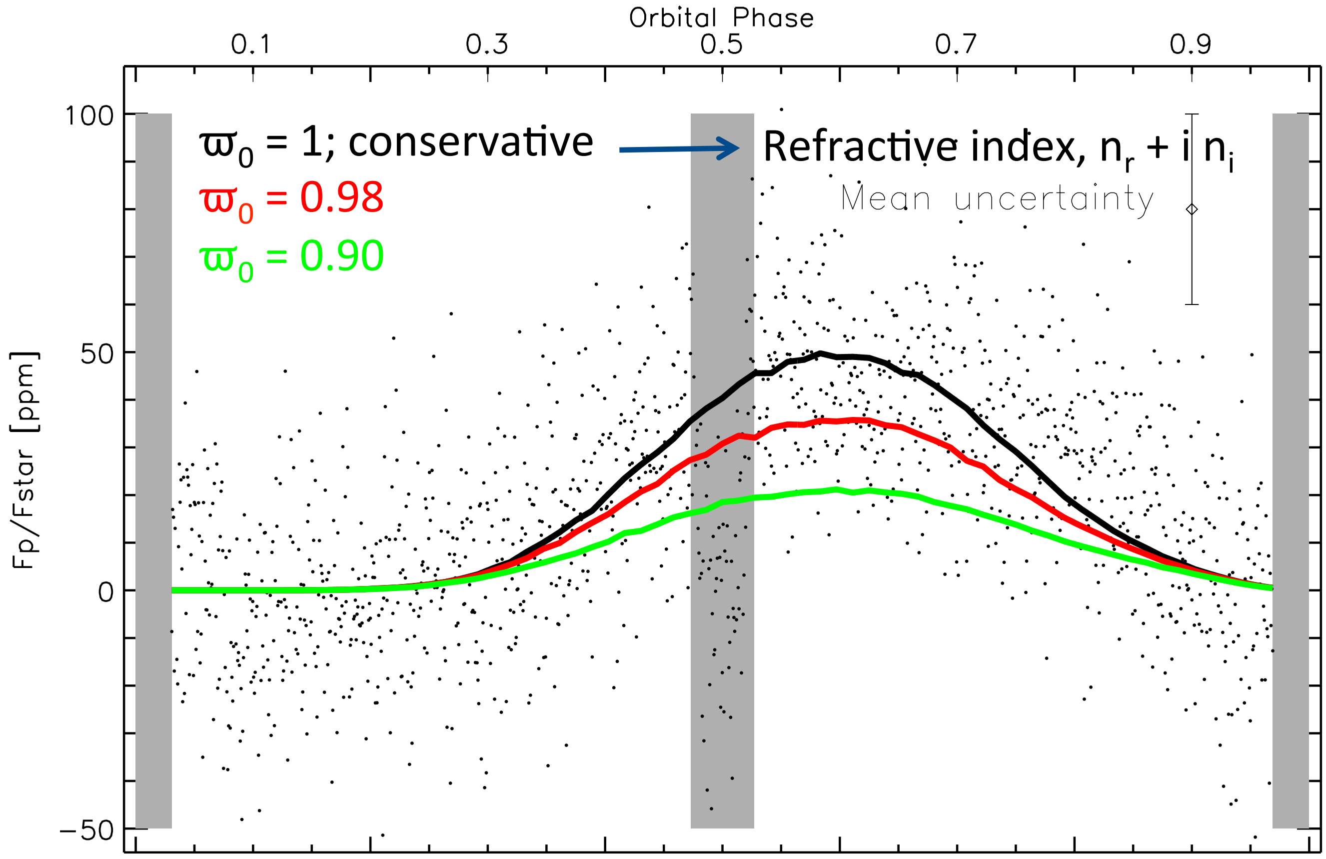
Kepler-7b

Perturbation in particle effective size



Kepler-7b

Perturbation in single scattering albedo



Some final thoughts

Optical phase curves can constrain atmospheric properties:
Both GOOD optical + NIR data are needed.

Separating the planet & star signals of integrated photometry:

$$\frac{f_{\rm tot}}{f_\star} = 1 + \frac{f_{\rm th,day} + f_{\rm th,night} + f_{\rm ref} + f_{\rm ell} + f_{\rm dop}}{f_\star}$$

f_{ref}: often rely on 'template' (*Lambertian*) phase curve shape.
Implications for e.g. planetary mass (Mislis et al., A&A, 2012)