Investigating close-in exoplanet atmospheres with optical phase curves

Antonio García Muñoz (¶) & Kate Isaak

Scientific Support Office, SRE,

ESA/ESTEC, Noordwijk, Netherlands

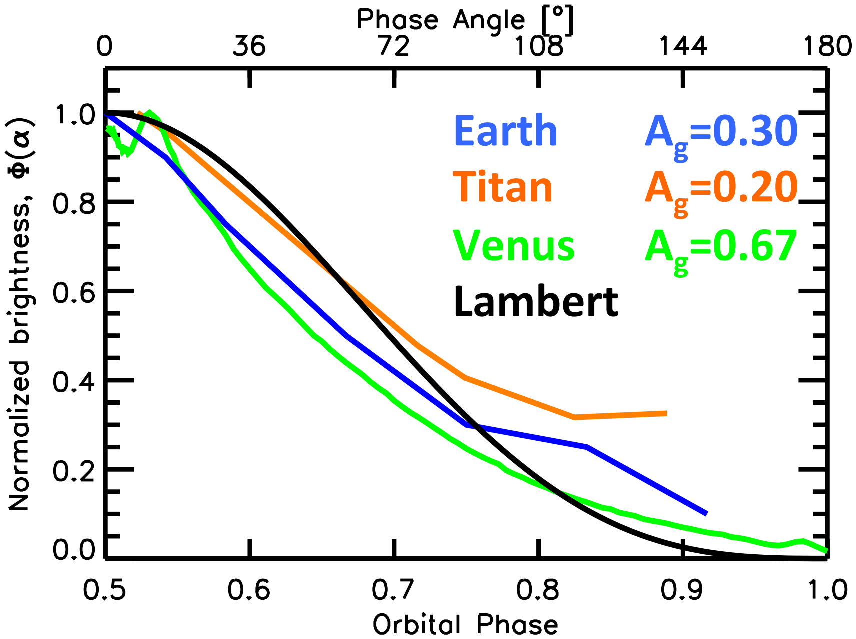
¶: ESA Research Fellow

From super-Earths to Brown Dwarfs: Who's Who? – 3rd July 2015, IAP, Paris

Optical phase curves. Solar System

Planet have phases: In the optical we see reflected starlight

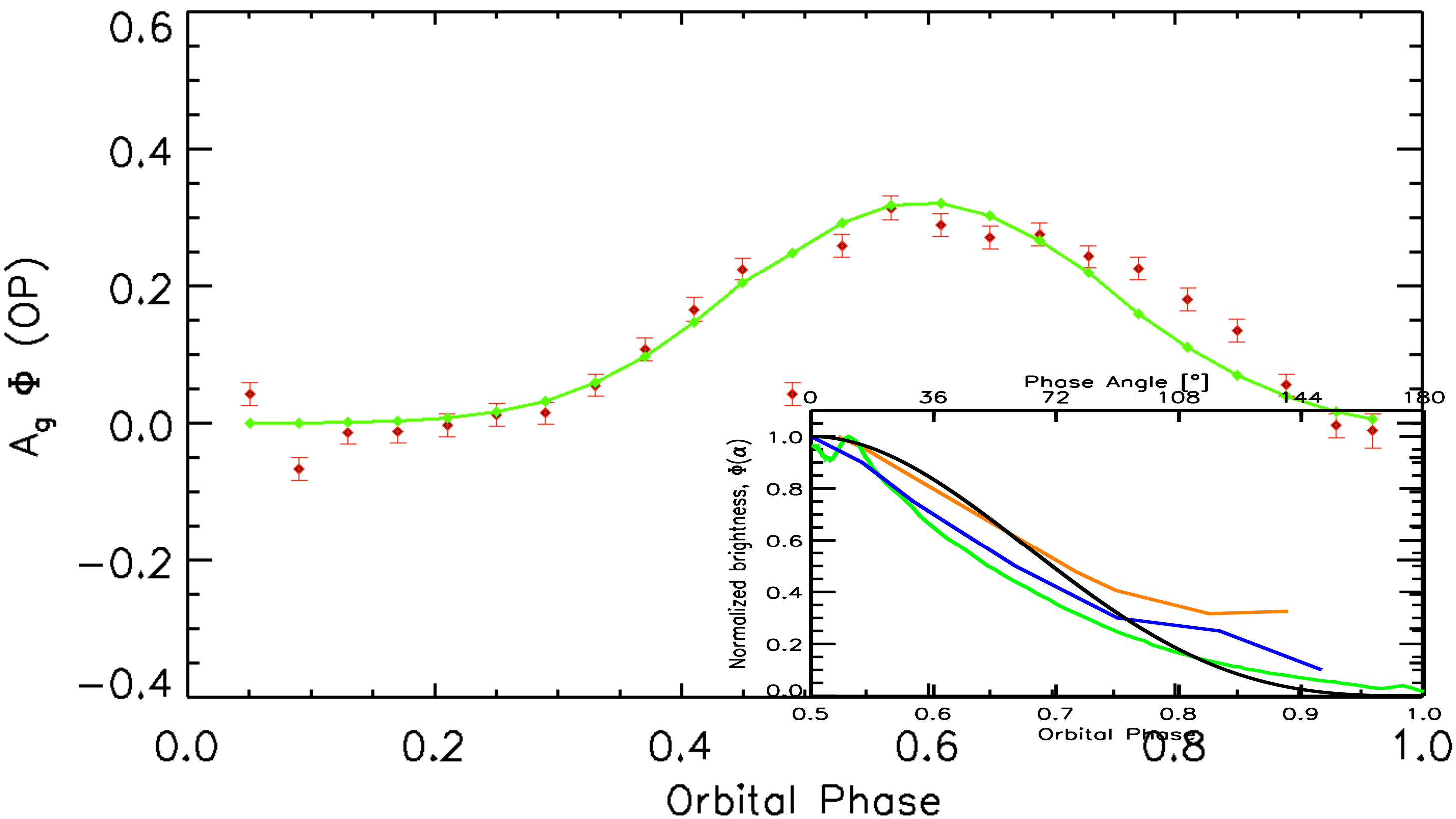
Reflected starlight contains unique information on planet envelopes



Can we do it with exoplanets?

Optical phase curves. Exoplanets

Past/Preset: MOST, CoRoT, Kepler
Future: CHEOPS, TESS, PLATO, JWST, WFIRST
Refs.: Angerhausen+ '14, Demory+ '13, Esteves+ '15, Hu+ '15, Webber+ '15



A theory that helps extract atmospheric information

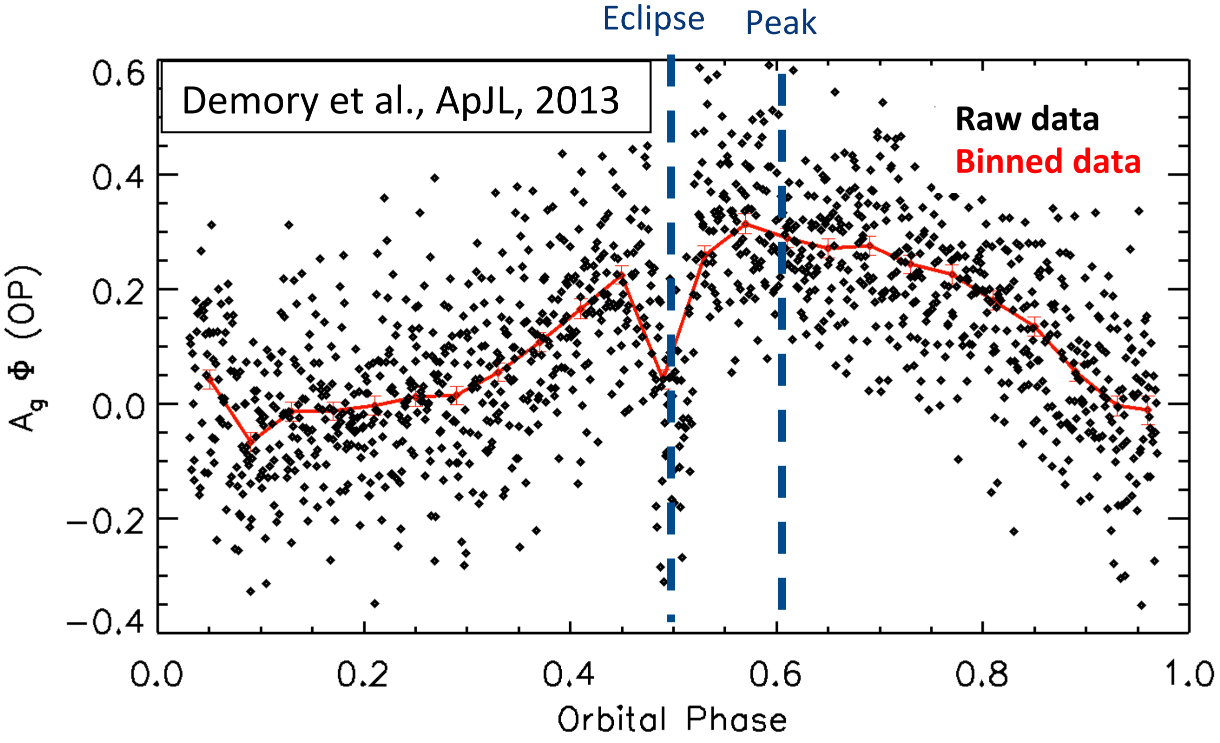
Objectives of ongoing work

Demonstrate that:

Atmospheric info can be extracted from exoplanet phase curves

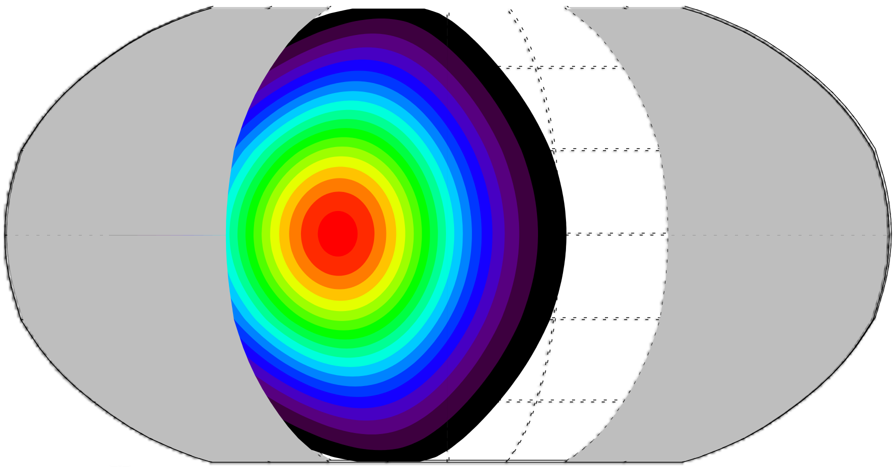
(García Muñoz & Isaak, submitted)

Kepler-7b. Unique: Both visible & IR data; Puffy ($g/g_J \sim 1/6$).



Methodology. Atmospheric model

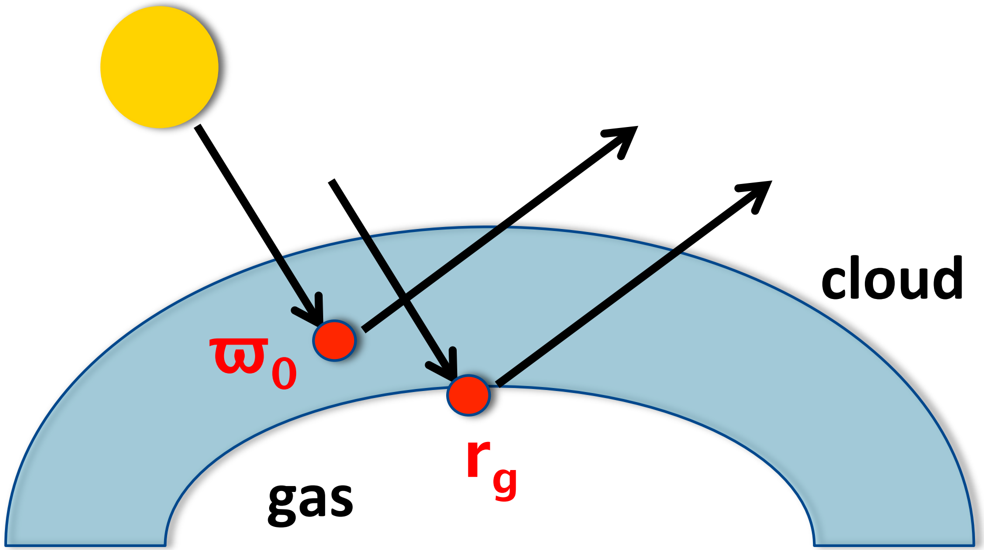
6 parameters: trade-off, realistic but simple → Multiple scattering



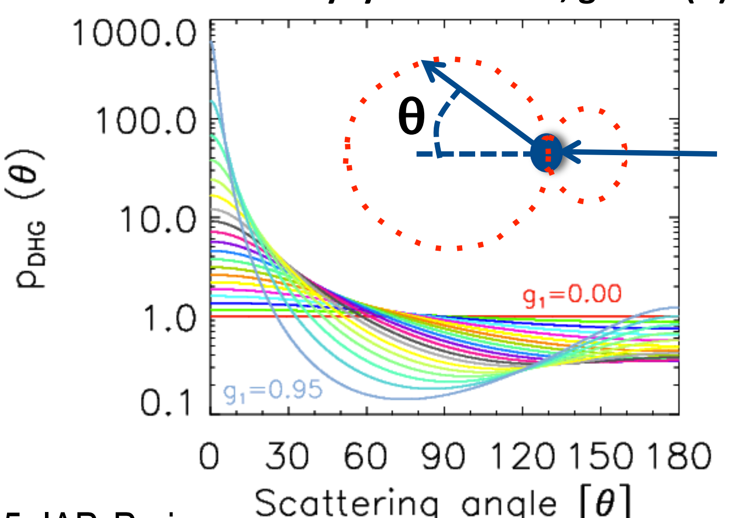
$\tau = \tau(\tau_c, \sigma_c, \Delta\phi_c)$

τ_c : central optical thickness
σ_c : offset
$\Delta\phi_c$: width

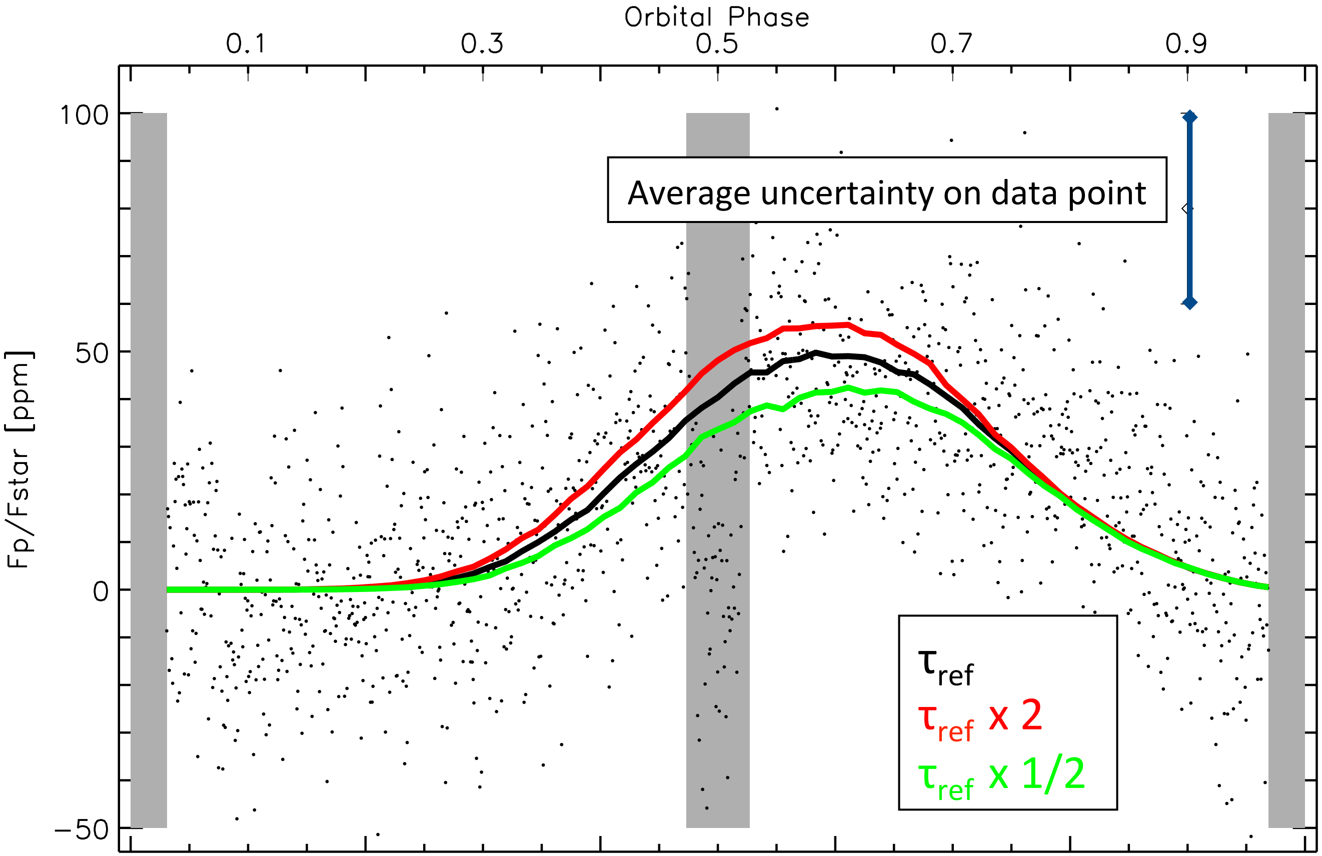
ϖ_0 : single scattering albedo
r_g : 'surface' albedo
g : asymmetry parameter



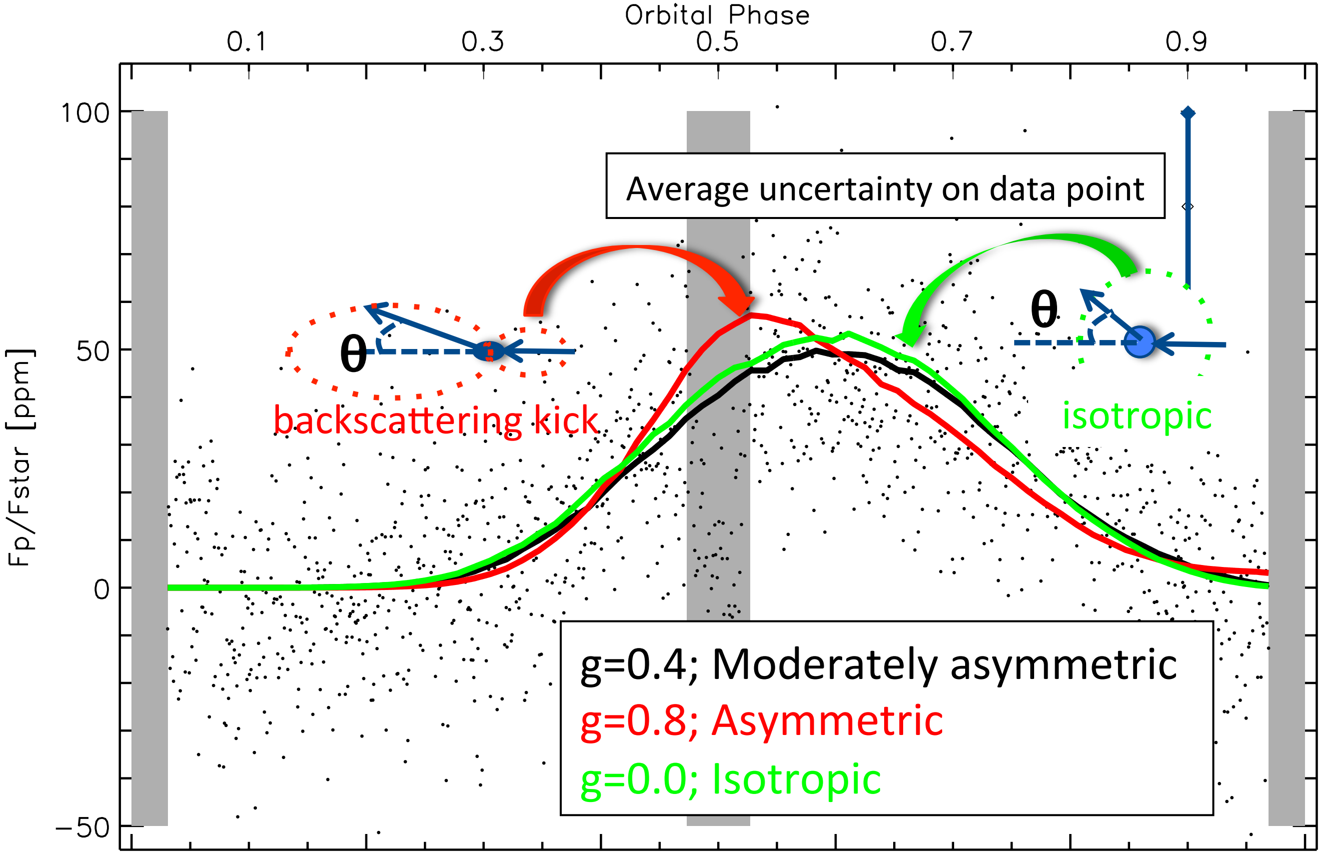
Particle scattering:
Double Henyey-Greenstein; g=<cos(α)>



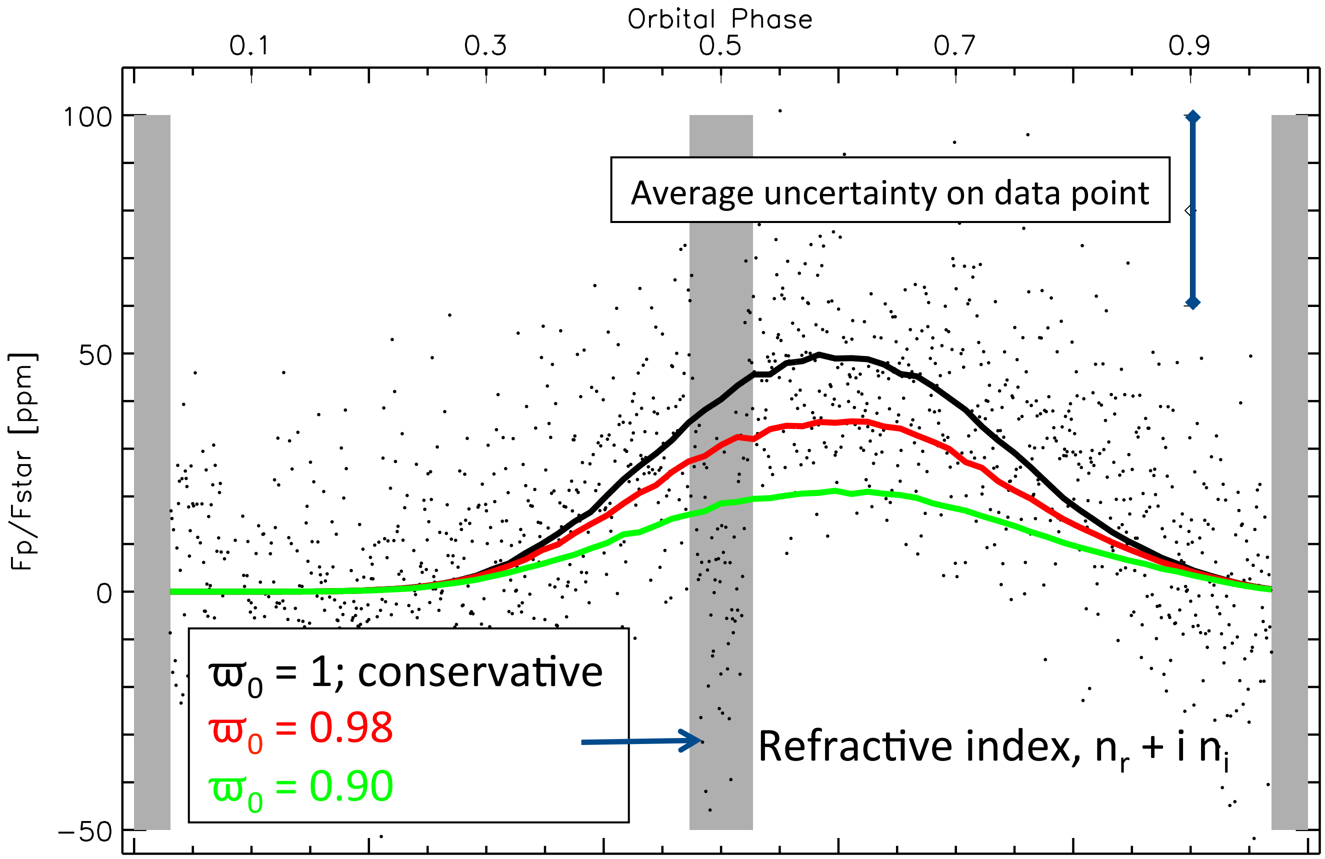
Methodology. Sensitivity to central cloud optical thickness, τ_c



Methodology. Sensitivity to assymmetry parameter, g



Methodology. Sensitivity to ϖ_0



Methodology

Model-Observations comparison

- Multiple scattering problem for non-uniform atmosphere.
- 6 parameters → 3,000,000 phase curves.

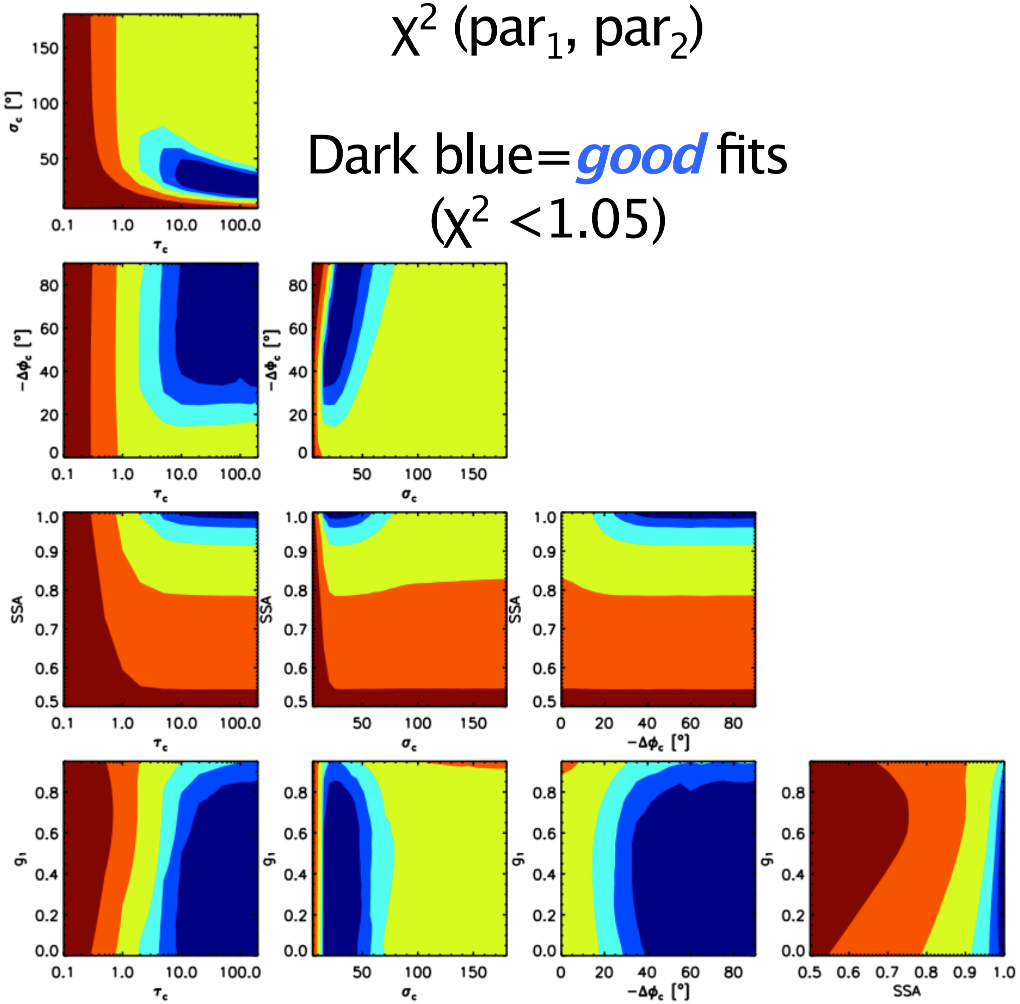
- $\chi^2 = \Sigma_i [(O_i - M_i)/\sigma_i]^2 = f(\tau_c, \sigma_c, \Delta\phi_c, \varpi_0, g, r_g)$
  i=1, …, 1320 observation datapoints

- Search the 6-parameter grid ➔ pick smallest χ^2 value(s).

A degenerate problem:

multiple $\{\tau_c, \sigma_c, \Delta\phi_c, \varpi_0, g, r_g\}$ combinations lead to comparably good χ^2's

Degeneracies



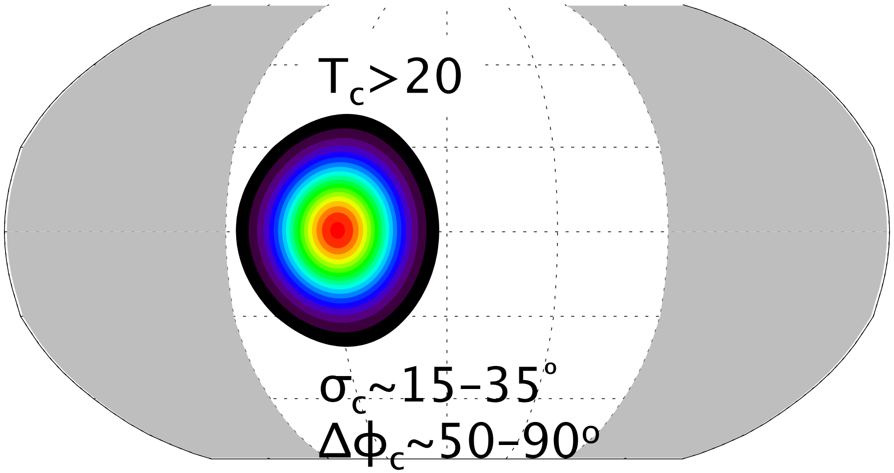
χ^2 (par$_1$, par$_2$)

Dark blue=***good*** fits
(χ^2 <1.05)

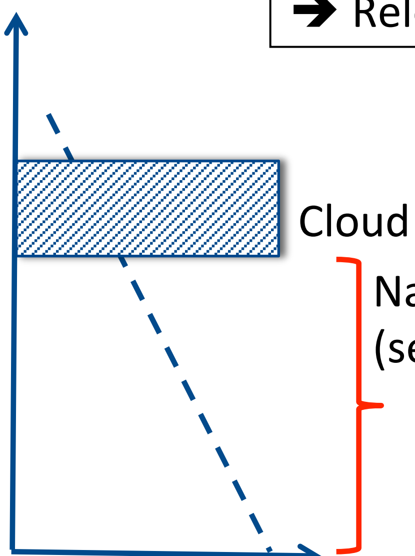
<u>Bracketing χ^2 <1.02 regions:</u>

τ_c ~ 20 – 200
σ_c [°] ~ 15 – 35
$\Delta\phi_c$ [°] ~ 50 – 90

Kepler-7b. Overall picture. Implications



→ Relevant to interpretation with GCMs



Na → Na^+ @ p~10^{-4} bar
(see Lavvas et al. 2014)

<u>For r_{eff}~0.1:</u>

Enough Mg, Si to condense into $MgSiO_3$

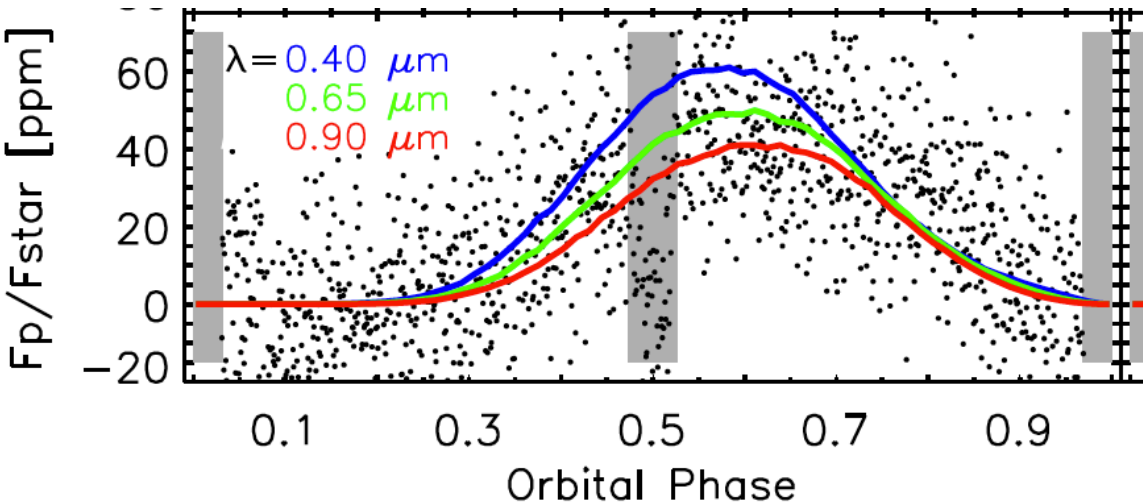
Eddy diffusion coeff.: $K_{zz} \sim v_{sett}/H$

→ Relevant to photochemistry & microphysics

Two predictions. Summary

Transmission spectroscopy:
Flat-ish spectrum with Rayleigh slope

Multi-color photometry:



Summary

Optical phase curves contain valuable atmospheric information;
Complementary to other techniques

We need ***GOOD*** visible + NIR data…