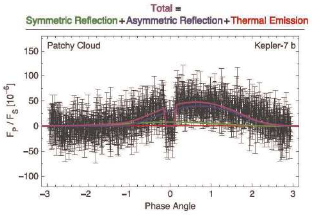
How Do We Interpret Phase Curves? New Approach



Hu et al. (2015, ApJ, 802, 51)

thermal emission

- Temperature map
- Background temperature (efficiency & Bond albedo)
- Phase shift

reflected light

- Single-scattering albedo
- Scattering asymmetry factor
- Geometric albedo
- Spherical albedo
- Phase integral

Code originally written by Brett Morris (https://github.com/bmorris3/kelp)

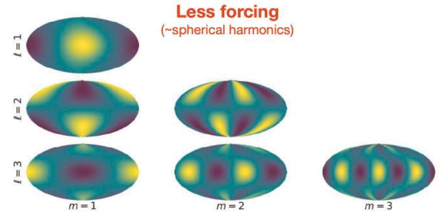
Fitting thermal emission component

Rotating, heated sphere with friction/drag
(Heng & Workman 2014, ApJS, 213, 27)

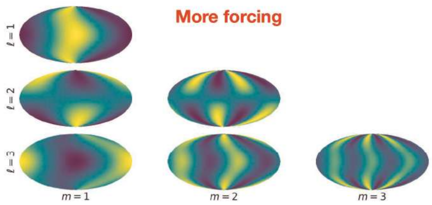
Advantages:

1. Parameters are physical
2. Much better than fitting ad hoc sines and cosines
3. Less parameters needed

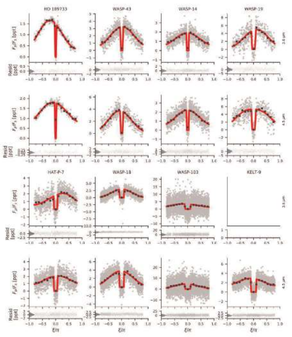
Less forcing (~spherical harmonics)



More forcing

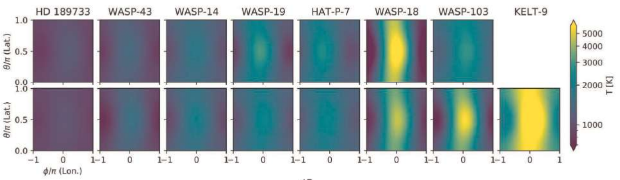


Morris, Heng et al. (2022, A&A, 660, A123)



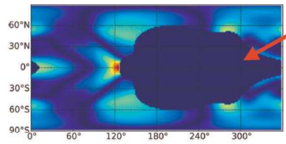
Fitting thermal emission component

We can fit all of the Spitzer phase curves in existence + GCM-generated maps with just 3 parameters



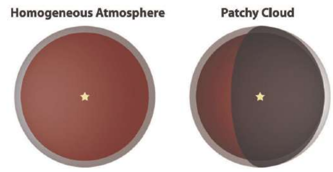
Morris, Heng et al. (2022, A&A, 660, A123)

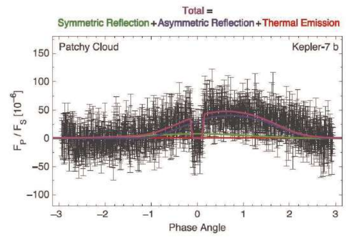
Reflected light phase curves: westward peak offsets are direct evidence for inhomogeneous cloud/haze cover



Hotter regions are darker in reflected light, because aerosols/clouds cannot condense out!

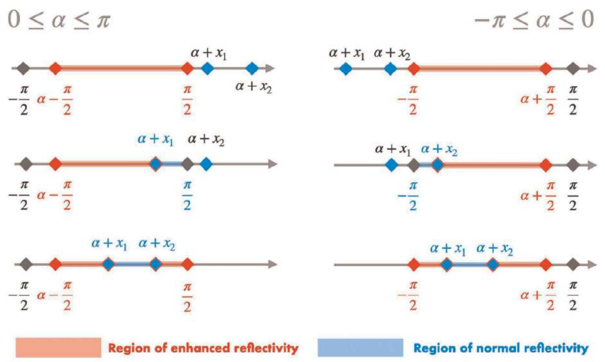
Oreshenko, Heng & Demory (2016, MNRAS, 457, 3420)





Hu et al. (2015, ApJ, 802, 51)

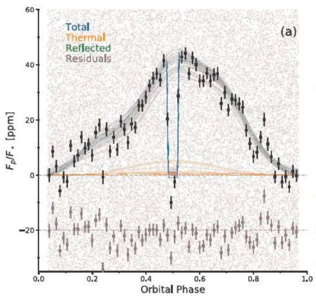
Results can be generalised for inhomogeneous spheres/atmospheres!

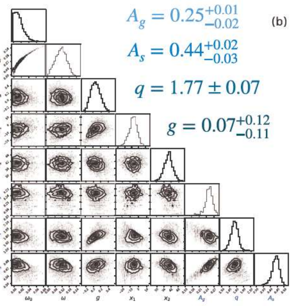


Extended Data Fig. 4 | Regions of normal and enhanced reflectivity for an inhomogeneous atmosphere. Regions of normal and enhanced reflectivity for an inhomogeneous atmosphere in terms of the longitude Φ within the observer-centric coordinate system. In the local longitude of the exoplanet (where the substellar point sits at $x = 0$), the atmosphere has a baseline single-scattering albedo of ω_0 across $x_1 \le x \le x_2$. When this region is within view of the observer, it is highlighted with a thick blue line. Regions of enhanced reflectivity (with a total single-scattering albedo of $\omega = \omega_0 + \omega'$) that are within the observer's view are highlighted with thick red lines.

Heng, Morris & Kitzmann (2021, Nature Astronomy, 5, 1001)

Re-interpretation of Kepler-7b phase curve [Kepler data]



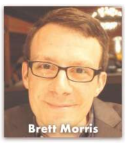


$A_g = 0.25^{+0.01}_{-0.02}$

$A_s = 0.44^{+0.02}_{-0.03}$

$q = 1.77 \pm 0.07$

$g = 0.07^{+0.12}_{-0.11}$



Spherical albedo and **phase integral** may be retrieved directly from reflected light phase curve of transiting exoplanet (for the first time)!

Aerosols are small and have a condensation temperature ~1600 K.

Heng, Morris & Kitzmann (2021, Nature Astronomy, 5, 1001)