Detecting and characterizing non-transiting exoplanets with optical phase curves

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Introduction

Optical phase curves can be used to characterize planetary atmospheres. Important properties such as the Bond albedo [(a)] or the possible presence of clouds [(b)] have been inferred for a number of planets already, based on high-precision photometry. Here we investigate the potential of planned space missions such as PlaTO 2.0 [(c)] to detect and characterize non-transiting planets with optical phase curves.

Conclusions and future work

- Optical phase curves (Sun-like star, photon noise only) allow to **detect most short-period giant planets**
- Using several bands enables **characterization (albedo, mass, radius) of short-period giant planets**

- Future work: realistic noise and stellar variability assumptions (variable stars, non-white noise)
- Future work: realistic atmospheric properties instead of single albedo value (scattering, absorption, etc)

Phase curve model

- **Assumptions:** uniform planet, stationary atmosphere
- **Wavelength range:** 2 bands (500-1000nm, 500-700nm)
- **Physics:** Lambertian scattering, thermal emission, ellipsoidal variations [(d)]
- **Planetary parameters:** mass, radius, Bond albedo, heat redistribution
- **Orbital parameters:** period, inclination, eccentricity, argument of periastron

Using 2 bands allows to break the degeneracy between albedo and radius.

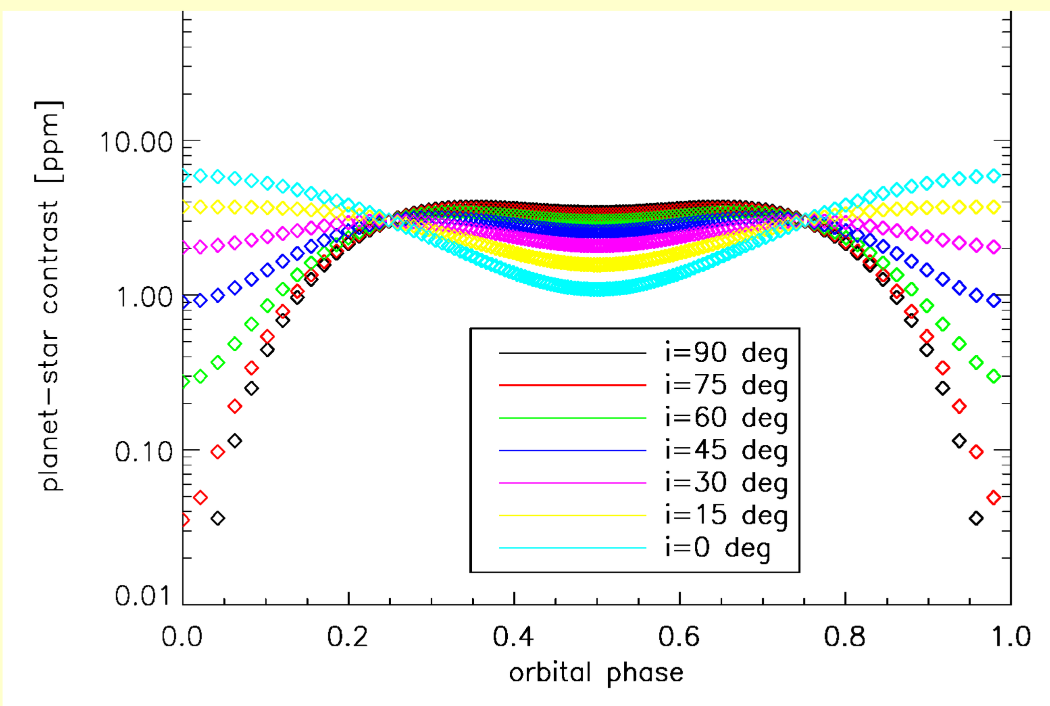


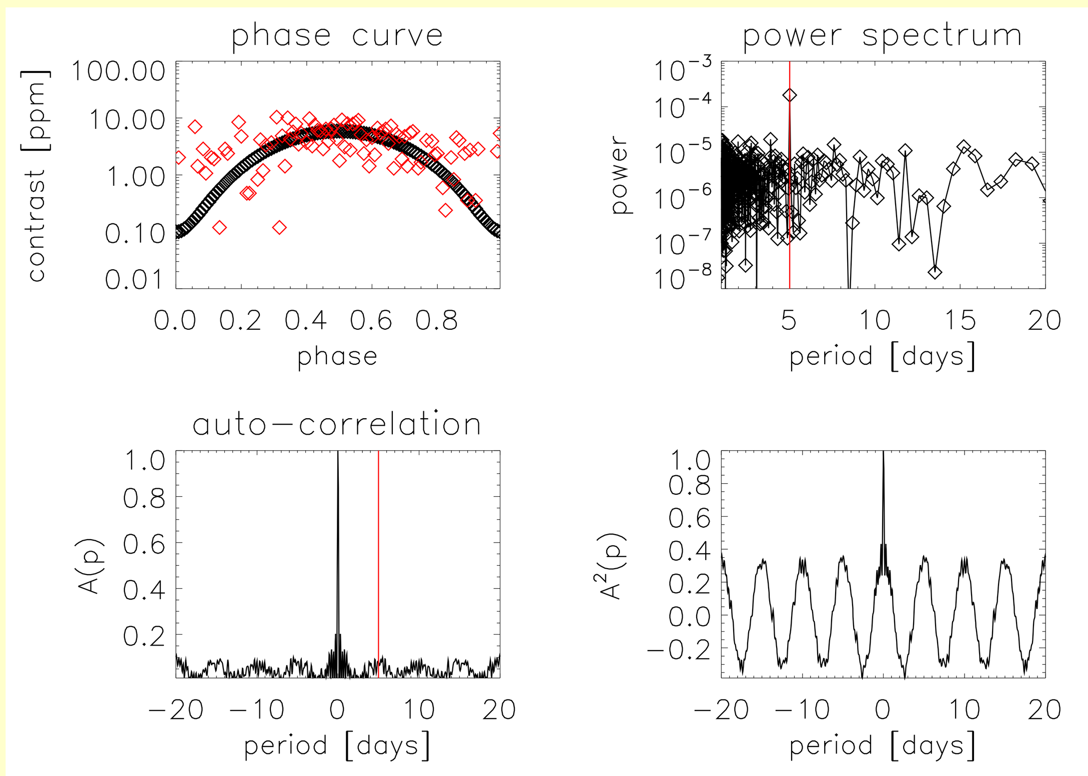
Fig. 1: Phase curve for different values of inclination. Orbital period, albedo and planetary radius fixed at 5 days, 0.15 and 1 R_{Jup}, respectively. Eccentricity and argument of periastron are 0.4 and 0°, respectively. Transits and occultations excluded (at i=90°).

Retrieval method for short-period planets

- **1st step:** Determine orbital period via periodogram/auto-correlation function
- **2nd step:** use gradient-based algorithm to fit 5 parameters (M_p, R_p, A_{Bond}, ε, i), assuming a circular orbit

Results

Fig. 2: noise 20 ppm, 1 year observation, 1hr cadence, no stellar variability. Main parameters: $1R_{Jup}$, A_{surf}=0.15, i=30°



- **(1) Determining orbital period:** signal can be recovered in the periodogram

This condition is met when the peak-amplitude of the phase curve is about ¼ of the noise. From there, we determine the minimum inclination of a non-transiting planet to be detectable (Fig. 3) as a function of noise level and orbital period.

This indicates that most of the short-period Jupiters and a few hot Super-Earths will be detectable via phase curves.

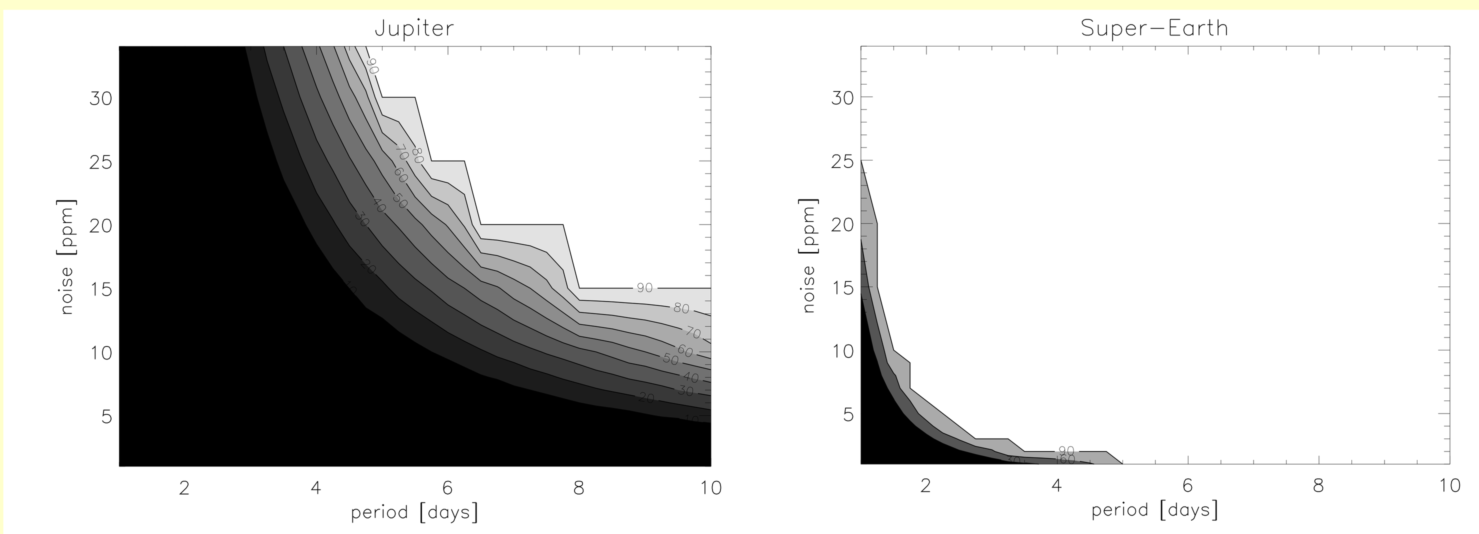


Fig. 3: Minimum inclination for detecting a non-transiting planet with phase curves. Left: $R=R_{Jup}$, right: $R=2R_{earth}$

Stellar variabilty could reduce the potential detectability to shorter periods or larger planets.

Phase folding significantly reduces the resulting noise in the phase curve to a few ppm or below

- **(2) Idealized fitting:** no noise, random initial conditions

Inclination: very well-constrained, better than 10%
Albedo: broadly constrained, mostly within 30%
Radius: well-constrained, usually within about 20%

Compared to single-band phase curves, precision of retrieval improves by about a factor of 2 in radius and mass and a factor of 3 for the inclination.

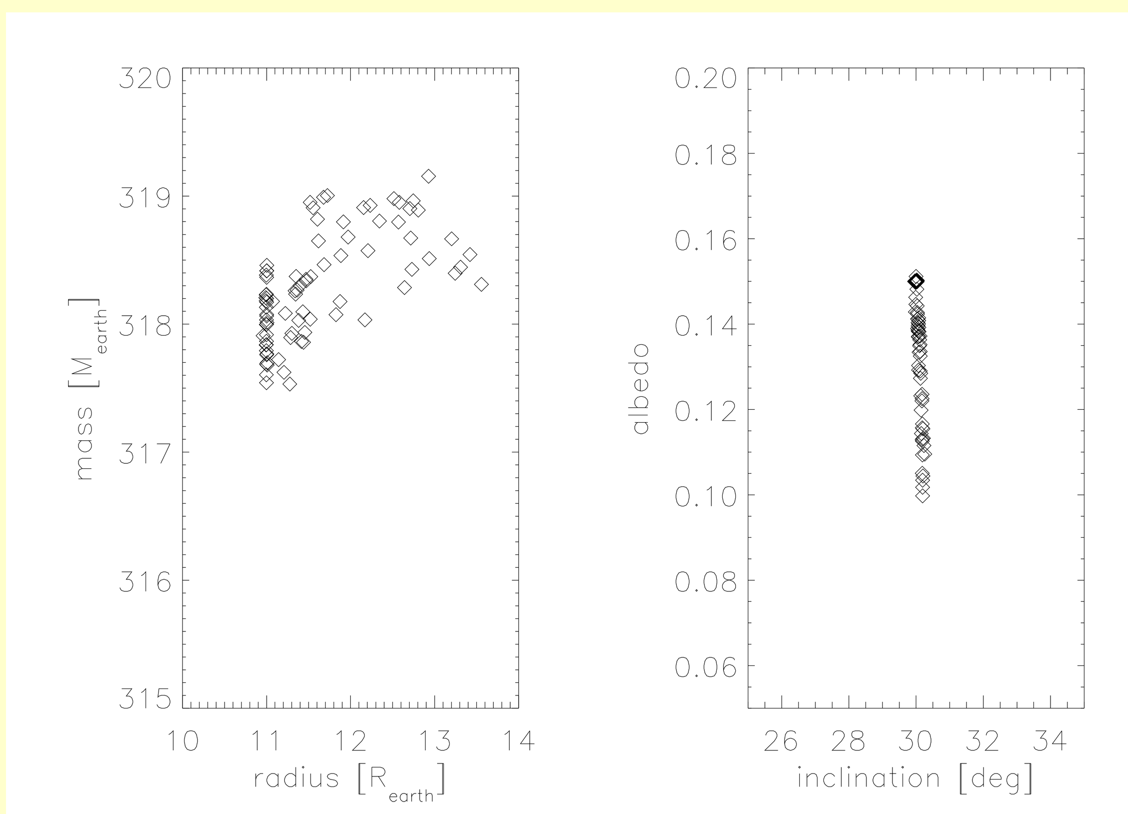


Fig. 4: Fit results for 100 random initializations

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References:
(a) Esteves et al. (2013), Astrophys. J., vol. 729 (b) Demory et al. (2013), Astrophys. J. Letters, vol. 776 (c) Rauer et al. (2014), submitted to Exp. Astron. (d) Quintana et al. (2013), Astrophys. J., vol. 767