Photometric Phase Variations of Long-Period Eccentric Planets

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The Evolving Study of Exoplanets

- The field of exoplanetary science is rapidly moving from simply detecting exoplanets to characterizing them
- The changing phases of an exoplanet provide an opportunity to further characterize radial velocity planets
- Current studies of exoplanetary atmospheres have been mostly confined to short period planets
- **Long period planets with eccentric orbits provide an opportunity for targeted searches for phase variations**

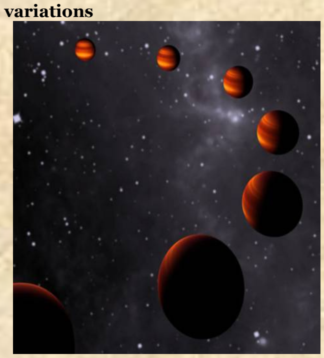

Figure 1: Artist's rendition of an exoplanet moving through some of its phases as it orbits its parent star.

Resonant Systems

- We currently know of several systems that contain planets in resonant eccentric orbits
- The periodic simultaneous periastron passage of two planets produces a distinct phase amplitude signature
- **Depending on the observations cadence and precision, the signature could be misinterpreted as from a single-planet**

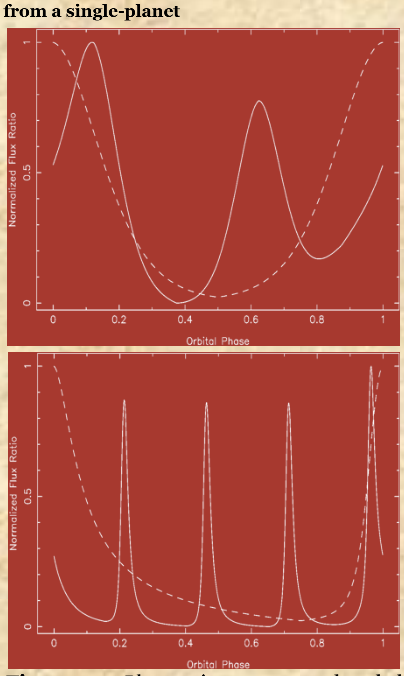

Figure 4: Phase signatures produced by planets in 2:1 (top), and 4:1 resonance (bottom) The solid line is the normalized flux ratio and the dashed line is the phase function of the outer planet. If one is unable to discern the amplitude difference between the peaks, the outer planet will remain hidden, and will be perceived as a single-planet system.

The Flux Ratio Components

- Atmospheric models show a dependence of giant planet geometric albedo, A_g, on semi-major axis.
- **In eccentric orbits, all flux ratio components are time dependent**
- The strong irradiation in short-period orbits, or periastron passage of eccentric orbits results in the removal of reflective condensates from the planet's upper atmosphere

Planet/Star Flux Ratio:

$$\varepsilon(\alpha,\lambda) \equiv \frac{f_p(\alpha,\lambda)}{f_*(\lambda)} = A_g(\lambda) g(\alpha,\lambda) \frac{R_p^2}{r^2}$$

Where for an eccentric orbit:

- ***r:*** Star-Planet Separation – time variable
- ***$A_g(\lambda)$:*** Geometric Albedo – time variable, based on *r*
- ***$g(\alpha,\lambda)$:*** Phase Function – time variable, based on Pioneer observations of Jupiter and Venus

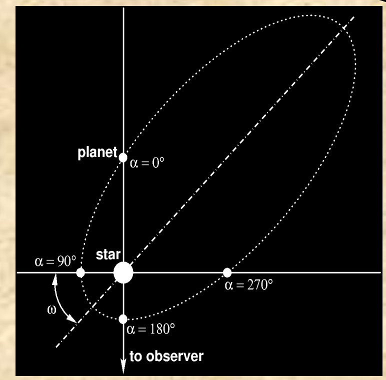

Figure 2: Top-down view of an elliptical planetary orbit. The phase angle is defined to be zero degrees when the planet is at superior conjunction (i.e. "full" phase).

Maximum Flux Ratio Depends on Inclination

- The orbital inclination is usually preferred to be edge-on for optimal detection of phase variations since this ensures that full phase will be observed
- However, depending on the eccentricity and periastron argument ω, the maximum flux ratio may occur when the orbit is face-on

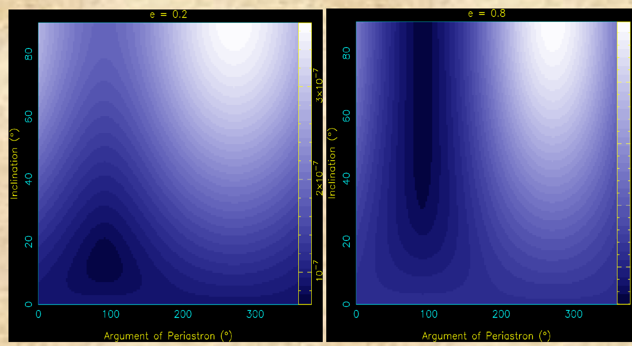

Figure 3: Peak flux ratio intensity maps, calculated over a grid of inclinations and periastron arguments for eccentricities of 0.2 (left) and 0.8 (right). In each case, the peak flux ratio occurs where the full phase of the planet coincides with the smallest star-planet separation. ***However,* when the periastron argument is close to 90 degrees, the phase function and star-planet separation components compete for dominance of the flux ratio.**

Application to Known Exoplanets

- We have applied our phase model to the most eccentric planets currently known
- Flux ratios of these planets tend to be dominated by the semi-major axis, except when the eccentricity is exceptionally high (see HD 80606b)
- **Orbital refinement is required in order to detect many of these long period planets**

ϵ_{max} AND Δt FOR ECCENTRIC EXOPLANETS.

Planet	P (d)	e	ω (°)	Δt	$\epsilon_{max}(10^{-5})$
HD 80606 b	111.43	0.93	300.60	0.005	3.8029
HD 20782 b	585.86	0.93	147.00	0.006	0.0946
HD 4113 b	526.62	0.90	317.70	0.008	0.1939
HD 156846 b	359.51	0.85	52.23	0.017	0.0249
HD 45350 b	963.60	0.78	343.40	0.030	0.0160
HD 30562 b	1157.00	0.76	81.00	0.050	0.0022
HD 20868 b	380.85	0.75	356.20	0.035	0.0388
HD 41004 A b	963.00	0.74	97.00	0.060	0.0030
HD 37605 b	54.23	0.74	211.60	0.038	0.5608
HD 222582 b	572.38	0.73	319.01	0.043	0.0263
HD 2039 b	1120.00	0.71	344.10	0.045	0.0091
iota Dra b	511.10	0.71	91.58	0.073	0.0036
HD 96167 b	498.90	0.71	285.00	0.055	0.0281
HD 86264 b	1475.00	0.70	306.00	0.055	0.0078
HAT-P-13 c	428.50	0.69	176.70	0.050	0.0167
HD 159868 b	986.00	0.69	97.00	0.081	0.0021

Table showing orbital period, *P*, eccentricity, *e*, argument of periastron, ω, the time between min and max flux ratio in units of orbital phase (Δ t), and maximum flux ratio (ε_{max})

Extension into the Infra-Red (IR)

- IR observations can give insight into the thermal properties of exoplanet atmospheres, and have mostly been pursued on short-period planets
- Eccentric planets will have detectable signatures that depend on its atmosphere's heat redistribution efficiency as it passes through periastron passage
- **Several of the known eccentric planets will be suitable targets for warm-Spitzer and JWST observations**

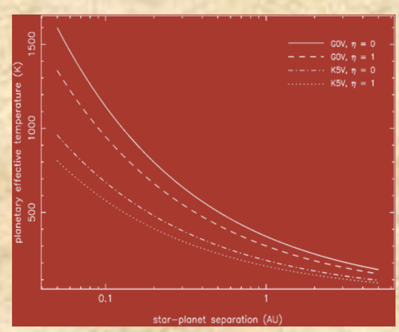

Figure 5: The predicted planetary effective temperature as a function of star-planet separation, *r*, for G0V and K5V stars with redistribution efficiencies of 0 (no redistribution) and 1 (complete redistribution).

References:

- Gelino, D.M., et al. 2006, ApJ, 642, 438
- Kane, S.R., et al. 2009, PASP, 121, 1386
- Kane, S.R., & Gelino, D.M. 2010, ApJ, 724, 818
- Kane, S.R., & Gelino, D.M. 2011, ApJ, 729, 74
- Kane, S.R., & Gelino, D.M. 2011, ApJ, submitted
- Sudarsky, D., et al 2005, ApJ, 627, 520