Kepler-76b: The first planet discovered through the beaming effect and optical detection of superrotation

Evidence of superrotation also for KOI-13, HAT-P-7 and TrES-2

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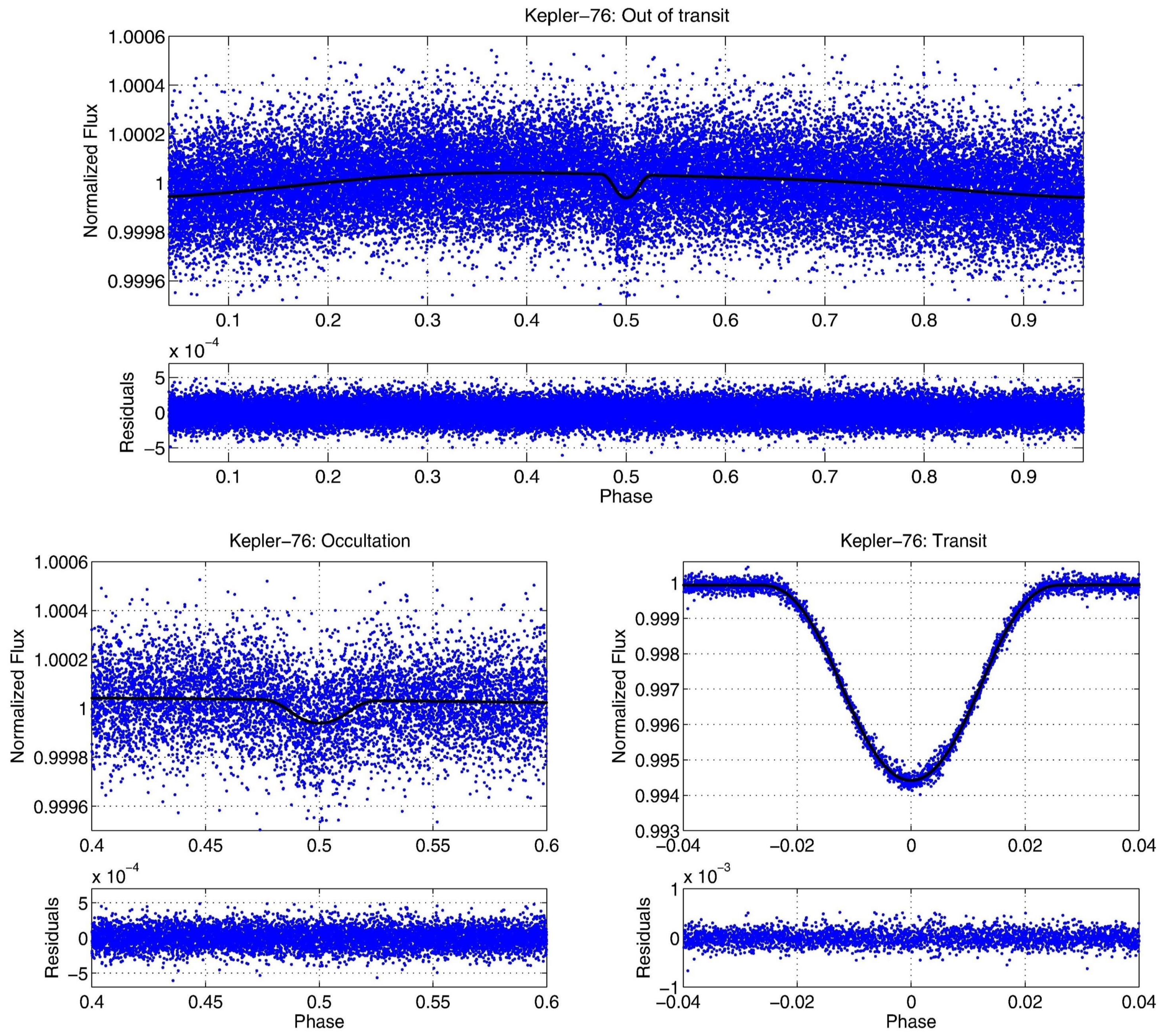
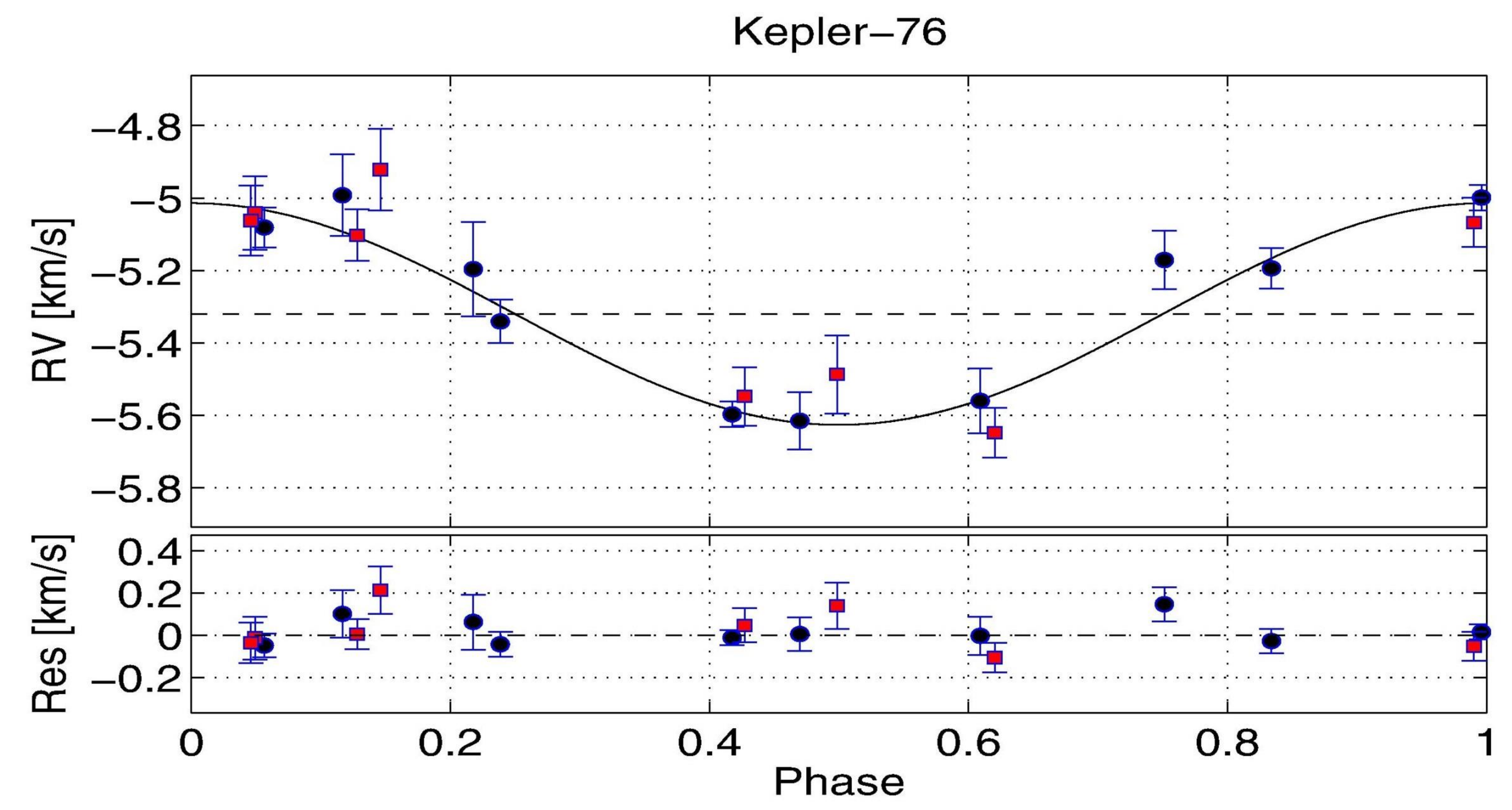
Kepler-76b was identified by the BEER algorithm, which detected the BEaming (sometimes called Doppler boosting) effect together with the Ellipsoidal and Reflection/emission modulations (BEER), at an orbital period of 1.54 days, suggesting a planetary companion orbiting the 13.3 mag F star. Further investigation revealed that this star appeared in the Kepler eclipsing binary catalog with estimated primary and secondary eclipse depths of 5×10^{-3} and 1×10^{-4}, respectively.

Spectroscopic radial velocity follow-up observations with the Tillinghast Reflector Echelle Spectrograph (TRES), at the Fred Lawrence Whipple Observatory, and SOPHIE, at Observatoire de Haute-Provence, confirmed Kepler-76b as a transiting 2.0 ± 0.26 M_{Jup} hot Jupiter.



Kepler-76 cleaned and detrended light curve data points folded at the orbital period. In the top panel of each plot, the solid line represents the best-fit model, and the dots represent the data points.
The residuals are plotted in the bottom panel.
Note the different scales of the upper and lower panels of each plot.



Kepler-76 spectroscopic radial velocity measurements folded at the orbital period. In the top panel, the solid line represents the photometry-constrained orbital RV model and the horizontal-dashed line indicates the center-of-mass velocity.
Circles denote SOPHIE RV points and squares denote TRES RV points.
The residuals are plotted at the bottom panel.
Note the different scales of the upper and lower panels.

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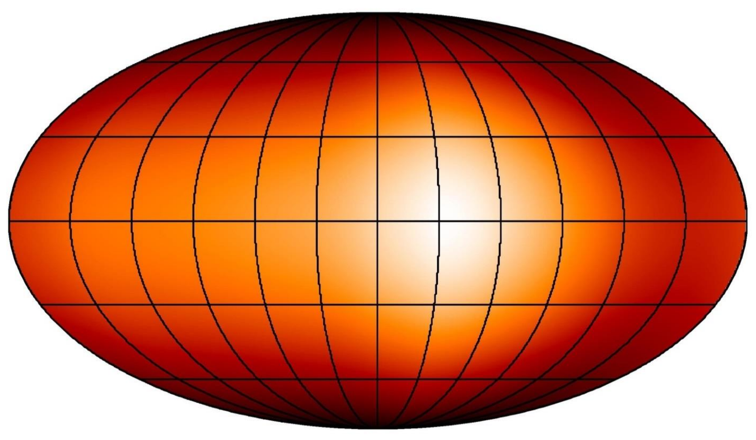
We explain the apparently inflated photometric beaming amplitude of Kepler-76 as a result of a phase shift of the reflection/emission modulation, due to equatorial superrotation of its hot-Jupiter companion.
Our modified BEER model supports superrotation and provides a photometry-consistent estimate of the planetary mass. The superrotation BEER model fits the data better than a zero phase-shift null model also for other hot Jupiters (see table), making it a viable method for estimating hot-Jupiters mass from the photometric BEER modulations of their parent stars.

Parameter	KOI-13	HAT-P-7	TrES-2	Kepler-76
Period (day)	1.76	2.20	2.47	1.54
Reflection (ppm)	70.7 ± 0.7	33.1 ± 1.0	1.7 ± 0.4	50.4 ± 2.0
Beaming (ppm)	9.4 ± 0.7	5.8 ± 1.1	3.4 ± 0.4	13.5 ± 2.0
Ellipsoidal (ppm)	68.0 ± 0.7	20.1 ± 1.2	2.8 ± 0.5	20.2 ± 1.4
Phase shift (deg)	1.2 ± 0.4	4.1 ± 0.6	37 ± 18	10.2 ± 0.2
Planet mass (M_{Jup})	8.6 ± 1.3	2.0 ± 0.2	1.0 ± 0.3	2.1 ± 0.4

Superrotation of a tidally locked hot Jupiter involves an eastward displacement from the substellar point, of the planet thermal hot spot, showing in the star light curve as an angle shift of the planet reflection/emission phase modulation.



From Knutson et al. 2007, Nature, 447, 183.
Superrotation model of HD 189733b

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