Mapping a star with transits: orbit precession effects in the Kepler-13 system

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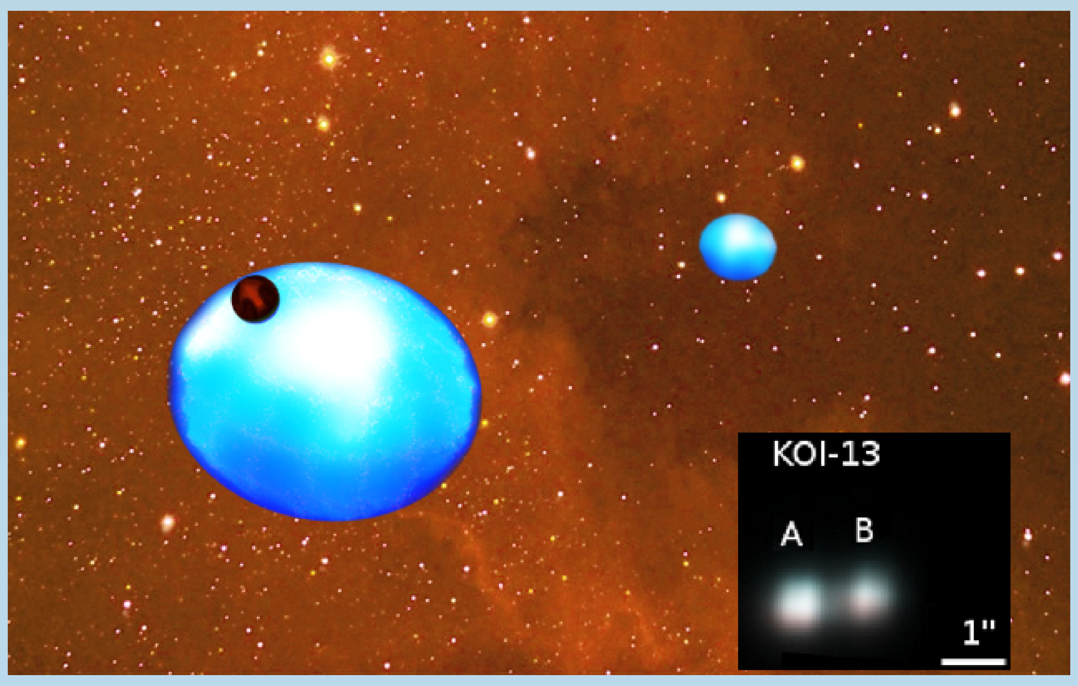
Synopsis



Kepler-13 hosts a planet-sized companion (Mazeh et al. 2012, Shporer et al. 2011, Mislis & Hodgkin 2012) with 1.76 days period on oblique orbit.

The system is a prime astrophysical laboratory showing how stellar rotation and the orbit of the planet interacts with each other. This system has uncovered fundamental processes due to this interaction (Szabó et al. 2011; 2012; 2013):

- **Light curve asymmetry** emerges due to gravity darkening of a rotating star if the transit path is oblique

  —Similar distortions has been found for other systems (e.g. Barnes et al. 2013)

- **Dynamical harmony.** Stellar rotation knows about the orbital period of close-in planets

  —Low-order resonances between stellar rotation and orbital period is a general characteristic for close-in planets (Walkowicz & Basri 2013)

  Stellar rotation causes orbital precession, leading to variation of transit duration (TDV)

  —Also found in other systems (Barnes et al. 2013)

- **Stellar surface.** Due to the resonant orbit, Kepler-13 has confirmed the unexpected surface of an A-type star: there are a few well-defined spots with considerable contrast. This is in contrast with earlier expectations counting on low-contrast features extending up to a half of the stellar surface.

References

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[5] Mislis, D., Hodgkin, S. 2012, MNRAS, 422, 1512

[6] Shpohrer, A. et al., 2011, AJ, 142, 195

[7] Szabó, Gy. M. et al., 2011, ApJ, 736, L4

[8] Szabó, Gy. M. et al., 2012, MNRAS, 421, 122

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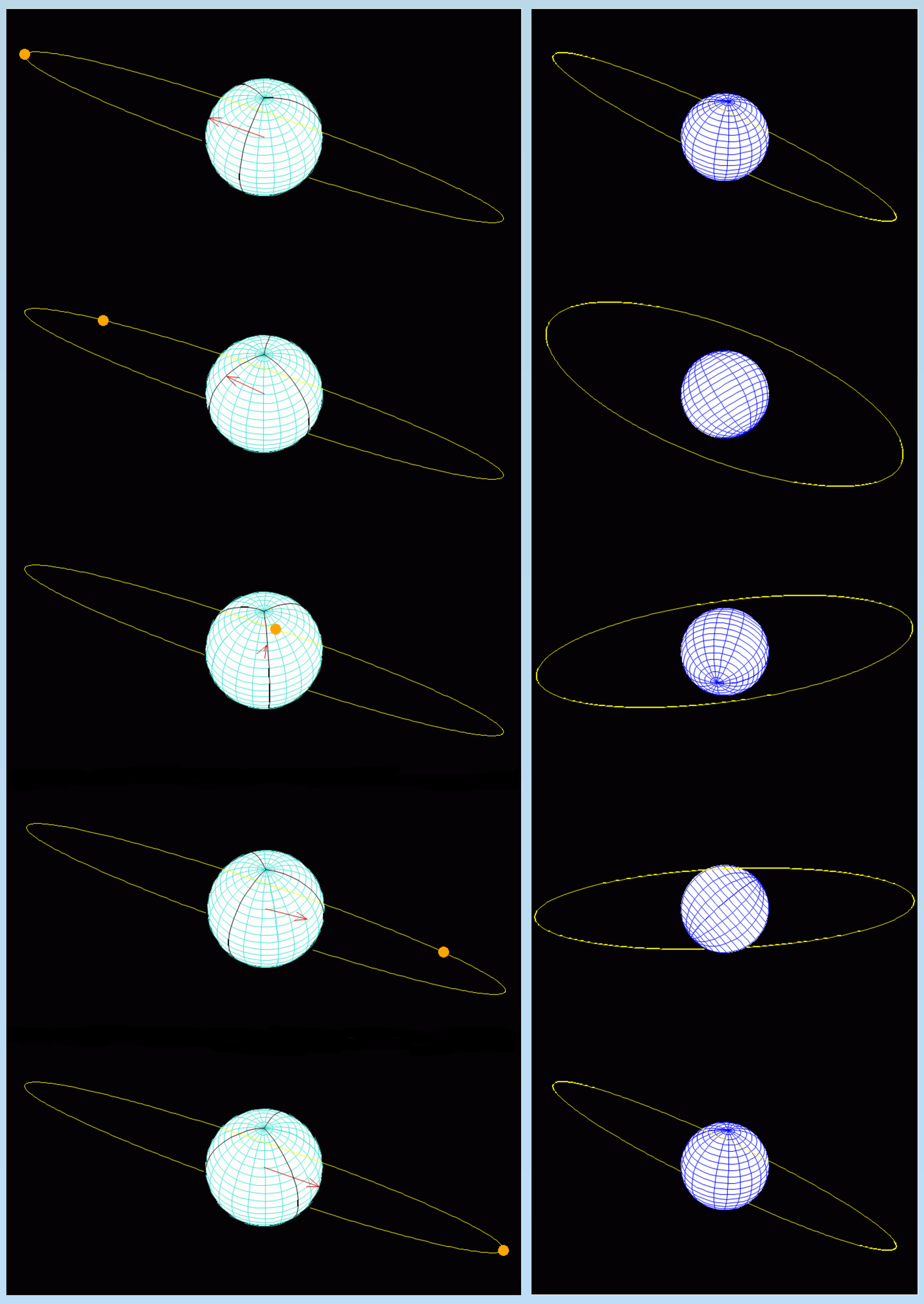
[10] Walkowicz, L., Basri, G. S., 2013, MNRAS, in press

Dynamical harmony

Kepler-13 has been the first exoplanet system with exact spin-orbit resonance.

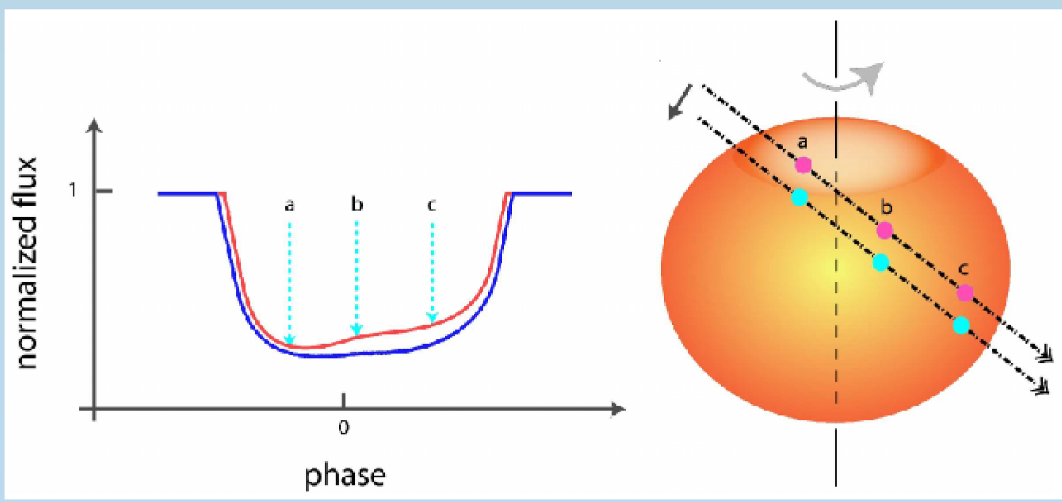


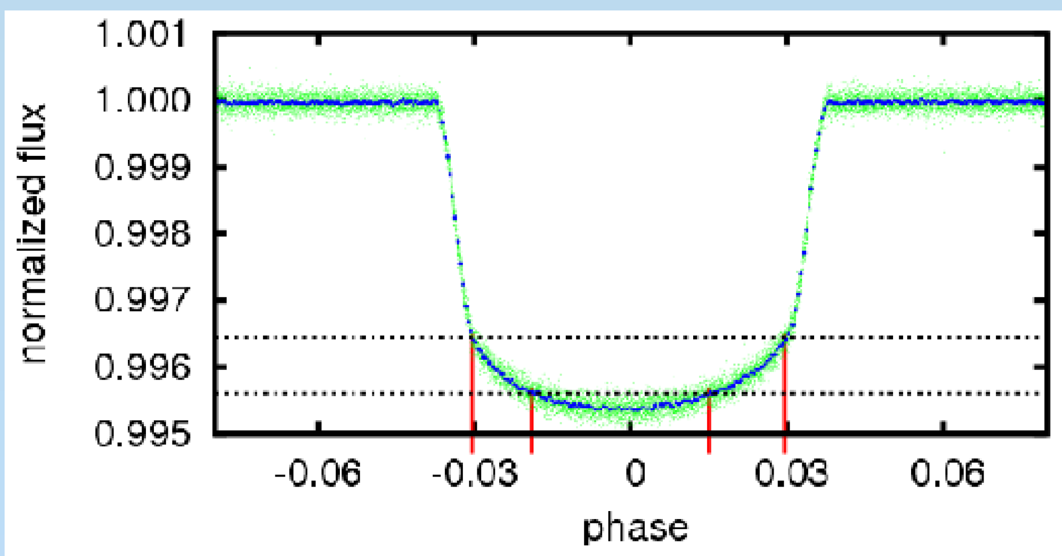
Left-side animation: the planet's orbit and stellar rotation (left panel) which are in 3:5 resonance. There is also a quasi-resonance when the planet is near extremal latitudes.

Right-side animation: The joint precession of the star and the orbital plane with ≈75 yr period. In a few years, Kepler-13 will be a non-transiting planet, while the transit path maps through the surface.

This is a proof for the exact 3:5 spin-orbit resonance.

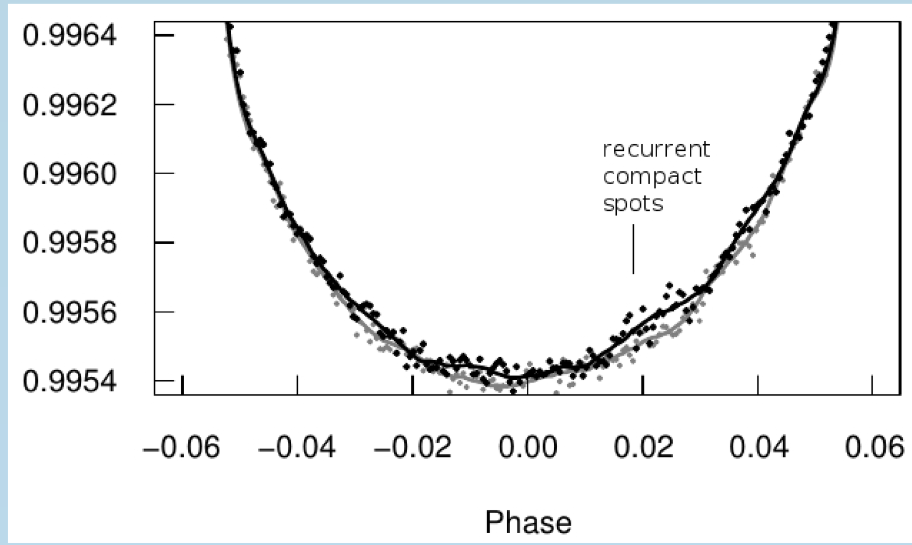
Light curve asymmetry



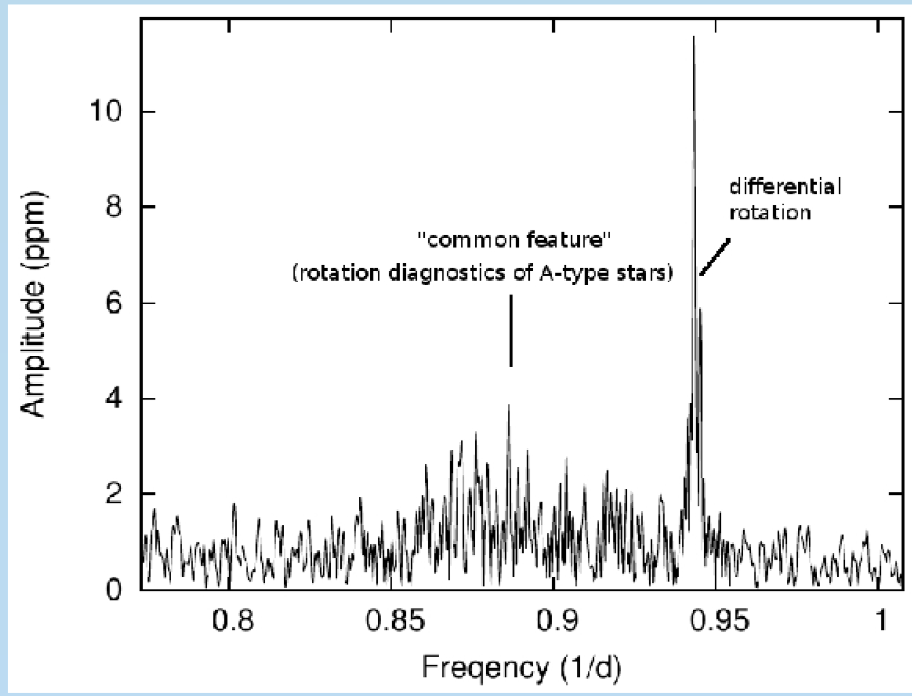


Upper panel: Illustration of how a transiting planet on a precessing orbit can map the entire stellar surface. Left panel shows the expected differences in light variation. The transiting path interacts with gravity darkening, leading to a light curve distortion (following Barnes 2009). **Lower panel:** The asymmetry is indeed observed.

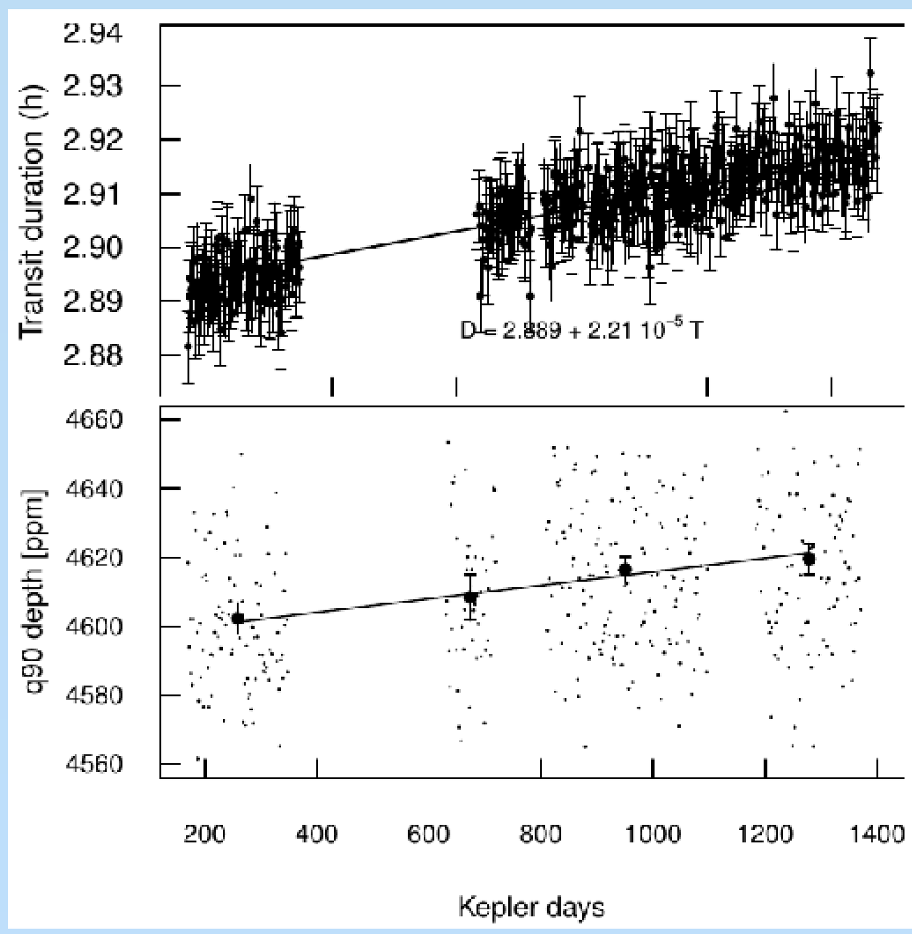
Stellar surface



Comparison of folded and averaged light curves three transits apart (i.e. belonging to the very same stellar surface) in thirty days data. Note the appearing compact spots that has a lifetime of ≈ 30–60 days.



Fourier spectrum of Kepler-13 light curve in the vicinity of 25.4 hour period. The "common feature" of rotating A-stars (Balona 2013) can be seen at the left side of the peak, proving that the peak has a rotational origin. Note also the splitting due to differential rotation.



Upper panel: Variation of transit duration (TDV) has been observed in Kepler- 13 due to the precession of the orbital plane.

Lower panel: Variation of the transit depth, expressed in term of q90, i.e. the 90% quantile of occulted light in photometric points belonging to a transit.

Acknowledgement

This project has been supported by the Hungarian OTKA Grants K76816, K83790, K104607, the HUMAN MB08C 81013 grant of the MAG Zrt., KTIA URKUT_10-1-2011-0019, NSF PHY05-51164, the "Lendület-2009 Young Researchers" Program of the Hungarian Academy of Sciences and by the City of Szombathely under agreement No.S-11-1027. GyMSz and RSz were supported by the Janos Bolyai Research Fellowship of the Hungarian Academy of Sciences.