Updated Masses for Kepler-90's Gas Giants Via Transit-Timing Variation and Radial Velocity Observations

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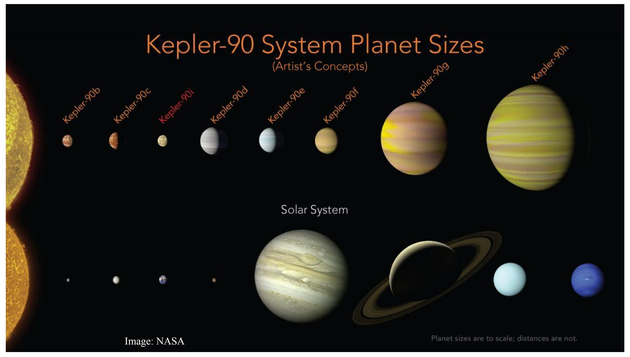
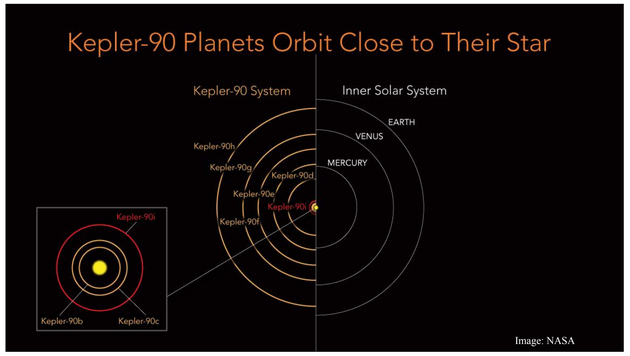
The Kepler-90 System

The Kepler-90 system contains eight known planets, matching our own solar system for the greatest multiplicity of planets found to date.



This system is dynamically rich, and knowledge of the planetary masses and orbital parameters is essential to compare it to planetary formation theories and mechanisms.



References

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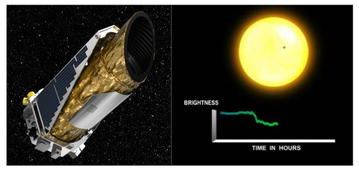
[6] Lauren M. Weiss and Geoffrey W. Marcy. "The Mass-Radius Relation for 65 Exoplanets Smaller than 4 Earth Radii". In: 783.1, L6 (Mar. 2014), p. L6. DOI: 10.1088/2041-8205/783/1/L6. arXiv: 1312.0936 [astro-ph.EP].

Method 1: Transit-Timing Variations

All eight planets are transiting and were originally detected in photometry from the NASA Kepler primary mission.



Images: NASA

The giant planets g and h exhibit significant transit-timing variations.

Figure 5 reproduced from Cabrera et al. 2014[2]

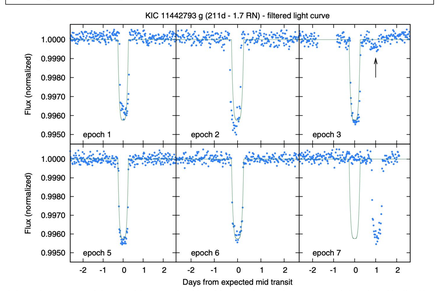


Figure 5. Individual observed transit events of planet g and the expected position of those transits assuming a constant period, marked with a line. Note the irregularities in the transit depth and duration at epochs 1 and 2 and the displacement from the expected position of epoch 7. The additional transit like event marked with an arrow close to epoch 3 is discussed in the text.

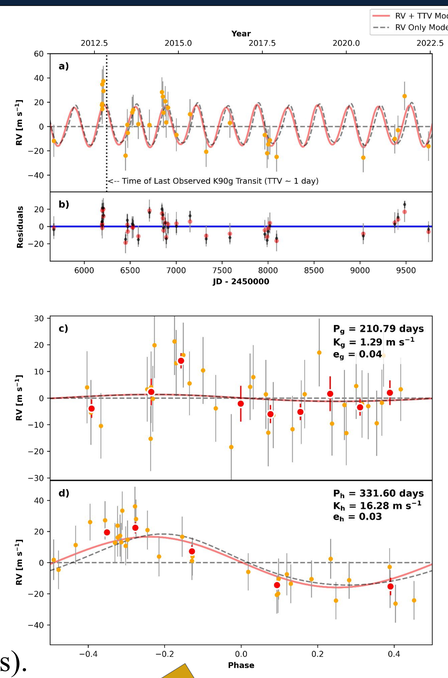
We model the variations in the observed transit times of planets g and h via TTVFaster[1], but observing only a small number of their transits means that masses for these outer planets are difficult to determine precisely given the number of free parameters needed to model their transit times.

Method 2: Radial Velocity

We have measured 34 radial velocities of the Kepler-90 host star over an eleven year baseline using the HIRES spectrograph on the W. M. Keck Observatory.

Image: W. M. Keck Observatory

The figure to the right shows the results of modelling the host star's radial velocity only (dashed lines) via Radvel[4] and jointly modelling the radial velocity and transit-timing variations (solid red line and labels).



Determining Masses for the Gas Giant Planets

After jointly modeling the transit-timing variations and radial velocity with a chi-squared goodness of fit metric and computing posteriors through a Markov chain Monte Carlo analysis using the Python package emcee[3], we determine the following masses for the outer two giant planets:

	Planet g [M_{Earth}]	Planet h [M_{Earth}]
Our Results (Methods 1 + 2)	$13.0^{+0.6}_{-0.6}$	190^{+3}_{-3}
Literature[5] (Method 1 Only)	$15.0^{+0.9}_{-0.8}$	203^{+5}_{-5}

The figure to the right shows mass vs. period for each planet in the Kepler-90 system along with our own solar system in blue. Masses for the inner six Kepler-90 planets are estimated using their measured radius and an empirical mass-radius relation[6]. Error bars are generally too small to be seen on this scale. Radius values for planets g and h are from Cabrera et al. 2014[2].

From these results, we see that the Kepler-90 planets have about half of the total mass of the solar system planets, but it is all contained within about 1 AU (Earth's Orbit).