On the Frequency of Additional Planets in Short-Period Hot-Jupiter Systems from Transit Timing Variations

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ABSTRACT

The large number of hot Jupiter planets allows one to probe these systems for additional unseen planets via transit timing variations (TTVs). Even relatively small terrestrial planets, when placed in an energetically favorable mean motion resonance (MMR) can cause detectable TTVs with an amplitude of several minutes in the directly detected hot Jupiter's orbit (Holman and Murray 2005). In an effort to discover and characterize such companions, we have embarked on a systematic study of known transiting hot Jupiters, utilizing the University of Arizona's 1.55 meter Kuiper telescope on Mt. Bigelow to measure multiple individual transits in a single observing season to within 30 second precision, and constrain the nature of any planetary companions. As of September 2010, we have obtained 28 transits of 12 different planets. Here we present current and preliminary results of this study and show that the systems HAT-P-5, HAT-P-6, HAT-P-8, HAT-P-9, WASP-11/HAT-P-10, HAT-P-11, and WASP-10 likely do not contain small mass companions in MMRs or moderate mass companions in close enough proximity to induce TTVs on the order of ~1.5 minutes. These observations are surprising since one might expect as Jupiter's migrate inwards they would sweep smaller earth-like plaents into MMRs, but we (and others) find no evidence that hot Jupiter systems (P < 4 days) have additional inner planets down to terrestrial size in MMRs.

OBSERVATIONS AND REDUCTIONS

Almost all data were taken at the University of Arizona's 1.55 meter Kuiper Telescope on Mt. Bigelow with the Mont4K CCD, binned 3x3 to 0".43/pixel. For all objects, data were taken with Arizona-I filter. We utilized reference stars scattered relatively evenly around the target star, and integration times that yielded the maximum amount of photons in the target and reference stars without saturating. Each data image was bias-subtracted, and flat-fielded in the usual manner. The transit was fit with the method of Mandel and Agol (2002). Limb-darkening laws were taken from Claret (2000) using the appropriate stellar parameters for the target.

HAT-P-5[1]

$N_{transits}$ = 2 (01 June 2010, 24 July 2010)
P=2.7884740 ± 0.0000008 days. (Improved 1 order of magnitude)

HAT-P-6[12]

$N_{transits}$ = 14 (2008-2010, Kuiper, FLWO, Mearth, DEMONEX)
P=3.85299 ± 0.00003 days

HAT-P-8[9]

$N_{transits}$ = 1 (22 October 2009)
R_p/R_* =0.0876 ± 0.0010 (~8σ smaller than Latham et al. 2009)
P=3.076329 ± .000001 days

HAT-P-9[13]

$N_{transits}$ = 3 (14, 18 February, 05 April 2010)
P=3.922814 ± 0.000002 days

WASP-11/HAT-P-10[2,14]

$N_{transits}$ = 3 (30 September, 11 and 25 November 2009)
R_p/R_* = 0.1263 ± 0.0004
P = 3.7224690 ± 0.0000067 days

HAT-P-11[3]

$N_{transits}$ = 1 (01 May 2009)
P = 4.8878045 ± 0.0000043 days

WASP-10[4]

$N_{transits}$ = 3 (14 October 2009, 15 and 18 September 2010)
P = 3.092728 ± 0.0000027 days
No evidence for Maciejewski et al. (2010) companion

Hot-Jupiter Companions

To date, the only hot-Jupiter (P < 4 days) with a confirmed planetary companion is HAT-P-13b. Currently, we have studied 12 hot-Jupiter systems, with several more currently undergoing monitoring, with no significant detections of transit timing variability. Despite the relatively small number of systems surveyed, we can conclude that the multiplicity fraction among hot-Jupiter systems is relatively small. The *Kepler* mission, surveying ~150,000 stars, is poised to address the question of planet multiplicity in general, and hot-Jupiter companions in particular, in unprecedented detail.

Acknowledgements

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HAT-P-5:

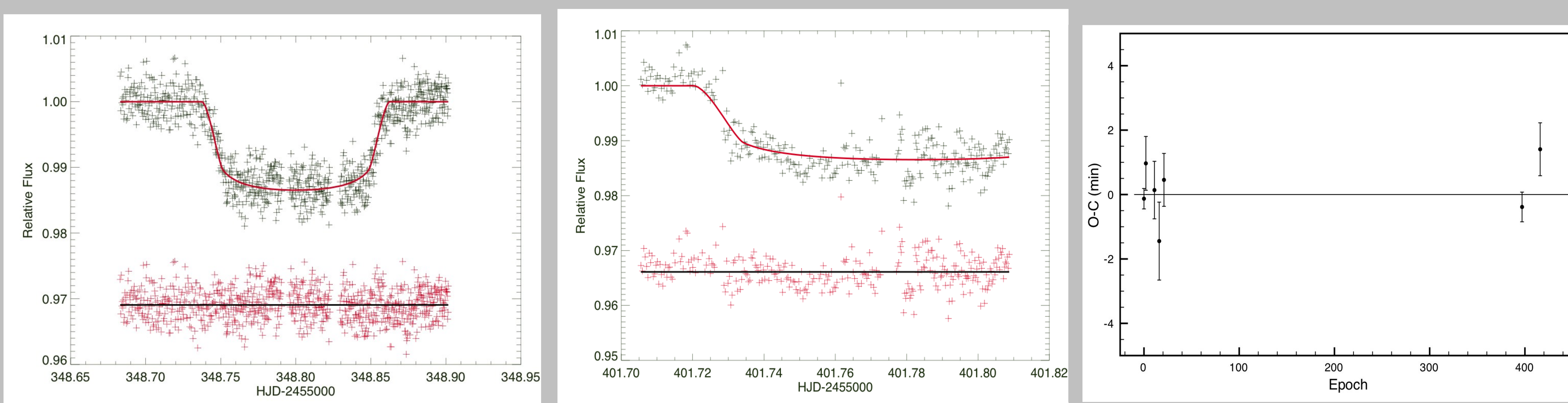


Figure 1: *Left*: HAT-P-5b transit taken on the night of 31 May 2010. *Middle:* Partial HAT-P-5b transit taken on the night of July 23, 2010. *Right:* Observed minus Calculated (OC) plot for our new ephemeris using all available HAT-P-5b data. (Dittmann et al. In prep a)

HAT-P-6:

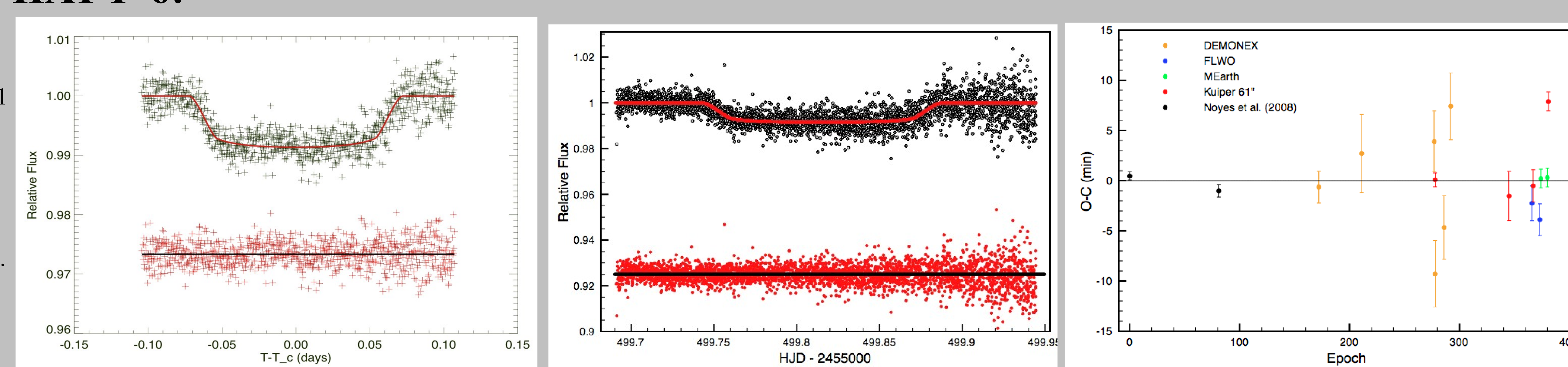
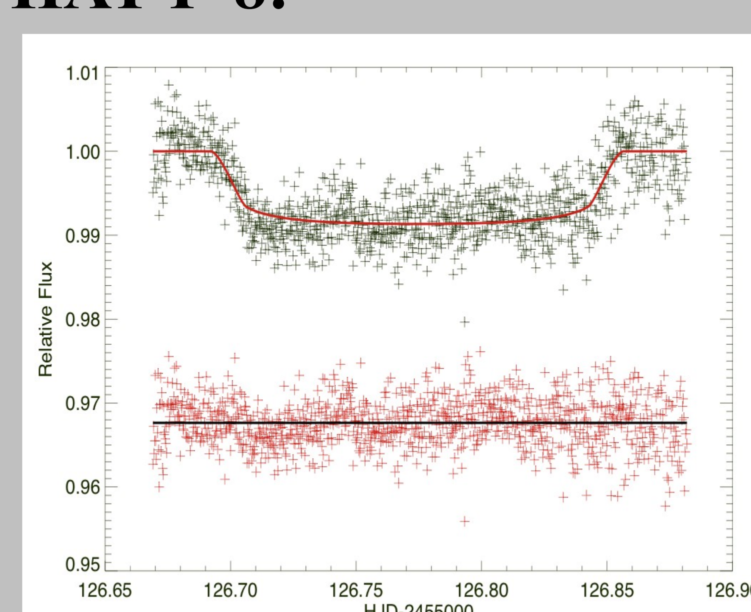


Figure 2: *Left*: Transit of HAT-P-6b taken from the University of Arizona's 1.55 meter Kuiper telescope on 01 October 2009. *Middle:* Transit of HAT-P-6b taken from the MEarth Observatory on Mt. Hopkins on 29 October 2010. *Right:* Observed minus Calculated (OC) plot for our new ephemeris using all available HAT-P-6b data, color-coded by observatory. (Dittmann et al. In prep b).

HAT-P-8:



HAT-P-11:

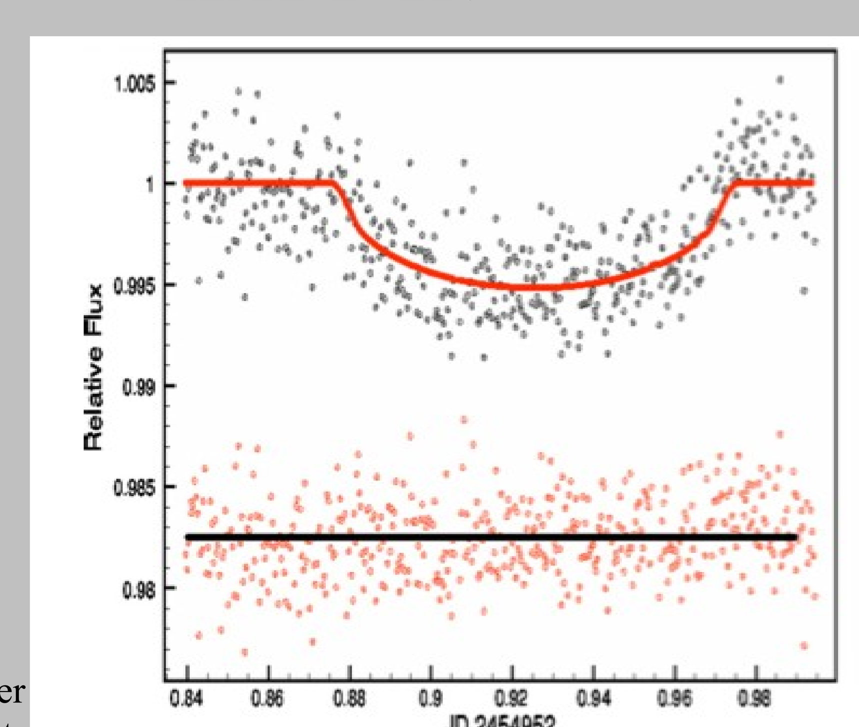


Figure 3: *Left:* Transit of HAT-P-8b taken from the University of Arizona's 1.55 meter Kuiper telescope on 22 October 2009. *Right:* Transit of HAT-P-11b taken from the University of Arizona's 1.55 meter Kuiper telescope on 01 May 2009

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HAT-P-9:

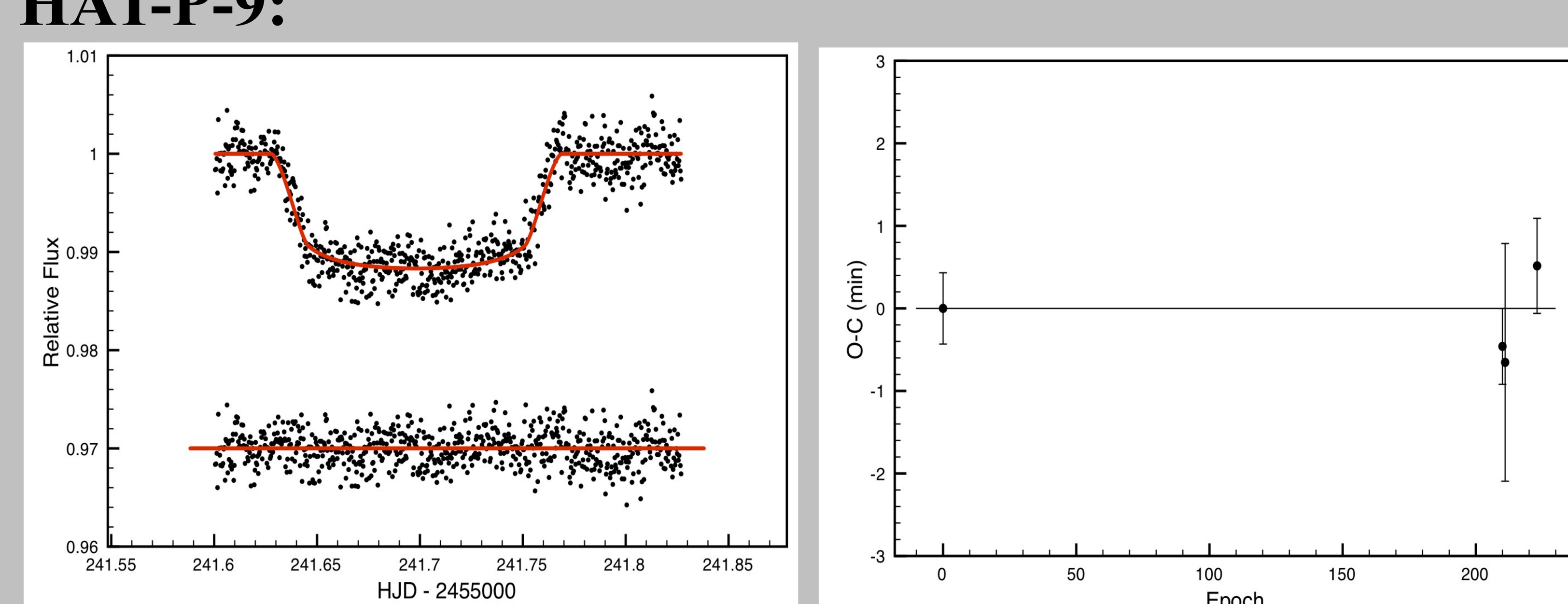

Figure 4: *Left:* Transit of HAT-P-9b taken from the University of Arizona's 1.55 meter Kuiper Telescope taken on 13 February 2010. *Right:*Observed minus calculated (OC) plot for our new ephemeris using all available transits of HAT-P-9b. We find no evidence for TTVs.

WASP-11/HAT-P-10:

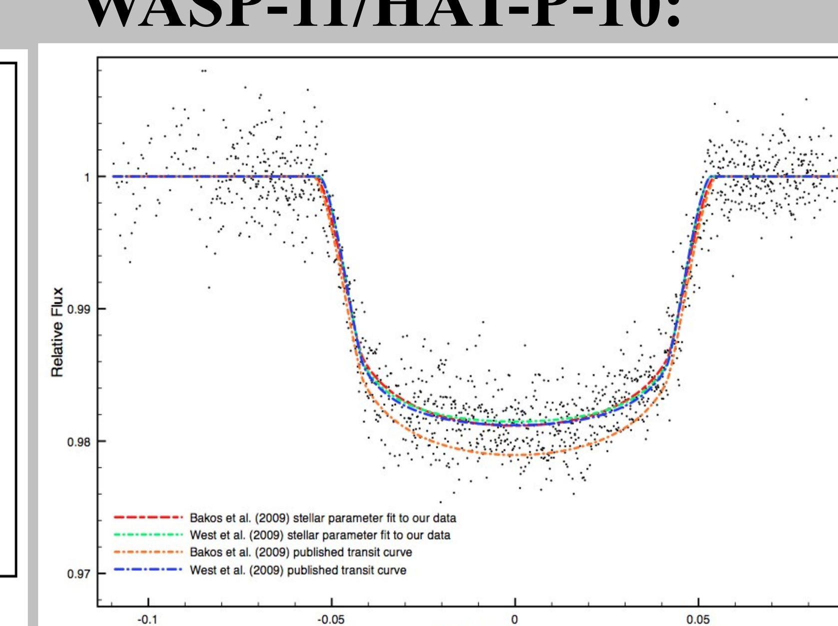

Figure 5: Three transits of WASP-11/HAT-P-10 b taken from the University of Arizona's 1.55 meter Kuiper Telescope with previous model fits super-imposed.

WASP-10:

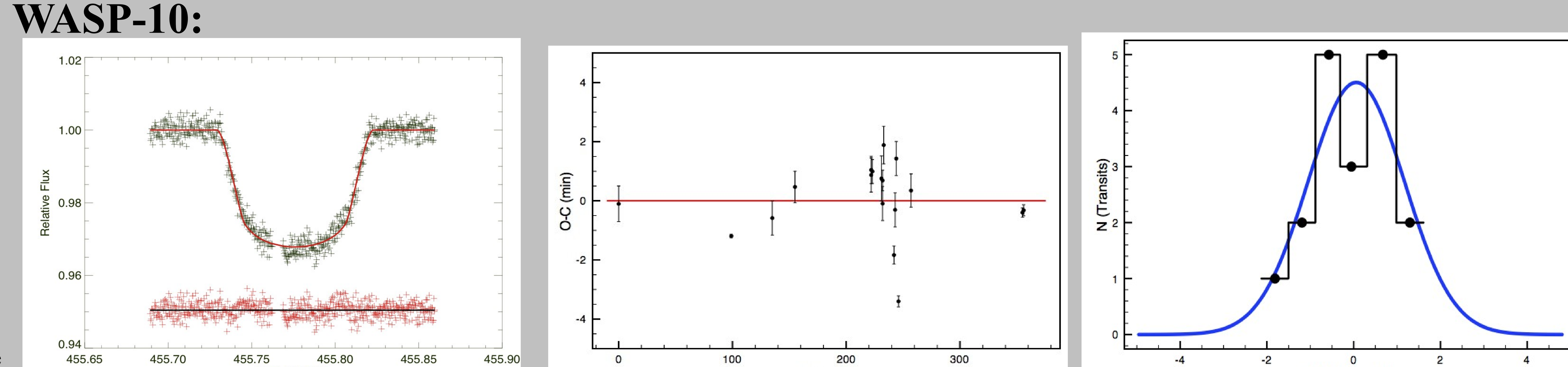

Figure 6: *Left*: Transit of WASP-10b taken from the University of Arizona's 1.55 meter Kuiper Telescope on 15 September 2010. *Middle:* Observed minus Calculated (OC) plot for all available WASP-10b transits fit to our revised linear ephemeris. *Right:* Histogram of our OC diagram (middle). We find that all current transits of WASP-10 are well described by a linear ephemeris with gaussian scatter with a width of ~1 minute. This argues against the results of Maciejewski et al. (2011).