# Using Transit Color Signature to Confirm Transit Candidates

**Hannu Parviainen**

**RoPACS Network Meeting, Madrid**

**28.11.2011**

# Introduction

- Kepler has found a huge number (1235) of transit candidates
- CoRoT isn't doing too bad either

- Large fraction of the candidates are transiting faint stars
  - RVs difficult or impossible to measure
- RV measurements consume a lot of telescope time
  - Slow, other people want to use the telescopes also.

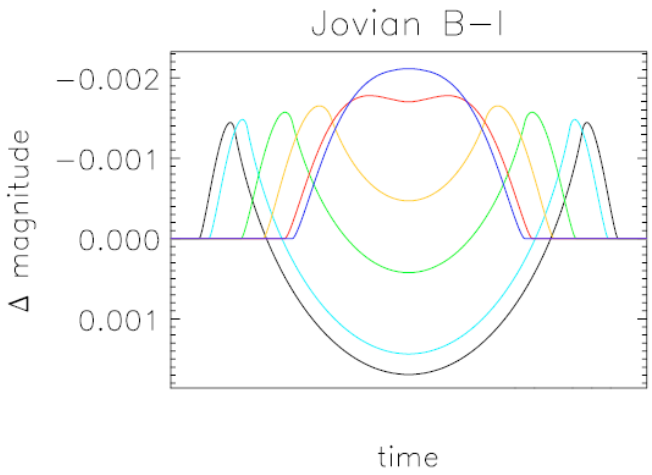
- Most of the candidates cannot be verified by traditional methods
  - We have to come up with something different

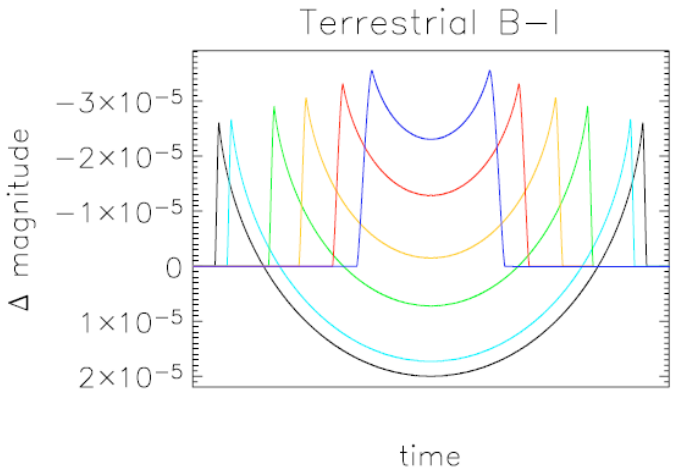
# Introduction II

- A good fraction of the false alarms is caused by contaminating eclipsing binaries (CEBs)
  - Eclipsing binary on the same line of sight as the bright target star
  - The light from the target star diffuses the eclipse, making it look like a planetary transit
- Even if RV observations possible, can be difficult to recognize
  - The light from the target star dominates the RV signal
- We need a way to identify the CEBs that
  - Can be carried out with relatively small telescopes
  - Can be applied to faint targets

# Transit color signature

- Transit shapes for CEBs and planets have differences in wavelength dependency
  - Tingley, B. A&A 425, 1125-1131(2004)
  - CEBs have different transit depths in different passbands, unless the components happen to have same colors
  - Ingress/egress shape dependent on the radius of the eclipsing/transiting object

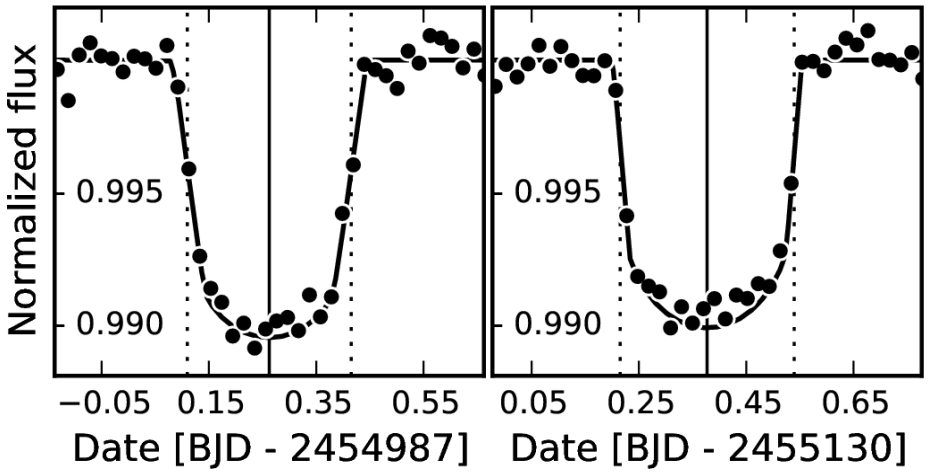


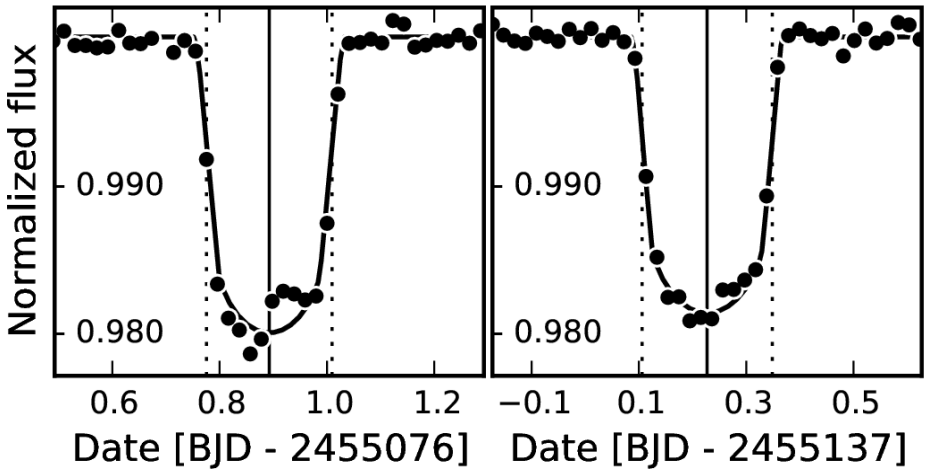



# Colors

## KOI 806

- We selected KOI 806 for testing the method
  - ”We” a lot of people from the IAC, including B. Tingley, F. Murgas, H. Deeg, E. Palle
  - A system with three transiting planet candidates
  - Periods close to 1:2:5 resonance
- We wanted to confirm the nature of KOI 806.02
  - Long period (60d), long transit duration (6.6h)
    - Allows us to get good S/N for the transit in multiple colors



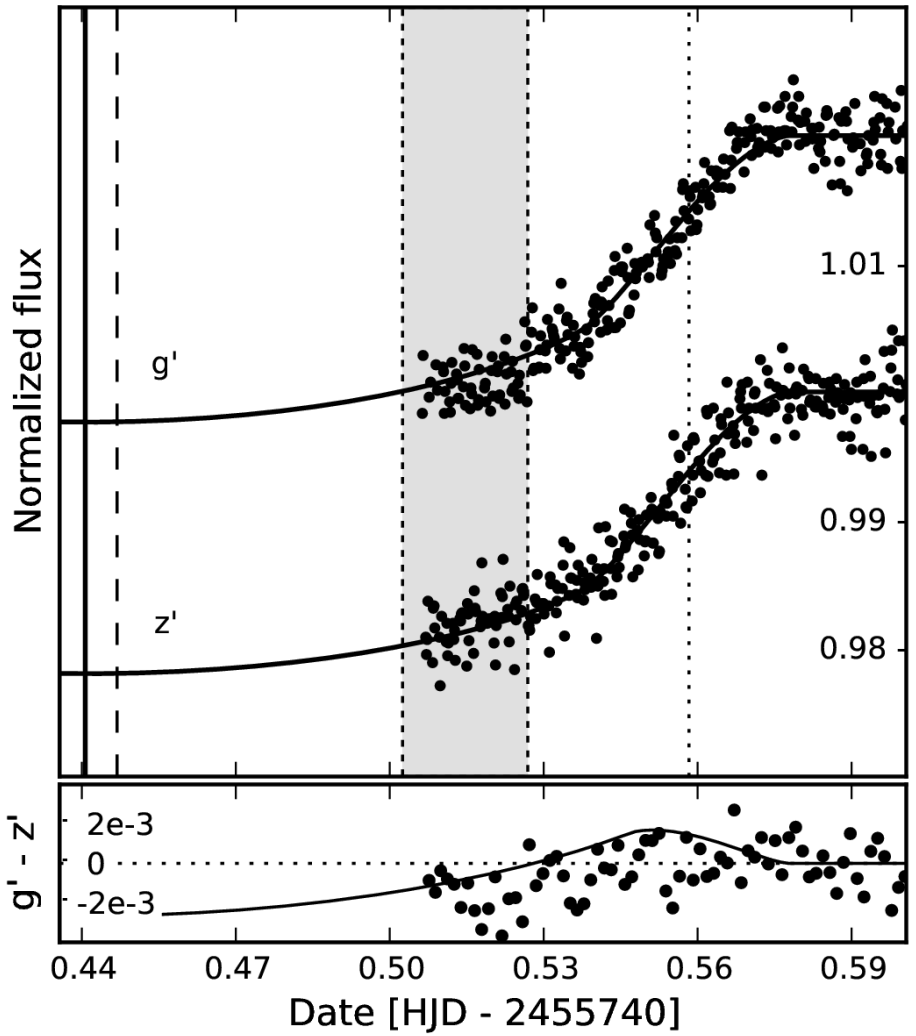
# Observations

- Observations with GTC
  - 5 hours on 27th of June
  - Semi-simultaneous multicolor photometry
    - Alternating four 5s exposures in z' with four 5s exposures in g'
  - Approx. 1800 Images
  - Basic reduction in IRAF
  - Photometry with Vaphot
  - Transit analysis with MCMC
    - My part of the job

# Colors

## GTC Observations

- Nominal color signature
  - Shape agrees with a planet-sized transiting object
- No difference in transit depths
  - If CEB, the components need to have very closely the same color
- And something funny



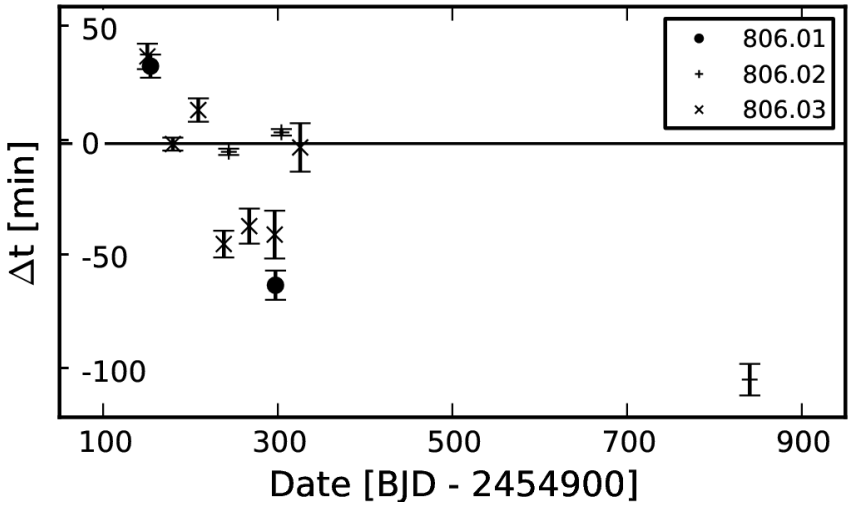
# TTVs

TTVs

- -103 minute TTV against the ephemeris published by Borucki et al.
  - 15σ detection

# TTVs

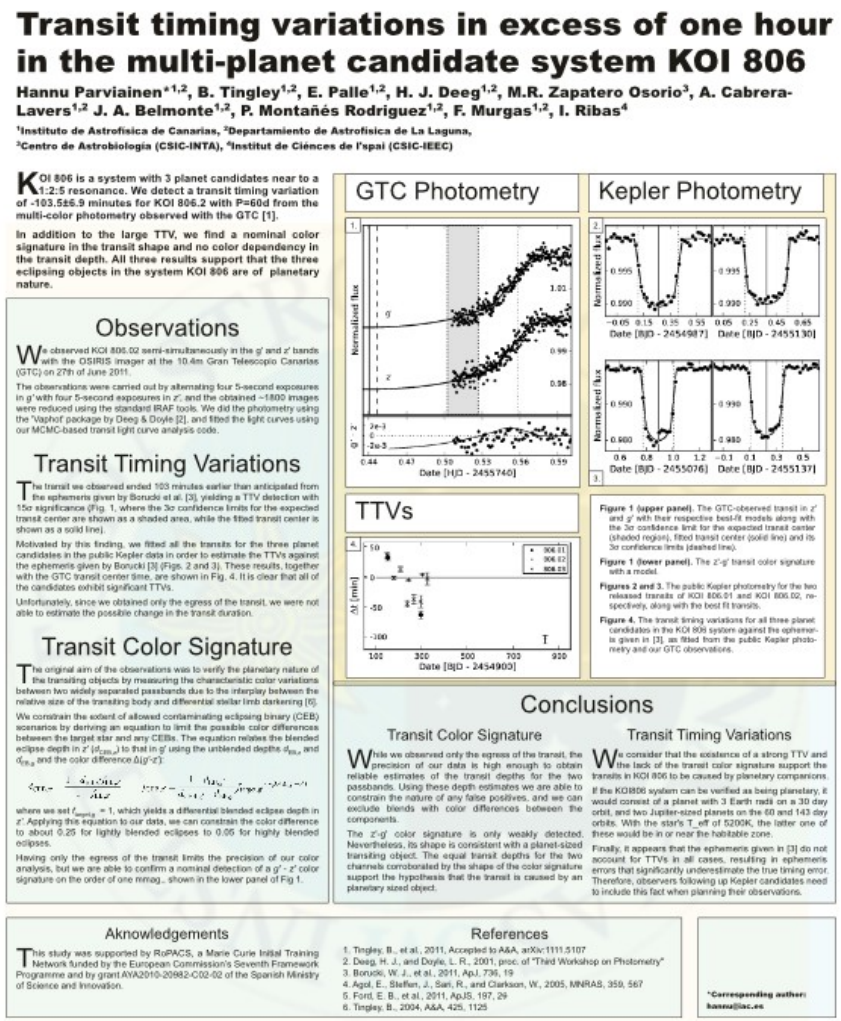
- We fitted all the transits for KOI 806 in the public Kepler light curves
  - TTVs close to one hour against to the published ephemerides
  - Reported timing errors do not include TTVs
    - May cause gray hairs for observers planning to follow up Kepler targets



# TTVs

## Results

- Planetary system?
  - Large TTVs
  - No differences in z' and g' transit depths
  - Egress color signal (while nominal) in agreement with an eclipsing object of planetary size
- All strongly support that the three objects in KOI 806 are planets
- B. Tingley, E. Palle, H. Parviainen et al., accepted to A&A
- Poster in the First Kepler Science Conference



**Transit timing variations in excess of one hour in the multi-planet candidate system KOI 806**


Hannu Parviainen*[1,2], B. Tingley[1,2], E. Palle[1,2], H. J. Deeg[1,2], M.R. Zapatero Osorio[3], A. Cabrera-Lavers[1,2] J. A. Belmonte[1,2], P. Montañés Rodriguez[1,2], F. Murgas[1,2], I. Ribas[4]

[1]Instituto de Astrofisica de Canarias, [2]Departamiento de Astrofisica de La Laguna,
[3]Centro de Astrobiologia (CSIC-INTA), [4]Institut de Ciénces de l'spai (CSIC-IEEC)



KOI 806 is a system with 3 planet candidates near to a 1:2:5 resonance. We detect a transit timing variation of ~103.5±6.9 minutes for KOI 806.2 with P≈60d from the multi-color photometry observed with the GTC [1].

In addition to the large TTV, we find a nominal color signature in the transit shape and no color dependency in the transit depth. All three results support that the three eclipsing objects in the system KOI 806 are of planetary nature.


GTC Photometry

Kepler Photometry

TTVs

Observations

We observed KOI 806.02 semi-simultaneously in the g' and z' bands with the OSIRIS imager at the 10.4m Gran Telescopio Canarias (GTC) on 27th of June 2011.

The observations were carried out by alternating four 5-second exposures in g' with four 5-second exposures in z', and the obtained ~1800 images were reduced using the standard IRAF tools. We did the photometry using the 'Vaphot' package by Deeg & Doyle [2], and fitted the light curves using our MCMC-based transit light curve analysis code.

Transit Timing Variations

The transit we observed ended 103 minutes earlier than anticipated from the ephemeris given by Borucki et al. [3], yielding a TTV detection with 15σ significance (Fig. 1, where the 3σ confidence limits for the expected transit center are shown as a shaded area, while the fitted transit center is shown as a solid line).

Motivated by this finding, we fitted all the transits for the three planet candidates in the public Kepler data in order to estimate the TTVs against the ephemeris given by Borucki [3] (Figs. 2 and 3). These results, together with the GTC transit center time, are shown in Fig. 4. It is clear that all of the candidates exhibit significant TTVs.

Unfortunately, since we obtained only the egress of the transit, we were not able to estimate the possible change in the transit duration.

Transit Color Signature

The original aim of the observations was to verify the planetary nature of the transiting objects by measuring the characteristic color variations between two widely separated passbands due to the interplay between the relative size of the transiting body and differential stellar limb darkening [6].

We constrain the extent of allowed contaminating eclipsing binary (CEB) scenarios by deriving an equation to limit the possible color differences between the target star and any CEBs. The equation relates the blended eclipse depth in z' ($d_{z',bl}$) to that in g' using the unblended depths $d_{g',ubl}$ and $d_{z',ubl}$ and the color difference Δ(g'-z').



where we set $f_{margin,g'} = 1$, which yields a differential blended eclipse depth in z'. Applying this equation to our data, we can constrain the color difference to about 0.25 for lightly blended eclipses to 0.05 for highly blended eclipses.

Having only the egress of the transit limits the precision of our color analysis, but we are able to confirm a nominal detection of a g' - z' color signature on the order of one mmag., shown in the lower panel of Fig 1.

Conclusions

Transit Color Signature

While we observed only the egress of the transit, the precision of our data is high enough to obtain reliable estimates of the transit depths for the two passbands. Using these depth estimates we are able to constrain the nature of any false positives, and we can exclude blends with color differences between the components.

The z'-g' color signature is only weakly detected. Nevertheless, its shape is consistent with a planet-sized transiting object. The equal transit depths for the two channels corroborated by the shape of the color signature support the hypothesis that the transit is caused by an planetary sized object.

Transit Timing Variations

We consider that the existence of a strong TTV and the lack of the transit color signature support the transits in KOI 806 to be caused by planetary companions.

If the KOI806 system can be verified as being planetary, it would consist of a planet with 3 Earth radii on a 30 day orbit, and two Jupiter-sized planets on the 60 and 143 day orbits. With the star's T_eff of 5200K, the latter one of these would be in or near the habitable zone.

Finally, it appears that the ephemeris given in [3] do not account for TTVs in all cases, resulting in ephemeris errors that significantly underestimate the true timing error. Therefore, observers following up Kepler candidates need to include this fact when planning their observations.


Aknowledgements

This study was supported by RoPACS, a Marie Curie Initial Training Network funded by the European Commission's Seventh Framework Programme and by grant AYA2010-20982-C02-02 of the Spanish Ministry of Science and Innovation.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*Corresponding author: hannu@iac.es

# THANK YOU!