PTFO 8-8695b: An Extremely Young T-Tauri-Transiting Planet

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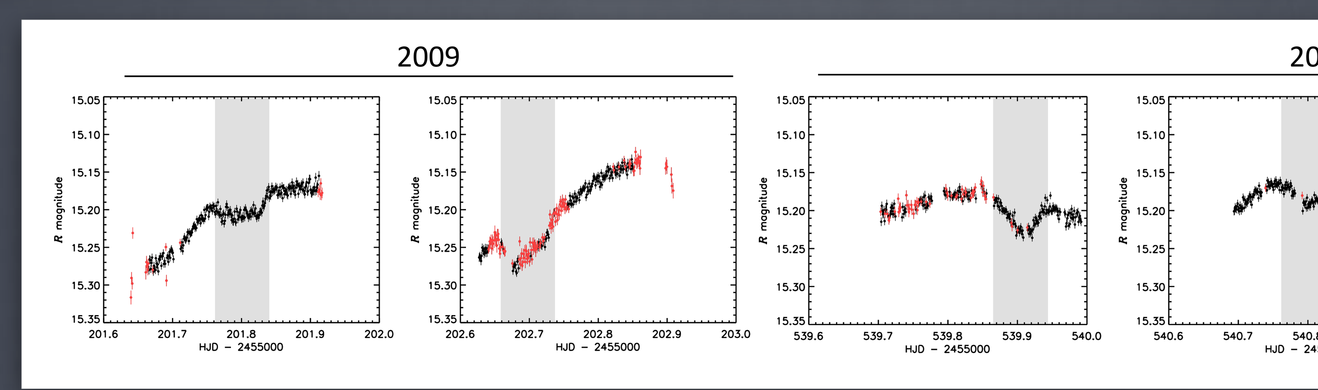
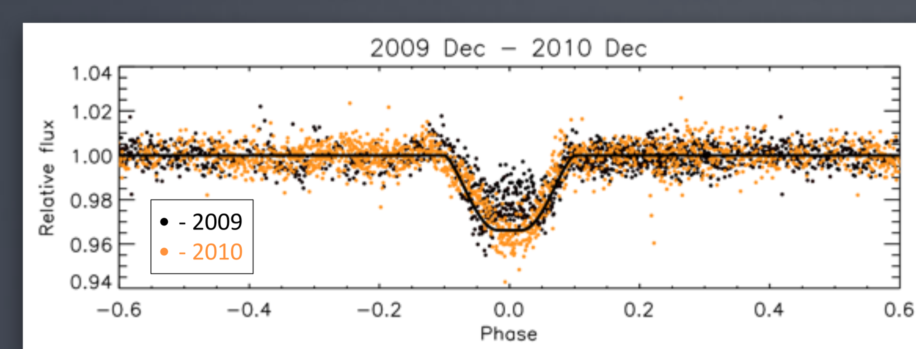
Estimated at only ~3Myr old, PTFO 8-8695b is a candidate for the youngest transiting planet yet found, and presents a potentially valuable snapshot of a close-in pre-main-sequence planet still in its infancy. Ongoing investigation is painting an unusual but increasingly compelling picture: orbiting a rapidly-rotating, oblate, and gravitationally darkened T-Tauri star at just under a half-day period, it appears the planet's orbit may be inclined and precessing on timescales as short as hundreds of days – a timescale easily accessible to observation. The star shows substantial flaring activity, and the planet's measured radius suggests that it may be actively be losing mass. The unusual properties of this object make it particularly interesting for continued investigation.

The object was first identified in 2009 photometric data from the Palomar Transit Factory (PTF) Orion survey (van Eyken et. al 2012), with radial velocities placing the mass clearly in the planetary regime. We were able to fit the data by fully modeling the orbital precession and gravity darkening, though some degeneracy remained in the fit (Barnes et. al, 2013). More recently we have obtained followup with Spitzer, Keck NIRSPEC, and the Las Cumbres Observatory Global Telescope network (LCOGT) to provide stronger constraints and fully confirm the object. Preliminary analysis appears to be consistent with the previous model fits for a 0.34$M_\odot$ host star.

1) Original PTF Orion discovery data (van Eyken et al. 2012)

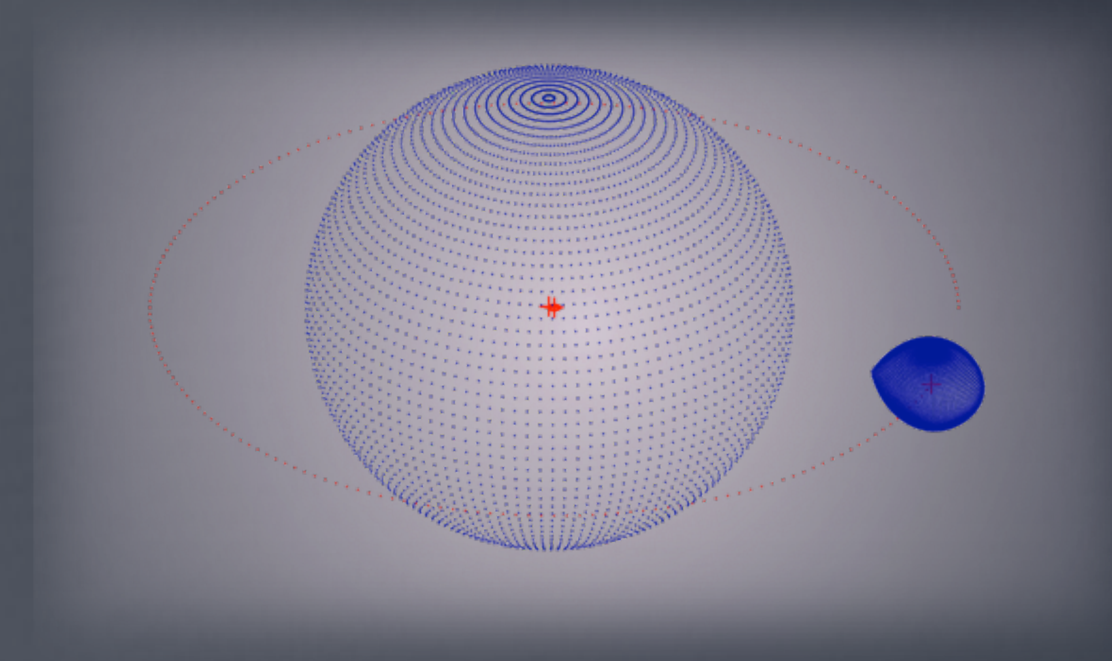


Examples of a few of the transit light curves. Grey regions mark transit window. Red indicates flagged data points where photometry may be non-optimal.



All transit data after folding and removing stellar variability

- Star shows marked intrinsic variability, with transits superposed (top)
- Distinct variation in transit shape between 2009/2010 (above)
- Simple analysis of combined data gives first order picture:
  - Inflated hot Jupiter orbiting a ~10% oblate, co-rotating, M3 T-Tauri star
  - Orbits at its Roche limit with P=0.4484 d

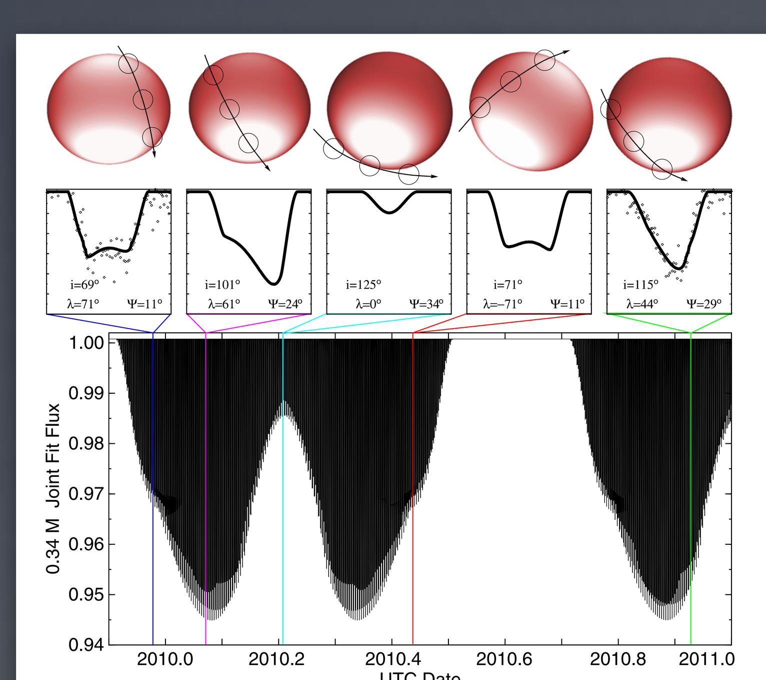


Approx. scale rendering of PTFO 8-8695 on basis of simple fit to original data

2) Modelling the transit shape change (Barnes et al. 2013)

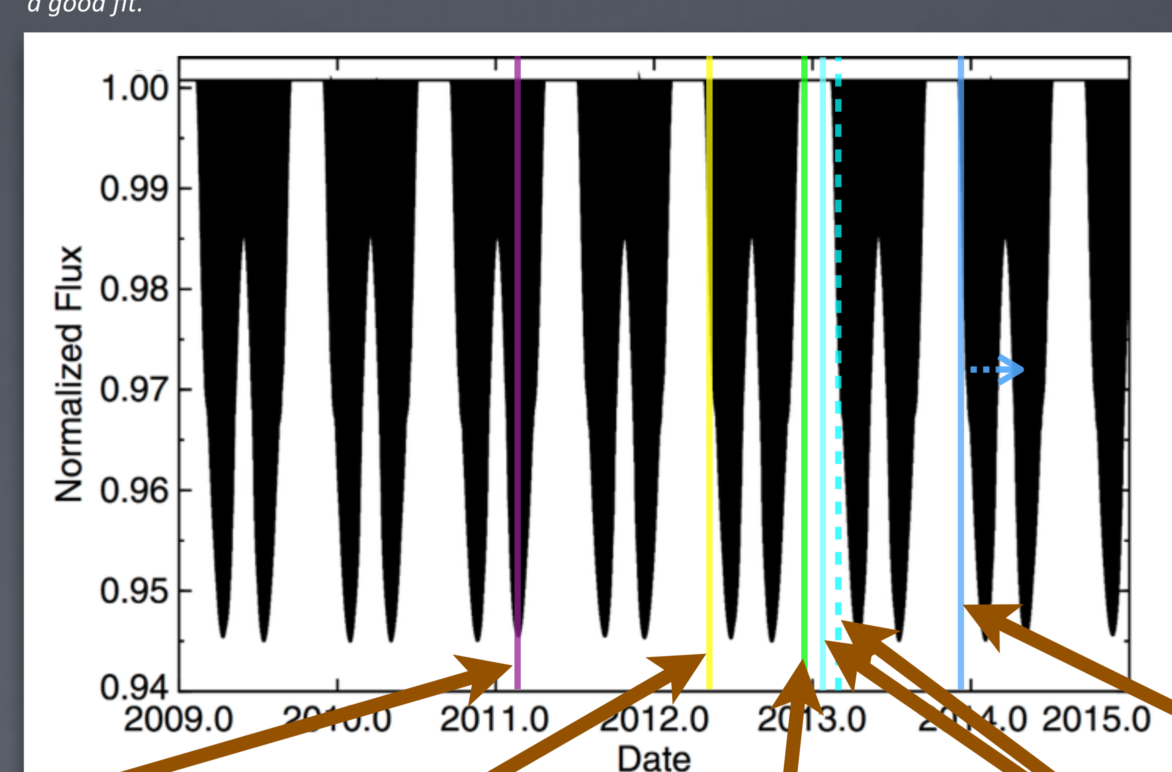
Barnes et al. 2013 developed full transit models including stellar oblateness, gravitational darkening and orbital/stellar precession, to see if it was possible to explain the change in transit shape observed between 2009 and 2010.

- Able to fit the discovery data fully consistently.
- Performed fit for two stellar masses, 0.34 and 0.44$M_\odot$ (corresponding to Seiss and Baraffe stellar models).
- Star and planet orbit mutually precess.
- In both cases, transits should *disappear* for several months per year.
- More data can independently constrain the stellar mass.
- **0.34 $M_\odot$ model seems to predict newer data quite well**



Model fit for M_* =0.34$M_\odot$. Upper panel shows system orientation at different times; center panel shows corresponding model transit shapes, and e.g. fits to the data where present; lower panel shows expected transit depth evolution during the course of the year.

Predicted transit depth evolution over the years following the discovery data for the same model. Comparison with new data (below) shows consistency, suggesting the model may already be close to a good fit.



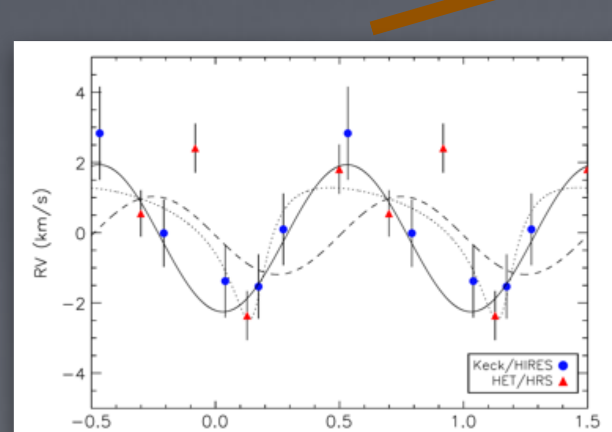
FIT PARAMETERS FOR PTFO 8-8695b

	M_*=0.34$M_\odot$	M_*=0.44$M_\odot$
Period, *P*	0.448410 ± 0.000004 d	0.448413 ± 0.000001 d
Planet mass, M_p	3.0 ± 0.2M_{Jup}	3.6 ± 0.2M_{Jup}
Planet radius, R_p	1.64 ± 0.2R_{Jup}	1.68 ± 0.07R_{Jup}
Stellar radius, R_*	1.04 ± 0.01$R_\odot$	1.03 ± 0.01$R_\odot$
Obliquity, φ	69° ± 3°	73.1° ± 0.6°
Precession period, P_Ω	292.6 d	581.2 d
Stellar oblateness, *f*	10.9%	8.3%

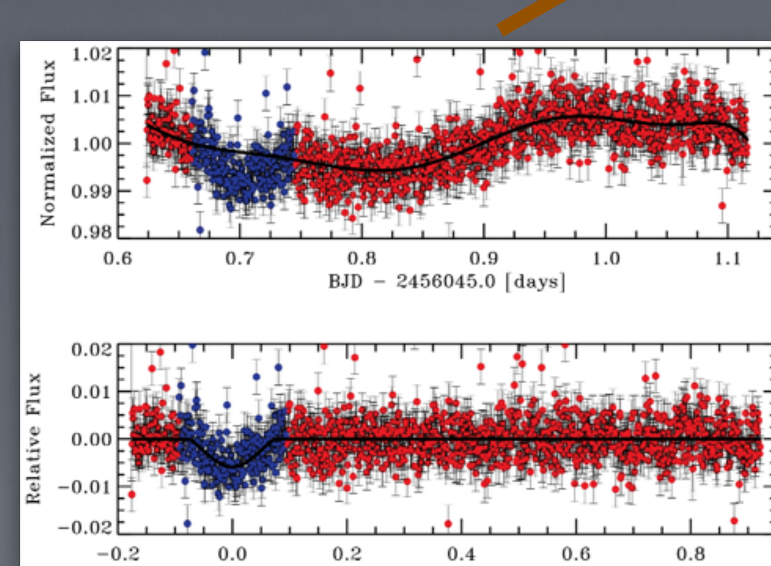
Some of the fit parameters for the two models; most parameters are quite similar - largest difference is in the precession period.

3) New data in relation to precession model for M_* = 0.34$M_\odot$

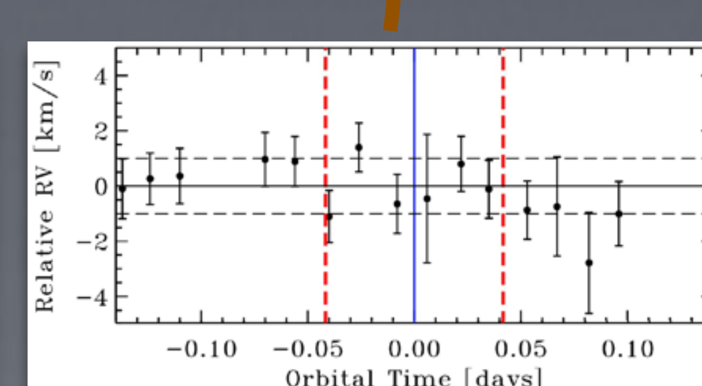
- Model is largely consistent with previous RV data (left), as well as new Spitzer, Keck NIRSPEC, and LCOGT data.
- Transit seems to disappear as predicted.



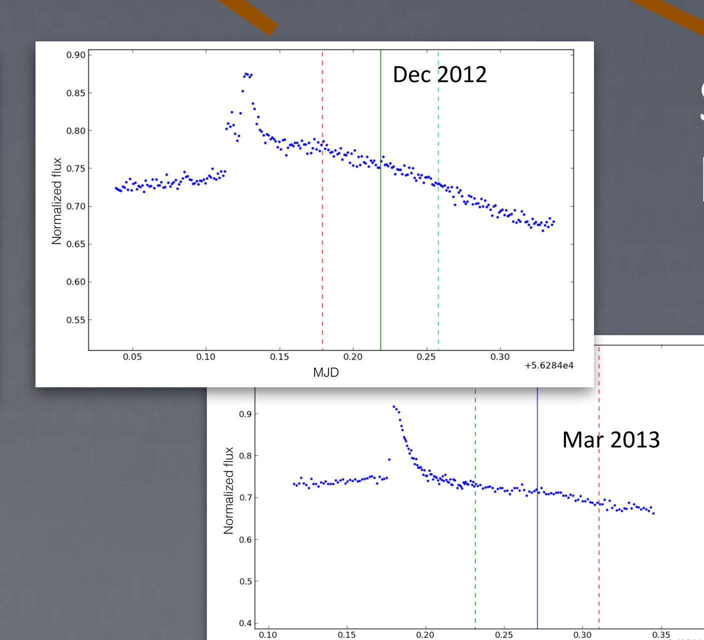
Radial velocity (RV) data from the original discovery paper shows an outlier that is consistent with strong Rossiter McLaughlin effect, suggestive of a deep transit. Broken lines show Keplerian fits, but main RV signal is interpreted as star-spot dominated (sinusoidal solid line).



Spitzer 4.5μm photometry, Apr 2012. Top panel: normalized photometry, with solid line indicating fit to stellar variability; bottom panel: stellar variability removed. Blue indicates transit window. Transit is shallow, but evident, consistent with model.



New radial velocity data with Keck NIRSPEC, Dec 2012, during transit window (edges/center marked by vertical dashed/solid lines). No Rossiter McLaughlin effect is evident, suggesting no transit, consistent with model.



See (4) below

*LCOGT photometry from early 2013 shows flares, but **no obvious transit** (transit window edges/center marked by vertical dashed/solid lines). Model suggests should be a shallow transit in Mar '13 — possibly below detection threshold, or model fit needs refining.*

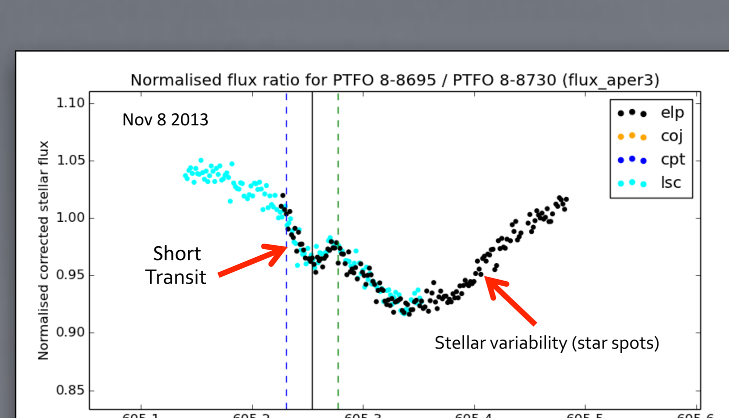
4) Latest LCOGT data

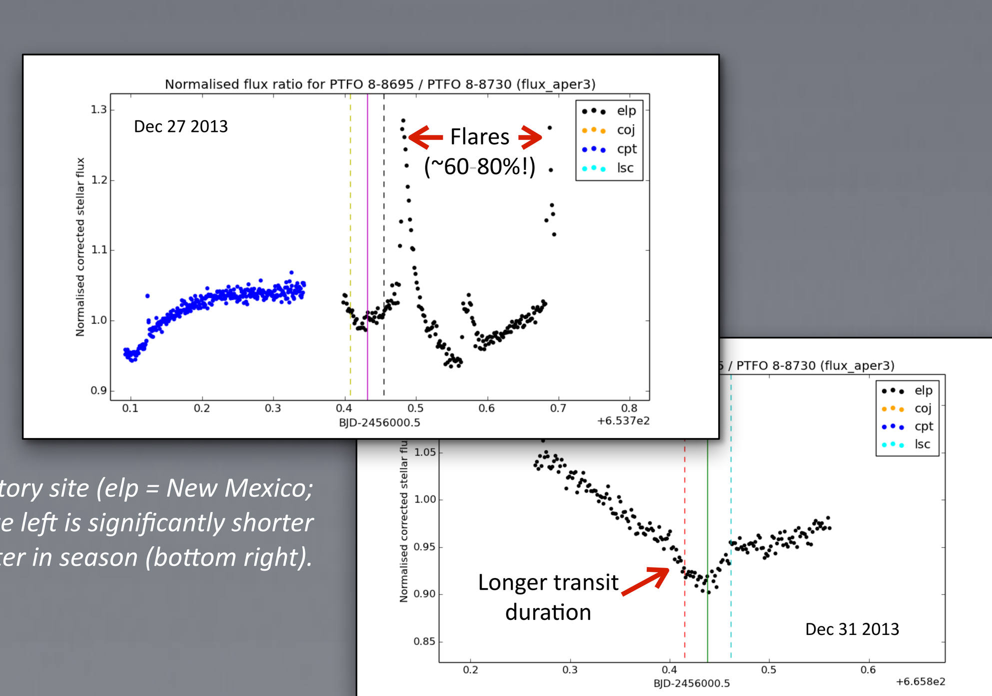
New data using the full LCOGT network indicates the transits have now returned, again consistent with the model.

Longitude coverage of the LCOGT network enabled many more transits to be observed than would otherwise be possible, as well as investigation of the full period stellar variability on ~day-long of timescales.

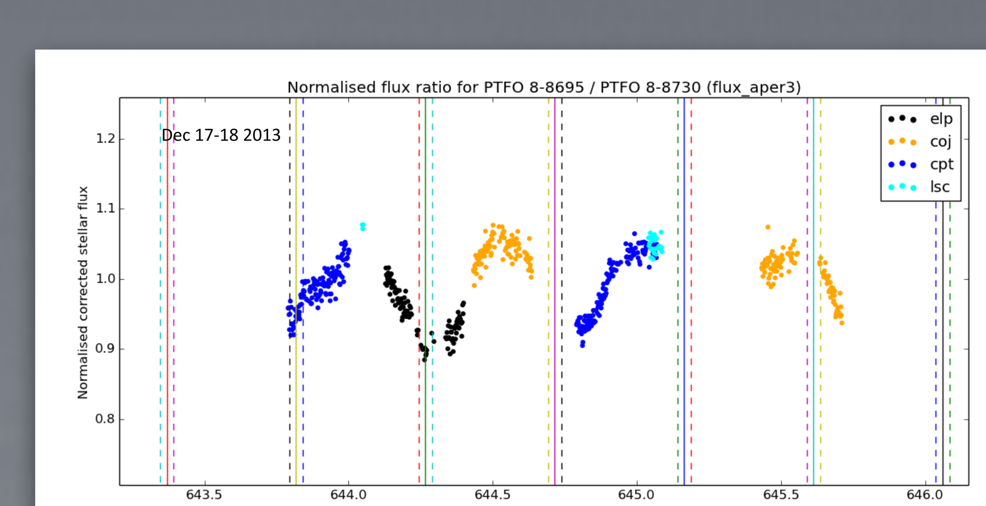
Transits in Nov 2013 were significantly shorter than previously, as might be expected for more grazing transits; they have lengthened during the course of the season.

We are currently in the process of including the new data in the model fits. This should help pin down the system parameters and remove degeneracy in the solutions.





Example transits from late 2013. Colors indicate observatory site (elp = New Mexico; coj = Australia; cpt = South Africa; lsc = Chile). Transit above left is significantly shorter duration than later in season (bottom right).



Near continuous photometry over 48hrs combining data from LCOGT sites shows form of stellar variability.

REFERENCES: Barnes et al. 2013 ApJ 774, 53; van Eyken et al. 2012 ApJ 755, 42; van Eyken et al. 2014, in prep.