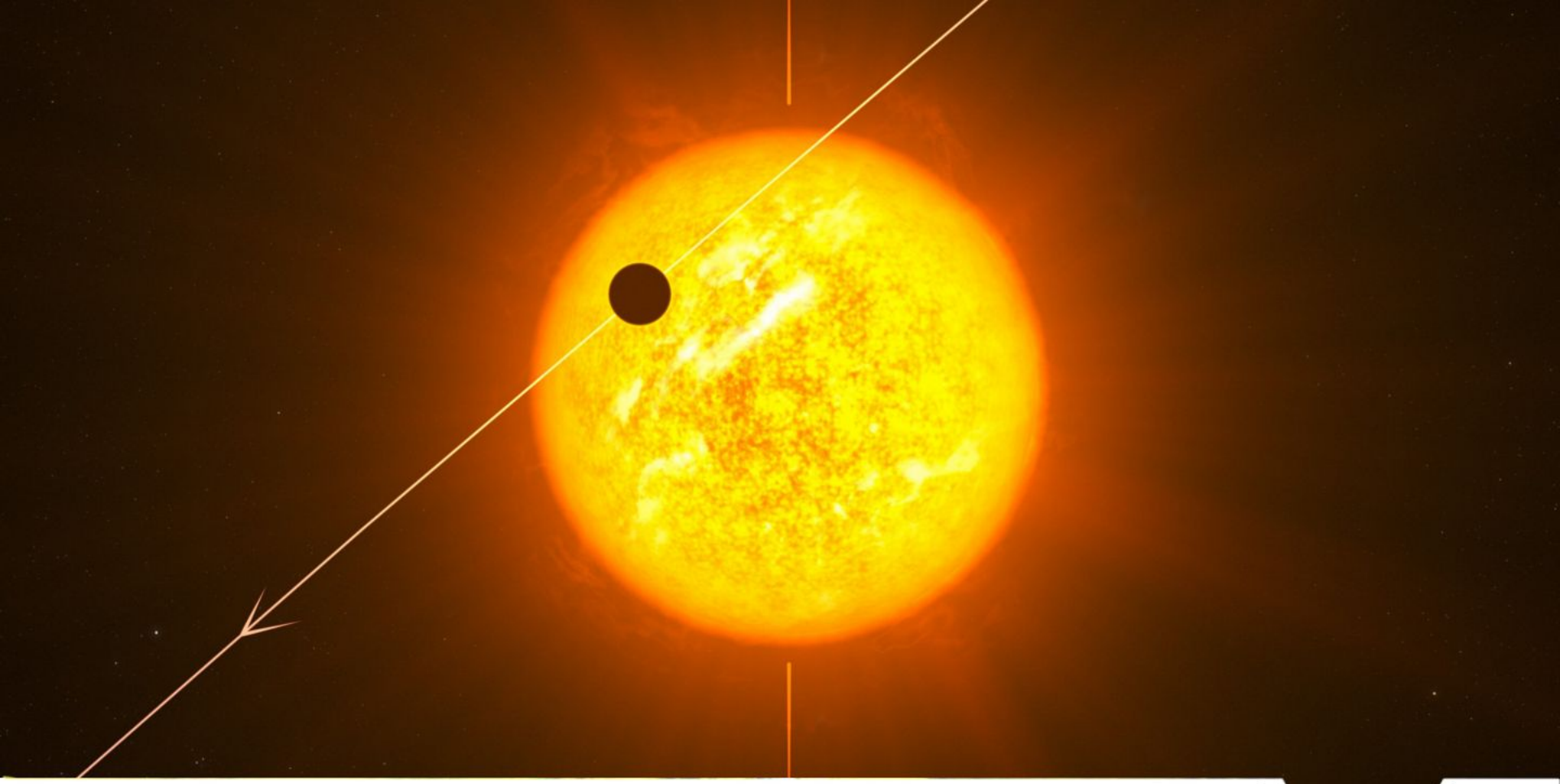
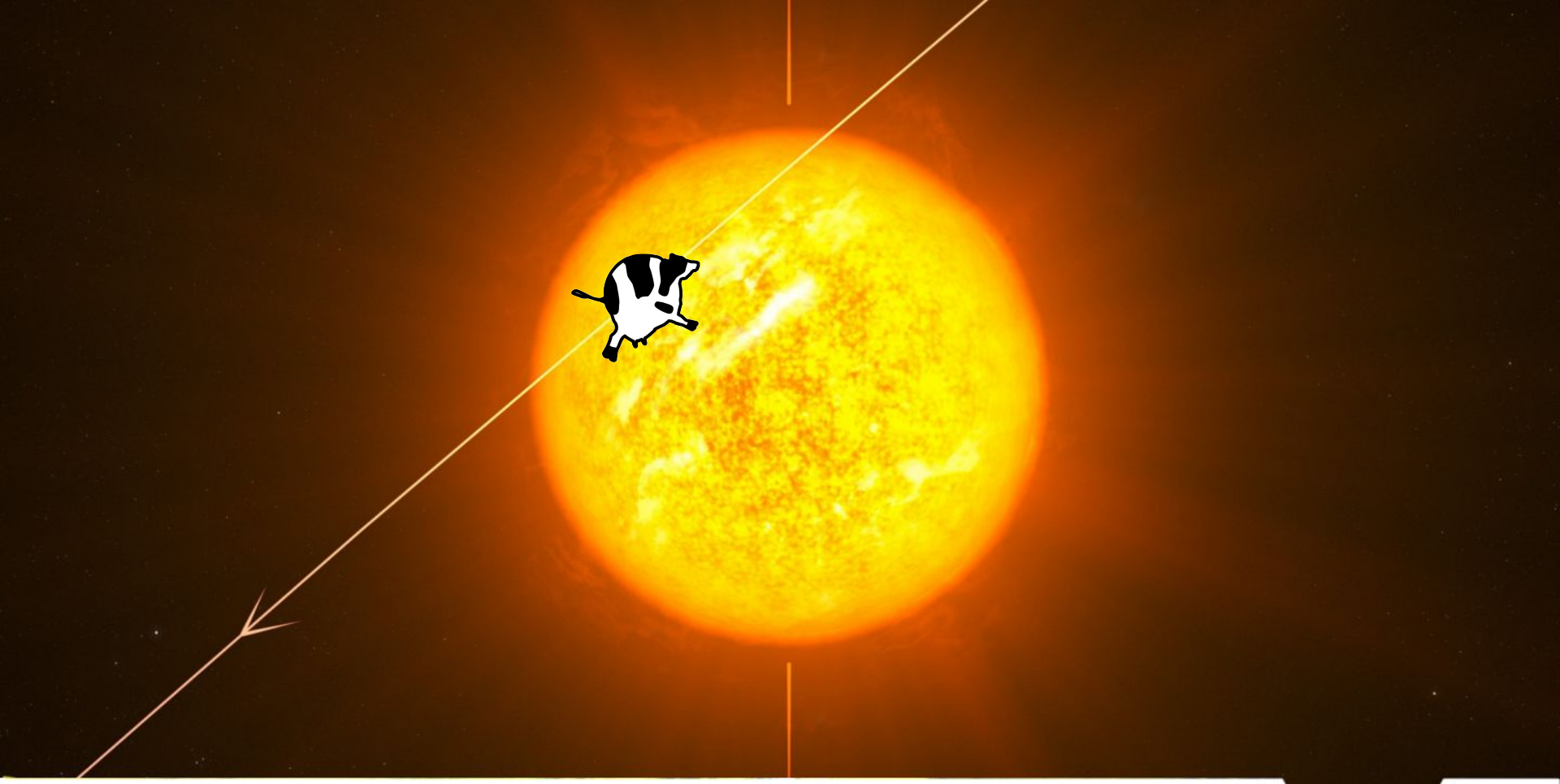


Single transit detections in the era of high-precision photometry

WARWICK

Hugh Osborn, Don Pollacco et al.

@HughO2



Single transit detections in the era of high-precision photometry

WARWICK

Hugh Osborn, Don Pollacco et al.

@HughO2

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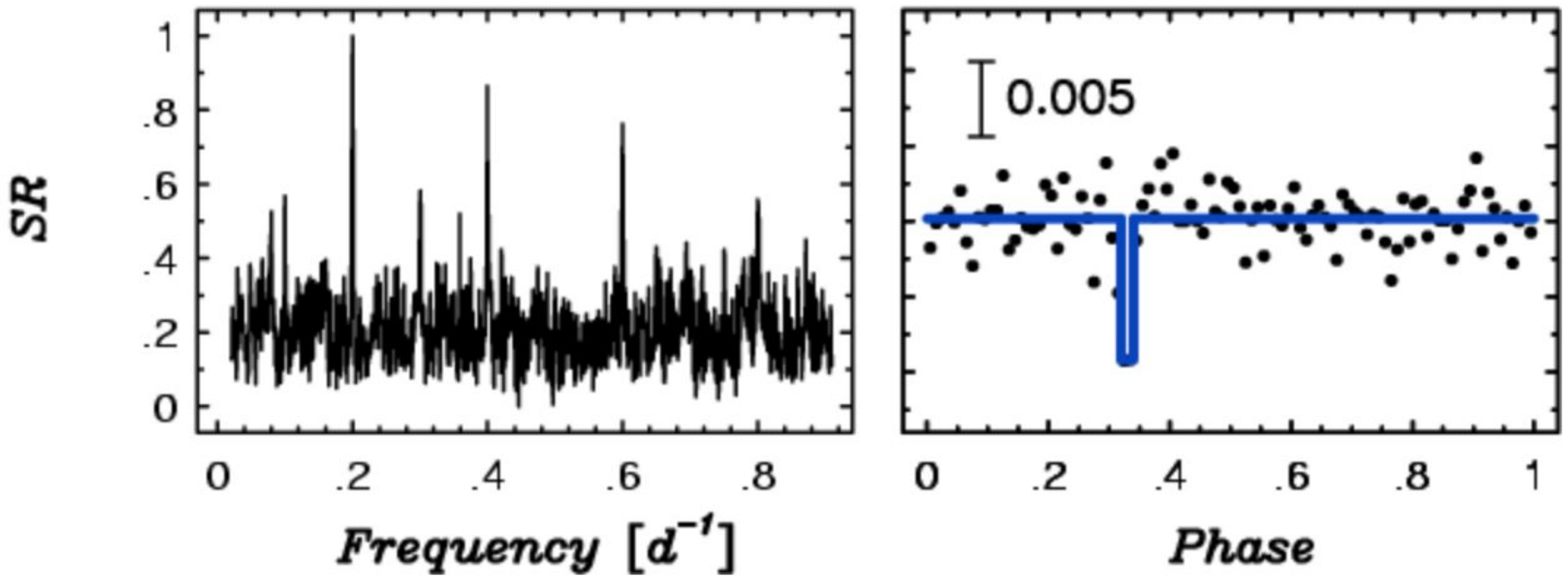
Outline

- What are Single Transits?
- How we can detect them?
- What we can do with them?
- Results from K2
- The future - NGTS, TESS and Plato

How we detect transits



- Transit searching done by phase-folding lightcurves.

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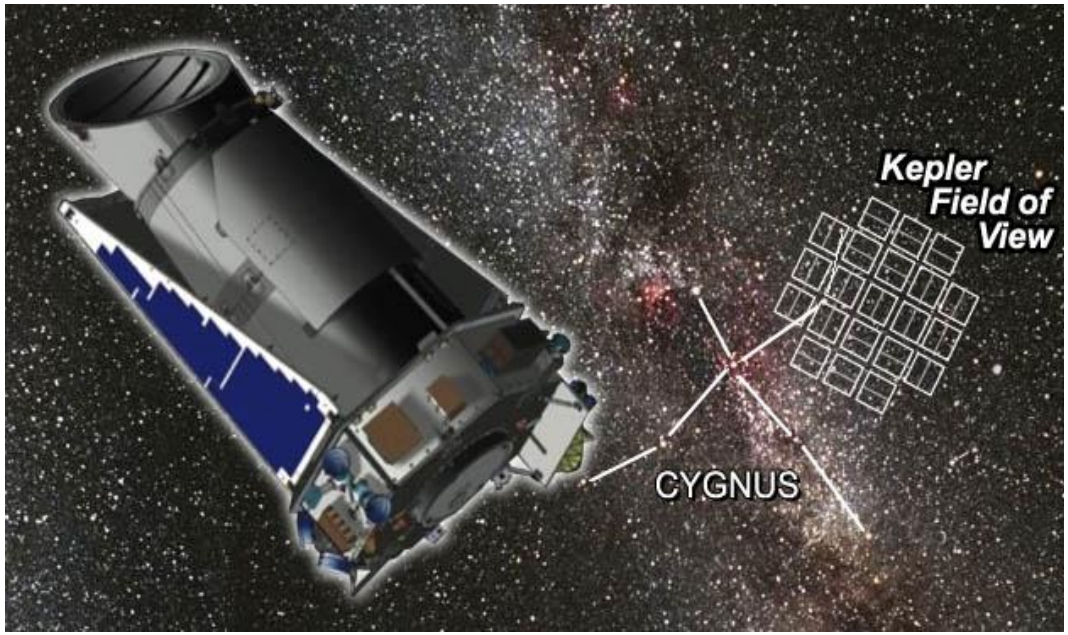
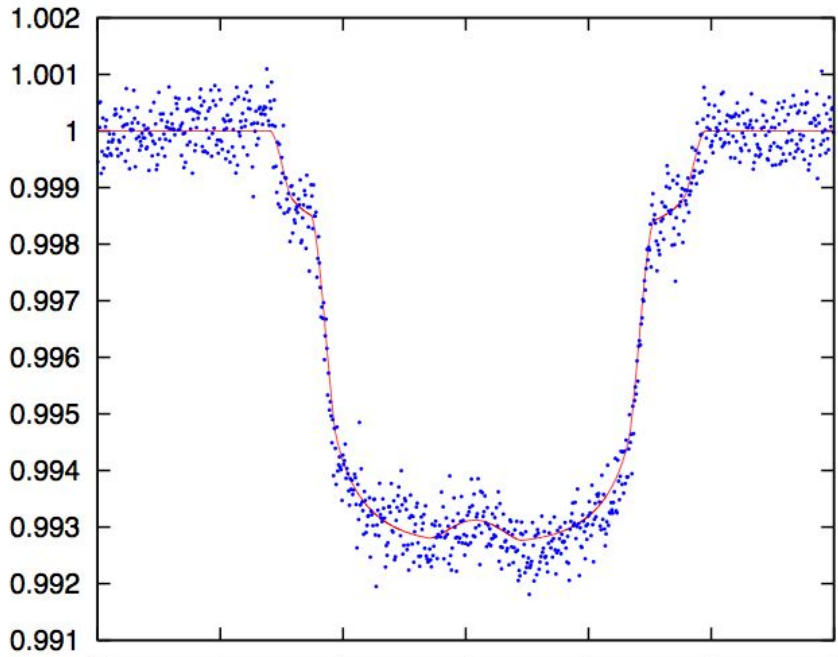
Kepler

- Typical precision of 100ppm hr^{-1}
- 4 year mission duration
- 1000 planets. 4000 candidates





The new era - K2

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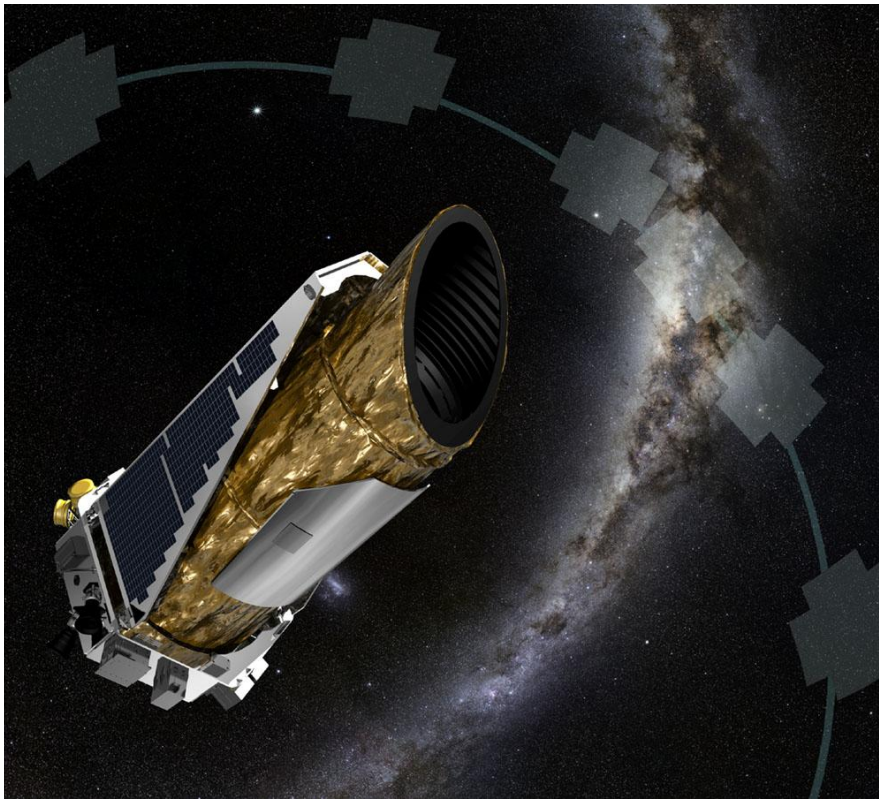
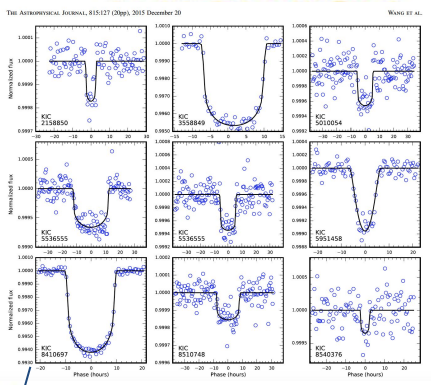
- Slightly reduced photometric precision
- 80-day campaigns on the ecliptic plane
- >100 planet candidates after 5 fields



K2 and Kepler



How Many Single Transits?

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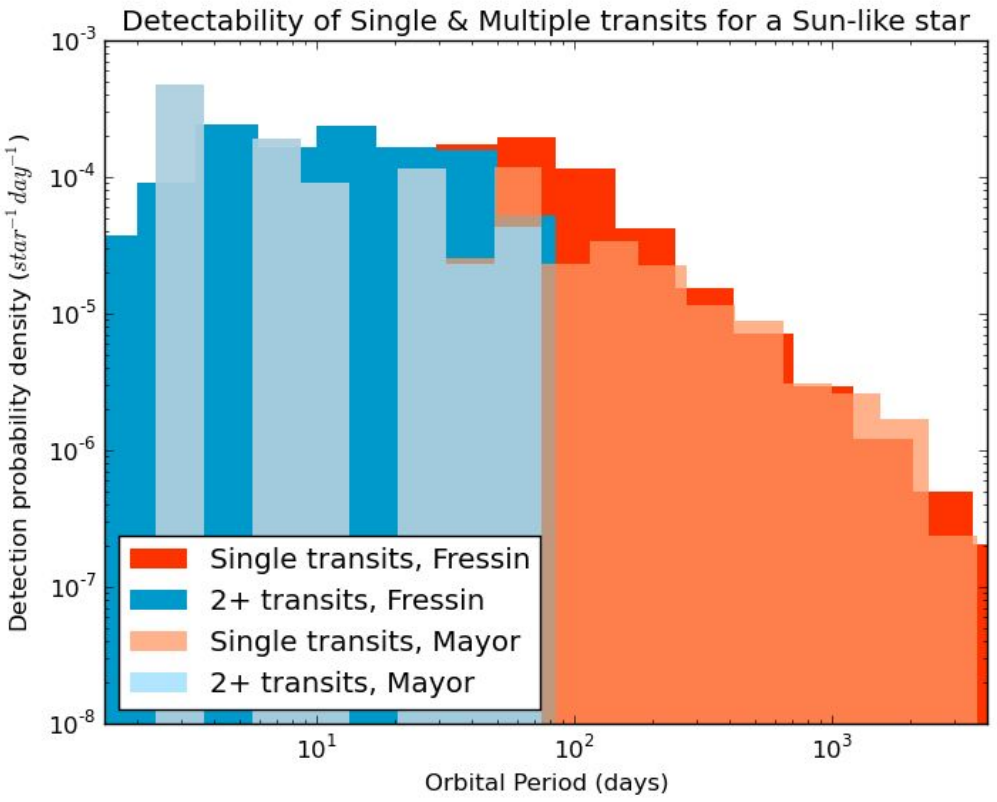
- ~0.15% of FGK stars have large transiting planets.
- Single transits on >0.(0.03% of FGK stars.
- >1 per 4000 stars.
- 10,000+ stars per fiel(



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Why Search for Long-Period Planets in K2?

- Many bright stars; follow-up possible
- Test planet formation (eg RM)
- Sample different atmospheres with, eg, JWST
- Habitable Zone, Exomoons
- Mass-radius relationship dominated by hot (inflated) planets.
- Improve occurrence rates

Single Transit Fitting

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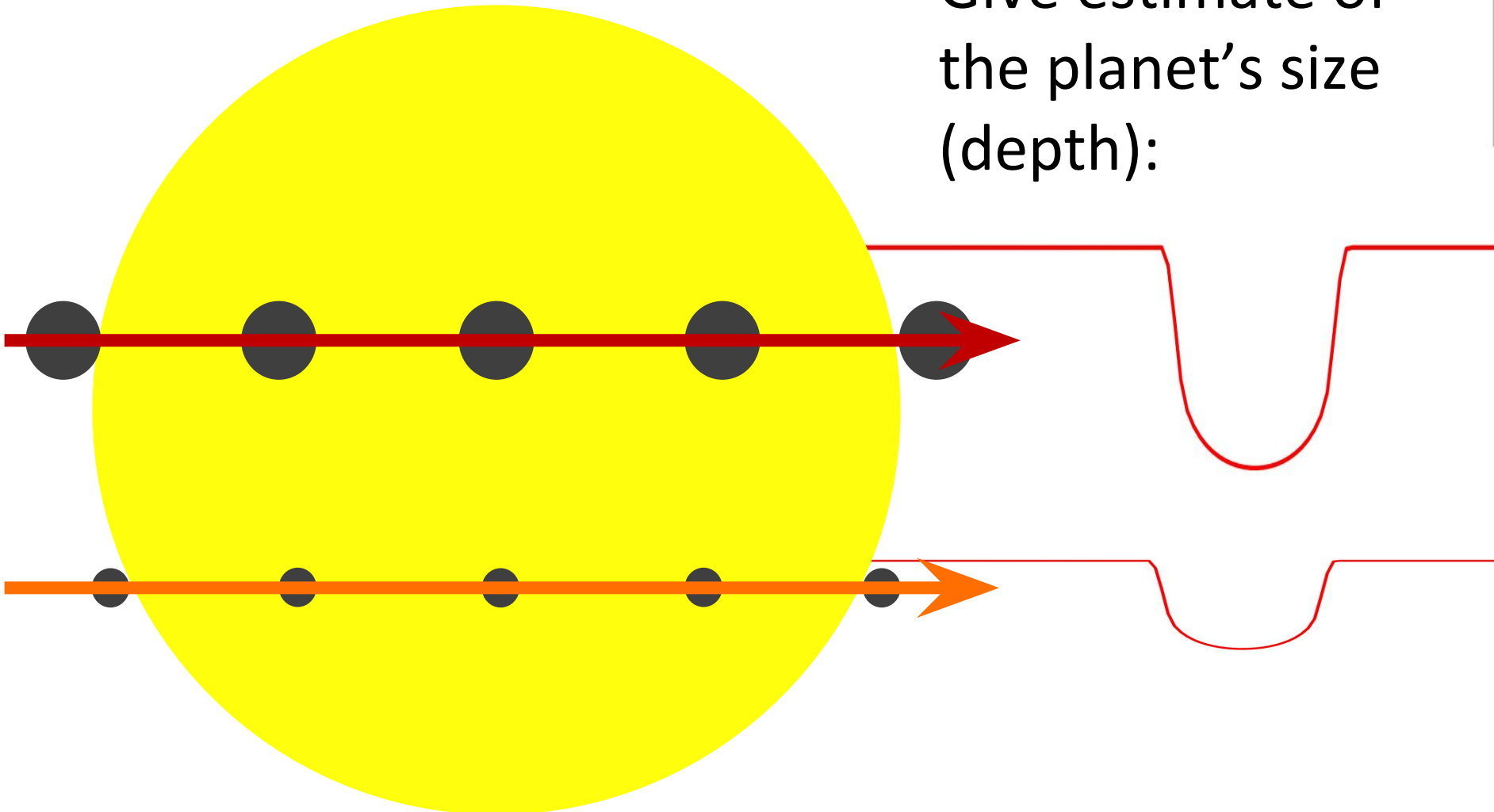
- Give estimate of the planet's size (depth):



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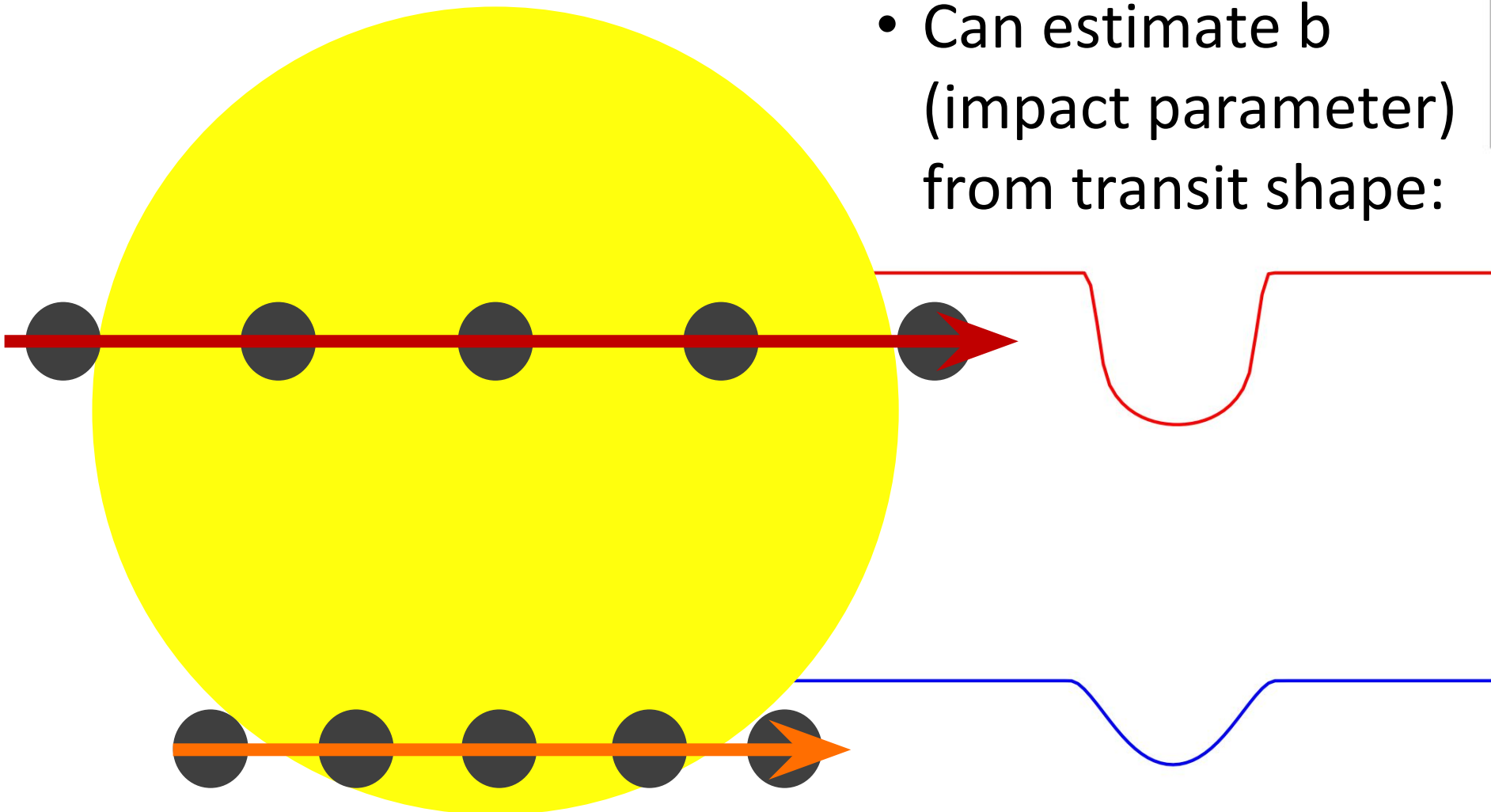
Single Transit Fitting

- Can estimate b (impact parameter) from transit shape:



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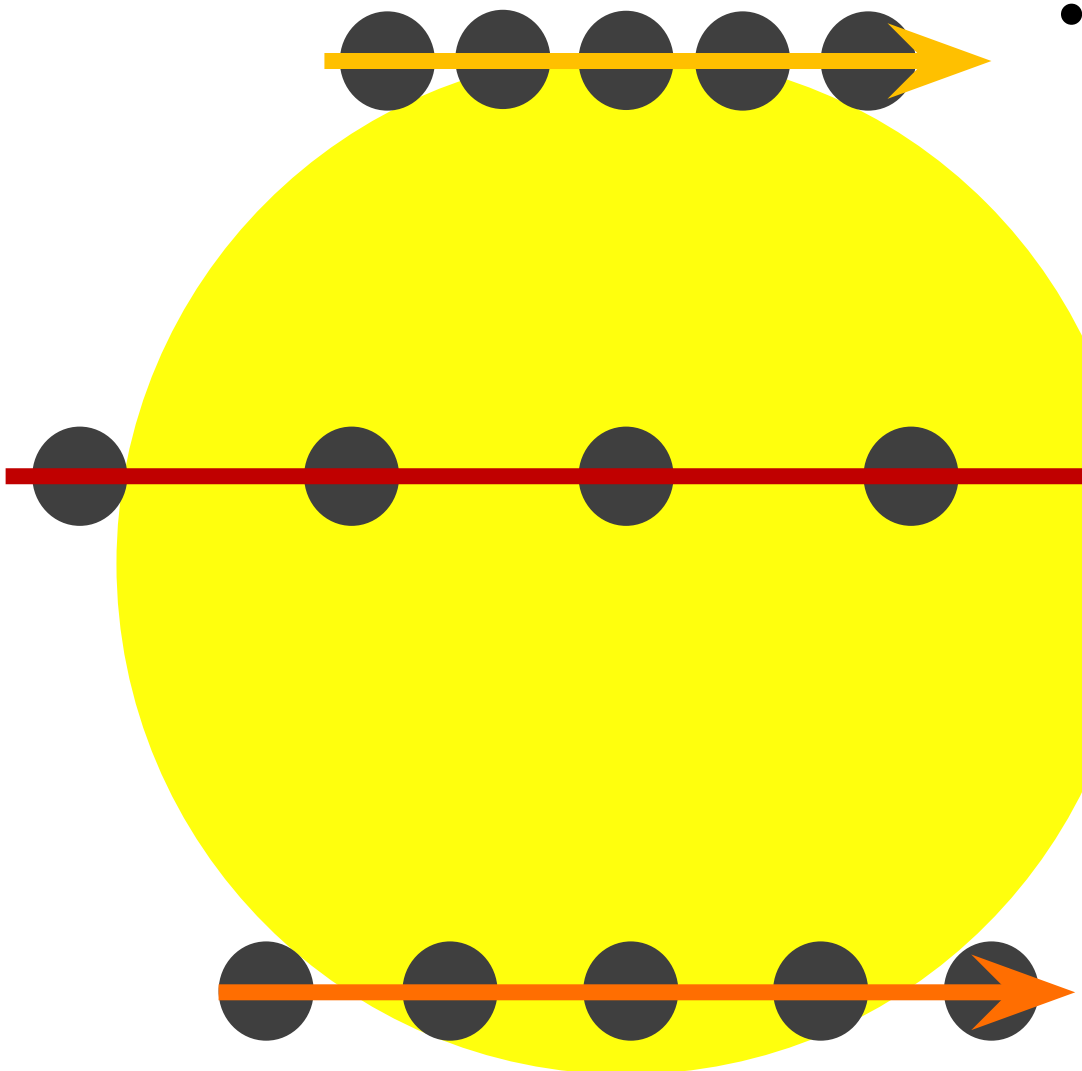
Single Transit Fitting



- Impact parameter tells you the length of the path the planet crosses

- Duration & b gives the planet's velocity across the stellar disc

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Single Transit Fitting

- From Velocity, can estimate a circular period from Kepler's laws:

$$P_{\rm circ} = \frac{8\pi^2 G}{3}\frac{\rho_\star}{v'^3} = 2\pi\frac{g}{R_\star v'^3}$$

- Need to know the stellar density (often poorly constrained)

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Single Transit Fitting

Problems:

- Impact Parameter is poorly constrained for small bodies.
- Grazing transits can be caused by any size occulter - star or planet.
- Eccentricity is unknown - have to assume a circular orbit.

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Namaste

- "*Namaste*: An Mcmc Analysis of Single Transiting Exoplanets"*
- Bayesian fitting code for Single Transits
- MCMC used to estimate uncertainties
- Now includes Gaussian Processes

* (Available at https://github.com/HPOsborn/Namaste)

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Namaste

- T_star from Photometric colours (V,J,H,K)
- Assume the star is Main Sequence to estimate Rs & Ms.
  - Density uncertainties often ~50%.
- Assume eccentricity = 0
- Limb Darkening estimated from Ts

Testing Namaste: Kep-167e

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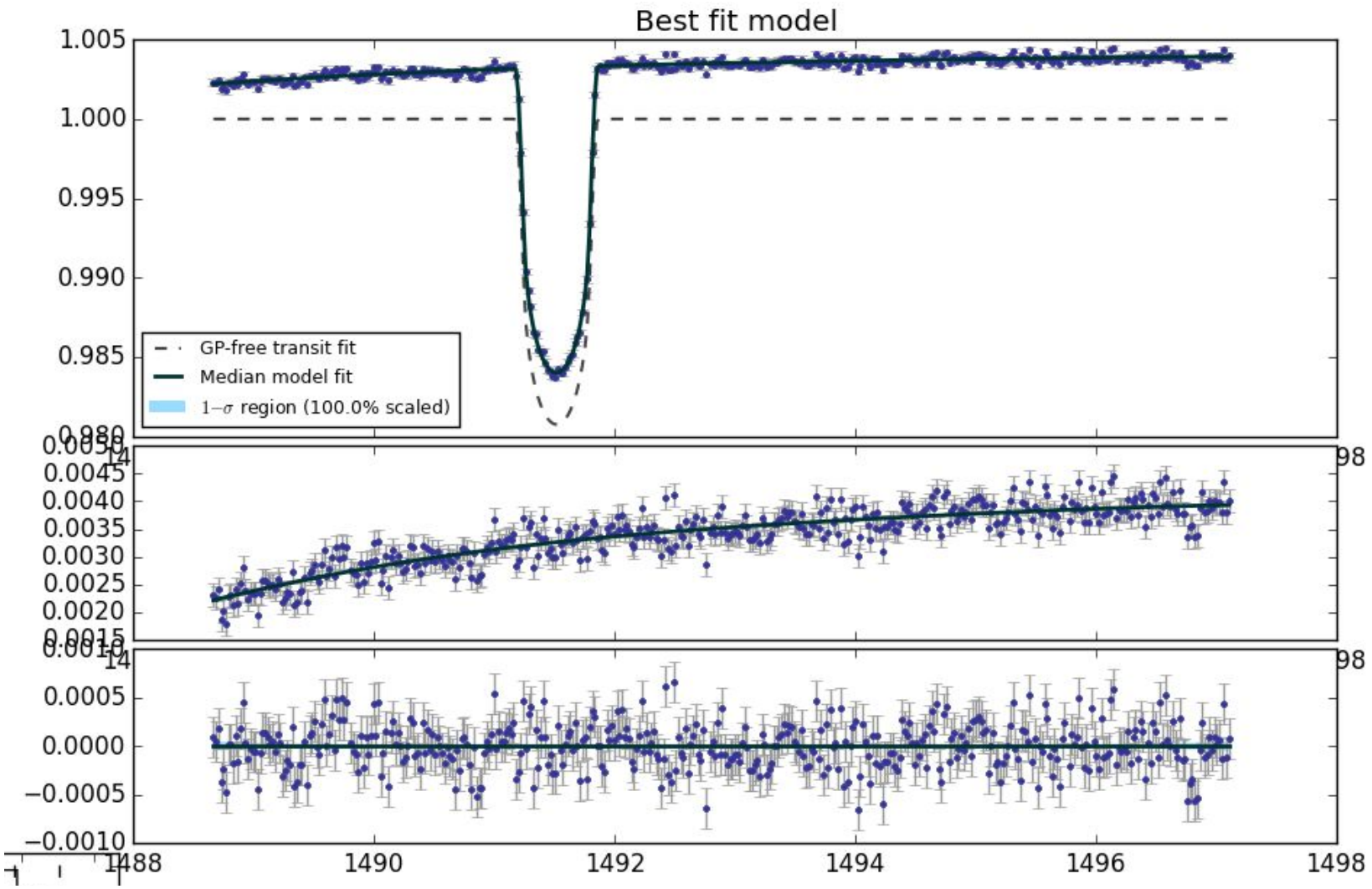
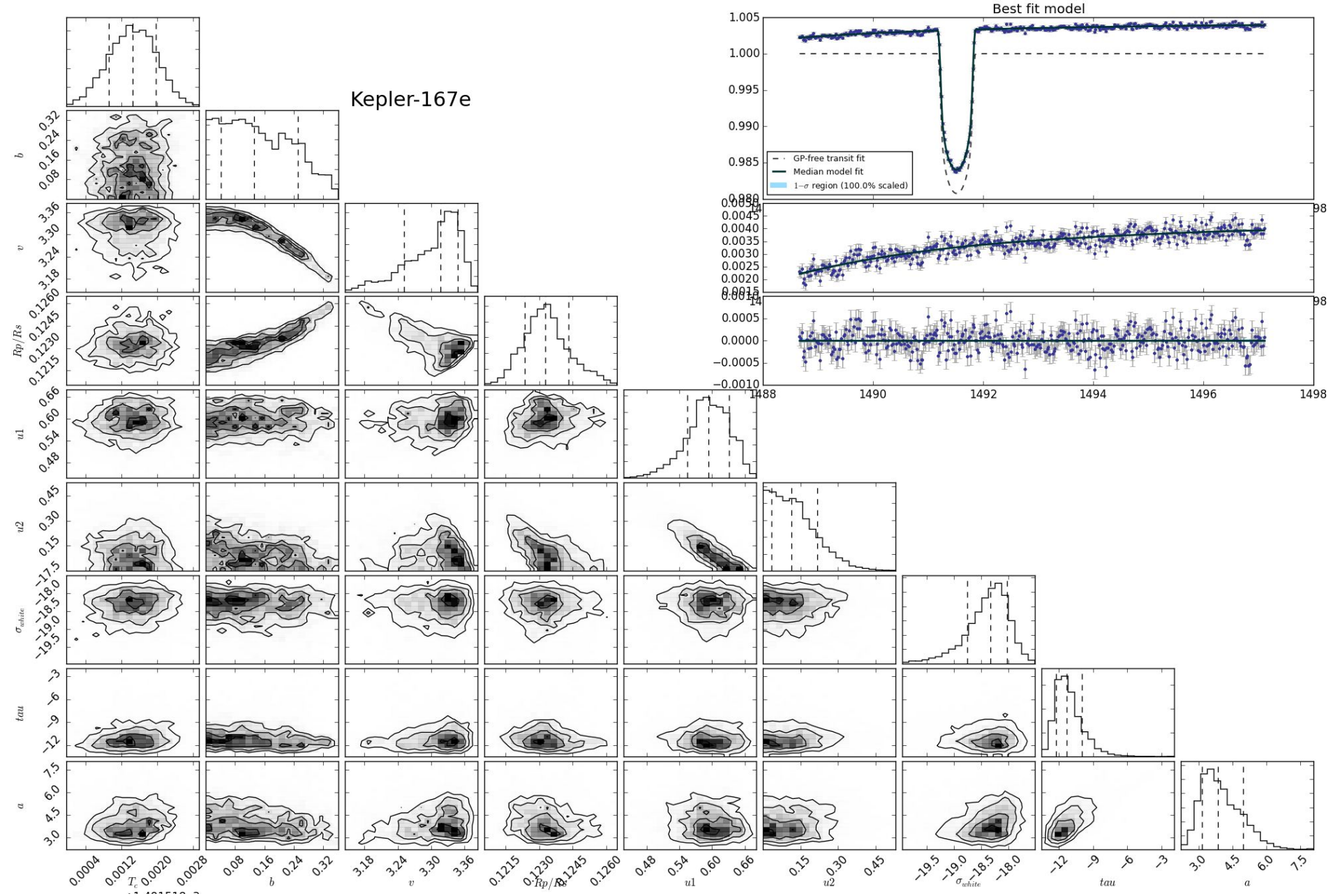


Hugh Osborn


Kepler-167e
Best fit model
GP-free transit fit
Median model fit
1−σ region (100.0% scaled)
b
v
Rp/Rs
u1
u2
σwhite
tau
a
Tc

Testing Namaste: Kep-167e

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- Precise stellar parameters
- Density constrained by other planet transit durations.

Orbital period:

- From Kipping, 2016: 1071d
- From Namaste: 1014+/-90days.

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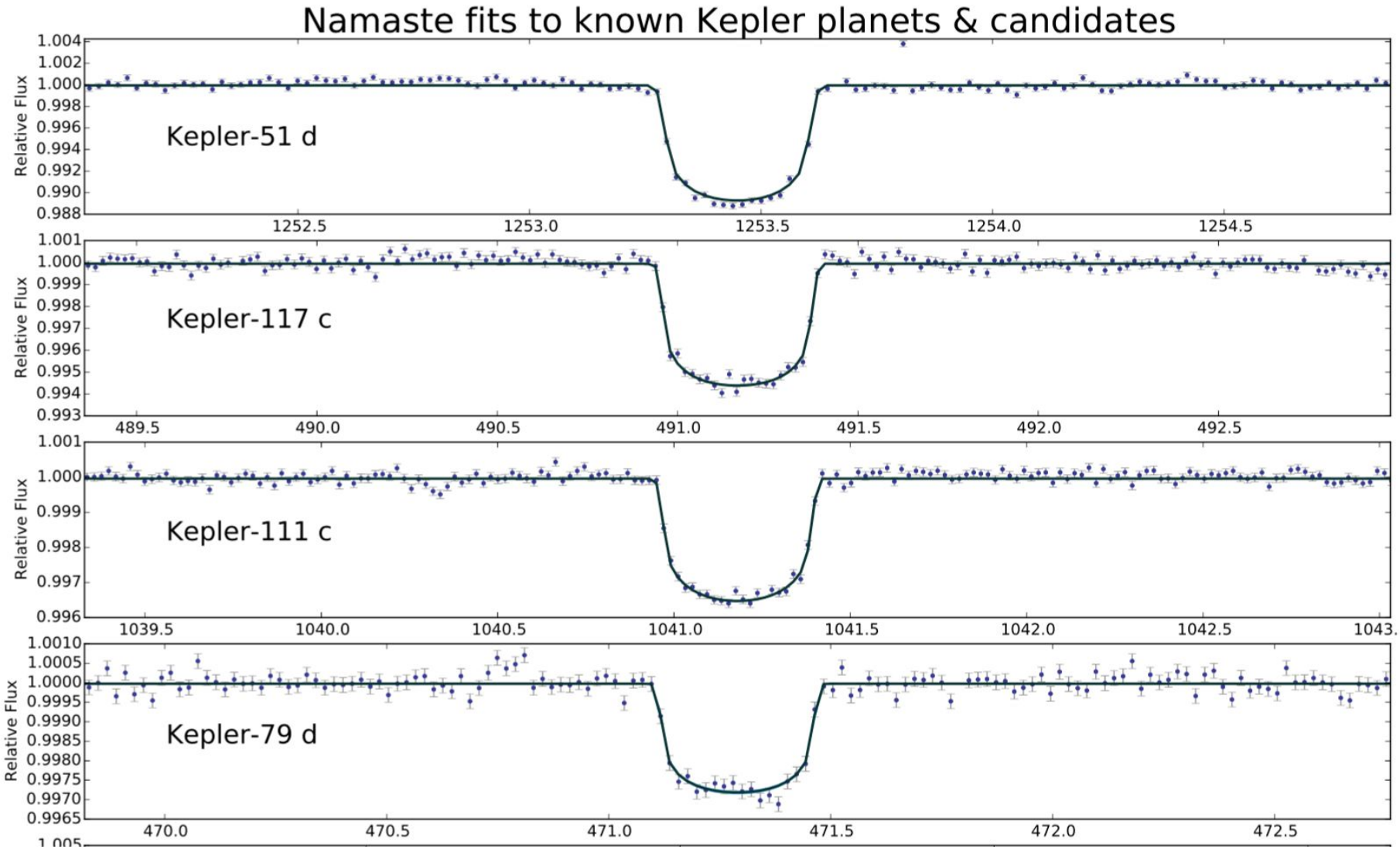
Testing Namaste



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Namaste

- Kepler 51 d:

  Period: **138** +20/-10 True: **130.2**
- Kepler-117 c:

  Period: **53** +5/-19 True: **50.79**
- Kepler-111 b:

  Period: **240** +130/-90 True: **224.78**
- Kepler-79 d:

  Period: **55** +71/-3 True: **52.09**

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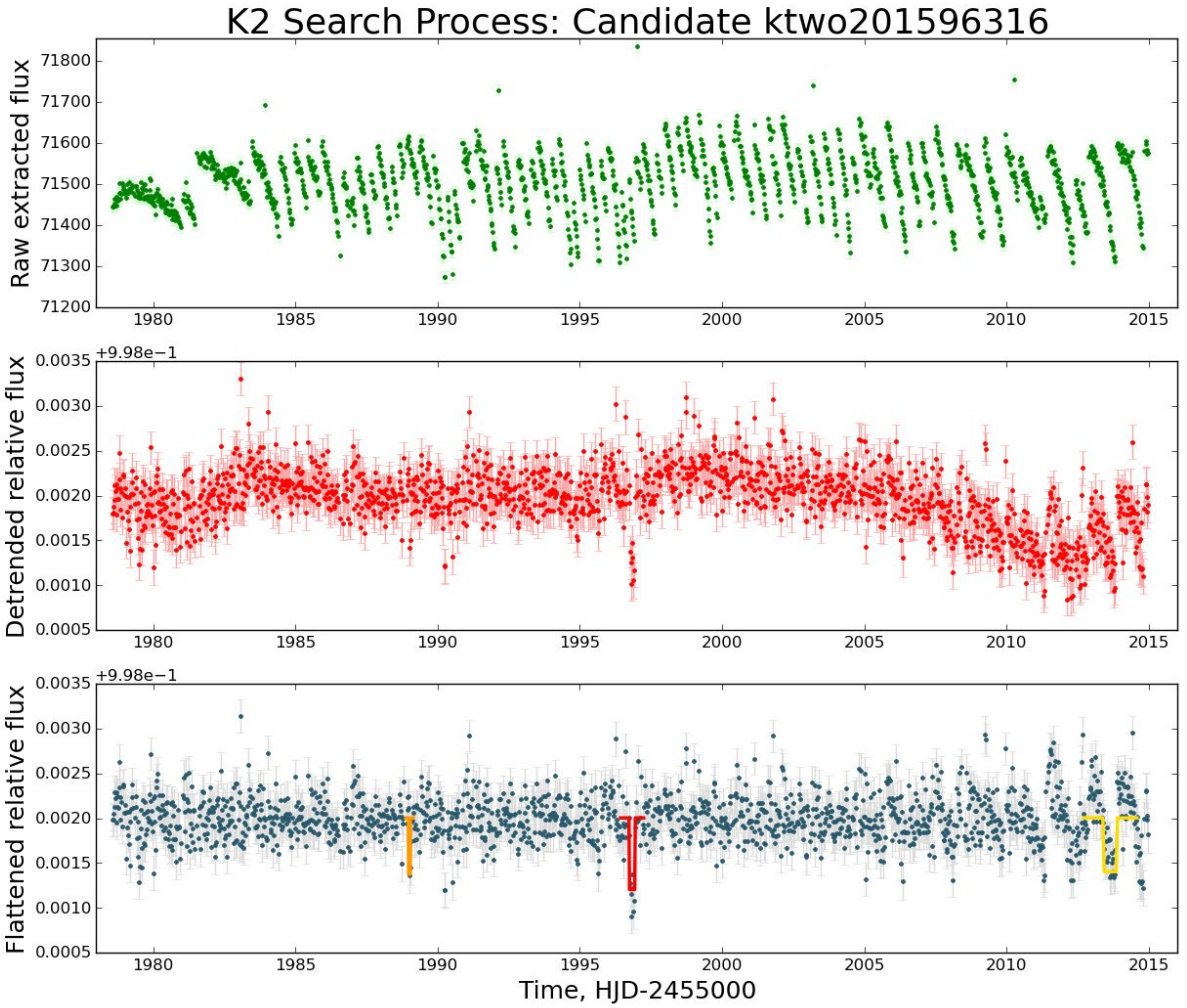
K2 Planet Search

- Detrended lightcurves
- Iterative search with transit models.
- Eyeball best candidates



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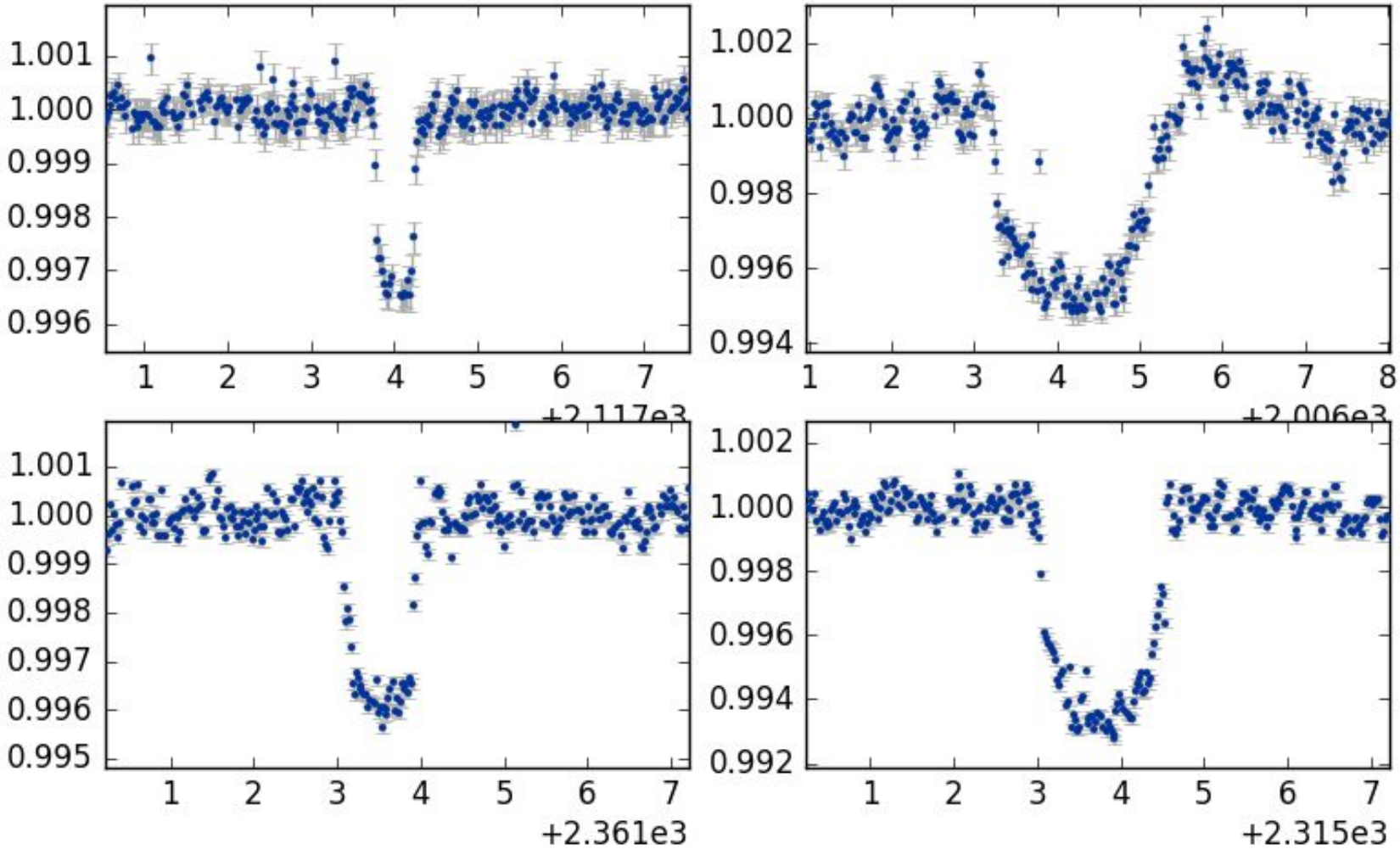
Results - Neptunes



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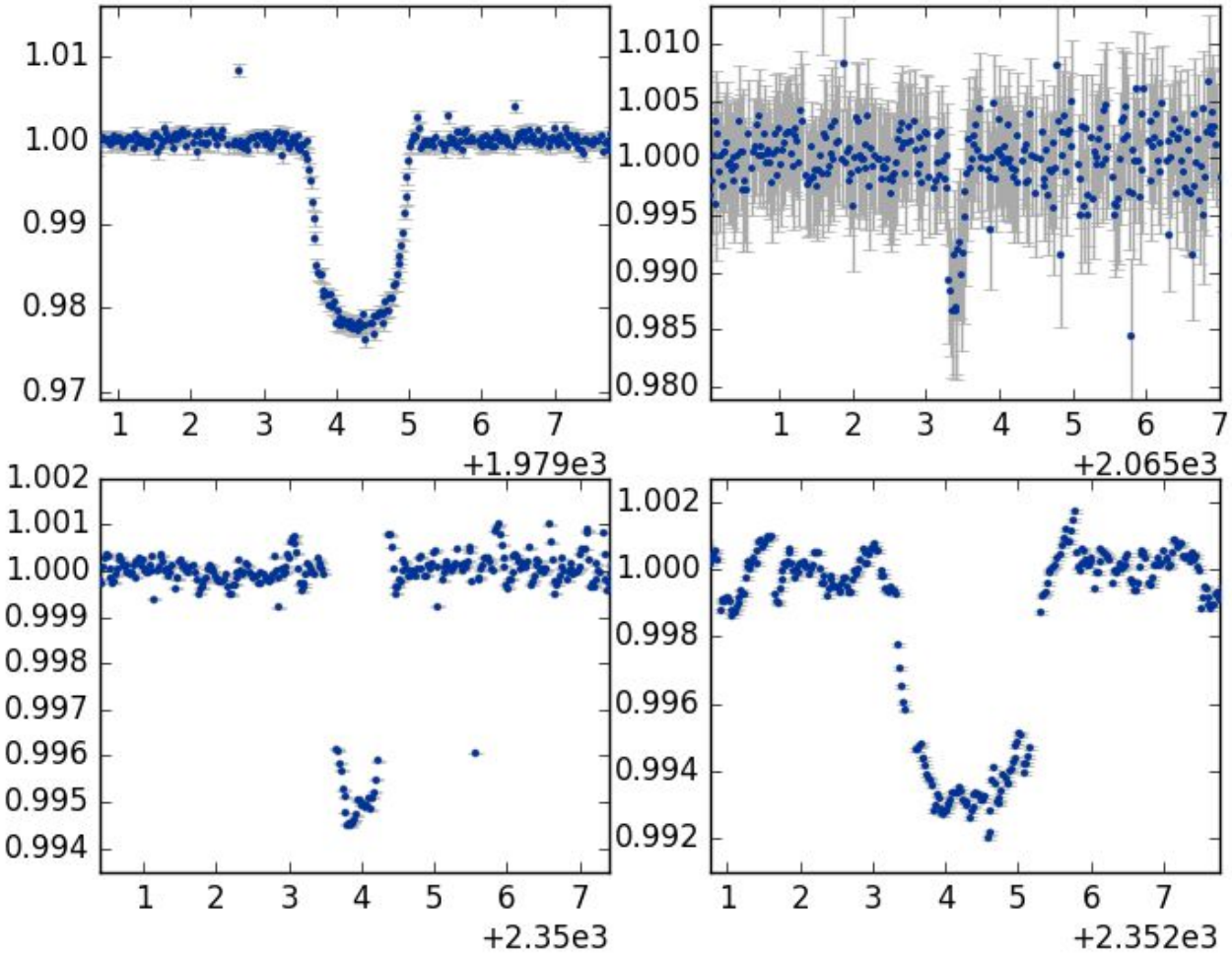
Results - Jovians



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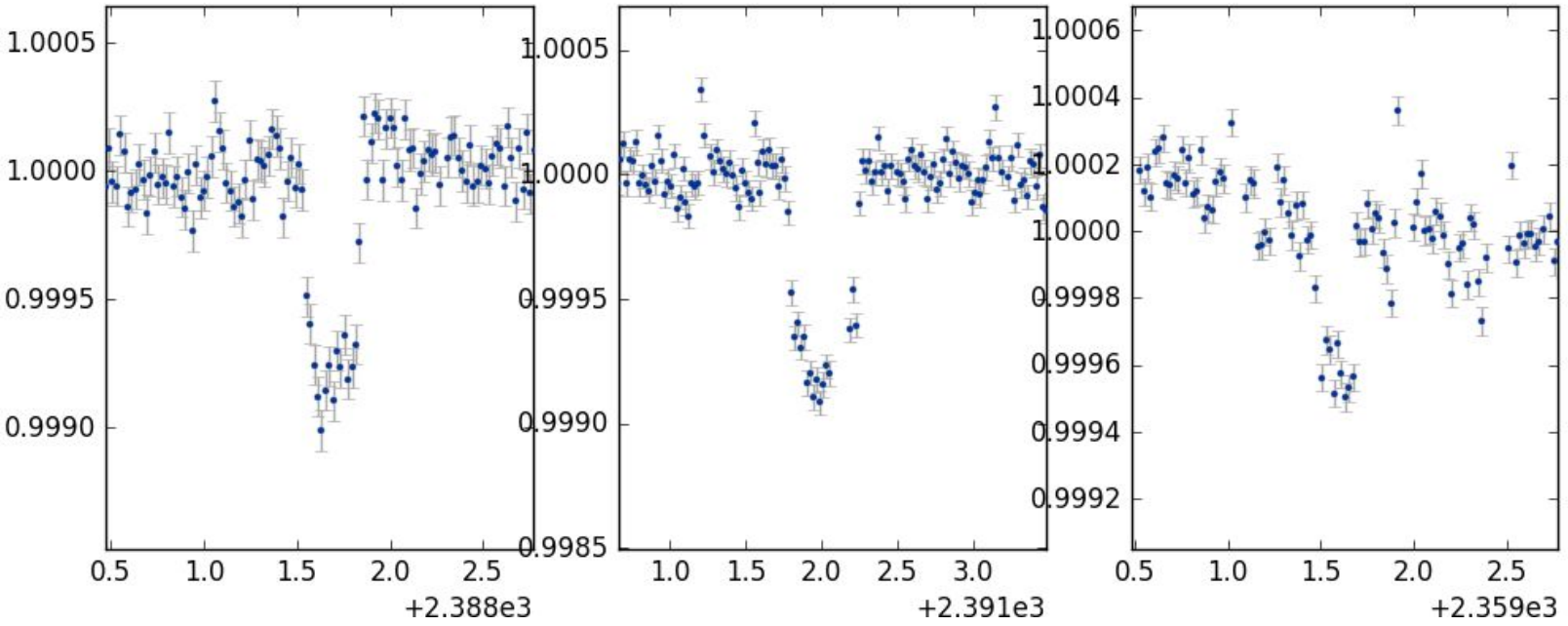
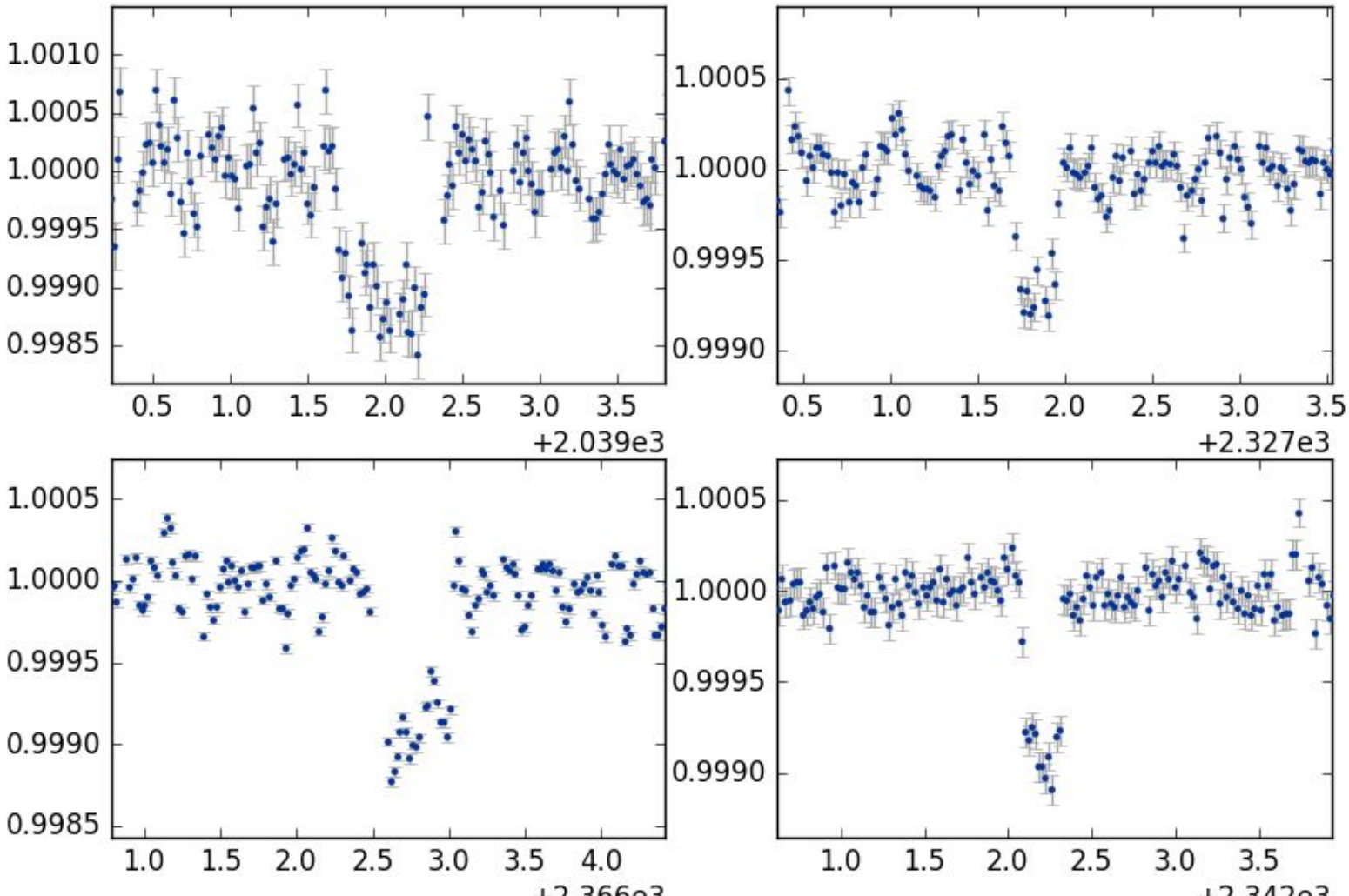
Results - Super-Earths

Depths < 1mmag



WARWICK

Results - Super-Earths



Results - High-b or high-ecc?

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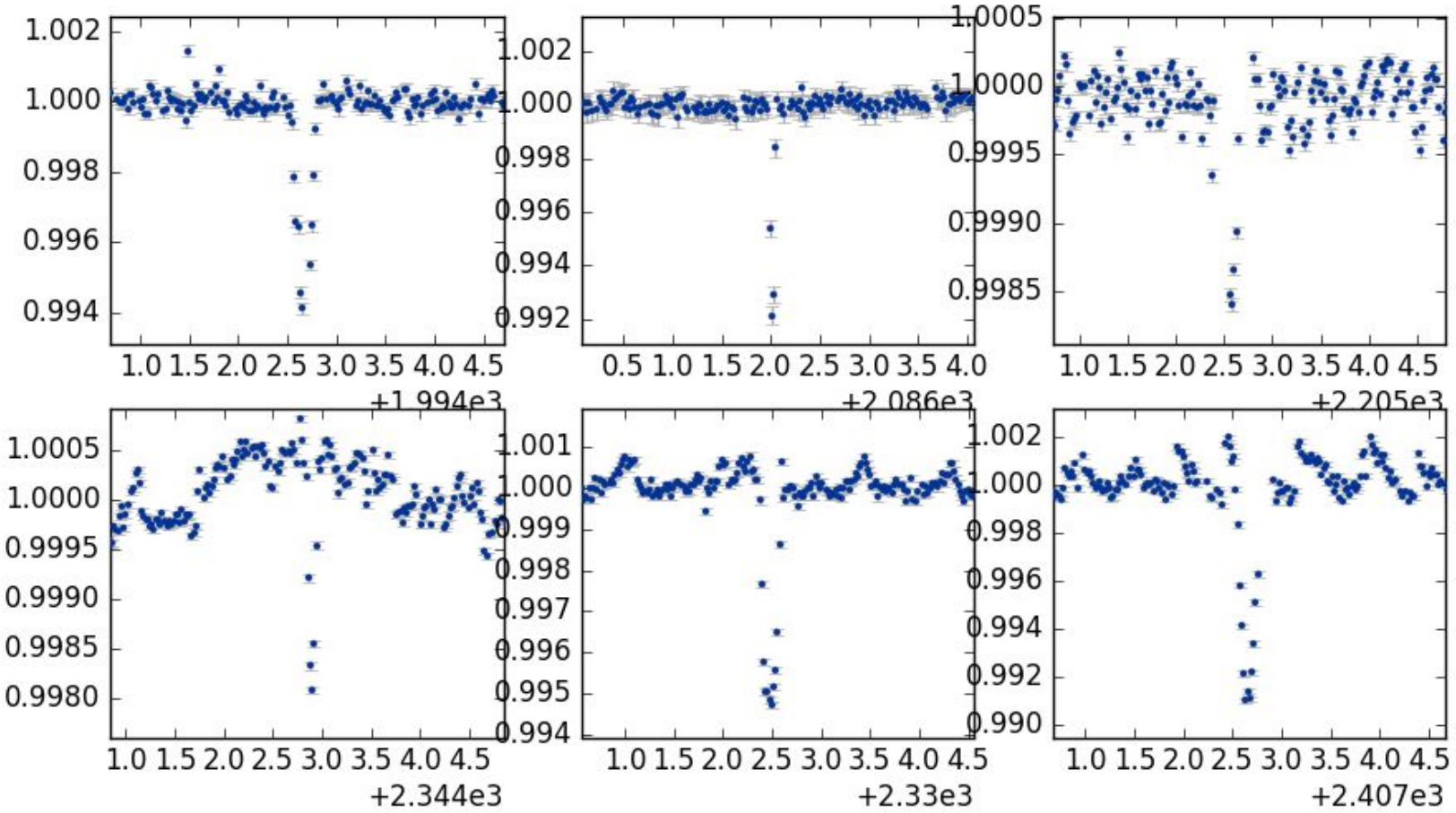

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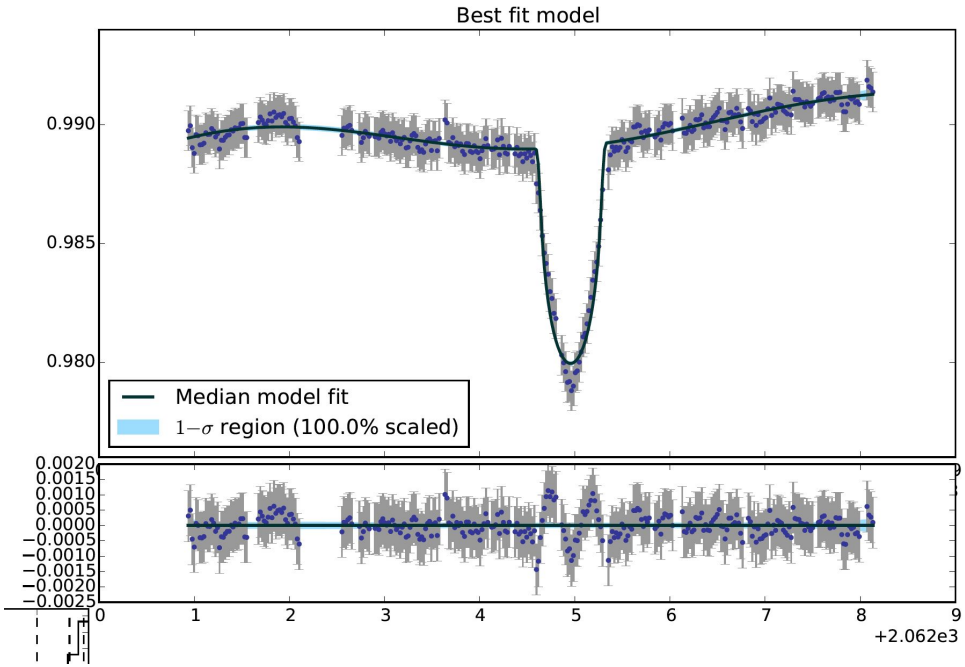
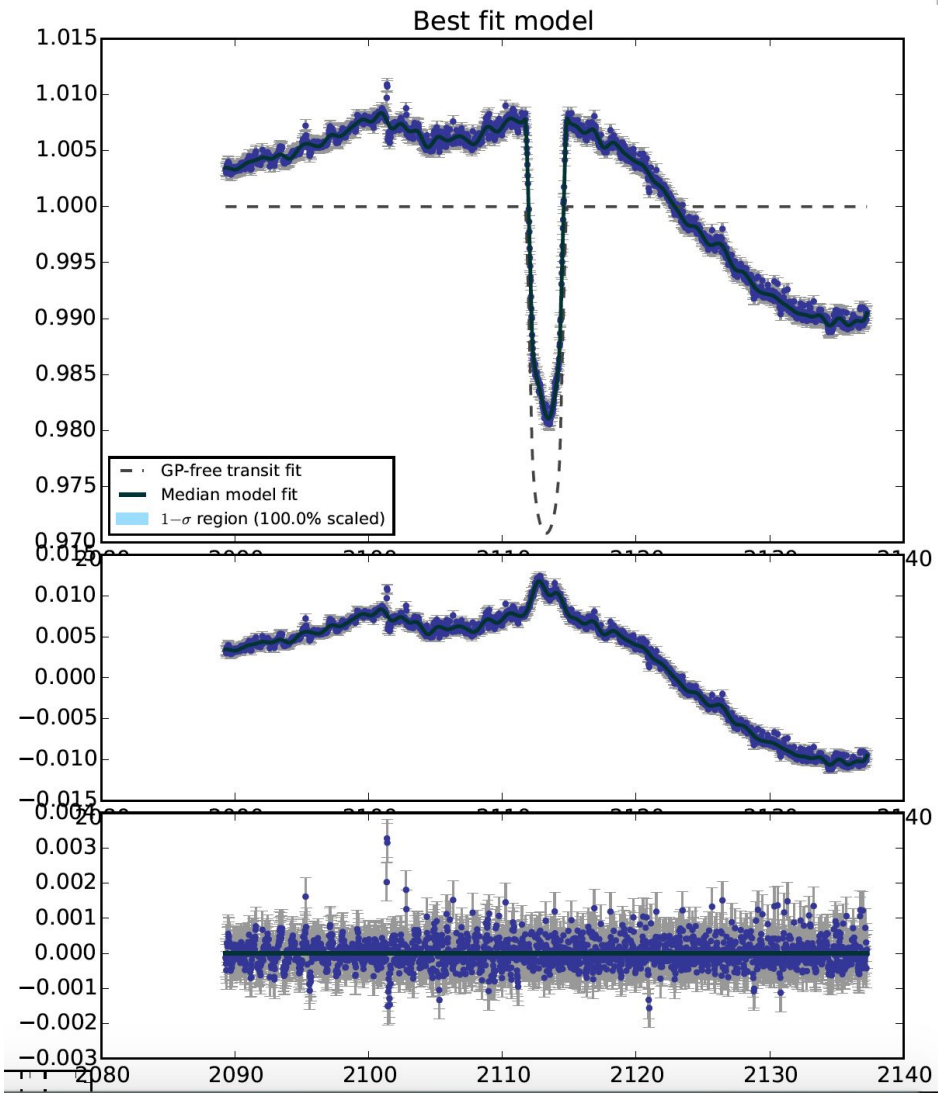
Results

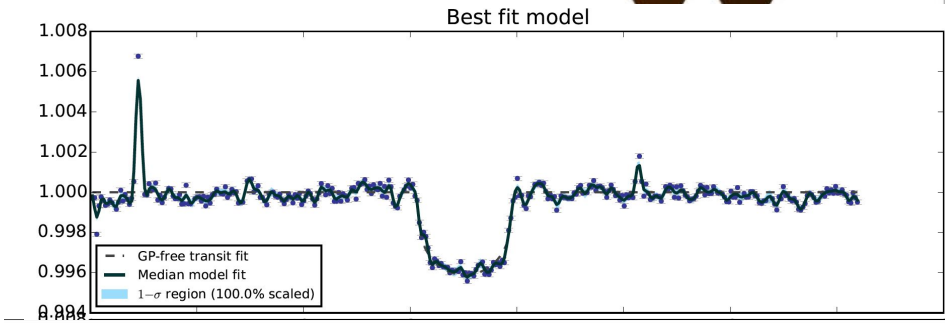
- False Positives

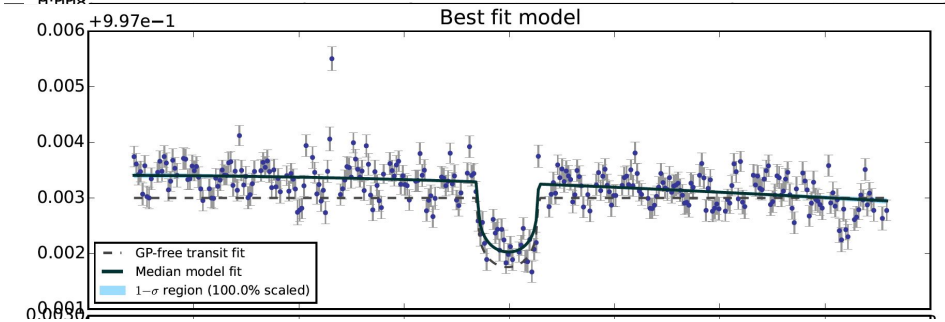


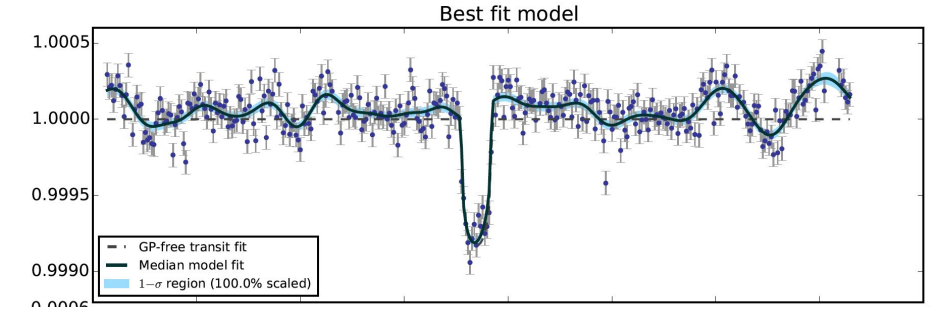


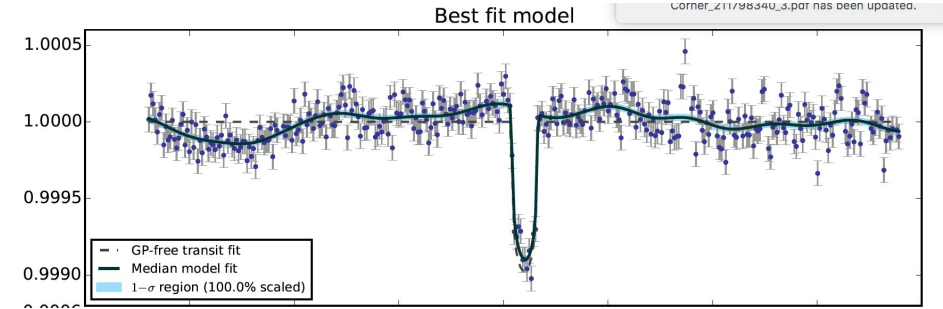
Results

- ~35 Candidates
- ~15 ‘A’ Candidates to be followed up
- Gaussian Process fits & orbit predictions ongoing



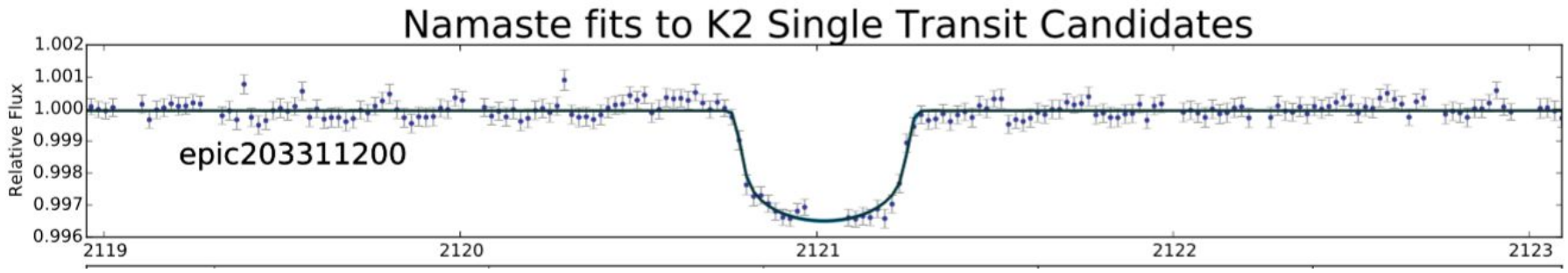






WARWICK

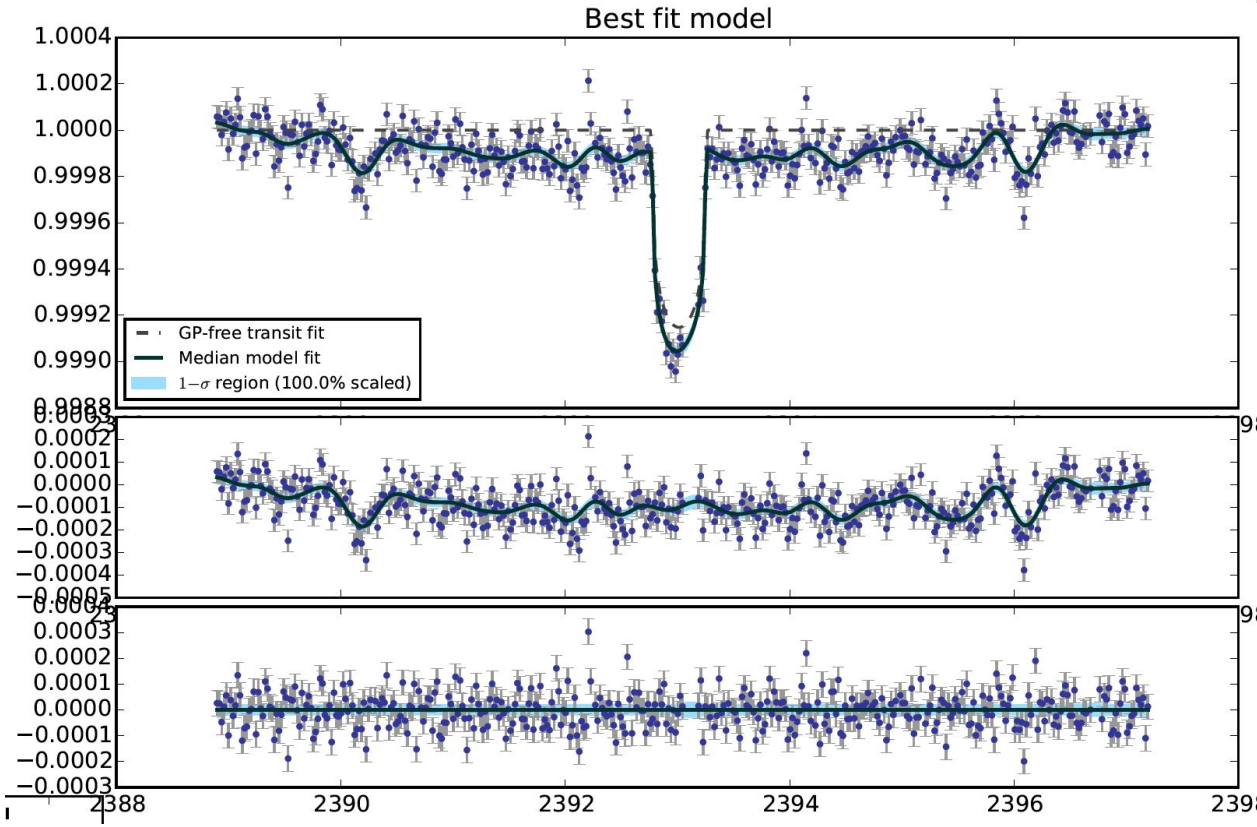
Results



- EPIC 203311200:
  - Kepmag: 11.9
  - T_star: 5200K±200K
  - Radius: 0.51±0.05Rjup
  - Period: 540d+410/-230

New Results

- Kepmag: 11.193
- T_star: 5300±150
- Radius: 2.4±1.0 R_earth
- Period: 250+800/-160 d



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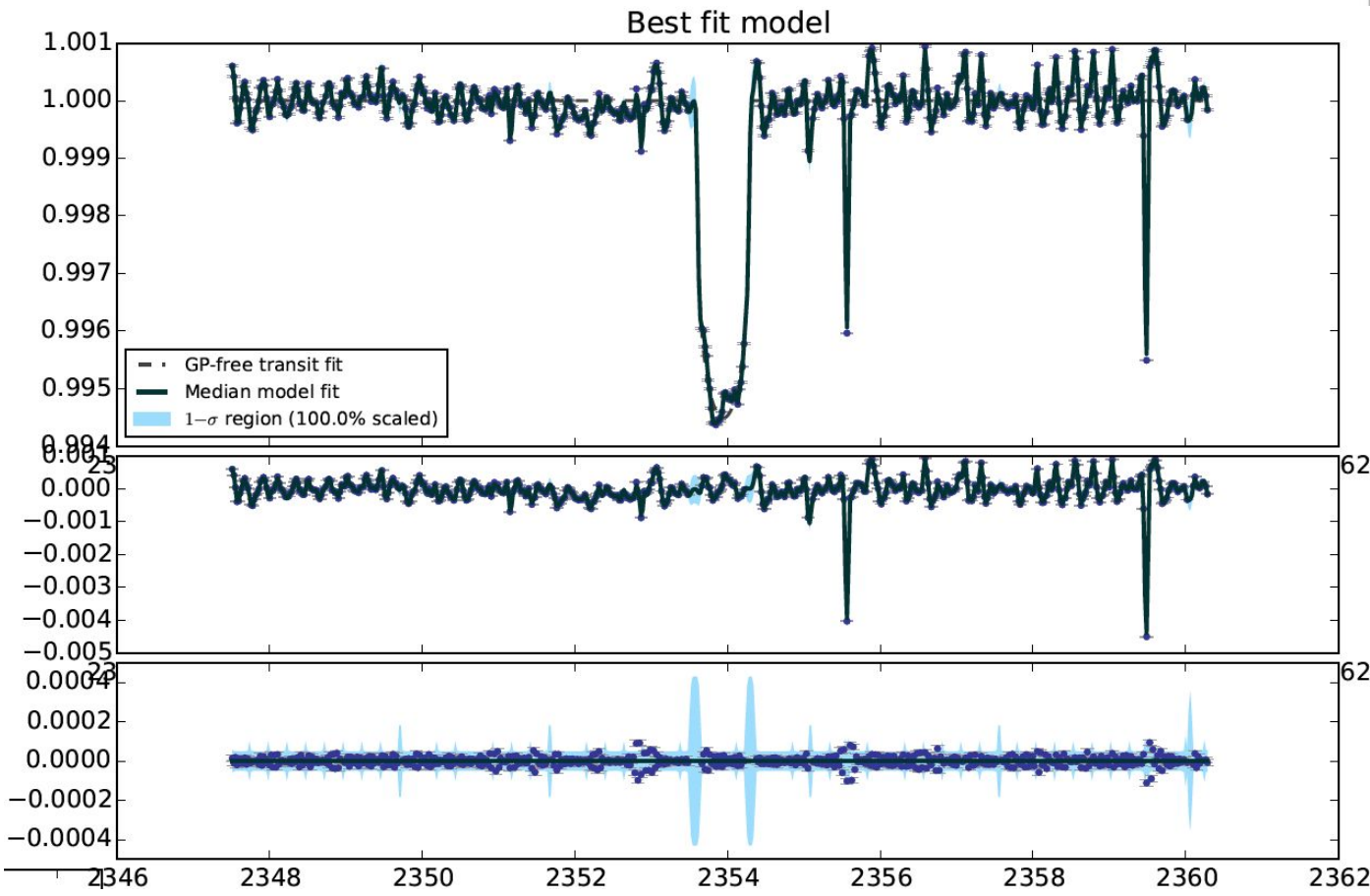
Results

- Kepmag: 9.128
- T_star: 4900±400
- Radius: 0.6±0.2 R_Jup
- Period: 1000+4000/-700 d



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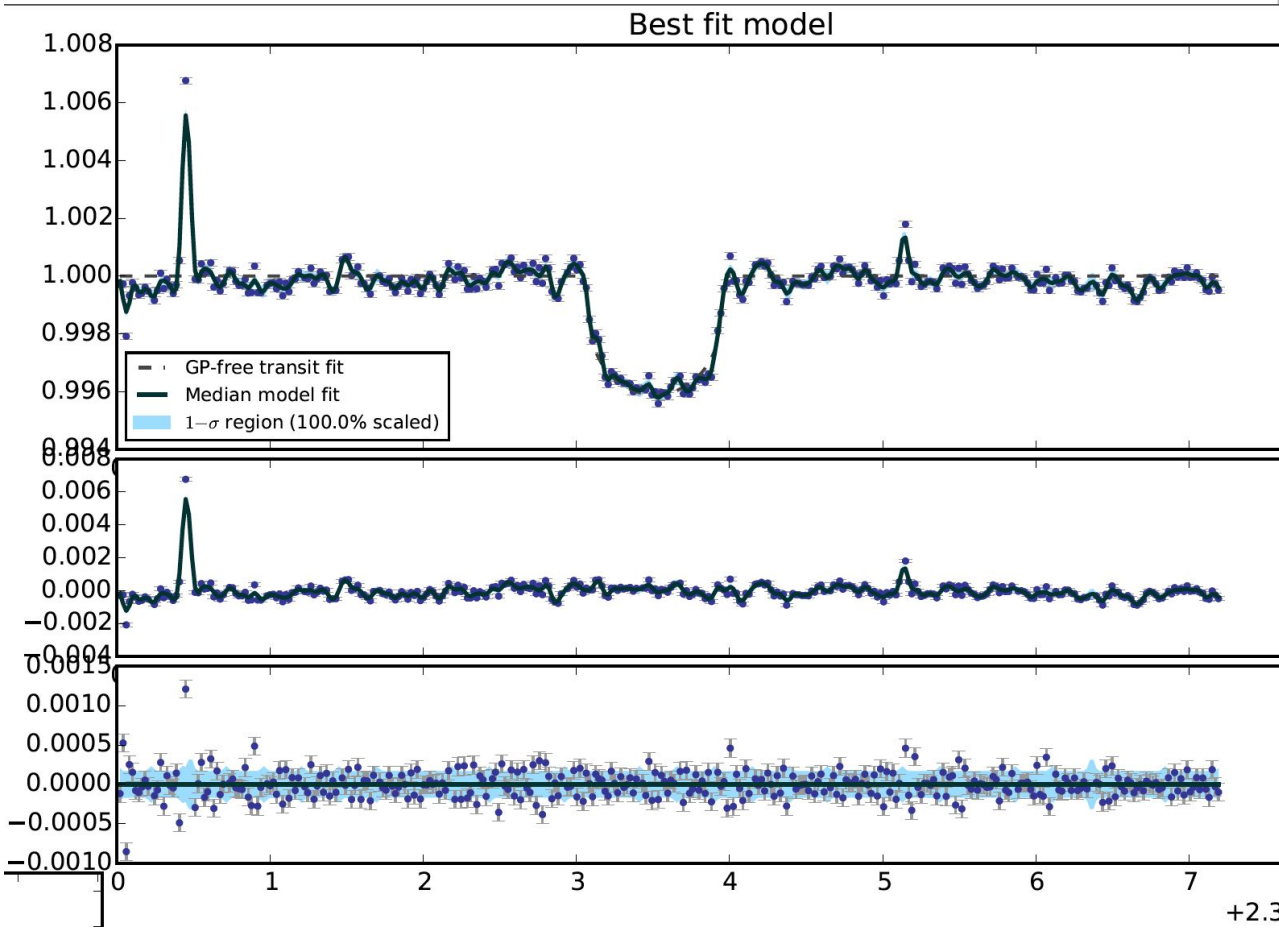
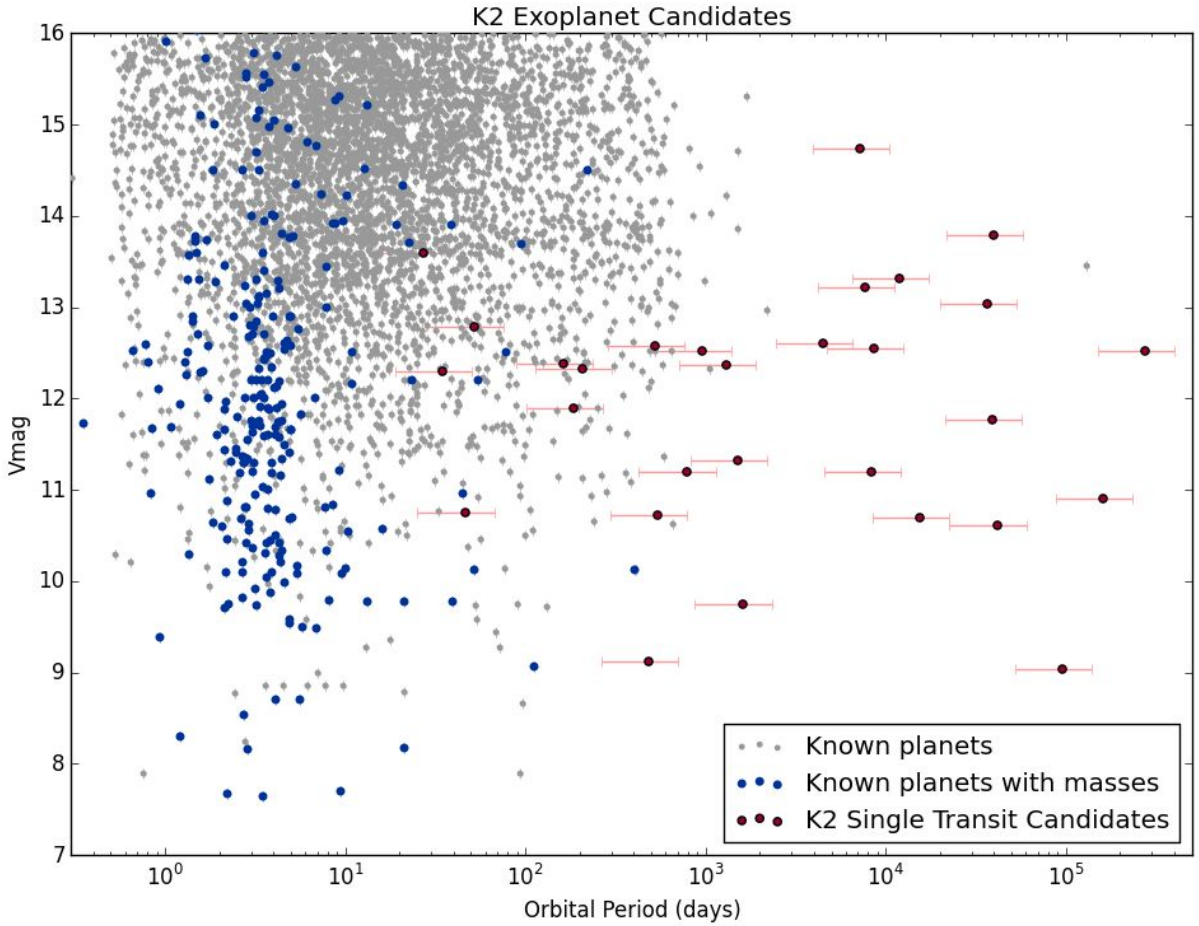
Results

- Kepmag: 13.2
- T_star: 4500±300
- Radius: 4.6±1.8 R_earth
- Period: 2650-1200/+10800 d



WARWICK

Results



- *Minimised fits used to estimate periods (σ=50%)

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Follow-up

- Spectral Typing
  - ANU Spectra this month.
- Radial Velocities for the massive objects
  - Coralie (Geneva) & Sophie (K2 consortium) searches underway.
- Lucky Imaging
  - AstroLux images
- Wait for Gaia?

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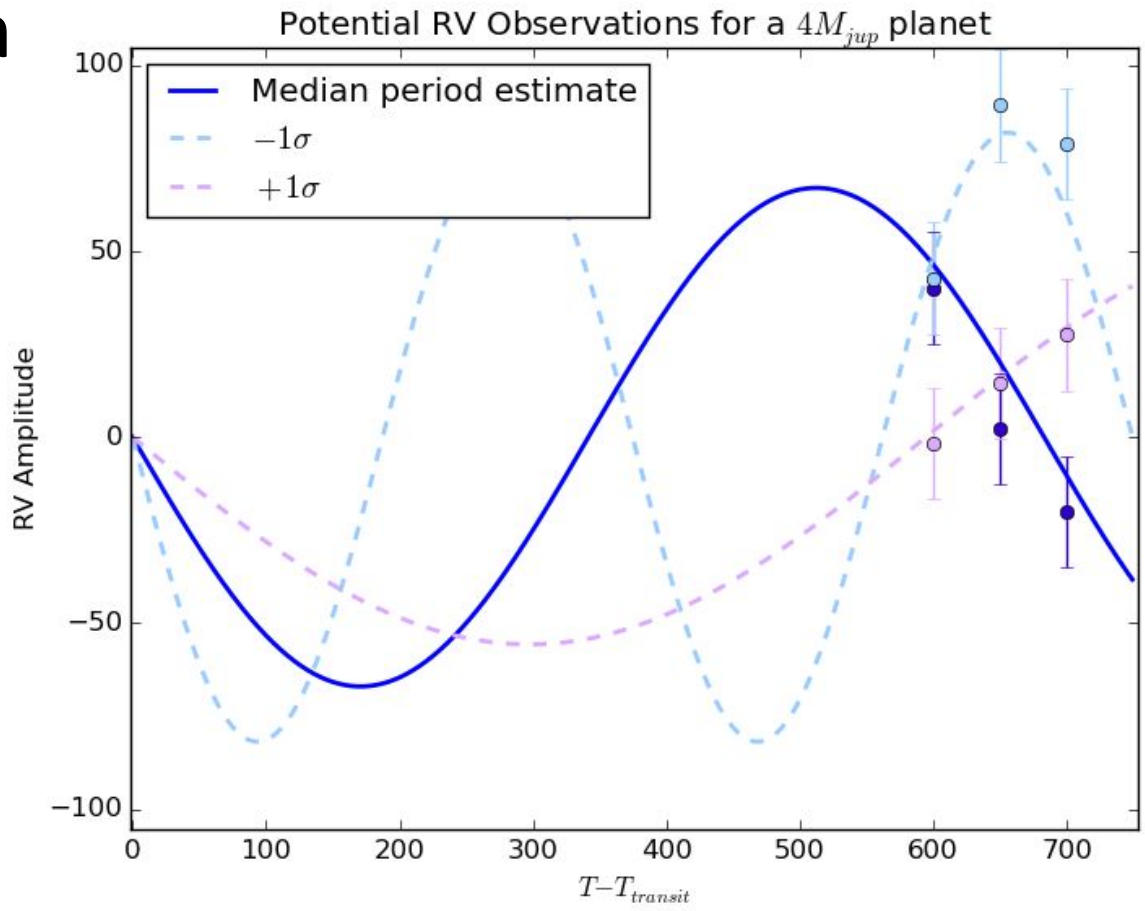
Confirmation

- RVs can constrain Period enough to search for repeat transits.
- Repeat transits require directed searches from the ground - NGTS?



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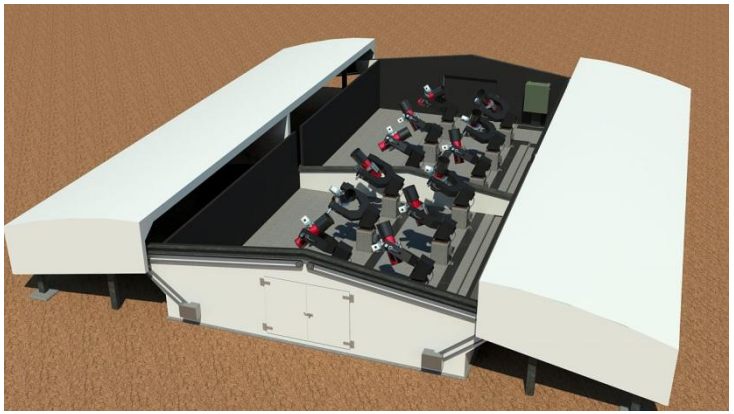
Validation

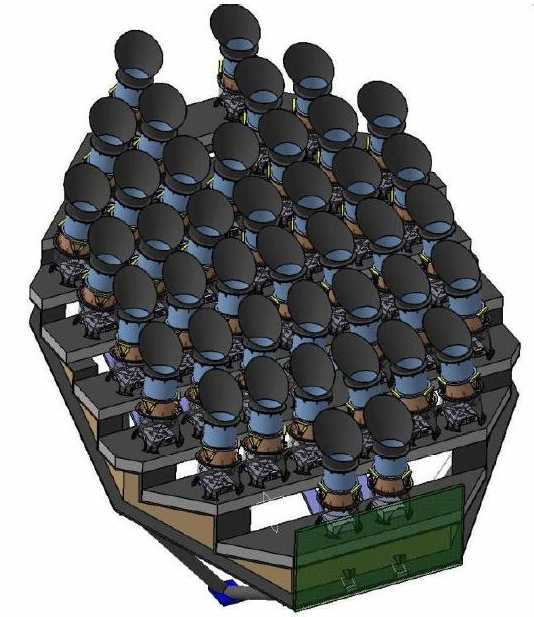
- Probabilistically rule out false-positives using:
  - Ruling out nearby blended binaries using high-res images
  - Radial Velocity variation upper limits

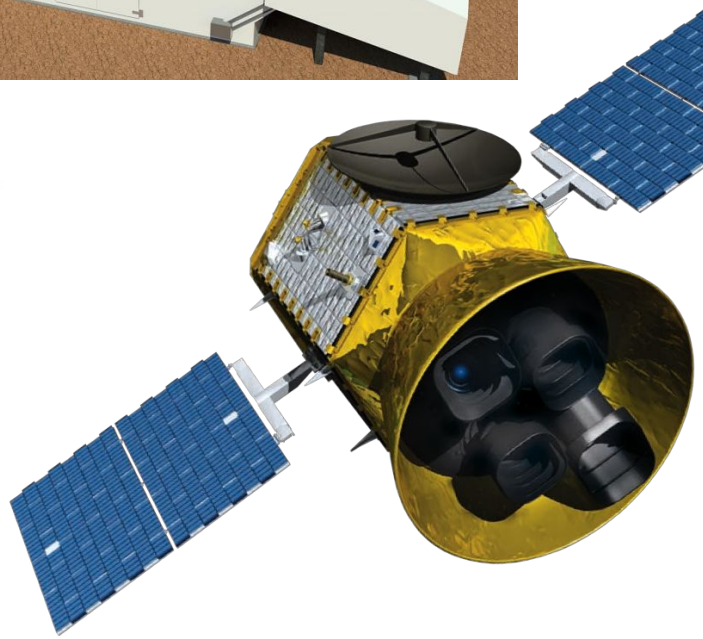
- Has already been performed for 3 single-transiting Kepler planets (Wang, 2015)

The Future

- >10 more fields from K2
- NGTS (now)
- TESS (2017)
- PLATO (2024)







The Future - NGTS

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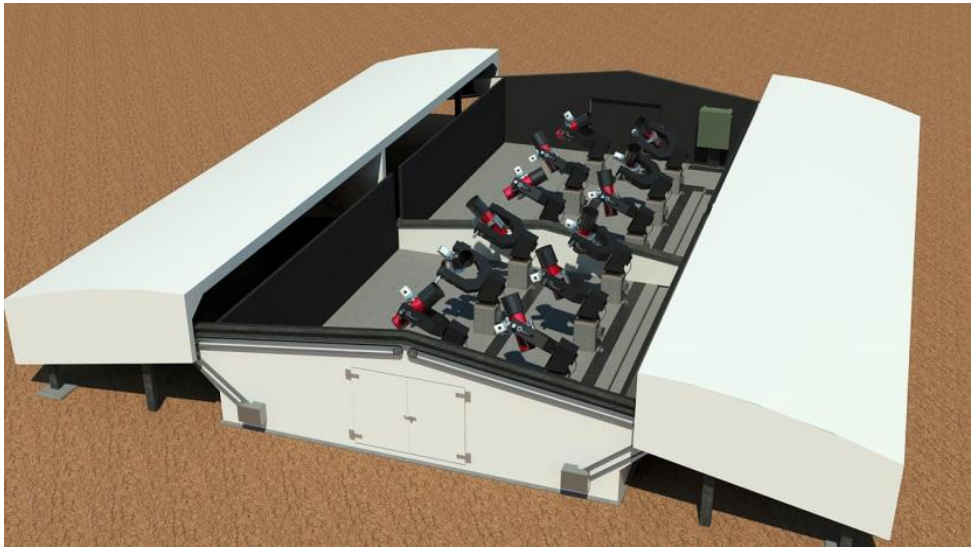
- 1.5mmag noise per hour for 12th mag star
- 1 million stars over 4 years.
- 5mmag Single Transits detectable



The Future - NGTS

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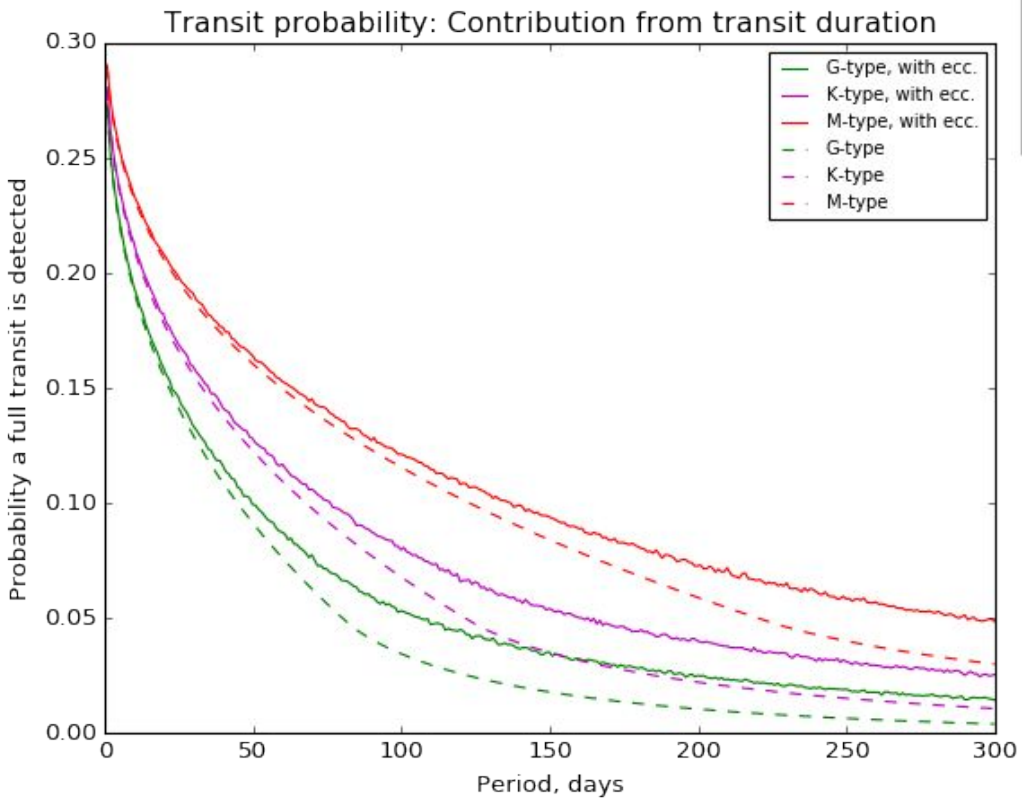
- Ability to detect a full single transit in one night decreases with orbital period
- Still expect dozens of single transits per year.



The Future - Space

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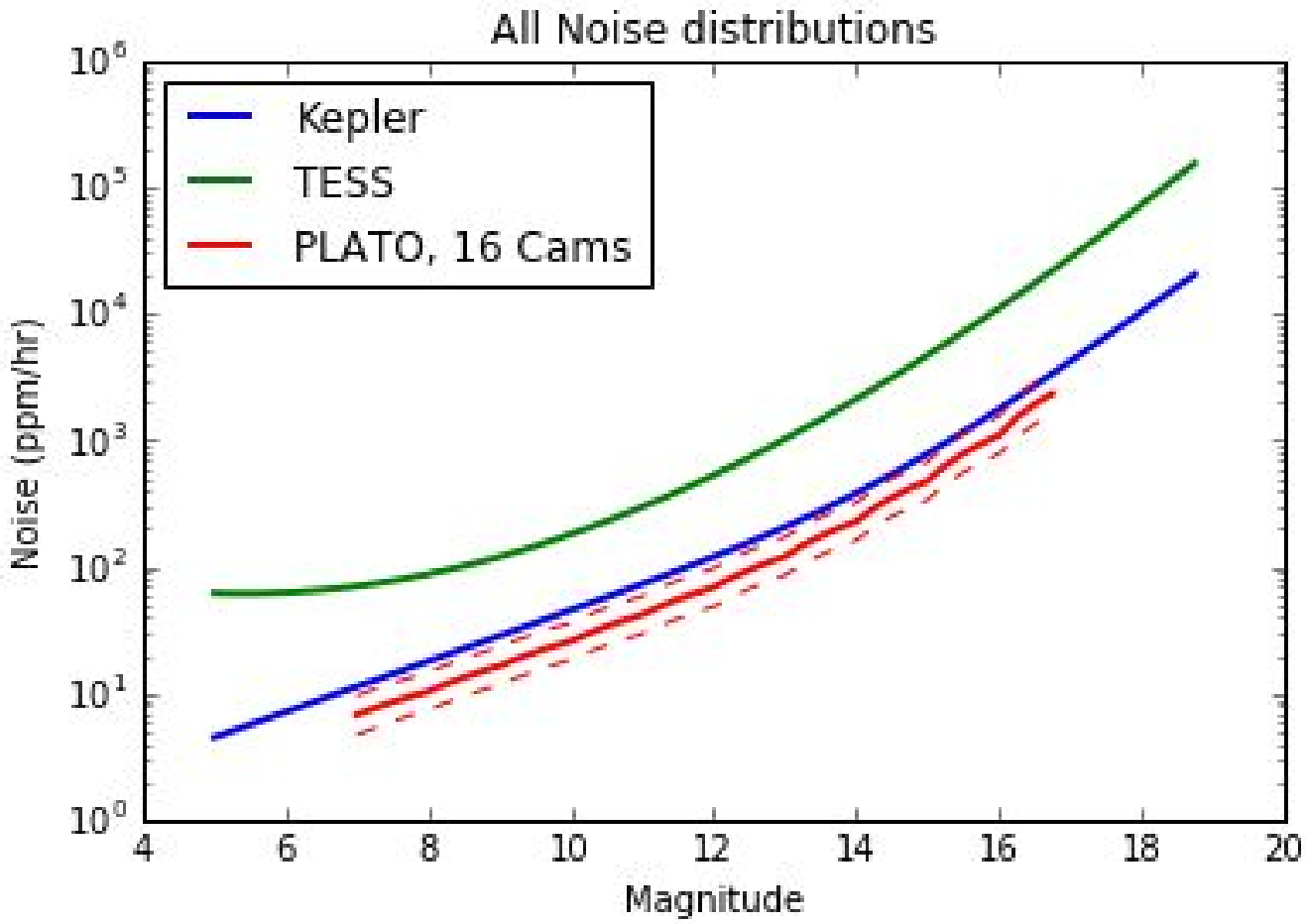

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TESS

- Launches in 2017
- 200,000 stars with 2min cadence
- 1.5 million in full-frame images (30min cad)
- ~450sq deg at poles observed for one year.
- 15,000sq deg observed for <27days

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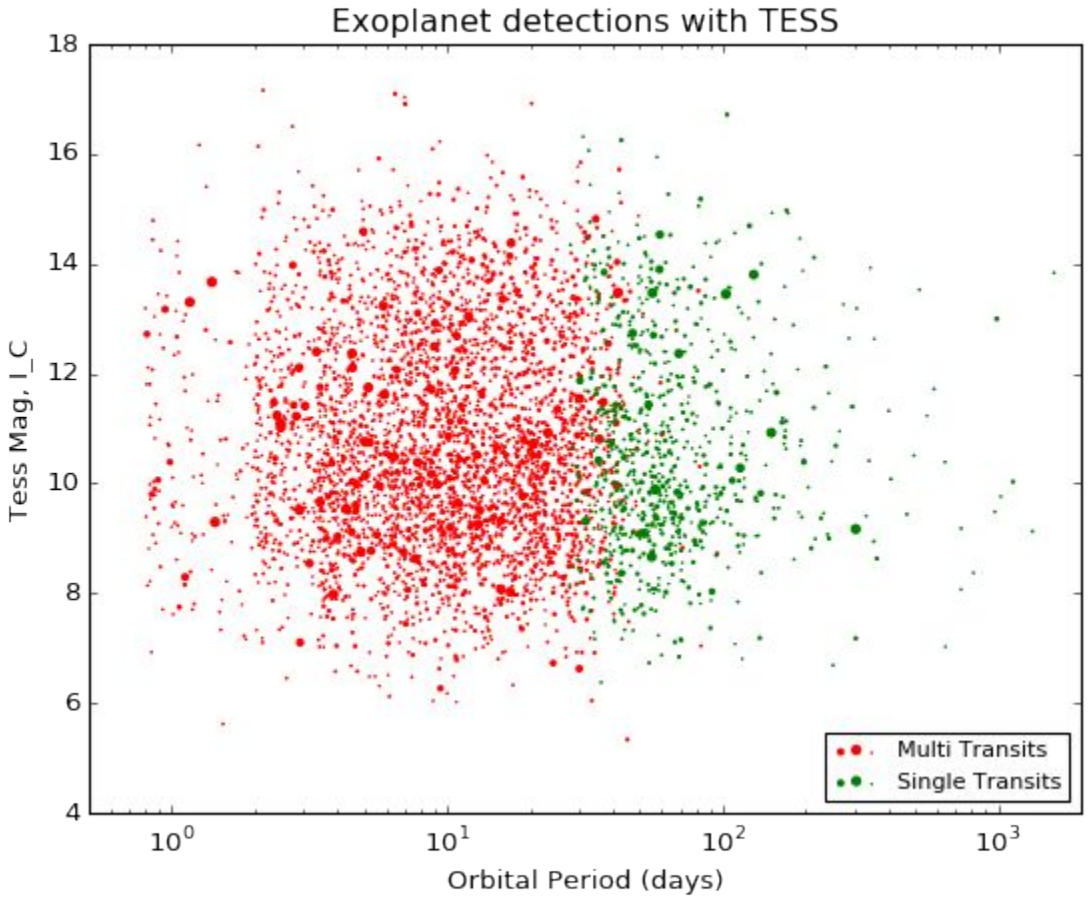
TESS - Number of STEs



- Number of Multi-transiting Planets ~4500
- Number of Single Transits: ~750

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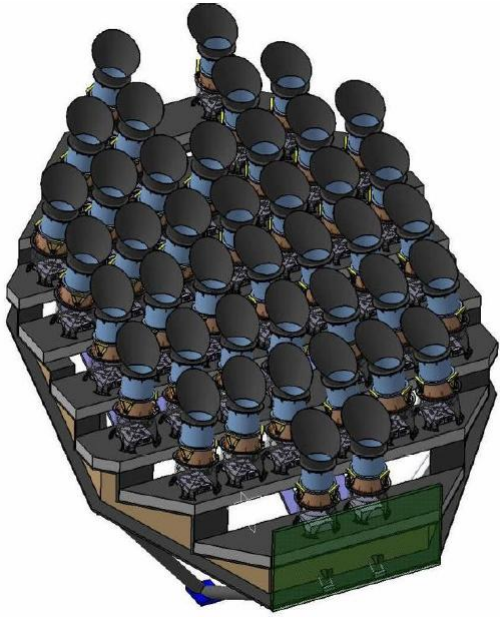
PLATO - Stellar Densities



- 2025 launch
- 150,000 faint stars & 12,000 bright stars (mv<12) per pointing
- 200x larger field than Kepler
- 4th - 16th mag
- Asteroseismology for 85000 stars
  - Densities to 10%

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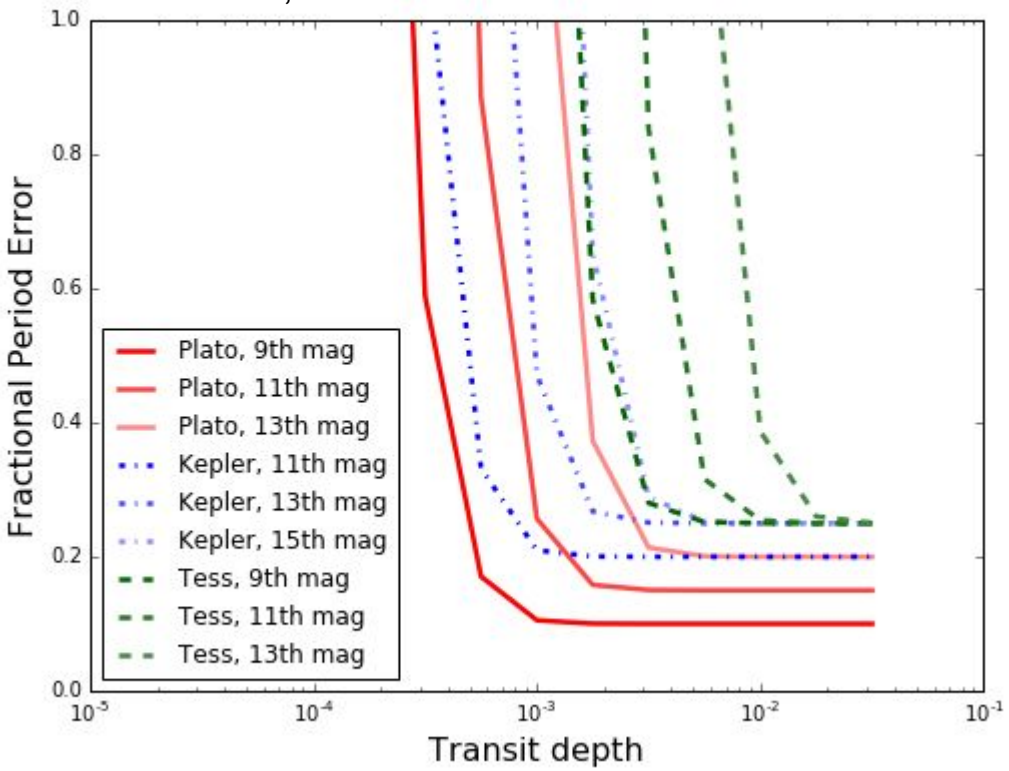
PLATO

- Will enable much more precise period estimates from single transits
- Number of single transit detections dependant on field durations (TBD)

Precision on Period estimates from a Single transit: K2, Tess and Plato



Summary

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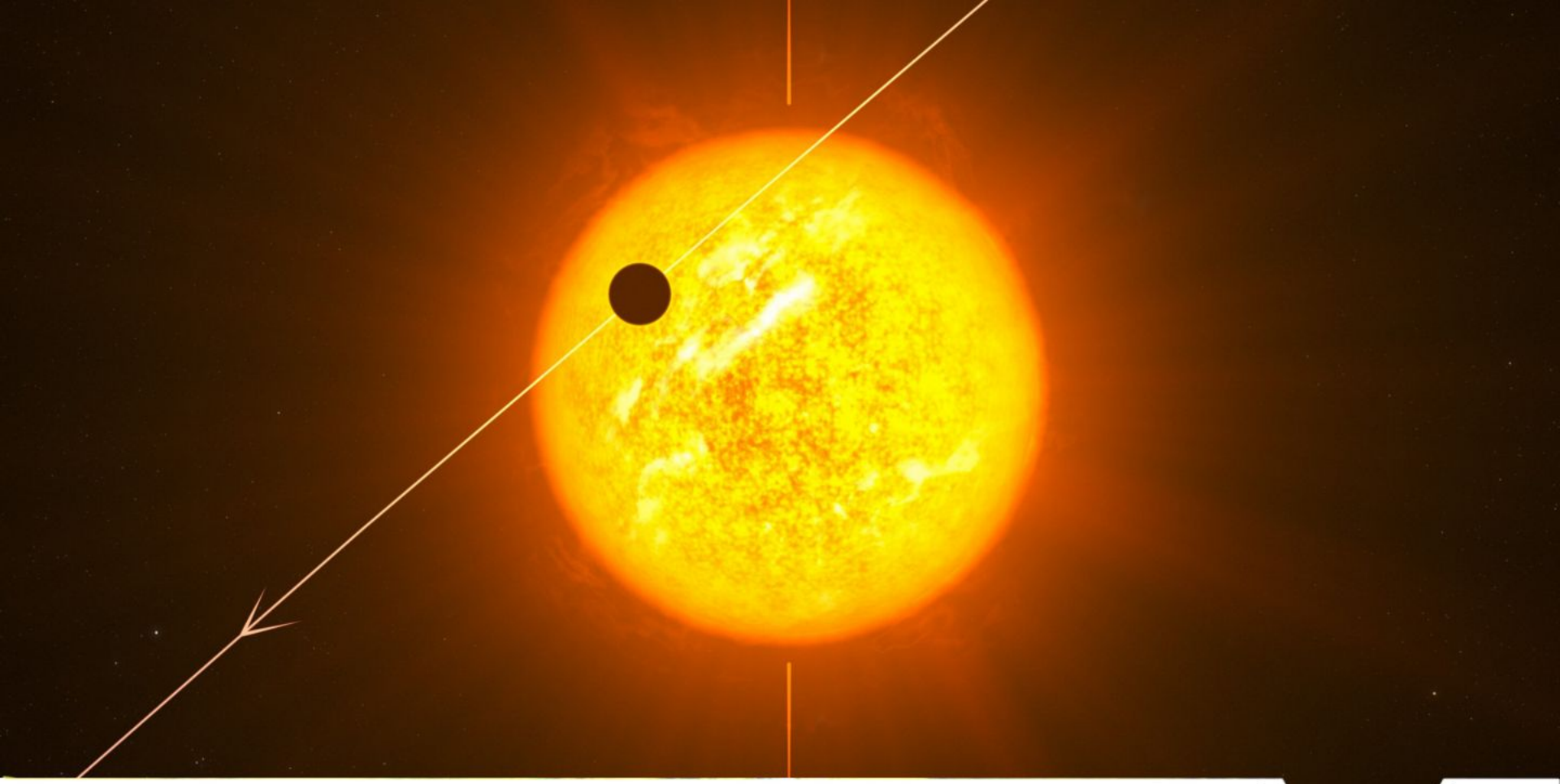
- Single transits can extend transit surveys to long periods
- The best candidates allow orbital estimates directly from the lightcurve.
- We have found dozens of candidates in K2
  - confirmation & validation of these ongoing
- NGTS, TESS and Plato have the potential to detect many more, with greater precision



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Thanks

Hugh Osborn

@HughO2