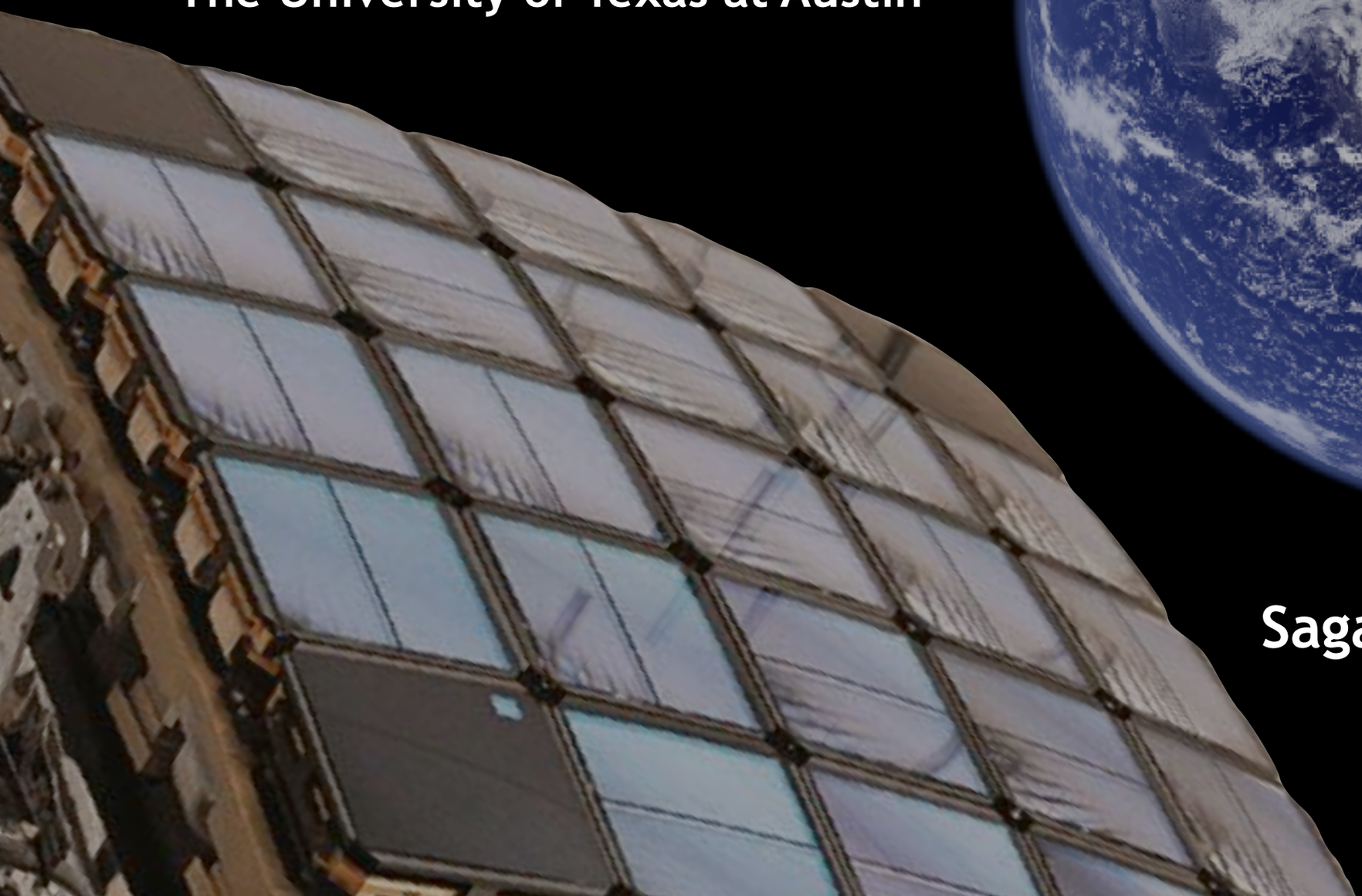
From Pixels to Planets

The process of validating transiting exoplanets

Andrew Vanderburg
NASA Sagan Fellow
The University of Texas at Austin



Sagan Summer Workshop
July 23, 2018

Images: NASA

The Process of Validating Transiting Exoplanets

K2 Pixel Data

Light Curves

Transit Search

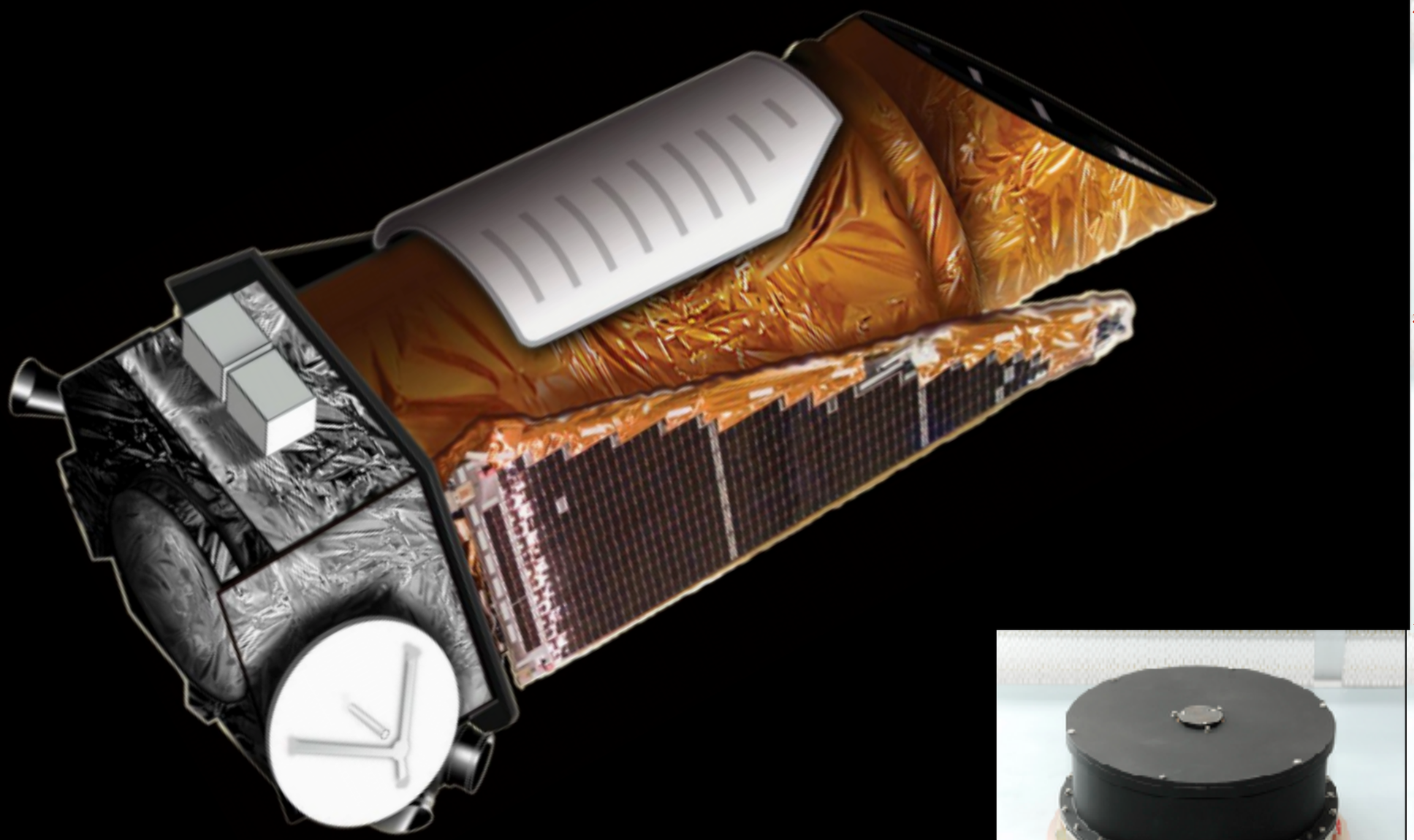
Threshold Crossing Events

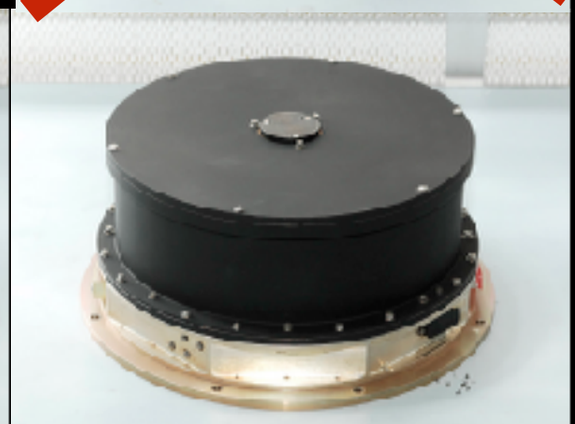
Planet Candidates

Validated Planets

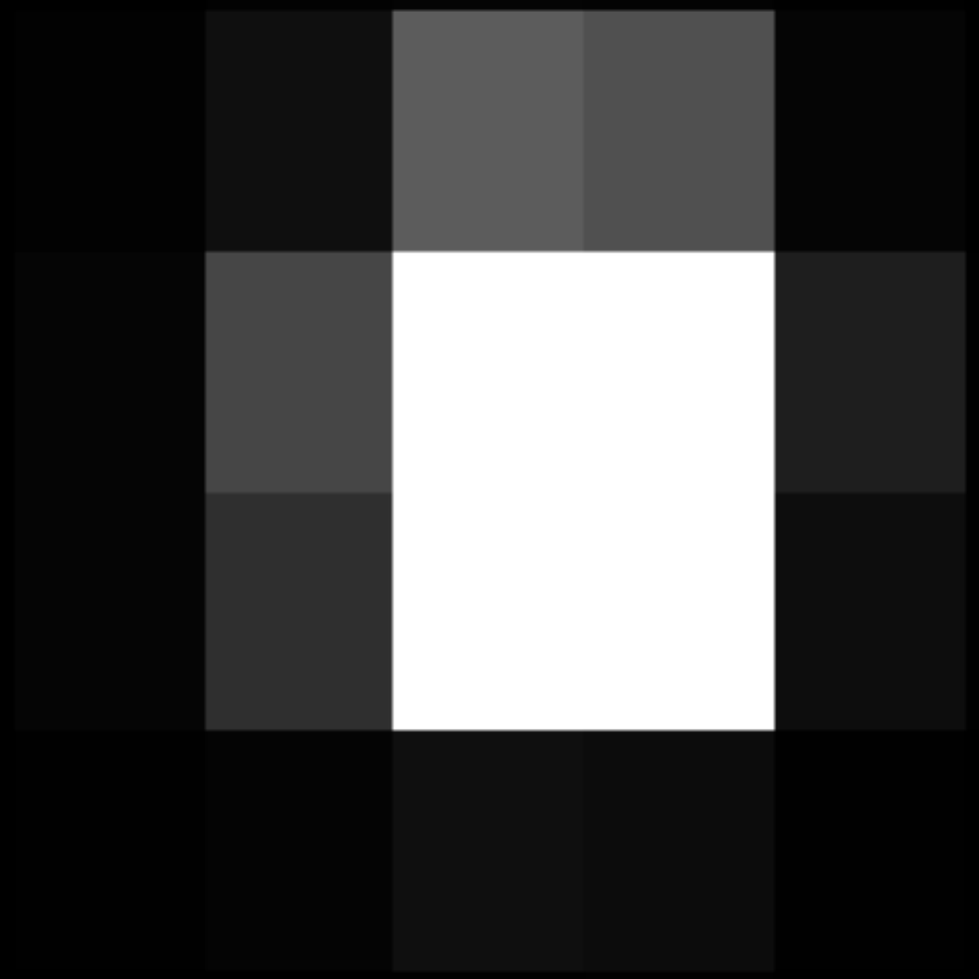
Confirmed Planets

The K2 Mission





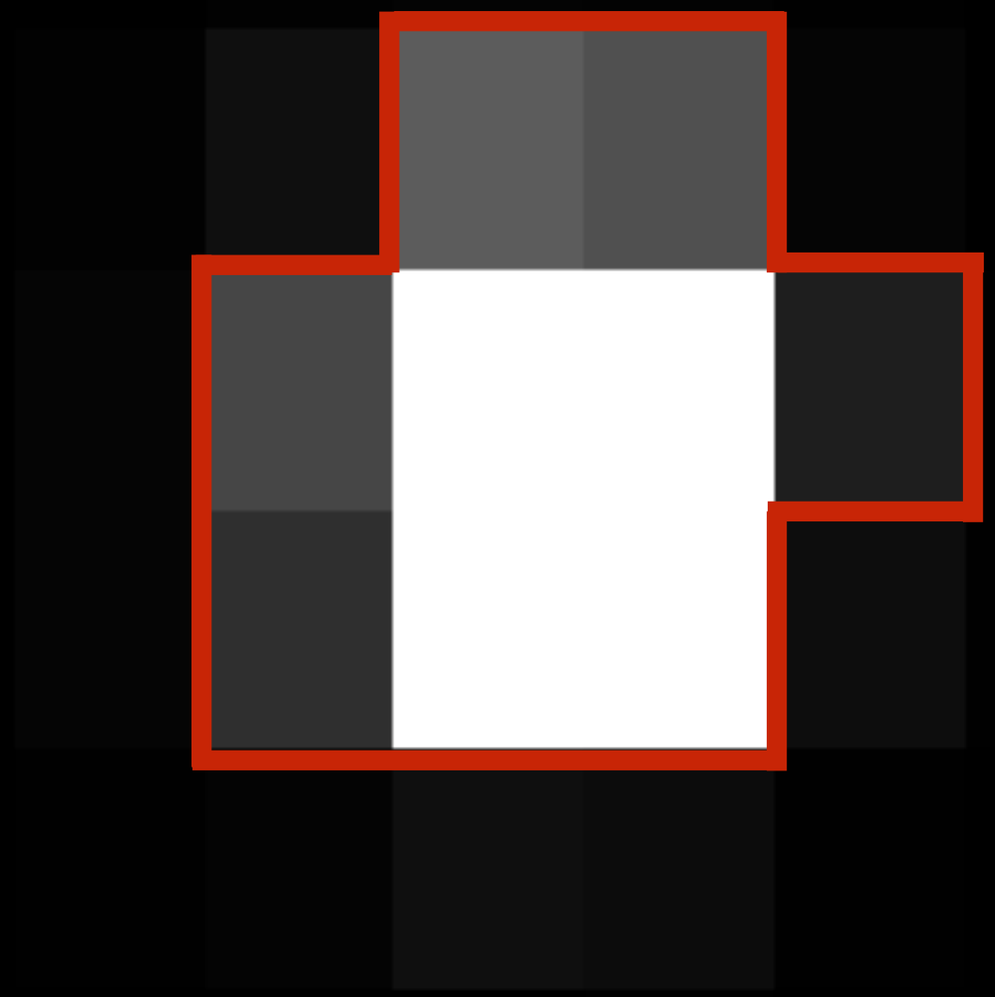
K2 Pixel Data



EPIC 212521166 2015-07-25 02:16:06

Animation: k2flix (Geert Barentsen)

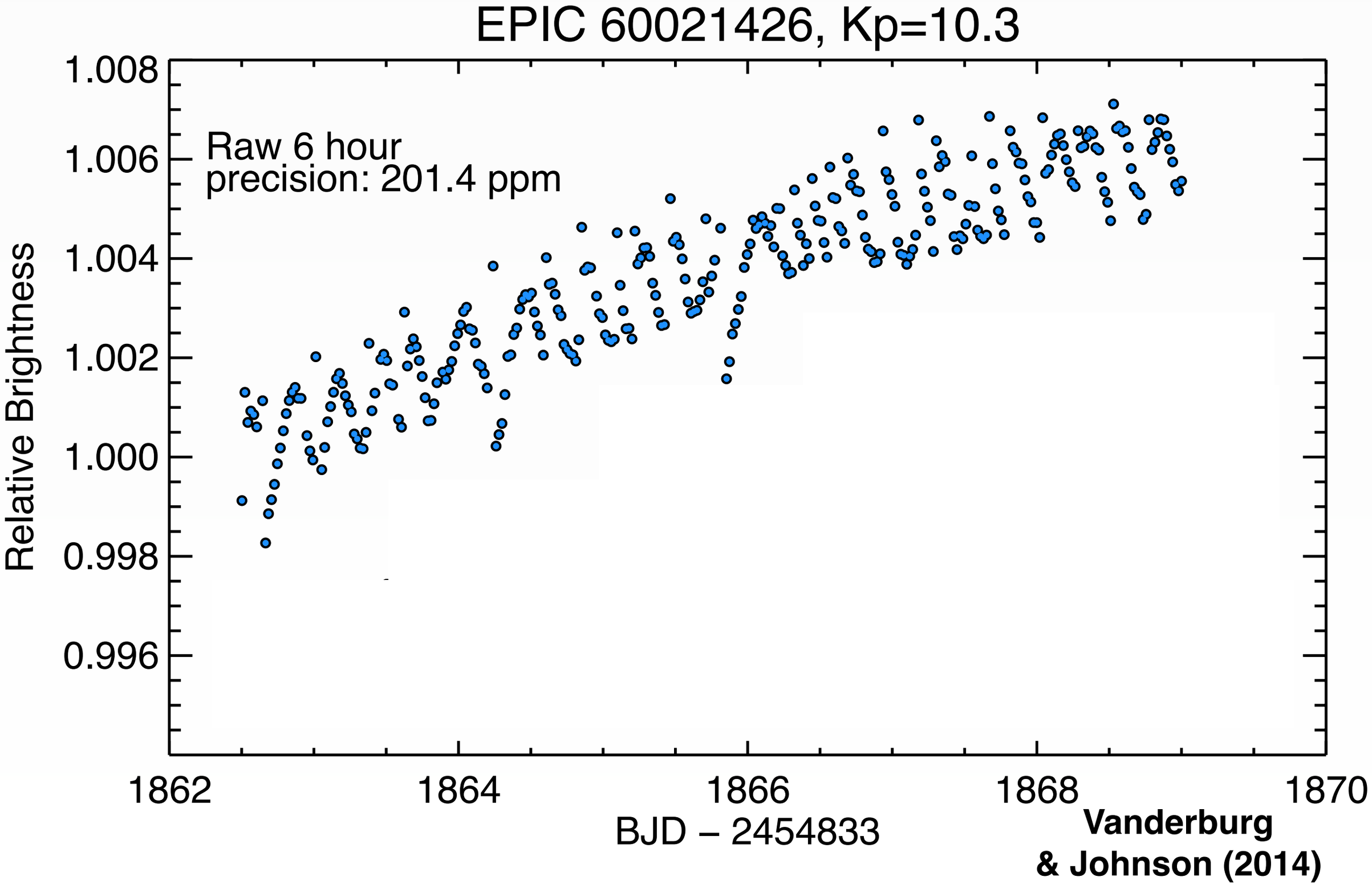
Sum the Pixels



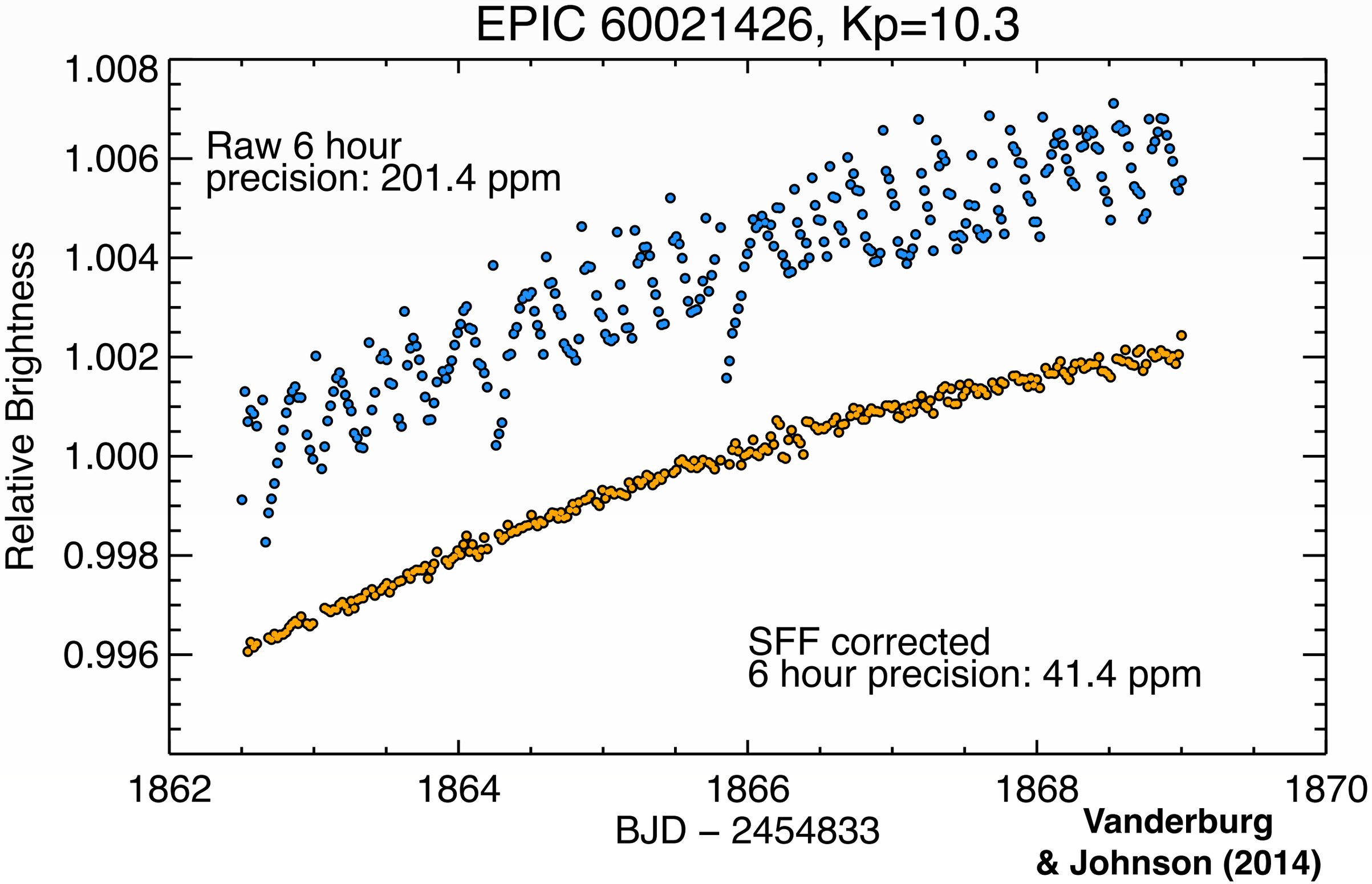
EPIC 212521166 2015-07-25 02:16:06

Animation: k2flix (Geert Barentsen)

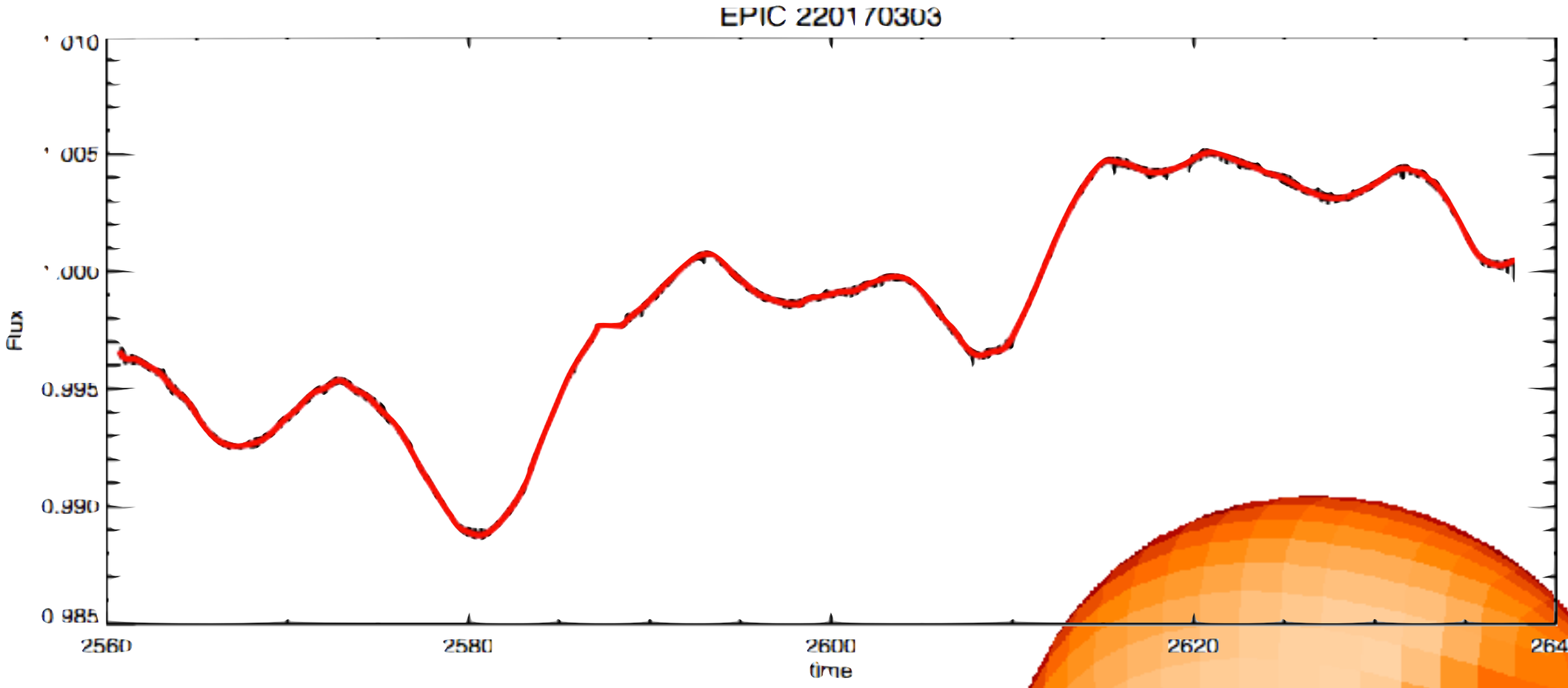
Light Curves

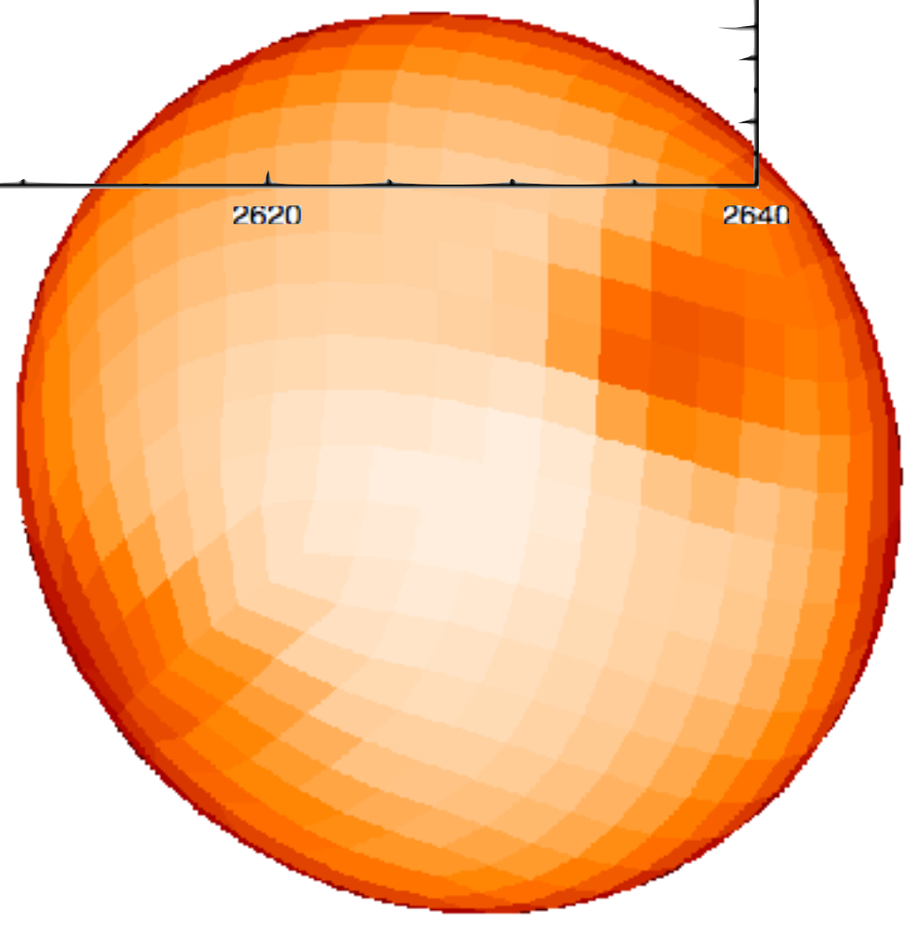


Remove systematics



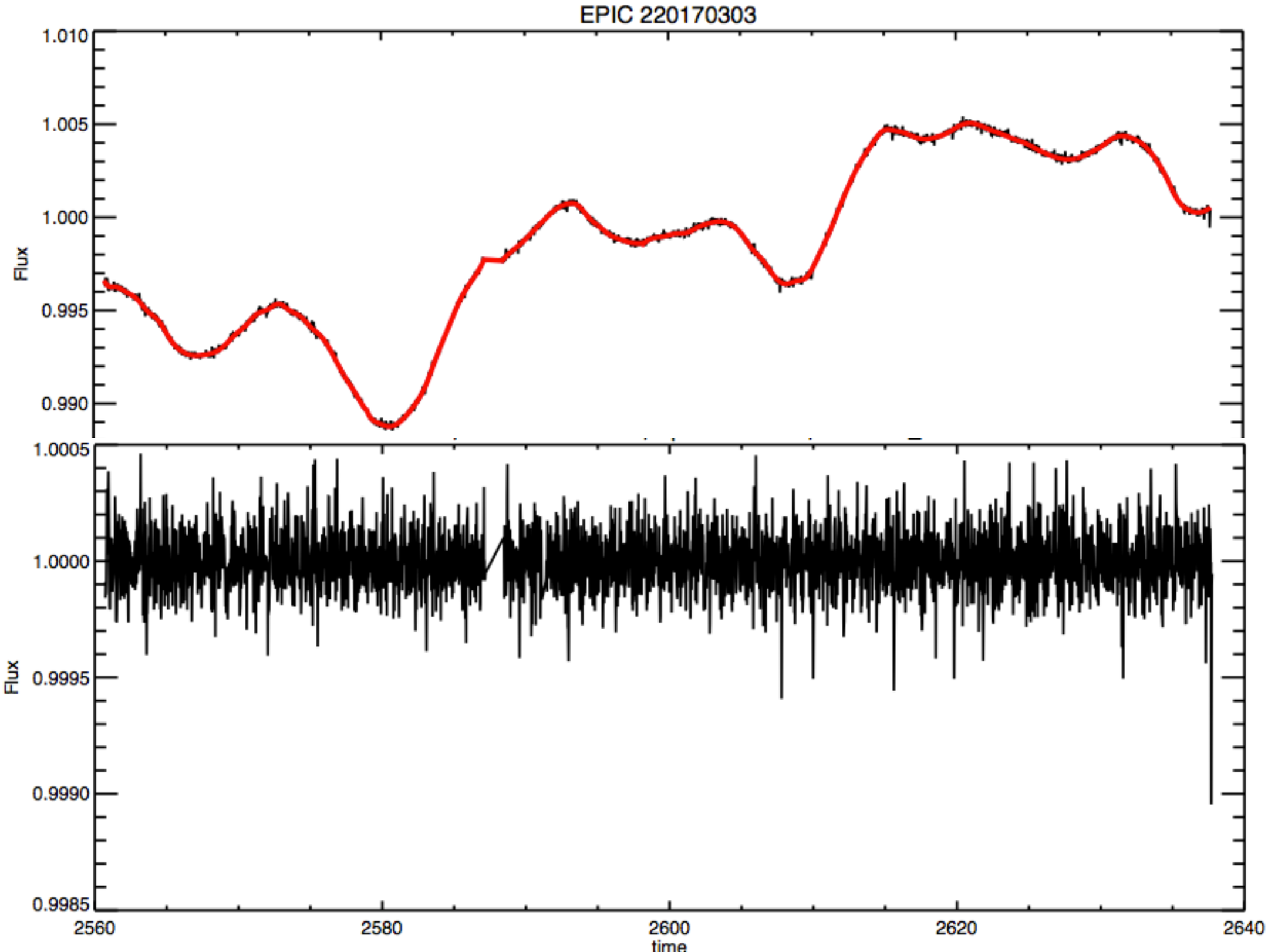
Remove low-frequency trends



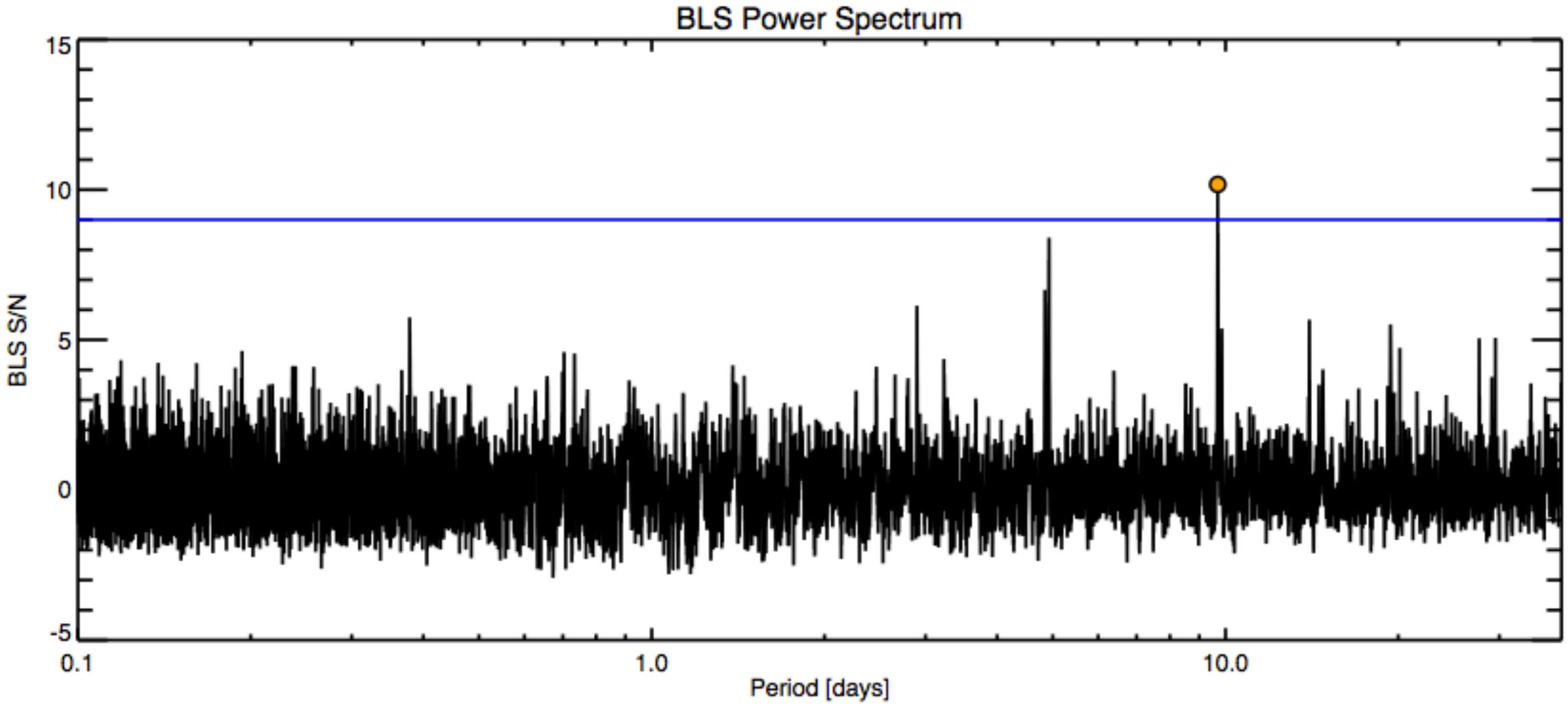


Animation: Roettenbacher+ 2016

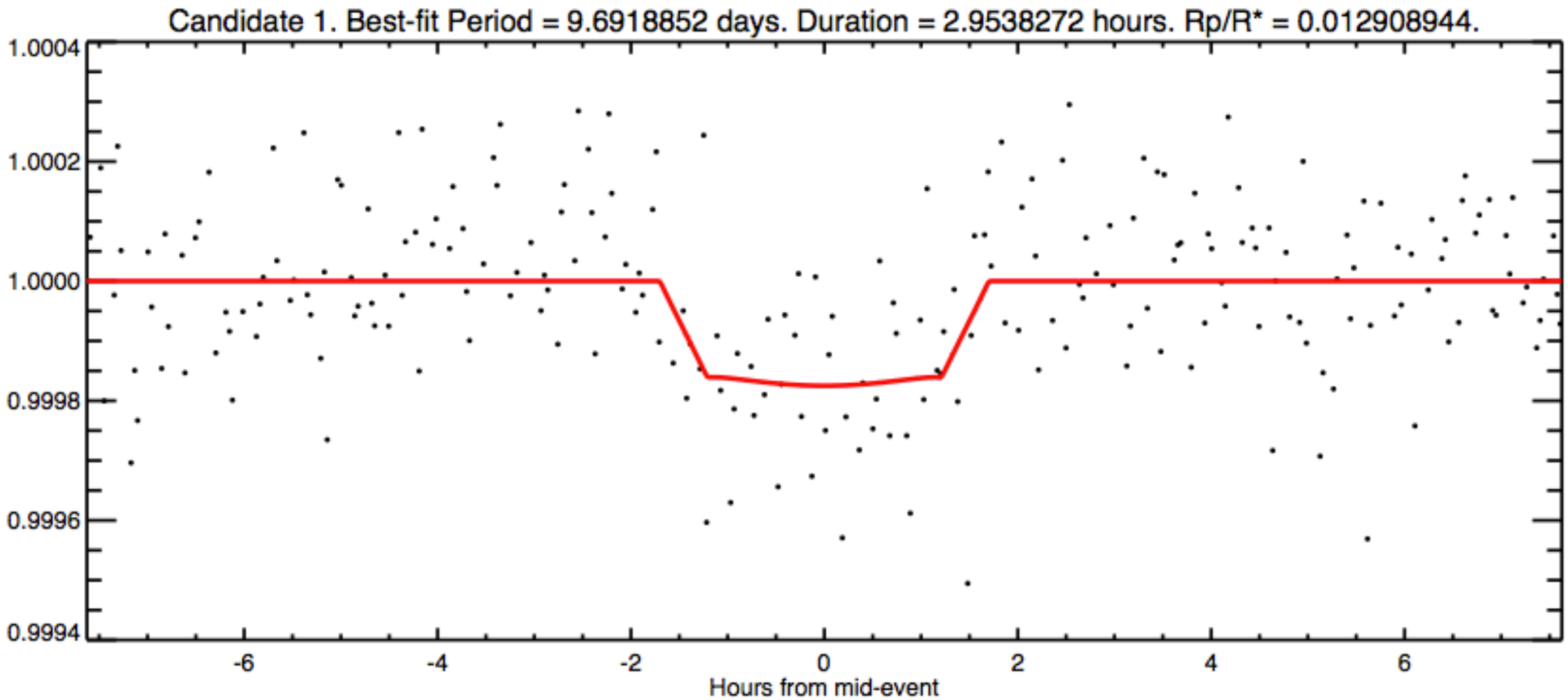
Remove low-frequency trends



Transit Search (Box Least Squares Periodogram)



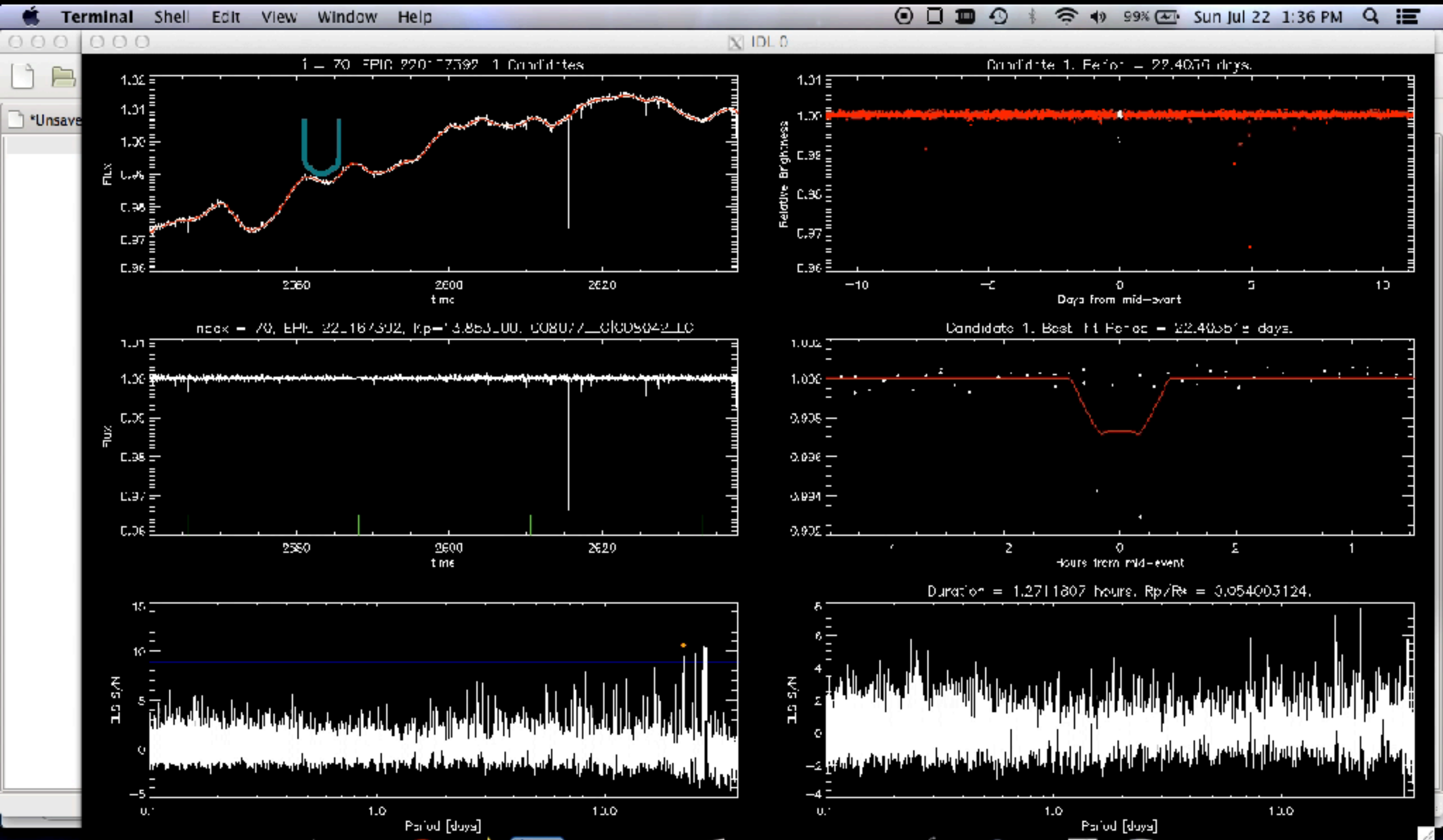
Transit Search (Box Least Squares Periodogram)



Threshold Crossing Event (TCE):

any possible transit signal (period, t0, duration) in a light curve strong enough for a transit search pipeline to identify.

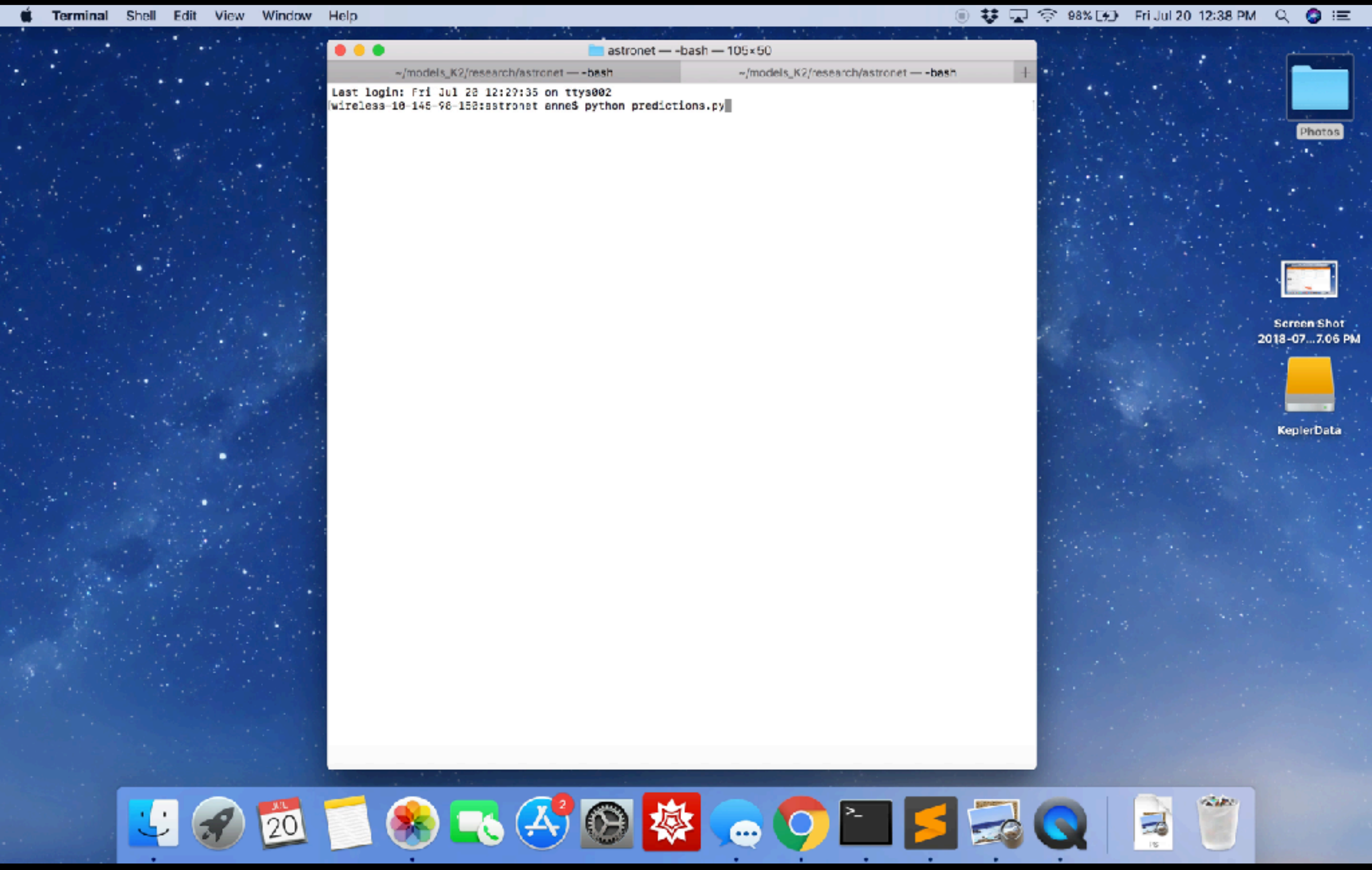
Triage


Terminal Shell Edit View Window Help
Sun Jul 22 1:36 PM
IDL 0
Flux
time
Relative Brightness
Days from mid-event
Hours from mid-event
Period [days]
Duration = 1.2711807 hours, Rp/Re = 0.054003124.

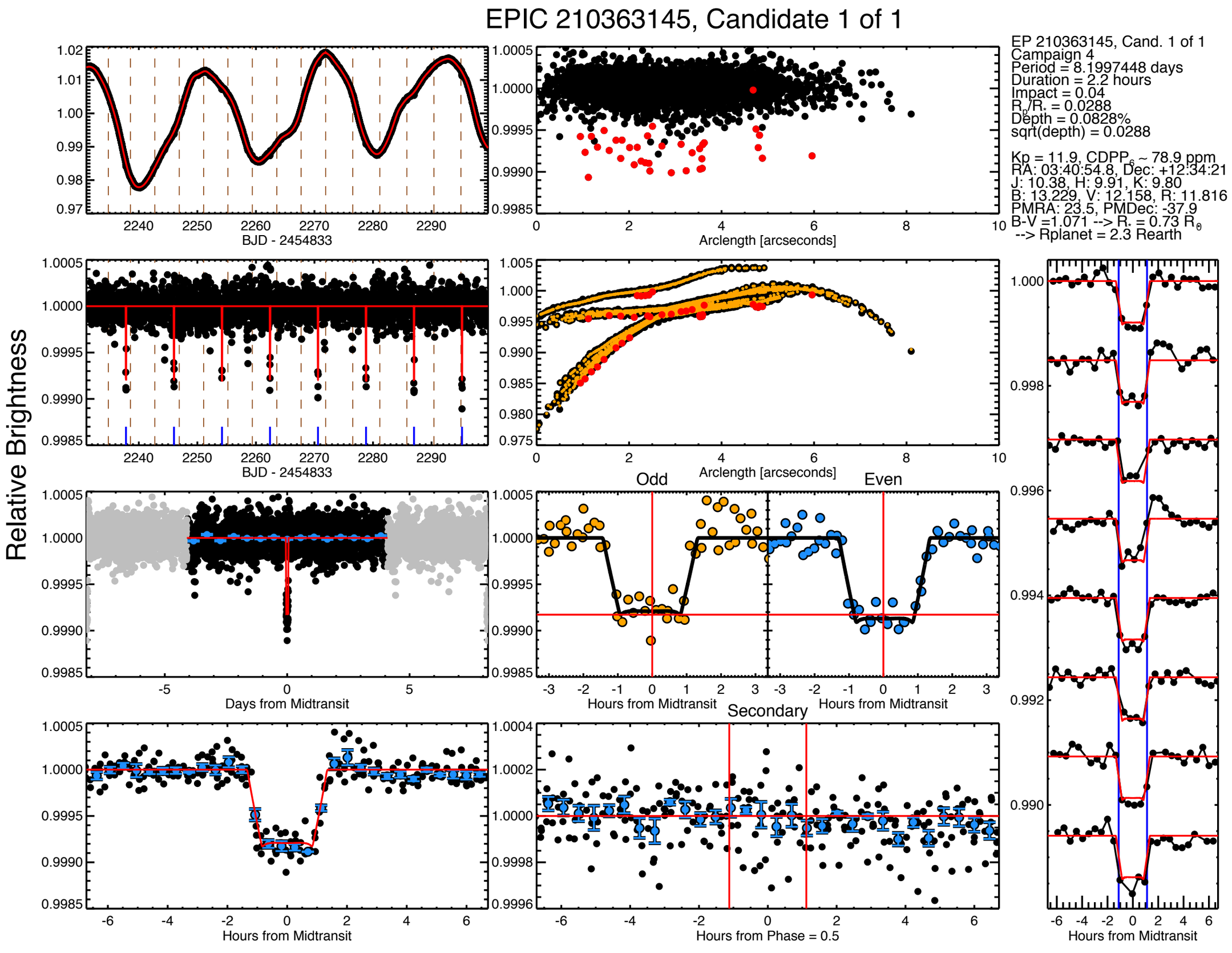
Speeding up triage for K2 with deep neural networks

Anne Dattilo, UT Austin rising senior undergraduate

3000 signals, 98% accuracy, 20 seconds

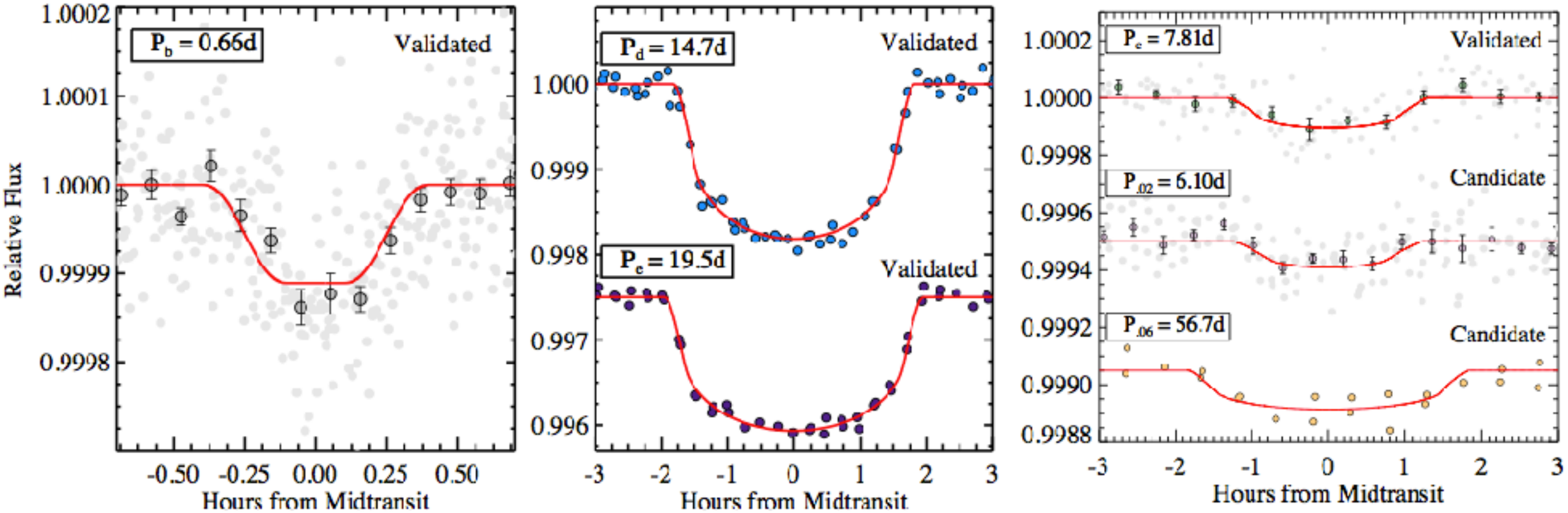


Post-triage vetting



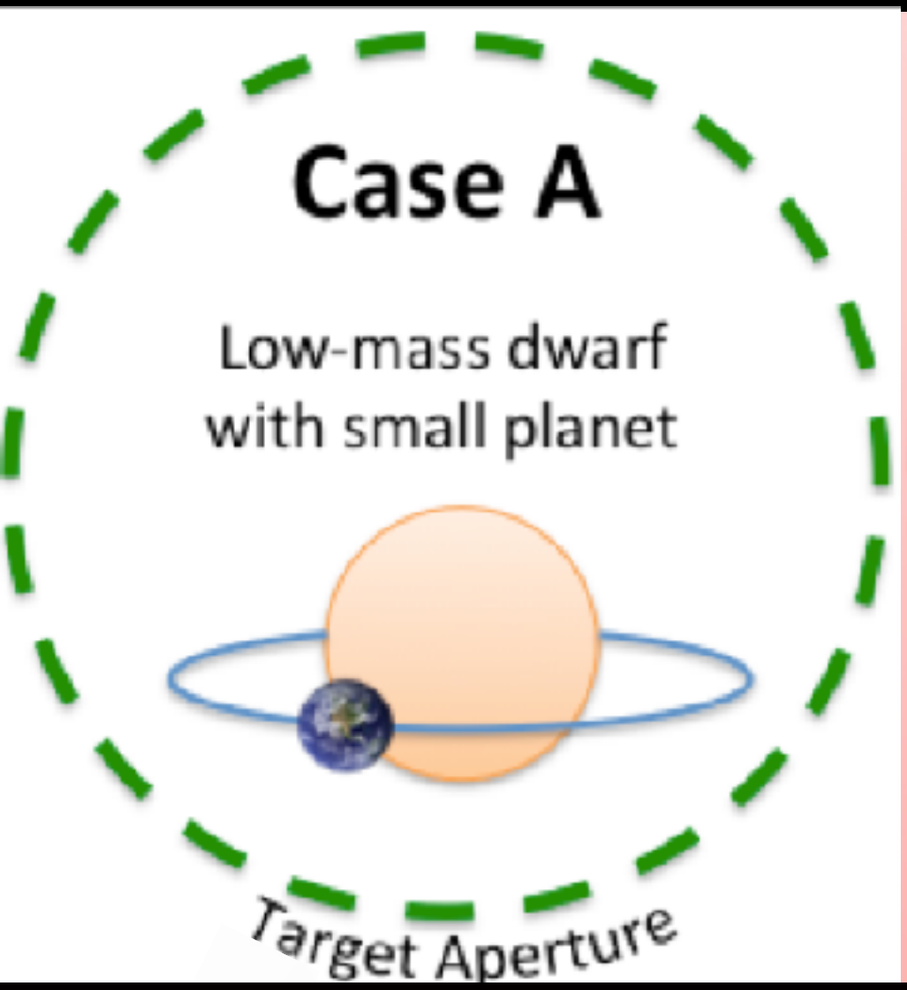
Planet Candidate:
A TCE which has passed initial triage inspection and additional vetting to identify false positives.

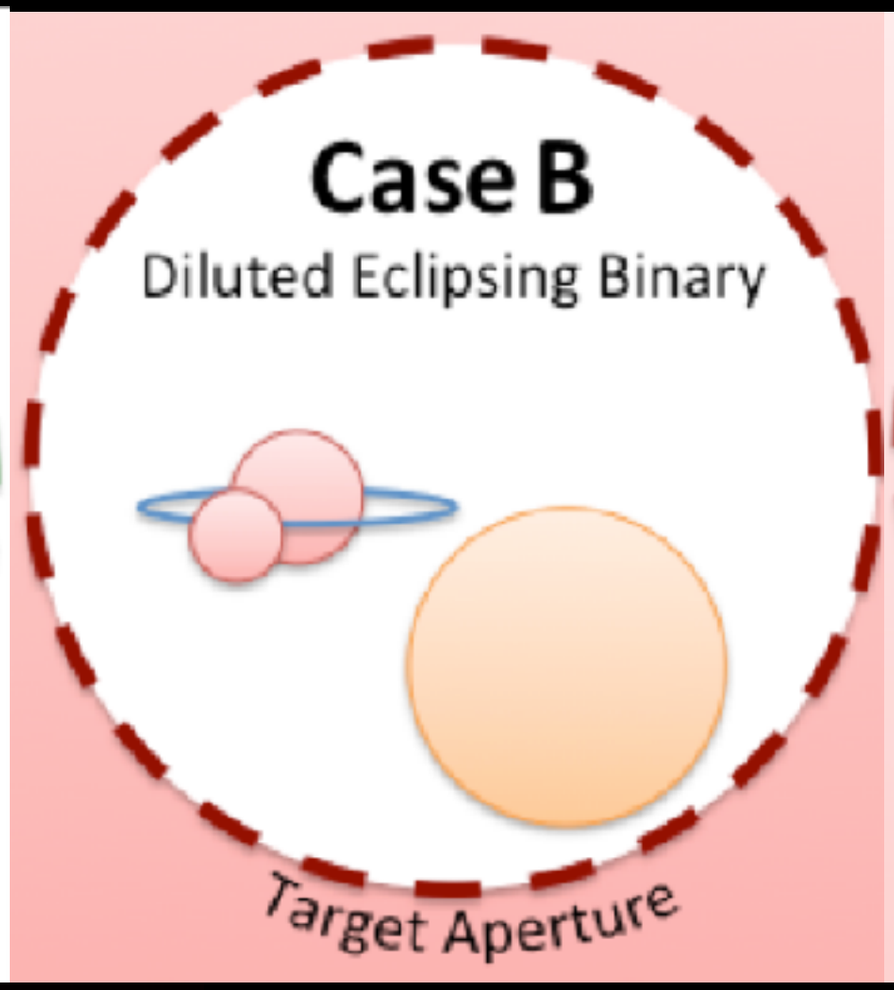
Example: EPIC 248435473

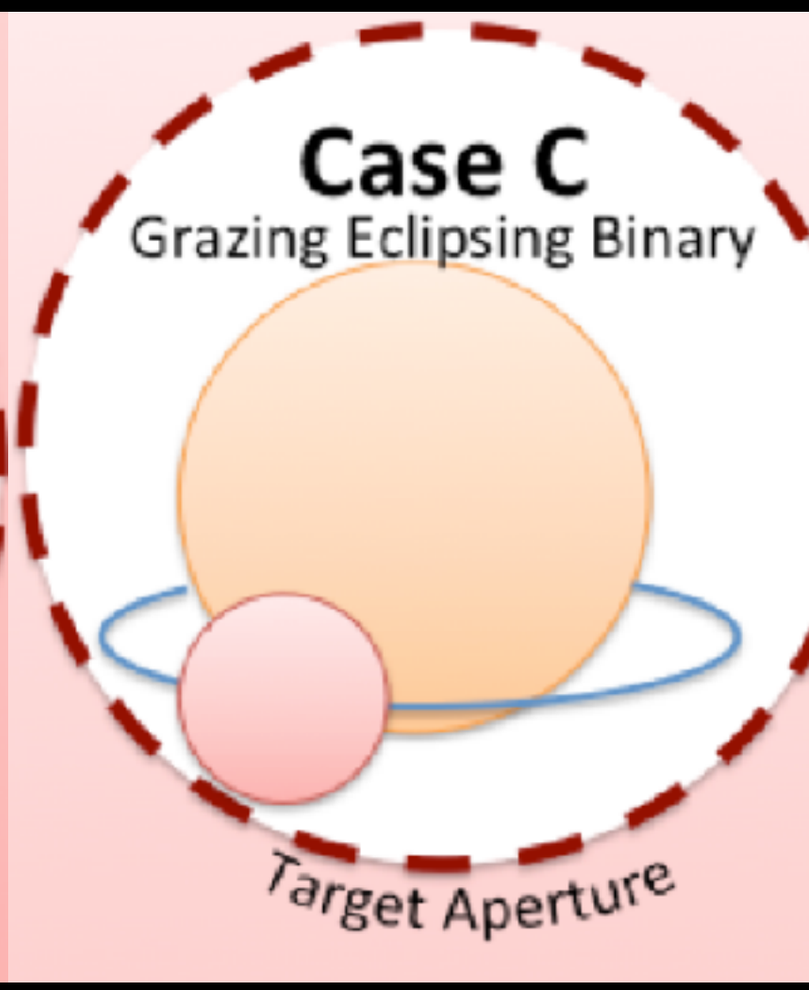


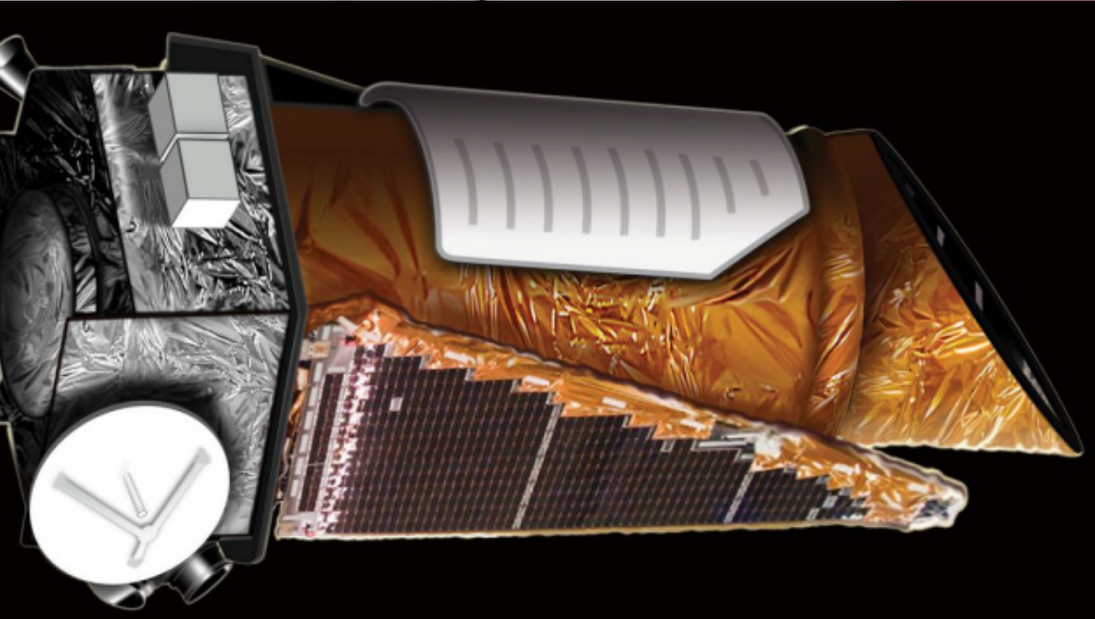
Rodriguez+ 2018

Ruling out False Positives





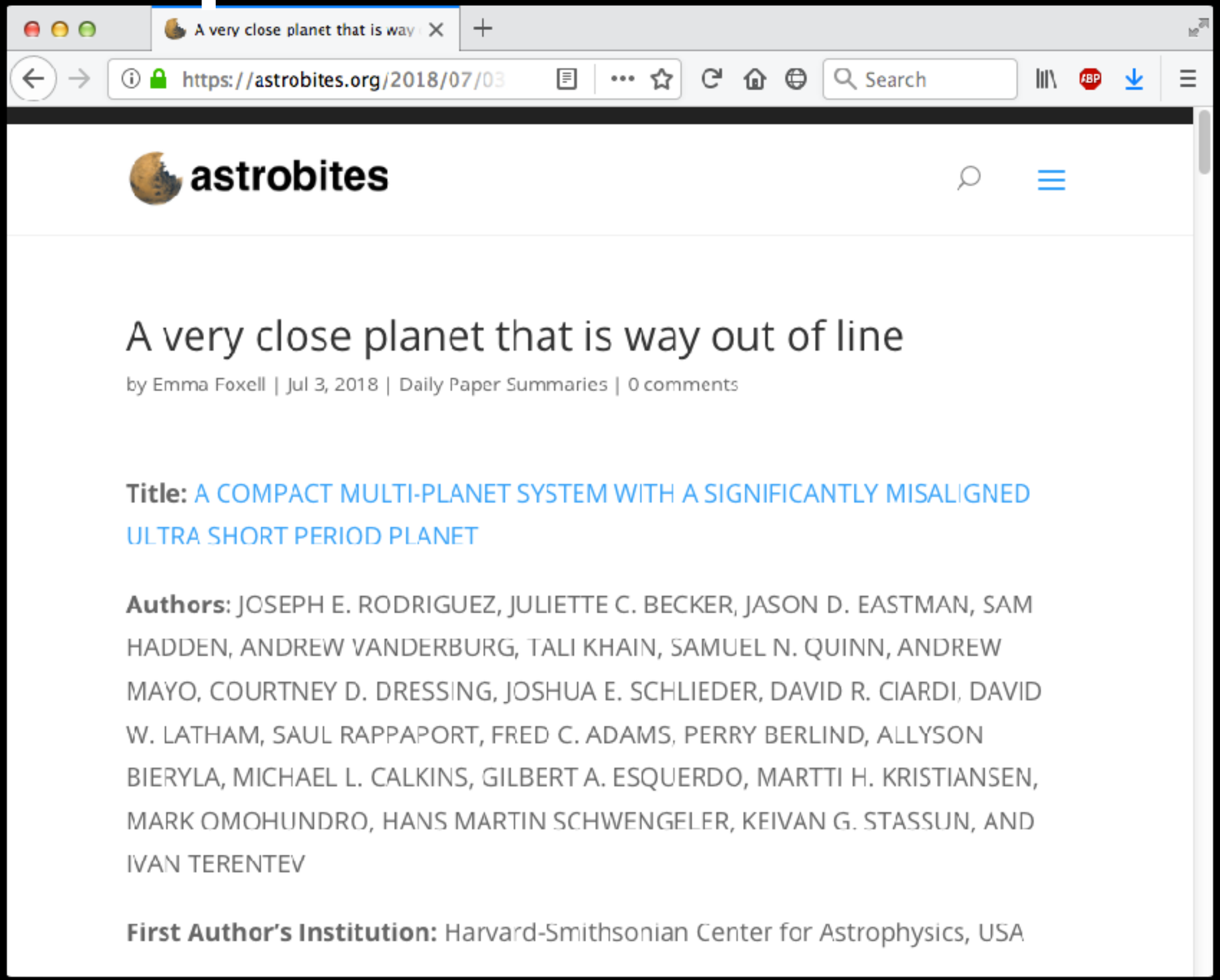




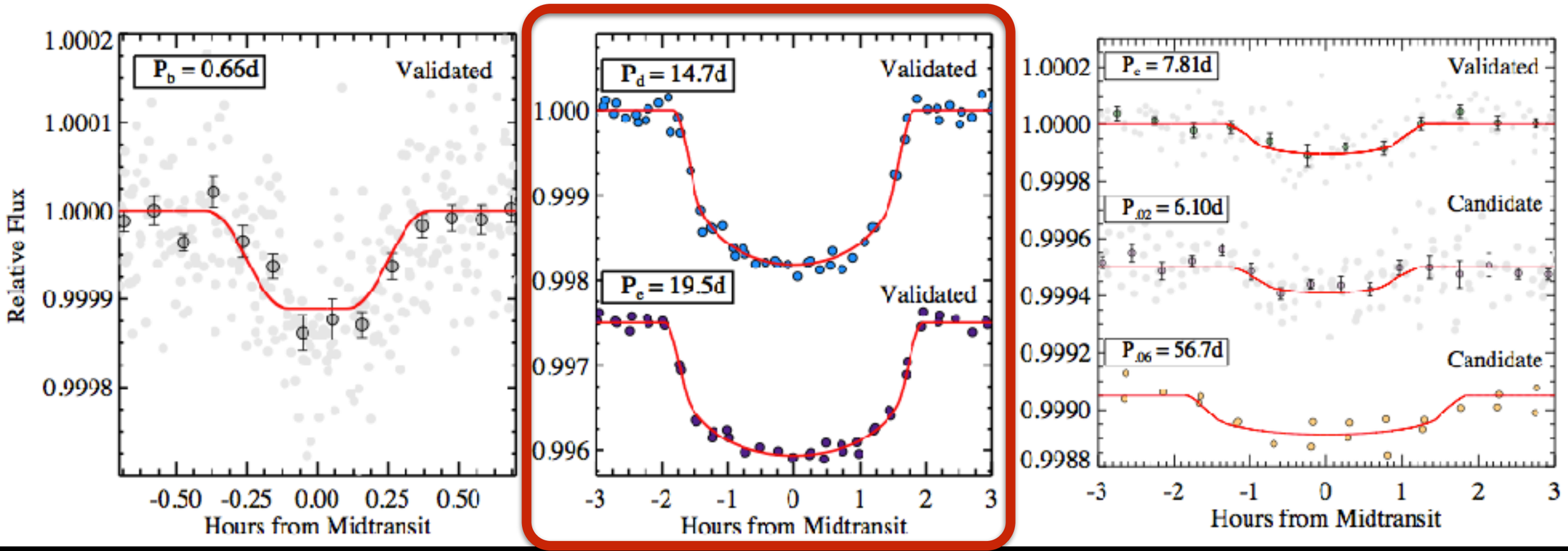
Case D
Instrumental Glitch

Images: Courtney Dressing, NASA

Example: EPIC 248435473



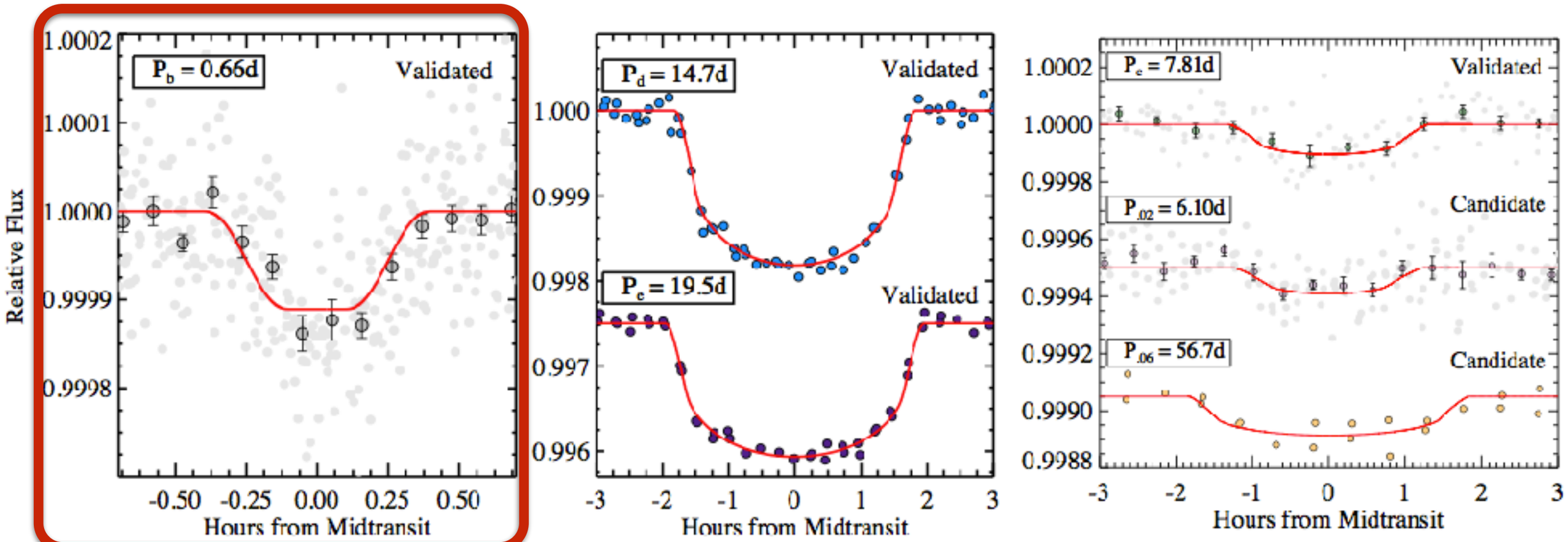
Example: EPIC 248435473



Two sub-Neptune candidates detected at ~110σ near resonance.

Rodriguez+ 2018

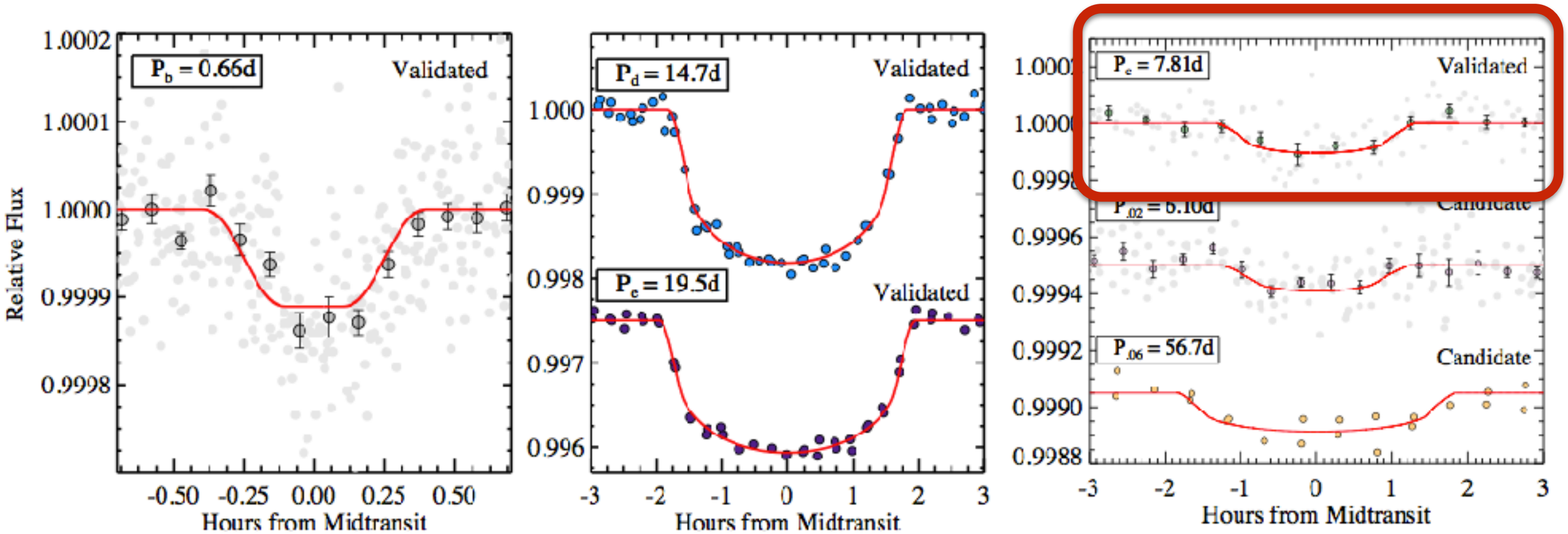
Example: EPIC 248435473



One ultra-short-period super-Earth candidate detected at ~13 sigma

Rodriguez+ 2018

Example: EPIC 248435473



One Mars-sized planet candidate detected at ~10 sigma

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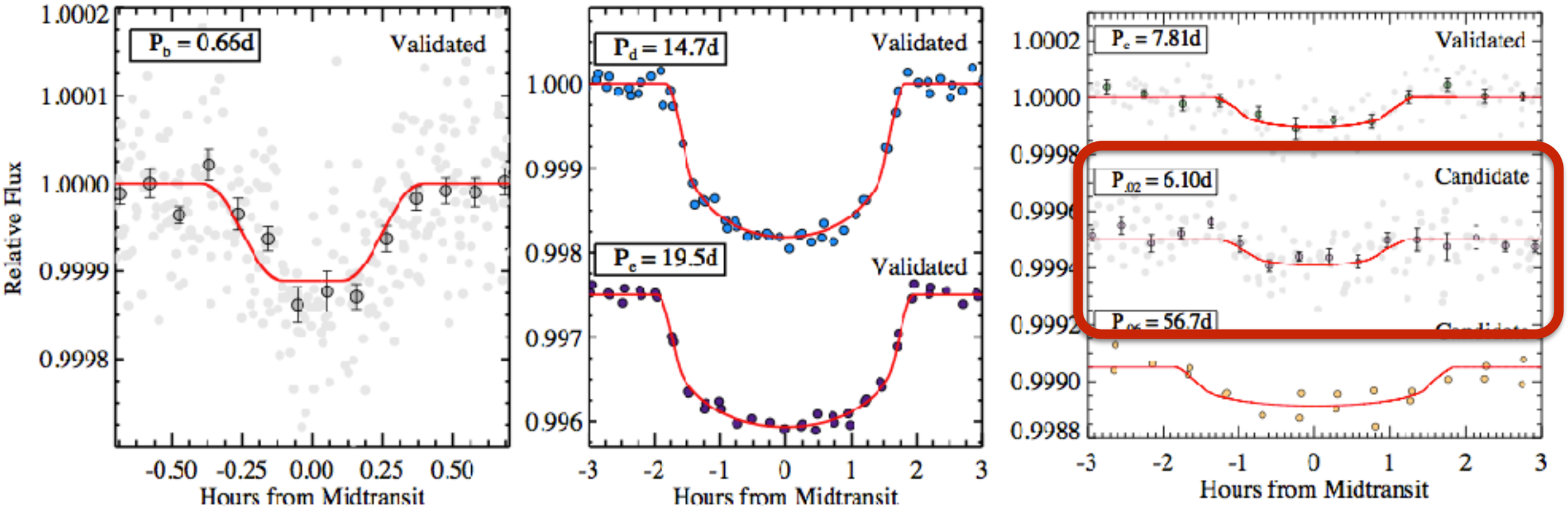
Example: EPIC 248435473



One Mars-sized planet candidate tentatively detected at ~8 sigma

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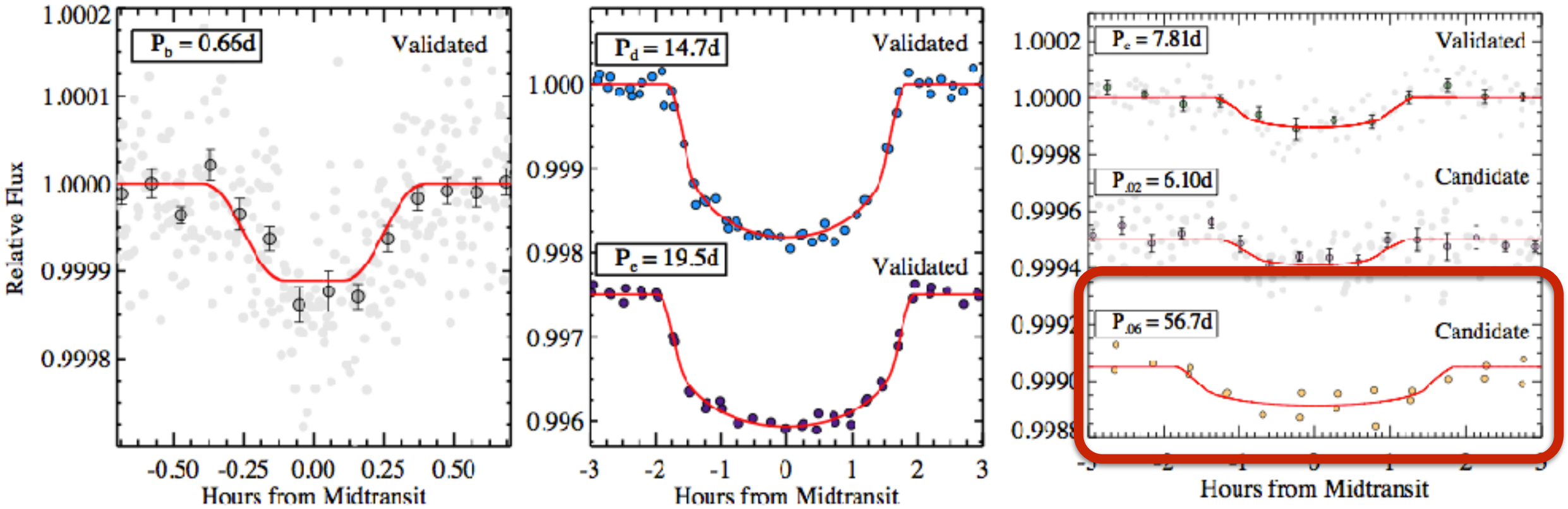
Example: EPIC 248435473



One sub-Earth-sized planet candidate tentatively detected at ~7 sigma

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Follow-up Observations: Spectroscopy

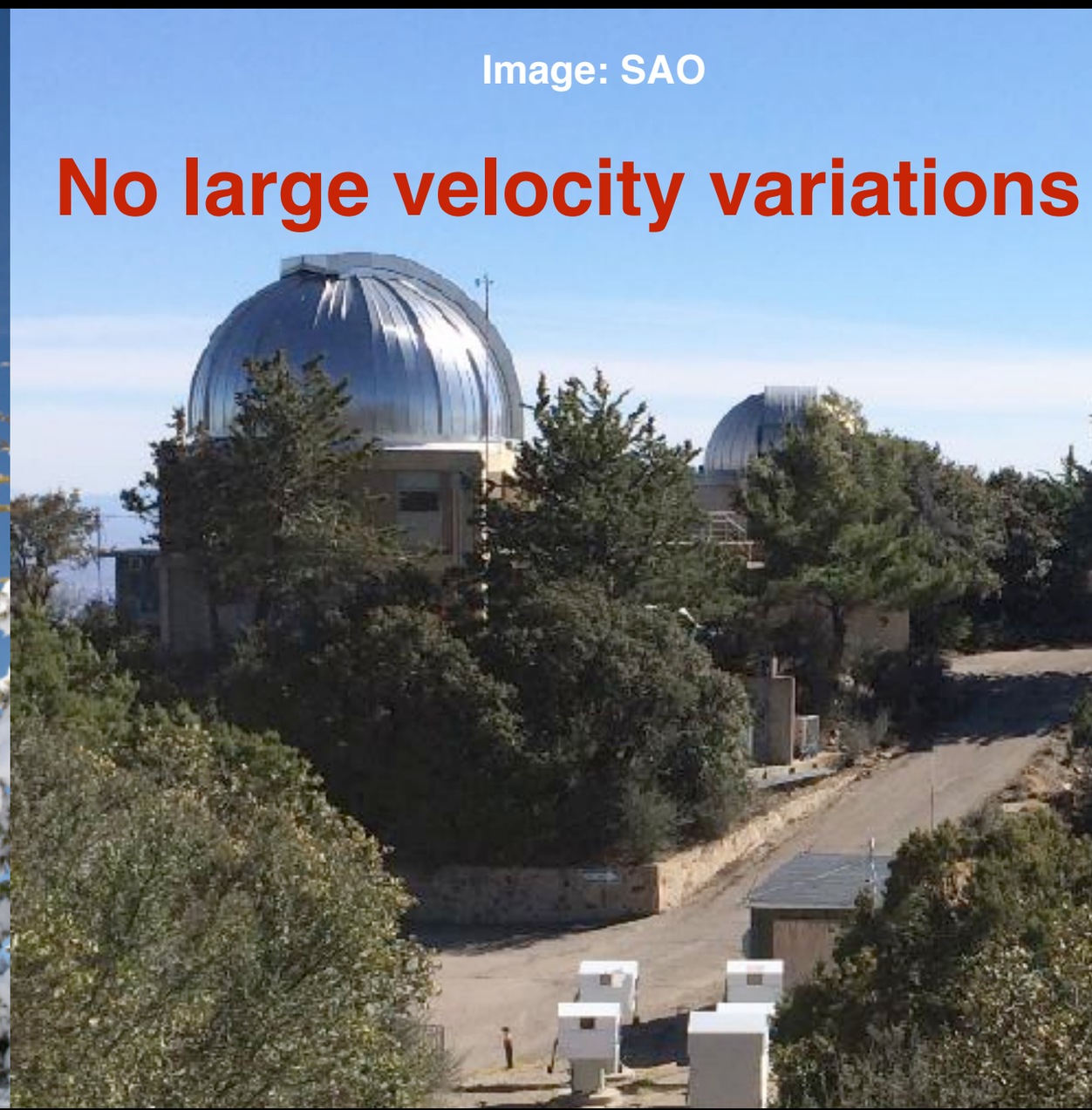
Palomar 200” NIR low resolution spectrum

Mt. Hopkins 60” optical high resolution spectra

Image: Caltech

Determine stellar parameters

Image: SAO



No large velocity variations

Follow-up Observations: Spectroscopy

Palomar 20 **ns 60” optical**
low resolution **lution spectra**

Image: (

Determine stella

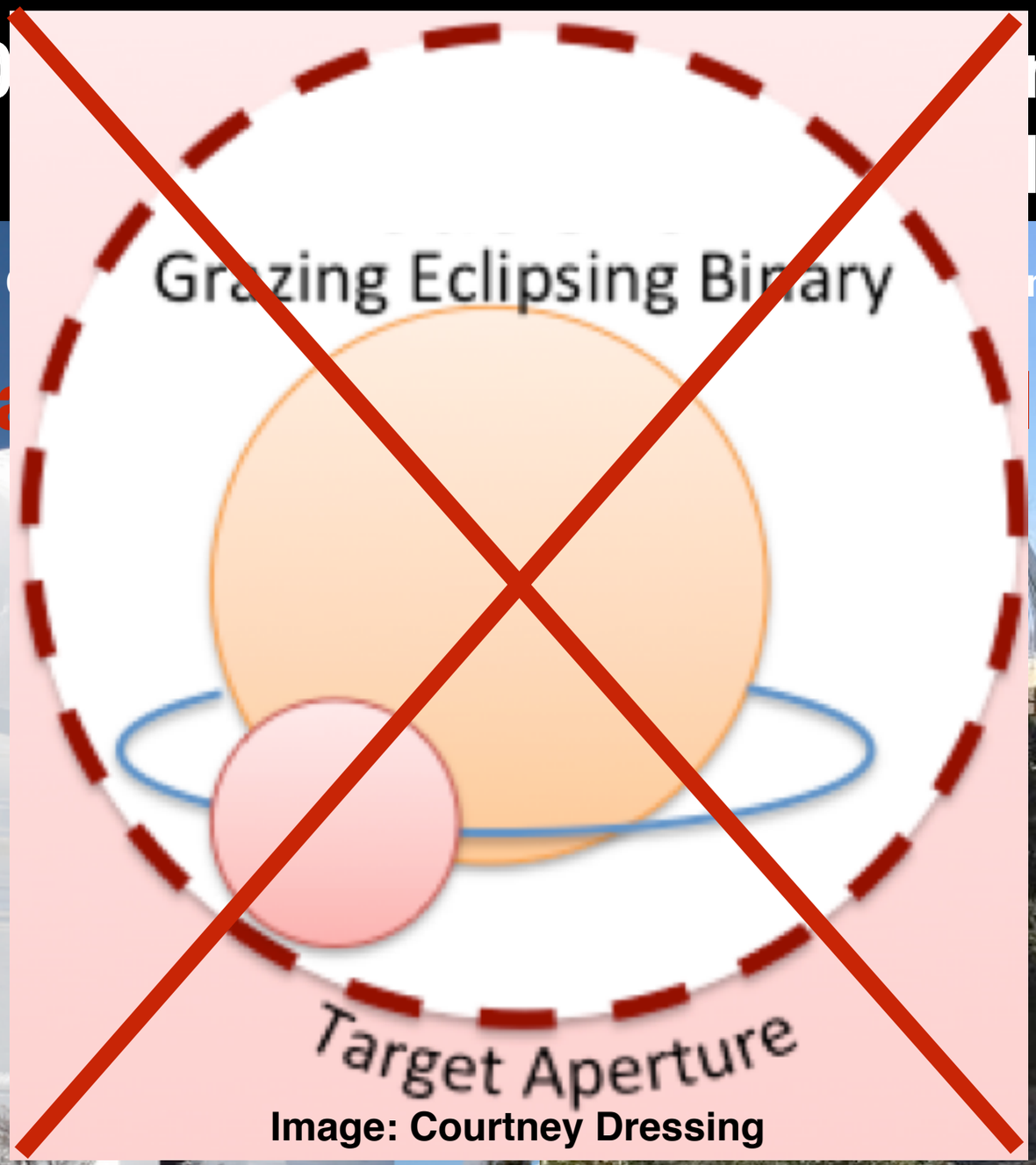


Image: Courtney Dressing

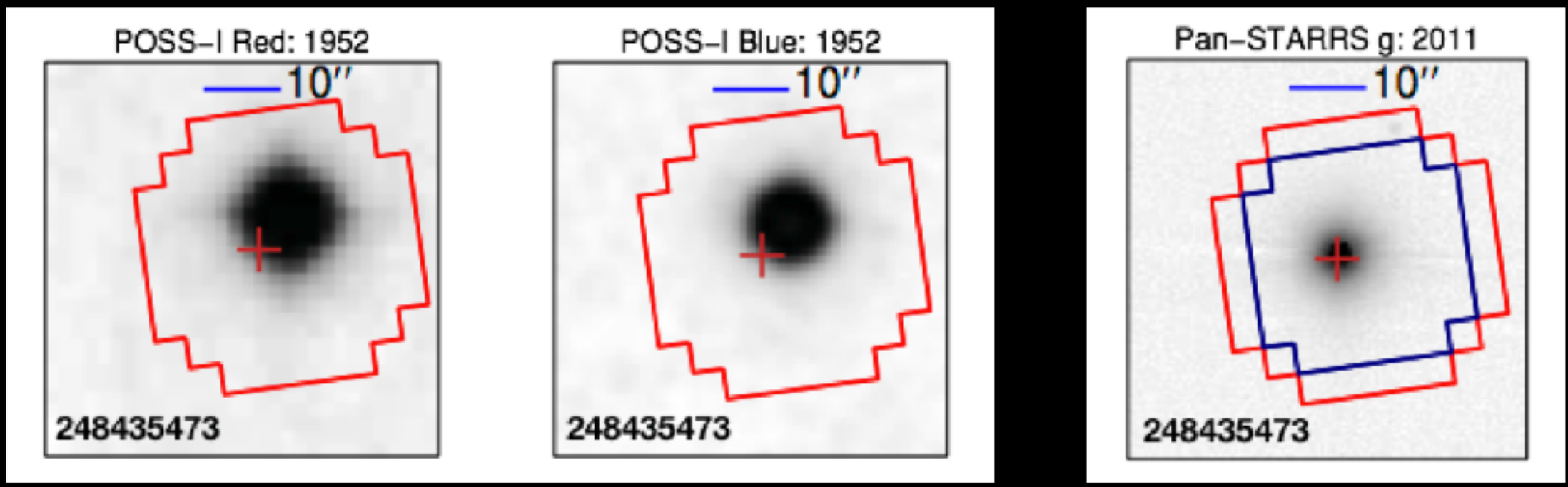
Image: SAO

ocity variations

Follow-up Observations: Archival Imaging

Palomar Observatory Sky Survey

Pan-STARRS Data Release 1



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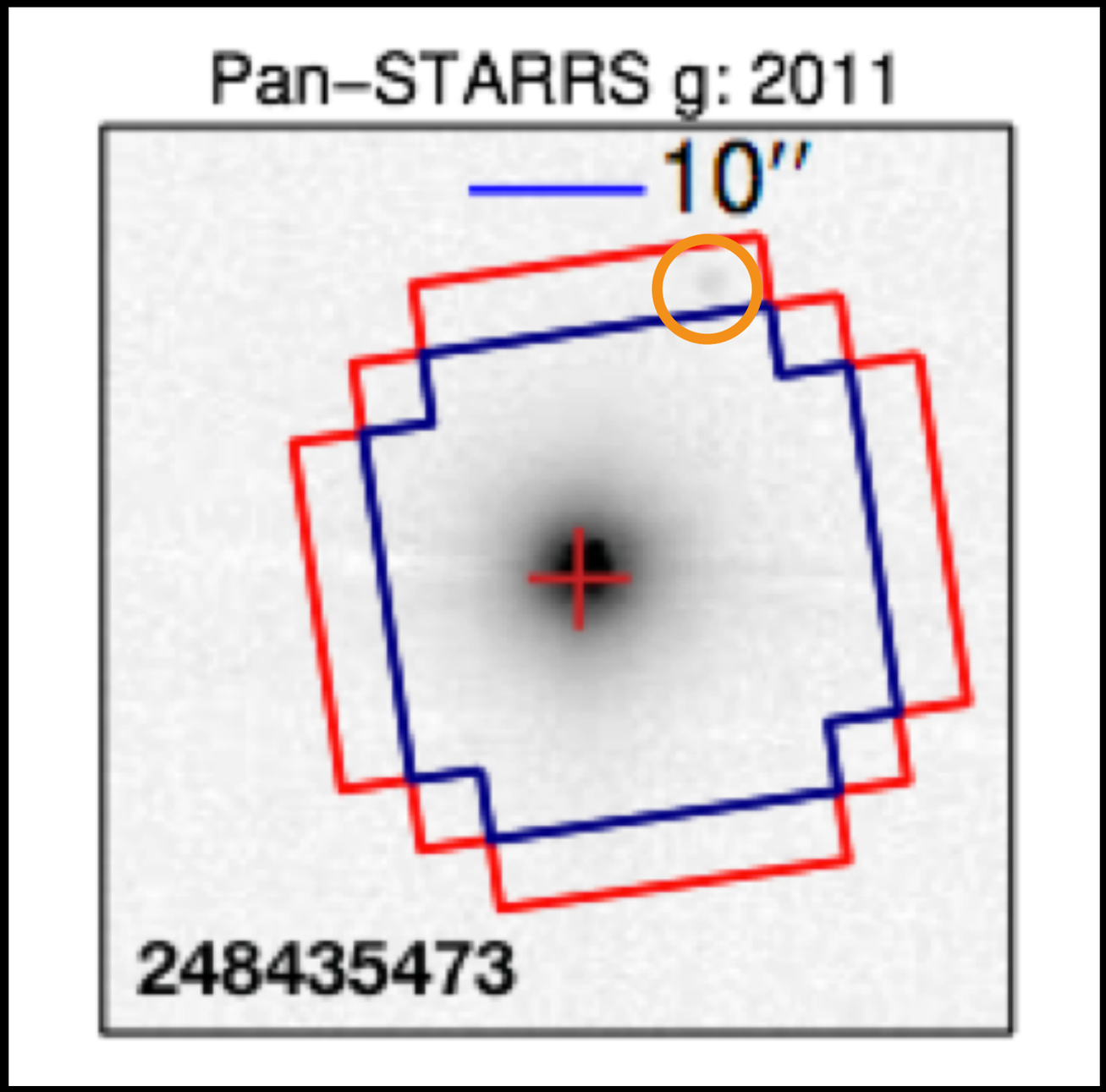
Follow-up Observations: Archival Imaging



Pan-STARRS Data Release 1

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Follow-up Observations: Adaptive Optics Imaging

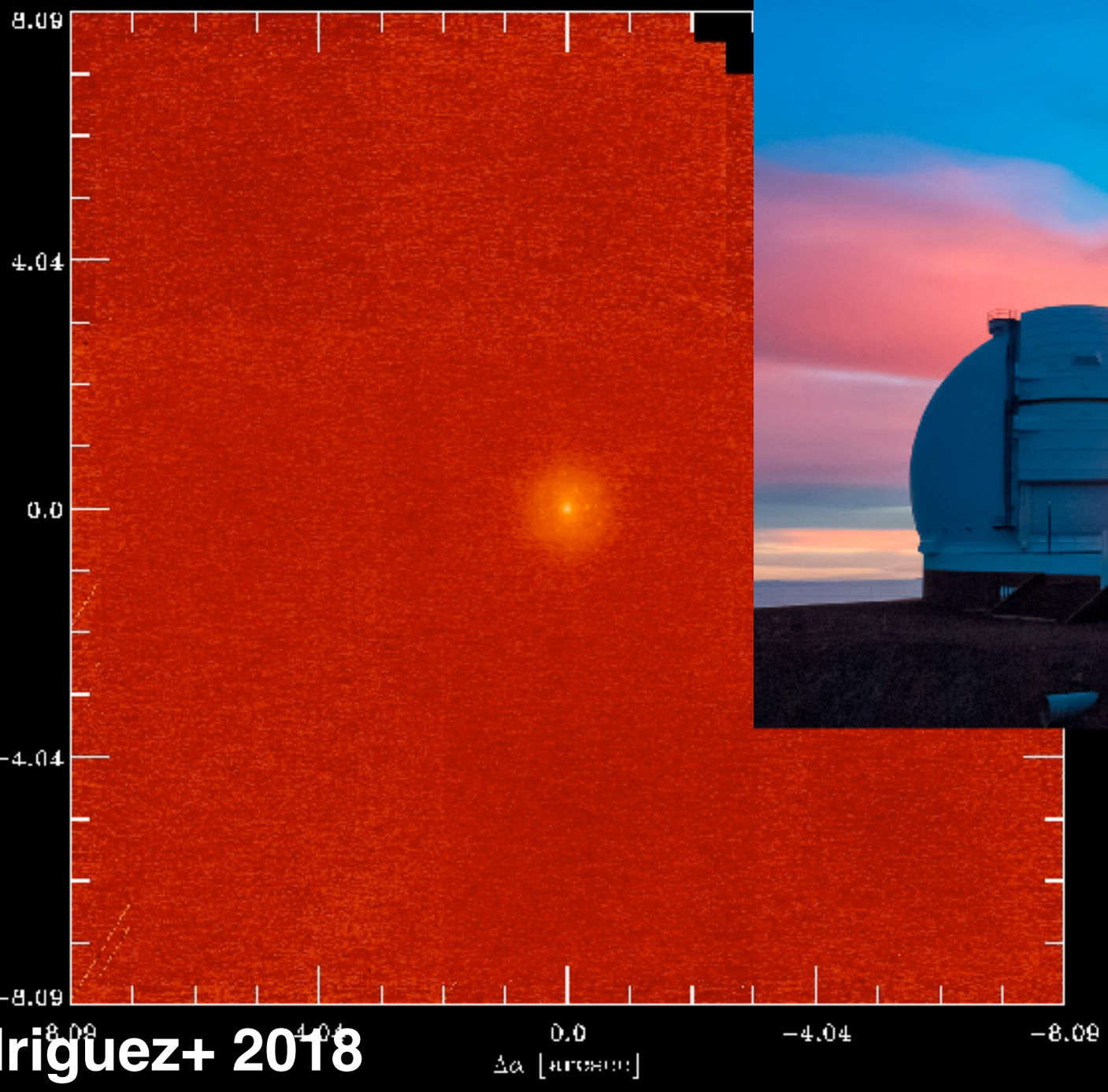

Image: Big Island Now

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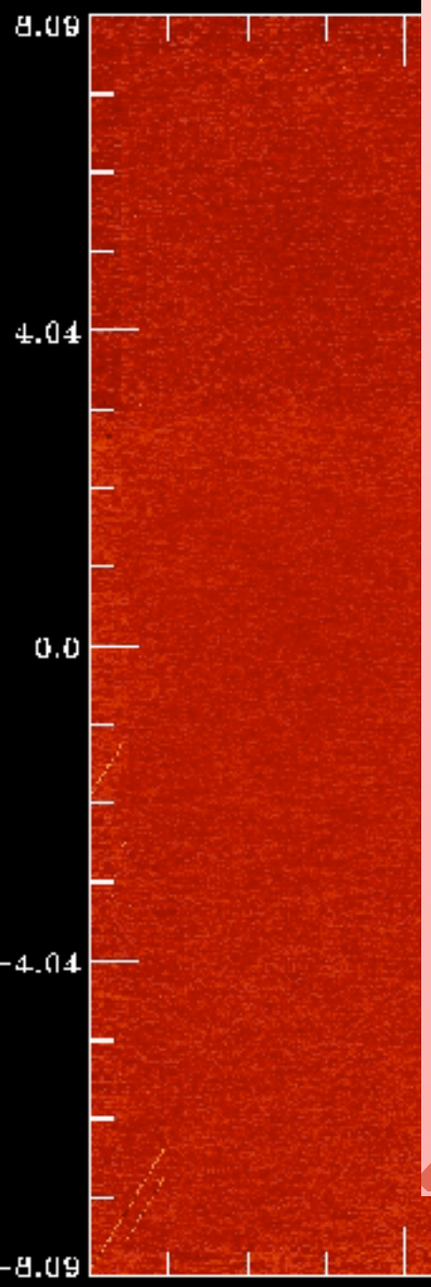
Follow-up Observations: Ada ging



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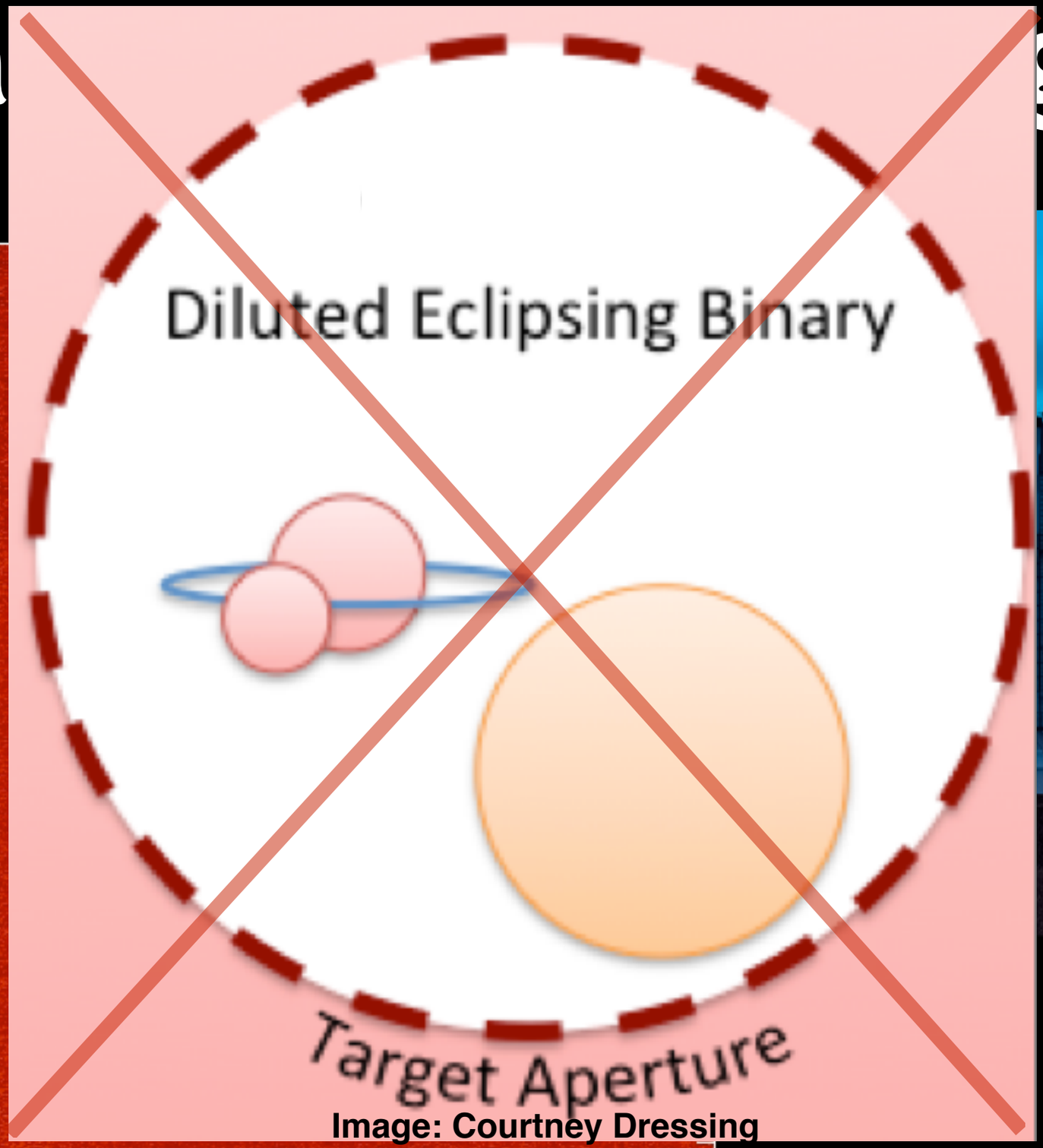


Image: Courtney Dressing

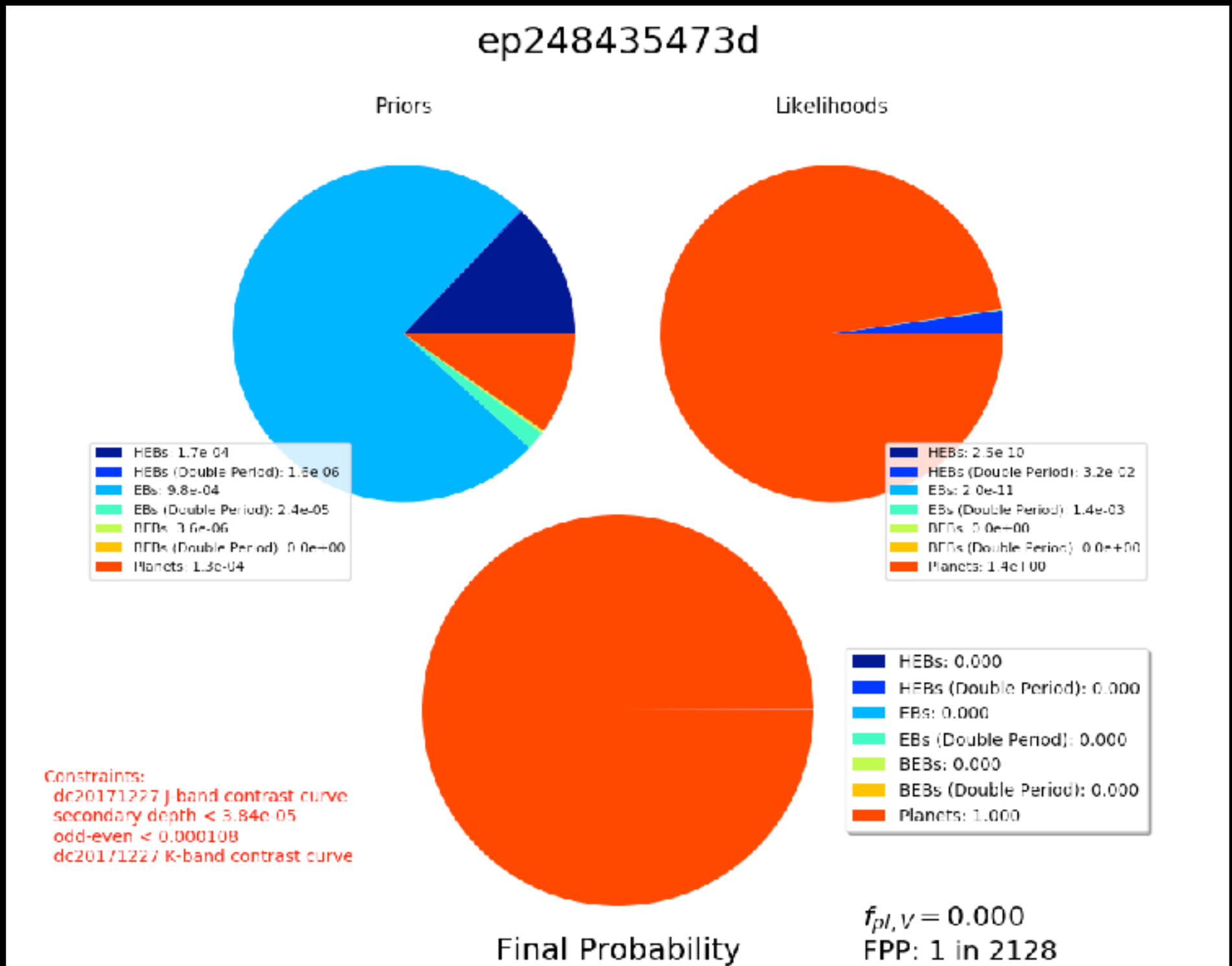
Image: Big Island Now

Ruling out Instrumental False Positives

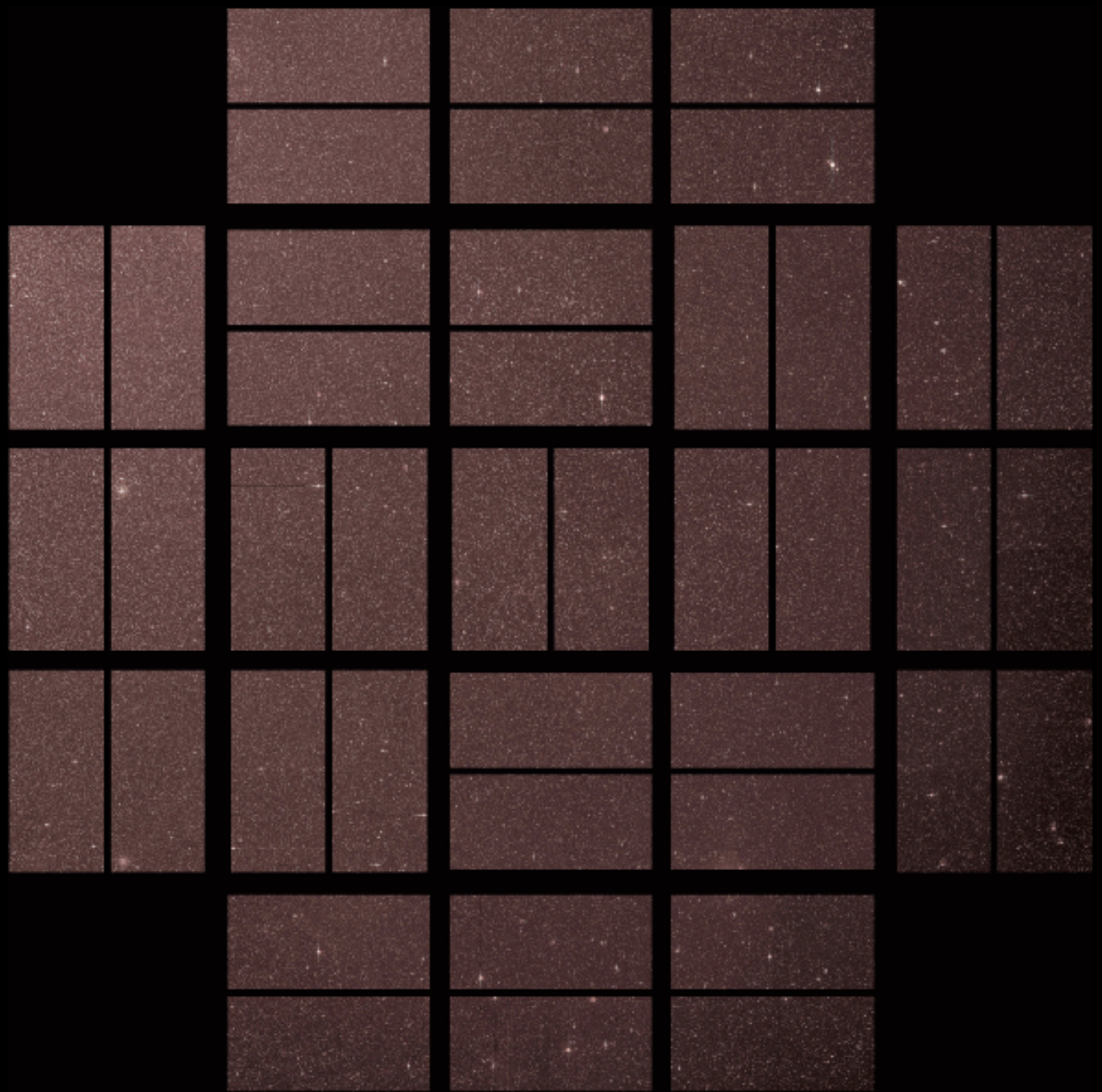
EPIC 248435473.01: 114.6 sigma
EPIC 248435473.02: 111.5 sigma
EPIC 248435473.03: 13.0 sigma
EPIC 248435473.05: 10.6 sigma

EPIC 248435473.04: 8.3 sigma
EPIC 248435473.06: 6.6 sigma

False Positive Probability Calculation with vespa



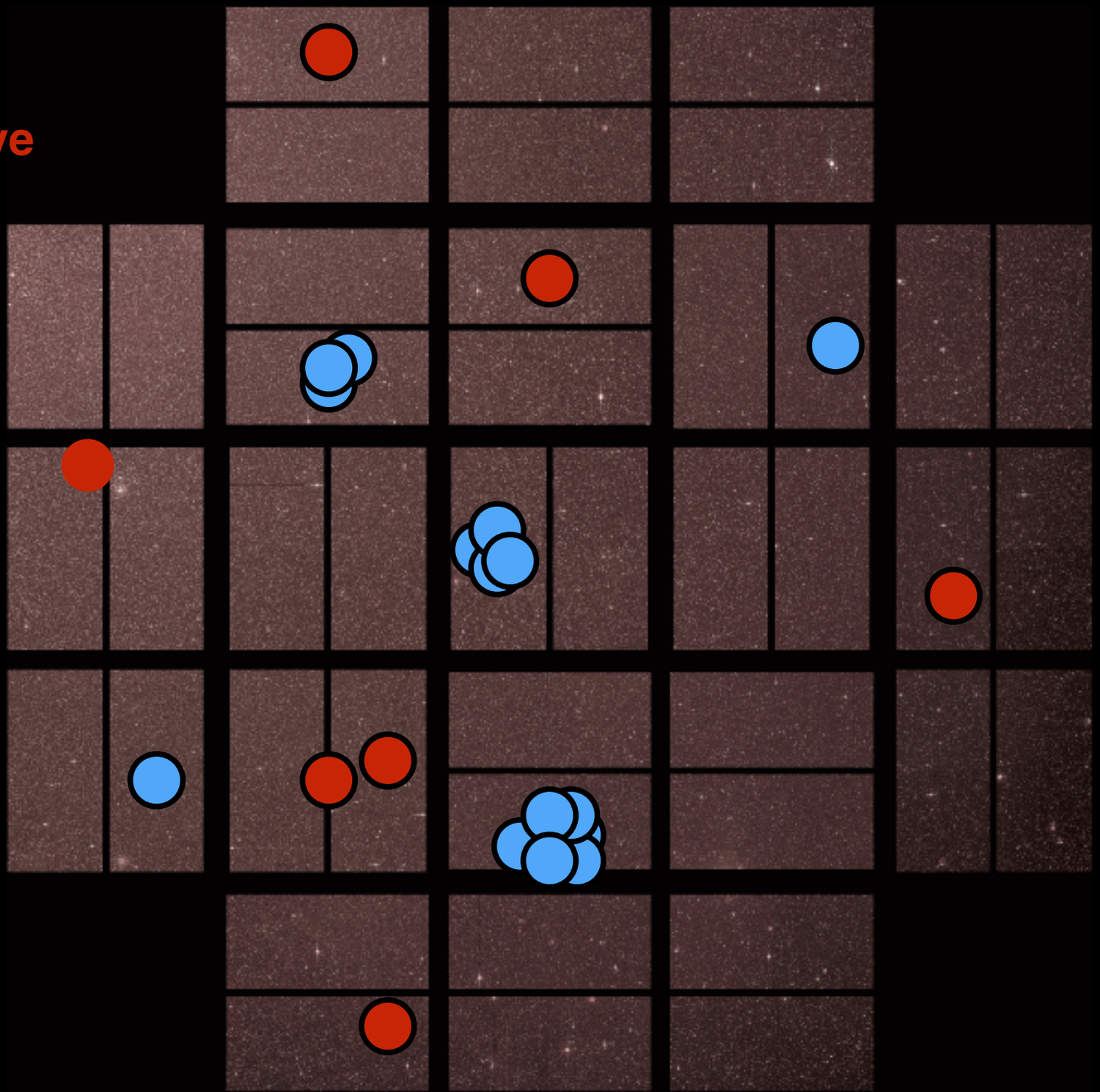
Multiple candidates around one star are more likely planets



Multiple candidates around one star are more likely planets

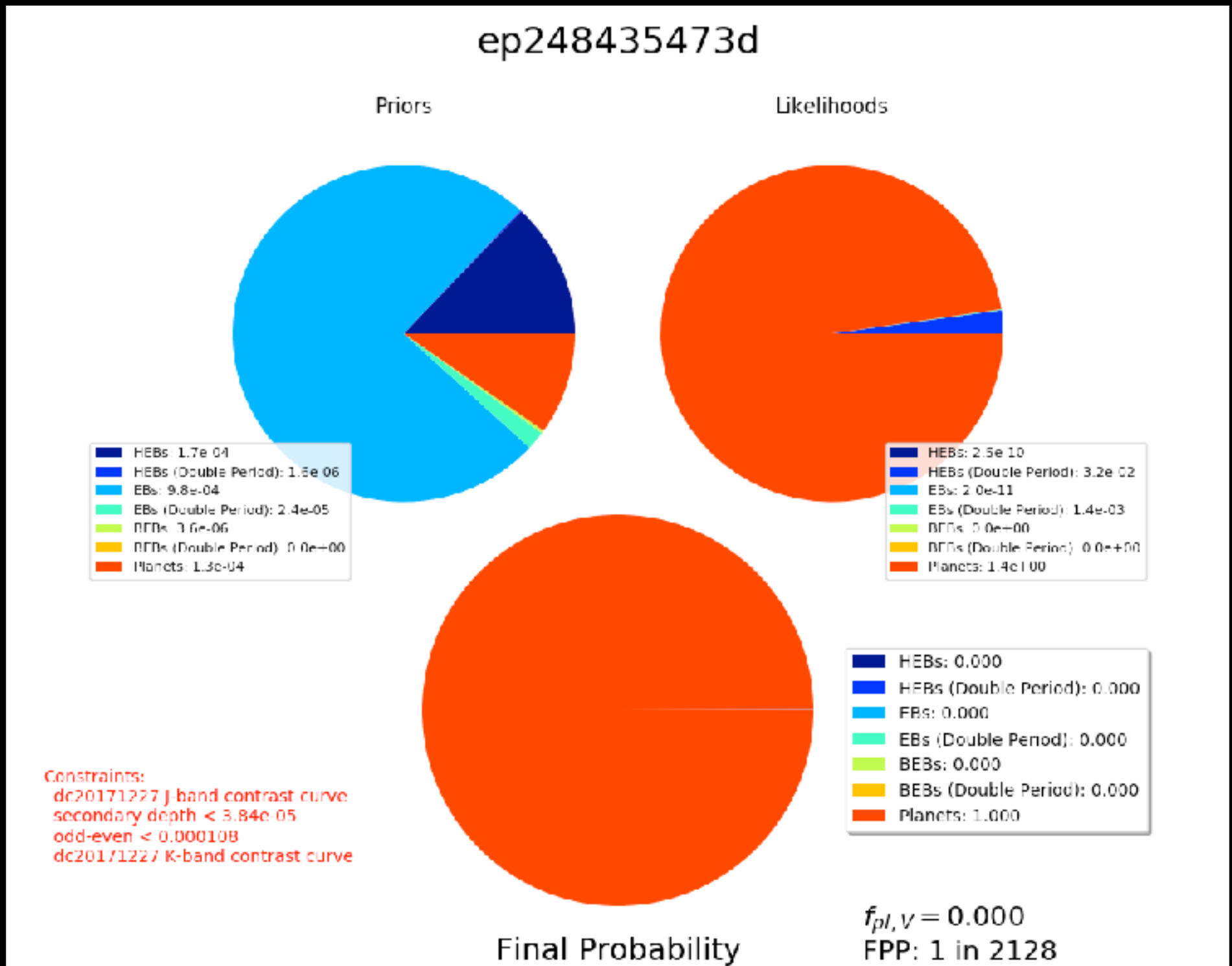
Candidate

False Positive



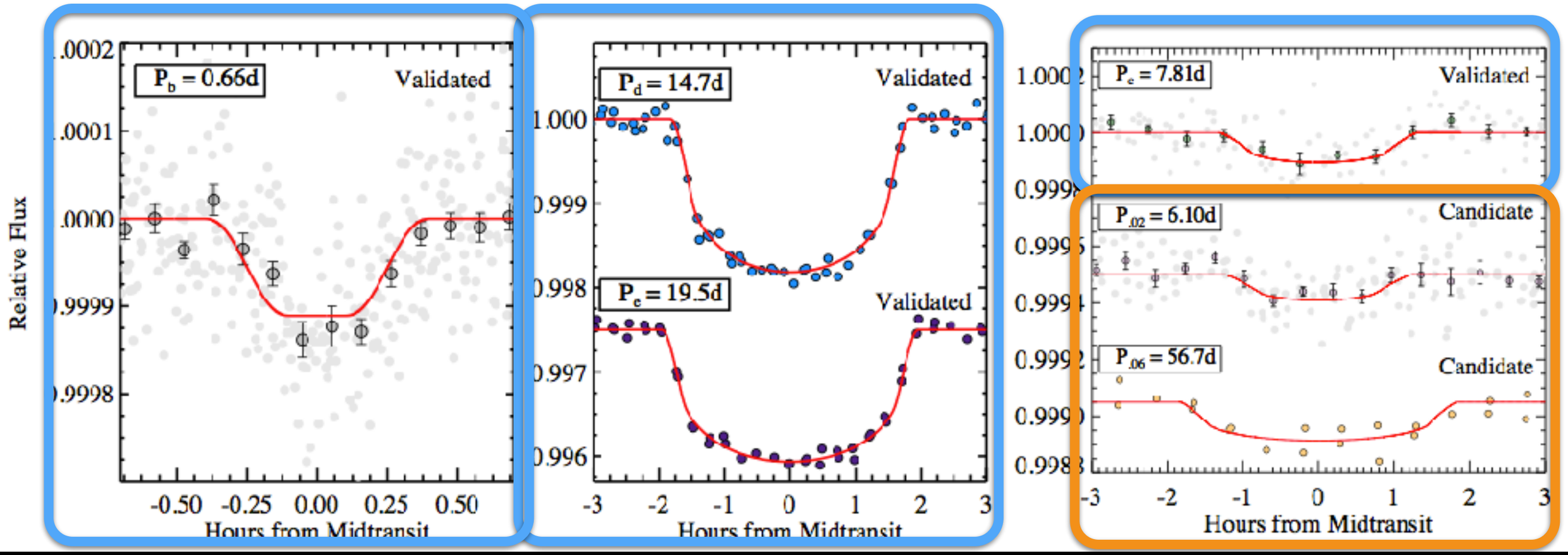
Candidates in multi systems are 20-50 times more likely to be planets than candidates in single systems.

False Positive Probability Calculation with vespa



Validated Planet:
A vetted planet candidate which has a calculated False Positive Probability (FPP) less than some threshold value (often 1% or 0.1%).

Example: EPIC 248435473



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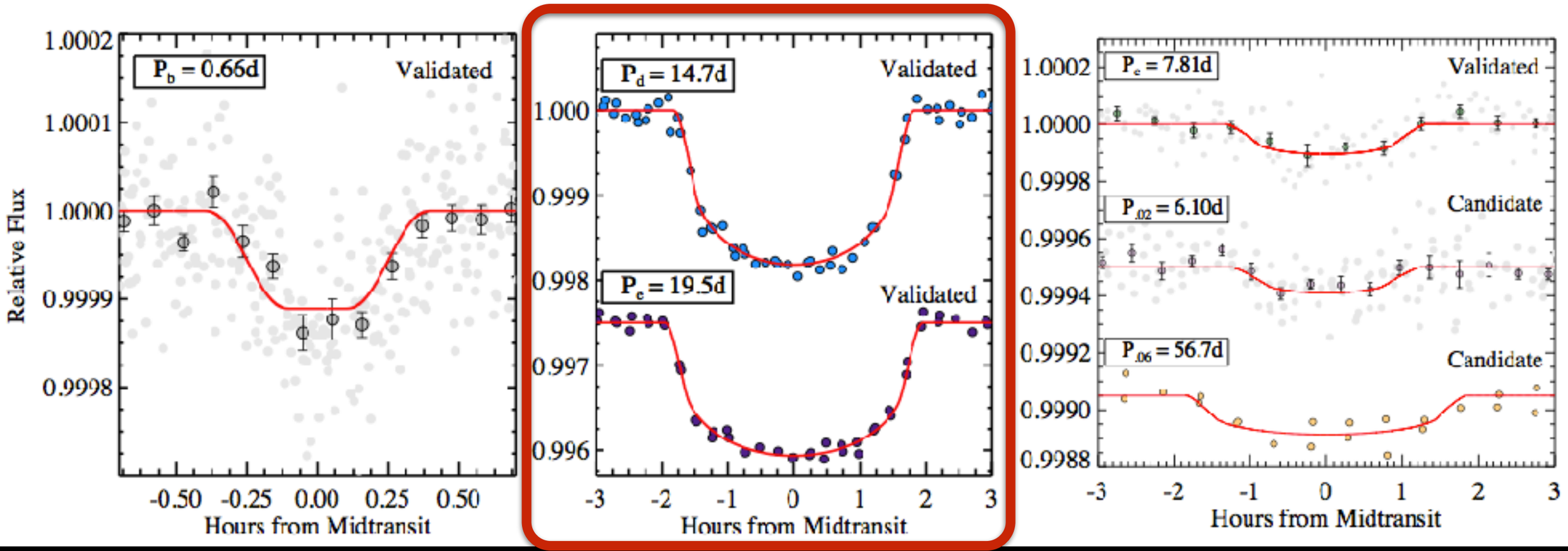
Confirmed Planet:
A planet candidate which either has a mass measurement (showing the companion is planetary mass) or has been detected by some other technique (e.g. Doppler Tomography).

Example: EPIC 248435473



Two sub-Neptune validated planets detected at ~110σ near resonance.

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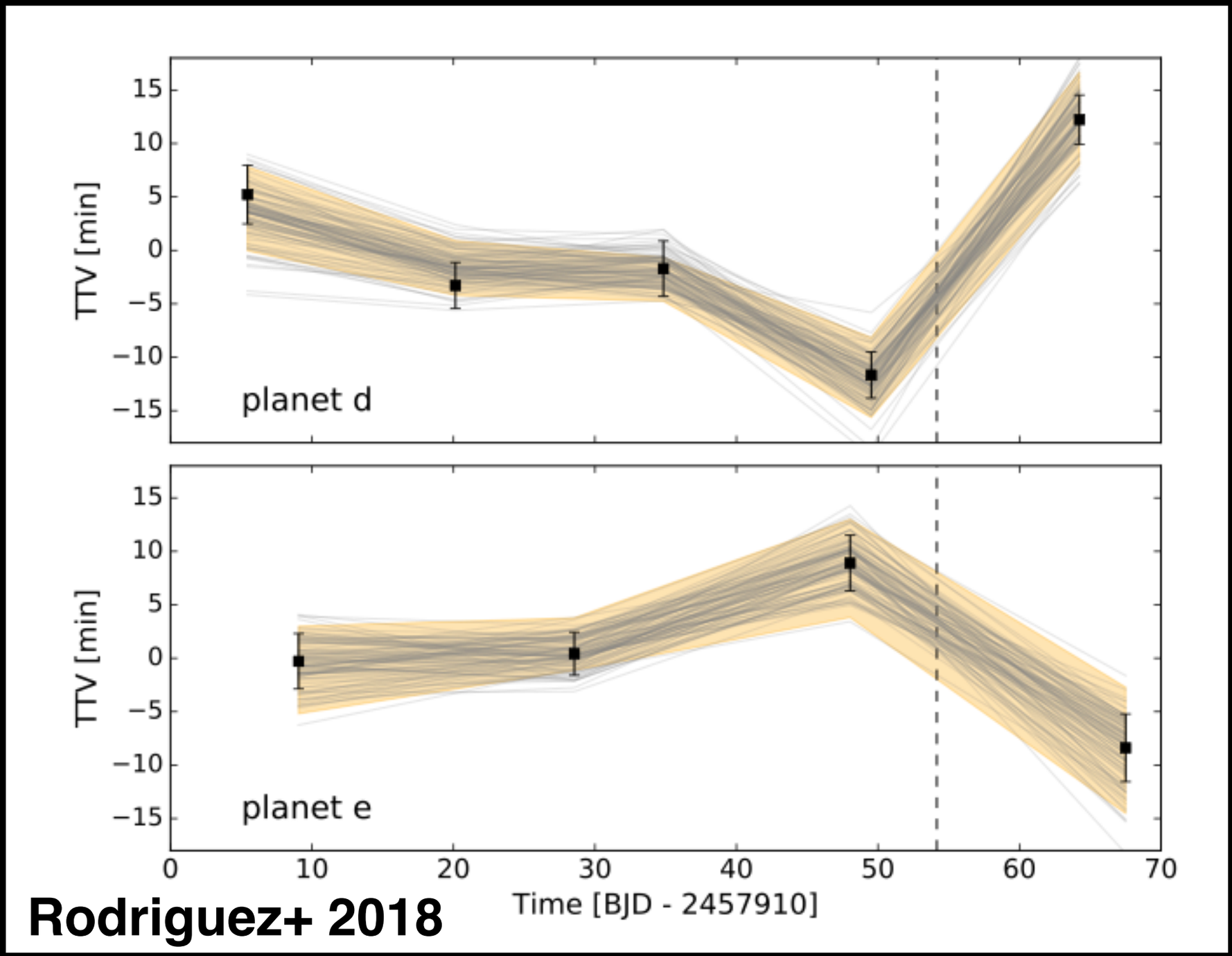
Example: EPIC 248435473 TTV confirmation



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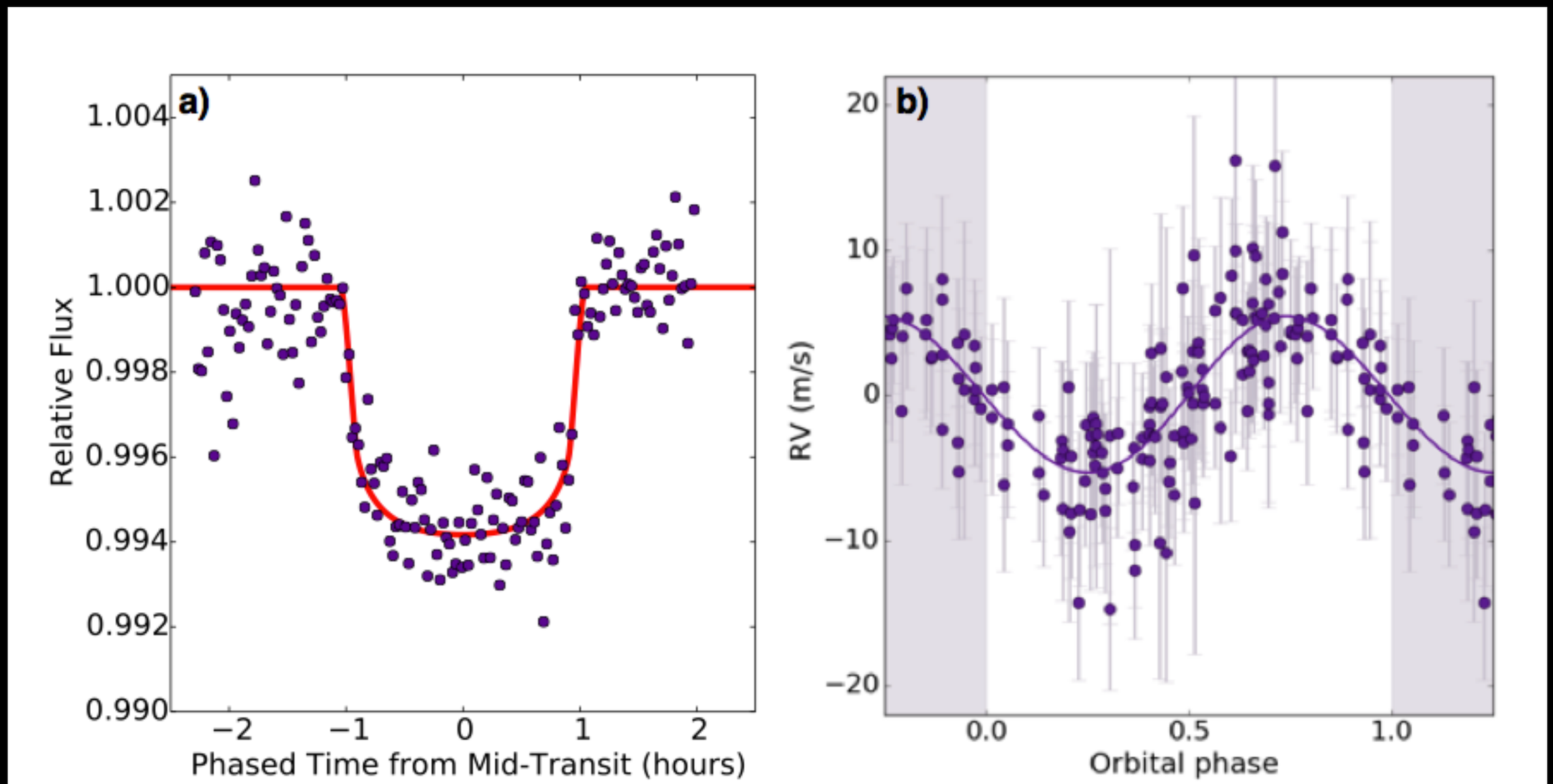
Another Example: LHS 1140b



Dittmann+ 2017

The Process of Validating Transiting Exoplanets

K2 Pixel Data

Sum the pixels to get

Light Curves

Remove systematics and slow variability and perform a

Transit Search

to find signals where the brightness may be decreasing, or

Threshold Crossing Events

and identify which are astrophysical and not false positives, or

Planet Candidates

and obtain follow-up observations and calculate FPP to yield

Validated Planets

and in some cases, use other independent information to get

Confirmed Planets