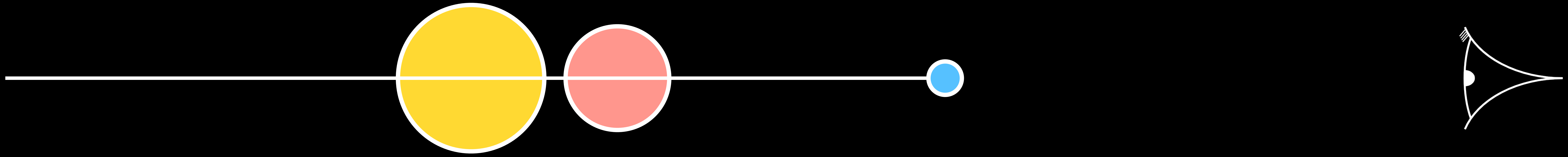
“The Photometric Method of Detecting Other Planetary Systems”

Borucki & Summers, 1984

“Two methods for selecting stars... #2 eclipsing binary stars”



Pro: increased transit probability

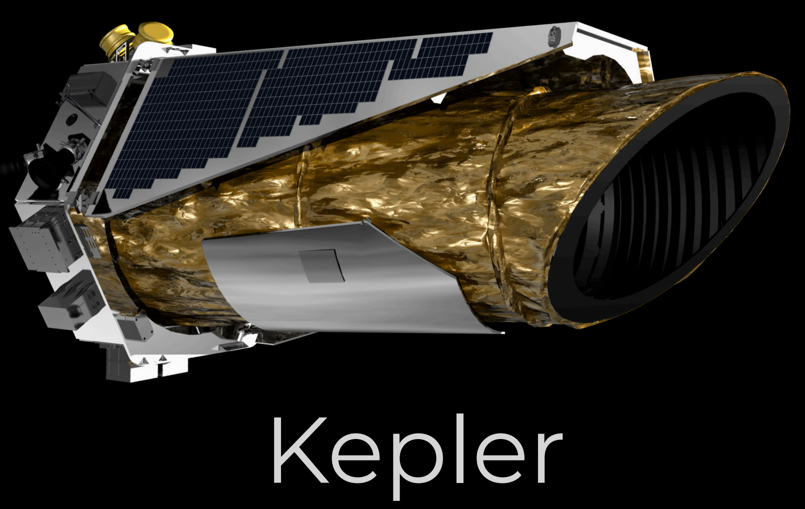
Con: ... dilution?

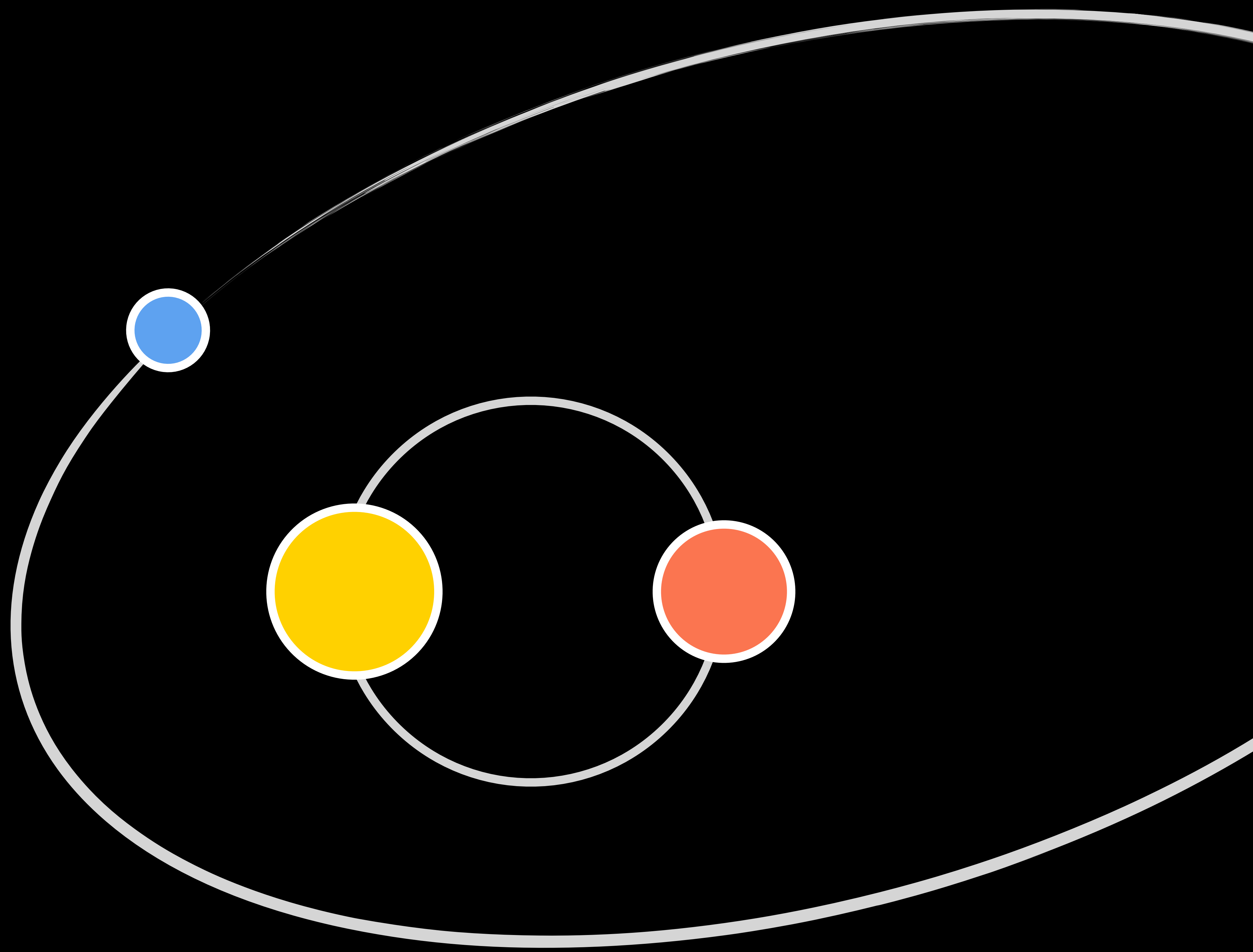
The #1 Problem: Geometry

The #1 Problem: Geometry

The #2 Problem: Dynamics

1. Orbital timescale

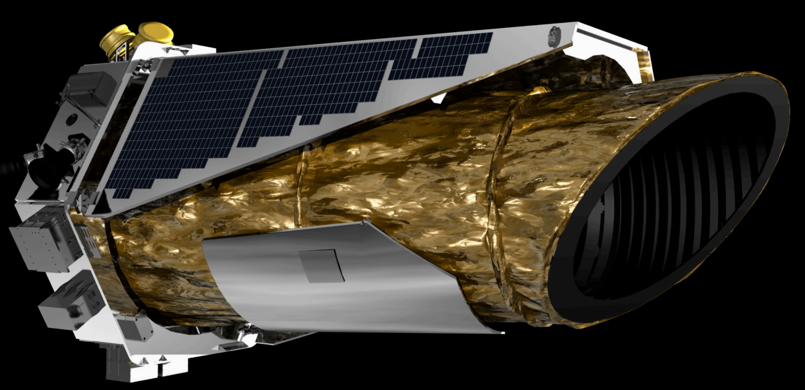




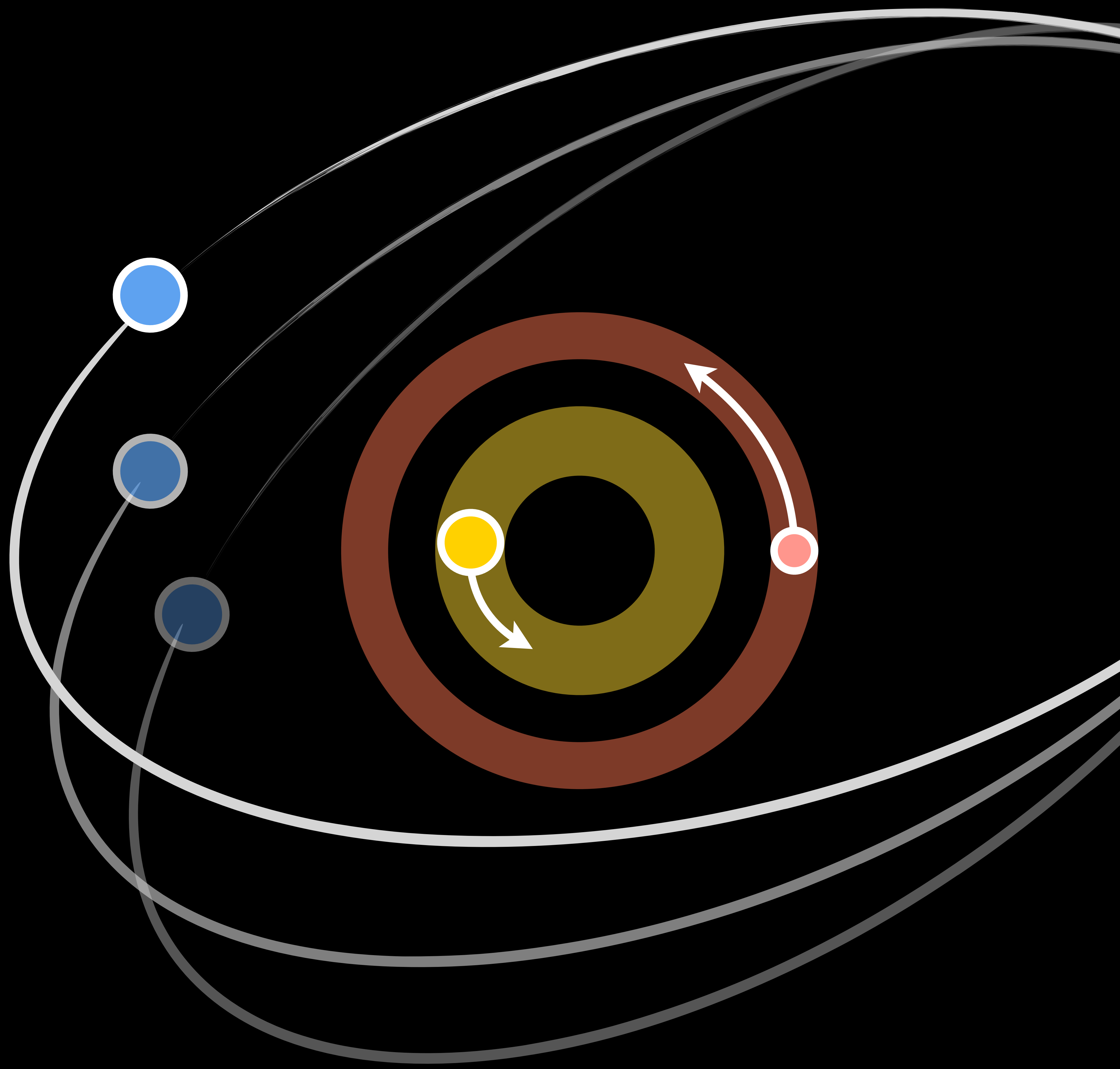
The #2 Problem: Dynamics

1. Orbital timescale

2. Secular timescale



Kepler



and Geometry

Finding Circumbinary Planets with Orbital Dynamics

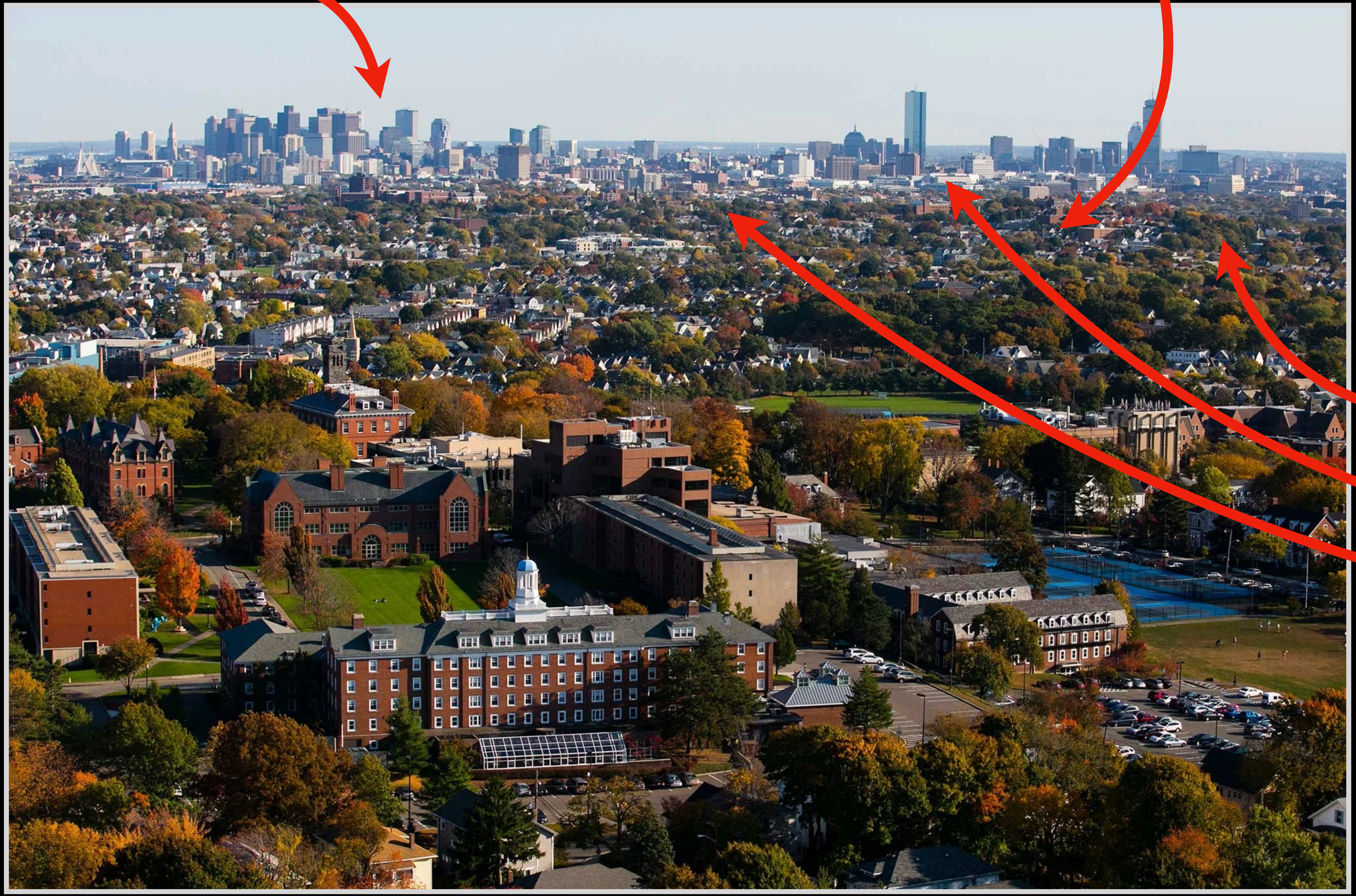
David V. Martin

Tufts University

Boston

Cambridge

Tufts
UNIVERSITY



A bunch of other universities that you've probably never heard of

Problems

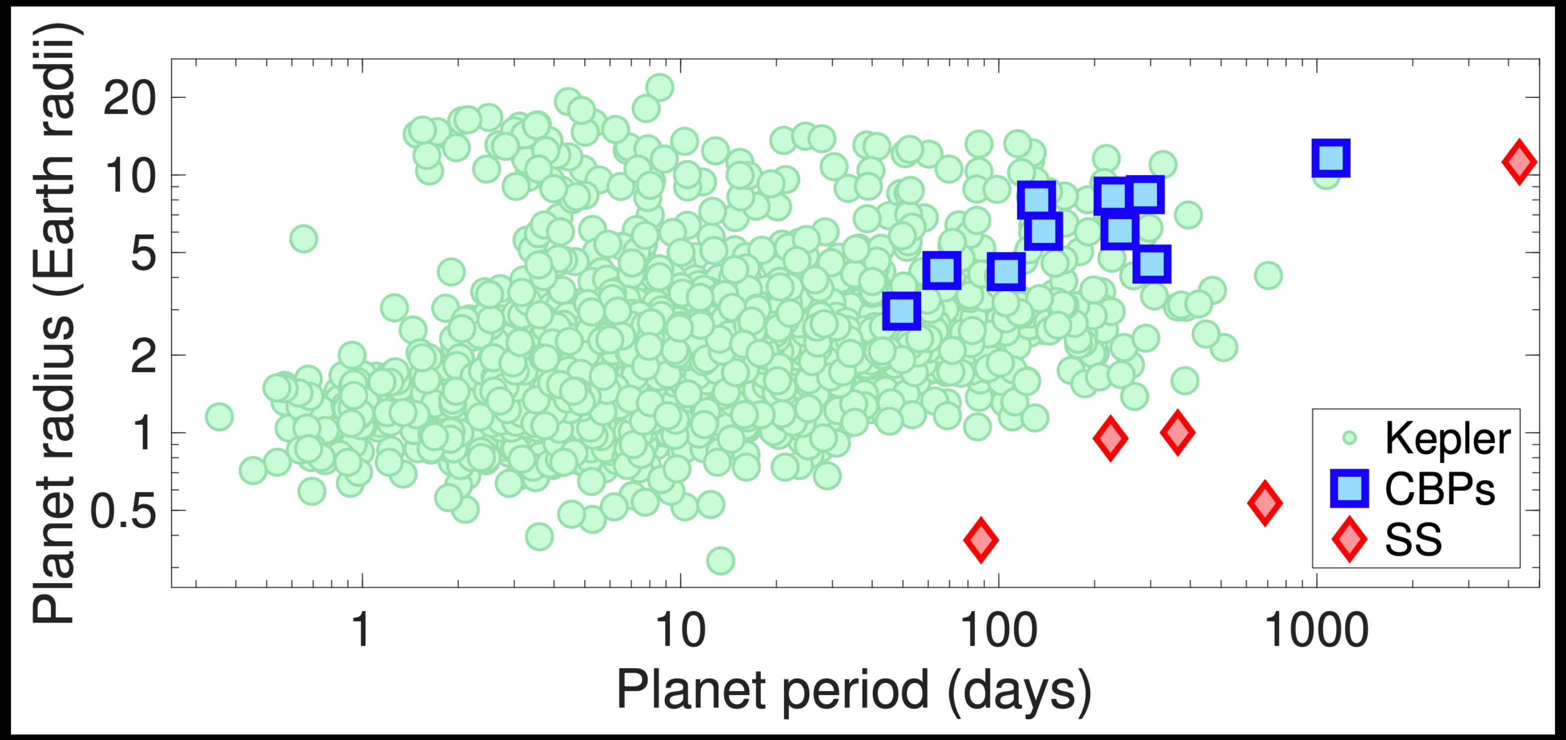
1. Geometry
2. Dynamics

Goal

Find CBPs as easily as single star planets

Status

12 Kepler, 2 TESS



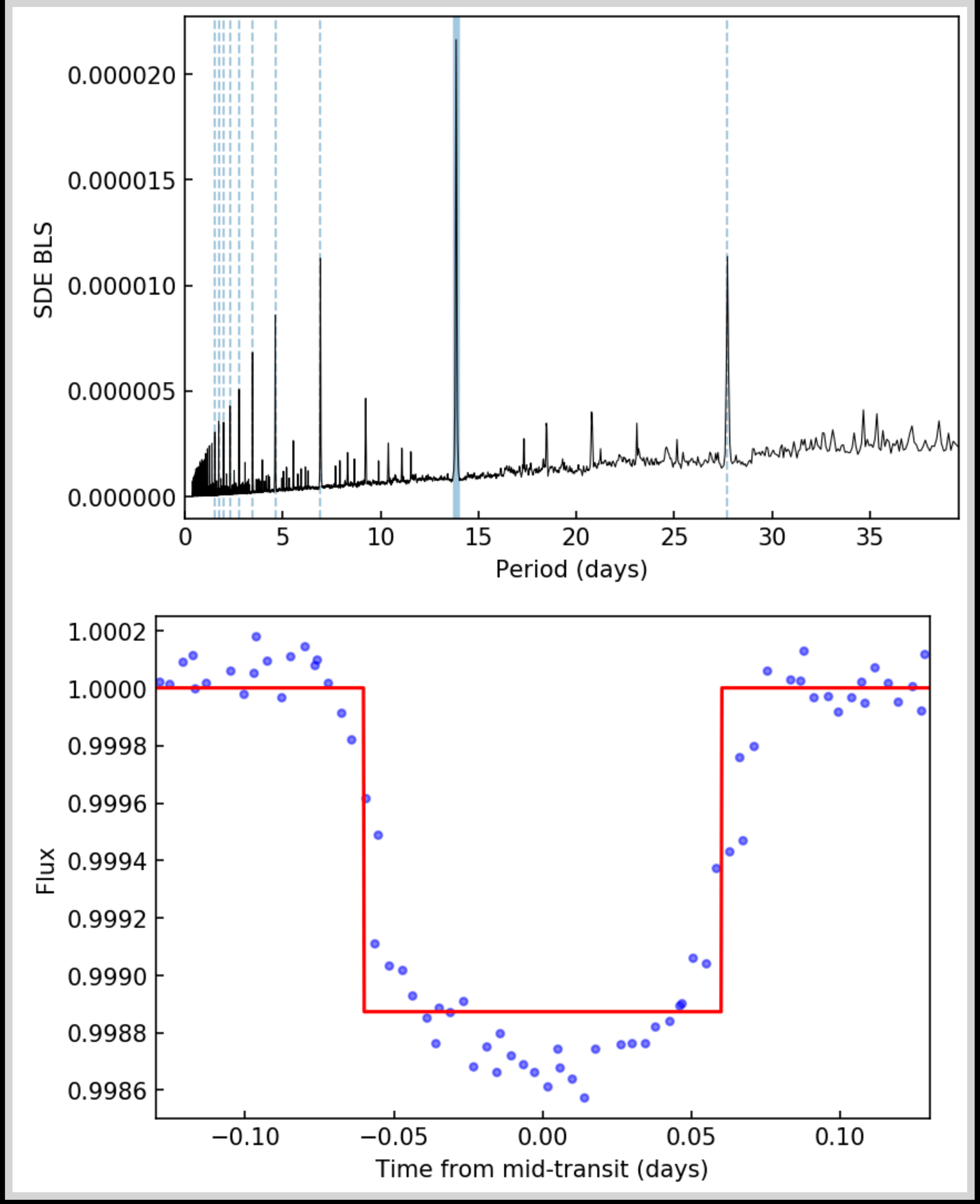
Solutions

...

Solutions?

Kovacs+ 2002 - BLS

Phase-fold on strict periodicity

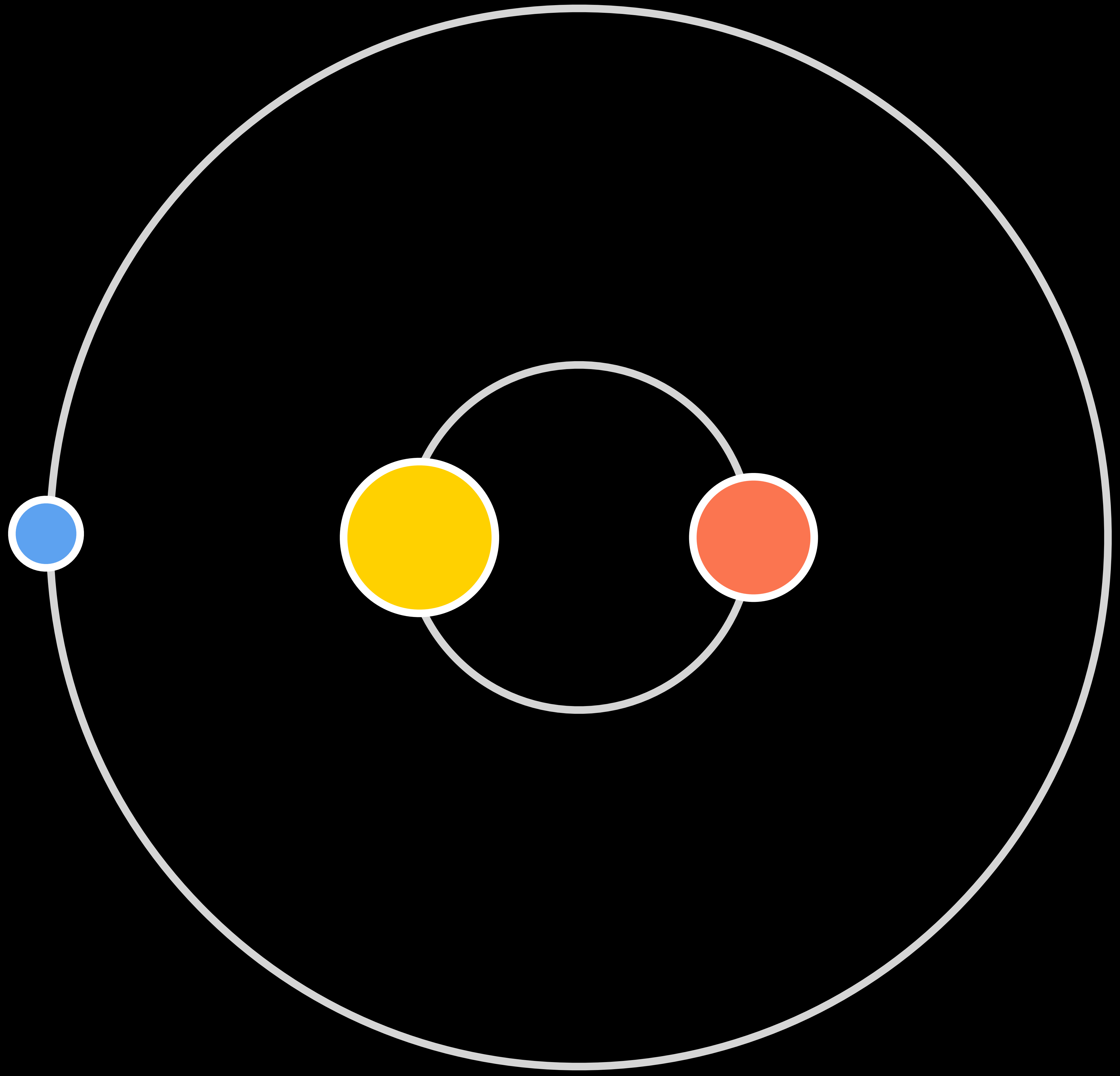


Solutions?

Kovacs+ 2002 - BLS

Ofir 2008 - CB-BLS

Phase-fold accounting for binary movement, not dynamics



Solutions?

Kovacs+ 2002 - BLS

Ofir 2008 - CB-BLS

Carter & Agol - QATS

BLS but allows for quasi-period transit intervals.

Not physically motivated but can find planets with large TTVs

Solutions?

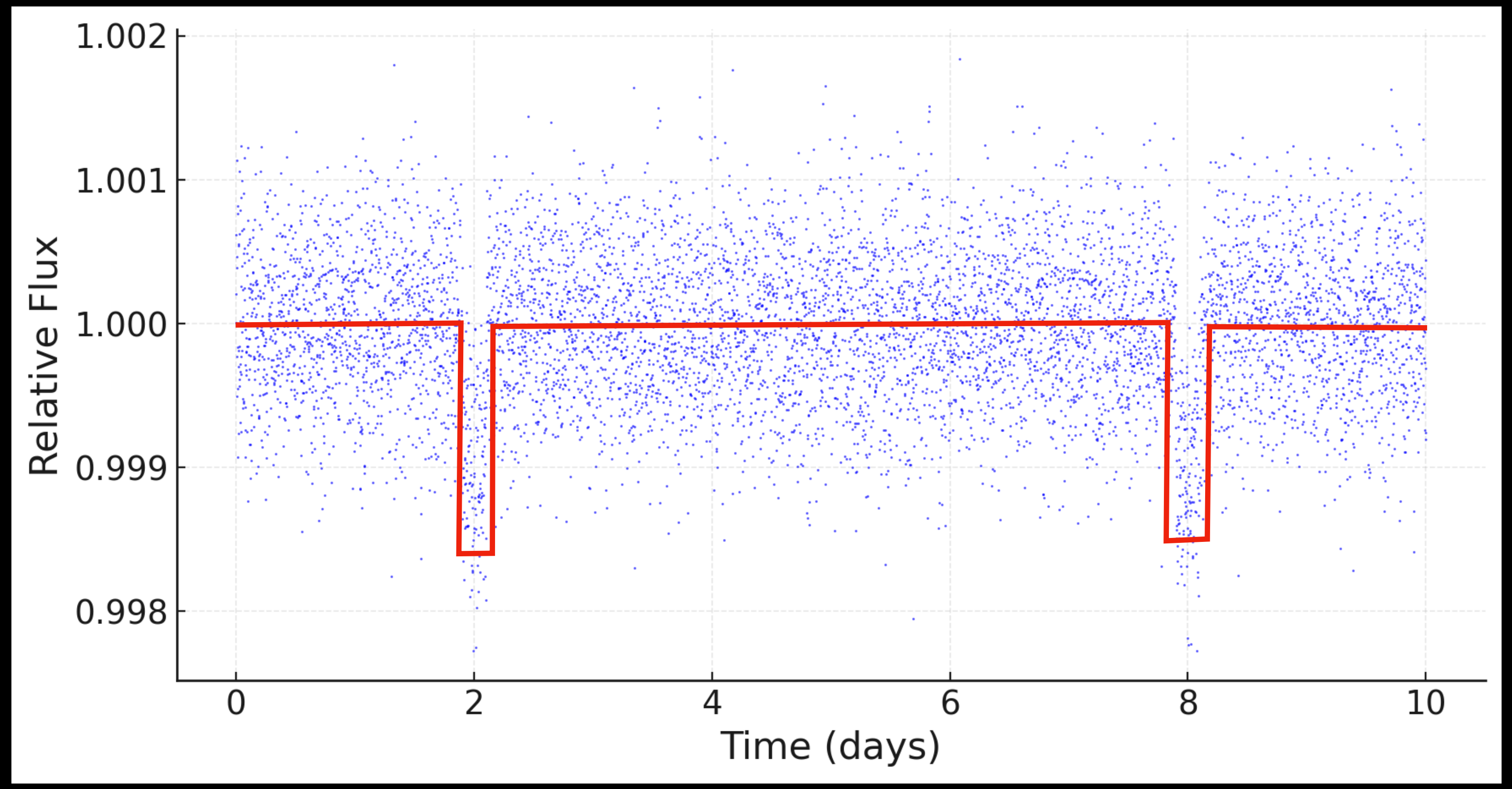
Kovacs+ 2002 - BLS

Ofir 2008 - CB-BLS

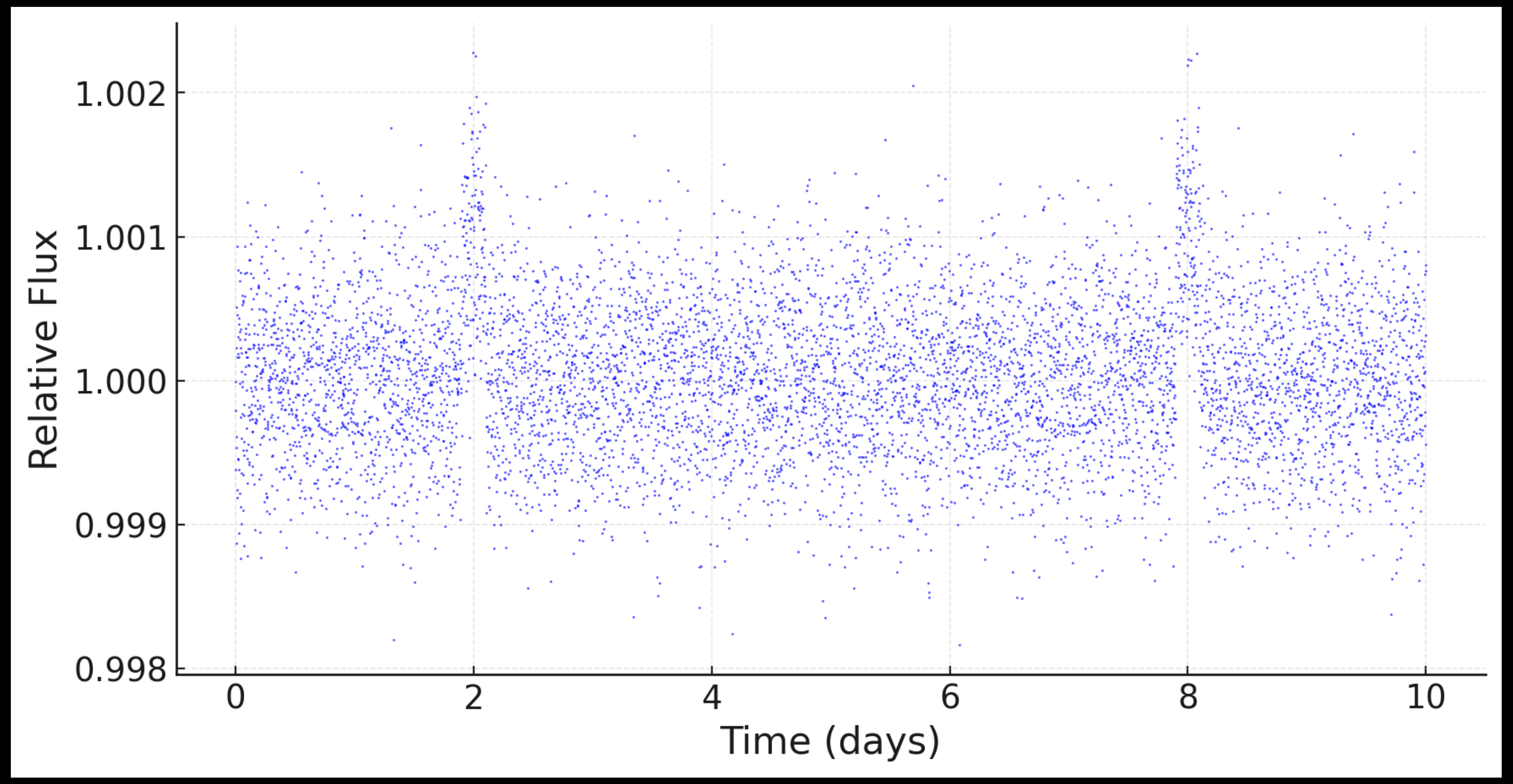
Carter & Agol - QATS

Kostov+ 2013/14

BLS in 2-transit segments



Flip light curve and run BLS again - did you just find noise?



Solutions?

Kovacs+ 2002 - BLS

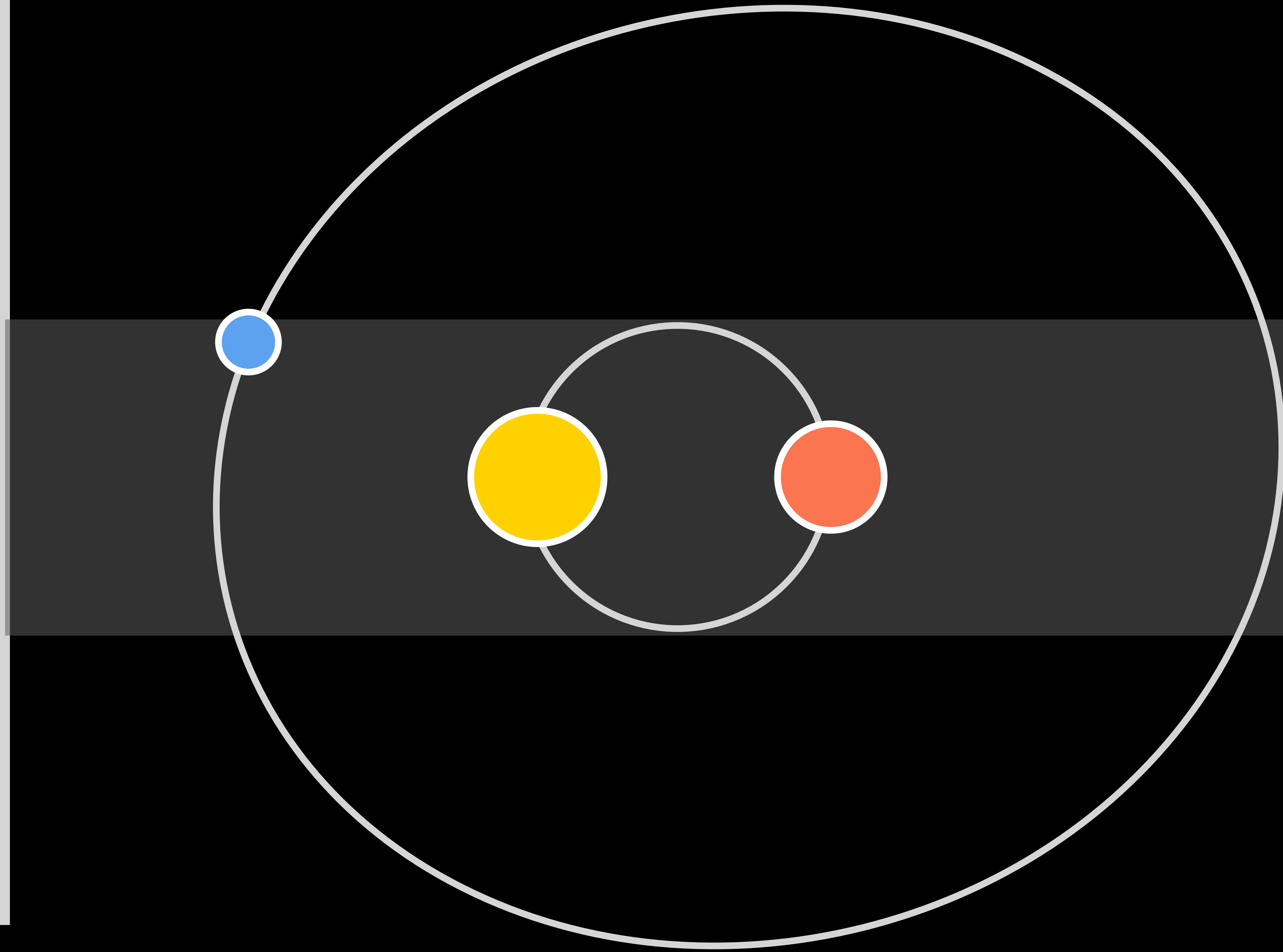
Ofir 2008 - CB-BLS

Carter & Agol - QATS

Kostov+ 2013/14

Armstrong+ 2013/2014

Phase-fold into window of possible times, account apsidal for precession



Solutions?

Kovacs+ 2002 - BLS

Ofir 2008 - CB-BLS

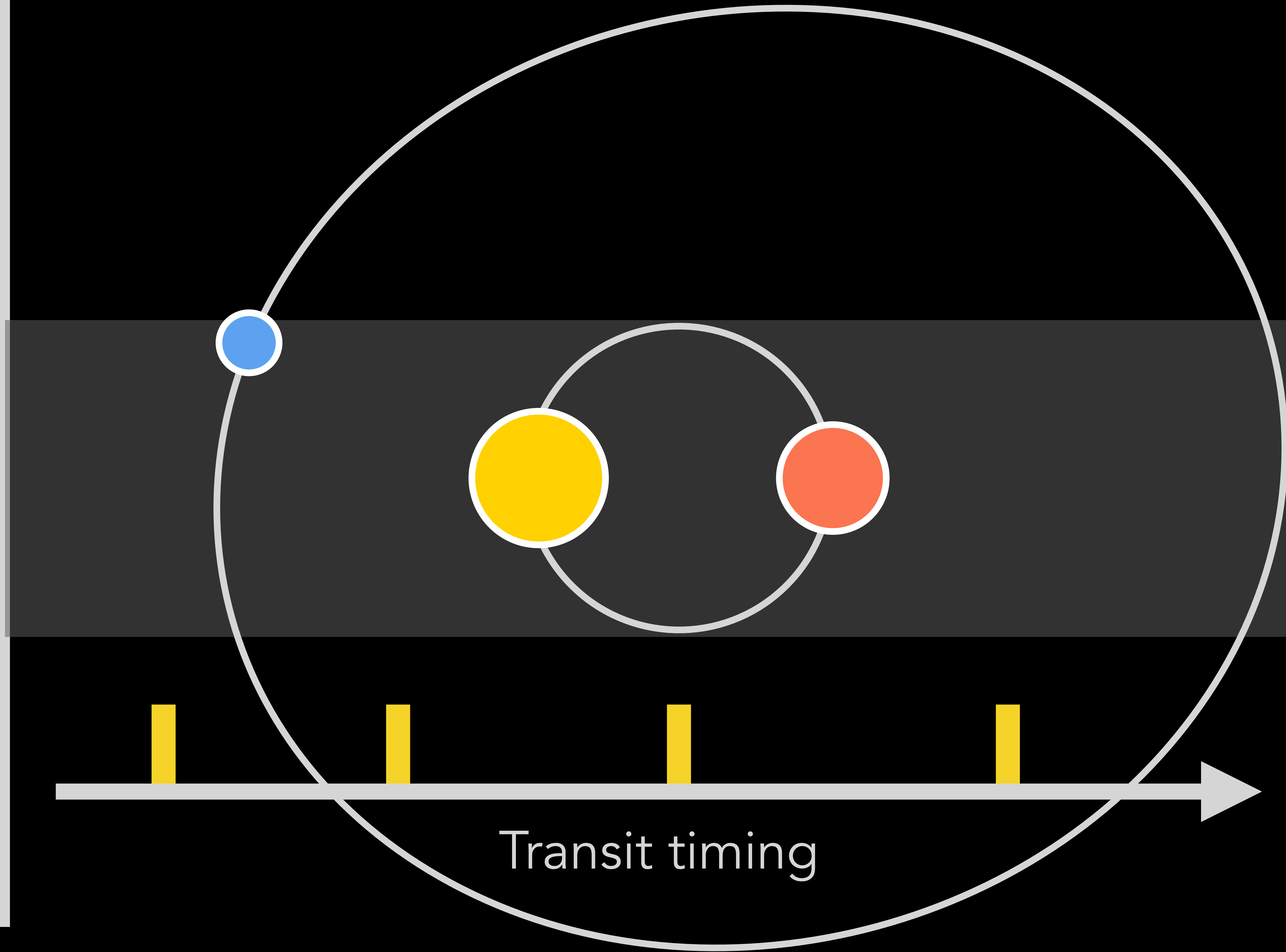
Carter & Agol - QATS

Kostov+ 2013/14

Armstrong+ 2013/2014

Klagyivik+ 2017

QATS within a window defined by Armstrong+ 2013



Solutions?

Kovacs+ 2002 - BLS

Ofir 2008 - CB-BLS

Carter & Agol - QATS

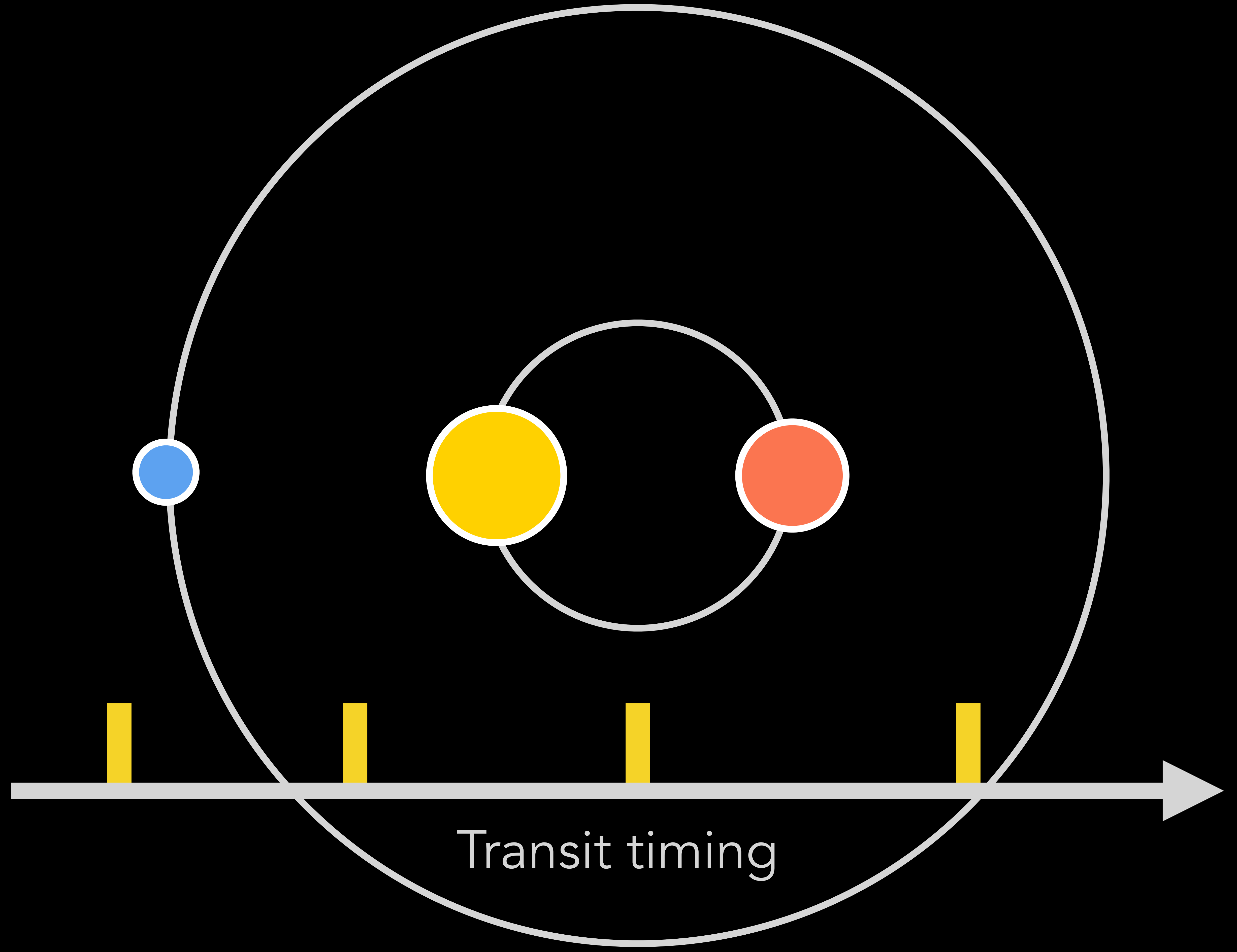
Kostov+ 2013/14

Armstrong+ 2013/2014

Klagyivik+ 2017

Windemuth+ 2019 - QATS-EB

“Regularized light curve” from 2 Keplerians. Then run QATS.



Solutions?

Kovacs+ 2002 - BLS

Ofir 2008 - CB-BLS

Carter & Agol - QATS

Kostov+ 2013/14

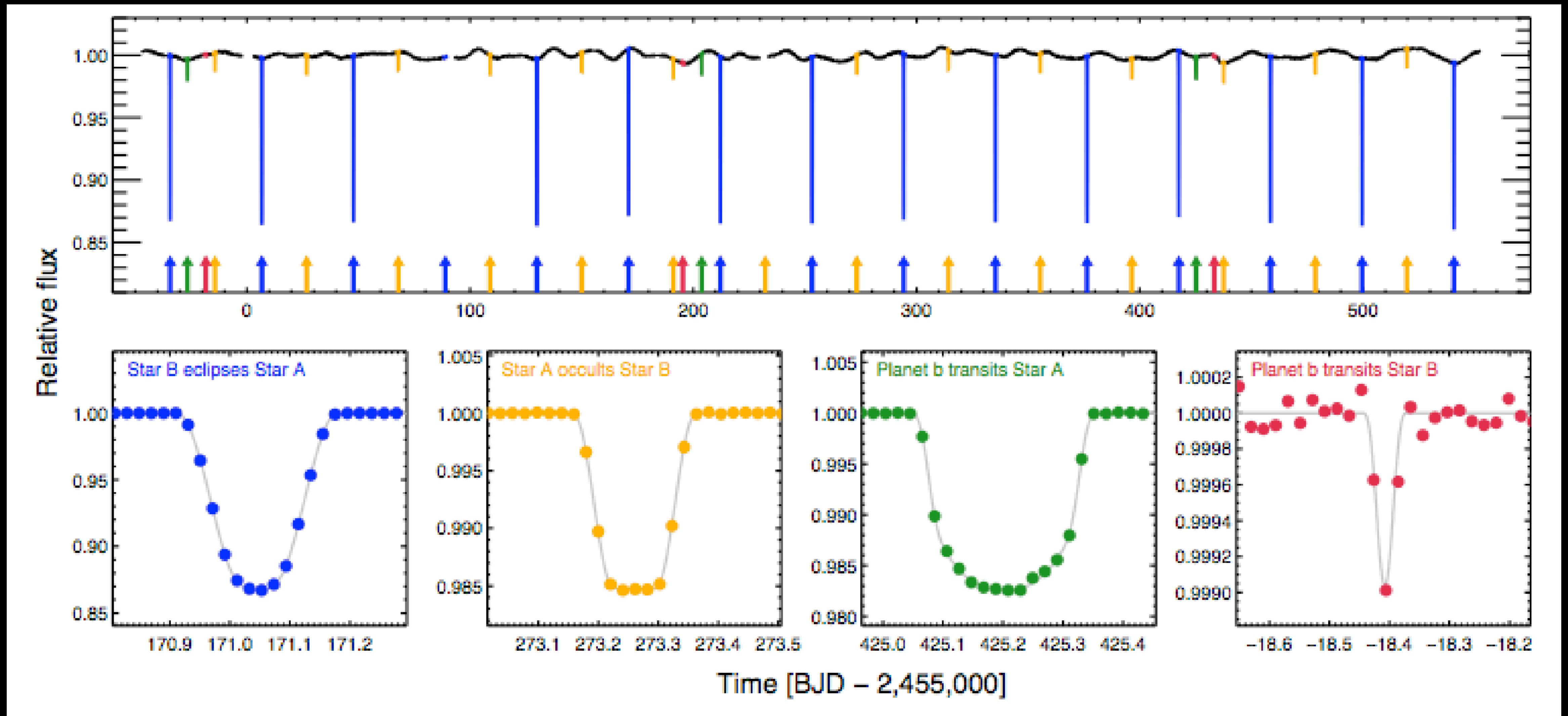
Armstrong+ 2013/2014

Klagyivik+ 2017

Windemuth+ 2019 - QATS-EB

The Human Eye

Perhaps “easy” for Kepler-16



Solutions?

Kovacs+ 2002 - BLS

Ofir 2008 - CB-BLS

Carter & Agol - QATS

Kostov+ 2013/14

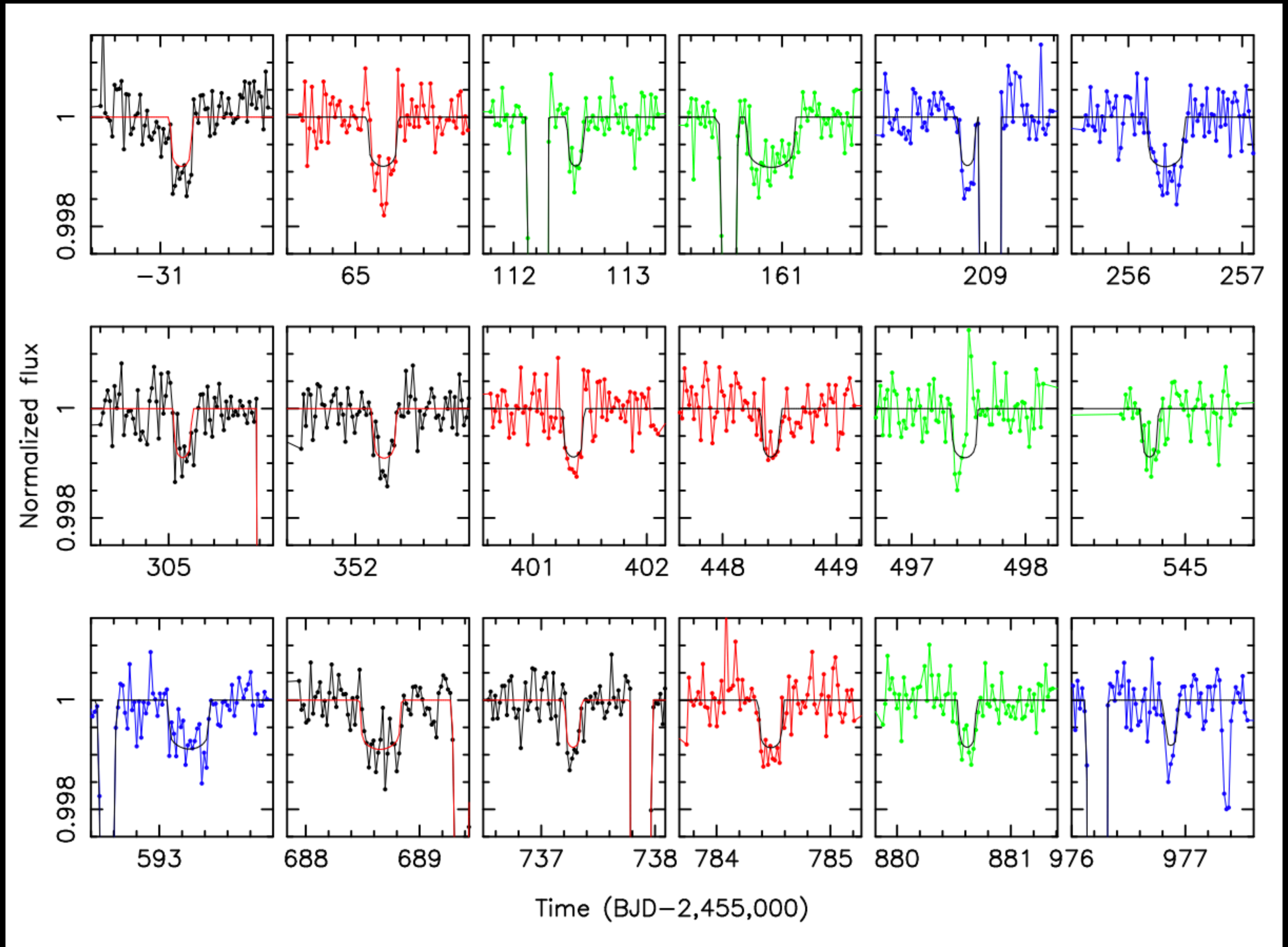
Armstrong+ 2013/2014

Klagyivik+ 2017

Windemuth+ 2019 - QATS-EB

The Human Eye

Gets tough for Kepler-47 and others

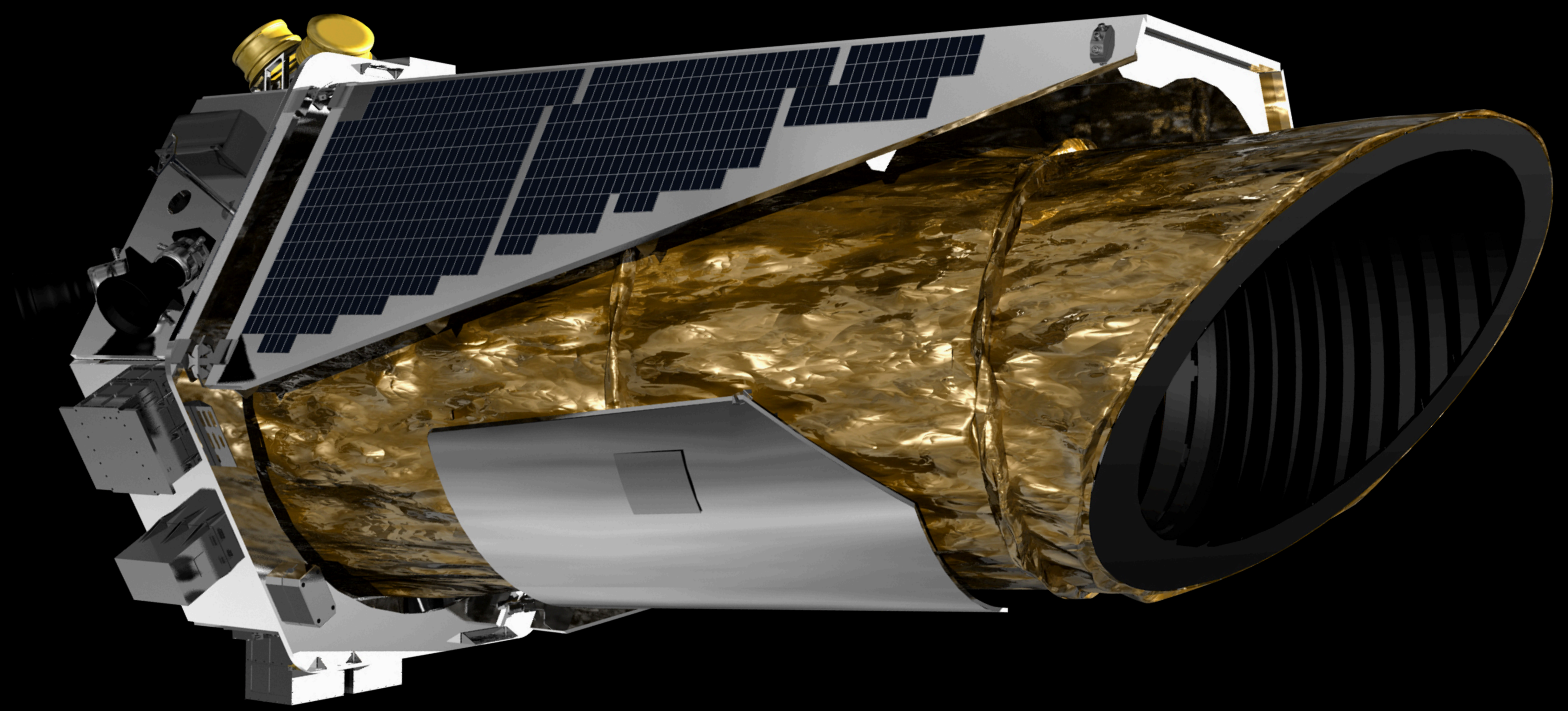


More recent approaches

TESS

Kostov+ 2020 “1-2 punch”
Dominic Oddo “FORCES”
Benjamin Davies [catchy name TBD]

Large Numbers of Large Planets



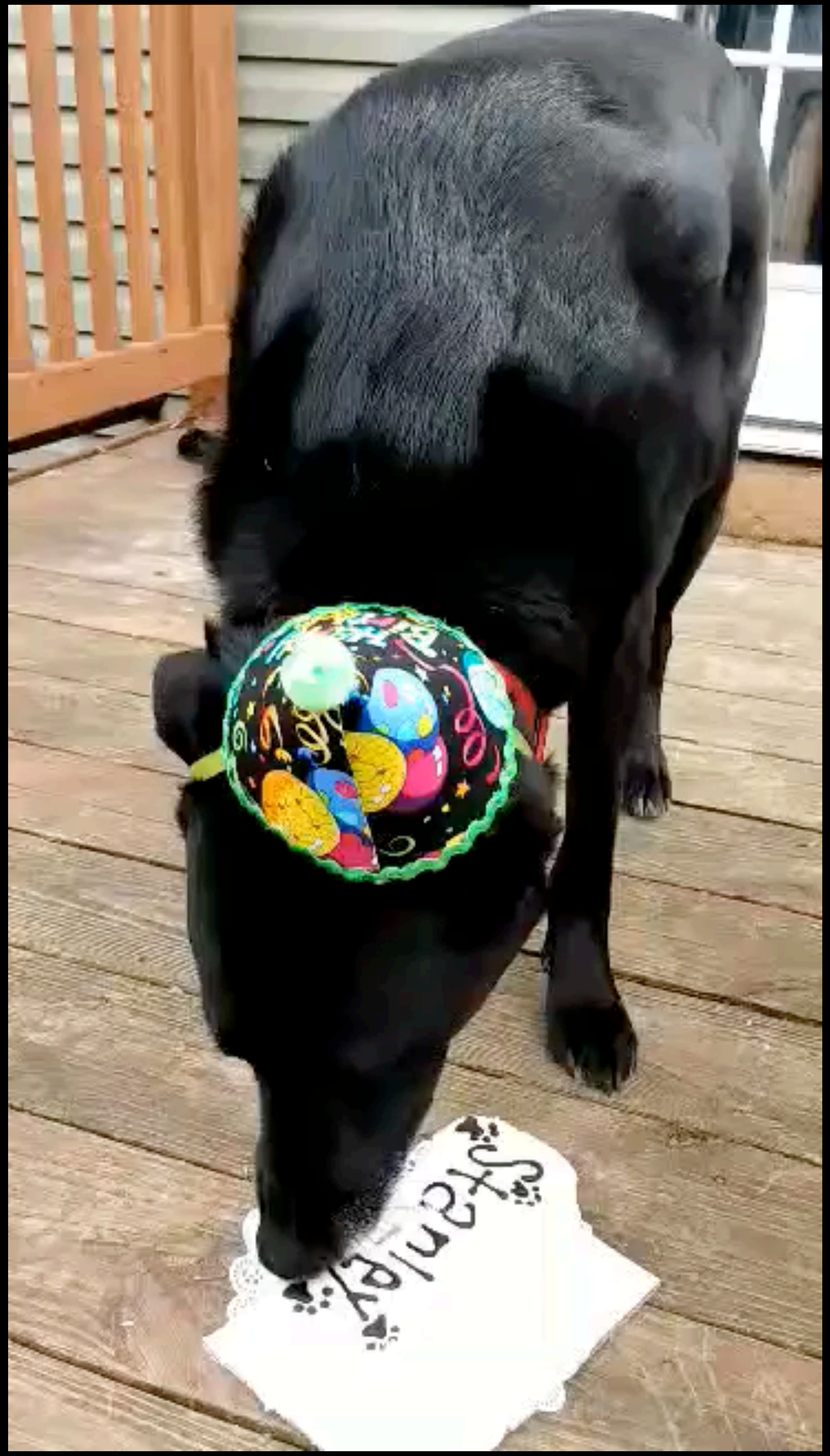
Kepler

Martin & Fabrycky 2021 “Stanley”
+ new students

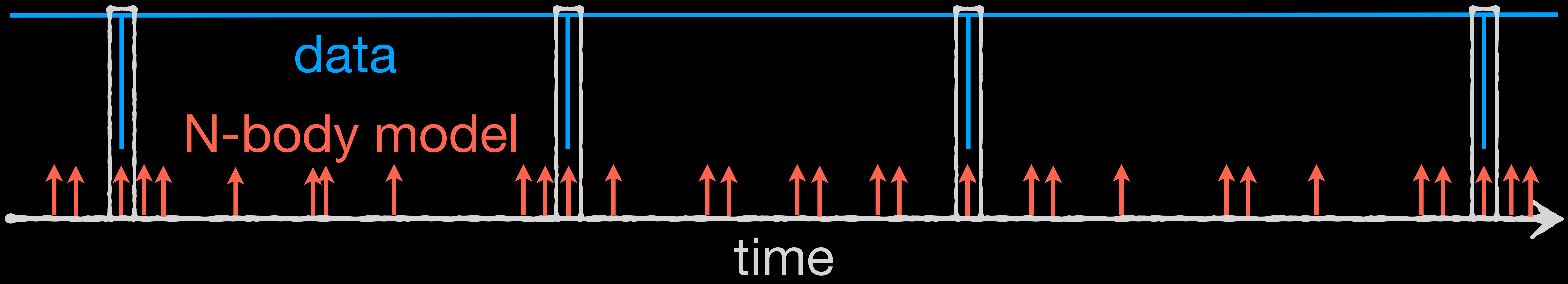
Small Numbers of Small Planets

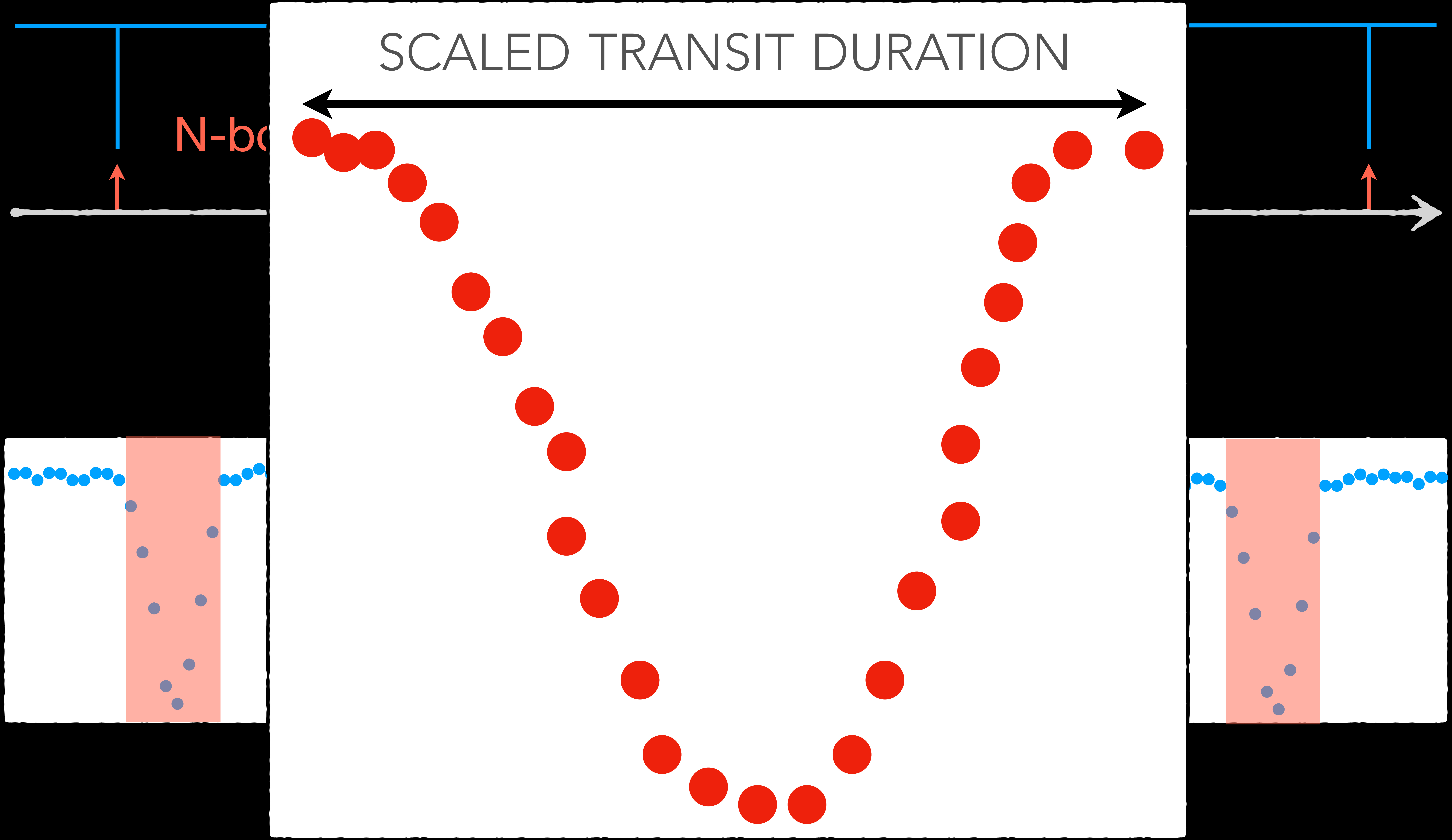
Searching for Small Circumbinary Planets
I. The STANLEY Automated Algorithm and No New Planets in Existing Systems

David V. Martin[1,2,3] and Daniel C. Fabrycky[2]



Stanley is an N-body Search Grid


data
N-body model
time


SCALED TRANSIT DURATION
N-bo

Difficulties

Difficulties

1. Speed

Parameter List

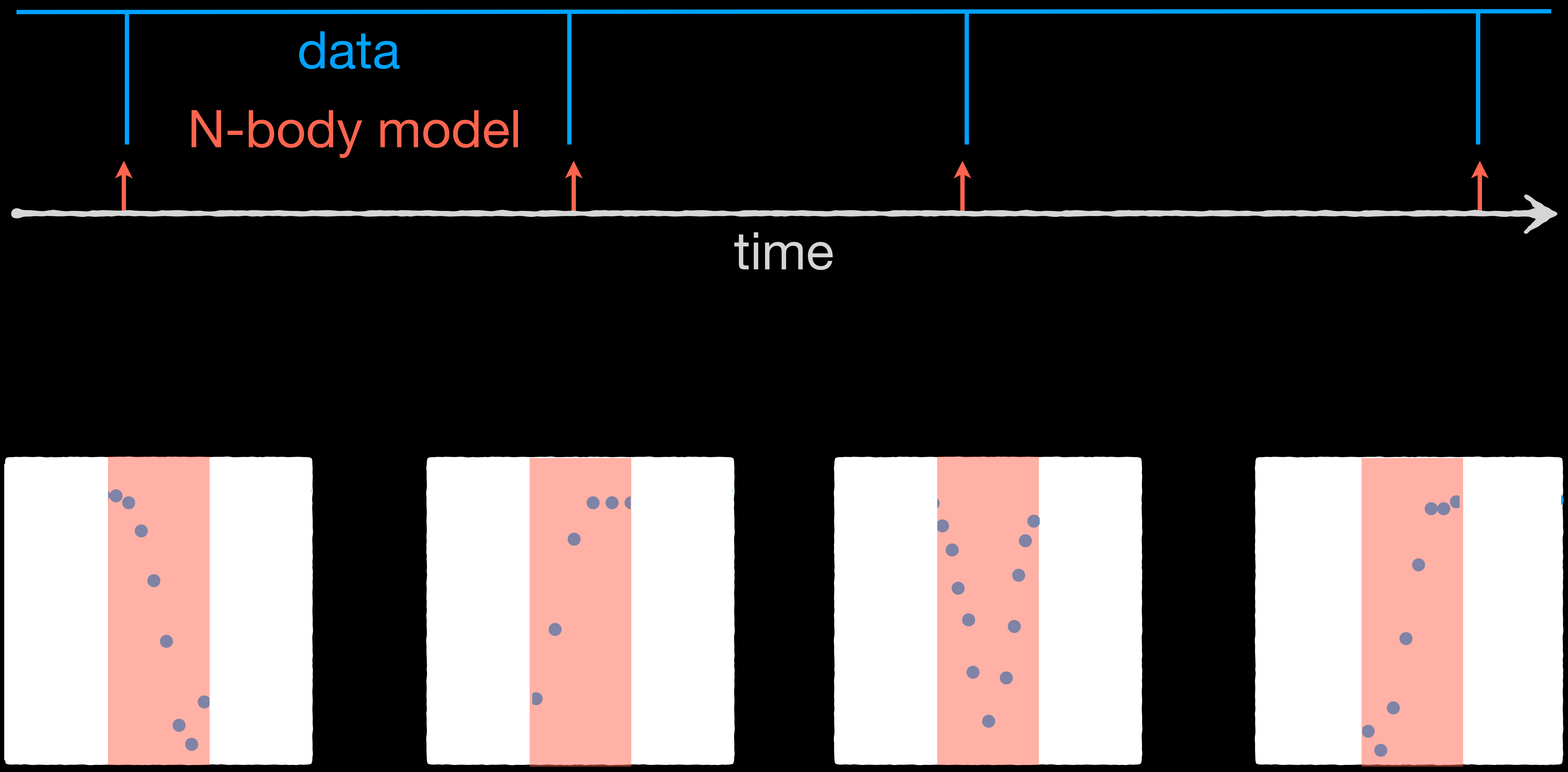
Binary	Planet	Bodies
Period, P	Period, P	M_A
Eccentricity, e	Eccentricity, e	M_B
Argument periapse, ω	Argument periapse, ω	M_p
Orbital phase, ϑ	Orbital phase, ϑ	R_A
Inclination, I	Inclination, I	R_B
Long. Ascending Node, Ω	Long. Ascending Node, Ω	R_p

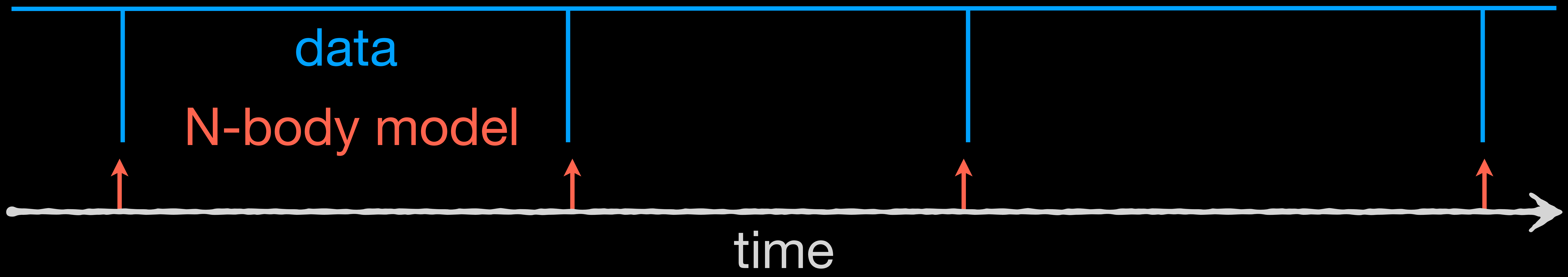
Up to 18 parameters

10,000,000 N-body sims per target

Difficulties

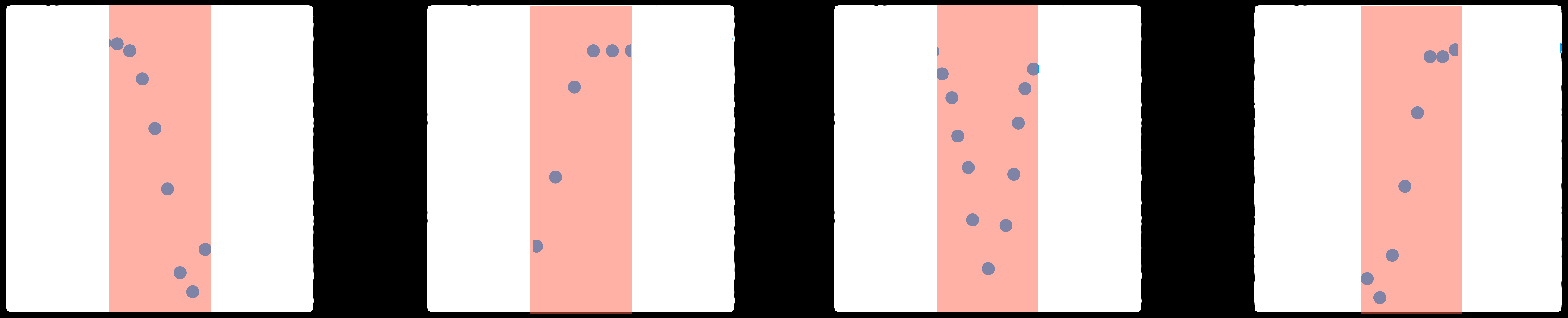
1. Speed
2. Precision


data
N-body model
time



TTVs from n-body: ~ 90%

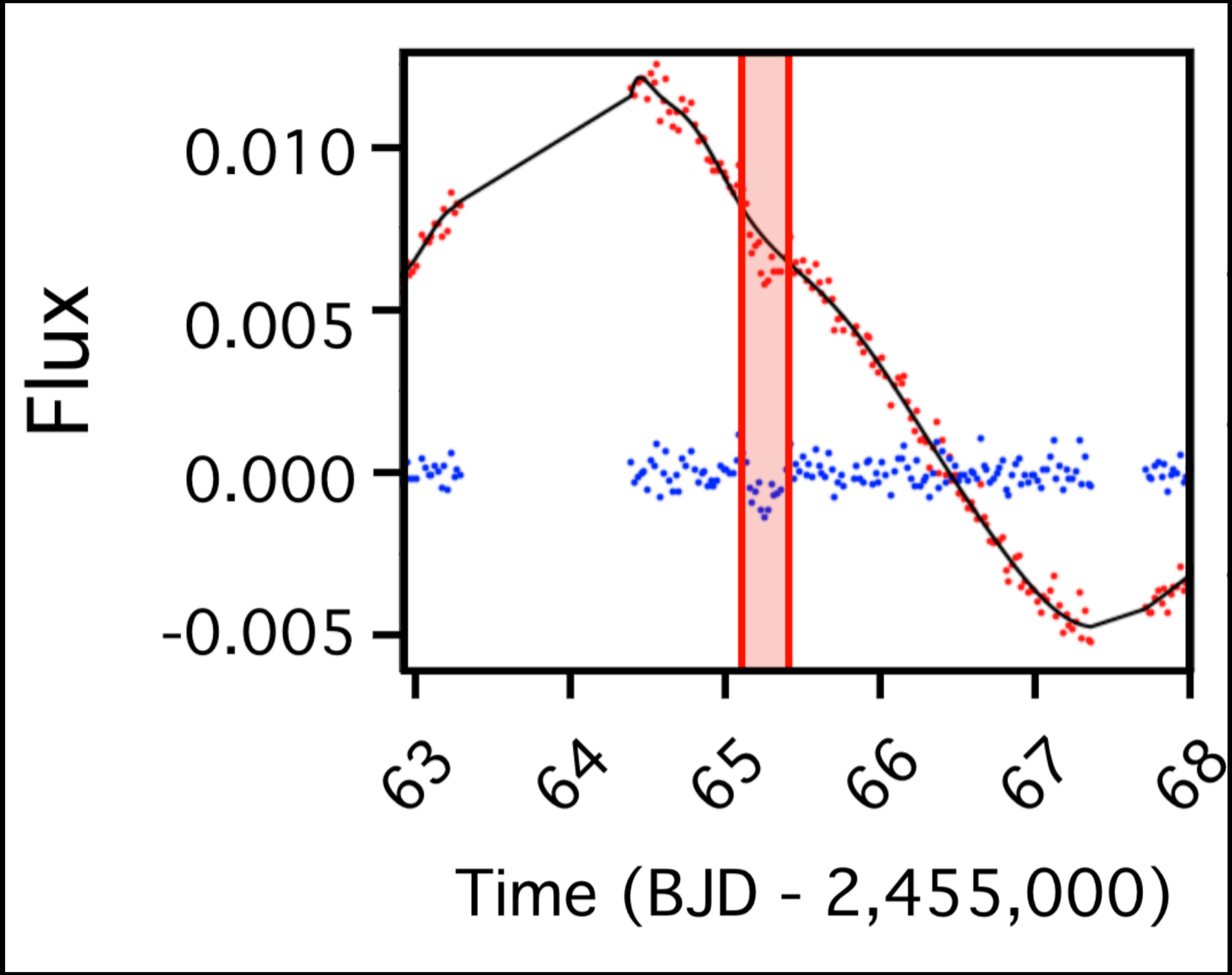
TTVs from sliding: ~ 10%



Difficulties

1. Speed
2. Precision
3. Detrending

Be careful what you get rid of

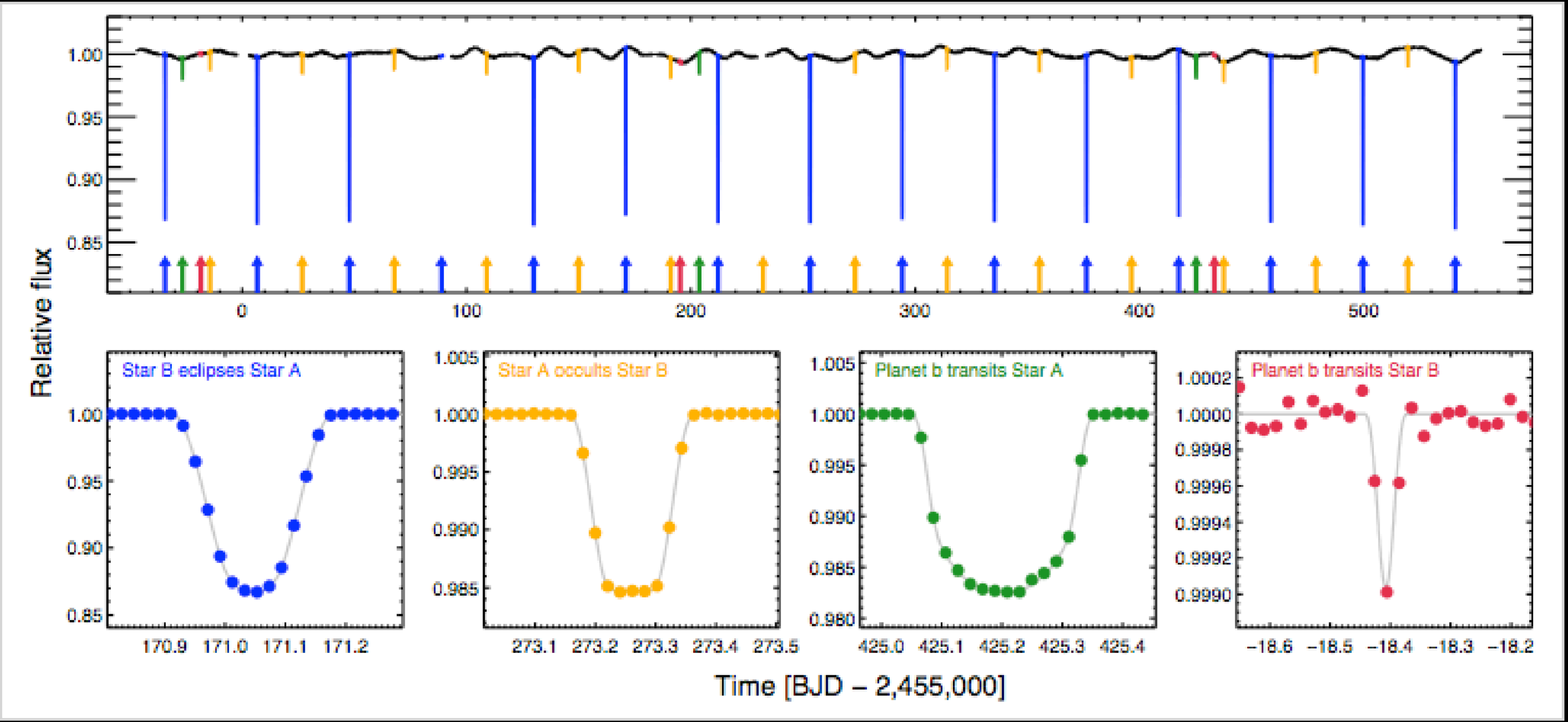


- Eclipses
- Stellar variability/rotation x2
- Doppler beaming/boosting
- Ellipsoidal variation
- Reflection
- Variable transit duration

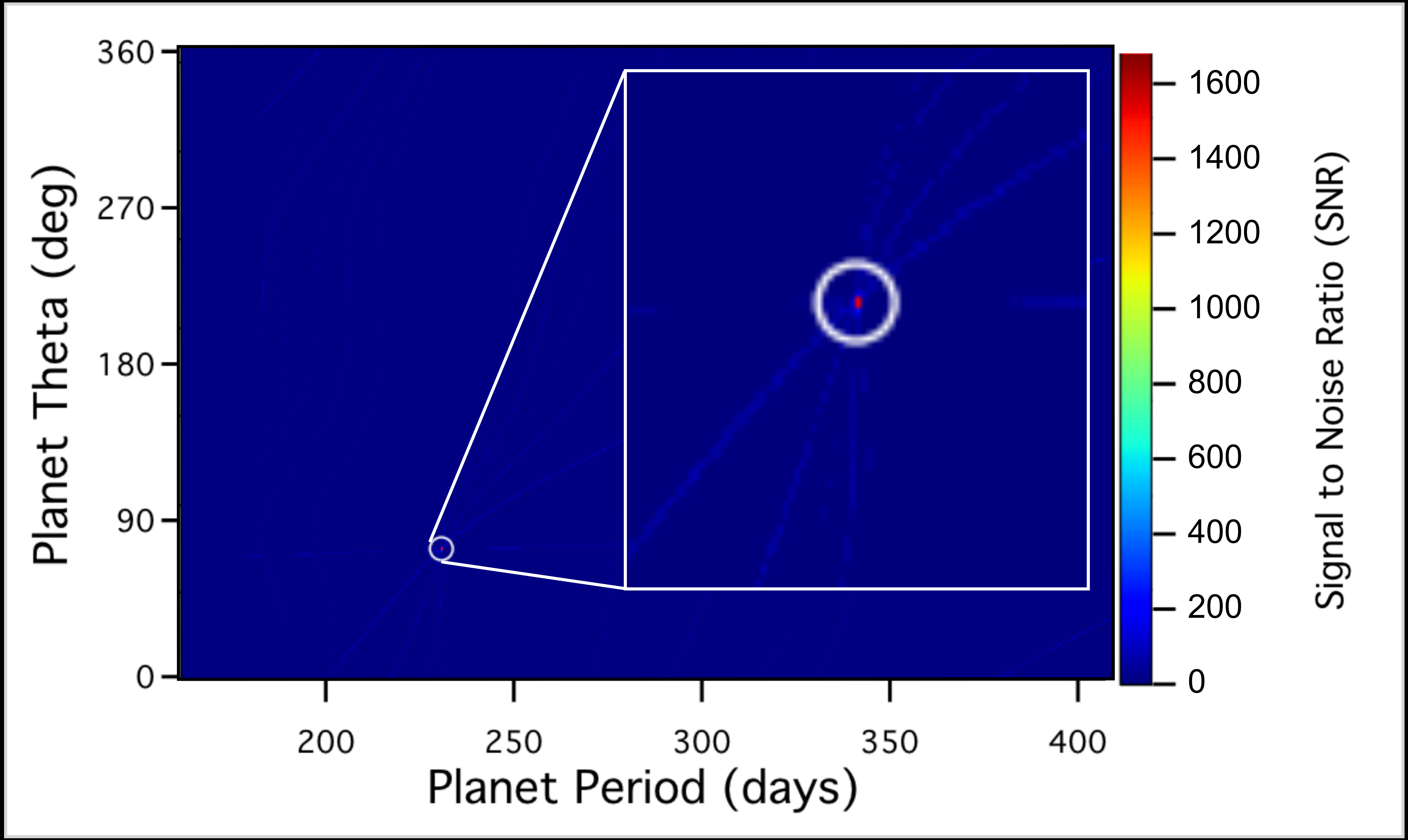
Difficulties

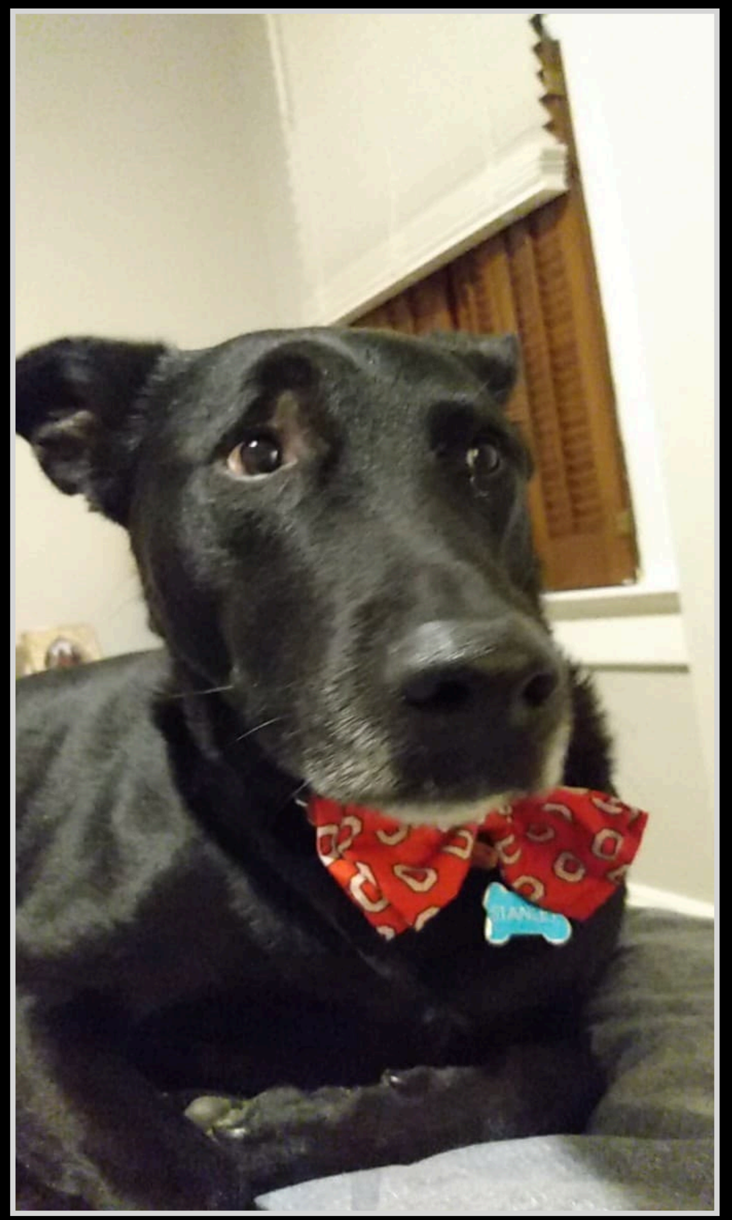
1. Speed
2. Precision
3. Detrending
4. False-Positives

Finding Kepler-16 (8 R⊕)

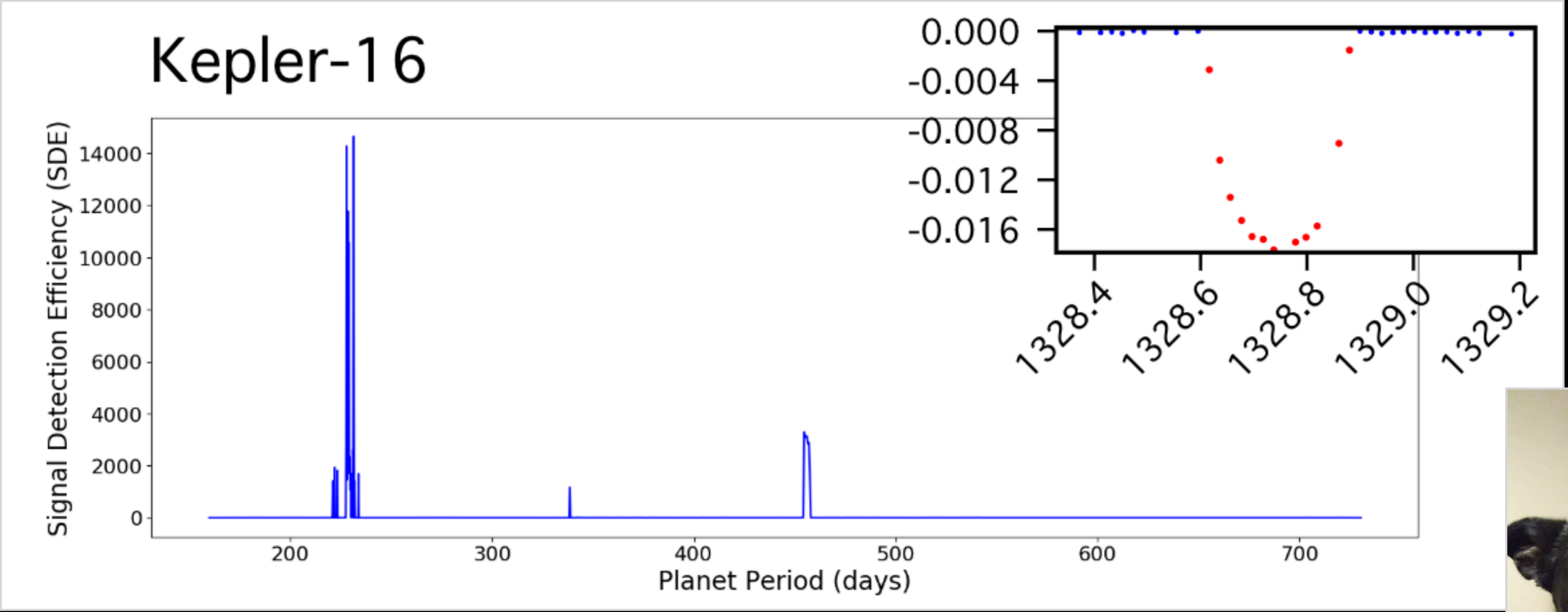


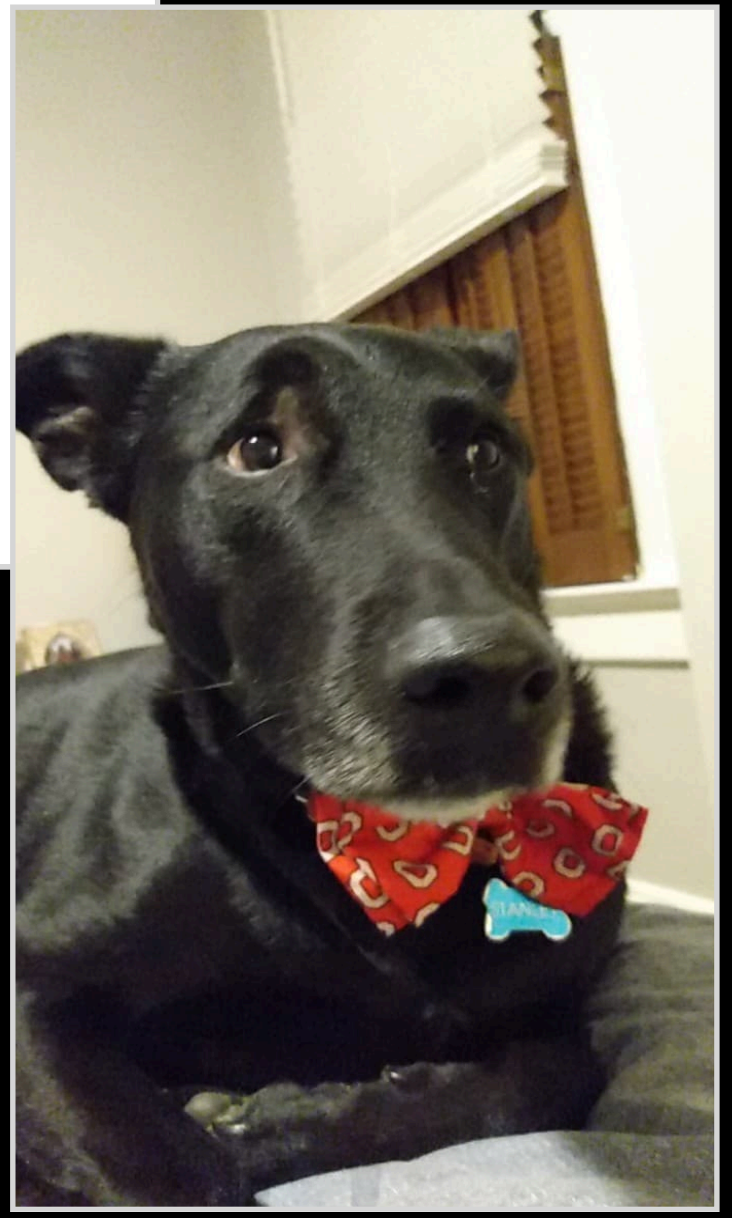
Finding Kepler-16 (8 $R_\oplus$)





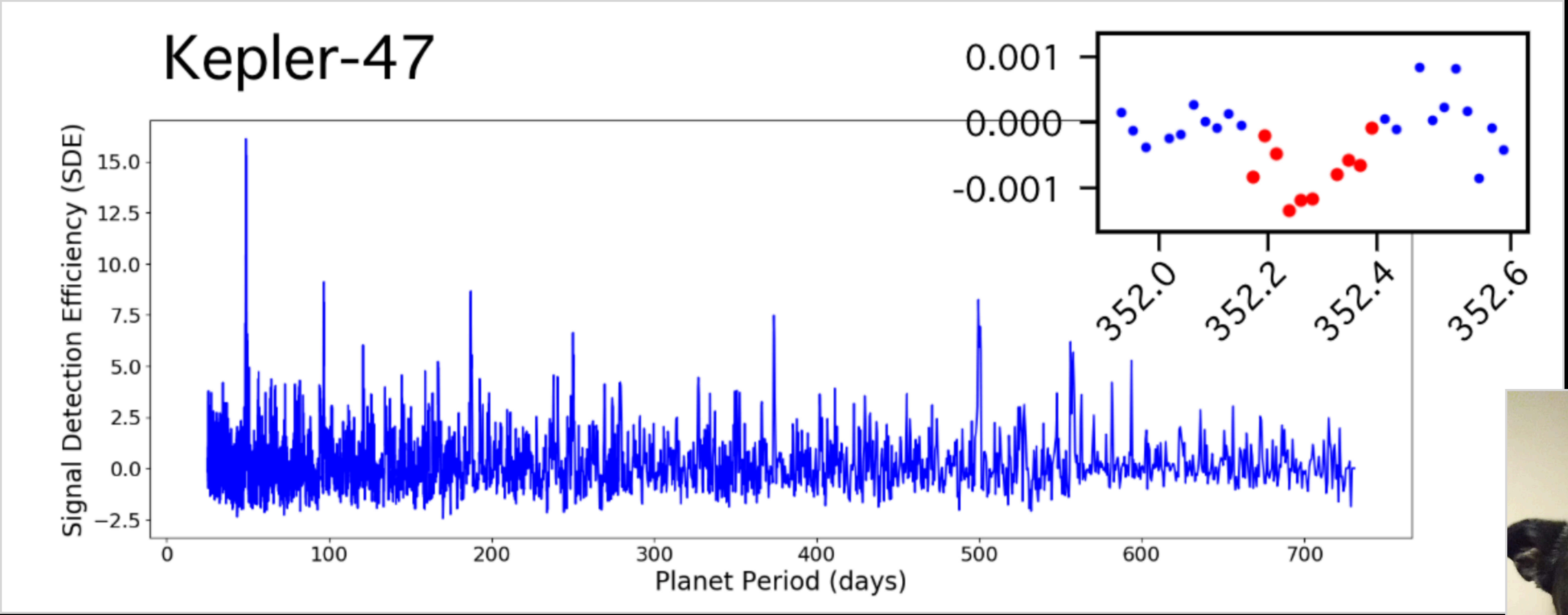
Finding Kepler-16 (8 R⊕)

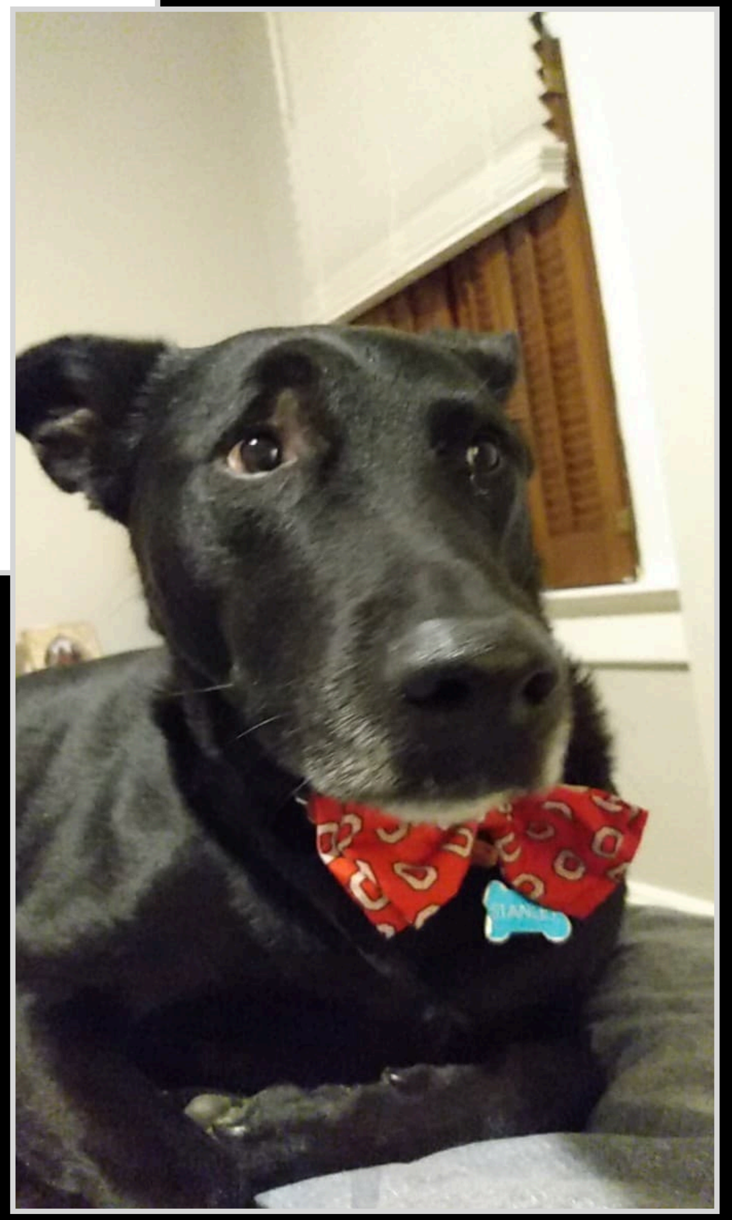




SDE > 8 for detection

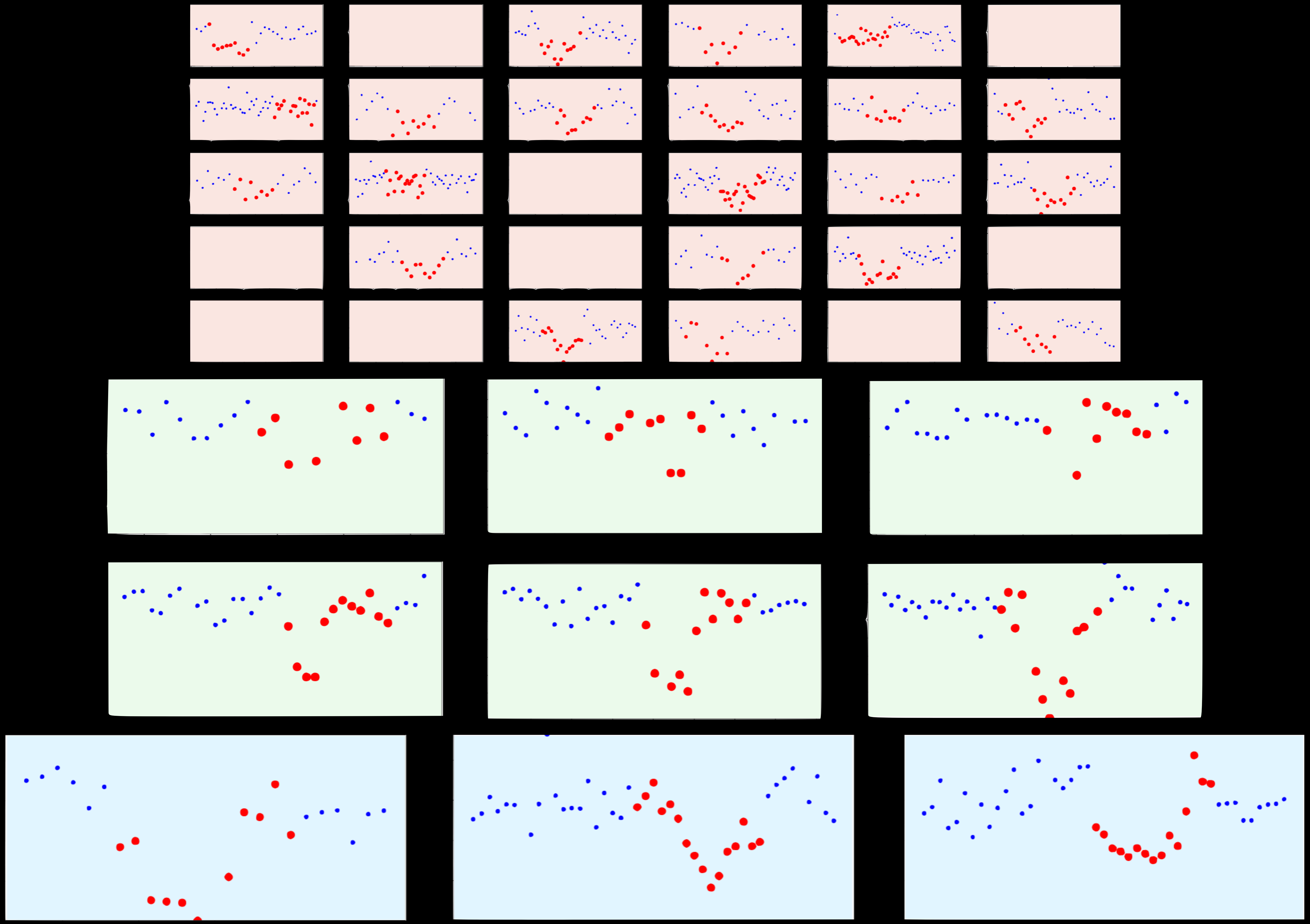
Finding Kepler-47b (3 $R_\oplus$)





SDE > 8 for detection

Finding Kepler-47b, c and d

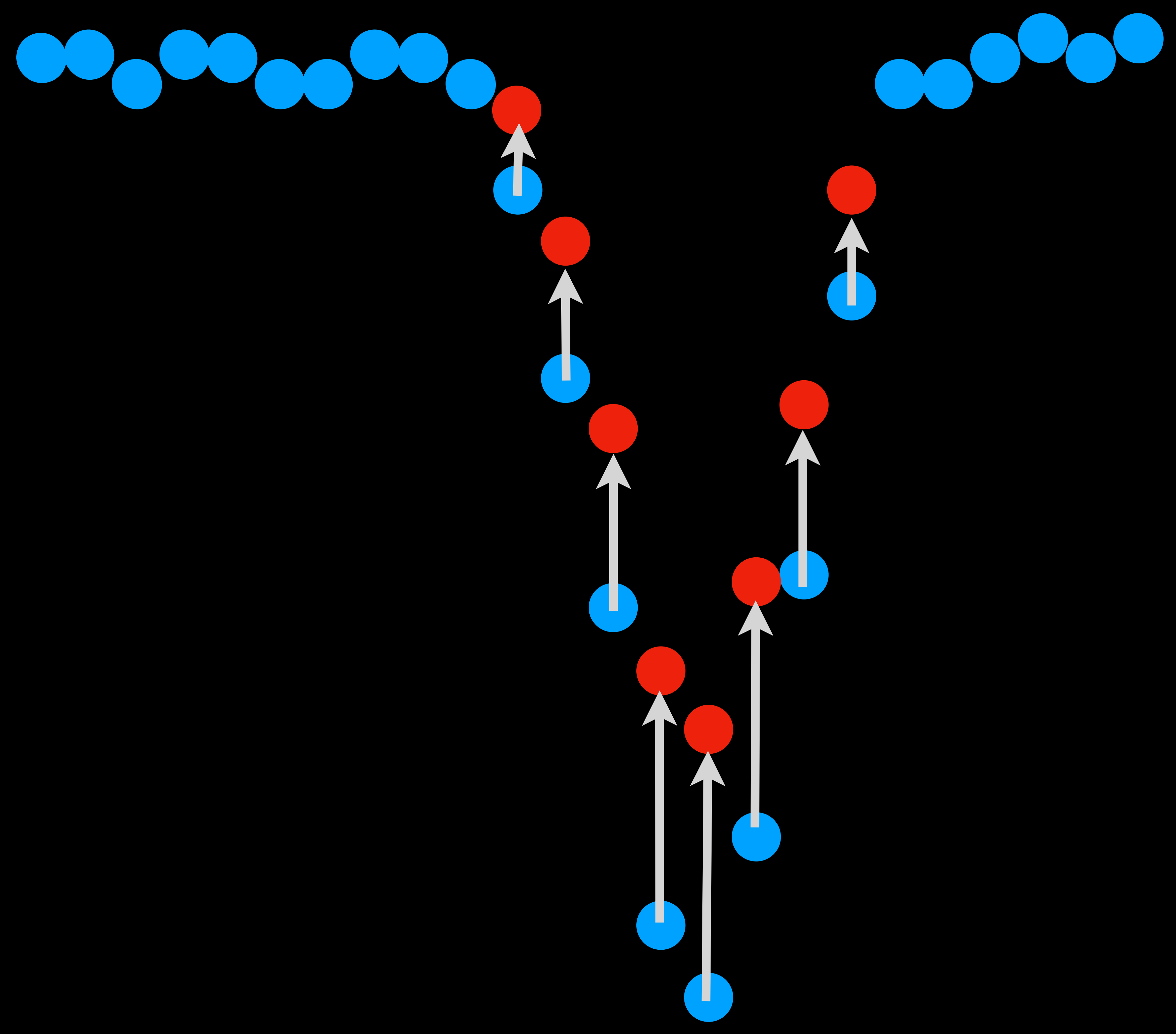


“b”
49 days

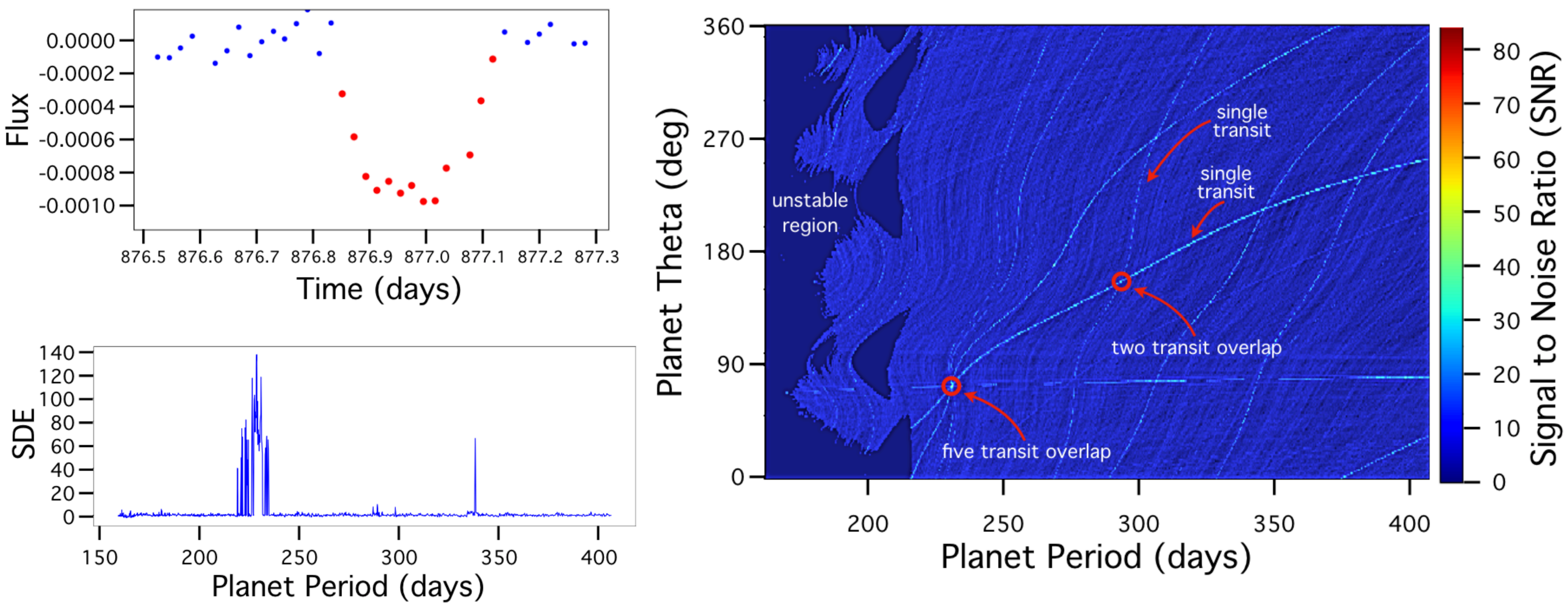
“d”
187 days

“c”
303 days

Pushing detection limits



Finding Kepler-16 @ 2R⊕



Finding Kepler-16 @ 1R⊕

Echoes of the past…

Suggestion for students

“do a literature review before starting a project”

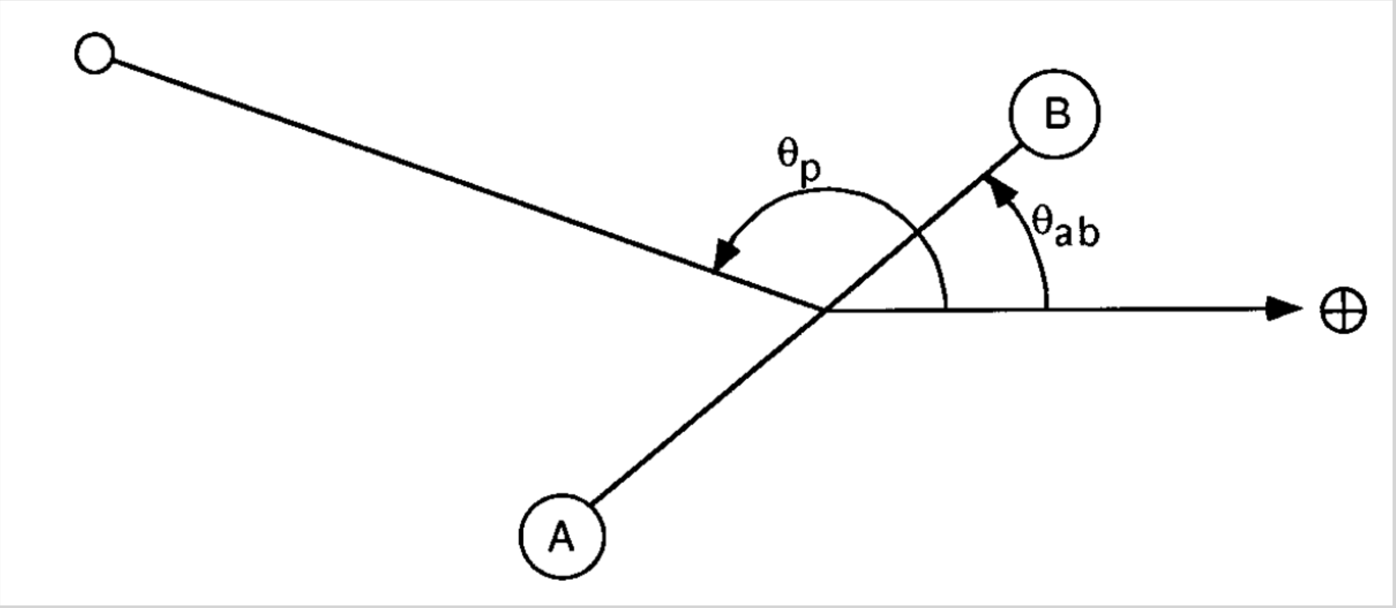
I have a confession to make…

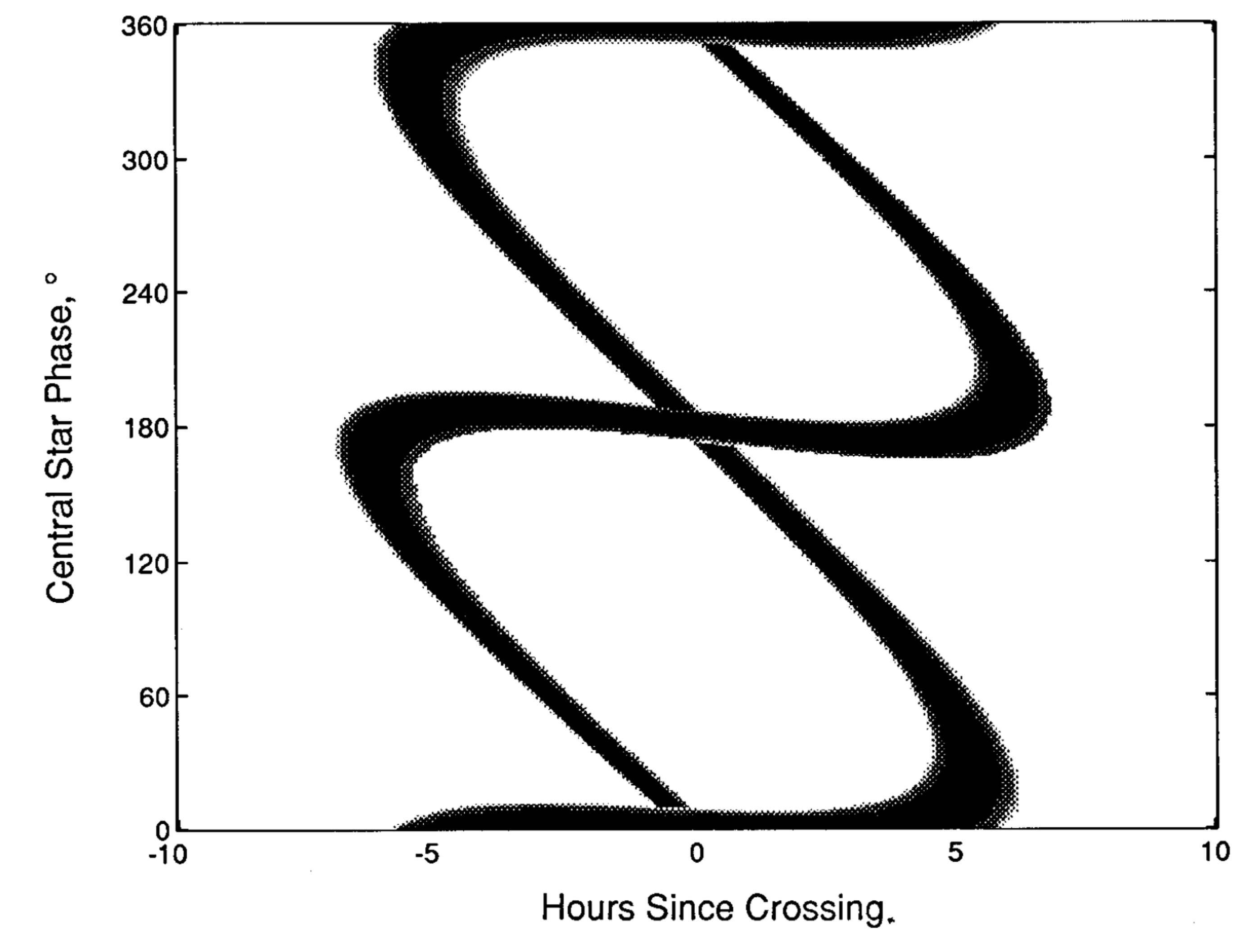
“… I did the literature review when I wrote the paper”

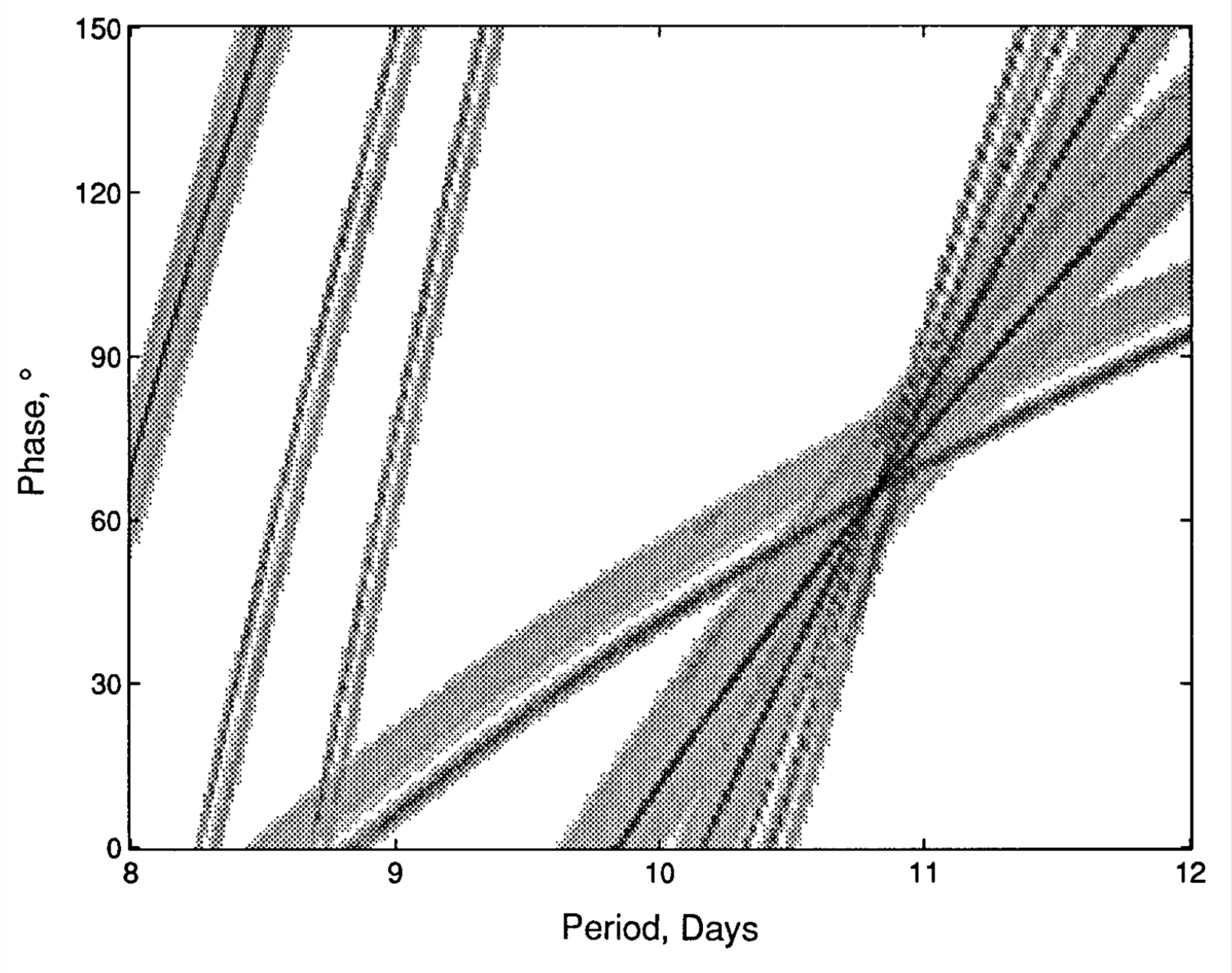
A Matched Filter Method for Ground-Based Sub-Noise Detection of Terrestrial Extrasolar Planets in Eclipsing Binaries: Application to CM Draconis

1996

JON M. JENKINS, LAURANCE R. DOYLE, AND D. K. CULLERS

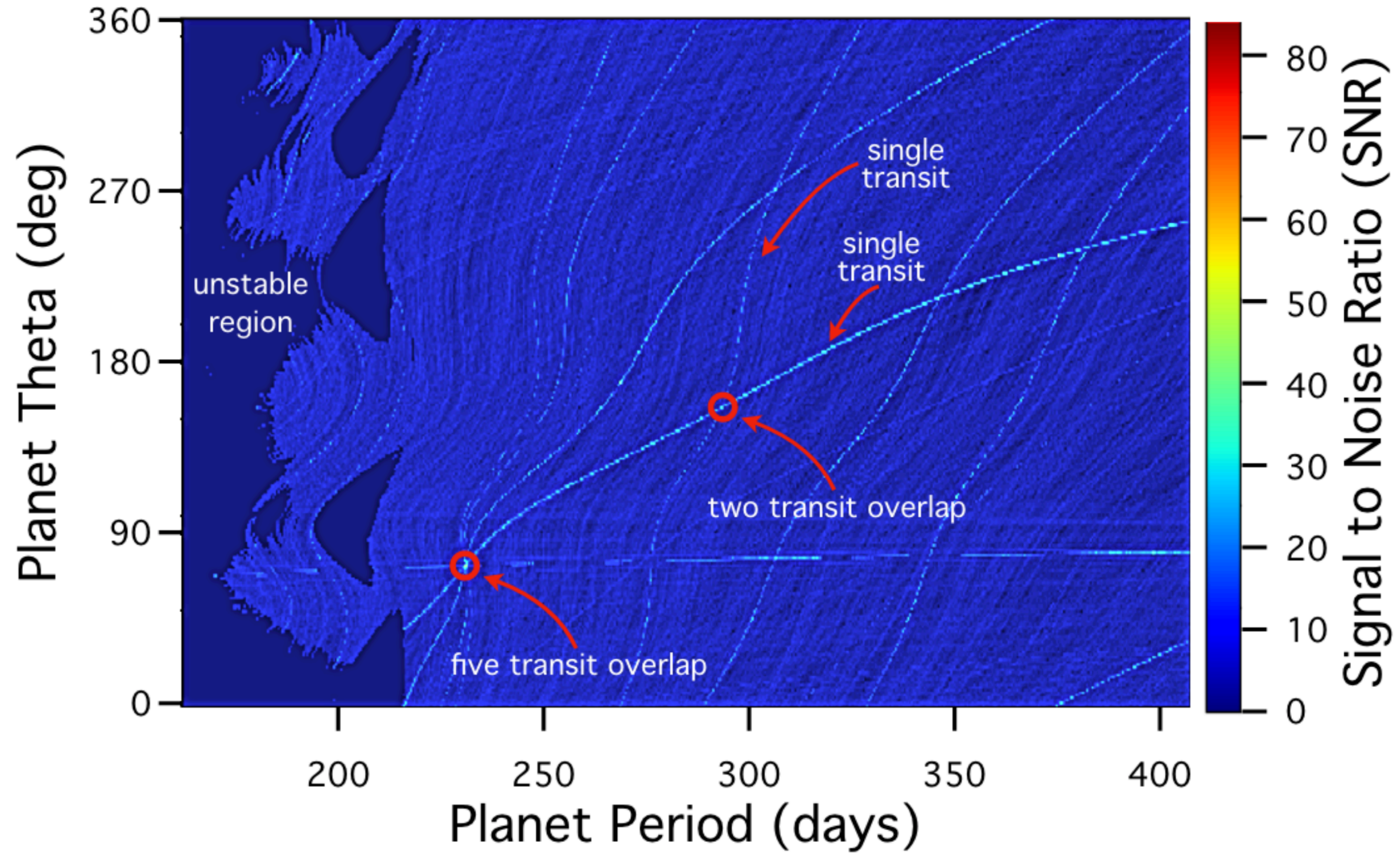


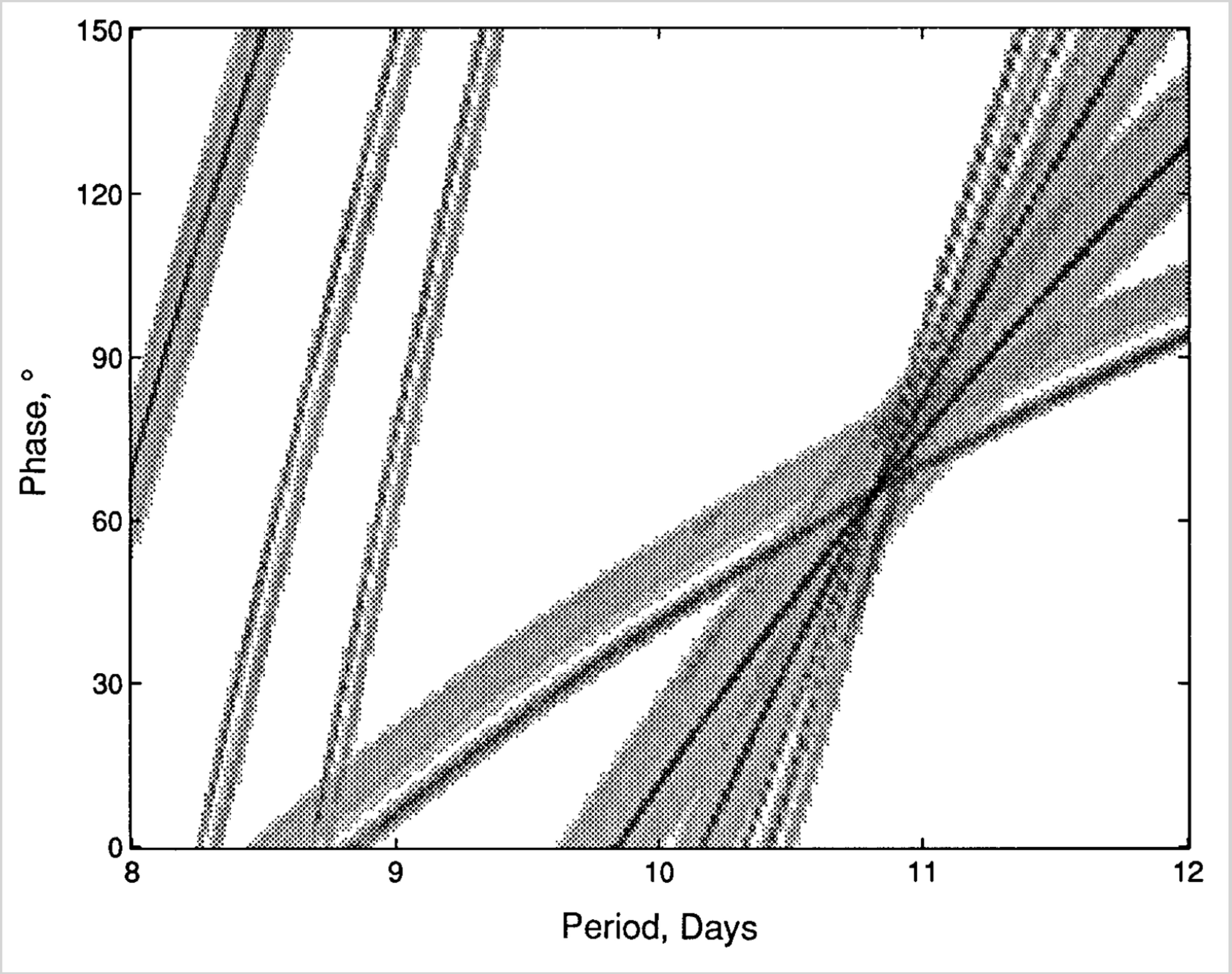




A Matched Filter Method for Ground-Based Sub-Noise Detection of Terrestrial Extrasolar Planets in Eclipsing Binaries: Application to CM Draconis

Jon M. Jenkins, Laurance R. Doyle, and D. K. Cullers





A Preliminary Search By Stanley

~200 best eclipsing binaries

A Preliminary Search By Stanley

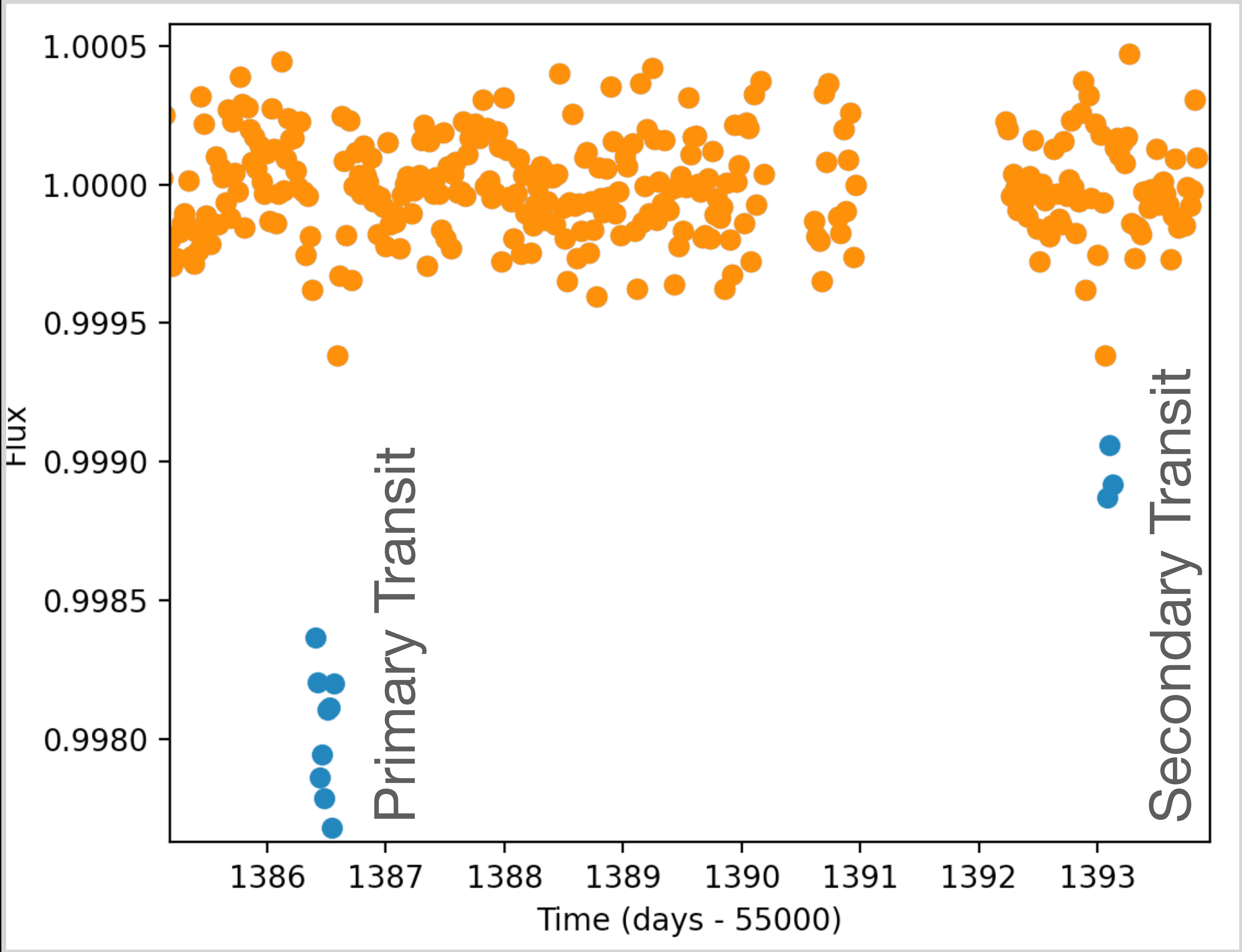
Number known pre-search: 12

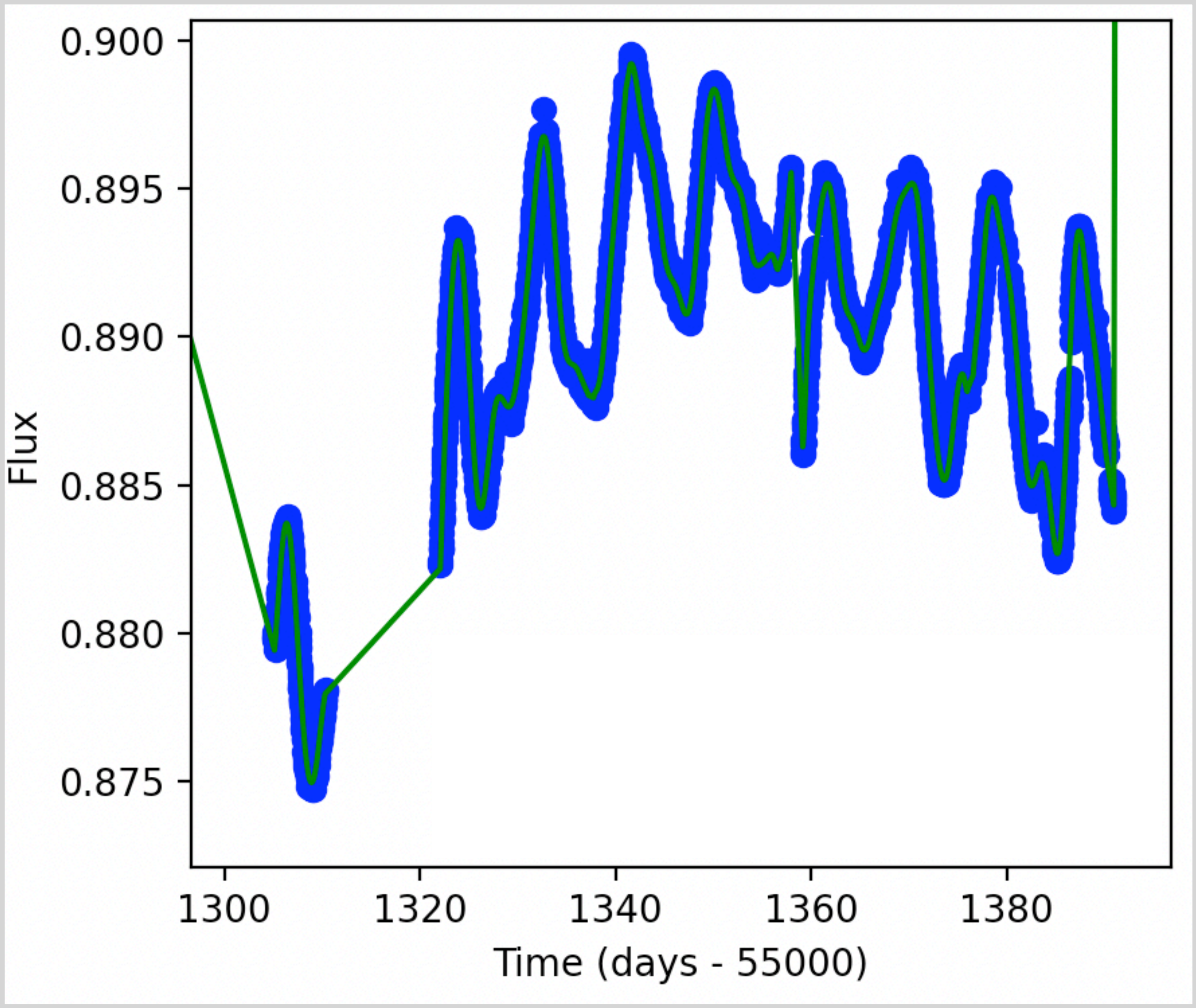
A Preliminary Search By Stanley

Number known pre-search: 12

Number known post-search: 13

KIC 10753734





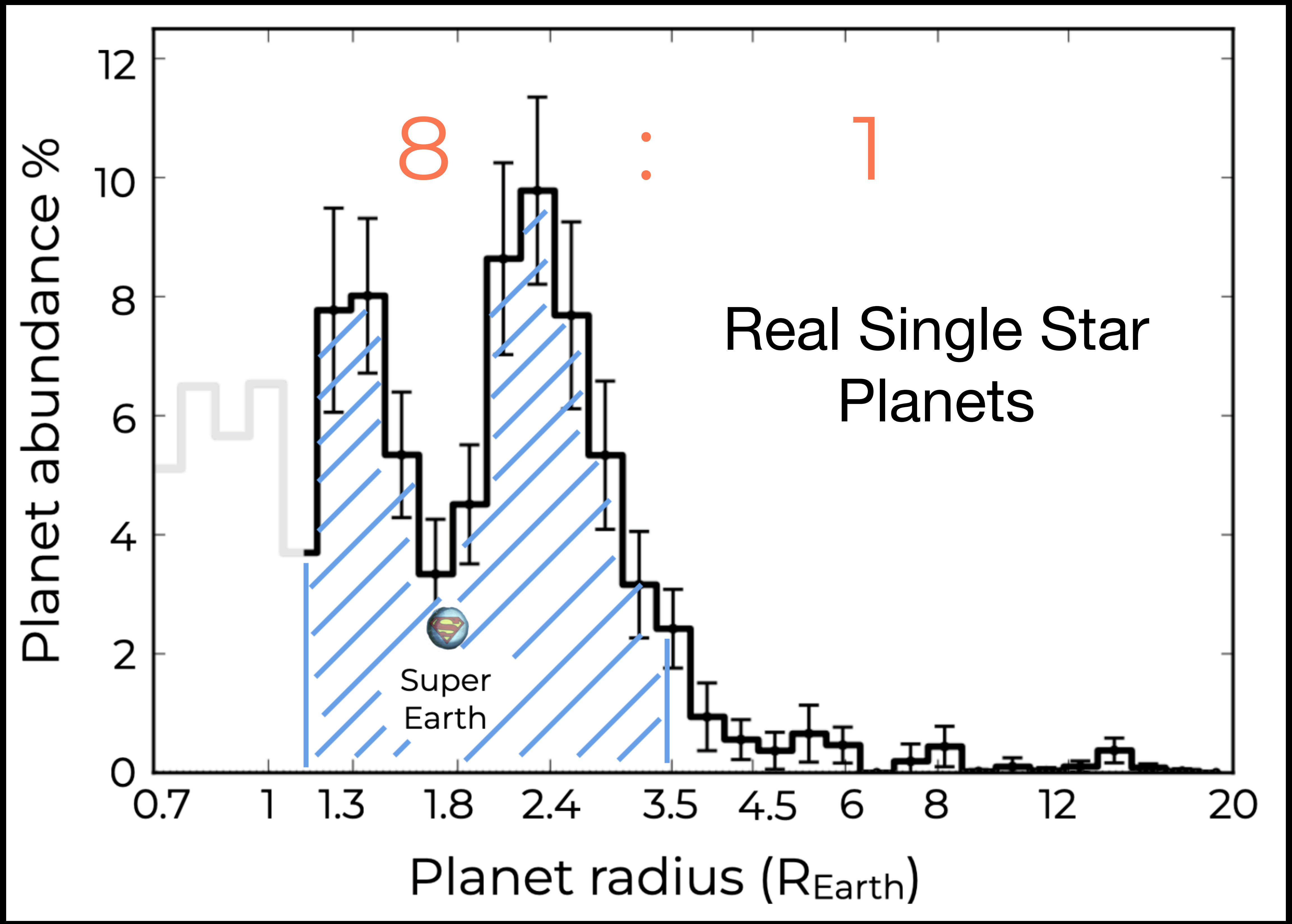
Circumbinary Planets at the K/T (Kepler-TESS) Boundary

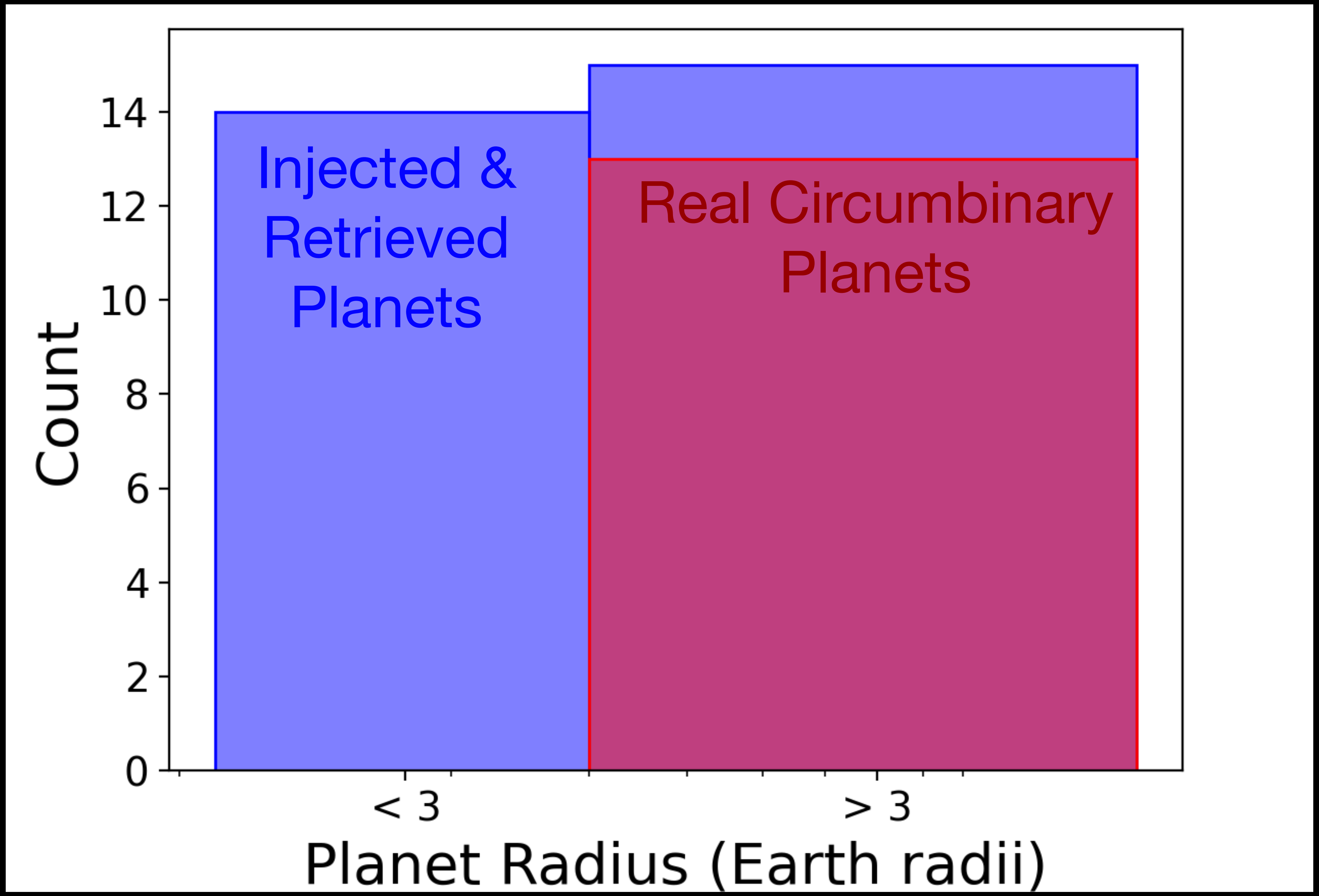
Show affiliations

Welsh, William F. August 2019

Eight years ago at the ESS II conference, we presented the first Kepler circumbinary planets. Since then, 11 planets in 9 systems have been discovered. In this talk we present the last two unpublished, unambiguous Kepler transiting circumbinary planets: KOI-3152 and KIC 10753734. Both systems have planets with rapidly precessing orbits and significantly spotted stars which has made their characterization difficult. The orbital periods are 28.2 and 19.4 days for the binaries, and 171 and

Injection-Retrieval





The size distribution of planets differs!

Transiting CBPs slowed down a tad

1. Found CBPs with RV's and ETV's
2. Did some theory (DO small CBPs exist? Multis? Moons?)

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **512,** 602–616 (2022) https://doi.org/10.1093/mnras/stac090
Advance Access publication 2022 January 17

Running the gauntlet – survival of small circumbinary planets migrating through destabilizing resonances

David V. Martin ★† and Evan Fitzmaurice

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **512,** 5023–5036 (2022) https://doi.org/10.1093/mnras/stac741
Advance Access publication 2022 March 21

Sculpting the circumbinary planet size distribution through resonant interactions with companion planets

Evan Fitzmaurice,[1★] David V. Martin[1†] and Daniel C. Fabrycky[2]

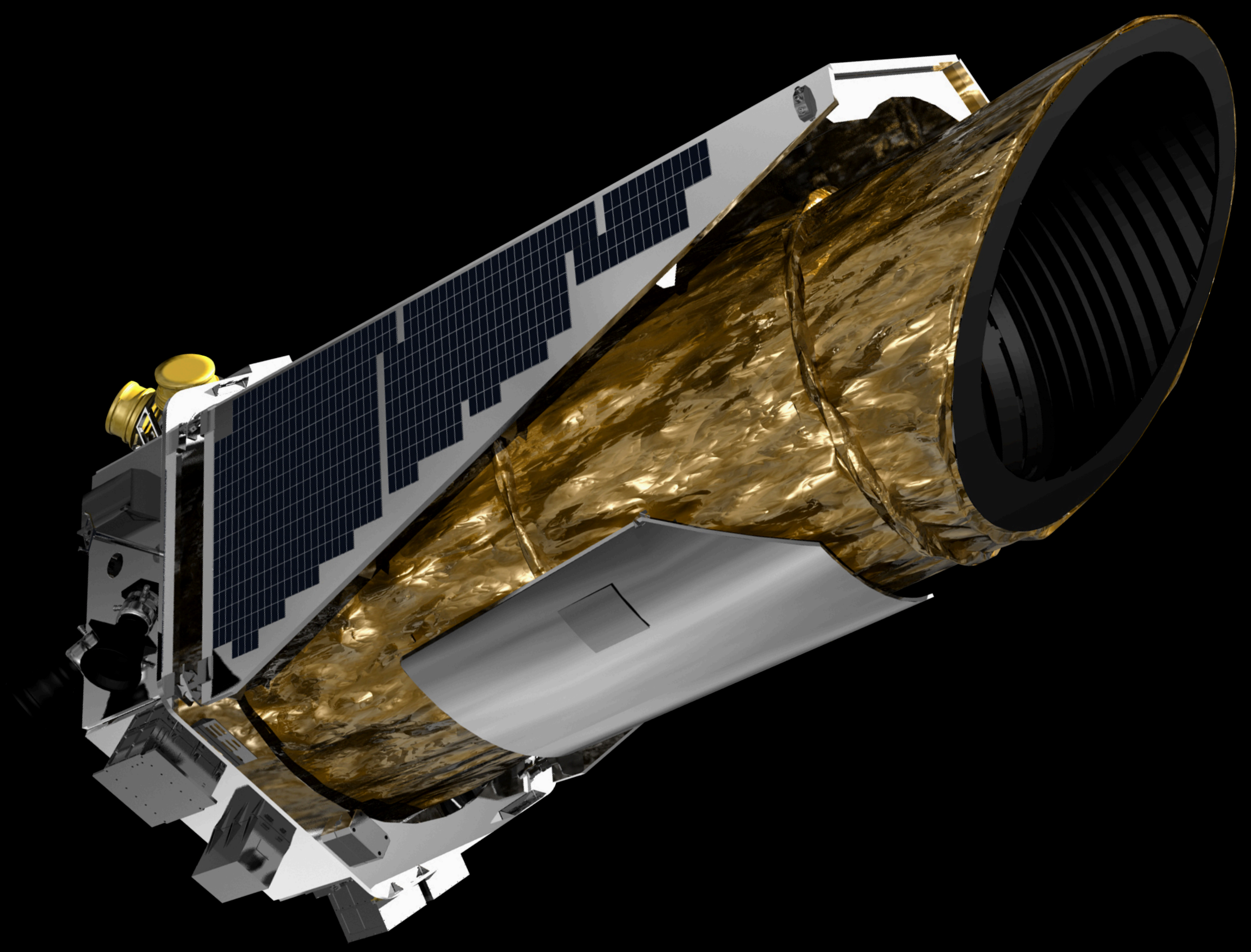
Exomoons of Circumbinary Planets

Ben R. Gordon,[1] Helena Buschermöhle,[1] Wata Tubthong,[1] David V. Martin,[1] Sean Smallets,[1] Grace Masiello,[1] and Liz Bergeron[1]

[1] *Department of Physics & Astronomy, Tufts Astronomy, 574 Boston Avenue, Medford, MA, USA*

3. Did some *shock horror* non-CBP stuff
4. But now... we're back!

Improved Kepler search



What's been added:

1. Improved detrending
2. Smarter injection/retrieval
3. Interpolated search grid
4. Larger sample
5. Preliminary results: still a lack of small planets

Wata Tubthong

4th year PhD student

Applications to TESS

Tess Kleanthous

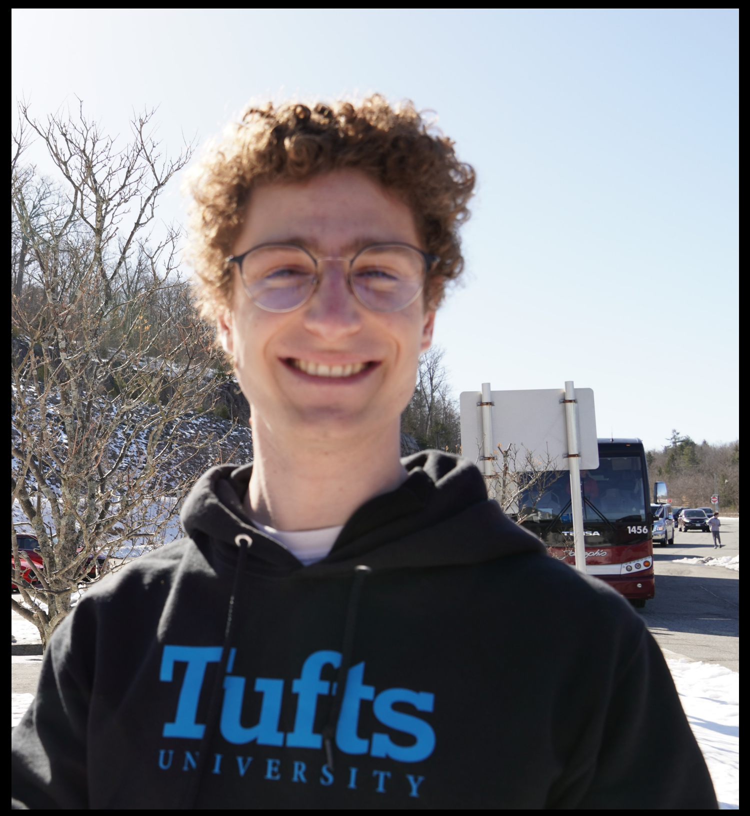
(Masters)

Arielle Weinstein

(Undergrad)

Izzy Ward

(Undergrad)



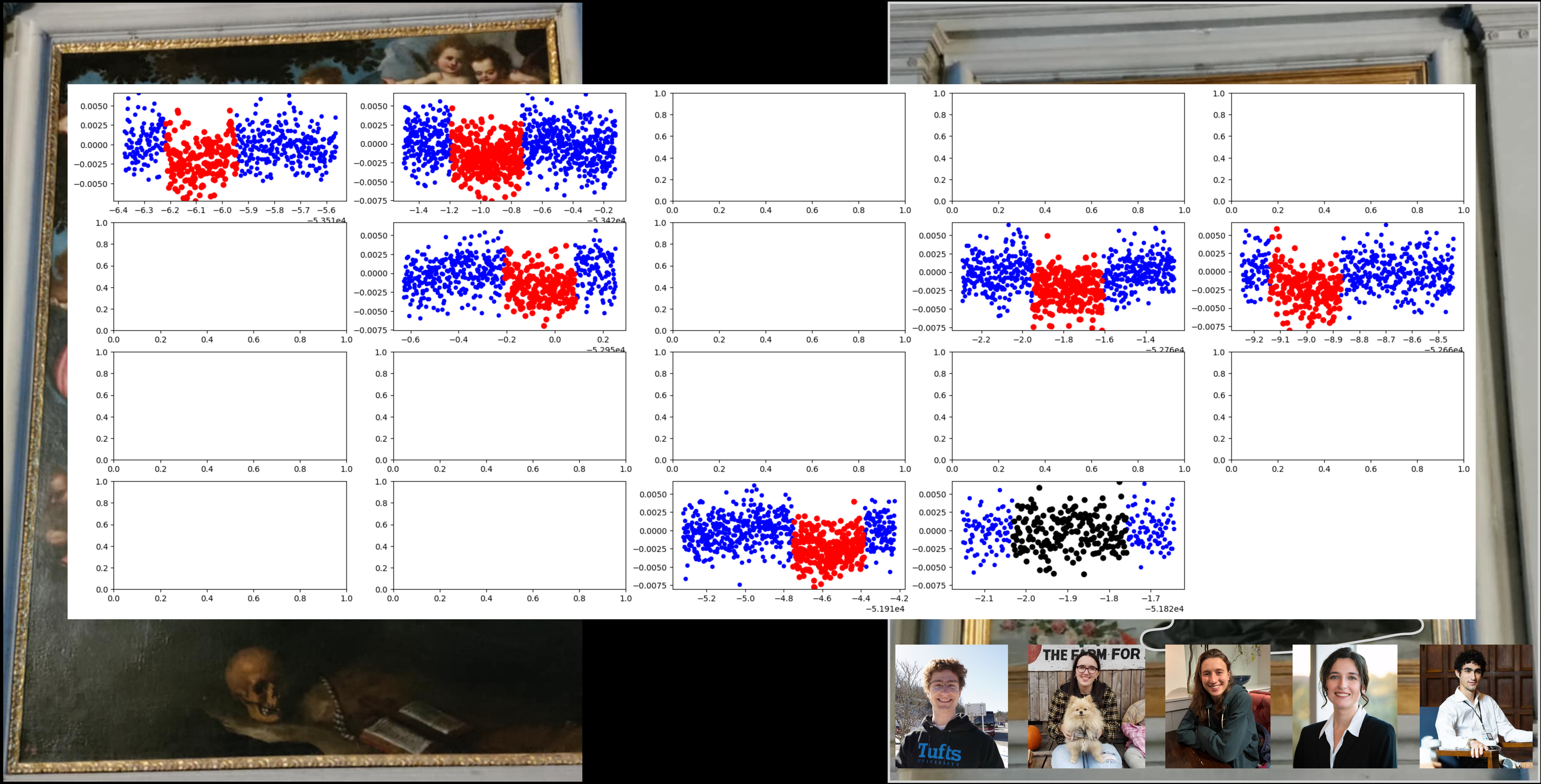
Noah Stiegler

(Undergrad)

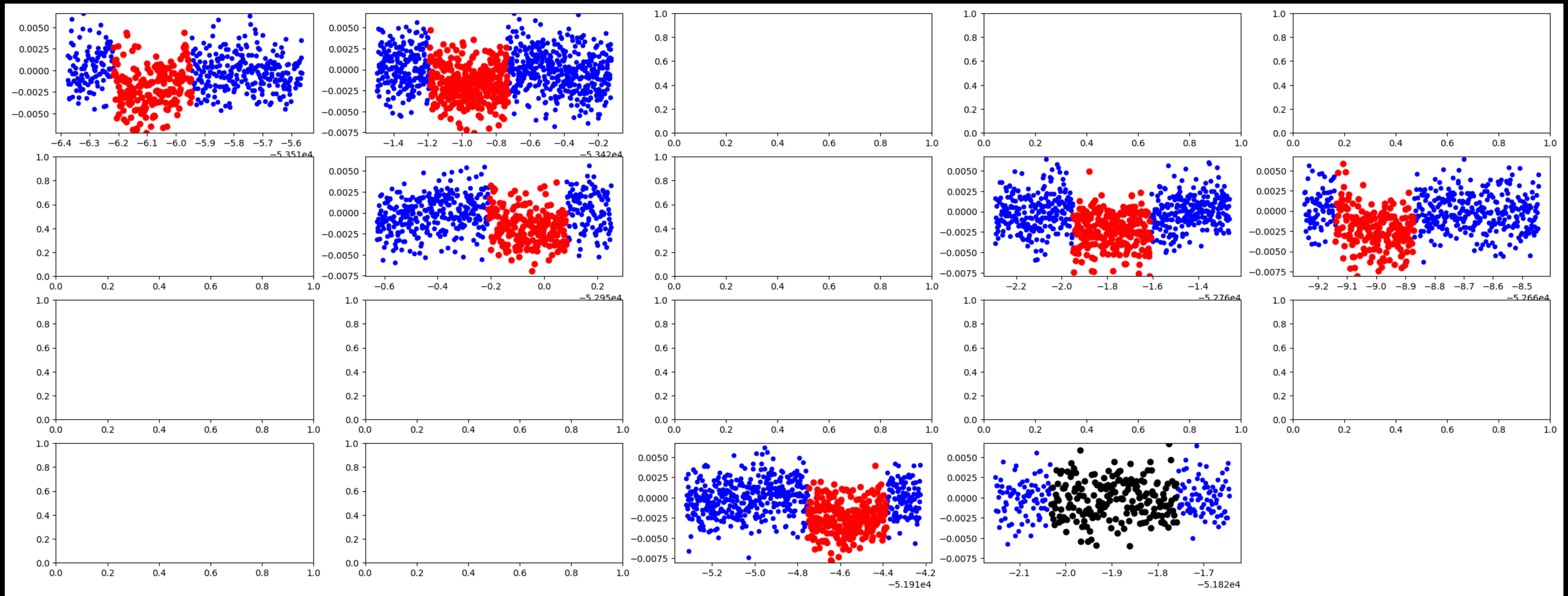
Casey Hartman

(Undergrad)

Early TESS results



Early TESS results



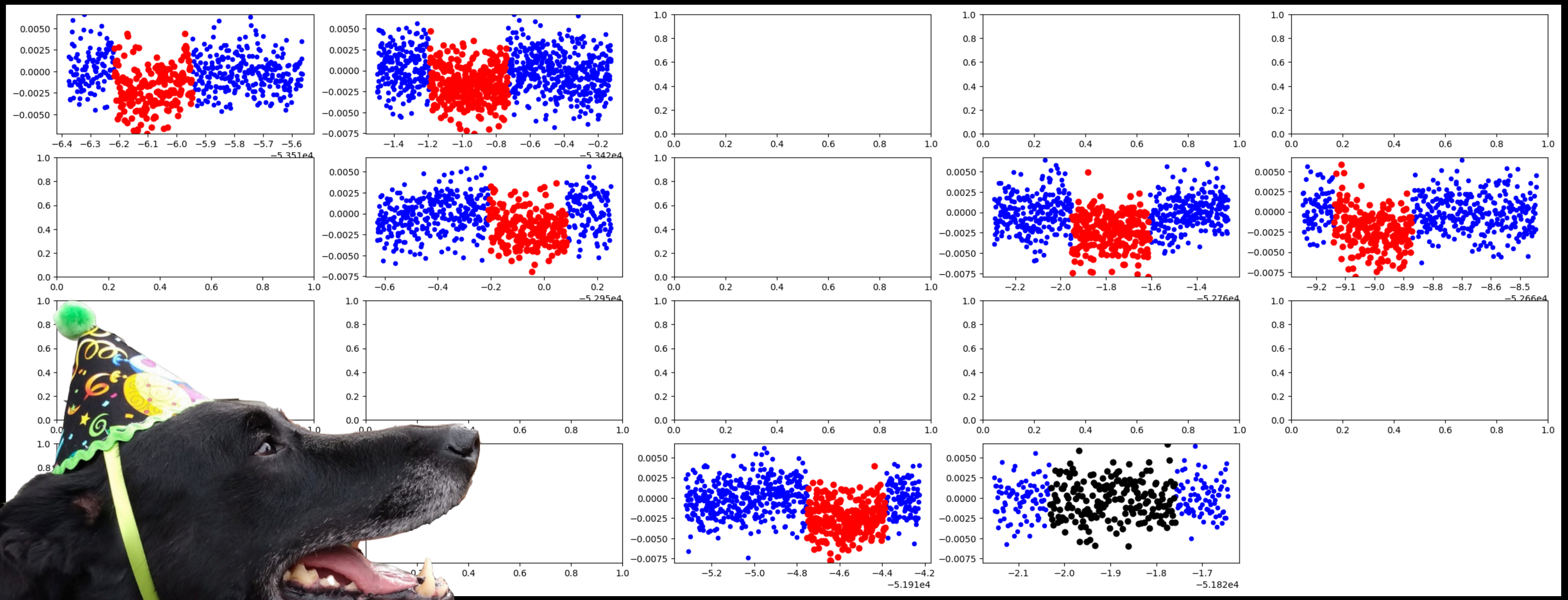
How's Your Internship Going? This Teen Found a Planet

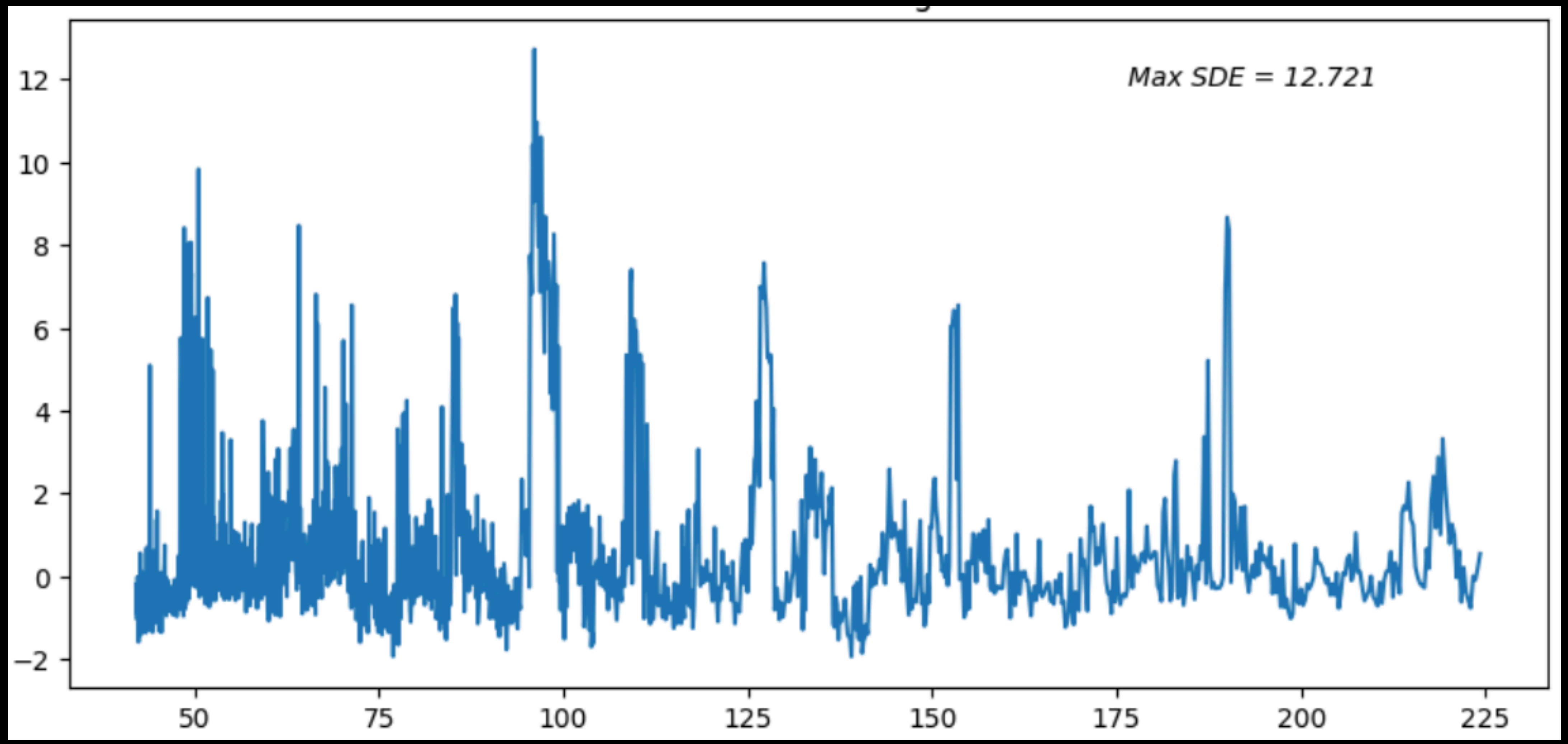
Wolf Cukier, 17, was analyzing brightness of stars during an internship with NASA last year when he made the discovery.

Early TESS results

Stanley finds TOI-1338 “easily”

Next step: entire EBLM/BEBOP sample





Conclusions

1. Automatic methods of CBP detection are challenging
2. Community effort
3. Small circumbinary planets are genuinely "rare"
4. TESS is a different beast
5. Improved Stanley results and code on the way

Conclusions

1. Automatic methods of CBP detection are challenging
2. Community effort
3. Small circumbinary planets are genuinely “rare”
4. TESS is a different beast
5. Improved Stanley results and code on the way

Common false positives

270 Eclipsing Binaries

9 deepest fluxes per target