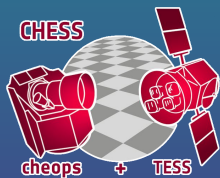
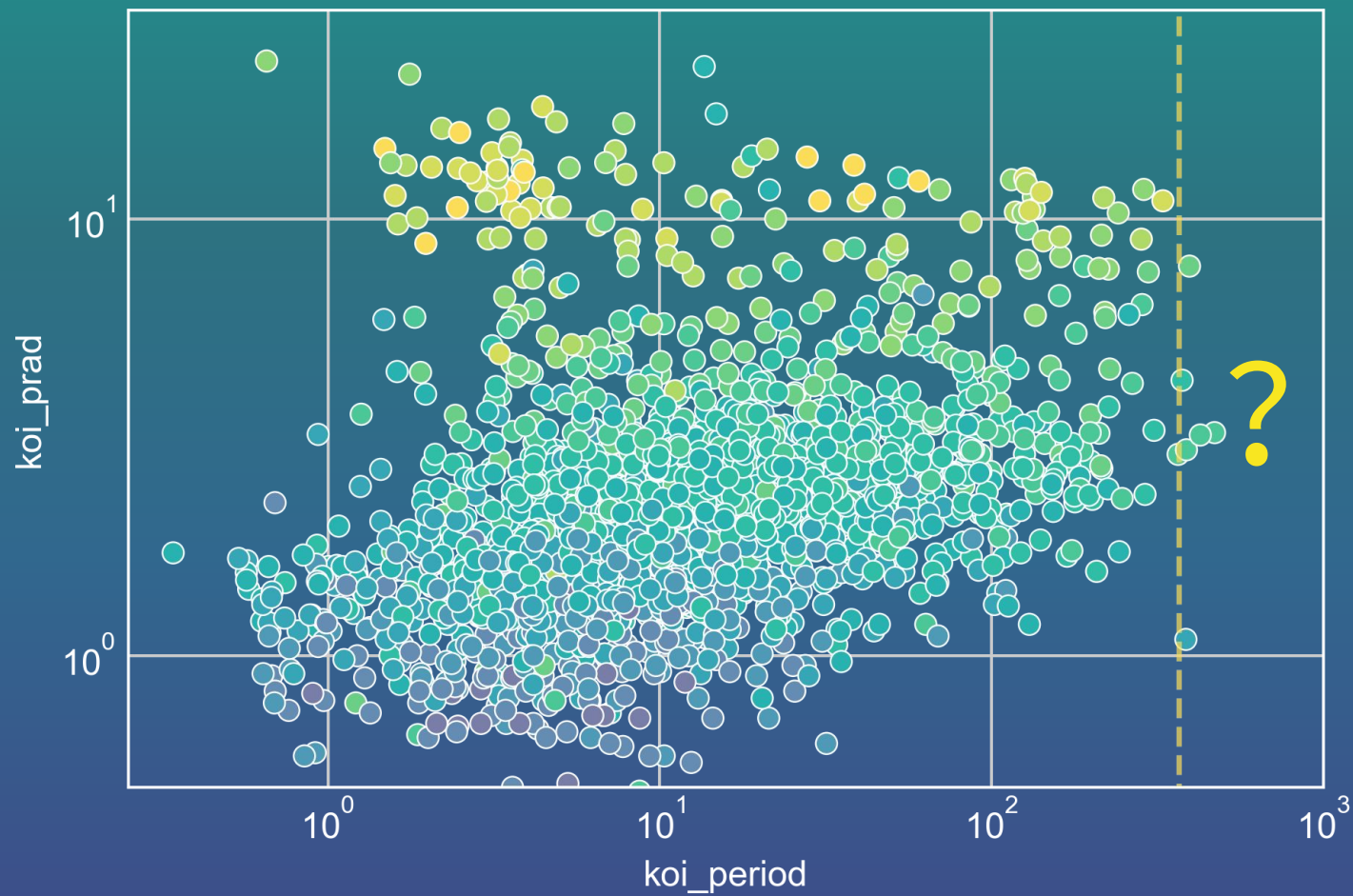


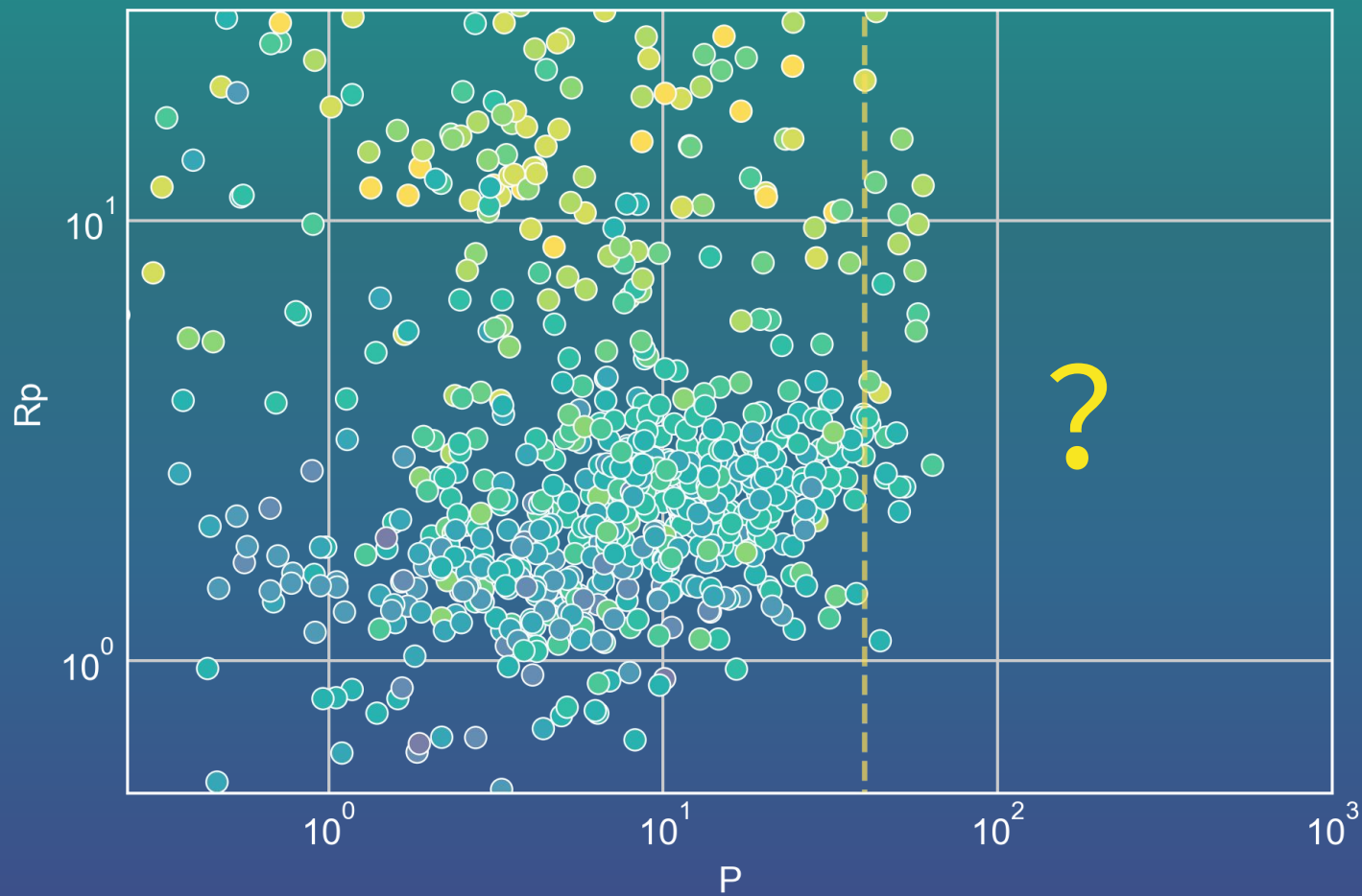
LONG-PERIOD EXOPLANET CANDIDATES FROM COROT, KEPLER, K2 & TESS

Hugh Osborn,
MIT & University of Bern

+ M. Kristiansen, W. Benz, G. Ricker

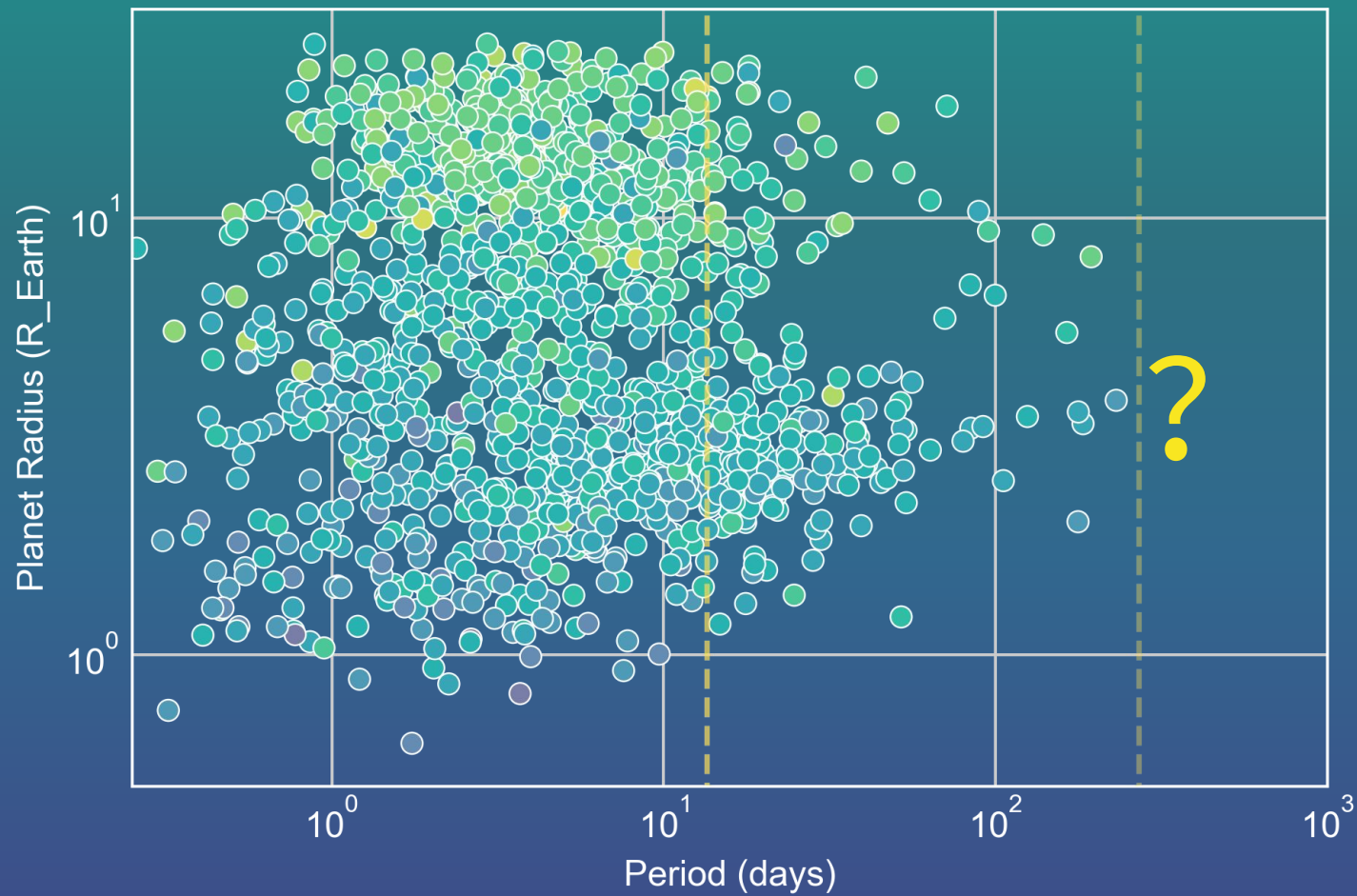


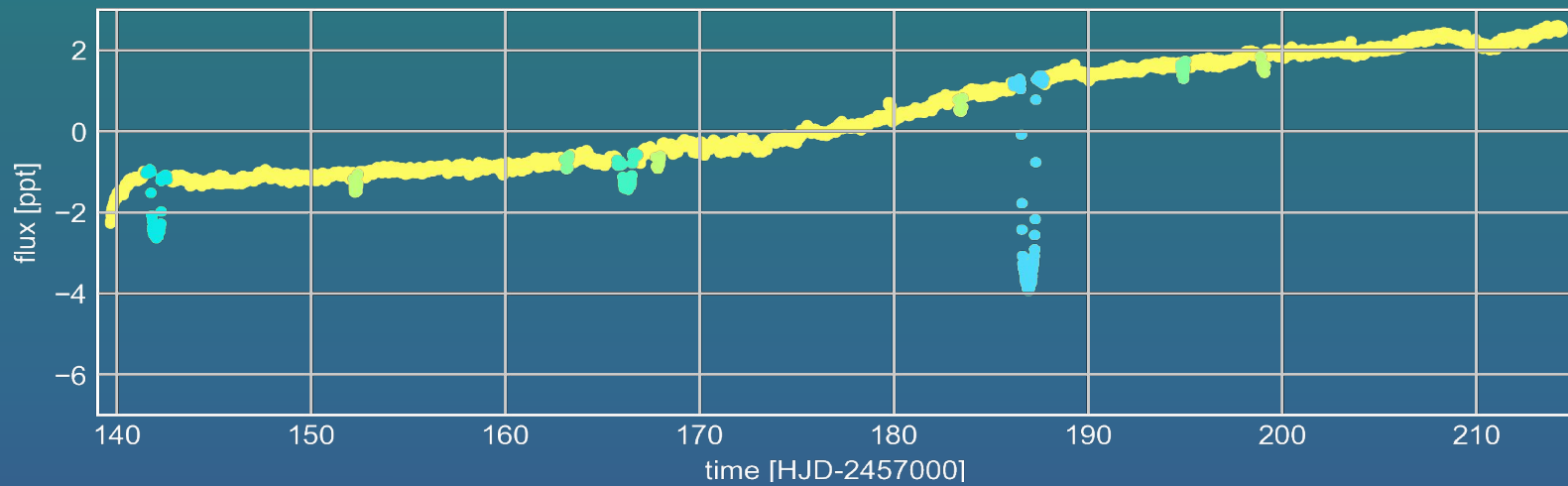




K2 PCs

TOIs

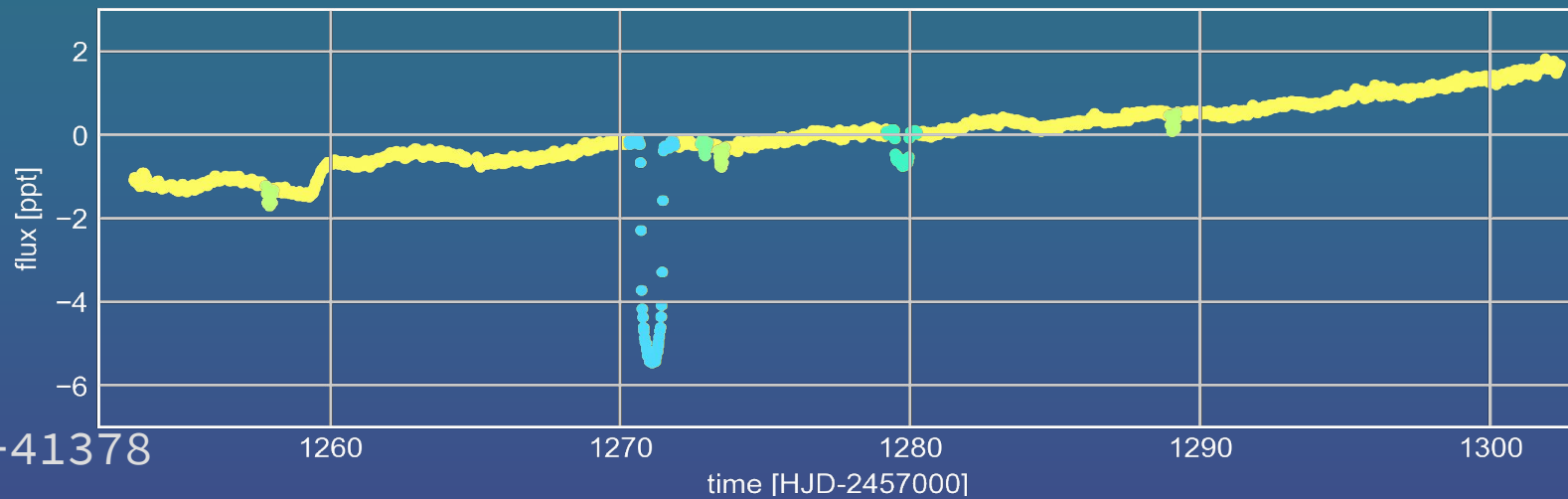
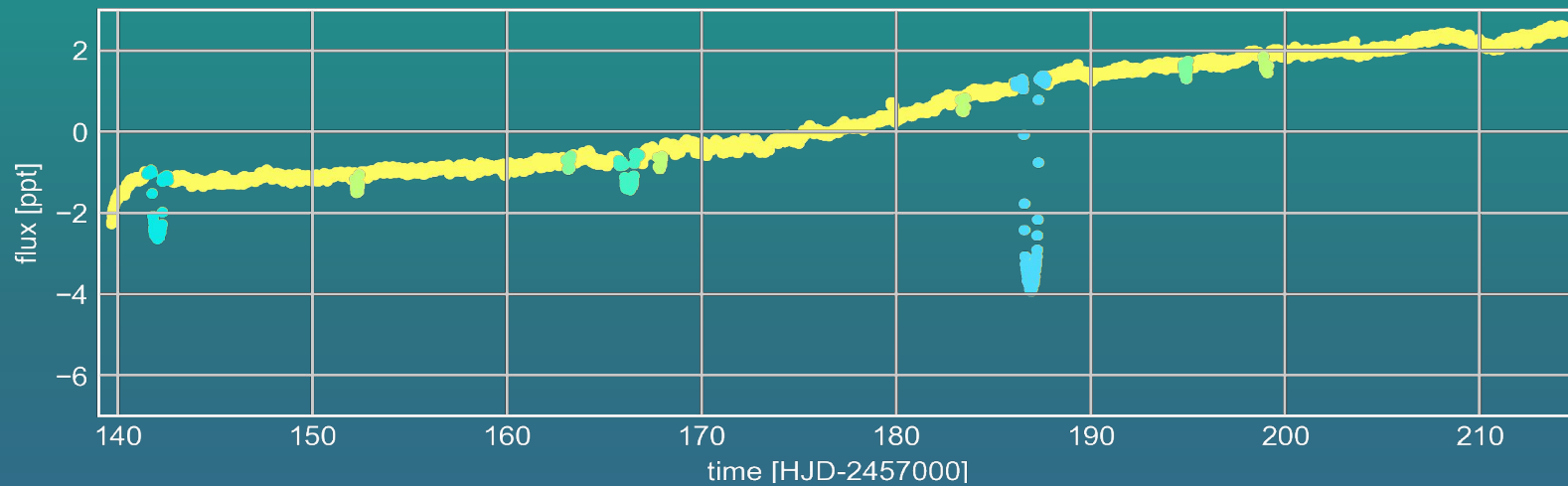




HIP-41378

WHY BOTHER WITH LONG-PERIOD PLANETS?

- Giant planets are more common at the ice line (1-3AU)
- Hot/Warm jupiter formation theories
- Atmospheres of temperate worlds
- Worlds sculpted by formation, not evaporation
- Circumplanetary objects are stable (e.g. moons & rings)



THE OPEN QUESTIONS

- Is it real?
- What kind of a planet is it?
- How can we observe it again?

Answering these problems require **estimating** a period

MODELLING

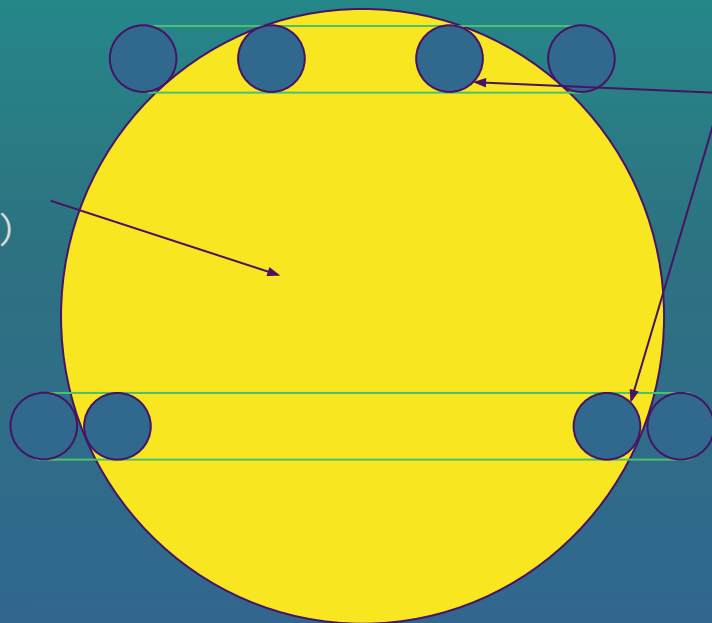
Information we have:

- Shape and depth of transit
- Stellar information (e.g. density)
- Information from other planets (e.g. constraints on eccentricity of outer candidates and stellar density)
- Minimum period from lightcurve
- Physically-motivated priors on unknown parameters

MODELLING

1) Stellar density (e.g. other planets, Gaia, logg)

2) Radius from depth



3) Impact parameter from ingress/egress

Velocity \sim transit chord \div duration

Period \sim density \div velocity³

Past efforts:

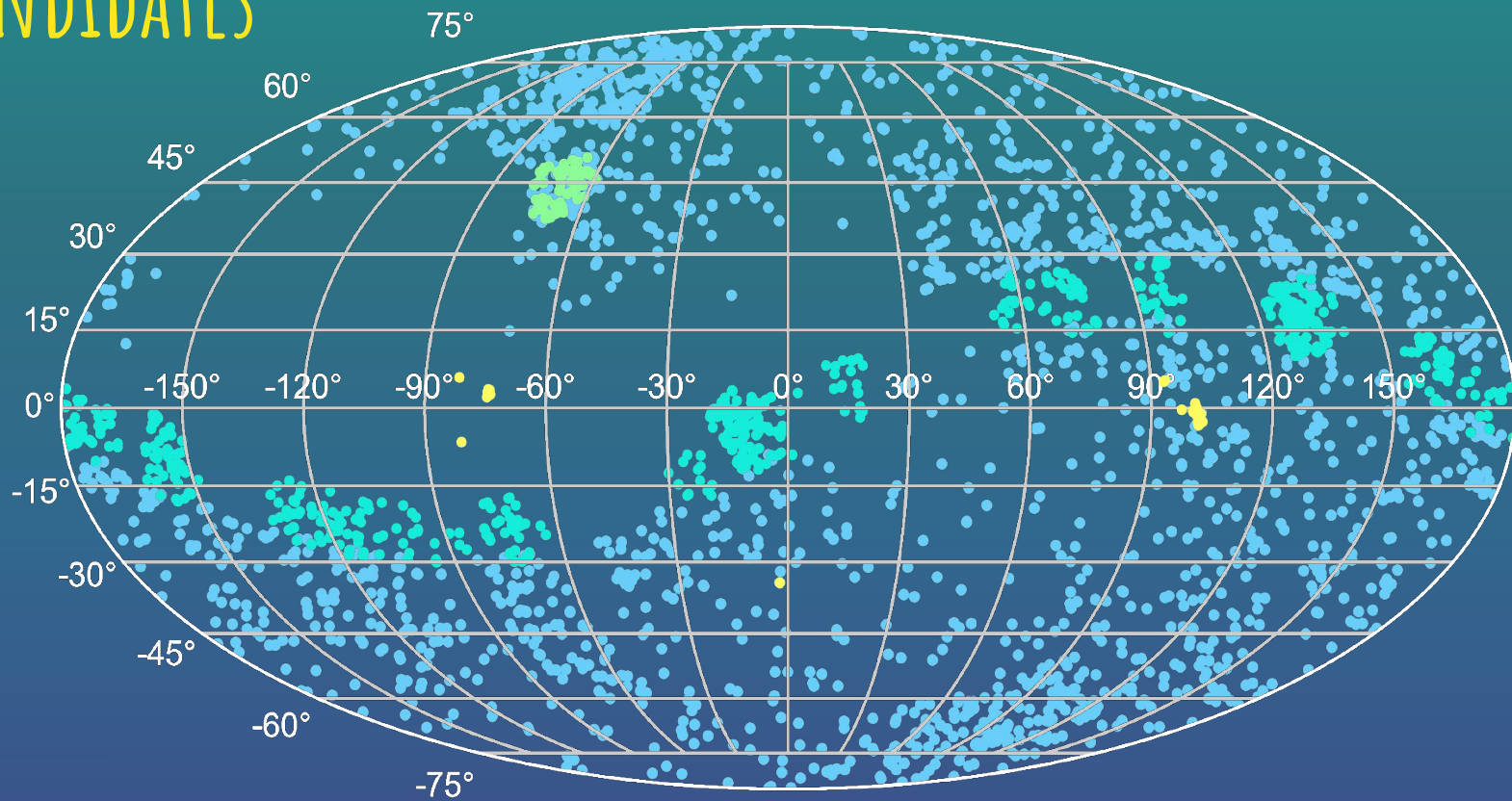
- Theory: Yee & Gaudi (2008)
- K2 candidates - Osborn (2016)
- Period priors - Kipping (2018)
- Multinest - Sandford (2019)
- Single systems - Becker, Giles, etc

Marginalise over everything else (e.g. eccentricity)

MONOTOOLS

- Uses all available photometry (e.g. K2+TESS)
 - Models eccentricity & other planets in the system
 - GPs for stellar variability
 - Works on:
 - Candidates with two disparate transits
 - Single transits with multiple gaps
- } Marginalisation!
- Uses Hamiltonian Monte Carlo (with Dan Foreman-Mackey's implementation of PyMC3: *exoplanet*)
 - Open source python <https://github.com/hposborn/MonoTools>

CANDIDATES



CANDIDATES

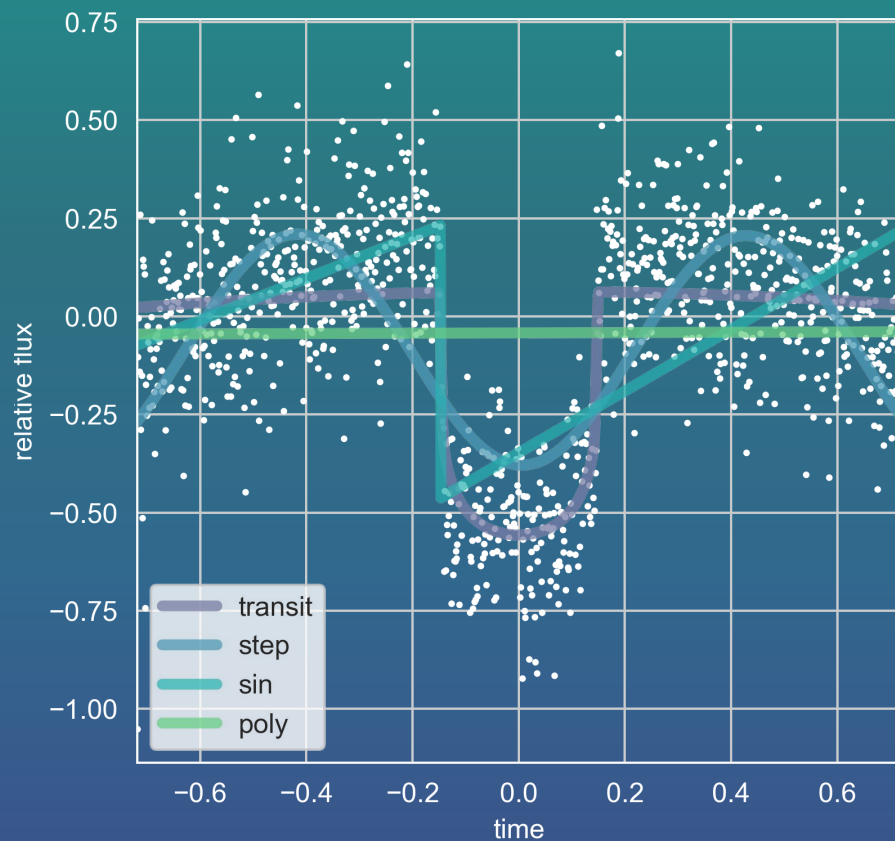
- >3000 in total
- Everything from published & confirmed planets to low-significance candidates from amateurs
- Many are False-positives
- Too many to manually search/vet!

Need **automated vetting** for monotransit candidates...

MONOTOOLS VETTING

Bayesian model comparison with the transit lightcurve:

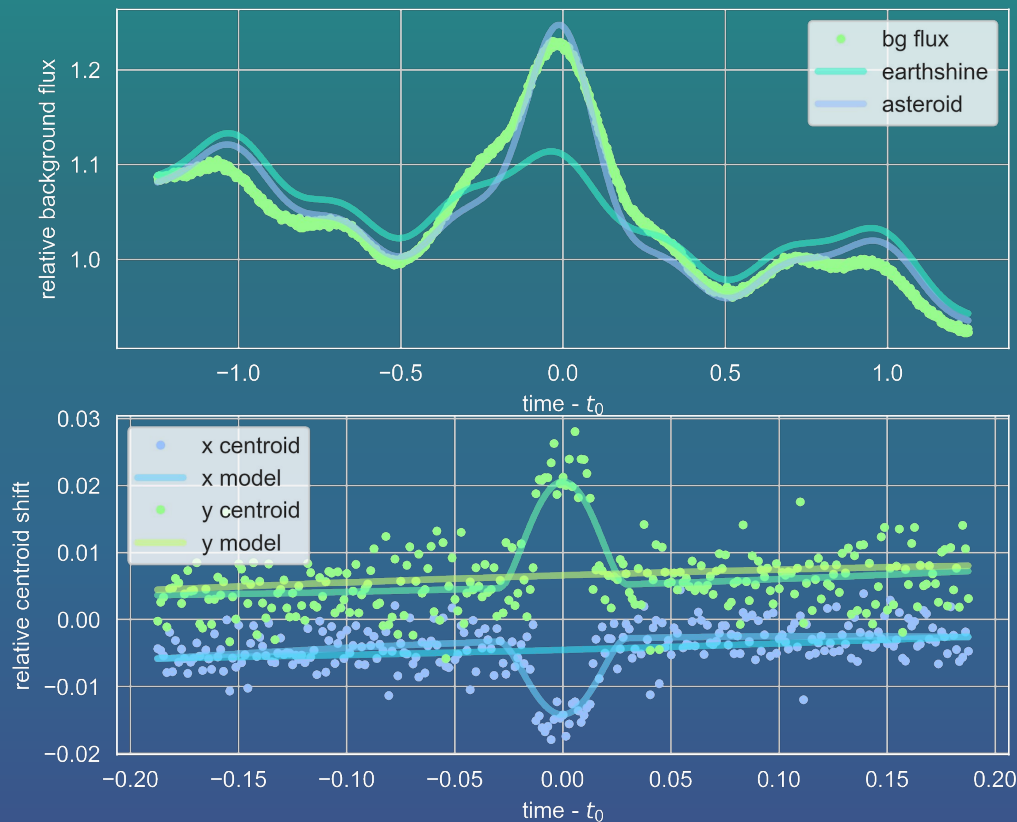
- A transit model
- Variability (sin & polynomial)
- Instrumental effect (step model)



MONOTOOLS VETTING

Bayesian model comparison
with other time-series:

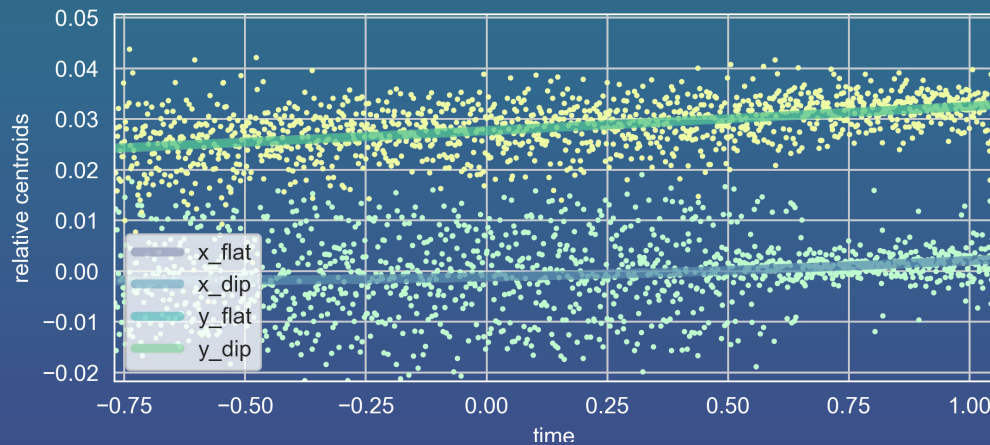
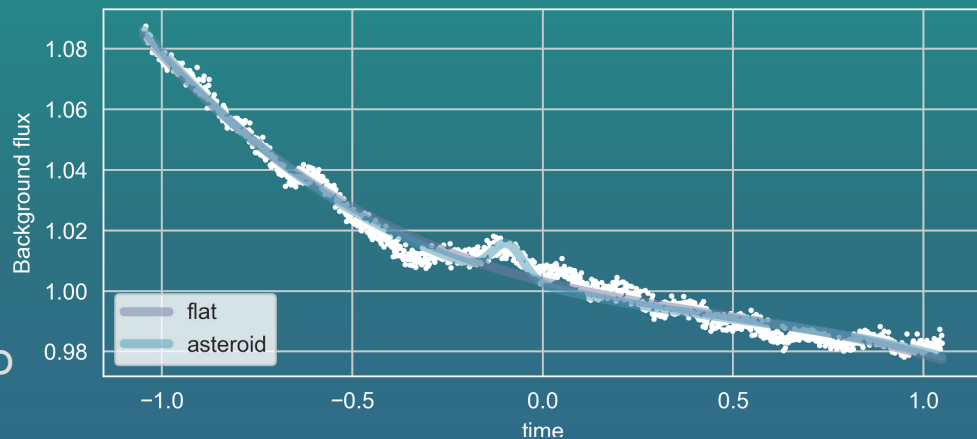
- Background flux (to identify asteroids)
- Centroids (to identify EBs)



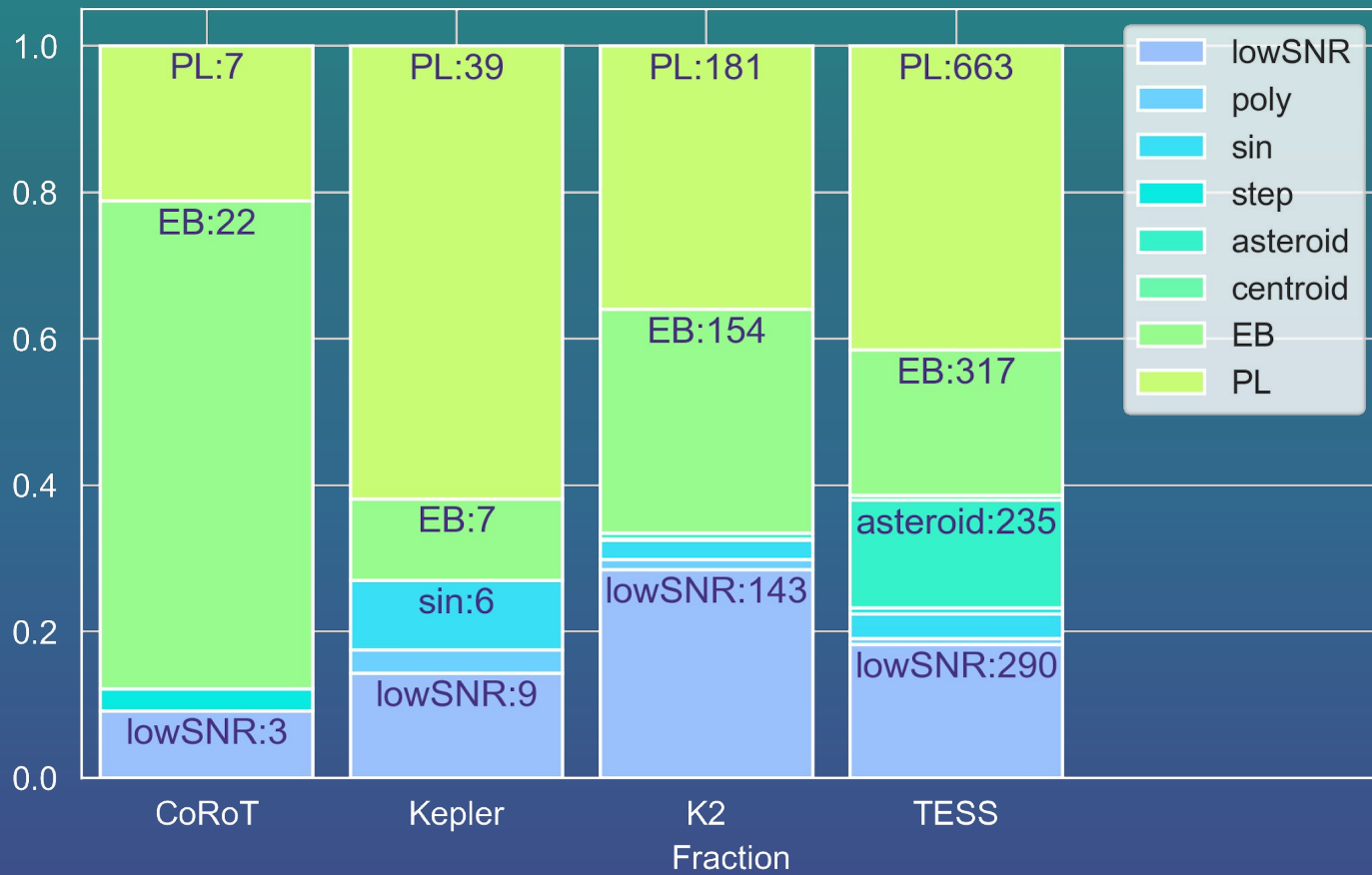
MONOTOOLS VETTING

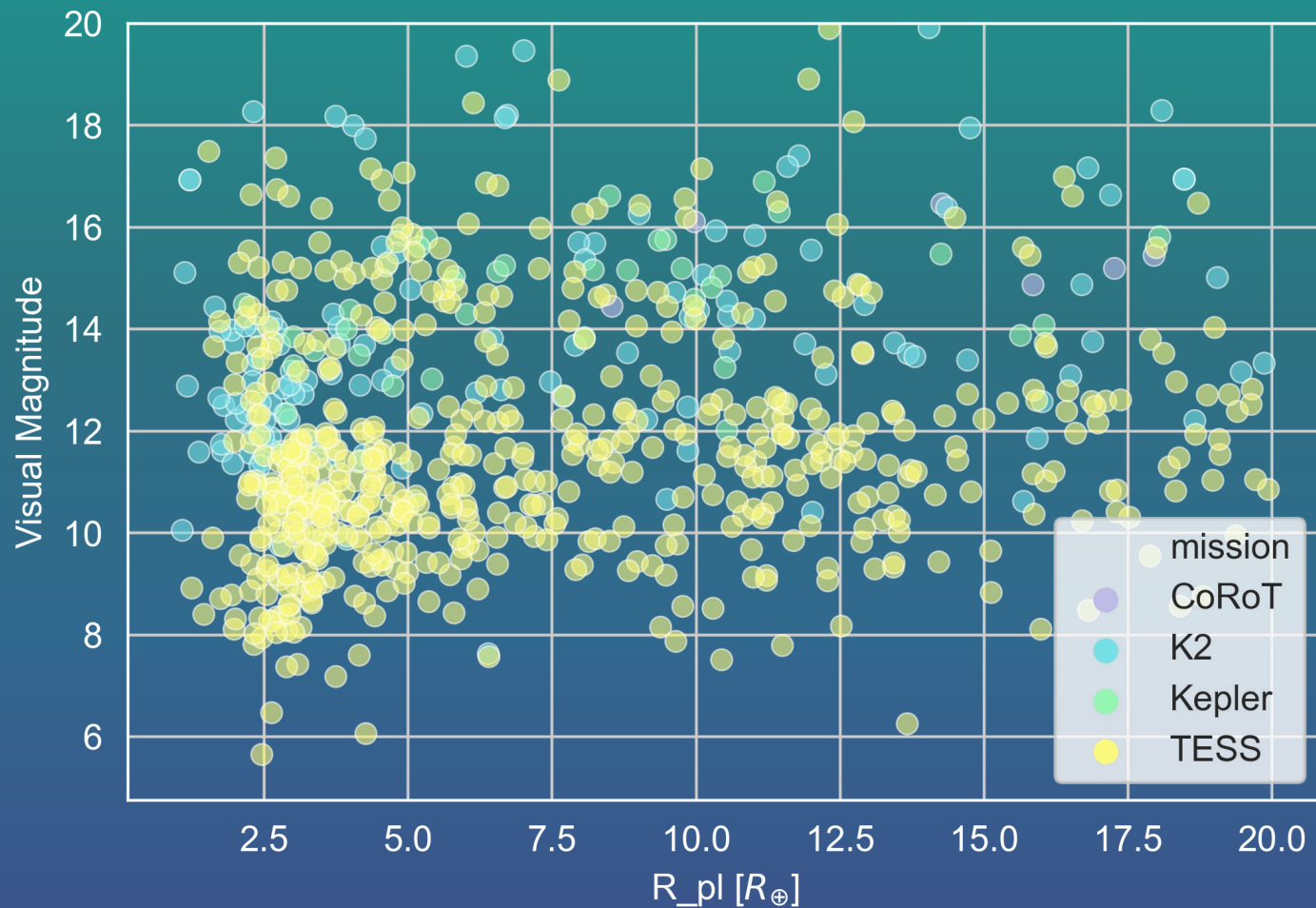
Model comparison on other data:

- Background timeseries (to identify asteroids)
- Centroids (to identify EBs)

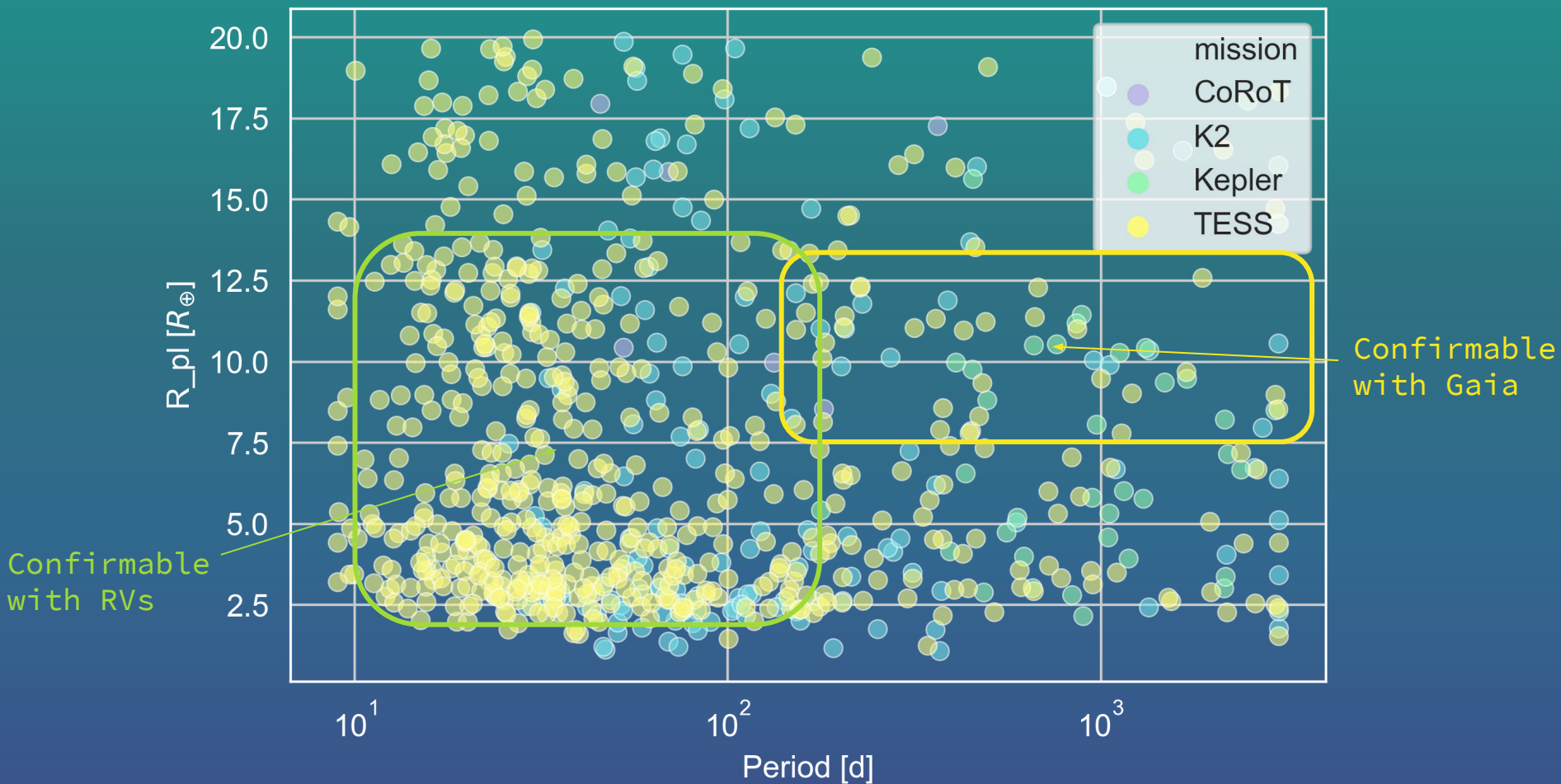


CANDIDATES



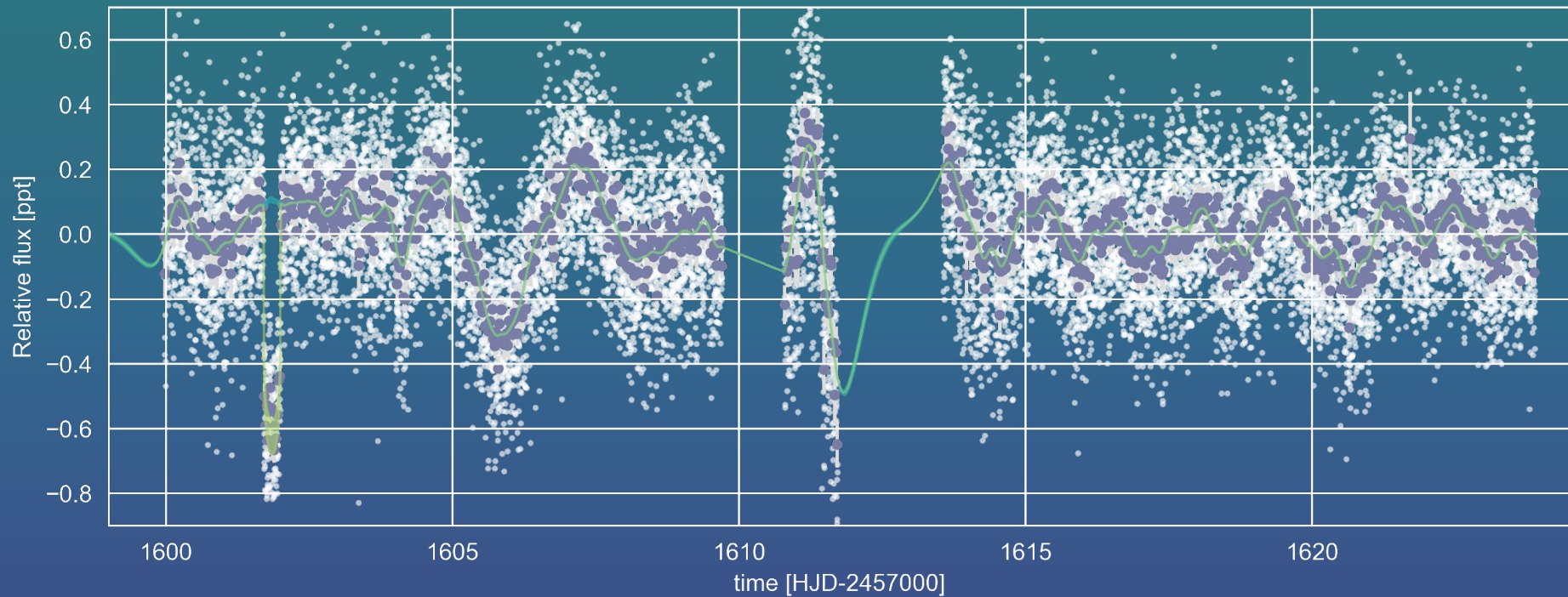


MCMC fits not yet complete - these are initial best-fit values*



MCMC fits not yet complete - these are initial best-fit values*

TIC 128...

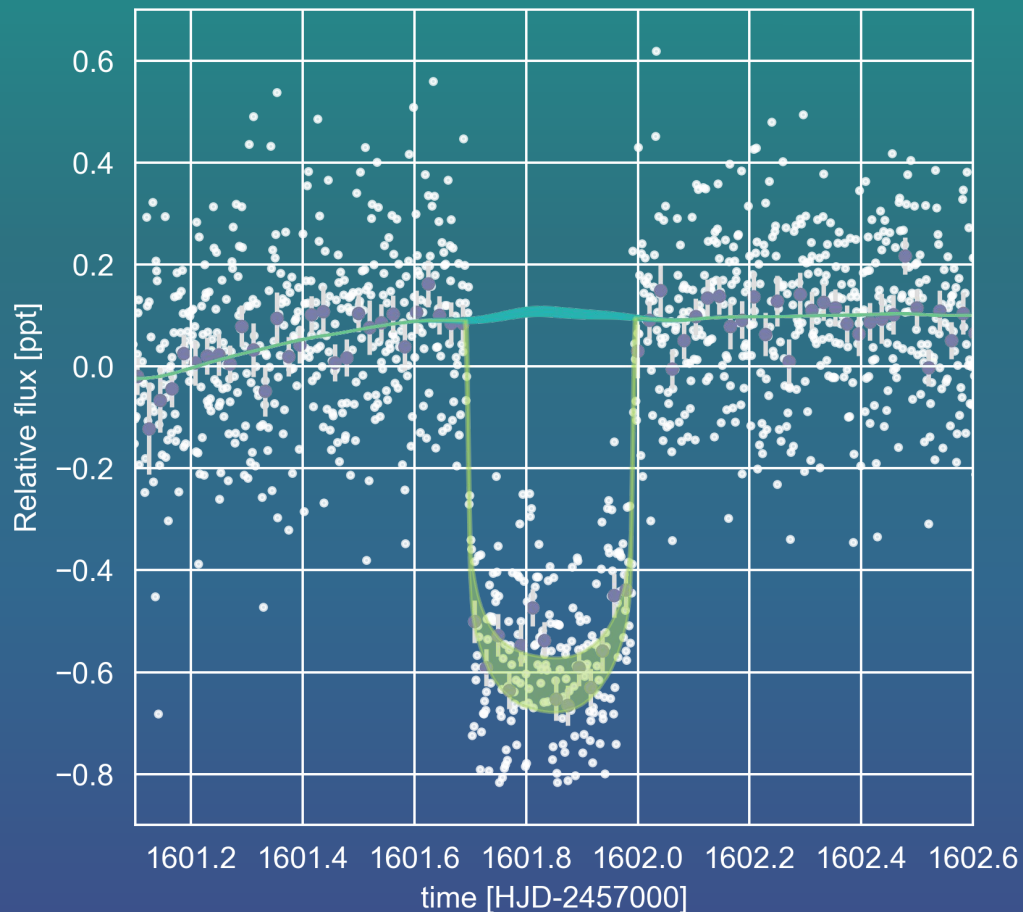


TIC 128...

Naked-eye host star ($V=6$)

Neptune-radius planet ($4.6R_{\oplus}$)

RVs show active star but
planetary-mass companion



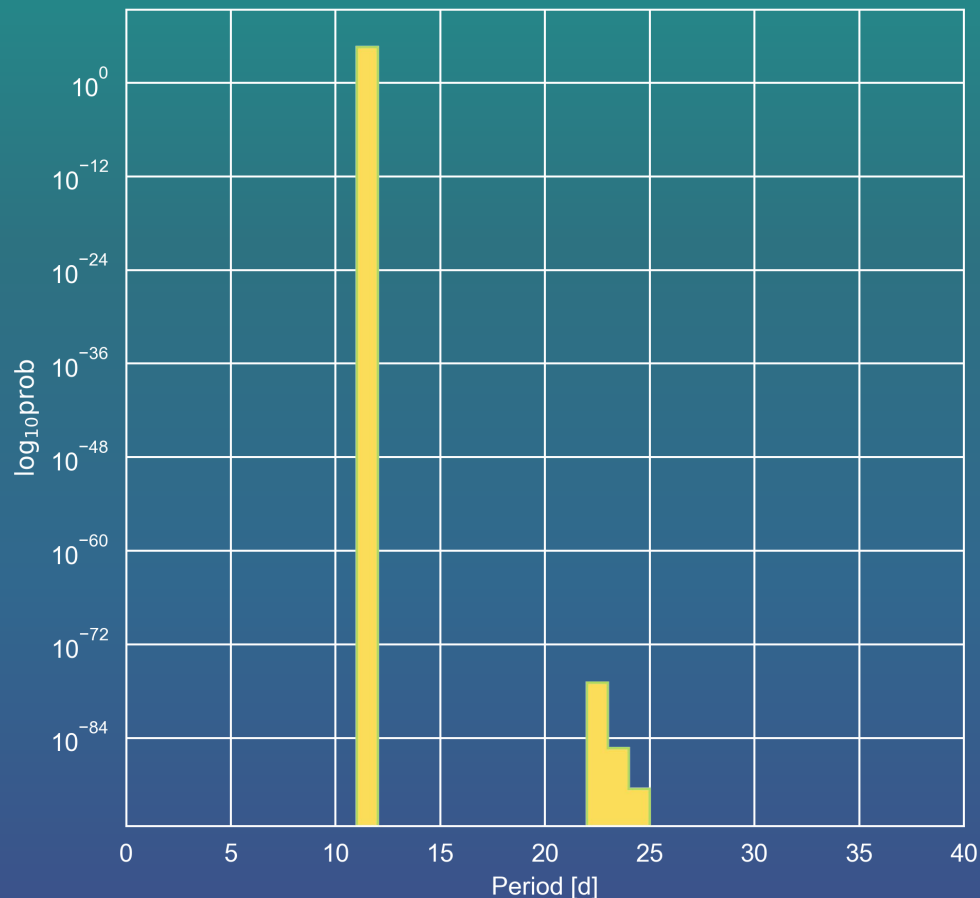
TIC 128...

Naked-eye host star ($V=6$)

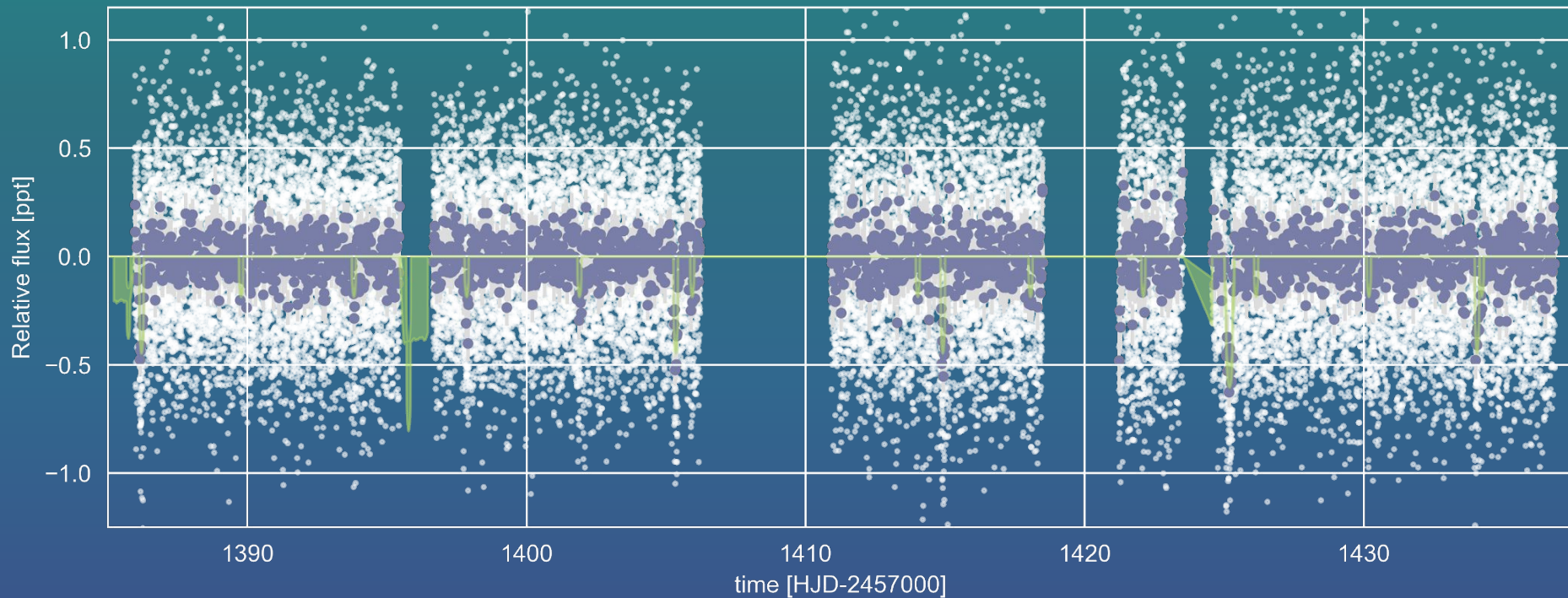
Neptune-radius planet ($4.6R_E$)

RVs show active star but
planetary-mass companion

Model prefers $P=12\text{d}$ period in
gap ($\sigma P \sim 8\%$)



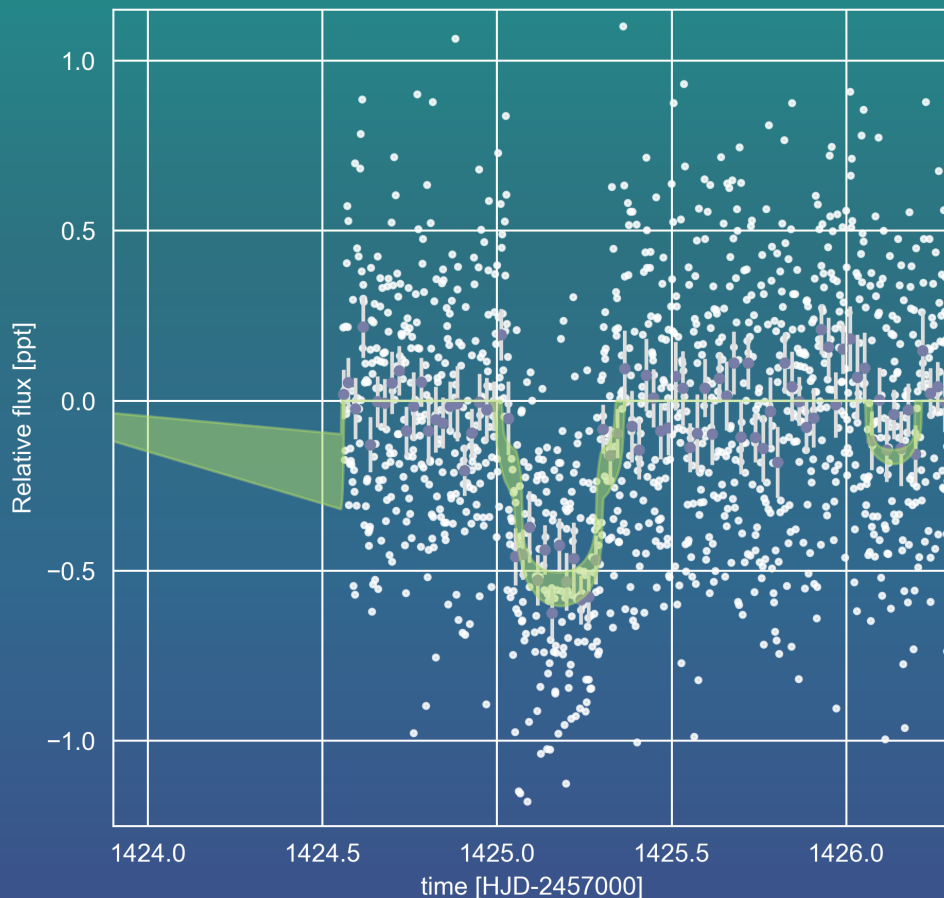
TOI-411



TOI-411

3-planet system:

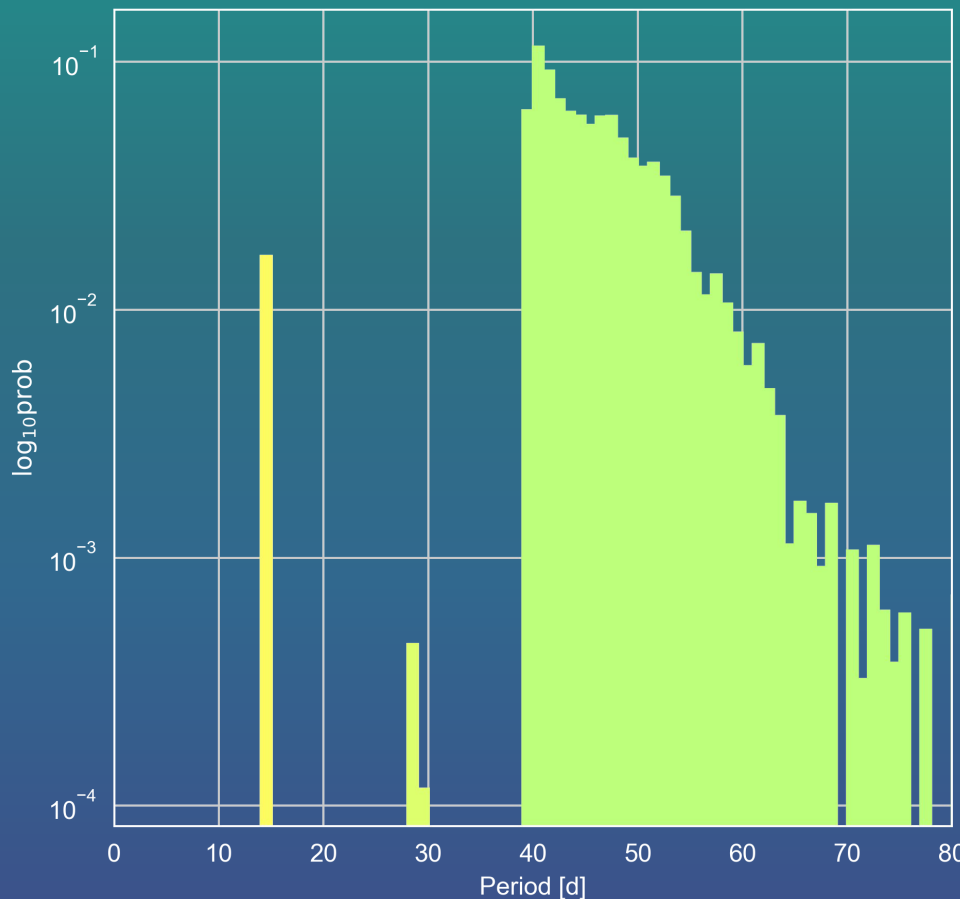
- Single-transiting 2.9Re mini-Neptune
- Depth only is 500ppm



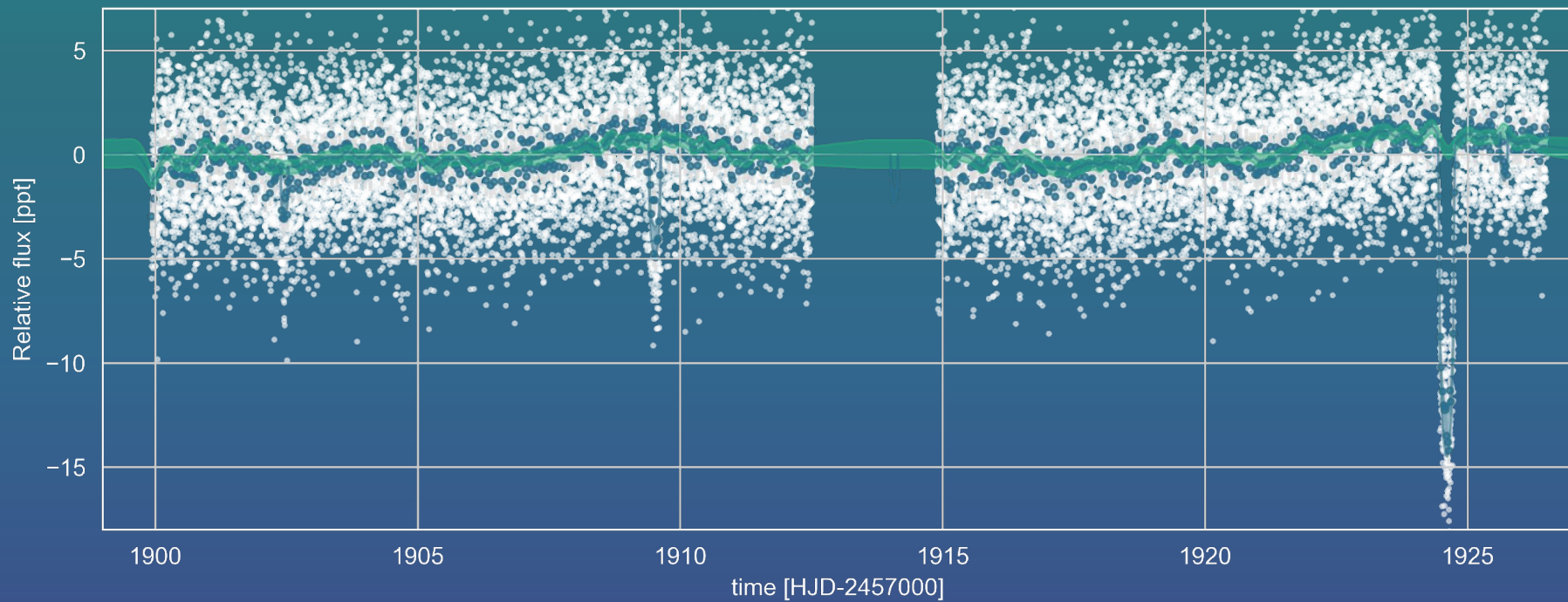
TOI-411

3-planet system:

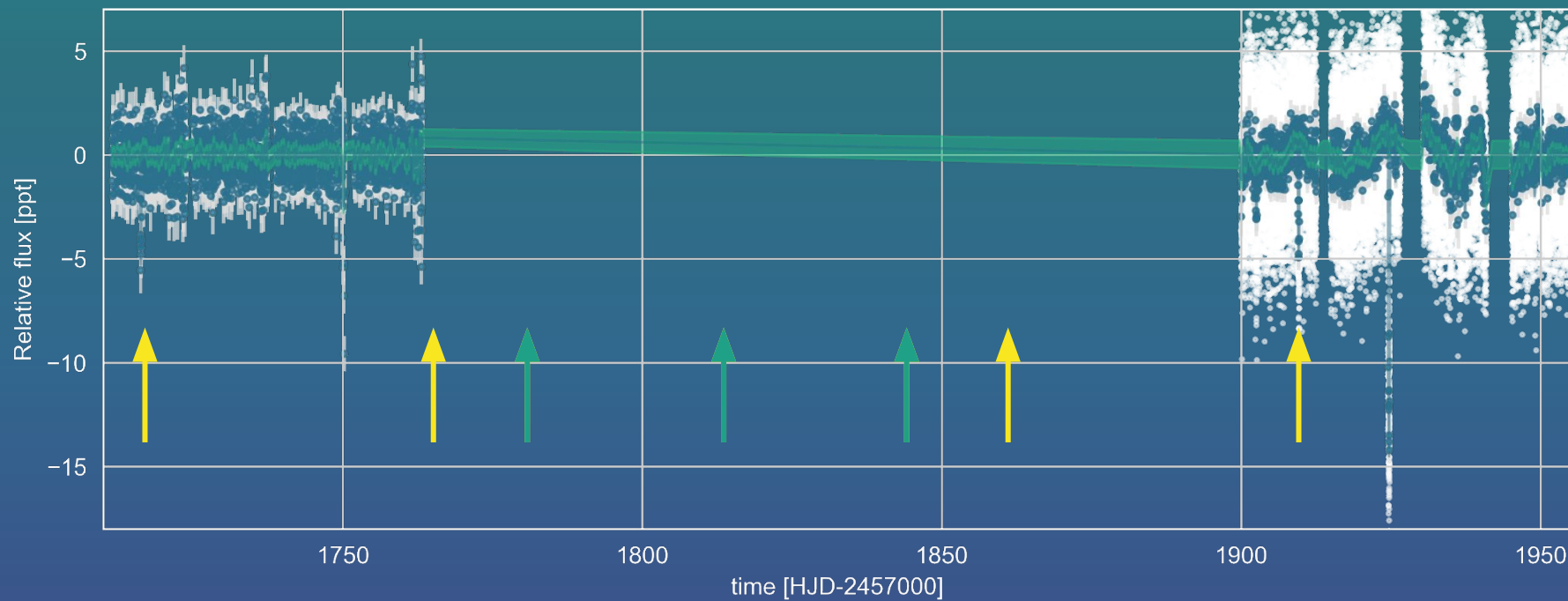
- Single-transiting 2.9Re mini-Neptune
- Depth only is 500ppm
- Likely has $P=40-60\text{d}$ ($\sigma P \sim 20\%$)



TOI-1812

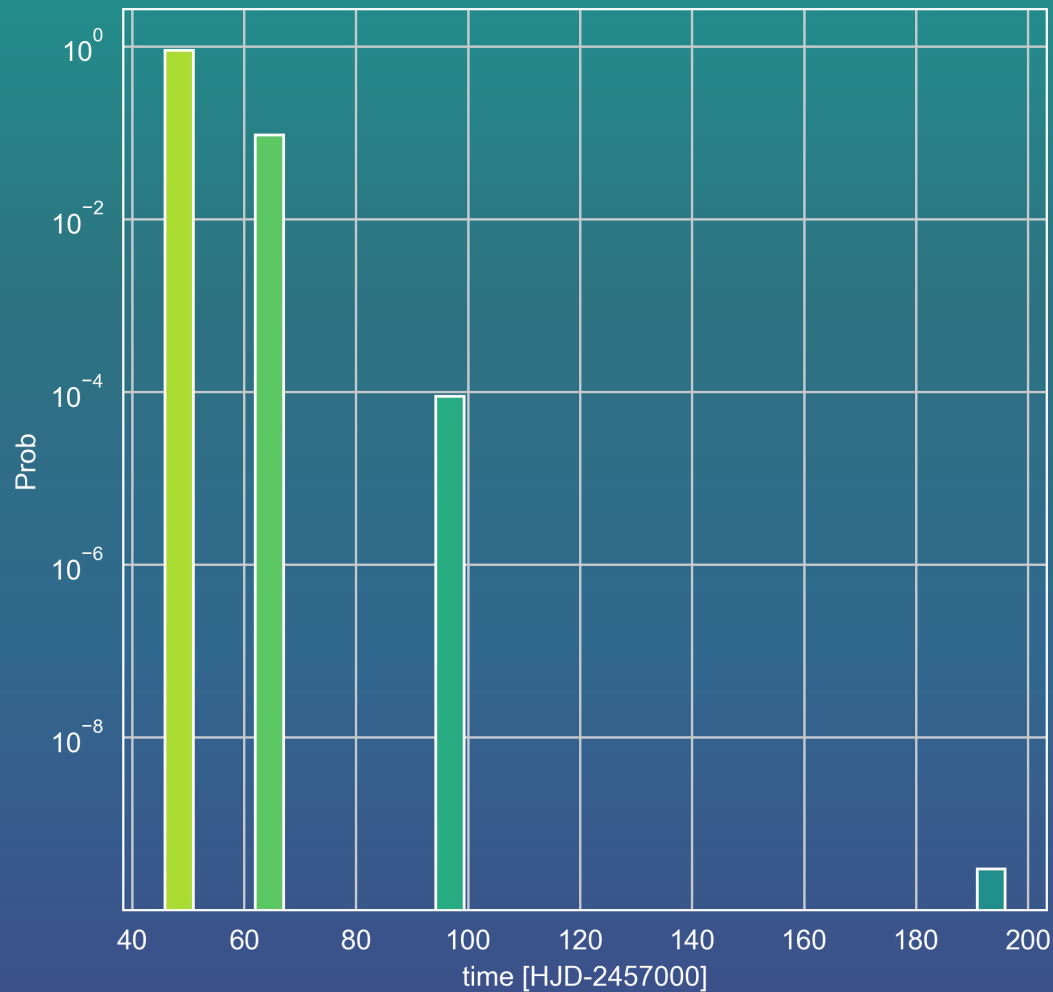


TOI 1812

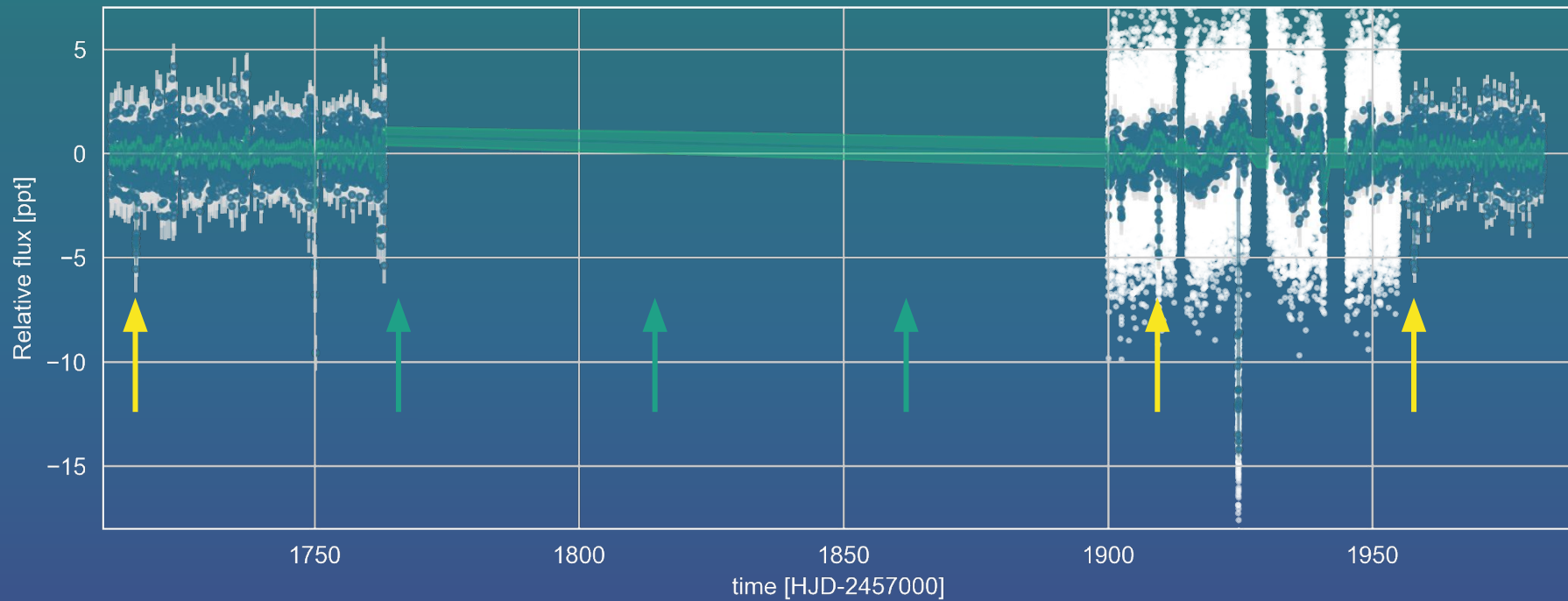


TOI-1812

Predicted 48d period
with prob~90%



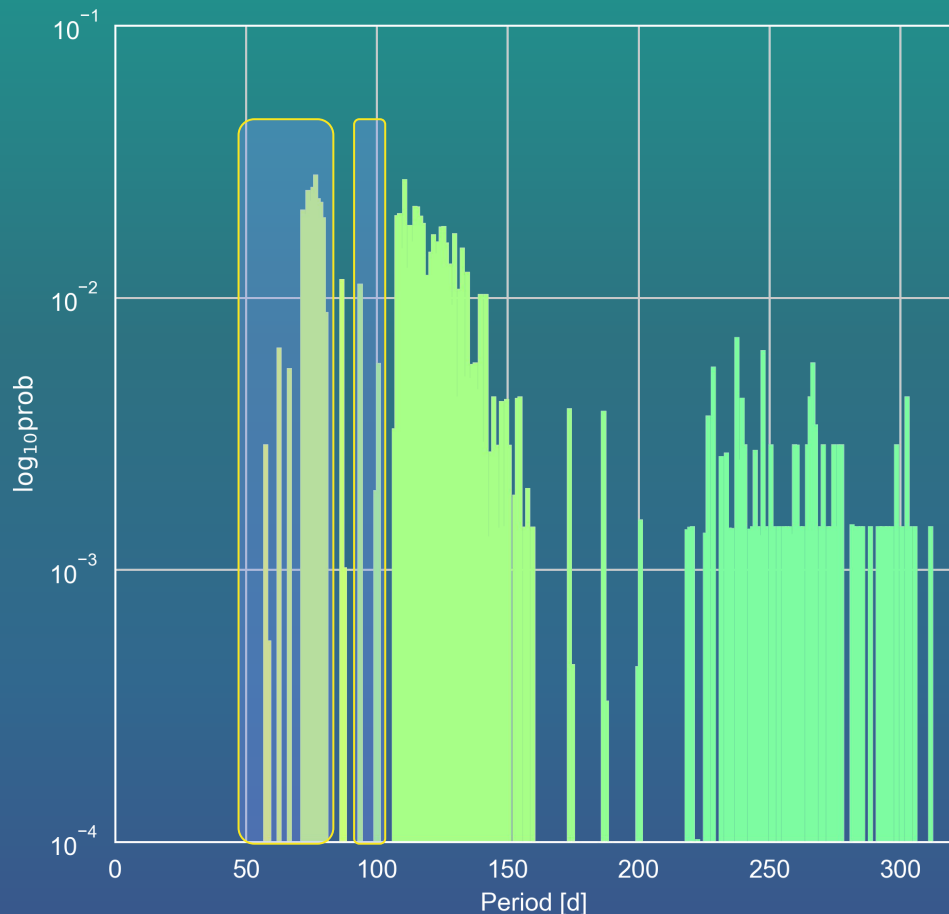
TOI 1812



TOI 1812

Outer planet:

- 9Re giant planet
- Has complex period posterior
- 60-80d should be covered by S25
- SG1 observations rule out gaps around 100d
- $P=125\pm 20\text{d}$ looking likely ($\sigma P \sim 16\%$)



CONCLUSIONS

- >500 planet candidates missed by transit surveys
- Some are interesting candidates which could be confirmed and explored in the future.
- A uniform catalogue benefits follow-up teams who can prioritise based on candidate parameters.
- Catalogue will be published soon
- Code is publically available at <https://github.com/hposborn/MonoTools>

THANKS!

QUESTIONS?

Hugh Osborn, MIT/University of Bern