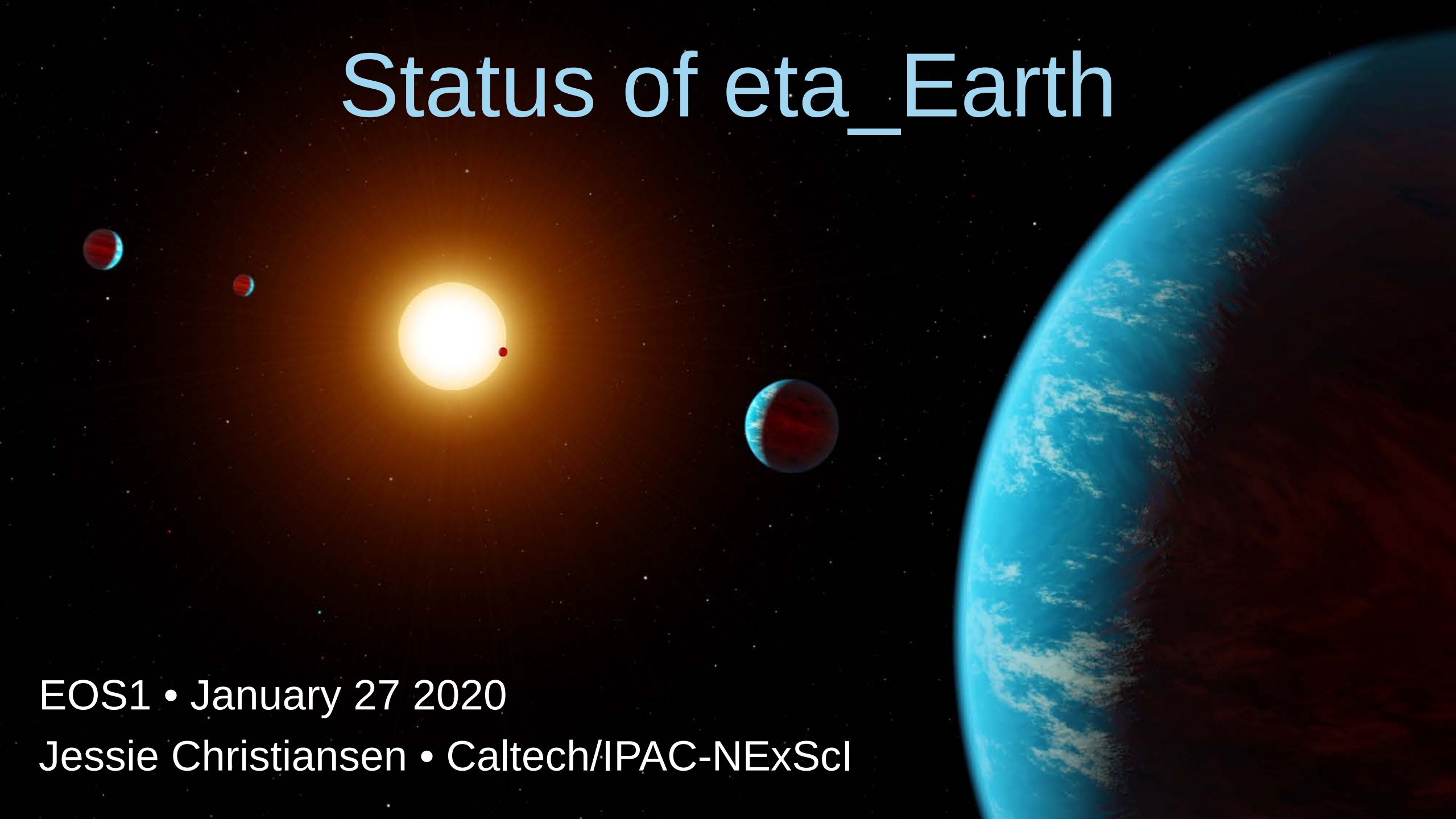
Status of eta_Earth



EOS1 • January 27 2020

Jessie Christiansen • Caltech/IPAC-NExScI

Definition of eta_Earth

"$\eta_\oplus$: The frequency of Earth-like planets in the habitable zone of Sun-like Stars"

"0.8—2 $R_\oplus$"

"0.5—1.4 $R_\oplus$"

"0.5—2 $R_\oplus$"

"G"

"GK"

"FGK"

"0.95 au < *a* < 1.37 au"

"0.75 au < *a* < 1.8 au"

"0.72 au < *a* < 2.0 au"

"0.80 au < *a* < 1.8 u"

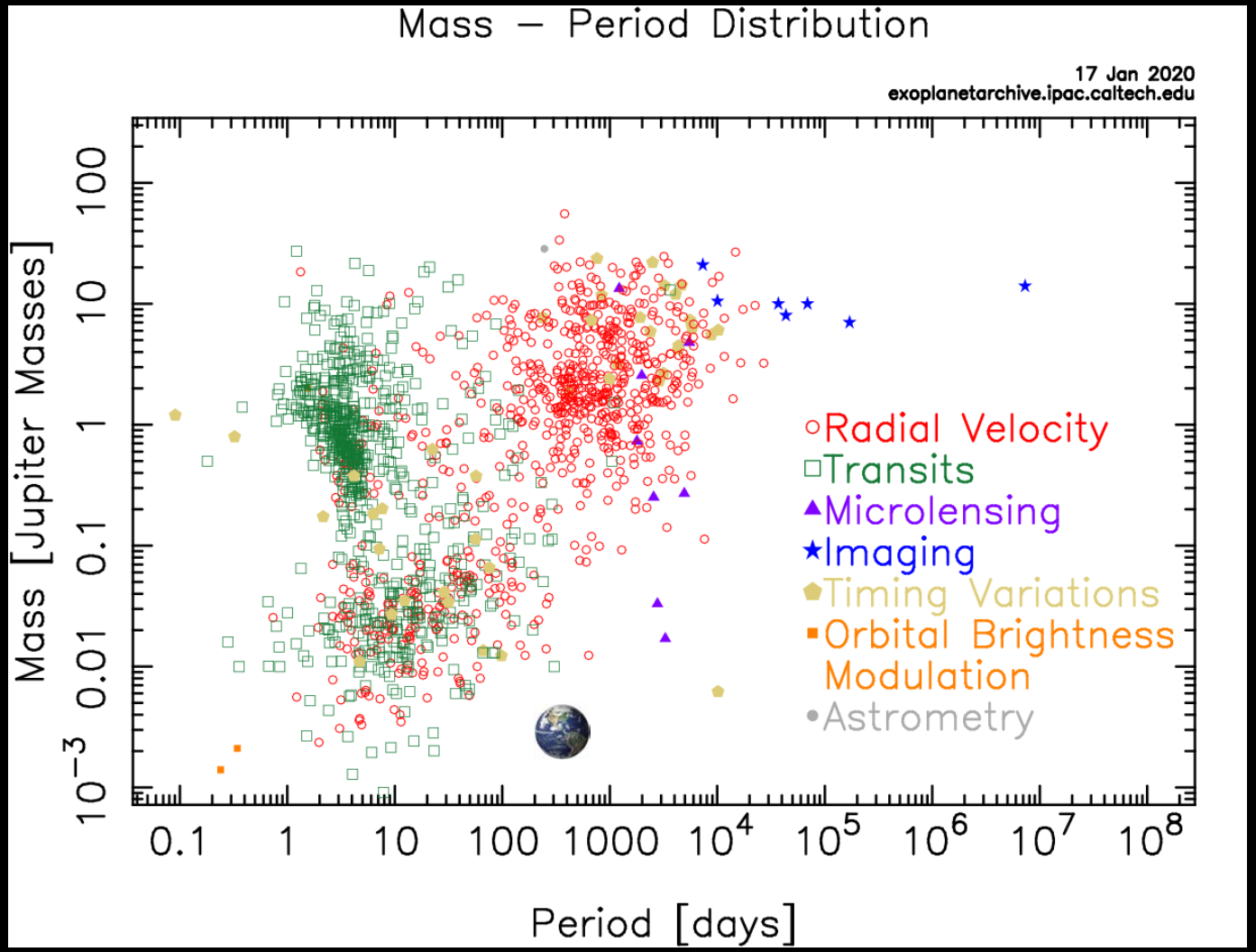
"0.95 au < *a* < 1.67 au"

"0.97 $S_\oplus$ < *S* < 1.67 $S_\oplus$"

"0.99 $S_\oplus$ < *S* < 1.67 $S_\oplus$"

"$\Gamma_\oplus$: Your model population evaluated at $R_p = 1R_\oplus$ and P_{orb} = 1 year"

Available detection methods



~~Radial velocity: ~0.09m/s~~

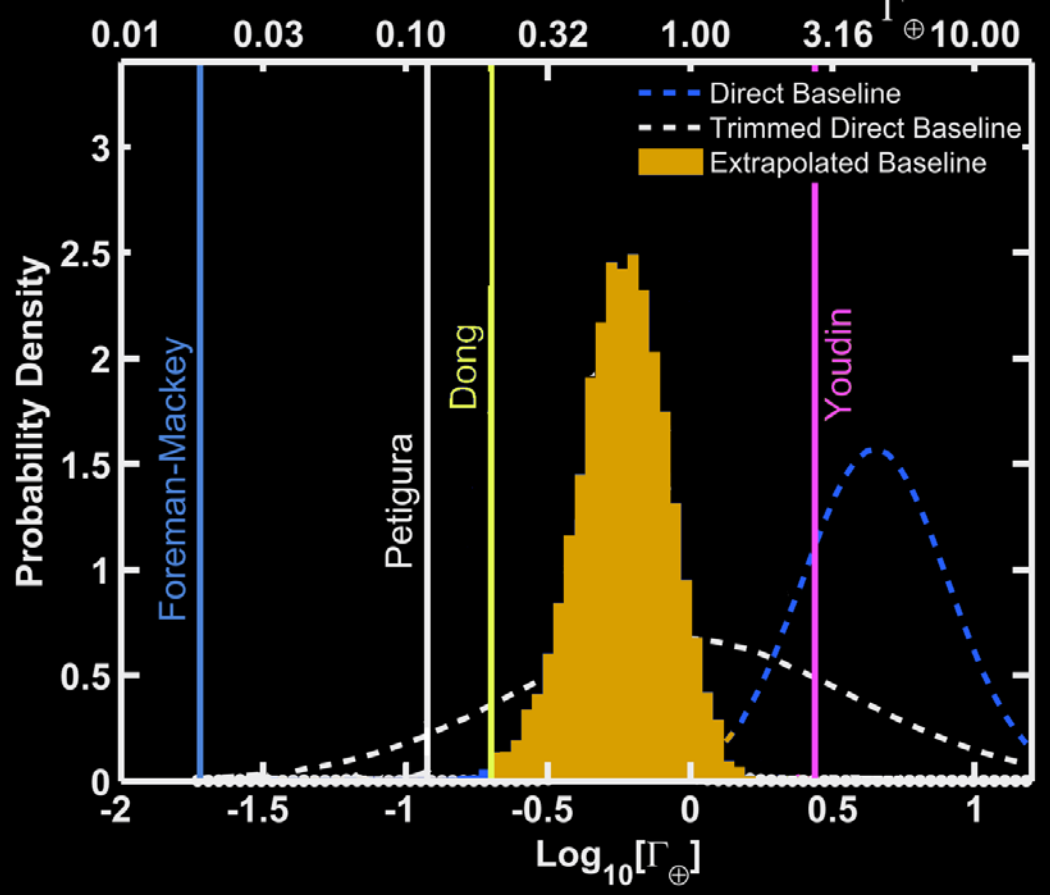
Transits: ~85ppm

~~Astrometry: ~0.3μas~~

~~Imaging: ~10^{-10} contrast~~

~~Microlensing: q ~ $3x10^{-5}$~~

$\Gamma_\oplus$ (2015)



Burke, Christiansen+2015

Youdin: Kepler Q0-Q2| Parametric PLDF | SNR=10 cut | No reliability | Extrapolation from 50 days

Petigura: TERRA | Inverse detection, bins R, P | TERRA completeness | No reliability | Extrapolation from 250 days (flat in logP)

FM: TERRA | Hierarchical Bayesian inference, smooth in R, P | TERRA completeness | No reliability | Extrapolation from 200 days (smooth in P)

D&Z: Kepler Q1-Q6 | Parametric PLDF | SNR=8 cut | No reliability | Extrapolation from 250 days (power law in logP)

Burke: Kepler Q1-Q16 | Parametric PLDF | Kepler detection efficiency | No reliability | Extrapolation from 200 days

ExoPAG SAG#13

Key objectives and questions:

1. Propose standard nominal conventions, definitions, and units for occurrence rates/distributions to facilitate comparisons between different studies.
2. Do occurrence estimates from different teams/methods agree with each other to within statistical uncertainty? If not, why?
3. For occurrence rates where extrapolation is still necessary, what values should the community adopt as standard conventions for mission yield estimates?

R_p = {0.67, 1.0, 1.5, 2.3, 3.4, 5.1, 7.6, 11, 17, …} $R_\oplus$
P_{orb} = {10, 20, 40, 80, 160, 320, 640, …} days

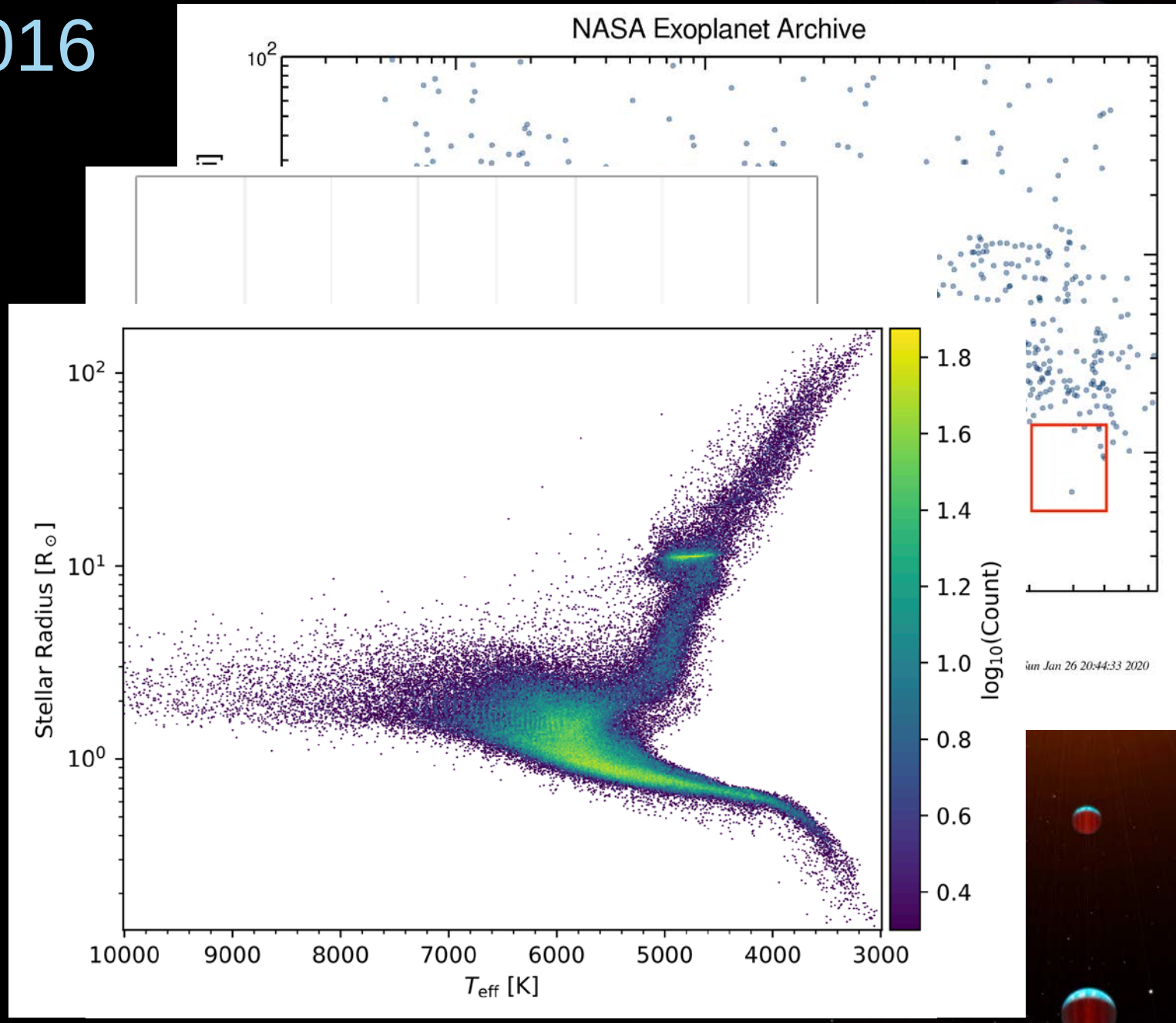
$\eta_{\sim\oplus}$ ($237 < P_{orb} < 860$ days, $0.5 < R_p < 1.5\ R_\oplus$) = **0.58**

Major updates since 2016

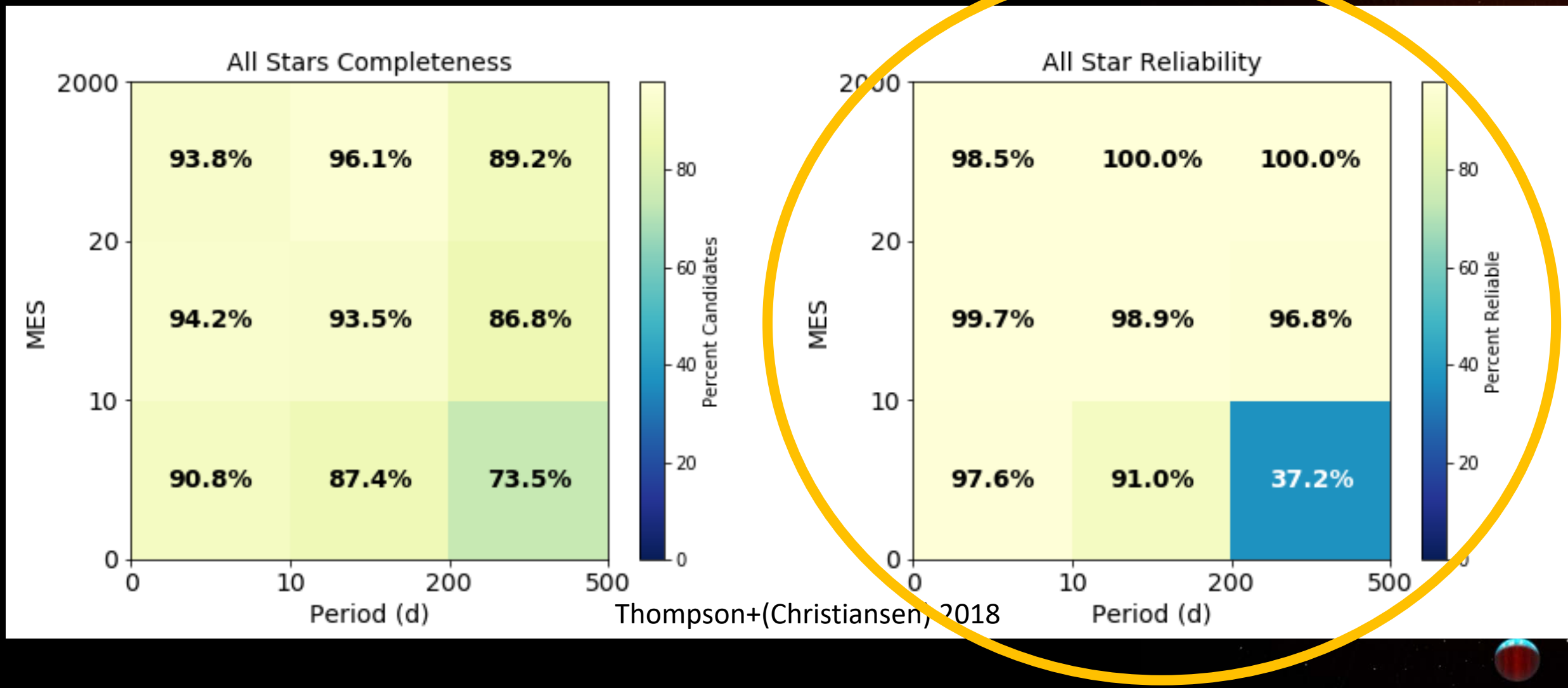
Kepler DR25 Final Planet Candidate Catalog (Thompson+2018) with quantified completeness and for the first time, *reliability*

Gaia DR2: Updated stellar parameters (animation by J. Dotson and E. Mamajek)

Gaia DR2: Updated, *uniformly-derived* stellar parameters (Berger+2020)



Kepler DR25 Completeness and Reliability



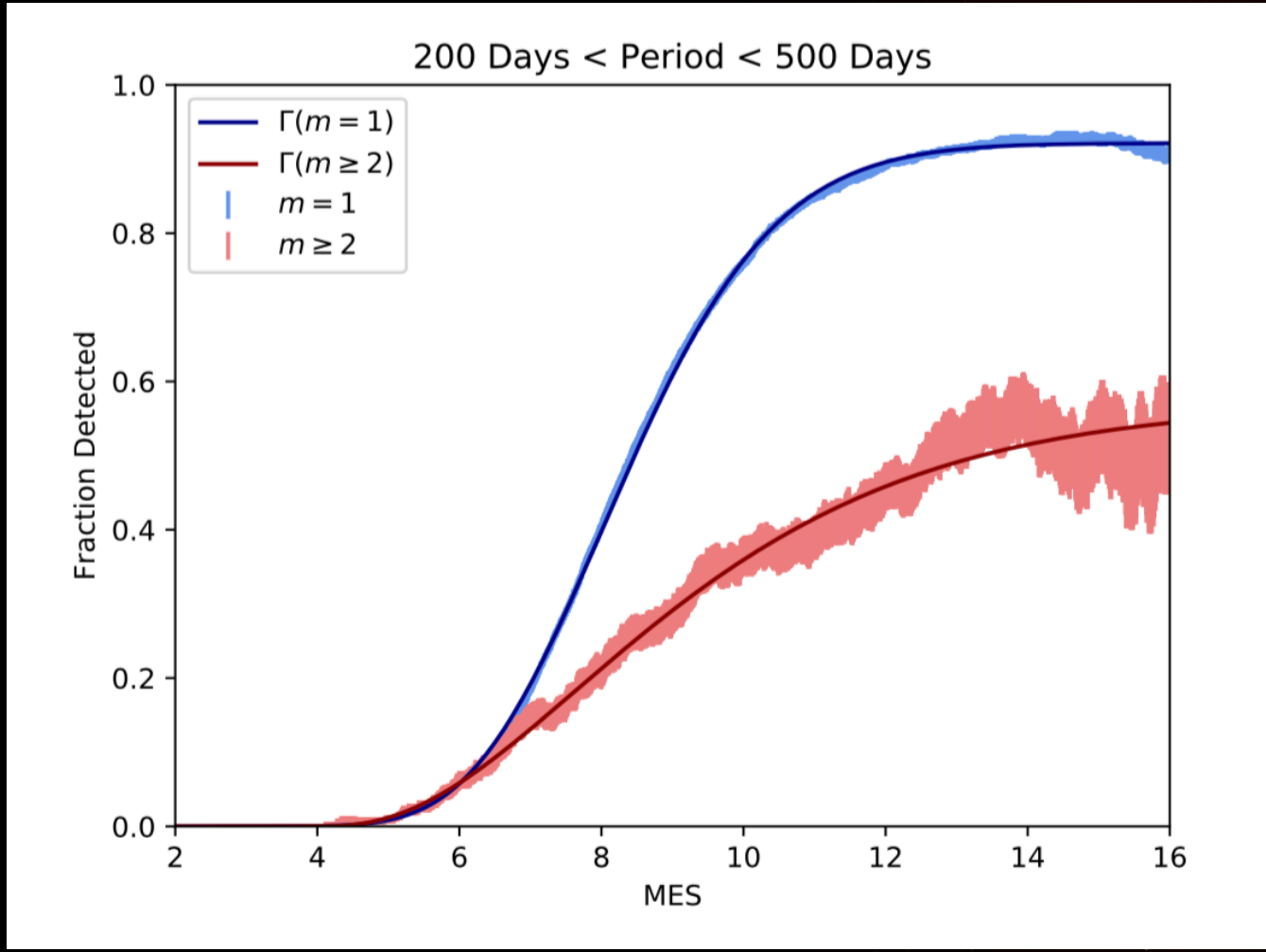
Thompson+(Christiansen) 2018

Completeness: planet multiplicity

The detection efficiency of multiple transit signals in the same light curve cannot be treated independently

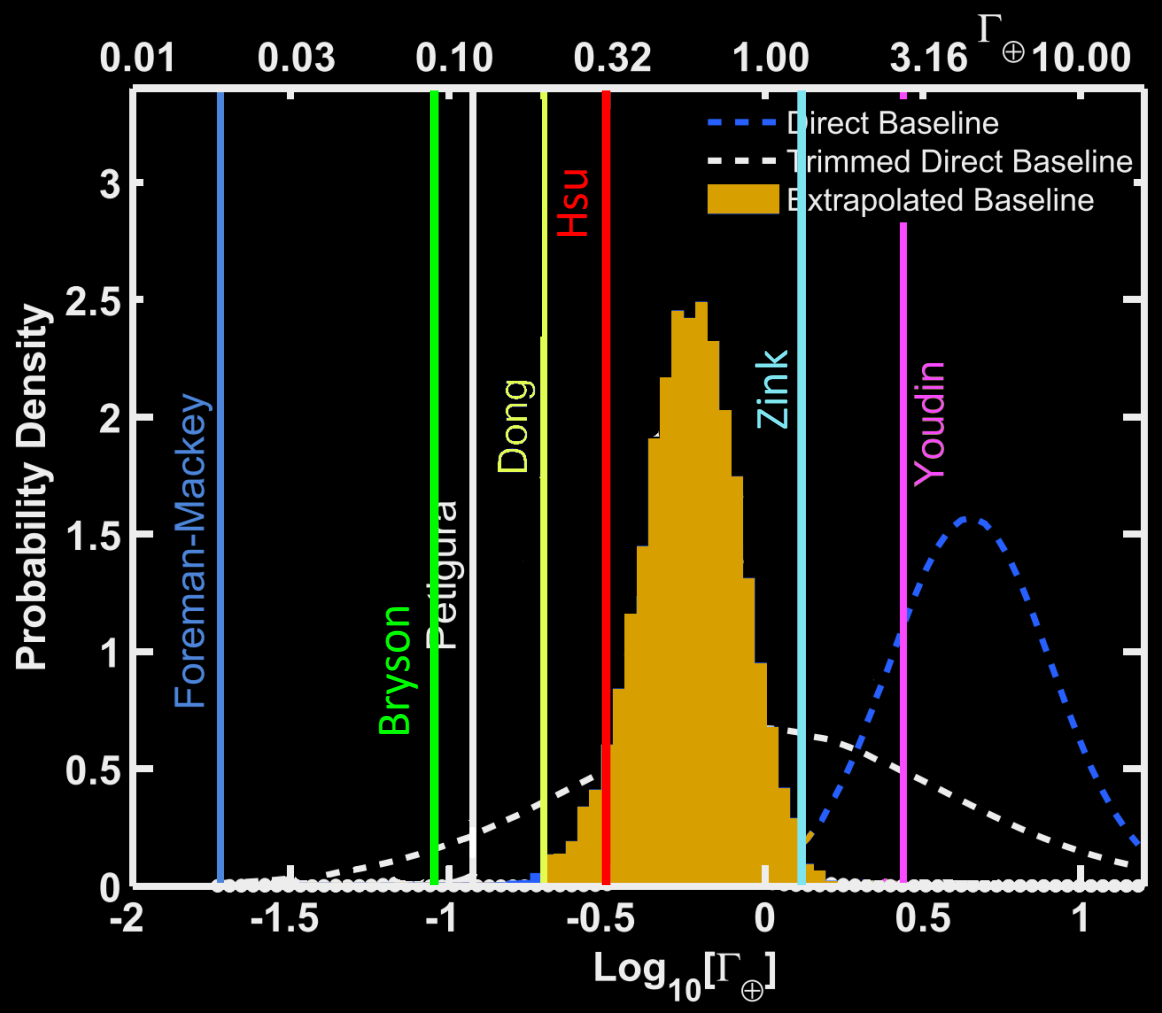
Long-period planet signals are especially penalized

(The Kepler Dichotomy can be largely explained by detection efficiency losses)



Zink, Christiansen & Hansen (2019)

Implications for $\Gamma_\oplus$



Burke, Christiansen+2015

Bryson+2020: Kepler DR25 | Parametric PLDF | Kepler detection efficiency | Kepler reliability |

Calculated to 400 days = 0.09

Hsu+2019: Kepler DR25 | Approximate Bayesian Computation (in bins) | Kepler detection efficiency | No reliability |

Calculated to 500 days = 0.32

Zink+2019: Kepler DR25 | Parametric PLDF | Kepler detection efficiency | No reliability | Includes planet multiplicity correction |

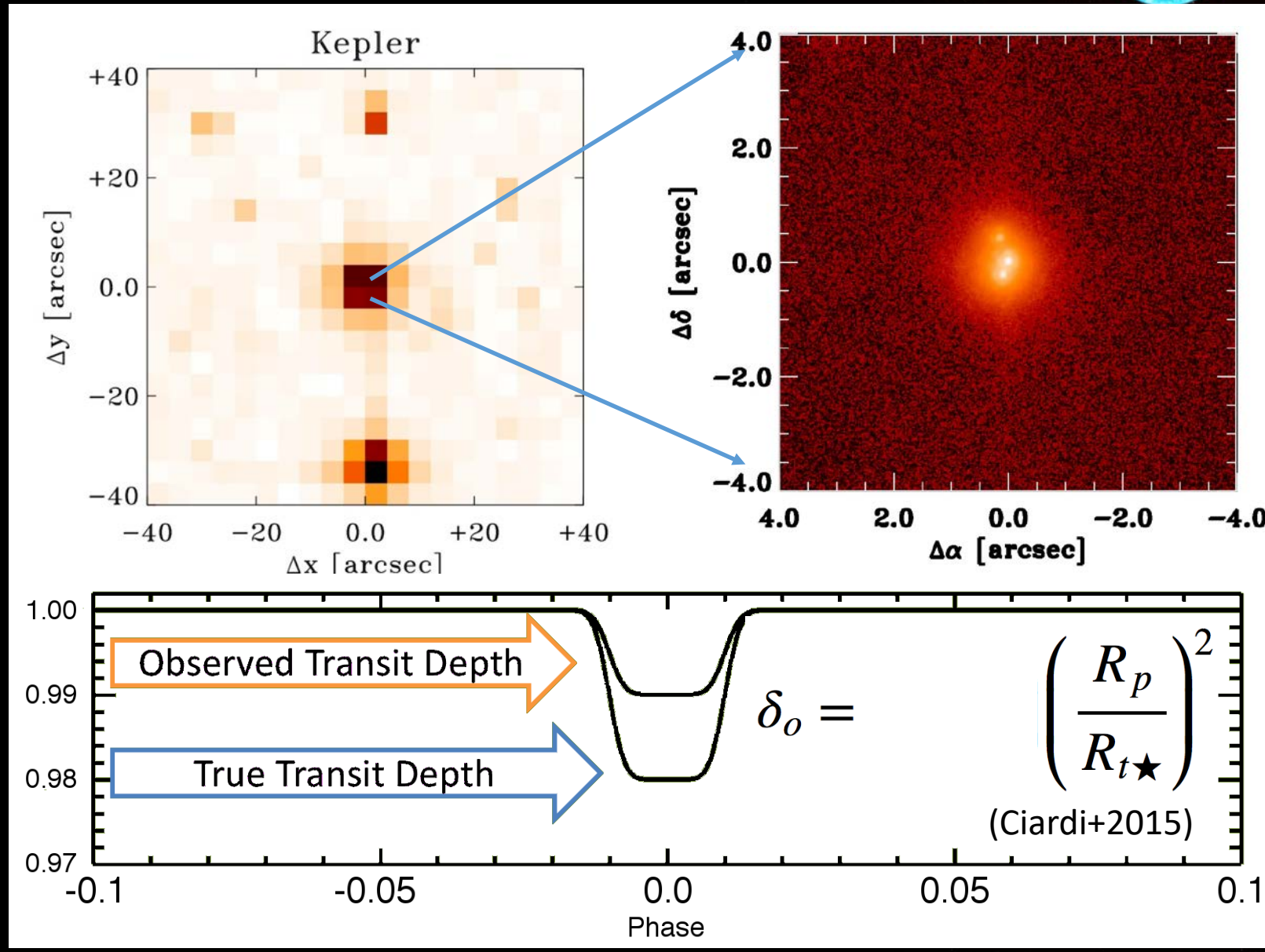
Calculated to 500 days = 1.31

Still to address: stellar multiplicity

Only 56% of nearby (<25pc) solar-type stars are single (Raghavan+2010)

The Kepler Input Catalog (KIC; Brown+2011) assumed that unresolved flux sources (typically 1-2” resolution) were single stars

The Kepler stellar properties catalog (Mathur+2017) for DR25 **still uses KIC values for 73% of stars**



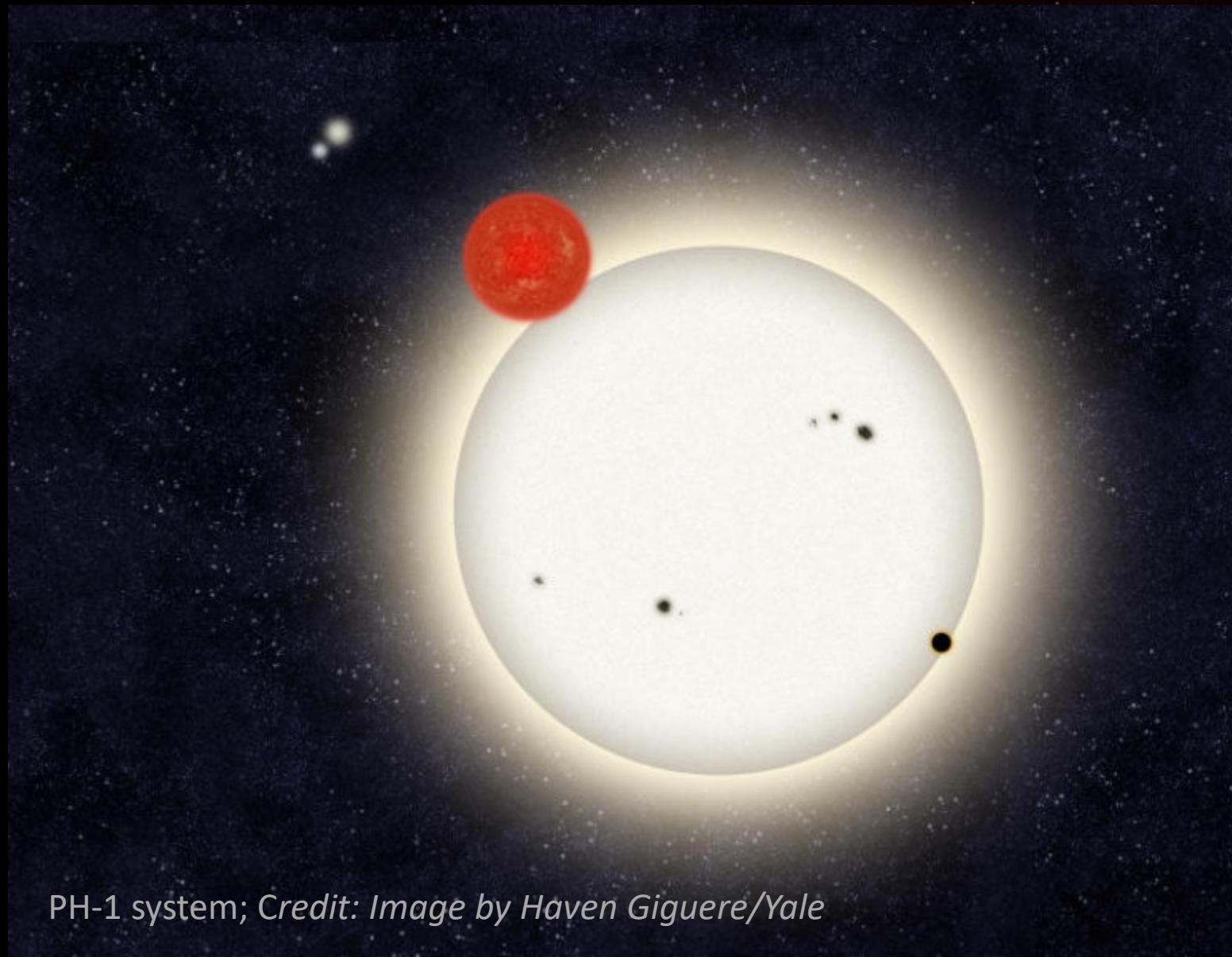
Still to address: stellar multiplicity

If we assume the Kepler target stars are singles…

... for the host stars, we derive incorrect planet parameters

… for the non-host stars, we infer incorrect detectability

We are completing a survey of the 200 stars with the Palomar/PHARO instrument and the Lick/Shane AO system



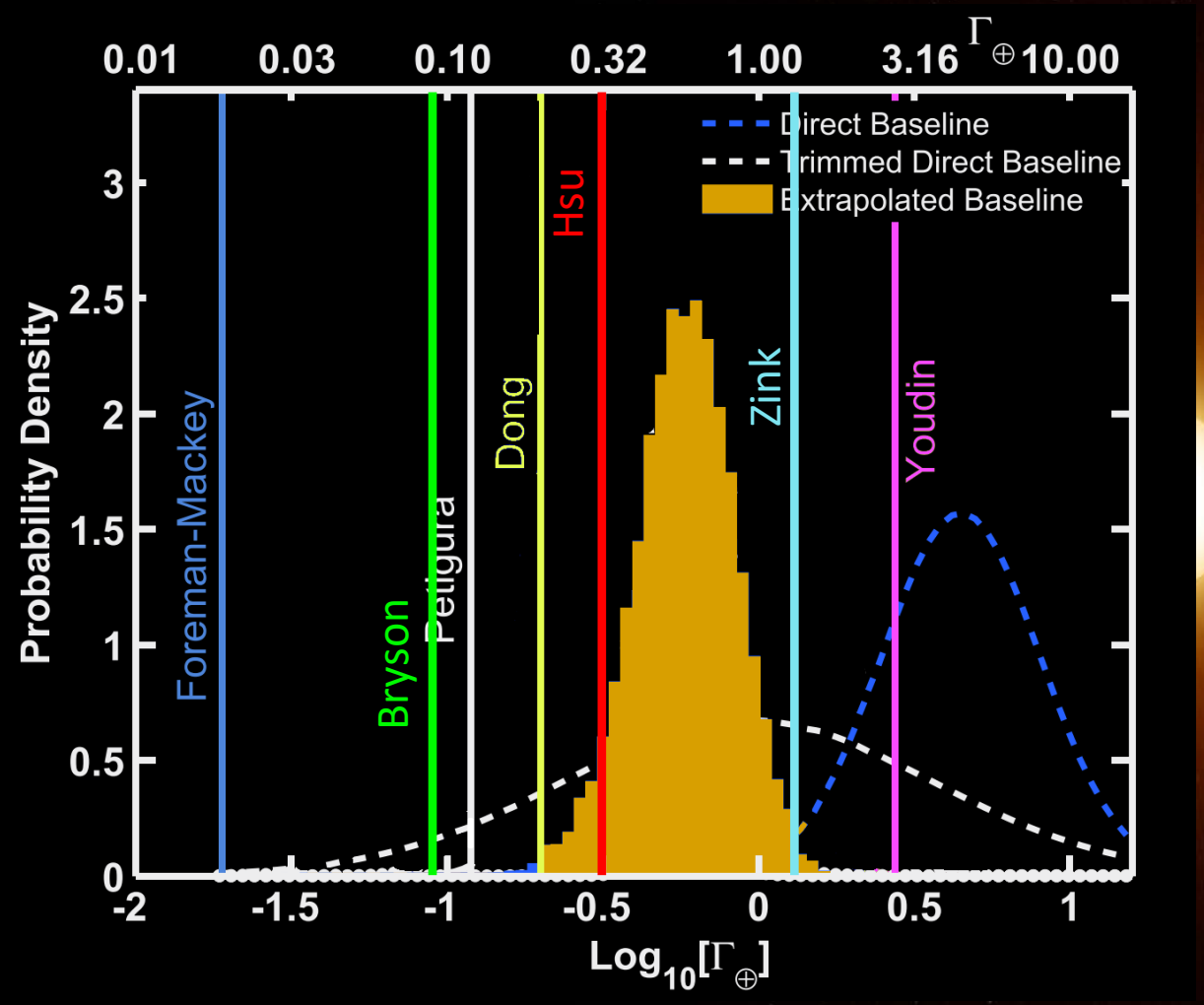
PH-1 system; *Credit: Image by Haven Giguere/Yale*

Still to address: dangers of extrapolation

Pascucci+2019: Many short period (<25d) Earth-sized planets will be stripped cores of larger planets

BUT we are using them to anchor our extrapolations to long periods

"$\Gamma_{\oplus}$ drops by a factor of 4—8" if you don't include the short period planets



Burke, Christiansen+2015

Moving forward…

With Kepler data…

- Incorporate new Gaia data, stellar+planet multiplicity corrections
- Improve treatment of reliability
- Potentially confirm a statistical sample of candidates (e.g. with HST)
- Improve population model to include two-component fit at short periods

New data sets…

- EarthFinder?
- WFIRST?
- PLATO will return to the Kepler FOV (precision goal of 34ppm in 1hr)?