Exoplanet occurrence rates for Alpha Centauri AB

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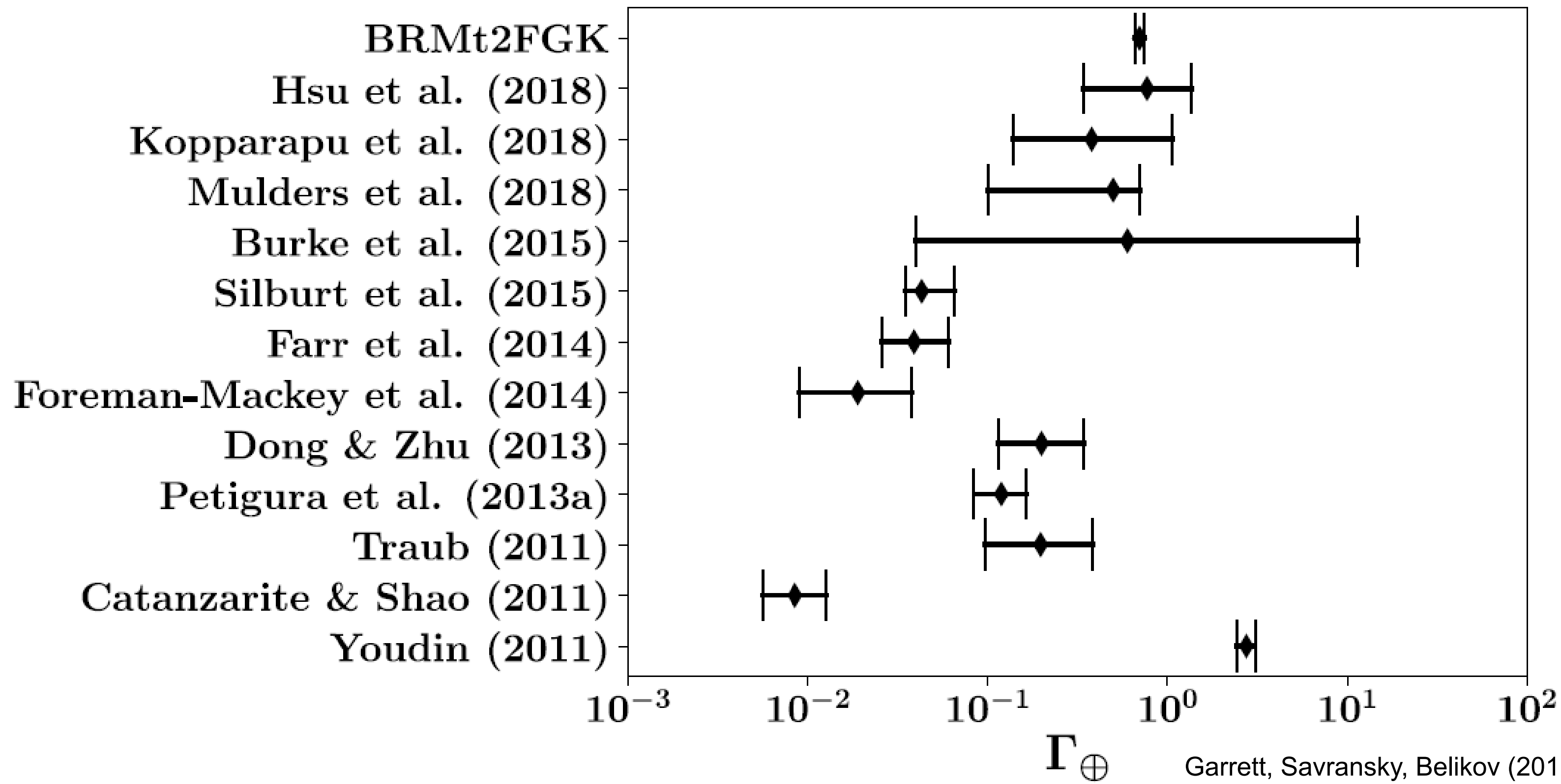
11/20/18

Exoplanet Occurrence Rates for single Sun-like Stars

Γ_{earth} (an alternative to η_{earth})
Literature agreement improving



Garrett, Savransky, Belikov (2018)
based on an original plot by Leslie Rogers

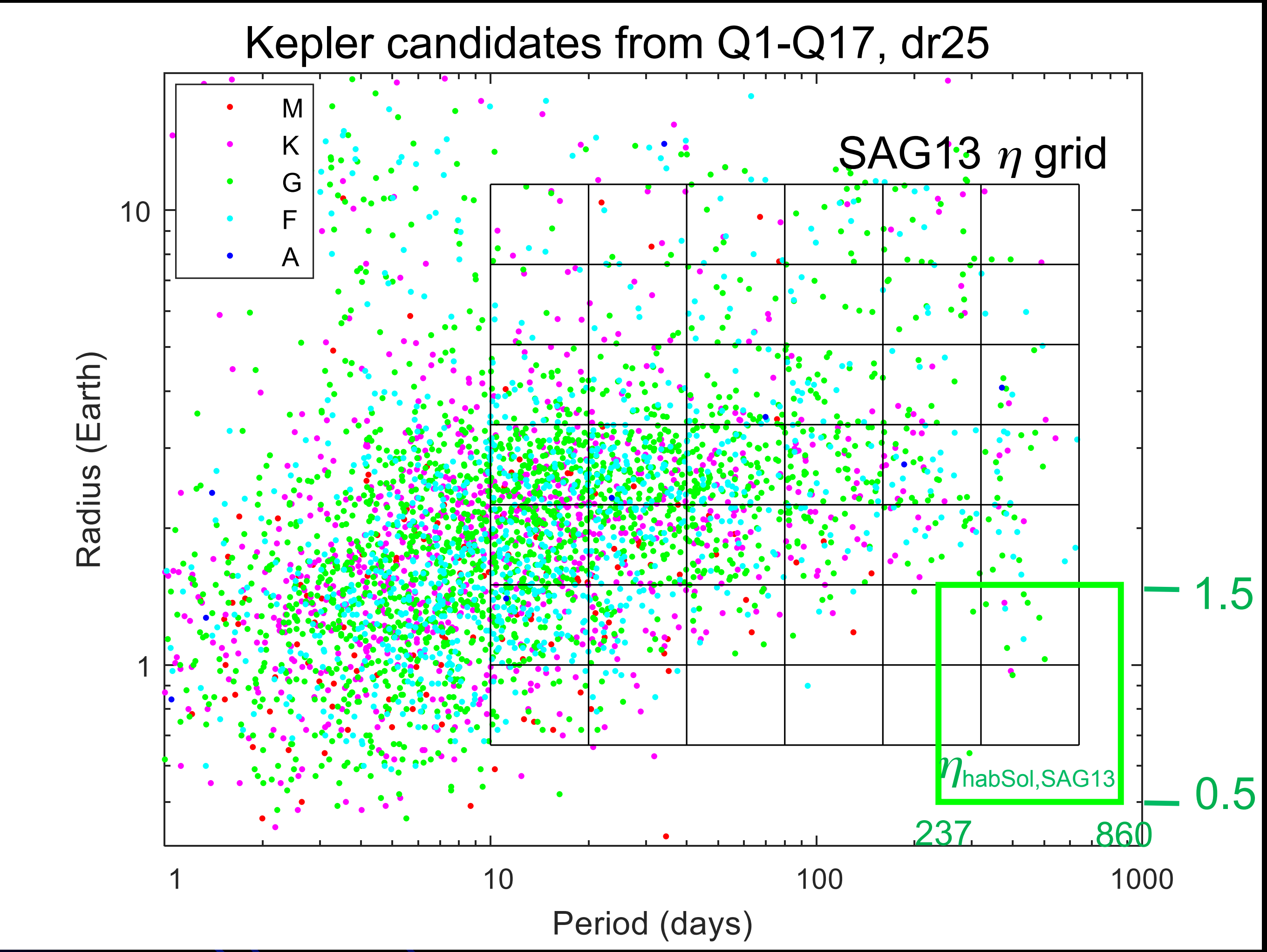
For most definitions of η_{Earth} ,
$\Gamma_{earth} \sim \eta_{Earth}$

$\Gamma_{earth} = \partial^2 N(R,P)/\partial \ln R \, \partial \ln P \,|_{R=1,\, P=1y}$

Γ_{earth} is independent of definitions of HZ or habitable size range

Burke et al. 2015: “We generally find higher planet occurrence rates and a steeper increase in planet occurrence rates towards small planets than previous studies of the Kepler GK dwarf sample”

Kepler candidates and SAG13 effort



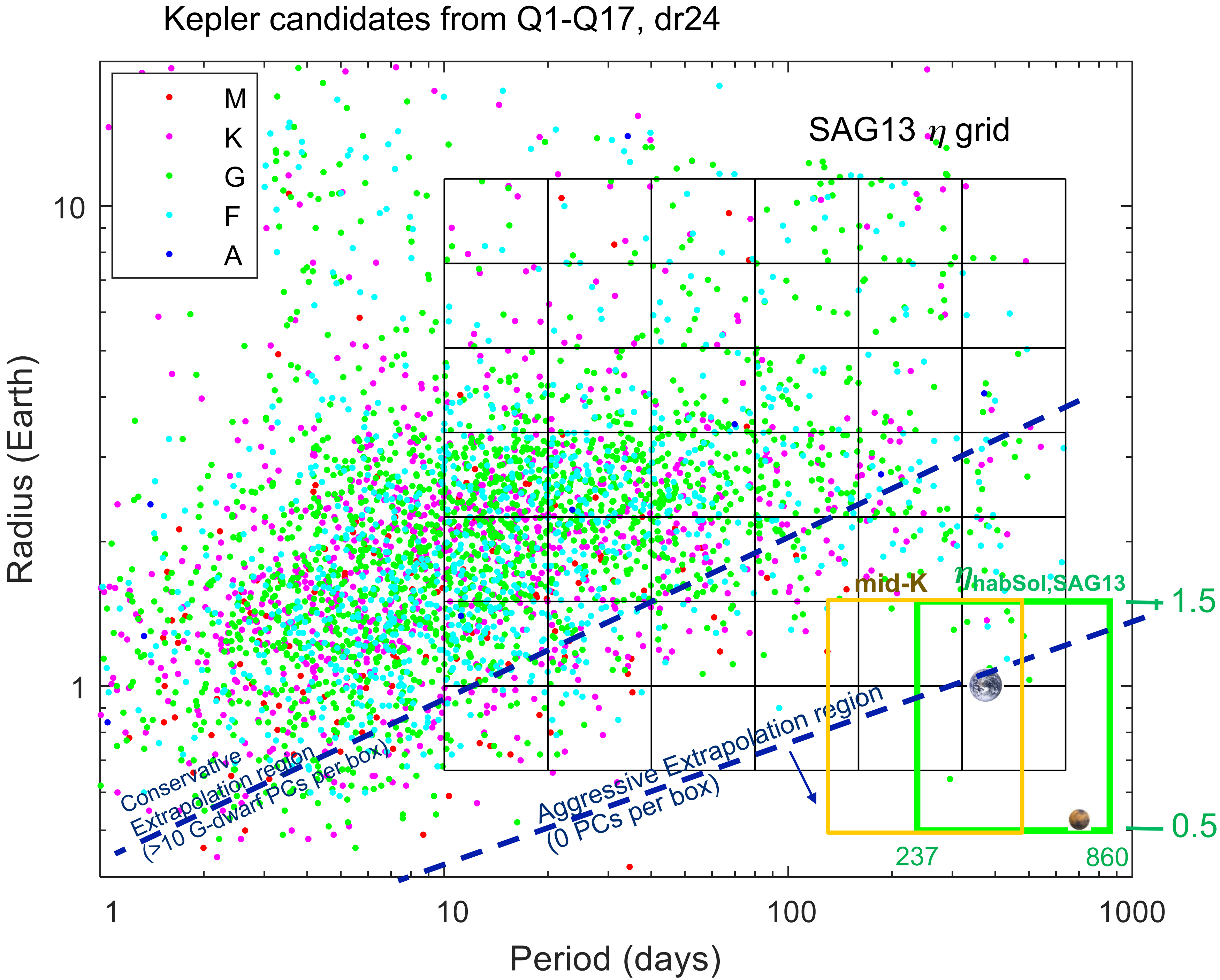
12+ community sourced occurrence tables

- Batalha, Natalie (2)
- Belikov, Rus
- Burke, Chris
- Catanzarite, Joe (2)
- Dressing, Courtney*
- Farr, Will
- Foreman-Mackey, Daniel*
- Fulton, BJ
- Kopparapu, Ravi
- Mulders, Gijs (2)
- Petigura, Erik*
- Traub, Wes*

*dataset was based on prior publications and re-integrated across SAG13 bins by Burke

All datasets and documents can be found on SAG13 repository: https://drive.google.com/drive/folders/0B520NCfkP4aOOW1SWDg2cHpYOVE

- $\eta_{\mathrm{habSol,SAG13}}$
  - R = [0.5 – 1.5], P = [237 860] (Kopparapu optimistic HZ for Sol twin)
  - This is not exactly η_{Earth} , just a rough representation



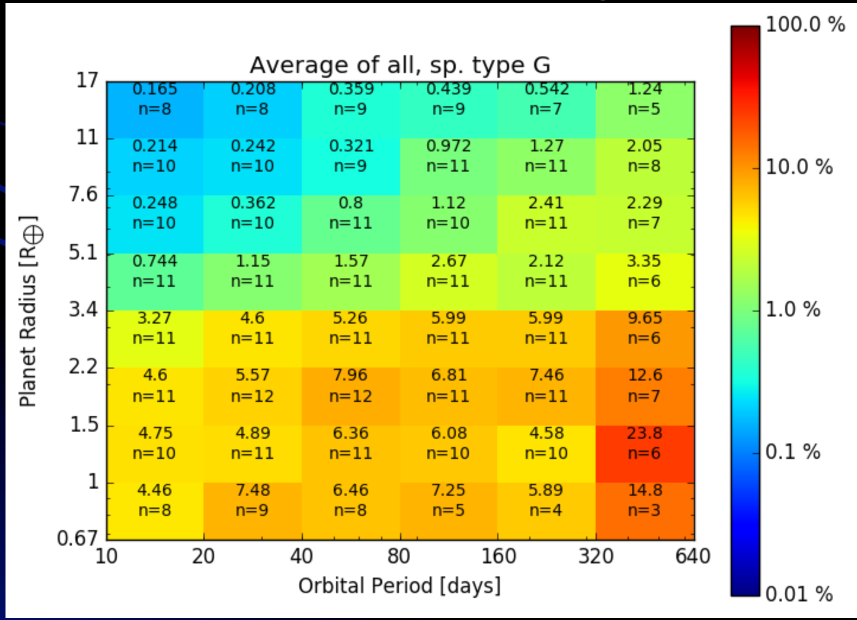
Kepler candidates from Q1-Q17, dr24
M
K
G
F
A
SAG13 η grid
Radius (Earth)
10
1
Period (days)
1
10
100
1000
mid-K
$\eta_{habSol,SAG13}$
1.5
0.5
237
860
Conservative
Extrapolation region
(>10 G-dwarf PCs per box)
Aggressive Extrapolation region
(0 PCs per box)

SAG13 parametric fit (for G-dwarfs)

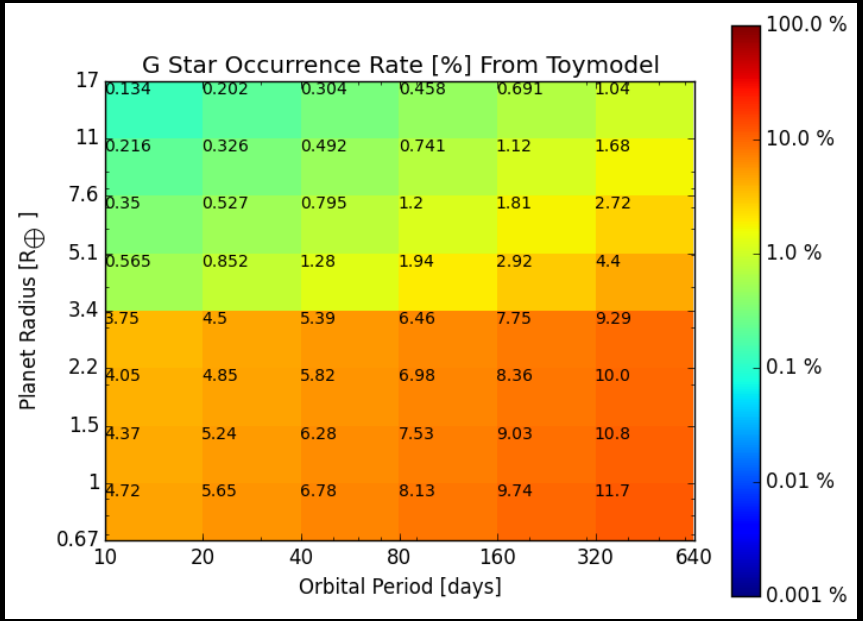
$$\frac{\partial^2 N(R,P)}{\partial \ln R \, \partial \ln P} = \Gamma_i R^{\alpha_i} P^{\beta_i}$$ in region $R_{i-1} \le R < R_i$

Γ_i	α_i	β_i	R_i
0.38	**-0.19**	**0.26**	**3.4**
0.73	-1.18	0.59	Inf

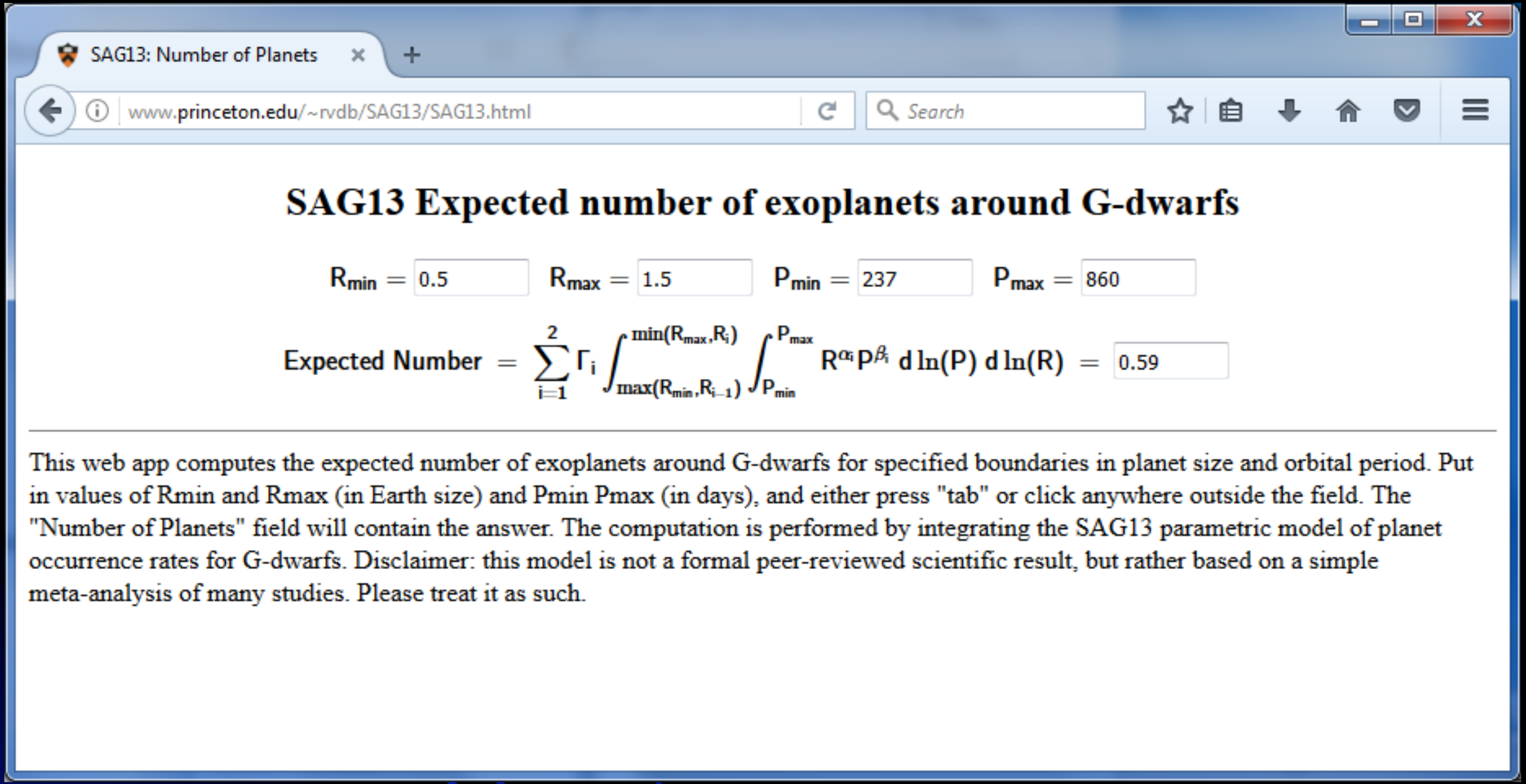
Submission average



Parametric fit (integrated across bins)



Online occurrence rate calculator


SAG13: Number of Planets

www.princeton.edu/~rvdb/SAG13/SAG13.html

SAG13 Expected number of exoplanets around G-dwarfs

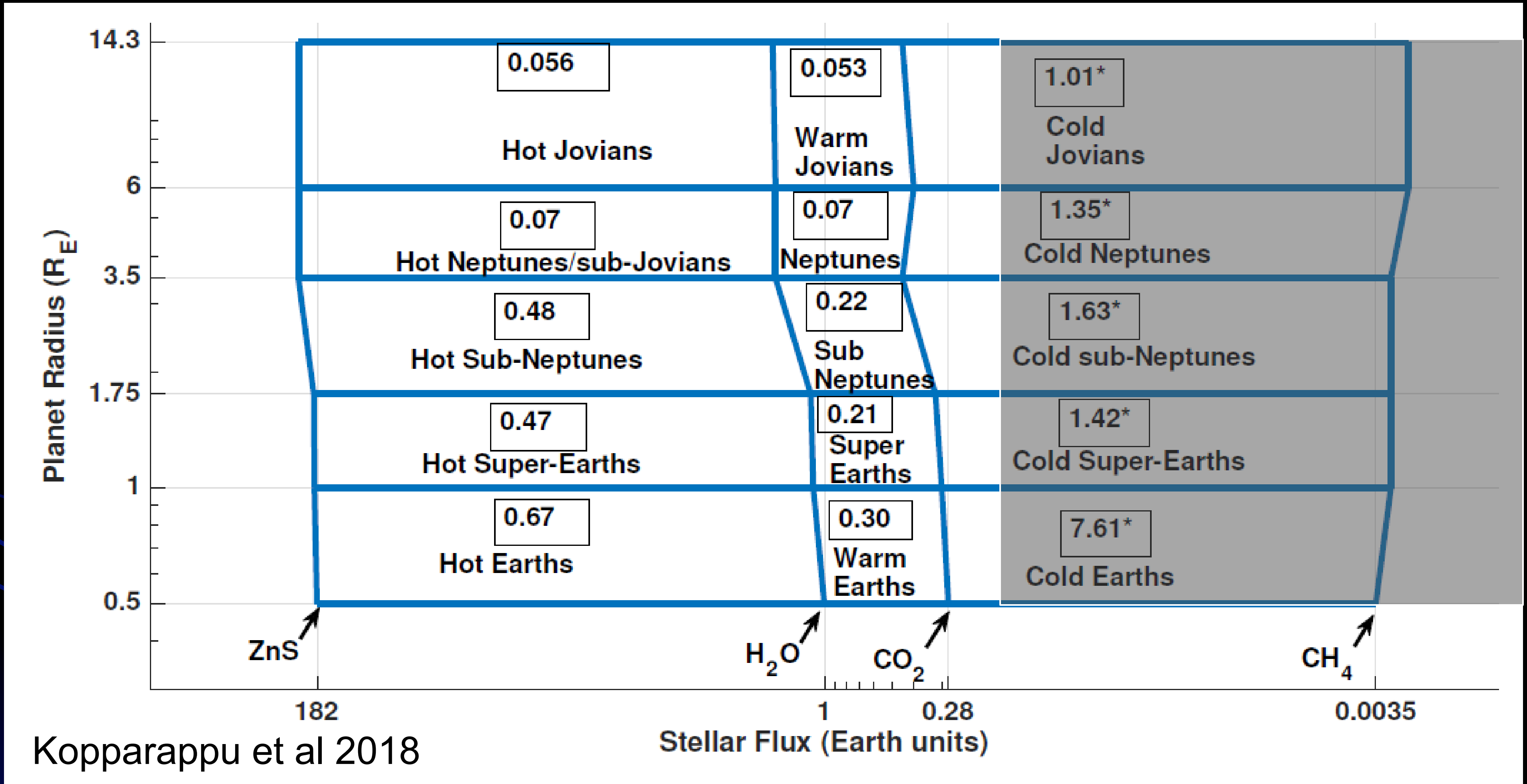
R_{min} = 0.5 R_{max} = 1.5 P_{min} = 237 P_{max} = 860

$$\text{Expected Number} = \sum_{i=1}^{2} \Gamma_i \int_{\max(R_{min},R_{i-1})}^{\min(R_{max},R_i)} \int_{P_{min}}^{P_{max}} R^{\alpha_i} P^{\beta_i} \, d\ln(P)\, d\ln(R) = 0.59$$

This web app computes the expected number of exoplanets around G-dwarfs for specified boundaries in planet size and orbital period. Put in values of Rmin and Rmax (in Earth size) and Pmin Pmax (in days), and either press "tab" or click anywhere outside the field. The "Number of Planets" field will contain the answer. The computation is performed by integrating the SAG13 parametric model of planet occurrence rates for G-dwarfs. Disclaimer: this model is not a formal peer-reviewed scientific result, but rather based on a simple meta-analysis of many studies. Please treat it as such.

- Online implementation (by Bob Vanderbei)
- Model currently used for LUVOIR and HabEx yield estimates
- Disclaimer: the SAG13 model used in this tool is NOT a formal peer-reviewed scientific result, but rather based on a simple meta-analysis of many studies. Please treat it as such.

Occurrence rates for different planet types



Total hot and warm planets ~3 per star
(similar to the Solar system!)

*Cold planet numbers are based on extrapolations and are likely overestimated
Most cold planets would be on unstable orbits around Alpha Centauri AB

Calculations of habitable occurrence rates (example for G-dwarfs)

Integrating SAG13 parametric fit
web app: http://www.princeton.edu/~rvdb/SAG13/SAG13.html

		Habitable Zone*	
		Conservative	Optimistic
Planet radius range	1.0-1.5	$\mathbf{0.14_{-0.04}^{+0.12}}$	$\mathbf{0.2_{-0.06}^{+0.18}}$
	0.5-1.5	$\mathbf{0.40_{-0.14}^{+0.48}}$	$\mathbf{0.58_{-0.2}^{+0.7}}$

Using Burke et al. 2015 posterior tool
https://github.com/christopherburke/KeplerPORTs

		Habitable Zone*	
		Conservative	Optimistic
Planet radius range	1.0-1.5	$\mathbf{0.21_{-0.08}^{+0.08}}$	$\mathbf{0.31_{-0.1}^{+0.1}}$
	0.5-1.5	$\mathbf{0.5_{-0.2}^{+0.4}}$	$\mathbf{0.73_{-0.3}^{+0.6}}$

(uncertainties correspond to 1-sigma equivalent deviations across submissions)

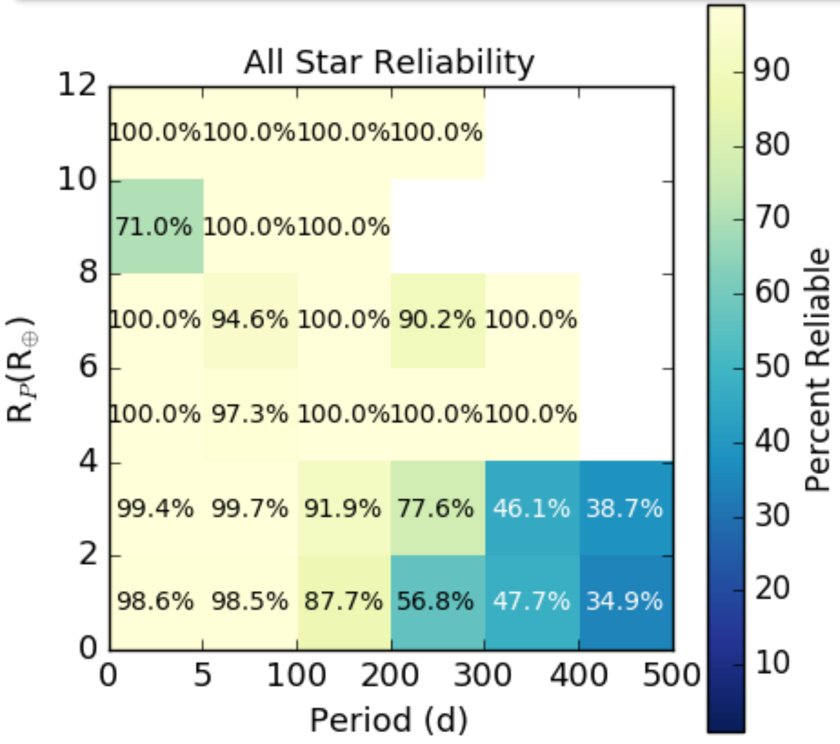
$\eta_{\mathrm{habSol,SAG13}}$

*Habitable zone definitions are from Kopparapu 2013 for Solar twin
Conservative: 338-792 days; Optimistic: 237-864 days

Source of uncertainty #1: Reliability

- For Rp < 4 Re, P > 100 days you must account for reliability
  - Some PCs are not real planets
- DR25 is the first catalog to measure reliability
  - *Inverted* and *Scrambled* data measure instrumental reliability
  - Offset and EB injections provide insight into which astrophysical false positives are undetectable
- FPP table measures astrophysical reliability
- Accounting for reliability in occurrence rate estimates is an open problem

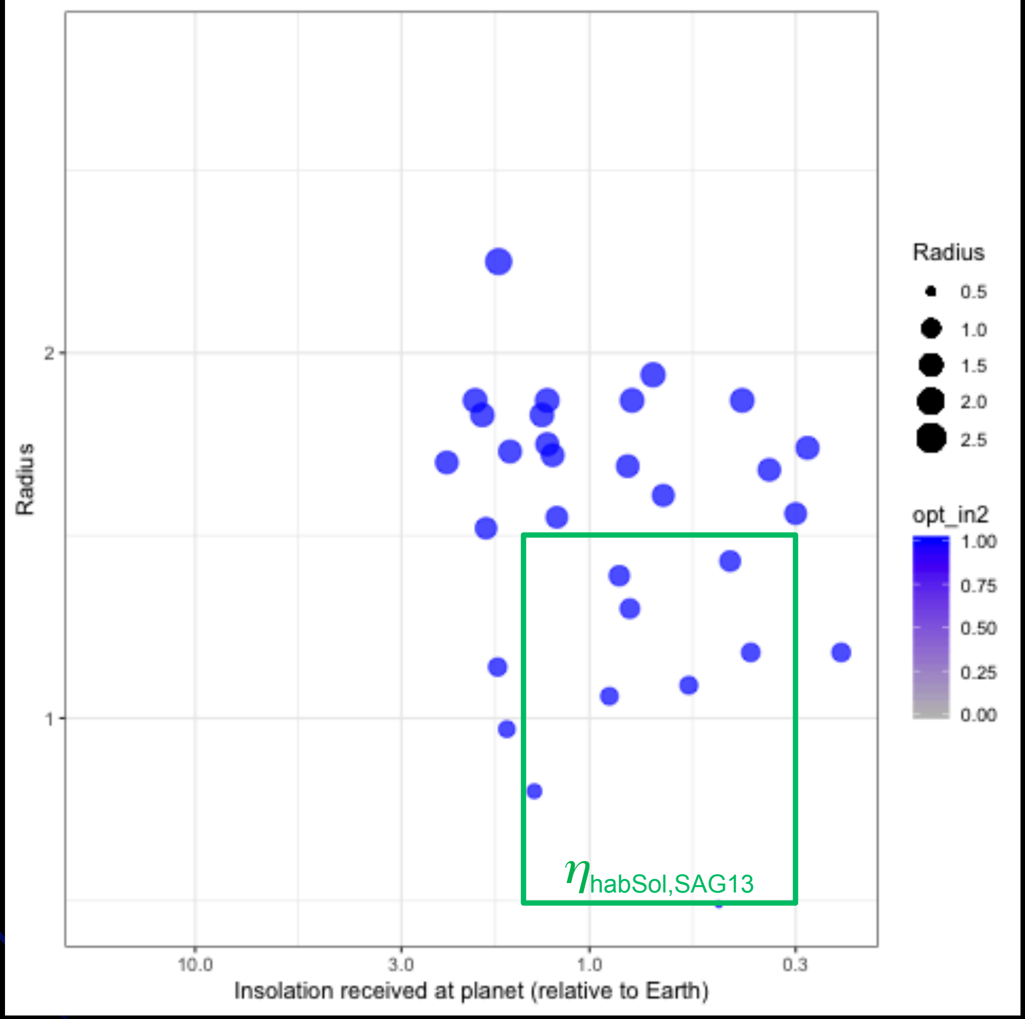
DR25 measured instrumental reliability



courtesy of Stephen Bryson

Source of uncertainty #2: errors in Stellar parameters

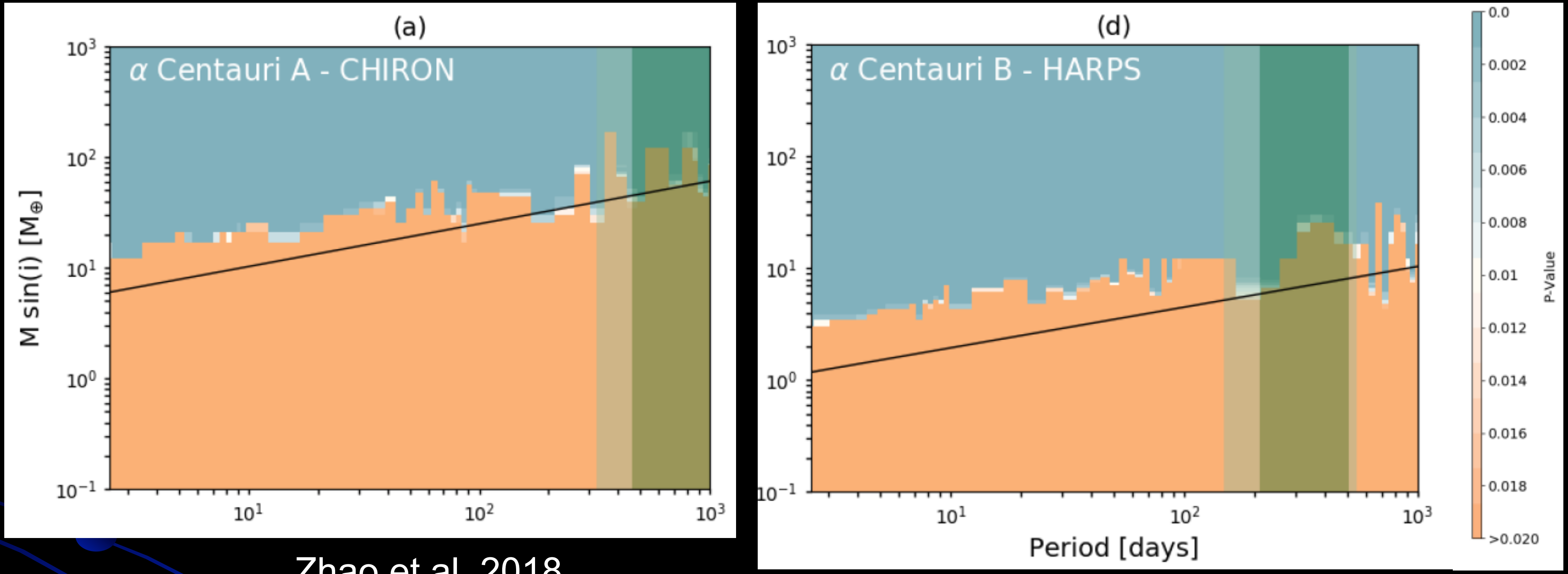
Gaia updates to stellar properties of Kepler stars causes changes to potentially habitable planet parameters



Animation by E. Mamajek, based on Gaia updates to Kepler Stellar parameters from Berger et al. 2018

What do we currently know about planets in the Alpha Centauri System?

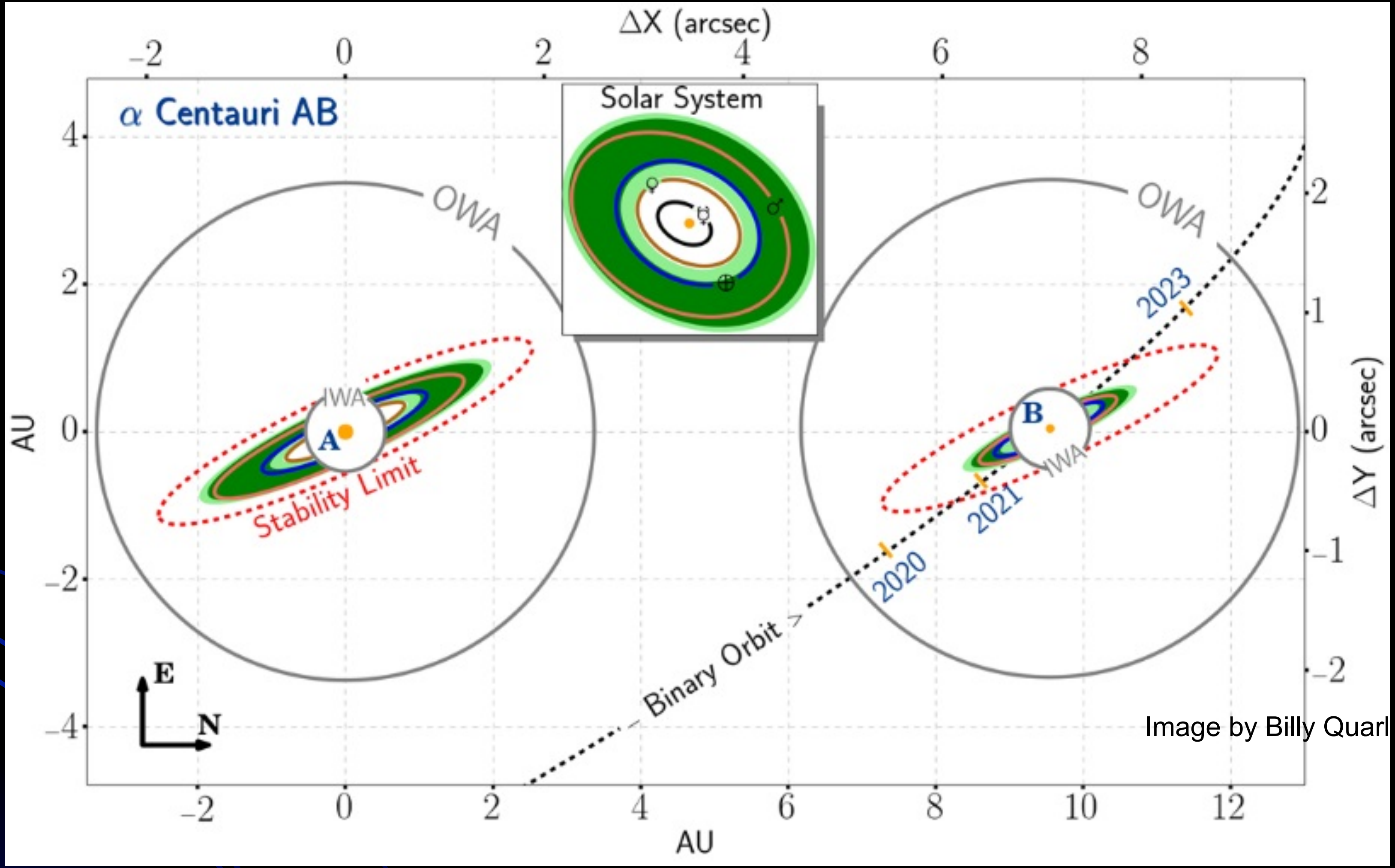
m sin(i) limits from RV non-detections



Zhao et al. 2018

- Limits for habitable zone (p-value = 0.01)
  - 53 M_Earth (0.17M_Jup) for aCen A
  - 8.4 M_Earth (0.026M_Jup) for aCen B
  - (For reference, Neptune mass: ~17 Earths)

Habitable Zones and Stable Orbits around αCen AB



see Quarles and Lissauer 2016 for aCen stability
https://arxiv.org/abs/1604.04917

- Both HZs are fully accessible with a 0.4” (0.5AU) inner working angle (IWA)
- Orbits are stable out to ~ 2.5 AU (Holman & Wiegert 1999, Quarles and Lissauer 2016)

Posterior distributions

(accounting for dynamical stability)

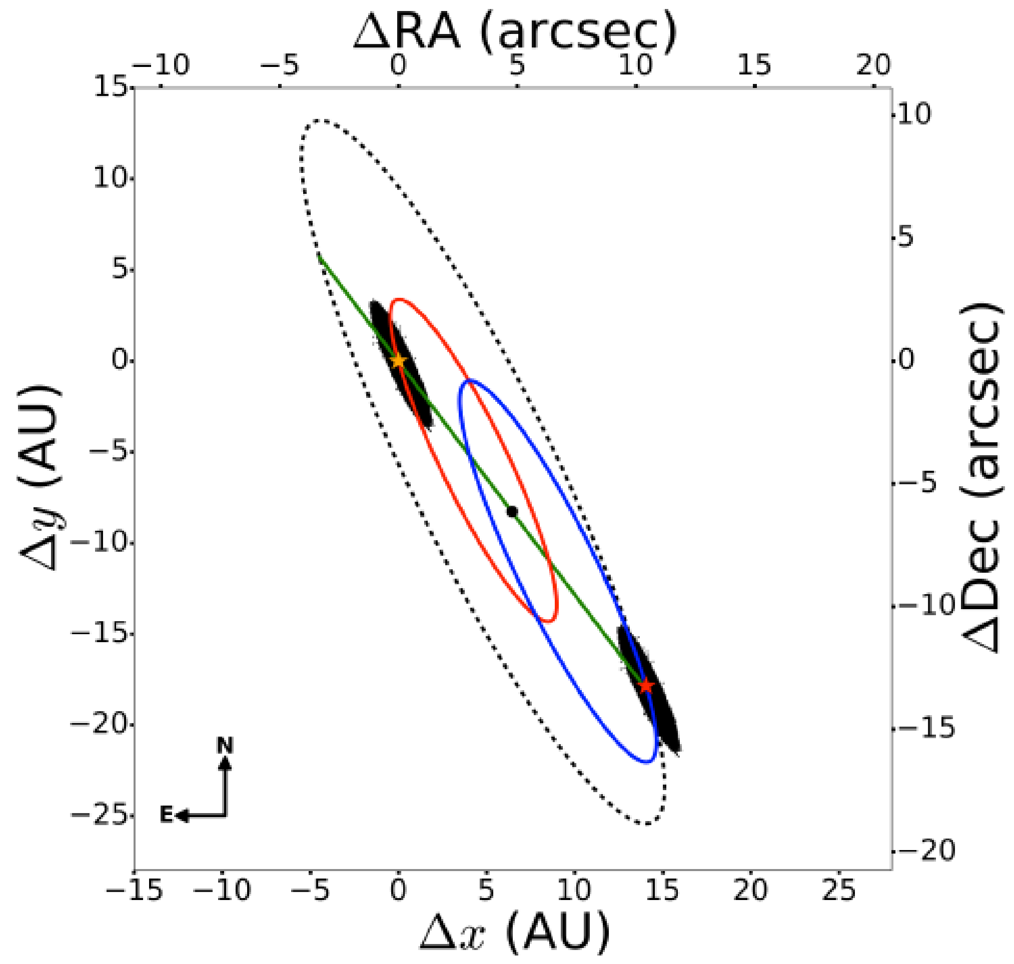
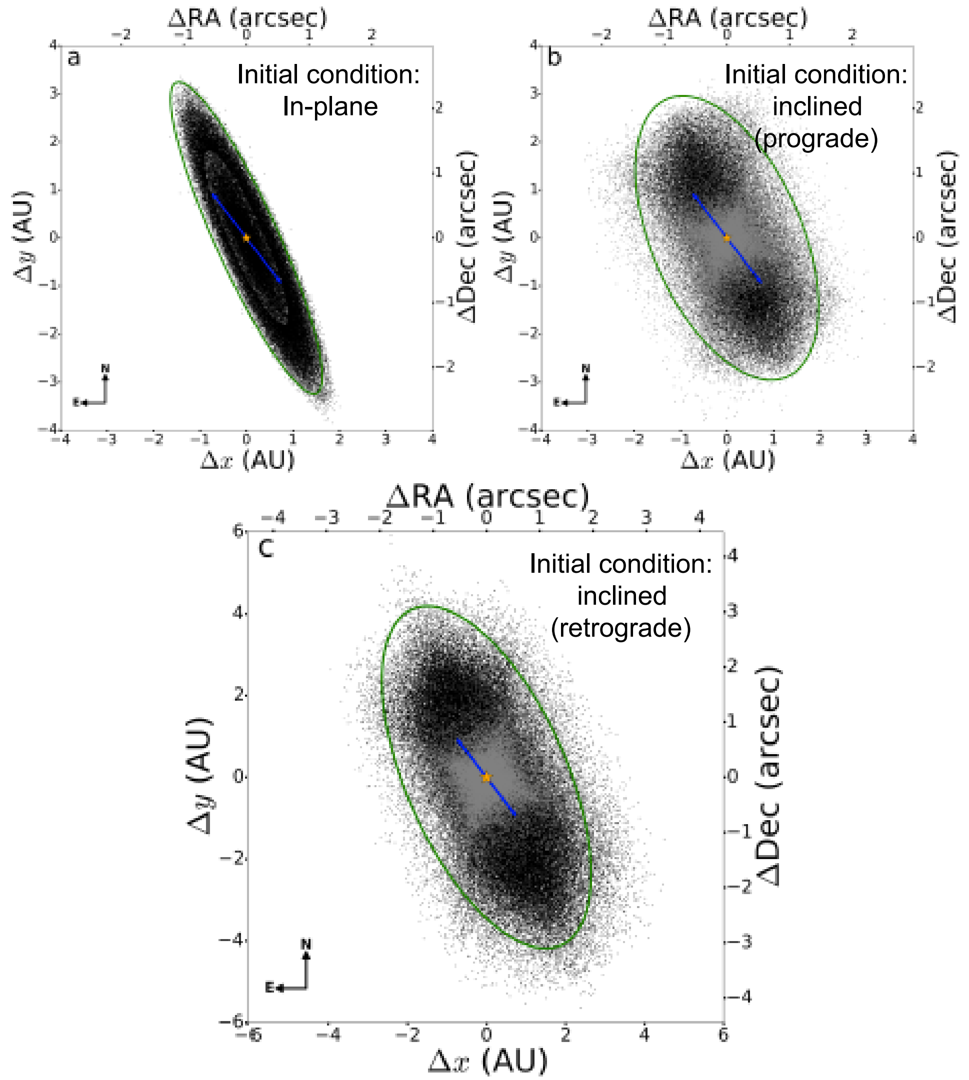
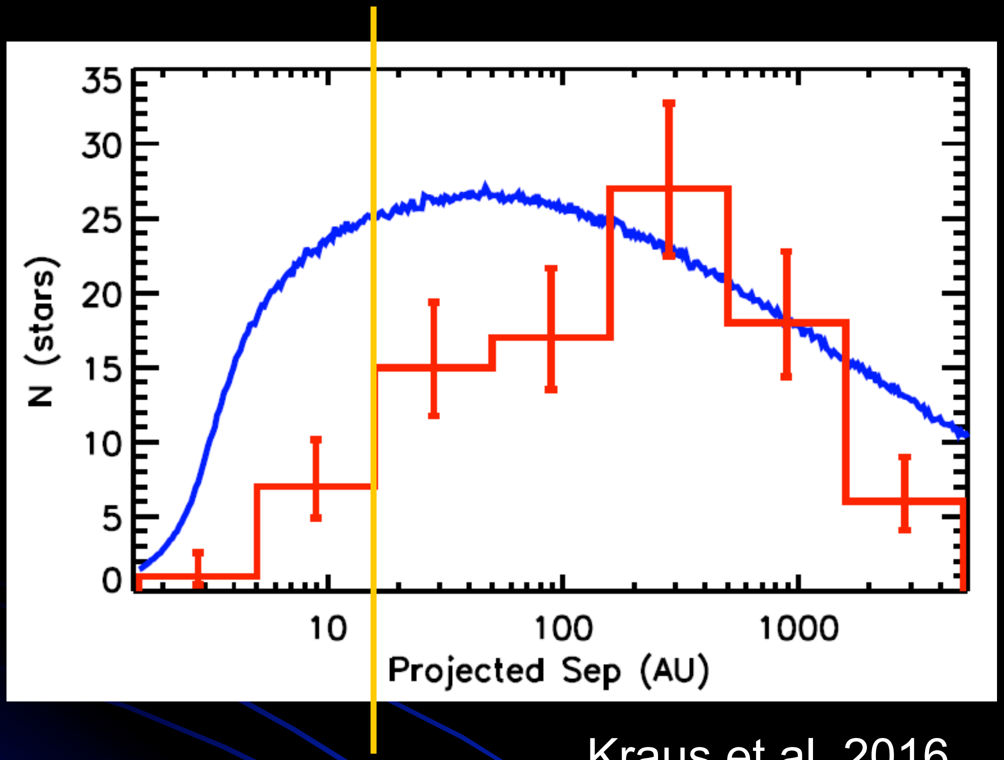


Figure 9. Projection of the stellar orbit of α Cen AB at apastron onto the sky. The astrocentric orbit α Cen B about α Cen A is shown by the dashed curve, with the stars shown at apastron. The center of mass (dot near the center of the image) is shown along with the barycentric ellipses for both α Cen A (red) and α Cen B (blue). Disks have been placed around each star to illustrate the areal coverage of stable test particles orbiting with the plane of the binary. The scale for potential observers in Right Ascension and Declination is given on the top and right axis, respectively.



Quarles and Lissauer, 2016

Does binarity affect planet rates?



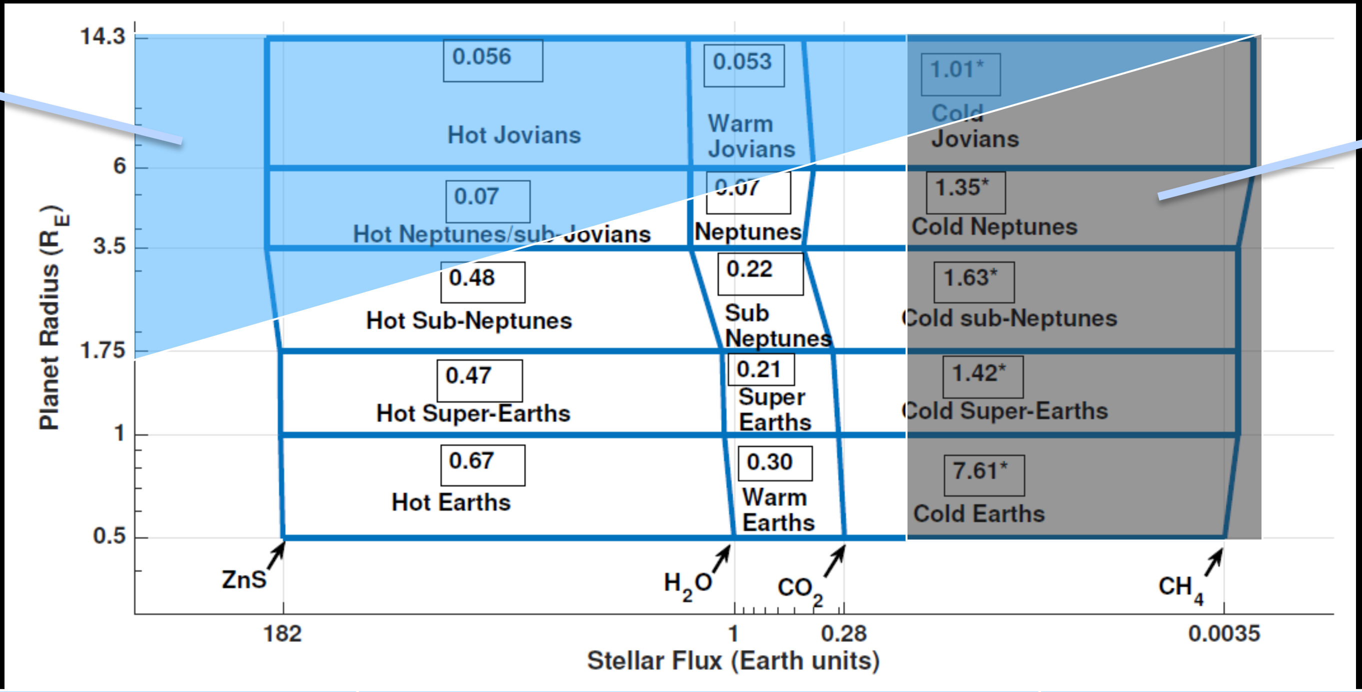
α Cen AB

Kraus et al. 2016

- Kepler space telescope has detected planets around binaries (with separations comparable to Alpha Centauri)
- Kraus et al. 2016 suggests planet formation around binaries with SMA < 47_{-23}^{+59} is suppressed by a factor of $0.34_{-0.15}^{+0.14}$
- However, Matson et al. 2018 “do not see evidence of companion suppression”

Putting everything together:
what occurrence rates can we expect around Alpha Centauri AB?

Ruled out by RV non-detections
(note: this region boundary is very uncertain due to mass-radius relationship ambiguity)



Ruled out by dynamical stability

	Total number of planets (per star)	Number of Potentially habitable (per star)
unmodified SAG13 model	**~ 3**	**~ 0.6**
+ reliability correction (qualitative guess)	small	not yet known, best guess is ~ 0.3-0.6
+ Gaia correction (qualitative guess)	small	not yet known, best guess is ~ 0.2-0.6
+ correction due to binarity suppression	~ 1-3	~ 0.07 – 0.6
+ other uncertainties (qualitative guess)	~ 1-5	~ 0.04 – 1.2

Note: as soon as any planet is found, the binarity suppression effect goes away, and the probability of additional planets goes up significantly