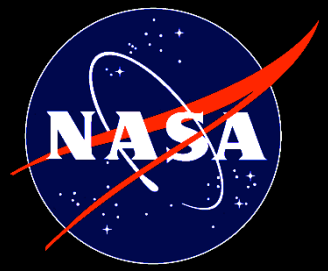



# ExoPAG SAG 13: Exoplanet Occurrence Rates and Distributions

Ruslan Belikov
NASA Ames Research Center

on behalf of SAG13

# SAG13 members

Belikov, Ruslan (Chair, rulsan.belikov@nasa.gov)
Stark, Christopher (Co-chair)
Batalha, Natalie (Steering Committee)
Burke, Chris (Steering Committee)
Angerhausen, Daniel
Apai, Daniel
Bendek, Eduardo
Bennett, David
Blackwood, Gary
Boss, Alan
Brown, Robert
Bryden, Geoff
Cahoy, Kerri
Catanzarite, Joe
Ciardi, David
Cowan, Nick
Danchi, William
Domagal-Goldman, Shawn
Dressing, Courtney
Foreman-Mackey, Daniel
Fressin, Francois
Gaudi, Scott
Ge, Jian
Gould, Andy
Hogg, David W
Howard, Andrew
Kasting, James
Kopparapu, Ravi
Macintosh, Bruce
Mandell, Avi
Mendez, Abel
Meyer, Michael
Morgan, Rhonda
Mulders, Gijs
Nielsen, Eric
Petigura, Erik
Ragozzine, Darin
Roberge, Aki
Savransky, Dmitry
Serabyn, Gene
Shao, Mike
Solmaz, Arif
Sparks, William
Stahl, Philip
Stapelfeldt, Karl
Still, Martin
Suzuki, Daisuke
Swain, Mark
Traub, Wes
Turnbull, Margaret
Unwin, Stephen
Vanderbei, Robert
Walkowicz, Lucianne

# Charter

Over 5000 exoplanets and exoplanet candidates have been discovered to date. Many studies have been published and are on-going to determine exoplanet occurrence rates and distributions, particularly for potentially habitable worlds. These studies employ different statistical and debiasing methods, different definitions of terms such as eta_Earth and habitable zone, different degrees of extrapolation, and present distributions in different units from each other. The primary goal of this SAG is to evaluate what we currently know about planet occurrence rates, and especially eta_Earth, by consolidating, comparing, and reconciling discrepancies between different studies. A secondary goal is to establish a standard set of occurrence rates accepted by as much of our community as possible to be used for mission yield estimates for missions to be considered by the decadal survey.

**Key objectives and questions:**

v.1 of standards document created →

1. Propose standard nominal conventions, definitions, and units for occurrence rates/ distributions to facilitate comparisons between different studies.

Current focus →

2. Do occurrence estimates from different teams/methods agree with each other to within statistical uncertainty? If not, why?

Future activity →

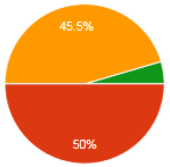
3. For occurrence rates where extrapolation is still necessary, what values should the community adopt as standard conventions for mission yield estimates?

# Status and delivered products

- July 21st: SAG approved by APS
- July – Oct: discussions and online poll helped converge to a consensus on standard eta bins
  - https://docs.google.com/forms/d/14dBTg7hHmqxvfwoNXfsTENQ4aflUtBxfw4WBt3WtR78/viewanalytics
- Oct: Draft “standard eta bins” document created
  - delivered to Kepler hack week, where selected etas were calculated by 9 participants, all within statistical uncertainty of one another
- Nov: Final v.1 “standard eta bin” approved by SAG13 members
  - http://exep.jpl.nasa.gov/exopag/
- Dec – Jan: Computation / crowdsourcing of SAG13 eta tables
  - 5 so far
  - Preliminary comparisons show consistency in some etas as well as disparity in others

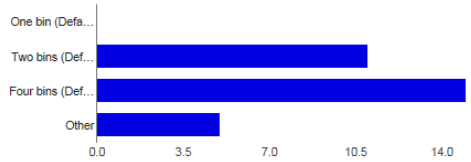
# Completed online poll

**Should we work in linear space or log space of period and planet size?**



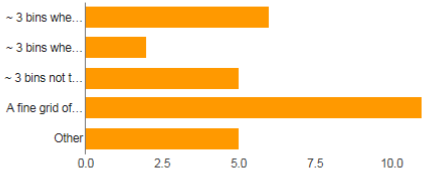

| | | |
|---|---|---|
| Linear | 0 | 0% |
| Log | 11 | 50% |
| linear R, log P | 10 | 45.5% |
| log R, linear P | 1 | 4.5% |
| Other | 0 | 0% |

**When comparing planet occurrence rates, how would we like to see focus group members treat stellar type?**



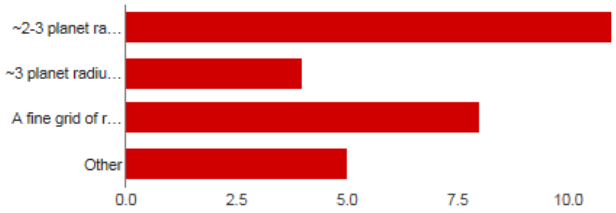

| | | |
|---|---|---|
| One bin (Default: (F)GKM stars as a single group) | 0 | 0% |
| Two bins (Default: (F)GK and M) | 11 | 45.8% |
| Four bins (Default: (F), G, K, and M) | 15 | 62.5% |
| Other | 5 | 20.8% |

**When comparing planet occurrence rates, how would we like to see focus group members treat period?**




| | | |
|---|---|---|
| ~ 3 bins where one of them is the Solar twin HZ (Default = 65-237; 237-864; 864-3150 days) | 6 | 25% |
| ~ 3 bins where one of them is a K5 star HZ (Default: 20-78; 78-305; 305-1196 days) | 2 | 8.3% |
| ~ 3 bins not tied to any HZ (Default = 10-40; 40-160; 160-700 days) | 5 | 20.8% |
| A fine grid of bins (Default = k*2^n days, where k = 12.5; n=1,2,3,...) | 11 | 45.8% |
| Other | 5 | 20.8% |

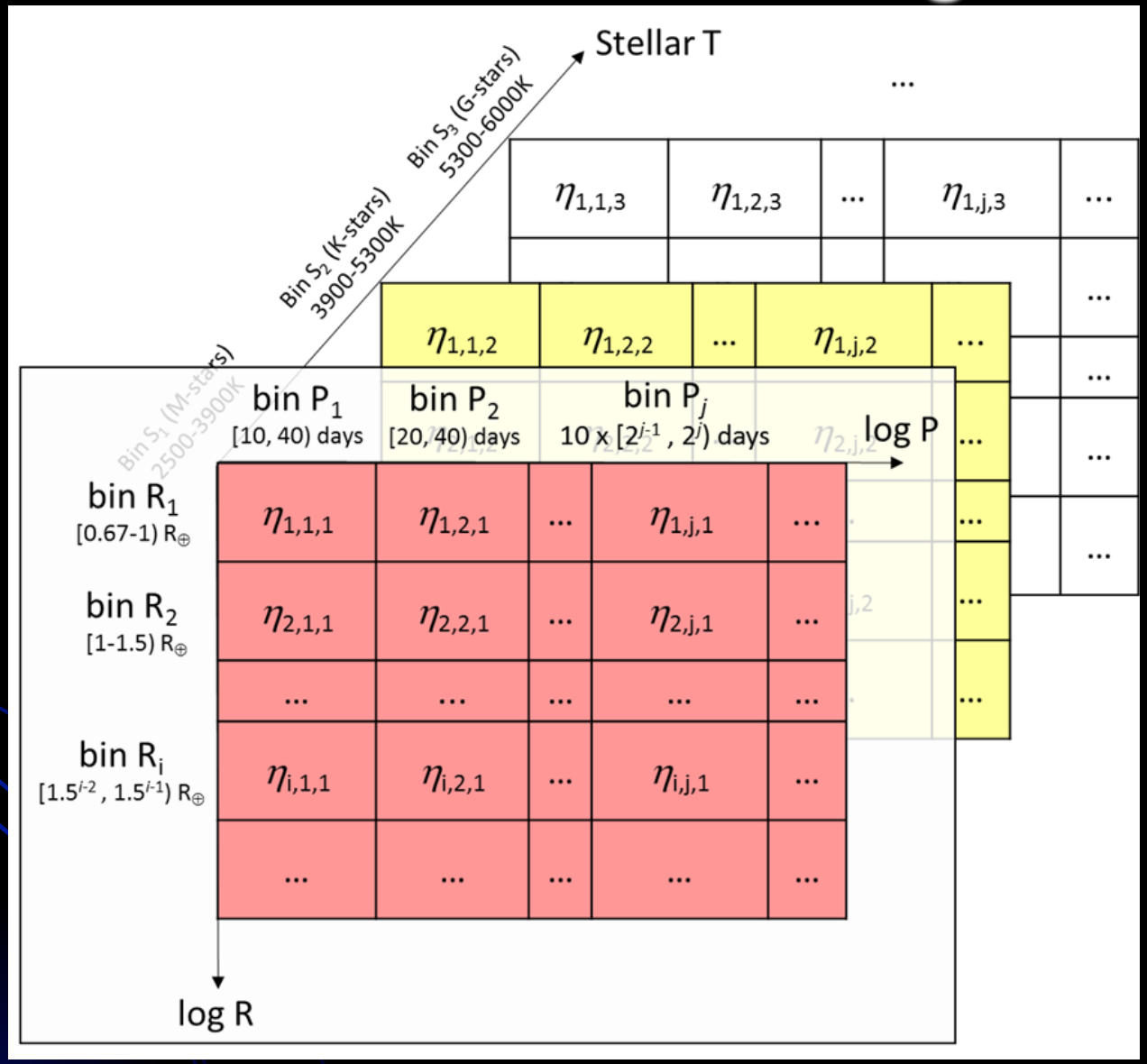
**When comparing planet occurrence rates, how would we like to see focus group members treat planet radius?**




| | | |
|---|---|---|
| ~2-3 planet radius bins where one of them is rocky (Default = 1-1.5 Earth radii, and > 1.5 Earth radii) | 11 | 47.8% |
| ~3 planet radius bins not tied to rocky planets (Default = 1-2; 2-4; 4-8) | 4 | 17.4% |
| A fine grid of radius bins (Default = 2^n Earth radii, where n=-1,0,1,2,...) | 8 | 34.8% |
| Other | 5 | 21.7% |

- 24 participants
- Exposed key challenges and concerns
  - Saved for posterity: https://docs.google.com/forms/d/14dBTg7hHmqxvfwoNXfsTENQ4afIUtBxfw4WBt3WtR78/viewanalytics
- Facilitated convergence to consensus on standard eta definitions

# Standardized eta grid




See SAG13 document "SAG13_Standard_eta_definitions.pdf" at
http://exep.jpl.nasa.gov/exopag/ (navigate to SAG13 section) for more detail and background

# Selected eta comparisons from Hack Week

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $\eta_{3,3,G}$ | 0.089 +/-0.018 | 0.100 +0.018 -0.021 | 0.089 +/-0.017 | 0.083 +0.021 -0.017 | 0.086 +/-0.017 | 0.088 +/-0.07 | 0.092 +/-0.018 | 0.091 +0.01 -0.009 |
| $\eta_{2,3,M}$ | 0.3 +/-0.11 | 0.26 +/-0.11 -0.08 | 0.23 +/-0.09 | 0.23 +0.1 -0.08 | 0.32 +/-0.1 | 0.26 +/-0.09 | 0.25 +/-0.1 | 0.185 +0.064 -0.052 |
| $\eta_{3,3,K}$ | | 0.12 +0.04 -0.03 | 0.1 +/-0.027 | | 0.077 +/-0.024 | 0.1 +/-0.027 | | 0.108 +0.004 -0.013 |
| $\eta_{2,3,K}$ | | 0.06 +0.02 -0.01 | 0.06 +/-0.014 | | 0.051 +/-0.013 | 0.06 +/-0.014 | | |

Cuts:

1. e_cycle > 0.33
2. T_span*e_cycle > 365.25*2
3. MES >= 15
4. Log(g) >=4
5. 1.5 <= Rp < 2.3 (SAG13 j=3)
6. 20 <= P < 40 (SAG13 i = 2); 40 < = P < 80 (SAG13 i = 3)
7. 2400 <= T < 3900; 3900 <= T < 5300; 5300 <=T < 6000 (SAG13 M, K, G)

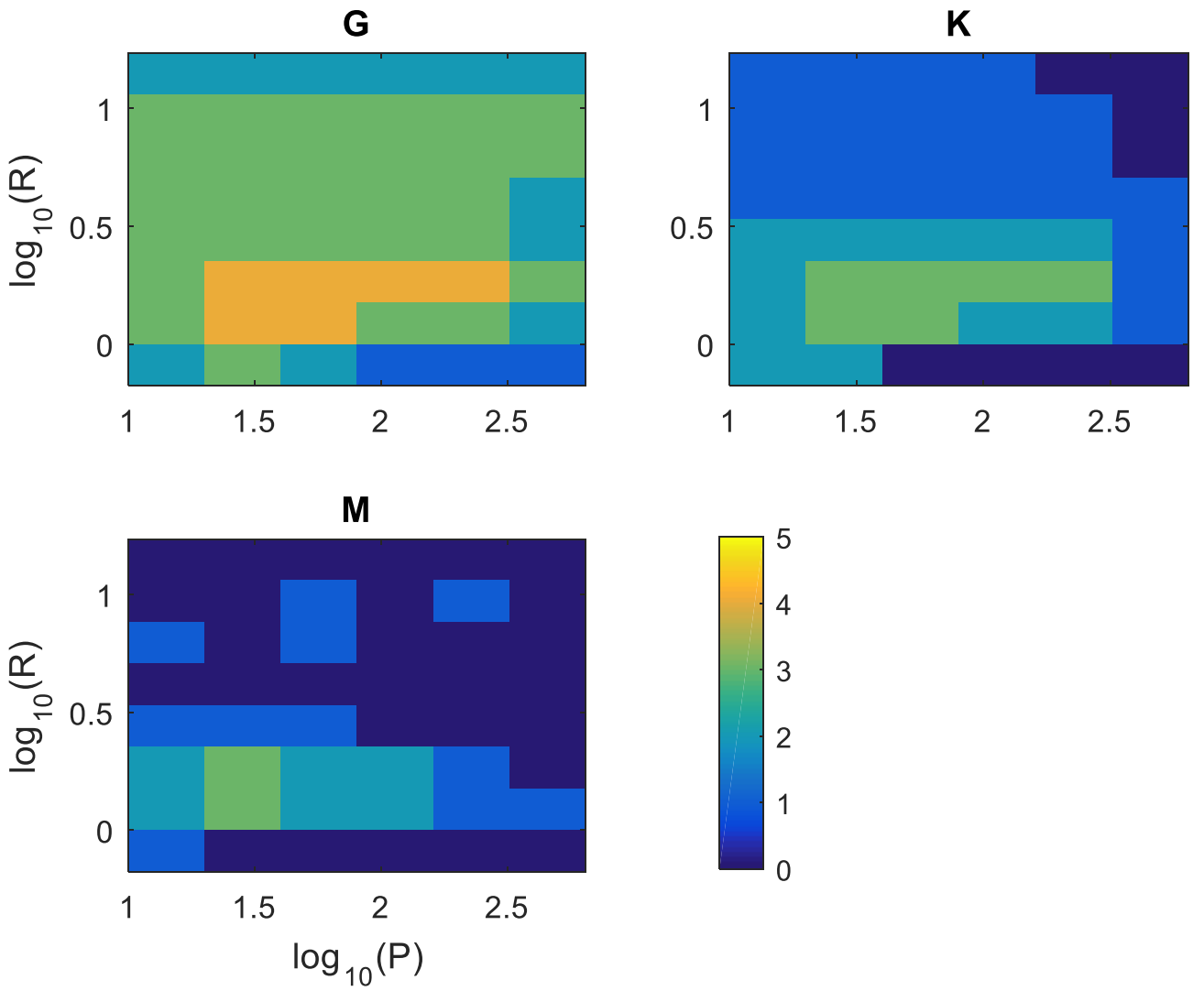
# Current activity: crowdsourcing eta values

- Focus group members
  (i.e. SAG13 members who agreed to perform computations)
- Batalha, Natalie
- Belikov, Rus *
- Burke, Chris
- Catanzarite, Joe *
- Farr, Will *
- Foreman-Mackey, Daniel
- Howard, Andrew
- Kopparapu, Ravi *
- Mulders, Gijs *
- Petigura, Erik
- Traub, Wes

* values submitted

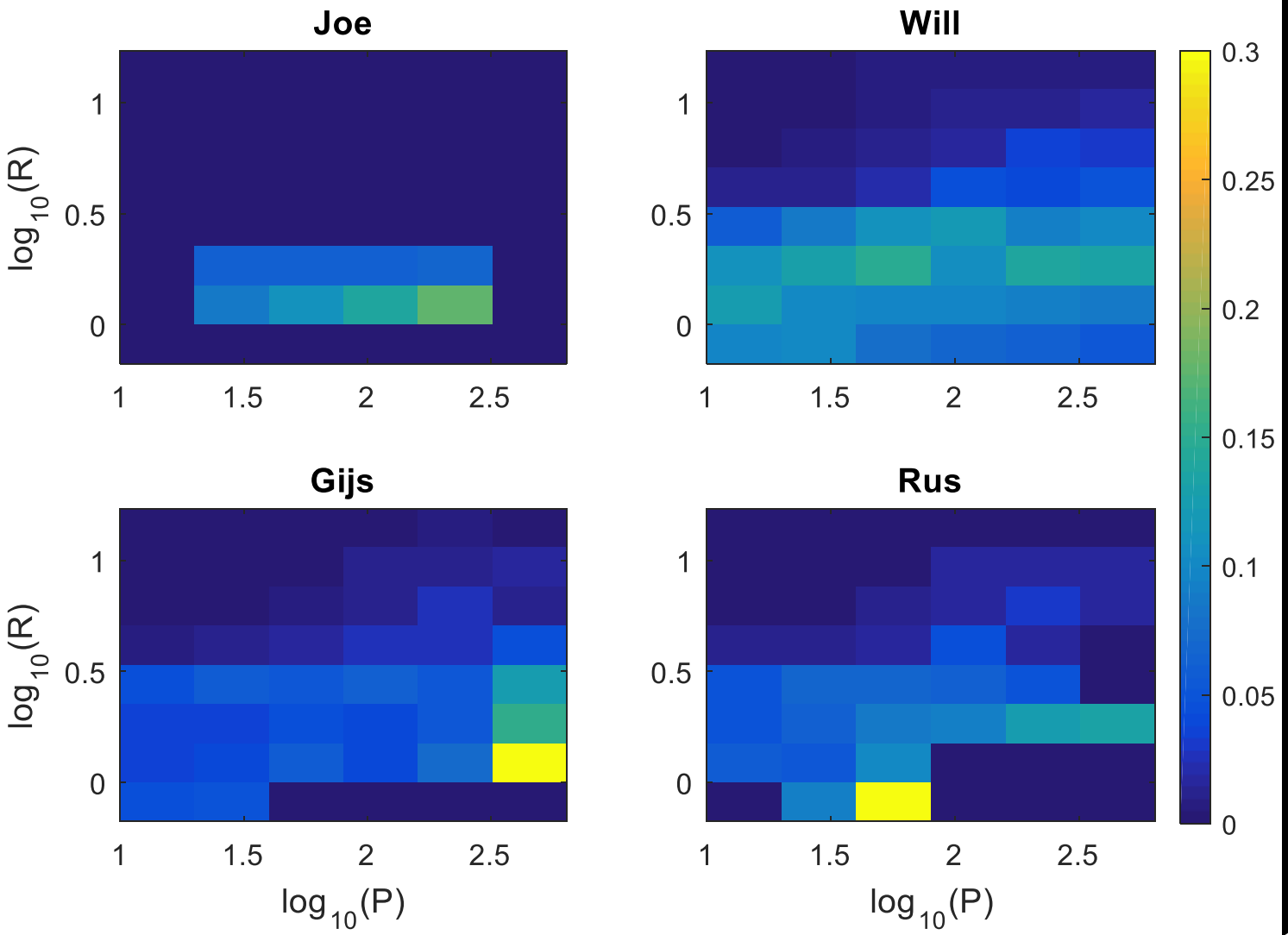
Please contact the SAG if you would like to participate!
(Ruslan.Belikov@nasa.gov)

# Number of submissions of *preliminary* eta values so far



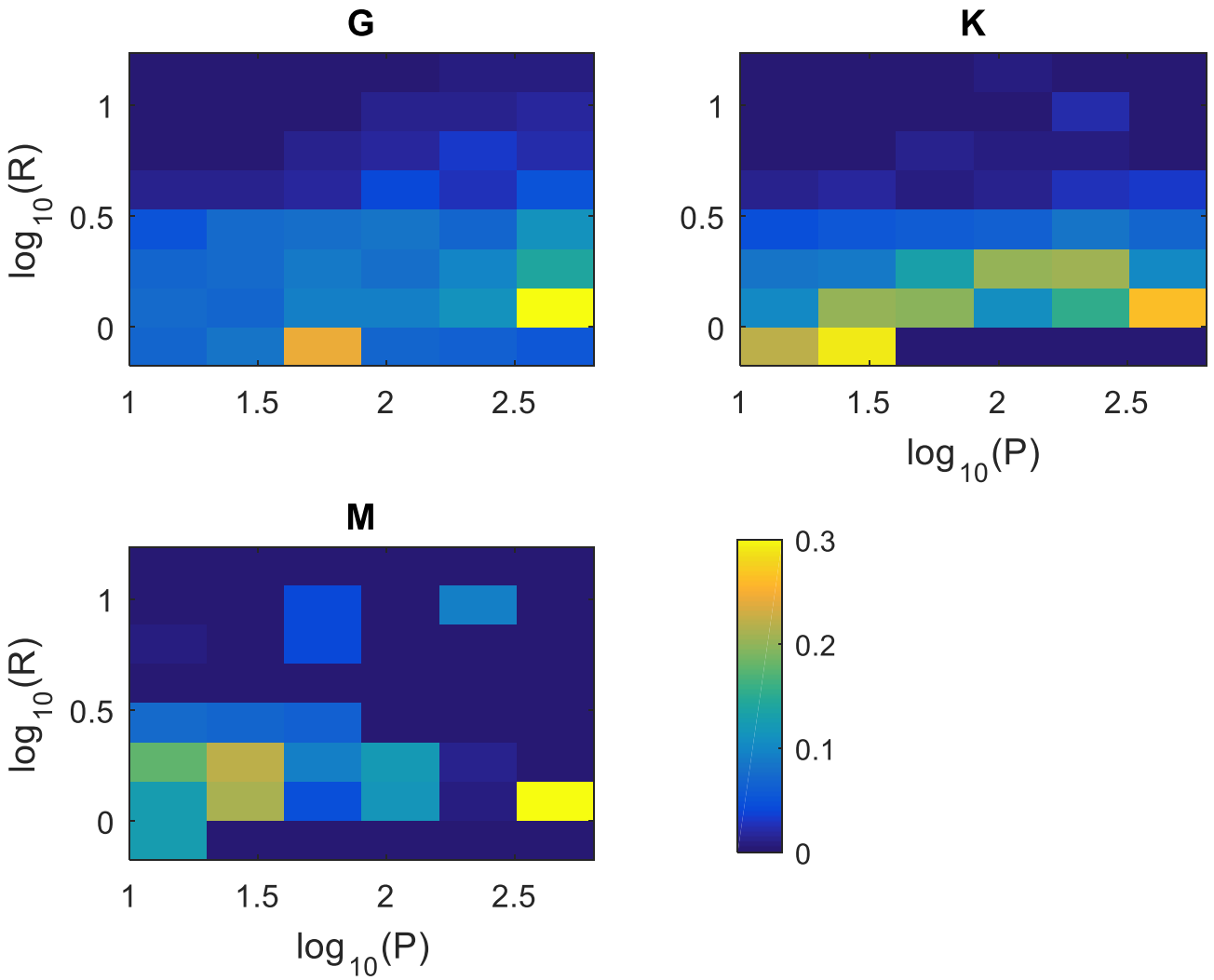

Data from:
Joe Catanzarite
Will Farr
Ravi Kopparapu
Gijs Mulders
Rus Belikov

# Example: eta value submissions for G-stars



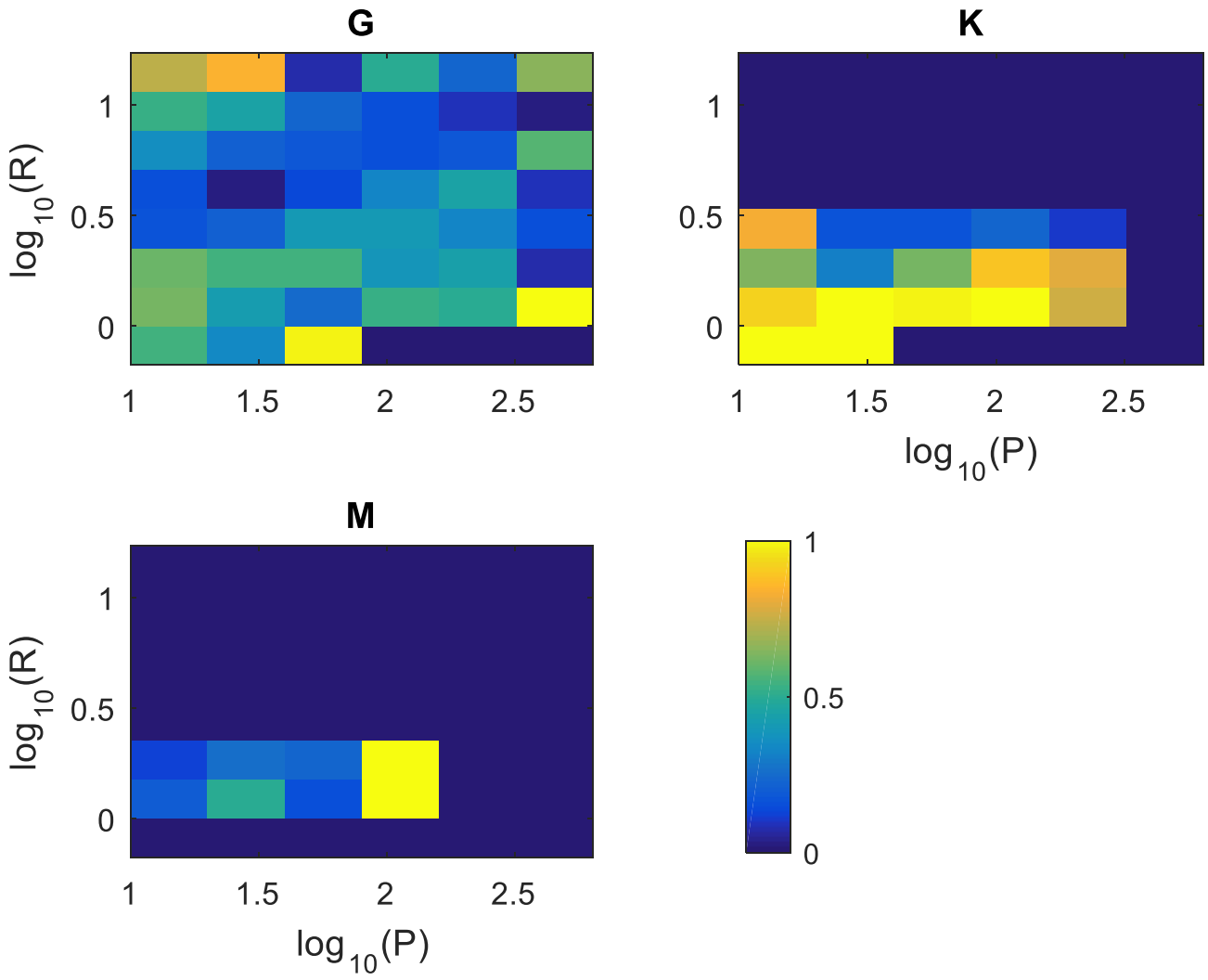

Data from:
Joe Catanzarite
Will Farr
Ravi Kopparapu
Gijs Mulders
Rus Belikov

# Means
## (ignoring NaN values)




Data from:
Joe Catanzarite
Will Farr
Ravi Kopparapu
Gijs Mulders
Rus Belikov

# Standard deviation / mean
## (ignoring NaN values)




Data from:
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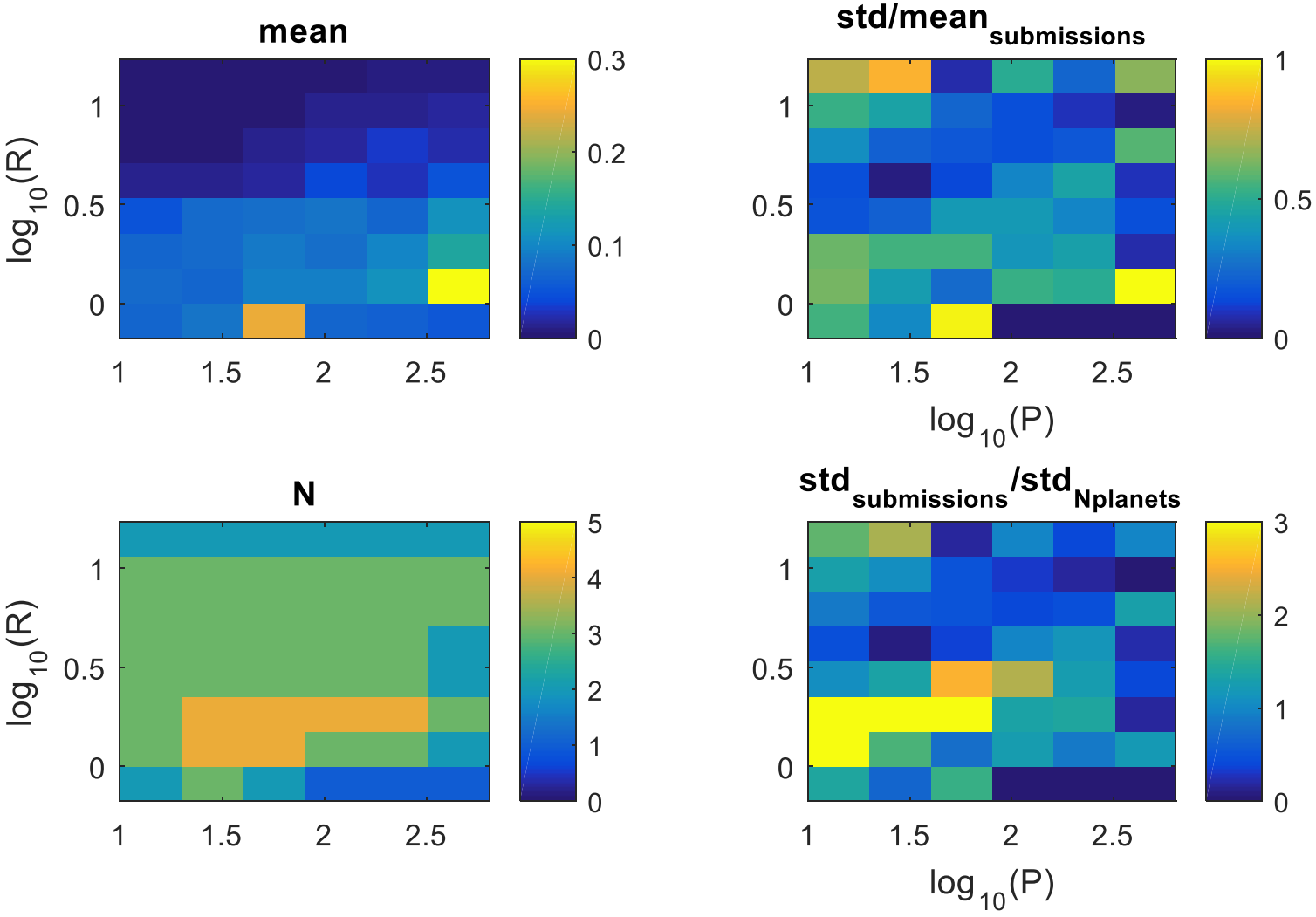
Will Farr
Ravi Kopparapu
Gijs Mulders
Rus Belikov

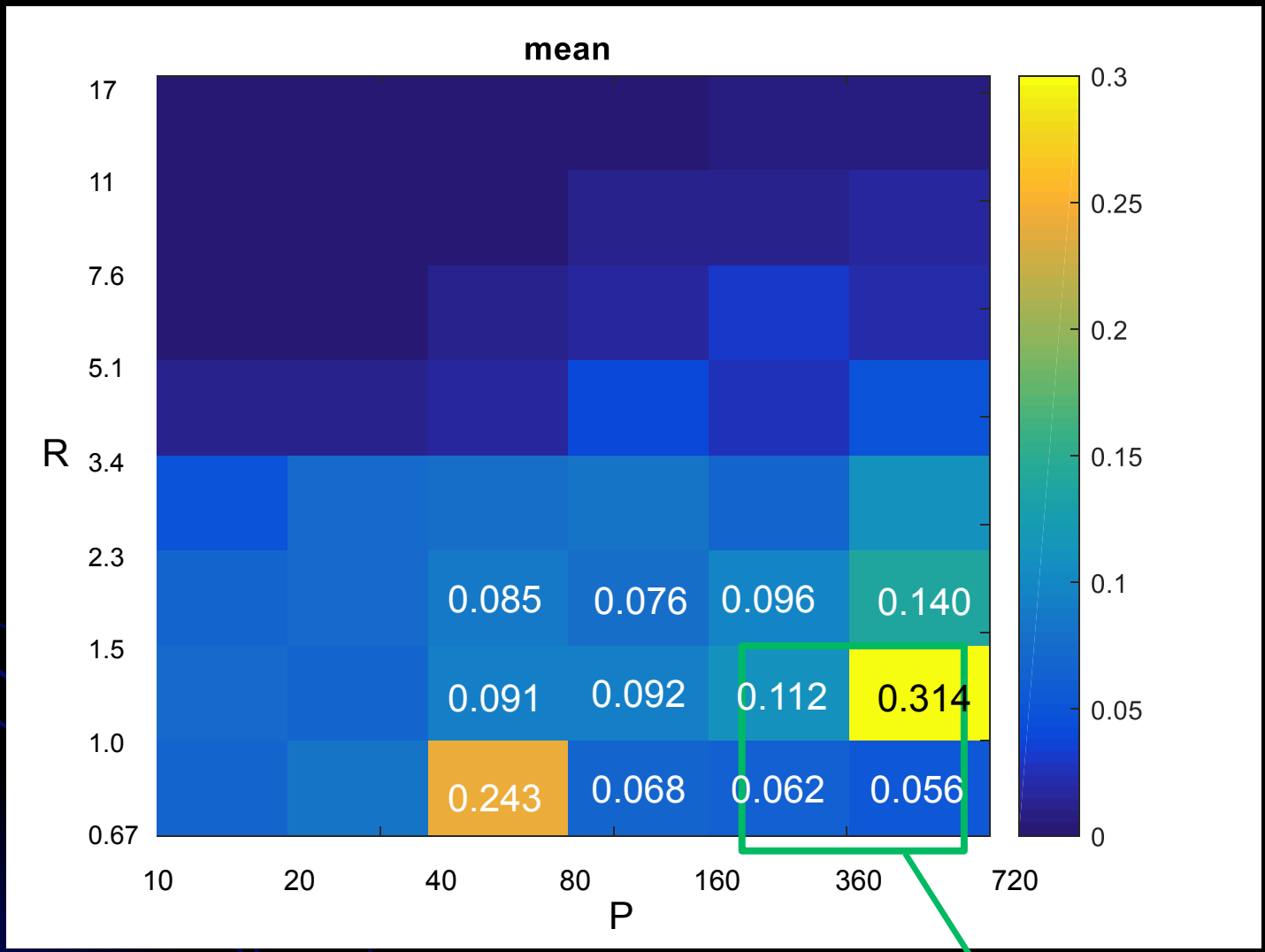
# Statistics for G stars






Data from: Joe Catanzarite; Will Farr; Ravi Kopparapu; Gijs Mulders; Rus Belikov

# Preliminary look at potentially habitable regime (G-dwarfs)




Caution: green box value is *very* preliminary, and with huge uncertainties

# Conclusions

- SAG13 converged on a consensus for “standard eta bins”
  - http://exep.jpl.nasa.gov/exopag/ (Navigate to SAG13 section)
  - In the process of crowdsourcing and analyzing values
- New members welcome (especially if you can compute occurrence rates)
  - Please email ruslan.belikov@nasa.gov
  - next meeting / telecon is this Thursday at 4pm