Synthesizing Results from Multiple Exoplanet Detection Techniques

{ The Demographics of Planets Orbiting M Dwarfs

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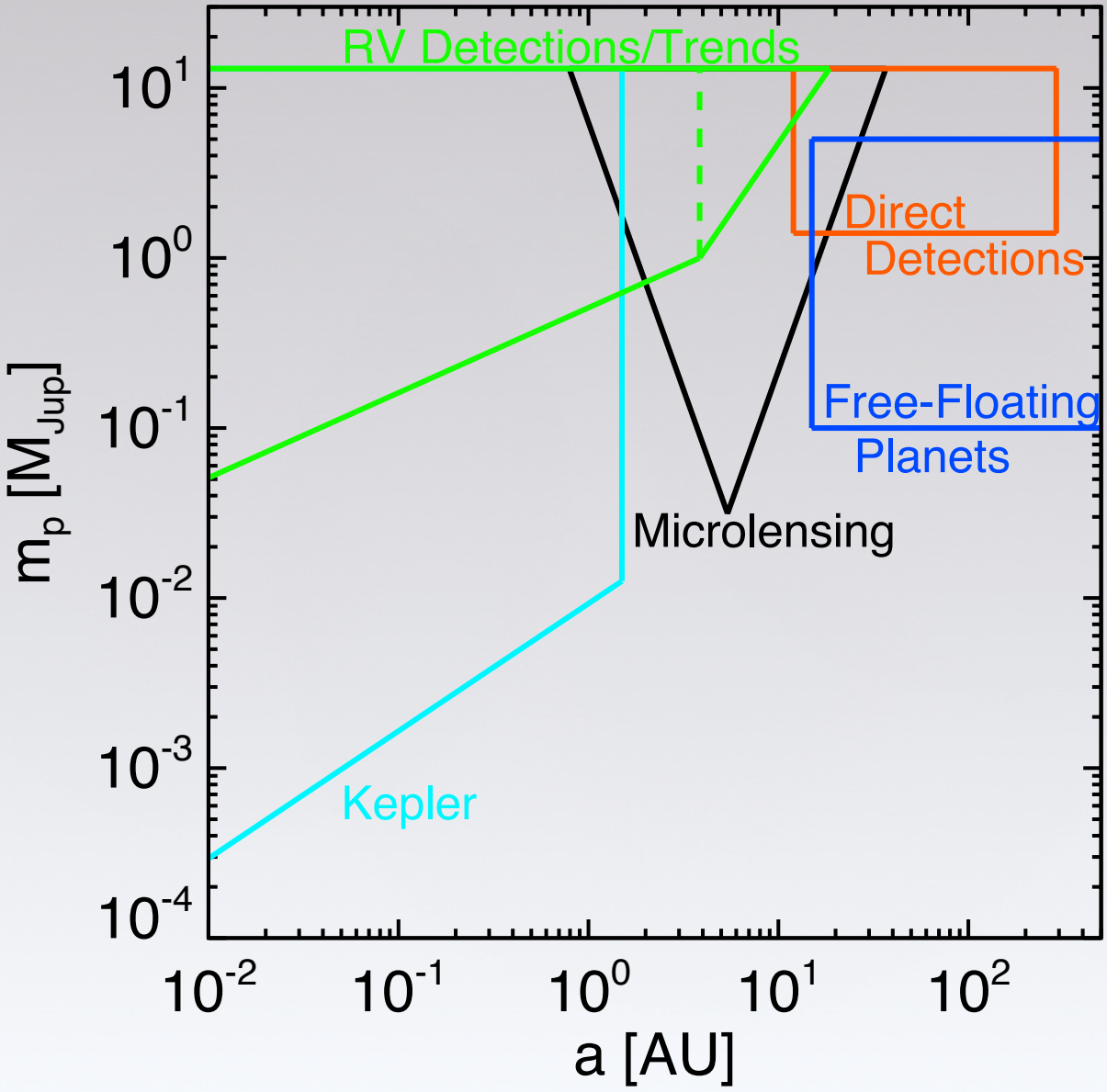
19th Annual Microlensing Meeting
20 January 2015

M Dwarfs

- Common
- Most well-characterized stellar population in terms of exoplanet demographics
- Existing constraints from several observational techniques

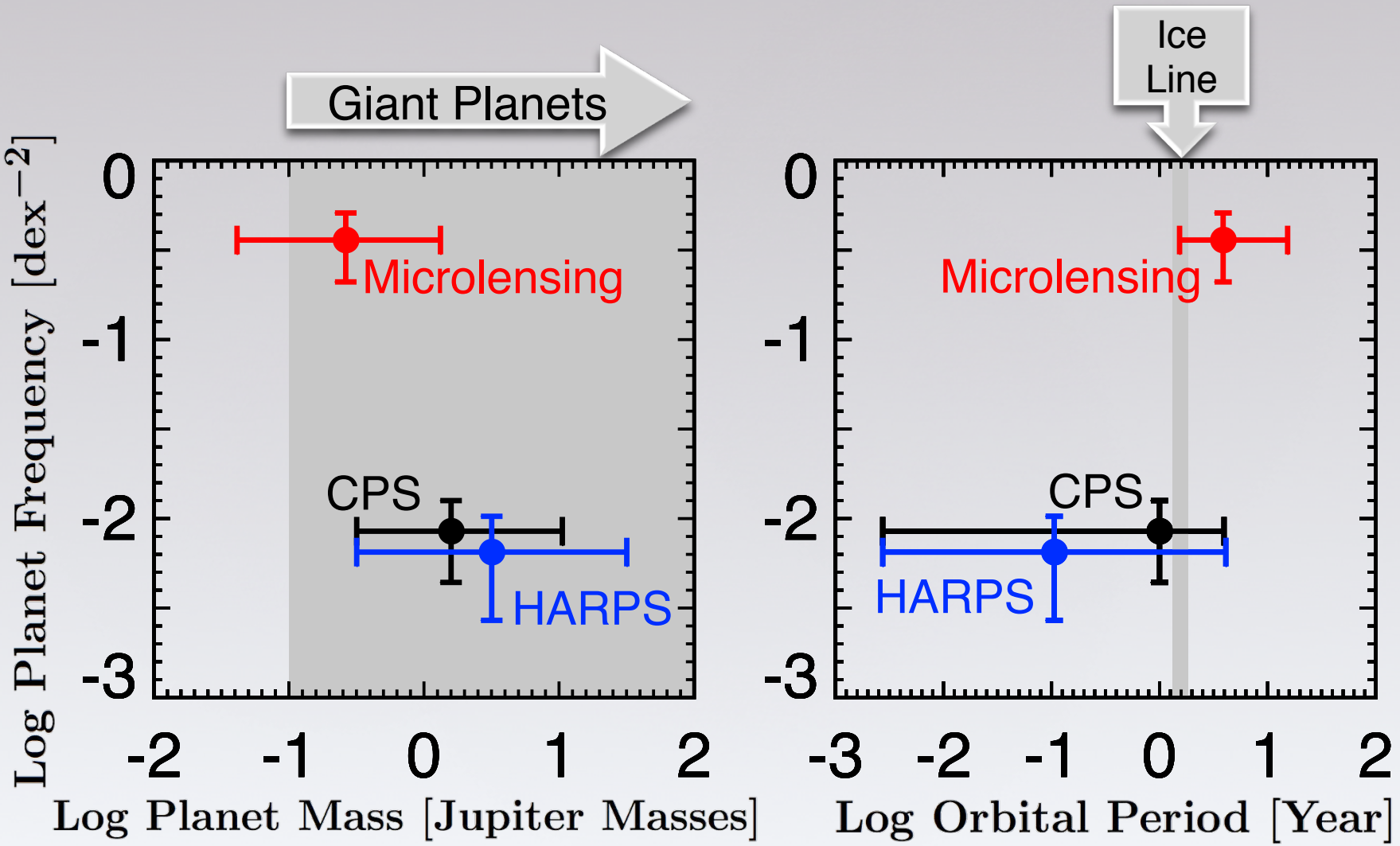
Sensitivity of Various Methods



Comprehensive Picture of Exoplanet Demographics

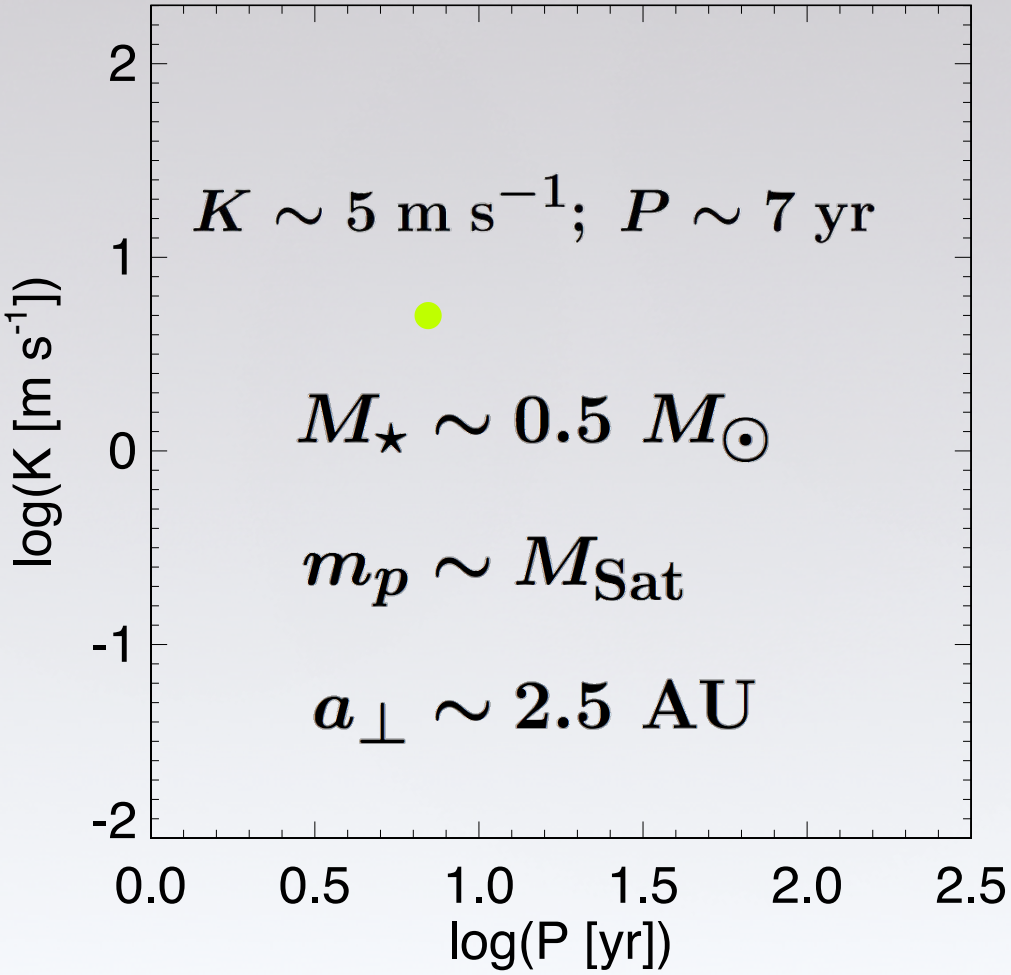
- Combine results from these various techniques
  - Clanton & Gaudi (2014ab)

Tension Between RV and Microlensing Results



CPS: Johnson+ 2010; Montet+ 2013
HARPS: Bonfils+ 2013
Microlensing: Gould+ 2010

Mapping of ''Microlensing Planets'' into RV Observables



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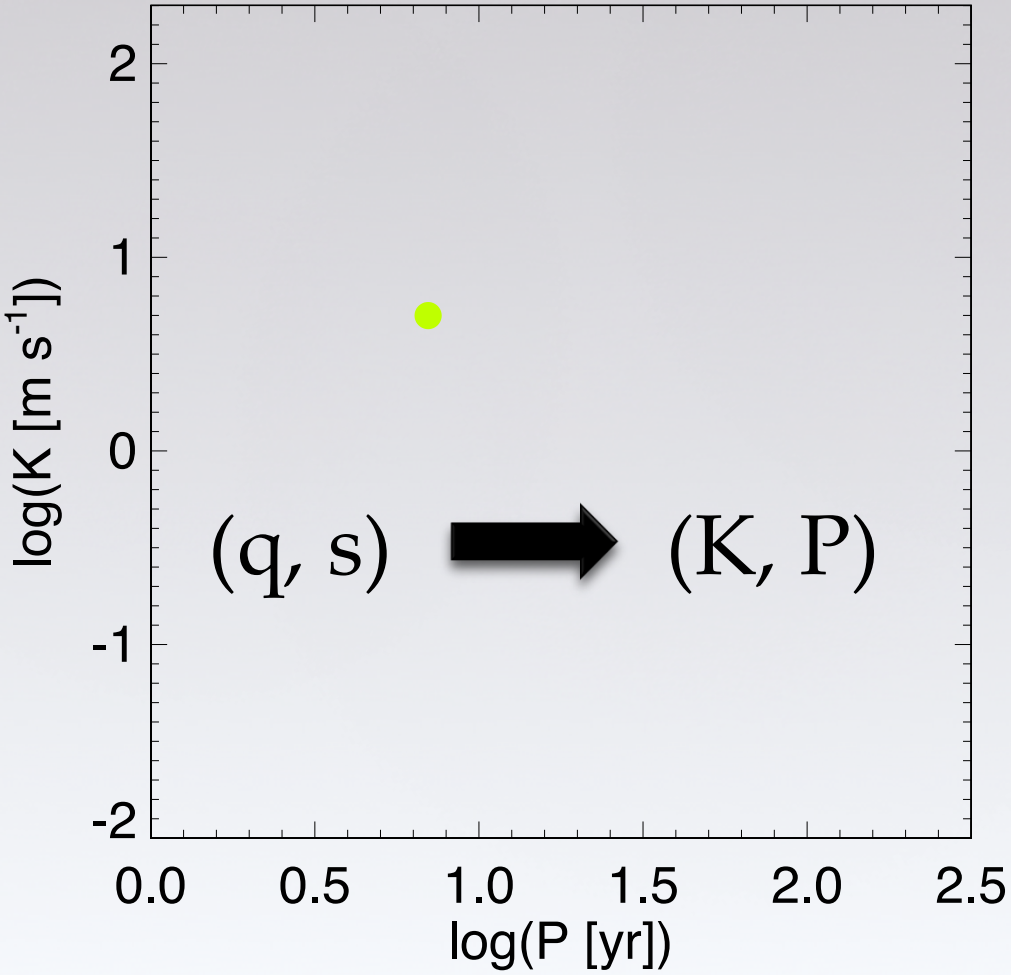

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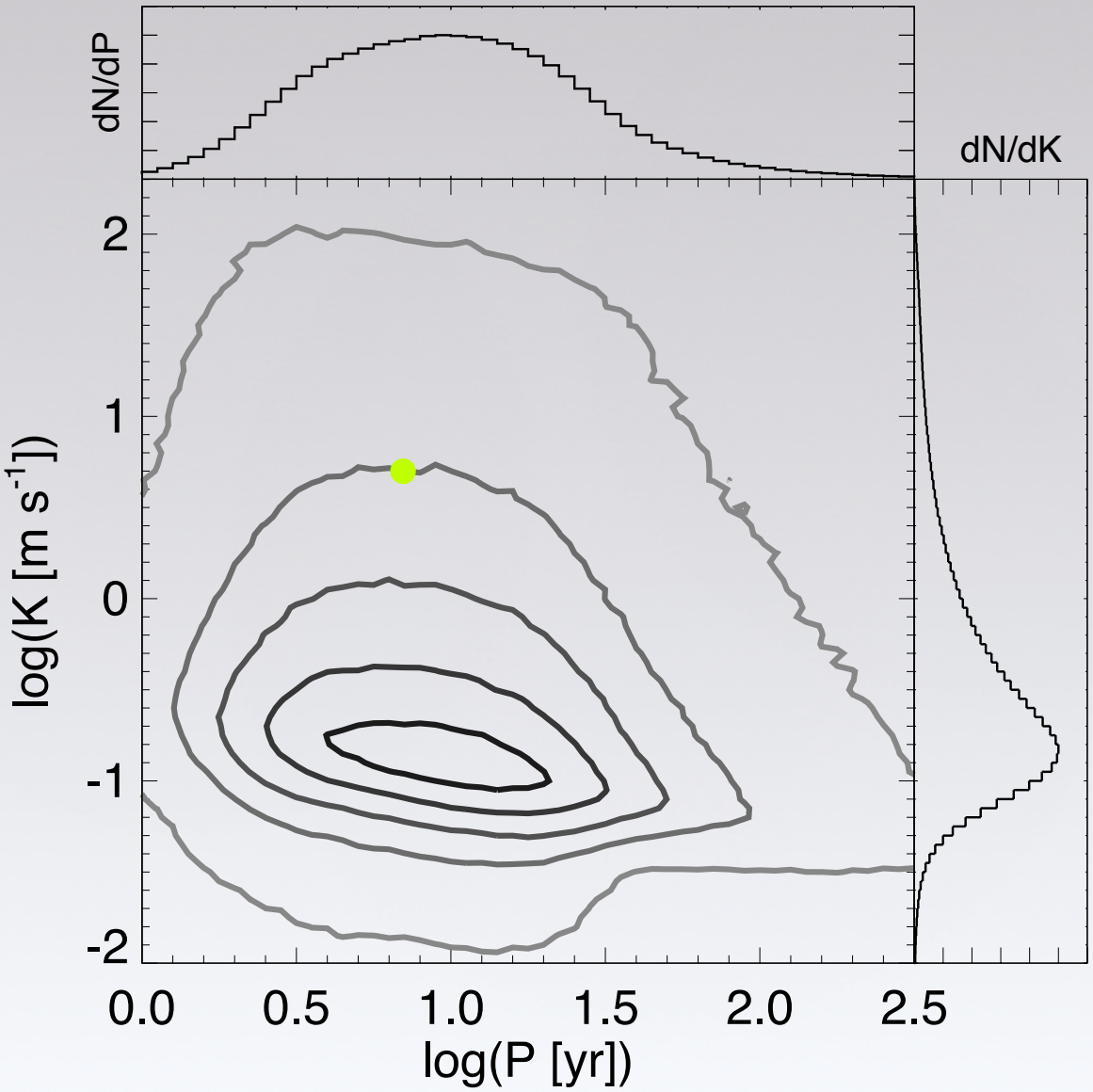

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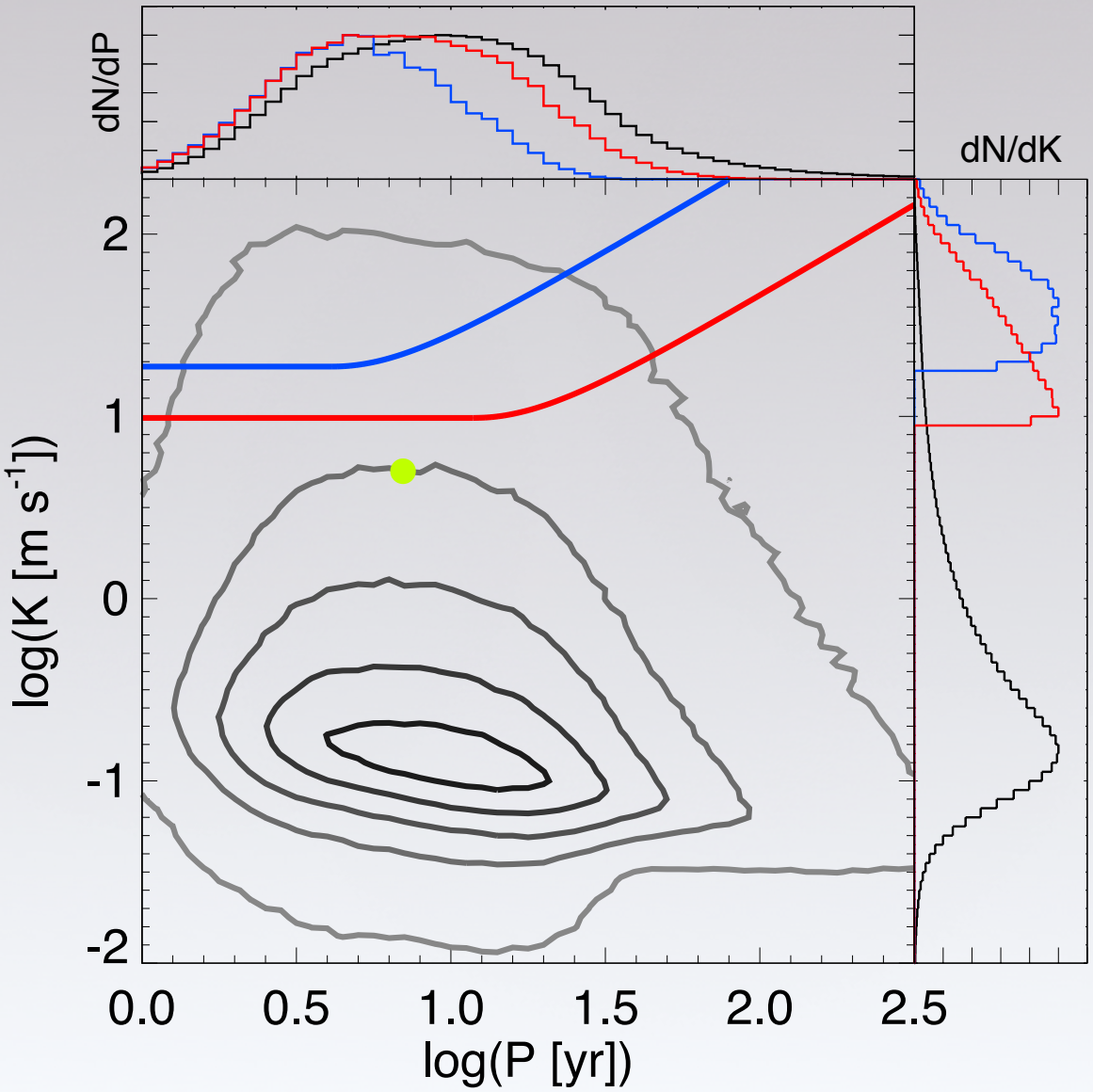
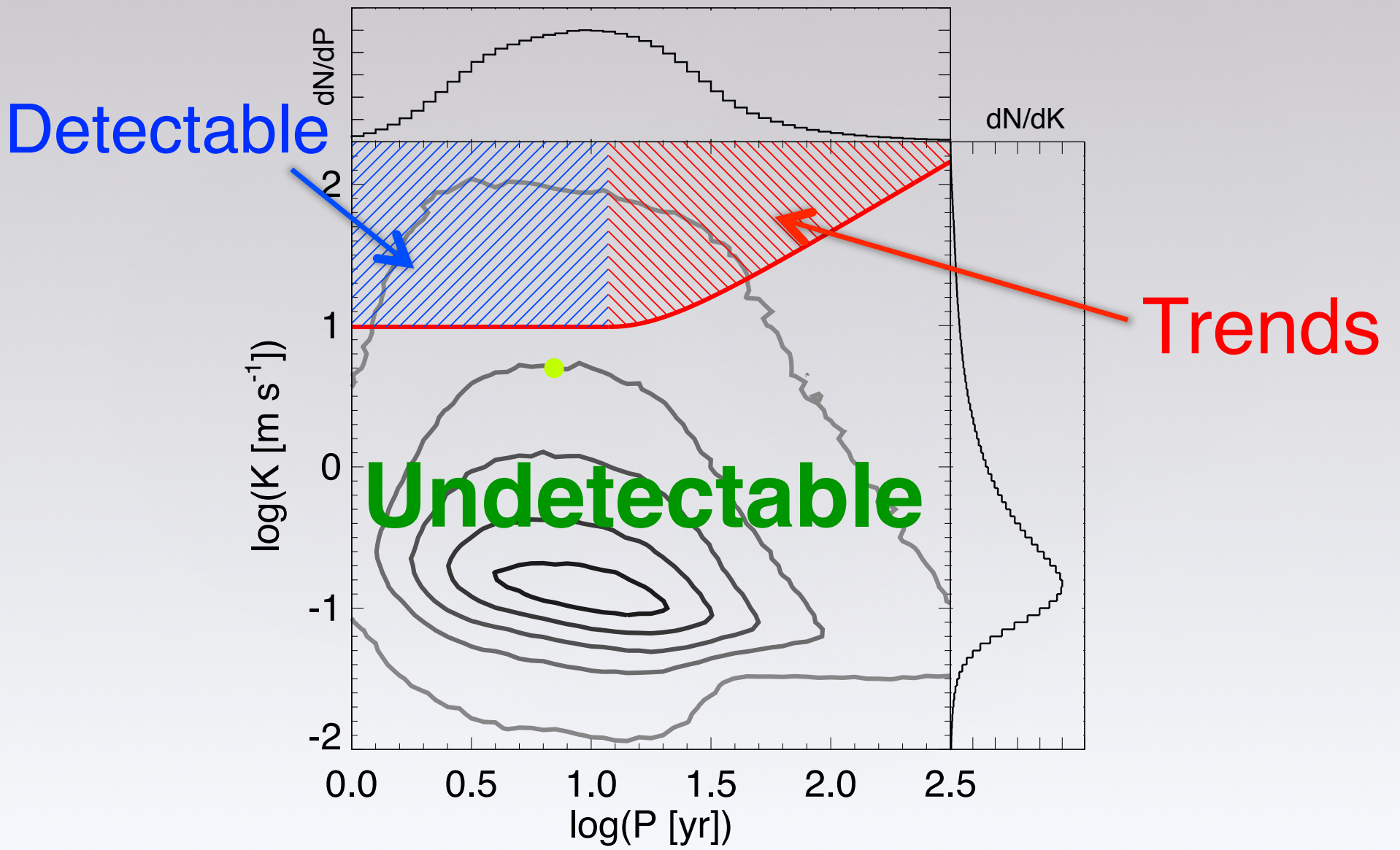


Mapping of ''Microlensing Planets'' into RV Observables



Comparison with HARPS (Bonfils+ 2013)

Expected Number:

1.1 ± 0.8

Actual Number:

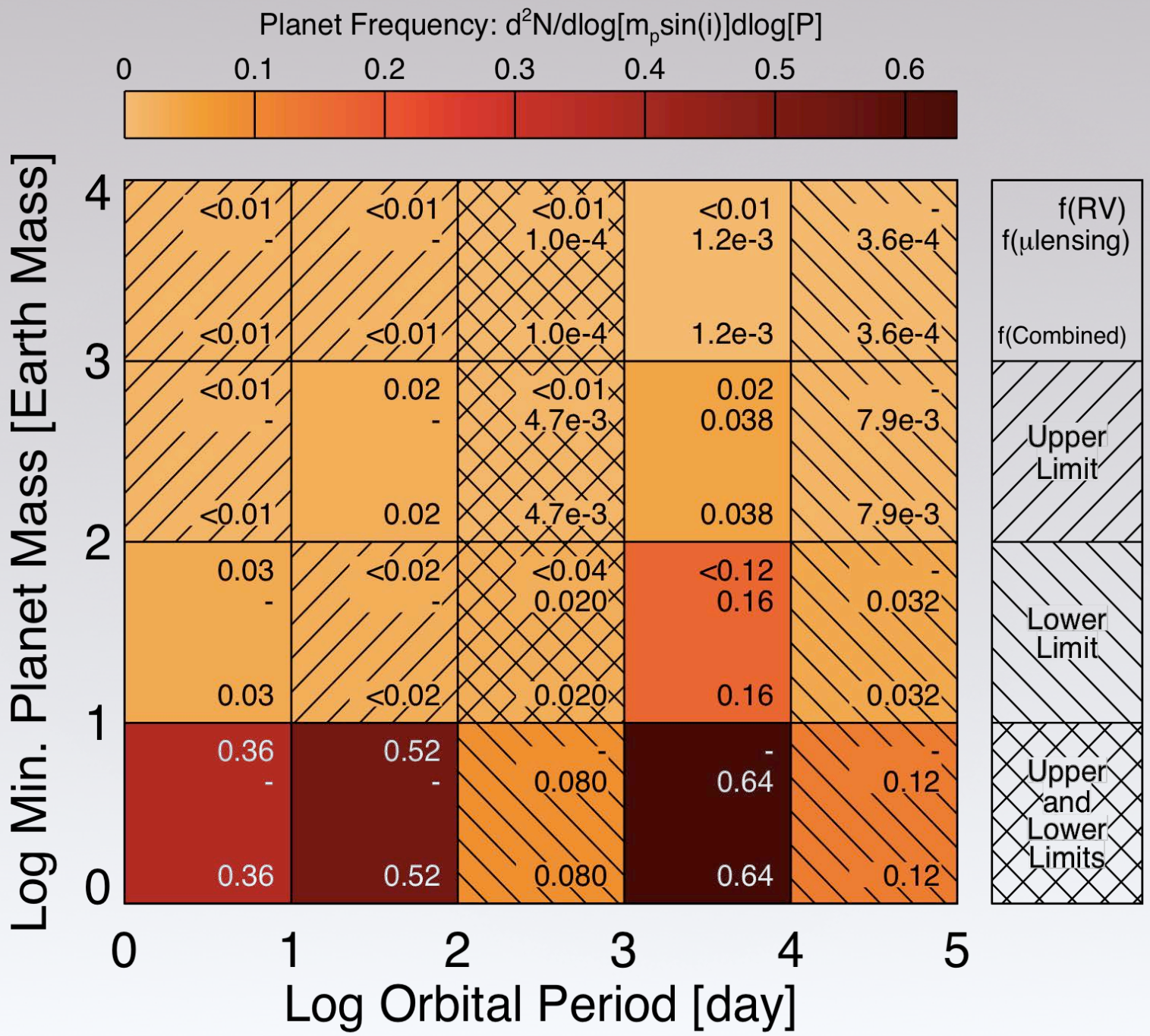
1

Mass Range

$$1 \lesssim \frac{m_p \sin i}{M_{\rm Jup}}$$

Period Range

$$3 \lesssim \frac{P}{\rm year} \lesssim 10$$


Planet Frequency: d²N/dlog[m_p sin(i)]dlog[P]
0
0.1
0.2
0.3
0.4
0.5
0.6
Log Min. Planet Mass [Earth Mass]
Log Orbital Period [day]
0
1
2
3
4
5
<0.01 - <0.01
<0.01 - <0.01
<0.01 1.0e-4 1.0e-4
<0.01 1.2e-3 1.2e-3
- 3.6e-4 3.6e-4
<0.01 - <0.01
0.02 - 0.02
<0.01 4.7e-3 4.7e-3
0.02 0.038 0.038
- 7.9e-3 7.9e-3
0.03 - 0.03
<0.02 - <0.02
<0.04 0.020 0.020
<0.12 0.16 0.16
- 0.032 0.032
0.36 - 0.36
0.52 - 0.52
- 0.080 0.080
- 0.64 0.64
- 0.12 0.12
f(RV)
f(μlensing)
f(Combined)
Upper Limit
Lower Limit
Upper and Lower Limits

Microlensing + RV Results

- Steep mass function primarily responsible for perceived difference
- 2 planets per star (1-10^4 $M_\oplus$; 1-10^4 days)
- 0.15 giant planets per star (30-10^4 $M_\oplus$; 1-10^4 days)
- 0.03 Jupiters/Super-Jupiters per star (1-13 M_{jup}; 1-10^4 days)

Constraints on Long-Period, Giant Planets and Free-Floating Planets

Microlensing Surveys	Radial Velocity Surveys	Direct Imaging Surveys
Gould+ (2010) Sumi+ (2010) Sumi+ (2011)	Montet+ (2014)	Bowler+ (2014) Lafreniere+ (2007)

$$\{\alpha, \beta, \mathcal{A}, a_{\rm out}\}$$

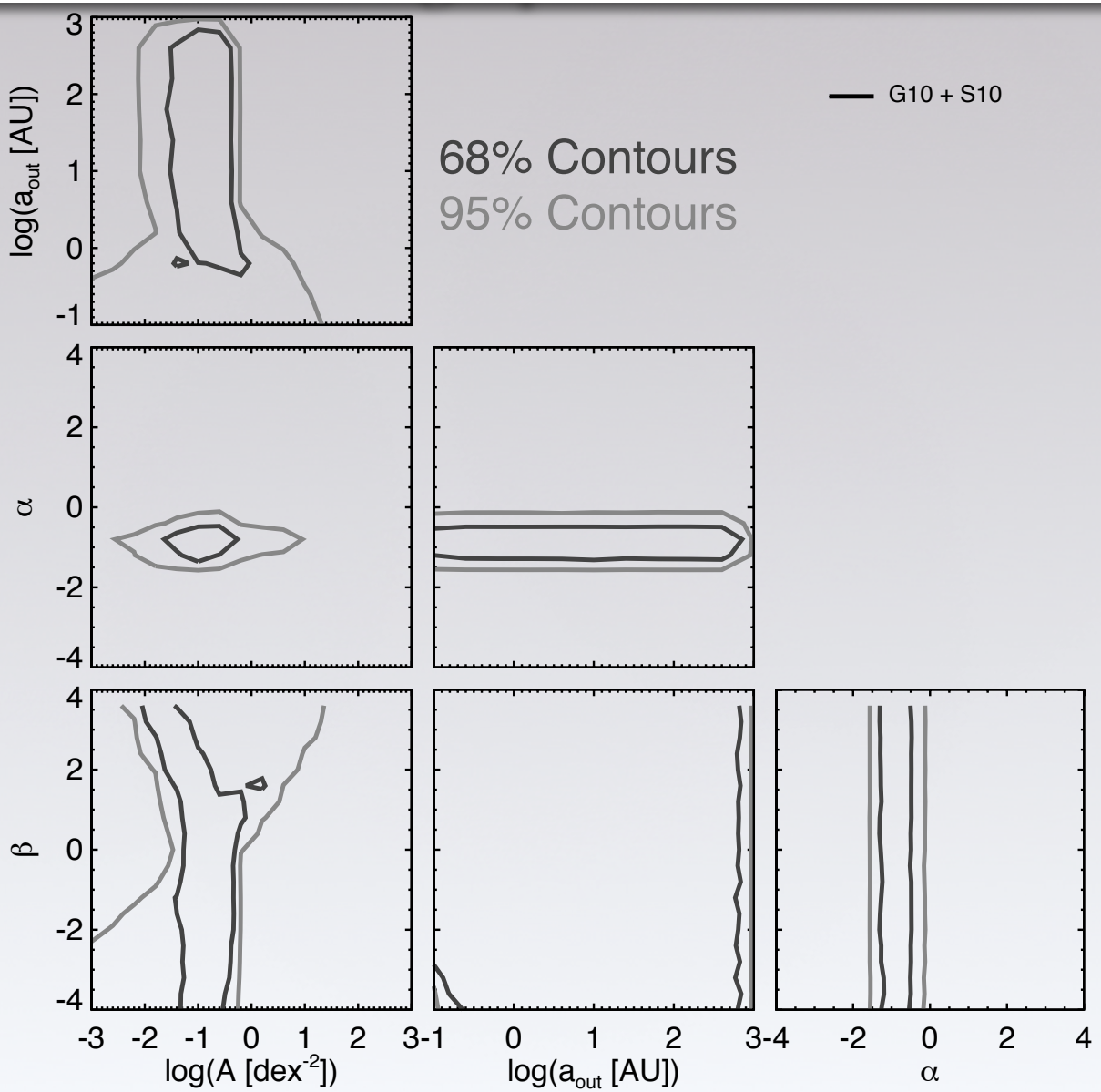
$$\frac{d^2 N_{\rm pl}}{d\log m_p \; d\log a} = \mathcal{A}\left(\frac{m_p}{M_{\rm Sat}}\right)^{\alpha}\left(\frac{a}{2.5\ {\rm AU}}\right)^{\beta}$$

$$\mathcal{F} = \int_{\log(0.1\ {\rm AU})}^{\log(a_{\rm out})}\int_{\log(1\ M_\oplus)}^{\log(13\ M_{\rm Jup})}\frac{d^2 N_{\rm pl}}{d\log m_p \; d\log a} d\log m_p \; d\log a$$

Combined Demographic Constraints

** Preliminary Results **

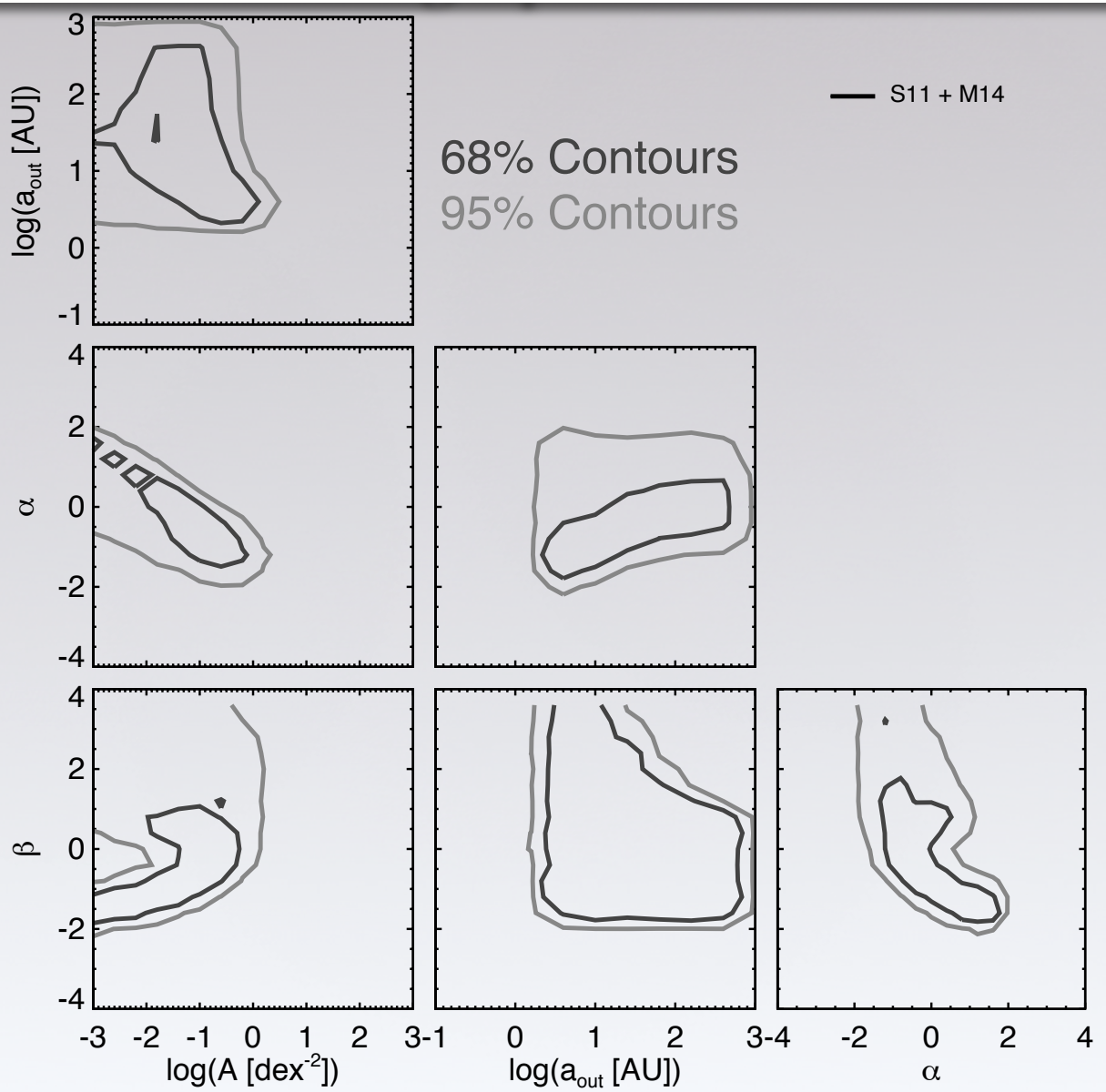
Constraints:
Gould+ (2010)
Sumi+ (2010)



Combined Demographic Constraints

** Preliminary Results **

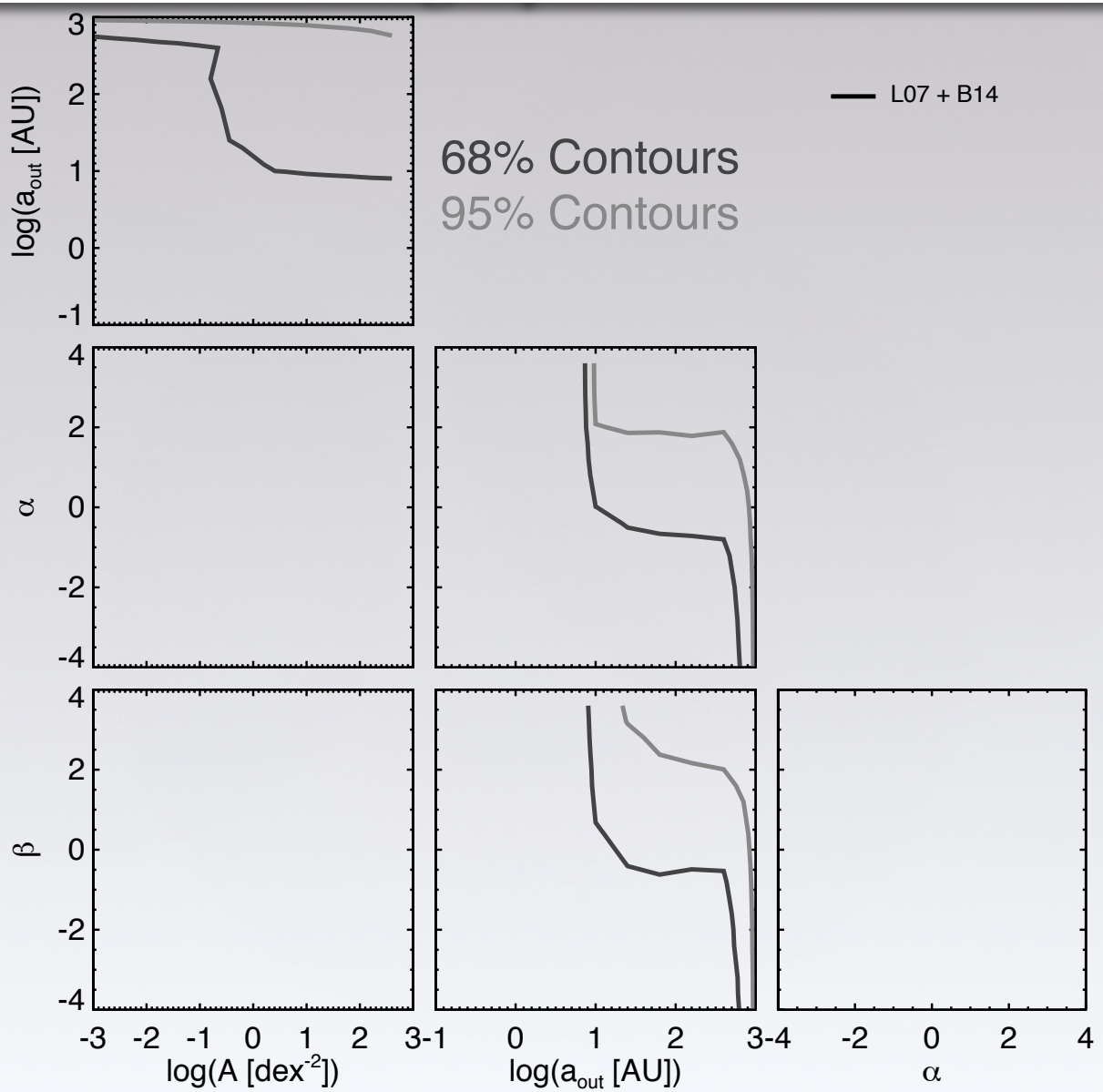
Constraints:
Montet+ (2014)
Sumi+ (2011)



Combined Demographic Constraints

** Preliminary Results **

Constraints:
Bowler+ (2014)
Lafreniere+ (2007)



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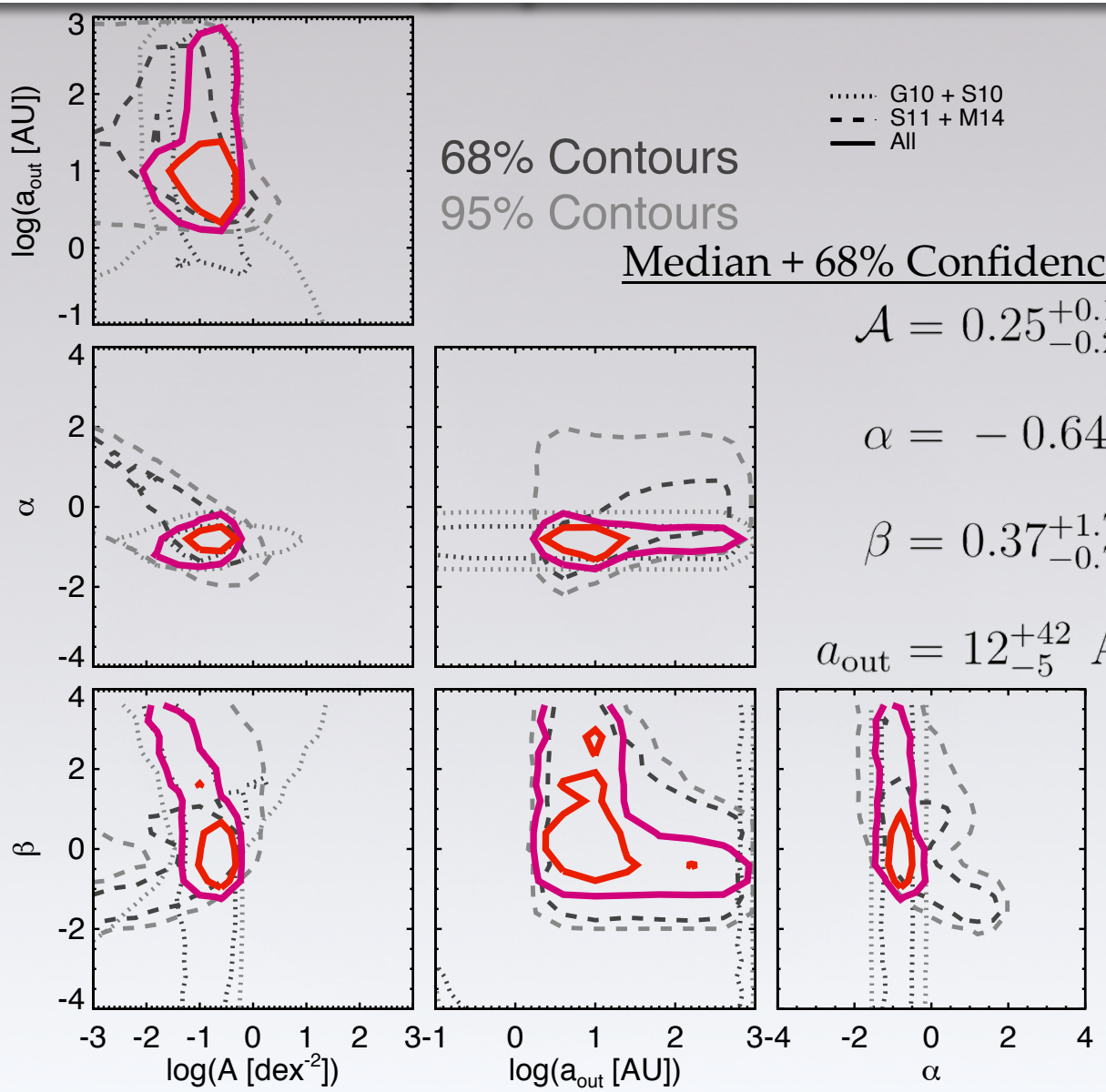

Median + 68% Confidence Intervals:

$$\mathcal{A} = 0.25^{+0.10}_{-0.20}\ \mathrm{dex}^{-2}$$

$$\alpha = -0.64^{+0.17}_{-0.19}$$

$$\beta = 0.37^{+1.7}_{-0.72}$$

$$a_{\mathrm{out}} = 12^{+42}_{-5}\ \mathrm{AU}$$

Preliminary Results + Work in Progress

- Class of models consistent with all surveys
  - Also consistent with the interpretation of the overabundance of short timescale events identified by Sumi+ (2011) as a bound population
- Full Simulations to come!

Primary References

Microlensing + RV:
1) Clanton, C., & Gaudi, B. S., 2014, ApJ, 791, 90
2) Clanton, C., & Gaudi, B. S., 2014, ApJ, 791, 91

Microlensing + RV + Direct Imaging:
Clanton, C., & Gaudi, B. S., in prep.