STATISTICAL ANALYSIS OF EXOPLANET POPULATIONS FROM LARGE-SCALE DIRECT IMAGING SURVEYS

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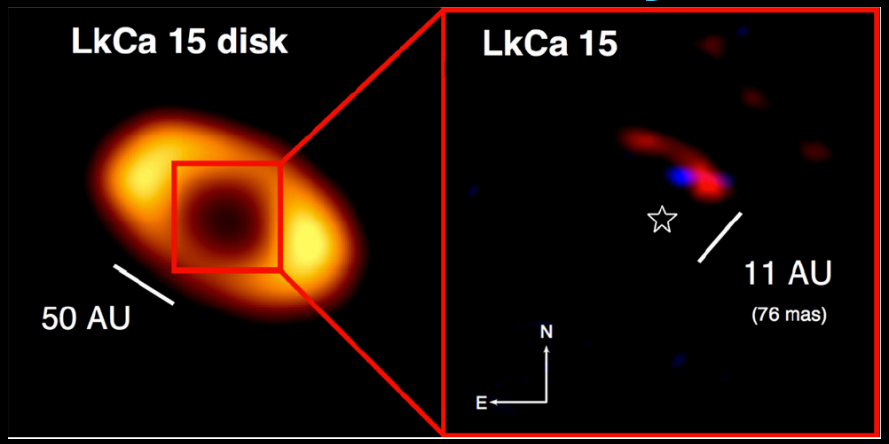
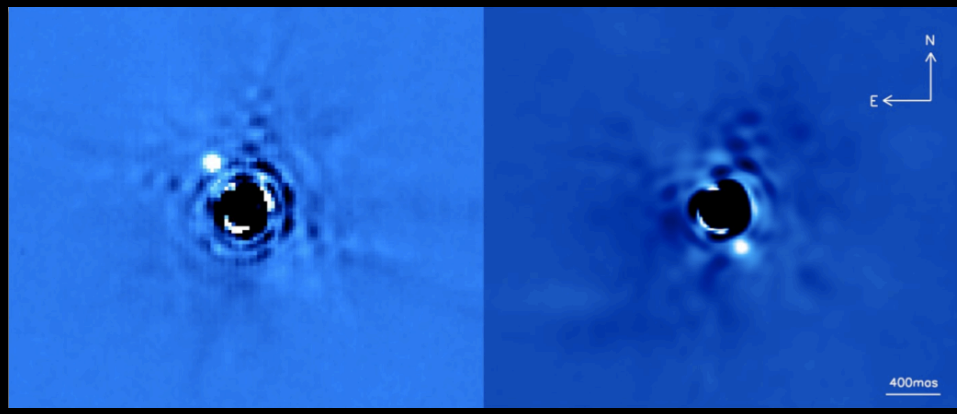
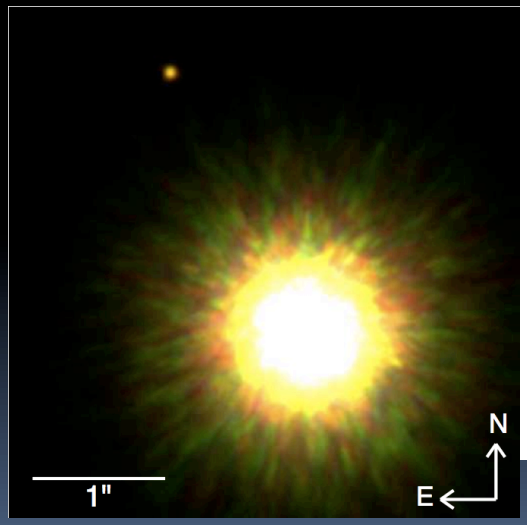
~10 Directly Imaged Exoplanets...



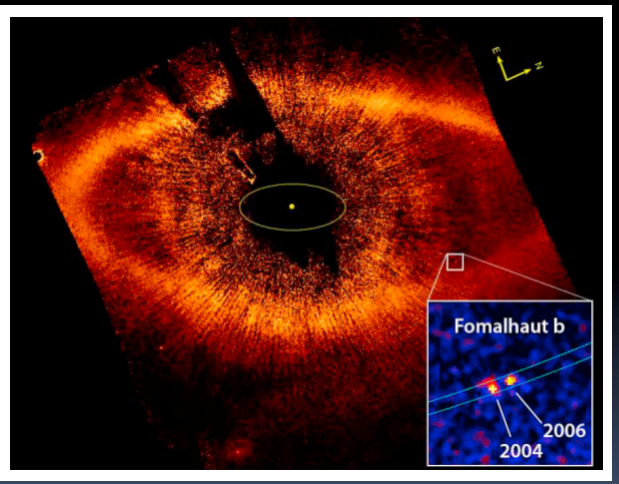
Kraus and Ireland 2012



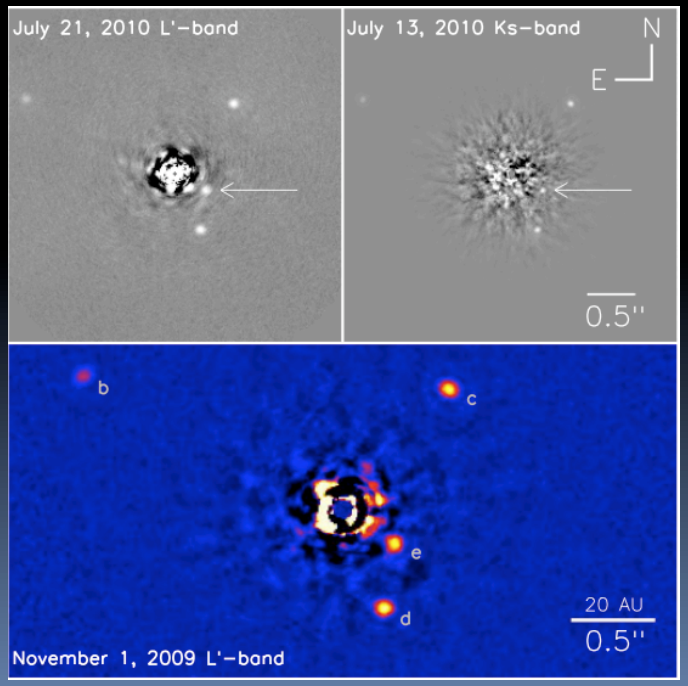
Lagrange et al. 2008,2010



Lafrenière et al. 2008,2010

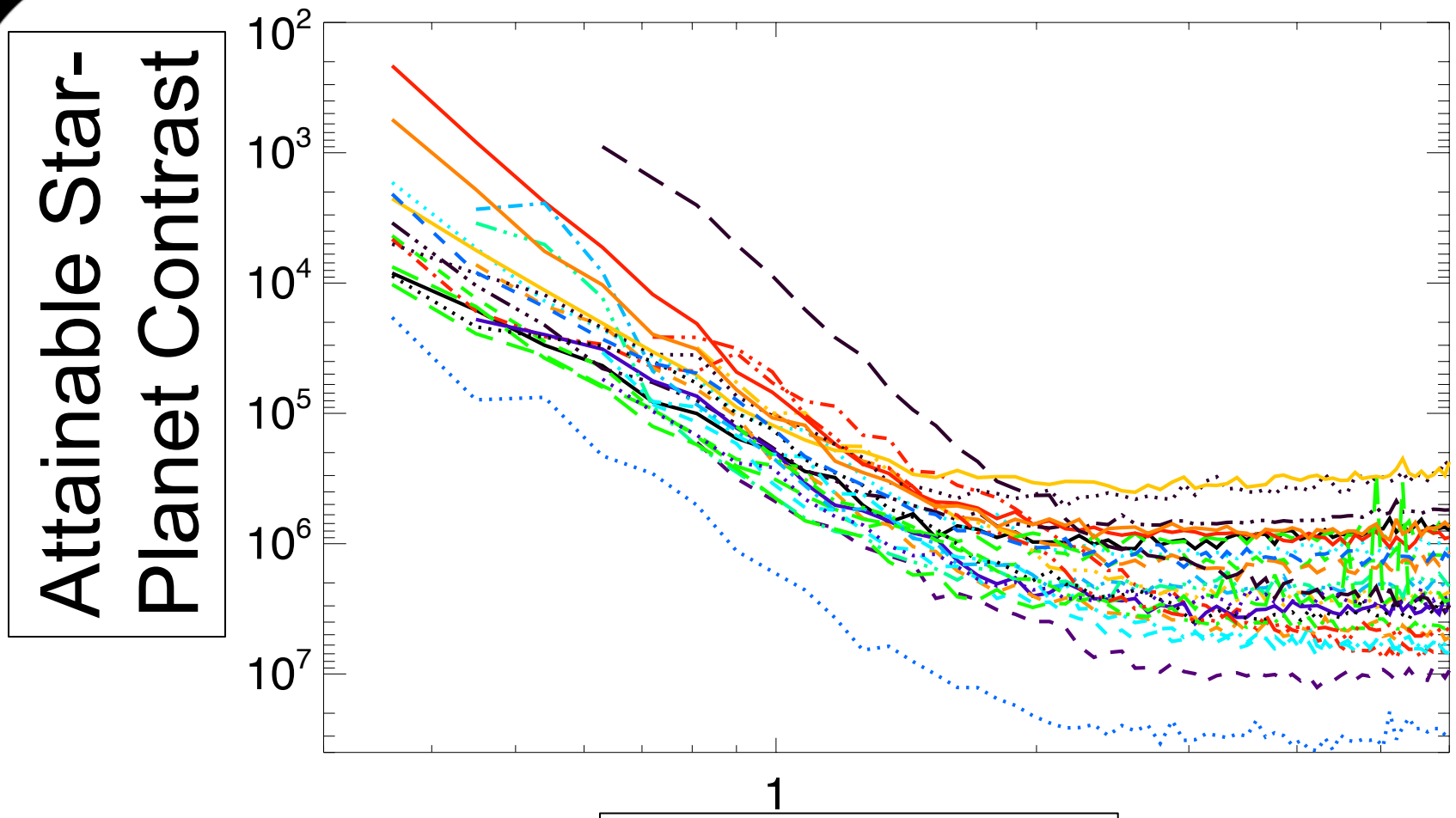


Kalas et al. 2008



Marois et al. 2008,2010

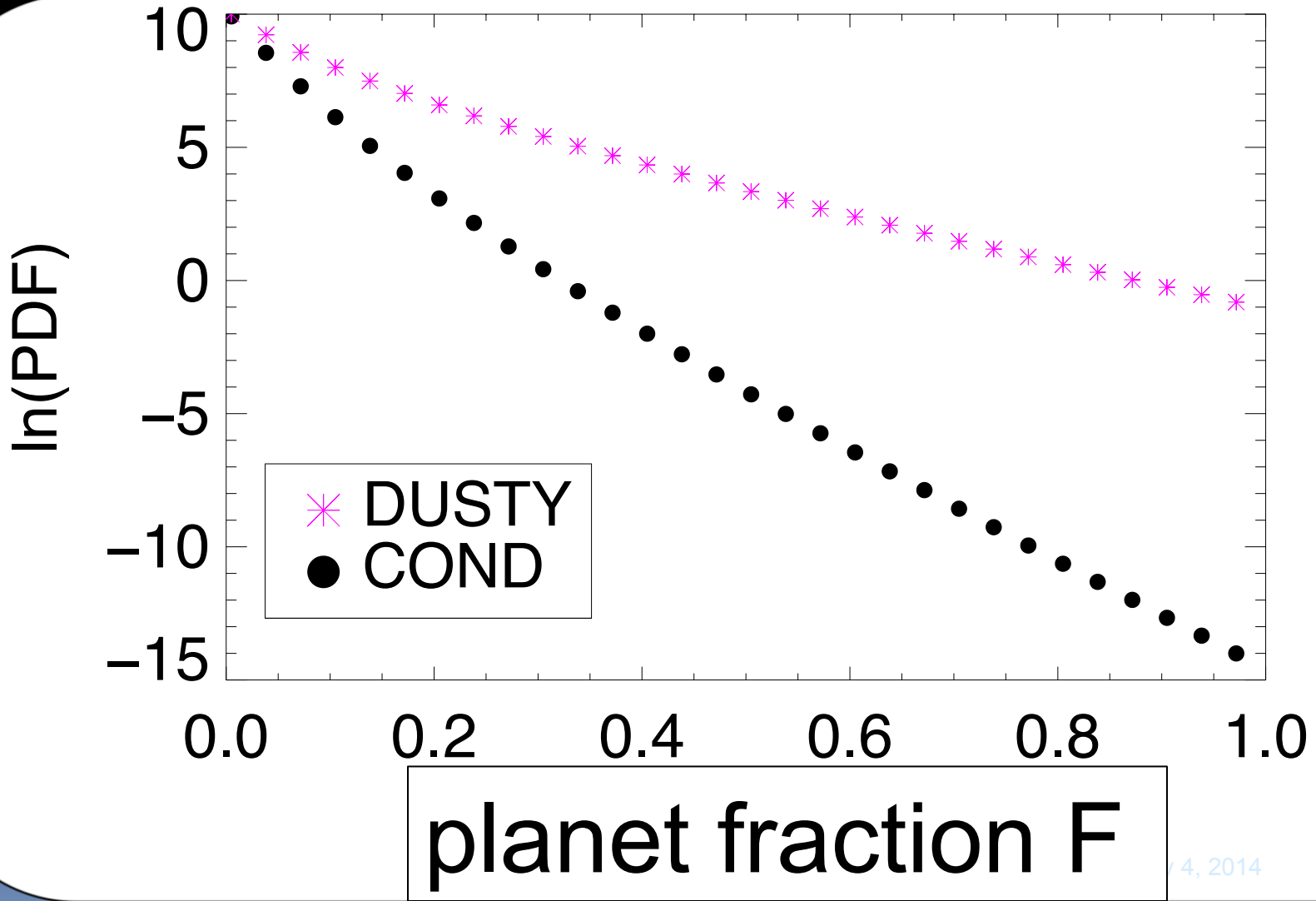
Out of 100s of stars surveyed to quite deep contrasts...



Biller et al. 2013

Current Survey Statistics already place strong constraints

Biller et al. 2013



Strongest Constraint on Planet Fraction to date from 78 NICI Campaign stars:

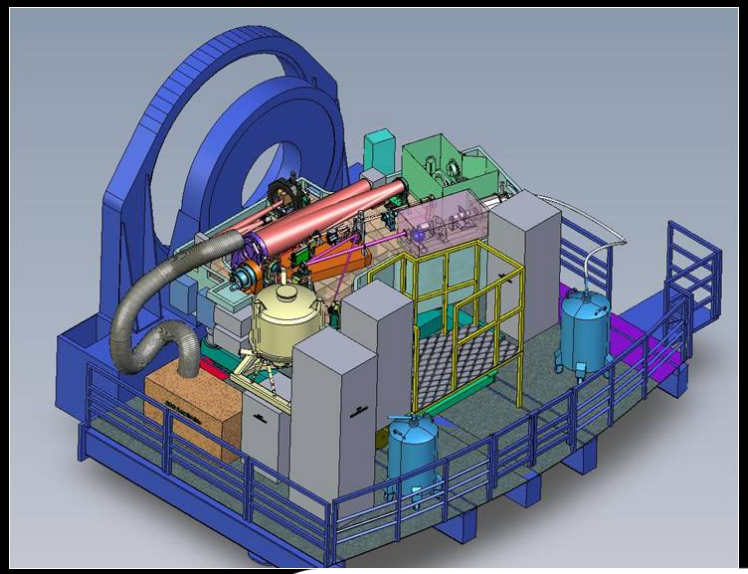
≤8% host 1-20 Mjup planets at semi-major axes of 10-150 AU

(95% confidence level, COND models)

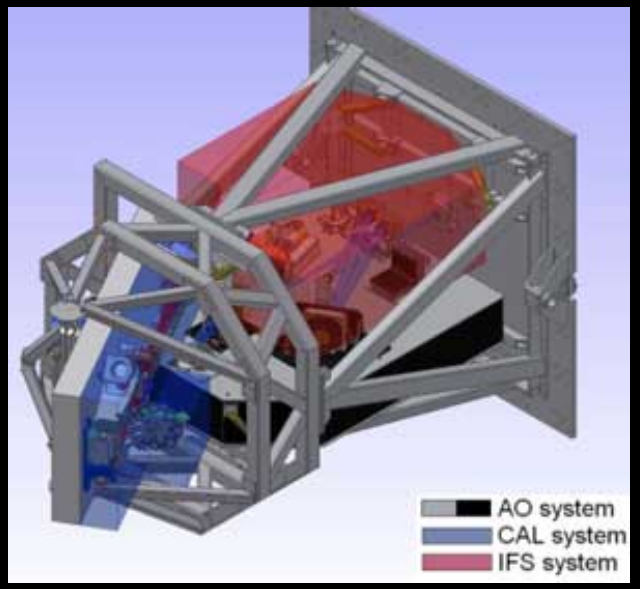
Biller et al. 2013

Upcoming Instruments

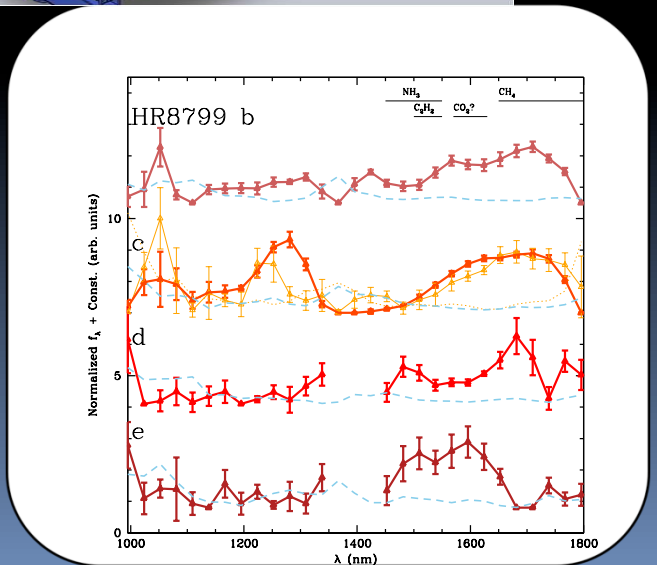
SPHERE @ VLT



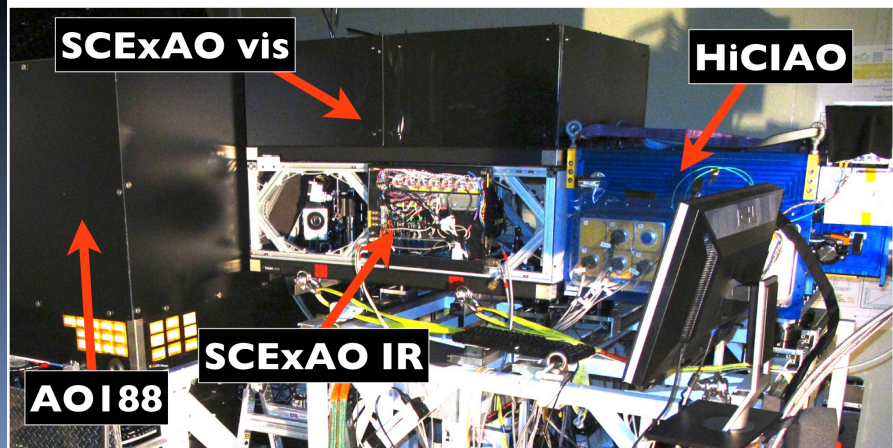
GPI @ Gemini



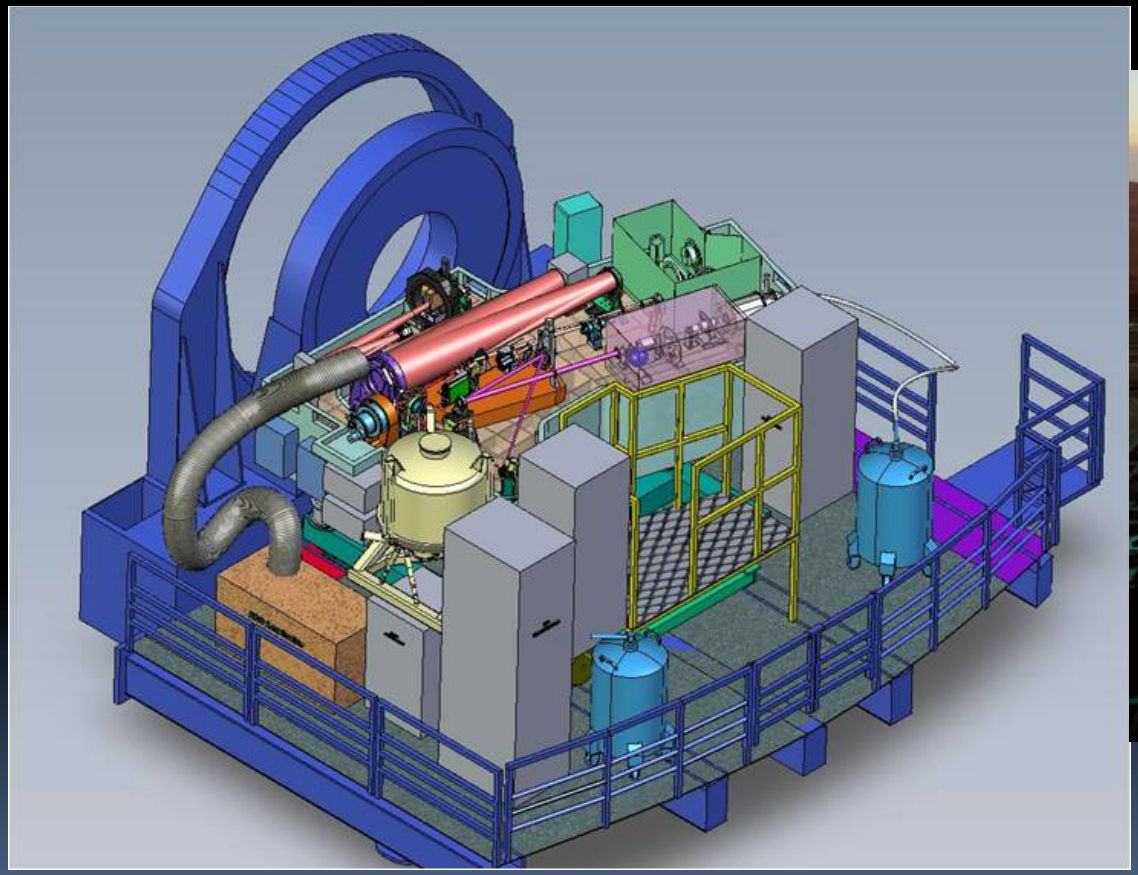
Project 1640



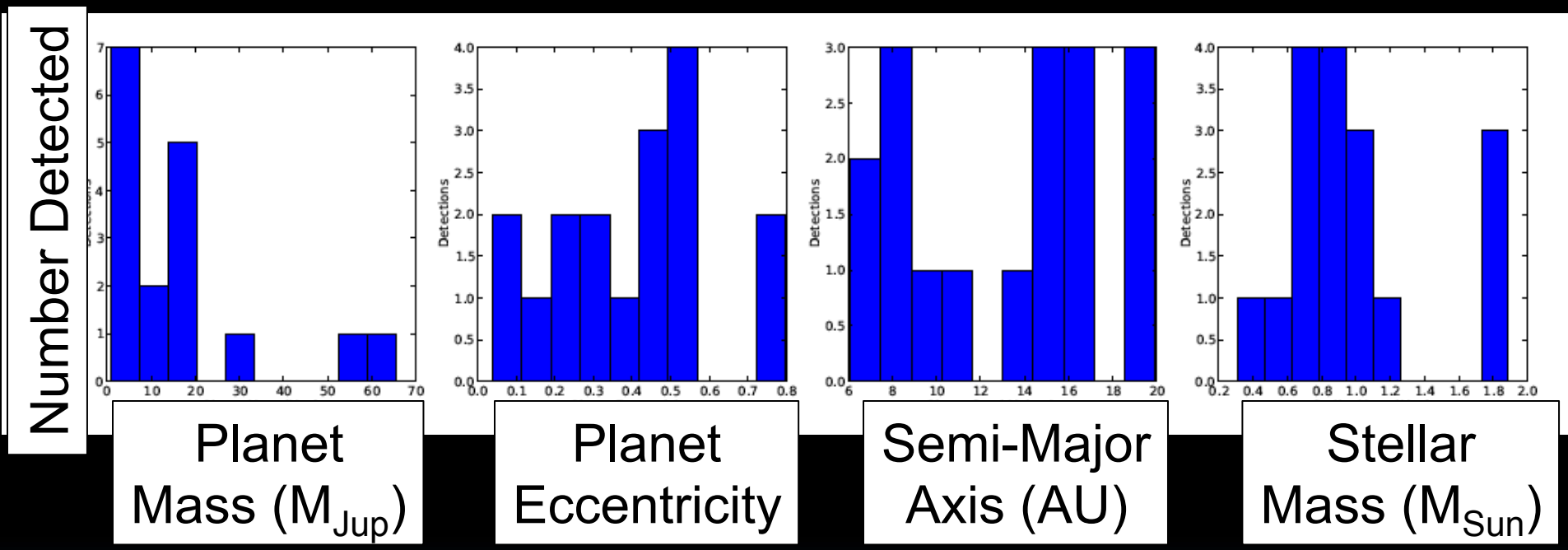
SCExAO



NIRSUR with SPHERE @ VLT – predicted start in 2015



Simulated Surveys for SPHERE NIRSUR



Monte Carlo simulation following the approach of Nielsen & Close, 2010 and Bonavita et al. 2012.

Assumed Planet Distribution

$$dN/dm \propto m^{\alpha},\ \alpha = -0.63$$

$$dN/da \propto a^{\beta},\ \beta = -1.16$$

until cutoff radius

Cumming et al. 2008 found $\alpha \sim -0.63$ and $\beta \sim -1.16$ for RV planets out to ~8 AU

$$R(a, M \mid \alpha, \text{cutoff}, \beta, C) = CM^{\beta}a^{\alpha}$$

(until cutoff, where C is a normalization factor related to planet frequency F)

Normalize to known RV planets

Fischer and Valenti 2005 find a planet frequency of 3.94% for planets with:

- Mass 1-13 Mjup
- separations 0.3 – 2.5 AU
- stellar mass: 0.7 – 1.6 Msun
- [Fe/H]: -0.5 – +0.5

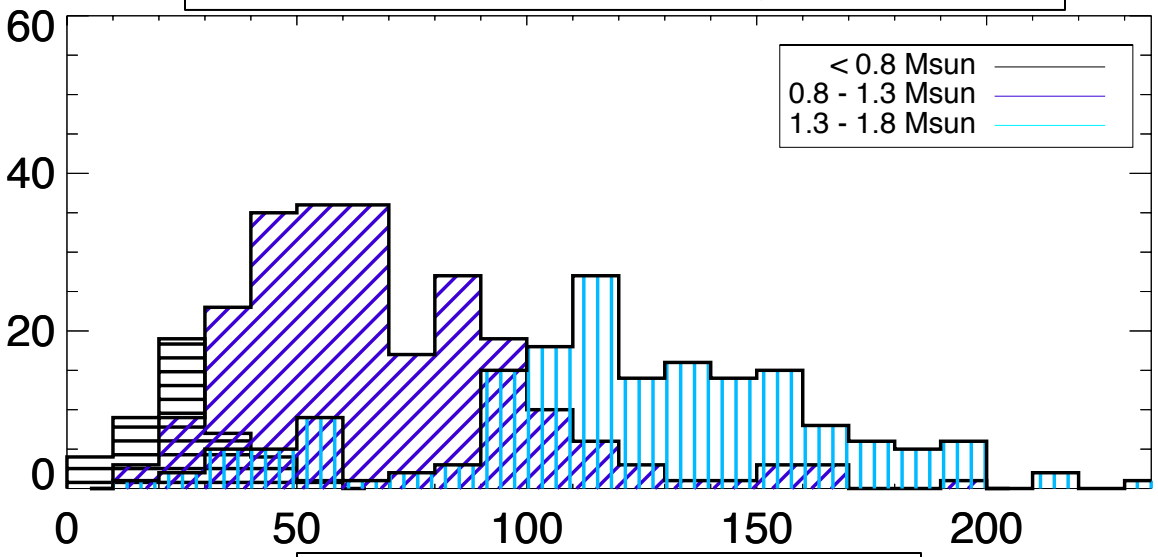
Mass-Scaled Planet Distribution

$$dN/dm \propto m^{\alpha} M^{-\alpha}$$

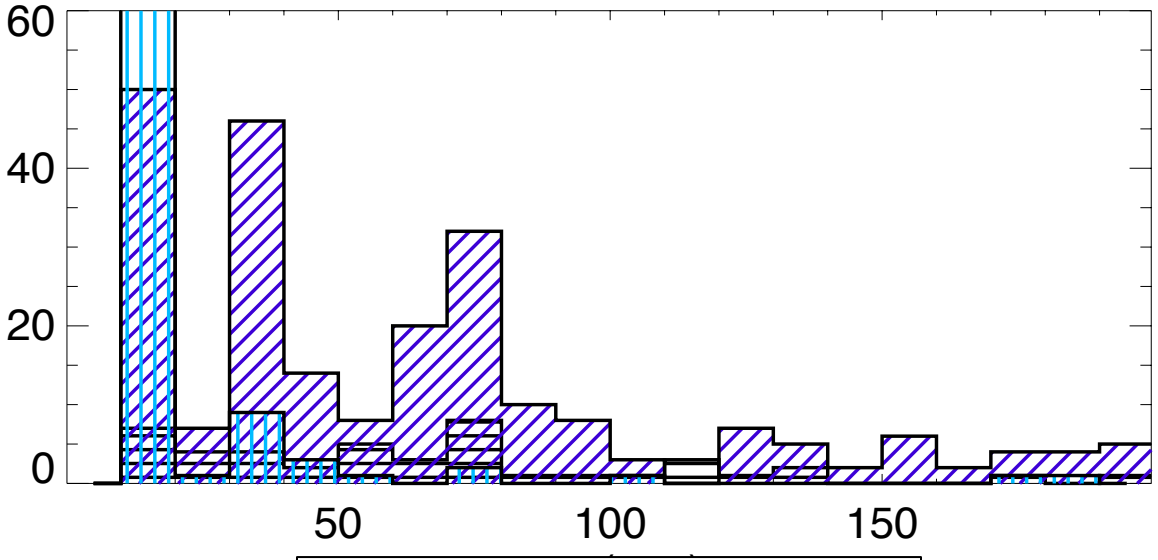
$$dN/da \propto a^{\beta} \text{ until cutoff radius}$$

Cumming et al. 2008 found $\alpha \sim -0.63$ and $\beta \sim -1.16$ for RV planets out to ~8 AU

400 star 8 – 200 Myr sample



Distance (pc)

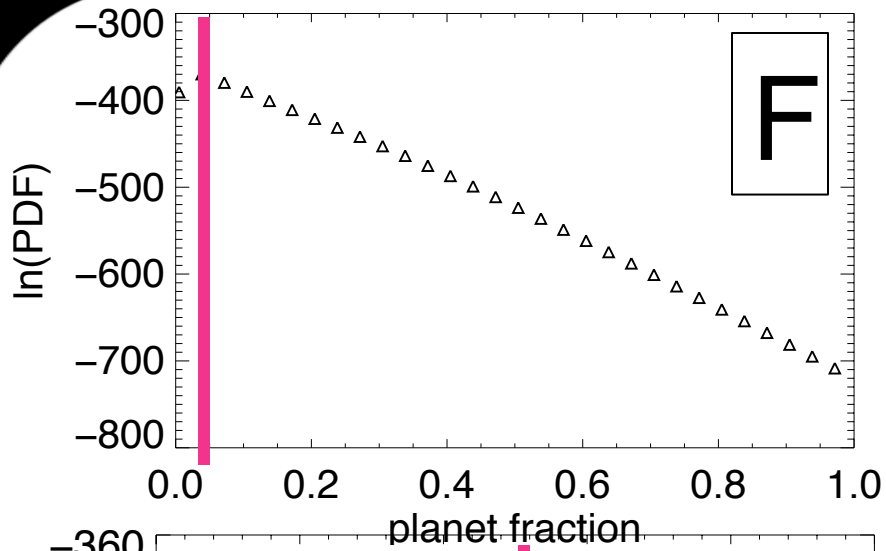


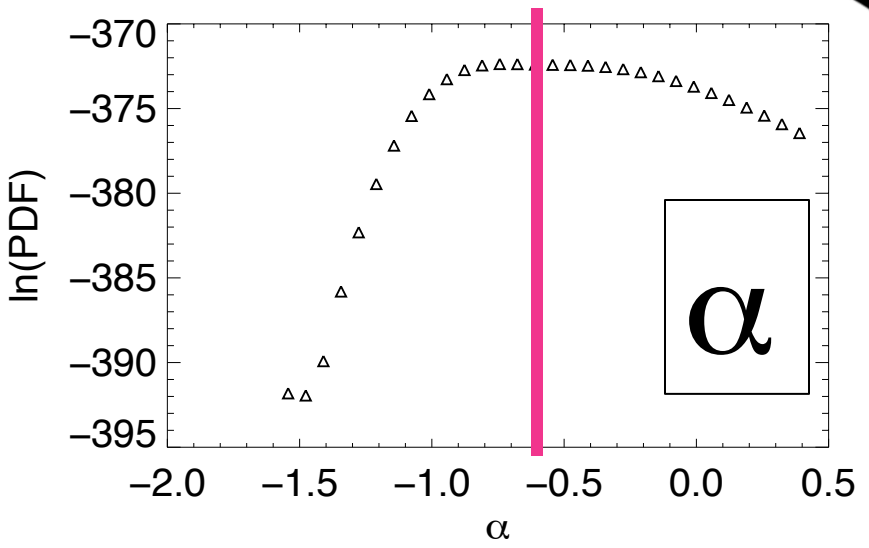
Age (myr)

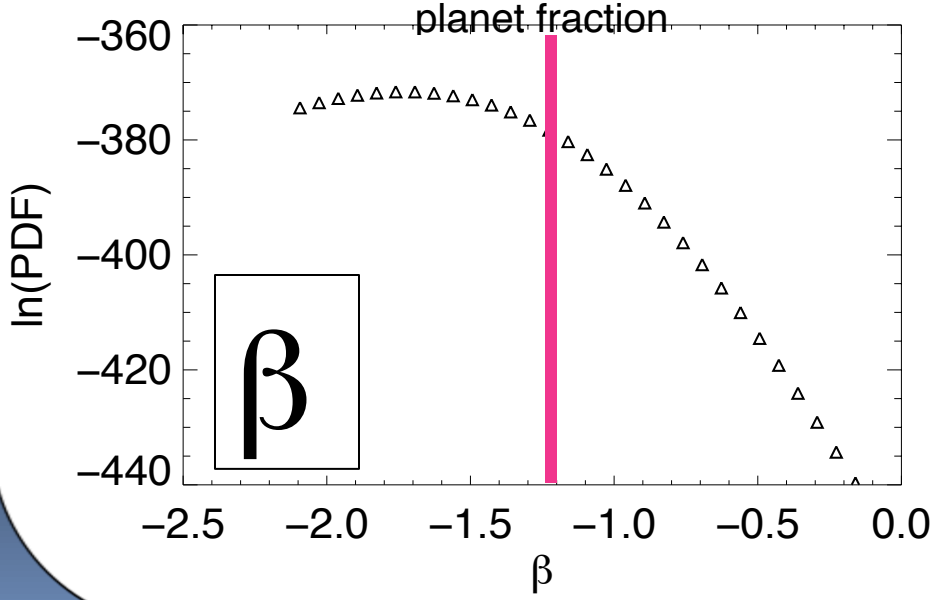
Predicted # of detections vs. cutoff

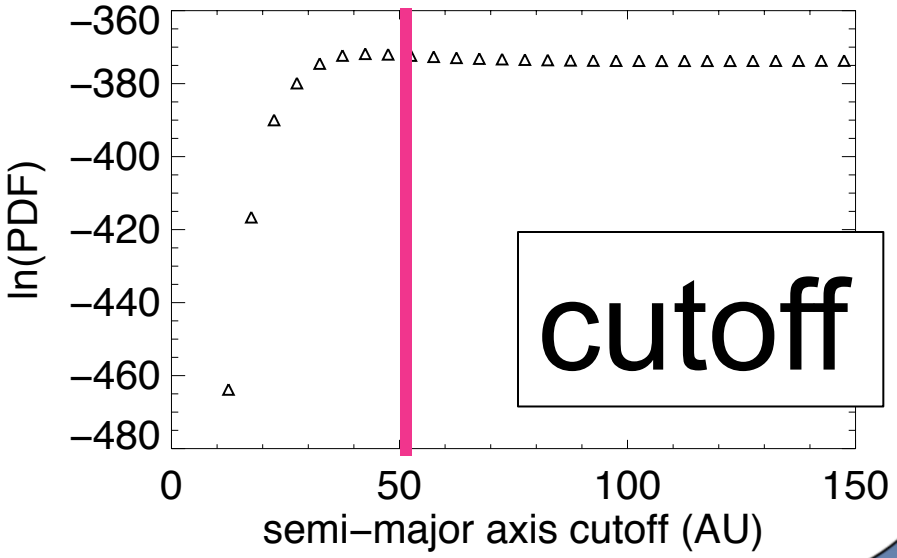
SMA Cutoff	Unscaled	Mass-Scaled
20 AU	17 ± 4	27 ± 6
30 AU	26 ± 7	46 ± 3
40 AU	34 ± 5	57 ± 5
50 AU	43 ± 4	66 ± 5

Bayesian retrieval of simulation parameters









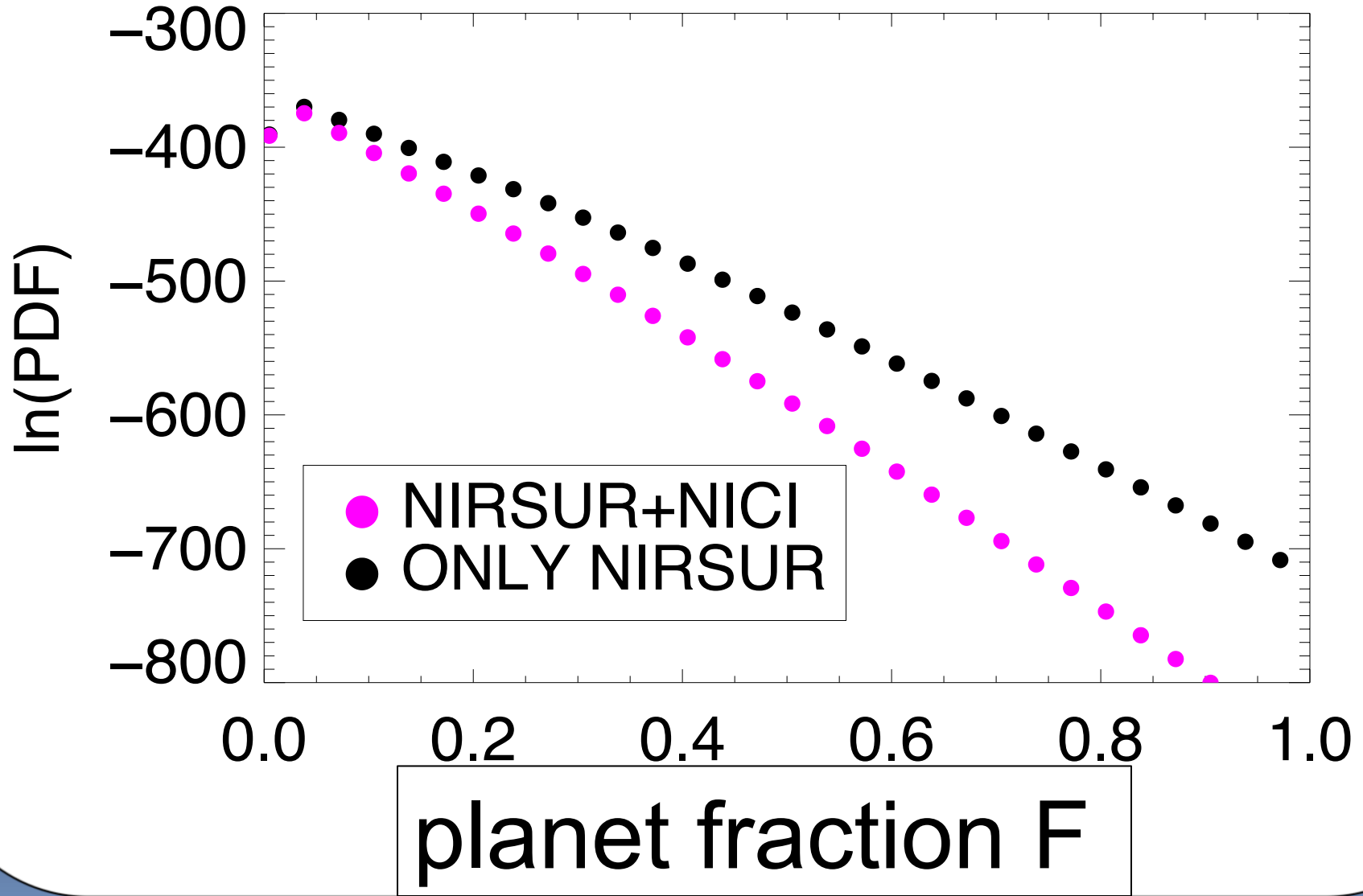
Current surveys are the prior for future surveys

Constraints from Current + Future Surveys

- 400 star simulated NIRSUR

- 78 MG stars from Biller et al. 2013

Bayesian retrieval of simulation parameters



Conclusion

Strongest constraints will likely continue to be for:

planet fraction F

Bayes' Theorem

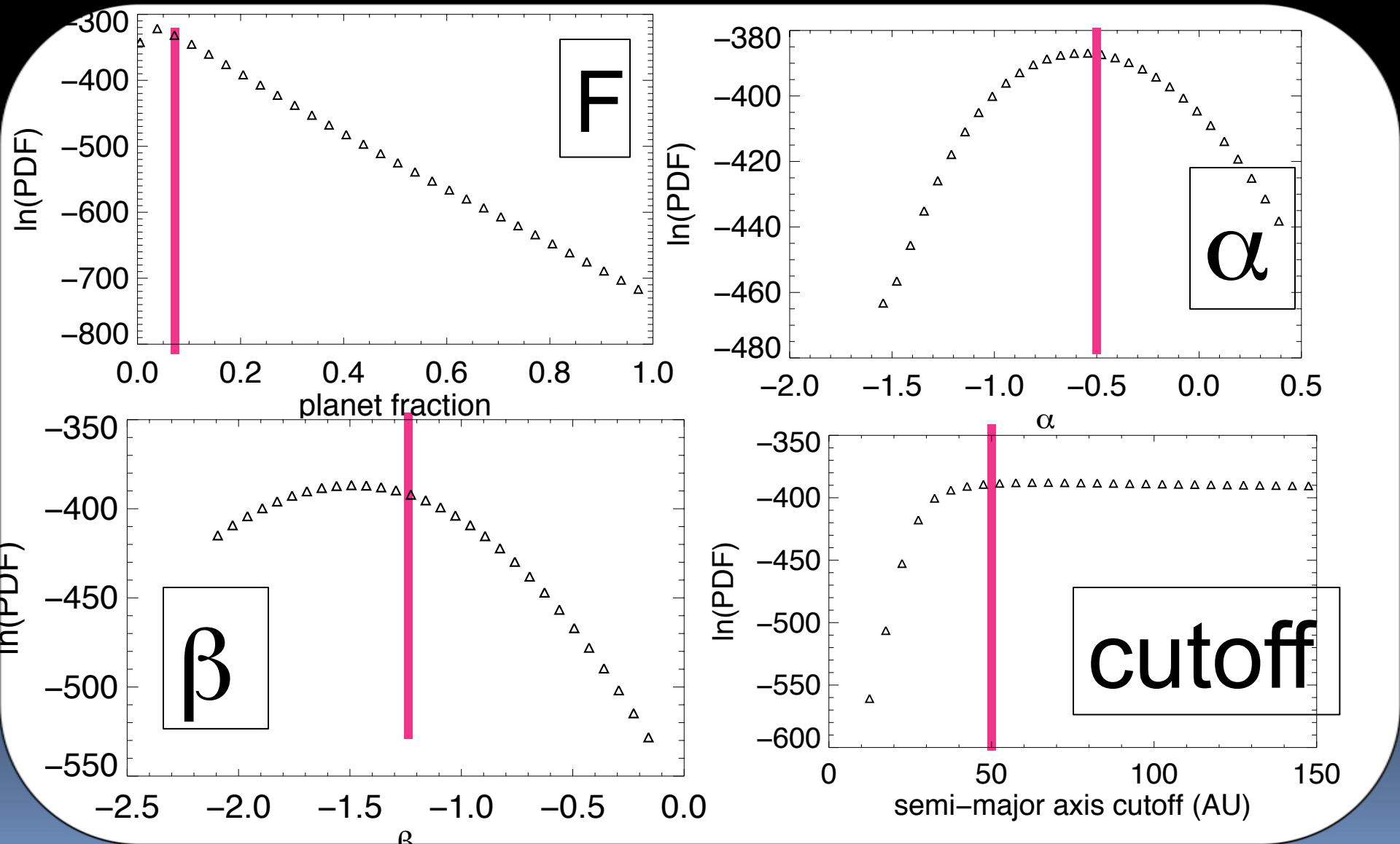
Posterior PDF

$$\text{prob}(\text{model}|\text{data},I) \propto \text{prob}(\text{data}|\text{model},I) \times \text{prob}(\text{model}|I)$$

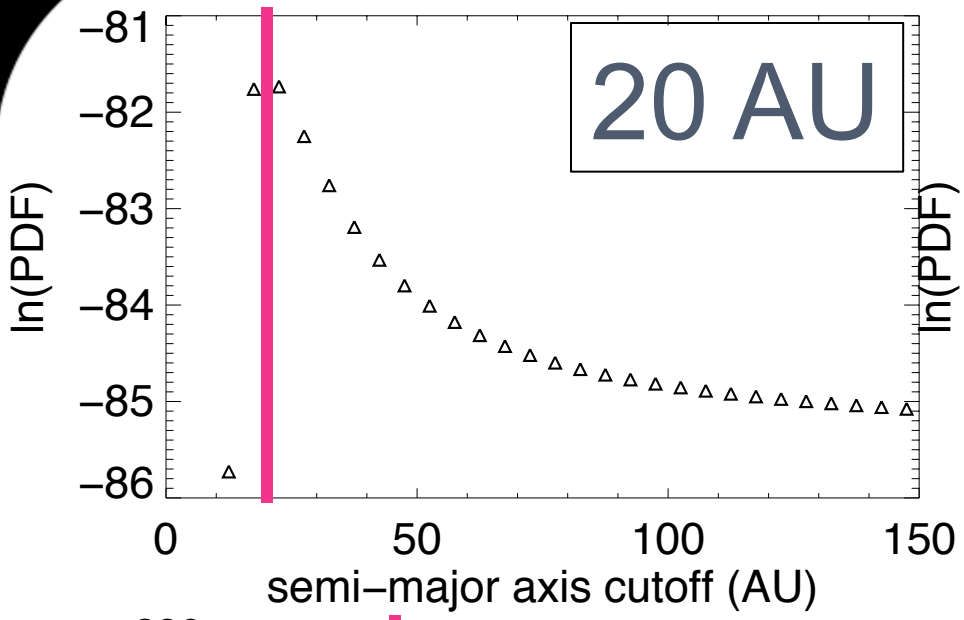
Likelihood Function

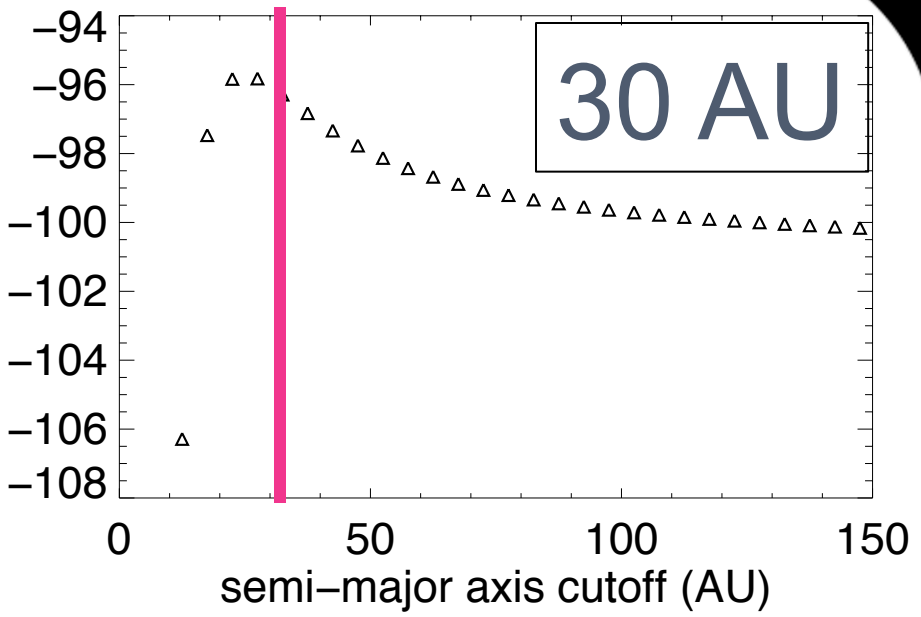
Prior

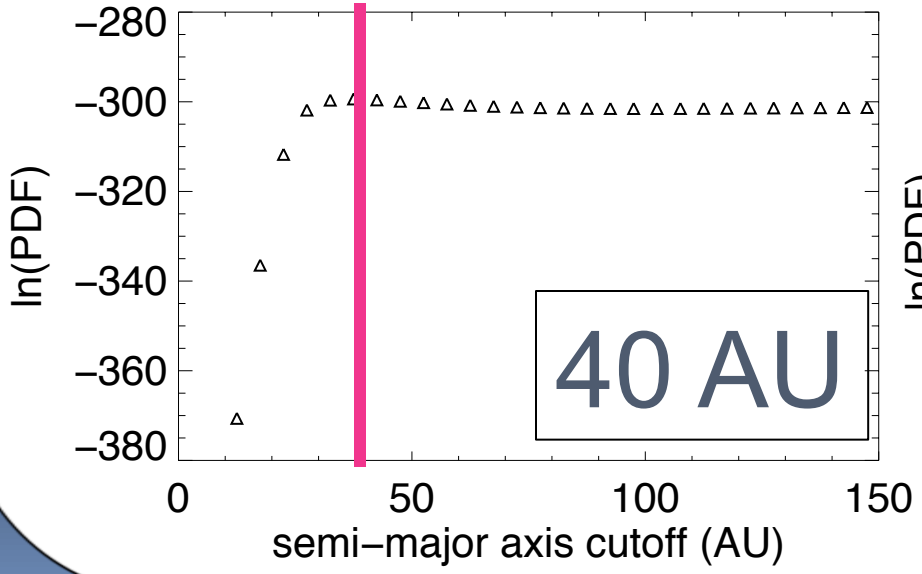
Same thing, Gaussian priors on α and β

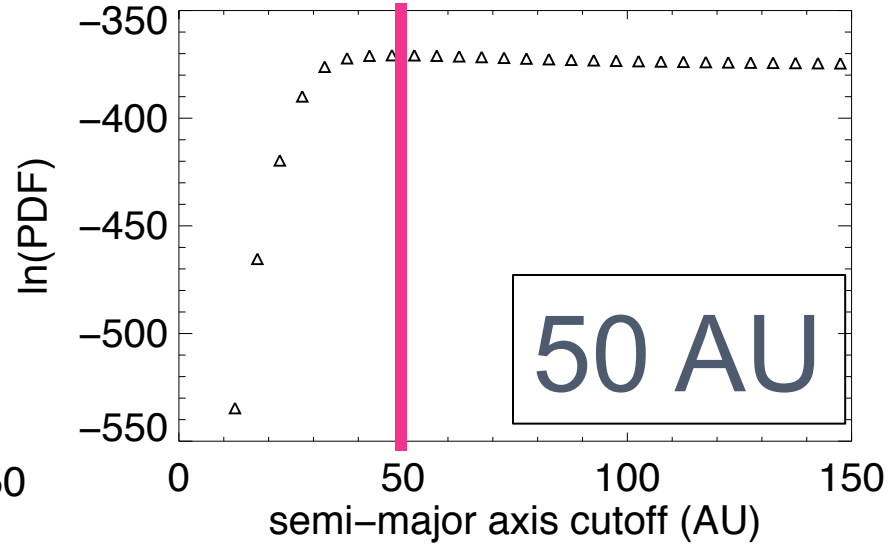


Constraints on Cutoff









Constraints on Cutoff- Gaussian Priors