Gemini NICI Planet-Finding Campaign: Statistical Constraints on Planet Populations

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and the NICI Planet-Finding Campaign Team

Gemini NICI Planet-Finding Campaign

Three-year campaign at Gemini South 8.1m telescope for direct imaging of exoplanets, PI Michael Liu.

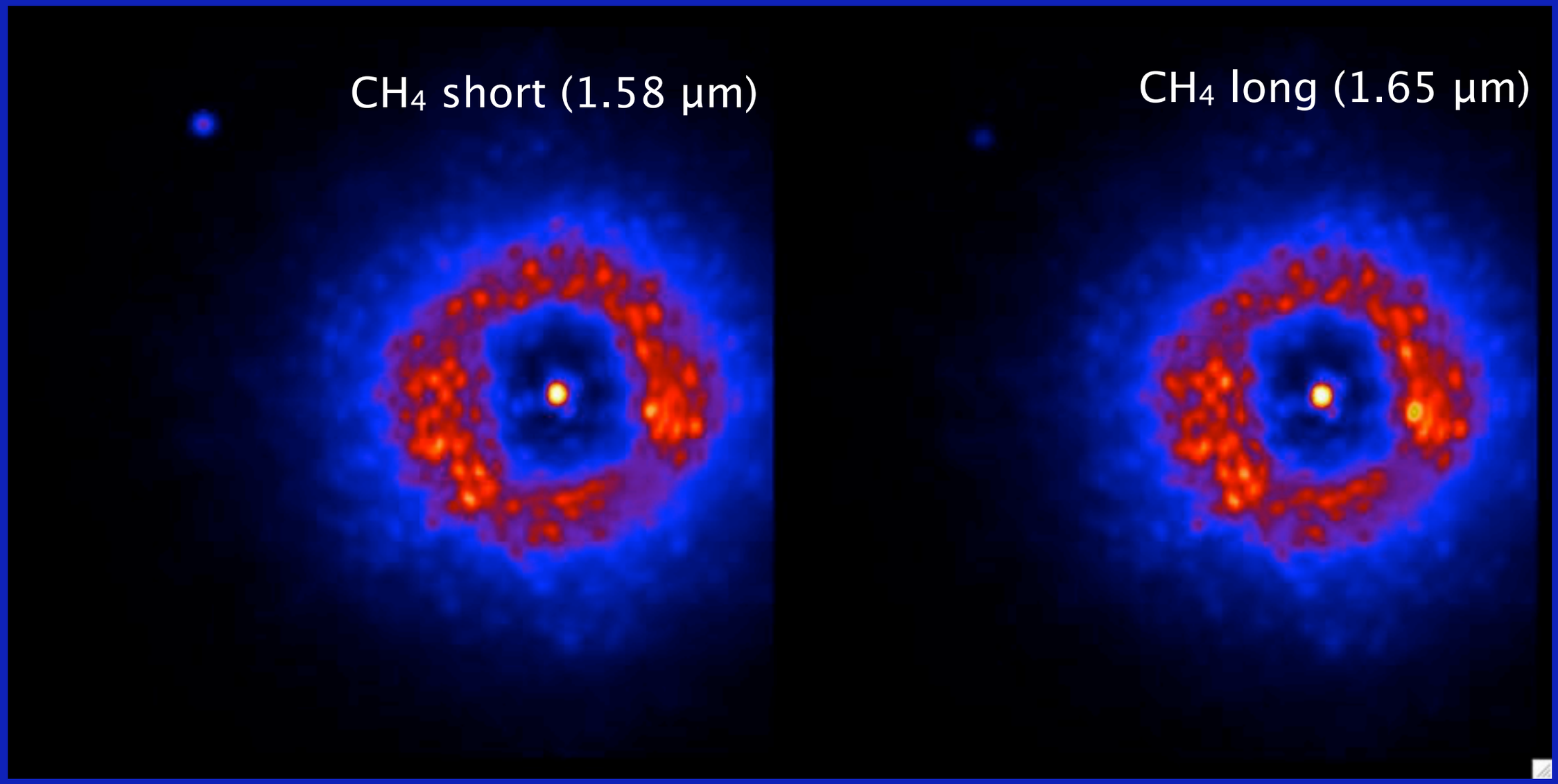
500 queue hours, ~300 young stars

Campaign science questions:

1. What is the **frequency** of gas-giant planets at >5-10 AU?
2. How does planet frequency **depend on stellar mass?**
3. What do the **SEDs** of young planets look like?

Started in December 2008, completion mid 2012

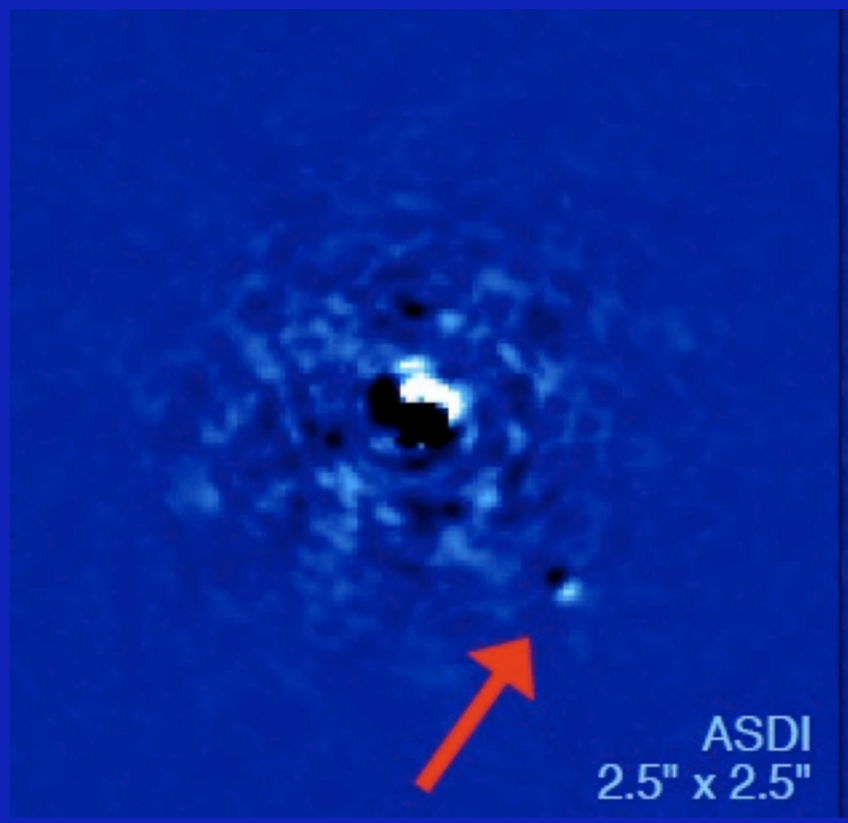
NICI = Dedicated exoplanet imager

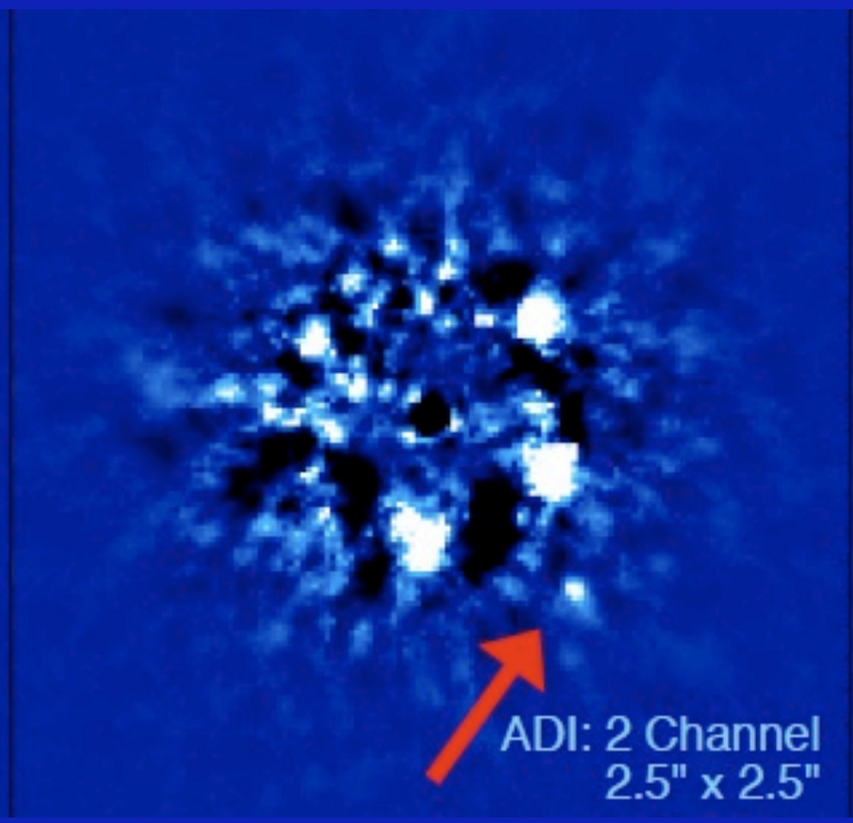


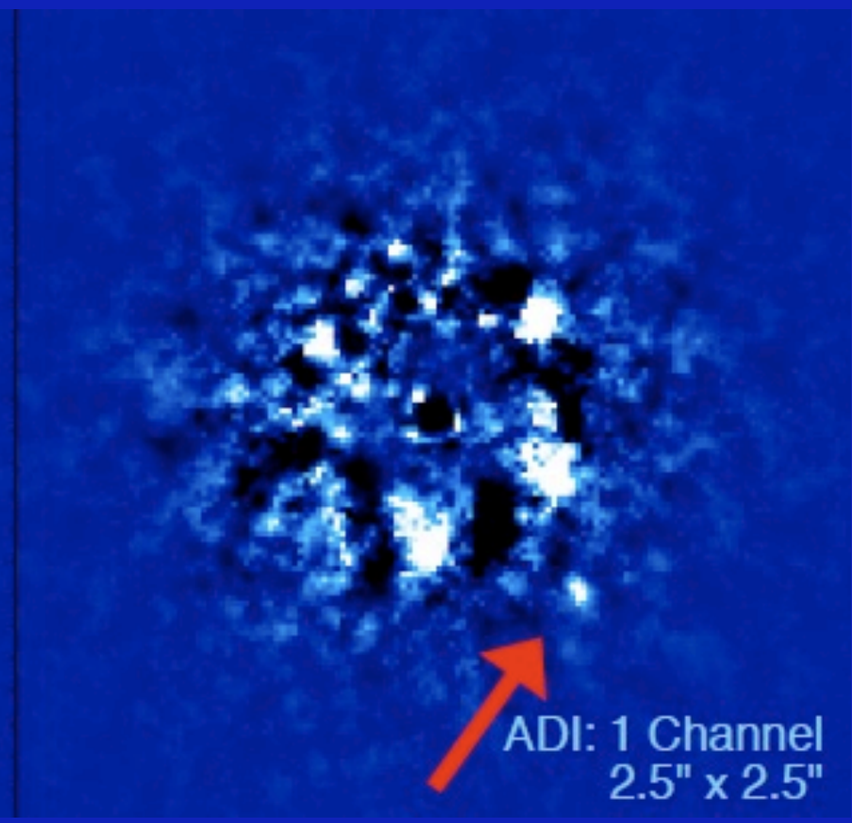
1. High-order NGS AO: UH 85-element curvature system
2. Spectral Differential Imaging (SDI)
3. Roll subtraction (ADI = Angular Differential Imaging)
4. Lyot Corongraphy

What if young exoplanets don't have methane?

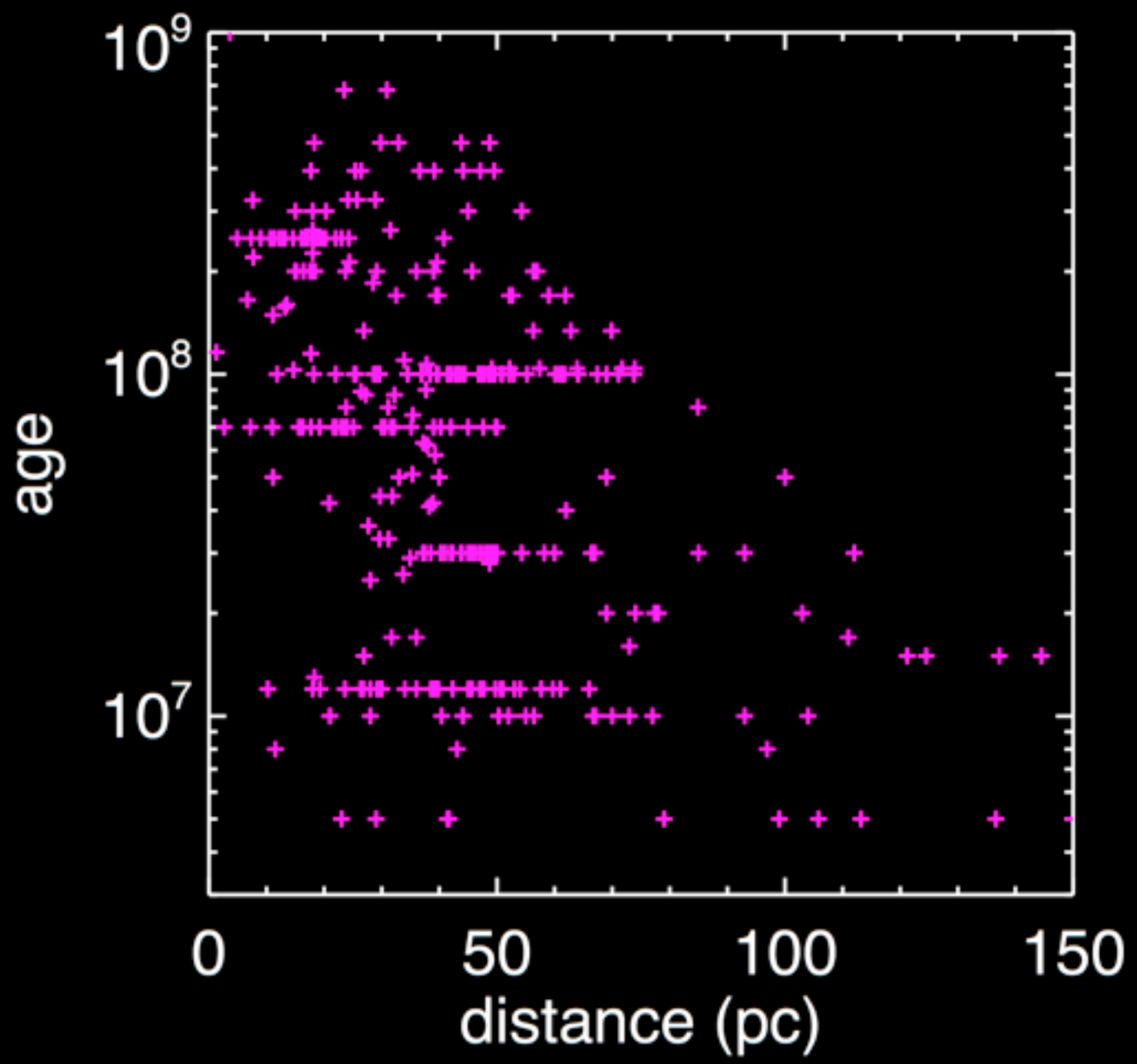
NICI is sensitive to faint companions with AND without CH_4

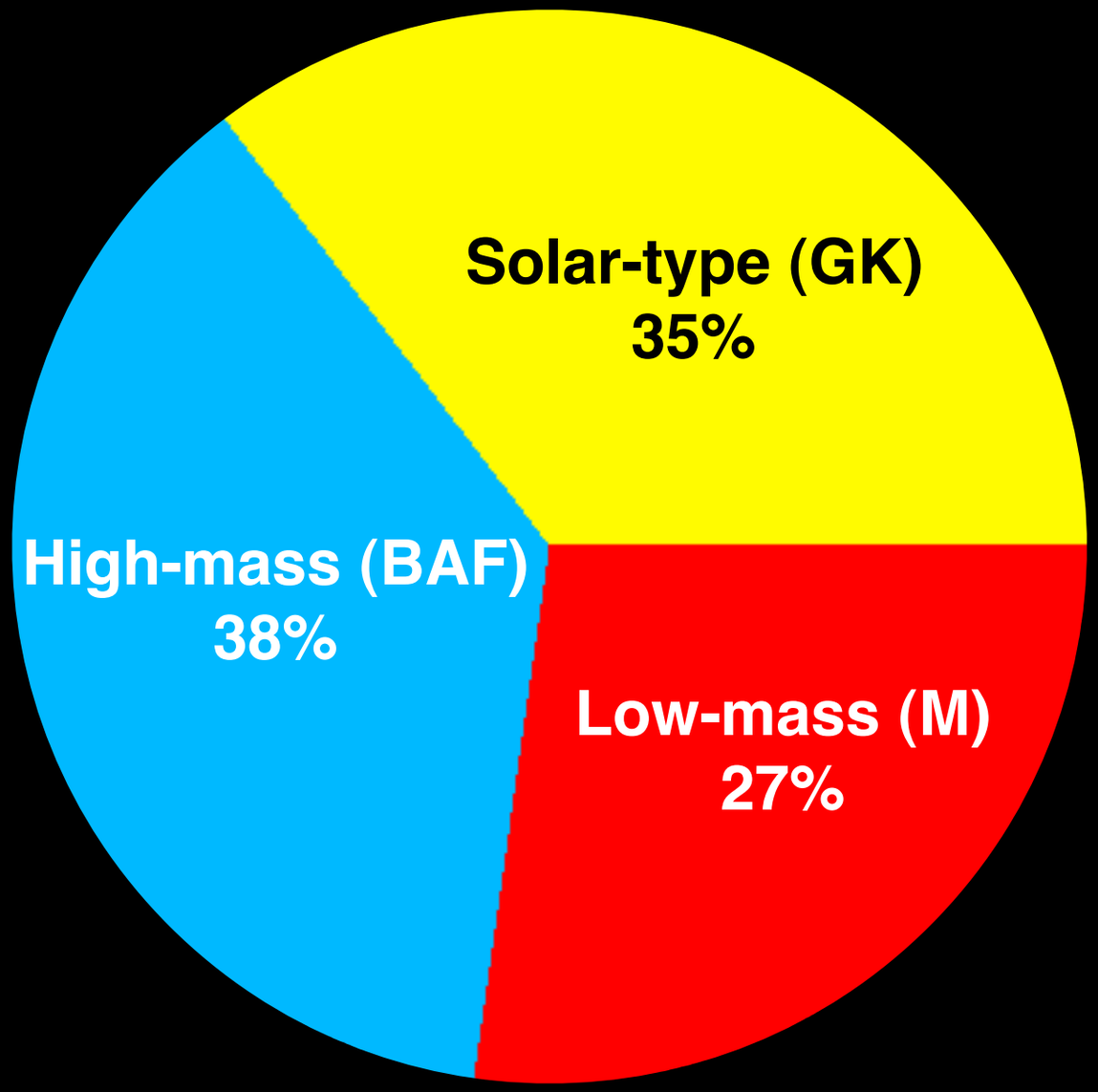






The NICI Campaign is targeting ~300 carefully chosen stars, spanning a range of ages, distances, and masses





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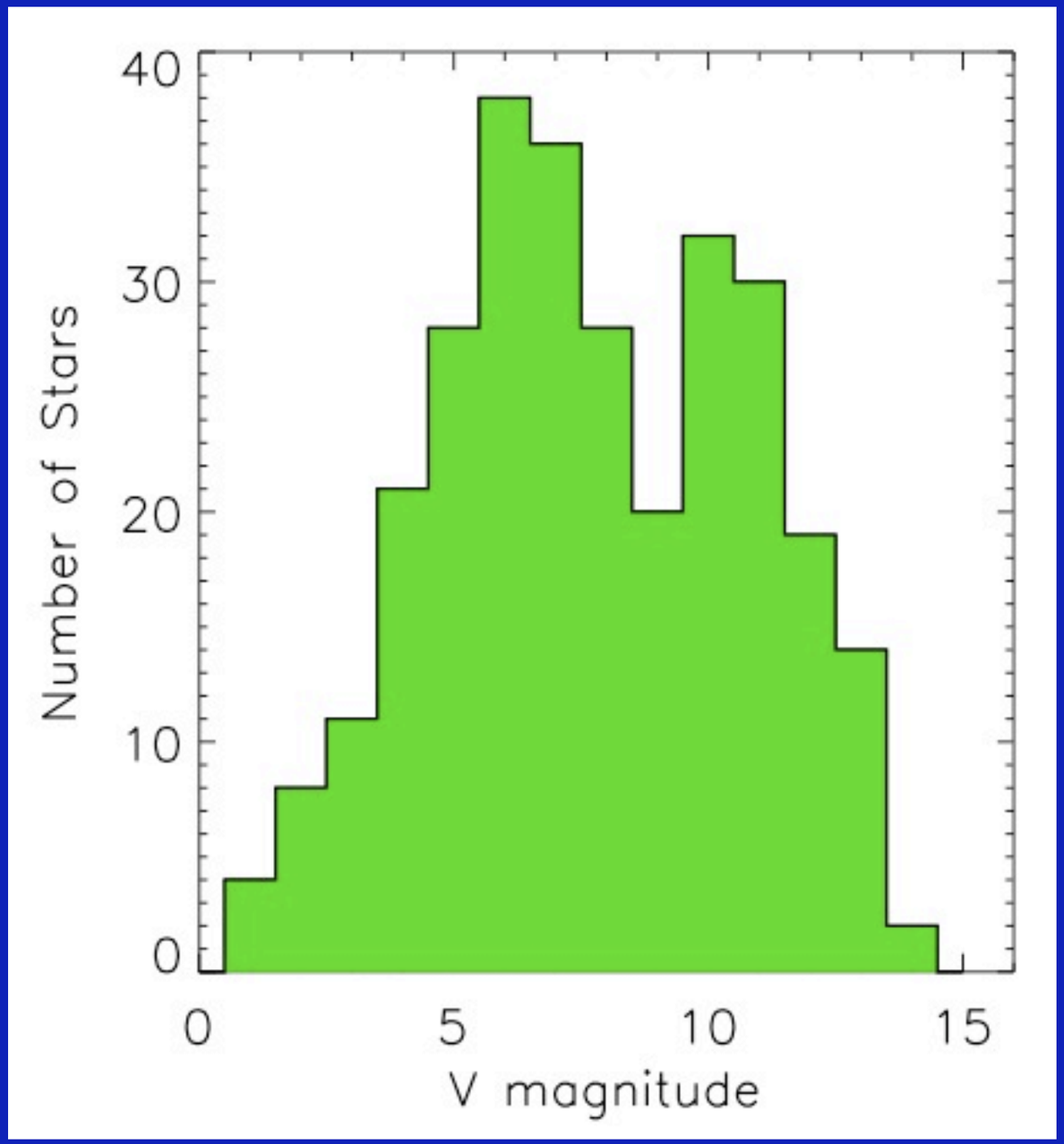
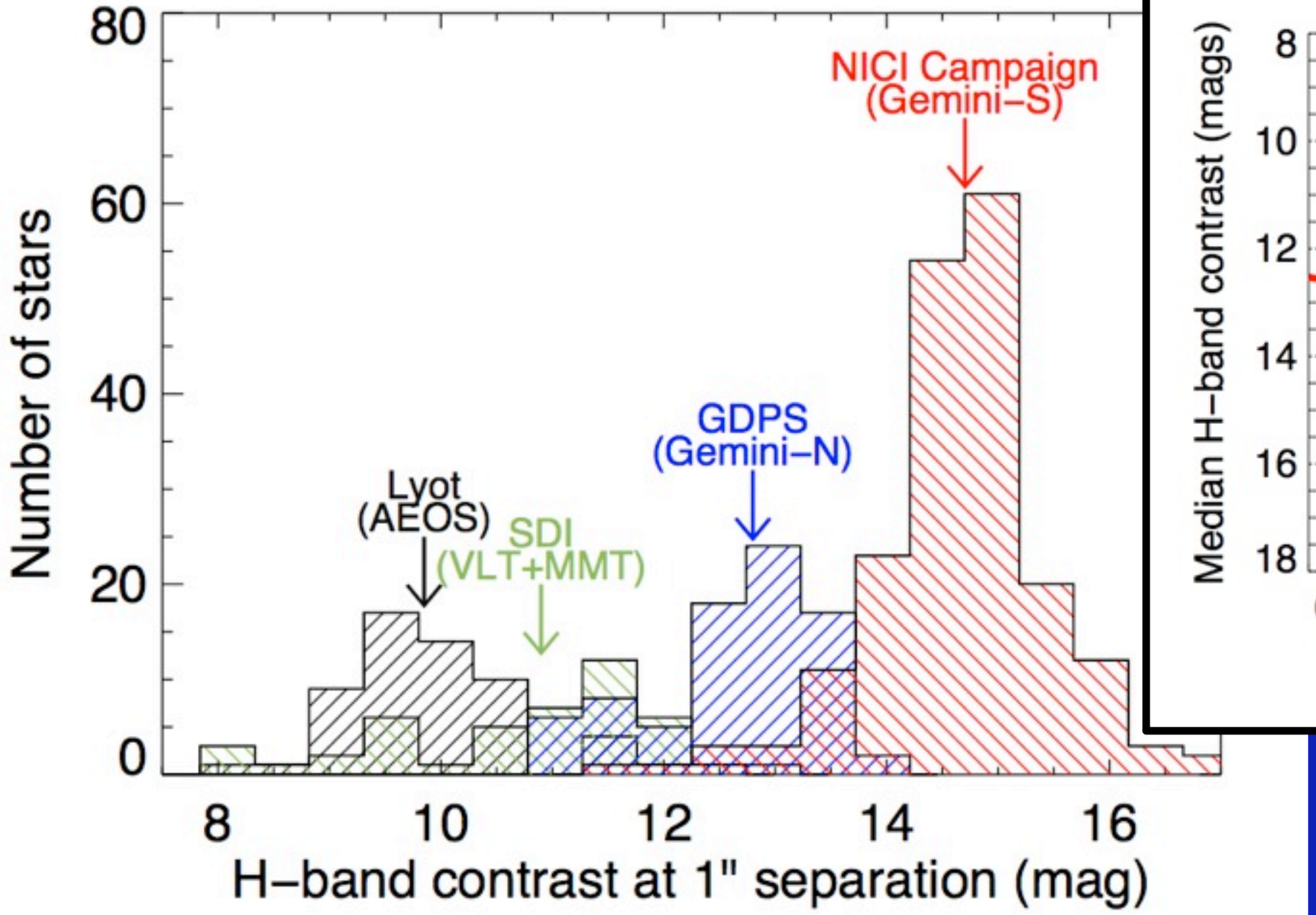
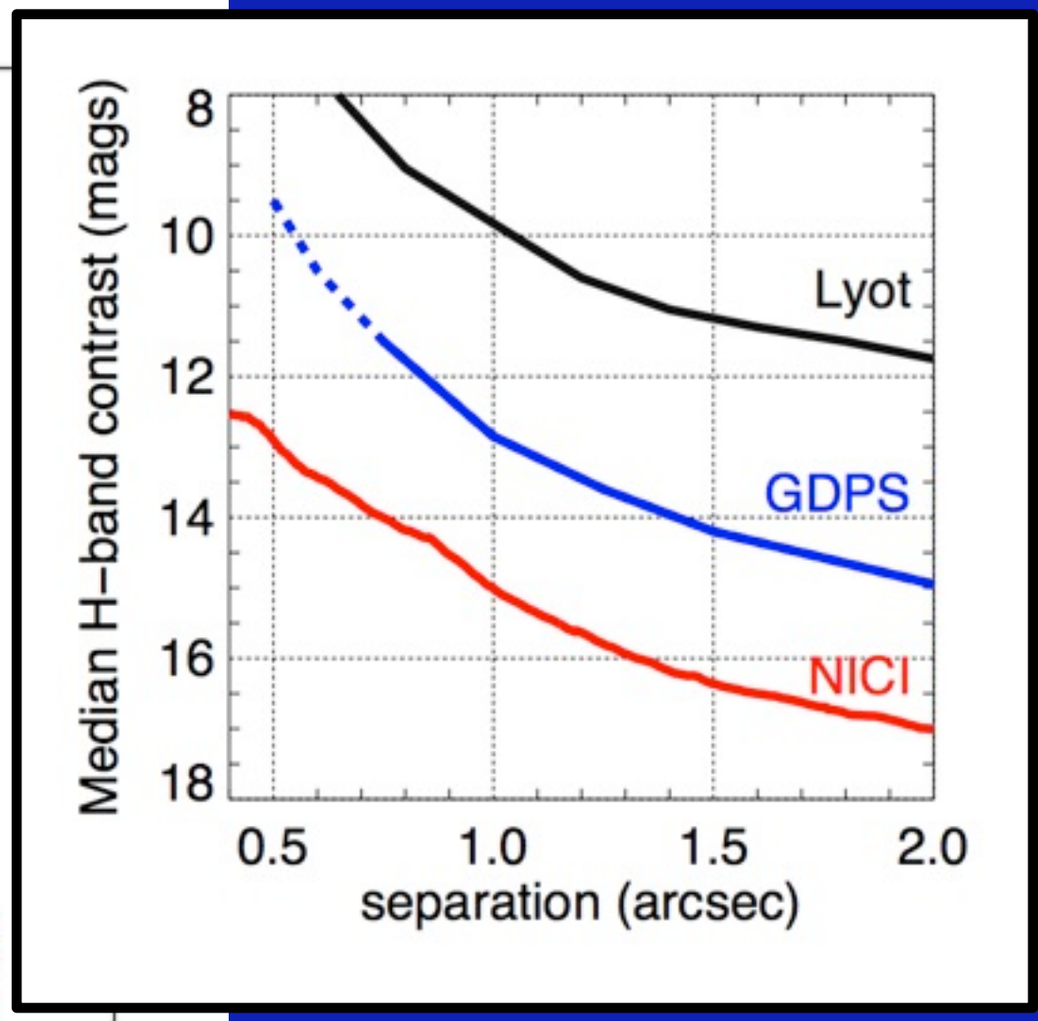


NICI is the largest, deepest direct imaging survey for exoplanets conducted to date





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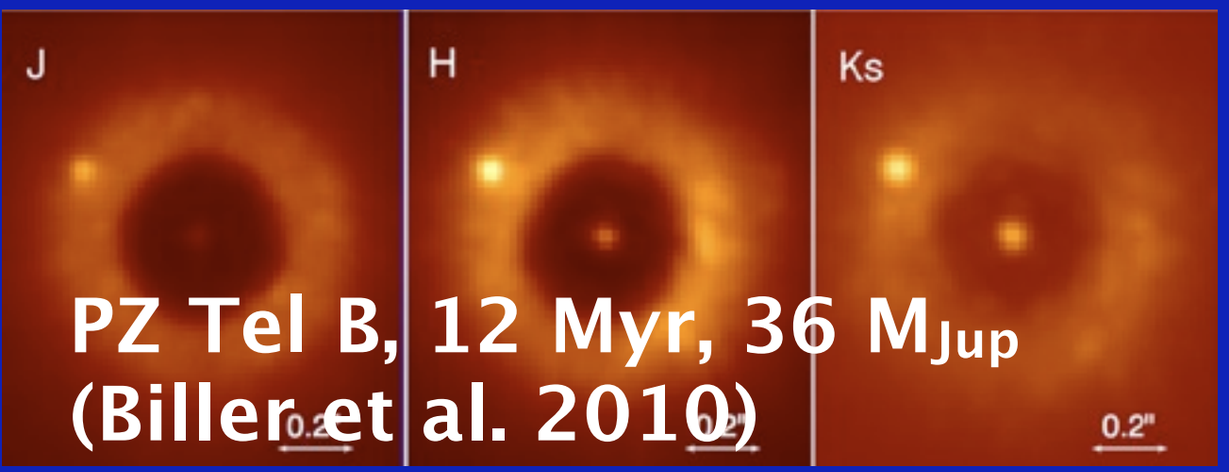
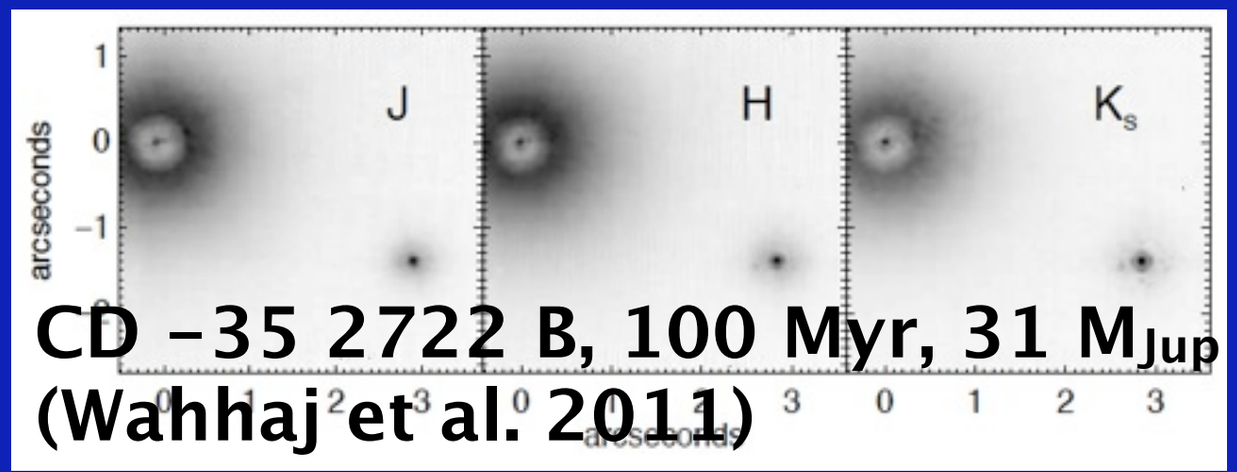
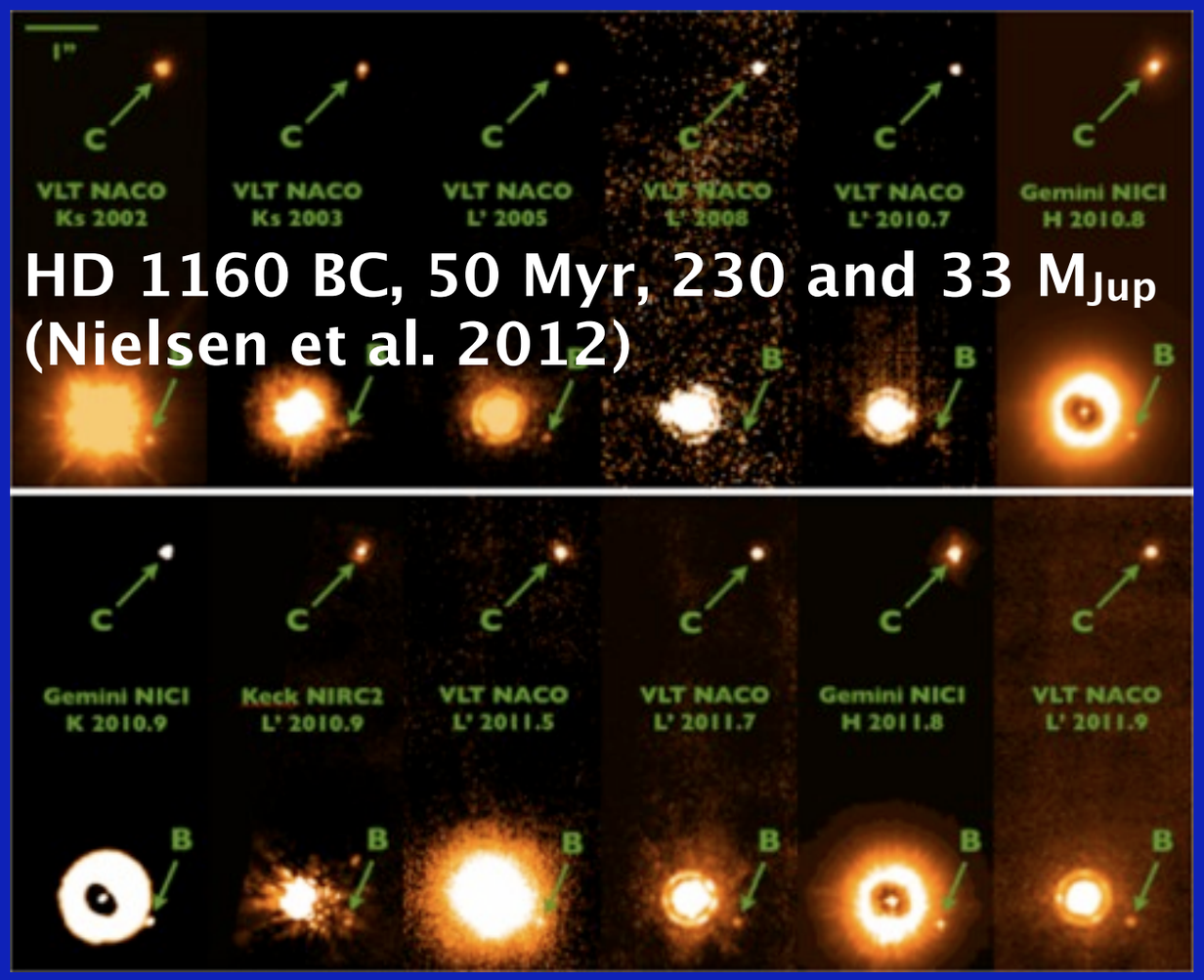


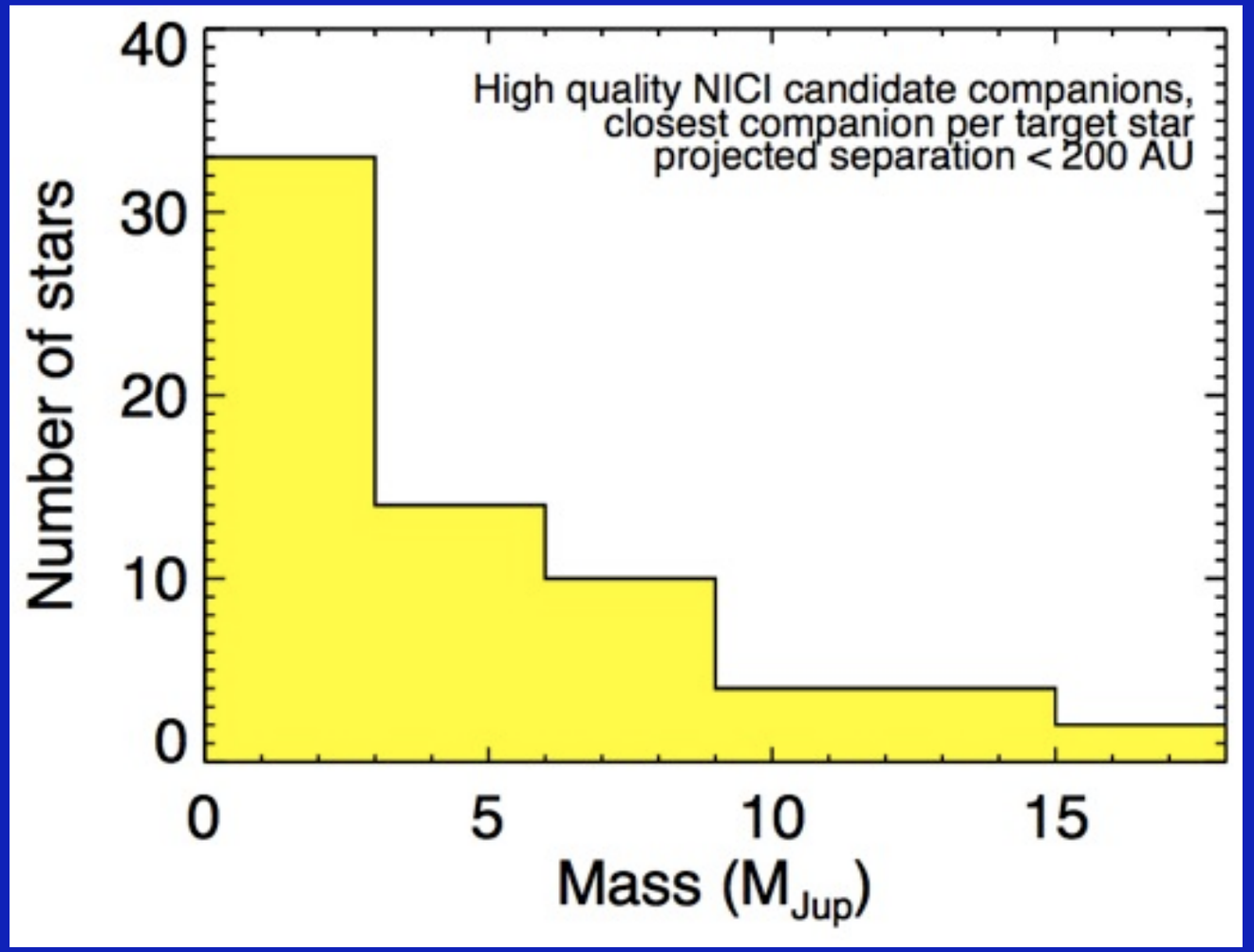
PZ Tel B, 12 Myr, 36 M_{Jup} (Biller et al. 2010)



CD −35 2722 B, 100 Myr, 31 M_{Jup} (Wahhaj et al. 2011)

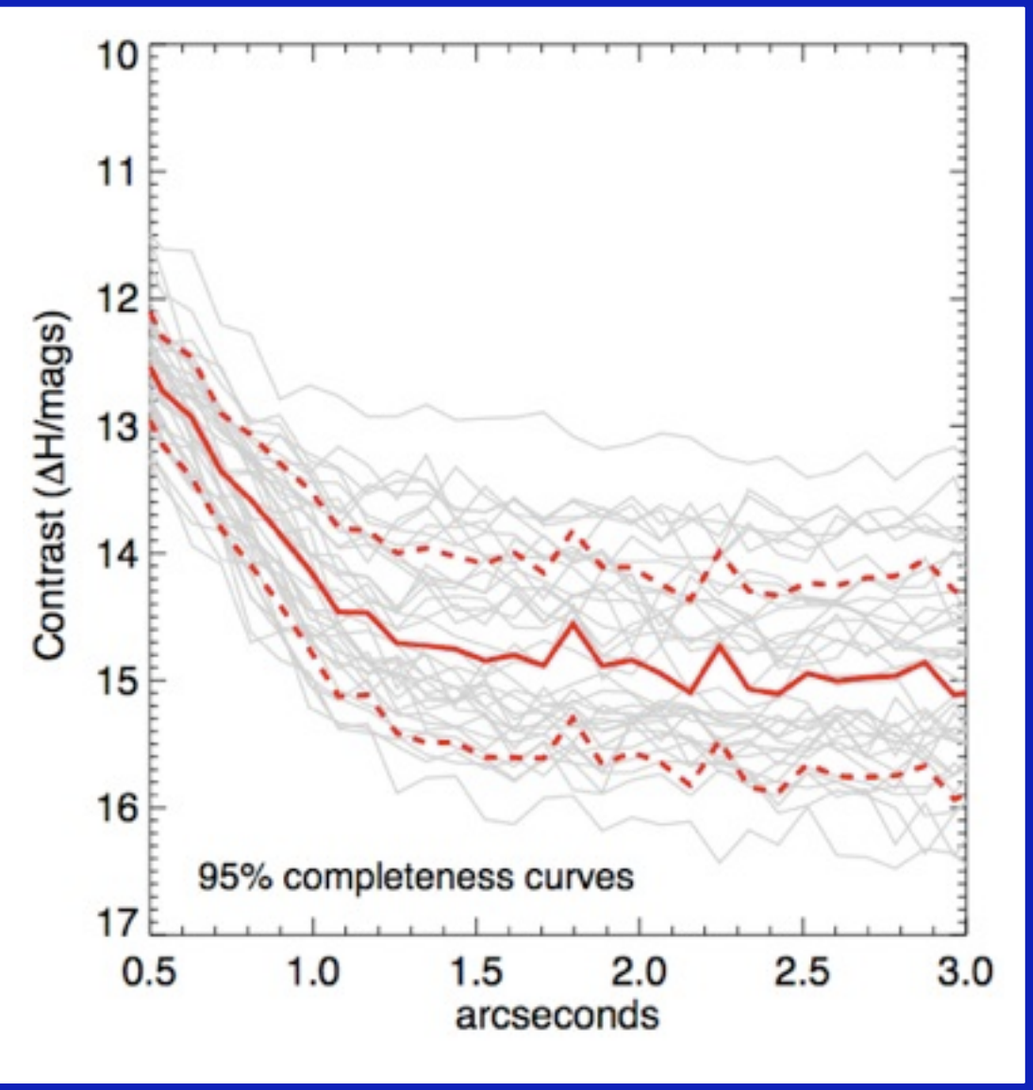


HD 1160 BC, 50 Myr, 230 and 33 M_{Jup} (Nielsen et al. 2012)



Turning contrast curves into constraints on extrasolar planet populations

Data



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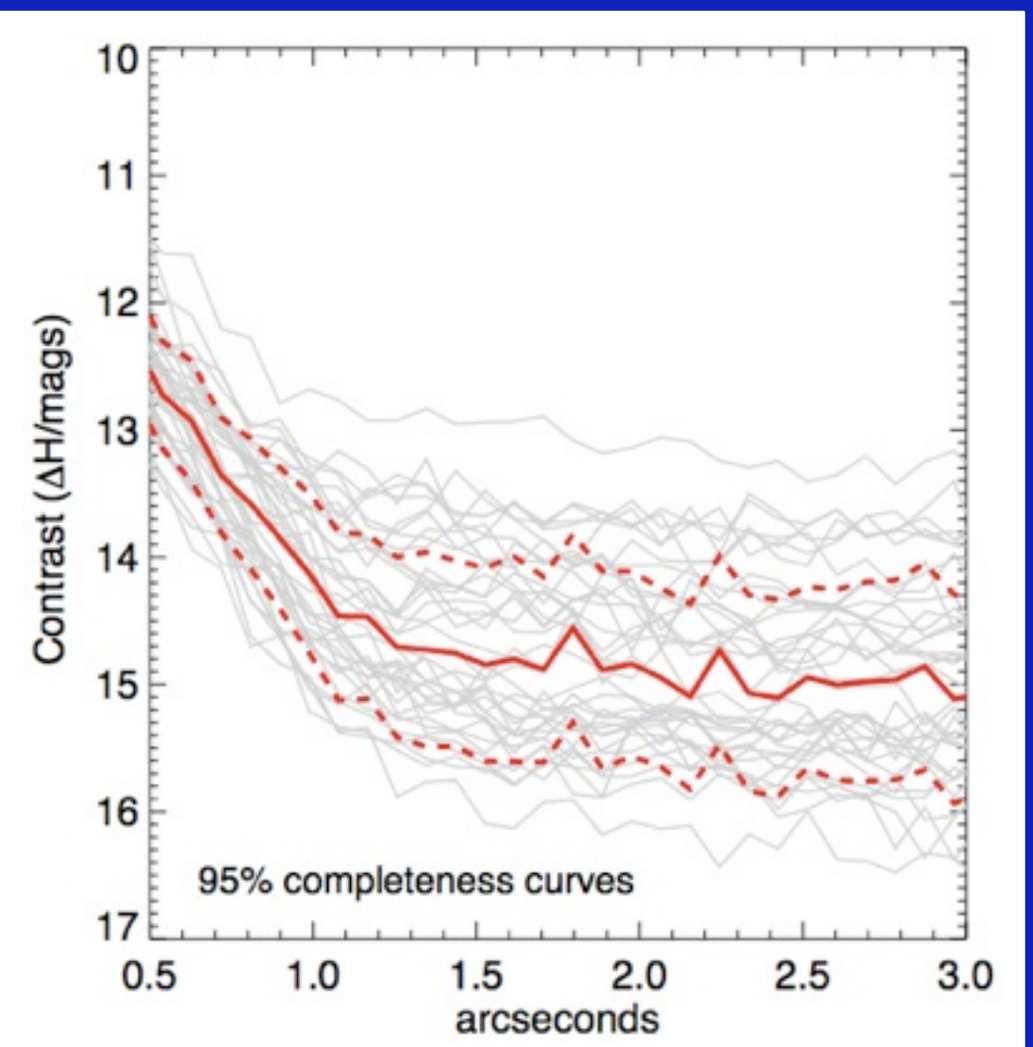


Planet Properties

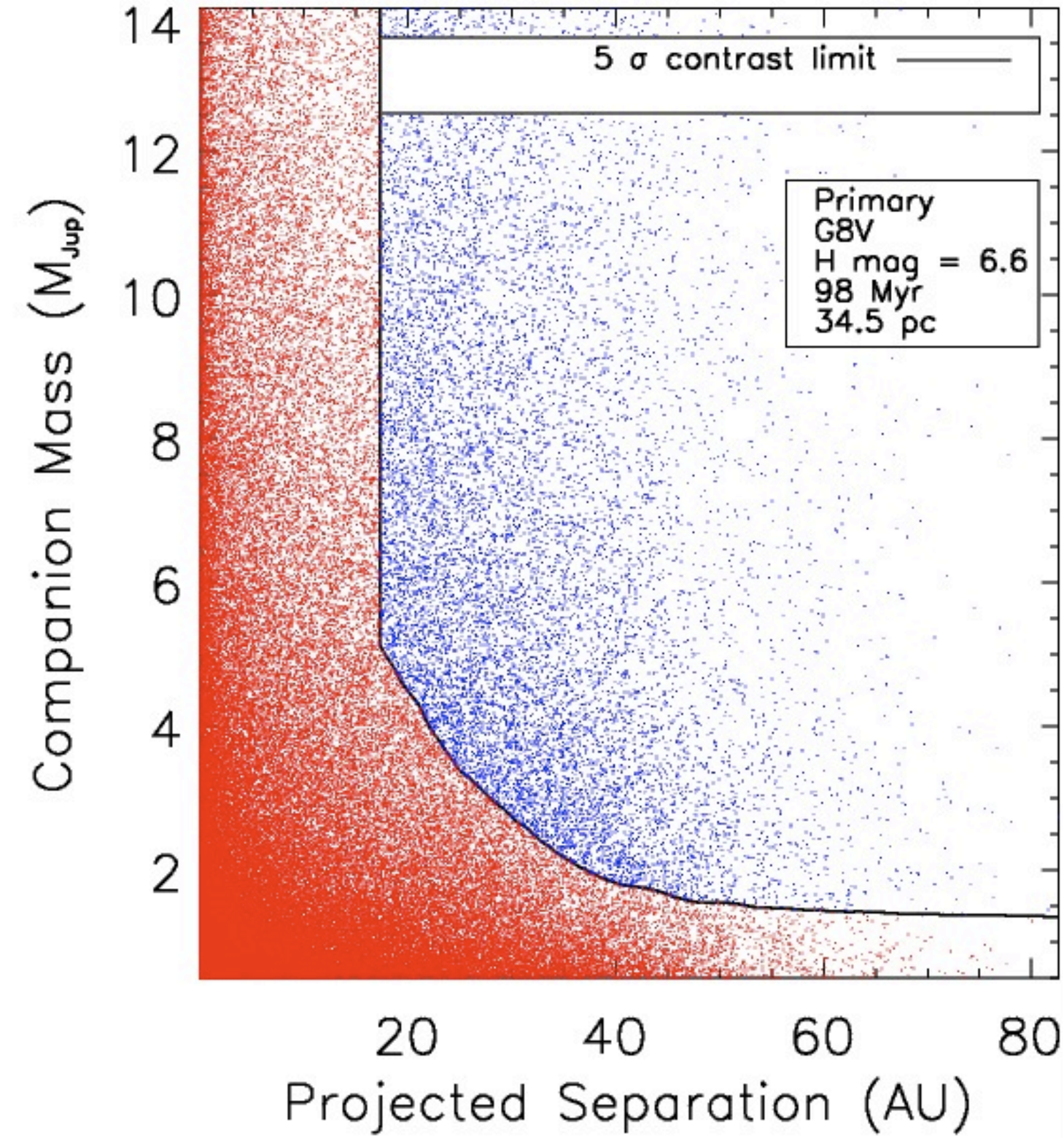
1. Planet frequency (and mass dependence)

2. Mass distribution ($dN/dM \propto M^{\alpha}$)

3. Semi-major axis distribution ($dN/da \propto a^{\beta}$)

4. Semi-major axis upper cut-off

Turning contrast curves into constraints on extrasolar planet populations



Simulations follow Nielsen et al. (2008) and Nielsen & Close (2010)

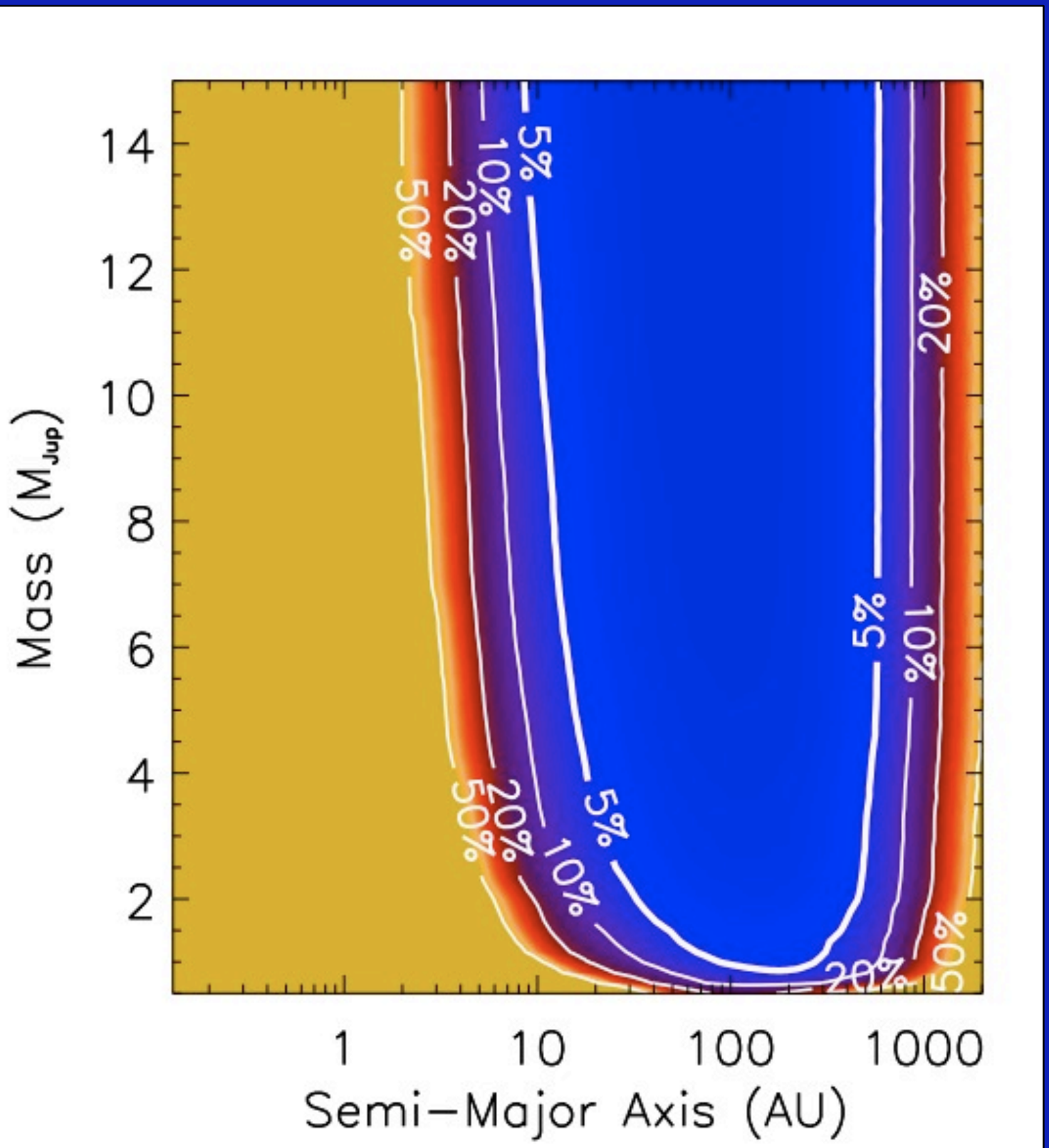
Simulation inputs:

1. Planet luminosity model (in this talk, hot start models of Burrows et al. 2003)

2. RV eccentricity distribution

3. Stellar host mass/planet frequency relation (Johnson et al. 2010)

Limits on Fraction of Stars with Planets



227 NICI stars (so far)

+ 118 previously-observed stars (Nielsen & Close 2010)

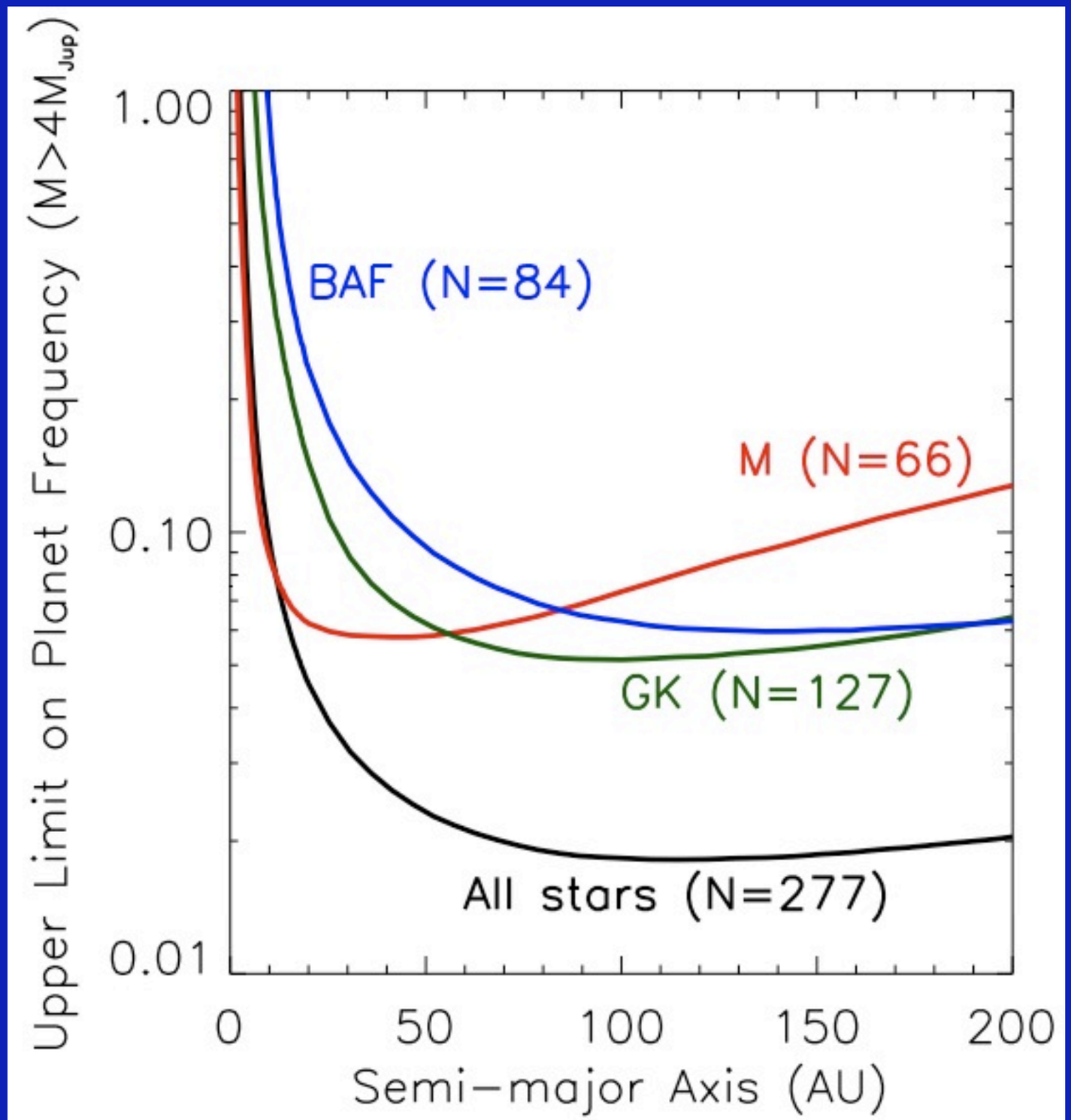
– 68 overlap stars

= 277 unique target stars

Contours show the upper limits on planet frequency, at 95% confidence

Inside inner contour, **fewer than 5%** of stars can have a giant planet (>4 M_{Jup}, 18–530 AU)

Constraints on Fraction of Stars with Long-Period Giant Planets



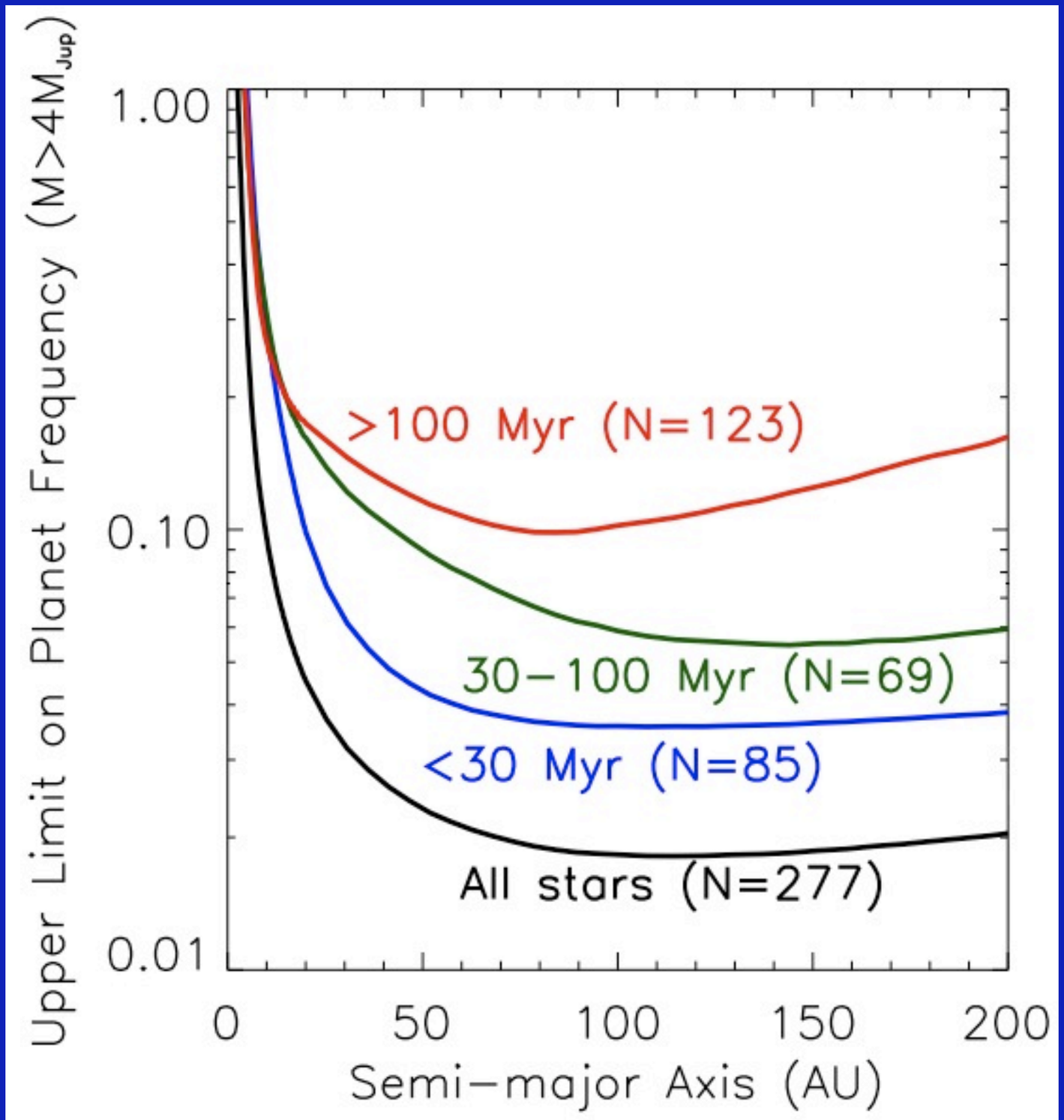
Upper limits on frequency of imaged planets (at 95% confidence) using hot start models:

<57% of high-mass stars should have a β Pic b (8 M_{Jup}, 9.6 AU)

<6% of high-mass stars should have an HR 8799 b (9 M_{Jup}, 68 AU)

Combining data from all spectral types, **less than 1 in 10** solar-type stars has a hot start giant planet (>4 M_{Jup}) **outside 10 AU**

Constraints on Fraction of Stars with Long-Period Giant Planets

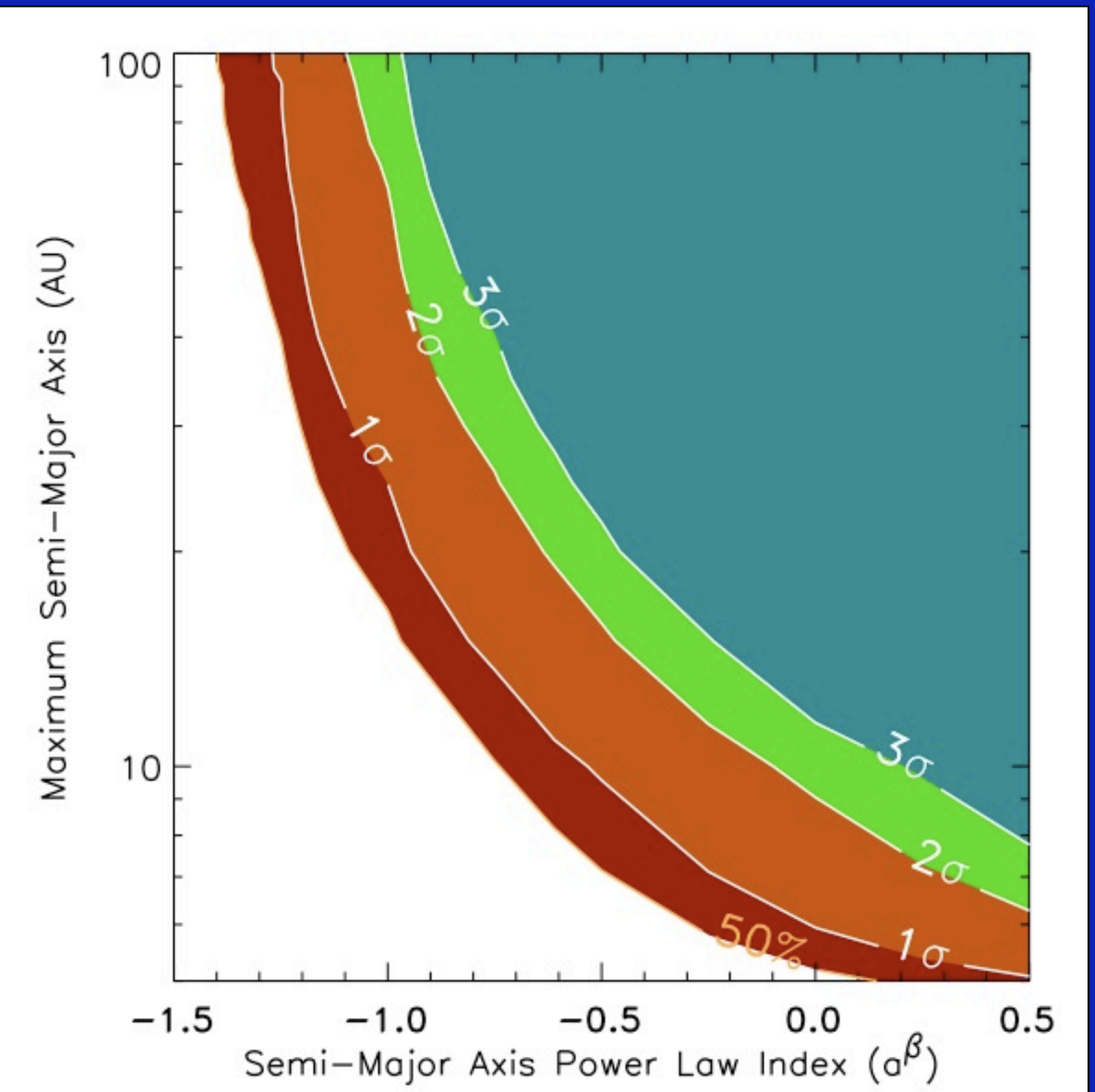


Constraints on planet frequency as a function of stellar age

Best constraints are for youngest stars (with the brightest planets)

Giant planets are rare at large separations at all ages

NICI's Preliminary Constraints on Semi-major Axis Distribution



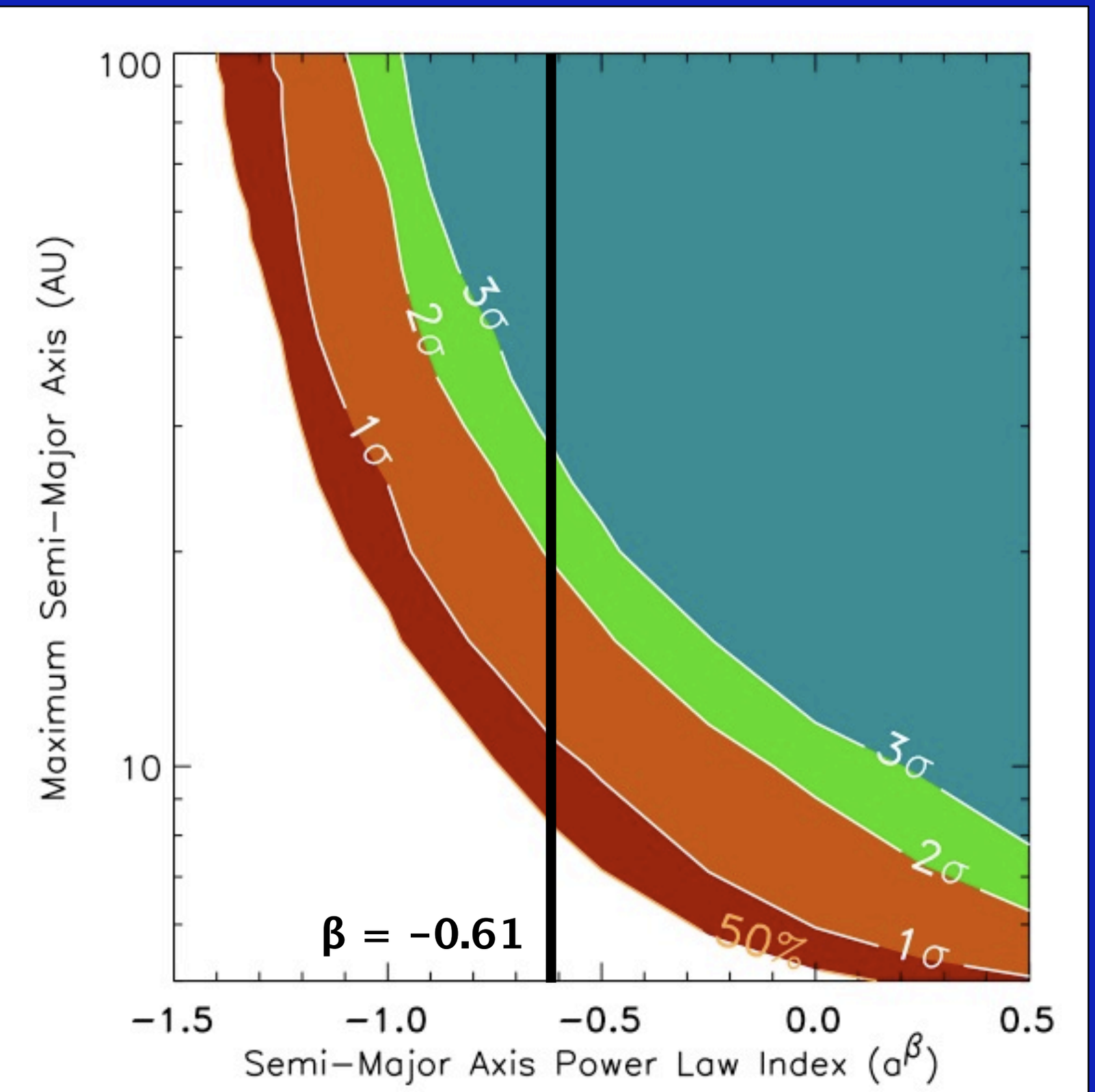
Assuming long-period planets follow RV semi-major axis distribution, 2σ limit on outer cut-off:

without NICI is 62 AU

with NICI is 19 AU

Assuming hot start models, RV planets and directly-imaged hot start planets must follow different distributions

NICI's Preliminary Constraints on Semi-major Axis Distribution



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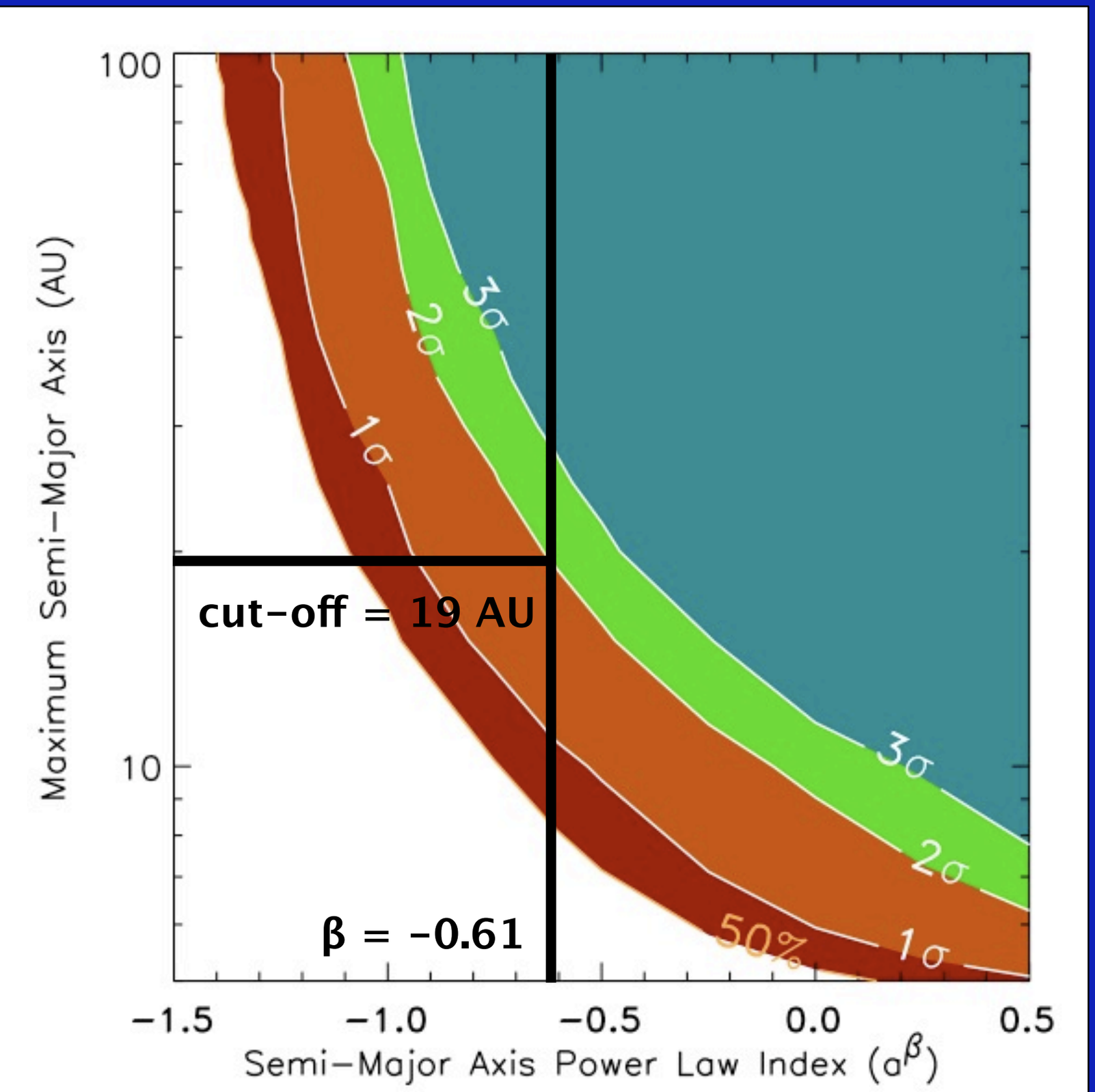

Assuming long-period planets follow RV semi-major axis distribution, 2σ limit on outer cut-off:

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Conclusions

We aim to finish the NICI Campaign in mid-2012, our main focus now is 2nd epoch follow-up of candidates.

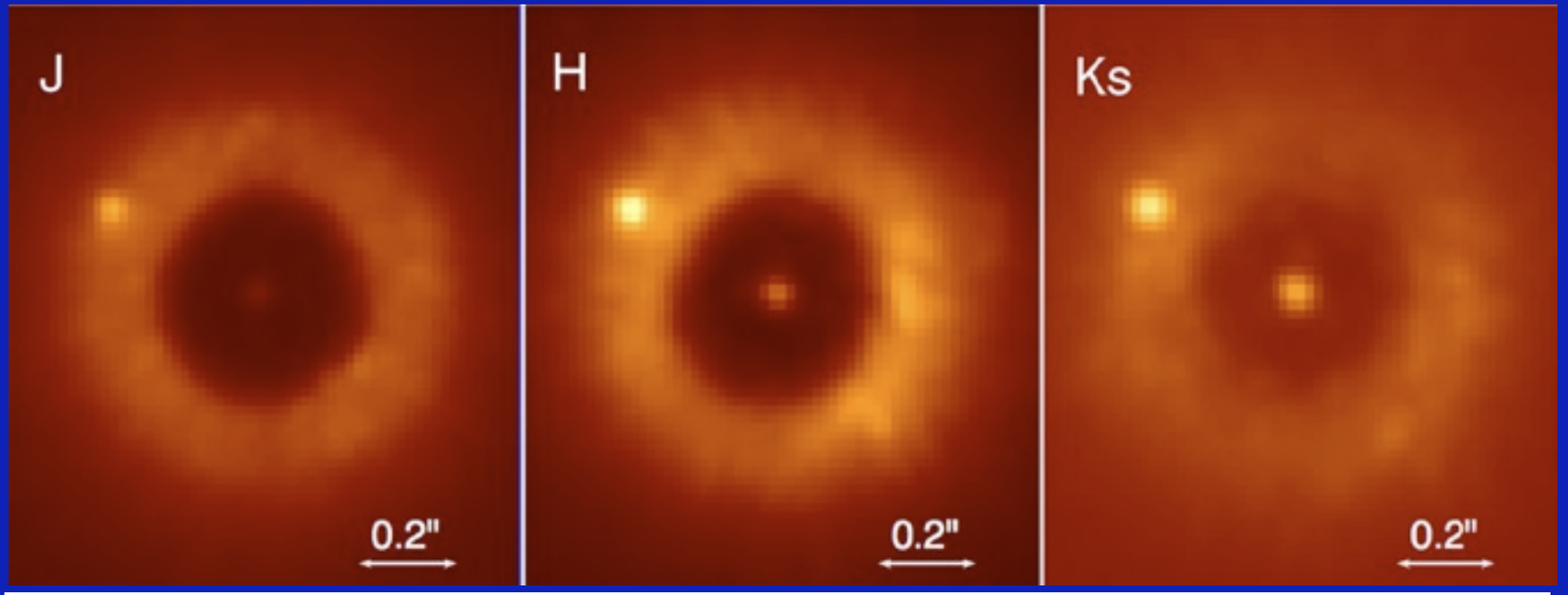
Preliminary results, assuming all non-detections:

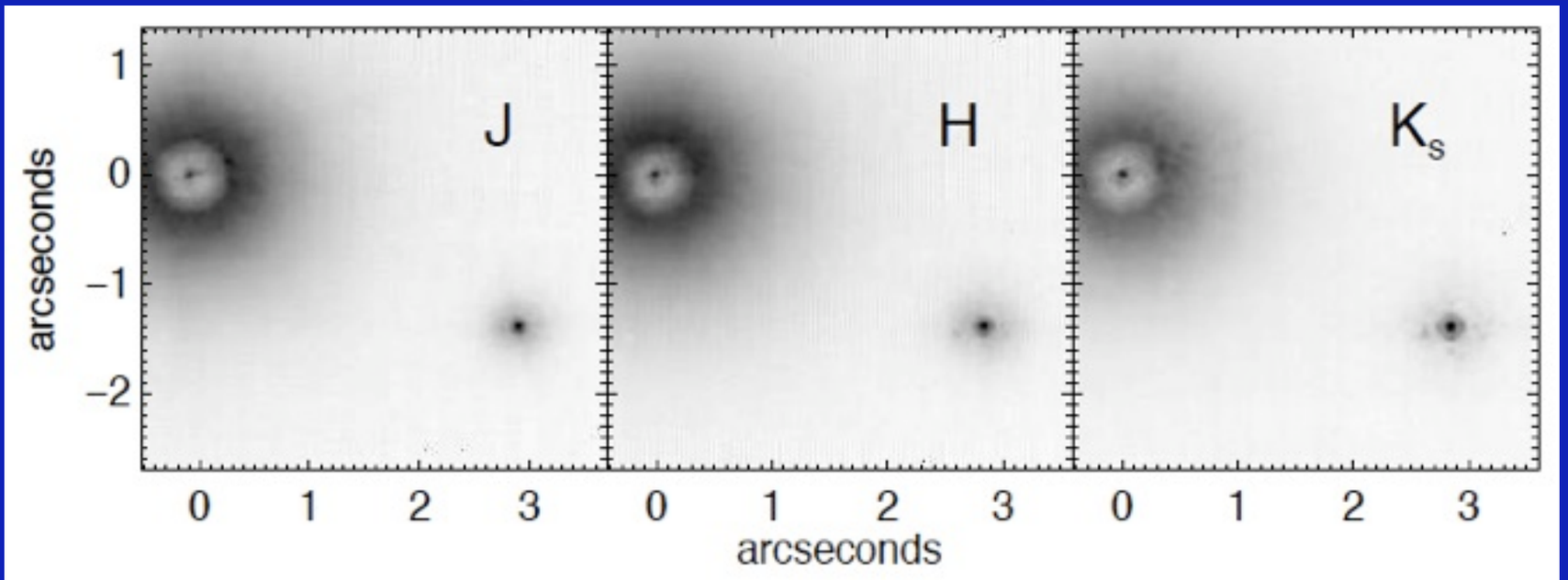
- **Less than 10%** of Sun-like stars have >4 M_{Jup} hot start planets **beyond 10 AU**.
  - Planets like HR 8799 b are rare: **fewer than 6%** of A stars should host such planets.

Scaling radial velocity giant planet distributions to large separations is **NOT consistent** with direct imaging detections and null results.

NICI's high contrasts and large sample size are placing unprecedented constraints on populations of extrasolar giant planets at large separations.

Extra slides

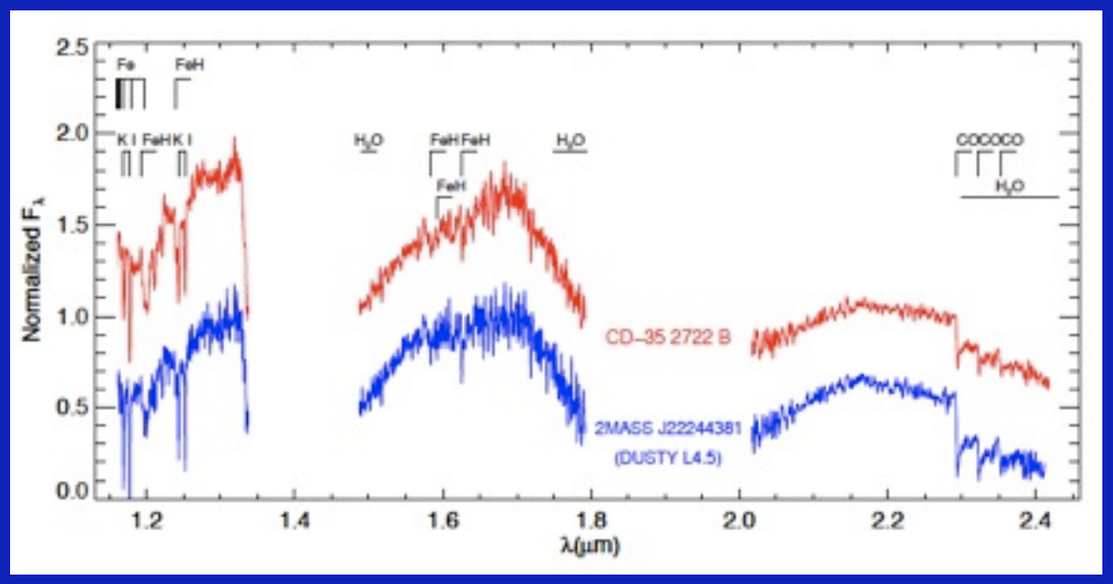




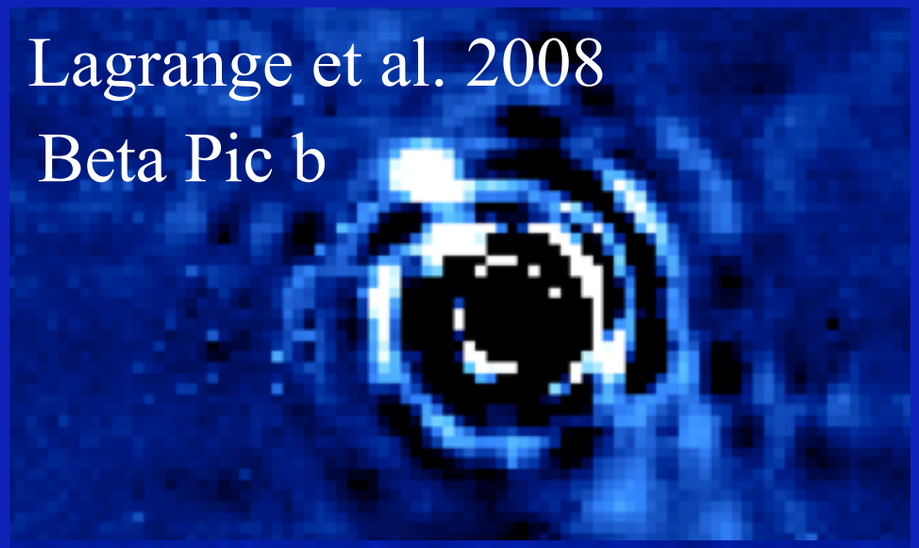
Biller et al. (2010)

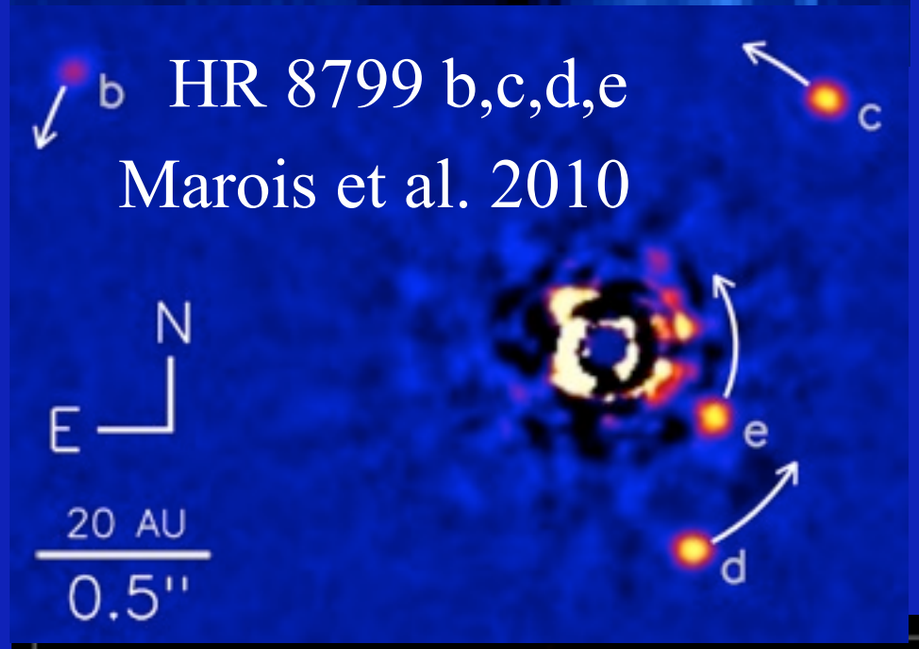
- PZ Tel B
- 36 M_{Jup}
- 0.36” (16 AU)

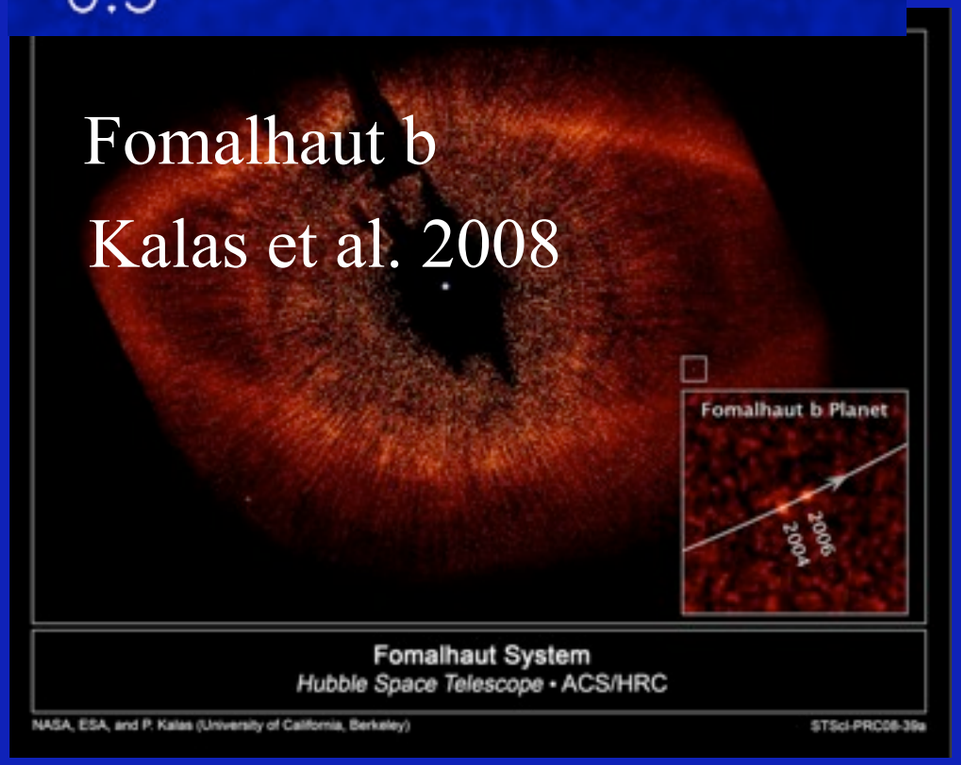
Published NICI Results



- Wahhaj et al. (2011)
  - CD −35 2722 B
  - 31 M_{Jup}
  - 3.1” (67 AU)


Lagrange et al. 2008
Beta Pic b


b
c
HR 8799 b,c,d,e
Marois et al. 2010
N
E
20 AU
0.5''
e
d


Fomalhaut b
Kalas et al. 2008
Fomalhaut b Planet
2006
2004
Fomalhaut System
Hubble Space Telescope • ACS/HRC
NASA, ESA, and P. Kalas (University of California, Berkeley)
STScI-PRC08-39a