First results of the International Deep Planet Survey: frequency of wide-orbit massive planets around A-stars

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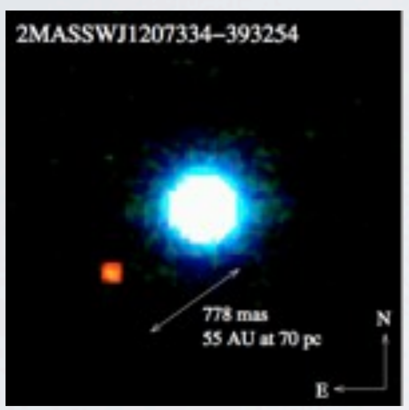
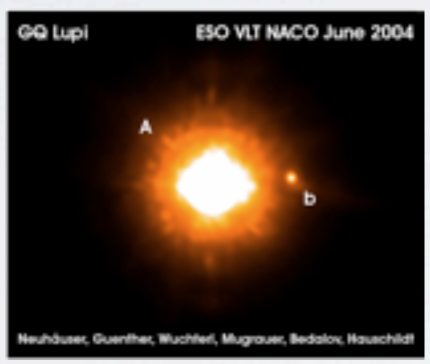
Motivations

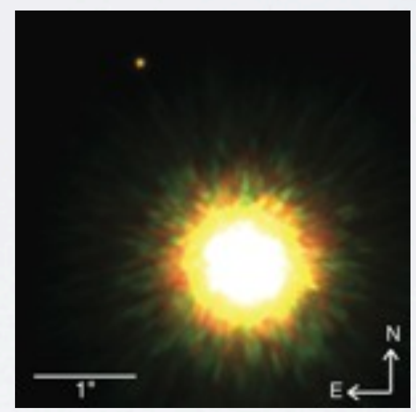
- Previous surveys focused on Solar-type stars
  (Masciadri et al. 2005; Lafrenière et al. 2007; Kasper et al. 2007; Leconte et al. 2010; Chauvin et al. 2007)
- Very few detections of sub-stellar companions
  → 2M 1207, AB Pic, 1RXS 1609, CT Cha, GQ Lup, ...



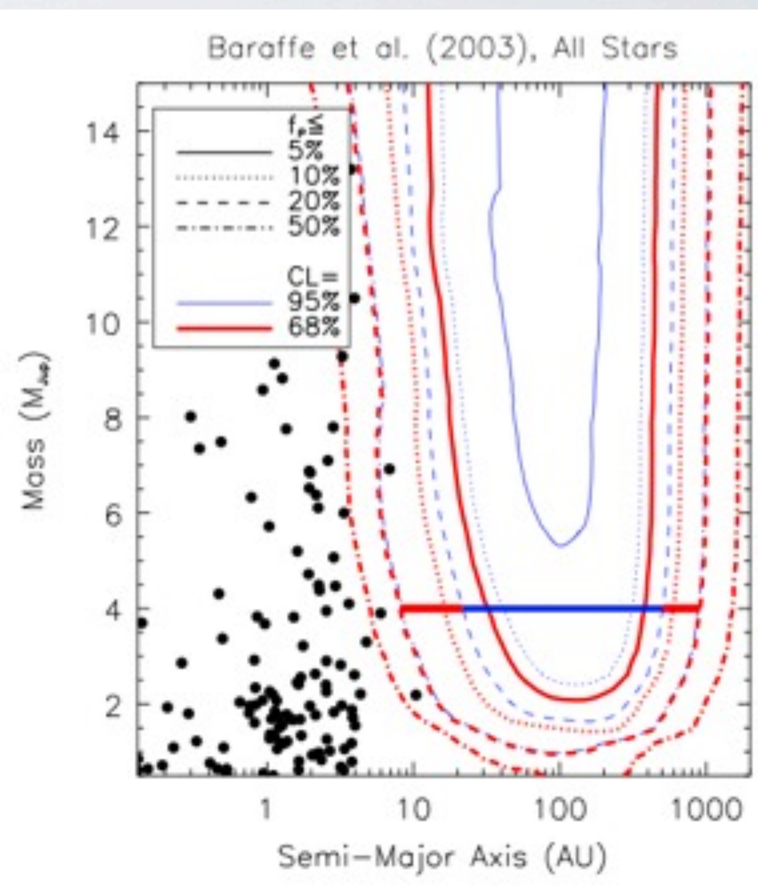
Chauvin et al. (2004)



Neuhauser et al. (2005)



Lafrenière et al. (2008)



Nielsen & Close (2010)

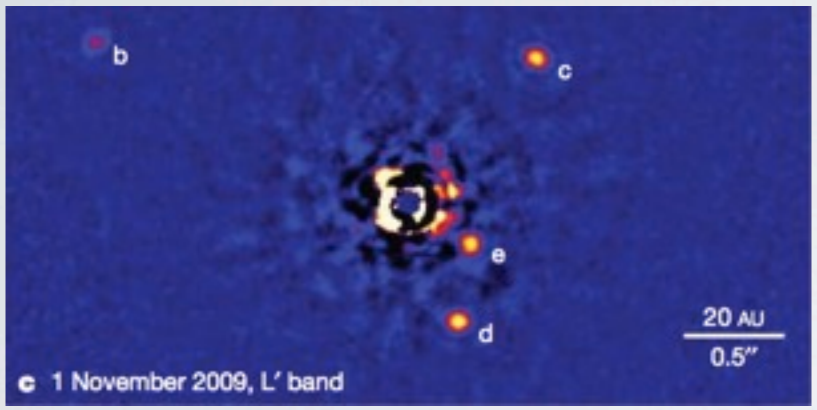
- 2012: few surveys focused on other types
  - very massive stars (Janson et al. 2011)
  - low-mass stars (Delorme et al. 2012)

Main conclusion: planets are rare around FGKM stars

Motivations

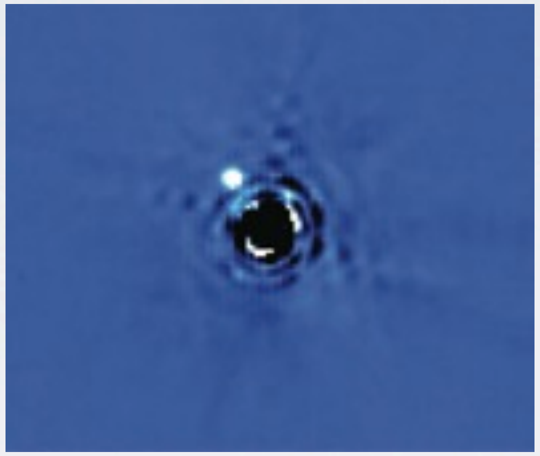
- Recent breakthrough discoveries around young A stars

HR 8799 - 30 Myr



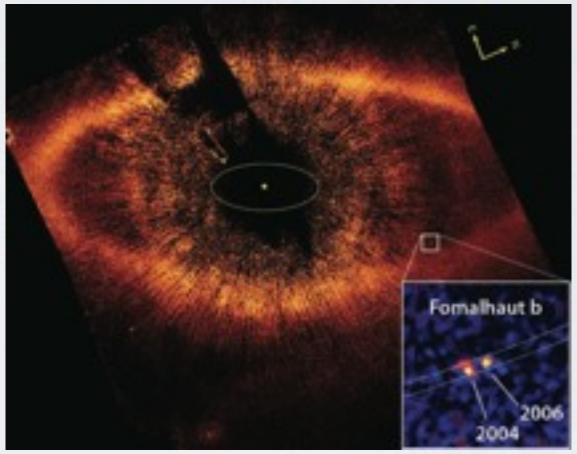
Marois et al. (2008, 2010)

β Pictoris - 12 Myr



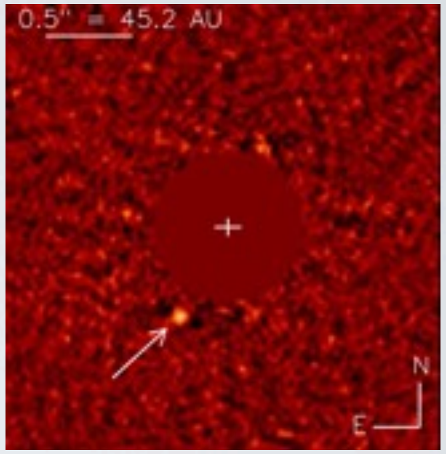
Lagrange et al. (2010)

Fomalhaut - 100-300 Myr



Kalas et al. (2008, 2013)

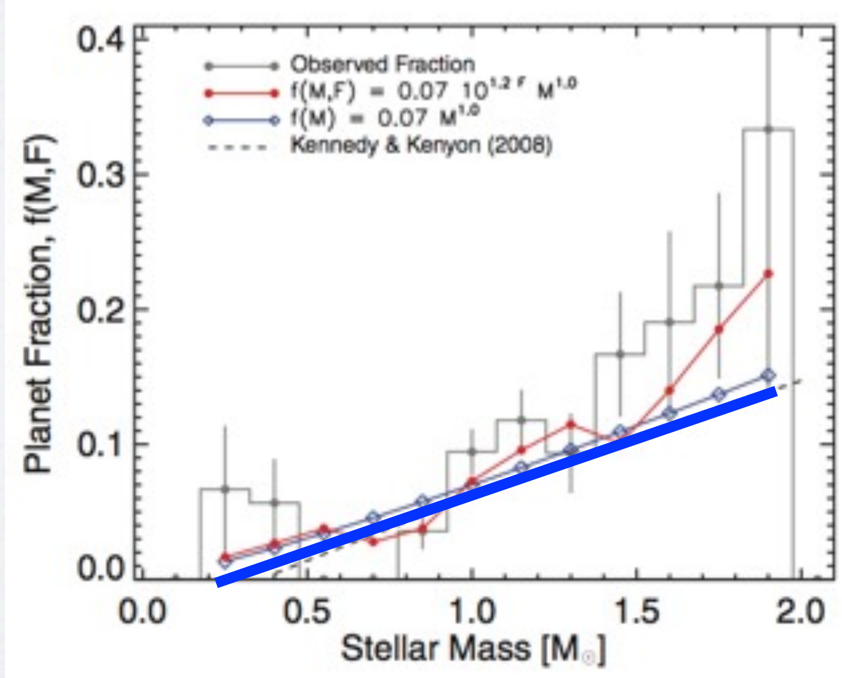
HD 95086 - 17 Myr



Rameau et al. (2013)

- Recent discoveries of RV planets around old A stars
  Lick and Keck subgiant surveys
  (Johnson et al. 2010, 2011; Bowler et al. 2010)

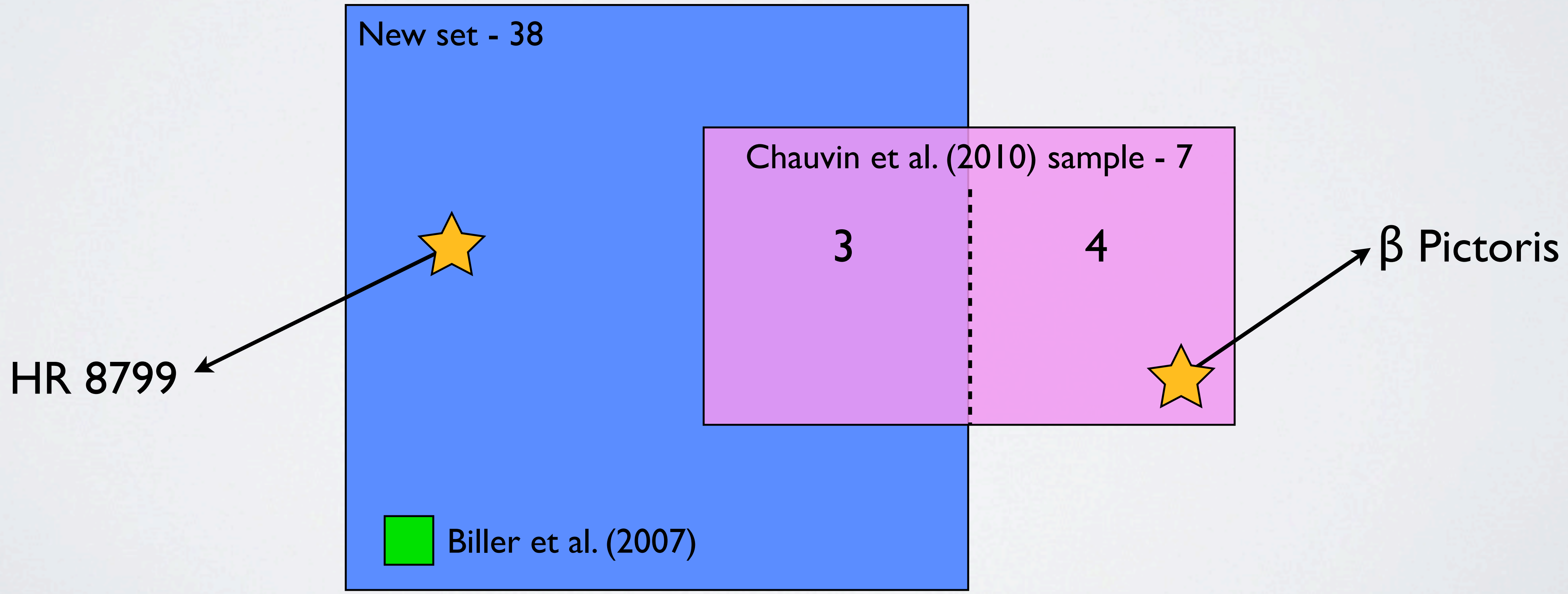
  → strong correlation between stellar mass and planet mass



Johnson et al. (2010b)

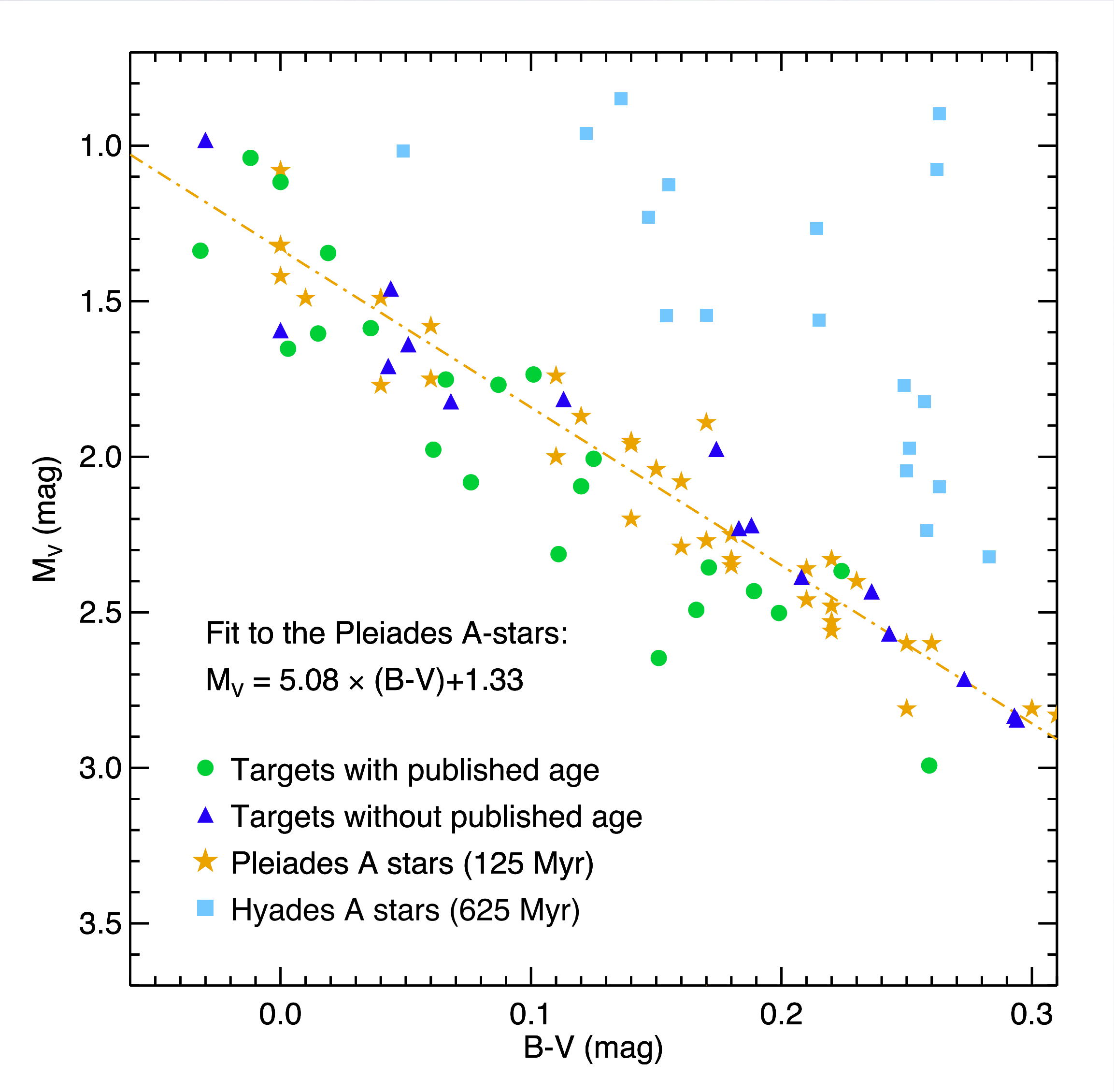
Sample selection

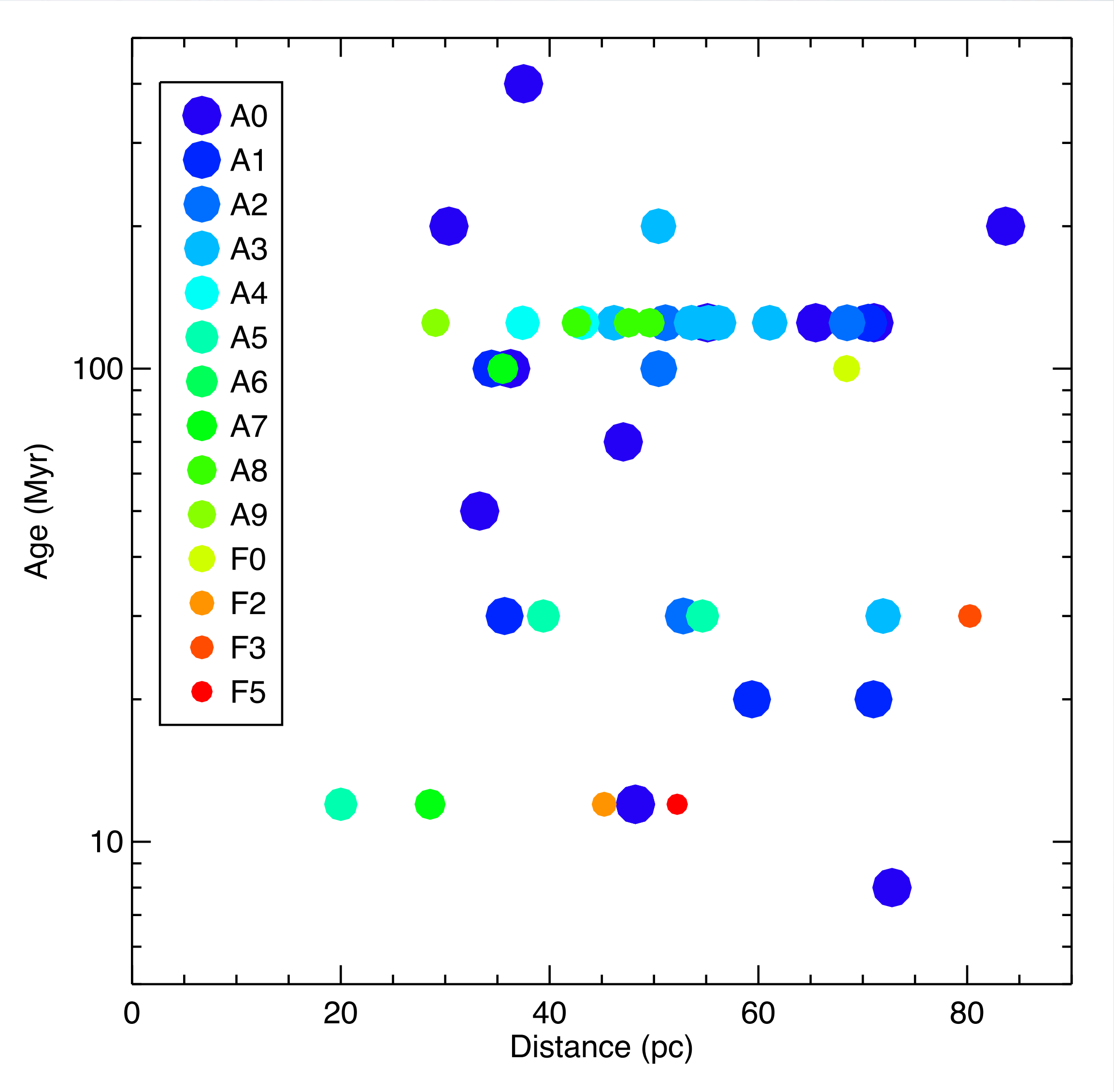
- Our sample includes a total of 42 stars:
  - a new set of young (median age 100 Myr), nearby (d ≤ 85 pc) A-stars (+4 early F)
  - A-stars previously observed in planet-search surveys



Sample selection

- Selection of the new set of targets:
  - initial fit to the *Pleiades* A-stars (125 Myr)
  - search for published ages in initial selection





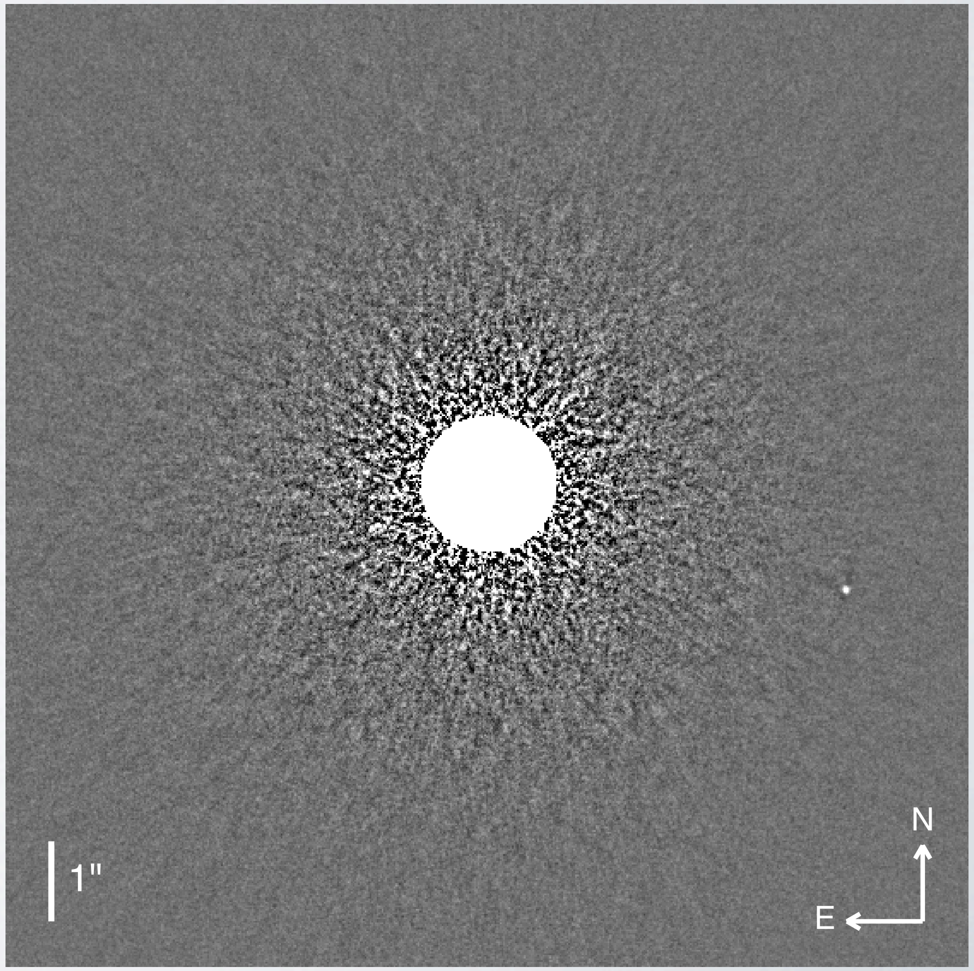
Observations

	VLT/NaCo	Gemini/NIRI
Targets	18	20
Filters	Ks	K' + CH4short
Periods	2009-2012	2007-2010
Pixel size	~13.20 mas	~21.4 mas
FoV	~13.5"	~22"
Obs. mode	Saturated imaging Angular differential imaging (ADI)	

- typical field of view rotation = 30°
- conditions from poor to excellent

Data reduction and analysis

- standard data reduction
- frame registration using Moffat profile fitting
- frame selection based on encircled energy and maximal flux
- unsaturated PSF used for normalization
- analysis of the data sets with LOCI (Lafrenière et al 2007):
  - N_δ = 0.75 FWHM
  - N_A = 300-500 PSF footprints

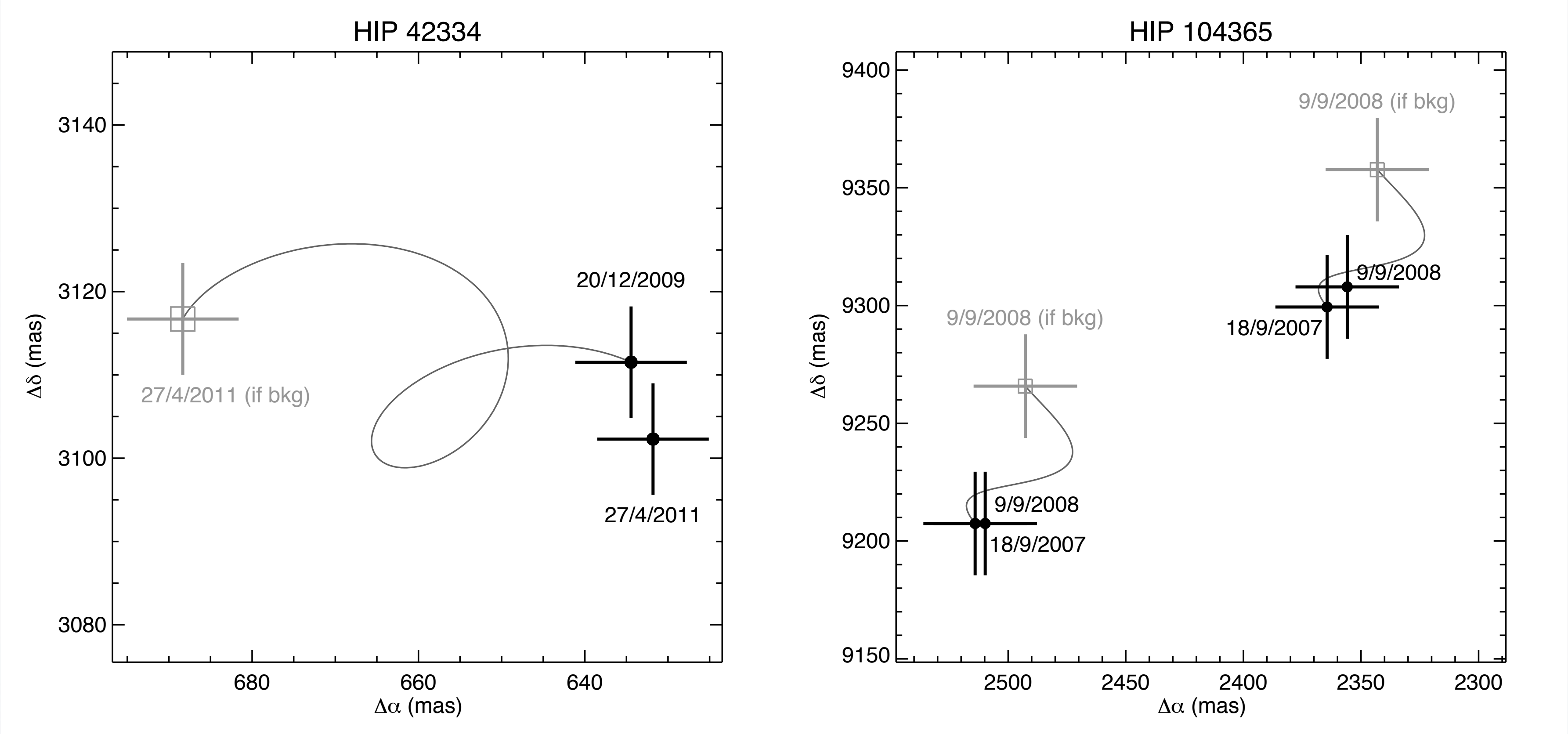


Companion candidates

- candidates identified by eye on images and SNR maps
- ~50 candidates ≥5σ around 22 of the targets
- second epoch for candidates with separation ≤ 320 AU
- no new substellar companions

HIP 42334
- A0V
- 125 Myr
- 71 pc

0.07-0.11 $M_\odot$ companion

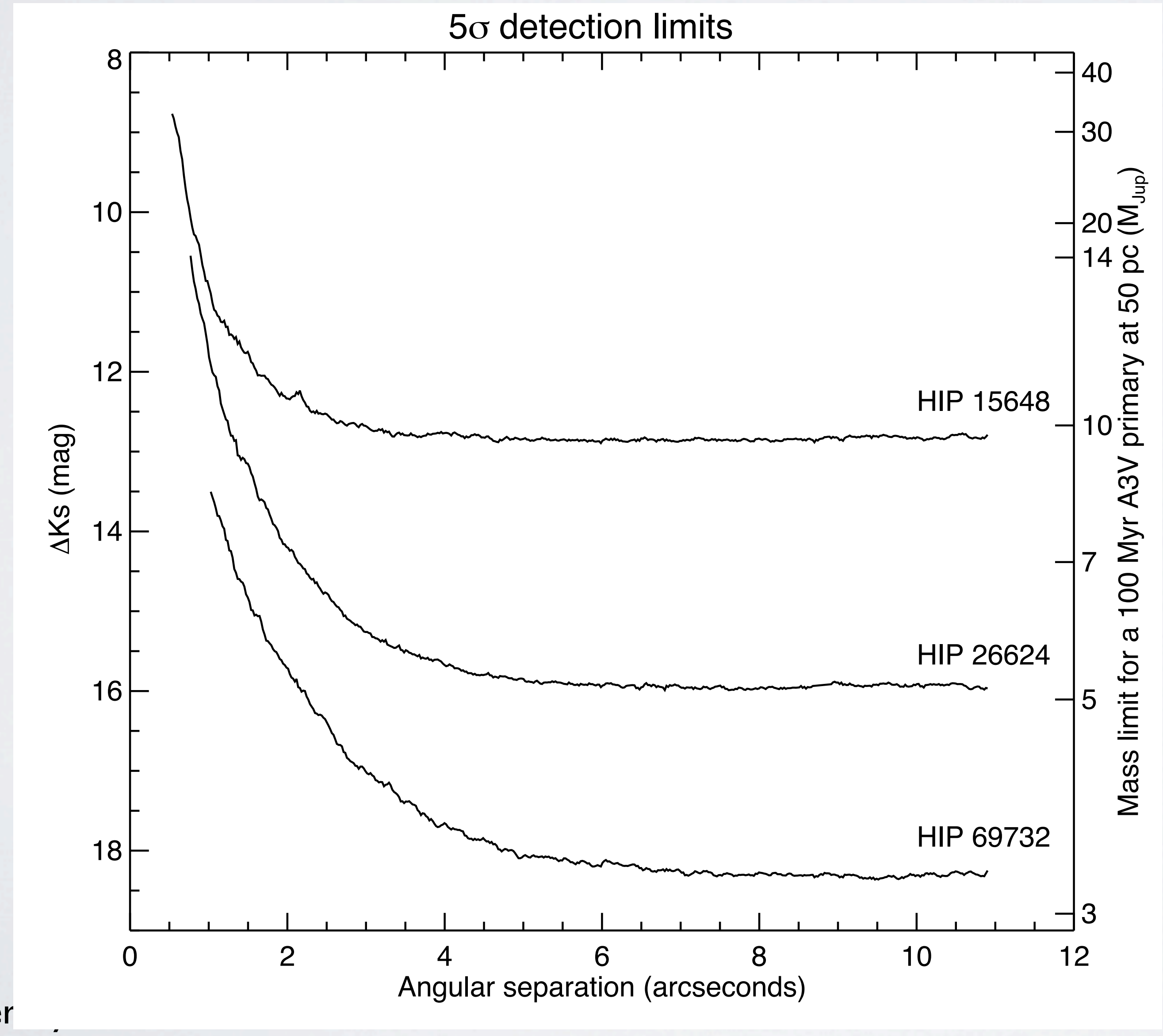


HIP 104365
- A0V
- 125 Myr
- 55 pc

0.09-0.14 $M_\odot$ companions

Detection limits

- noise in annuli of increasing radius ➙ 5σ detection limits
- normalisation by unsaturated PSF obtained with neutral density (NaCo) or narrow-band filters (NIRI)



Median target of the sample
- A3V
- 100 Myr
- 50 pc

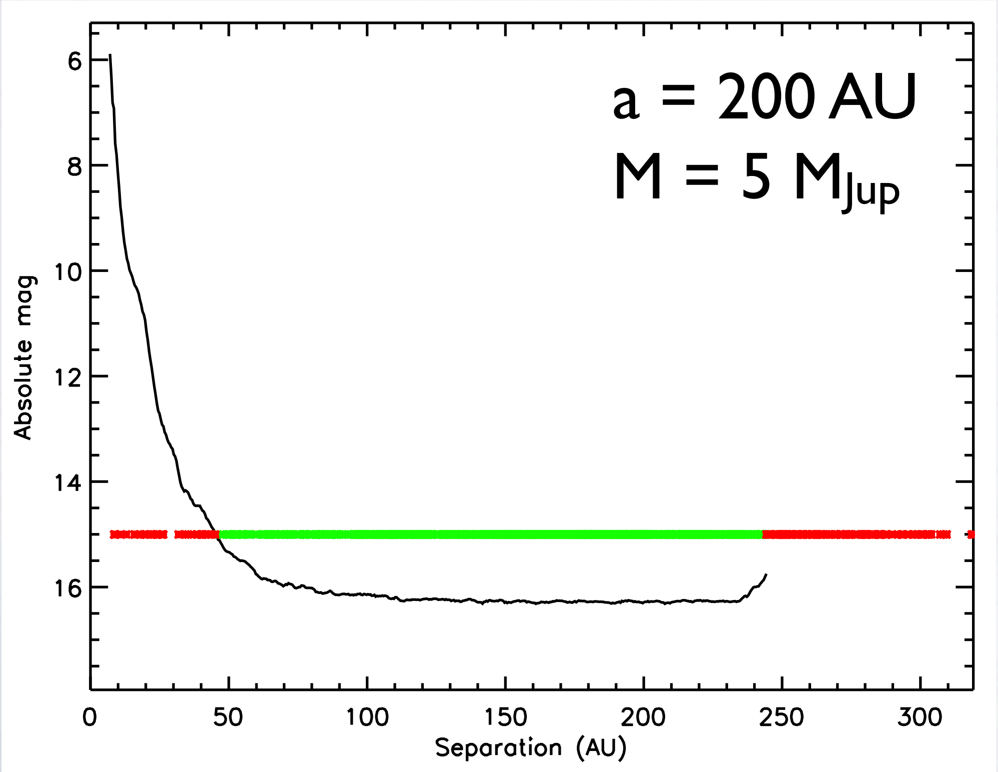
➙ reach 3-10 M_{Jup}

Statistical analysis

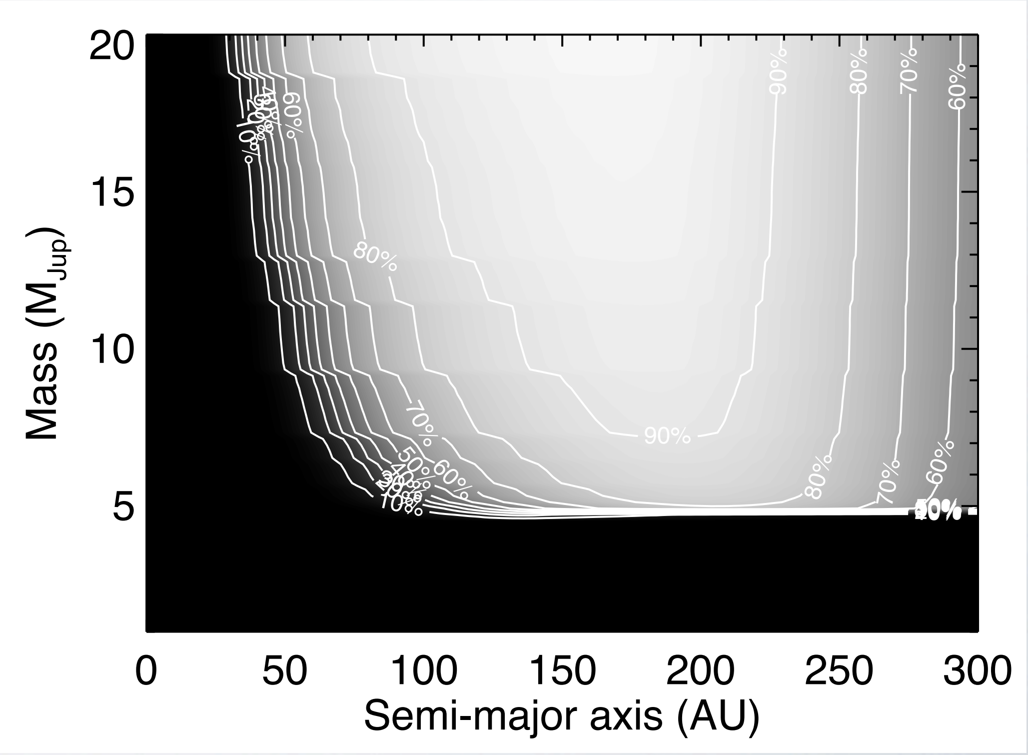
- What statistical properties can be inferred from the data?
- Previous surveys have used non-detections to:
  - set upper limits on the fraction of stars with planets
  - set constraints on the population of planets at wide separation
- Now that there are detections: what can we say?

Statistical analysis: general approach

- Monte Carlo simulations ➙ MESS (Bonavita et al. 2012)
  - generate lots of planets on a grid of mass/semi-major axis
  - random other orbital parameters
  - check detectability against detection limits
  - "probability of detection" map for each target

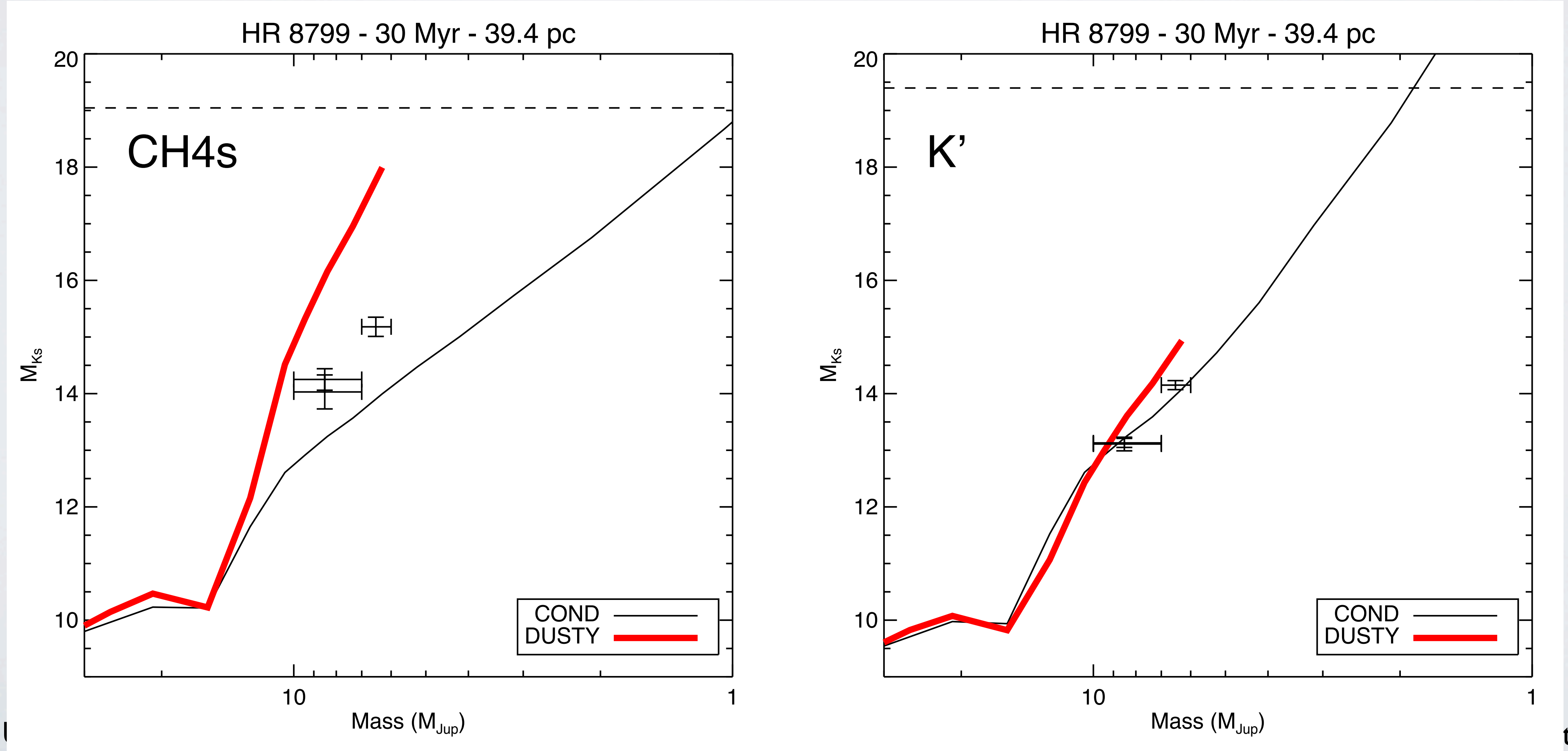


magnitude to mass conversion ➙ COND models (Baraffe et al. 2003)

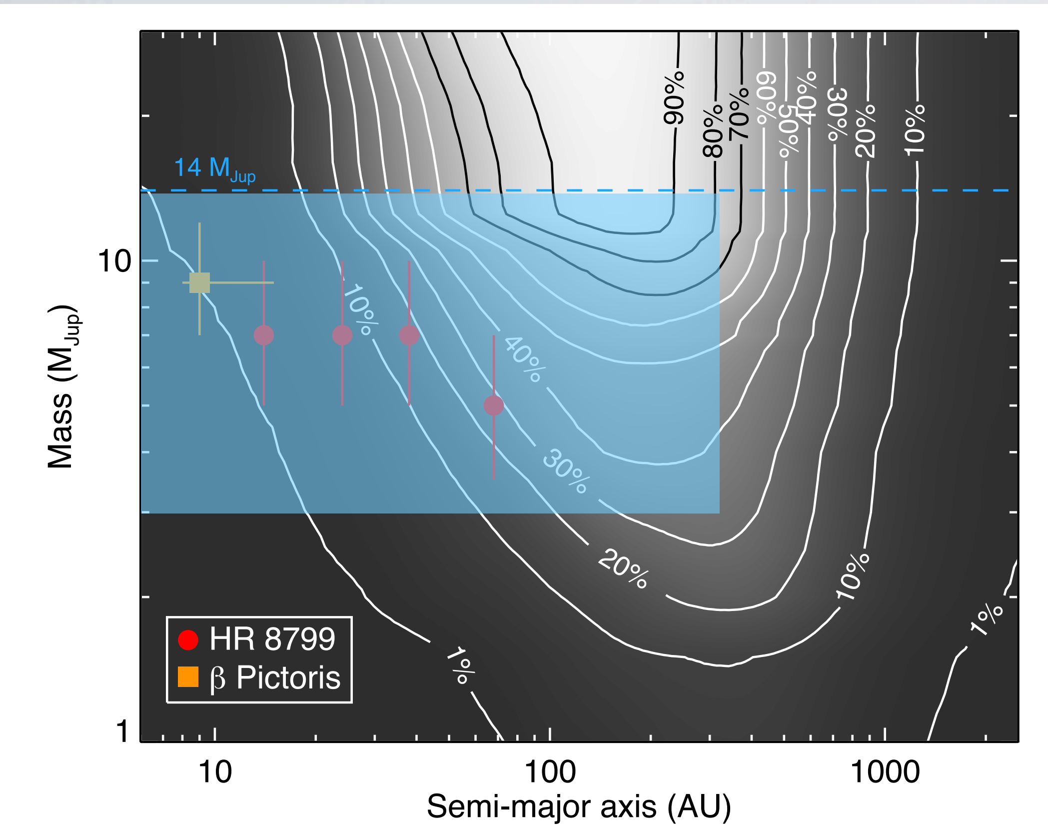


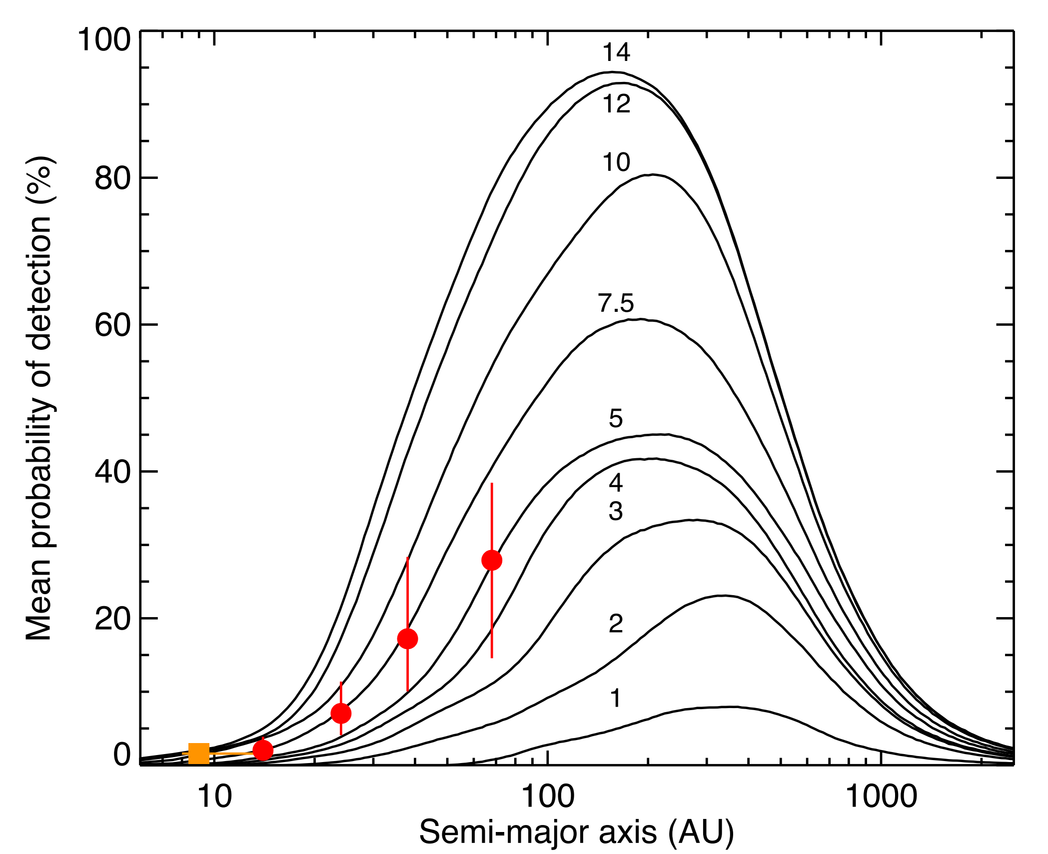
Choice of evolutionary models

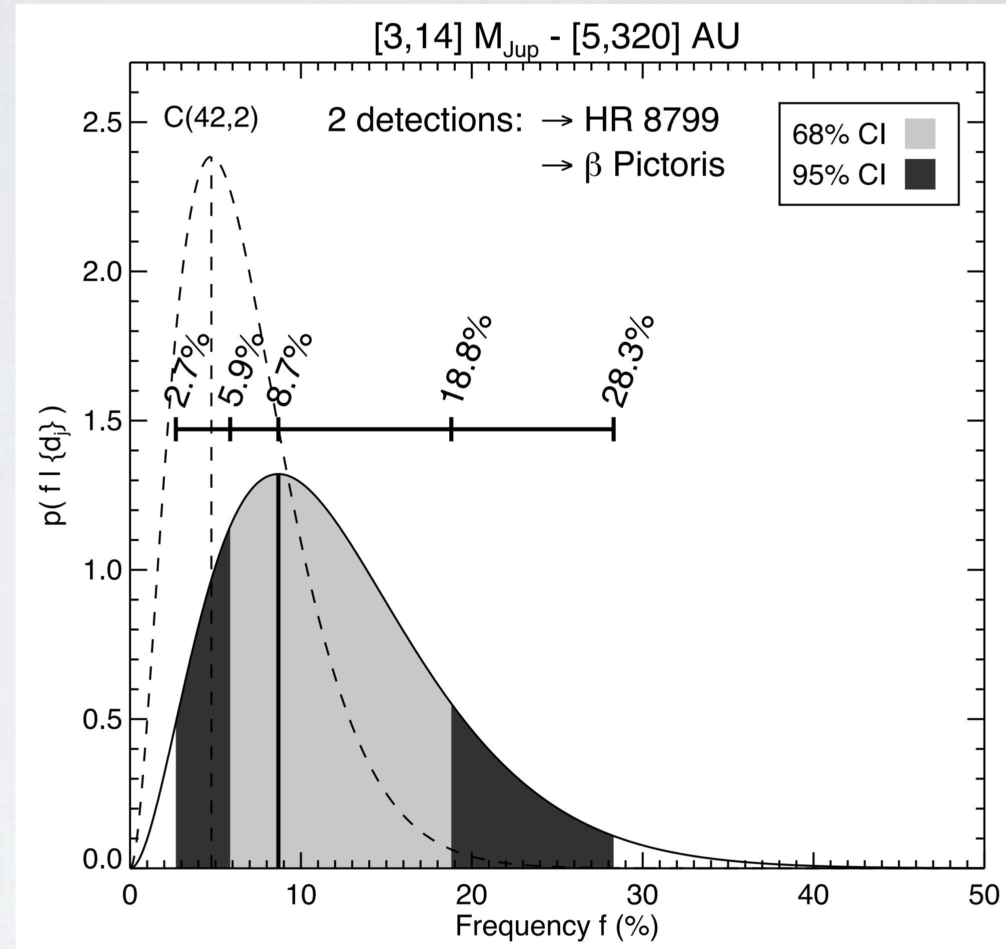
- only COND (Baraffe et al. 2003) are going deep enough
- COND are in agreement with data in Ks, but less in CH4s
- main effect: underestimation of detectable masses, increasing with obs. depth (i.e. with angular separation)



Wide-orbit planets frequency







$f \in [5.9\%, 18.8\%]$ at 68% confidence

- $3\ M_{Jup} \leq \text{mass} \leq 14\ M_{Jup}$
- $5\ AU \leq a \leq 320\ AU$

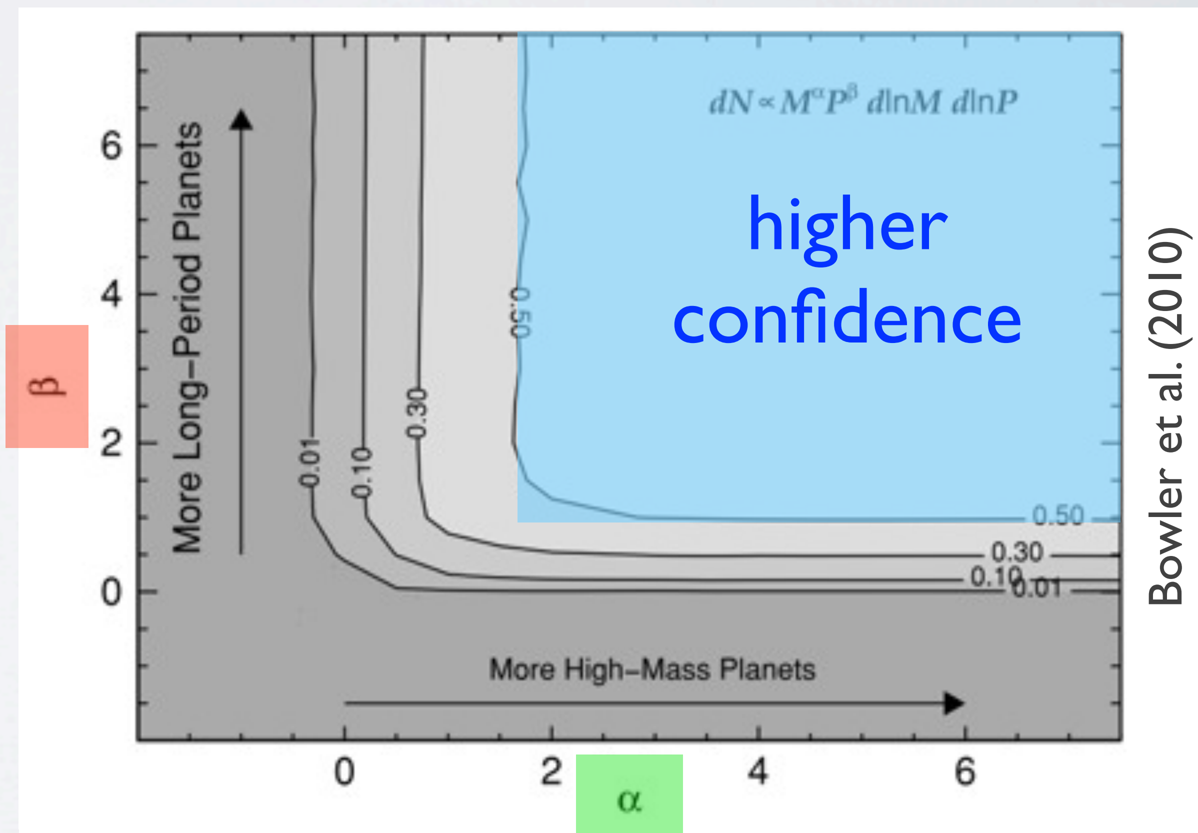
Result confirmed by Rameau et al. (2013)
In agreement with NICI survey (Nielsen et al. 2013)

Constraints on wide-orbit planets population

- Extrapolation of RV survey results
- Solar-type stars ➞ Cumming et al. (2008) measure
  f = 10.5%
  for 0.3-10 M_{Jup} planets with P < 1826 days

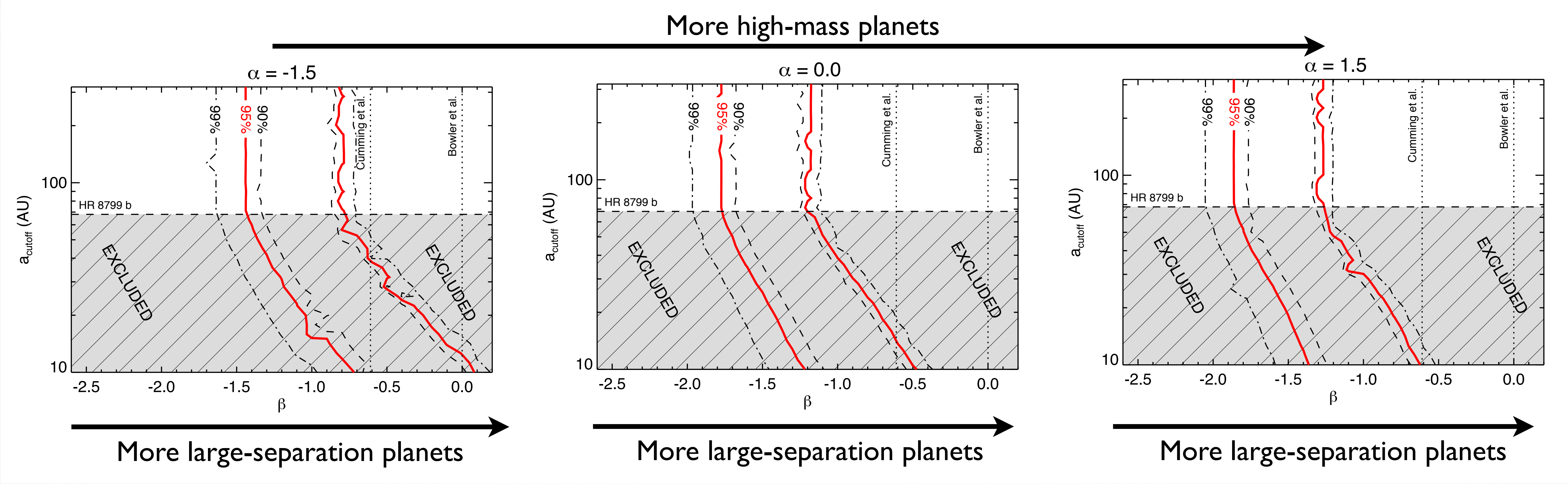
$$dN \propto M^{-1.31} dM$$
$$dN \propto a^{-0.61} da$$

- Early-type stars (old stars)
  - ➞ Johnson et al. (2010) measure f = 11 ± 2% for 0.5-14 M_{Jup} in 0.1-3.0 AU
  - ➞ Bowler et al. (2010) bring some constraints on α and β



Constraints on wide-orbit planets population

- MC simulations with populations drawn from powerlaws
- assumed frequency f = 11 ± 2% in 0.5-14 M_{Jup} and 0.1-3.0 AU (Johnson et al. 2010)



- values not in agreement with RV constraints from Bowler et al.
  - ➝ different planet population at wide orbit?
  - ➝ population cannot be described by a single powerlaw?

Conclusions

- survey of 42 A and early-F stars
- data from NaCo and NIRI analysed with LOCI
- Monte Carlo simulations for the statistical analysis
- wide-orbit planet frequency $f \in [5.9\%, 18.8\%]$ @ 68% confidence
  - 3 MJup ≤ mass ≤ 14 MJup 10 AU ≤ a ≤ 320 AU
  - value confirmed by Rameau et al. (2013)
- constraints on the population show differences with RV studies

Thanks for your attention!