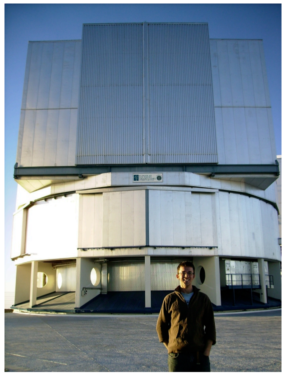
Companions to A-stars – from stars to planets

Jenny Patience

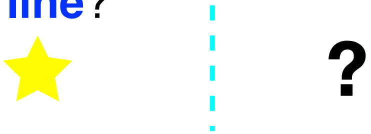
R. De Rosa, R. King, J. Bulger, A. Vigan,

C. Marois, B. Macintosh, T. Barman, B. Zuckerman, I. Song, D. Lafreniere, R. Doyon

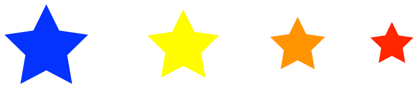
Scientific Questions

- **Scientific questions:**

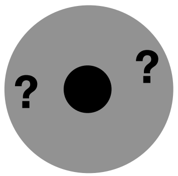
- What is the frequency and outer limit of giant planets in orbits **beyond the snow line**?



- How do the characteristics and frequency of outer planets vary with **host star mass**?



- What are the properties of giant planet **atmospheres**?



- **Advantages of direct imaging:**

- Search two decades of orbital radius, **~2-100 AU**, including orbital periods too long for other techniques

- Possible to target **A-stars** which cannot be observed with RV (lack of lines)
- A-stars also **young** – test of formation models

- **Spectra** separate from host star, comparison to irradiated planets

AO Imaging Planet Search around A-stars

- A-stars more massive than the Sun
- **Favorable conditions for giant planet formation**

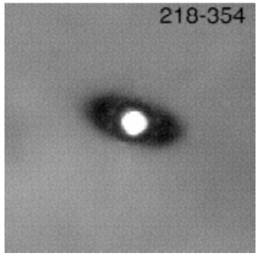
Pre-Main Sequence
Large disks present, enough mass for planets
(e.g. Mannings & Sargent 1997)

Main Sequence
Debris disks from planetesimal collisions
(e.g. Holland et al. 1998)

Post-Main Sequence
Evidence of higher planet frequency, wider orbits
(e.g. Johnson et al. 2007)

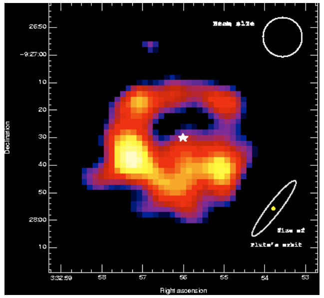
Theoretical Predictions
Planet mass scales with stellar mass
(e.g. Lin & Ida 1997)

Pre-Main Sequence



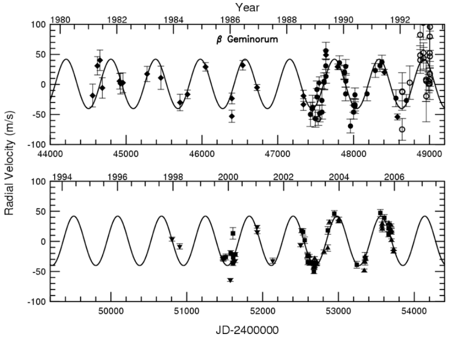
(McCaughrean & O'Dell 1996)

Main Sequence



(Greaves et al. 1998)

Post-Main Sequence



(Hatzes et al. 2005)

- **Pursuing two A-star companion search programs – (1) snapshot VAST, (2) deep IDPS**

A-star Companion Search Survey I: VAST

- **VAST (Volume-limited A-STar) Survey**

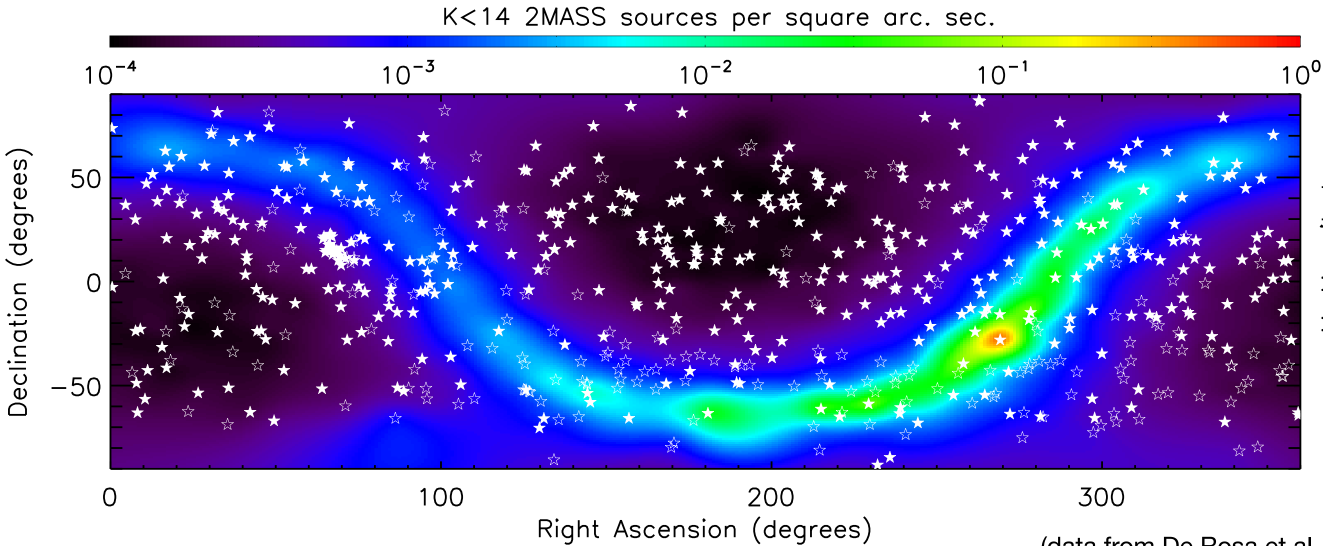
- **AO snapshot survey – Gemini, VLT, Palomar, CFHT, Lick**

  D < 75pc and <5% parallax error

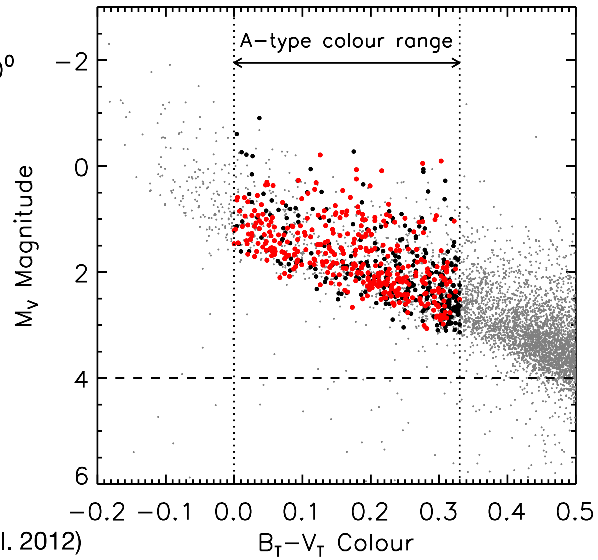
  435 A-stars observed

  Sensitive to bottom of the MS (and BD depending on age)

Distribution of VAST sample



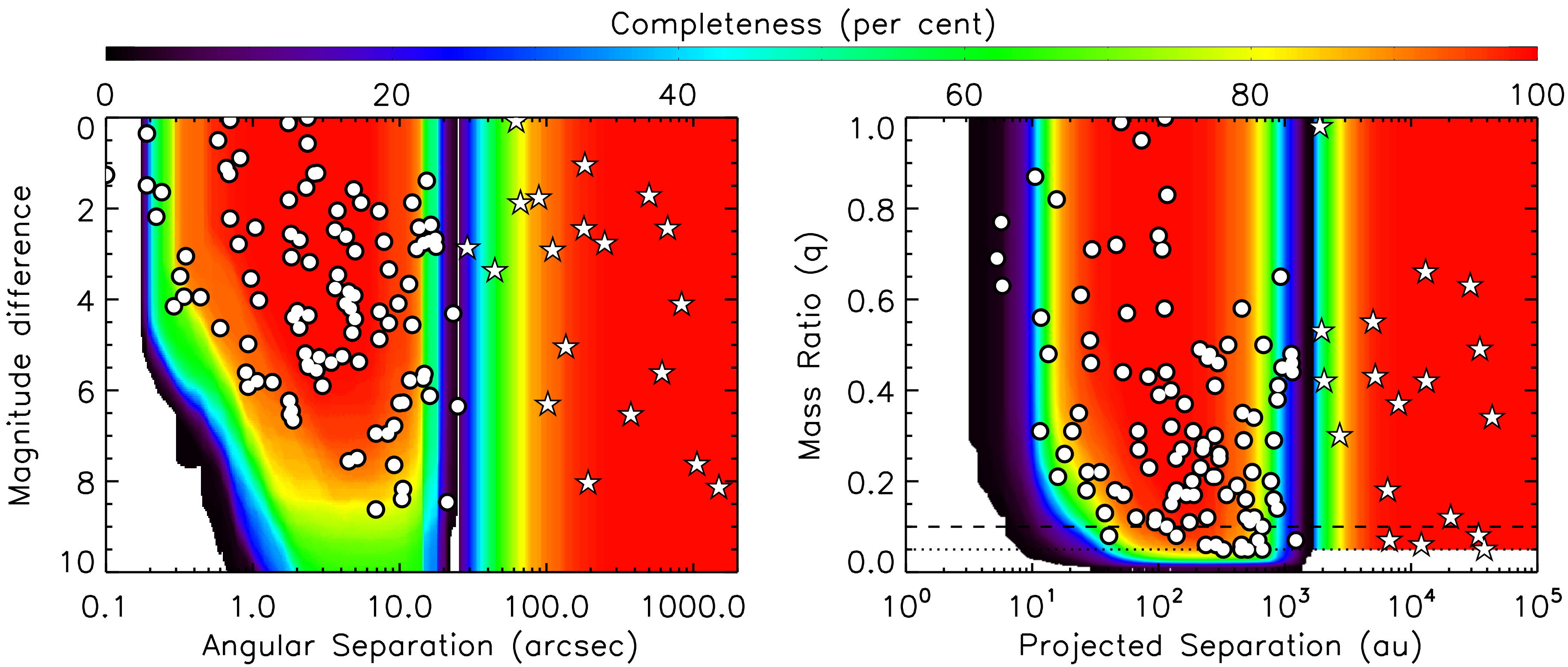
CMD of VAST sample



(data from De Rosa et al. 2012)

- **Science Goals**
  - **Measure binary statistics of A-stars**
  - **Investigate unexpected X-ray emission**
  - **Determine substellar frequency**

VAST Companion Detections



(De Rosa, Patience et al., in prep.)

- Binaries resolved from 0”.1 - 10”.0 with AO

  <5% chance background object

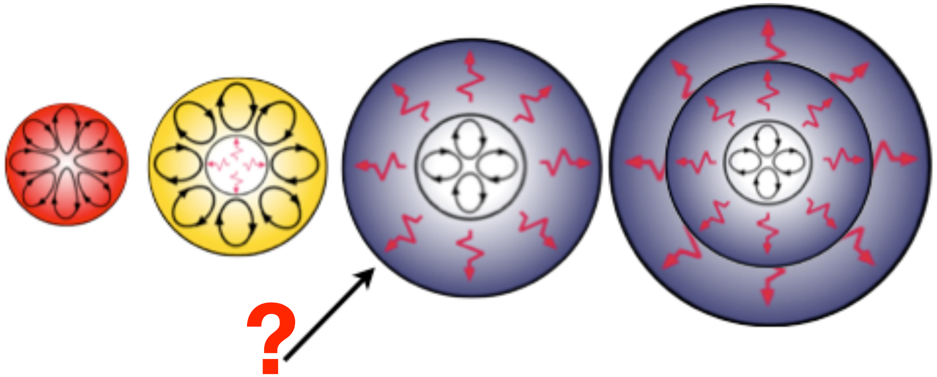
- Common proper motion companions from all sky surveys

X-ray Emission and A-star Binaries

- **A-stars not expected to generate X-rays**

  Detections from ROSAT

  Unresolved companions may be source



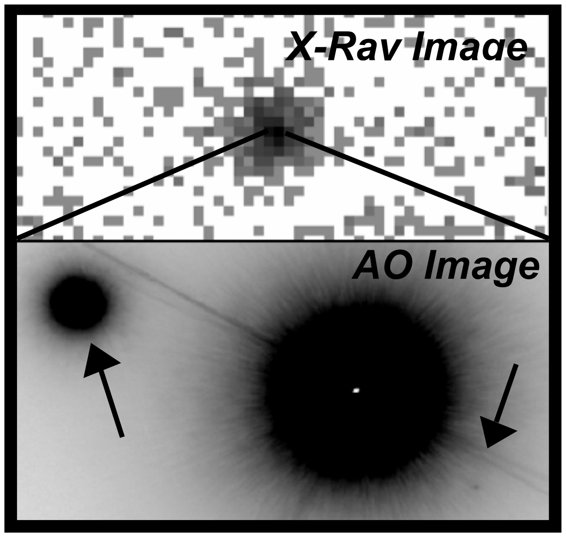
- **A-star Survey tests companion hypothesis**

  Construct X-ray / non-X-ray samples with same sensitivity

  Compare fraction of multiples

X-ray binaries	60%
Control binaries	20%

(De Rosa et al. 2011)



ROSAT

Gemini

VAST Binary Separation Distribution

- **Combine AO + plates to build distribution**

  AO data covers ~30-800 AU

  Plates cover ~7000-38,000 AU

  Include binaries to mass ratio 0.1

  Sample per bin sensitive to >95% of bin

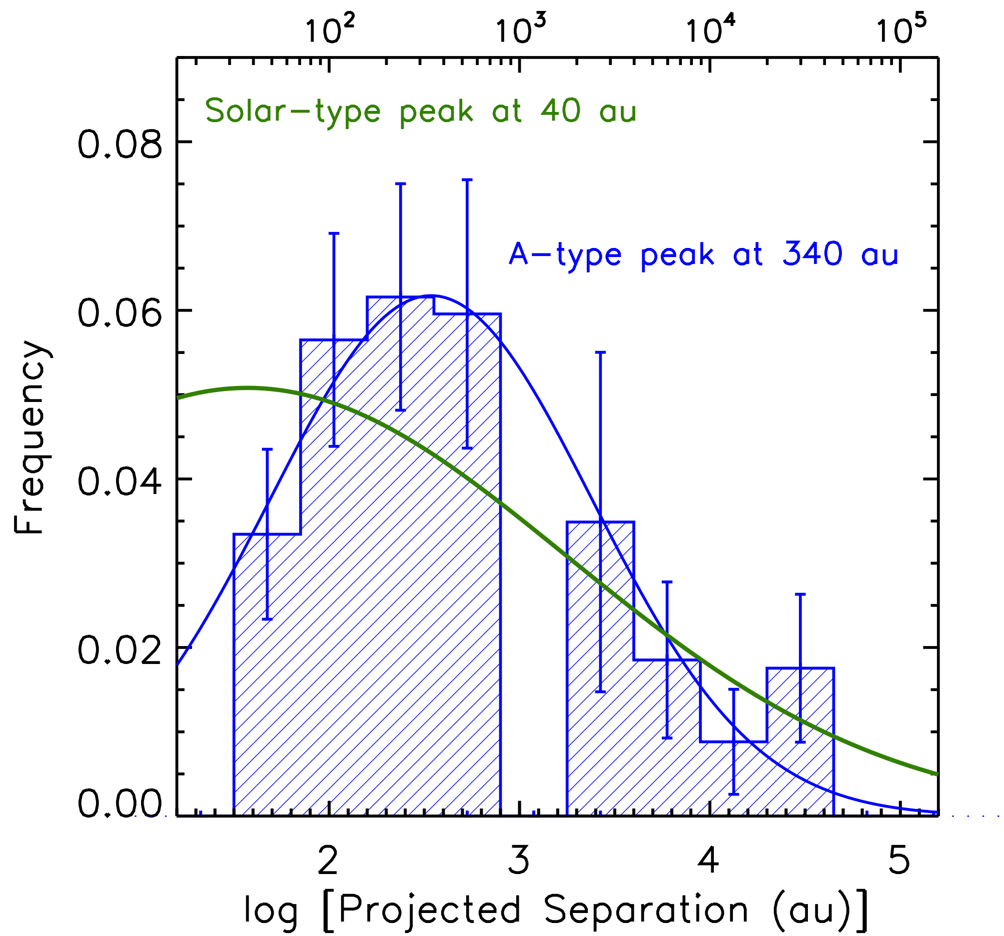
- **Peak of distribution**

  300 AU for A-stars

  Wider than for G-stars, M-stars

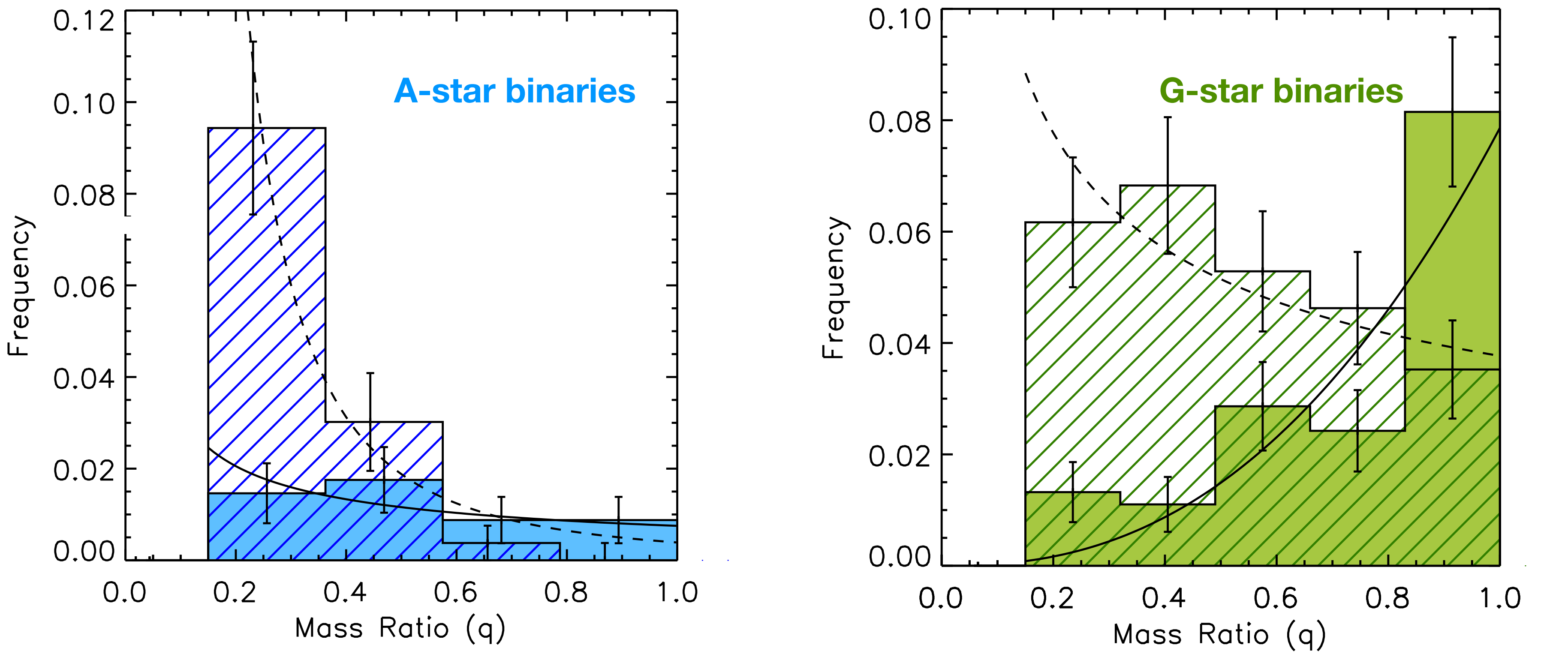
- **Future work**

  Interferometry for closer binaries



(De Rosa, Patience et al., in prep.)

VAST Mass Ratio Distribution



(De Rosa, Patience et al., in prep.)

- **Mass ratio distribution varies with separation**

  Difference for both A-stars and G-dwarfs

  Outer distribution has more lower mass ratios systems

  Inner distribution more similar mass ratio systems

Binary Fraction vs. Primary Mass

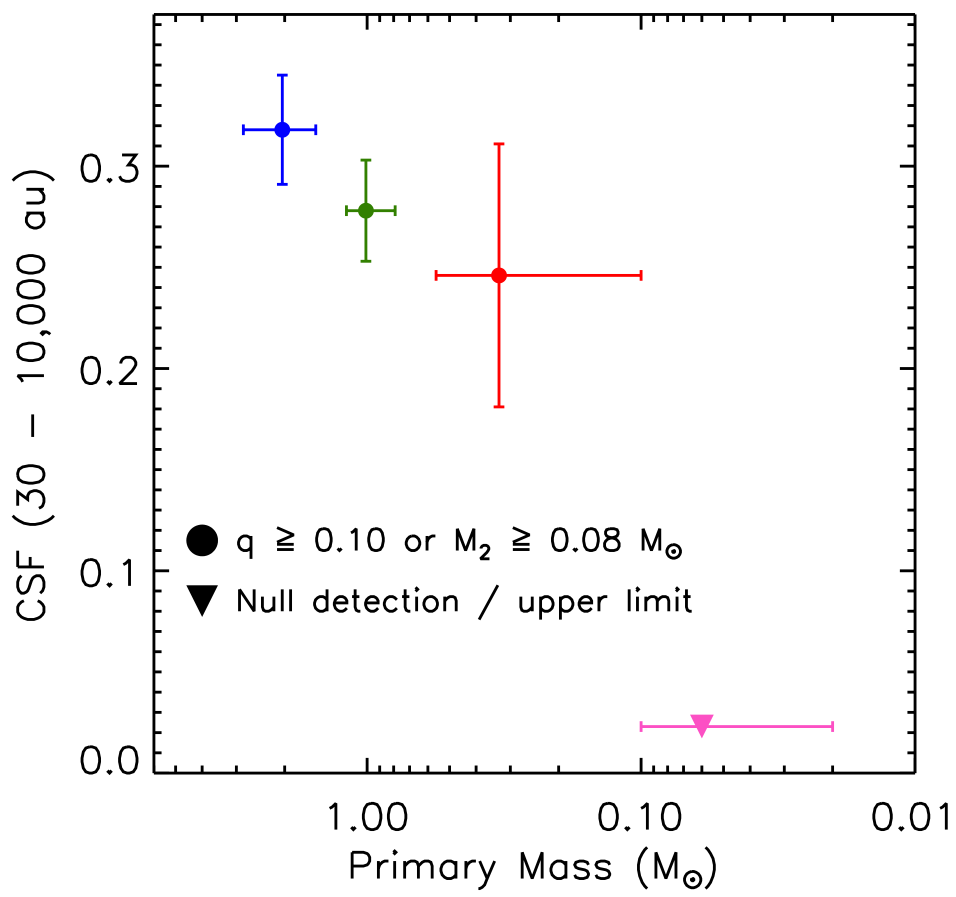
- **Companion star fraction declines with mass**

  Separation range considered: **30-10000 AU**

  A-star value integrated over separation curve

  G/M-dwarf values sensitive to bottom of MS
  (Raghavan et al. 2010, Fischer & Marcy 1992)

  L/T-dwarf upper limit, binaries all closer
  (Allen et al. 2007)



(De Rosa, Patience et al., in prep.)

Future work: A-star Substellar Candidates

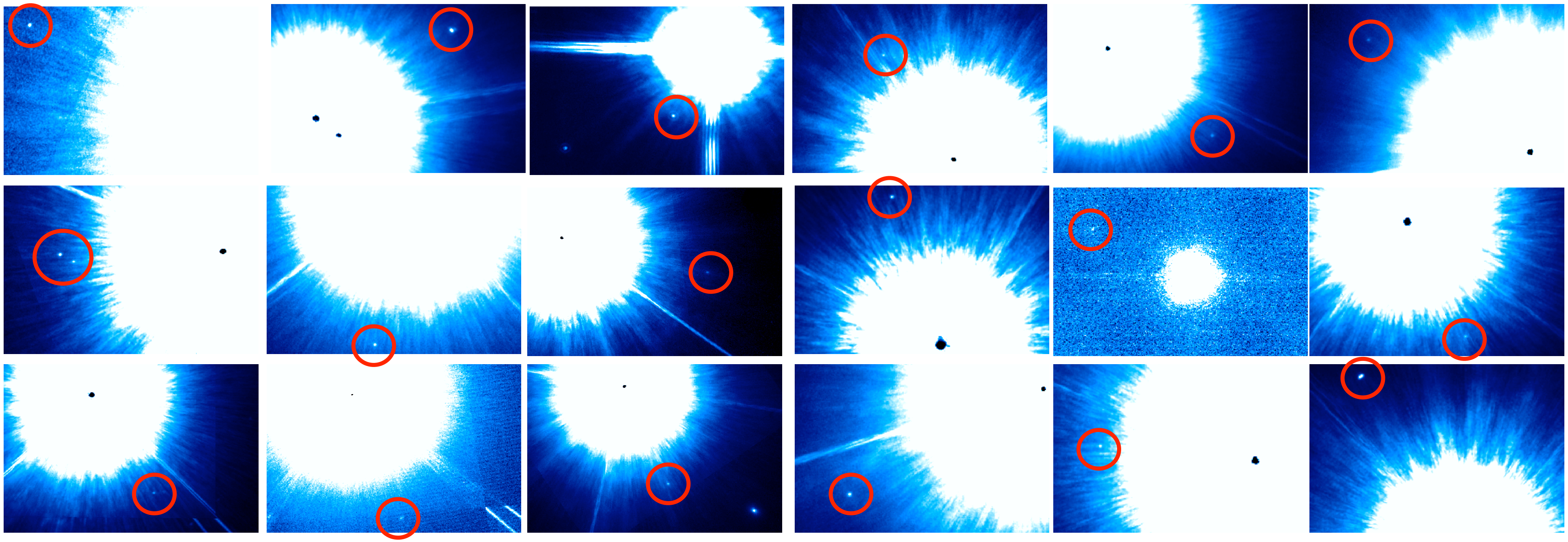
- **18 Candidate substellar companions**

  Proposal submitted for follow-up observations

- **First statistics on substellar companions to A-stars from a large sample**

  Currently only 2 known brown dwarf companions to an A-star

  Comparison study to WD/BD searches – <5% over 60-200 AU (Hogan et al. 2008)



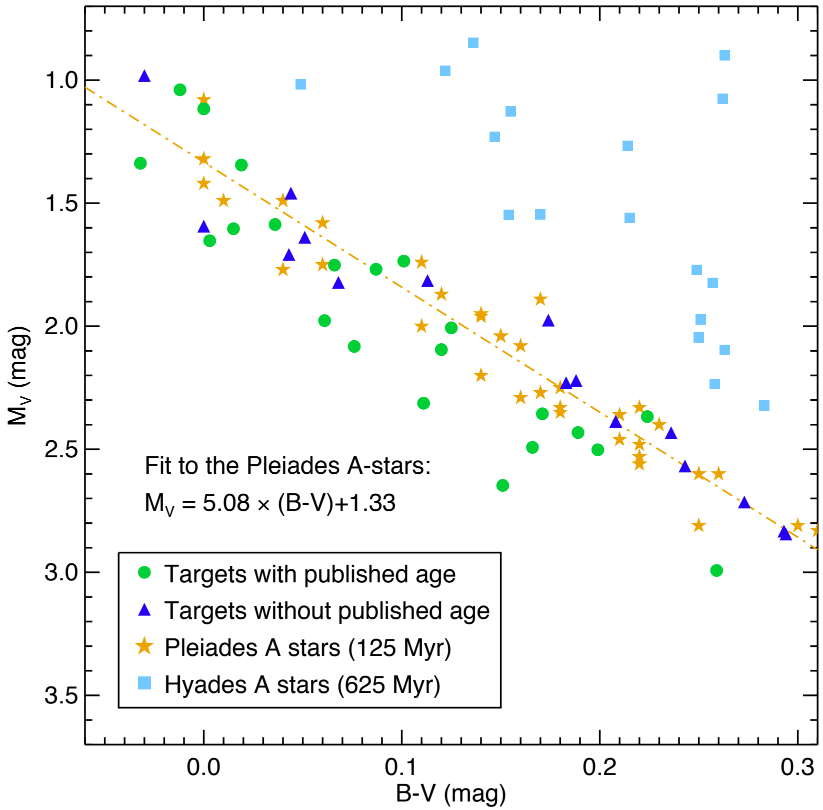
A-star Companion Search Survey II: IDPS

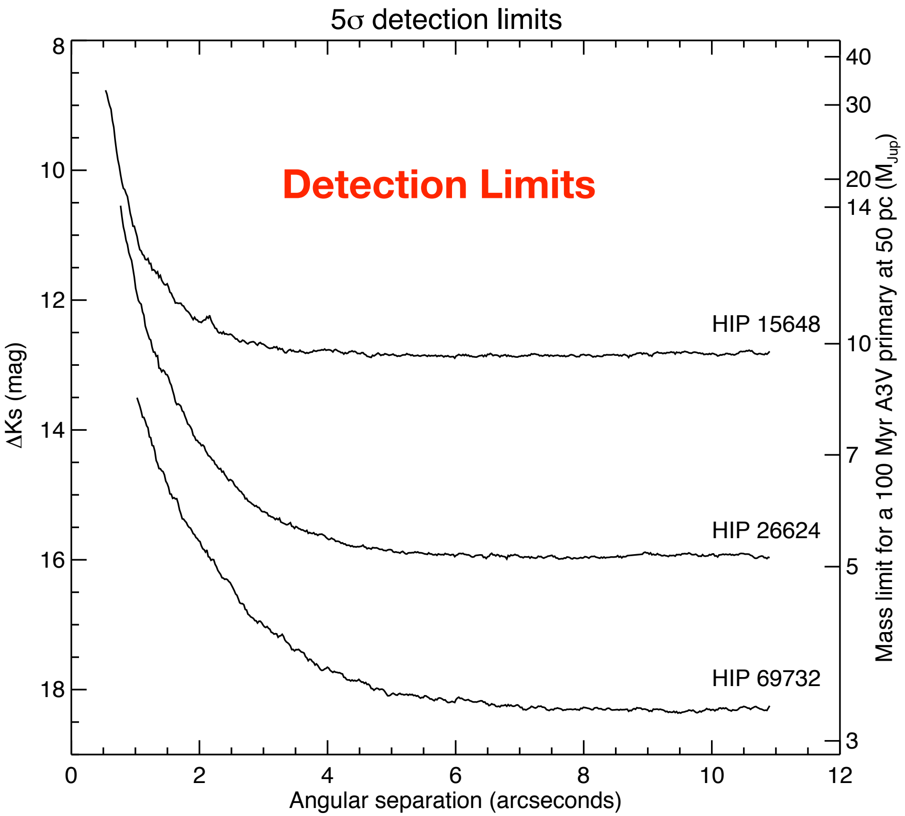
- **Young stars reduce the star-planet contrast**

  42 stars – 38 A-stars / 4 F-stars – 90% 125 Myr or younger, D < 75pc

  All A-stars observed in previous AO stars and new VLT/Gemini observations

  Sample includes stars with and without debris disks

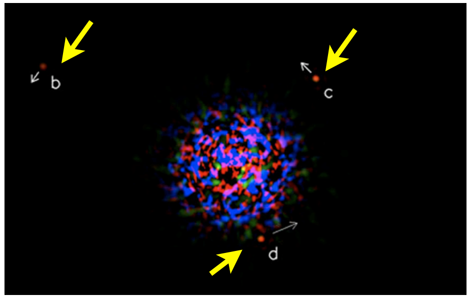




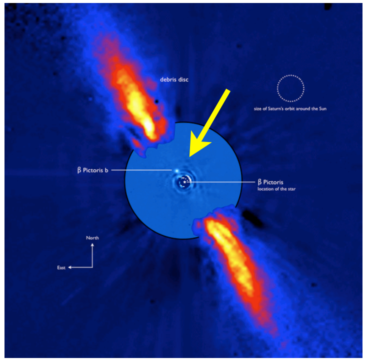
(Vigan, Patience et al. 2012)

Detections and Survey Sensitivity

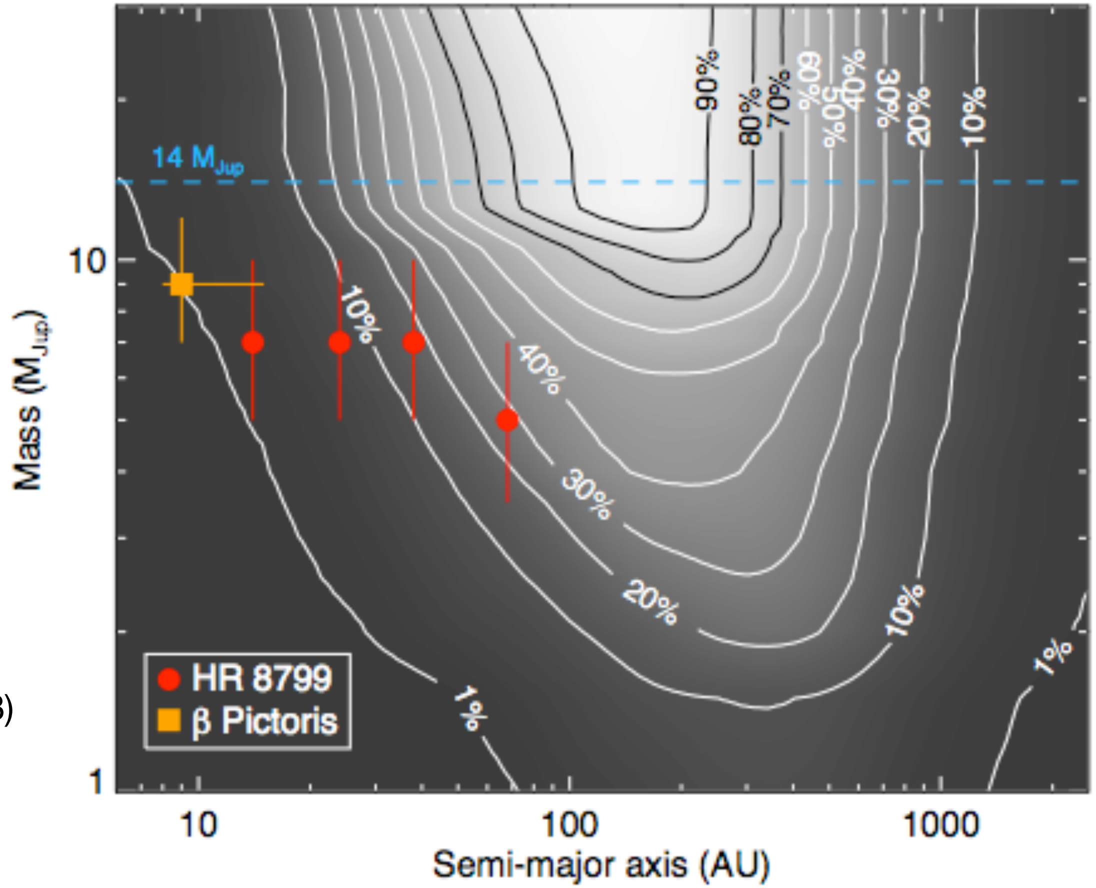
- **Summary of sensitivity and planet detections**
  - COND models to convert limits/masses
  - DUSTY do not reach limits
- **Companion Detections**
  - 2 low mass stellar binaries
  - 1 brown dwarf
  - 2 planetary systems



(Marois et al. 2008)



(Lagrange et al. 2009)

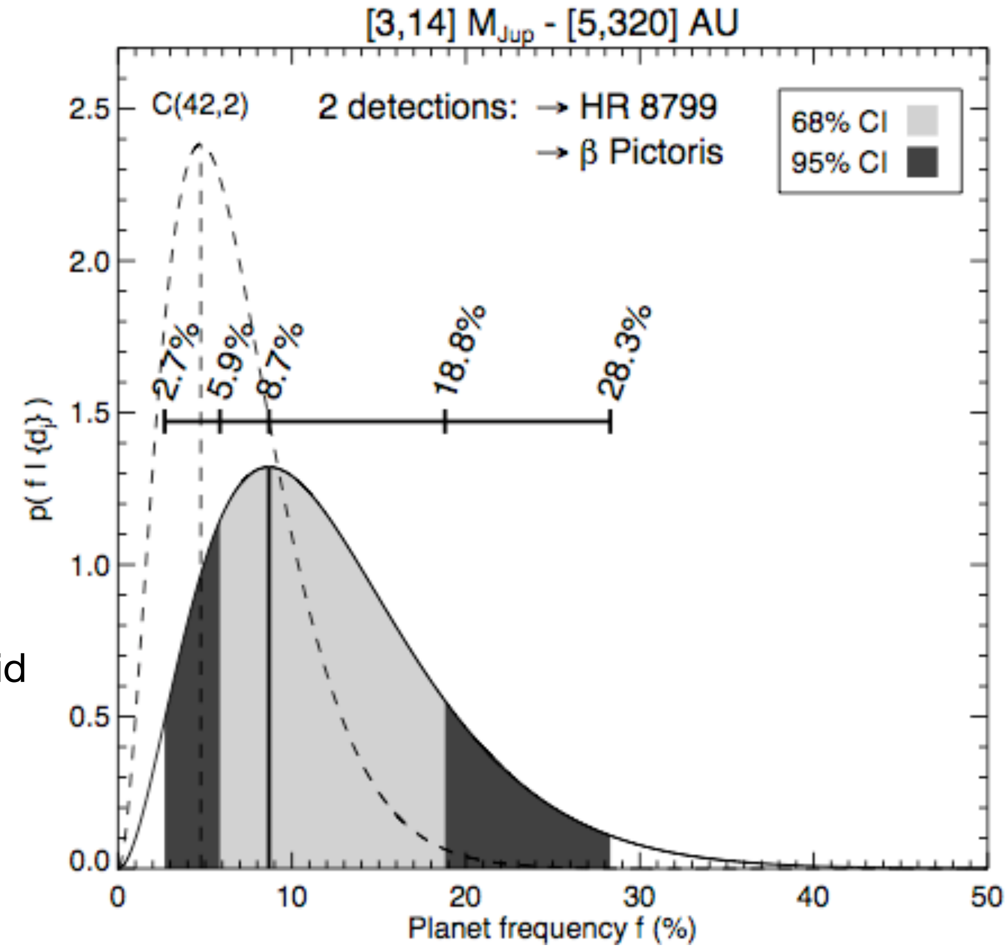


(Vigan, Patience et al. 2012)

Frequency of Planetary Systems around A-stars

- **Planet frequency**
  - **5 - 320 AU** range
  - planet mass limit **3-14 Mjup**
  - **9%** peak of prob. density function
  - ~**3-19%** for 68% confidence interval

- **Monte Carlo simulation of planet population**
  - mass/sep of planets generated from large grid
  - sample over orbital parameters
  - convert luminosity to magnitude
  - compare with limits to gauge detectability

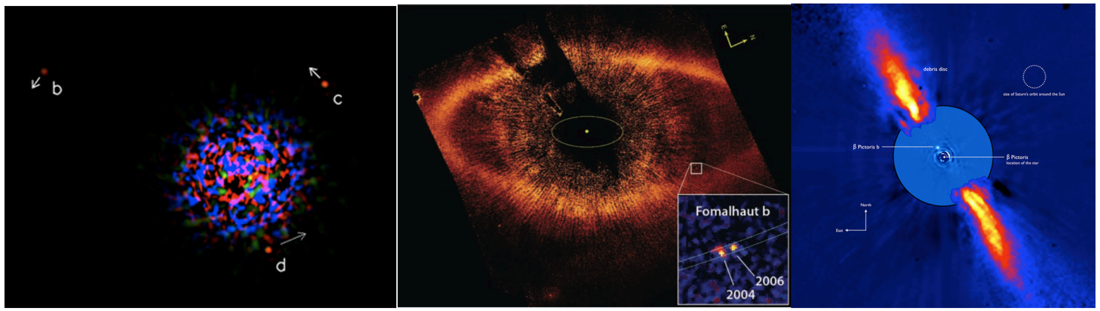


(Vigan, Patience et al. 2012)

Planet Frequency Comparisons

- **A-stars and debris disks**
  - 17/42 targets in sample have debris disks
  - Both **planets** in sample **in debris disk systems**

    also Fomalhaut
  - **Brown dwarf in debris disks system**



(Marois et al. 2008, Kalas et al. 2008, Lagrange et al. 2009)

- **A-star planets and brown dwarfs**
  - Brown dwarf frequency

    ~**2-8%** for 68% confidence interval

    Not higher than planet frequency
  - Some instability models predict higher BD frequency compared to planets (Kratter et al. 2010)

A-star Planet Overview

- **A-stars and "retired" A-stars**
  - "retired" A-stars

    0.1 - 3 AU range

    planet mass limit >0.2-1.3 Mjup

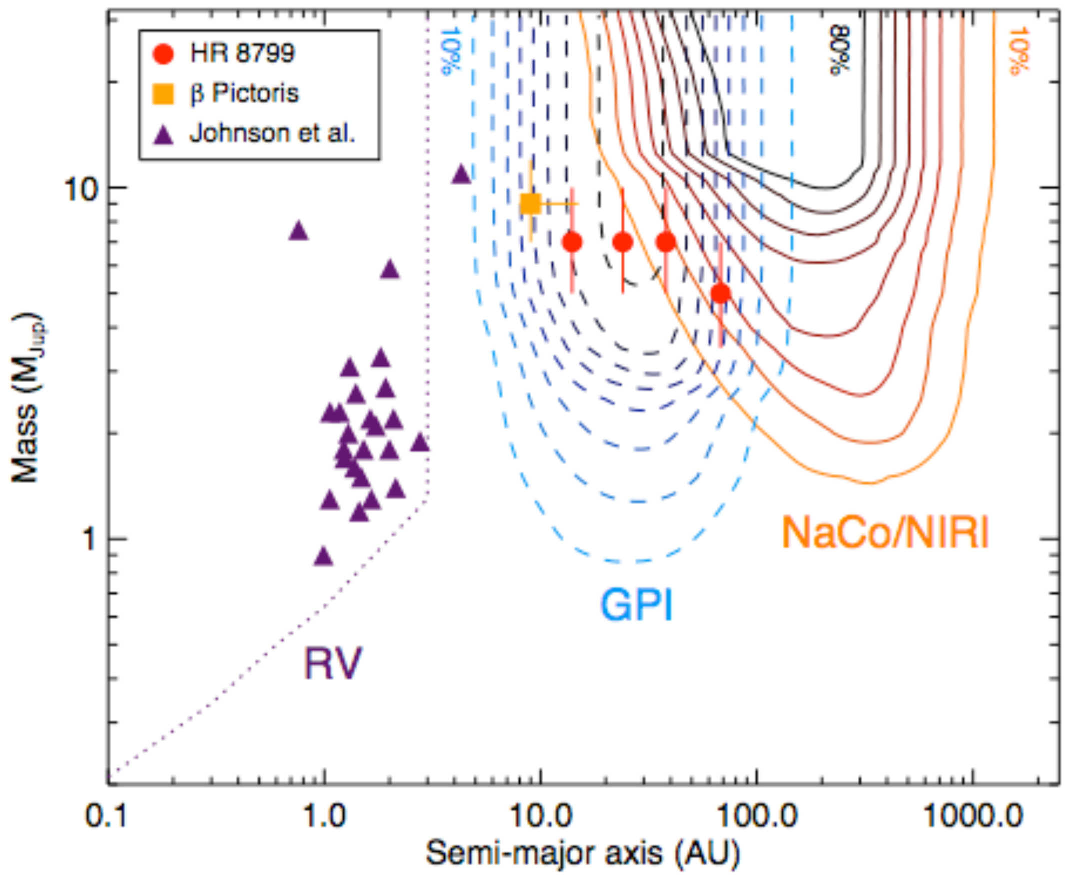
    11% ± 2%

  - Similar to **3-19%** of A-stars, **BUT**

    RV results show rising function of semi-major axis

    Increase in planet numbers turns over between RV and AO ranges

Overview of A-star planets



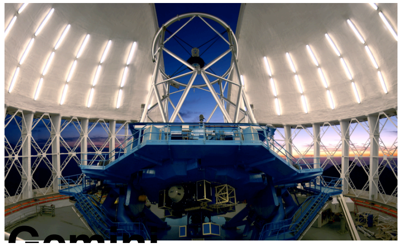
(Vigan, Patience et al. 2012)

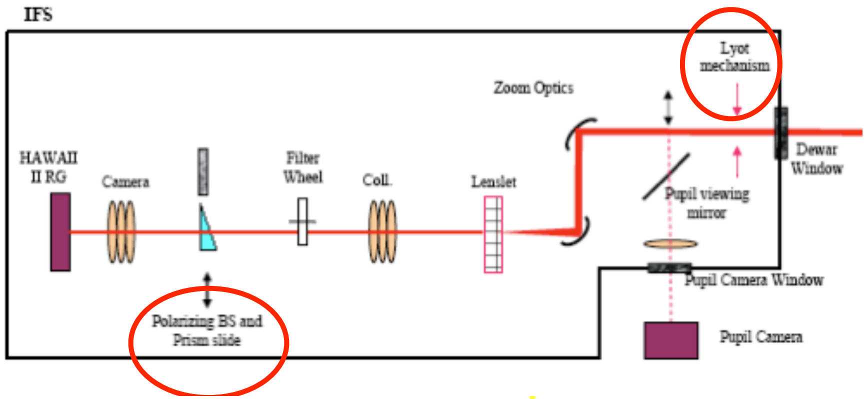
Upcoming Instruments to Image Planets – GPI

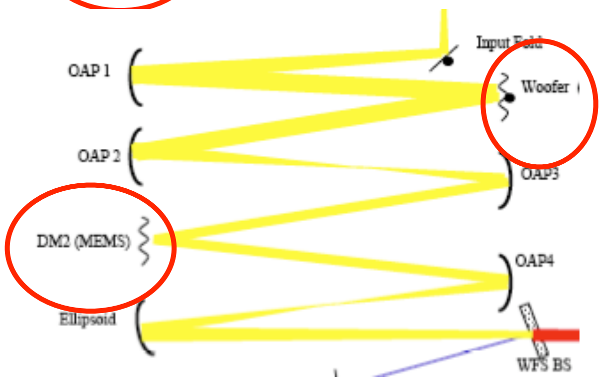
- **Gemini Planet Imager**

  Extreme AO system for high Strehl

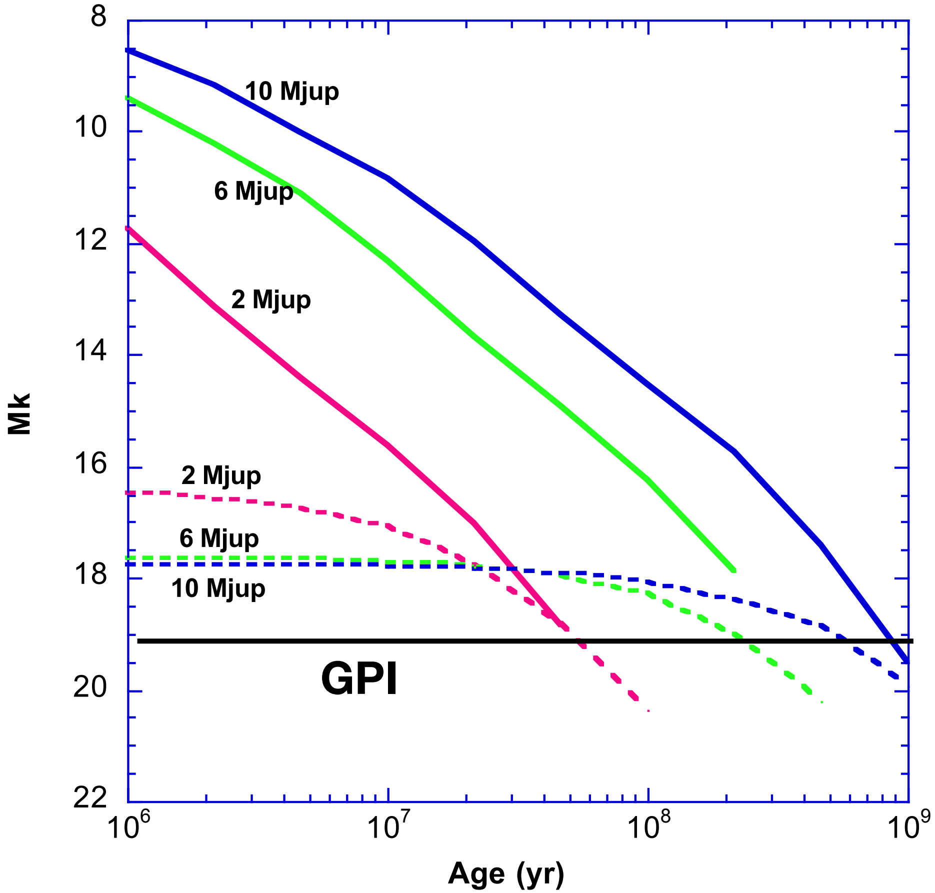
  Coronograph for contrast







- Planet physical properties transformed into observables

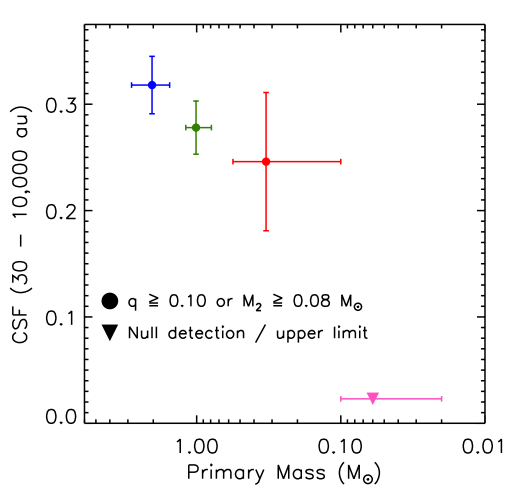


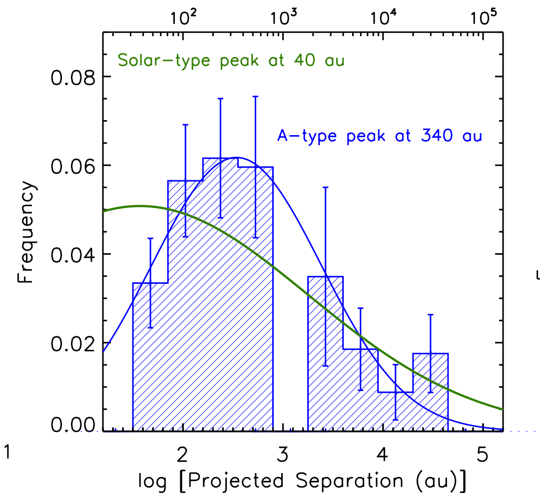
(Fortney et al. 2008)

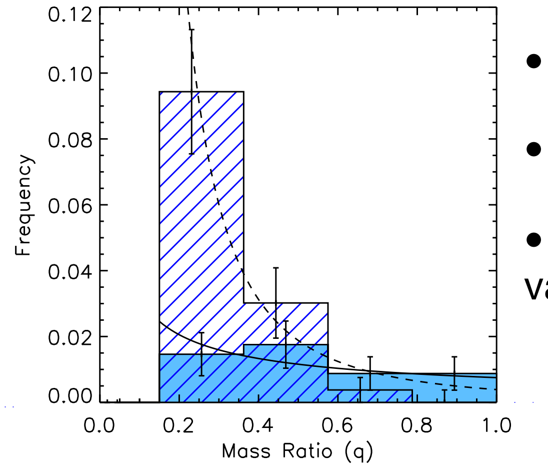
Example for an Mk=1.5 primary (median)

Summary

- **VAST snapshot survey of A-stars within 75pc**

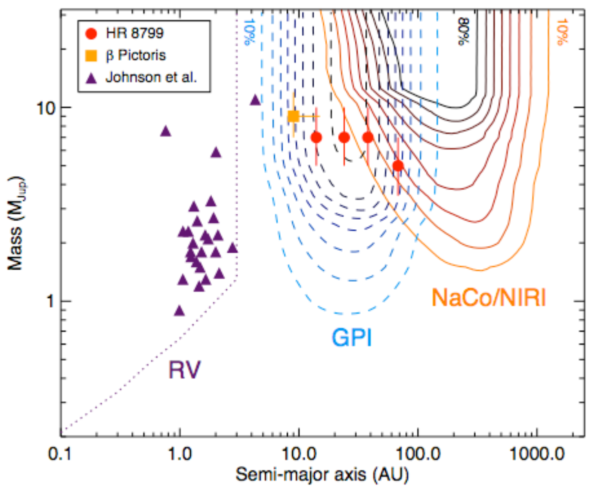






- Frequency higher
- Separations wider
- Mass ratio distribution varies with separation

- **IDPS deep survey for exoplanets around A-stars**



- A-star planet frequency ~9% (-6,+10%) from initial survey
- Brown dwarf frequency ~3% (-1,+5%) from initial survey
- Detected planets/brown dwarfs in debris disk systems
- Planet population changes from close to wide orbits
- Future work w/GPI