The Gemini Deep Planet Survey (GDPS)

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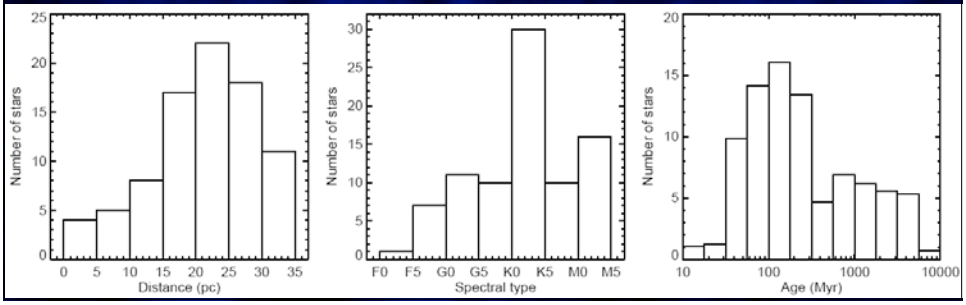
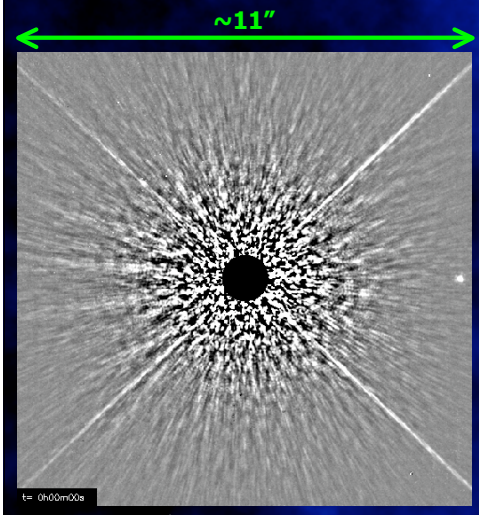
GDPS target sample

- 85 FGKM young stars
  - Li abundance & X-ray emission (Wichmann et al. 2003)
  - Members of young associations (Zuckerman & Song 2004)
  - Kinematics suggestive of youth (Montes et al. 2001)
  - ~2/3 of the stars have an estimated age < 300 Myr
- Distance < 35 pc (mean of 22 pc)
- Observations at Gemini N. (2004-2006)
  - Altair + NIRI + Angular Differential Imaging (ADI)



Angular Differential Imaging (ADI)

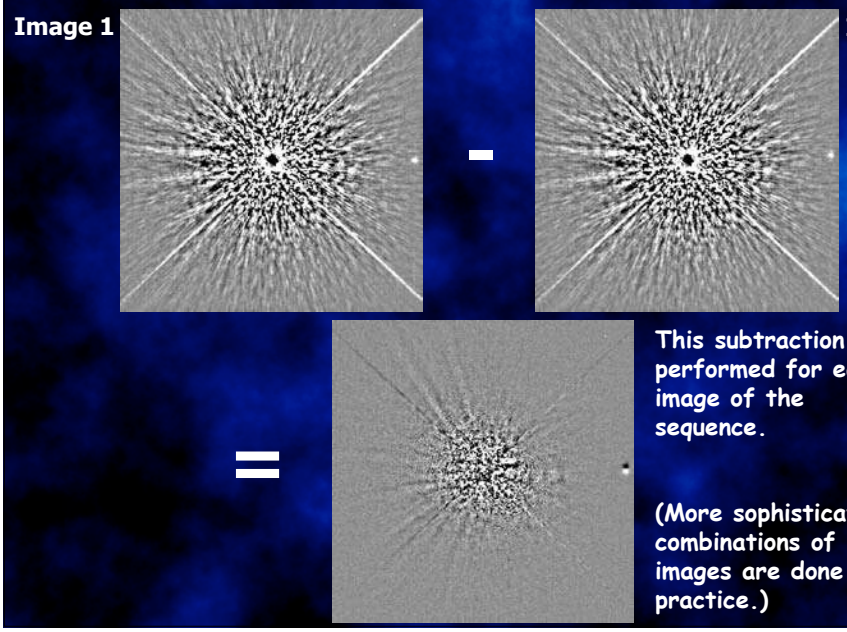


1-hour sequence
(High-pass filter applied)
(Data typically saturated within 0.50″ - 0.75″)

- Telescope operated with instrument rotator turned OFF
- A sequence of several ~30 s images is acquired
- Specke noise is suppressed by subtraction of images

For more detail, see
Marois et al. (2006, ApJ, 441, 556)
Lafrenière et al. (2007, ApJ, 660, 770)

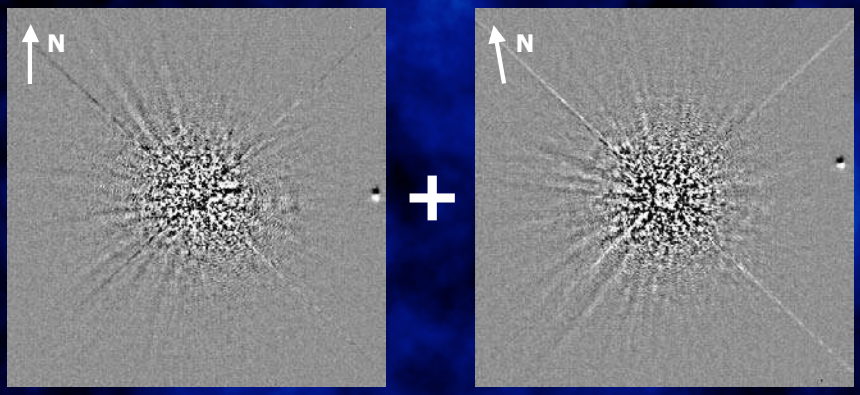
ADI Speckle Suppression



This subtraction is performed for each image of the sequence.

(More sophisticated combinations of images are done in practice.)

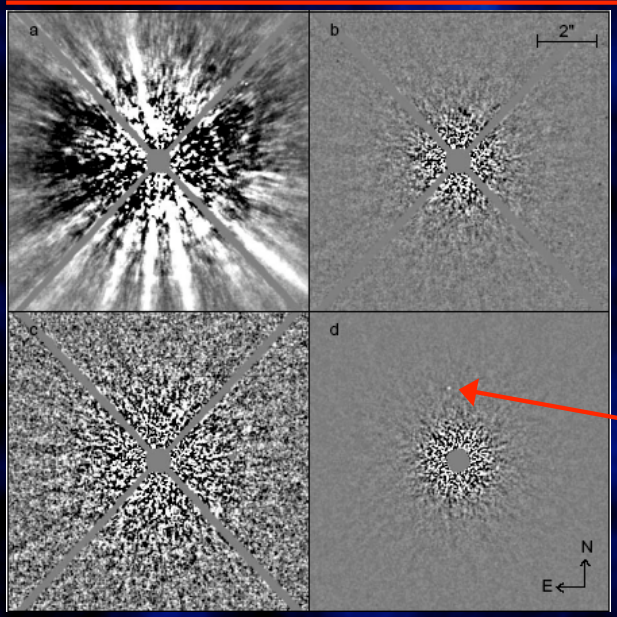
Co-addition of residual images



Im1 - Im2 Im10 - Im11

- Residuals of additional images are added incoherently
- Average flat-field, remove bad pixels and detector defects… while maintaining stable PSF

Complete ADI processing example



a) 30s exposure

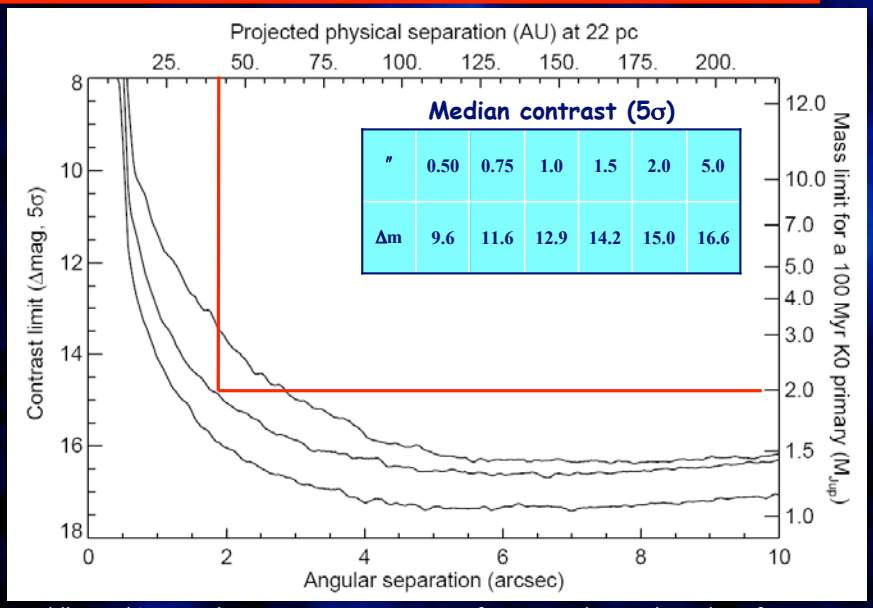
b) Single ADI subtraction

c) Same as (b) with 5x intensity scale

d) Combination of 117 residual images (~1 hr)

Δm=14.9 (H=21.2) at 2.4"

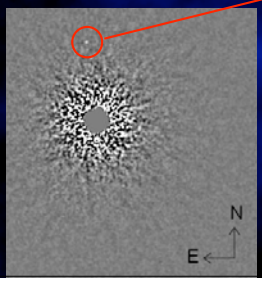
Detection Limits

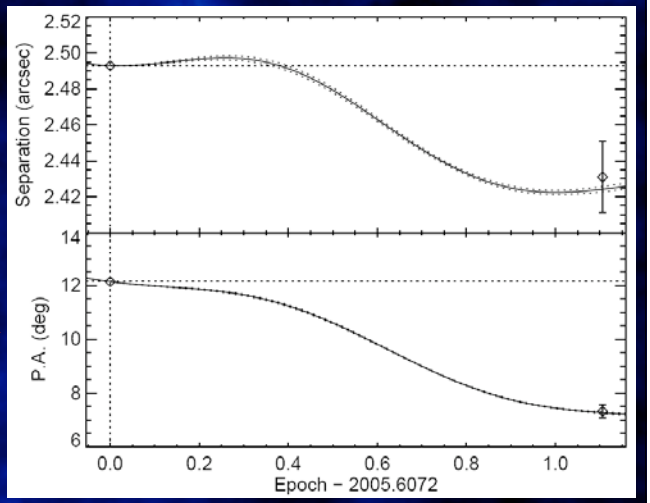


Top, middle, and bottom lines are representative of poor, median and good performance, resp.

Candidates detected

- ~300 candidates around 54 stars
- 2nd epoch obtained for 48/54, and all candidates are background stars ☹

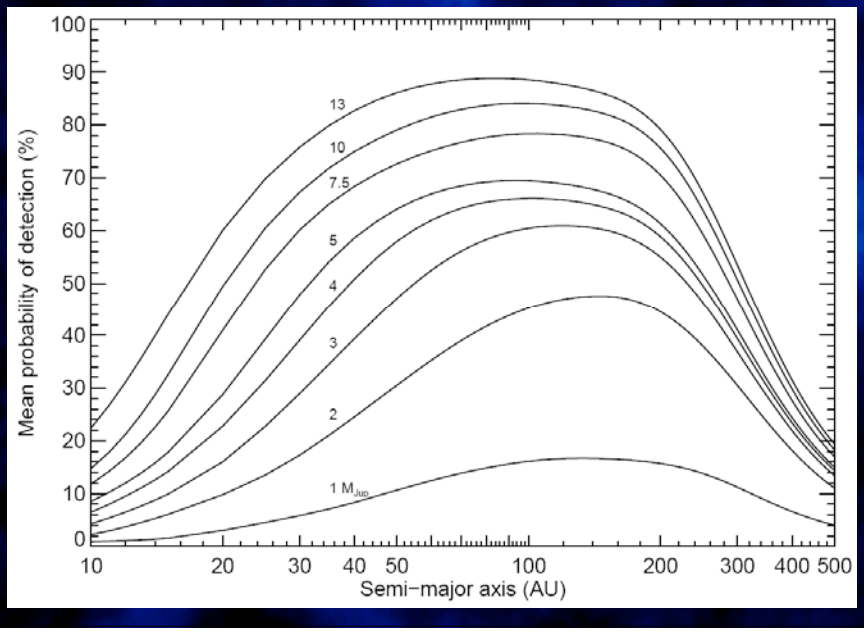




Detection probability determination

- Assuming that a planet of some specific mass and semi-major axis exists around a star, what is the probability of detecting it given our sensitivity?
- Monte Carlo simulation
  - For each star, generate 10000 fiducial exoplanets
    - Age sampled uniformly within estimated age range for each star.
    - Orbital phase and orientation sampled uniformly.
    - Eccentricity sampled assuming RV exoplanets eccentricity distribution.
    - Mass converted into flux and Δm based on models of Baraffe et al. (2003).
  - Detection probability "p" = fraction of exoplanets lying above the 5σ contrast curve.

Average detection probability



Statistical (Bayesian) analysis

- We seek to constrain f
  - the fraction of stars harboring at least one planet in the mass interval $[m_{min}, m_{max}]$ and semi-major axis interval $[a_{min}, a_{max}]$.
- First calculate the "Likelihood function"
  - probability of obtaining the observed data $\{d_j\}$ given that the planet frequency is f

$$\mathcal{L}(\{d_j\}|f) = \prod_{j=1}^{N} (1 - f p_j)^{(1-d_j)} (f p_j)^{d_j}$$

where p_j is the detection probability for star j, and d_j=1 if detection for star j, or 0 if no detection

Planet frequency probability density function

- Probability that the planet frequency is f given a set of observations $\{d_j\}$ ("posterior" distribution of f)

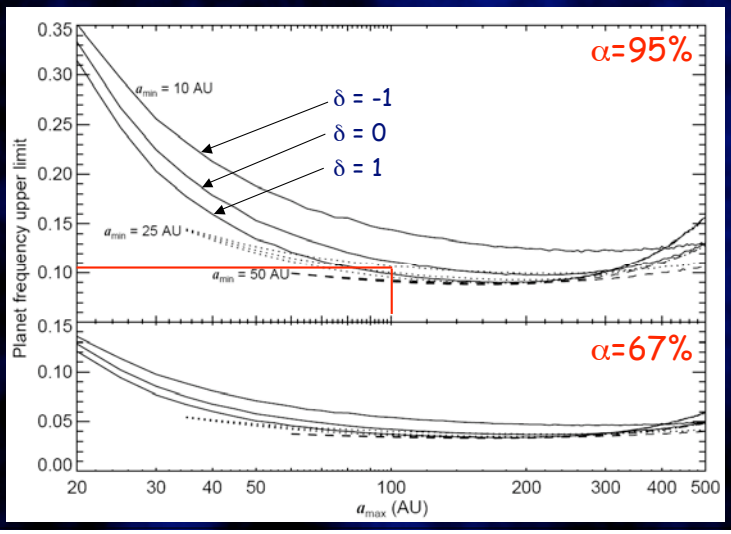
$$p(f|\{d_j\}) = \frac{\mathcal{L}(\{d_j\}|f)p(f)}{\int_0^1 \mathcal{L}(\{d_j\}|f)p(f)\mathrm{d}f}$$

where P(f) is the "prior" distribution of f
  - Use most ignorant prior: P(f) = constant
- Determine an α=95% credible interval for f: $[0, f_{max}]$

$$\alpha = \int_0^{f_{\max}} p(f|\{d_j\})\mathrm{d}f$$

Results

- m in [0.5, 13] M_J with $dN/dm \propto m^{-1.2}$
- a in $[a_{min}, a_{max}]$ with $dN/da \propto a^{\delta}$ ($dN/d\log P \propto P^{0.26}$ $\Rightarrow \delta$=-0.61)



Example:

a_{min}=25 AU

a_{max}=100 AU

δ=-1

$\Rightarrow f < 0.11$

Results (95% credible interval)

- With $dN/da \propto a^{-1}$
- With $dN/dm \propto m^{-1.2}$
- m in [0.5, 13] M_J

a range (AU)	f_{max}
10-25	0.29
25-50	0.13
50-250	0.09

- For BD companions in 50-250 AU, [redacted]

GDPS paper submitted to ApJ

On astro-ph: 0705.4290