A Survey of 54 Close, Young Stars with the Simultaneous Differential Extrasolar Planet Imager (SDI) at the VLT and MMT

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The Need for Dedicated Planet Finding Instruments

- Telescope + AO system surveys for self-luminous giant extrasolar planets have yielded useful limits but few confirmed giant planet candidates (just a few examples: Macintosh et al 2001, Kaisler et al 2003, Masciadri et al 2005, Chauvin et al 2004, Neuhauser et al 2005)
- To go deeper, VLT, Gemini, and Keck are all developing dedicated planet-finding cameras
- SDI: one of the first dedicated planet-finding instruments to come online.

Difficulties with Direct Detection 1

- Two major difficulties:

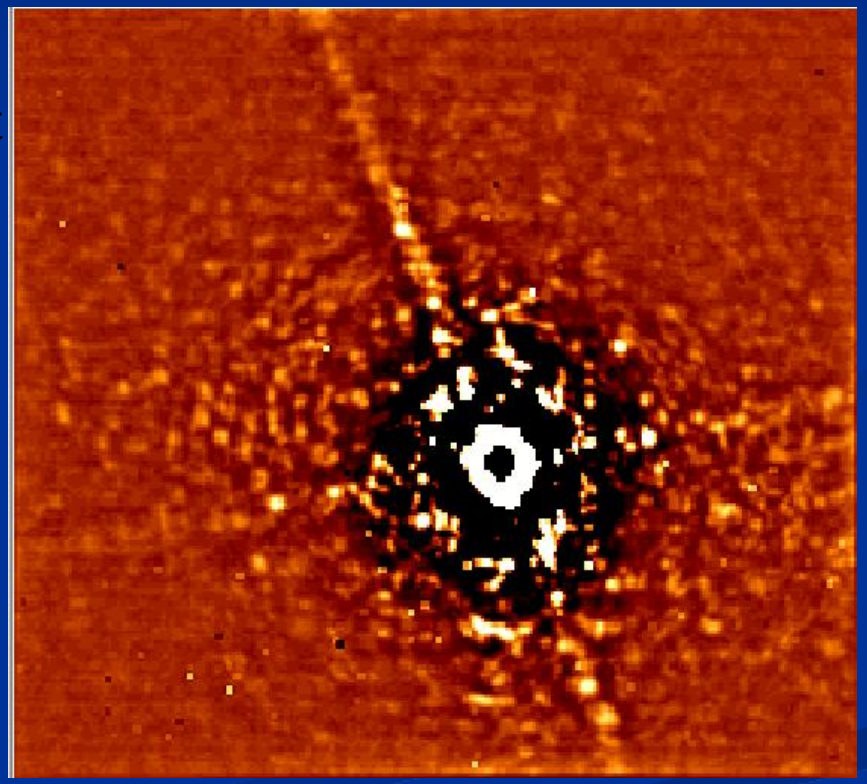
1) Huge contrast difference between planet and star:

- Old (>2 Gyr) giant gas planets >10^8 fainter than primary and lie within ~1" of primary.
- However, young planets are still self-luminous and ~10^{4-7} times fainter than primary.
- Adaptive optics systems that are photon noise limited can detect (1 hr exposure) an object up to 10^{5-6} times fainter than and >1" from its primary.

Difficulties with Direct Detection (2)

2) Speckle Noise –

Within 1" of star, the field is filled with super speckles left over after adaptive optics correction.

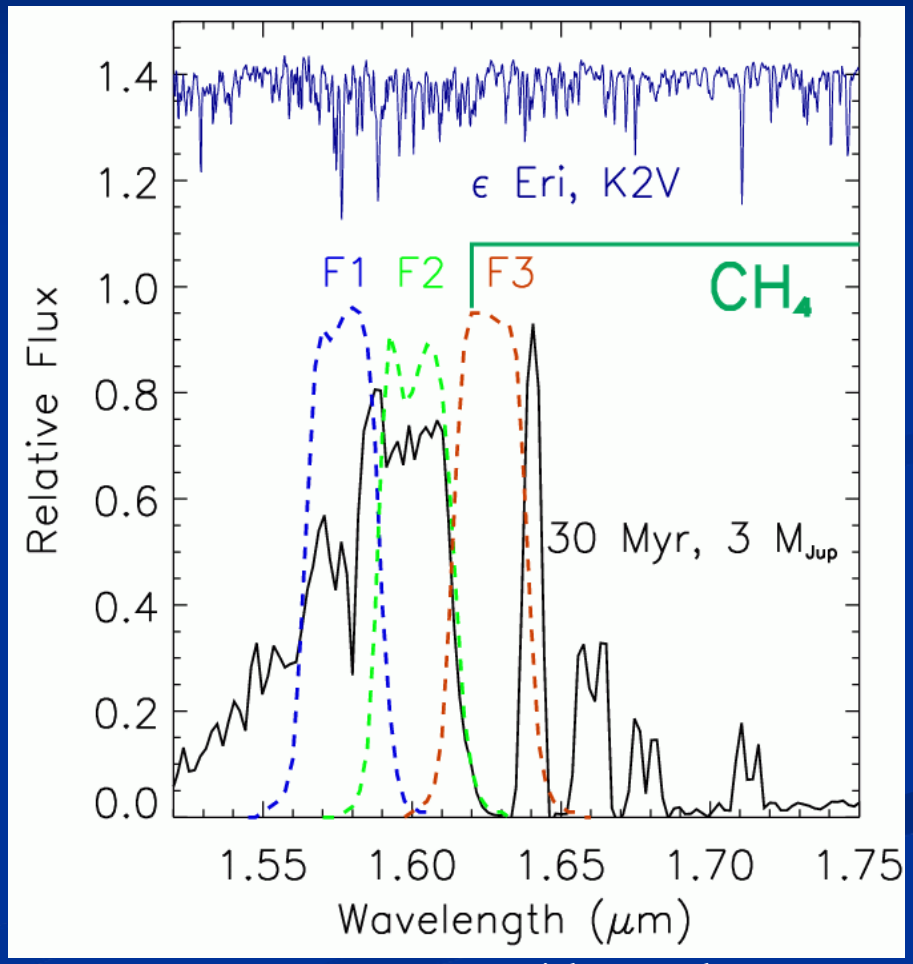


For photon-noise limited data:
$S/N \sim t_{exp}^{0.5}$

For speckle-noise limited data:
S/N does not increase with time past a speckle noise floor.

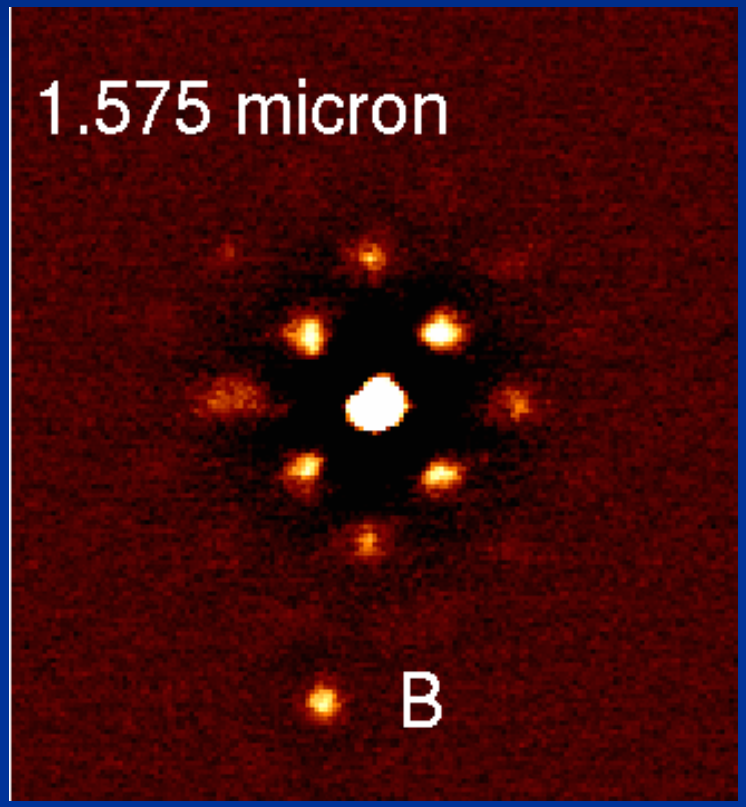
The Simultaneous Differential Imaging (SDI) Technique

- Pioneered by Marois et al. 2000.
- Sample inside and outside of the strong CH_4 (methane absorption) bandhead at 1.62 μm in extrasolar giant planets (T < 1200 K)
- Subtract out star and speckles between filters – any CH_4 rich companion should remain.

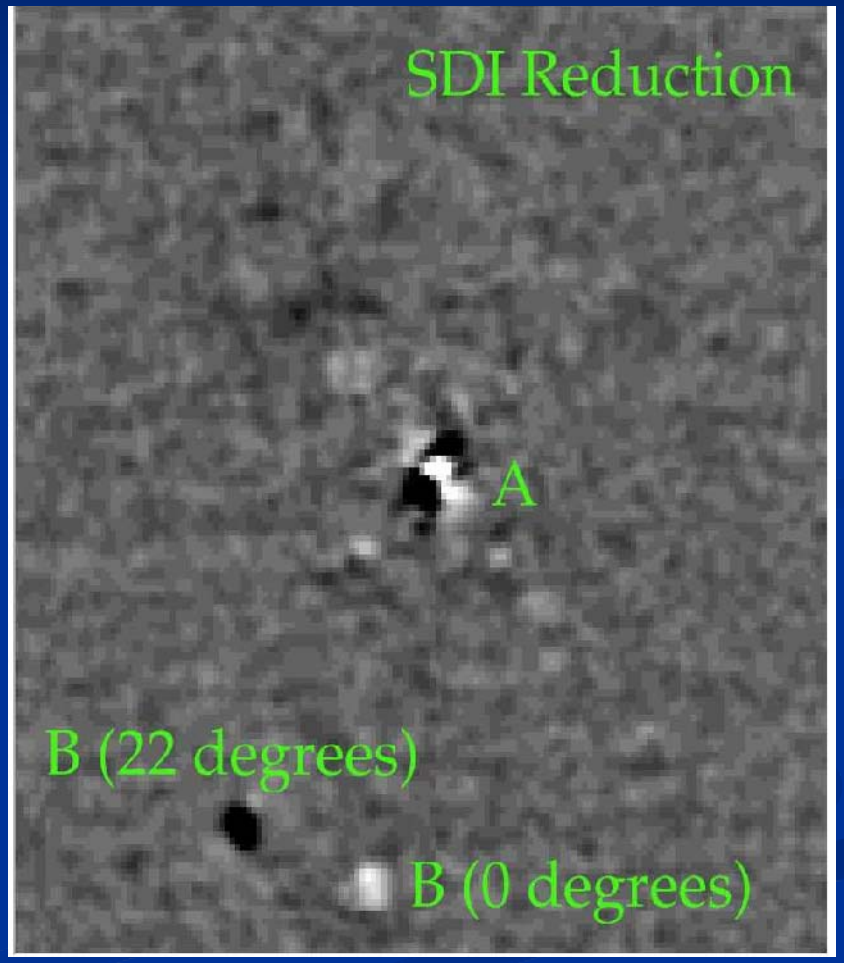


Nielsen et al. 2006

Proof of Concept – The Methane Rich Brown Dwarf SCR 1845B



M8.5 + T5.5

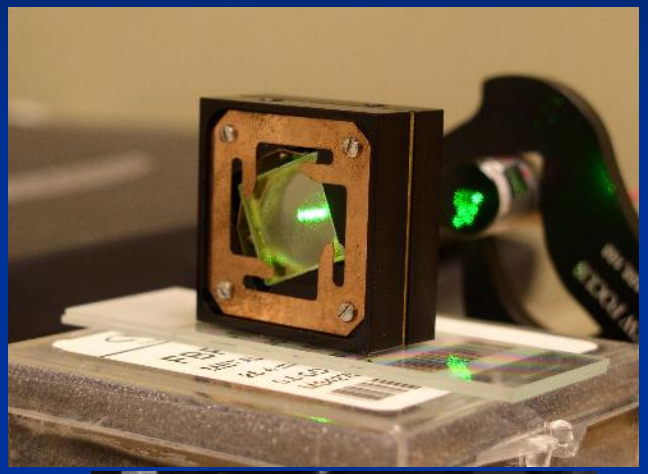


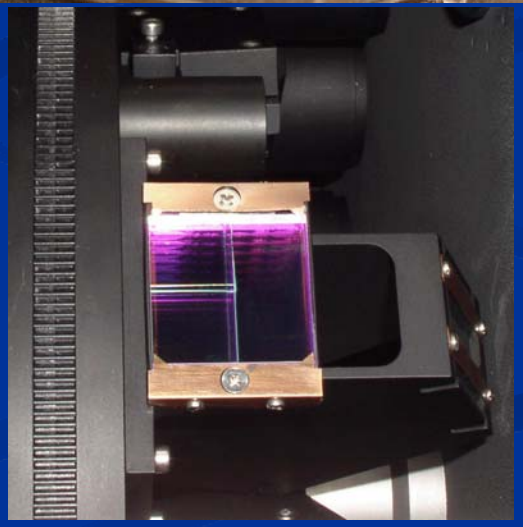
Biller et al. 2006

SDI Hardware

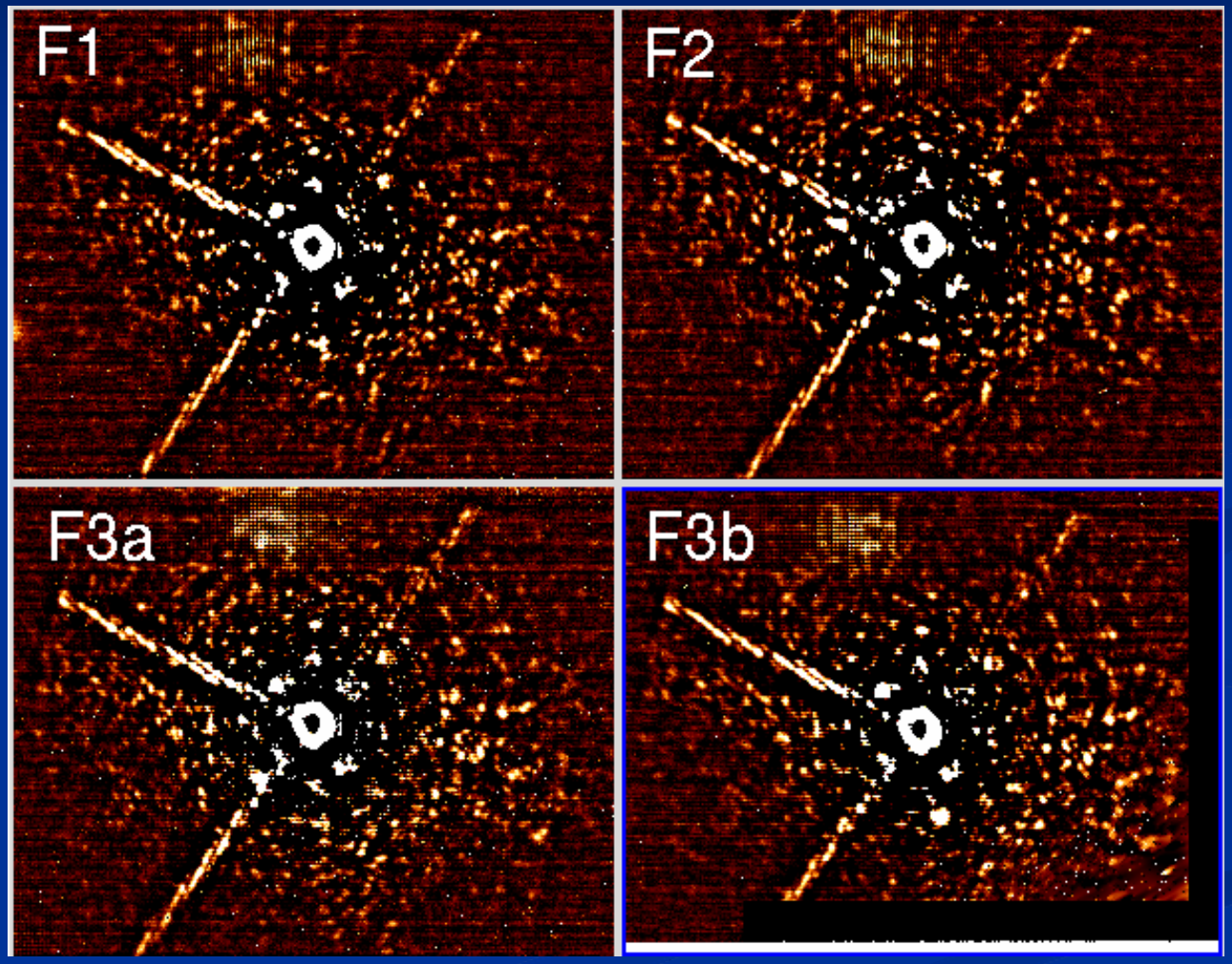
Double Wollaston and Quad Filter– Calcite Prisms split beam into 4 identical beams while minimizing non common path error (Close et al. 2004).

- Installed in the ARIES camera at the MMT AO system by Don McCarthy and Laird Close and in the CONICA camera inside the VLT NACO AO system by Laird Close and Rainer Lenzen.
- NACO and ARIES SDI fully commissioned.

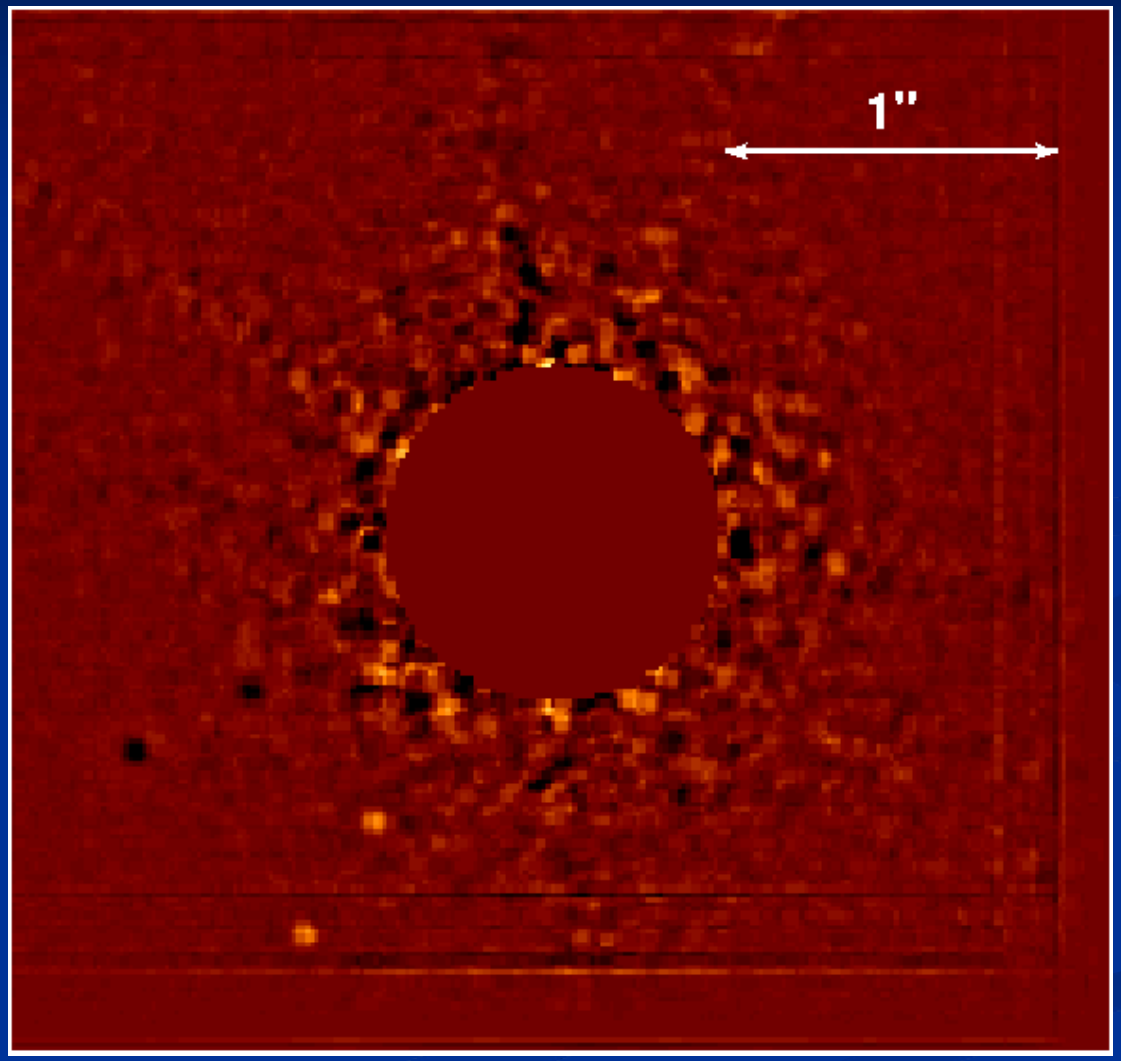




Raw Data from the VLT Device

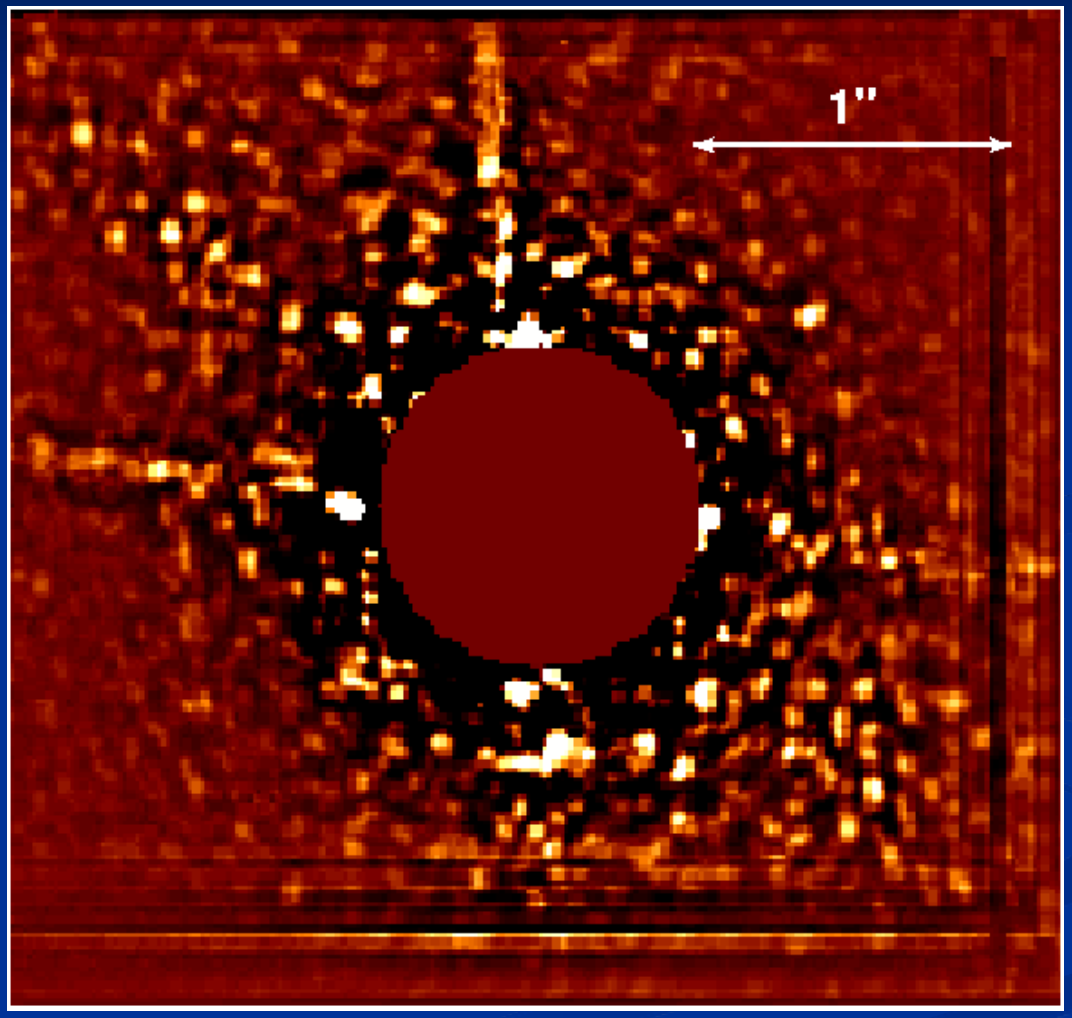


Reduced Data – 0° – 33° Roll Angle



Biller et al. 2006

Reduced Data – Standard AO vs. SDI



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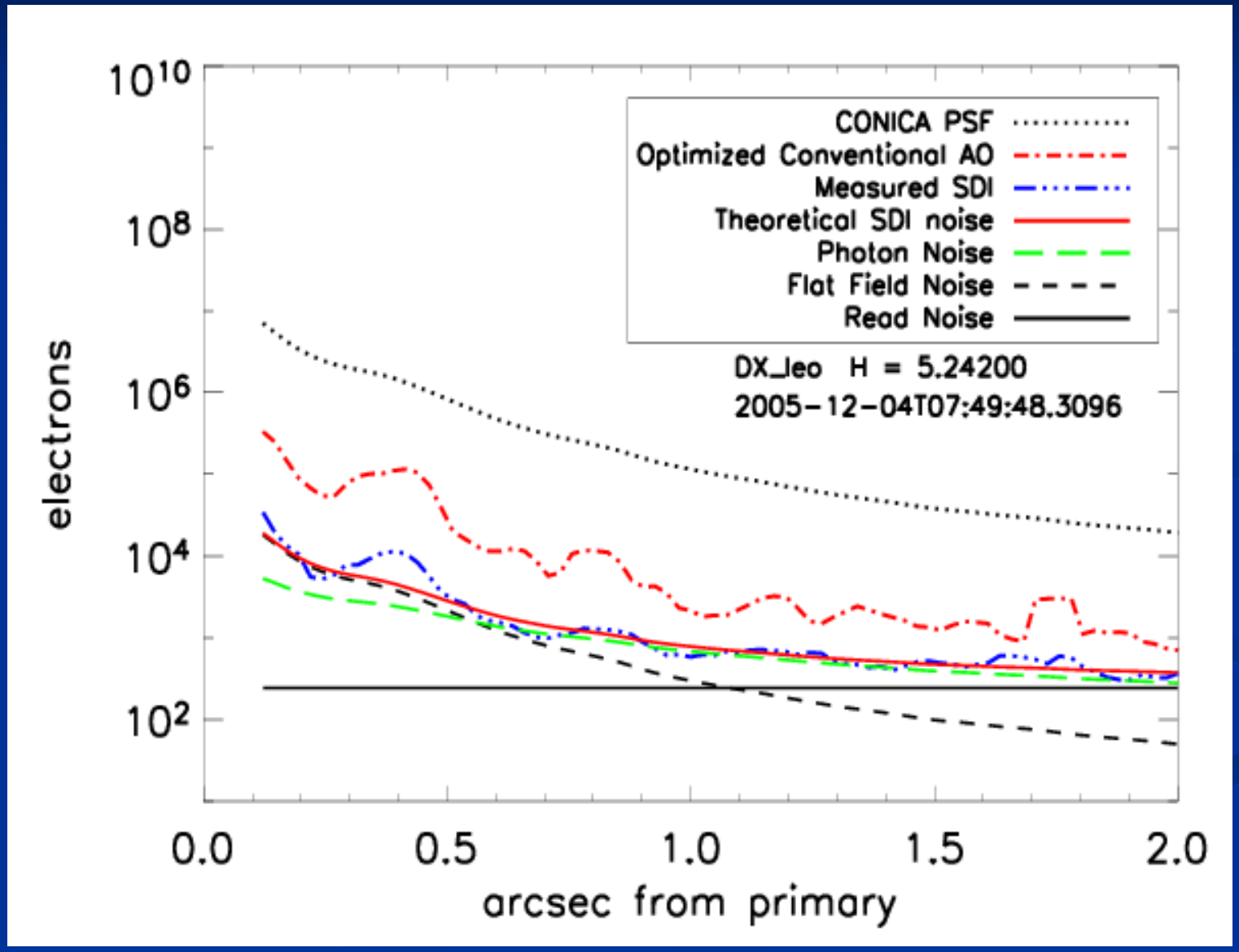
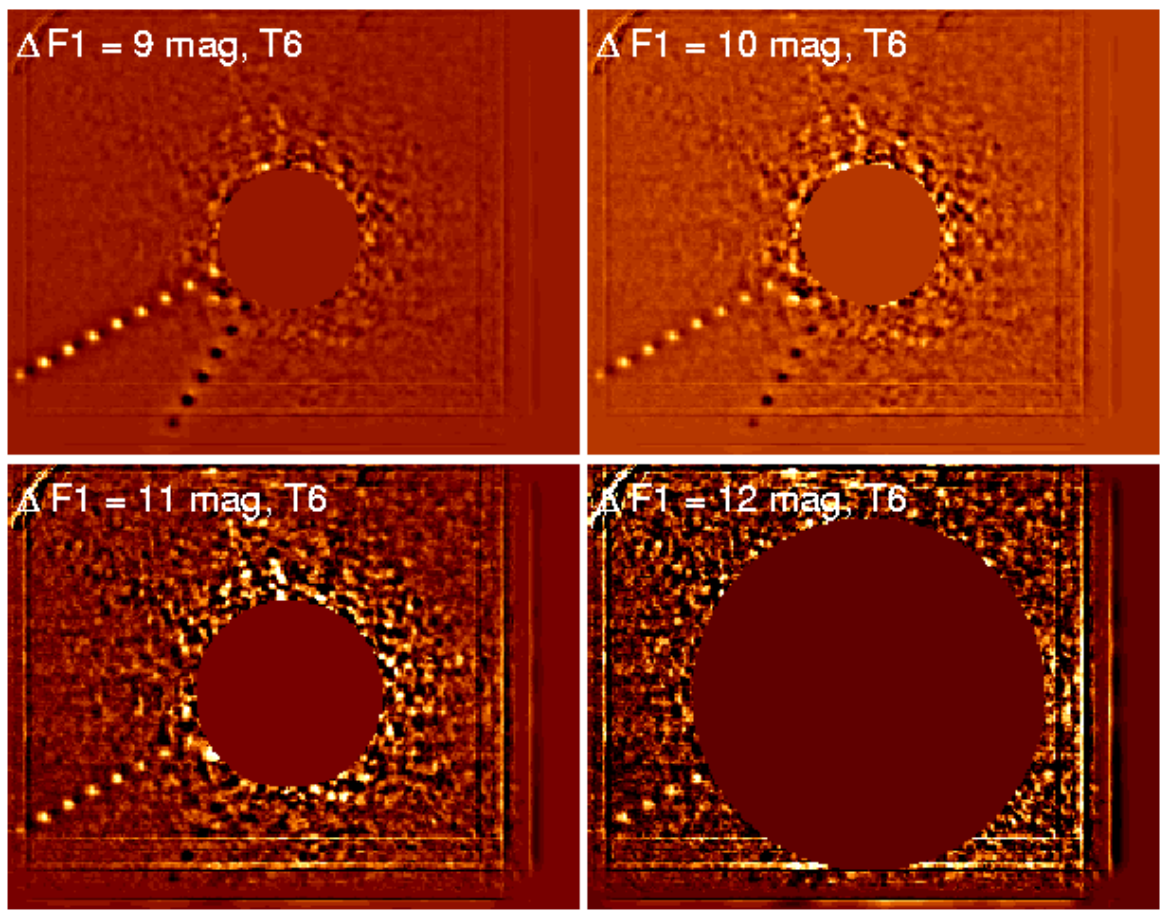
Noise Sources



Case Study: Achievable Contrasts for AB Dor (K1V, 15 pc, ~70 Myr, V=6.88)



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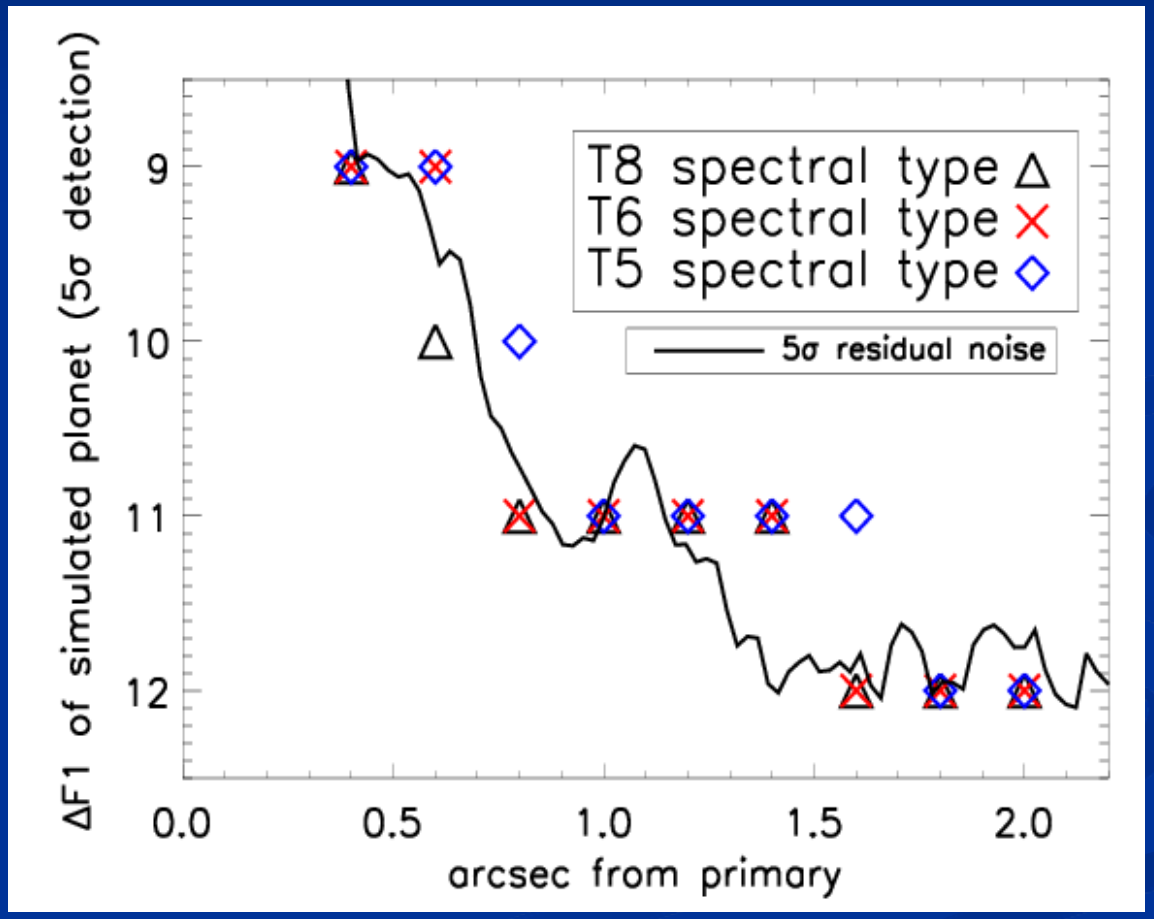
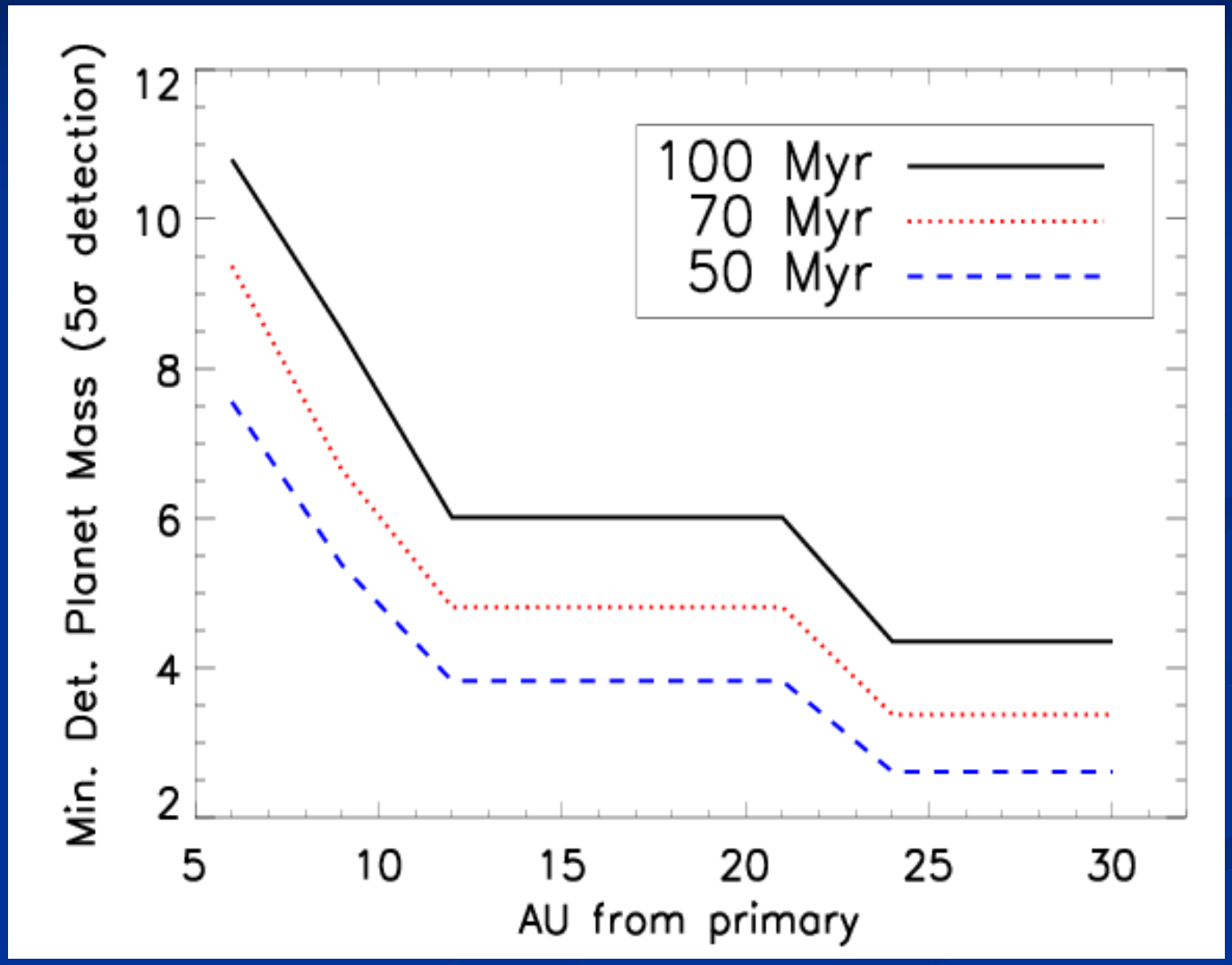
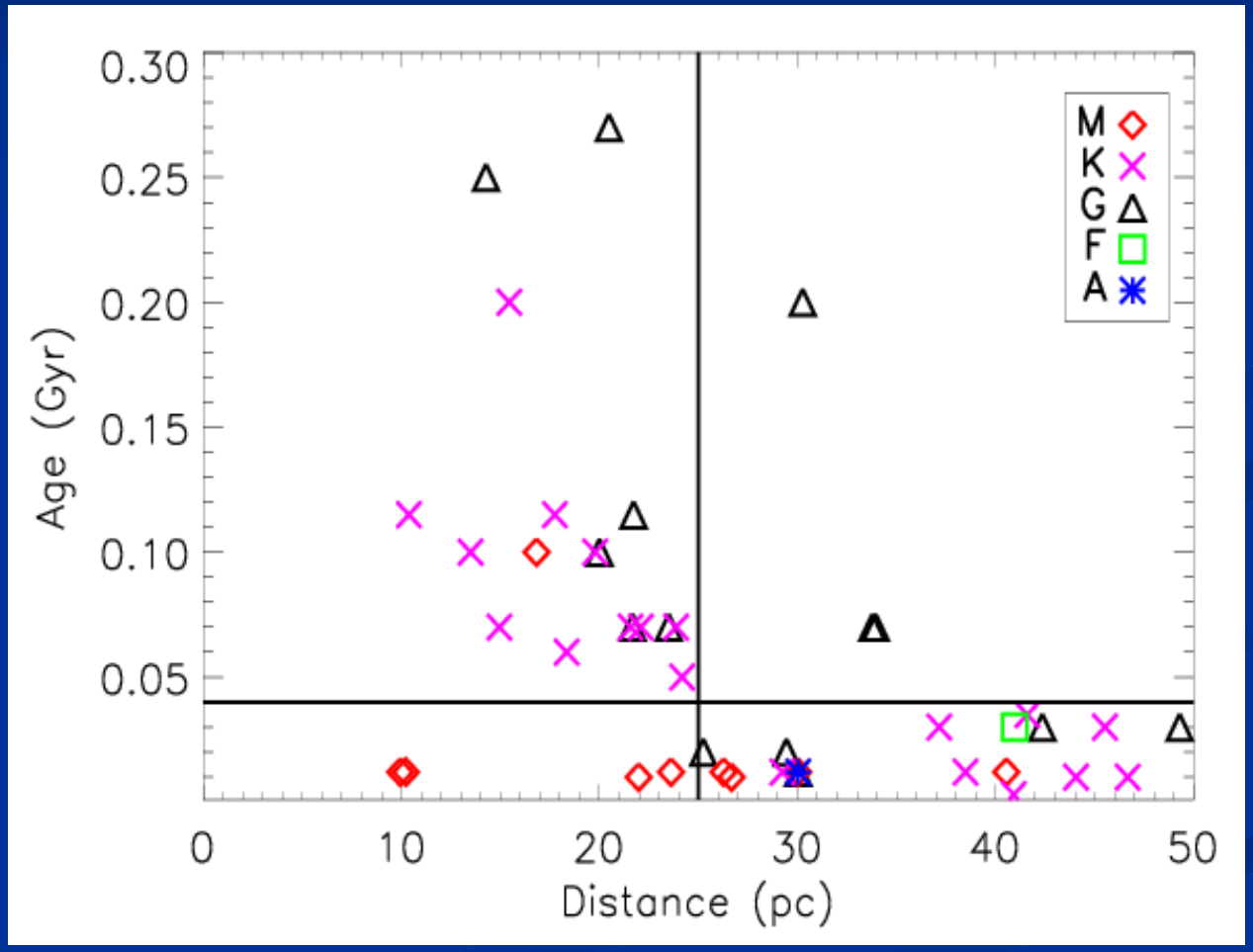


Minimum Detectable Mass for AB Dor

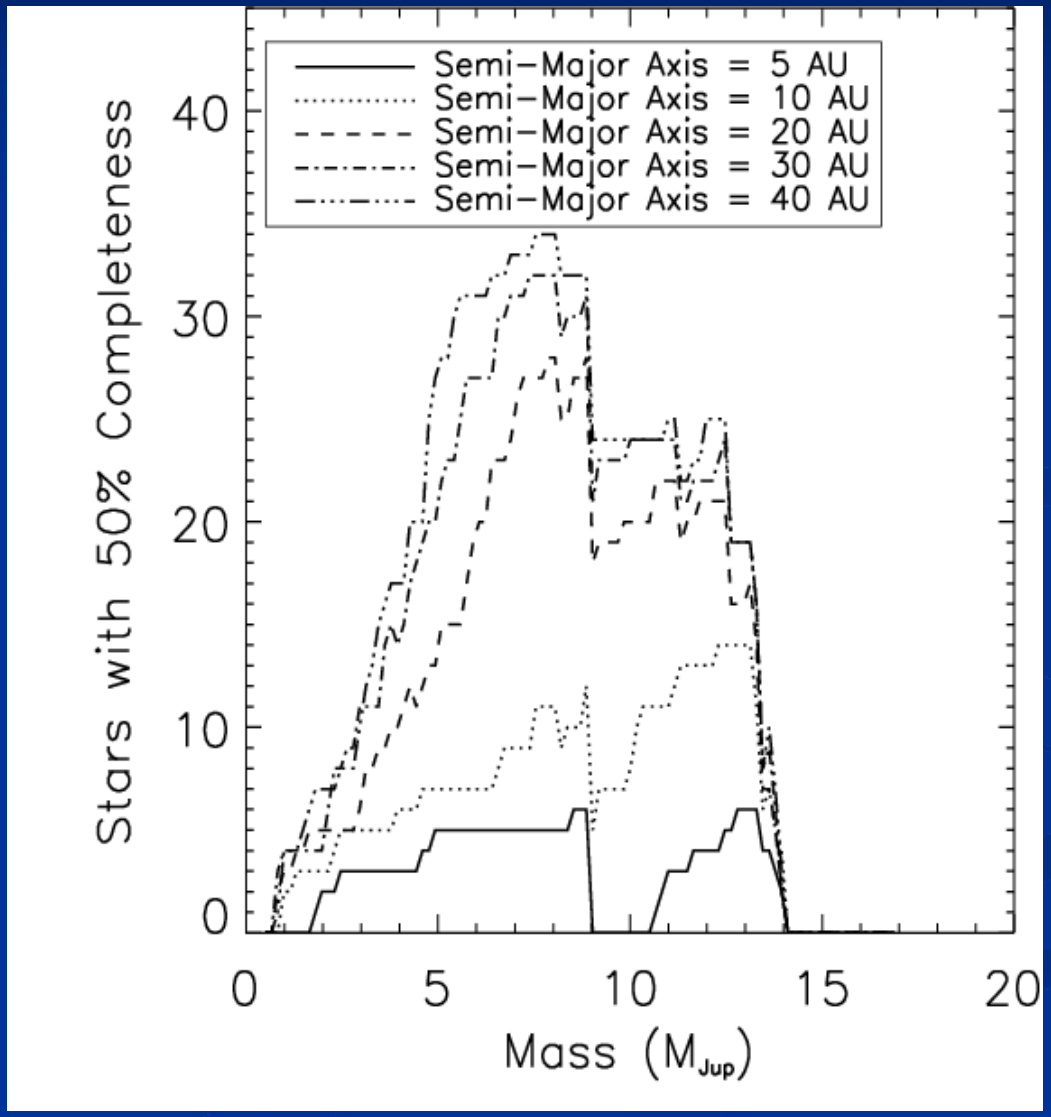


SDI Survey Target Objects

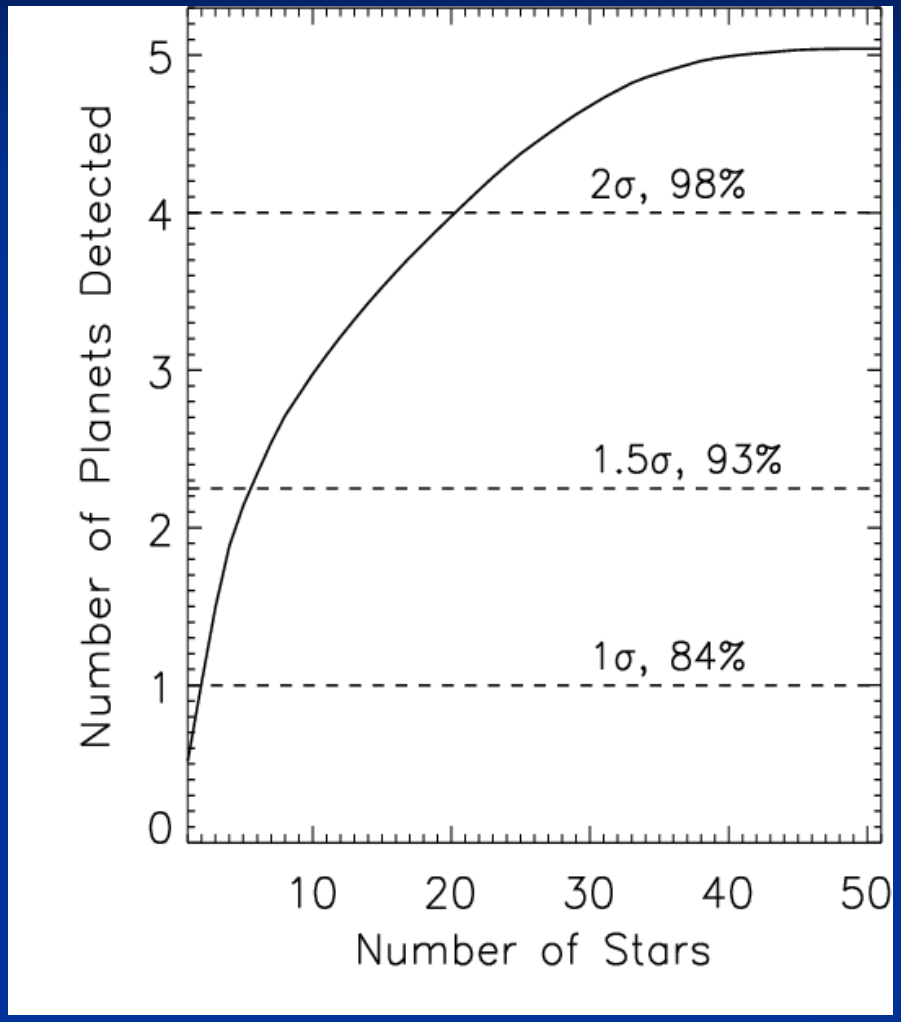
The "median" survey object: K2V star, 50 Myr old, at a distance of 25 pc.



SDI Survey Completeness for Extrasolar Planets



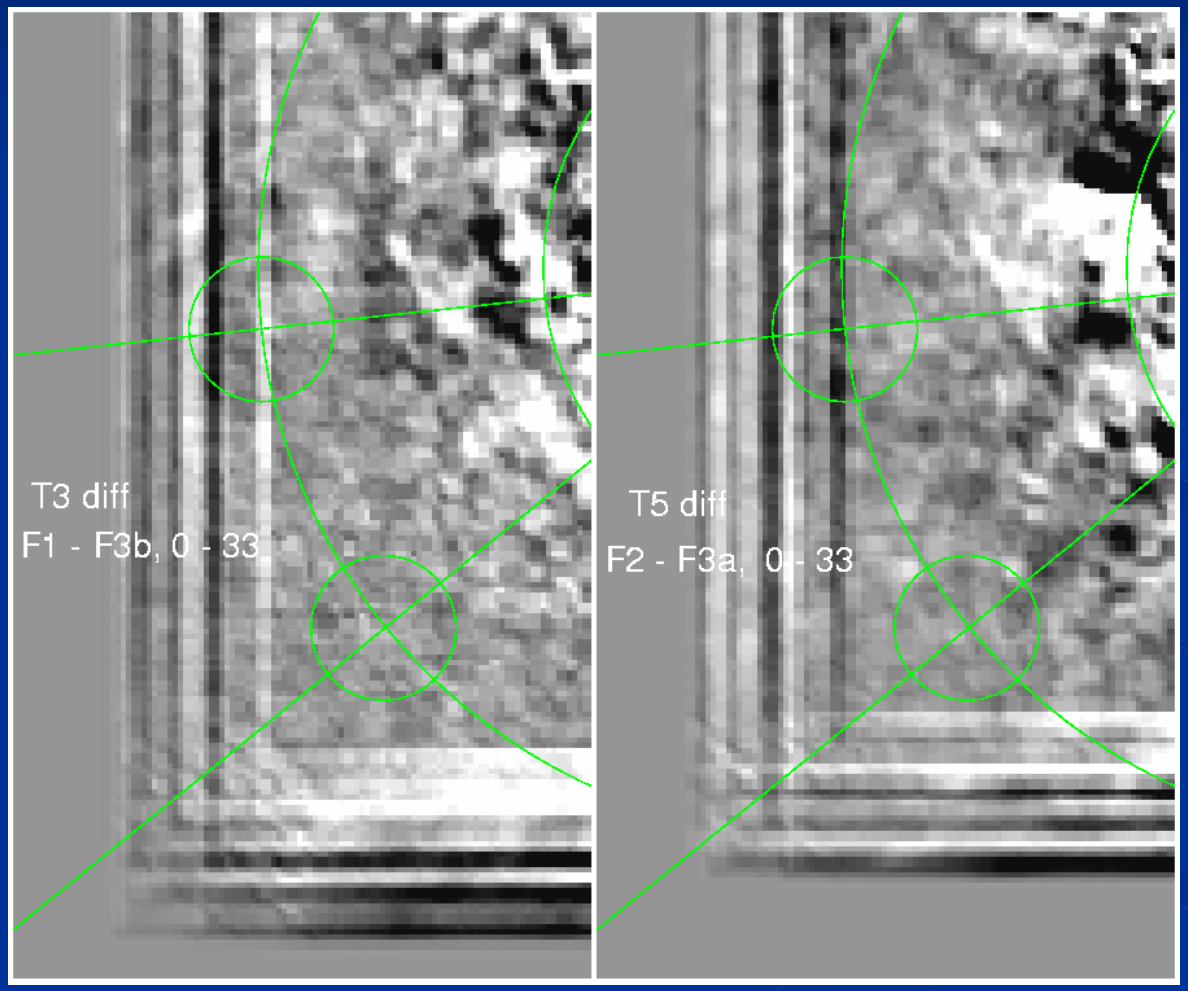
So what does this all mean?



Nielsen et al. 2007

- Determine detection probabilities from Monte Carlo simulations of 10^6 objects per star with $N(a) \propto a$ (assuming each star has 1 planet)
- For a ~50 object survey, we expect to detect ~4 planets (from Monte Carlo simulations using realistic scaling laws (Marcy et al. 2003) and models (Burrows et al. 2003))
- **Even with a null result (no planets), we will be able to place strong constraints ($\geq 2\sigma$) on the frequency and semimajor axis distribution of young massive extrasolar planets >5 AU from their primaries.**

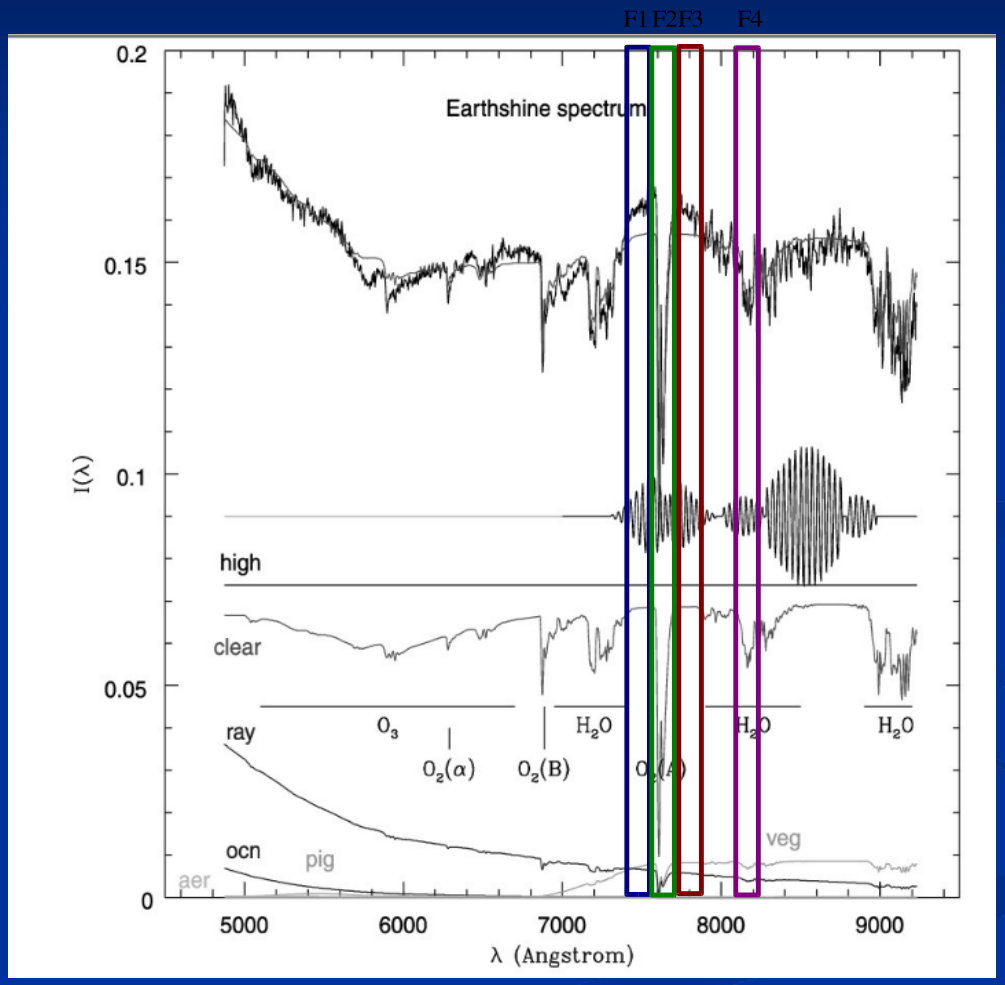
ε Eri B – Likely to be the first directly detected planet



- Used recent orbital determination of Benedict et al. 2006 to locate planet in our SDI data.
- Upper limit on ε Eri B flux of H=20

Janson et al. 2006

"SDI" Experiment for the HCIT



Earthshine Spectrum from Woolf et al. 2002

Current Status

- We achieve $\Delta F1(1.575\ \mu m) > 10$ mag (5σ) at a separation of 0.5" from the star with both the VLT and MMT SDI devices.
- Already a number of exciting discoveries from the SDI devices:

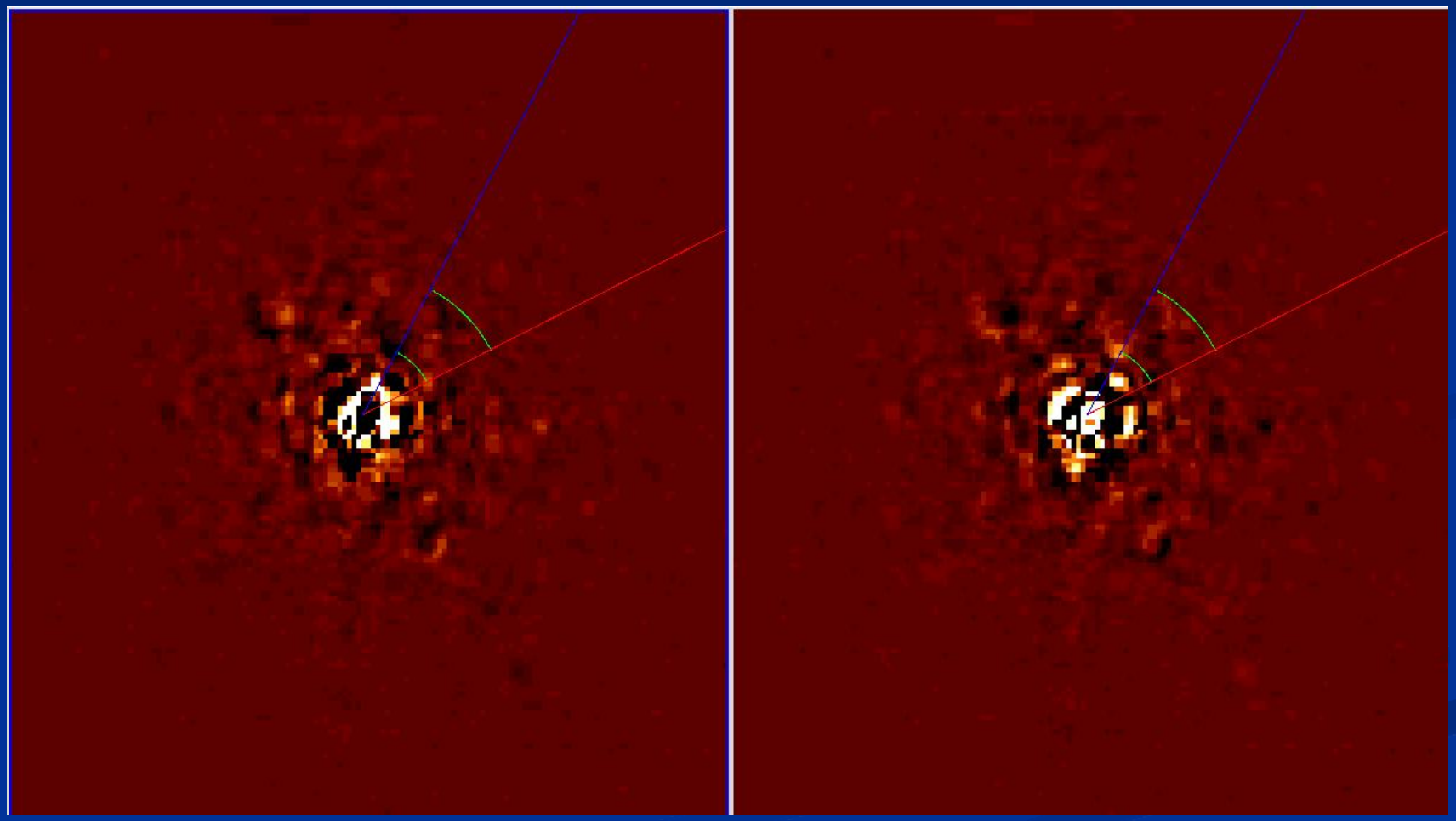
  SCR 1845B -- a very nearby (3.85 pc) T5.5 brown dwarf companion to a a low mass star (Biller et al. 2006)

  AB Dor C – the tightest ($\Delta F1 \sim 7.5$ mag, 0.16" separation) low mass companion yet discovered (Close et al. 2005)

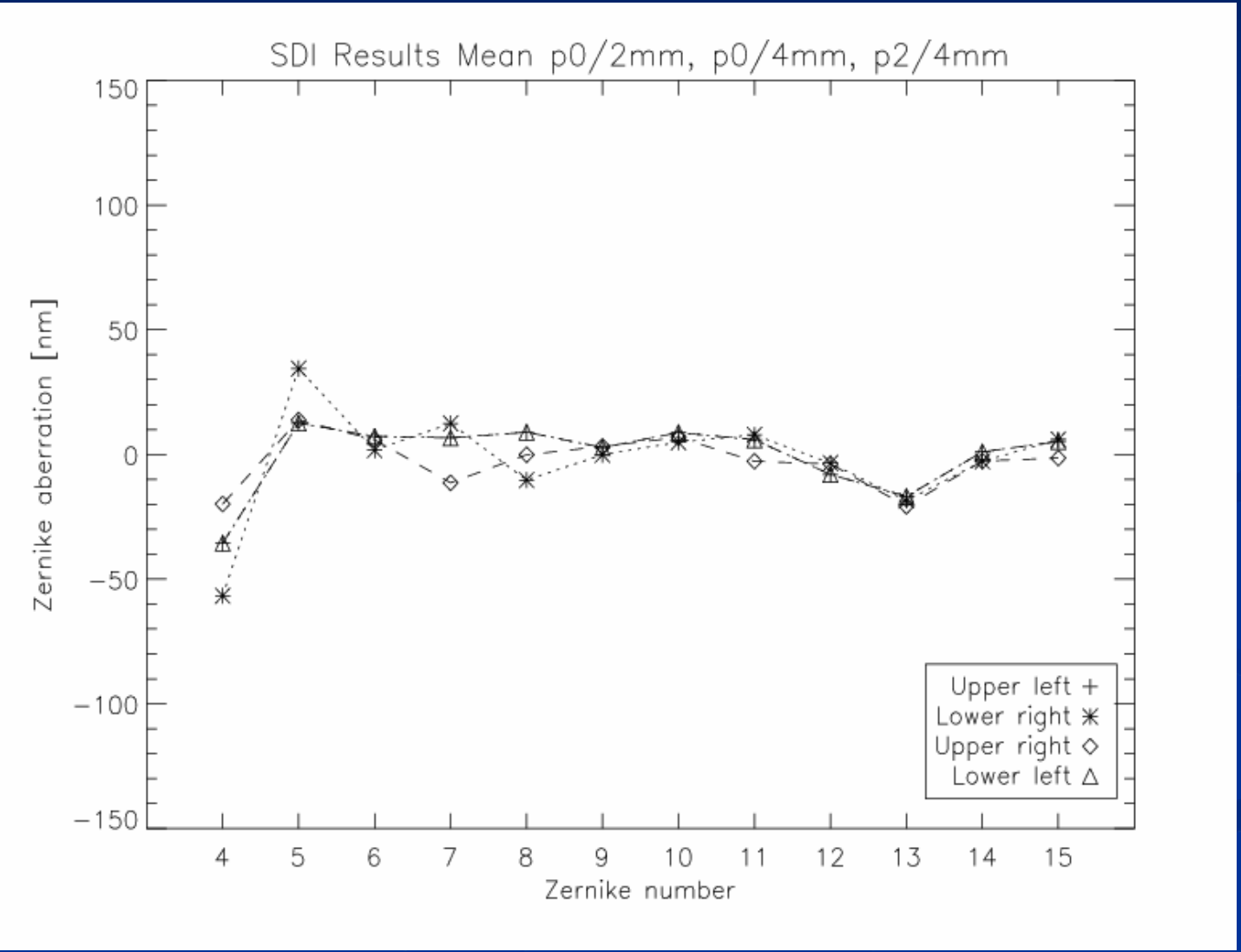
  The first surface maps of Titan (Hartung et al. 2004)

  Eps Indi Ba-Bb – the nearest binary brown dwarf (McCaughrean et al. 2005)
- We have observed 54 stars and completed followup observations for 8 tentative candidates. (None of these candidates were confirmed.)

A Tentative Candidate Faint Companion

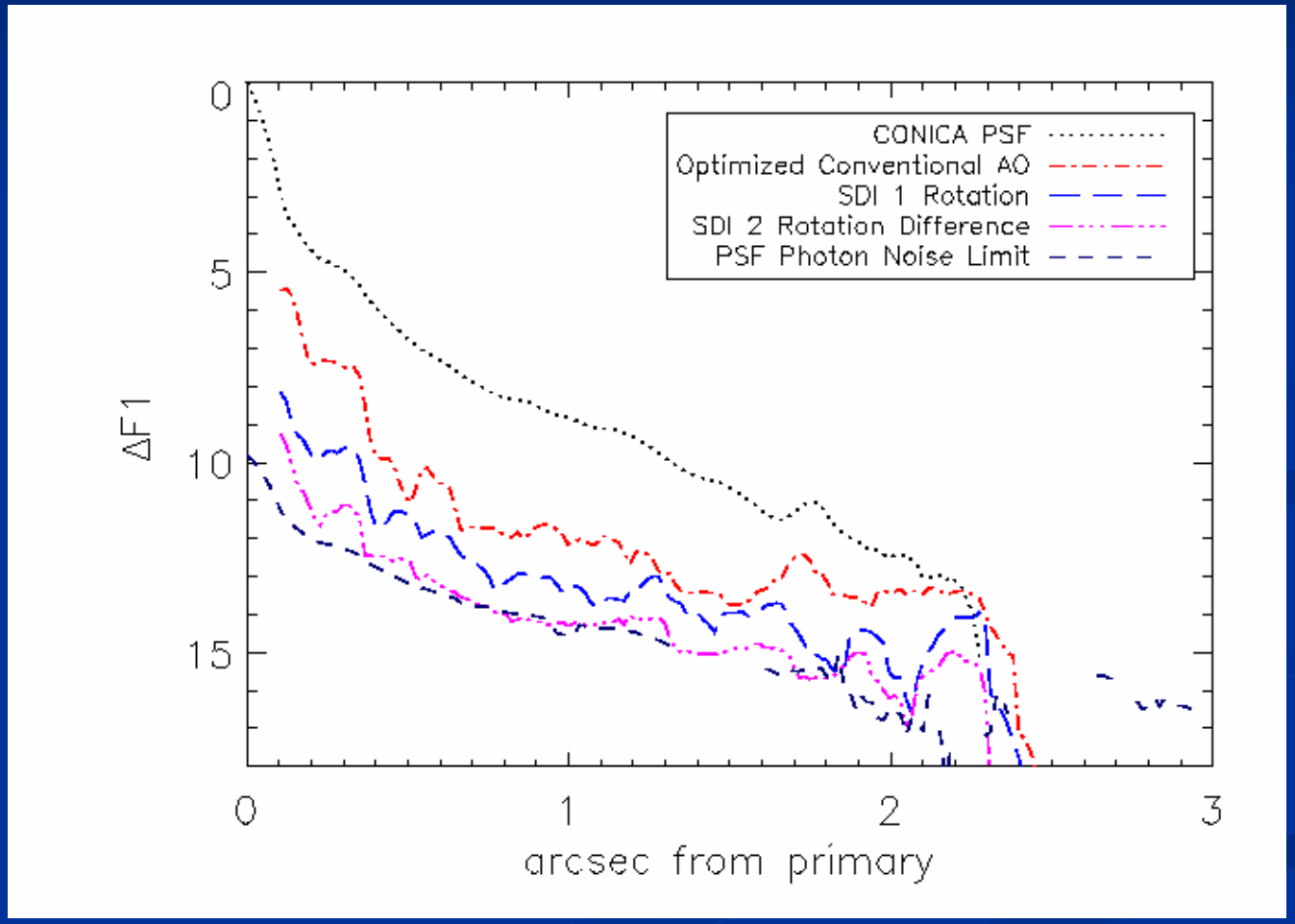


Non-common Path Errors



Lenzen et al. 2004

1 vs. 2 Roll Angles



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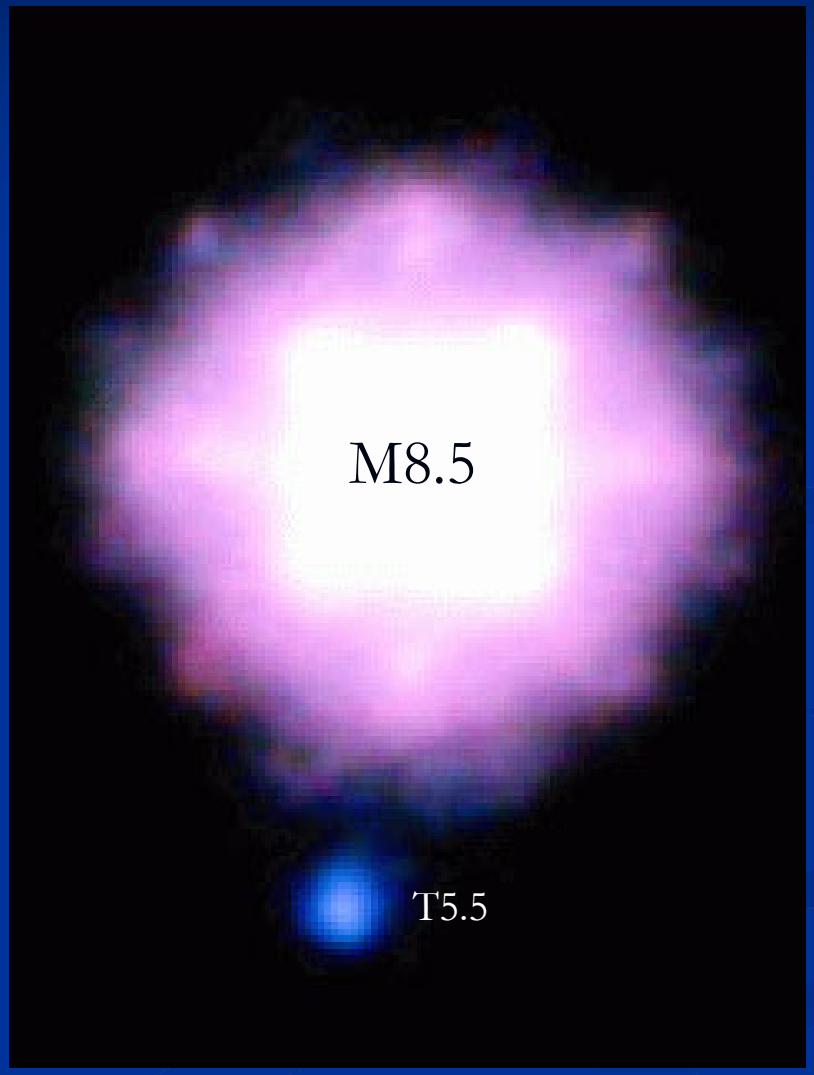

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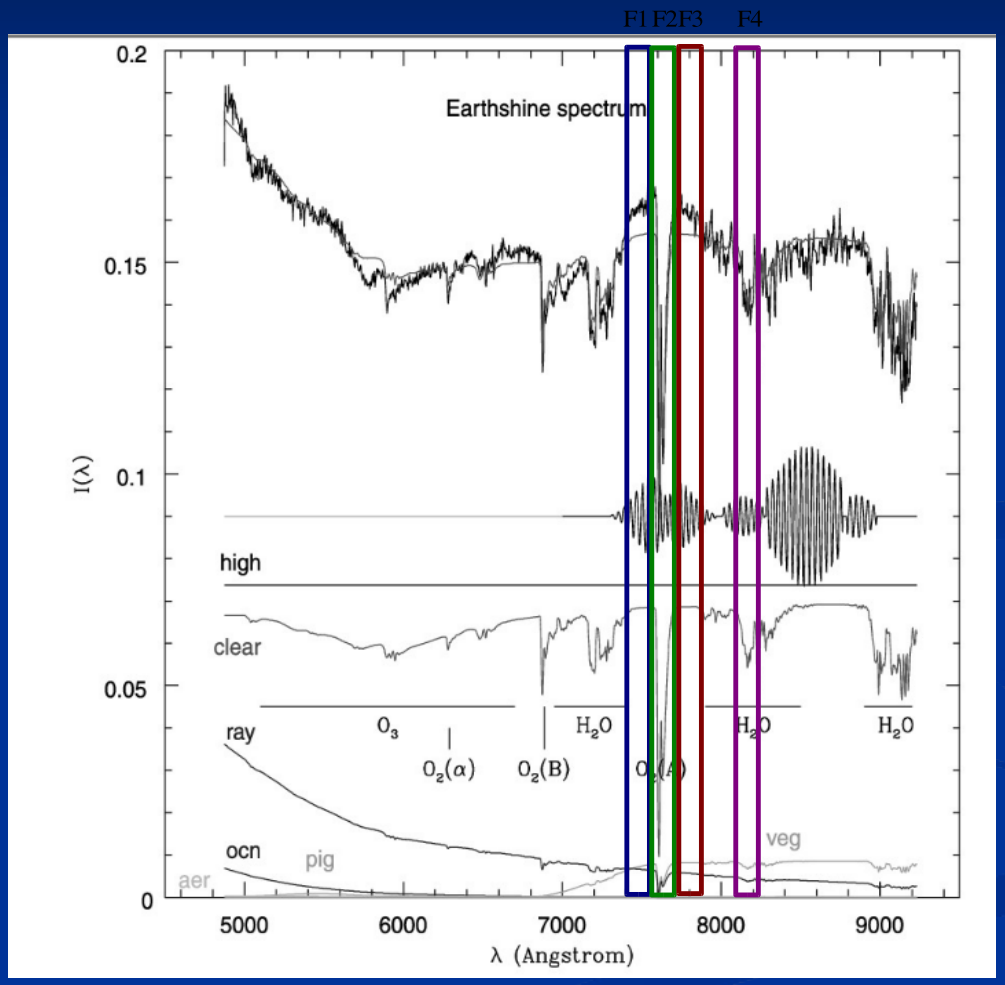

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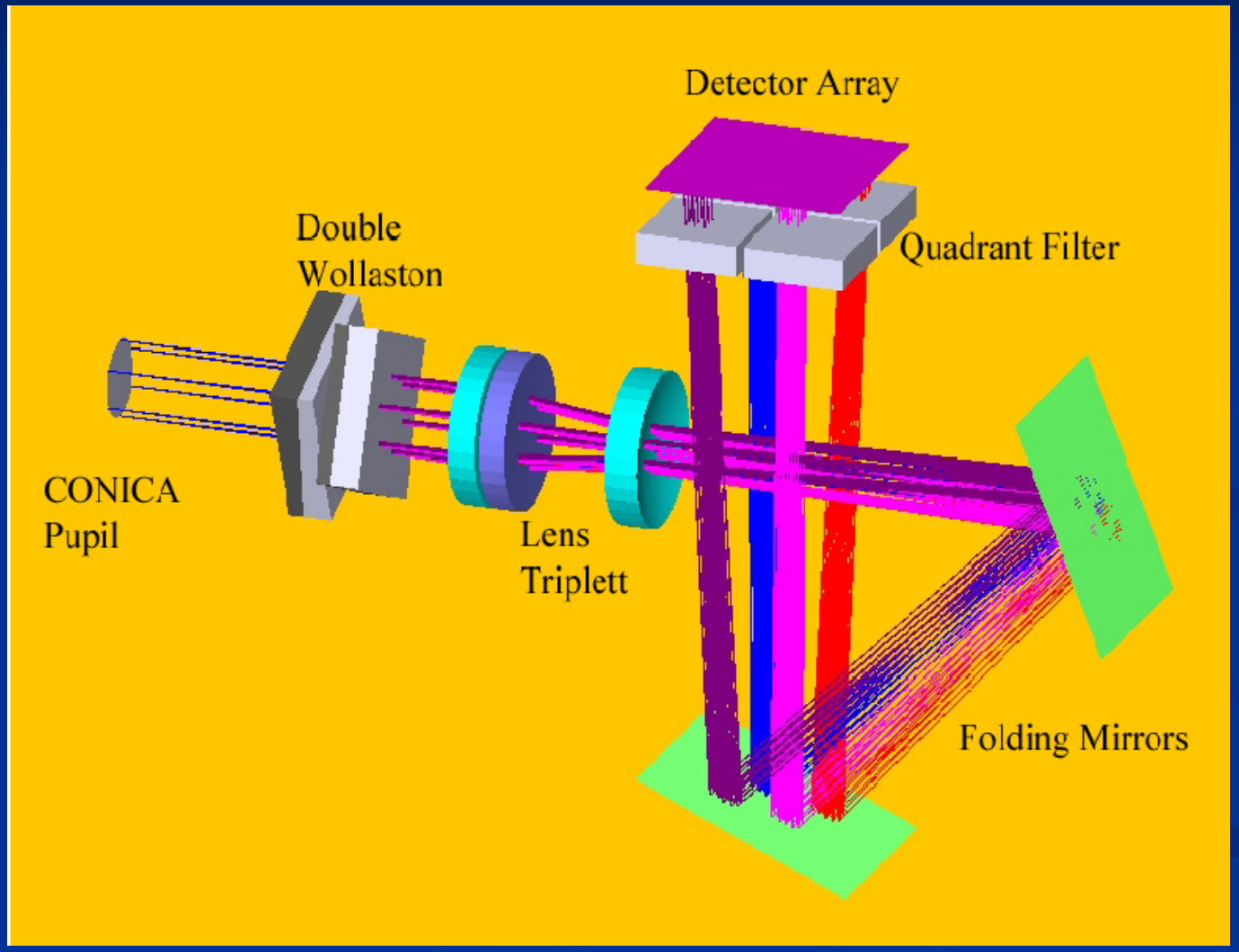
Optical Design for NACO SDI



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