Searching for Extrasolar Planets with Simultaneous Differential Imaging

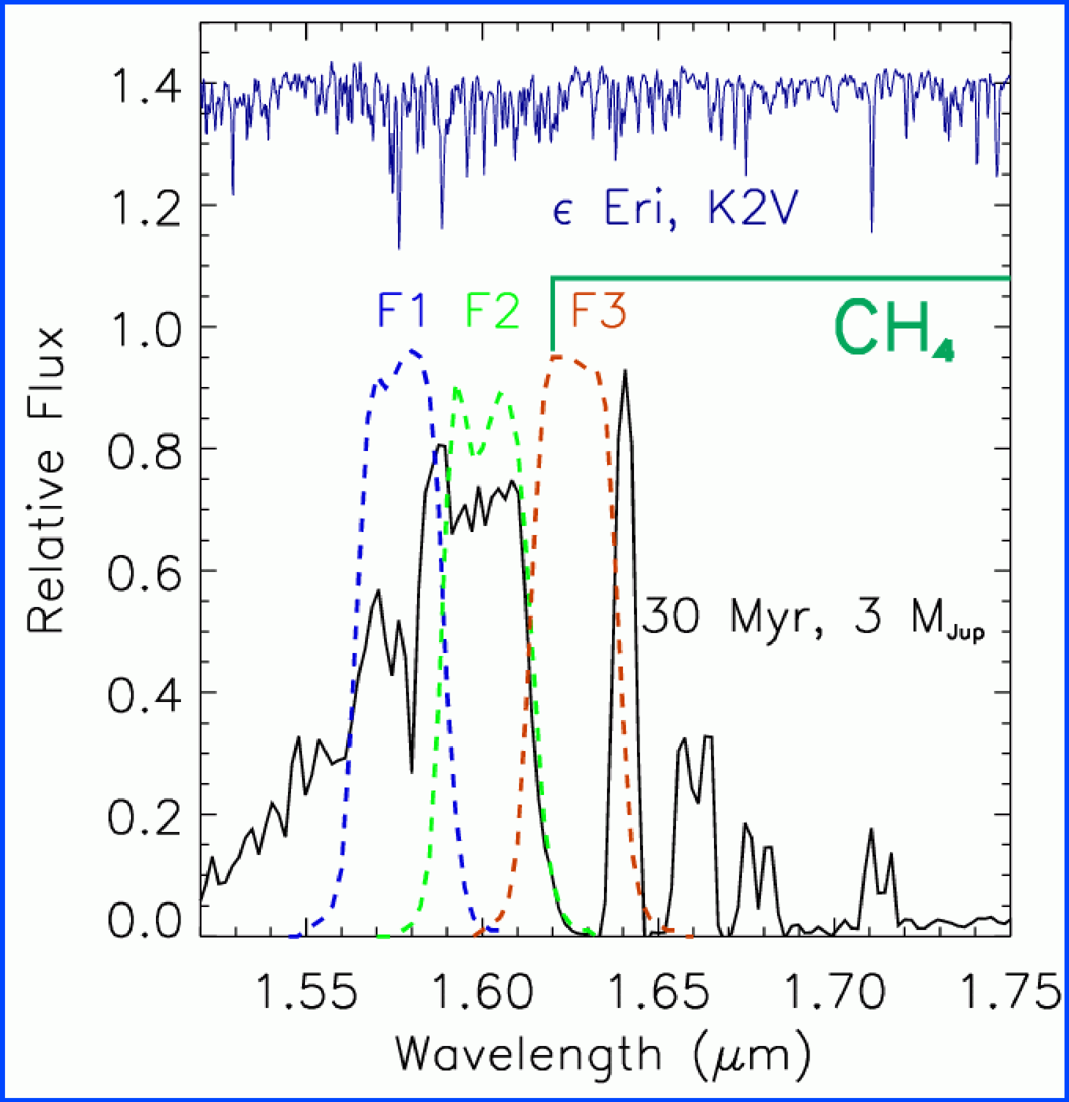
Eric L. Nielsen, Steward Observatory

Michelson Fellow Symposium, Pasadena 2005

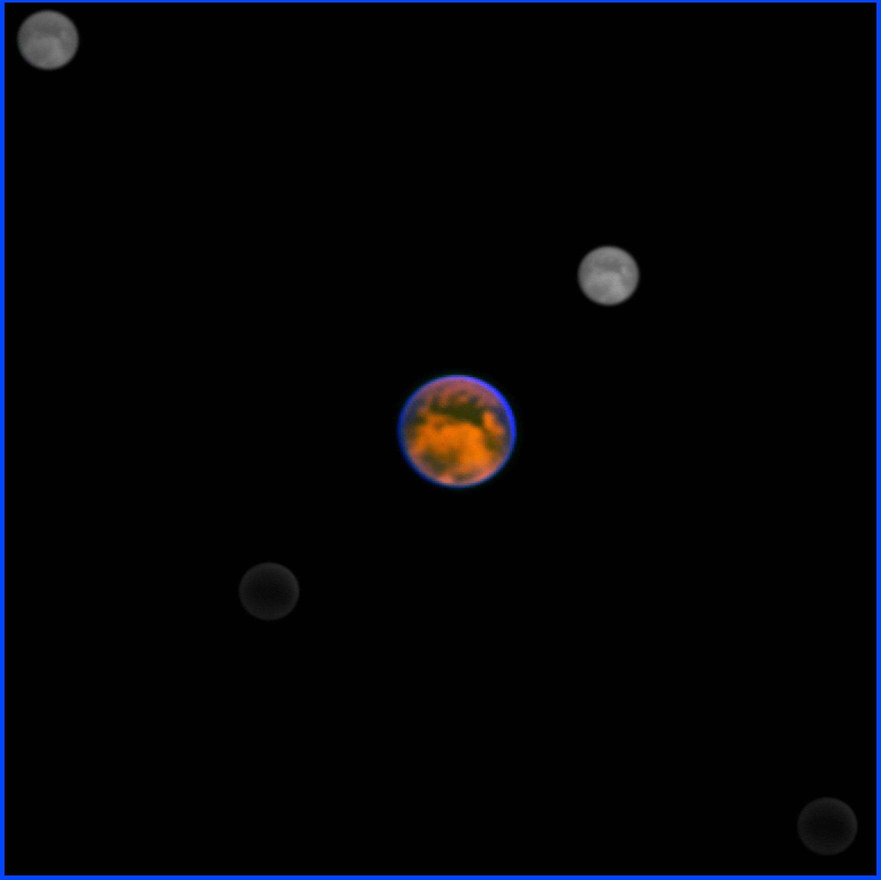
Motivation

- Imaging young, self-luminous extrasolar planets requires high contrast (>10^4) very close to the target star (<1”)
- Even with high-strehl AO systems reducing the size of the scattered light halo, “speckles” (diffracted light from the star), fill the inner arcsecond, greatly complicating planet detection
- This speckle noise floor does not integrate away with increased exposure time, and so must be addressed directly
- Speckle pattern is a function of time, optical path, and wavelength.
- Idea behind SDI: exploit the fact that speckles (scattered light from the star) and the planet will have very different spectral signatures.

Simultaneous Differential Imaging (SDI)



- Technique for imaging close companions at very high contrasts.
- Wollaston beam splitters produce four identical beams, passed through a quad-filter, with narrow band passes at 1.575, 1.600, and 1.625 microns.



Model planet spectrum from D. Sudarsky (private communication), eps Eri spectrum from Meyer et al. 1998. Titan image from L. Close and M. Hartung.

Speckles with SDI

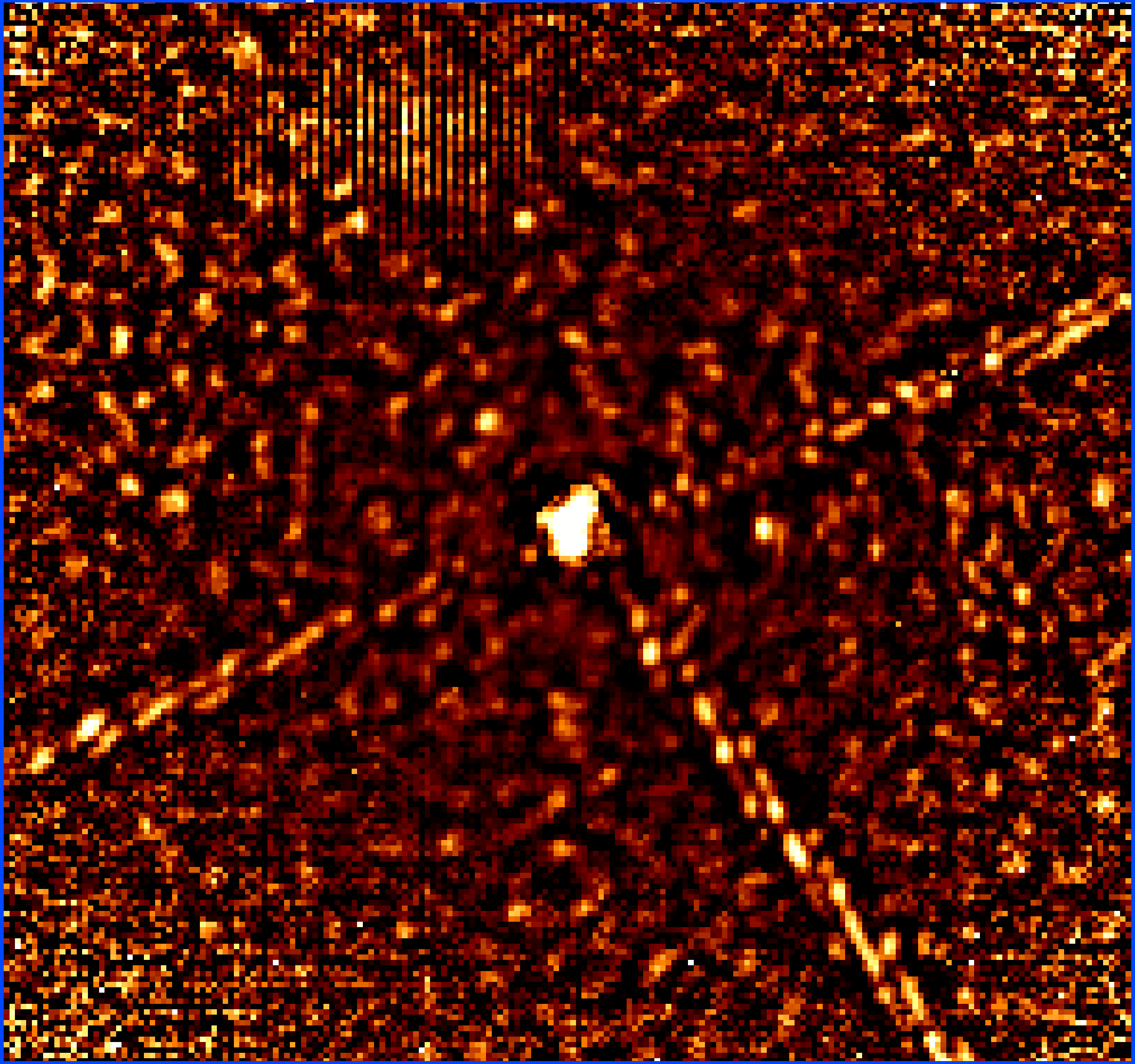


Image from Laird Close and Beth Biller

SDI: Suppressing Speckle Noise

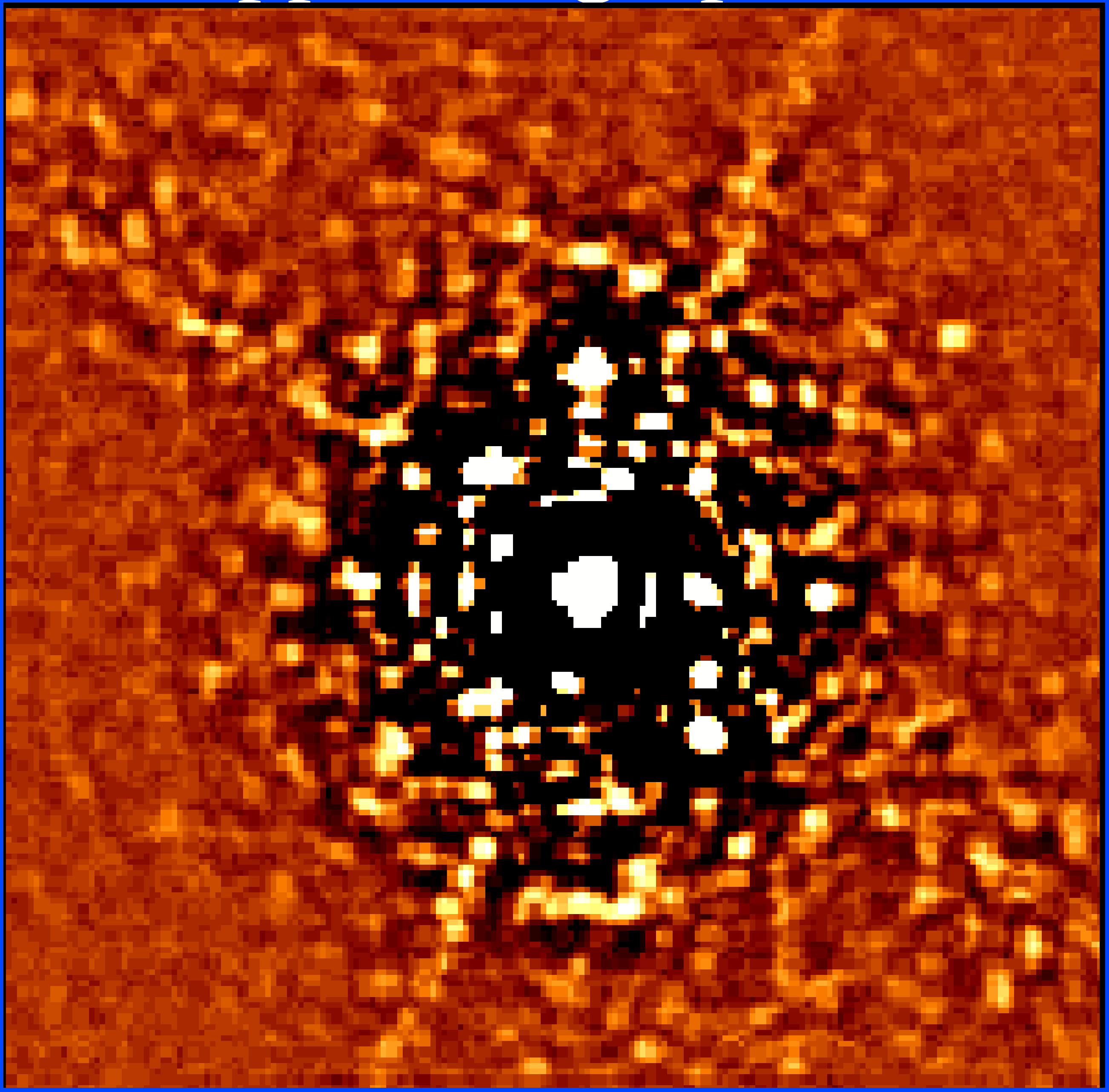
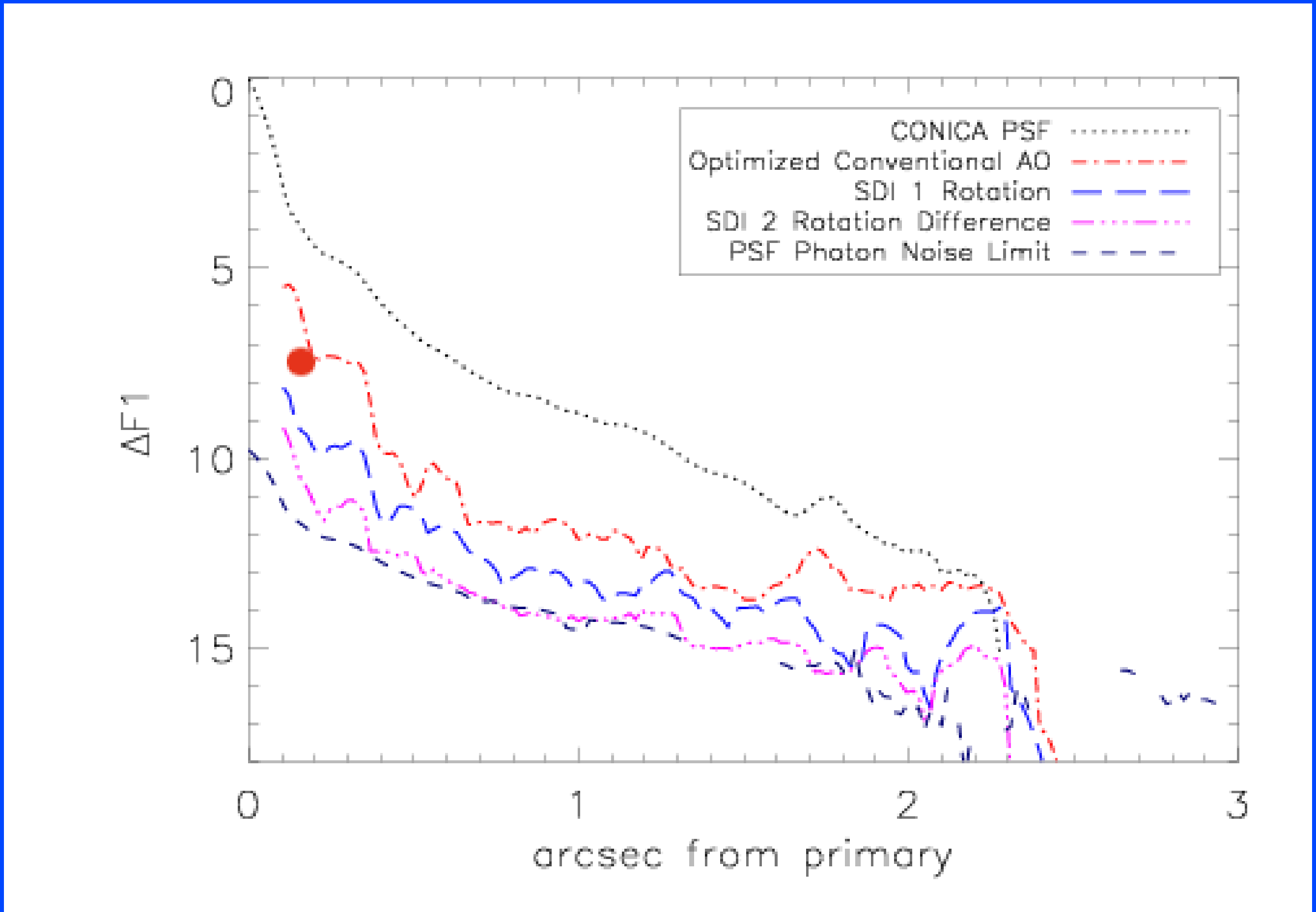


Image from Laird Close and Beth Biller

Looking for AB Dor C with NACO SDI at the VLT



B. Biller et al. SPIE, 2004.

- With VLT adaptive optics, AB Dor C is still a 1-sigma detection after 40 minutes
- SDI allows for a very convincing detection

SDI detection of AB Dor C

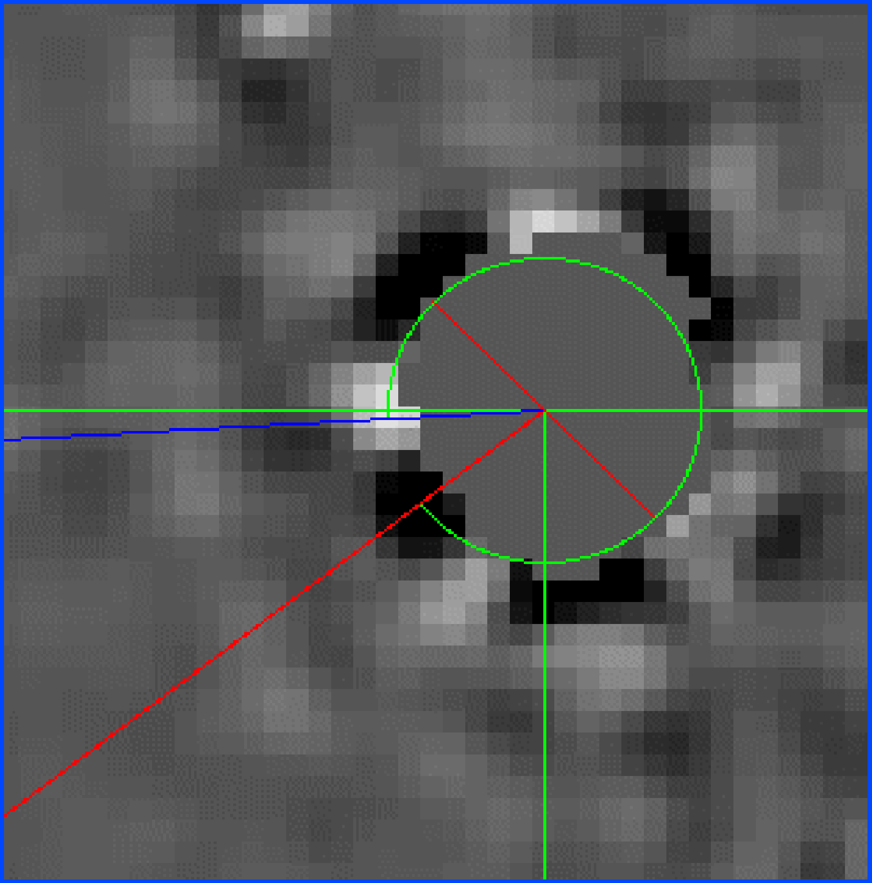
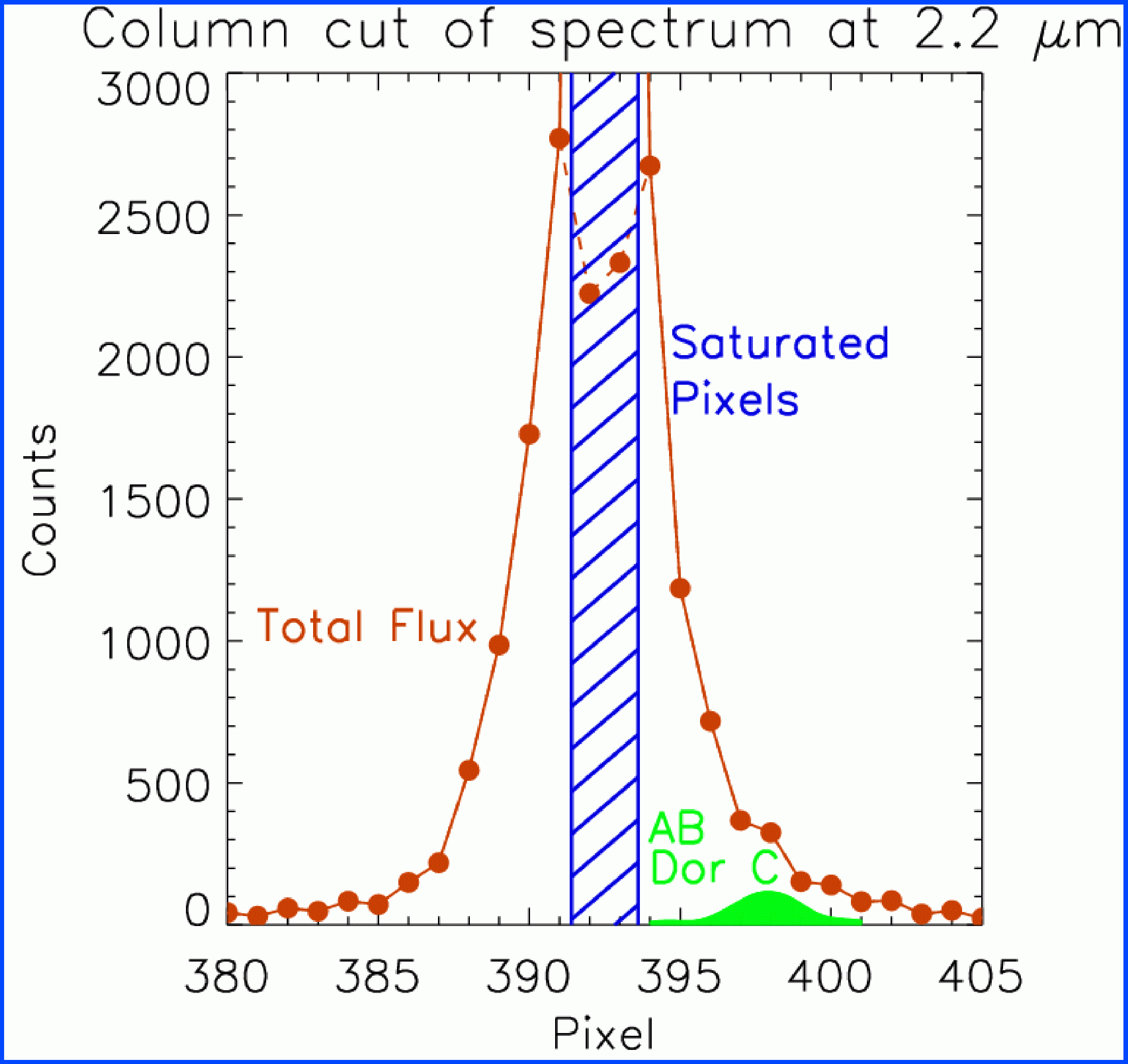


Image from Laird Close

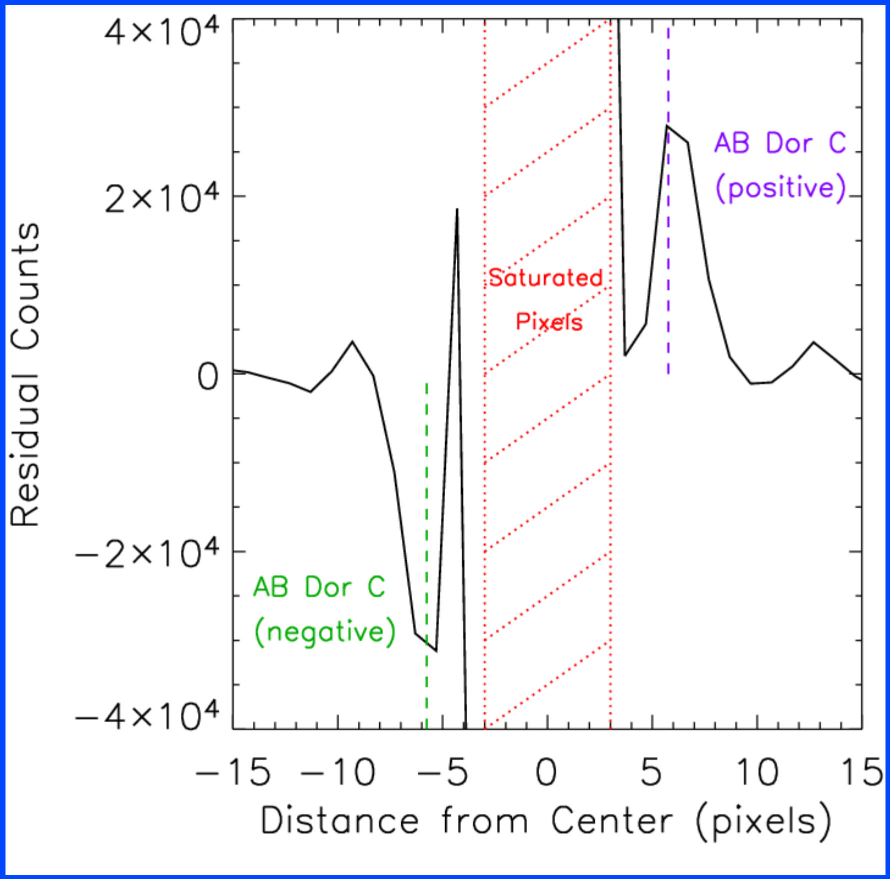
- Commissioning run of VLT SDI device in February 2004
- Offset from AB Dor A is 0.156 arcseconds (2.3 AU)
- Initial detection with standard SDI pipeline (B. Biller et al. SPIE symposium 5490 in press 2004). Companion spotted within one hour of observations.
- Immediate detection allowed follow-up spectroscopy and photometry.

Spectral Reduction



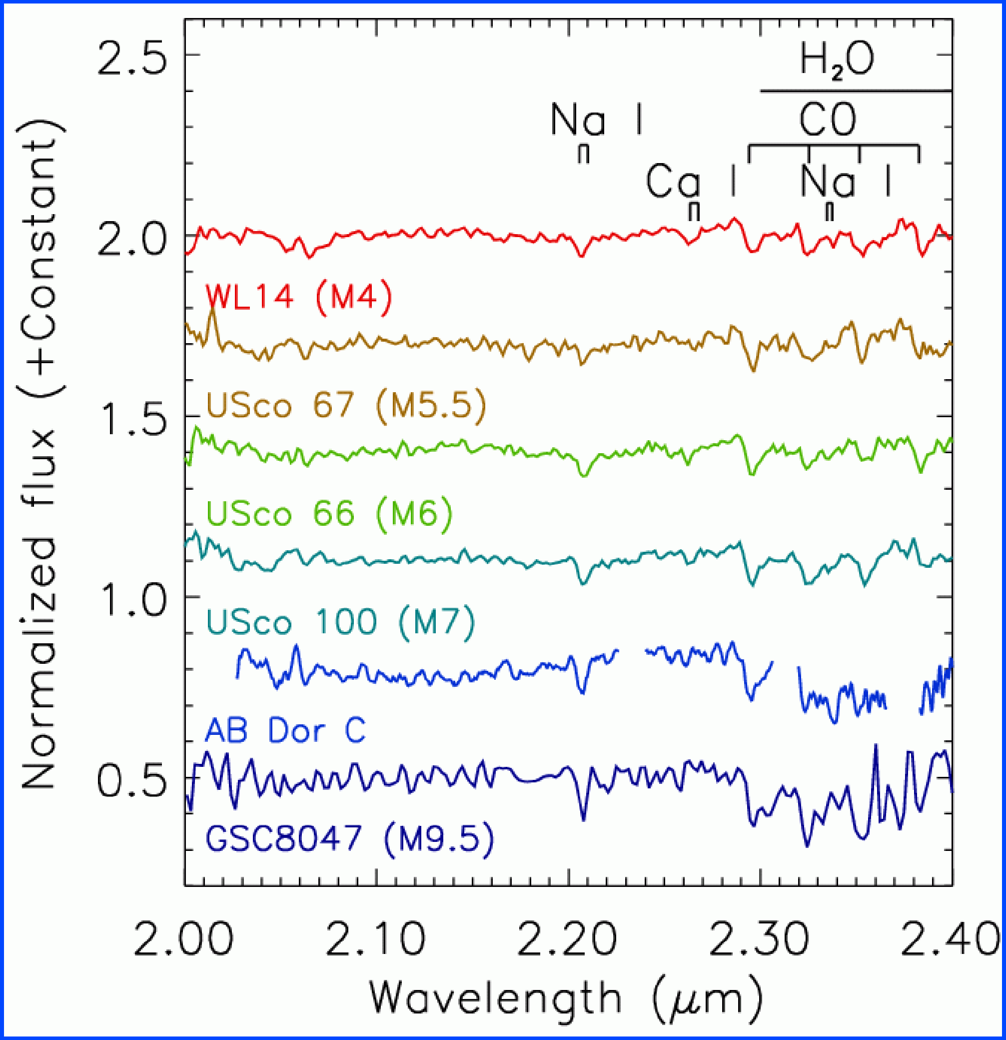
- AB Dor C is ~80 times fainter at K-band
- Offset from AB Dor A is 162 mas (6 pixels)
- Inner pixels of AB Dor A spectrum are intentionally saturated
- Derotator rotated by 180º between exposures, allowing subtraction of AB Dor A spectrum

Spectral Reduction (Continued)



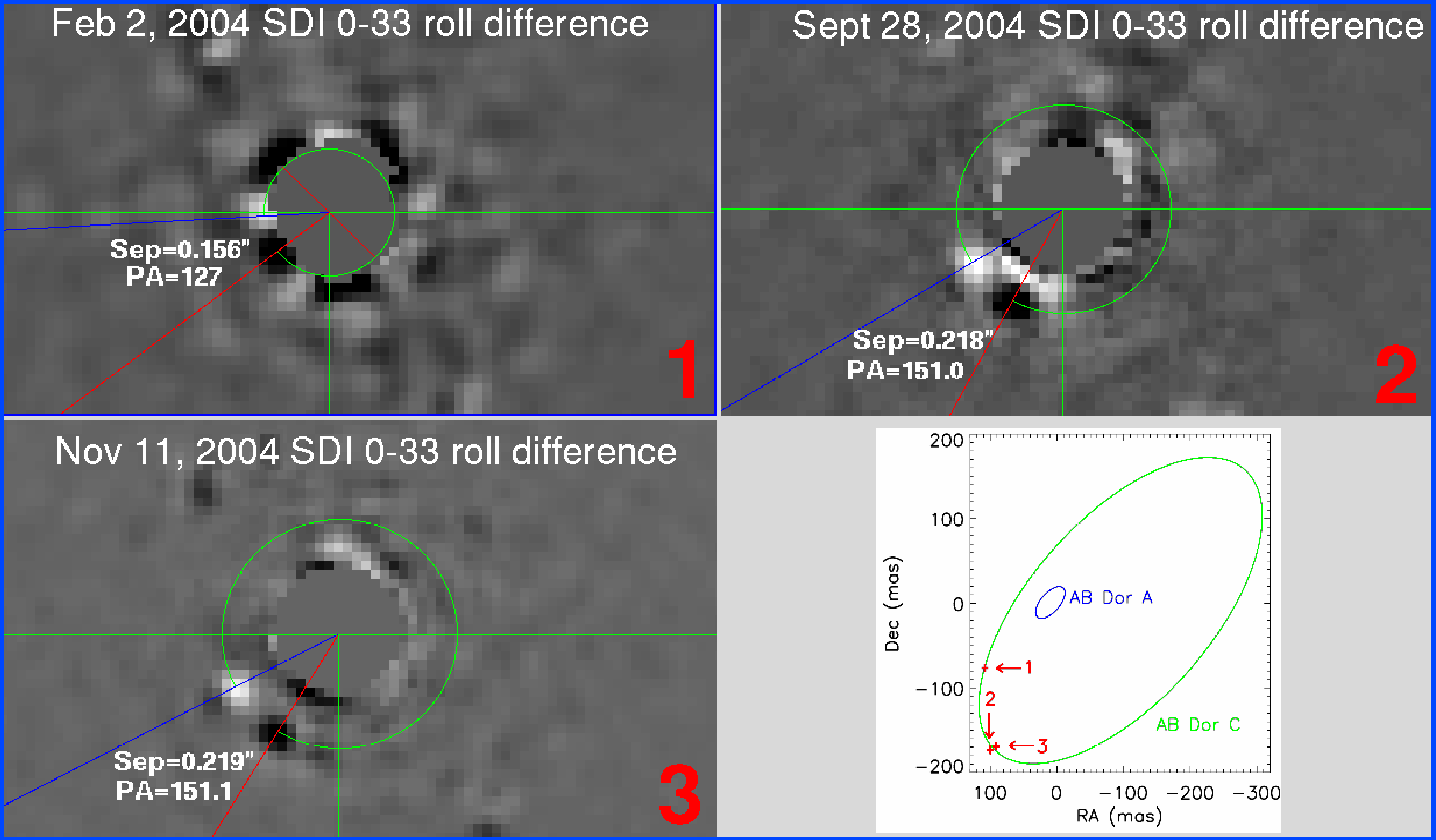
- Subtraction of 0º and 180º spectra removes signal from AB Dor A
- AB Dor C seen as a positive and negative signal on opposite sides of the PSF center

AB Dor C Spectral Type



- AB Dor C plotted against a series of young spectral standards, from Gorlova et al. 2003 (WL14, Usco 66, 67,100) and Chauvin et al. 2005 (GSC 8047)
- Sequence constrains AB Dor C between spectral types of M7 and M9.5

AB Dor Orbit



Figures from Laird Close, orbital solution from Jose Guirado

AB Dor C and Evolutionary Models

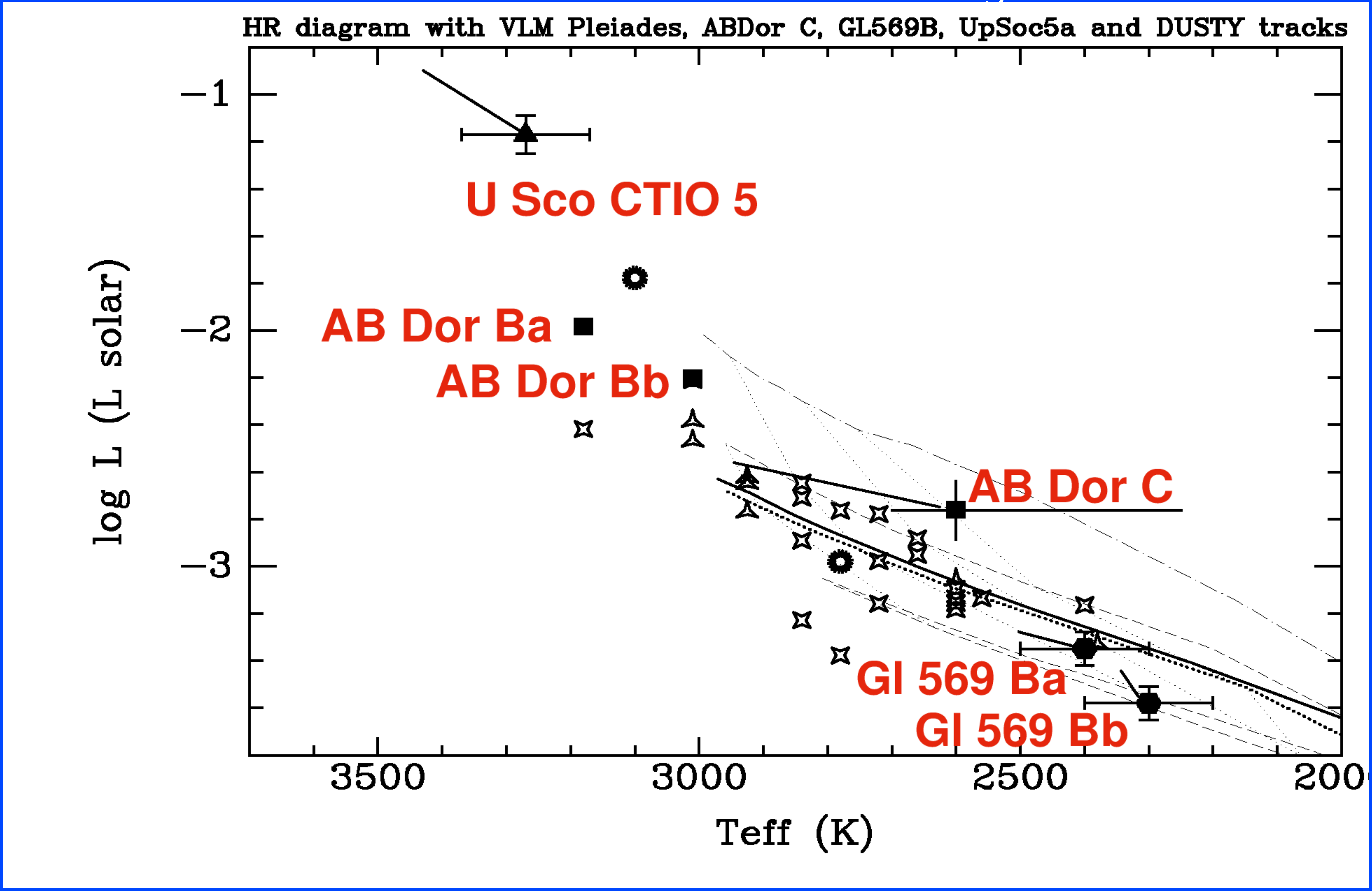
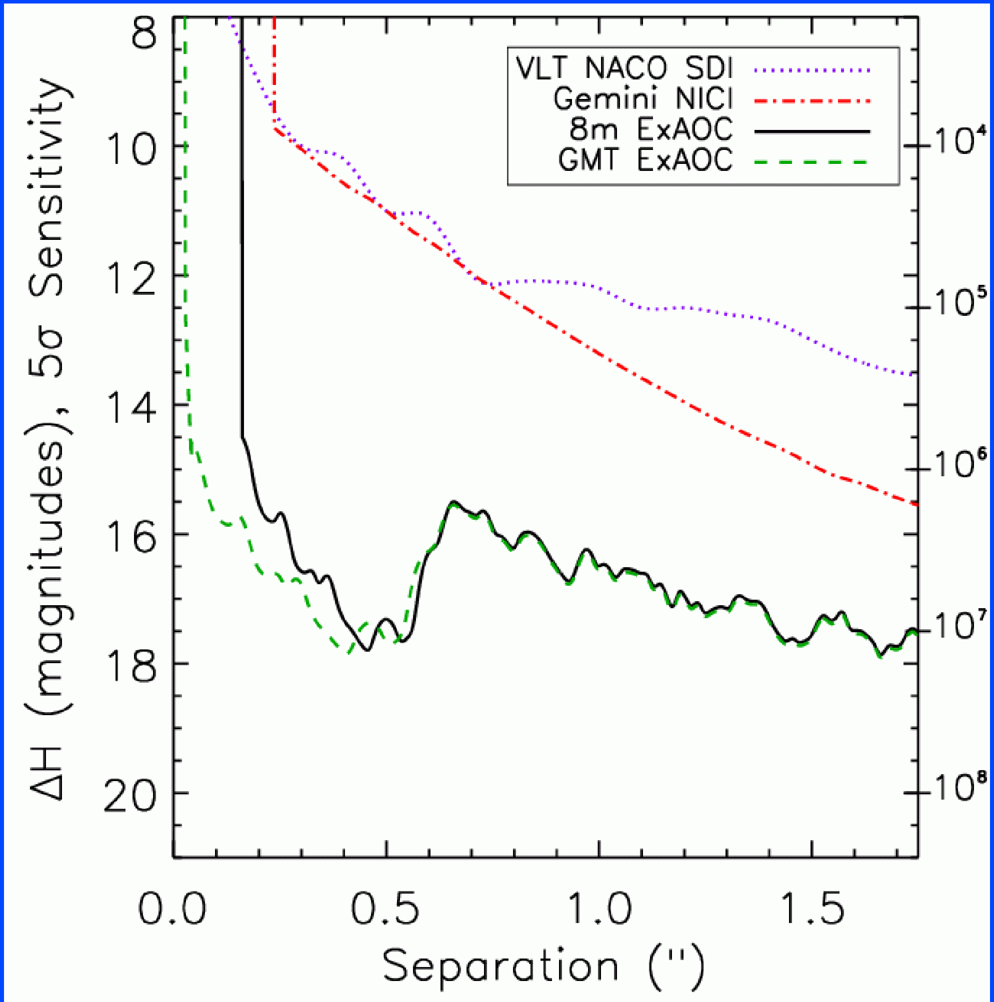


Figure from Laird Close

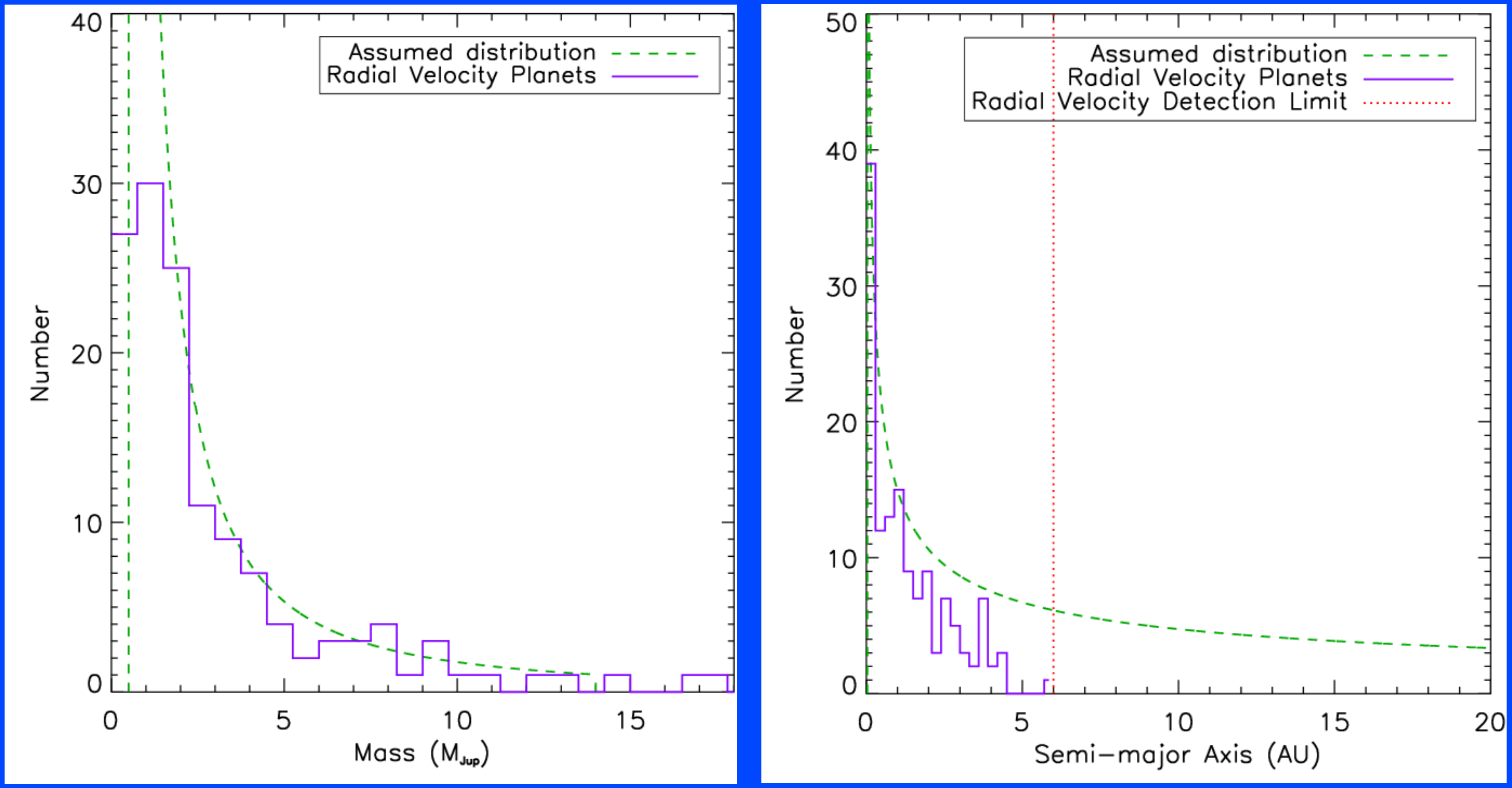
Simulating Extrasolar Planet Populations



Contrast curves from Beth Biller (NACO), Gemini Request for Proposals (NICI), and Johanan Codona, Roger Angel, Laird Close, and Dan Potter (ExAOC)

- NACO SDI: 8.2m VLT, 200 element SH WFS, SDI
- NICI: 8.1m Gemini, 85 element curvature WFS, coronograph, SDI
- 8m ExAOC: 8m telescope, 1000 element, spatially-filtered SH WFS, coronograph, FPWFS, SDI
- GMT ExAOC: 24m GMT, 7000 element, spatially-filtered SH WFS, coronograph, FPWFS, SDI

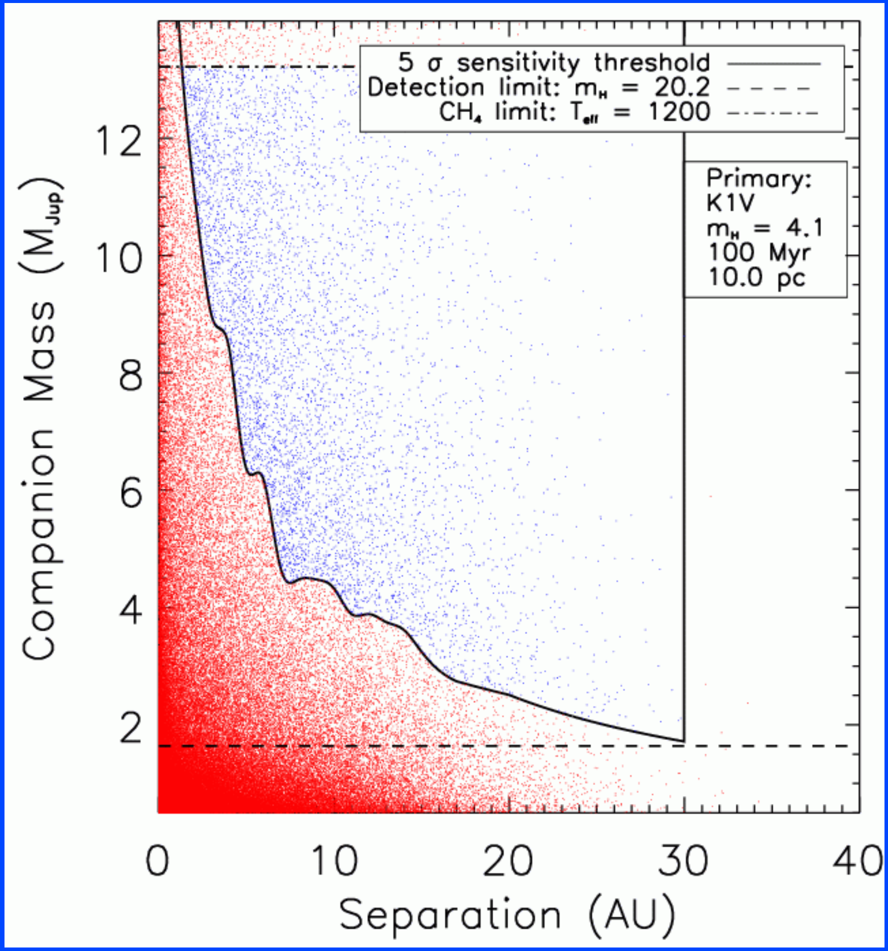
Assumed Extrasolar Planet Distributions



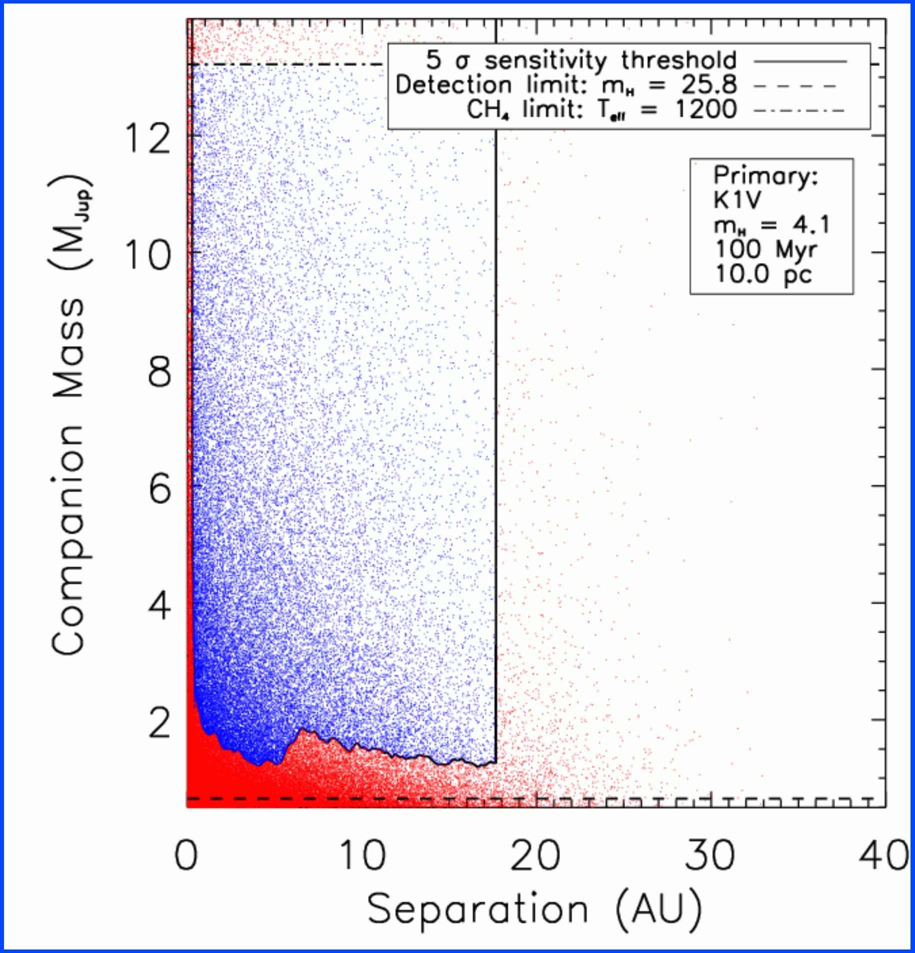
Radial velocity distributions from exoplanets.org

Simulation Results

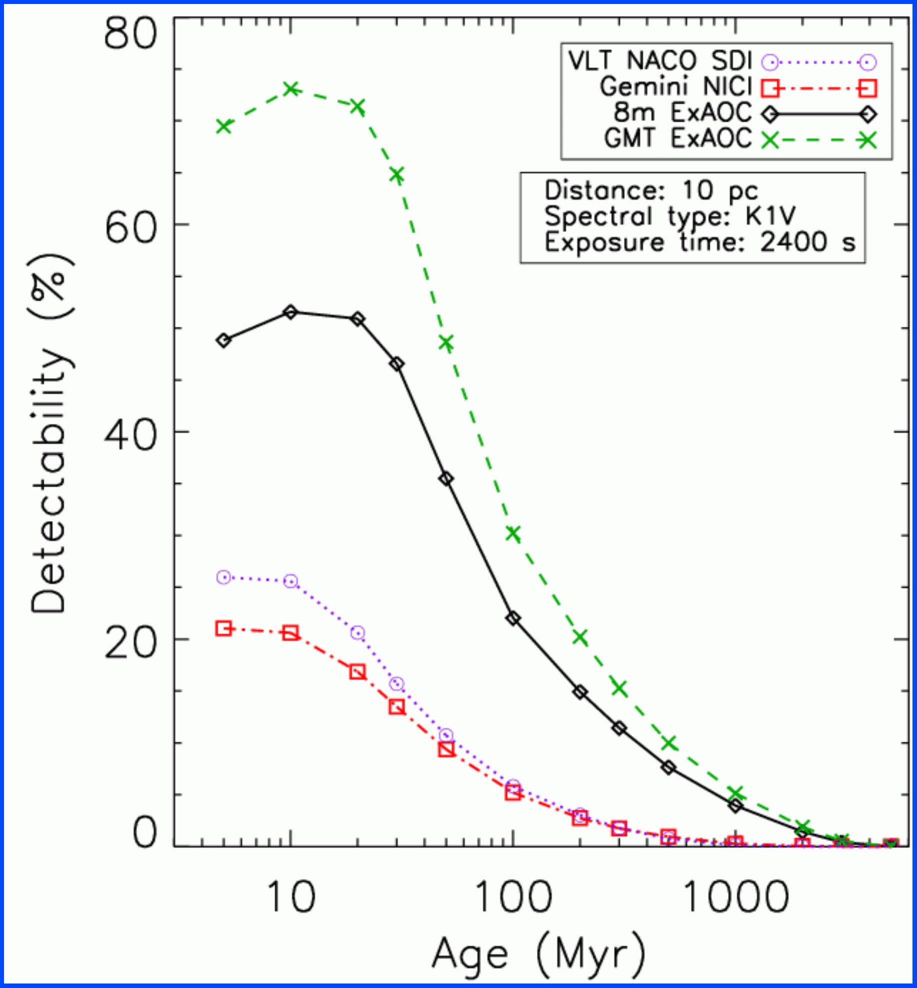
VLT NACO SDI, 40 minutes of data, 6% of planets detected

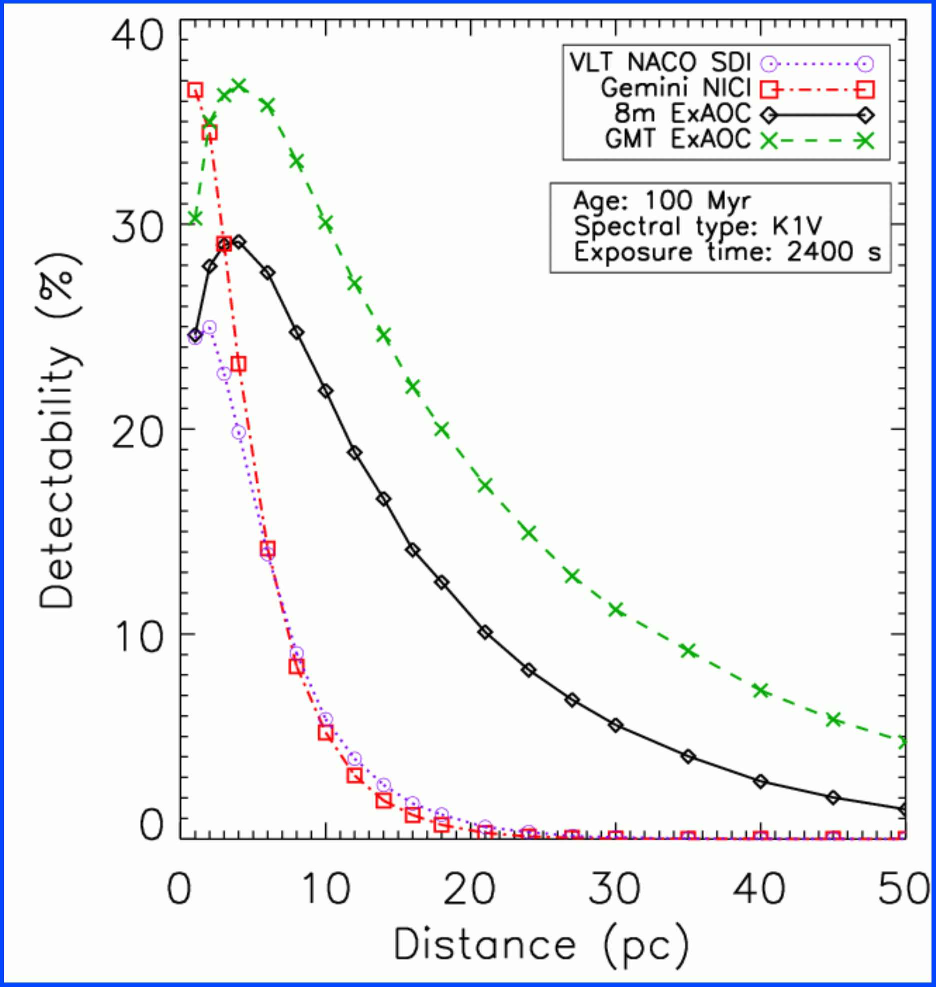


GMT ExAOC, 2.8 hours of data, 35% of planets detected

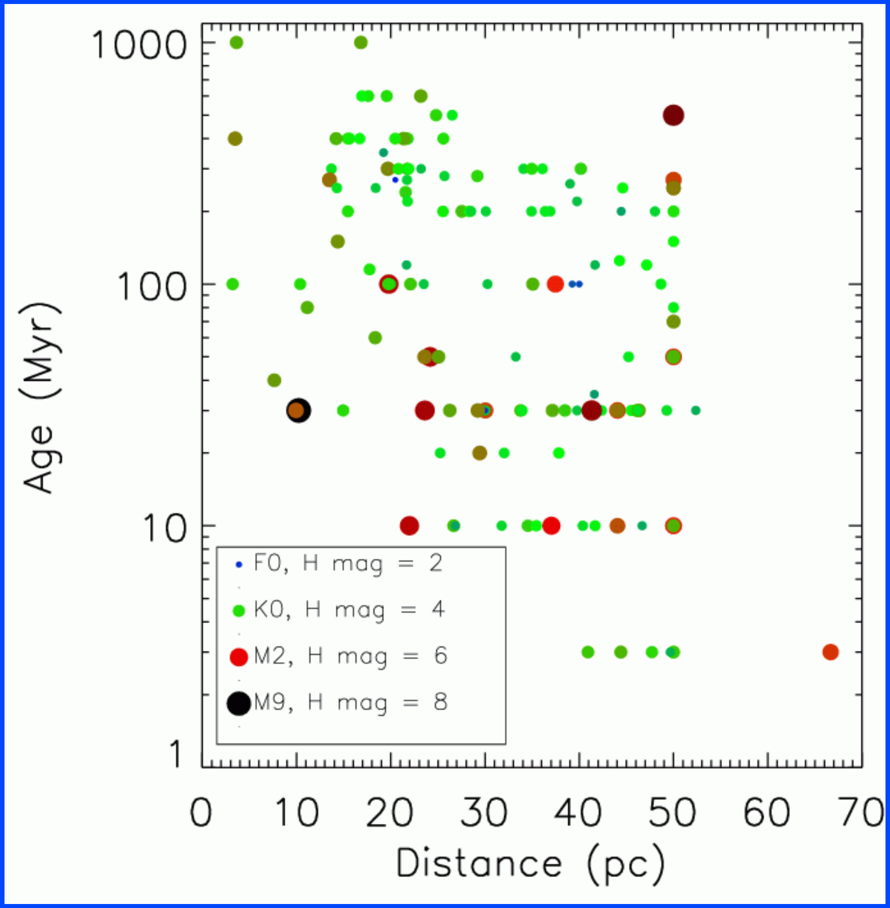


Trends with Age and Distance

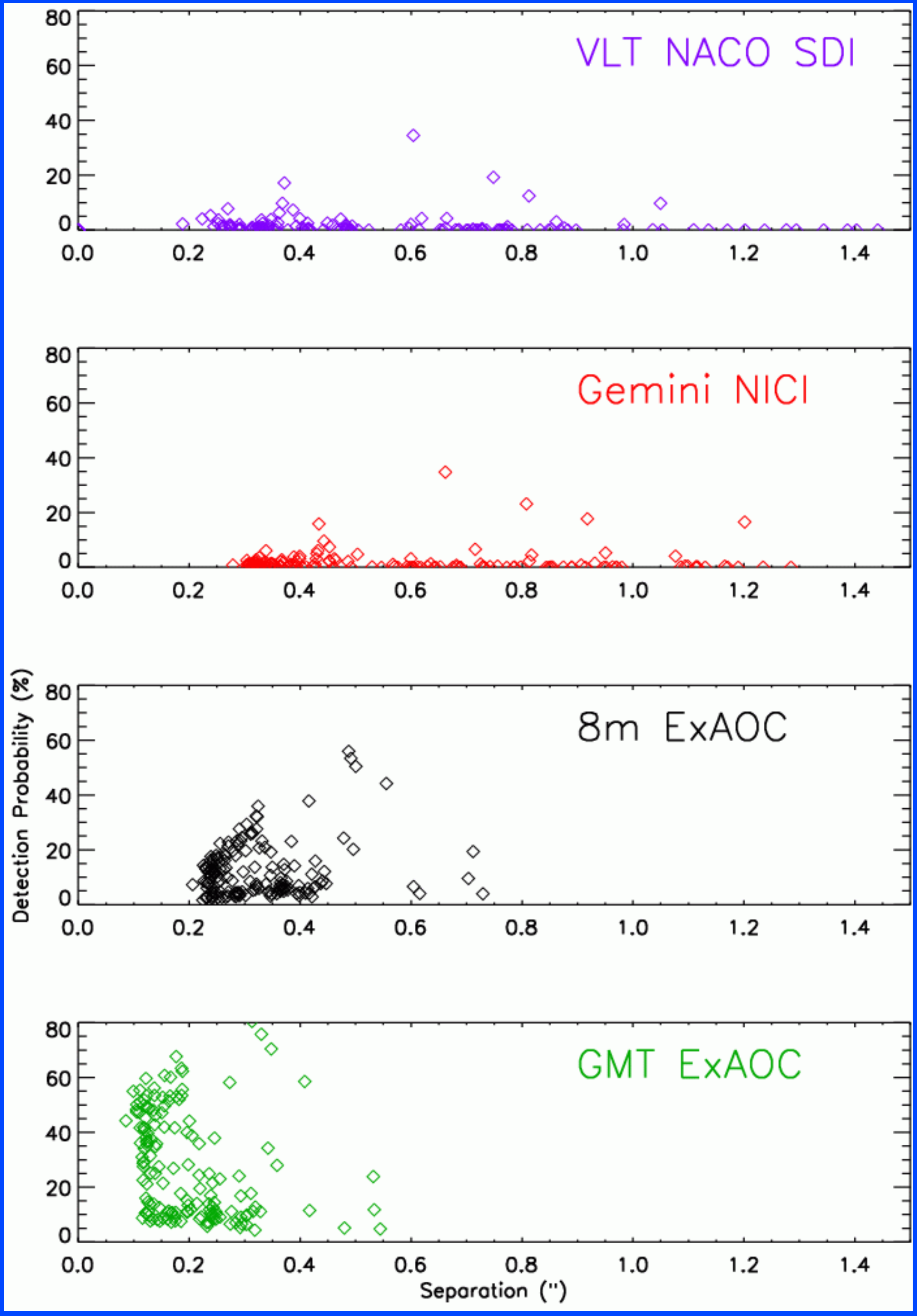




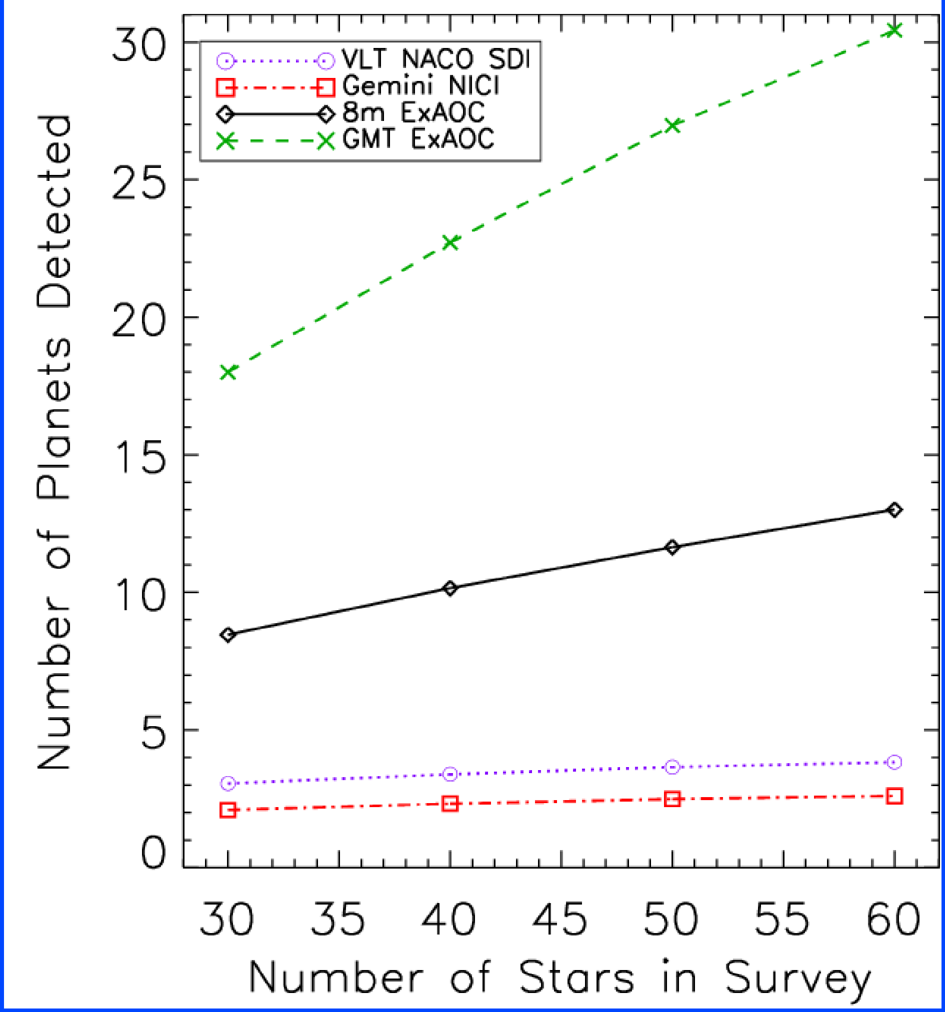
Target List and Properties of Detected Planets



For each target star, simulate 100,000 planets, compute fraction above sensitivity curve (y-value of each point), and median value of separation between star and planet for detected planets (x-value)



Survey Design



- For each instrument, choose the best 30, 40, 50, and 60 stars based on percentage of planets that are detectable
- Best stars are observed early on in a survey, with a slower gain in planets detected as less optimal stars are observed.

Papers

- SDI
  - Biller, B. A., Close, L. M., Lenzen, R., Brandner, W., McCarthy, D. W., Nielsen, E. L., and Hartung, M. SPIE 5490, 389 2004.
- AB Dor C
  - Close, L. M., Lenzen, R., Guirado, J. C., Nielsen, E. L., Mamajek, E. E., Brandner, W., Hartung, M., Lidman, C., and Biller, B.A., Nature 433 286 2005
  - Nielsen, E. L., Close, L. M., Guirado, J. C., Biller, B. A., Lenzen, R., Brandner, W., Hartung, M., and Lidman, C. Astron. Nachr. submitted 2005, astro-ph/0509400
- Planet Simulations
  - Nielsen, E. L., Close, L. M., and Biller, B. A., proceedings to IAUC 200, in prep 2005.

Conclusions

- The SDI technique is able to move beneath the speckle noise floor to the photon noise limit, as shown by the AB Dor C detection, making it a very powerful search method
- A survey for self-luminous, giant extrasolar planets is being conducted for young, nearby stars, using SDI cameras at the 8.2m VLT and 6.5m MMT
- Basic simulations of planet populations, extrapolating from what we already know about exoplanets, can inform survey target selection (as we're doing for the current VLT/MMT SDI survey) and design of future planet-search instruments (ability to detect planets is set largely by the inner working radius)