GMT

# EXO-PLANETARY, PLANETARY & BROWN DWARF SCIENCE WITH THE GMT AO SYSTEM

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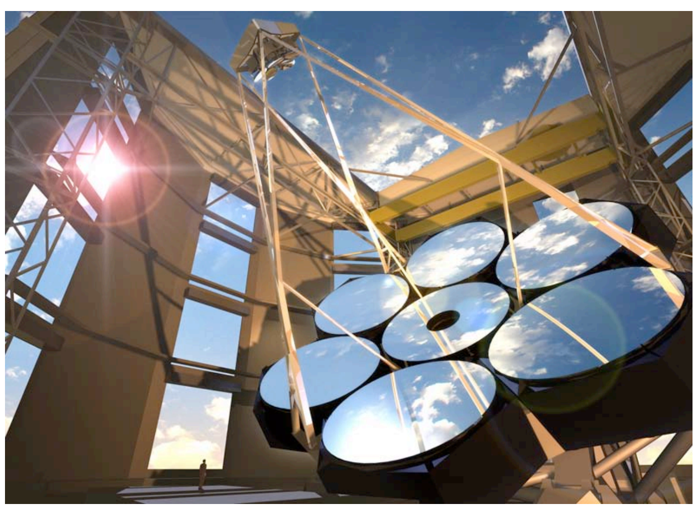
13.4-1

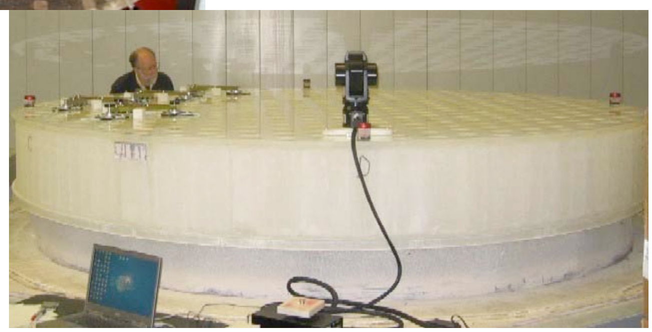
GMT

The GMT is a 24.5-meter primary of 7 off-axis 8.4-meter mirrors with an adaptive secondary AO system with ~4000 actuators. To come on line around 2016.

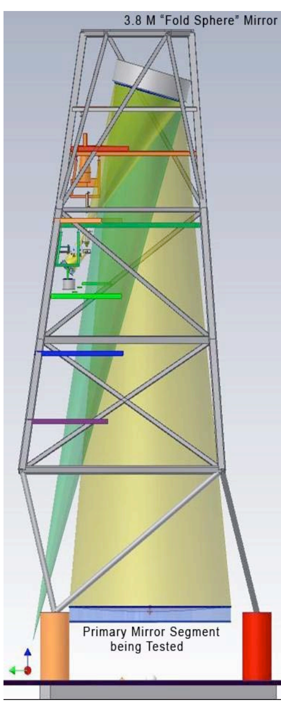


http://www.gmto.org/overview

13.4-2

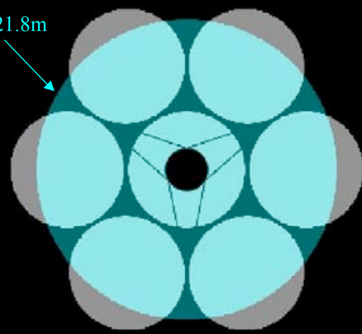


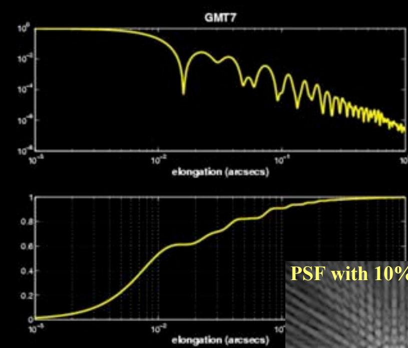
13.4-3

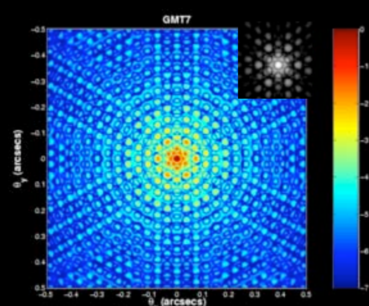

3.8 M "Fold Sphere" Mirror
Primary Mirror Segment being Tested

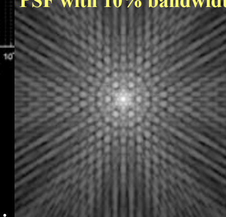
13.4-4

# The GMT7 PSF




Area: 368 $m^2$

FWHM @ 1.65 microns

Fraction Encircled Energy in Core: 67%

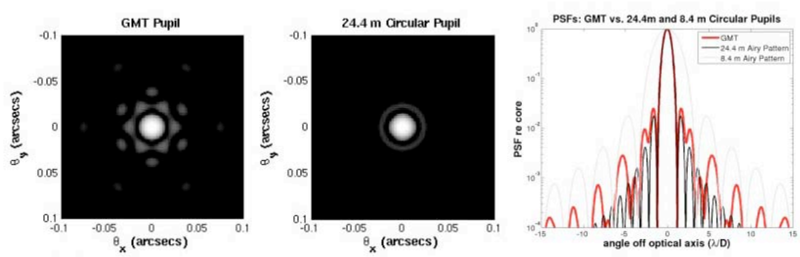



**Figure 9-2.** Aberration-free PSFs for the GMT (left) and a filled 24.4 m disc (middle) which has the same FWHM. Scale in arcsec is for 1.65 μm where the FWHM is 14 mas. Cuts through the radially averaged PSFs are shown on the right, along with the Airy pattern of the individual 8.4 m segments, in a log intensity plot.

13.4-6

| λ (μm) | $r_0$ (cm) | $\tau_0$ (ms) | **Strehl (200 nm)** | **Strehl (120 nm)** |
|---|---|---|---|---|
| 0.65 | 19.6 | 2.8 | 0.024 | 0.26 |
| 0.9 I | 29.0 | 4.2 | 0.14 | 0.49 |
| 1.25 J | 42.9 | 6.2 | 0.36 | 0.69 |
| 1.65 H | 59.9 | 8.7 | 0.56 | 0.81 |
| 2.2 K | 84.6 | 12 | 0.72 | 0.89 |
| 3.6 L | 153 | 22 | 0.88 | 0.96 |
| 5 M | 227 | 33 | 0.94 | 0.98 |
| 10 N | 521 | 75 | 0.98 | 0.99 |
| 20 Q | 1200 | 173 | 0.99 | 1.00 |

FWHM FOV

0.008” 8”

0.011” 12”

0.014” 18”

0.019” 25”

0.029” 44”

0.042” 66”

0.085” 150”

0.170” 300”

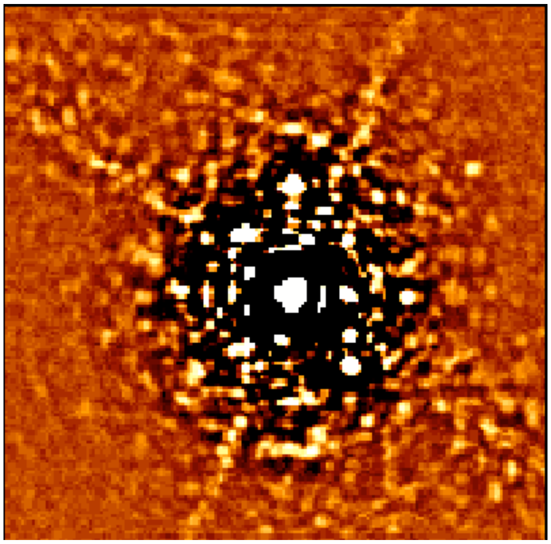


# What will be interesting in the ELT era?

1) How common are Large Outer Gas Giants? And what are they composed of?

-- May need to have outer giant planets to produce wet inner terrestrial planets (Chambers et al. 2006), also useful for biostabiliers after life has taken hold…

# SDI: Suppressing Speckle Noise



Here we see real SDI data from the NACO SDI AO camera.

Fake planets ($10^5$ times fainter in the H band) are only easy to spot once the speckle noise is removed.

They are placed at 0.4, 0.6, 0.8 and 1.0” separations from the star AB Dor

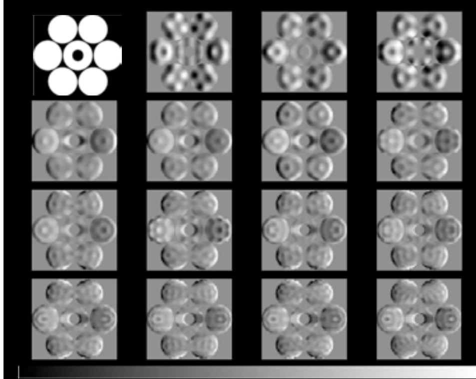
13.4-9

**Phase Apodization Coronagraphy (PAC) with the GMT**

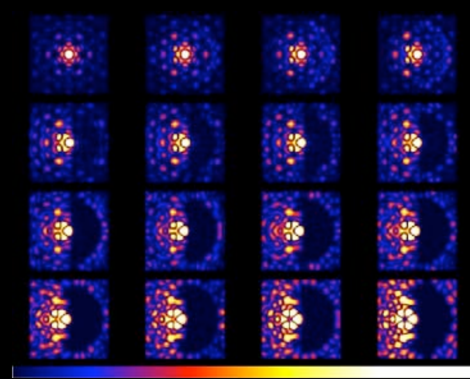
Johanan L. Codona, "Exoplanet Imaging with the Giant Magellan Telescope", *SPIE Proceedings on Advancements in Adaptive Optics*, eds. D. Bonaccini, B. Ellerbroek & R. Ragazzoni, Proc. SPIE, **5490**, Glasgow, Scotland, U.K., 2004.

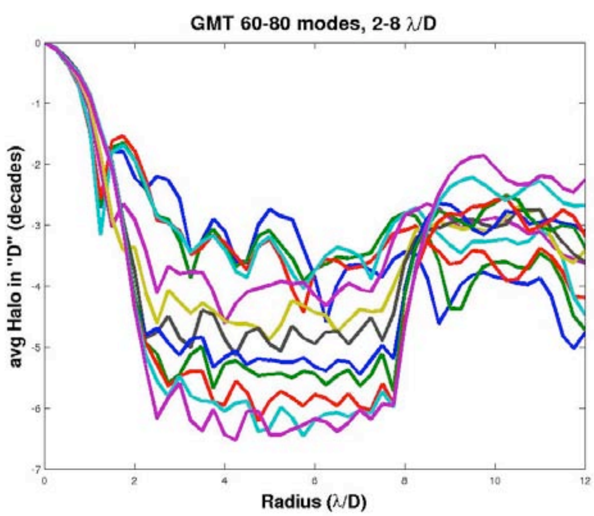
# GMT 1.25 – 8 λ/D Phase Masks

**APPs 40 – 180 modes**



**log-stretch PSFs**



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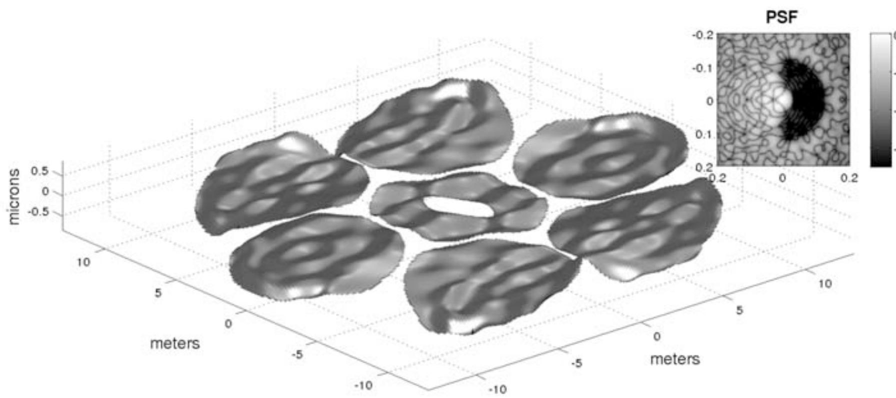


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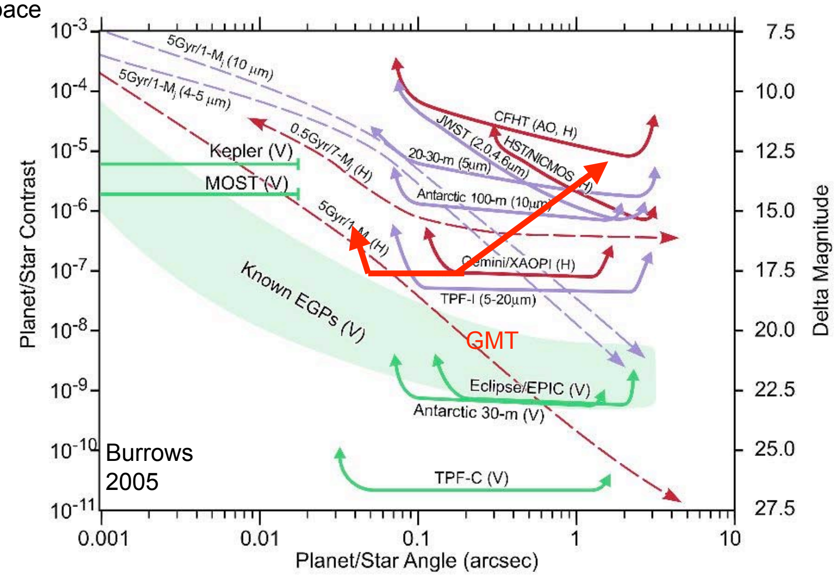
GMT

## Summary

- *First-generation ExAO architecture should start with a phase plate to suppress diffraction at the science wavelength.*
- *Use a modified Lyot Coronagraph to gain access to the PSF core for use as an interferometric probe of the halo.*
- *Continuously measure the complex halo as a function of time and compute its time-averaged value.*
- *The fast residual speckles will change phase and average out. "Super speckles" will remain and become detectable and can be "dialed out" using the DM.*
- *Going after the fast speckles will be photon-starved, but may be possible with bright stars. Complex speckle tracking will be needed to make it work. This feature is advanced and should be post-baseline.*

GMT Can Probe (Angel et al. 2006; Codona 2007) to new exoplanet search space

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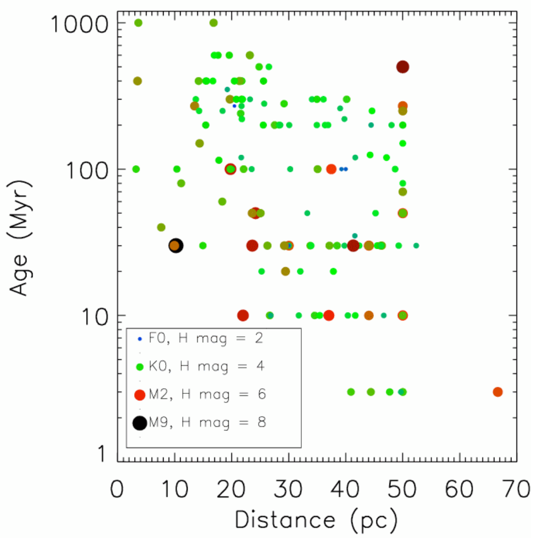
# Simulating Extrasolar Planet Populations to Evaluate Direct Imaging Surveys with GMT


Eric Nielsen

Steward Observatory, University of Arizona


13.4-16

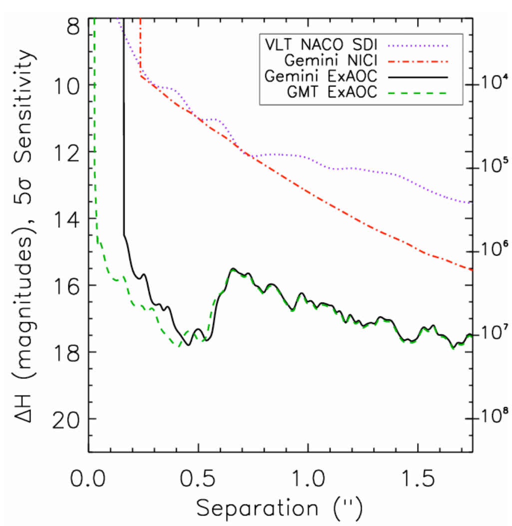
# Target Selection




- Possible targets limited to nearest, youngest stars
- There are only ~100 targets suitable for direct-imaging planet searches!
- Target quality depends on age, distance, and spectral type

13.4-17

# Starting Point: Contrast Curves




- Each planet-finding system is characterized by some curve like these
- How do these curves translate to what we really care about: number of planets detected?

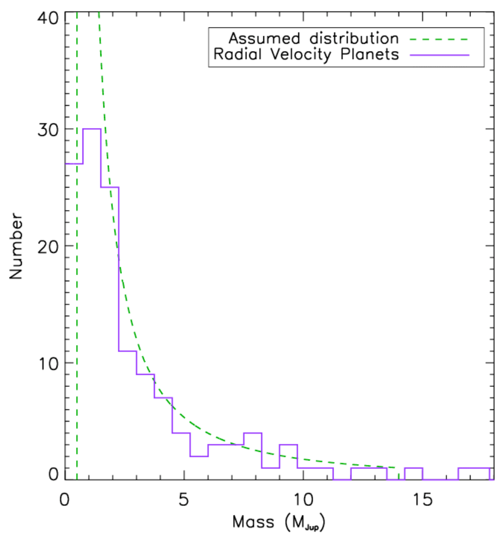
13.4-18

## Strategy

- For each target star, simulate an ensemble of planets ($\sim 10^6$, say)
- Randomly assign:
  - semi-major axis, mass, and eccentricity based on assumed distributions of planets
  - orbital phase and viewing angle based on Kepler's laws and geometric arguments
  - Combination of these give separation on the sky
- Assign H magnitude to each planet based on mass and system age, using theoretical models (e.g., Burrows et al. 2003)
- Determine what fraction lie above contrast curve

13.4-19

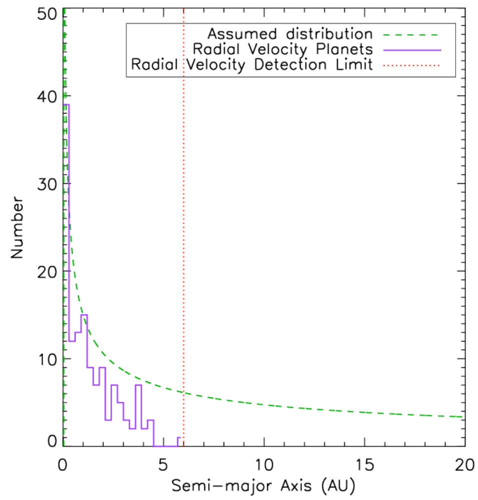
## Mass Distribution




- Assume power law distribution (with high and low mass cut-offs)
- Expect a bias against radial velocity detections at lower masses

13.4-20

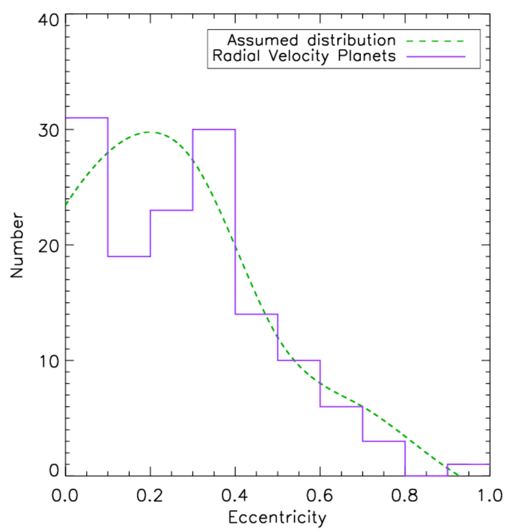
## Semi-major Axis Distribution




- Again, assume a power law with cut-offs at the high and low end
- Radial velocity searches are limited by the time baseline of the survey (currently at ~6 AU)

13.4-21

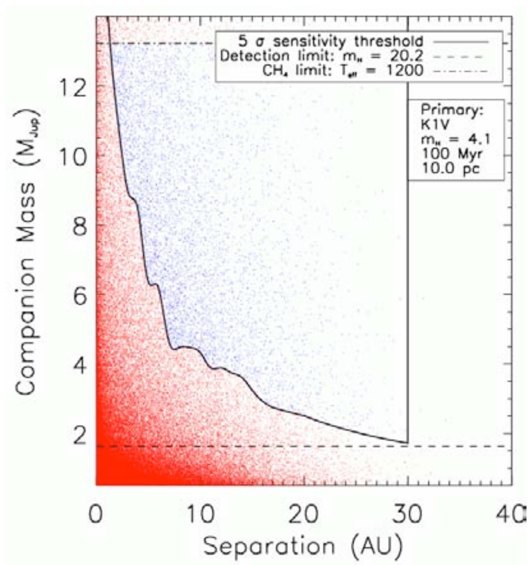
## Eccentricity Distribution




- Just assumed to be some smooth function, as fit to the radial velocity distribution.
- Mass, semi-major axis, and eccentricity most likely aren't independent

13.4-22

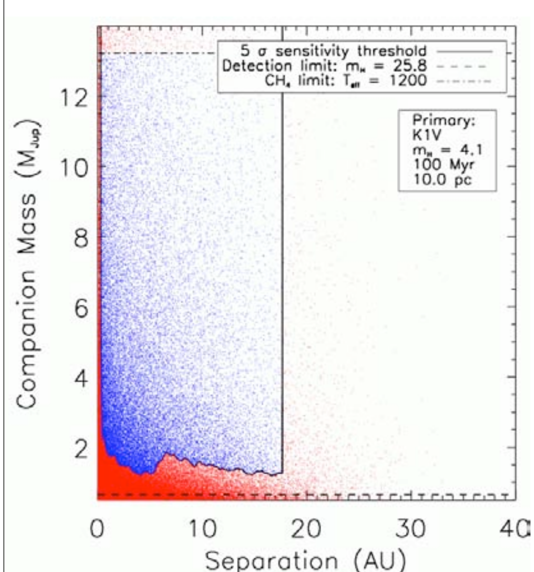
## Simulation Example




- VLT NACO SDI sensitivity curve based on 40 minutes of data
- Blue points are detected planets, Red non-detections (5-sigma)
- For this star, expect to detect ~6% of planets

13.4-23

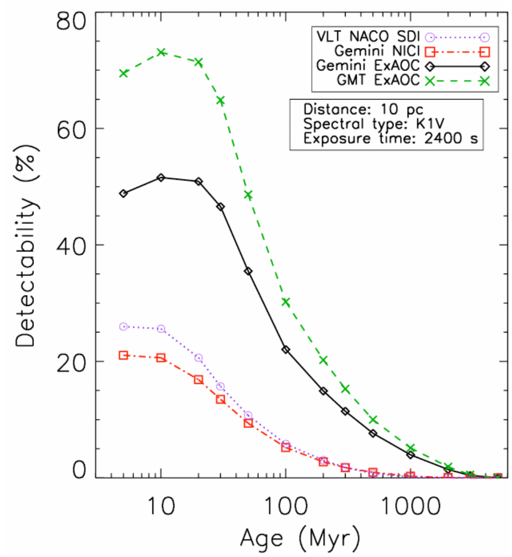
## Simulation Example




- GMT sensitivity curve based on 3 hours of data
- Blue points are detected planets, Red non-detections (5-sigma)
- For this star, expect to detect 35% of planets (a sixfold increase from current systems)

13.4-24

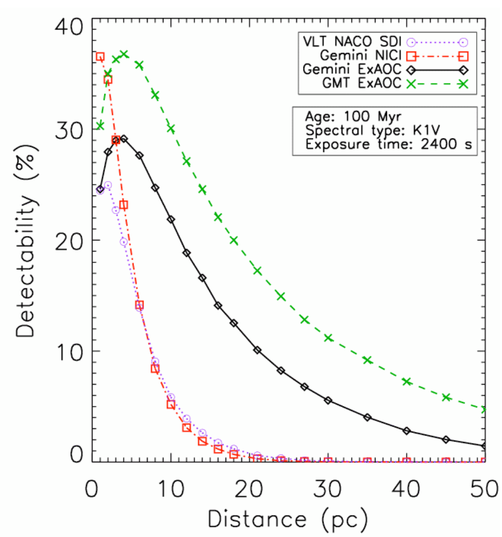
## Trends with Age




- Younger planets are brighter, easier to detect
- Very little expected value in observing older (>1 Gyr) targets

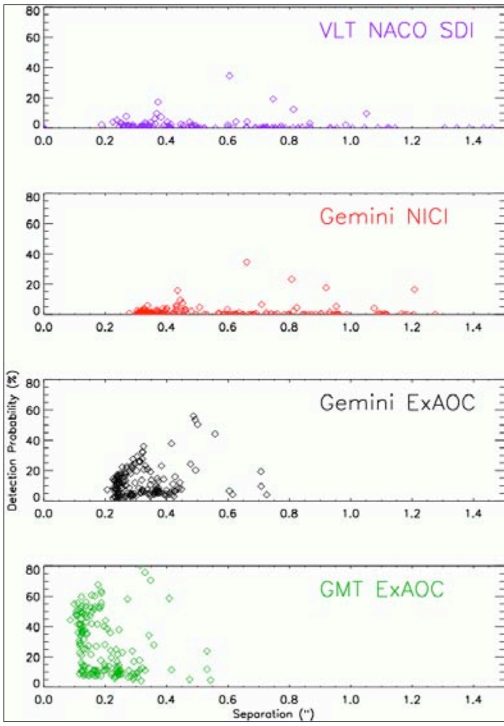
13.4-25

## Trends with Distance




- Planets around nearby stars are easier to detect
- Outer working radius is only a factor for target stars within 5pc (most planets are in the inner arcsecond)

13.4-26

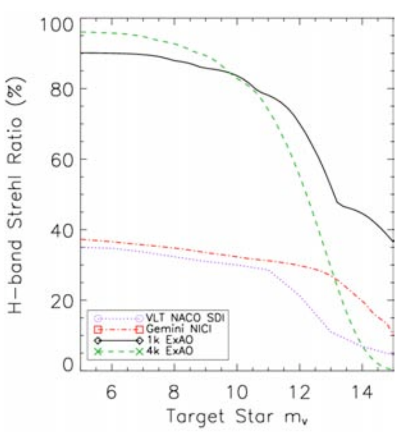



## Separation

- Each point is an individual target star: the median observed separation from parent star of all detected planets
- The key to detecting planets is the inner fraction of an arcsecond

13.4-27

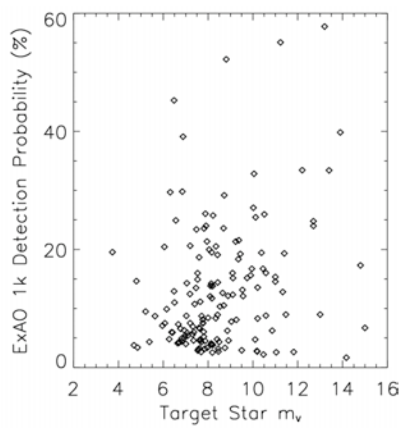
## Strehl Ratio and Guide Stars




- Strehl Ratios decline with fainter guide stars
- More complex AO systems require brighter guide stars (only so many photons to go around)

13.4-28

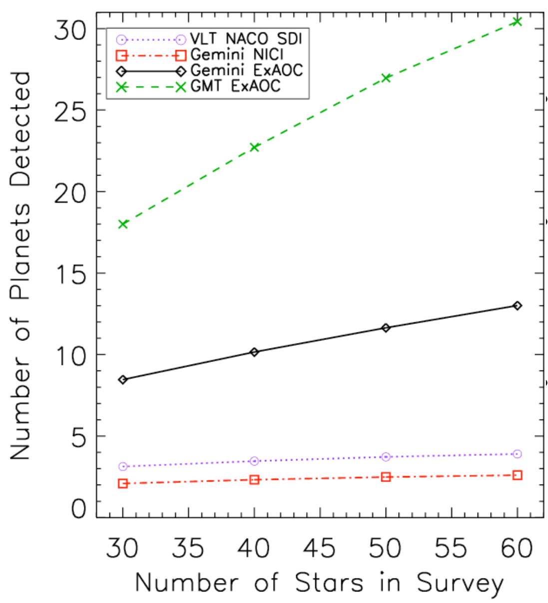
# Available Targets




- Many of the best targets for direct-imaging planet searches are faint stars
- Important to consider target selection and limiting magnitude of AO system when designing ExAO systems

13.4-29

# Survey Size and Planets Detected




- Expect to find the most planets from the 30 best target stars for 8m class.
- Slow gain after that in planets detected as survey size is increased for 8m
- BUT for GMT there is a steady gain! A uniquely powerful exoplanet machine.

13.4-30

## Conclusions

- These basic simulations can inform target selection and survey analysis for existing AO systems, as well as design of the ExAO system for GMT
- The ability to reach the smallest separations (inner working radius) defines the ultimate success of the system – GMT is uniquely powerful in this regard
- The GMT is ~3-6x more effective at finding planets around nearby stars than 8m class systems.
- Most of the best target stars are faint, both because they tend to be later spectral type, and the youngest stars are typically further away: limiting guide star magnitude is an important consideration.

13.4-31

GMT exoplanet summary: directly detect and obtain R~500 IFU spectra NIR of Jupiter and higher mass planets at *a*<4 AU.

NGS ExAO (H-band) 120 nm residual AO error

*Will require contrasts at ~0.035-0.4" (2λ/D @ H) of $10^4$ for 1 Myr targets (D~140 pc)*

*Or contrasts at ~0.05-0.5" of $10^6$ for 100 Myr targets* (D~50 pc)

*Or contrasts at ~0.1-2.0" of $10^8$ for 5 Gyr old targets (D~10 pc)*

*First light AO ExAO mode*

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GMT AO summary:

Must be able to use all ExAO, LGS, NGS AO Modes

130nm & 200 nm residual AO error modes

*AO contrasts of $10^{2\text{-}3}$ over FOV~0.01-120"*

*ExAO contrasts of $10^{4\text{-}8}$ over FOV~0.05-2"*

*Resolution 0.01" ($\lambda$/D @ J)*

*Must be able to reach H & K~25*

⇩

IFU: R~500-2000 5mas pixels FOV:~2" (178k x 178k ??)

HRCAM: 5 & 10 mas pixels (FOV 20 & 40"; 4k x 4k)

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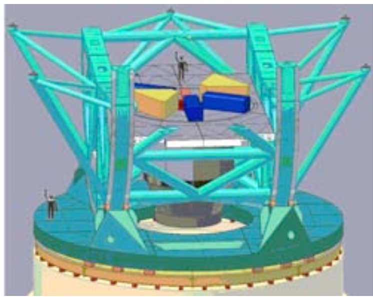
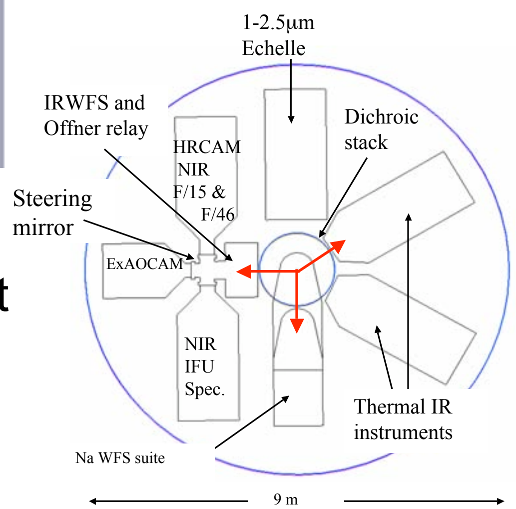
GMT

# HRCAM

13.4-34



## Upper Instrument Platform




GMT

# HRCAM Modes

Spectral Range: 1-2.5μm J,H,Ks + narrow-bands

Detector: 4096 x 4096 focal plane array

<u>f/15 LTAO Imaging and Spectroscopy</u>

- 10 mas pixel pitch for imaging
- 40″ x 40″ field of view
- Spectroscopic mode
  - 50 x 50 IFU w/ 20 mas pitch
  - R = 3000 - 5000

<u>f/46 High Definition Imaging</u>

- 3.3 mas pixels
- 13″ x 13″ field of view
- 4″ x 4″ SDI field

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