Contributions to Exoplanet Studies with Ground-based Extremely Large Telescopes

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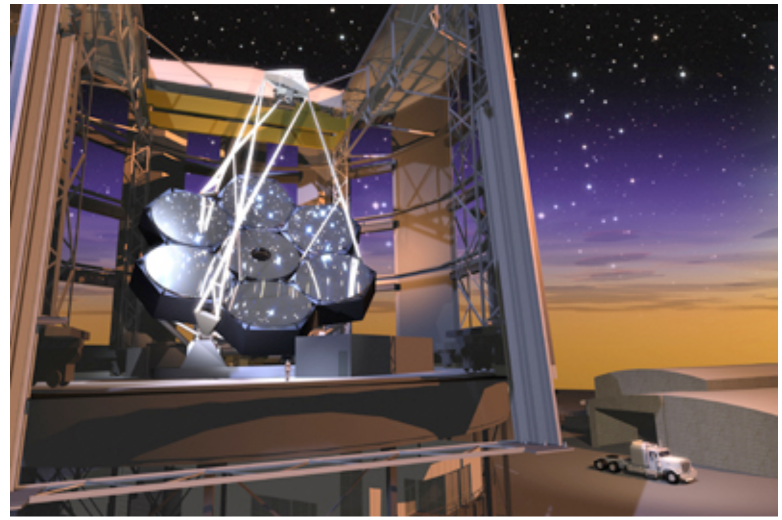
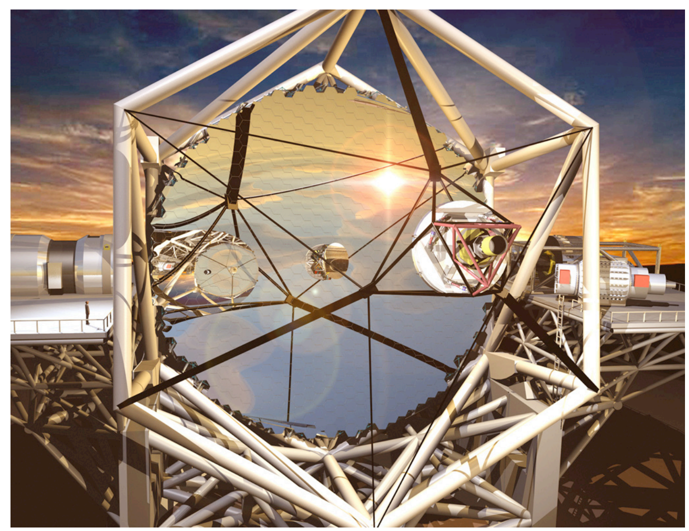
Extremely Large Telescopes

- Giant Magellan Telescope
  - 25 m with seven 8.5 m segments
- Thirty Meter Telescope
  - 30 m from 500-800 small segments
- European Extremely Large Telescope
  - 42 m multiply segmented





Could have completion dates by end of this decade

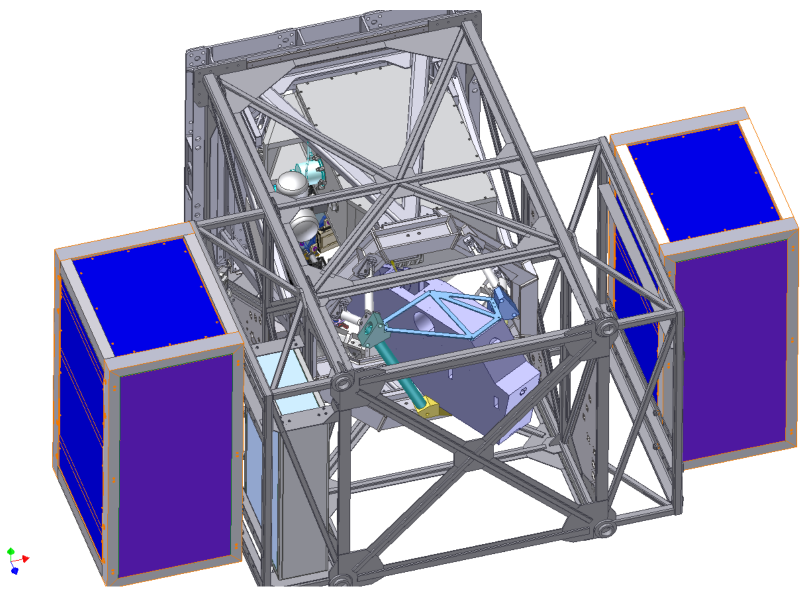
Planet finder instruments not guaranteed for first light

0. A Preface on 8m science: ExAO systems circa 2011

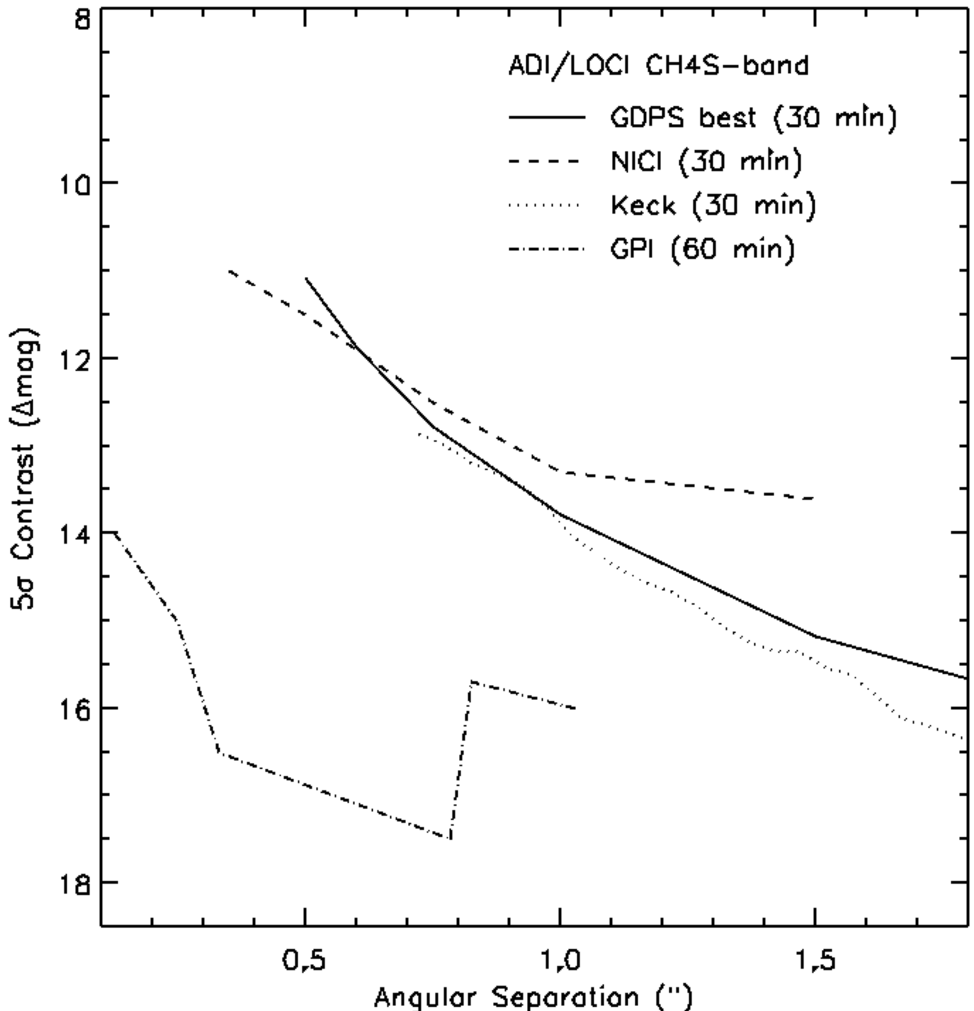
- Gemini
  - GPI (GS)
    - NGS ExAO coronograph system reaching 95% Strehl.
- Subaru
  - HiCIAO+ExAO
    - ExAO system using focal plane techniques for faint object detection
- Palomar 5m
  - Palm 3000+Proj. 1640
- ESO/VLT
  - Sphere (Spectro-Polarimetric High contrast Exoplanet Research)
- LBT (2 x 8.4m)
  - Two Adaptive Secondary Mirrors – Na LGS
  - LBTI (UA) – Nulling Imaging Camera

Much will be learned in the coming few years

Current and future systems



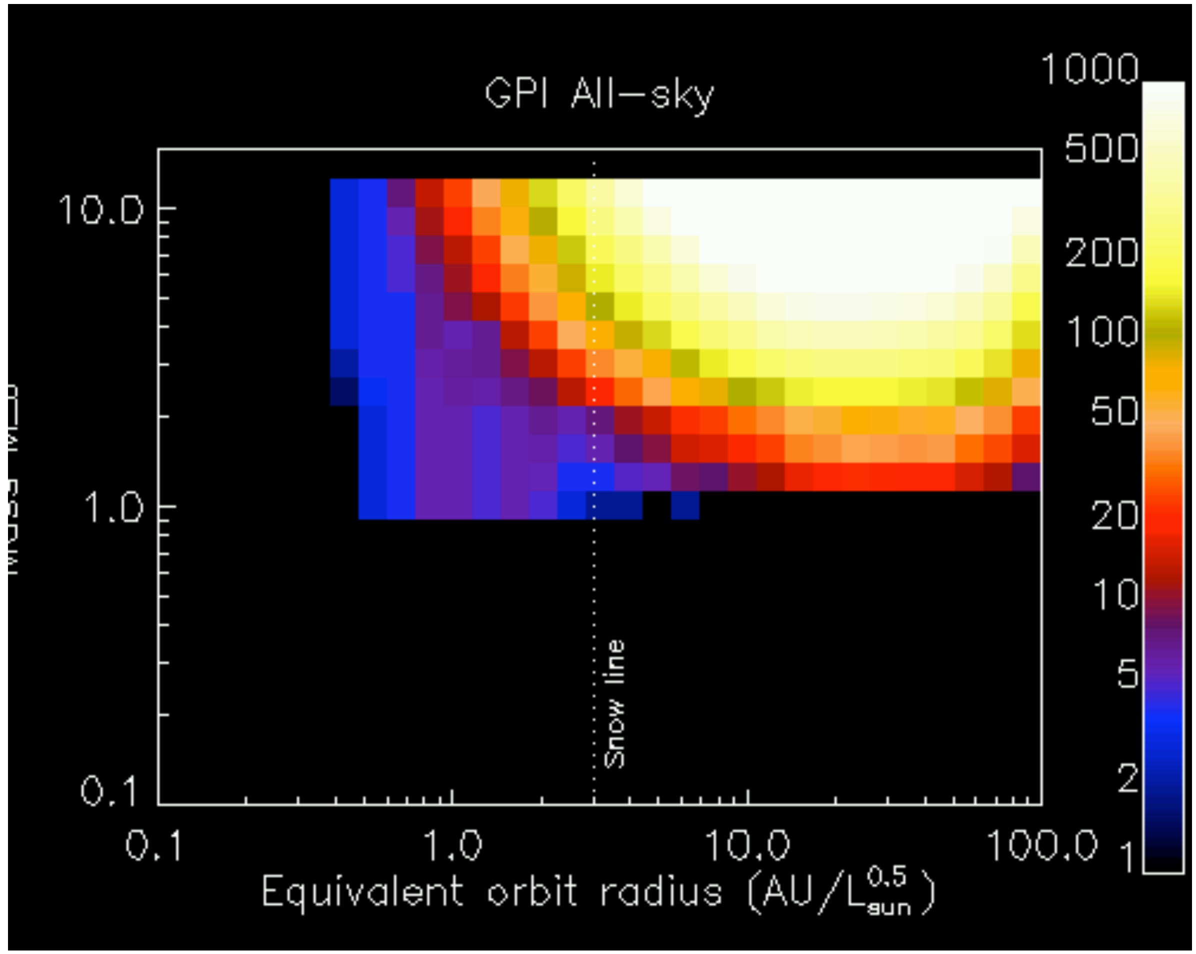
Gemini Planet Imager



Christian Marois

GPI science reach

- ExoPTF "Depth of Search Plot"
  - Depth of search is product of number of targets and completeness
- 8-m ExAO sensitive to giant planets 2-10 MJ 3-100 AU



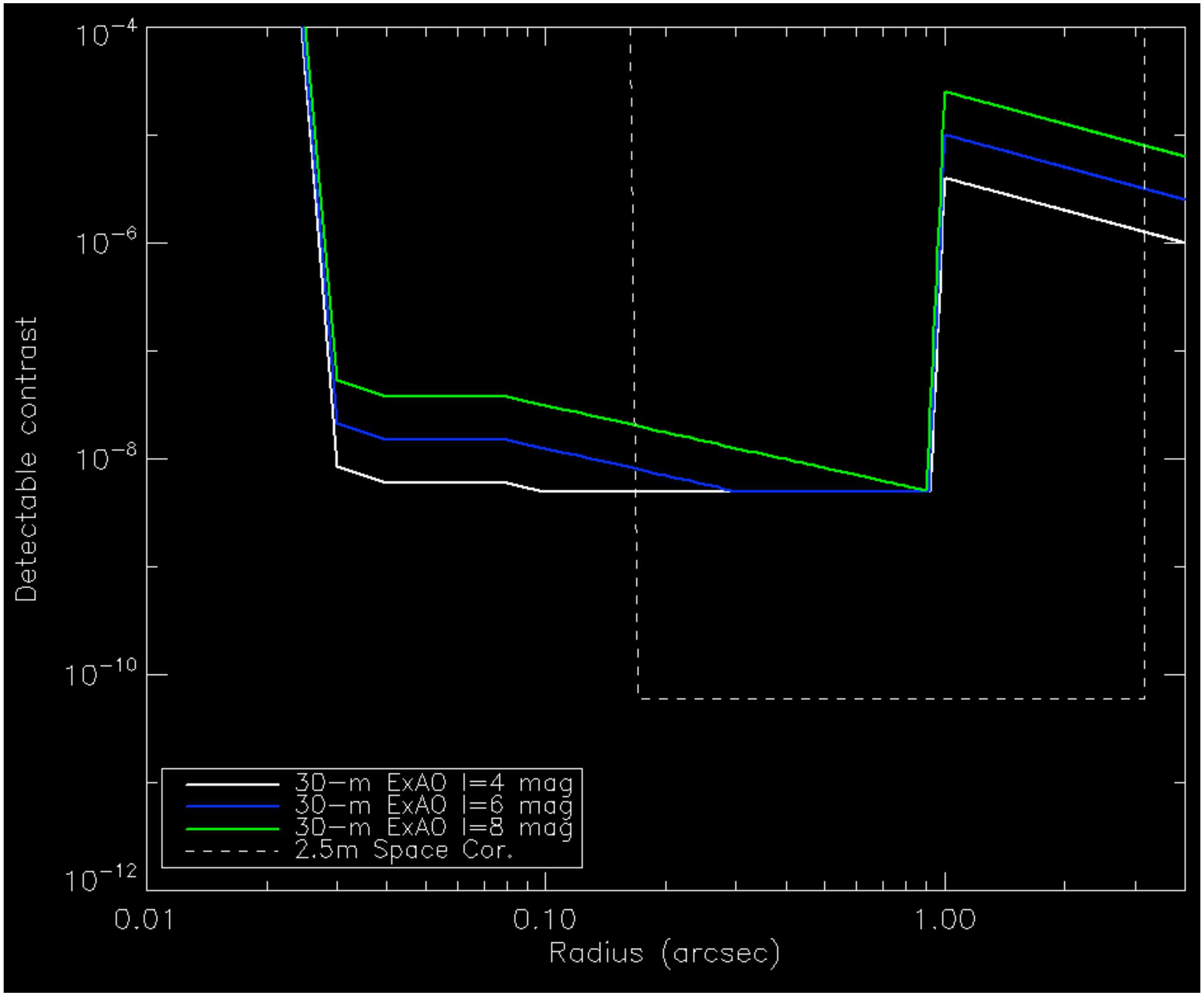
1. Planet Imaging

- Adaptive optics feed ⇛ near-infrared
- 2 λ/D (D=30 m)

  = 22 mas at 1.6 μm ⇛ 1 AU at 45 pc
- Contrast at 2 λ/D ~10^{-8}

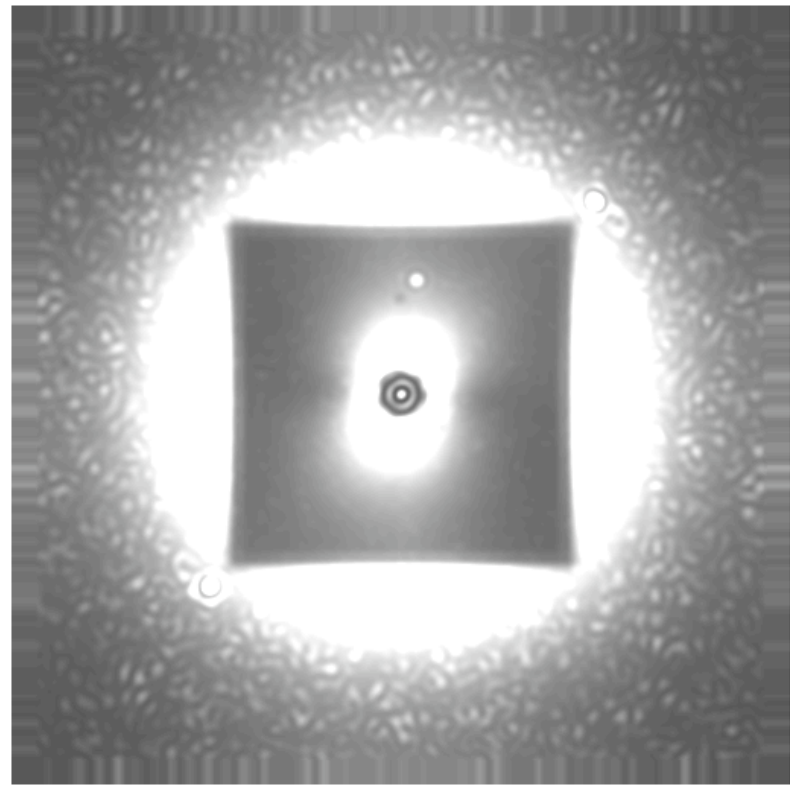
Ground-based Extreme AO

- ExAO photon + speckle noise analytic contrast model
- Static-aberration contrast floor at 0.5×10^{-8} (H = 3)



Uncertainties in contrast models

- Dynamic errors
  - Atmosphere, measurement, etc
  - Some uncertainty in analytic scaling (speckle lifetimes) but can be almost fully modeled for short exposures
- Quasi-static errors set floor
  - Optics, calibration, Fresnel effects, chromaticity…
  - Can be modeled (good models exist for 8-m) but have mostly been done only analytically
- Interaction between static and dynamic errors would require thousands of CPU-hours to model properly



Fresnel-simulated Gemini Planet Imager H-band data cube (wavelength 1.5 to 1.8 microns) Christian Marois / HIA

Planet Sensitivity

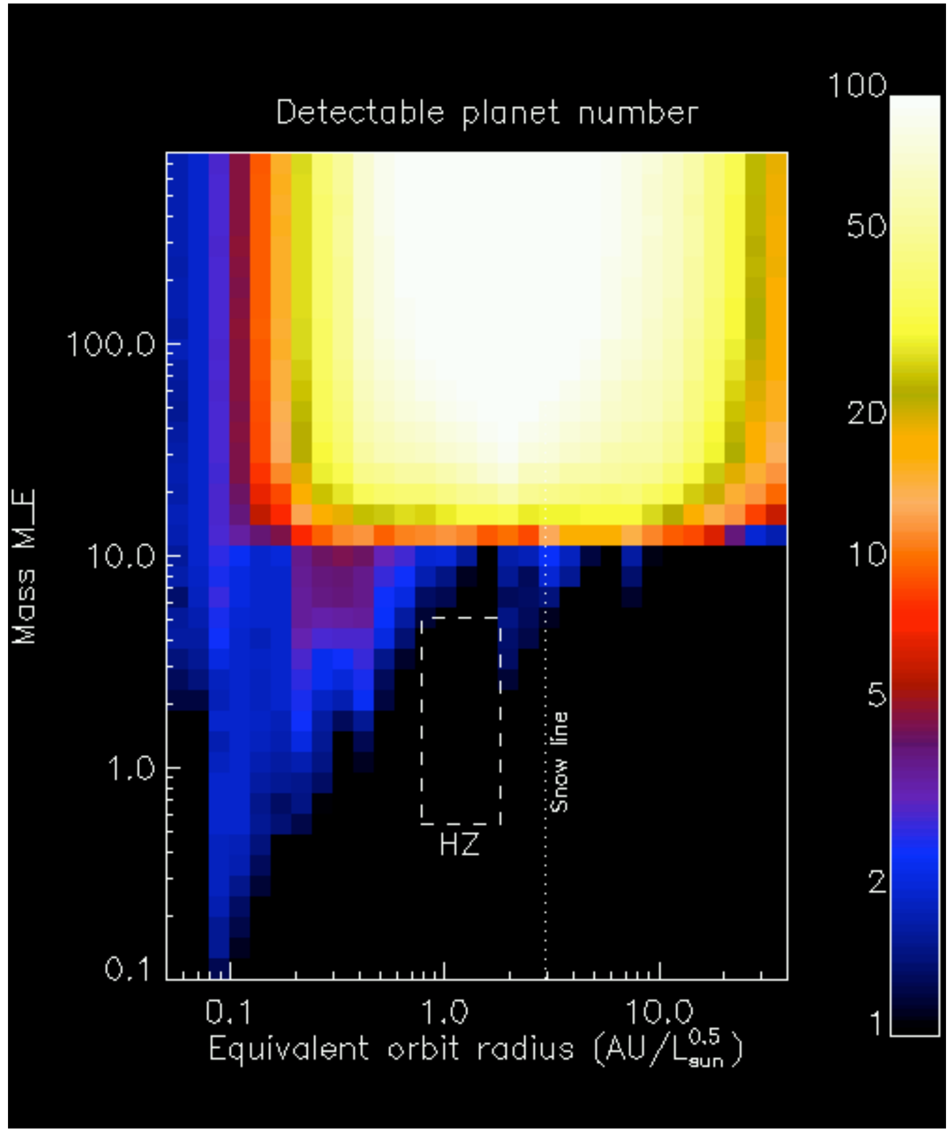
ExoPTF Depth of Search Plot

- •Depth of search is product of number of targets and completeness
- •Planets > 10 M_E are giants (core+hydrogen), <10M_E are rock+iron

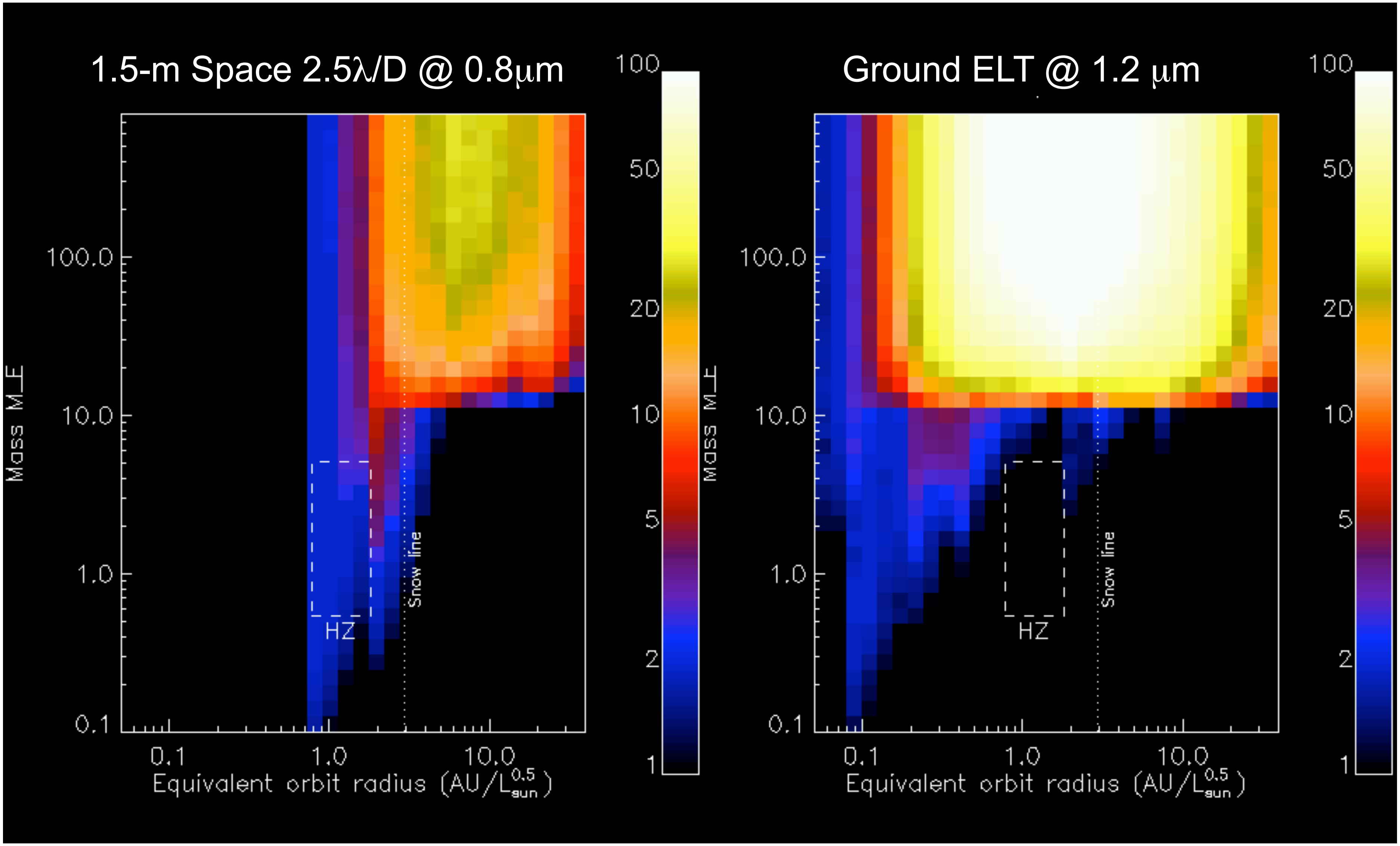
•500 star nearby star survey, 1 hour per star, 2 visits, reflected light only (no thermal)

•Ground ELT is very powerful for characterizing exoplanet atmospheres over large parameter space

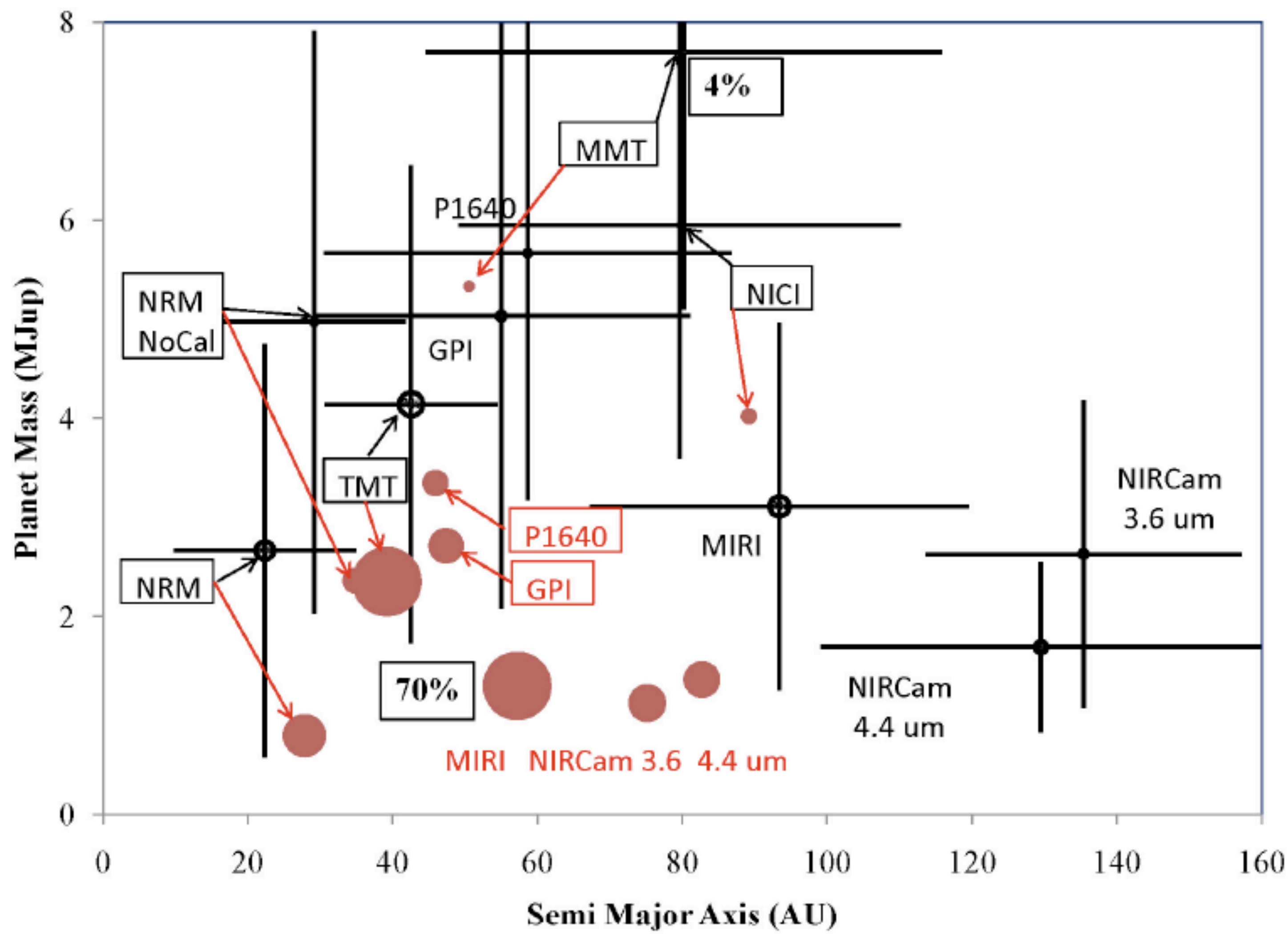
• Additional 500-star young survey adds many hundreds to depth above 1 M_J



Comparison to space 1.5-m PIAA coronagraph

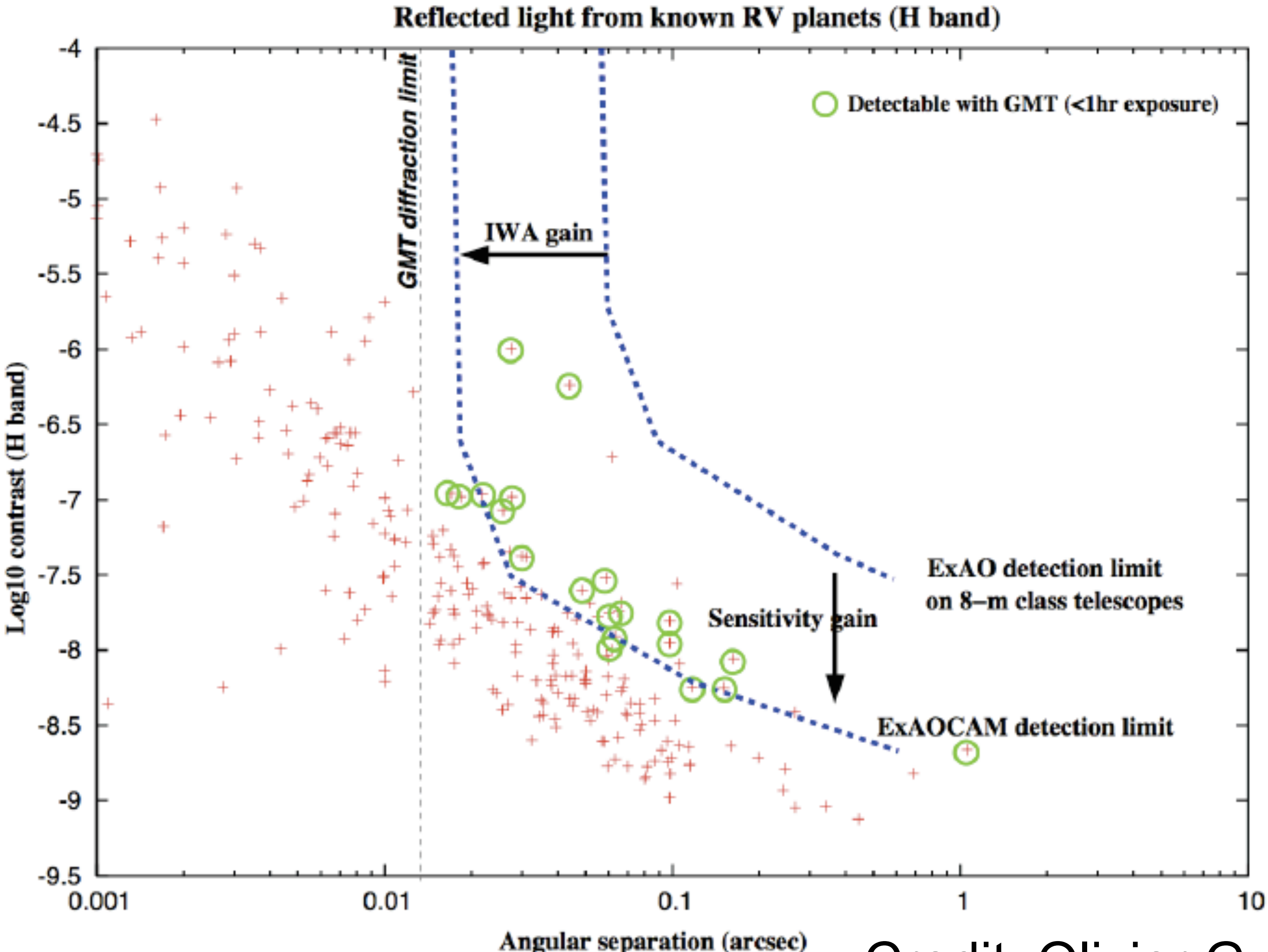


Monte Carlo for Young Planets



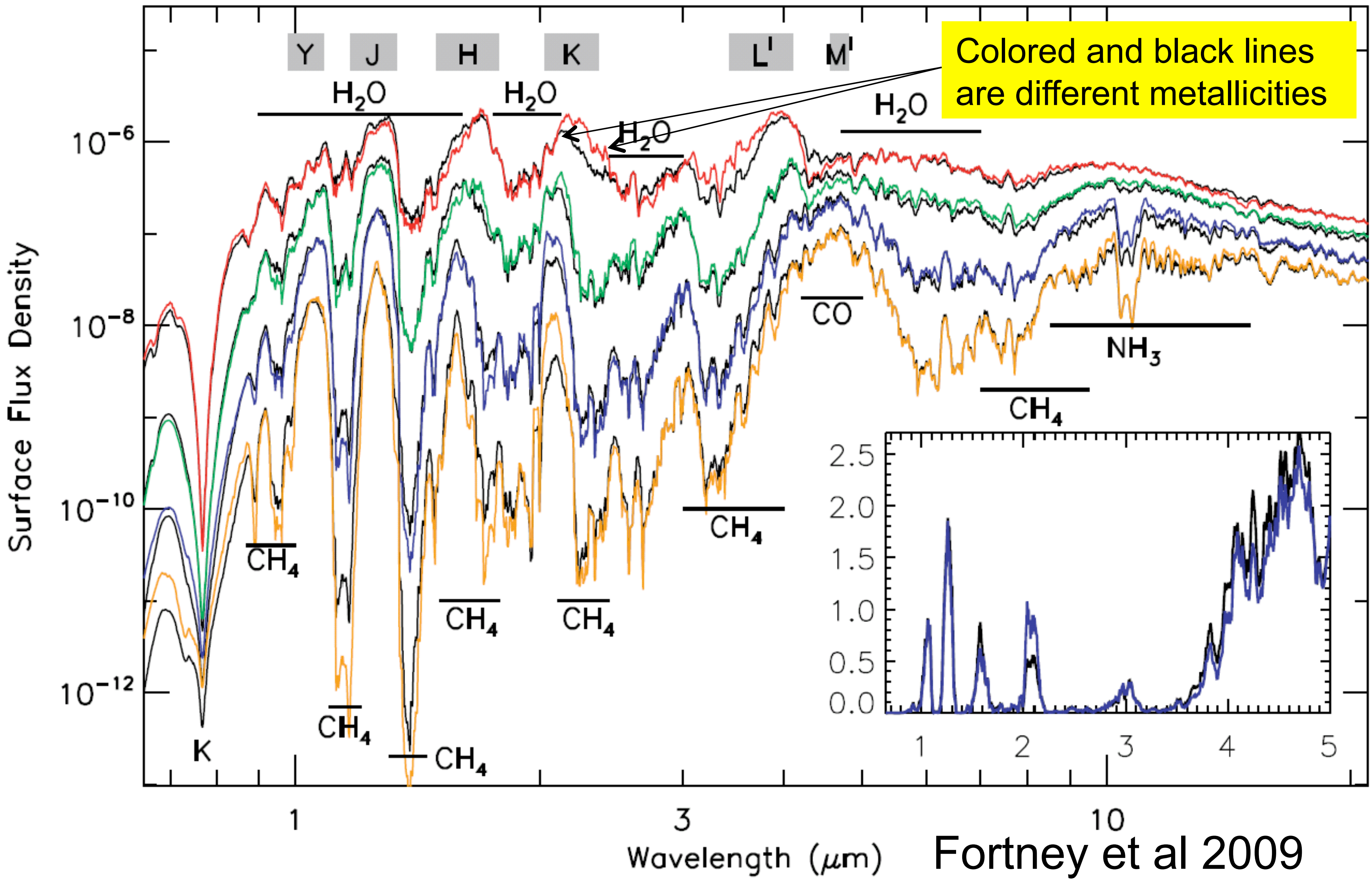
Beichman et al. 2010

ELTs can see RV planets



Credit: Olivier Guyon

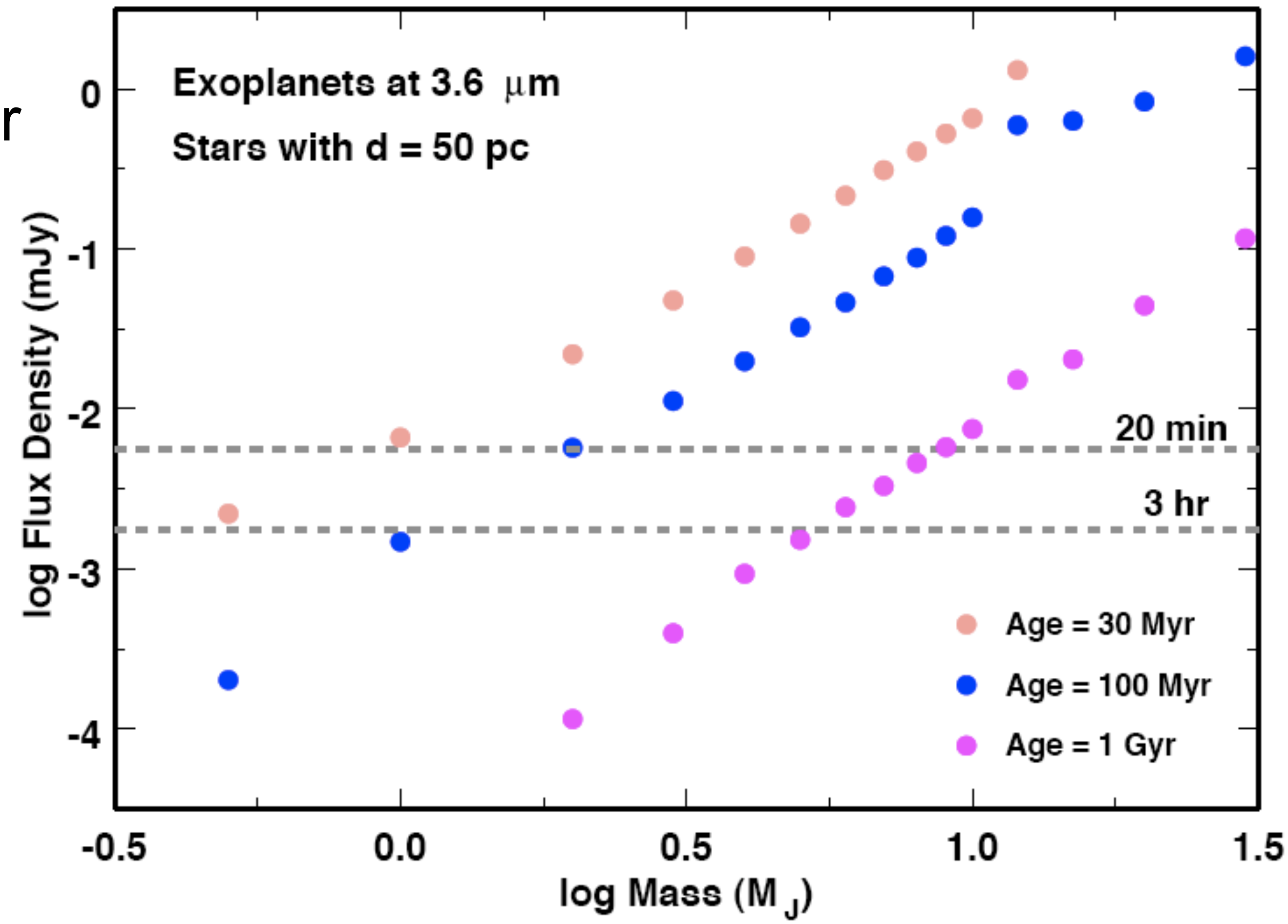
High SNR spectra can distinguish compositiona and hence formation scenarios



Fortney et al 2009

Thermal Infrared

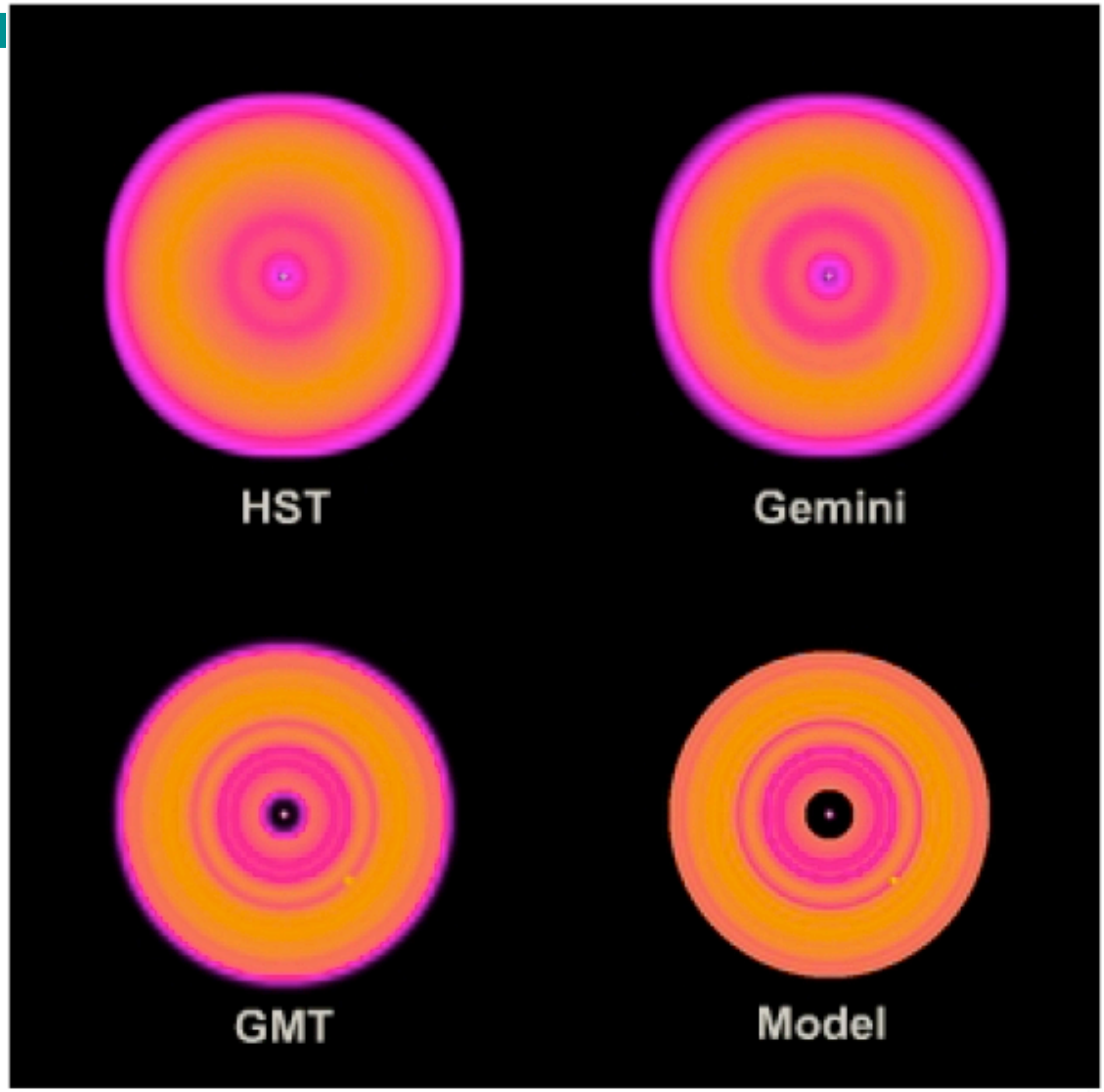
- Contrast of young giant planet and star ~10^{-6} makes them easier to image



Credit: Phil Hinz

Images of Disks and Planets

With "Extreme Adaptive Optics" ELT could see gaps and other structures (A 30 Myr old disk based on simulations by S. Kenyon for the GMT)

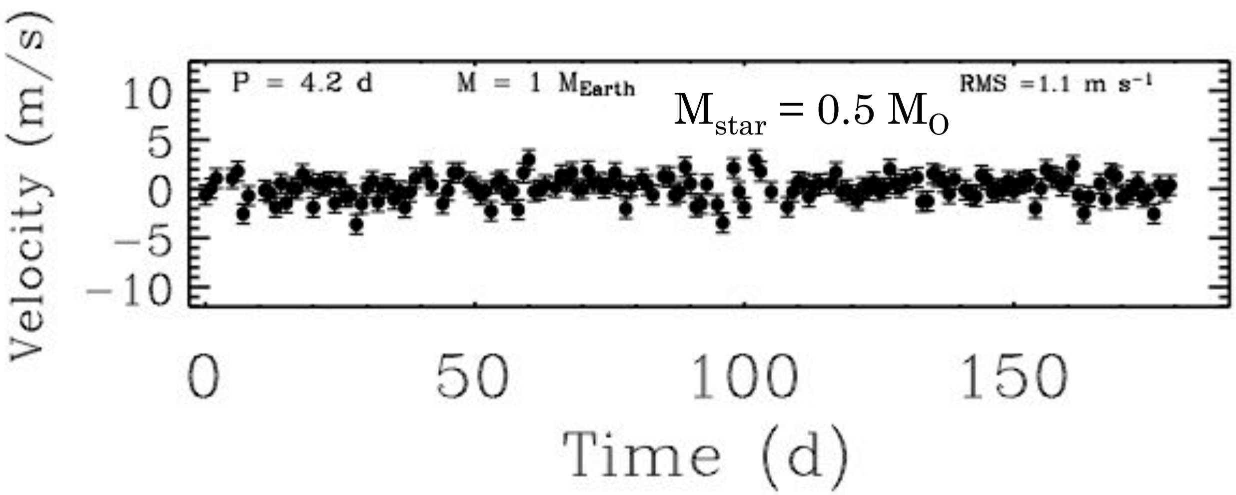


Main ELT Imaging Projects

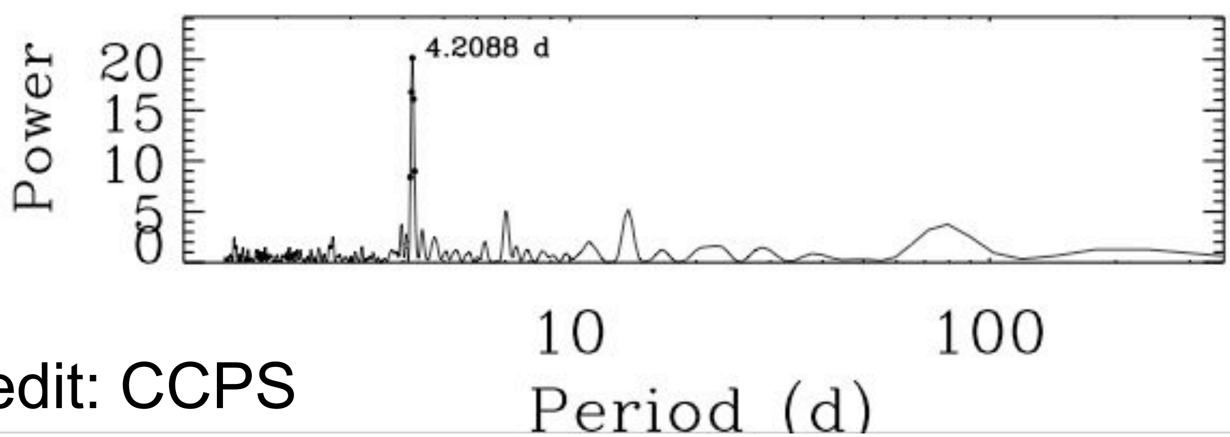
- Atmospheric characterization (1 - 5 μm) of known giant planets from Doppler studies + new systems
- Detection and atmospheric studies of young planets
    - Easier to see because they are brighter, but young stars are further away
    - Sensitivity is to M > 0.5 Mjup
- Detection of any hot planet at even 1 AU (e.g. molten proto-terrestrials)
    - 22 mas IWA probes 3 AU in nearby star-forming regions; can image planet formation process

Other Potential (non-AO) ELT Projects

1. Precision Radial Velocities: Goal Earth-like planets



Advantage of ELT depends on extent to which precision is photon-noise limited



Want to take 1 m/s from 8 m to 0.1 m/s for 30 m for V<12

Credit: CCPS

Other projects, continued

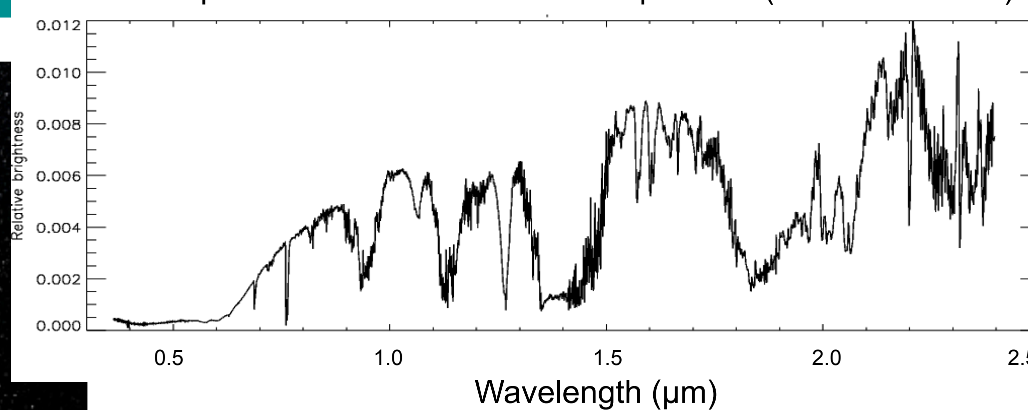
2. Atmospheric Spectroscopy

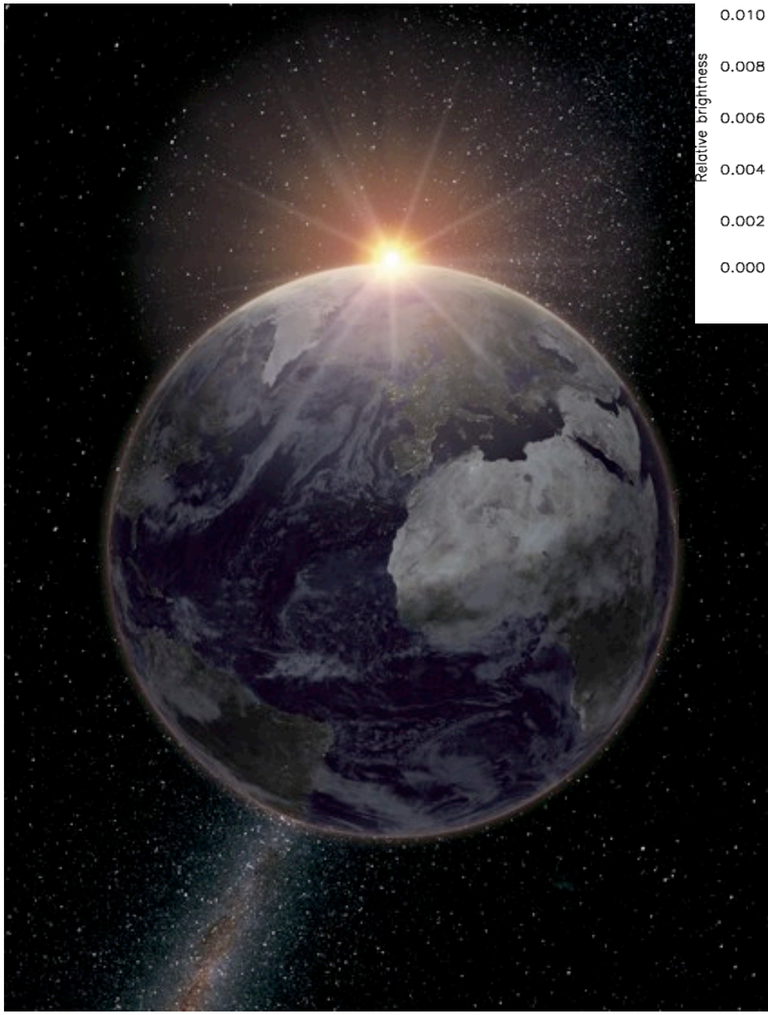
- Transmission spectra (during transit)
- Reflectance spectra (for known Doppler planets)

Competition is JWST with better sensitivity but lower spectral resolution

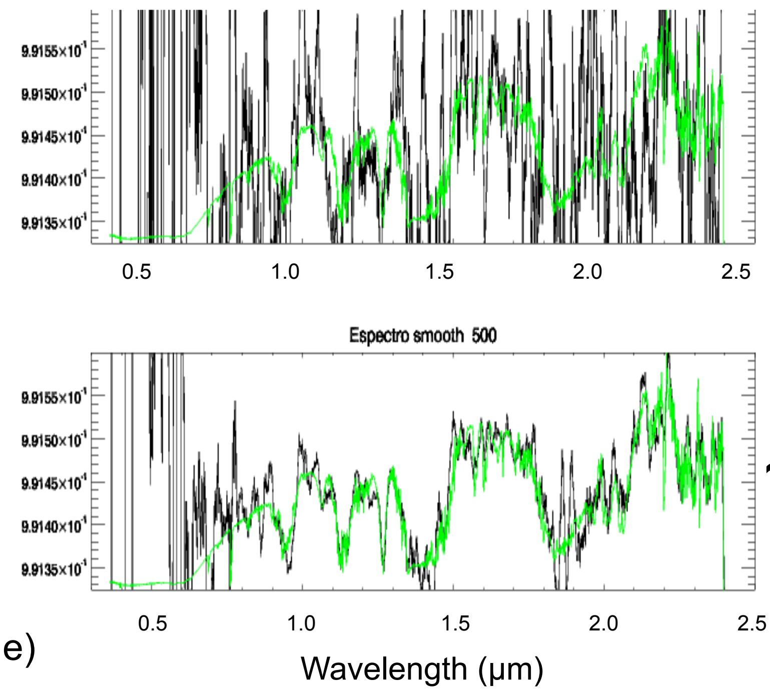
Transmission Spectroscopy

Earth's optical to near-IR transmission spectrum (Palle et al. 2009)





M8 star + 1 Earth ... with the 42-m E-ELT



~ 25 h

~ 150 h

(Simulations courtesy of Enric Palle)

Other Techniques

Astrometry: Narrow angle (< arcmin FOV), Ground-layer AO
10s microarcsecond accuracy

and from interferometers, e.g. VLTI, Keck

Radio - SKA work on self-luminous planets