

Characterizing Extra-Solar Planets

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OVERVIEW

Goal: Characterize exo-planets

- Atmospheric structure
- Chemistry
- Rotation
- “Weather”

Measurements: R ~ 10 photometry & R ~ 200 spectra

- Near-infrared (reflected light)
- Mid-infrared (thermal emission)

Role of GSMT: Enable measurements via

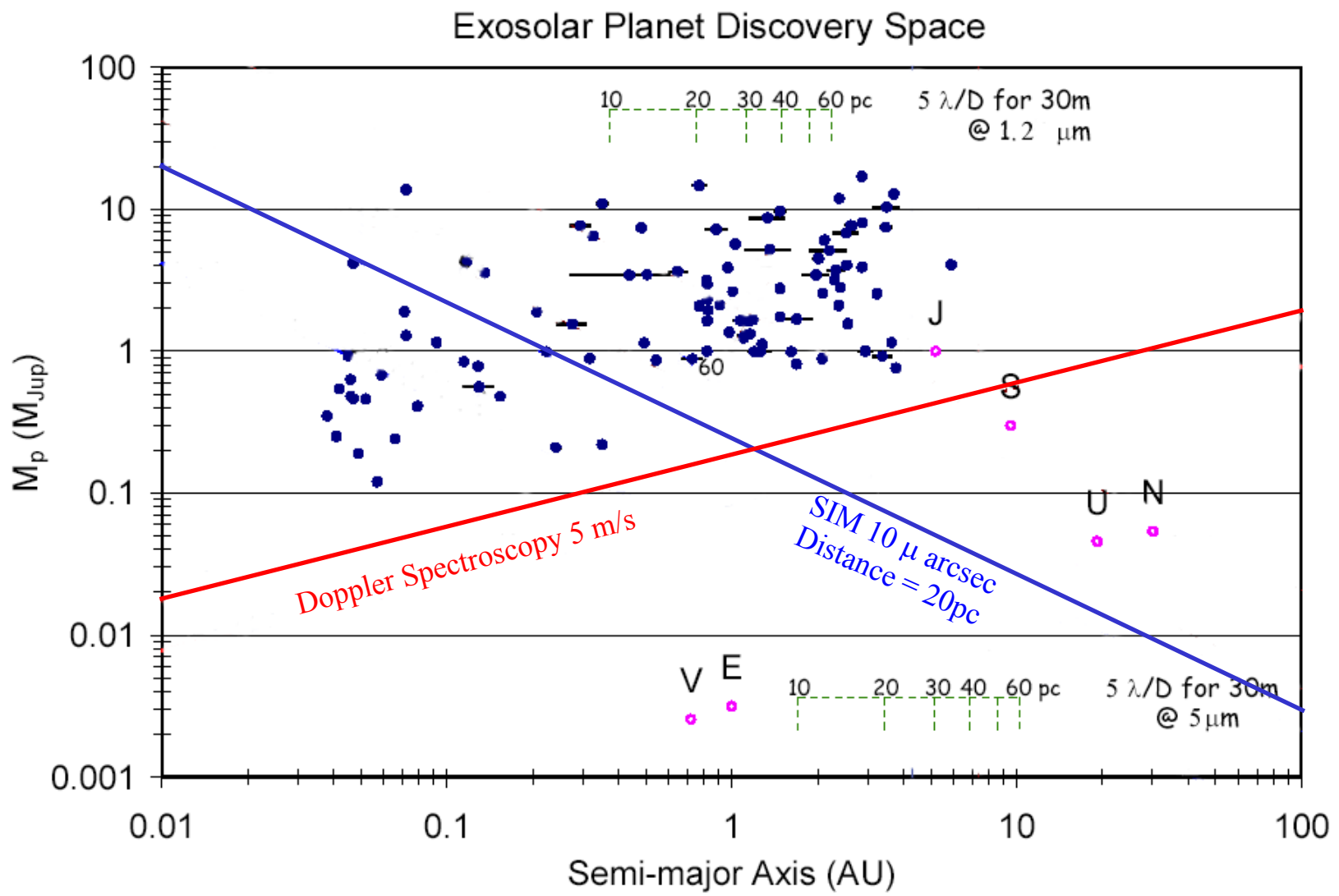
- High sensitivity
- High angular resolution

KEY PARAMETERS: 30m GSMT

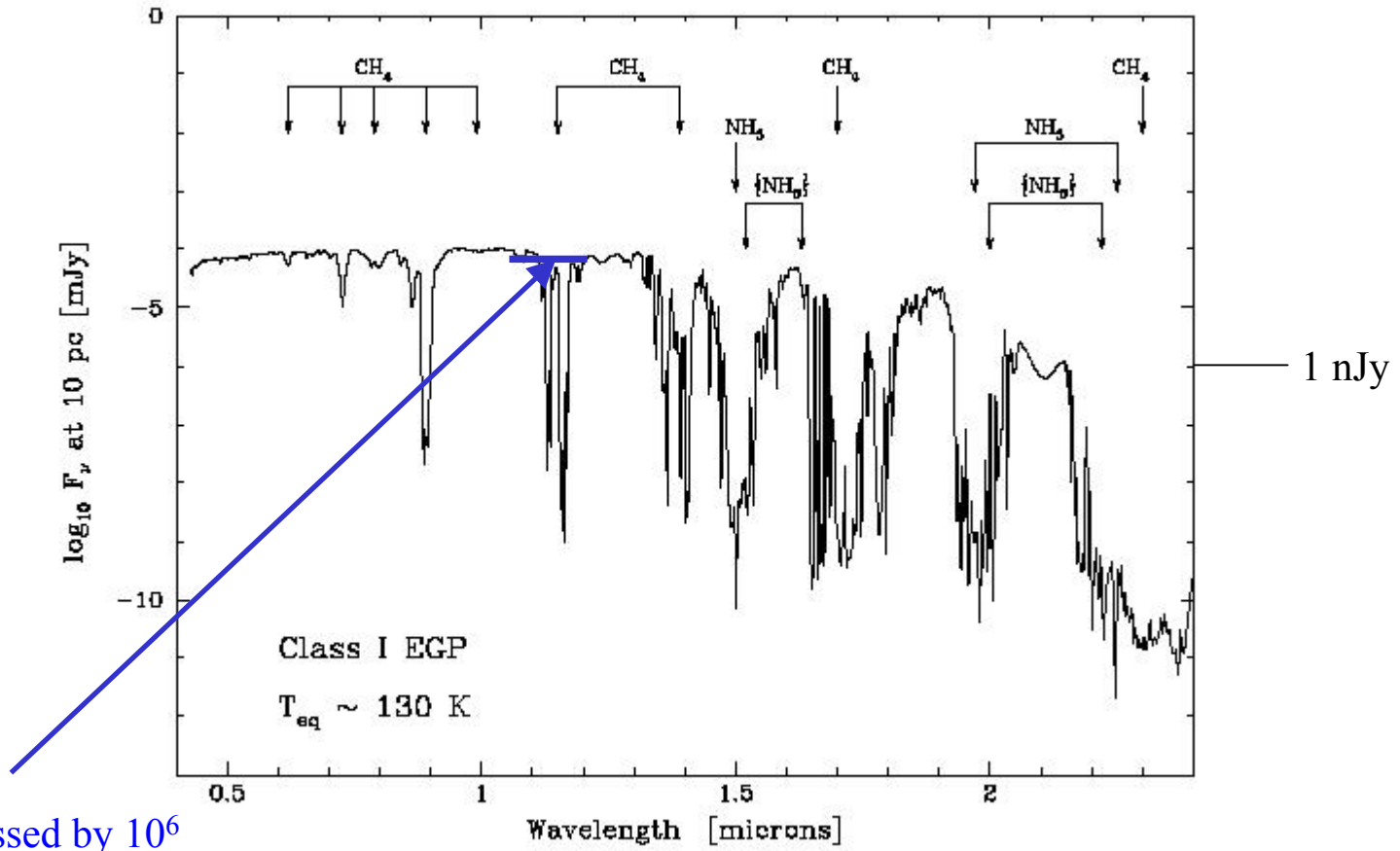
λ	$5 \lambda/D$	Separation @ 10pc
1.2 μ	40 mas	0.4 AU
4.7 μ	160 mas	1.6 AU

Aperture is critical to enable separation of planet from stellar image

The Realm of 30m Telescopes

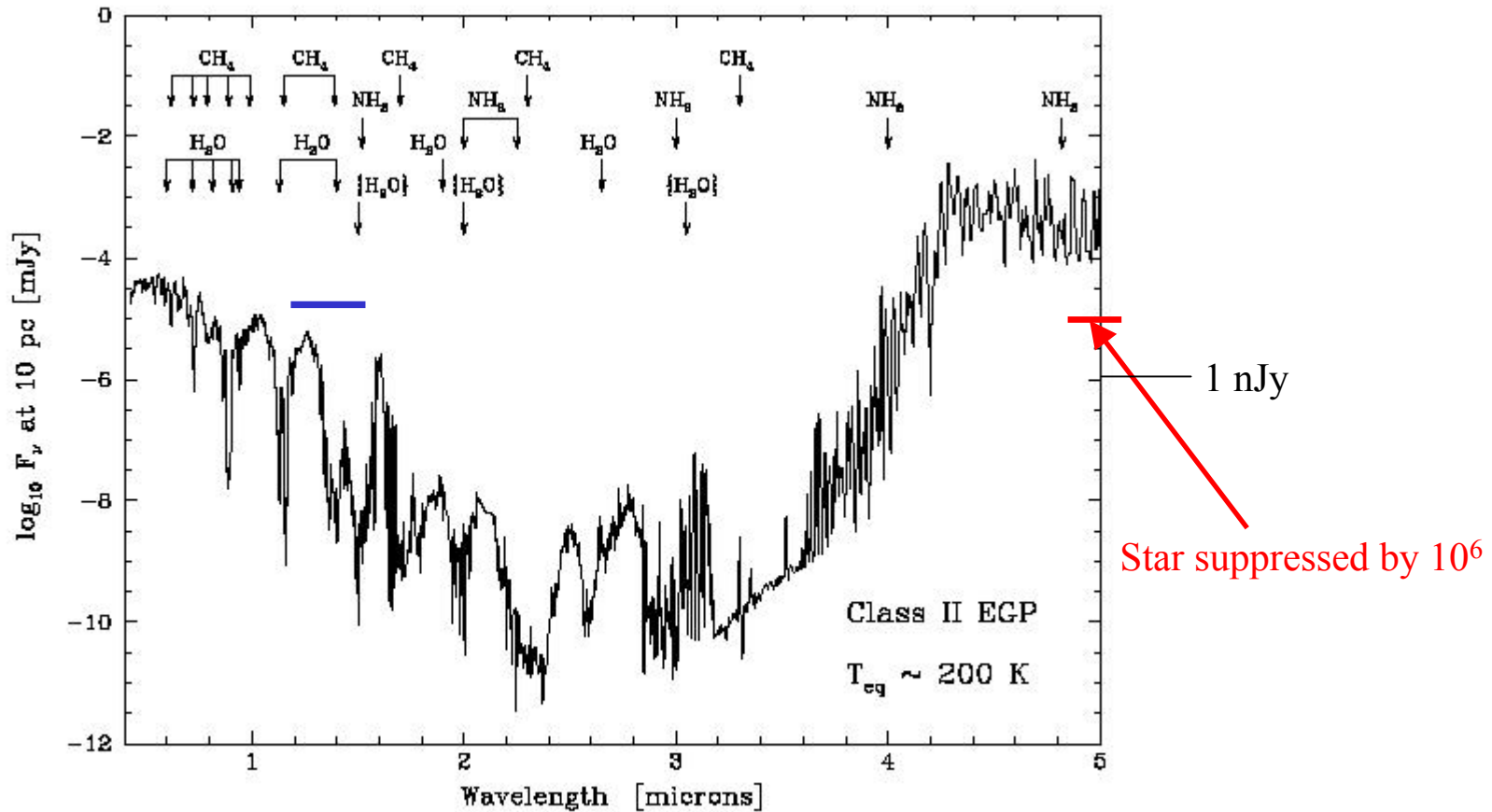


Exo-Jupiter Examples



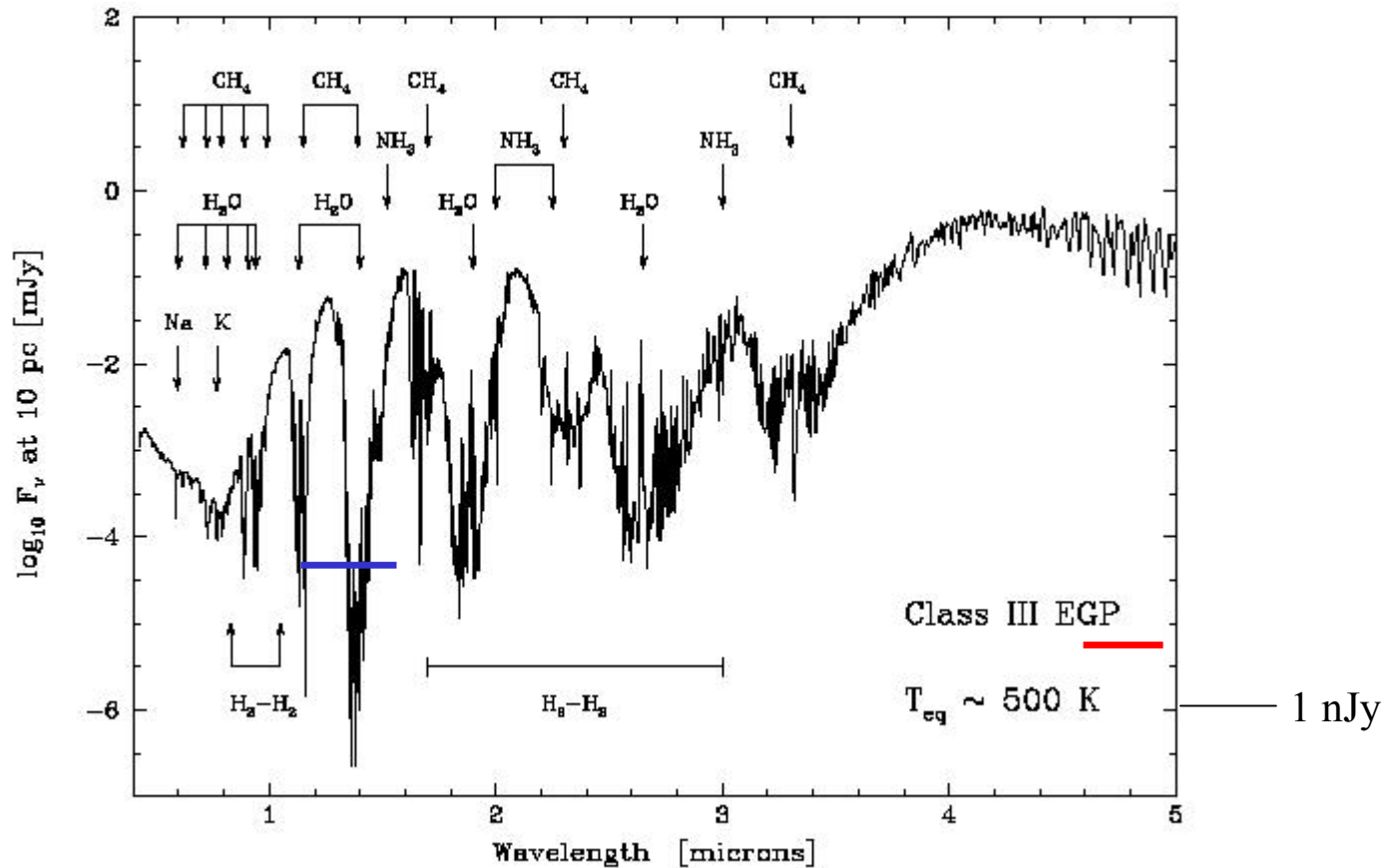
Class I EGP: Cold Jupiter Mass Planet at 5 AU

Ammonia Ice and Water Clouds produce high reflectivity in near IR



Class II EGP: Cool Jupiter-Mass Planet at 1.5 AU

Ammonia gaseous; water clouds in troposphere, enhancing NIR reflectivity



Class III EGP: Warm Jupiter-Mass Planet at $\sim 0.5 \text{ AU}$

Absorption by gaseous Water, Methane and Molecular Hydrogen Dominate

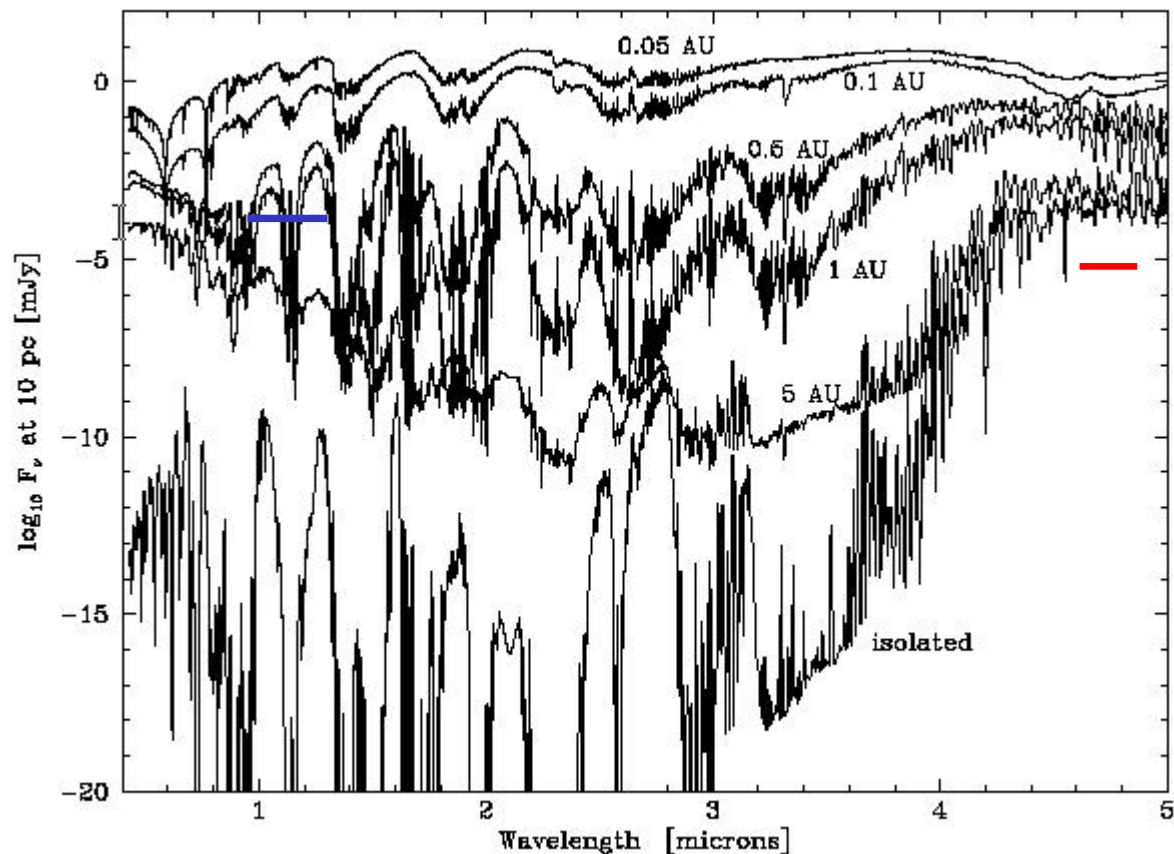
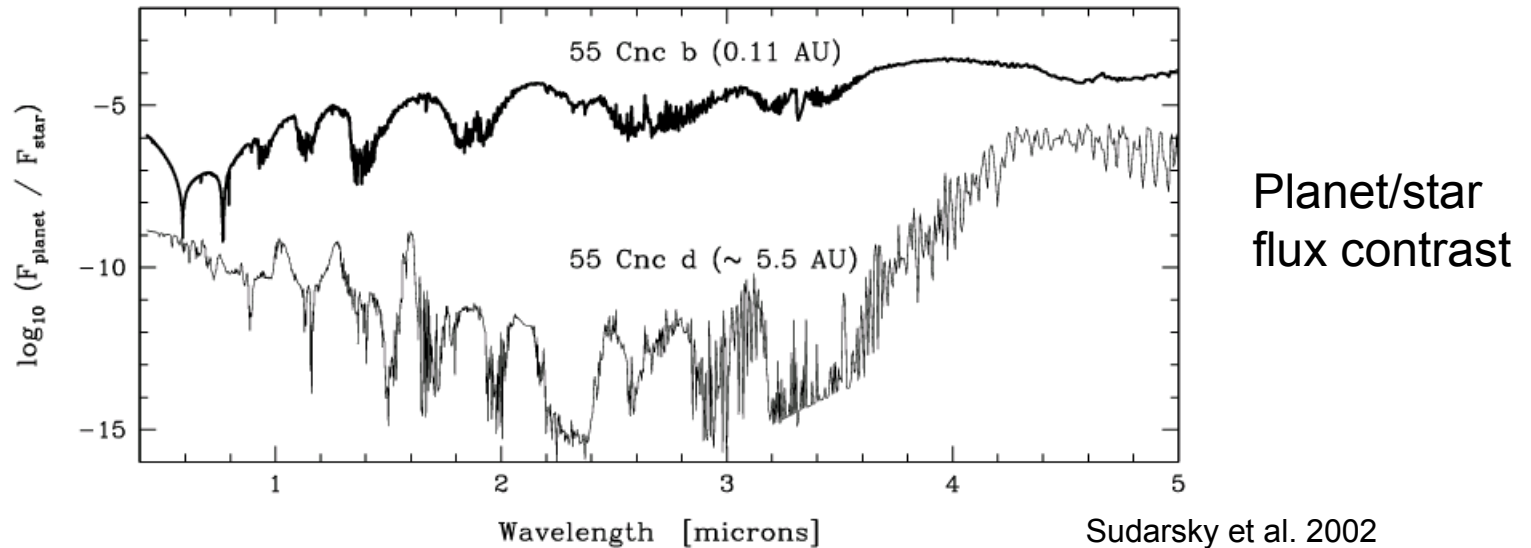
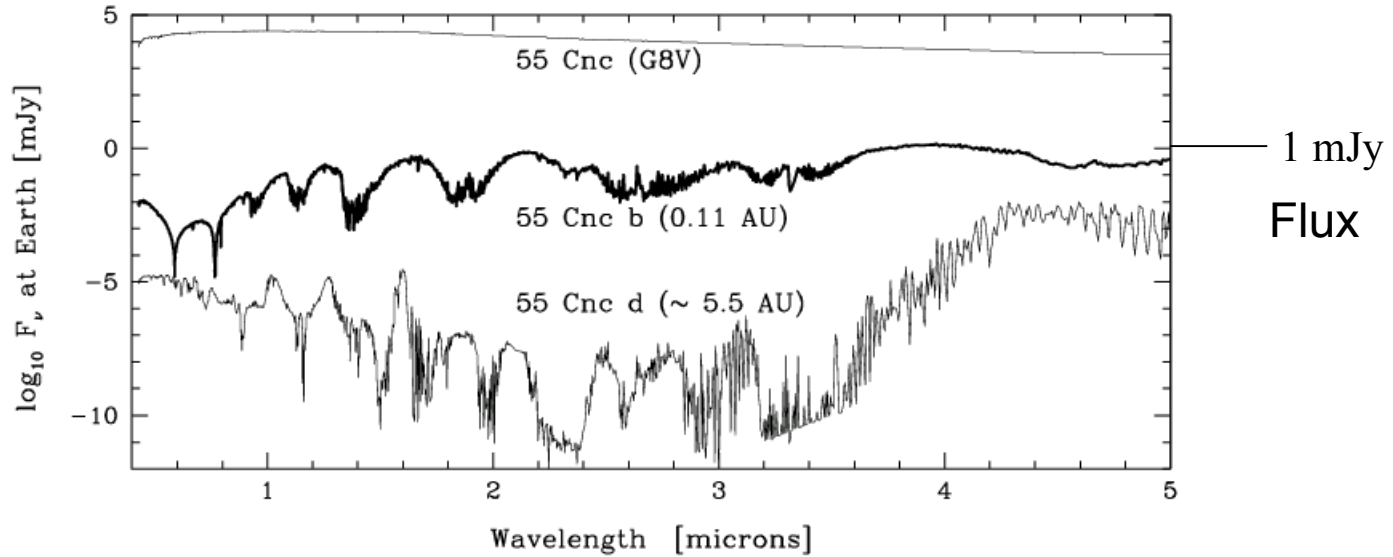


Fig. 13.— Cloud-free EGP emergent spectra as a function of orbital distance from a GOV primary. From top to bottom, the orbital distance is 0.05 AU, 0.1 AU, 0.5 AU, 1 AU, and 5 AU. Additionally, the bottom curve is that of an isolated EGP/brown dwarf. In all cases, the gravity is $3 \times 10^3 \text{ cm s}^{-2}$ and the lower boundary flux is set equal to that of an isolated object with $T_{\text{eff}} = 125 \text{ K}$. (Note that we have alternated between thin and thick line types in order to facilitate a correspondence with the profiles in Figure 12.)

Example: 55 Cnc d

($M_p=4M_J$, $a_p=5.9\text{AU}$, $d=15\text{pc}$)



Near-IR Characterization of Exo-Jupiters

1.2 μm $R \sim 10$ $S/N = 25$

Object Class	Integration Time	Contrast Ratio
Class I (~5 AU) 32nJy @ 1.2 μm	1.5 hours	5×10^8
Class II (~1.5 AU) 1nJy @ 1.2 μm	1,500 hours	1.5×10^{10}
Class III (~0.5 AU) 100nJy @ 1.2 μm	0.17 hours	1.5×10^6

NB: Calculated times assume NO contribution from parent star

Near-IR Characterization of Exo-Jupiters

1.2 μm $R \sim 200$ $S/N = 25$

Object Class	Integration Time	Contrast Ratio
Class I (~5 AU) 32nJy @ 1.2 μm	17 hours	5×10^8
Class II (~1.5 AU) 1nJy @ 1.2 μm	12,000 hours	1.5×10^{10}
Class III (~0.5 AU) 100nJy @ 1.2 μm	2 hours	1.5×10^6

NB: Calculated times assume NO contribution from parent star

Mid-IR Characterization of Exo-Jupiters

4.7 μm $R \sim 10$ $S/N = 25$

Object Class	Integration Time GSMT $R \sim 10$	Contrast Ratio	Integration Time JWST $R \sim 10$
Class I (~5 AU) 300nJy @ 4.7 μm	3,000 hours	2×10^7	0.2 hrs
Class II (~1.5 AU) 1000nJy @ 4.7 μm	250 hours	7×10^6	0.03 hrs
Class III (~0.5 AU) 30000nJy @ 4.7 μm	0.3 hours	2×10^5	3 seconds

NB: Calculated times assume NO contribution from parent star

Mid-IR Characterization of Exo-Jupiters

4.7 μm $R \sim 200$ $S/N = 25$

Object Class	Integration Time GSMT $R \sim 200$	Contrast Ratio	Integration Time JWST $R \sim 1000$
Class I (~5 AU) 300nJy @ 4.7 μm	20,000 hours	2×10^7	80 hrs
Class II (~1.5 AU) 1000nJy @ 4.7 μm	2,000 hours	7×10^6	10 hrs
Class III (~0.5 AU) 30000nJy @ 4.7 μm	2 hours	2×10^5	0.1 hrs

NB: Calculated times assume NO contribution from parent star

Exo-Earths: Simple Examples

Exo-Earth Characterized via Scattered Light

1.2 μm $R \sim 10$ $S/N = 25$ Albedo ~ 0.5

Earth-Sun Distance	Integration Time 30m GSMT	Contrast Ratio	Integration Time 100m OWL
1 AU (5 nJy @ 1.2 μm)	61 hours	10^{10}	0.5 hours
0.4 AU (30nJy @ 1.2 μm)	2 hours	2×10^9	0.01 hours

NB: Calculated times assume NO contribution from parent star

Exo-Earth Characterized via Scattered Light

1.2 μm $R \sim 200$ $S/N = 25$ Albedo ~ 0.5

Earth-Sun Distance	Integration Time 30m GSMT	Contrast Ratio	Integration Time 100m OWL
1 AU (5 nJy @ 1.2 μm)	611 hours	10^{10}	5 hours
0.4 AU (30nJy @ 1.2 μm)	18 hours	2×10^9	0.15 hours

NB: Calculated times assume NO contribution from parent star

Exo-Earth Characterized via Thermal Emission

4.7 μm $R \sim 10$ $S/N = 25$ Distance = 1 AU

Temperature	Integration Time 30m GSMT	Contrast Ratio	Integration Time 100m OWL
500 K (Warm Earth) (1.3 μJy @ 4.7 μm)	150 hours	5×10^6	1 hour
300K (29nJy @ 4.7 μm)	3×10^5 hours	2×10^8	2500 hours

NB: Calculated times assume NO contribution from parent star

Exo-Earth Characterized via Thermal Emission

4.7 μm $R \sim 200$ $S/N = 25$ Distance = 1 AU

Temperature	Integration Time 30m GSMT	Contrast Ratio	Integration Time 100m OWL
500 K (Warm Earth) (1.3 μJy @ 4.7 μm)	1,200 hours	5×10^6	9.5 hours
300K (29nJy @ 4.7 μm)	2×10^6 hours	2×10^8	18,000 hours

NB: Calculated times assume NO contribution from parent star

Conclusions

- A 30m GSMT will detect and classify Jovian mass planets -- from ‘roasters’ to ‘old, cold’ Jupiters-- located at $\sim 5\text{AU}$ for stars at distances $< 10\text{pc}$
 - Via photometry ($R \sim 10$)
 - Requires star suppression $\sim 10^6$
 - Old, cold Jupiters are very challenging
- Detailed characterization of Jovian planets via spectroscopy is very challenging
 - *Still photon starved at 30m aperture*
- Detection of lower mass planets is possible, but star suppression must exceed 10^8
 - Characterization via spectroscopy not possible
- GSMT will contribute to, but not dominate exo-planet studies
 - JWST will be competitive for background-limited cases for nearby stars
 - OWL will represent *strong* competition because of D^4 advantage
 - TPF/Darwin will be the facility of choice by 2020

Further Work

- Calculate exposure times for a finer grid of planetary masses and ages
- Identify range of masses and ages for which analysis via high R spectroscopy is possible
- Identify range of parameters (distance; separation) where earth-like planets can be detected
 - Likely to be very narrow, with ‘very challenging’ requirements on AO system performance