Characterizing Extra-Solar Planets

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OVERVIEW

Goal: Characterize exo-planets

- Atmospheric structure; chemistry; rotation; “weather”
- Determine formation mechanism for EGPs

Measurements: R~ 10 photometry & R ~ 200 spectra

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

Role of GSMT: Enable measurements via

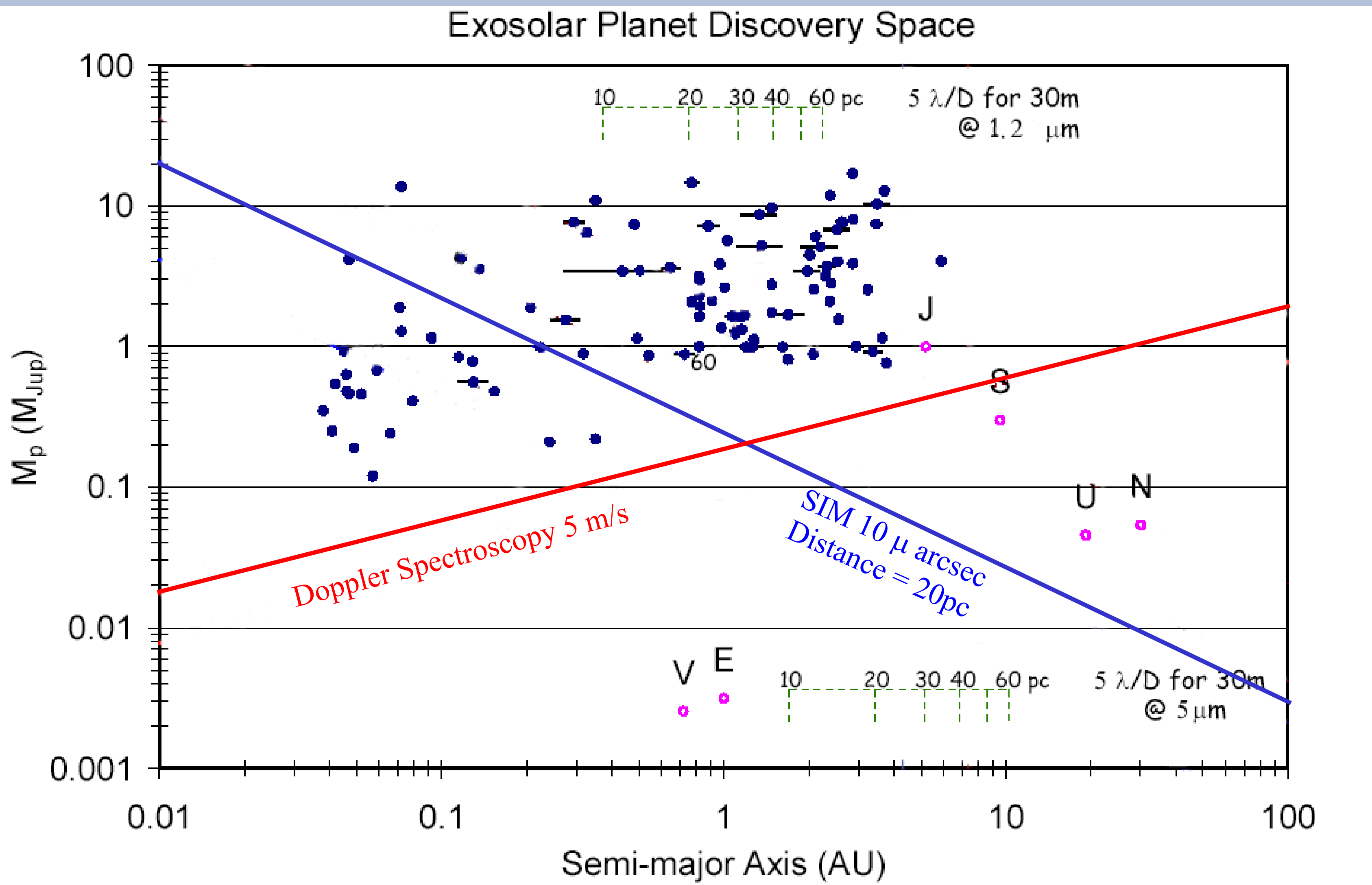
- High sensitivity
- High angular resolution

KEY PARAMETERS: 30m GSMT

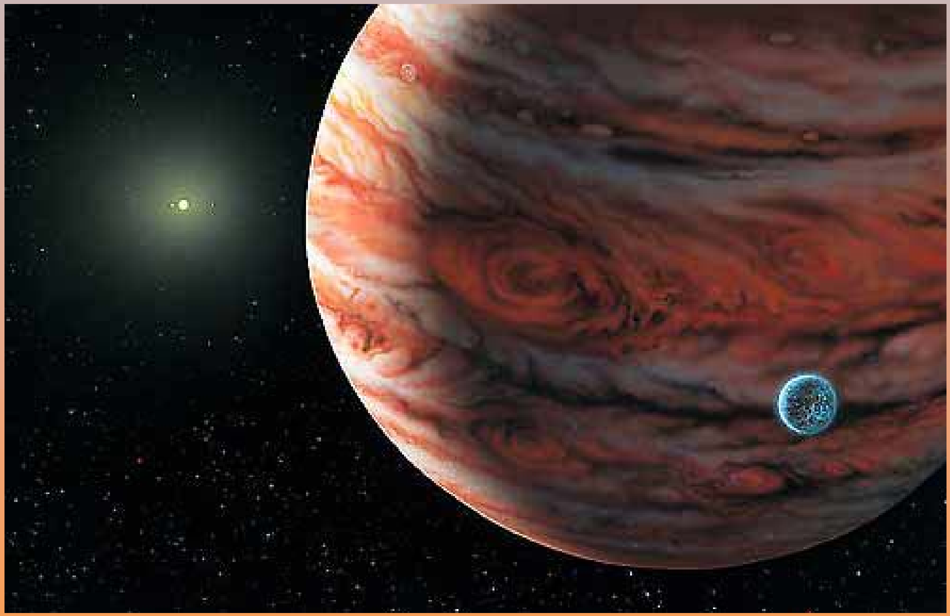
λ	**5 λ/D**	**Separation @ 10pc**
1.2 μ	40 mas	0.4 AU
4.7 μ	160 mas	1.6 AU

Aperture is critical to enable separation of planet from stellar image

The Realm of 30m Telescopes

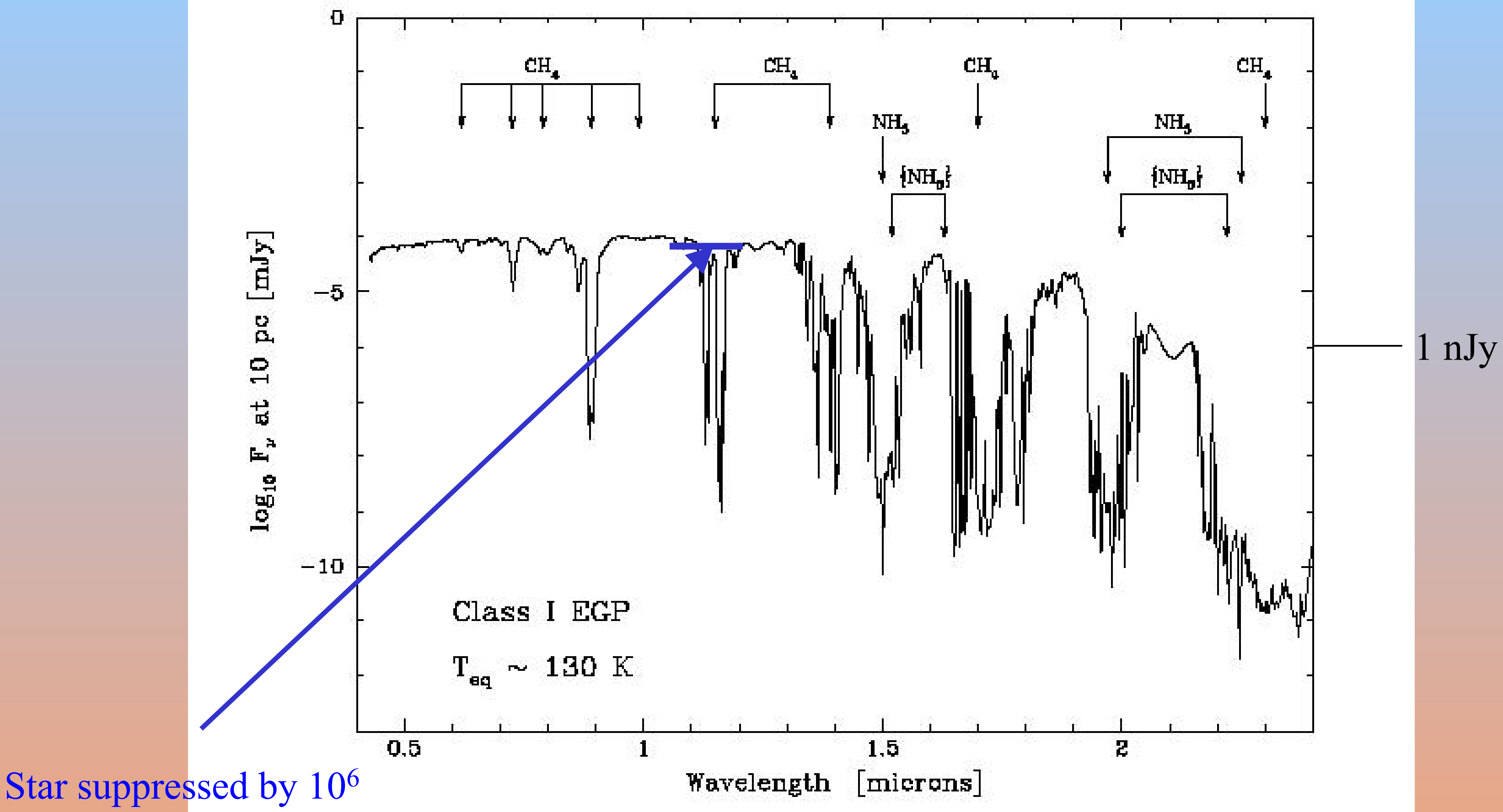


Exo-Jupiter Examples



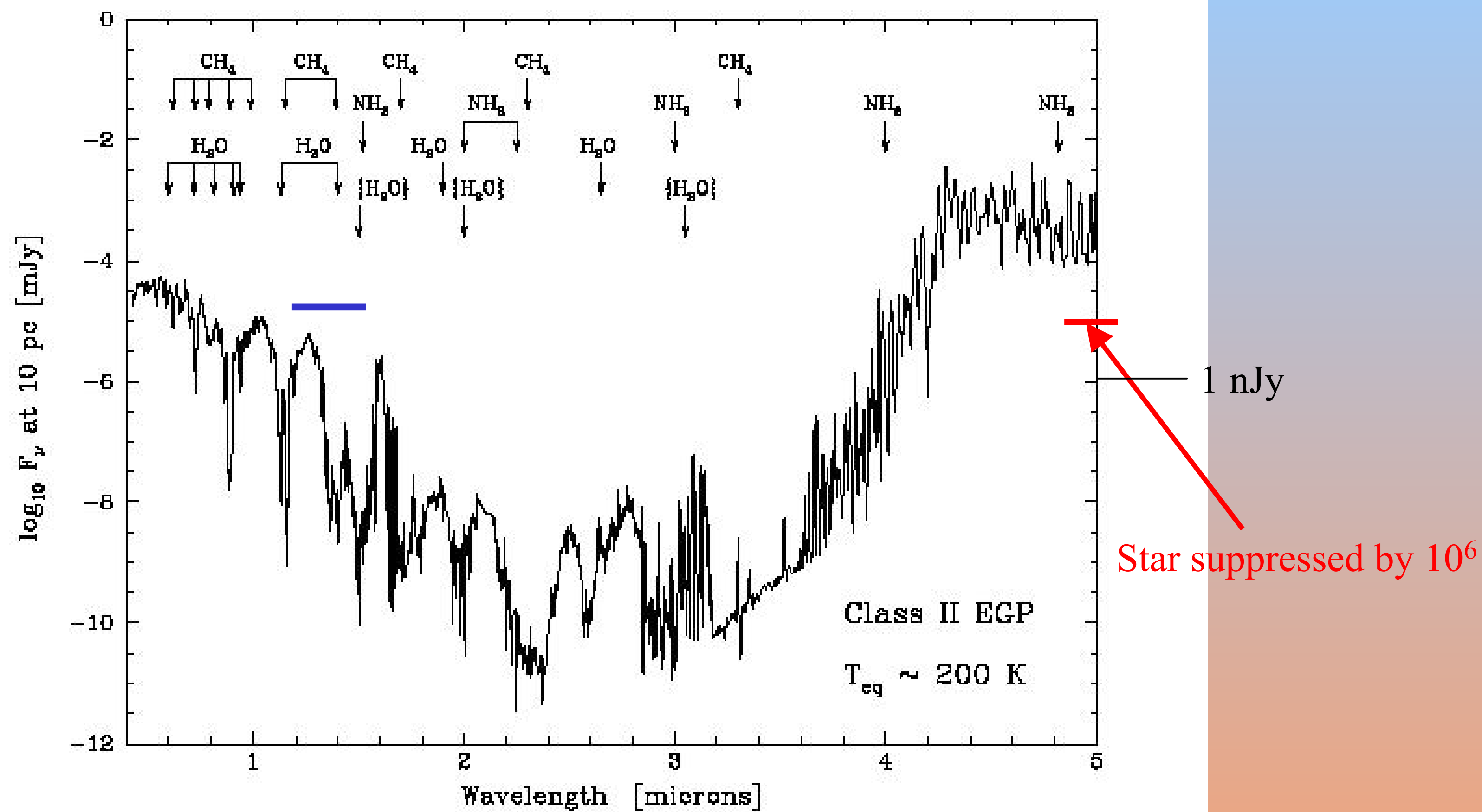
Goals

- Image planet at multiple wavelengths (R ~ 10)
- Classify planet from broad spectral features (R ~ 100)
- Analyze atmospheric structure and chemistry (R ~ 1000)
- Understand origin via (C,N,O)/H ratios
  - High metal abundance suggests an agglomeration origin
  - Low metal abundance suggests origin in disk instability
- Determine rotation & weather via synoptic observations



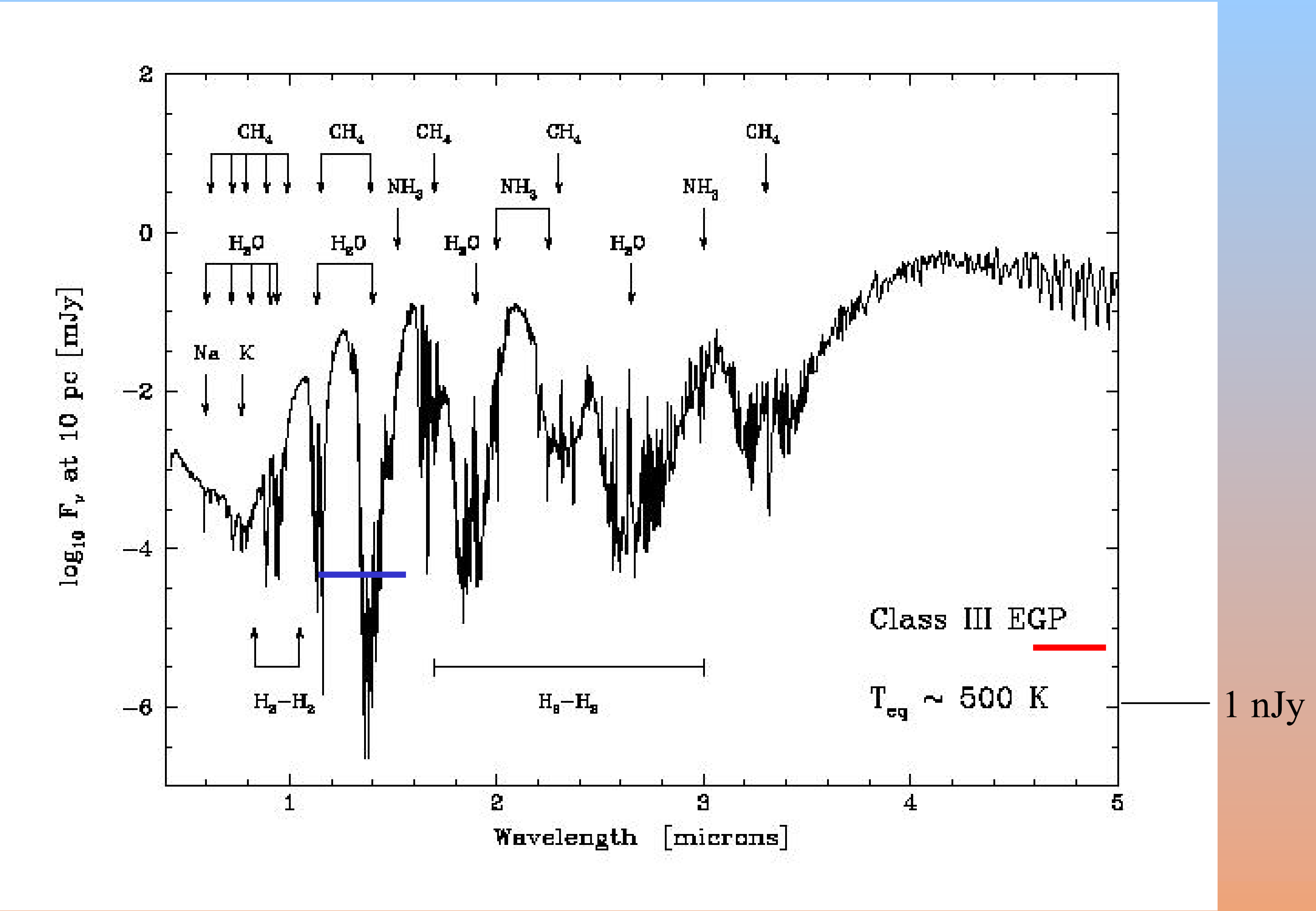
Class I EGP: Cold Jupiter Mass Planet at 5 AU

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 ~ 0.5 AU

Absorption by gaseous Water, Methane and Molecular Hydrogen Dominate

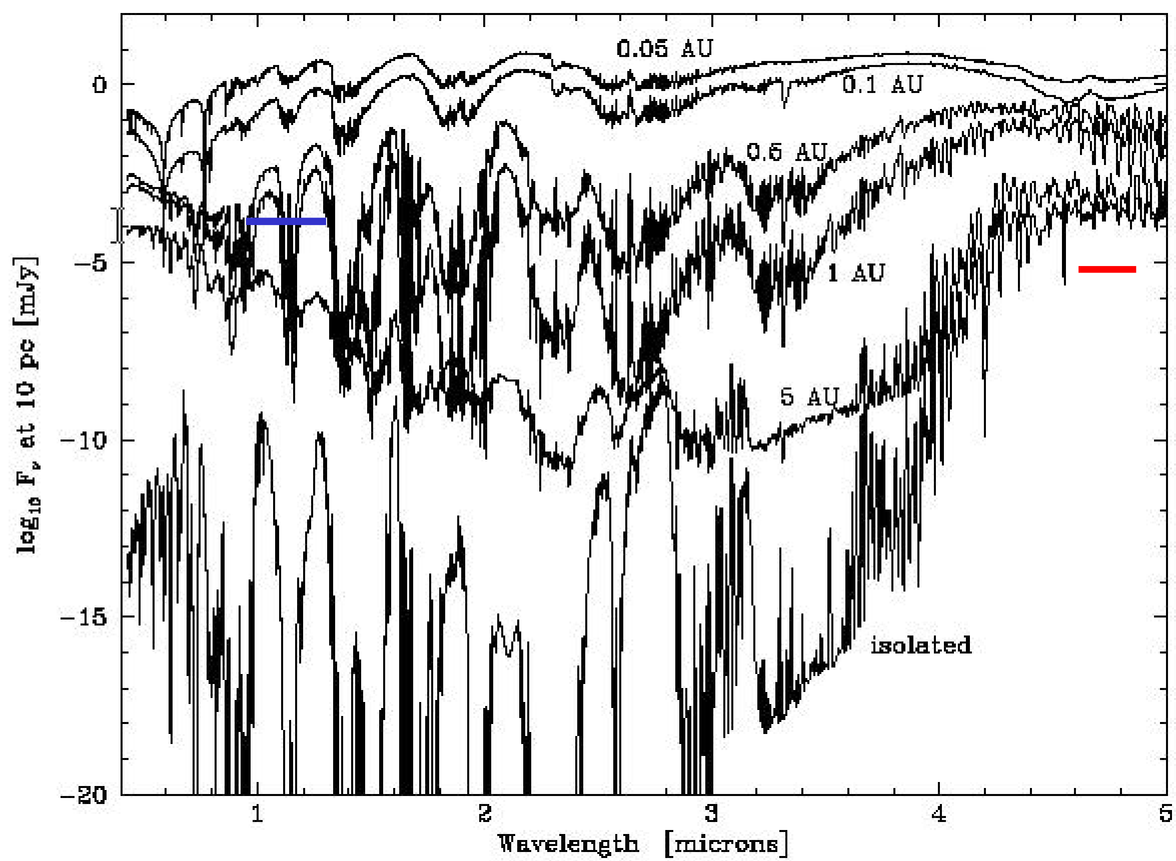
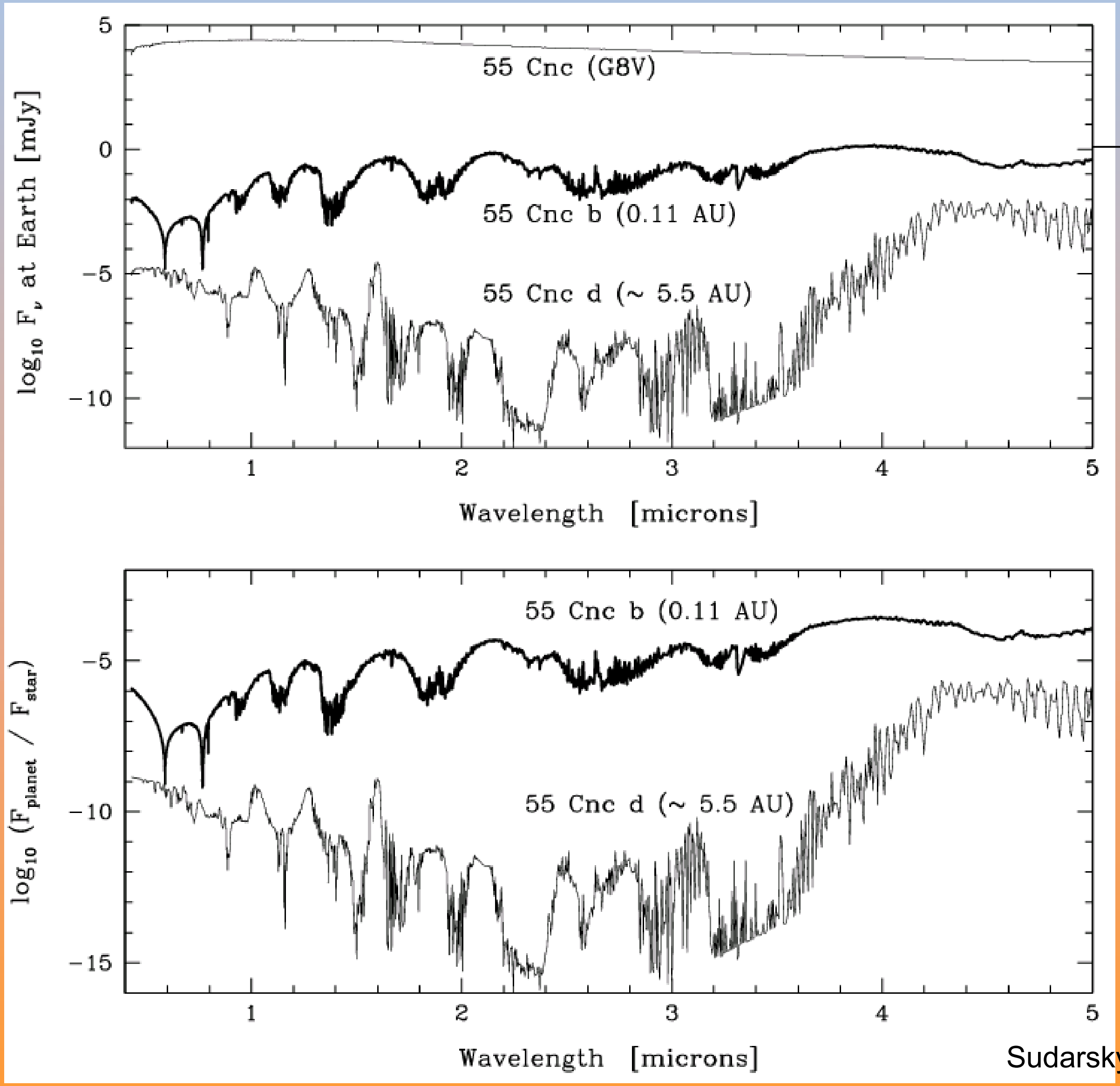


Fig. 13.— Cloud-free EGP emergent spectra as a function of orbital distance from a G0V primary. From top to bottom, the orbital distance is 0.05 AU, 0.1 AU, 0.5 AU, 1 AU, and 5 AU. Additionally, the bottom curve is that of an isolated EGP/brown dwarf. In all cases, the gravity is 3×10^3 cm s^{-2} and the lower boundary flux is set equal to that of an isolated object with $T_{eff} = 125$ 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

($M_p=4M_J$, $a_p=5.9AU$, $d=15pc$)



1 mJy

Flux

Planet/star flux contrast

Sudarsky et al. 2002

Near-IR Characterization of Exo-Jupiters

1.2 µm   R ~ 10   S/N = 25

Object Class	Integration Time	Contrast Ratio
Class I (~5 AU) 32nJy @ 1.2 µm	1.5 hours	$5x10^8$
Class II (~1.5 AU) 1nJy @ 1.2 µm	1,500 hours	$1.5x\ 10^{10}$
Class III (~0.5 AU) 100nJy @ 1.2 µm	0.17 hours	$1.5\ x10^6$

NB: Calculated times assume NO contribution from parent star

Near-IR Characterization of Exo-Jupiters

1.2 μm   R ~ 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 ~ 10 S/N = 25

Object Class	Integration Time GSMT R ~ 10	Contrast Ratio	Integration Time JWST R ~ 10
Class I (~5 AU) 300nJy @ 4.7 μm	3,000 hours	$2x10^7$	0.2 hrs
Class II (~1.5 AU) 1000nJy @ 4.7 μm	250 hours	$7x10^6$	0.03 hrs
Class III (~0.5 AU) 30000nJy @ 4.7 μm	0.3 hours	$2x10^5$	3 seconds

NB: Calculated times assume NO contribution from parent star

Mid-IR Characterization of Exo-Jupiters

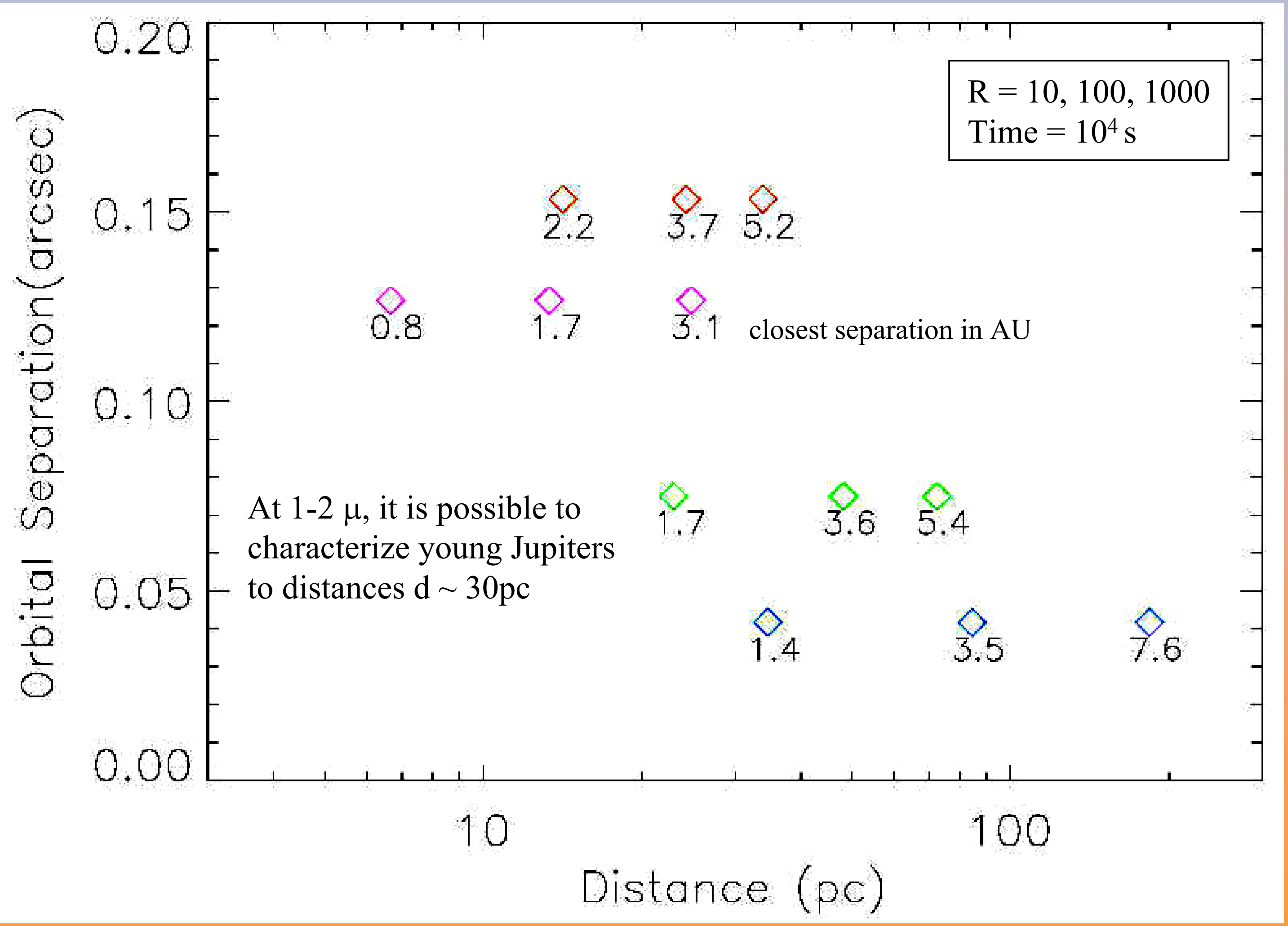
4.7 μm R ~ 200 S/N = 25

Object Class	Integration Time GSMT R ~ 200	Contrast Ratio	Integration Time JWST R ~ 1000
Class I (~5 AU) 300nJy @ 4.7 μm	20,000 hours	$2x10^7$	80 hrs
Class II (~1.5 AU) 1000nJy @ 4.7 μm	2,000 hours	$7x10^6$	10 hrs
Class III (~0.5 AU) 30000nJy @ 4.7 μm	2 hours	$2x10^5$	0.1 hrs

NB: Calculated times assume NO contribution from parent star

Summary of EGP Detection Limits

Limiting Distance and Orbital Separation
$1\ M_J$ 100 Myr



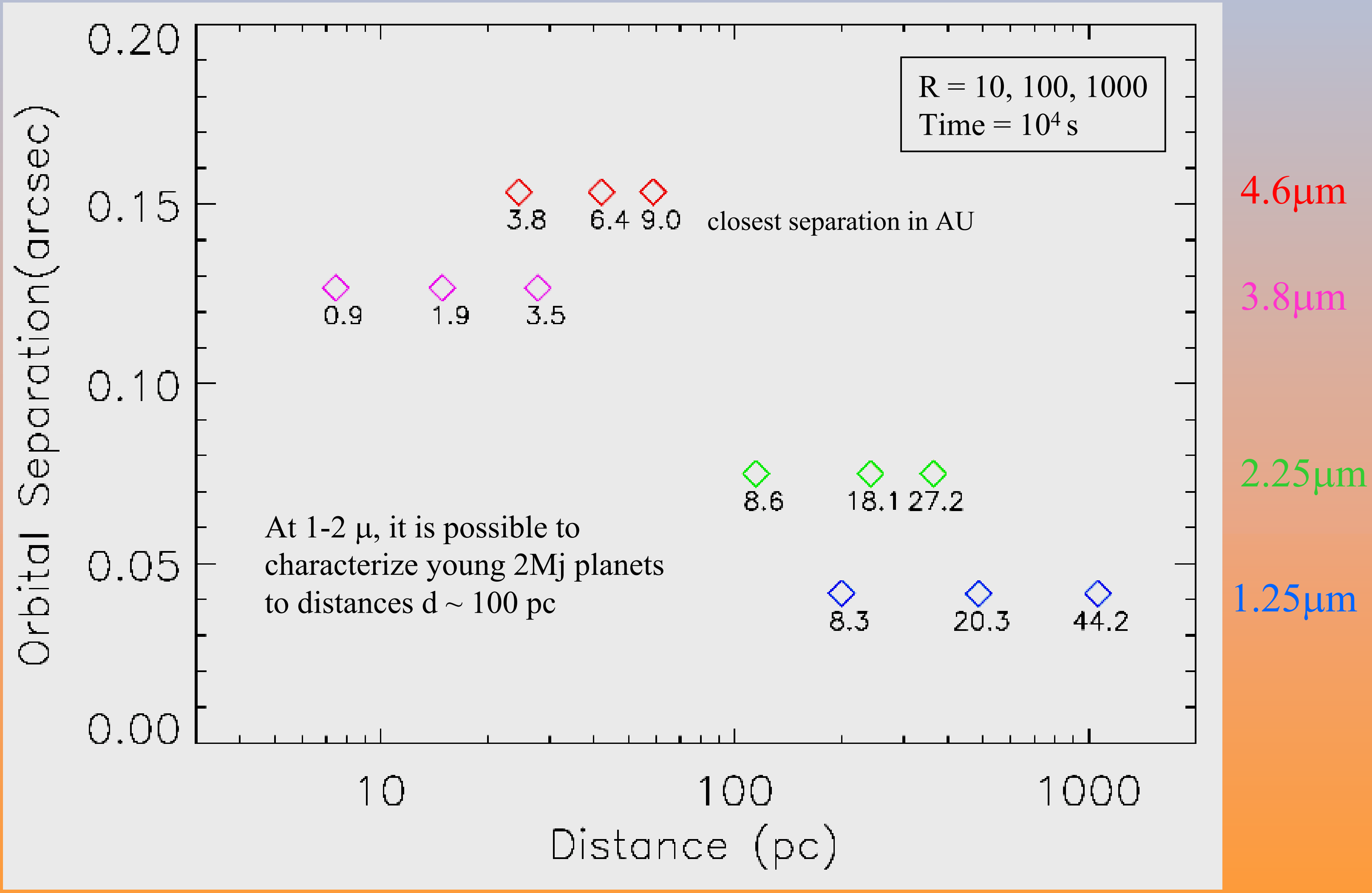
4.6μm

3.8μm

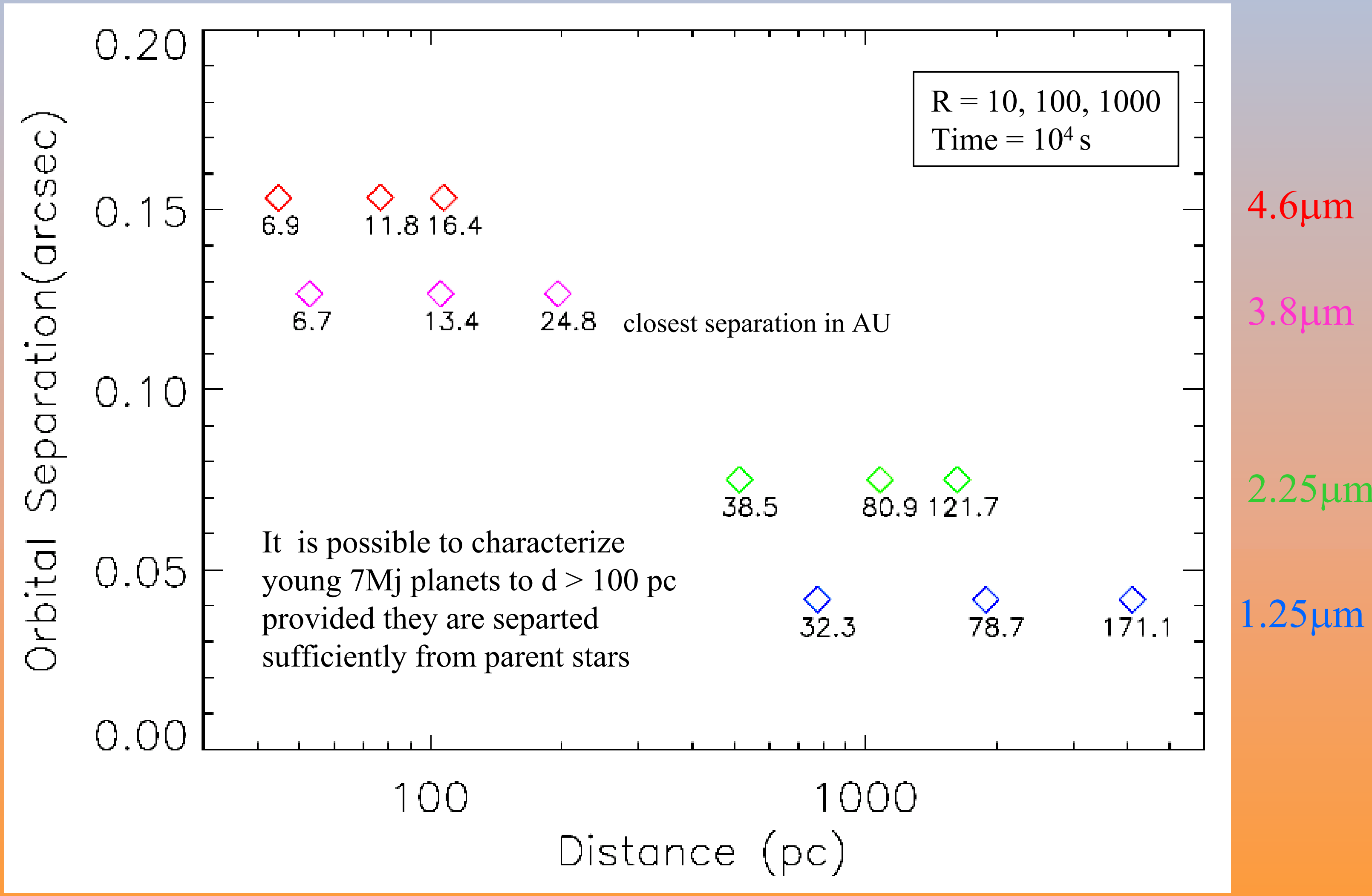
2.25μm

1.25μm

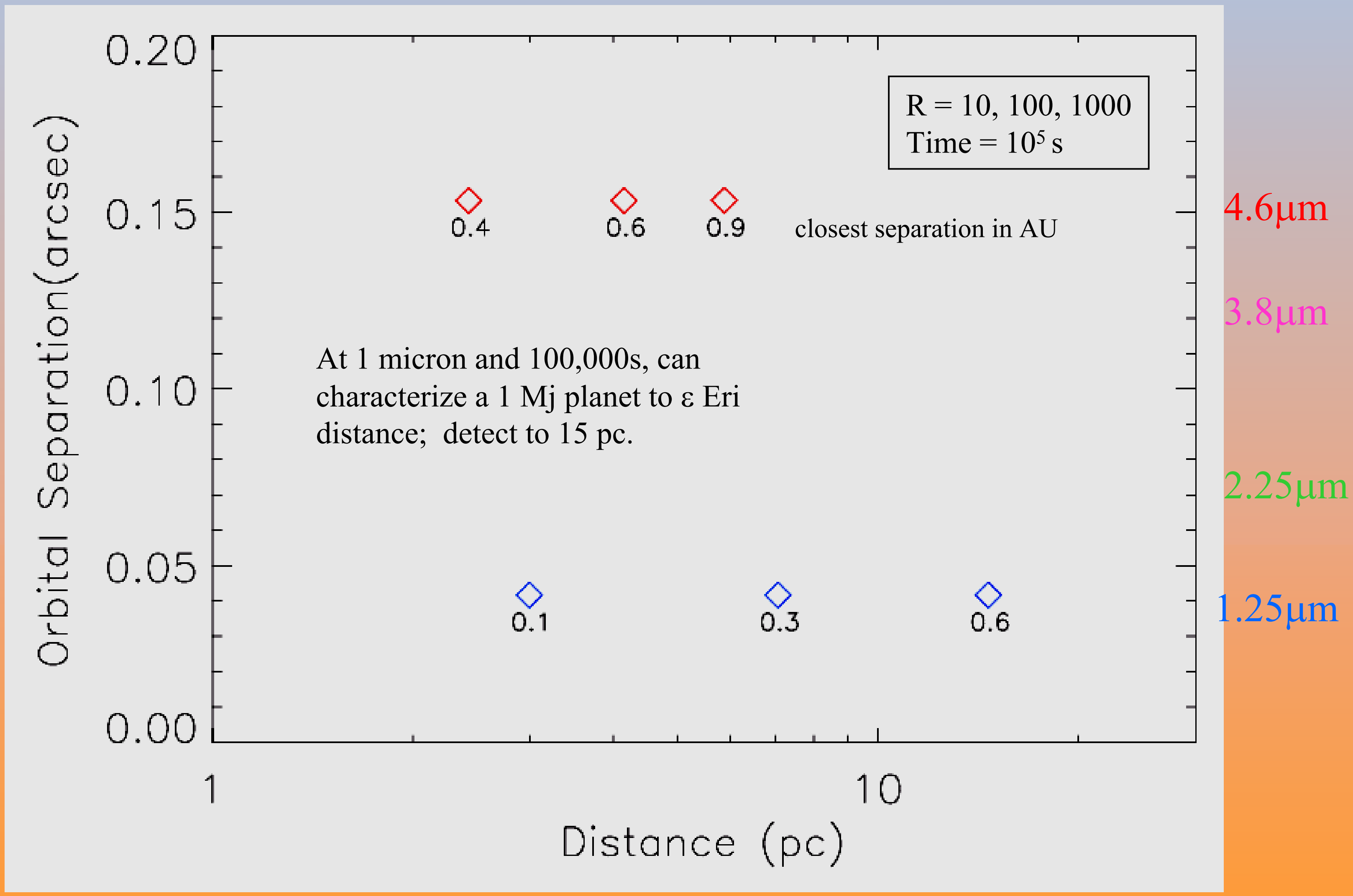
Limiting Distance and Orbital Separation
2 M_J 100 Myr



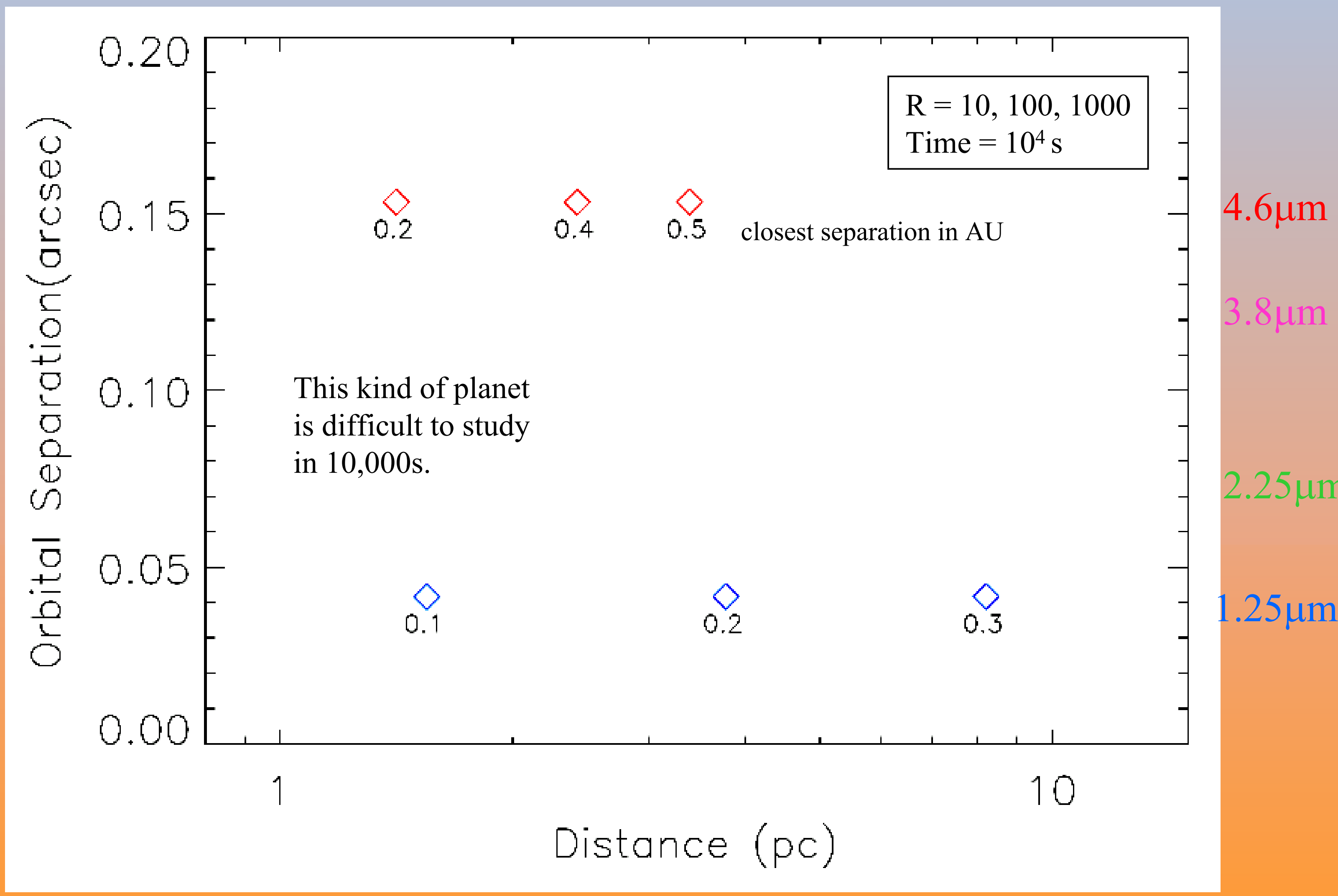
Limiting Distance and Orbital Separation
7 M_J 100 Myr



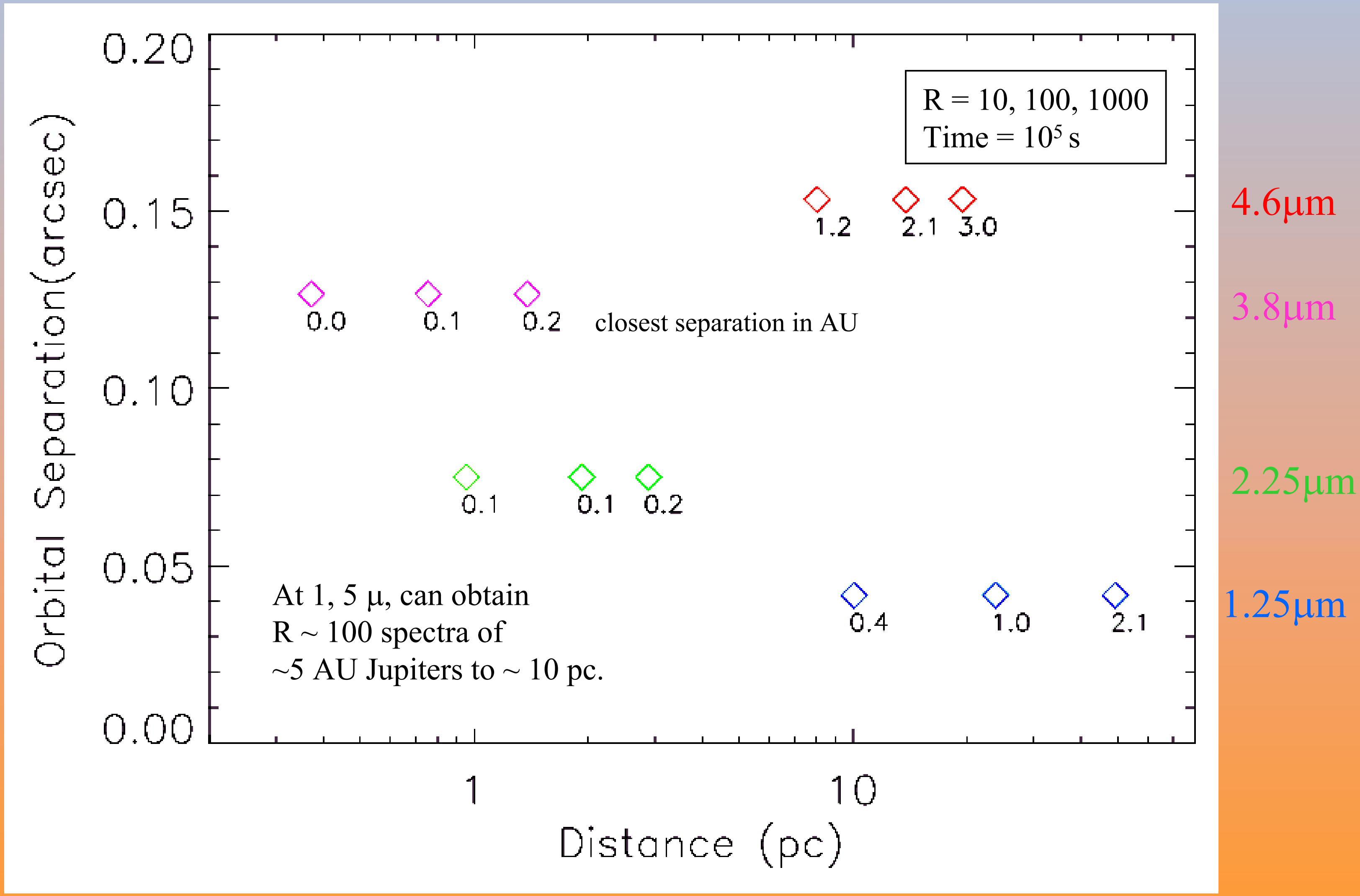
Limiting Distance and Orbital Separation
1 M_j Water Planet (a ~ 1 AU)



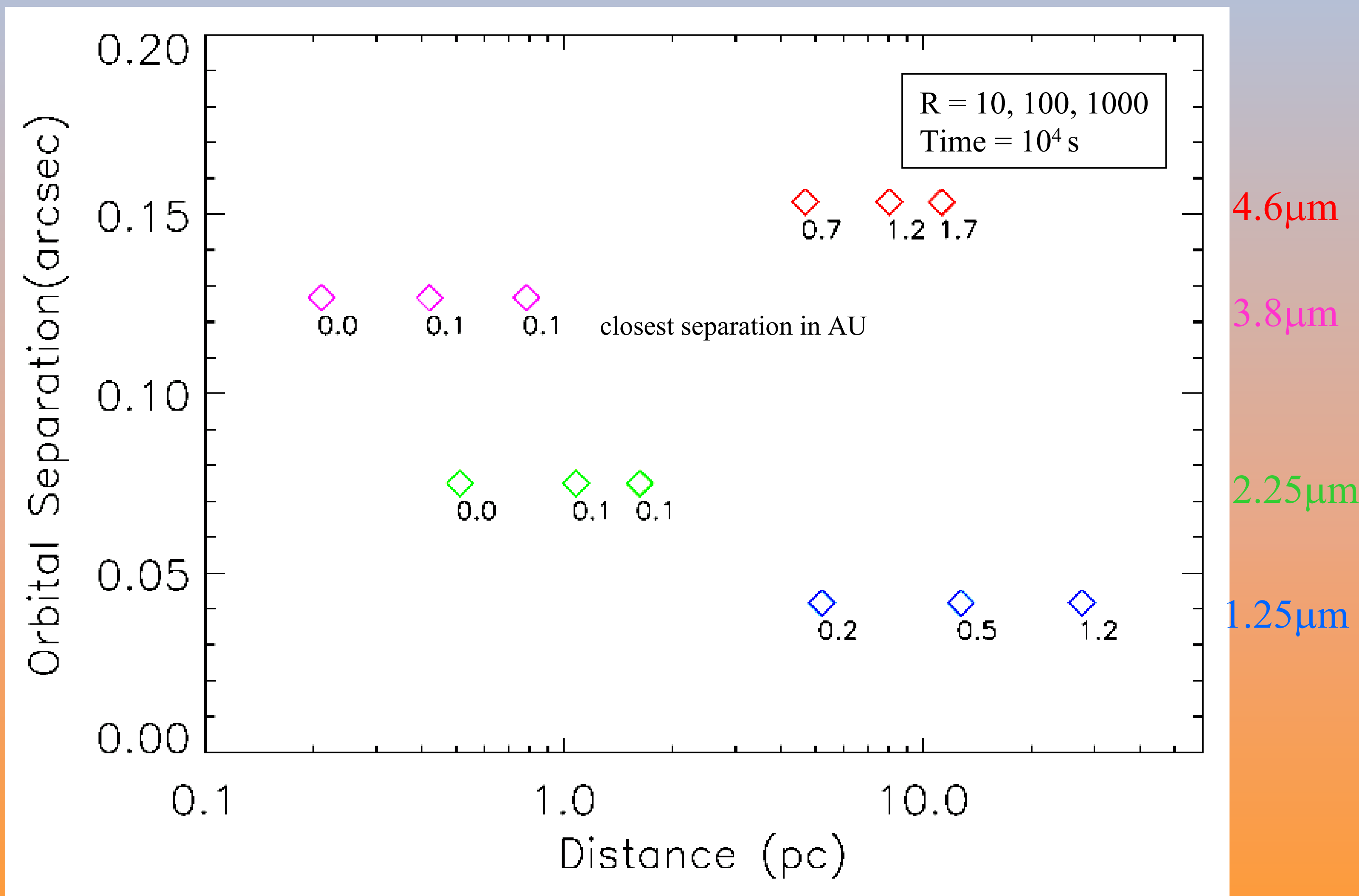
Limiting Distance and Orbital Separation
1M_j Water Planet (a ~ 1 AU)



Limiting Distance and Orbital Separation
55 Cnc d ($4M_j$ =5.9 AU)



Limiting Distance and Orbital Separation
55 Cnc d (a =5.9 AU)



Exo-Earths: Simple Examples

Exo-Earth Characterized via Scattered Light

1.2 μm   R ~ 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	$2x10^9$	0.01 hours

NB: Calculated times assume NO contribution from parent star

Exo-Earth Characterized via Scattered Light

1.2 μm   R ~ 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	$2x10^{9}$	0.15 hours

NB: Calculated times assume NO contribution from parent star

Exo-Earth Characterized via Thermal Emission

4.7 μm R ~ 10 S/N = 25 Distance = 1 AU

Temperature	Integration Time 30m GSMT	Contrast Ratio	Integration Time 100m OWL
500 K (Warm Earth) (1.3μJy @ 4.7 μm)	150 hours	$5x10^6$	1 hour
300K (29nJy @ 4.7 μm)	$3x10^5$ hours	$2x10^8$	2500 hours

NB: Calculated times assume NO contribution from parent star

Exo-Earth Characterized via Thermal Emission

4.7 μm R ~ 200 S/N = 25 Distance = 1 AU

Temperature	Integration Time 30m GSMT	Contrast Ratio	Integration Time 100m OWL
500 K (Warm Earth) (1.3μJy @ 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 can:
  - Detect; classify; analyze young (t < 100 Myr) EGPs to ~ 30pc
    - Young EGPs more massive than 1 Mj can be seen to TW Hya distance
    - Observations can constrain origin scenarios
  - Detect & classify old EGPs in the solar neighborhood (d < 10pc)
  - Detect earth-radius planets to distances of several pc
    - Star rejections ~ 10^9 needed

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