Characterizing Exoplanets and Brown Dwarfs With JWST

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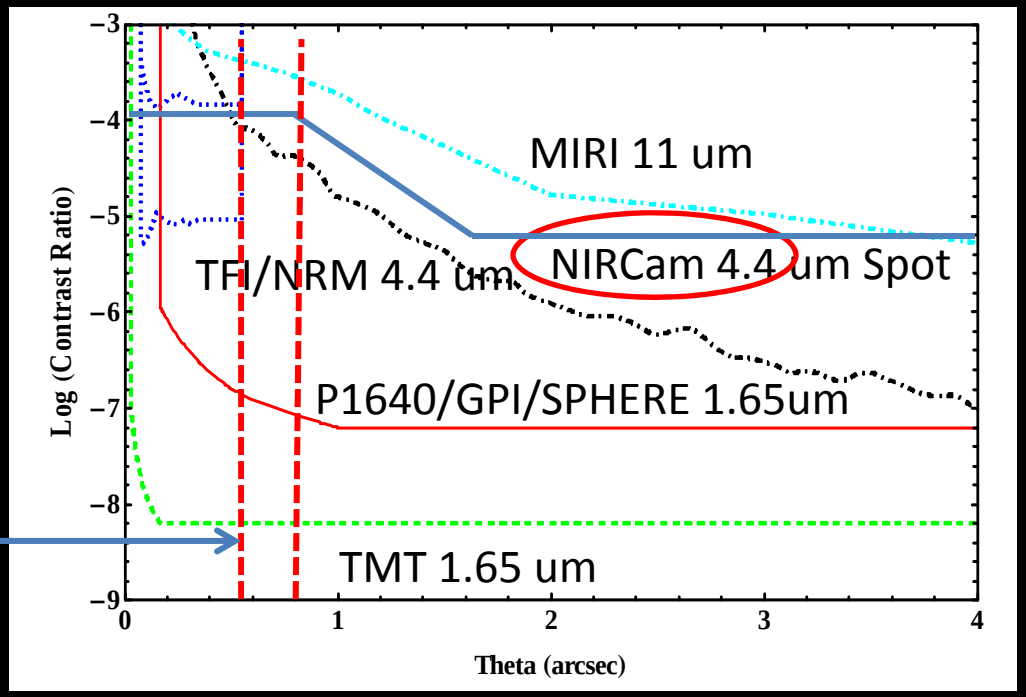
Major Themes for Exoplanets

1. Coronagraphic Imaging of Young Planets (CAB)
   - Determine atmospheric composition and physical properties to understand formation mechanism of exterior planets
   - Extend to lower mass limits compared to ground based observations
2. Spectroscopy of Young Planets (Hodapp)
   - Determine atmospheric composition and physical properties to understand formation mechanism of exterior planets
3. Survey nearby young M stars (Meyer, Schleider)
   - Provide census of Jovian mass planets at few 10s of AU
4. Coronagraphic Imaging of Debris Disks (Gaspar)
   - Assess composition and structure of disks, e.g. H2O and other ices
   - Search for planets shepherding or sculpting disks
5. Transit Spectroscopy of Mature Planets (Greene)
   - Determine atmospheric composition and physical properties to understand formation mechanism of interior planets
6. Observations of Brown Dwarfs (Roelling)
   - Understand atmospheres of cool, low mass brown dwarfs as analogs for Jovian mass exoplanets

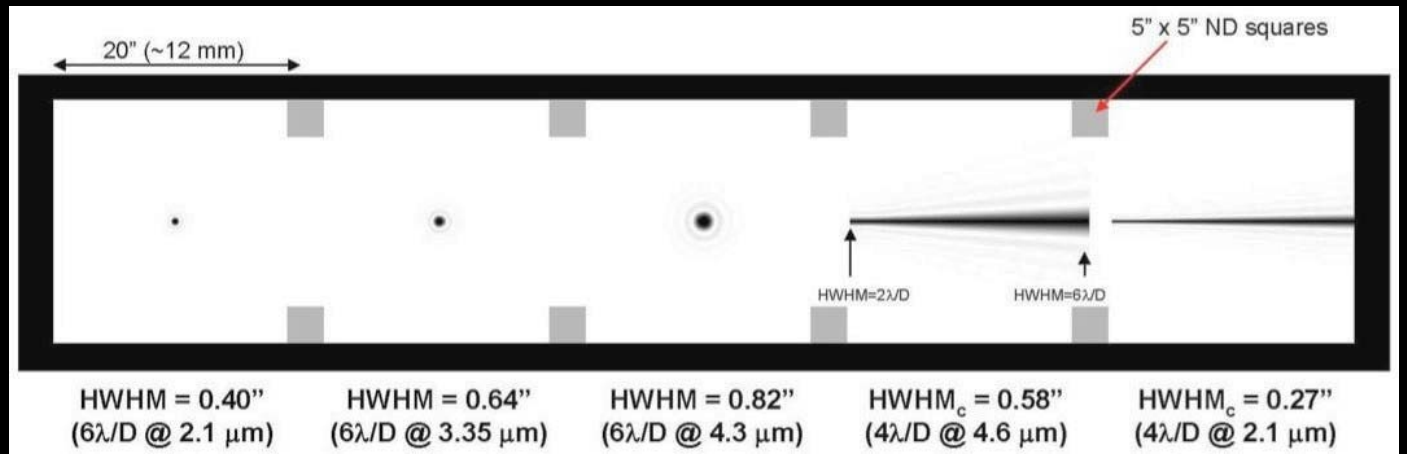
CORONAGRAPHIC IMAGING OF KNOWN PLANETARY SYSTEMS

JWST Coronagraph More Sensitive Than Ground at 3-15 um



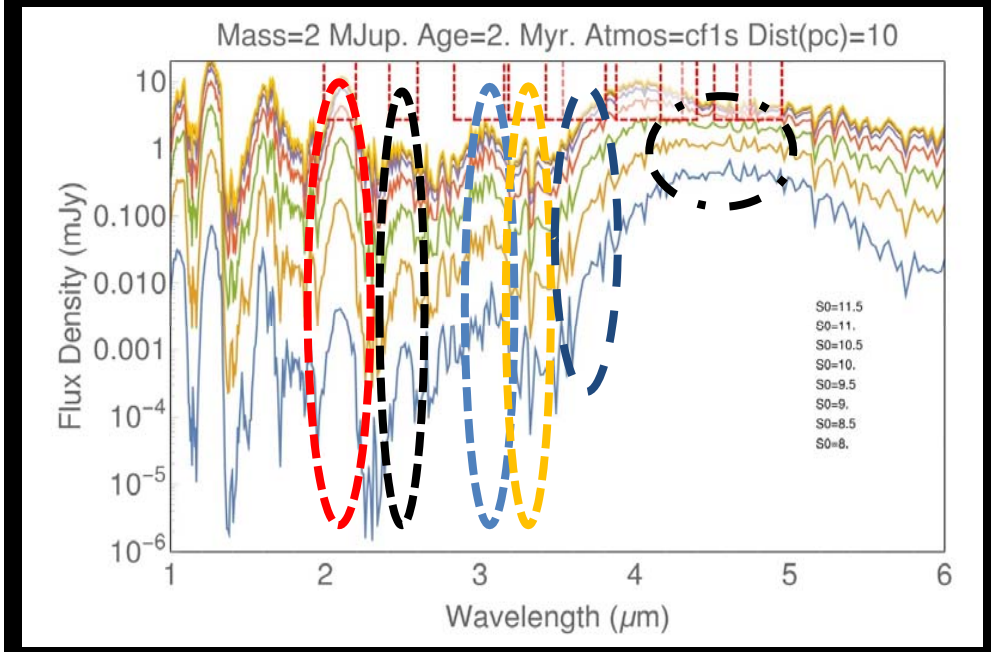
Keck Vector Vortex at L

5λ/D at 3.5 and 4.8 μm

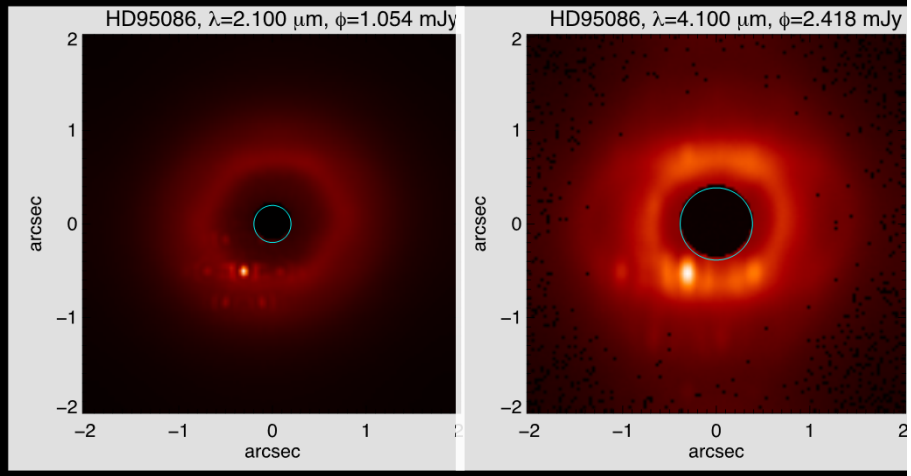


Coronagraphic Observations

- Observe ~5 known planetary systems with the NIRCam and MIRI coronagraphs to recover physical and atmospheric properties
- Search for lower mass planets down to ~0.1-0.3 MJup
- Select targets in angular separation range 0.4”-3”, masses<13 M_{jup}
- *Moonshot* planet searches toward Vega, beta Leo, eps Eri



Spiegel and Burrows 2012

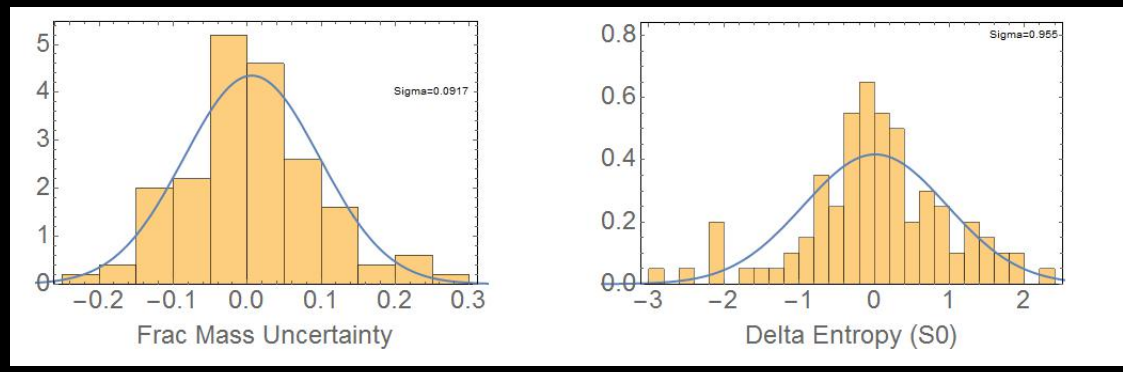


HD 95086

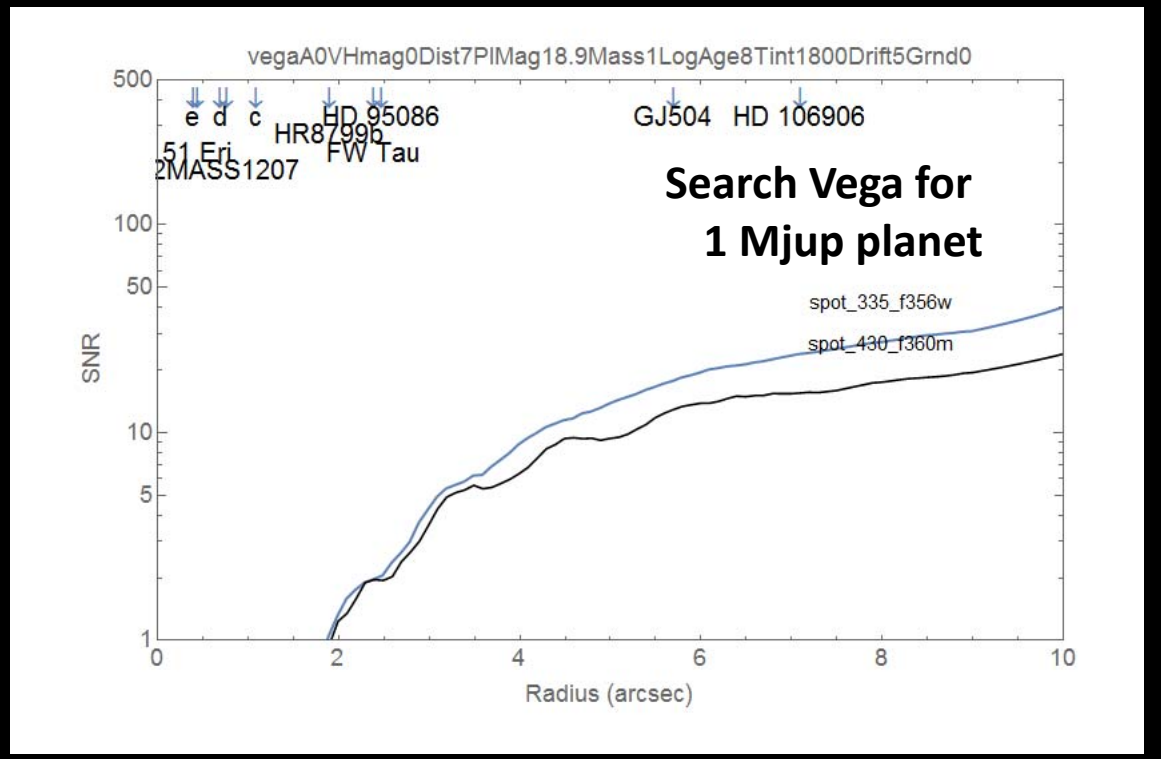
R = 0.6”, Δmag ≥ 9.2 (L’ 3.8 um)

Coronagraphic Observations

- Monte Carlo analysis over broad range of masses, ages, shows NIRCam (F250M, F300M, F335M, F430M) + MIRI (F1065C, F1140C, F1550C) yields masses, radii, entropy, etc to 10% for known planets.

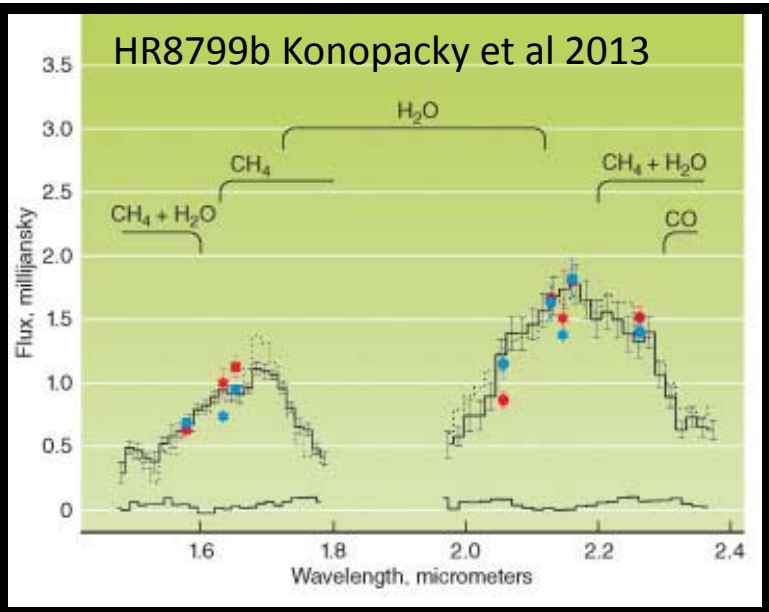


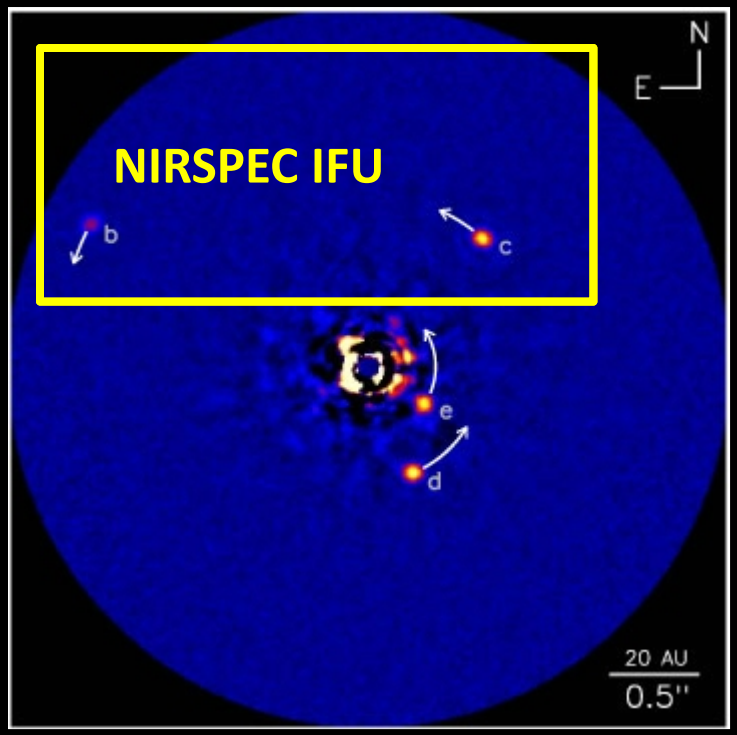
- Are systems like HR8799 the exception or rule?
- Use JWST's sensitivity to probe to lower masses outside of ~1-2" in F444W where planets brightest and F322W2 to reject stars & galaxies



Direct Spectroscopy of Exoplanets

- At separations >1” use the NIRSpec IFU to obtain R~1,000 spectrum of known planets
- At separations beyond 10” study planets directly at high resolution with NIRSpec and MIRI LRS/MRS





Potential Imaging and Spectroscopy Targets

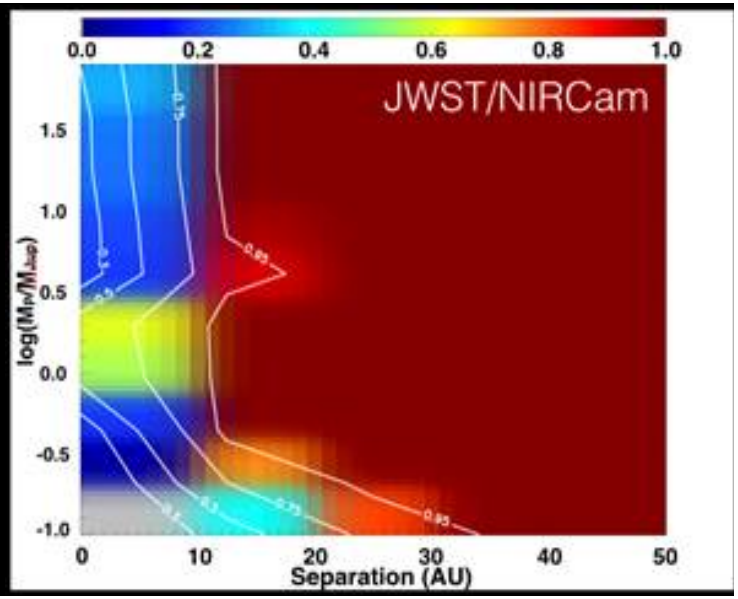
- Model masses <10 Mjup separation between 0.5” (>4 λ/D at 3.5 um) and 3-5” (direct spectroscopy becomes possible).
- Program is closely coordinated with European MIRI team

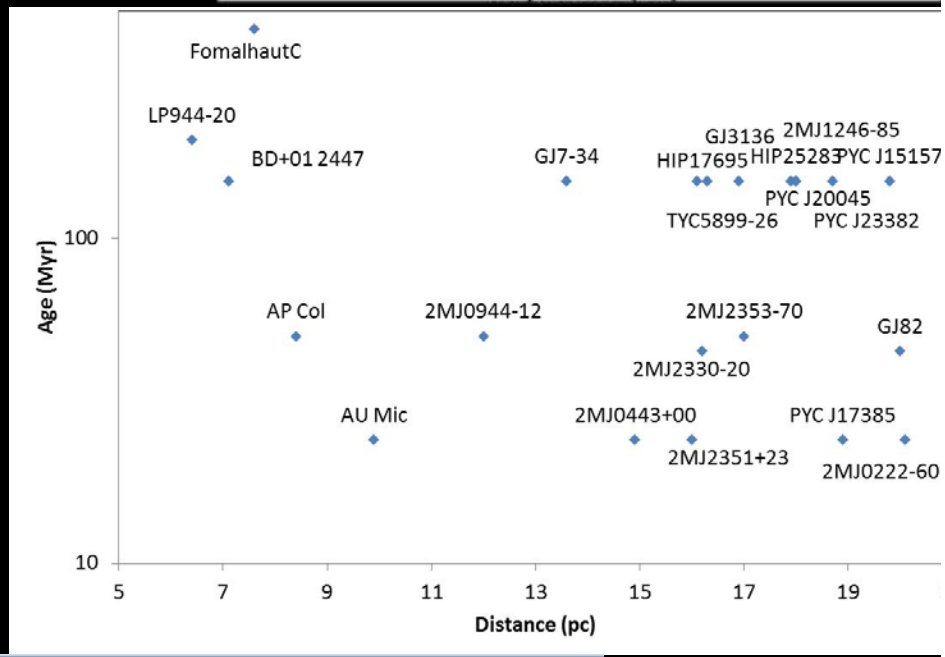
HostName	HostName	Mjup	Dist(pc)	st_spstr	Kmag	Angle(")	Age (My
51 Eri	51 Eri	2	29	F0IV	4.8	0.45	20.0
HR 8799d	HR 8799	10	40	F0V	5.2	0.60	50
HD 95086	HD 95086	5	92	A8 III	6.8	0.61	10~1
2MASS J1207	2MASS J120	4	52	M8	11.9	0.88	8.0
HR 8799c	HR 8799	10	40	F0V	5.2	0.95	50
ROXs 42 B	ROXs 42 B	11	135	M0	8.7	1.11	1-
HR 8799b	HR 8799	7	40	F0V	5.2	1.70	50
1RXS J160929.1-210524	1RXS J1609	8	145	K7 V	8.9	2.28	5-1
FW Tau	FW Tau	10	145	M4	9.4	2.28	2.0
DH Tau	DH Tau	11	140	M0.5	8.2	2.36	1.0
GJ 504	GJ 504	4	18	G0 V	4.0	2.42	160.0
HD 106906	HD 106906	11	92	F5 V	6.7	7.08	13.0
Fomalhaut	Fomalhaut	3	8	A3 V	0.9	14.95	400-50
GU Psc	GU Psc	11	48	M3	9.6	42.00	100.0
Gl 494/Ross458C	Ross458C	6	11	M0.5	5.6	102.19	<100
WD 0806-661	WD 0806-66	8	19	WD	13.8	130.21	2000.0

SURVEY OF NEARBY YOUNG M STARS

M Star Survey

- Kepler and microlensing suggest abundant small planets orbiting M stars
- NIRCam coronagraphy can reach Saturn - Uranus masses for <150 Myr planets within 15 pc.
  - With IWA of ~0.5" NIRCam will probe 10-20 AU which is near CO snow line favored for formation of ice giants
  - Survey ~10 objects at F322W2 (veto stars and galaxies) and F444W at 3.5 hr/object

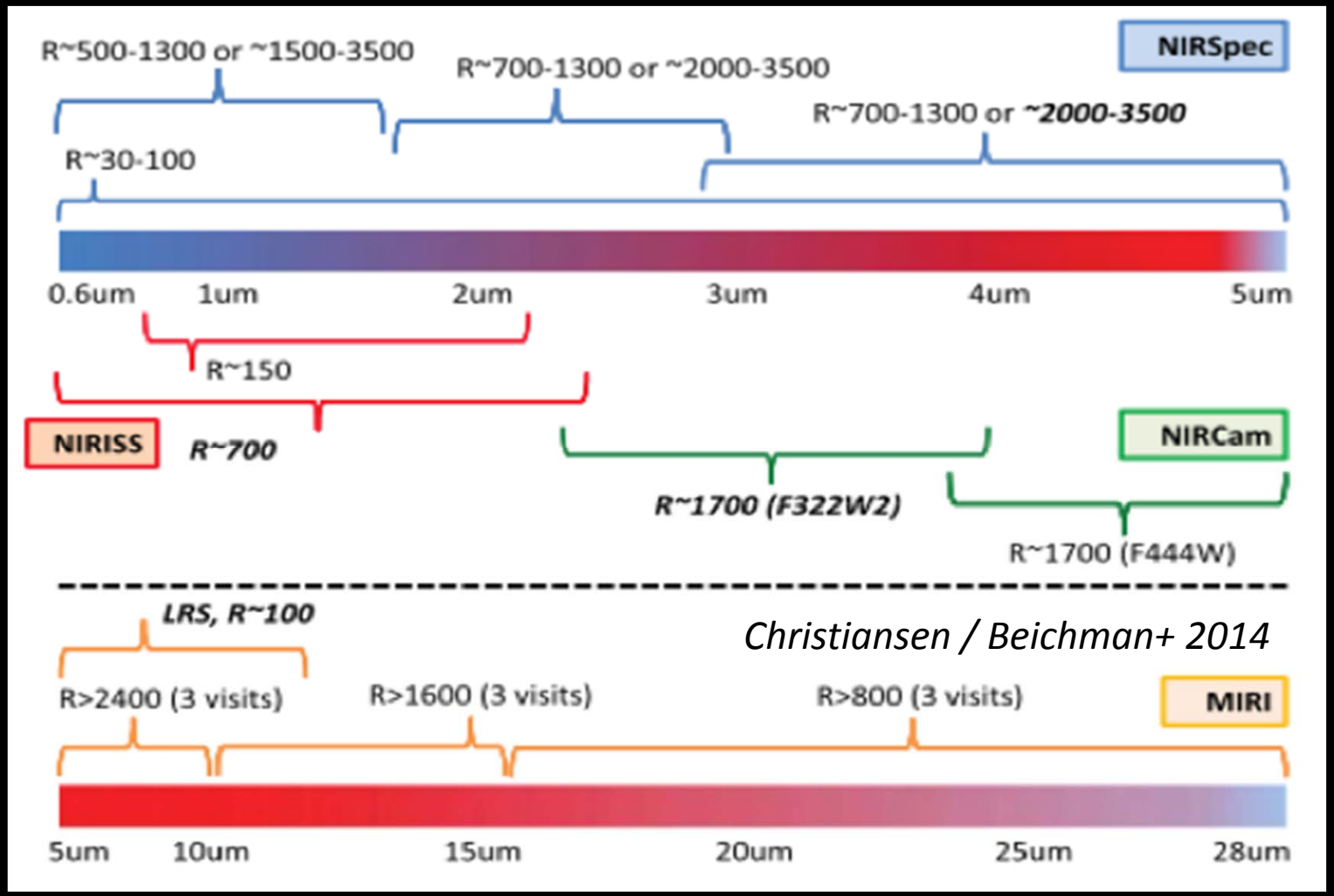




Dist (pc)	Med Spec Type	Min Age (Myr)	Med Age (Myr)	MaxAge (Myr)	WISE W2 (Mag)
16.25	M4	24	150	440	7.26

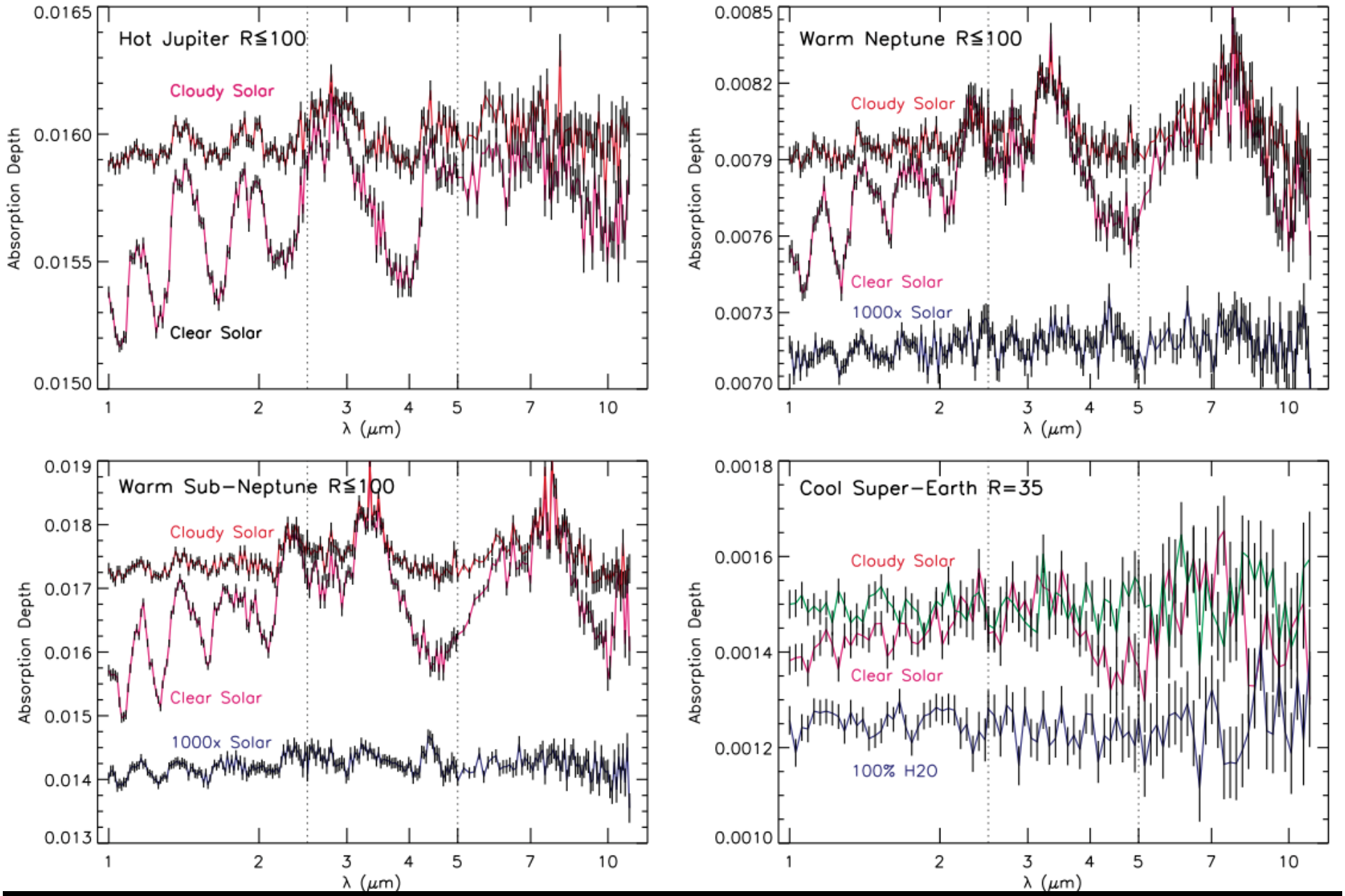
TRANSIT SPECTROSCOPY OF KNOWN PLANETARY SYSTEMS

The many JWST spectroscopic modes

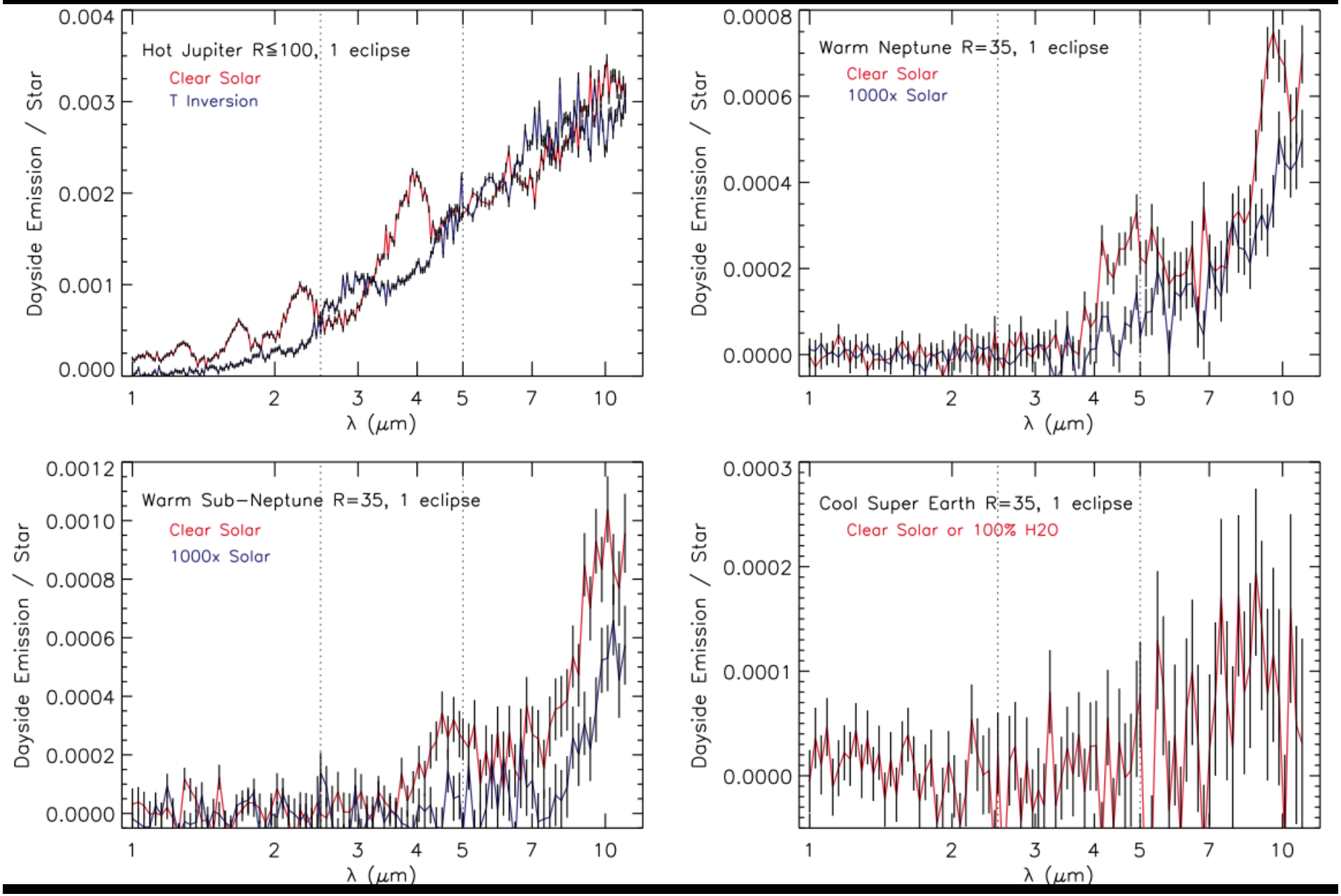


- Numerous modes for transits and direct (IFU) exoplanet spectroscopy
- Covering 0.6 – 12 μm requires 2 – 4 separate transits or eclipses

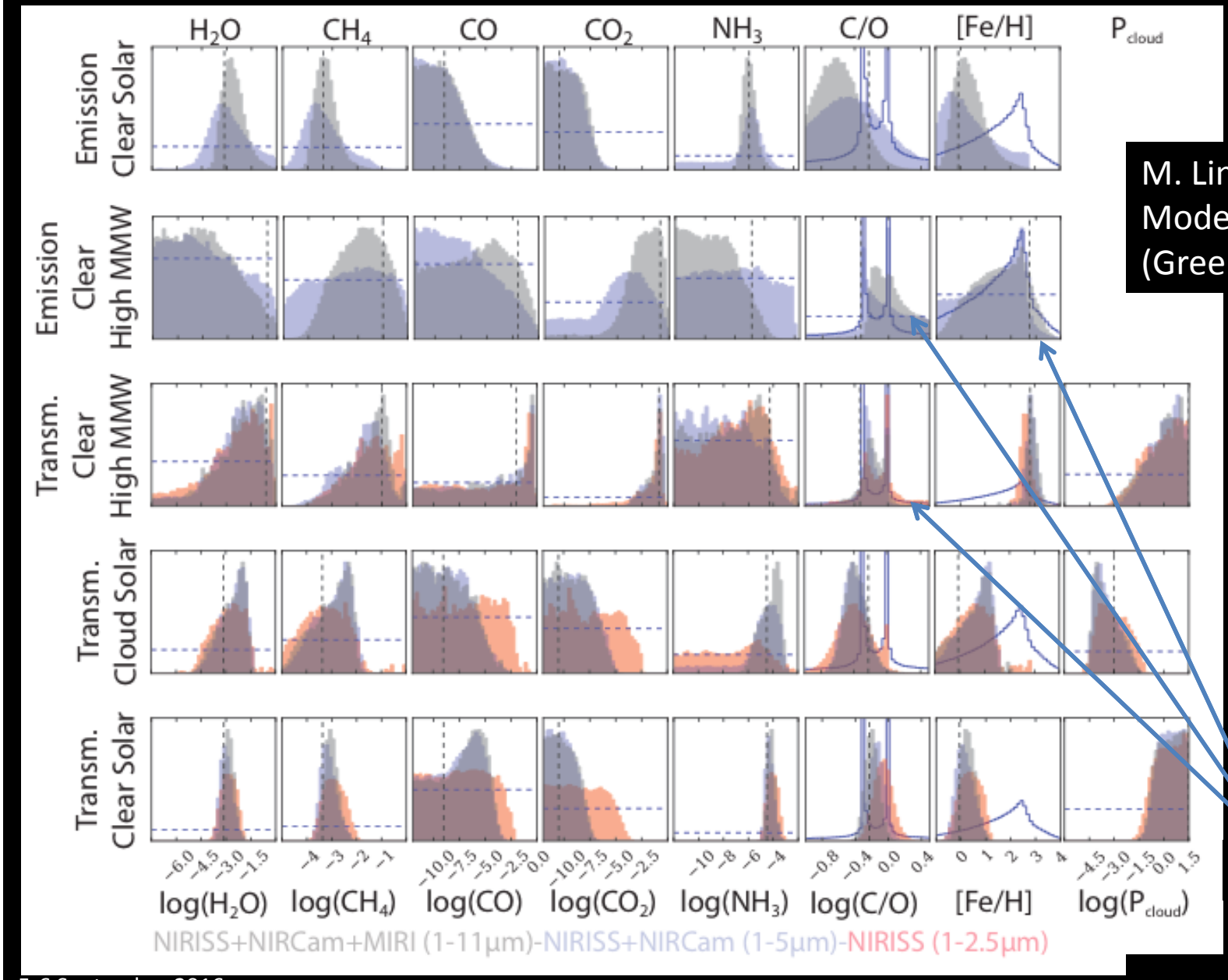
Simulated JWST Transmission Spectra (1 transit)



Simulated JWST Emission Spectra (1 eclipse)



Retrieval Results: Warm Neptune Gasses



M. Line CHIMERA Models & retrievals (Greene+ 2016)

Priors

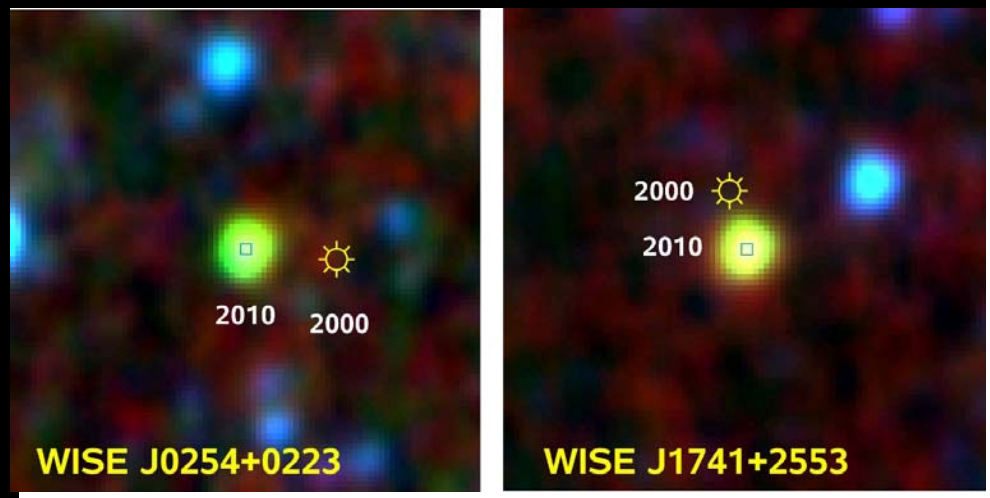
Illustrative NIRCam+MIRI Transit Program

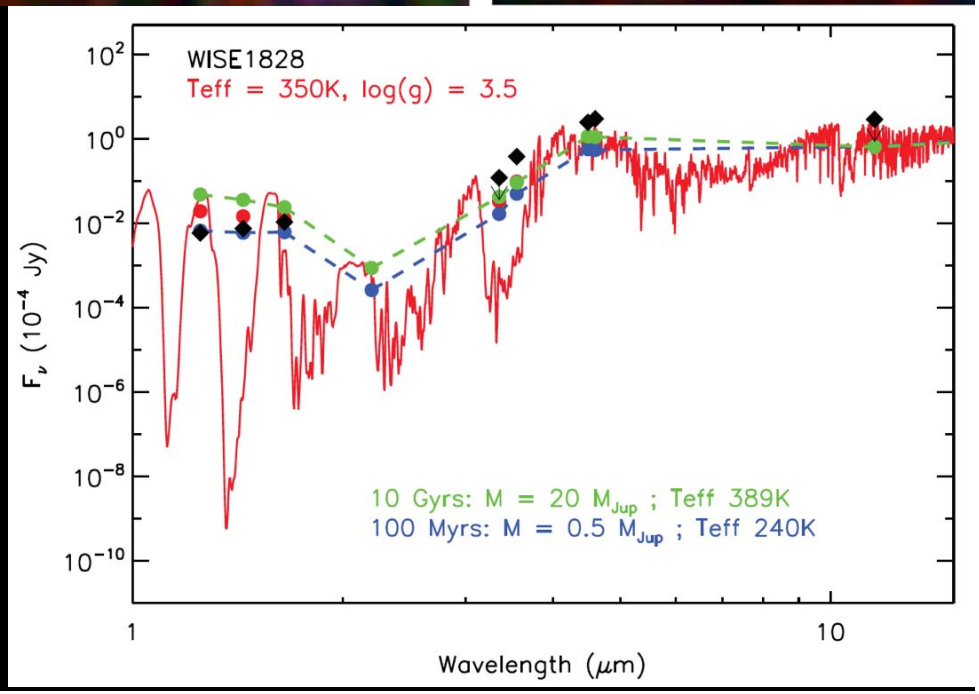
Name	K(mag)	T_{eq}(K)[a]	$R_p(R_\oplus)$	$M_p(M_\oplus)$	T_{14} (hr)	Geometry[b]	Visits	Mode	NCam T(hr)[c]	MIRI T(hr)[c]
HD 189733 b	5.5	1190	12.5	360	1.82	EMIS	1	NC F322W2	8.3	
HD 189733 b	5.5	1190	12.5	360	1.82	EMIS	1	NC F444W	8.3	
WASP-80 b	8.4	850	10.7	180	2.11	EMIS	1	NC F322W2	9.3	
WASP-80 b	8.4	850	10.7	180	2.11	EMIS	1	NC F444W	9.3	
WASP-80 b	8.4	850	10.7	180	2.11	EMIS	1	MIRI LRS		9.3
WASP-80 b	8.4	850	10.7	180	2.11	TRANS	1	NC F322W2	9.3	
WASP-80 b	8.4	850	10.7	180	2.11	TRANS	1	NC F444W	9.3	
WASP-80 b	8.4	850	10.7	180	2.11	TRANS	1	MIRI LRS		9.3
HAT-P-19b	10.5	1010	12.7	93	2.84	EMIS	1	NC F322W2	11.8	
HAT-P-19b	10.5	1010	12.7	93	2.84	EMIS	1	MIRI LRS	11.8	
HAT-P-19b	10.5	1010	12.7	93	2.84	EMIS	1	NC F322W2		11.8
GJ 436 b	6.1	700	4.2	22	0.76	EMIS	3	NC F322W2	13.8	
GJ 436 b	6.1	700	4.2	22	0.76	EMIS	3	NC F444W	13.8	
GJ 436 b	6.1	700	4.2	22	0.76	EMIS	3	MIRI LRS		13.8
HAT-P-26 b	9.6	1000	6.2	19	2.46	TRANS	1	NC F322W2	10.5	
HAT-P-26 b	9.6	1000	6.2	19	2.46	TRANS	1	NC F444W	10.5	
HAT-P-26 b	9.6	1000	6.2	19	2.46	TRANS	1	MIRI LRS		10.5
GJ 3470 b	8.0	700	4.1	14	1.92	TRANS	1	NC F322W2	8.6	
GJ 3470 b	8.0	700	4.1	14	1.92	TRANS	1	NC F444W	8.6	
GJ 1214 b	8.8	600	2.6	6.5	0.88	TRANS	2	NC F322W2	9.9	
GJ 1214 b	8.8	600	2.6	6.5	0.88	TRANS	2	NC F444W	9.9	
GJ 1214 b	8.8	600	2.6	6.5	0.88	TRANS	2	MIRI LRS		9.9
TOTAL									162	64.6

OBSERVING COOL BROWN DWARFS AS EXOPLANET ANALOGS

Y dwarfs As Exoplanet Analogs Or Low Mass End of IMF?

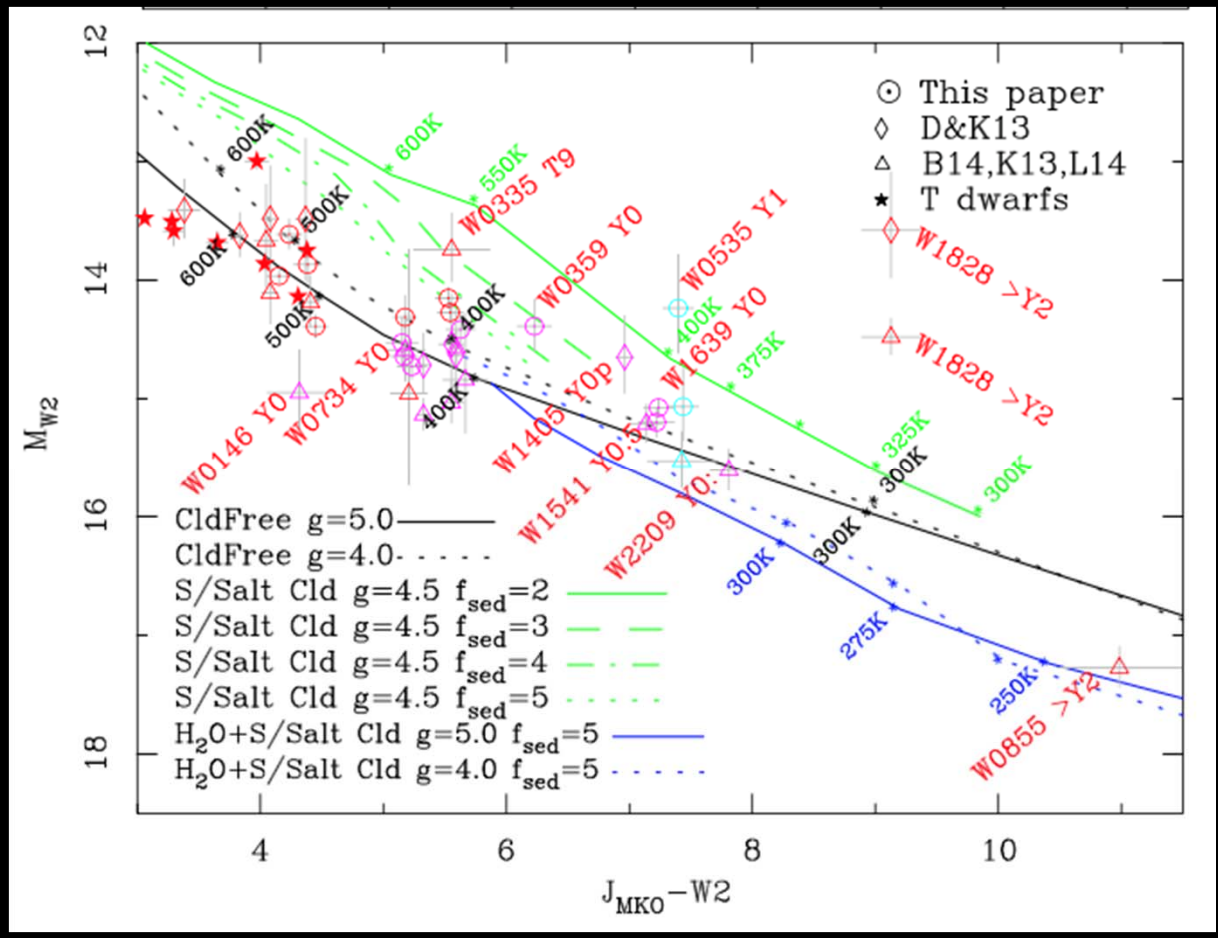
- 24 known WISE Y dwarfs have 750< T_{eff}<500 K, 5-10 M_{jup}
- Formation in quiescent dense cores or ejected from disks of more massive stars
- Valuable for modeling of exoplanet atmospheres





NIRCam, MIRI, NIRSpec Program for Y Dwarfs

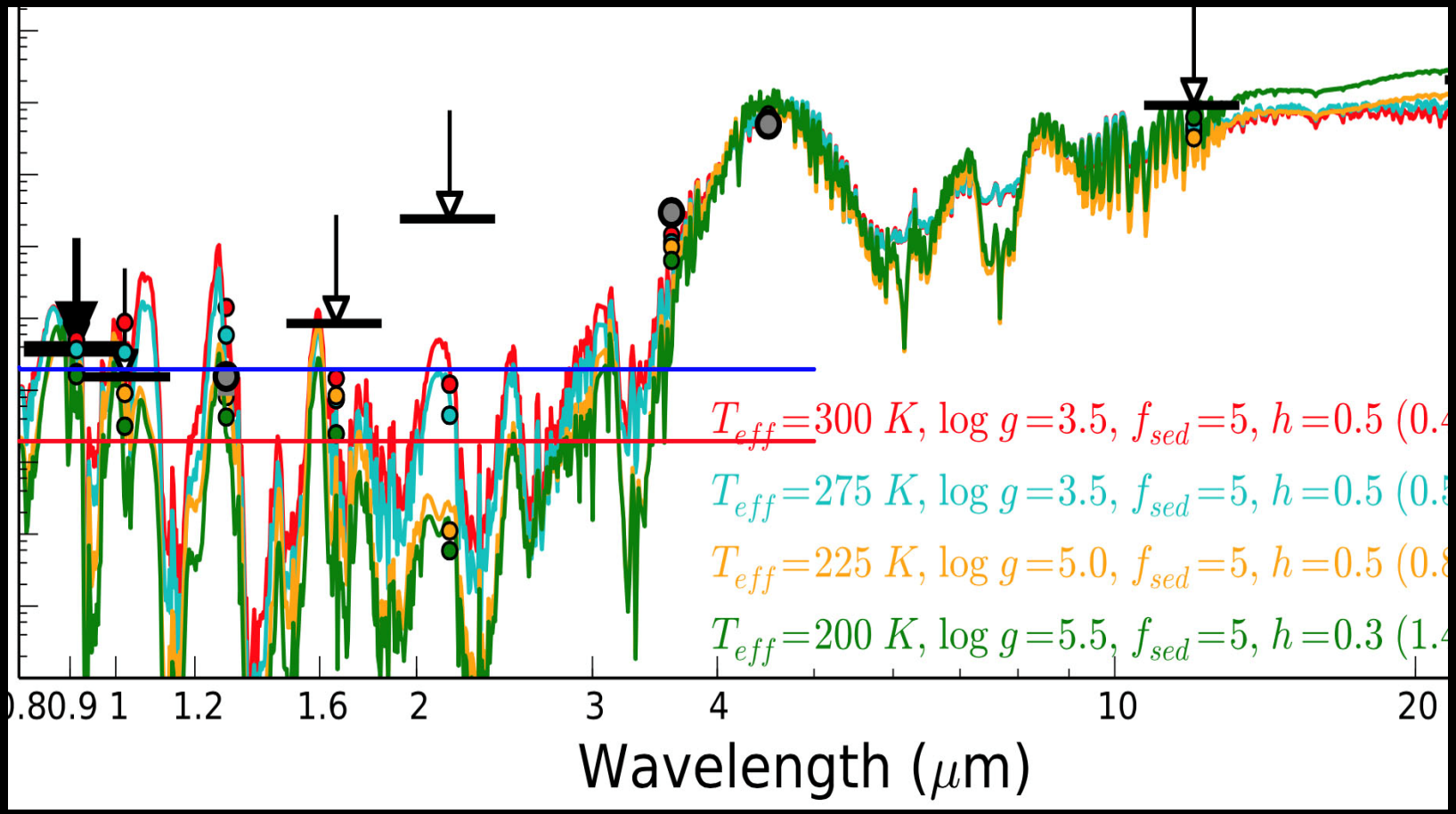
- Select 10 targets selected for being the closest, or coldest, in binary systems, rapid rotators
- NIRCam & MIRI photometry to for SED →Teff and luminosity



- NIRSpec and MIRI spectra to characterize late T and Y
- NIRISS/NRM Imaging to search for lower mass companions at few AU separation

WISE J0855-07

- Faint WISE object with a high proper motion (8.1”/yr)
- Coldest (~250K) & nearest (2.2 pc) Y-dwarf, 3-10 M_{jup}
- Water clouds ***may*** be needed to make sense of SED



Conclusions

- NIRCam in conjunction with instrument teams and other GTOs will carry out detailed program of exoplanets science
- Goal is to do a small number of objects well taking full advantage of JWST's multi-wavelength capabilities
- There will lots of room for many other investigations in all aspects of exoplanet research