BLAZING THE TRAIL:
RESOLVING TERRESTRIAL PLANETS WITH ELTS?

Michael R. Meyer
Institute for Astronomy
Department of Physics

Silvan Hunziker
Christophe Lovis (Geneva)
Sascha Quanz
Hans Martin Schmid
Ignas Snellen (Leiden)
Stephane Udry (Geneva)
and many others…

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

#PathwaysII
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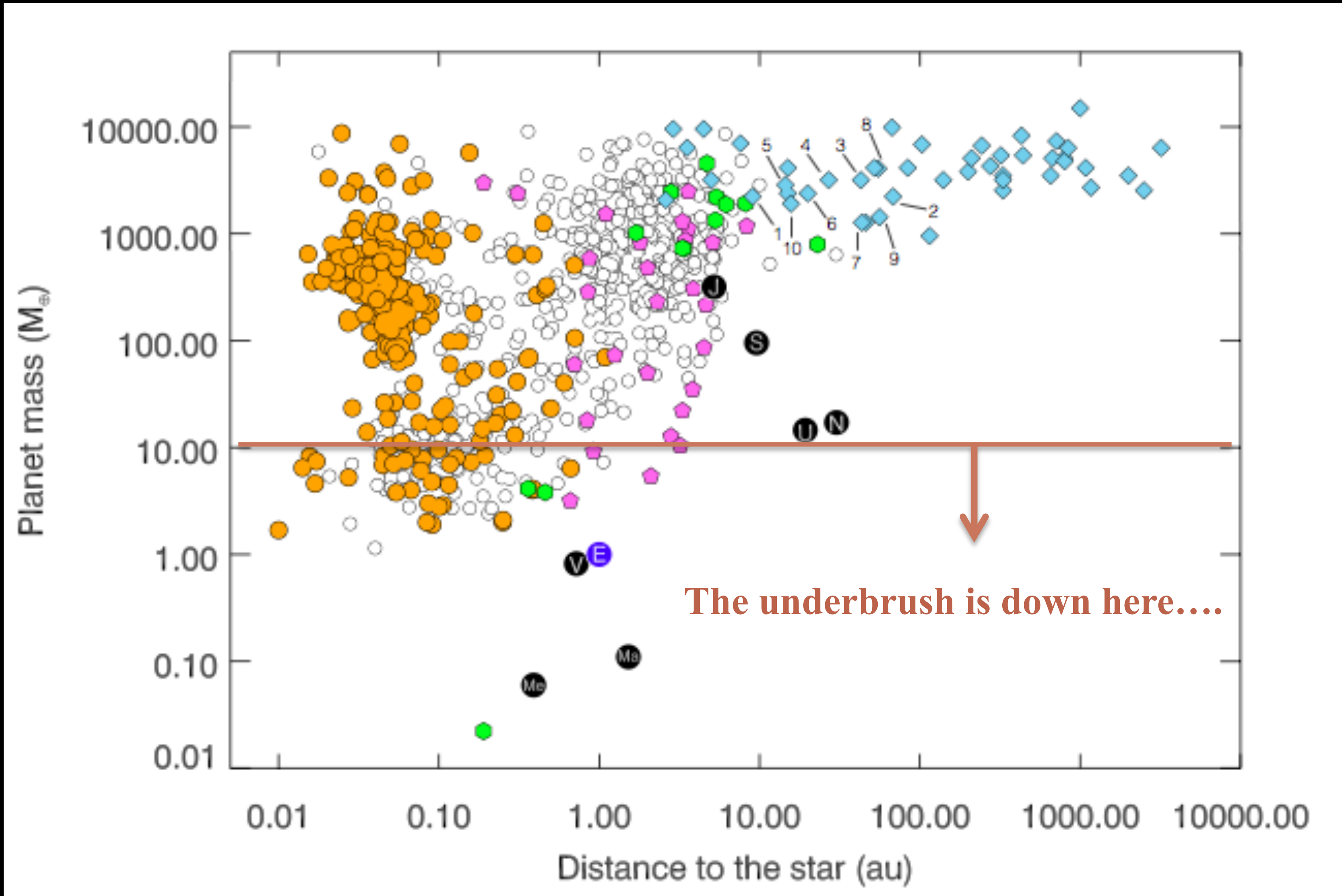
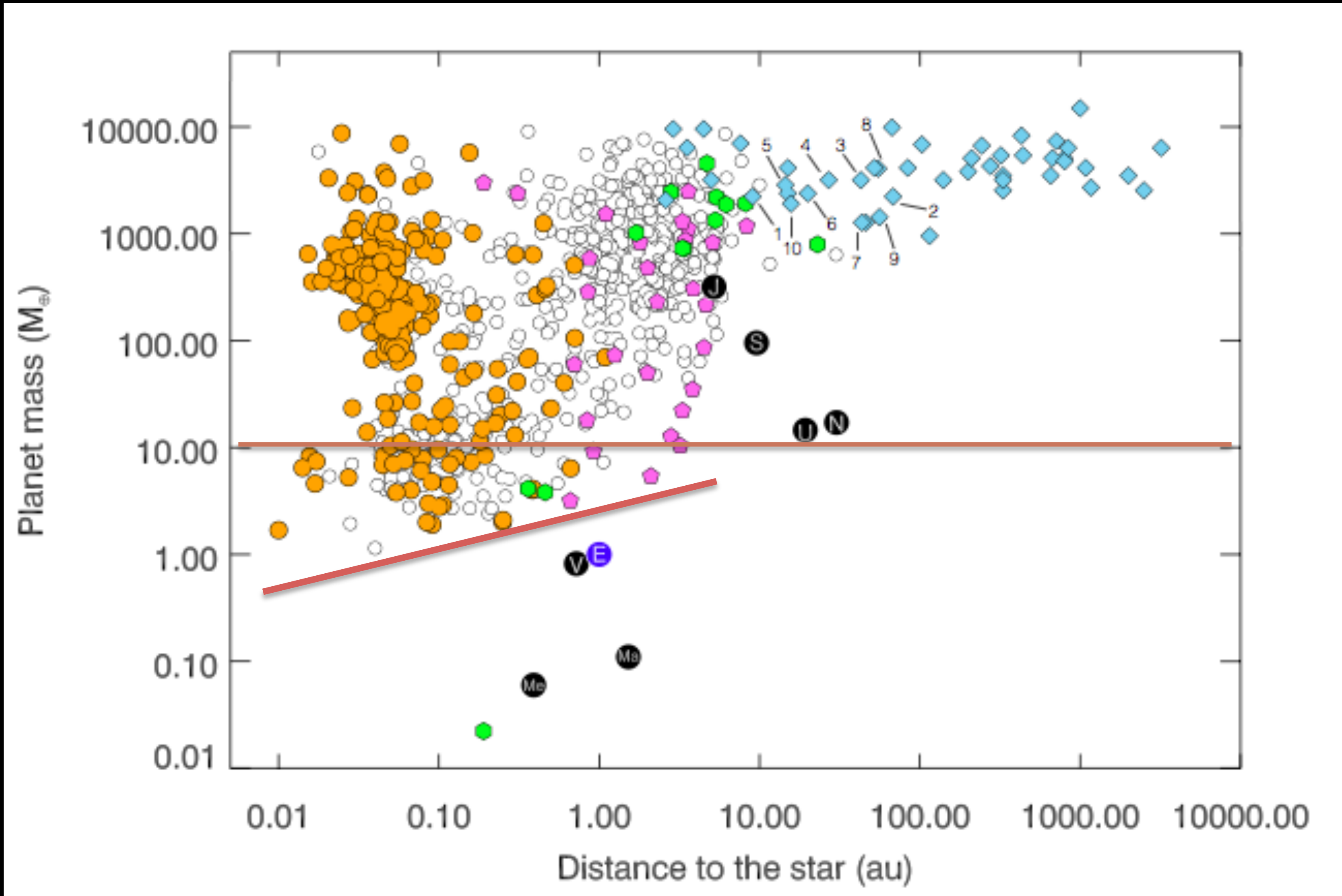
PlanetS
National Centre of Competence in Research

The trail thusfar…



Pepe, Ehrenreich, & Meyer, 2014, Nature, V513, 358

Notching planets with 1 m/s RV…

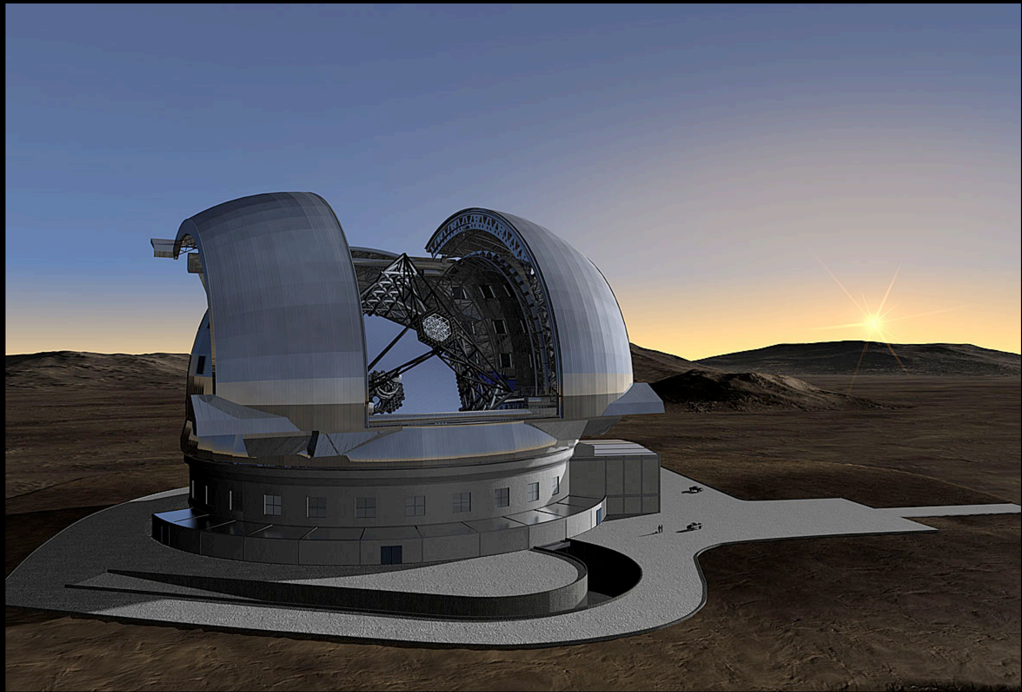


Pepe, Ehrenreich, & Meyer, 2014, Nature, V513, 358

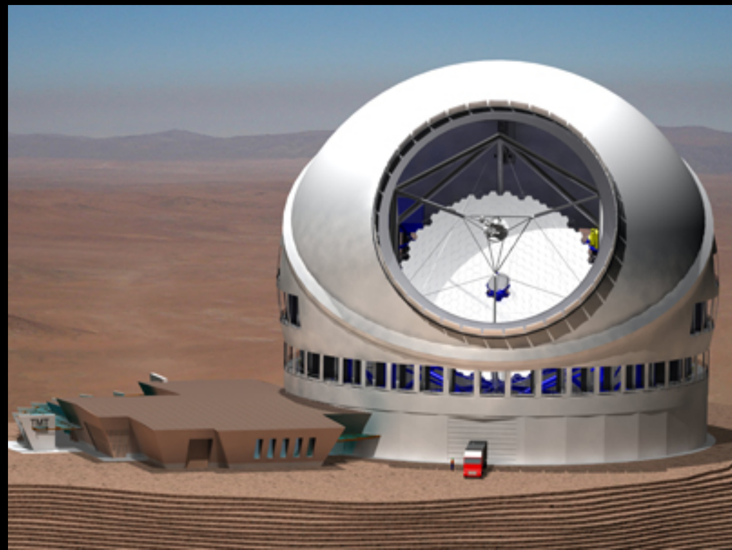
PRECISION RV (< 1 m/s) CURRENT/PLANNED

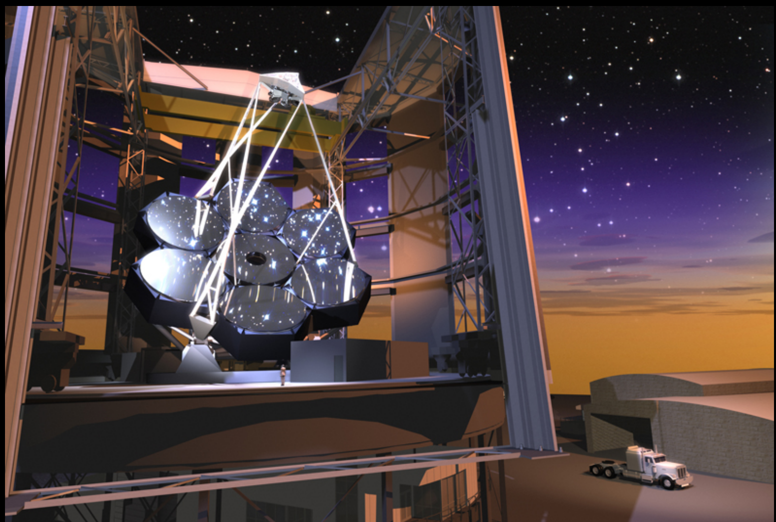
Instrument/ Technique	Telescope/ Observatory	Start of operations	Band [μm]	Spectral resolution	Efficiency [%]	Precision [m s^{-1}]
HARPS[55]	3.6-m ESO La Silla	2003	0.38-0.69	115,000	6	< 0.8
PFS[188] Self calibration	Magellan II Las Campanas	2010	0.39 – 0.67	38,000 – 190,000	10	1
CHIRON[190] Self calibration	1.5-m CTIO	2011	0.41-87	80,000	15	< 1
HARPS-N[191] Sim. reference	TNG ORM	2012	0.38-0.69	115,000	8	< 1
LEVY[192] Self calibration	APF Lick	2013	0.37-0.97	114'000-150'000	10 - 15	< 1
IRD[92] Sim. reference	Subaru Mauna Kea	*2014*	*0.98-1.75*	*70,000*	*TBD*	*1*
CARMENES[91] Sim. reference	Zeiss 3.5-m Calar Alto	*2015*	*0.55-1.7*	*82,000*	*10 - 13*	*1*
PEPSI[64] Sim. reference	LBT Mt. Graham	*NA*	*0.38-0.91*	*120,000 -320,000*	*10*	*NA*
ESPRESSO[62] Sim. reference	All UTs-VLT ESO Paranal	*2017*	*0.38-0.78*	*60'000 - 200,000*	*6 - 11*	*0.1*
SPIROU[95] Sim. reference	CFHT Mauna Kea	*2017*	*0.98-2.35*	*70,000*	*10*	*1*
G-CLEF[61] Sim. reference	GMT Las Campanas	*2019*	*0.35-0.95*	*120,000*	*20*	*0.1*

Follow-up with transit e.g. CHEOPS (more likely edge-on) but imaging tough.



ELTs





Objects consisting of many mirrors may be slightly smaller or arrive later than they currently appear.

ELTs and their approved instruments

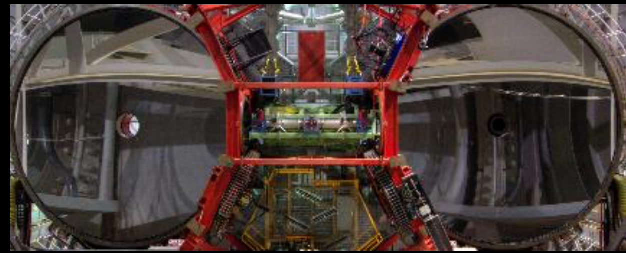
LBTI: **NOMIC, LMIRCam (2015),** LINC-NIRVANA

GMT: **G-CLEF (2019)**, GMACS (2019), **GMT-IFS (2021)**

TMT: **IRIS**, MOBIE, IRMS (first light in 2022)

E-ELT: **HARMONI and MICADO (2024), METIS (2025)**

LBTI (P. Hinz talk Thurs.)

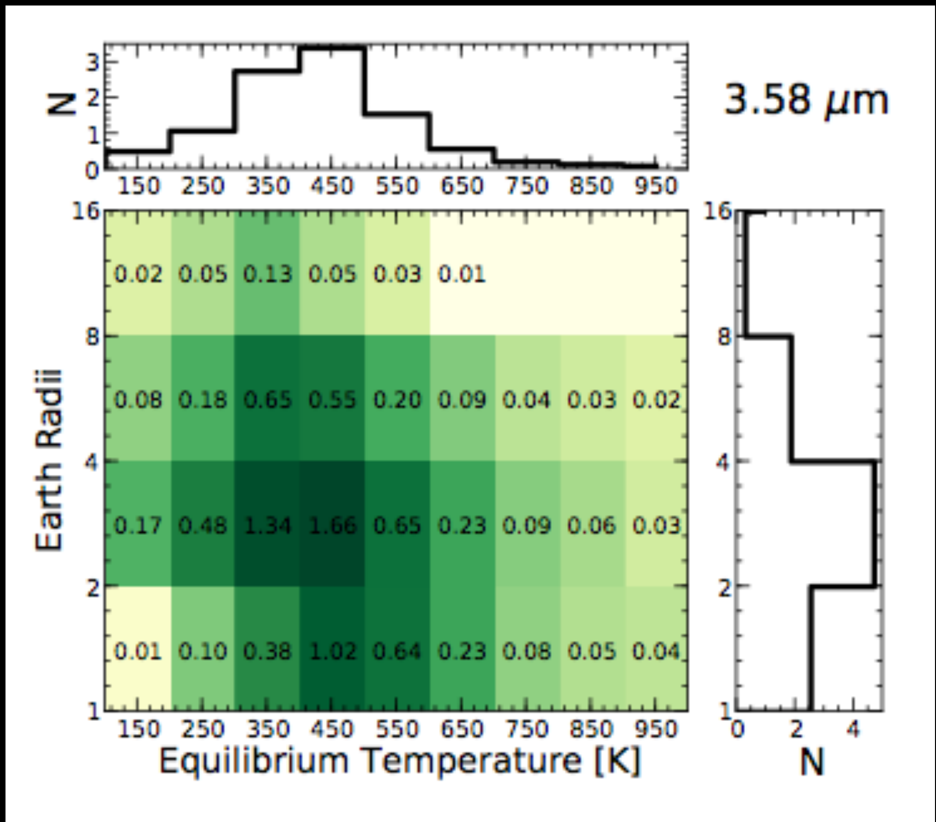


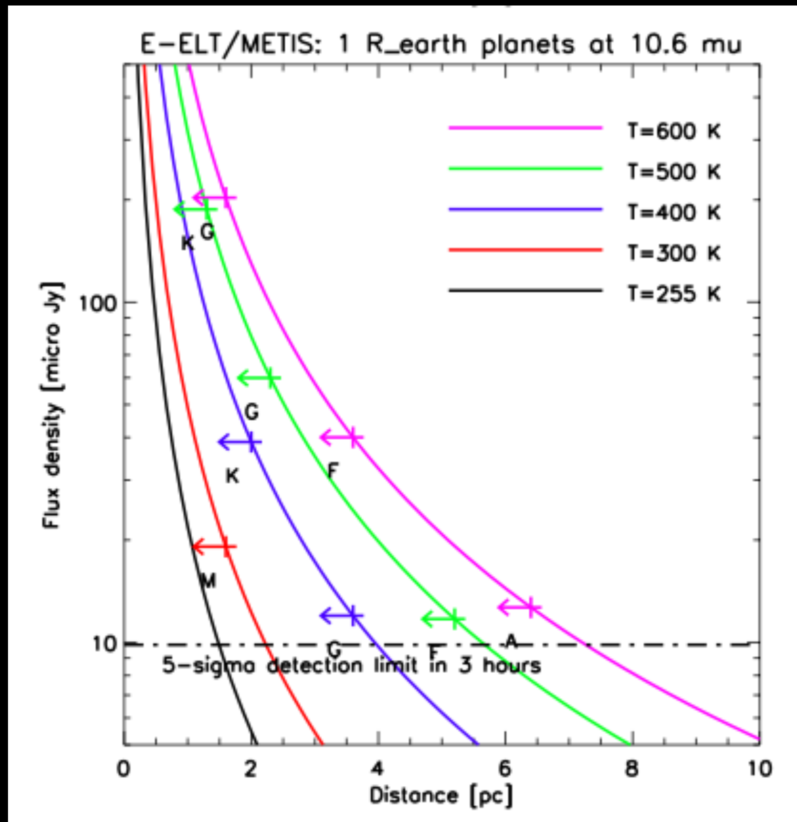
Name	Spec. Type	Dist. [pc]	Avrg. Nr. of planets detectable
Sirius A	A0.5V	2.6	0.3415
Procyon A	F5 IV-V	3.5	0.0382
Altair	A7 V	5.1	0.0063
Vega	A0 V	7.7	0.0032
Fomalhaut	A4 V	7.7	0.0008

There are a few of stars d < 10 pc where LBTI (LMIRCam) ***could*** *detect a super-earth > 5λ/D with sensitivity L_{flux} > 10 μJ.*

Mid-IR Emission: Earths in Sun-like “Sweet Spot”

Kepler stats (Howard et al. 2012) + instrument model gives estimate # of detectable Super-Earths around nearest stars.



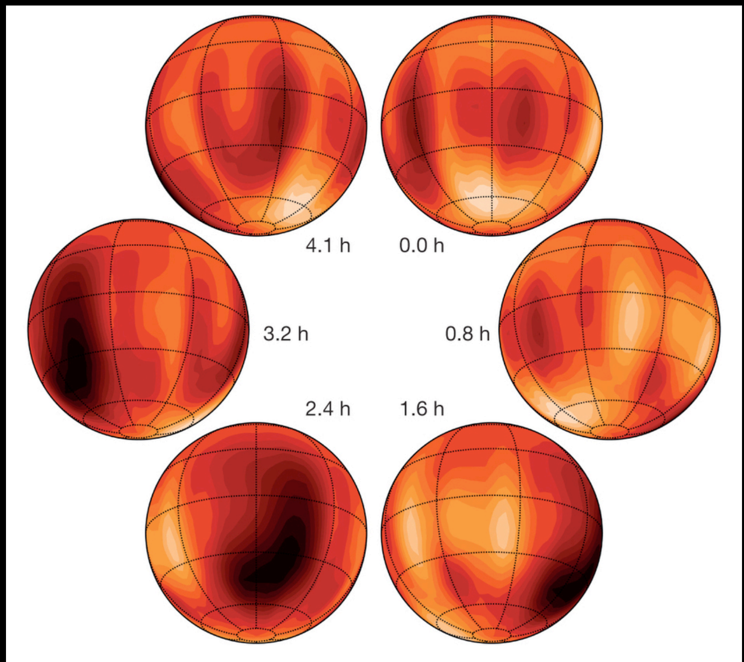


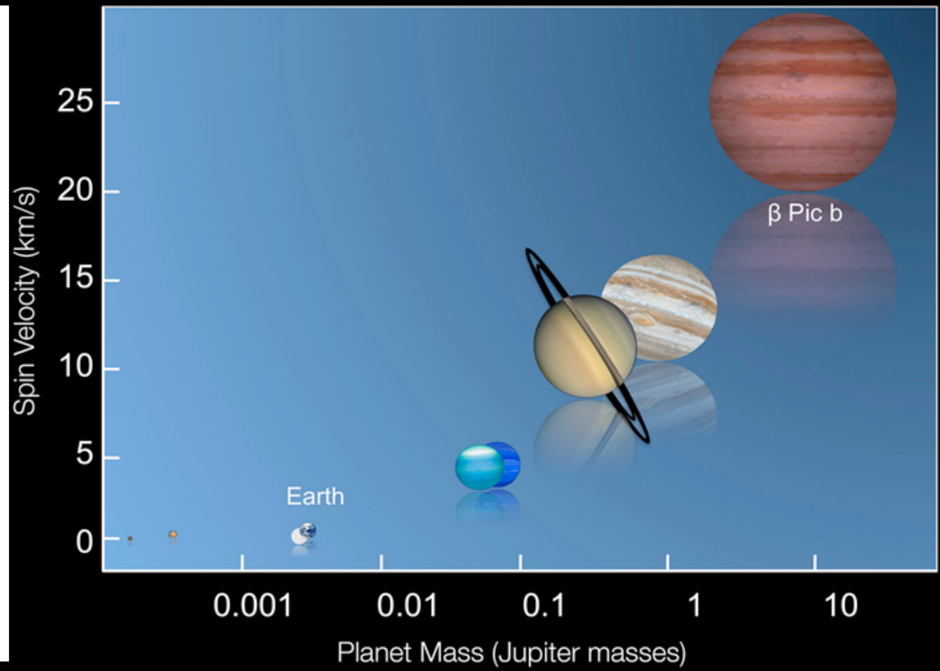
Quanz, Crossfield, Meyer et al. (2015)   NB: Pole-on better targets!

Super-earth yield from mid-IR? Background/Star ~ 10^{-6}

See Hinz et al. (astro2010 white paper) and Quanz et al. (2015)

Characterization with High Resolution Spectra: G-CLEF (GMT) as well as HIRES & METIS (E-ELT)

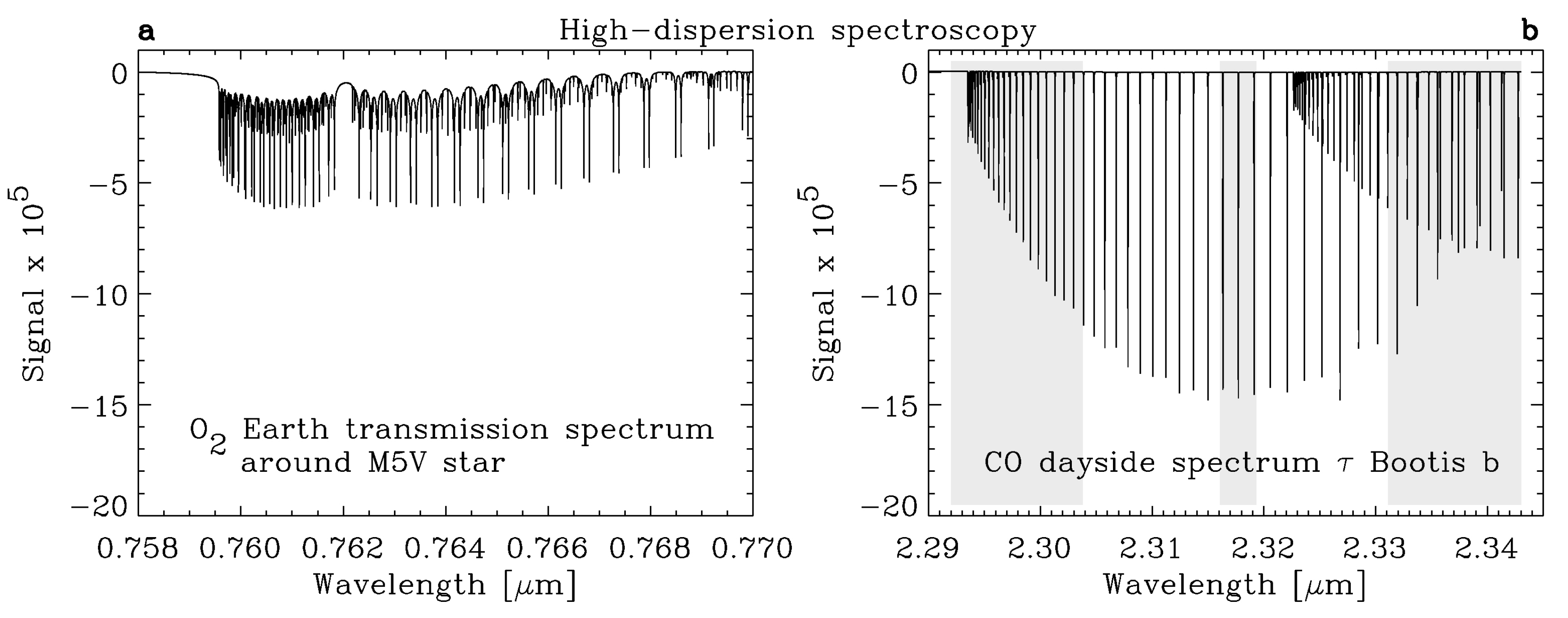




Brown dwarf doppler imaging CRIRES
Crossfield et al. (2014)

Wind speeds on planets with CRIRES
Snellen et al. (2014)

HIRES@E-ELT: Red Transmission O_2 Spectra



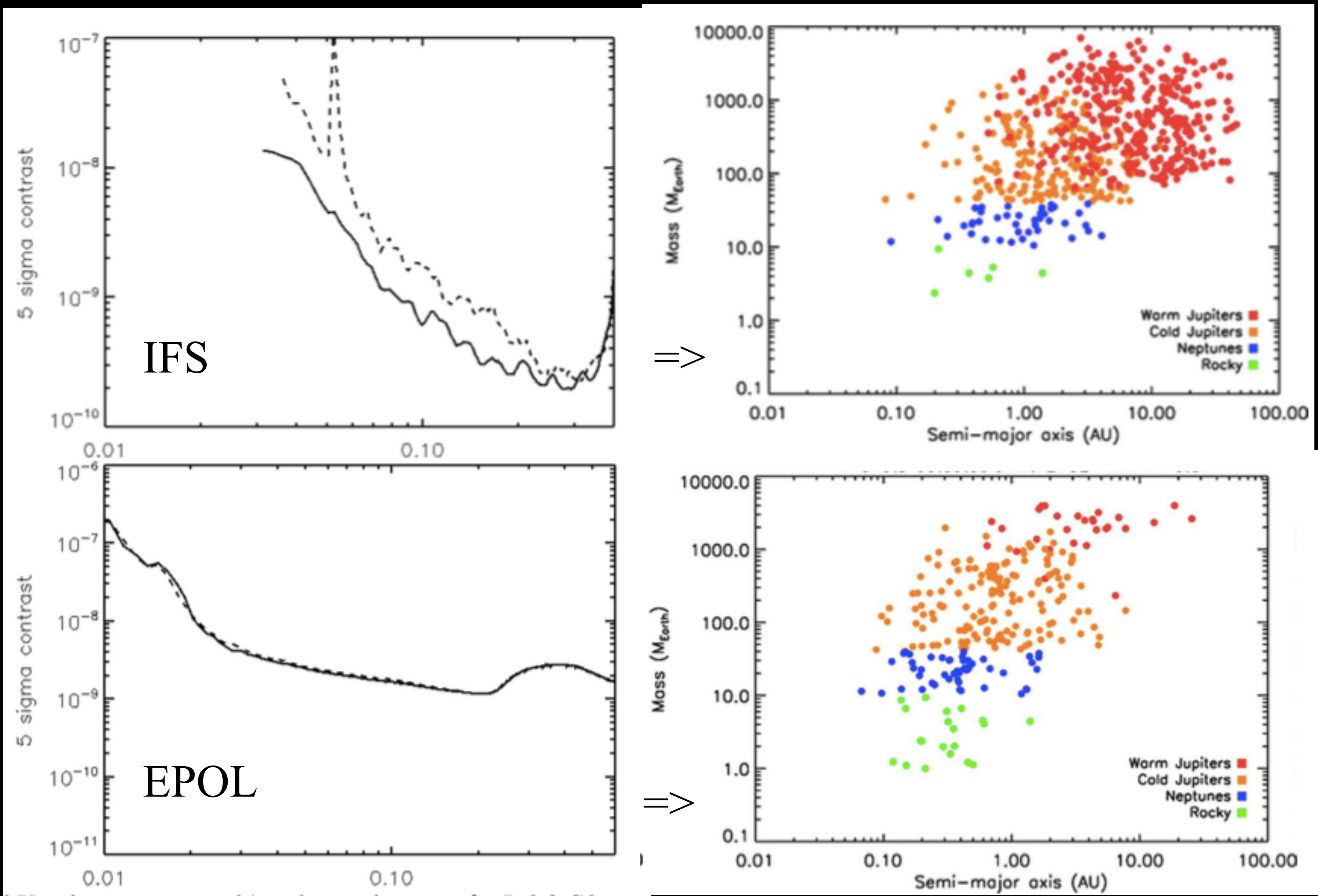
Stellar type	R_* [R_{sun}]	M_* [M_{sun}]	a_{HZ} [au]	Prob [%]	P_{HZ} [days]	Dur. [hrs]	I (η_e=1) [mag]	Line Contrast	SNR σ	Time (yrs)
G0-G5	1.00	1.00	1.000	0.47	365.3	13	4.4 - 6.1	2×10^{-6}	1.1-2.5	80-400
M0-M2	0.49	0.49	0.203	1.12	47.7	4.1	7.3 - 9.1	8×10^{-6}	0.7-1.5	20-90
M4-M6	0.19	0.19	0.058	1.52	11.8	1.4	10.0-11.8	5×10^{-5}	0.7-1.7	4-20

Snellen et al. (2013)

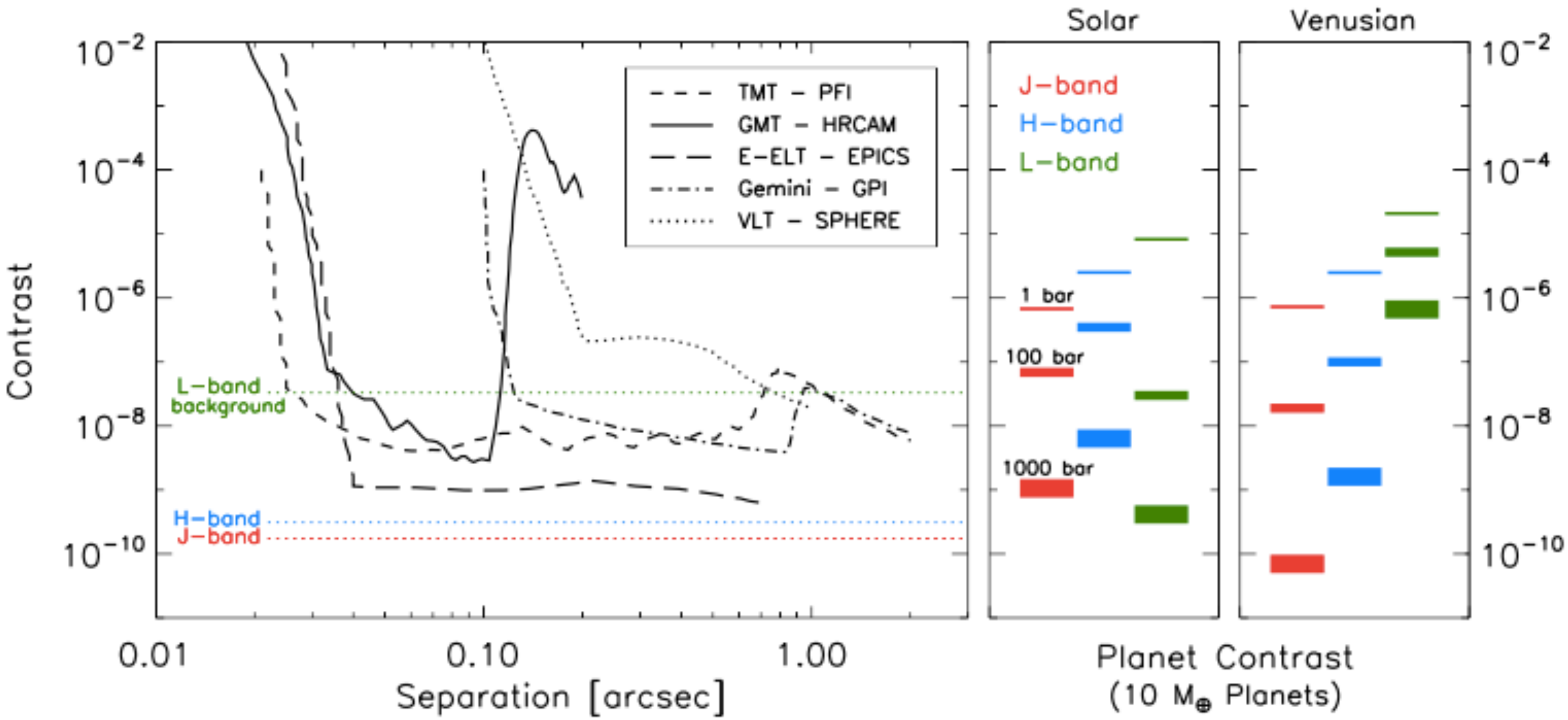
Brightest expected systems

SNR for ELT in 1 transit

Reflected Light: EPICs@E-ELT (Kasper et al. 2010; cf PFI@TMT)

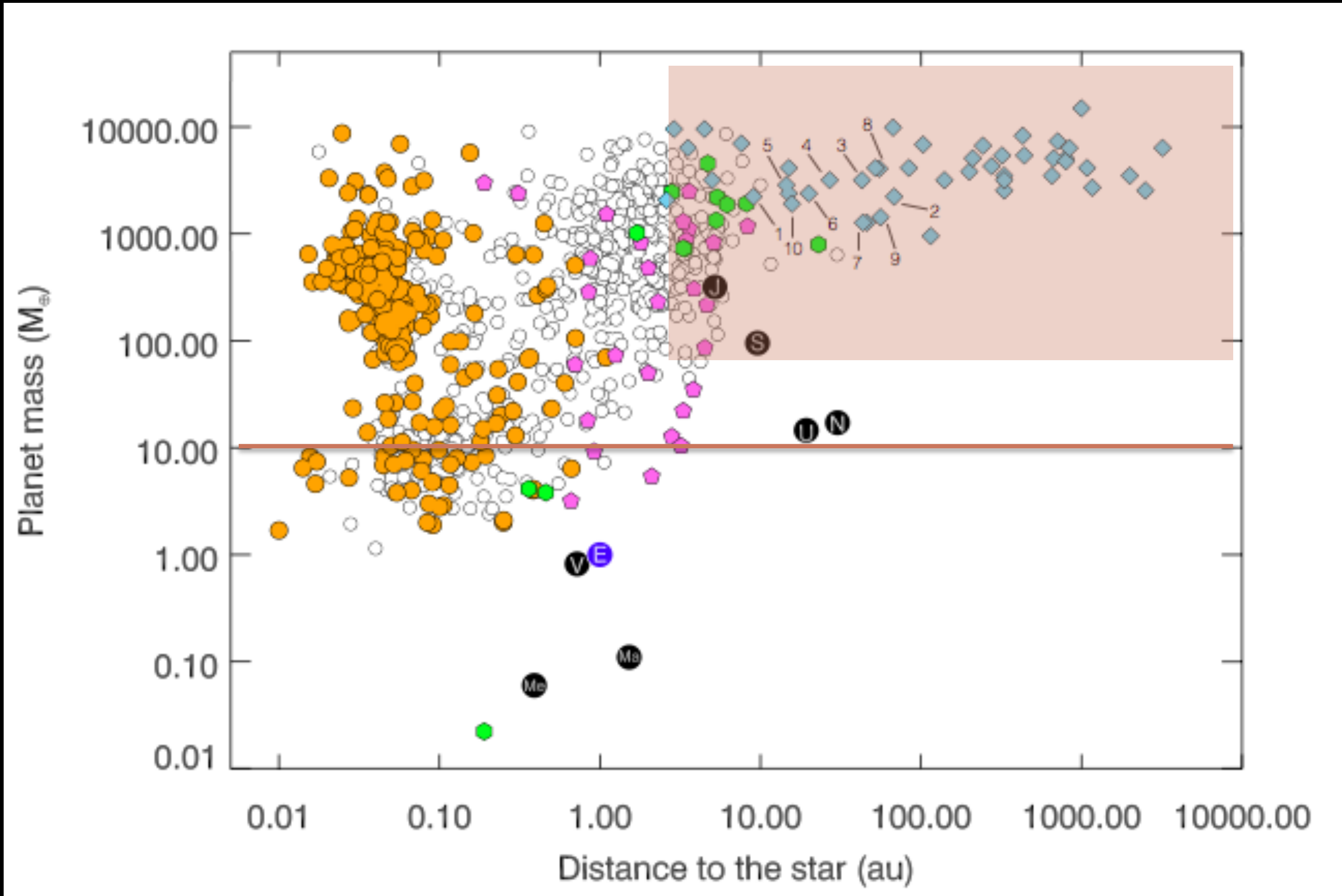


Hot Proto-planet Collision Afterglows: Terrestrial Planets in Formation

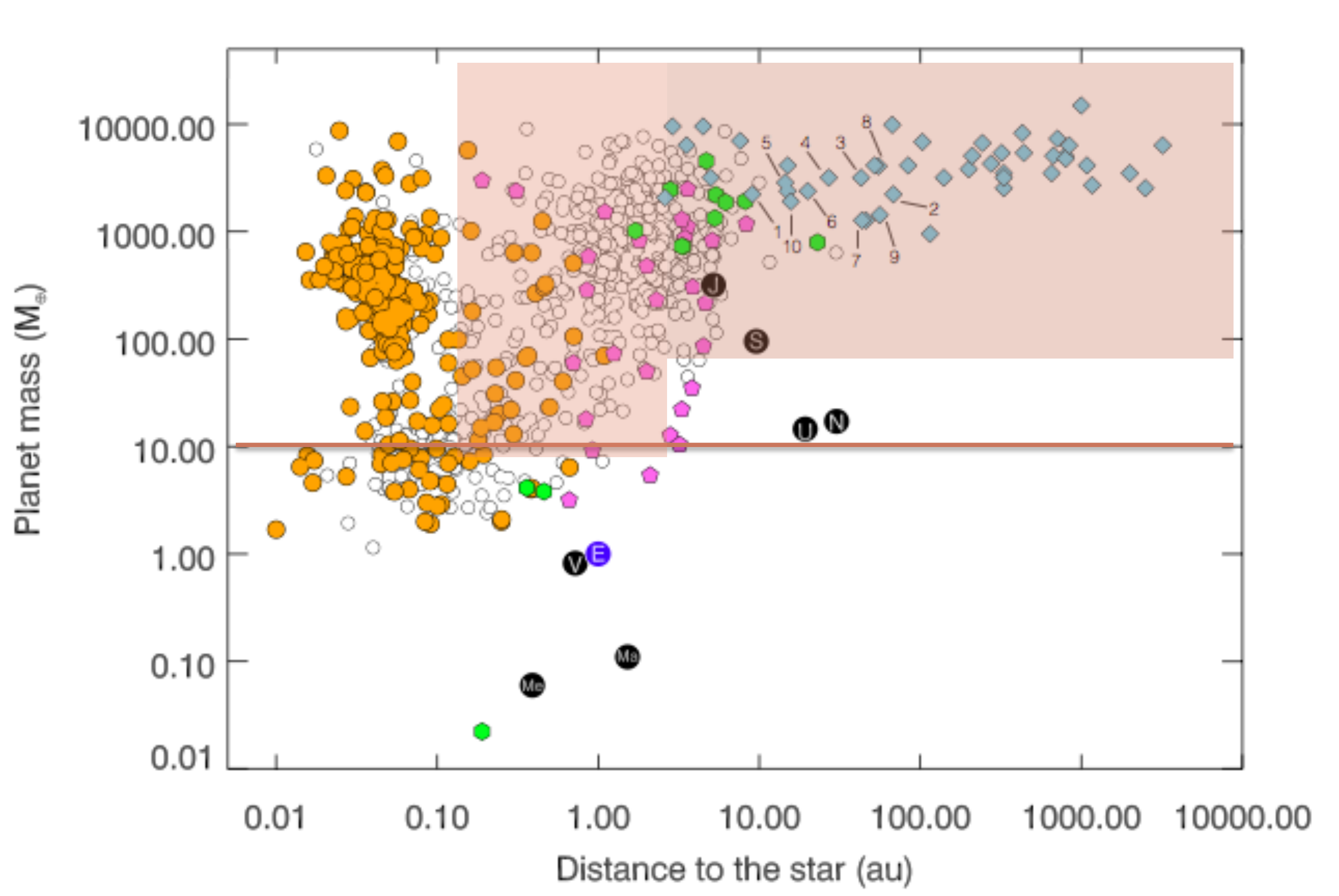


Stern (1994); Mamajek & Meyer (2007); Miller-Ricci, Meyer, Seager, & Elkins-Tanton (2009); Lupu et al. (2014)

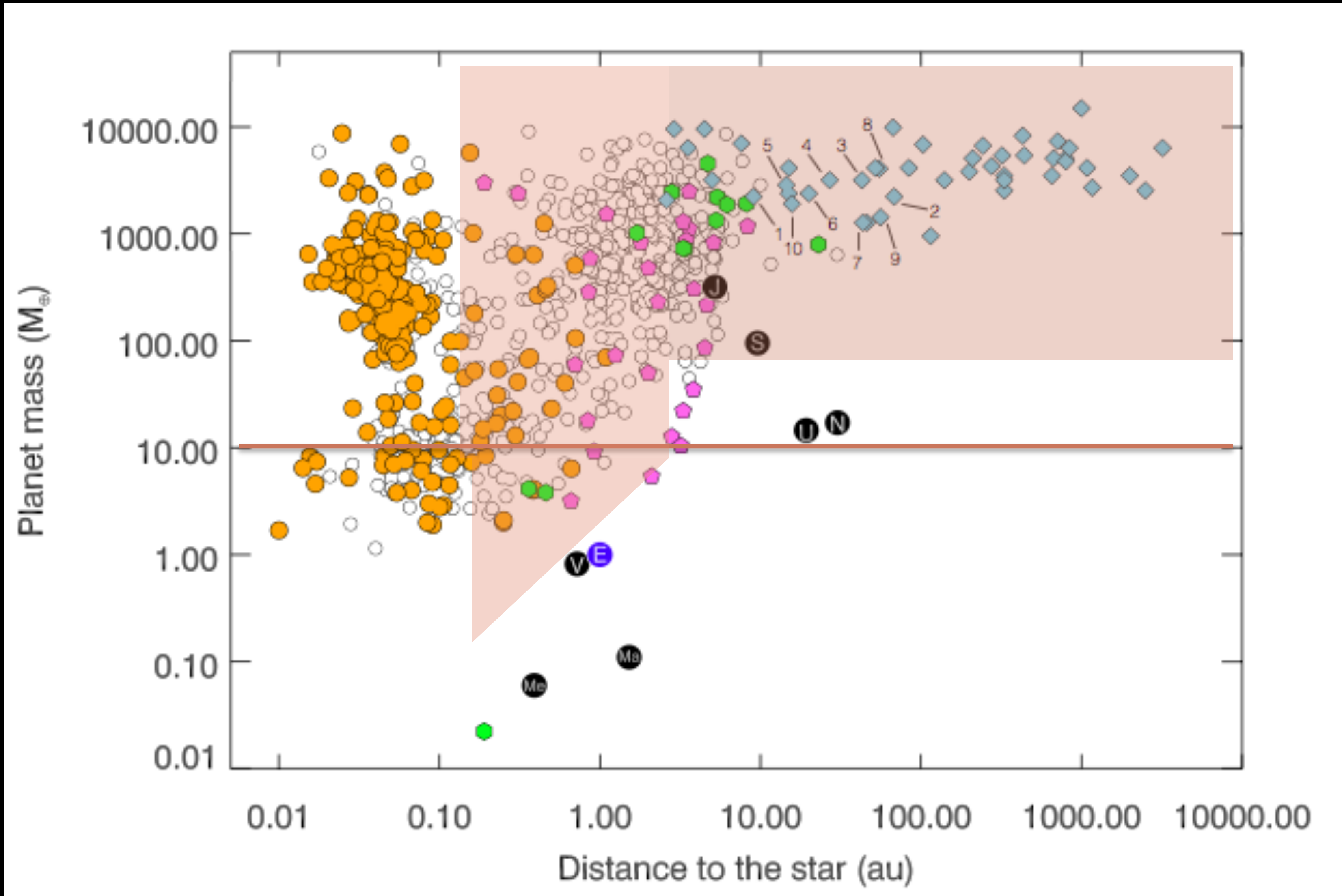
The ELT Thermal Imaging Discovery Space



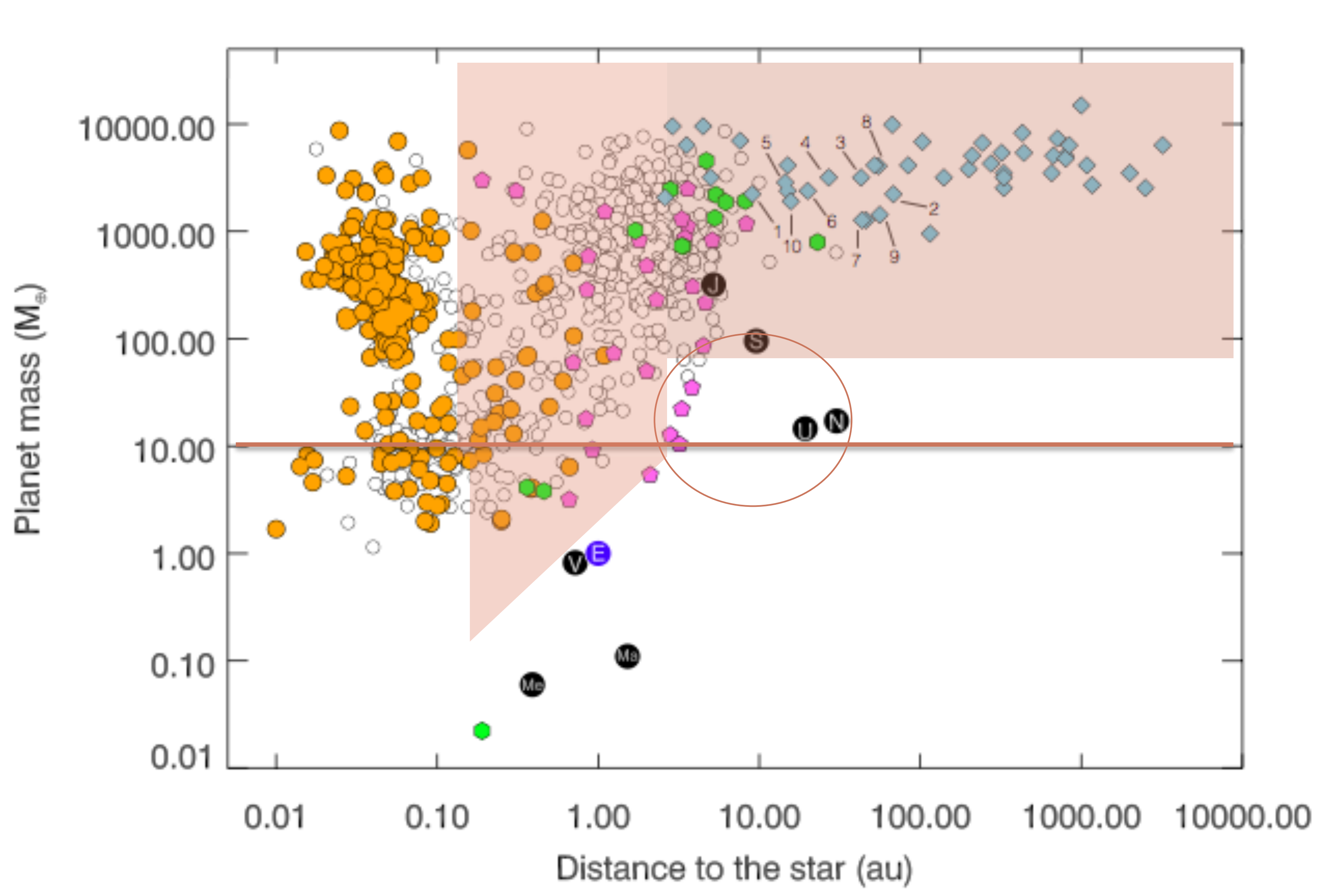
The ELT Thermal+Reflected Discovery Space



ELT Thermal + Reflected + “Terrestrial Wedge”



Thermal + Reflected + “Wedge” + Hot PCAs



So what does this mean?

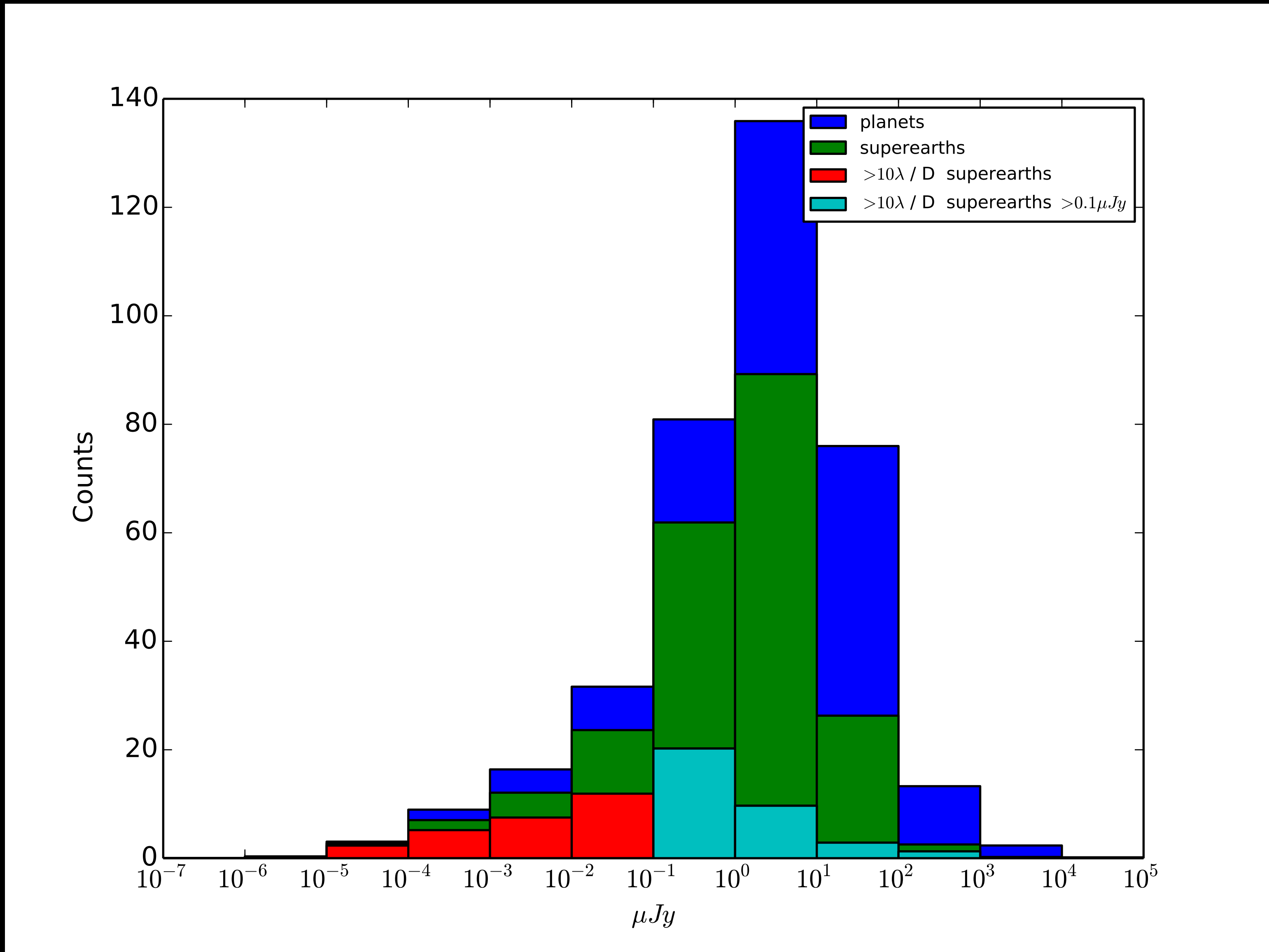
First super-earth planet may be detected in thermal emission by ELTs before 2030.

ELTs will further characterize spectroscopically and polarimetrically in reflected light.

RV detected planets in M dwarf habitable zones:
. UV/optical coronagraph in reflected light.
. mid-IR high-precision photometer?

Bottom-line: Space-based IR interferometer (> 300 meter bl with 4 x 2 meters area) or UV/optical > 8m needed to characterize the diversity of worlds around Sun-like stars.

Space-based mid-IR interferometer
(based on Kepler statistics + 600 meter 4 x 2 meter)



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