PCS: E-ELT Planet finder

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Italian activity for PCS

- Update of the science case of PCS: assessment of the detection capability of PCS using Monte Carlo simulations
- Development and application of high contrast imaging techniques
  - SPHERE
  - High Contrast imaging surveys
- Combination of high spatial and spectral resolution (D'Orazi talk)
- Further acquisition of competence in the scientific design of High Contrast Imagers (D'Orazi talk)

Main topics in exo-planetary science for the next 15 years – my view

- **Planets formation**
  - How planets form?
  - Why planets have different masses and separation from the stars? What is the impact of disk-planet interactions?
  - What is the impact of the environment?
- **Early evolution**
  - What is the evolution of young planets?
  - How are their atmospheres made and what are their chemical composition?
  - What is the impact of planet-planet interactions?
- **Search for habitable planets**
  - How common are rocky planets in the habitable zone?
  - What is the structure of small mass planets?
  - What is the composition of their atmospheres?
  - Are we able to detect bio-signatures?

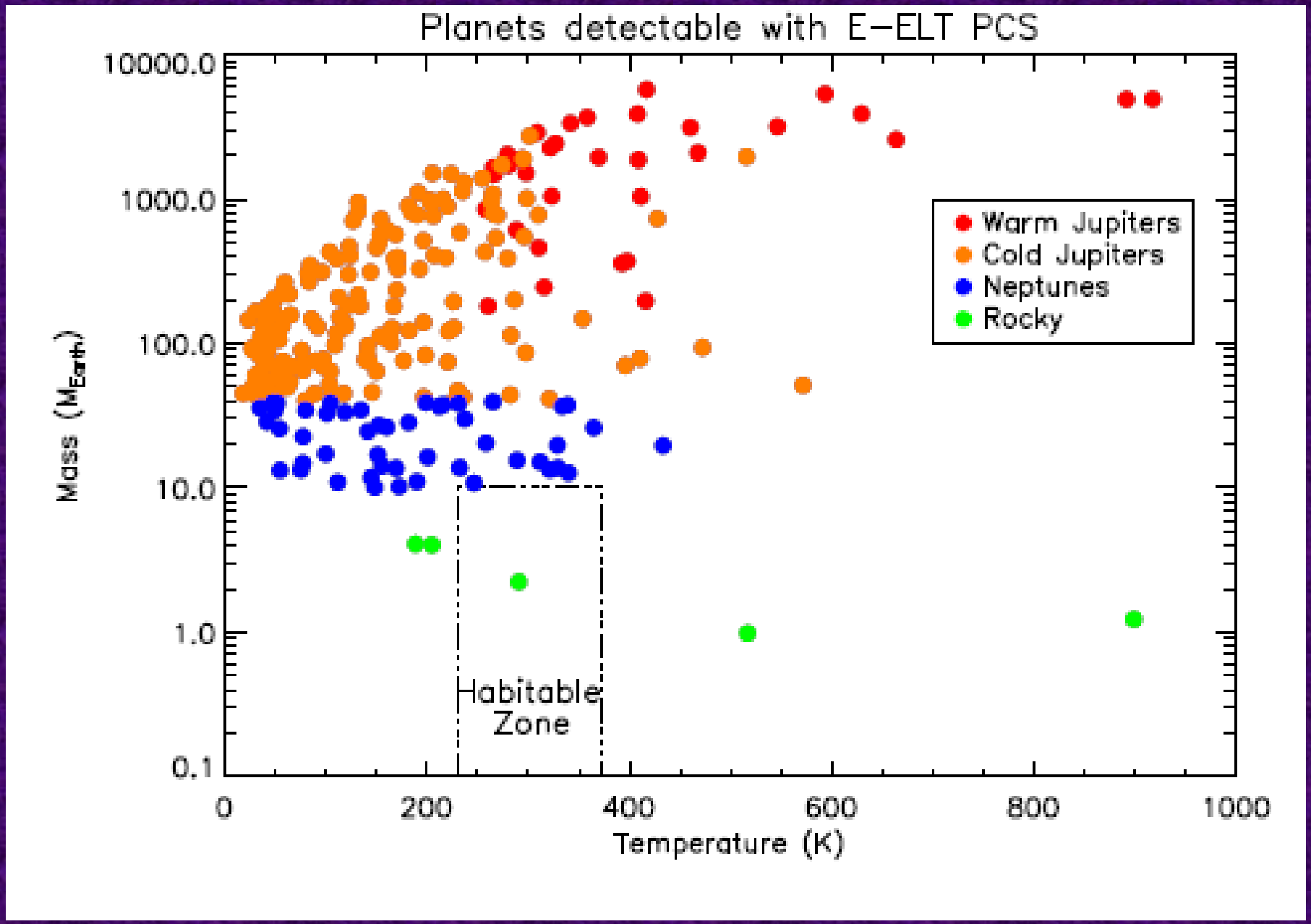
Schematic of methods goals

	Hot planets (P~days)	< snow-line (P~a few years)	> snow-line (P~several years)
Discovery: detection and statistics	Radial Velocities Transits	Radial velocities Space Astrometry (GAIA) Microlenses **E-ELT imaging**	8m imaging
Dynamical characterization & Structure	Radial Velocities + Transits	Radial velocities Space Astrometry (GAIA) **E-ELT imaging**	Coupling 8m imaging and GAIA?
Atmospheric characterization & search for biosignatures	Transits - Duration - Transmission spectroscopy - Secondary transit	**E-ELT imaging**	8m imaging (and) JWST ELT MIR

However, situation may differ for specific target groups (M-stars)!

Detection capability of PCS using MESS

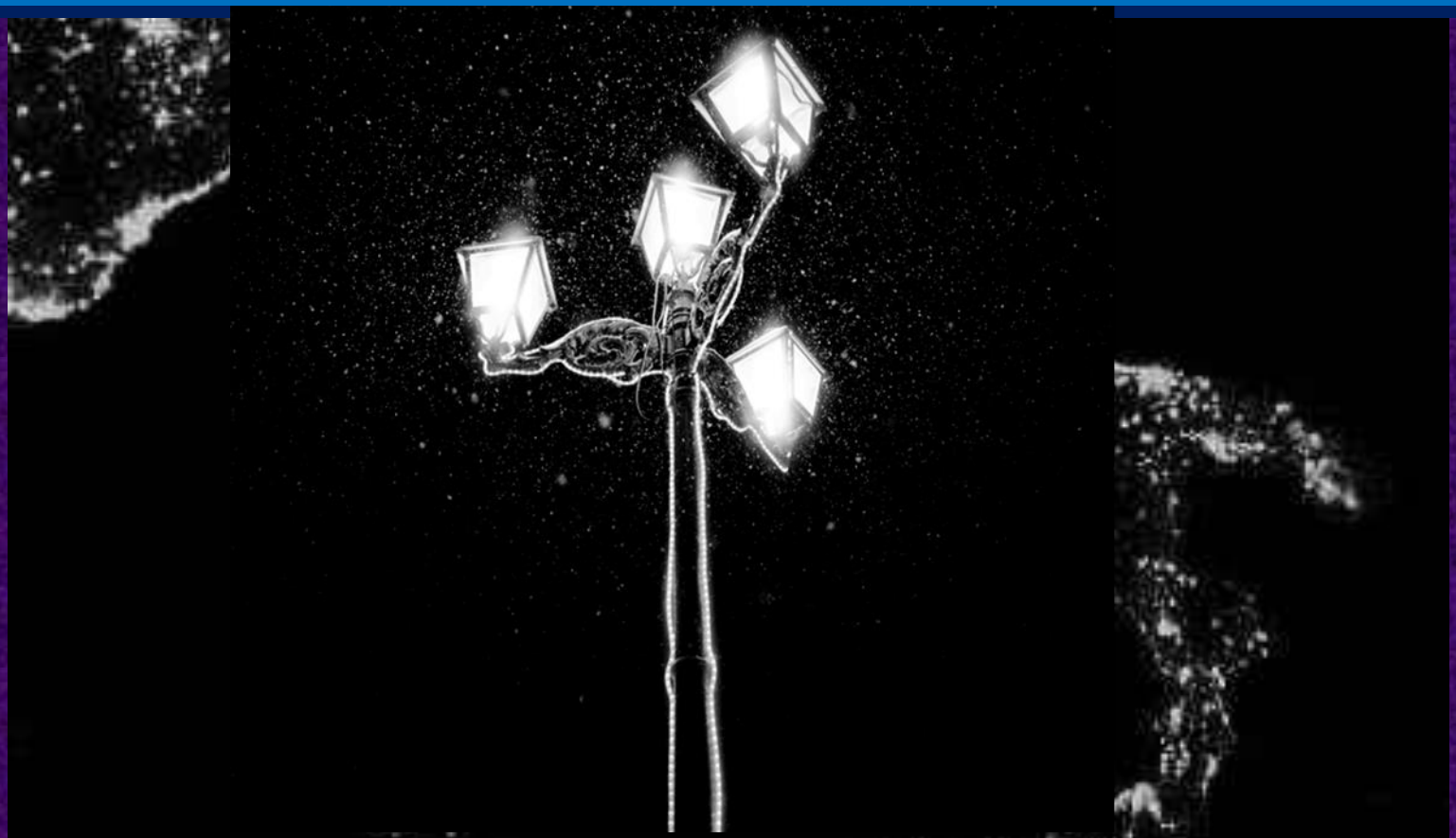
- MESS: Multi-purpose Exoplanet Simulation System - Bonavita et al. 2012
- compares expected properties of a population of exoplanets with detection limits for different instruments, using various techniques (imaging, RV, astrometry, transits)
- Papers at:
  - Exoplanets with the E-ELT (Feb. 2014, Garching)
  - Exoplanets, Biosignatures and Instruments (March 2014 Tucson)


Planets detectable with E-ELT PCS
10000.0
1000.0
100.0
10.0
1.0
0.1
Mass (M_{Earth})
0
200
400
600
800
1000
Temperature (K)
Warm Jupiters
Cold Jupiters
Neptunes
Rocky
Habitable Zone

Planets expect to be discovered in the next 15 years with foreseen imagers

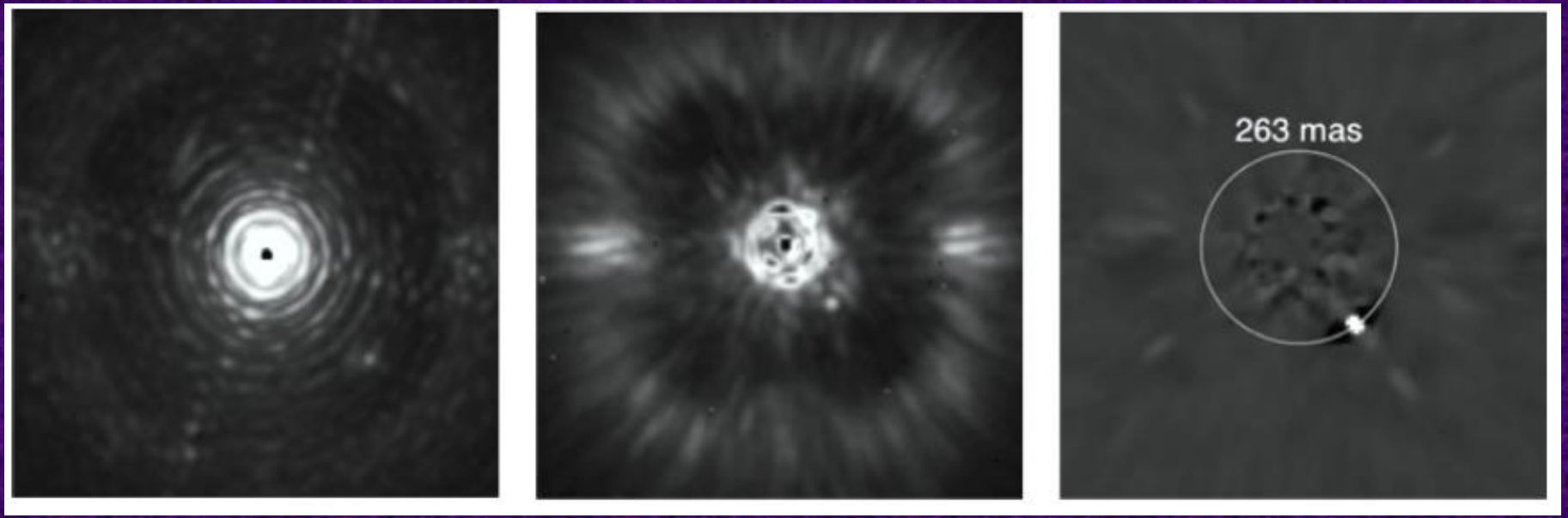
	Year	Young Giants	Reflected light planets			
			Giants	Neptunes	Rocky	Habitable
Ground Based 8m	2013	tens	few			
JWST	2018	tens	few			
1.5m Space Coronagraphs	?	tens	tens	tens	few	??
ELTs	> 2020	hundreds	hundreds	tens	few	??

Required high contrast performances to see a young giant planet are equivalent to those required to see a moth flying around a street-lamp from a satellite at 500 km height



Those required to discover an habitable rocky planet are 1000 times better at 5 times further distance!

High contrast imaging (e.g. with SPHERE)



Raw on sky image
→XAO
VLT~10^3-10^4
E-ELT~10^5

Raw on sky image
→Coronagraph
VLT~10^4-10^5
E-ELT~10^6-10^7

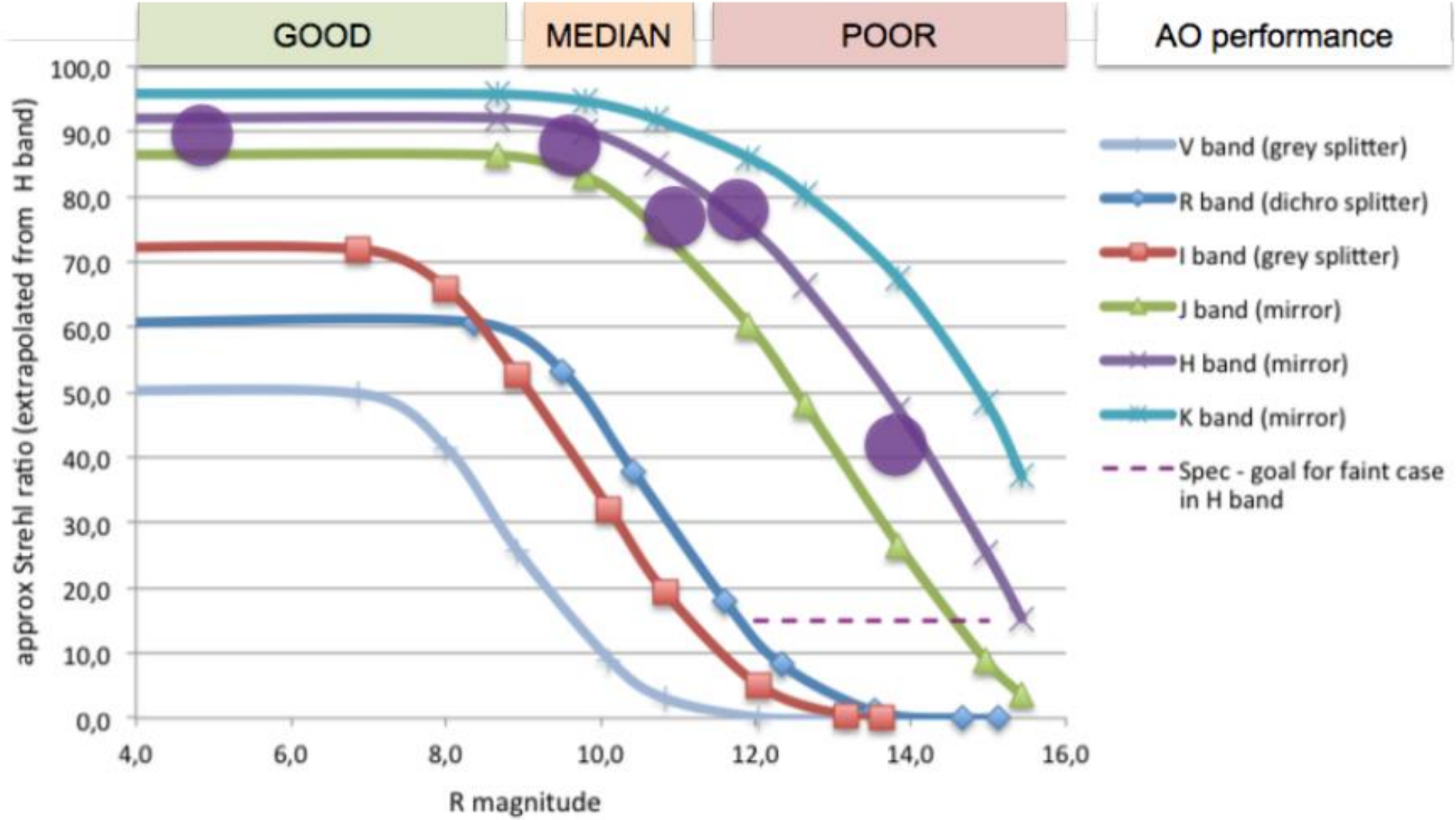
After data analysis
→ADI
VLT~10^6-10^7
E-ELT~10^8-10^9

HIGH CONTRAST IMAGER MAIN PROPERTIES

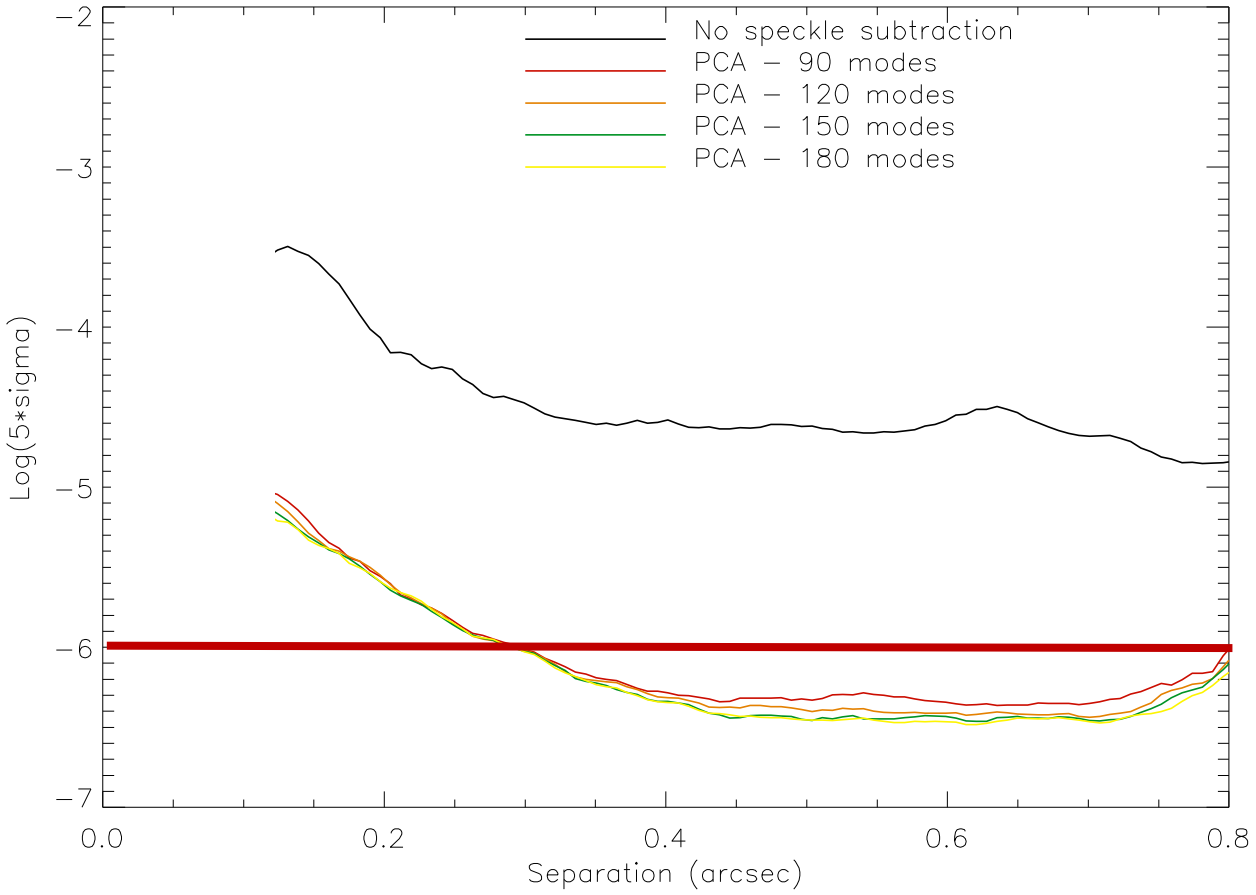
VIS/NIR		GPI/SPHERE	ELT IFU	ELT PCS (XAO)	JWST-NIRI	WFIRST-AFTA
NIR Ground: 0.6-2.5 µm JWST (NIRCam): 0.6-2.5 µm	Contrast	10^{-6}-10^{-7}	10^{-6}-10^{-7}	10^{-8}-10^{-9}	10^{-6}	10^{-9}
	IWA (mas)	100	20	20	270	100-250
	Spec.Res.	50	4000	100	-	70
	Star mag	I<10		I<10		-
	Targets	Young giants	Young giants Reflecting giants	Young Giants Neptunes Reflecting giants, Neptunes, super-Earths?	Young giants Nearby stars	Young Giants, Neptunes Reflecting giants, Neptunes, super-Earths?
MIR		LMIRCAM	ELT MIR		JWST-MIRI	
MIR Ground: 3.4-14 µm JWST (MIRI): 5-28.3 µm FGS: M-band	Contrast	3 10^{-5}	10^{-4}		10^{-4}	
	IWA (mas)	200	80		350 MIRI 100 FGS	
	Spec. Res.	-	5000 (slit)		-slit	
	Targets	Young giants	Young giants Nearby stars		Young giants Nearby stars	


First results with SPHERE IFS

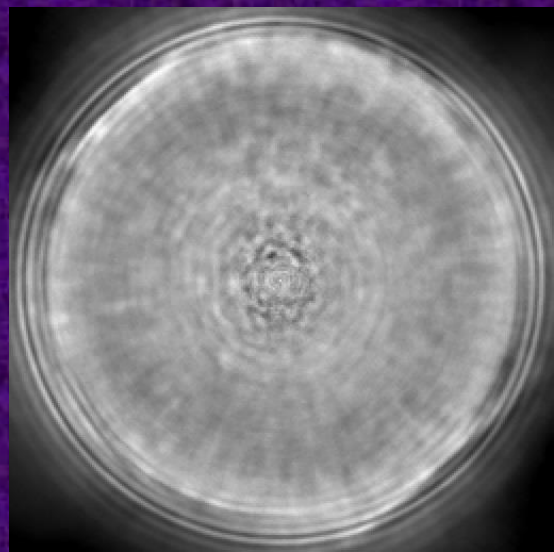
SAXO (AO)


GOOD
MEDIAN
POOR
AO performance
approx Strehl ratio (extrapolated from H band)
100,0
90,0
80,0
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
4,0
6,0
8,0
10,0
12,0
14,0
16,0
R magnitude
V band (grey splitter)
R band (dichro splitter)
I band (grey splitter)
J band (mirror)
H band (mirror)
K band (mirror)
Spec - goal for faint case in H band

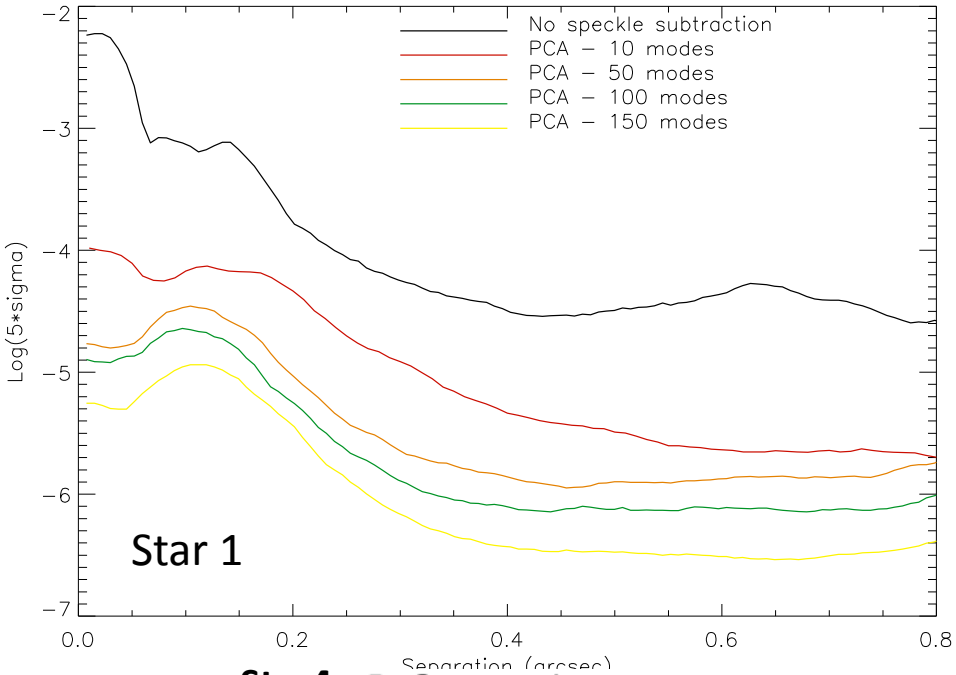
High contrast imaging

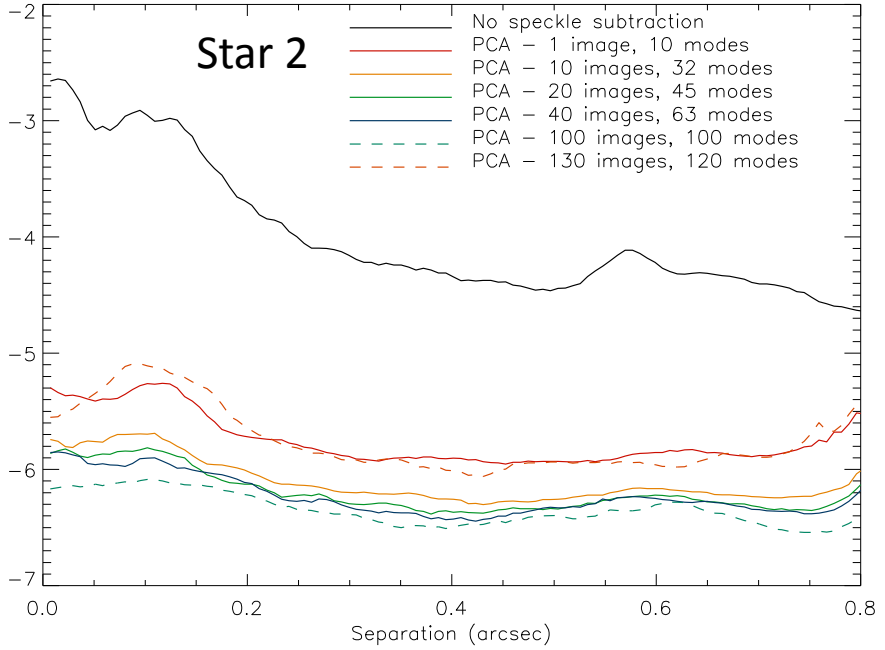


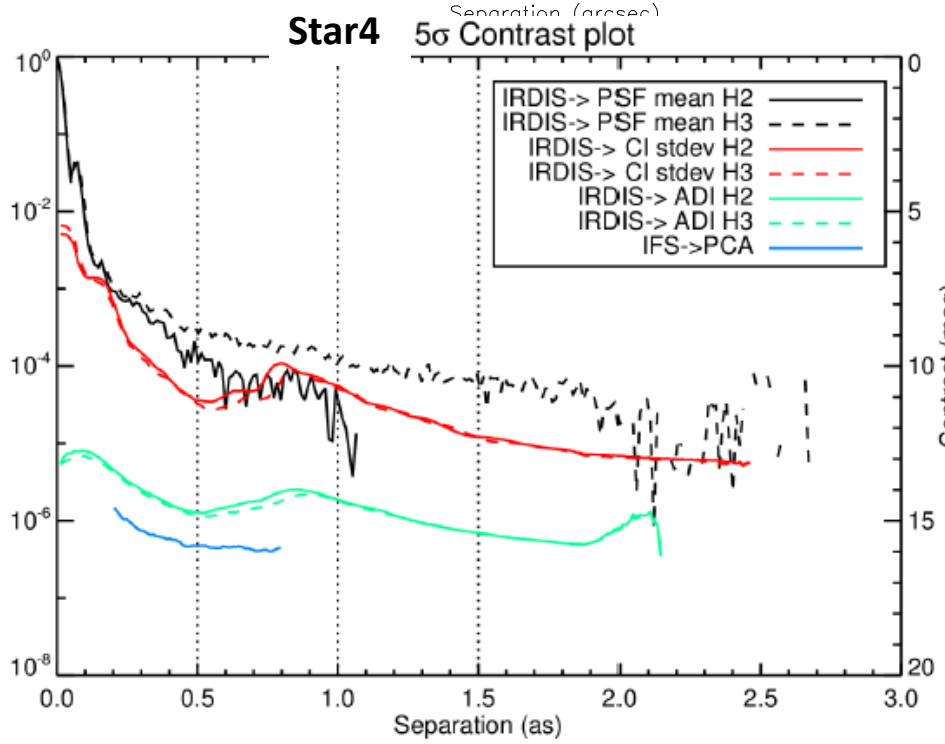
- Best contrast obtained until now with SPHERE

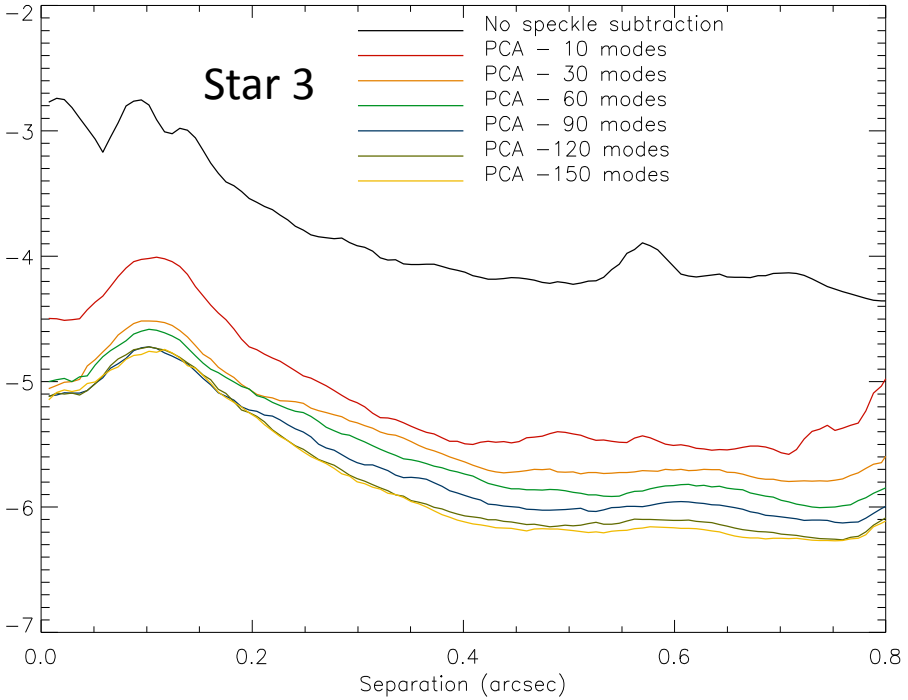


No planet found for τ Ceti

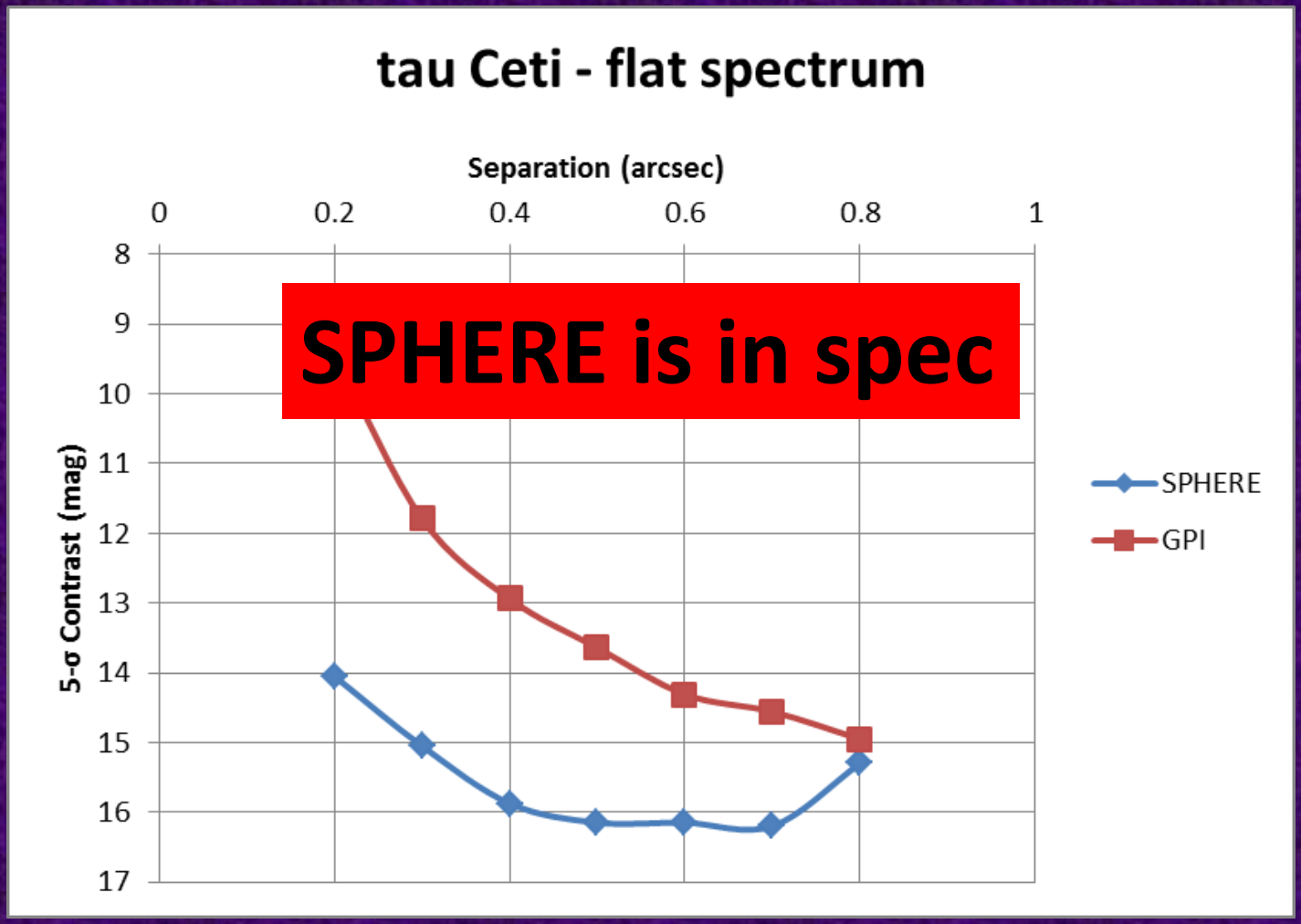

No speckle subtraction
PCA – 10 modes
PCA – 50 modes
PCA – 100 modes
PCA – 150 modes
Star 1
Log(5*sigma)
Separation (arcsec)


Star 2
No speckle subtraction
PCA – 1 image, 10 modes
PCA – 10 images, 32 modes
PCA – 20 images, 45 modes
PCA – 40 images, 63 modes
PCA – 100 images, 100 modes
PCA – 130 images, 120 modes
Separation (arcsec)


Star4
5σ Contrast plot
IRDIS-> PSF mean H2
IRDIS-> PSF mean H3
IRDIS-> CI stdev H2
IRDIS-> CI stdev H3
IRDIS-> ADI H2
IRDIS-> ADI H3
IFS->PCA
Contrast (mag)
Log(5*sigma)
Separation (as)


Star 3
No speckle subtraction
PCA – 10 modes
PCA – 30 modes
PCA – 60 modes
PCA – 90 modes
PCA –120 modes
PCA –150 modes
Separation (arcsec)

These are the deepest images ever at such separation



Publication list

- Bonavita, M., et al. A New Sub-stellar Companion around the Young Star HD 284149, Astrophysical Journal, 791, L40
- Zurlo, A. et al. Performance of the VLT Planet Finder SPHERE II. Photometry and astrometry precision with IRDIS and IFS in laboratory, Astronomy and Astrophysics, 572, A85, 2014 (arXiv:1410.1754)
- D. Mesa, et al. Performances tests on SPHERE IFS. Astronomy and Astrophysics, 576, 121, 2015 (arXiv:1503.02486)
- A. Vigan, et al. Detection and characterization of the GJ 758B companion with VLT/SPHERE, Astronomy and Astrophysics, submitted, 2015
- A.-L. Maire, et al. The physical properties and the architecture of the young systems of PZ Tel and HD 1160 revisited with VLT/SPHERE, Astronomy and Astrophysics, submitted, 2015
- A. Zurlo, et al. Spectrophotometry and astrometry of the HR8799 exoplanetary system with VLT/SPHERE, Astronomy and Astrophysics, submitted, 2015
- D. Mesa, et al. New constraints on the mass of HD142 Ac from SPHERE high contrast imaging data, Astronomy and Astrophysics, submitted, 2015
- M. Bonavita, et al. Finding and characterizing exoplanetary systems in the E-ELT era: synergies and complementarity of planet finding instruments, in Search for Life Beyond the Solar System. Exoplanets, Biosignatures & Instruments. Online at http://www.ebi2014.org, id.P4.73, 2014
- Bonavita, M., et al. R, Quick-MESS: A fast statistical tool for Exoplanet Imaging Surveys. Exploring the Formation and Evolution of Planetary Systems, Proceedings of the International Astronomical Union, IAU Symposium, Vol. 299, p. 28 , 2014