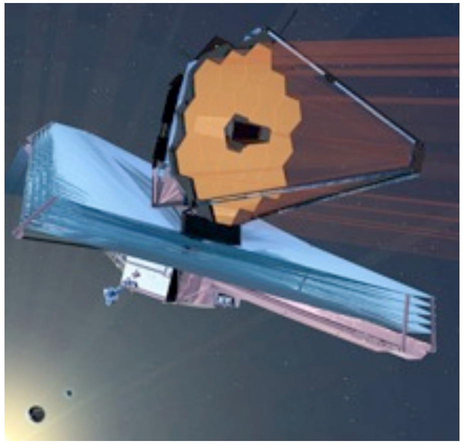
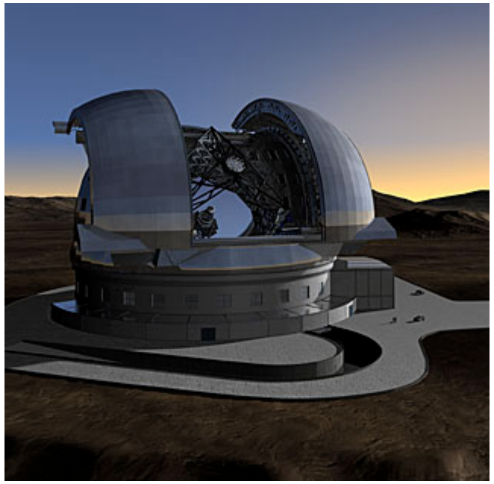


MIRI, METIS and the exoplanets

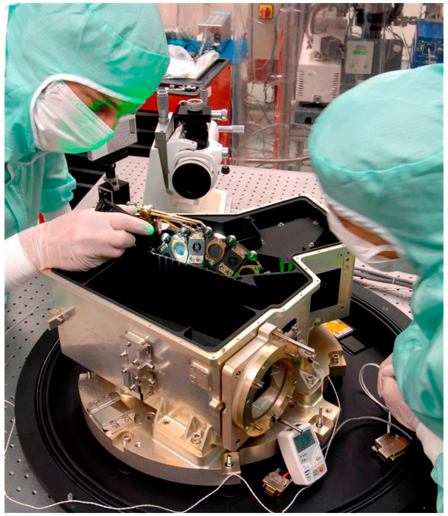
P.O. Lagage
CEA Saclay

French Co-PI of JWST-MIRI and
Coordinator of European MIRI GTO on exoplanets
Member of the ELT-METIS science team



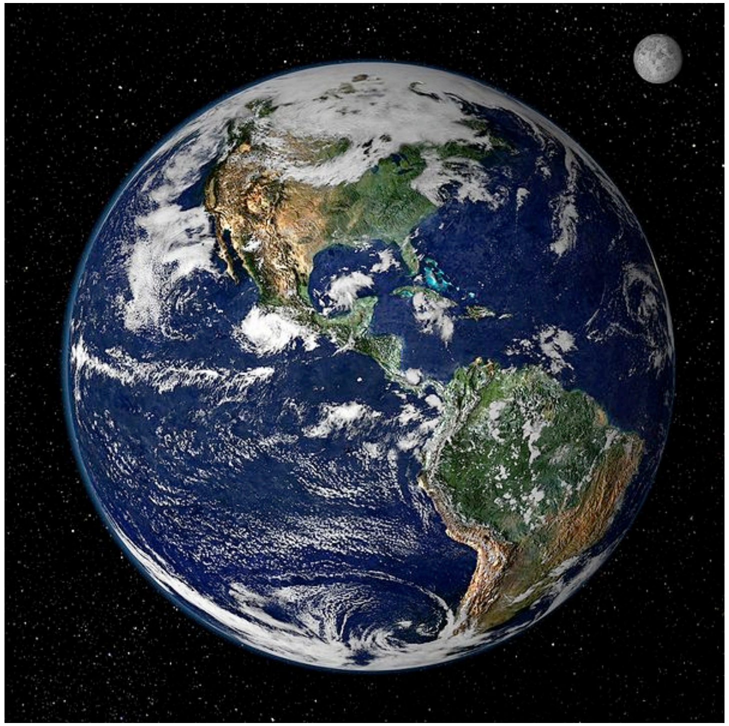
Why MIRI and METIS ?

Because of my own biais!

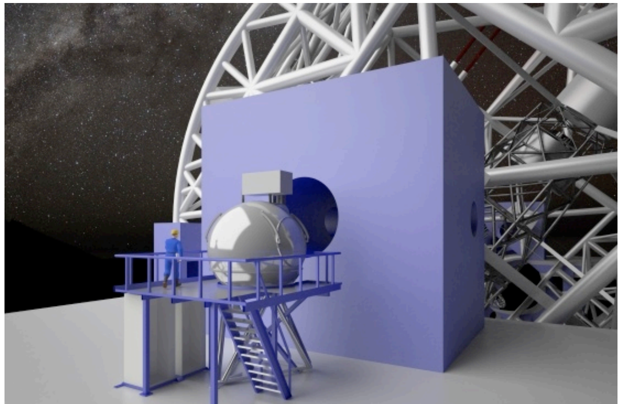


Inspection at Saclay of the flight model of MIRIM, the MIRI imager; Now at RAL for integration in MIRI

5 to 28.5 microns
(600 K – 100 K)



Black-body at 300 K → 10 microns



ELT-METIS on the télescope Nasmyth platform; 2018 photo!

3 to 14 microns
(900 K – 200 K)

Complete census of Planets

→ **Architecture of planetary systems**

Planet Characterisation

Internal structure (M,R)

Characterisation of the atmosphere (temperature, composition..)

Planet formation – migration → related to disk observations

Planet detection ?

Already a lot!

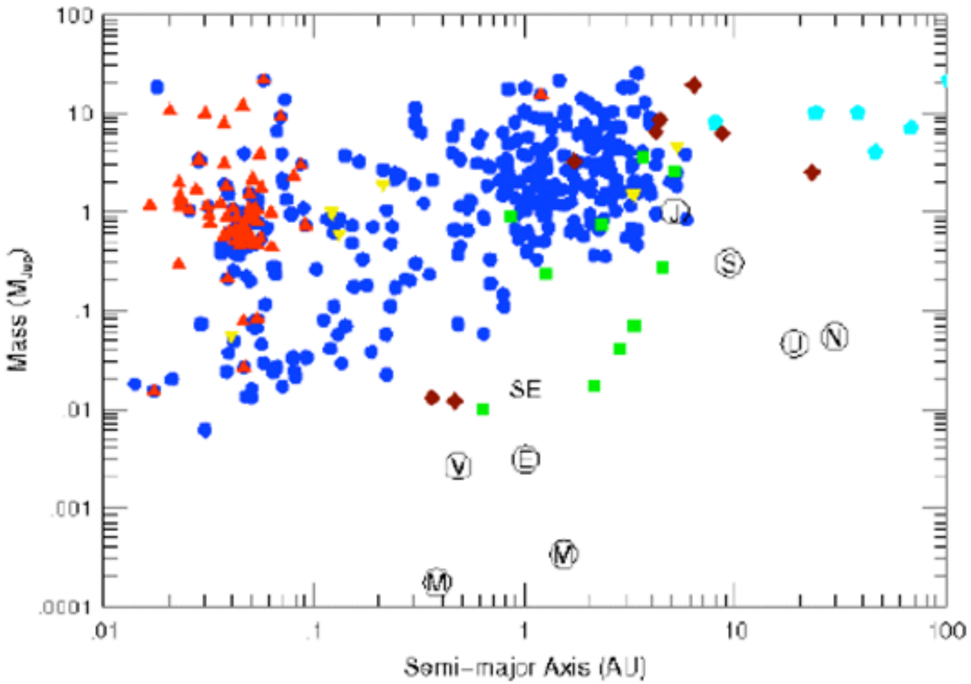


Fig. 1 Exoplanet discoveries from the various search methods in the Mass-Semi-major axis plane. Blue dots: Radial velocity detections; Red triangles: Transit detections; Inverted yellow triangles: astrometric detections; Green squares: Microlensing detections; Blue Pentagons: Imaging detections; Red diamonds: Timing detections. The letters mark the location of the planets in the solar system. “SE” denotes a Superearth with 5 M_{Earth}.

More to come!

A lot of progresses expected with current space missions (Corot, Kepler) or forthcoming (Gaia; 2012) or ground-based (VLT-SPHERE…)

In discussion : cosmic VISIOn : Plato (transit), Euclid (microlensing)
US : SIM light …

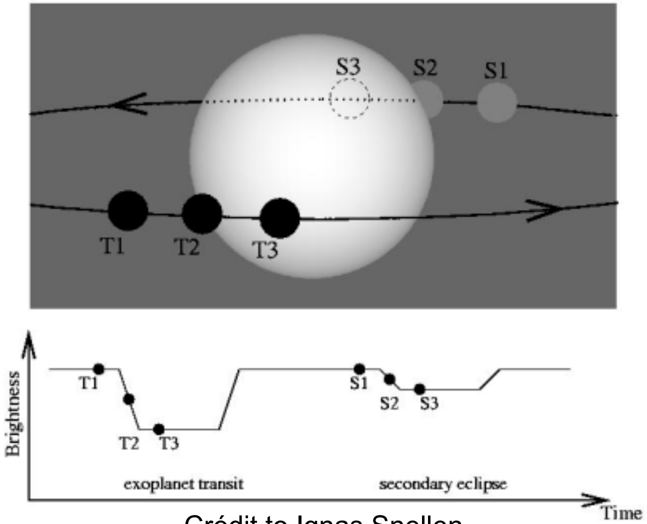
According to me the main contribution of MIRI and METIS to exoplanet field will be :

Exoplanet Characterization
(mainly atmosphere)

Even if a « niche » exists for planet detection by MIRI **(C. Beichman et al PASP 2010)**
(focus to be made on system architecture; not finding new objects)

Two main ways to observe planet atmosphere

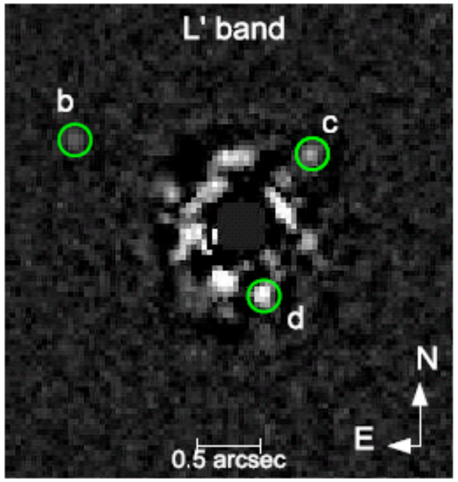
Time Separation (S and S+P)
Transit (primary and secondary)
With high photometry precision



Crédit to Ignas Snellen

Advantage : planet R and M known

Angular Separation
between the star and the planet
with contrast problem → need of coronagraphy

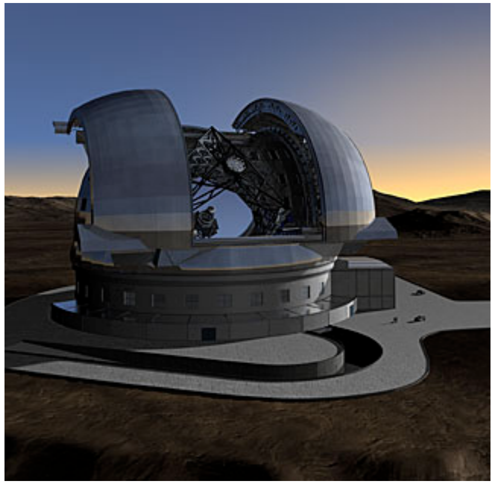


HR 8799; Hinz et al 2010
See also W. Brandern justafter

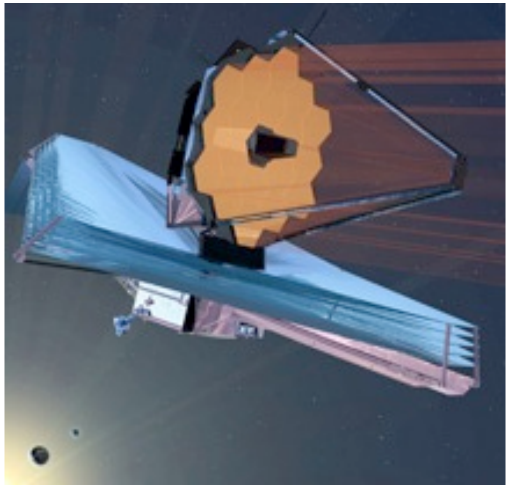
Advantage : source sample not limited by transit probability

To be schematic

Angular resolution
Ground-based = large télescope
(diffraction limited with « moderate » AO in the mid-IR)



Photometry
Space ; large stability
(be careful to cosmic-rays bombardement)

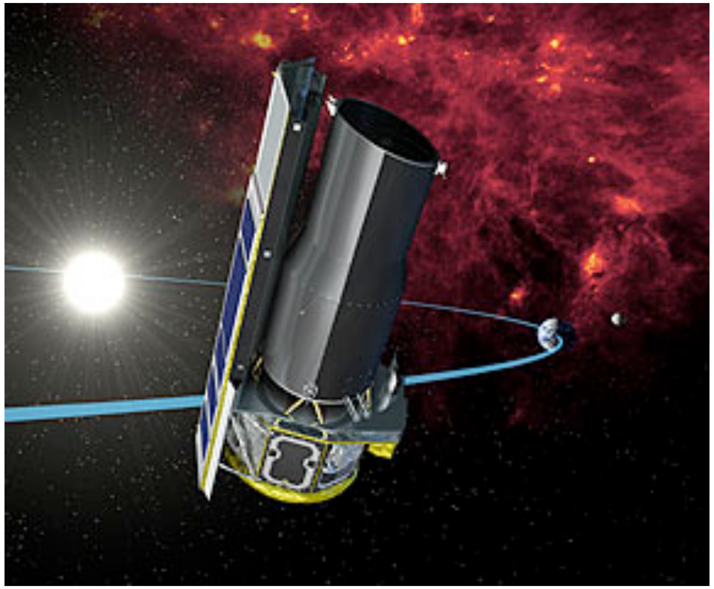


But of transit observations possible from the ground and coronographic observation from space

From Spitzer

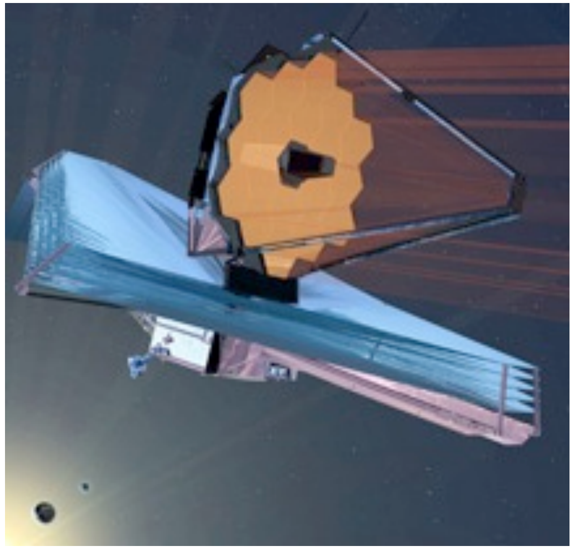
S x 50

To JWST



Telescope size : 85 cm

Amazing Photometric precision
(about 10^{-4})

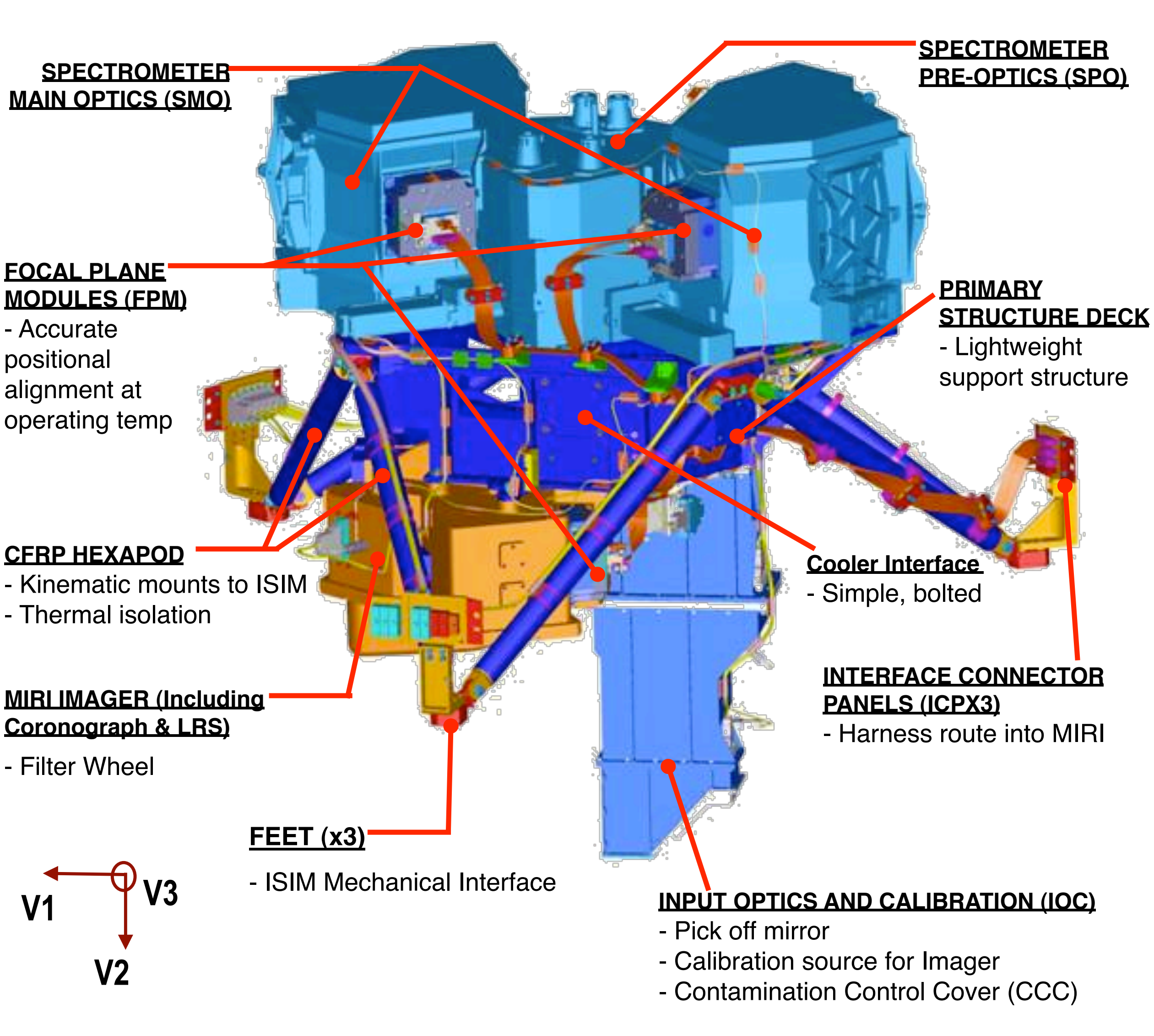


Telescope size 660 m

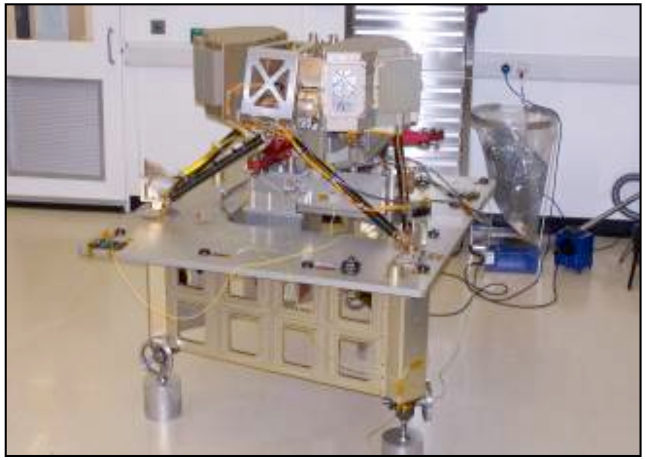
At the same photometric
from photometry (R=2) to spectroscopy
Need enhanced photometric precision

MIRI Design Overview

All Aluminum design provides athermal performance and matched CTEs

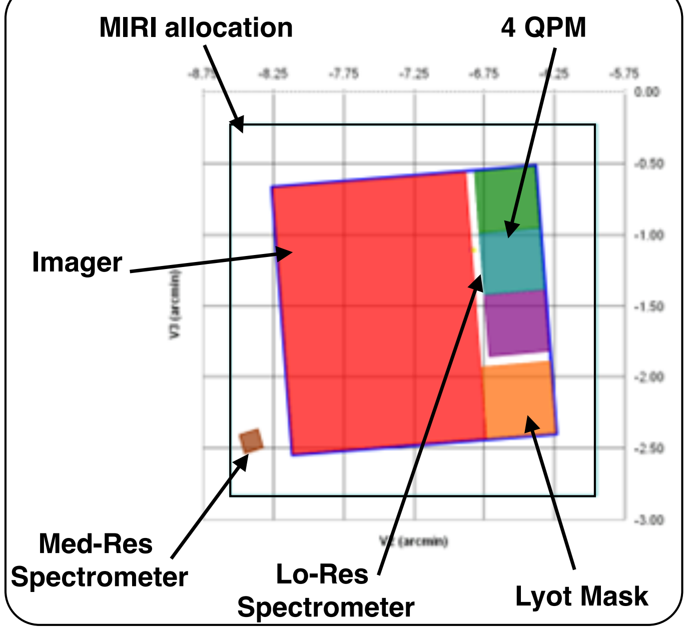


Note: MLI and MLI support frame not shown



Optics Module Verification Model

Input optics define fields of view



A. Glasse presentation first day

Characterization of giant exoplanets

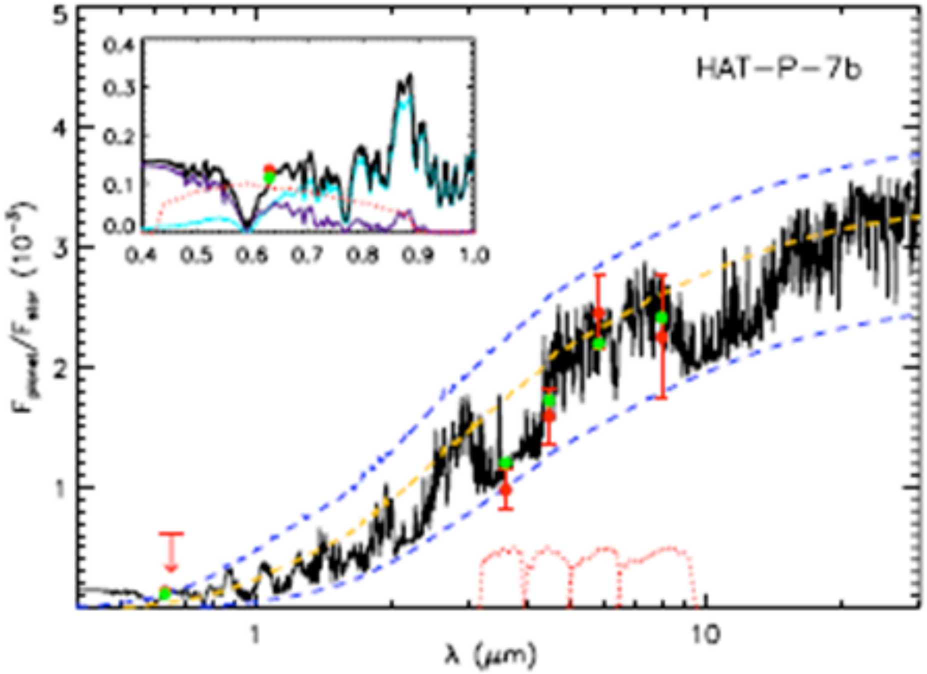


Figure 7. *EPOXI*, *Spitzer*, and *Kepler* secondary eclipse measurements of HAT-P-7b. The solid line is a representative best-fit model, with a temperature inversion. The points with error bars are the observed measurements; the points without error bars are the bandpass-integrated model values. The dashed lines show blackbody spectra corresponding to 2029 K, 2600 K and 2974 K, for reference. The dotted lines are the instrument response curves. The inset is an expansion of the optical region of the spectrum, showing the *Kepler* measurement and response curve. The cyan and purple lines are the thermal and scattered components of the model, respectively.

Christiansen et al. 2010

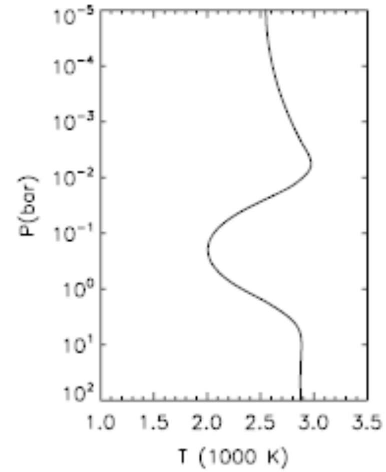


Figure 8. Temperature–pressure profile of HAT-P-7b corresponding to the atmosphere model shown in Figure 7, showing a temperature inversion.

Temperature Inversion

But model with 15 free parameters;
Only 5 data points
→ need spectroscopic obs
MIRI LRS
Or for bright enough sources

Another very existing prospect : characterization of super-Earths

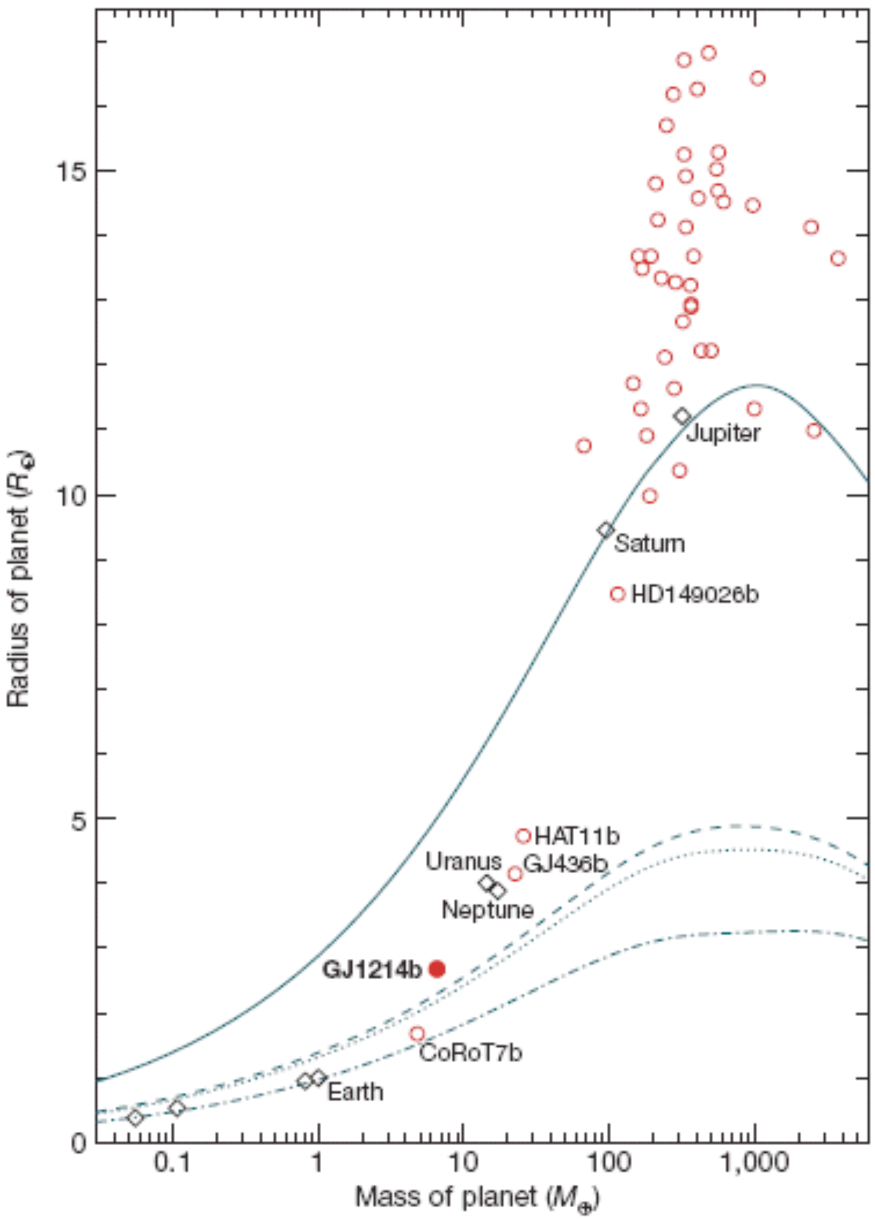


Figure 3 | Masses and radii of transiting planets. GJ 1214b is shown as a red filled circle (the 1σ uncertainties correspond to the size of the symbol), and the other known transiting planets are shown as open red circles. The eight planets of the Solar System are shown as black diamonds. GJ 1214b and CoRoT-7b are the only extrasolar planets with both well-determined masses and radii for which the values are less than those for the ice giants of the Solar System. Despite their indistinguishable masses, these two planets probably have very different compositions. Predicted[16] radii as a function of mass are shown for assumed compositions of H/He (solid line), pure H_2O (dashed line), a hypothetical[16] water-dominated world (75% H_2O, 22% Si and 3% Fe core; dotted line) and Earth-like (67.5% Si mantle and a 32.5% Fe core; dot-dashed line). The radius of GJ 1214b lies 0.49 ± 0.13 $R_\oplus$ above the water-world curve, indicating that even if the planet is predominantly water in composition, it probably has a substantial gaseous envelope.

D. Charbonneau et al. 2009

Two explanets Corot 7b and GJ1214b
With about the same mass but different
Radius → different density
rocky planet for Corot7B
gaz layer (H2?) for GJ1214b

Various atmospheric compositions possible

Good news :
MIRI LRS (5-10 microns) will tell!

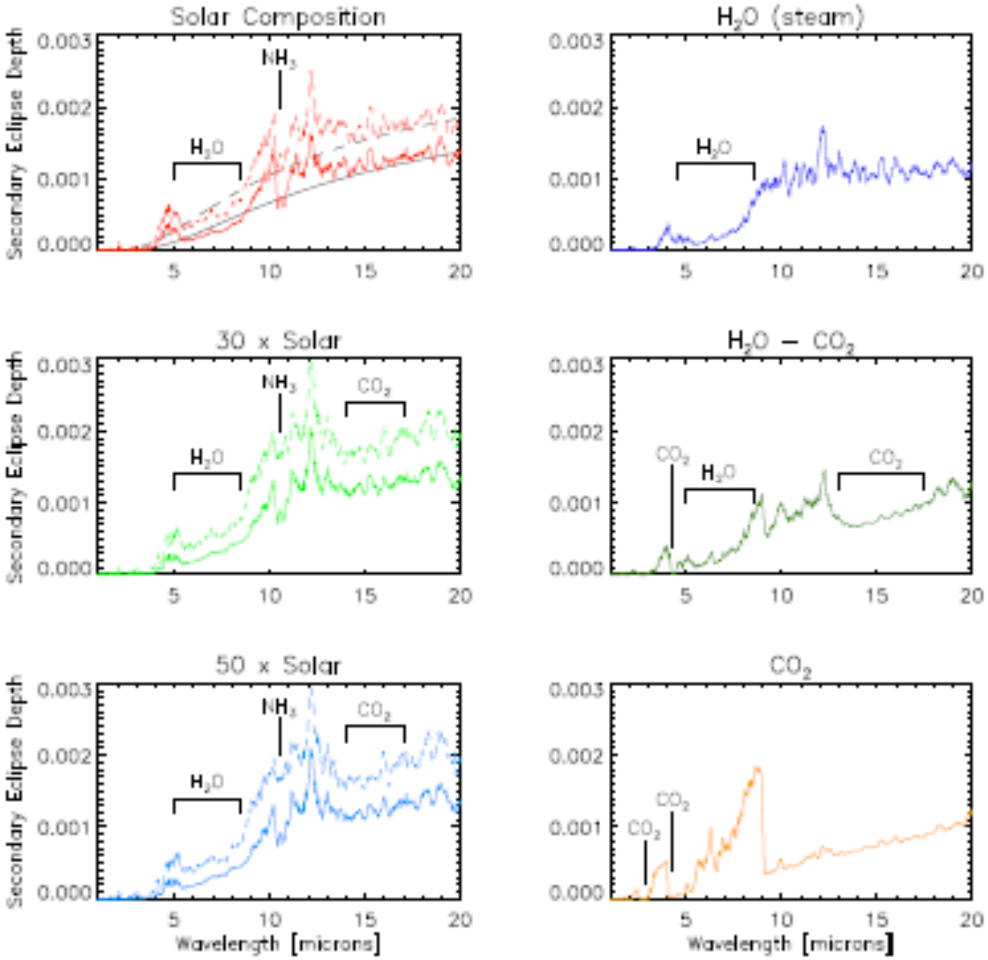
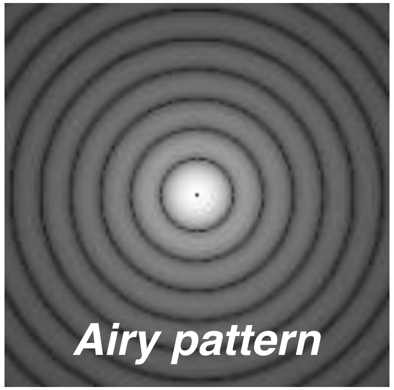
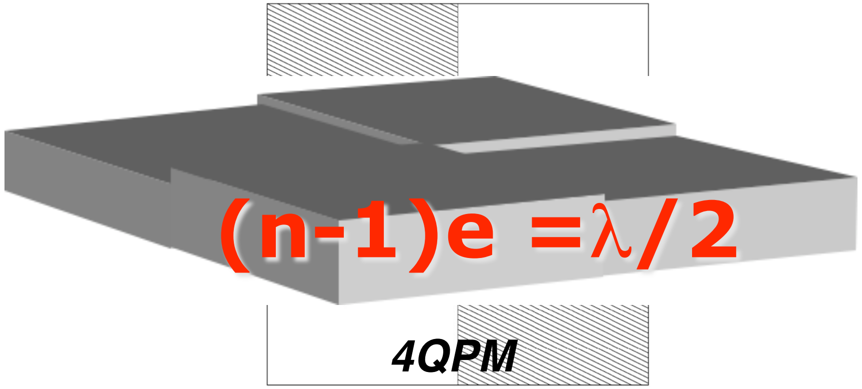


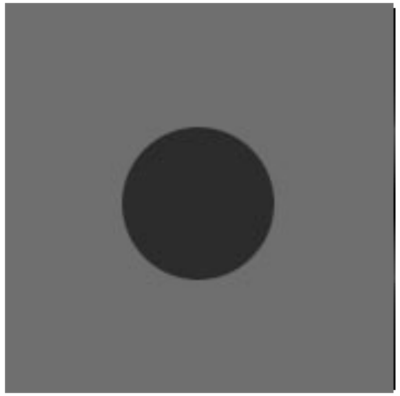
Fig. 4.— The contrast ratio between the day-side emission from GJ 1214b and the emitted light from its M-dwarf host star, plotted as a function of wavelength for 6 different possible atmospheric compositions. In the top left panel we overplot the contrast ratios that would be expected if the planet and star both emitted as blackbodies, with planetary T_{eff} of 555 K and 660 K (thin black lines). Dashed lines are spectra for models with inefficient day-night heat redistribution. Solid lines denote models with efficient heat circulation.

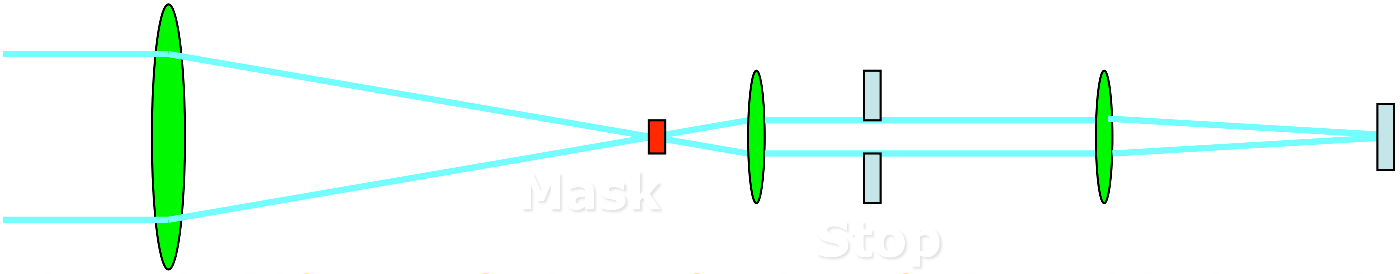
E. Miller Ricci, J. Fortney 2010

Principle of 4QPM

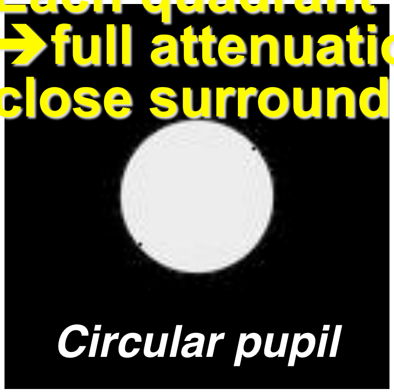


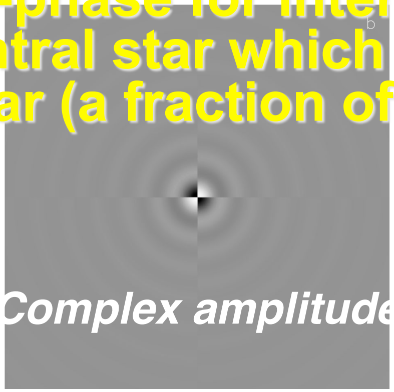


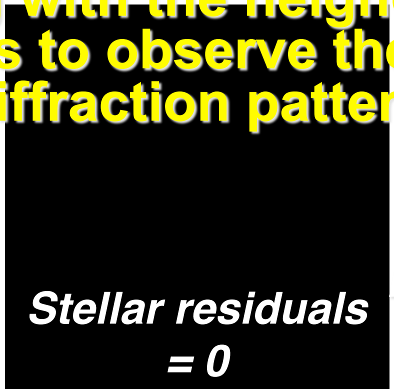




Each quadrant is 90° out-of-phase for interfering with the neighouring one
→full attenuation of the central star which allows to observe the extremely close surrounding of the star (a fraction of the diffraction pattern).

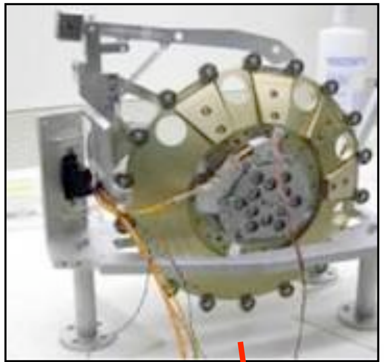






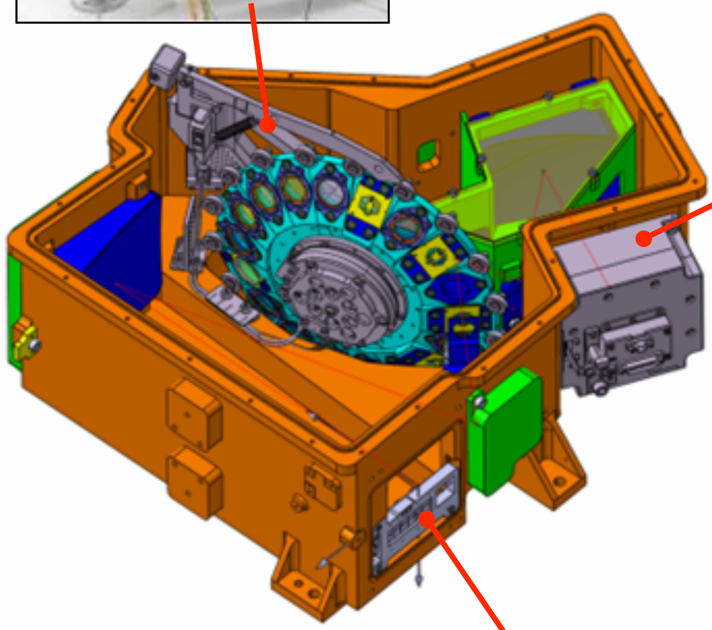
On-axis object is cancelled (for 1 λ)

MIRI Design – 2. Imager Module



18 Station Filter Wheel

- Filters (10), LRS prism (1), chronographic diaphragms and filters (4), open (1), closed+PAR(1), lens (1)

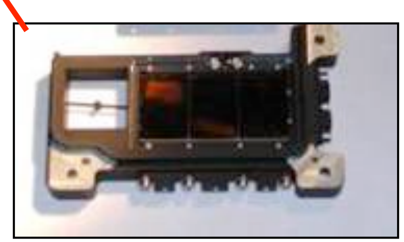


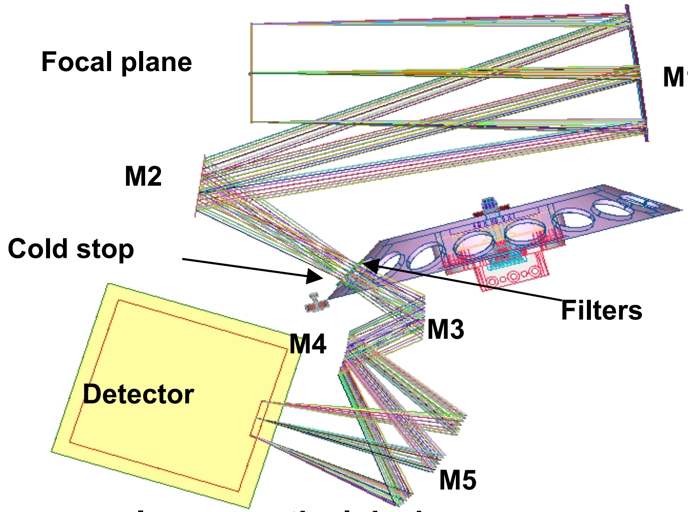
Focal Plane Module

- 6.7K operating temperature
- 1024 x 1024 Si:As detector array thermally and electrically isolated from housing

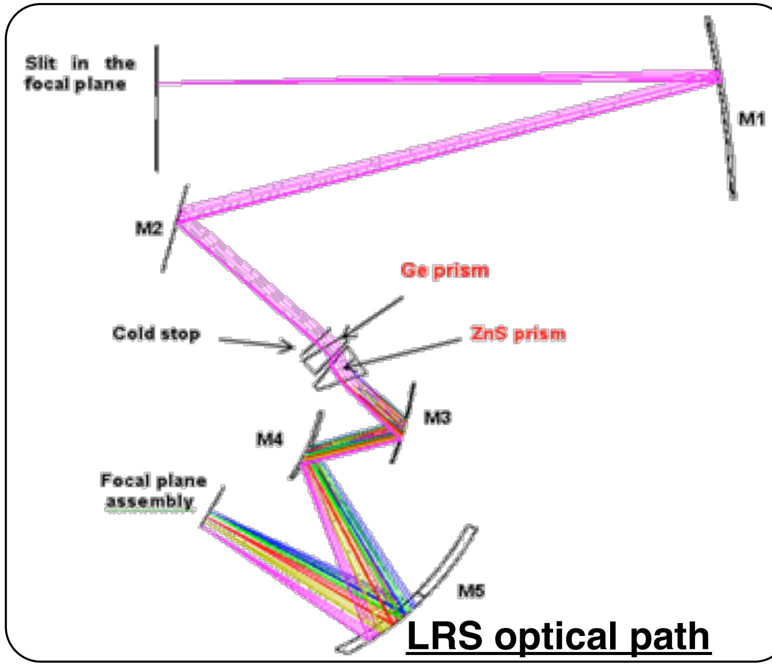
Coronagraphic masks

- 4QPM (3)
- Lyot mask (1)



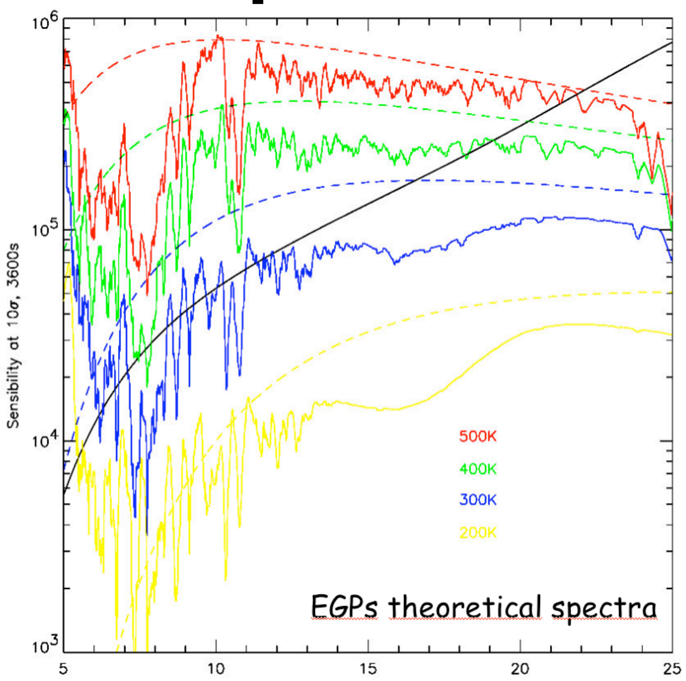


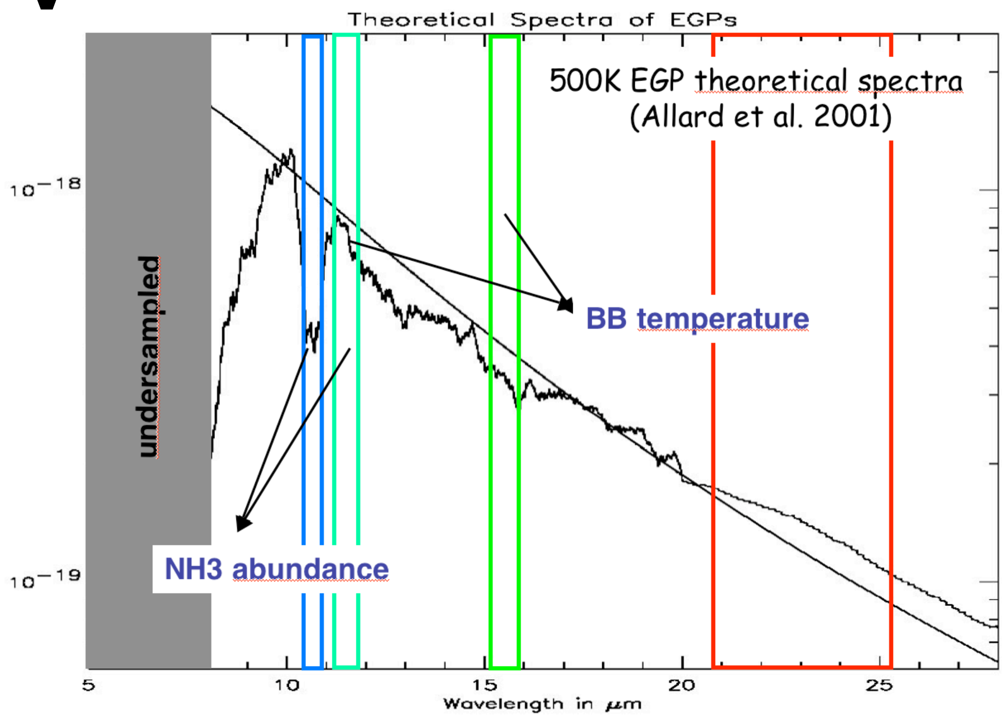
Imager optical design



LRS optical path

Measurements: photometry

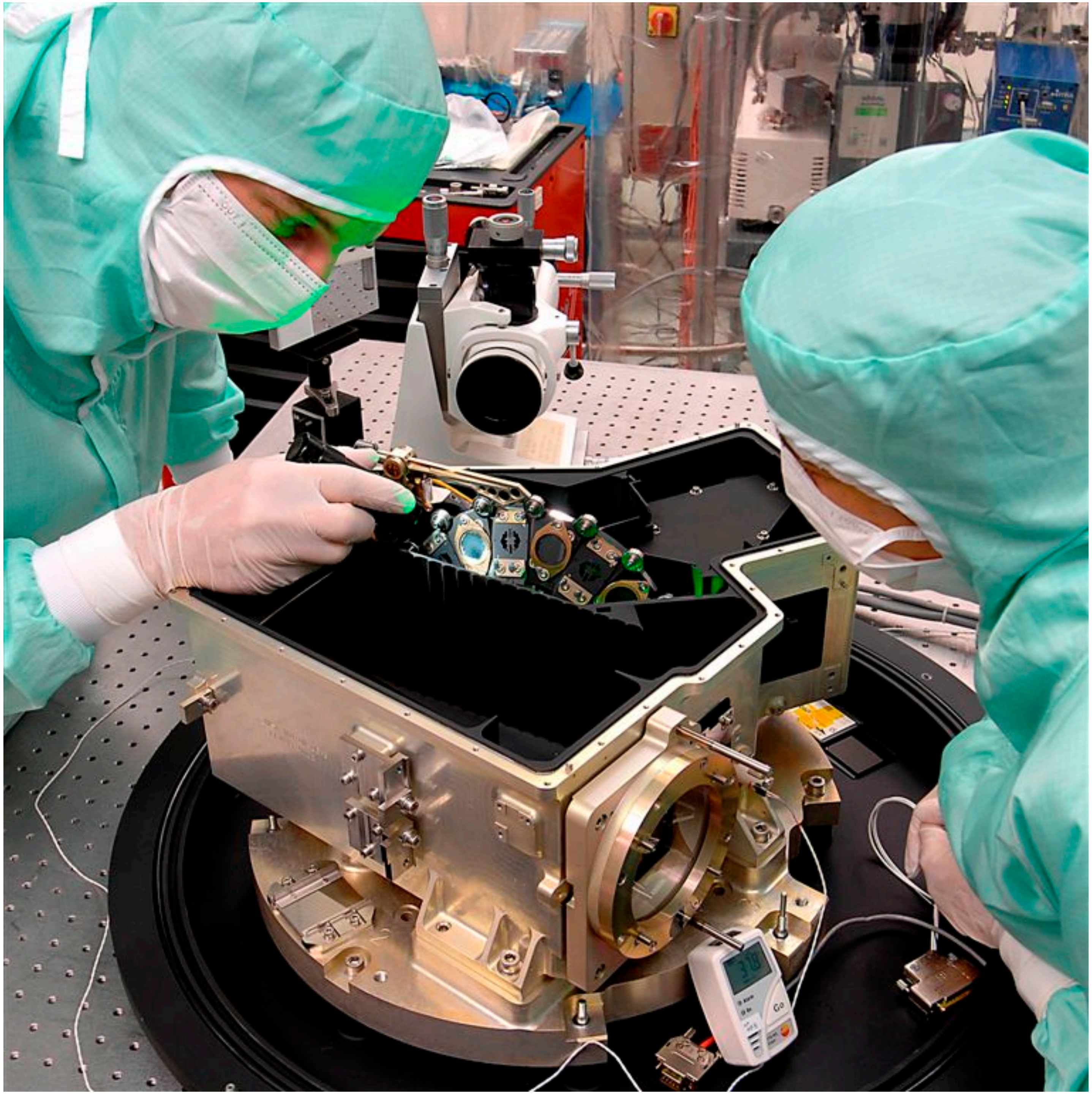




F1550C or (F1550C+ F1140C) => Teff , CO_2, clouds
F1065C + F1140C => Ammonia, clouds
F0560W => water
F0770W => methane
All + modeling => some atmospheric parameters

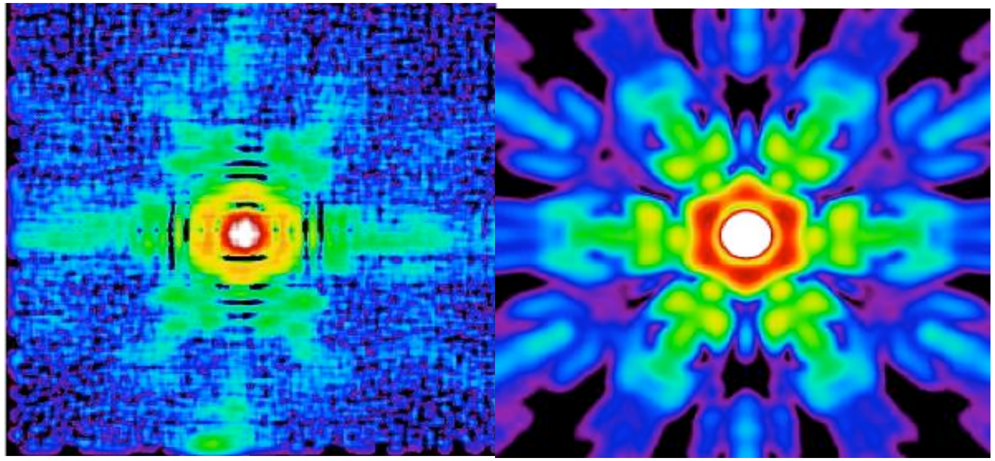
Some degeneracies exist => combination with NIR is crucial


THORLABS

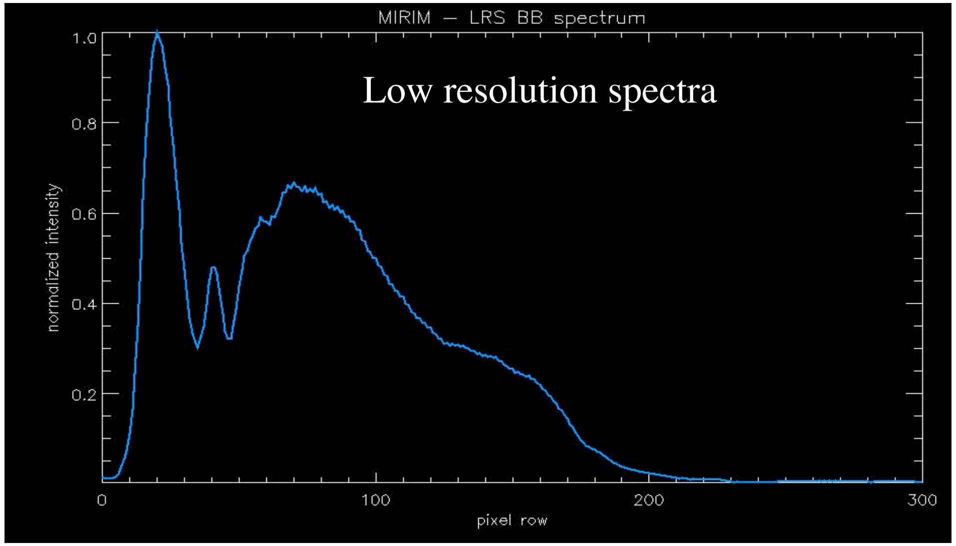


MIRIM FM Test Results

- FM Imager, 5 cryotest campaigns show requirements will be met



“Point source” at 5.6um



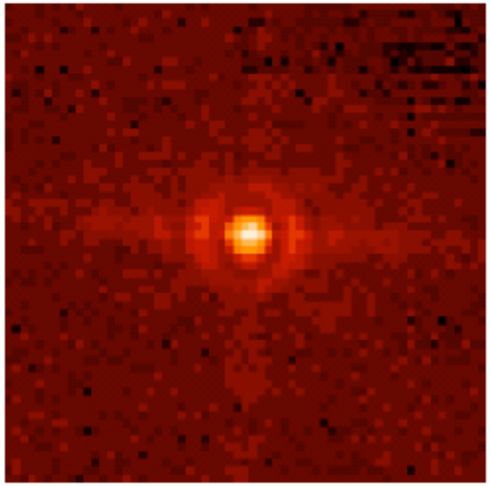


Figure 45: PSF at 11.4µm

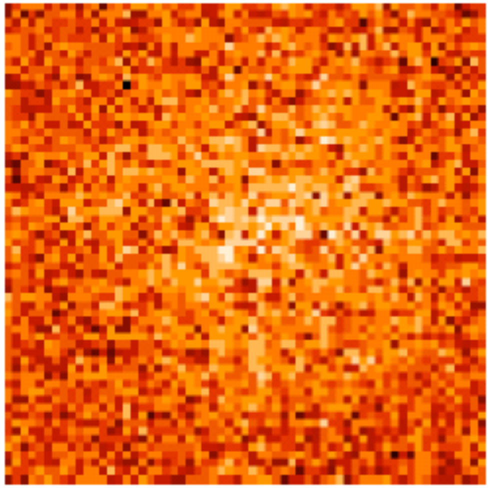


Figure 46: Coronagraphic image at 11.4µm

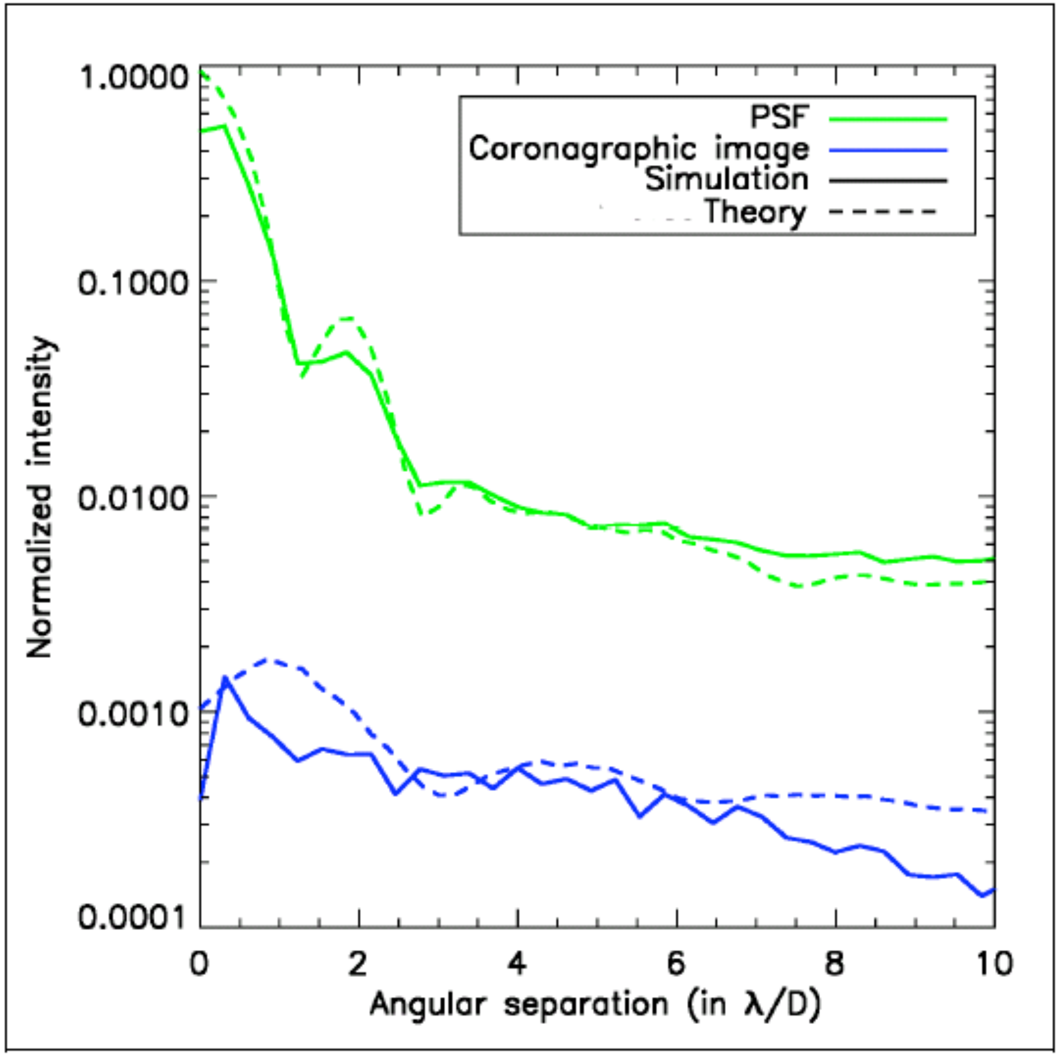


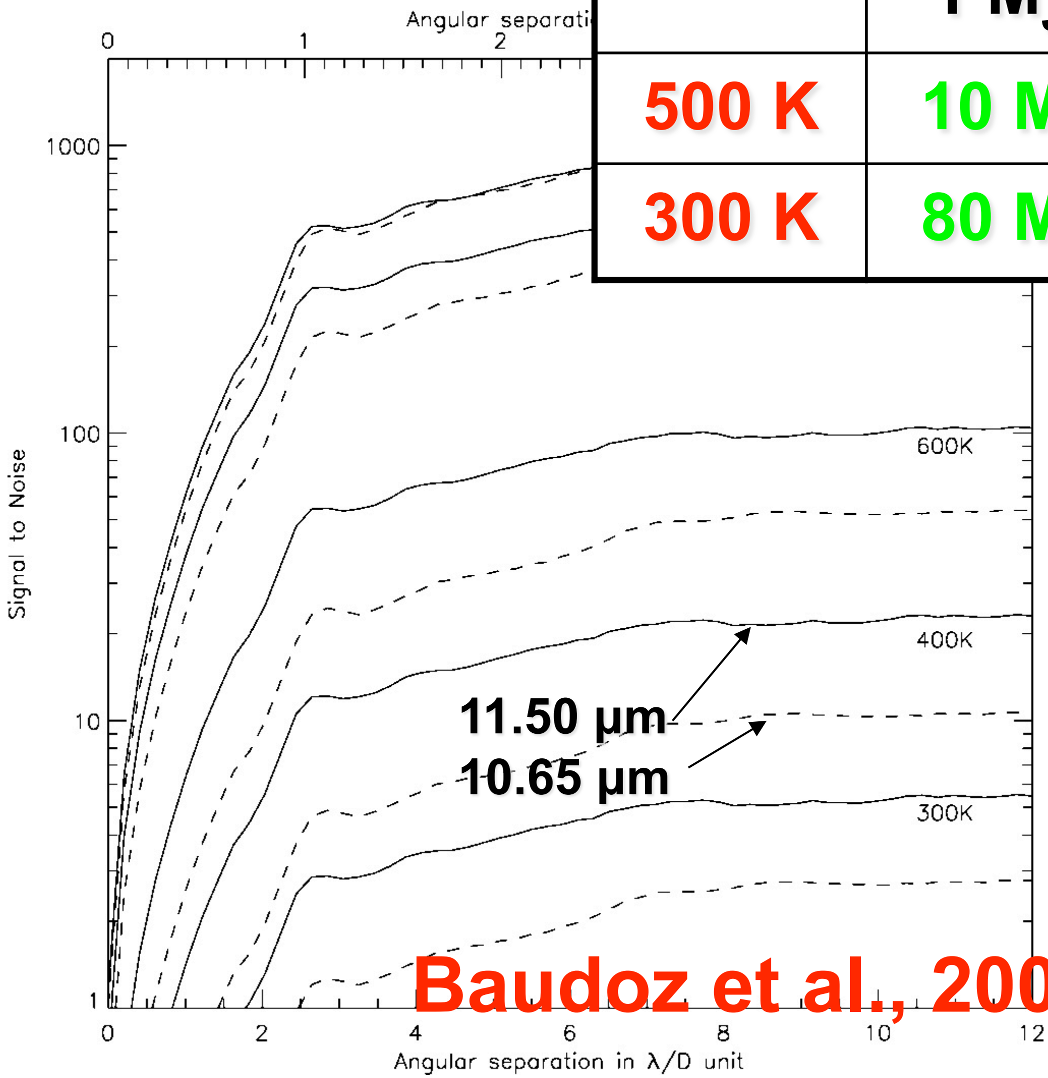
Figure 47: Normalized coronagraphic profile (blue line) and PSF (green line) compared to simulated profiles (doted lines) at 11.4µm

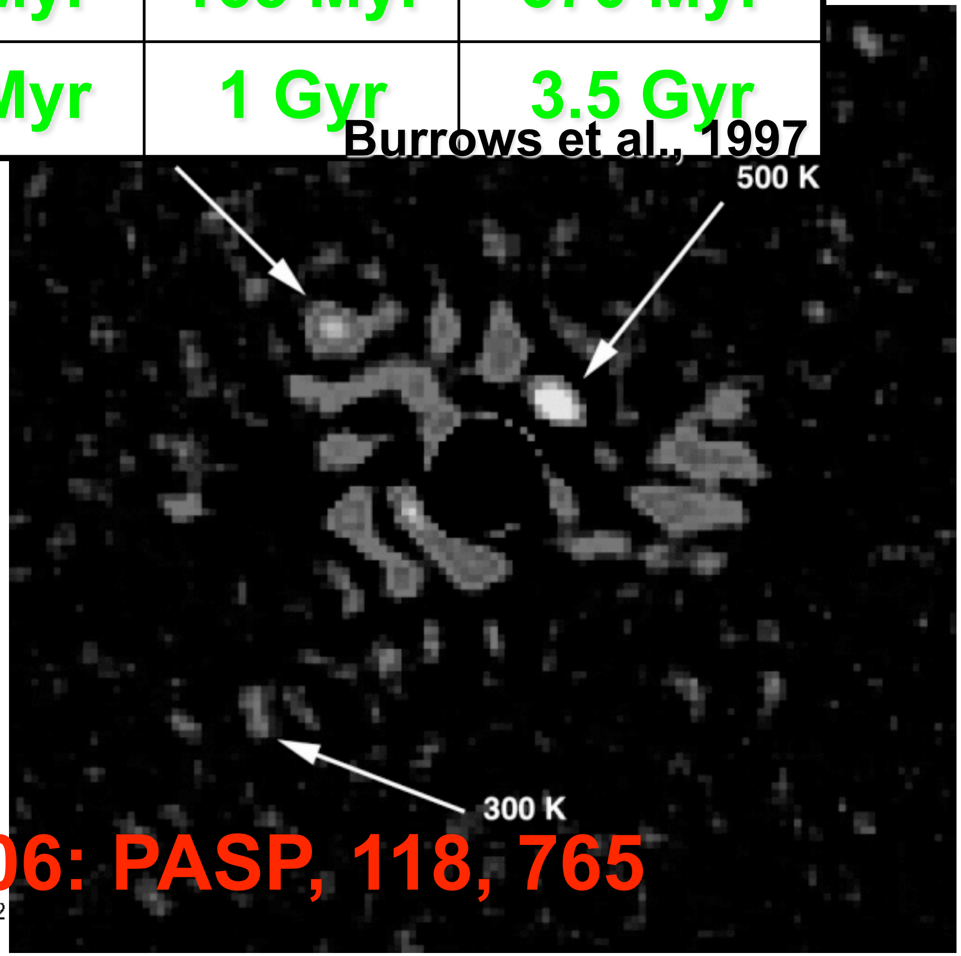
From S. Ronayette et al., MIRIM FM Optical Tests Results, MIRIM-RP-00919-CEA

S/N of EGPs with MIRI CORONAGRAPHS

	1 M_{Jup}	5 M_{Jup}	10 M_{Jup}
500 K	10 Myr	165 Myr	670 Myr
300 K	80 Myr	1 Gyr	3.5 Gyr

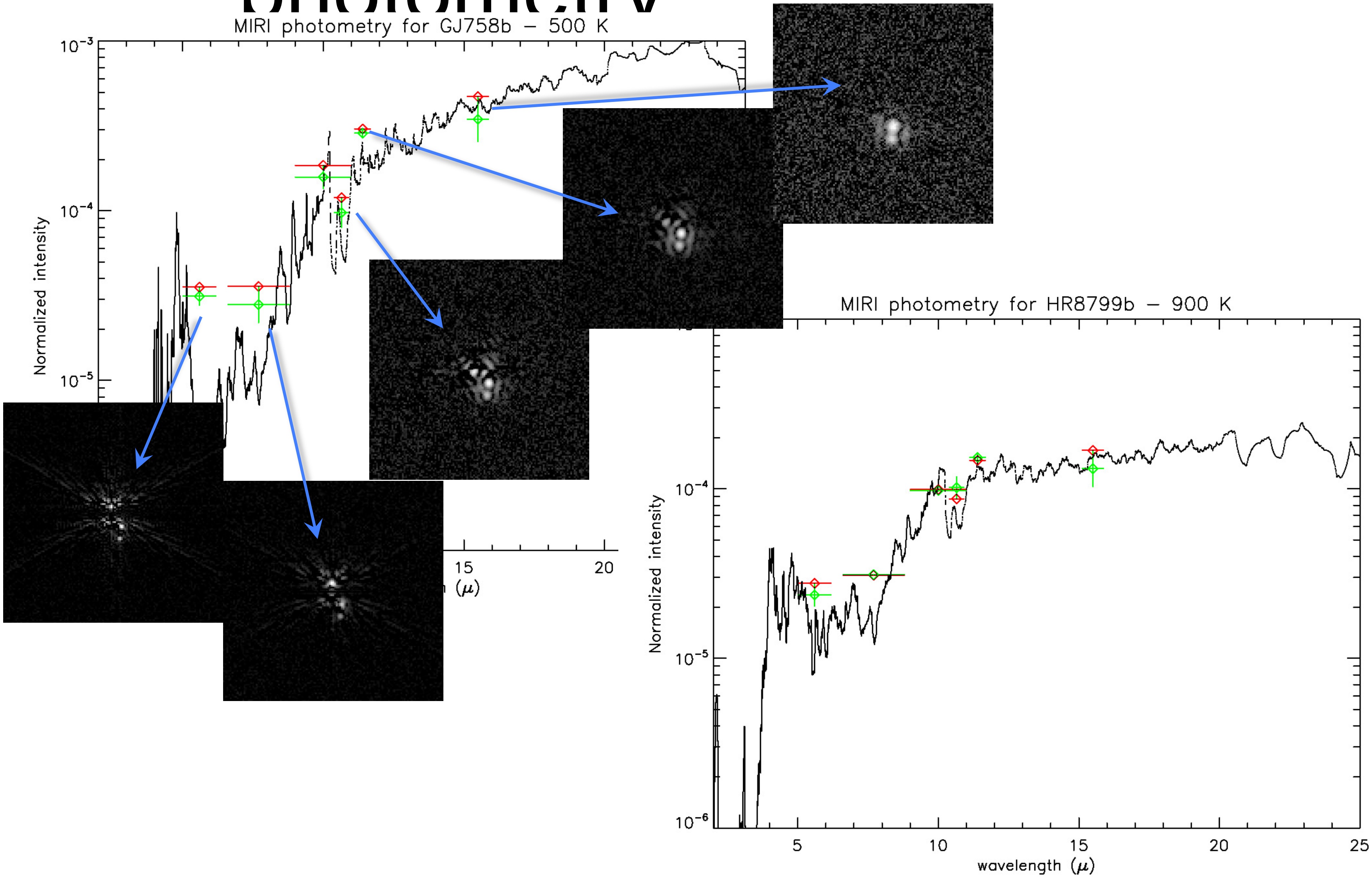
Burrows et al., 1997



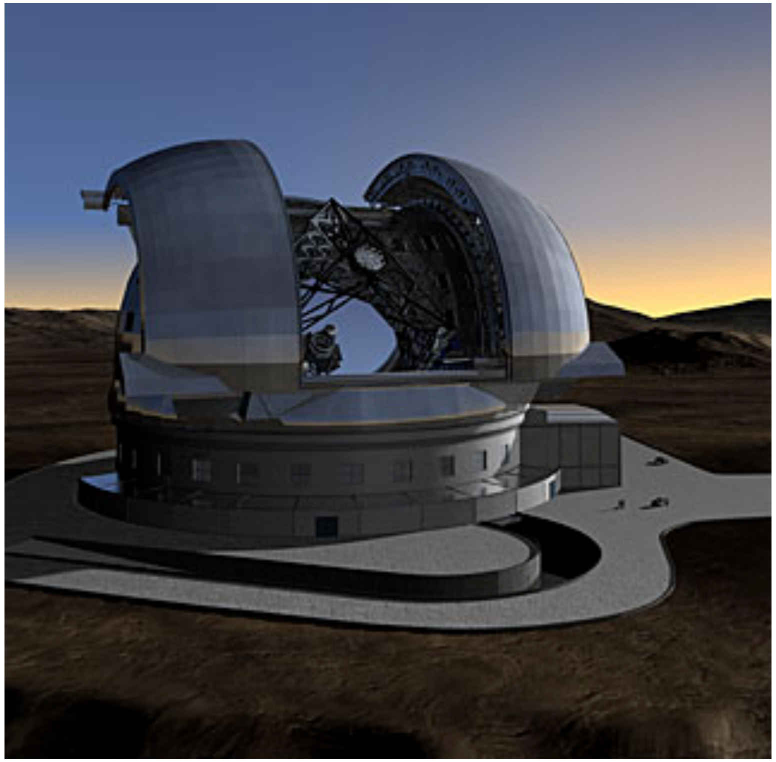


Baudoz et al., 2006: PASP, 118, 765

Measurements: photometry



METIS the mid-IR spectro-imager on the E-ELT

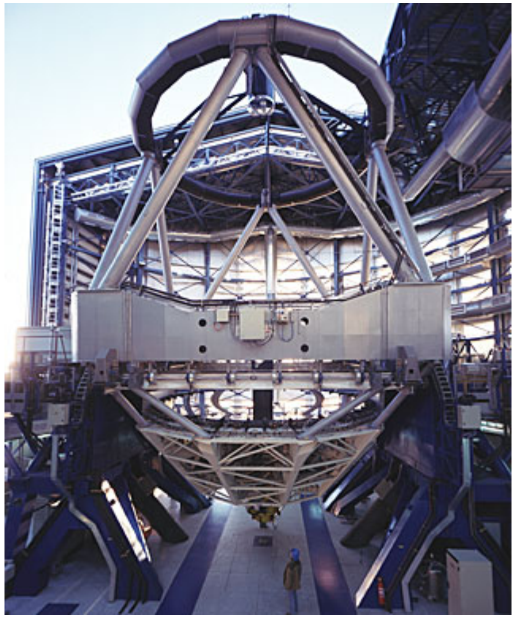


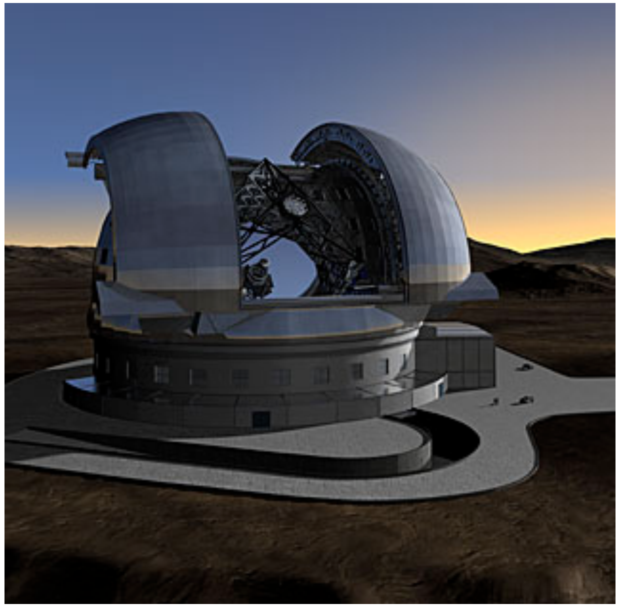
See B. Brandl poster about the complementary nature of JWST and ELT in the mid-IR

Avantages :

- **high angular resolution**
- **high spectral resolution (up to 100 000)**

Perfectly adapted to follow-up of VLT-sphere exoplanet detections





From 8.2 To 42 m

→

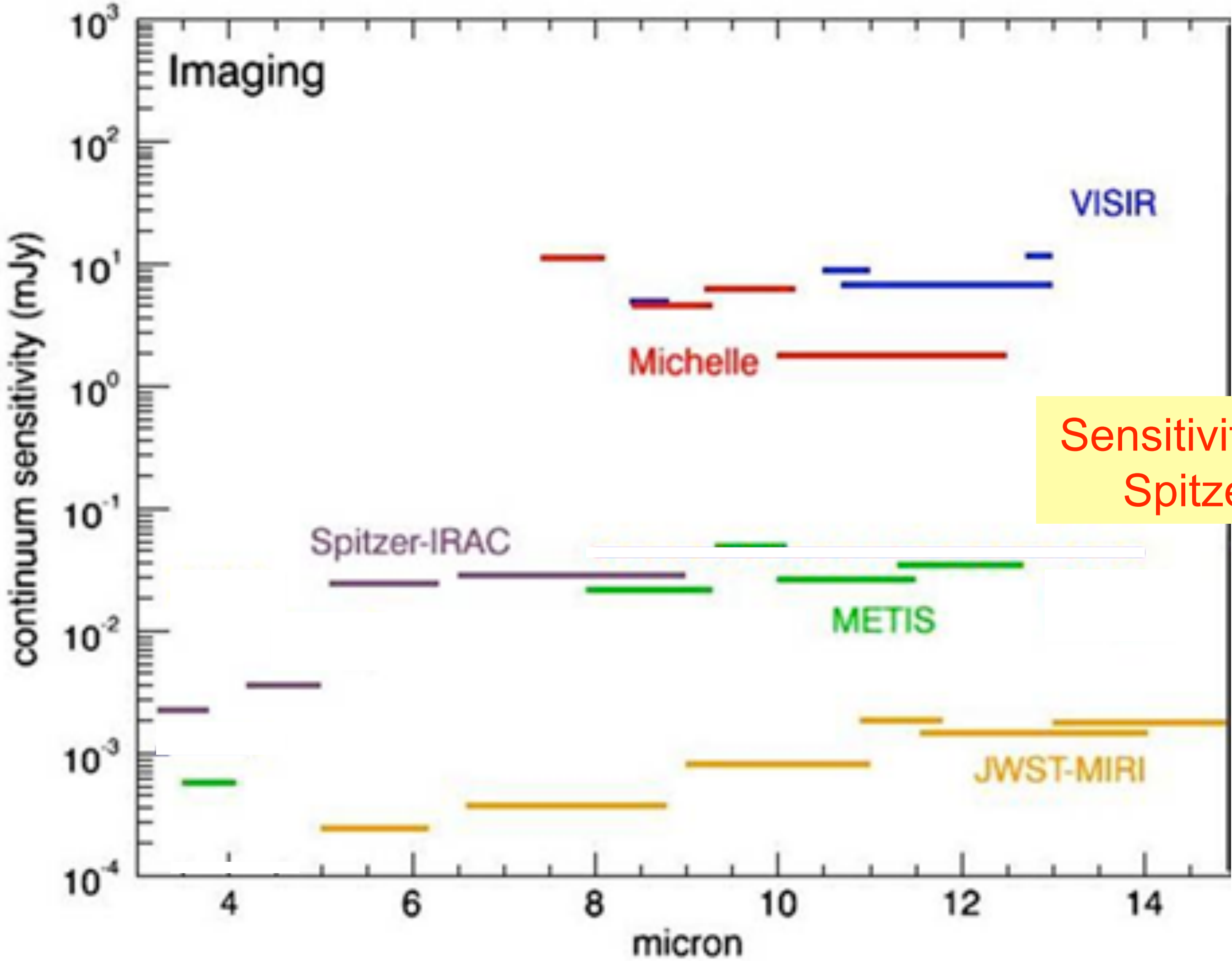
same angular resolution at 10 microns on the E-ELT

as at 2 microns on the VLT

The Potential of the E-ELT

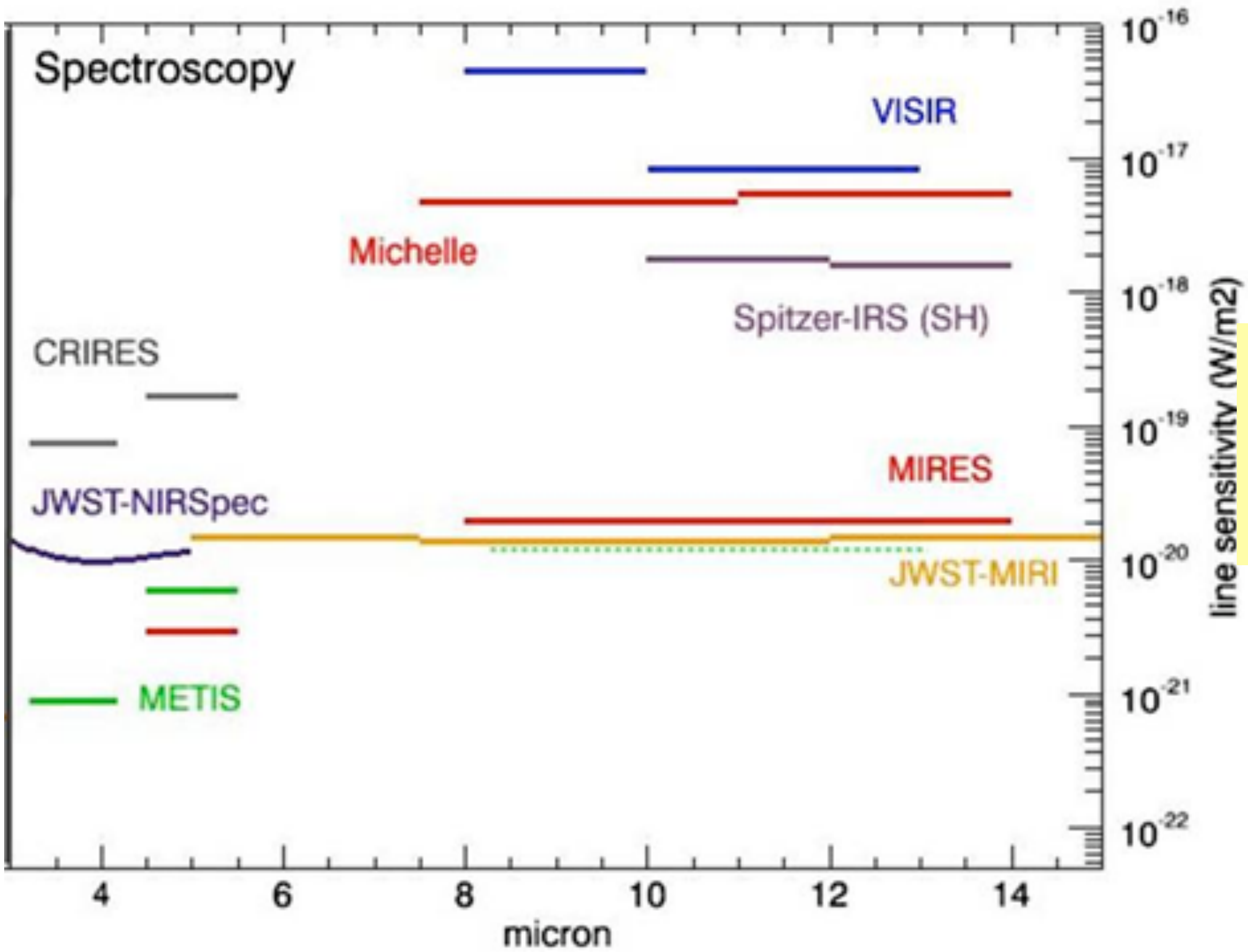
The angular resolution:

Target	**Distance from Earth**	**L-band (3.5µm) resolution**	**N-band (10µm) resolution**
Planet Jupiter	$7.8 \cdot 10^8$ km	79 km	227 km
Exoplanet around nearby star	5 pc	0.1 AU	0.3 AU
Nearby star forming region	140 pc	2.9 AU	8.4 AU
Large Magellanic Cloud	50 kpc	0.005 pc	0.015 pc
Starburst galaxy M82	3.2 Mpc	0.33 pc	0.93 pc
Galaxy at z = 1	1659 Mpc	169 pc	482 pc



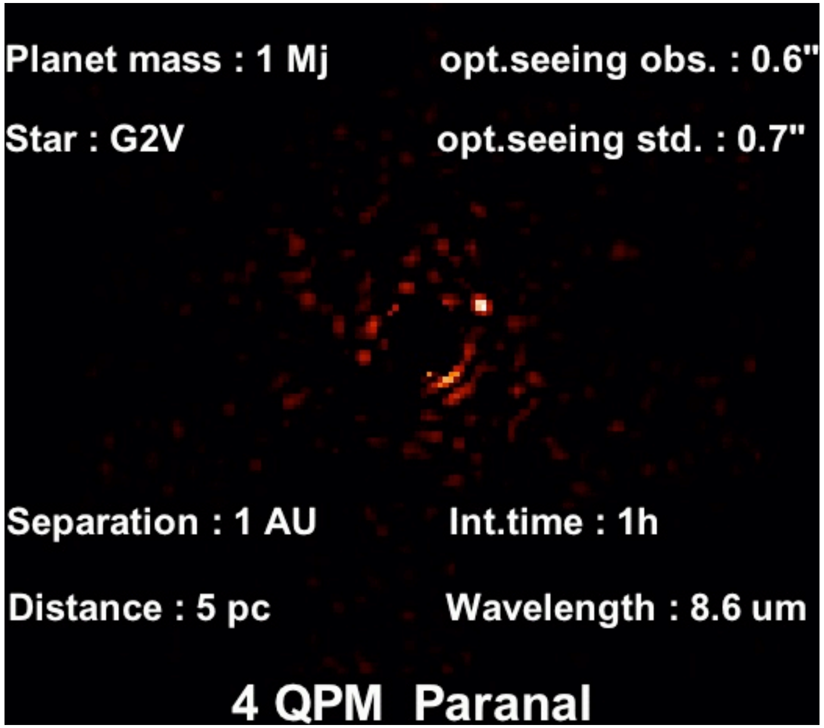
Sensitivity similar to the Spitzer sensitivity

SPHERE follow-up



As sensitive as MIRI for high spectral resolution observations (unresolved lines)

Not yet test results as for MIRI! But simulations!



From E. Pantin et al. METIS Science Analysis Report N° EE-TRE-MET-503-0004

But the most interesting in the field will be

The unexpected!

The field is developping so rapidly!!

A taste of surprises
from W. Brandner, next talk