Super Earth Explorer : SEE - COAST

P. Baudoz and the SEE-COAST team
(J. Schneider, A. Boccaletti, G. Tinetti, D. Stam, etc…)

l'Observatoire de Paris LESIA

Direct Imaging overview

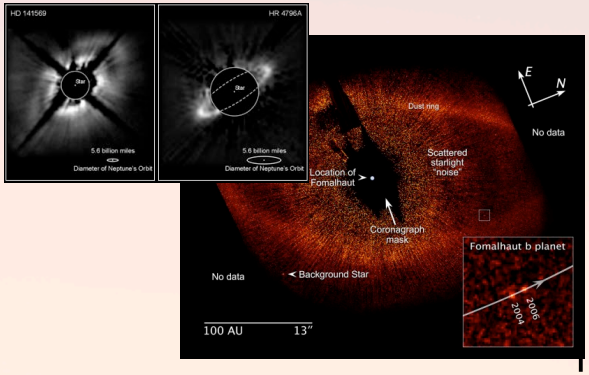
SEE
Super Earth Explorer

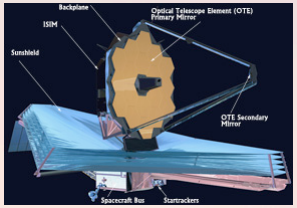
Space-based

Opportunity for Space projects

In the Visible

HST



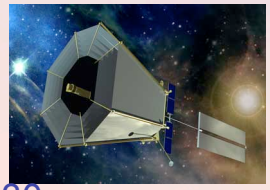


JWST
NIR + MIR:
Old EGPs

SEE COAST
Vis/NIR: Old Jupiter
+ Super Earth

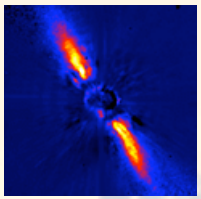
Darwin/TPF-I
MIR: Earth

TPF-C
Vis: Earth

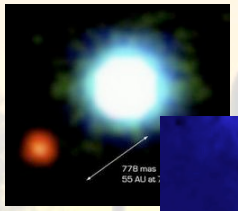


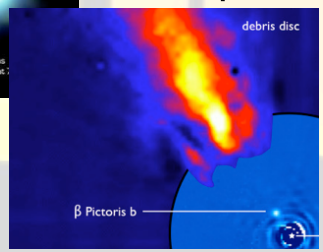
1995 2000 2008 2011 2017-2020 >2025-30

4m + OA
Silla, CFH



8m + OA
VLT, Keck,
Gemini

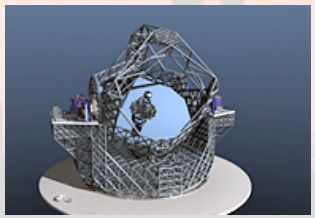




8m + XAO
SPHERE / GPI
NIR : EGPs
young/massive/nearby

Ground-based

30/42m + XAO
EPICS/ELTs
NIR : EGPs
intermediate
Old + Super-Earth ?



l'Observatoire de Paris LESIA

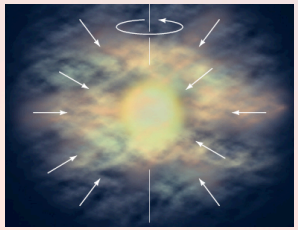
P. Baudoz & SEE-COAST team

Science Goals of SEE-COAST

Explore the diversity of physicochemical properties of planets

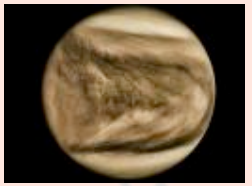
Main objectives :

- Jupiter-like planets



- exo-zodiacal disks

- Super-Earths around nearby stars



Philosophy:

- Stay Open-minded (Ready for the unexpected)
- Exhaustive observation on a few objects rather than a survey

SEE - COAST management

SEE-COAST stands for :

Super Earth Explorer - Coronagraphic Off-Axis Space Telescope

- a scientific precursor to DARWIN/TPF-I & TPF-C

- a technological precursor to TPF-C

PI : J. Schneider (Obs. Paris)

A large European consortium :
(France, Belgium, Switzerland, Italy, Nederland, UK, Germany)

ULg / CSL / LESIA / LUTH / LUAN / ETH-Zurich / IAP / Obs. Geneva
U. Bern / UCL / ROE / U. Hertfords. / MSSL / SRON / Astron / U. Utrecht
LAOG / ONERA / DLR / U. Vienna / U. Nantes / U. Torino

contact Jean.Schneider@obspm.fr

Why the visible ?

- **Resolve the Star-Planet system with modest telescope size**
- **No direct spectroscopic analysis in the visible from ground-based project**

$$\begin{cases} Position(t) \\ Flux_{Refl}(\lambda, t, \vec{P}) = F_*(\lambda) \times A(\lambda, t, \vec{P}) \times \left(\frac{R_{pl}}{2d(t)} \right)^2 \times \phi(t) \end{cases}$$

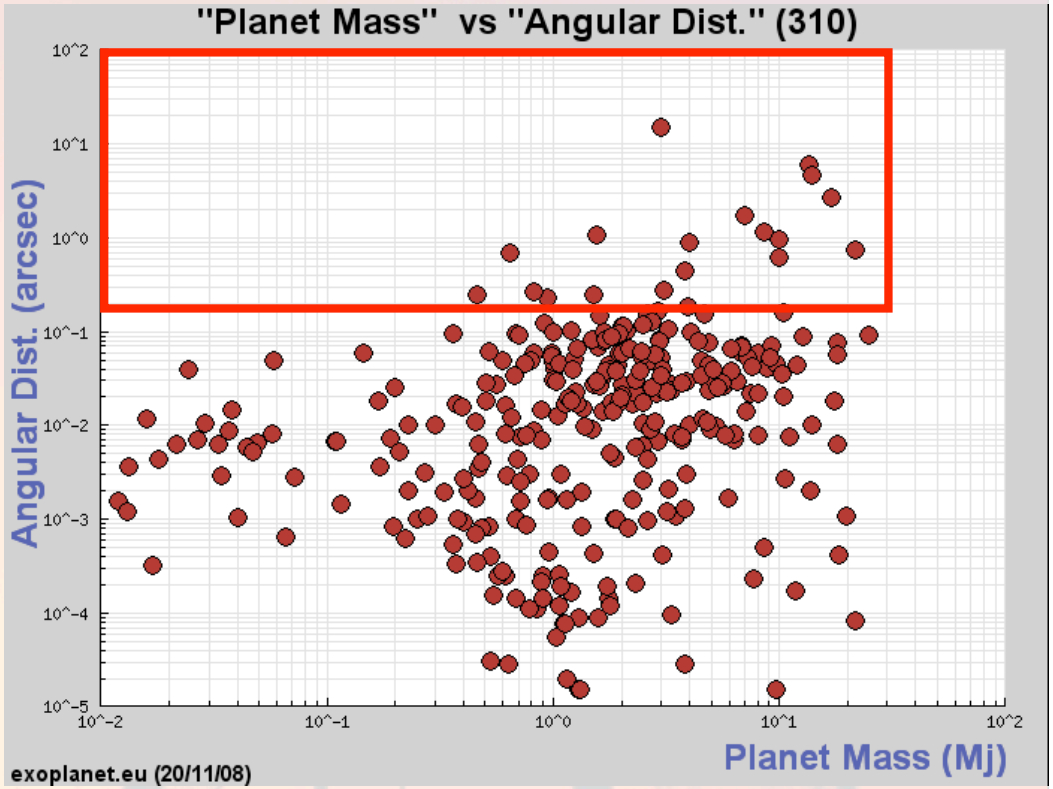
Species Clim. State of surf. "Shape"

- **Explore diversity of planets in the visible :**
  - atmospheric composition, clouds, (spectra)
  - atmospheric pressure : (Rayleigh scat.)
  - albedo & internal structure
  - surface properties
  - large surface morphology
  - seasonal variabilities, planet rotation
  - surroundings (rings, companions)

Which Planet to SEE ?

- **Jupiter-like planets**

- Targets already exist



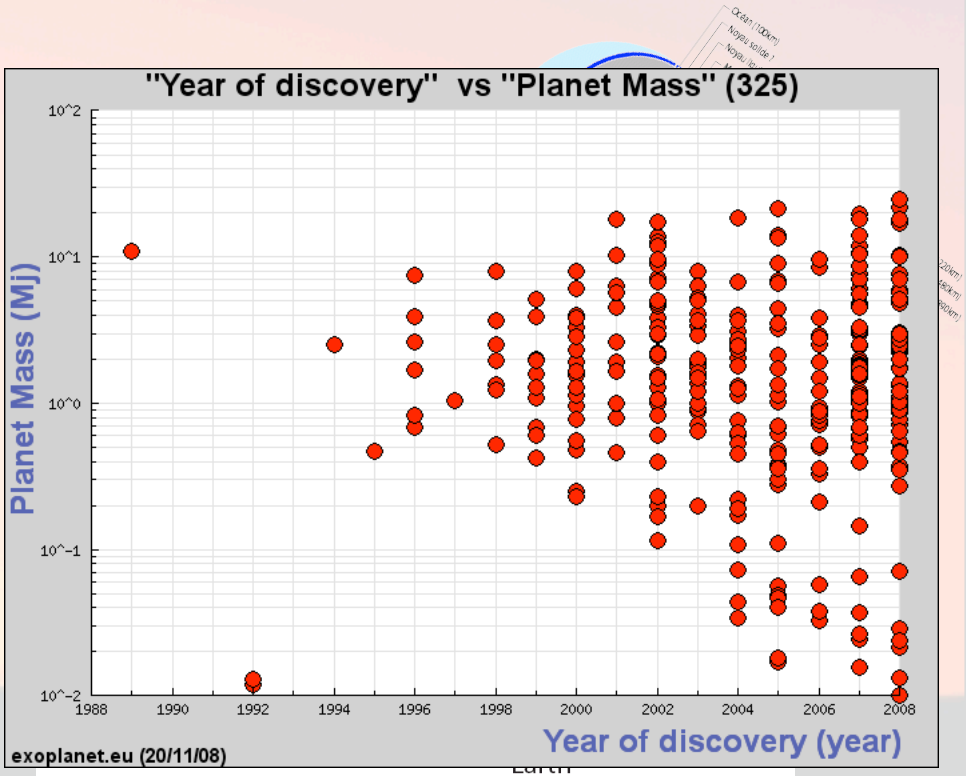
P. Baudoz & SEE-COAST team

Which Planet to SEE ?

- **Jupiter-like planets**
- **Super-Earth planets**

- Targets are on their way

(30% of star with Super-Earth, >40 candidates in the RV pipeline)



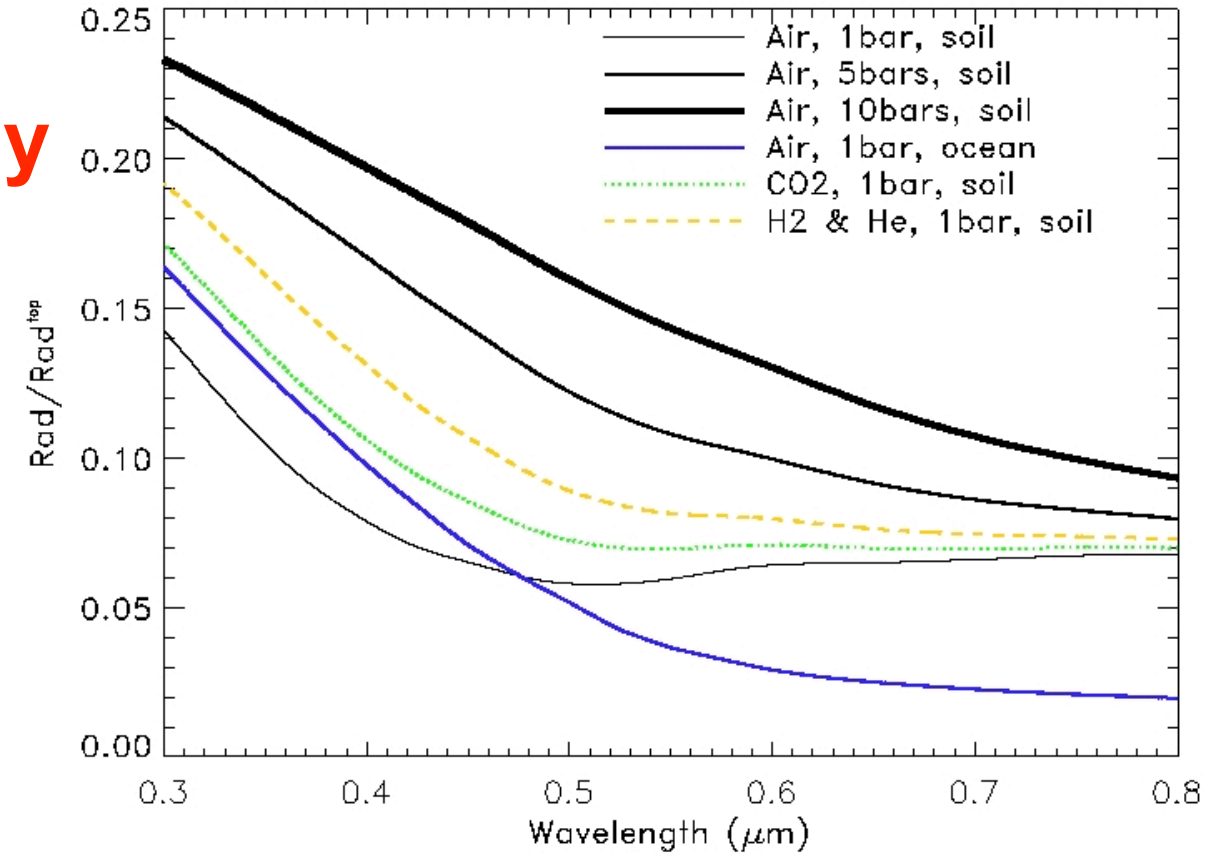
P. Baudoz & SEE-COAST team

Explore the diversity

- **Spectroscopy**

  - Spectra => Chemical composition

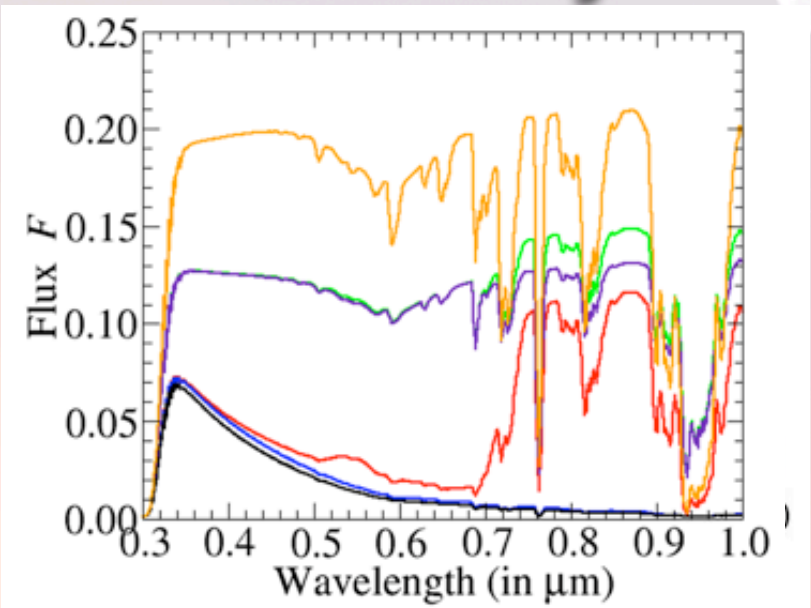
  - Rayleigh scatterring => pressure, surf. reflectivity



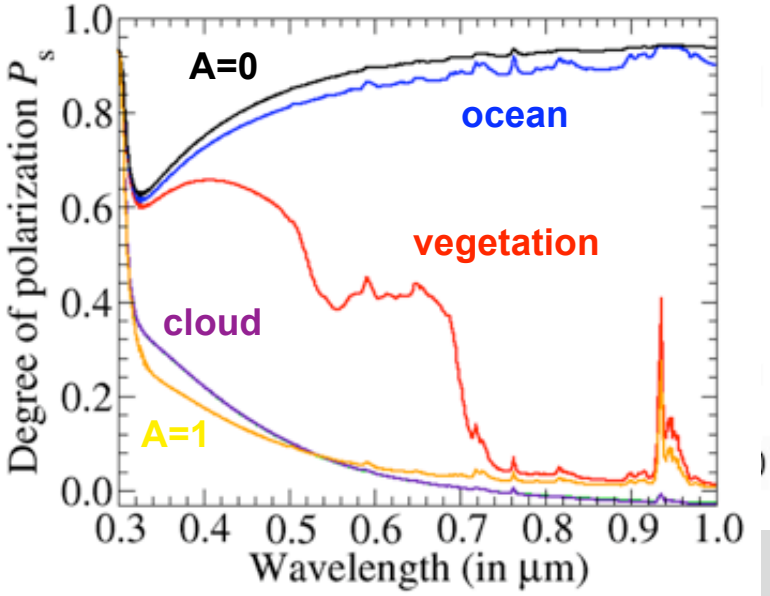
Explore the diversity

- **Spectroscopy**
- **Polarimetry**

- Polarization
=> Clouds / albedo



Earth-like planet - Stam et al. 2008



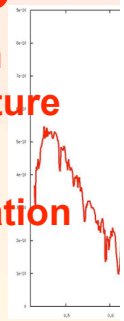
P. Baudoz & SEE-COAST team

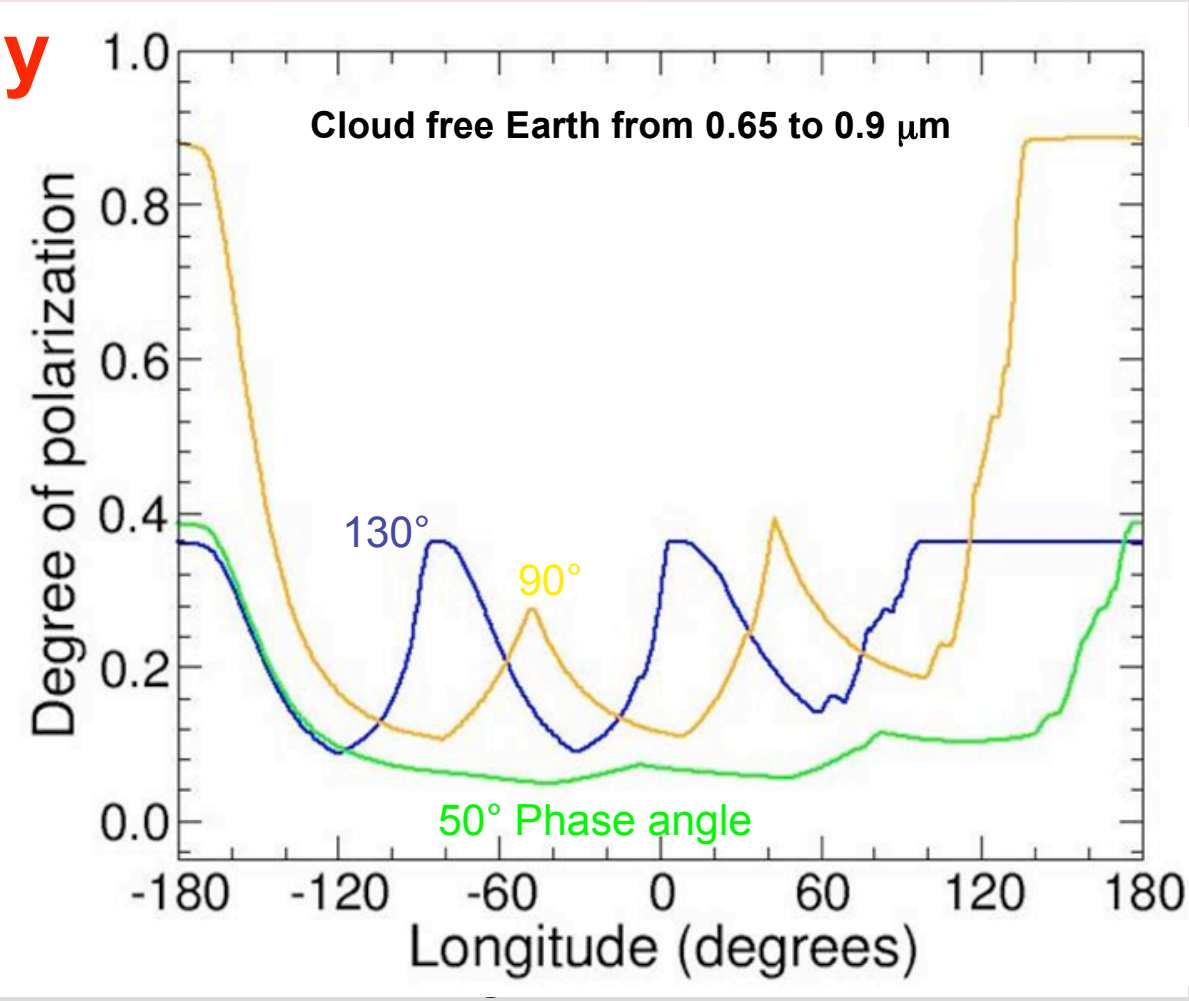
Explore the diversity

- **Spectroscopy**
- **Polarimetry**
- **Variability**

- Spectral time variation
=> variation of temperature
=> surface properties

- Polarimetric time variation
=> surface properties





P. Baudoz & SEE-COAST team

Mission concept

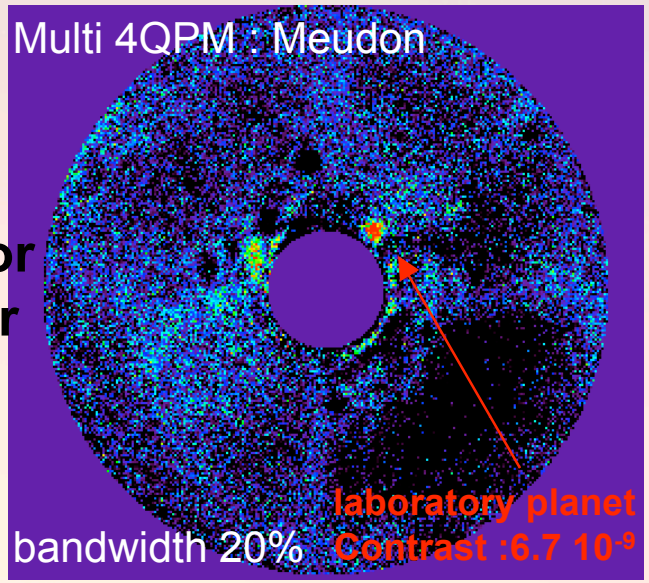
- *Visible off-axis Telescope @ L2*
- *1,5 m in diameter (as a minimum)*
- *Optimized for High contrast imaging*
- *Ultra-smooth mirror (WFE λ/100 rms @ 633 nm)*
  - *+ coronagraphy*
  - *+ calibration (differential imaging)*
  - *+ active correction ?*
- *FOV : 3 x 3 ”*
- *Spectral range : 0.4 - 1.2 μm*
- *Spectral resolution : 40*
- *Polarimetric capability*

Technology Challenges ?

Ultra-smooth Mirror

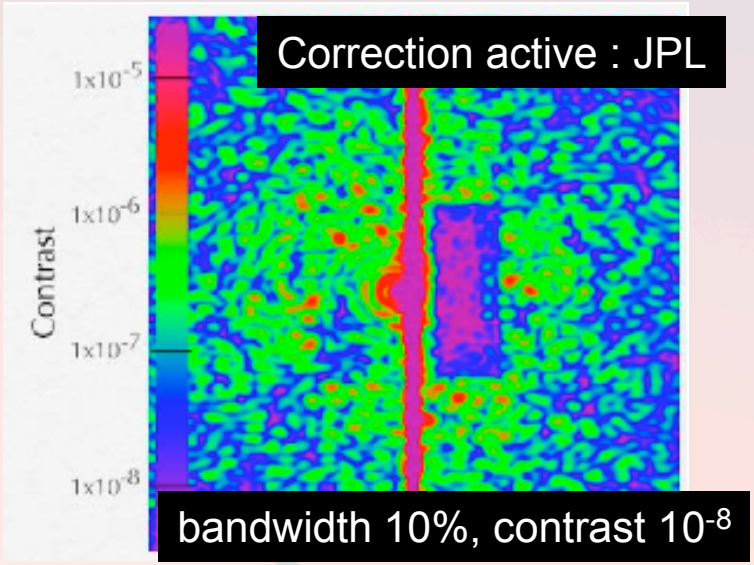
Challenging but feasible (EUV mirror with 0.4m diameter already exist

Coronagraphy



Baudoz et al. 2007, 2008

Active correction



Trauger & Traub 2007

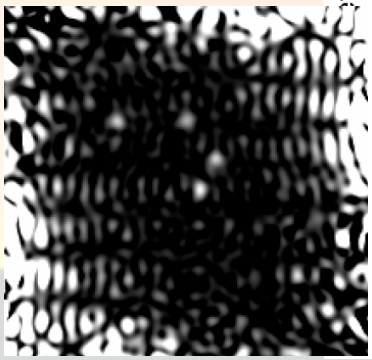
Almost where we want to be (factor 5 to 10)…

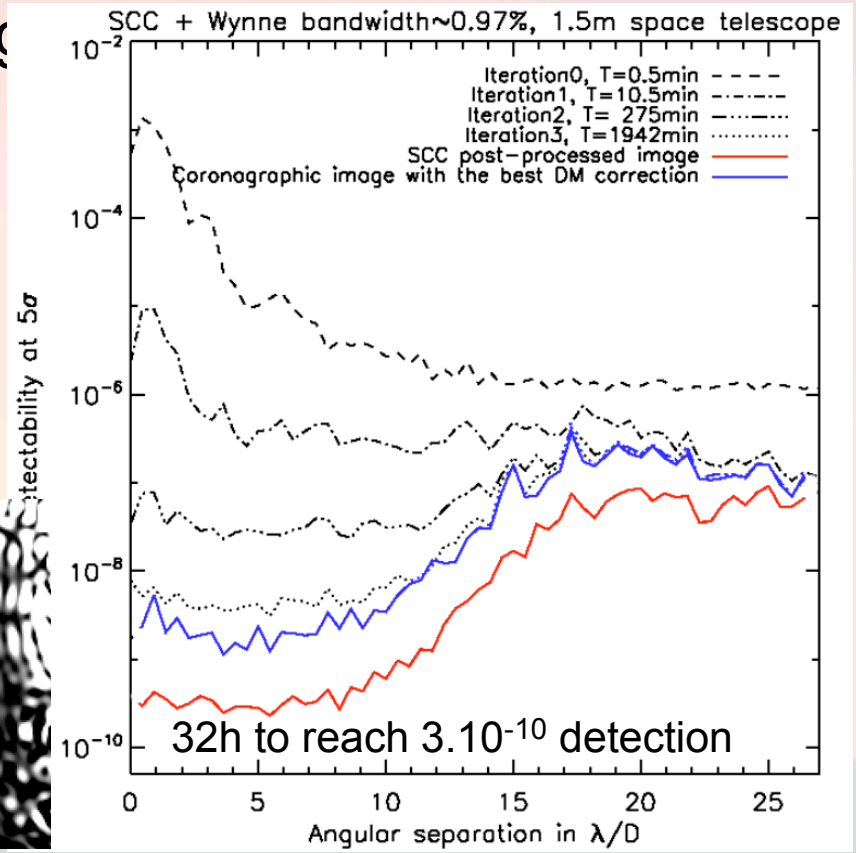
But … Need development (mirror diameter, from lab to sky…) !!!

Need for efficient speckle calibration

- Differential Spectral Imaging
  Integral Field Spectroscopy (heritage from SPHERE/GPI/EPICS study)
- Differential Polarimetric Imaging
  Also from SPHERE/EPICS study
- Use of coherence
  Self-Coherent Camera
  ⇒ used for aberration correction and speckle calibration (Galicher et al. 2008)

  could be coupled with IFS…

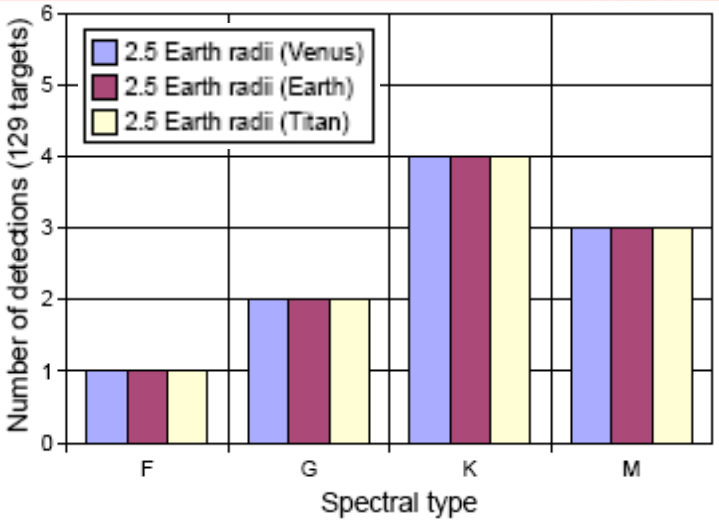


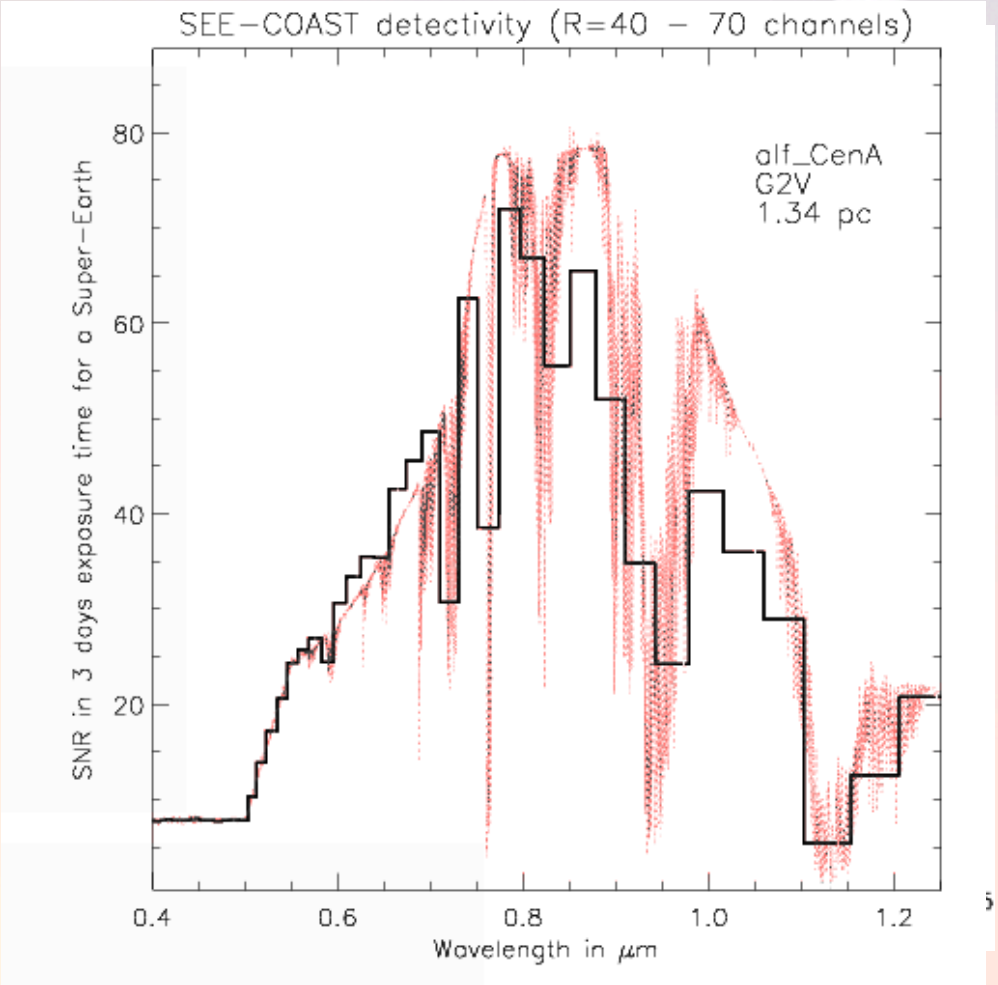


Performance estimates

Preliminary simulations :

- > 600 targets considered (FGKM)





=> a few Super Earths potentially detectable

P. Baudoz & SEE-COAST team

Conclusions

SEE COAST Strategy :

Stay Open-minded -- Get the diversity !

Variability of Spectroscopy & Polarimetry

=> Exo-Planetology science for old Jupiter and Super-Earth

=> First steps toward longer term projects aiming for habitable Earths and astrobiology

SEE COAST Project :

- Spectral Range: Visible to NIR (complement to JWST, SPHERE/GPI, EPICS)

- "Simple" Monolithic Coronagraphic Telescope

- Complexity at the instrument level (still need technology development)