Super-Earths Explorer

J. Schneider, P.Riaud, G. Tinetti et al.

ULg / CSL / LESIA / LUAN / ETH-Zurich / U. Vienna

LUTH / IAP / Obs. Geneva / U. Amsterdam / U. Torun

LAOG / U. Nantes / Obs. Tautenburg .....

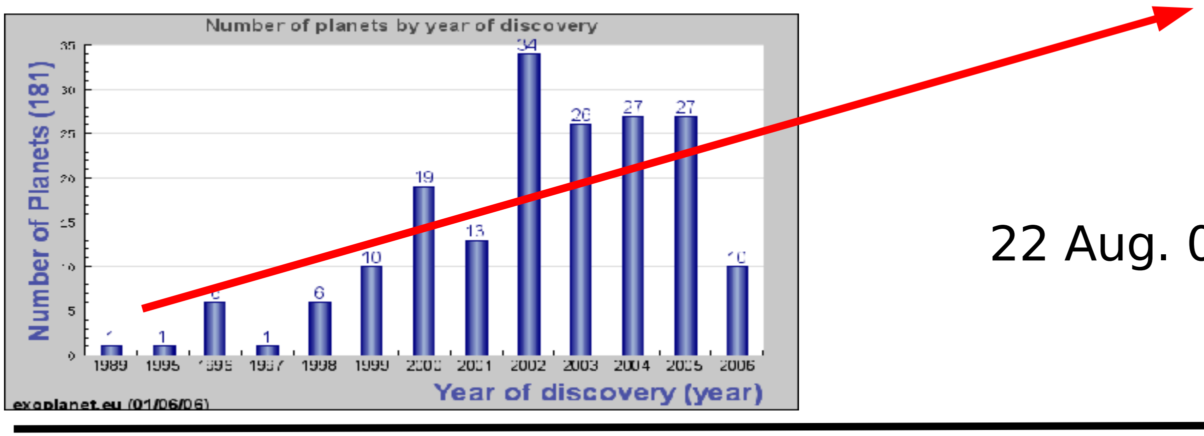
Mission philosophy

The utlimate goal of exoplanetology is the search for life on exoplanets.

For a better characterization of exo-lifes, it is necessary to have a good knowledge of their environmental conditions.

Science goal

1/ Physical characterisation of planets already detected (in 2016!) by radial velocity (and astrometry).



22 Aug. 06: 203 planets

1995 2005 2015

2/ Compare characteristics of different planets in different systems

===> **comparative exoplanetology**

3/ Compare reflected light to thermal emission (**Darwin**) approach

Science goal

Physical characterization - understand how planets work:

- Atmospheric gas: composition, density, ..
- Clouds: opacity
- Surface: reflectivity, inhomogeneities
- Environment: rings? (==> satellites)

Present experience:

- diversity of Solar System bodies
- diversity and surprises on orbits (radius, eccentricities)
- diversity of masses

==>**anticipate diversity** of other characteristics and

new surprises ==> stimulation for Darwin

Science goal

- Other science:
  - Exo-zodi
  - Debris disks
  - UV imaging (parent star characteristics, AGNs etc)
  - Follow-up of planetary transits (ground, CoRoT, Kepler, ...)
  - Reflected light of hot Jupiters (5 x better than CoRoT)

Science goal

How to make the physical characterization ?

Stellar flux reflected by the planet:

==> very rich information content.

$$F_{pl} = F(D, a, \lambda, \vec{P}, t) \sim \boxed{\left(\frac{1}{aD}\right)^2 \times A(\lambda, \vec{P}, t) \times R_{pl}^2} \longleftrightarrow M_{pl}(\mathrm{RV})$$

Chemicals

State of surf.

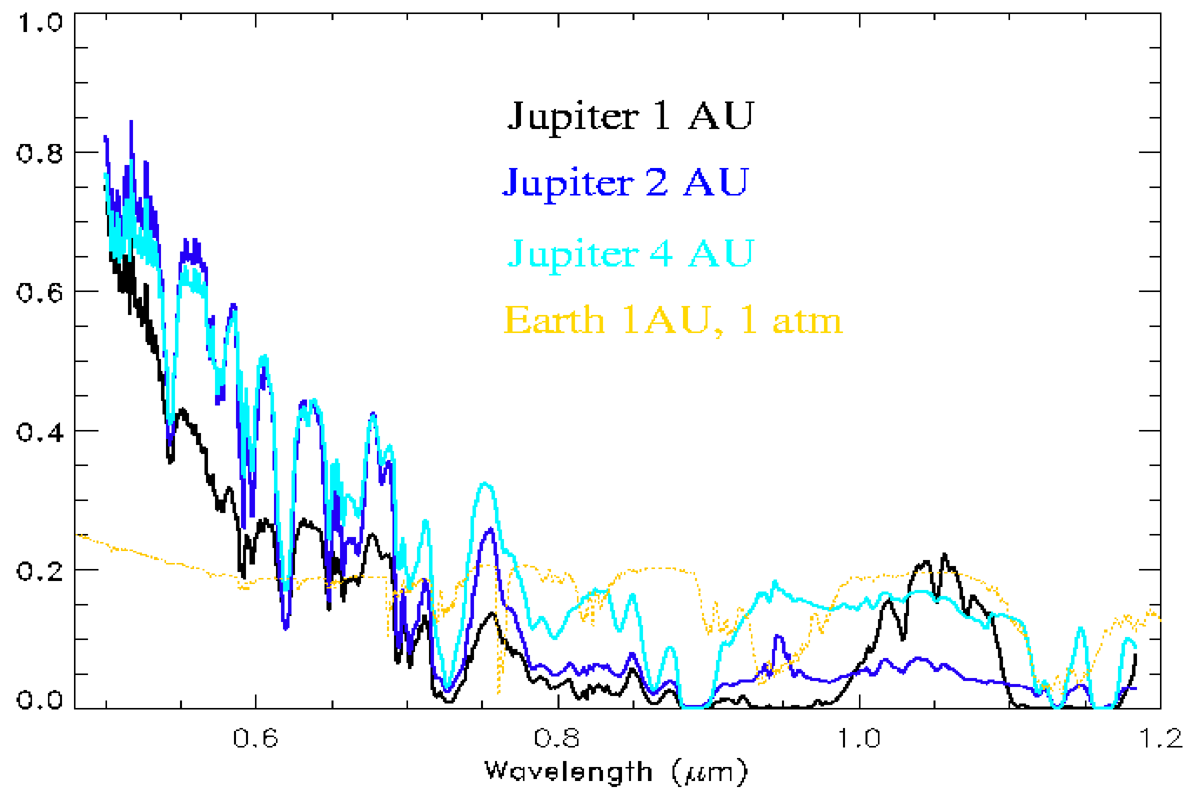
''Climat'', etc.

Science goal

$$\boxed{F_{pl}(\lambda)}$$

Jupiter to Super-Earth like planets

First detection of cold giant planets (> 1 AU and < 5AU) around nearby stars



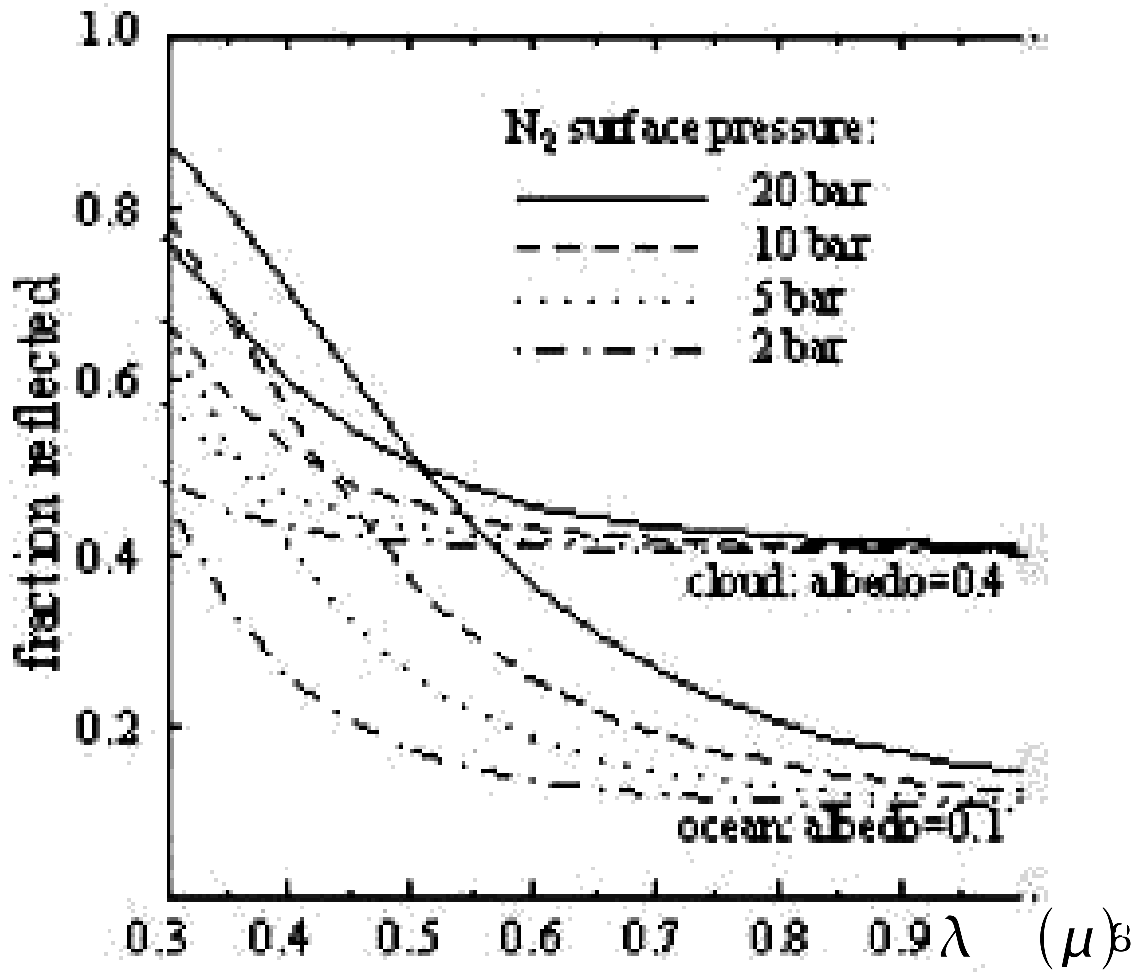
Science goal $\boxed{F_{pl}(\lambda)}$

Atmosphere's transparency and clouds

Rayleigh scattering

e.g.: Saturn

Europ



Science goal $\boxed{F_{pl}(\lambda)}$

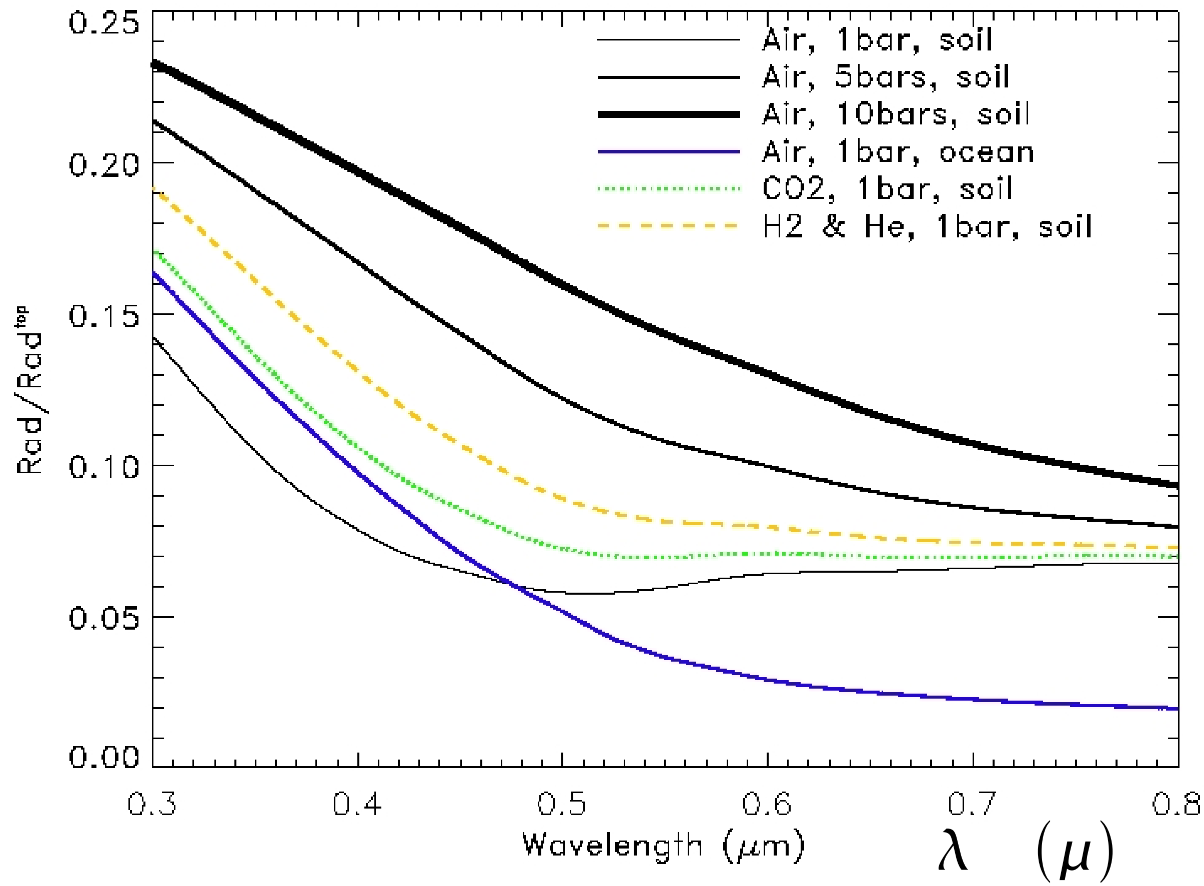
Atmosphere transparency and clouds

Size parameter ~ a/λ

where a from 10^{-4} μ
to ~ 100 μ

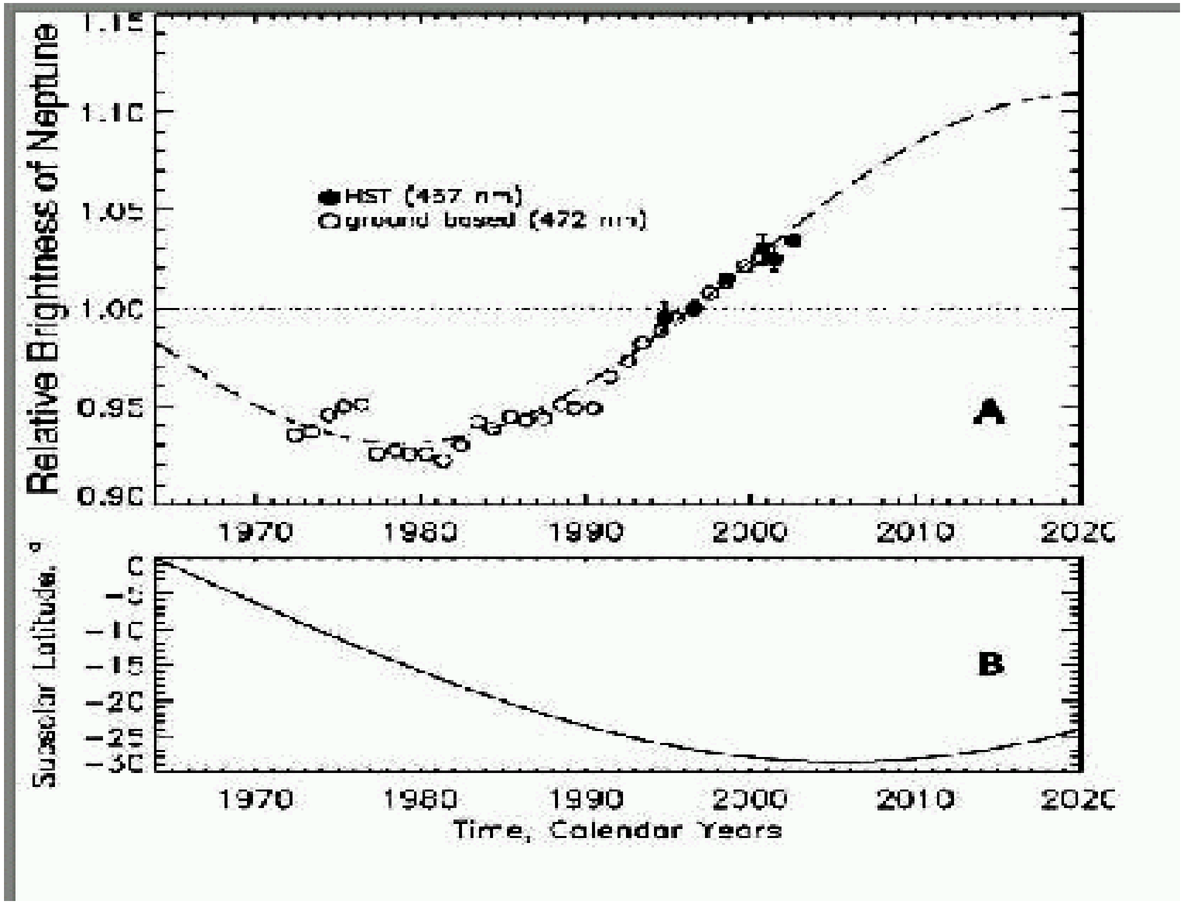
==>

Pressure, surf. reflectivity



Science goal $\boxed{F_{pl}(t)}$

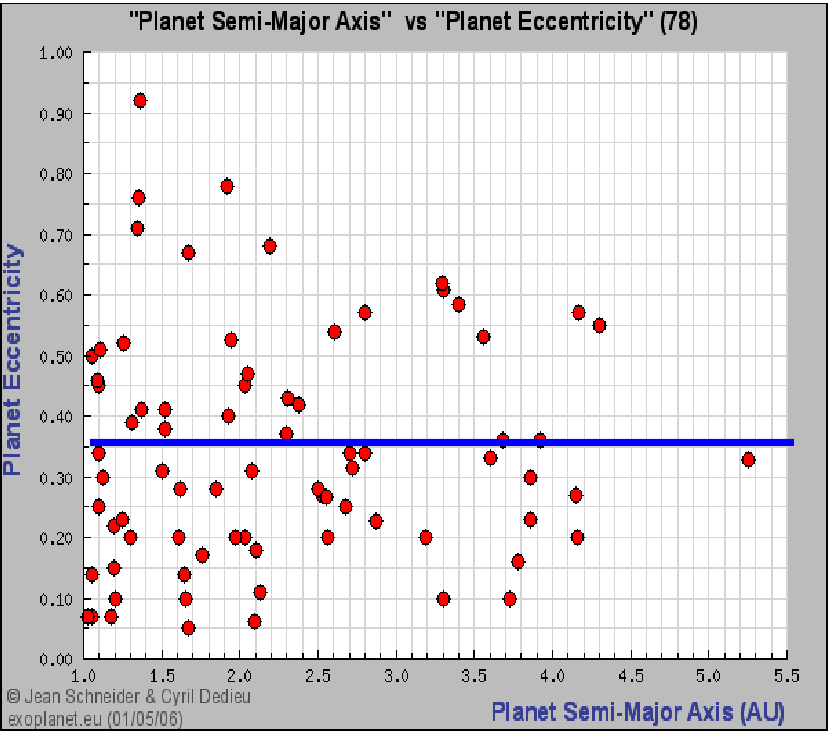
« Climat » variation: example of Neptune



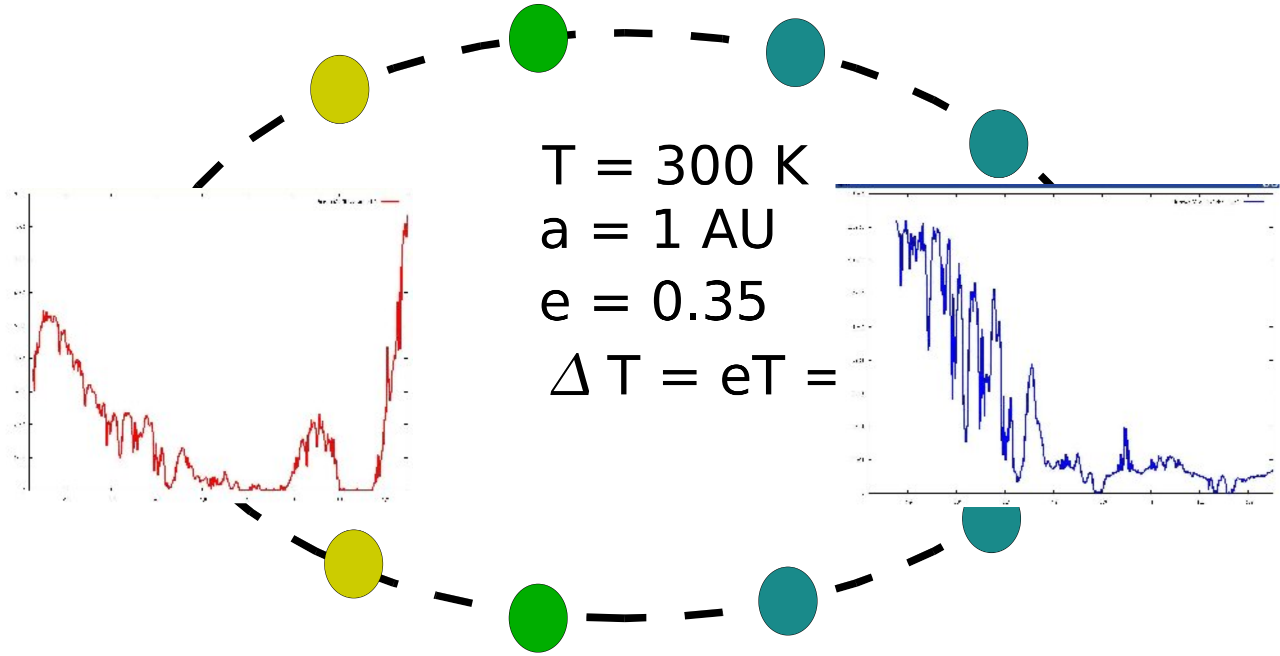
Science goal

$$\boxed{F_{pl}(t)}$$

50 % of orbits have an eccentricity > 0.35



Time variation of the spectrum along the orbit

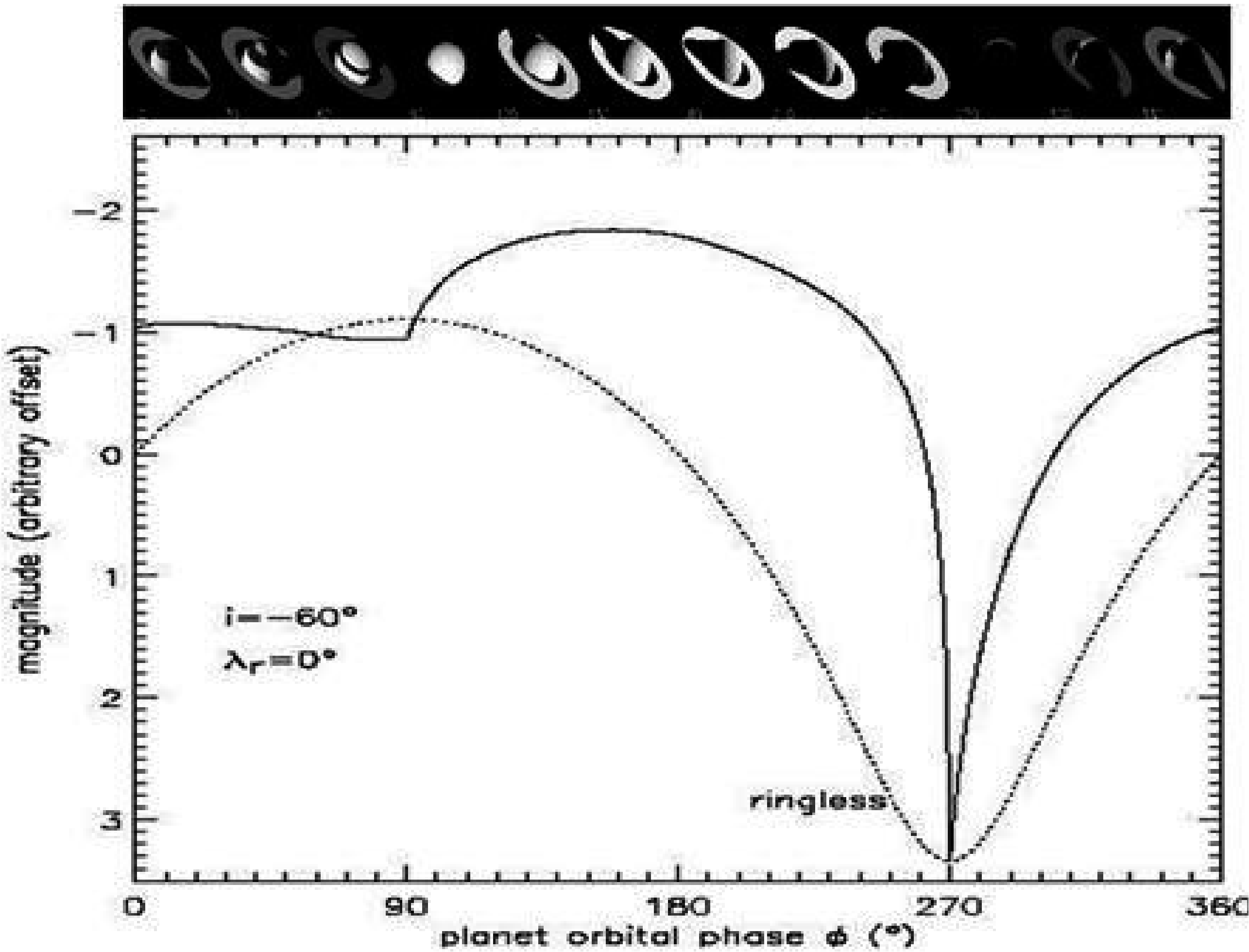


Science goal

$$\boxed{F_{pl}(t)}$$

Surroundings

Example: rings



Relevance:

indicative of presence

of satellites

6 june: a ring

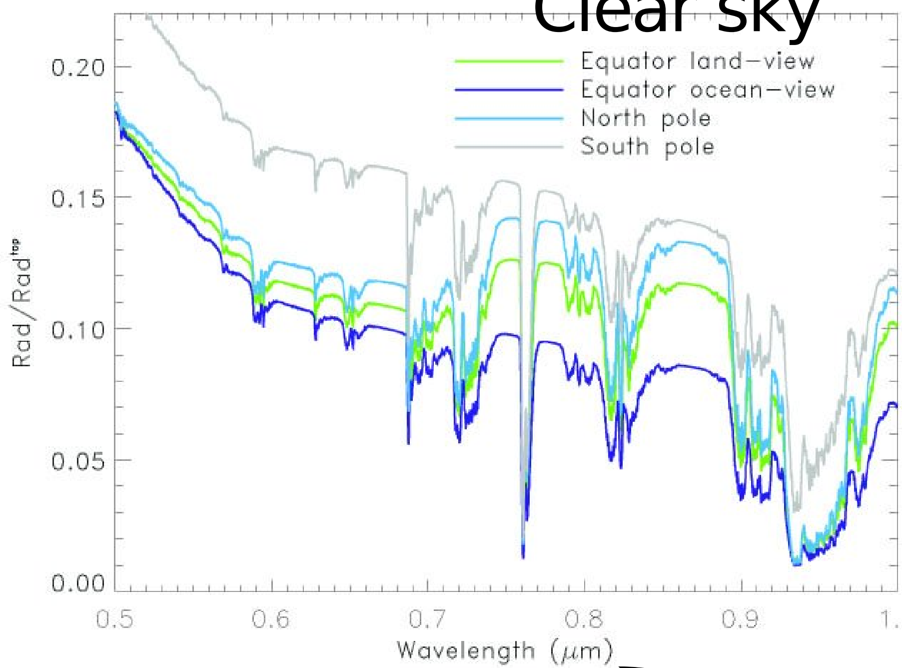
around 2M12072 ?

Science goal

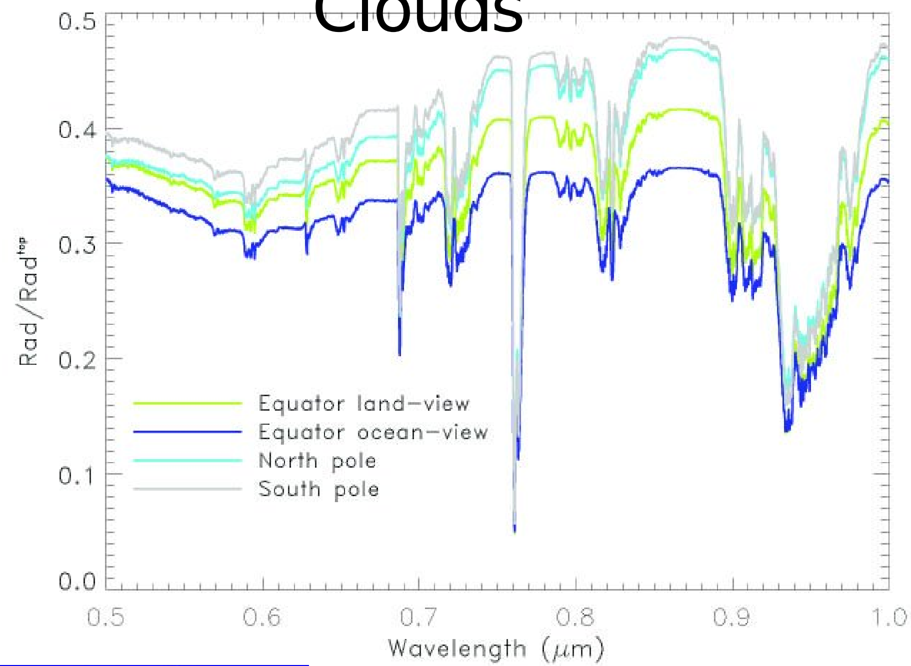
$$\boxed{F_{pl}(t)}$$

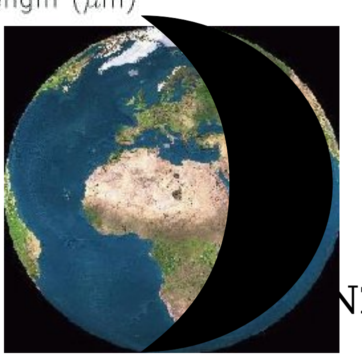
Sensitivity to viewing geometry

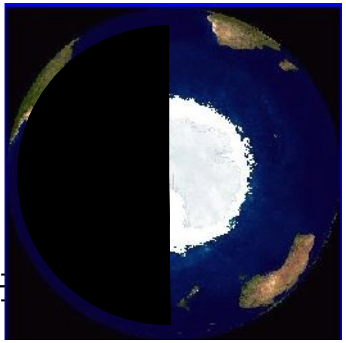
Clear sky



Clouds







Tinetti et al 2006

Science goal

$$F_{pl}(\vec{P})$$

- For Rayleigh scattering by molecules or haze particles

- => Strong phase dependence expected:

  inclination = 0°

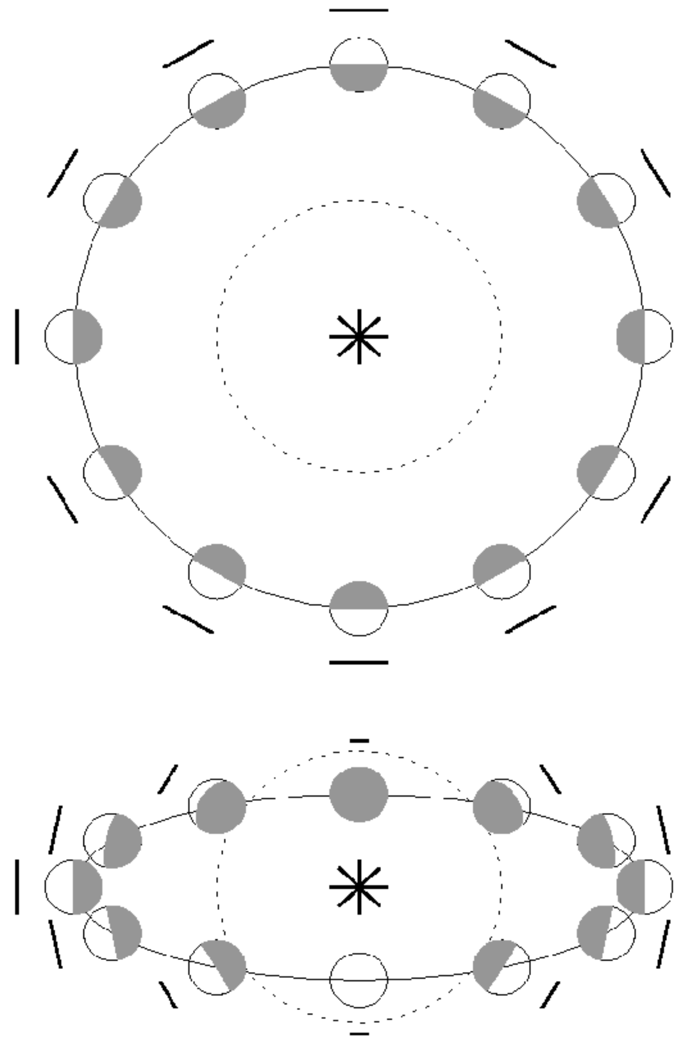
  p=constant & high

  pos. angle rotates

  inclination = 70°

  p=high for large separation

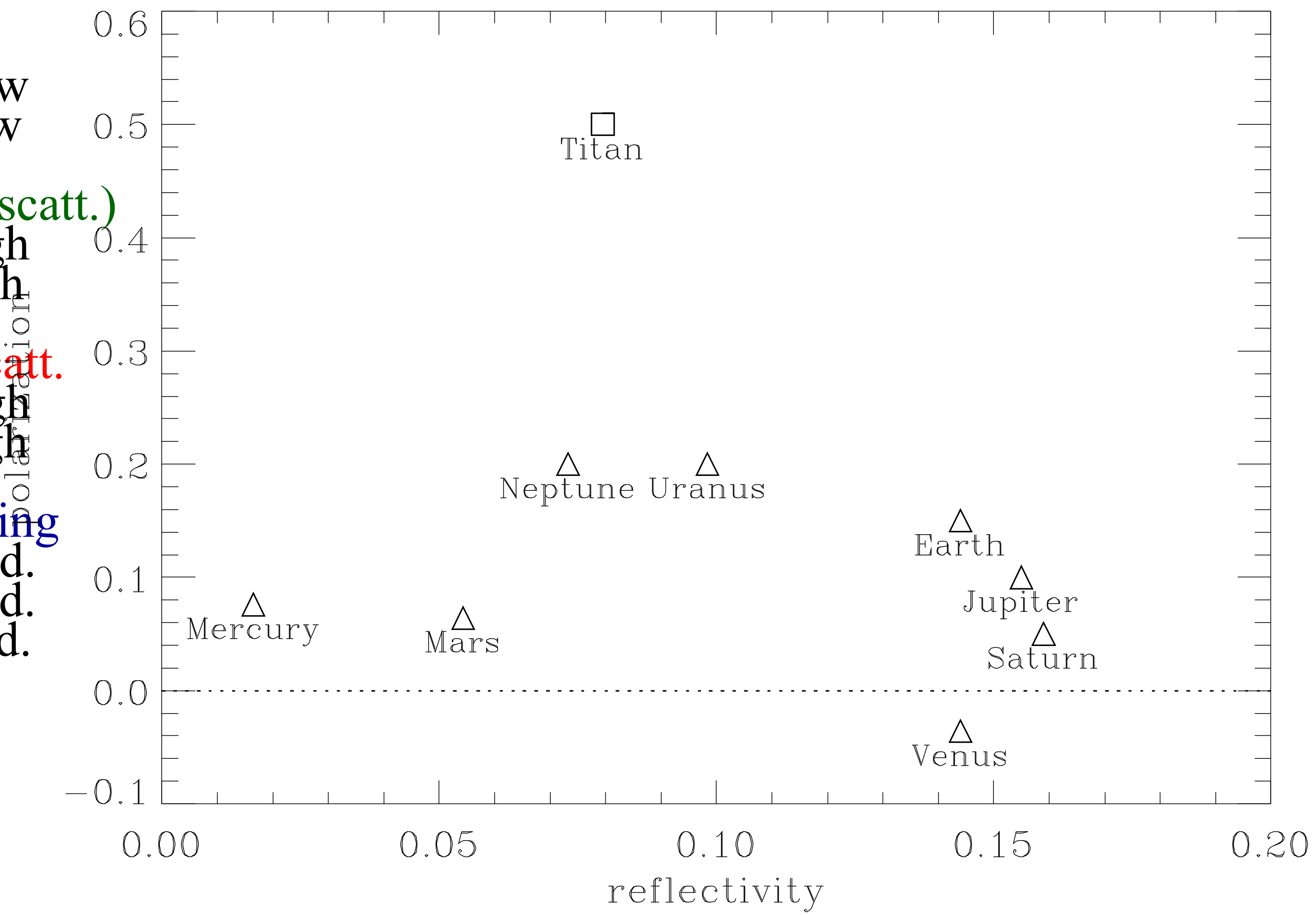
- Scattering by clouds produces only little polarization



Science goal

$$\boxed{F_{pl}(\vec{P})}$$

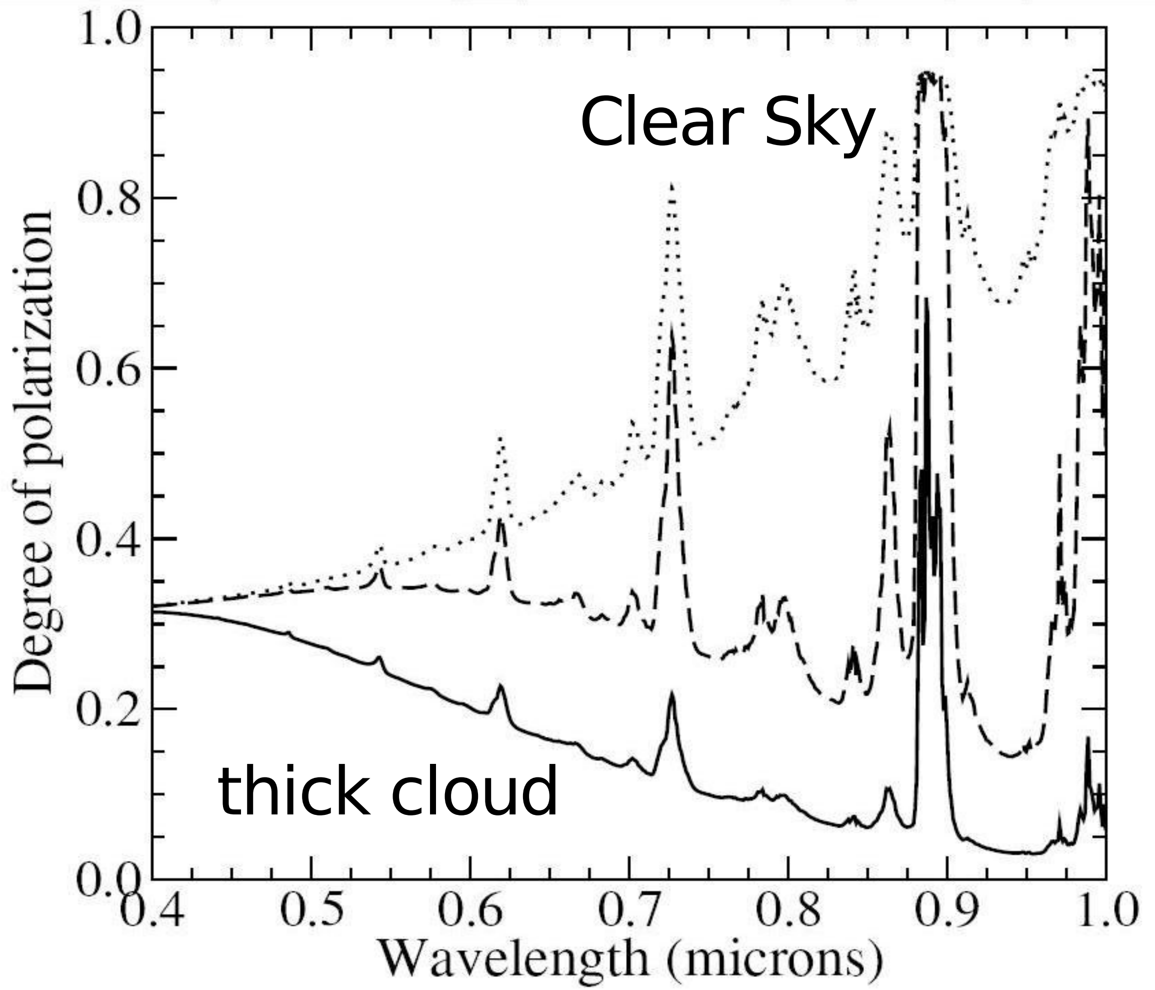
	p(90)	f(90)
Rocky		
Mercury	5-10%	low
Mars	5-10%	low
cloudy (little Rayleigh scatt.)		
Venus	<5% (–)	high
Saturn	<5%	high
cloudy and Rayleigh scatt.		
Jupiter	5-20%	high
Earth	5-20%	high
strong Rayleigh scattering		
Uranus	>15%	med.
Neptune	>15%	med.
Titan	50%	med.



Science goal

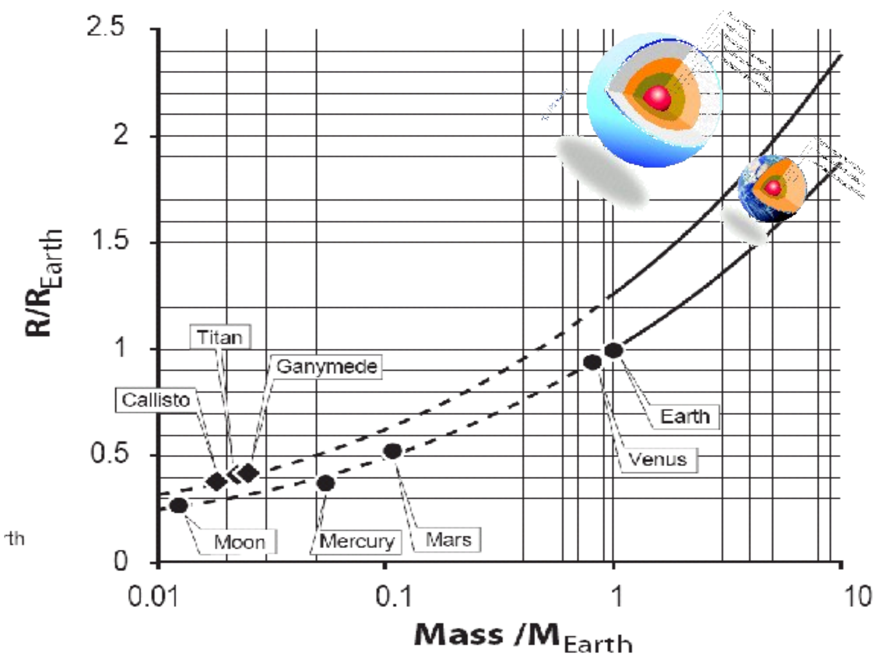
$$F_{pl}(\vec{P})$$

Jupiter at 1 AU (orbital phase 90°)



Science goal

Some open questions:



- Ambiguity on planet radius: from Si to C dominated planet, radius increases by a factor 1.3 (Grasset et al 2006)

  ==> ambiguity on Albedo 1.7
  ==> need Darwin to know the planet radius

- Large planets without
  or tenuous atmosphere ?
  Possible scenario: gas in protoplanetary disk blown off
  by strong stellar wind: ==> bare giant planet cores = Super-Earths
  with teneous atmosphere

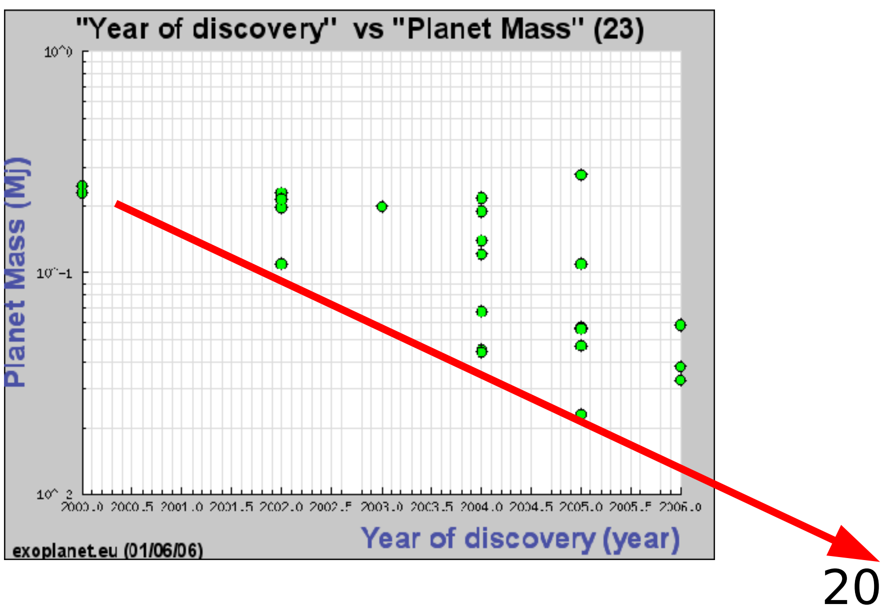
Science goal

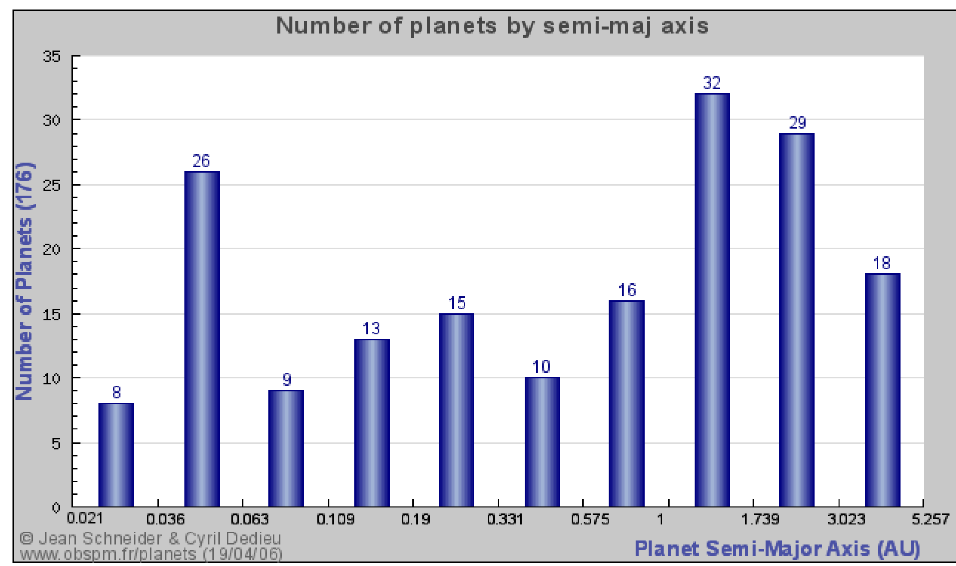
Type of planets.

Controlled by telescope size (1.5 m)

Flux limit: $R_{pl} > 3\, R_{\oplus}$ **super-Earths**

Ang. Resol. limit: orbits 1 – 5 UA « **cold** » **planets**

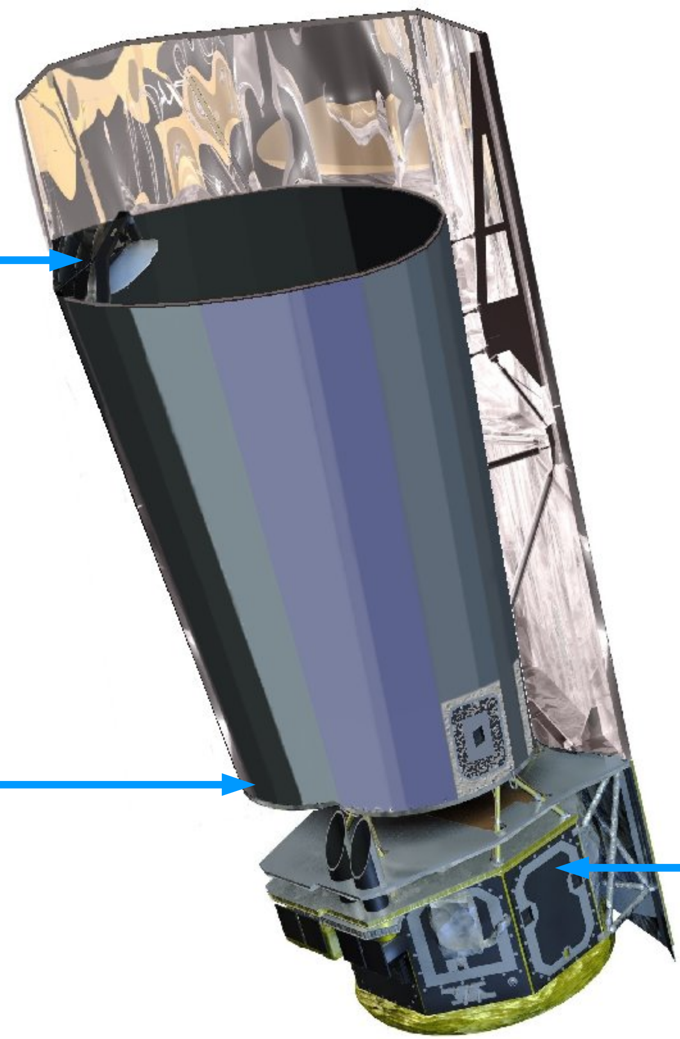




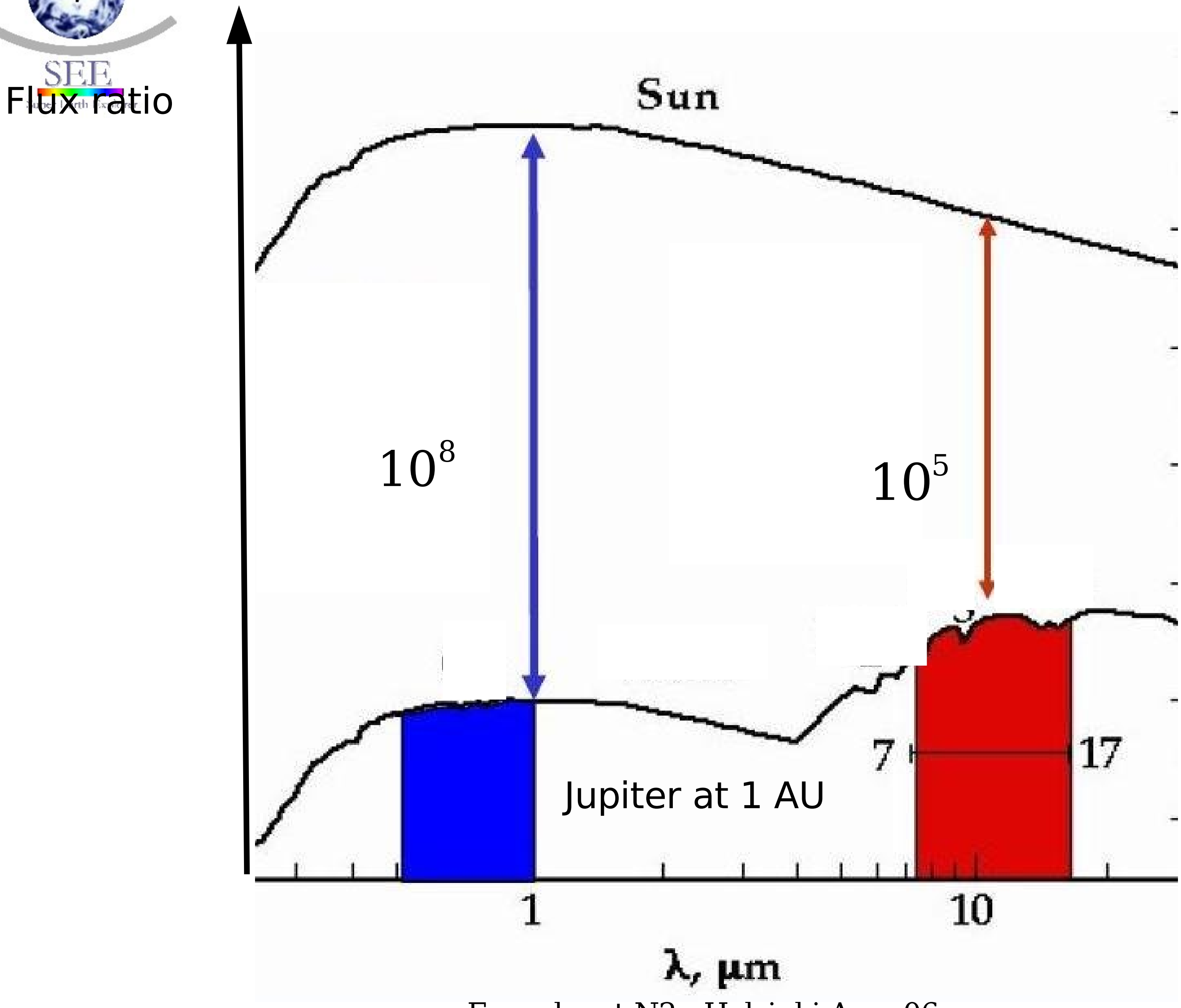
Payload Concept:
Coronagraphic Off-Axis Telescope
SEE-COAST

Secondary mirror
($\phi = 0{,}35$ m)

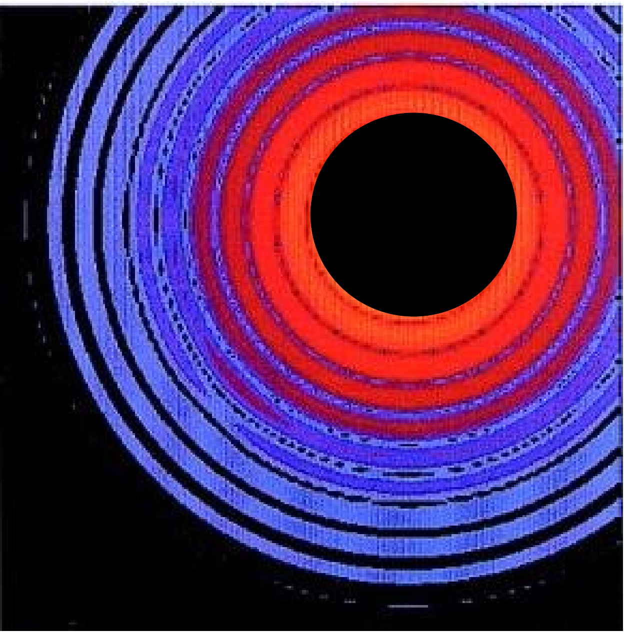
Primary mirror
($\phi = 1{,}5$ m)

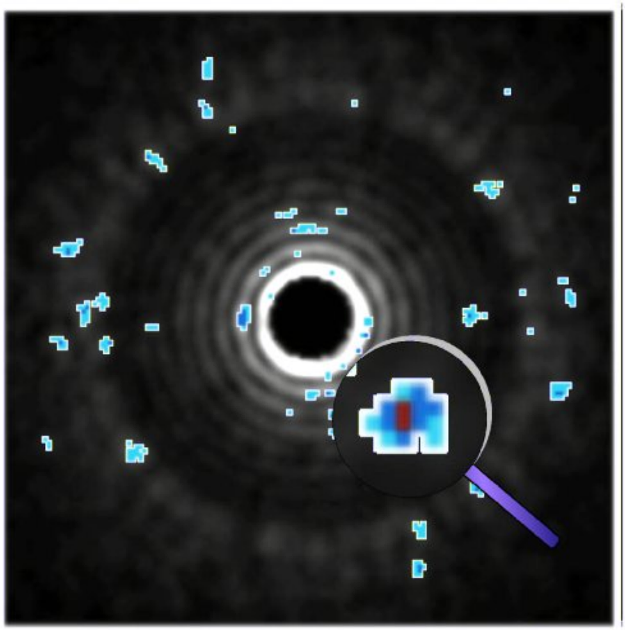


Electronics and instrumentation

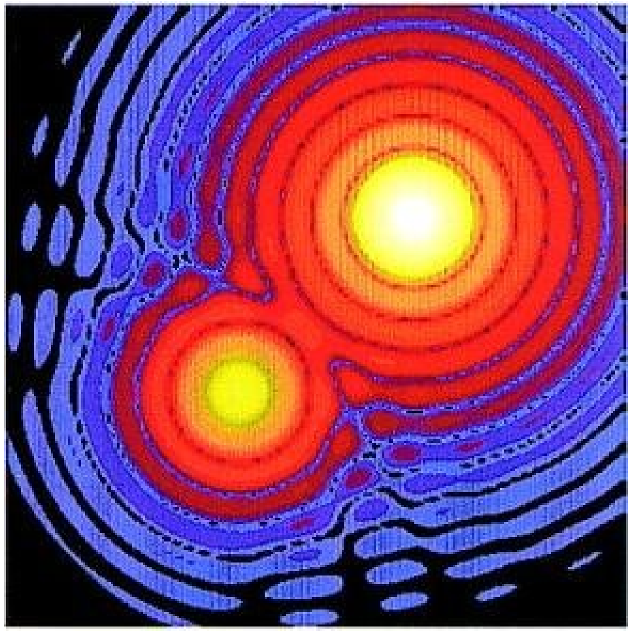


Flux ratio
Sun
10^8
10^5
7
17
Jupiter at 1 AU
1
10
λ, μm





Extra-solar planet detection map computed on data simulated with the CAOS software (*Carbillet et al., MNRAS 2005*). The colors correspond to detections with different probabilities of false alarm (*Ferrari et al., IAUC 200*). The lens is at the location of the simulated planet.



Spacecraft philosophy

UV-Visible off-axis Telescope

1,5 m in diameter (minimum)

Optimized for High contrast imaging (Coronagraphy)

Ultra-smooth mirror (WFE λ/100 rms @ 633 nm)

Low resolution spectroscopy

for planetary characterisation in Visible

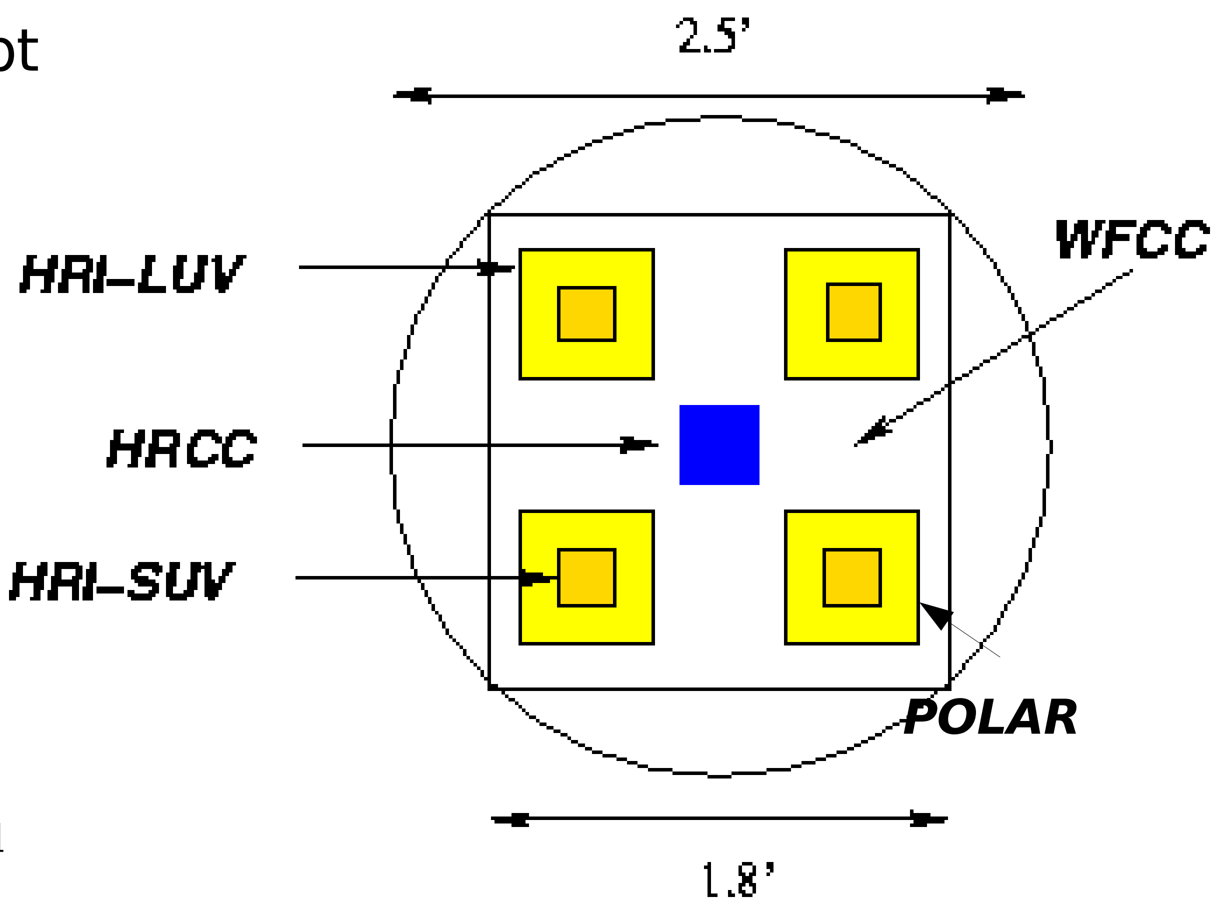
Payload Concept

Instruments

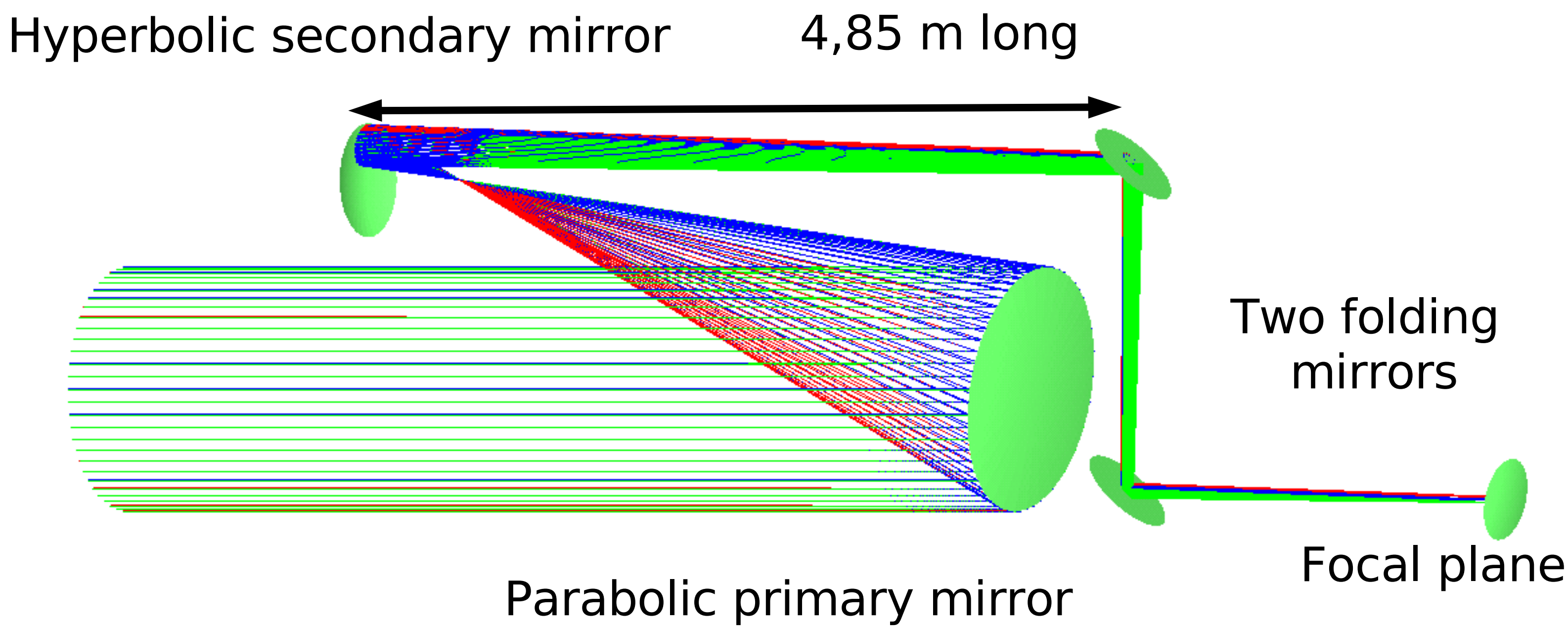
Multiple field of view concept

Optimisation for a larger
Field of view

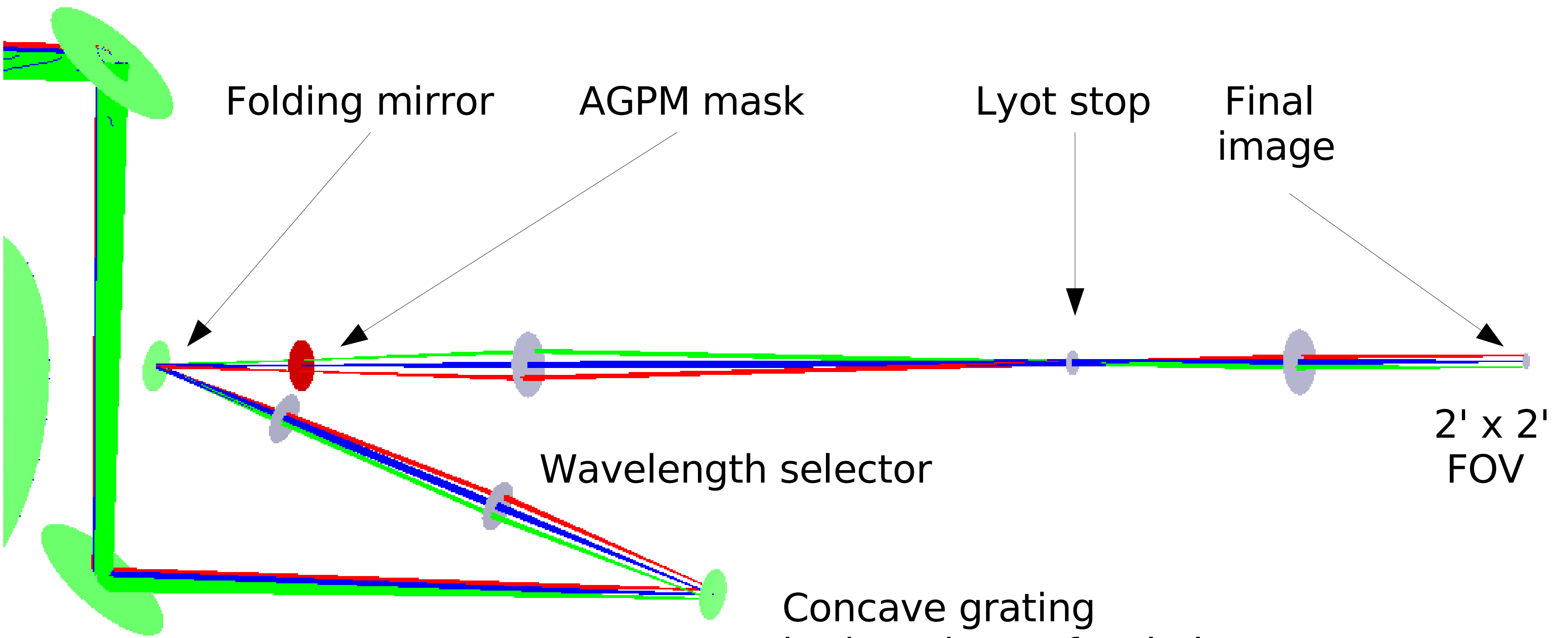
$$\frac{\lambda}{\Delta\lambda} = 40$$



Optical Concept (I)



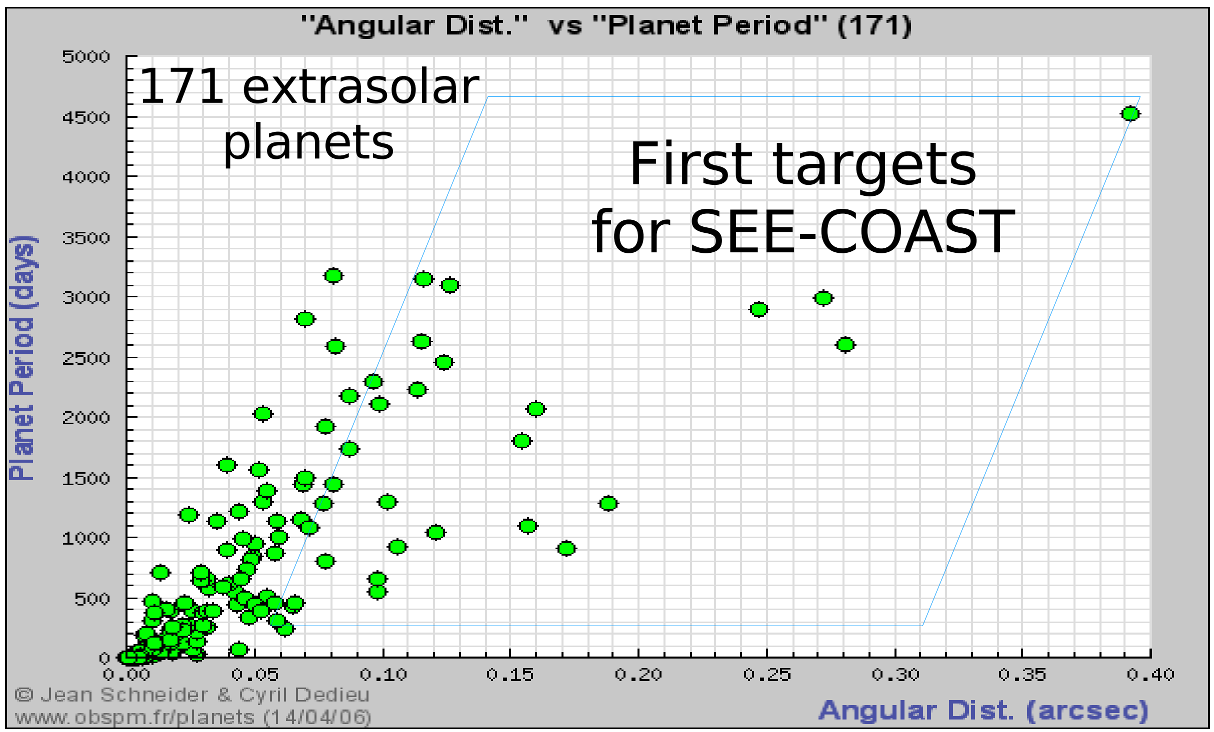
Optical Concept (III) example with the AGPM coronagraph



Phase-Mask coronagraphs: FQPM / AGPM / PKC / Apodized ...

The HRCC camera possesses three wavelength bands

Planets known from RV (2006)



Constraints on mass, *inclination*, *eccentricity* , Albedo in visible and presence of CH_4 and CO2 compounds

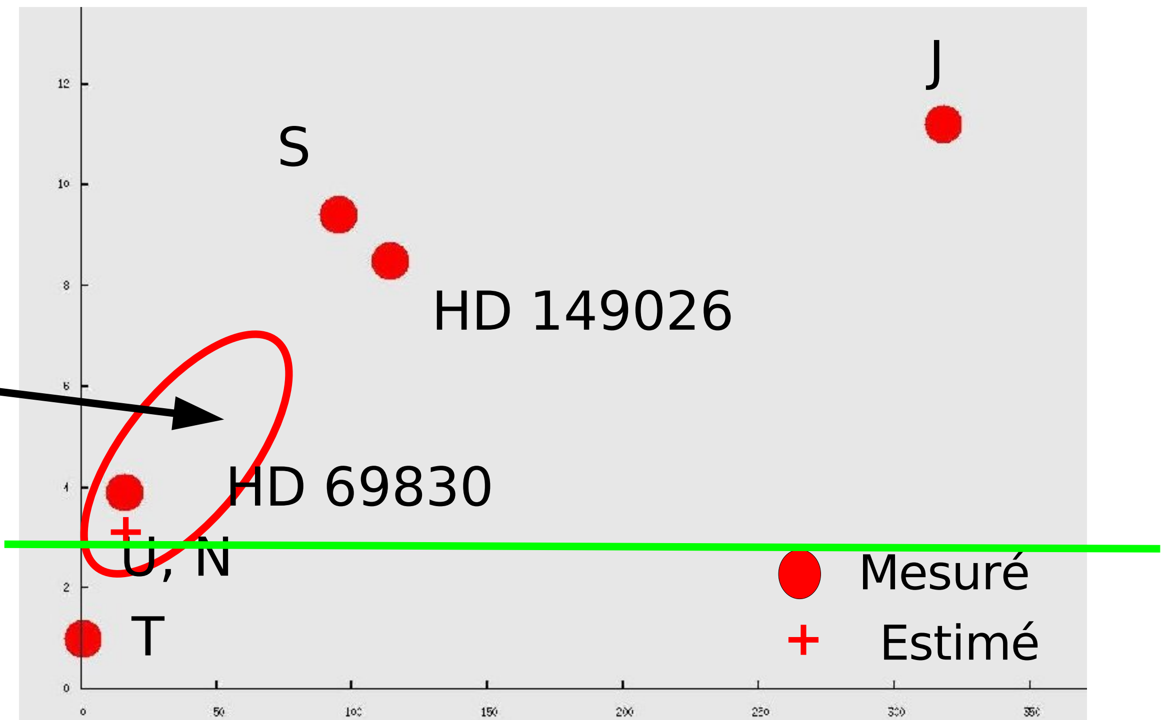
Super-Earths?

Contrast ratio

10^{-9} for a "super" Earth

Possible detection

of "super" Earth planets



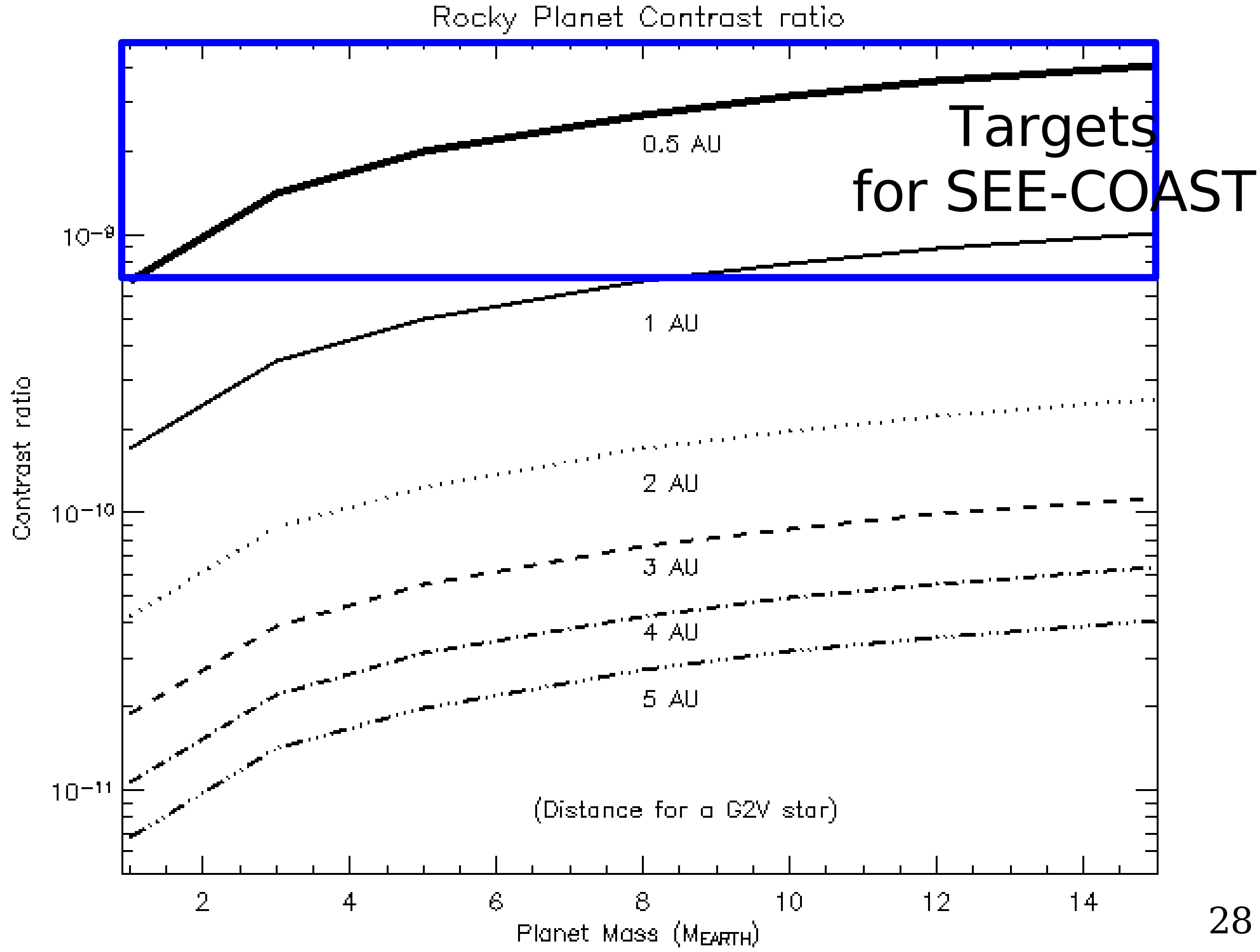
H2O-planets ?

Carbon-planets ? (cf β *Pic*)

Others ?

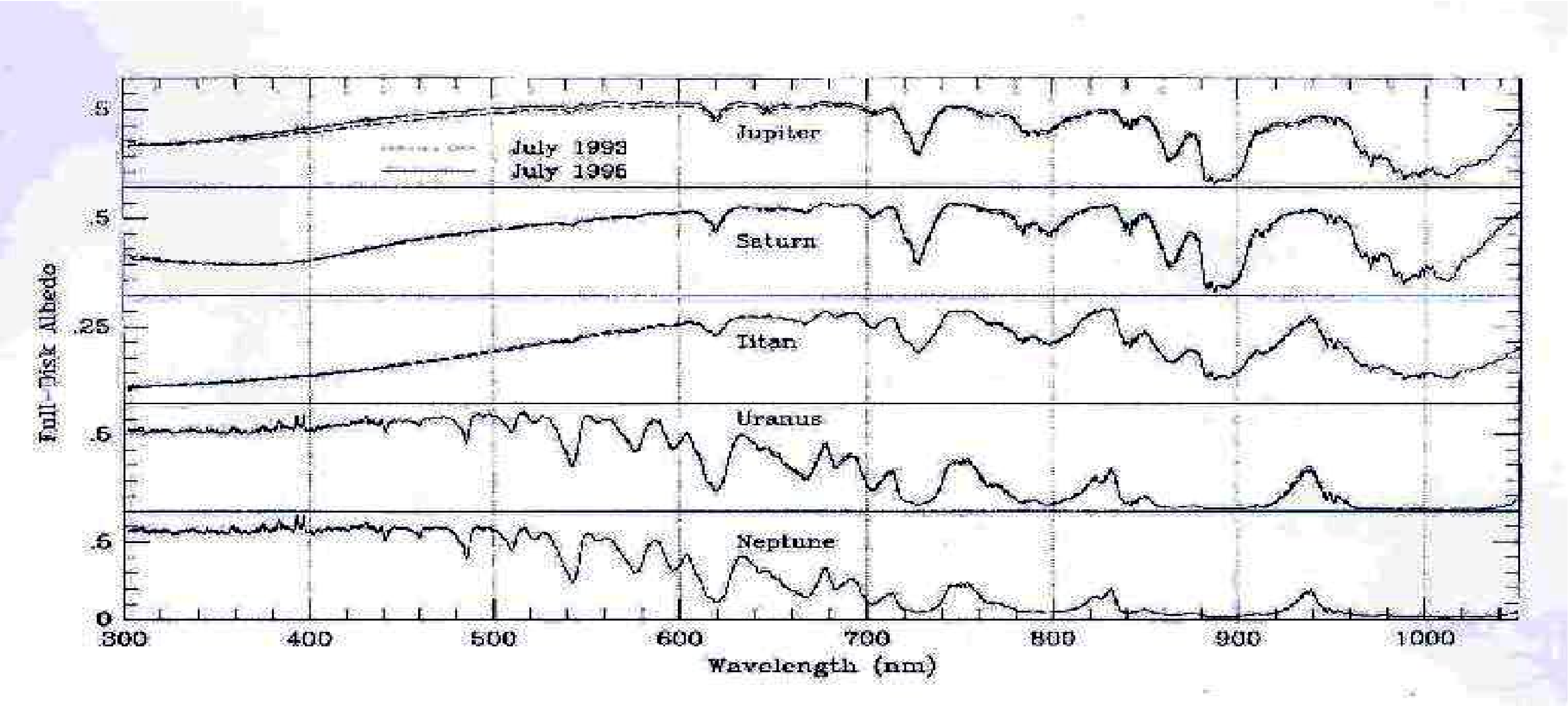
Science with SEE-COAST

Super-Earths?



- High contrast UV imaging

Giant planet characterization ?



Mission strategy

Two extreme options:

Exhaustive monitoring of a few (10-30) planets

Systematic survey of 100-150 targets

Mission duration: >5 years

Payload Concept

Instruments (I)

	HRCC (High Resolution Coronagraphic Camera)	WFCC (Wide Field Coronagraphic Camera)	HRI-SUV (High resolution Imager – Short UV)	HRI-LUV (High resolution Imager – Long UV)
Spectral Coverage	500 – 1000 nm	400 – 1000 nm	92 – 200 nm	200 – 400 nm
Detector Size	1 – 2048 x 2048	1 – 4096 x 4096	4 – 2048 x 2048	4 – 2048 x 2048
Type	CCD (red – 16 bis)	CCD (broadband – 16 bits)	MCP (CsRbTe – 12 / 16 bits)	MCP (CsRbTe – 12 / 16 bits)
Dynamic	10^5	10^5	10^5	10^5
Qe	~ 85%	~ 70%	~ 40%	~ 40%
FOV	17" x 17"	1,8' x 1,8'	4 x 13" x 13"	4 x 30" x 30"
IFOV	34 mas	27 mas	6 mas	13 mas
Angular resolution	68 mas	55 mas	12 mas	27 mas
	Phase-mask coronagraphy	Coronagraphy	Coronagraphy	Coronagraphy
Readout noise	1 e- / Photon counting	2 e-	Photon counting	Photon counting
Dark current	10 e-/h	10 e-/h	9 10^4 cnts/s/pixel	8 10^6 cnts/s/pixel

Two cameras in the visible wavelengths
Two UV-camera (parallele mode with the HRCC camera)

The priority is the ***HRCC*** camera (Phase-Mask coronagraphy)

Instruments (II)

All cameras have various coronagraphic devices

The **HRCC** camera allows simultanous imaging of three different bands (650-760 nm / 750-860 nm / 850-960 nm)

Each bands can provide three different images for low spectral resolution capabilities and spectral differential imaging (R ~30)

Three calibration frames (one per band) can be added on the CCD

The CCD 2048 x 2048 → 9 to 12 simultanous images

One of the two HRI cameras can be exploited simultanously in the four extended field of view

Instruments (IV)

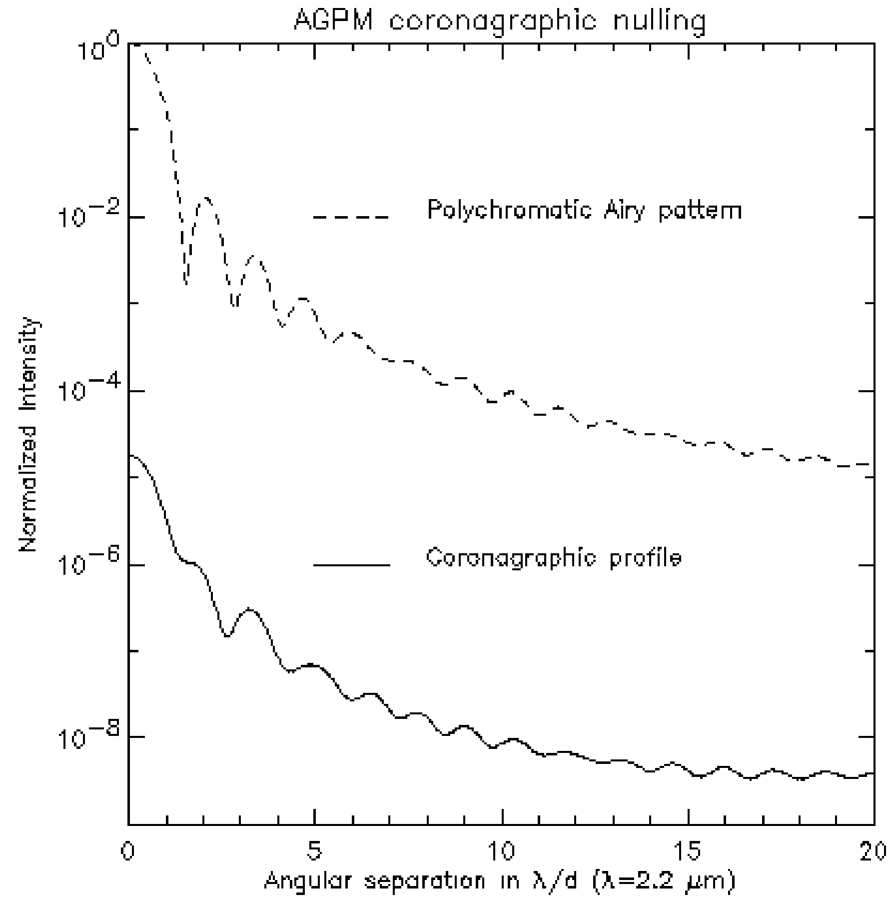
Polarimetric channel

En cours (Zimpol-Zurich)

Phase-Mask Coronagraphy

- Ex: Coronagraphic results in K band **(VLT-PF prototyping)**
  - WFE of λ/70 rms
  - both polarizations (vectorial analysis)
  - Residual chromatism
  - Amplitude mismatches

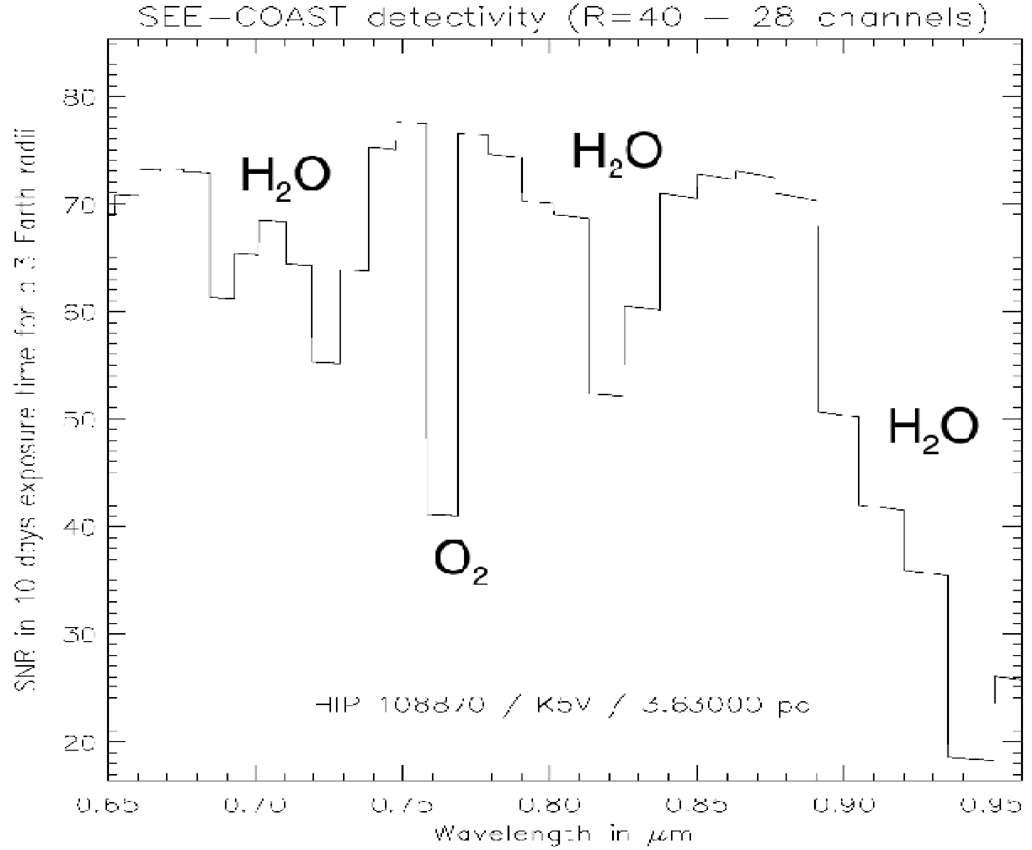
Filters	**Ic (R=5)**	**K (R=5.5)**	**N (R=4.86)**
Null Depth	3.5×10^{-5}	1.7×10^{-5}	4×10^{-5}
Contrast at 3 /d	2.9×10^{-7}	1.4×10^{-7}	3.3×10^{-7}
Grating period (C	305 nm	740 nm	3.3 m



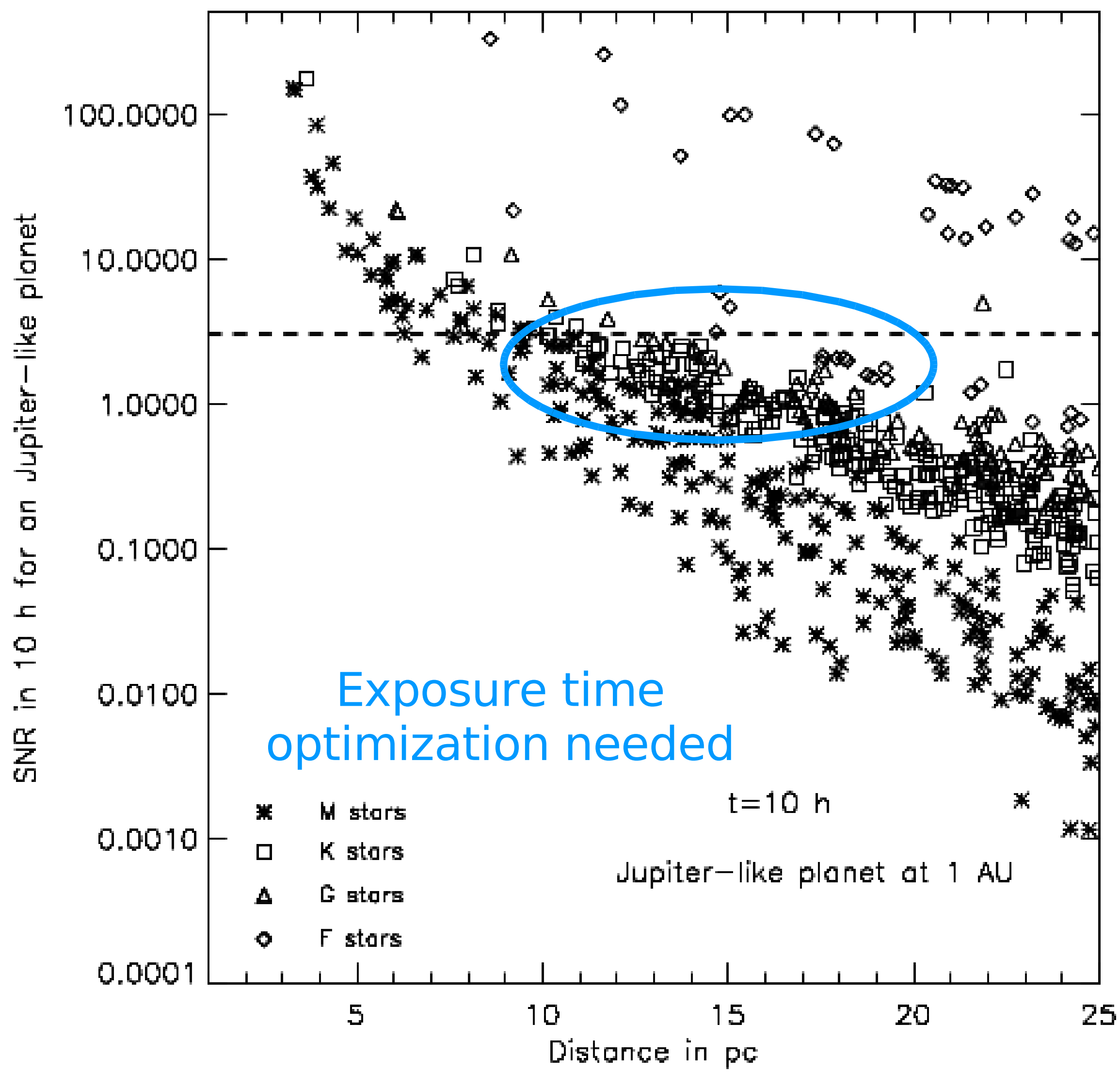
SEE performances

Detection simulation:

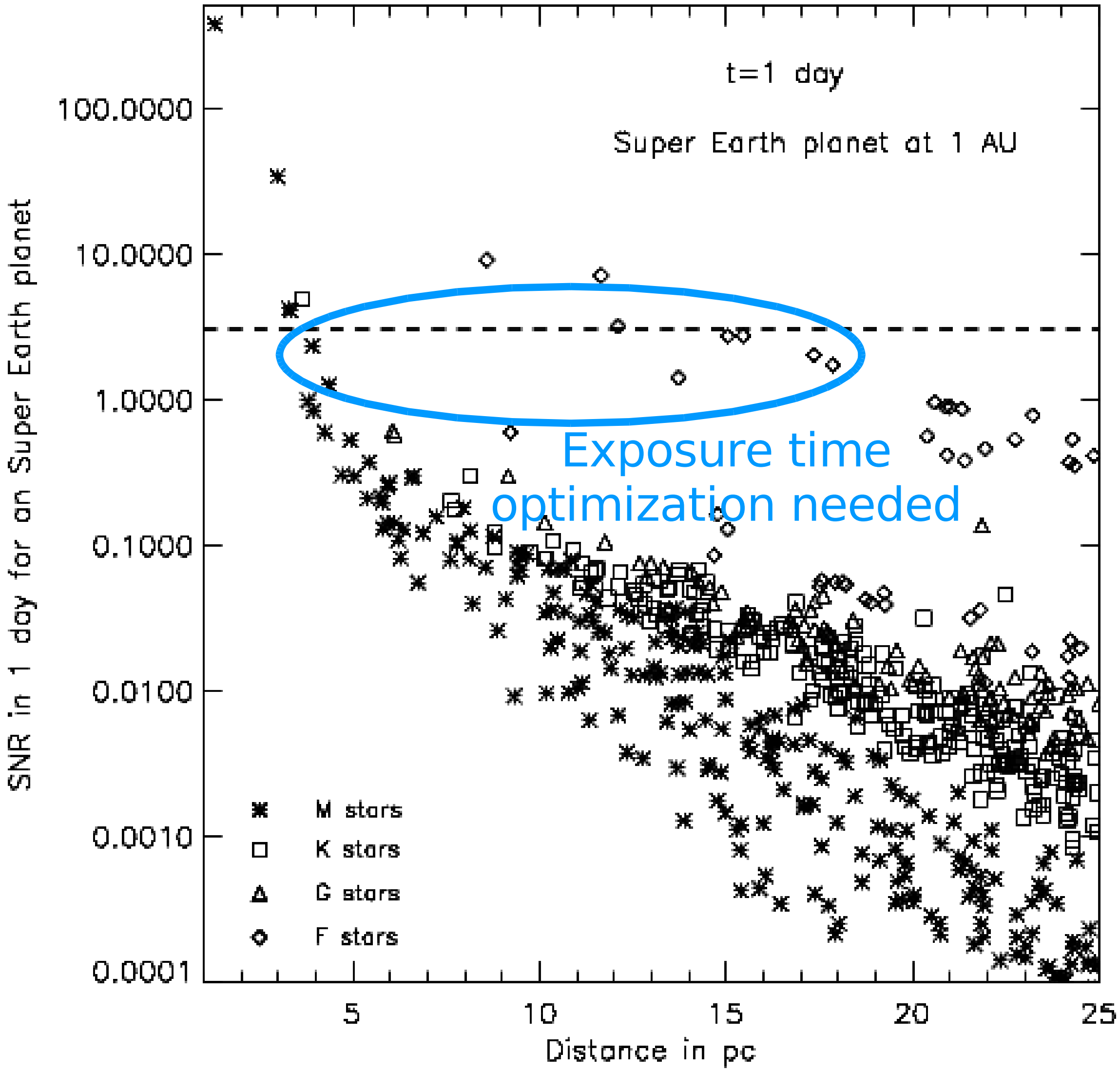
SNR for $3\,R_{\oplus}$ Super-Earth at 3.6 pc in 10 days exposure



Results of CoastSim



Results of CoastSim



<u>CoastSim is ready but :</u>

Add the telescope DSP
Add powerfull subtraction analysis
Add planetary UV flux

This first signal to noise simulation shows good opportunities to detect Exo-Zodiacal dust down to 1-10 Zod and Jupiter-like planets.

Comparison with other instruments

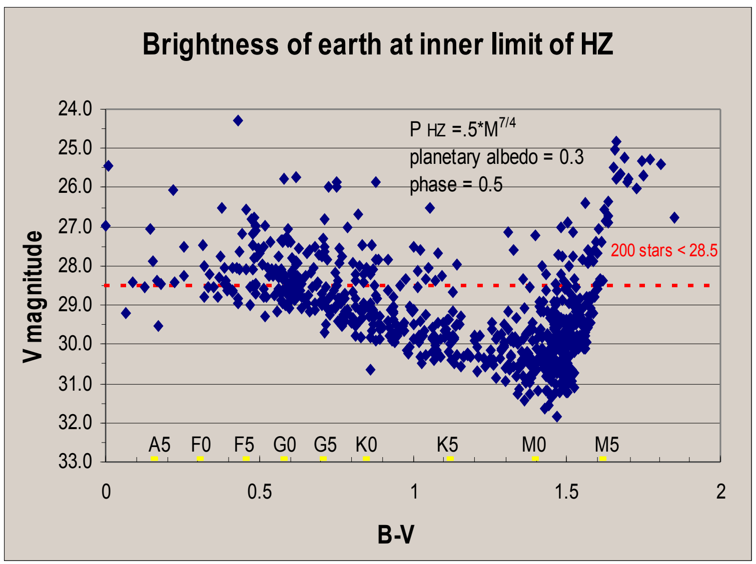
Jupiter-like planets

- JWST/MIRI in thermal IR only allows detection of hot giant planets with T>350-400K
- VLT-PF complementarity: characterisation in the visible with SEE-COAST

Giant planets detection around DARWIN targets allows quantifying the contamination effect of these planets in the beam of the interferometer in thermal infrared

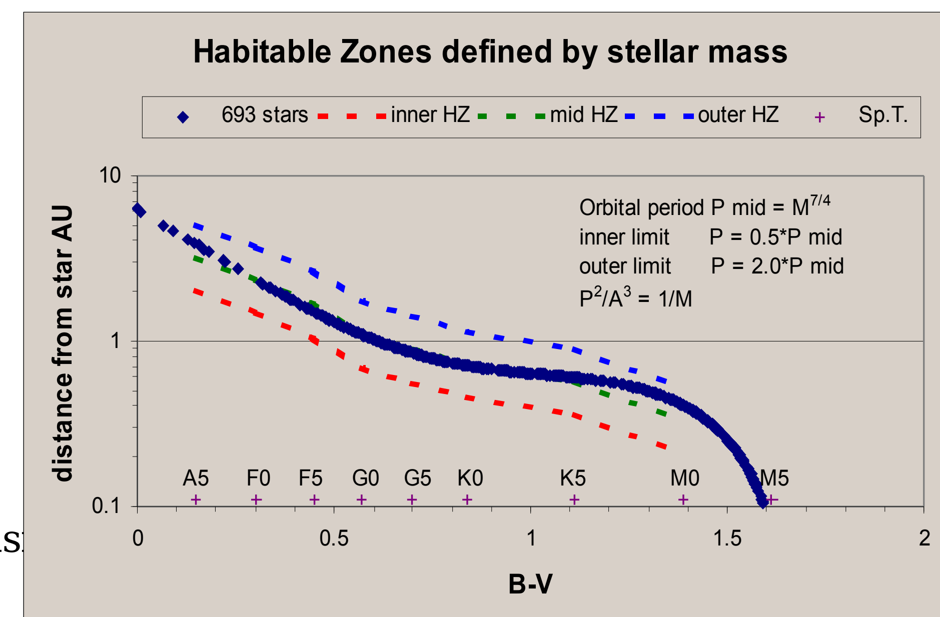
Targets of SEE-COAST

Super-Earths



TPF/DARWIN catalog for nearby stars

Habitable Zone for various stars depending the spectral type



200 potential targets for rocky planets

Present status

- To be submitted to ESA « Cosmic Vision » call for mission
- Launch forseen for 2016

Conclusion

Super-Earths Explorer will open a new era in « exo-geophysics »

Participation from Europlanet atmosphere modellization experts is welcome