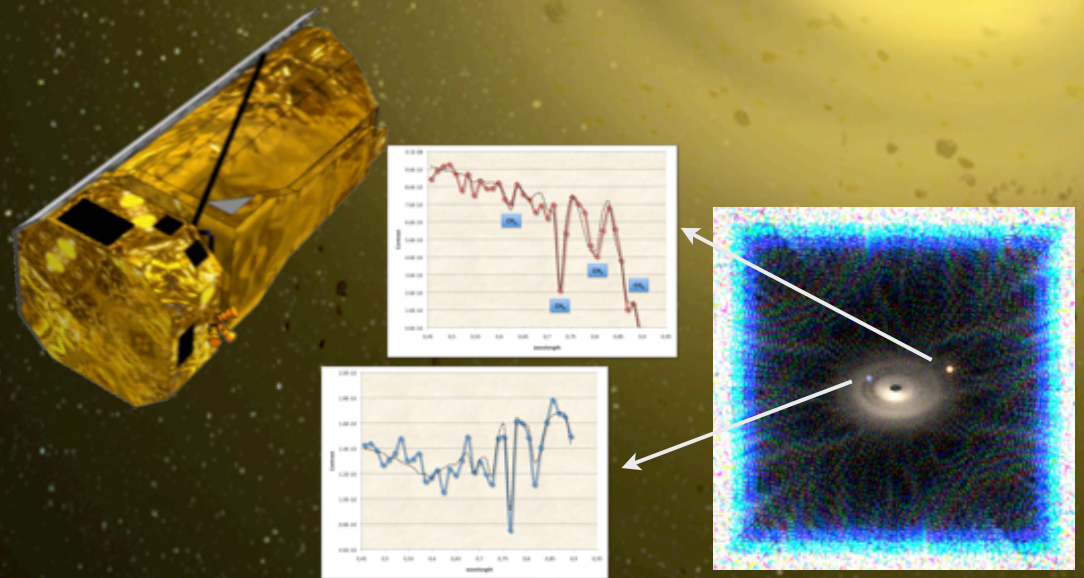
SPECTRO-POLARIMETRIC IMAGING AND CHARACTERIZATION OF EXOPLANETARY SYSTEMS

FROM PROTOPLANETARY DISKS TO NEARBY SUPER EARTHS

Cold planets, warm stars !!!



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Daphne Stam (SRON - Netherland
... and the SPICES Team
(70 members from EU/US/Japan)

PROPOSAL

- former proposal **SEE COAST** (Schneider et al.) in 2007 to ESA Cosmic Vision M1/2 (450M€, 2017-18)

- second proposal **SPICES** (Boccaletti et al.) in 2010 to ESA Cosmic Vision M3 (450M€, 2020-22):

Small coronagraph observing in the visible ....

Science cases, technical aspects :

Boccaletti et al. 2012, Exp. Astronomy 34, 355

Performance assessment :

Maire et al. 2012, A&A 541, 83

TOP-LEVEL SCIENCE

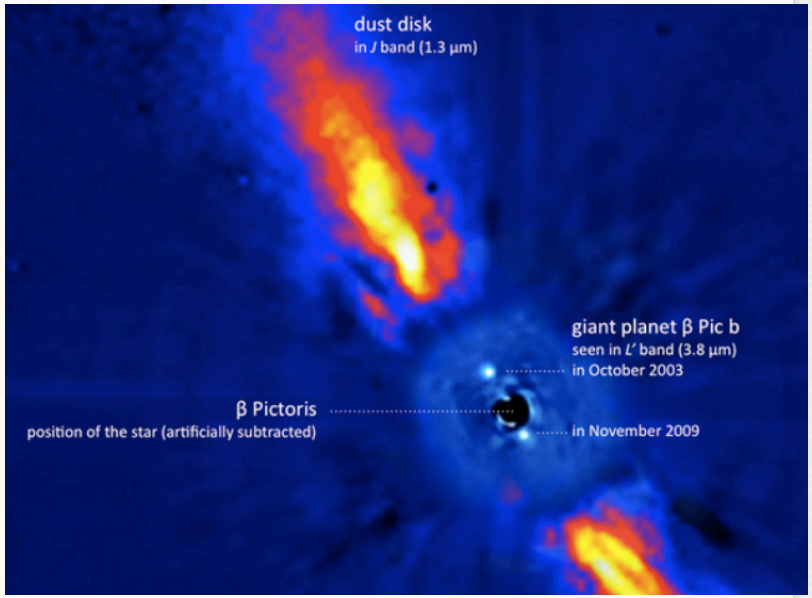
l'Observatoire de Paris — LESIA
Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique

SPICES stands for :

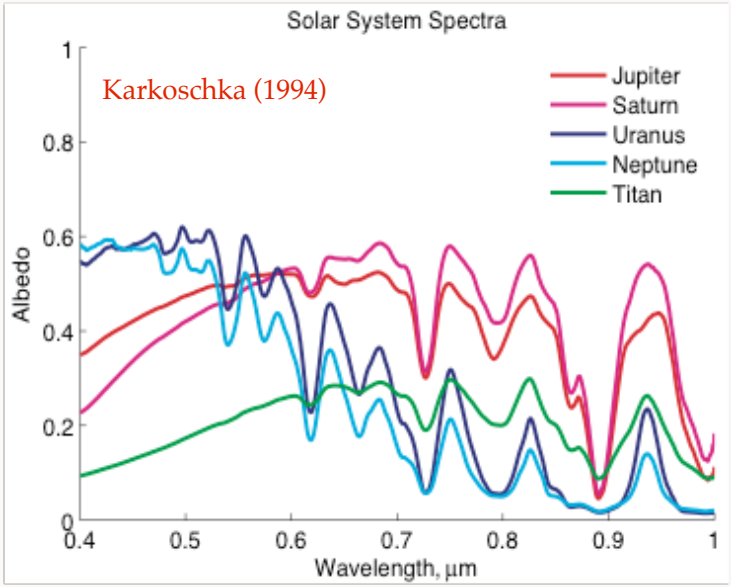
Spectro-**P**olarimetric **I**maging and **C**haracterization of **E**xoplanetary **S**ystems

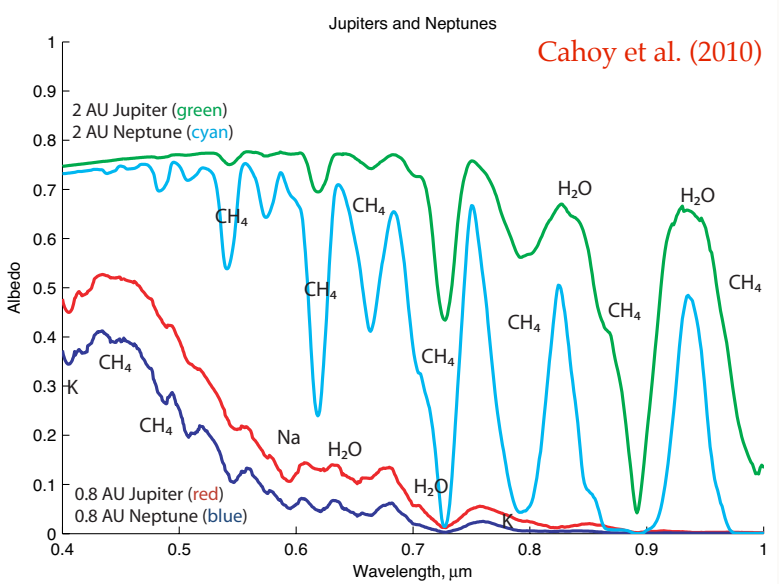
1 objective : Study planetary systems as a whole

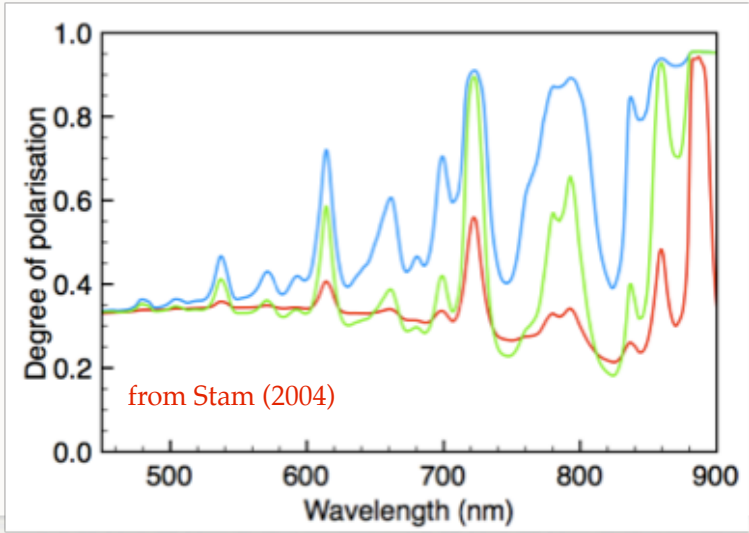
1. characterization of known mature giants planets to Super Earths
2. characterization of known young giants planets + new detections
3. characterization of known disks (protoplanetary, debris, exozodii) + new detections

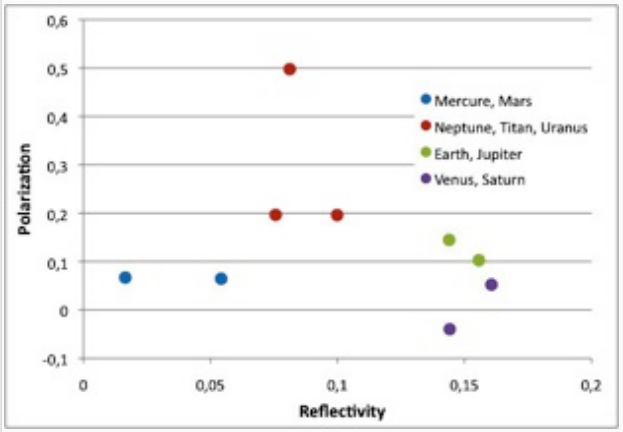


SCIENCE - GIANTS







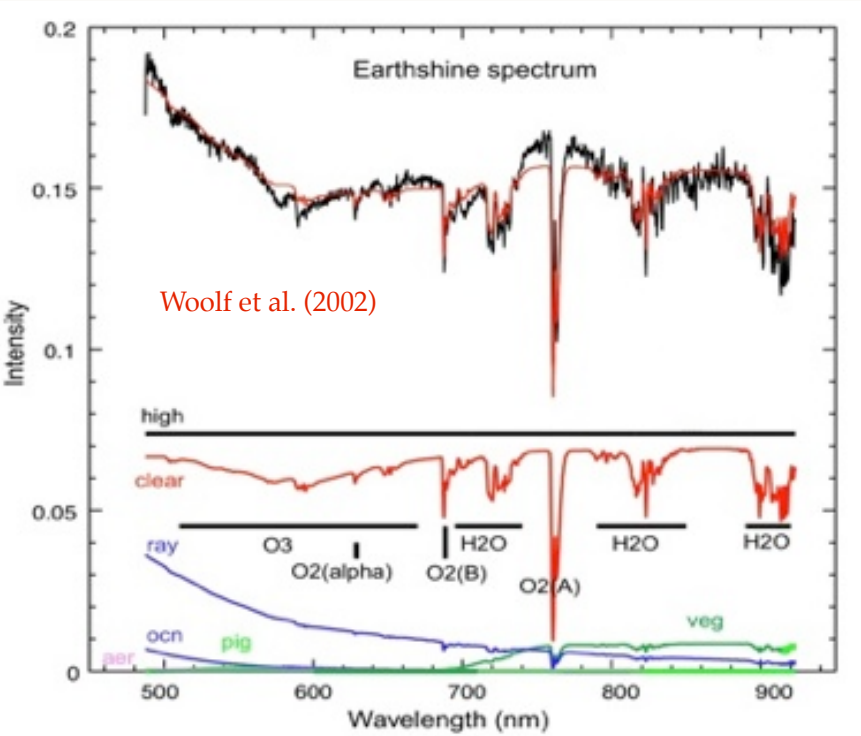


Schmidt et al. (2010)

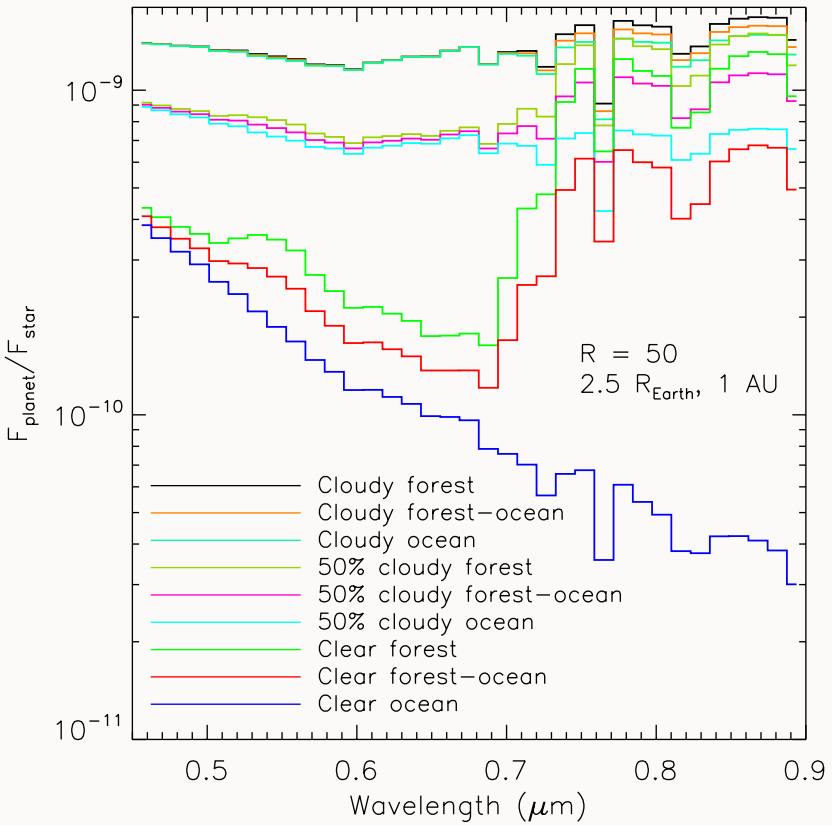
atmospheric information is rich in the visible: molecules CH_4, H_2O .. Rayleigh scat., metallicity effect ...

SCIENCE - TELLURICS

The Earth



some Earths



from Stam (2008)

atmospheric information is rich in the visible:
molecules O_3, O_2, H_2O .. Rayleigh scat.
surface effect : vegetation, clouds

INSTRUMENTAL RECIPE

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High Optical Quality Telescope:
5-10 nm on M1

Coronagraph with small Inner Working Angle:
Optical Vortex 4
(Mawet et al.)

wavefront sensing:
Self Coherent Camera
(Baudoz et al. 2006, Galicher et al. 2010)

wavefront correction:
Xinetics DM 64x64

Polarimetric device:
modulator / analyzer compatible with OVC4

Spectroscopic device:
Integral Field Spectrograph compatible with SCC
(Antichi et al. 2009)

MISSION PARAMETERS

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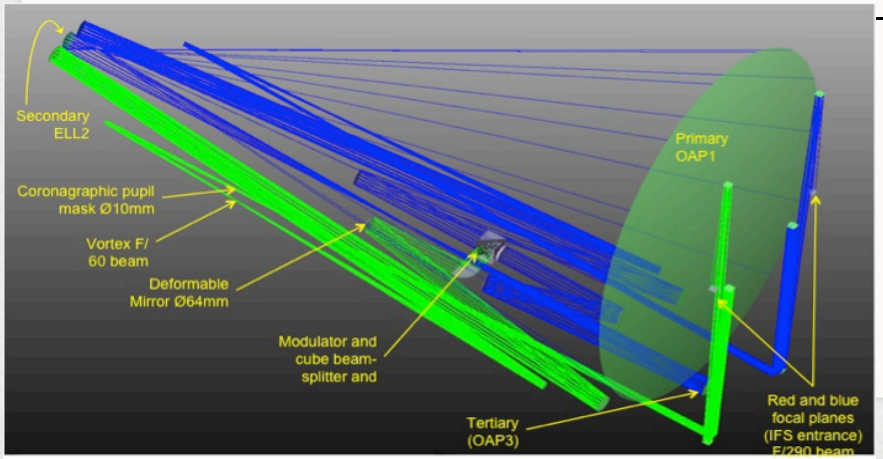
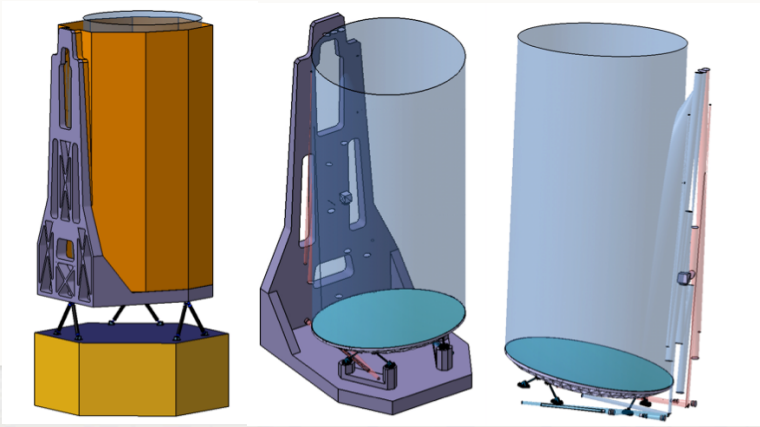
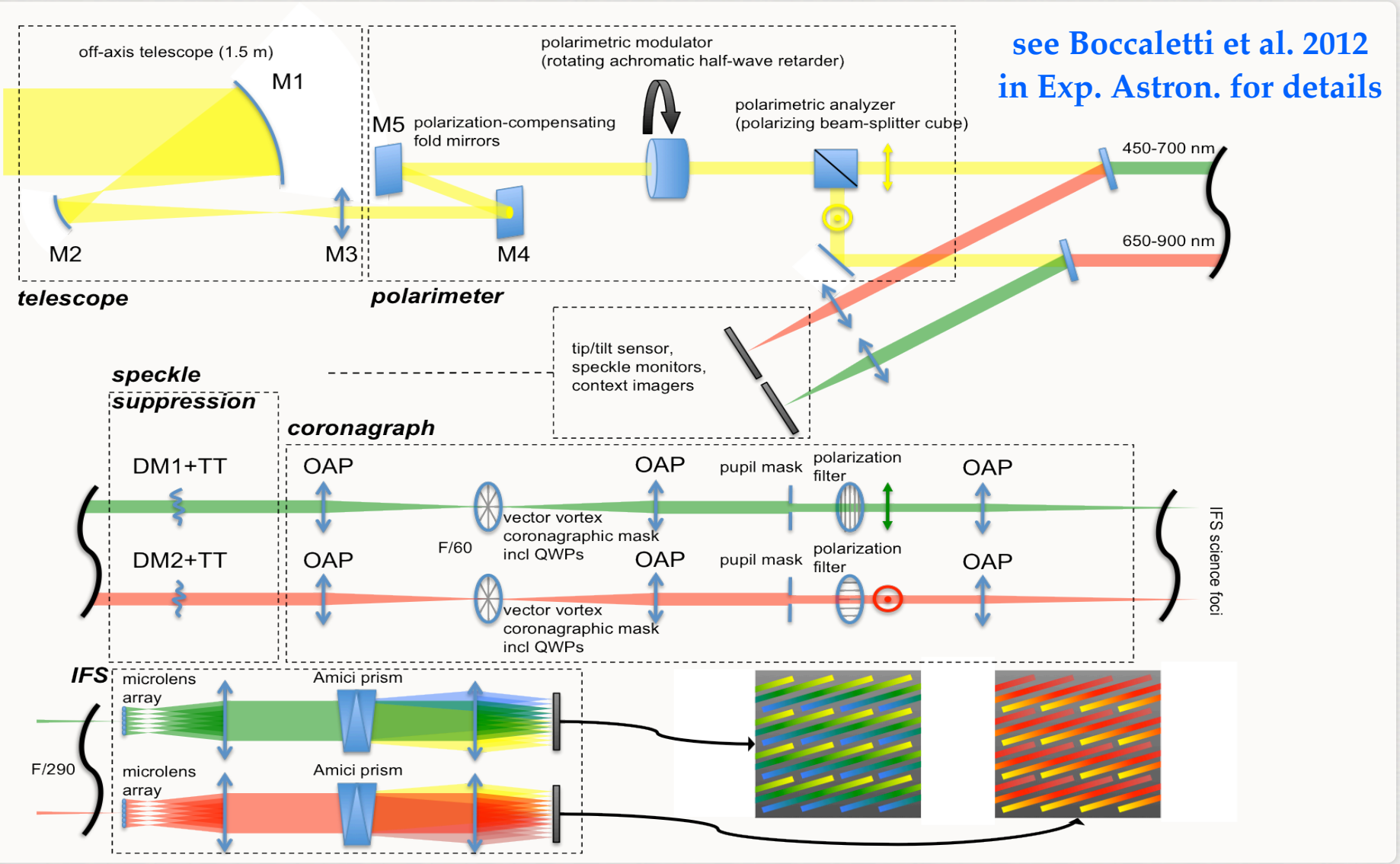
Parameters	Values
Telescope diameter (D)	1.5 m
Bandwidths	450 - 900 nm (goal: 400 - 950 nm)
Equivalent spatial resolution	62 - 120 mas (goal: 55 - 127 mas)
Blue channel / Red channel	450 - 700 nm / 650 - 900 nm
Observable Stokes parameters	I, Q, U
Contrast at 2 lambda/D	a few 10^{-9}
Contrast at 4 lambda/D	a few 10^{-10}
Deformable mirror, nb. of elements	64 × 64 actuators
FOV corrected blue/red channel	6" / 8"
FOV imaged blue/red channel	9" / 12"
WFE static	20 nm rms
WFE DM	10 pm rms
Final pointing accuracy	0.5 mas (goal 0.1 mas)
Polarimetric sensitivity	10^{-3}

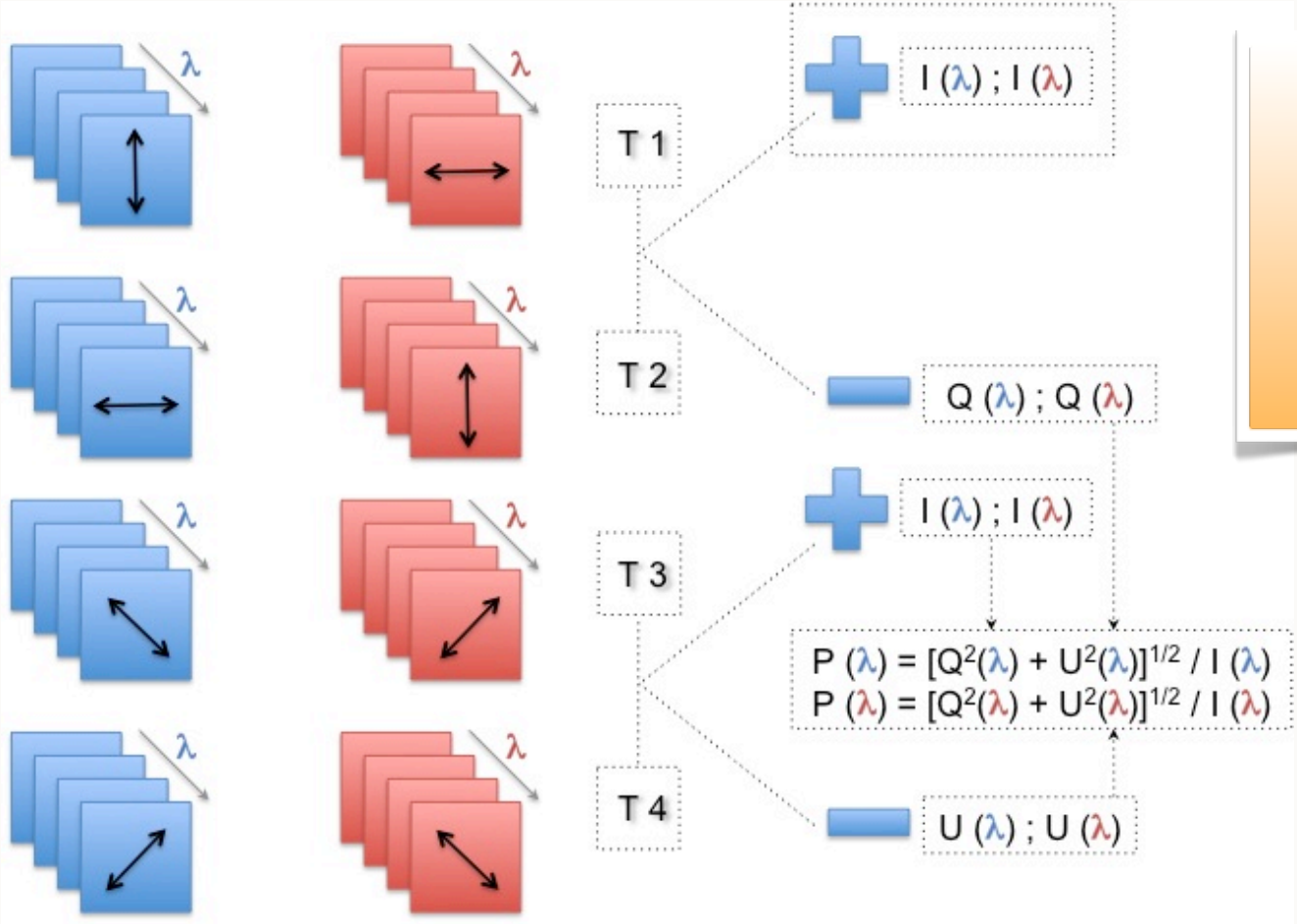




GENERIC CONCEPT



OBSERVING SEQUENCE

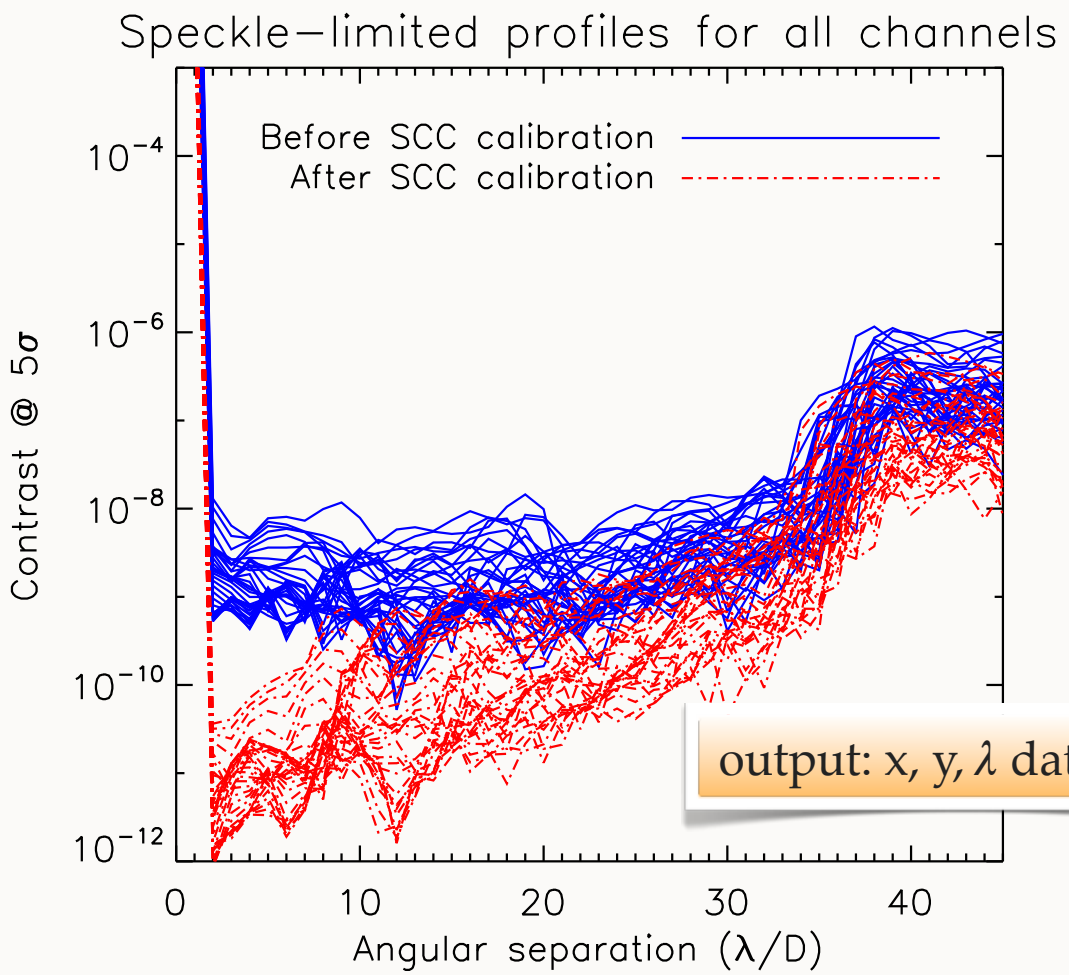


2 observations for Intensity

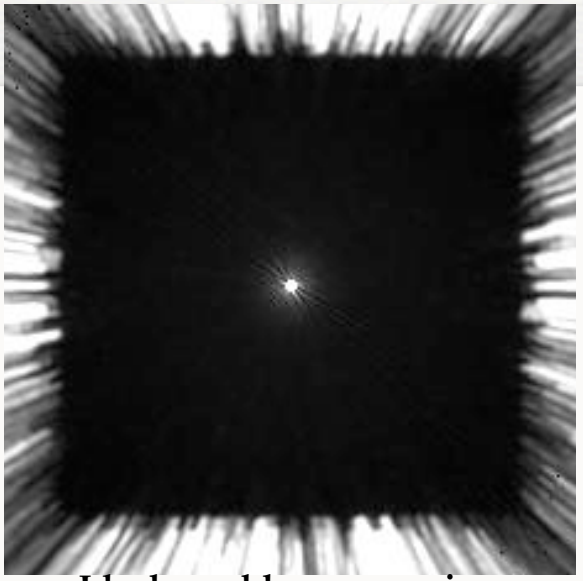
4 observations for Intensity and Polarization

RAW CONTRAST

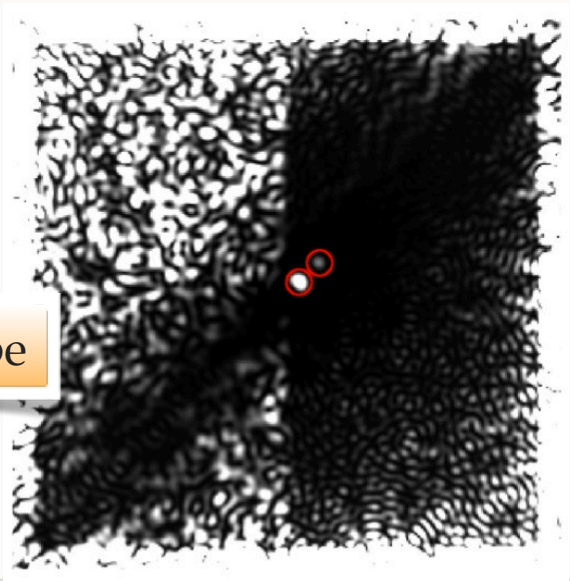
Instrumental simulations developed at Obspm by **R. Galicher and A.L. Maire**



output: x, y, λ data cube



Ideal speckle suppression



Realistic speckle suppression with SPICES

PERFORMANCE: MATURE PLANETS

- intensive simulations to assess the **characterization capabilities** (not just detection !!!)
- Fake planets injected in data cubes
- **Gas / Ice Giants** : Cahoy et al. (2010) models
- **Telluric** : Stam (2008) models
- SNR-based criterion to distinguish between models

Spectral type	Luminosity ($L_\odot$)	Separations (AU)			
A0	28	4.2	10.6	26.5	53.0
F0	4.8	1.8	4.4	11.0	21.9
G2	1	0.8	2	5	10
K0	0.45	0.5	1.3	3.4	6.7
M0	0.09	0.24	0.6	1.5	3

see Maire et al. 2012 in A&A for details

Planet	Parameter	SNR_r	Note
Jupiter	0.8/2 AU	15	
Jupiter 0.8 AU	metallicity 1/3x	30	
Jupiter 2 AU	metallicity 1/3x	30	CH_4 bands
Jupiter 5 AU	metallicity 1/3x	30	CH_4 bands
Neptune	0.8/2 AU	15	
Neptune 0.8 AU	metallicity 10/30x	30	
Neptune 2 AU	metallicity 10/30x	25	CH_4 bands
Forest Earth	0/50/100% clouds	25	blue channels
Ocean Earth	0/50/100% clouds	25	blue channels
Clear Earth	0/50/100% forests	12	red channels
50% cloudy Earth	0/50/100% forests	30	red channels
Cloudy Earth	0/50/100% forests	220	red channels

PERFORMANCE - SPECTRAL TYPE

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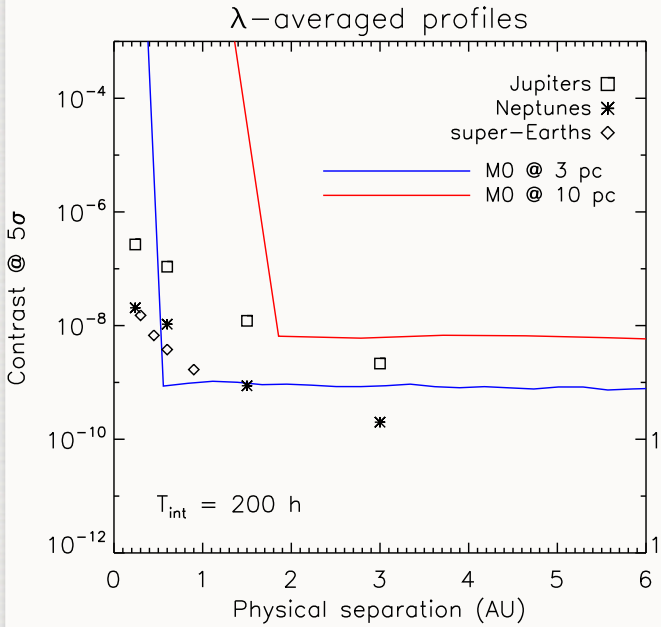
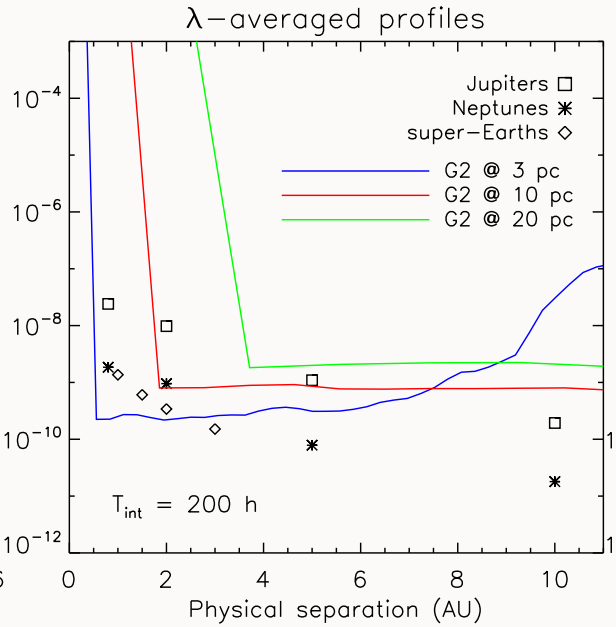
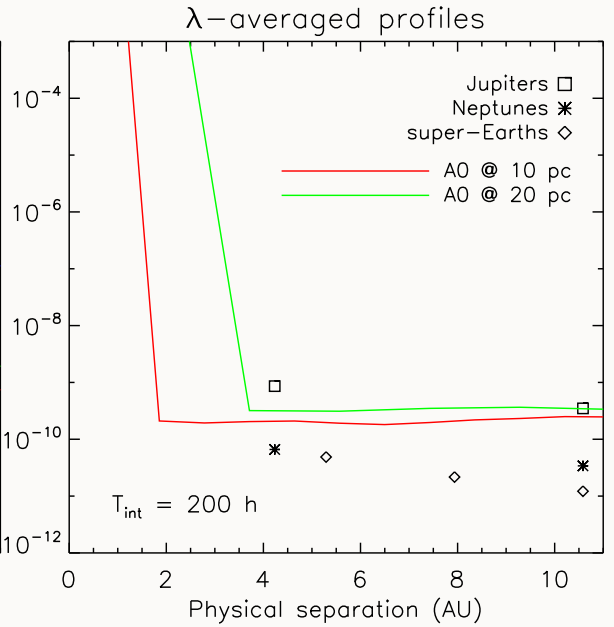
M stars



G stars



A stars



	limit in separation [AU]		
	Jupiter	Neptune	Super Earth
A0 < 20 pc	1 - 10	1 - 3	1 - 3
G2 < 10pc	1 - 6	1 - 3	1 - 2
M0 < 7.5pc	0.5 - 4	0.5 - 1.5	0.5 - 1

possibly habitable planets

SPECTROSCOPY - GIANTS

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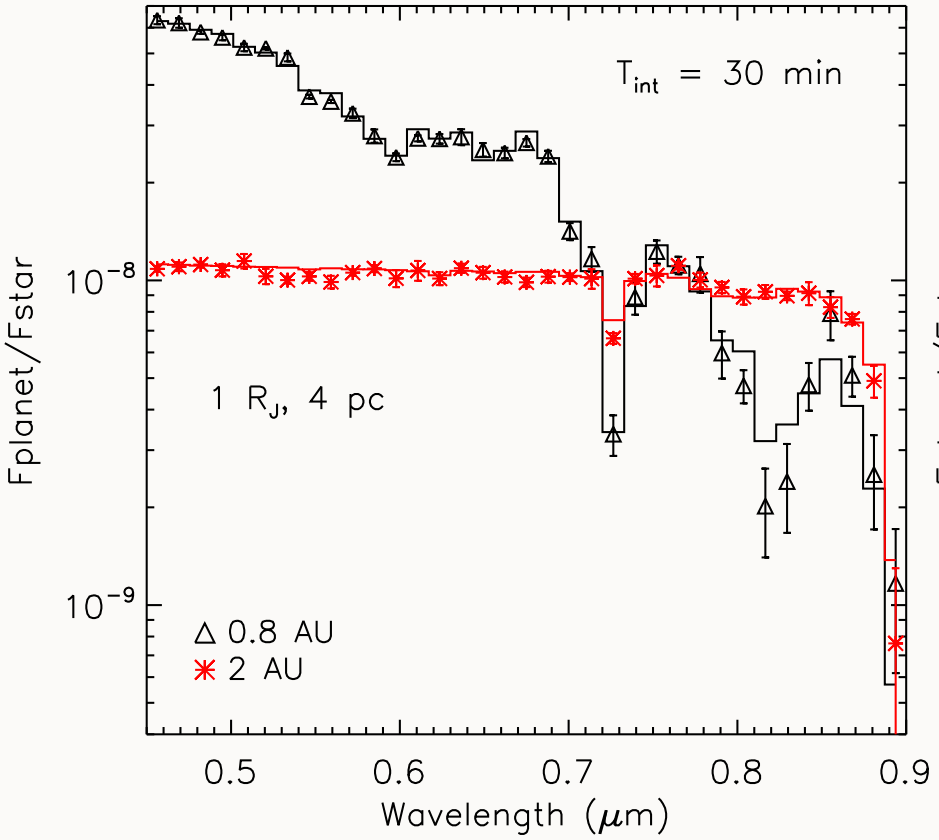
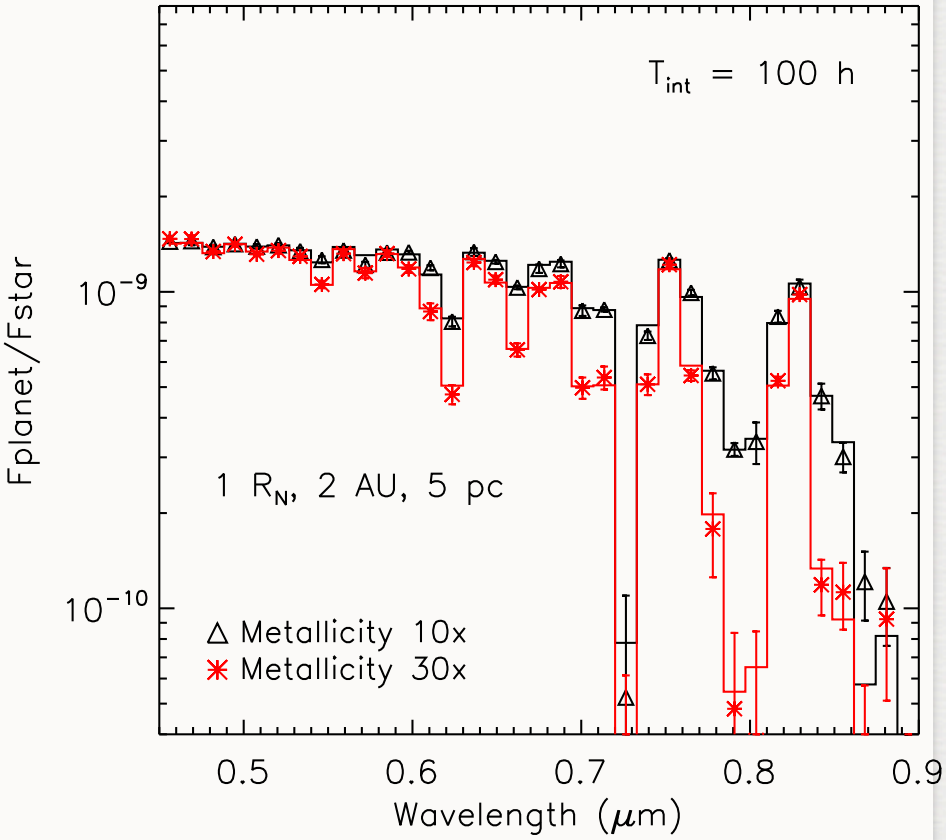
G stars only

dist. / Rayleigh scat.



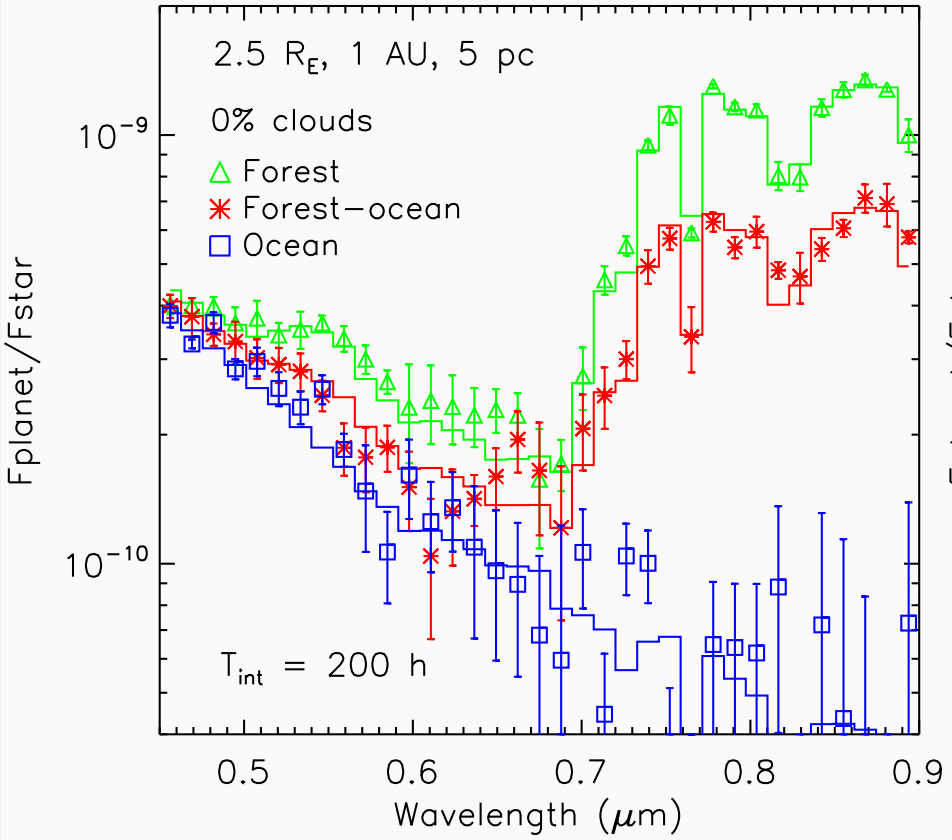
metallicity



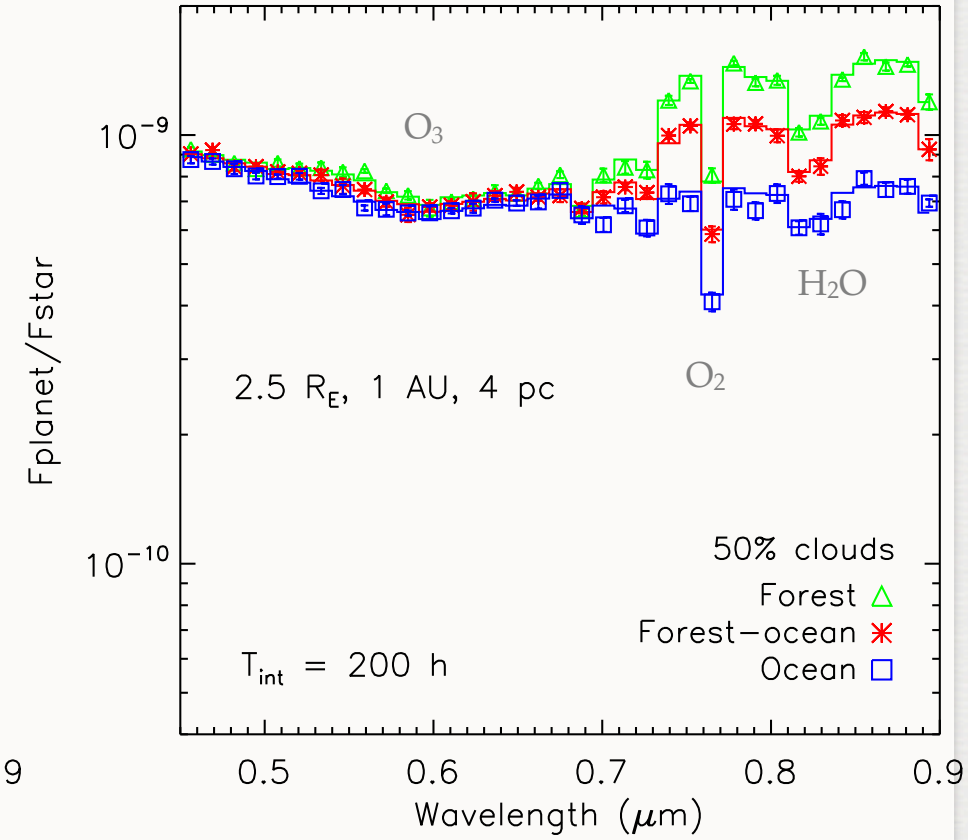
SPECTROSCOPY - TELLURIC

G stars only

No clouds



50% Clouds



GLOBAL PERFORMANCE

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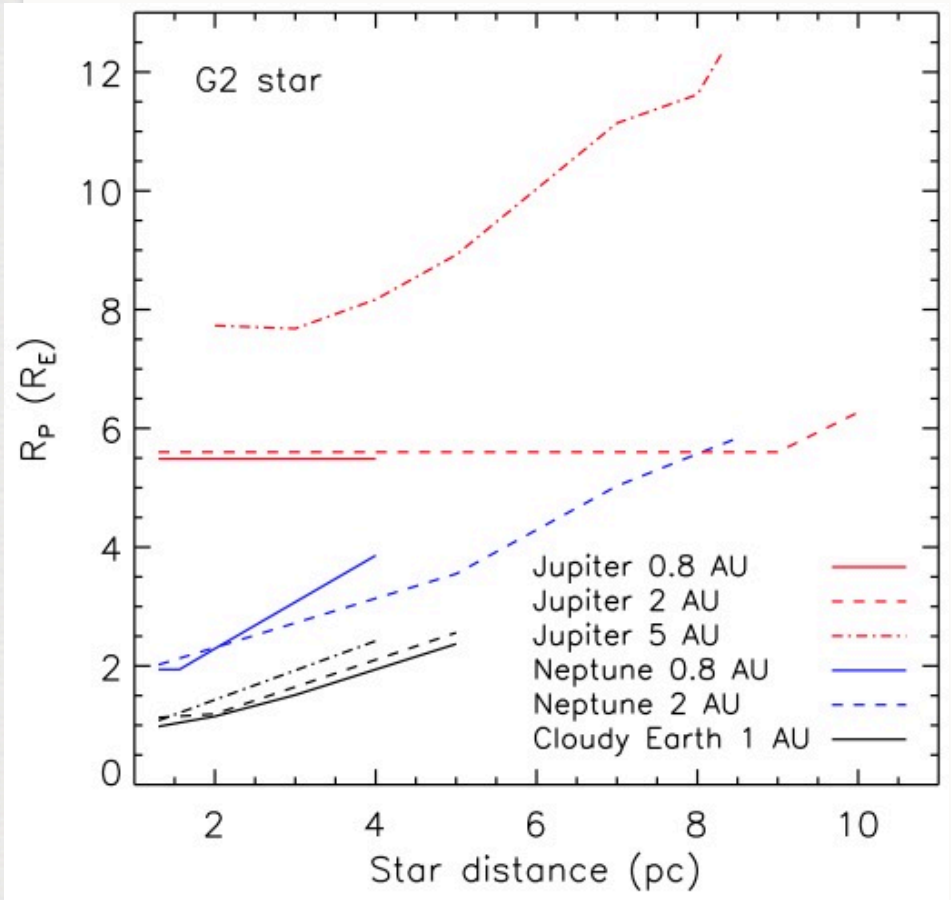
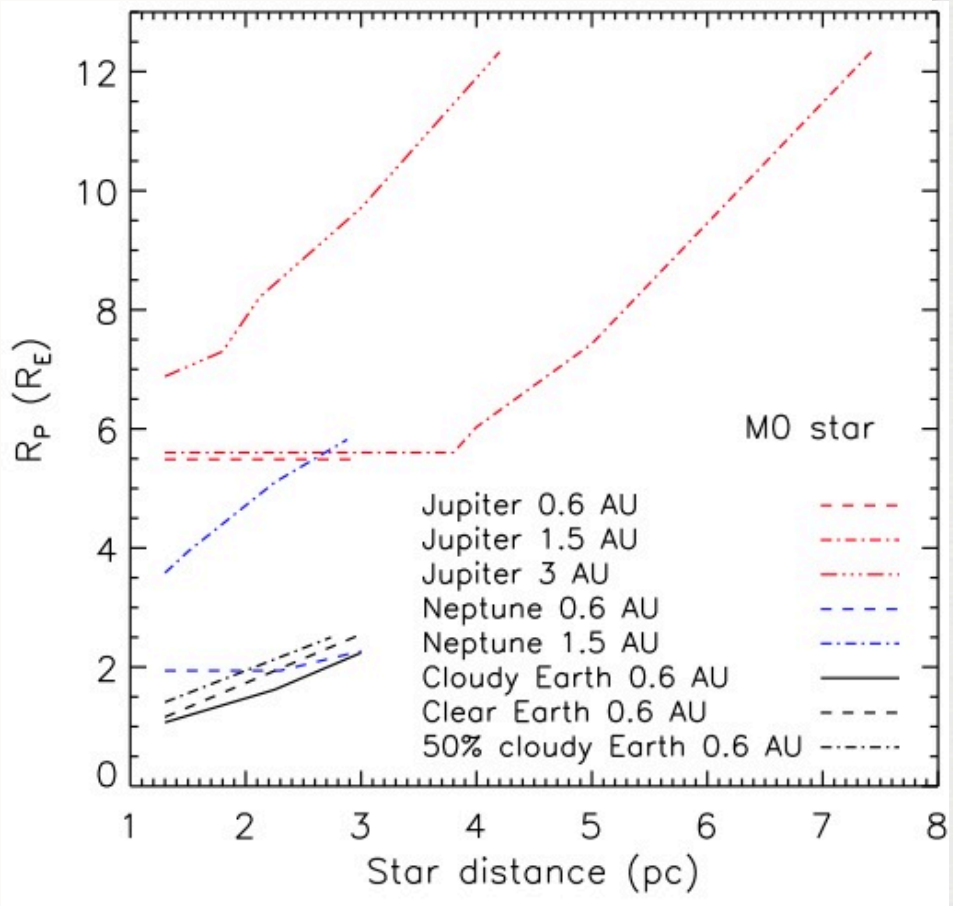
Minimal Radius achievable for characterization





SUMMARY

- **More details about SPICES in :**
  - Boccaletti et al. 2012 : summary of the ESA proposal (Exp. Astron)
  - Maire et al. 2012 : performance in terms of characterization (A&A)
  - several SPIE papers about sub-systems (SCC, IFS, DM ...)
- SPICES capabilities are **clarified** with our simulations :
  - which type of planets, stars, separations, distance
  - which atmospheric properties can be measured
- Polarimetric capabilites are still to be investigated
- SPICES target sample is large. A 5-year mission allows to observe ~100 targets
- Target sample is provided by **Radial Velocity & Astrometric** programs (ESPRESSO, GAIA)
- Marginal characterization of **Earth-size planet**(s) is possible around the nearest star(s)

WHAT'S NEXT ?

- SPICES not selected in M3
- Concerns raised by ESA :
  Technology readiness / time for development / cost envelope
- for the future :
  - M4 opportunity: but other exoplanet missions were downselected by ESA (PLATO, ECHO, EUCLID)
  - «think bigger»: submit SPICES as L class mission: 650M€+ collaborations

Anyone interested is invited to join ...