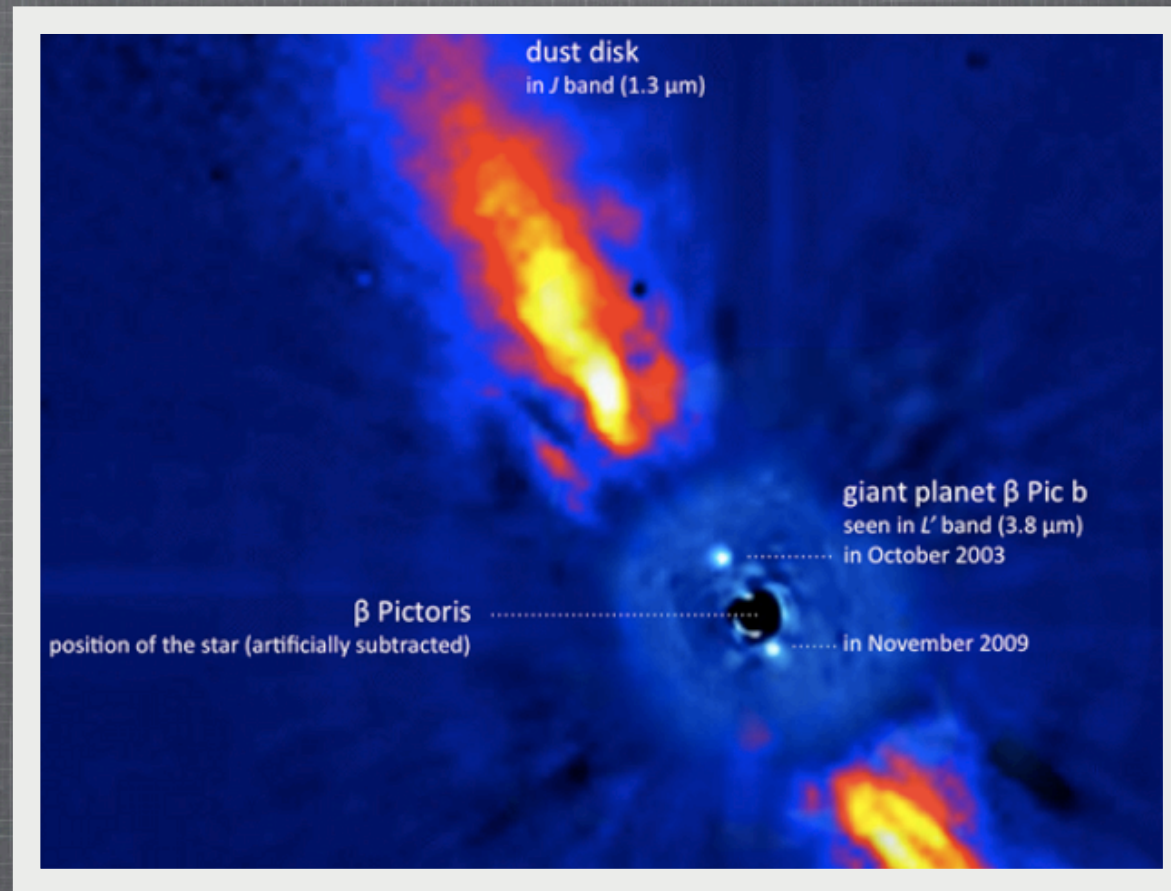
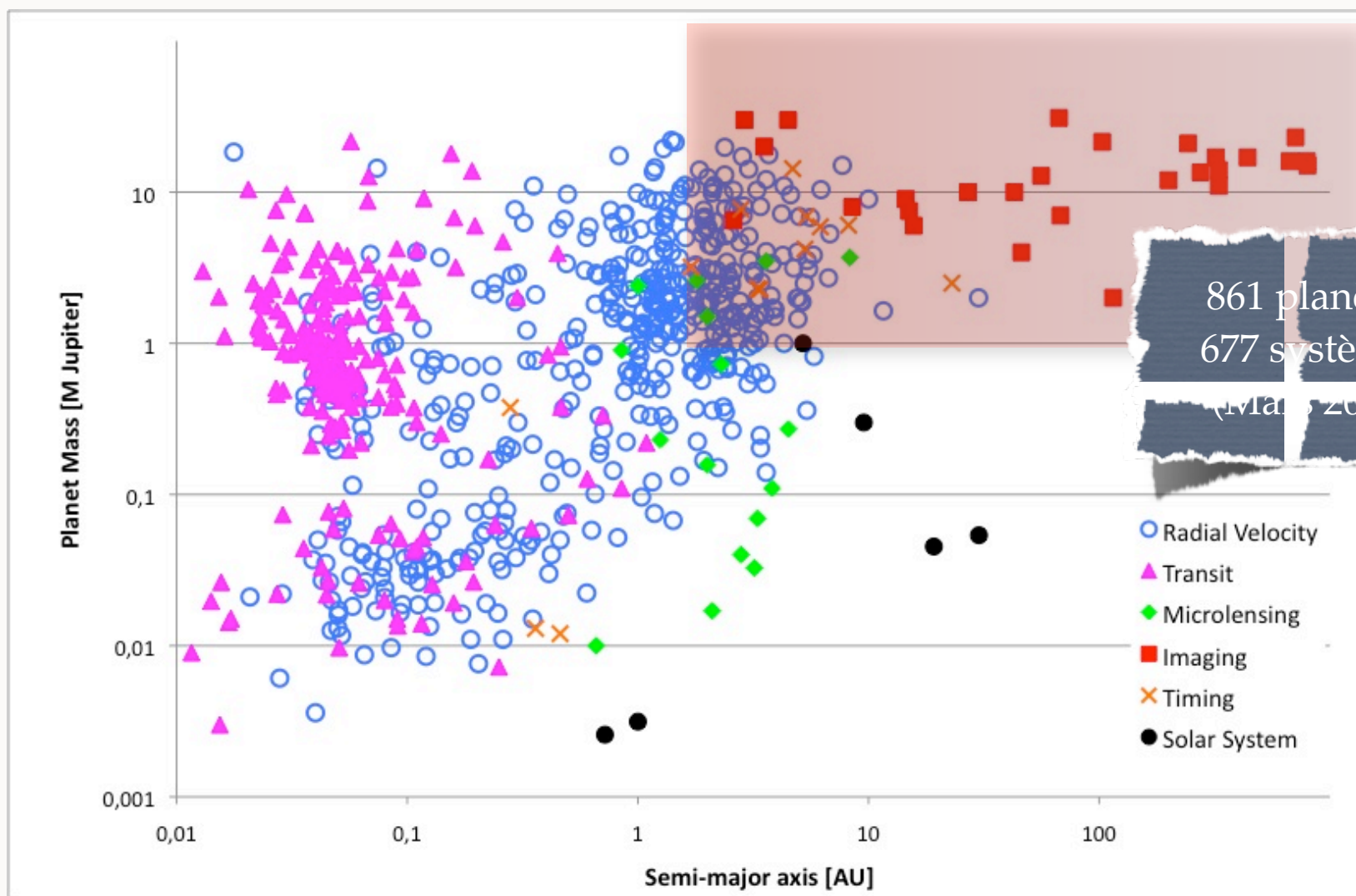


IMAGERIE DE PLANÈTES EXTRASOLAIRES (SOL/ESPACE)



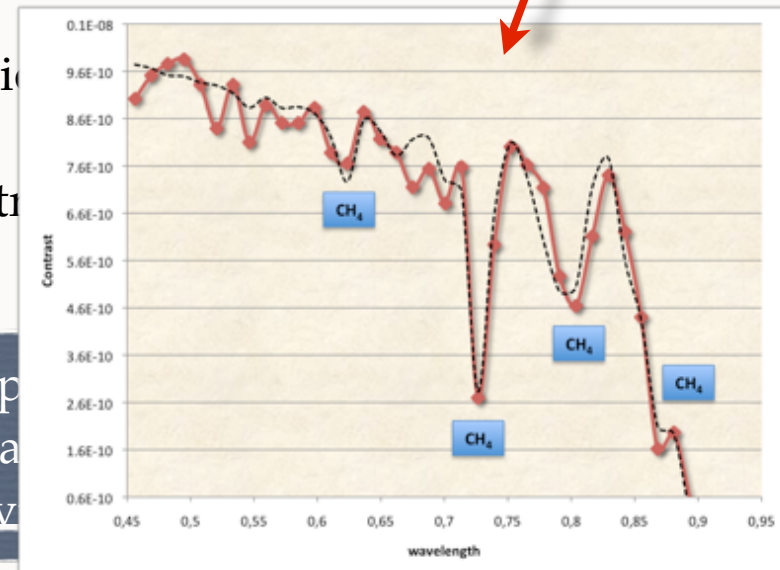
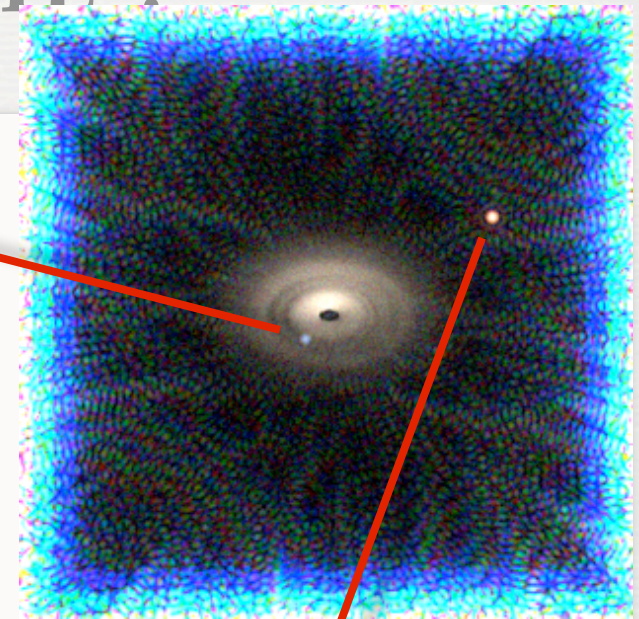
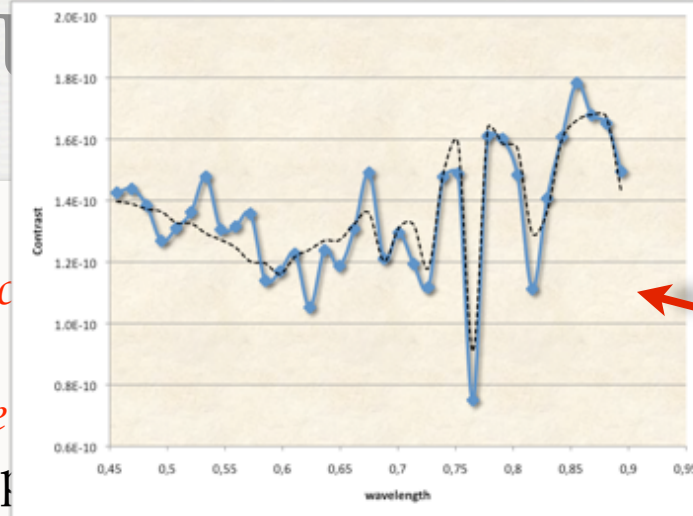
Anthony Boccaletti (LESIA)

ÉTAT DES LIEUX



POURQUOI L'IMAGERIE ?

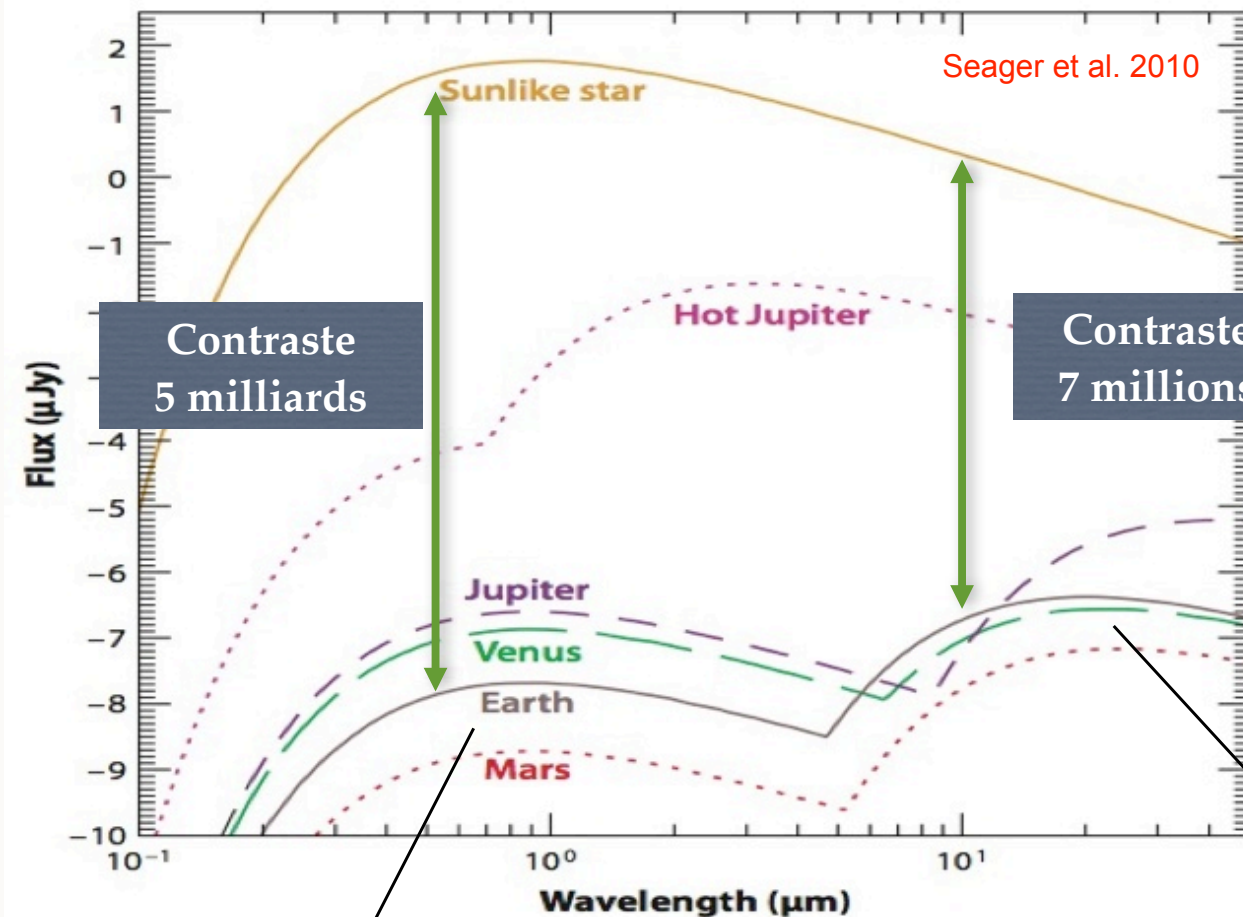
- ❖ *Sensible à toutes les composantes*
- ❖ *Position dans l'image*
 - **position orbitale (t):** position des systèmes planétaires, distribution de la poussière
- ❖ *Flux (intensité & polarisé): $F(\lambda, t)$, $P(\lambda, t)$*
 - **spectre/polarisation** => physique et chimie de l'atmosphère (composition, température, pression, masse, gravité, nuages, sols)
 - variations temporelles (saisons, anneaux, excentricité)
 - habitabilité, bio signatures



L'imagerie directe est un outil pour
étudier les atmosphères exoplanétaires.
Toutes les λ sont intéressantes du visible à l'infrarouge.

PROBLÉMATIQUES

Contraste



Lumière réfléchie
irradiated planets

$$F_p = a(\lambda, t) \varphi(t) \cdot \frac{r_p^2}{4d^2} B(\lambda, T_s) \cdot r_s^2$$

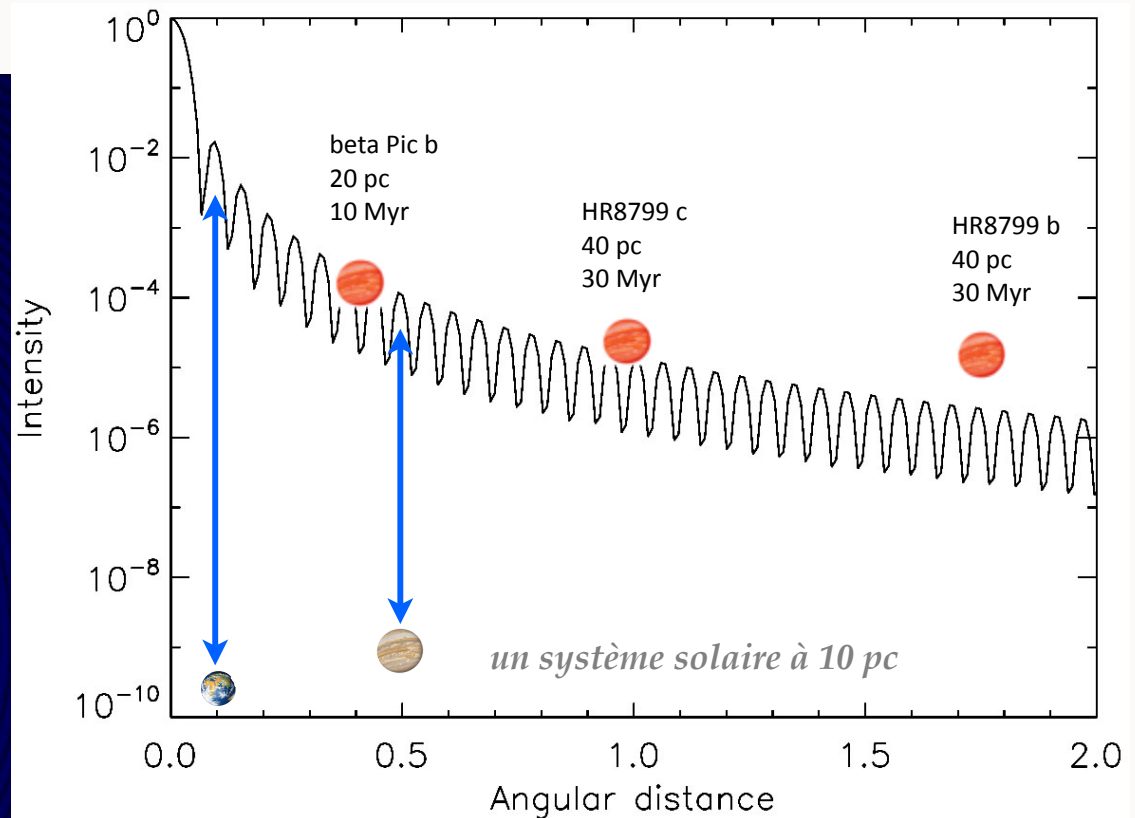
$F_p = \varepsilon_{IR} B(\lambda, T_p) r_p^2$
Émission thermique
self luminous planets

PROBLÉMATIQUES

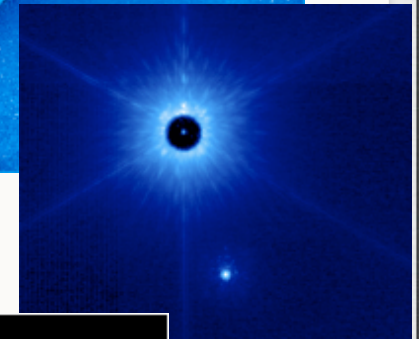
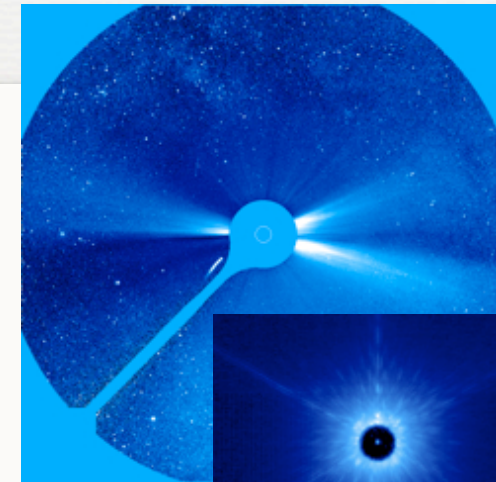
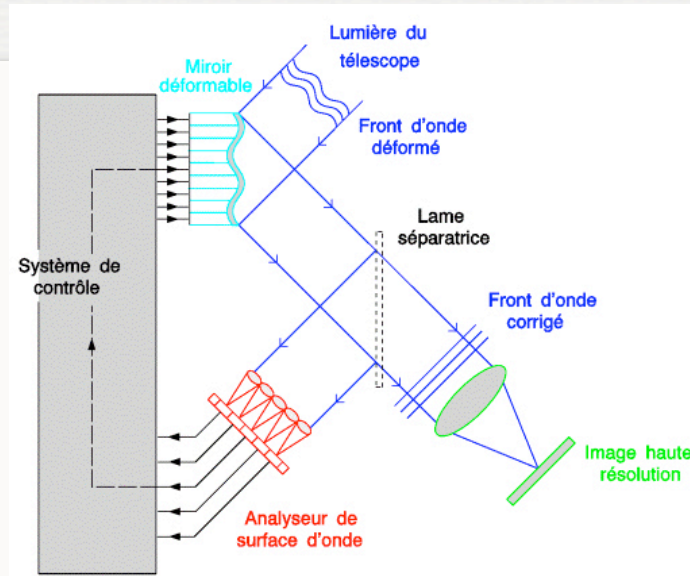
Résolution angulaire

Télescope
diamètre D

Image au foyer obtenu
à la longueur d'onde λ

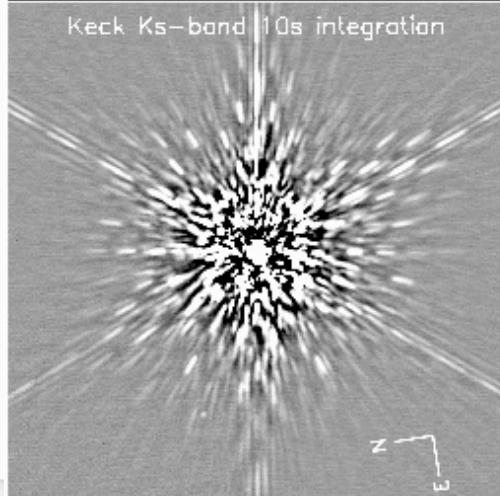


TECHNIQUES DE DÉTECTION

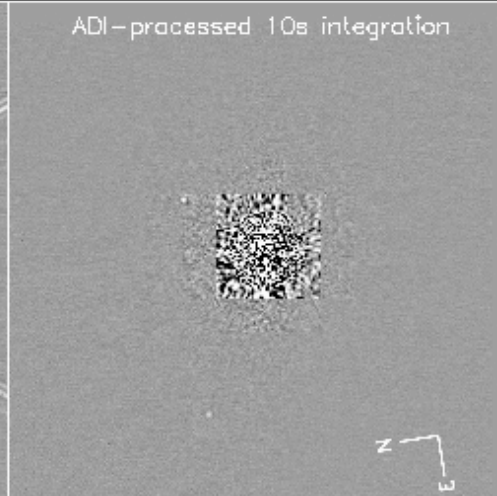


Angular Differential Imaging (ADI)

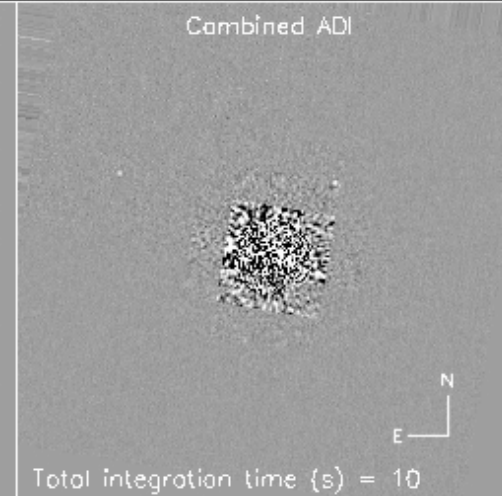
Keck Ks-band 10s integration



ADI-processed 10s integration

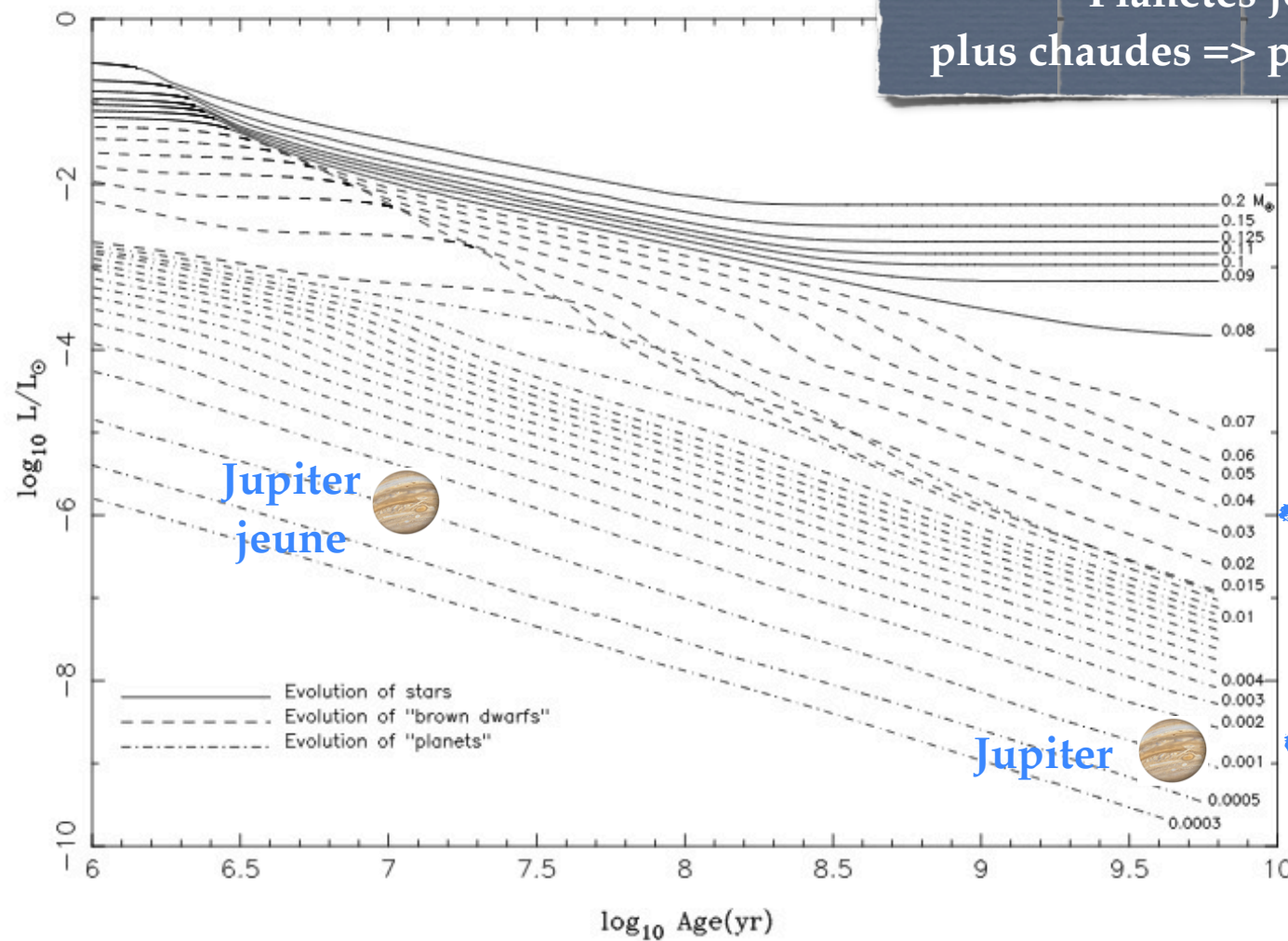


Combined ADI



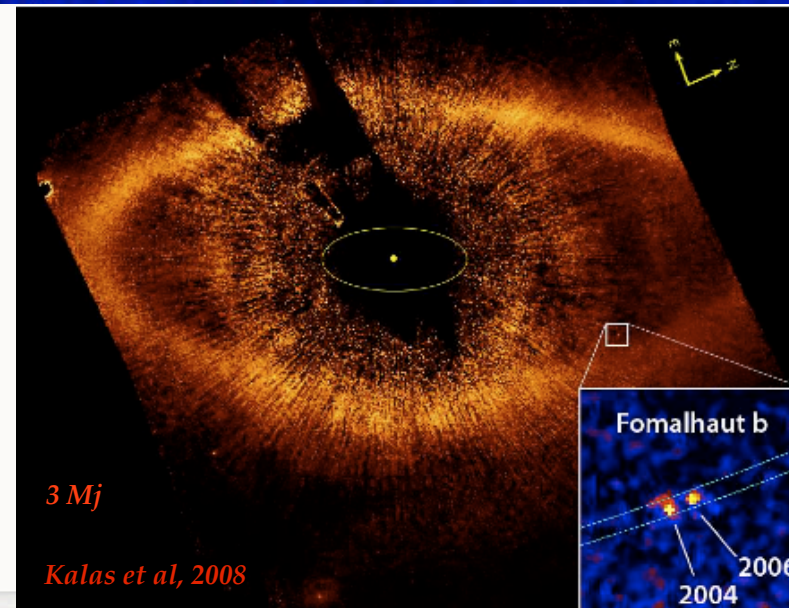
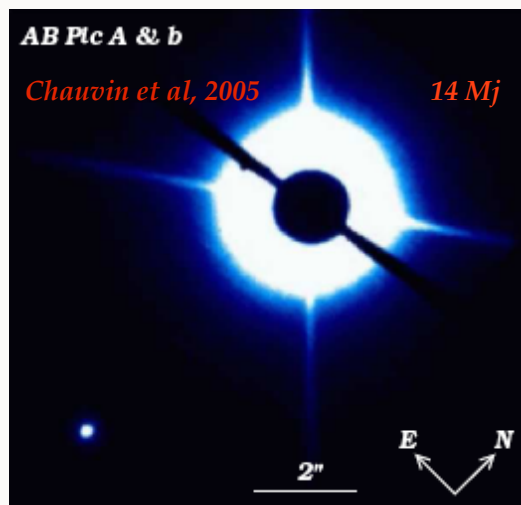
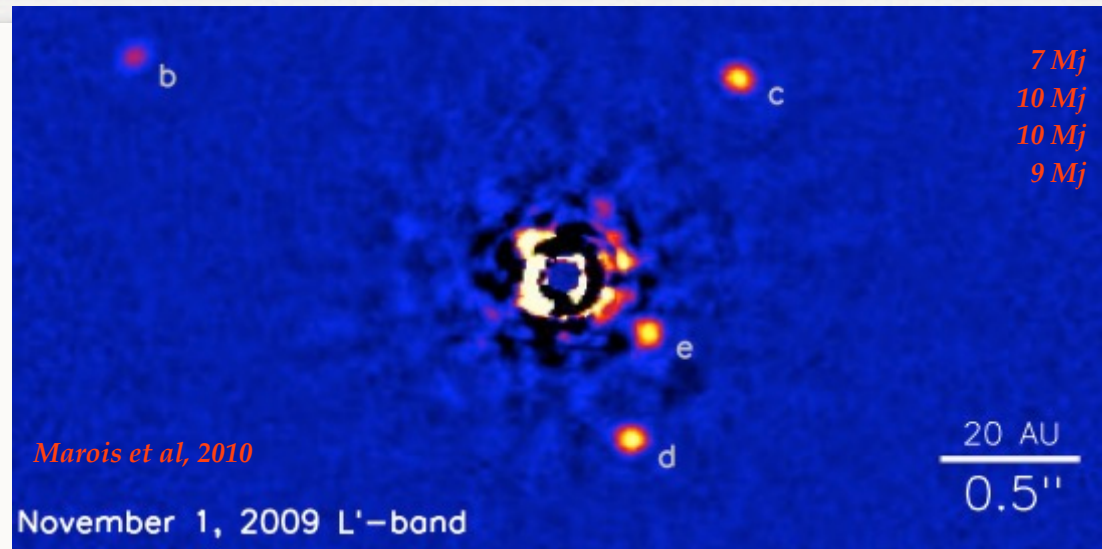
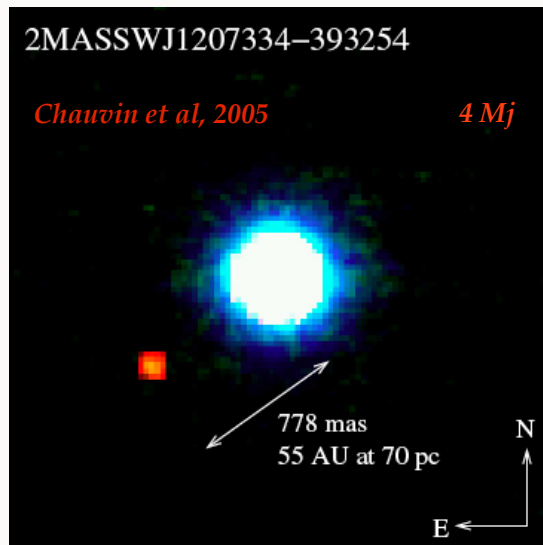
COUP DE CHANCE !!!

Planètes jeunes
plus chaudes => plus brillantes

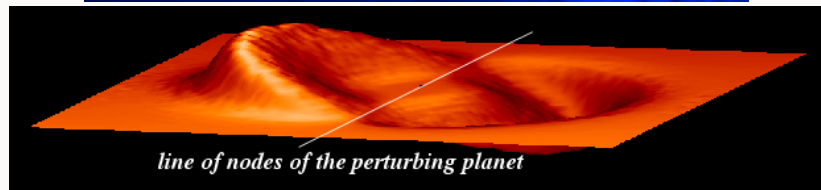
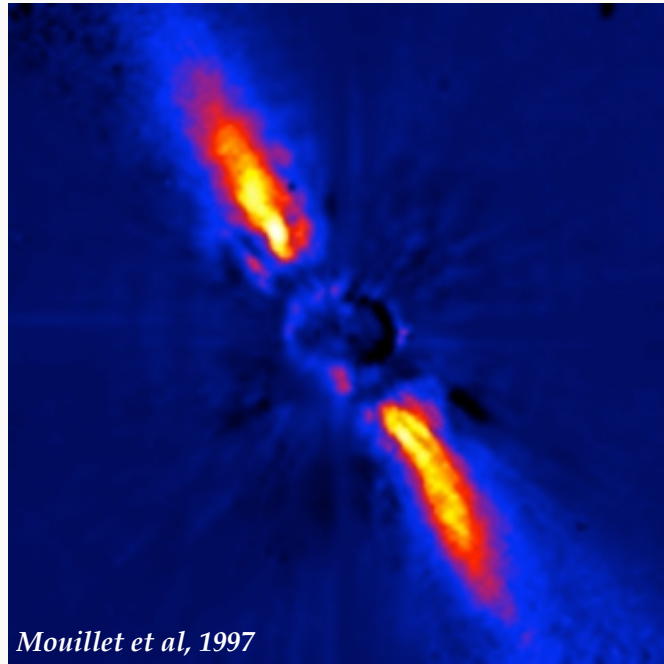


Burrows et al. 1997

EXEMPLES DE PLANÈTES IMAGÉES

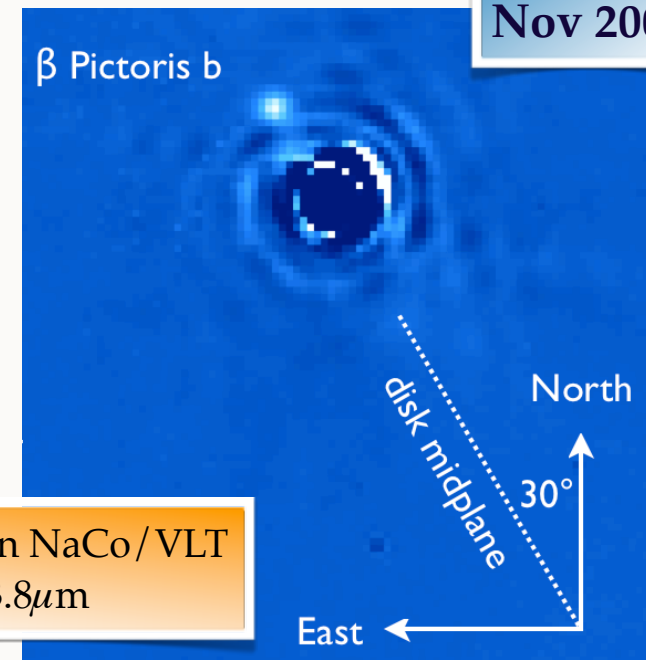


LA PLANÈTE β PICTORIS b



*Modélisation du disque de planétésimaux
Augereau et al. 2001*

Prédiction : ~10 MJ à ~10 AU



Observation NaCo/VLT
bande L' : $3.8\mu\text{m}$

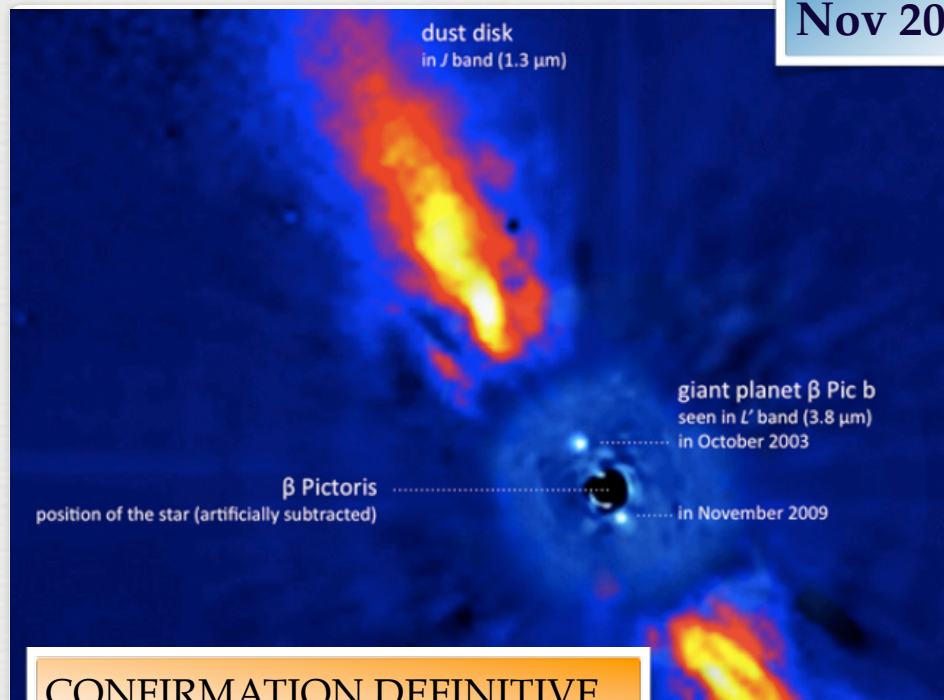
Lagrange et al, 2009

- ◆ séparation: 410 ± 10 mas $\Rightarrow$ 8-9 AU projetée
- ◆ PA = $31.8 \pm 1.3^\circ$
- ◆ $\Delta L' = 7.7 \pm 0.3$ mag $\Rightarrow L' = 11.2$ mag
- ◆ 8-9 MJ (hot start model)

LA PLANÈTE β PICTORIS b

Nov 2009

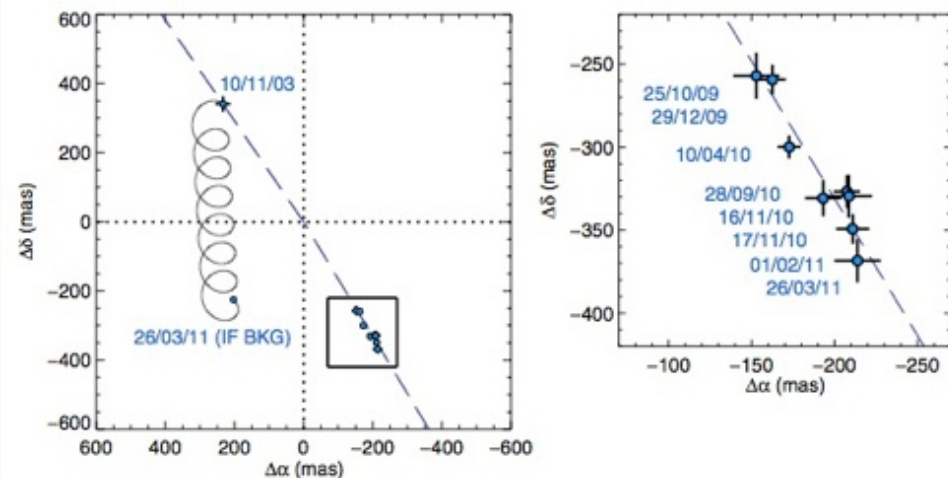
- suivi régulier en 2010/2011
- obs/réduction homogène



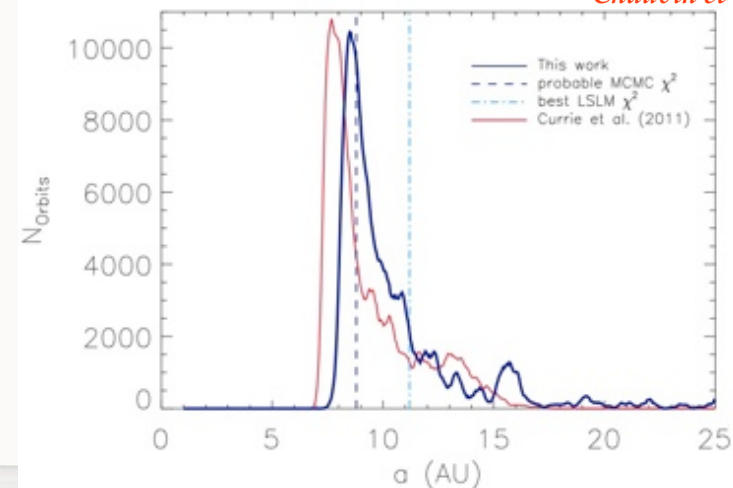
CONFIRMATION DEFINITIVE

Lagrange et al, 2010

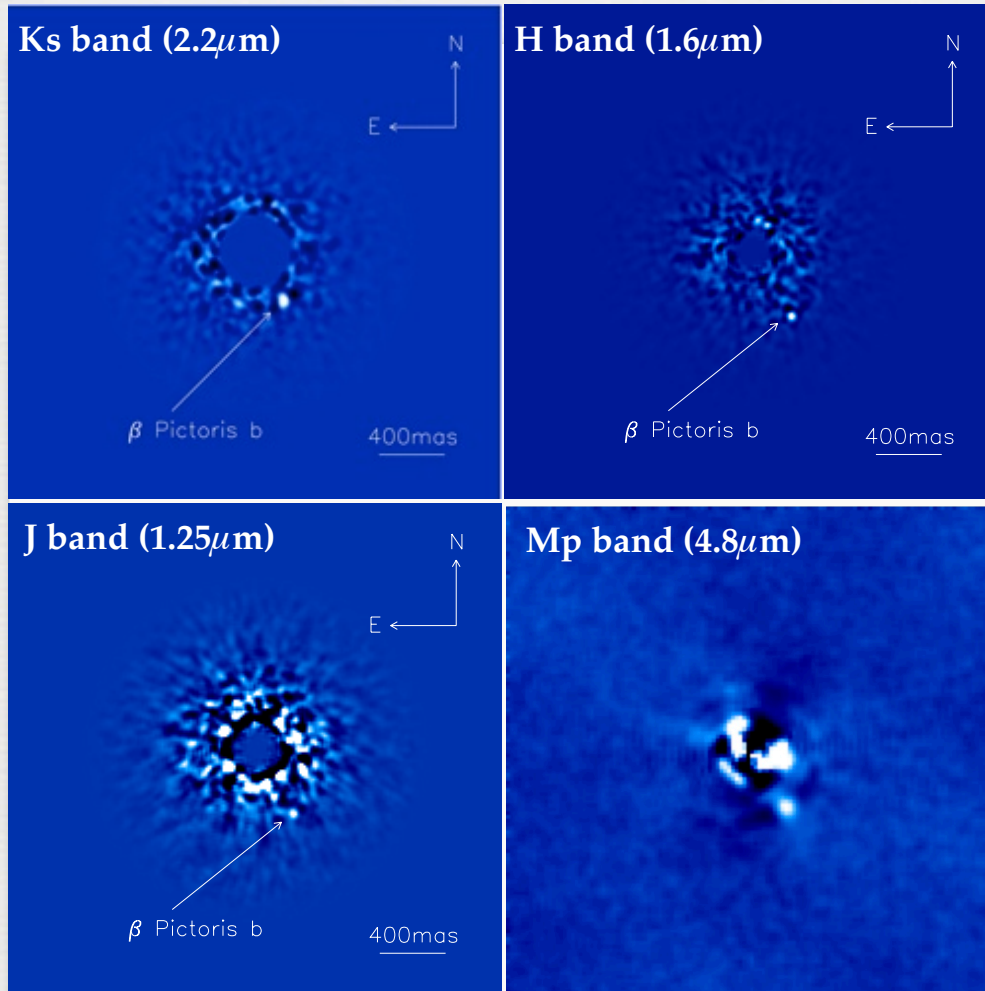
2003/10 : 0.4" NE
2009/01 : pas détecté
2009/11 : 0.3" SW



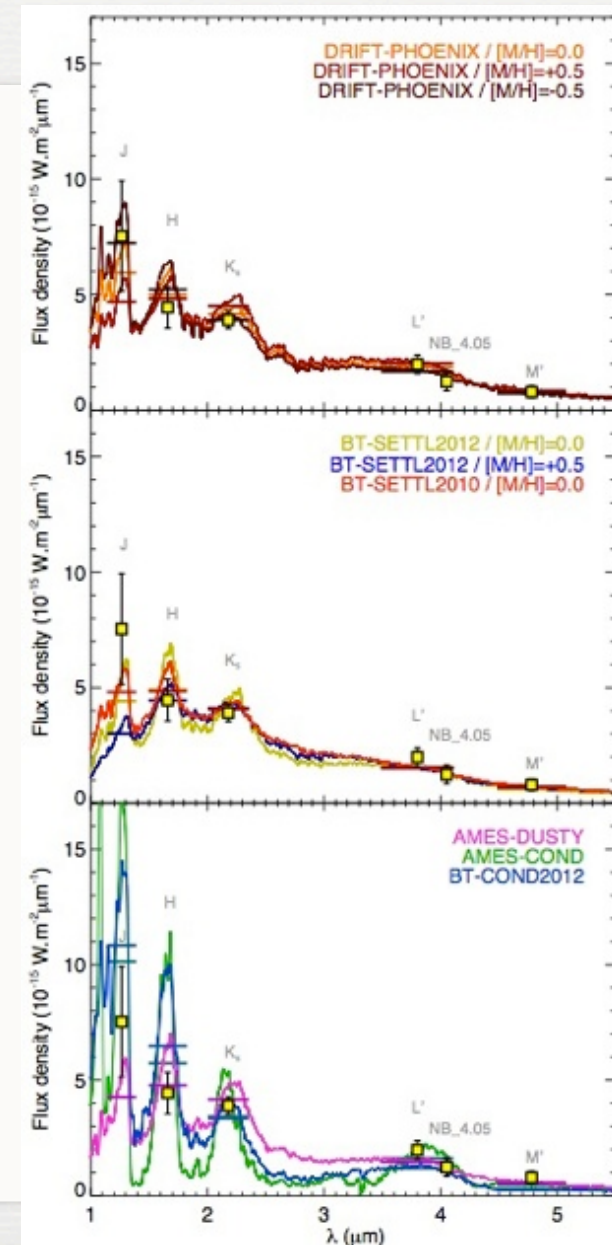
Chauvin et al, 2012



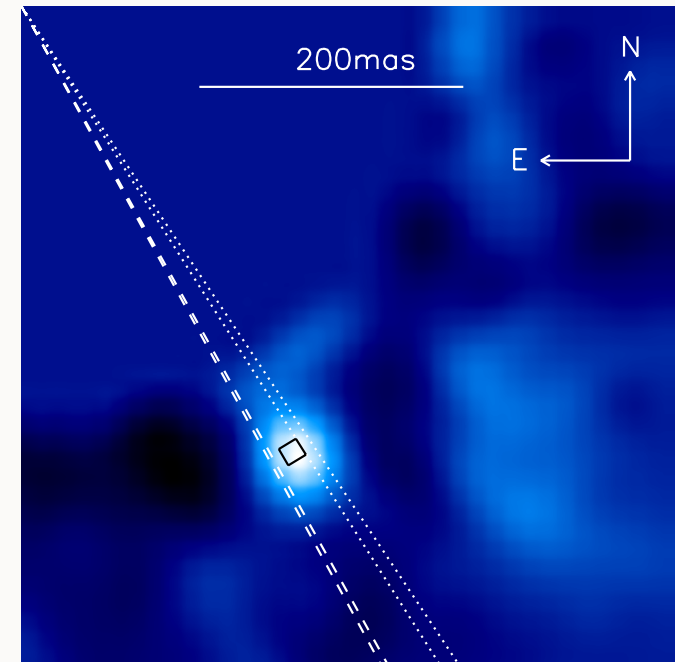
LA PLANÈTE β PICTORIS b



Bonnefoy et al. 2013



LA PLANÈTE β PICTORIS b



Lagrange et al, 2012

relation planète - disque
=> la planète cause du warp

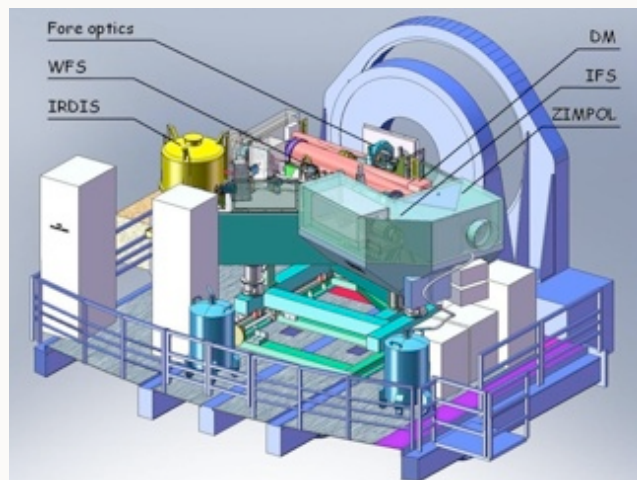
PLANET FINDERS

2013



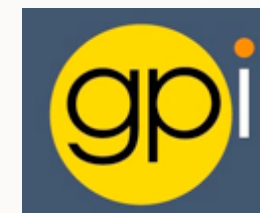
European Consortium, VLT

- camera IR
- Spectrographe IR
- camera polarimétrie Visible



Recherche de planètes dans :

- associations d'étoiles jeunes (10 Myrs <100pc)
- étoiles avec planètes connues (RV surveys)
- étoiles d'âge intermédiaire (0.1-1 Gyr)
- étoiles très proches (<20 pc)



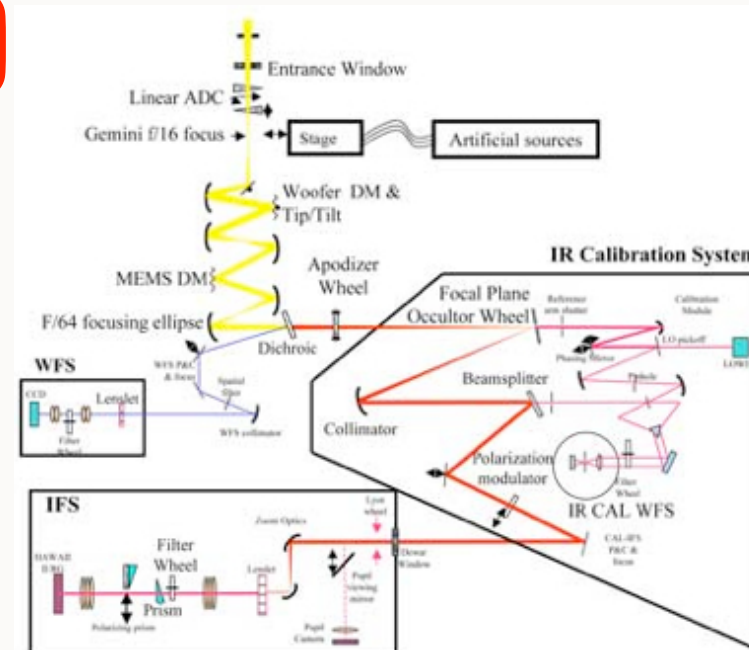
US, Gemini South

Spectrographe IR

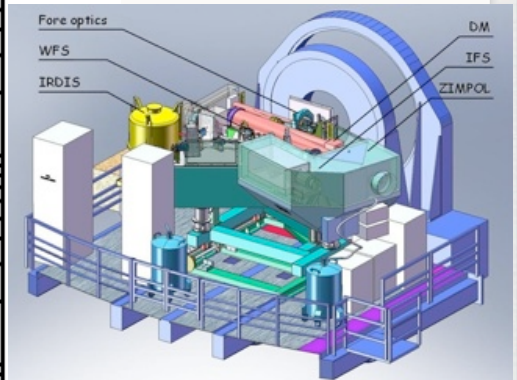
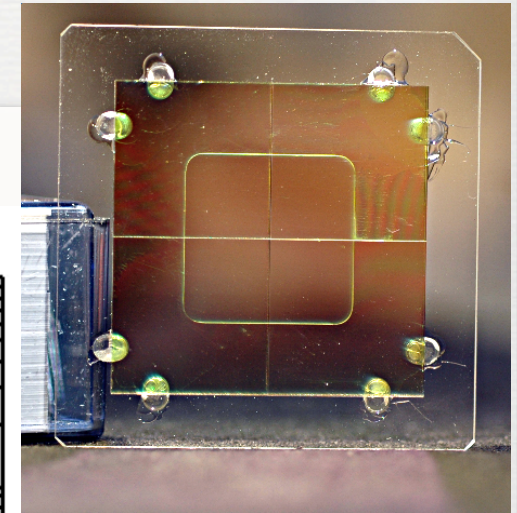
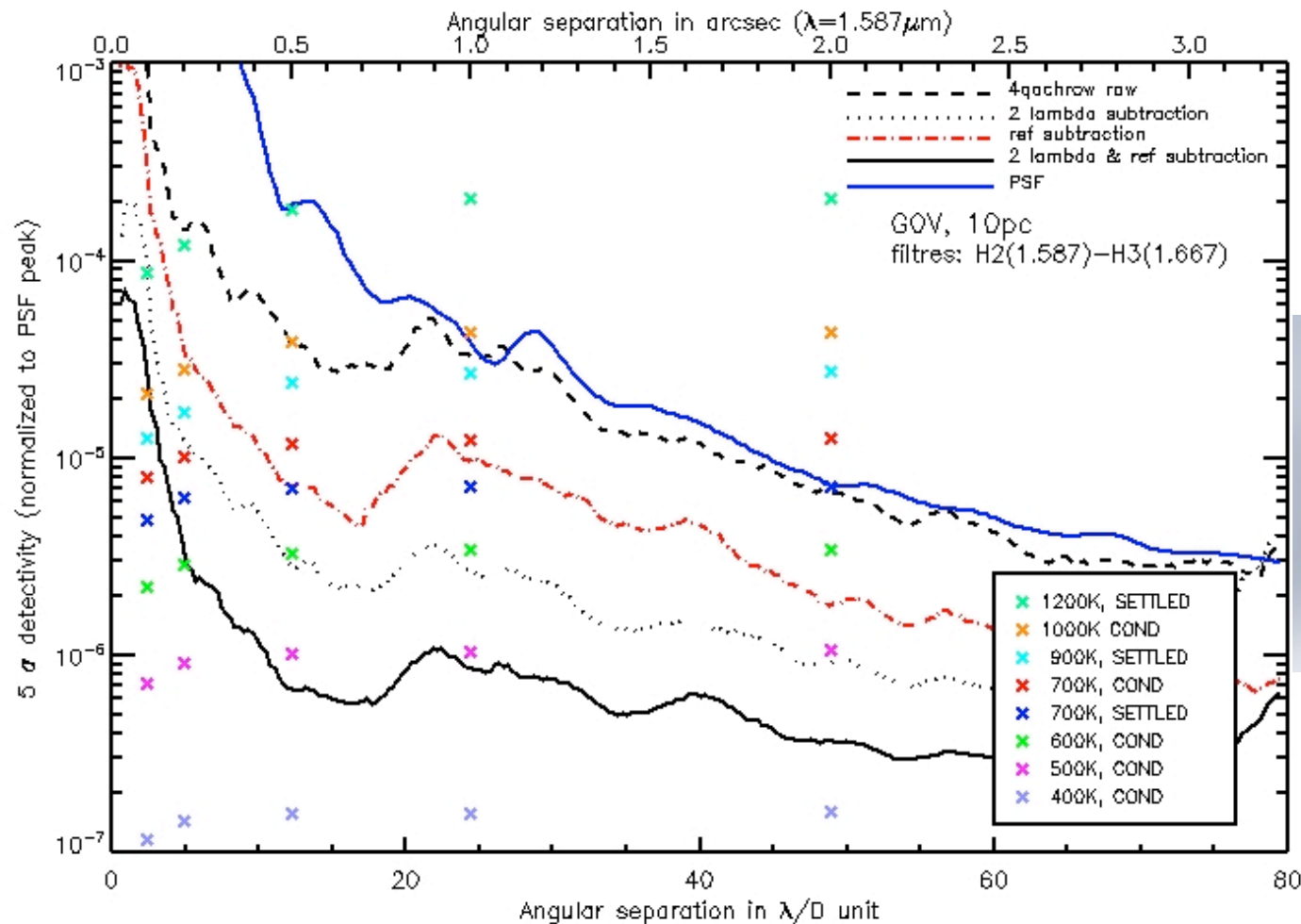
HiCIAO

Japan, Subaru

- camera IR
- polarisation IR

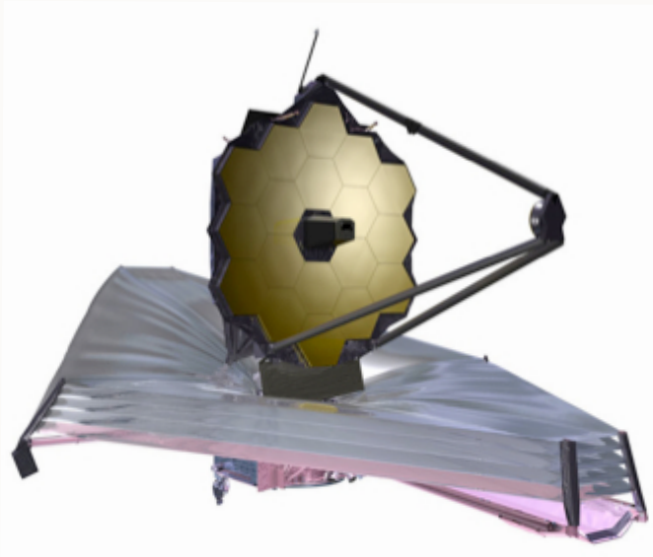


SPHERE PERFORMANCE



JAMES WEBB SPACE TELESCOPE

2018



NIRCAM

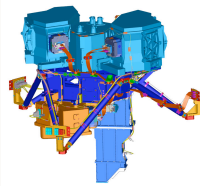


US

0.6 - 5 μm

coronographie + spectro transit

MIRI

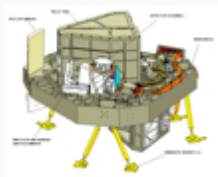


Europe / US

5 - 28 μm

coronographie + spectro transit

NIRISS

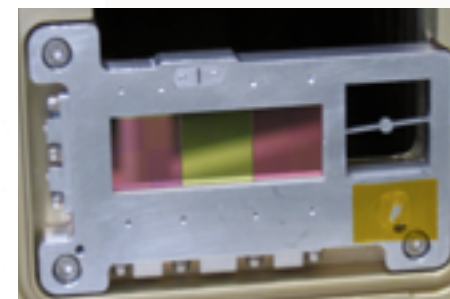
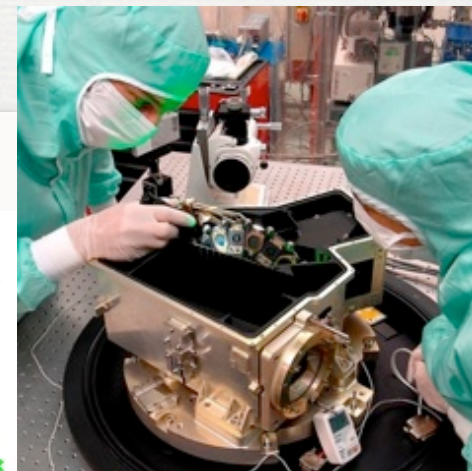
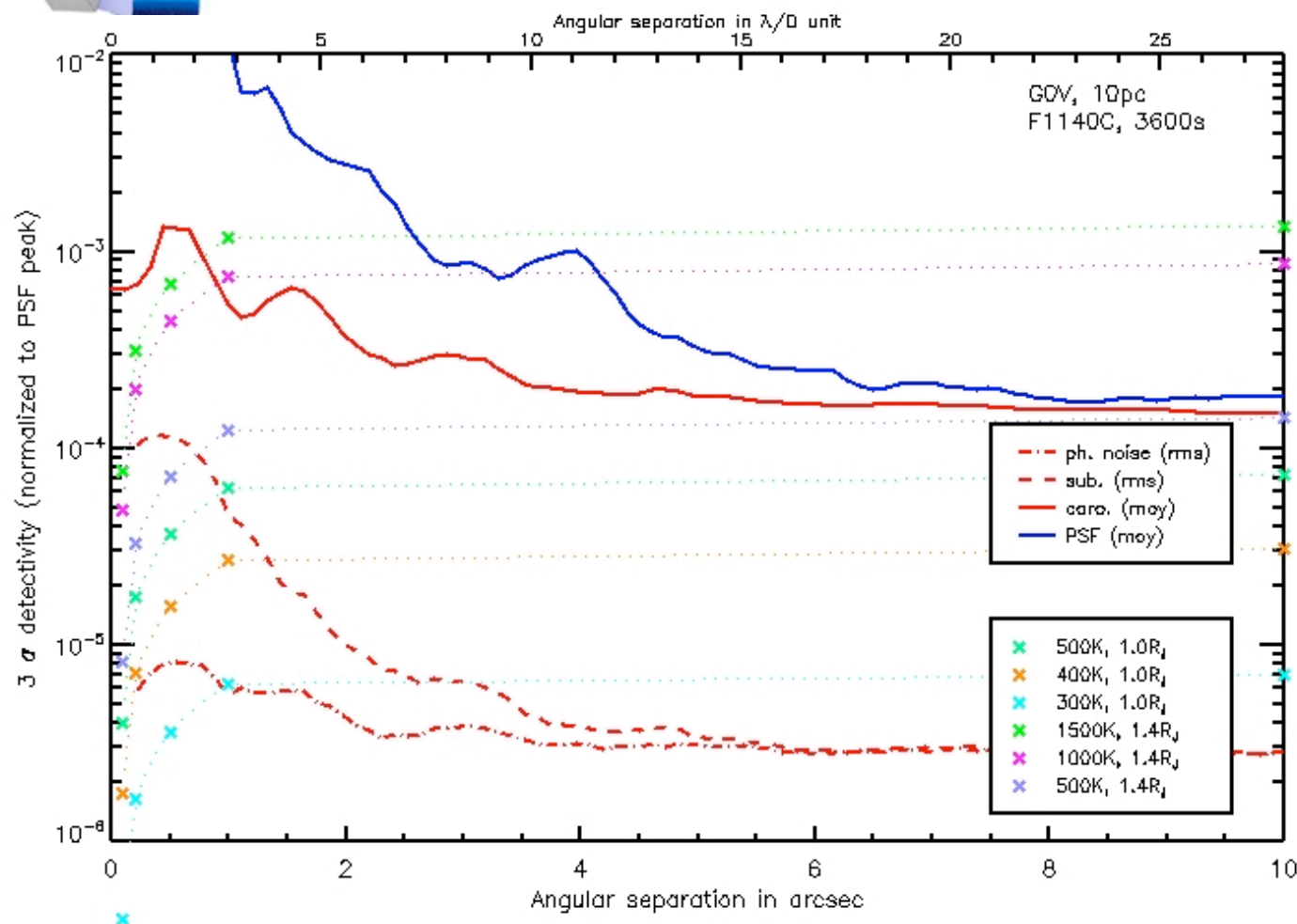


Canada

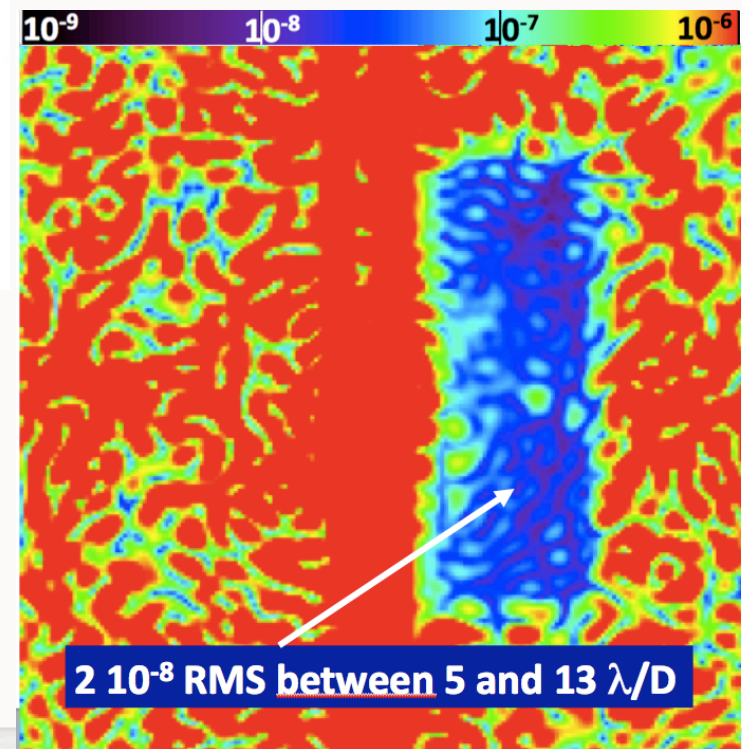
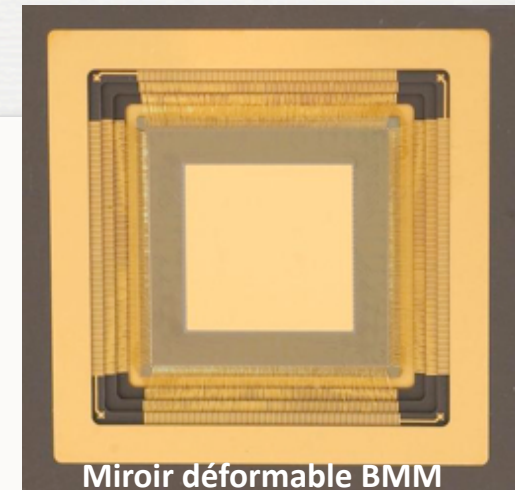
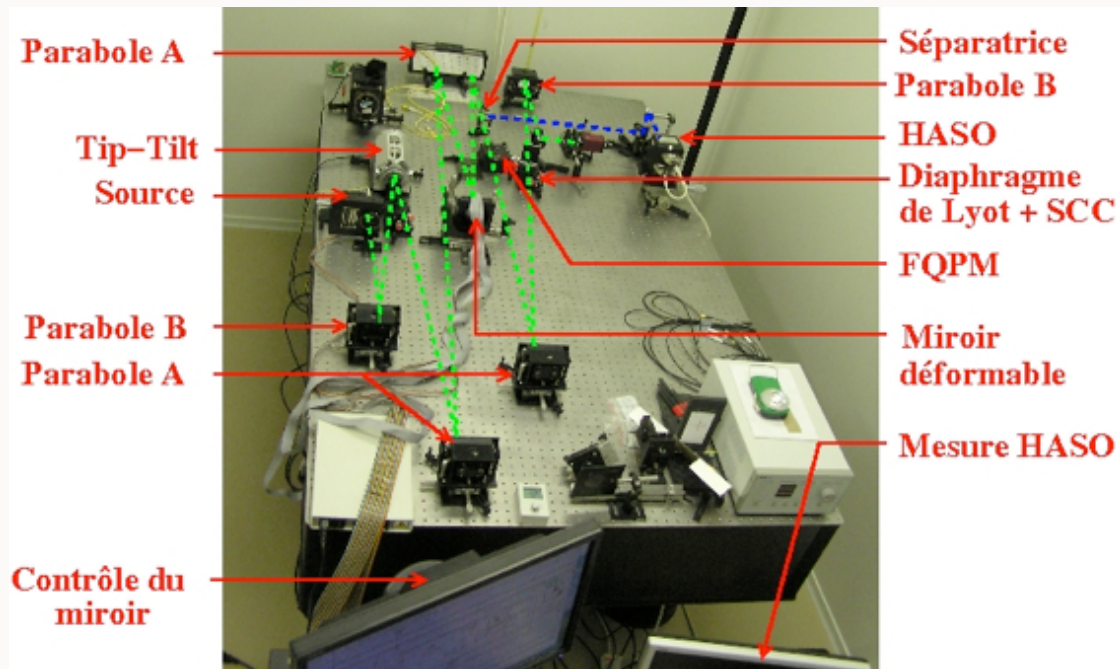
1 - 5 μm

coronographie + spectro transit

MIRI PERFORMANCE



BANC TRÈS HAUTE DYNAMIQUE (LESIA)



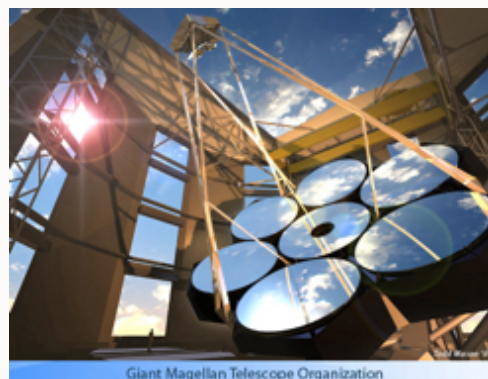
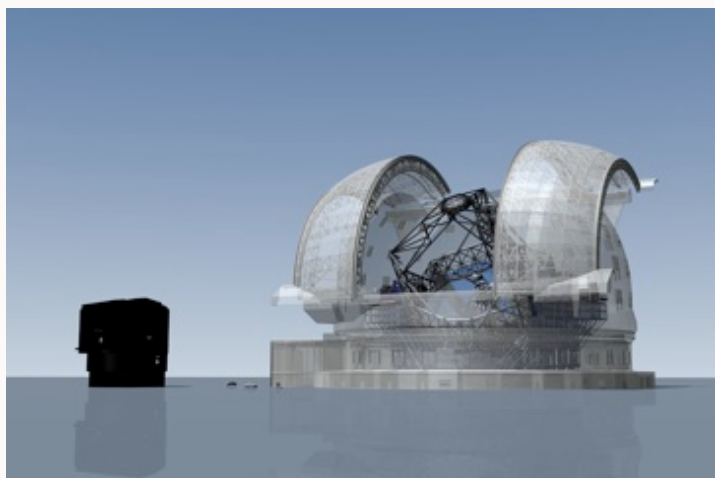
Baudoz et al. 2010, 2011, 2012
Galicher et al. 2008, 2010, 2012

EXTREMELY LARGE TELESCOPES

> 2022

VERS :

- la caractérisation Géantes / Super Terres matures
- la détection Terres / Super Terres



3 grands projets :

- TMT (Thirty Meter Telescope, US), 30m - Hawaii
- GMT (Giant Magellan Telescope, US), 25m - Chili
- E-ELT (European Extremely Large Telescope), 42m - Chili

E-ELT

- CODEX: spectro optique haute résolution
- EPICS: imageur haut contraste
- HARMONI: spectro-intégral de champ
- METIS: imageur/spectro mid IR

TMT

- HROS: spectro optique haute résolution
- NIRES: spectro échelle nearIR
- PFI: imageur haut contraste

SPICES



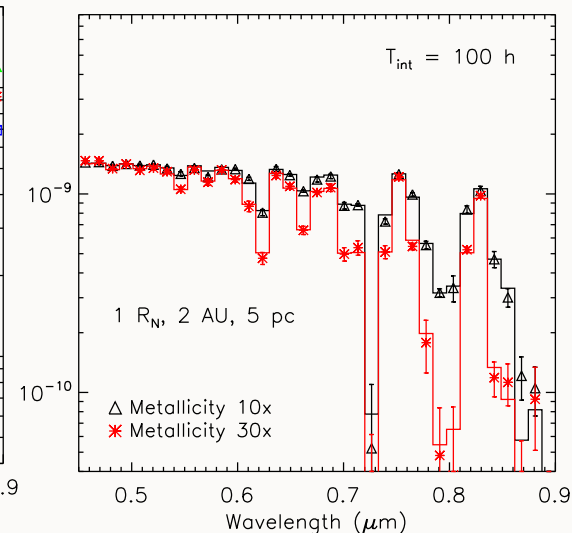
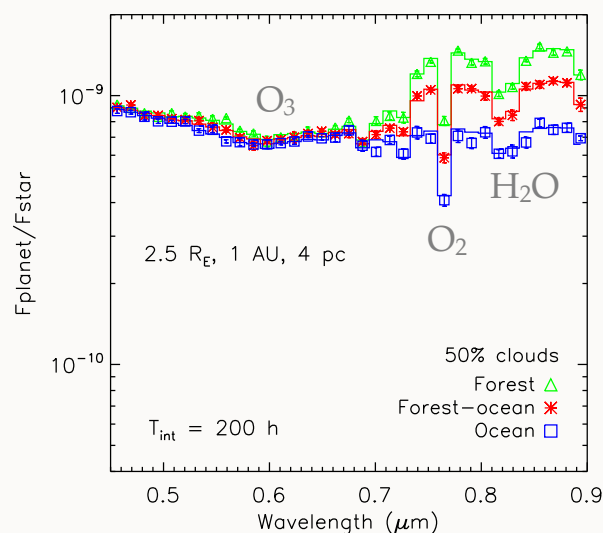
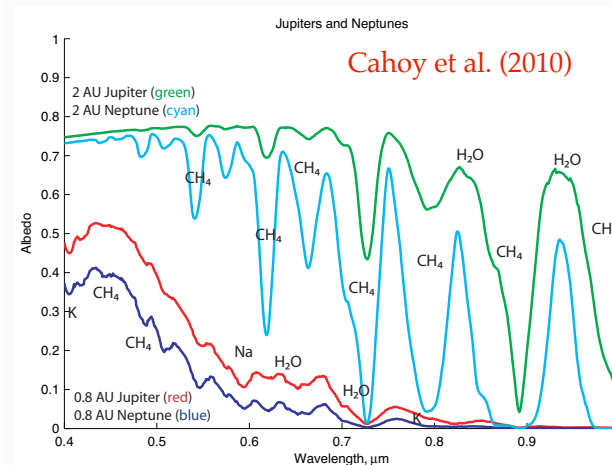
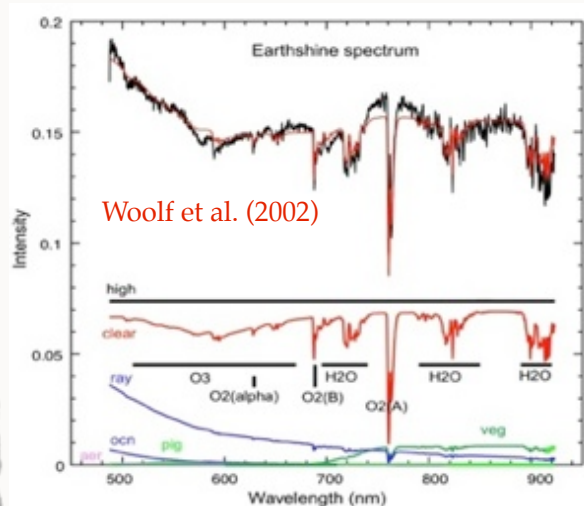
planètes matures : géantes,
glacées, super Terres
aux longueurs d'ondes visibles

Boccaletti et al. 2012

Maire et al. 2012

proposés en 2007 (SEE COAST)
et 2010 (SPICES) à l'ESA (Cosmic
Vision)

objectif : prochain appel à
mission (classe L)



RÉSUMÉ

- astrométrie : identification / architecture syst. stell. / parm. orbitaux
- photométrie (Vis, NIR, MIR) : albedo / rayon, température, molécules,
- formation / évolution
- relation disques / planètes : dynamique, formation

