Exoplanètes : enjeux et défis

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Exoplanètes : questions et outils

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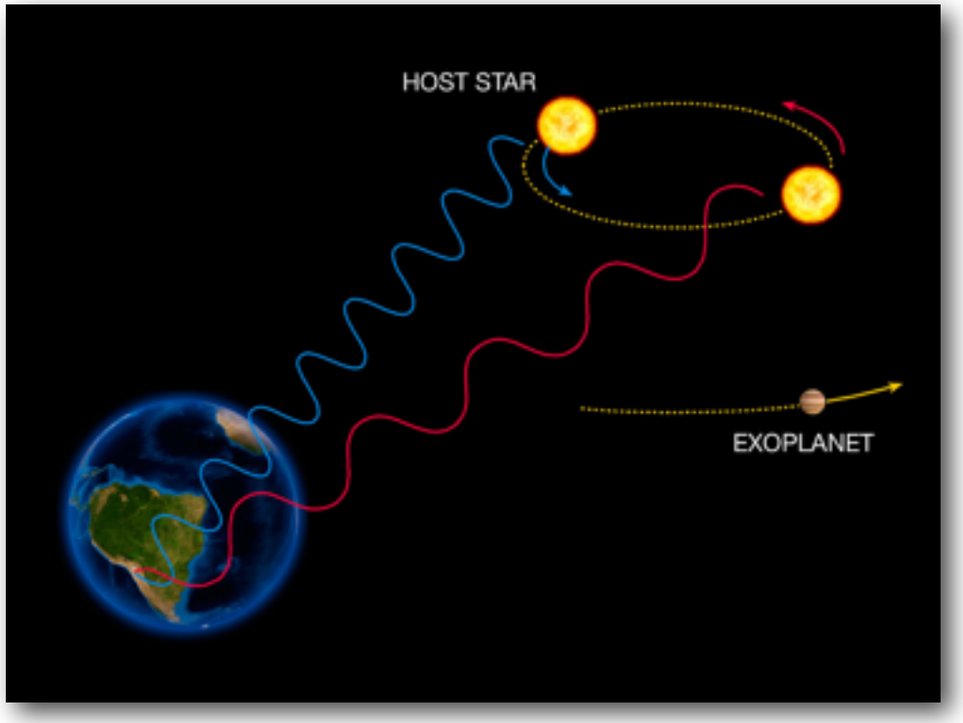
Démographie des exoplanètes

- Combien sont-elles ?
- Quelle proportion d'étoiles possède un cortège planétaire ?
- Quelle est l'architecture de ces cortèges
  - Distribution en taille, structure, paramètres orbitaux (semi grand axe, excentricité, obliquité/inclinaison)

- *En fonction de l'étoile hôte (âge, métallicité, multiplicité)*
- *Un test des modèles de formation et d'évolution*
  - *Formation par nucléation ou effondrement gravitationnel ?*
  - *Rôle de la migration ?*

Outils de recensement

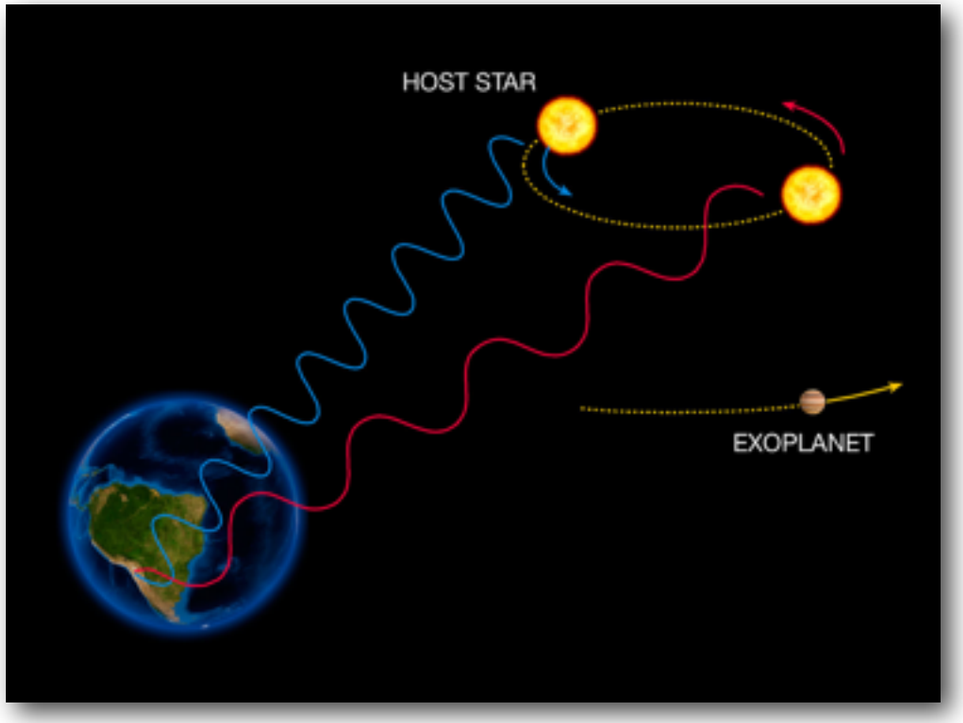
- Vitesses radiales



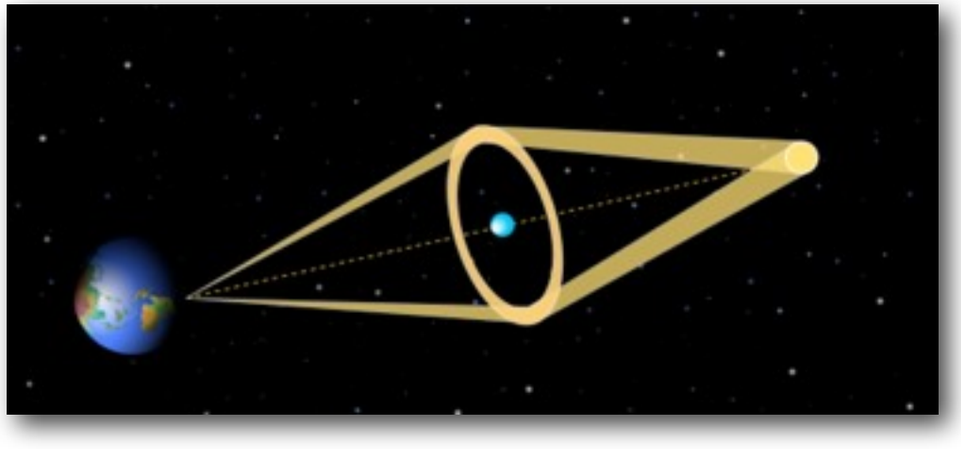
Vitesses radiales

Outils de recensement

- Vitesses radiales
- Lentilles gravitationnelles



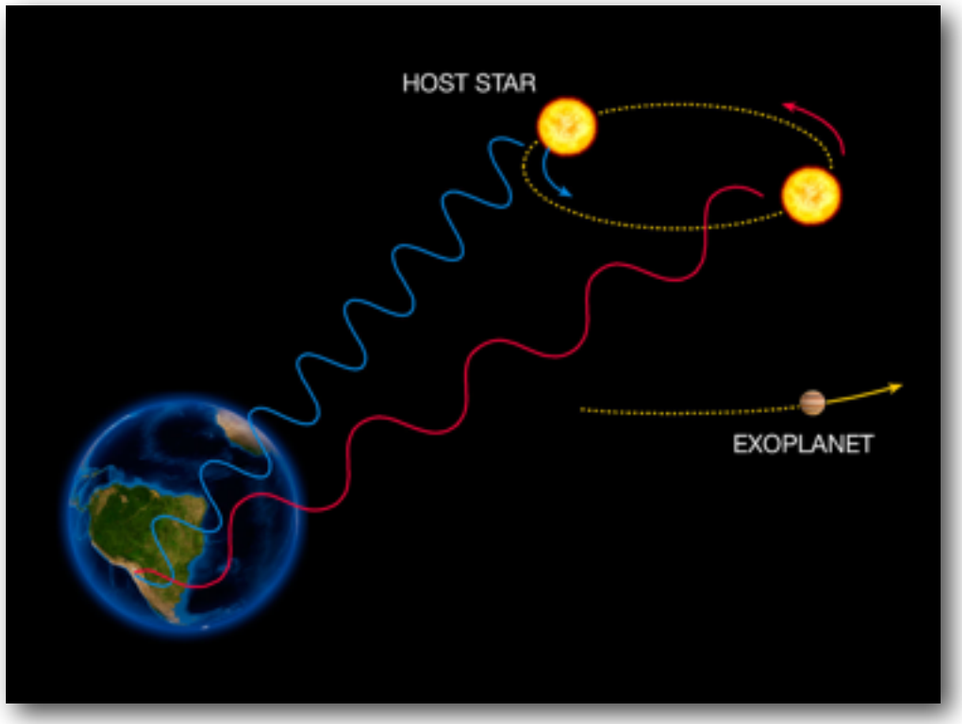
Vitesses radiales



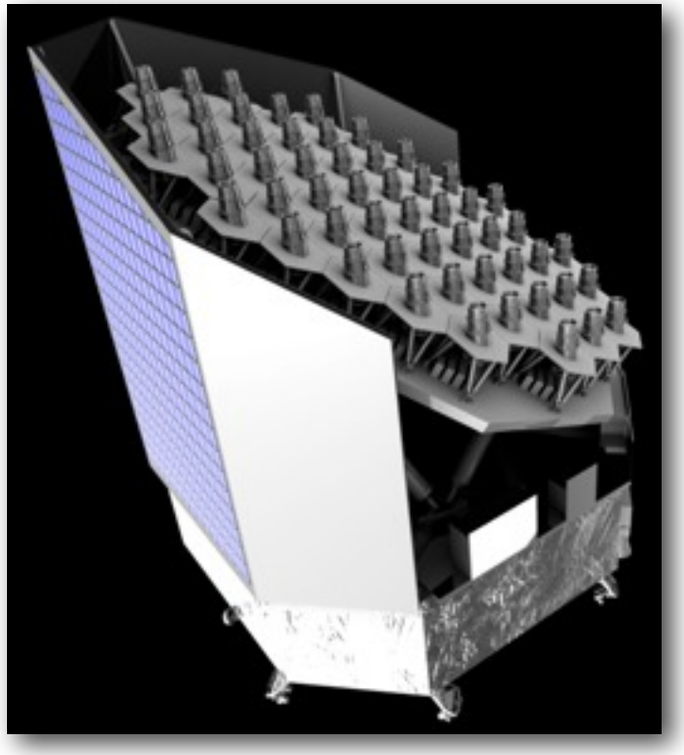
Lentilles gravitationnelles

Outils de recensement

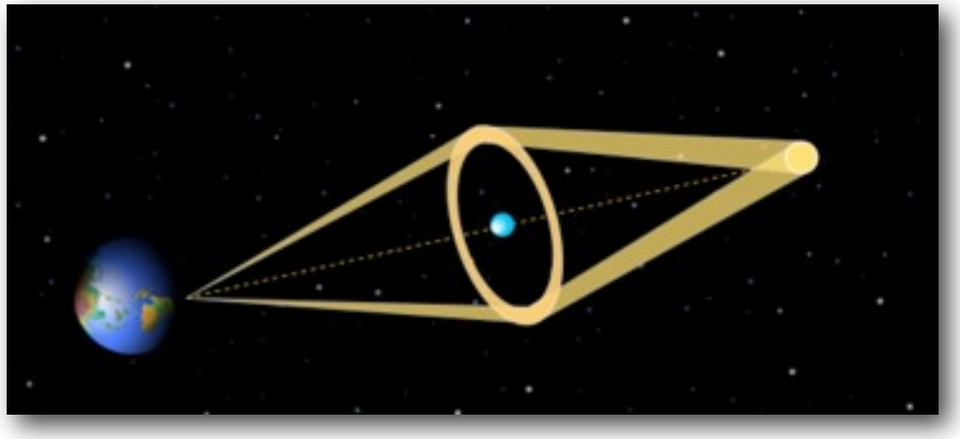
- Vitesses radiales
- Lentilles gravitationnelles
- Surveys photométriques



Vitesses radiales



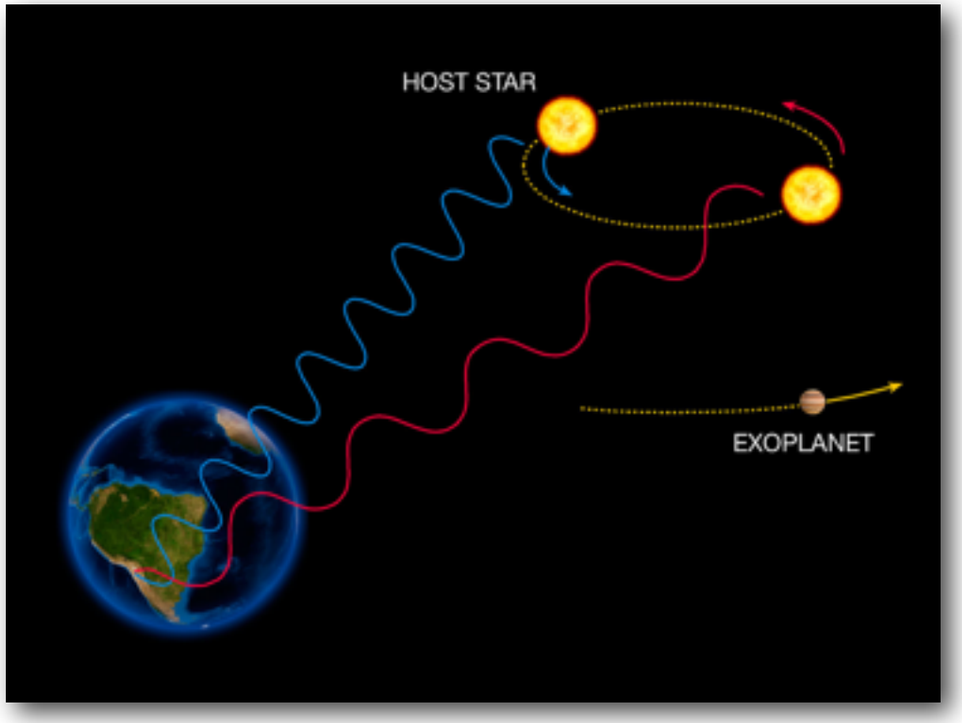
PLATO (ESA M3 candidate)



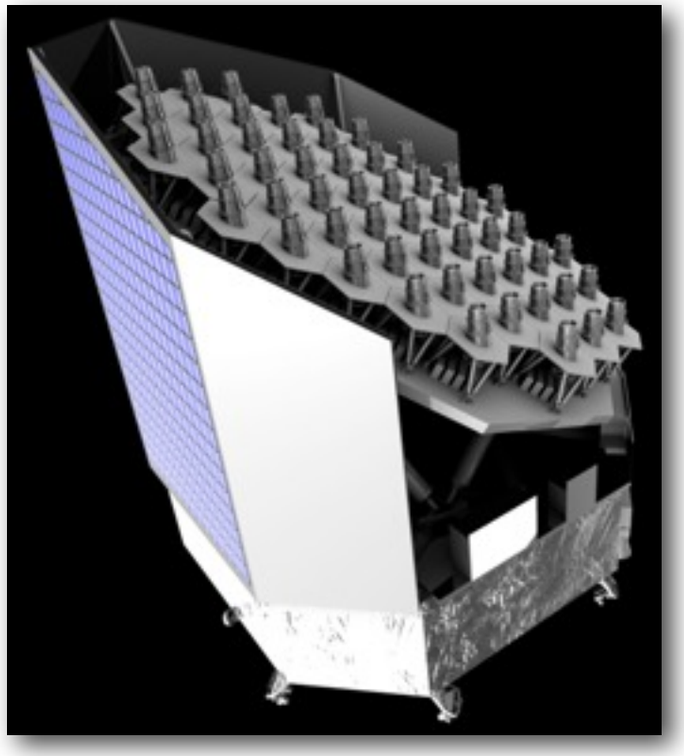
Lentilles gravitationnelles

Outils de recensement

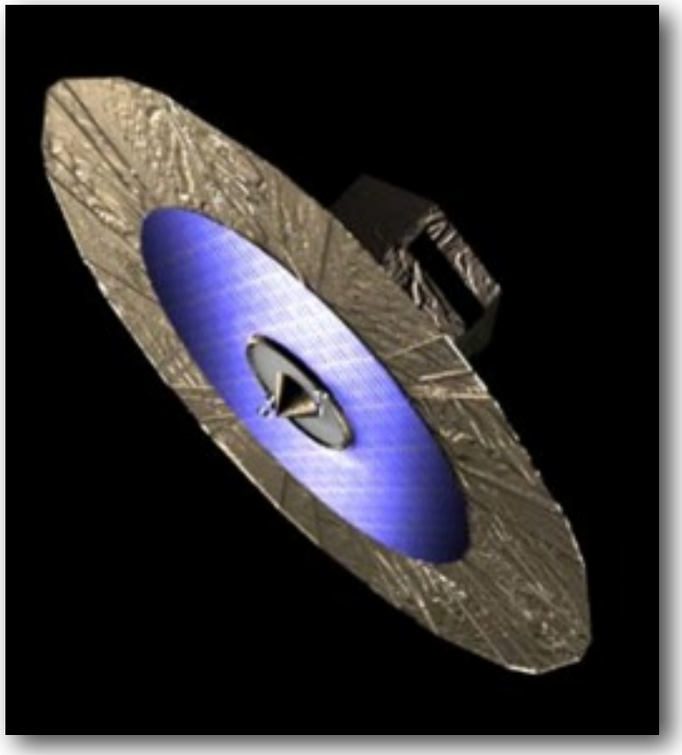
- Vitesses radiales
- Lentilles gravitationnelles
- Surveys photométriques
- *Astrométrie*



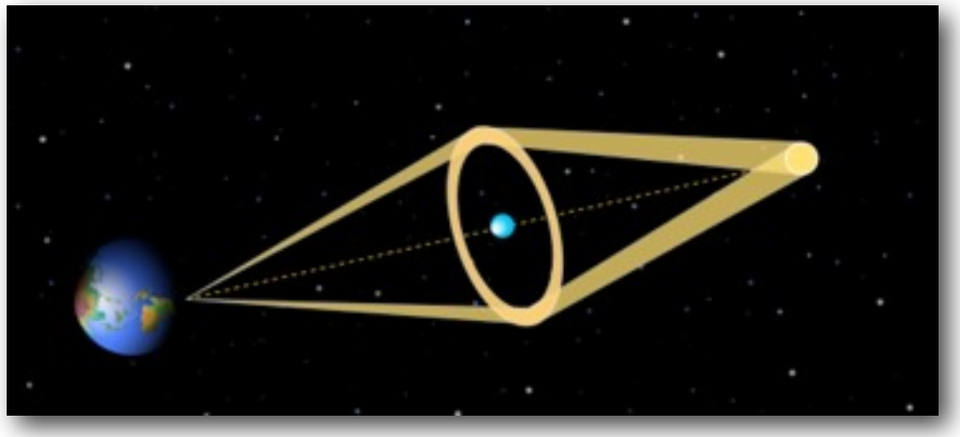
Vitesses radiales



PLATO (ESA M3 candidate)



Gaia



Lentilles gravitationnelles

www.exoplanet.eu

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Catalog

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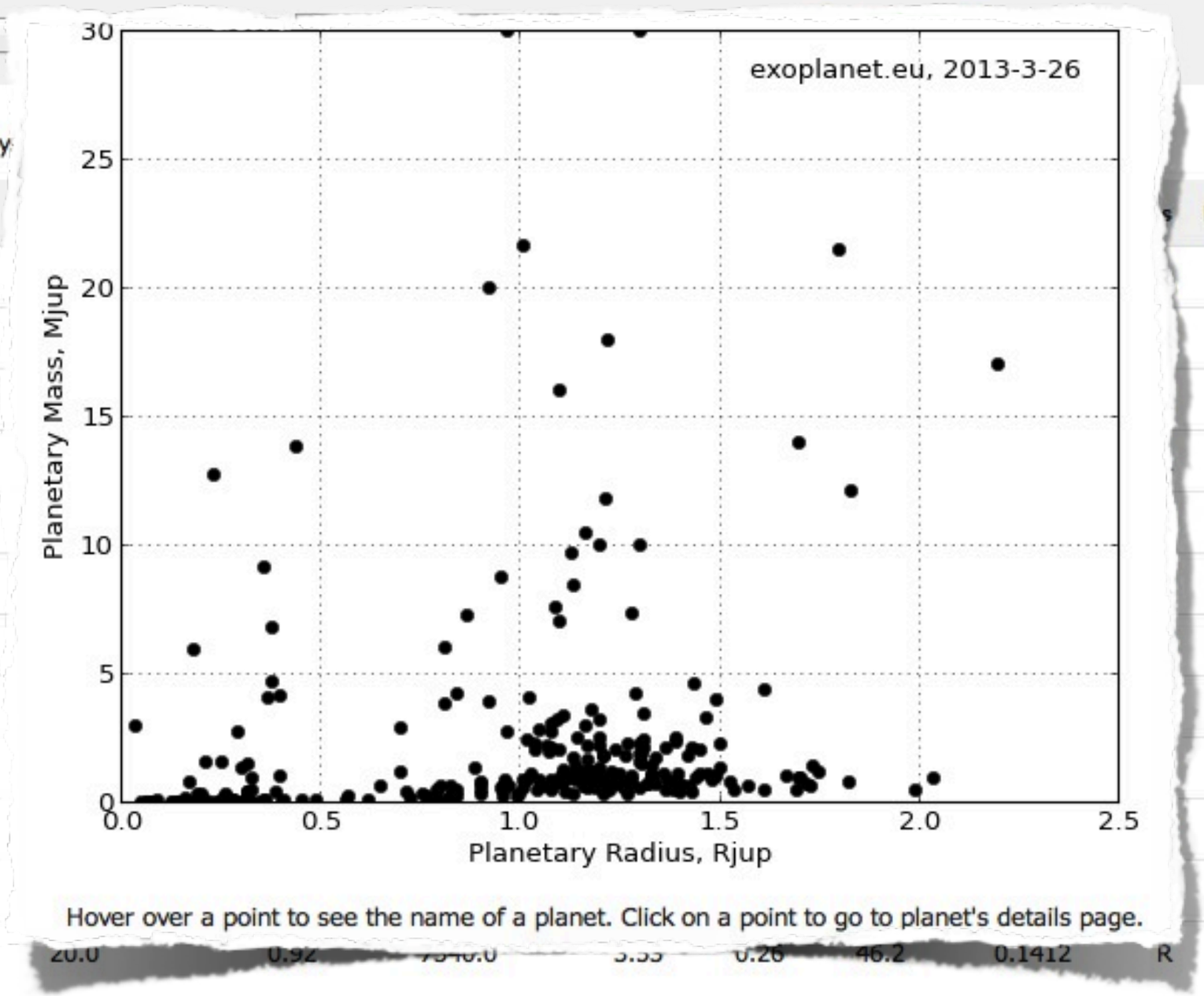
All planets

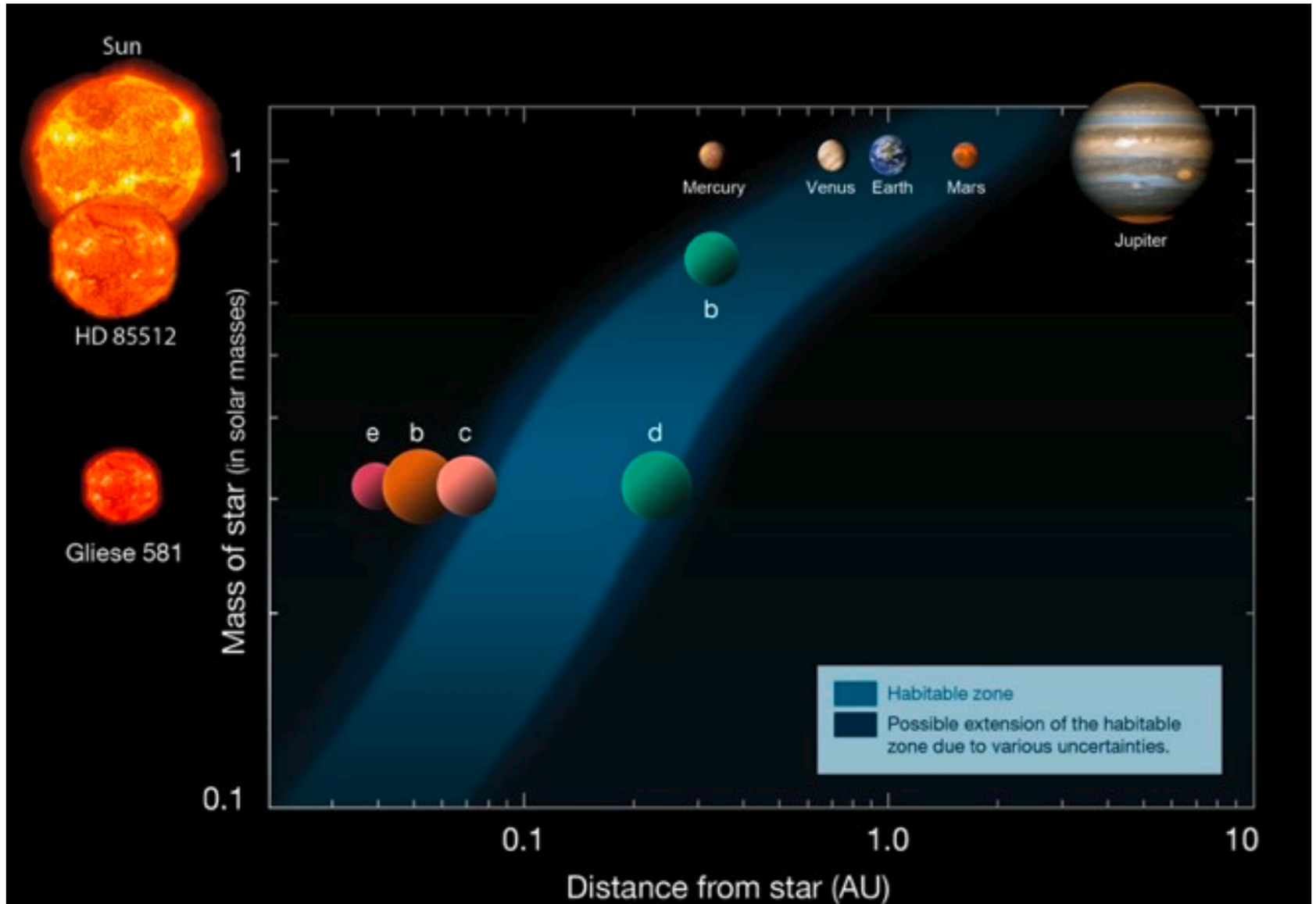
Showing 677 planetary sy

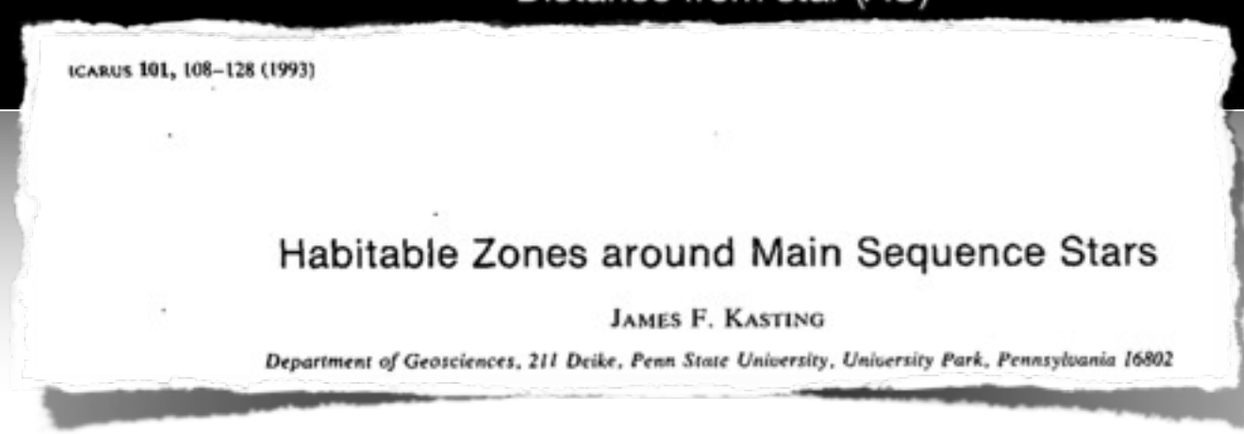
All fields



Planet △									Discovery	Update
11 Com b									2008	2011-12-23
11 UMi b									2009	2009-08-13
14 And b									2008	2012-08-21
14 Her b									2002	2009-10-07
16 Cyg B b									1996	2012-12-18
18 Del b									2008	2008-02-20
1RXS1609 b									2008	2011-12-14
24 Sex b									2010	2010-07-28
24 Sex c									2010	2010-07-28
2M 044144 b									2010	2010-04-06
2M 0746+20 b									2010	2012-01-20
2M 2140+16 b	20.0	0.92	7540.0	3.33	0.26	46.2	0.1412	R	2010	2012-01-20

Zones d'habitabilité





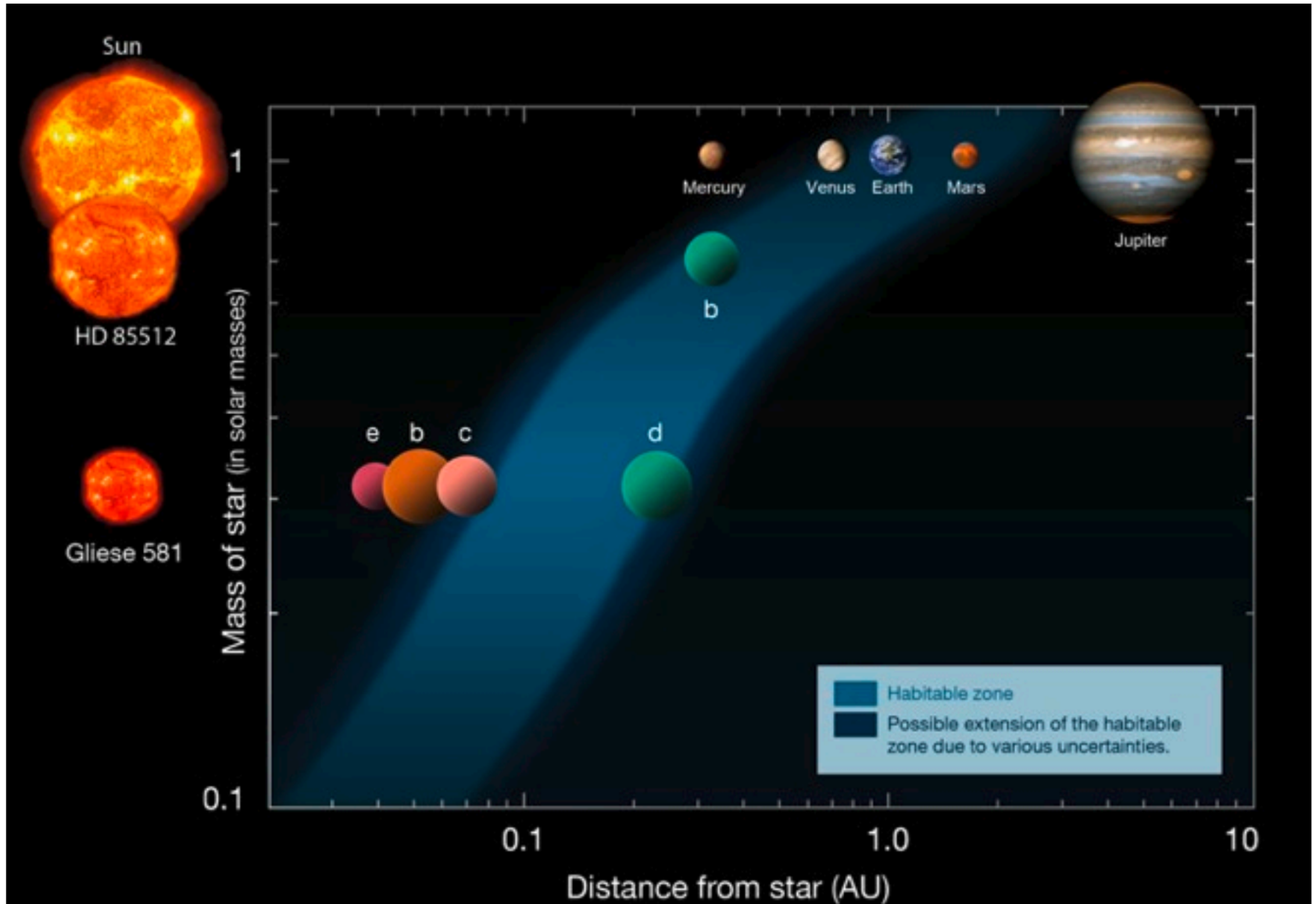
ICARUS 101, 108–128 (1993)

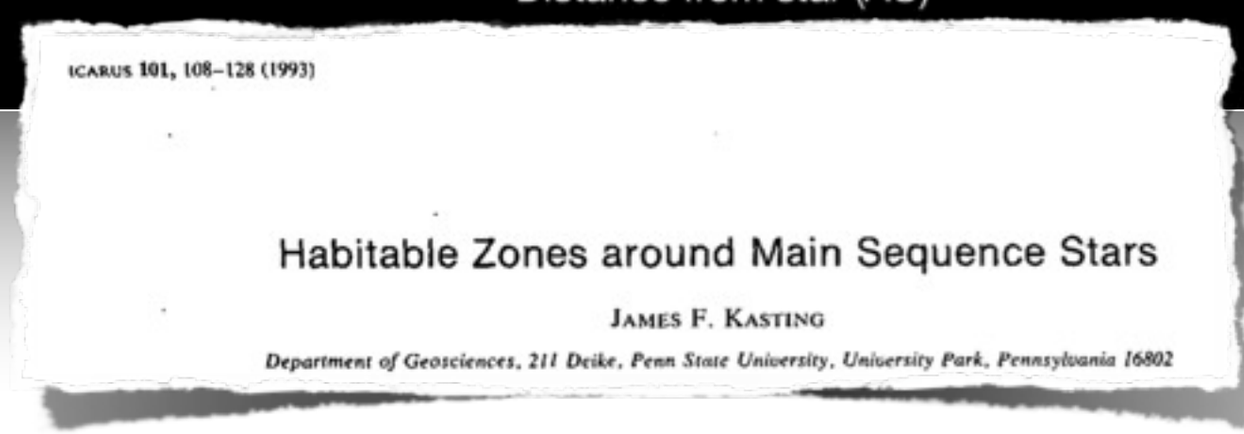
Habitable Zones around Main Sequence Stars

JAMES F. KASTING

Department of Geosciences, 211 Deike, Penn State University, University Park, Pennsylvania 16802

Zones d'habitabilité *observable*





ICARUS 101, 108–128 (1993)

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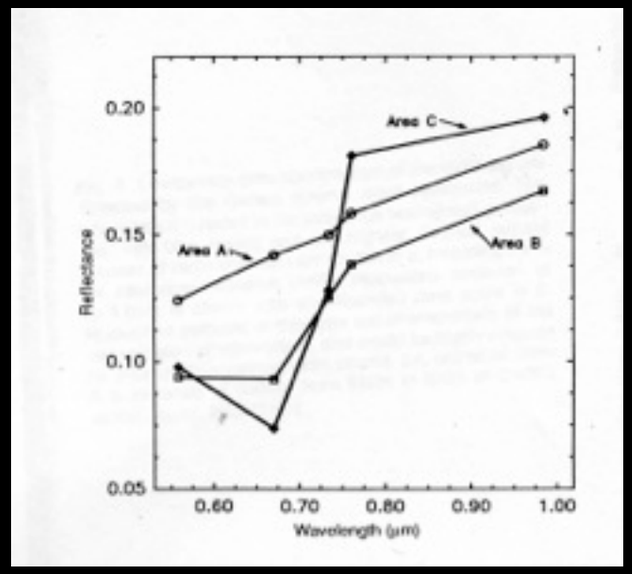
A search for life on Earth from the Galileo spacecraft

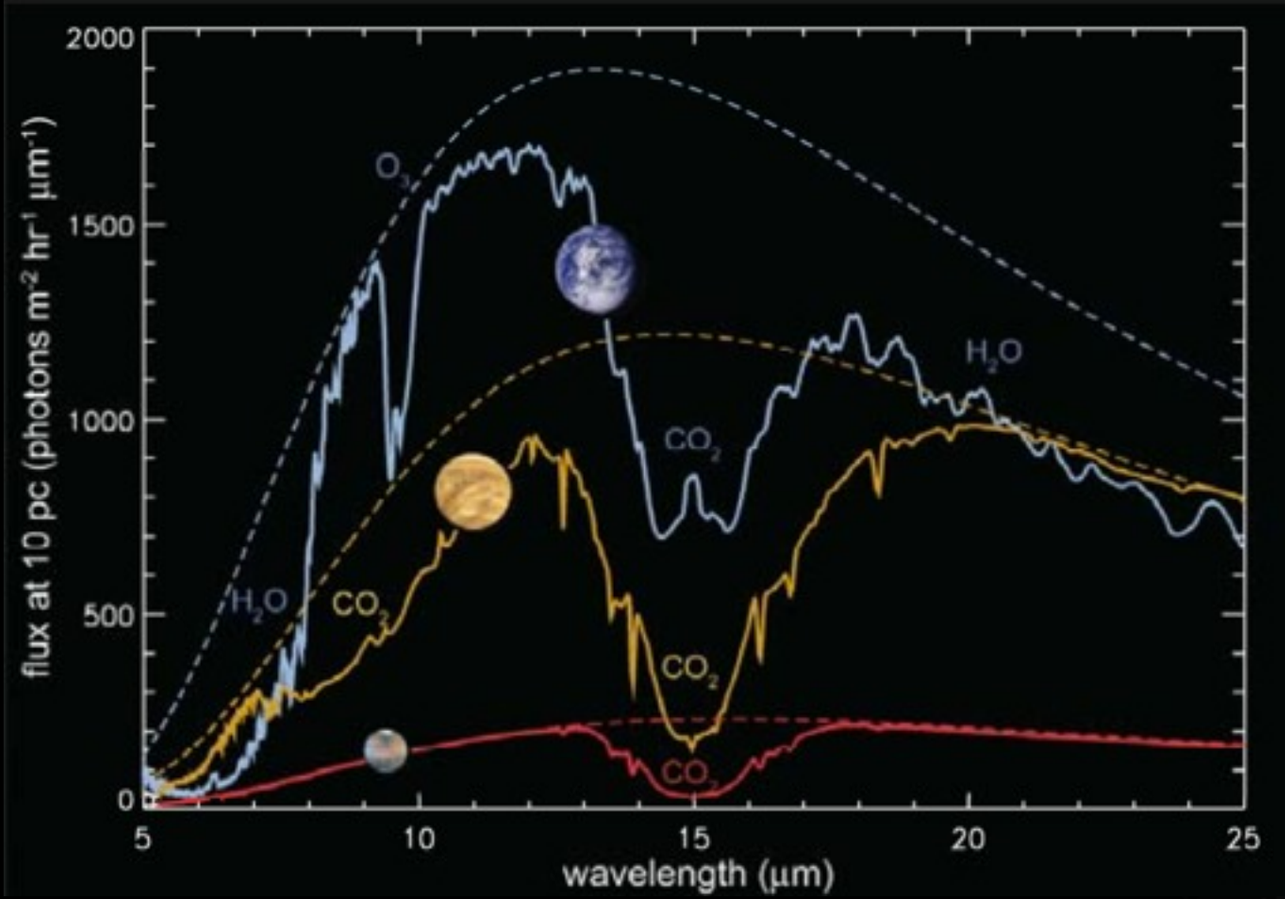
Carl Sagan*, W. Reid Thompson*, Robert Carlson†, Donald Gurnett‡ & Charles Hord§

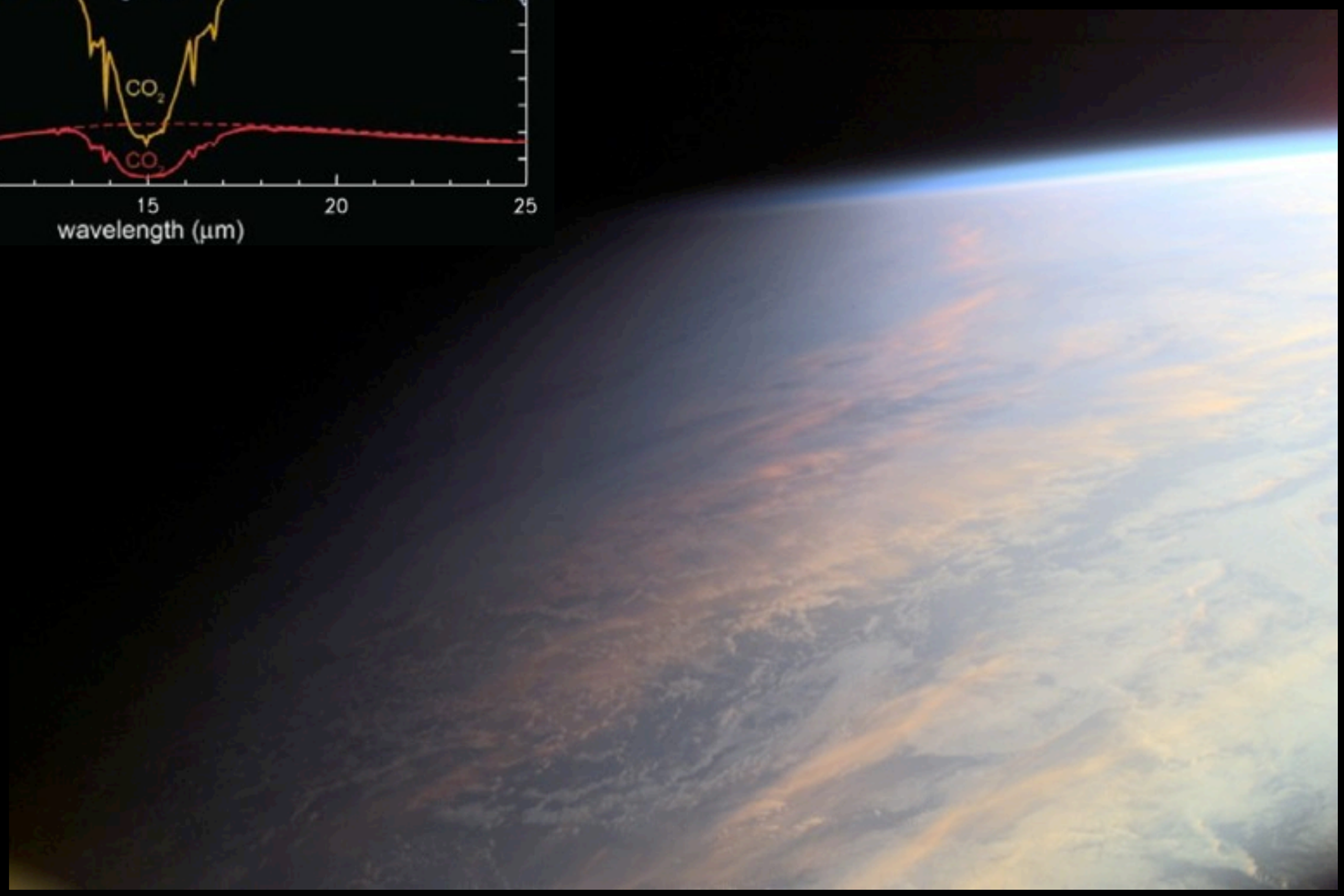
* Laboratory for Planetary Studies, Cornell University, Ithaca, New York 14853, USA
† Atmospheric and Cometary Sciences Section, Jet Propulsion Laboratory, Pasadena, California 91109, USA
‡ Department of Physics and Astronomy, University of Iowa, Iowa City, Iowa 52242-1479, USA
§ Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, Colorado 80309, USA

In its December 1990 fly-by of Earth, the Galileo spacecraft found evidence of abundant gaseous oxygen, a widely distributed surface pigment with a sharp absorption edge in the red part of the visible spectrum, and atmospheric methane in extreme thermodynamic disequilibrium; together, these are strongly suggestive of life on Earth. Moreover, the presence of narrow-band, pulsed, amplitude-modulated radio transmission seems uniquely attributable to intelligence. These observations constitute a control experiment for the search for extraterrestrial life by modern interplanetary spacecraft.

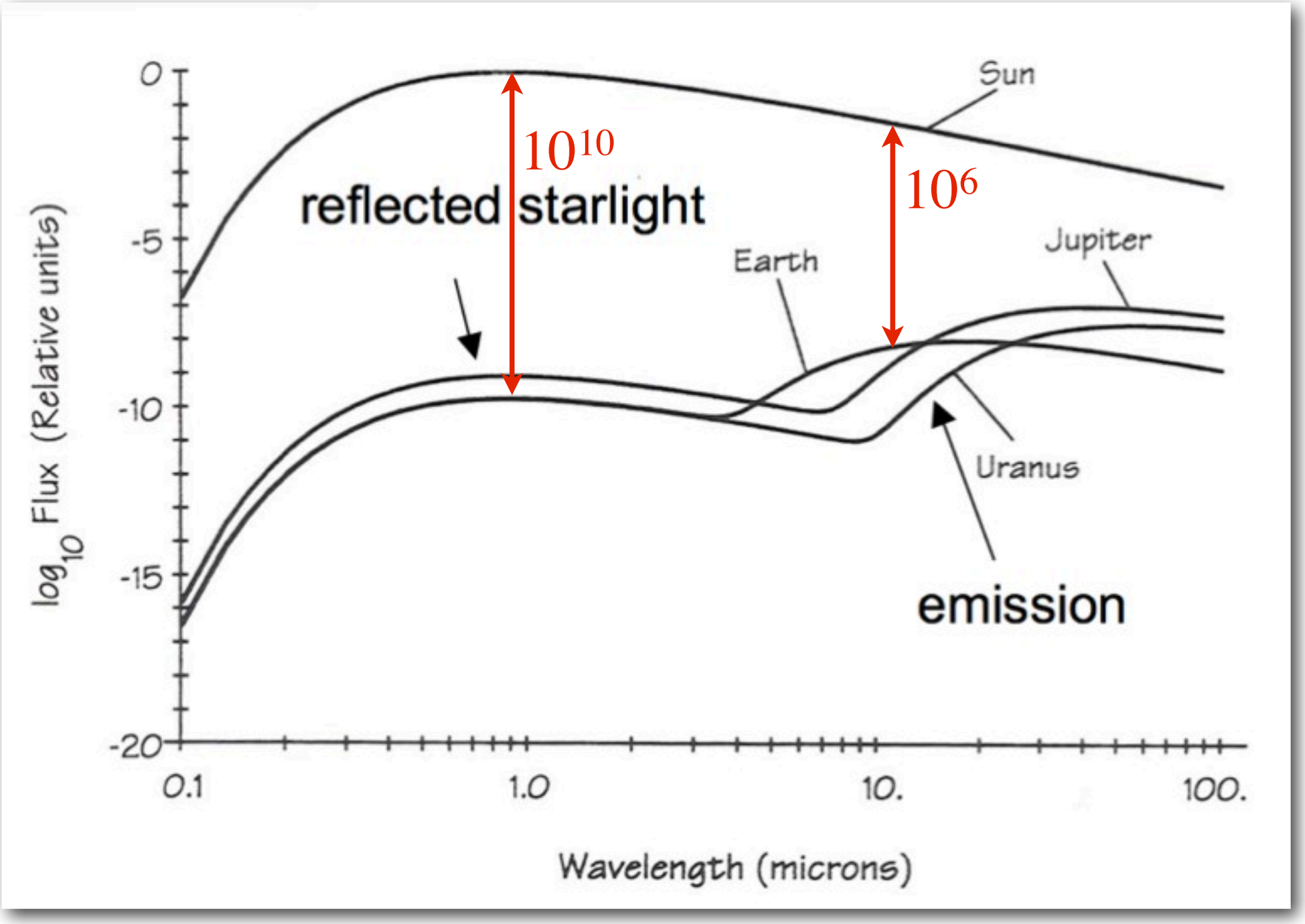
Nature ***365***, *715 (1993)*




flux at 10 pc (photons m^{-2} hr^{-1} μm^{-1})
2000
1500
1000
500
0
5
10
15
20
25
wavelength (μm)
O_3
H_2O
CO_2
H_2O
CO_2
CO_2
CO_2



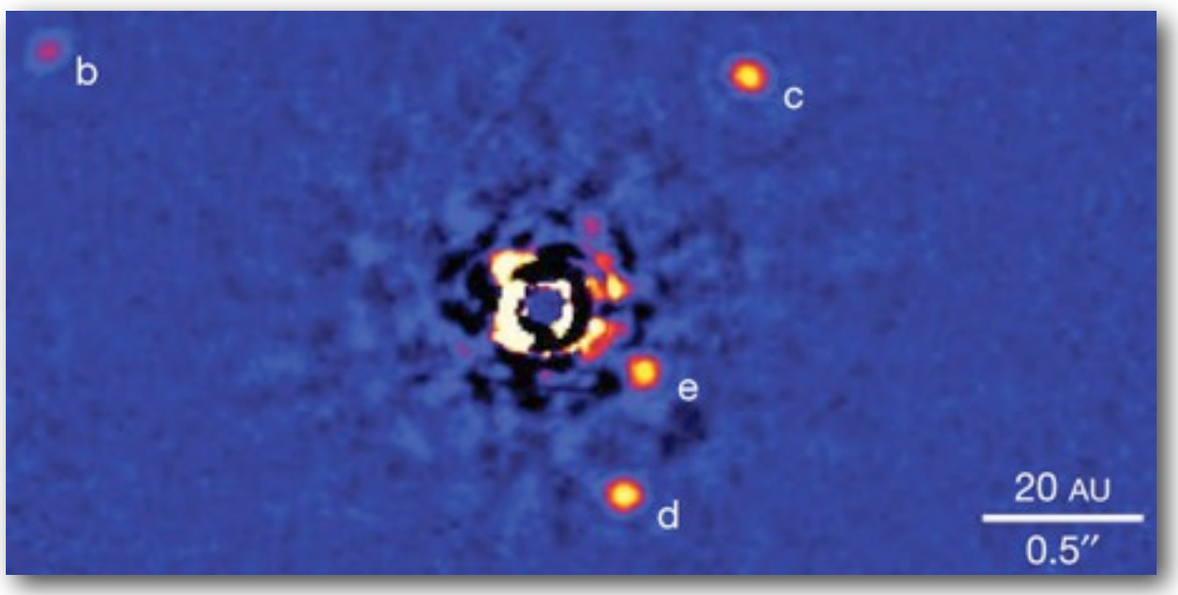
La problématique de la dynamique



Séparation spatiale : coronographie

HR 8799

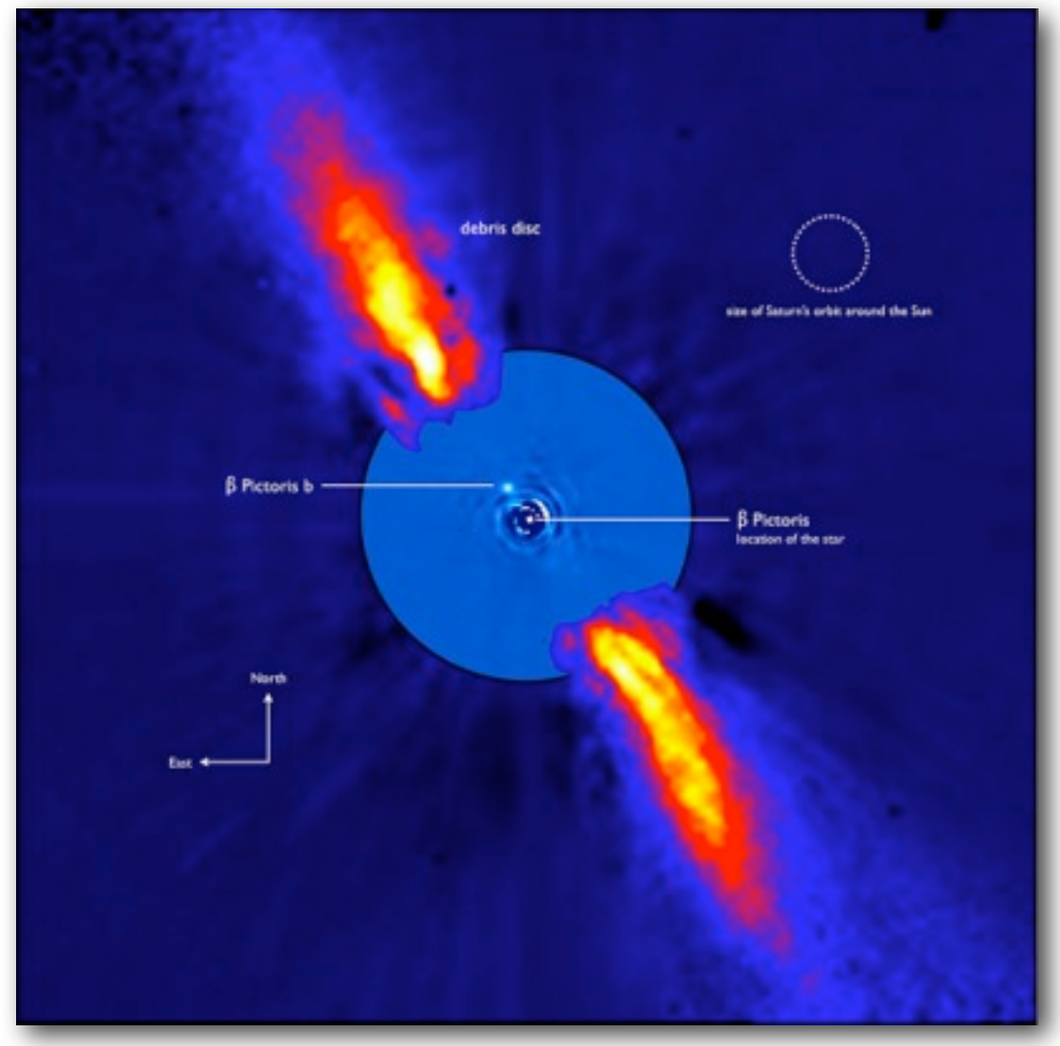
(K5 @ 39pc, 30Myrs)



Marois et al. 2008

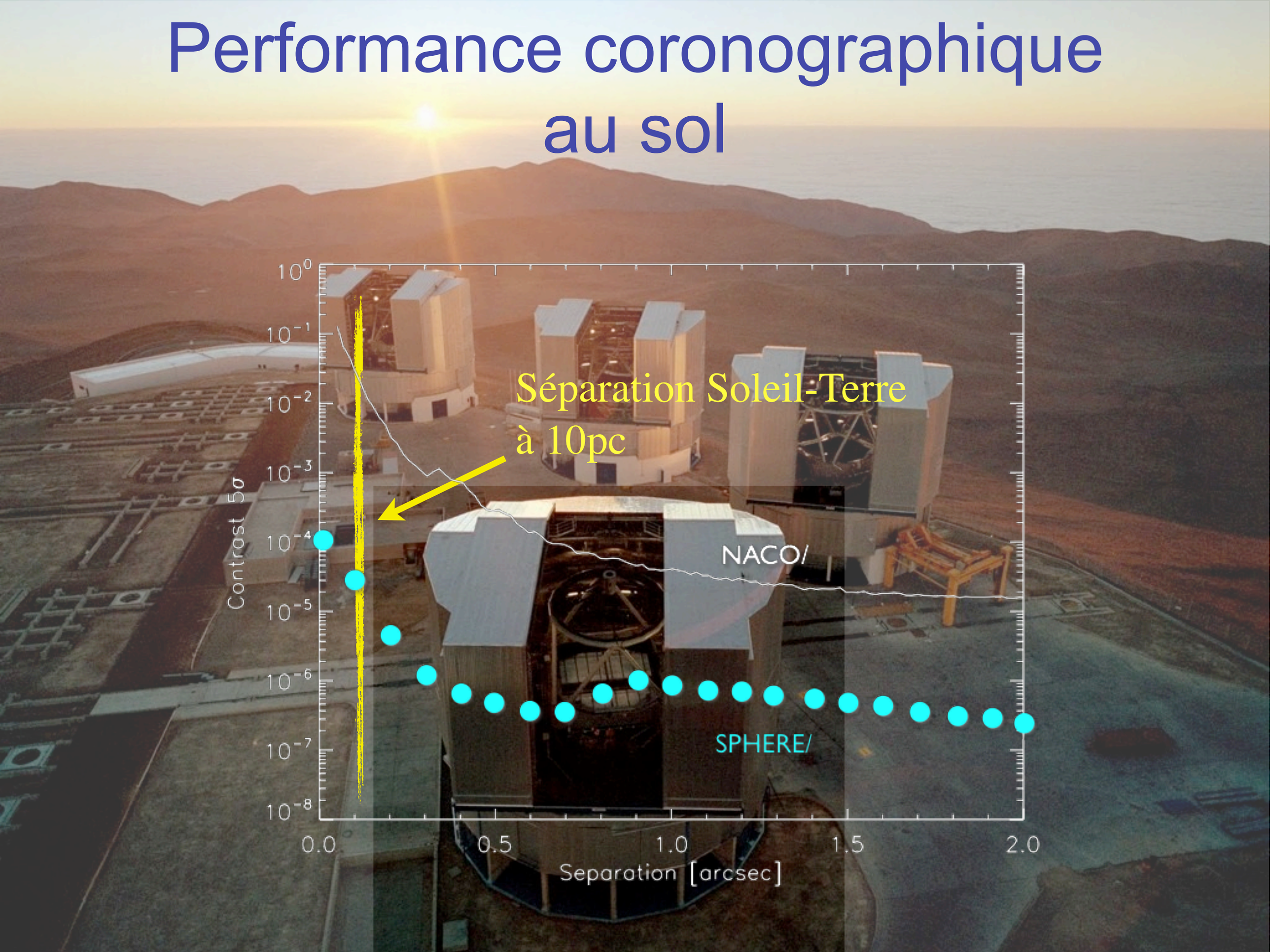
beta Pictoris

(A5 @ 19pc, 20Myrs)



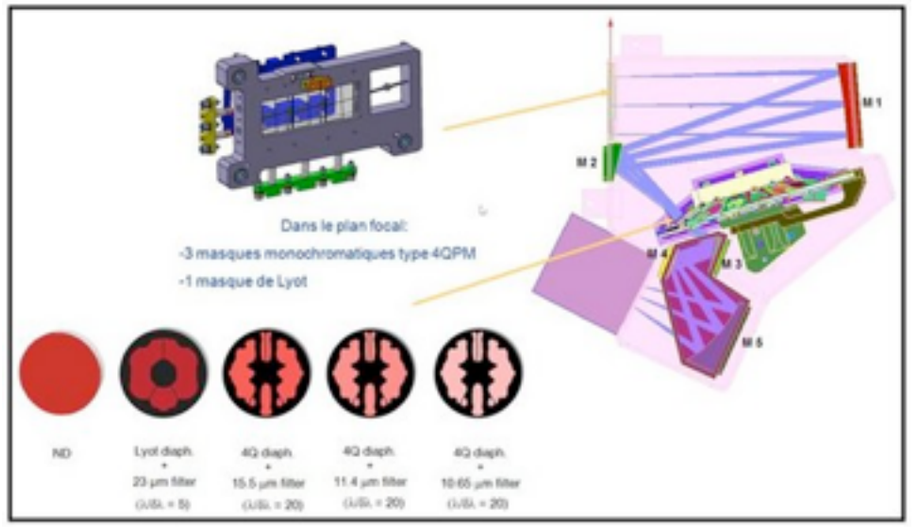
Lagrange et al. 2010

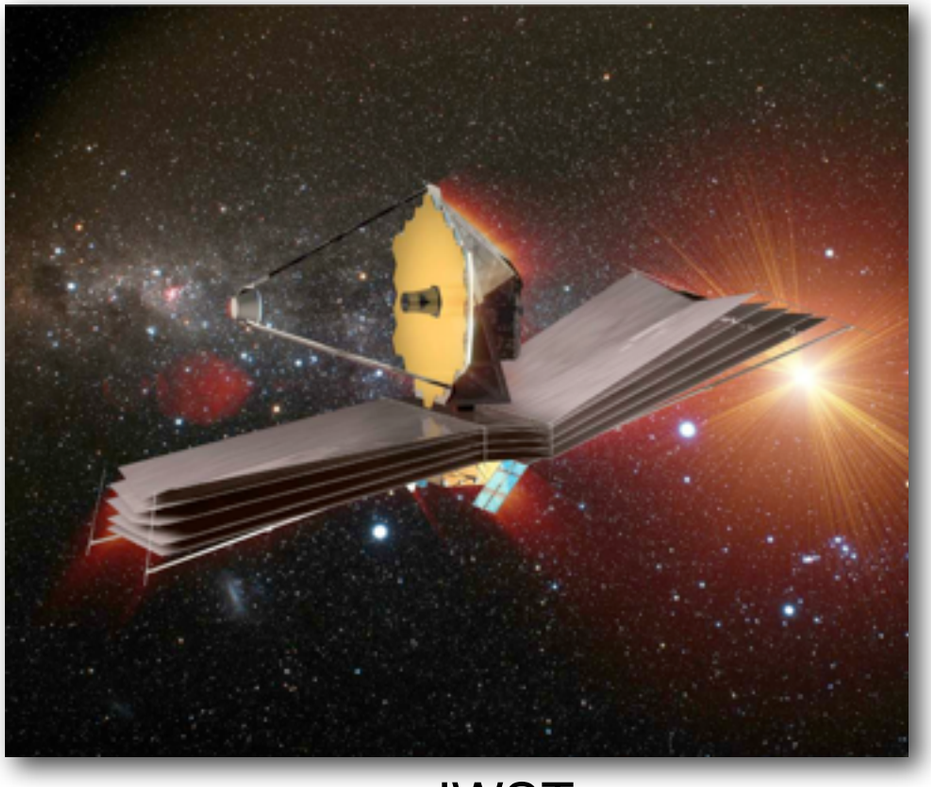
Performance coronographique au sol



Imagerie: perspectives spatiales

- JWST : MIRI

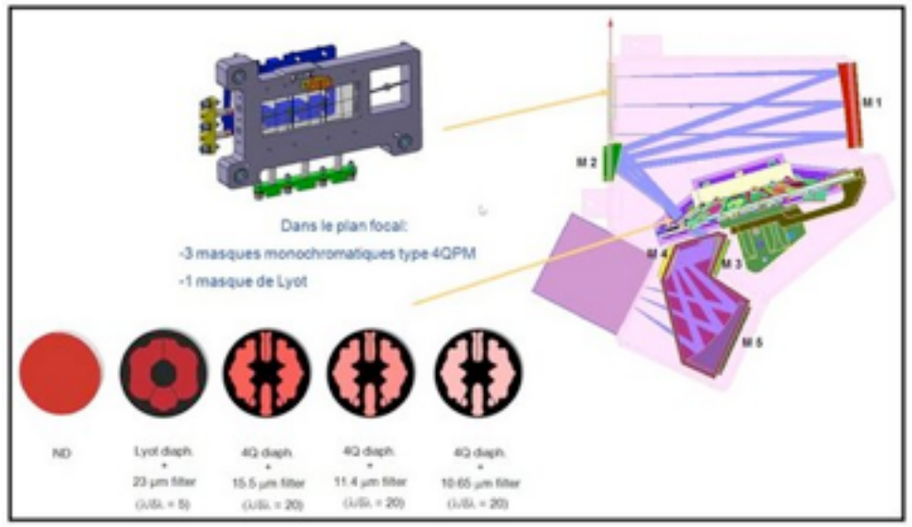


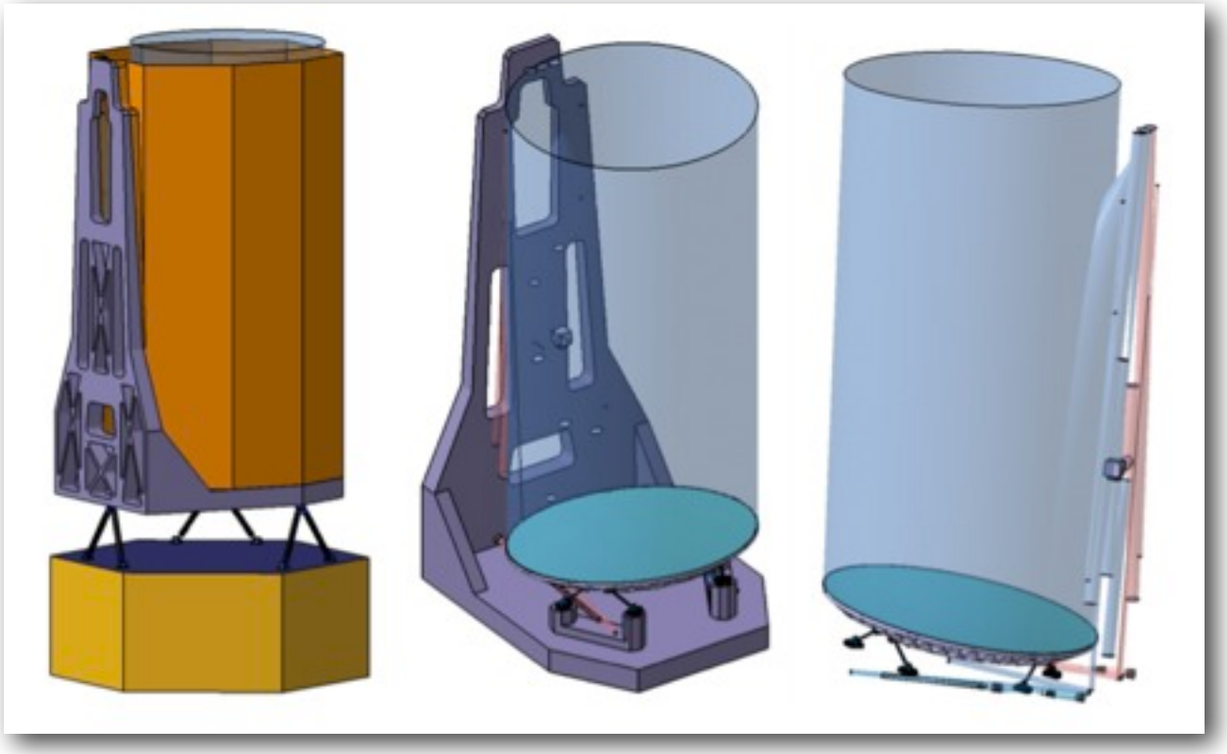


JWST

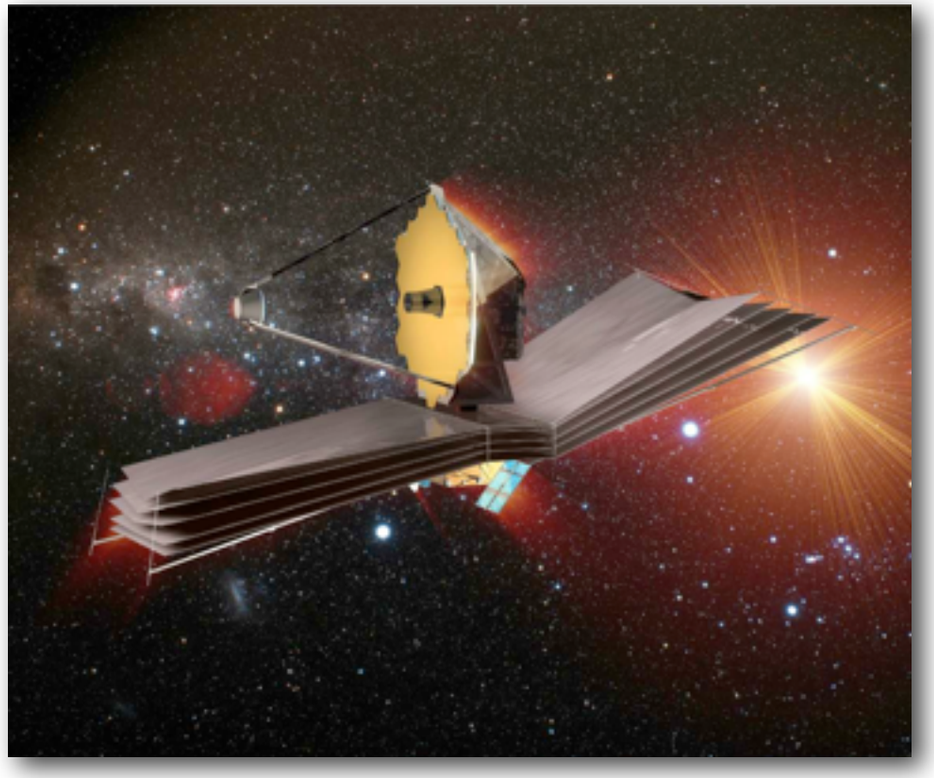
Imagerie: perspectives spatiales

- JWST : MIRI
- SPICES ?



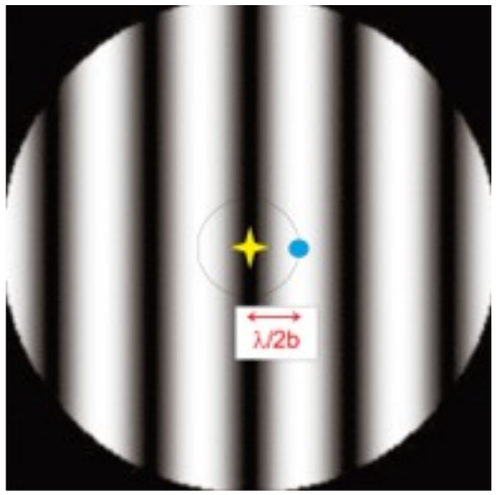


SPICES
(Boccaletti et al. 2010)

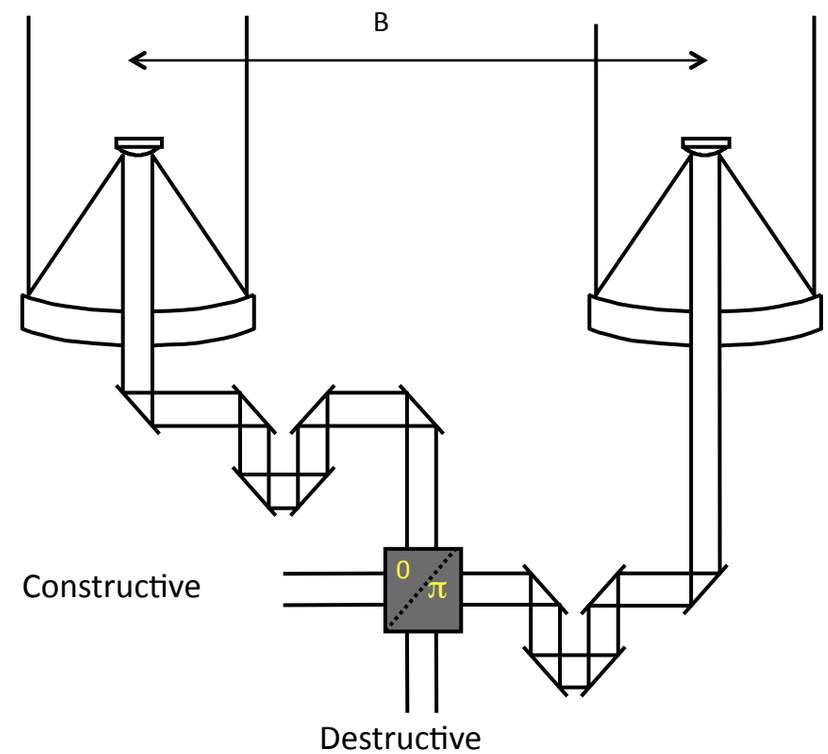


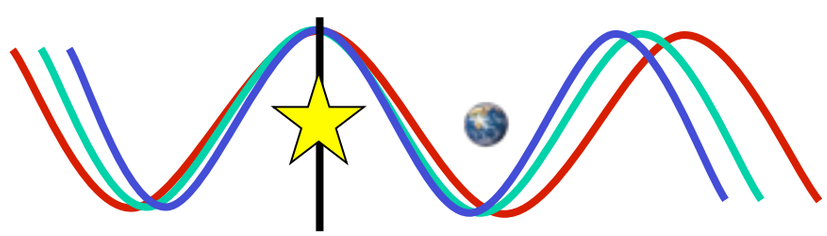
JWST

Coronographie interférométrique (nulling)

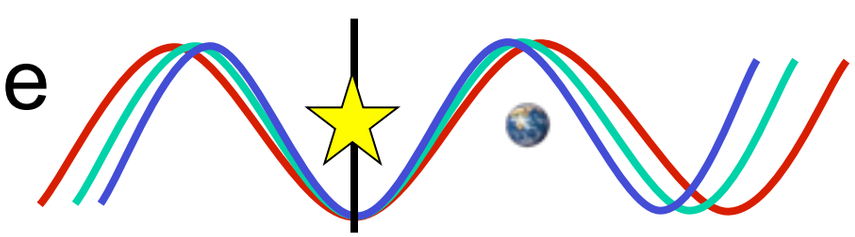


- Principe :
  - Phase stabilisée entre les deux faisceaux
  - Introduction d'un saut de π achromatique





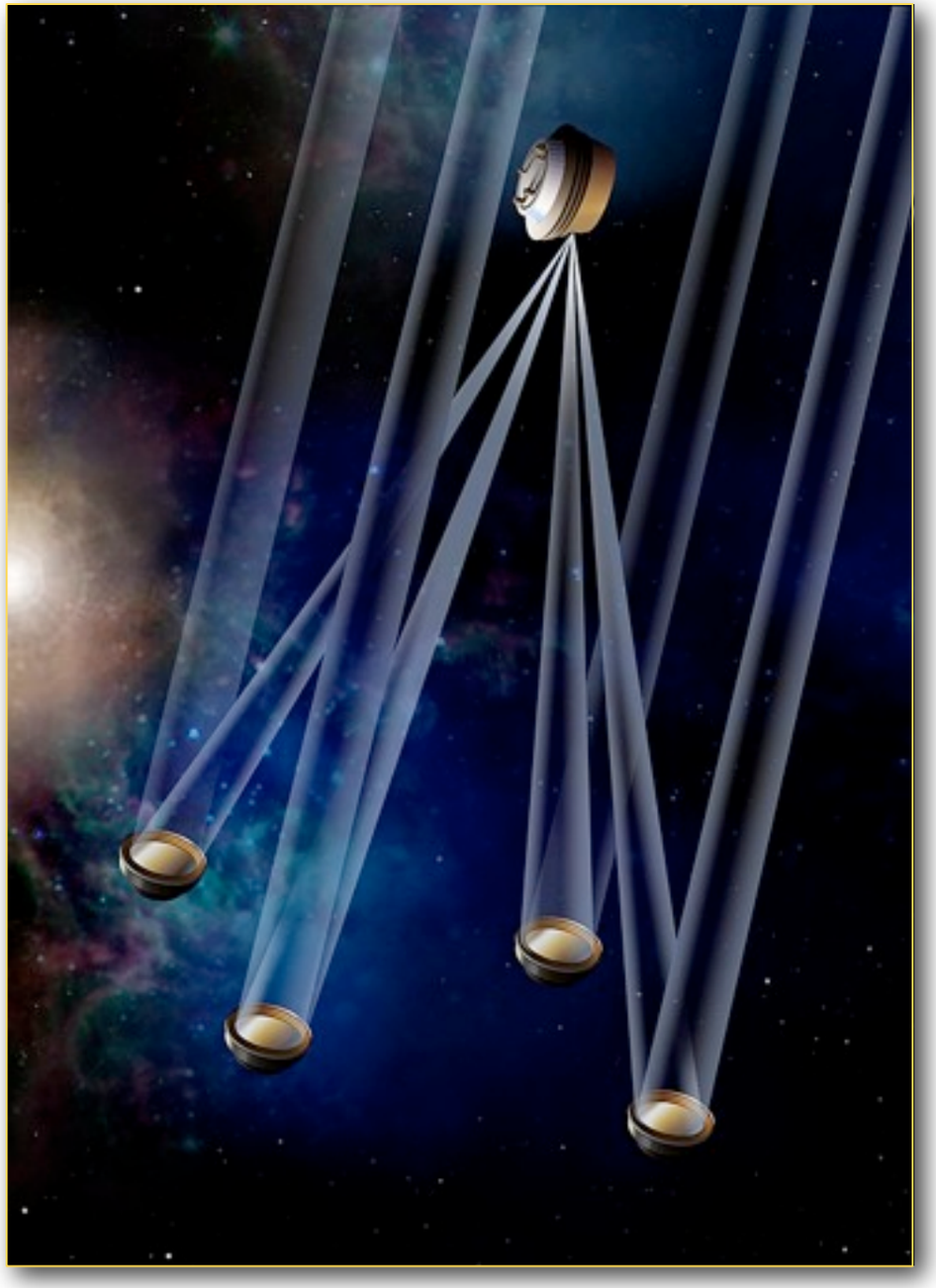
=> un système à transmission nulle sur l'axe (étoile) et maximale à l'emplacement de la planète



Interférométrie annulante pour la caractérisation des planètes telluriques en zone habitable

- Concept Darwin / TPF (1993–2010)
  - Recensement de *toutes* les planètes de type terrestre autour des *analogues* du Soleil
  - Spectroscopie dans l'IR moyen des planètes habitables
    - Bio-signatures: H_2O, CO_2, O_3
- Besoin d'une flottille interférométrique spatiale
  - Au moins 3 télescopes pour la modulation de phase

Darwin ESA proposal (2007)



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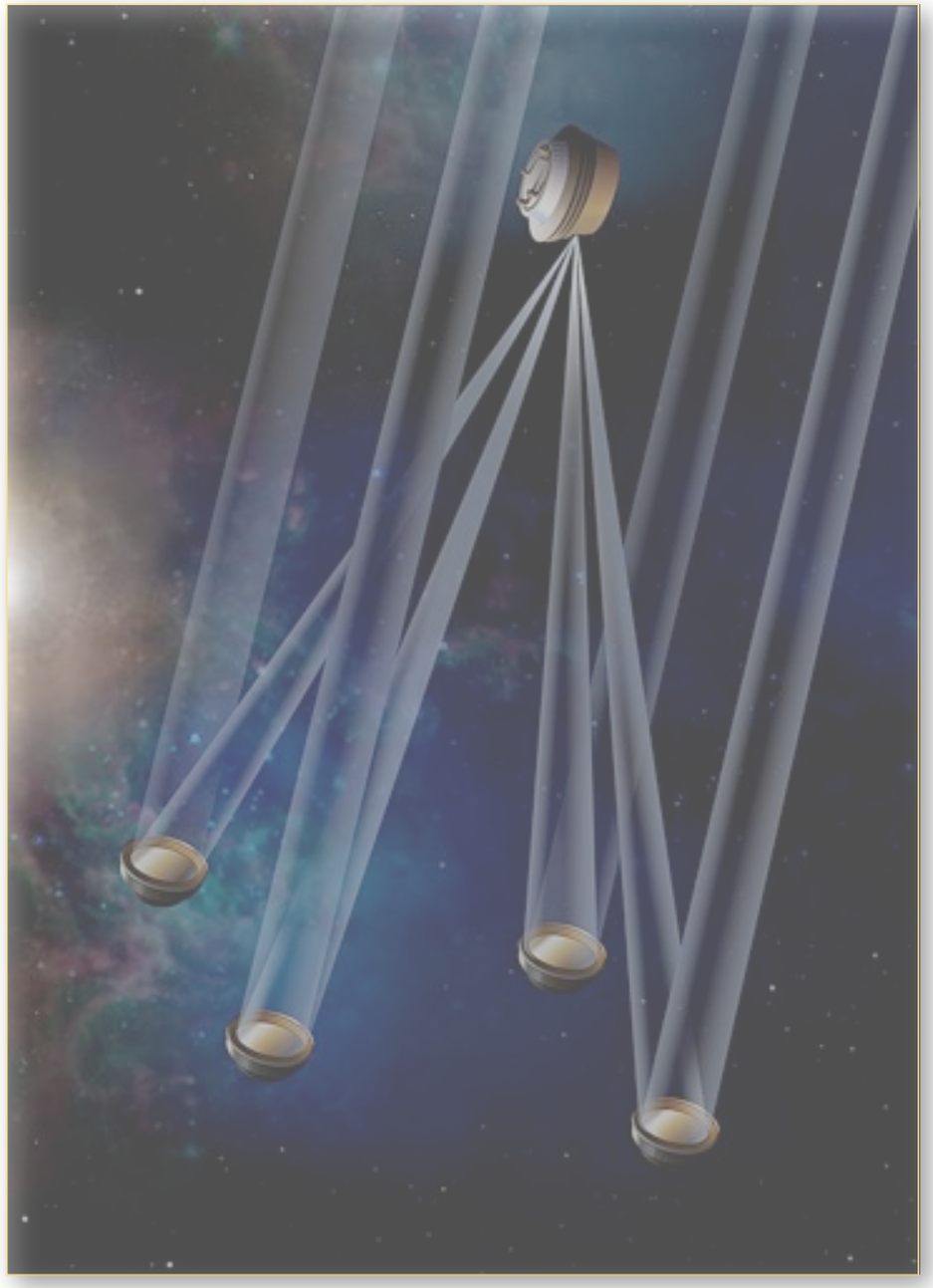
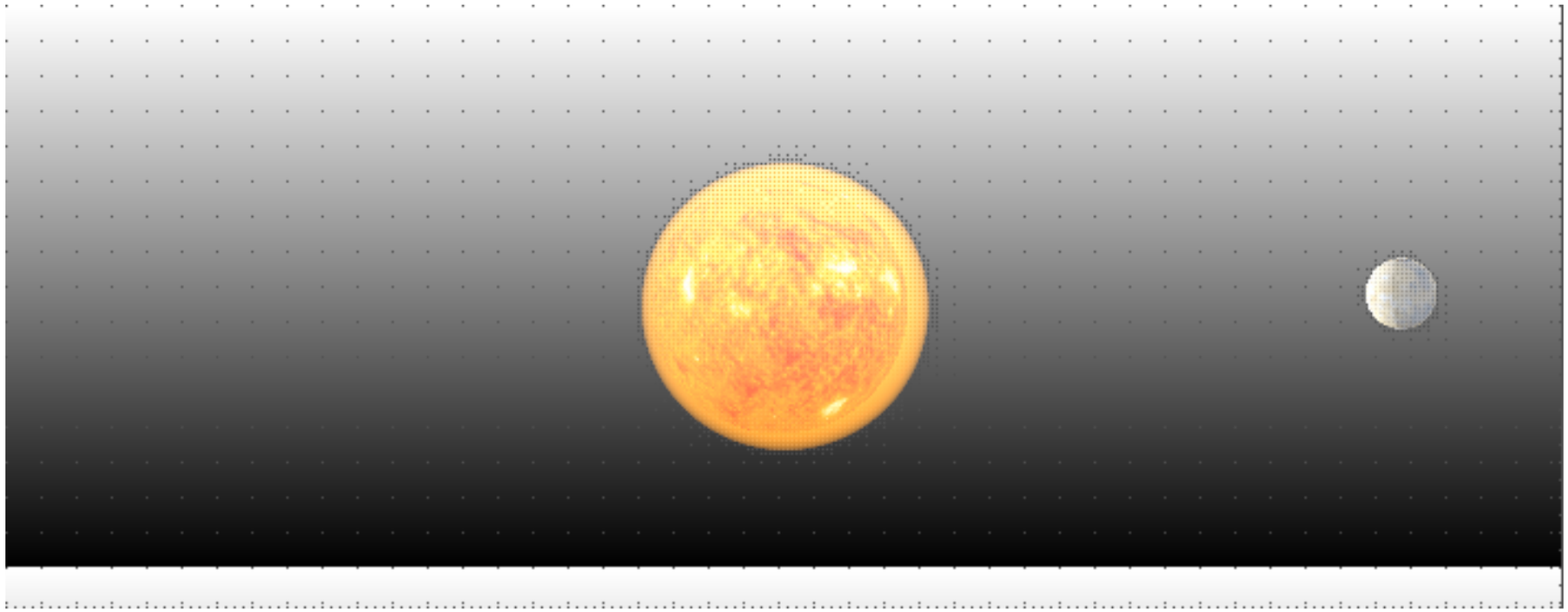
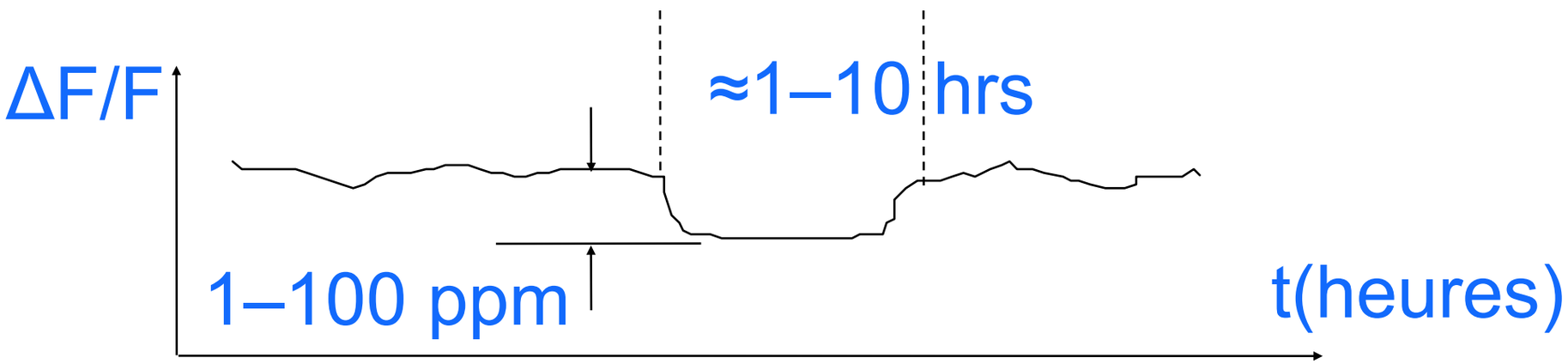


Séparation temporelle: transits

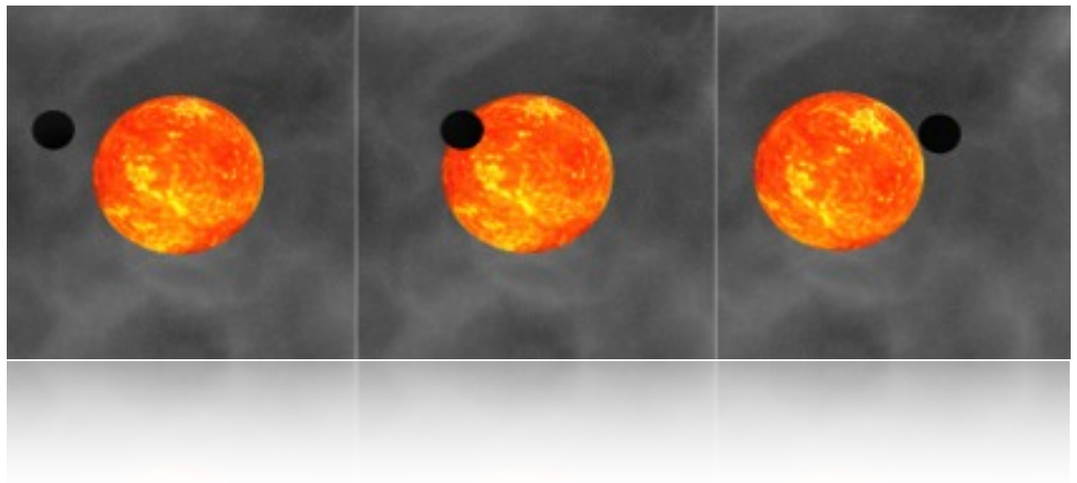




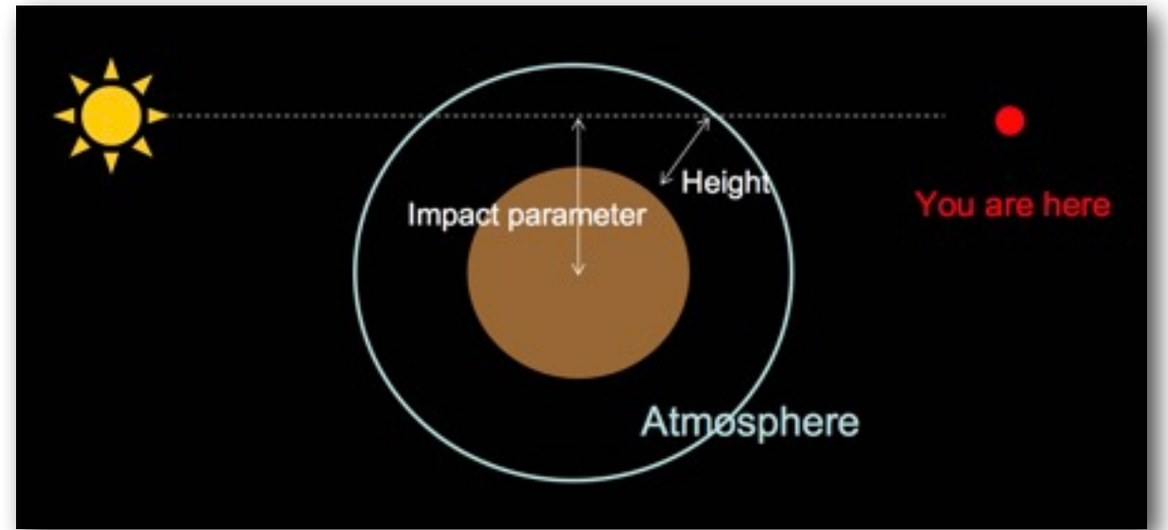
Probabilité de visibilité = D_*/D_{orb}

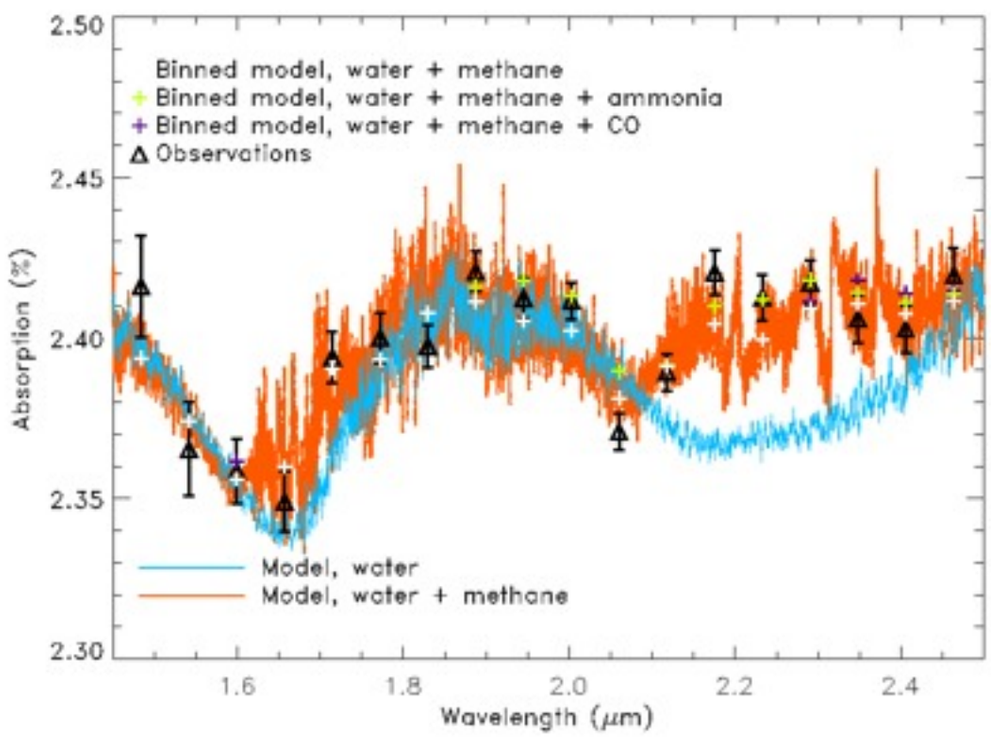
- 0.5% pour Terre / Soleil
- 10% pour un Jupiter chaud

Transit primaire



HD189733b, terminator

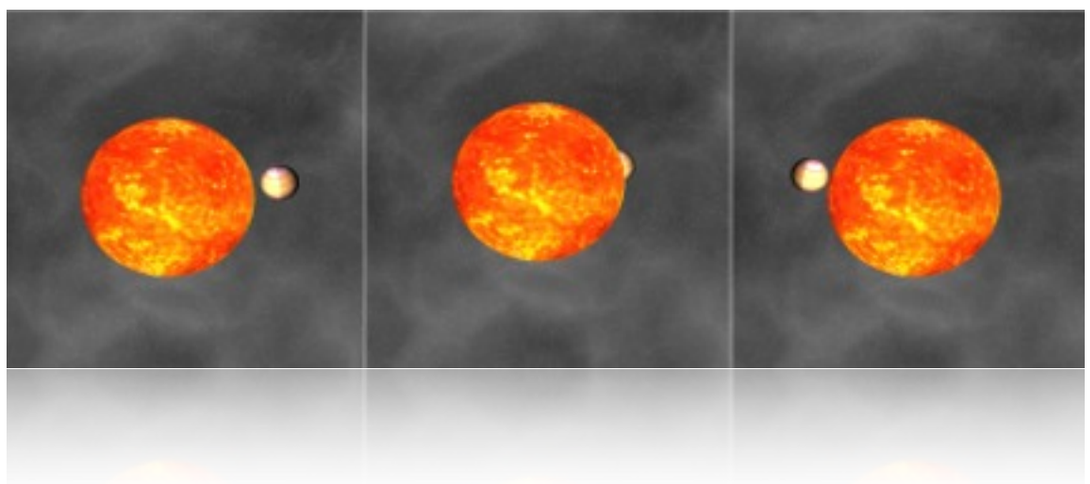


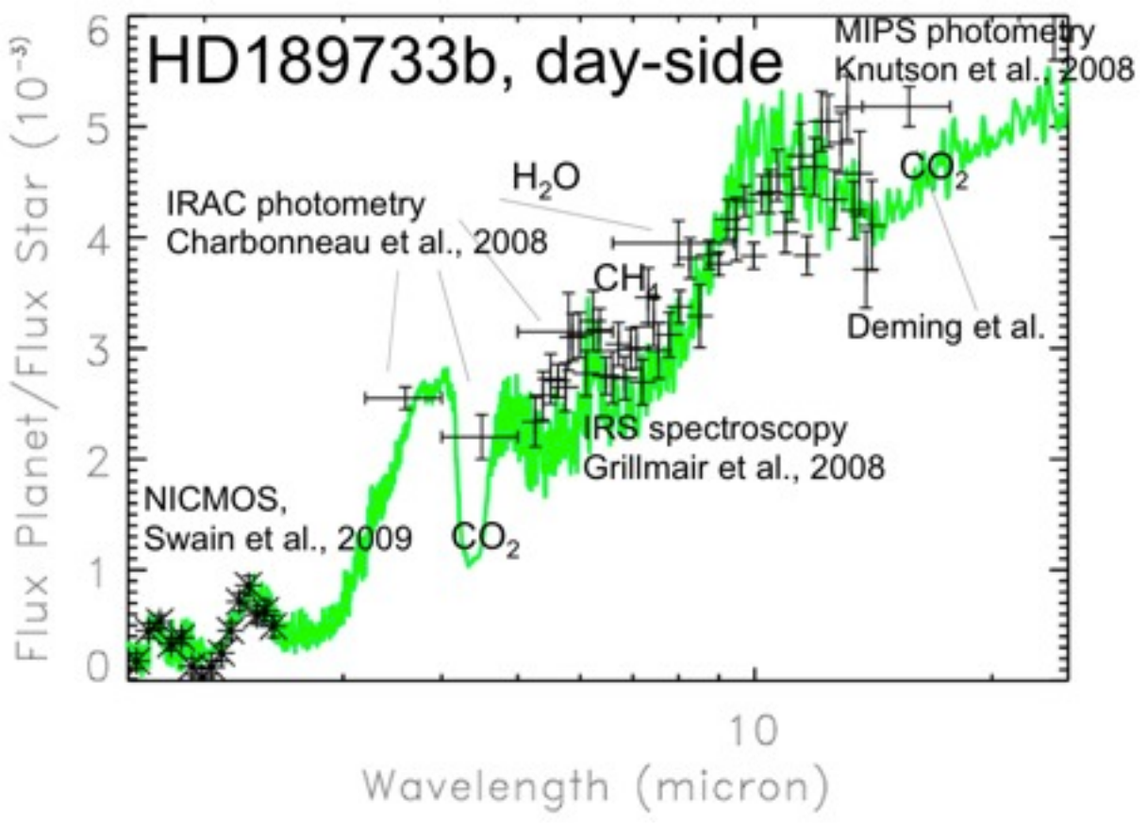


Swain, Vasisht, Tinetti, Nature, 2008

- Spectroscopie en transmission
- Sonde les hautes couches de l'atmosphère au terminateur
- Signal proportionnel à l'échelle de hauteur (dépend de T et du poids moléculaire)

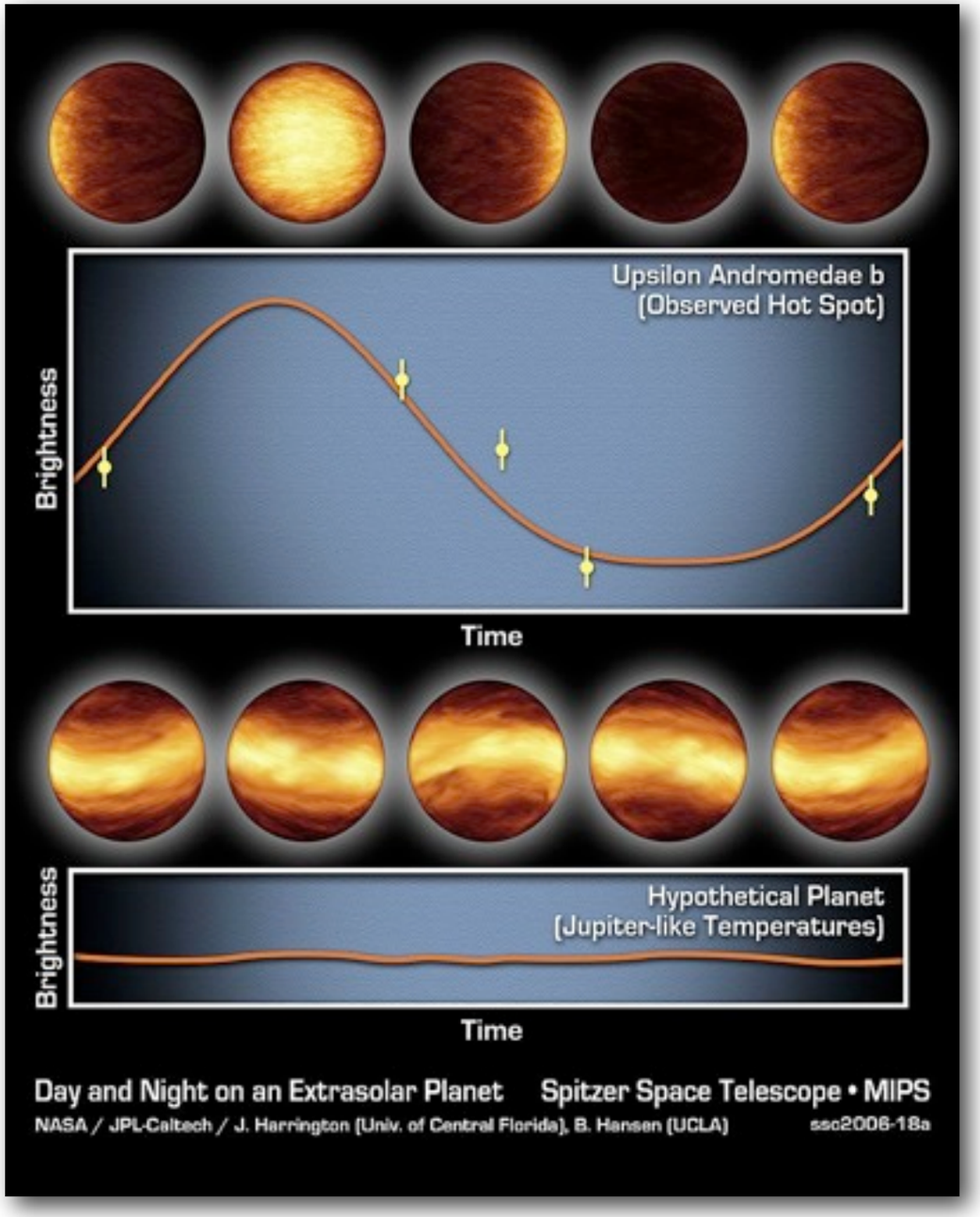
Transit secondaire





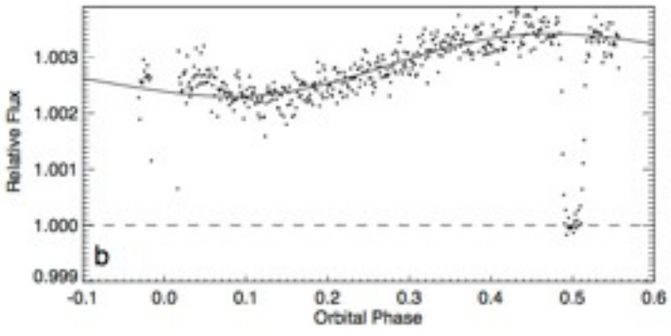
- Spectre du côté jour
- Emission thermique (modulée par les bandes moléculaires) dans l'infrarouge :
  - Depend du gradient vertical de T
  - Sonde les couches plus denses de l'atmosphère
- Lumière visible réfléchie dominée par la diffusion et les nuages

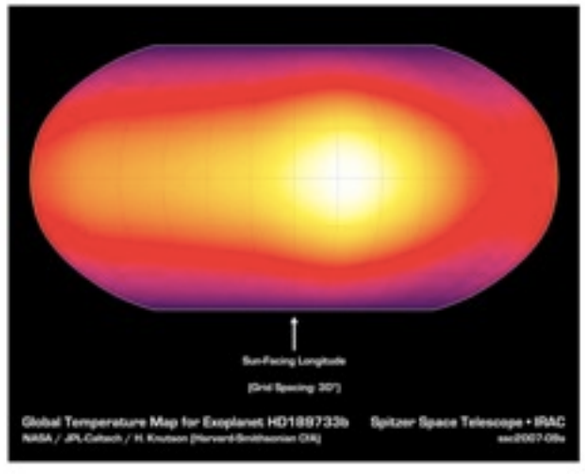
Fonction de phase



Ups And
(Harrington et al. 2006)

- Peut être mesurée sur des planètes non transitantes
- Nécessite une stabilité à long terme : ne peut être observée que depuis l'espace
- Fournit l'information sur la dynamique de l'atmosphère et la redistribution jour/nuit de l'énergie stellaire absorbée

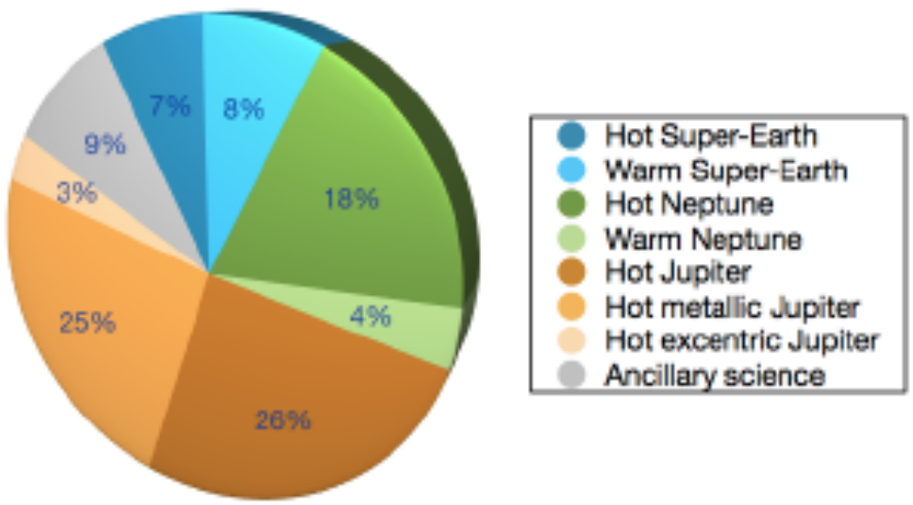


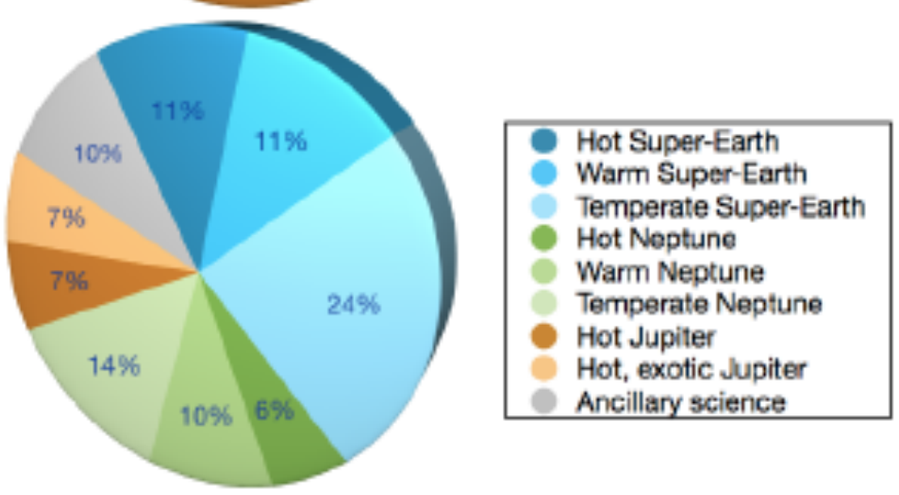


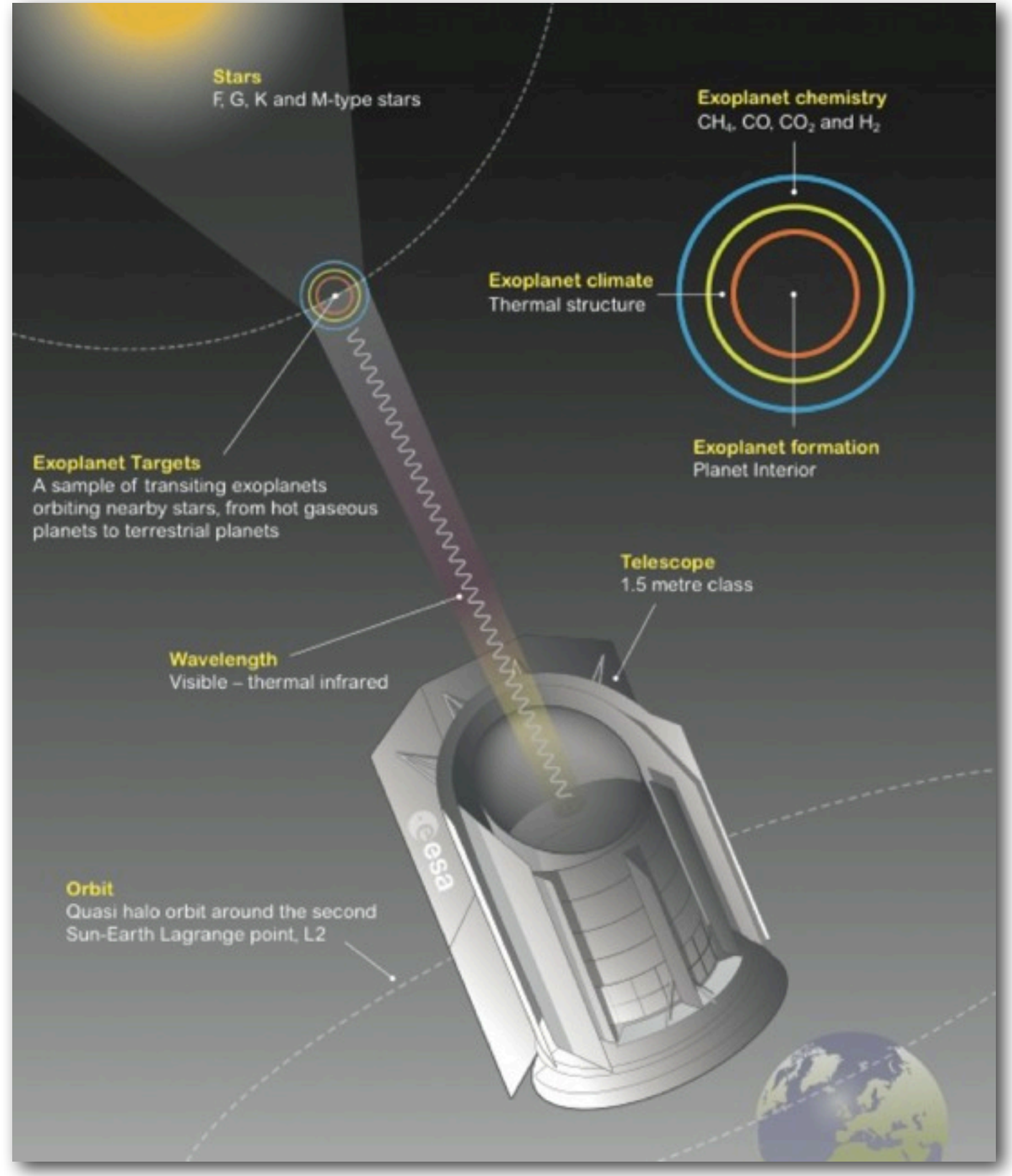
HD189733b
(Knutsen et al. 2007)

ECho

Exoplanet Characterization Observatory

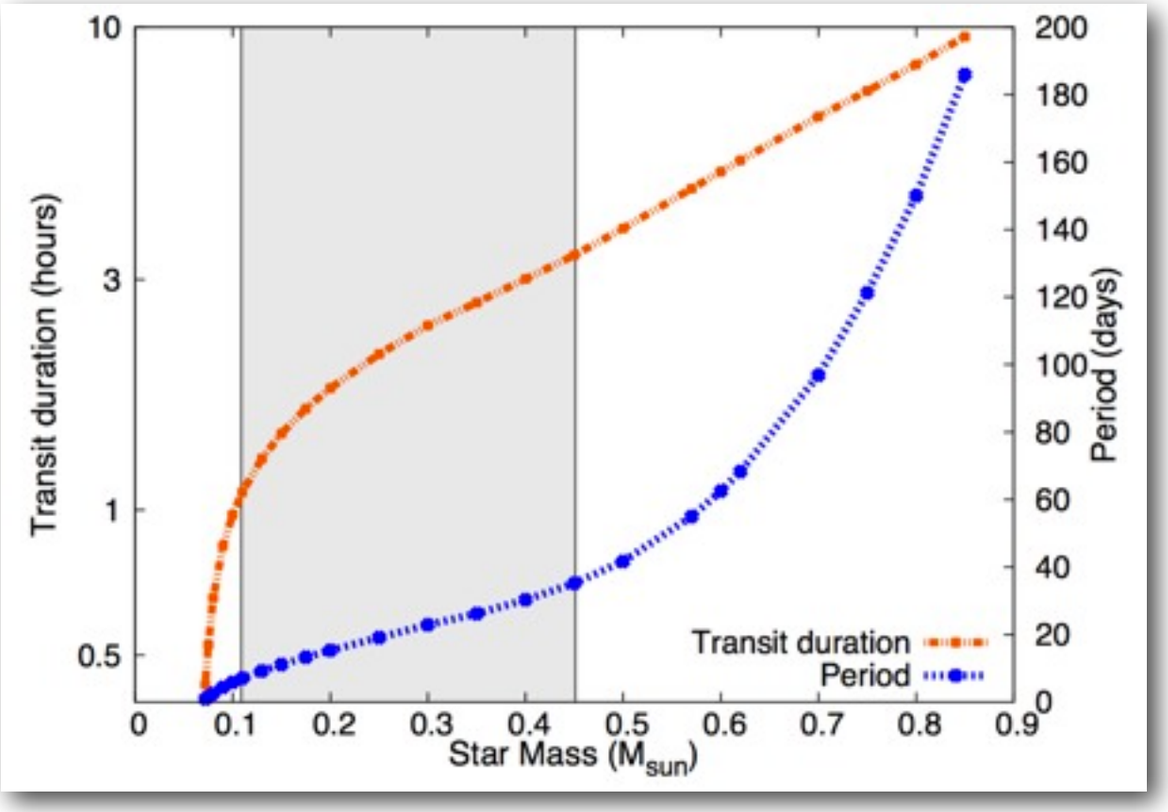






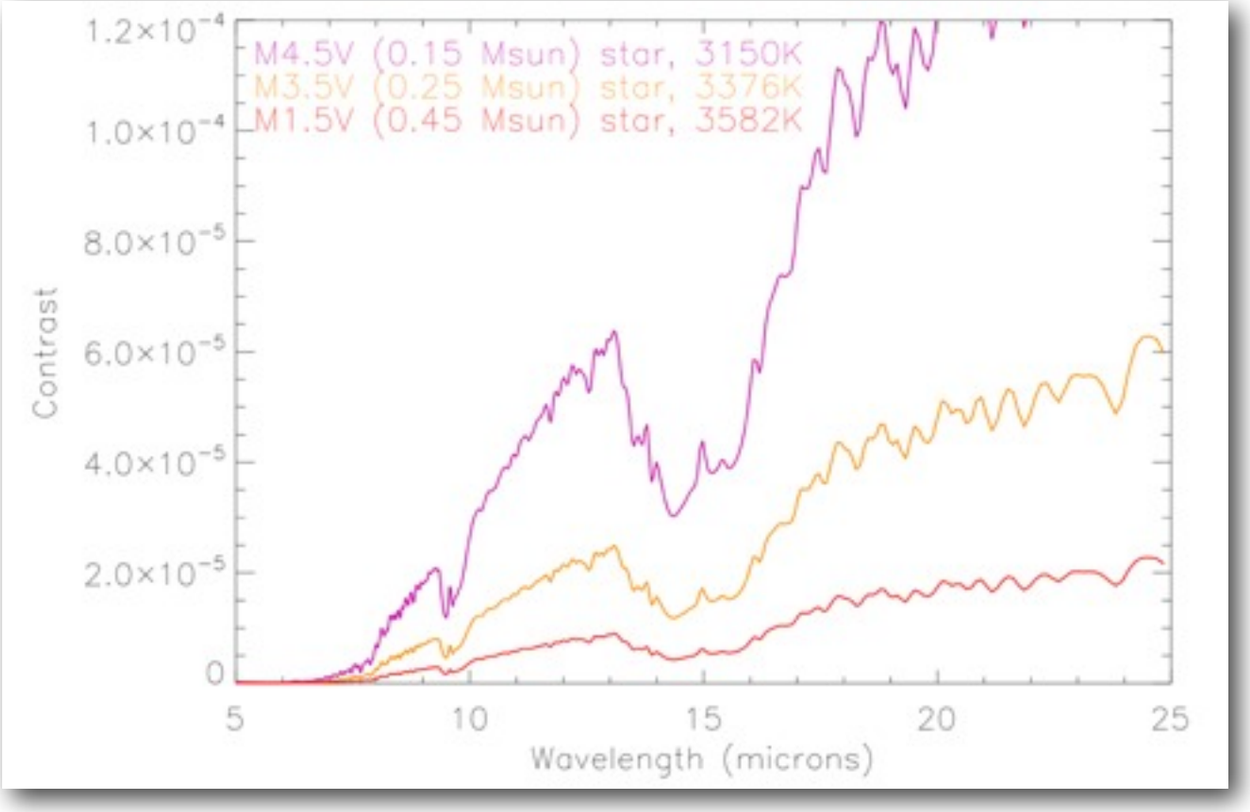
http://echo-spacemission.eu

Observion des super Terres dans la zone tempérée des naines M



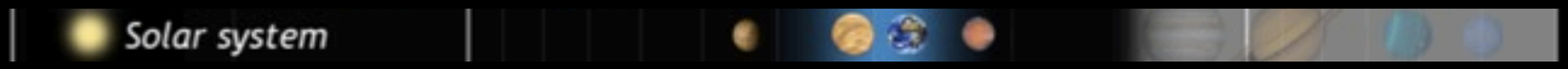
Tessenyi et al. 2011

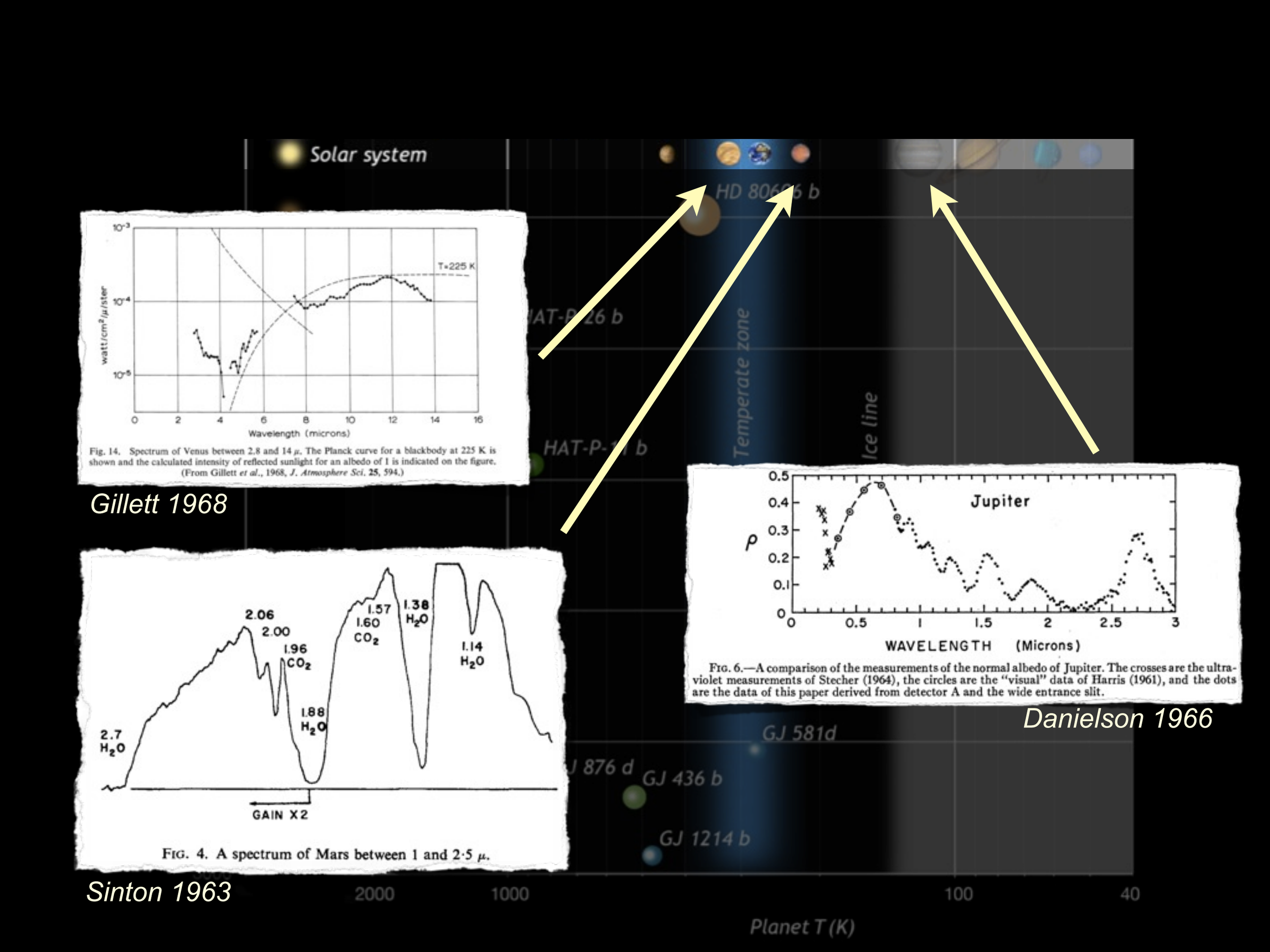
Durée du transit et période orbitale en fonction de la masse stellaire



Tessenyi et al. 2011

Contraste de flux pour une super-Terre orbitant différents types d'étoile M (M1.5V, M3.5V and M4.5V), en supposant une atmosphère de type terrestre


Solar system


Solar system
HD 80606 b
HAT-P-26 b
HAT-P-11 b
Temperate zone
Ice line
GJ 581d
GJ 876 d
GJ 436 b
GJ 1214 b
2000
1000
100
40
Planet T (K)
T=225 K
watt/cm²/μ/ster
Wavelength (microns)
Fig. 14. Spectrum of Venus between 2.8 and 14 μ. The Planck curve for a blackbody at 225 K is shown and the calculated intensity of reflected sunlight for an albedo of 1 is indicated on the figure. (From Gillett et al., 1968, J. Atmosphere Sci. 25, 594.)
Gillett 1968
2.06
2.00
1.96 CO2
1.88 H2O
2.7 H2O
1.57
1.60 CO2
1.38 H2O
1.14 H2O
GAIN X2
FIG. 4. A spectrum of Mars between 1 and 2·5 μ.
Sinton 1963
Jupiter
ρ
WAVELENGTH (Microns)
FIG. 6.—A comparison of the measurements of the normal albedo of Jupiter. The crosses are the ultraviolet measurements of Stecher (1964), the circles are the "visual" data of Harris (1961), and the dots are the data of this paper derived from detector A and the wide entrance slit.
Danielson 1966

Conclusion : le double changement de paradigme

- Exoplanètes: de l’ère de la découverte à celle de l’exploration
- Habitabilité : de la recherche de la similarité à l’exploration de la diversité

Vers une convergence de la planétologie et l’exoplanétologie ?