La découverte de 51 Peg B

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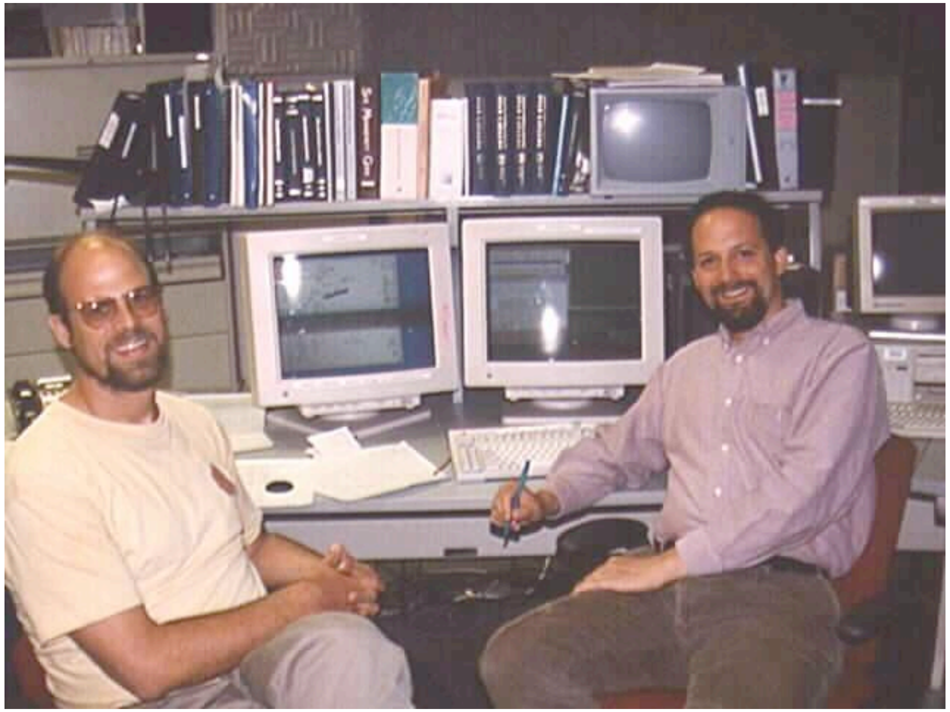
Institut d'Astrophysique Spatiale d'Orsay

Prix Nobel de physique 2019

Une rivalité scientifique



Paul Butler / Geoff Marcy

Michel Mayor / Didier Queloz

Contexte historique et scientifique

Un peu d'histoire… 1 : L'ère des intuitifs

- Epicure (~ -300) : Adresse à Hérodote

  "Ce n'est pas seulement le nombre des atomes, c'est celui des mondes qui est infini dans l'Univers. Il y a un nombre infini de mondes semblables au nôtre et un nombre infini de mondes différents [...] On doit admettre que dans tous les mondes, sans exception, il y a des animaux, des plantes, et tous les êtres que nous observons […]"

- Giordano Bruno (1600) : L'infini, l'Univers et les mondes

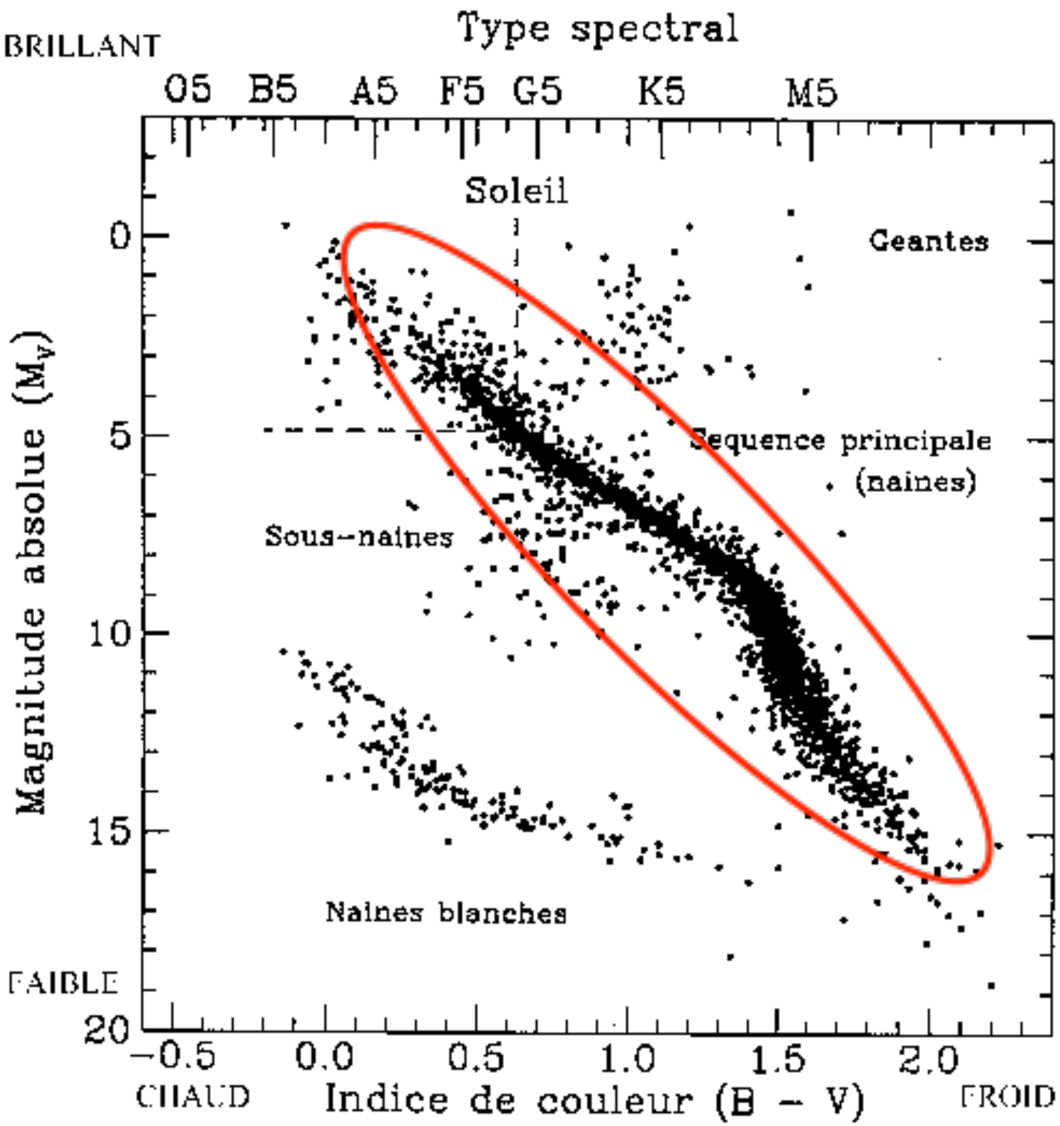
- Huygens (1629-1695) :

  "N'hésitons pas, nous, à admettre avec les principaux Philosophes de notre temps, que la nature des étoiles et celle du Soleil est la même. D'où résulte une conception du monde beaucoup plus grandiose que celle qui correspond aux vues antérieures plus ou moins traditionnelles. Car qu'est-ce qui empêche maintenant de penser que chacune de ces étoiles ou Soleils a des Planètes autour d'elle et que ces planètes à leur tour sont pourvues de Lunes ?"

A LA RECHERCHE DES ETOILES DE FAIBLE MASSE
ET DES OBJETS SUB-STELLAIRES

La diversité des étoiles

Le diagramme Hertzsprung-Russel (~1910)



Séquence principale

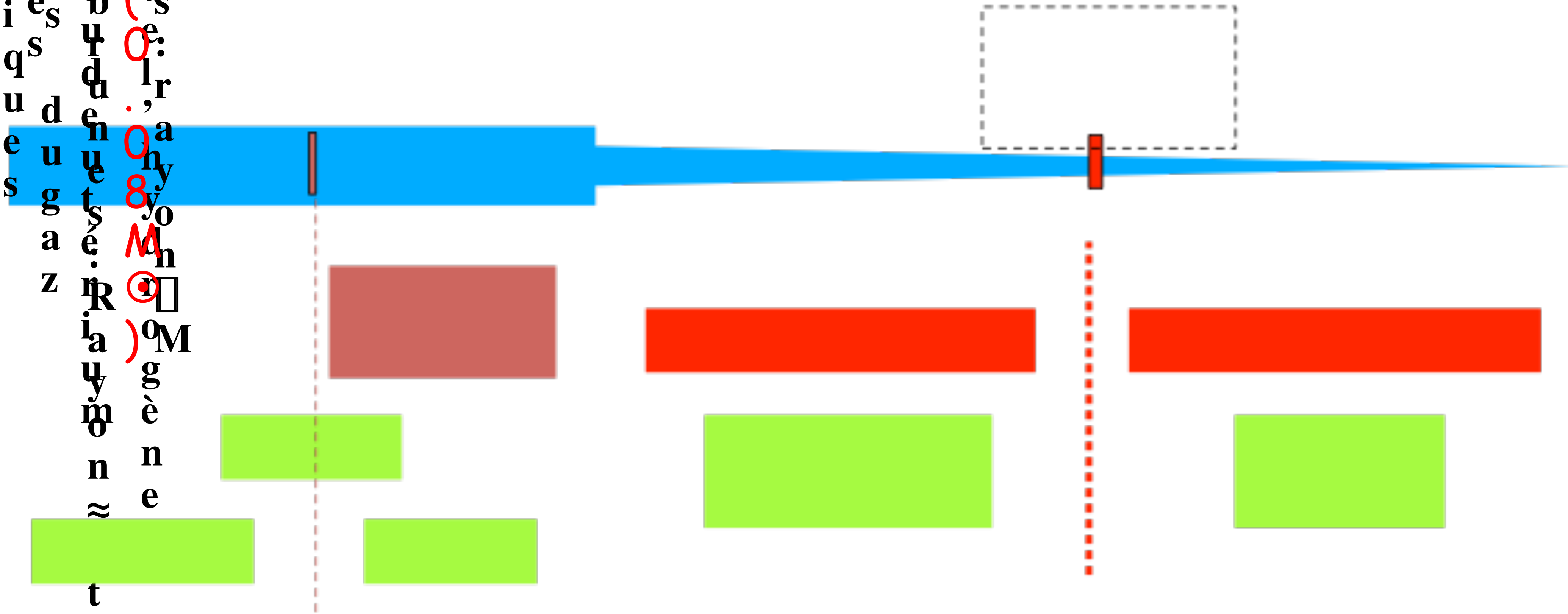
- 90 % des étoiles
- Relation univoque entre :
  - Température
  - Luminosité
  - Masse
  - Durée de vie

$$t_{vie} \approx 10^{10} \left(\frac{m_{Soleil}}{m} \right)^2 \approx 10^{10} \left(\frac{L_{Soleil}}{L} \right)^{2/3}$$

Masse minimale des étoiles

Physique gouvernée principalement par la masse des objets

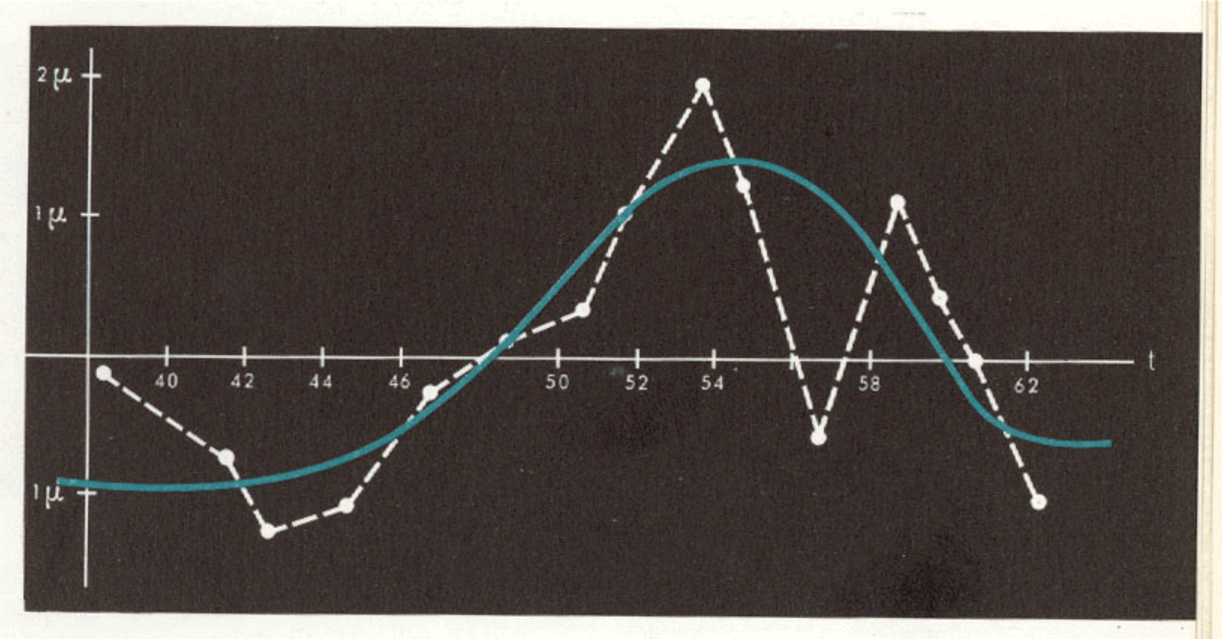
- Gravitation
- Processus nucléaires

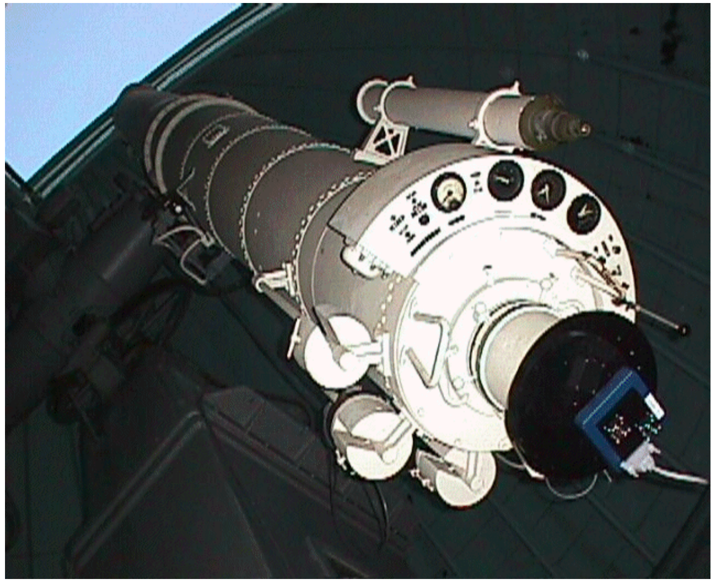


Un peu d'histoire : 2 : l'ère des observateurs

- 1931 : Berman : m= 45Mj
- 1960 : Van de Kamp : étoile de Barnard

Etoile de Barnard





Observations 1916-1963
2413 clichés

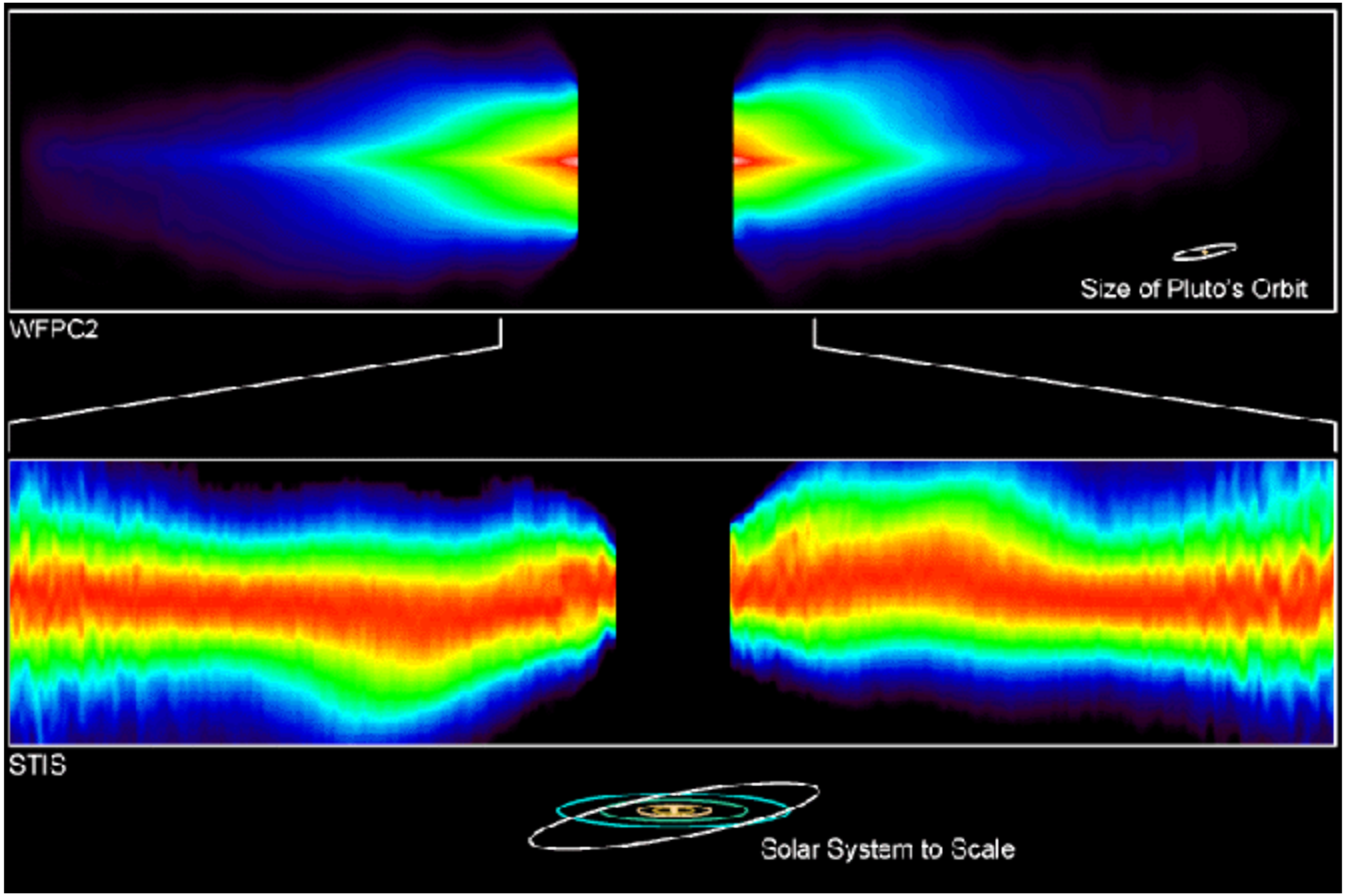
□

D = 5,98 a.l.
m = 1.6 Mj
e = 0.77
a = 4.42 ua

Un peu d'histoire : 2 : l'ère des observateurs

- 1931 : Berman : m= 45Mj
- 1960 : Van de Kamp : étoile de Barnard
- 1981 : □ pictoris

β Pictoris



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- 1960 : Van de Kamp : étoile de Barnard
- 1981 : pictoris
- 1985 : Mc Carthy et al. : Van Biesbroeck 8 B

VB-8B

INFRARED DETECTION OF A CLOSE COOL COMPANION TO VAN BIESBROECK 8

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Steward Observatory, University of Arizona

Received 1984 October 23; accepted 1984 November 29

ABSTRACT

We have detected, via infrared speckle interferometry, a cool object 1″ from the very low-luminosity star VB 8, 3 mag fainter than VB 8 at 2.2 μm. Measurements at 1.6 and 2.2 μm give $T_e = 1360$ K and (assuming a physical association) $R = 0.09\ R_{\odot}$, $L = 3 \times 10^{-5}\ L_{\odot}$, consistent with a substellar brown dwarf. These observations may constitute the first direct detection of an extrasolar planet.

Subject headings: infrared: sources — planets: general — stars: late-type

VB-8B (2)

THE ASTROPHYSICAL JOURNAL, **312**:L27–L30, 1987 January 1

ON THE BINARY NATURE OF VAN BIESBROECK 8[1]

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Observatoire de Lyon
Received 1986 June 26; accepted 1986 October 9

ABSTRACT

We report observations by infrared speckle interferometry at 2.2 and 3.6 μm of the nearby M dwarf Van Biesbroeck 8. This low-luminosity star has raised much interest since the 1985 discovery by McCarthy and colleagues of a close cool companion (VB 8B) at 1″, presented as the first observational evidence of the existence of brown dwarfs. At the time of our observations, no companion could be detected at a distance greater than 0″.4 (2.5 AU). Constraints on the dynamics of the system are deduced; the nature of VB 8B is discussed; and its existence is questioned.

Subject headings: infrared: sources — interferometry — stars: binaries — stars: late-type

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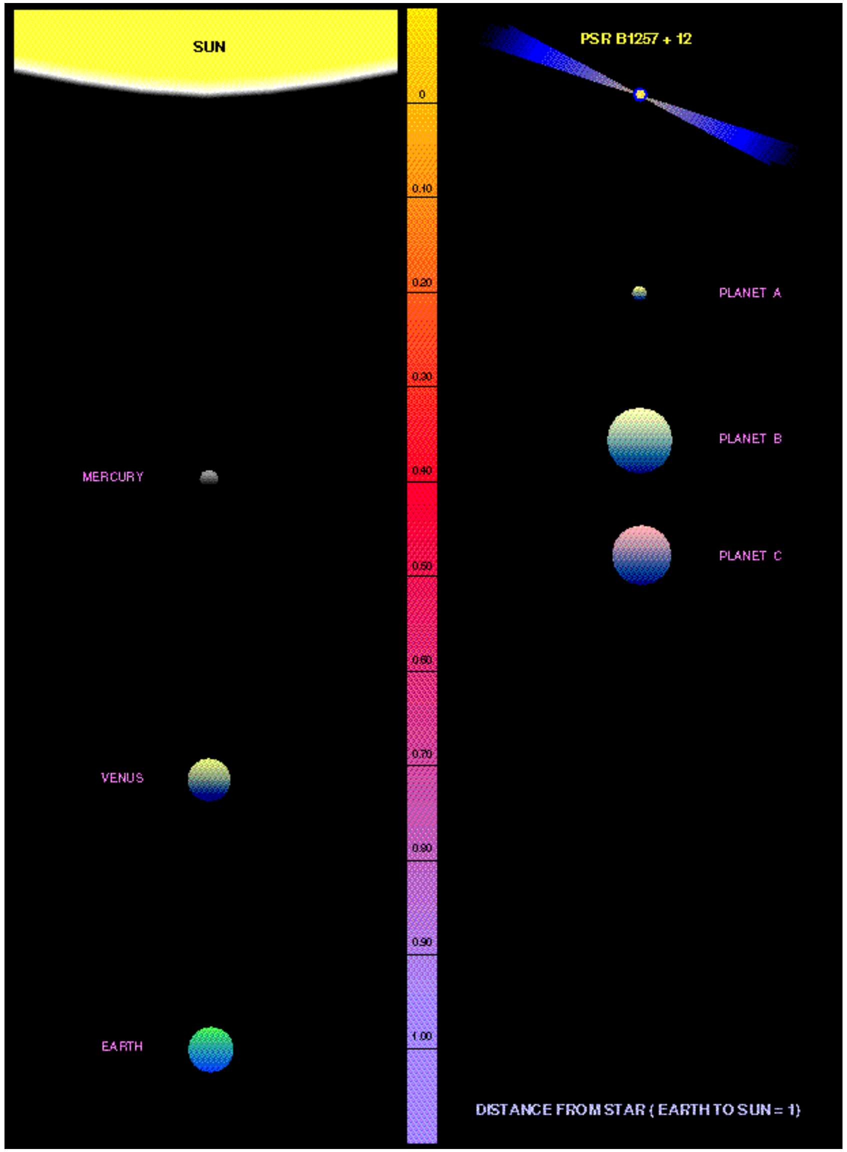
- 1985 : Mc Carthy et al. : Van Biesbroeck 8 B
- 1992 : Wolszczan : PSR 1257 +12

PSR 1257+12



3 planètes

M (m□)	a (ua)	période (j)
0.015	0.19	25.34
3.4 66.54	0.36	
2.8 98.22	0.47	

Mais PSR1829-10 : Lyne et al. 91 et 92

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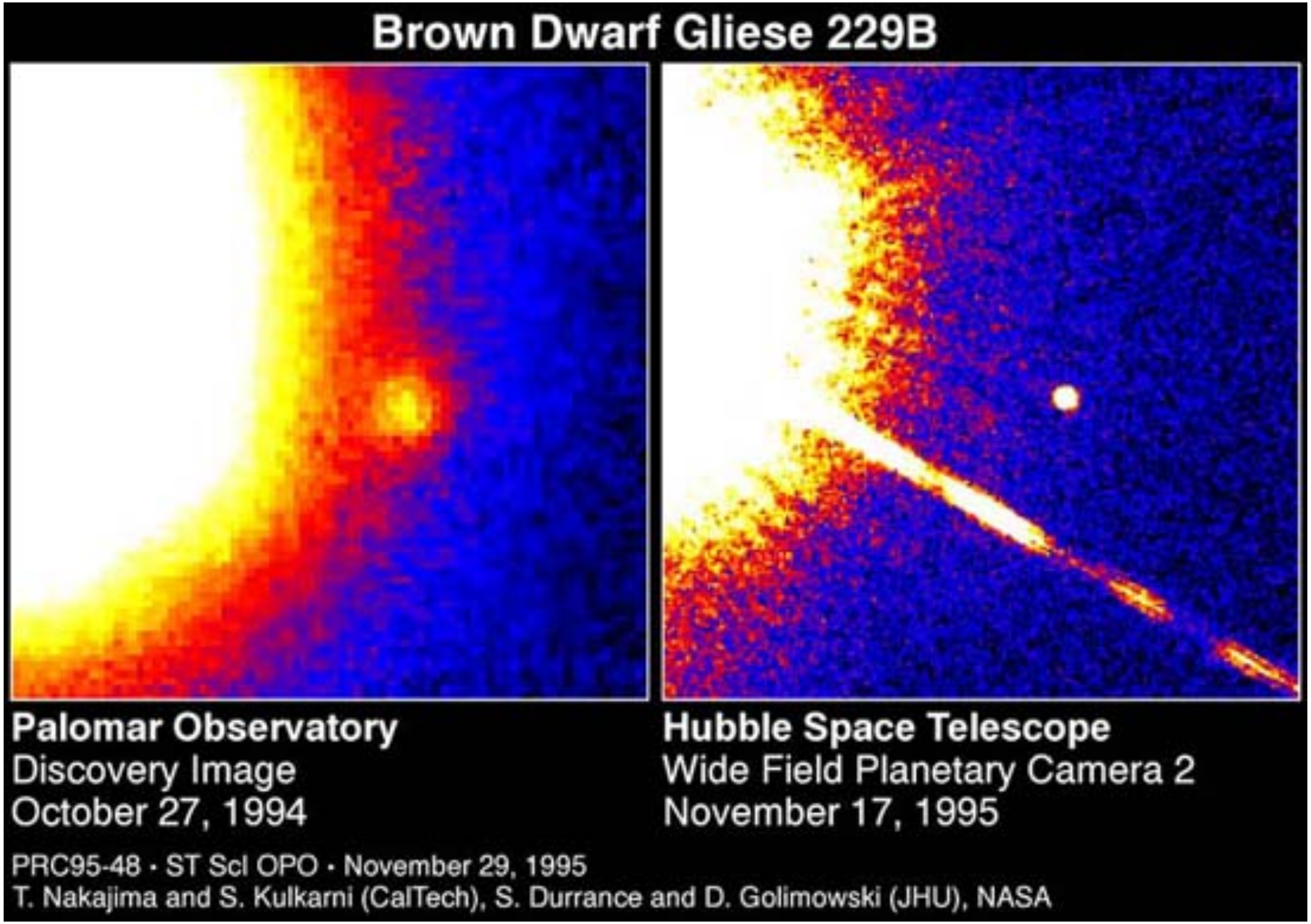
- 1994 : Première observation directe d’une naine brune : Nakajima et al.

1994 : Naine brune : Gl 229 b



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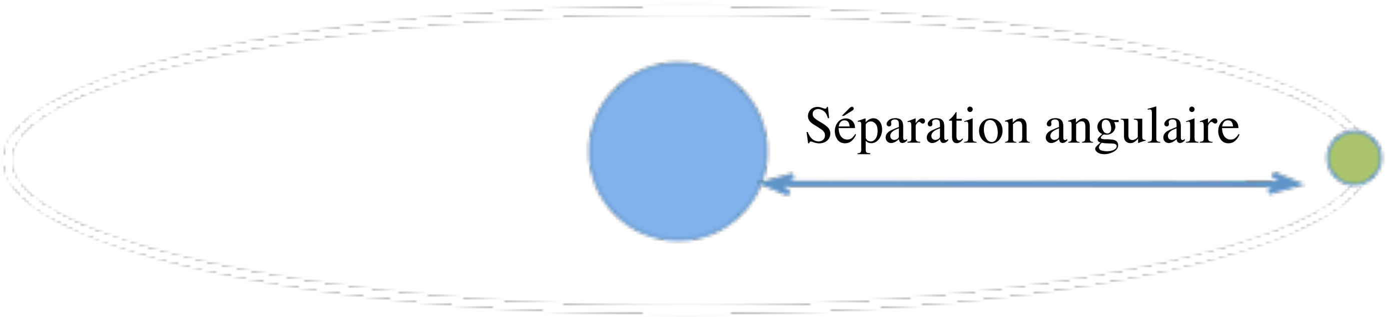
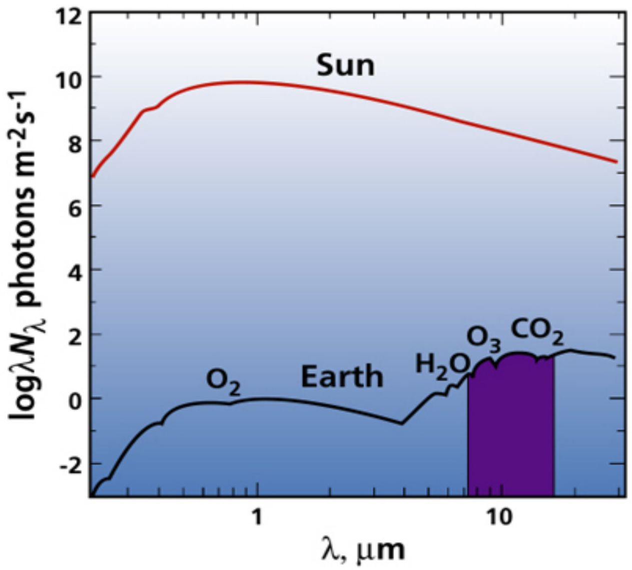
- 1992 : Wolszczan : PSR 1257 +12
- 1994 : Première observation directe d'une naine brune : Nakajima et al.
- 1995 : Walker : rien en dessus de 3 Mj autour de 21 étoiles

Observer une exoplanète (1)



	Rayon (R⊕)	Masse (M⊕)	Distance (u.a.)	Séparation angulaire (arcsec) @ 10 pc
Jupiter chaud	11	320	0,05	**5 x 10-3**
Terre chaude	1	1	0,05	5 x 10-3
Terre	1	1	1	**0,1**
Jupiter	11	320	5,2	0,5
Neptune	4	17	30	3

Observer une exoplanète (2)



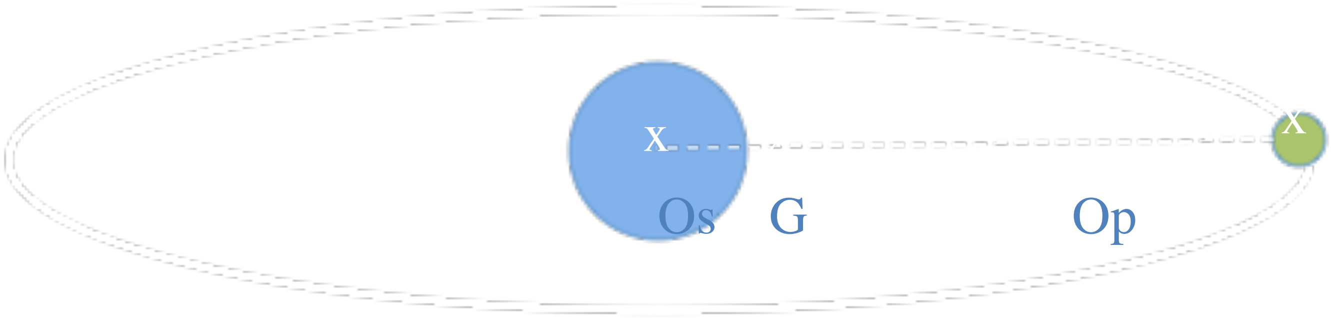
Emission thermique de la planète

Flux réfléchi par la planète (émission stellaire)

	Rayon (R⊕)	Masse (M⊕)	Distance (u.a.)	Contraste Vis (0,3-2 µm)	Flux Vis @ 10 pc (ph / s / m2)	Contraste IR (6-20 µm)	Flux IR @ 1 pc (ph / s / m2)
Soleil	109	3,32 x 105	-	1	**1,5 x 109**	1	**7 x 107**
Jup chaud	11	320	0,05	**104**	**1,5 x 105**	**103**	**7 x 104**
Terre chaude	1	1	0,05	106	1,5 x 103	105	700
Terre	1	1	1	**5 x 109**	**0,3**	**7 x 106**	**10**
Jupiter	11	320	5,2	5 x 108	3	5 x 107	1,4
Neptune	4	17	30	1011	0,015	1010	0,007

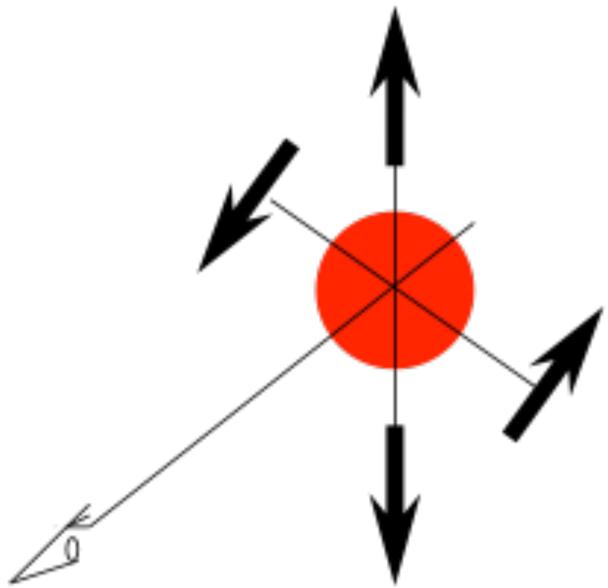
R⊕ = 6,378 106 m, M⊕ = 5,976 10 24 kg, 1 u.a. = 1,495979 1011 m

Détections indirectes : effets gravitationnels

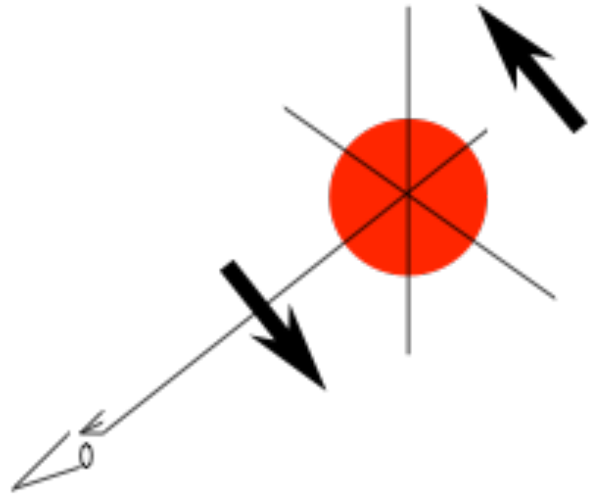


$$\overline{GO_p} = \frac{m_s}{m_s + m_p}\,\overline{O_sO_p}$$

➔ l'étoile tourne autour de G



Astrométrie



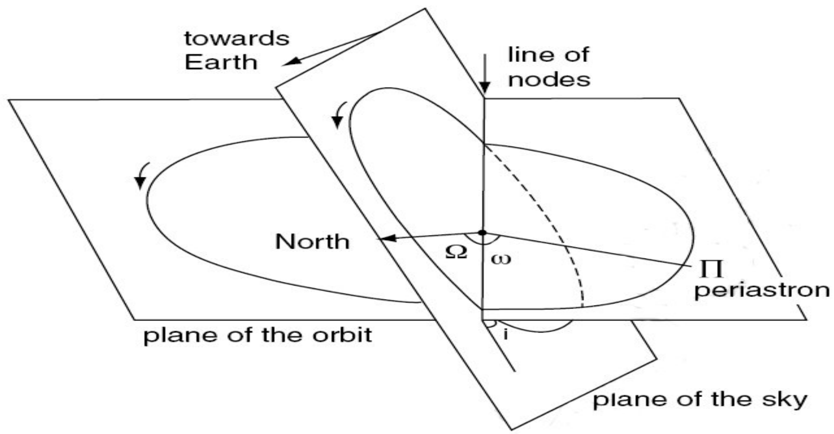
Mesure de la vitesse radiale
Chronométrage

Vitesse radiale d'une étoile

- Mouvement orbital :

$$r(\nu) = \frac{a(1-e^2)}{1+e\cos(\nu)}$$

a = 1/2 grand axe de l'orbite
e = excentricité
ν = position angulaire/ périastre



- Position de l'étoile sur la ligne de visée:

$$z(t) = r.\sin(\nu(t)+\omega).\sin(i)$$

- 2nd loi de Kepler (loi des aires) :

$$r^2\frac{d\nu}{dt} = 2\pi P^{-1}a^2\sqrt{1-e^2}$$

- Vitesse radiale de l'étoile :

$$V_r = \frac{2\pi}{P}\frac{a\sin(i)}{\sqrt{1-e^2}}\left[\cos(\nu(t)+\omega+e\cos(\omega)\right]$$

Vitesse radiale d'une étoile (2)

- On note: $$K_* = \frac{2\pi}{P}\frac{a_* \sin(i)}{\sqrt{1-e^2}}$$
- Syst à 2 corps : 3ème loi de Kepler: $$a^3(m_* + m_p)^{-1} = P^2 G(4\pi^2)^{-1}$$

avec : a = a* + ap et m*.a*=mp.ap : $$a_*^3 = P^2 G(4\pi^2)^{-1}.m_p^3(m_* + m_p)^{-2}$$

- et $$\frac{(m_p \sin(i))^3}{(m_* + m_p)^2} = \frac{P}{2\pi G}K_*^3(1-e^2)^{3/2}$$
- Il n'est pas possible de déterminer mp et m* simultanément. Si mp peut être négligée / m* et m* peut être déterminée autrement (e.g. : HR diagram) alors :

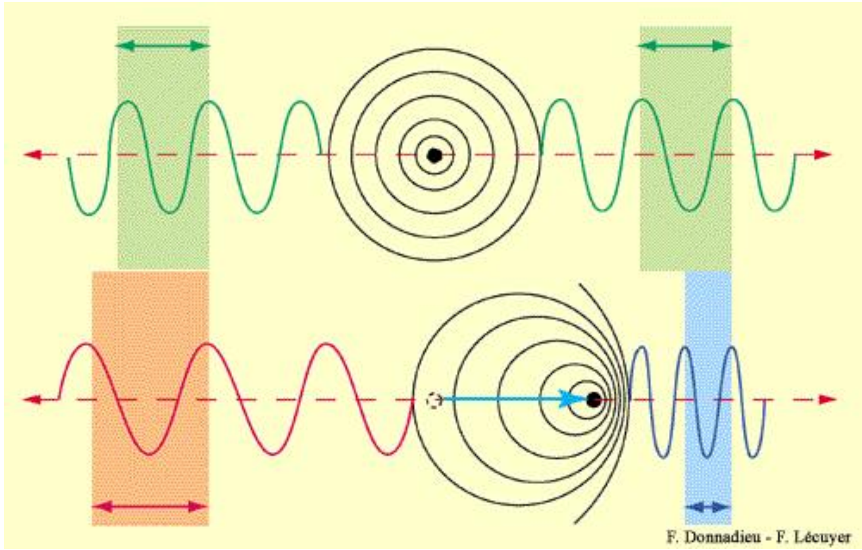
$$m_p \sin(i) \approx \left(\frac{P}{2\pi G}\right)^{1/3} K_* m_*^{2/3}\sqrt{1-e^2}$$

Amplitude de la vitesse radiale

Objet	mp(m□)	ap(u.a)	a* (r☉)	T (jours)	K*(m.s-1)
Jupiter	317.83	5.2	1.07	4332.6	12.5
Saturne	95.15	9.54	0.59	10759.2	2.8
Uranus	14.54	19.18	0.18	30685.4	0.3
Neptune	17.23	30.06	0.33	60189	0.28
Terre	1	1	6.5 10-4	365.25	0.09

Comment mesurer la vitesse radiale ?

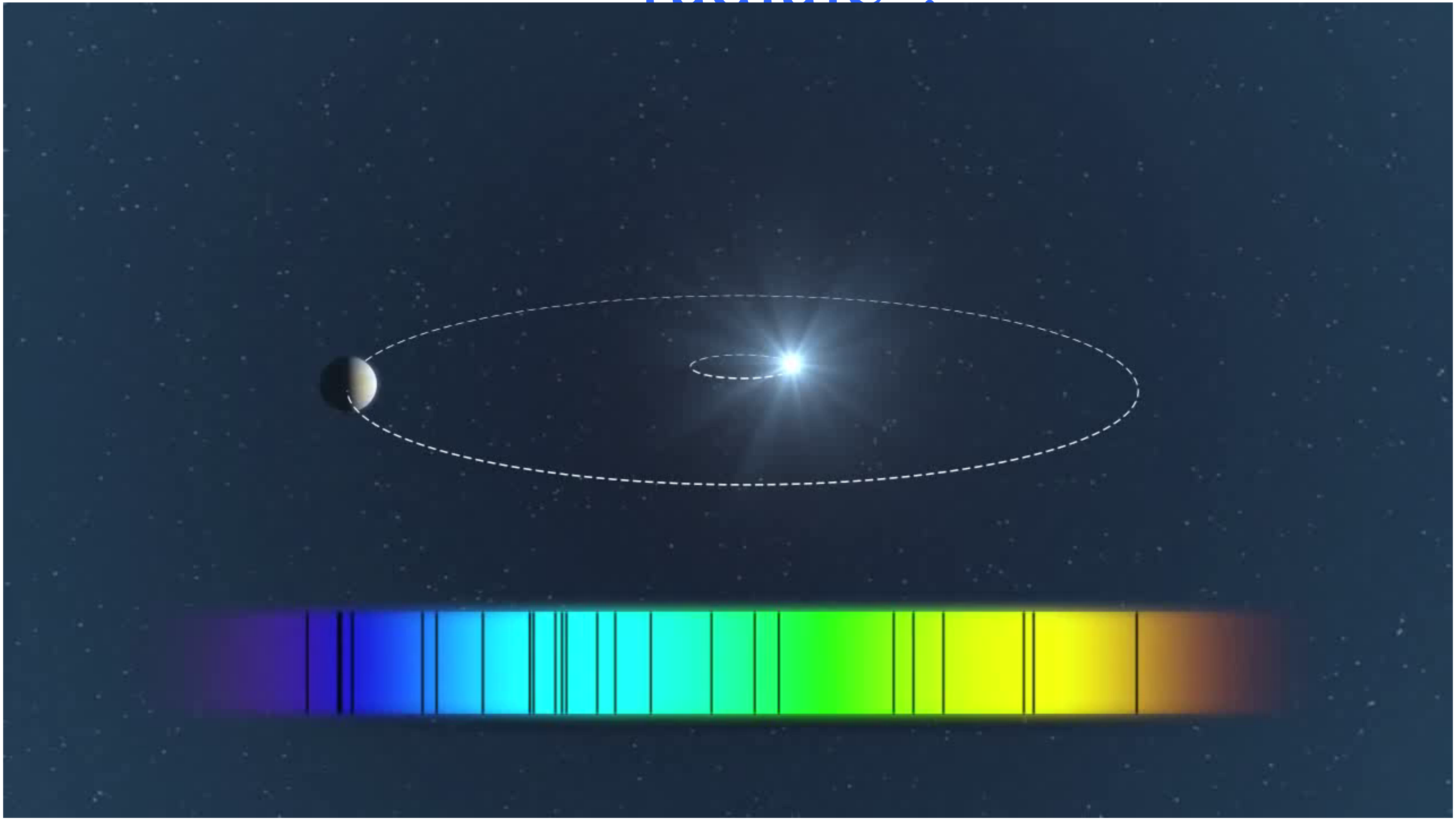
- Effet Doppler-Fizeau relativiste



$$\lambda_{obs} = \lambda_{source}\sqrt{\frac{1-\frac{V_r}{c}}{1+\frac{V_r}{c}}}$$

si K* = 10 m.s-1, $\frac{\lambda_{obs}-\lambda_{source}}{\lambda_{source}} = \frac{\Delta\lambda}{\lambda} = \frac{V_r}{c} \approx 3,3\times10^{-9}$

Comment mesurer la vitesse radiale ?

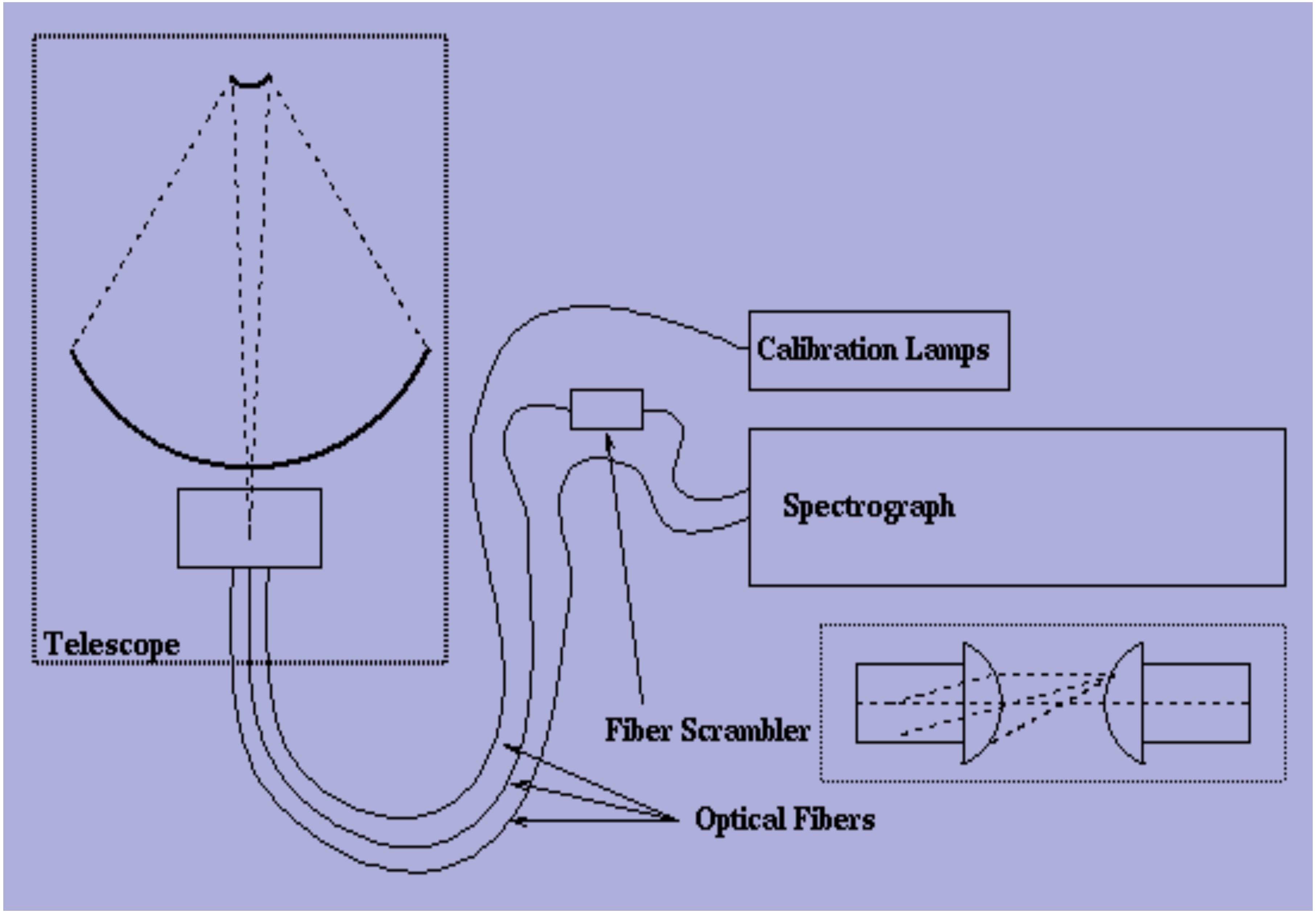


Comment mesurer la vitesse radiale (2) ?

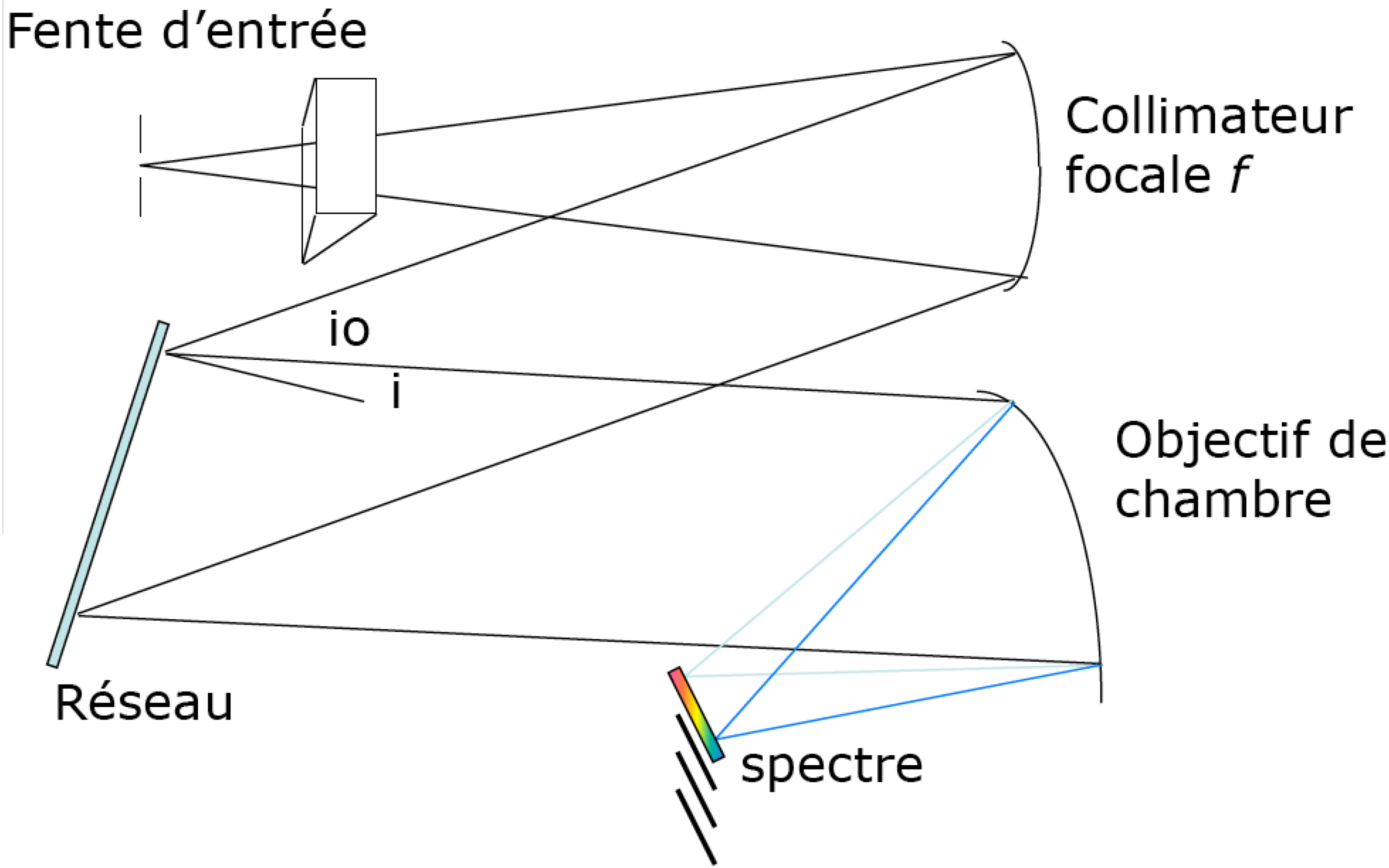
- Spectroscopie à haute résolution
  - $\lambda/\delta\lambda \approx 100000$; Shannon : 200000 px ; dans la pratique 400000 px : $\delta\lambda/\lambda = 3{,}3 \times 10^{-9}$ à mesurer
  - Amplitude du décalage : $1{,}3 \times 10^{-3}$ px

- Principe de la mesure
  - Observation simultanée de plusieurs ordres spectraux (dispersion croisée)
  - Comparaison (corrélation) avec un spectre stabilisé en fréquence
  - Correction des biais

Mesure de la vitesse radiale

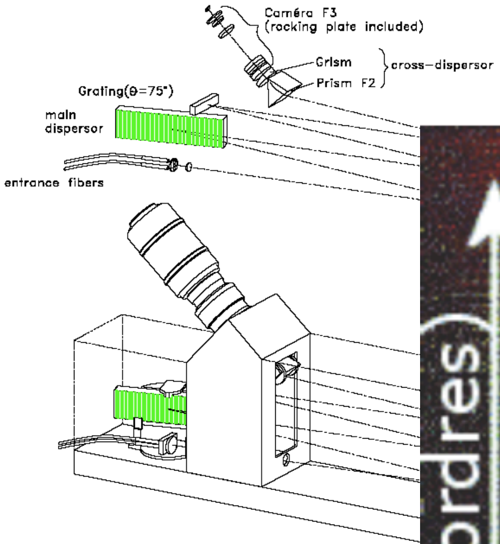


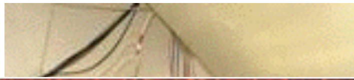
Spectrographe à dispersion

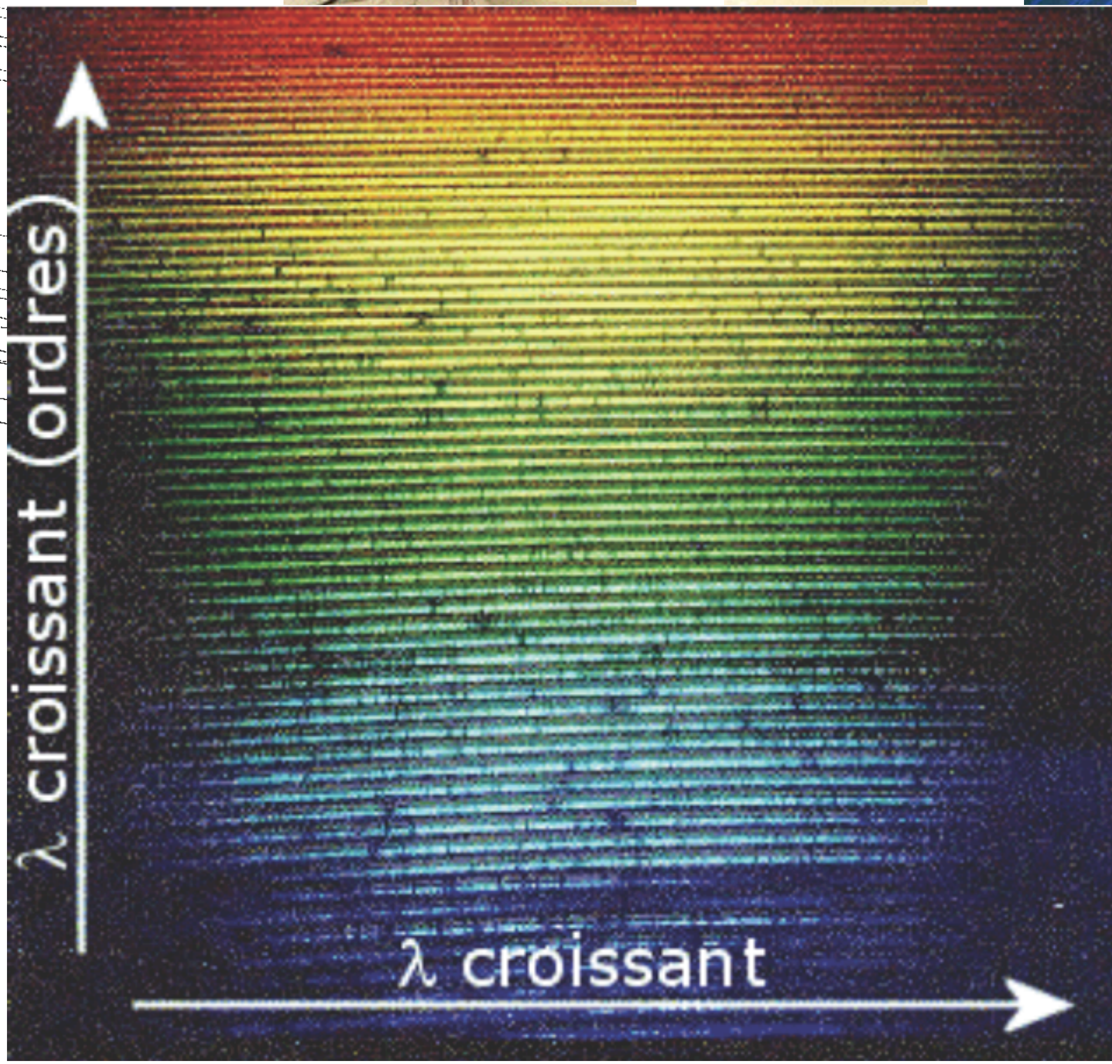


Précision et stabilité instrumentales

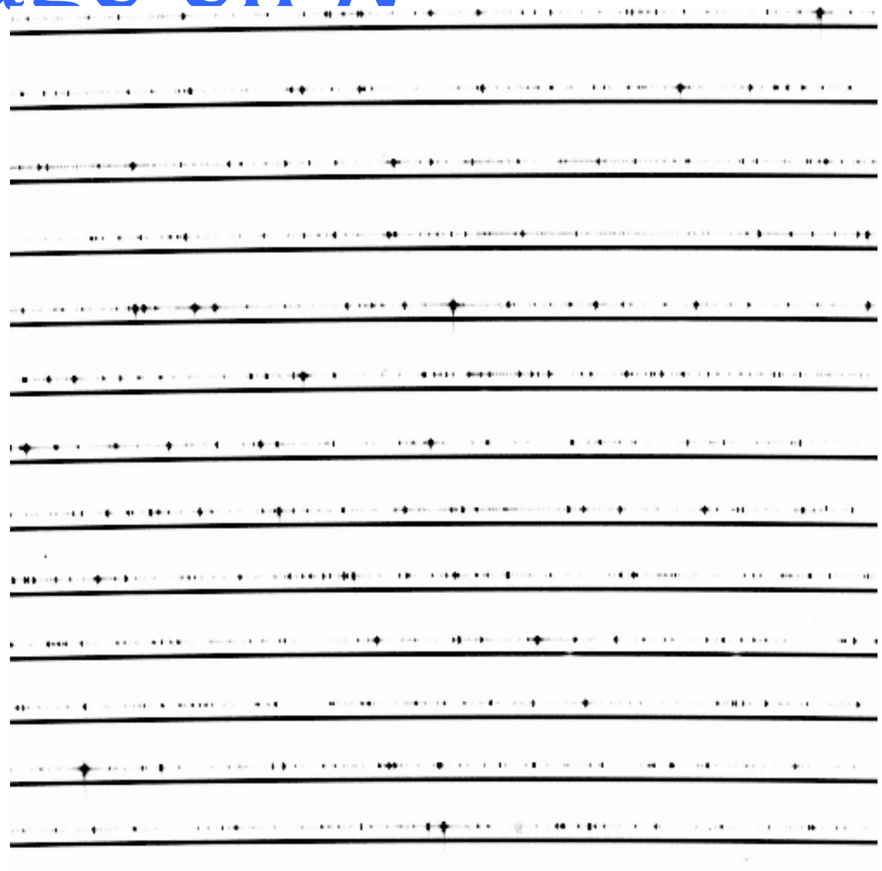
- Spectrographe haute résolution



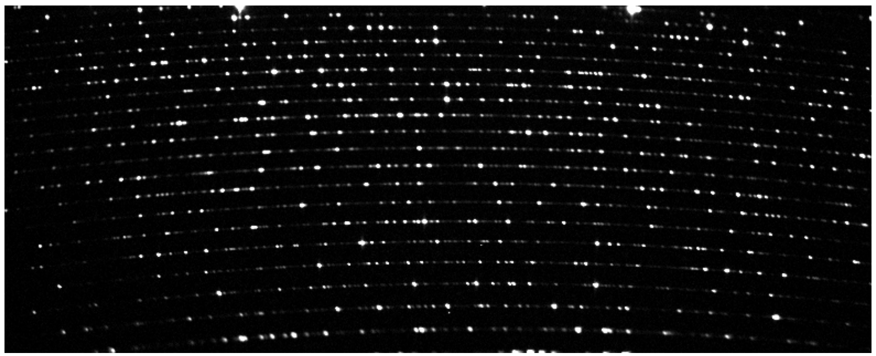




Etalonnage en λ

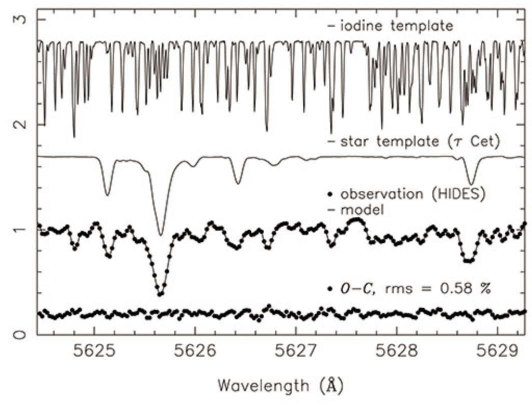


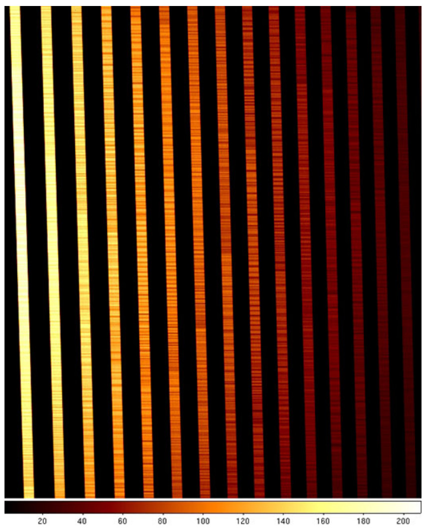
- La dispersion n'est jamais linéaire en λ
- Il faut étalonner le spectre, i.e. établir une correspondance entre la position des raies sur le spectre et la longueur d'onde dans la direction de la dispersion
- Plusieurs méthodes
  - Utilisation d'une lampe spectrale : les 2 spectres (lampe et

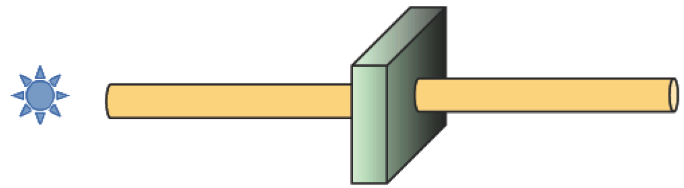


Etalonnage en λ

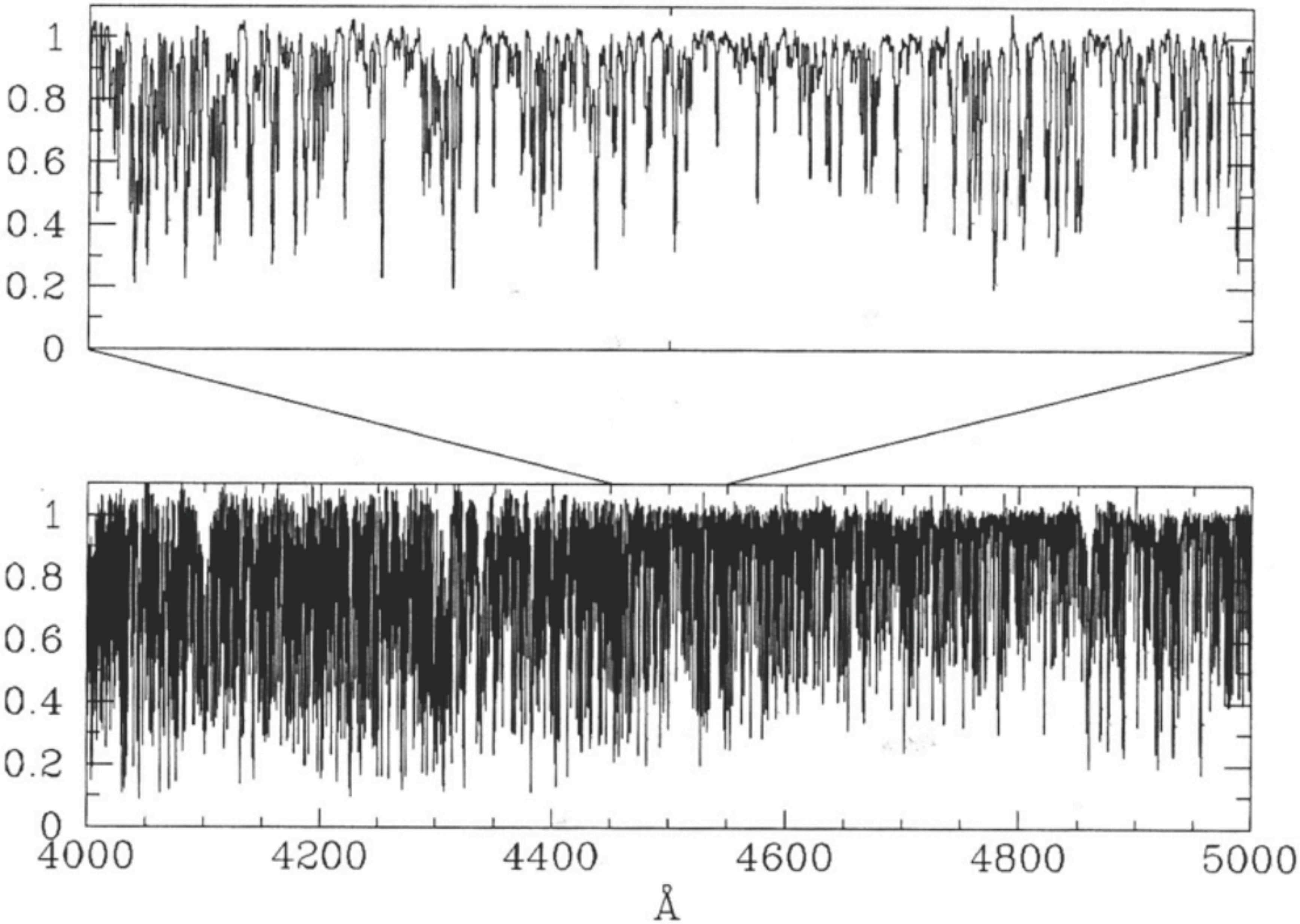
- Absorption par un gaz de référence
  - Cuve à gaz (P,T) : la lumière traverse une cuve remplie d'un gaz de référence : raies en absorption
  - Ex: iode
  - Avantage : fiabilité : agit directement sur le faisceau de la source
  - Inconvénient : absorbe une partie du flux de la source







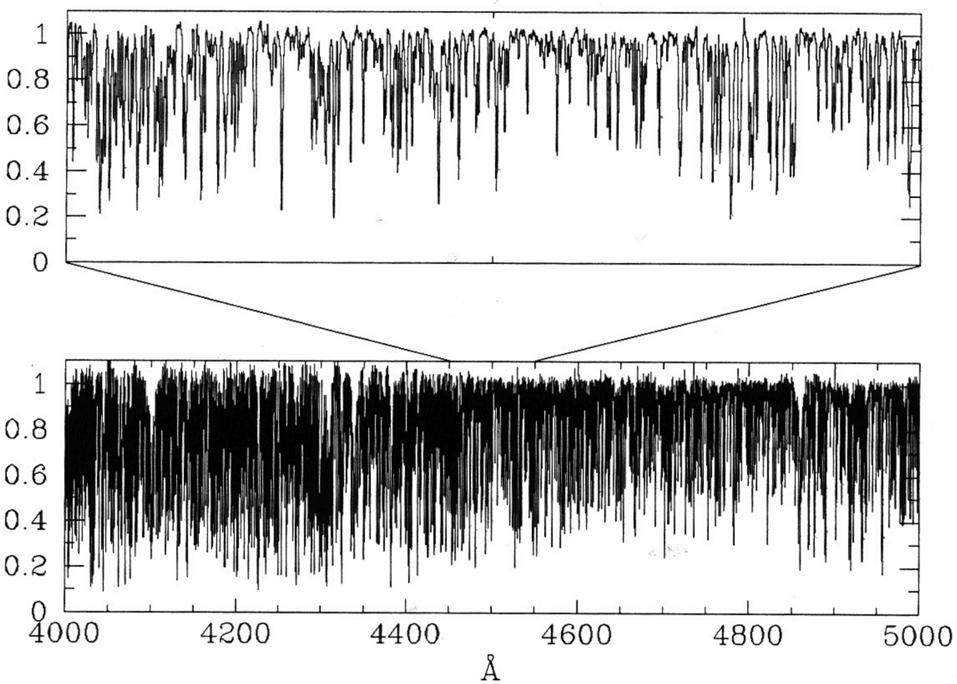
Spectre haute résolution

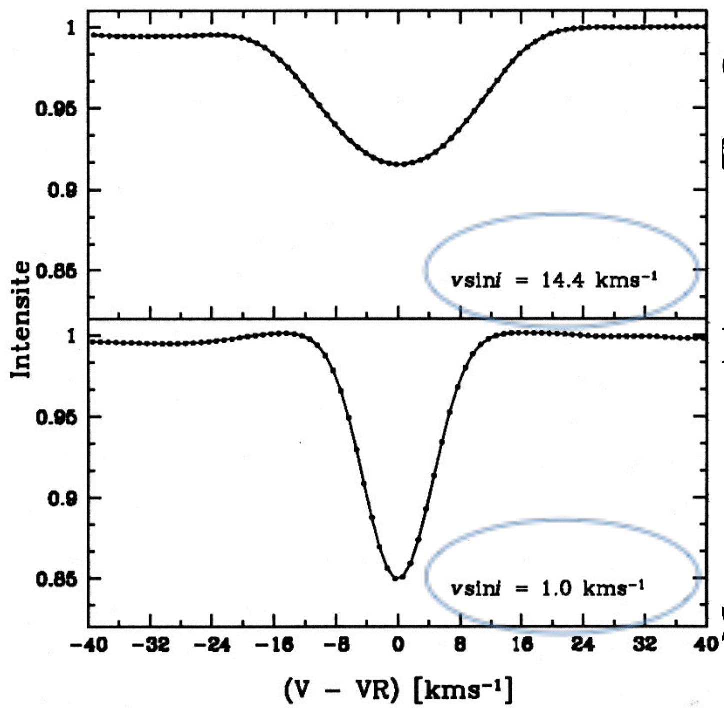


Analyse d’un spectre

- Décalage Doppler
  - On utilise une grandeur qui intègre la contribution d’un maximum de raies : la fonction de corrélation croisée (cross-correlation function, CCF)

$$f(\Delta\lambda) = \frac{\int F(\lambda)\, R(\lambda+\Delta\lambda)\, d\lambda}{\sqrt{\int F(\lambda)^2\, d\lambda \int R(\lambda)^2\, d\lambda}}$$



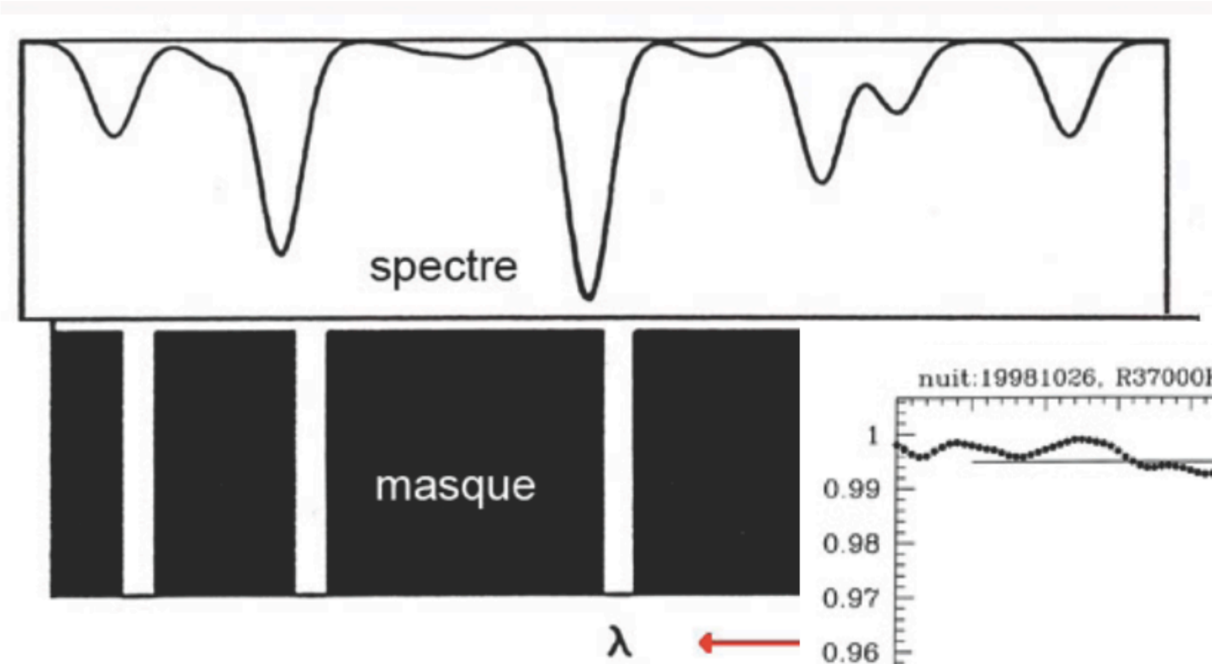


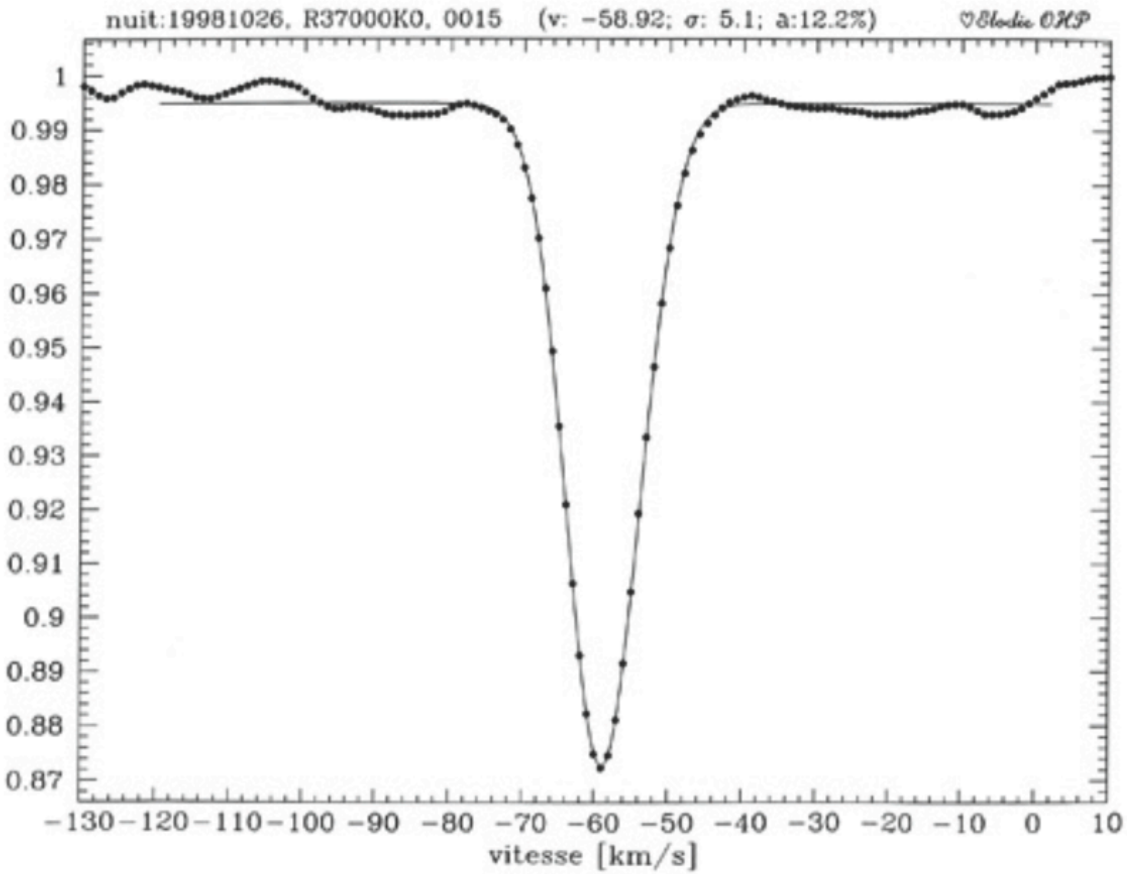
et un
e étoile
ntre
e
ons
(rotation, activité…)

La vitesse de rotation élargit la fonction de corrélation

Mesure de la vitesse radiale

- Corrélation avec la référence : masque binaire



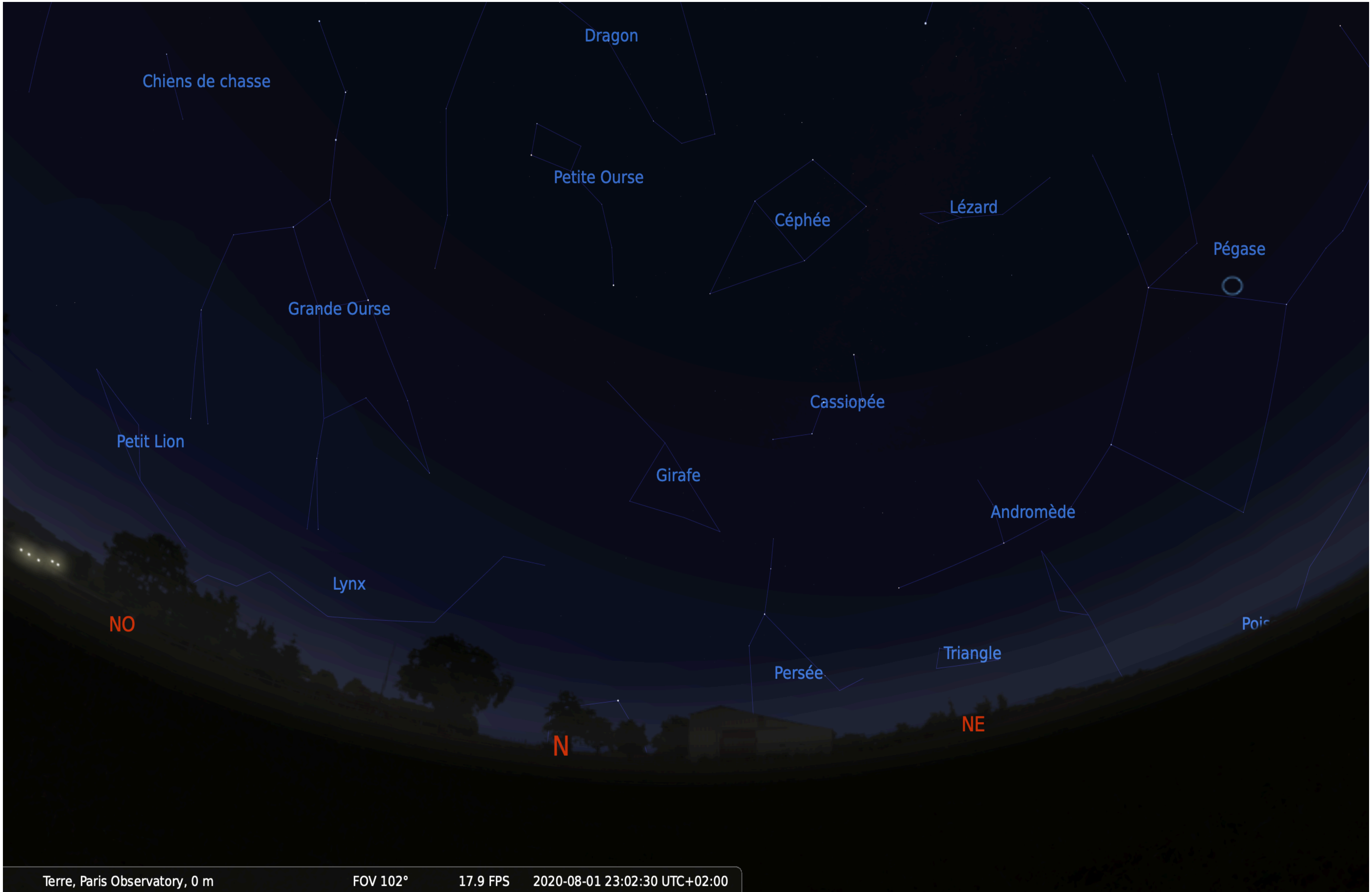


maximum de corrélation =>
vitesse radiale

Mesure de la vitesse radiale

- Correction des biais :
  - Rotation de la Terre (période 23h 56 min 4 sec)
  - Révolution de la Terre (période 365,25 jours)
  - Mouvement propre du Soleil dans le système Solaire
  - Mouvement du Système Solaire dans la Galaxie
  - Mouvement de l'étoile cible dans la Galaxie

51 Pegase


Dragon
Chiens de chasse
Petite Ourse
Céphée
Lézard
Pégase
Grande Ourse
Cassiopée
Petit Lion
Girafe
Andromède
Lynx
NO
Pois
Triangle
Persée
NE
N
Terre, Paris Observatory, 0 m
FOV 102°
17.9 FPS
2020-08-01 23:02:30 UTC+02:00

IAS
Institut d'Astrophysique Spatiale
Orsay

Première exoplanète autour d’une étoile comme le soleil

ARTICLES

A Jupiter-mass companion to a solar-type star

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The presence of a Jupiter-mass companion to the star 51 Pegasi is inferred from observations of periodic variations in the star’s radial velocity. The companion lies only about eight million kilometres from the star, which would be well inside the orbit of Mercury in our Solar System. This object might be a gas-giant planet that has migrated to this location through orbital evolution, or from the radiative stripping of a brown dwarf.

Nature 378, 355

Première exoplanète autour d'une étoile comme le soleil

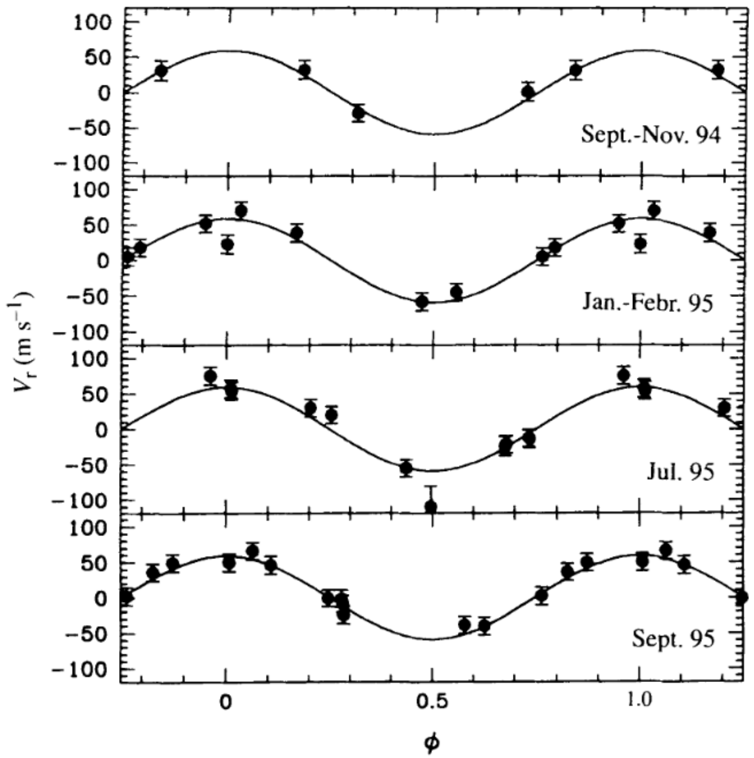


FIG. 2 Orbital motion of 51 Peg at four different epochs corrected from the γ-velocity. The solid line represents the orbital motion fitted on each time span with only the γ-velocity as a free parameter and with the other fixed parameters taken from Table 1.

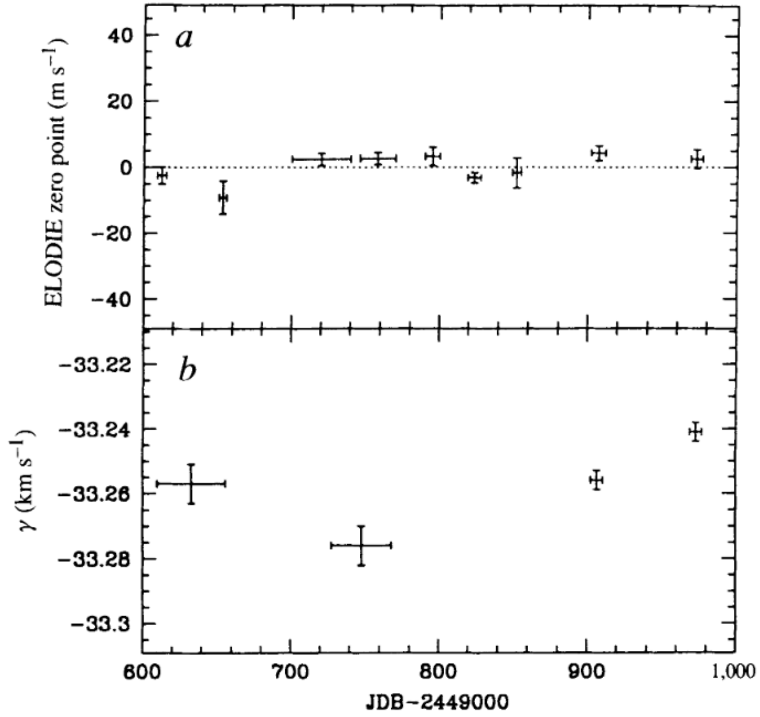


FIG. 3 *a*, ELODIE zero point computed from 87 stars of the sample having more than two measurements and showing no velocity variation. No instrumental zero point drift is detected. *b*, Variation of the γ-velocity of 51 Peg computed from the orbital fits displayed in Fig. 2. Considering the long-term stability of ELODIE this perturbation is probably due to a low-mass companion.

Mayor et Queloz, Nature 378, 355

Première exoplanète autour d'une étoile
nme le soleil

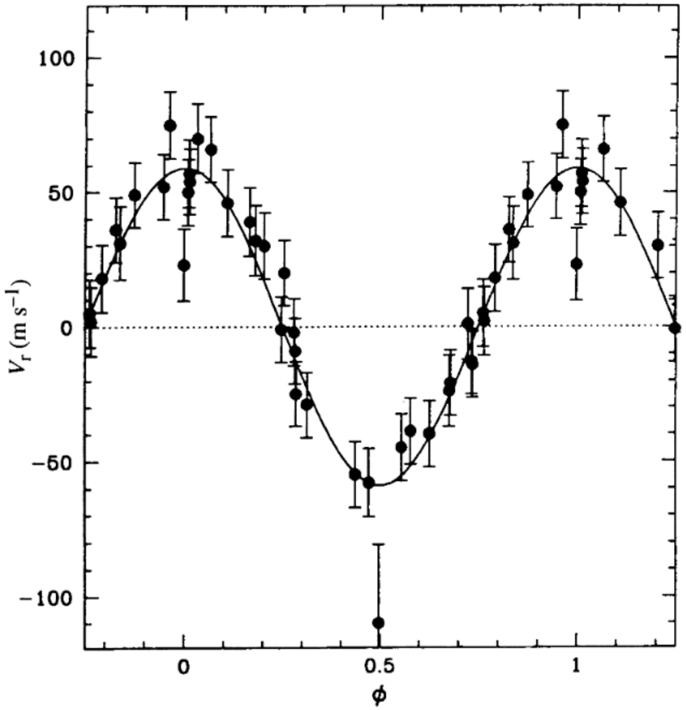


FIG. 4 Orbital motion of 51 Peg corrected from the long-term variation of the γ-velocity. The solid line represents the orbital motion computed from the parameters of Table 1.

Nature 378, 355

Etoile
Type = G2V
mV = 5,49
D = 50,9 a.l.
V Prop : 33,25 km/s
δRV = 50,2 m/s

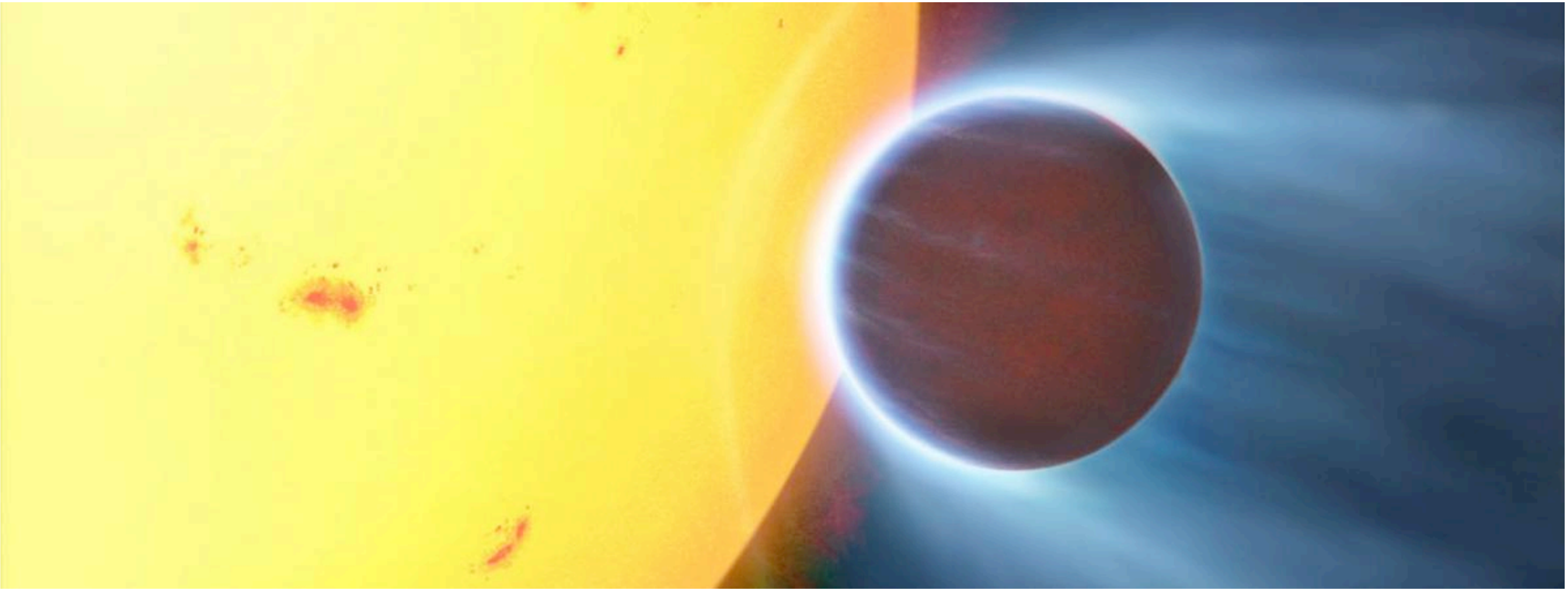
Planète
Période = 4,230785 +/- 0,000036 j
a = 0,0527. +/- 0,003 u.a
e = 0,013 +/- 0,012

Et les suivantes

- Toutes annoncées par Marcy / Butler
  - 70 Vir b (96)
  - 16 Cyg b (96)
  - 47 Uma b (96)
  - 55 Cnc b (96)
  - Ups And b (96)
  - Tau Boo A b (96)
  - ….

(Marcy et Butler découvrent 70 des 100 premières exoplanètes détectées)

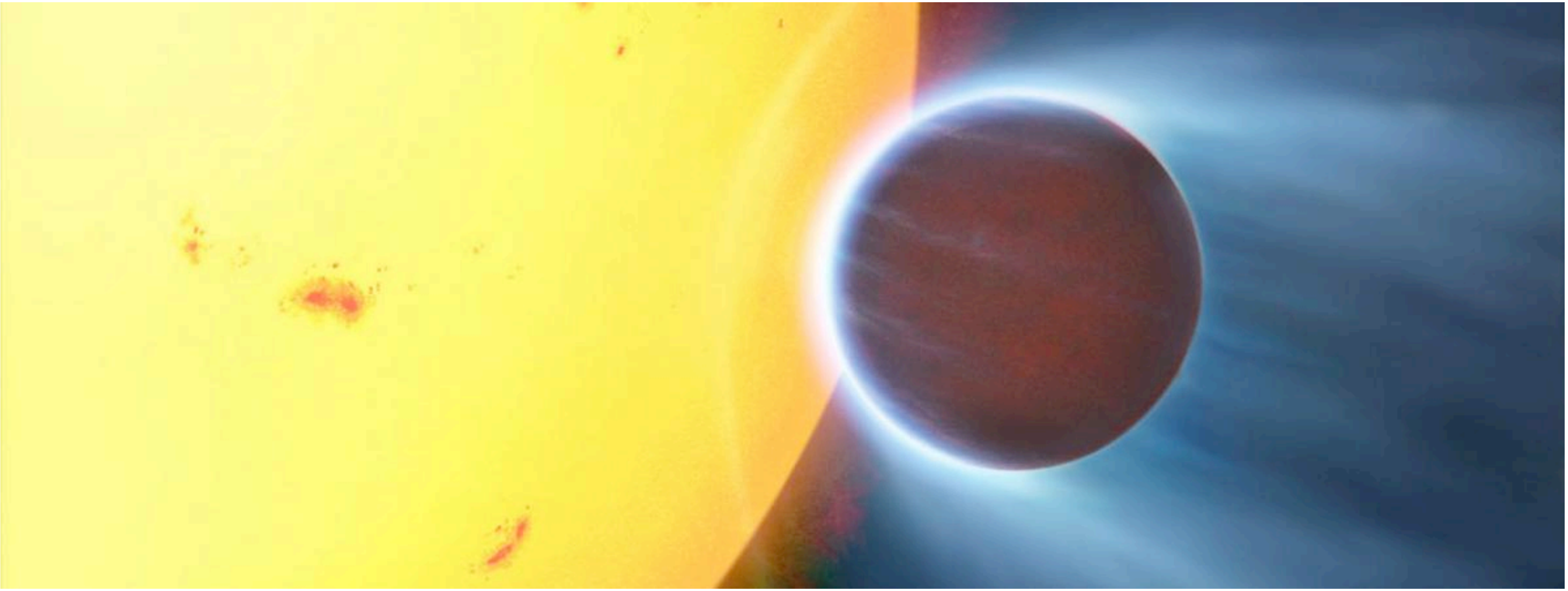
51 Pegase B : quelques problèmes



1) Condensation des matériaux réfractaires à T< 1500K
Or à r = 0.05 u.a., Tdisque ~ 2000 K
En général on considère pour les planètes géantes et une étoile = soleil:
limite de formation ~ 5 u.a. = condensation de la glace

2) Avec les modèles actuels de disques : densité trop faible pour faire un noyau solide à r < 0.5 a.u.

51 Pegase B : quelques problèmes



3) Densité de gaz trop faible pour faire une planète géante à r < 0.5 u.a.

4) Les modèles d 'évolution planétaire prédisent un diamètre 10 fois plus grand pour la planètes lors de sa formation par rapport à son stade final

- ➔ Vitesse d 'échappement réduite
- ➔ Evaporation de la planète avant son stade final

Un problème de spectroscopie

ROTATION OF ARCTURUS AND ACTIVE LONGITUDES 1113

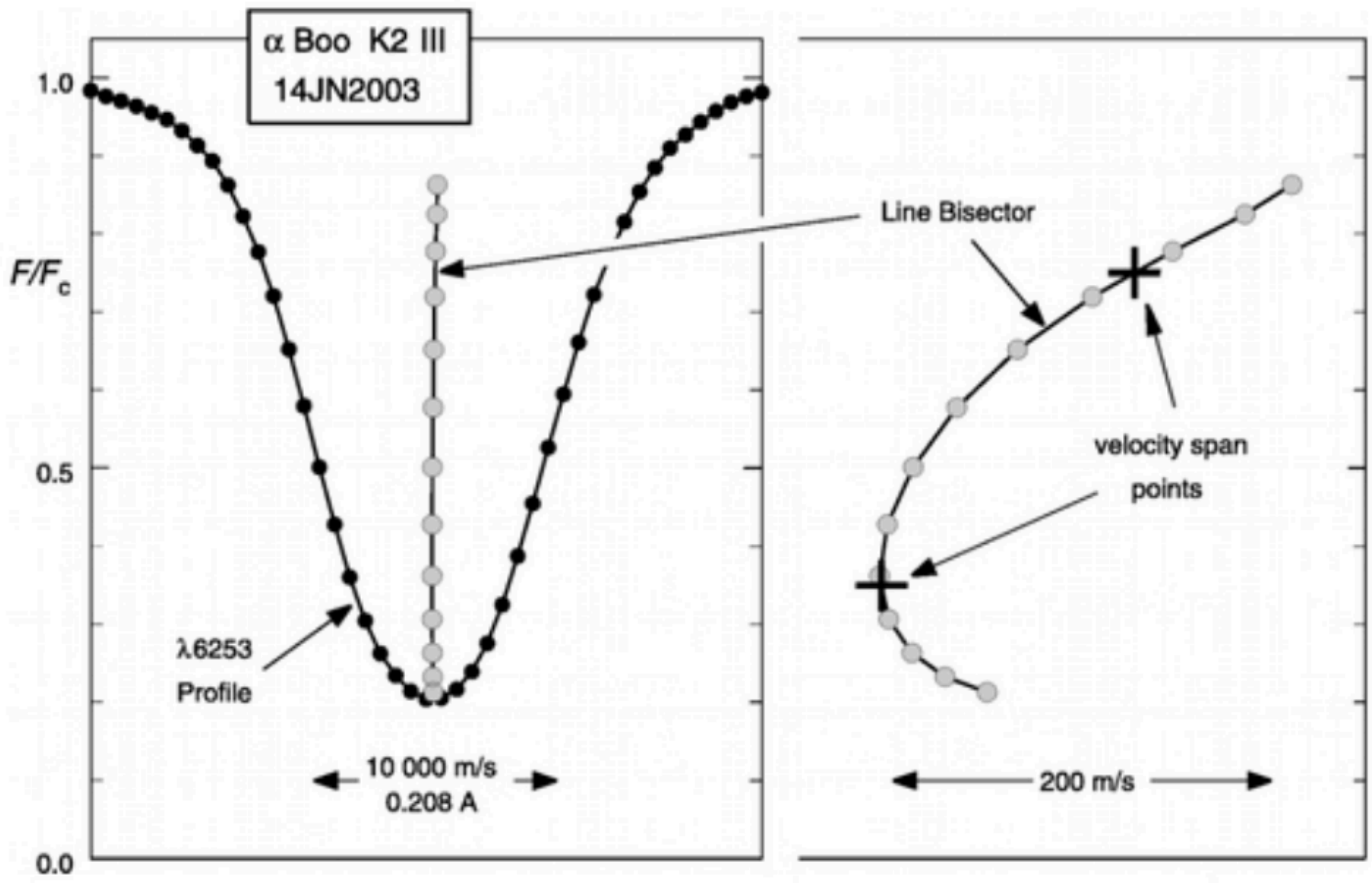


FIG. 1.—*Left*: Line profile of Fe I λ6253 (*black circles*) for one CCD exposure. The gray circles through the middle show points on the line bisector plotted on the same wavelength scale as the profile. It is difficult to see that this is not a straight vertical line. *Right*: Expanded wavelength scale showing the shape of this same bisector. The plus signs indicate the two points used to compute the velocity span.

Qui a un impact sur la planète…

Absence of a planetary signature in the spectra of the star 51 Pegasi

Hide affiliations

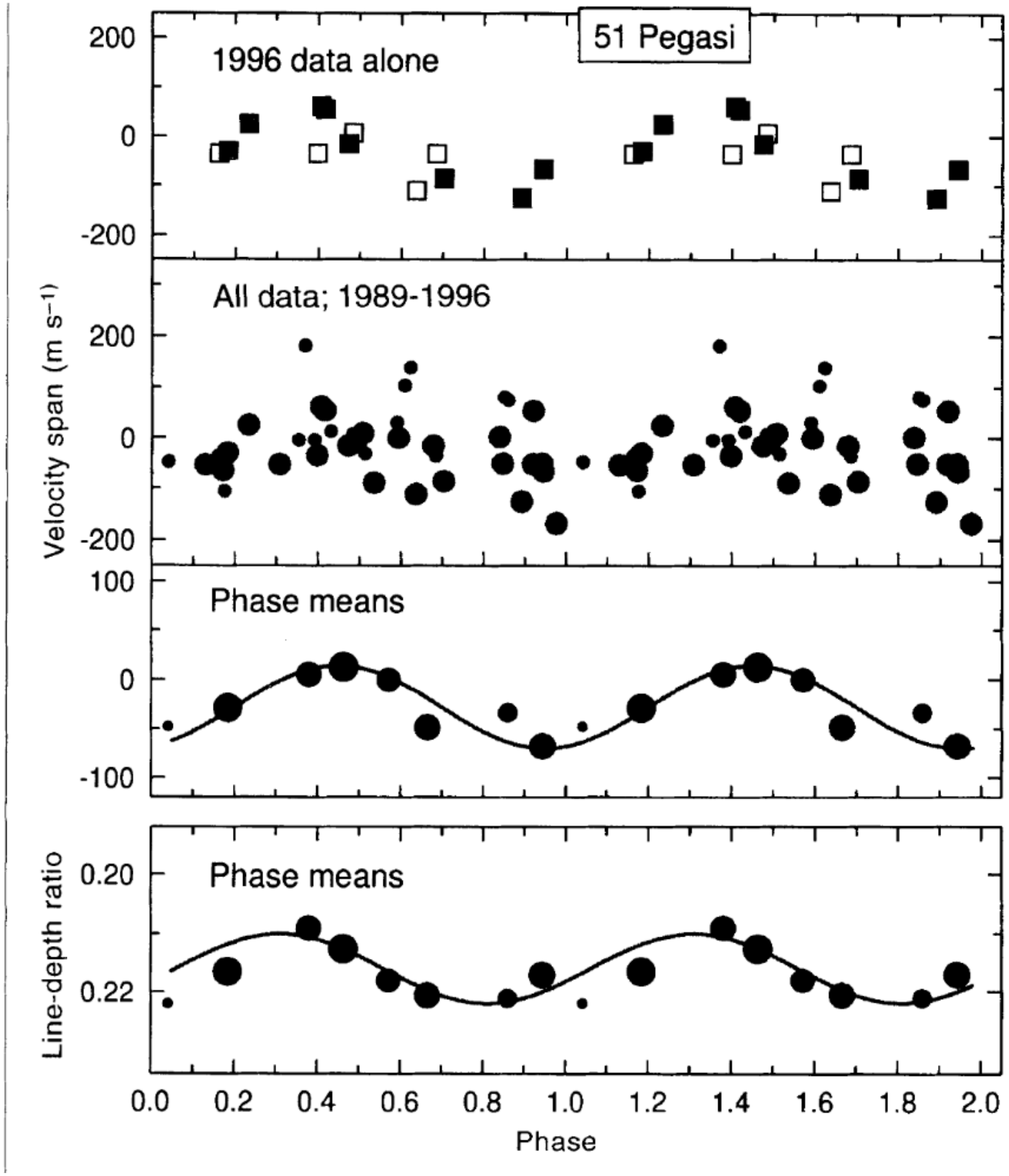
Gray, David F. (*Department of Physics and Astronomy, University of Western Ontario, London, Ontario N6A 3K7, Canada*)

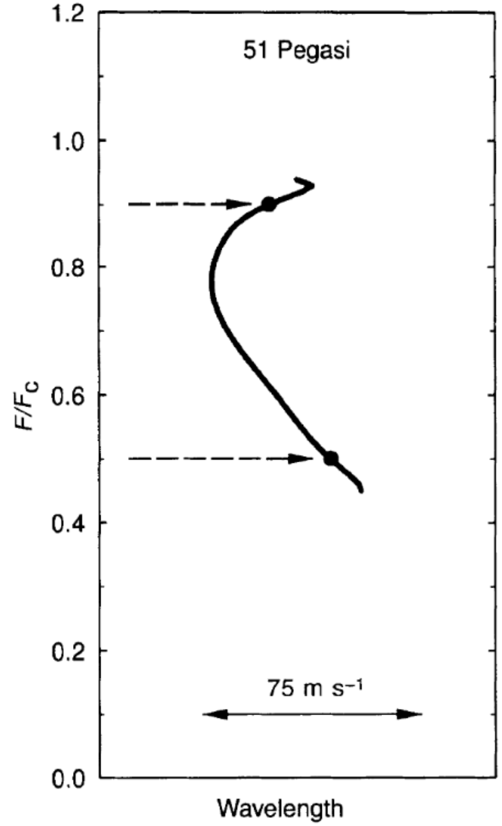
51 Pegasi, one of many nearby Sun-like stars, was undistinguished until the recent detections of apparent variations in its radial velocity, which have been attributed to reflex motion caused by a planetary companion[1,2]. The velocity variation inferred from variations in the spectral lines of 51 Peg has an amplitude of 56-59 m s^{-1} and a period of 4.23 days, implying a planet of at least half the mass of Jupiter moving in an embarrassingly small orbit of 0.05 astronomical units. But the techniques currently used to identify these exceedingly small radial velocity variations do not allow for the possibility that changes of comparable size might be occurring in the intrinsic shapes of the spectral lines; such variations are expected when a star pulsates or has spots on its surface, and could be mistaken for radial velocity variations. Here I present high-spectral-resolution observations of 51 Peg that show that its spectral lines exhibit intrinsic shape variations with a period of 4.23 days, and an amplitude comparable to that previously attributed[1,2] to radial velocity variations. As the presence of a planet will not influence the shapes of spectral lines, these variations are likely to reflect a hitherto unknown mode of stellar oscillation. The presence of a planet is not required to explain the data.

Publication: Nature, Volume 385, Issue 6619, pp. 795-796 (1997).

Pub Date: February 1997

Qui a un impact sur la planète…





Gray, Nature, 385, 795

Pendant ce temps…

Planet	Mass (M_{Jup})	Radius (R_{Jup})	Period (day)	*a* (AU)	*e*	*i* (deg)	Ang. dist. (arcsec)	Discovery	Update
51 Peg b	0.47	1.9	4.2308	0.052	0.0069	80	0.003537	1995	2017-01-26
Teide 1	54	—	—	—	—	—	—	1995	2018-09-03
GJ 229 B	35	—	52890	19.433	0.03	—	—	1995	2020-01-09
70 Vir b	—	—	116.67	0.48	0.43	—	0.021818	1996	2010-12-28
16 Cyg B b	—	—	799.5	1.68	0.689	—	0.078468	1996	2014-08-27
47 Uma b	—	—	1078	2.1	0.032	—	0.150322	1996	2014-08-27
PSR J2051-0827 b	28.3	—	0.099110266	—	0	—	—	1996	2015-10-26
55 Cnc b	0.84	—	14.65314	0.11339	0.0023	89.73	0.009303	1996	2017-06-11
ups And b	0.62	—	4.61711	0.059	0.01186	90	0.00438	1996	2019-08-16
tau Boo A b	5.84	1.06	3.31249	0.046	0.0787	45	0.002949	1996	2019-12-13
HD 210277 b	—	—	442.1	1.1	0.472	—	0.051667	1998	2006-09-05
HD 195019 b	—	—	18.20163	0.1388	0.014	—	0.003715	1998	2006-11-24
HD 187123 c	—	—	3810	4.89	0.252	—	0.0978	1998	2013-05-20
HD 187123 b	—	—	3.0965828	0.0426	0.01	—	0.000852	1998	2013-05-20
HD 168443 b	—	—	58.11247	0.2931	0.52883	—	0.007841	1998	2016-01-10
HD 217107 c	—	—	4210	5.27	0.517	—	0.267241	1998	2017-03-02
HD 217107 b	—	—	7.12689	0.073	0.132	—	0.003702	1998	2017-03-02
G 196-3 b	15	—	—	—	—	—	—	1998	2018-12-21

Retour aux observations

A planetary companion for 51 Pegasi implied by absence of pulsations in the stellar spectra

Hide affiliations

Gray, David F. (*Western Ontario, Univ.*)

Systematic variations in the Doppler shifts of absorption lines in the spectrum of the star 51 Pegasi were interpreted as indicating the presence of a planet about half the mass of Jupiter, very close to the star,. But that interpretation was called into question when variations in the line shapes that tracked the apparent orbital phase were reported,; this suggested that a planet was an inadequate explanation of the radial-velocity data. Here I report results from recent monitoring of 51 Peg; the oscillations I previously published are not evident in the new data. When combined with two other high-precision observations of 51 Peg (refs 5-7), that also see no changes in line shape, a planet may indeed be the best explanation for the radial-velocity results.

Publication: Nature, Volume 391, Issue 6663, pp. 153-154 (1998).

Pub Date: January 1998

Retour aux observations

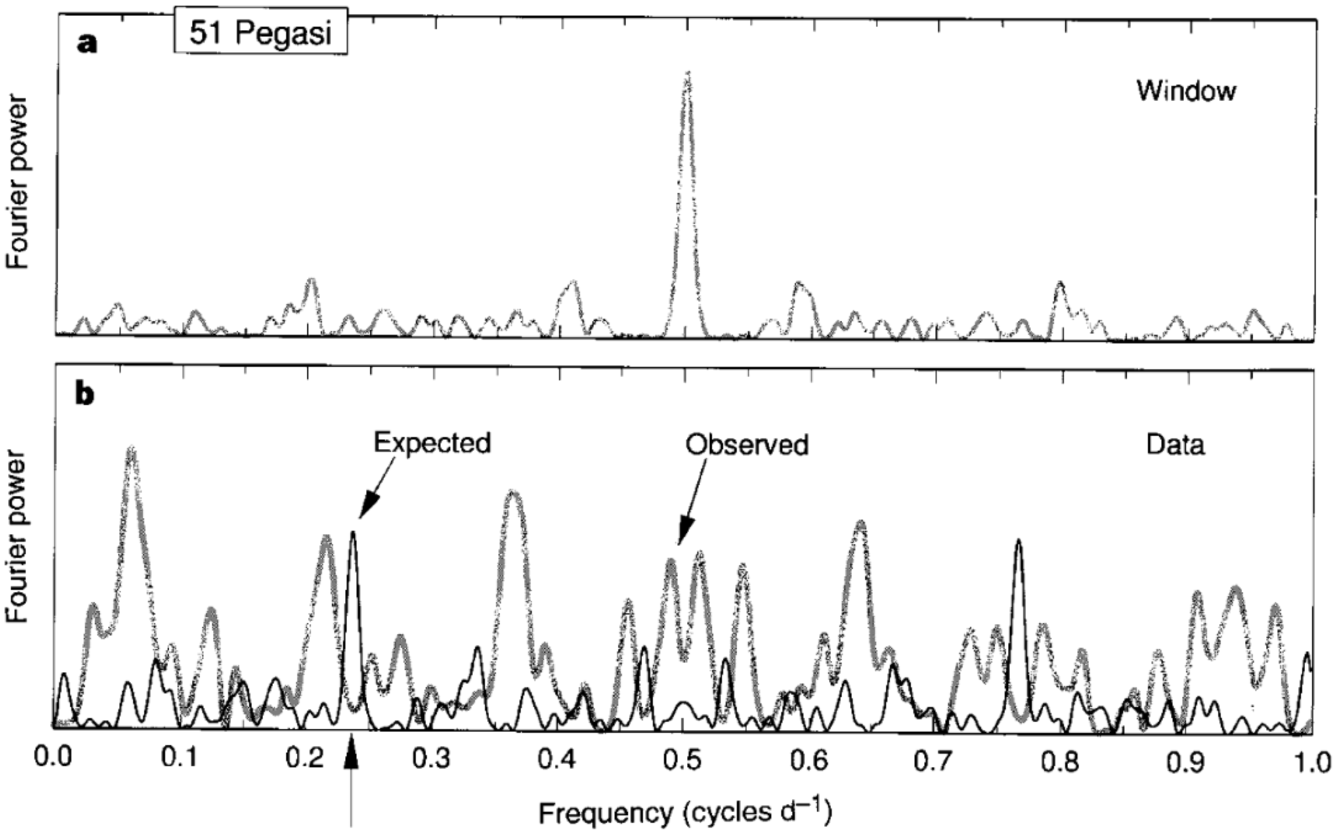


Figure 1 The periodogram of the bisector curvature for the frequency range 0.0–1.0 cycles d^{-1}. **a**, The window pattern for the times of the data spacing. **b**, The thick line labelled 'Observed' shows the periodogram of the data; the thin line labelled 'Expected' is for the expected oscillation with an amplitude of 45 m s^{-1}. No significant power occurs at the frequency of 0.2365 cycles d^{-1} (indicated by the vertical arrow below the horizontal axis), corresponding to the 4.23-d period seen in the earlier data.

Gray, Nature, 391, 153

Retour aux observations

Further evidence for the planet around 51 Pegasi

Show affiliations

Hatzes, Artie P.; Cochran, William D.; Bakker, Eric J.

The discovery of a planet around the solar-type star 51 Pegasi marked a watershed in the search for extrasolar planets. Since then, seven other planets have been discovered, of which several have surprisingly short orbital periods, like the planet around 51 Peg. These planets were detected using the indirect technique of measuring variations in the Doppler shifts of lines in the spectra of the primary stars. But it is possible that regular oscillations of the stars themselves (or other effects) could mimic the signature of the planets, particularly the short-period planets. The apparent lack of spectral and brightness variations, however, led to widespread acceptance that there is a planet around 51 Peg. This conclusion was challenged by the observation of systematic variations in the line shapes of 51 Peg, which suggest stellar oscillations. If these observations are correct, then there is no need to invoke a planet around 51 Peg to explain the data. Here we report observations of 51 Peg at a much higher spectral resolution than those in ref. 9, in which we find no evidence for systematic changes in the line shapes. The data are most consistent with a planetary companion to 51 Peg.

Publication: Nature, Volume 391, Issue 6663, pp. 154-156 (1998).

Pub Date: January 1998

Retour aux observations

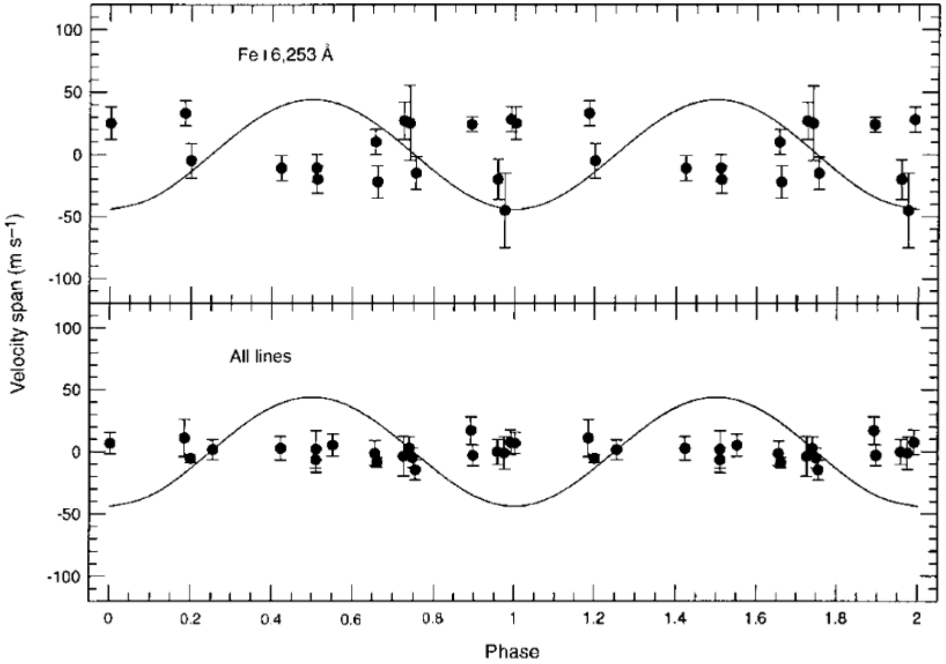


Figure 1 Velocity span measurements of 51 Peg. Top panel, the velocity span of 6,252.57-Å Fe I as a function of phase (data points) according to the ephemeris of Marcy *et al.*[12]. The solid line represents the variations reported by Gray[9]. Bottom panel, the average velocity span (data points) for the spectral lines: 5,296.70-Å Cr I, 5,638.27-Å Fe I, 6141.74-Å Fe I and 6,252.57 Fe I. Again, the solid line represents the predicted curve from Gray[9].

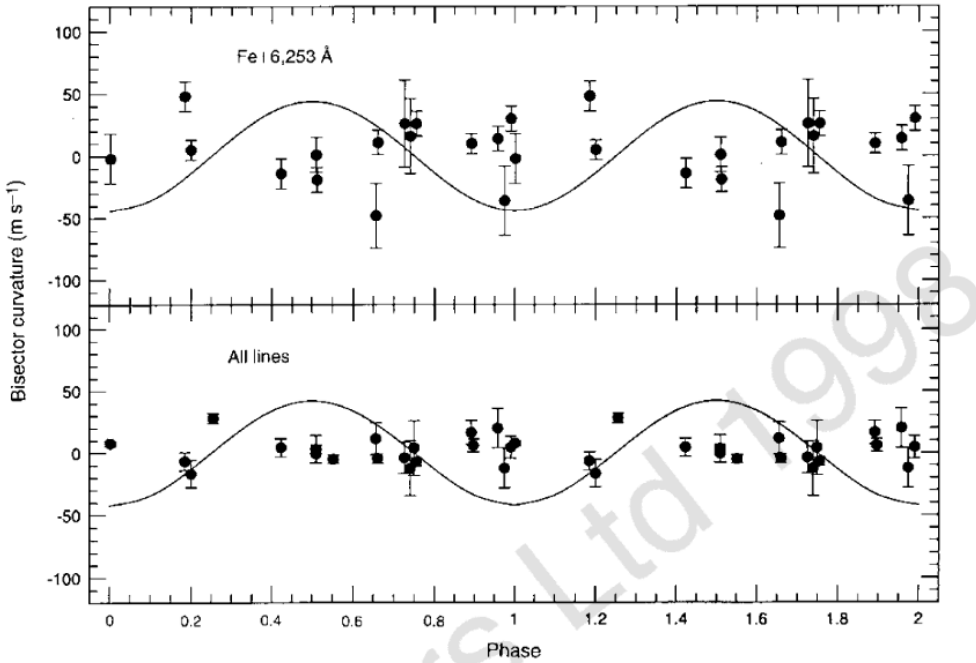


Figure 2 Bisector curve measurements of 51 Peg. Top panel, the bisector curvature of 6,252.57-Å Fe I (data points) as a function of phase. The solid line represents the variations reported by Gray and Hatzes[10]. Bottom panel, the average bisector curvature for five spectral lines (data points) along with the predicted curve of Gray and Hatzes[10].

Hatzes et al, Nature, 391, 154

Retour aux observations

THE ASTROPHYSICAL JOURNAL, 508:380–386, 1998 November 20

THE LACK OF SPECTRAL VARIABILITY IN 51 PEGASI: CONFIRMATION OF THE PLANET HYPOTHESIS

ARTIE P. HATZES, WILLIAM D. COCHRAN, AND ERIC J. BAKKER
McDonald Observatory, University of Texas at Austin, Austin, TX 78712
Received 1998 May 13; accepted 1998 June 25

ABSTRACT

We present-high resolution ($R > 200{,}000$), high signal-to-noise spectral data for 51 Pegasi spanning a complete orbital period of the purported planetary companion. A detailed examination of the line bisectors from eight spectral lines as well as the ratio of the line depth of the V I 6251 Å line to the Fe I 6253 Å line were performed. The changes in the mean bisector velocity span and curvature are about 1 m s^{-1} and 4 m s^{-1}, respectively. These variations are an order of magnitude less than the variations reported by Gray and are small enough to exclude all nonradial sectoral pulsation modes. The line-depth ratio of V I/Fe I also shows no significant variations, and a least-squares sine fit using the planet period of 4.23 days yields an amplitude of 0.00038 for any line-depth ratio variations. This corresponds to a disk-integrated temperature variation (peak-to-peak) of less than 1.7 K. We conclude that the radial velocity variations are not due to a dynamical stellar atmosphere and that a planetary companion remains as the only viable explanation for the observed radial velocity variations. The lack of bisector variability in our data indicates that the contribution to the observed spectra due to reflected light from the planet is at least 2000 times less than that of the primary light. Assuming a planetary albedo of unity, this places an upper limit of 0.2 $R_\odot$ for the radius of the planet.

Subject headings: line: profiles — planetary systems — stars: individual (51 Pegasi) — stars: oscillations

Retour aux observations

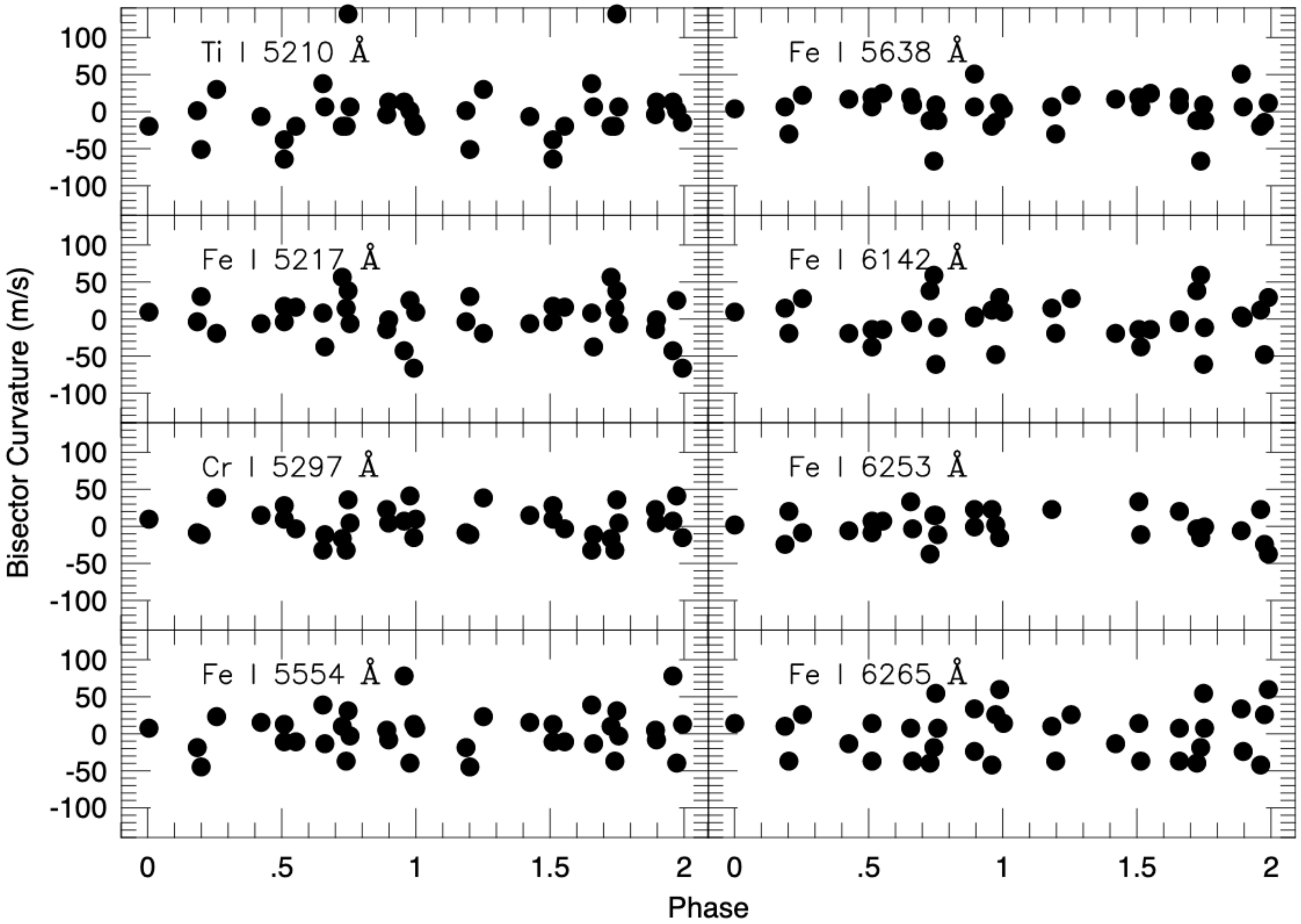


FIG. 3.—Bisector curvature as a function of orbital phase for the eight spectral lines

Hatzes et al. 1998

Retour aux observations

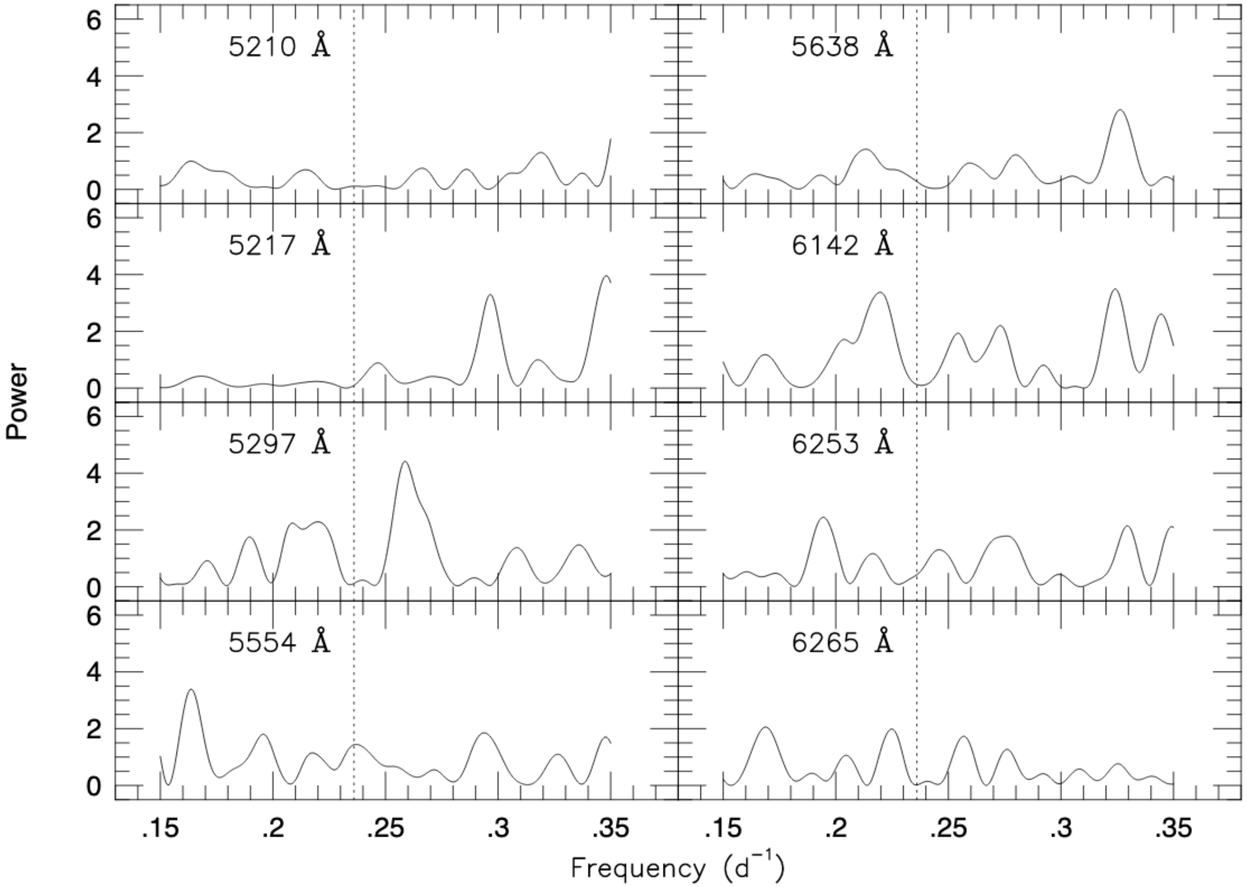
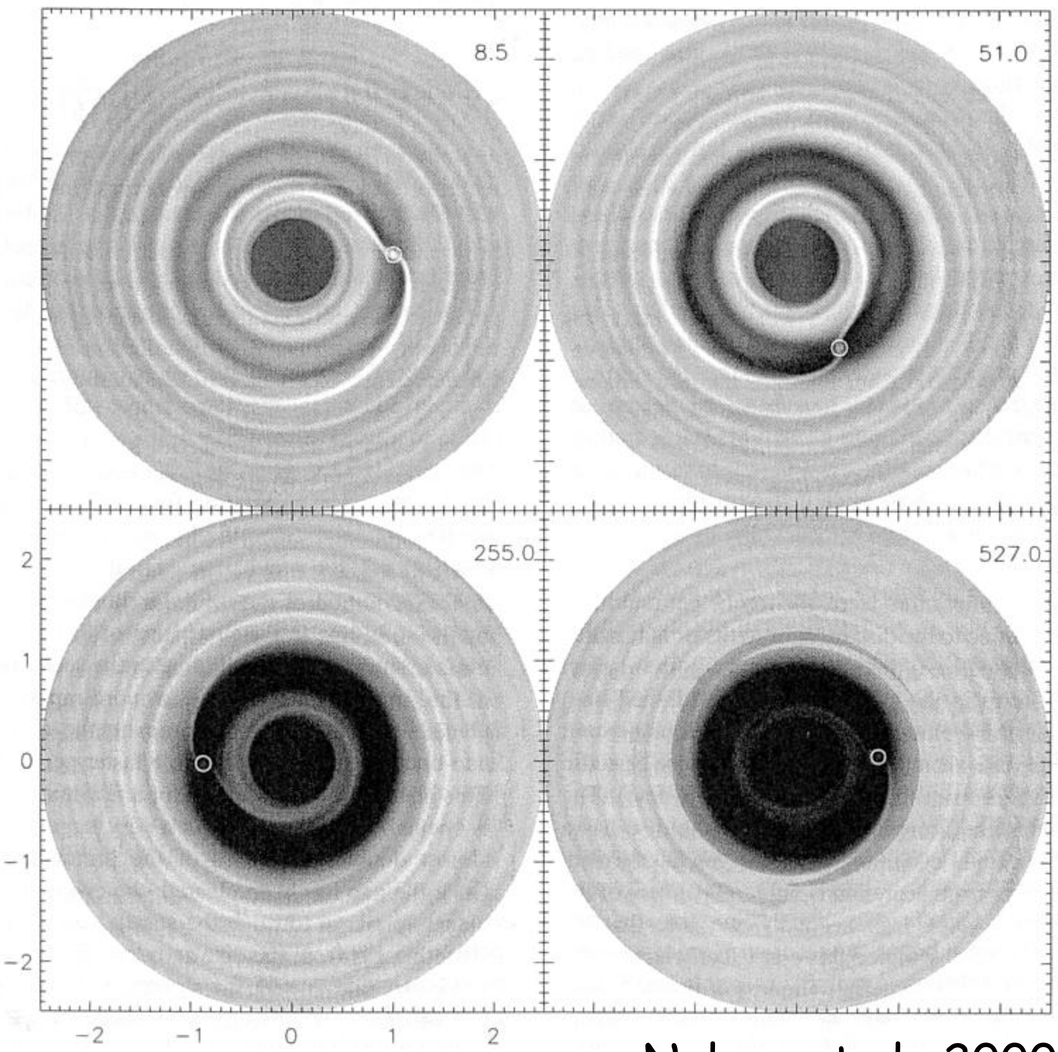


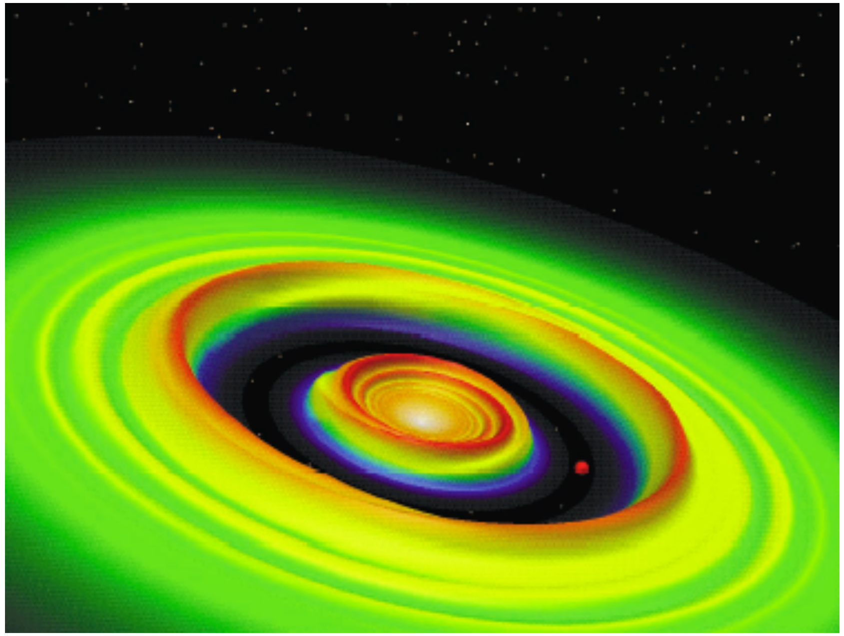
FIG. 4.—Scargle-type periodograms for the bisector span measurements from the individual spectral lines. The horizontal line indicates the orbital frequency of the planet.

Mécanismes de migrations d ’orbites

Transfert de moment angulaire entre une planète et un disque (4)



Nelson et al., 2000

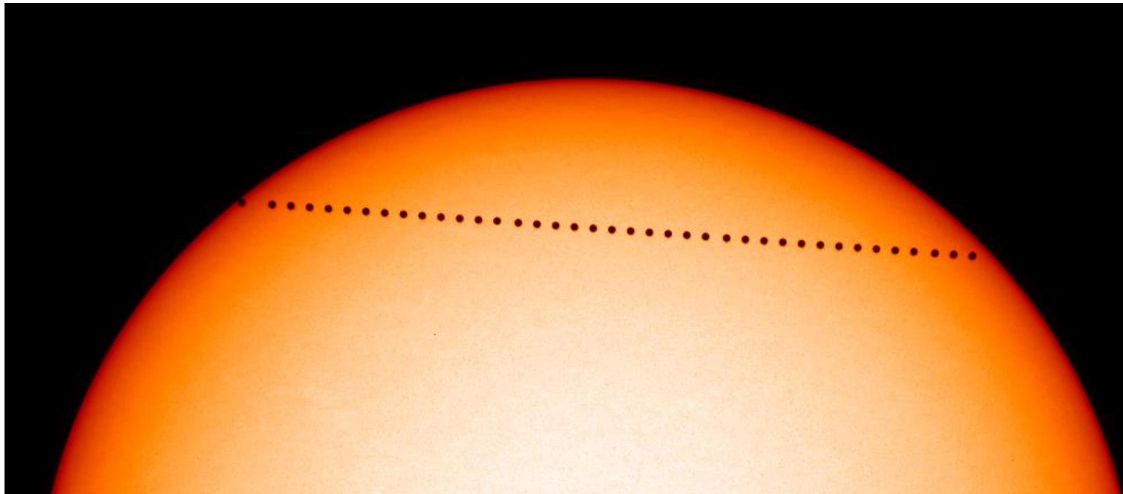


Bryden et Lin

Observation des transits

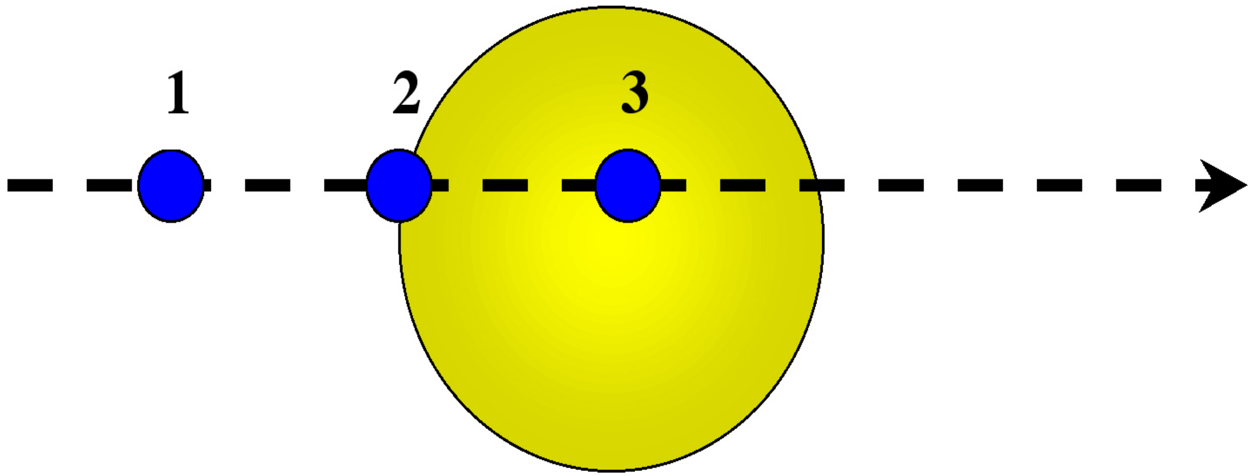
- Concerne uniquement les systèmes planétaires observés par la tranche, pour lesquels les planètes peuvent occulter partiellement leur étoile centrale.

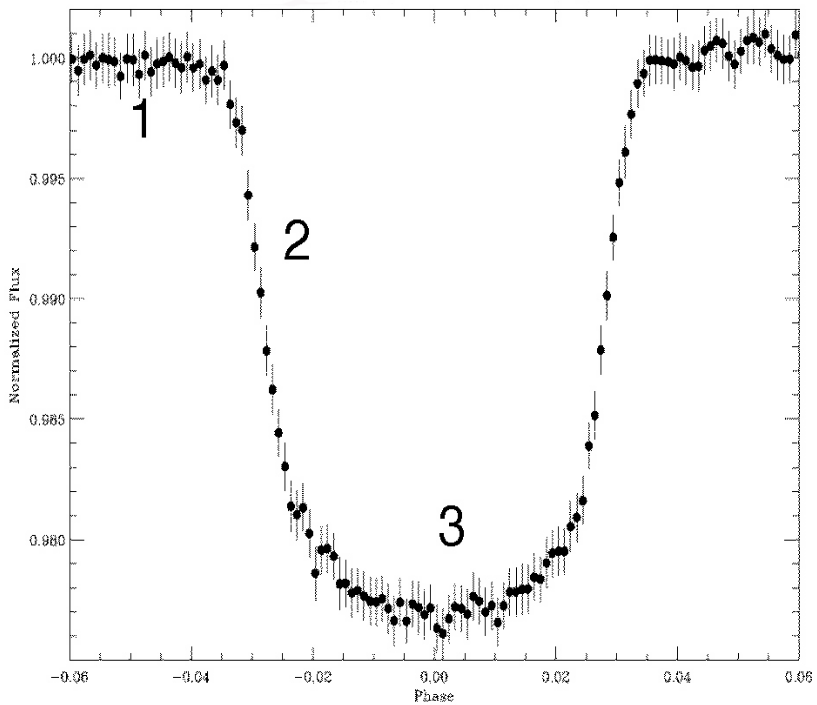
Venus : 8 juin 2004



Mercure : 7 mai 2003
vue par SOHO

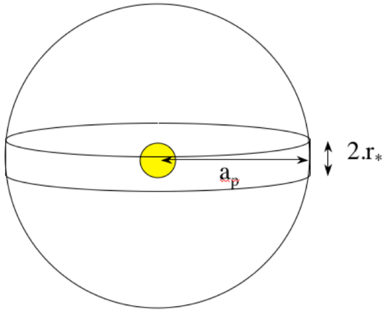
Effet photométrique : transit





Effet photométrique : transit

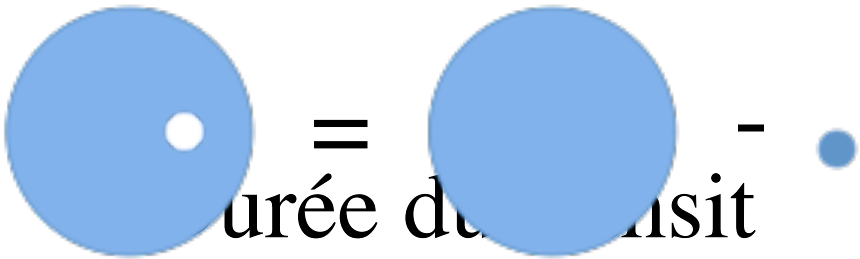
- Probabilité de transit :



$$P = \frac{2\pi a_p . 2 r_*}{4\pi a_p^2} = \frac{r_*}{a_p} = \frac{r_*}{P^{2/3}}\left(\frac{4\pi^2}{G m_*}\right)^{1/3}$$

Objet	P
Jupiter chaud	0.1
Terre	0.005
Jupiter	0.001

- Profondeur du transit :



$$\frac{\Delta F}{F} \approx \left(\frac{r_p}{r_*}\right)^2$$

Objet	ΔF/F
Jupiter	10-2
Terre	10-4

- Durée du transit

$$\tau = \frac{(2\pi)^{2/3} 2 r_* \sqrt{1-b^2}}{(G m_*)^{1/3}} P^{1/3}$$

Objet	T (b=0)
Jupiter chaud	≈ 3 heures
Terre	≈ 14 heures
Jupiter	≈ 30 heures

Premières observations des transits (HD209458)

THE ASTROPHYSICAL JOURNAL, 529:L45–L48, 2000 January 20

DETECTION OF PLANETARY TRANSITS ACROSS A SUN-LIKE STAR

DAVID CHARBONNEAU,[1,2] TIMOTHY M. BROWN,[2] DAVID W. LATHAM,[1] AND MICHEL MAYOR[3]
Received 1999 November 19; accepted 1999 November 23; published 1999 December 16

ABSTRACT

We report high-precision, high-cadence photometric measurements of the star HD 209458, which is known from radial velocity measurements to have a planetary-mass companion in a close orbit. We detect two separate transit events at times that are consistent with the radial velocity measurements. In both cases, the detailed shape of the transit curve due to both the limb darkening of the star and the finite size of the planet is clearly evident. Assuming stellar parameters of 1.1 $R_\odot$ and 1.1 $M_\odot$, we find that the data are best interpreted as a gas giant with a radius of 1.27 ± 0.02 $R_{\rm Jup}$ in an orbit with an inclination of 87°.1 ± 0°.2. We present values for the planetary surface gravity, escape velocity, and average density and discuss the numerous observations that are warranted now that a planet is known to transit the disk of its parent star.

Subject headings: binaries: eclipsing — planetary systems — stars: individual (HD 209458) — techniques: photometric — techniques: radial velocities

HD 209458 b : 8ème Jupiter chaud, détecté en 1999

Premières observations des transits (HD209458)

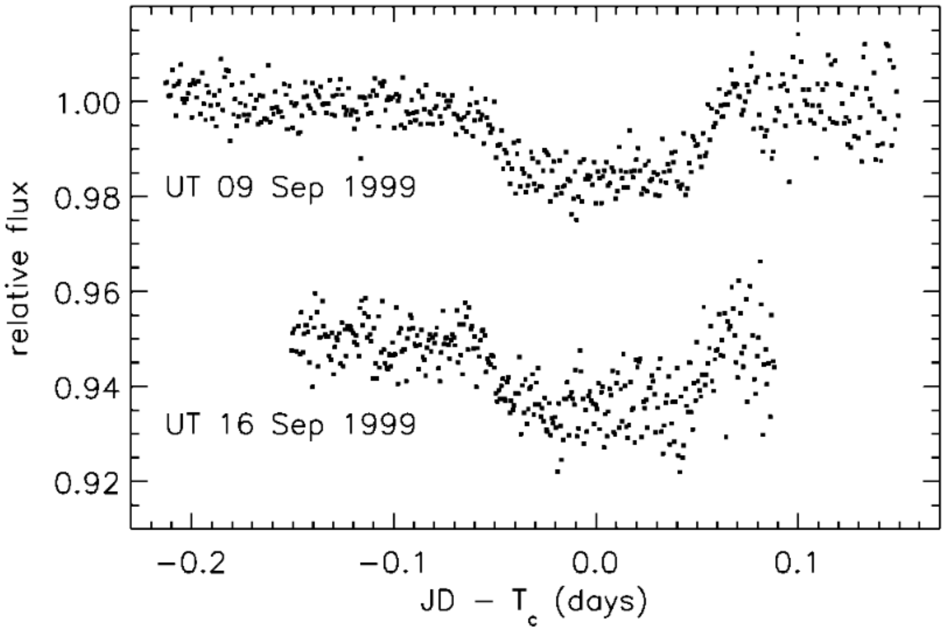


FIG. 1.—Shown are the photometric time series, corrected for gray and color-dependent extinction, for 1999 September 9 and 16 plotted as a function of time from T_c. The rms of the time series at the beginning of the night on September 9 is roughly 4 mmag. The increased scatter in the September 16 data relative to the September 9 data is due to the shorter exposure times. The data from September 16 are offset by −0.05 relative to those from September 9.

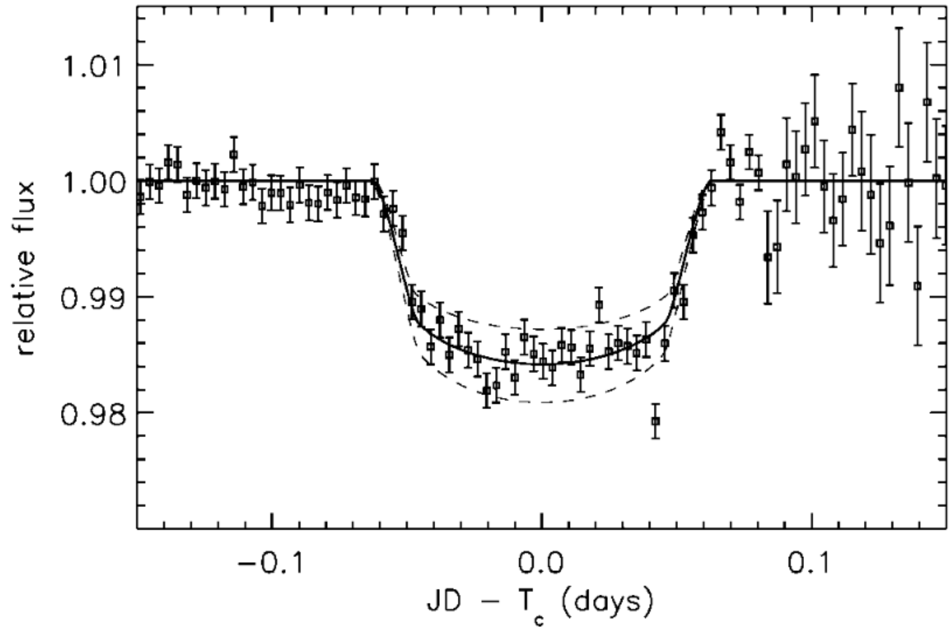


FIG. 2.—Shown are the data from Fig. 1 binned into 5 m averages, phased according to our best-fit orbit, plotted as a function of time from T_c. The rms variation at the beginning of the time series is roughly 1.5 mmag, and this precision is maintained throughout the duration of the transit. The increased scatter at the end of the time series is due to increasing air mass which occurred at roughly the same time for both transits, since the two occurred very nearly 1 week apart. The solid line is the transit shape that would occur for our best-fit model, $R_p = 1.27\ R_{\rm Jup}$, $i = 87\overset{\circ}{.}1$. The lower and upper dashed lines are the transit curves that would occur for a planet 10% larger and smaller in radius, respectively. The rapid initial fall and final rise of the transit curve correspond to the times between first and second and between third and fourth contacts, when the planet is crossing the edge of the star; the resulting slope is a function of the finite size of the planet, the impact parameter of the transit, and the limb darkening of the star. The central curved portion of the transit is the time between second and third contacts, when the planet is entirely in front of the star.

Charbonneau et al, ApJ, 529, L45

Et confirmation…

THE ASTROPHYSICAL JOURNAL, 529:L41–L44, 2000 January 20

A TRANSITING "51 PEG–LIKE" PLANET[1]

GREGORY W. HENRY,[2] GEOFFREY W. MARCY,[3] R. PAUL BUTLER,[4] AND STEVEN S. VOGT[5]
Received 1999 November 18; accepted 1999 December 3; published 1999 December 16

ABSTRACT

Doppler measurements from Keck exhibit a sinusoidal periodicity in the velocities of the G0 dwarf HD 209458, having a semiamplitude of 81 m s^{-1} and a period of 3.5239 days, which is indicative of a "51 Peg–like" planet with a minimum mass ($M \sin i$) of 0.62 M_{Jup} and a semimajor axis of 0.046 AU. Follow-up photometry reveals a drop of 0.017 mag at the predicted time (within the errors) of transit by the companion based on the velocities. This is the first extrasolar planet observed to transit its star. The radius of the planet derived from the magnitude of the dimming is 1.42 R_{Jup}, which is consistent with models of irradiated Jupiter-mass planets. The transit implies that $\sin i > 0.993$, leading to a true mass of 0.62 M_{Jup} for the planet. The resulting mean density of 0.27 g cm^{-3} implies that the companion is a gas giant.

Subject headings: planetary systems — stars: individual (HD 209458)

Et confirmation…

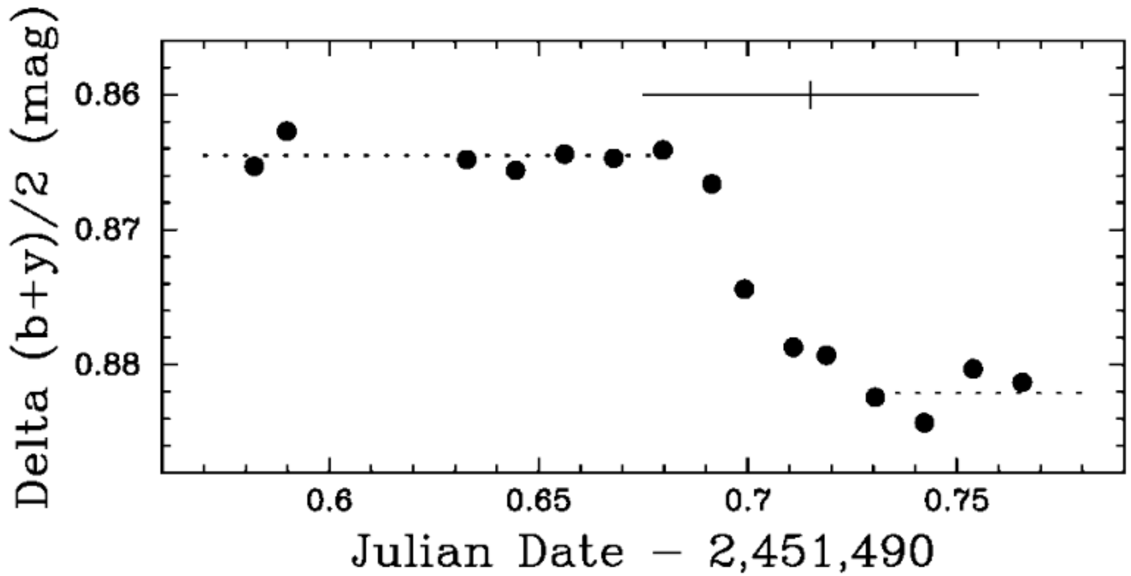


FIG. 3.—Photometric observations of HD 209458 from the night of 1999 November 7 UT showing ingress of the planetary transit. The measured transit depth is 0.017 ± 0.002 mag or 1.58% ± 0.18%. The error bar shows the time of inferior conjunction and its uncertainty predicted from the radial velocities in this Letter.

Henry et al, ApJ, 529, L41

HD209458 b vue du ciel

THE ASTROPHYSICAL JOURNAL, 552:699–709, 2001 May 10

HUBBLE SPACE TELESCOPE TIME-SERIES PHOTOMETRY OF THE TRANSITING PLANET OF HD 209458[1]

TIMOTHY M. BROWN,[2] DAVID CHARBONNEAU,[2,3] RONALD L. GILLILAND,[4] ROBERT W. NOYES,[3] AND ADAM BURROWS[5]
Received 2000 November 21; accepted 2001 January 18

ABSTRACT

We have observed four transits of the planet of HD 209458 using the STIS spectrograph on the *Hubble Space Telescope* (*HST*). Summing the recorded counts over wavelength between 582 and 638 nm yields a photometric time series with 80 s time sampling and relative precision of about 1.1×10^{-4} per sample. The folded light curve can be fitted within observational errors using a model consisting of an opaque circular planet transiting a limb-darkened stellar disk. In this way we estimate the planetary radius $R_p = 1.347 \pm 0.060$ $R_{\rm Jup}$, the orbital inclination $i = 86\overset{\circ}{.}6 \pm 0\overset{\circ}{.}14$, the stellar radius $R_* = 1.146 \pm 0.050$ $R_\odot$, and one parameter describing the stellar limb darkening. Our estimated radius is smaller than those from earlier studies but is consistent within measurement errors and also with theoretical estimates of the radii of irradiated Jupiter-like planets. Satellites or rings orbiting the planet would, if large enough, be apparent from distortions of the light curve or from irregularities in the transit timings. We find no evidence for either satellites or rings, with upper limits on satellite radius and mass of 1.2 $R_\oplus$ and 3 $M_\oplus$, respectively. Opaque rings, if present, must be smaller than 1.8 planetary radii in radial extent. The high level of photometric precision attained in this experiment confirms the feasibility of photometric detection of Earth-sized planets circling Sun-like stars.

Subject headings: binaries: eclipsing — planetary systems — stars: individual (HD 209458) — techniques: photometric

HD209458 b vue du ciel

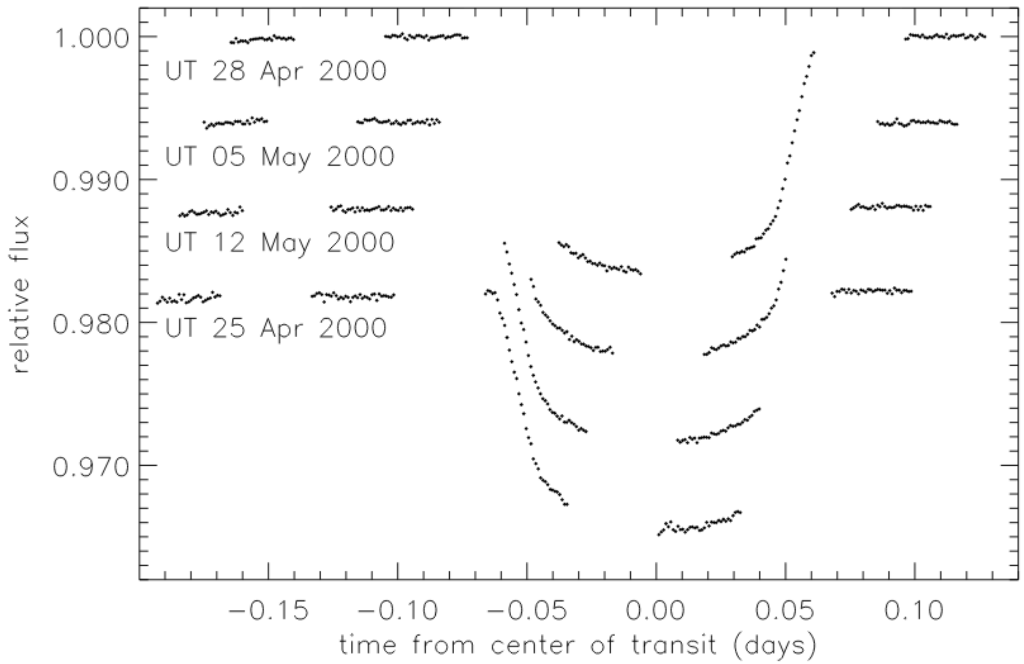


FIG. 2.—Time series of the corrected intensity shown separately for each of the four transits observed by *HST*, with successive transits offset by −0.006 for clarity. Note that, because the transit duration is almost two *HST* orbits, complete temporal coverage was not obtained for any one transit.

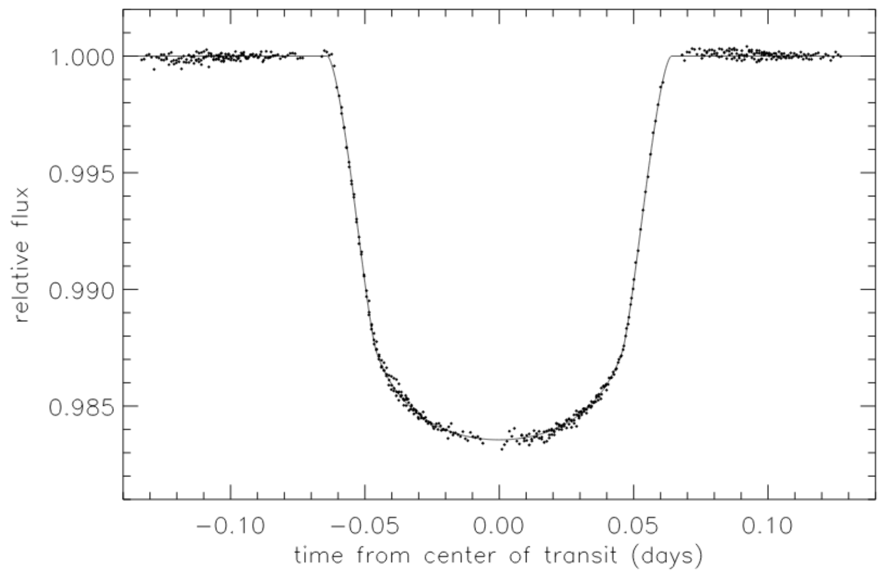


FIG. 3.—Phased light curve for all four transits, assuming a planetary orbital period of 3.52474 days. The time series for each transit has been scaled to have the same average intensity over the second and fifth (out-of-transit) orbits.

TABLE 1

HD 209458B FIT PARAMETERS

Parameter	Value
R_*	$1.146 \pm 0.050\ R_\odot$
R_p	$1.347 \pm 0.060\ R_{\rm Jup}$
i	$86\overset{\circ}{.}68 \pm 0\overset{\circ}{.}14$
$(u_1 + u_2)$......	0.640 ± 0.030
$(u_1 - u_2)$......	-0.055 ± 0.100

Brown et al, ApJ, 552, 699

Conclusions

- L’observation permet des découvertes fiables, si l’on est capable de comprendre, contrôler tous les biais
- Observer par 2 méthodes différentes aux biais différents est un argument massue
- Une découverte « fiable » est souvent celle qui fait consensus
  - Qualité des observations
  - Rigueur des analyses et des interprétations
  - Reproductibilité des mesures
  - Précision accrue des observables avec l’amélioration des techniques

Et pourquoi un Nobel aussi tardif ?