# Les exoplanètes

## Mesure d’un rayon planétaire

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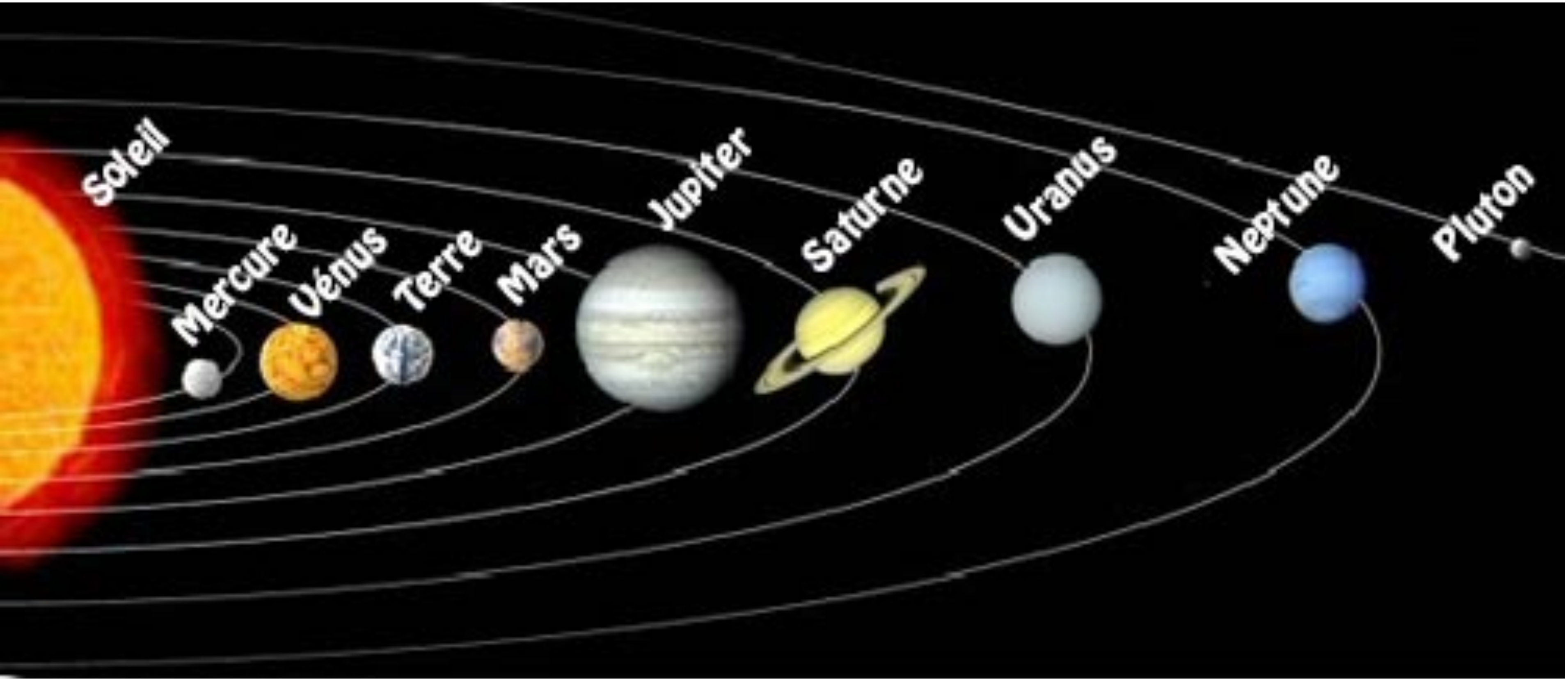
GICS, 14 janvier 2014


Soleil
Mercure
Vénus
Terre
Mars
Jupiter
Saturne
Uranus
Neptune
Pluton

# Introduction

- Exoplanète = planète extrasolaire
- Récent : 1990
- Enjeux :
  - Formation Système Solaire
  - Vie extrasolaire
- Rayon d'une exoplanète !

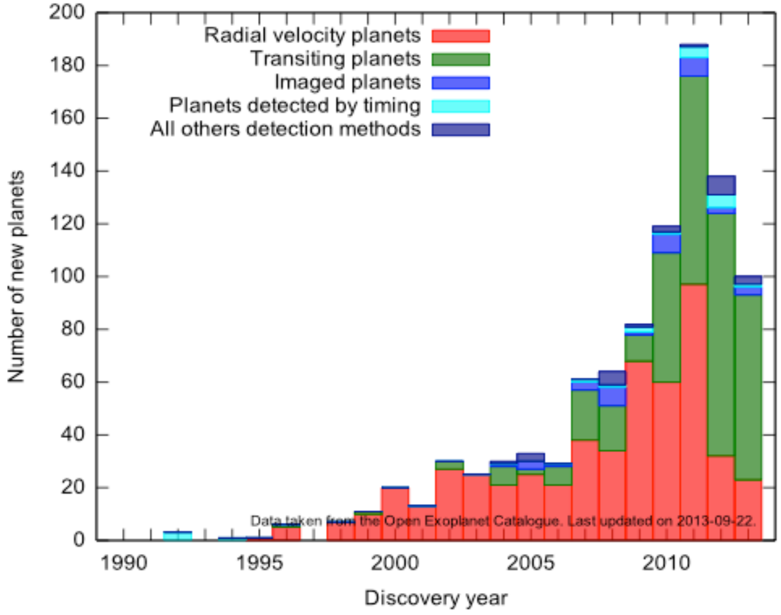
# Bref historique

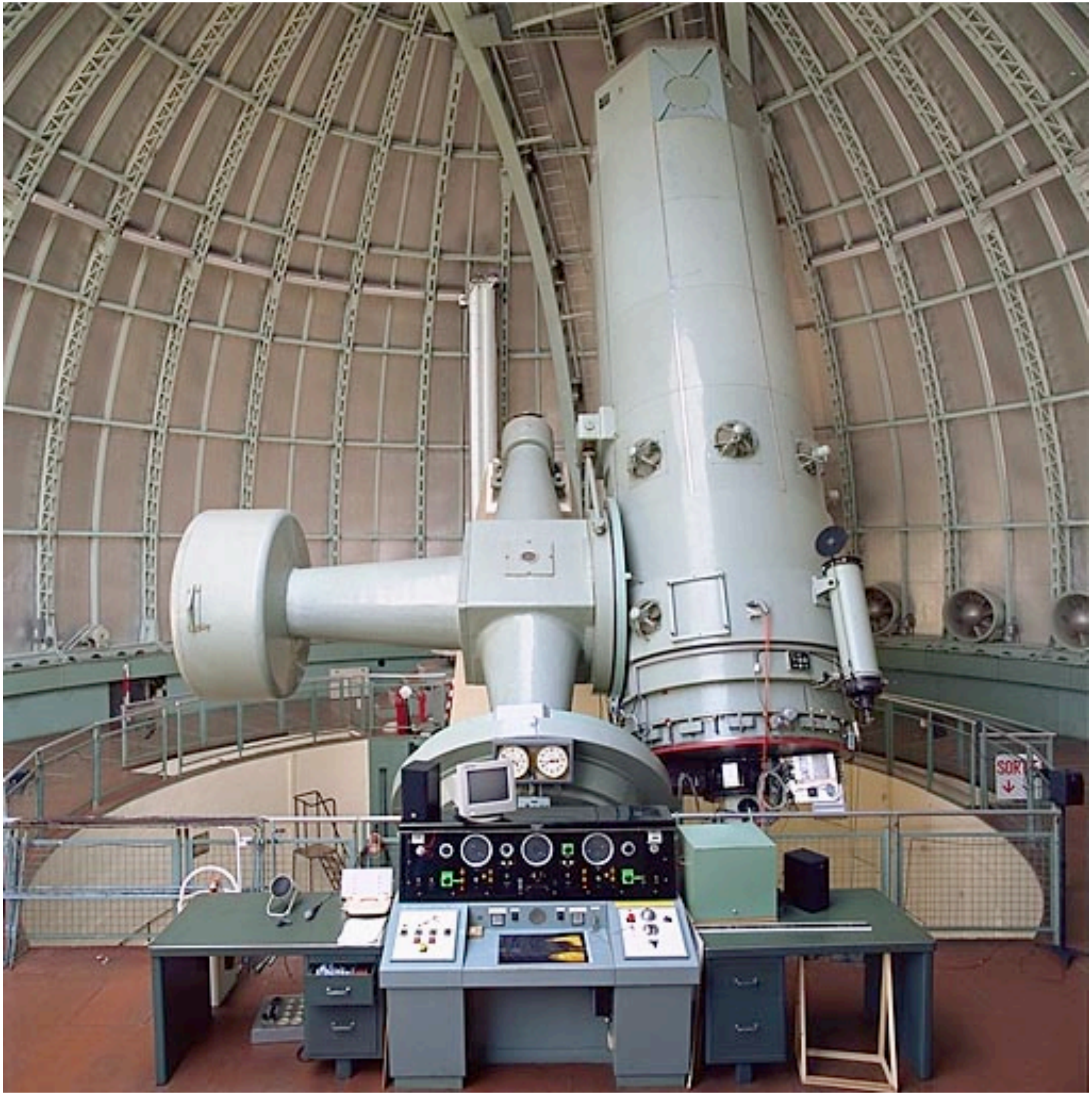
- 6 octobre 1995 : Michel Mayor & Didier Queloz (étoile type solaire) à l'OHP.

- Mars 2012 : 750

- Aujourd'hui : 900

- « Jupiter chaud »





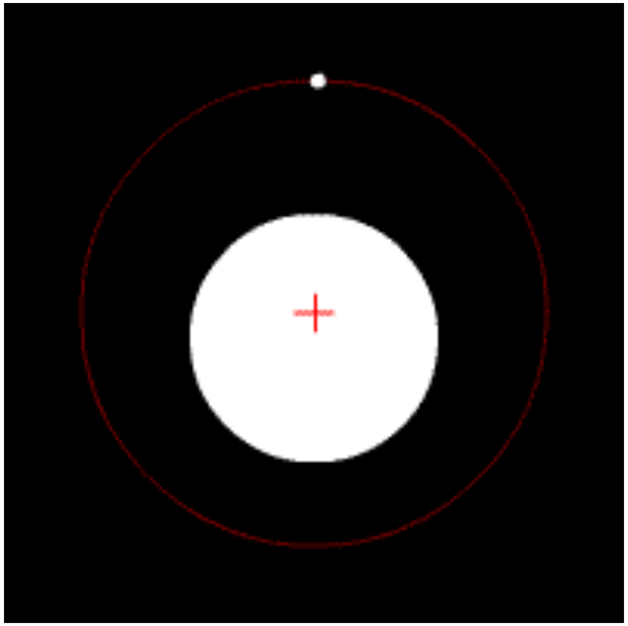
# Les méthodes de détection

Comment faire ?

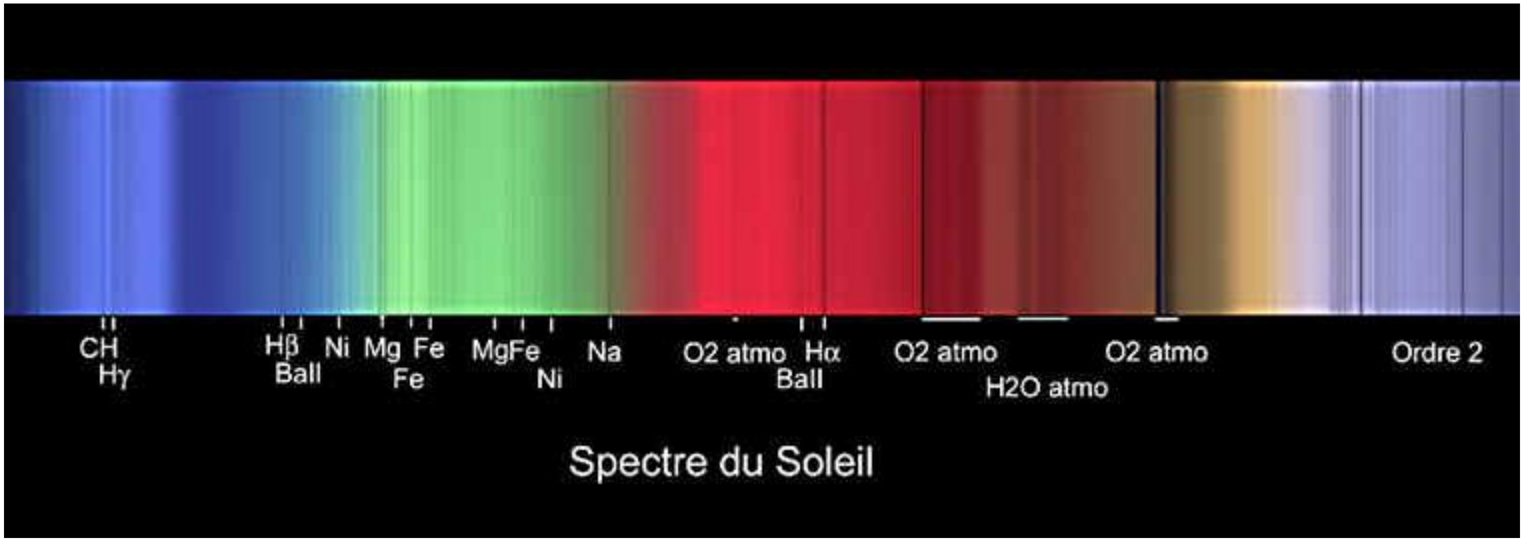
# Les méthodes de détection

## I Les vitesses radiales

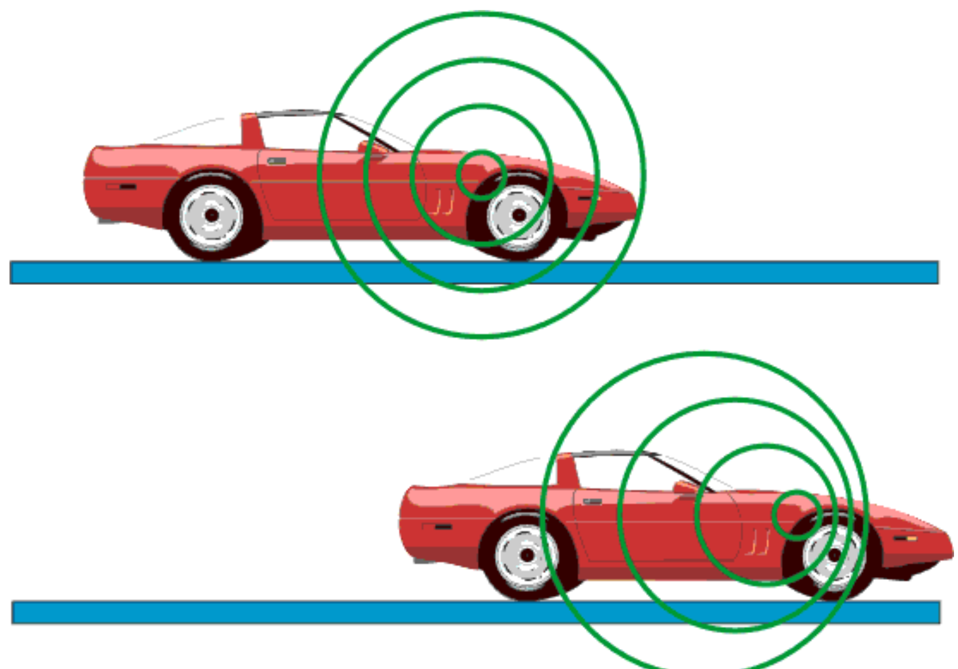
1. L’étoile bouge aussi !



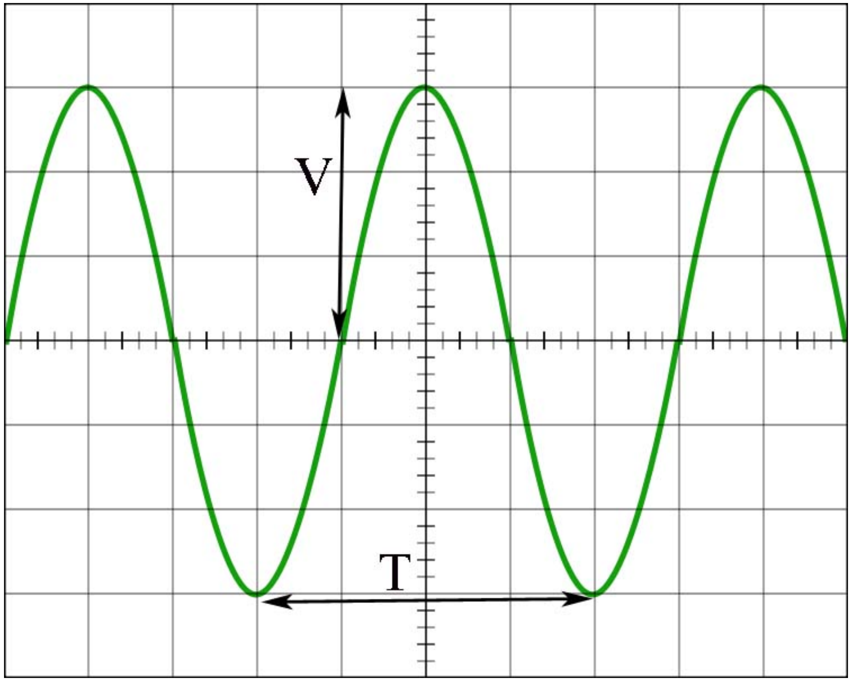
# 2) Décalage du spectre par effet Doppler

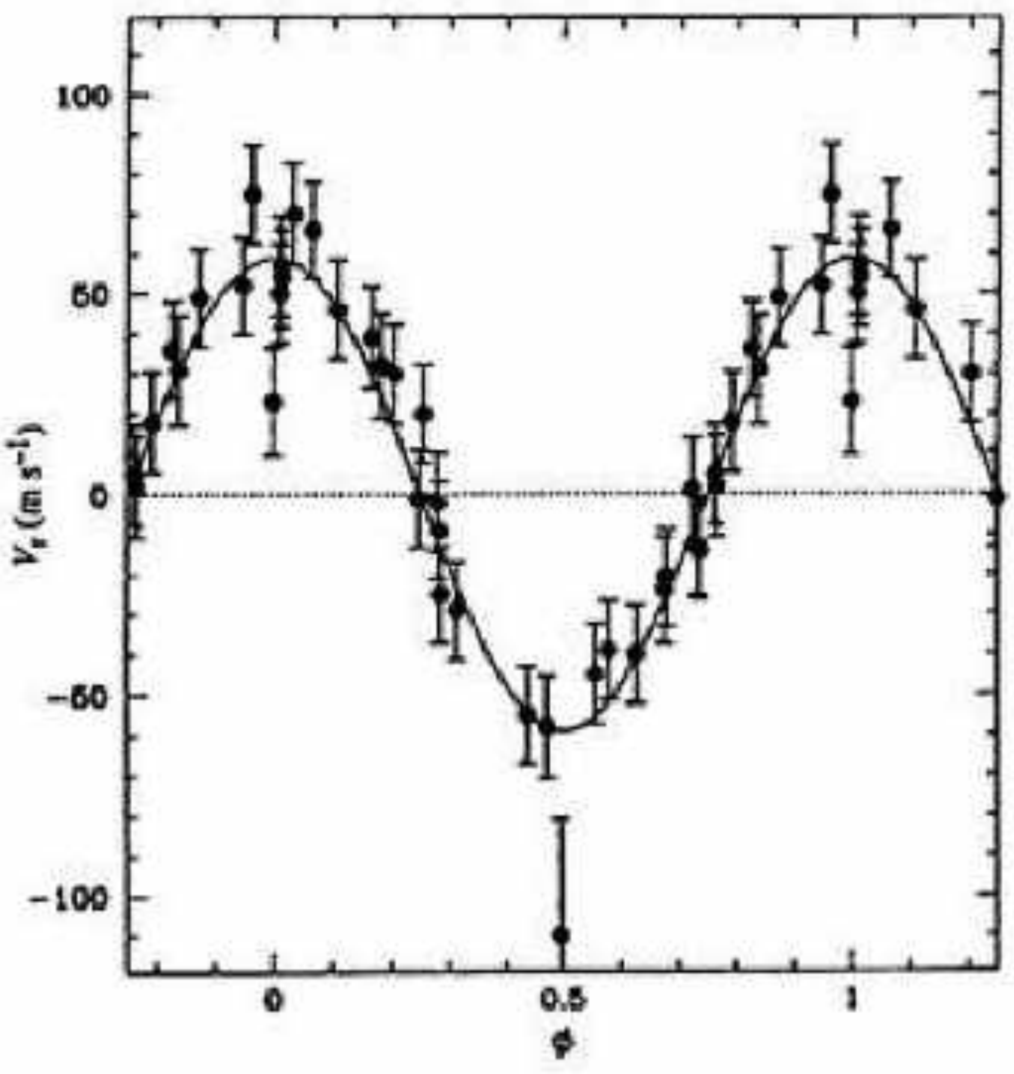



## L'effet Doppler



# Résultat de la mesure :

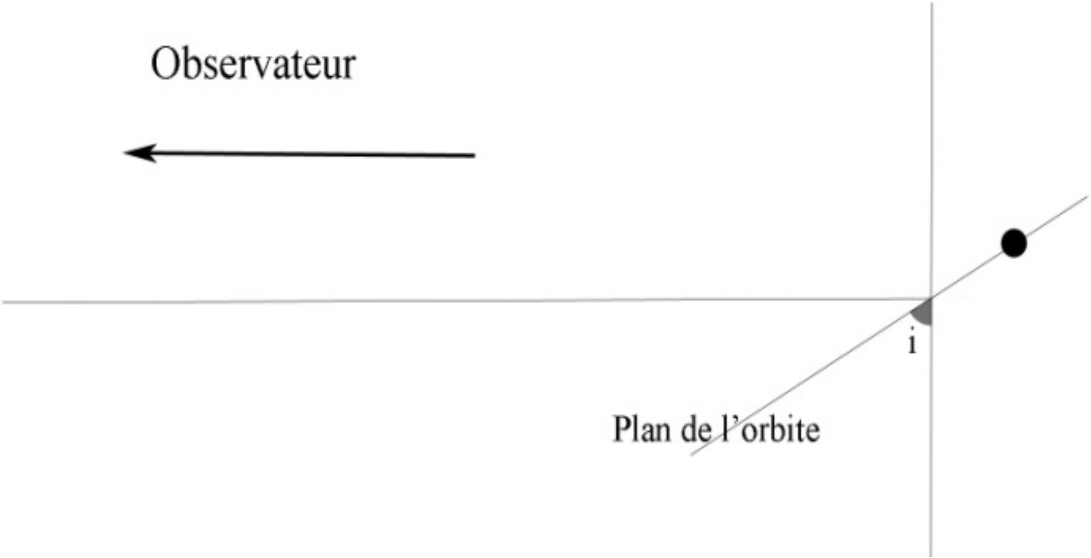





Mayor & Queloz

T = 4 jours !

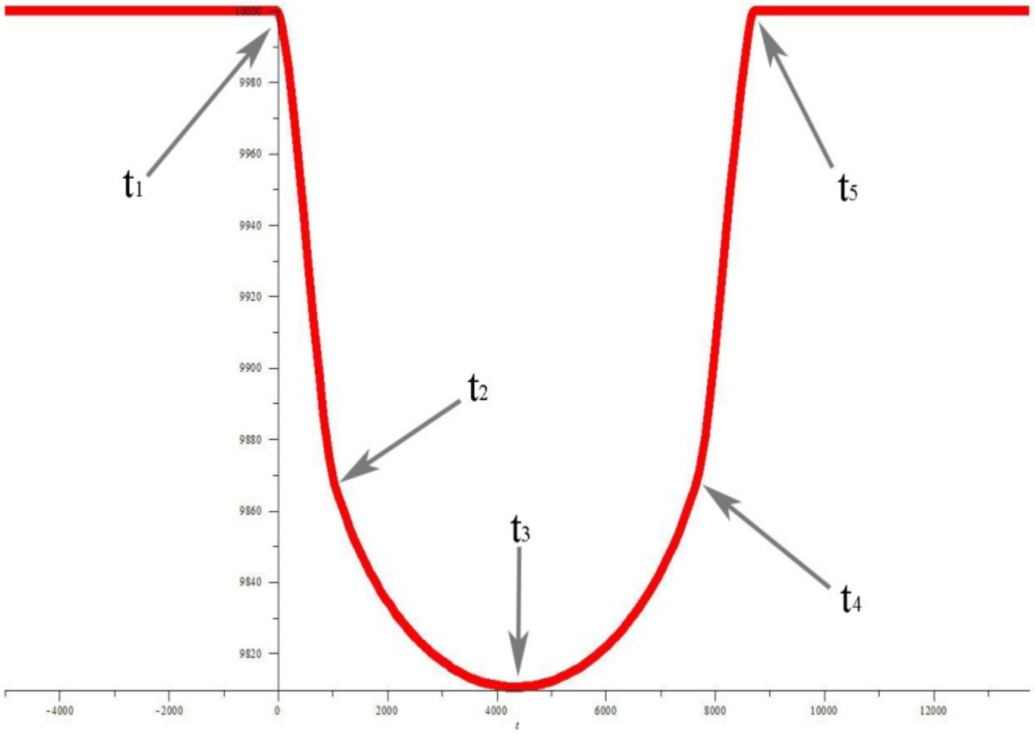
- Paramètres mesurés :
  - V -> m
  - T -> a
- Sin(i) !

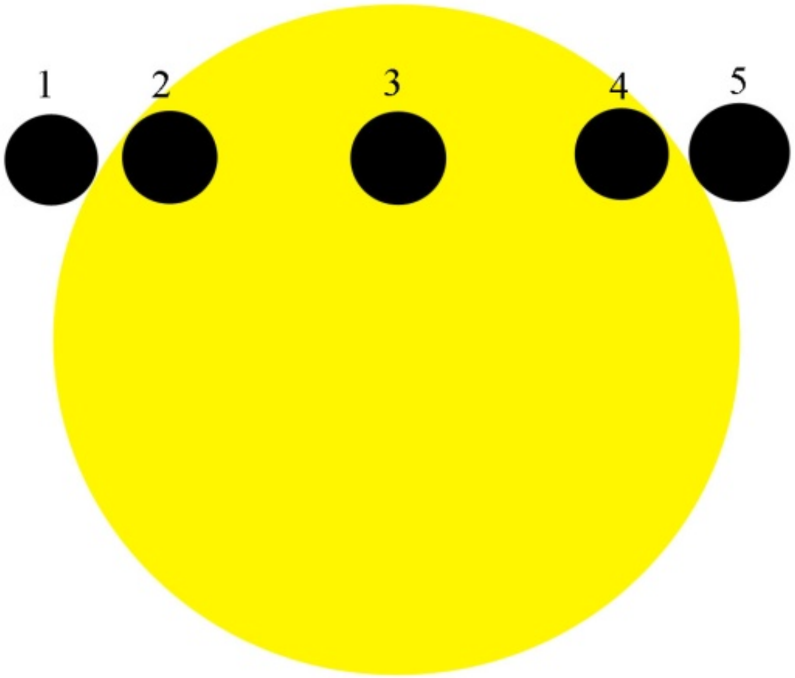



=> Masse mesurée : m.sin(i)

# Les transits

- Matériel d'astronome amateur

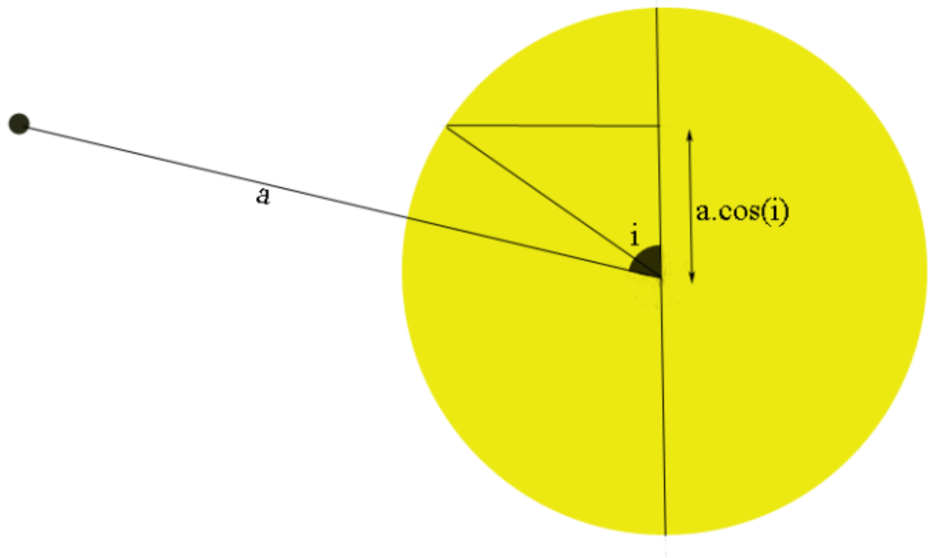


# Notations

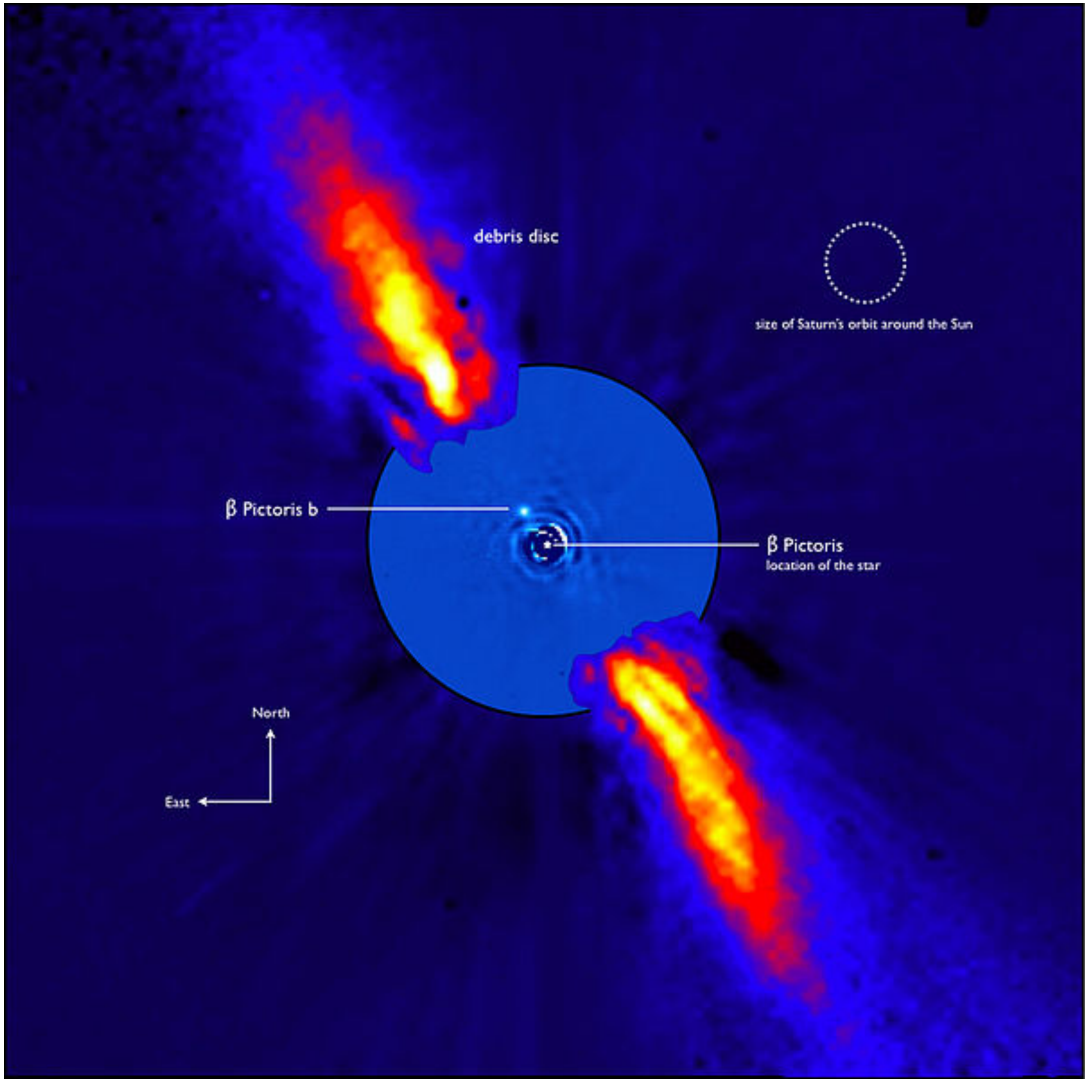
- $R_*$, $M_*$
- $R_p$, $M_p$
- $\tau$
- T
- a
- i
- d

- Paramètres mesurés :
  - T
  - $\varepsilon = \frac{R_p^2}{{R_*}^2}$
  - τ
- Paramètres déduits :
  - $R_p$
  - a (Kepler)
  - cos(i)



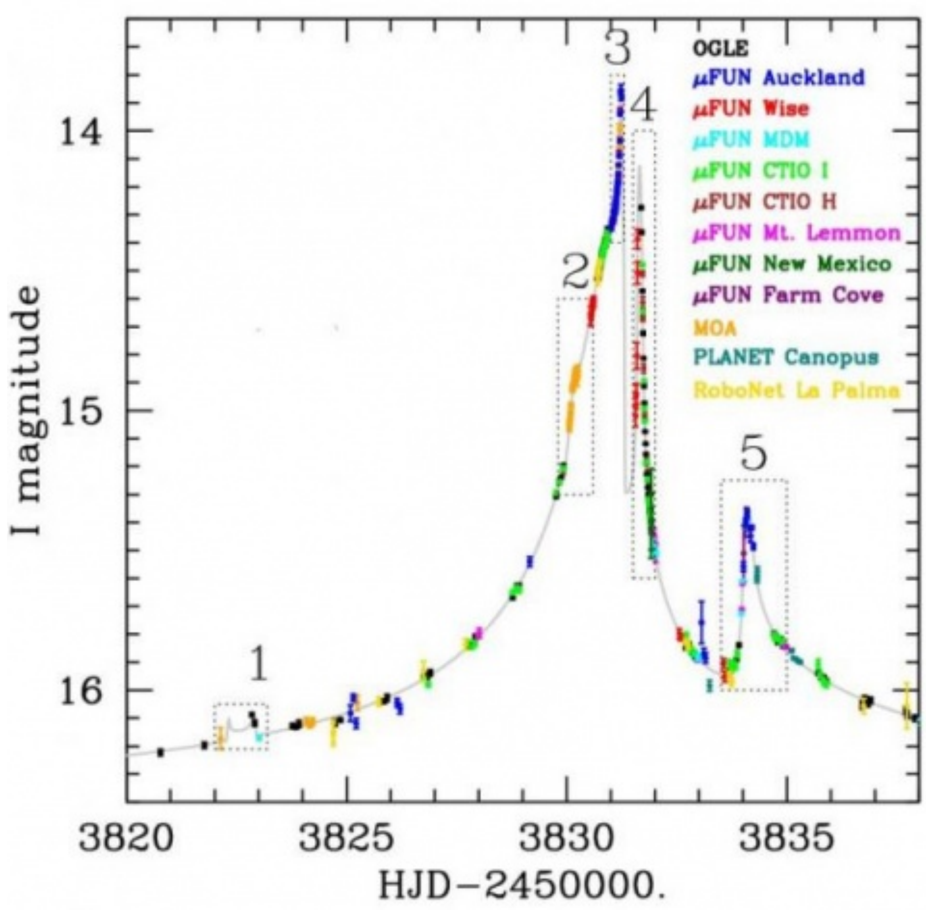
# Les autres méthodes

- Astrométrique
- Transit secondaire
- Détection directe !



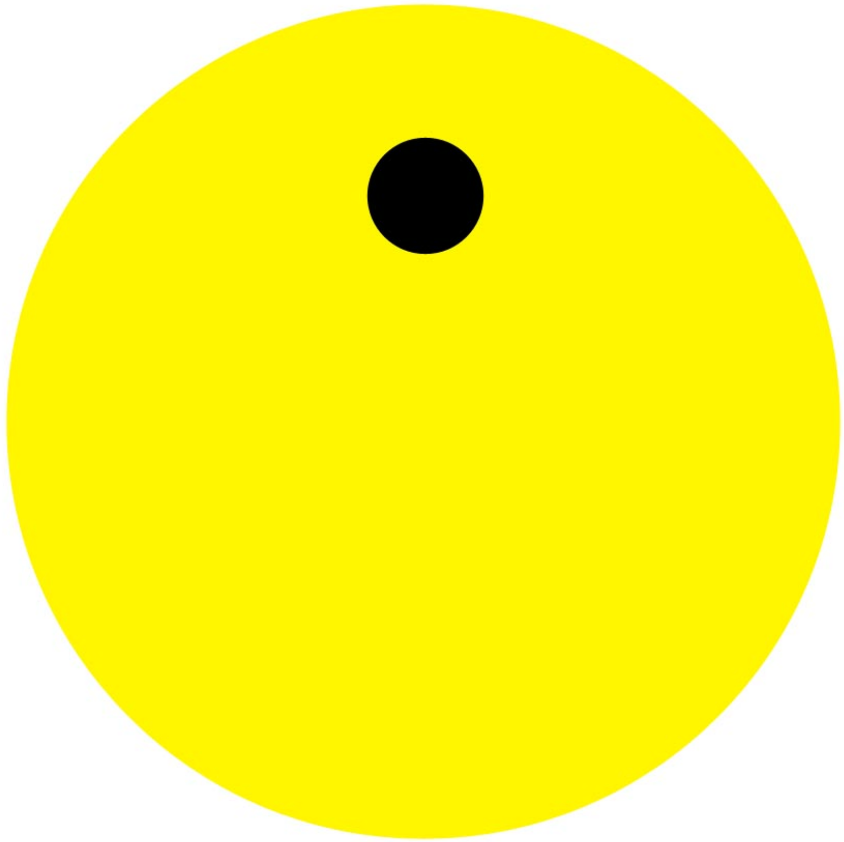

ESO

# Microlentille gravitationnelle

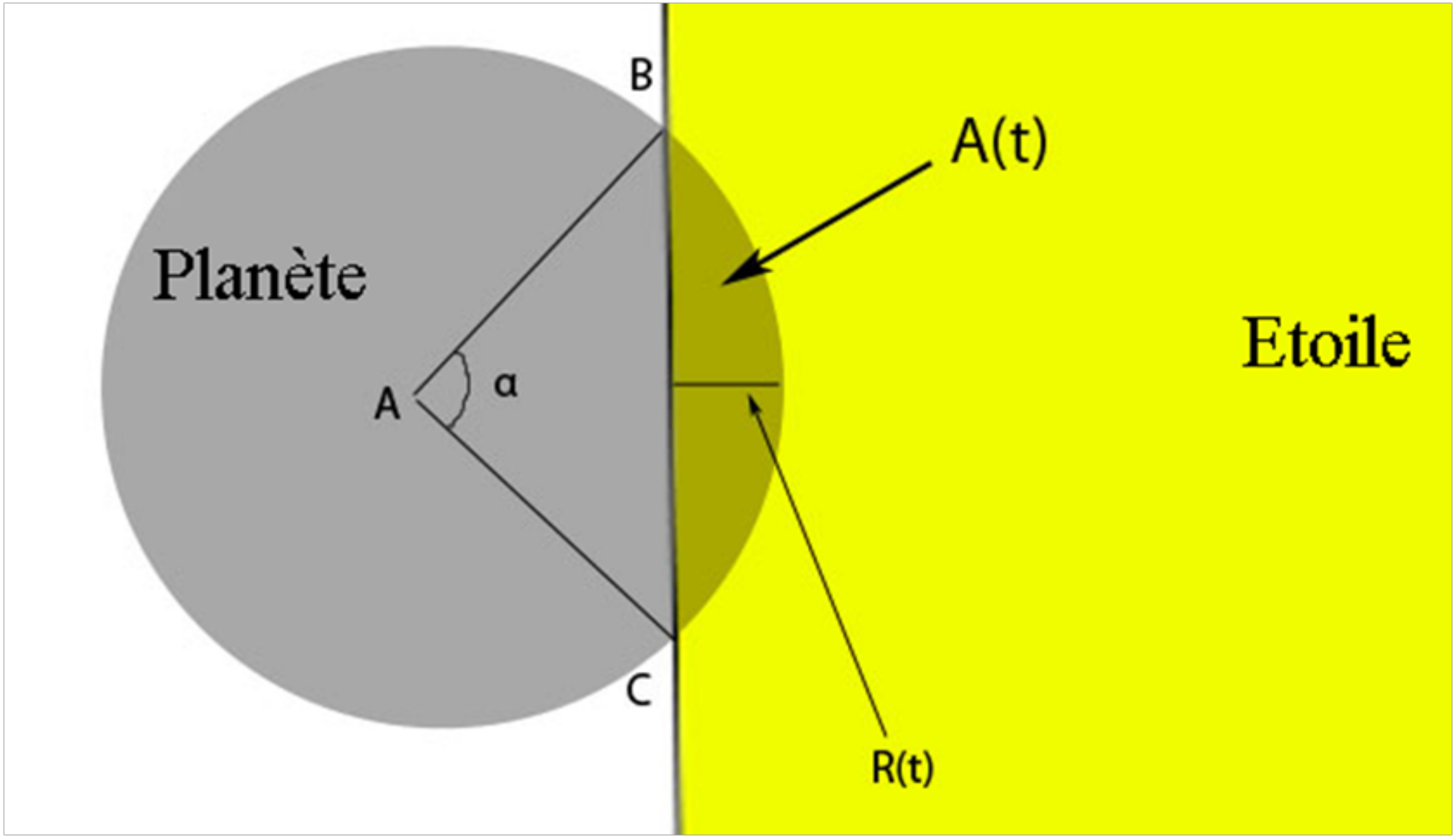



Science

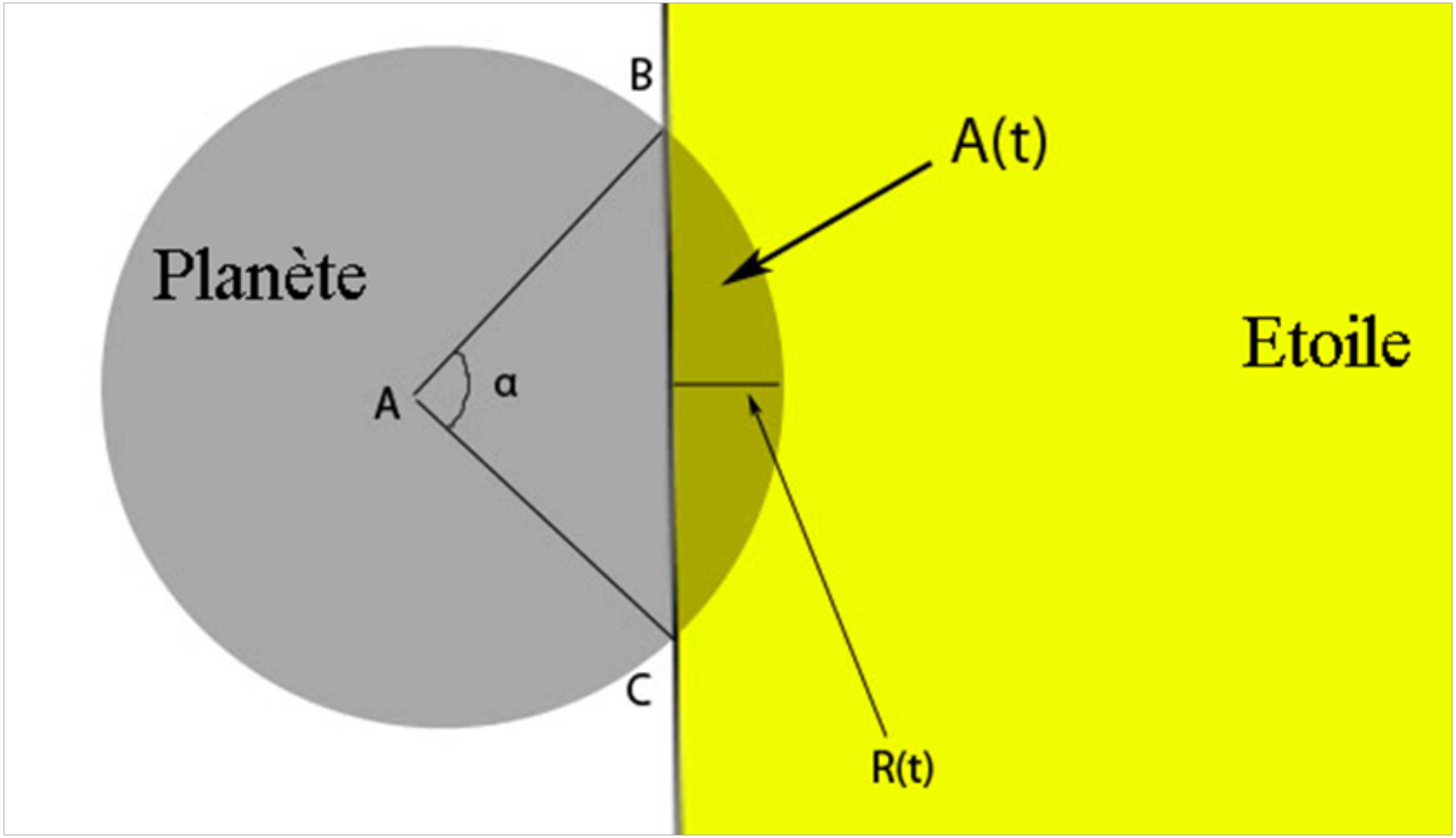
# Transit : une simulation précise



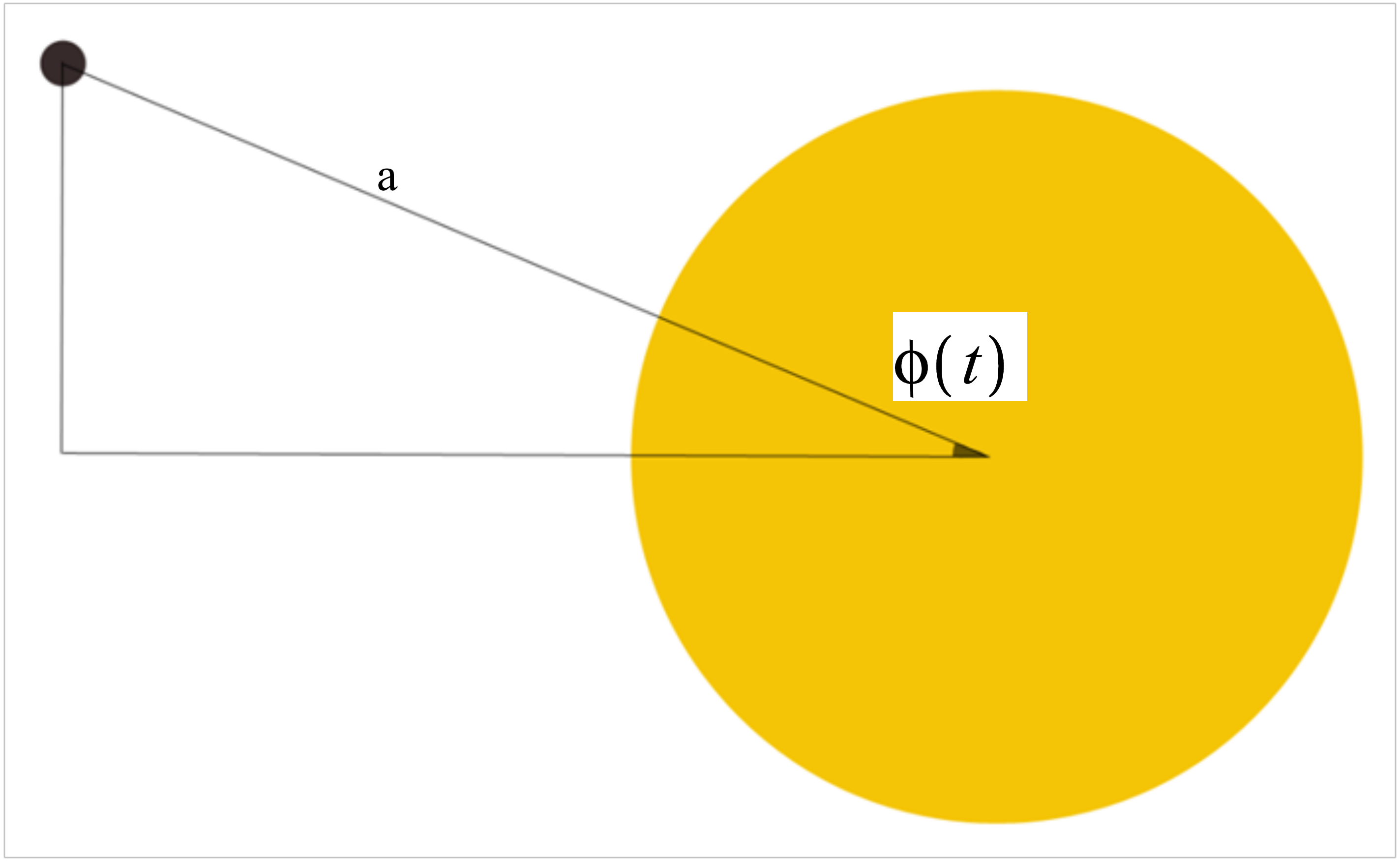
$$I_0\left(1-\frac{Rp^2}{Ret^2}\right)$$




$$I_0\left(1-\frac{A(t)}{\pi\cdot R_*^2}\right)$$



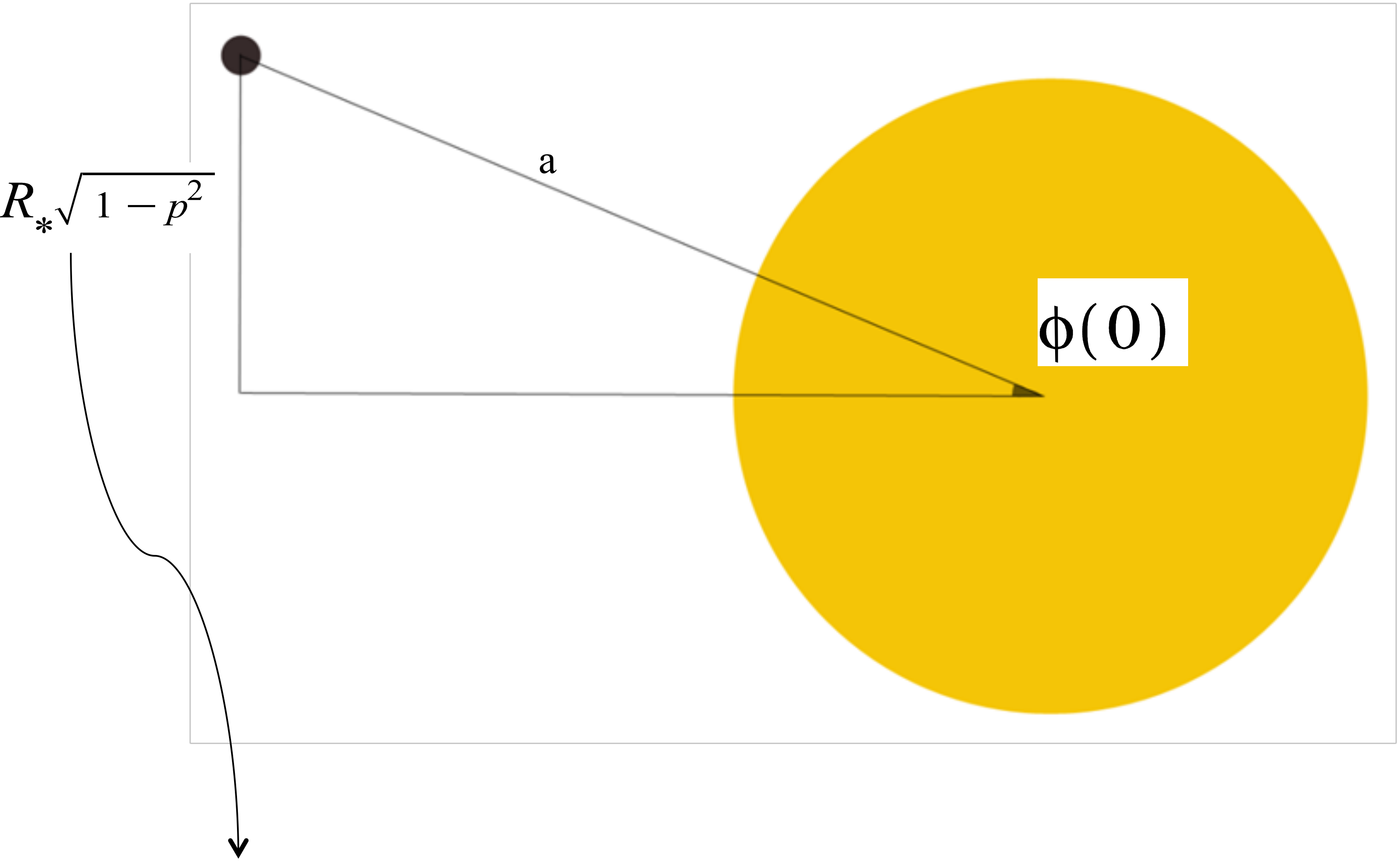

$$A(t) = \arccos\left(1 - \frac{R(t)}{Rp}\right) Rp^2 - (Rp - R(t))\sqrt{2\,Rp\,R(t) - R(t)^2}$$

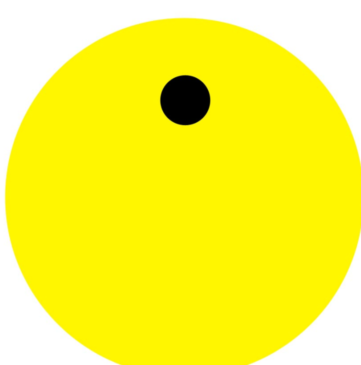



$$v = a \cdot \frac{\mathrm{d}}{\mathrm{d}t}\phi(t) = \sqrt{\frac{GM}{a}}$$

donc

$$\boldsymbol{\phi(t) = \sqrt{\frac{GM}{a^3}} \cdot t + \phi(0)}$$

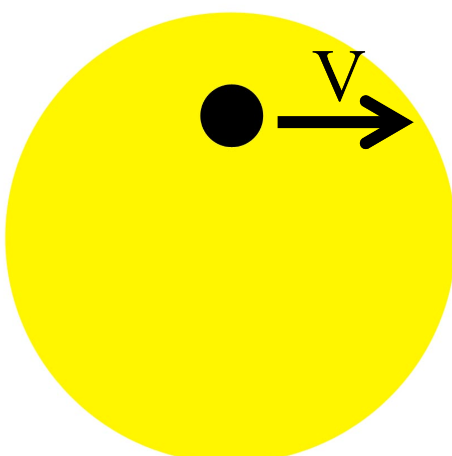


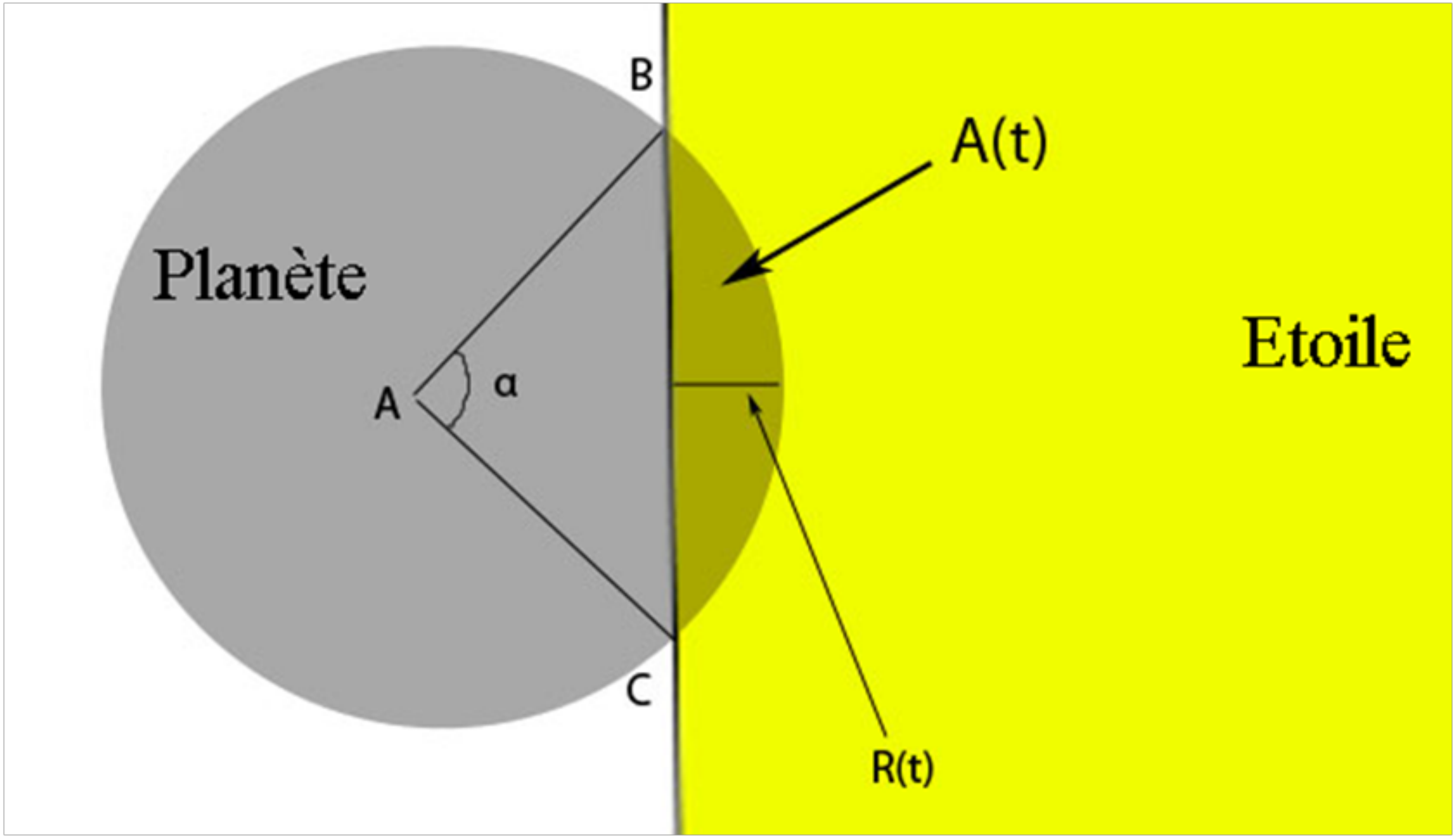



$$\phi(0) = -\arcsin\left(\frac{R_*\sqrt{1-p^2} + R_p}{a}\right)$$

# Finalement...

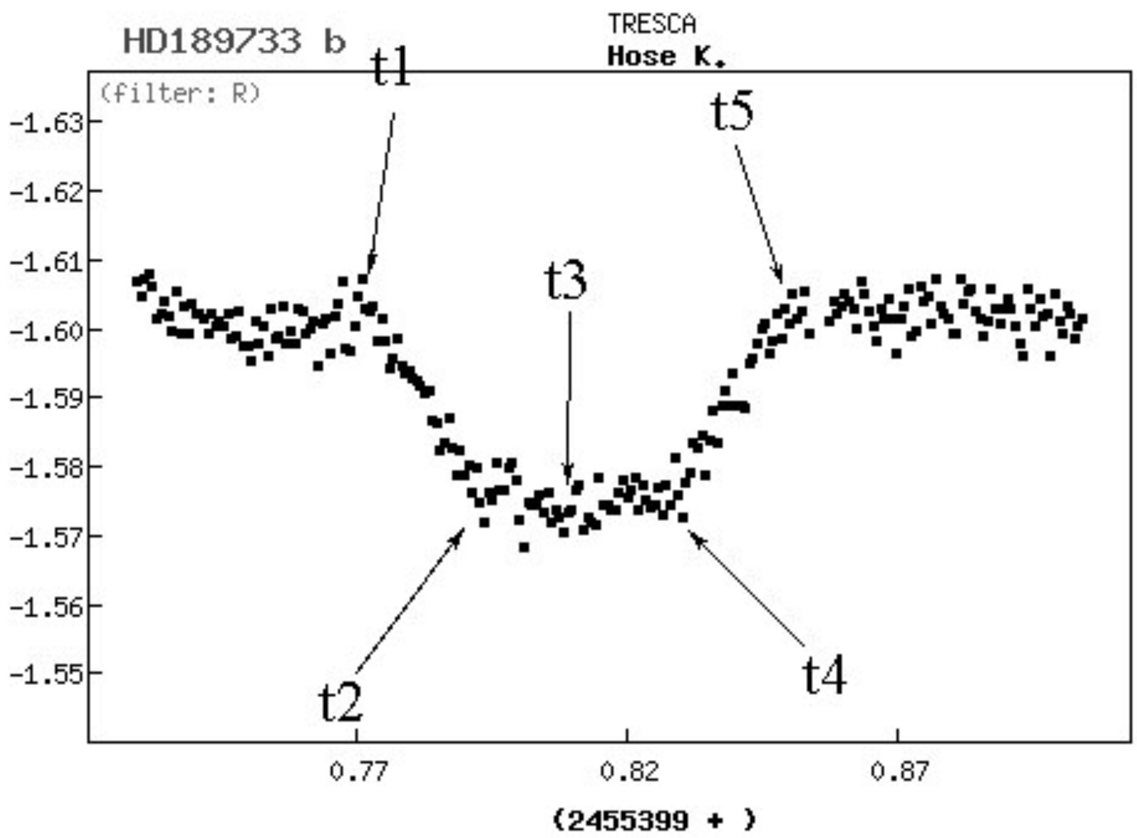
$$V(t) = v\cos\left(\phi(t)\right)$$



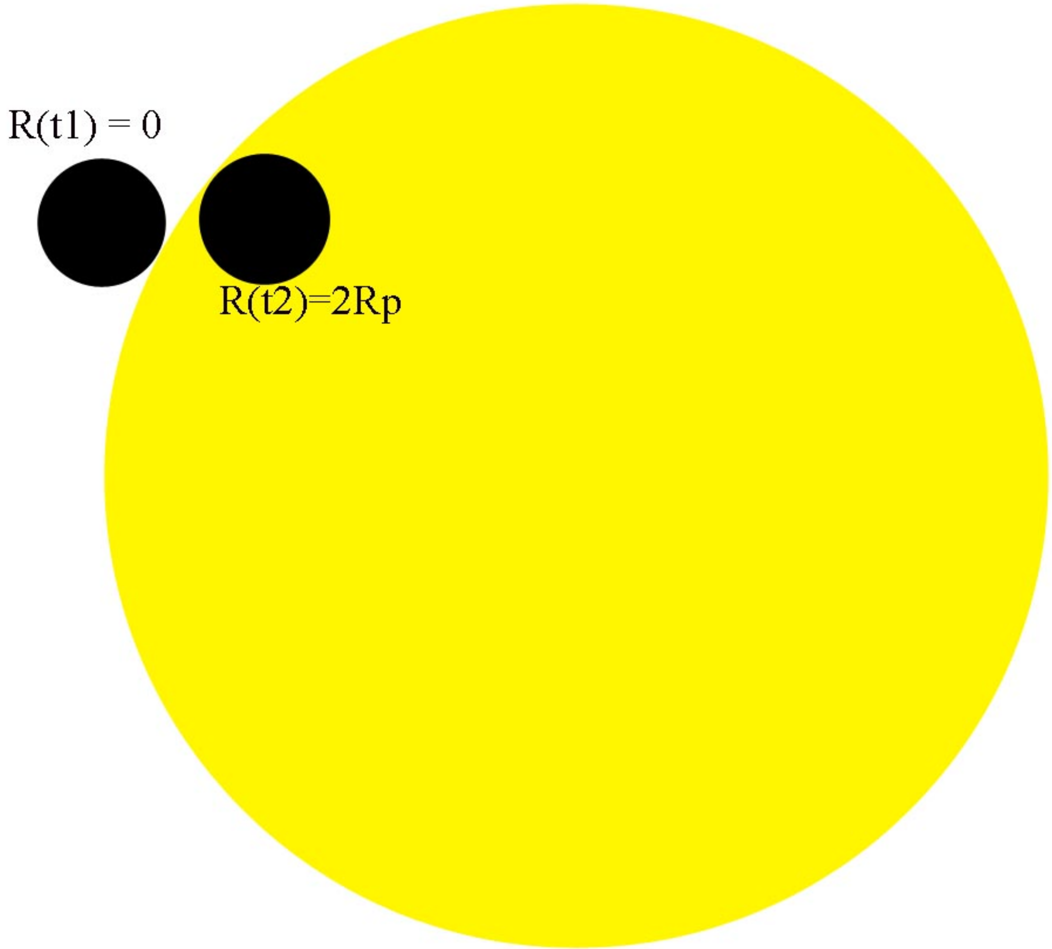



$$R(t) = V(t)\,t$$

# Temps caractéristiques



# Solution numérique !

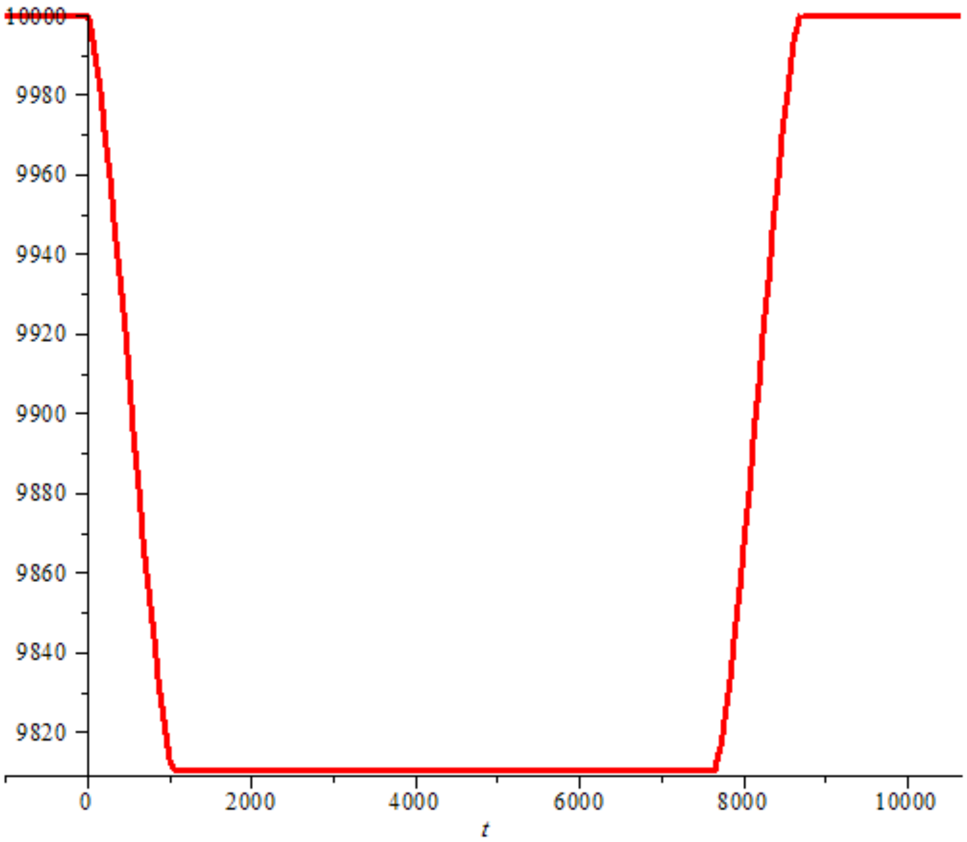


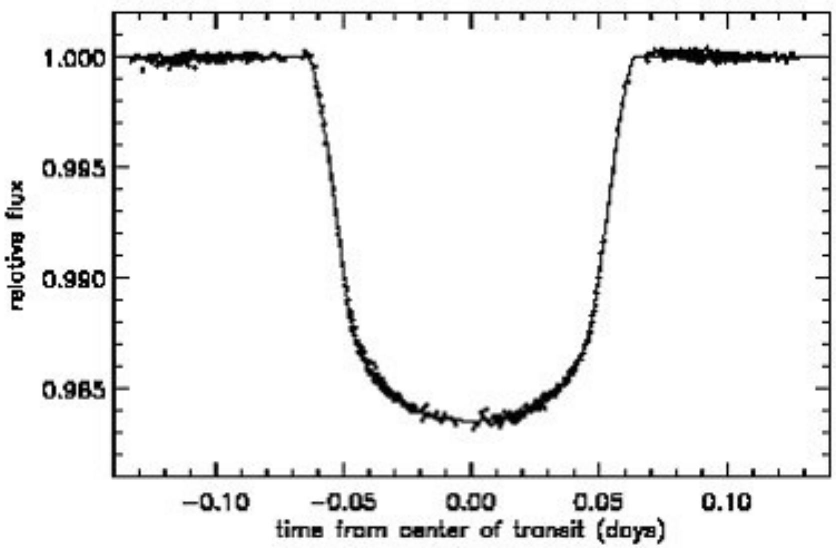
# Conclusion

$$
\mathrm{I(t)} = \begin{cases} I_0 & t \le t1 \\ I_0\left(1 - \dfrac{A(t)}{\pi\, Ret^2}\right) & t \le t2 \\ I_0\left(1 - \dfrac{Rp^2}{Ret^2}\right) & t \le t4 \\ I_0\left(1 - \dfrac{Rp^2}{Ret^2} + \dfrac{A(t - t4)}{\pi\, Ret^2}\right) & t \le t5 \\ I_0 & t5 \le t \end{cases}
$$

# Résultat

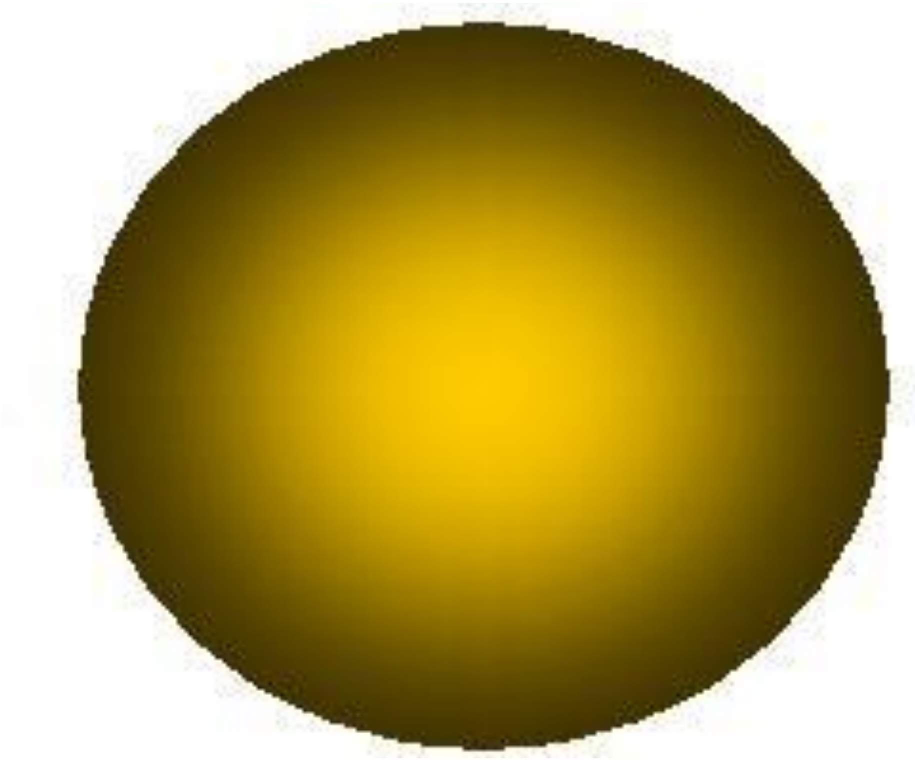
# Réalité

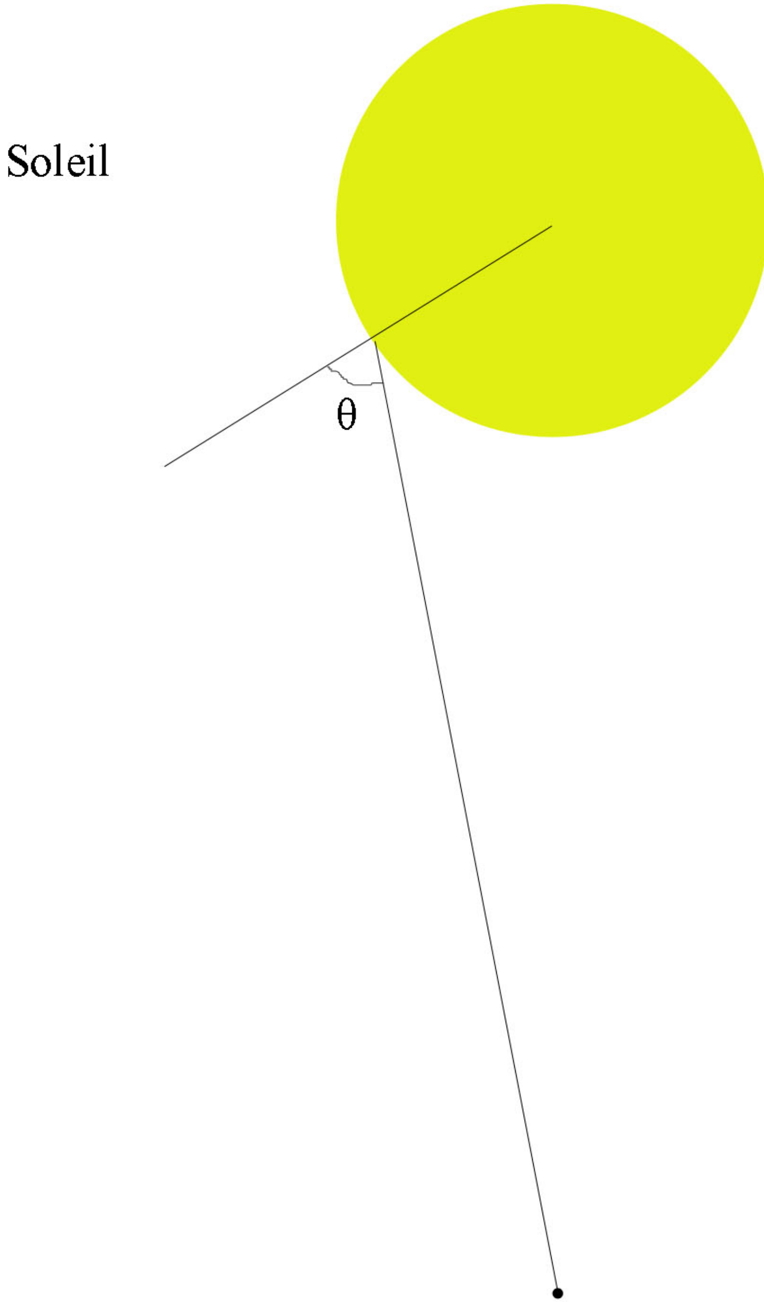



Problème !

# L’assombrissement centre-bord



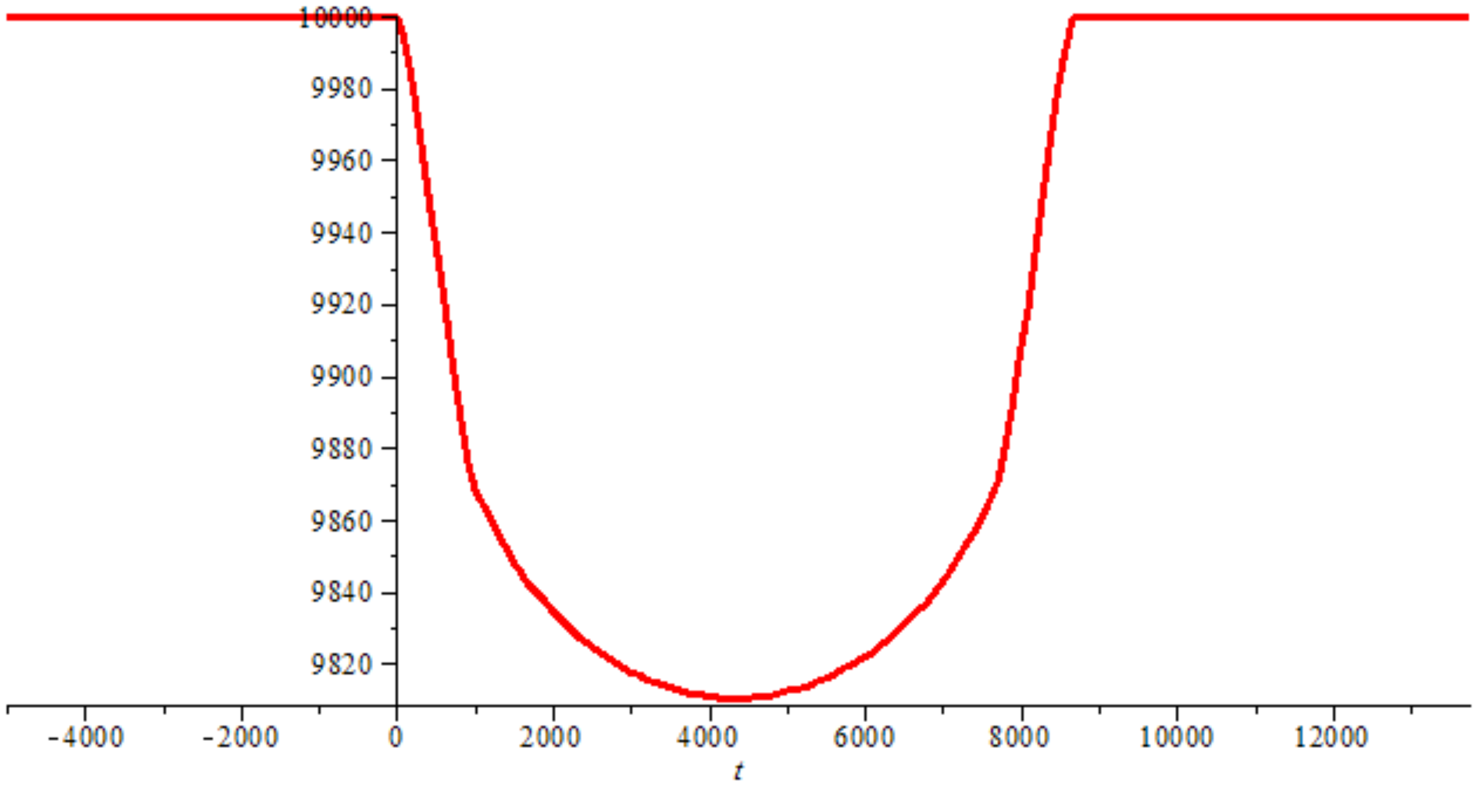



$$\mu = \cos(\theta)$$

$$\mathbf{I} = I_0\left(\frac{2}{5} + \frac{3}{5}\mu\right).$$

Observateur

# Après quelques calculs…




Mieux !

# Au travail !

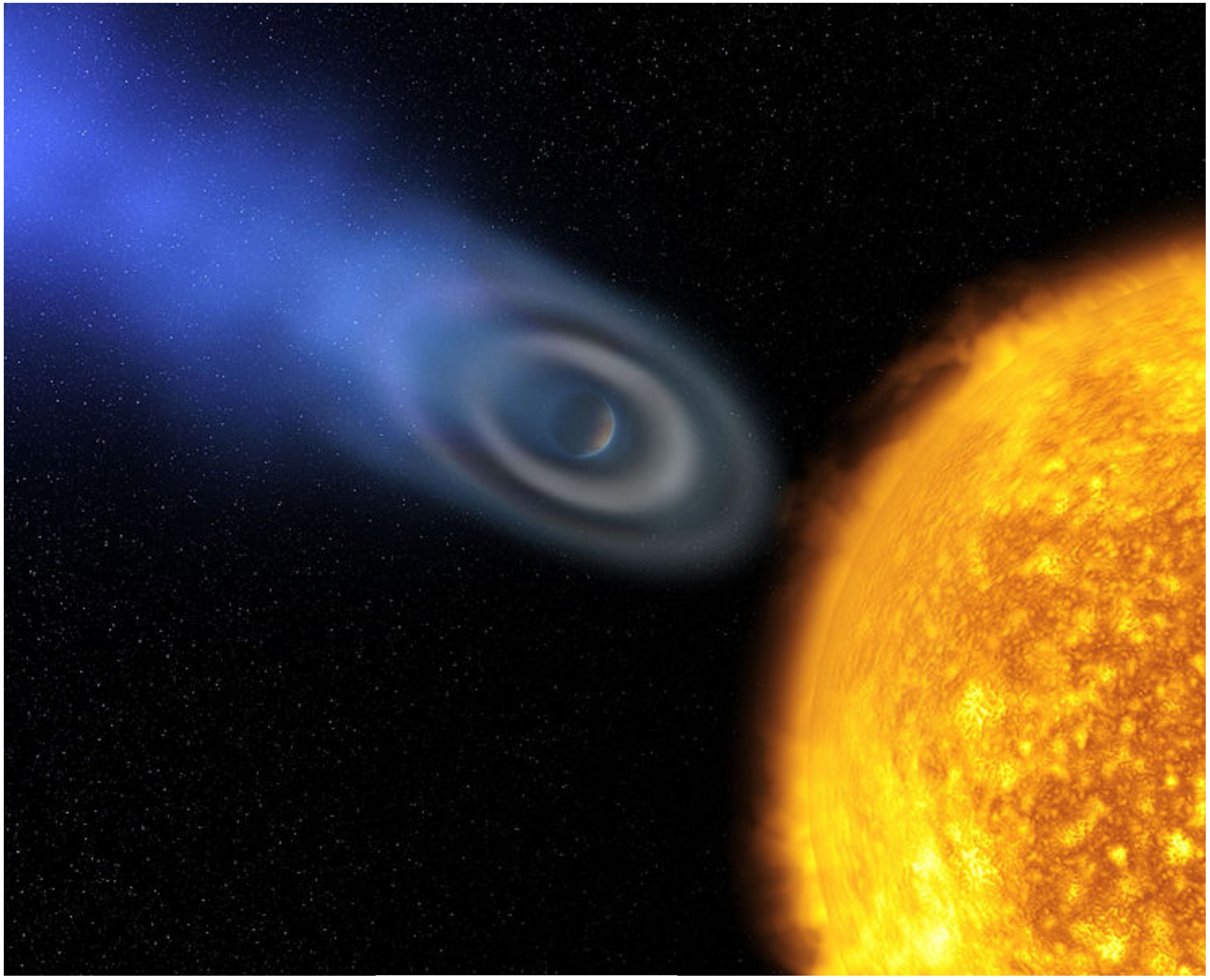
## Objectif : déterminer le rayon d'une exoplanète

- Valeur tabulée : 9.43 E7 m

# Et maintenant ?

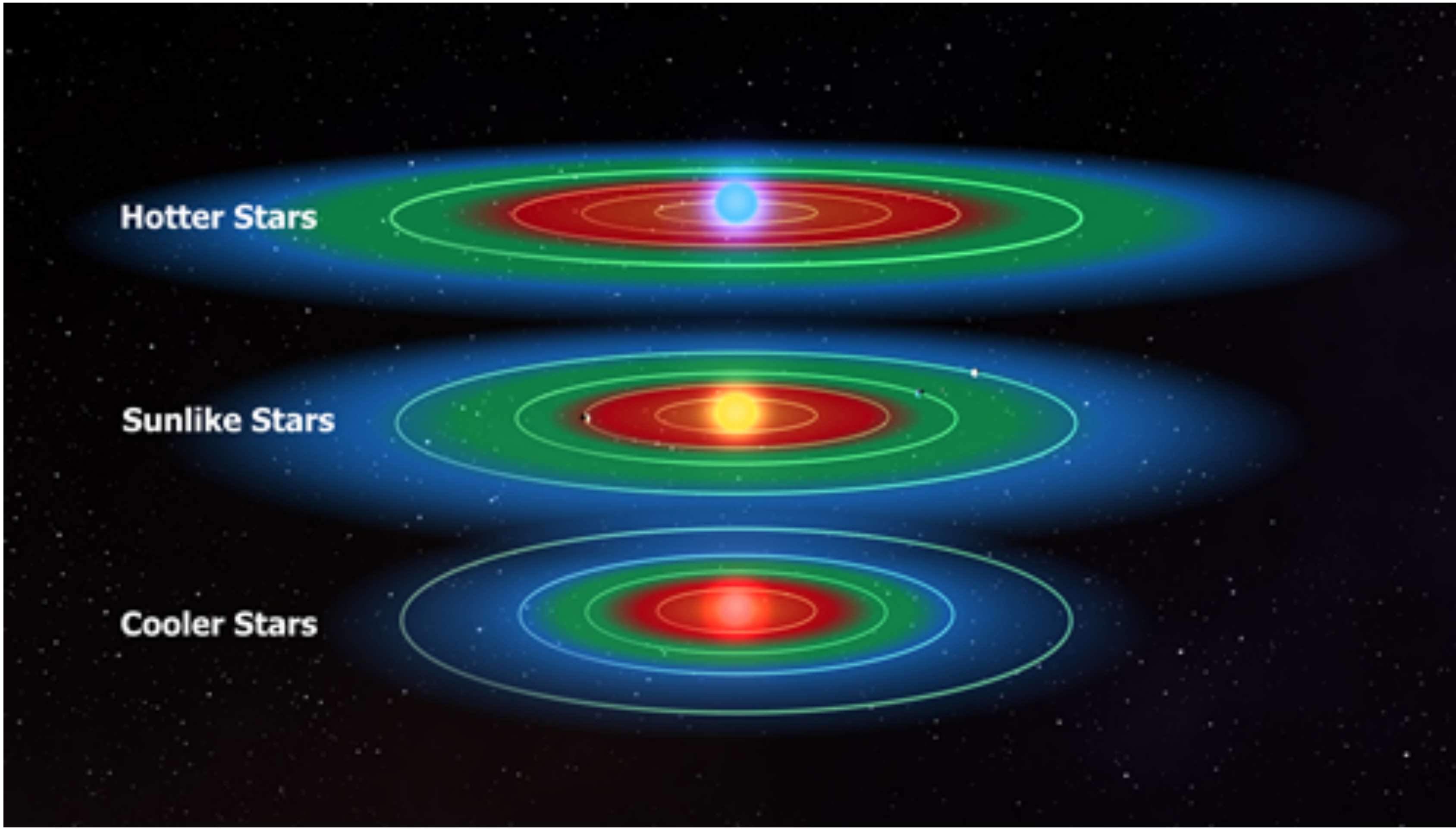
- Doppler -> m
- Densité -> Planète rocheuse ou gazeuse

- « Evaporation » des Jupiter chauds



$$10^{-14}$$

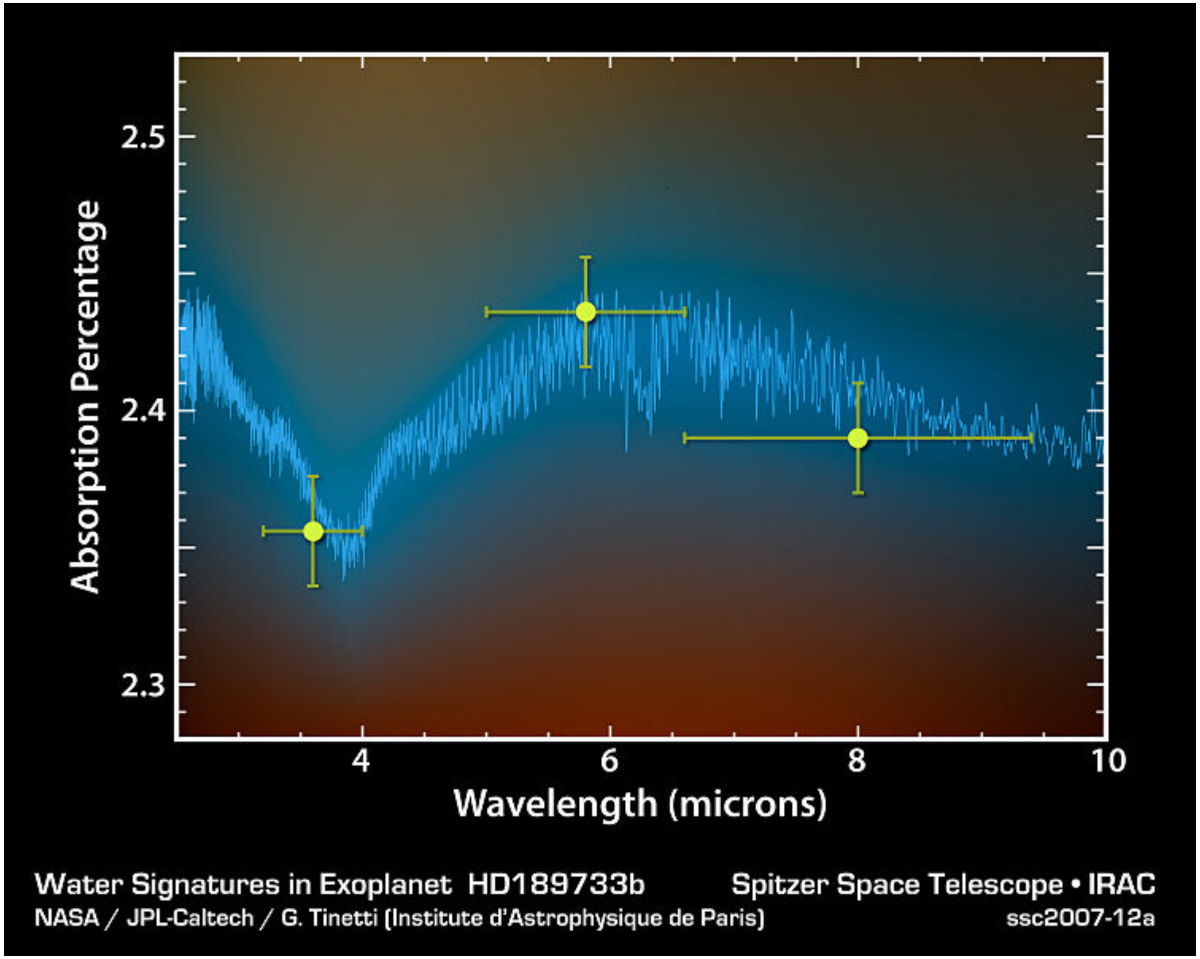
- Zone habitable




- Mais nombreux autres paramètres !

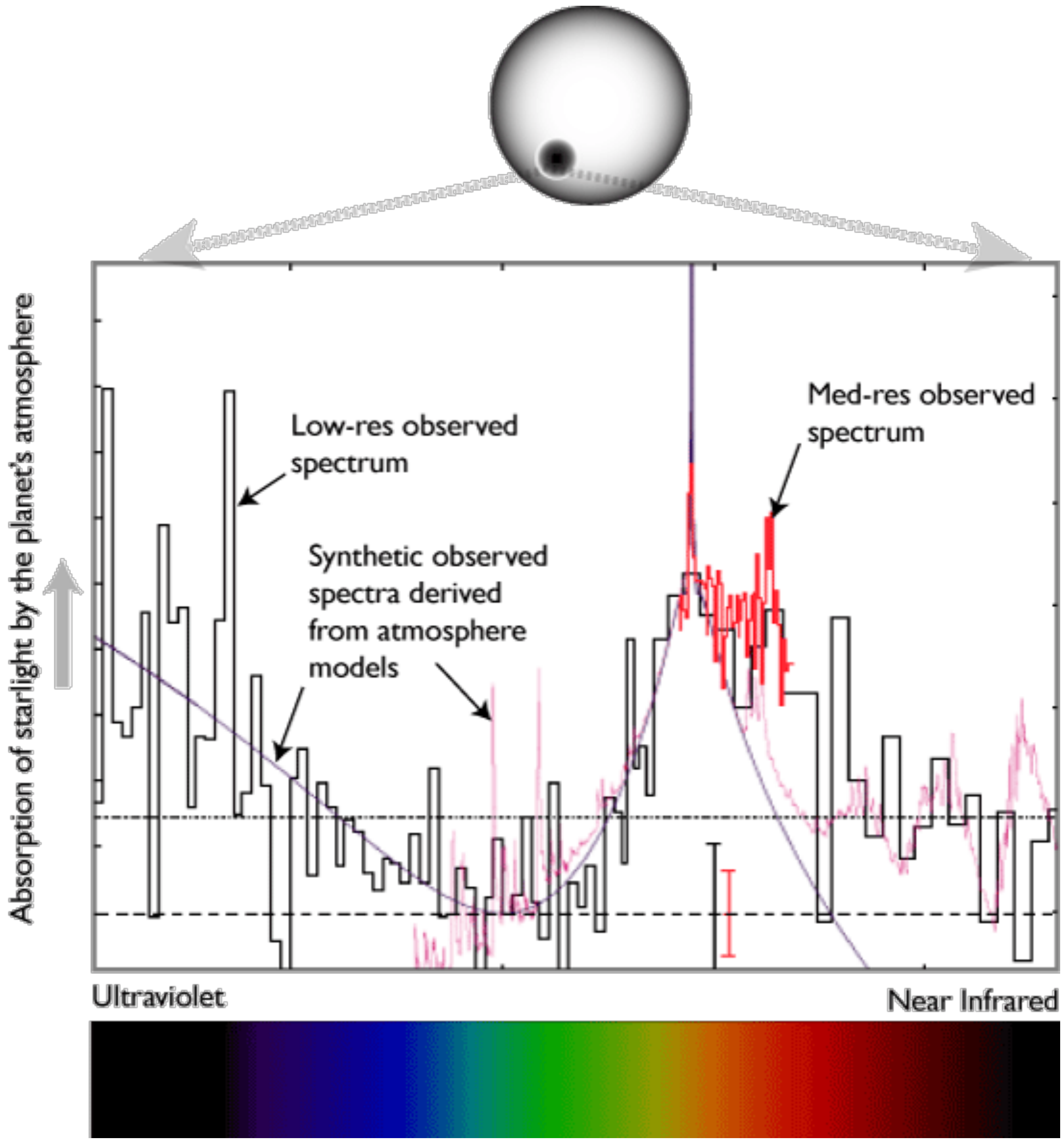
# L'atmosphère

- Derrière l'étoile : en IR, spectre d'émission




- CO, $H_20$

- Transit primaire : spectre d'absorption



# Conclusion

- Le but ultime !