

A dramatic landscape featuring a range of mountains under a sunset or sunrise sky. The foreground shows rugged, rocky terrain. In the upper right, a large, dark planet with a thin atmosphere is visible against the dark sky. The overall scene is atmospheric and evocative of a distant world.

**SONDER LES ATMOSPHÈRES  
DE MONDES LOINTAINS**



**ΕΧΟΠΛΑΝÈΤΕ?**

A view of Earth from space, showing the curvature of the planet and the atmosphere. A bright sun is visible in the upper left corner, and a small white rounded rectangle is centered on the image, containing the text "PLANÈTE?".

**PLANÈTE?**

# PLANÈTE

- Orbite autour du Soleil
- Masse suffisante pour que sa gravité la maintienne sous forme presque sphérique
- A éliminé tout objet de taille comparable se déplaçant sur son orbite

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# EXOPLANÈTE?

(= planète extrasolaire)

- Planète orbitant une autre étoile que le Soleil

# PLANÈTE

- Orbite autour du Soleil
- Masse suffisante pour que sa gravité la maintienne sous forme presque sphérique
- A éliminé tout objet de taille comparable se déplaçant sur son orbite

# EXOPLANÈTE

(= planète extrasolaire)

- Orbite étoiles, naine brunes ou rémanents stellaires (avec  $M > 25 \times M_{\text{exoplanète}}$ )
- Masse  $<$  masse permettant fusion thermonucléaire du deutérium (masse minimal même que pour système solaire)



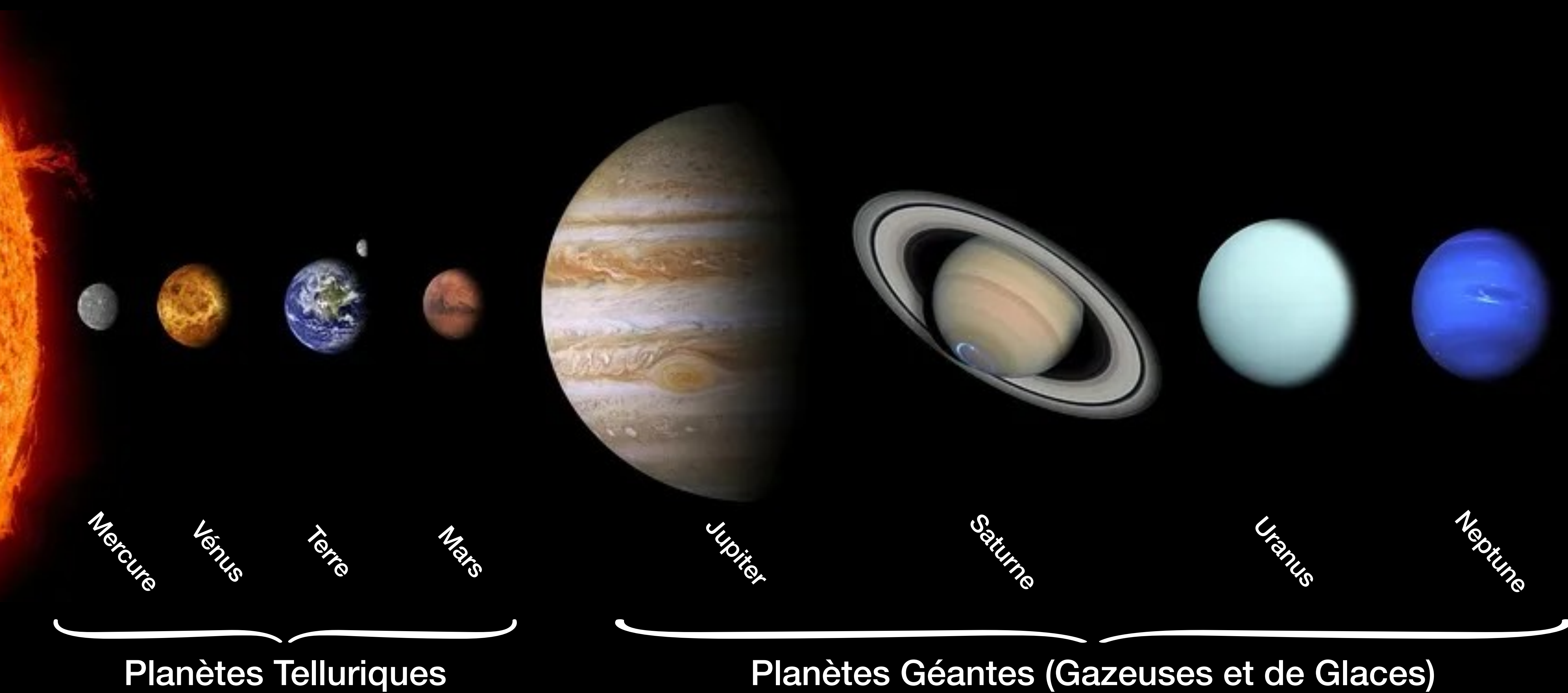
**POURQUOI SONDER LES  
ATMOSPHÈRES DE MONDES  
LOINTAINS ?**



# UNE DIVERSITÉ ÉNORME DE PLANÈTES



# Systeme solaire: exemple de diversité planétaire



Mercure

Vénus

Terre

Mars

Jupiter

Saturne

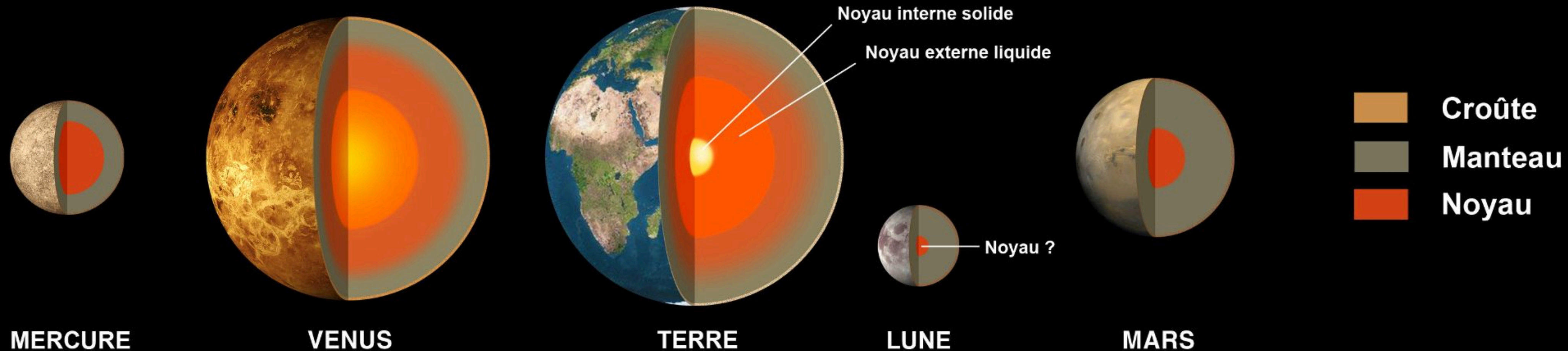
Uranus

Neptune

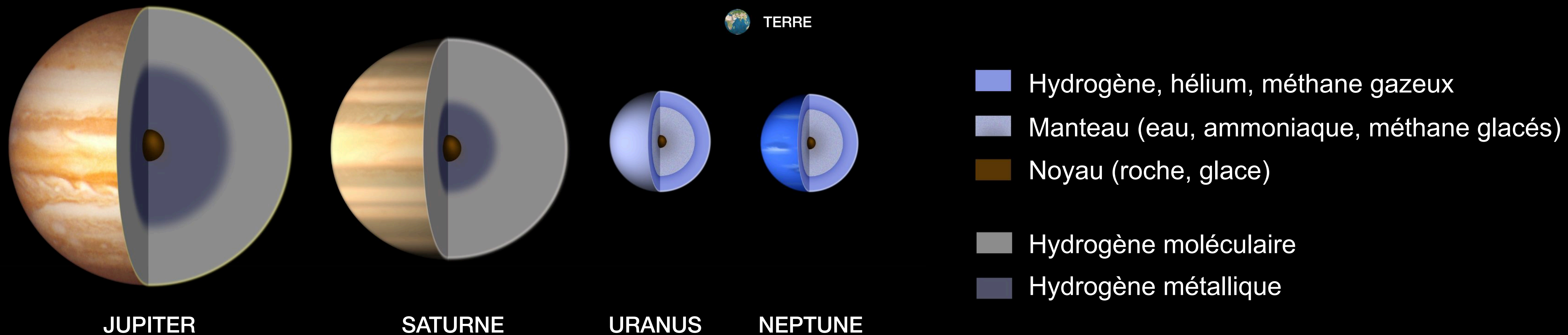
Planètes Telluriques

Planètes Géantes (Gazeuses et de Glaces)

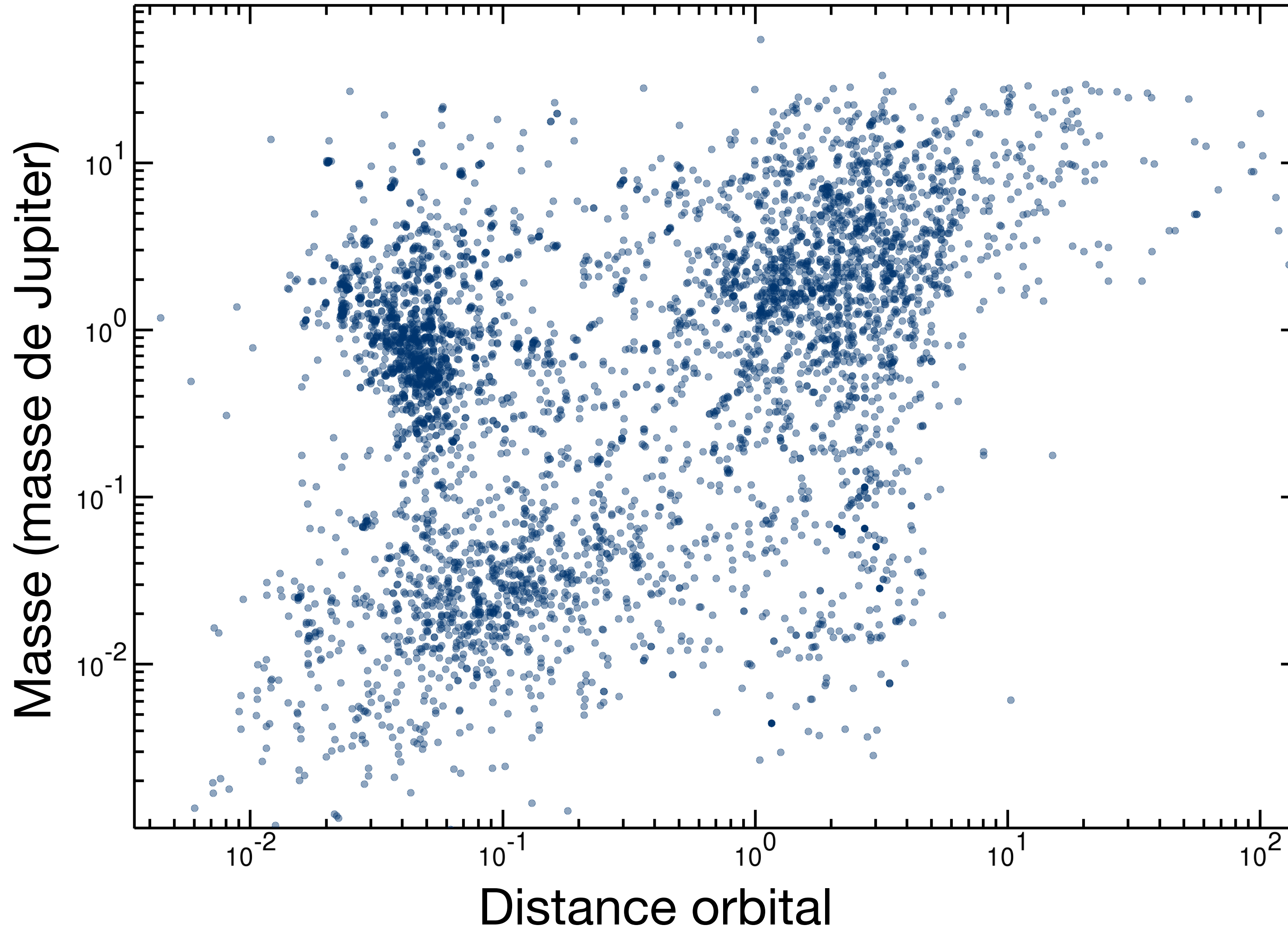
## Planètes Telluriques



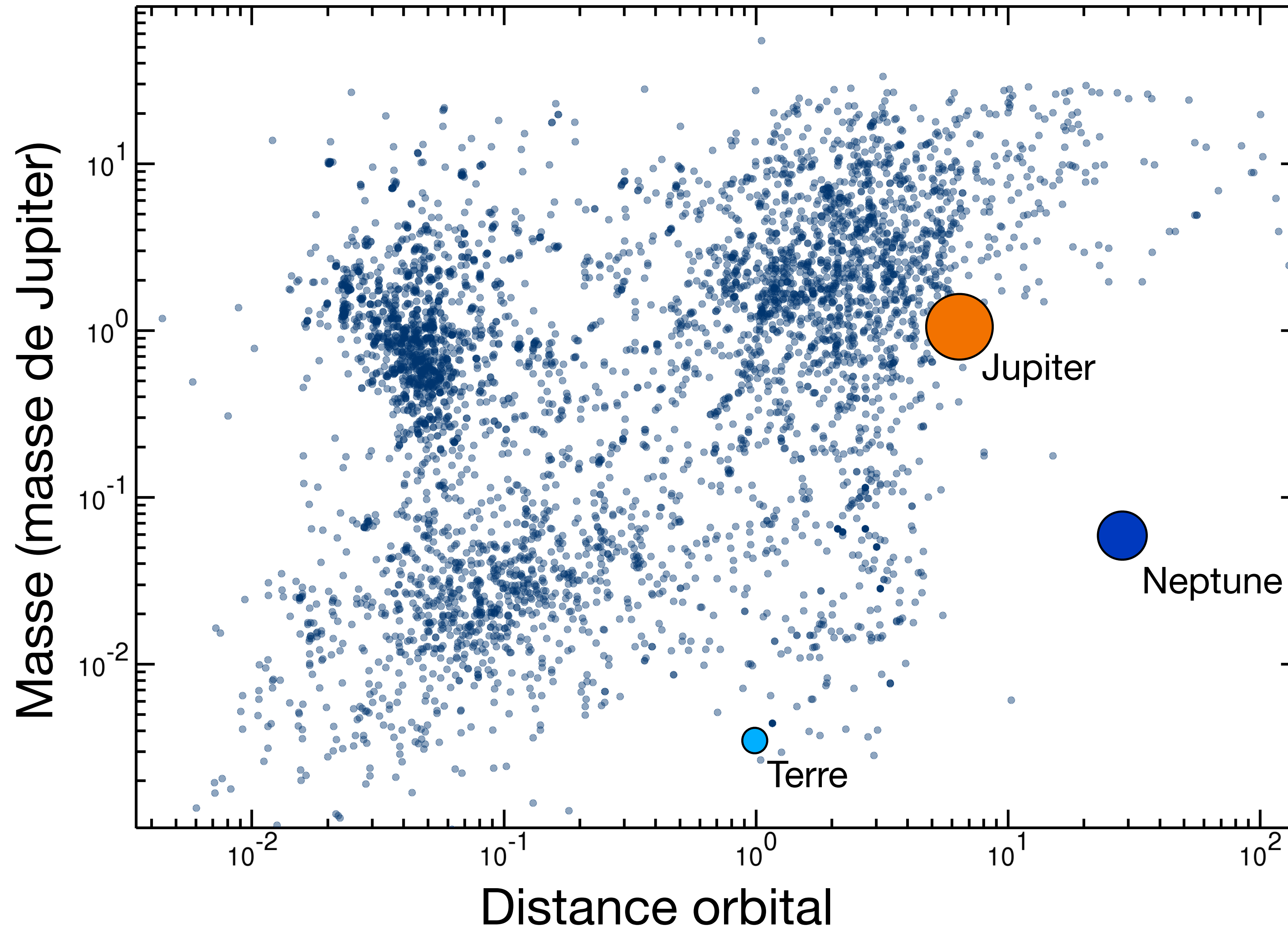
## Planètes Géantes (Gazeuses et de Glaces)



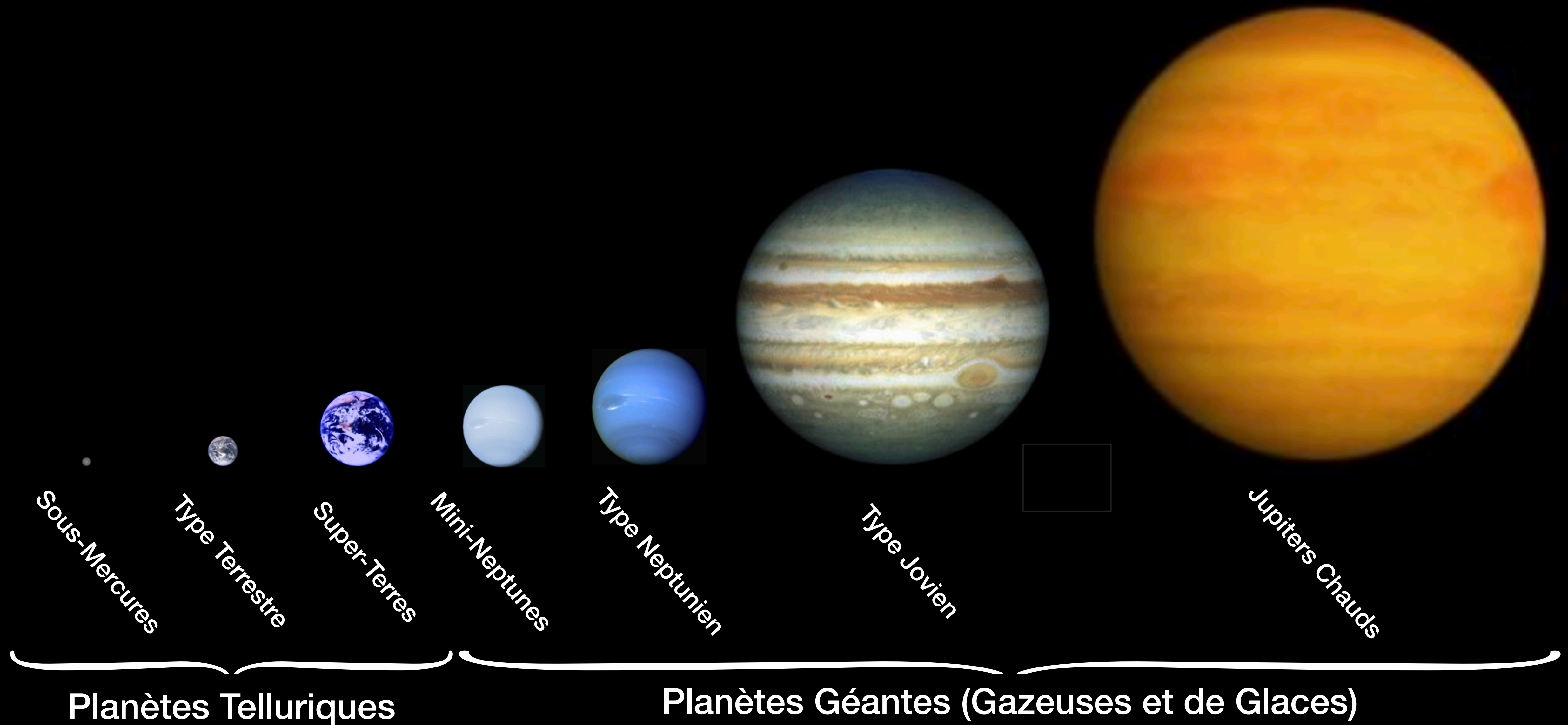
# Exoplanètes Confirmées



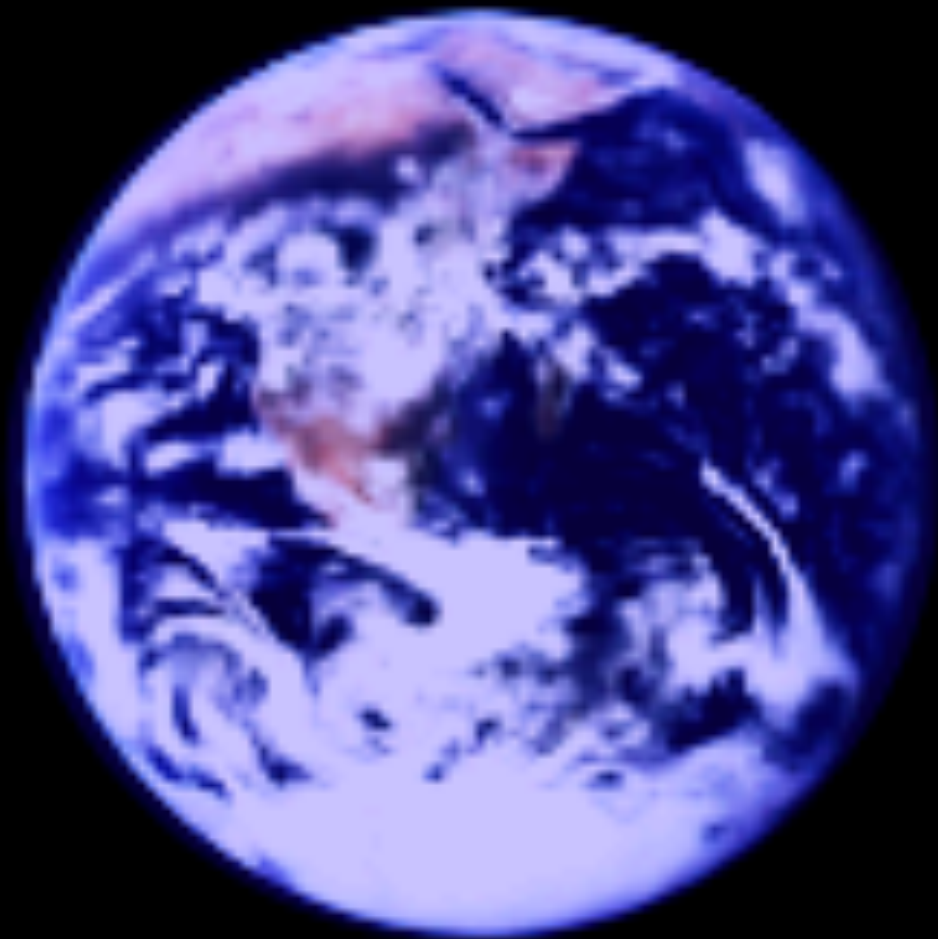
# Exoplanètes Confirmées



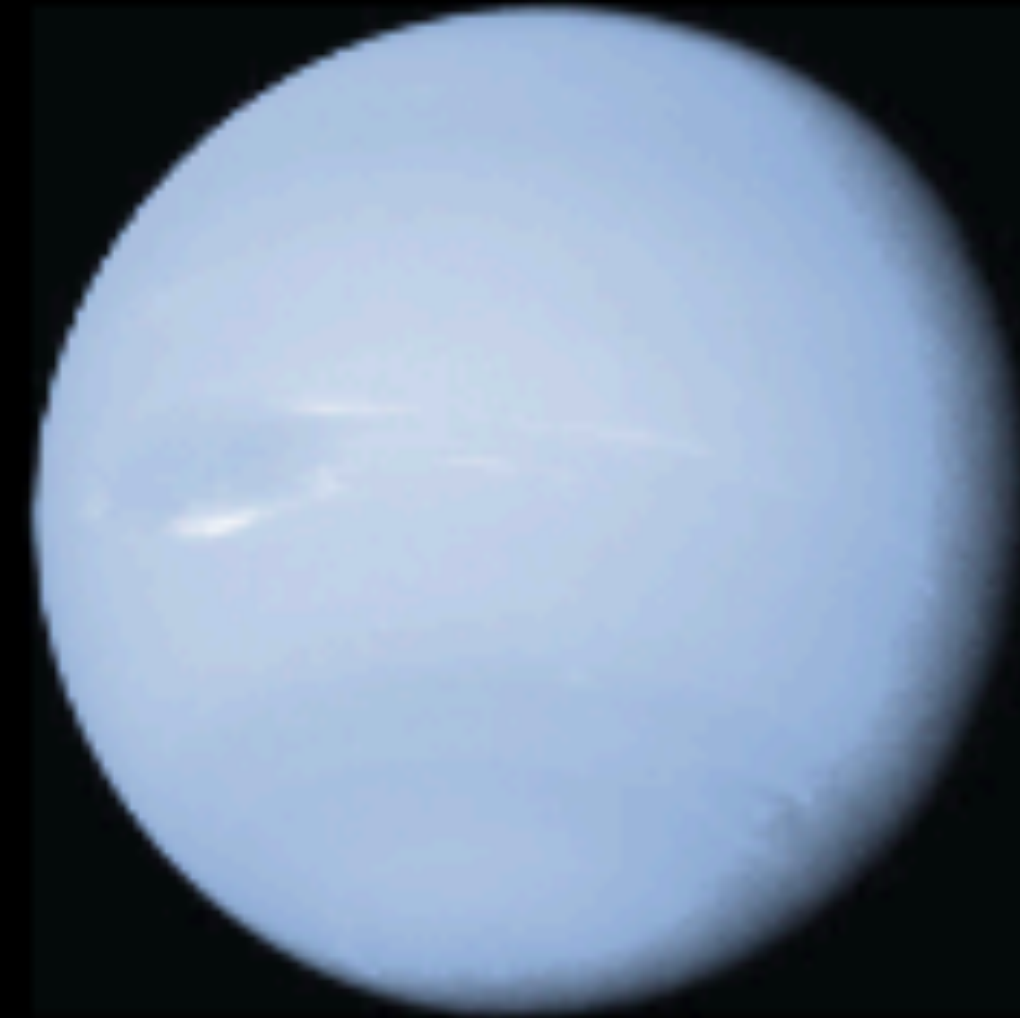
# Exoplanètes: une diversité planétaire énorme



# Des planètes similaires, mais très différents!



Super-Terres



Mini-Neptunes

Taille et masse comparable

# Des planètes similaires, mais très différents!

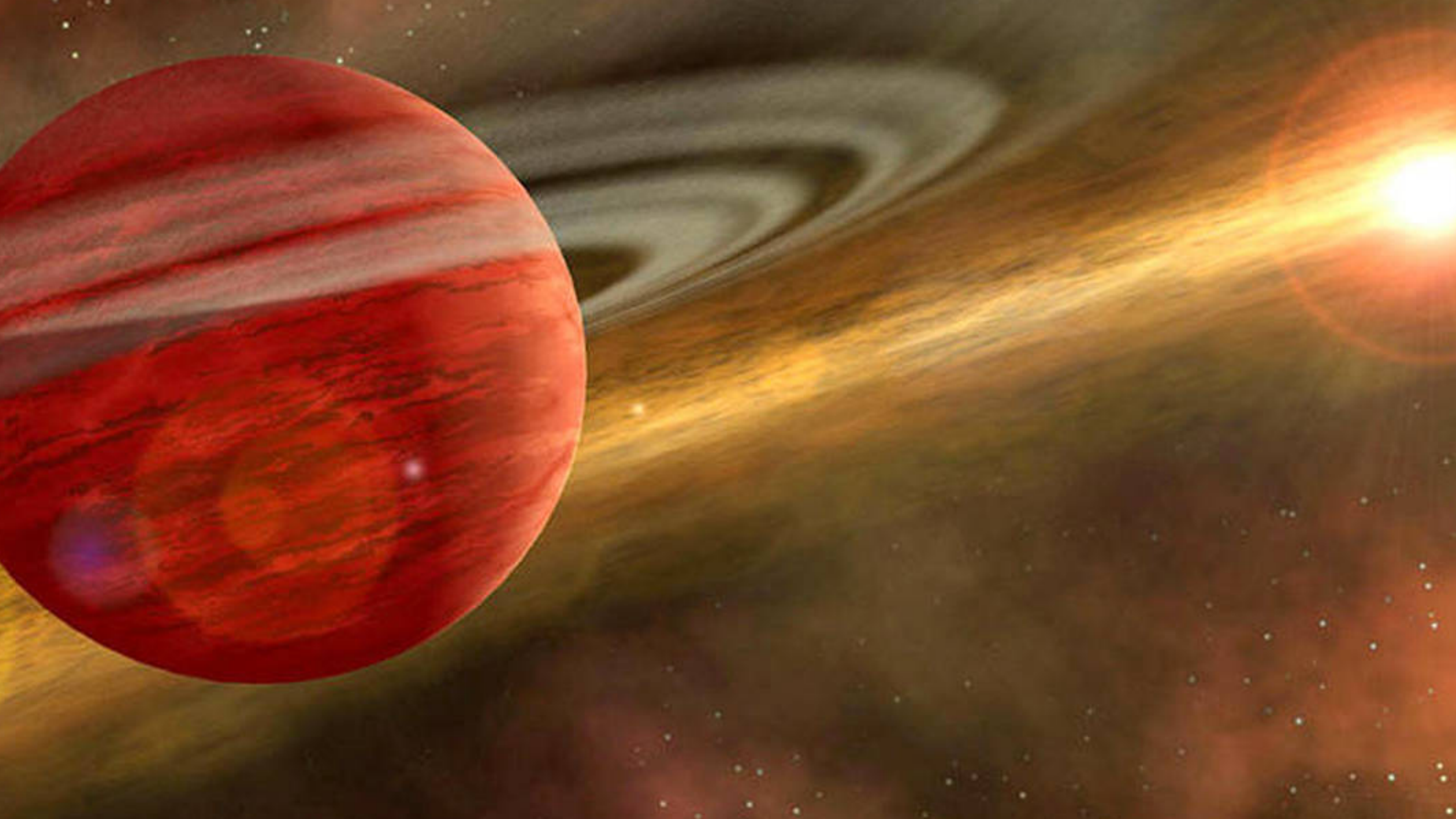


**Planètes telluriques  $\neq$  Planètes Géantes de Glaces**


**Super-Terres**

**Mini-Neptunes**

**Taille et masse comparable**

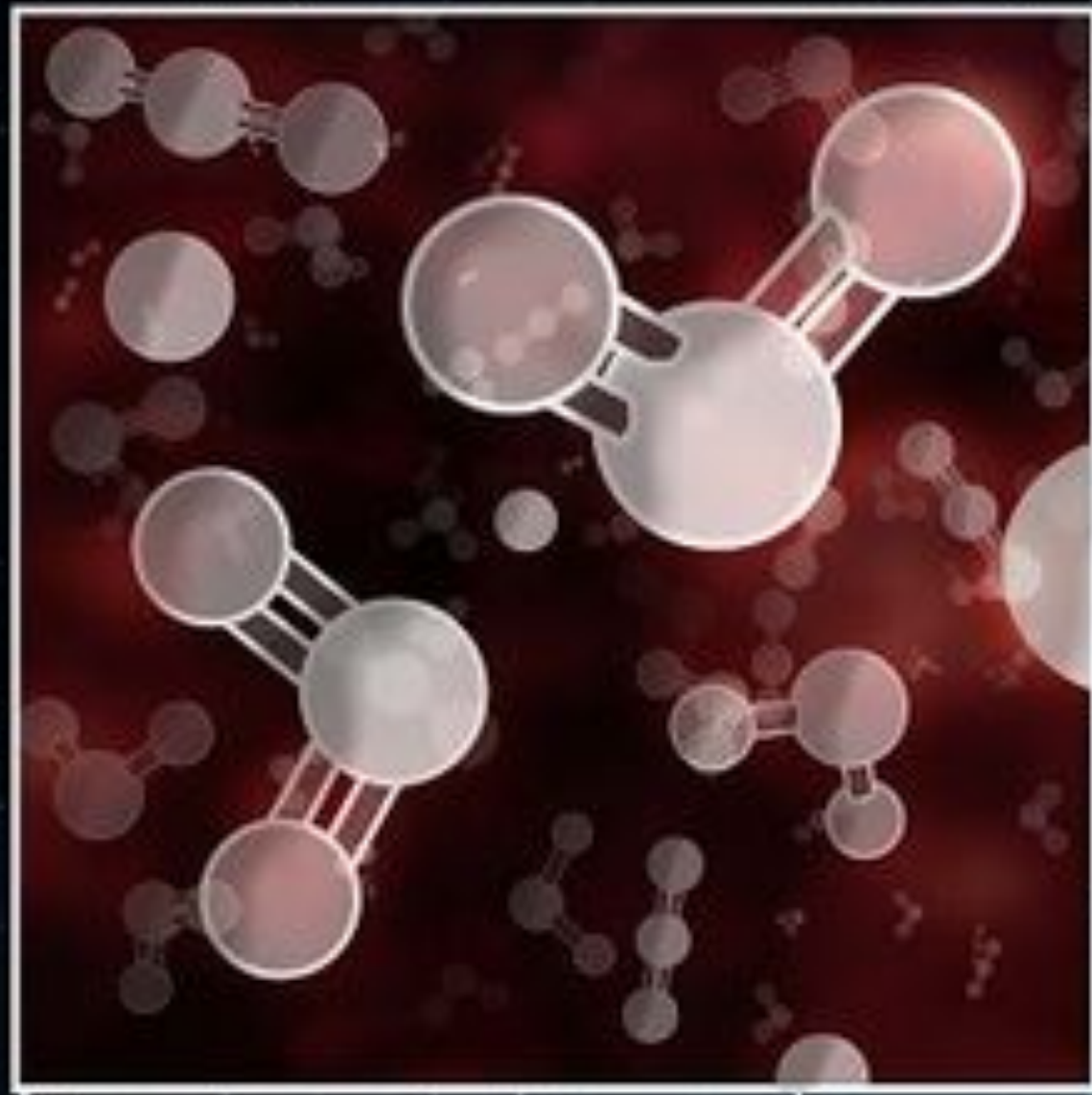






**Proxima Centauri b = la plus proche**  
**⇒ 40 000 milliards de km**  
**(4,2 années lumières)**

# Atmosphères, une fenêtre sur les propriétés planétaire



- Composition chimique
- Profil de température
- Dynamique de la planète et de l'atmosphère (rotation et vents)

...

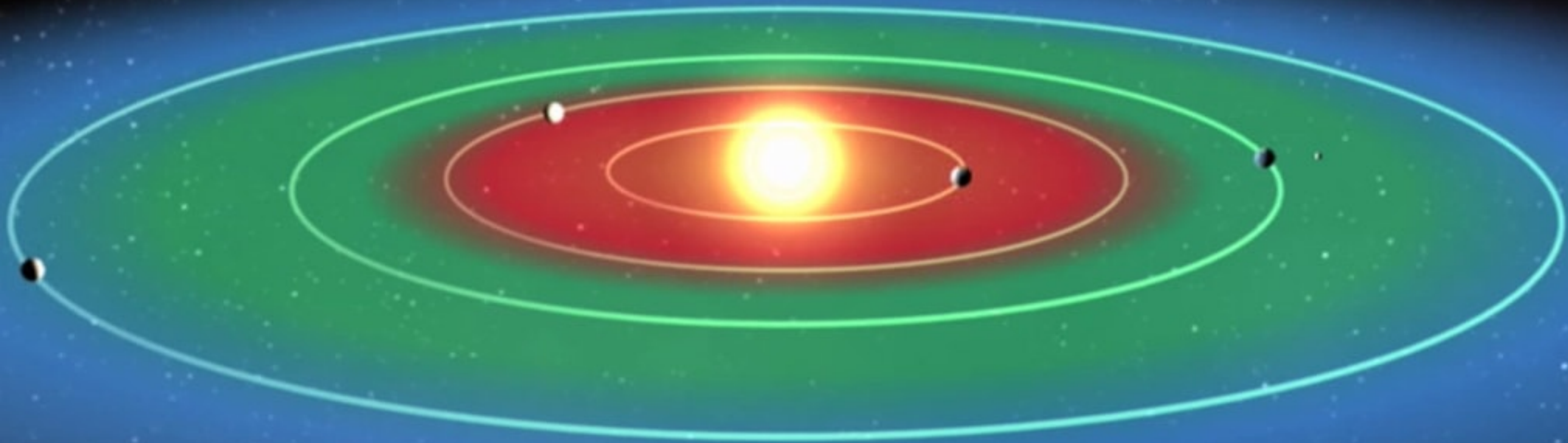
# Atmosphères, une fenêtre sur les propriétés planétaire

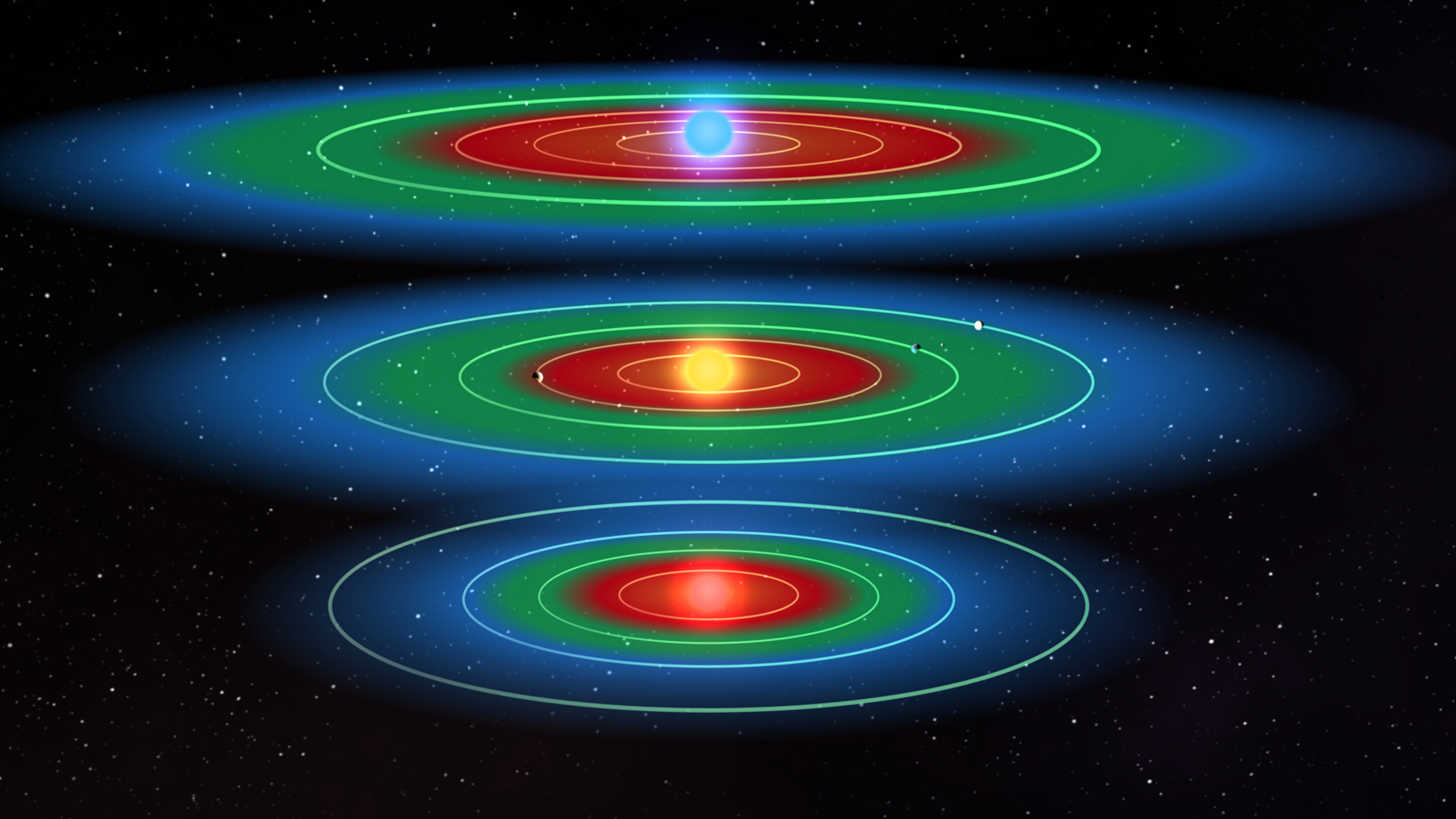


# HABITABILITÉ

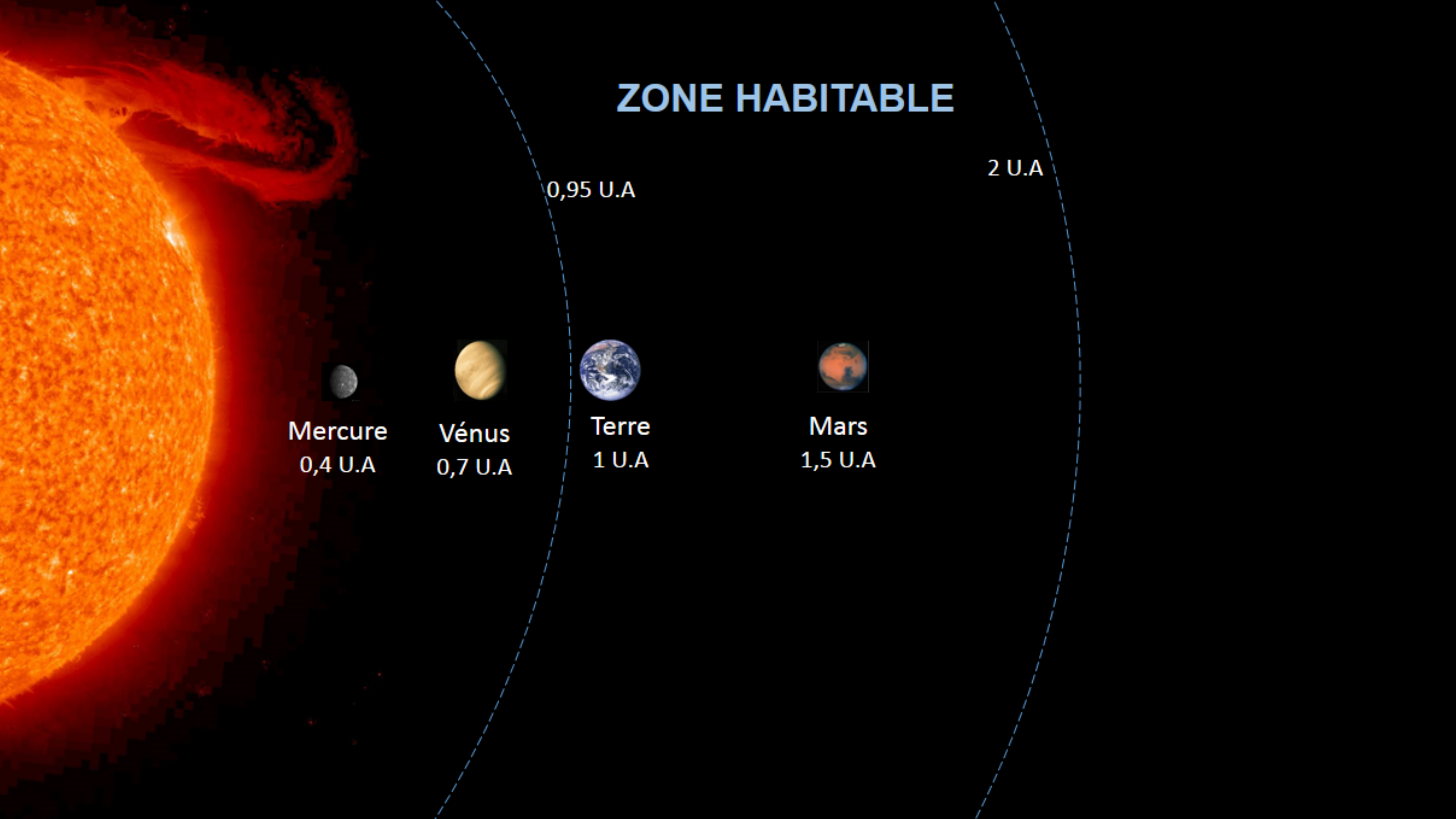
The image features a central yellow star with a red and orange glow. Several elliptical orbits are shown in shades of green and blue. Three planets are depicted: a small white planet on the innermost orbit, a larger grey planet on the middle orbit, and a planet with a white and black surface on the outermost orbit. A white rectangular box with rounded corners and a black border is positioned in the upper-middle part of the image, containing the word 'HABITABILITÉ' in a bold, black, sans-serif font.

**Zone habitable = région autour d'une étoile où les conditions sont favorables à l'apparition de la vie telle que nous la connaissons sur Terre**





# ZONE HABITABLE



0,95 U.A.

2 U.A.

Mercure  
0,4 U.A.

Vénus  
0,7 U.A.

Terre  
1 U.A.

Mars  
1,5 U.A.

The image is a composite of two planetary surfaces. The left side shows a desolate, orange-red landscape with dark, rocky patches, representing a planet without a significant atmosphere. The right side shows a lush, blue and green planet with white clouds, representing a habitable planet with a thick atmosphere. A bright sun is visible in the upper center, casting a glow over both scenes. A white text box with a black border is centered over the image.

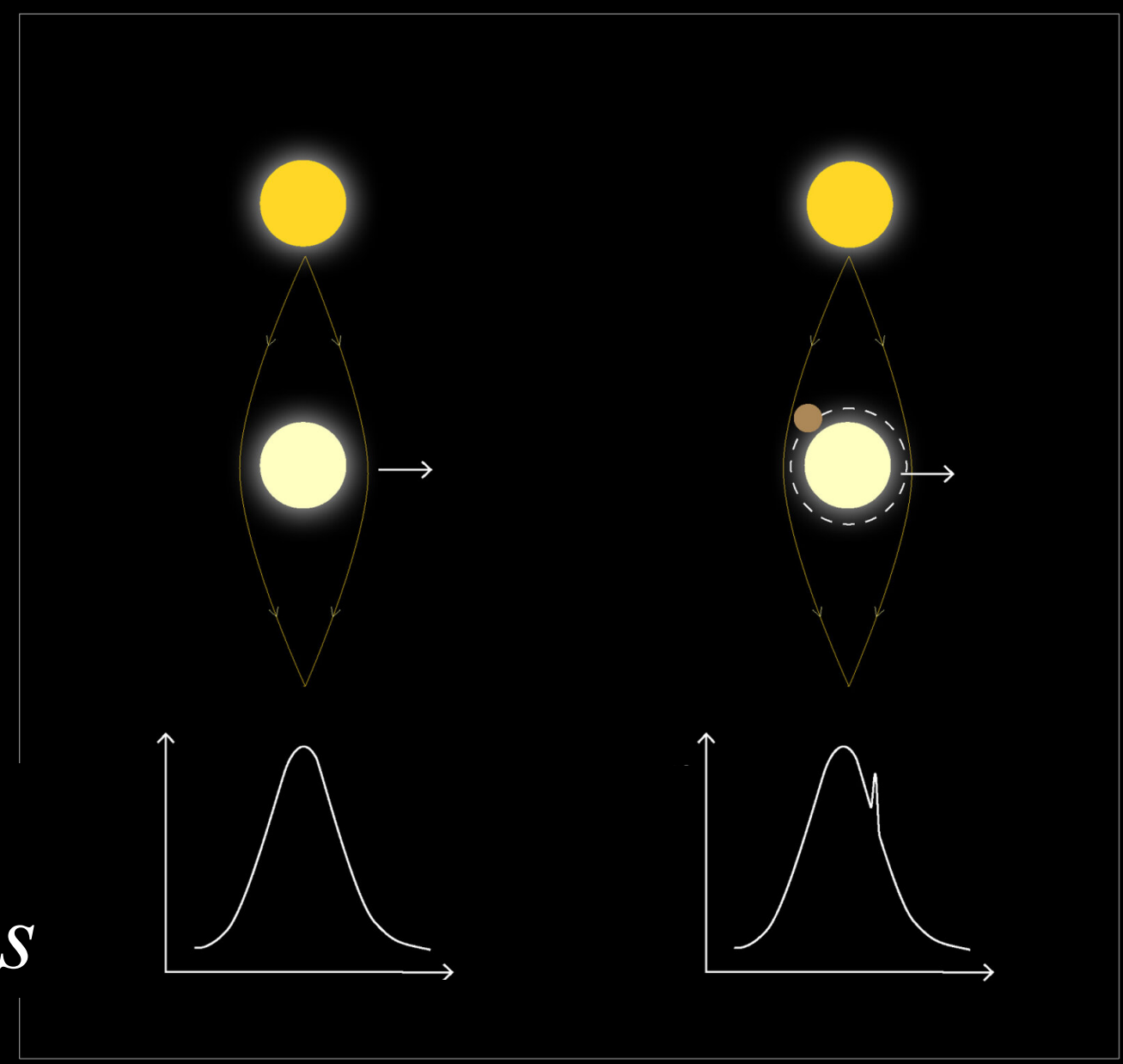
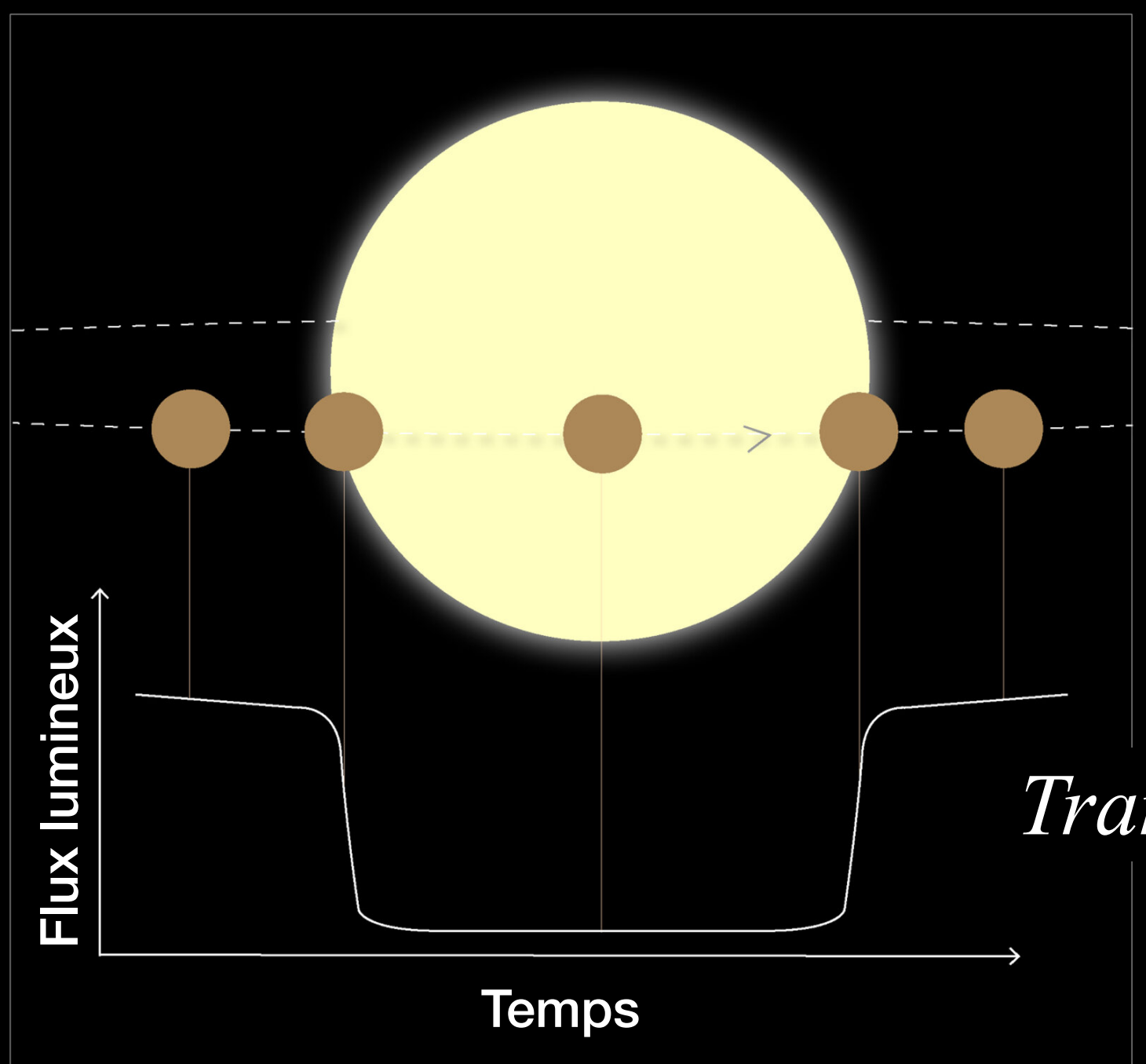
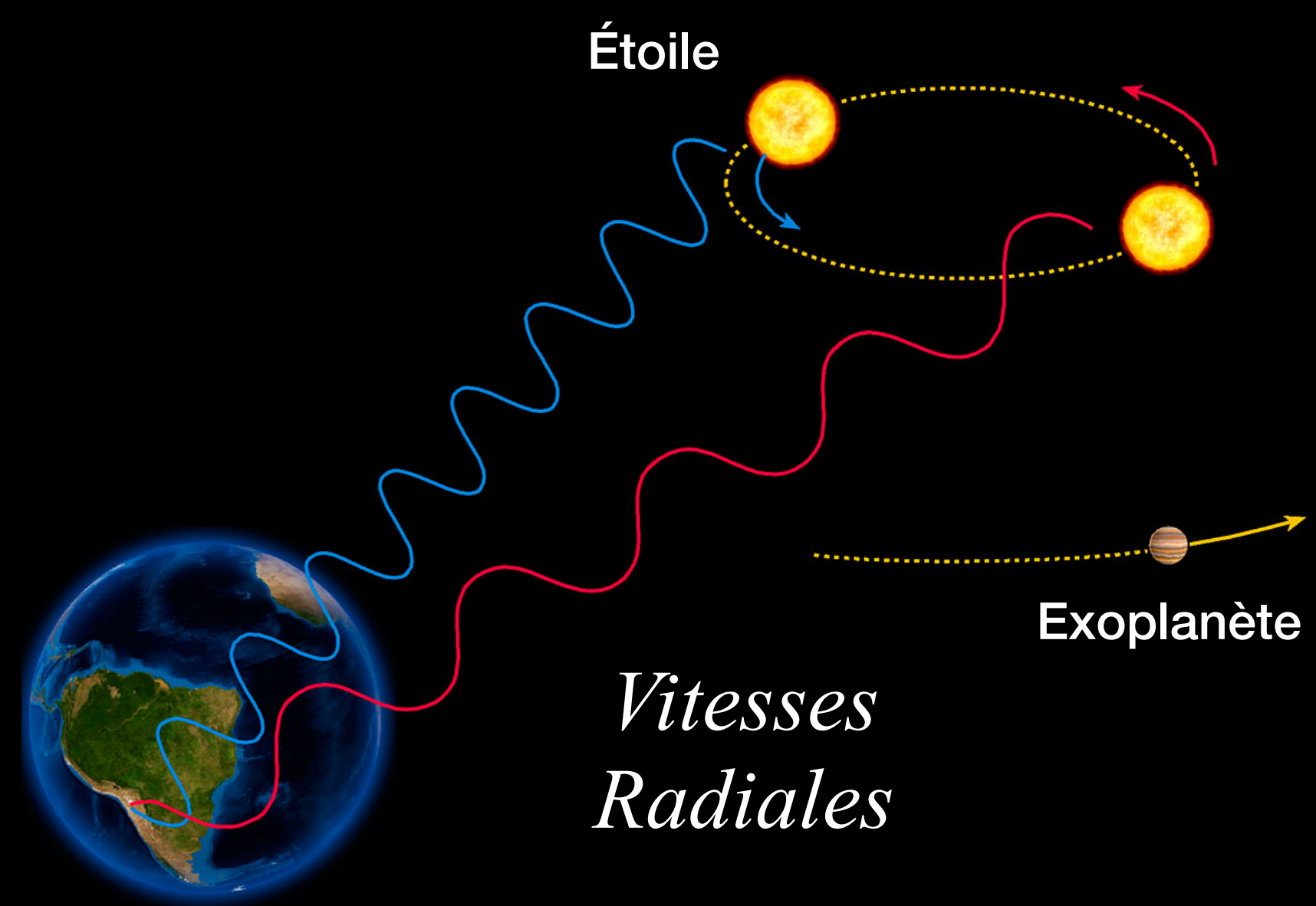
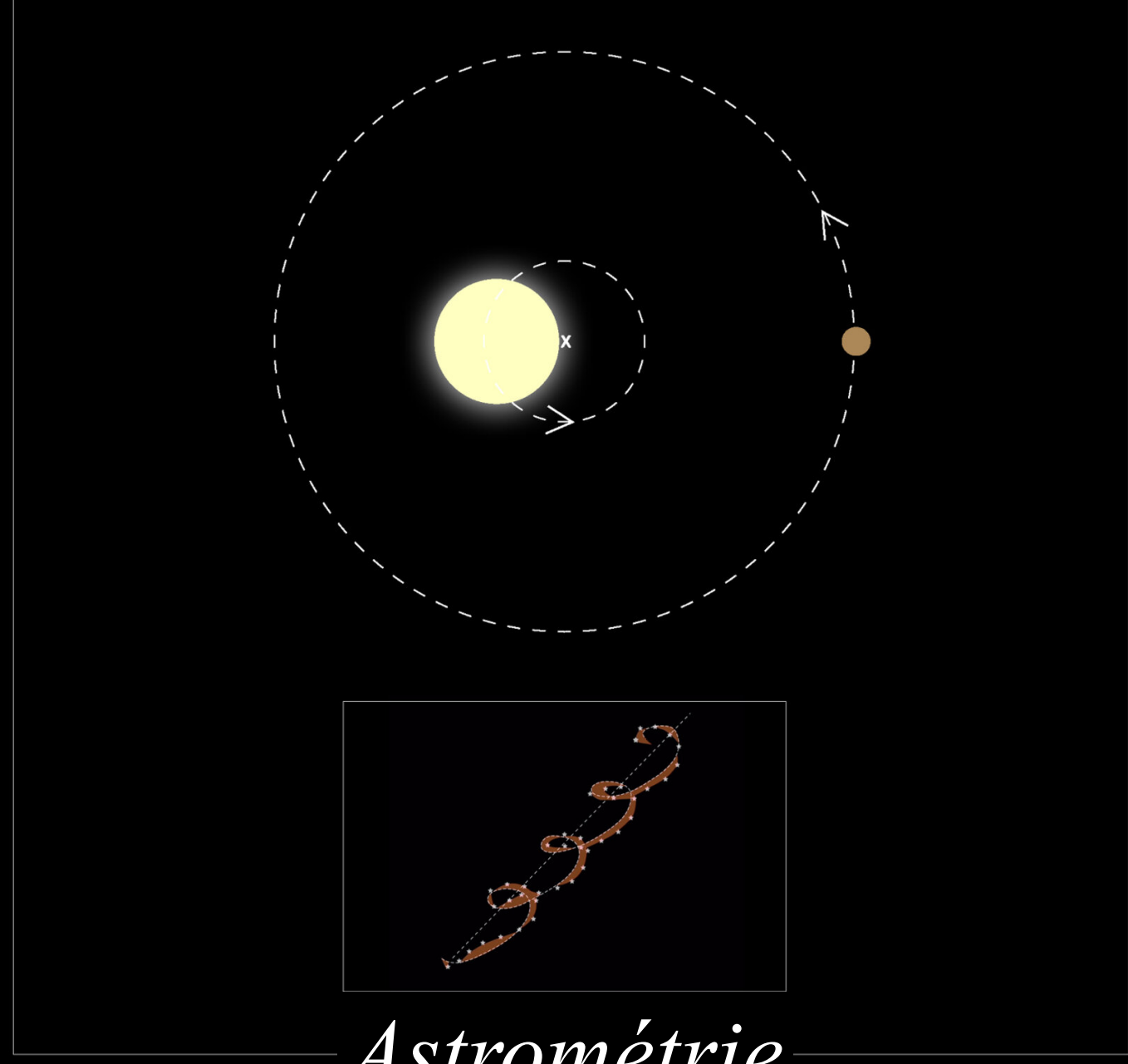
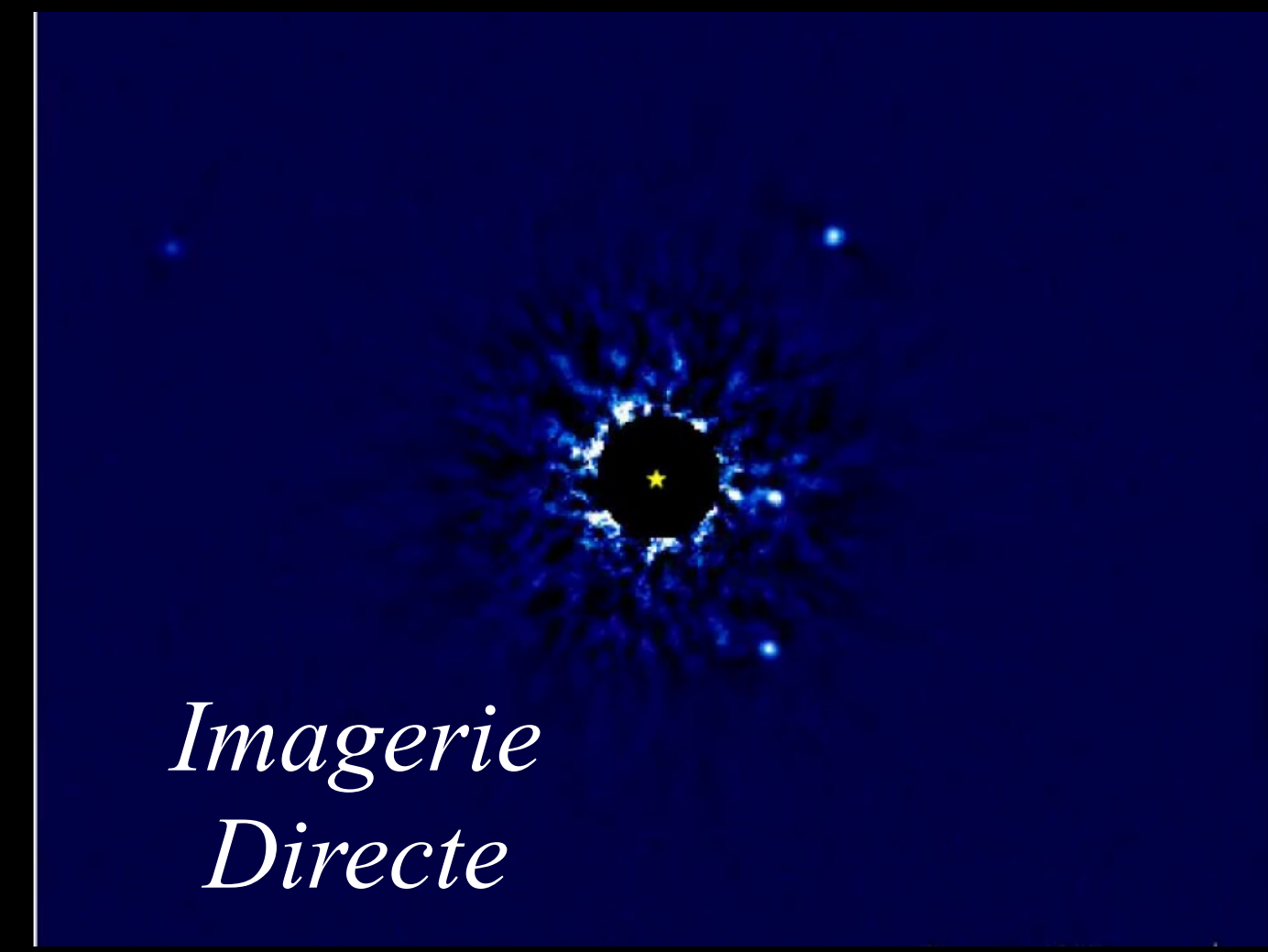
**Présence (ou non) d'un atmosphère impact  
l'habitabilité**



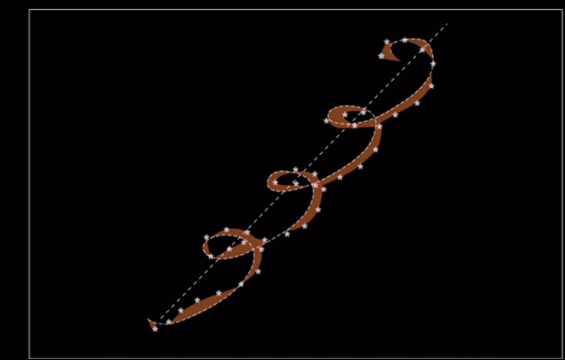
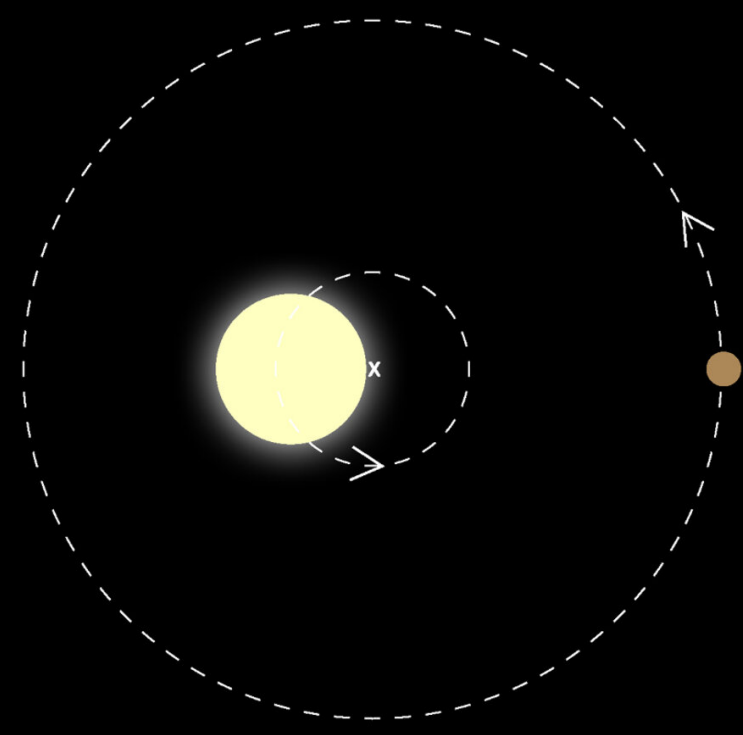
The background of the slide is a composite image of space. The top half shows a dark blue space with a bright light source and a faint rainbow-like spectrum. The bottom half shows the curved horizon of Earth with a reddish-orange surface, likely Mars, visible below. A white, rounded rectangular box with a black border is centered in the middle of the image.

**COMMENT SONDER LES  
ATMOSPHÈRES DE MONDES  
LOINTAINS ?**

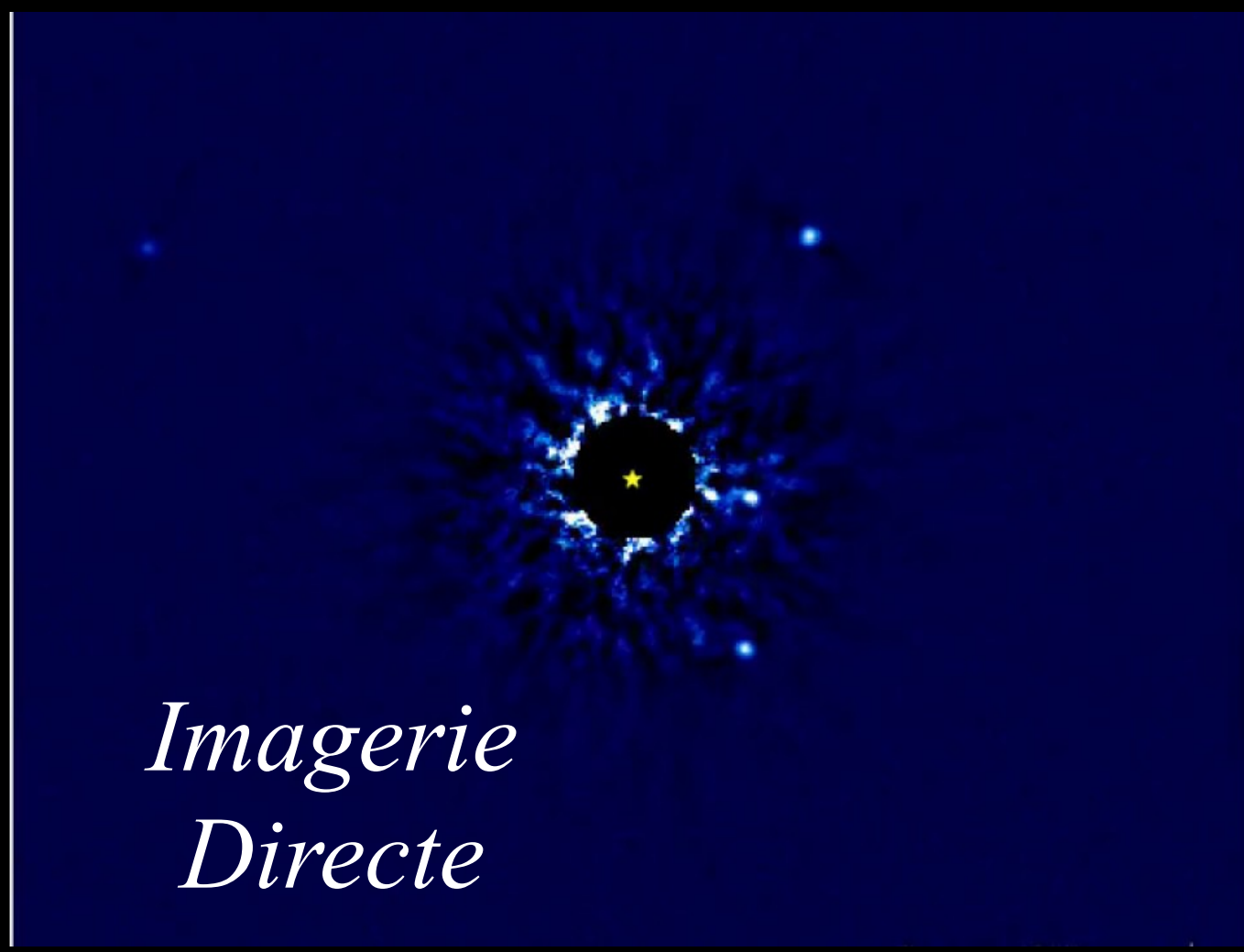
# Détection d'exoplanètes



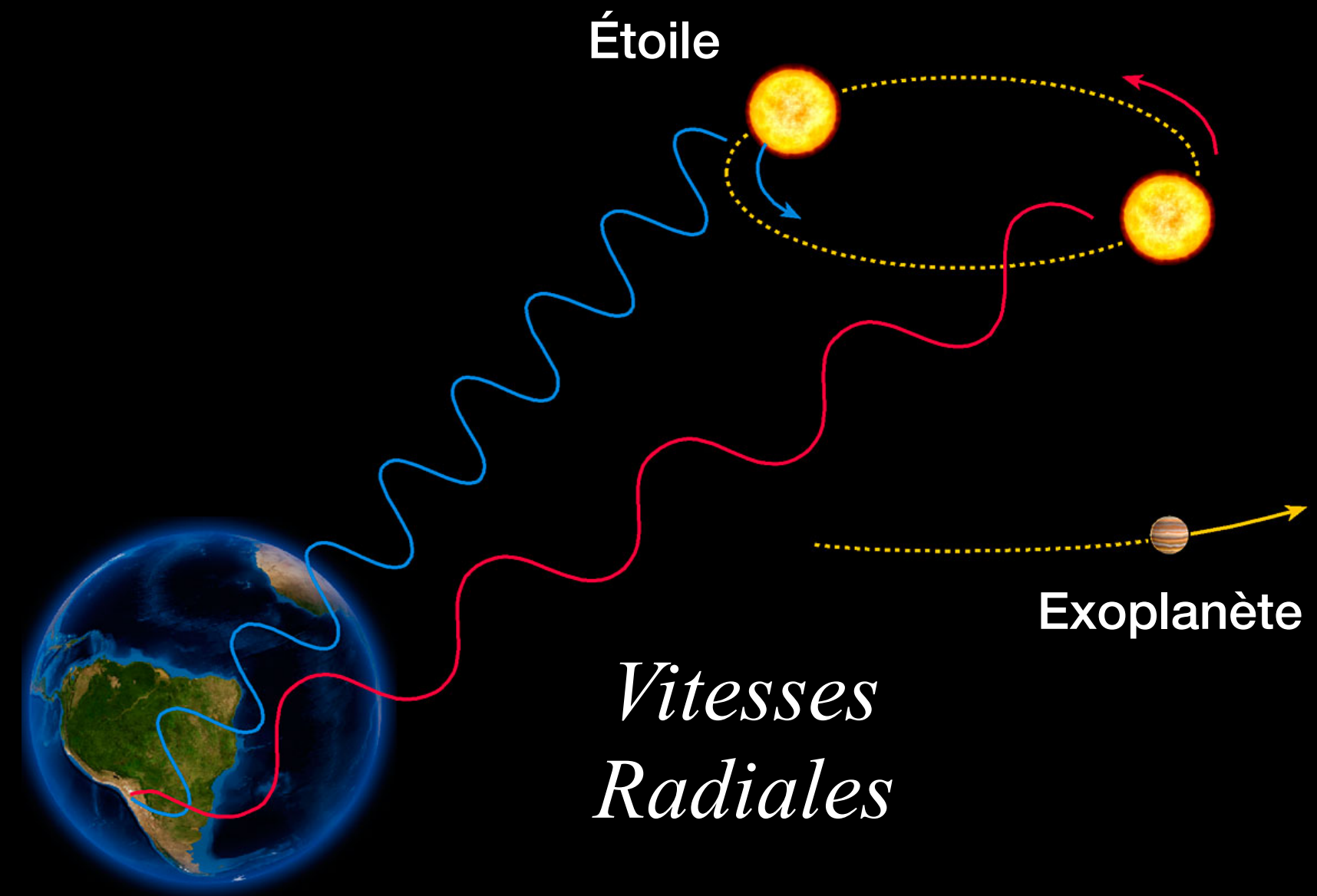
# Détection d'exoplanètes



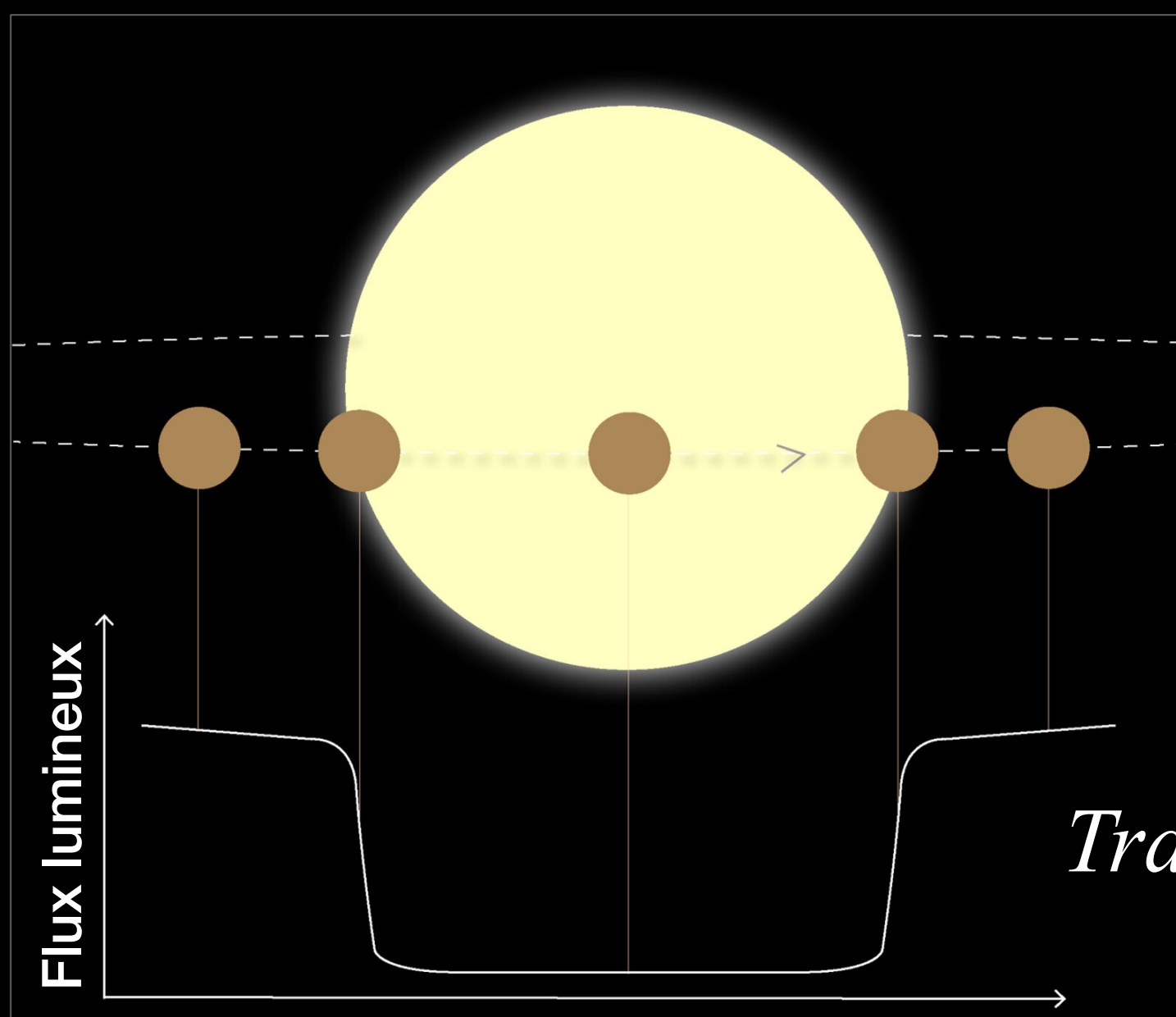
*Astrométrie*



*Imagerie Directe*

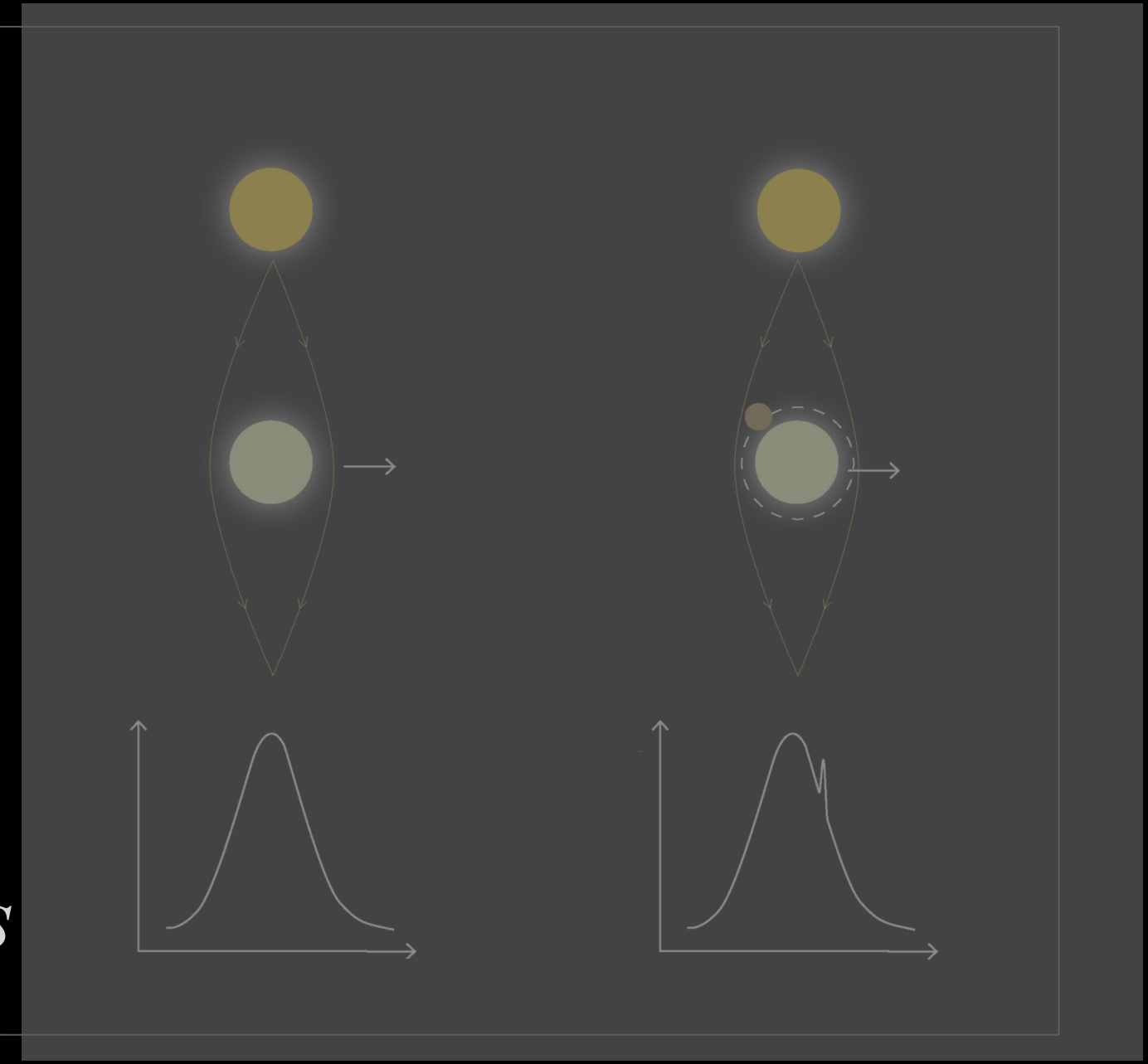


*Vitesses Radiales*



*Transits*

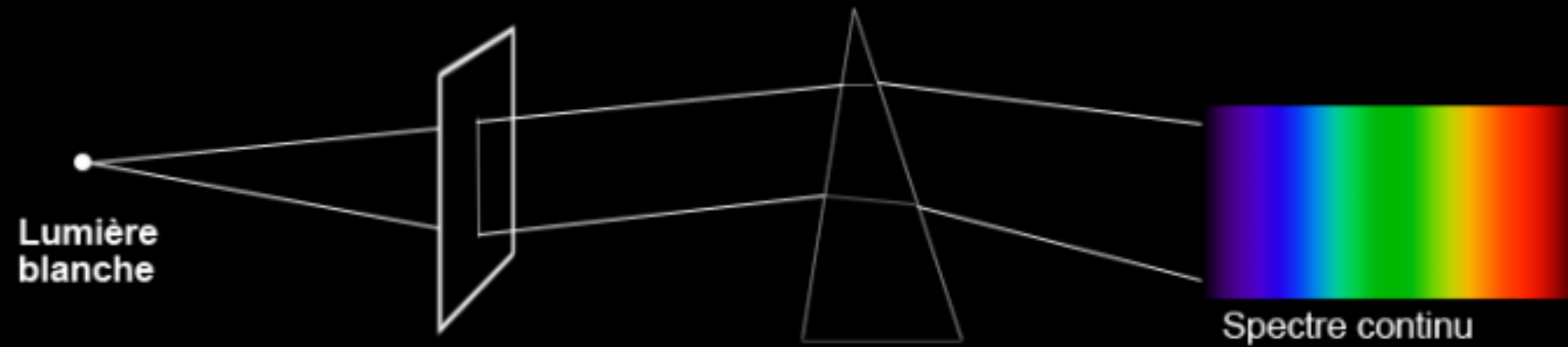
*Microlentilles Gravitationnelles*



# Spectroscopie

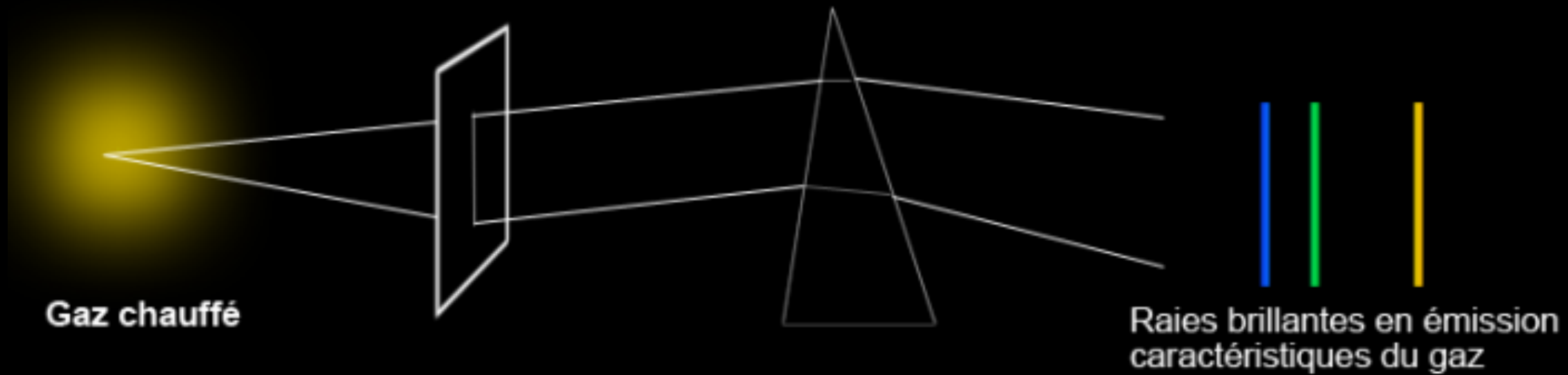
Source

Spectre obtenu



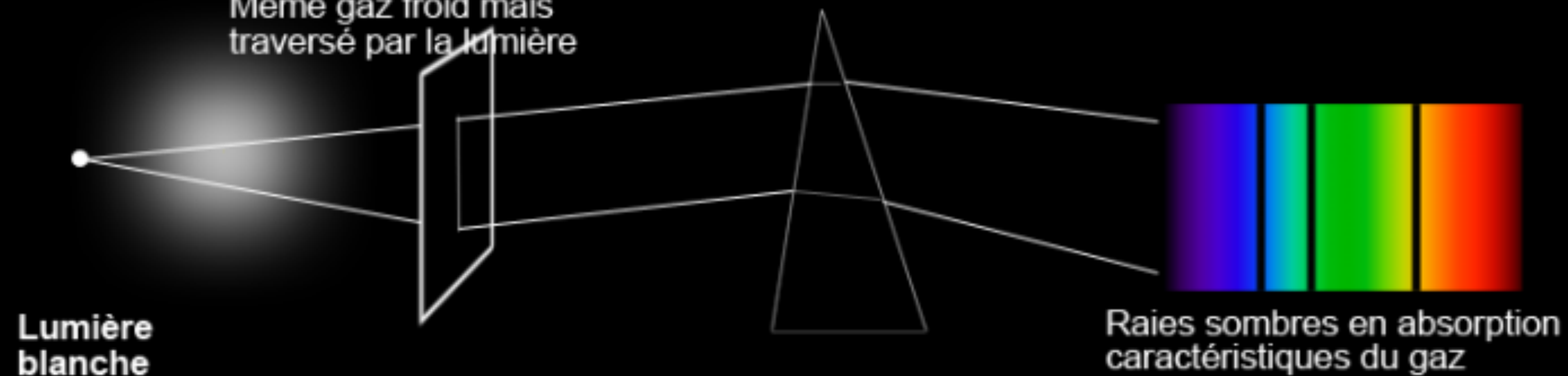
Gaz chauffé

*Émission*

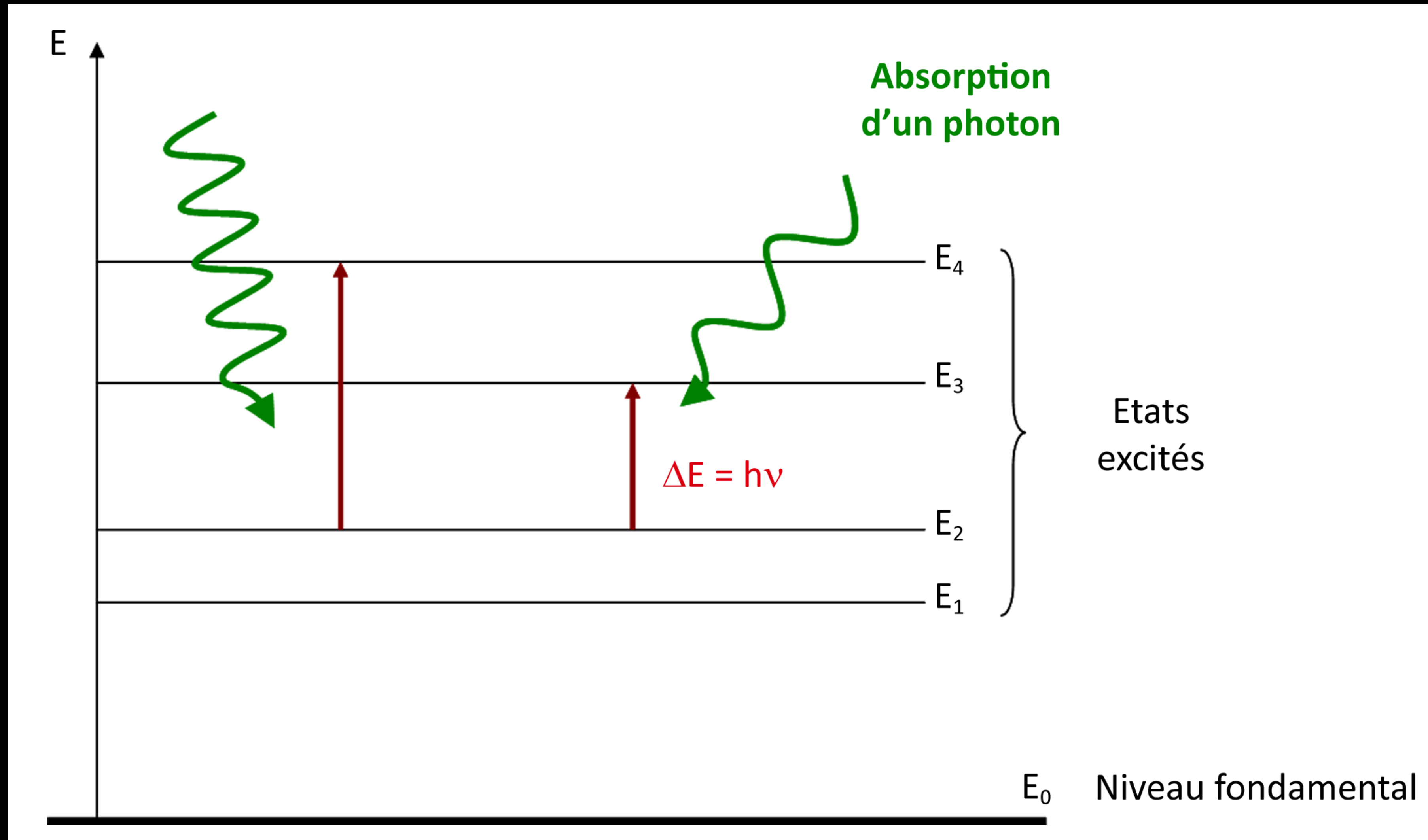


Même gaz froid mais  
traversé par la lumière

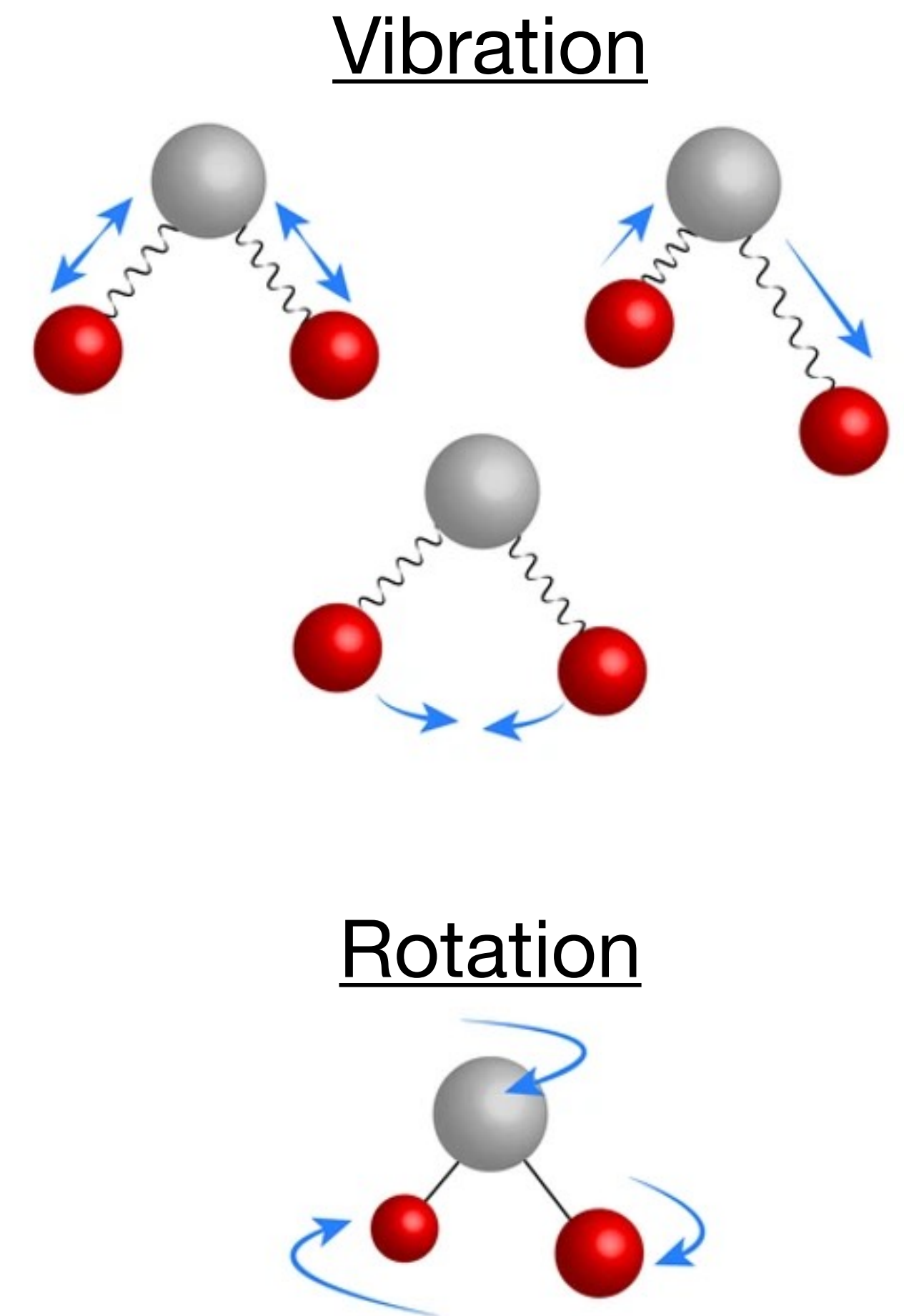
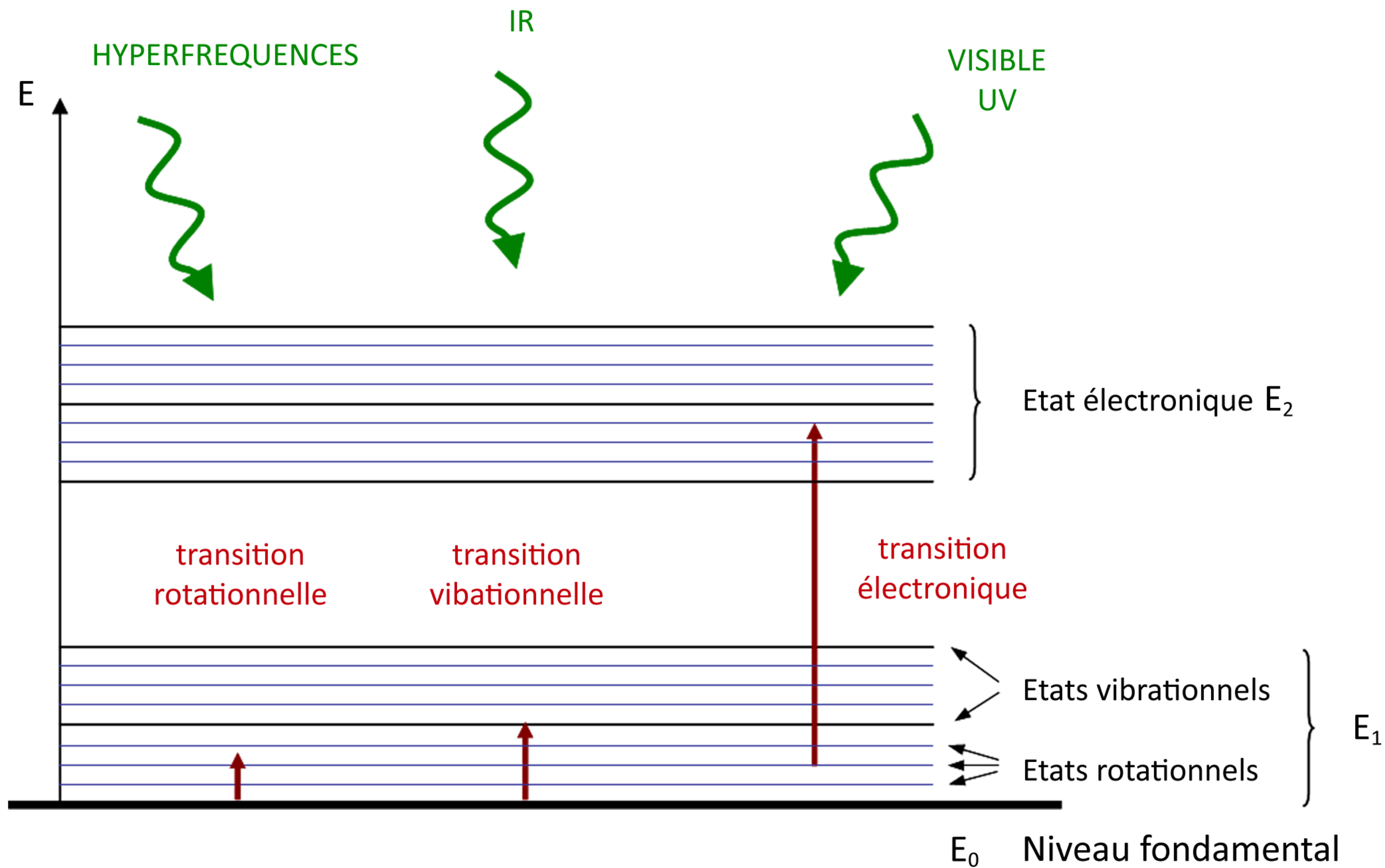
*Transmission*



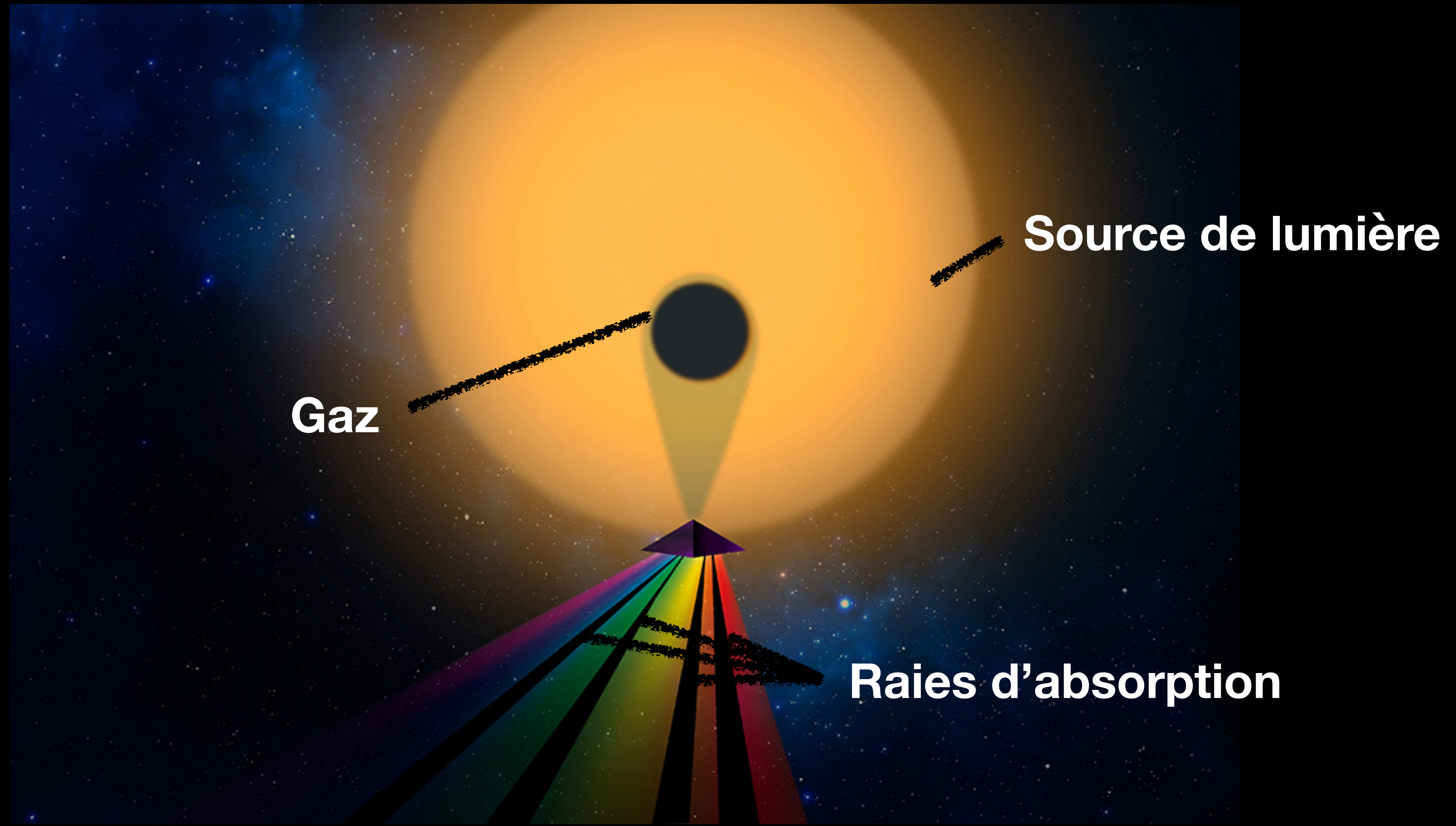
# Raies d'absorption/émission = Transitions énergétiques



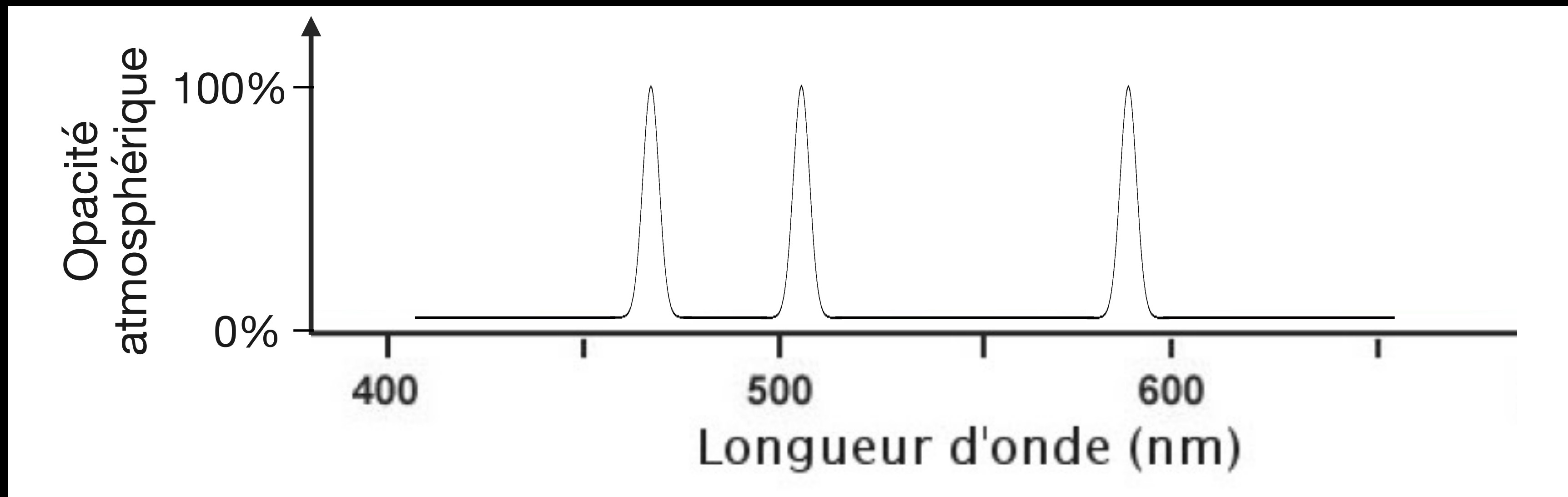
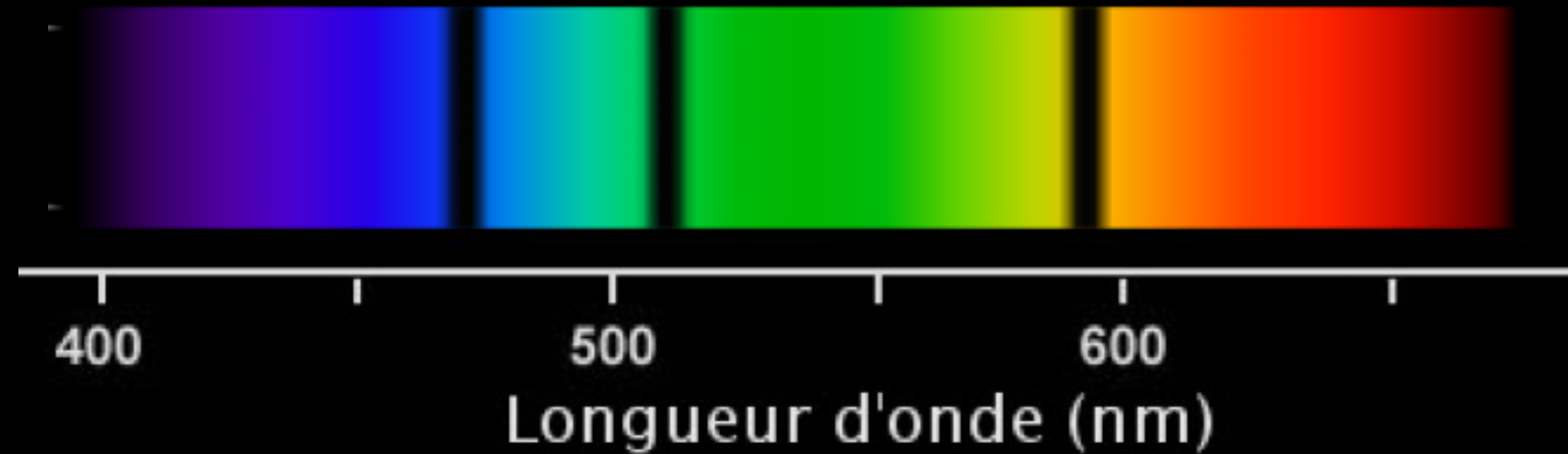
# Raies d'absorption/émission = Transitions énergétiques



# Spectroscopie des atmosphères

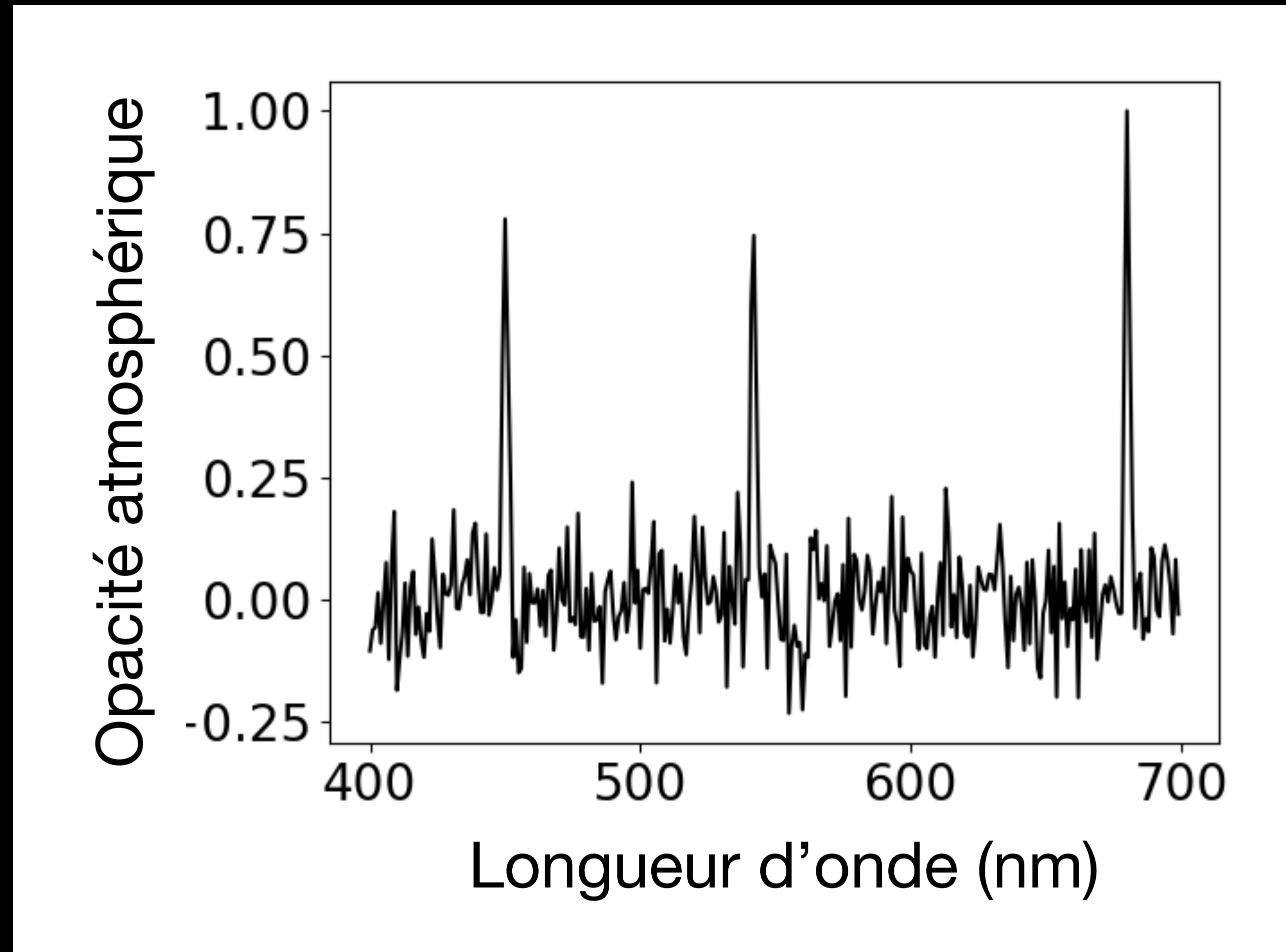


# Spectroscopie des atmosphères



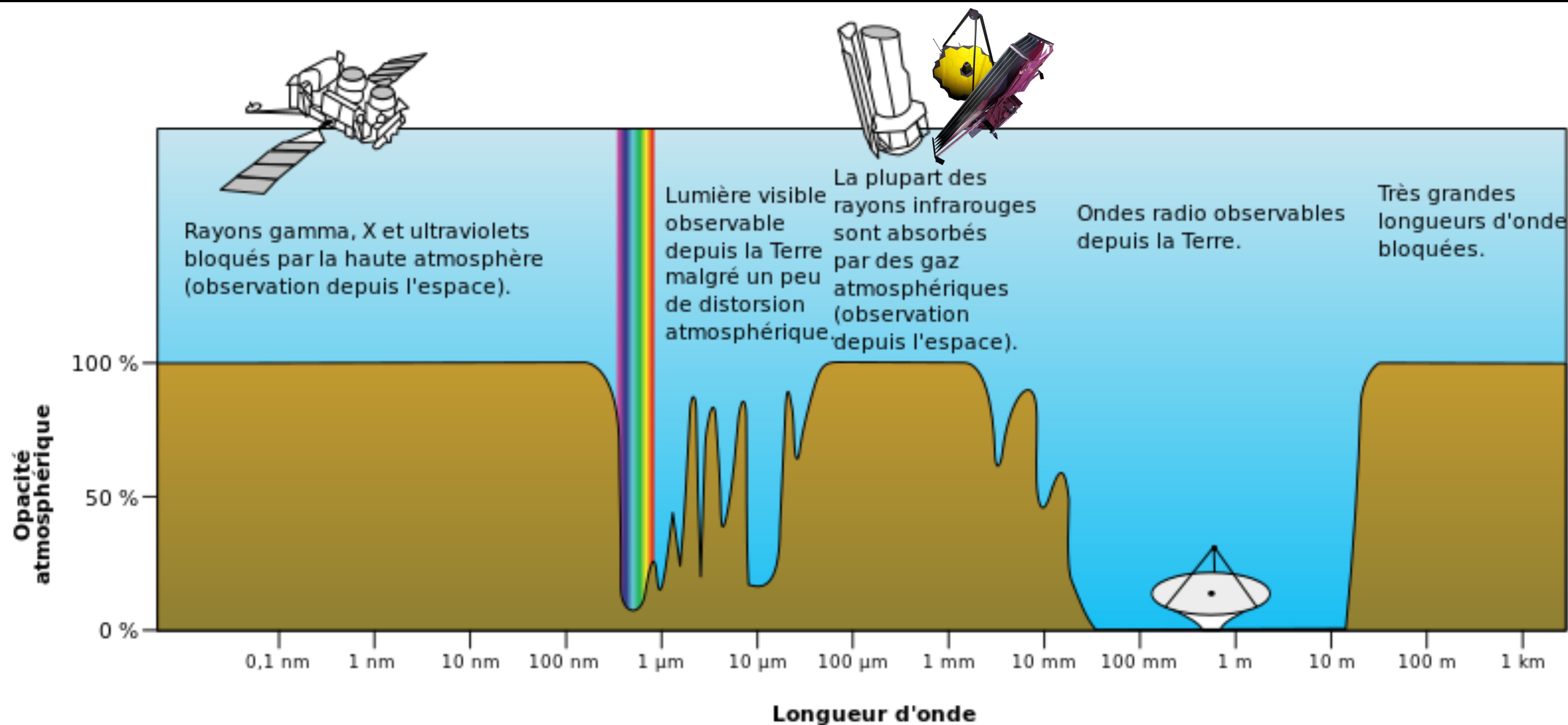


# Spectroscopie des atmosphères



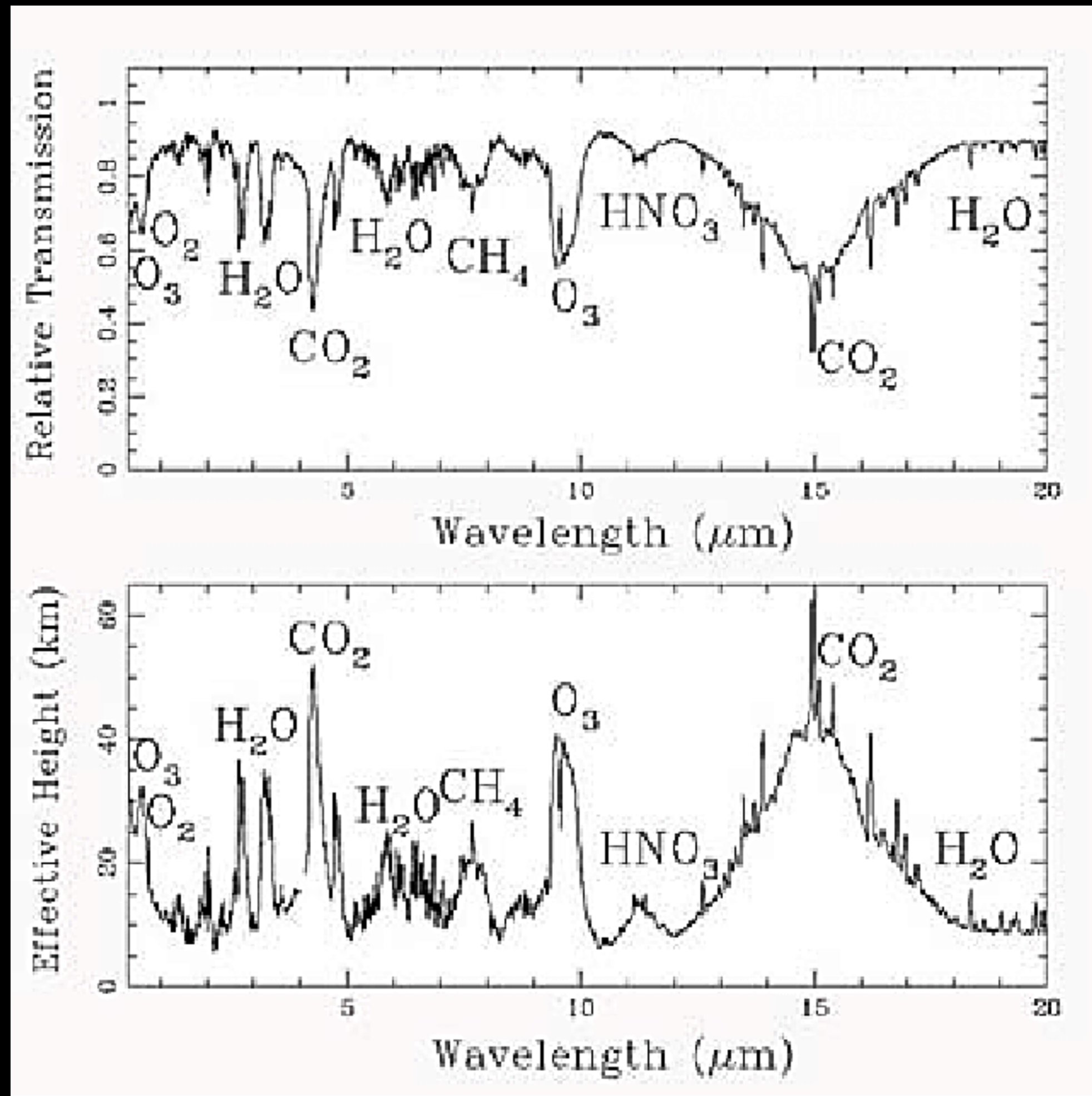
# Spectroscopie des atmosphères

*Exemple: spectre de l'atmosphère Terrestre*



# Spectroscopie des atmosphères

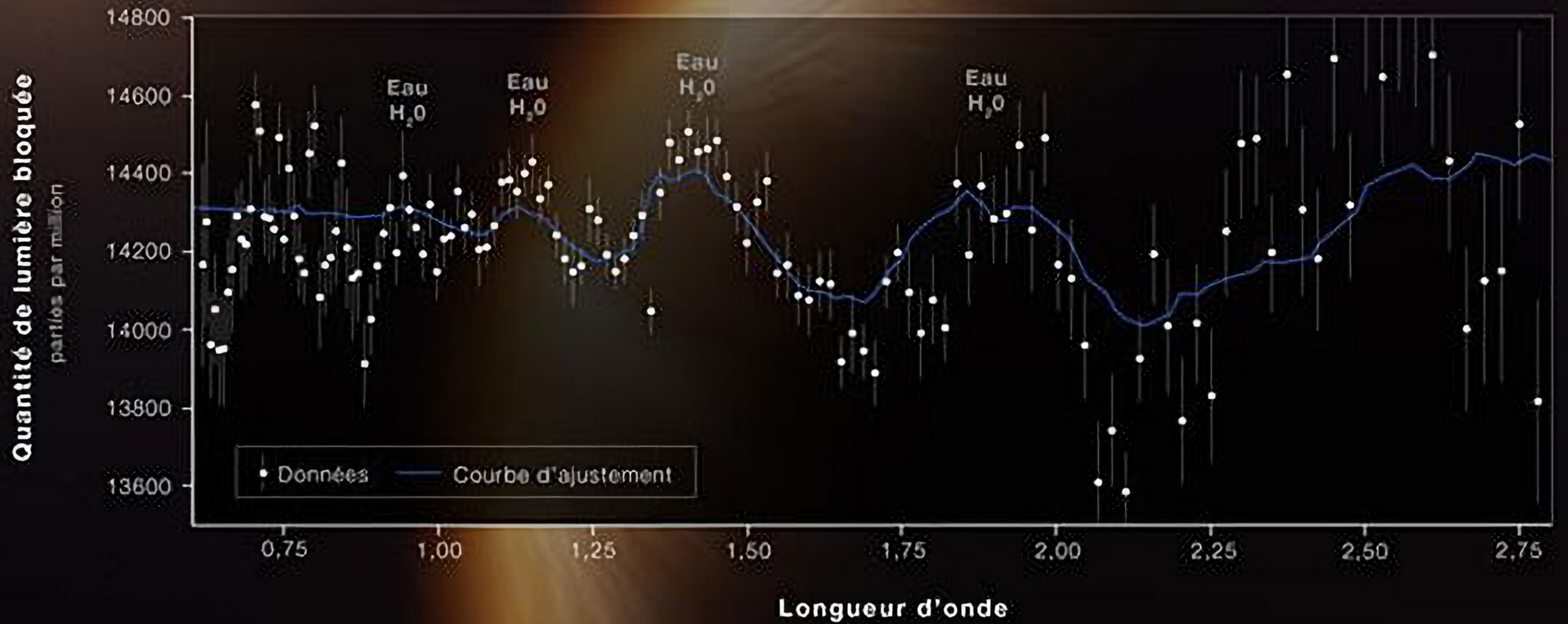
*Exemple: spectre de l'atmosphère Terrestre*



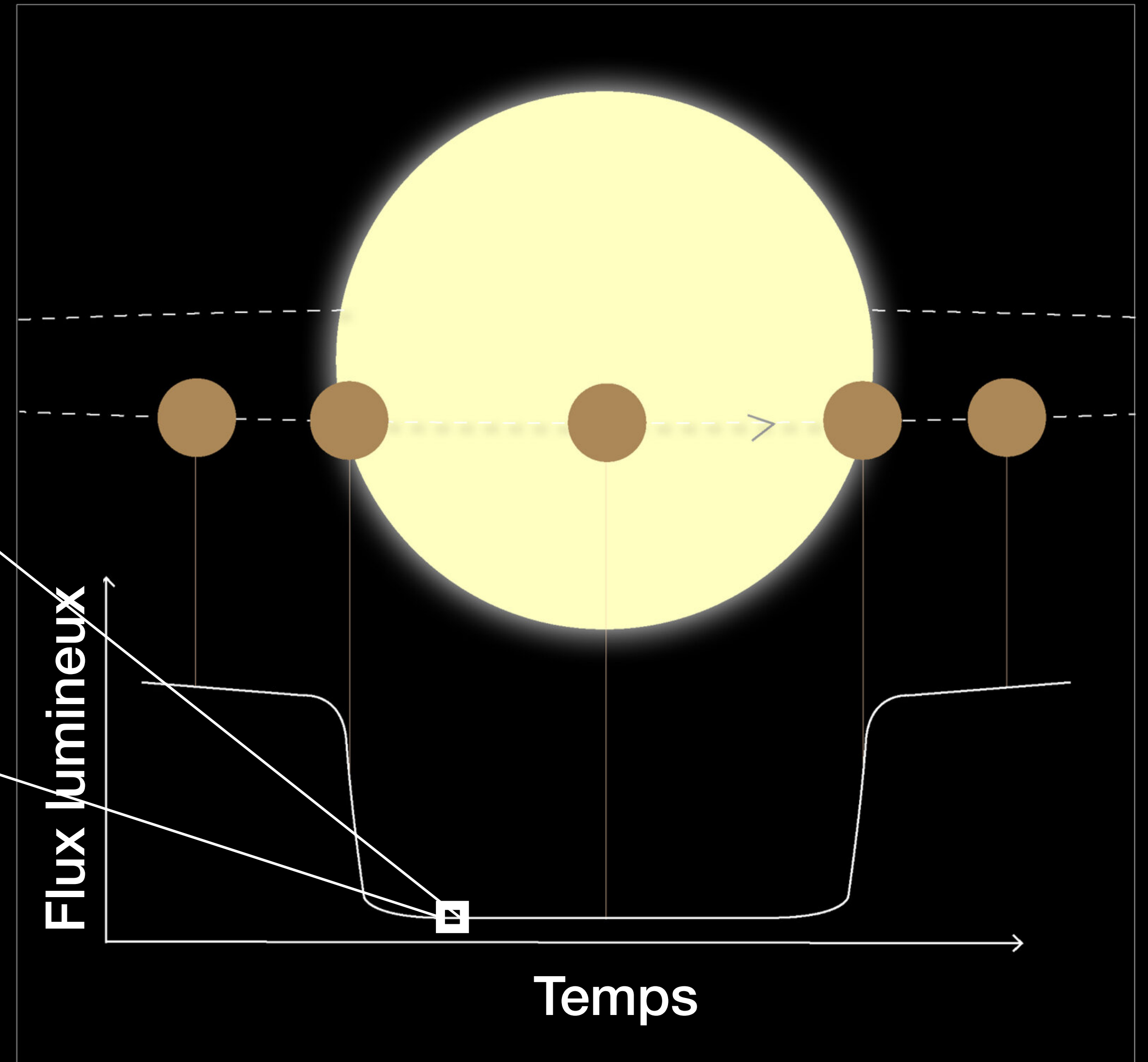
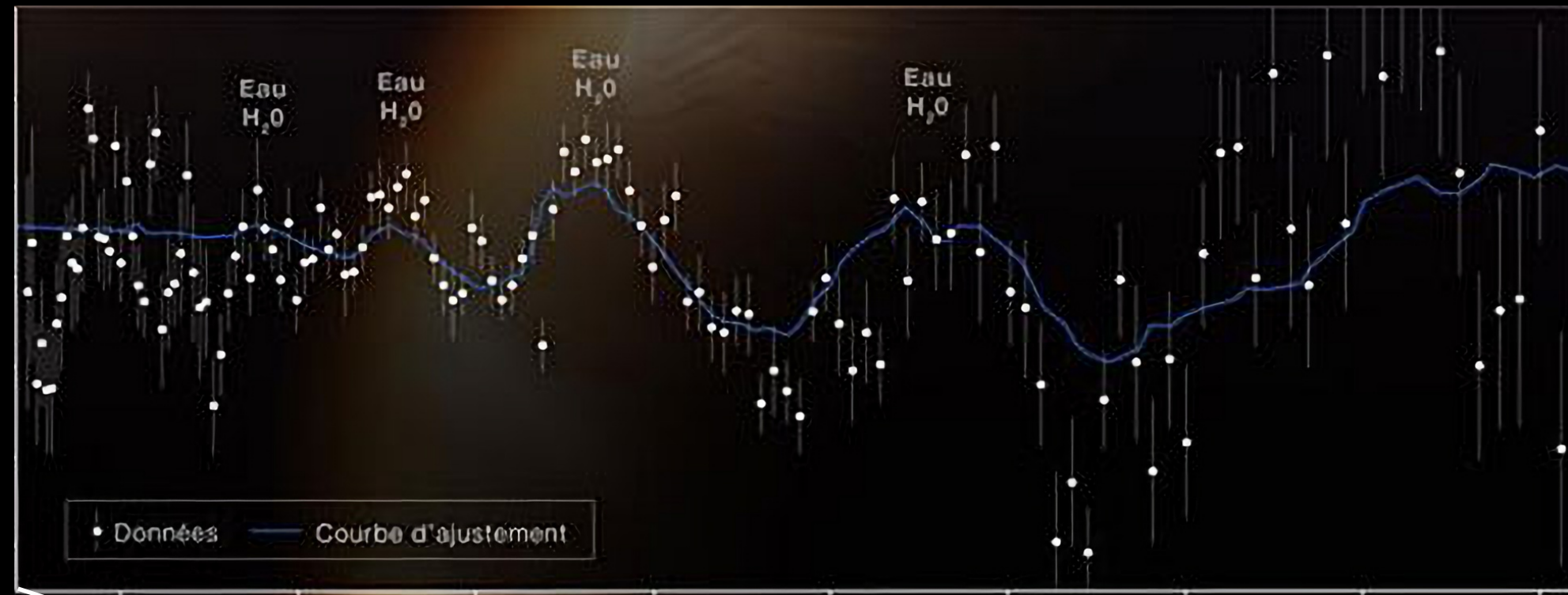
*Transmission*

*Émission*

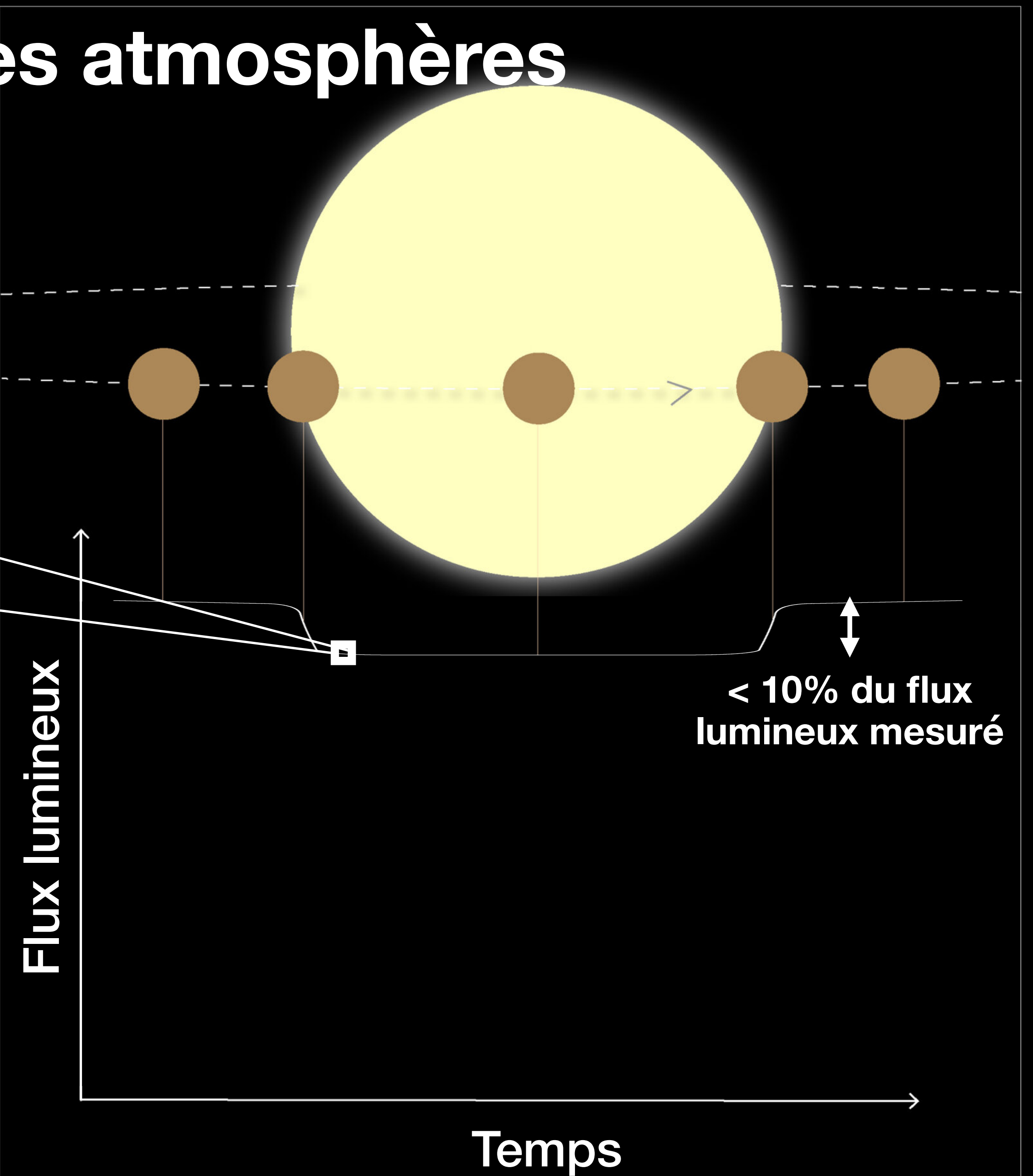
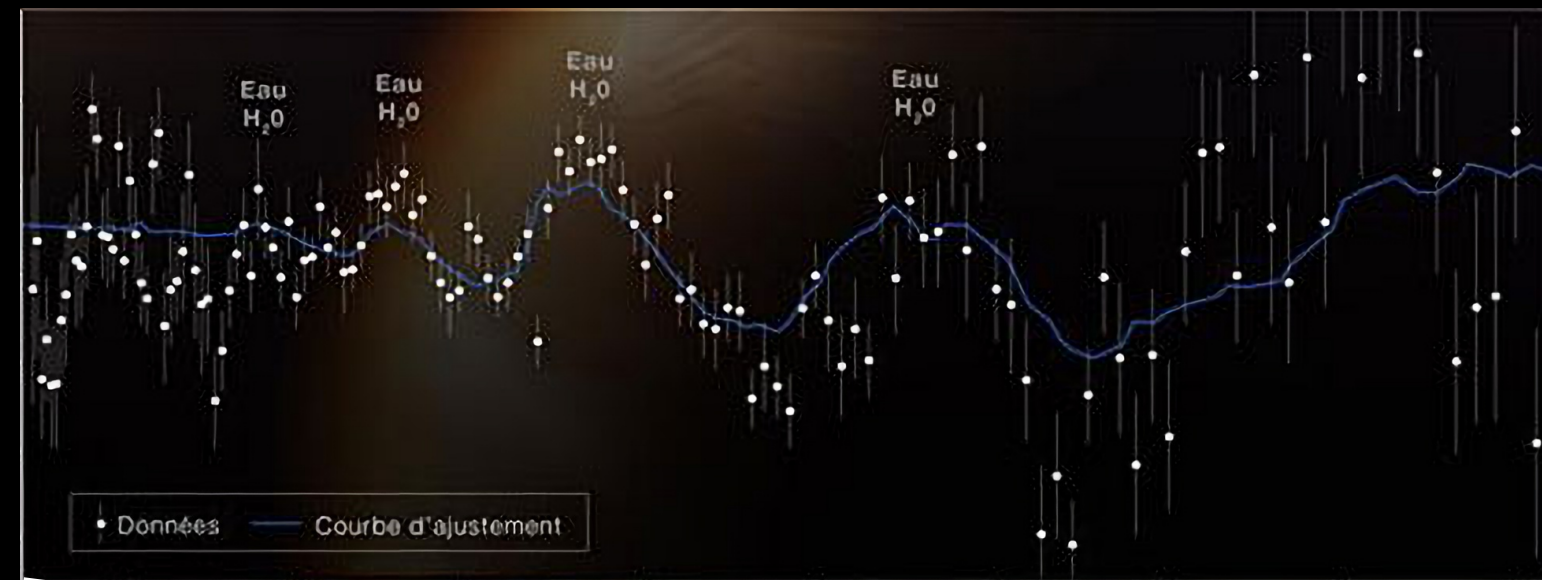
# Spectroscopie des atmosphères



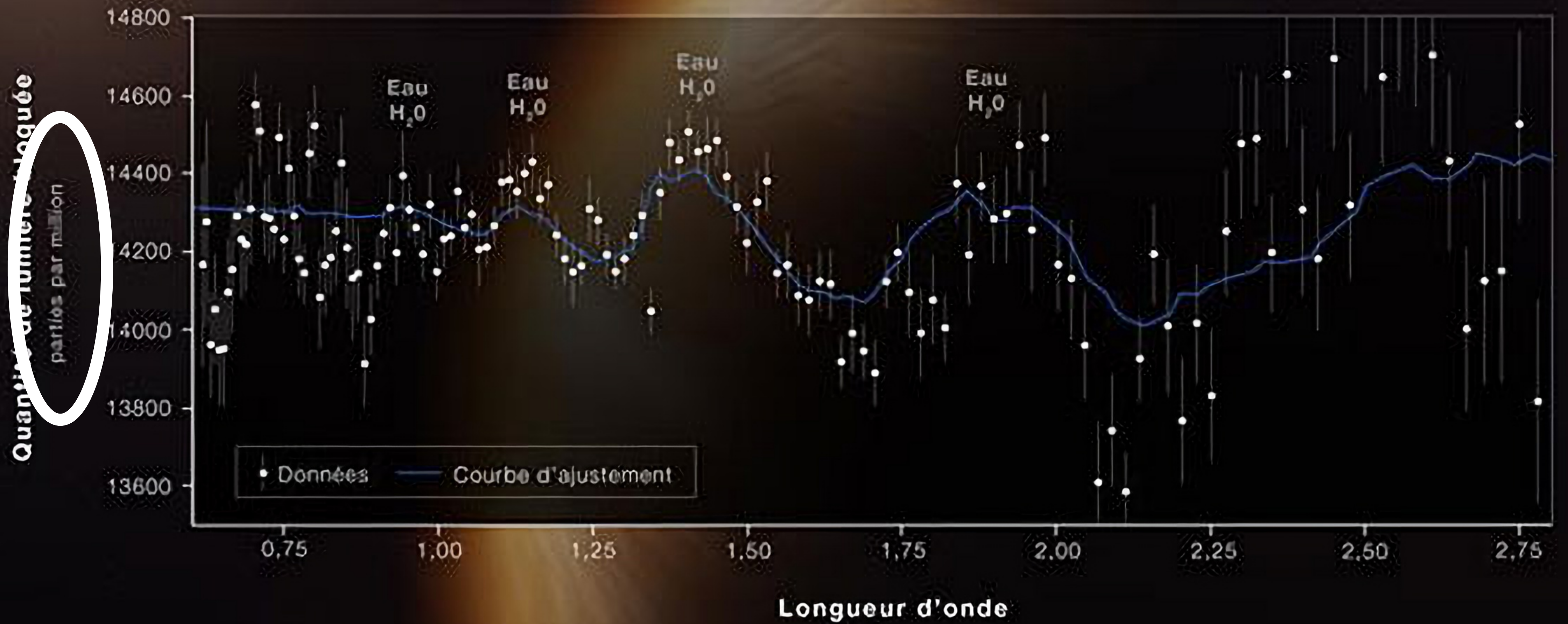
# Spectroscopie des atmosphères



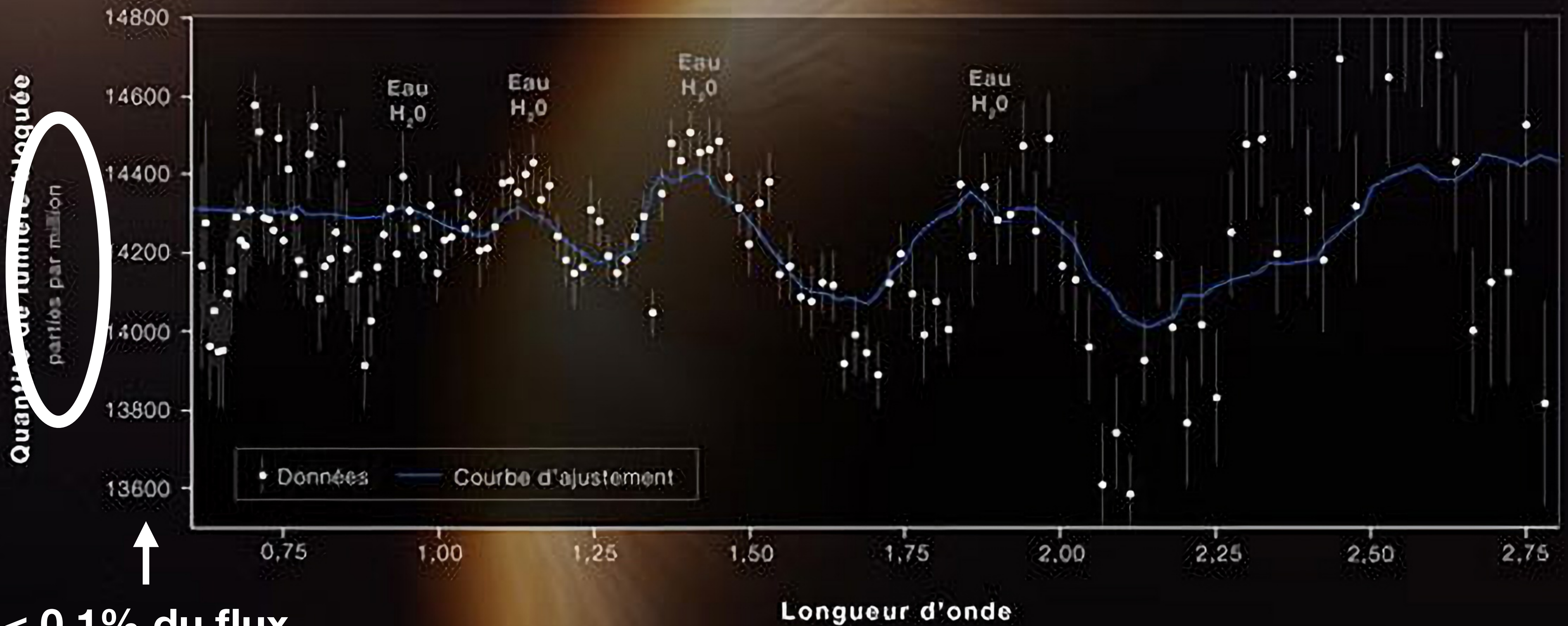
# Spectroscopie des atmosphères



# Spectroscopie des atmosphères



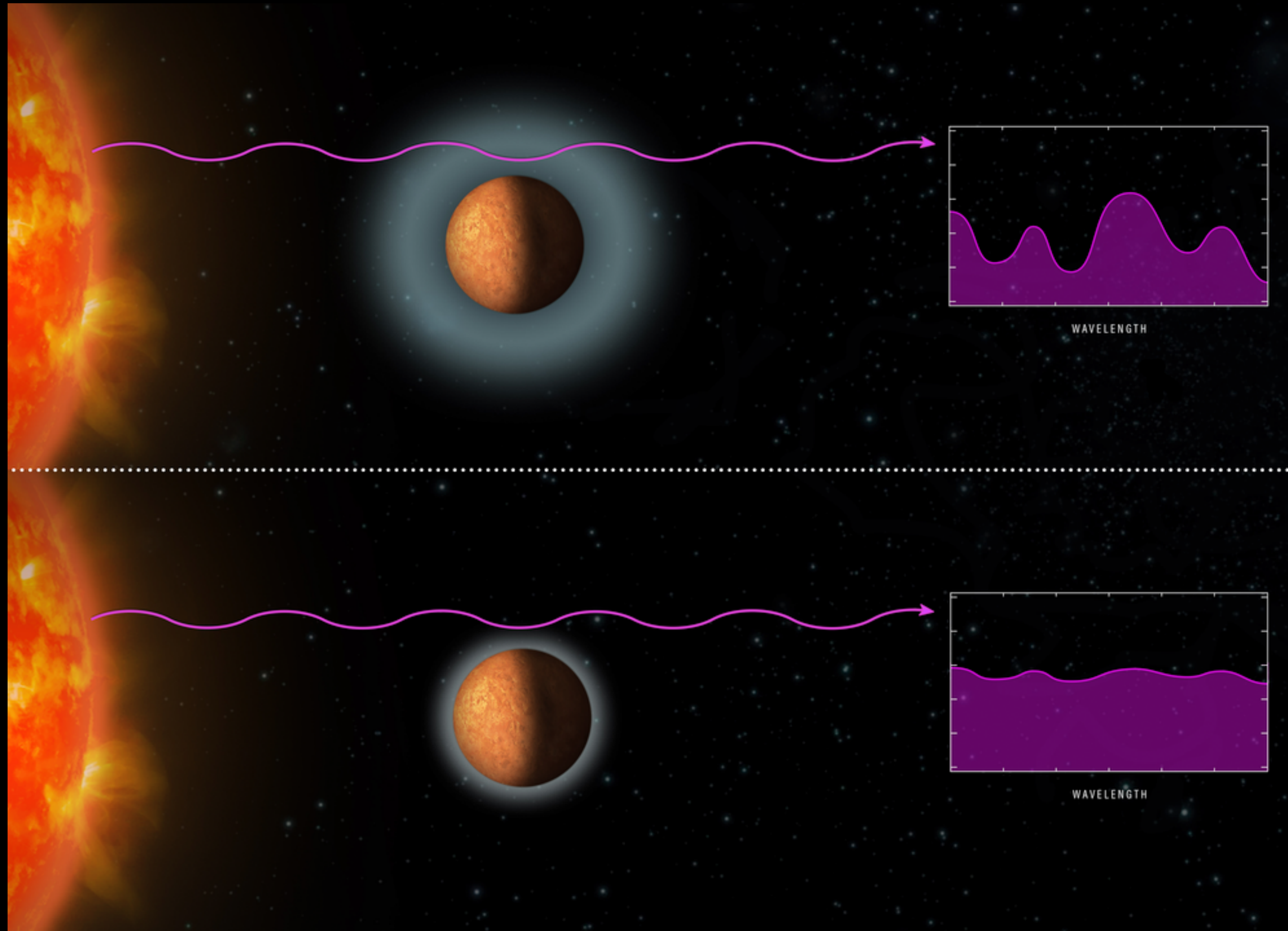
# Spectroscopie des atmosphères



< 0,1% du flux lumineux mesuré



# Taille de l'atmosphère important!

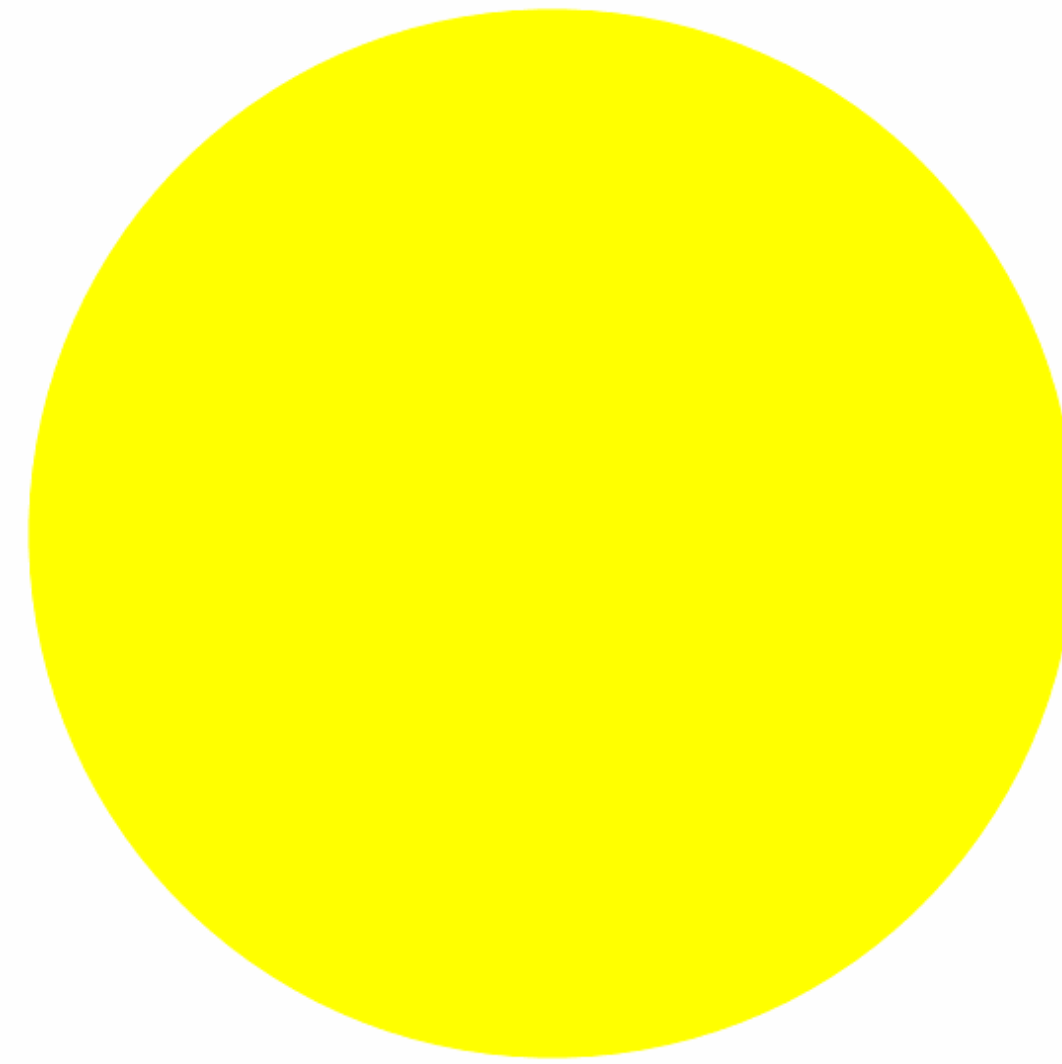
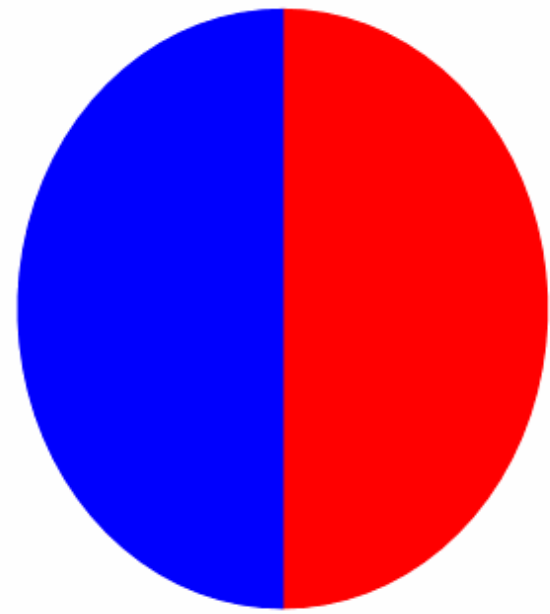


# Les meilleurs cibles: les Jupiters Chauds



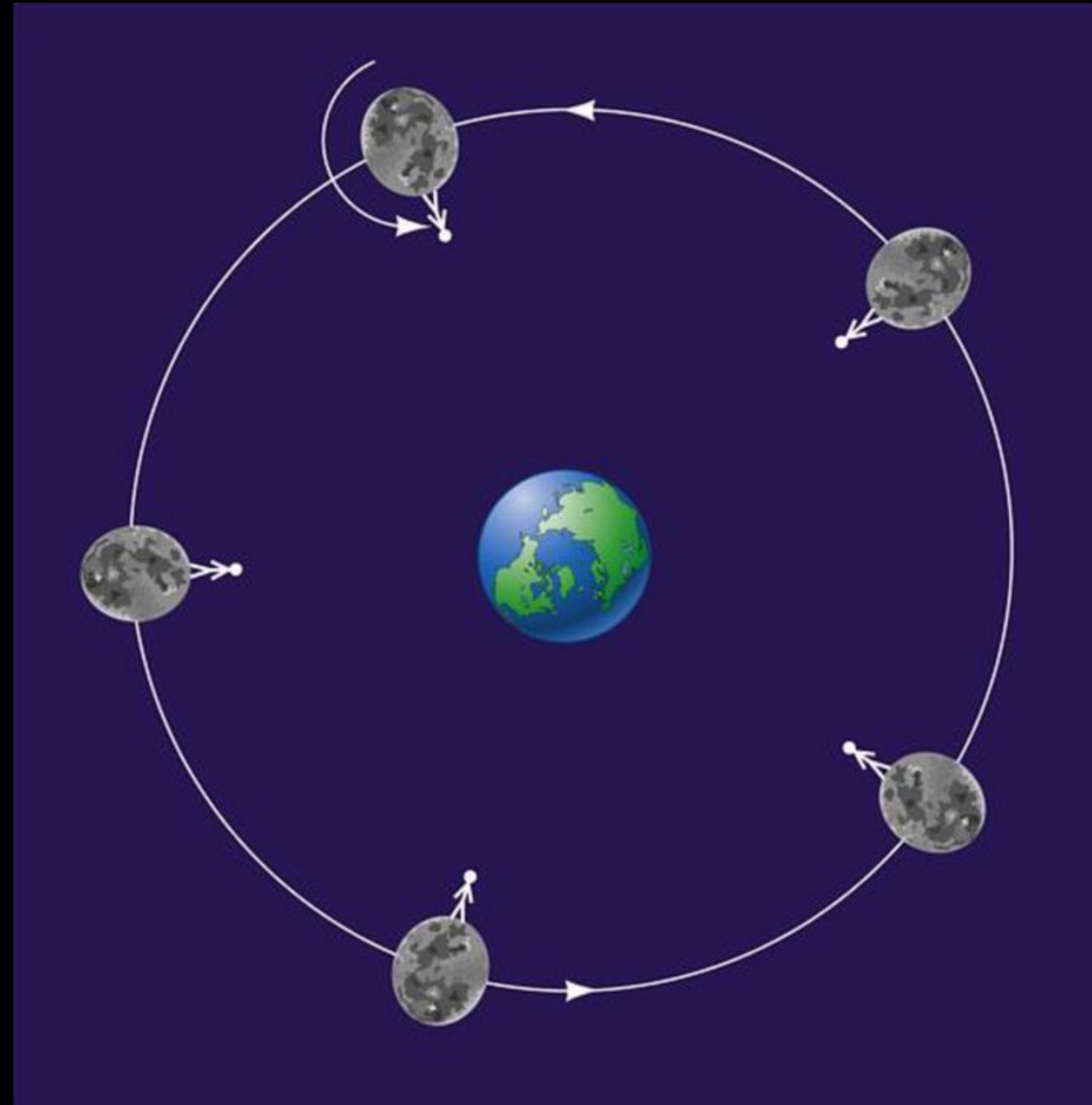
- Géantes gazeuses de la taille de Jupiter
- Orbitent très proche de leurs étoiles
- En rotation synchrone

# Jupiters Chauds: Rotation Synchrone

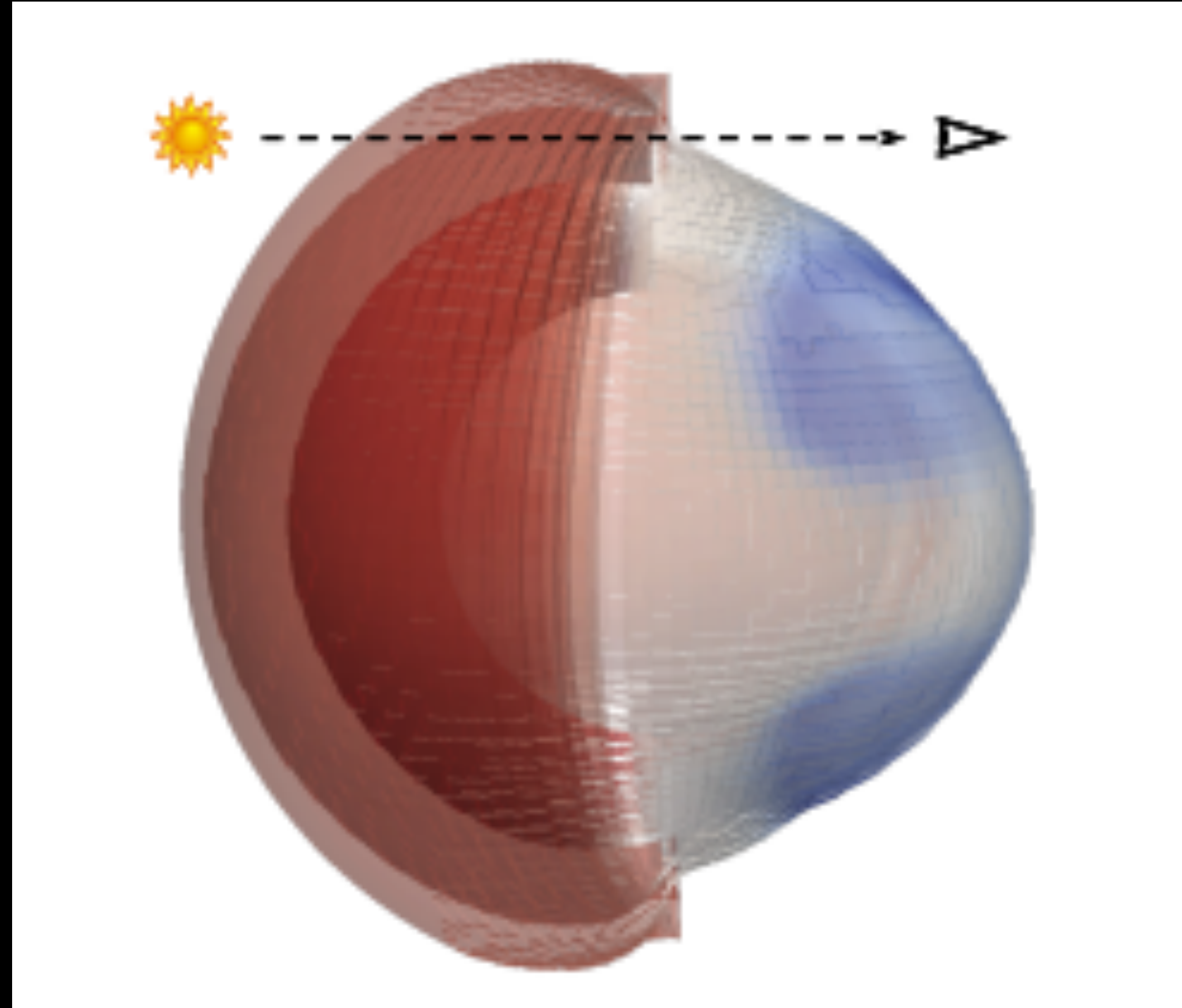


# Jupiters Chauds: Rotation Synchrone

*Exemple de rotation synchrone: la Lune autour de la Terre*



# Jupiters Chauds: Atmosphères étendues





# Multiplication du nombre d'observations

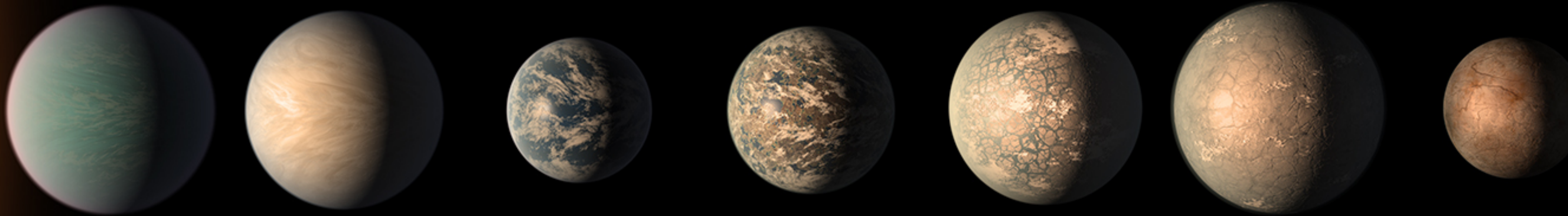
*TRAPPIST-1*



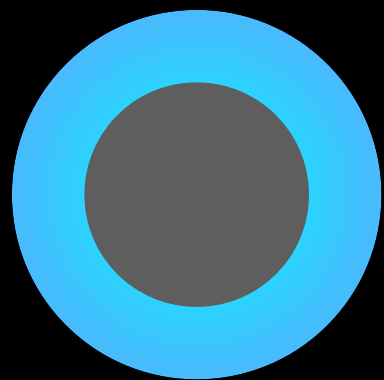
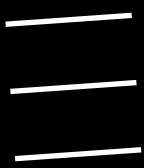
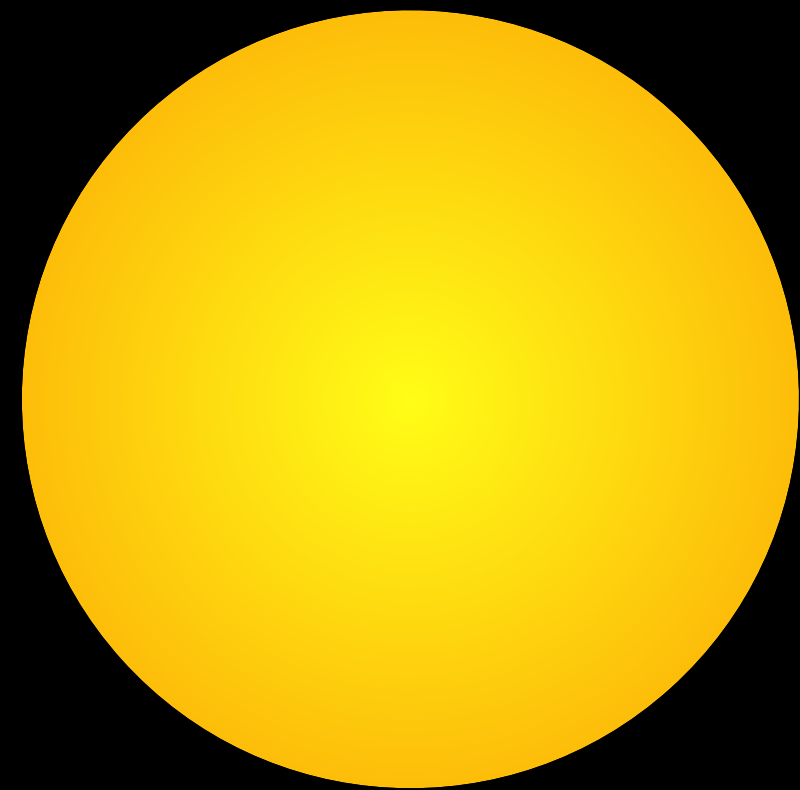
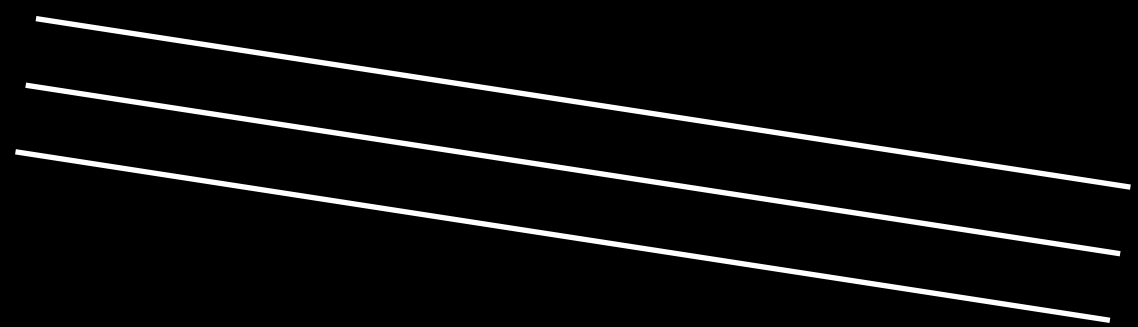
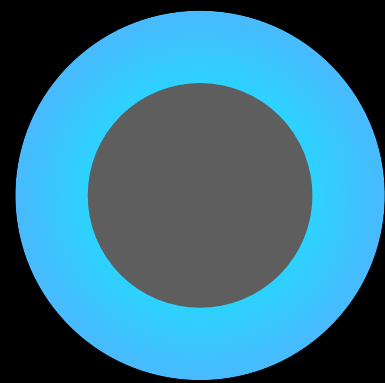
*~ 217h avec JWST*

*(~ 0.1% des exoplanètes confirmées,  
~ 0.05% avec exoplanètes candidats)*

*(~ 5% des observations d'exoplanètes/  
disques (proto)planétaire)*



*Emission*

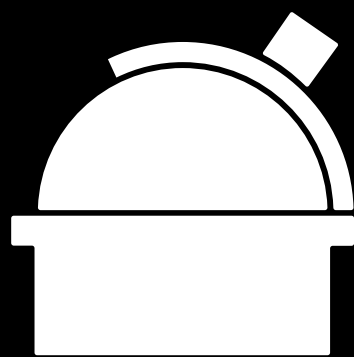
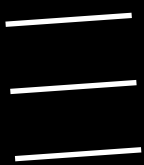
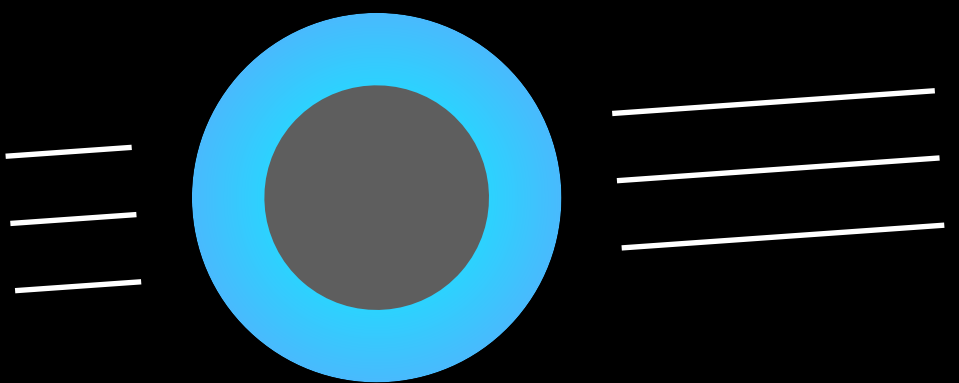
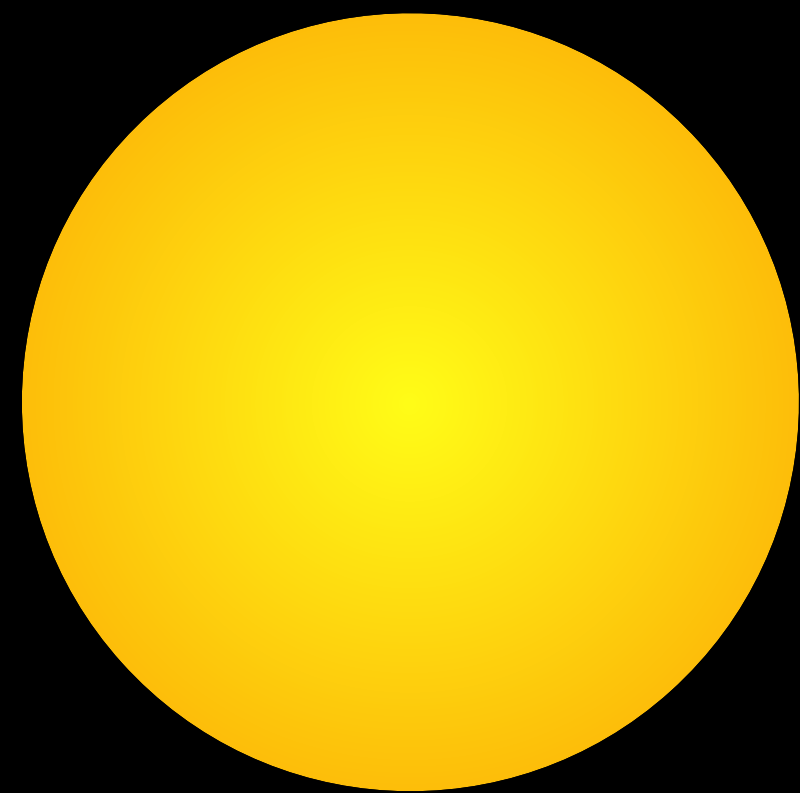
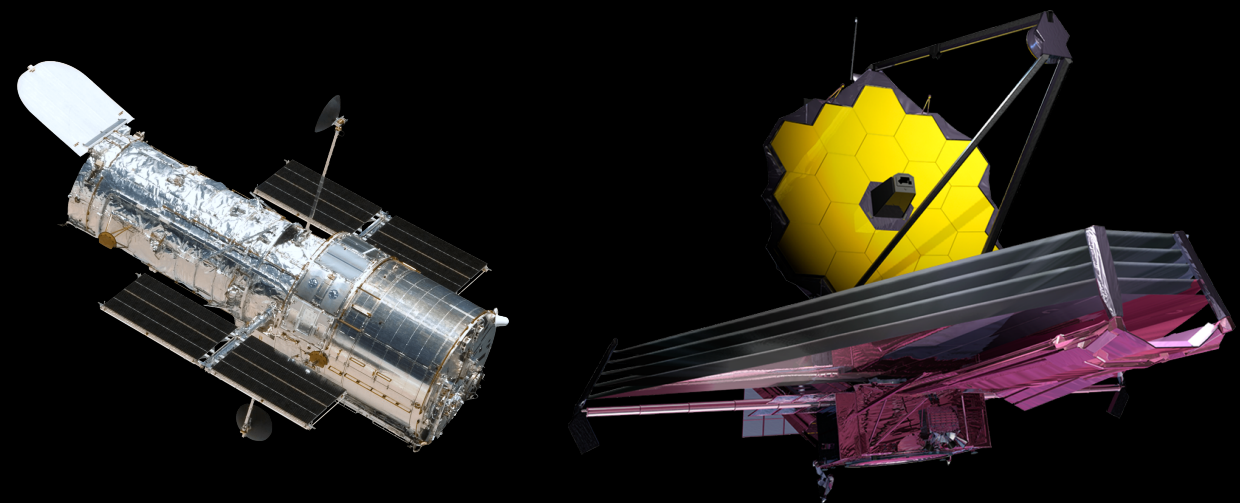
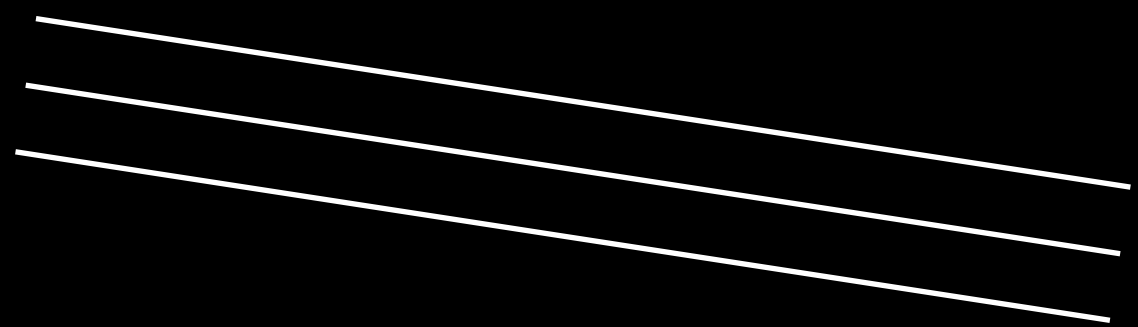
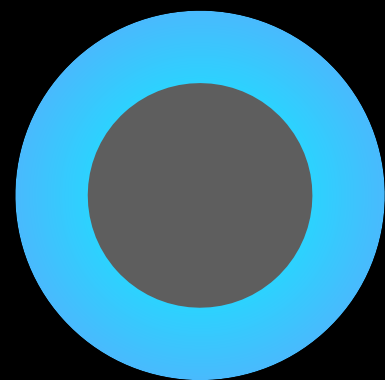


*Transmission*

**Cible**



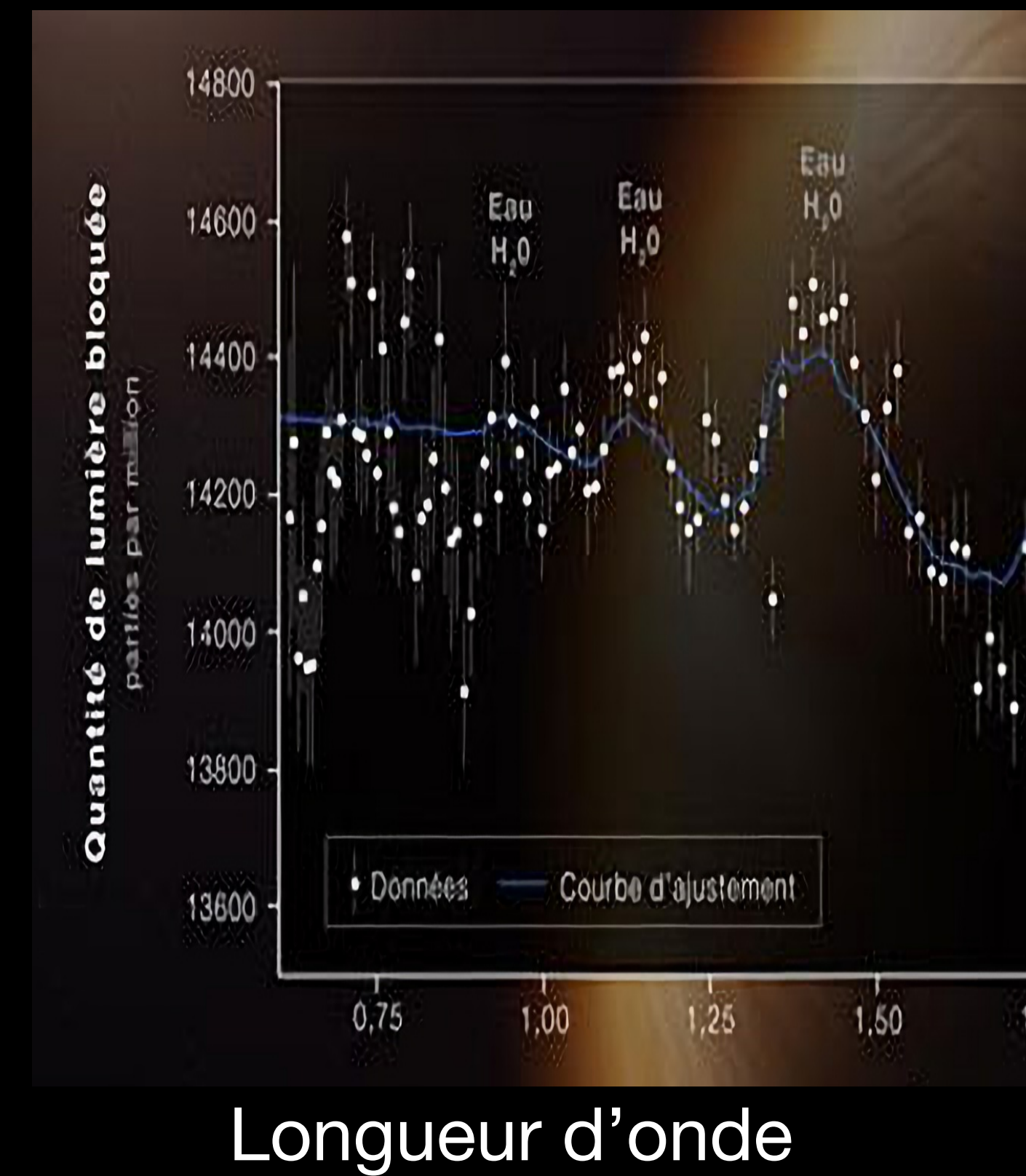
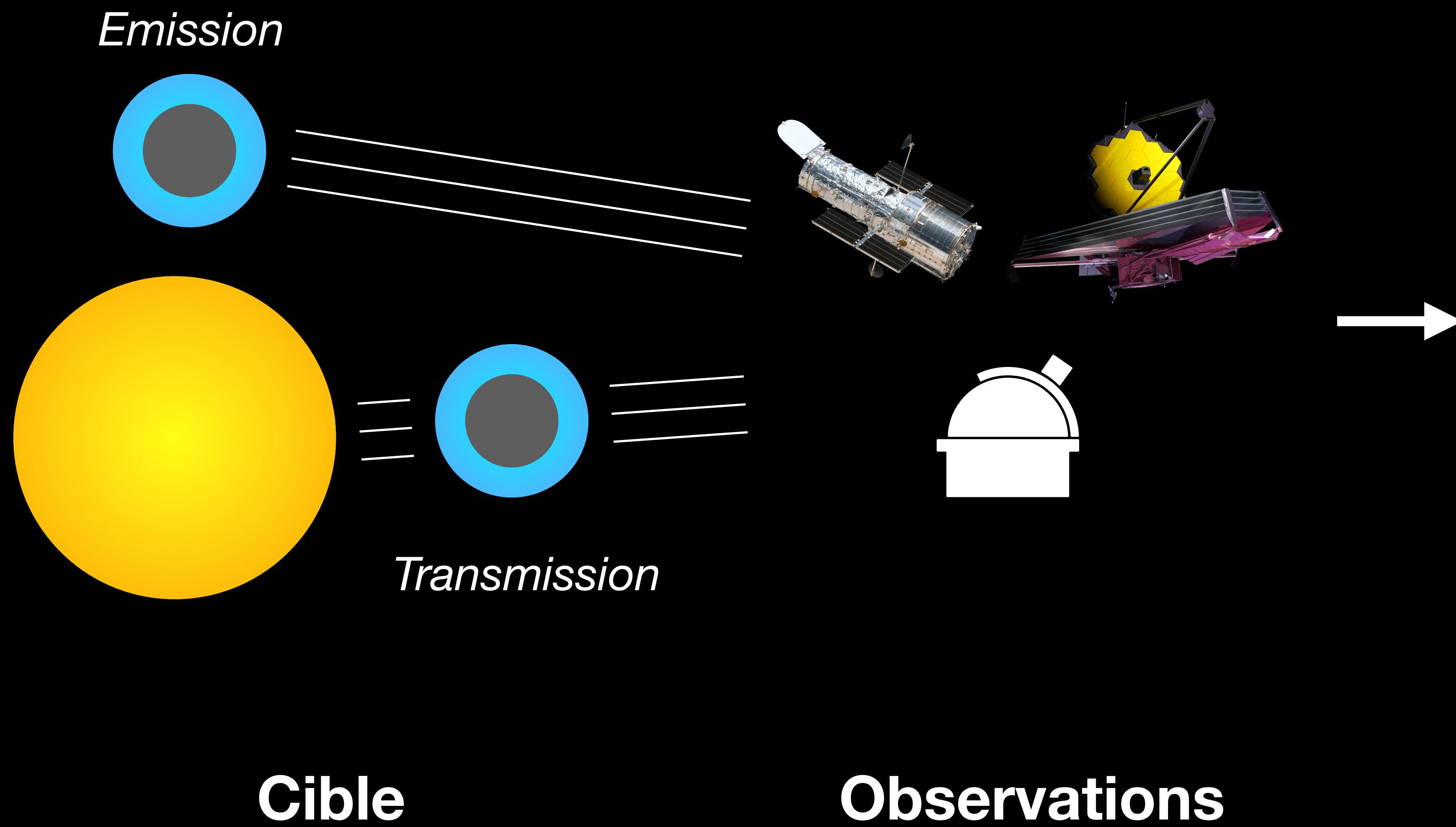
*Emission*



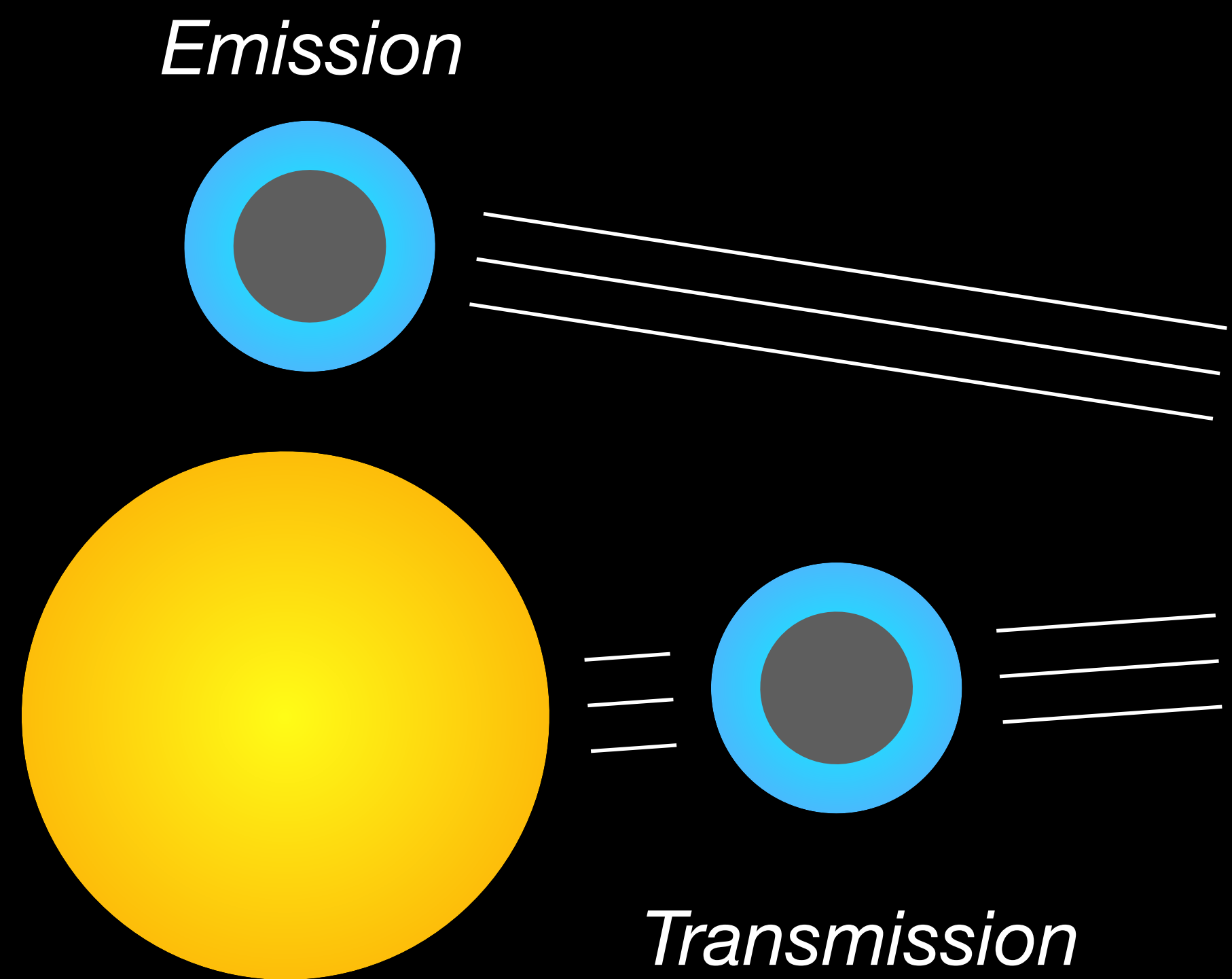
*Transmission*

**Cible**

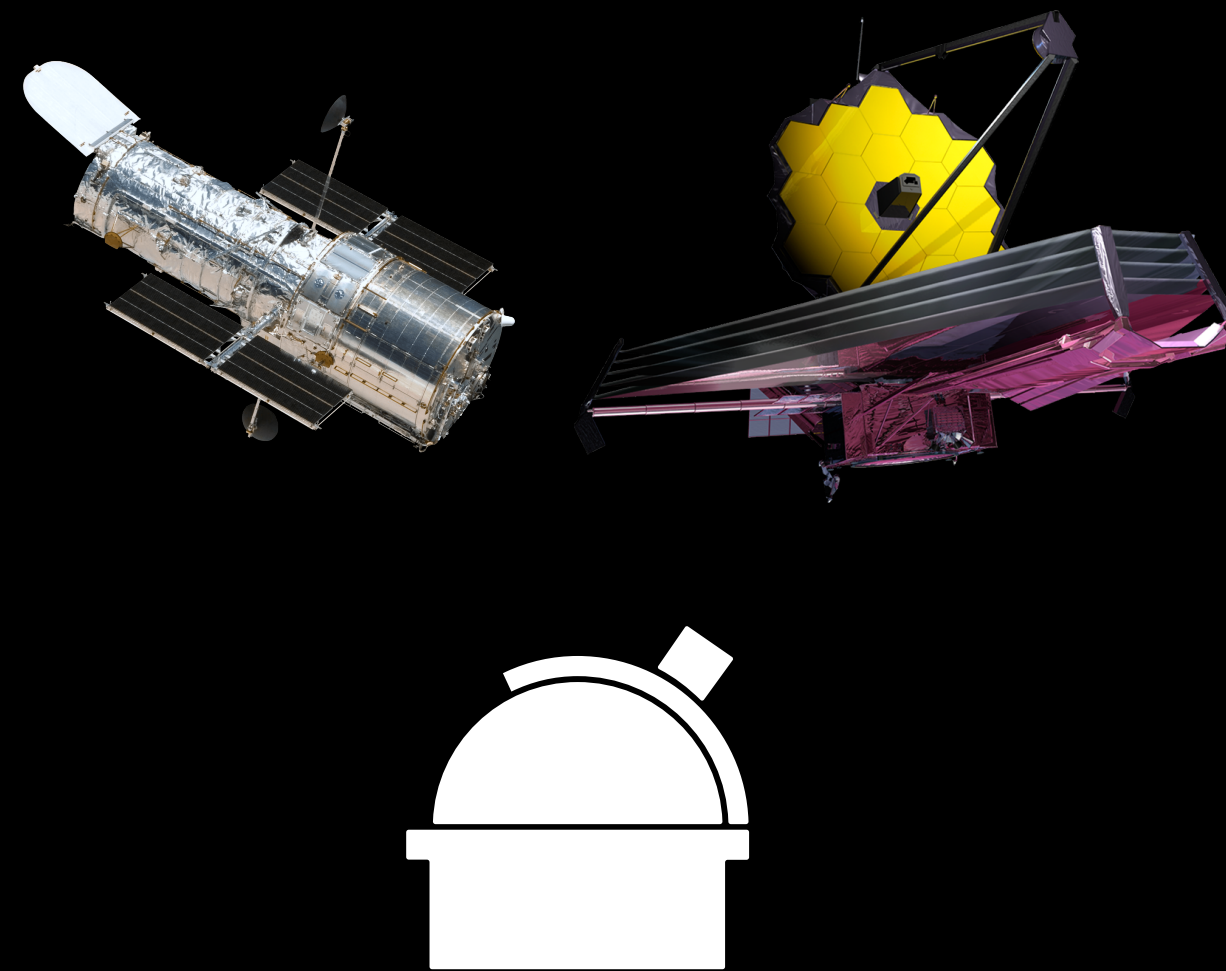
**Observations**



**Spectres?**



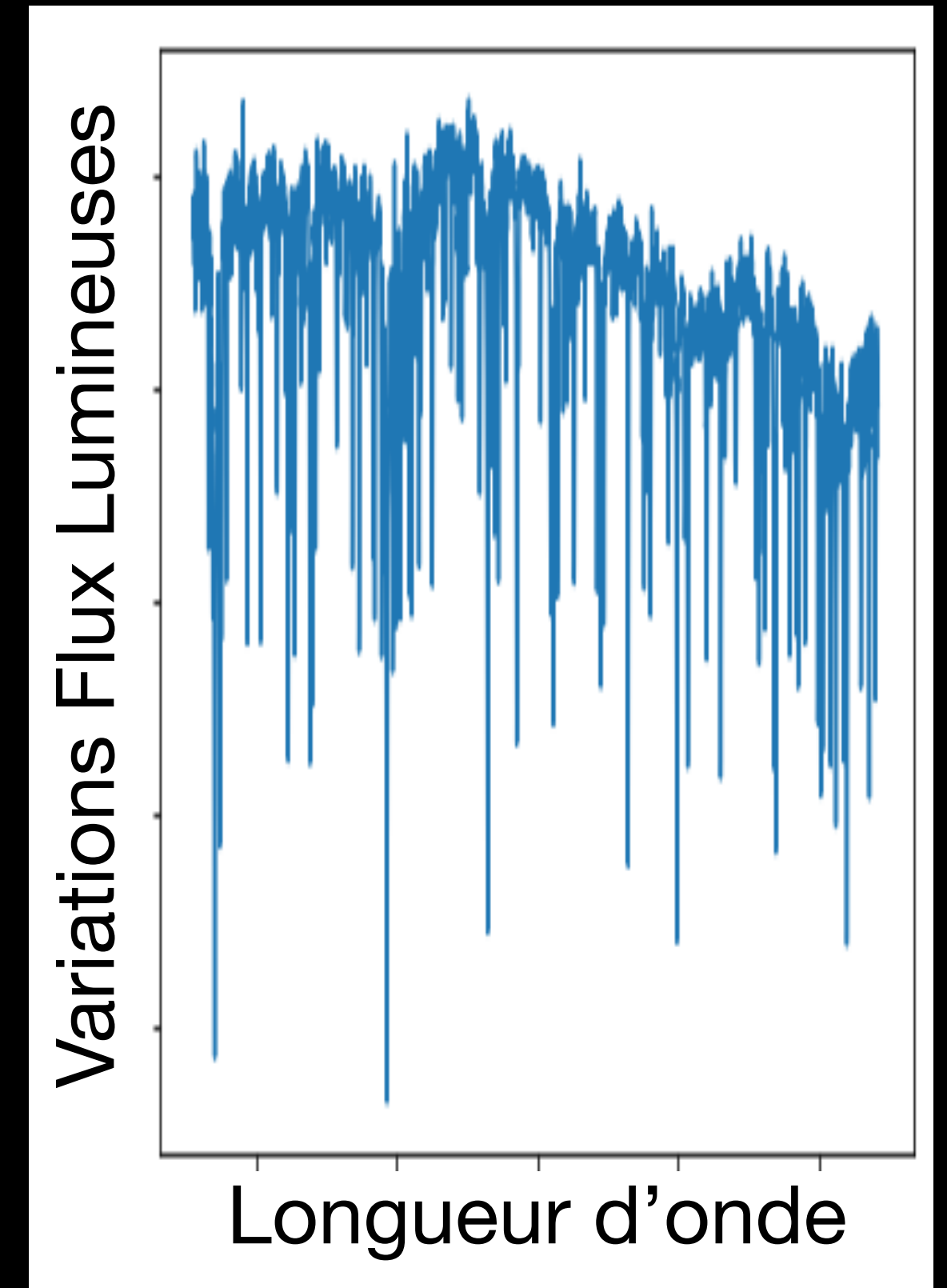
**Cible**



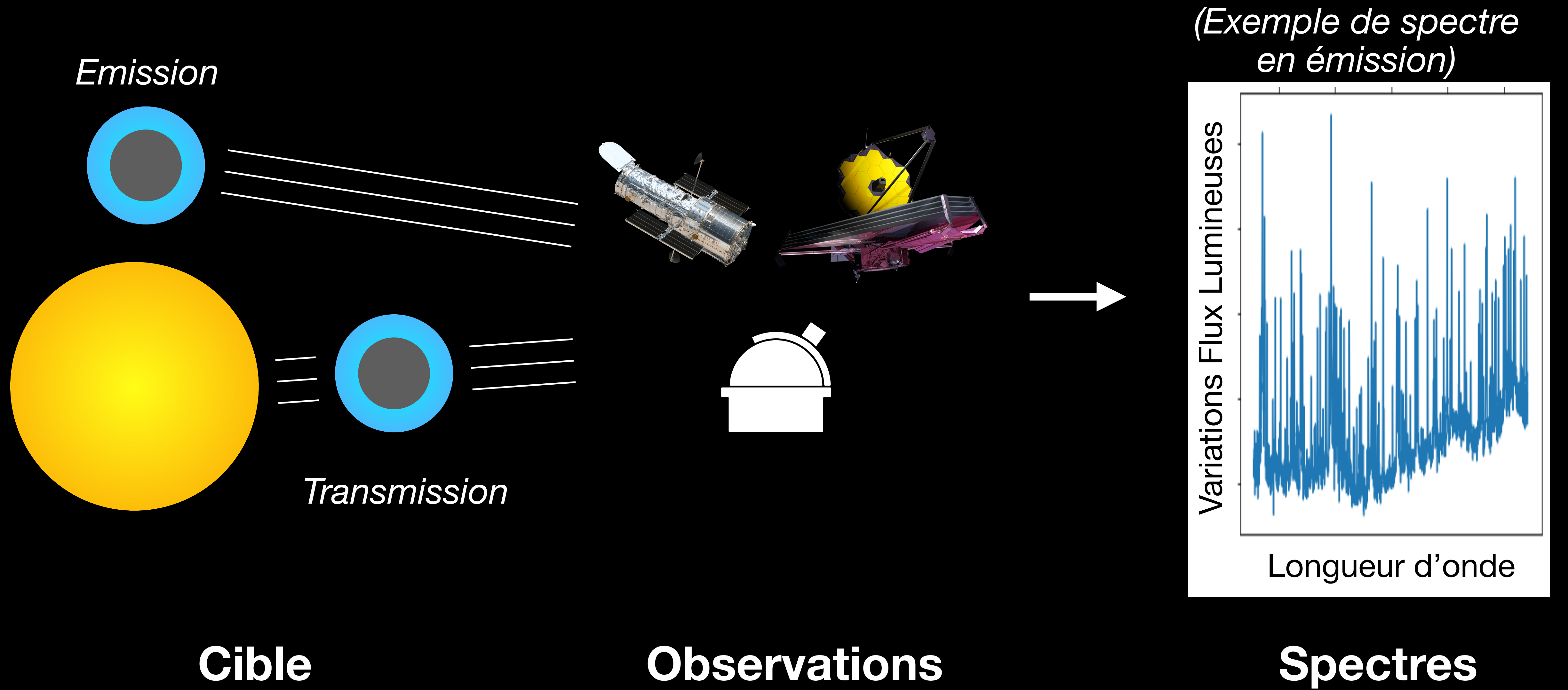
**Observations**



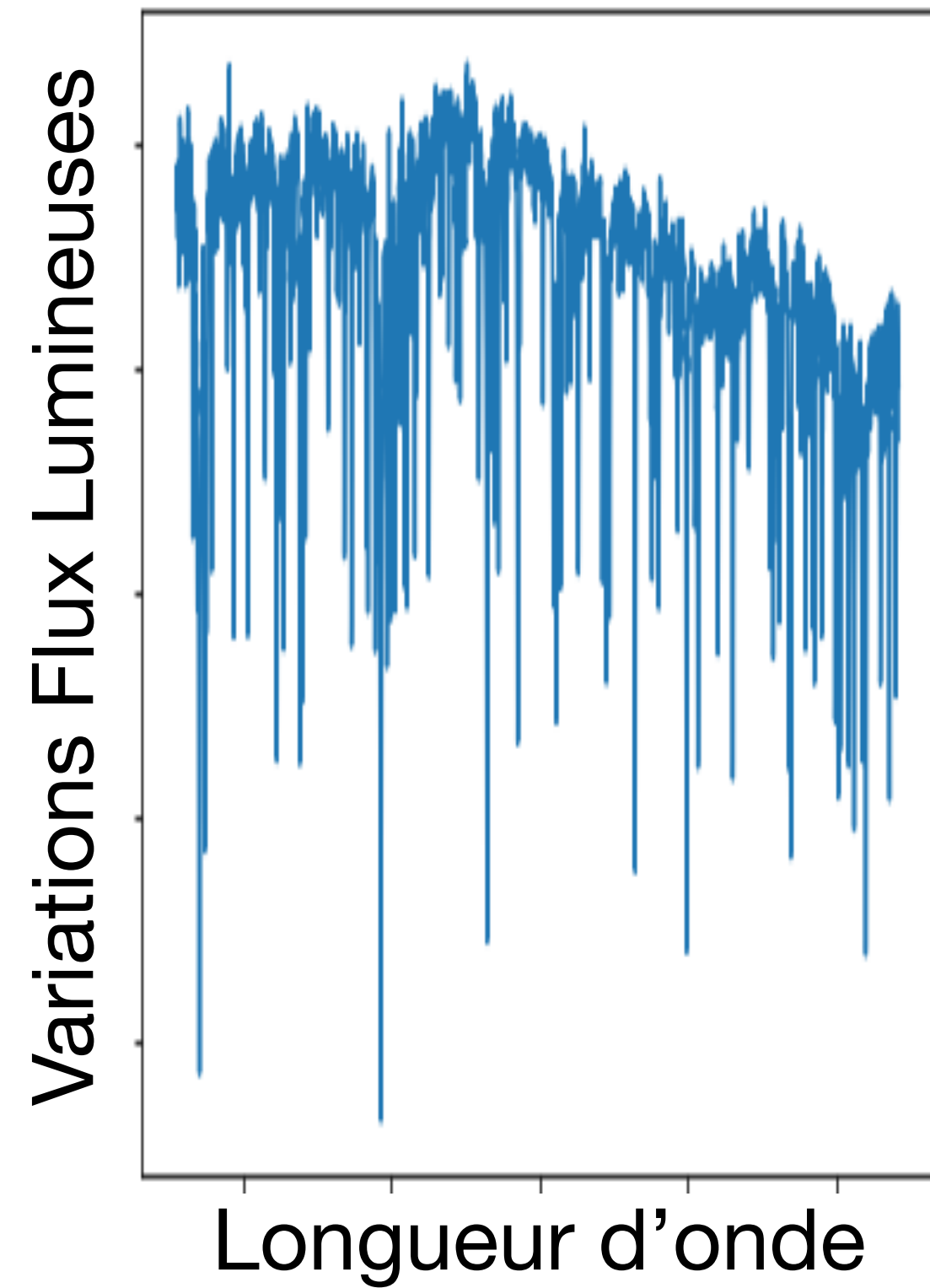
*(Exemple de spectre en transmission)*



**Spectres**



# Ma thèse!



- Composition chimique
- Profil de température
- Dynamique de la planète et de l'atmosphère (rotation et vents)

...

# Cas d'étude: Jupiter Ultra-Chaud WASP-76b

- Température  $> 2000$  K ( $> 1700^{\circ}\text{C}$ )
- Période orbitale = 1.8 jours
- Pluie de Fer du côté nuit!



**Merci!**