



La formation des étoiles

Jean-Louis Monin

Observatoire de Grenoble



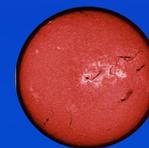
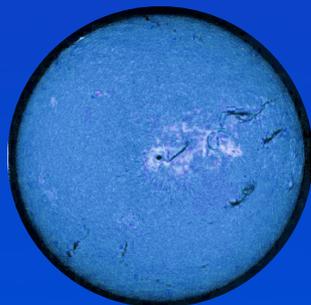
**Des étoiles de toutes les couleurs
et de toutes les luminosités**



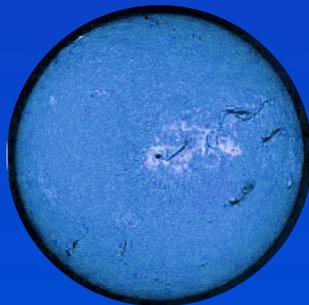
**Des étoiles de toutes les couleurs
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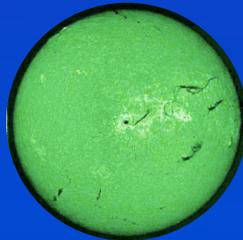
**Des étoiles de toutes les couleurs
et de toutes les luminosités**



10000 K



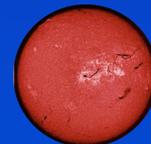
8000 K



6000 K



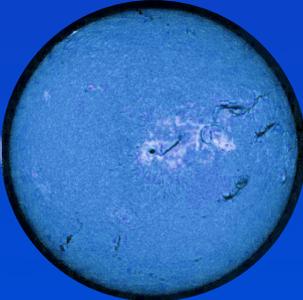
3-4000 K



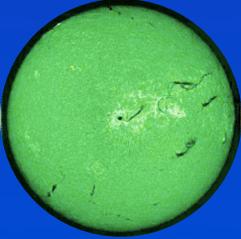


Température
(couleur)

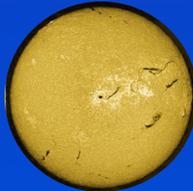
10000 K



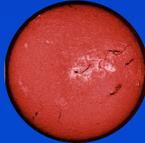
8000 K



6000 K



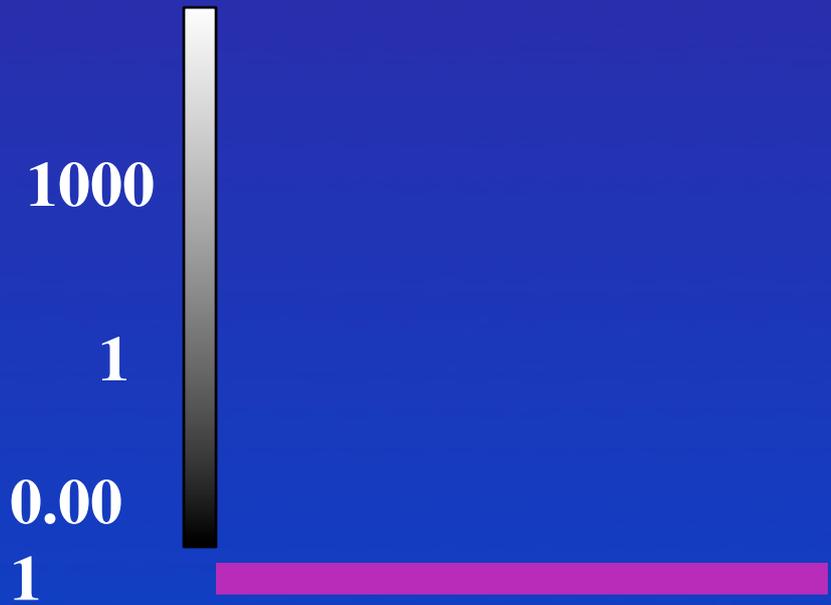
3-4000 K





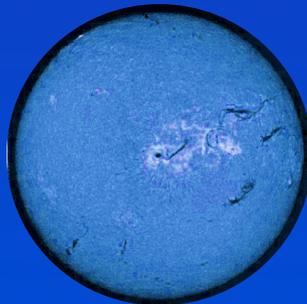
Luminosité

(par rapport au soleil)

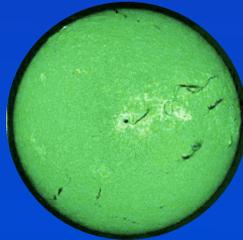


Température
(couleur)

10000 K



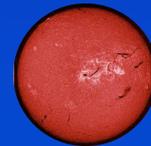
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6000 K



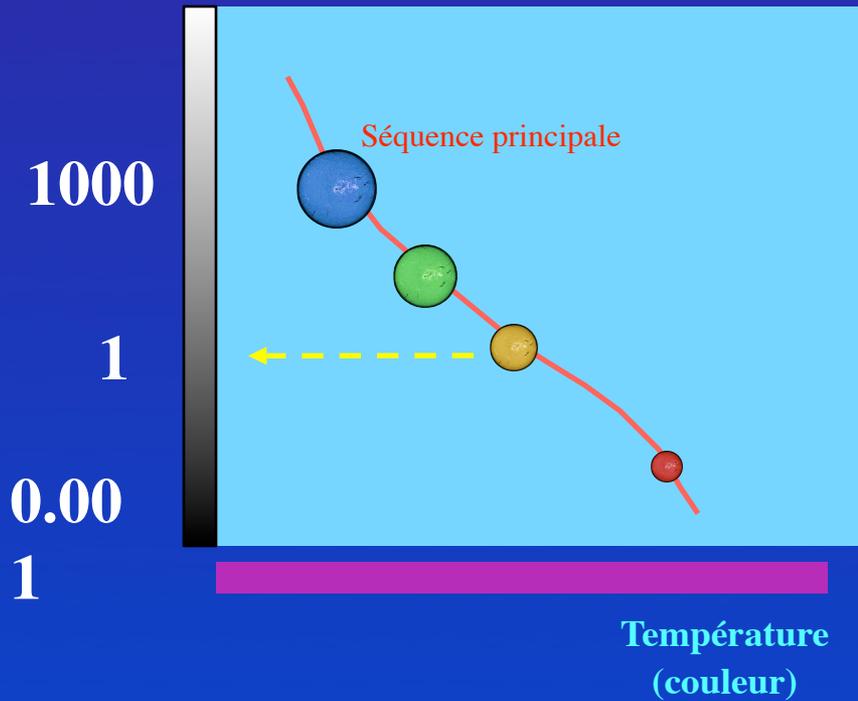
3-4000 K



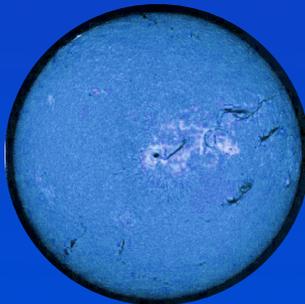


Luminosité

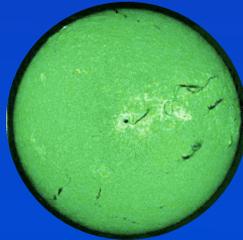
(par rapport au soleil)



10000 K



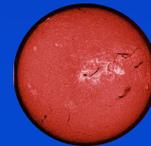
8000 K



6000 K



3-4000 K





Luminosité

(par rapport au soleil)

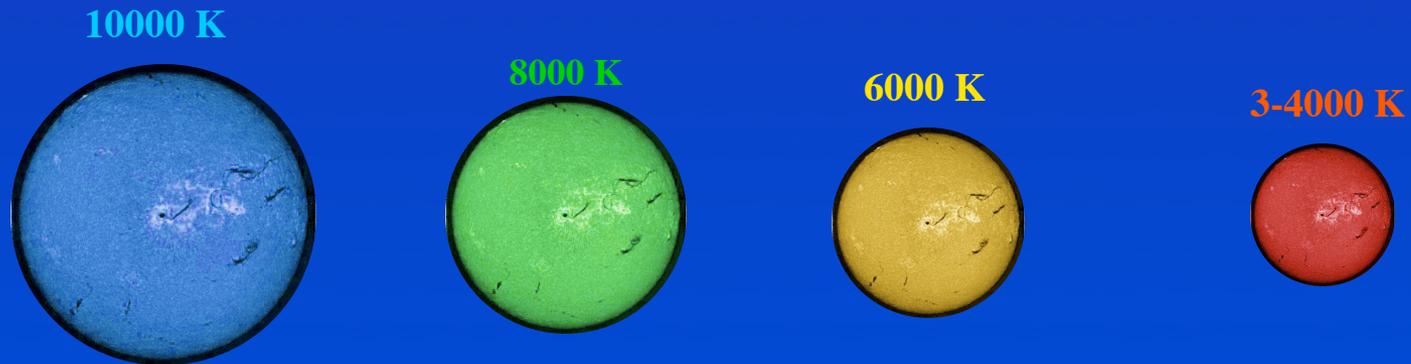
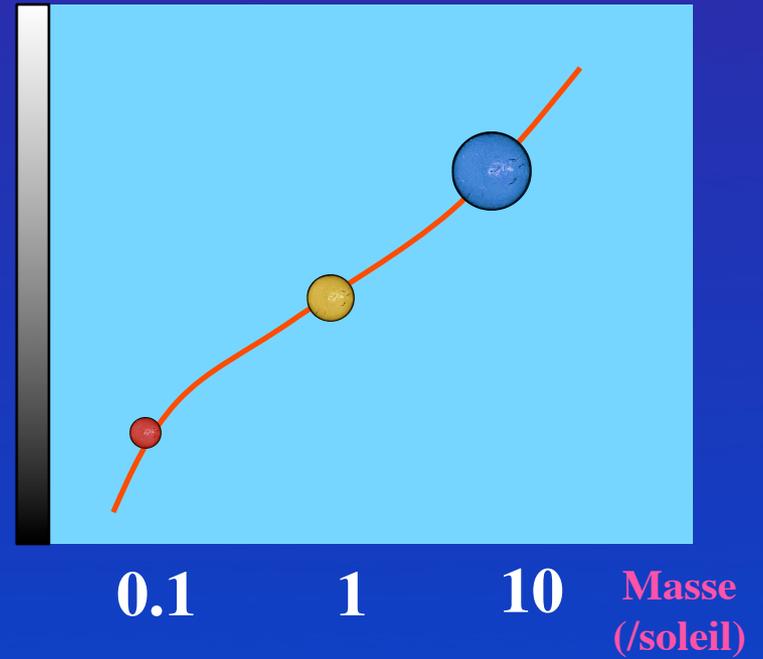
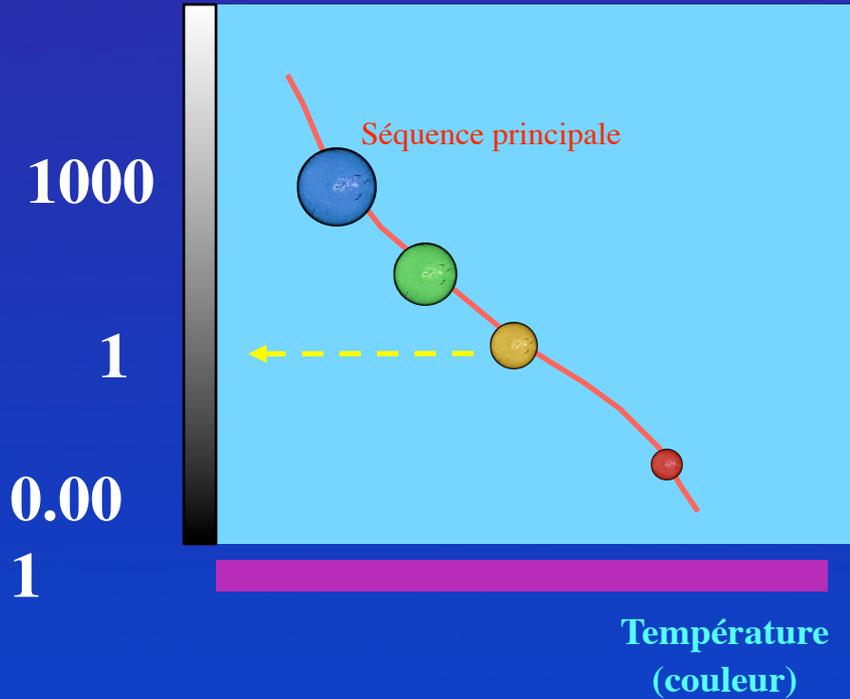
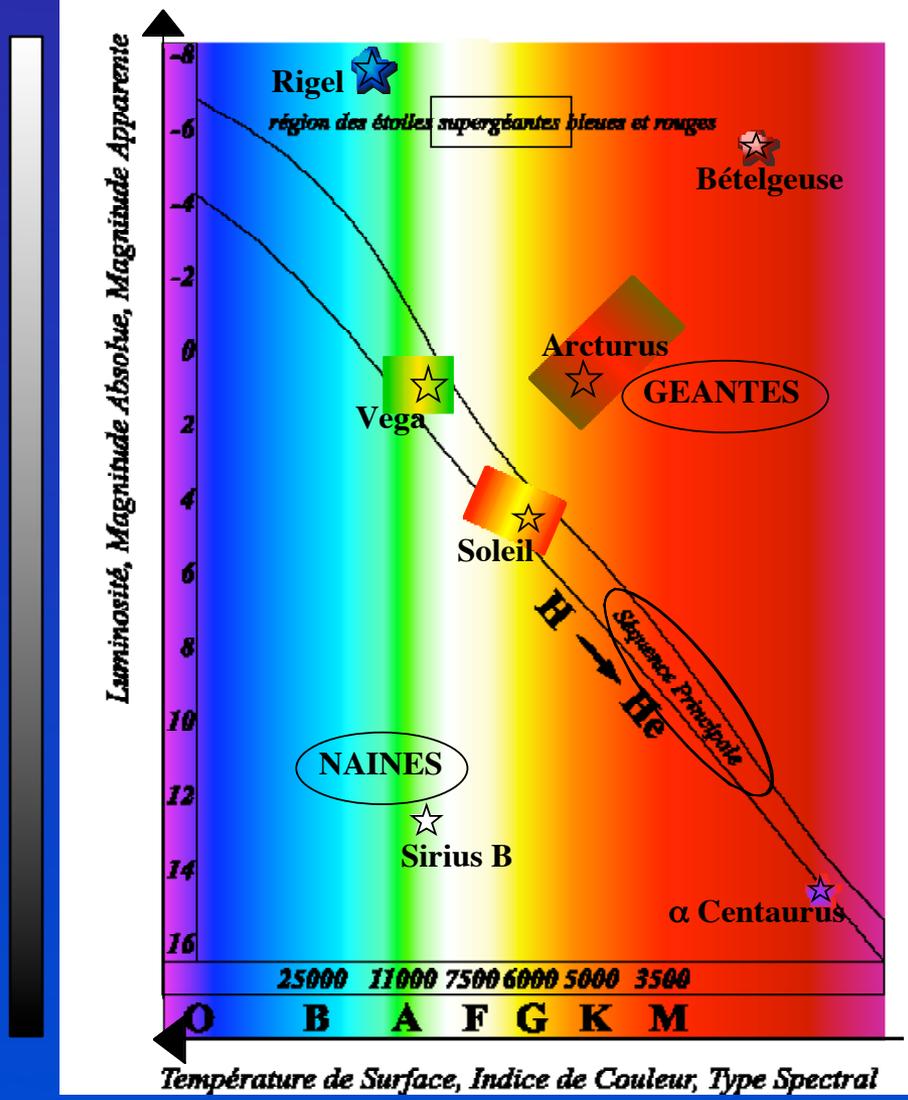


Diagramme Hertzsprung-Russell

Un outil puissant pour comprendre les étoiles :

le diagramme HR



Comment marche une étoile ?

- Une étoile brille parce qu'elle est chaude
- Plus elle est chaude et plus elle est bleue
- Plus elle est massive et plus elle est lumineuse
- Plus elle est massive et moins elle vit longtemps



M83 © Anglo-Australian Observatory Photo by David Malin

Les étoiles massives ne vivent pas très longtemps ...



M83 © Anglo-Australian Observatory Photo by David Malin

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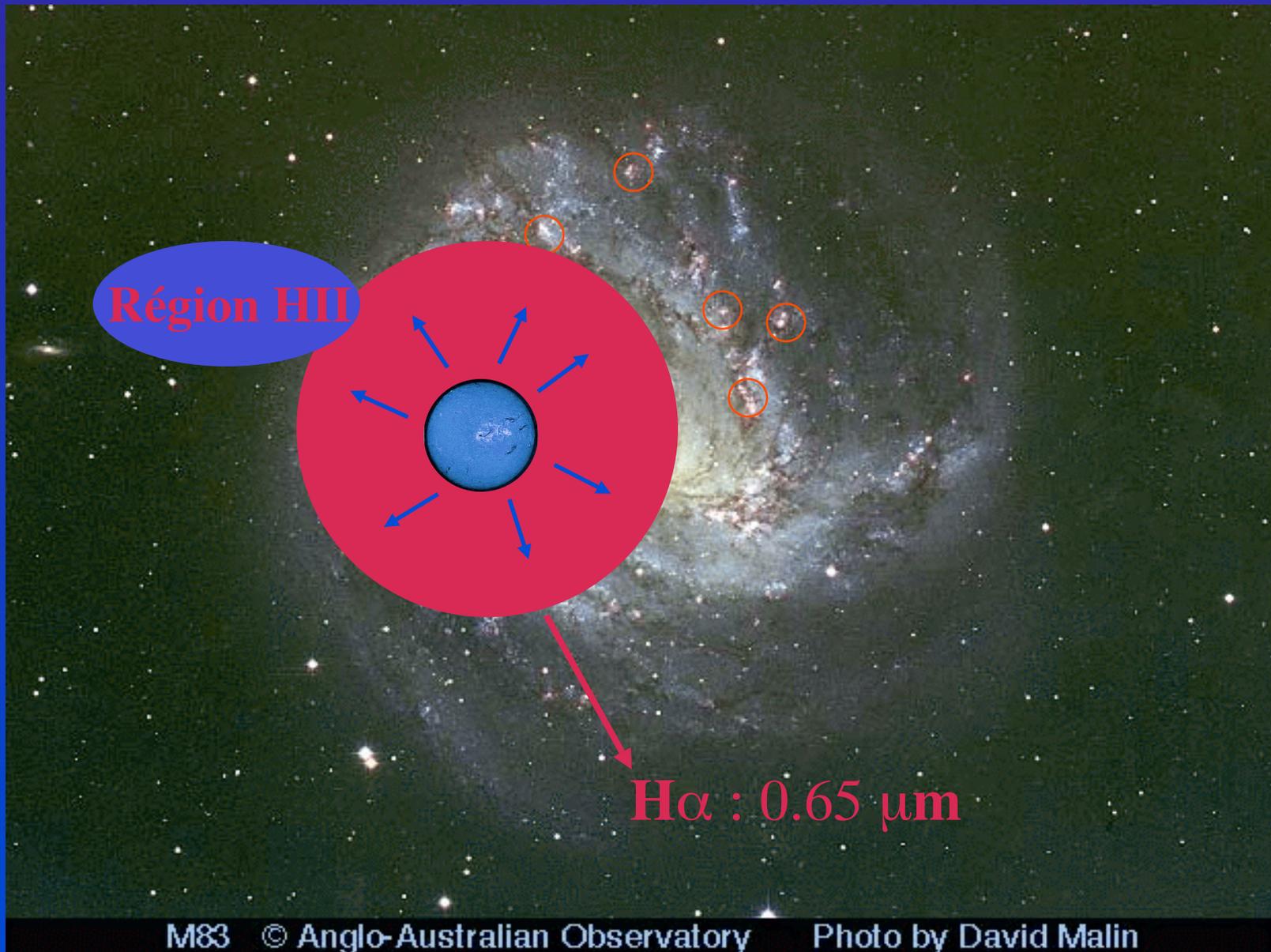


Les étoiles massives ne vivent pas très longtemps ...



M83 © Anglo-Australian Observatory Photo by David Malin

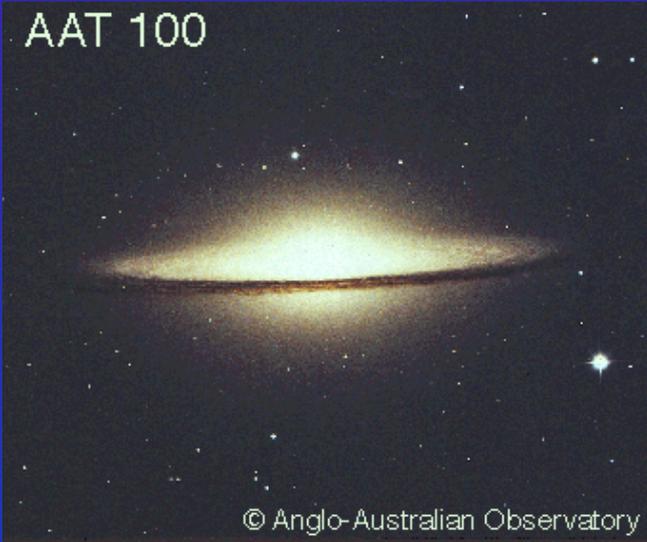
Les étoiles massives ne vivent pas très longtemps ...



Les étoiles naissent ...

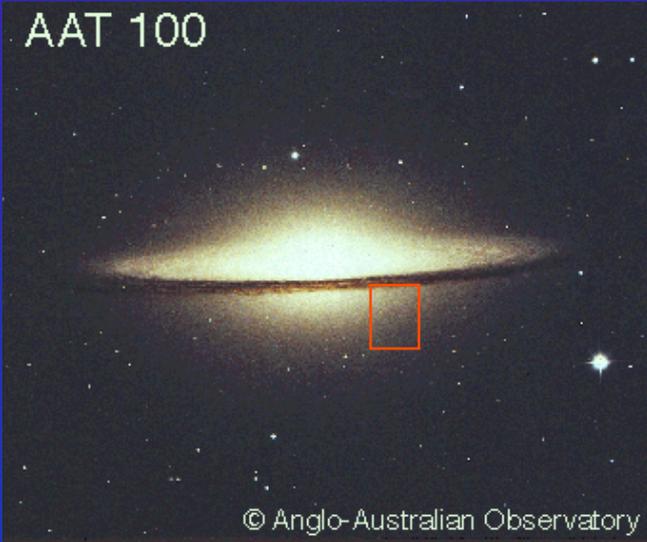


Les étoiles naissent ...



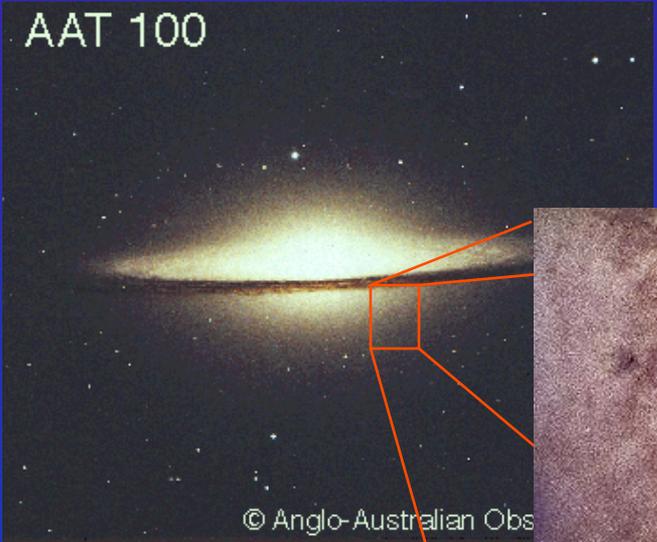
... dans la poussière.

Les étoiles naissent ...



... dans la poussière.

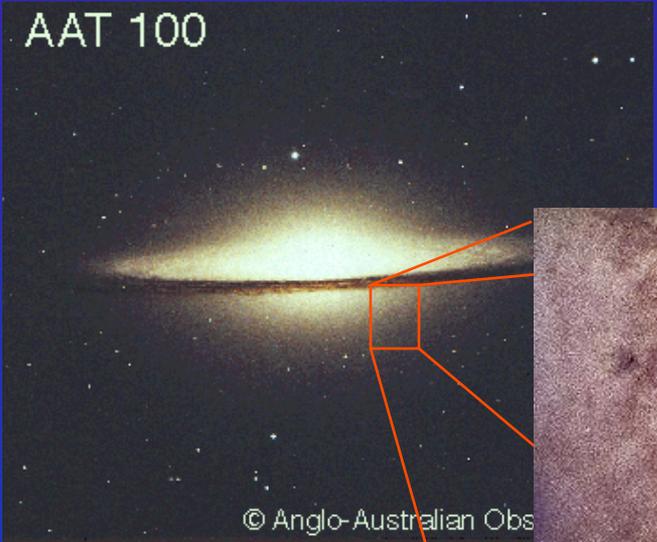
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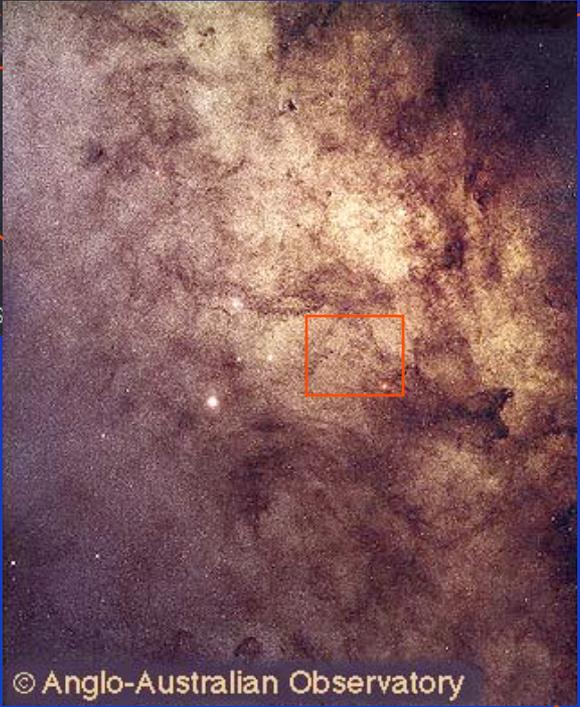
... dans la poussière.



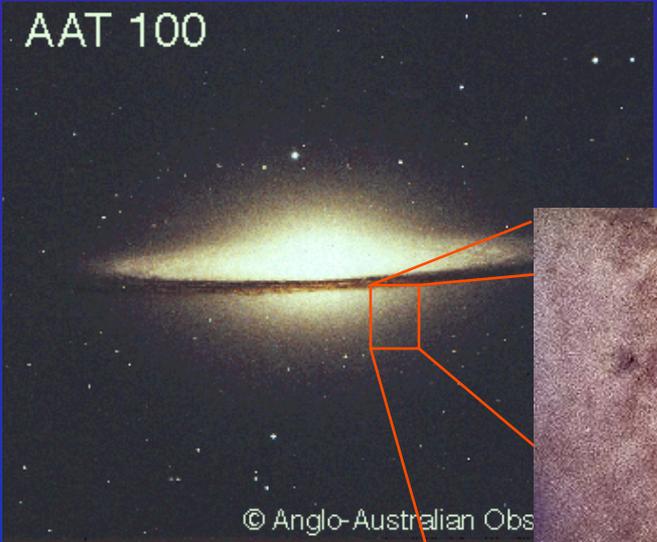
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Les étoiles naissent ...



... dans la poussière.



Les étoiles naissent ...

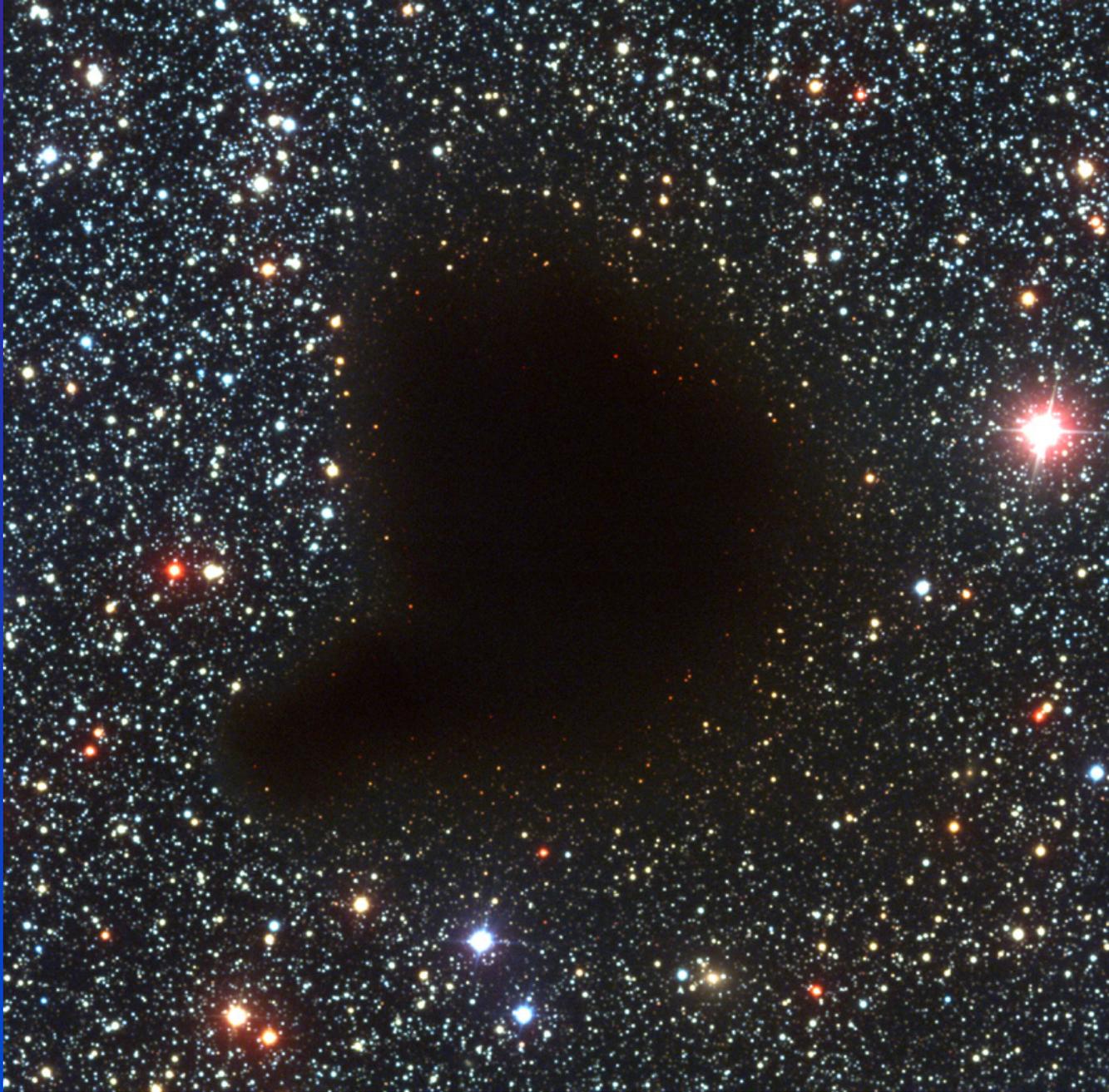


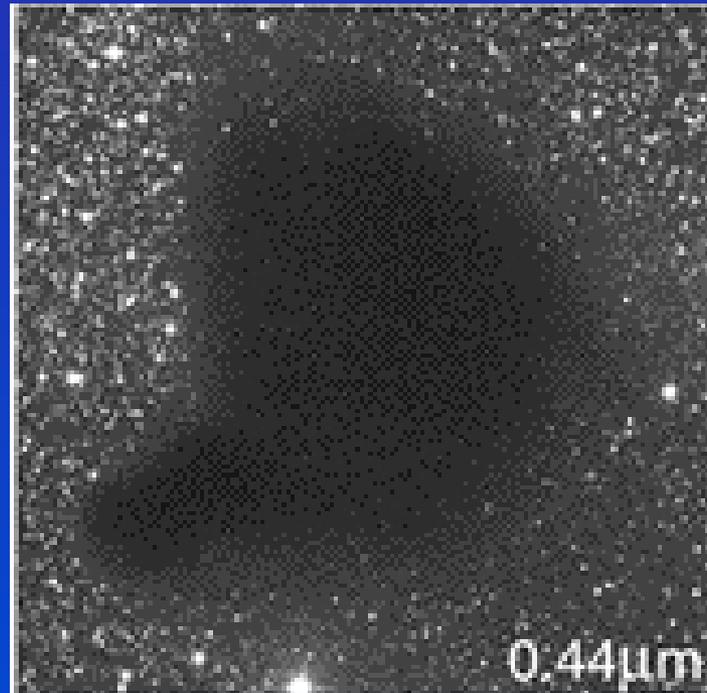
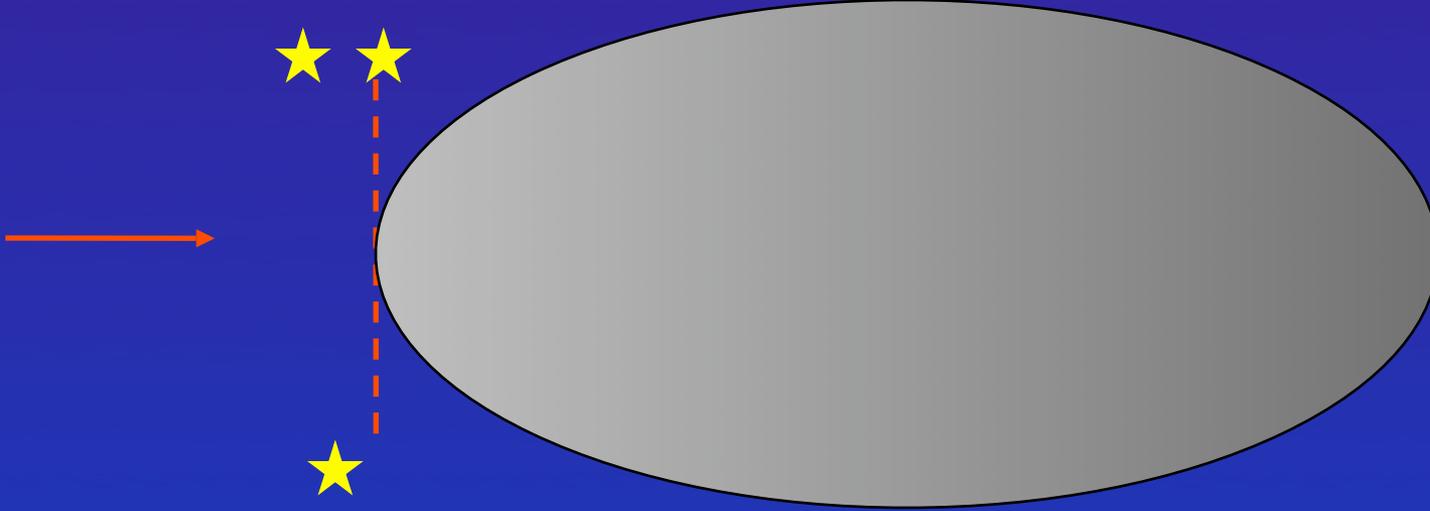


Nurseries stellaires ...



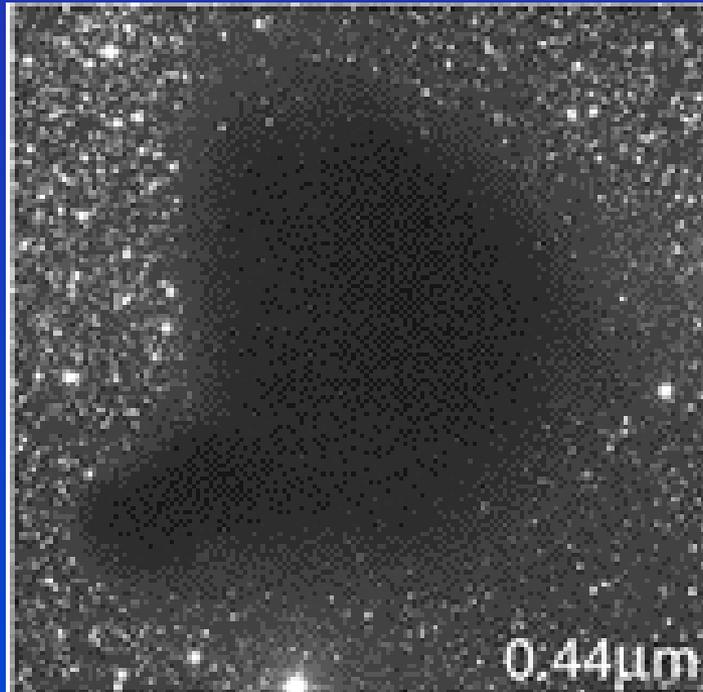
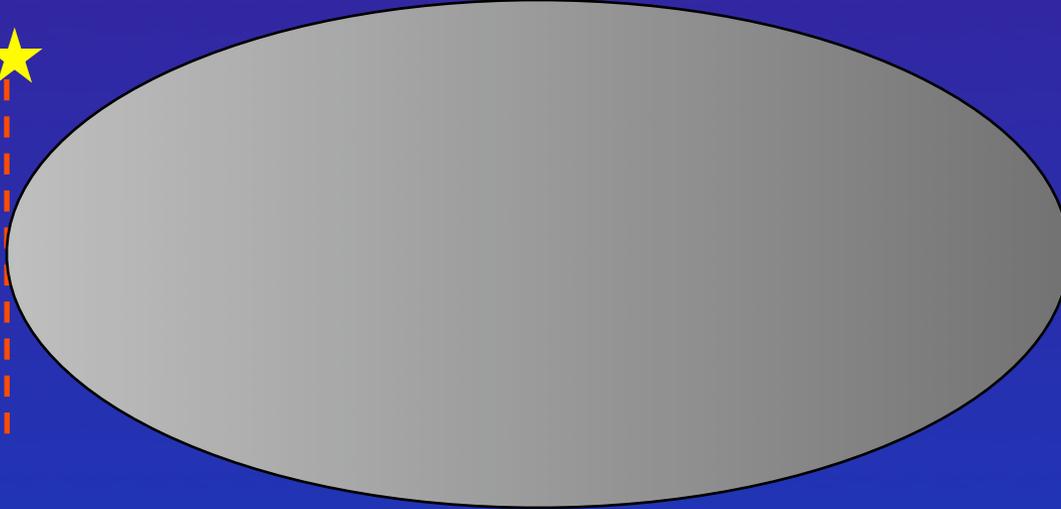
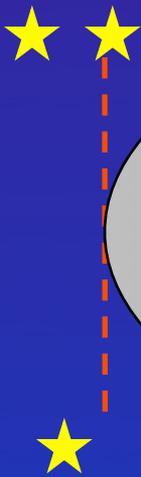






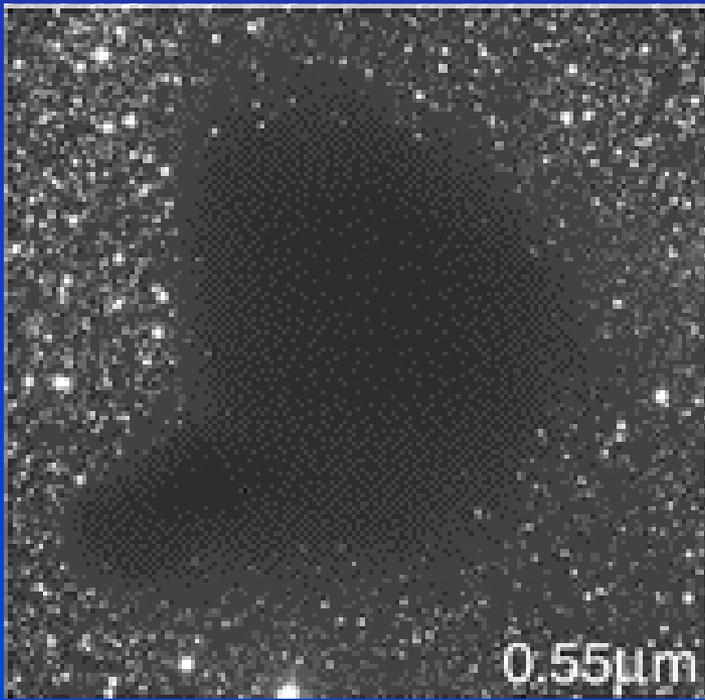
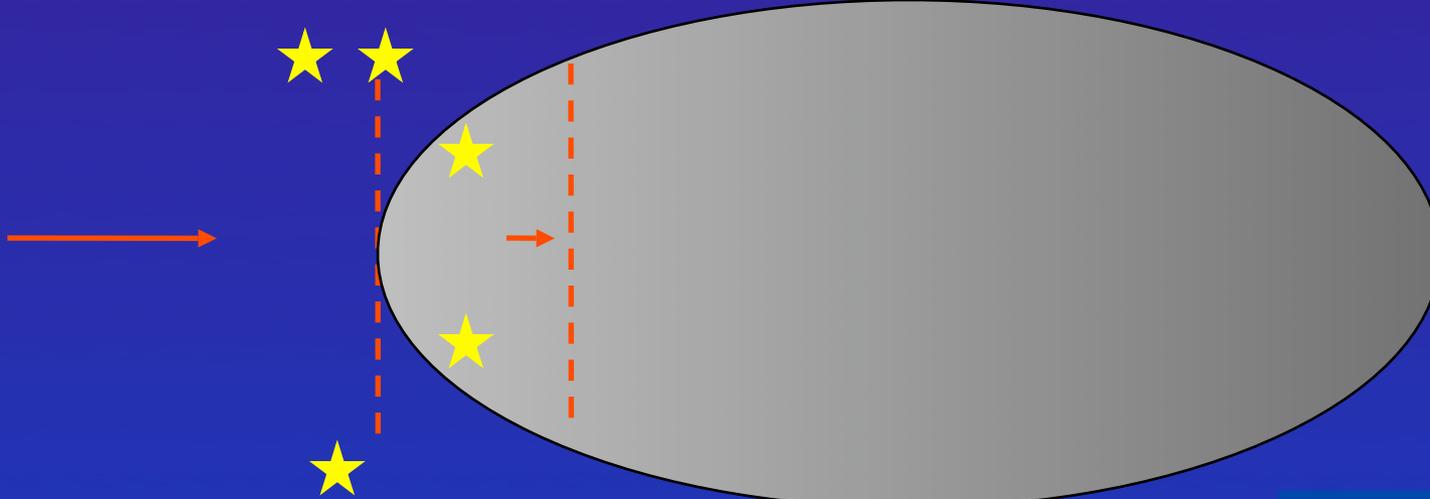
0.44 μm

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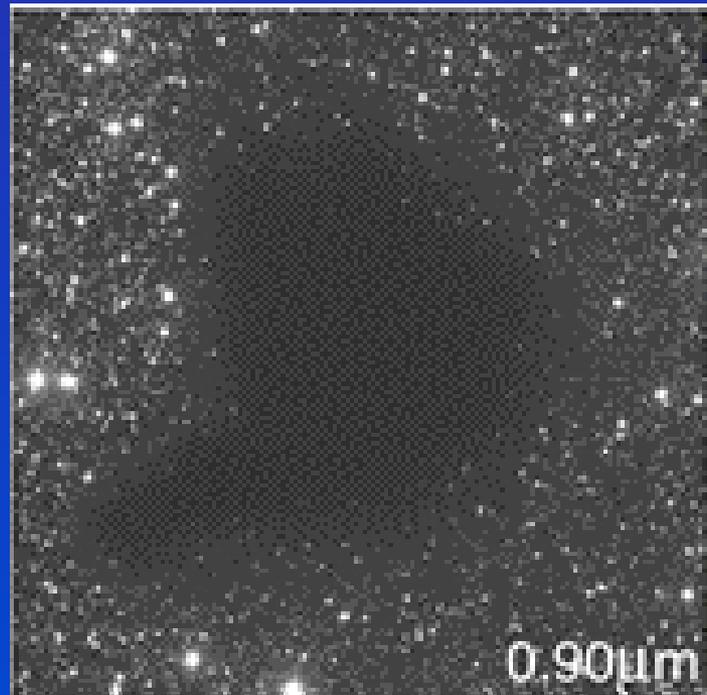
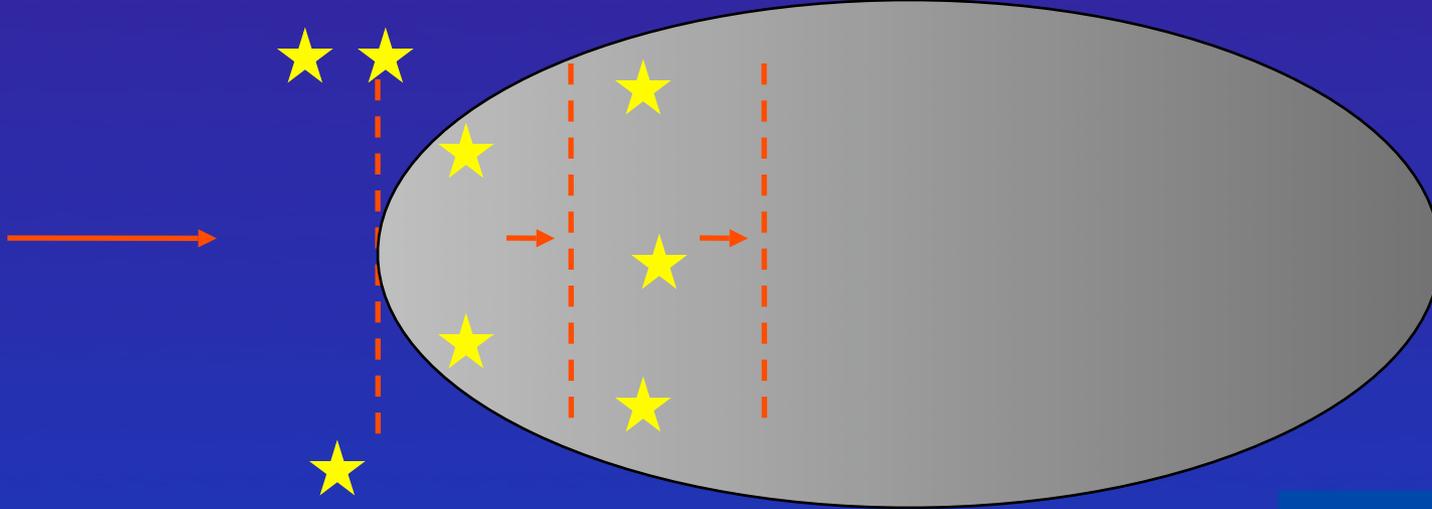


0.44 μm

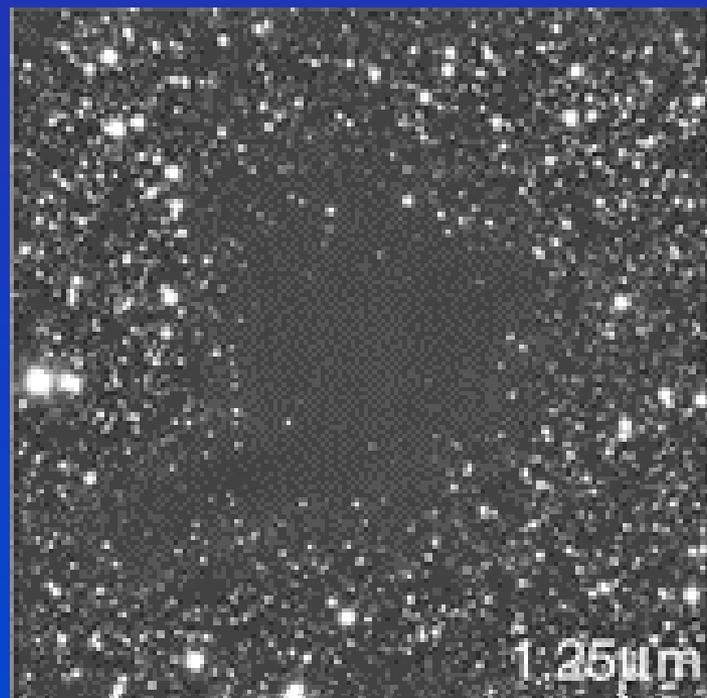
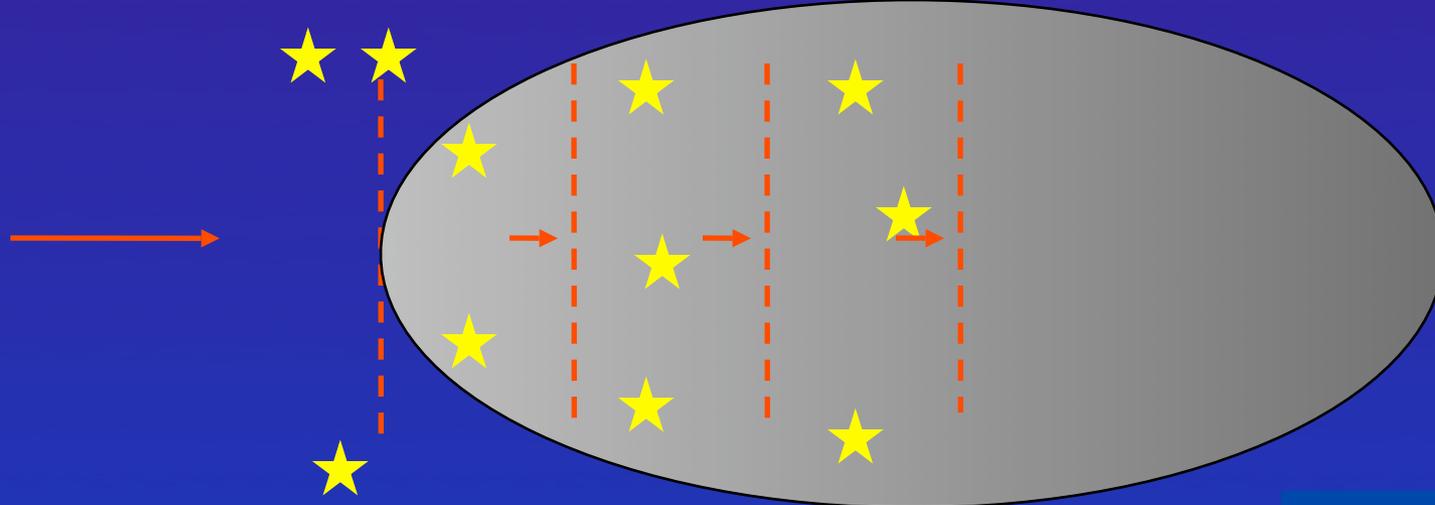
0.44 μm



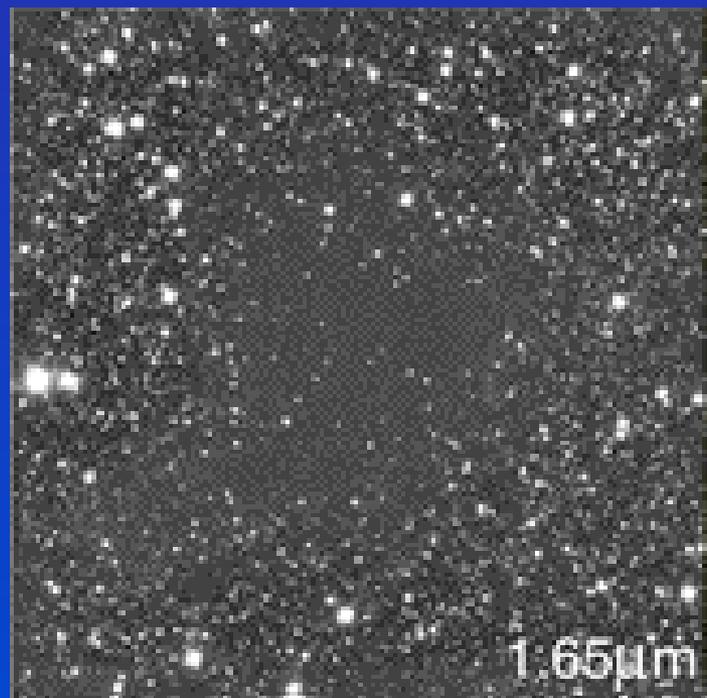
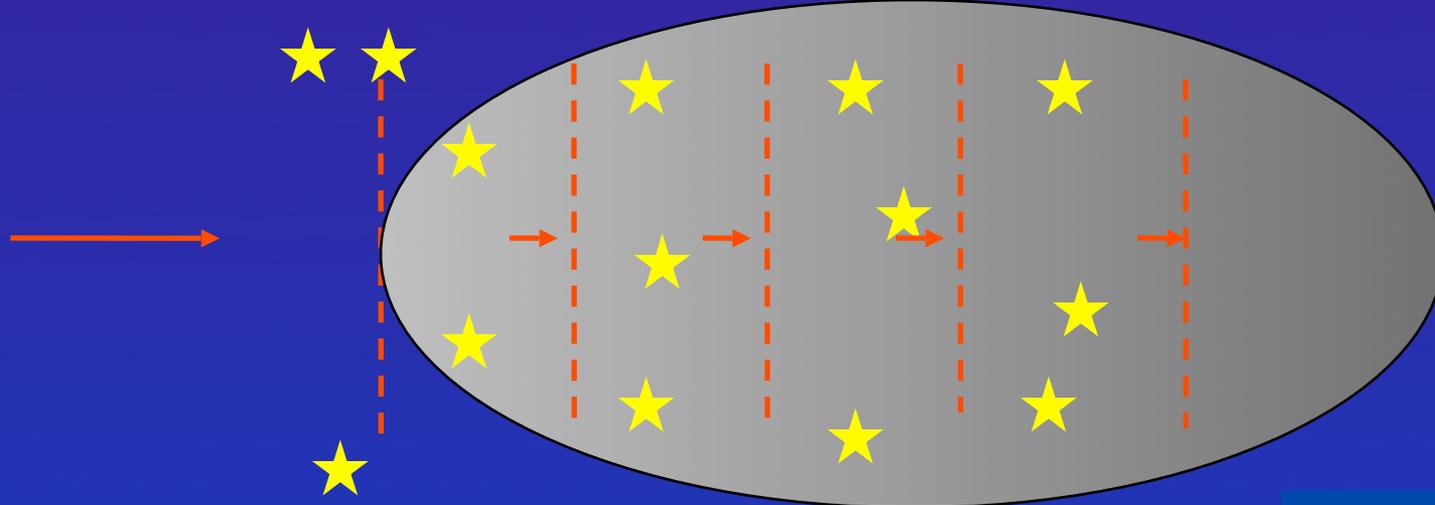
0.55 μm



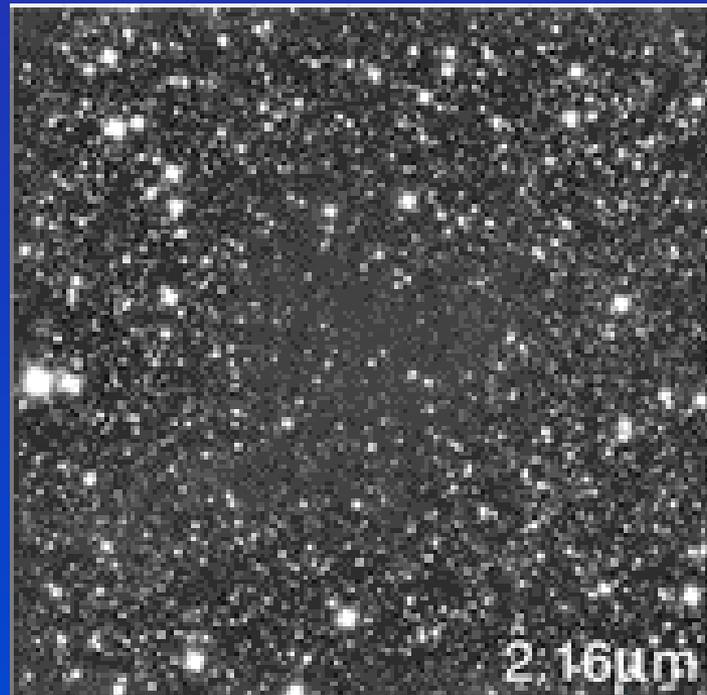
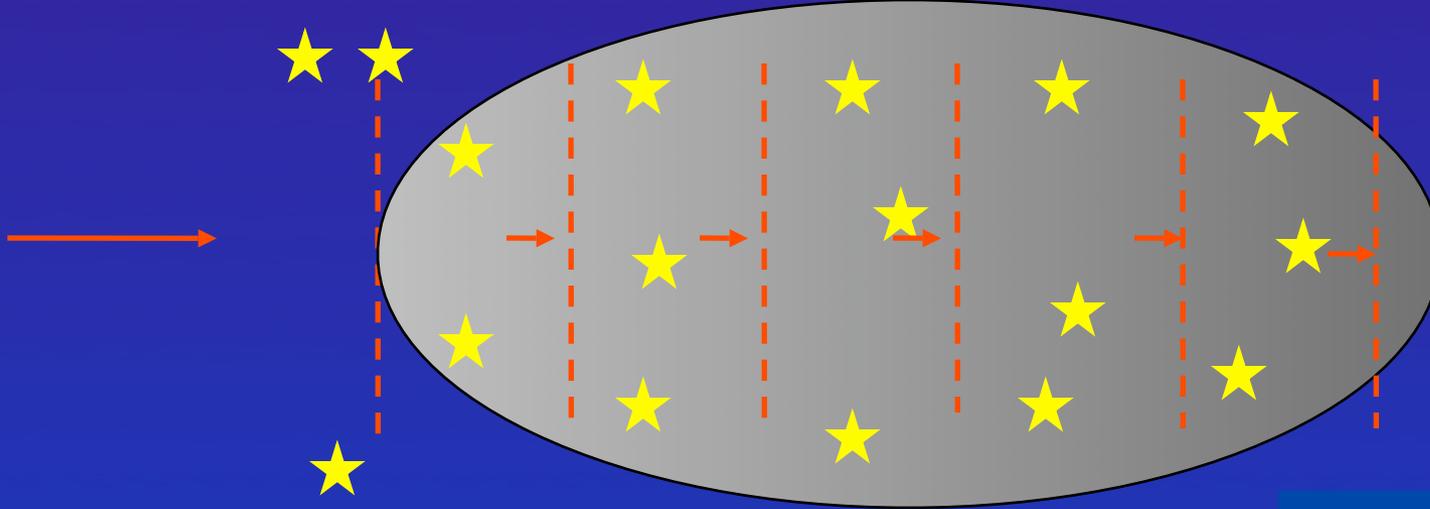
0.9 μm



$1.25\mu\text{m}$



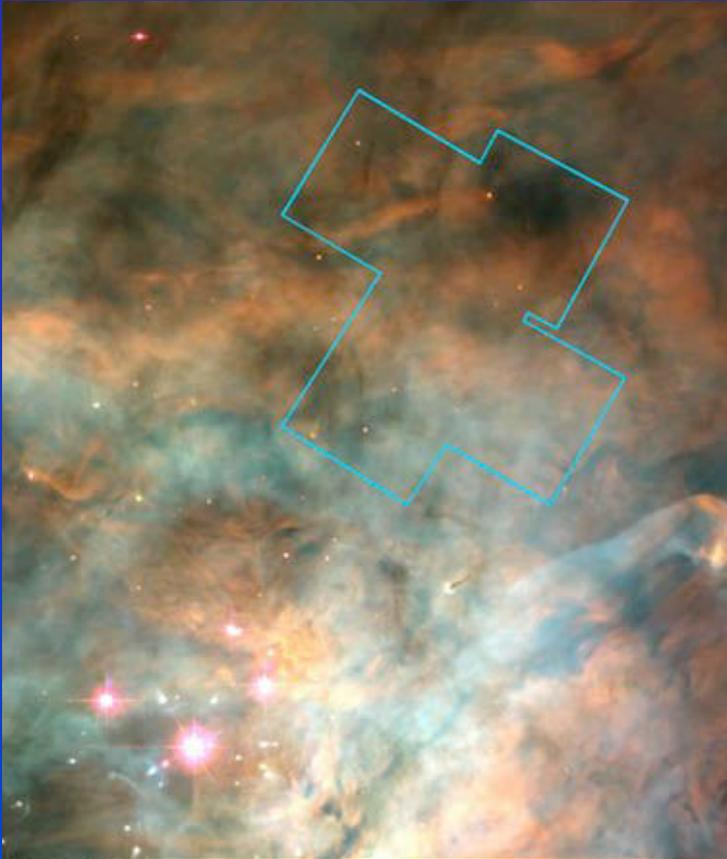
1.65 μm



2.2 μm

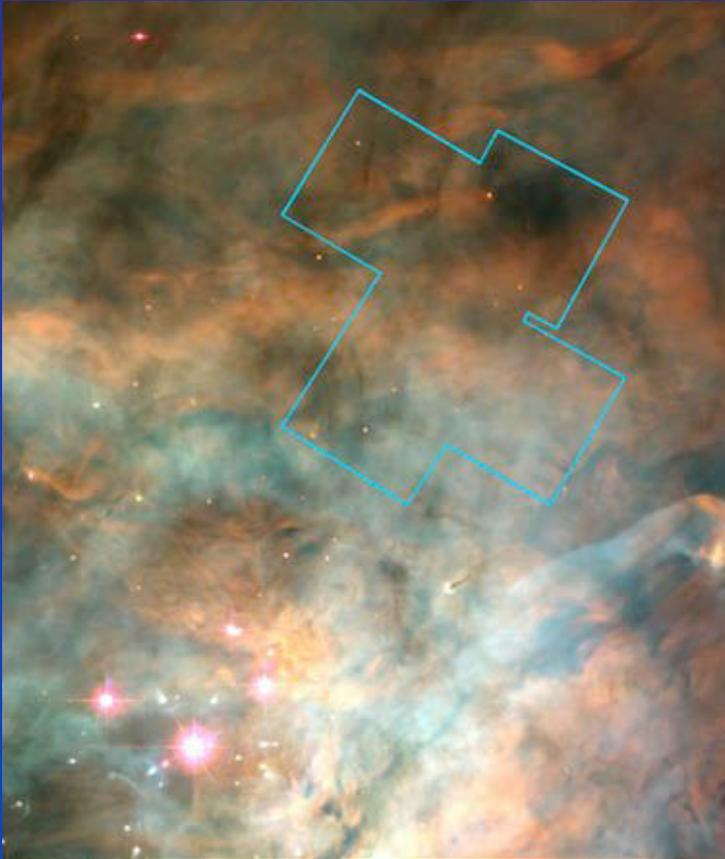


De jeunes étoiles invisibles à « l'œil nu » ...



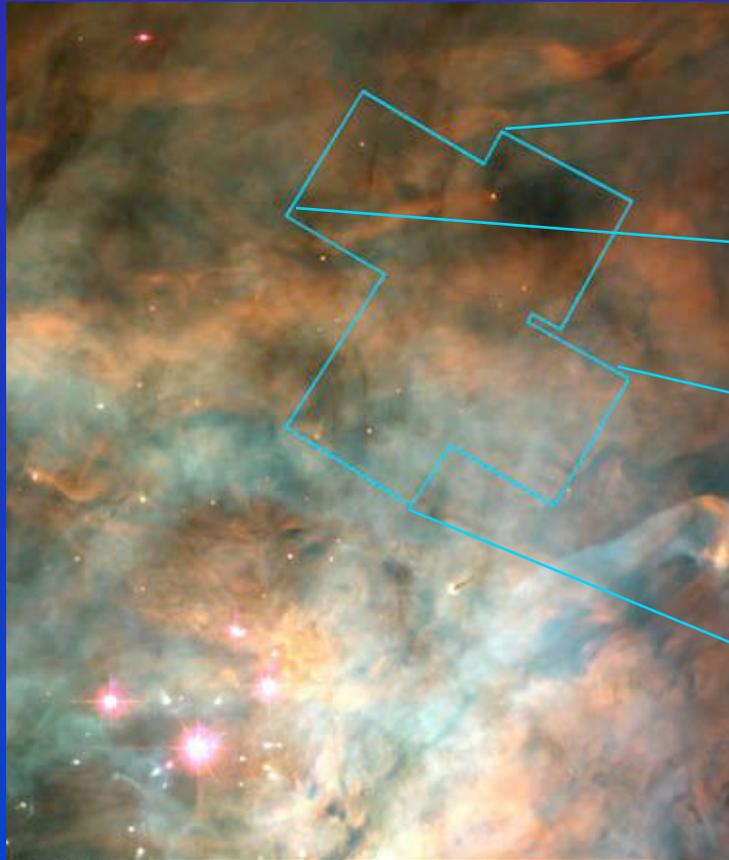
Dans le visible ($0.5 \mu\text{m}$)

De jeunes étoiles invisibles à « l'œil nu » ...

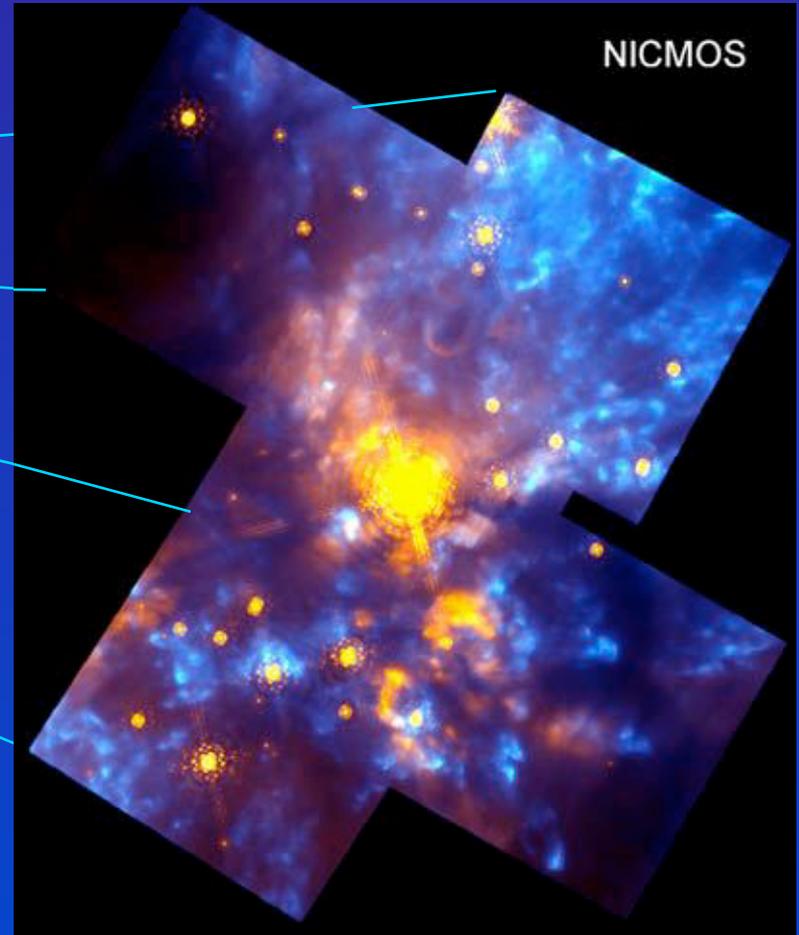


Dans le visible ($0.5 \mu\text{m}$)

De jeunes étoiles invisibles à « l'œil nu » ...



Dans le visible ($0.5 \mu\text{m}$)



Dans l'infrarouge ($2.2 \mu\text{m}$)

Vues par le télescope spatial Hubble (HST)



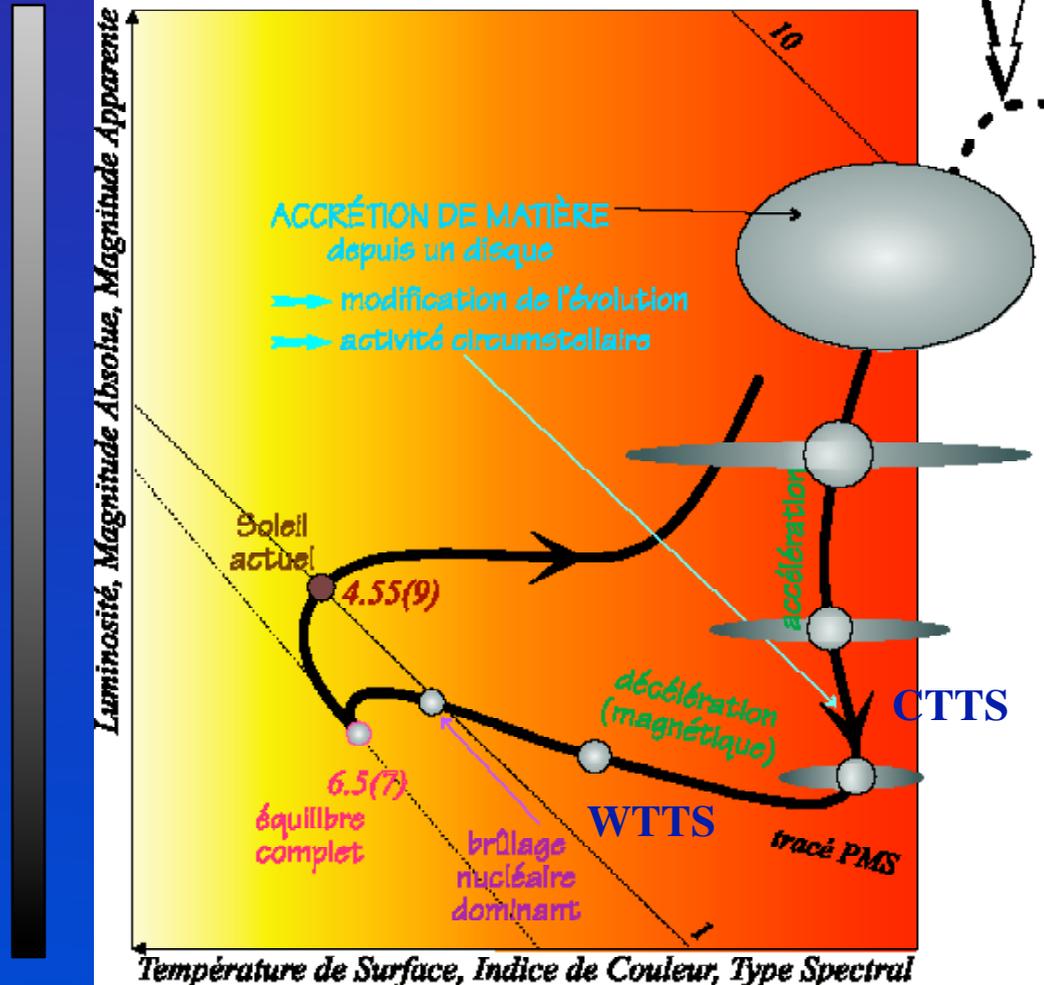
Luminosité

Premières phases d'évolution

phase PMS : fin du processus de formation stellaire
(accrétion de matière)
ralentissement de la contraction

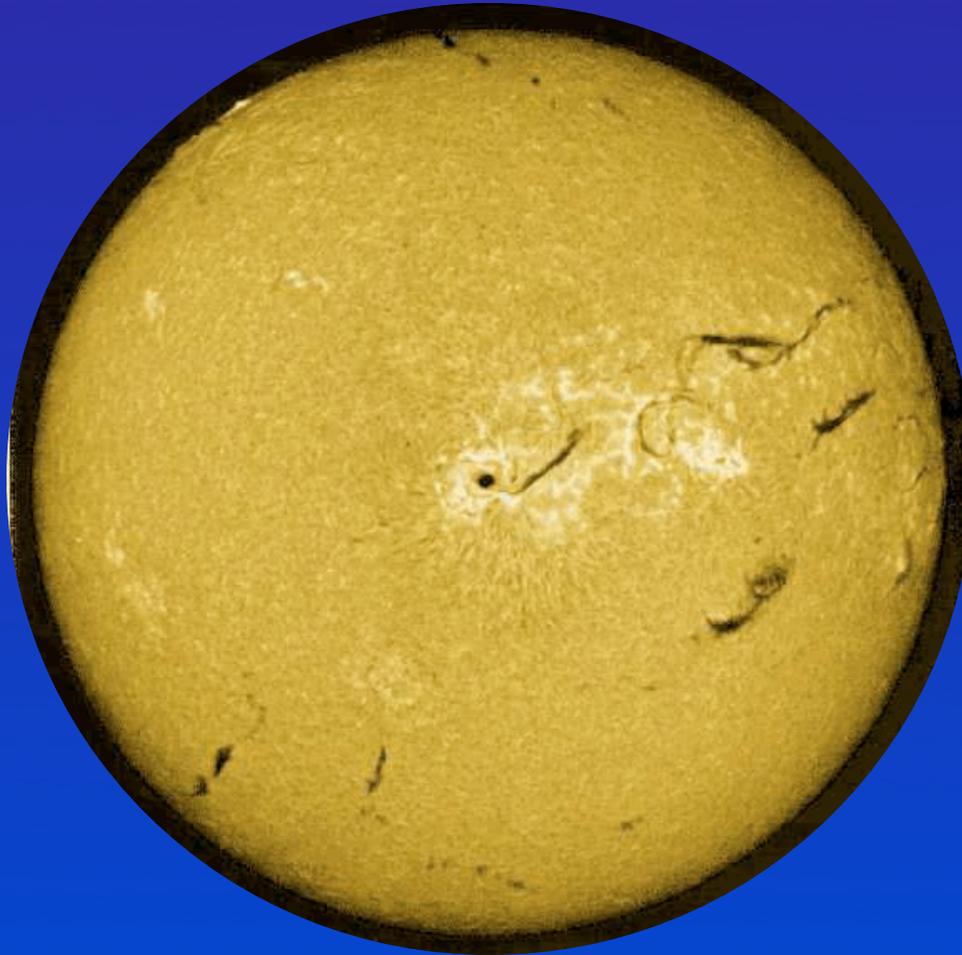
phase MS : source nucléaire dominante (brûlage de H)
augmentation progressive de L et R

Masse
de
Jeans



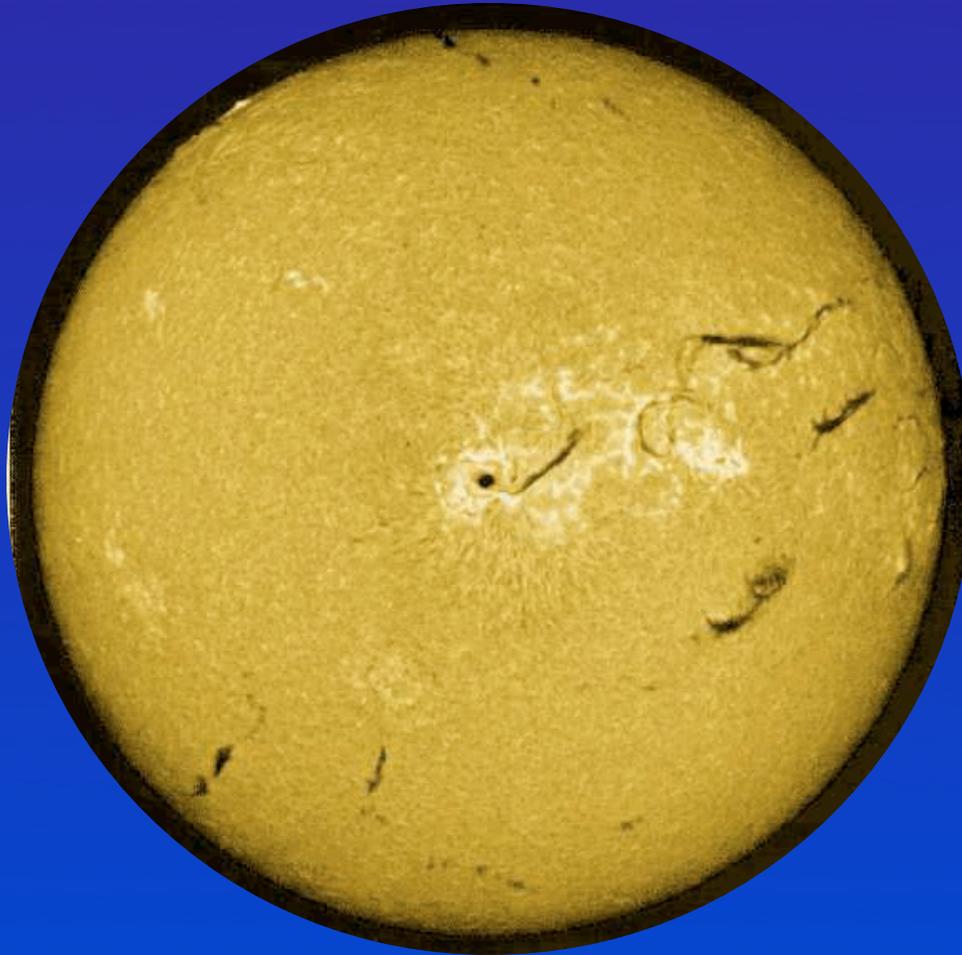
Température (froide)

Au cœur du soleil, les réactions nucléaires :



600.000 tonnes d'Hydrogène par jour

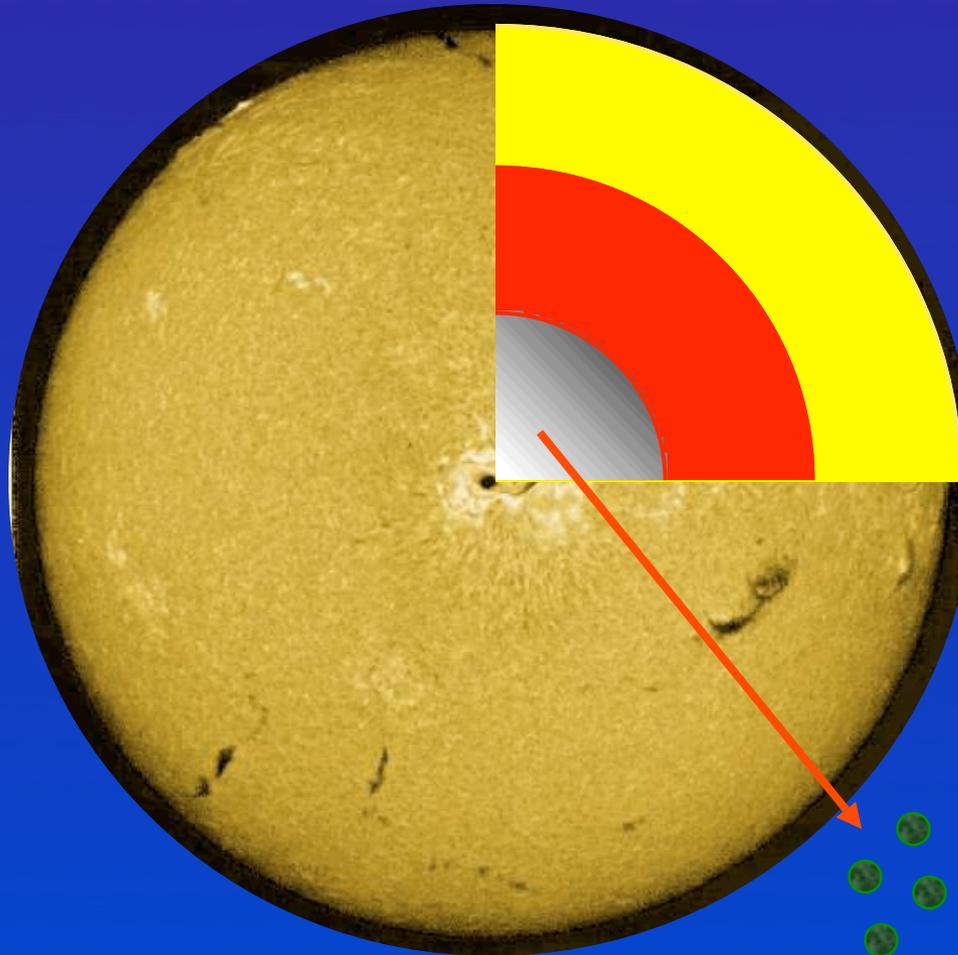
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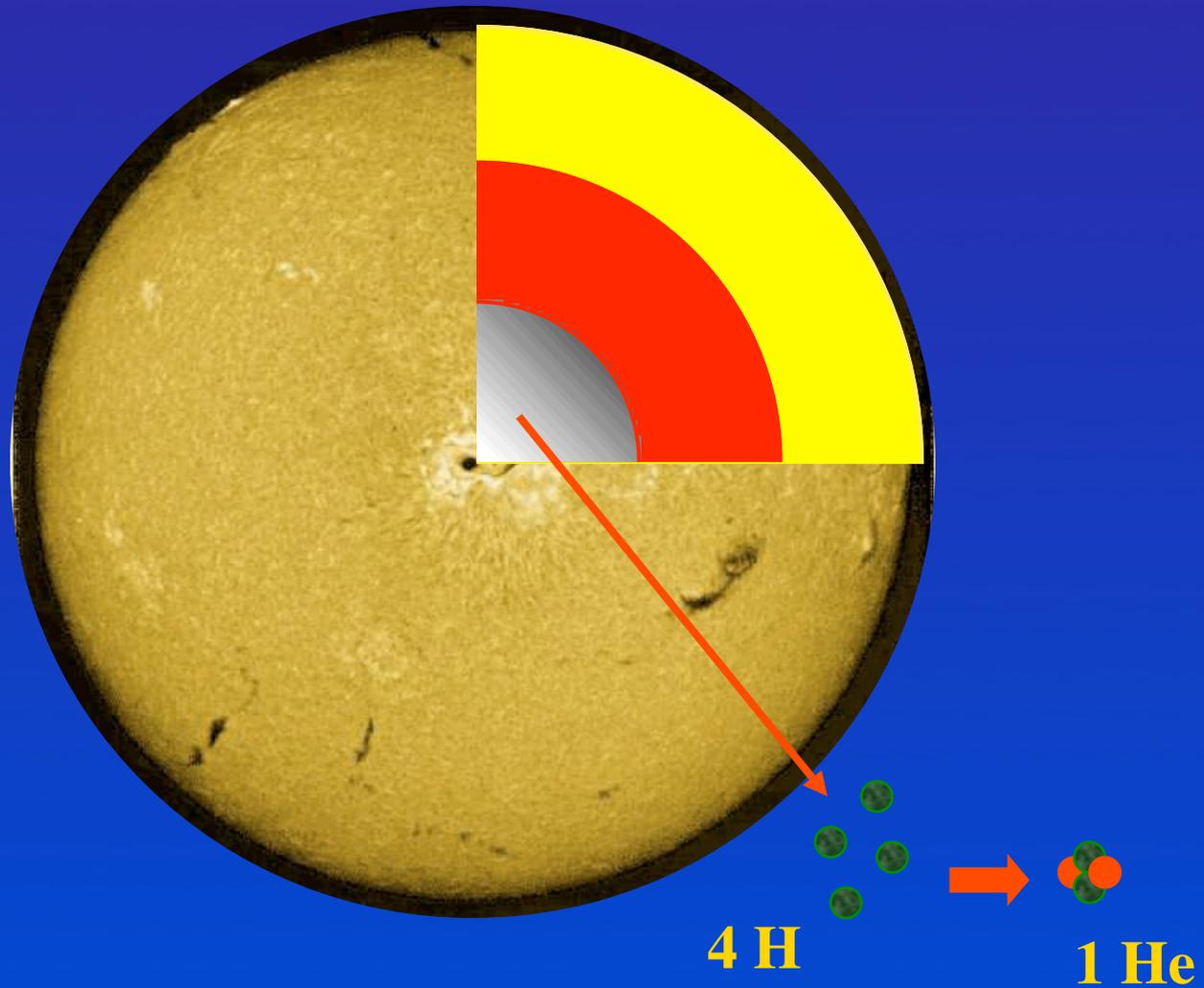
Au cœur du soleil, les réactions nucléaires :



4 H

600.000 tonnes d'Hydrogène par jour

Au cœur du soleil, les réactions nucléaires :

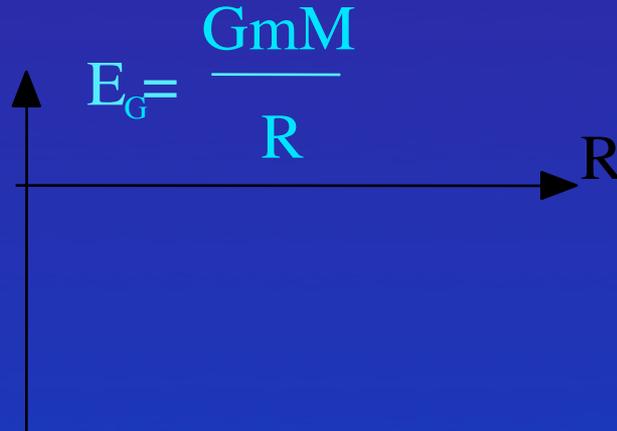


600.000 tonnes d'Hydrogène par jour



Fusion nucléaire :

$$E_N = 0.007 mc^2$$

$$E_G = \frac{GmM}{R}$$




$$\frac{E_G}{E_N}$$

Soleil : 0.03 %

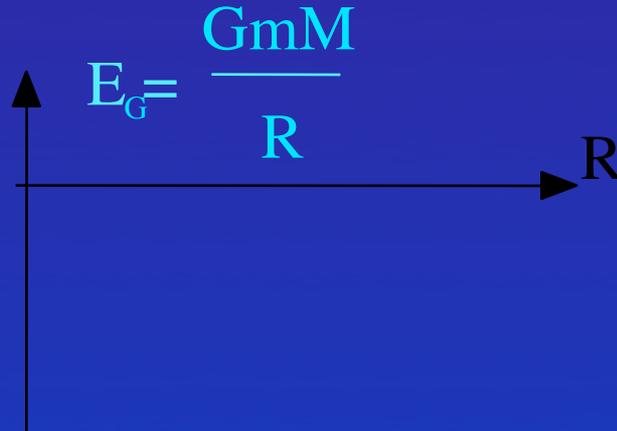
Naine blanche : 2 %

Etoile à neutrons : 20 (0.14 mc^2)

Trou noir : 70 ($\frac{mc^2}{2}$)

Fusion nucléaire :

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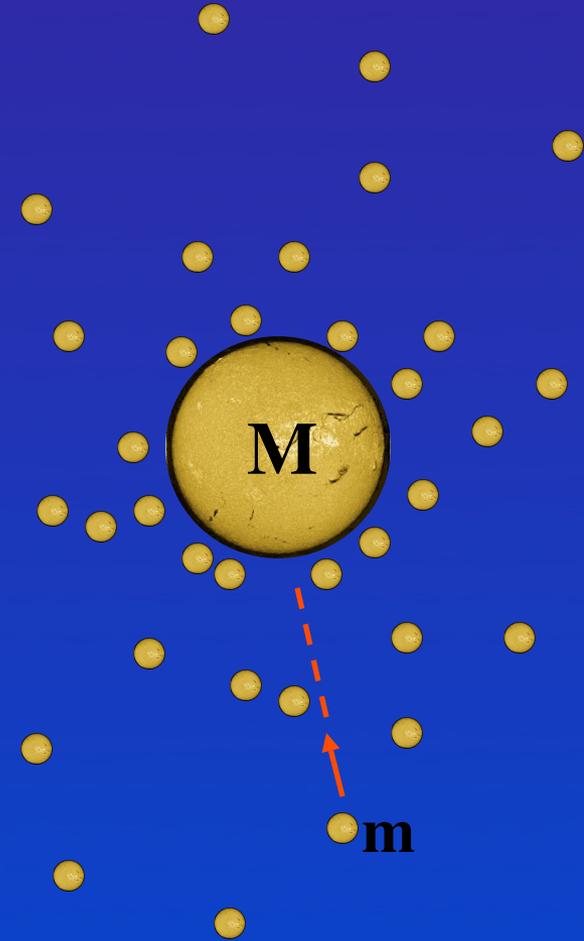
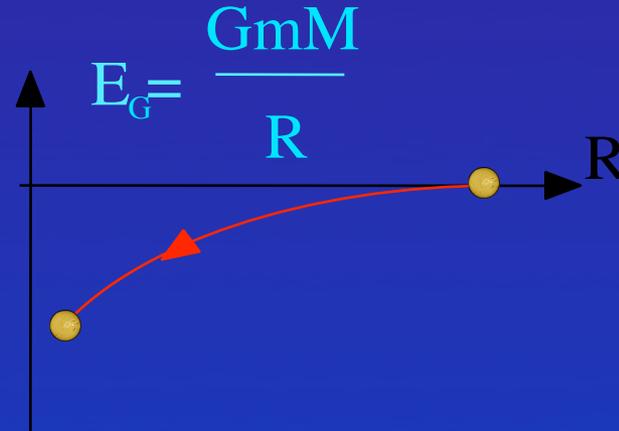
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Echelles de temps caractéristiques

Temps de chute libre

$$t_{cl} \propto \frac{1}{\sqrt{G \rho}}$$

Soleil : 1/2 heure !

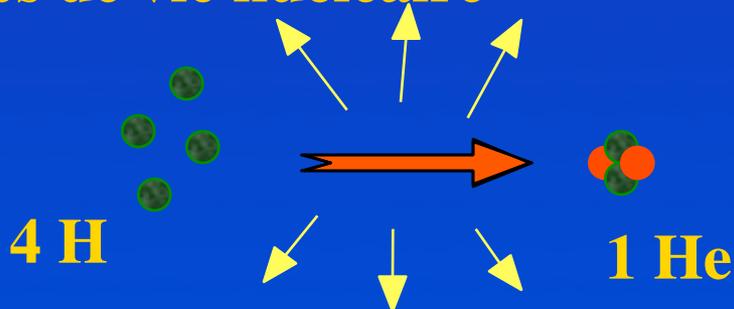
Etoile en formation :
200 000 ans

Temps d'ajustement thermique

$$\tau_{KH} : \frac{GM^2}{RL}$$

Soleil : 30 millions
d'années

Temps de vie nucléaire



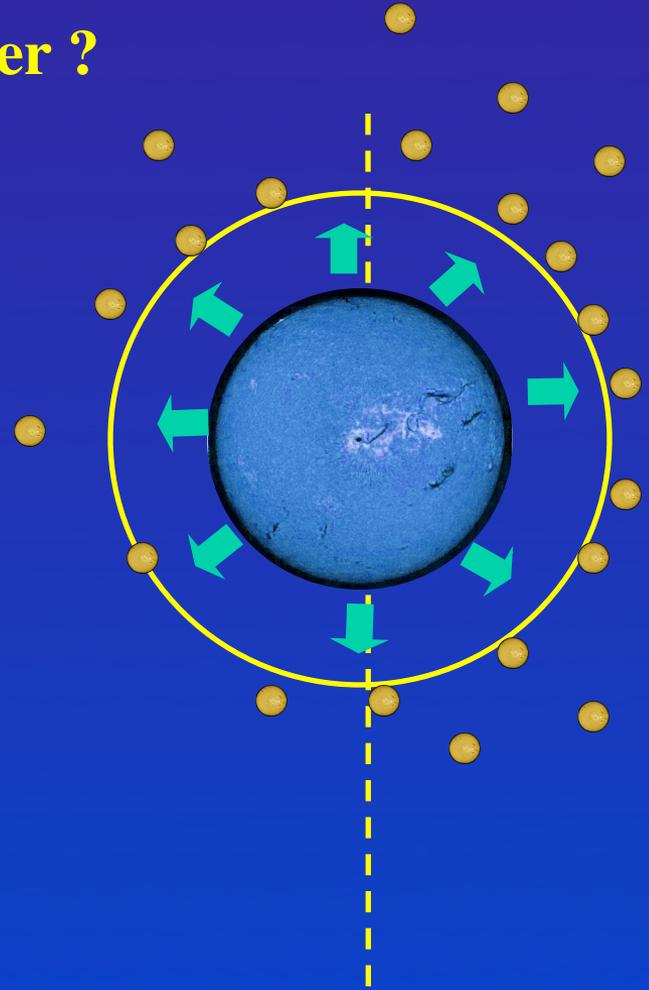
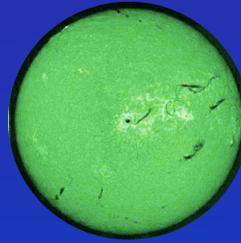
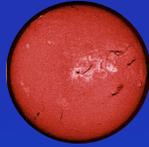
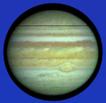
Soleil : 10 milliards
d'années

$$\tau_{nuc} \propto \frac{M}{L} \propto M^{-3}$$

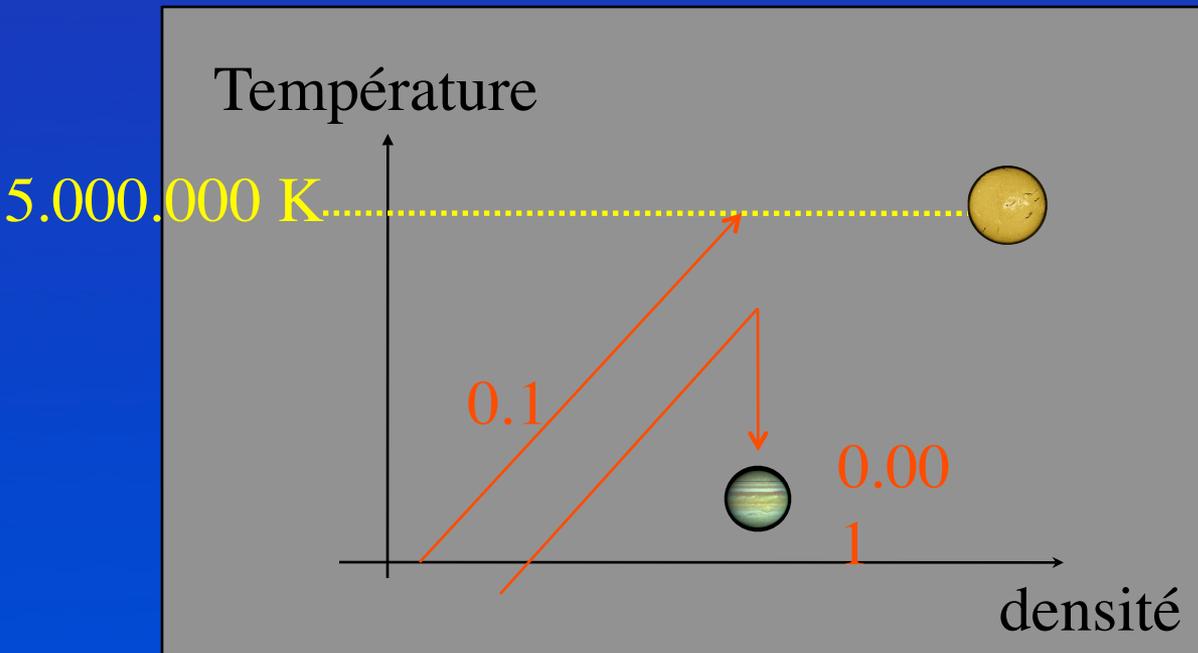
Quelles étoiles peuvent se former ?

0.08 M_{\odot}

Naines brunes
et planètes



60-100 M_{\odot}





Les instruments de l'étude de la formation stellaire

**Le télescope spatial
Hubble Space
Telescope
(HST)**



▼
**Les instruments de l'étude
de la formation stellaire**

**Le télescope spatial
Hubble Space
Telescope
(HST)**

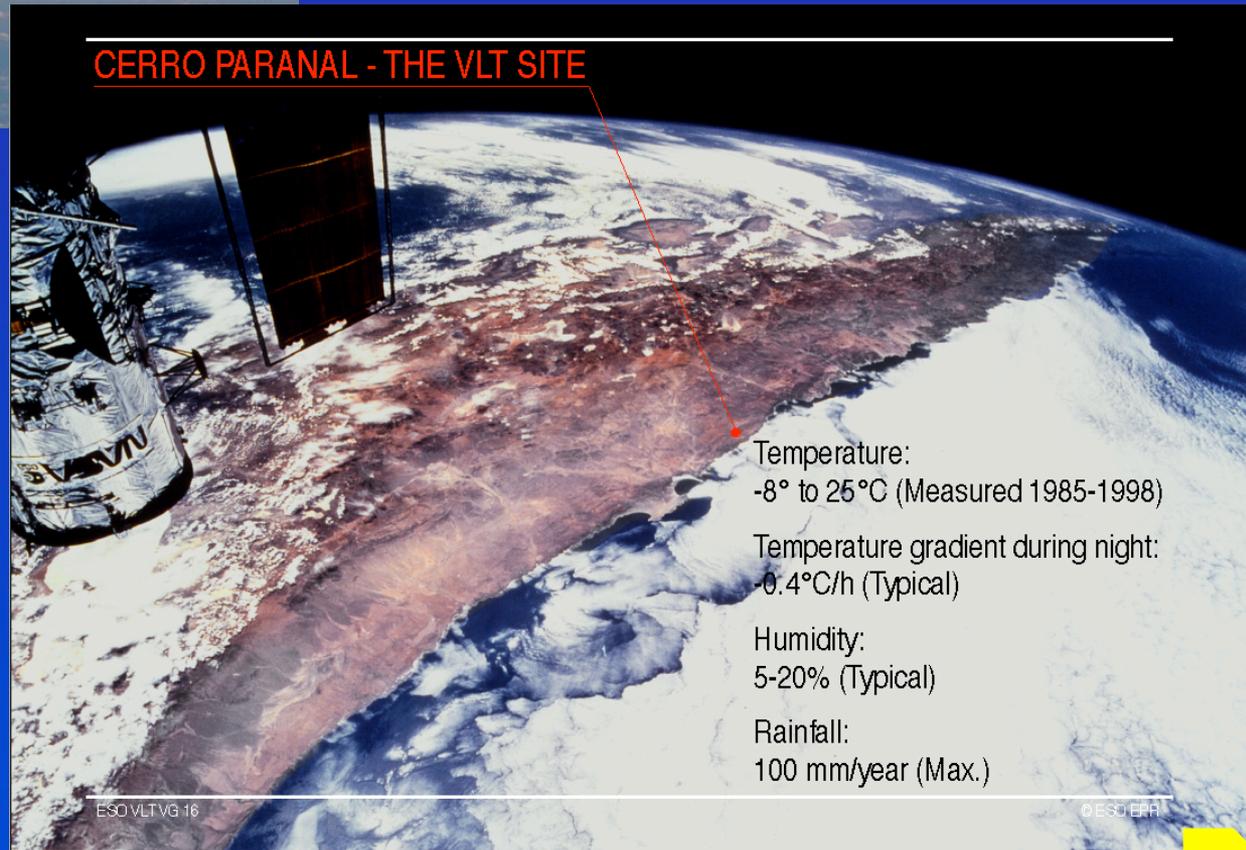


Les instruments de l'étude de la formation stellaire

Le très grand télescope Européen (VLT)



Le télescope spatial Hubble Space Telescope (HST)

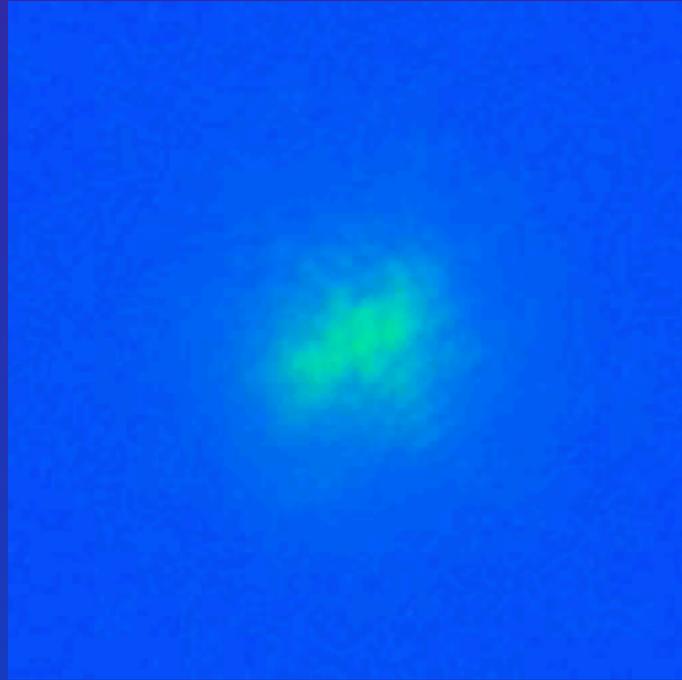




**Le très grand télescope européen
le VLT, installé au Chili.**

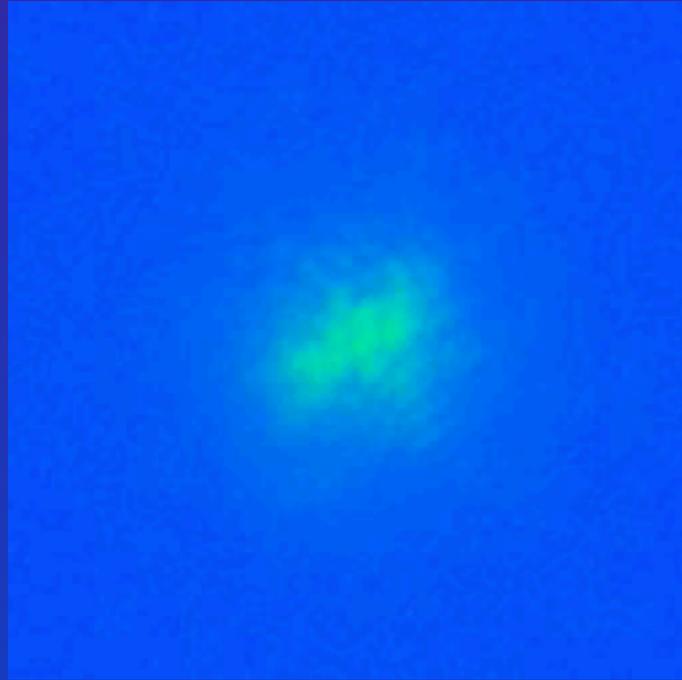


L'optique adaptative



**Une des clés de
l'étude de la
formation stellaire**

L'optique adaptative



**Une des clés de
l'étude de la
formation stellaire**





L'optique adaptative

Une des clés de l'étude de la formation stellaire

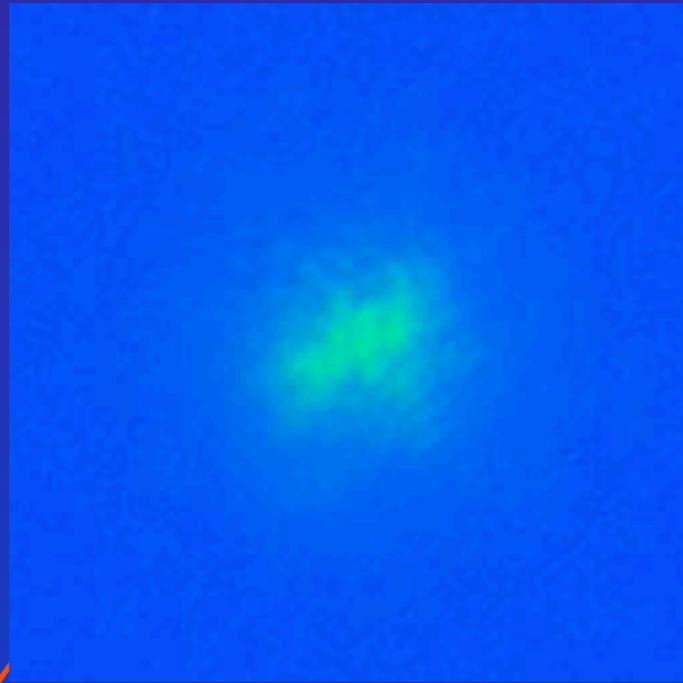
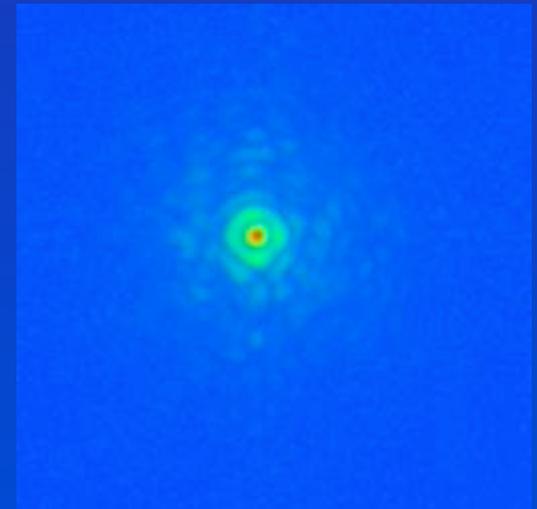


Image brute



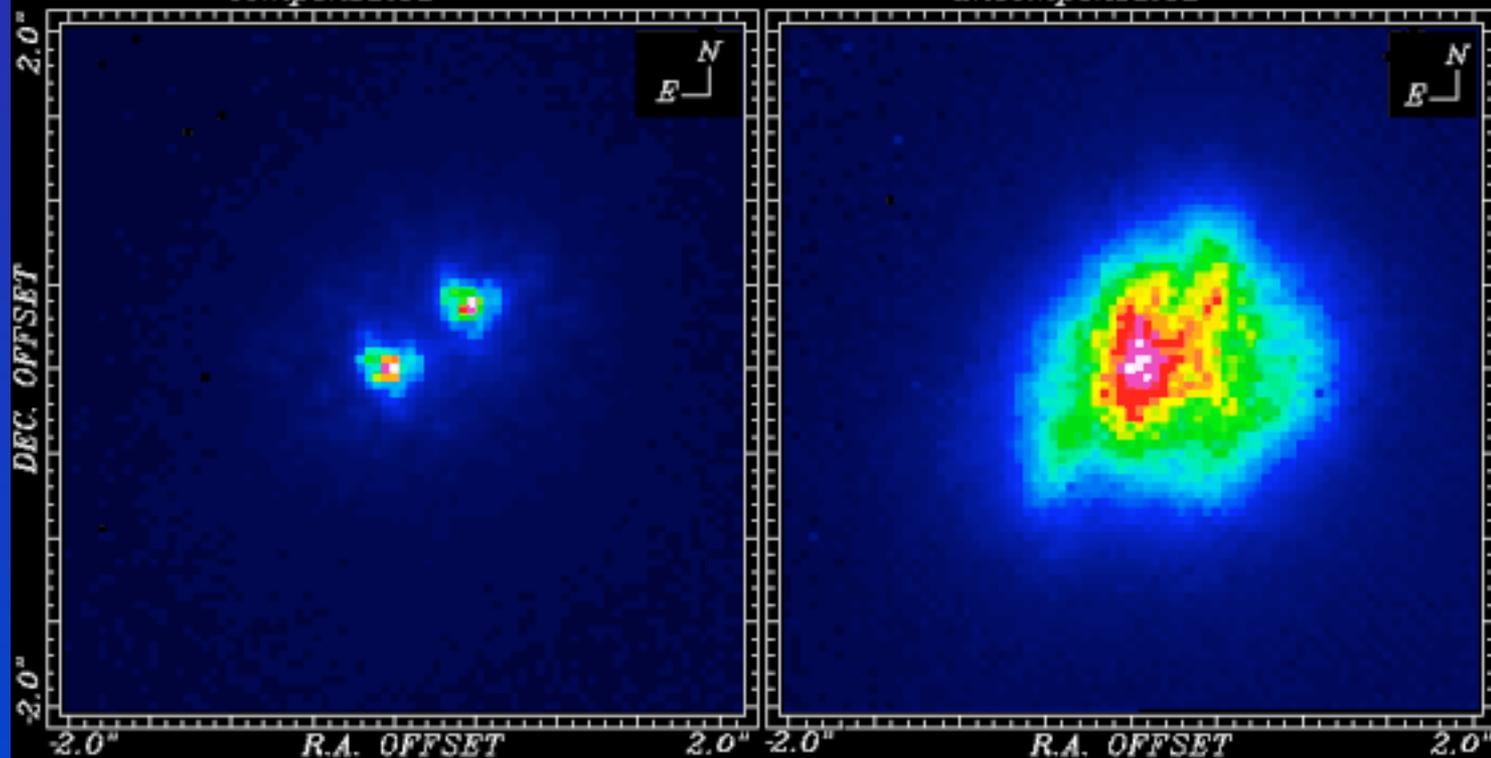
Image corrigée



M_v=13.1 Binary stars

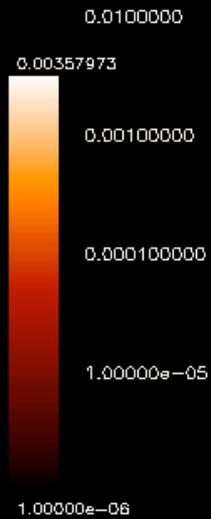
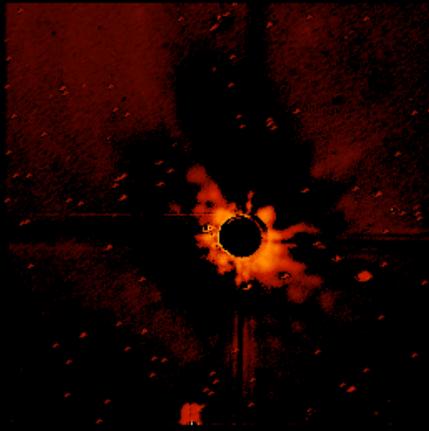
*H band (FWHM 0.12")
compensated*

*H band (seeing 1.7")
uncompensated*



COME-ON+/ESO 3.6m/Nov 93

HD 100546 dust disk, K' band



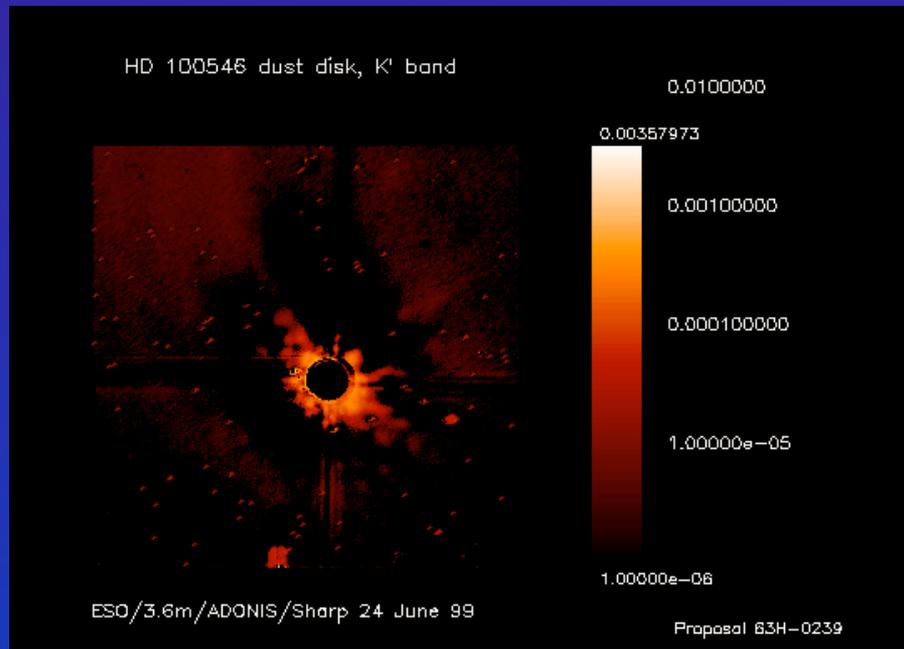
ESO/3.6m/ADONIS/Sharp 24 June 99

Proposal 63H-0239

Un disque de poussières autour d'une étoile détecté grâce à l'optique adaptative

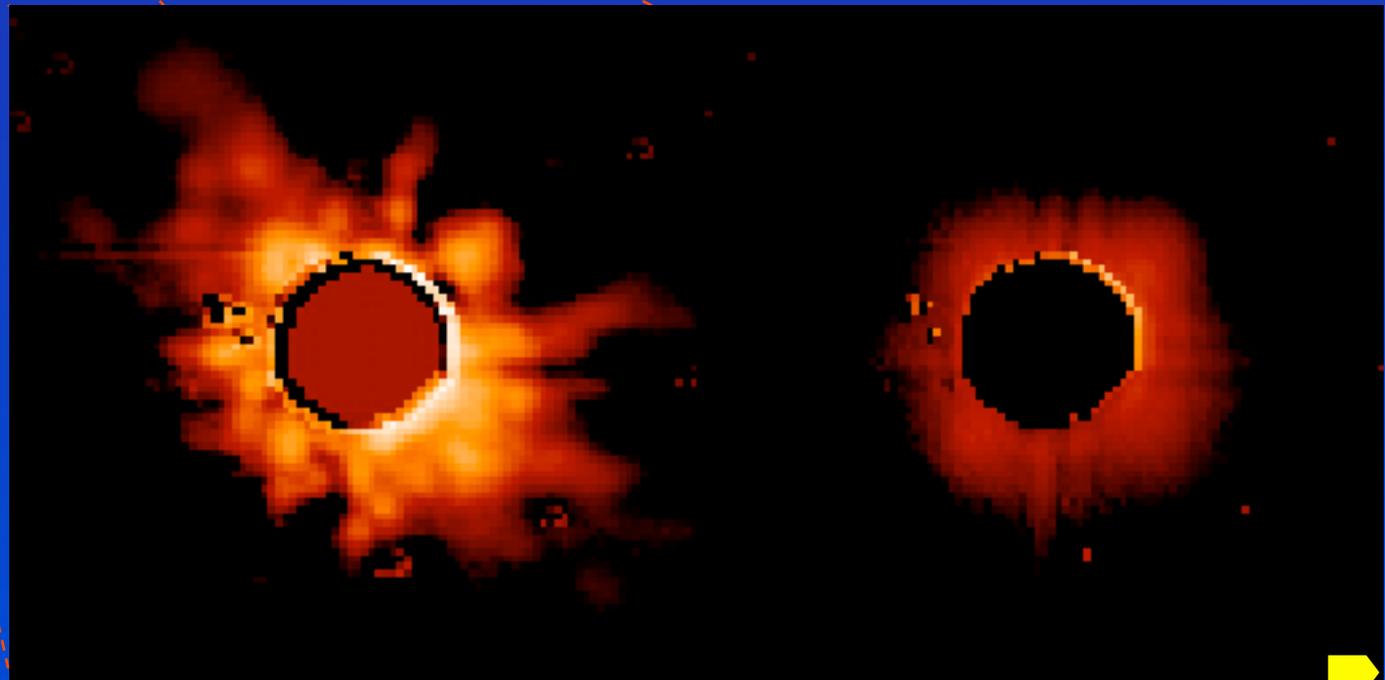
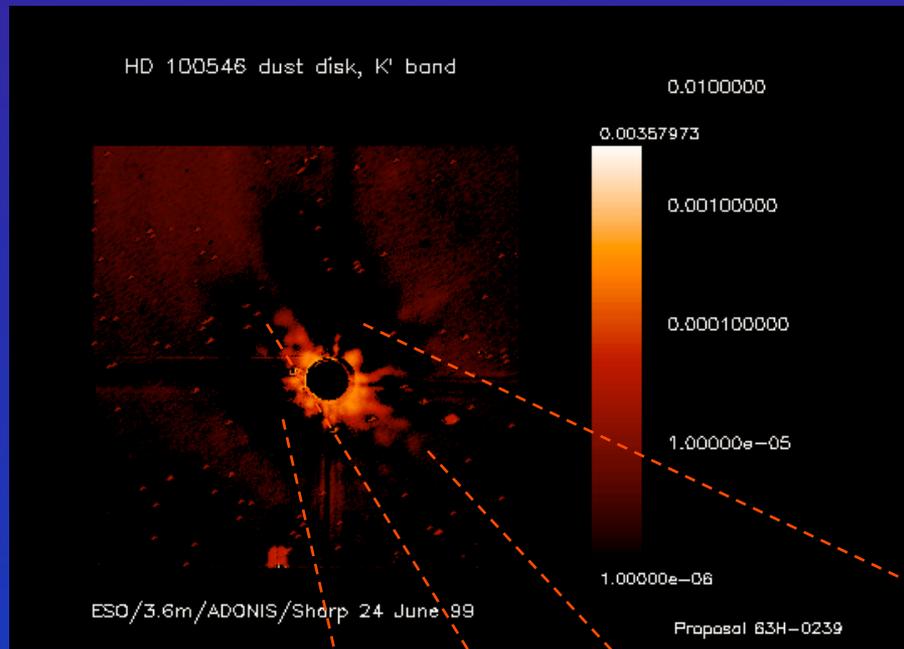


Un disque de poussières autour d'une étoile détecté grâce à l'optique adaptative

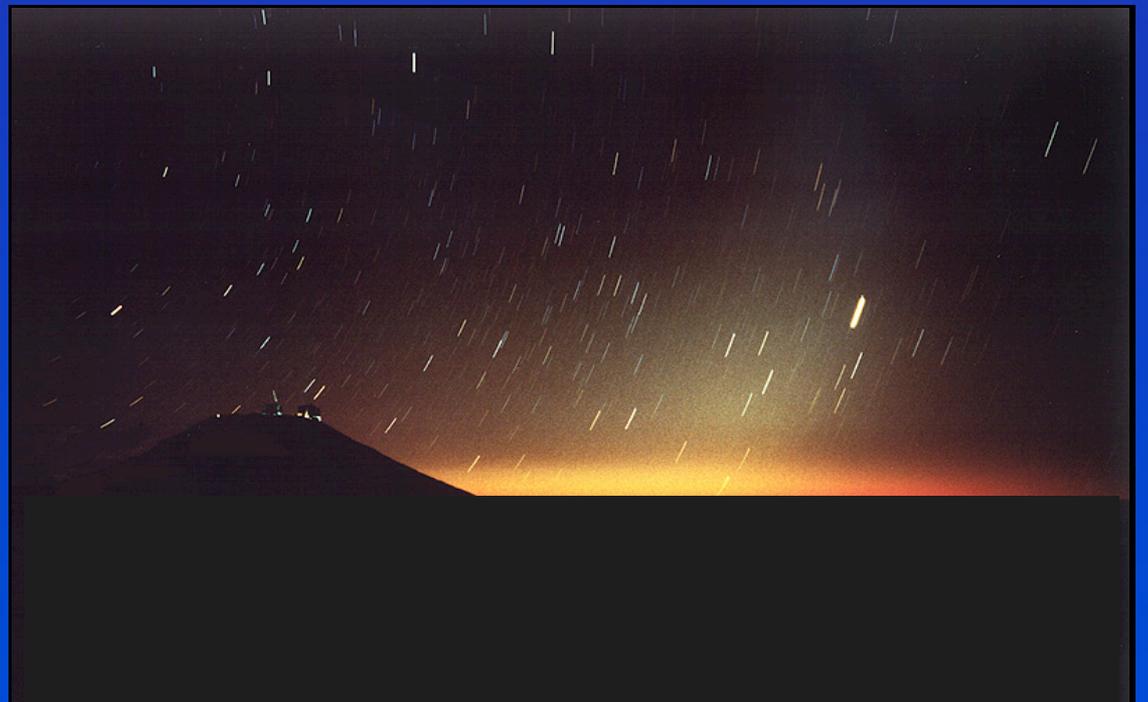




Un disque de poussières autour d'une étoile détecté grâce à l'optique adaptative

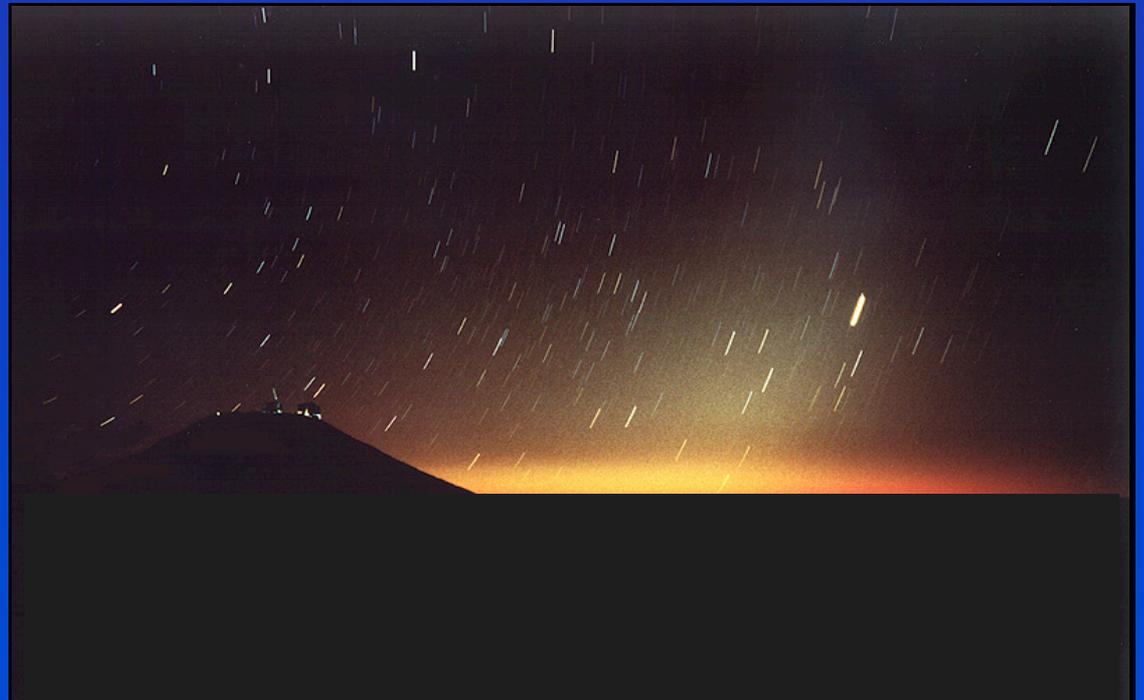


Lumière
Zodiacale
(poussières)



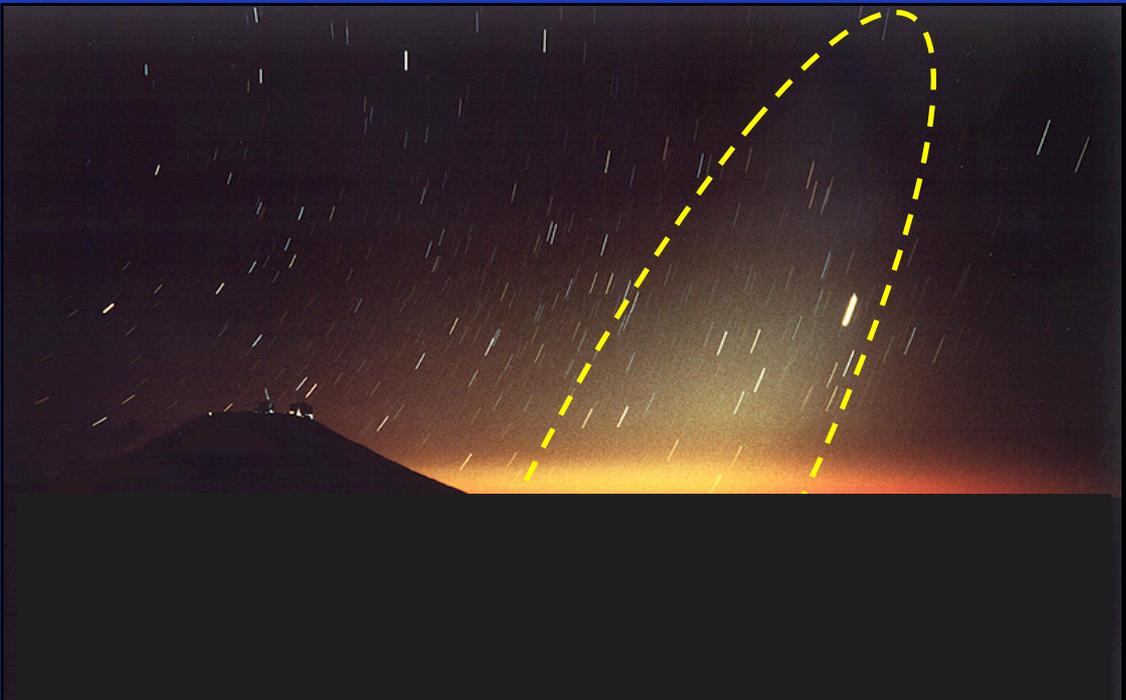


Lumière
Zodiacale
(poussières)



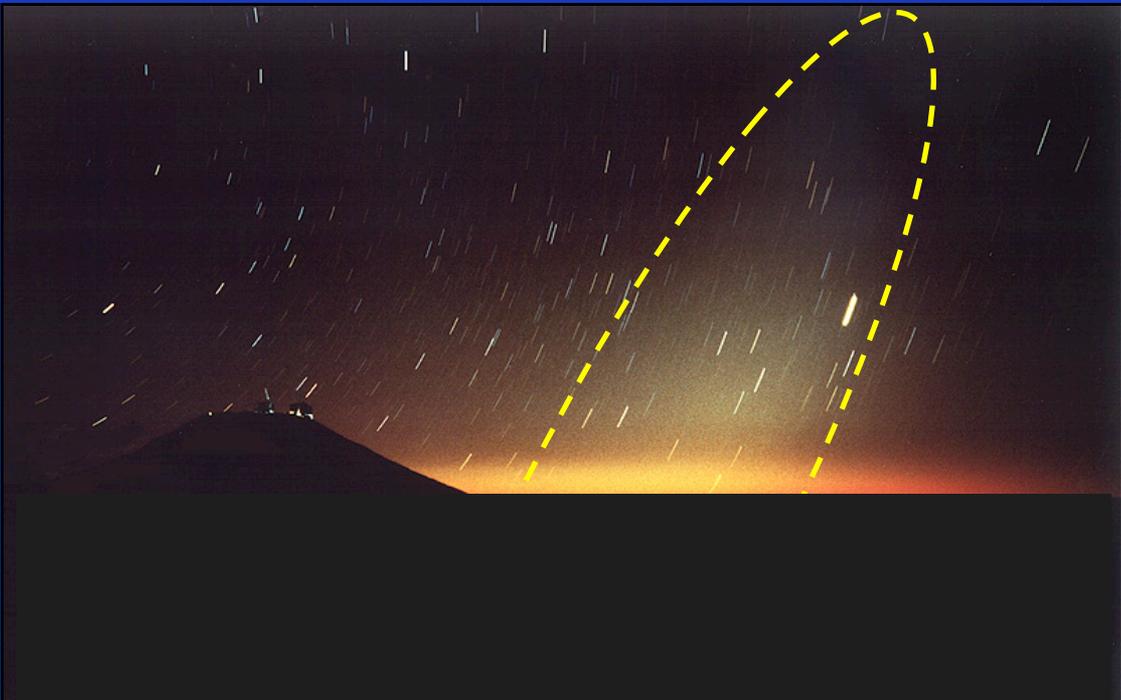


Lumière
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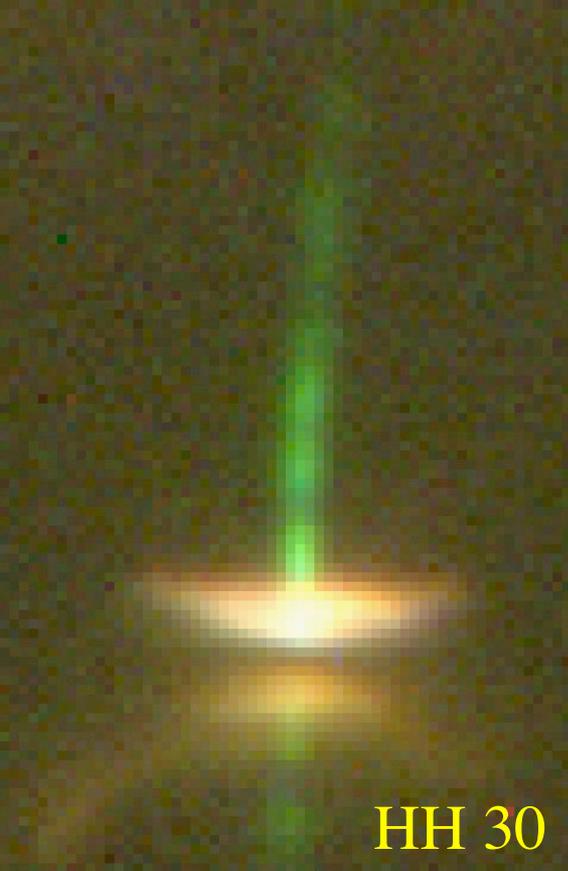




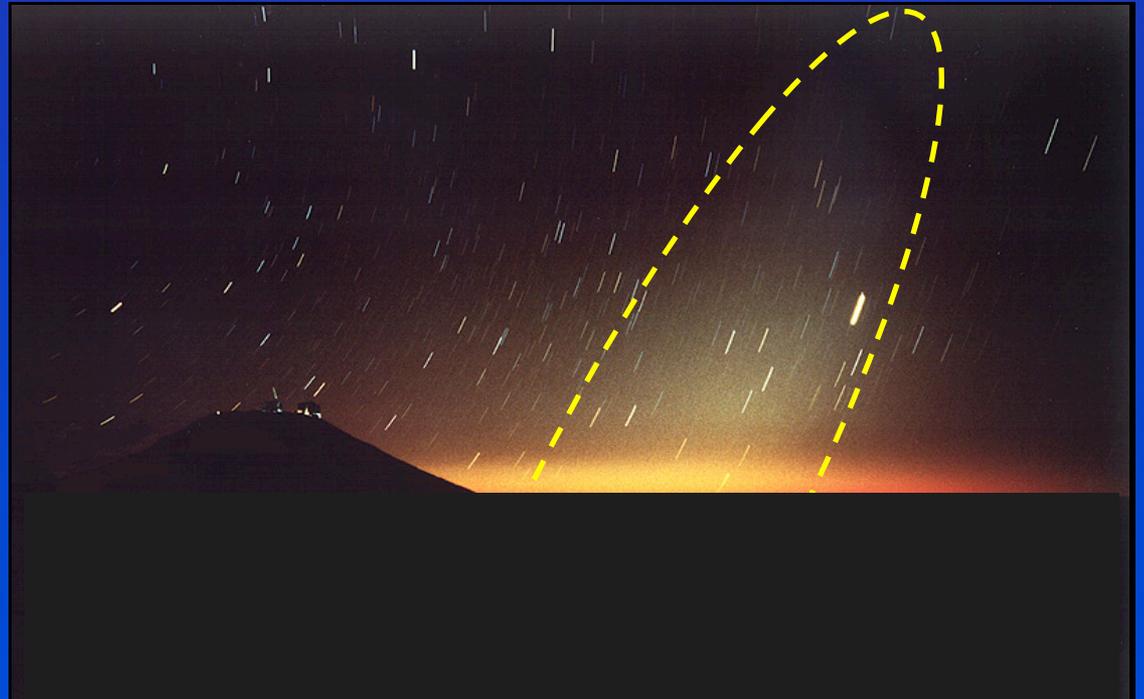
Lumière
Zodiacale
(poussières)



**Des disques de poussière
qui forment des planètes ?
(ils sont suffisamment massifs)**



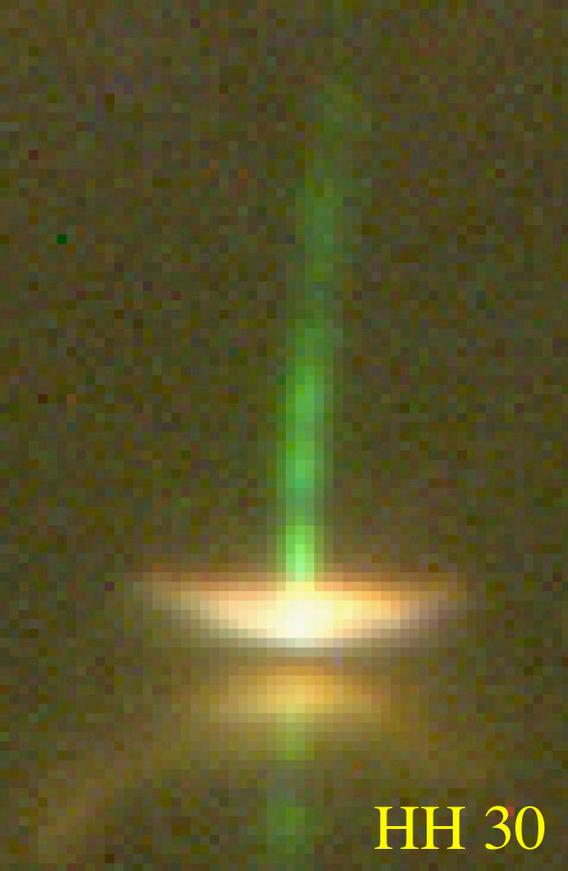
HH 30



Lumière
Zodiacale
(poussières)



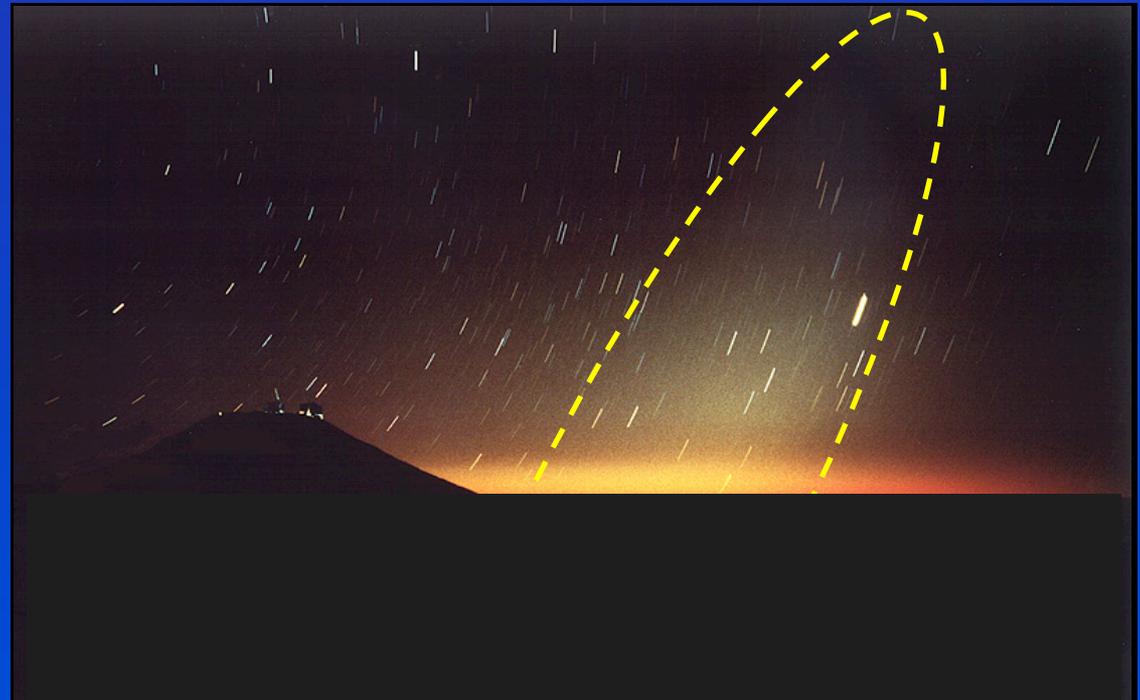
Des disques de poussière
qui forment des planètes ?
(ils sont suffisamment massifs)



HH 30



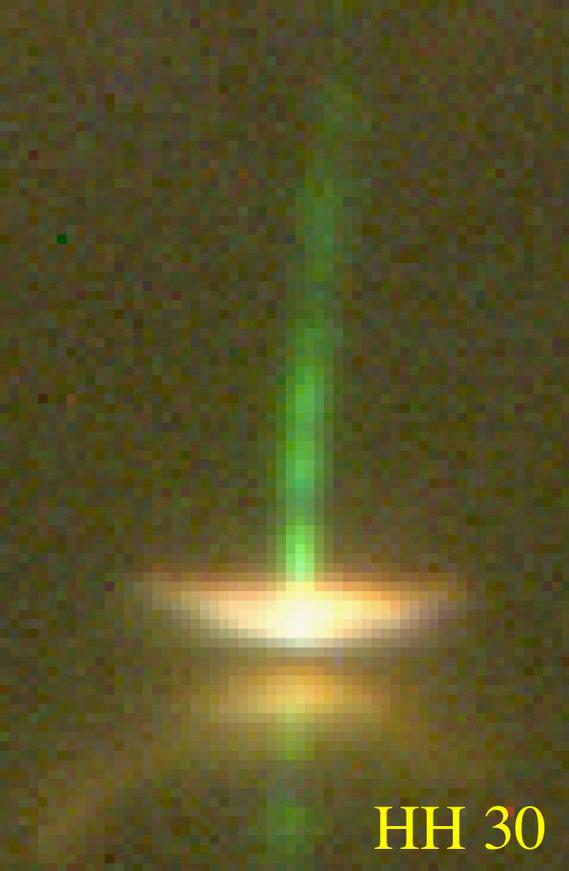
HK Tau



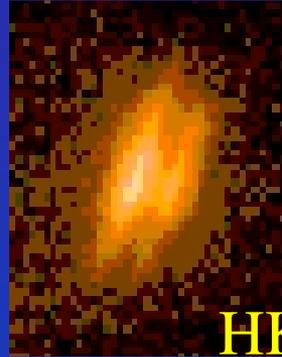
Lumière
Zodiacale
(poussières)



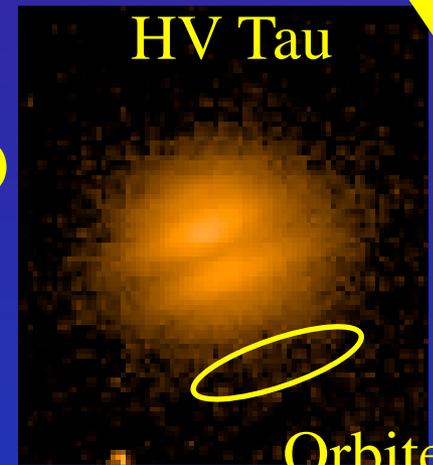
Des disques de poussière
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HH 30



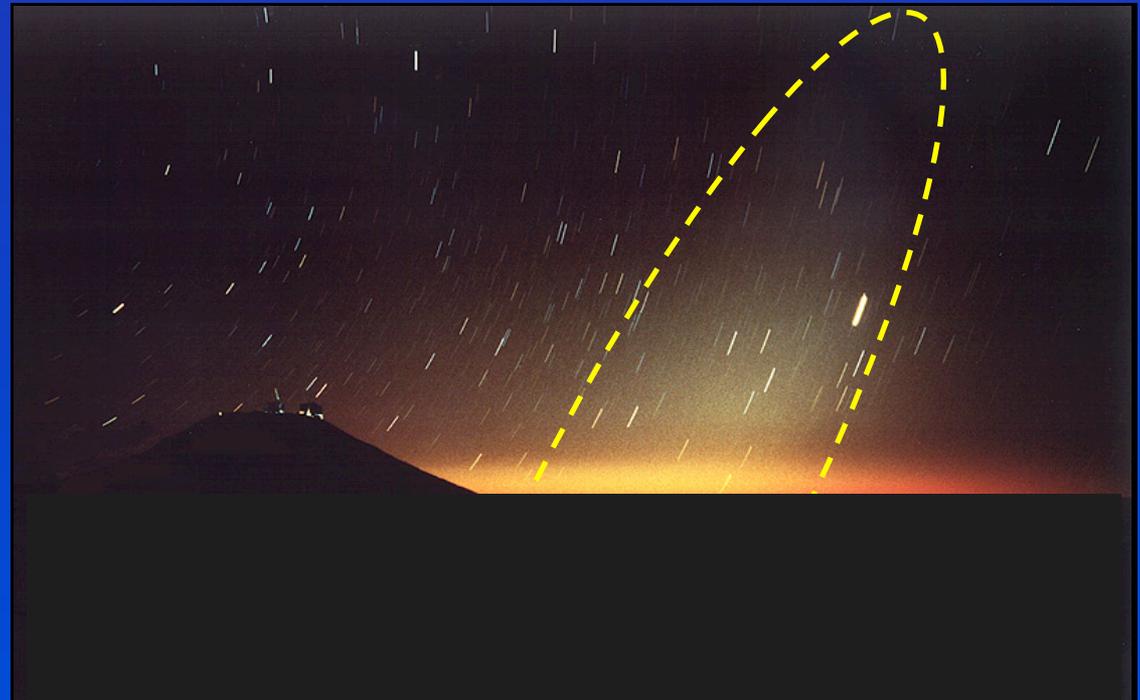
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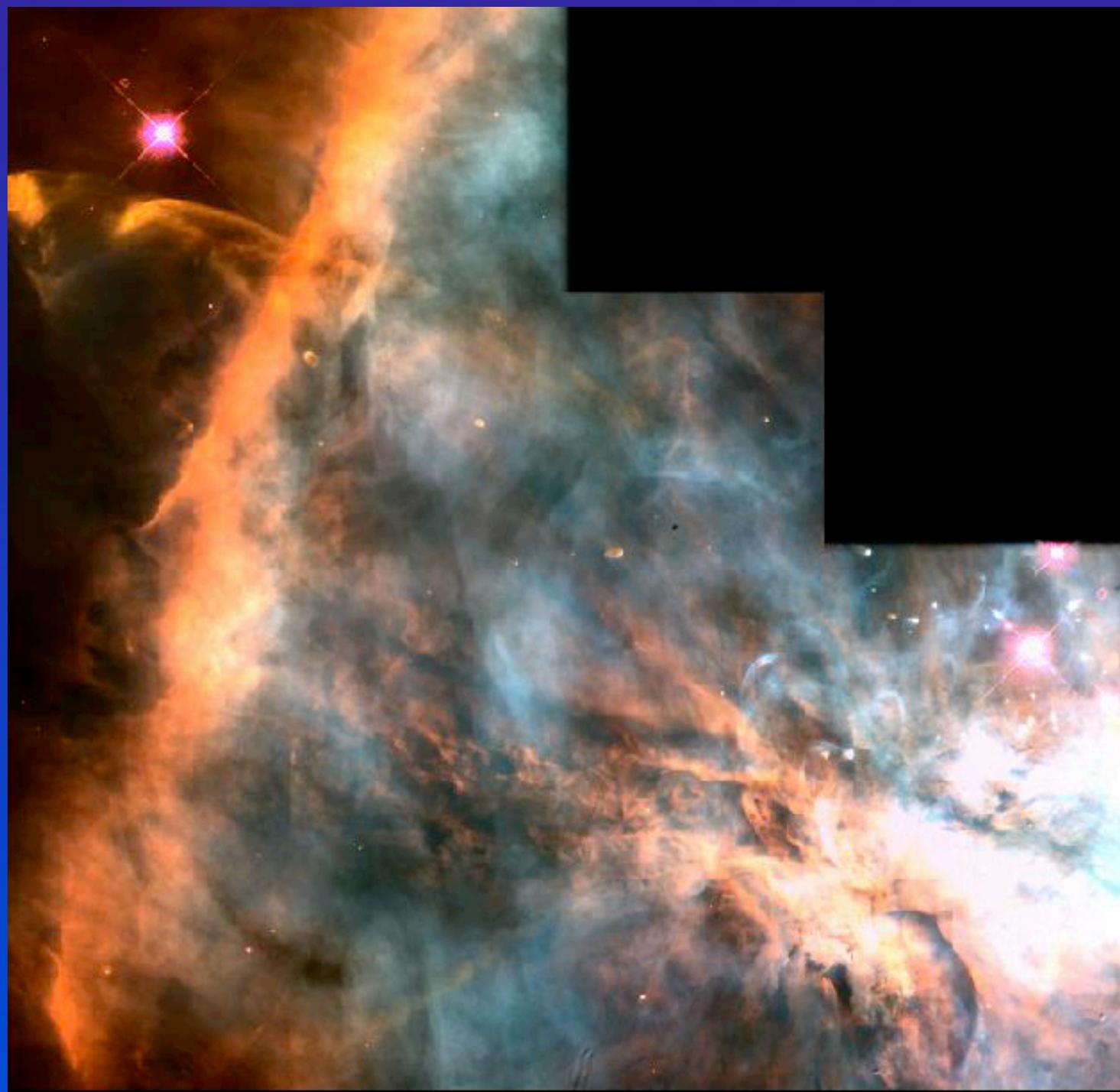


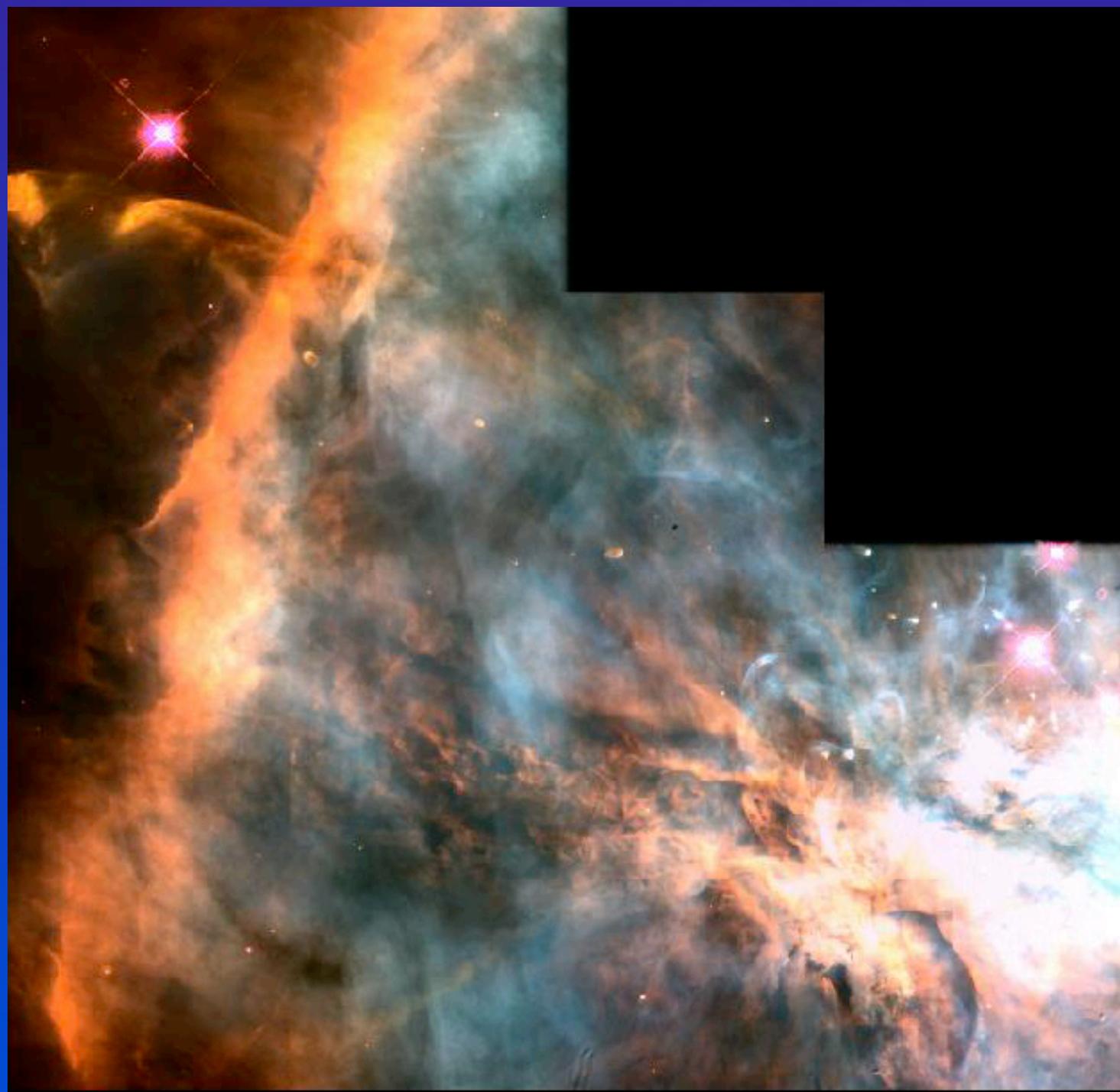
HV Tau

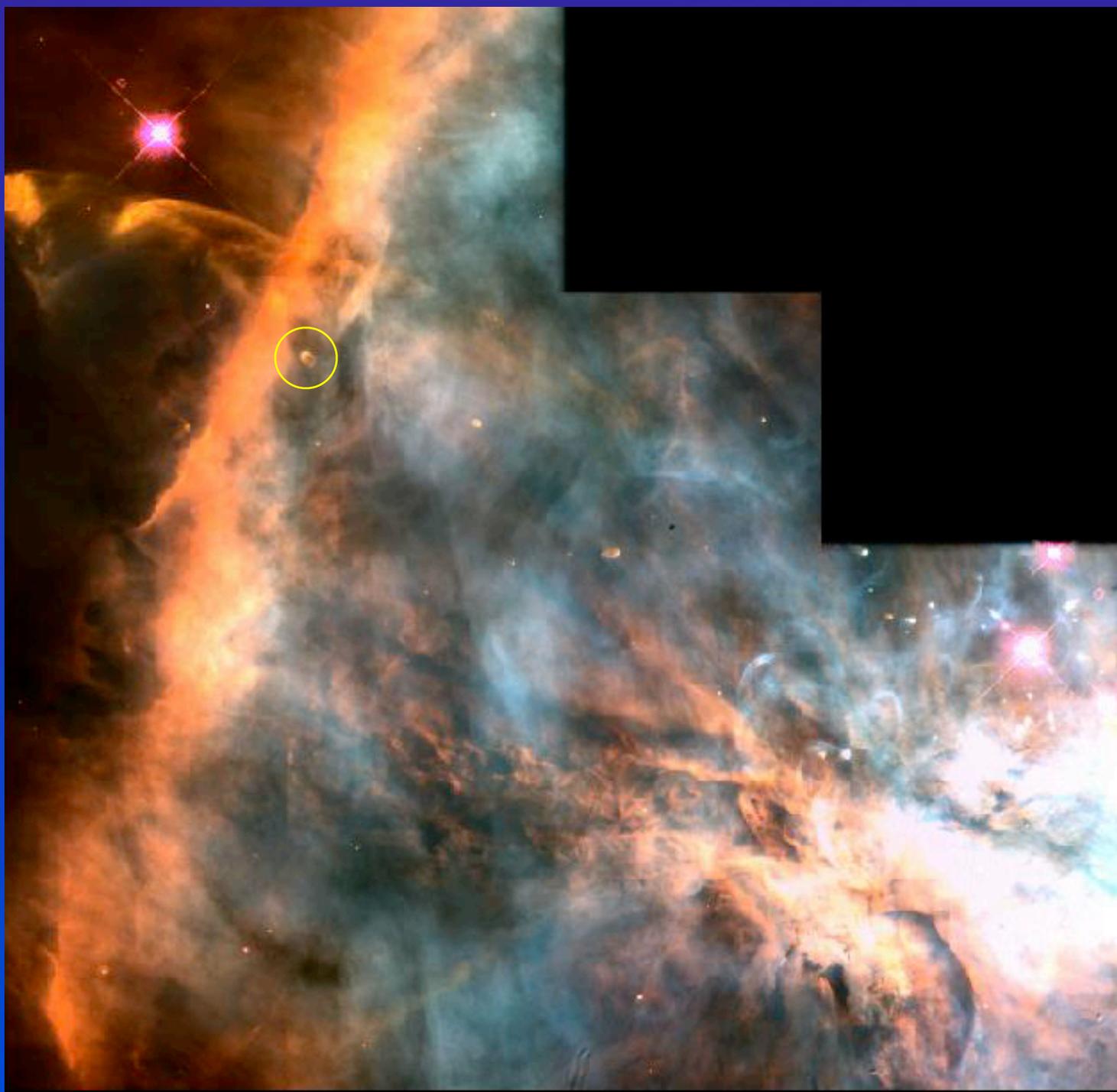
Orbite
de pluton

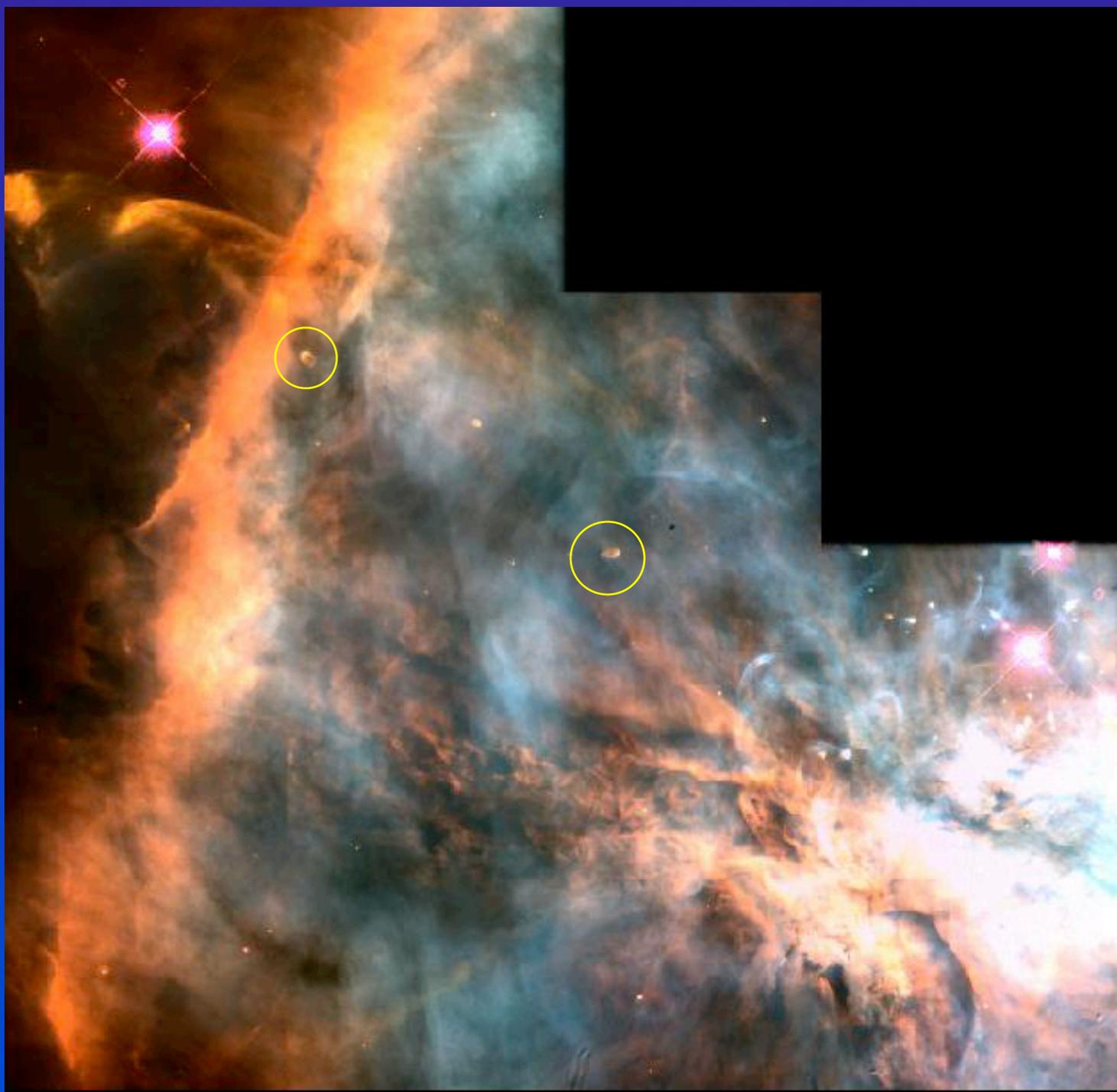
Lumière
Zodiacale
(poussières)

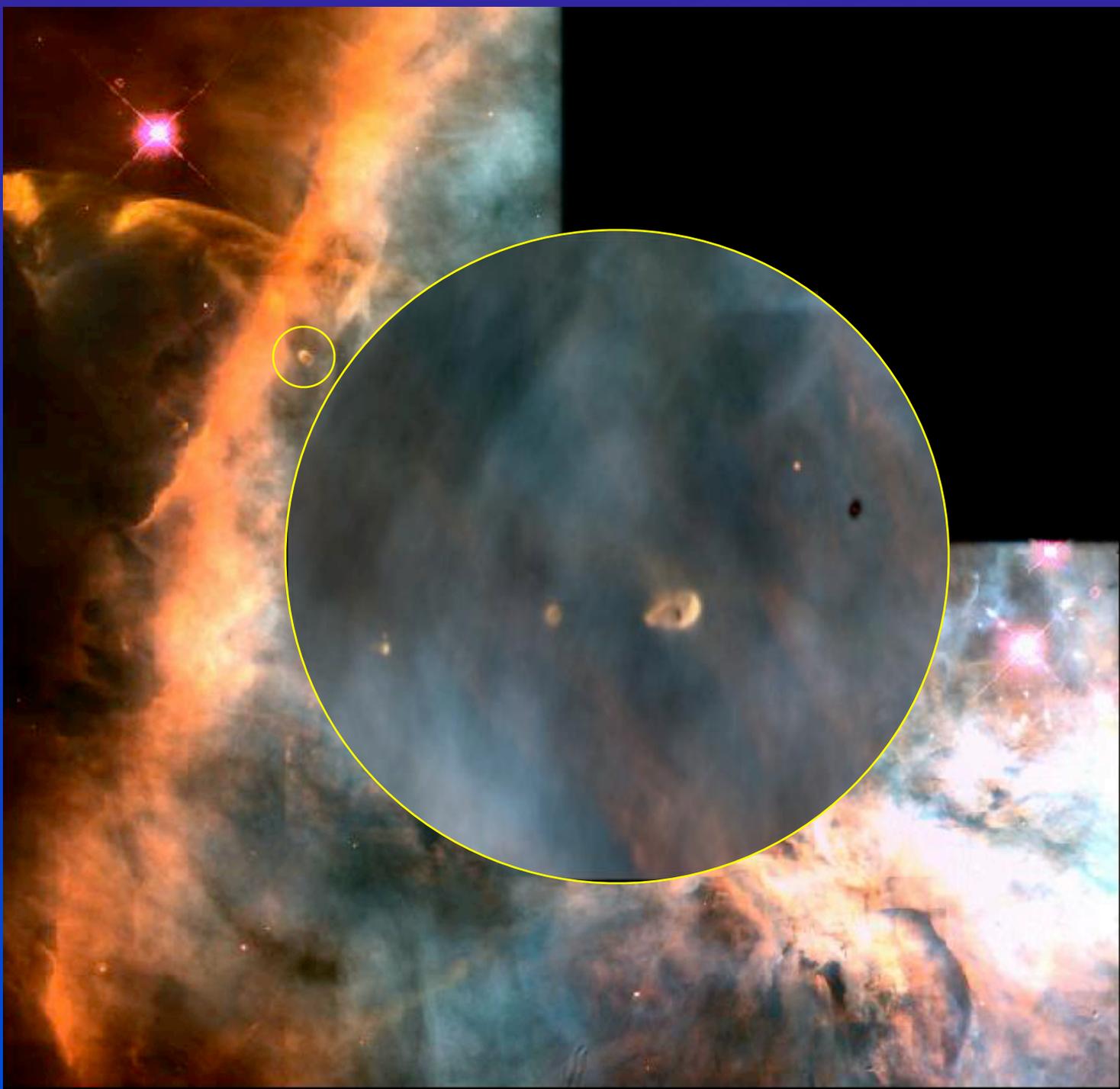


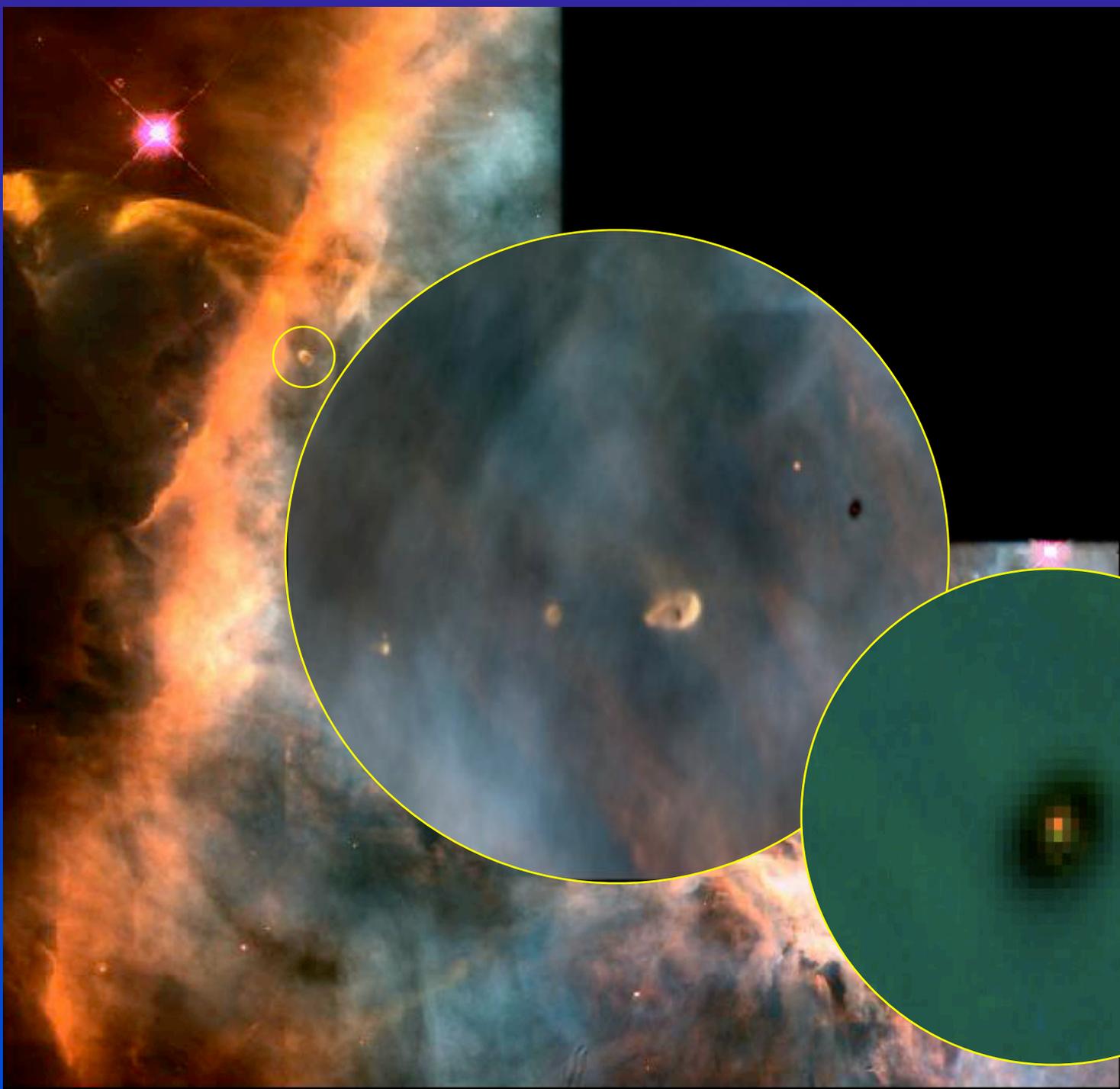


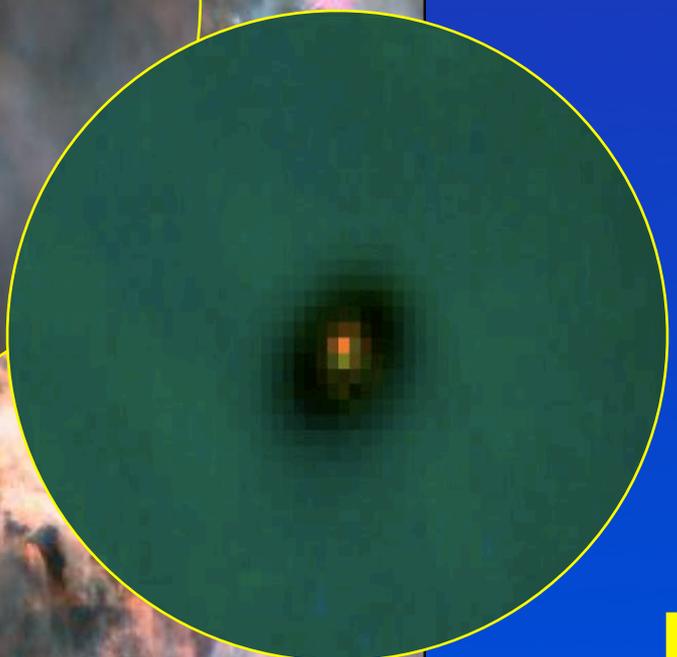
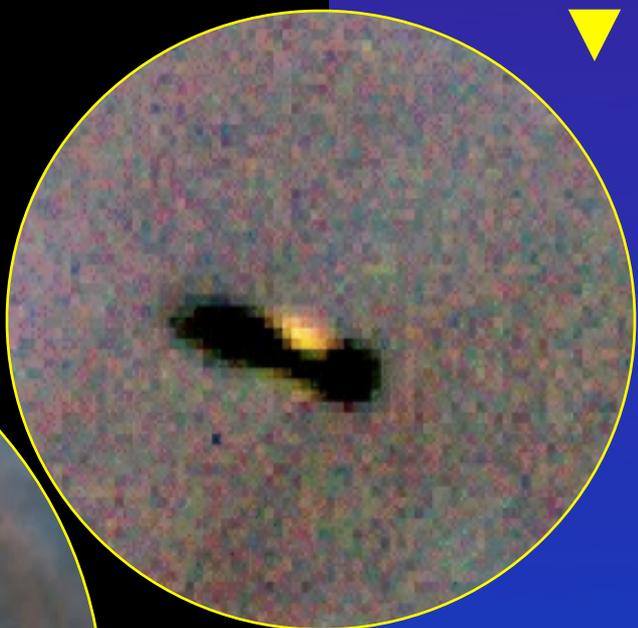
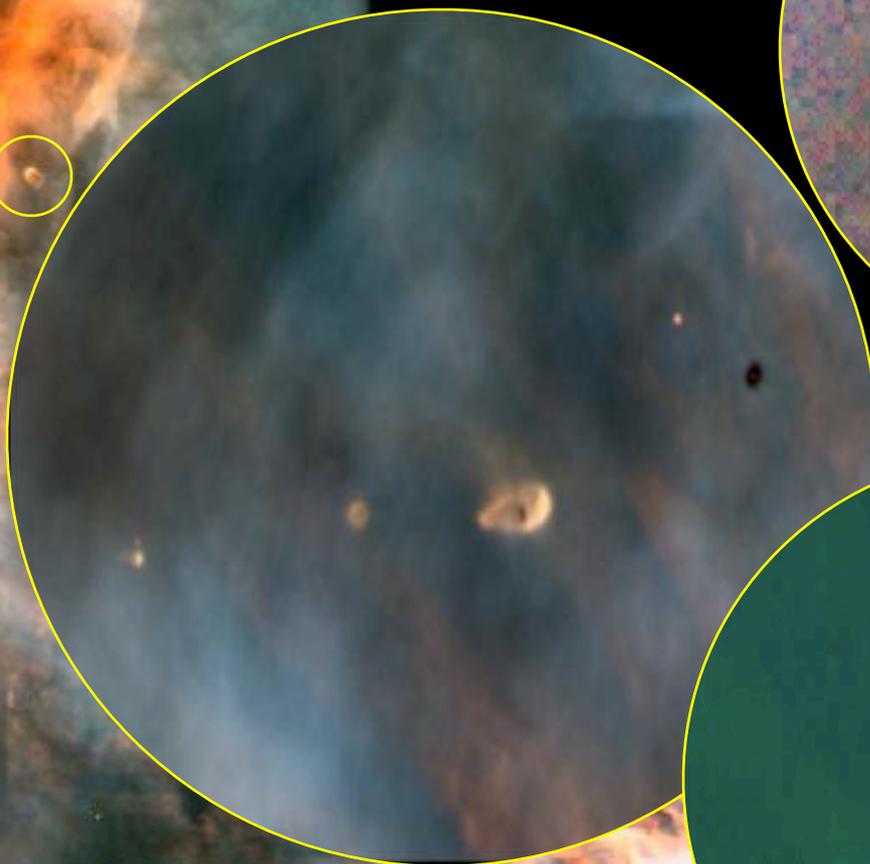
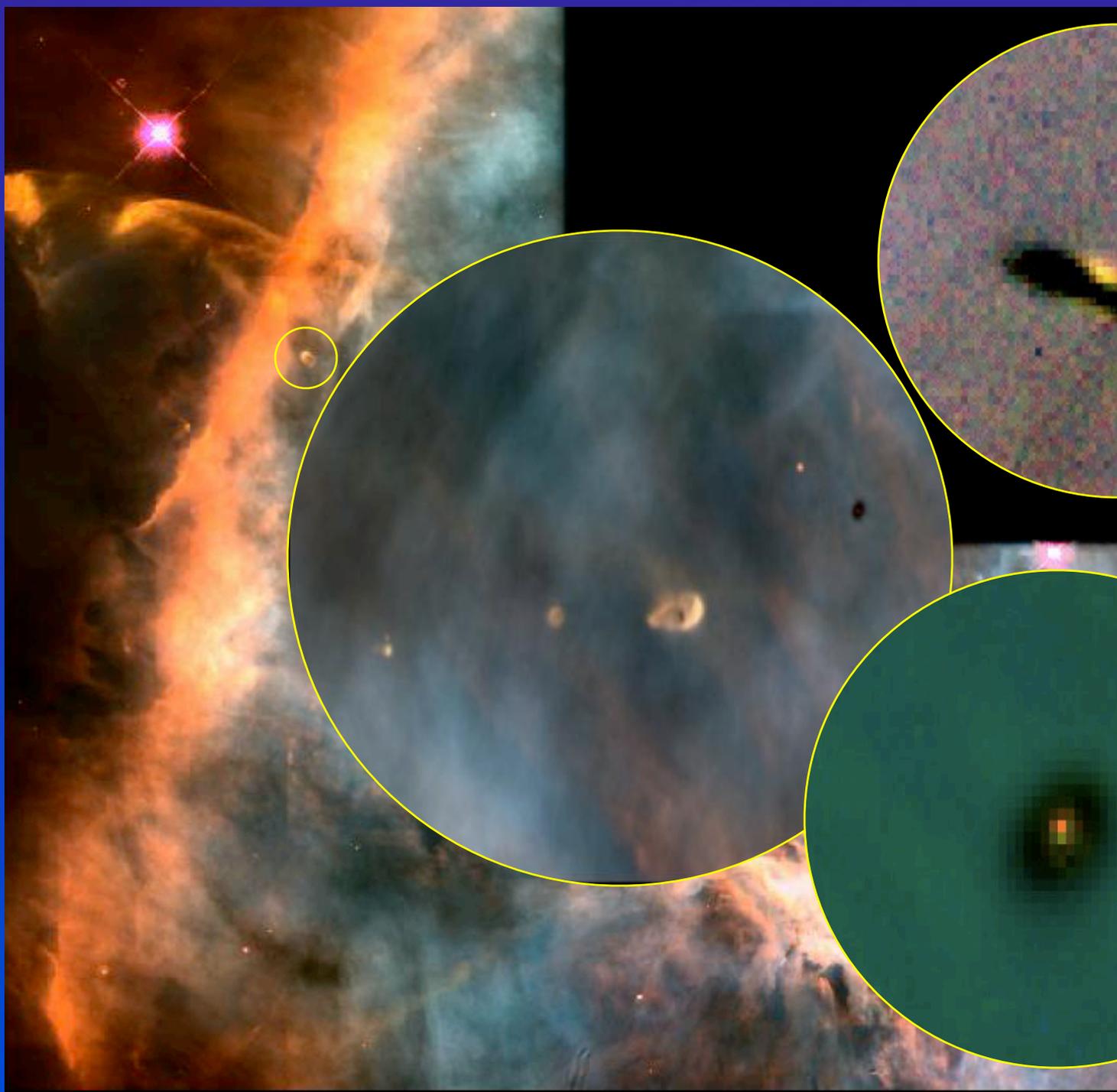




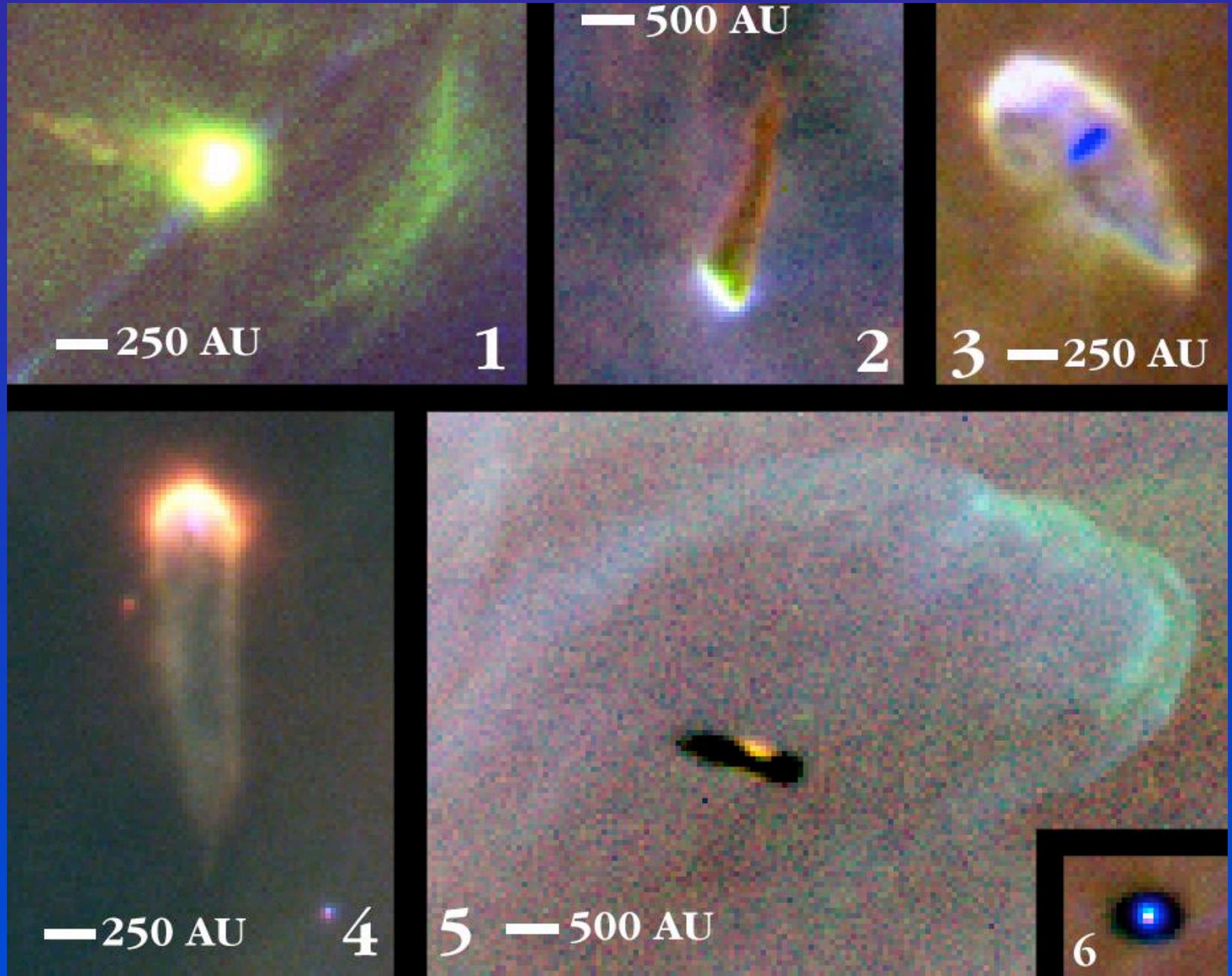








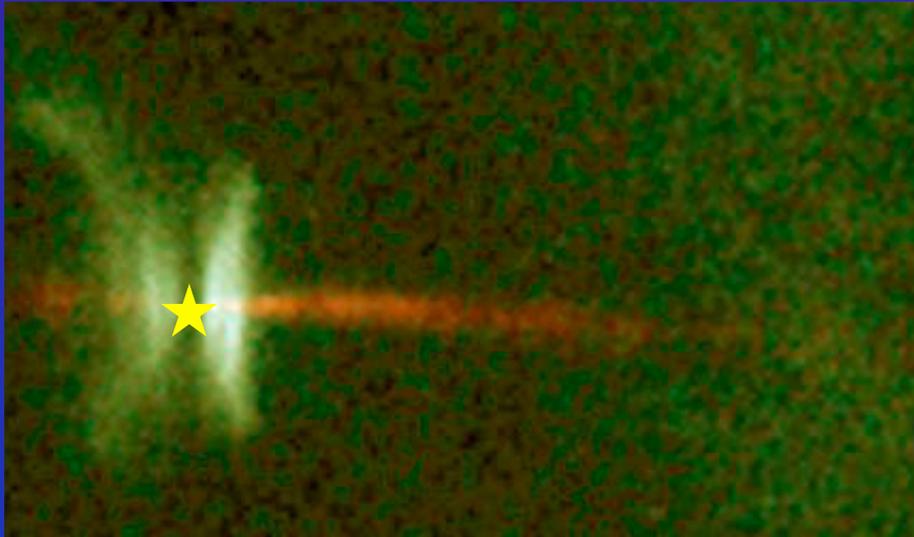
Galerie de portraits de systèmes planétaires dans Orion...



Les tenants et aboutissants de la formation stellaire ...



Les tenants et aboutissants de la formation stellaire ...

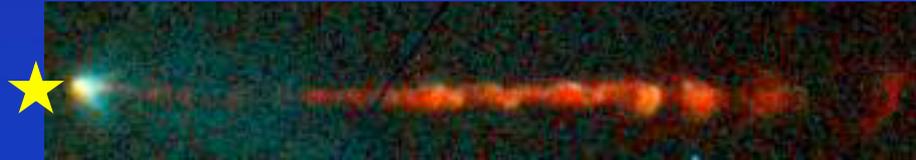
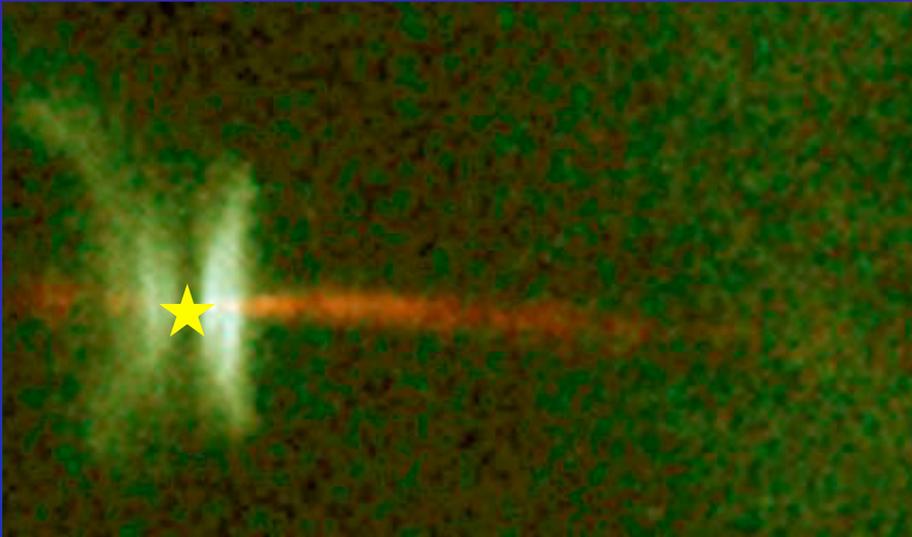


**Les tenants et aboutissants
de la formation stellaire ...**



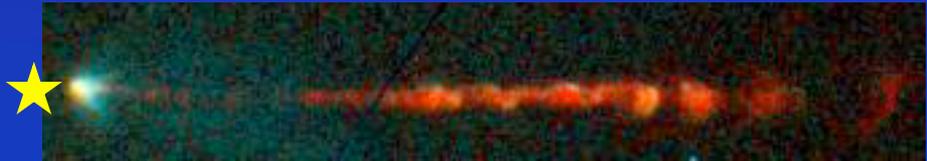
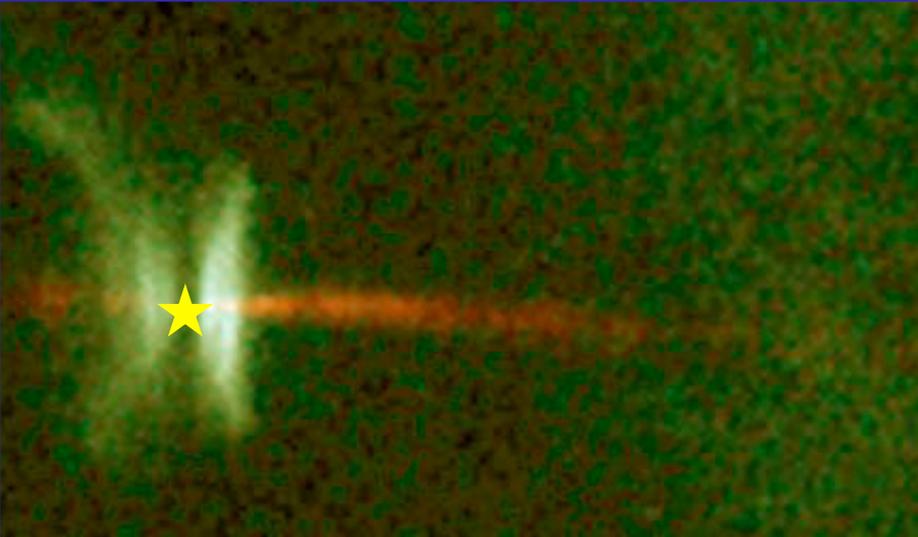


Les tenants et aboutissants de la formation stellaire ...





Les tenants et aboutissants de la formation stellaire ...





(image HST)

Nouvelles planètes ...

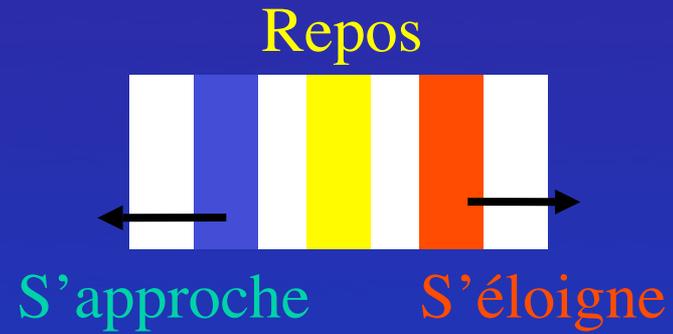
Nouvelles planètes ...



Nouvelles planètes ...



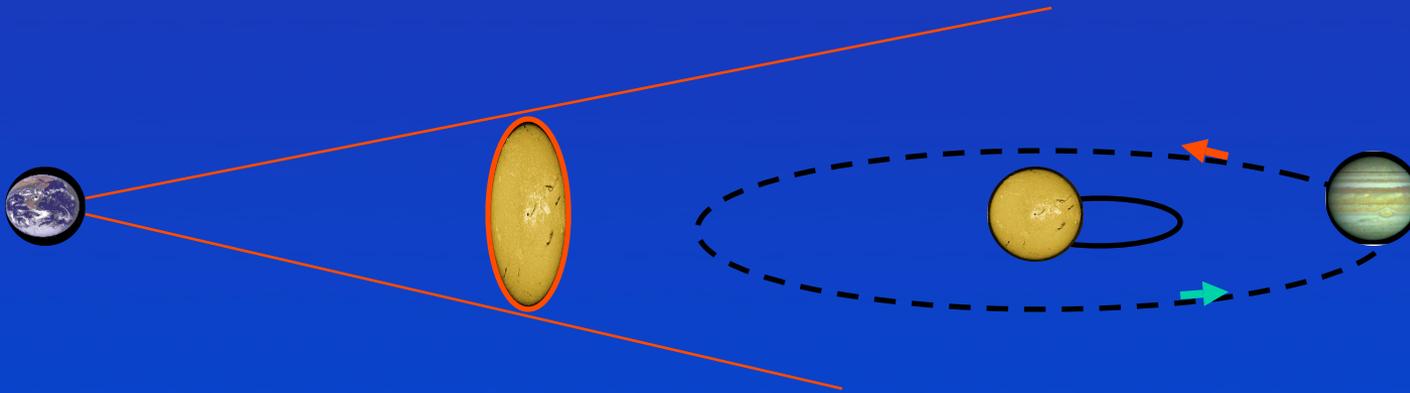
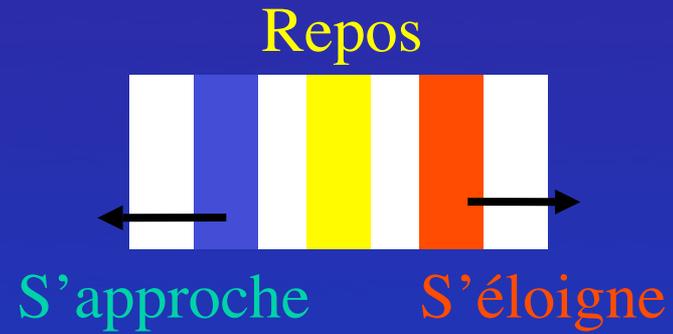
Effet Doppler :



Nouvelles planètes ...



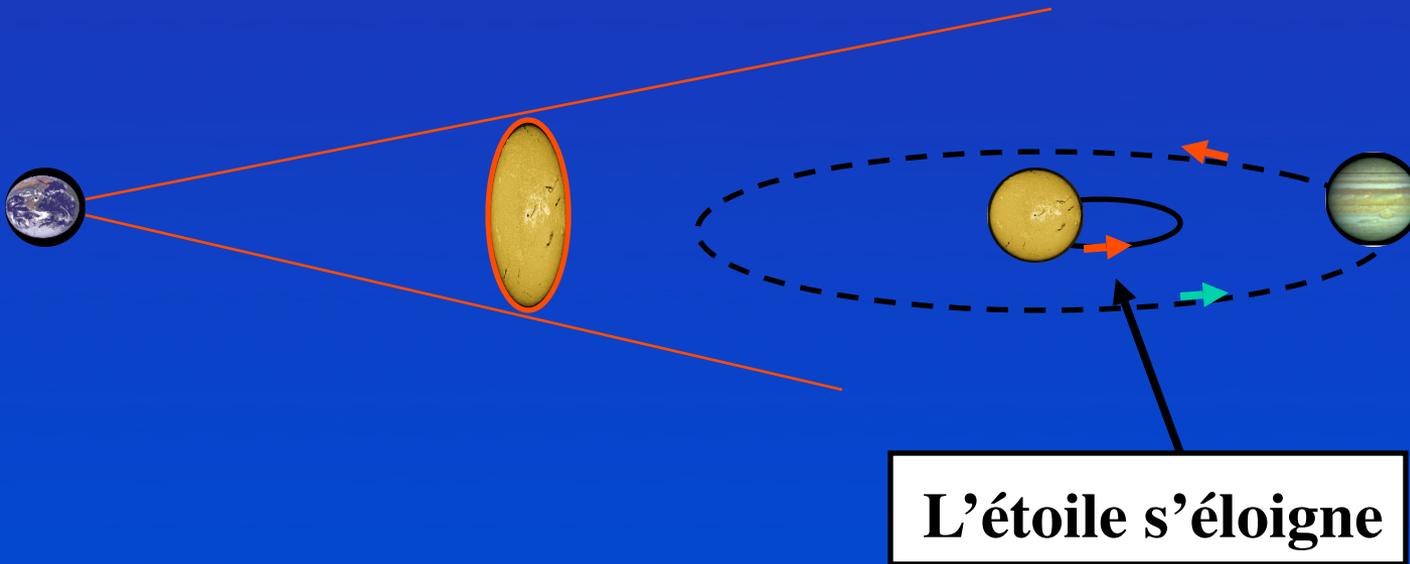
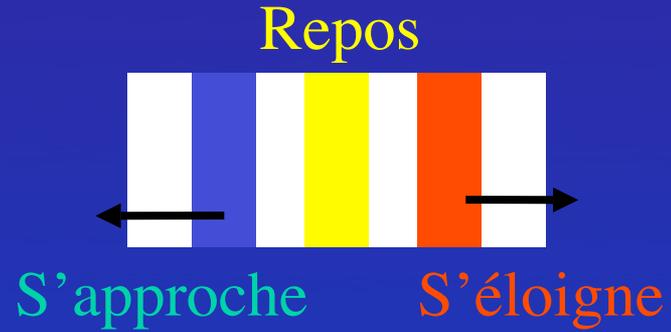
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Nouvelles planètes ...



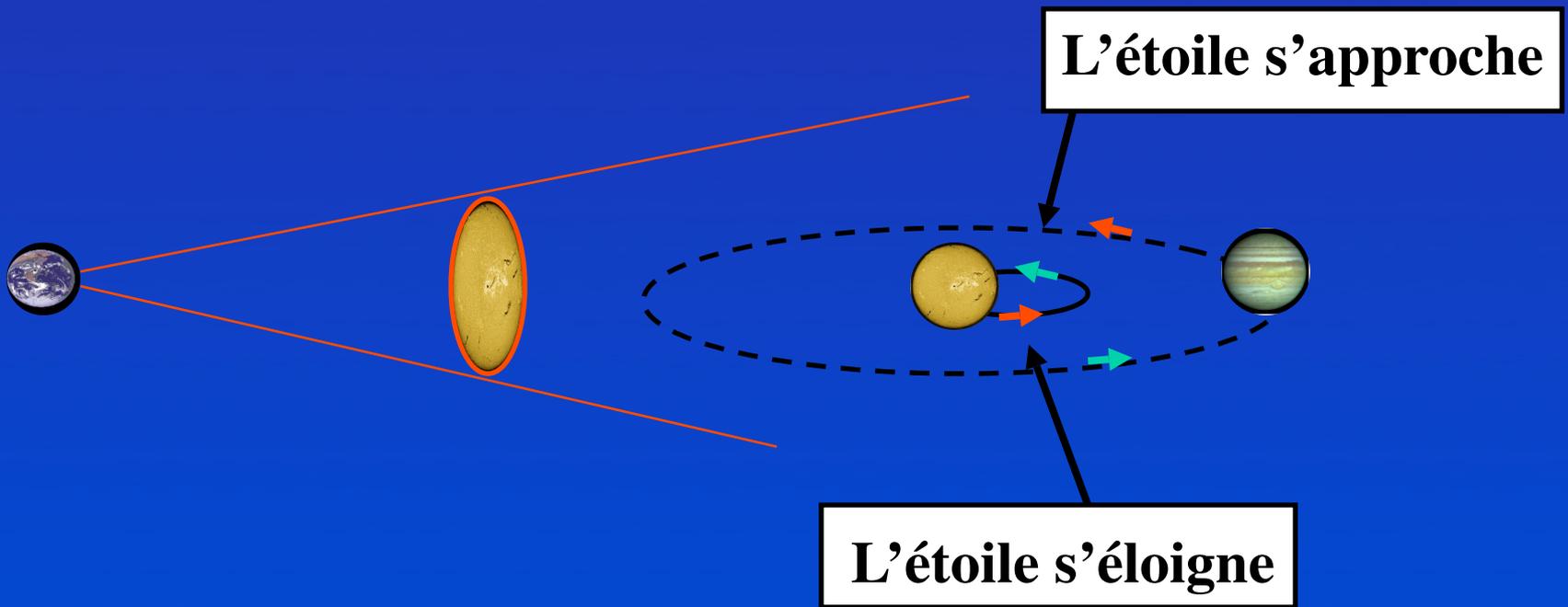
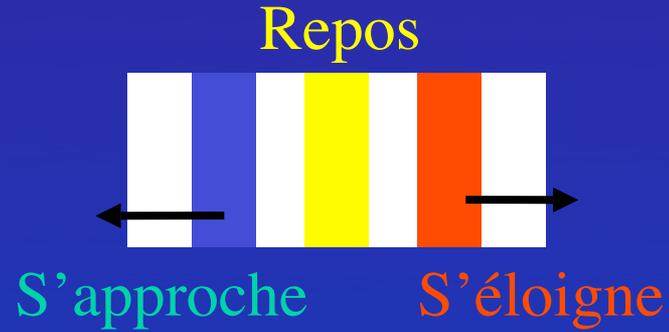
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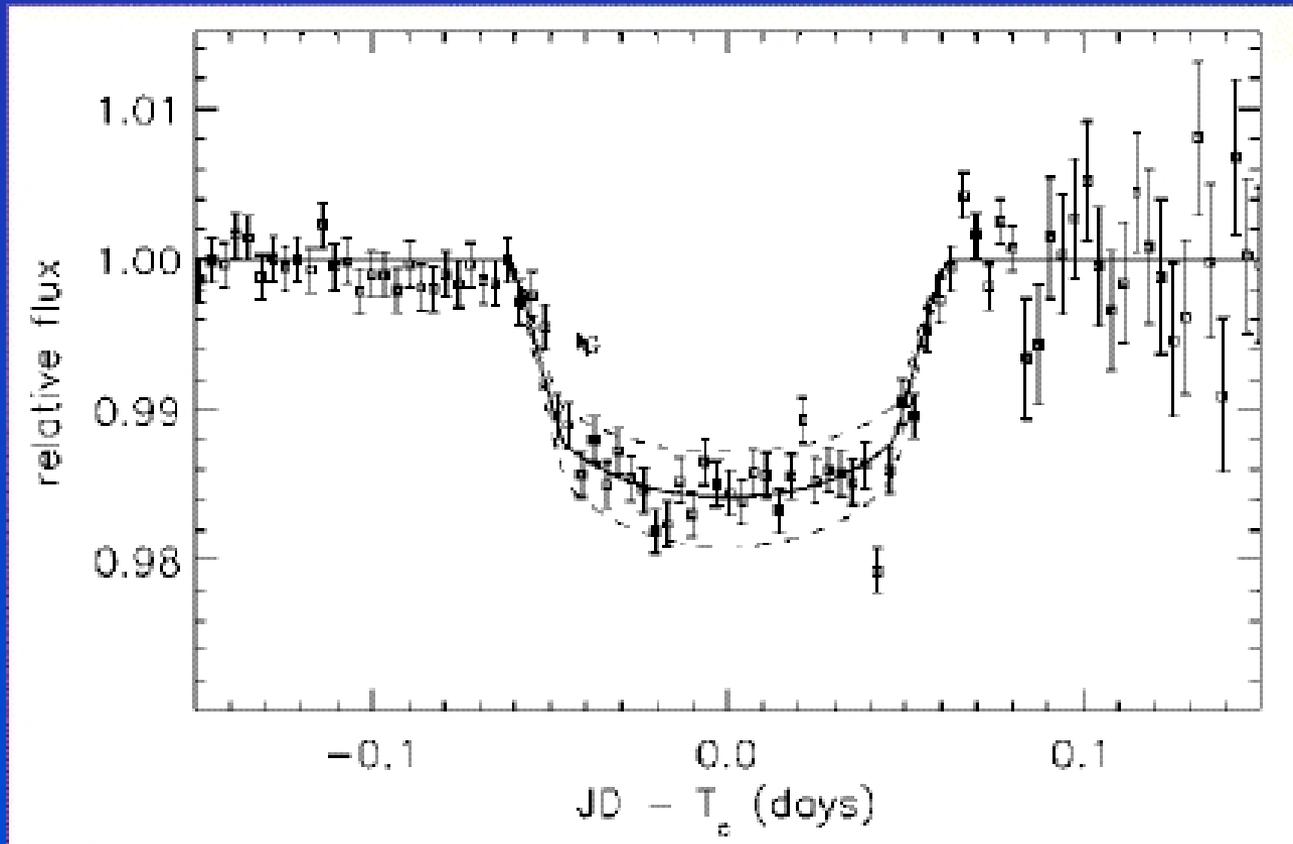
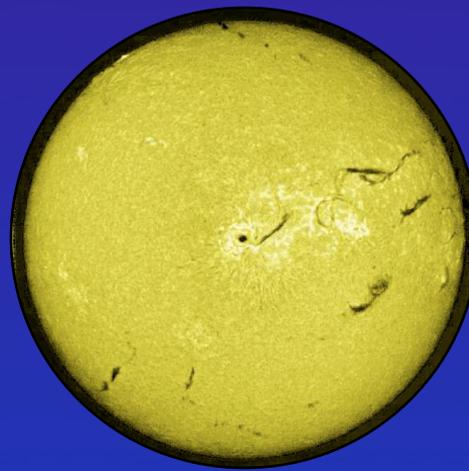
Nouvelles planètes ...



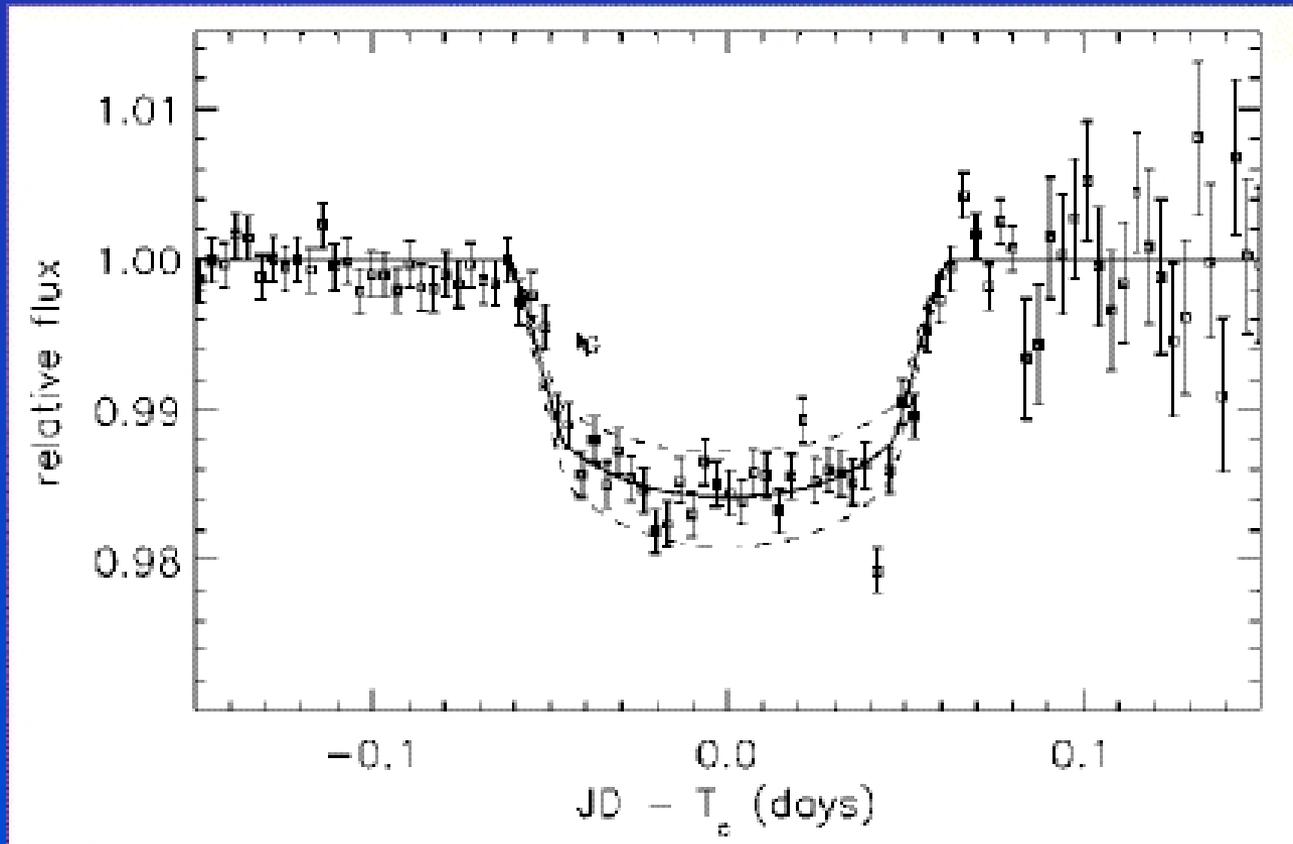
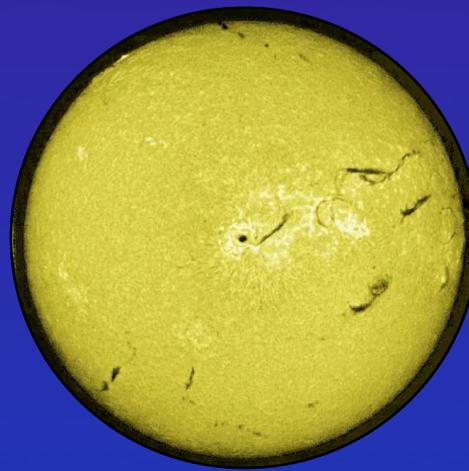
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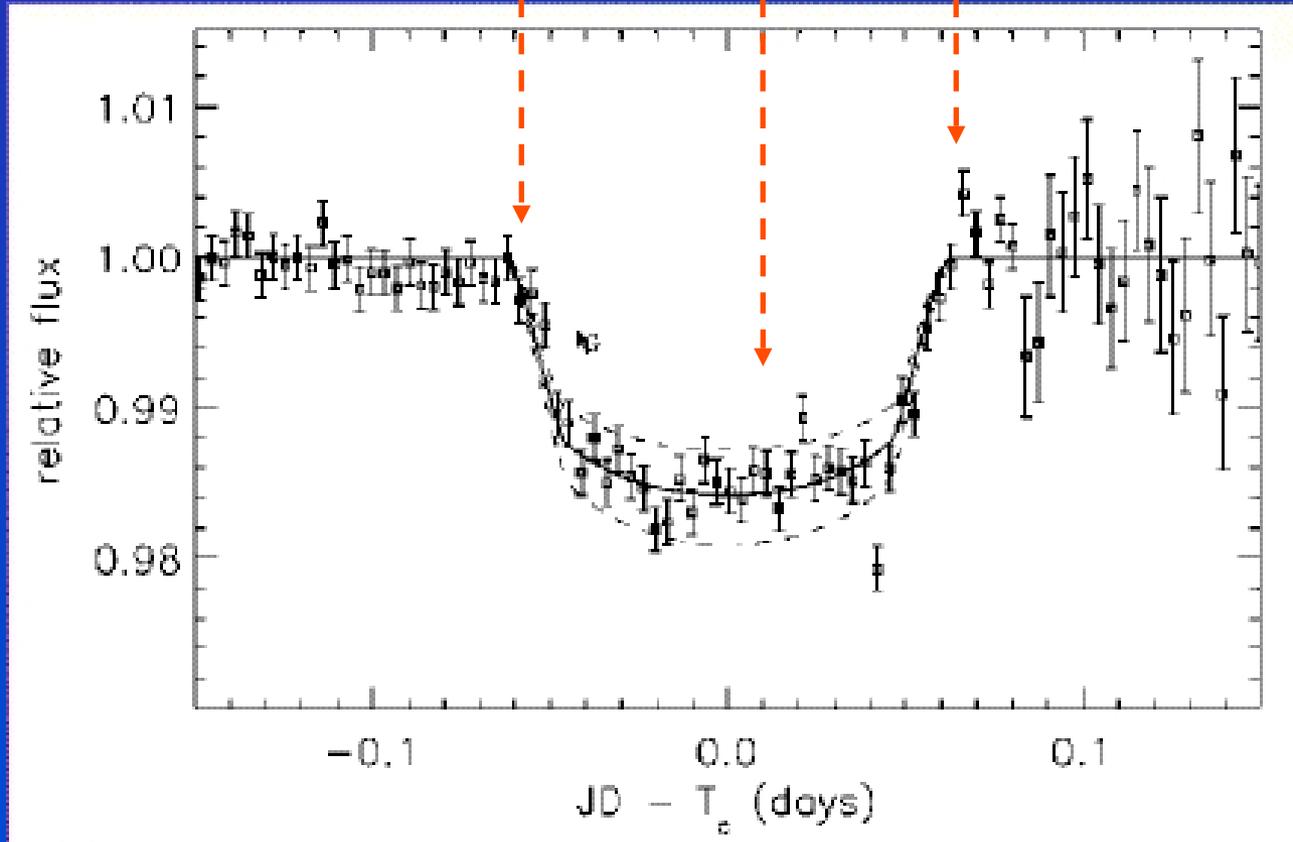
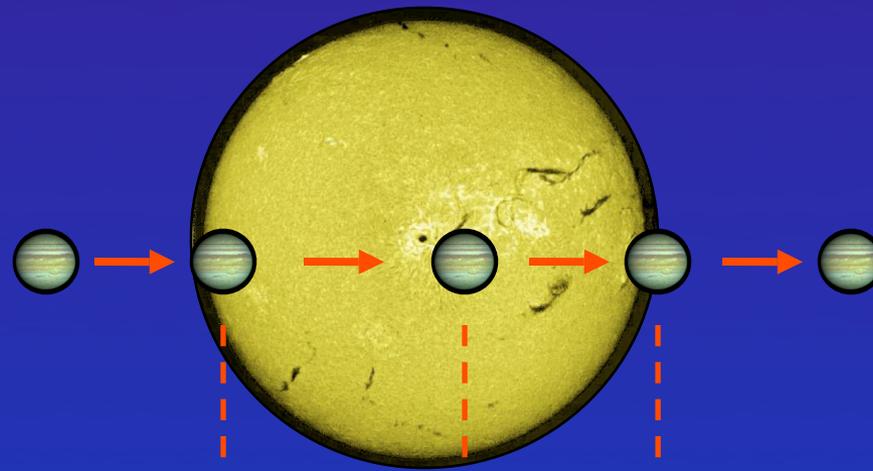
Occultation par une planète



Occultation par une planète



Occultation par une planète



Conclusions ...

Conclusions ...

Les étoiles trop massives ($>10 M_{\odot}$) ne vivent que quelques millions d'années.

Les étoiles comme le soleil se forment en 10-100 millions d'années et vivent plus de 10 milliards d'années.

Il est plus que probable que des planètes se forment dans le même temps que les étoiles ; en effet :

- ➔ On détecte la présence de planètes similaires à Jupiter autour d'étoiles proches.
- ➔ On voit actuellement la poussière nécessaire à la formation des planètes comme la Terre autour d'étoiles jeunes (mais on ne peut pas encore voir ces planètes).