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SPACE CLIMATE ON EXTRASOLAR PLANETARY SYSTEMS

Contents

- Space Climate
- Habitability
- Stellar variability
- Stellar activity cycles
- Maunder Minimum
- Cases studies of exoplanets

Space Weather

Définition

« the science aiming at studying the composition and the dynamic of the upper layers of the atmosphere of the Earth (magnetosphere, ionosphere and thermosphere) the perturbations of which are due to solar events or man-made pollution (such as space debris or radio waves). Effects can endanger human life in space, may have impacts on the performance and reliability of space-borne and ground-based technological systems, yielding economic upshots on our society » .

- Different from Solar-terrestrial links

- → Effets des perturbations solaires préjudiciables aux activités de la nos sociétés.

Space Climate

Définition:

« The physics (on the long term) of the heliosphere and its interactions with the planets magnetosphere “, up to the heliopause » .

Space climate symposium, Oulu (F), 2003

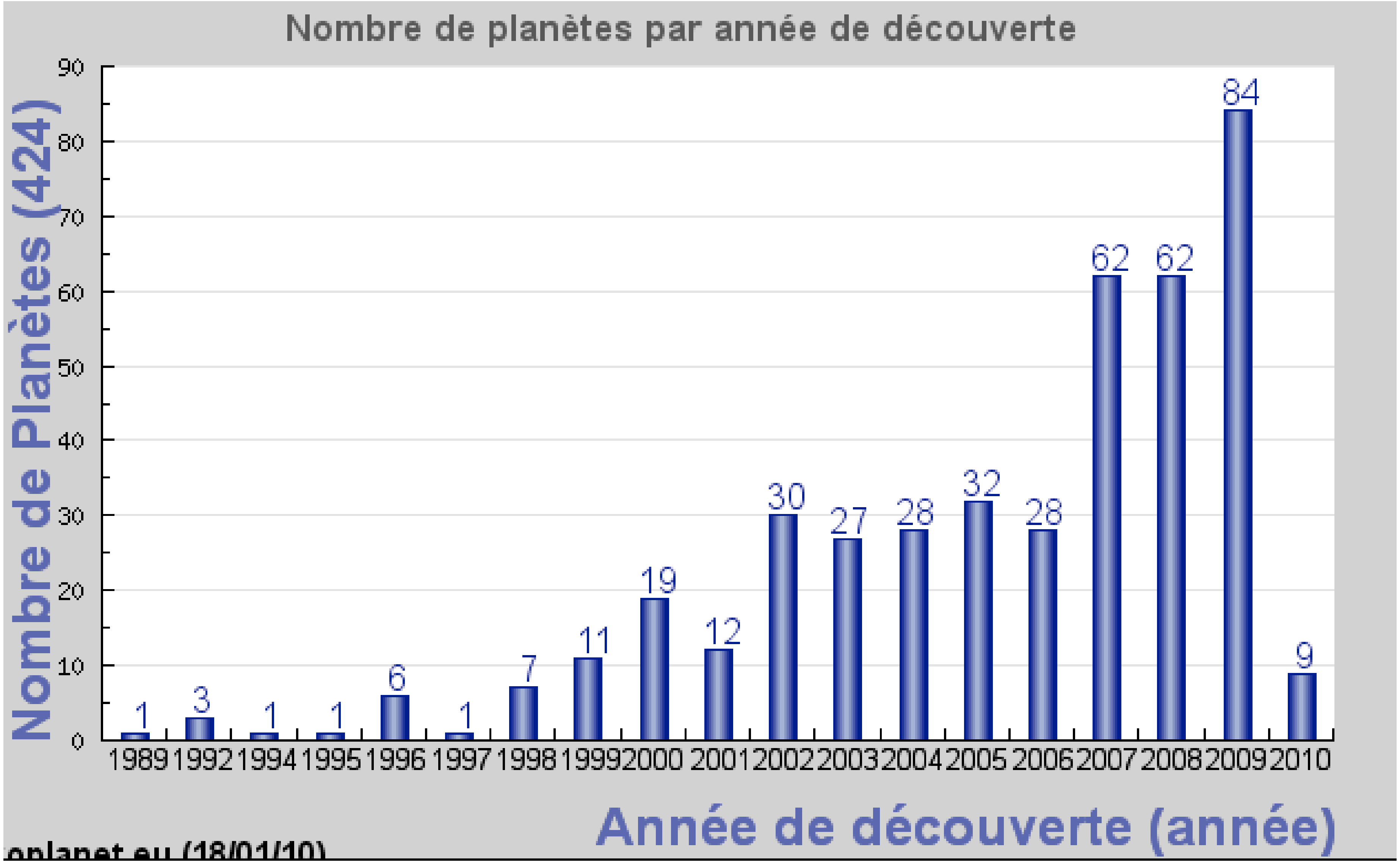
Lefebvre et Rozelot, LNP, 2006, Springer, 599

The Sun is not a « trivial » star

First discover on the Sun		*Then applied to Stars*
Magnetic activity and Solar cycles **Solar latitudinal rotation**	→	**Stellar activity**
Solar radial deplacements (helioseismology)	→	**Asteroseismology**
Solar shape distortions	→	**Consequences on other stars**
Place of the Earth within the solar system	→	**Exobiology**

Space climate applied to exoplanets

- Main drivers:
  – Stellar activity
  – Local properties of planetary systems
    - Asteroids
    - Comets
- Planet specification
  – Atmosphere
  – Magnetosphere



Thanks to C. Moutou

Extrasolar Planets

- Habitable Zones
  - Circumstellar HZ

53% of known system HZ
HZ around gas giants?
Galactic HZ

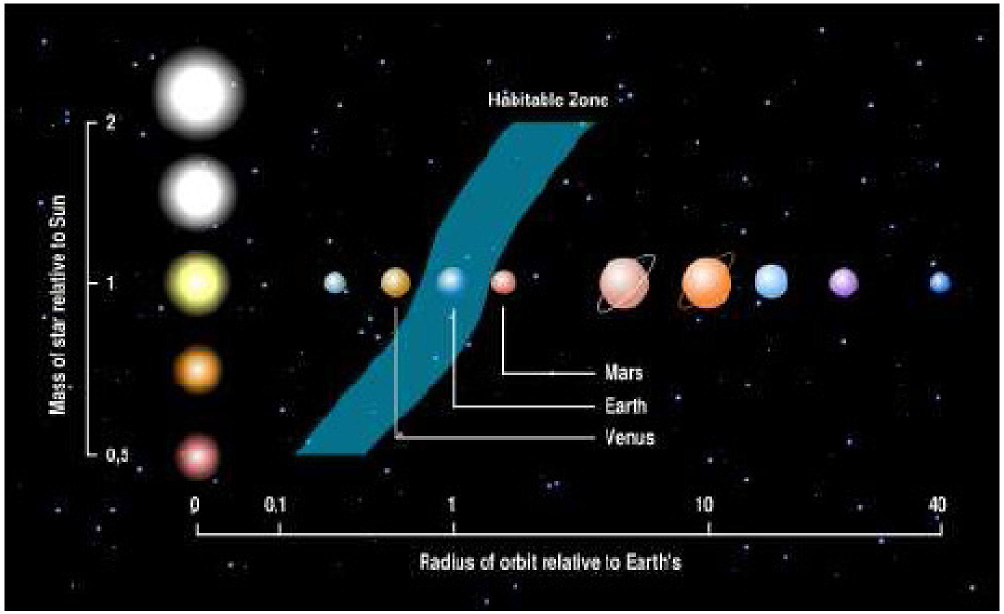


Figure 1.1: The location of the habitable zone for different masses of the central stars (left). Note that the abscissa is in logarithmic units. The solar system (at 1 solar mass) is given at the center.

$$d = \sqrt{\frac{L_*}{L_\odot}}$$

Center of a circumstellar HZ
2 L_o → d =1,41
0.5 L_o → d= 0,5

$$F_{\rm Venus} \sim 1/(0.7)^2 \sim 2$$

$$F_{\rm Mars} \sim 1/(1.4)^2 \sim 0.5$$

- Continuously HZ
  - The region in space where a planet remains habitable for a long period of time ~ Gyr

$$r_o/r_i \sim [L(3.5)/L(1.0)]^{1/2}$$

  - L(t) luminosity after t billion yr.
  - $R_0 \sim R_i$ for stars with M~ 0,83 M_o

La zone d'habitabilité

Zone où l'eau liquide peut se maintenir à la surface.

Sur une fraction inconnue de cette zone, la planète peut maintenir un biotope, où la photosynthèse et une production biologique est possible (eau et lumière présents simultanément).

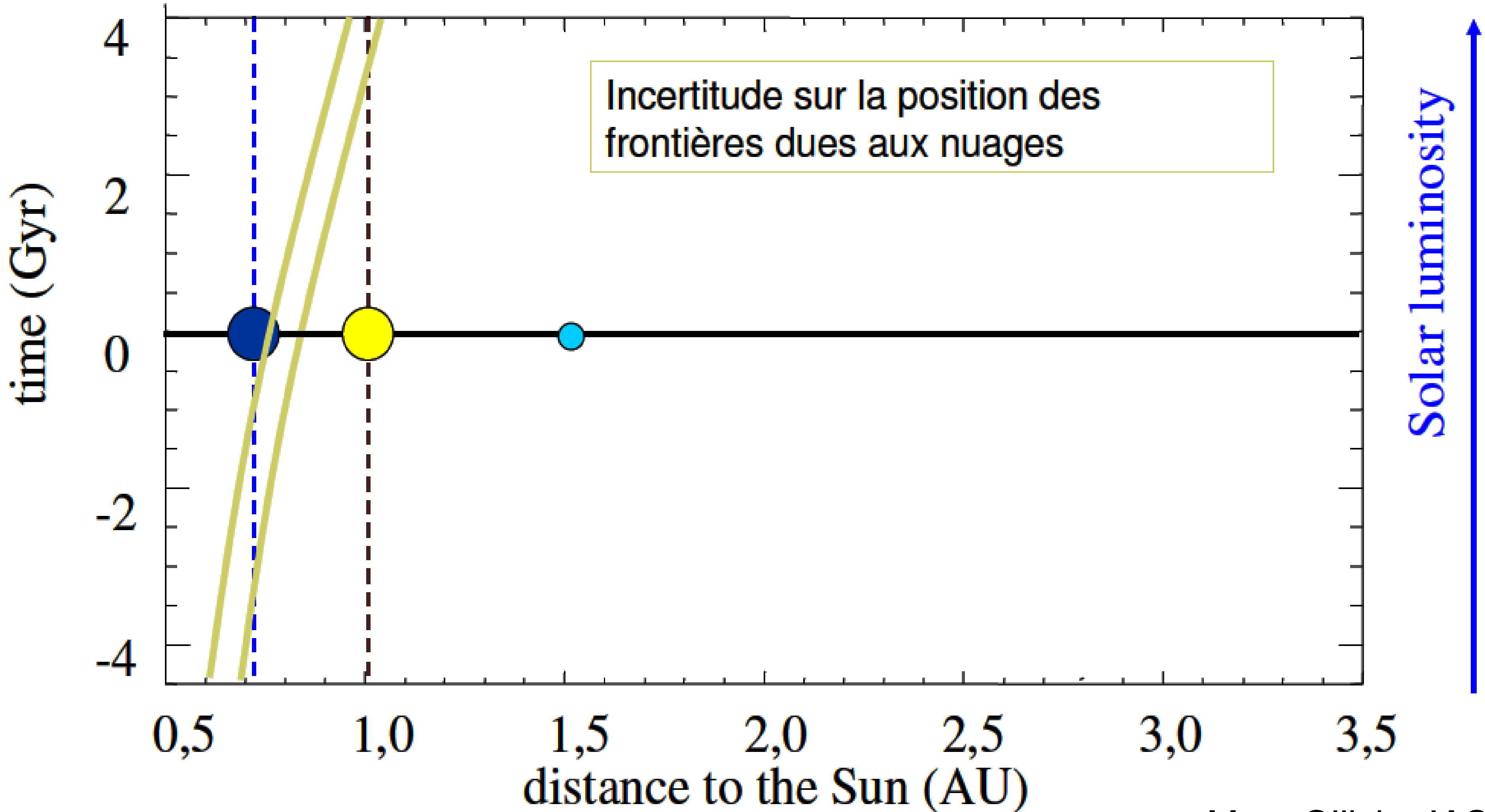
Une vie endolithique est possible sans eau à la surface (Mars) ou en dehors de la HZ (Europa) mais semble difficile à détecter à distance

Rosing et al. (2005, 2006)

Les paramètres qui limitent la ZH

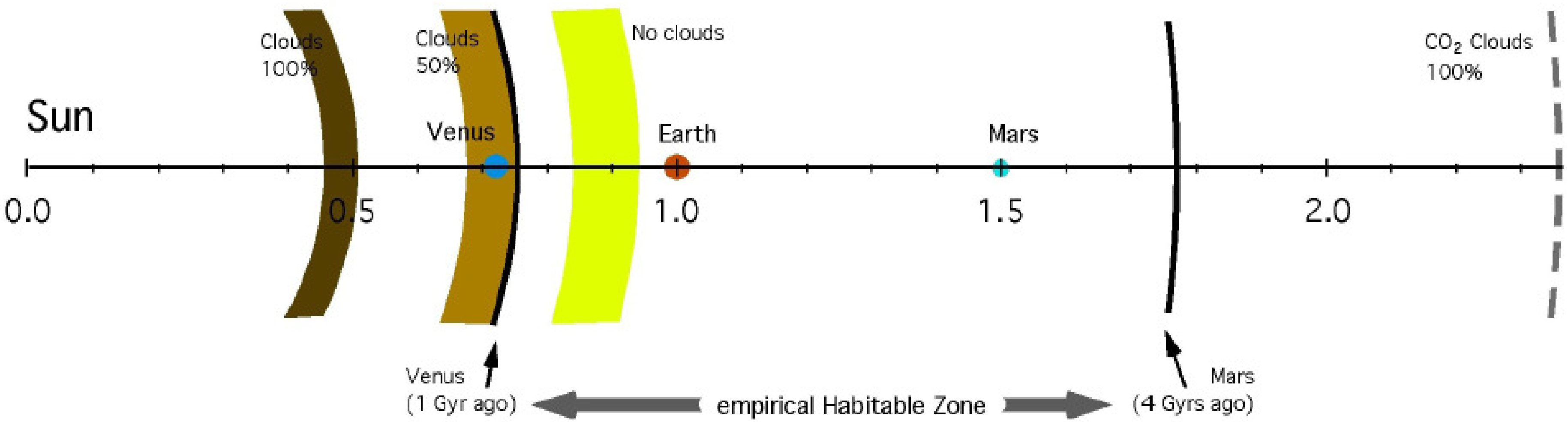
- Ensoleillement stellaire variable (soleil jeune ~ 70 % de la luminosité actuelle)
- Limite interne : rôle de l'eau et de l'opacité due aux nuages (albédo)
- limite externe : rôle des gaz à effet de serre

Limites interne de la ZH



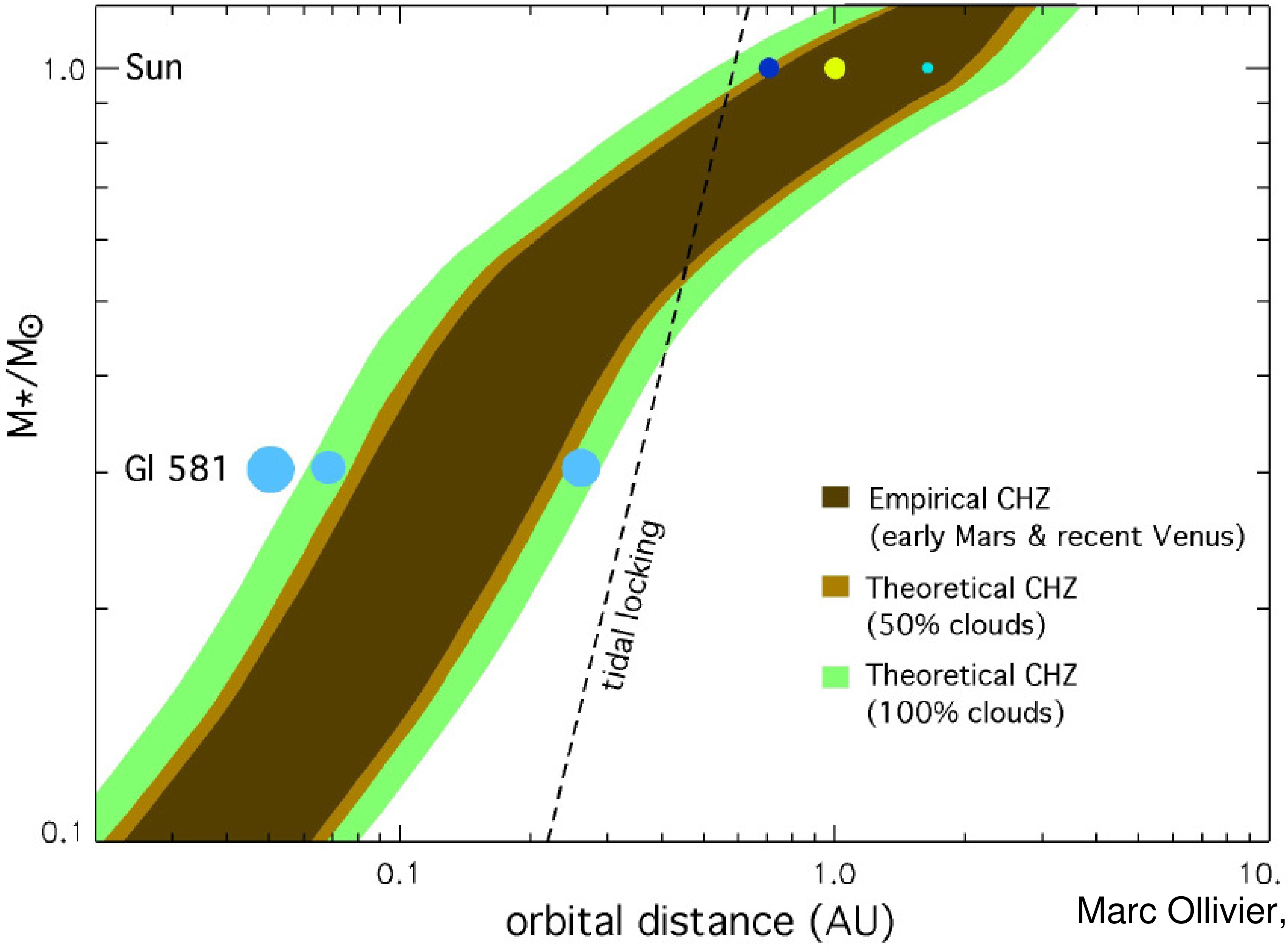
Marc Ollivier,IAS

La zone d'habitabilité du Système Solaire



Selsis et Kasting

Zone d'habitabilité et type stellaire



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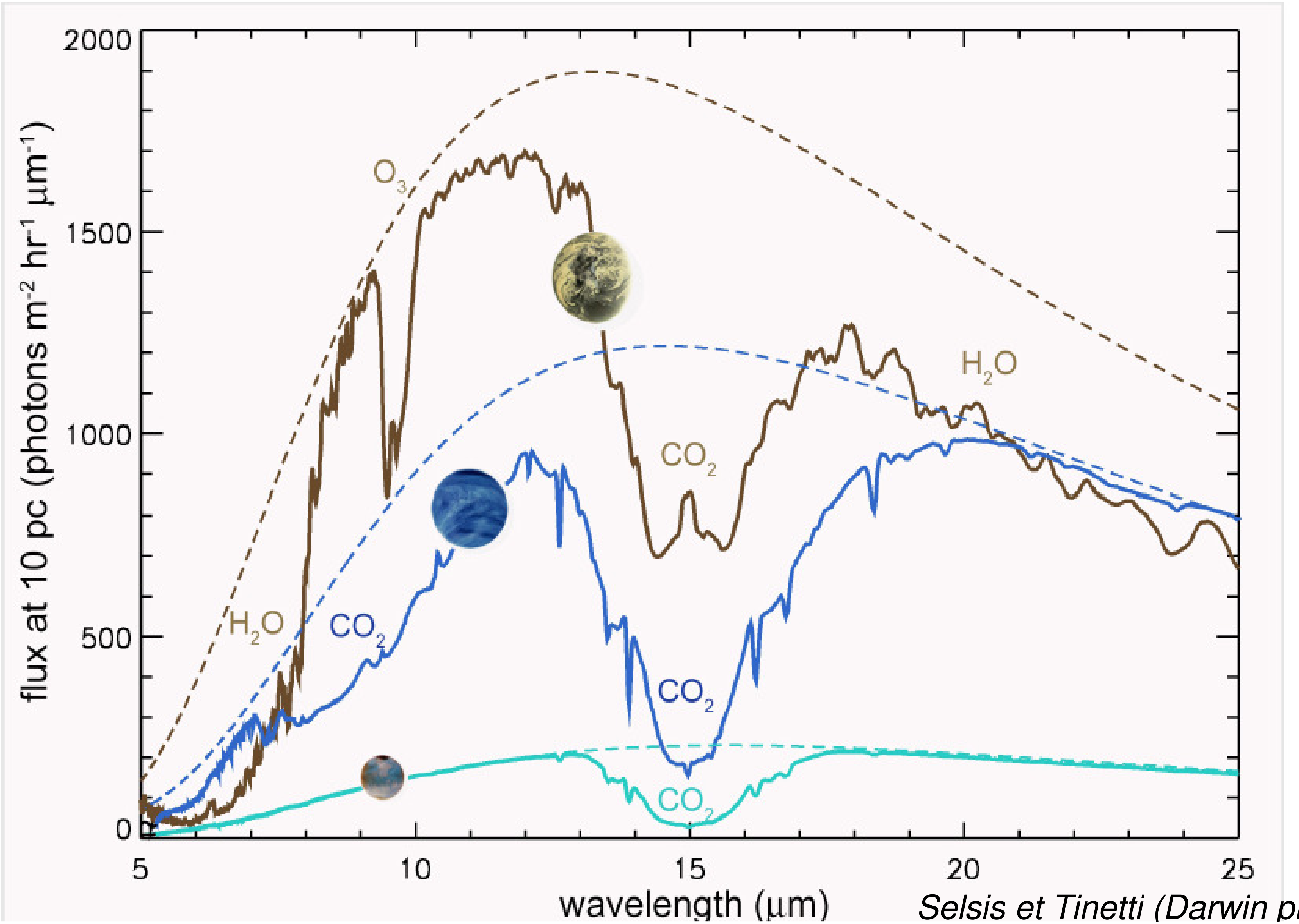
Finalement : quelle fraction habitable

- Nécessité de calculer la ZH pour chaque système planétaire
- Nécessité d'identifier l'eau et certains paramètres physico-chimique (T, albedo, ...)
- Nécessité de faire une observation directe des exoplanètes

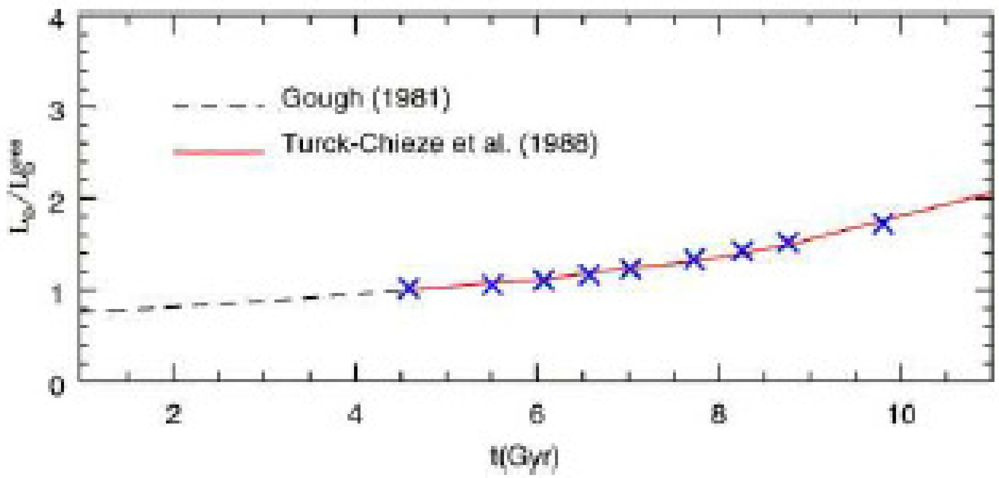
Critère d'habitabilité dans le Système Solaire



Selsis et Tinetti (Darwin proposal)

Table 3.4: Habitable zones and some stellar parameters.

Spectral Class	T_{eff} (K)	Life (y)	Abundance %	HZ (AU)
O6V	41 0000	10^6	4×10^{-5}	450-900
B5V	15 400	8×10^7	0,1	20-40
A5V	8200	10^9	0.7	2.6-5.2
F5V	6400	4×10^9	4	1.3-2.5
G5V	5800	2×10^{10}	9	0.7-1.4
K5V	4400	7×10^{10}	14	0.3-0.5
M5V	3200	3×10^{11}	72	0.07-0.15



Circumstellar HZ

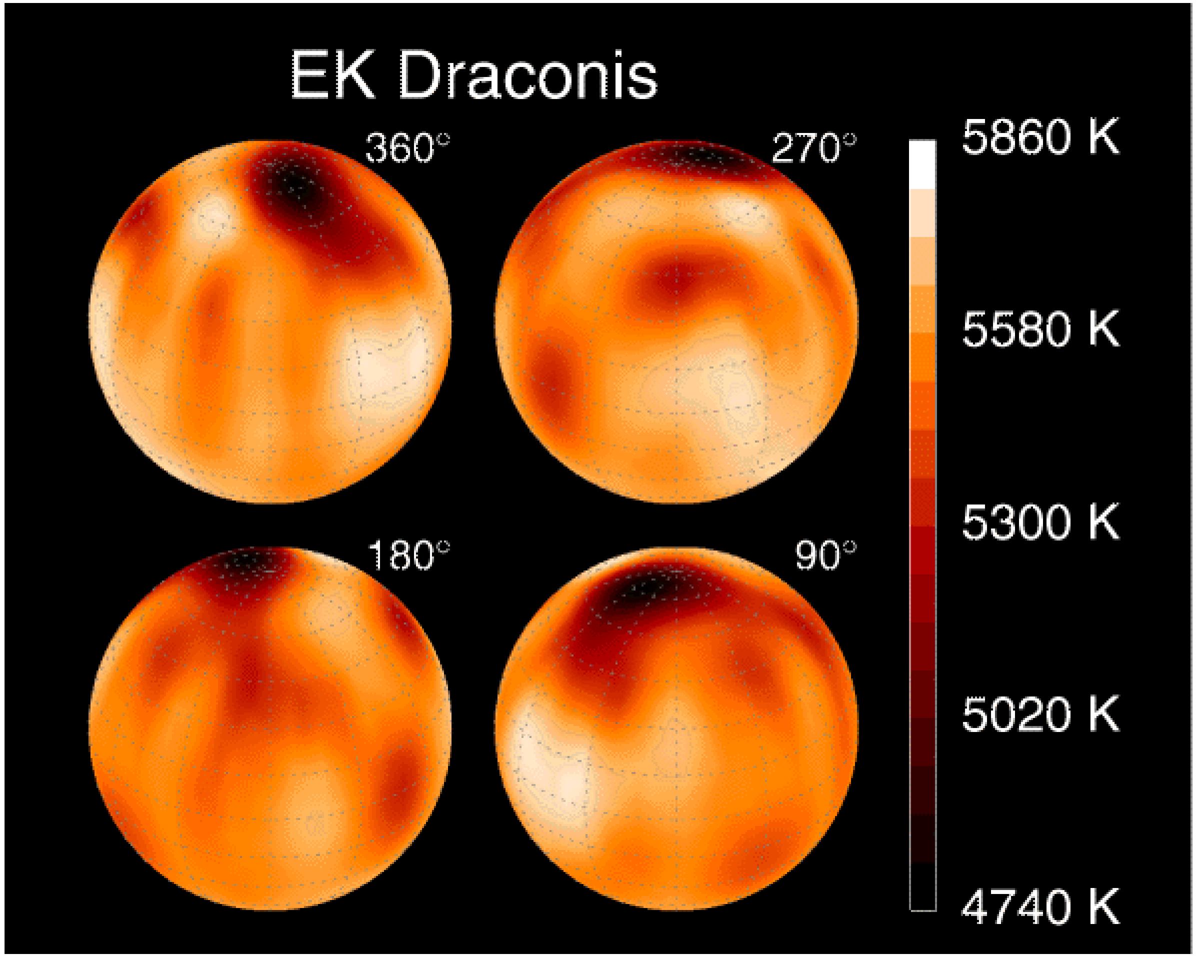
- Effects on the planetary atmospheres
  - Inner edge
  - Outer edge
- Inner Edge:
  - Star too close to planet, UV flux too high, photolysis of water; moist greenhouse effect
- Outer Edge:
  - Formation of CO_2 clouds; cool the planet‘s atmosphere, increase of albedo
- Planets with high CO2 concentration: greenhouse effect, extension of HZ

Influence on planetary atmospheres

- Emission of radiation
  - UV
  - X ray
- Emission of particles
  - Stellar winds
- Cosmic ray modulation
  - Cosmogenic isotopes

Planetary ionospheres
Chemistry in
Stratospheres
Tropospheres

Condensation nuclei



EK Dra
Single
G V
eq velocity 20
rot period: 2.6

As a young solar analogue, EK Draconis provides an opportunity to study the magnetic activity of the infant Sun.

Problem of polar spots

Flux tubes rise to surface

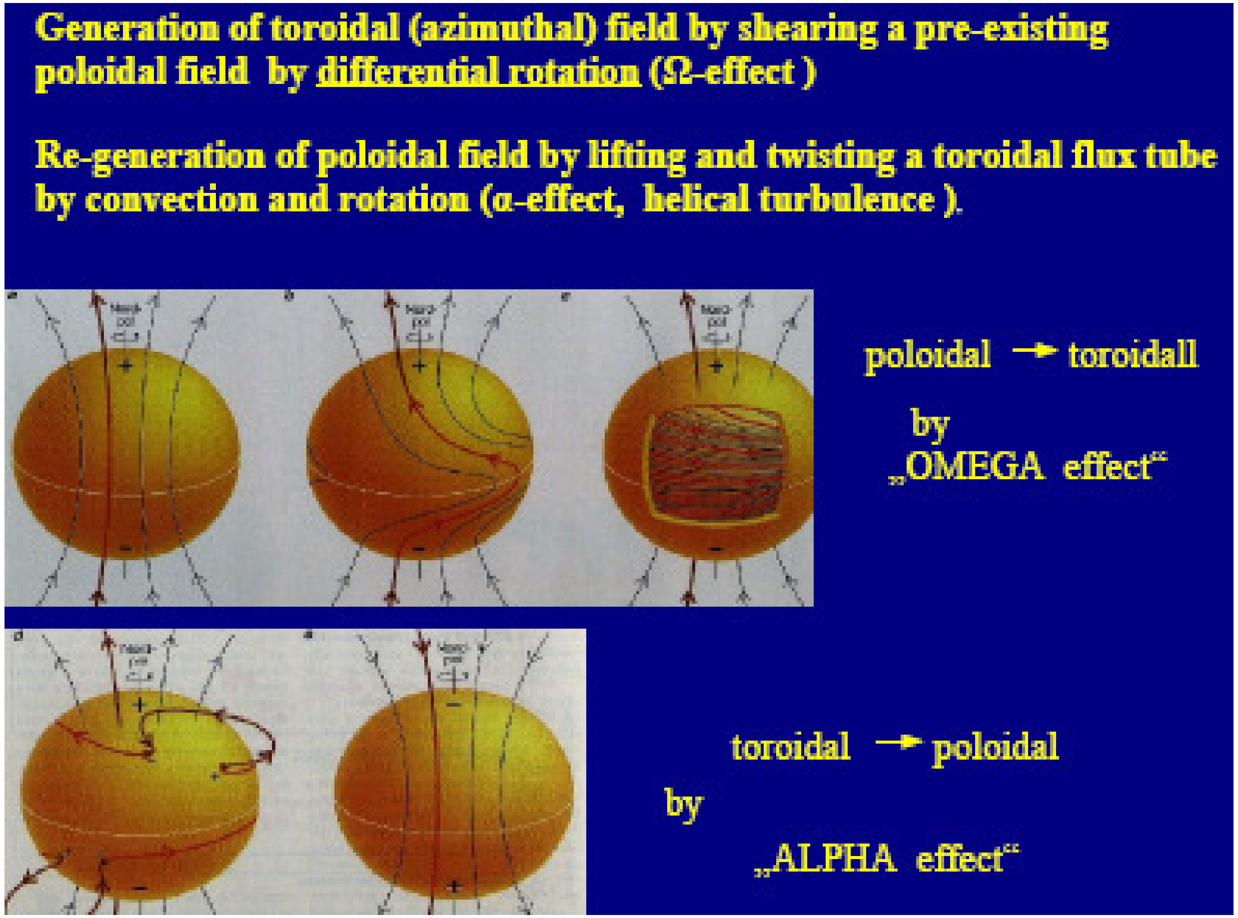
Are forced to higher latitudes by Coriolis force

Starspots can appear at higher latitudes than on the sun if core diameter is smaller or rotation rate higher

Fast rotating stars: polar activity zones
More active

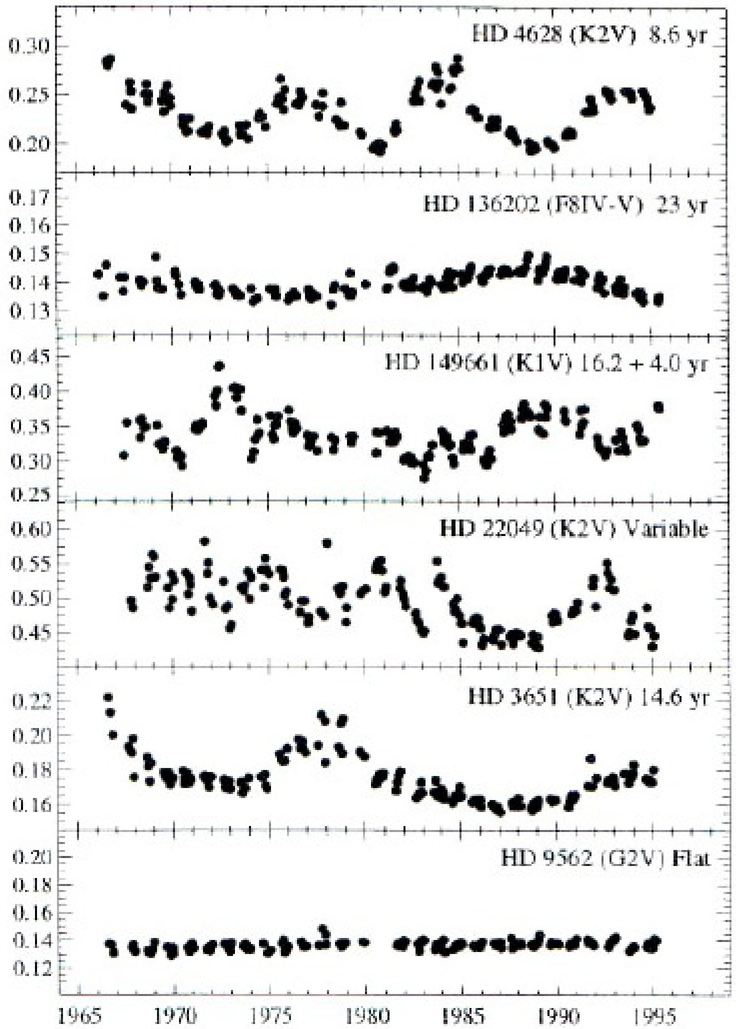
Space climate:
Planets in equatorial plane (?)
Effects smaller (polar outflows…)

Activity



Solar like stars

Stellar activity cycles



Monitoring chromospheric activity
CaII, H, K

Mt Wilson Survey

Solar variations: <few tenths of a percent
Stellar variability F7… K2

scoff, CNRS, 2011

Stellar activity during stellar evolution

- Activity in solar type stars declines with age
  - Related to a loss of angular momentum throughout the lifetime,
    - (Skumanich 1972, Noyes et al. 1984,… Güdel, 1997)
- Young stars
  - High average level of activity
  - Rapid rotation
- Stars as old as the Sun
  - Slower rotation rates
  - Lower activity

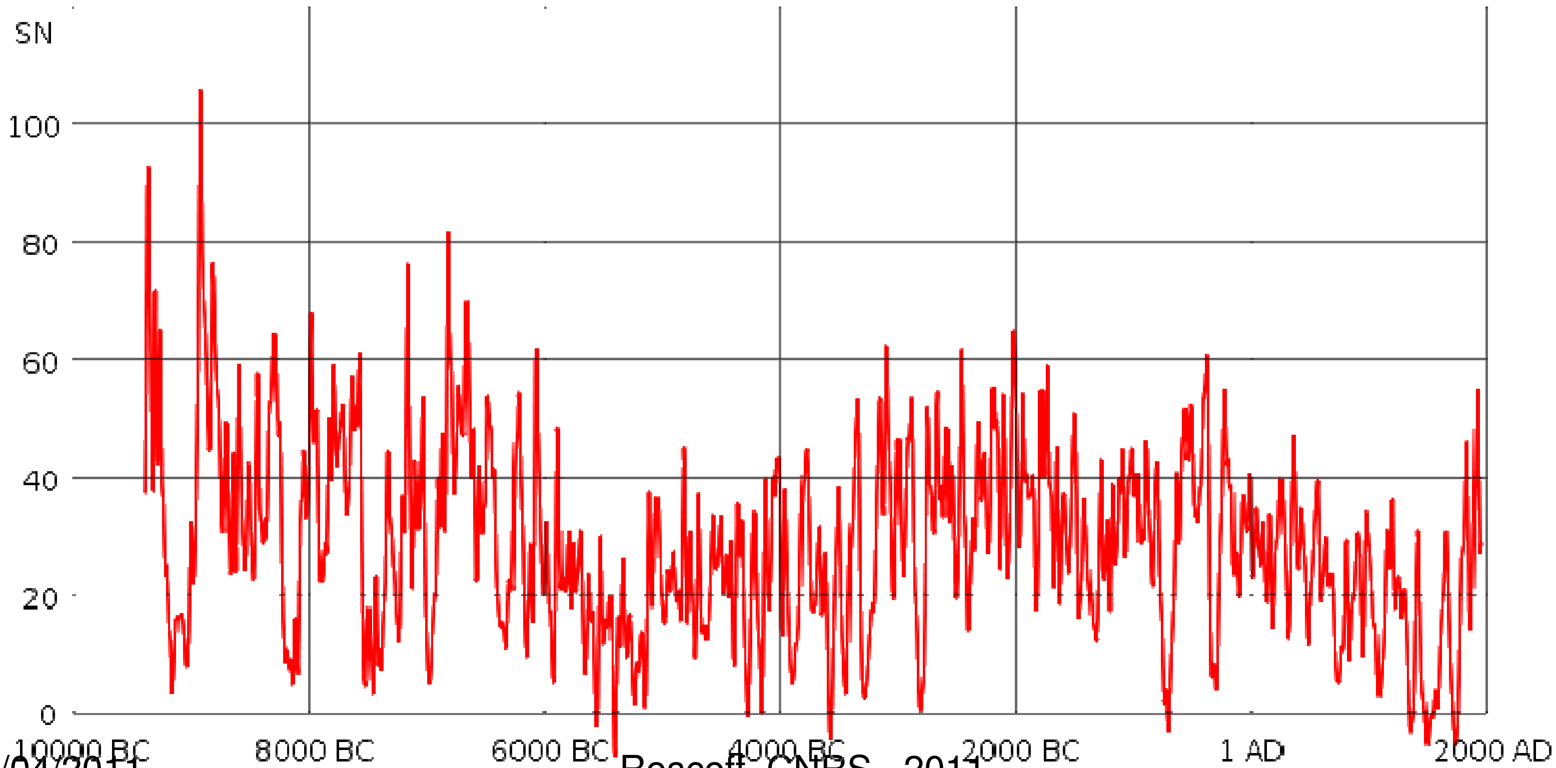
Solar activity cycles

- 11 yr, Schwabe cycle; 9-12 yr
- 22 yr, Hale cycle
- 87 yr, Gleißberg cycle; modulation of Schwabe cycle
- 210 yr, Suess cycle
- 2300 yr, Hallstatt cycle
- Other patterns

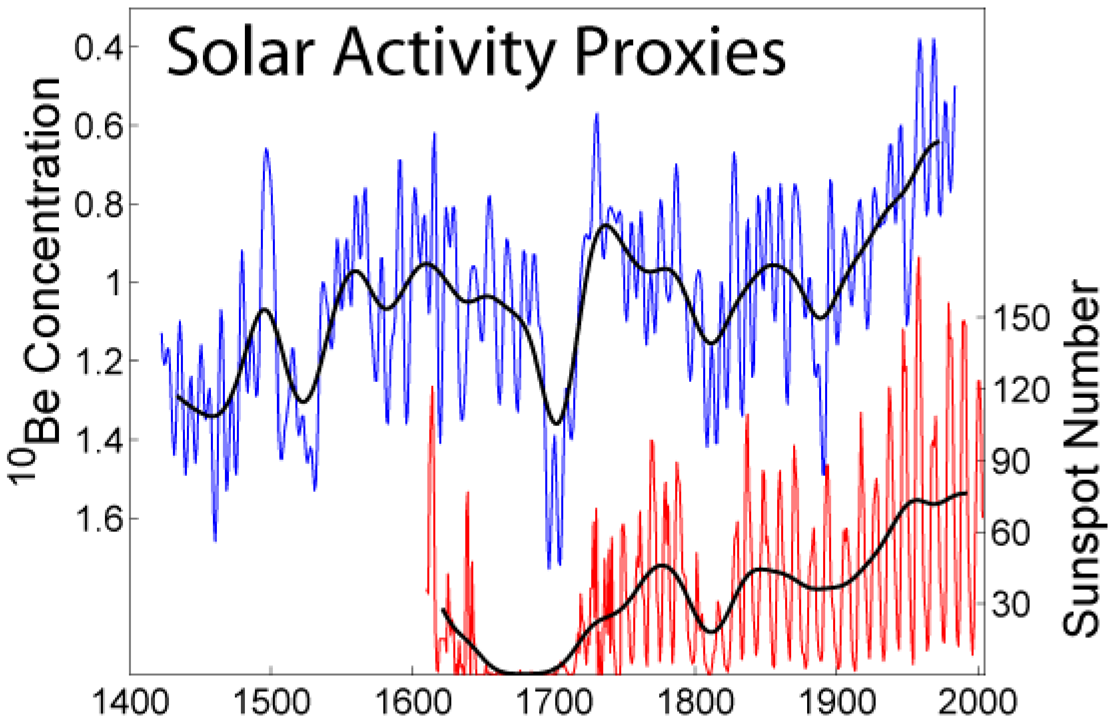
  C-14: 105, 131, 232, 385, 504,805, 2241 yr

Reconstruction of solar activity over last 10 k yr

Solanki, S.K., I.G. Usoskin, B. Kromer, M. Schüssler and J. Beer. 2004. An unusually active Sun during recent decades compared to the previous 11,000 years. Nature, Vol. 431, No. 7012, pp.1084-1087, 28 October 2004.



Solar activity proxies

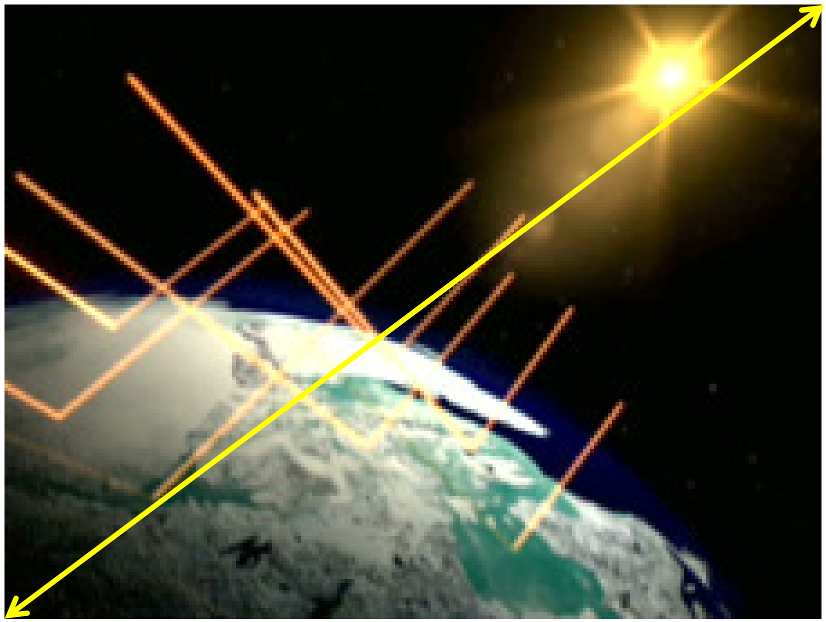


Anticorrelation

What are the consequences for Earth?

Fluctuations during solar cycle

At present ~ 0.1 %

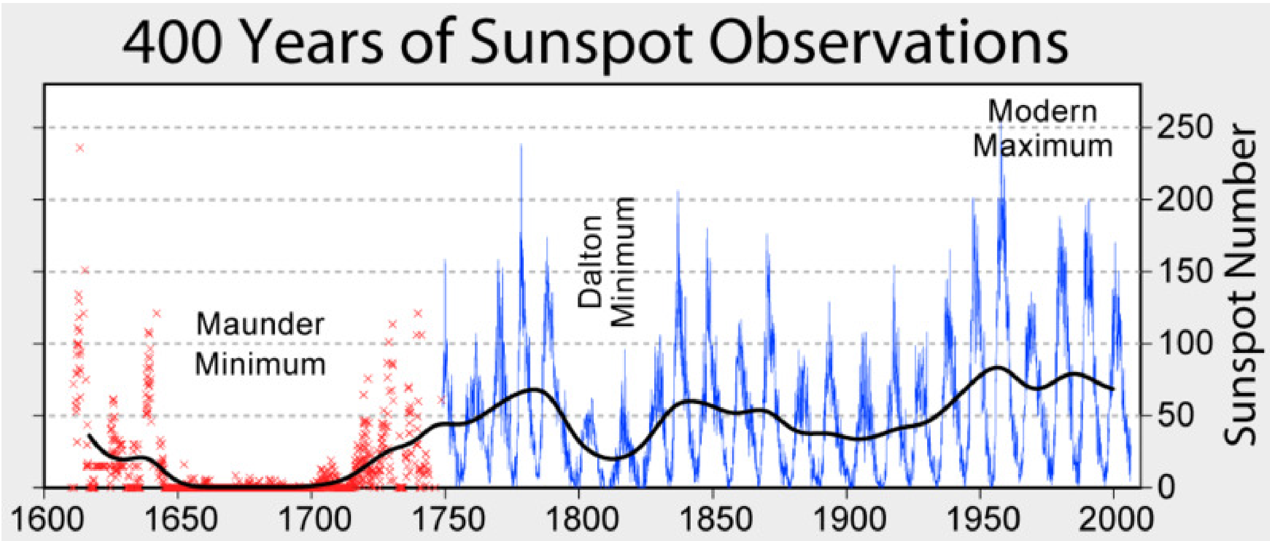


Earth: 0.1 C T variation

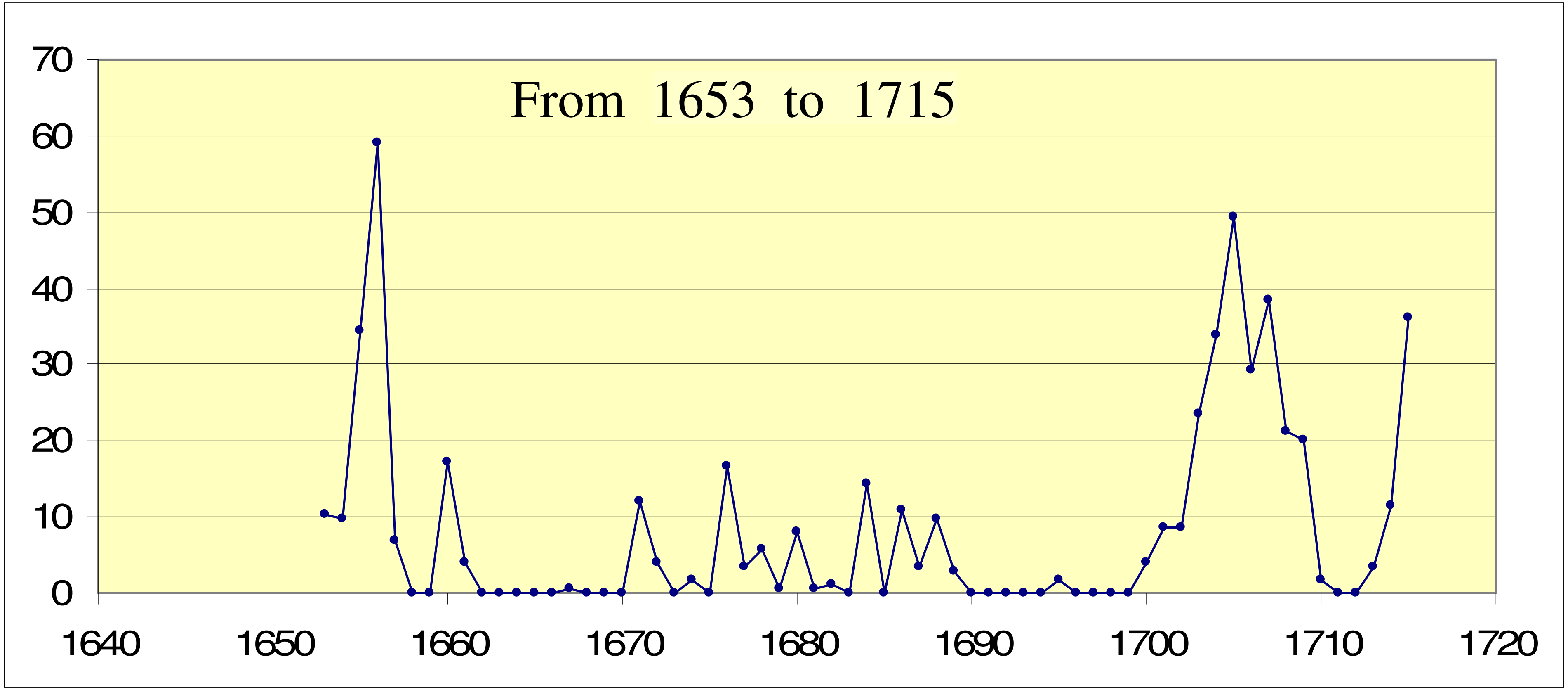
Sun:
Slightly hotter during Maximum
Slightly cooler duirng minimum

The Maunder Minimum

- J.A.Eddy, 1976 paper in Science.
- Lower than average global temperature
- During 30 yr period only 50 sunspots; modern values 40000-50000

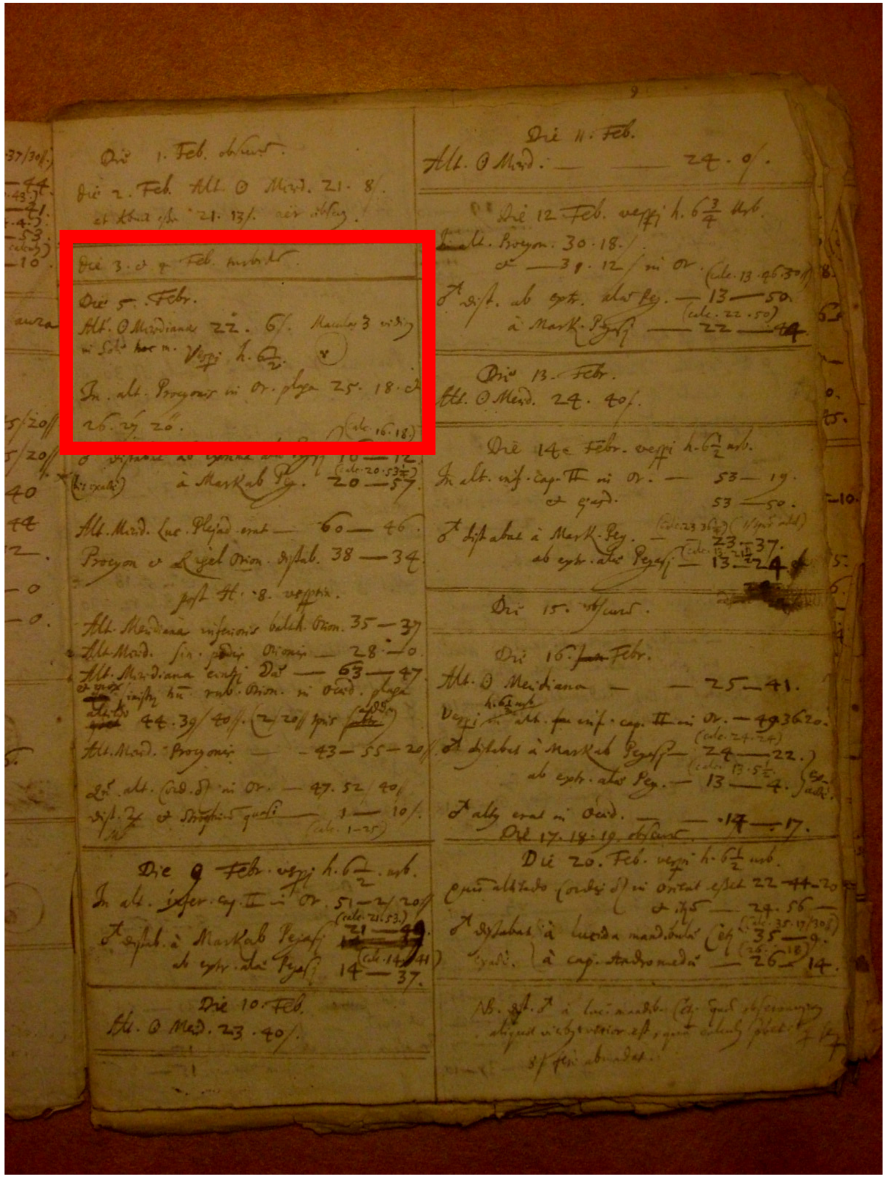


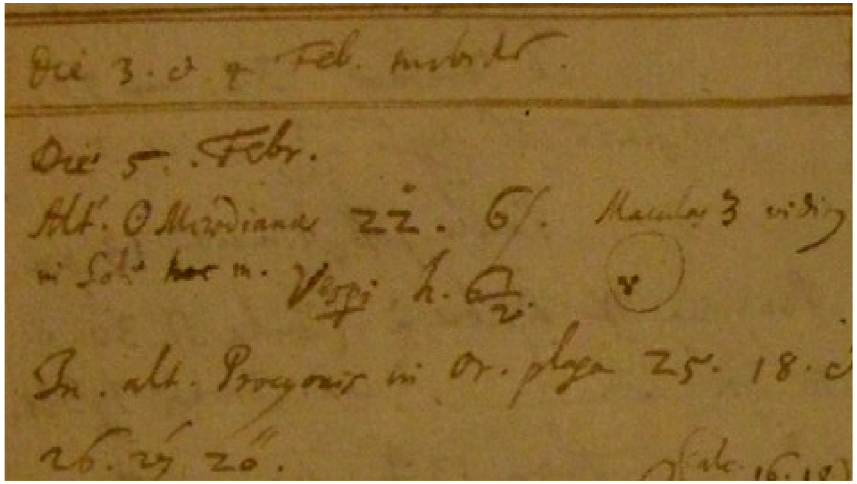
The activity cycle



Due to an abnormal N/S rotation?
Presence of spots in only one hemisphere ?
Was the Sun « bigger » ?
What was the luminosity?

→ Earth Climatic Effects?





DE SOLE ALFONSINO RESTITVTO,

SIMVL ET

DE DIAMETRIS ET

PARALLAXIBVS LVMINARIVM, SEMIDIAMETRO QVE VMBRÆ TERÆ

EPISTOLA,

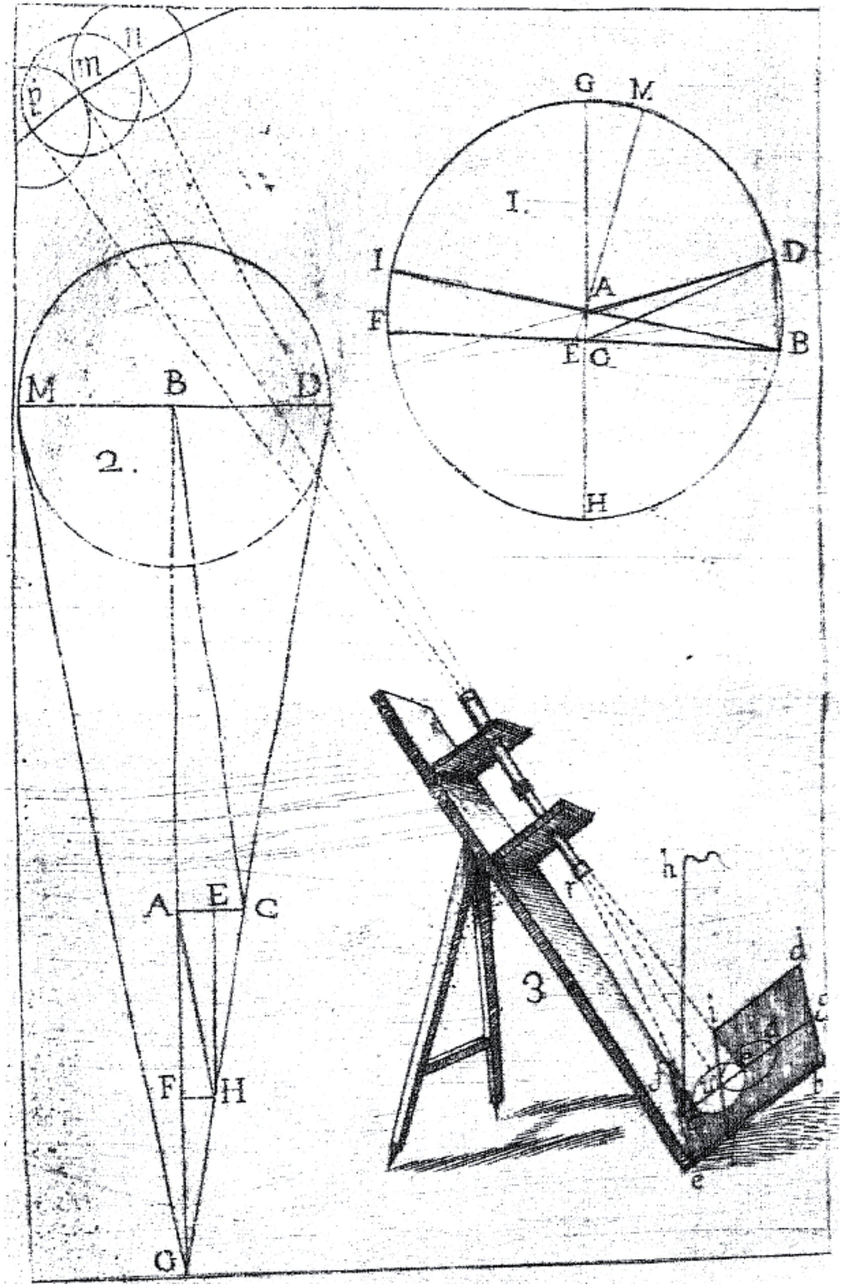
QVAM, AD EXCELL. D. COMITEM STABILEM CASTILIÆ, ET LEGIONIS SCRIBEBAT

D. VINCENTIVS MVT, INSTRVCTOR MILITIÆ, SIVE SARGENTVS MAIOR MAIORICE, &c.

Anno. 1649.

Palmæ, Typis Petri Guasp Impressoris.

CNRS,



What caused the Maunder Minimum

- Solar irradiance was lower by 1,2 % in 1683
- Solar Rotation rate?
  - Increase?
  - Decrease? (Nesme-Ribes 2%)
- Solar Diameter variation?

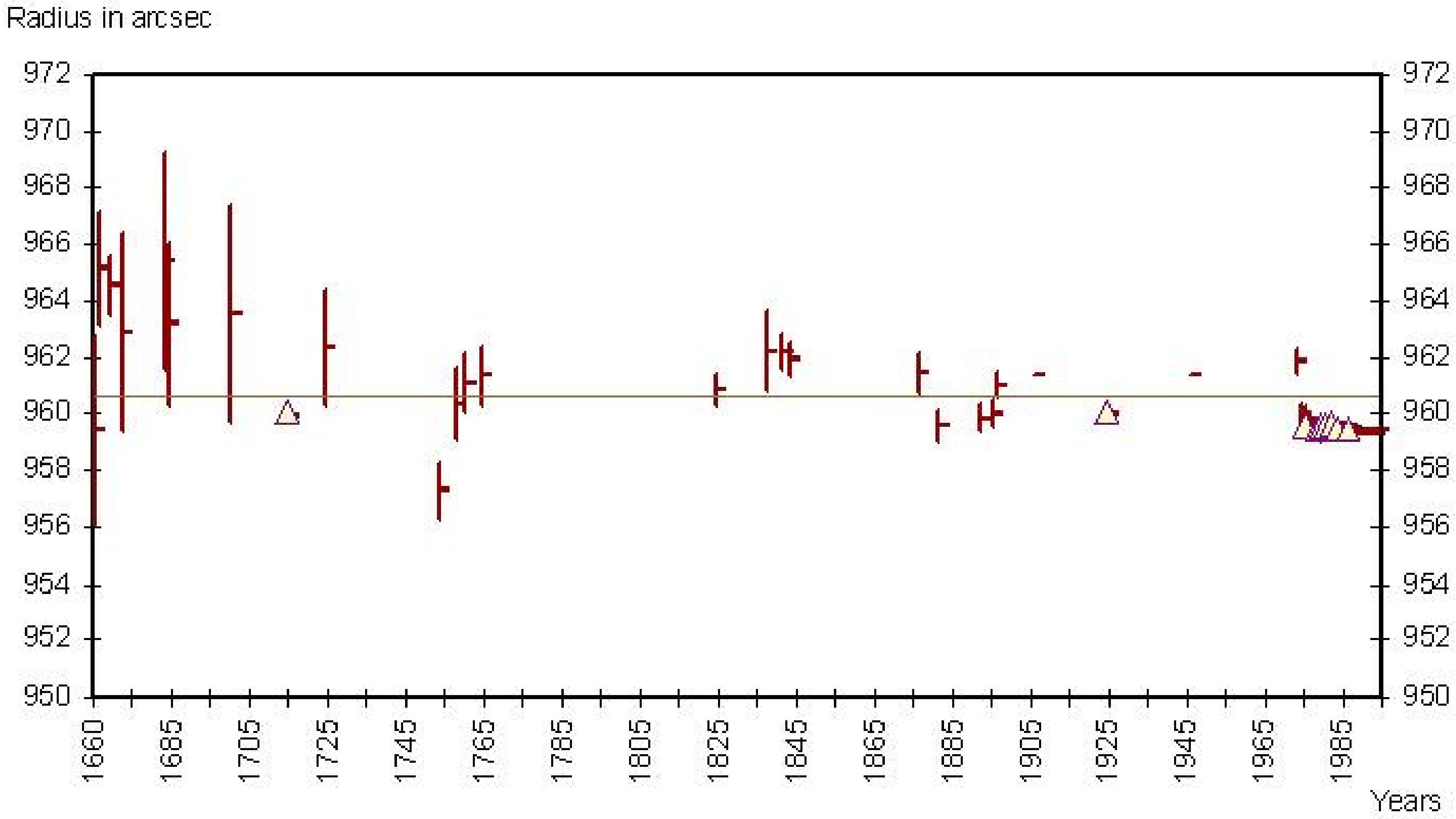
Radius variations

- Measurements by solar eclipses

SOLAR ECLIPSE DETERMINATIONS OF THE SOLAR RADIUS[a]

Eclipse Date	$(\Delta R/R) \times 10^4$	Reference
1715 May 3	$+5.4 \pm 2.1^b$	Dunham *et al.* 1980
1925 Jan 24	$+6.2 \pm 0.8^c$	Dunham *et al.* 1981
1976 Oct 23	-2.4 ± 1.5^c	Dunham *et al.* 1980
1979 Feb 26	-0.8 ± 0.9^c	Dunham *et al.* 1980
1980 Feb 16	-0.3 ± 0.4^c	Dunham *et al.* 1981

See also Kilcik et al., 2009, Sol. Physics.


Radius in arcsec
972
970
968
966
964
962
960
958
956
954
952
950
1660
1685
1705
1725
1745
1765
1785
1805
1825
1845
1865
1885
1905
1925
1945
1965
1985
Years

- Assuming that

$$\Delta R/R \approx 6 \times 10^{-4}\,, \qquad |\Delta L/L| \lesssim 5 \times 10^{-3}$$

- Ulrich, 1975: solar variability → change α
- Definition: α=mixing length/pressure scale height
- If this parameter increases, the efficiency of convection increases, R and L increase.
- Problem: luminosity perturbation decreases very slowly, R perturbation decreases more rapidly.

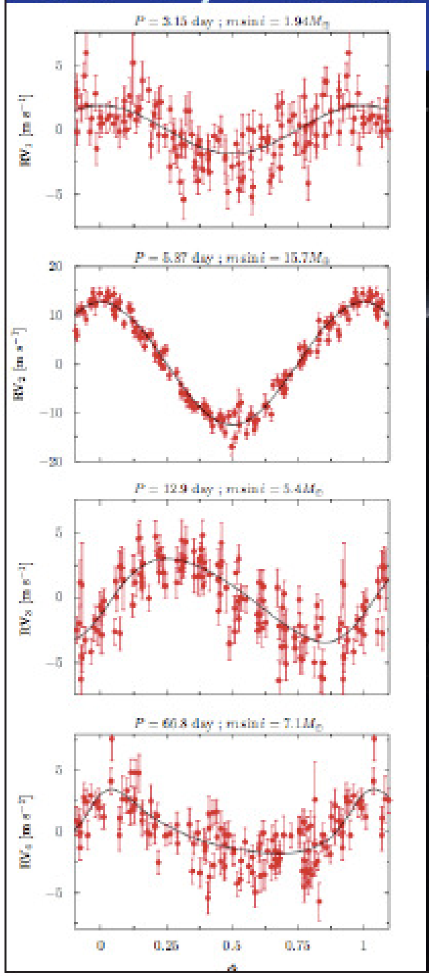
Gravitational energy is stored and relaxed according to the cyclic radius variations within the leptocline

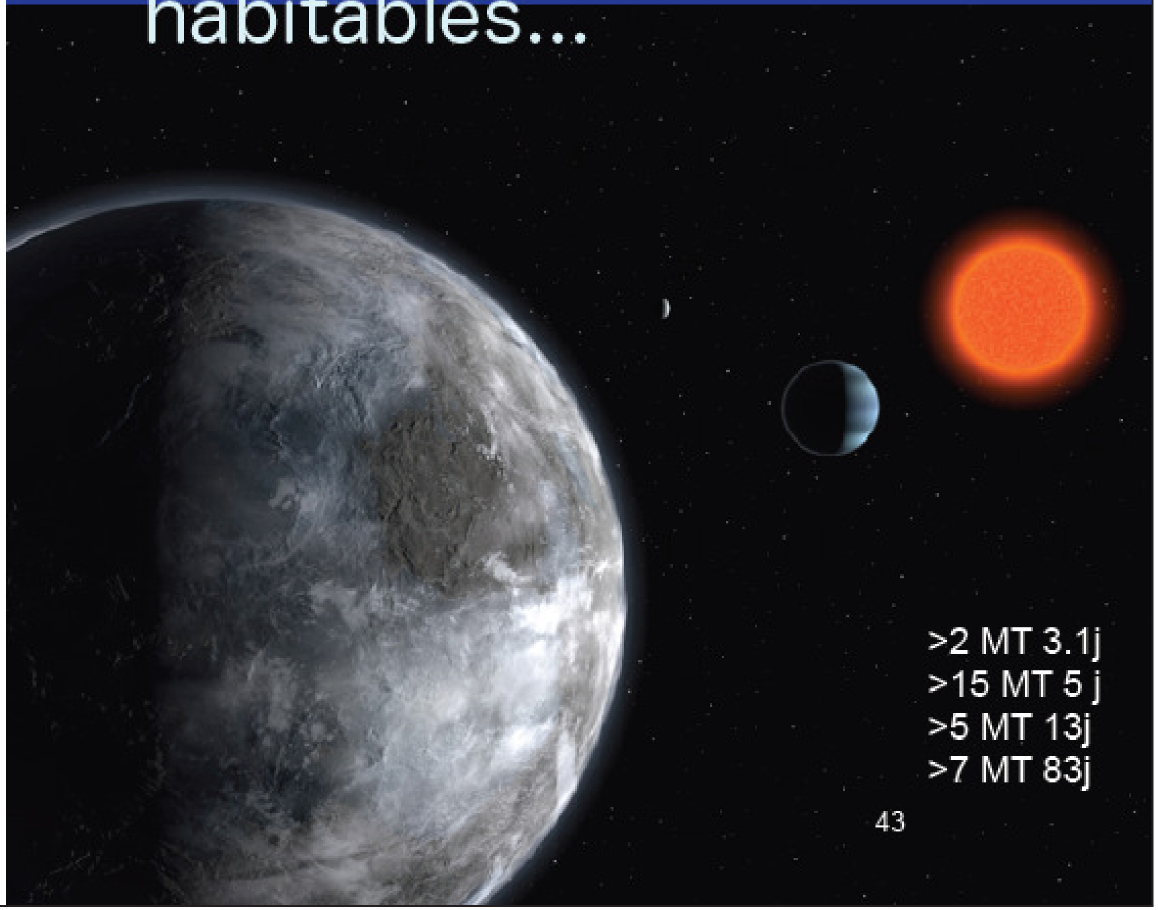
$$\frac{\Delta L}{L} = -\left[\frac{4n(\gamma-1)}{1-\alpha} + \frac{\frac{a}{c^2}(2a^2-b^2-ab)+\frac{b}{c^3}(2a^3-b^3-ab^2)\ln(\frac{a+c}{b})}{a+\frac{b^2}{c}\ln(\frac{a+c}{b})}\right]\frac{3b}{2b+a}\frac{\Delta R_{sp}}{R_{sp}}$$

Variations of the solar radius computed in two cases: monotonic (n=1) and non monotonic (n=2) expansion, and for two mean values of $L_\odot$. The sign (-) indicates a shrinking. The case $n = 2$ is the most likely.

ΔL/L = 0.0011	ΔL/L = 0.00073
ΔR/R = -1.70 $\times 10^{-5}$ (n=1), (or ΔR = 11.8 km)	ΔR/R = -1.13 $\times 10^{-5}$ (n=1) (or ΔR = 7.86 km)
ΔR/R = -8.38 $\times 10^{-6}$ (n=2), (or ΔR = 5.83 km)	ΔR/R = -5.56 $\times 10^{-6}$ (n=2) (or ΔR = 3.87 km)

Gl581
un système de petites planètes, presque habitables...

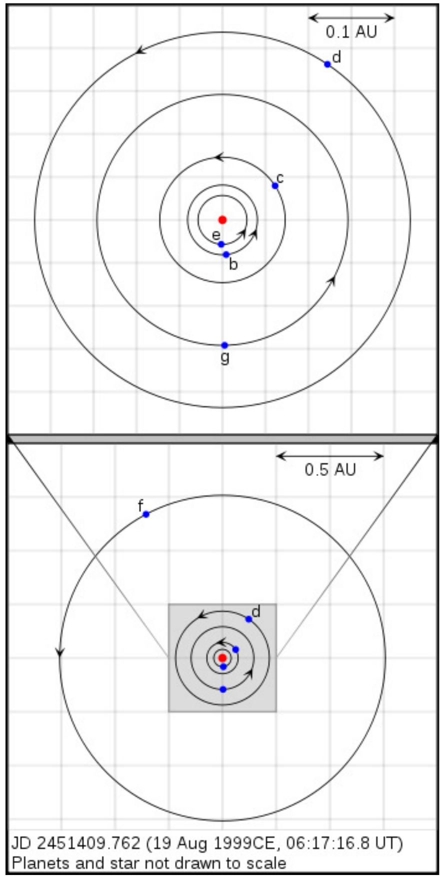




>2 MT 3.1j
>15 MT 5 j
>5 MT 13j
>7 MT 83j

- **Gliese 581** est une étoile naine rouge située dans la constellation de la Balance à 20,5 années-lumière du système solaire. Il s'agissait en janvier 2009 de la 87e plus proche étoile connue. Six exoplanètes ont été détectées autour de Gliese 581, dont deux, Gliese 581 c et Gliese 581 d sont les premières exoplanètes à avoir été trouvées dans la zone habitable de son étoile.

Gliese 581

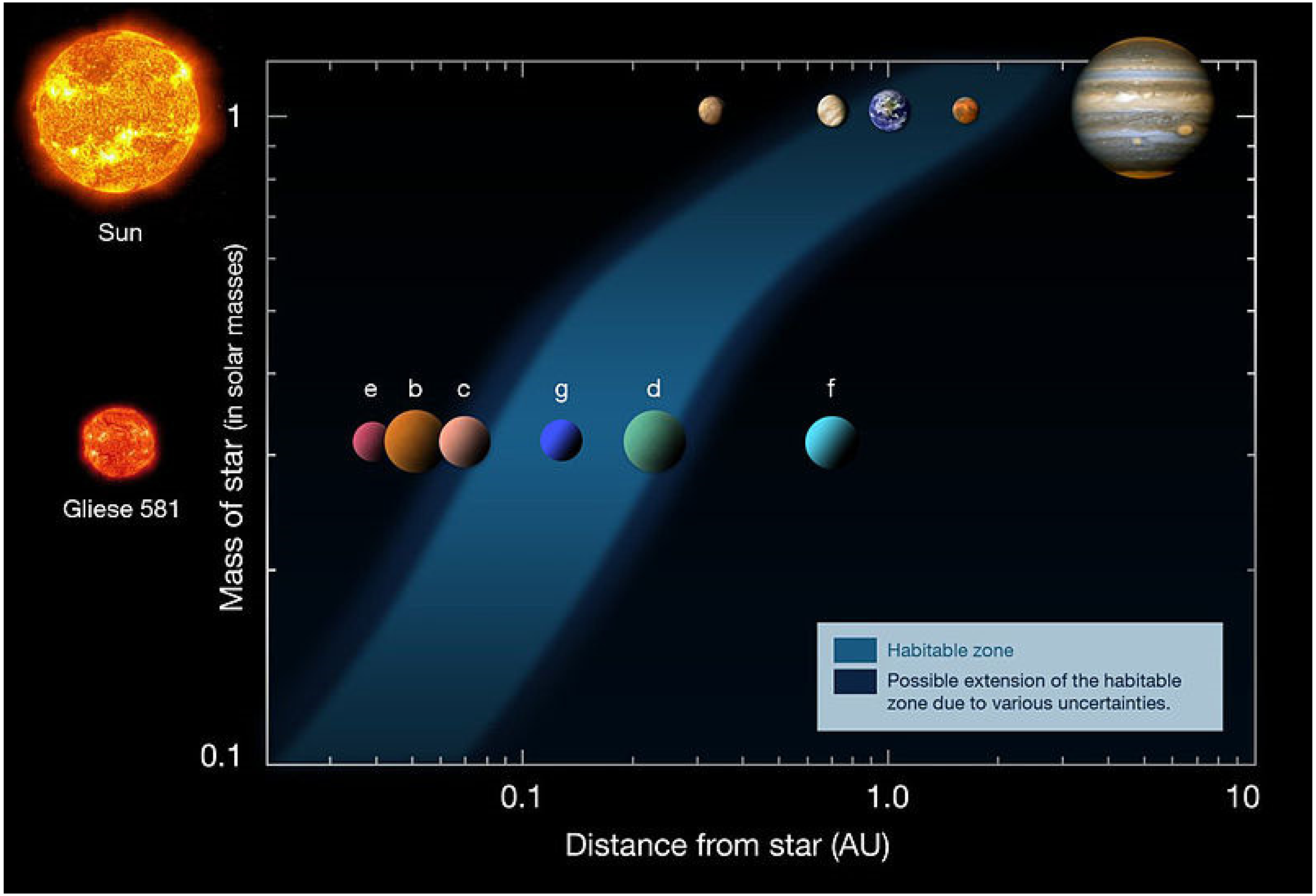


- Superearth
- Detected 2007
- 5 M_{Earth}, 0.073 AU ,
  - T -3 C if albedo ~ Venus or
  - T ~40 C with albedo ~Earth
- Gliese 581 c runaway greenhouse effect
- Gliese 581 d: 0.22 AU, 7 M_{Earth}; in HZ
- Gliese 581 g: 3 M_{Earth}, 0.17 AU

Caractéristiques des planètes du système Gliese 581

Planète	Masse (M_T)	Période orbitale (d)	Demi-grand axe (ua)	Excentricité
Gliese 581 b	15,65	5,3687	0,04	0 (fixé)
Gliese 581 c	5,36	12,929	0,07	0,17 ± 0,07
Gliese 581 d	7,09	66,8	0,22	0,38 ± 0,09
Gliese 581 e	1,94	3,1494	0,03	0 (fixé)
Gliese 581 f (non confirmée)	7,31	433	0,758	0 (fixé)
Gliese 581 g (non confirmée)	3.17	36,652	0,146	0 (fixé)

Gliese 581



Sun
Gliese 581
Mass of star (in solar masses)
1
0.1
e
b
c
g
d
f
Habitable zone
Possible extension of the habitable zone due to various uncertainties.
0.1
1.0
10
Distance from star (AU)

Thank you very much!

Comments, suggestions, etc.: