Estrelas

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AGA 0205

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Variedade de brilhos

Algumas estrelas aparentemente isoladas são na verdade sistemas duplos (ou binários)

Albireo : sistema duplo

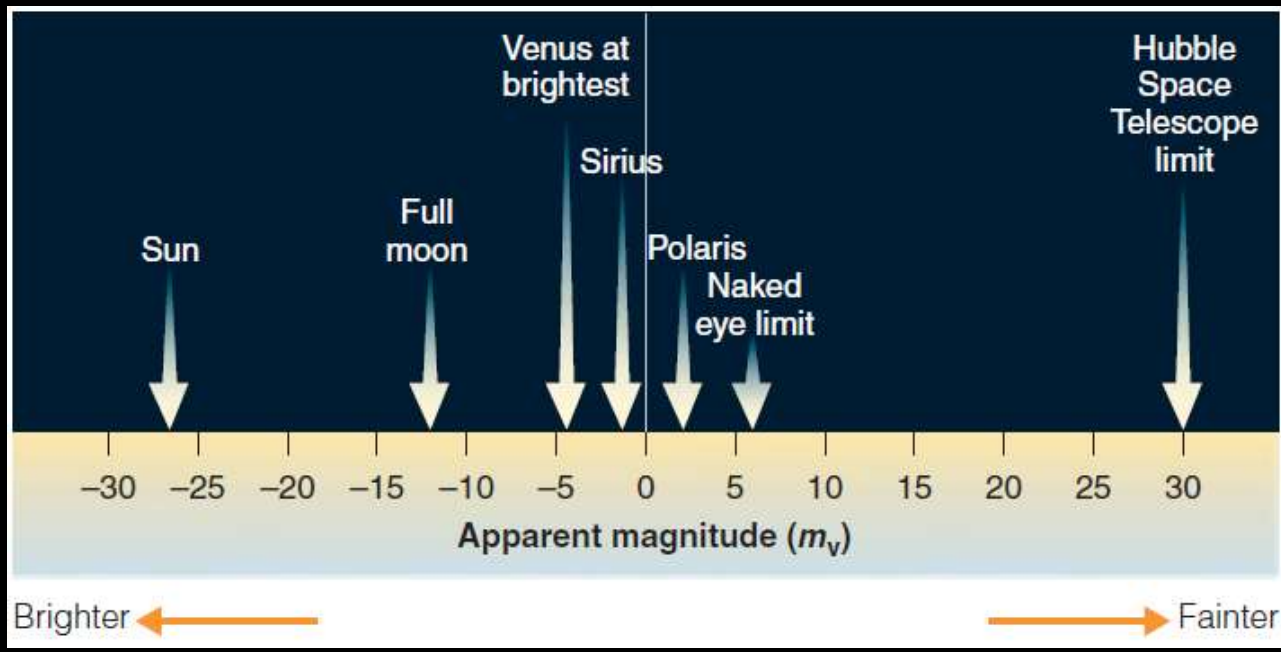
magnitude V: A: 3.18 B: 5.82

Magnitudes

estrelas mais brilhantes a olho nú: $m \sim -1$ a 0

mais fracas: $m \sim 5$ a 6

Escala logarítmica



Magnitude (m) vs. Fluxo (f)

$\Delta m = 5 \rightarrow f_1/f_2 = 100$

$$m_1 - m_2 = -2.5 \log(f_1/f_2)$$

m : magnitude aparente

Arcturus

Saturno

Lua

Marte

Cheia: m = -13

Quarter: m = -10

E

O

Rigil Kent

Hadar

Achernar

S

Exemplo: quão mais brilhante é a estrela *Vega* (m ~ 0) em relação a *18 Sco* (m ~ 5)

m_1 (Vega) = 0,0

m_2 (18 Sco) = 5,0

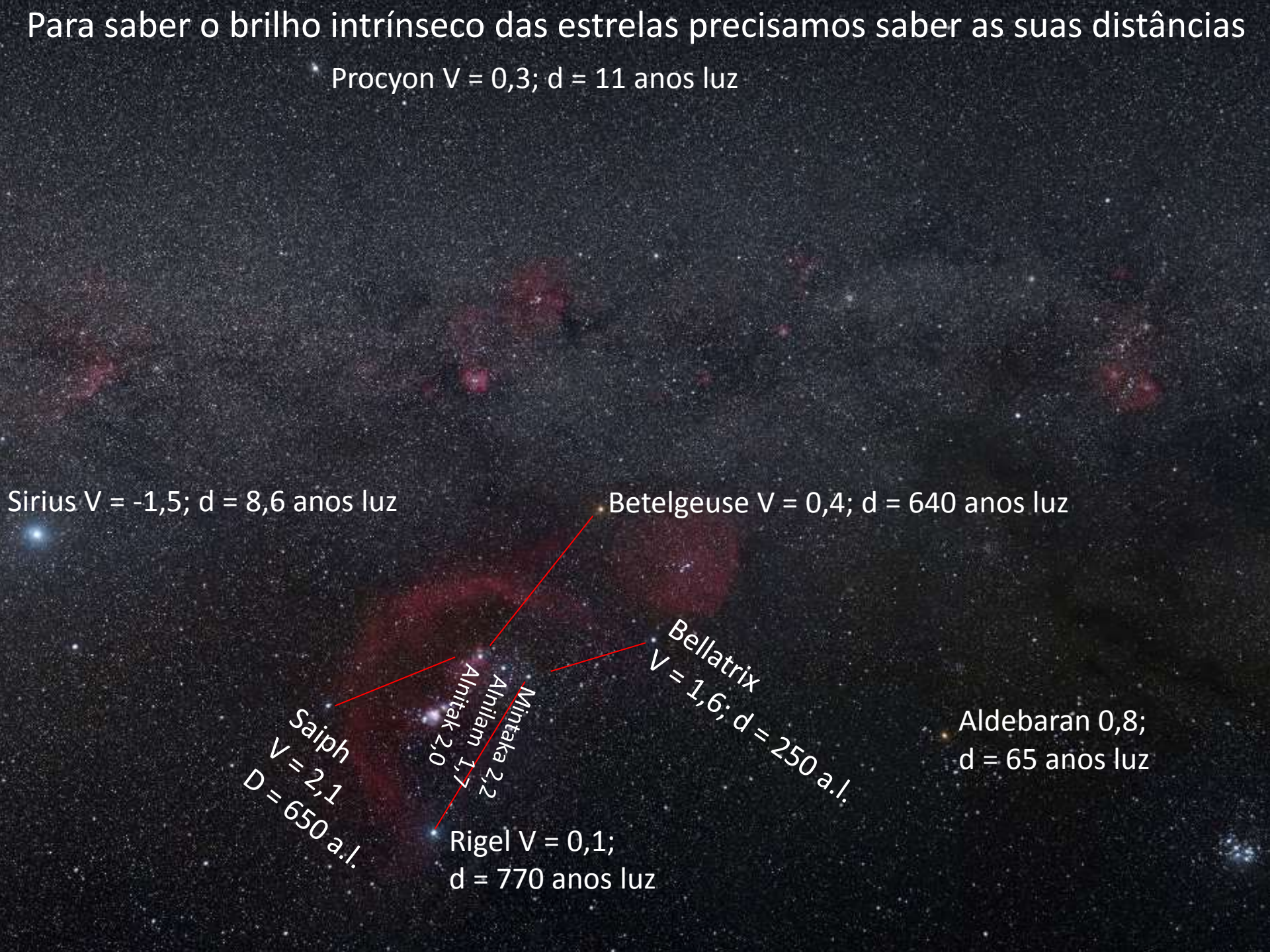
$m_1 - m_2 = -2{,}5 \log(f_1/f_2)$

$-5{,}0 = -2{,}5 \log (f_1/f_2)$

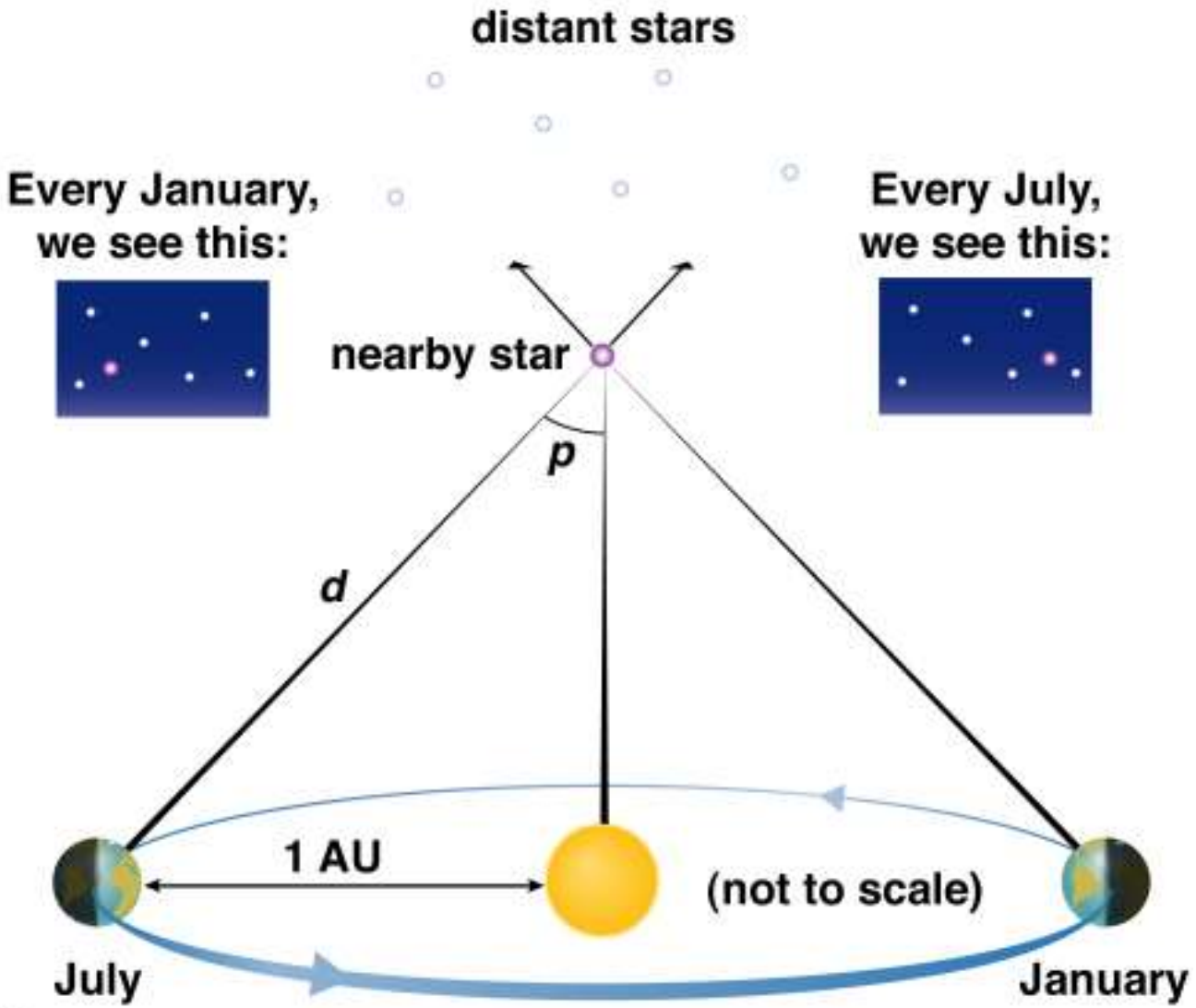
$2{,}0 = \log (f_1/f_2)$

$f_1/f_2 = 10^2 = 100$

Vega é 100 vezes mais brilhante que 18 Sco


Para saber o brilho intrínseco das estrelas precisamos saber as suas distâncias
Procyon V = 0,3; d = 11 anos luz
Sirius V = -1,5; d = 8,6 anos luz
Betelgeuse V = 0,4; d = 640 anos luz
Bellatrix
V = 1,6; d = 250 a.l.
Saiph
V = 2,1
D = 650 a.l.
Alnitak 2,0
Alnilam 1,7
Mintaka 2,2
Aldebaran 0,8;
d = 65 anos luz
Rigel V = 0,1;
d = 770 anos luz

Distância



Distância

$d = 1/ p(”)$

p : em segundos de arco

d: em unidades de parsecs

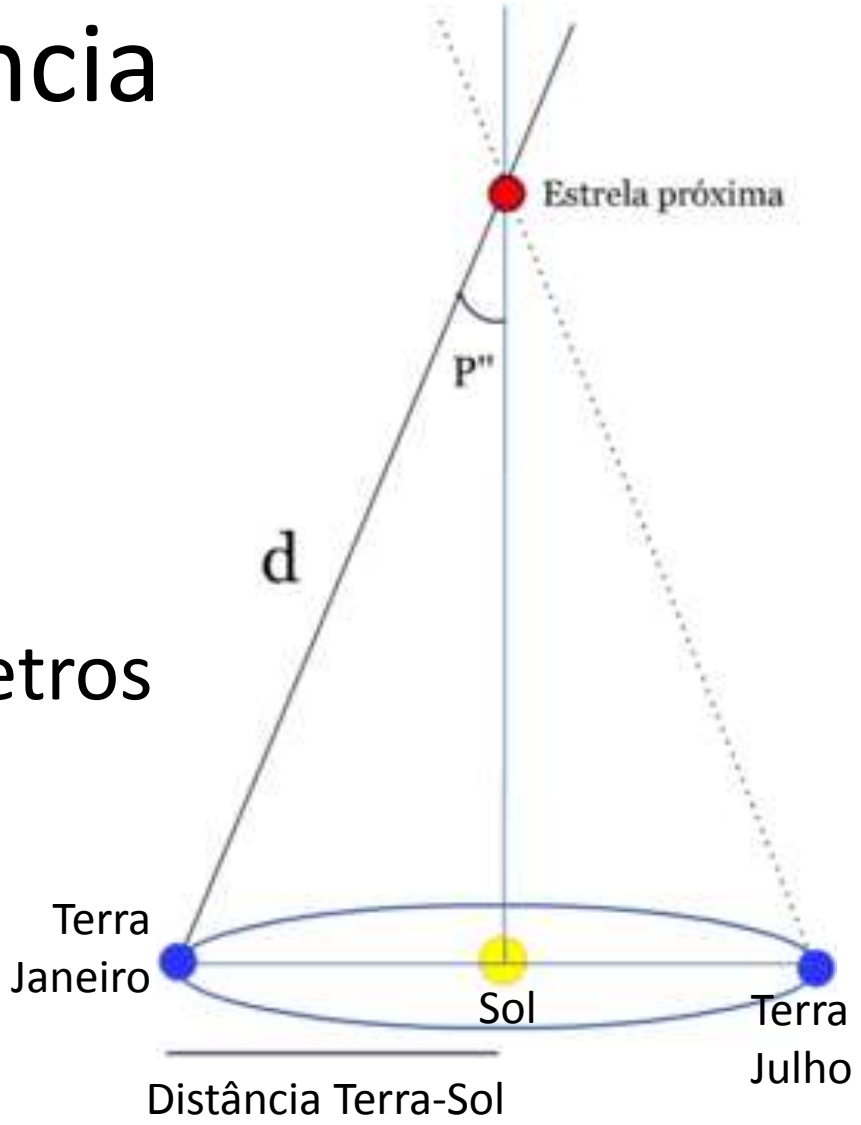
1 parsec = $3{,}0857 \times 10^{16}$ metros

= 3,2616 anos-luz

Exemplo:

p = 0,5”

d = 2 parsec = 6,5 anos-luz

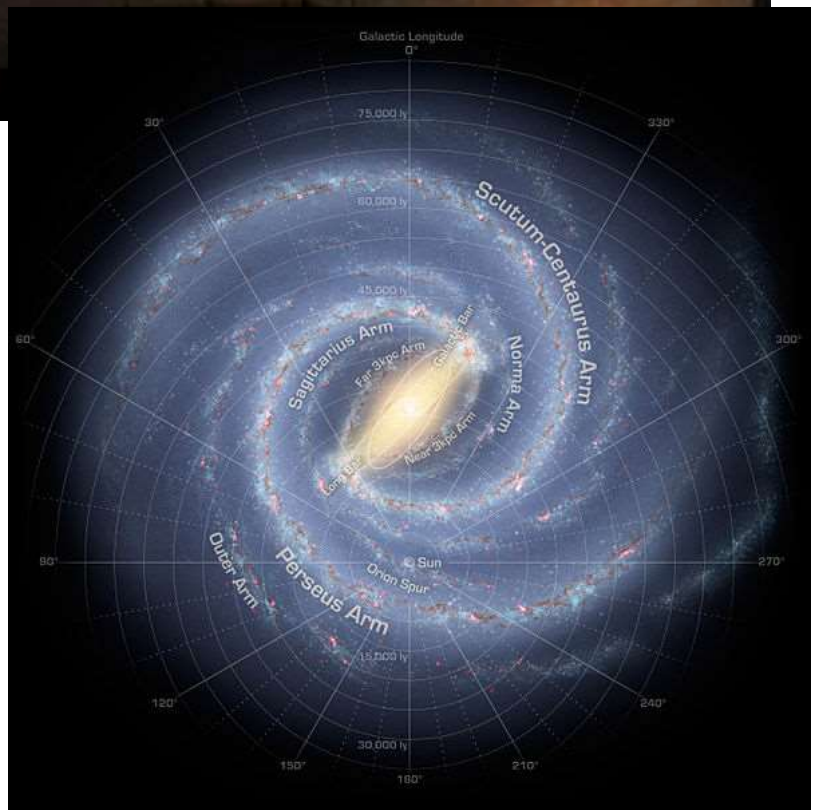


Escala de distâncias

1 parsec = 3,086 × 10^{16} metros
= 3,26 anos-luz

Diâmetro ~ 100 000 anos-luz
(30 000 parsecs ou 30 kpc)

Distância Sol-Centro da Via Láctea : ~ 8 kpc



Magnitude Absoluta: M

Magnitude absoluta M: a magnitude aparente m que teria um objeto a 10 pc de distância

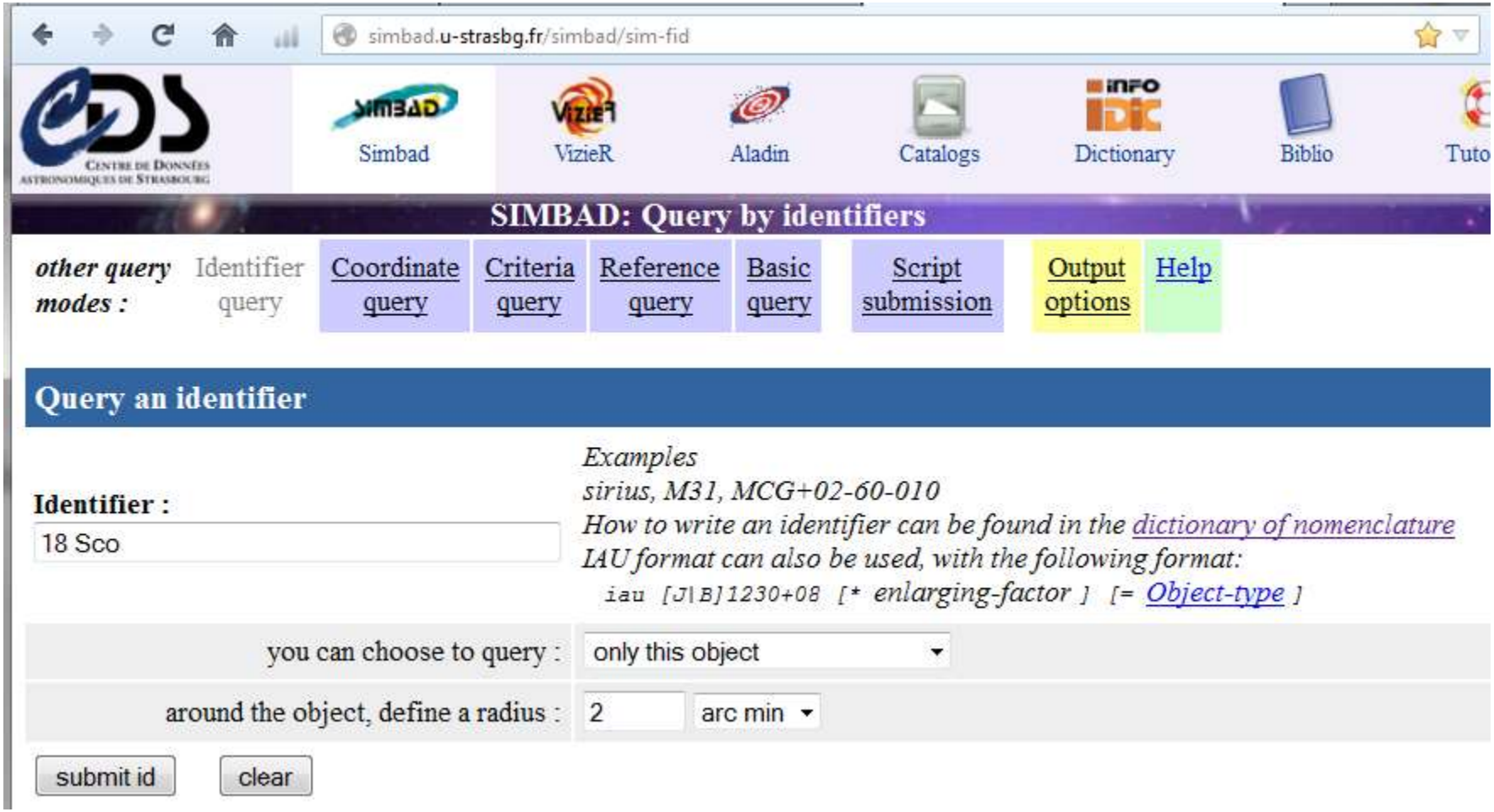
$$M = m + 5 - 5 \log d$$

$$M = m + 5 + 5 \log p$$

d : parsecs
p : “ (arcsec)

Exemplo: Magnitude Absoluta de gêmea solar *18 Sco*

http://simbad.u-strasbg.fr/simbad/sim-fid



simbad.u-strasbg.fr/simbad/sim-id?Ident=18+Sco&NbIdent=1&Radius=2&Radius.unit=arcmin&submit=submit+ic

Basic data :

* 18 Sco -- Variable Star

query around with radius

Other object types:	* (*,BD,CSI,GC,GCRV,GEN#,GJ,HD,HIC,HIP,HR,L [B10]) , **PM*** (Ci,LFT,LHS,LTT,NLTT,PM) , ** (TD1)
ICRS coord. (ep=J2000) :	16 15 37.26946 -08 22 09.9870 (Optical)
FK5 coord. (ep=J2000 eq=2000) :	16 15 37.269 -08 22 09.99 (Optical) [4
FK4 coord. (ep=B1950 eq=1950) :	16 12 53.98 -08 14 19.0 (Optical) [25.
Gal coord. (ep=J2000) :	004.6952 +29.1570 (Optical) [4.48 2.90
Proper motions *mas/yr* [error ellipse]:	230.77 -495.53 [0.51 0.33 0] A 2007A&A...
Radial velocity / Redshift / cz :	V(km/s) 10.6 [2] / z(~) 0.000035 [0.00000
Parallaxes *mas*:	71.94 [0.37] A 2007A&A...474..653V
Spectral type:	G2Va C 2011ARep...55...31S
Fluxes (5) :	B 6.15 [~] C ~
	V 5.50 [~] C ~

m.a.s. = 10^{-3} ”

Magnitude m_V

p = 71,94 x 10^{-3} ”

m_V = 5,5

Magnitude Absoluta de *18 Sco*

Magnitude absoluta M: a magnitude aparente *m* que teria um objeto a 10 pc de distância

$$M = m + 5 - 5 \log d \quad \text{[d: parsecs]}$$

$$\mathbf{M = m + 5 + 5 \log \textit{p}} \ \textit{[p: parallax em ”]}$$

$$\mathbf{m_V = 5{,}5;\ \textit{p} = 71{,}94 \times 10^{-3}\ ”}$$

$$M_V = 5{,}5 + 5 + 5 \log (71{,}94 \times 10^{-3})$$

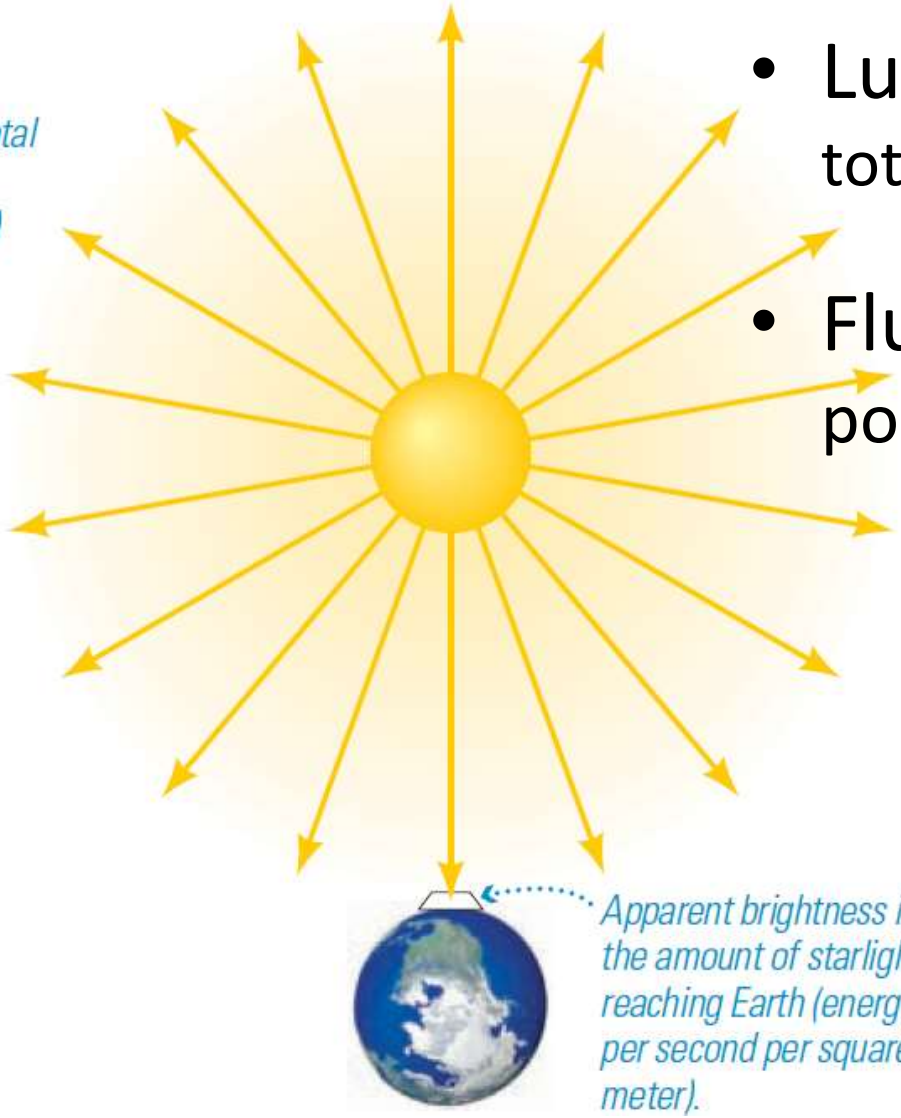
$$= 10{,}5 + 5 \times (\mathbf{-1.14})$$

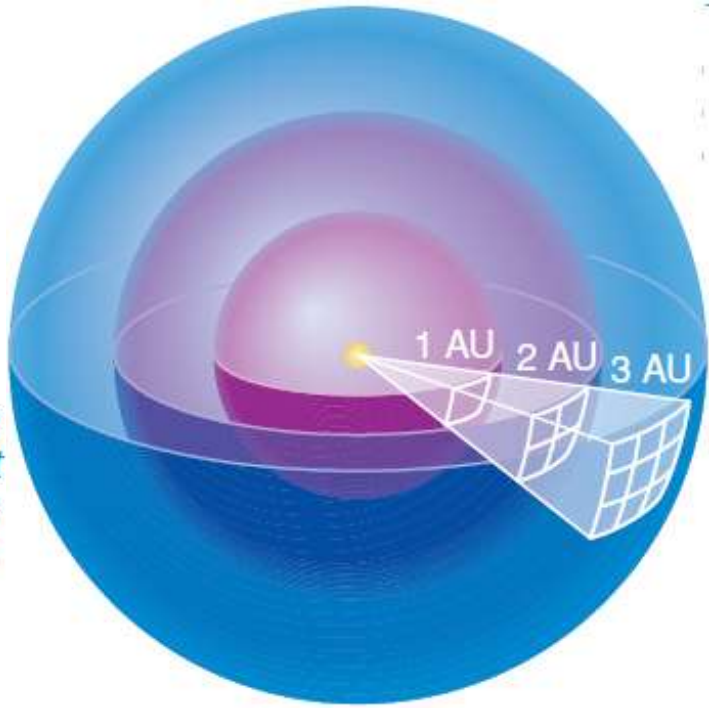
$$= 4{,}8$$

Para comparação, Sol tem $M_V = 4.83$

Fluxo e Luminosidade

- Luminosidade : energia total por unidade de tempo
- Fluxo : Luminosidade por unidade de área





Sol

Luminosidade:
L é a potência
(energia / unid. tempo)
emitida Pelo Sol.

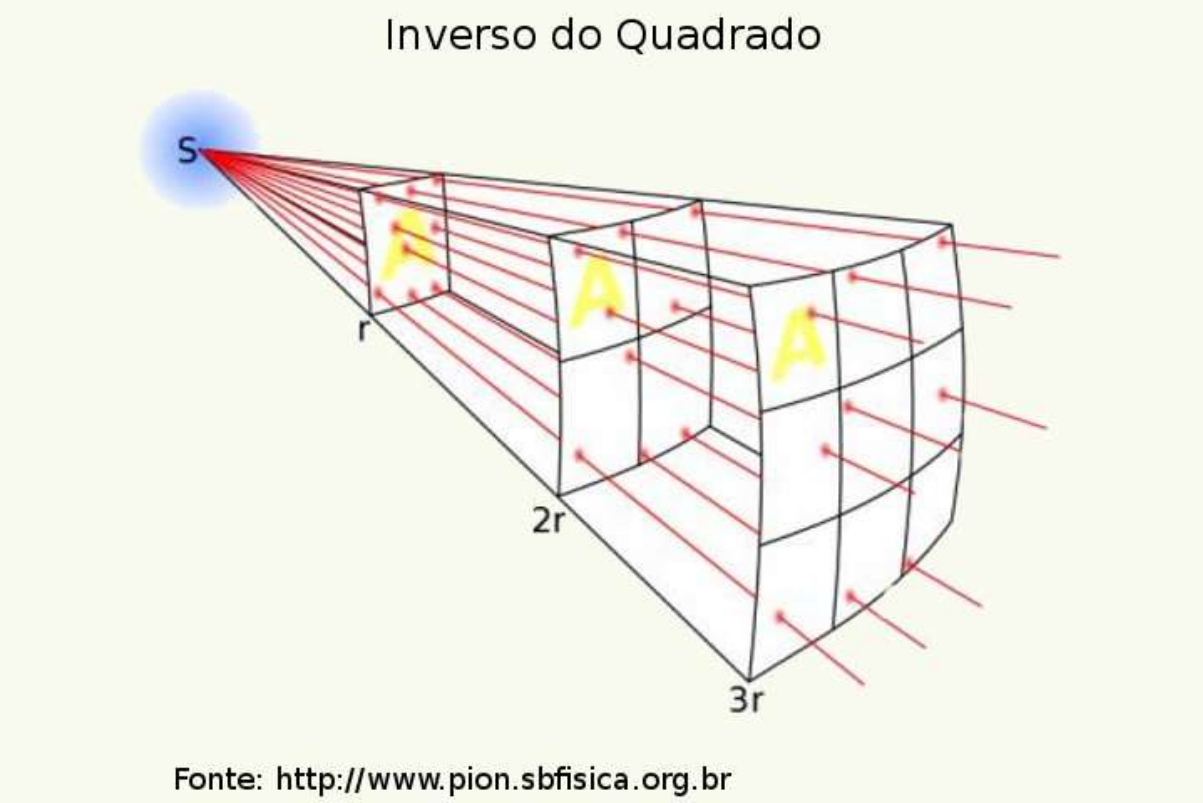
Luminosidade
$3{,}845 \times 10^{26}$ W
~4 septilhões de lâmpadas de 100 W

Raio
696 mil km

Luminosidade é constante
(em curtas escalas de tempo)

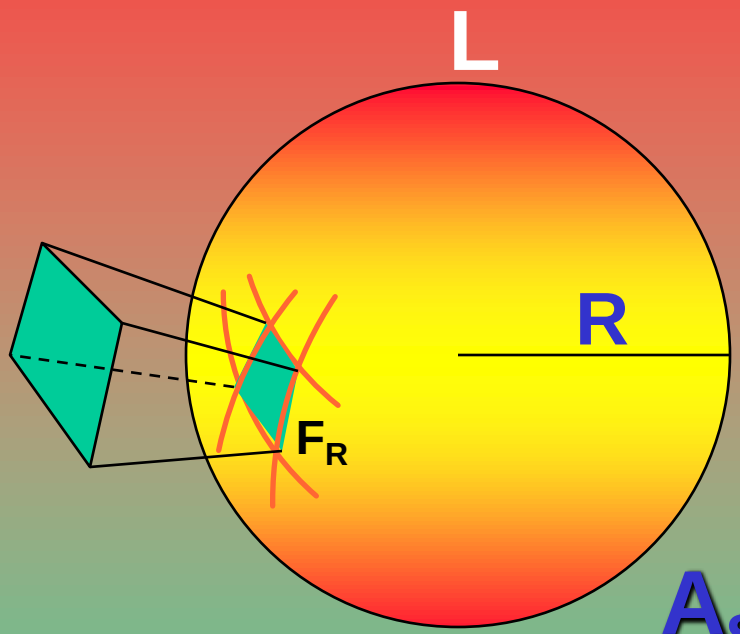
O Fluxo (energia/área) não é constante:

inversamente proporcional ao quadrado da distância



Fluxo Solar Superficial

É a potência emitida por unidade de área do Sol.

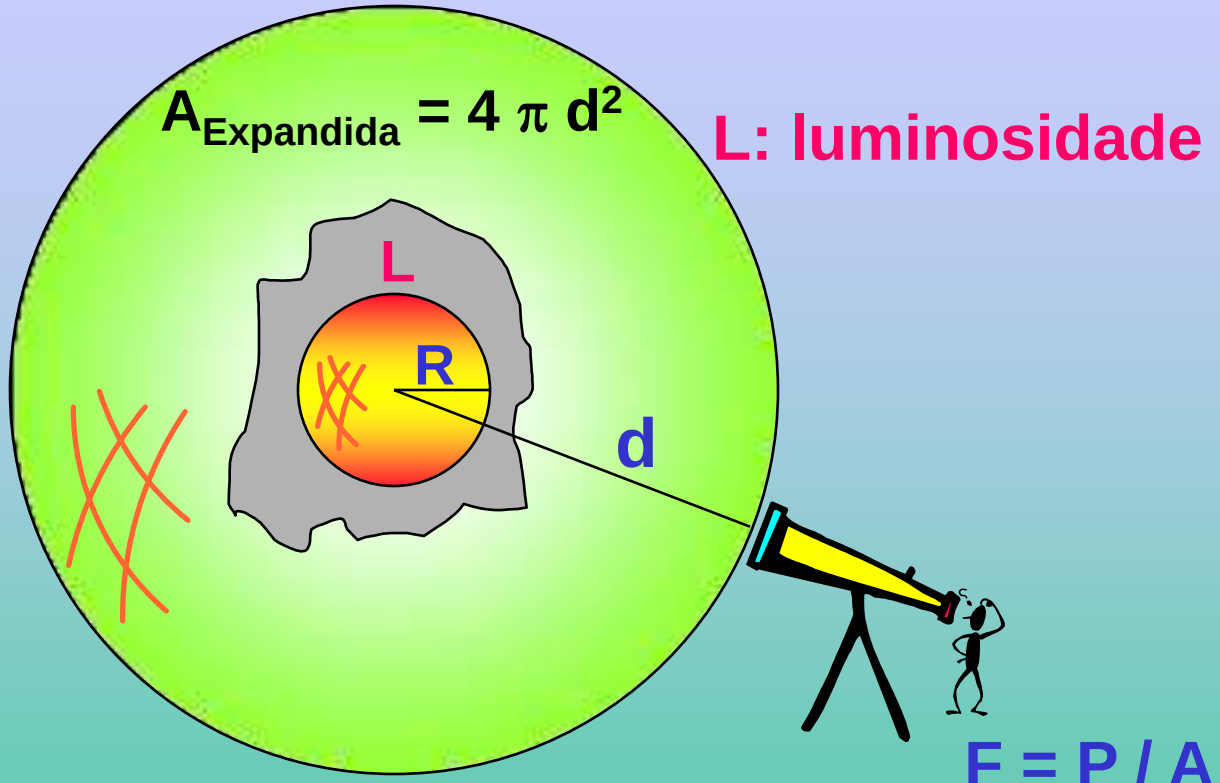


$$A_{Superficial} = 4 \pi R^2$$

$$F_R = L / (4 \pi R^2)$$

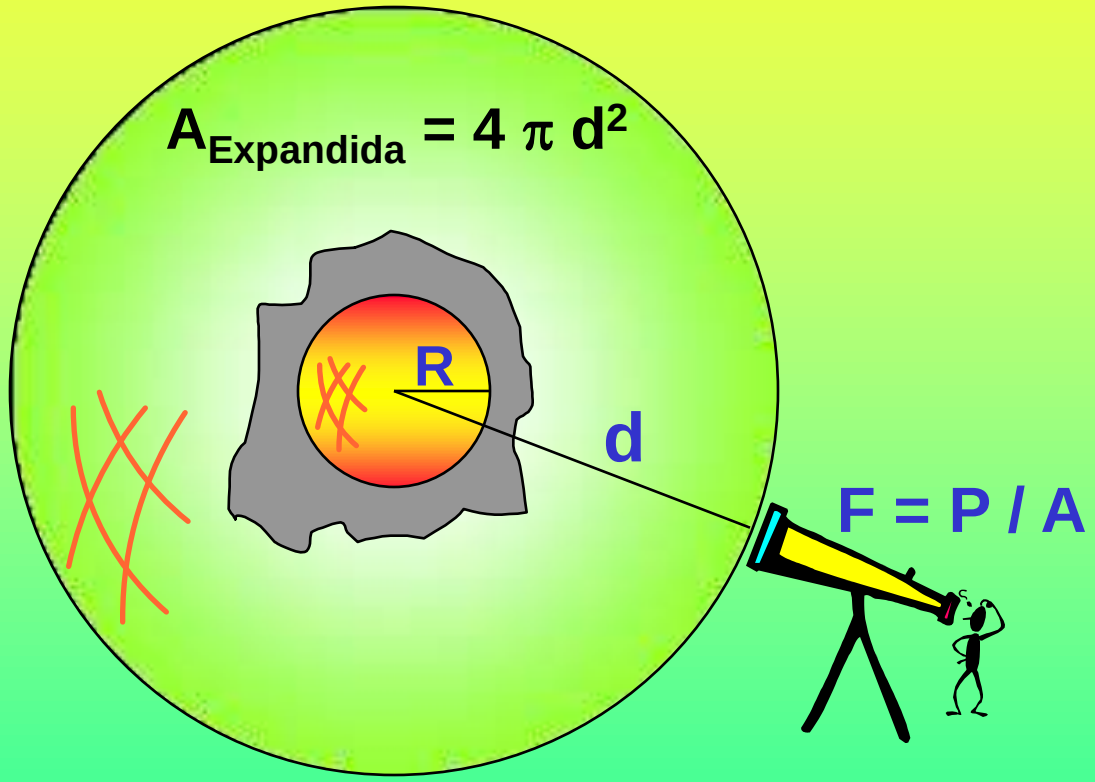
Fluxo Solar à distância d

É a potência medida por unidade de área a uma distância d do centro do Sol.



$$F = F_d = L / (4\pi d^2)$$

Variação do Fluxo em função da distância d



$$F_d = L / (4\pi d^2)$$

$$F_R = L / (4\pi R^2)$$

$$F_d / F_R = R^2 / d^2$$

$$F_d \cdot d^2 = F_R \cdot R^2$$

Qual o fluxo solar recebido por Vênus em relação ao fluxo recebido na Terra (constante solar, S_0)?

Fluxo recebido pela Terra: S_0
Distância Terra-Sol: DTS = 1 U.A. = 150 milhões de km
Fluxo recebido por Vênus = F_Vênus
Distância Vênus-Sol: DVS = 0,72 U.A.

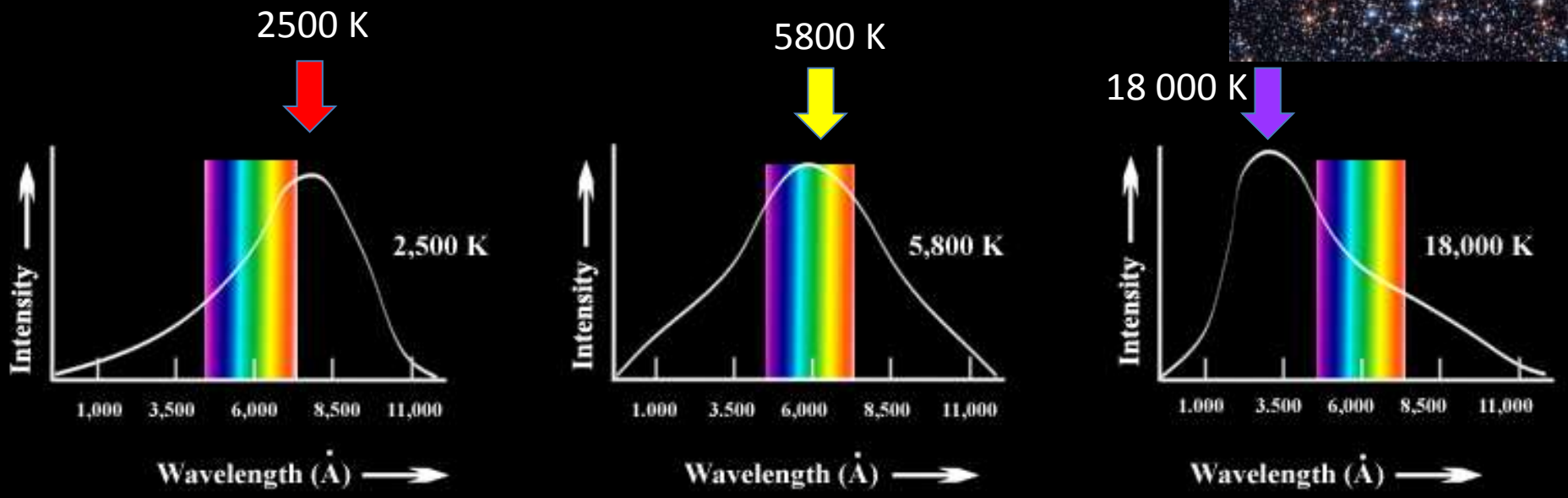
$$S_0 \text{ X } DTS^2 = F\_Vênus \text{ x } DVS^2$$

$$F\_Vênus = S_0 \text{ X } (DTS/DVS)^2$$

$$F\_Vênus = 1{,}93\ S_0$$

Variedade de cores

Classificação de estrelas usando cores



Colors are exagerrated

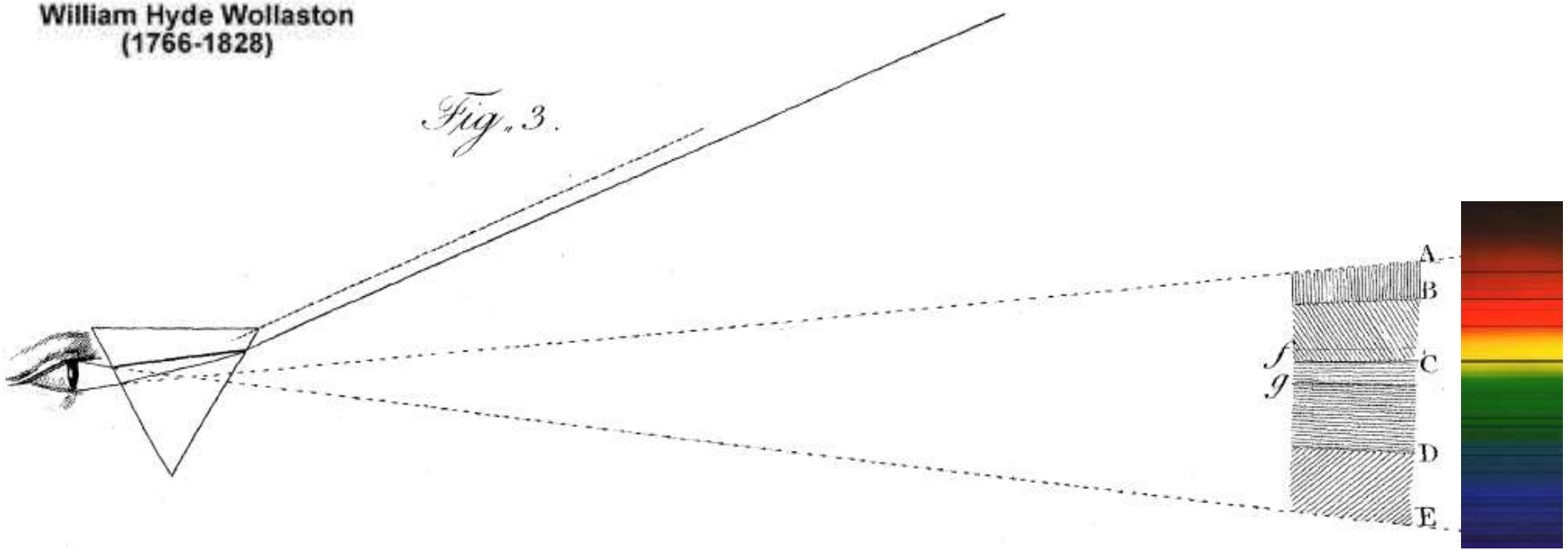
Classificação usando o espectro das estrelas

Newton (1643-1727)

Wollaston (1802) found 7 lines in the solar spectrum

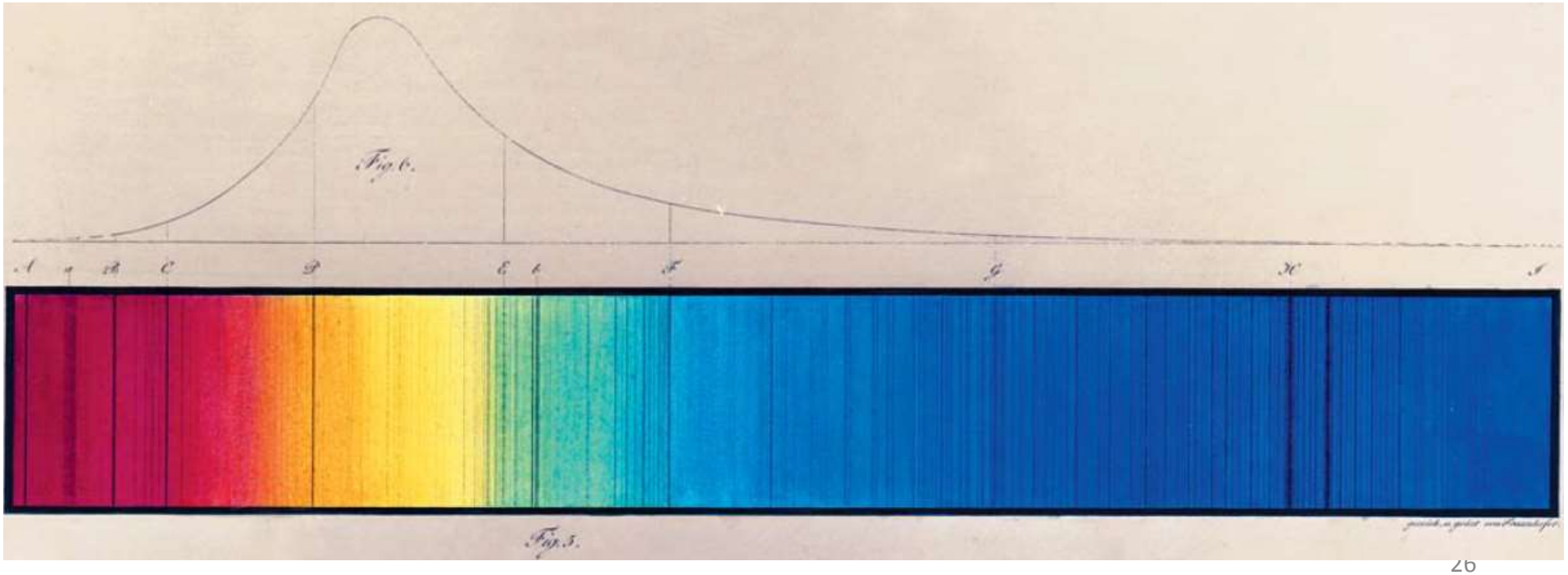
William Hyde Wollaston
(1766-1828)

The line A that bounds the red side of the spectrum is somewhat confused, which seems in part owing to want of power in the eye to converge red light. The line B, between red and green, in a certain position of the prism, is perfectly distinct; so also are D and E, the two limits of violet. But C, the limit of green and blue, is not so clearly marked as the rest; and there are also, on each side of this limit, other distinct dark lines, *f* and *g*, either of which, in an imperfect experiment, might be mistaken for the boundary of these colours.



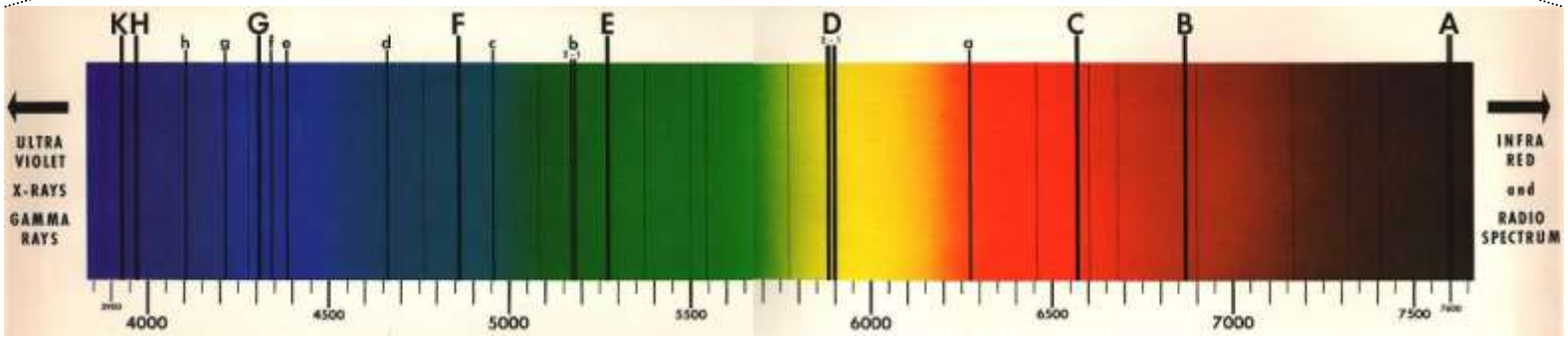
Fraunhofer found 574 lines in the solar spectrum (1817)

Joseph von Fraunhofer
(1787-1826)



Espectro solar

Linhas A e B são devidas à atmosfera terrestre



Linhas C – K são da atmosfera solar

Linhas de Fraunhofer (1817)

C: Hα indicador de temperatura

b1,b2: tripleto de Mg, gravidade superficial

H, K: CaII lines, atividade estelar

Classificação de estrelas

Padre Angelo Secchi (1860-1870): 4 tipos

- Tipo I: **branco-azul**

  moderna classe A & F ”cedo”
- **Tipo II: amarelas, de tipo solar**

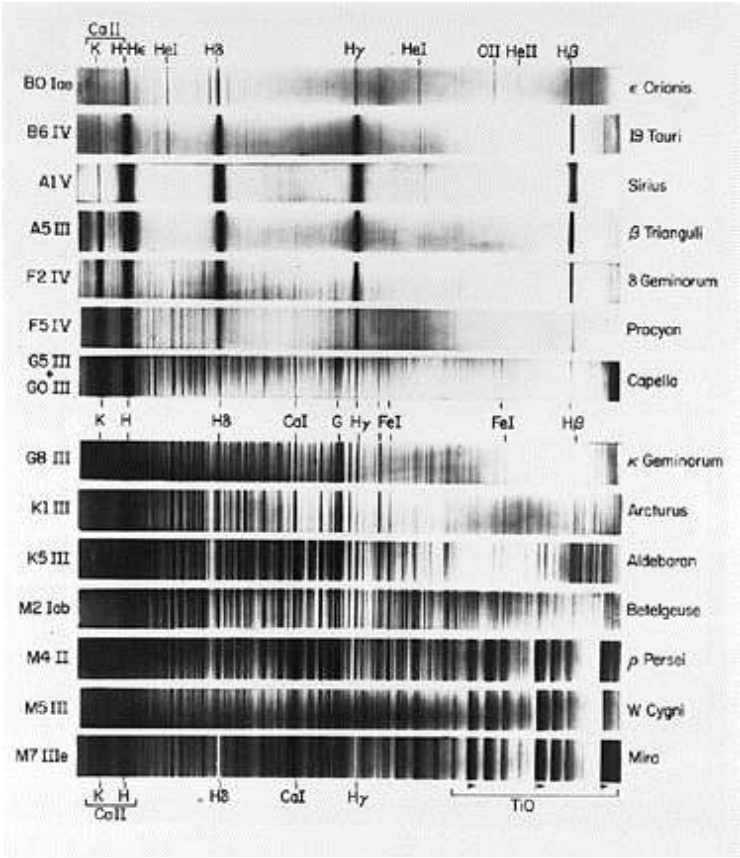
  atual classe G, K, F tardio
- Tipo III: **laranja-vermelho**,

  moderna classe M
- Tipo IV: estrelas com linhas de emissão

O sistema de classificação de Harvard

- 1890-1900s: classificação de Harvard (E.Pickering + Williamina Fleming + Antonia Maury + Annie J. Cannon):

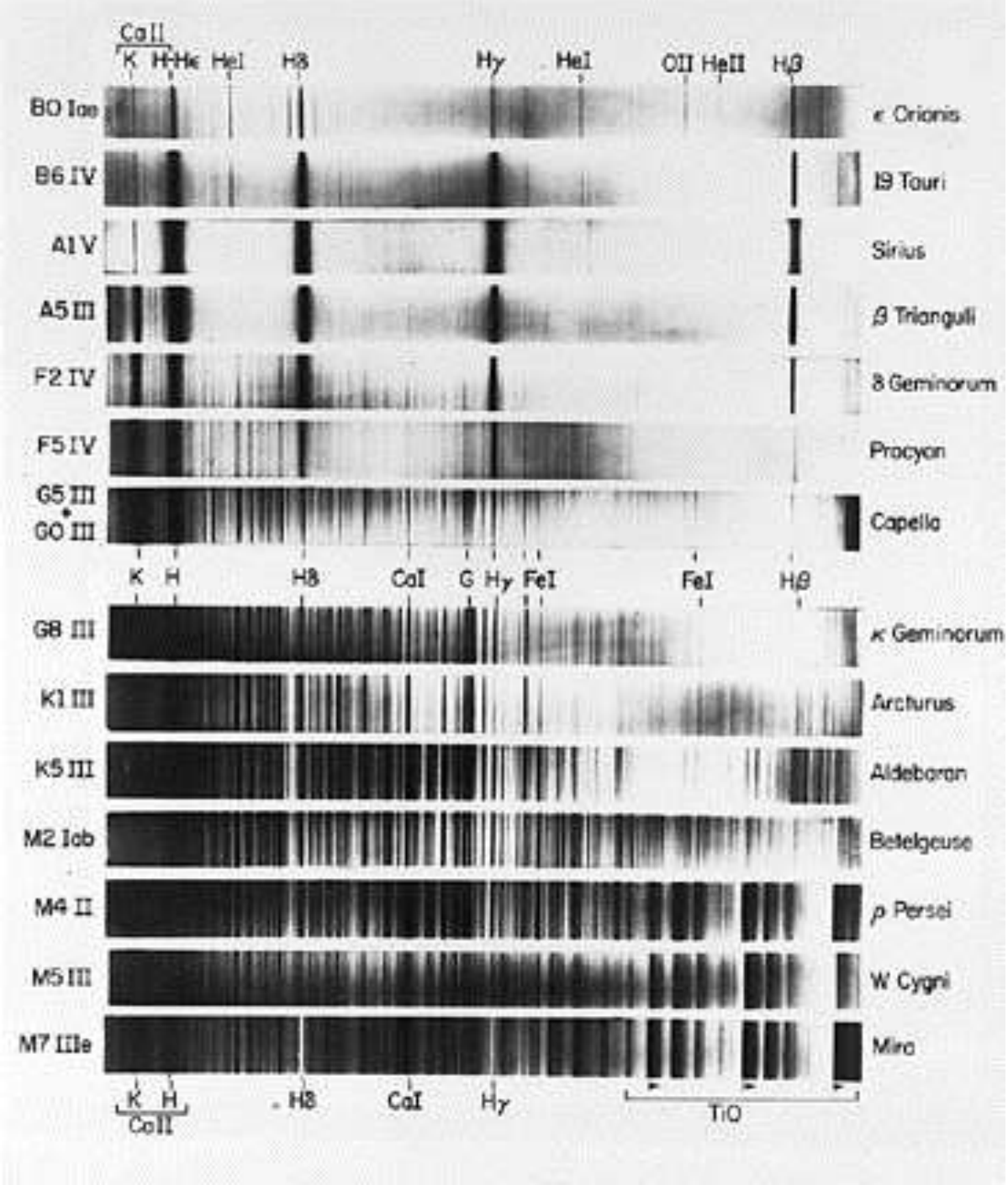
O, B, A, F, G, K, M

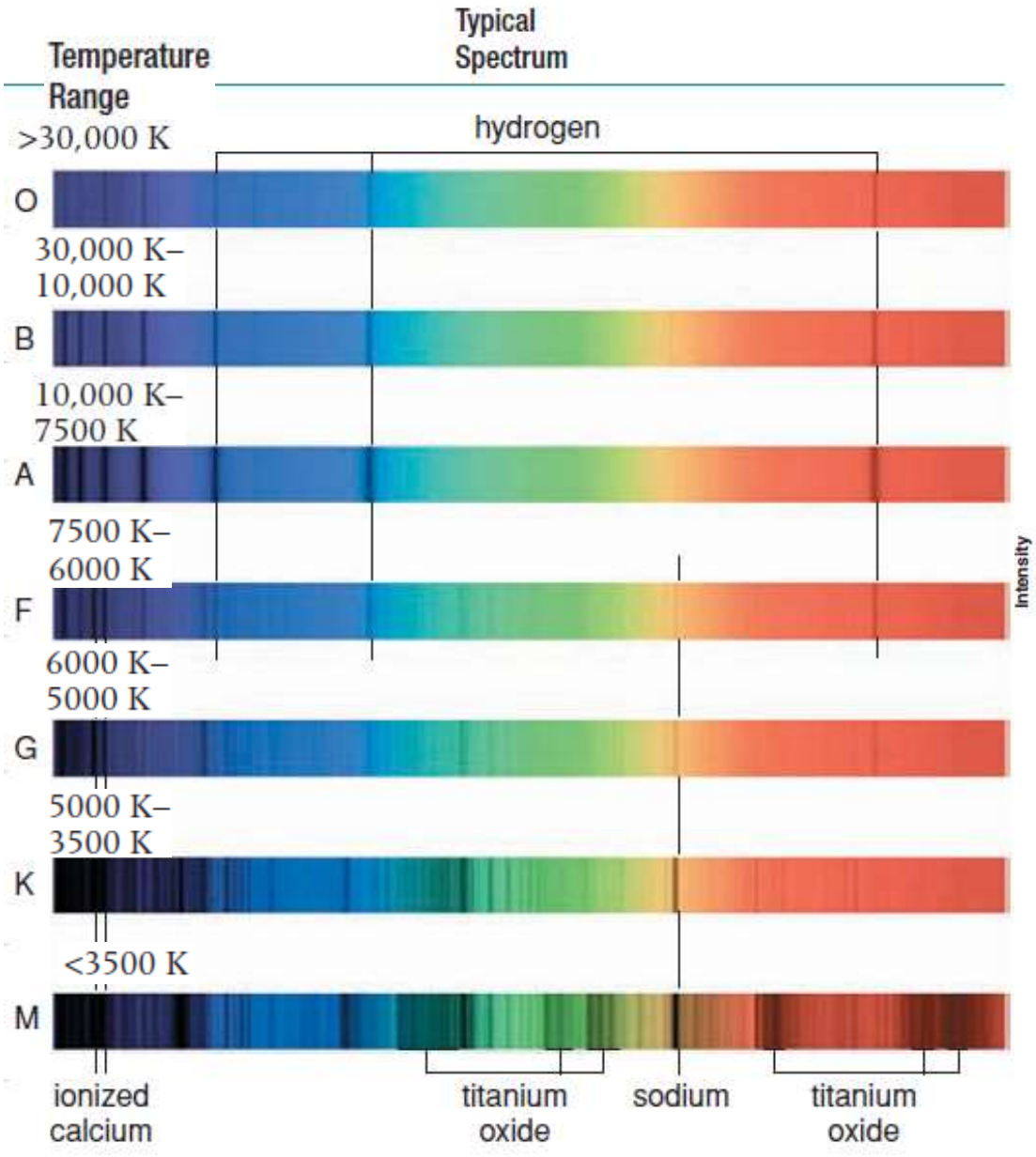


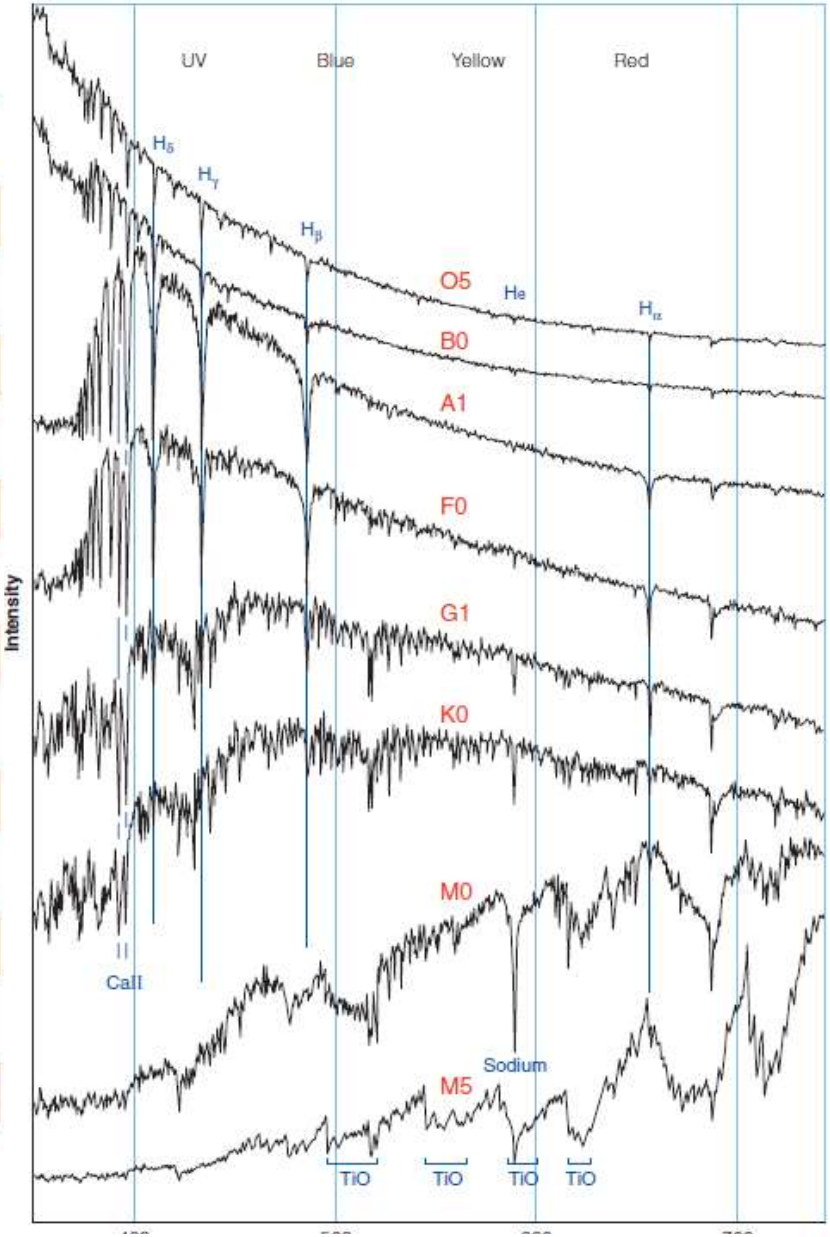
Classificação estelar:
O, B, A, F, G, K, M

Baseado em espectros das estações Harvard Norte (U.S.A.) & Sul (Arequipa, Peru)

Annie J. Cannon classificou mais de 250 000 espectros!




Temperature Range
Typical Spectrum
hydrogen
>30,000 K
O
30,000 K–
10,000 K
B
10,000 K–
7500 K
A
7500 K–
6000 K
F
6000 K–
5000 K
G
5000 K–
3500 K
K
<3500 K
M
ionized calcium
titanium oxide
sodium
titanium oxide


UV
Blue
Yellow
Red
Intensity
O5
B0
A1
F0
G1
K0
M0
M5
CaII
Sodium
TiO
TiO
TiO
TiO
400
500
600
700
Comprimento de onda (nm)

Cecilia Payne-Gaposchkin (1925)

A classificação de estrelas (O, B, A, F, G, K, M) é explicada como uma sequência de temperaturas

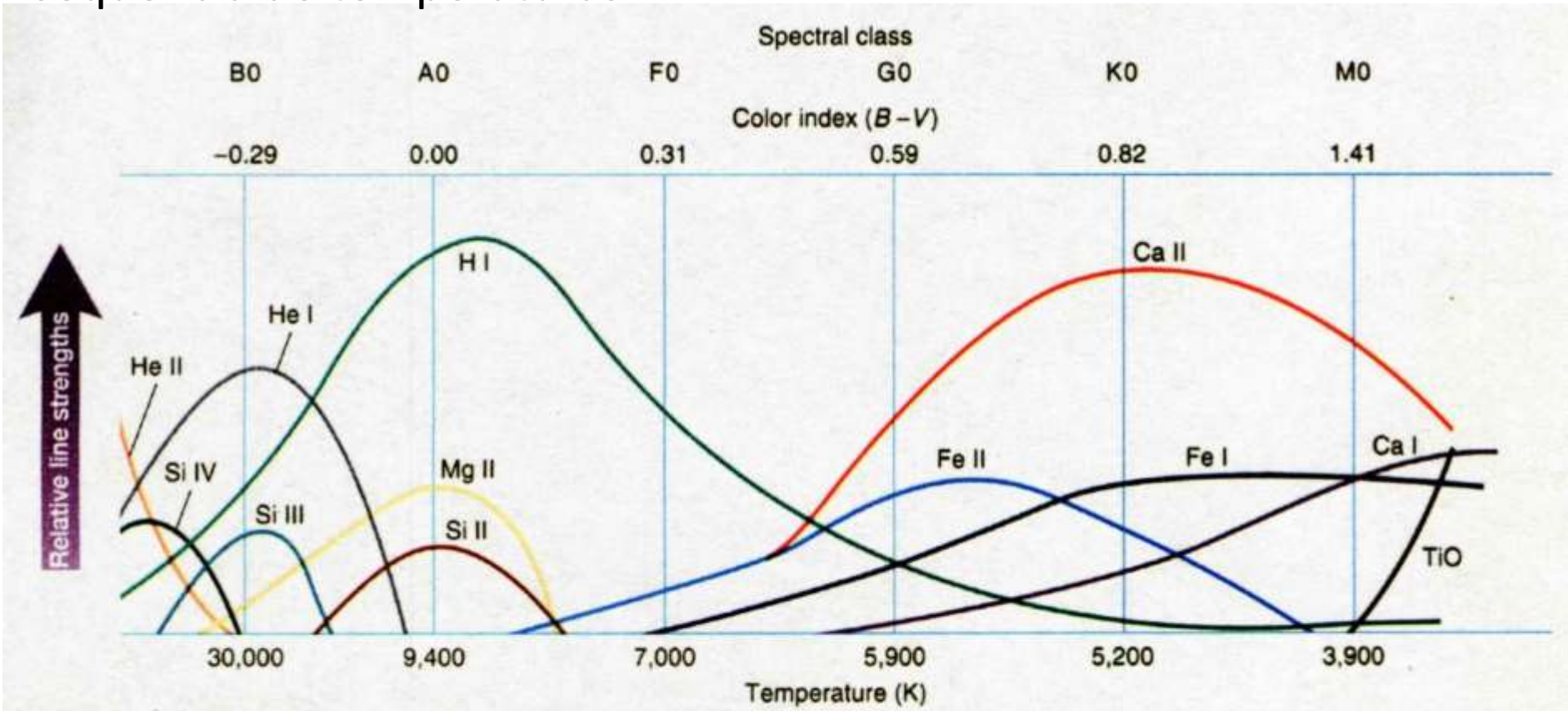
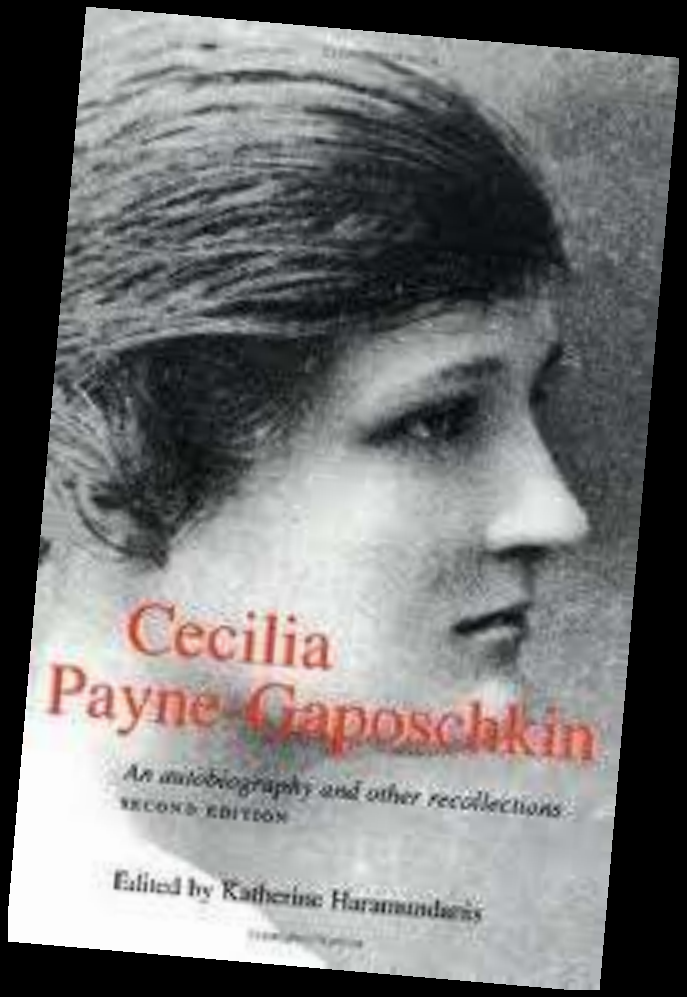


Figure 19.16 *Different atoms, ions, and molecules produce their spectra at different temperatures. Molecules are populous only in class M. Neutral metals are present at low temperatures. Toward higher temperatures, more highly ionized species are created.*

Composição química de estrelas:

Cecilia Payne-Gaposchkin

(May 10, 1900 – December 7, 1979)

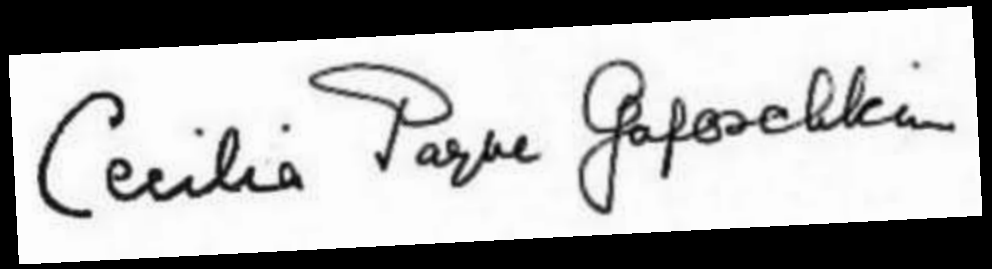


1919: Botânica, Física e Química em Cambridge (UK)

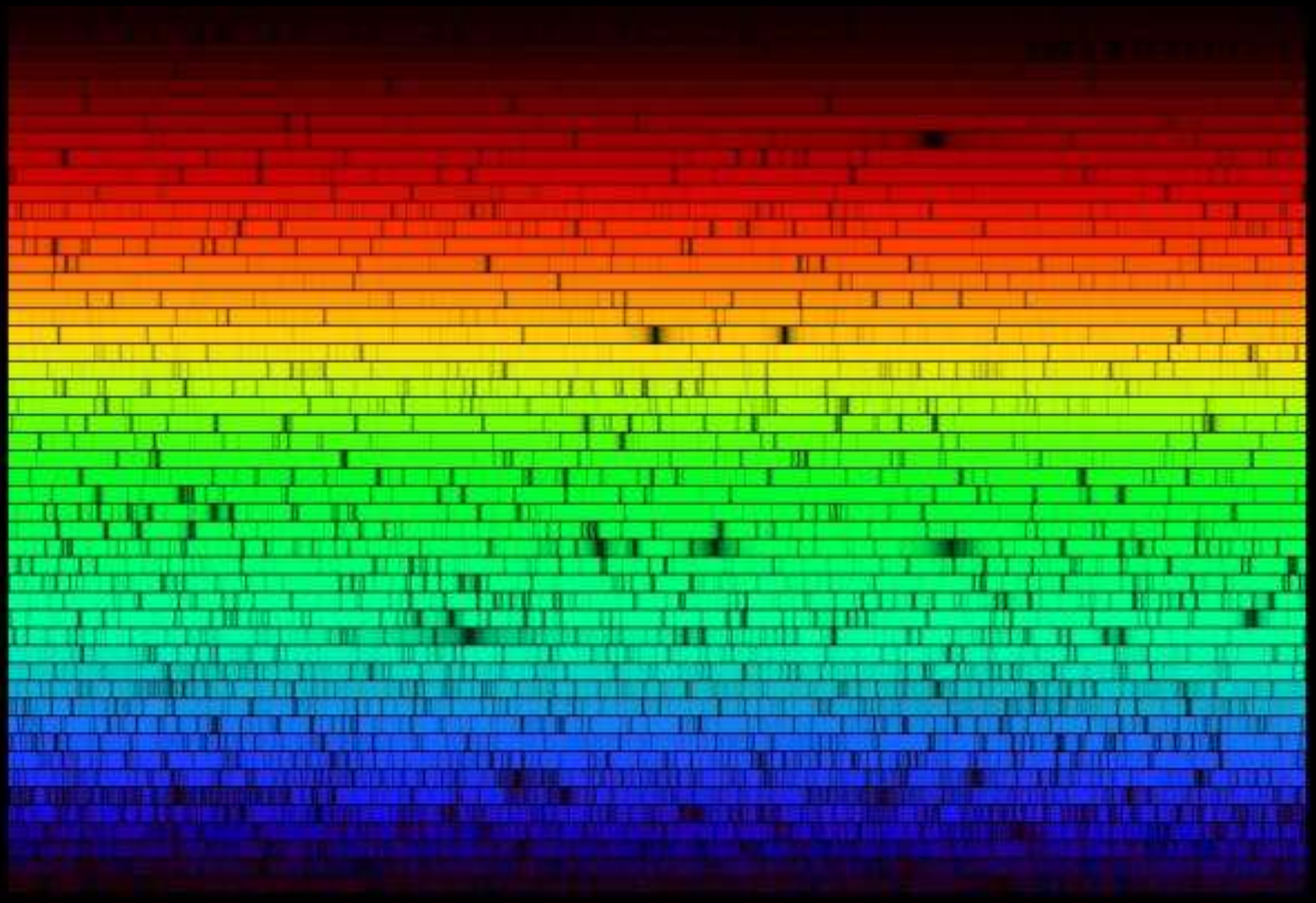
1922: iniciar estudos de astronomia nos Estados Unidos (Harvard)

1925: Tese de doutorado

H e He são os elementos mais abundantes em estrelas



Mas a maioria de linhas no espectro de estrelas é devida ao ferro ...



Professor Russell (Princeton)

É impossível !,
o Sol NÃO é
composto maiormente
de H e He

Shapley: diretor do Harvard observatory
(supervisor da Cecilia Payne)

Cecilia foi praticamente obrigada a mencionar na tese de doutorado que seus resultados sobre a alta abundância de H e He poderiam estar errados

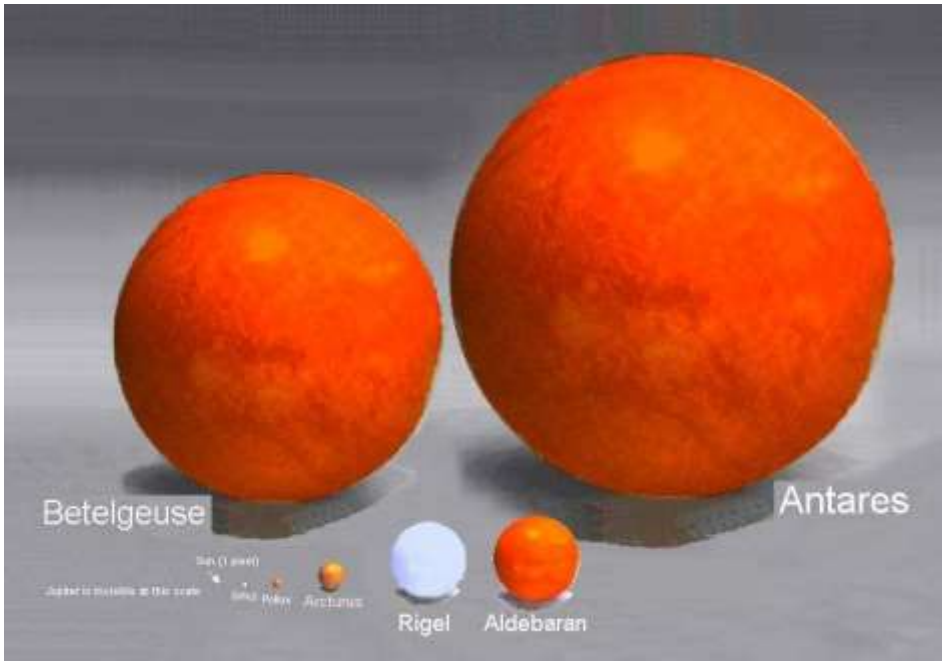
4 anos depois Russell publicou um paper anunciando que o Sol é maiormente H ...

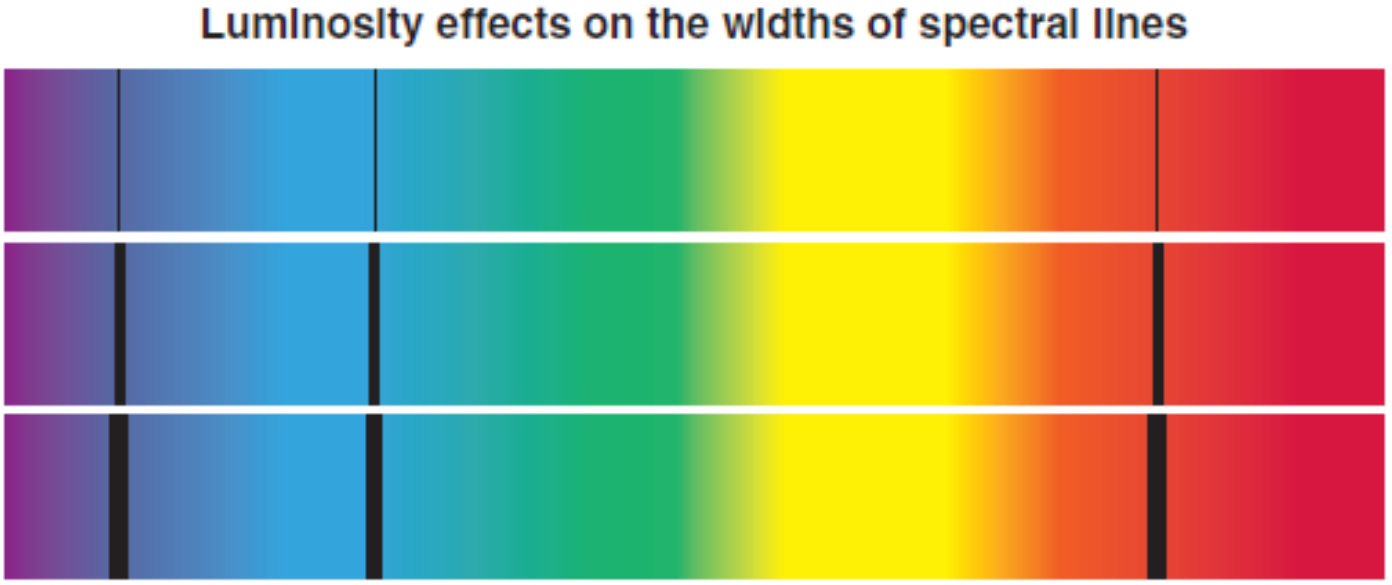
Cecilia Payne, uma astrônoma brilhante mas injustiçada

“PROBLEMAS”:

- **Mulher**
- **Jovem (doutorado aos 25 anos, em 1925)**
- **Excepcionalmente brilhante**
- **Foi obrigada a mudar de area**
- **Foi subestimada ...**
- **Contratada apenas como assistente**
- **Foi nomeada Professora apenas em 1956**

Mais sobre classificação espectral: classe de luminosidade





Supergigante

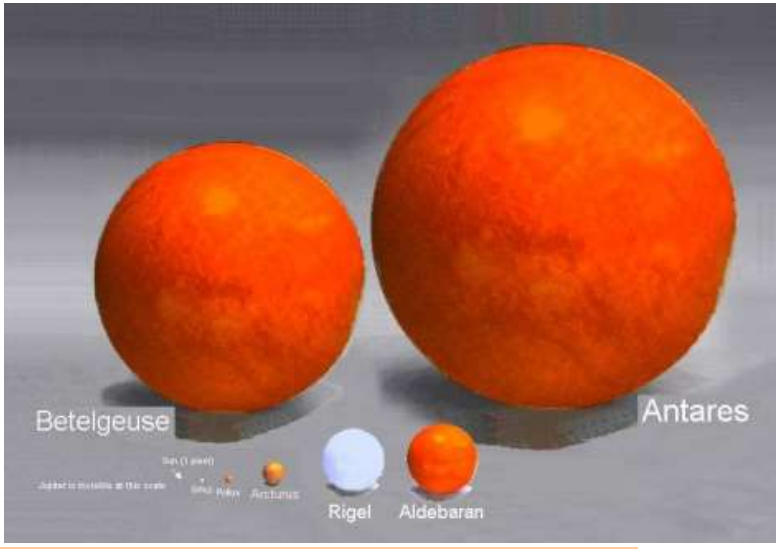
Gigante

Anã

sequência principal

Classe de luminosidade

Antonia Maury : foi contratada em 1888 por E. Pickering (Harvard) para classificar espectros. Ela propôs um novo sistema de classificação levando em conta tb a forma das linhas, mas o sistema foi ignorado por Pickering.



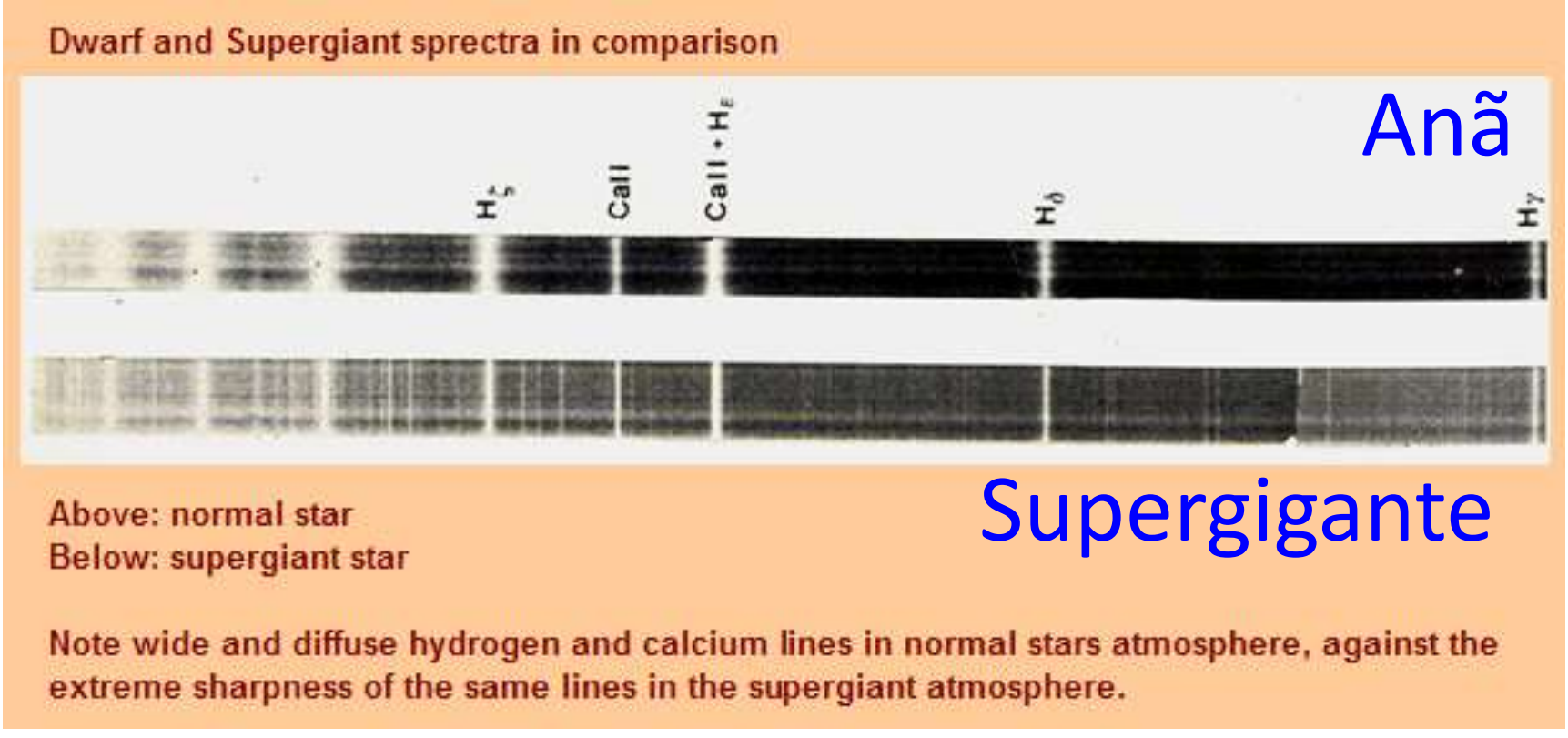


Diagrama H-R (Hertzsprung - Russell)

O B A F G K M

30 MSOL

10 MSOL

1 MSOL

0.1 MSol

Super-gigantes (lum. I)

Gigantes (lumino-sidade III)

Sequência principal (luminosidade V)

Anãs brancas

SUPERGIANTS

GIANTS

MAIN SEQUENCE

WHITE DWARFS

Deneb

Rigel

Canopus

Polaris

Antares

Arcturus

Aldebaran

Pollux

β Centauri

Spica

Bellatrix

Archemar

Vega

Sirius A

Procyon A

α Centauri A

Sun

α Centauri B

τ Ceti

ε Eridani

61 Cygni A

61 Cygni B

Barnard's Star

Proxima Centauri

Sirius B

Procyon B

60 Solar Masses

30 Solar Masses

10 Solar Masses

6 Solar Masses

3 Solar Masses

1 Solar Mass

0.3 Solar Masses

10 Solar Radii

1 Solar Radius

0.1 Solar Radii

0.01 Solar Radii

0.001 Solar Radii

100 Solar Radii

1000 Solar Radii

Luminosidade (Sol = 1)

10^{6} 10^{5} 10^{4} 10^{3} 100 10 1 0.1 0.01 0.001 10^{-4} 10^{-5}

O B A F G K M

30 000 10 000 6000 3000 K

Temperatura superficial (Kelvin)

Fluxo na superficie de uma estrela:

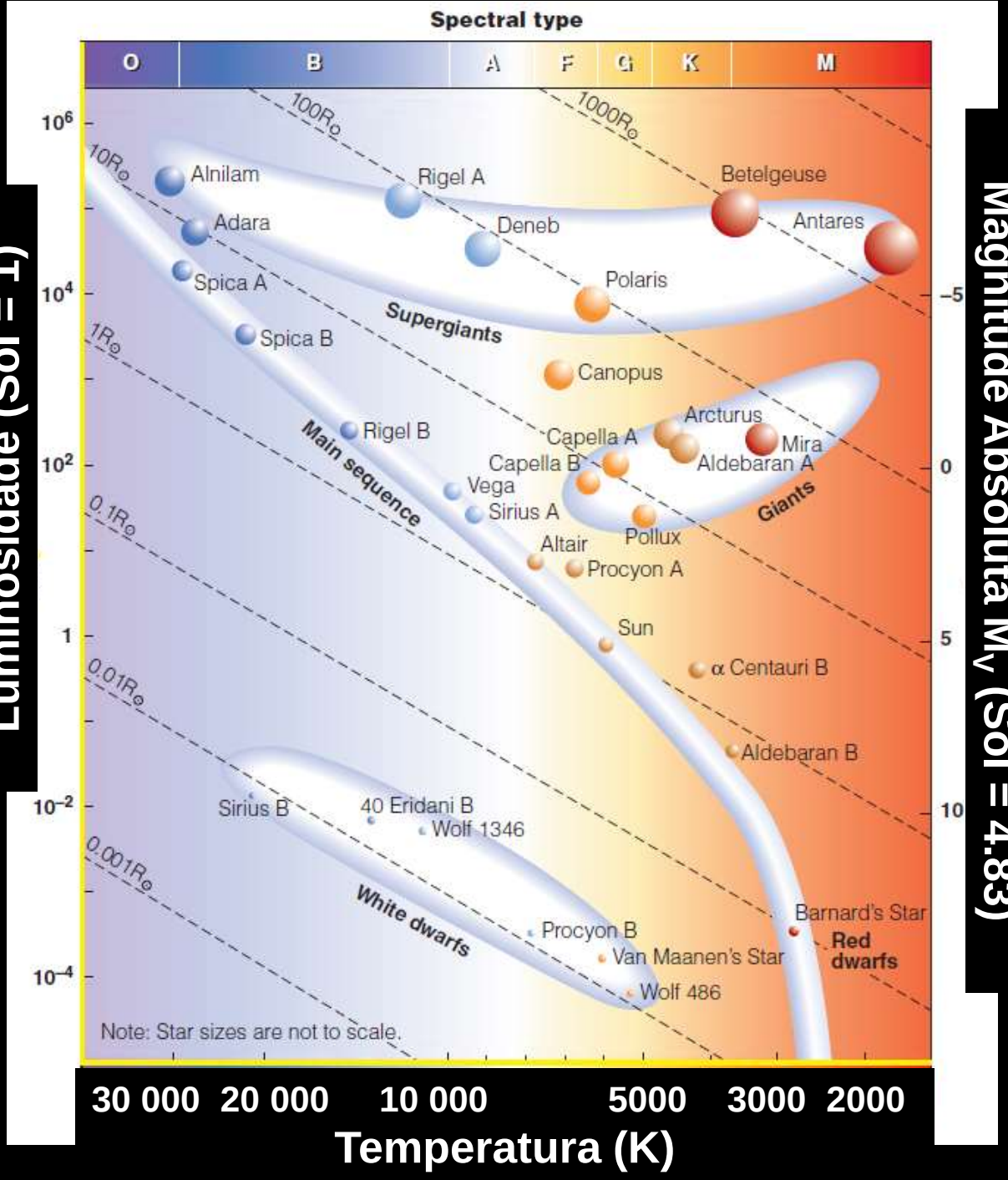
$F = \sigma T_{eff}^4$

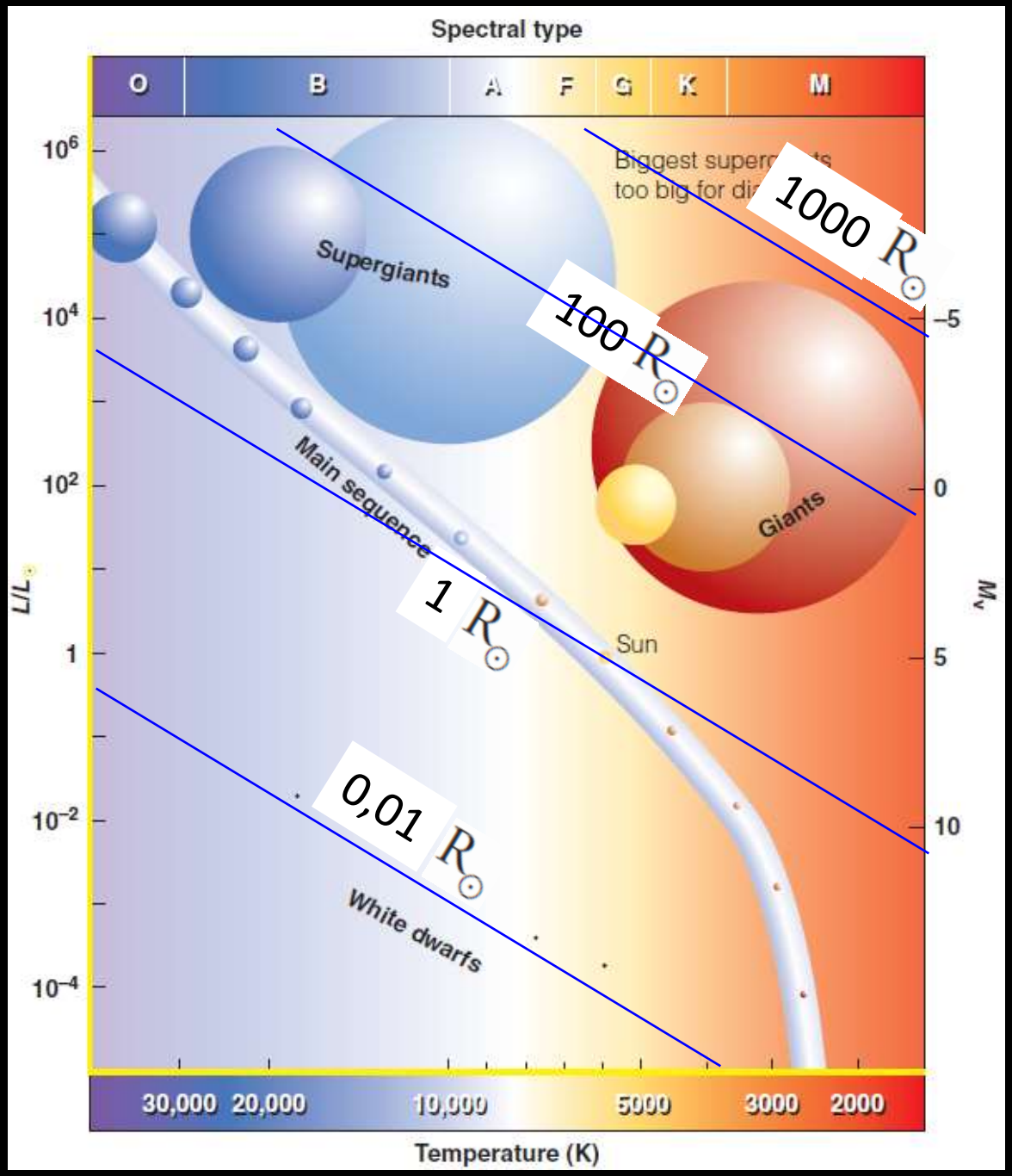
$T_{eff}(Sol) = 5777\ K$

Luminosidade:

$L = F \cdot \text{área}$

$L = 4\pi R^2\ \sigma T_{eff}^4$





$$L = 4\pi R^2 \sigma T_{eff}^4$$

$1\ R_\odot = 696\ 342 \pm 65$ km (Emilio et al. 2012)

Outras medidas:

695 950 ± 250 km !

Diferença de 0,06%

O brasileiro que mediu o raio do Sol com maior precisão

Marcelo Emílio
Diretor do Observatório Astronômico da UEPG
(Universidade Estadual de Ponta Grossa)

Fez doutorado no IAG/USP

MEASURING THE SOLAR RADIUS FROM SPACE DURING THE 2003 AND 2006 MERCURY TRANSITS

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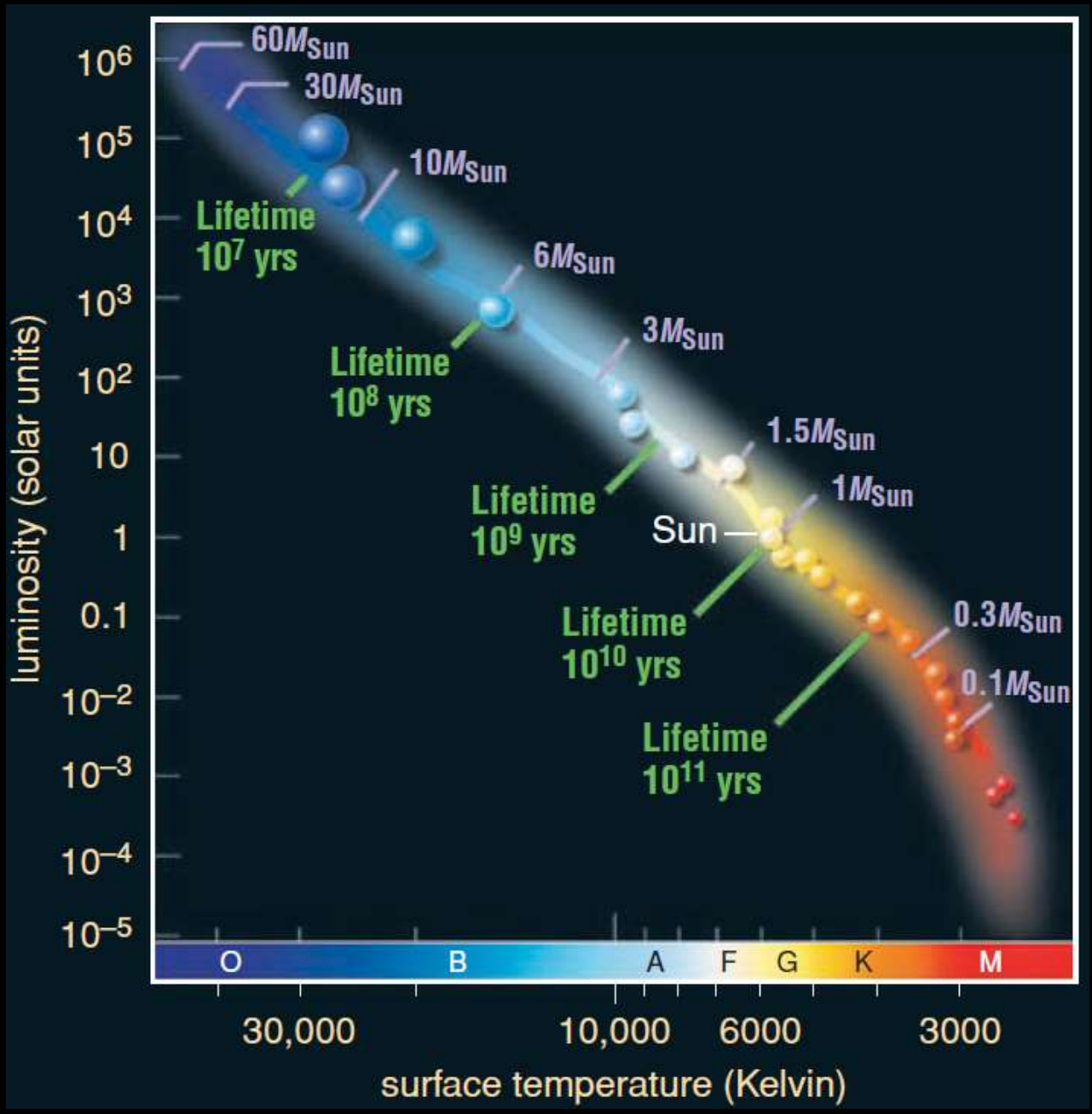
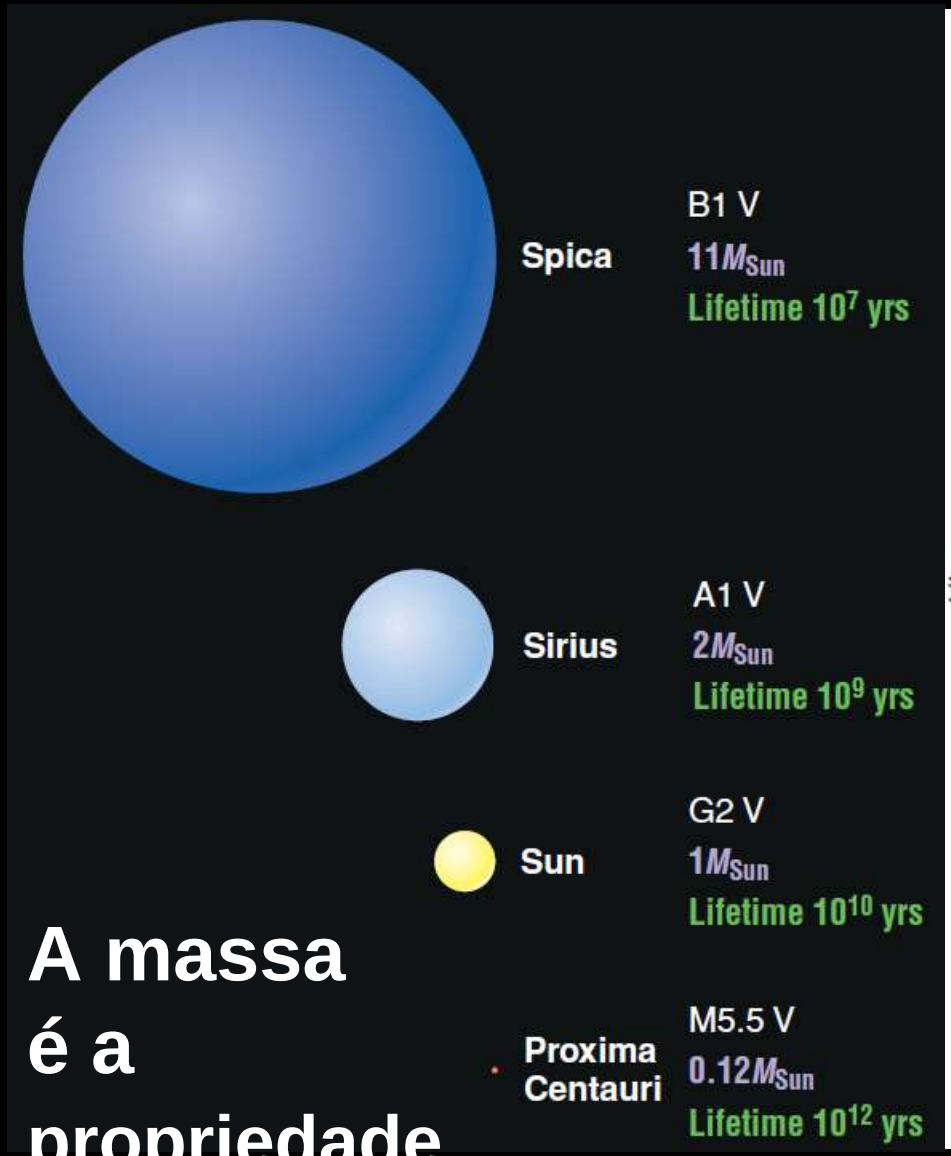
ABSTRACT

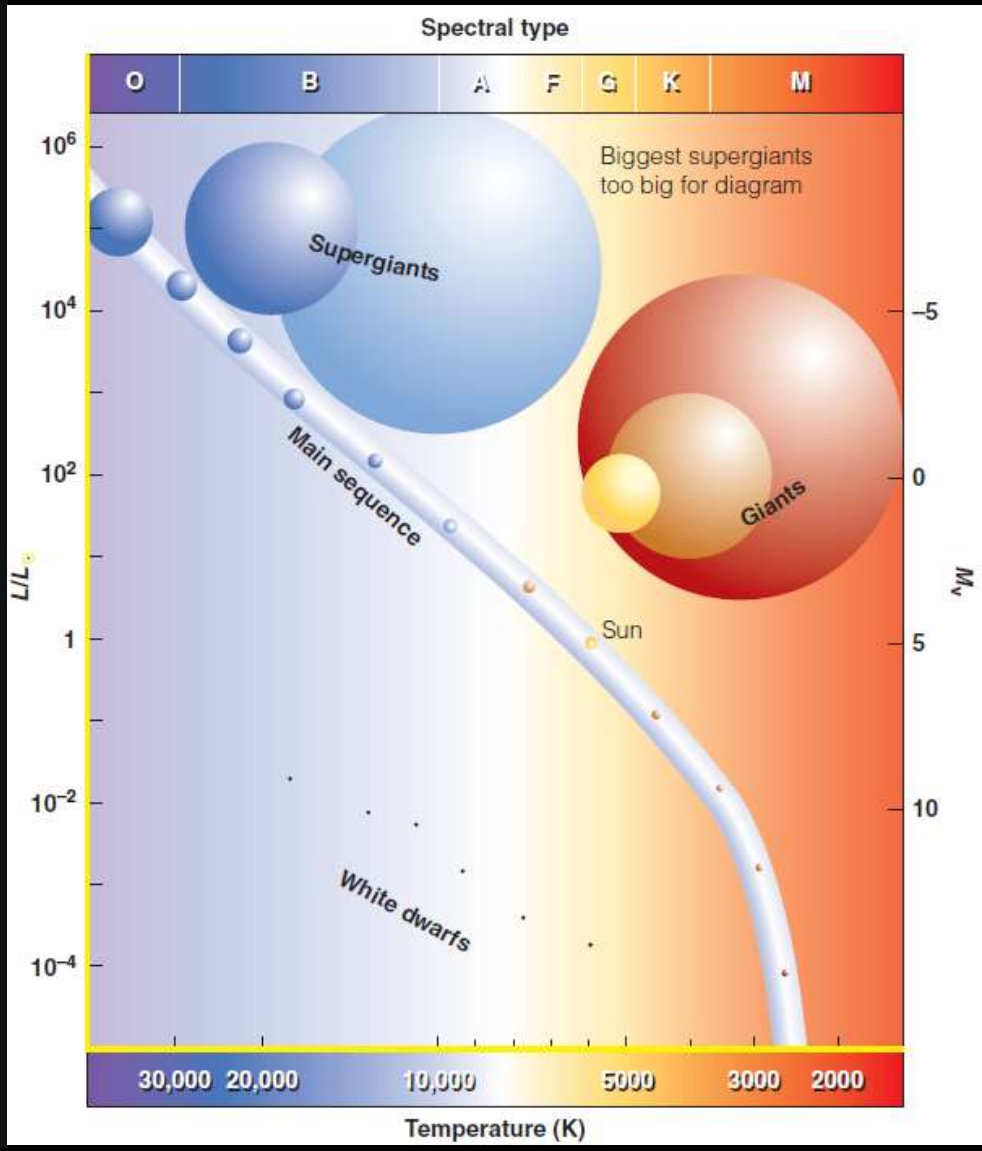
The Michelson Doppler Imager (MDI) aboard the *Solar and Heliospheric Observatory* observed the transits of Mercury on 2003 May 7 and 2006 November 8. Contact times between Mercury and the solar limb have been used since the 17th century to derive the Sun's size but this is the first time that high-quality imagery from space, above the Earth's atmosphere, has been available. Unlike other measurements this technique is largely independent of optical distortion. The true solar radius is still a matter of debate in the literature as measured differences of several tenths of an arcsecond (i.e., about 500 km) are apparent. This is due mainly to systematic errors from different instruments and observers since the claimed uncertainties for a single instrument are typically an order of magnitude smaller. From the MDI transit data we find the solar radius to be $960".12 \pm 0".09$ ($696,342 \pm 65$km). This value is consistent between the transits and consistent between different MDI focus settings after accounting for systematic effects.

Subject headings: astrometry, Sun: fundamental parameters, Sun: photosphere

Massas e idades







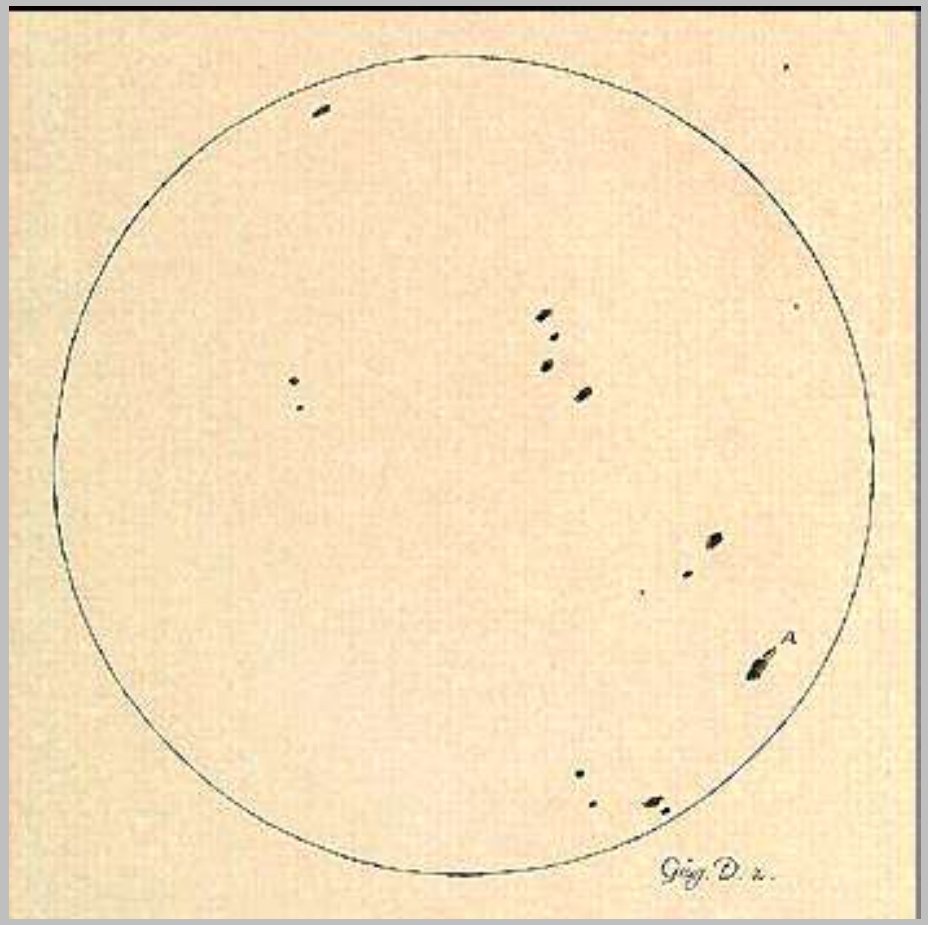
A massa é a propriedade mais básica de uma estrela

Propriedades fundamentais na seqûencia principal (V): R, M, L em unidades solares

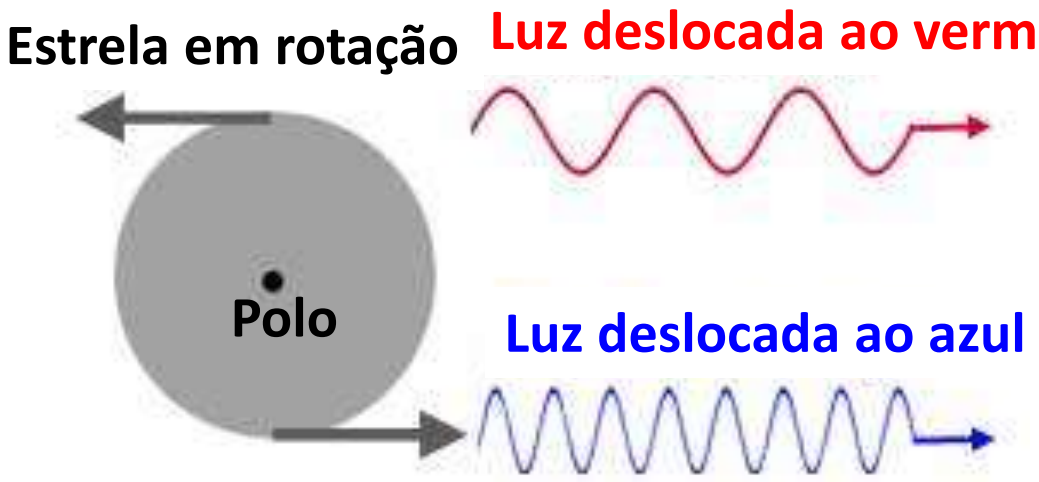
Classe estelar	RAIO	MASSA	Luminosidade	Temperatura
	$R/R_\odot$	$M/M_\odot$	$L/L_\odot$	K
O2	16	158 ?	2 000 000	54 000
O5	14	58	800 000	46000
B0	5,7	16	16 000	30 000
B5	3,7	5,4	750	15 200
A0	2,3	2,6	63	9 500
A5	1,8	1,9	24	8 700
F0	1,5	1,6	9,0	7 200
F5	1,2	1,35	4,0	6 400
G0	1,05	1,08	1,45	6 000
G2	1,0	1,0	1,0	5 800
G5	0,98	0,95	0,70	5 500
K0	0,89	0,83	0,36	5 250
K5	0,75	0,62	0,18	4 450
M0	0,64	0,47	0,075	3 850
M5	0,36	0,25	0,013	3 200
M8	0,15	0,10	0,0008	2 500
M9.5	0,10	0,08	0,0001	1 900

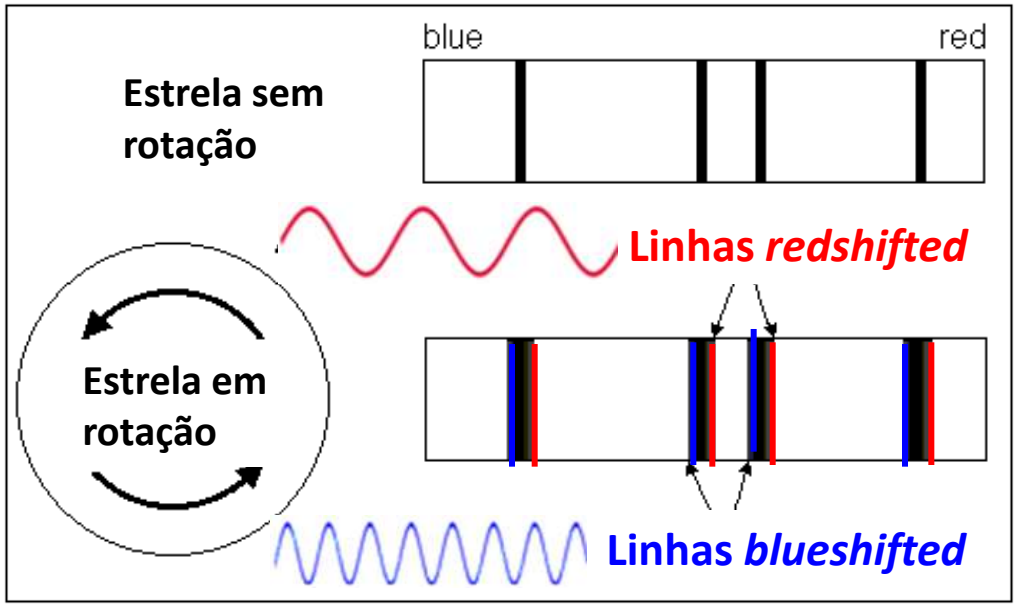
Animação de manchas solares observadas por Galileo

2 Jun – 8 Jul 1613: rotação do Sol !

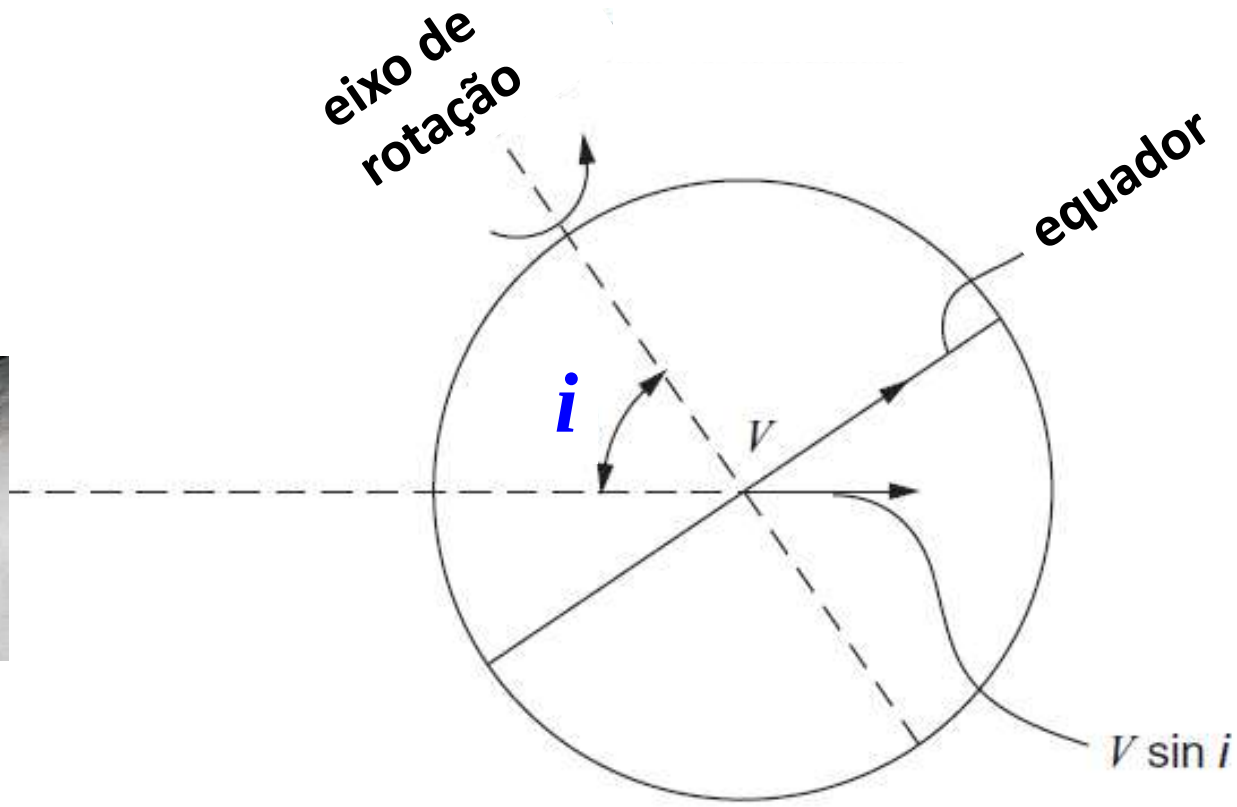


Efeito da velocidade de rotação nas linhas do espectro estelar

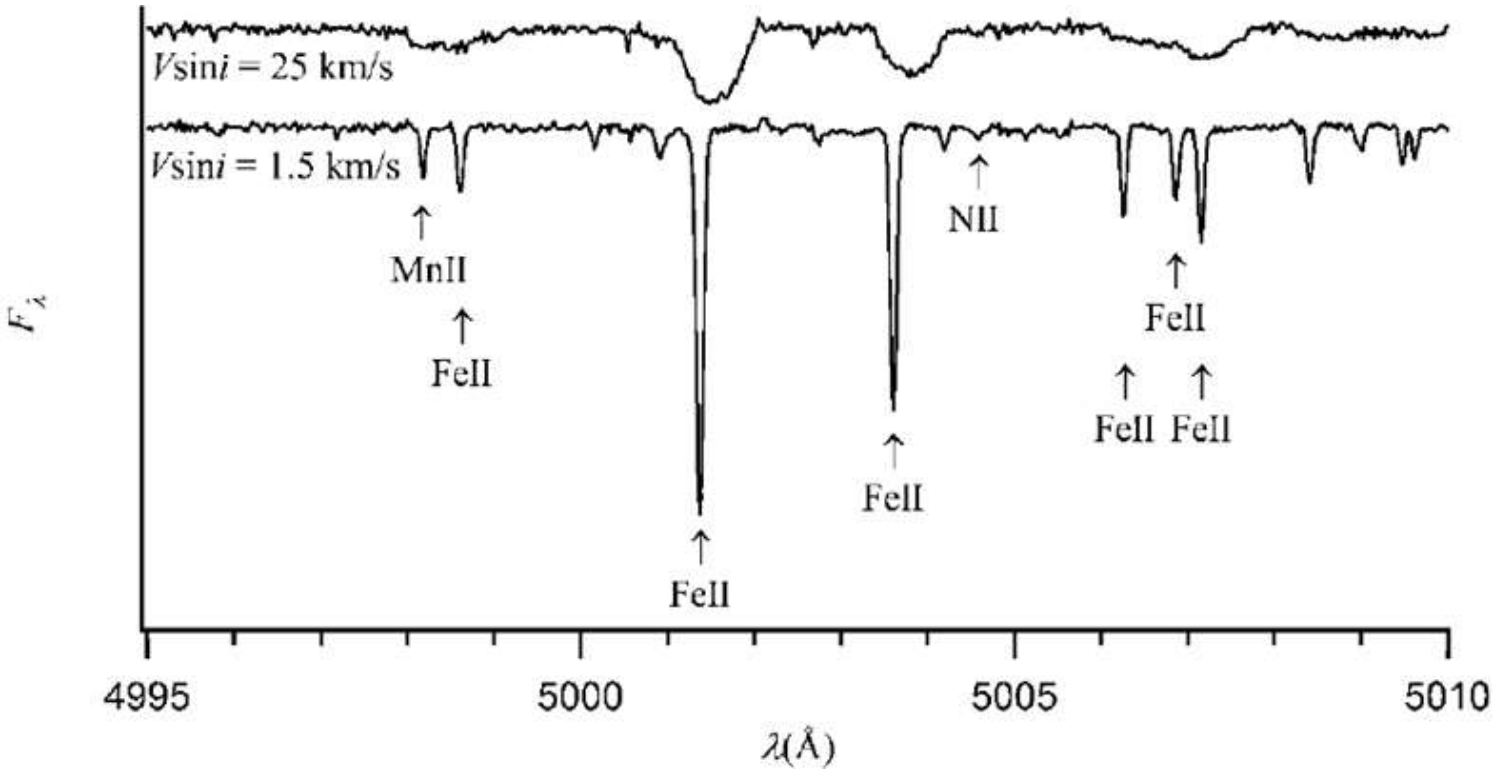




Efeito do ângulo de inclinação *i*

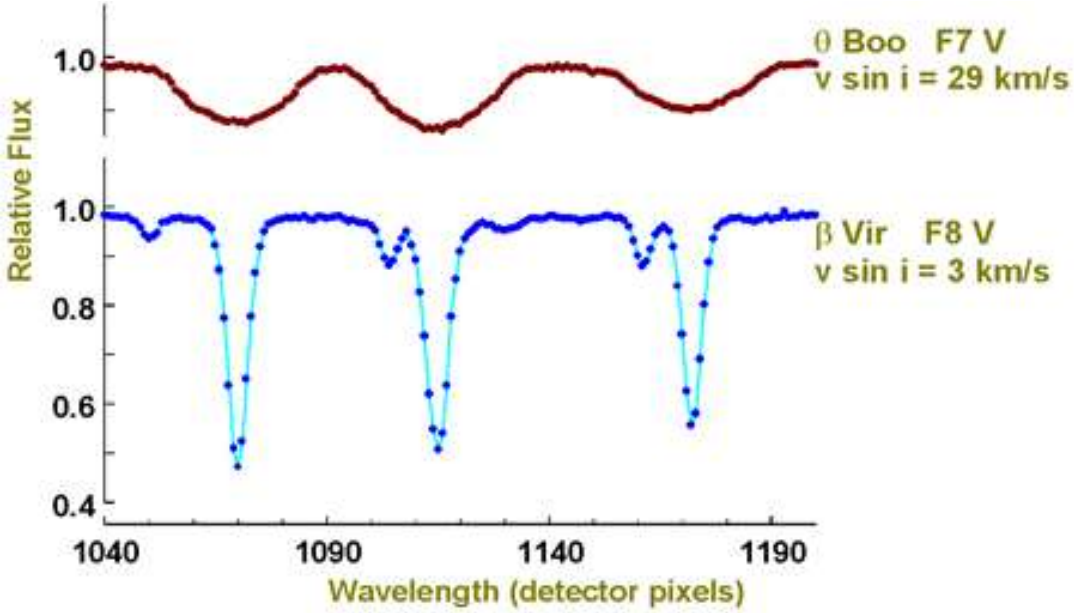


Devido à inclinação do eixo de rotação é observada a componente da velocidade V sin *i*

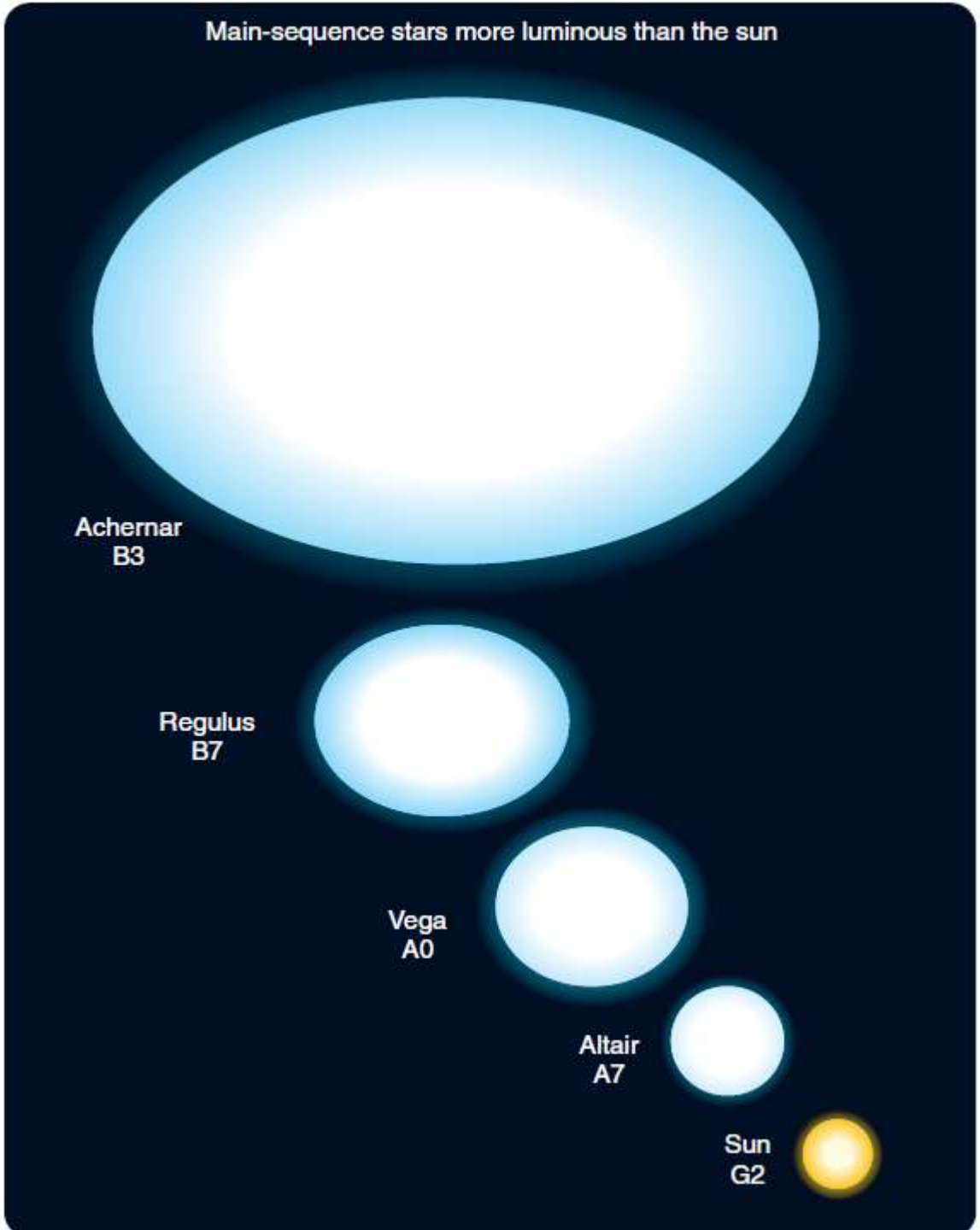


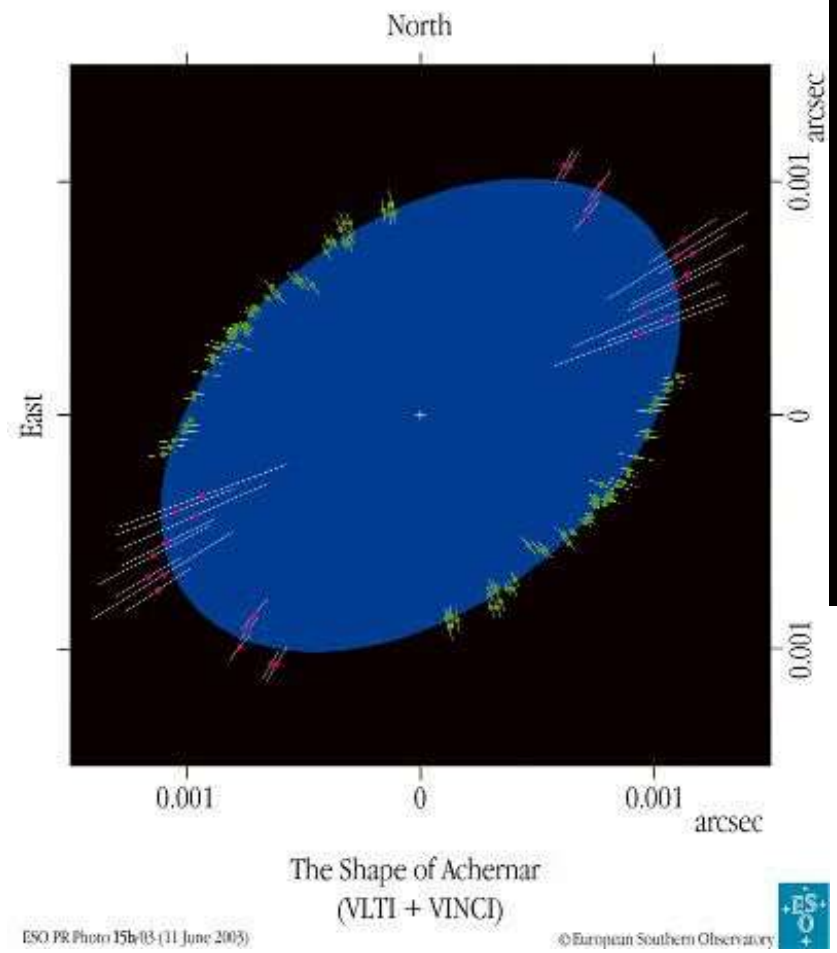
Estrelas de tipo A0 com diferentes *V*sin*i*

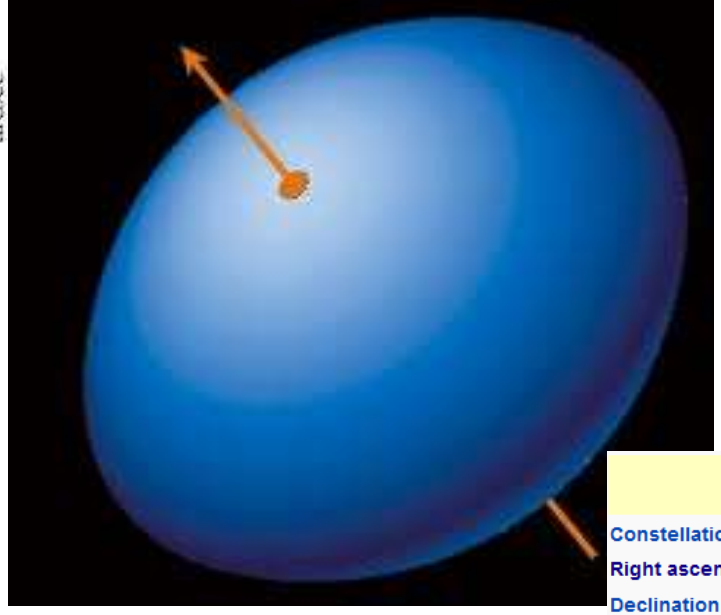
Efeito da velocidade de rotação nas linhas espectrais



Efeito da alta velocidade de rotação em estrelas massivas



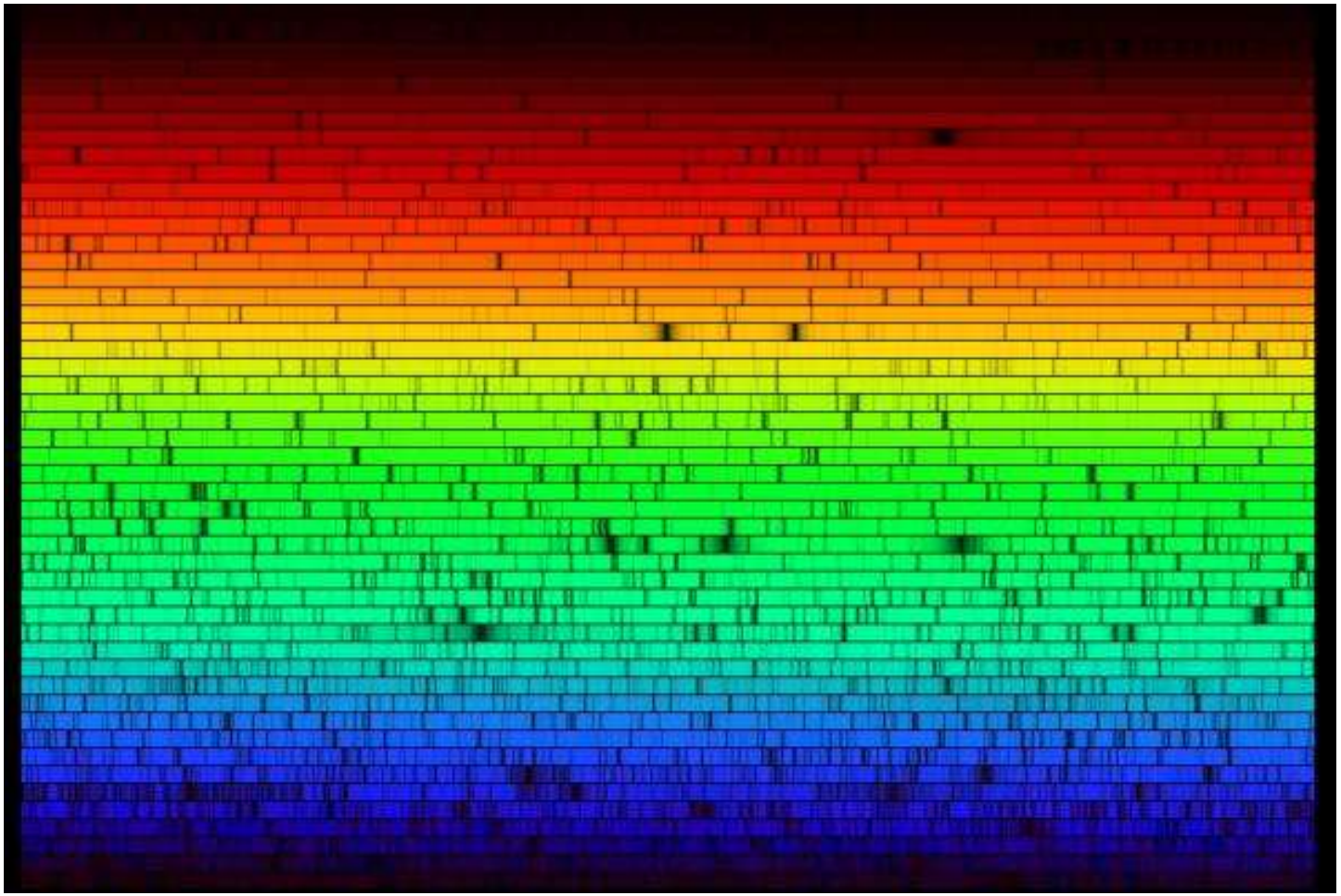




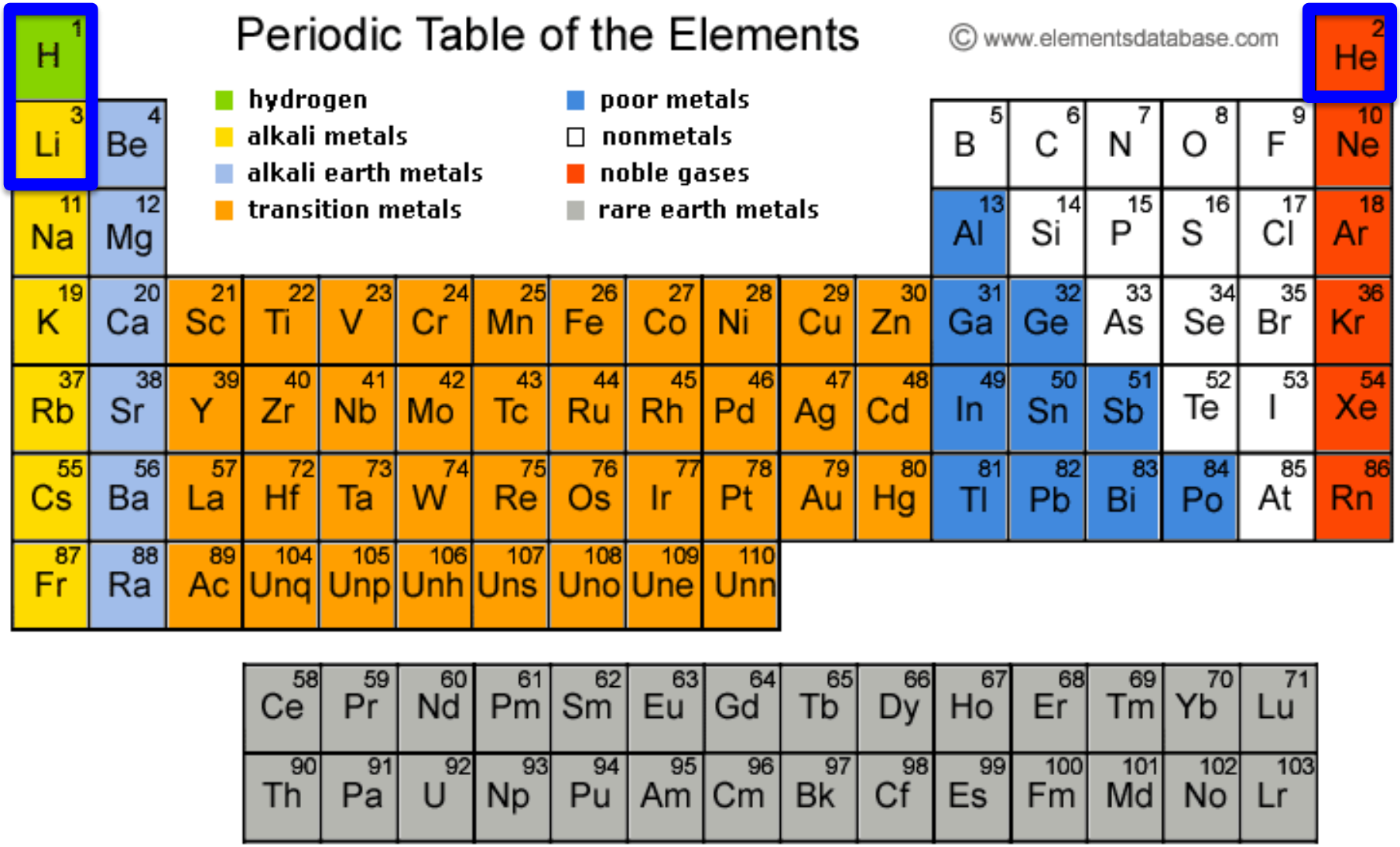
Observation data	
Epoch J2000 Equinox J2000	
Constellation	Eridanus
Right ascension	$01^h\ 37^m\ 42.84548^s$[1]
Declination	−57° 14′ 12.3101″[1]
Apparent magnitude (V)	0.445[2]
Characteristics	
Spectral type	B6 Vep[3]
U−B color index	−0.64[2]
B−V color index	−0.17[2]
Variable type	Lambda Eridani
Astrometry	
Radial velocity (R_V)	+16[4] km/s
Proper motion (μ)	RA: 87.00 ± 0.58[1] mas/yr Dec.: −38.24 ± 0.50[1] mas/yr
Parallax (π)	23.39 ± 0.57[1] mas
Distance	139 ± 3 ly (43 ± 1 pc)
Details	
Mass	6–8[5] $M_\odot$
Radius	7.3 × 11.4[6] $R_\odot$
Luminosity	3,150[6] $L_\odot$
Surface gravity (log *g*)	3.5[7]
Temperature	~15,000[7] K
Rotational velocity (*v* sin *i*)	250[7] km/s
Age	1–5 × 10^8[*citation needed*] years

Dr. Armando Dominiciano de Souza
Côte d'Azur, França
(ex-aluno do IAG/USP)

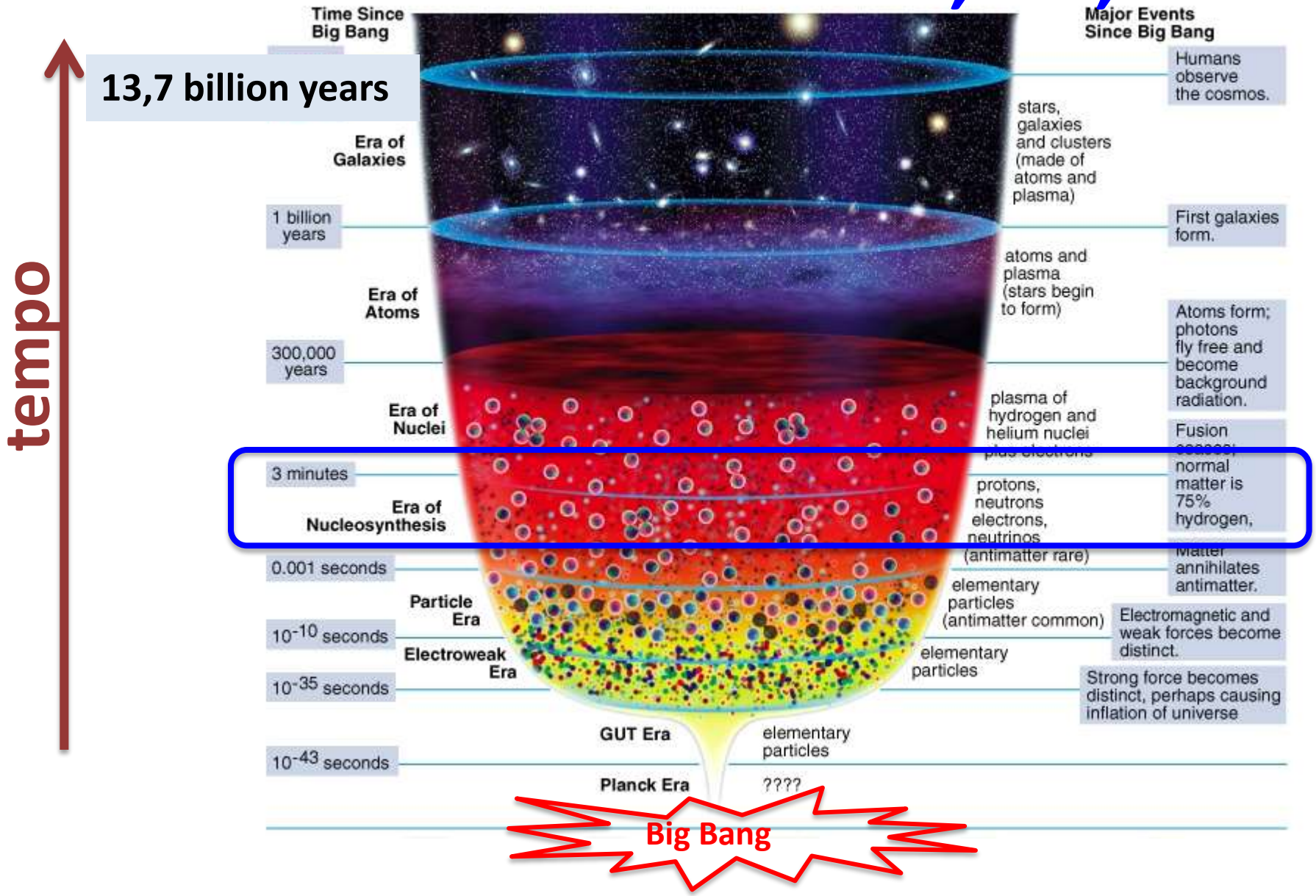
Estrelas F, G, K : vínculos cosmológicos e sobre a evolução química da Galáxia



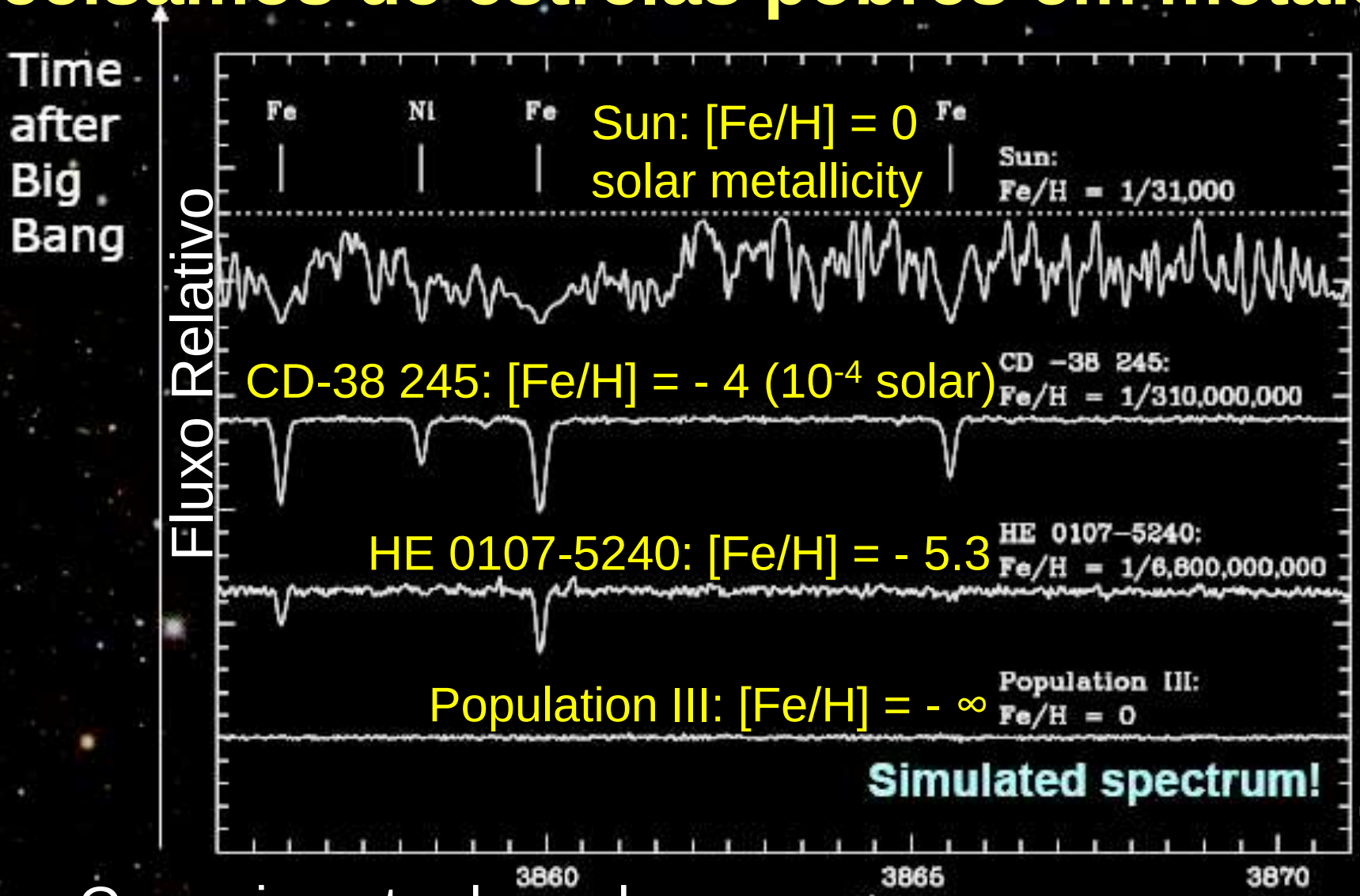
Primeiros elementos no universo:
H, He, Li



Evolução de nosso universo
Primeiros minutos: H, He, Li



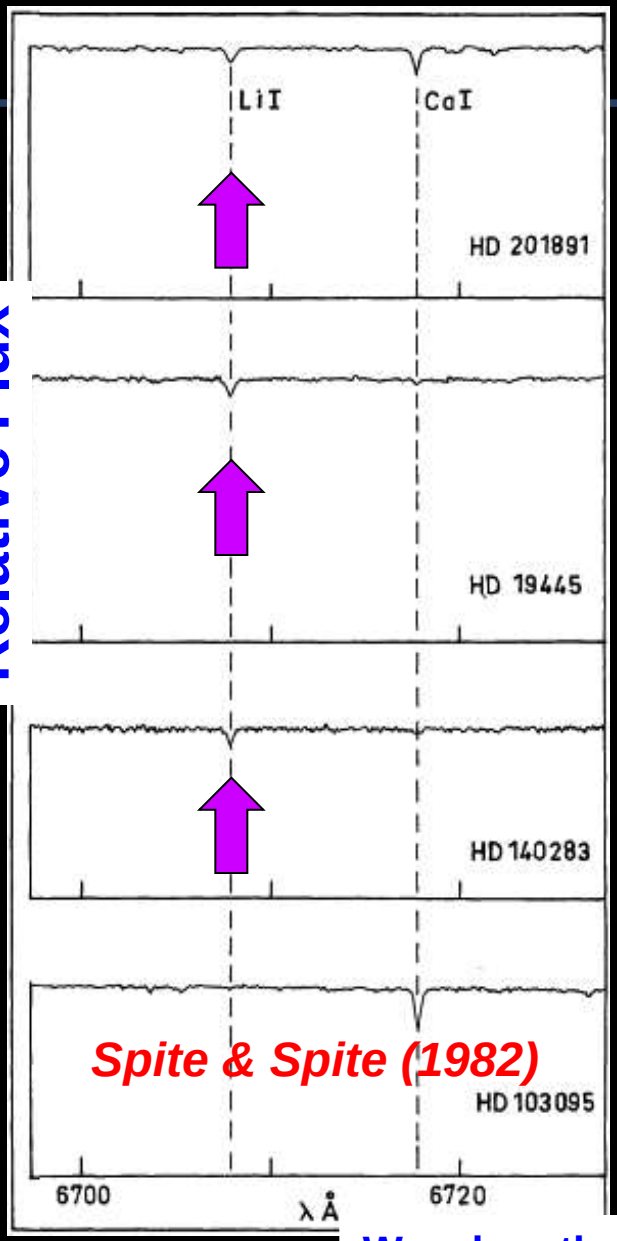
Para estudar a nucleossíntese primordial precisamos de estrelas pobres em metais



Comprimento de onda

credits: N. Christlieb

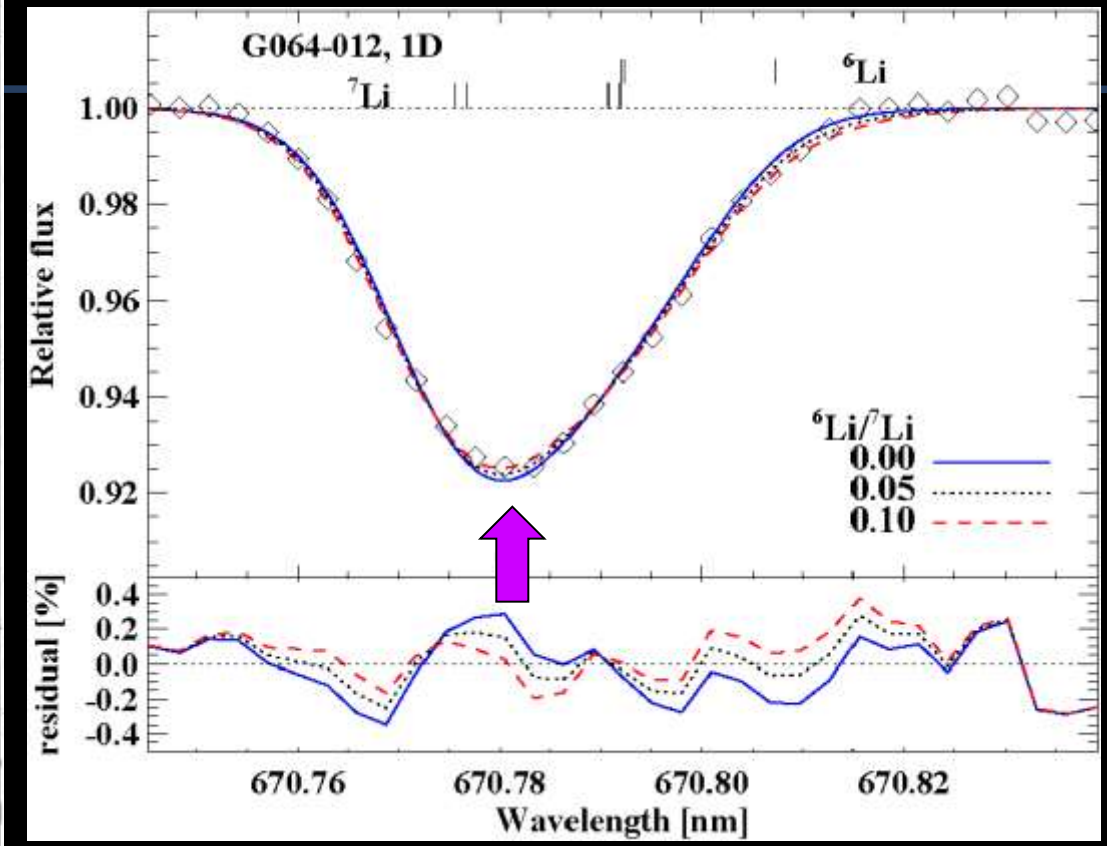
Lítio primordial em estrelas pobres em metais !



Relative Flux

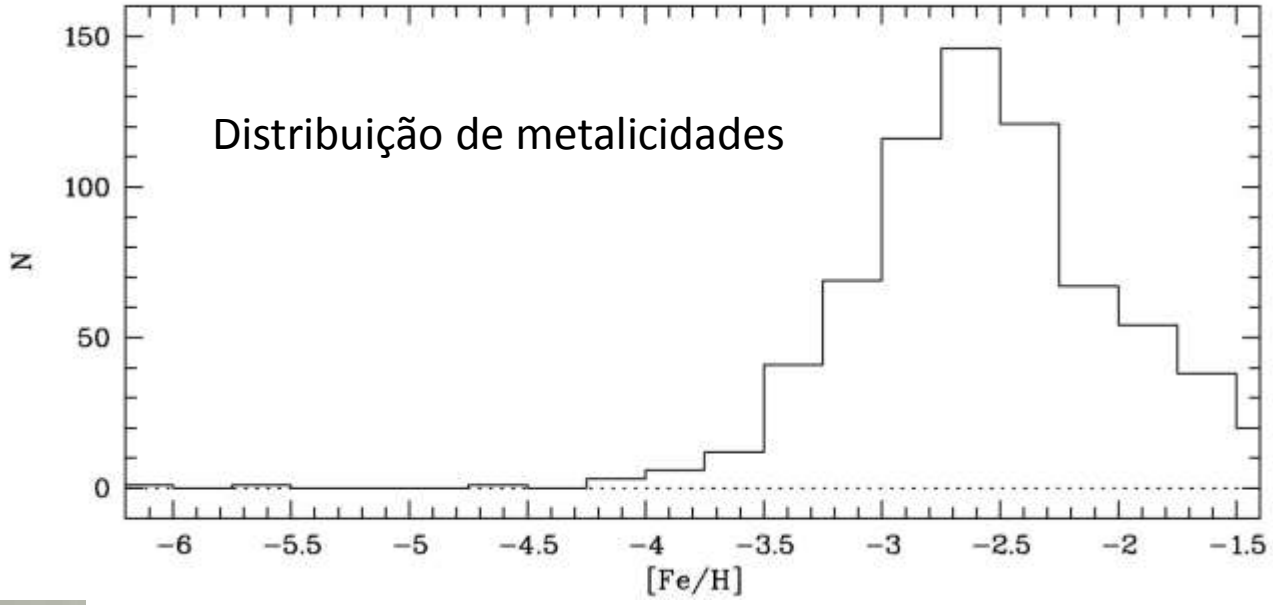
Spite & Spite (1982)

Wavelength (A)



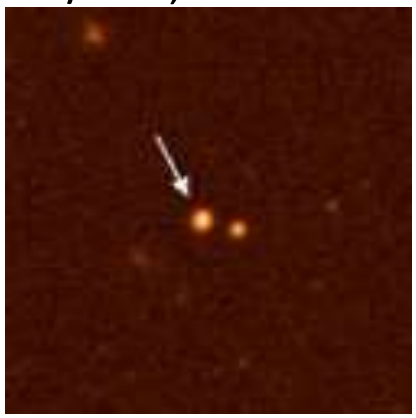
Asplund & Melendez (2008). Estrela com [Fe/H] = -3 (mil vezes menos metais que no Sol)

Procura de estrelas pobres em metais



Dr. Vinicius Placco recebendo o prêmio destaque do doutorado do IAG/USP

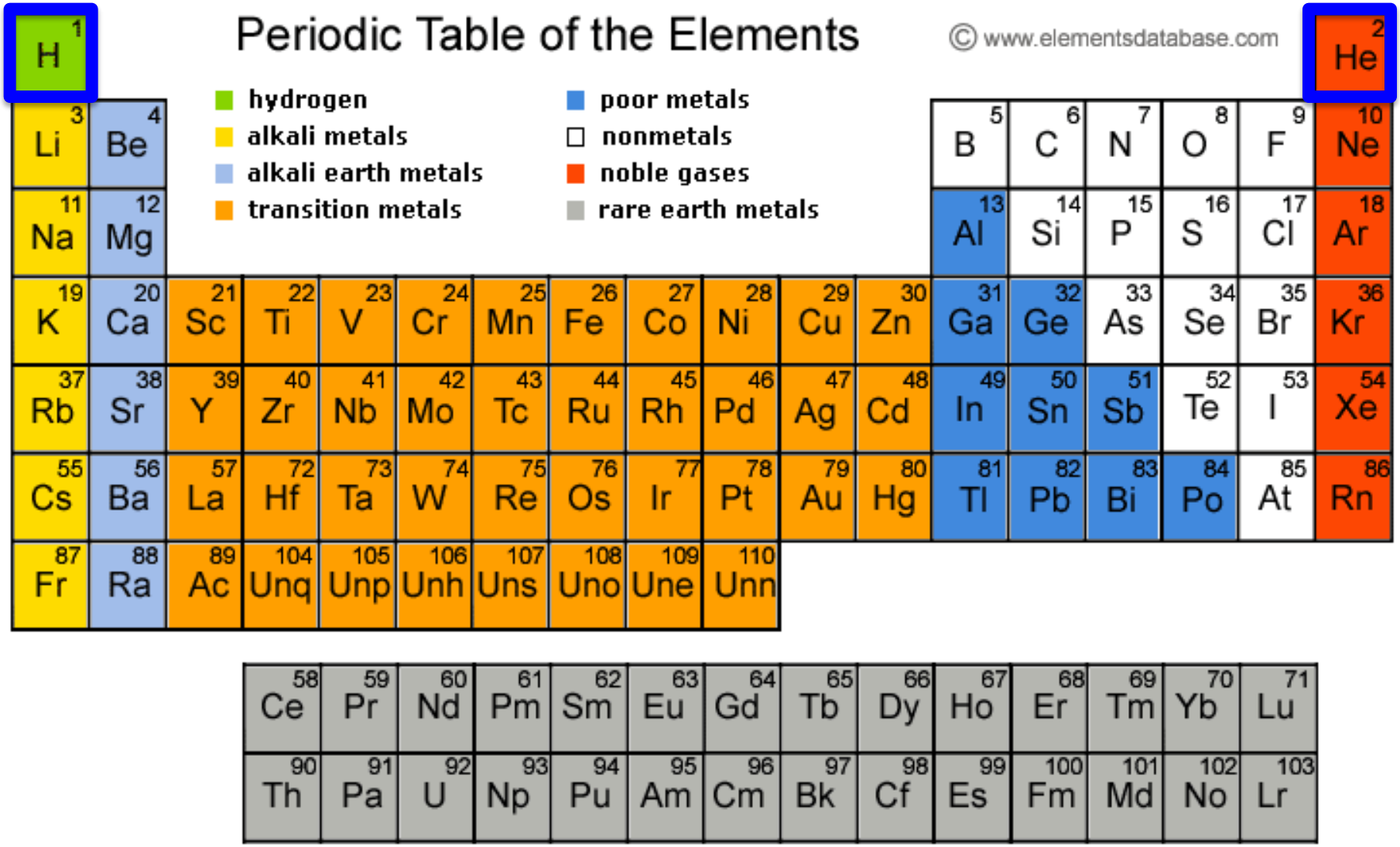
HE0107-5240
[Fe/H] = −5,2
1/200,000 Sol



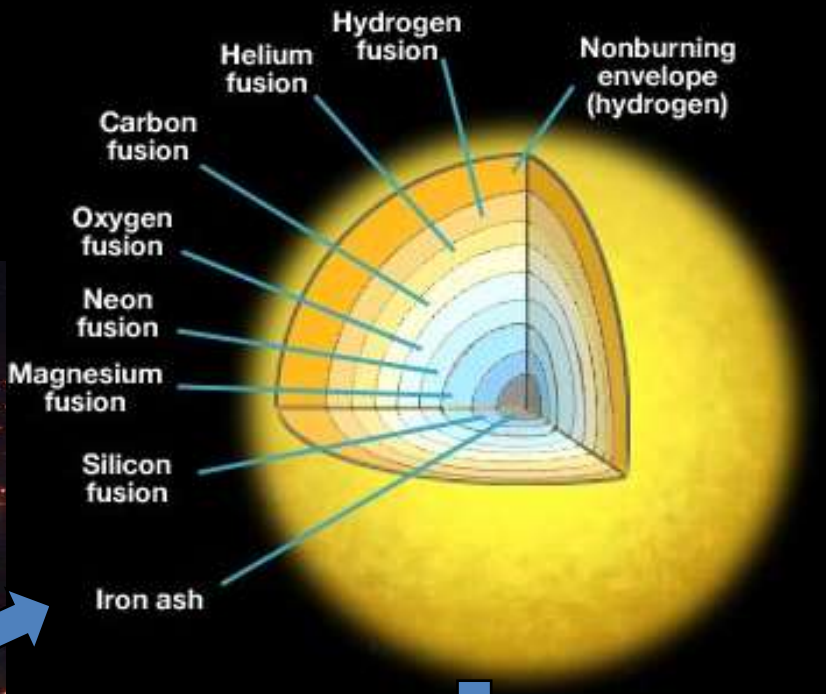
Prof. Silvia Rossi, IAG/USP

Evolução dos elementos químicos

De *H* e *He* a "metais"



As primeiras estrelas e a formação de metais (elementos mais pesados que H & He)



Supernova: restos ricos em metais

Evolução Estelar

Supernova Tipo II

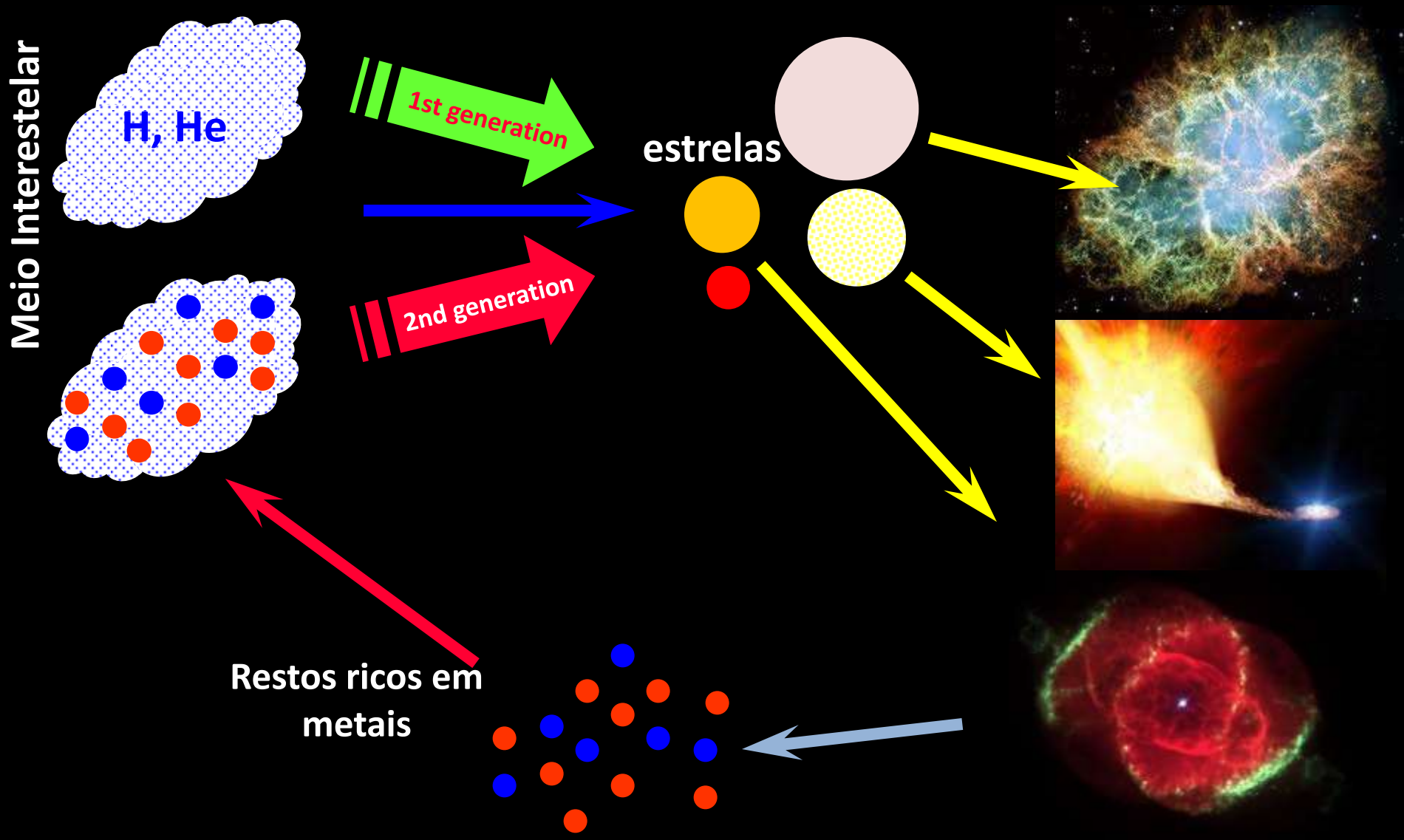
O Mg Ca S

Nebulosa Planetaria

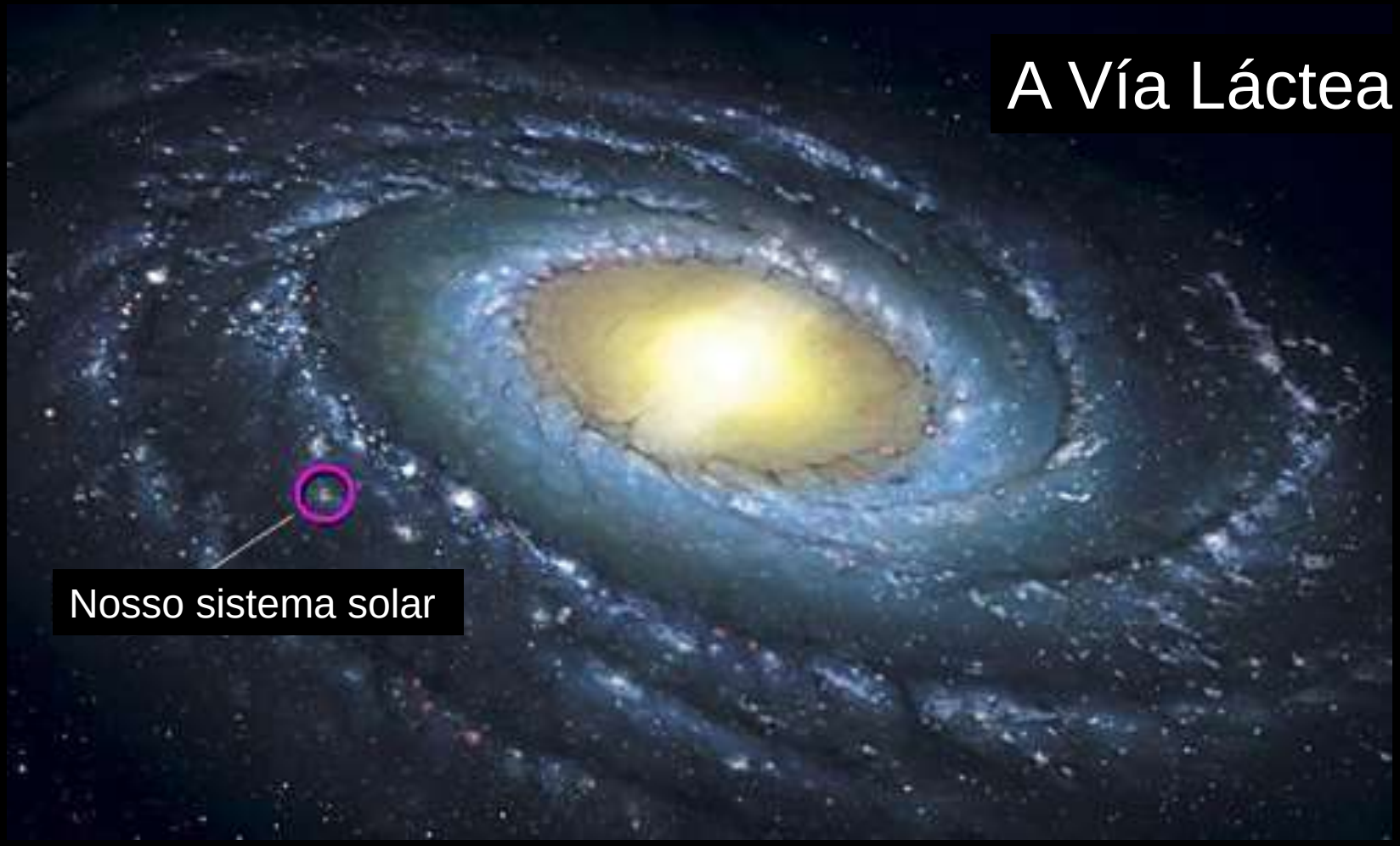
Supernova Tipo Ia

(artist's concept)

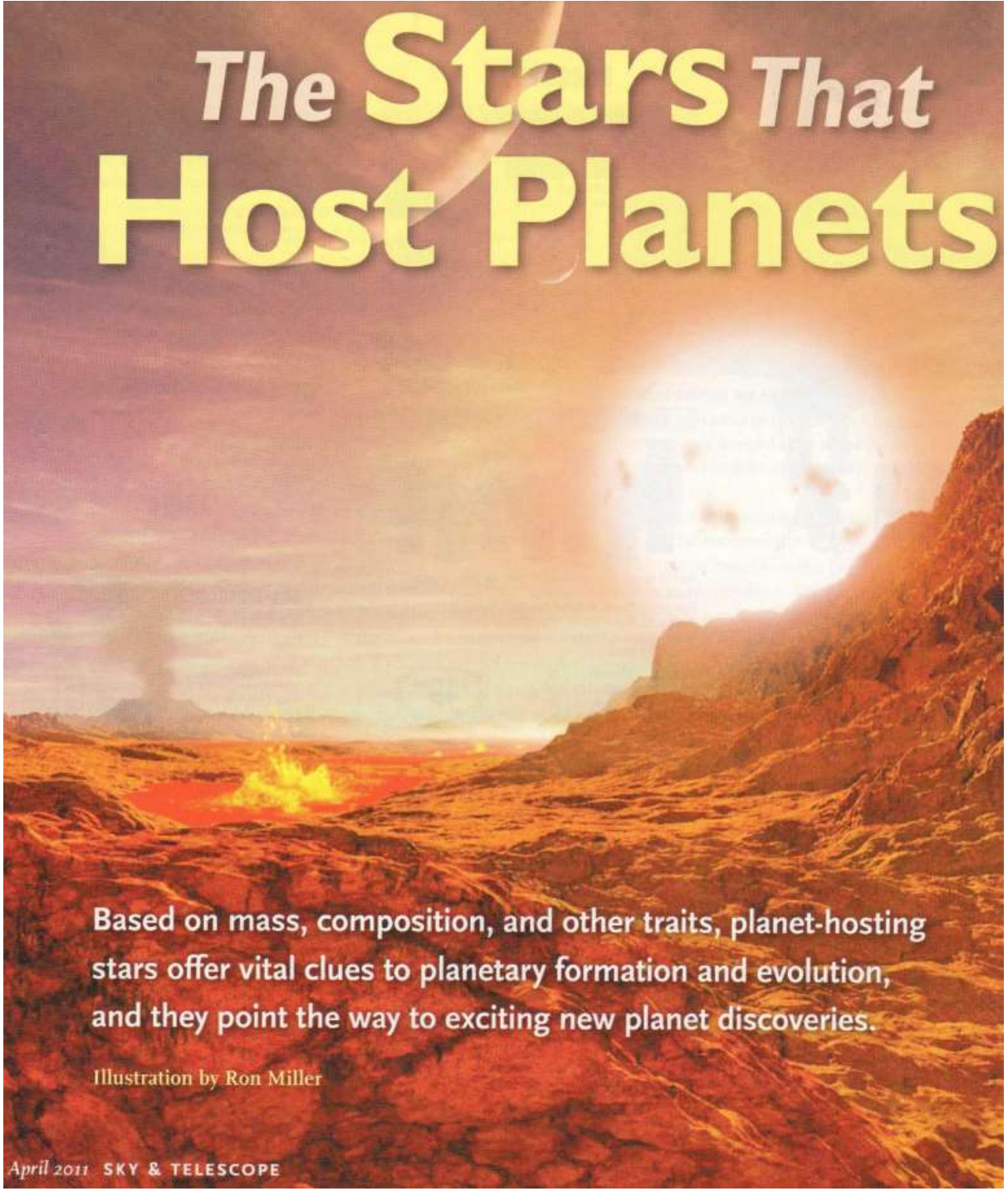
Evolução química da Galáxia



Após 12 bilhões de anos de *evolução química* em nossa Galáxia, as estrelas têm produzido soment 2% de "metais", sendo o resto (98%) H & He



Conexão entre Estrelas e planetas



Planetas ao redor de outras estrelas

Efeito gravitacional de Júpiter no Sol

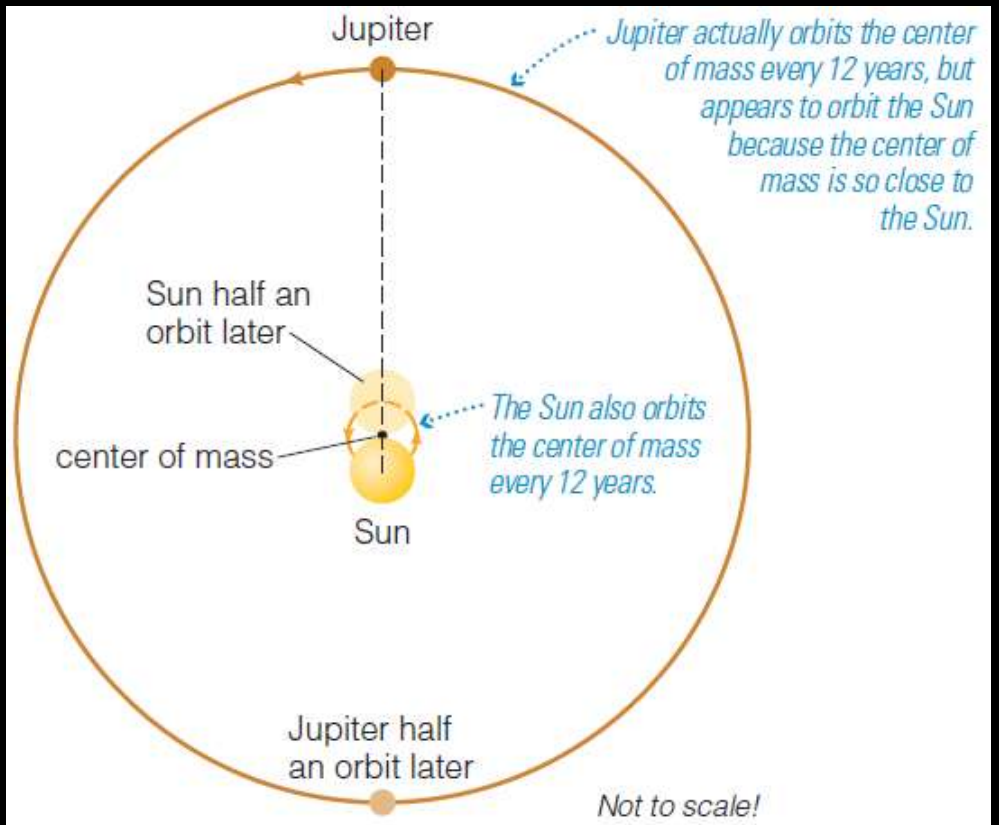


Figure 6.26

This diagram shows how both the Sun and Jupiter actually orbit around their mutual center of mass, which lies very close to the Sun. The diagram is not to scale; the sizes of the Sun and its orbit are exaggerated about 100 times compared to the size shown for Jupiter's orbit, and Jupiter's size is exaggerated even more.

Orbita do Sol (efeito de Júpiter e Sat)

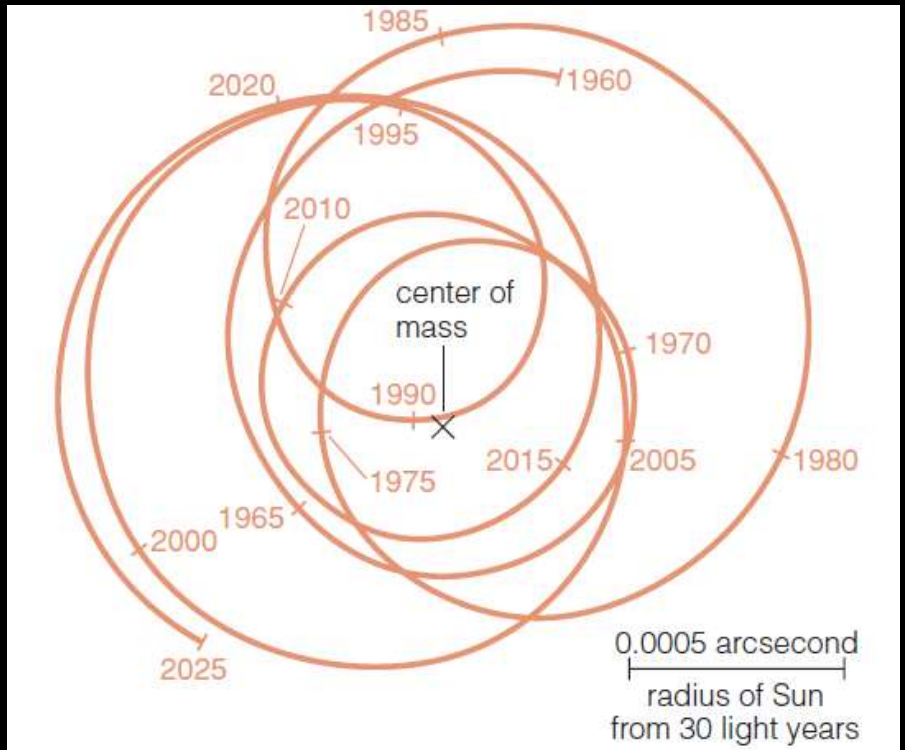
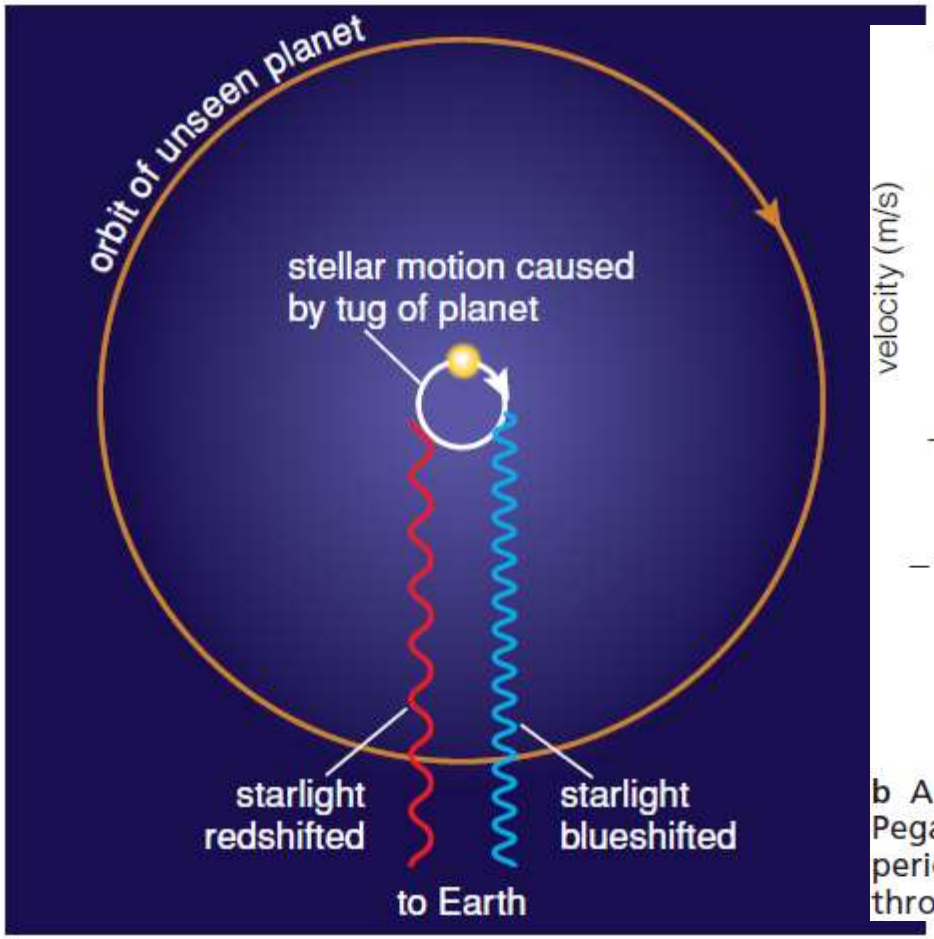


Figure 6.27

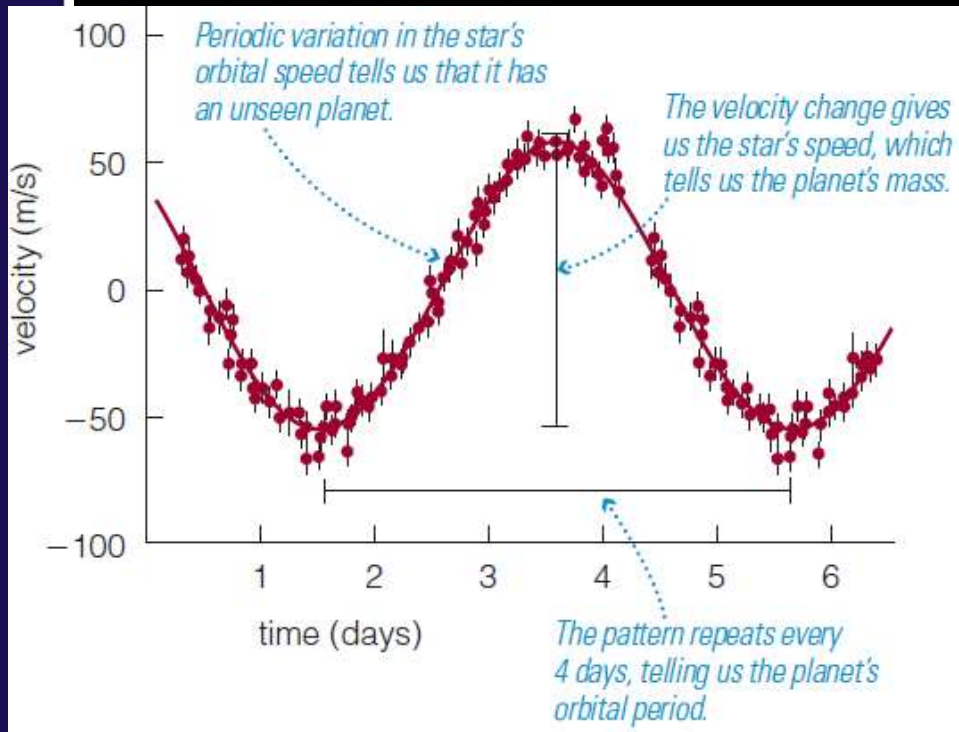
This diagram shows the orbital path of the Sun from 1960 to 2025 around the center of mass of our solar system, as it would appear if viewed face-on from a distance of 30 light-years away. The complex motion reveals the gravitational effects of the planets (primarily Jupiter and Saturn). The *astrometric technique* for detecting extrasolar planets works by looking for similar changes in the position of other stars. Notice that the entire range of motion during this period is only about 0.0015 arcsecond, which is almost 100 times smaller than the angular resolution of the Hubble Space Telescope.

Planetas ao redor de outras estrelas

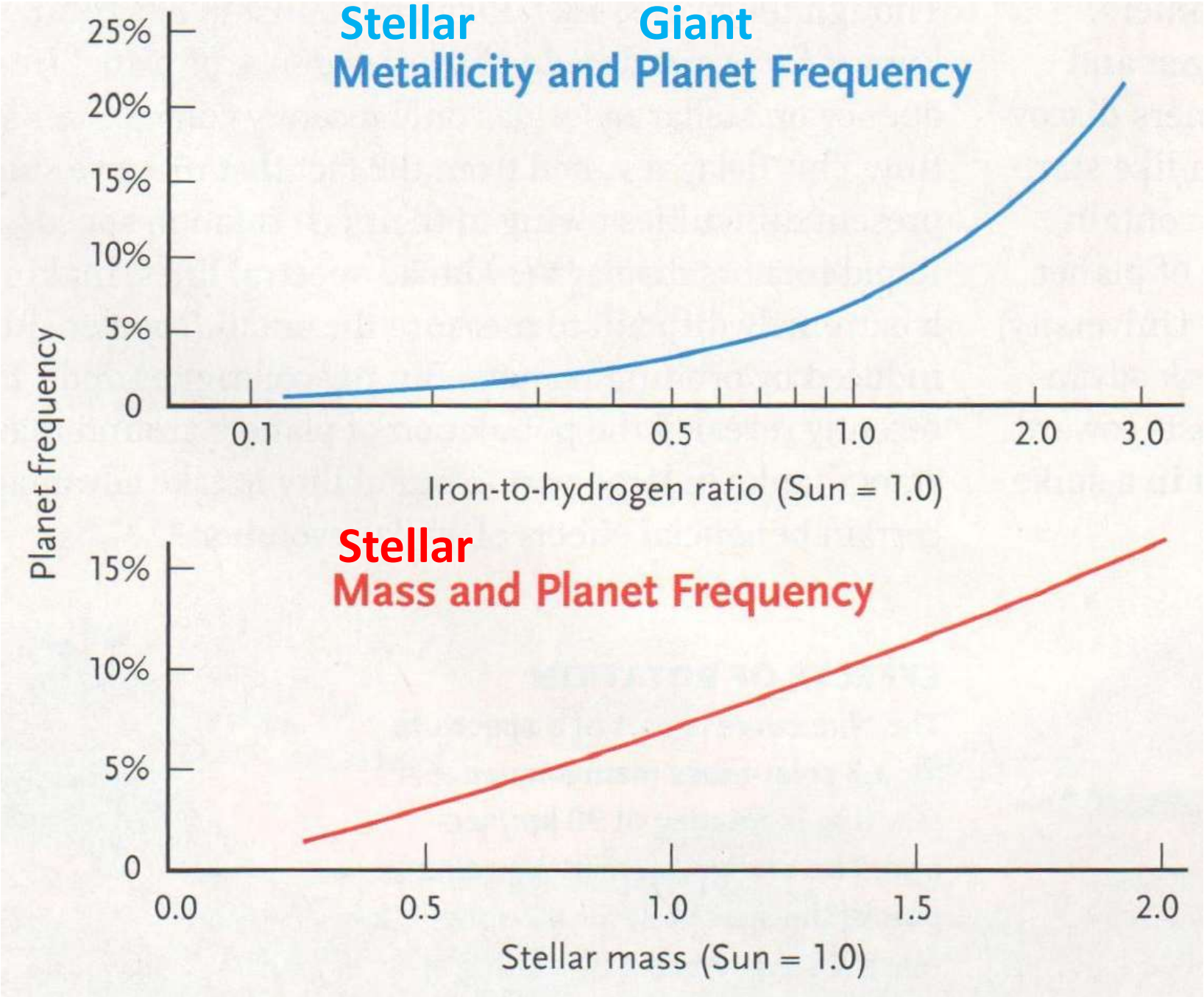
Deteção de planetas pelo método espectroscópico (Doppler)



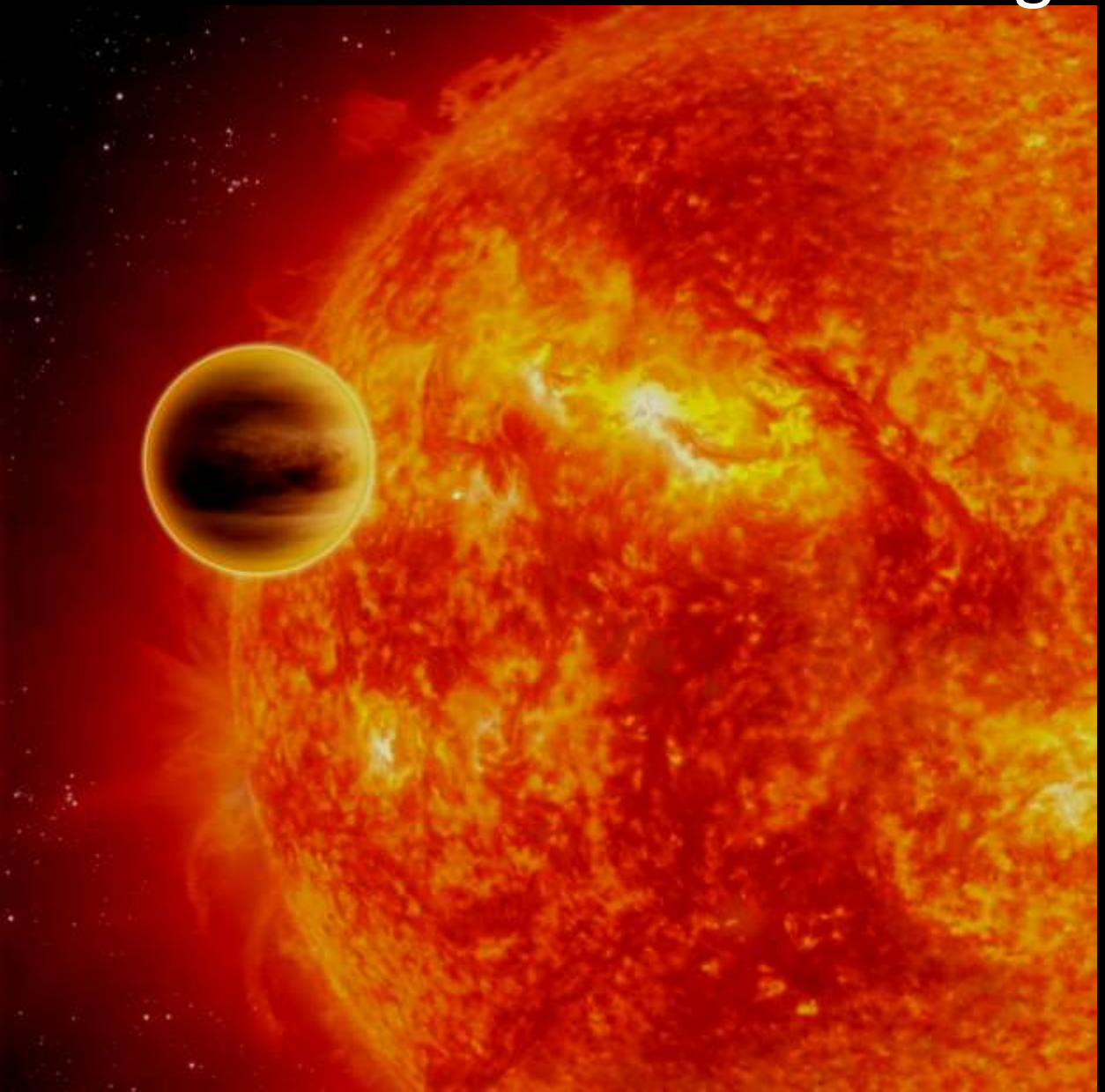
a Doppler shifts allow us to detect the slight motion of a star caused by an orbiting planet.



b A periodic Doppler shift in the spectrum of the star 51 Pegasi shows the presence of a large planet with an orbital period of about 4 days. Dots are actual data points; bars through dots represent measurement uncertainty.


Stellar Giant
Metallicity and Planet Frequency
25%
20%
15%
10%
5%
0
Planet frequency
0.1
0.5
1.0
2.0
3.0
Iron-to-hydrogen ratio (Sun = 1.0)
Stellar
Mass and Planet Frequency
15%
10%
5%
0
0.0
0.5
1.0
1.5
2.0
Stellar mass (Sun = 1.0)

Mais de 600 sistemas planetários conhecidos até agora

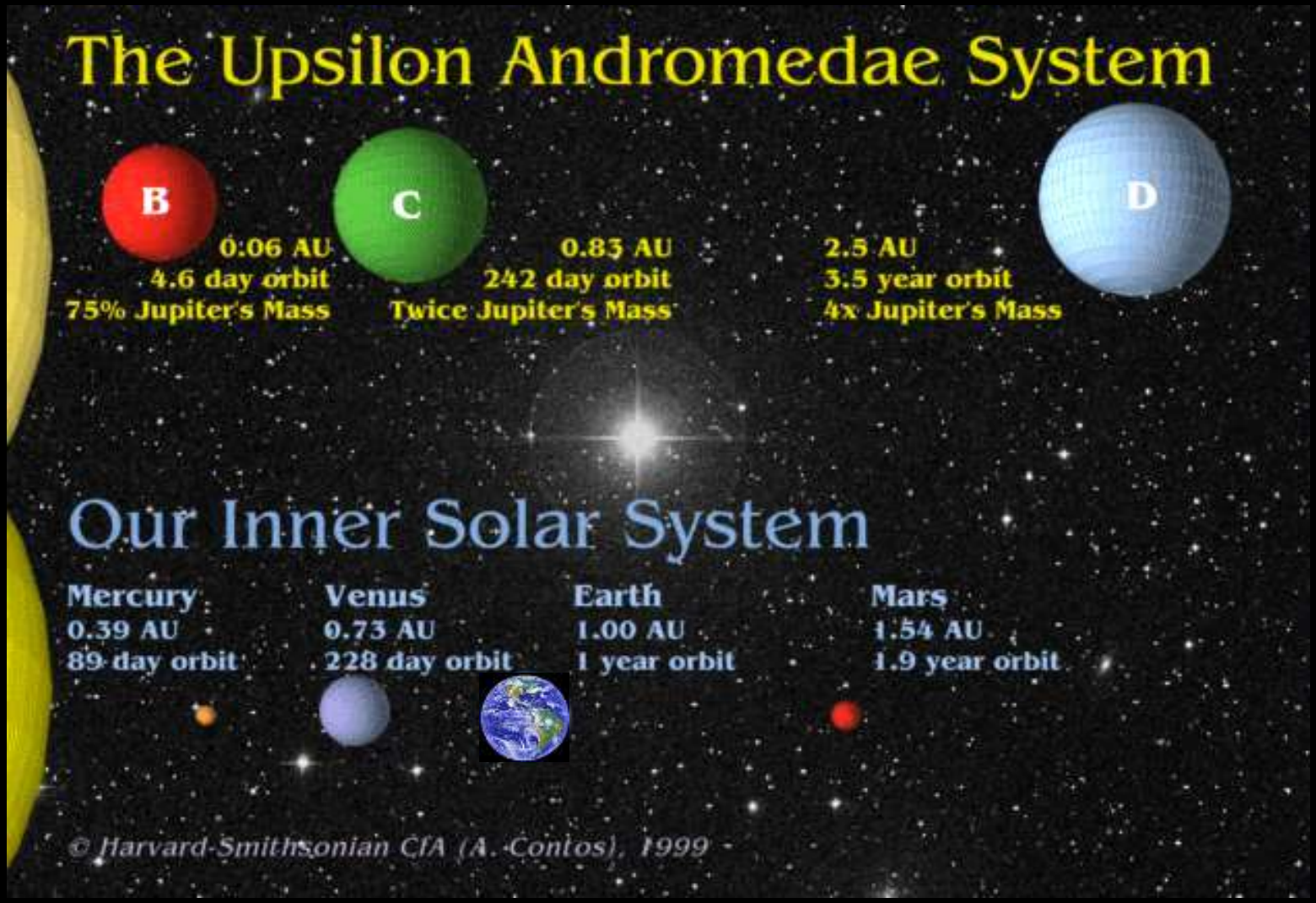


Porem a maioria não se parece com o nosso sistema solar

C. Carreau / ESA

Sunset in Paracas, Peru
(c) www.flickr.com/photos/rodrigocampos/

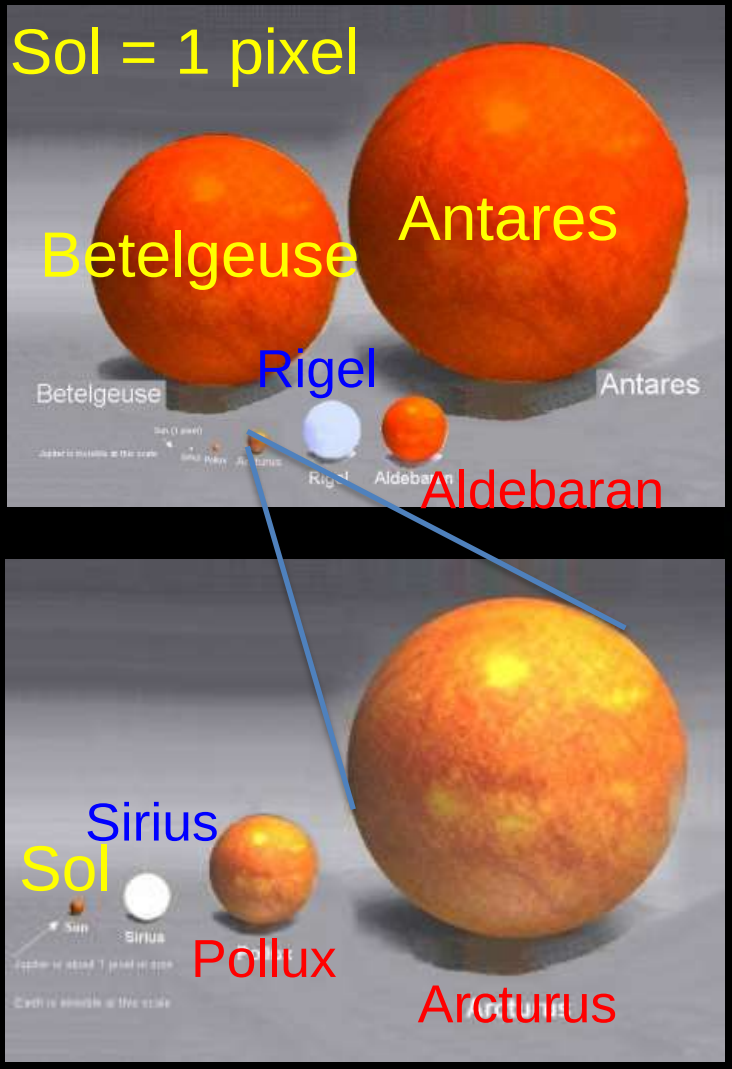
Most planetary systems found so far have inner **giant planets**, unlike the inner **rocky planets** of our solar system

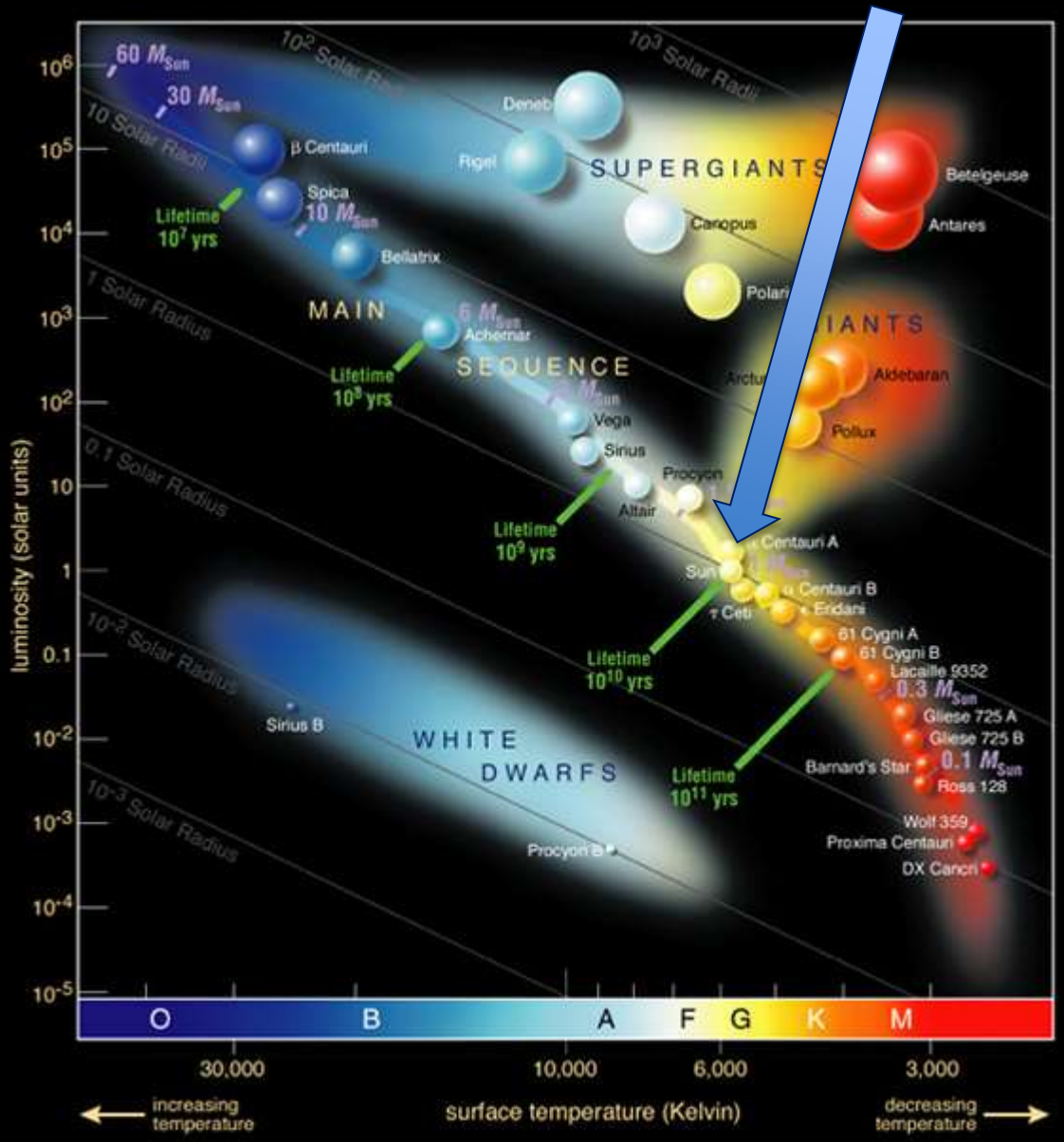


How to find a planetary system similar to our own?

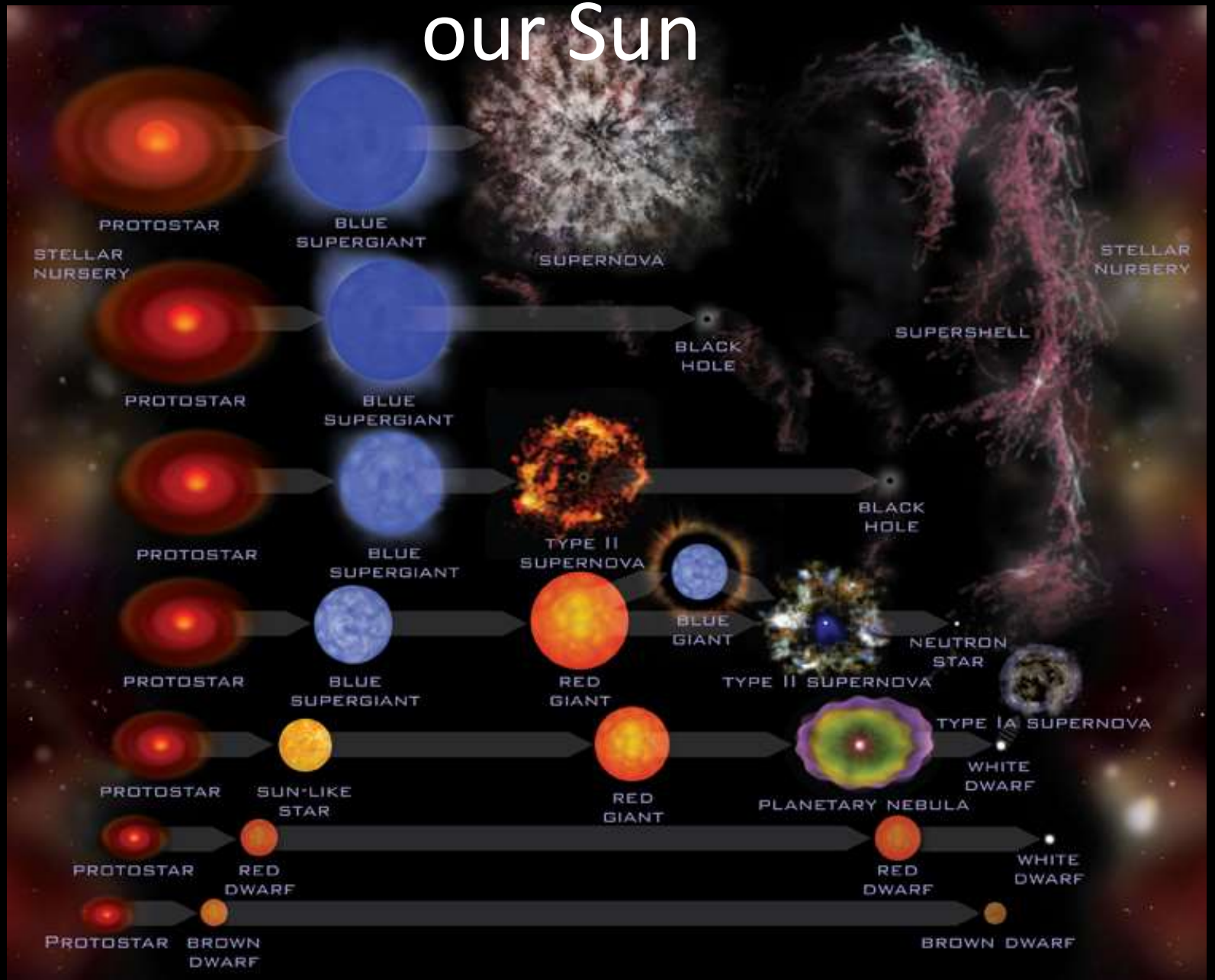
Credits: Nasa

1. Search for stars similar to our Sun

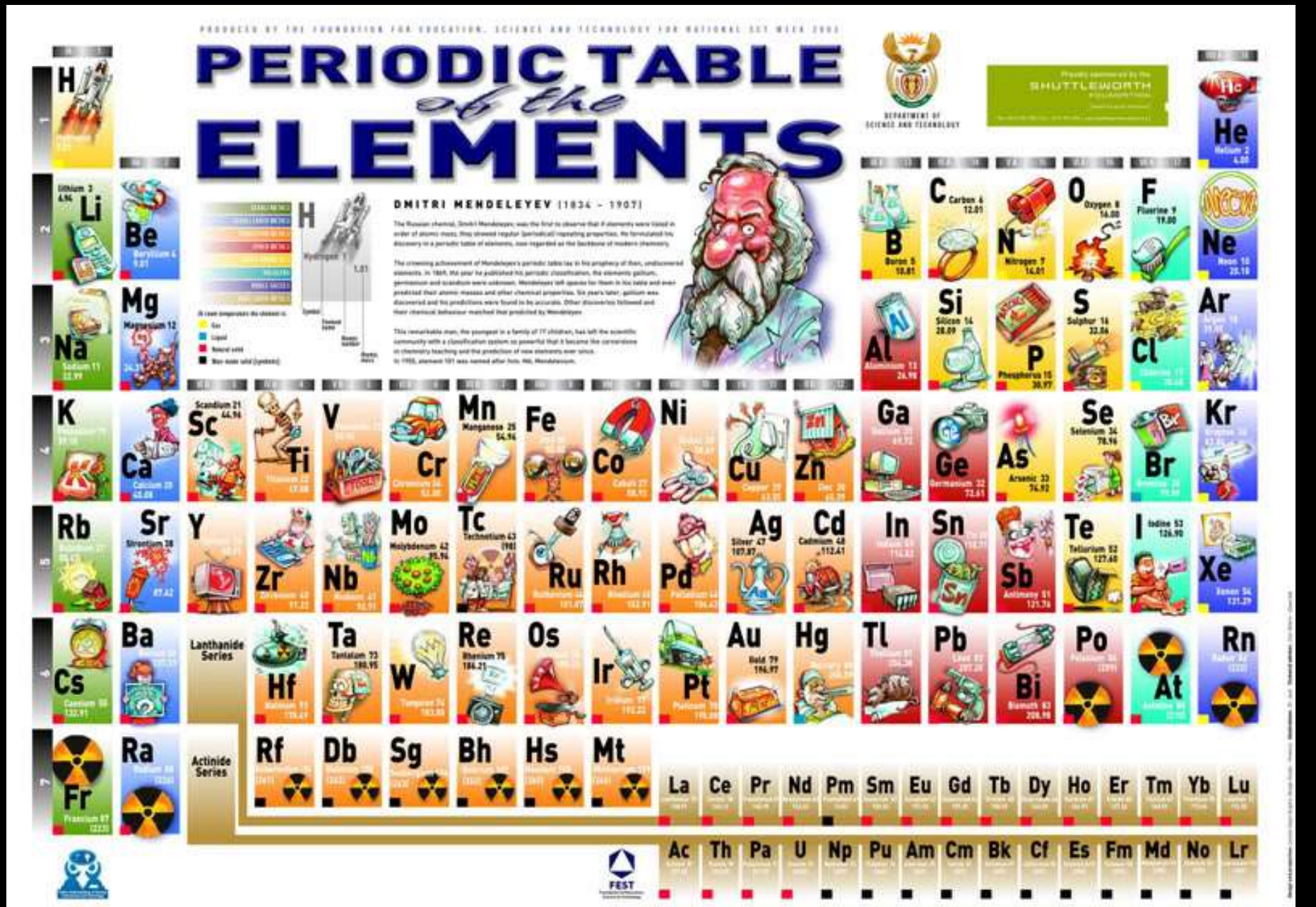




2. In the same evolutionary stage as our Sun

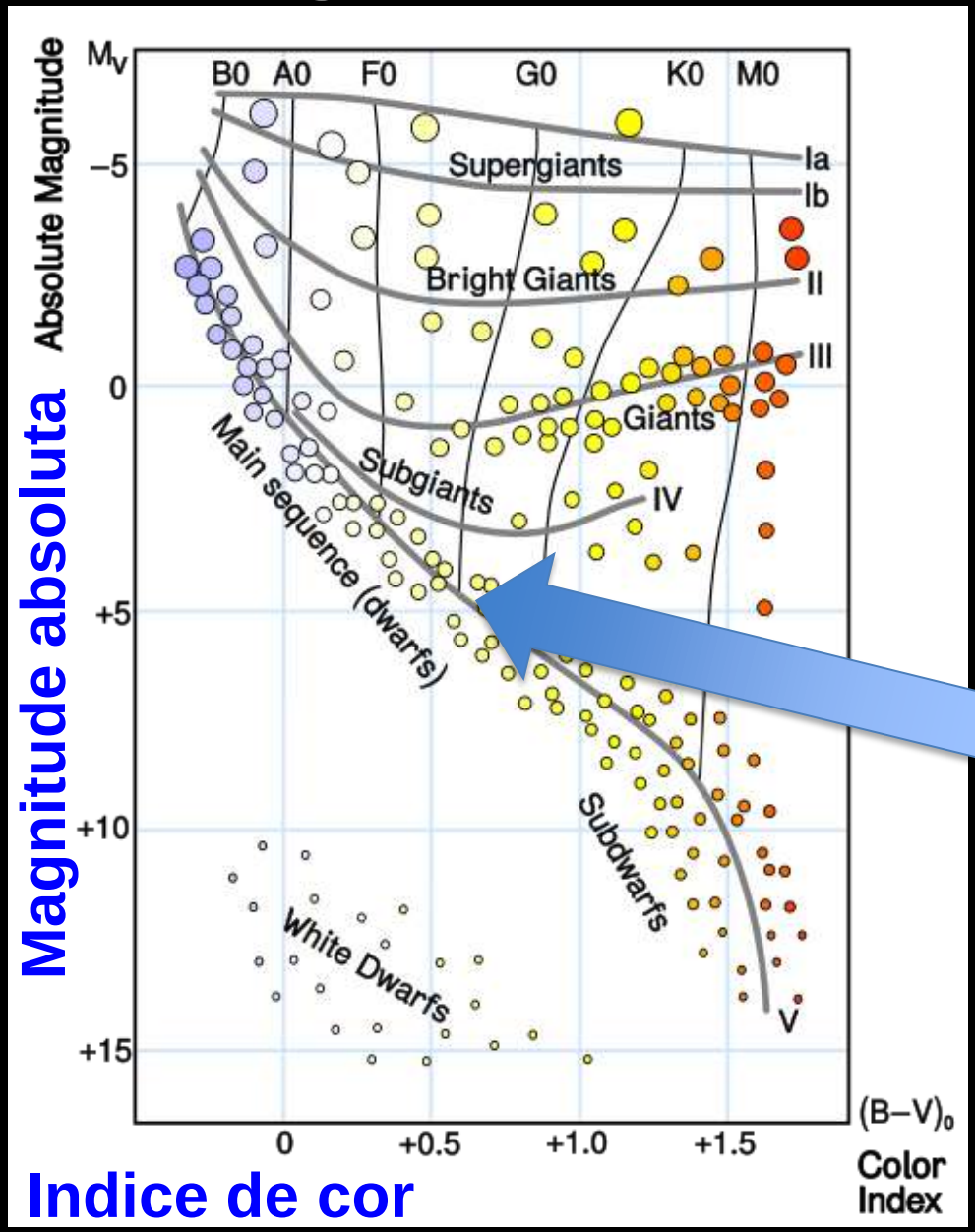


3. Chemical composition ~ solar?



But there are myriad stars in the sky … how can we find solar twins?

Diagrama H-R



SOL

$M_v = 4.82$

B-V ~ 0.65

- Nos primeiros 25 anos de pesquisa não foi encontrada nenhuma gêmea solar (Cayrel de Strobel et al. 1996)

Astron. Astrophys. 63, 383—390 (1978)

The Sun among the Stars

I. A Search for Solar Spectral Analogs*

J. Hardorp

Astron. Astrophys. 94, 1–11 (1981)

In Search of Real Solar Twins

G. Cayrel de Strobel[1,2], N. Knowles[1], G. Hernandez[2], and C.

Astron. Astrophys. 274, 825–837 (1993)

In search of real solar twins. III.*

E. Friel[1], G. Cayrel de Strobel[1], Y. Chmielewski[2], M. Spite[1**], A. Lèbre [1], and C. Bentolila[1]

Primeira gêmea do Sol descoverta apenas em 1997: **18 Sco**

THE ASTROPHYSICAL JOURNAL, 482:L89–L92, 1997 June 10

HR 6060: THE CLOSEST EVER SOLAR TWIN?[1]

G. F. PORTO DE MELLO[2,3] AND L. DA SILVA[3]

[2] Universidade Federal do Rio de Janeiro, Departamento de Astronomia, Observatório do Valongo, Ladeira do Pedro Antônio, 43, CEP 20080-090 Saude, Rio de Janeiro, Brazil; gustavo@ov.ufrj.br.

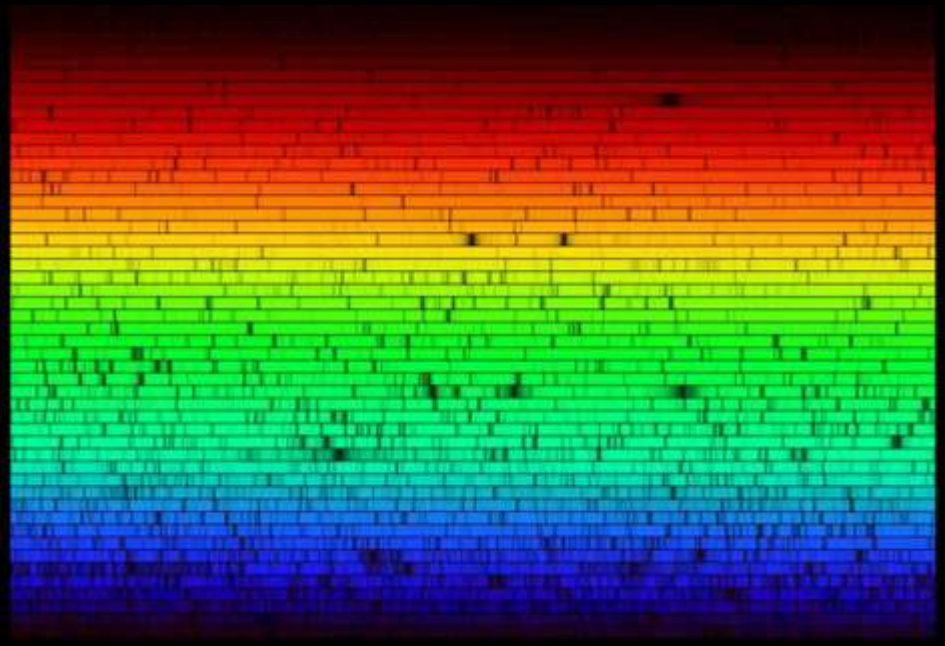
[3] CNPq/Observatório Nacional, Departamento de Astronomia, Rua General José Cristino 77, 20921-400 São Cristovão, Rio de Janeiro, Brazil; licio@on.br.

Parameter	Sun	HR 2290	**18 Sco** HR 6060	16 Cyg A	16 Cyg B
$\Delta T_{\rm eff}$ (K)	0	0	12 ± 30	8 ± 25	−17 ± 20
$\Delta \log g$	0	0.07 ± 0.20	0.05 ± 0.12	−0.16 ± 0.07	−0.09 ± 0.07
$L/L_{\odot}$	1.00	1.05 ± 0.27	1.05 ± 0.02	1.63 ± 0.03	1.28 ± 0.02
[Fe/H]	0	0.13 ± 0.04	0.05 ± 0.06	0.06 ± 0.04	0.02 ± 0.04
$(B-V)$	0.648	0.66	0.65	0.64	0.66
$(U-B)$	0.178	0.20	0.17	0.19	0.20
Spectral type	G2 V	G3 V	G2 Va	G1.5 V	G2.5 V

Programa de busca de gêmeas do Sol

- *Programa observacional desde 2005*

- Keck (Havaí, USA)
- McDonald (Texas, USA)
- Magellan (Chile)
- VLT/UVES (Chile)
- La Silla / HARPS (Chile)



Colaboração: Australia, França, Portugal, U.S.A., Brasil, Chile, México, Inglaterra, Alemanha

Segunda gêmea solar identificada em 2006: HD 98618

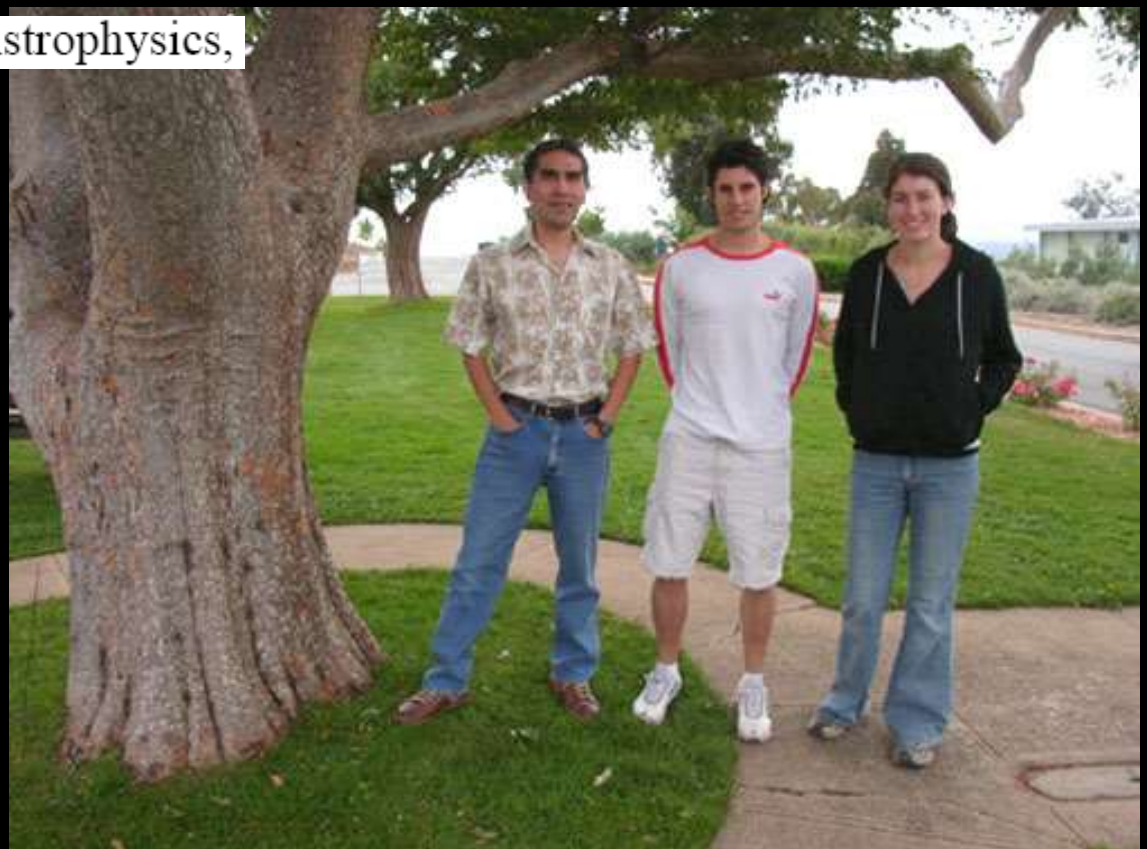
THE ASTROPHYSICAL JOURNAL, 641:L133–L136, 2006 April 20

HD 98618: A STAR CLOSELY RESEMBLING OUR SUN[1]

JORGE MELÉNDEZ,[2] KATIE DODDS-EDEN, AND JOSÉ A. ROBLES

Research School of Astronomy and Astrophysics,
Mount Stromlo Observatory

- Projeto de IC de verão de Katie Dodds-Eden



HD 98618: Destaque na imprensa

http://www.20minutos.es/noticia/107450/0/sol/estrella/astronomos/

Astrónomos australianos descubren una estrella idéntica al Sol

Se llama HD98618 y es prácticamente idéntica al Sol: tiene su misma edad, su mismo tamaño, su misma temperatura y su misma composición, según los científicos de la Escuela de Astronomía australiana.

Los expertos esperan que este hallazgo ayude a

El mellizo del
(Imagen: Web

A Solar Twin in t

By Ken Croswell

March 10, 2006

A yellow star in the Big Dipper's bo
scientists search the star for signs of

Solar twins are stars with the same
more light than the typical star in th
extraterrestrial intelligence.

Jorge Meléndez, Katie Dodds-E
high-resolution spectra of HD 98
126 light-years from Earth, almo

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News Update

with Dave Reneke

New solar twin sheds light on twin Earth

Astronomers at the Australian National University (ANU) have discovered a nearby solar twin which may shed light on the search for Earth-like planets capable of supporting life.

and to the other closest Sun twin, a star known as 18 Scorpii, which was discovered a decade ago.

The spin-offs of this discovery are tantalising. Solar twins are ideal for the absolute calibration of astronomical measuring instruments. They can provide data useful in modelling the solar phenomena that may affect climate change and will help settle the argument about the uniqueness or otherwise of our Sun and Solar System.

With a number of sample stars to study, HD 98618 was one of the last on the list to be analysed. Team members were quite surprised when they discovered how it stood out from the other candidates along with 18 Scorpii. "It was very exciting – I had to blink twice to be sure I wasn't imagining it," Ms Dodds-Eden said.

The researchers made the discovery using the largest telescope in the world, the 10metre Keck I telescope on the summit of Hawaii's dormant Mauna Kea volcano. A paper detailing this amazing discovery is expected to be published shortly.

Source: ANU

New 'earthly' planet found in our galaxy

A ground-breaking discovery in the search for planets that may support life in our galaxy has been made by an international team of astronomers, with much critical data provided by

A colour-enhanced close-up around the newly discovered HD 98618, one of the most Sun-like stars

WEEKLY | NEWS IDEAS INNOVATION

NewScientis

8 April 2006 No2546 Australia $6.50 (Inc.GST) New Zealand NZ$6.95 (Inc.GST) Print Post Approved 230009/00015

SUN'S TWIN IS STRONG CANDIDATE FOR LIFE

Astronomers have found a twin of the sun, the first such star to be spotted in a decade and only the second ever. They say that these stars are our best bets for finding Earth-like planets with life on them.

Jorge Meléndez, Katie Dodds-Eden and José Robles of Mount Stromlo Observatory near Canberra, Australia,

have roughly the same concentratio
of heavy elements as the sun. These
elements are crucial to the formation
Earth-like planets and the emergence
of life (www.arxiv.org/astro-ph/060321

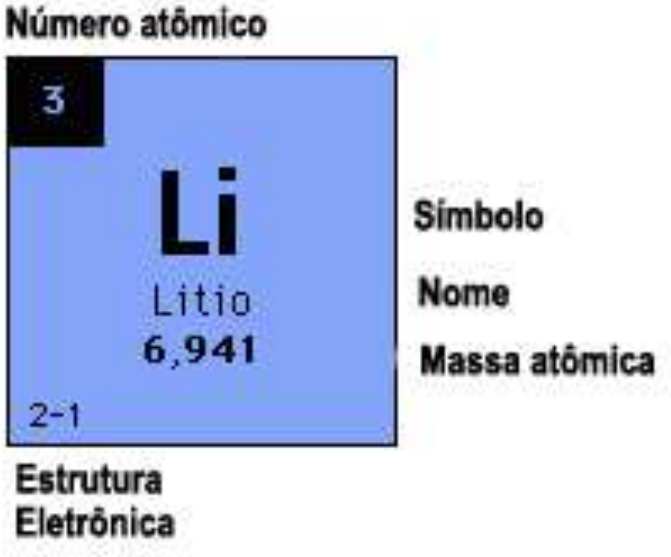
Another cause for optimism is the absence of "hot Jupiters", massive gas giants orbiting close to each star whose gravity could destabilise the orbits of

Mas 18 Sco e HD 98618 não são gêmeas solares perfeitas …

FUNDAMENTAL PARAMETERS **Estrela - Sol**

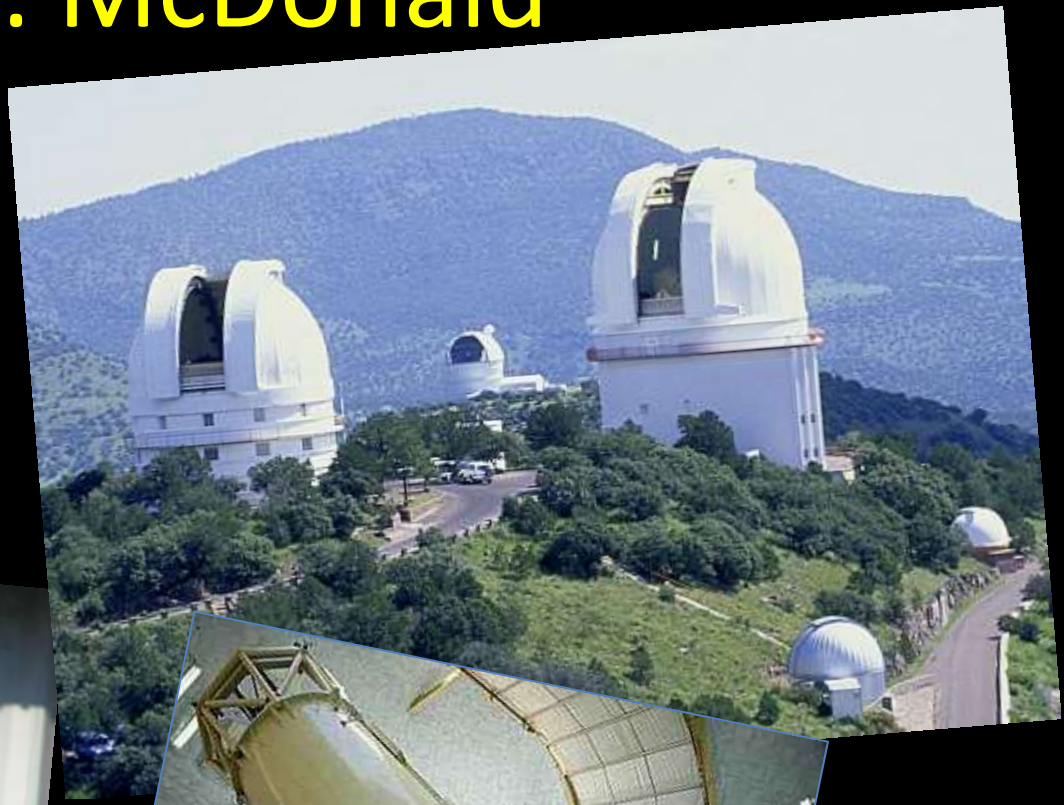
Parameter (Star − Sun)	18 Sco	HD 98618
Δv_t (km s^{-1})	+0.08 ± 0.15	+0.09 ± 0.15
$\Delta T_{\rm eff}$ (K)	+40 ± 30	+66 ± 30
$\Delta \log g_{\rm spec}$ (dex)	+0.01 ± 0.04	+0.01 ± 0.04
$\Delta \log g_{\rm Hip}$ (dex)	+0.01 ± 0.02	+0.01 ± 0.03
$\Delta \log g_{\rm adopted}$ (dex)	+0.01 ± 0.02	+0.01 ± 0.03
$\Delta L_{\rm spec}$ ($L_\odot$)	+0.02 ± 0.06	+0.04 ± 0.06
$\Delta L_{\rm Hip}$ ($L_\odot$)	+0.03 ± 0.03	+0.08 ± 0.07
$\Delta L_{\rm adopted}$ ($L_\odot$)	+0.03 ± 0.02	+0.06 ± 0.05
[Fe/H] (dex)	+0.02 ± 0.03	+0.05 ± 0.03
[O/H] (dex)	−0.03 ± 0.05	0.00 ± 0.04
[Li/H] (dex)	+0.53 ± 0.09	+0.47 ± 0.09
Δ mass ($M_\odot$)	+0.02 ± 0.03	+0.02 ± 0.03
Δ age$_{\rm isochro}$ (Gyr)	−0.8 ± 1.5	−1.1 ± 1.5
Δ age$_{\rm chromos}$ (Gyr)	−0.3[a]	+0.7[a]
Δ age$_{\rm rotation}$ (Gyr)	−1.1	−0.4
Δ age$_{\rm adopted}$ (Gyr)	−0.7 ± 0.4	−0.3 ± 0.9
Δ rotation period (days)	−2.5[b], −1[a]	−1[a]
$\Delta \log R'_{\rm HK}$ (dex)	0.0[a]	−0.05[a]
ΔM_V (mag)	−0.04 ± 0.04	−0.09 ± 0.07
$B-V$	0.65	0.64
Distance (pc)	14.0	38.7

- **Abundancias de lítio são muito altas, um fator de 3 maior que no Sol !**



Continuando a busca por gêmeas solares: McDonald

- 2.7-m tel. + 2dcoudé
- Observações em Abril, Out, Nov 2007
- **P.I.: Iván Ramírez**

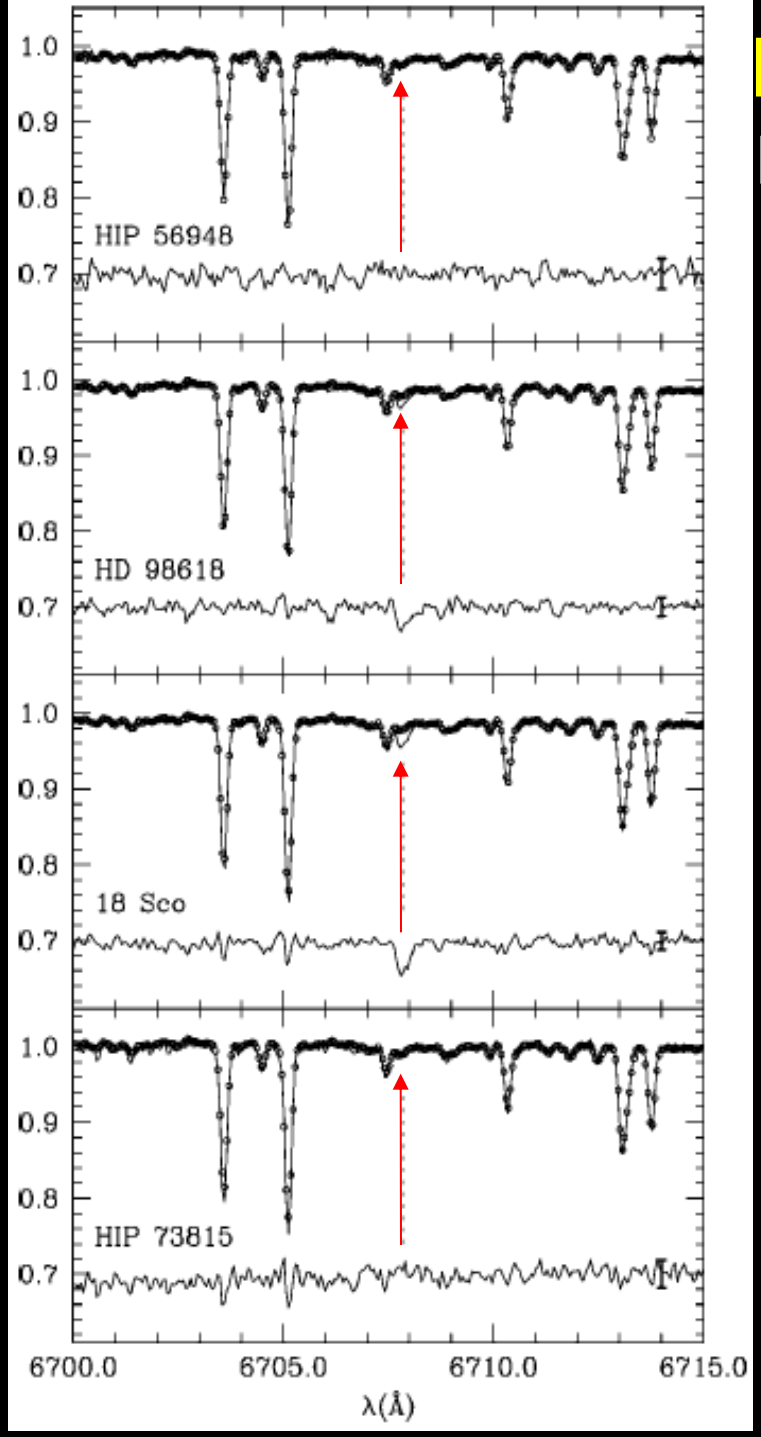


McDonald solar twin survey

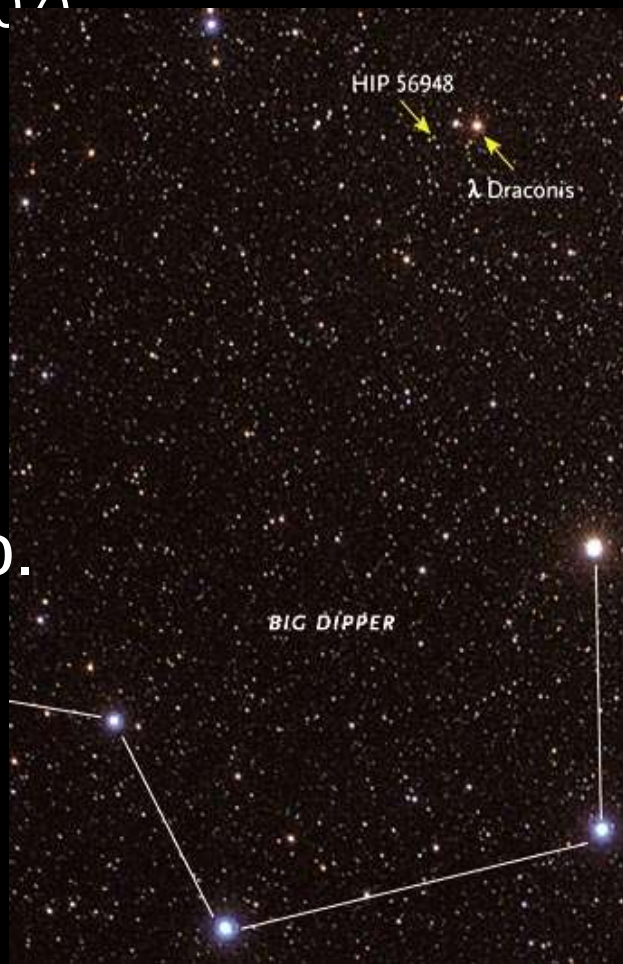
Novas gêmeas solares HIP 56948 & HIP 73815 tem baixo Li (~1.0)!

Muito parecido ao Sol !

(Melendez et al. 2006;Melendez & Ramirez 07)



HIP 56948 é a melhor gêmea solar, quase identica ao Sol, inclusive no lítio.



HIP 56948: destaque na imprensa

Work by Peter Hänggi of the University of Augsburg in Germany and his collaborators contradicts those early calculations. The group's one-dimensional models of particles in a gas show that the same temperature will be observed regardless of the observer's speed. The team admits, however, that this may not be true of two- or three-dimensional gases, and believes that further study is needed.

CLIMATE CHANGE

Irreducible sensitivity

PLANETARY SCIENCE

Identical twins

Astrophys J. **669**, L89–L92 (2007)

Astronomers have identified a star that is in many ways indistinguishable from the Sun.

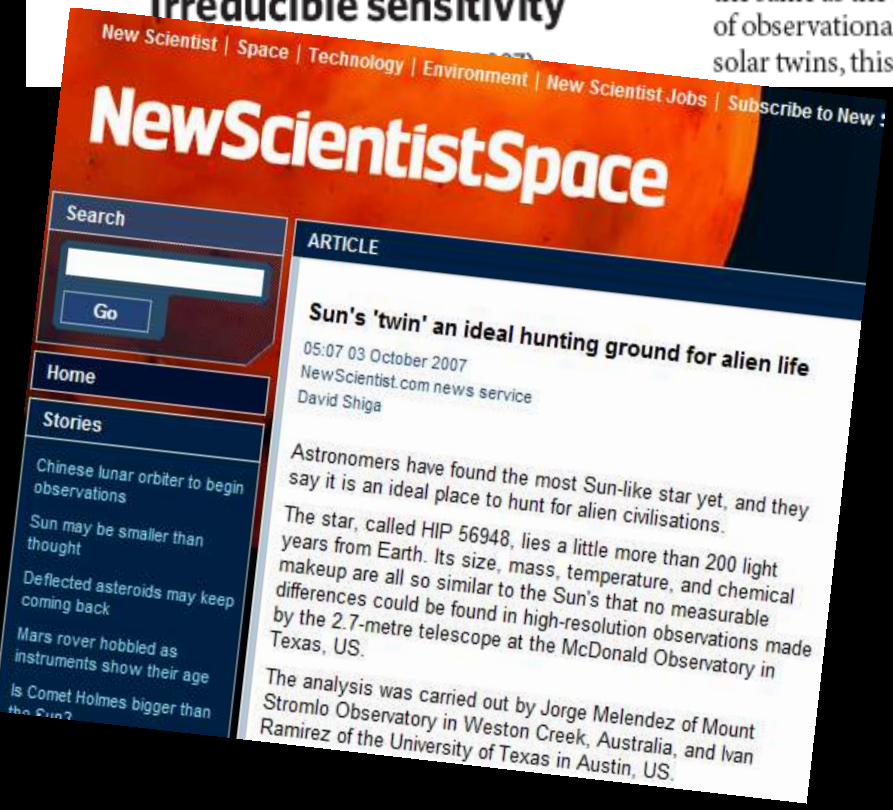
Peruvian astronomers Jorge Meléndez of the Australian National University, and Iván Ramírez at the McDonald Observatory of the University of Texas in Austin report that the parameters of HIP 56948, one of four 'solar twins' they have been studying, are exactly the same as the Sun's, within the constraints of observational accuracy. Unlike previous solar twins, this star — which resides 200

Medicine, California, USA

A systems biologist encourages modelling by the millions.

In a typical modelling study, we write down equations, solve them, and see whether they account for known data. If they do, we claim to understand some bit of biology. One huge caveat is that many other models might have matched the data just as well.

Researchers from Peking University in Beijing and the University of California,



HIP 56948: destaque na imprensa

The New York Times

TierneyLab

Putting Ideas in Science to the

NOVEMBER 13, 2007, 12:52 PM

Name This Solar Twin

By JOHN TIERNEY

The Sun's twin, unfortunate

Digitized

РУССКИЙ Newsweek

8 - 14 октября 2007 г. № 41 (165) » НАУКА

АСТРОНОМИЯ
ДВОЙНИК СОЛНЦА

Астрономы обнаружили звезду, по своим характеристикам практически неотличимую
Солнца. Объект, получивший название HIP 56948, находится на удалении 200 световы
лет от Земли. Его размер, масса, температура и химический состав настолько напомин
наше светило, что сколько-нибудь существенные отличия не в состоянии выявить даж
...самое главное.—рассказал Newsweek один из авторов

Astronomers find the sun's long-lost twin

Happy reunion unlikely, as the star is about 200 light-years away

By Dave Mosher
SPACE.com

updated 11/9/2007 7:04:06 PM ET Share

Somewhere out there, astronomers knew tl
long-lost relative aimlessly drifting through
they've found it.

Although a happy reunion is unlikely, as the
about 200 light-years away, it is now consid
"solar twin" out of four known candidates.

The wayward star challenges the idea that our
a unique composition, as it has a similarly low
element lithium — a lightweight byproduct of t
reactions that power stars.

Polski Portal Astronomiczny

ASTRONOMIA.PL

Pod patronatem Polskiego Towarzystwa Miłośników Astronomii

2007-11-12

Peruwiańczycy odkryli "bliźniaka" Słońca

Peruwiańscy astronomowie Jorge Melendez
University i Ivan Ramirez z University of Texas
teleskopu Obserwatorium McDonalda w Teksa
bliźniaczo podobna do naszego Słońca.

ECUADOR CIENCIA

Científicos peruanos descubren nuevo sol

Publicado: Viernes, 14/12/2007 - 15:2

Al parecer tiene todas las condiciones para albergar planetas similares a la Tierra con agua y aire.

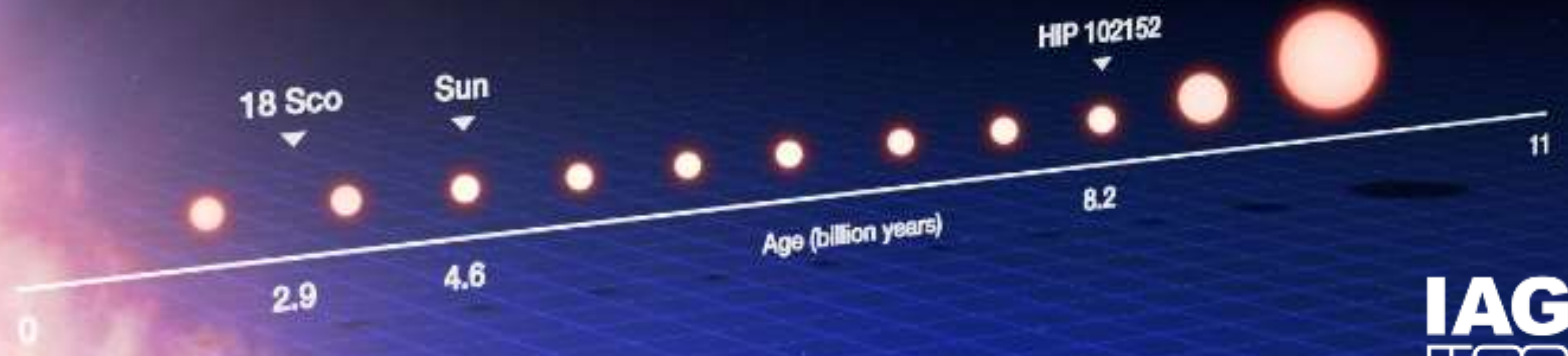
Dos astrónomos nacionales han hecho un descubrimiento que abonaría a la tesis de que la Tierra no es el único planeta del univers donde existe vida.

Jorge Meléndez, del Observatorio Stromlo de Australia, e Iván Ramírez, del Observatorio Mc Donald en Texas (EEUU), son los compatriotas que descubrieron la existencia de una estrella que, p sus características, podría ser considerada gemela del sol y que, parecer, tiene todas las condiciones para albergar planetas como Tierra.

HIP 102152: o mais velho gêmeo do Sol

novas pistas para solucionar o "mistério do lítio"

TalaWanda Monroe & Jorge Meléndez (IAG/USP)



Equipe internacional

Brasil: TalaWanda Monroe, Jorge Meléndez, Marcelo Tucci Maia, Fabrício Freitas (USP), Matthieu Castro, José Dias do Nascimento (UFRN)

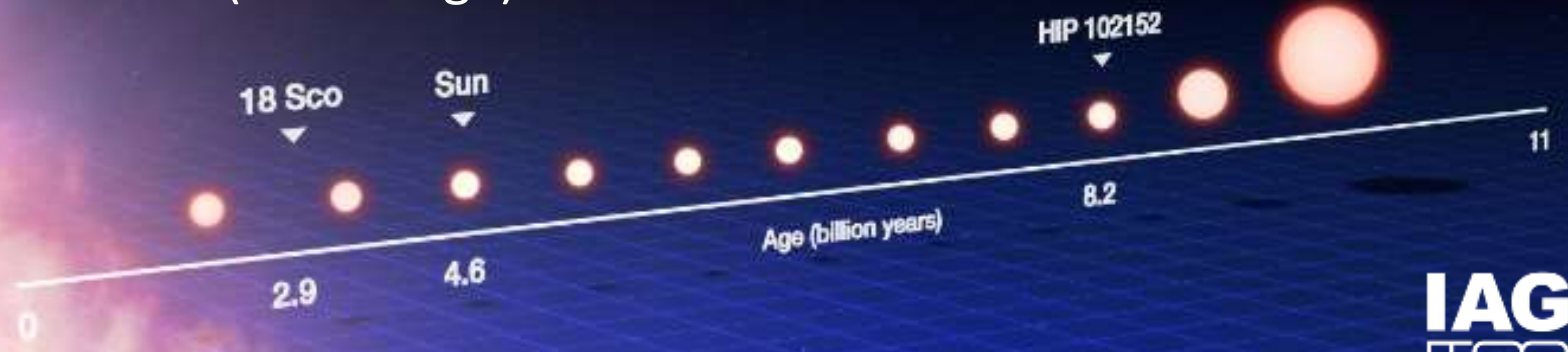
Estados Unidos: Iván Ramírez (Univ. Texas at Austin), Jacob Bean, Megan Bedell (Univ. Chicago);

Austrália: David Yong, Martin Asplund, Alan Alves-Brito, Luca Casagrande (ANU)

Portugal: Michael Bazot (Univ. Porto)

Alemanha: Maria Bergemann (Max Planck Institute)

Inglaterra: Karin Lind (Cambridge)



Solar Twins: Defined

- **Solar type stars** – late F, G, early K
- **Solar analogs** – about G2V and factor of 2 in composition
- **Solar twins** – very rare – stars with similar temperature (within 100 K), gravity and composition (0.1 dex) to the Sun's values.

Can also be defined as 1 solar mass stars with composition similar to the Sun

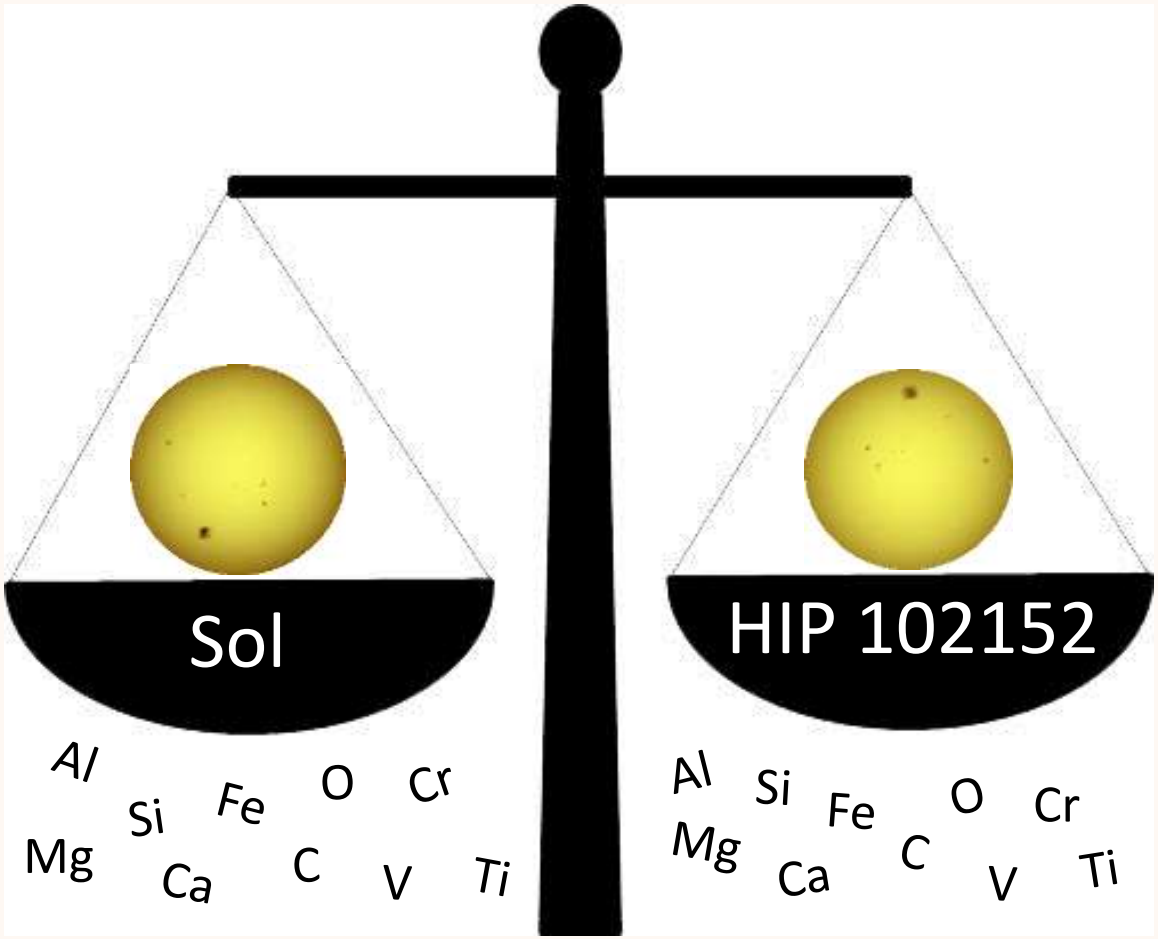
- **Solar sibling** – would be a star born from same natal cloud as the Sun. Could be any spectral type.

HIP 102152

- Situada na constelação do Capricórnio
- Distância: 250 anos-luz
- Estrela fraca (V = 9) mas visível em telescópios amadores

HIP 102152

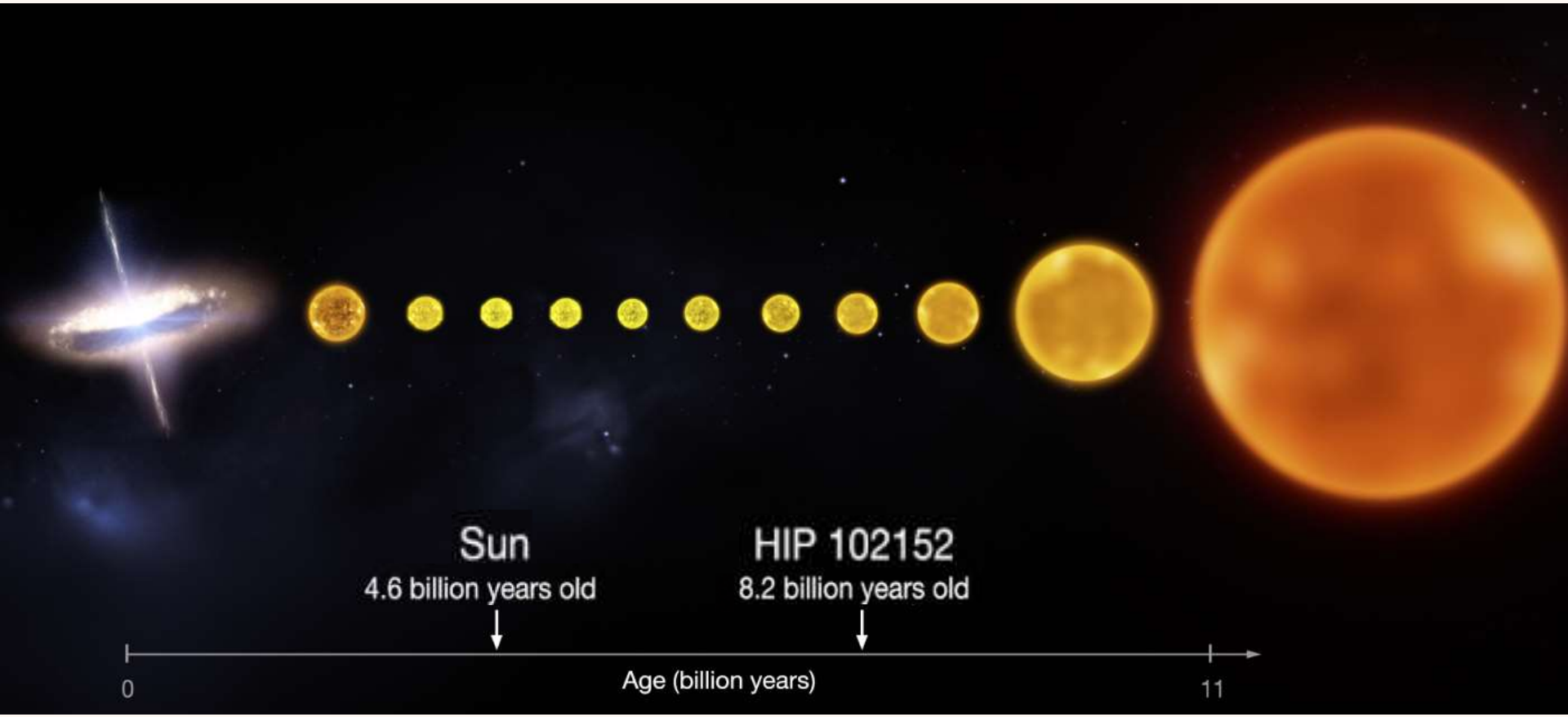
- Estrela mais parecida com o Sol em sua massa e composição química (gêmeo do Sol)



Composição química adequada para formar planetas como a Terra

HIP 102152

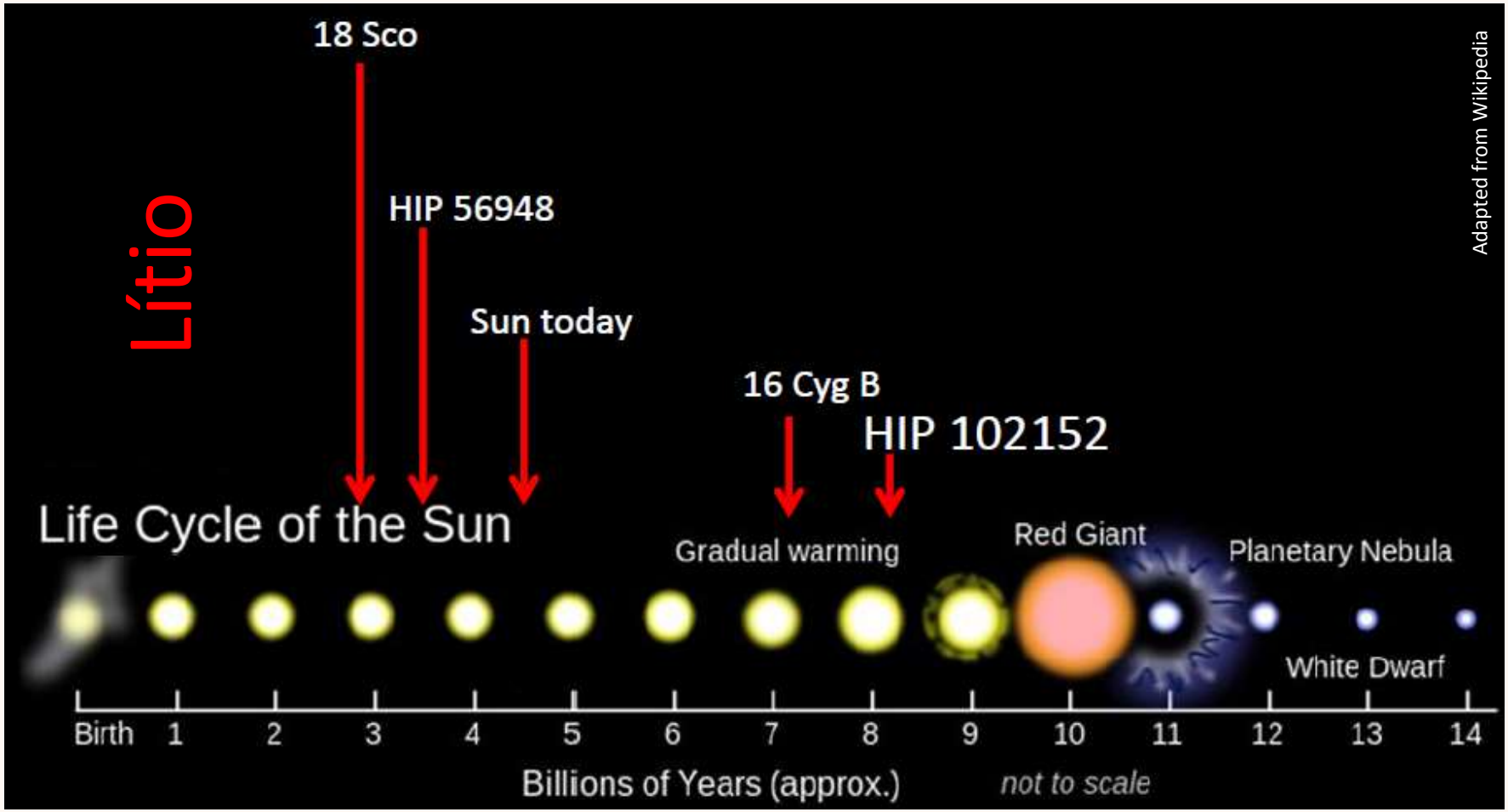
- O mais velho gêmeo do Sol identificado até agora (8,2 bilhões de anos)



Oportunidade sem precedentes de ver como será o Sol ao envelhecer

HIP 102152

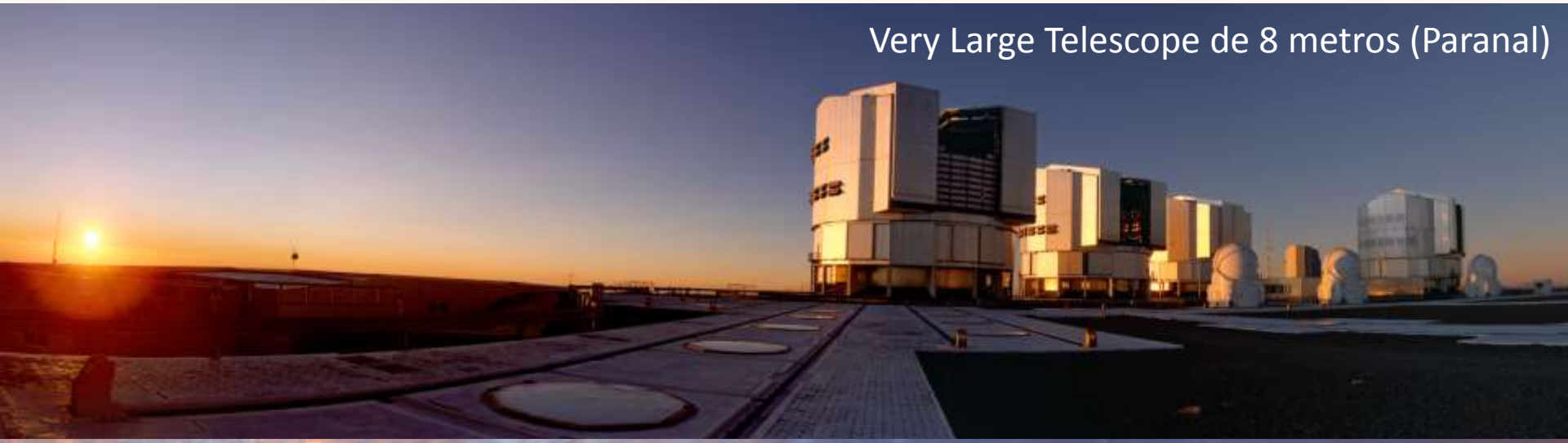
- Baixíssimo lítio para um gêmeo solar



HIP 102152 e outros gêmeos ajudaram a resolver o mistério do lítio

Como foi feito o trabalho?

- Usando observações obtidas no **ESO (Observatório Europeu do Sul).**
  Não existe instrumentação adequada no Gemini ou SOAR



Very Large Telescope de 8 metros (Paranal)

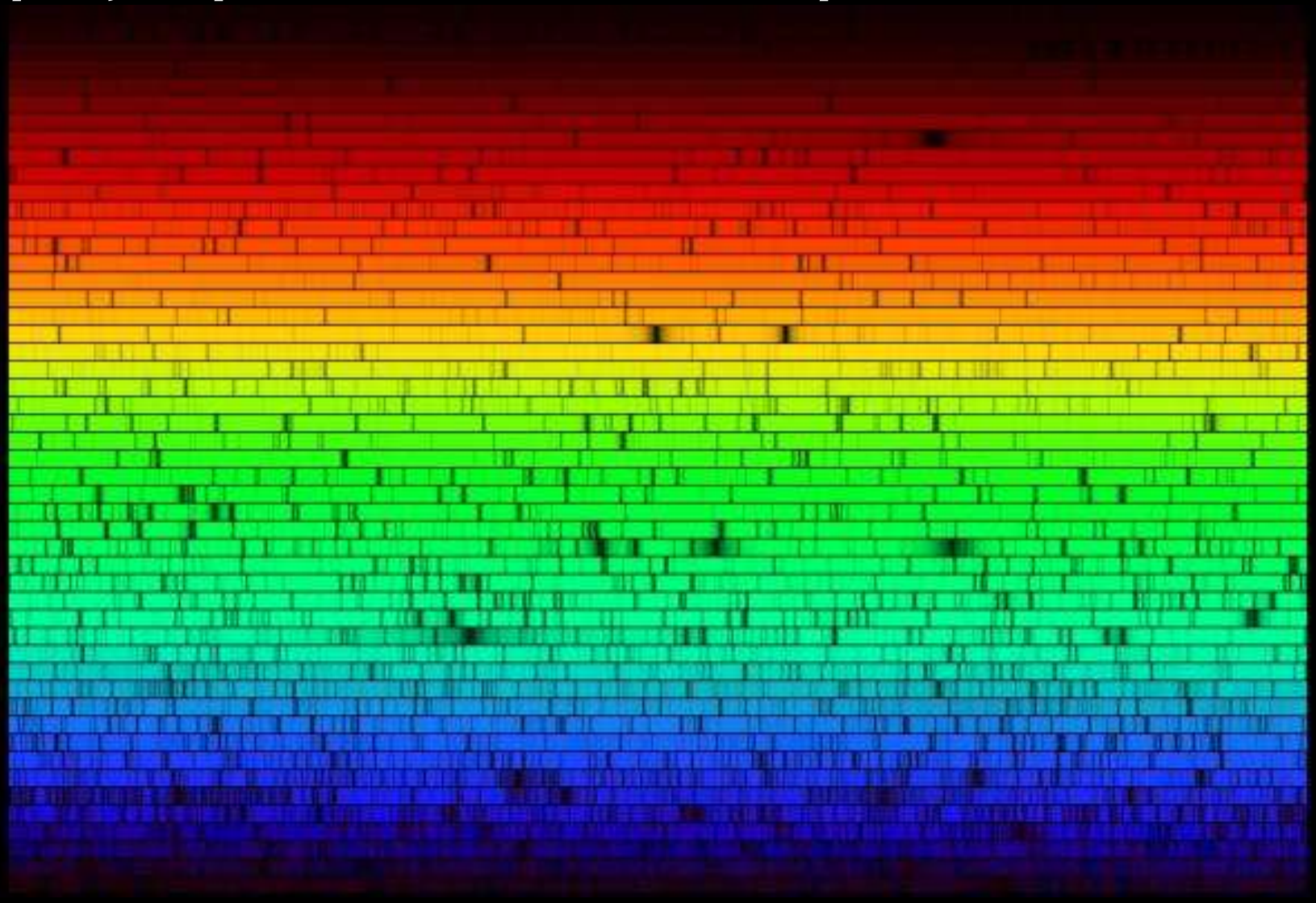
Telescópio de 3,6 metros (La Silla)

VLT control room
UVES spectrograph

La Silla
HARPS
spectrograph

Usamos a técnica de espectroscopia:

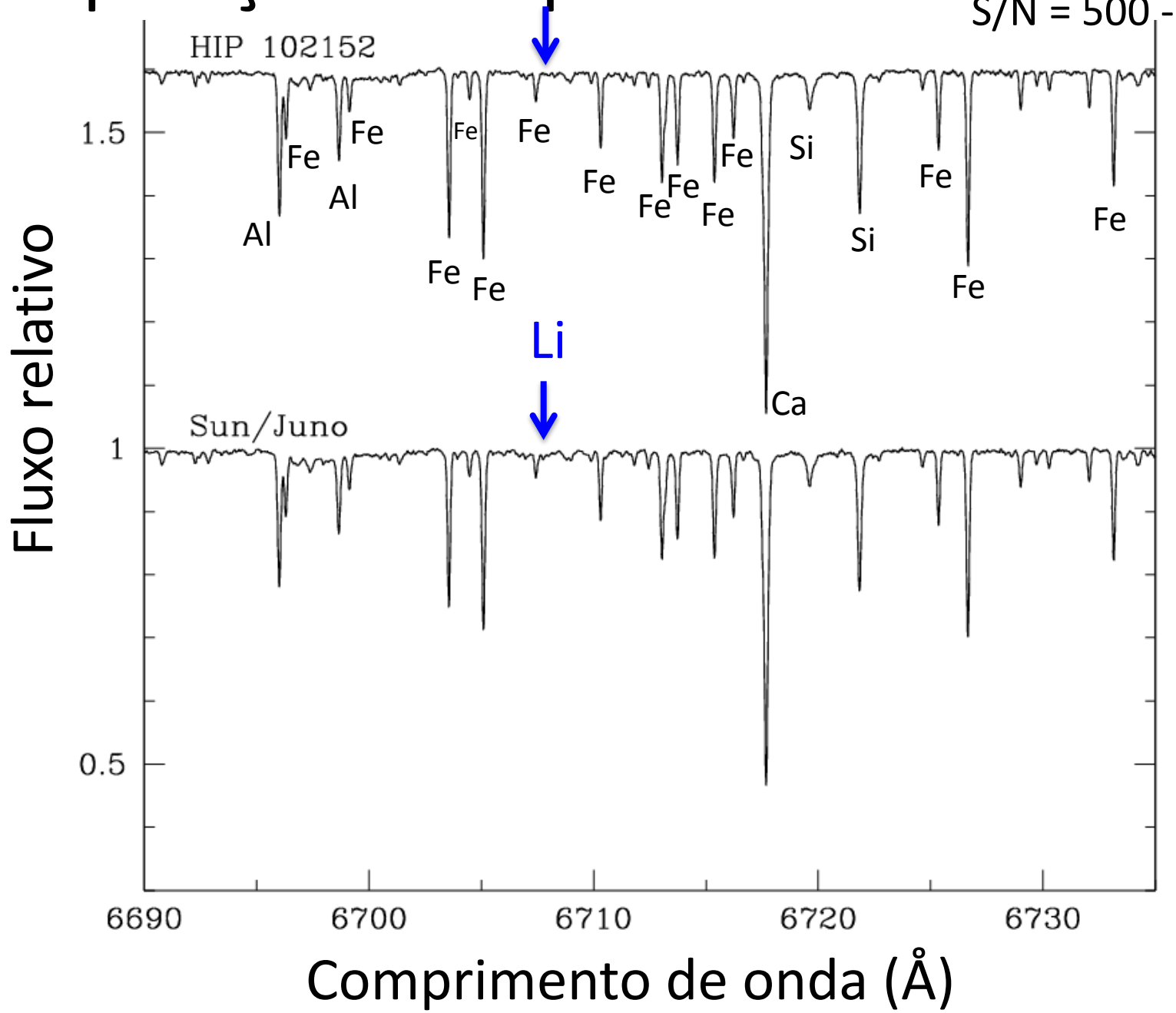
propriedades da estrela (temperatura, gravidade, massa, idade), composição química, atividade estelar, planetas



NOAO

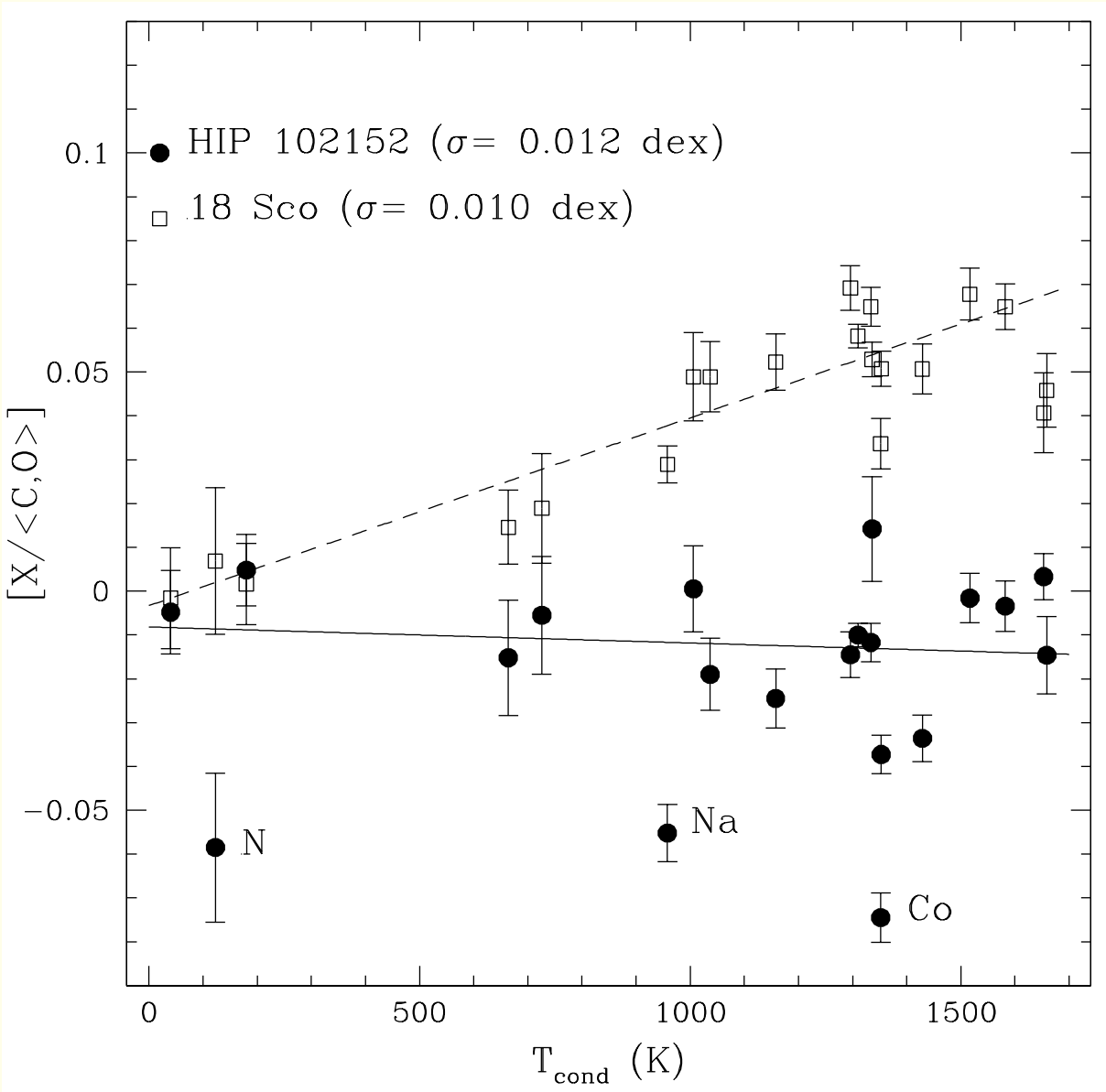
Comparação de espectros

R = 110 000
S/N = 500 - 1000



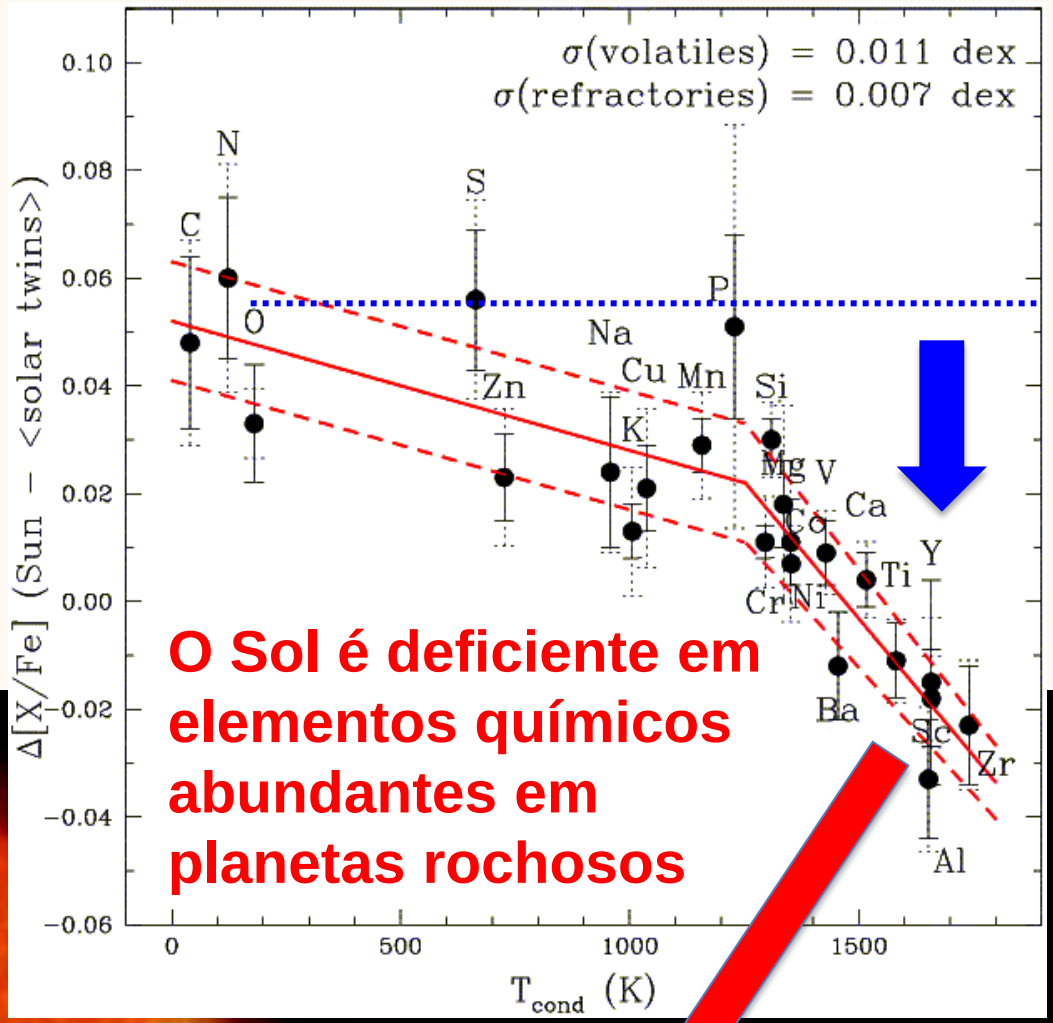
HIP 102152: Most “solar-like” abundance pattern

- 8.2 Gyr
- 3% fewer metals than Sun
- HIP 102152 has a solar abundance pattern
- Refractory elements depleted compared to other solar twins
- ΔTeff = -54K, Δlog g = -0.09 dex, Δv_t =0.00 km s^{-1}



Monroe, Meléndez, Ramírez et al. (2013)

Meléndez et al. 2009



O Sol é deficiente em elementos químicos abundantes em planetas rochosos

Porque HIP 102152 poderia ter planetas rochosos?

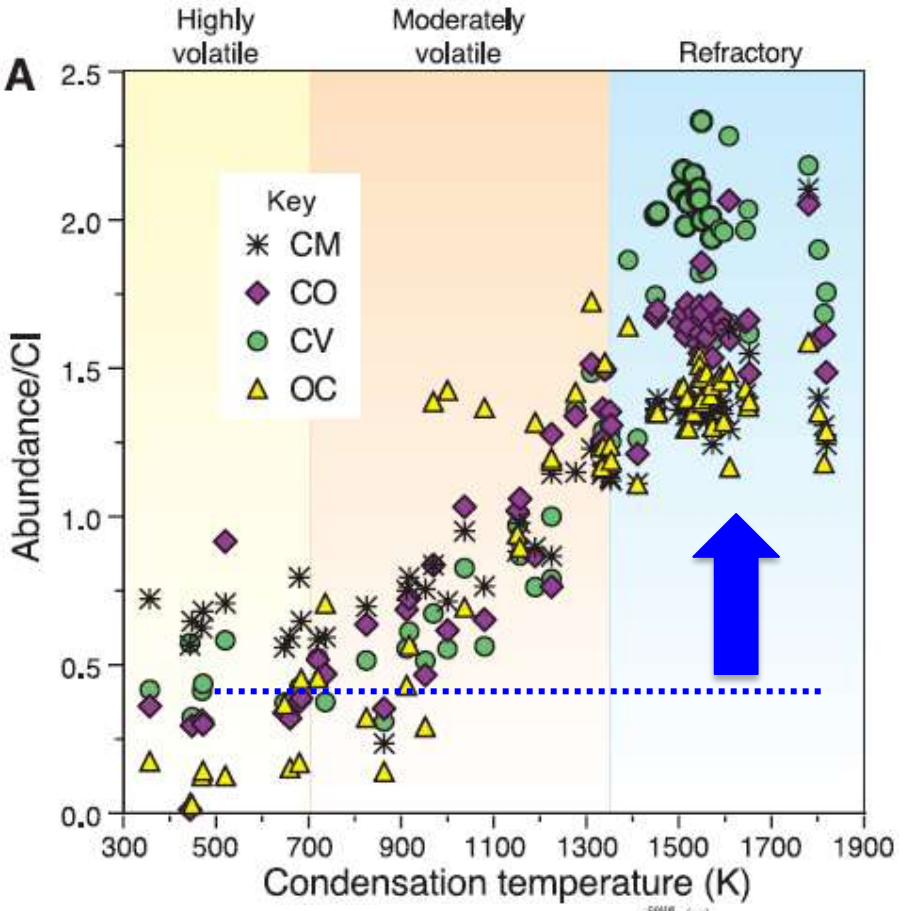
Tem composição similar ao Sol

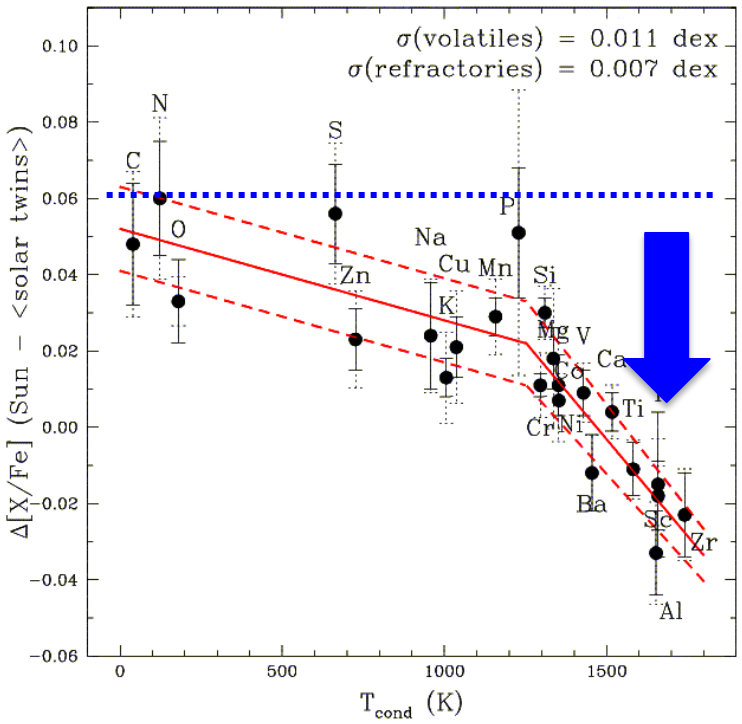
Relation with terrestrial planet formation:

T_{cond} trend in meteorites

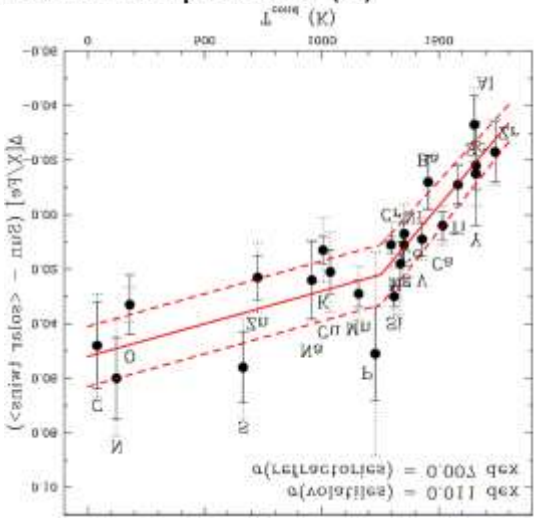
Alexander et al. (2001)

Fig. 2. (**A**) The CI chondrite normalized elemental abundances in bulk carbonaceous (CM, CO, and CV) and ordinary chondrites (OC) (*53*) versus their 50% condensation temperatures (*54*). The correlation between abundance and condensation temperature (volatility) is striking. The elements are divided into refractory (>1350 K), moderately volatile (700 to 1350 K), and highly volatile (<700 K). The common





The abundance pattern seen in meteorites is a mirror-image of the Sun's chemical composition



Relation with terrestrial planet formation:
Amount of dust removed from the Sun is enough to form terrestrial planets

How much dust-cleansed gas is required to affect the Sun in this way?

Assume gas accretion until solar convection zone reached ~ present size (~0.02 M_{sun}):

Refractories depleted in the Sun: ~2*10^{28} g ≈ 4 $M_{\oplus}$

Refractories locked-up in terrestrial planets: ~8*10^{27} g ≈ 1.3 $M_{\oplus}$

Large Programme: **88 nights at La Silla**
3.6m telescope + HARPS spectrograph

Procura de planetas em gêmeas solares

PI: Jorge Meléndez (IAG/USP)

Collaborators:

Brazil: T. Monroe, F. Freitas, M. Tucci Maia (IAG/USP)

Australia: Alan Alves Brito,
M. Asplund, L. Casagrande

USA: I. Ramírez, J. Bean

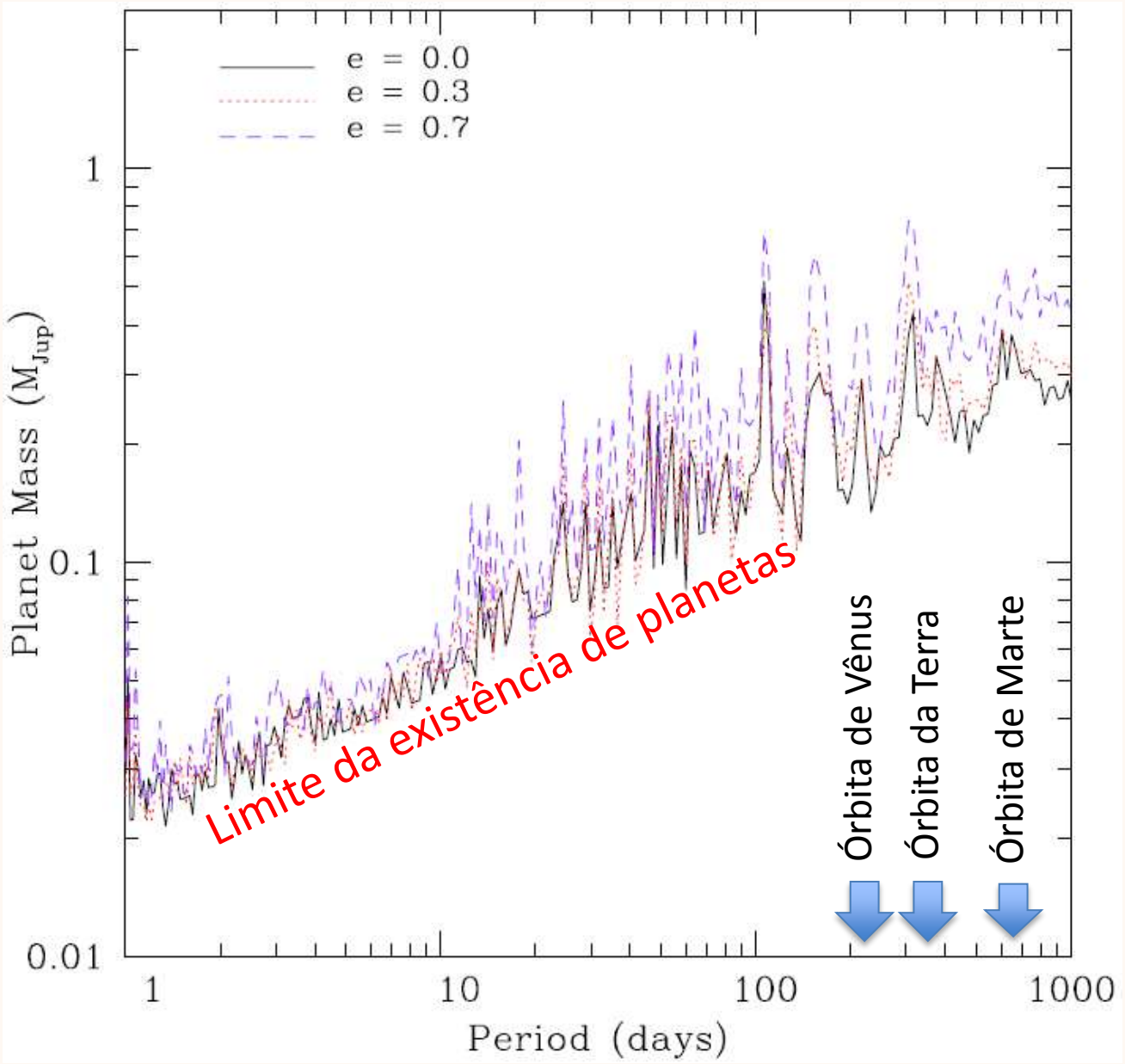
Germany: S. Dreizler

UK: Karin Lind

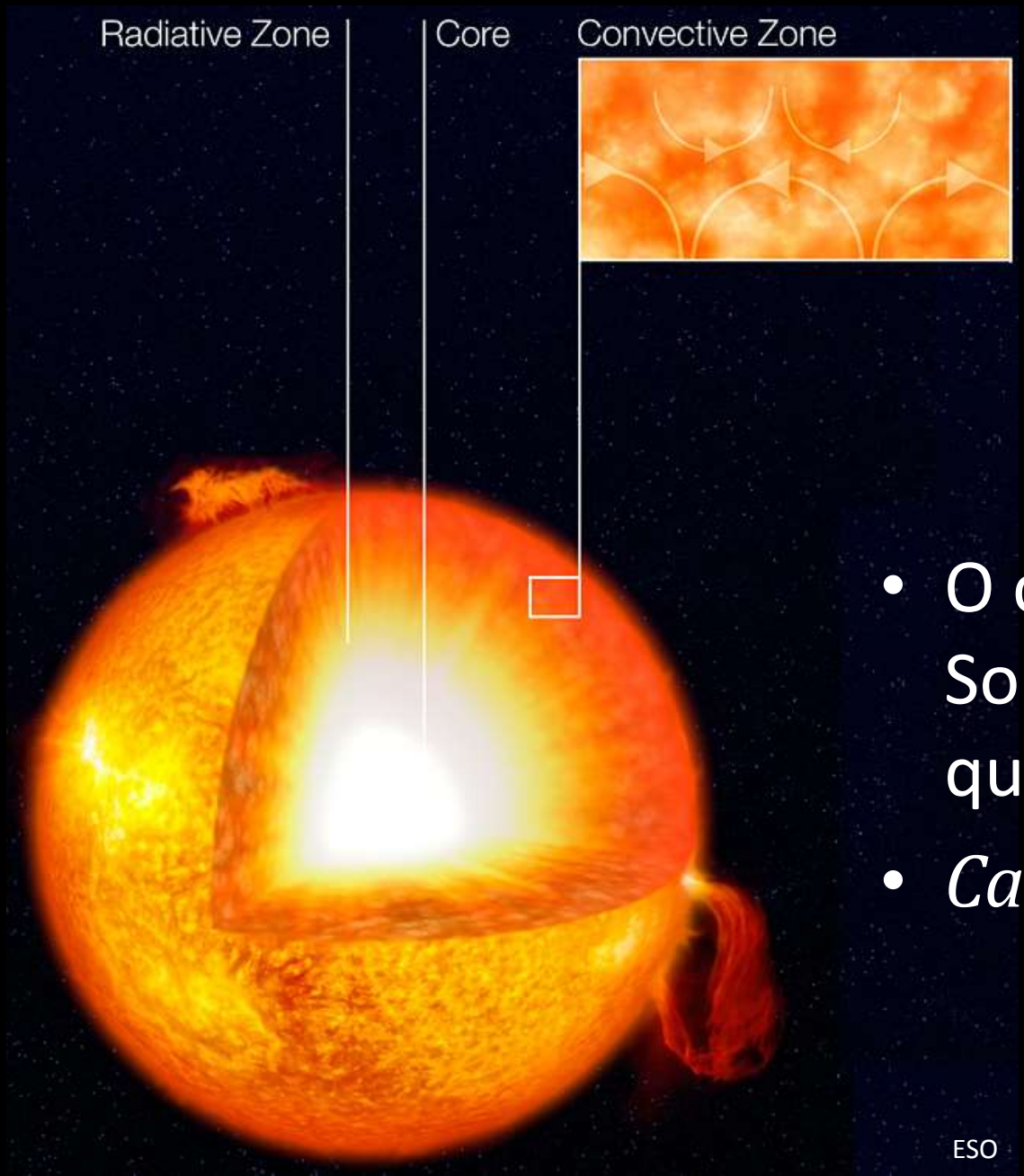
Há planetas em torno de HIP 102152?

- Não existem planetas gigantes na região habitável

Pequenos planetas rochosos (como a Terra) podem existir!



O mistério do lítio no Sol

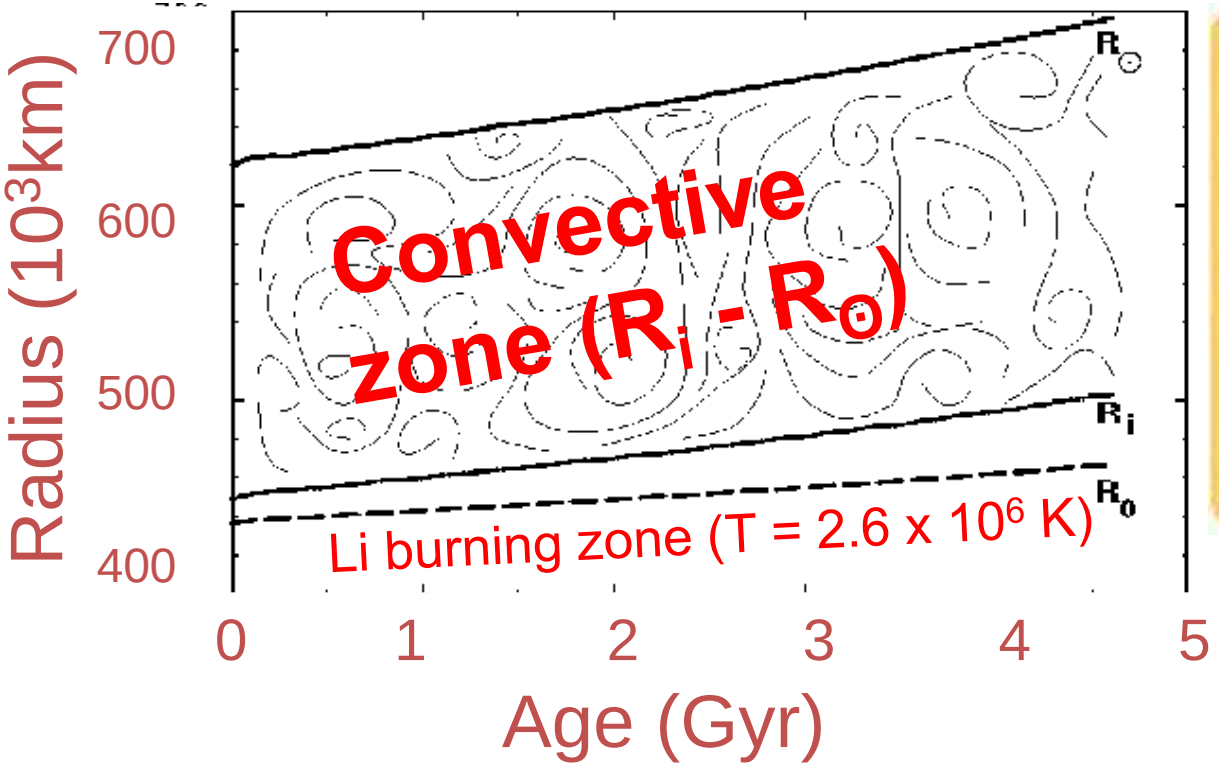


ESO


www.kgs.ku.edu/

- O conteúdo de lítio no Sol é 160 vezes menor que o de meteoritos.
- *Cadê o lítio do Sol?*

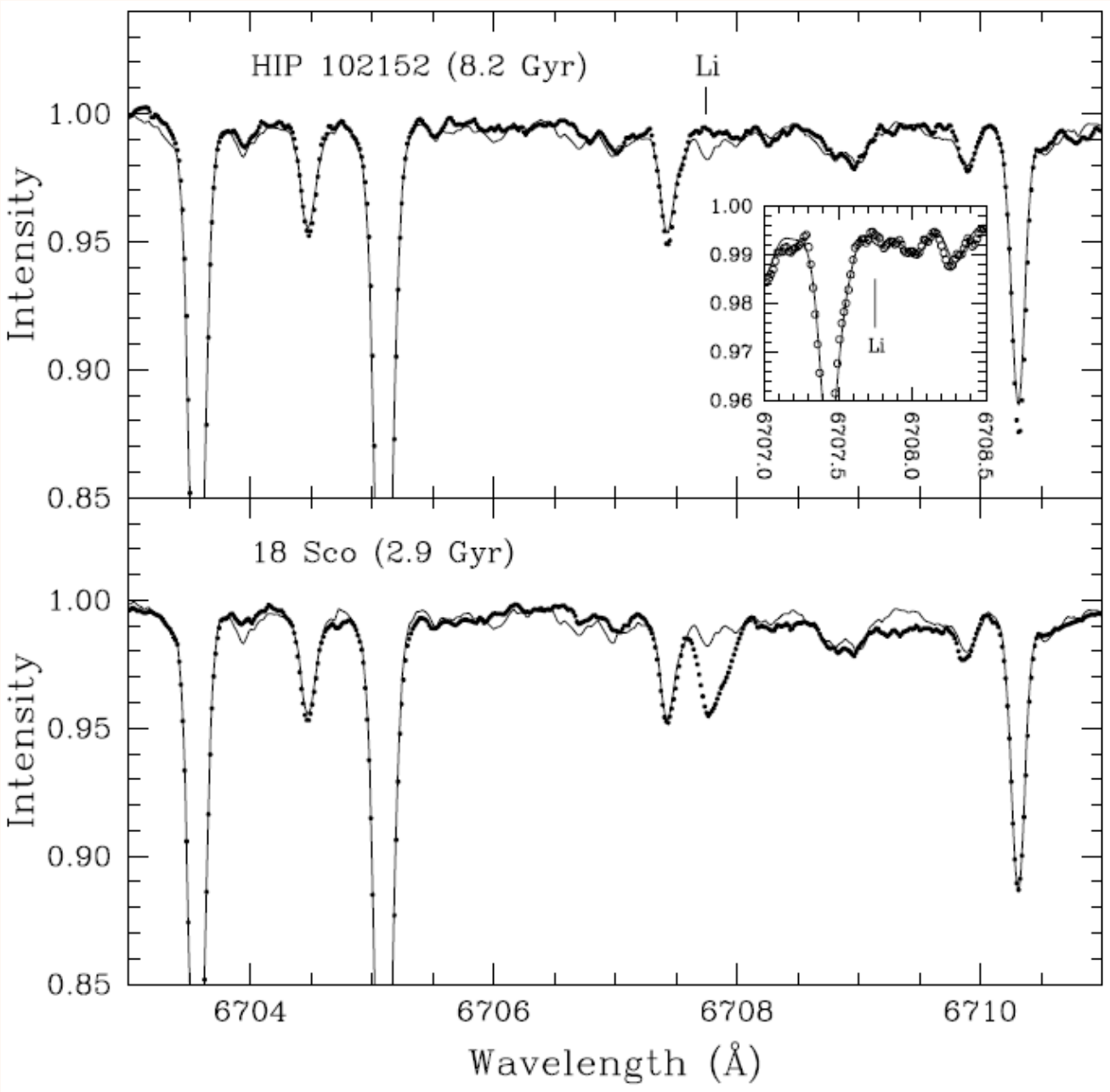
Problema da baixa abundância de lítio no Sol



$$p + {}^{7}_{3}Li \rightarrow {}^{8}_{4}Be \quad \text{(unstable)}$$

$${}^{8}_{4}Be \rightarrow 2\,{}^{4}_{2}He + \text{energy}$$

Comparação da linha de Li

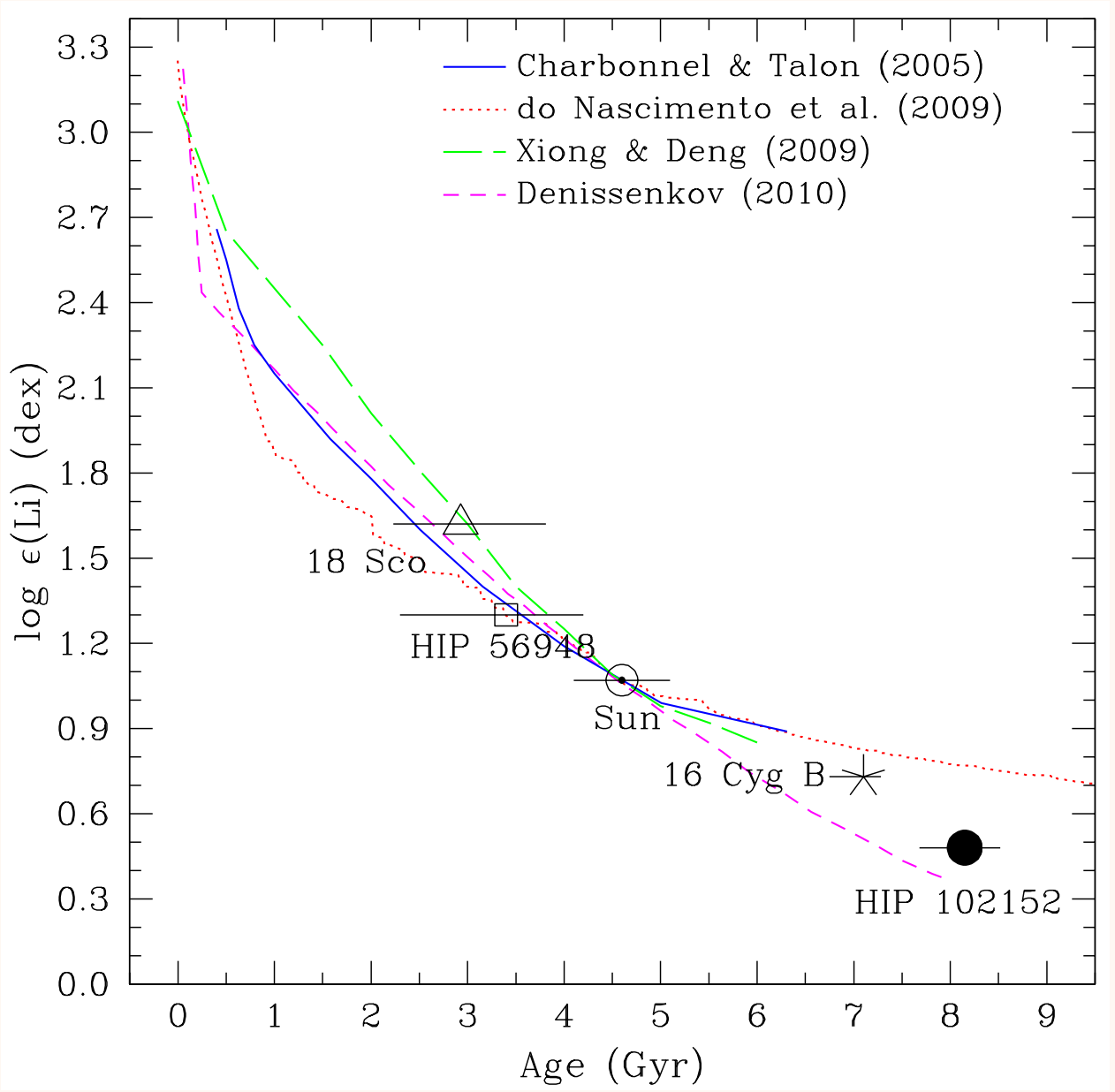


Monroe, Meléndez, Ramírez et al. (2013)

Explicando o “mistério” do lítio

- Mistério de 60 anos é explicado pela correlação entre lítio e idade

O Sol é normal em lítio para a sua idade!



The Astrophysical Journal Letters, 774:L32 (6pp), 2013 September 10 doi:10.1088/2041-8205/774/2/L32

HIGH PRECISION ABUNDANCES OF THE OLD SOLAR TWIN HIP 102152: INSIGHTS ON Li DEPLETION FROM THE OLDEST SUN*

TalaWanda R. Monroe[1], Jorge Meléndez[1], Iván Ramírez[2], David Yong[3], Maria Bergemann[4], Martin Asplund[3], Megan Bedell[5], Marcelo Tucci Maia[1], Jacob Bean[5], Karin Lind[6], Alan Alves-Brito[3], Luca Casagrande[3], Matthieu Castro[7], José-Dias do Nascimento[7], Michael Bazot[8], and Fabrício C. Freitas[1]

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ABSTRACT

We present the first detailed chemical abundance analysis of the old 8.2 Gyr solar twin, HIP 102152. We derive differential abundances of 21 elements relative to the Sun with precisions as high as 0.004 dex ($\lesssim$1%), using ultra high-resolution (R = 110,000), high S/N UVES spectra obtained on the 8.2 m Very Large Telescope. Our determined metallicity of HIP 102152 is [Fe/H] = -0.013 ± 0.004. The atmospheric parameters of the star were determined to be 54 K cooler than the Sun, 0.09 dex lower in surface gravity, and a microturbulence identical to our derived solar value. Elemental abundance ratios examined versus dust condensation temperature reveal a solar abundance pattern for this star, in contrast to most solar twins. The abundance pattern of HIP 102152 appears to be the most similar to solar of any known solar twin. Abundances of the younger, 2.9 Gyr solar twin, 18 Sco, were also determined from UVES spectra to serve as a comparison for HIP 102152. The solar chemical pattern of HIP 102152 makes it a potential candidate to host terrestrial planets, which is reinforced by the lack of giant planets in its terrestrial planet region. The following non-local thermodynamic equilibrium Li abundances were obtained for HIP 102152, 18 Sco, and the Sun: log ϵ (Li) = 0.48 ± 0.07, 1.62 ± 0.02, and 1.07 ± 0.02, respectively. The Li abundance of HIP 102152 is the lowest reported to date for a solar twin, and allows us to consider an emerging, tightly constrained Li-age trend for solar twin stars.

eso1337 — Science Release

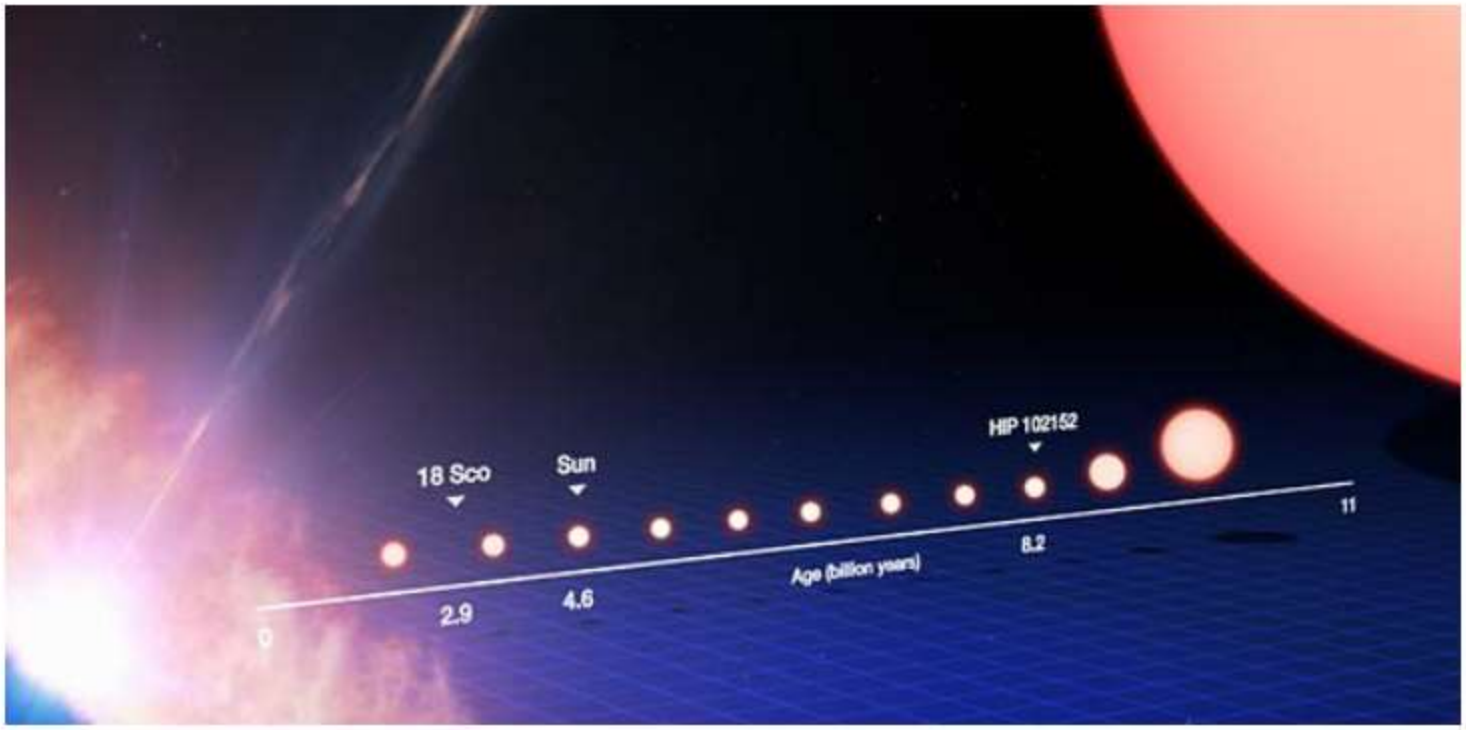
SPACE SCOOP

Choose your language:

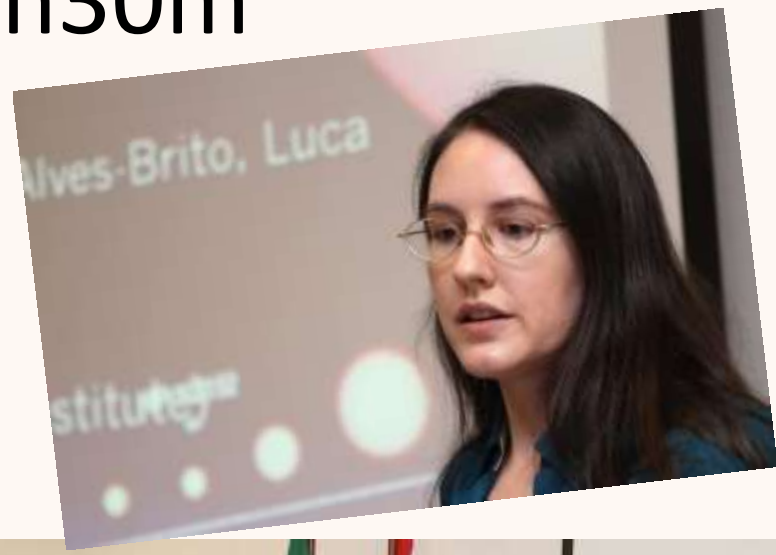
Oldest Solar Twin Identified

ESO's VLT provides new clues to help solve lithium mystery

28 August 2013



Coletiva de imprensa, Univ. São Paulo, 28/8/2013, 10h30m



Impacto na midia
(mais de 280 noticias)

- Sky & Telescope, Astronomy, Discovery Channel, Popular Science, Nature, Space …
- Fox News, NBC, La Tercera, Publico, EFE …
- Folha de Sao Paulo, Estadão, Jornal do Brasil
- Super Interessante, Info, Ciencia Hoje
- Veja, Epoca, Exame,
- TV Globo, SBT, RedeTV

Globo

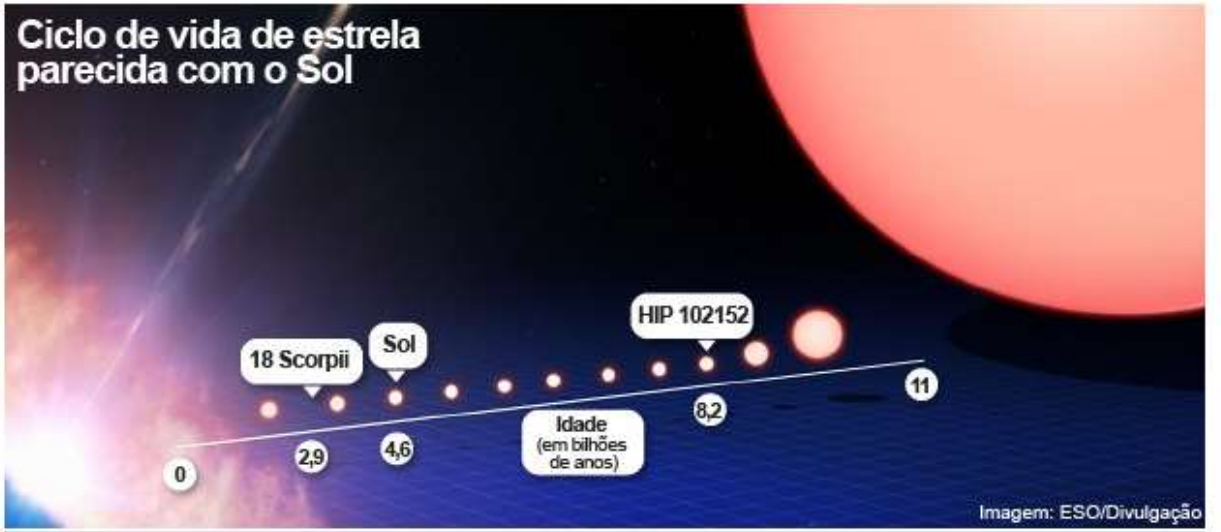
http://g1.globo.com/ciencia-e-saude/noticia/2013/08/equipe-da-usp-ajuda-descobrir-mais-velha-estrela-gemea-do-sol.html

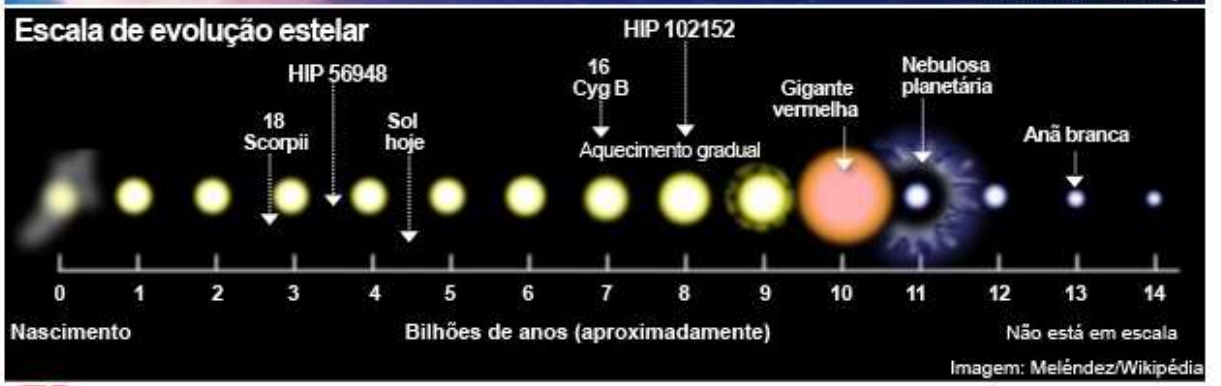
28/08/2013 10h29 - Atualizado em 29/08/2013 11h18

Equipe da USP ajuda a descobrir mais velha estrela 'gêmea' do Sol

HIP 102152 tem 8,2 bilhões de anos e fica a 250 anos-luz da Terra.
Estudo foi feito em parceria com o Observatório Europeu do Sul (ESO).

Luna D'Alama
Do G1, em São Paulo





G1.com.br

http://www.skyandtelescope.com/news/Sun-Loses-Lithium-with-Age-221836221.html

NEWS by Camille Carlisle

Sun Loses Lithium with Age

Observations of two solar twins — one old and one young — confirm that the Sun has probably destroyed its lithium over time.

I've blogged repeatedly here about the universe's missing lithium. But lithium is also a troublemaker in the solar system. Based on primitive meteorites that record the makeup of the nebula from which the solar system formed, the Sun seems to have destroyed more than 99% of its initial lithium.

CONCURSO CULTURAL

Serão aceitos os nomes enviados até as 23h59min do dia 18/10/2013

Conte a história do gêmeo do Sol!

Estrelas são identificadas na comunidade científica com códigos adotados em catálogos internacionais. Mas que tal criar um nome bem brasileiro para uma estrela parecida com o nosso Sol?

Para participar, envie para nós sua sugestão com um nome e uma história (real ou fictícia) para nossa estrela. Saiba mais no site:

www.iag.usp.br/astronomia/gemeosolar

1º prêmio: 01 Tablet Samsung Galaxy

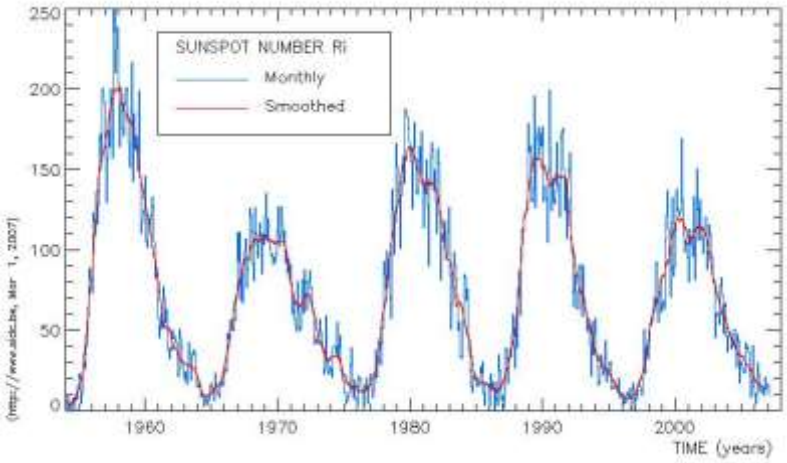
2º prêmio: 01 Telescópio de 60 – 70 mm

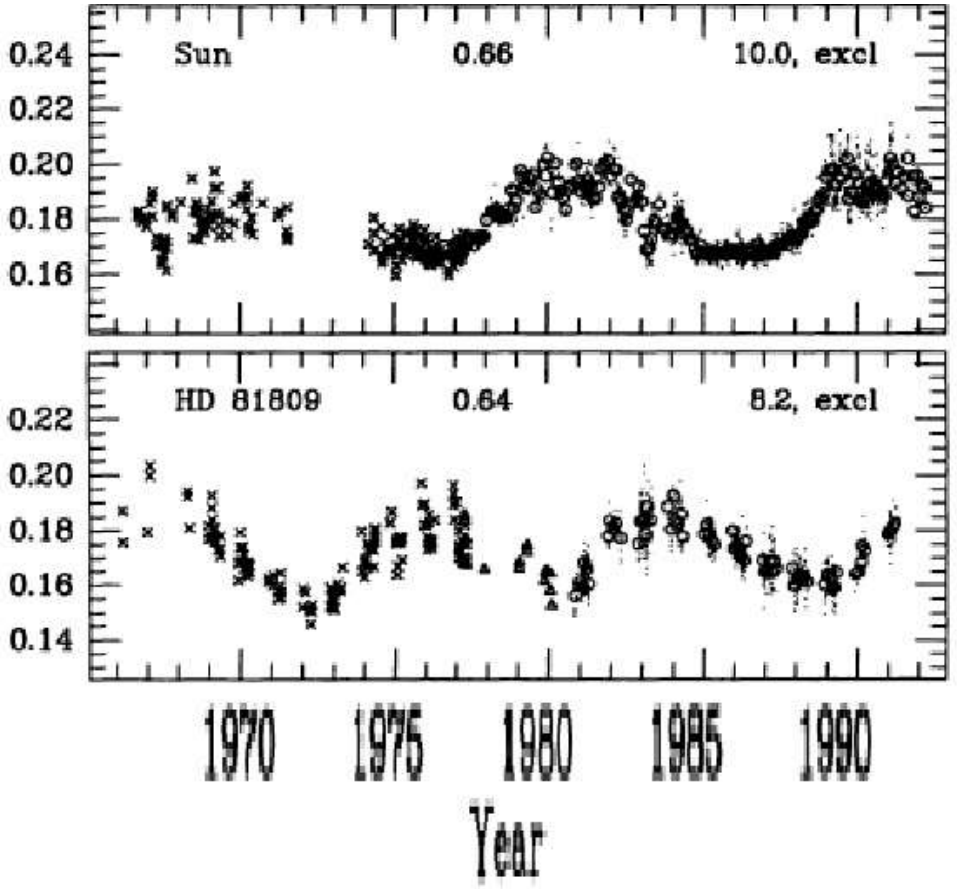
3º prêmio: conjunto de livros de Astronomia

O nome escolhido será informal e não substituirá o código HIP 102152. Este concurso não tem afiliação com a União Astronômica Internacional. Leia o regulamento no site www.iag.usp.br

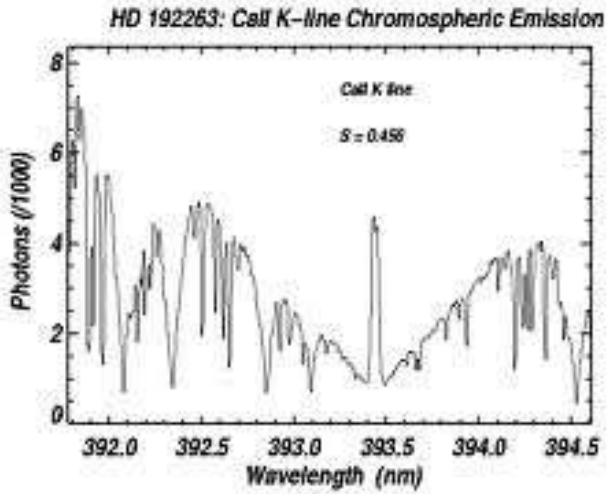
IAG USP

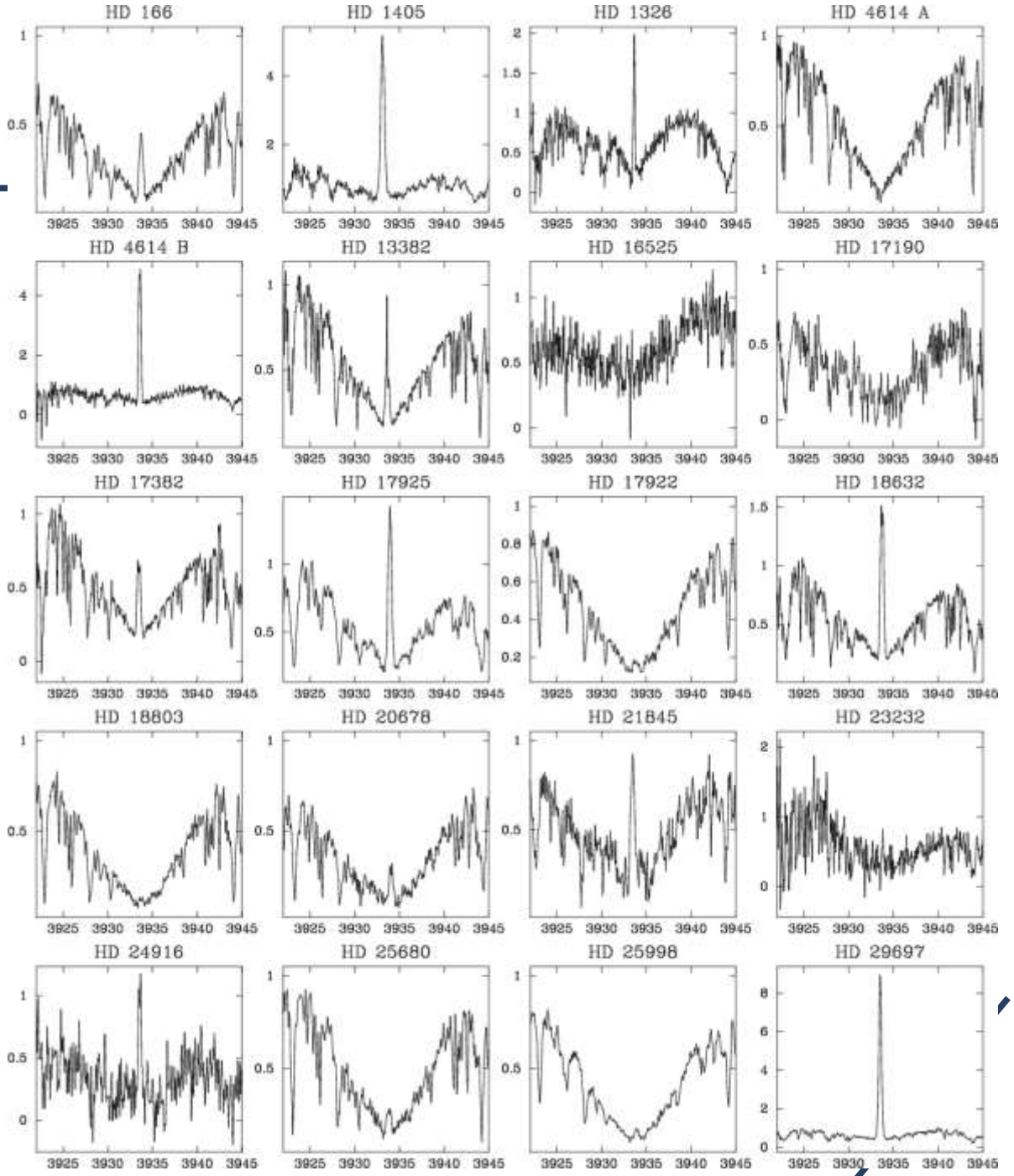
Atividade estelar





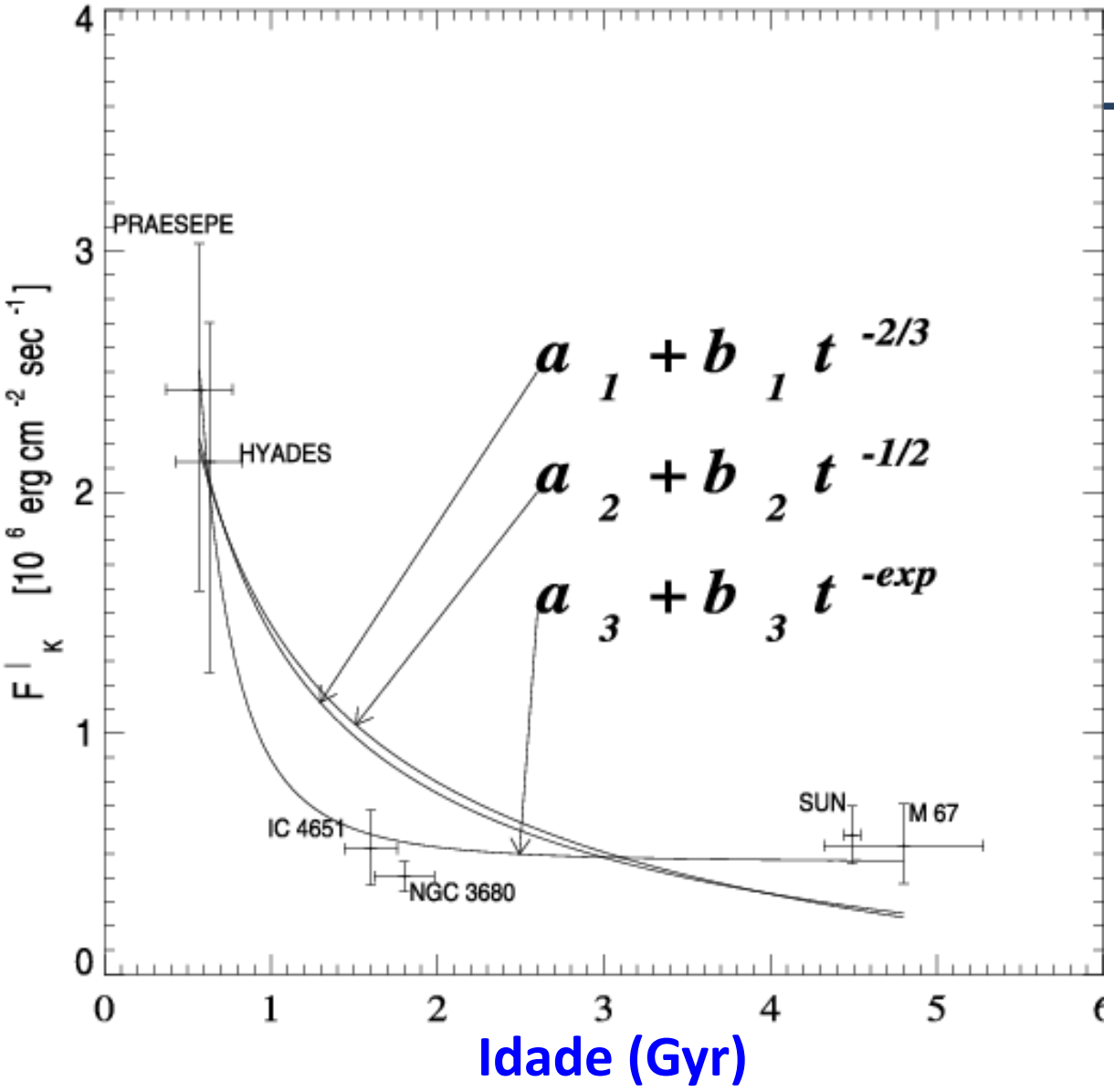
Atividade estelar (linhas de Ca II lines: H & K)



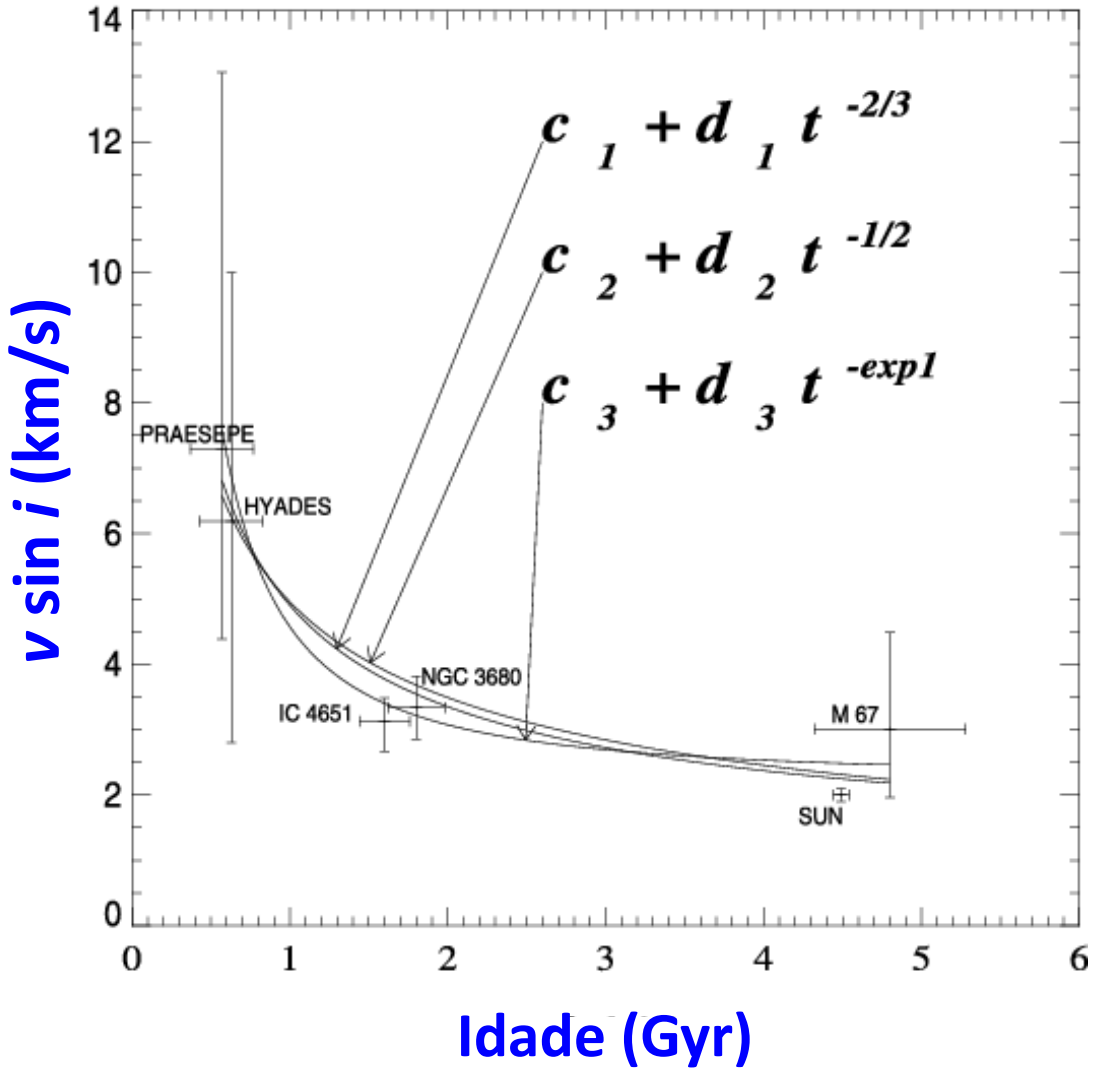


Conexão entre atividade estelar e idade

Excesso do Fluxo na linha K de CaII devido à atividade estelar

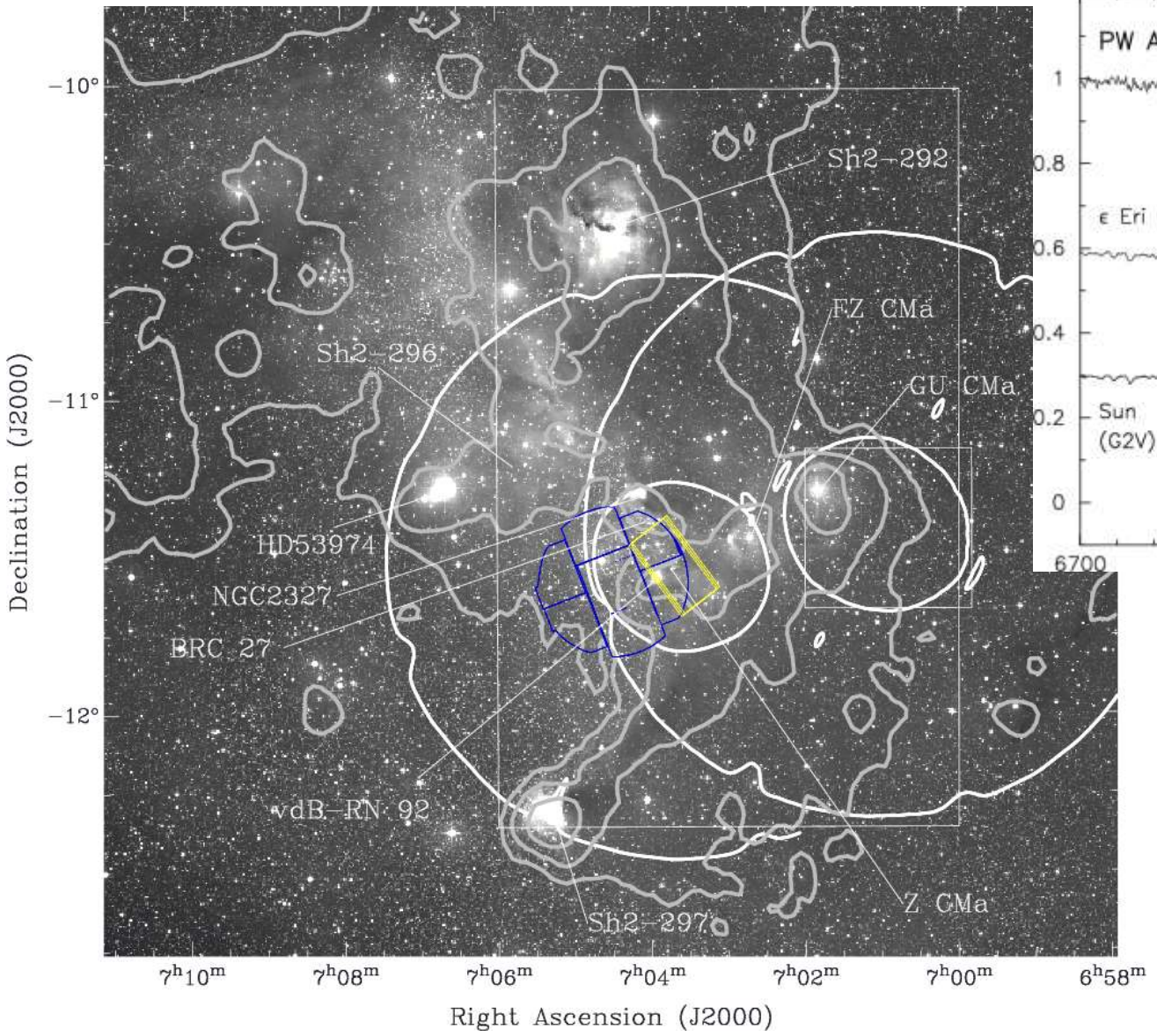


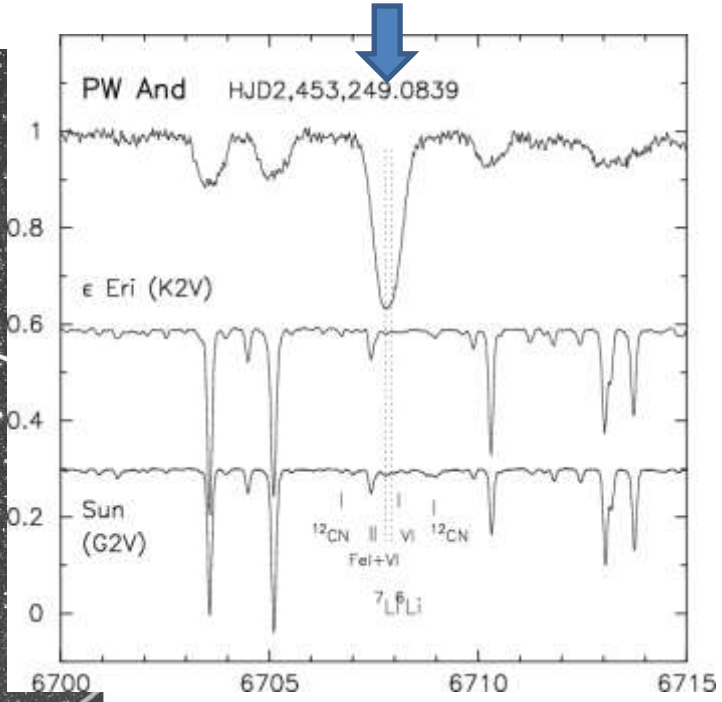
Conexão entre velocidade de rotação e idade



Estrelas jóvens

Lítio em estrela jovem





CMa R1 star-forming region

Profa. Jane Gregorio-Hetem