03/09/2010

Seminários de Iniciação Científica (Astronomia)

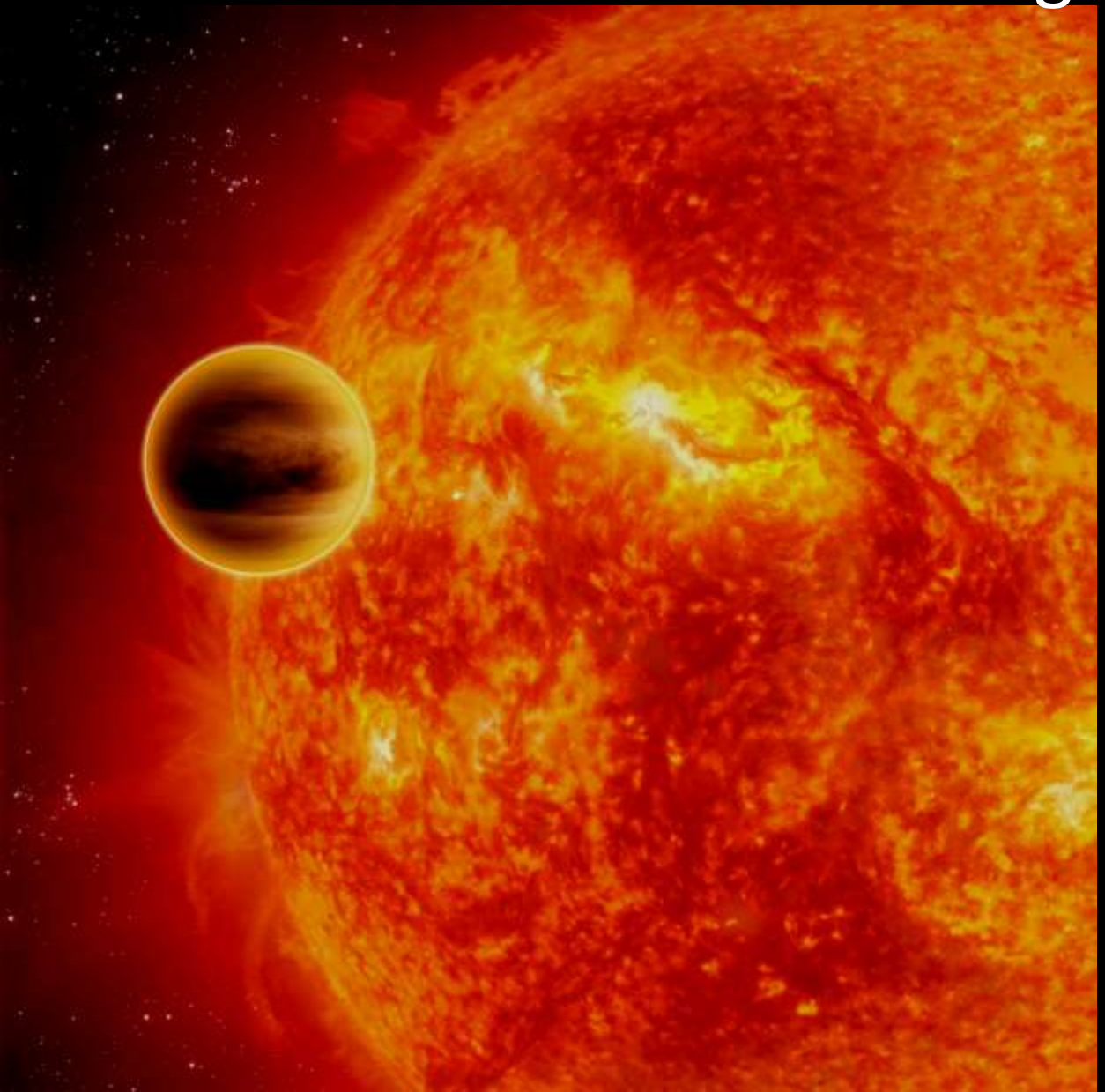
Em busca de gêmeos do sistema solar

Jorge Meléndez

Departamento de Astronomia do IAG/USP

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

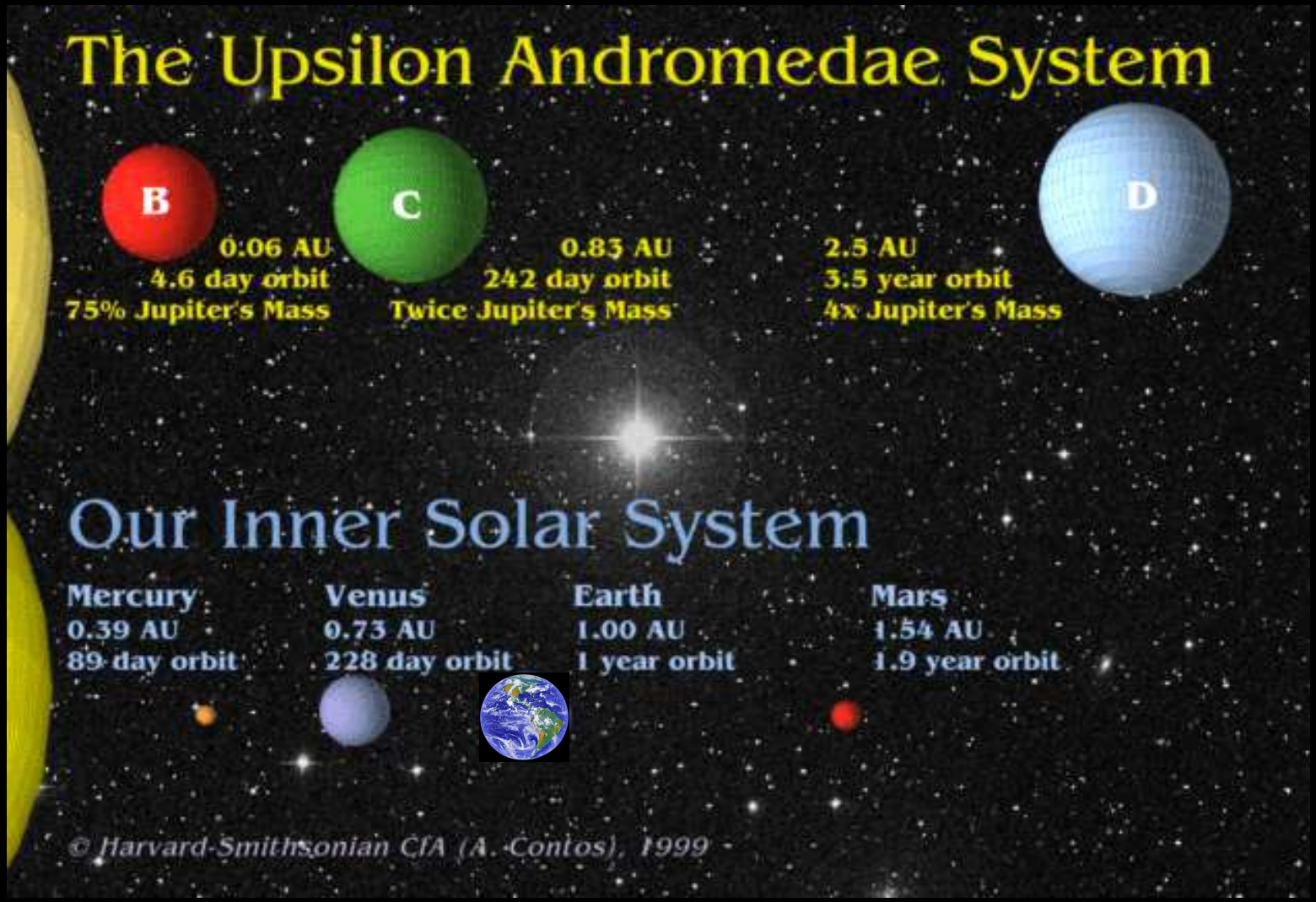
~ 400 sistemas planetários encontrados até agora



No entanto, a maioria deles não se parece em nada com nosso sistema solar

C. Carreau / ESA

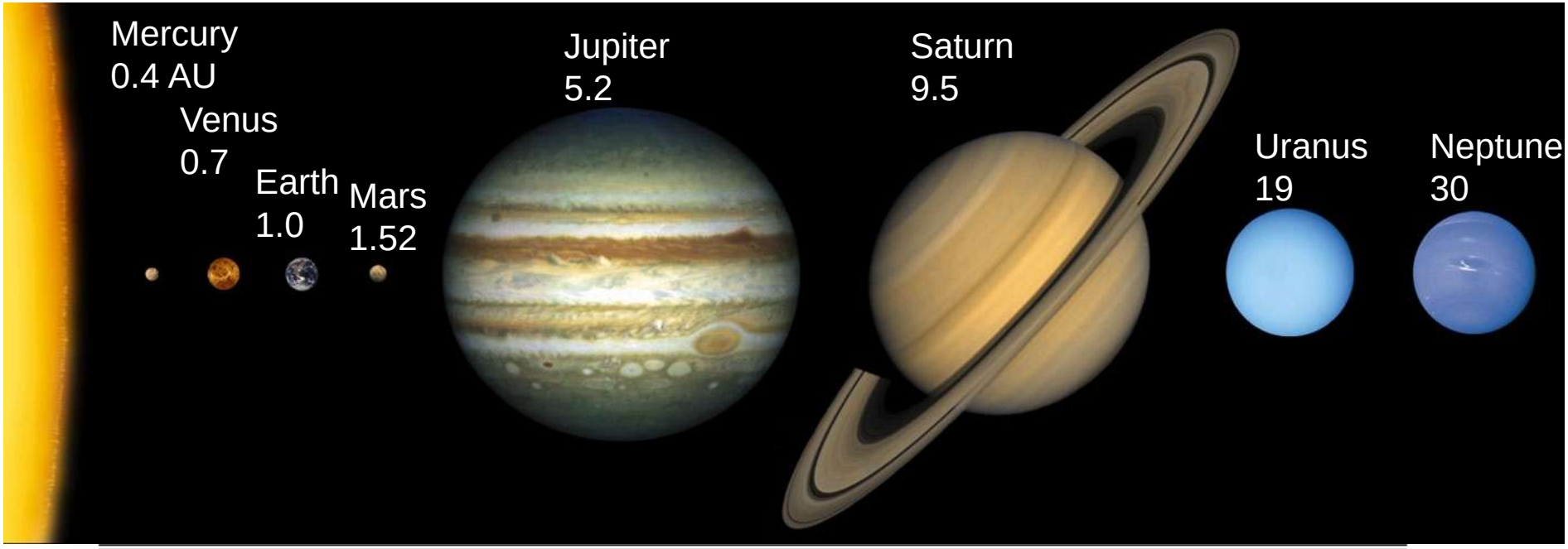
A maioria de sistemas planetários encontrados tem planetas gigantes internos, mas em nosso sistema solar os planetas internos são rochosos



Descoberto o Sistema Planetário Mais Rico em Planetas Conhecido Até Agora

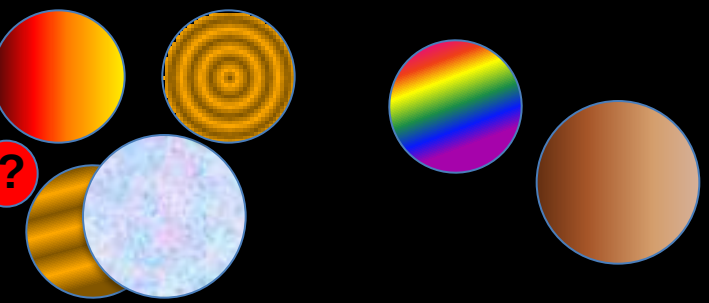
Até sete planetas em órbita de uma estrela do tipo solar (24 Agosto 2010)

Planetas em torno do Sol



Parameter	[unit]	HD 10180 b	HD 10180 c	HD 10180 d	HD 10180 e	HD 10180 f	HD 10180 g	HD 10180 h
$m \sin i$	$[M_\oplus]$	1.40 (±0.25)	13.16 (±0.59)	11.91 (±0.75)	25.3 (±1.4)	23.5 (±1.7)	21.3 (±3.2)	65.2 (±4.6)
a	[AU]	0.02226 (±0.00038)	0.0641 (±0.0010)	0.1286 (±0.0021)	0.2695 (±0.0048)	0.4924 (±0.0083)	1.422 (±0.030)	3.40 (±0.12)

Lovis et al. 2010

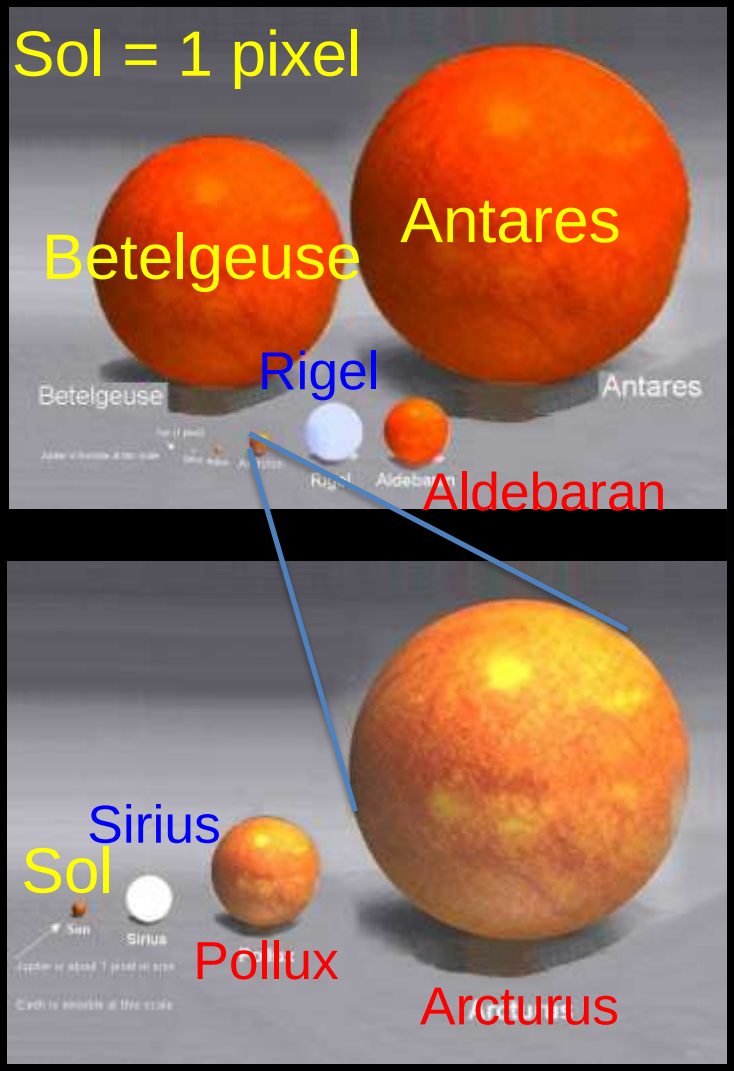


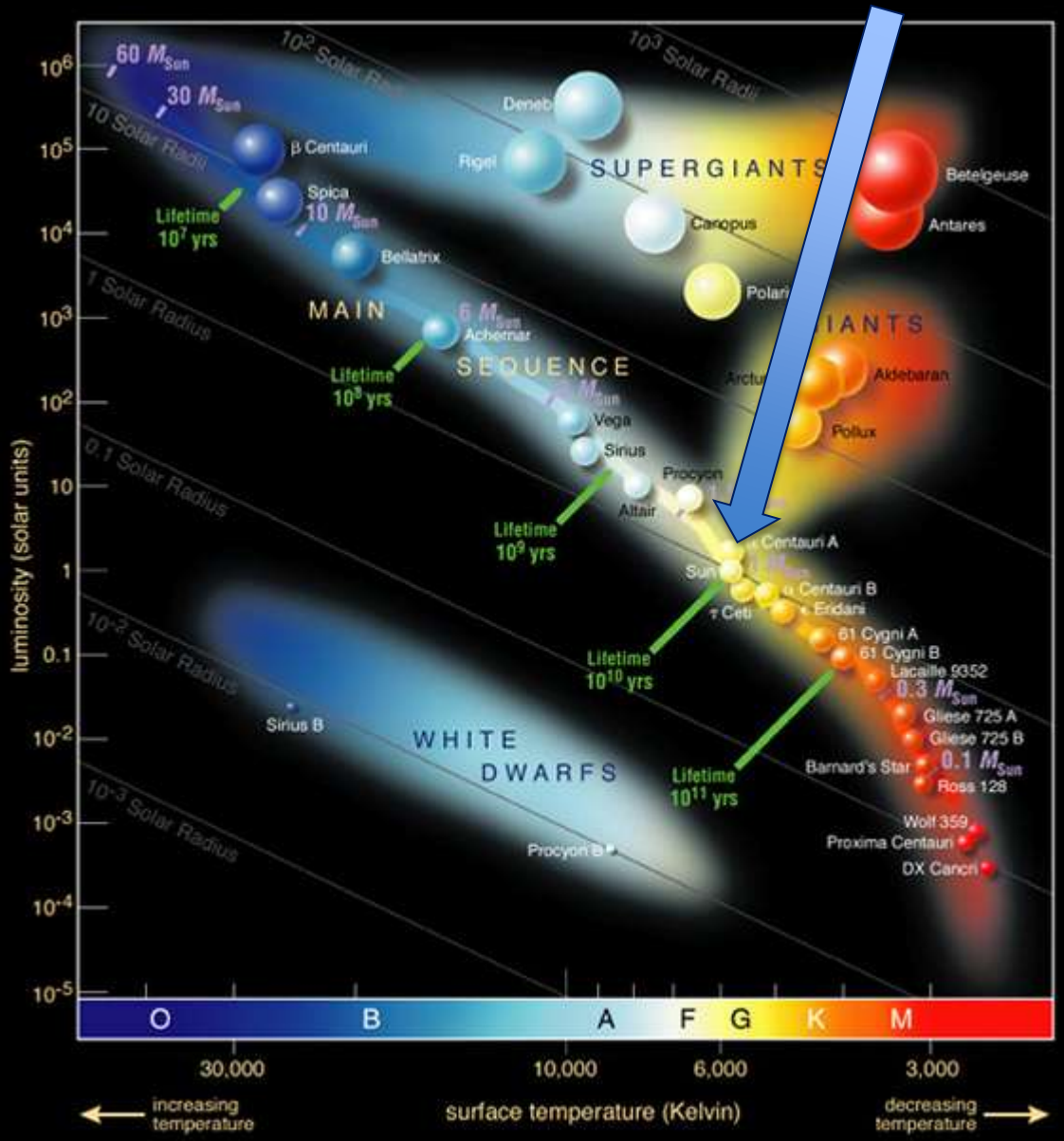
Planetas em torno de HD 10180

Como encontrar um sistema solar parecido ao nosso?

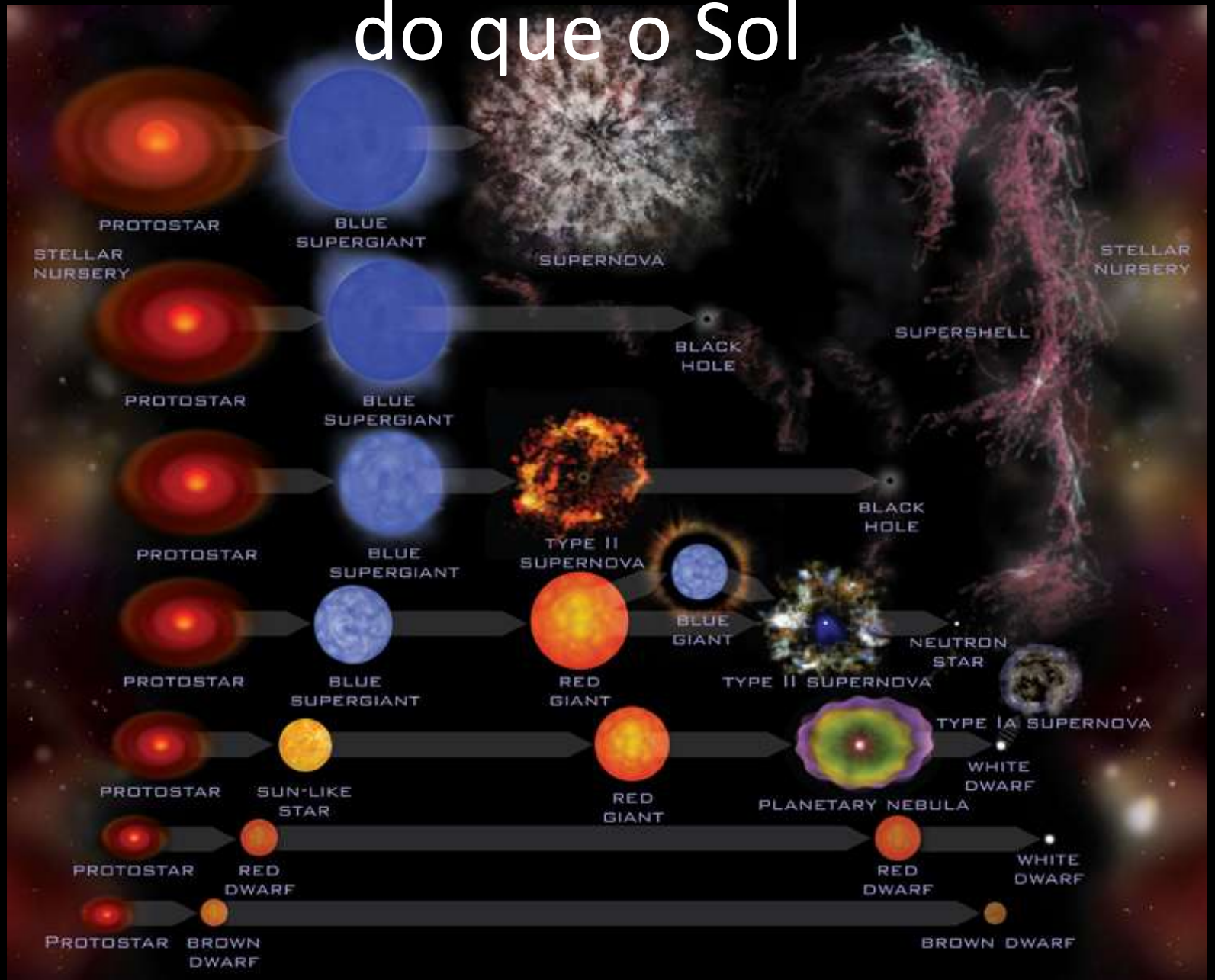
Credits: Nasa

1. Procurar estrelas similares ao Sol

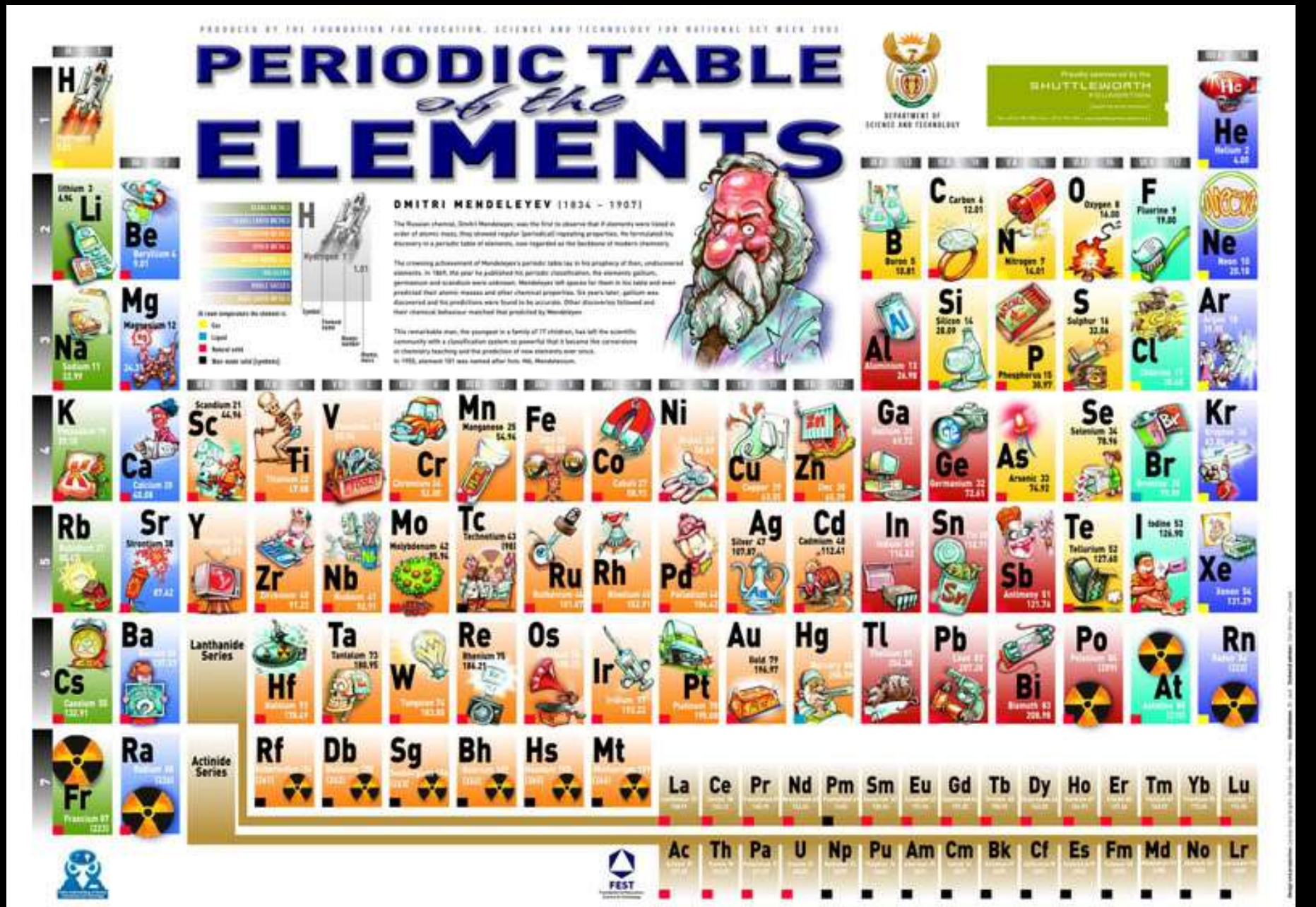




2. No mesmo estagio evolutivo do que o Sol



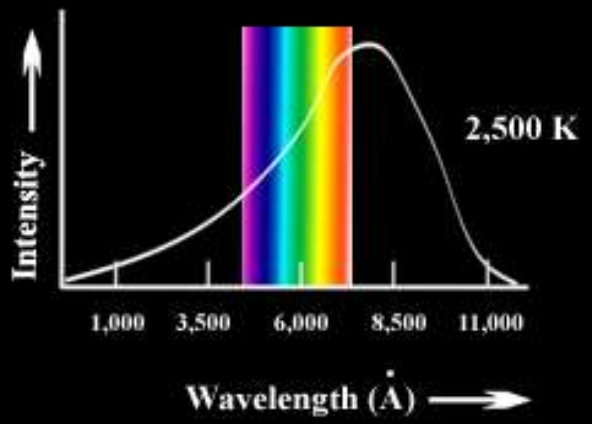
3. Composição química ~ solar?

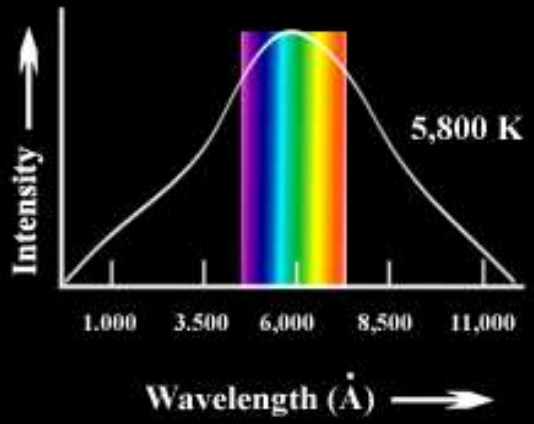


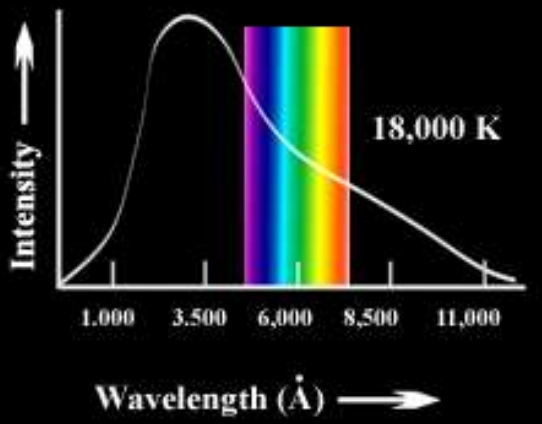
Com tantas estrelas no céu, como saber quais são similares ao Sol?

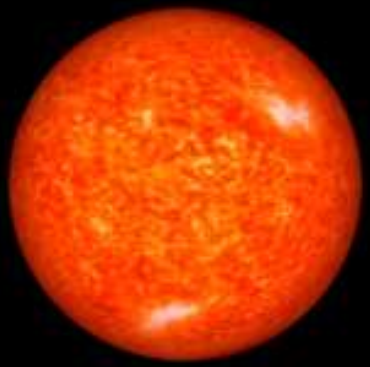
Primeiro passo: classificação

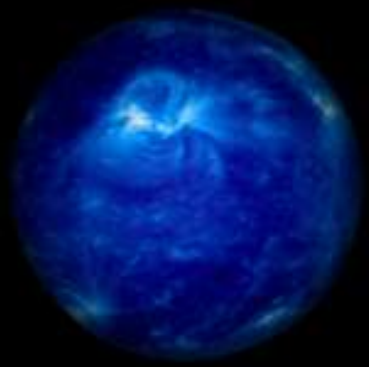
Classificação usando as cores





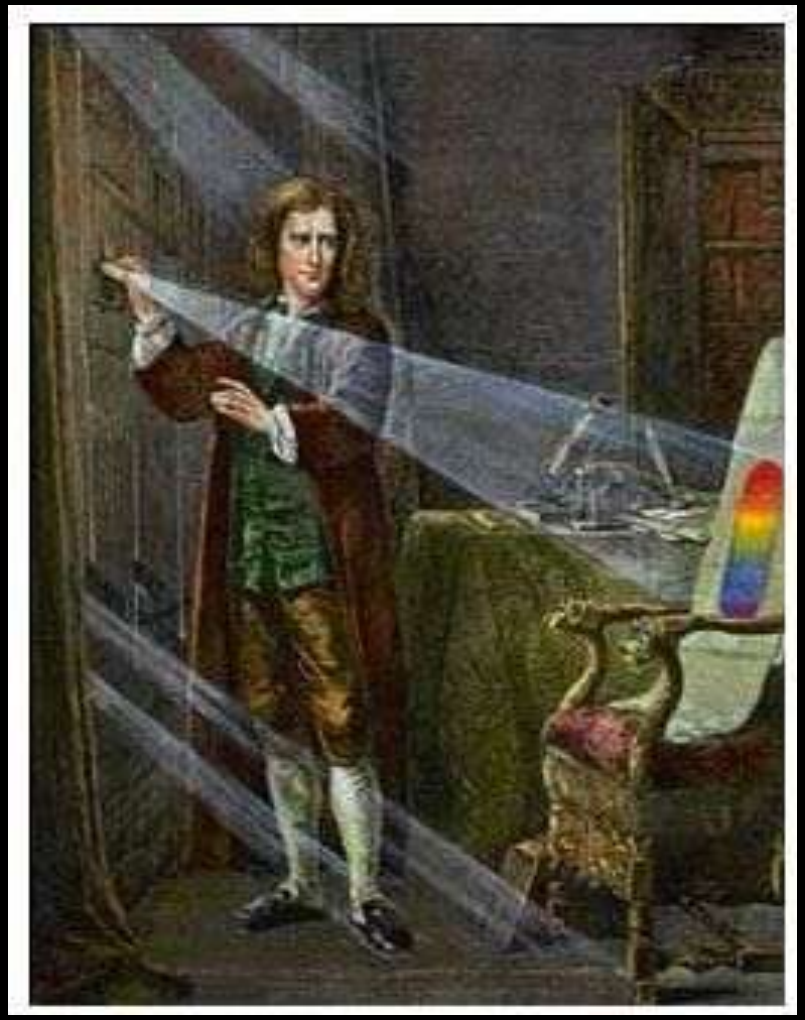






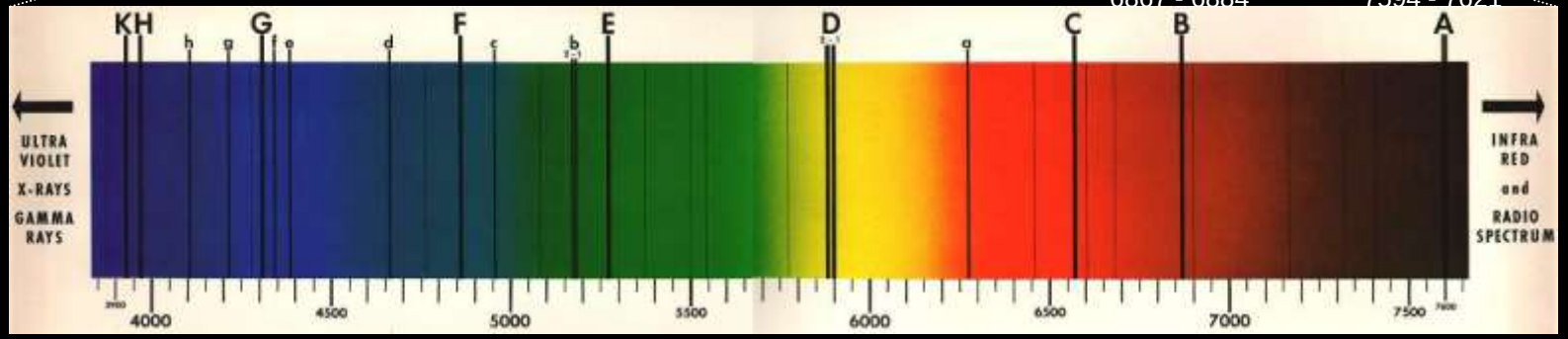
Colors are exagerrated

Classificação usando a luz das estrelas



Newton (1643-1727)

Espectro solar



Linhas de Fraunhofer (1817)

1802: The chemist and minerologist William Wollaston first observed dark lines in the solar spectrum which he incorrectly interpreted as gaps separating the colors of the sun

1817: Joseph Fraunhofer (1817) rediscovered the lines. He discounted Wollaston's colour boundary interpretation, he observed a continuous color change across the spectrum; no color discontinuities occurred at the dark lines

1836: Sir David Brewster found that certain lines had strengths that varied with the sun's elevation and with the seasons. He correctly ascribed these 'atmospheric lines' as originating in the terrestrial atmosphere. Remarkably, he failed to take into account Fraunhofer's observ. evidence for the stellar origin of certain solar absorption lines

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

Secchi's Four Classes of Stellar Spectra

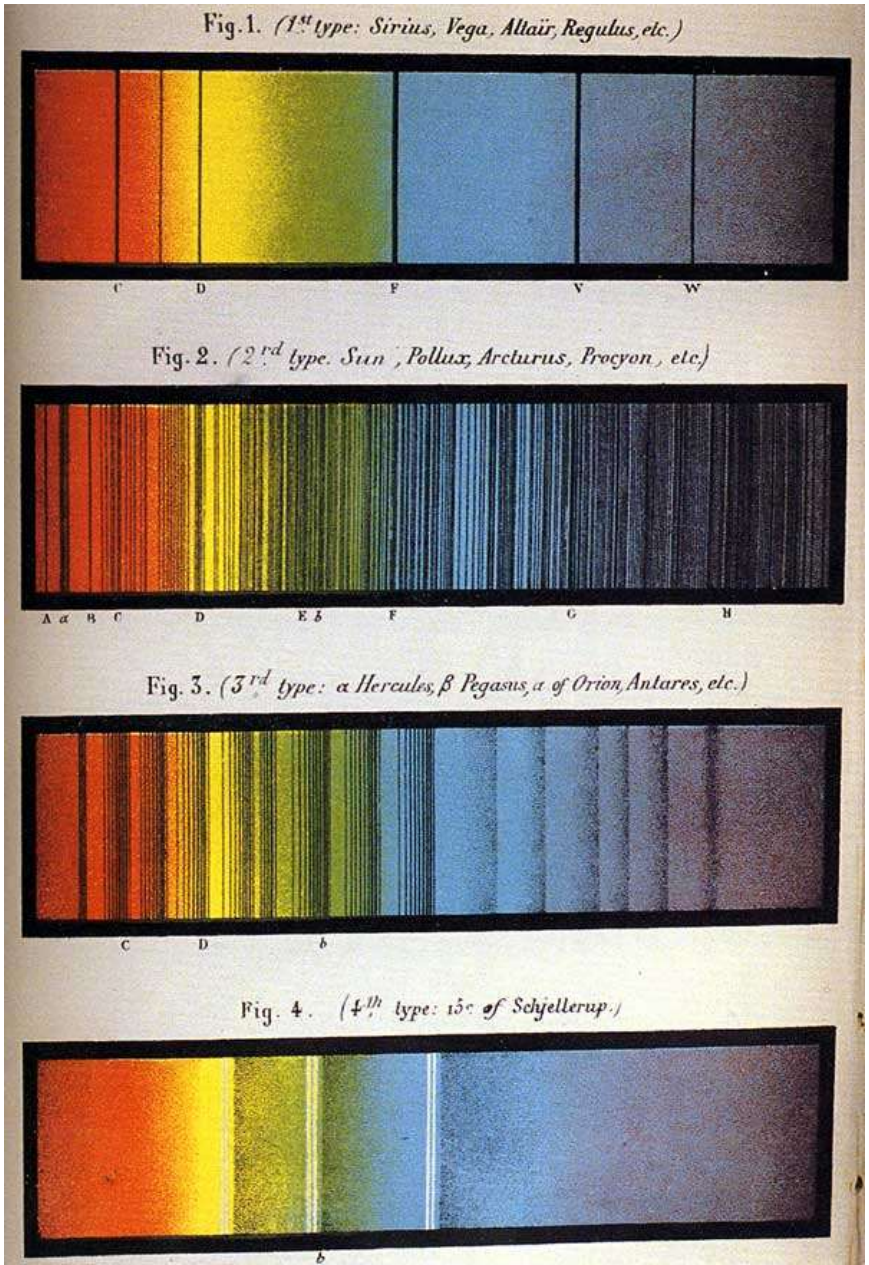
Tipo I

Tipo II

Tipo III

Tipo IV

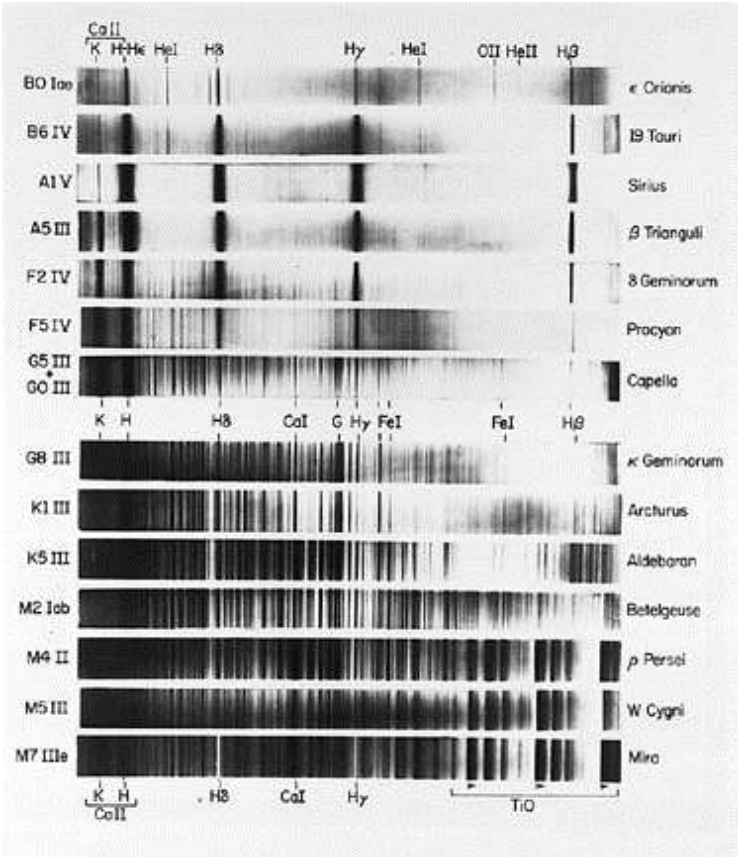
Secchi's four classes of stellar spectra, from a colored lithograph in a book published around 1870. This shows how someone looking through a spectrograph on a large telescope would see the spectrum from the brightest stars. The spectra would be much fainter for most stars, making for difficult observing. The principal spectral lines are identified underneath by letters that Fraunhofer assigned.



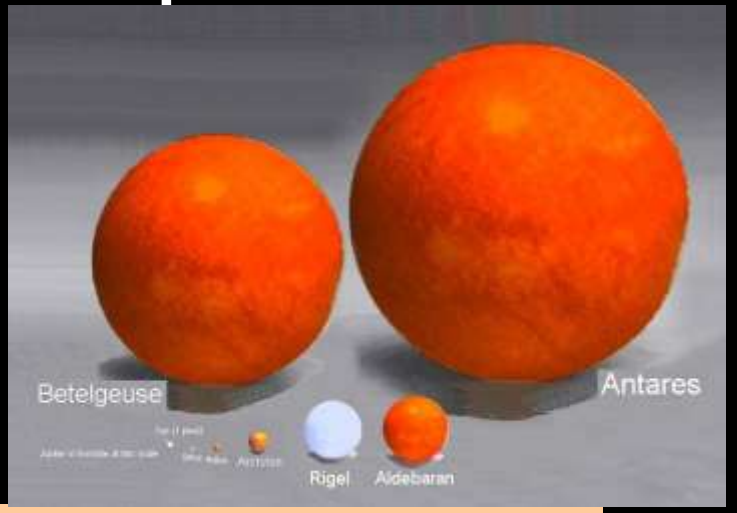
O sistema de classificação de Harvard

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

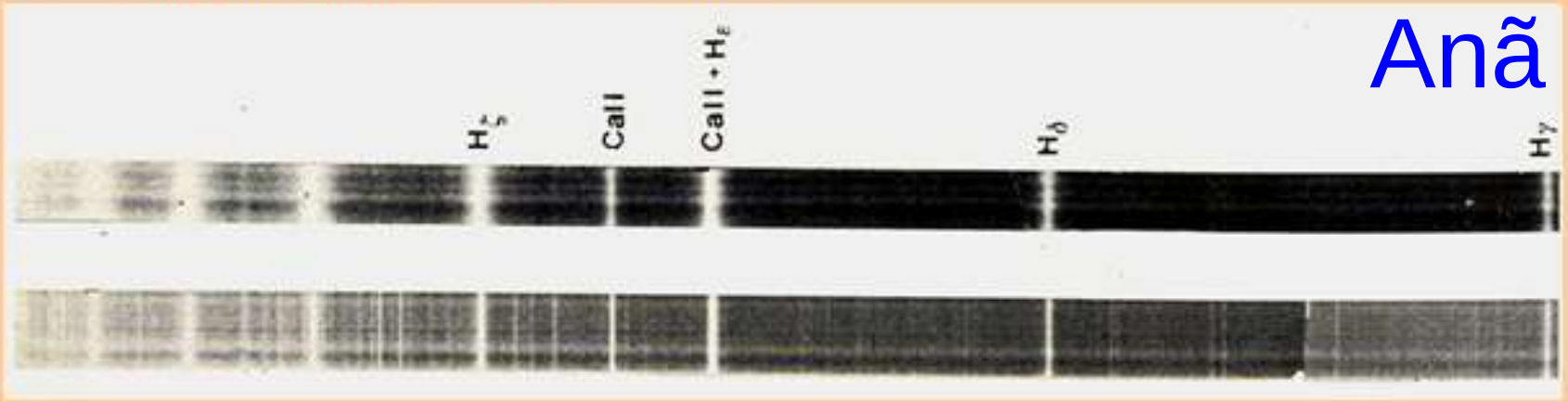
O, B, A, F, G, K, M



Mais sobre classificação espectral: classe de luminosidade



Dwarf and Supergiant sprectra in comparison



Anã

Supergigante

Above: normal star
Below: supergiant star

Note wide and diffuse hydrogen and calcium lines in normal stars atmosphere, against the extreme sharpness of the same lines in the supergiant atmosphere.

Procura de gêmas solares

- Tipo espectral: G2
- Classe de luminosidade: V (anãs)

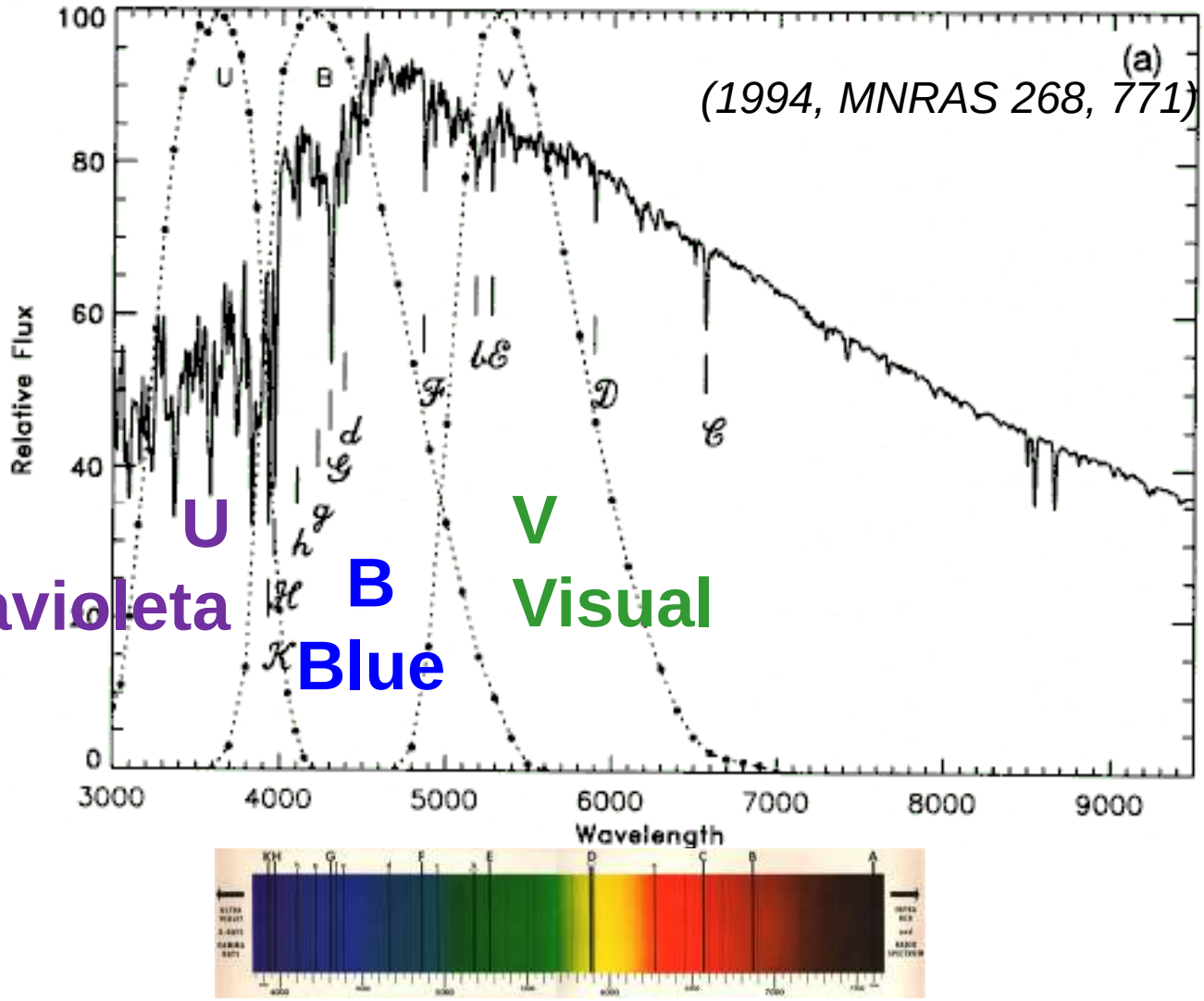
ou …

- **Índice de cor**
- **Magnitude absoluta**

Índice de cor B-V no sistema UBV

774 *R. A. Bell, G. Paltoglou and M. J. Tripicco*

B-V = mag B – mag V

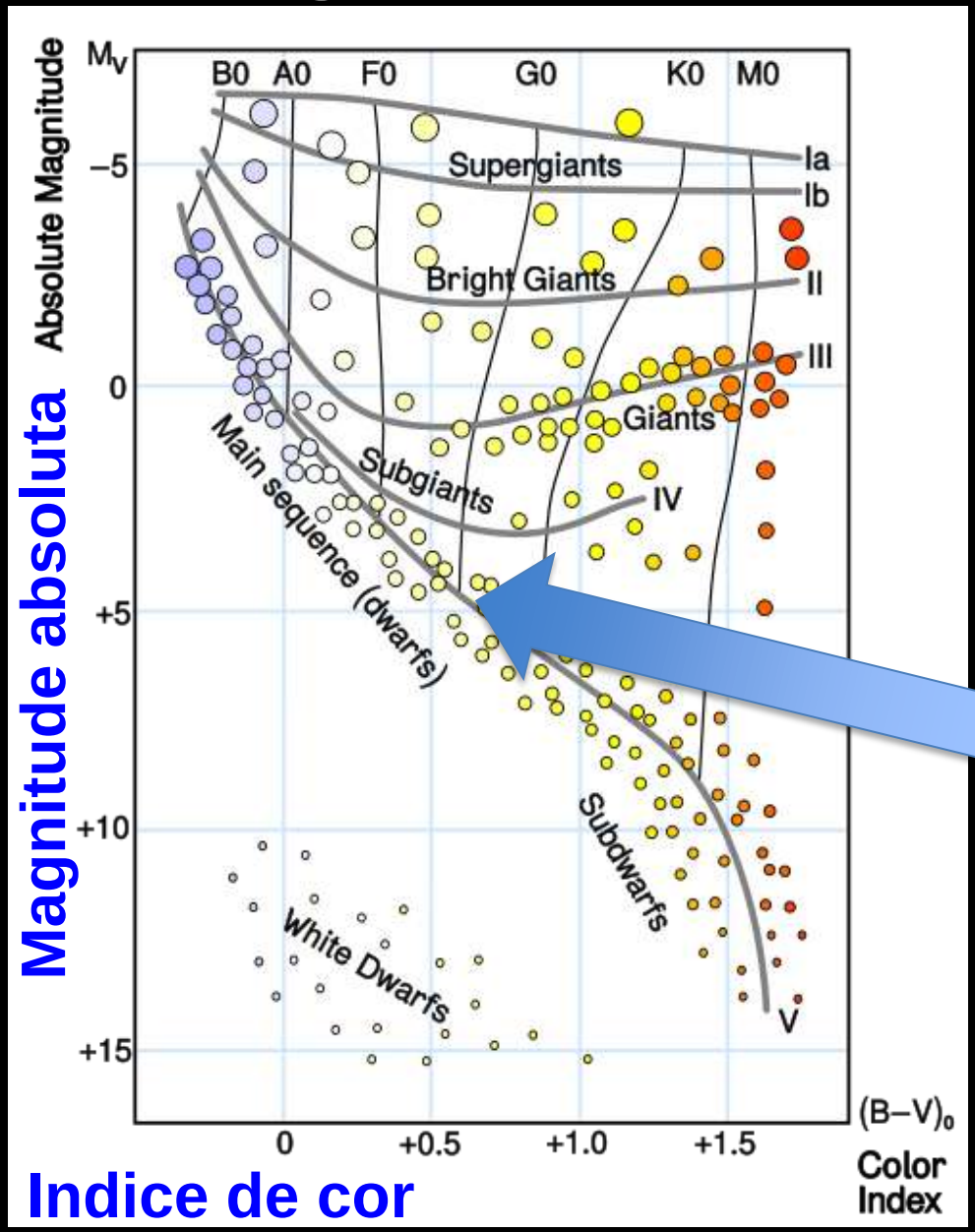


Magnitude Absoluta: M

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

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

Diagrama H-R



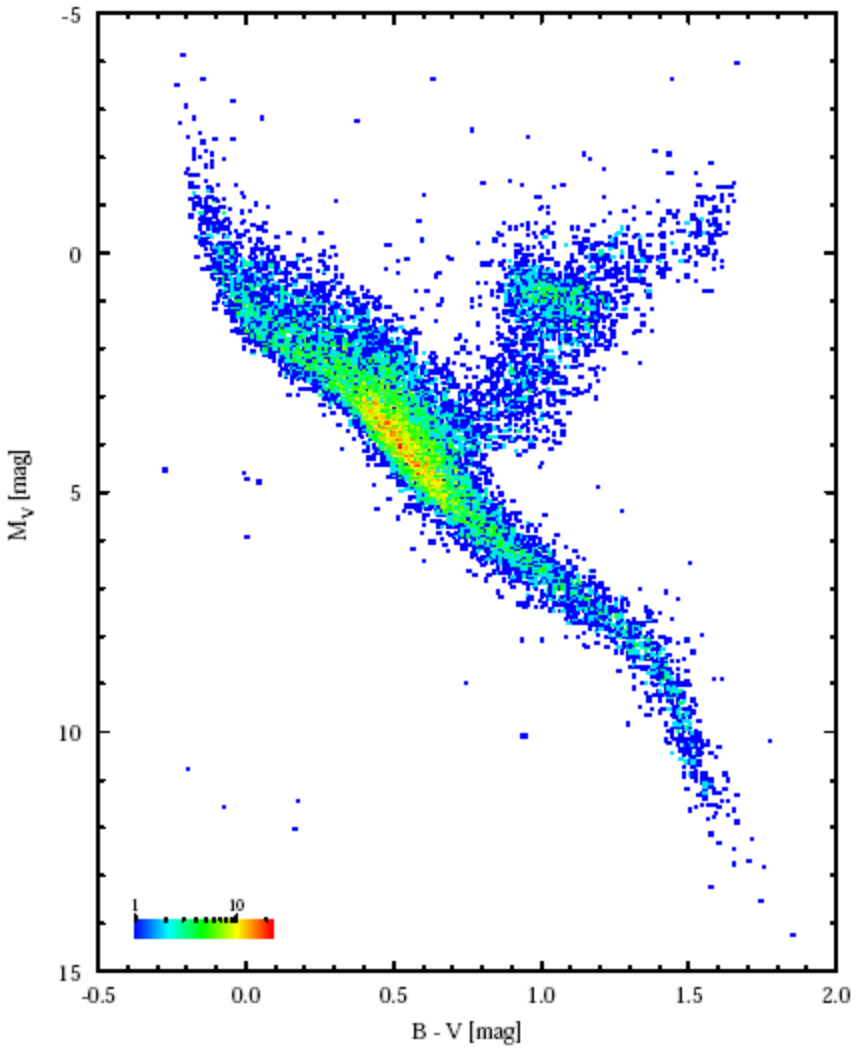
SOL

$M_v = 4.82$

B-V ~ 0.65

Procura por gêmeas solares usando o catálogo Hipparcos (+ Tycho)

- Cores B_T-V_T
- Magnitude absoluta V_T
- Outras cores (optico e infravermelho), indicadores de idade



- 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 solar descoberta 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.

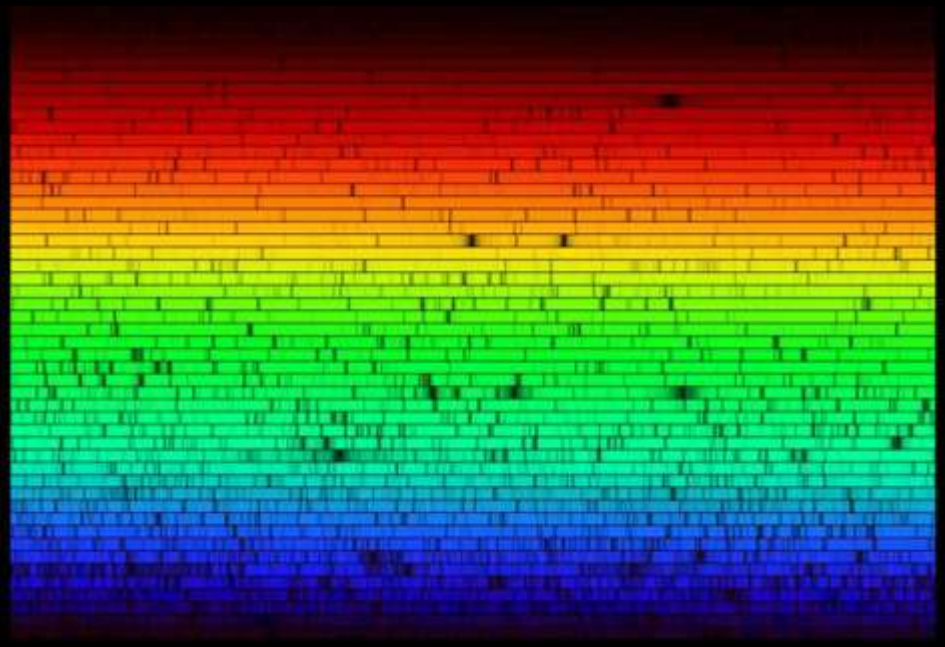
[3] CNPq/Observatório Nacional, Departamento de Astronomia, Rua General José Cristino 77, 20921-400 São Cristovão, Rio de Janeiro, Brazil; licio@on.br.

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

Em busca de gêmeos solares

- *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

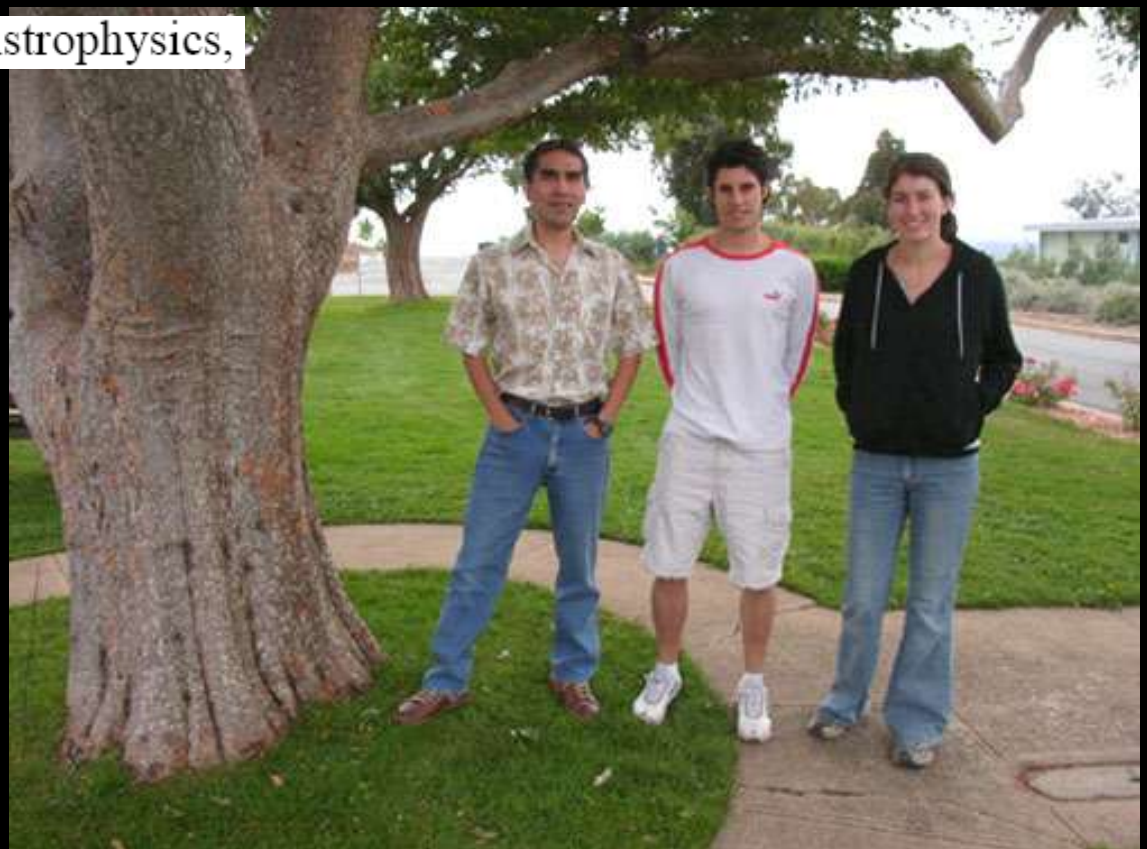
THE ASTROPHYSICAL JOURNAL, 641:L133–L136, 2006 April 20

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

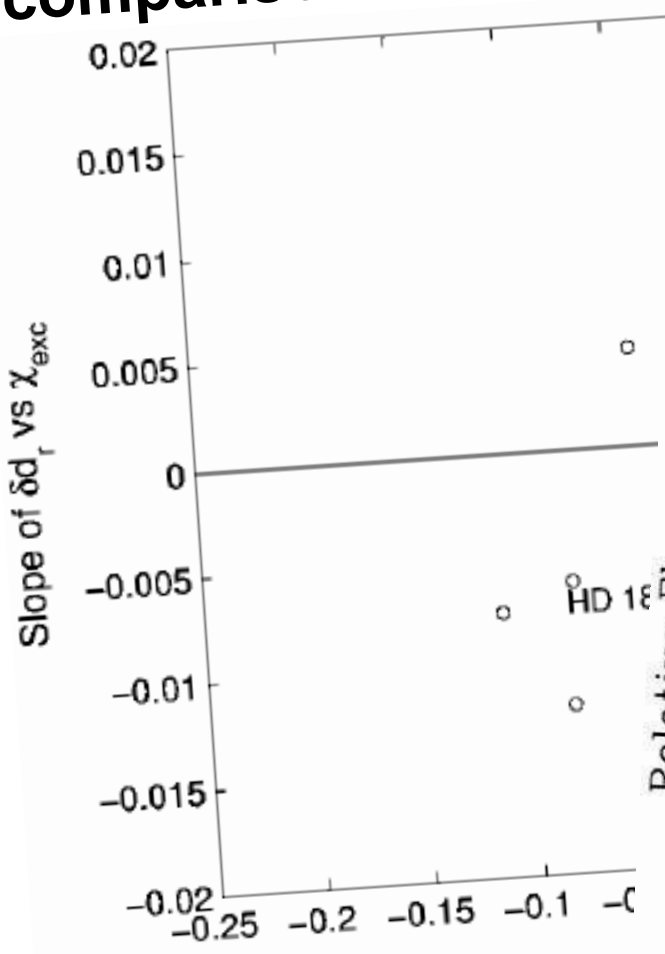
JORGE MELÉNDEZ,[2] KATIE DODDS-EDEN, AND JOSÉ A. ROBLES

Research School of Astronomy and Astrophysics,
Mount Stromlo Observatory

- Projeto de iniciação científica de Katie Dodds-Eden

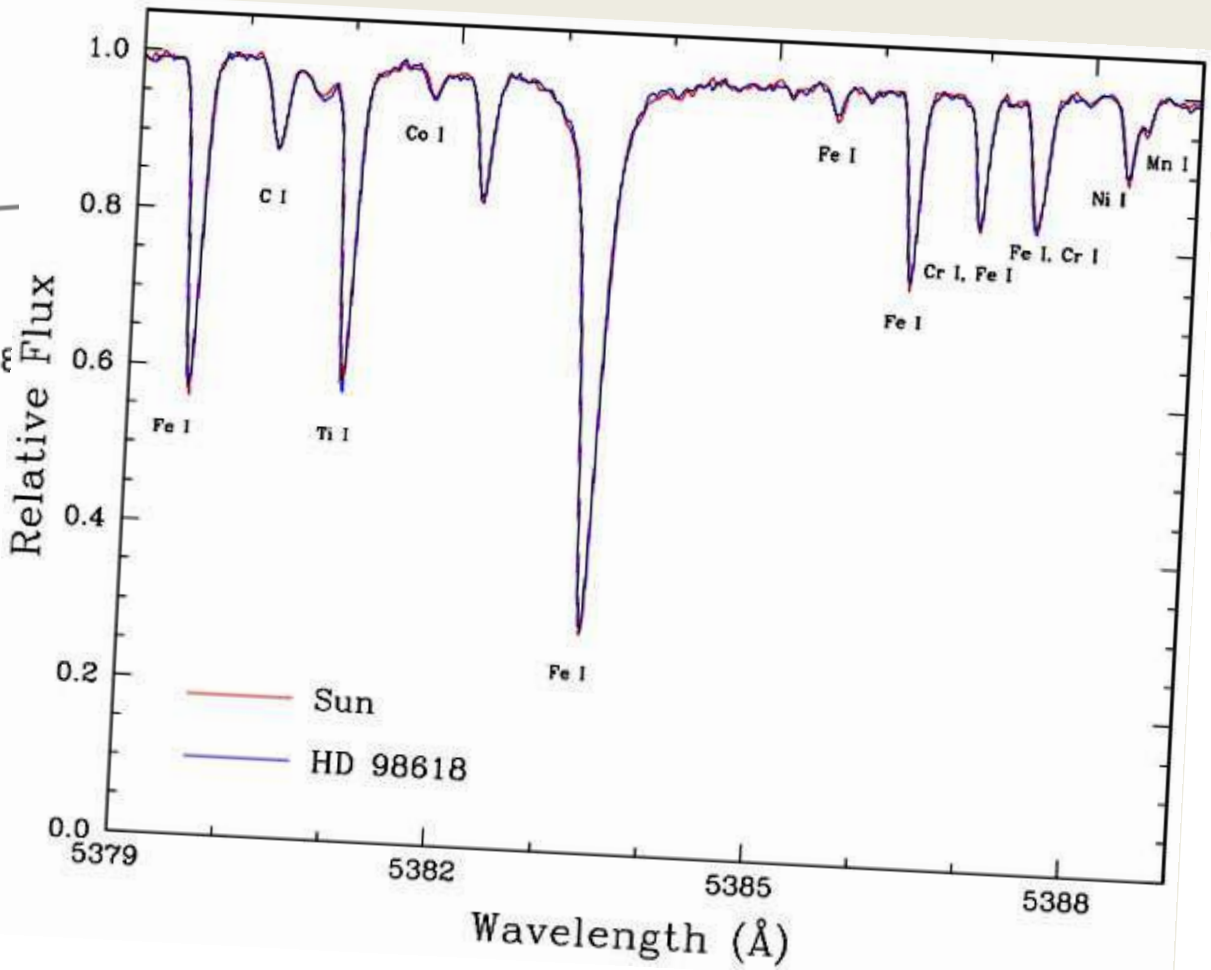


Model independent comparison



Comparison of sections of spectra of the Sun and HD 98618.

Note the almost perfect match for iron, carbon, titanium, cobalt, chromium, nickel and manganese. This shows that the chemistry of HD 98618 is almost exactly the same as that of the Sun.



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

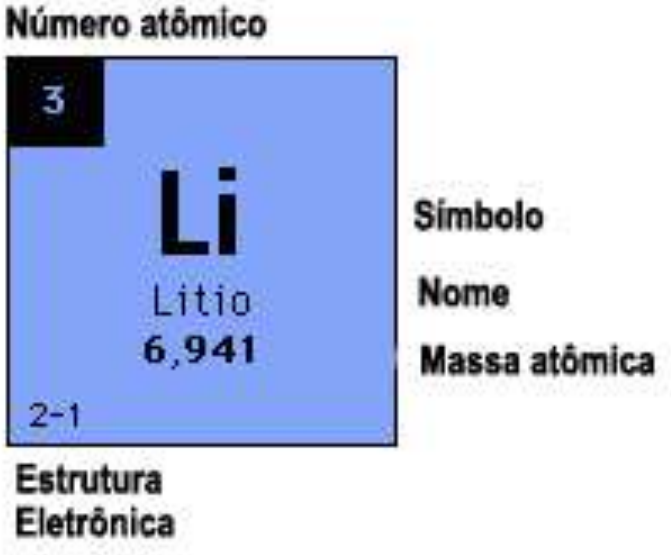
Another cause for optimism is the absence of "hot Jupiters", massive gas giants orbiting close to each star whose gravity could destabilise the orbits of

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

FUNDAMENTAL PARAMETERS **Estrela - Sol**

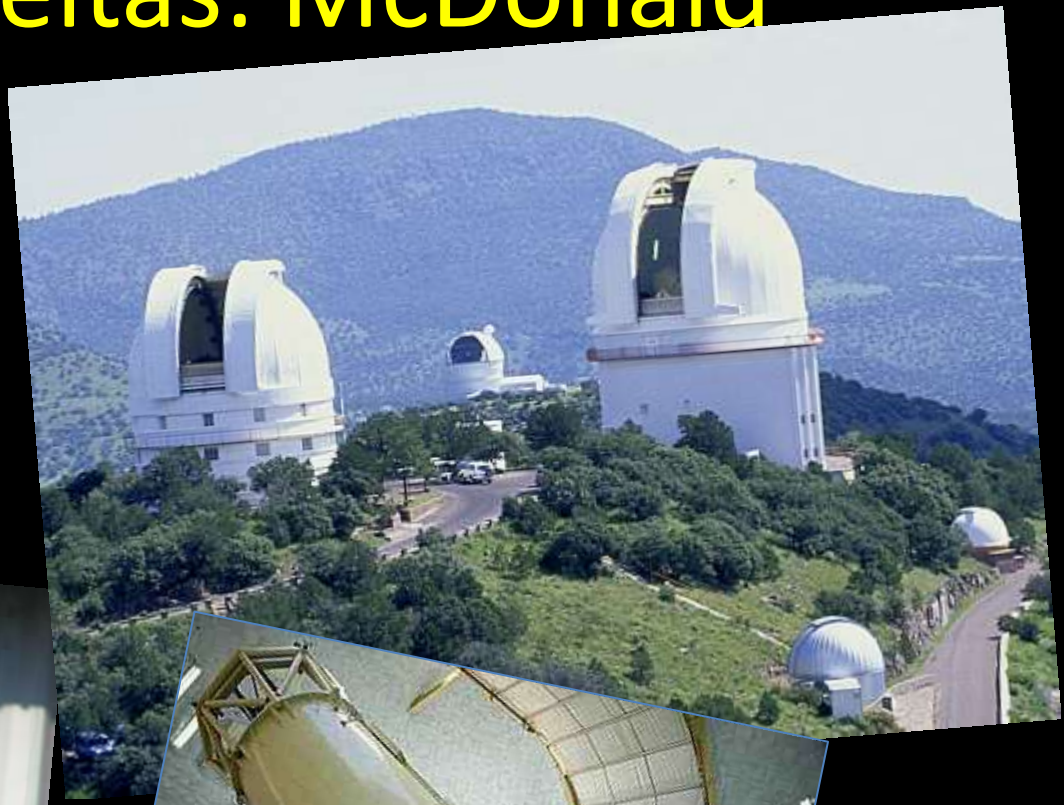
Parameter (Star − Sun)	18 Sco	HD 98618
Δv_t (km s^{-1})	+0.08 ± 0.15	+0.09 ± 0.15
$\Delta T_{\rm eff}$ (K)	+40 ± 30	+66 ± 30
$\Delta \log g_{\rm spec}$ (dex)	+0.01 ± 0.04	+0.01 ± 0.04
$\Delta \log g_{\rm Hip}$ (dex)	+0.01 ± 0.02	+0.01 ± 0.03
$\Delta \log g_{\rm adopted}$ (dex)	+0.01 ± 0.02	+0.01 ± 0.03
$\Delta L_{\rm spec}$ ($L_\odot$)	+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 procura por gêmeas solares perfeitas: McDonald

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

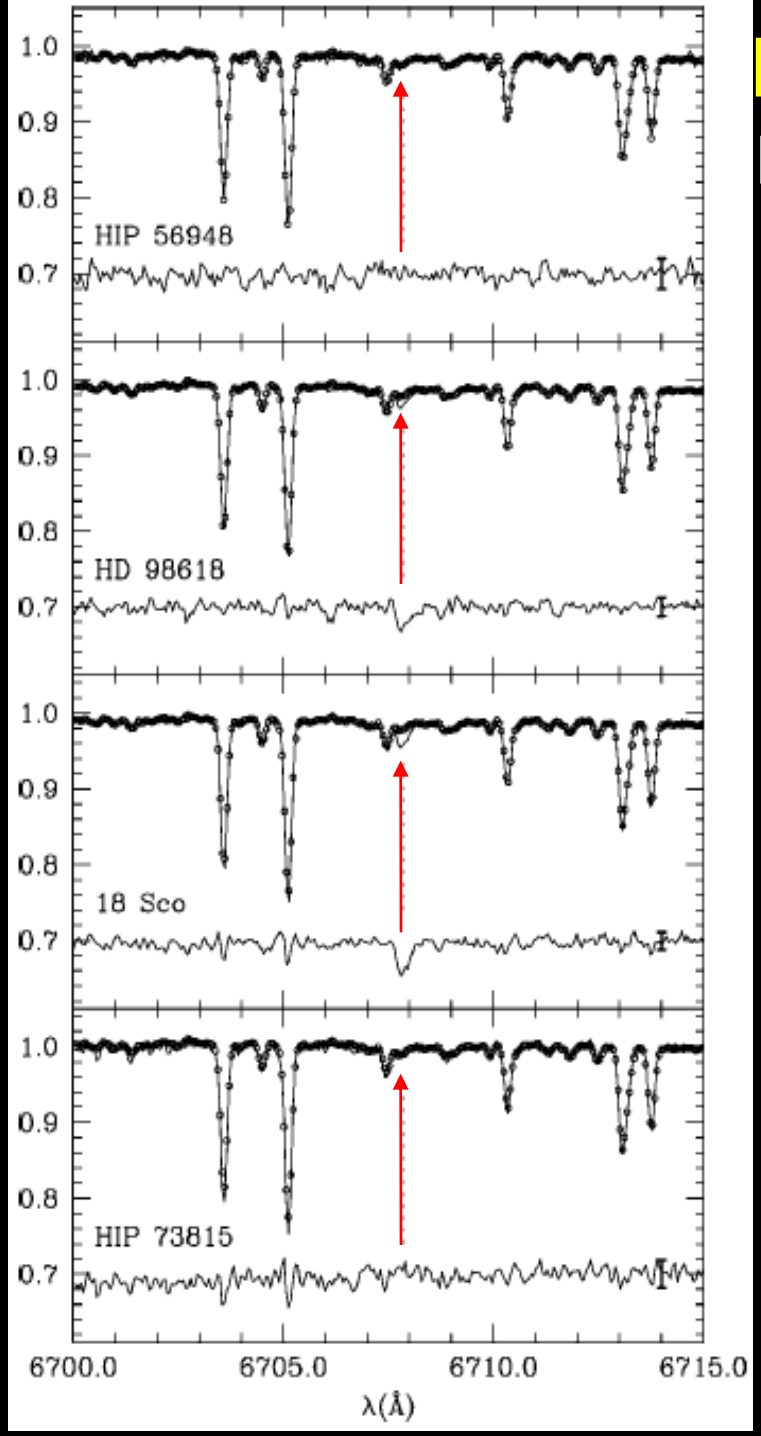


McDonald solar twin survey

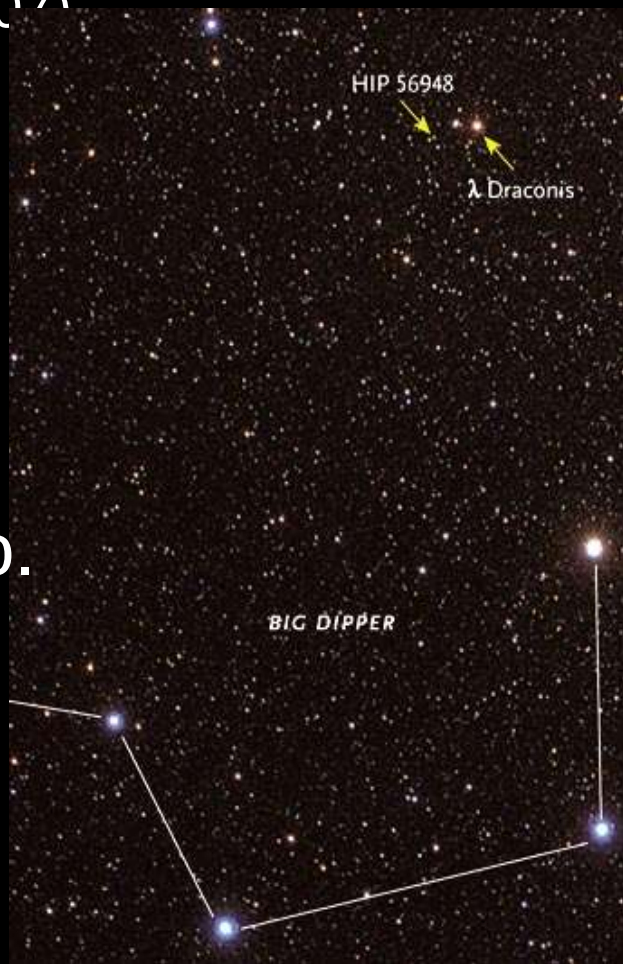
Novas gêmeas solares HIP 56948 & HIP 73815 tem baixo Li (~1.0)!

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.

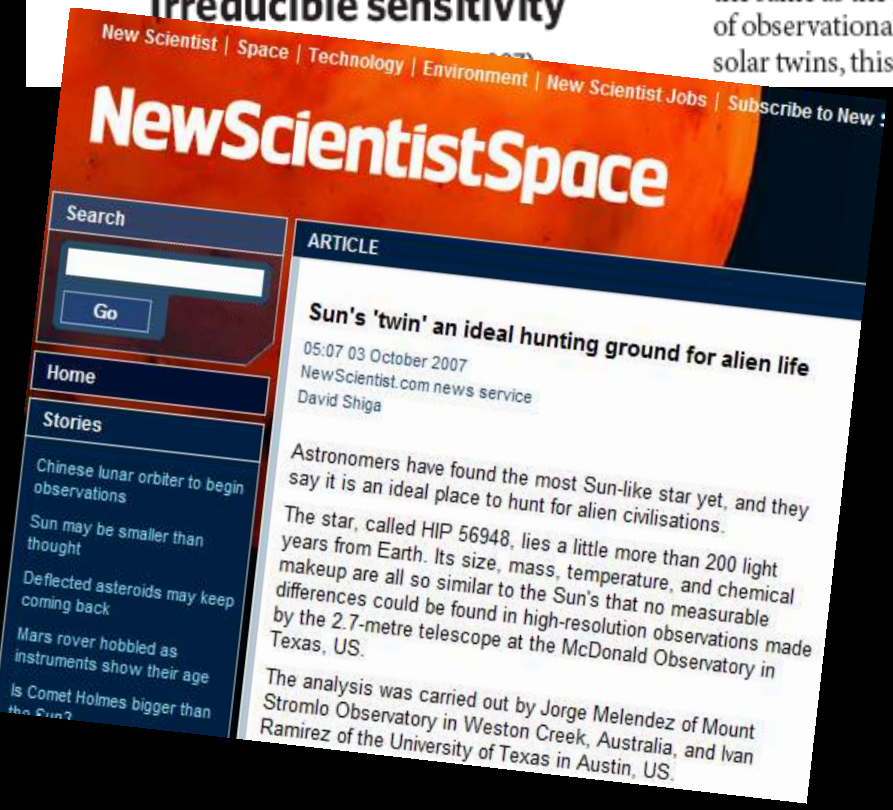
Peruvian astronomers Jorge Meléndez of the Australian National University, and Iván Ramírez at the McDonald Observatory of the University of Texas in Austin report that the parameters of HIP 56948, one of four 'solar twins' they have been studying, are exactly the same as the Sun's, within the constraints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

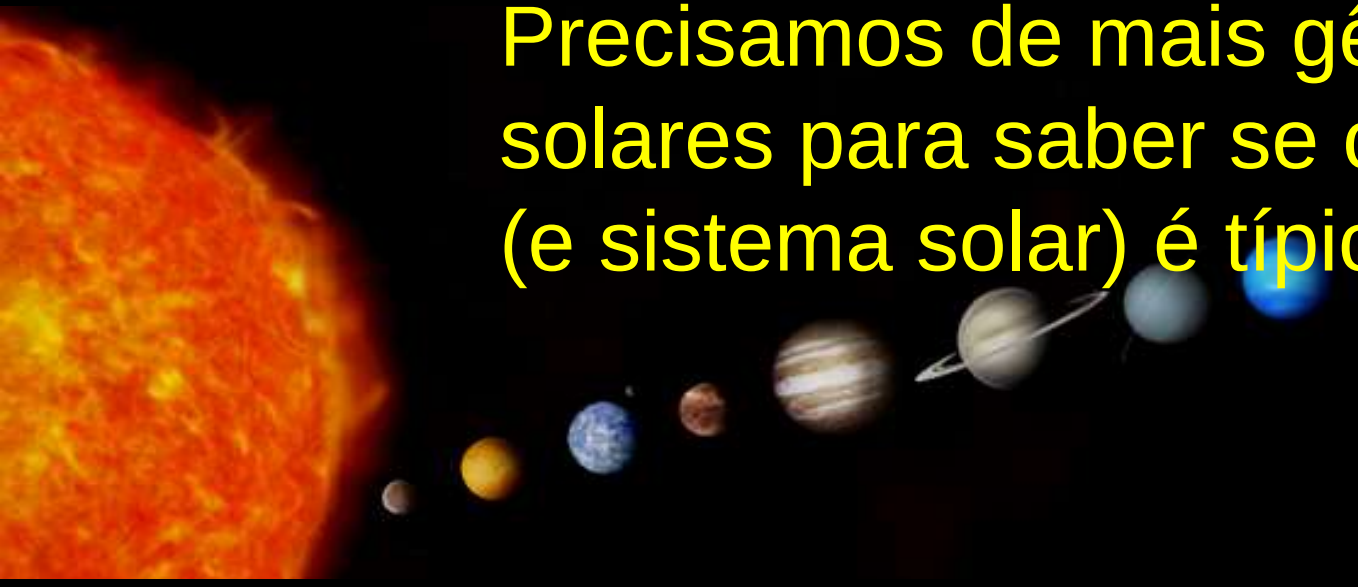
Jorge Meléndez, del Observatorio Stromlo de Australia, e Iván Ramírez, del Observatorio Mc Donald en Texas (EEUU), son los compatriotas que descubrieron la existencia de una estrella que, p sus características, podría ser considerada gemela del sol y que, parecer, tiene todas las condiciones para albergar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

Gêmeas solares conhecidas

Até 2007 apenas 3 gêmeas solares:

1. **18 Sco** (Porto de Mello & da Silva 1997)
2. **HD 98618** (Meléndez et al. 2006)
3. **HIP 56948** (Meléndez et al. 2007)

Precisamos de mais gêmeas solares para saber se o nosso Sol (e sistema solar) é típico

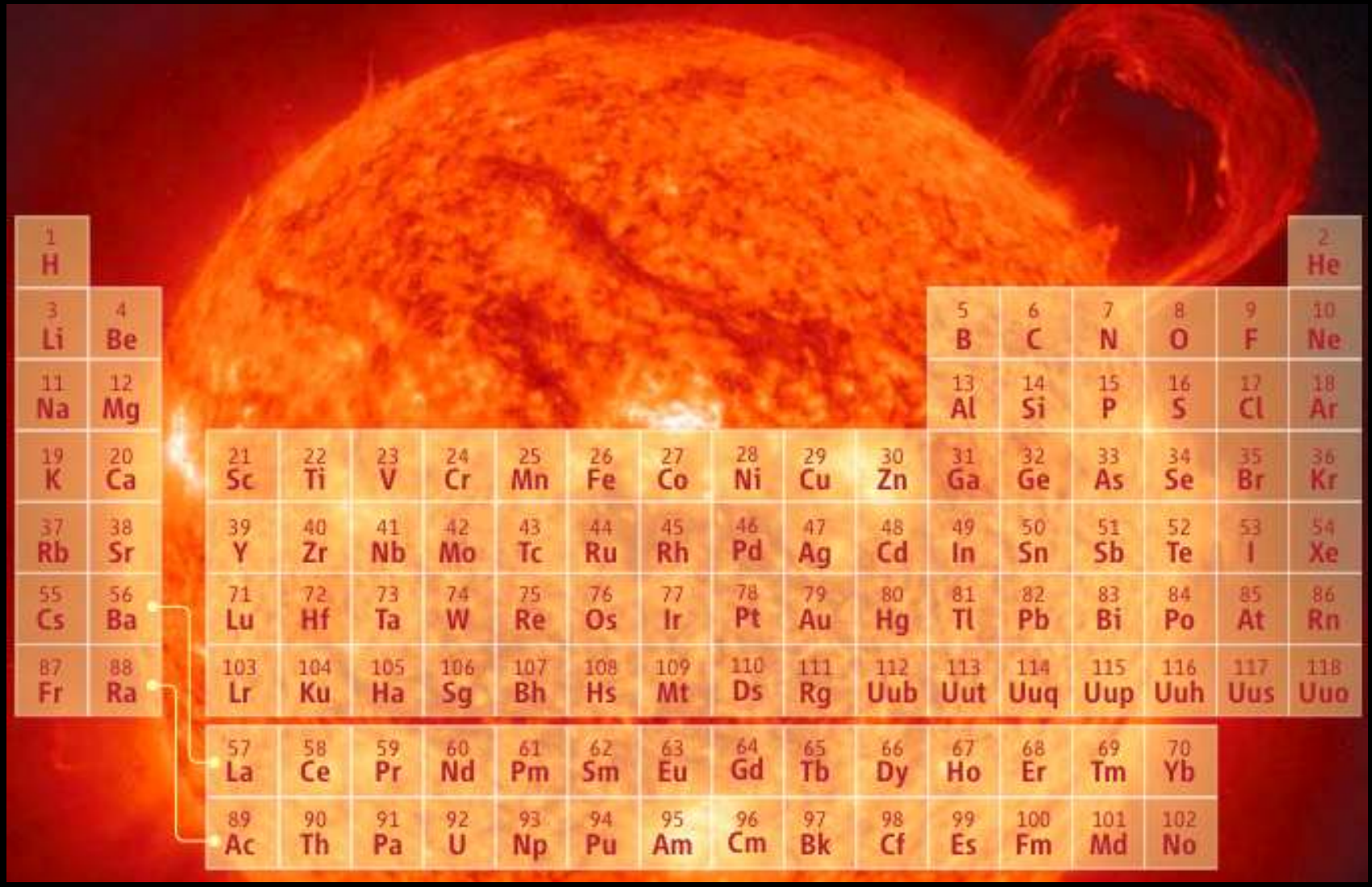


Existe alguma propiedade do Sol que possa indicar a formação de planetas?

Sunset in Barranca, Peru

http://www.flickr.com/photos/mannover

É a composição solar anomala?



Ou o Sol é uma típica estrela solar?

Por quase um seculo e meio o Sol foi considerado ”normal” na sua composição química

- Secchi (1868): Sol é tipico de estrelas de tipo solar
- Payne (1925): composição solar é universal
- Bent Gustafsson (1998, 2008): não sabemos devido às grandes incertezas (**0.05-0.10 dex**)
- Carlos Allende Prieto (IAU Symp 265 [Aug09] revisão sobre o disco fino): devemos melhorar nossas abundancias: <**0.05 dex (accuracy)**

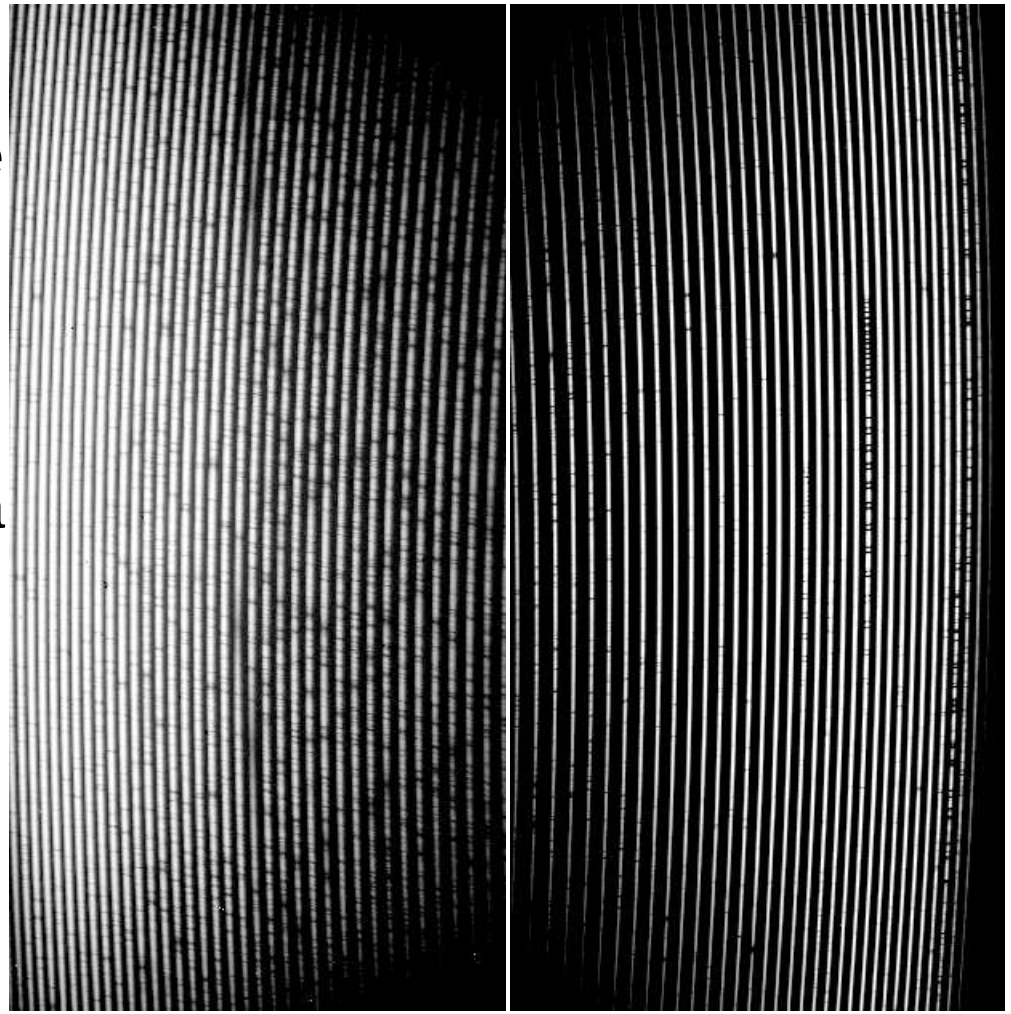
Estudo de abundancias químicas @ altísima precisão em gêmeas solares: Magellan (Clay 6.5m)

Jorge Meléndez (CAUP/Portugal), Martin Asplund (Max Planck), Bengt Gustafsson (Uppsala), David Yong (Stromlo)

Observações espectroscópicas

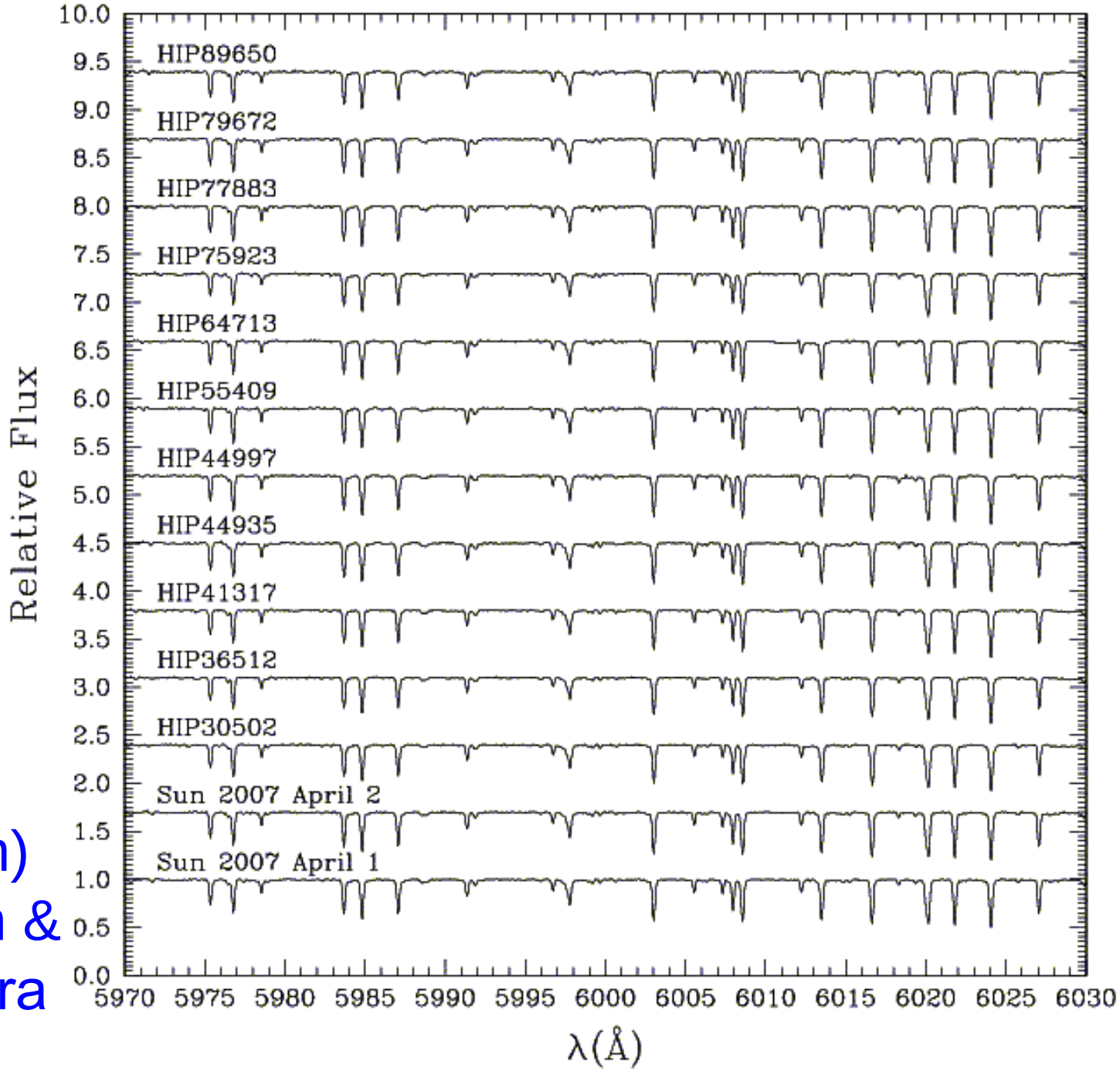
-Magellan 6.5m Clay Telescope
& Mike spectrometer
- R = $\lambda/\Delta\lambda$ = 65,000
- S/N = 450 per pixel
- coverage 340 – 1000 nm
- Solar spectrum:asteroid Vesta
- 3 nights of observations.

Observações da gêmea solar 18 Sco



BLUE frame **RED frame**

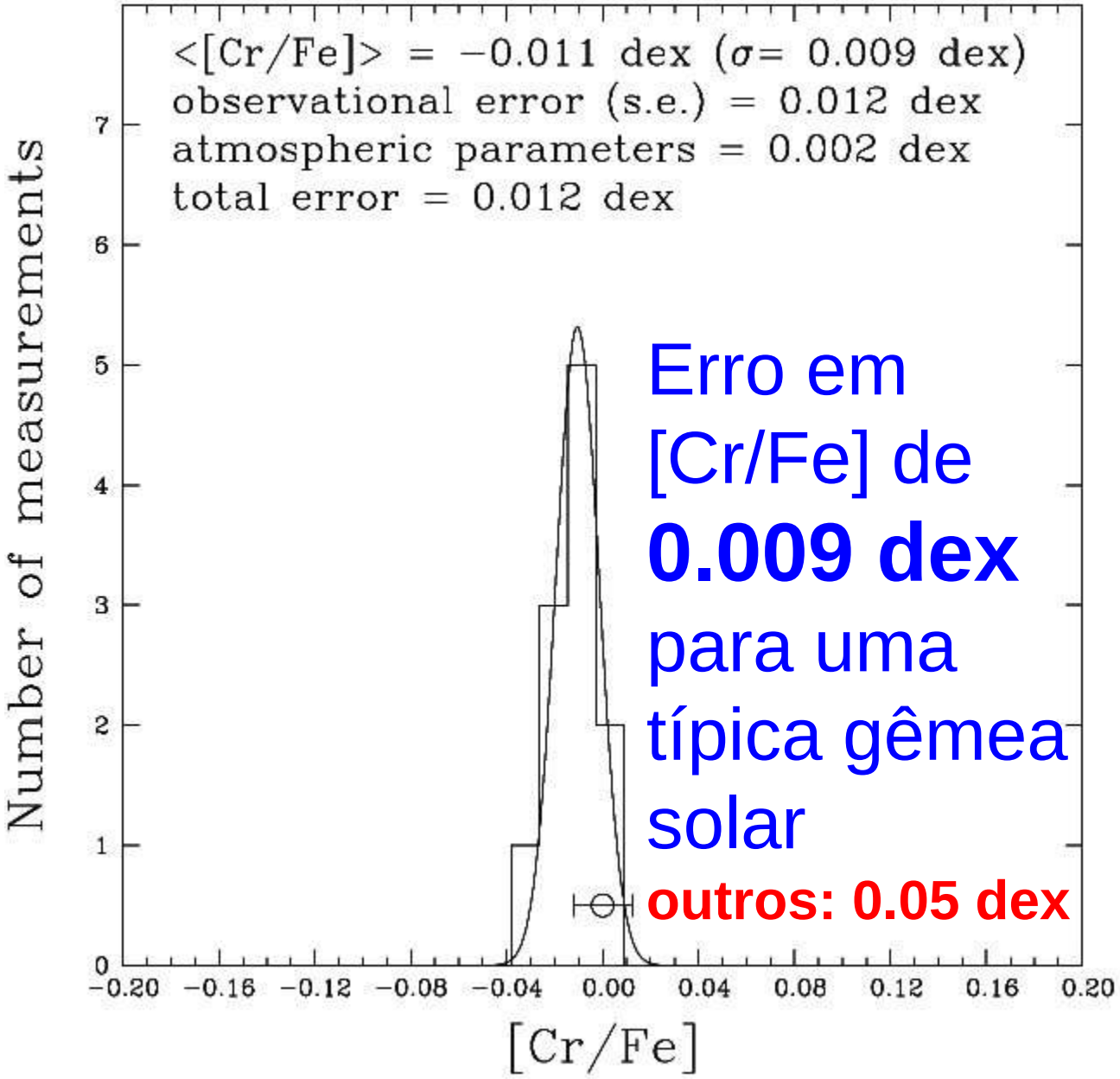
Small part (597-603nm) of solar twin & Sun's spectra



Análise de alta precisão

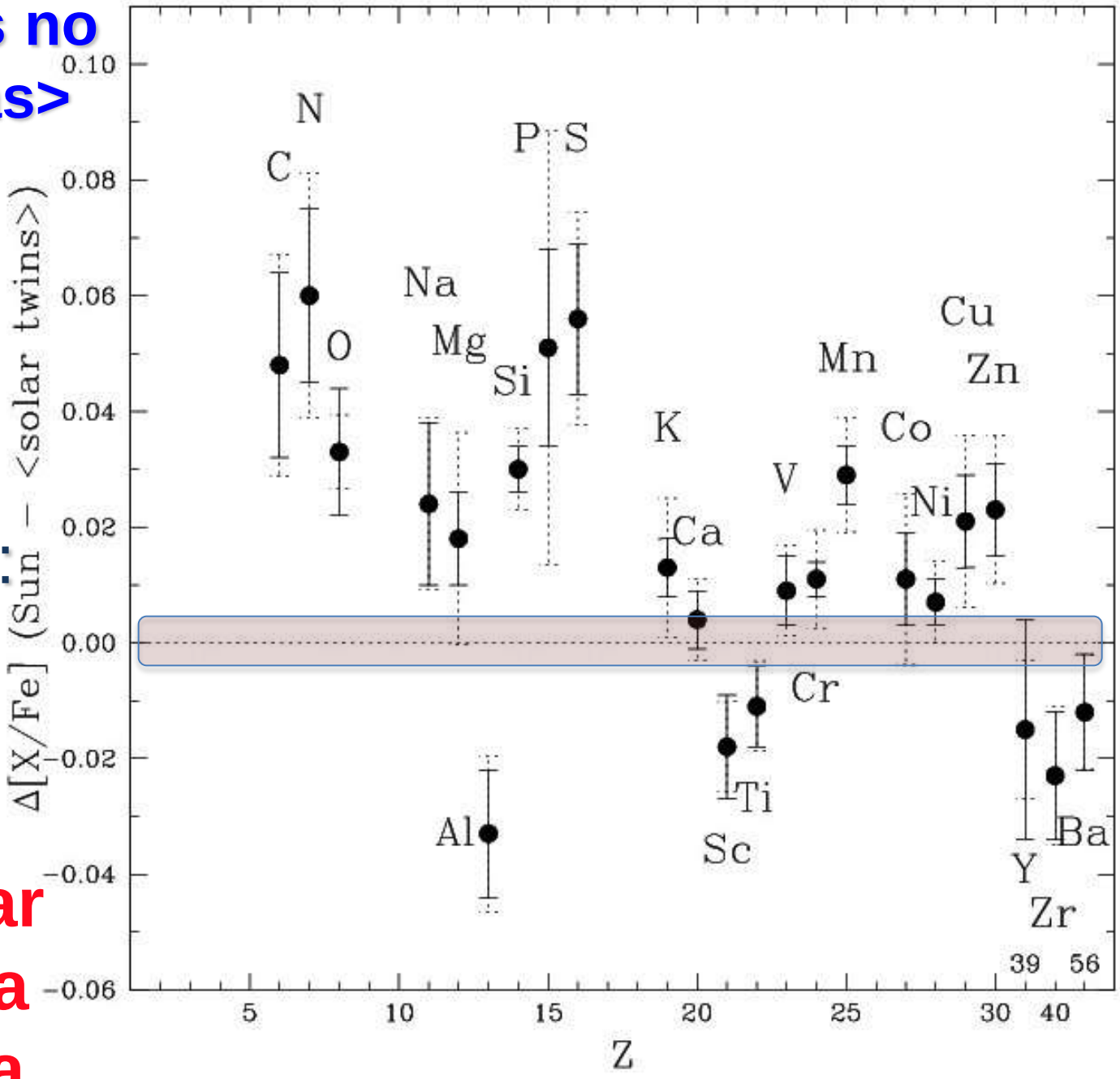
- Standard 1D model atmospheres
- T_{eff}, log *g* , v_t & [Fe/H] from FeI & FeII lines
- Line by line basis

High precision in stellar parameters (20 K in T_{eff}, 0.04 dex in log *g) and in abundance ratios [X/Fe] (0.01-0.02 dex)*



Abundancias no Sol - <gêmeas> vs. número atómico Z

Sol típico:
$\Delta = 0$
Sol anormal:
$\Delta \neq 0$

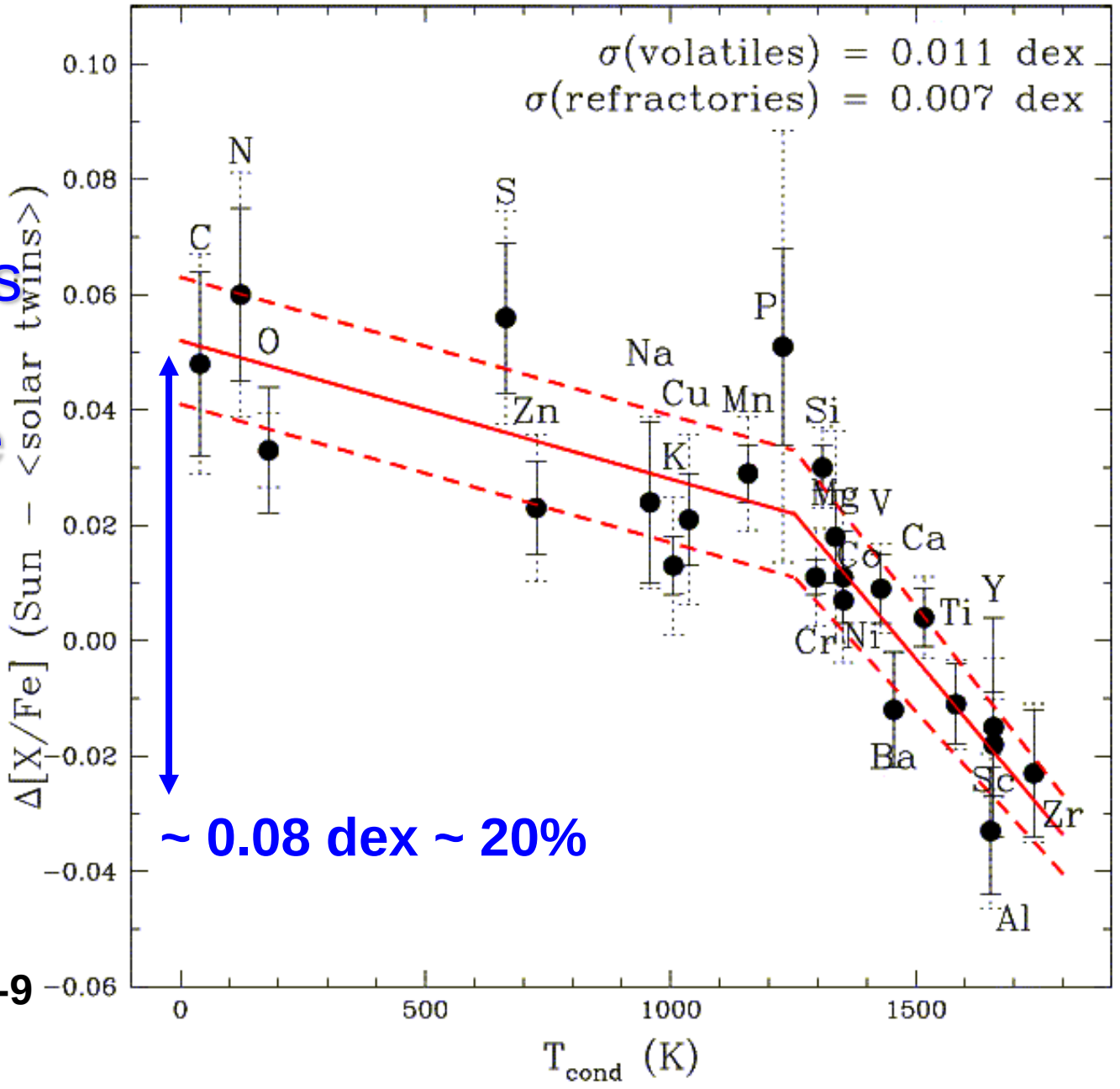


Nosso sistema solar não tem uma estrela típica

As anomalias na composição do Sol estão relacionadas com a formação do nosso sistema planetario?

The Sun & the Andes from the windows of Machu Picchu *http://www.flickr.com/photos/oscarpacussich*

Anomalias no Sol são fortemente correlacionadas com a temperatura de condensação (T_{cond}) dos elementos!

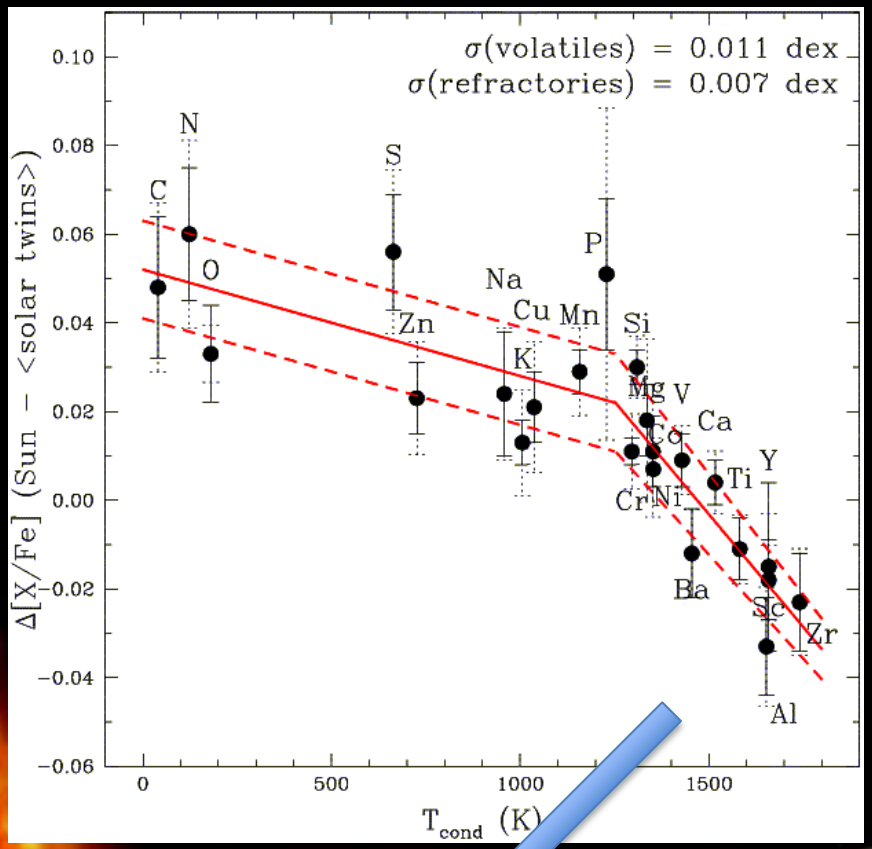


Correlação é altamente significativa

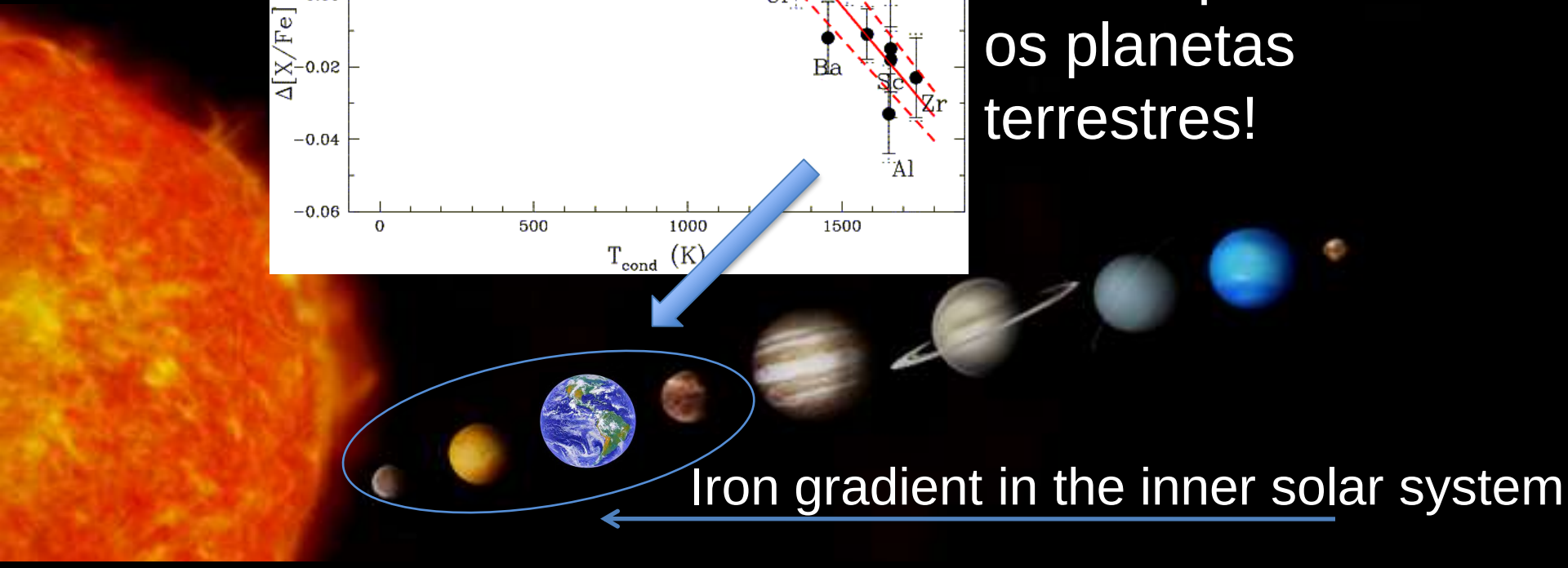
probabilidade ~10^{-9} de acontecer por acaso

Somente os elementos refractarios (e.g. Fe, Al, Sc) podem ter se condensado no sistema solar interno, formando poeira, planetesimais e finalmente planetas de tipo terrestre !

As camadas externas do Sol acretaram material deficiente em refractarios



O Sol é deficiente em refratarios porque esses elementos foram usados para formar os planetas terrestres!

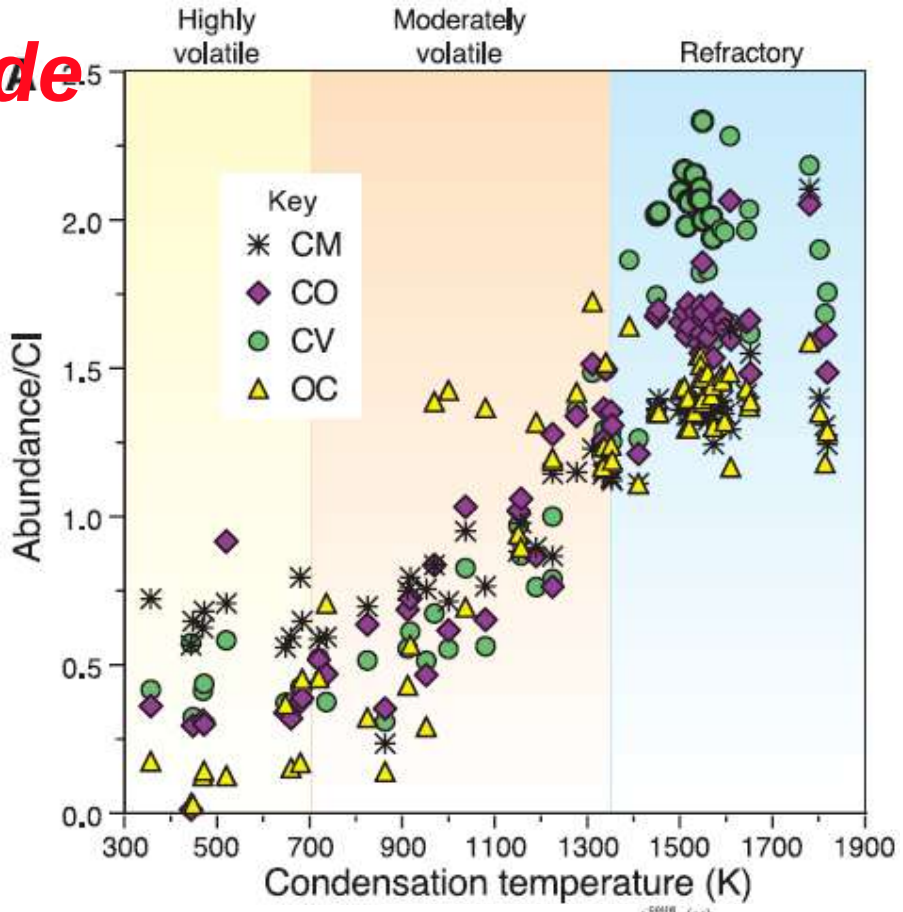


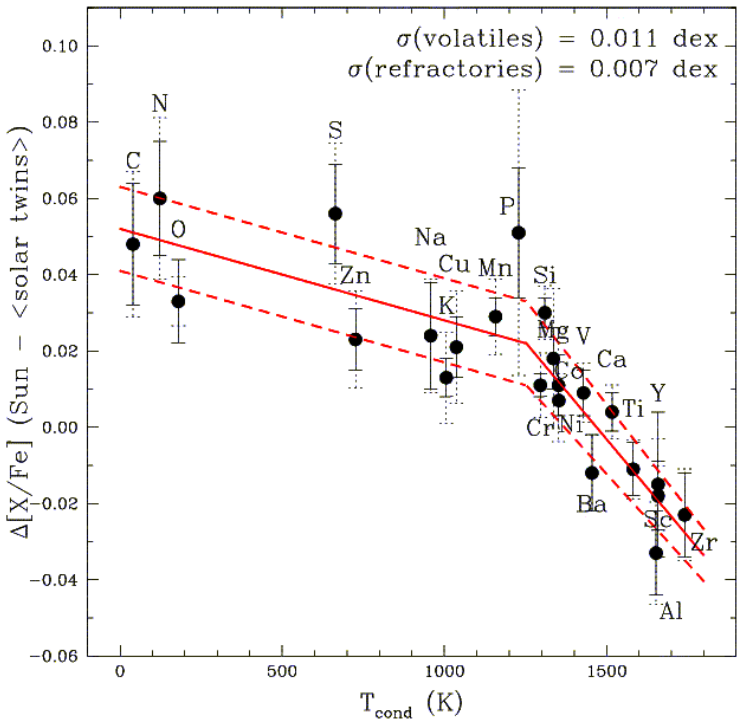
Iron gradient in the inner solar system

Relação com formação de planetas terrestres: meteoritos

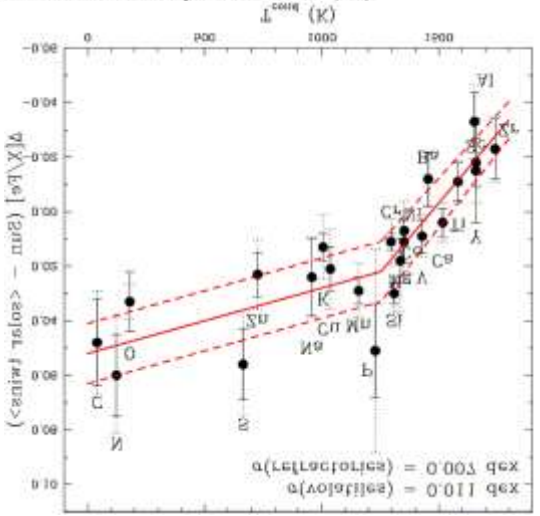
Alexander et al. (2001)

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





O comportamento do Sol é uma imagem espelho do seguido por meteoritos!



A quantidade de material que falta no Sol é da mesma ordem que a requerida para formar os planetas terrestres + asteroides

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

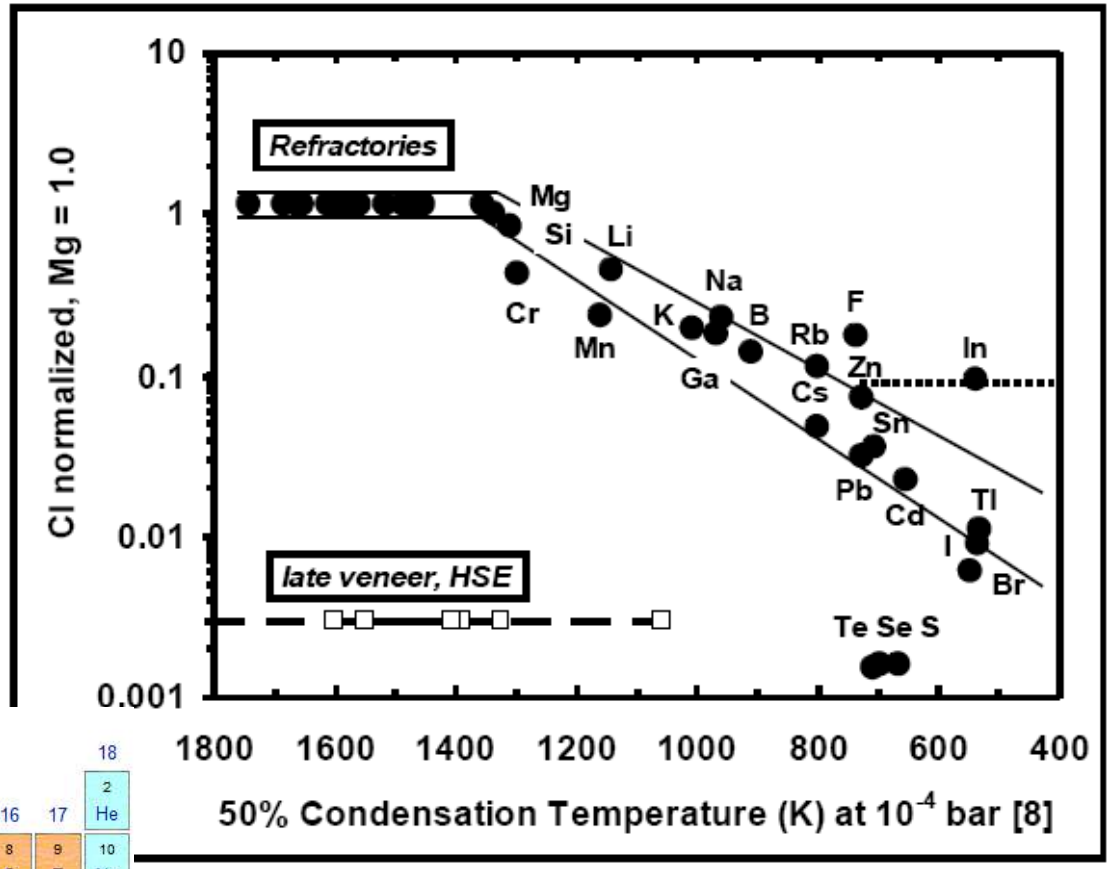
Assume gas accretion until solar convection zone reached ~ present size (~0.02 M_{sun}):

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

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

O manto terrestre também mostra abundancias compativeis com o nosso cenario

volatile elements in Earth's mantle are depleted !



Witt-Eickschen et al. (2007)

Depletion trend of volatiles in Earth's mantle probably reflects primary nebular depletion in the Earth making material (Witt-Eickschen et al. 2007).

Earth-making material was poor in volatiles, and the Sun rich in refractories !

Goldschmidt classification in the Periodic Table

	1												13	14	15	16	17	18
1	1 H	2																2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg	3	4	5	6	7	8	9	10	11	12	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	(43) Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57-71 Lan	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89-103 Act	(104) Rf	(105) Db	(106) Sg	(107) Bh	(108) Hs	(109) Mt	(110) Ds	(111) Rg	(112) Uub	(113) Uut	(114) Uuq	(115) Uup	(116) Uuh	(117) Uus	(118) Uuo
Lanthanides			57 La	58 Ce	59 Pr	60 Nd	(61) Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
Actinides			89 Ac	90 Th	91 Pa	92 U	(93) Np	(94) Pu	(95) Am	(96) Cm	(97) Bk	(98) Cf	(99) Es	(100) Fm	(101) Md	(102) No	(103) Lr	

Legend: Lithophile | Siderophile | Chalcophile | Atmophile | very rare

Lithophile: silicate loving

O Sol é unico ?

Não, o Sol é peculiar mas não é unico: ~ 10-20% de estrelas de tipo solar tem uma composição química similar ao Sol, e tal vez possam possuir planetas como a nossa Terra (e tal vez vida !)

$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

Destaques na imprensa sobre a composição peculiar do Sol

elcomercio.com.pe

06 de agosto del 2009

Astrónomo peruano halla forma de descubrir sistemas planetarios similares

16:28 | Se trata de Jorge Meléndez, quien el 17 de a
descubrimiento en la Biblioteca Nacional

IOP A website from the Institute of Physics

physicsworld.com

Home | News | Blog | Multimedia | In depth | Jobs | Events

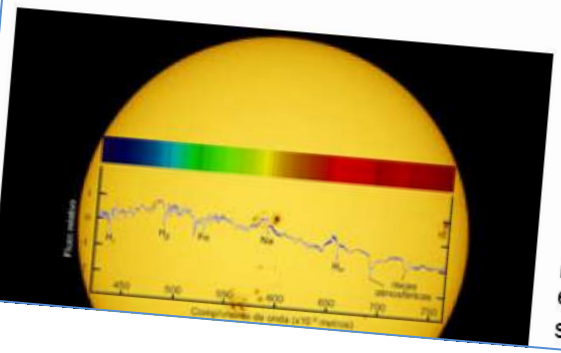
Chemical signature could help locate Earth-like planets

Oct 16, 2009 3 comments

Centro de Astrofísica da Universidade do Porto

Astronotícias

Composição do Sol fornece pistas para a descoberta de outras Terras



21 Setembro 2009

A equipa liderada por Jorge Meléndez, astrónomo do Centro de Astrofísica da Universidade do Porto (CAUP), descobriu uma relação entre a composição química do Sol e a presença de planetas rochosos. Este resultado poderá ser essencial para a descoberta de planetas semelhantes à Terra, à volta de estrelas

Destaques na imprensa sobre a composição peculiar do Sol

RARE SOLAR SYSTEM, RARE SUN

Print this ShareThis

12/14/2009
by Dr. Hugh Ross

The first discovered extrasolar planet was found in 199
Pegasi.[1] This finding persuaded many astronomers a
conclude that Carl Sagan was right—our Milky Way Ga
billions of planets, most of which would prove to be ar
solar system. Sagan concluded that this, in turn, woul
present on several million of them. The subsequent
extrasolar planets before the end of the twentieth cer
would be able to "explore strange new worl
before."

CiênciaHoje

Composição do Sol fornece pistas sobre outras «Terras»

Estudo publicado na Astrophysical Journal Letters

2009-09-18

*Um estudo publicado na revista «**Astrophysical Journal Letters**», da equipa liderada por Jorge Meléndez, astrónomo do*

a plan
solar twin has been

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Space / New Planets

Astronomers Discover 2 Shortcuts for Locating Earth-Like Planets

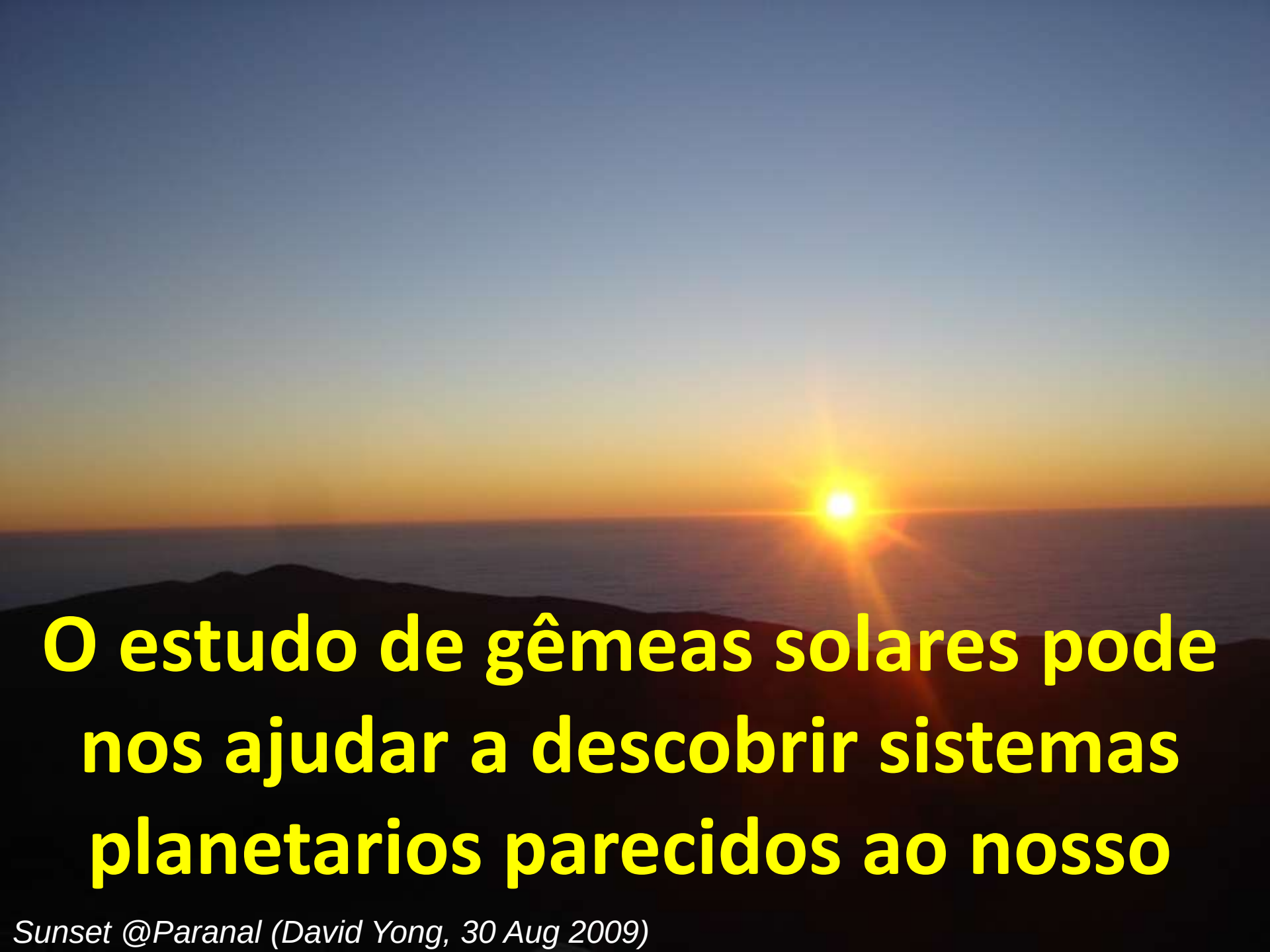
Stars orbited by planets are a little bit different than other stars, and scientists can use that to quickly home in on new planets.

by Andrew Moseman
From the March 2010 issue; published online March 23, 2010

Jorge Meléndez, an astronomer at the University of Porto in Portugal, has turned up a different indicator of planets
Meléndez identified 15 elements that are more abundant in sun-size stars with giant planets orbiting very close to
the stars. But these elements are scarce in our sun, which hosts distant giants and small, rocky inner planets. A
chemical signature like the sun's could be a clue to finding Earth-like worlds that could potentially support life.

Victor Stenger laments that
advanced life might exist.[2]

er Jorge Meléndez, has
[3] Meléndez has devoted much
he Sun, in the sense that the
he existence of advanced life on
rried out in the last few decades.



O estudo de gêmeas solares pode nos ajudar a descobrir sistemas planetarios parecidos ao nosso

Sunset @Paranal (David Yong, 30 Aug 2009)

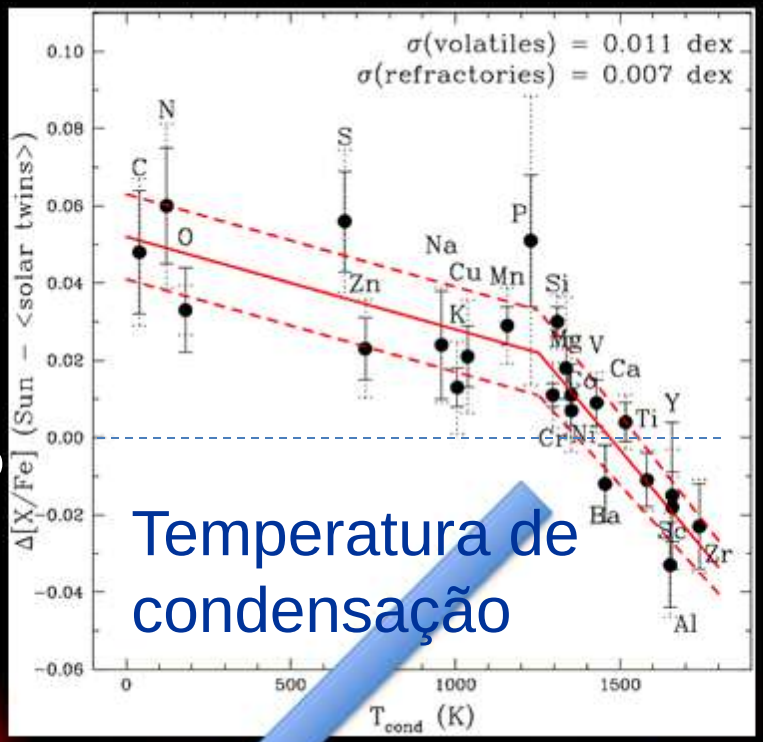
Temas de estudo no IAG/USP

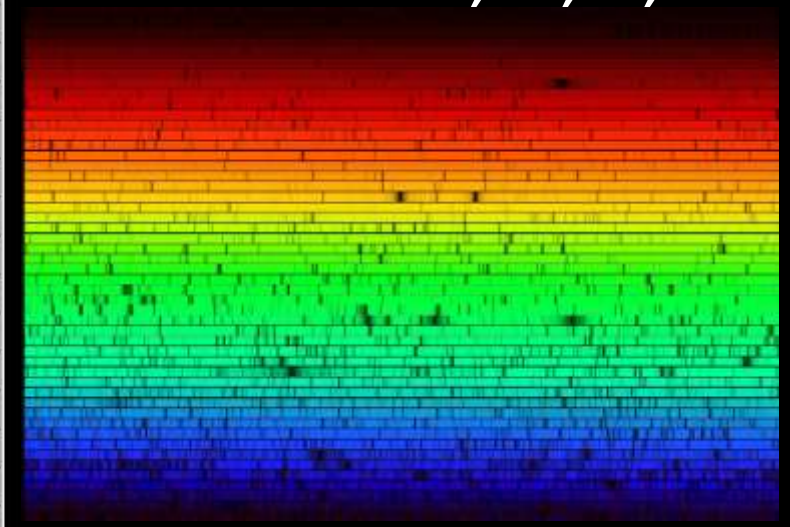
Espectros: propriedades físicas e químicas de estrelas

F, G, K, M

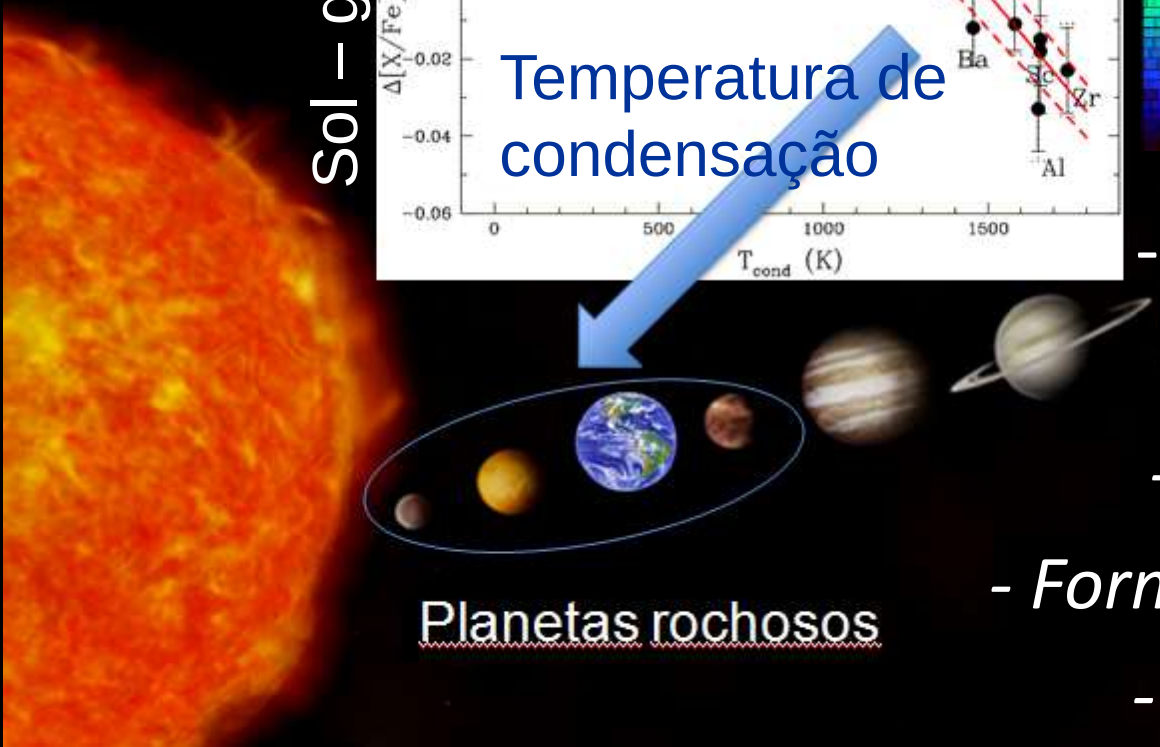
Meléndez, Asplund, Gustafsson, Yong 2009, ApJ letters

Sol – gêmeas solares





Temperatura de condensação



Planetas rochosos

- *Planetas como a Terra*
- *Atómos e Moléculas*
- *Propriedades estelares*
- *Formação da Nossa Galáxia*
- *Primordios do Universo*