

03/09/2010

Seminários de Iniciação Científica (Astronomia)

Em busca de gêmeos do sistema solar

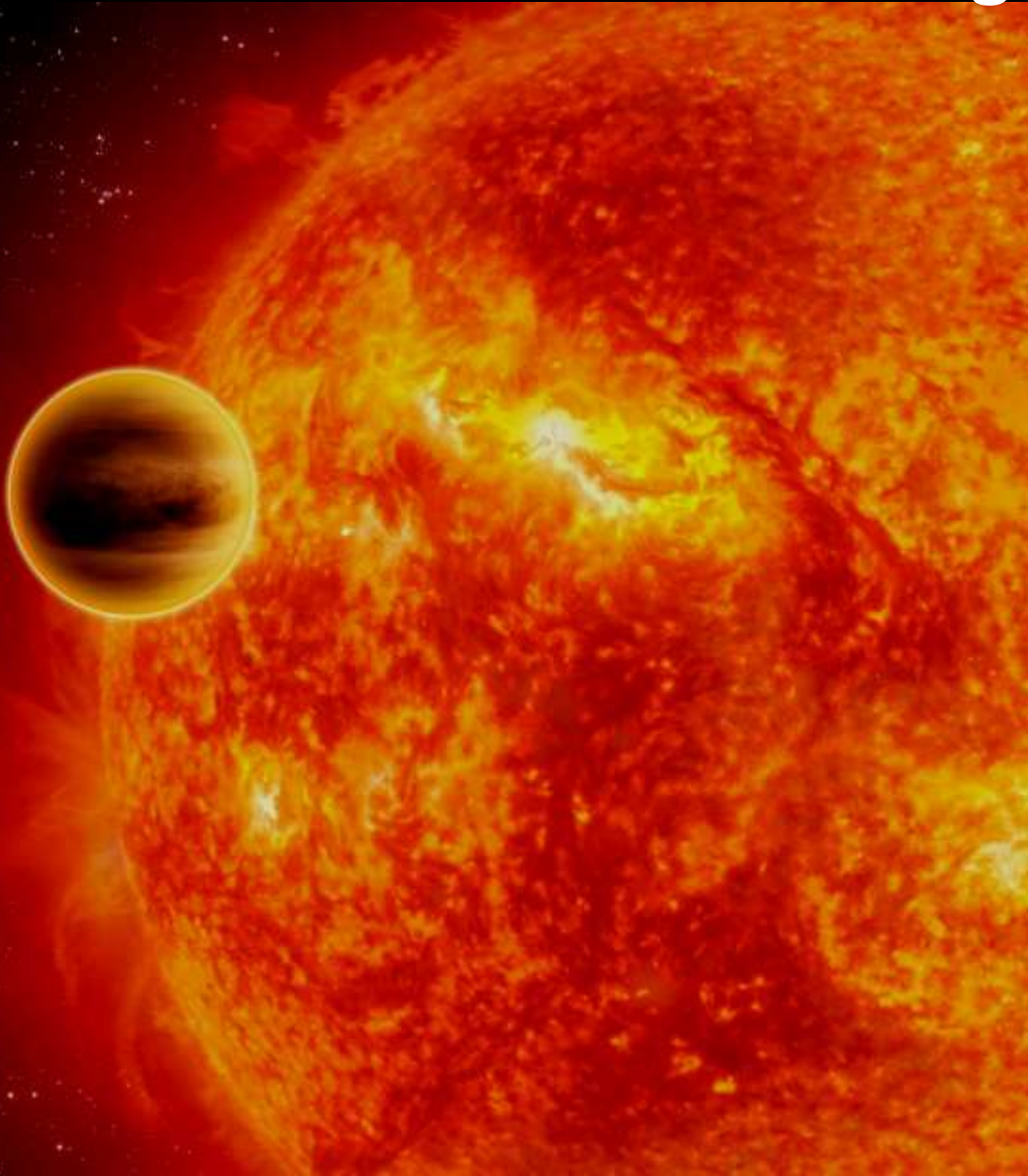
Jorge Meléndez

Departamento de Astronomia do IAG/USP

Sunset in Paracas, Peru

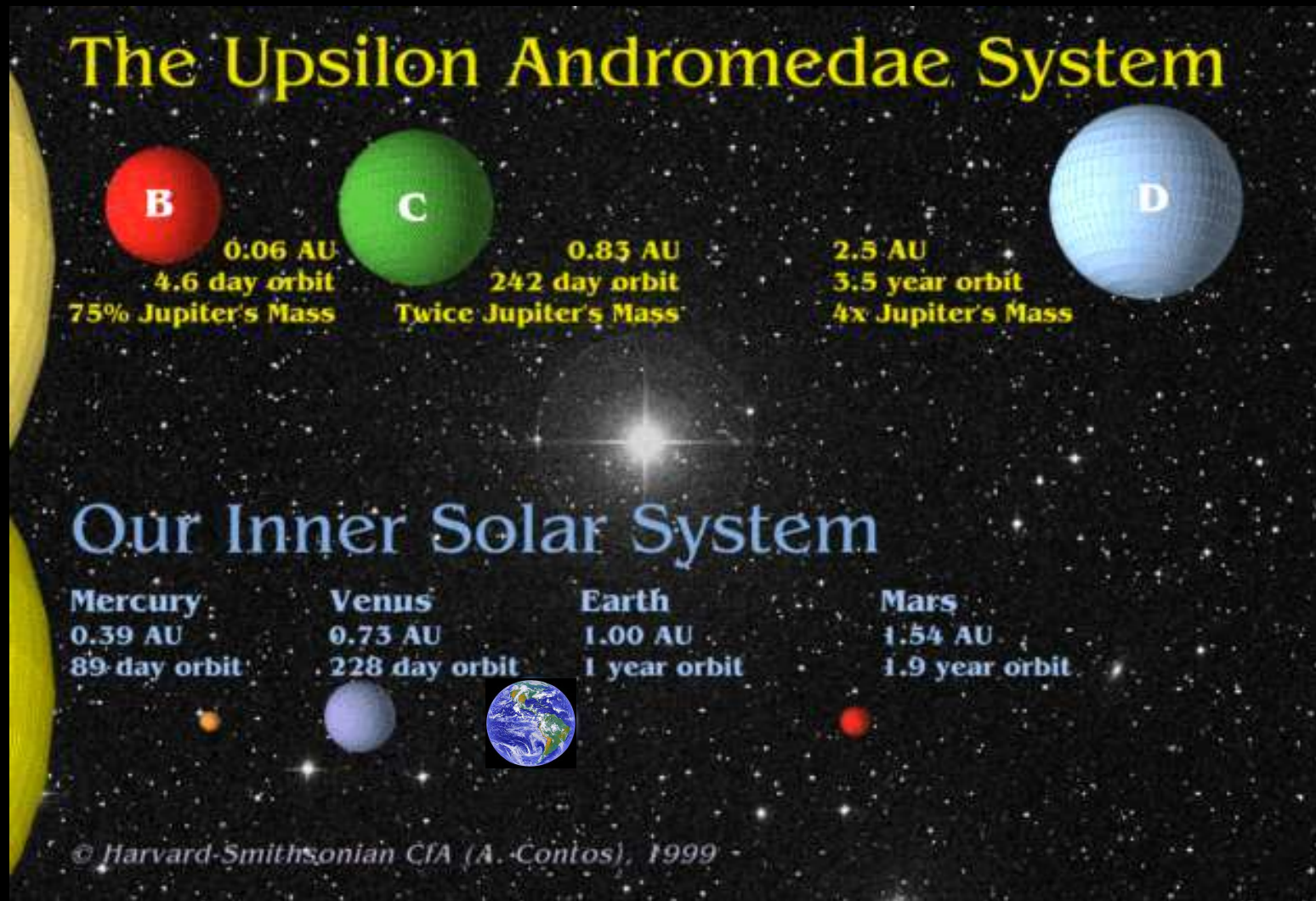
(c) www.flickr.com/photos/rodrigocampos/

~ 400 sistemas planetários
encontrados até agora



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

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

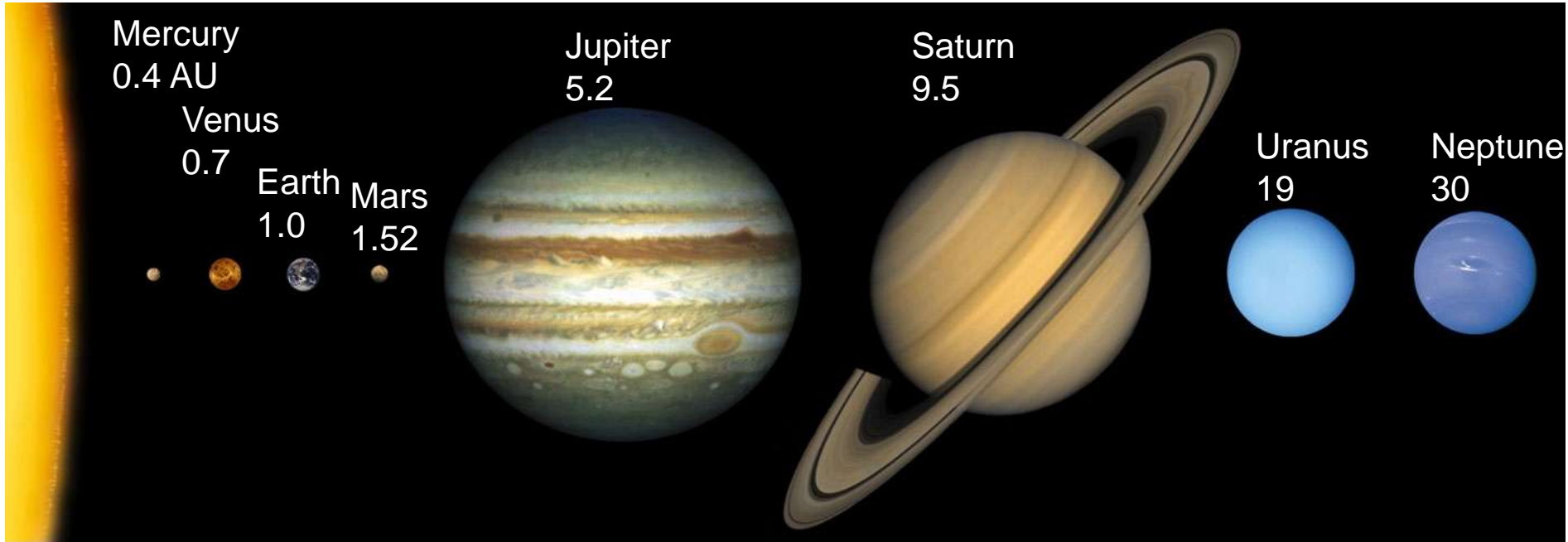


Descoberto o Sistema Planetário Mais Rico em Planetas Conhecido Até Agora

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

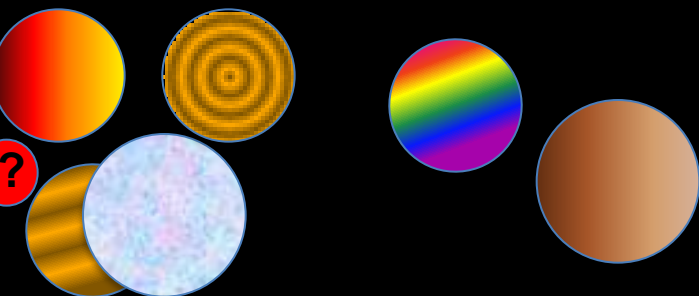


Planetas em torno do Sol



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

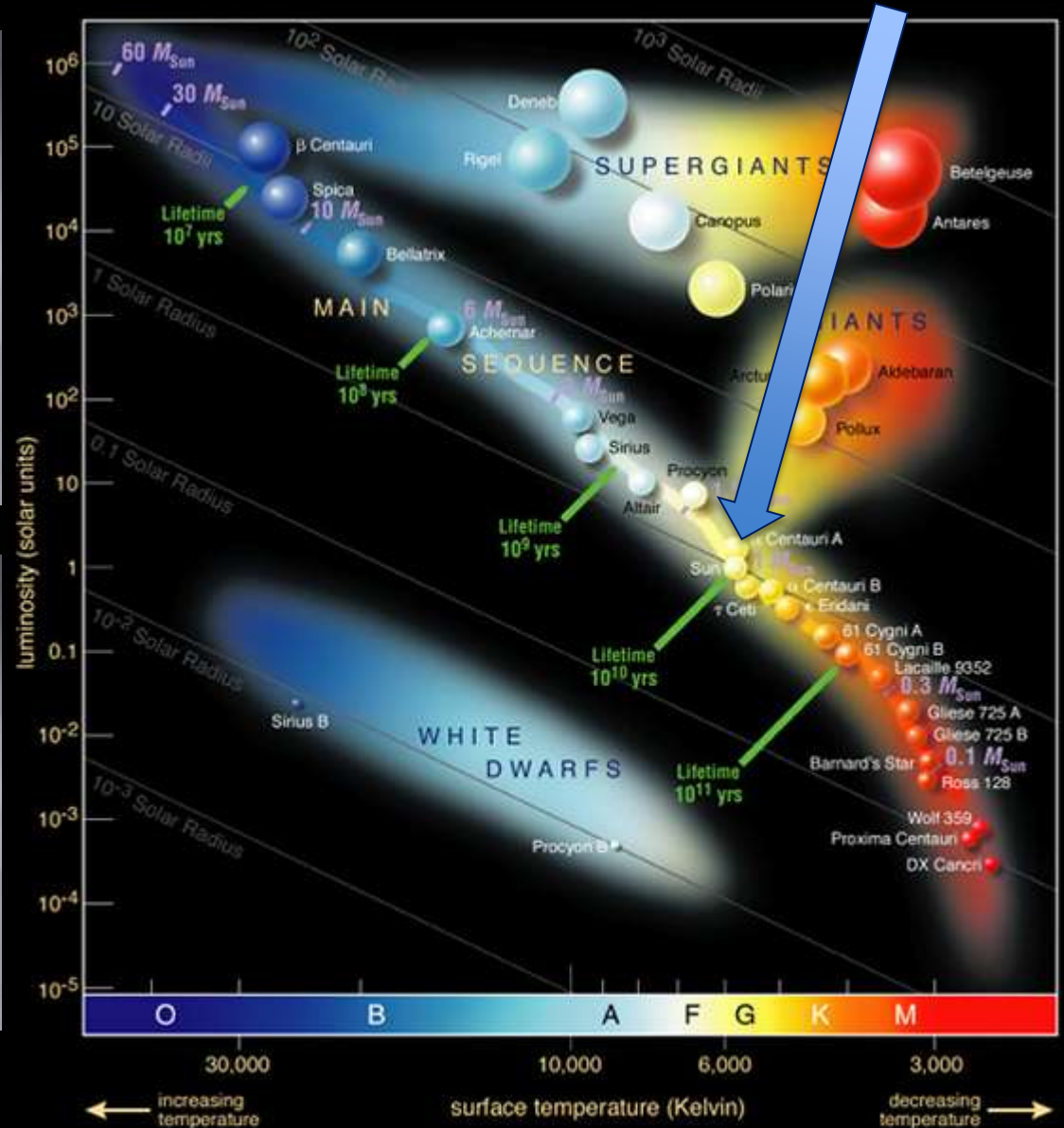
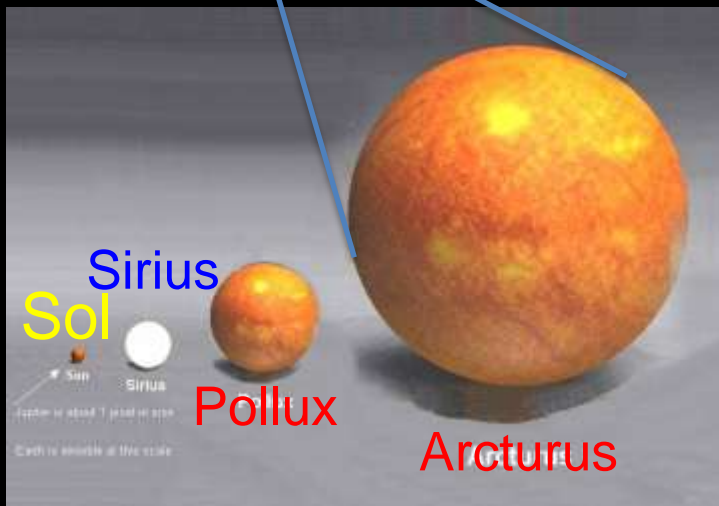
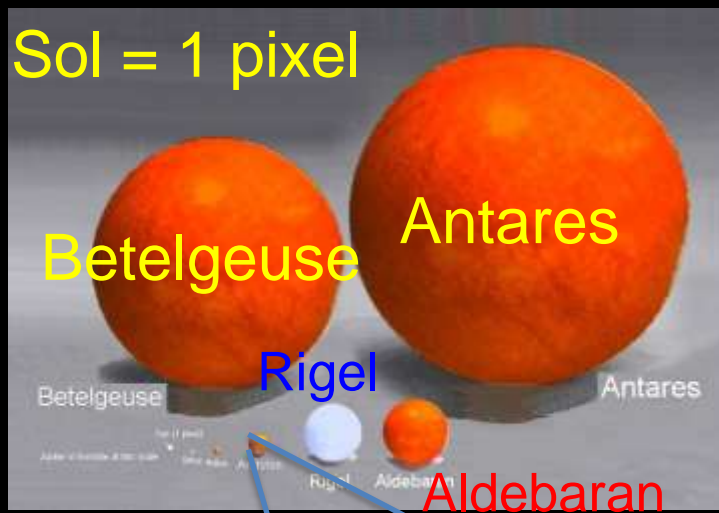


Planetas em torno de HD 10180

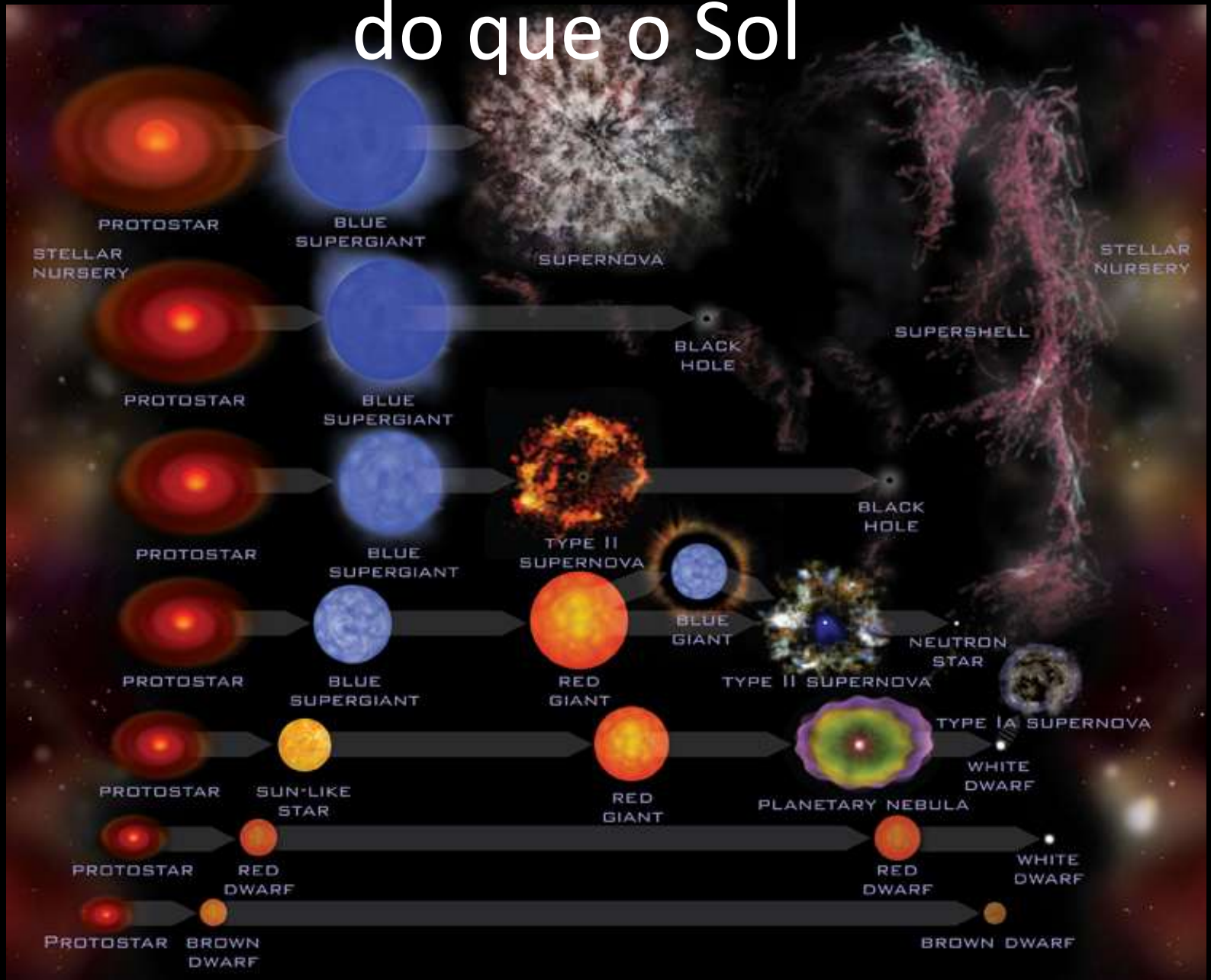
Como encontrar um sistema solar parecido ao nosso?



1. Procurar estrelas similares ao Sol



2. No mesmo estagio evolutivo do que o Sol



3. Composição química ~ solar?

PRODUCED BY THE FOUNDATION FOR EDUCATION, SCIENCE AND TECHNOLOGY FOR NATIONAL SET WEEK 2003

PERIODIC TABLE of the ELEMENTS

DMITRI MENDELEEV (1834 - 1907)
 The Russian chemist, Dmitri Mendeleev, was the first to observe that if elements were listed in order of atomic mass, they showed regular (periodical) repeating properties. He formulated his discovery in a periodic table of elements, now regarded as the backbone of modern chemistry.

The crowning achievement of Mendeleev's periodic table lay in his prophecy of then undiscovered elements. In 1869, the year he published his periodic classification, the elements gallium, germanium and scandium were unknown. Mendeleev left spaces for them in his table and even predicted their atomic masses and other chemical properties. Six years later, gallium was discovered and his predictions were found to be accurate. Other discoveries followed and their chemical behaviour matched that predicted by Mendeleev.

This remarkable man, the youngest in a family of 17 children, has left the scientific community with a classification system so powerful that it became the cornerstone of chemistry teaching and the prediction of new elements ever since. In 1955, element 101 was named after him, 106, Mendeleevium.

Legend:
 • Gas
 • Liquid
 • Solid metal
 • Non-metal solid (poisonous)

State of Matter Legend:
 • Gas
 • Liquid
 • Solid metal
 • Non-metal solid (poisonous)

DEPARTMENT OF SCIENCE AND TECHNOLOGY
SHUTTLEWORTH FOUNDATION

Periodic Table Elements:
 H (1.01), He (4.00), Li (6.94), Be (9.01), B (10.81), C (12.01), N (14.01), O (16.00), F (19.00), Ne (20.18), Na (22.99), Mg (24.31), Al (26.98), Si (28.09), P (30.97), S (32.06), Cl (35.45), Ar (39.95), K (39.10), Ca (40.08), Sc (44.96), Ti (47.88), V (50.94), Cr (52.00), Mn (54.94), Fe (55.85), Co (58.93), Ni (58.71), Cu (63.55), Zn (65.38), Ga (69.72), Ge (72.64), As (74.92), Se (78.96), Br (79.90), Kr (83.80), Rb (85.47), Sr (87.62), Y (88.91), Zr (91.22), Nb (92.91), Mo (95.94), Tc (98.91), Ru (101.07), Rh (101.07), Pd (106.32), Ag (107.87), Cd (112.41), In (114.82), Sn (118.71), Sb (121.76), Te (127.60), I (126.91), Xe (131.29), Ba (137.33), La (138.91), Ce (140.12), Pr (140.91), Nd (144.24), Pm (144.91), Sm (150.36), Eu (151.96), Gd (157.25), Tb (158.93), Dy (162.50), Ho (164.93), Er (167.26), Tm (168.93), Yb (173.05), Lu (174.97), Cs (132.91), Fr (223.02), Ra (226.03), Ac (227.03), Th (232.04), Pa (231.04), U (238.03), Np (237.05), Pu (244.06), Am (243.06), Cm (247.07), Bk (247.07), Cf (251.08), Es (252.08), Fm (257.10), Md (258.10), No (259.10), Lr (262.11)

FEST

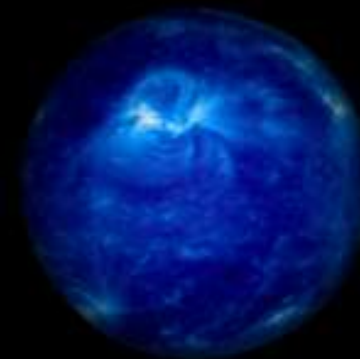
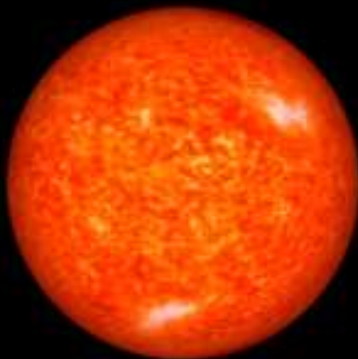
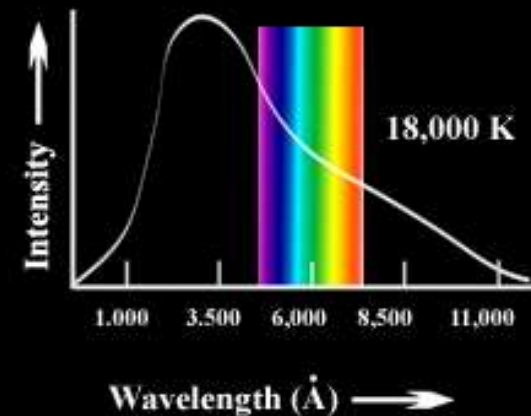
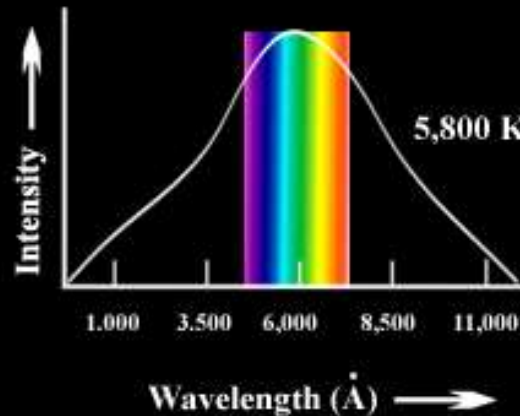
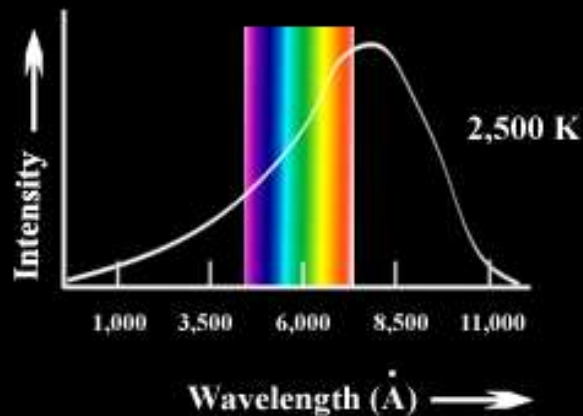
Com tantas estrelas no céu, como
saber quais são similares ao Sol?



Primeiro passo: classificação

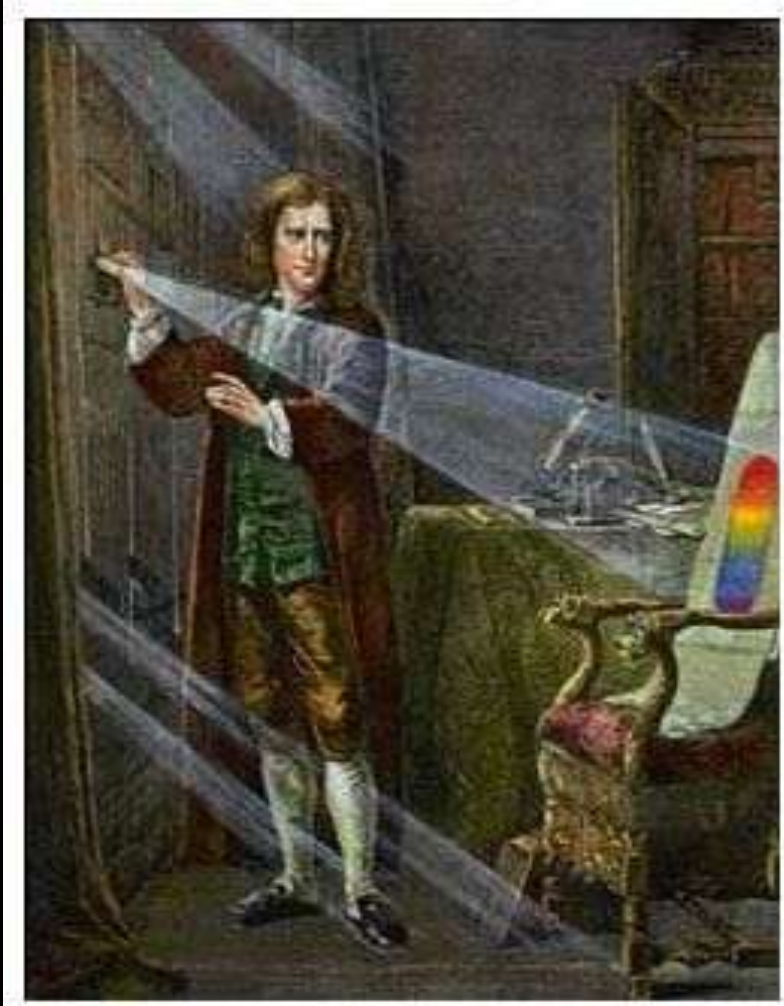


Classificação usando as cores



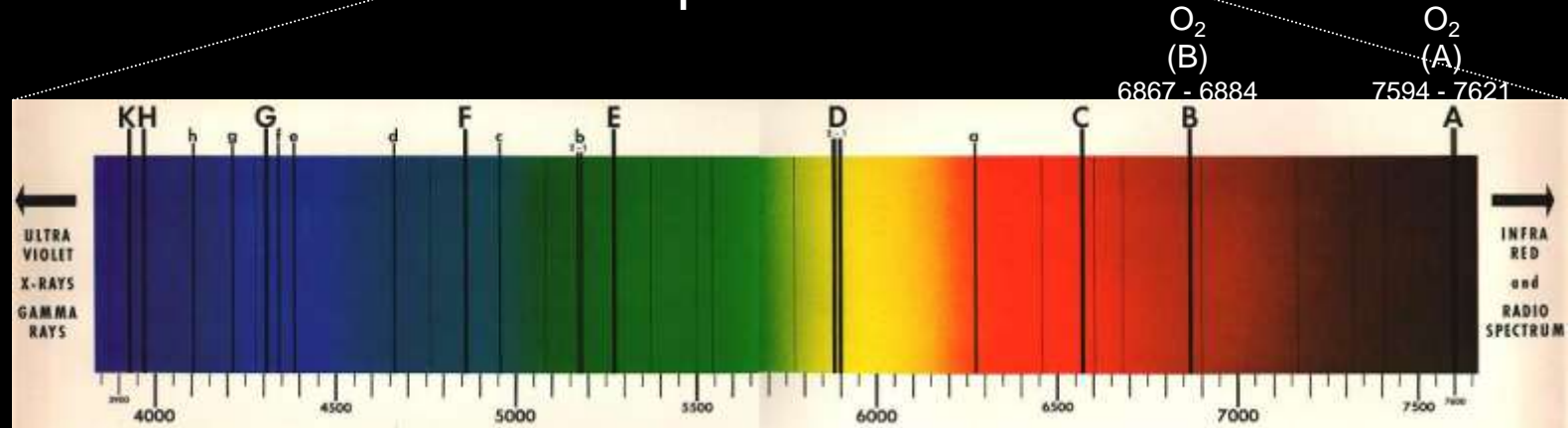
Colors are exaggerated

Classificação usando a luz das estrelas



Newton (1643-1727)

Espectro solar



Ca II (K) 3934	Ca II (H) 3968	Ca(g) 4227	Fe(e) 4384	Hδ (h) 4102	CH, Fe (G) 4308	Fe(d) 4668	Hβ (F) 4861	Fe (E) 5270	Mg (b ₁ , b ₂) 5184 & 5173	Fe (c) 4958	Na D ₂ 5890 & D ₁ 5896	Hα (C) 6563
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Linhas de Fraunhofer (1817)

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

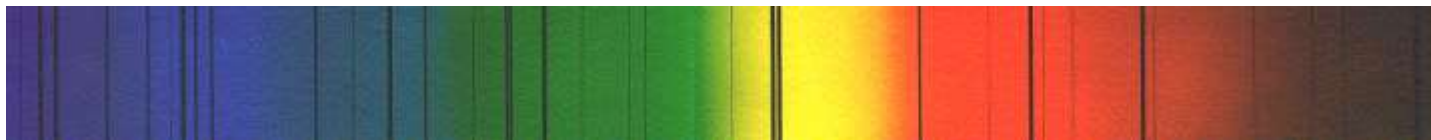
1817: Joseph Fraunhofer (1817) rediscovered the lines. He discounted Wollaston's colour boundary interpretation, he observed a continuous color change across the spectrum; no color discontinuities occurred at the dark lines

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

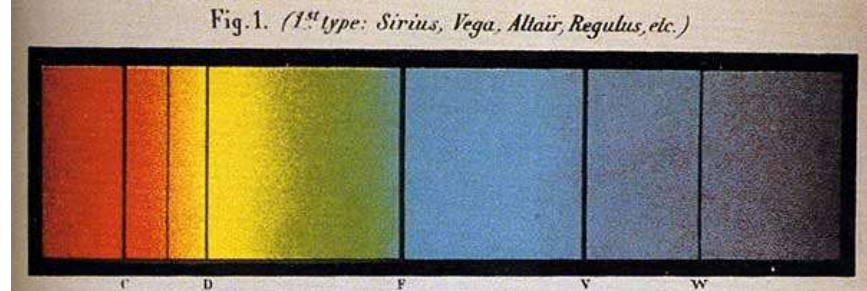
- Tipo I: **branco-azul**
moderna classe A & F "cedo"
- **Tipo II: amarelas, de tipo solar**
atual classe G, K, F tardio
- Tipo III: **laranja-vermelho**,
moderna classe M
- Tipo IV: estrelas com linhas de emissão



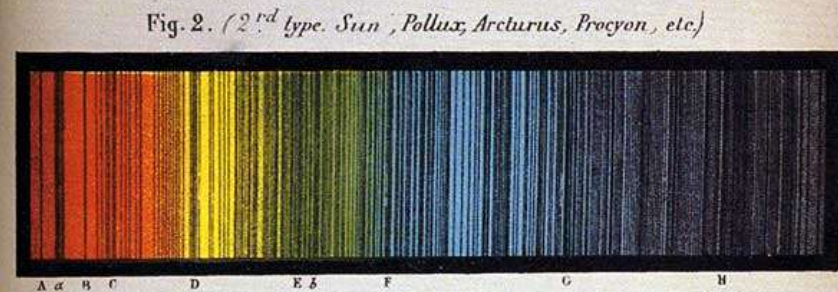
Secchi's Four Classes of Stellar Spectra

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.

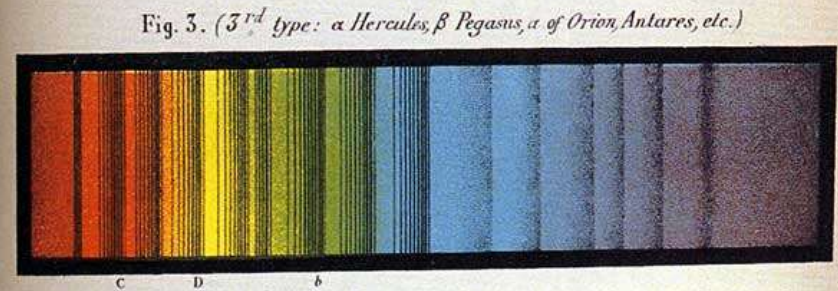
Tipo I



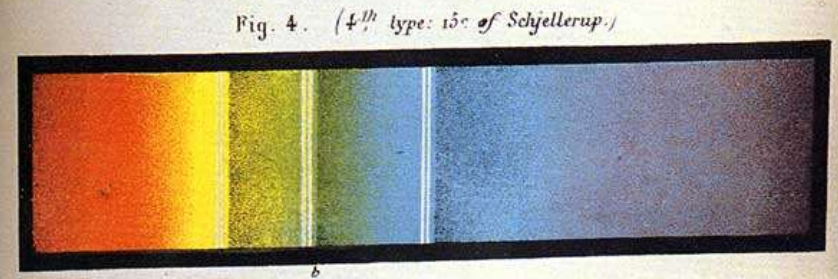
Tipo II



Tipo III



Tipo IV

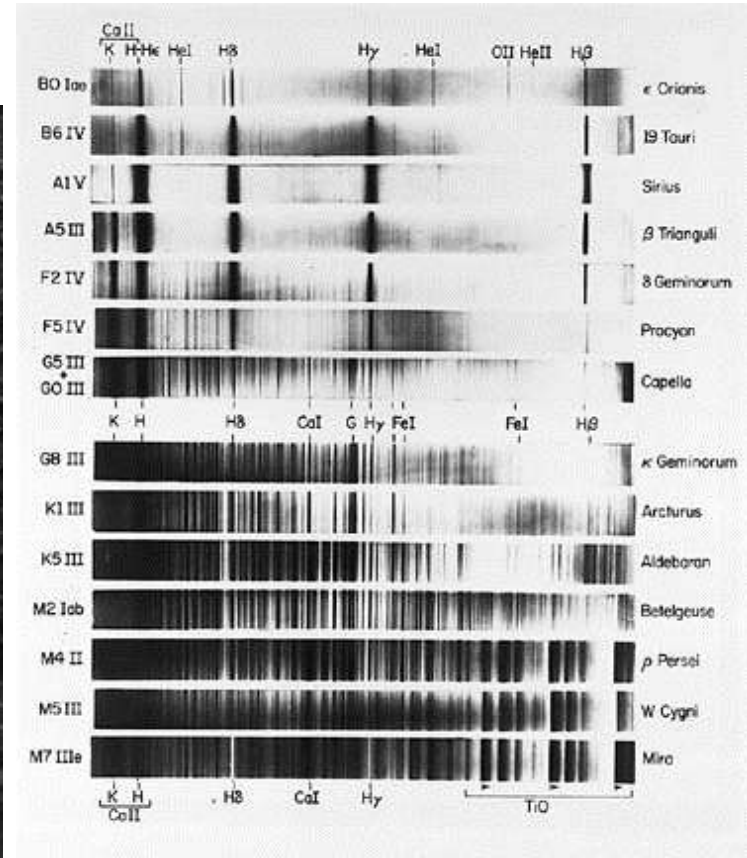


O sistema de classificação de Harvard

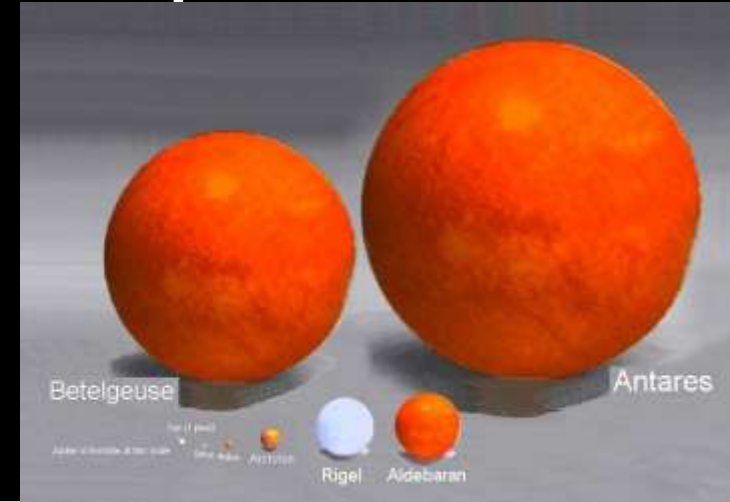
- 1890-1900s: classificação de Harvard (E. Pickering + Williamina Fleming + Antonia Maury + Annie J. Cannon):

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

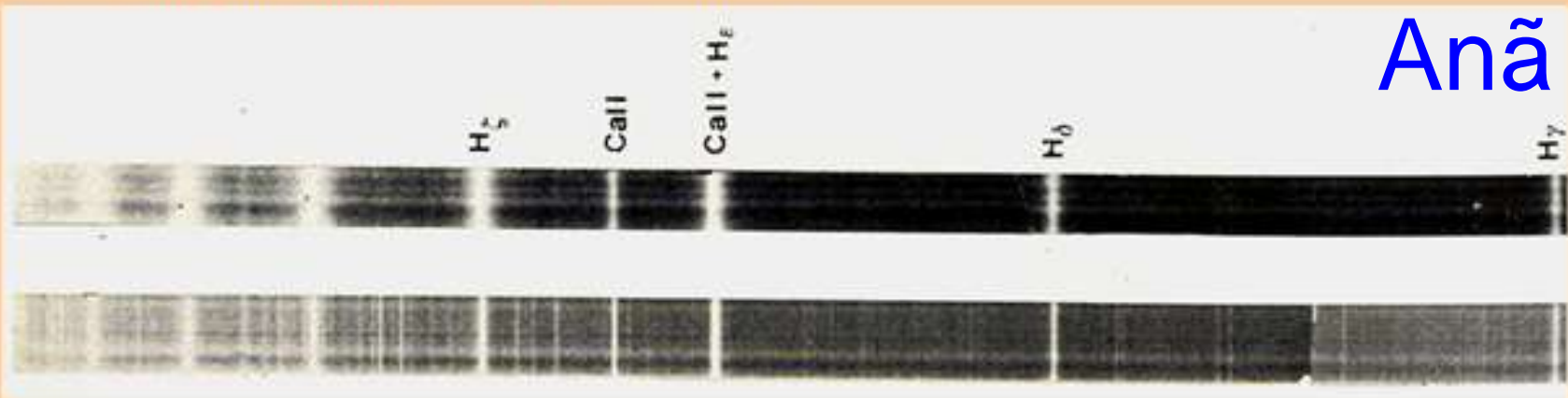
Mulheres astrônomas @ Harvard



Mais sobre classificação espectral: classe de luminosidade



Dwarf and Supergiant spectra in comparison



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 gêmeas solares

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

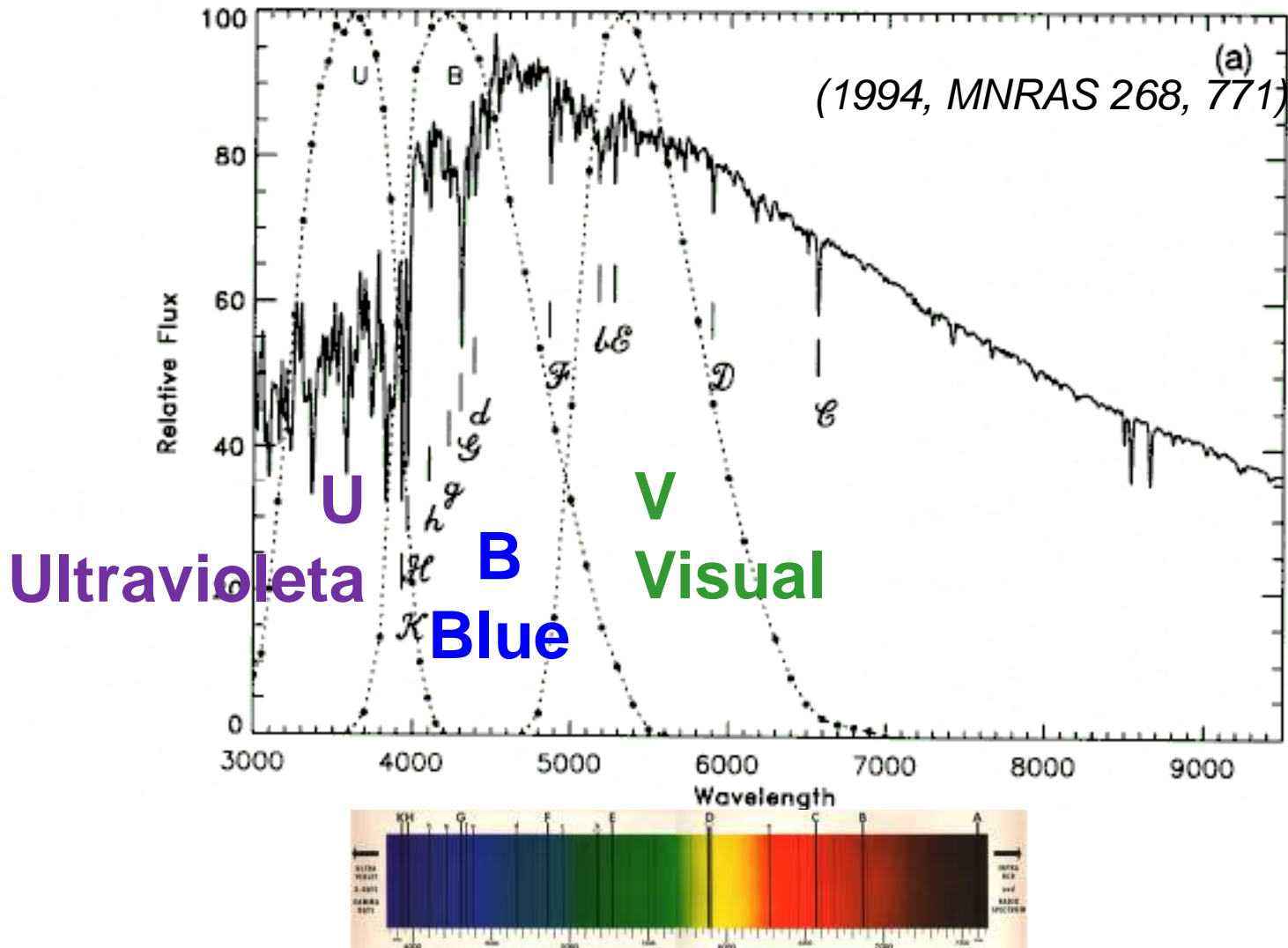
OU ...

- Índice de cor
- Magnitude absoluta

Índice de cor B-V no sistema UBV

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

$$B-V = \text{mag B} - \text{mag V}$$



Magnitude Absoluta: M

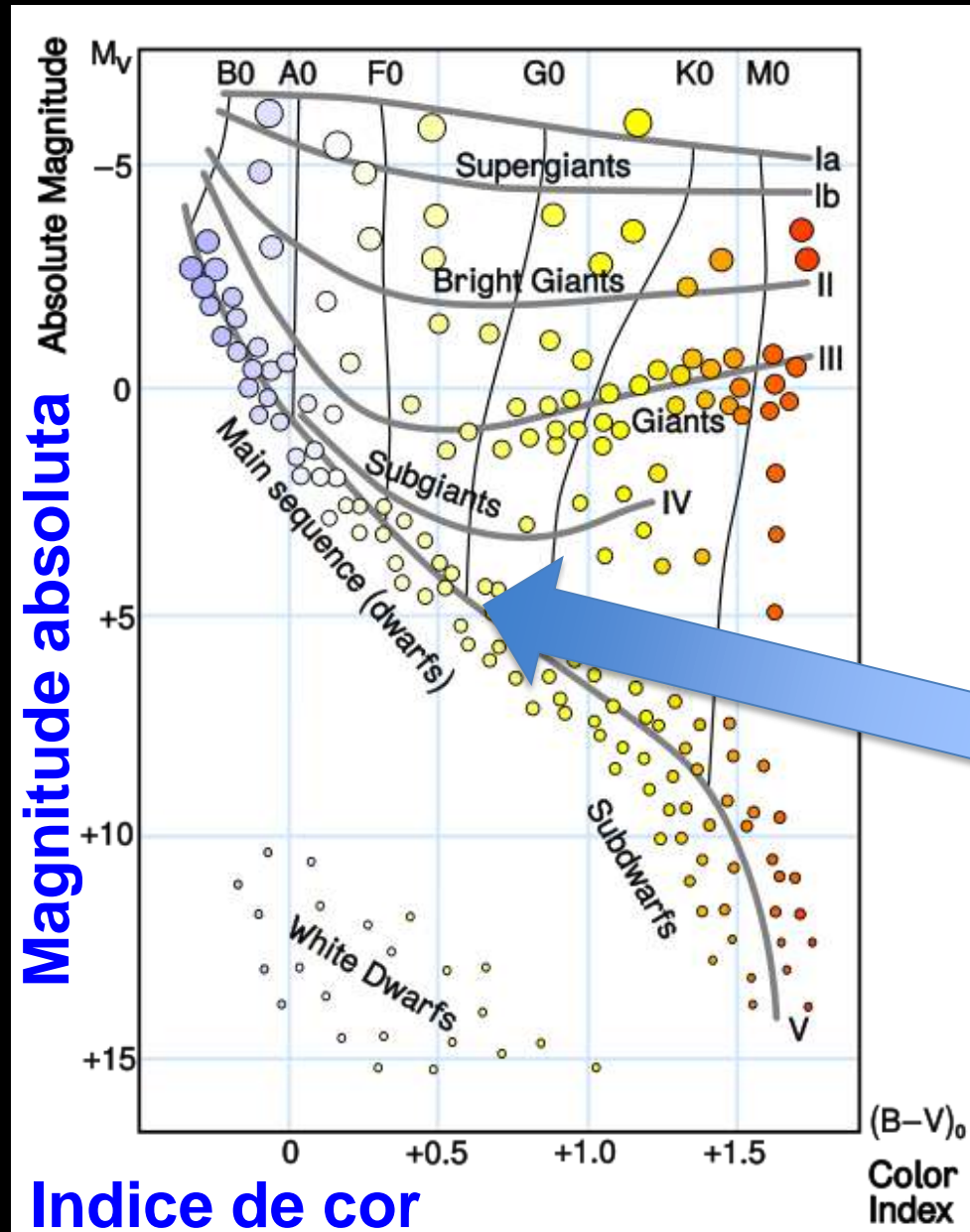
Magnitude absoluta **M**: a magnitude aparente **m** que teria um objeto a 10pc de **distancia**

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

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



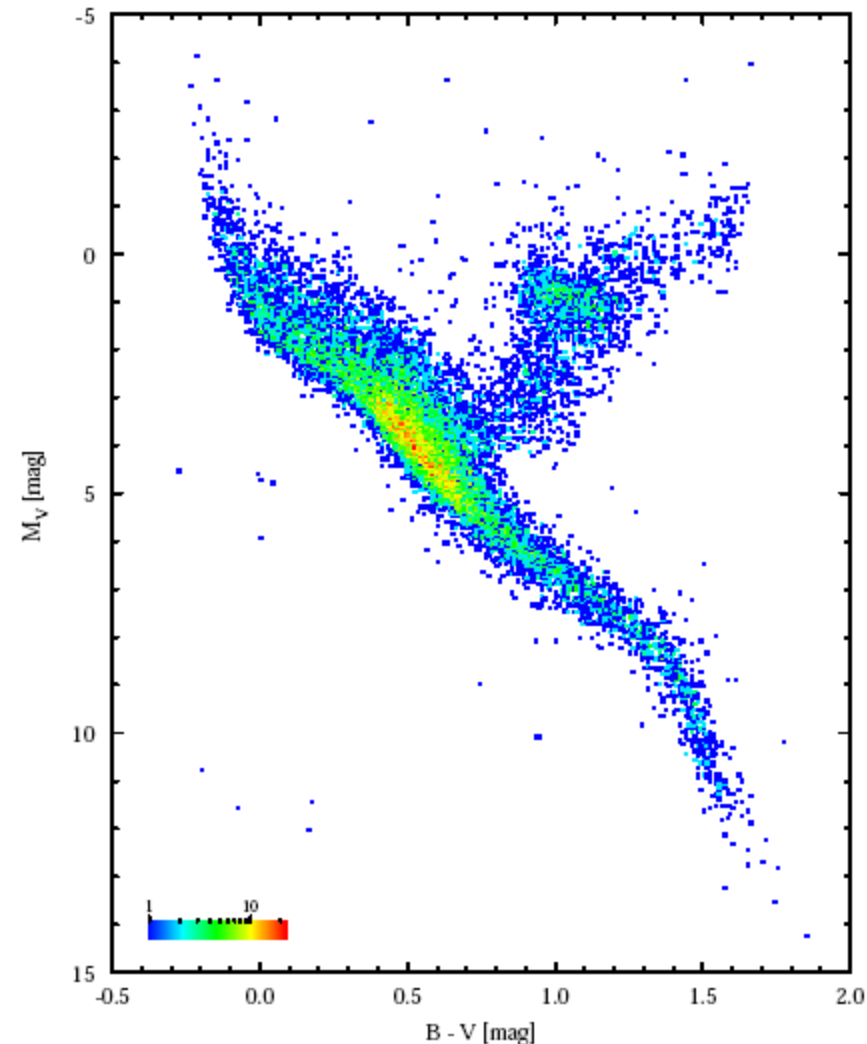
Diagrama H-R



SOL
 $M_V = 4.82$
 $B-V \sim 0.65$

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

- Cores $B_T - V_T$
- Magnitude absoluta V_T
- Outras cores (óptico 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. Knowles¹, G. Hernandez², and C.

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

In search of real solar twins. III.*

E. Friel¹, G. Cayrel de Strobel¹, Y. Chmielewski², M. Spite^{1**}, A. Lèbre¹, and C. Bentolila¹



Primeira gêmea solar descoberta apenas em 1997: 18 Sco

THE ASTROPHYSICAL JOURNAL, 482:L89–L92, 1997 June 10
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HR 6060: THE CLOSEST EVER SOLAR TWIN?¹

G. F. PORTO DE MELLO^{2,3} AND L. DA SILVA³

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.

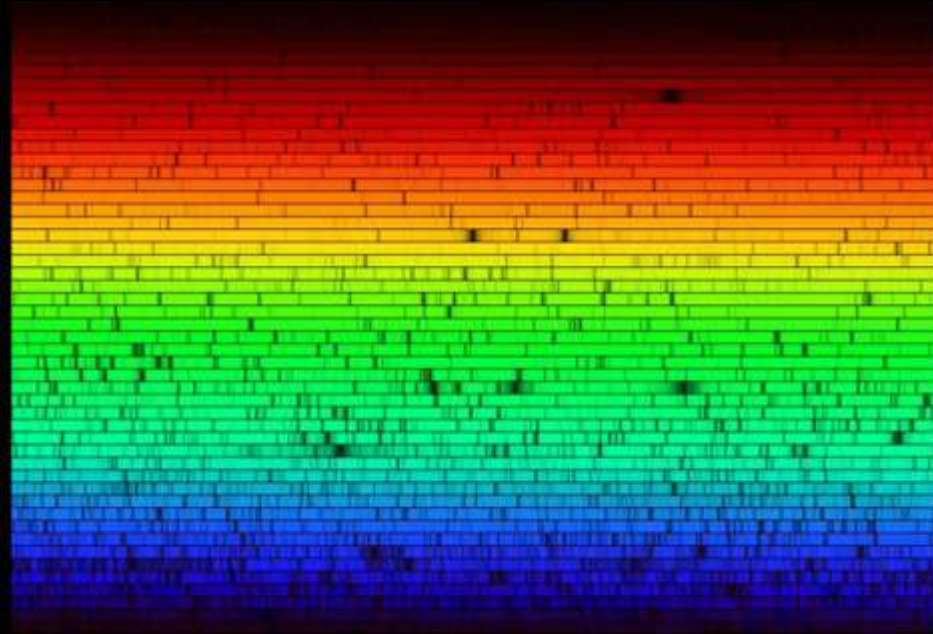


18 Sco

Parameter	Sun	HR 2290	HR 6060	16 Cyg A	16 Cyg B
ΔT_{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: Austrália, 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

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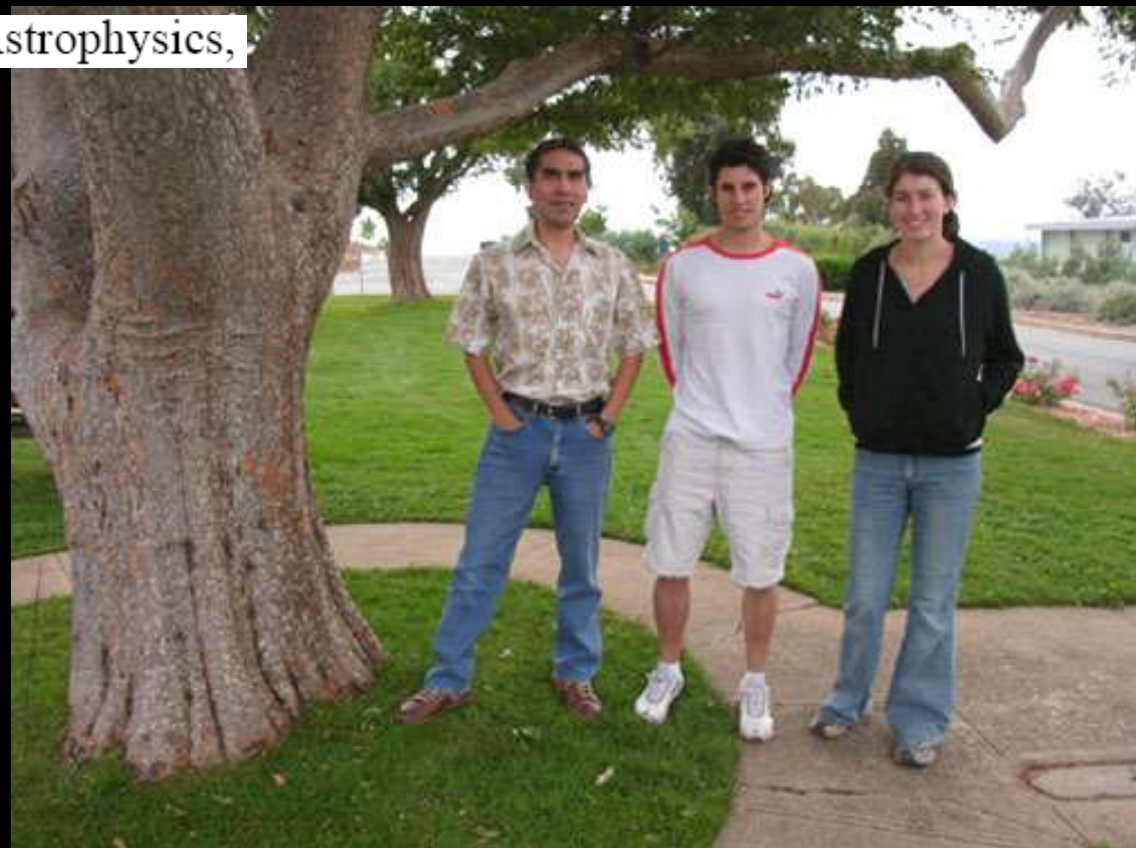
HD 98618: A STAR CLOSELY RESEMBLING OUR SUN¹

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

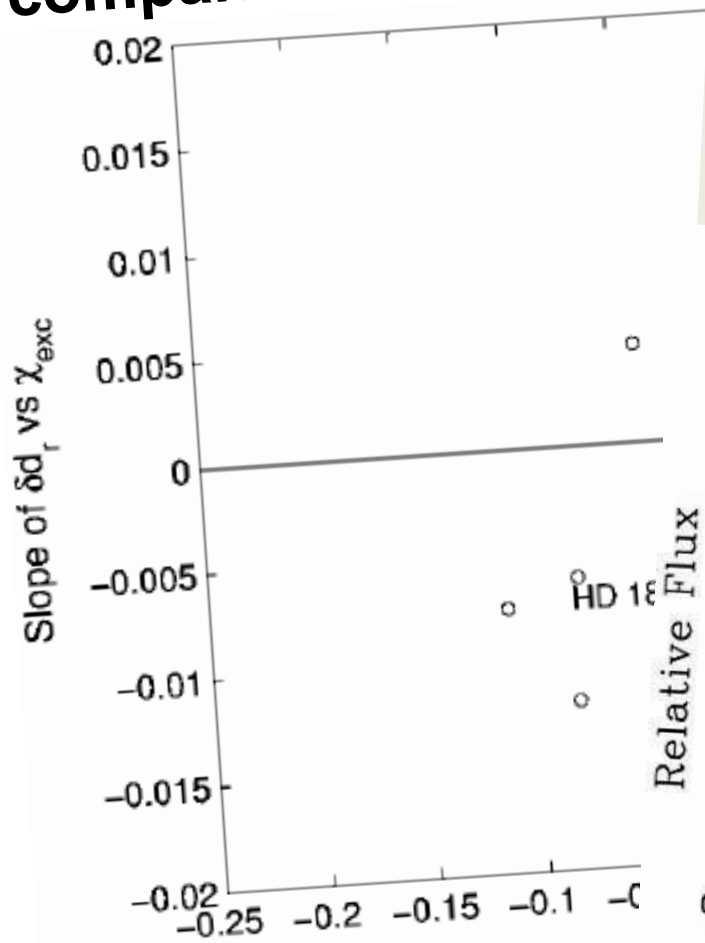
Research School of Astronomy and Astrophysics,

Mount Stromlo Observatory

- Projeto de iniciação científica de Katie Dodds-Eden

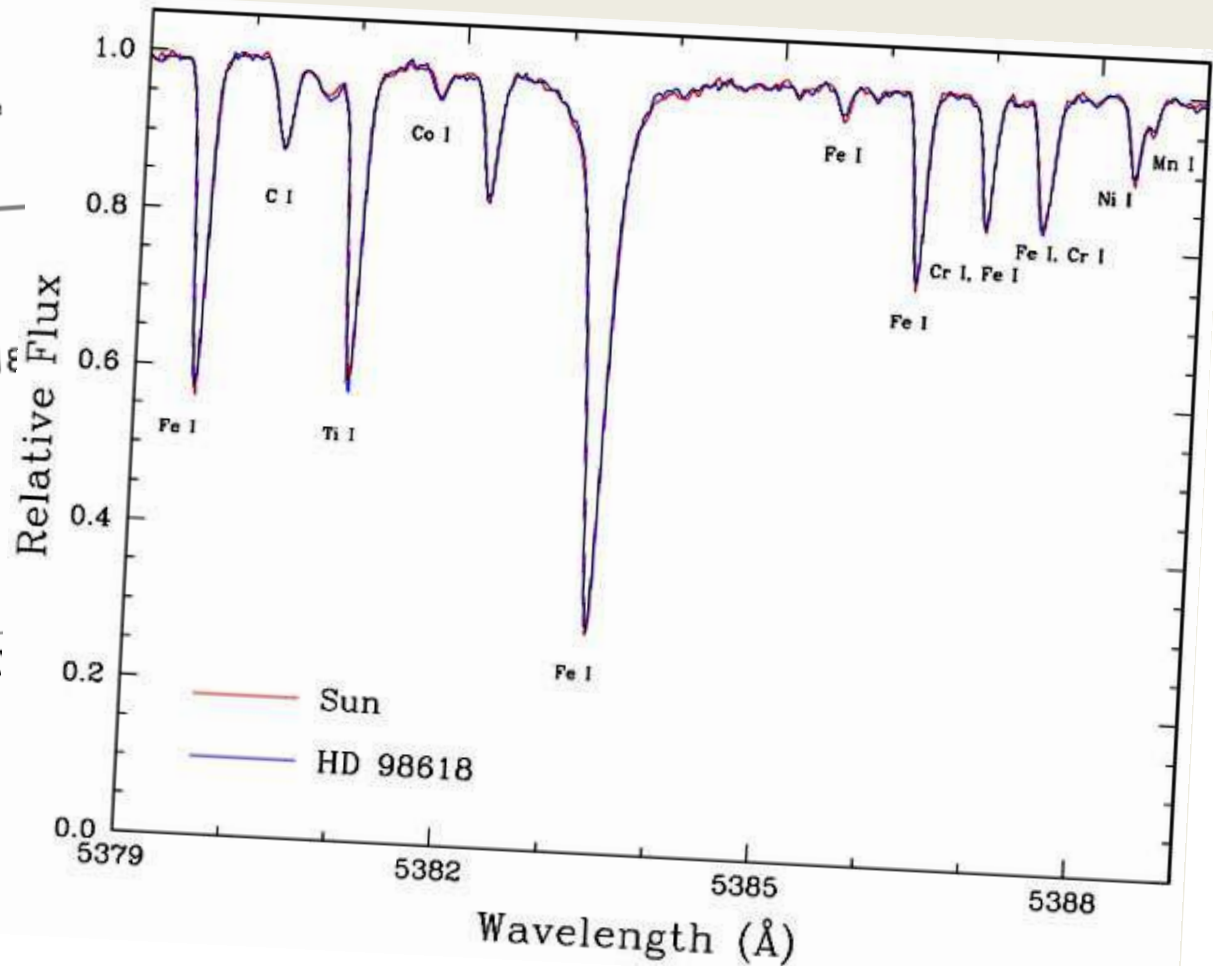


Model independent comparison



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 the Sky

By Ken Crowell
March 10, 2006



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

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

Jorge Meléndez, Katie Dodds-Eden high-resolution spectra of HD 98618, 126 light-years from Earth, almost

WEEKLY | NEWS IDEAS INNOVATION

NewScientist

8 April 2006 No2546 Australia \$4.50 (Inc.GST) New Zealand NZ\$4.95 (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 concentration of heavy elements as the sun. These elements are crucial to the formation of 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

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

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

FUNDAMENTAL PARAMETERS Estrela - Sol

Parameter (Star – Sun)	18 Sco	HD 98618
Δv_r (km s ⁻¹)	+0.08 ± 0.15	+0.09 ± 0.15
ΔT_{eff} (K)	+40 ± 30	+66 ± 30
$\Delta \log g_{\text{spec}}$ (dex)	+0.01 ± 0.04	+0.01 ± 0.04
$\Delta \log g_{\text{Hip}}$ (dex)	+0.01 ± 0.02	+0.01 ± 0.03
$\Delta \log g_{\text{adopted}}$ (dex)	+0.01 ± 0.02	+0.01 ± 0.03
ΔL_{spec} (L _☉)	+0.02 ± 0.06	+0.04 ± 0.06
ΔL_{Hip} (L _☉)	+0.03 ± 0.03	+0.08 ± 0.07
$\Delta L_{\text{adopted}}$ (L _☉)	+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
Δmass (M _☉)	+0.02 ± 0.03	+0.02 ± 0.03
$\Delta \text{age}_{\text{isochro}}$ (Gyr)	-0.8 ± 1.5	-1.1 ± 1.5
$\Delta \text{age}_{\text{chromos}}$ (Gyr)	-0.3 ^a	+0.7 ^a
$\Delta \text{age}_{\text{rotation}}$ (Gyr)	-1.1	-0.4
$\Delta \text{age}_{\text{adopted}}$ (Gyr)	-0.7 ± 0.4	-0.3 ± 0.9
$\Delta \text{rotation period}$ (days)	-2.5 ^b , -1 ^a	-1 ^a
$\Delta \log R'_{\text{HK}}$ (dex)	0.0 ^a	-0.05 ^a
ΔM_V (mag)	-0.04 ± 0.04	-0.09 ± 0.07
<i>B-V</i>	0.65	0.64
Distance (pc)	14.0	38.7

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

Número atômico



Símbolo

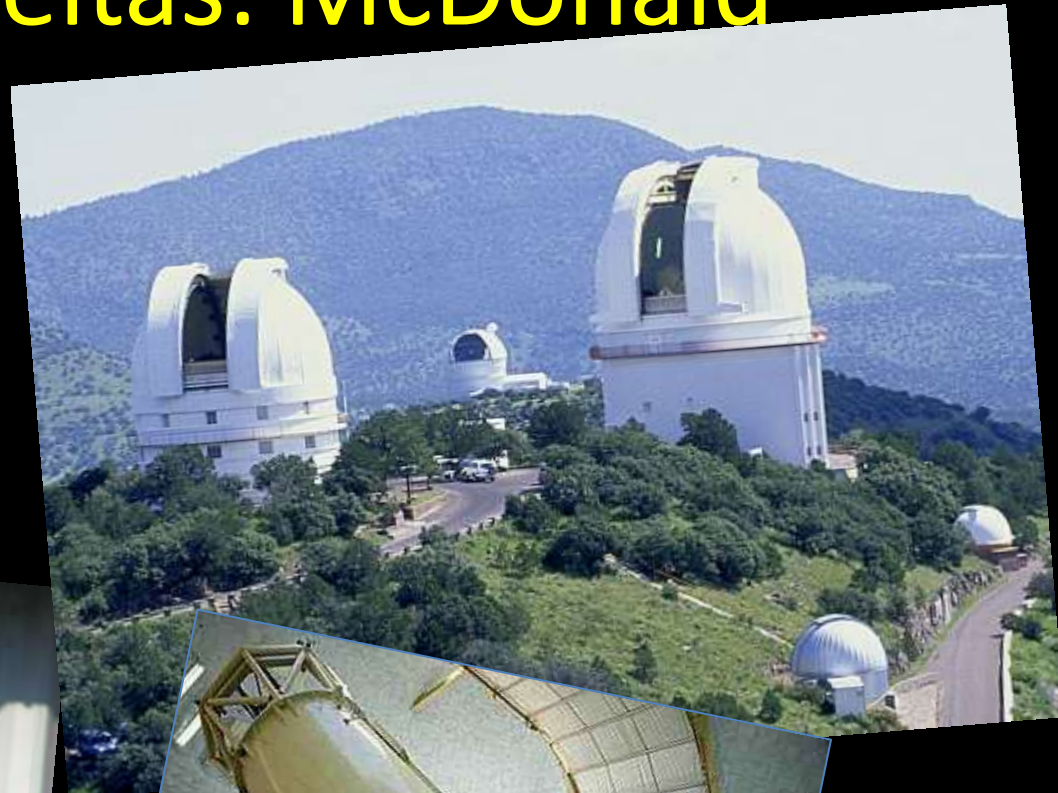
Nome

Massa atômica

Estrutura
Eletrônica

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

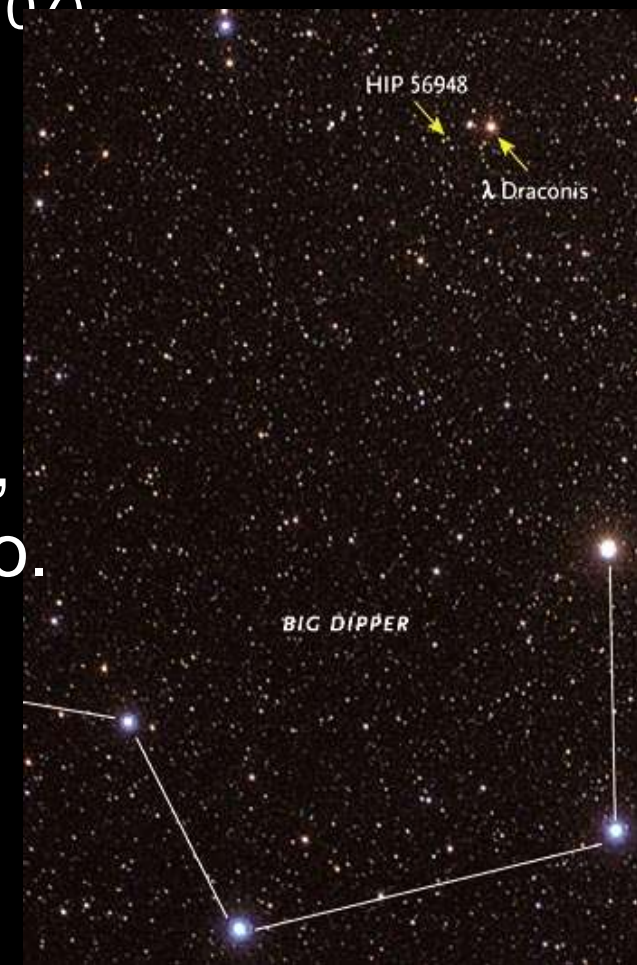
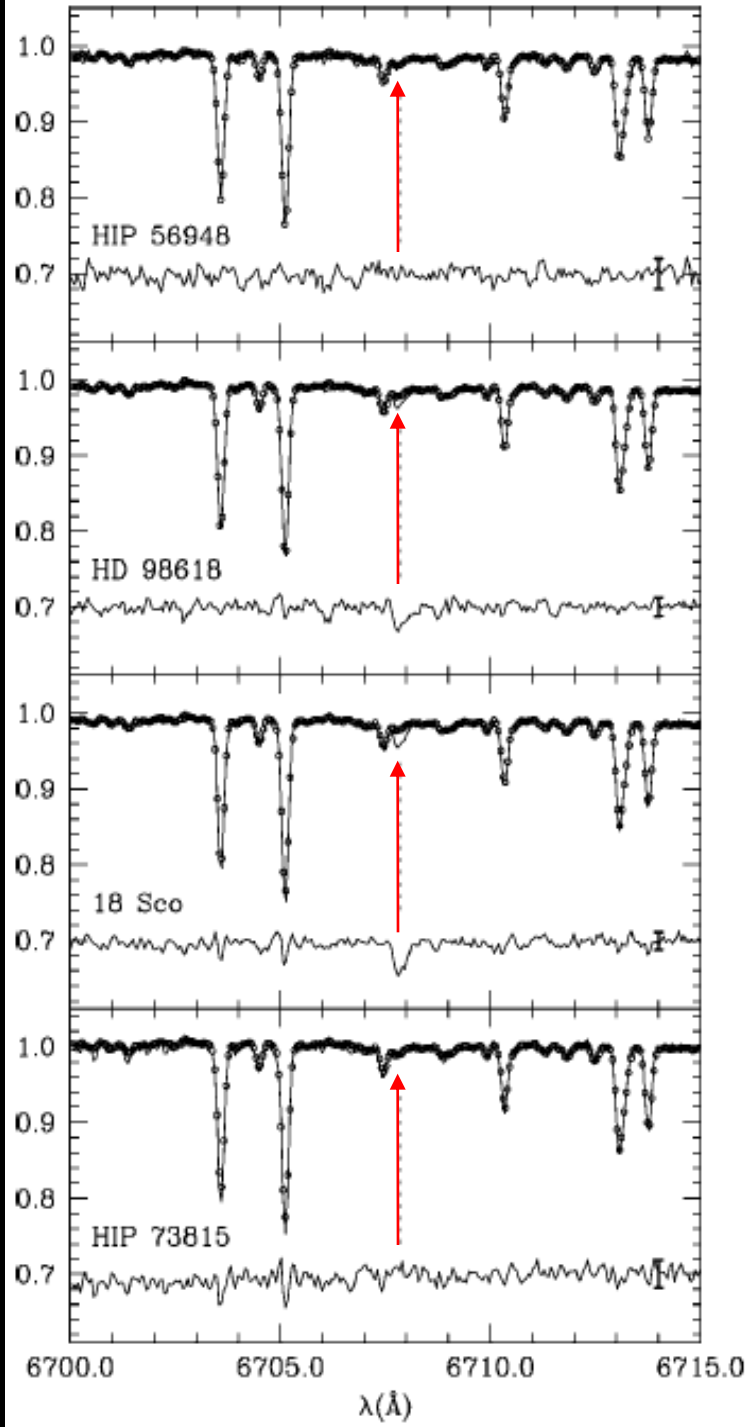
Novas gêmeas solares HIP 56948 & HIP 73815 tem baixo Li (~ 1.0)!

Muito parecido ao Sol !

(Melendez et al. 2006; Melendez & Ramirez

07)

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



HIP 56948: destaque na imprensa



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NEWS by Kelly Beatty

Our Sun's Twin



Every now and then someone tries to trip me up with that old trick question, "What's the closest star to Earth?"

"Hmm," I reply in mock contemplation. "Is it the Sun?"

This little exchange underscores how we've come to regard old Sol as a one-of-a-kind star. But now two astronomers think they've found the closest thing yet to the Sun's twin. It's not some long-lost, separated-at-birth companion, but rather a 9th-magnitude blip in the constellation Draco that's about 200 light-years away.

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 astronomer 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,

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- Is Comet Holmes bigger than the Sun?

ARTICLE

Sun's 'twin' an ideal hunting ground for alien life

05:07 03 October 2007
NewScientist.com news service
David Shiga

Astronomers have found the most Sun-like star yet, and they say it is an ideal place to hunt for alien civilisations.

The star, called HIP 56948, lies a little more than 200 light years from Earth. Its size, mass, temperature, and chemical makeup are all so similar to the Sun's that no measurable differences could be found in high-resolution observations made by the 2.7-metre telescope at the McDonald Observatory in Texas, US.

The analysis was carried out by Jorge Melendez of Mount Stromlo Observatory in Weston Creek, Australia, and Iván Ramírez of the University of Texas in Austin, US.

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POR MASA, TAMAÑO, TEMPERATURA Y COMPOSICIÓN QUÍMICA

Expertos peruanos en EEUU descubren una estrella 'gemela' de nuestro Sol

Actualizado jueves 04/10/2007 10:44 (CET)

ÁNGEL DÍAZ

MADRID.- A medida que se construyen mayores telescopios y se crean mejores sistemas de observación, los científicos siguen afanados en hallar, en algún recóndito rincón del cosmos, un espejo perfecto de nuestro mundo, cuya lejana luz pueda mostrarnos que no estamos tan solos como parece. Como no habría vida sin planetas como la Tierra, ni planetas como la Tierra sin su Sol, el hallazgo de una estrella idéntica a la nuestra, llamada HIP 56498, podría suponer un gran avance en esta dirección.

El gemelo del Sol se encuentra a 200 años luz de



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, unfortunately
Digitized by

Polski Portal Astronomiczny

ASTRONOMIA.PL

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2007-11-12

Peruwiańczycy odkryli "bliźniaka" Słońca
Peruwiańscy astronomowie Jorge Melendez University i Ivan Ramirez z University of Texas teleskopu Obserwatorium McDonalda w Teksas bliźniaczo podobna do naszego Słońca.

РУССКИЙ
Newsweek

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

АСТРОНОМИЯ
ДВОЙНИК СОЛНЦА

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

Astronomers find the sun's long-lost twin

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



By Dave Mosher

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

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

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

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

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 universo donde existe vida.

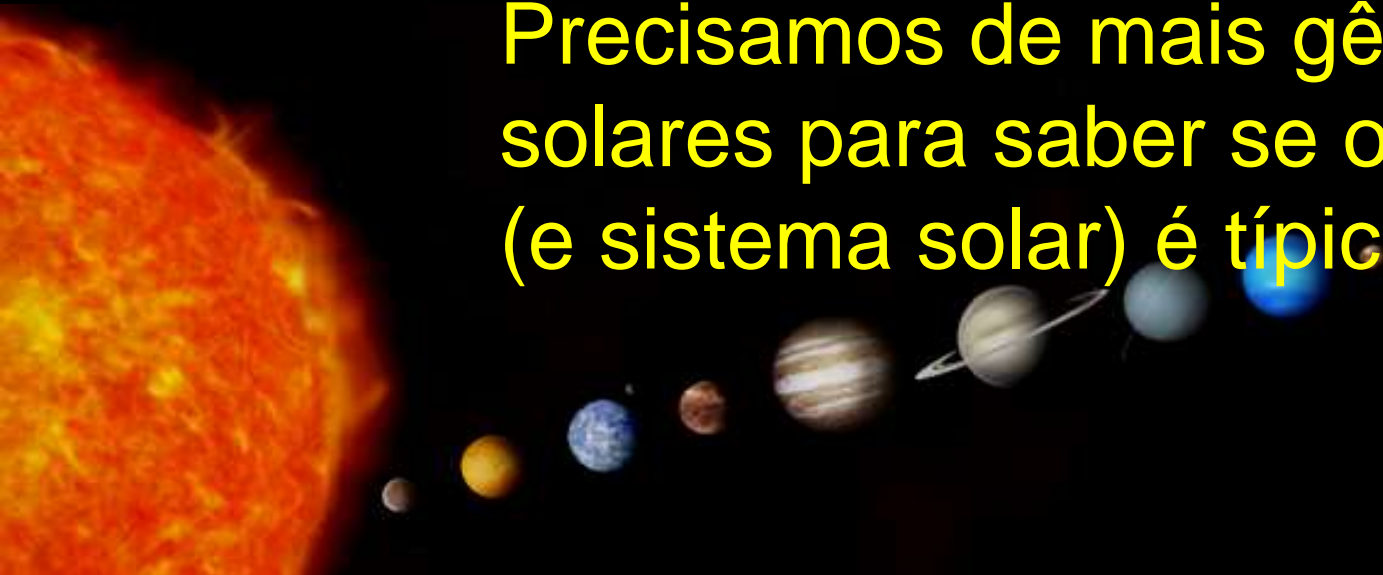
Jorge Meléndez, del Observatorio Stromlo de Australia, e Iván Ramírez, del Observatorio Mc Donald en Texas (EEUU), son los científicos que descubrieron la existencia de una estrella que, por sus características, podría ser considerada gemela del sol y que, al parecer, tiene todas las condiciones para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

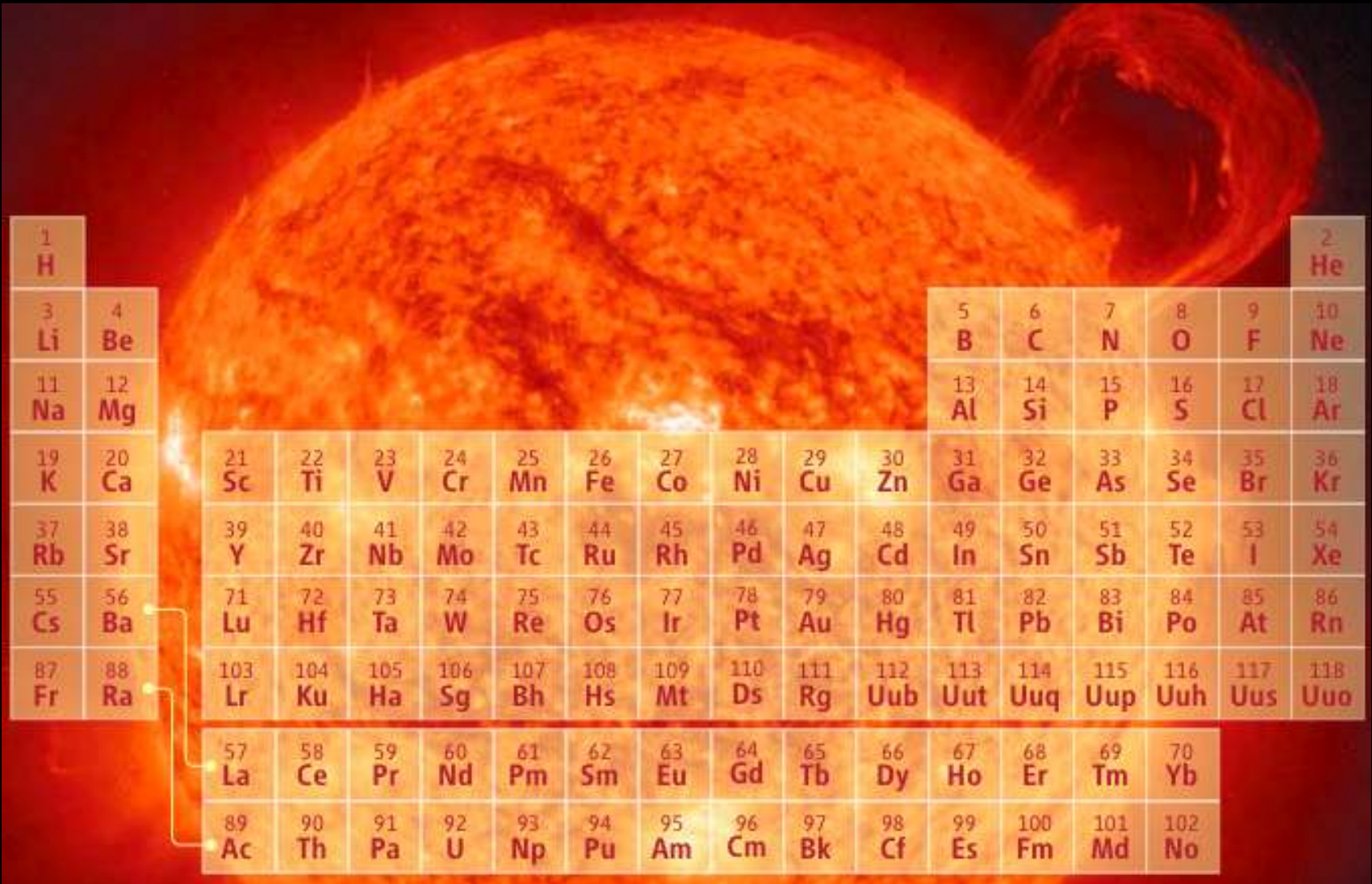


Existe alguma propriedade do Sol que possa indicar a formação de planetas?



Sunset in Barranca, Peru

É a composição solar anómala?



1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
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
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
55 Cs	56 Ba	71 Lu	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
87 Fr	88 Ra	103 Lr	104 Ku	105 Ha	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
		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		
		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		

Ou o Sol é uma típica estrela solar?

Por quase um século e meio o Sol foi considerado "normal" na sua composição química

- Secchi (1868): Sol é típico 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 abundâncias: **<0.05 dex (accuracy)**

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

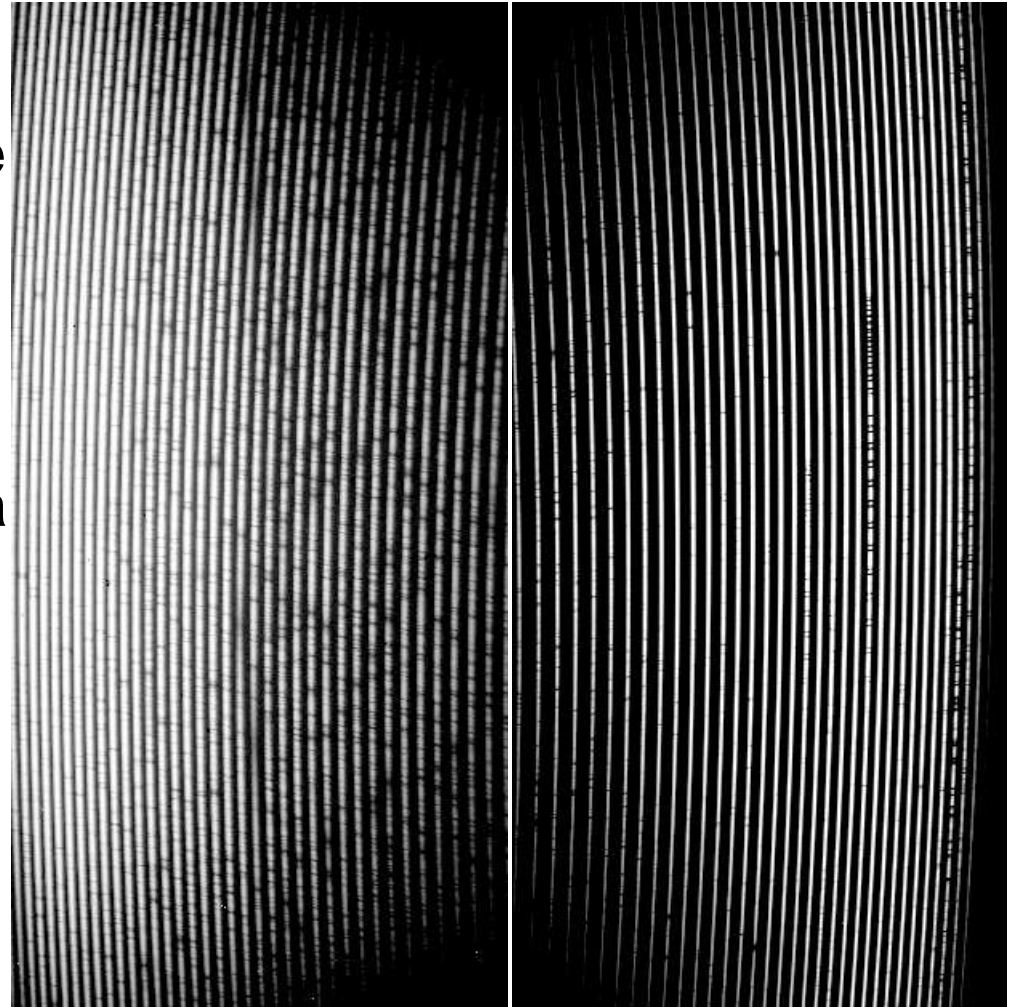


Jorge Meléndez (CAUP/Portugal), Martin Asplund (Max Planck),
Bengt Gustafsson (Uppsala), David Yong (Stromlo)

Observações espectroscópicas

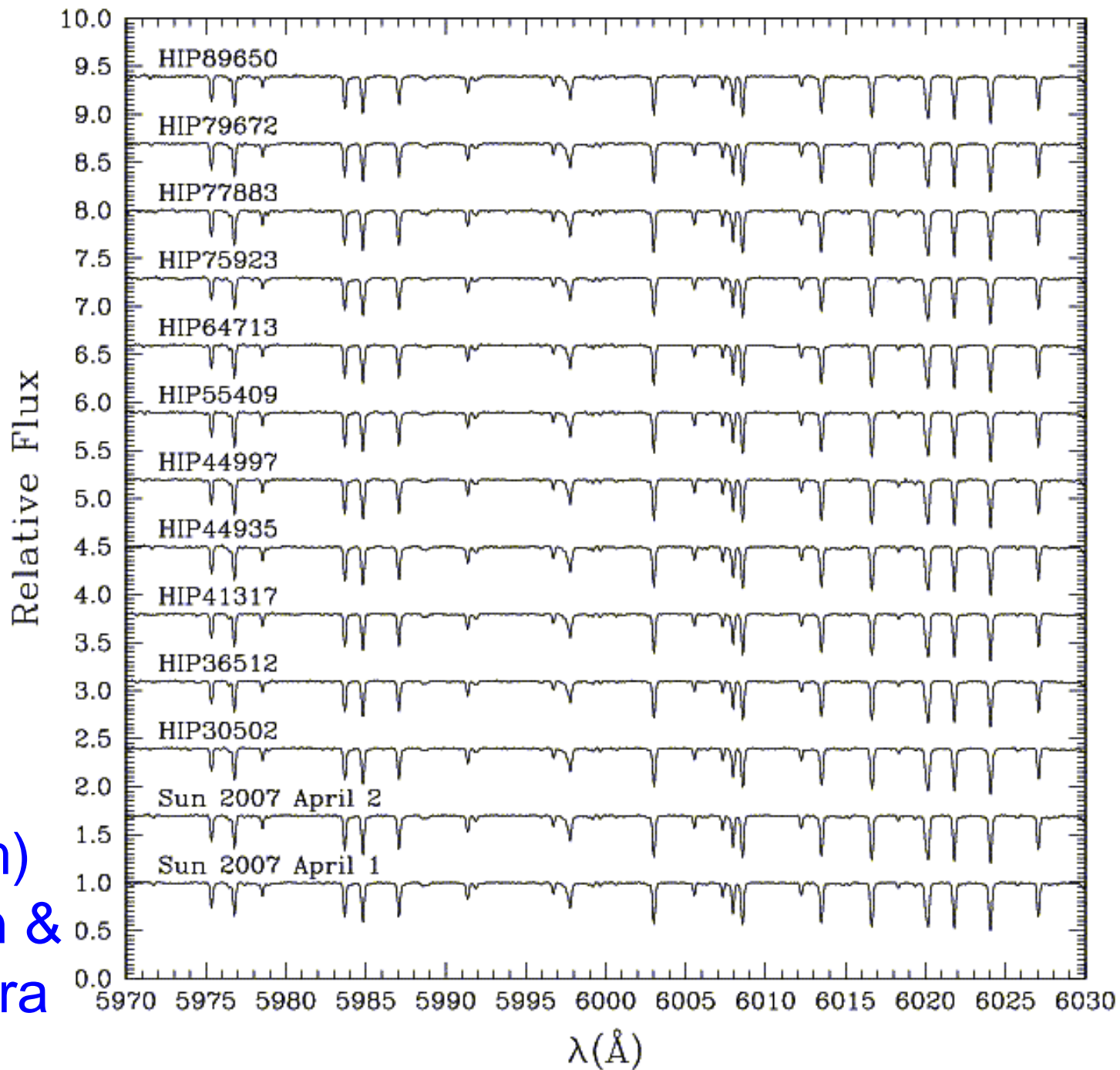
Observações da gêmea solar 18 Sco

- 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.



BLUE frame

RED frame

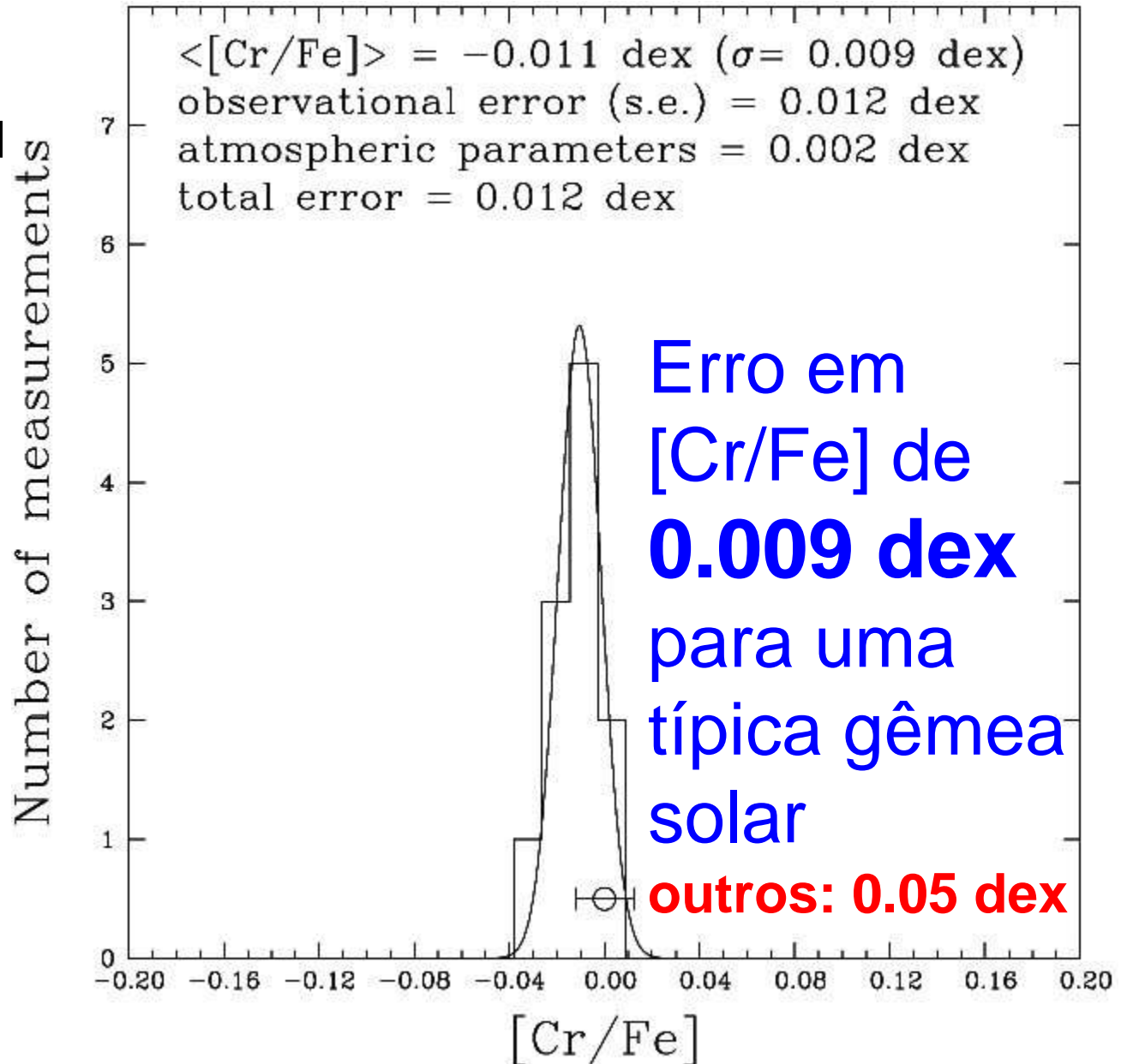


Small part
(597-603nm)
of solar twin &
Sun's spectra

Análise de alta precisão

- Standard 1D model atmospheres
- T_{eff} , $\log g$, v_t & $[\text{Fe}/\text{H}]$ from Fe I & Fe II 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 $[\text{X}/\text{Fe}]$ (0.01-0.02 dex)



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

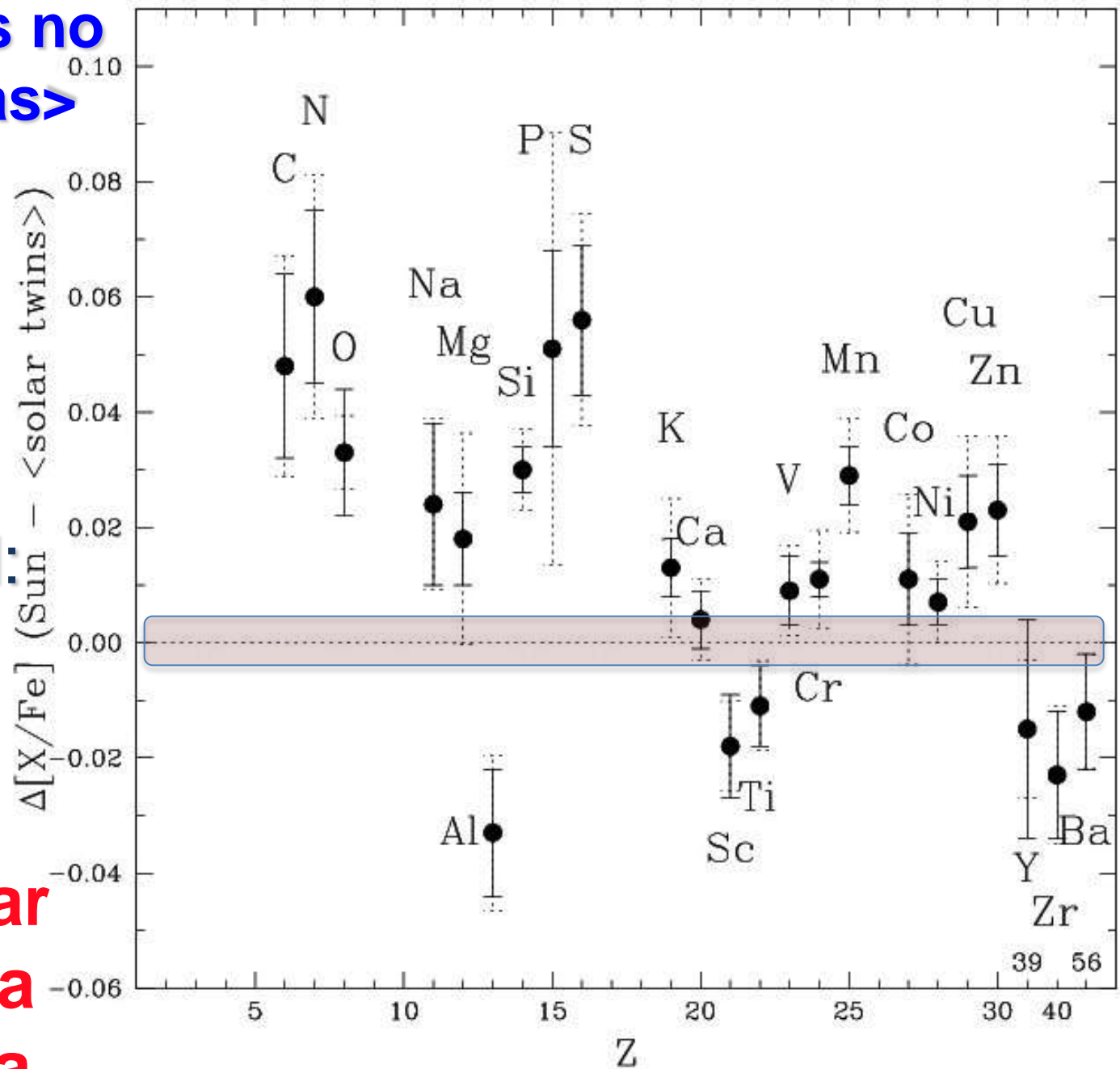
Sol típico:

$$\Delta = 0$$

Sol anormal:

$$\Delta \neq 0$$

Nosso sistema solar não tem uma estrela típica



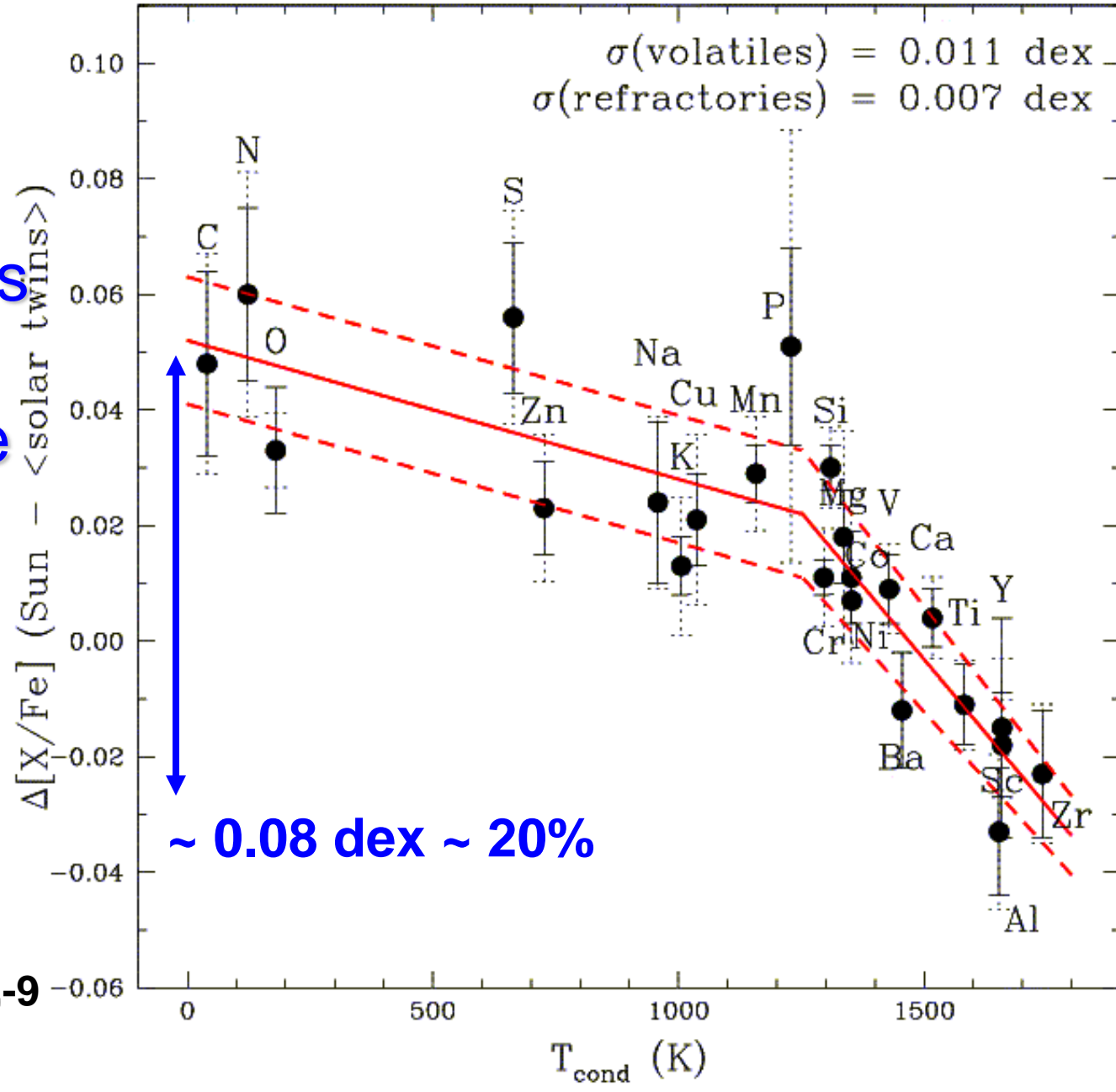
As anomalias na composição do Sol estão relacionadas com a formação do nosso sistema planetario?



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

Correlação é altamente significativa

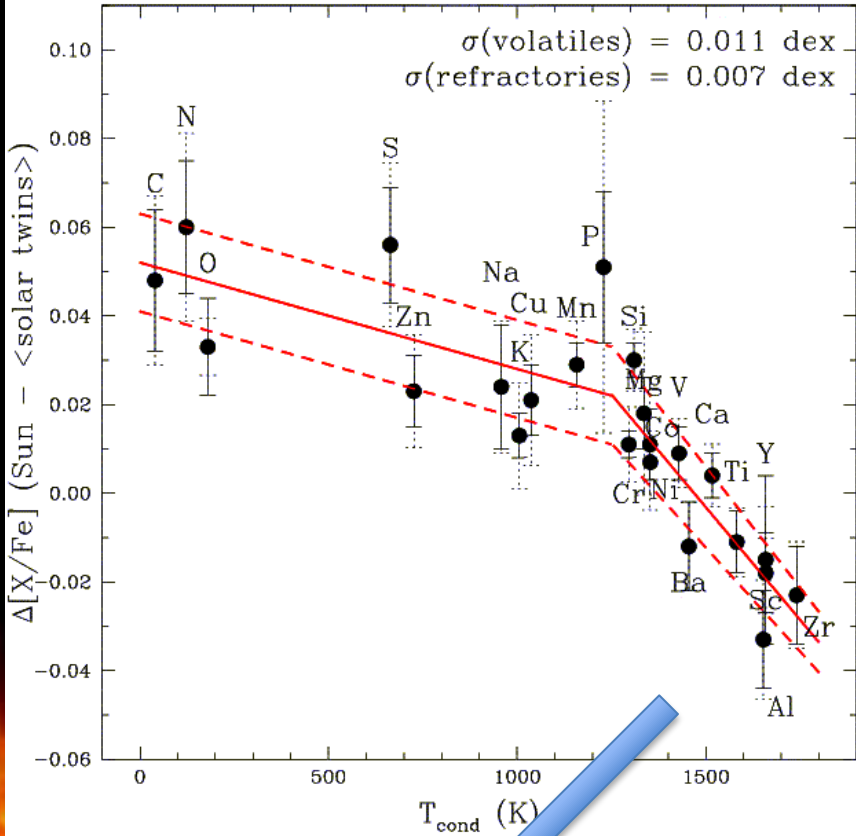
probabilidade $\sim 10^{-9}$ de acontecer por acaso



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



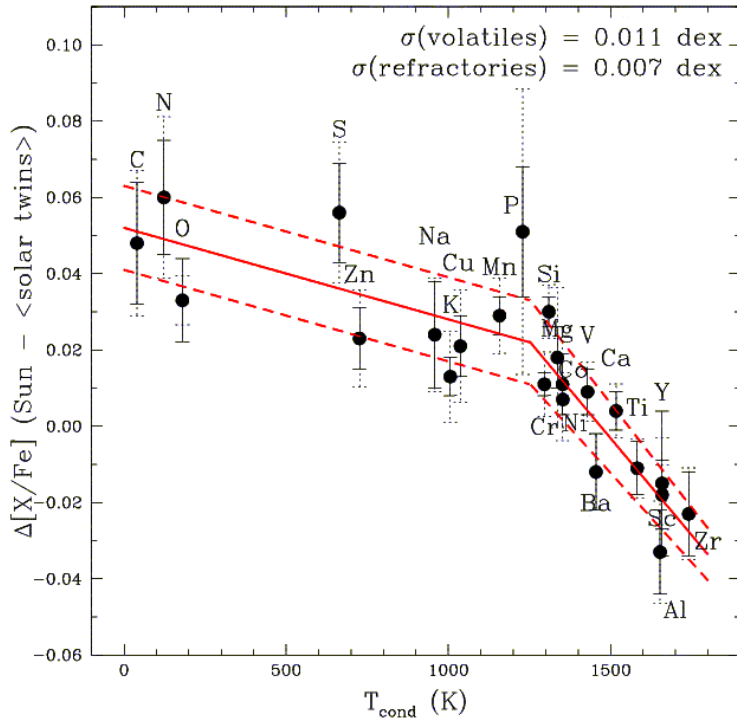
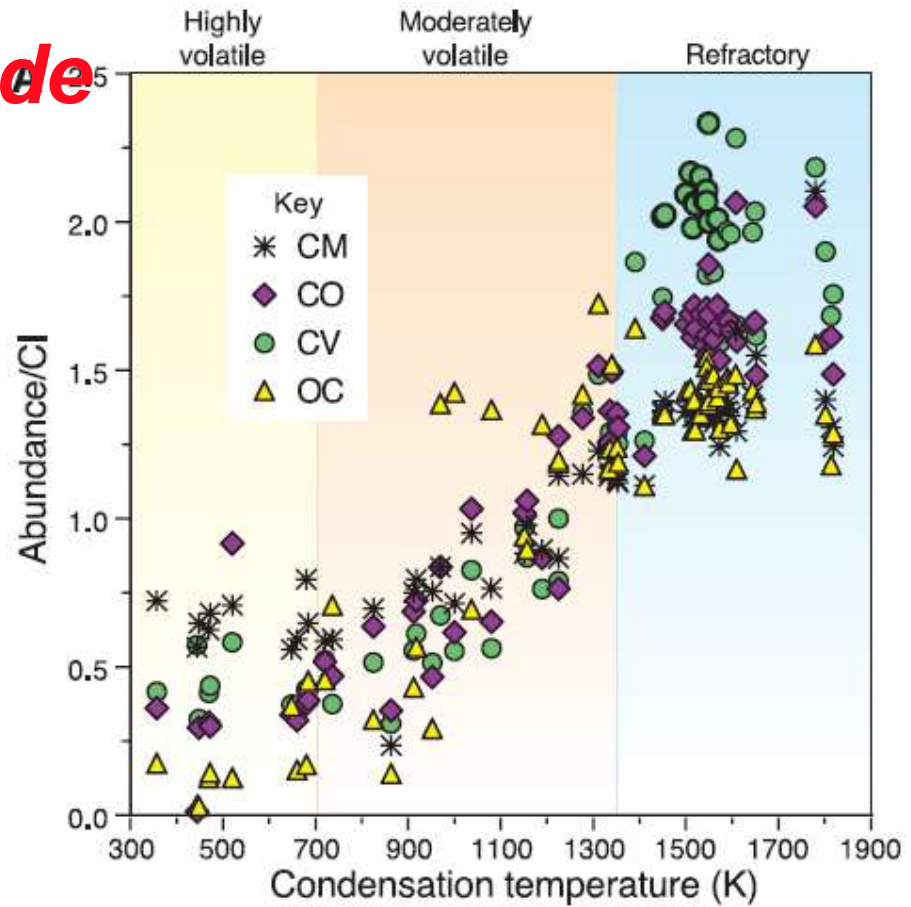
O Sol é deficiente em refratarios porque esses elementos foram usados para formar os planetas terrestres!



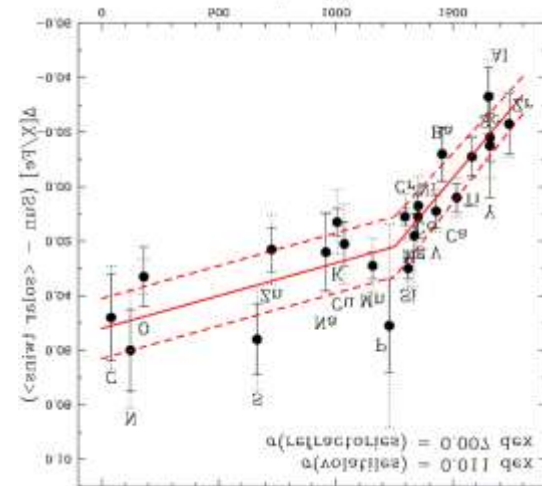
Relação com formação de planetas terrestres: meteoritos

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 ($\sim 0.02 M_{\text{sun}}$):

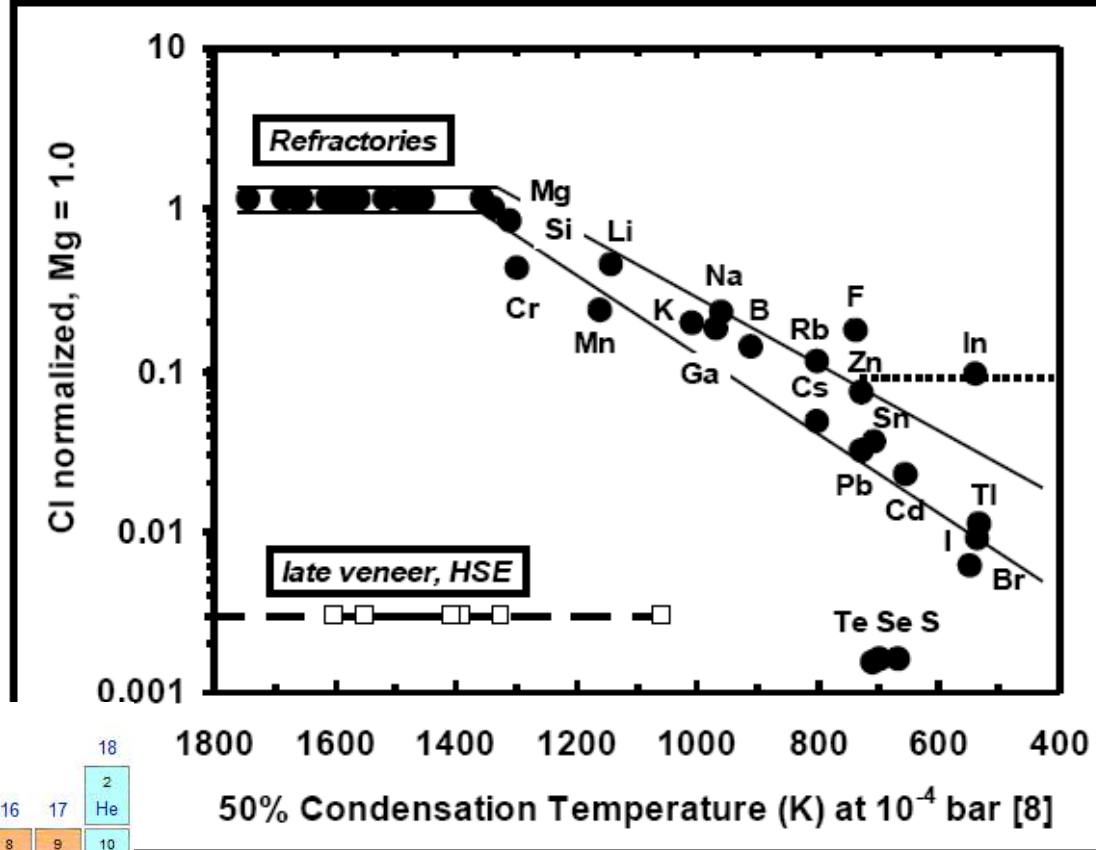
Refractories depleted in the Sun: $\sim 2 \cdot 10^{28} \text{ g} \approx 4 M_{\oplus}$

Refractories locked-up in terrestrial planets: $\sim 8 \cdot 10^{27} \text{ g} \approx 1.3 M_{\oplus}$

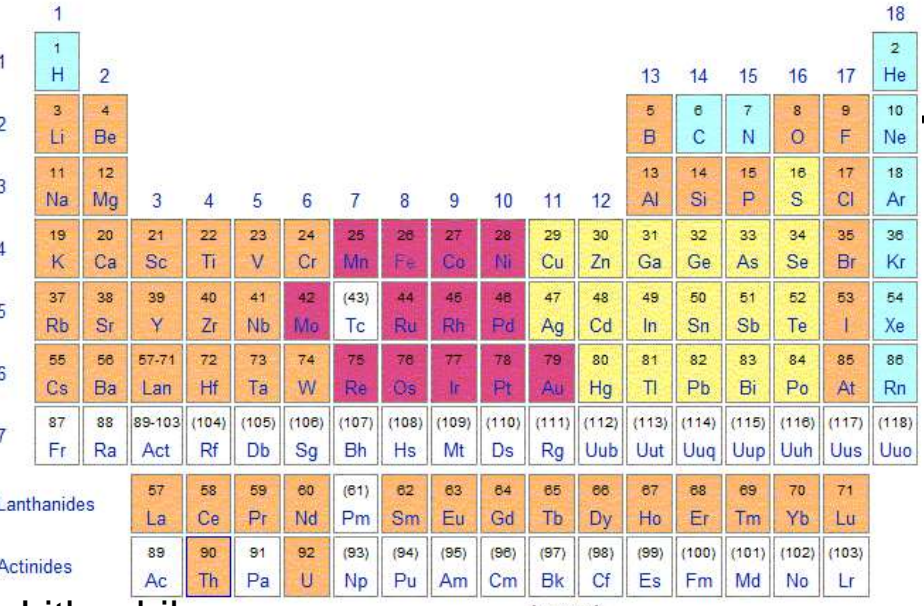


O manto terrestre também mostra abundancias compatíveis com o nosso cenário

volatile elements in Earth's mantle are depleted !



Goldschmidt classification in the Periodic Table



Lithophile: silicate loving



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 !

O Sol é único ?

Não, o Sol é peculiar mas não é único: ~ 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 !)



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

Destques 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 agosto descubrimiento en la Biblioteca Nacional

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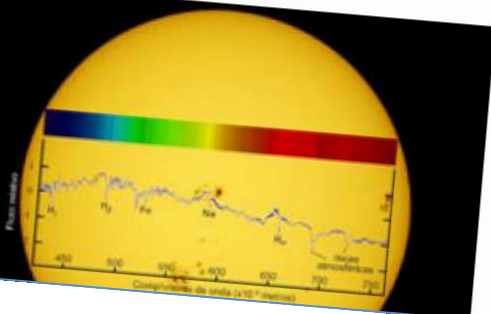
Centro de Astrofísica
da Universidade do Porto

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



Chemical signature could help locate Earth-like planets

Oct 16, 2009 3 comments



Destques na imprensa sobre a composição peculiar do Sol

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RARE SOLAR SYSTEM, RARE SUN

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12/14/2009
by Dr. Hugh Ross

The first discovered extrasolar planet was found in 1995 around the star 51 Pegasi.¹ This finding persuaded many astronomers to conclude that Carl Sagan was right—our Milky Way Galaxy contains billions of planets, most of which would prove to be alien solar systems. Sagan concluded that this, in turn, would be present on several million of them. The subsequent discovery of extrasolar planets before the end of the twentieth century would be able to “explore strange new worlds before.”

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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.

CiênciaHoje

Composição do Sol fornece pistas sobre outras «Terras»

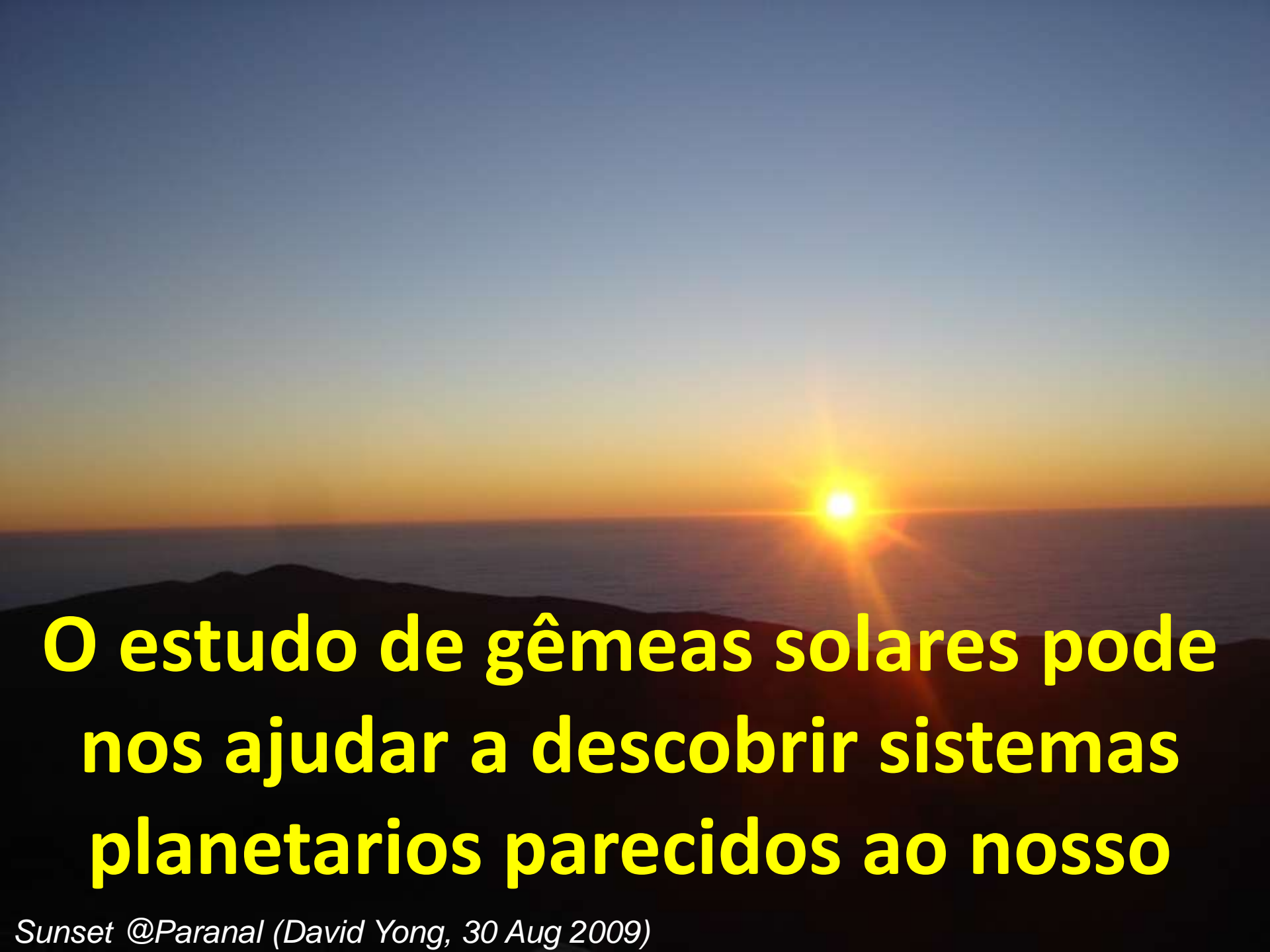
Estudo publicado na Astrophysical Journal Letters

2009-09-18



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

Victor Stenger laments that advanced life might exist.²
er Jorge Meléndez, has
³ Meléndez has devoted much
the Sun, in the sense that the
ne existence of advanced life on
carried out in the last few decades.

A photograph of a sunset over the ocean. The sun is a bright yellow-orange orb on the horizon, casting a long, horizontal lens flare across the sky. The sky transitions from a pale blue at the top to a deep orange near the horizon. In the foreground, the dark silhouettes of mountains or hills are visible against the bright sky. The overall scene is serene and captures the beauty of a sunset.

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

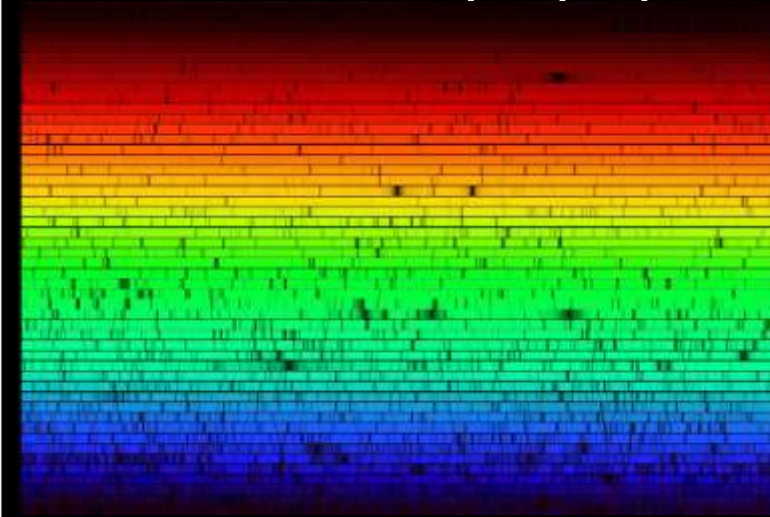
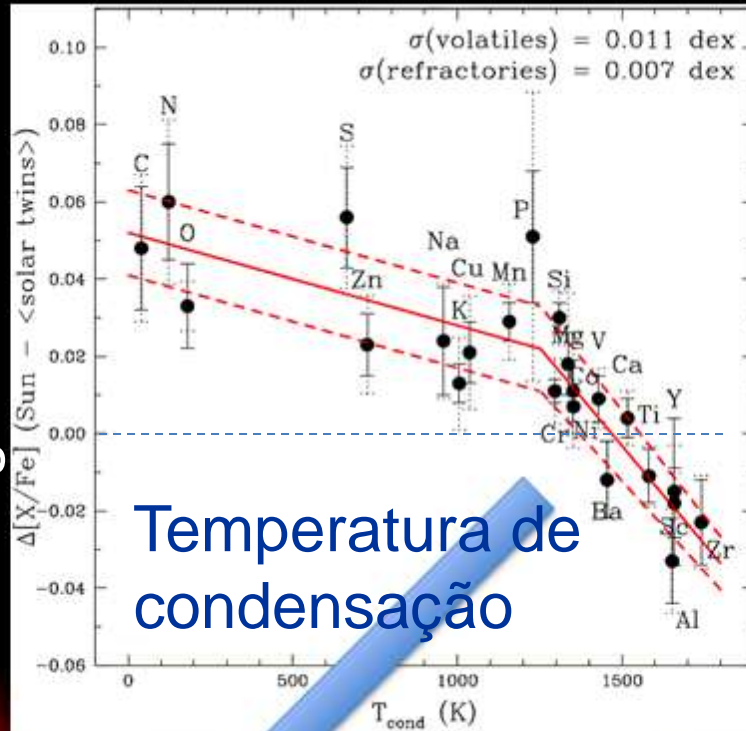
Sunset @Paranal (David Yong, 30 Aug 2009)

Temas de estudo no IAG/USP

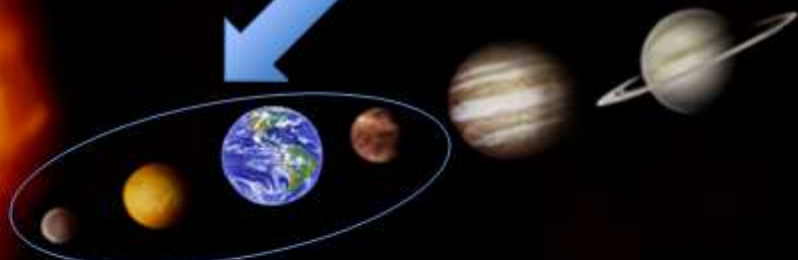
Espectros: propriedades físicas e químicas de estrelas

F, G, K, M

Sol – gêmeas solares



- Planetas como a Terra
- Átomos e Moléculas
- Propriedades estelares
- Formação da Nossa Galáxia
- Primórdios do Universo



Planetas rochosos

Meléndez,
Asplund,
Gustafsson,
Yong 2009,
ApJ letters