

# Os elementos químicos : do *Big Bang* aos planetas rochosos

*The chemical elements :  
from the Big Bang to terrestrial planets*



**Jorge Meléndez**  
*Departamento de Astronomia do IAG/USP*

# First elements in the universe: H, He, Li

Periodic Table of the Elements © www.elementsdatabase.com

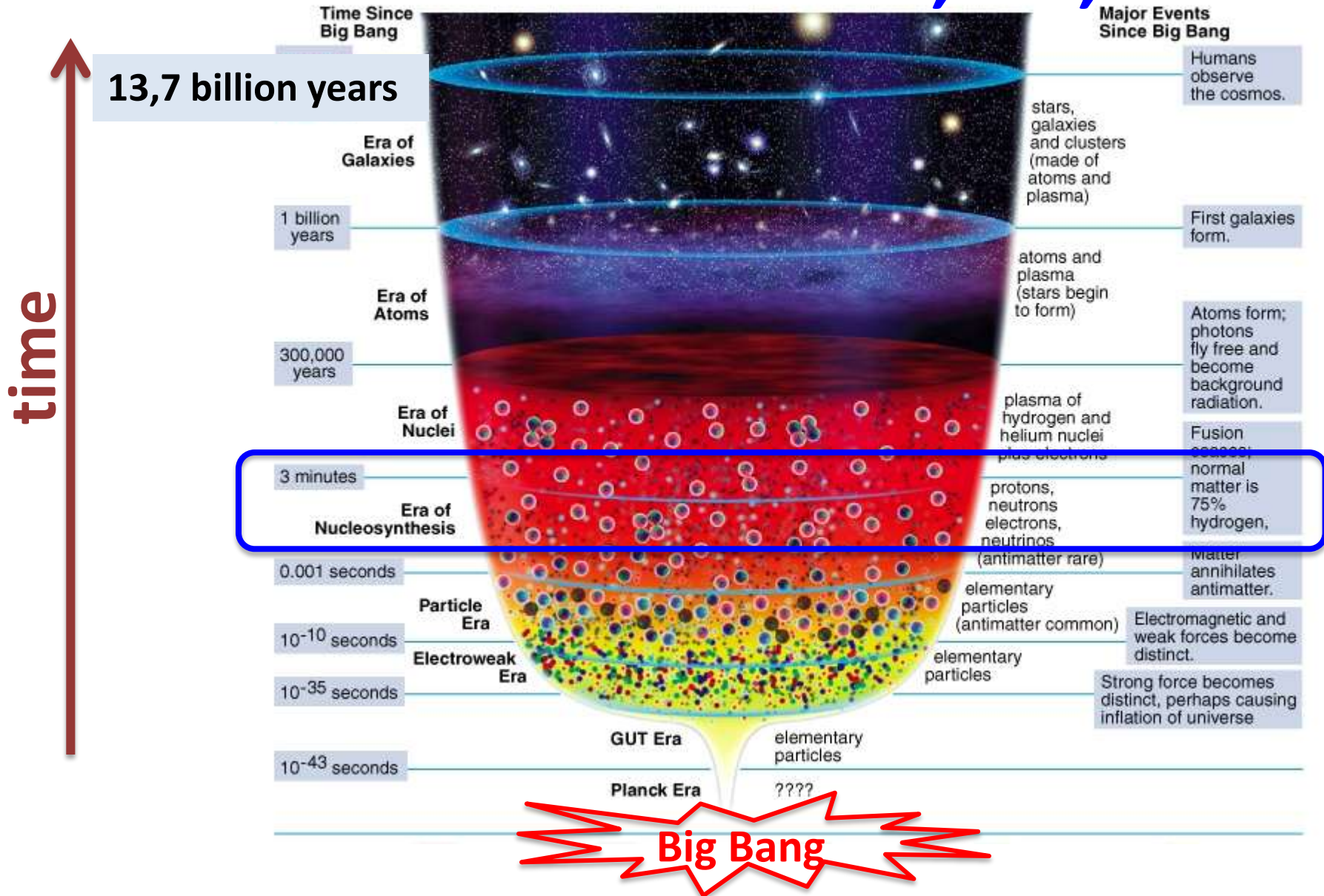
- hydrogen
- poor metals
- alkali metals
- nonmetals
- alkali earth metals
- noble gases
- transition metals
- rare earth metals

1 H																	2 He	
3 Li	4 Be																	10 Ne
11 Na	12 Mg																	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	57 La	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	89 Ac	104 Unq	105 Unp	106 Unh	107 Uns	108 Uno	109 Une	110 Unn									

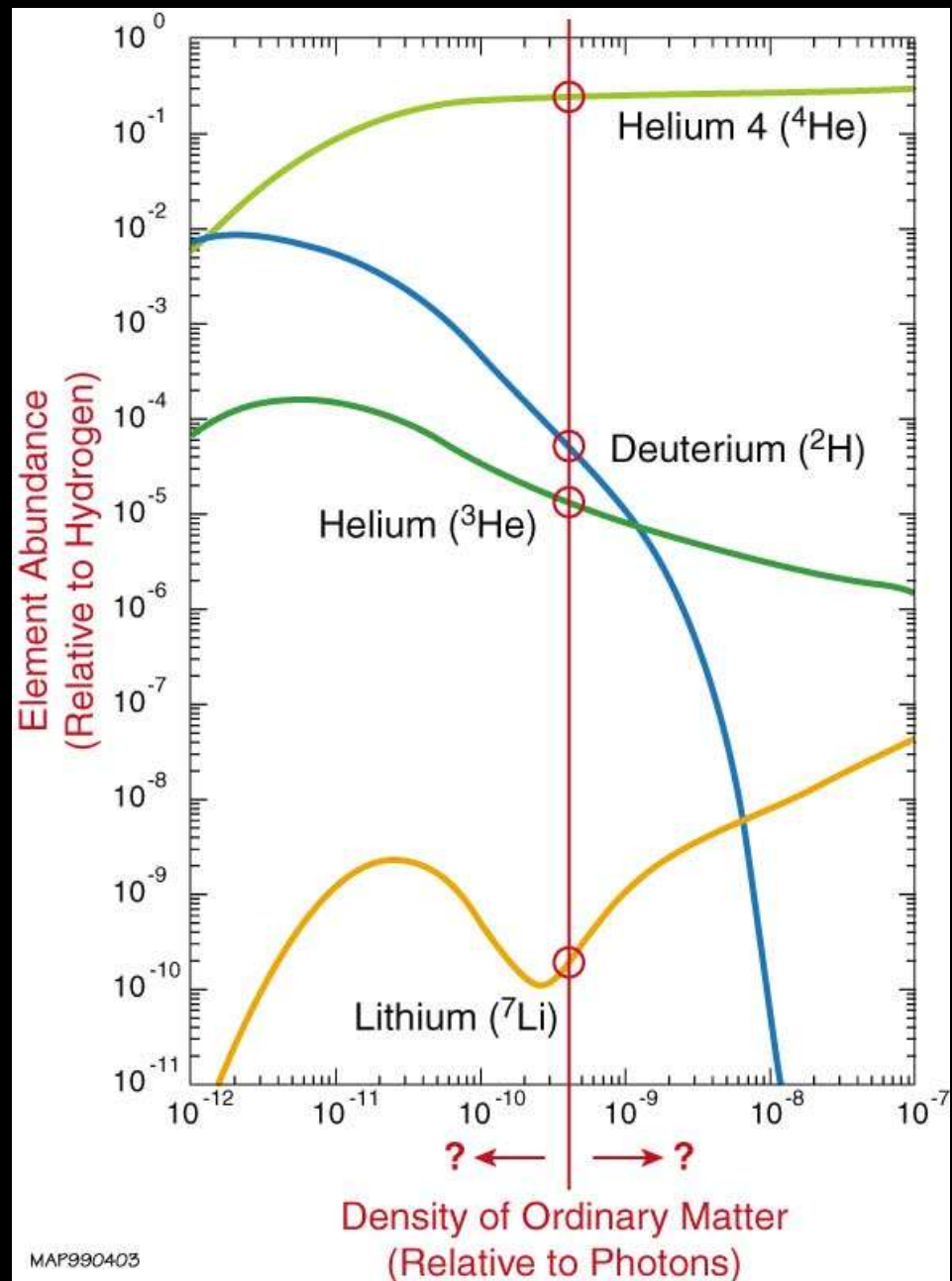
58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

# Evolution of our universe

## First few minutes: H, He, Li

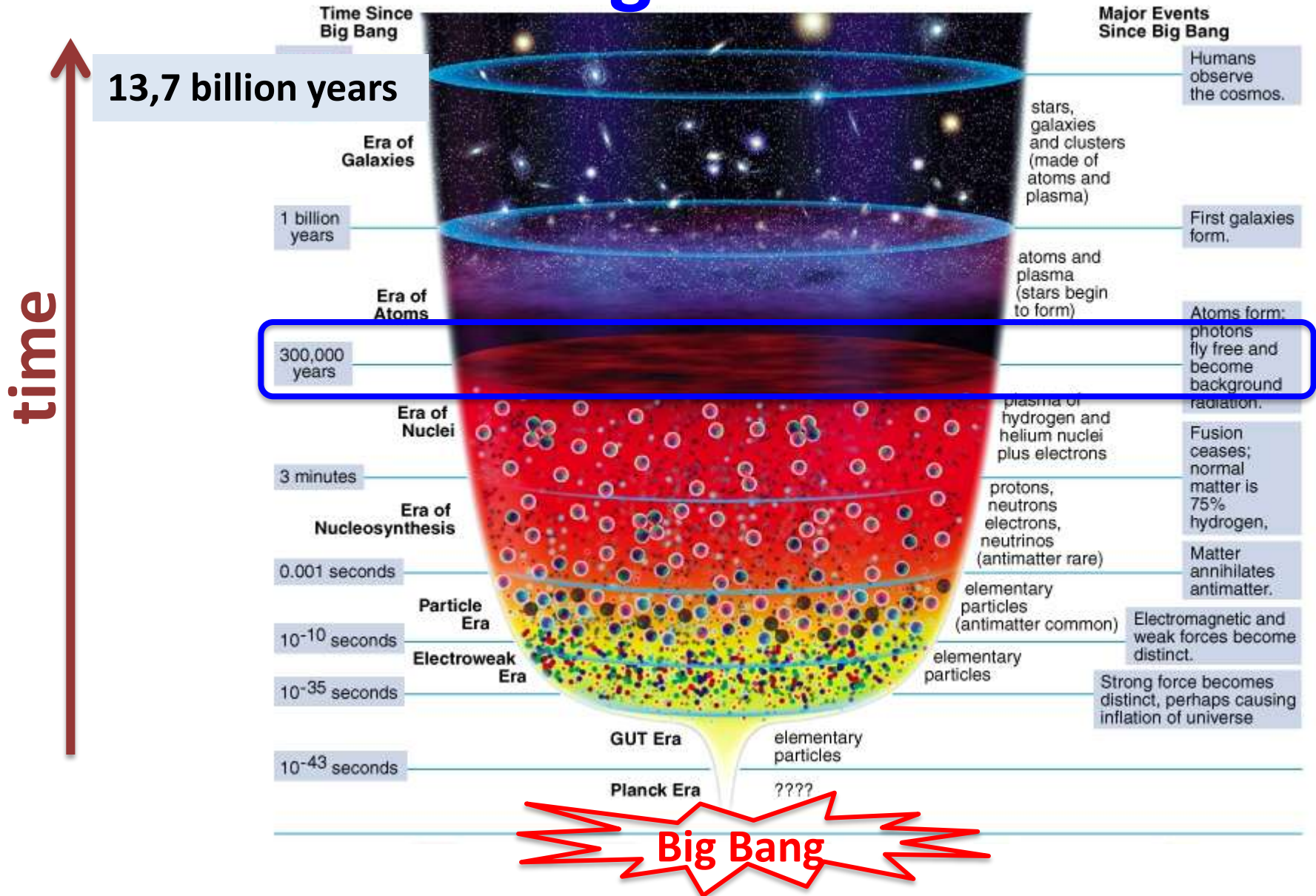


The abundances of the light elements (**H**, **He**, **Li**) formed a few minutes after the Big Bang depend only on  $\eta_{10}$  (baryon-to-photon ratio)



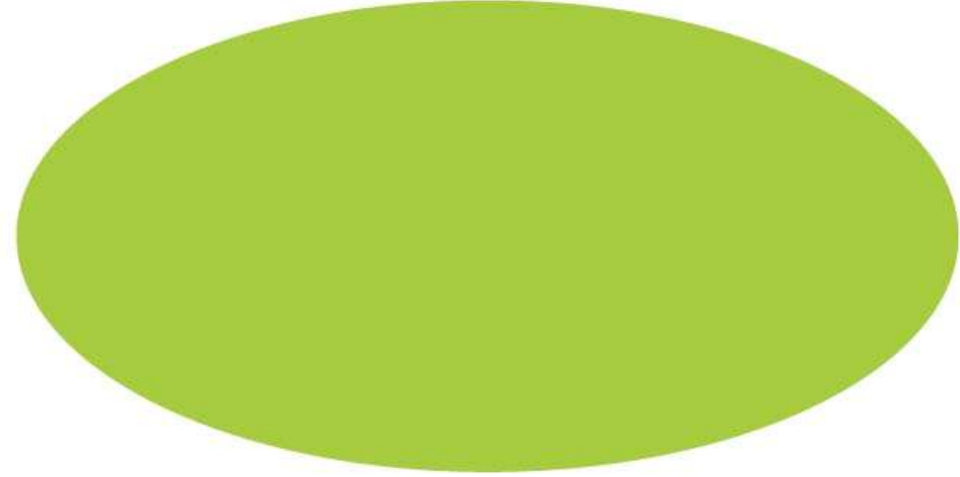
# Evolution of our universe

## Cosmic Background Radiation



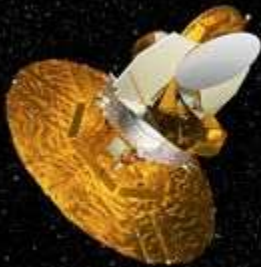
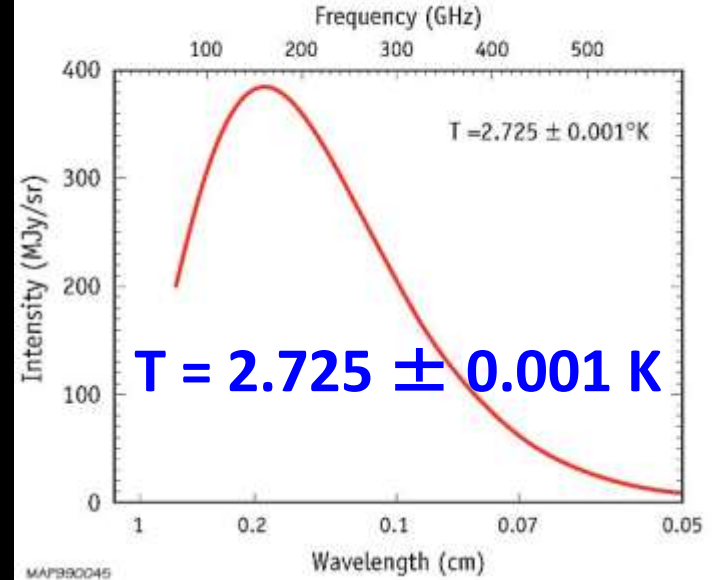
# Cosmic Background Radiation

## ISOTROPY OF THE COSMIC MICROWAVE BACKGROUND



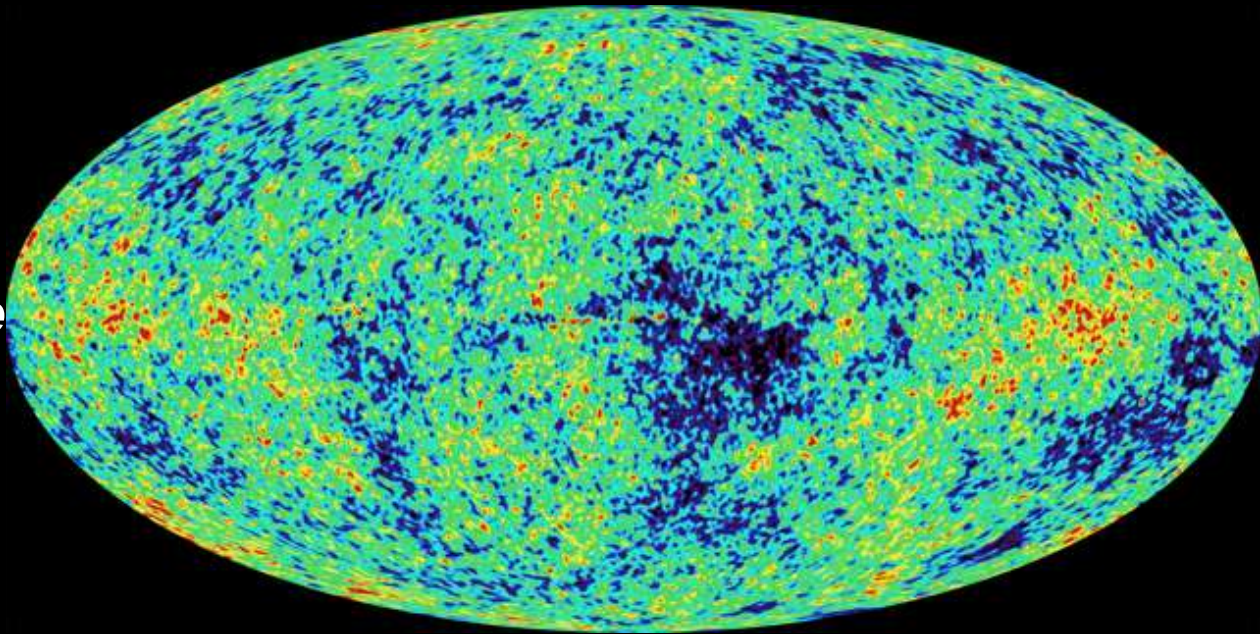
MAP990004

## SPECTRUM OF THE COSMIC MICROWAVE BACKGROUND



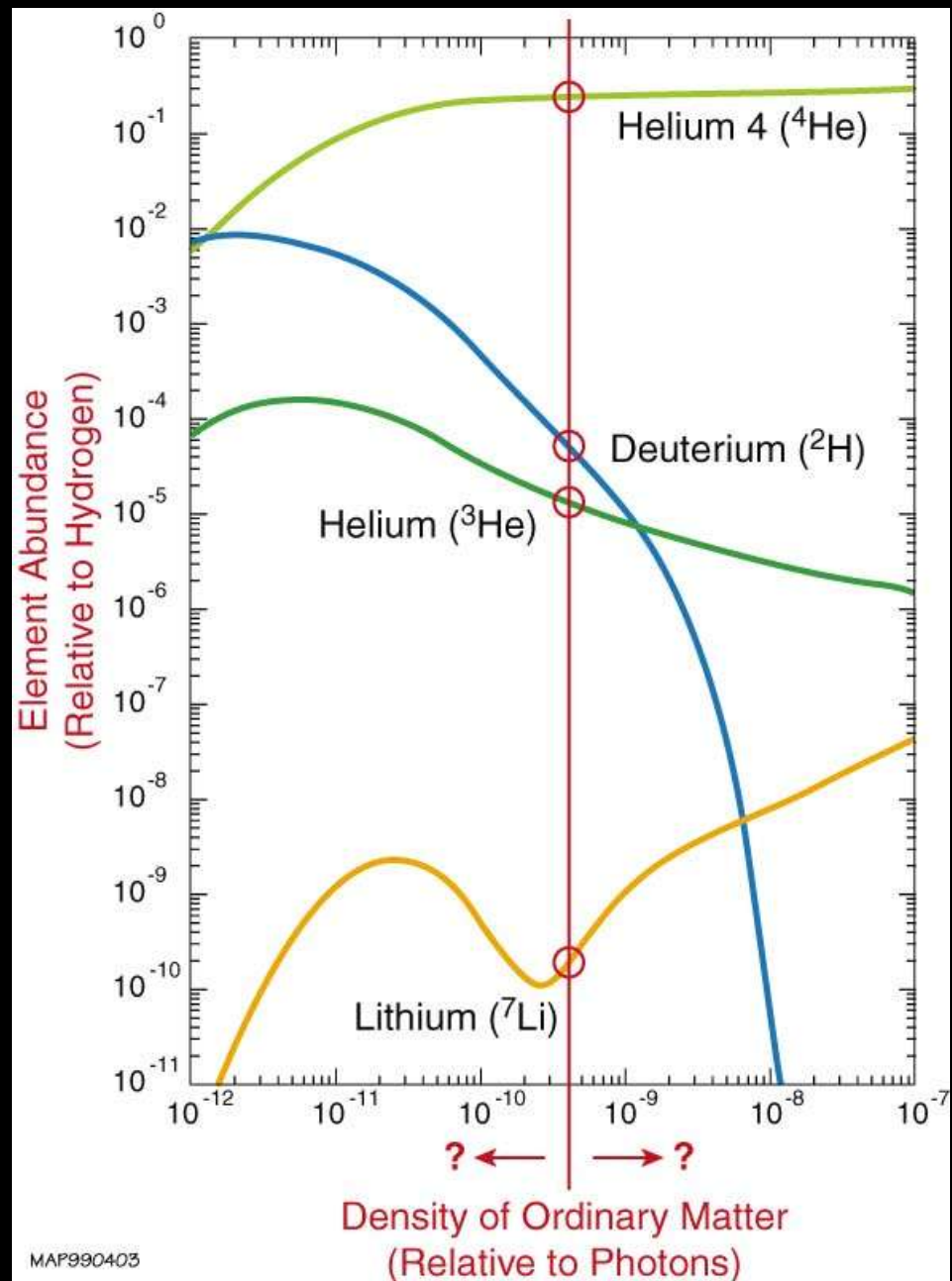
**WMAP**  
**satellite**

*small fluctuations in the  
cosmic radiation  $\rightarrow \eta_{10}$*

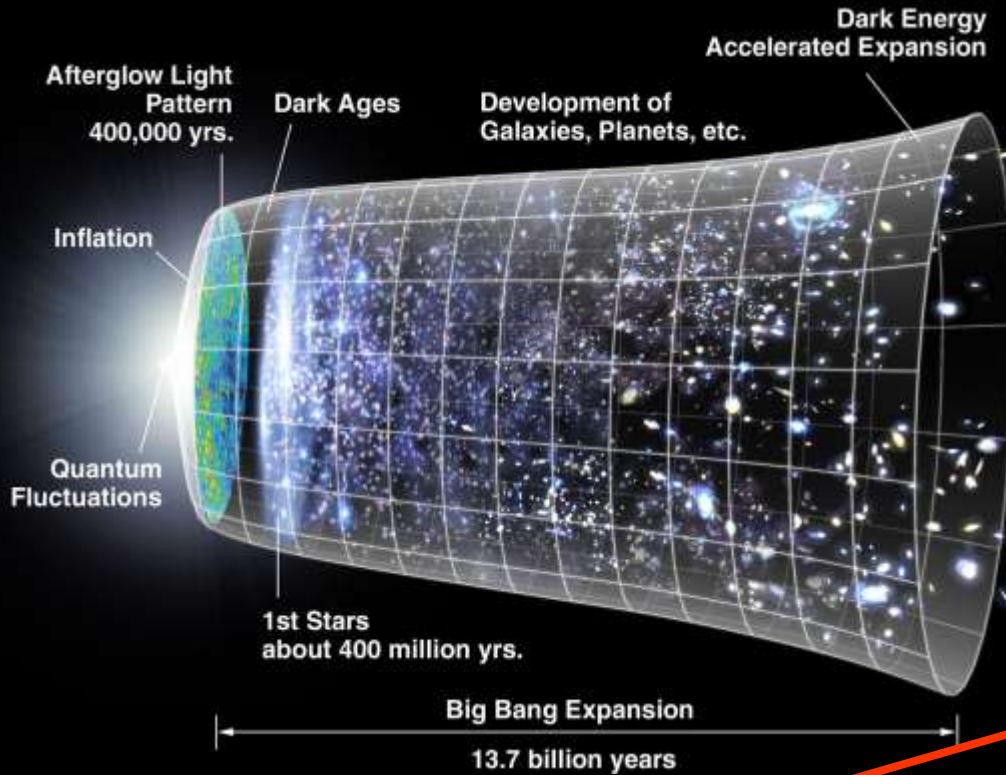


credits: NASA

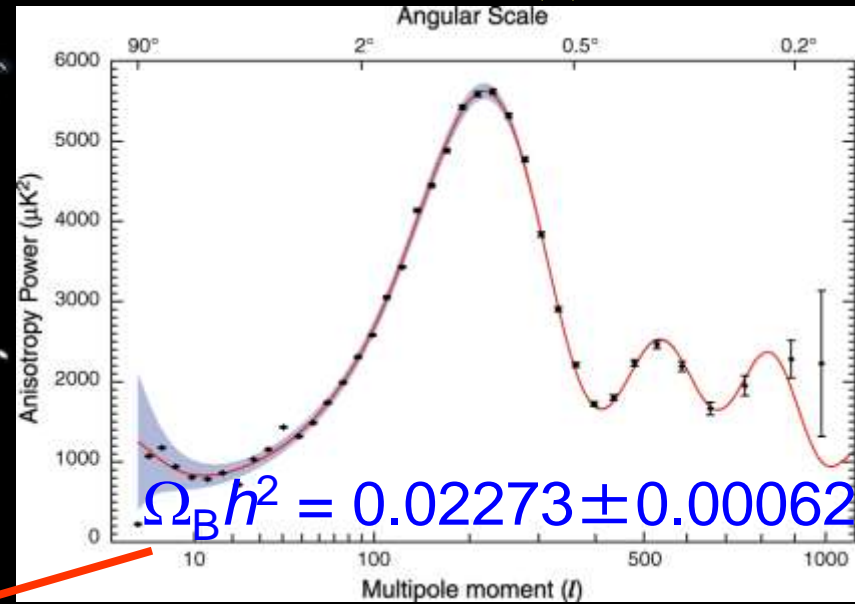
The abundances of the light elements (**H**, **He**, **Li**) formed a few minutes after the Big Bang depend only on  $\eta_{10}$  (baryon-to-photon ratio)



# Cosmic Microwave Background



WMAP



credits: <http://map.gsfc.nasa.gov>

$$n_{10} = 6.226 \pm 0.170 \text{ (Dunkley et al. 2009)}$$

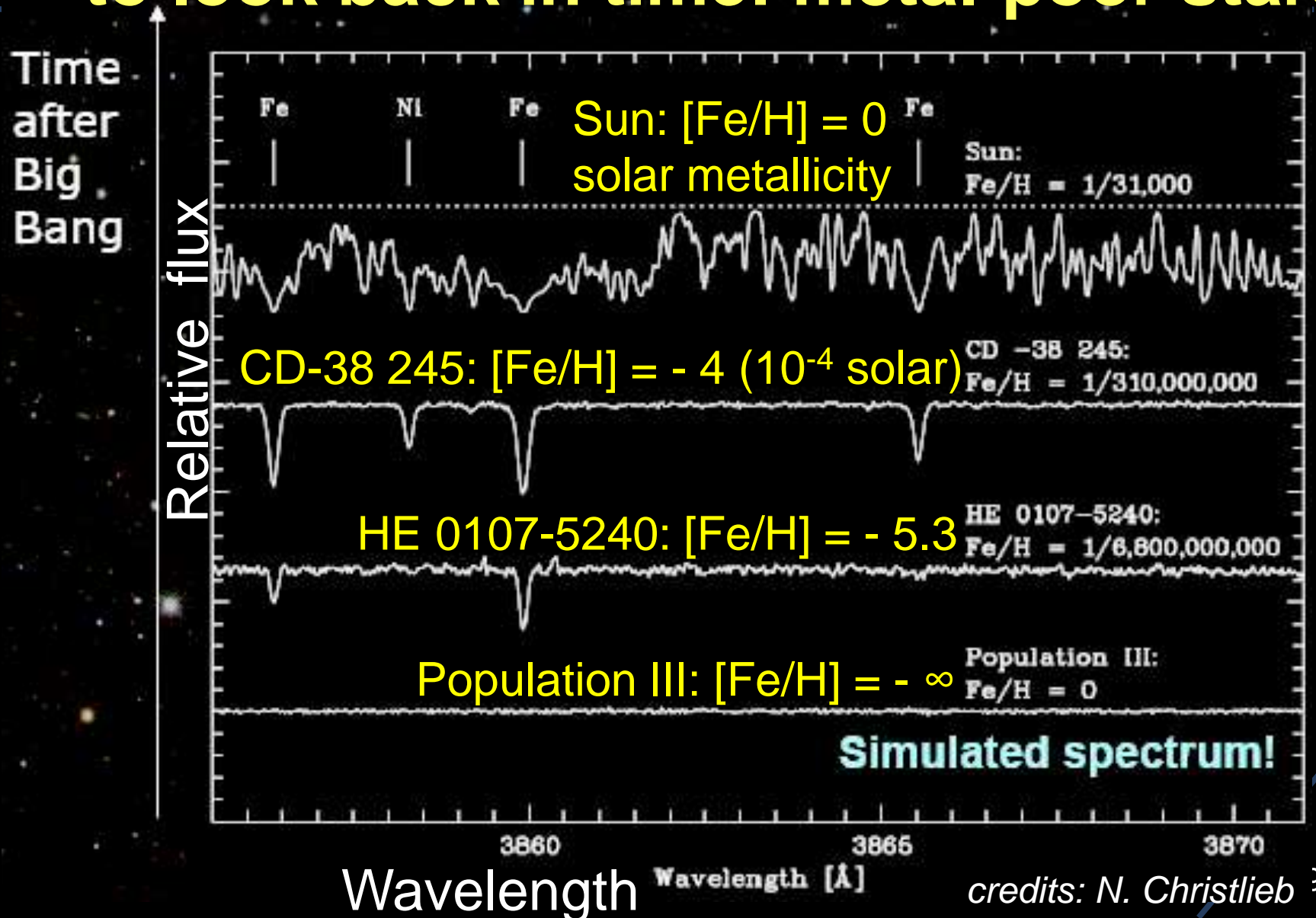
Predicted primordial lithium abundance:

$$A(\text{Li}) = 2.72 \text{ dex} \longrightarrow \text{Li}/\text{H} = 5.2 \cdot 10^{-10}$$

(Cyburt et al. 2008, see also Steigman 2009; Coc & Vangioni 2010)

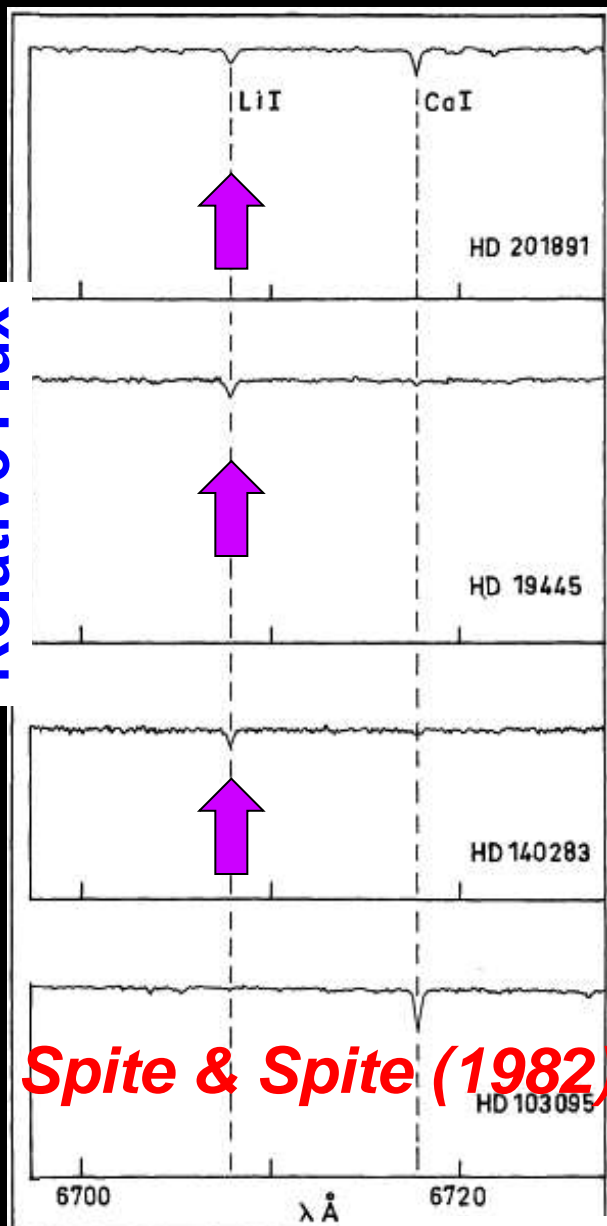


# To test Big Bang Nucleosynthesis we need to look back in time: metal-poor stars



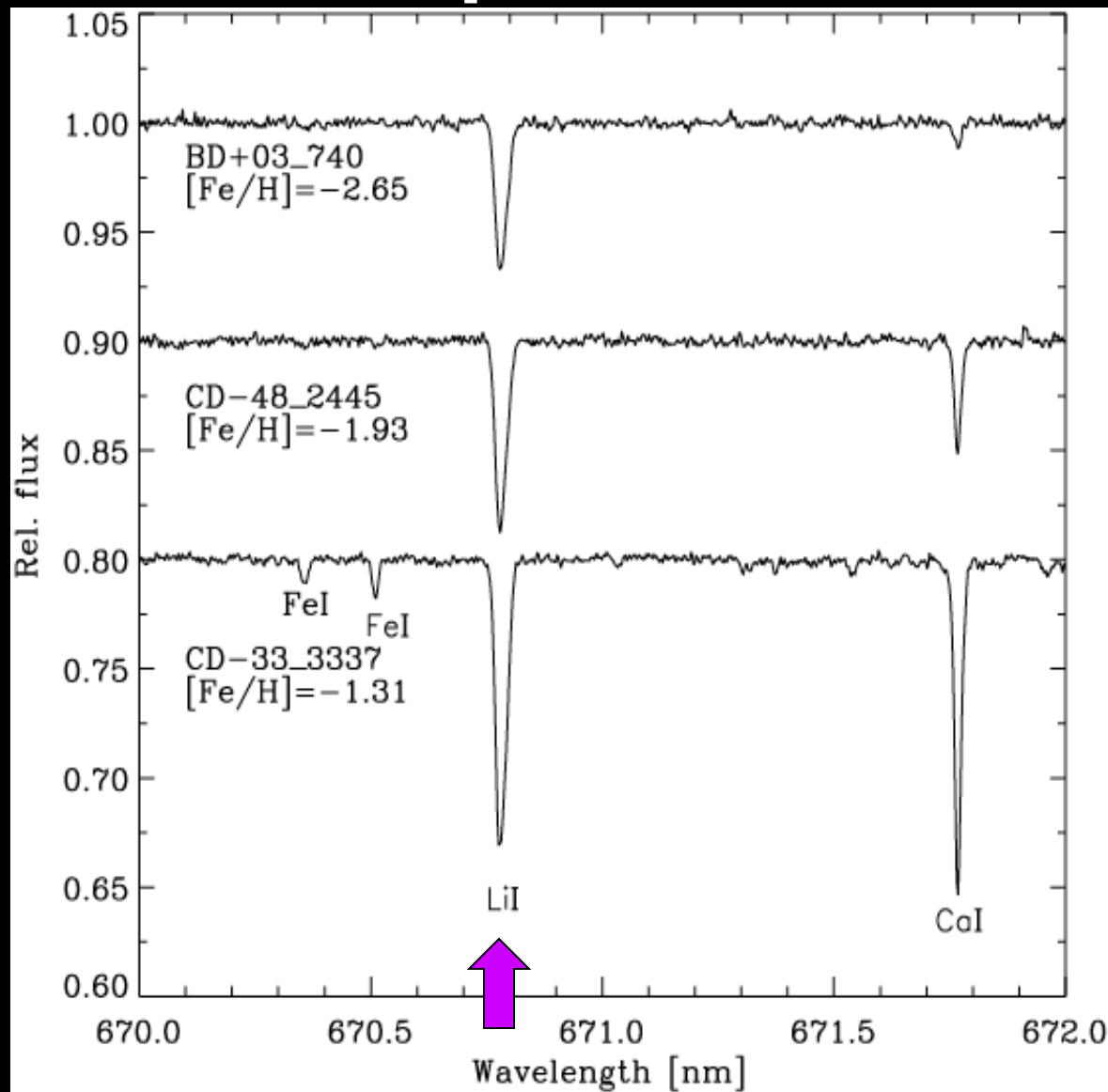
# Primordial Li in metal-poor stars !

Relative Flux



*Spite & Spite (1982)*

Wavelength



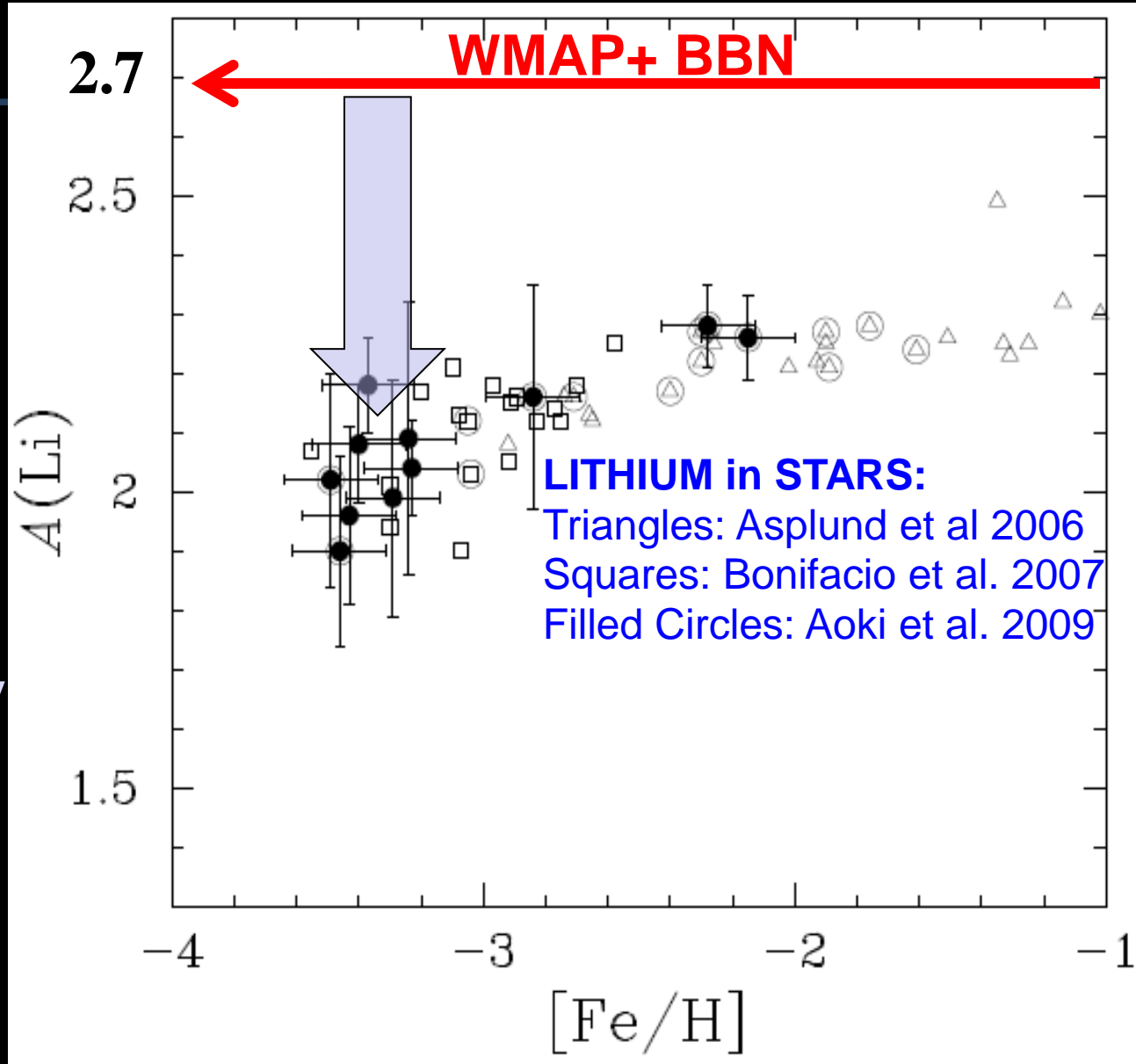
*Asplund et al. (2006)*

# Cosmological lithium problem

**WMAP+ BBN**  
**(Li = 2.72)**

**Stars**  
**(Li = 2.0 – 2.25)**

0.7 dex (factor of 5) discrepancy at the lowest metallicities between BBN+WMAP and stars



*Aoki et al. (2009)*

# The cosmological Li problem:

Li in stars is much lower (x 5) than the primordial Li predicted by BBN

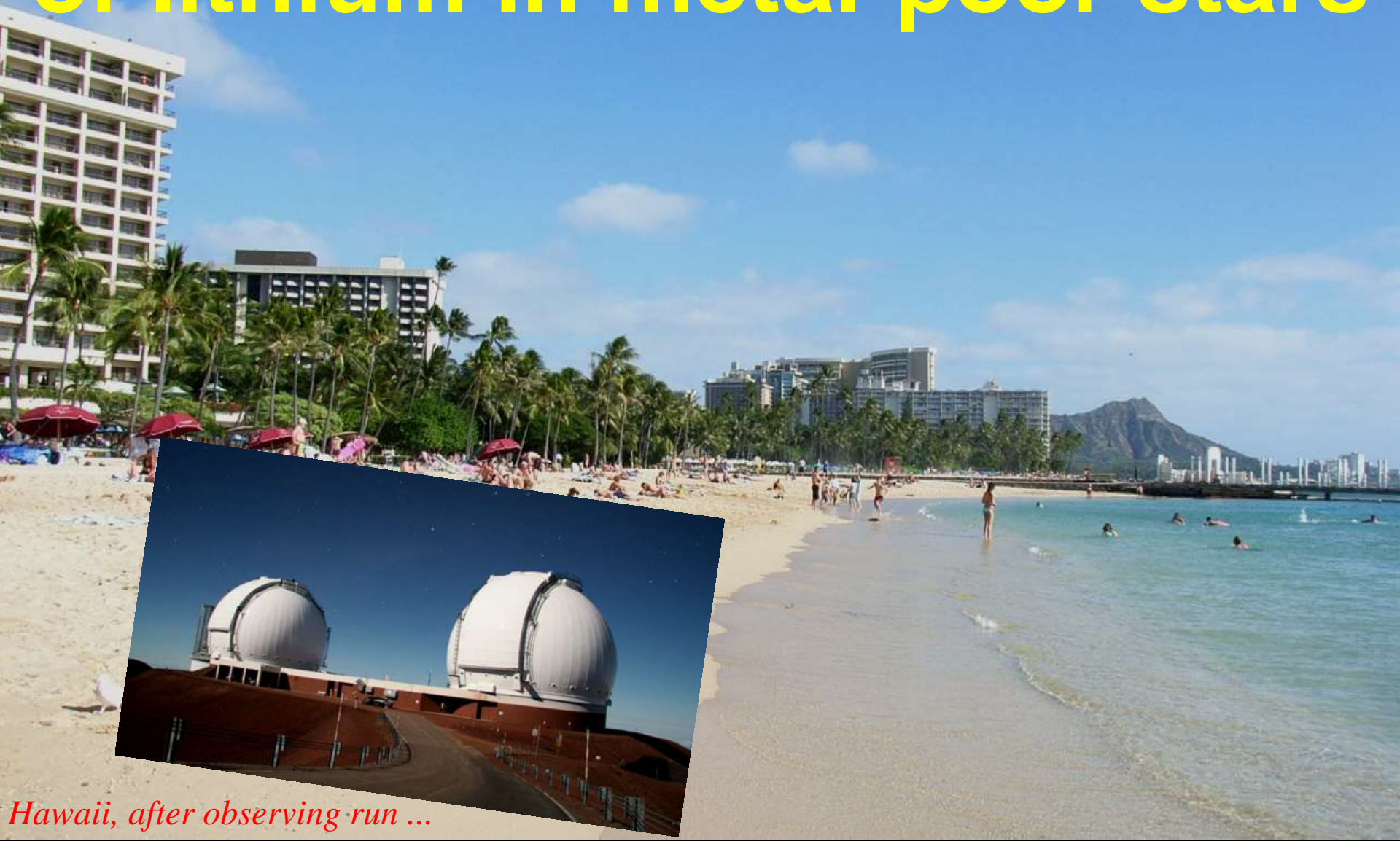
~~$T_{\text{eff}}$  scale~~

~~Errors in nuclear reaction rates~~

New physics / cosmology ?

Li depletion in stars ?

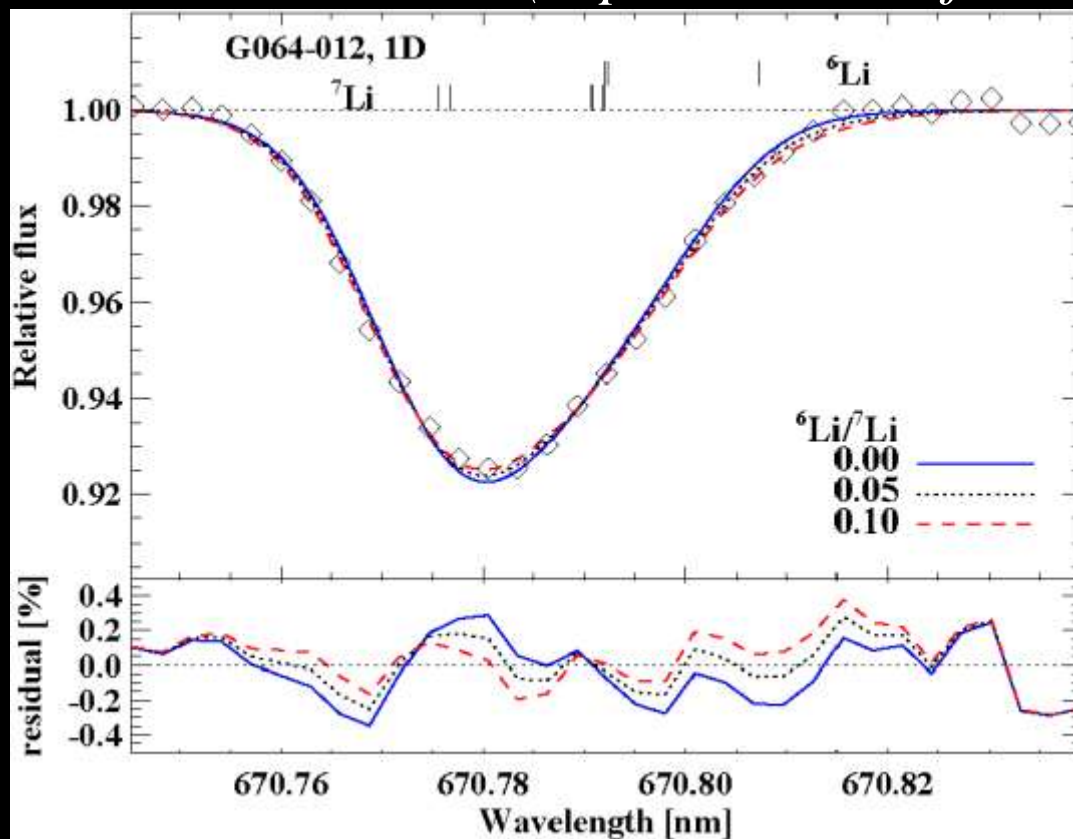
# Ultra high precision analysis of lithium in metal-poor stars



*Hawaii, after observing run ...*

# Ultra high precision analysis of lithium in metal-poor stars using Keck and VLT data

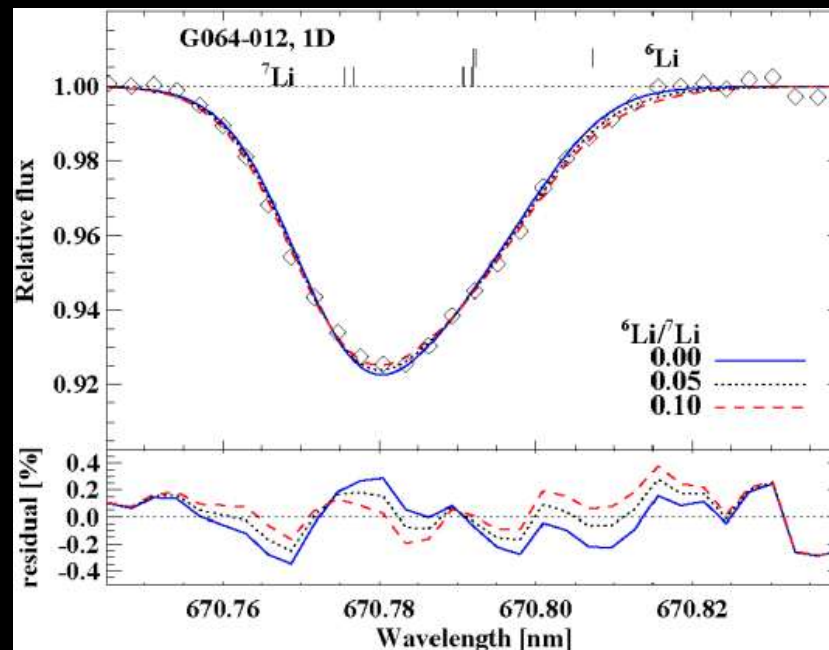
*Stellar spectrum observed with Keck (exposure time of 5 hours)*



*Asplund & Melendez (2008)*

# Next steps in solving the Li problem @ IAG/USP

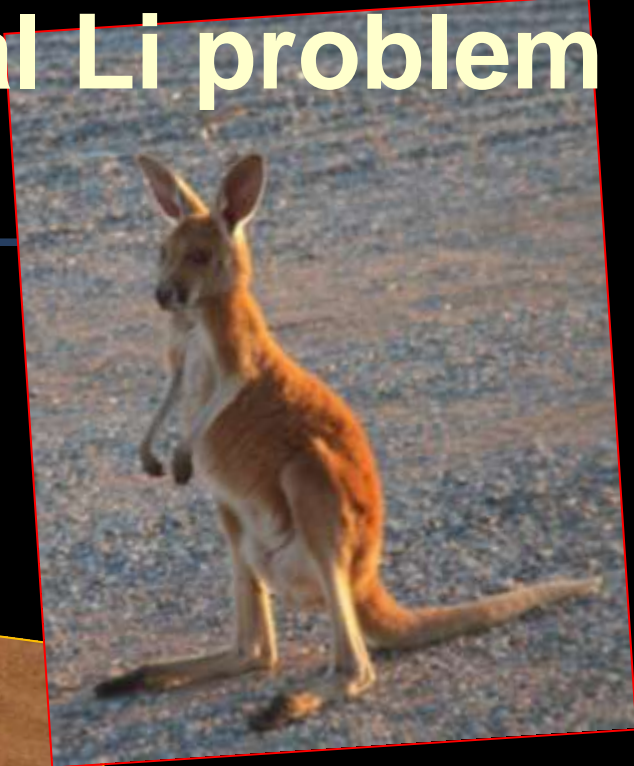
- Finish data reduction
- Accurate + precise stellar parameters
- Determination of Li and Be abundances
- Study of Li and Be depletion
- Li isotopes



# Solving the cosmological Li problem

## Team :

- Jorge Melendez (IAG)
- Martin Asplund (Australia)
- Luca Casagrande (Australia)
- Ivan Ramirez (Carnegie, USA)



**Help  
Welcome !**





# Periodic Table of the Astronomers .. From H and He to “metals”



**METALS**

# Chemical evolution of the elements

## From H and He to “metals”

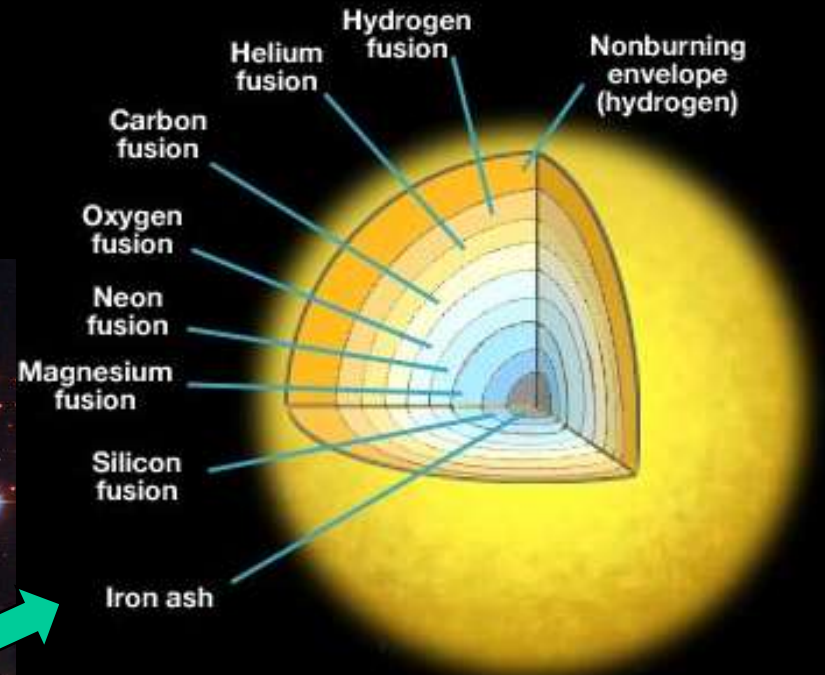
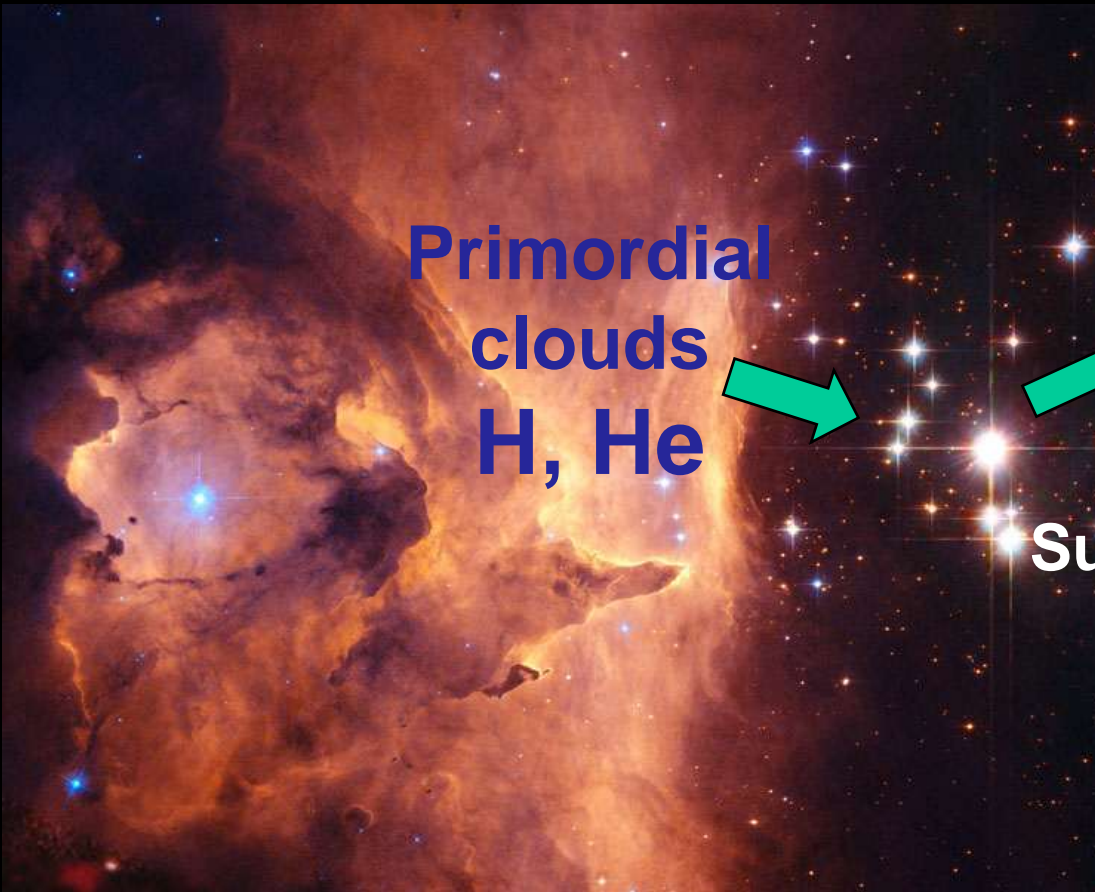
Periodic Table of the Elements © www.elementsdatabase.com

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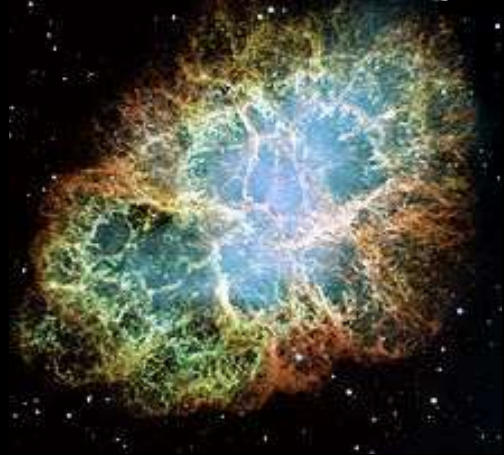
1 H																	2 He						
3 Li	4 Be																	5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg																	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
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90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

# The first stars and the formation of metals (elements heavier than H & He)



Supernova: metal-rich ejecta



# Stellar Evolution

Type II  
supernova

O Mg  
Ca  
S

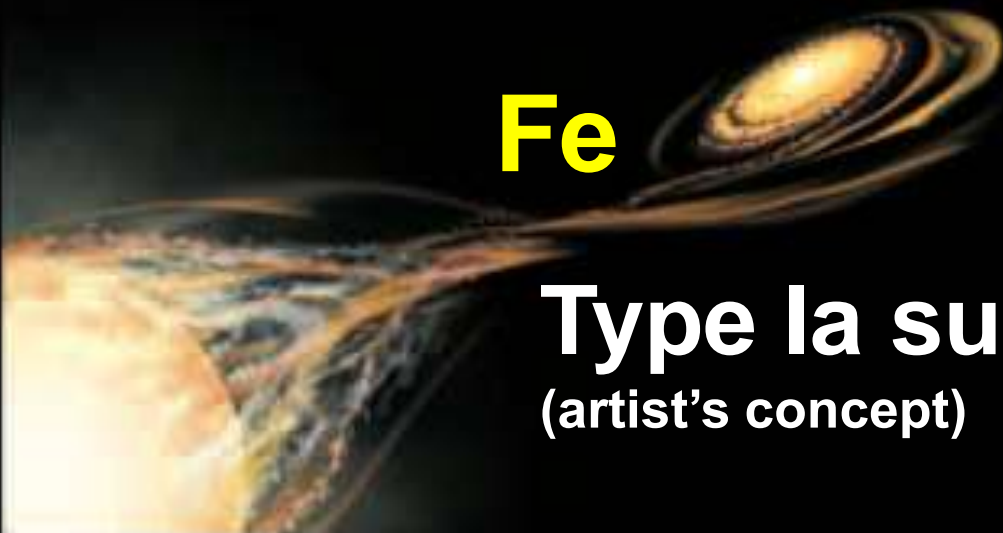


Planetary nebula



C  
N

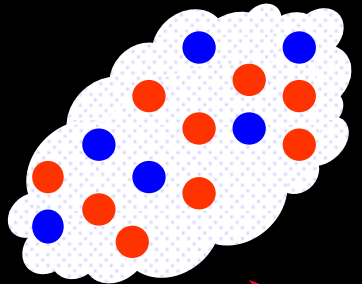
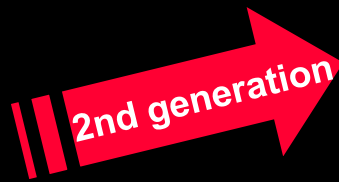
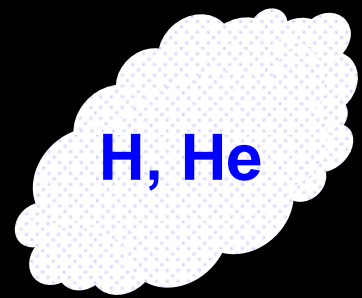
Fe



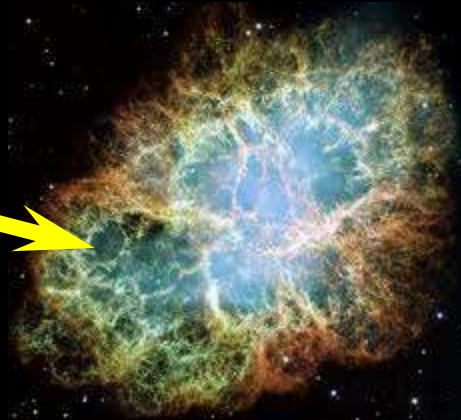
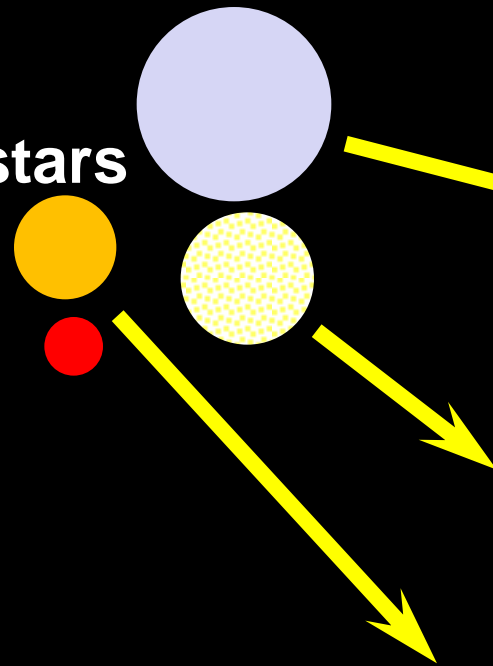
Type Ia supernova  
(artist's concept)

# Galactic chemical evolution

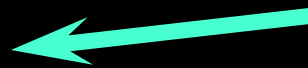
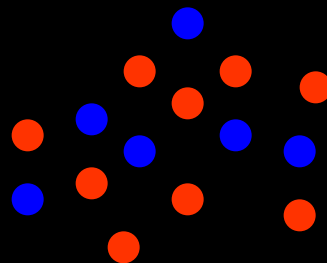
Interstellar medium



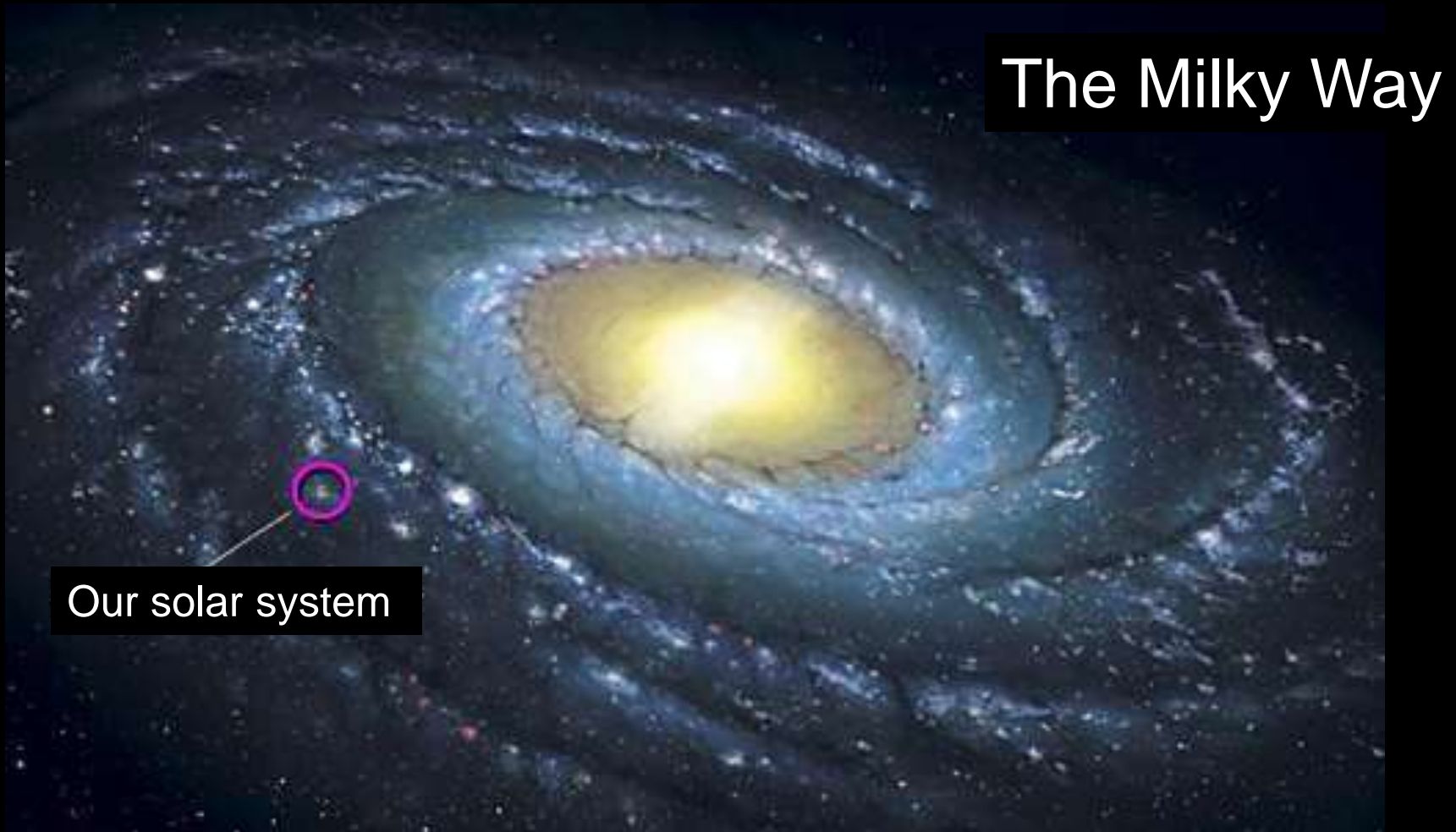
stars



Metal-rich ejecta



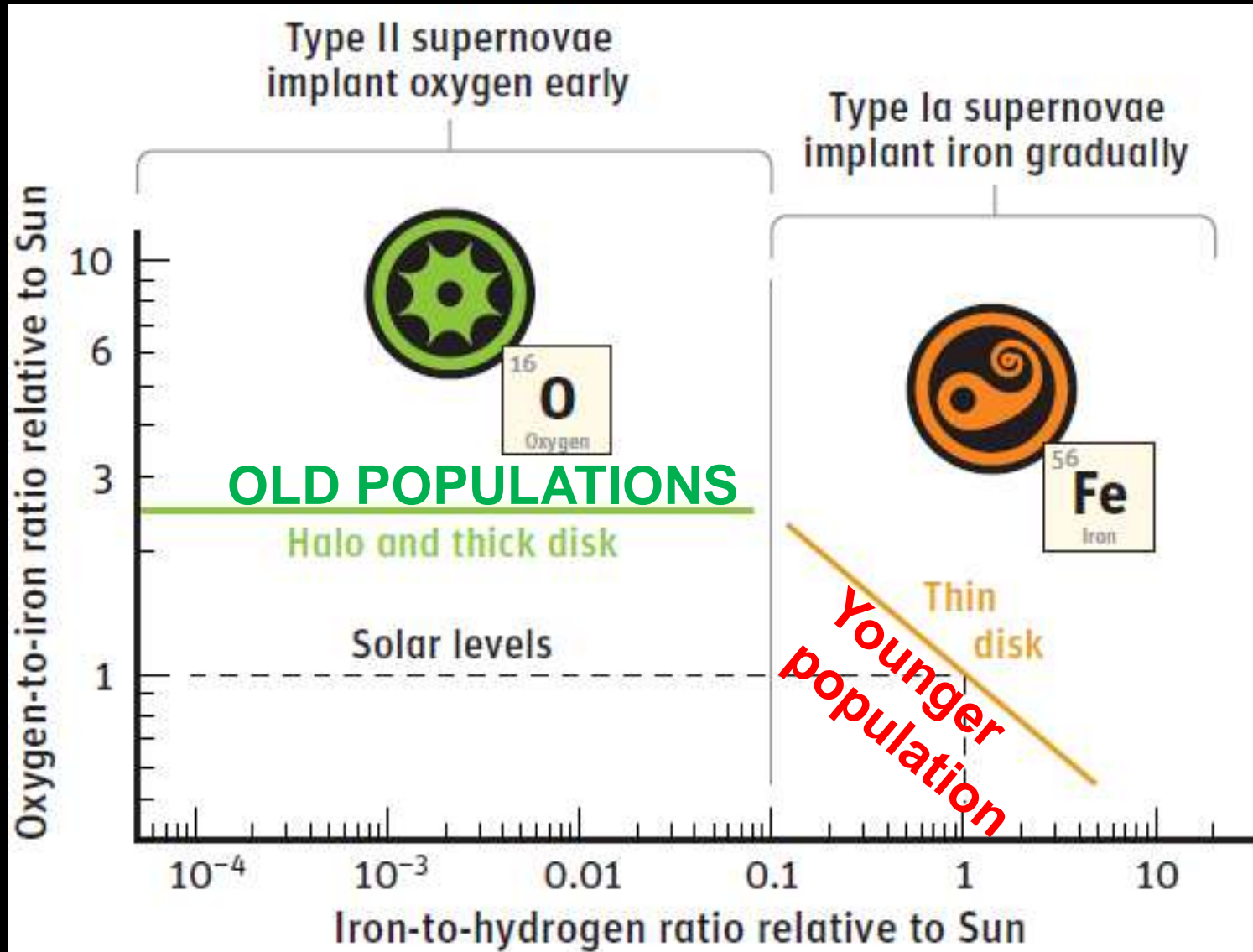
After 12 billion years of *chemical evolution* in our Galaxy, stars have produced only **2%** of “**metals**”, the rest (98%) being **H & He**



The Milky Way

Our solar system

# Galactic archaeology



# Galactic archaeology: disk(s)

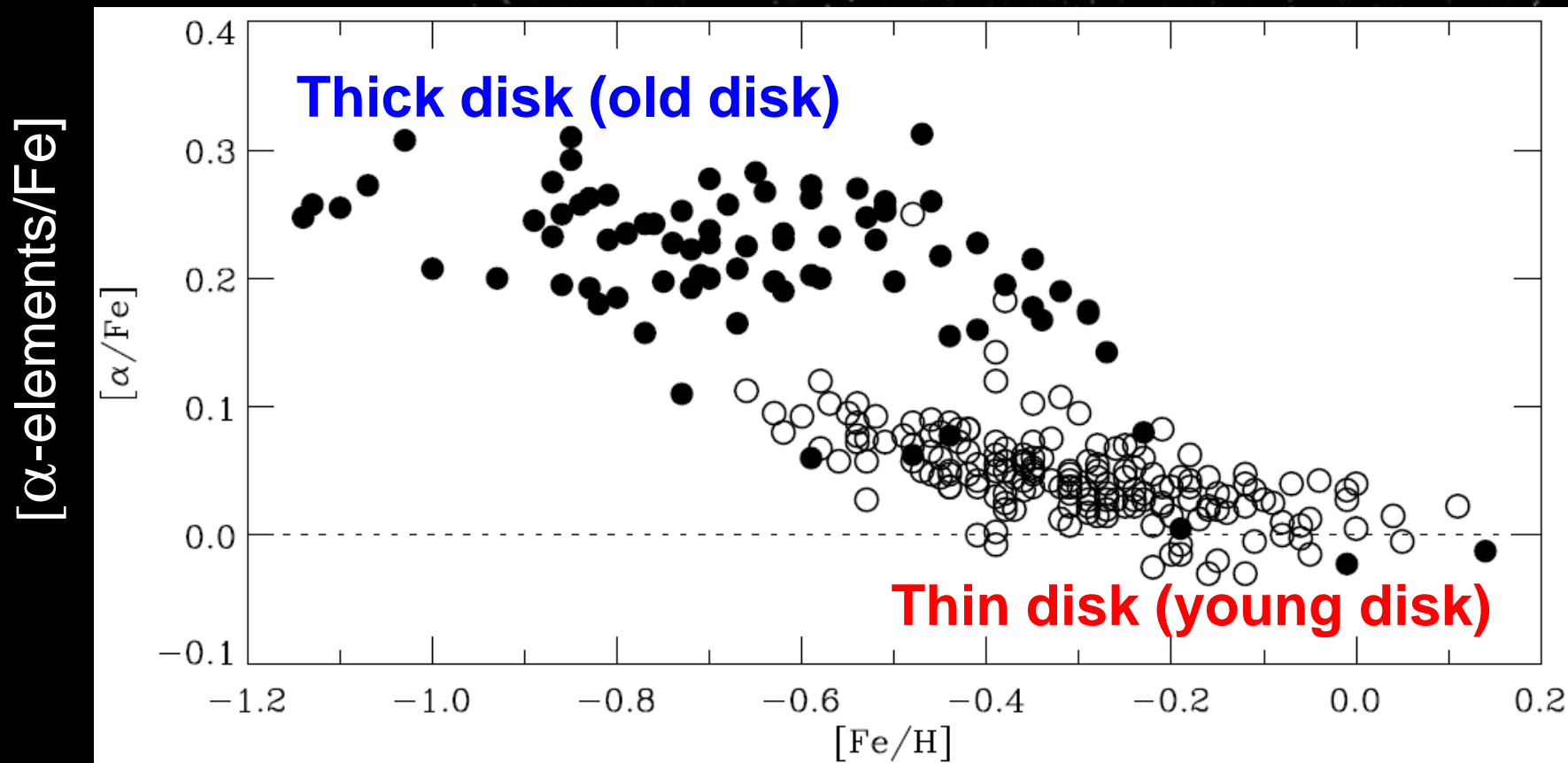


Fig. 7.  $[\alpha/\text{Fe}]$  as a function of  $[\text{Fe}/\text{H}]$  according to Reddy et al. (2003, 2006). Stars indicated by open circles have a probability  $P > 70\%$  of belonging to the thin disk, whereas stars represented by filled circles have  $P > 70\%$  of belonging to the thick disk.



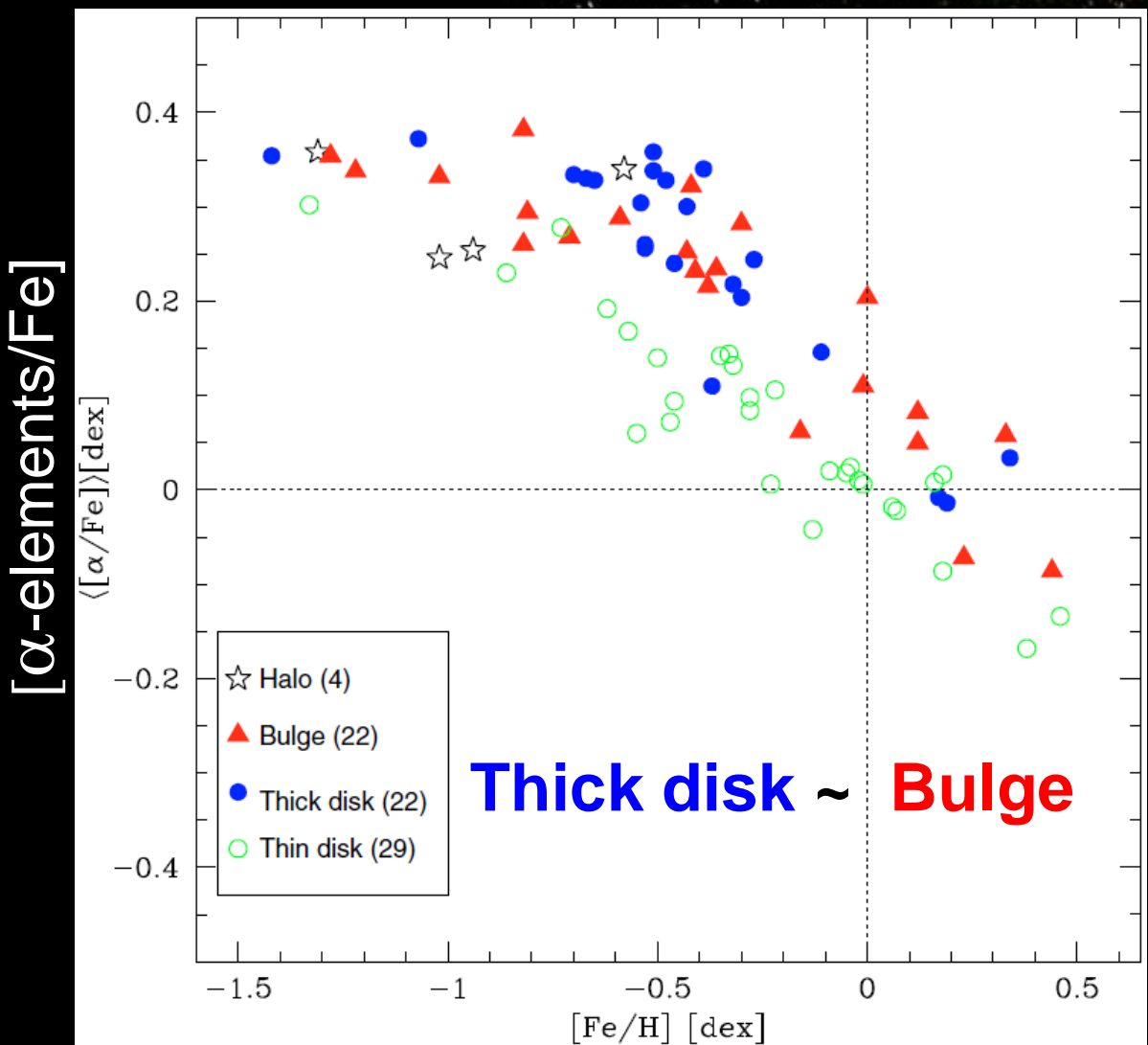
# Galactic archaeology: bulge

Chemical similarities between Galactic bulge and local thick disk  
red giants: O, Na, Mg, Al, Si, Ca, and Ti\*

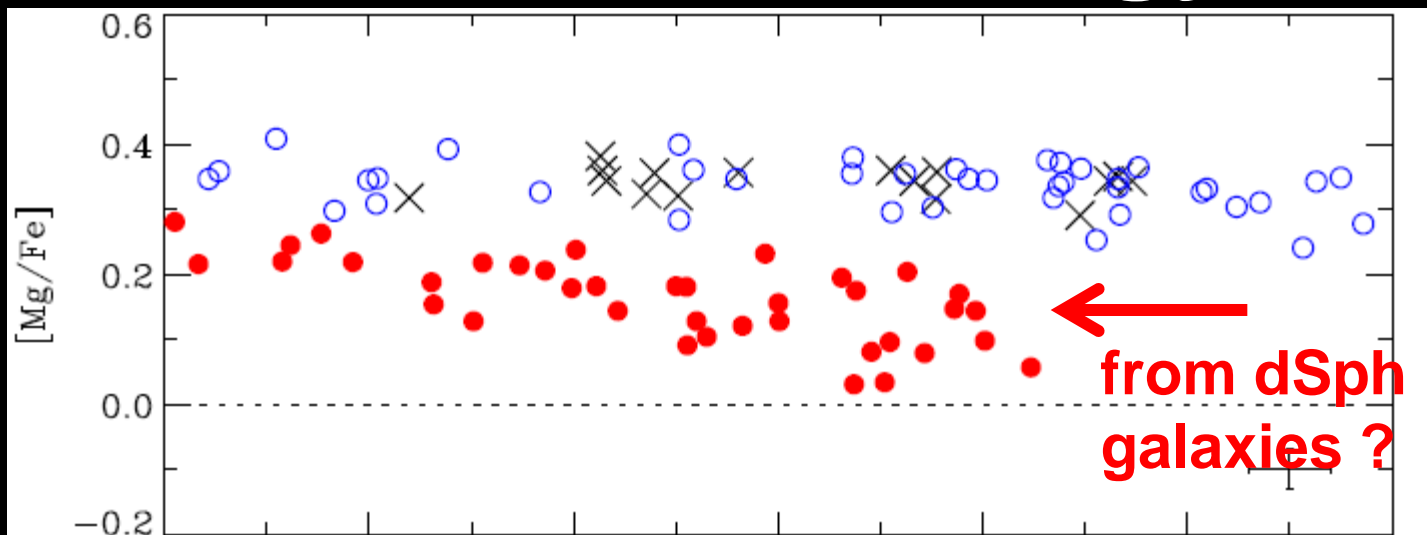
A. Alves-Brito<sup>1,2</sup>, J. Meléndez<sup>3</sup>, M. Asplund<sup>4</sup>, I. Ramírez<sup>4</sup>, and D. Yong<sup>5</sup>

A&A 513, A35 (2010)

Astronomy  
&  
Astrophysics

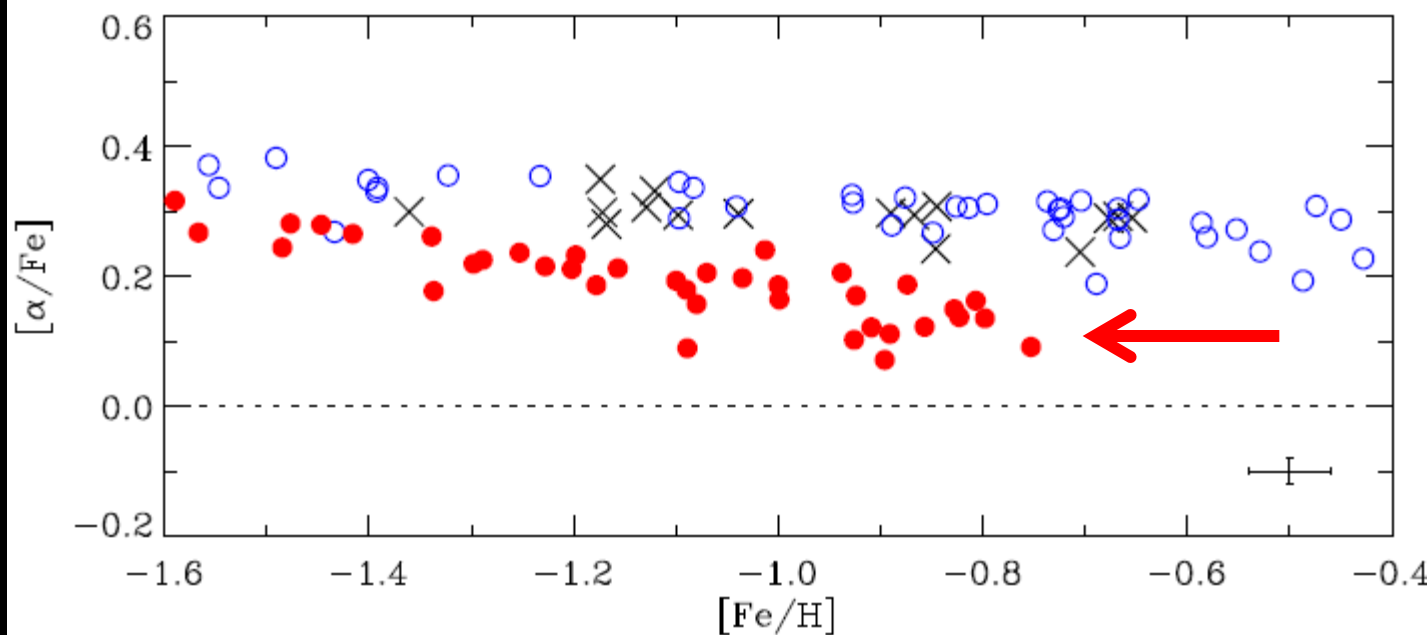


# Galactic archaeology: halo(s)



“true” halo stars?

from dSph galaxies?



Nissen & Schuster 2010

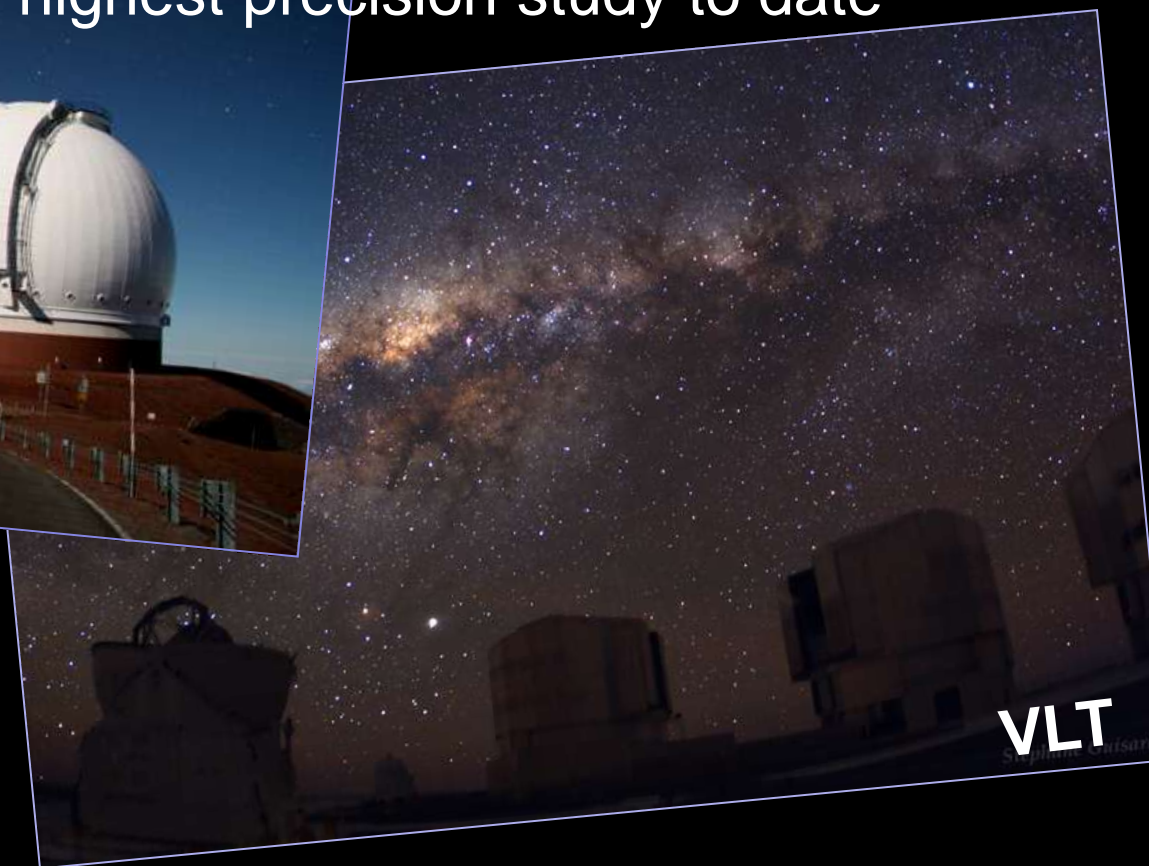
# High precision chemical abundances in metal-poor stars @ IAG / USP

High resolution ( $R = 100,000$ ) high S/N spectra (300-1000) available to perform the highest precision study to date



**Keck**

**HELP  
WELCOME !**



**VLT**

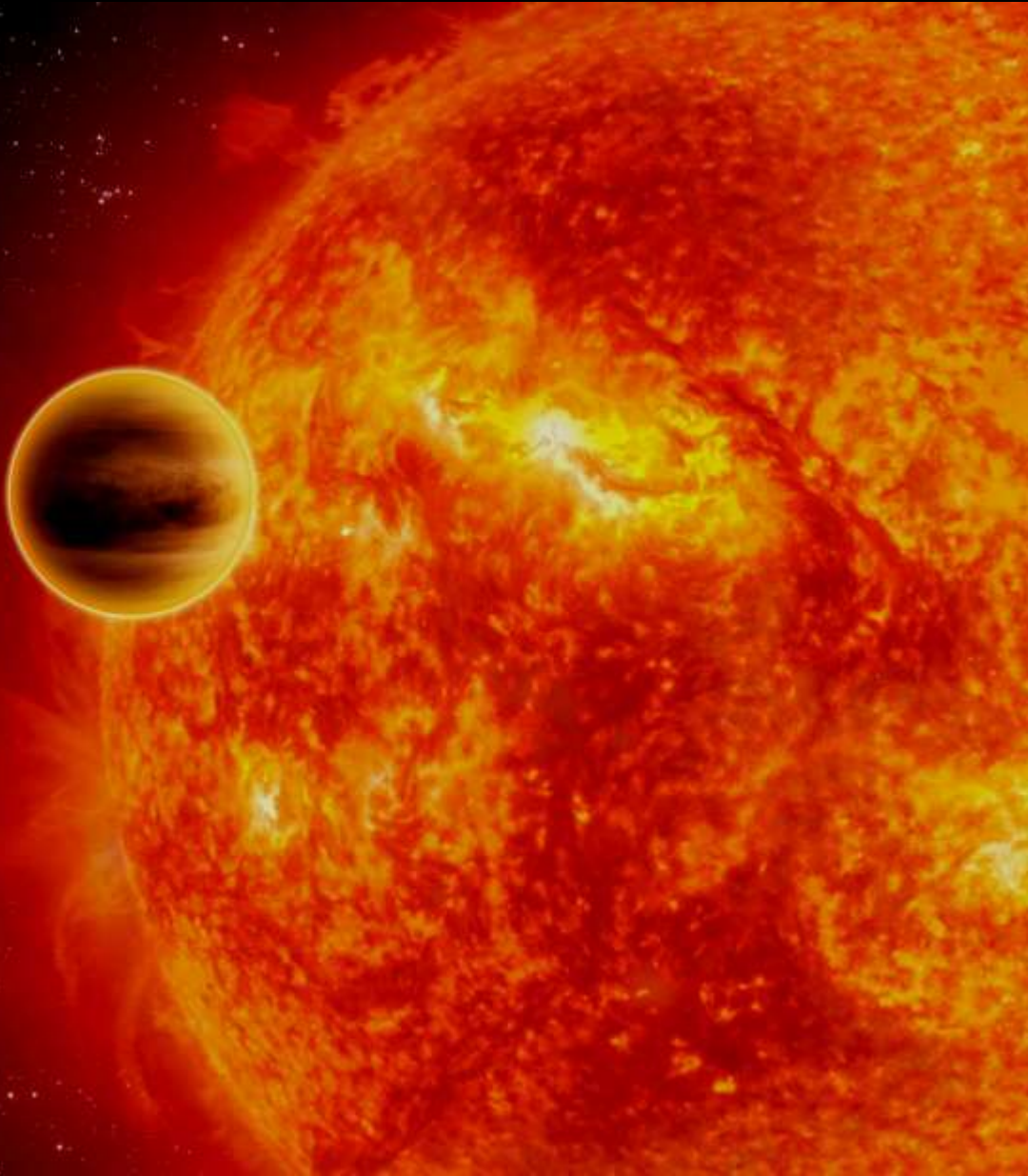
A photograph of a sunset over the ocean in Paracas, Peru. The sun is low on the horizon, creating a bright orange glow and a shimmering reflection on the water. The sky is a deep orange, and the water is dark blue. In the foreground, a sandy beach is visible. Two small boats are on the water in the distance. The text "Looking for planetary systems like our own" is overlaid in yellow.

# Looking for planetary systems like our own

*Sunset in Paracas, Peru*

*(c) [www.flickr.com/photos/rodrigocampos/](http://www.flickr.com/photos/rodrigocampos/)*

More than 500 planetary systems  
found until now



But ... most of  
them DO NOT  
resemble our own  
solar system

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

## The Upsilon Andromedae System

**B**  
0.06 AU  
4.6 day orbit  
75% Jupiter's Mass

**C**  
0.85 AU  
242 day orbit  
Twice Jupiter's Mass

**D**  
2.5 AU  
3.5 year orbit  
4x Jupiter's Mass

## Our Inner Solar System

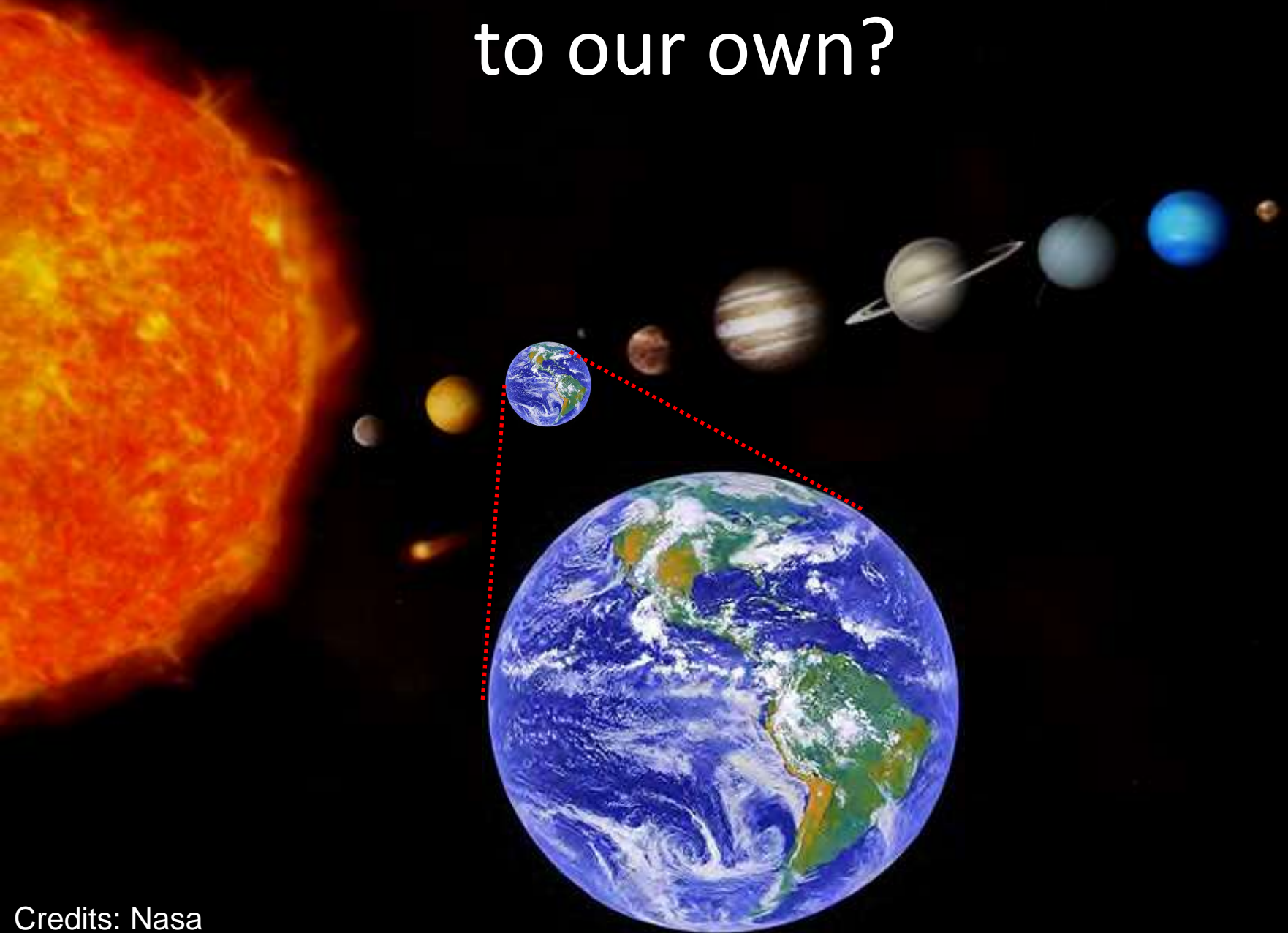
**Mercury**  
0.39 AU  
89 day orbit

**Venus**  
0.73 AU  
228 day orbit

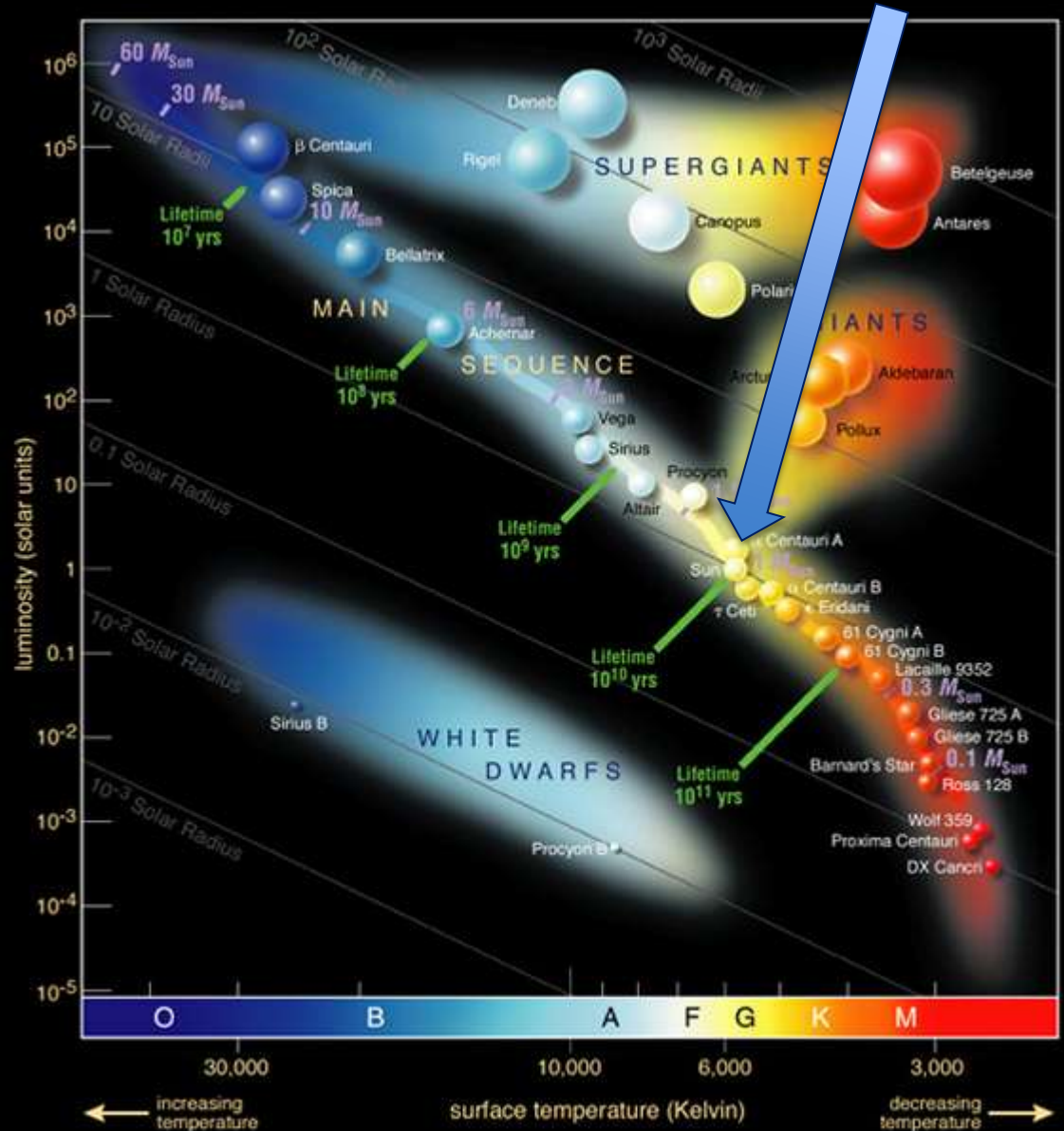
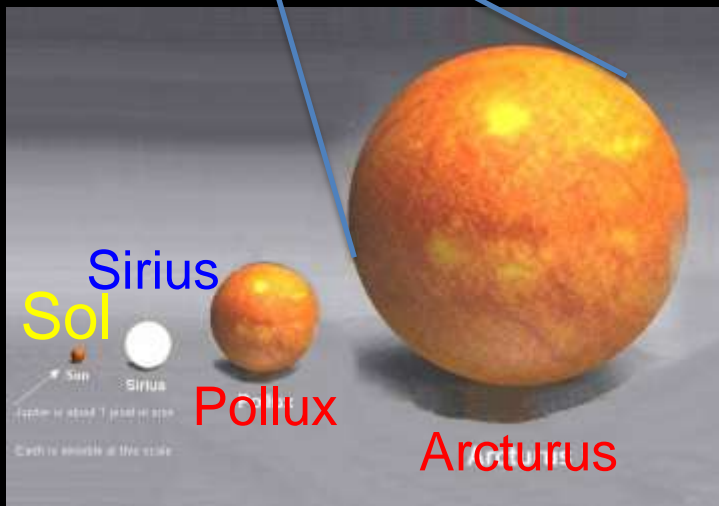
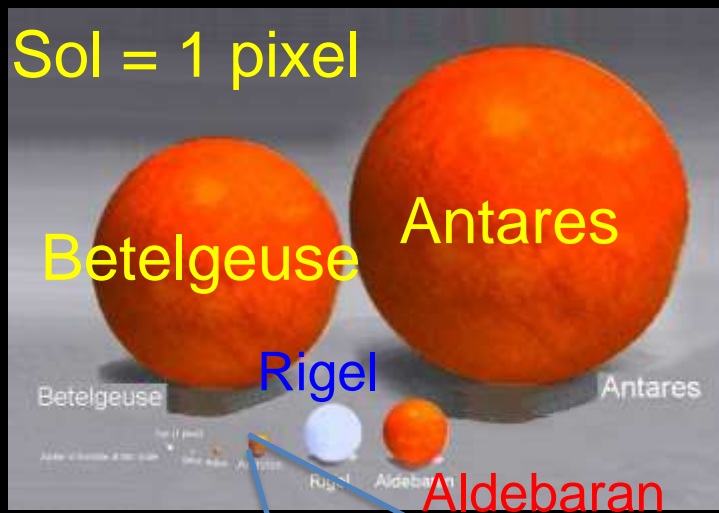
**Earth**  
1.00 AU  
1 year orbit

**Mars**  
1.54 AU  
1.9 year orbit

# How to find a planetary system similar to our own?

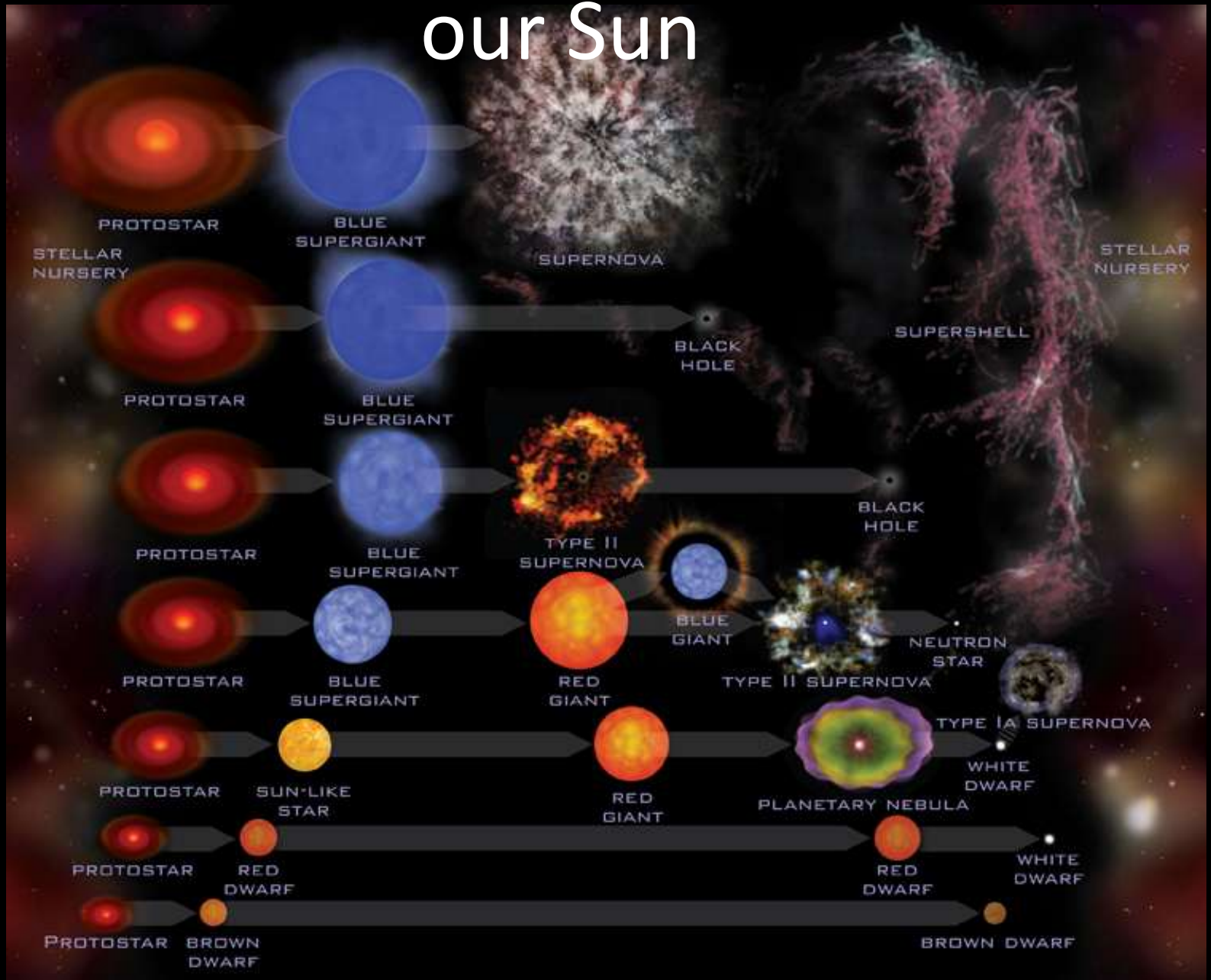


# 1. Search for stars similar to our Sun





# 2. In the same evolutionary stage as our Sun



# 3. Chemical composition ~ solar?

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

## PERIODIC TABLE of the ELEMENTS

DEPARTMENT OF SCIENCE AND TECHNOLOGY

Heavily inspired by the SHUTTLEWORTH FOUNDATION

DEPARTMENT OF SCIENCE AND TECHNOLOGY

He

He  
Helium 2  
4.00

Li  
Lithium 3  
6.94

Be  
Beryllium 4  
9.01

B  
Boron 5  
10.81

C  
Carbon 6  
12.01

N  
Nitrogen 7  
14.01

O  
Oxygen 8  
16.00

F  
Fluorine 9  
19.00

Ne  
Neon 10  
20.18

Mg  
Magnesium 12  
24.3

Na  
Sodium 11  
22.99

Al  
Aluminium 13  
26.98

Si  
Silicon 14  
28.09

P  
Phosphorus 15  
30.97

S  
Sulphur 16  
32.06

Cl  
Chlorine 17  
35.45

Ar  
Argon 18  
39.95

K  
Potassium 19  
39.10

Ca  
Calcium 20  
40.08

Sc  
Scandium 21  
44.96

Ti  
Titanium 22  
47.88

V  
Vanadium 23  
50.94

Cr  
Chromium 24  
52.00

Mn  
Manganese 25  
54.94

Fe  
Iron 26  
55.85

Co  
Cobalt 27  
58.93

Ni  
Nickel 28  
58.71

Cu  
Copper 29  
63.55

Zn  
Zinc 30  
65.39

Ga  
Gallium 31  
69.72

Ge  
Germanium 32  
72.61

As  
Arsenic 33  
74.92

Se  
Selenium 34  
78.96

Br  
Bromine 35  
79.90

Kr  
Krypton 36  
83.80

Rb  
Rubidium 37  
85.47

Sr  
Strontium 38  
87.62

Y  
Yttrium 39  
88.91

Zr  
Zirconium 40  
91.22

Nb  
Niobium 41  
92.91

Mo  
Molybdenum 42  
95.94

Tc  
Technetium 43  
(98)

Ru  
Ruthenium 44  
101.07

Rh  
Rhodium 45  
102.91

Pd  
Palladium 46  
106.42

Ag  
Silver 47  
107.87

Cd  
Cadmium 48  
112.41

In  
Indium 49  
114.82

Sn  
Tin 50  
118.71

Sb  
Antimony 51  
121.76

Te  
Tellurium 52  
127.60

I  
Iodine 53  
126.90

Xe  
Xenon 54  
131.29

Ba  
Barium 56  
137.33

La  
Lanthanide Series

Hf  
Hafnium 72  
178.49

Ta  
Tantalum 73  
180.95

W  
Tungsten 74  
183.85

Re  
Rhenium 75  
186.21

Os  
Osmium 76  
190.23

Ir  
Iridium 77  
192.22

Pt  
Platinum 78  
195.08

Au  
Gold 79  
196.97

Hg  
Mercury 80  
200.59

Tl  
Thallium 81  
204.38

Pb  
Lead 82  
207.2

Bi  
Bismuth 83  
208.98

Po  
Polonium 84  
(209)

At  
Astatine 85  
(210)

Rn  
Radon 86  
(222)

Cs  
Caesium 55  
132.91

Ba  
Barium 56  
137.33

Ra  
Radium 88  
(226)

Actinide Series

Rf  
Rutherfordium 104  
(261)

Db  
Dubnium 105  
(262)

Sg  
Seaborgium 106  
(263)

Bh  
Bohrium 107  
(264)

Hs  
Hassium 108  
(265)

Mt  
Meitnerium 109  
(266)

La  
Lanthanum 57  
138.91

Ce  
Cerium 58  
140.12

Pr  
Praseodymium 59  
140.91

Nd  
Neodymium 60  
144.24

Pm  
Promethium 61  
(145)

Sm  
Samarium 62  
150.36

Eu  
Europium 63  
151.96

Gd  
Gadolinium 64  
157.25

Tb  
Terbium 65  
158.93

Dy  
Dysprosium 66  
162.50

Ho  
Holmium 67  
164.93

Er  
Erbium 68  
167.26

Tm  
Thulium 69  
168.93

Yb  
Ytterbium 70  
173.05

Lu  
Lutetium 71  
174.97

Ac  
Actinium 89  
227

Th  
Thorium 90  
232.04

Pa  
Protactinium 91  
231.04

U  
Uranium 92  
238.03

Np  
Neptunium 93  
(237)

Pu  
Plutonium 94  
(244)

Am  
Americium 95  
(243)

Cm  
Curium 96  
(247)

Bk  
Berkelium 97  
(247)

Cf  
Californium 98  
(251)

Es  
Einsteinium 99  
(252)

Fm  
Fermium 100  
(257)

Md  
Mendelevium 101  
(258)

No  
Nobelium 102  
(259)

Lr  
Lawrencium 103  
(260)

DNITRI 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 core of chemistry teaching and the prediction of new elements ever since. In 1955, element 101 was named after him, 106, Mendeleevium.

He can improve the classroom:

- Gas
- Liquid
- Room temp
- Not seen solid (predicted)

Hydrogen 1  
1.01

Helium 2  
4.00

Lithium 3  
6.94

Beryllium 4  
9.01

Boron 5  
10.81

Carbon 6  
12.01

Nitrogen 7  
14.01

Oxygen 8  
16.00

Fluorine 9  
19.00

Neon 10  
20.18

Sodium 11  
22.99

Magnesium 12  
24.3

Aluminium 13  
26.98

Silicon 14  
28.09

Phosphorus 15  
30.97

Sulphur 16  
32.06

Chlorine 17  
35.45

Argon 18  
39.95

Potassium 19  
39.10

Calcium 20  
40.08

Scandium 21  
44.96

Titanium 22  
47.88

Vanadium 23  
50.94

Chromium 24  
52.00

Manganese 25  
54.94

Iron 26  
55.85

Cobalt 27  
58.93

Nickel 28  
58.71

Copper 29  
63.55

Zinc 30  
65.39

Gallium 31  
69.72

Germanium 32  
72.61

Arsenic 33  
74.92

Selenium 34  
78.96

Bromine 35  
79.90

Krypton 36  
83.80

Rubidium 37  
85.47

Strontium 38  
87.62

Yttrium 39  
88.91

Zirconium 40  
91.22

Niobium 41  
92.91

Molybdenum 42  
95.94

Technetium 43  
(98)

Ruthenium 44  
101.07

Rhodium 45  
102.91

Palladium 46  
106.42

Silver 47  
107.87

Cadmium 48  
112.41

Indium 49  
114.82

Tin 50  
118.71

Antimony 51  
121.76

Tellurium 52  
127.60

Iodine 53  
126.90

Xenon 54  
131.29

Barium 56  
137.33

Lanthanide Series

Hafnium 72  
178.49

Tantalum 73  
180.95

Tungsten 74  
183.85

Rhenium 75  
186.21

Osmium 76  
190.23

Iridium 77  
192.22

Platinum 78  
195.08

Gold 79  
196.97

Mercury 80  
200.59

Thallium 81  
204.38

Lead 82  
207.2

Bismuth 83  
208.98

Polonium 84  
(209)

Astatine 85  
(210)

Radon 86  
(222)

Caesium 55  
132.91

Barium 56  
137.33

Radium 88  
(226)

Actinide Series

Rutherfordium 104  
(261)

Dubnium 105  
(262)

Seaborgium 106  
(263)

Bohrium 107  
(264)

Hassium 108  
(265)

Meitnerium 109  
(266)

Lanthanum 57  
138.91

Cerium 58  
140.12

Praseodymium 59  
140.91

Neodymium 60  
144.24

Promethium 61  
(145)

Samarium 62  
150.36

Europium 63  
151.96

Gadolinium 64  
157.25

Terbium 65  
158.93

Dysprosium 66  
162.50

Holmium 67  
164.93

Erbium 68  
167.26

Thulium 69  
168.93

Ytterbium 70  
173.05

Lutetium 71  
174.97

Actinium 89  
227

Thorium 90  
232.04

Protactinium 91  
231.04

Uranium 92  
238.03

Neptunium 93  
(237)

Plutonium 94  
(244)

Americium 95  
(243)

Curium 96  
(247)

Berkelium 97  
(247)

Californium 98  
(251)

Einsteinium 99  
(252)

Fermium 100  
(257)

Mendelevium 101  
(258)

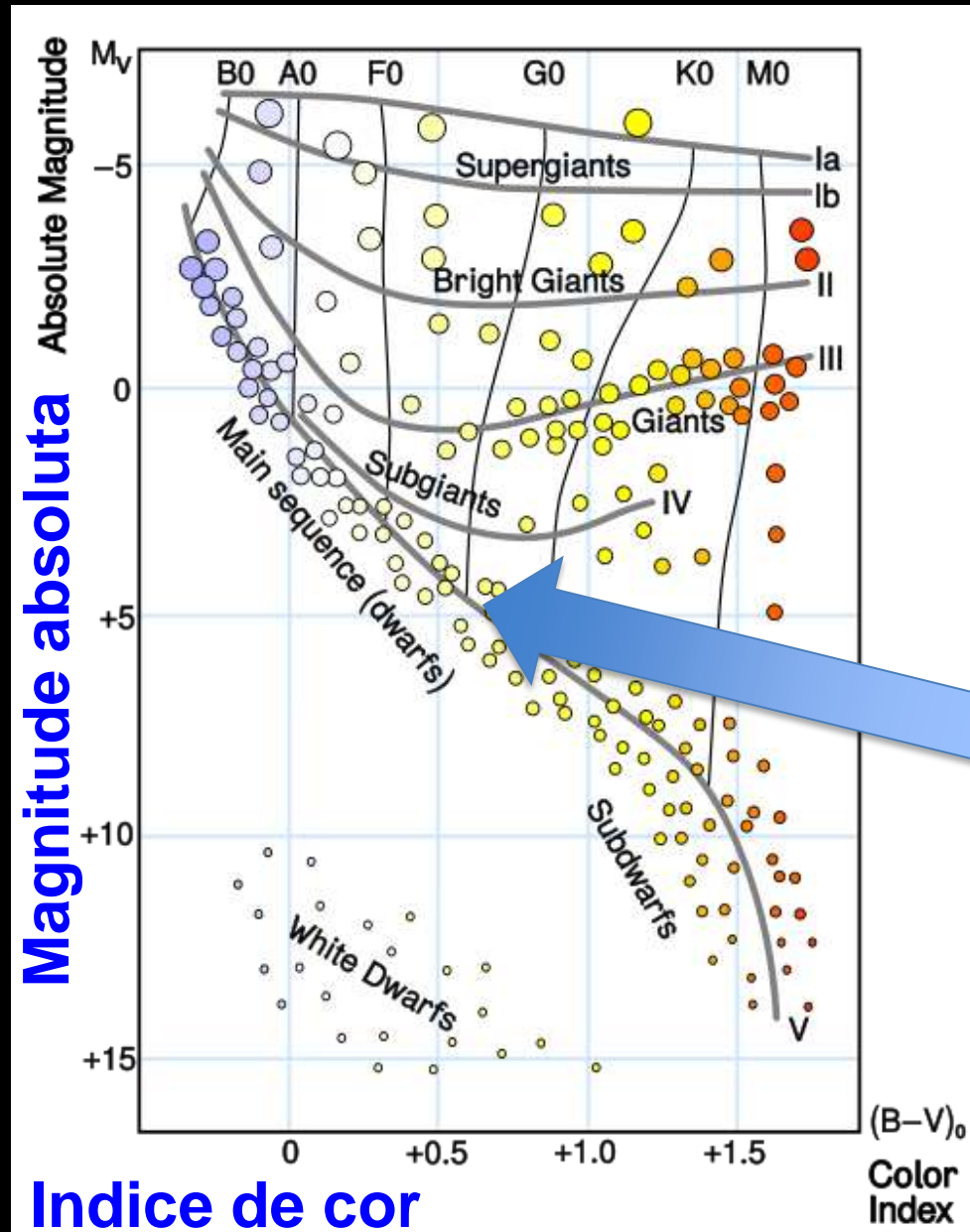
Nobelium 102  
(259)

Lawrencium 103  
(260)

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



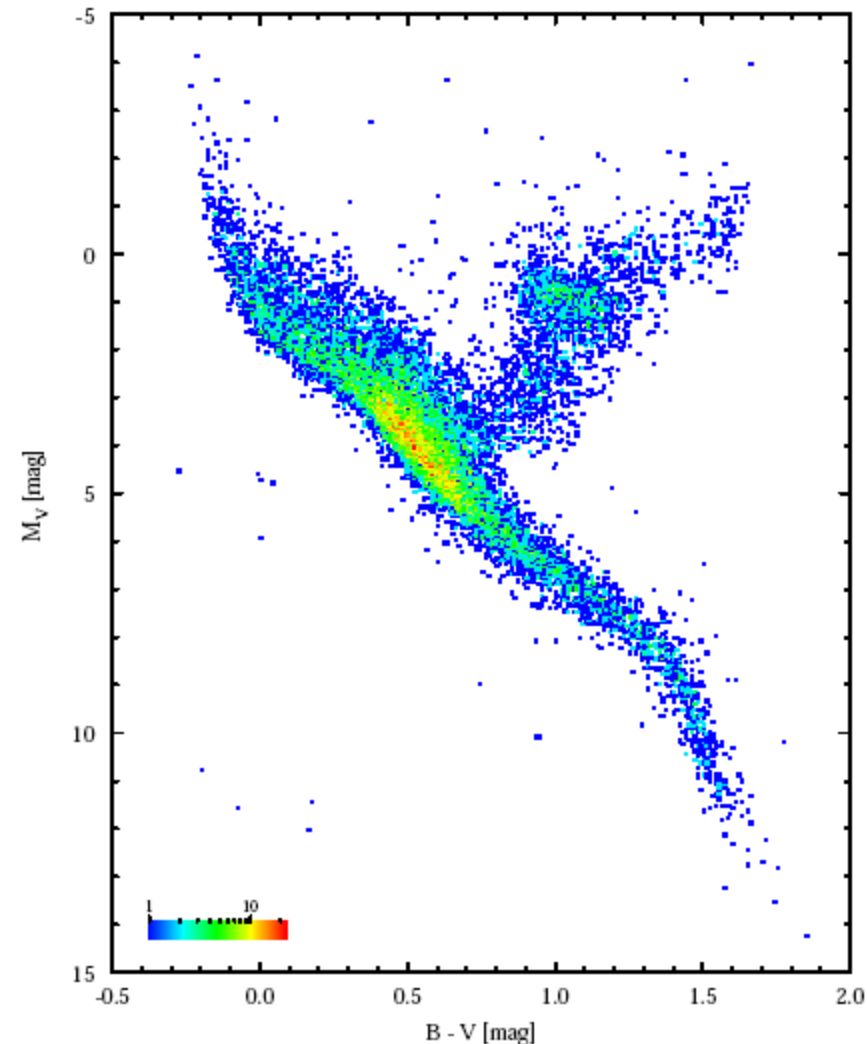
# Diagrama H-R



**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 (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<sup>1,2</sup>, N. Knowles<sup>1</sup>, G. Hernandez<sup>2</sup>, and C.

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

### **In search of real solar twins. III.\***

E. Friel<sup>1</sup>, G. Cayrel de Strobel<sup>1</sup>, Y. Chmielewski<sup>2</sup>, M. Spite<sup>1\*\*</sup>, A. Lèbre<sup>1</sup>, and C. Bentolila<sup>1</sup>



# First solar twin discovered only in 1997: 18 Sco

THE ASTROPHYSICAL JOURNAL, 482:L89–L92, 1997 June 10  
© 1997. The American Astronomical Society. All rights reserved. Printed in U.S.A.

## HR 6060: THE CLOSEST EVER SOLAR TWIN?<sup>1</sup>

G. F. PORTO DE MELLO<sup>2,3</sup> AND L. DA SILVA<sup>3</sup>

<sup>2</sup> 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.

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

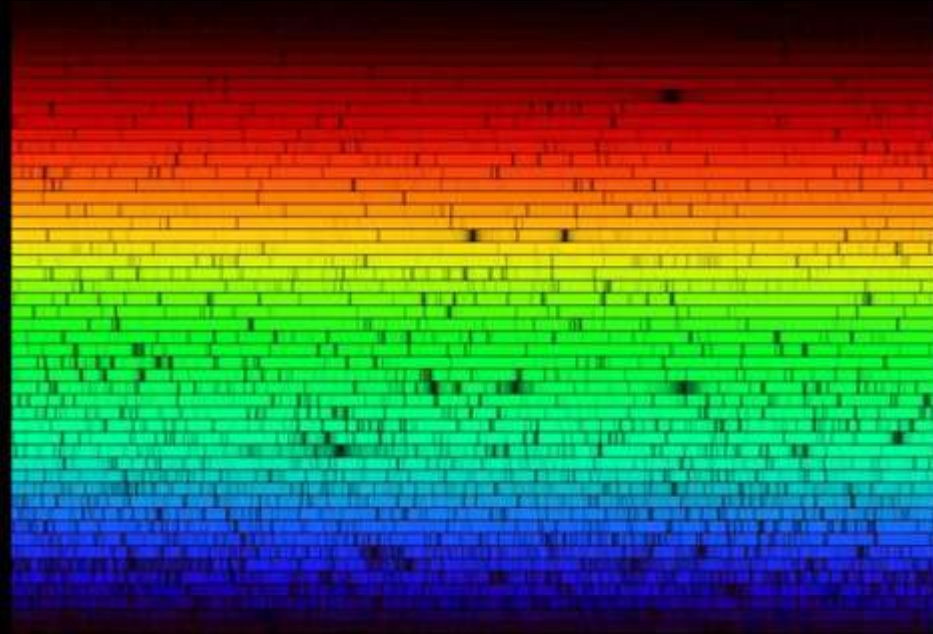


### 18 Sco

Parameter	Sun	HR 2290	HR 6060	16 Cyg A	16 Cyg B
$\Delta T_{\text{eff}}$ (K) .....	0	0	$12 \pm 30$	$8 \pm 25$	$-17 \pm 20$
$\Delta \log g$ .....	0	$0.07 \pm 0.20$	$0.05 \pm 0.12$	$-0.16 \pm 0.07$	$-0.09 \pm 0.07$
$L/L_{\odot}$ .....	1.00	$1.05 \pm 0.27$	$1.05 \pm 0.02$	$1.63 \pm 0.03$	$1.28 \pm 0.02$
[Fe/H] .....	0	$0.13 \pm 0.04$	$0.05 \pm 0.06$	$0.06 \pm 0.04$	$0.02 \pm 0.04$
$(B - V)$ .....	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

# Searching for solar twins

- *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**



# Second solar twin identified in 2006: HD 98618

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

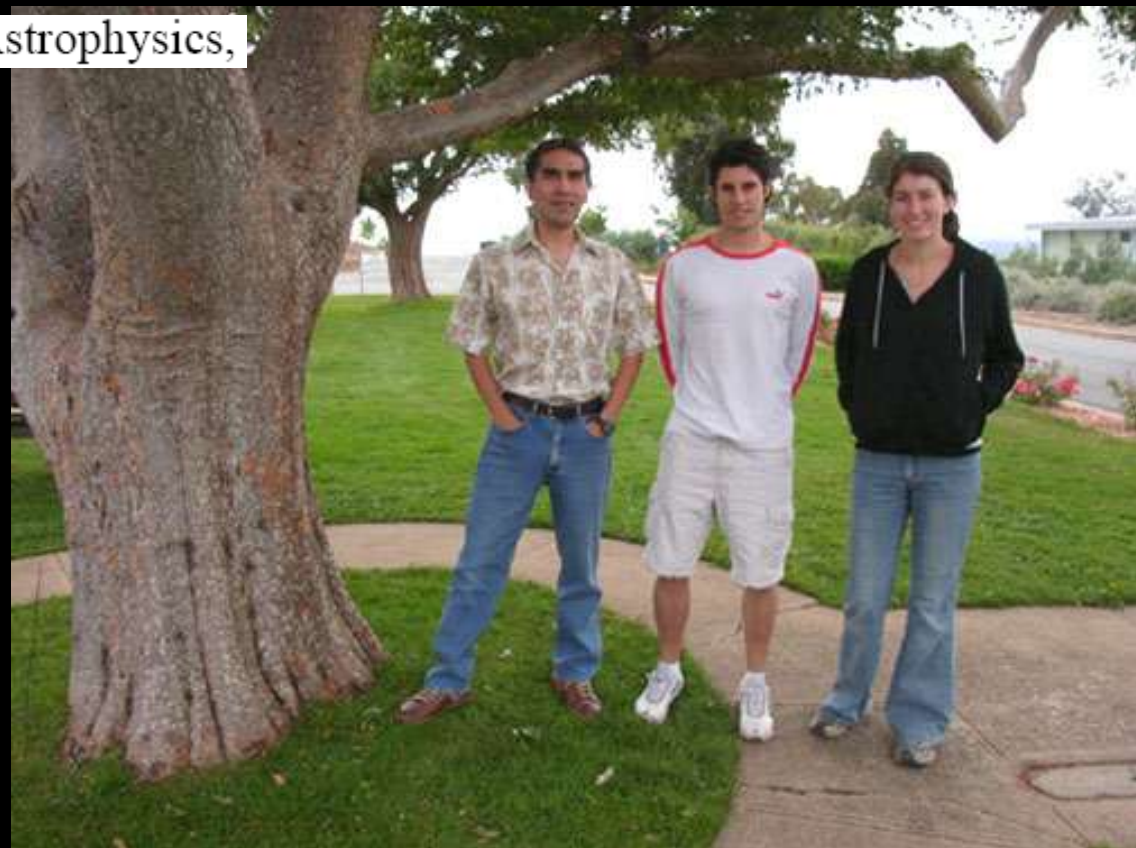
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HD 98618: A STAR CLOSELY RESEMBLING OUR SUN<sup>1</sup>

JORGE MELÉNDEZ,<sup>2</sup> KATIE DODDS-EDEN, AND JOSÉ A. ROBLES

Research School of Astronomy and Astrophysics,  
Mount Stromlo Observatory

- Undergrad *summer*  
research project of  
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 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

11 April 2006 N\$246 Australia \$4.50 (Inc.GST) New Zealand N\$34.95 (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](http://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
$\Delta v_r$ (km s <sup>-1</sup> )	+0.08 ± 0.15	+0.09 ± 0.15
$\Delta T_{\text{eff}}$ (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
$\Delta L_{\text{spec}}$ ( $L_{\odot}$ )	+0.02 ± 0.06	+0.04 ± 0.06
$\Delta L_{\text{Hip}}$ ( $L_{\odot}$ )	+0.03 ± 0.03	+0.08 ± 0.07
$\Delta L_{\text{adopted}}$ ( $L_{\odot}$ )	+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
$\Delta \text{mass}$ ( $M_{\odot}$ )	+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 <sup>a</sup>	+0.7 <sup>a</sup>
$\Delta \text{age}_{\text{rotation}}$ (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 <sup>b</sup> , -1 <sup>a</sup>	-1 <sup>a</sup>
$\Delta \log R'_{\text{HK}}$ (dex)	0.0 <sup>a</sup>	-0.05 <sup>a</sup>
$\Delta M_V$ (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 !

Número atômico



Símbolo

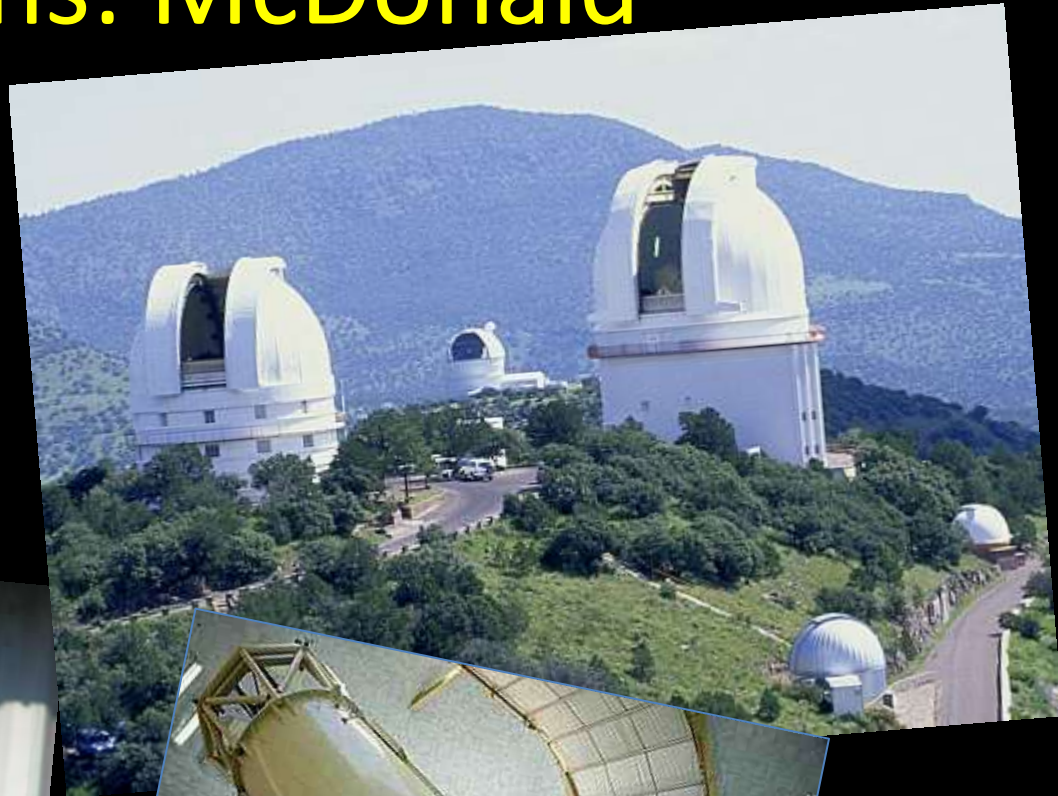
Nome

Massa atômica

Estrutura  
Eletrônica

# Continuing the search for perfect solar twins: McDonald

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



# McDonald solar twin survey

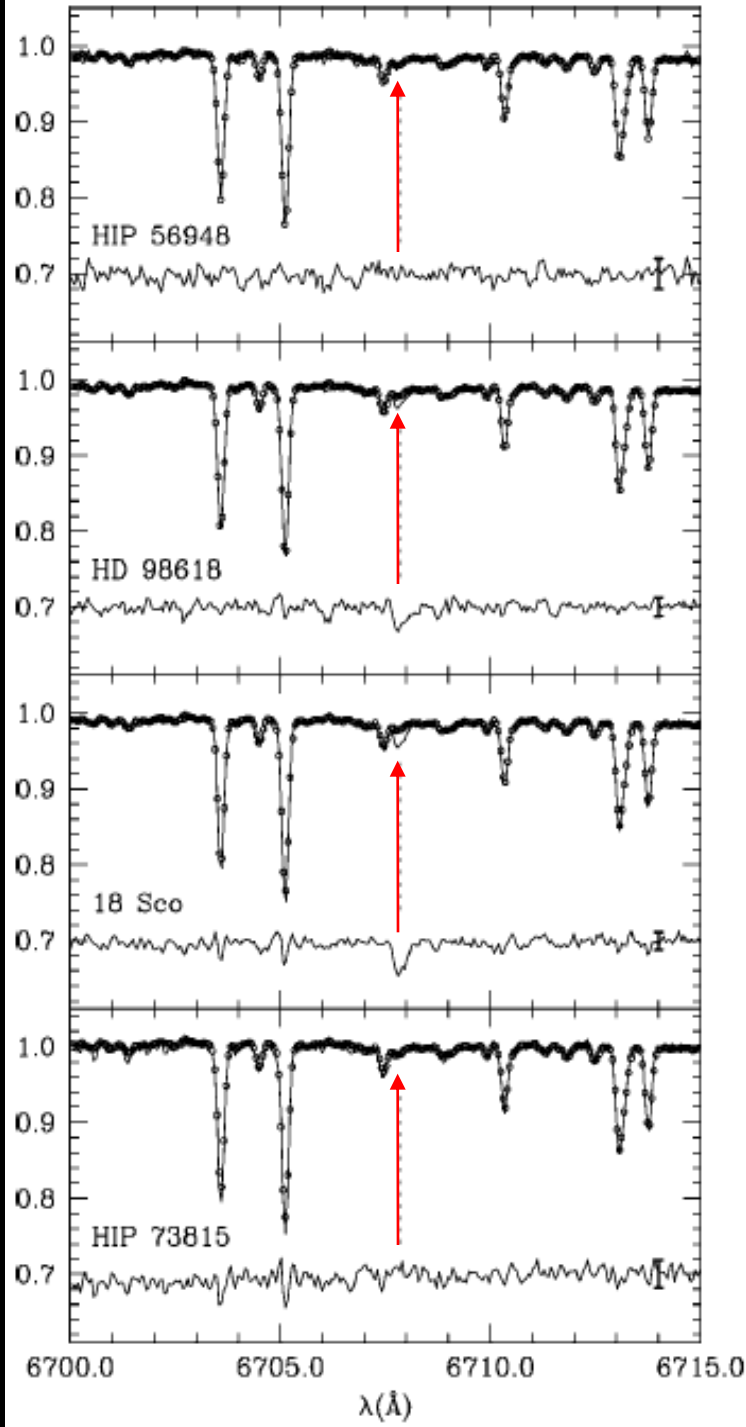
Novas gêmeas solares HIP 56948 & HIP 73815 tem baixo Li (~1.0)!

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, San Francisco

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- Mars rover hobbled as instruments show their age
- 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.

elmundo.es Ciencia y ecología

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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

**ASTRONOMIA.PL**

Pod patronatem Polskiego Towarzystwa Miłośników Astronomii

2007-11-12

**Peruwiańscy odkryli "bliźniaka" Słońca**  
Peruwiańscy astronomowie Jorge Melendez University i Ivan Ramirez z University of Texas, teleskopu Obserwatorium McDonalda w Teksasie, bliźniaczko 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 исследования.

## 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 space 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.

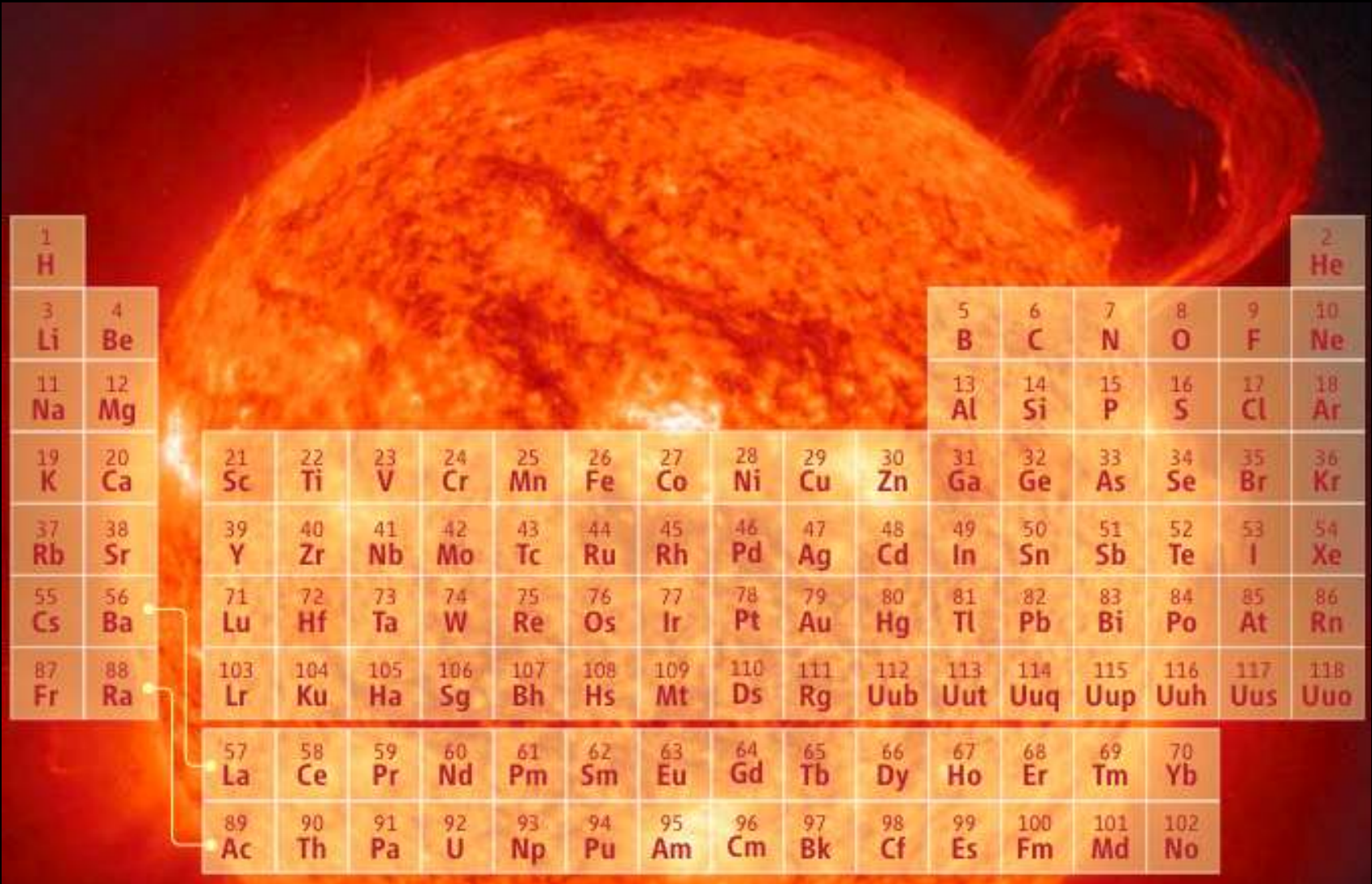
Dos astrónomos nacionales han hecho un descubrimiento que abonaría a la tesis de que la Tierra no es el único planeta del universo donde existe vida.

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.



# Is the Sun a normal solar-type star?

Are there any anomalies in the Sun's chemical composition?



# 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)**

# High precision chemical abundance study of solar twins: Magellan (Clay 6.5m)

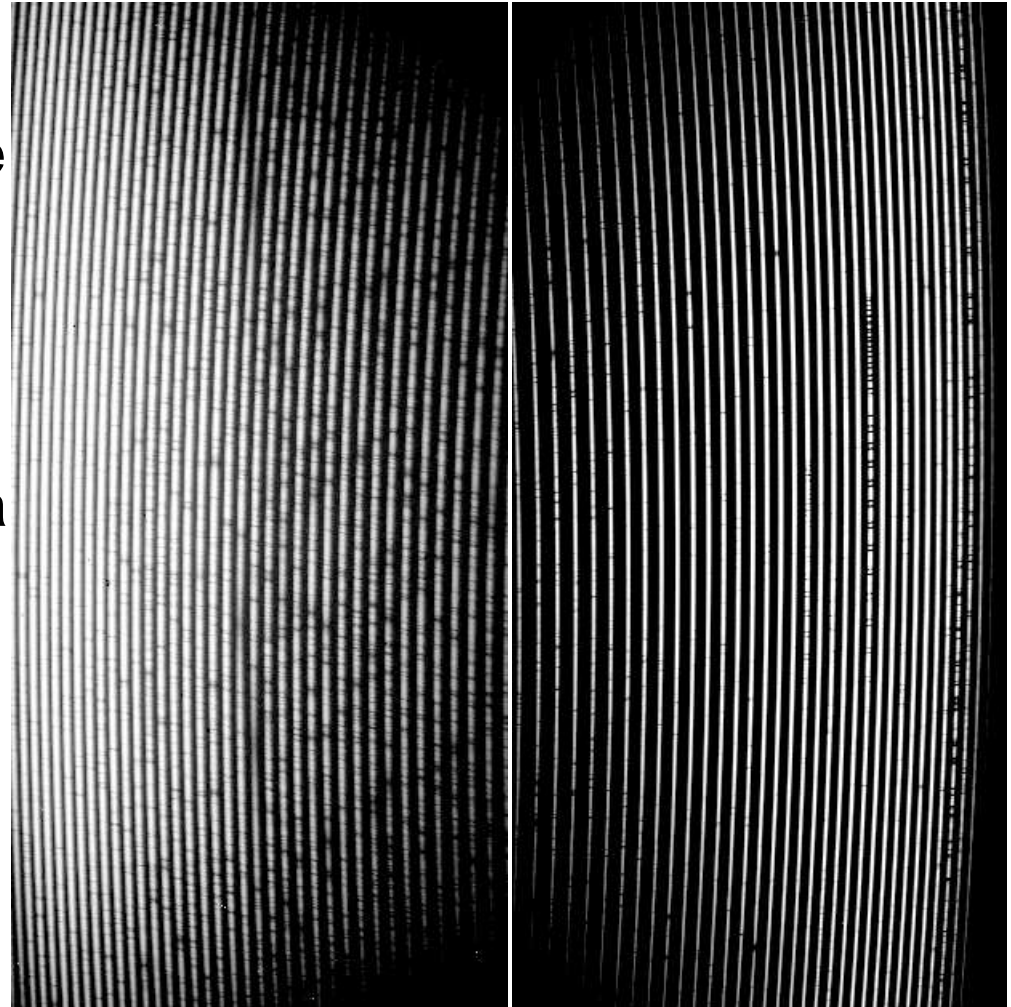


Jorge Meléndez (CAUP/Portugal), Martin Asplund (Max Planck),  
Bengt Gustafsson (Uppsala), David Yong (Stromlo)

# Observações espectroscópicas

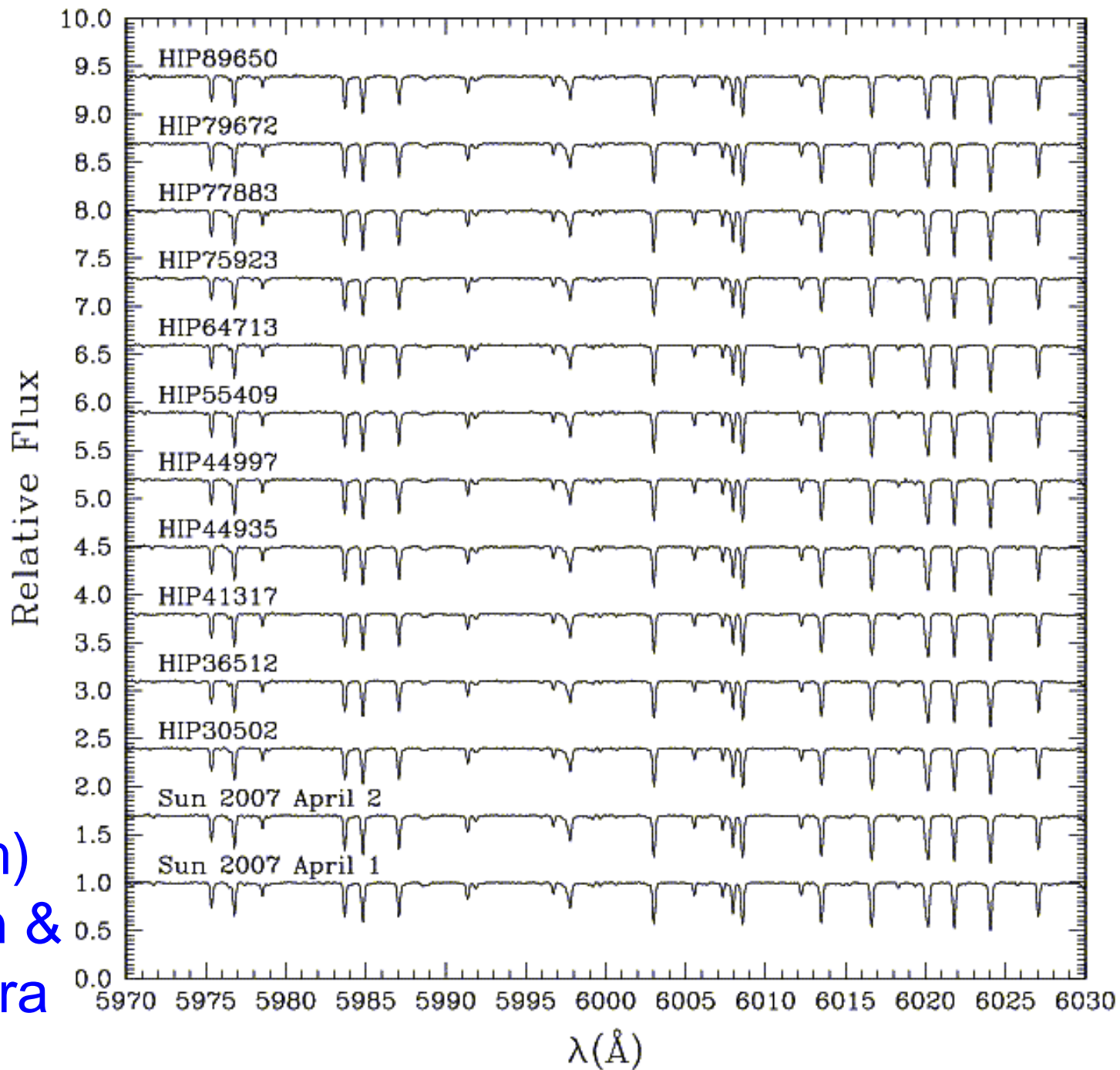
*Observações da gêmea solar 18 Sco*

- 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**



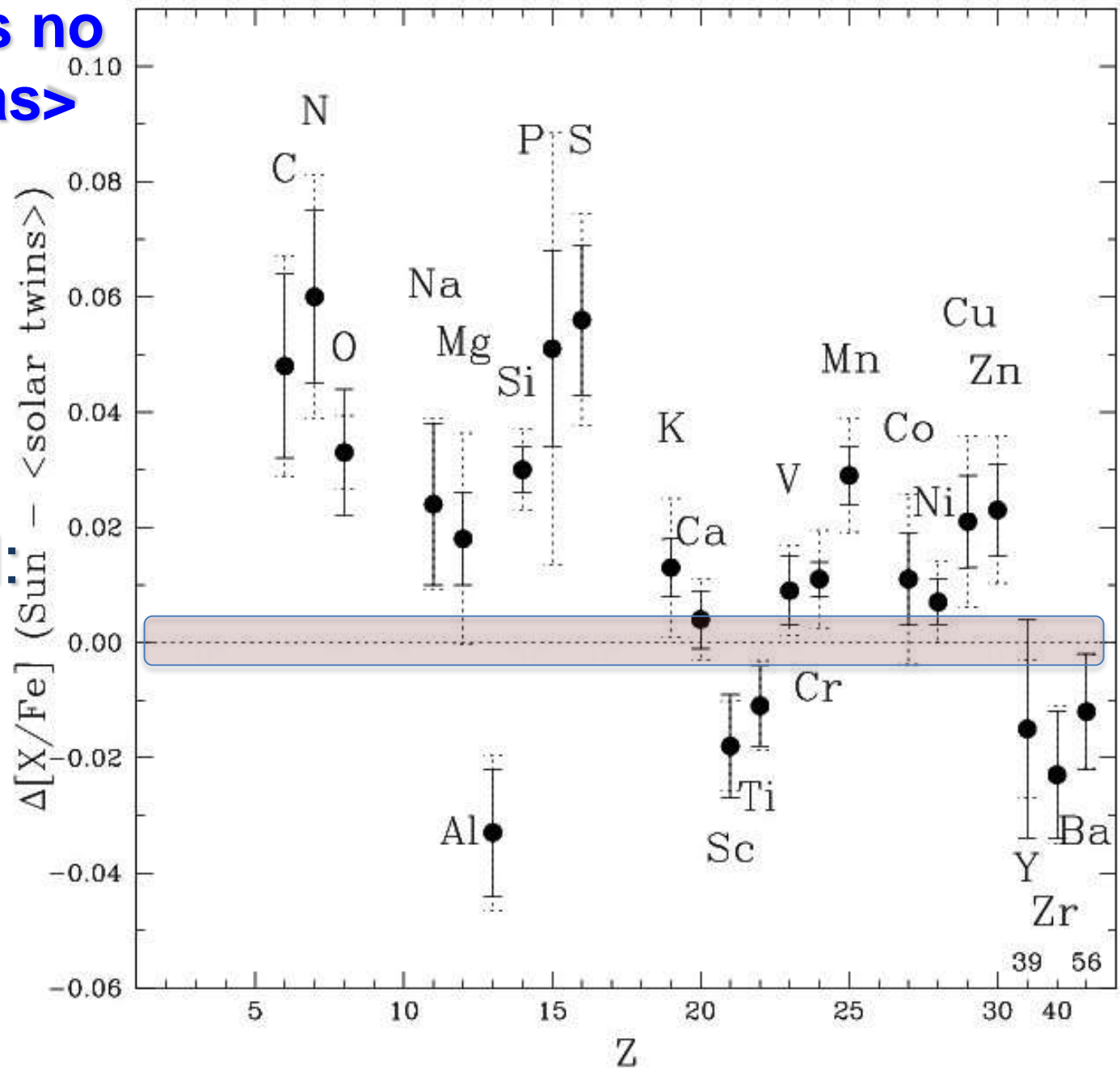
Small part  
(597-603nm)  
of solar twin &  
Sun's spectra

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

**Sol típico:**  
 $\Delta = 0$

**Sol anormal:**  
 $\Delta \neq 0$

**Our Sun is abnormal !**



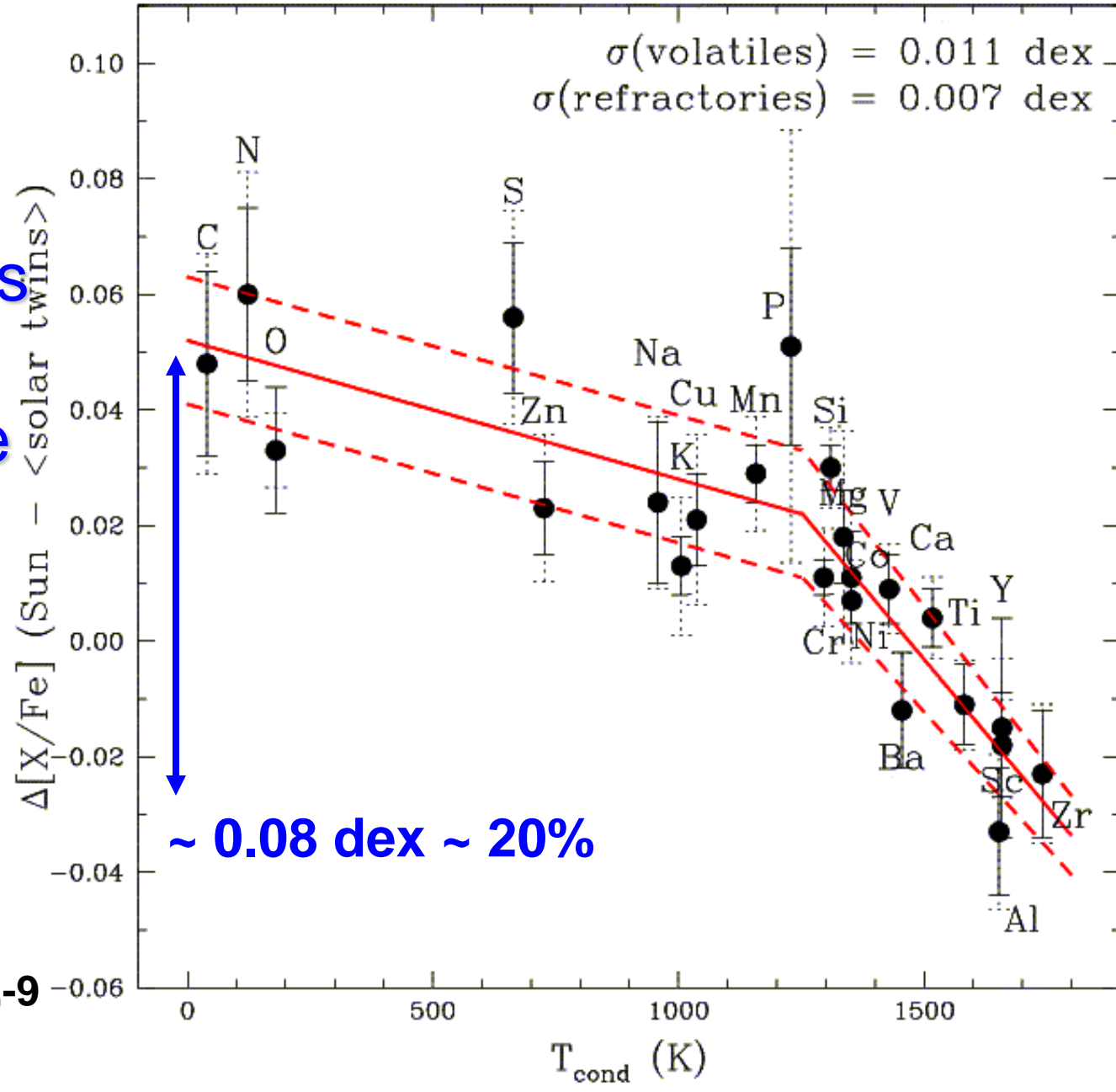
Are the anomalies in the Sun's composition related to the formation of our planetary system ?



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

Correlação é altamente significativa

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

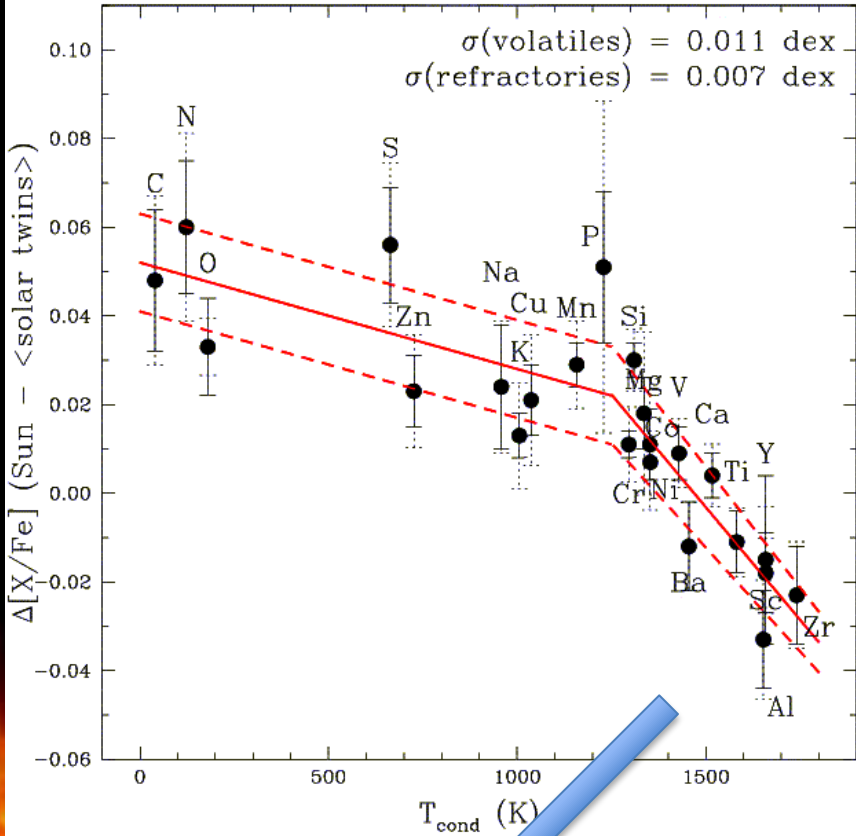




**Somente os elementos refractarios (e.g. Fe, Al, Sc) podem ter se condensado no sistema solar interno, *forming dust, planetesimals and finally rocky planets***



# As camadas externas do Sol acretaram material deficiente em refractarios



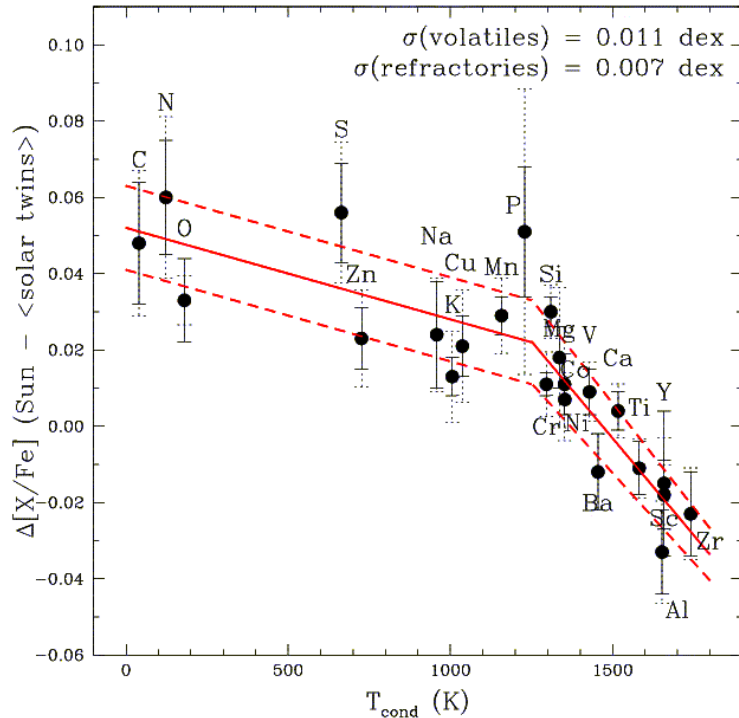
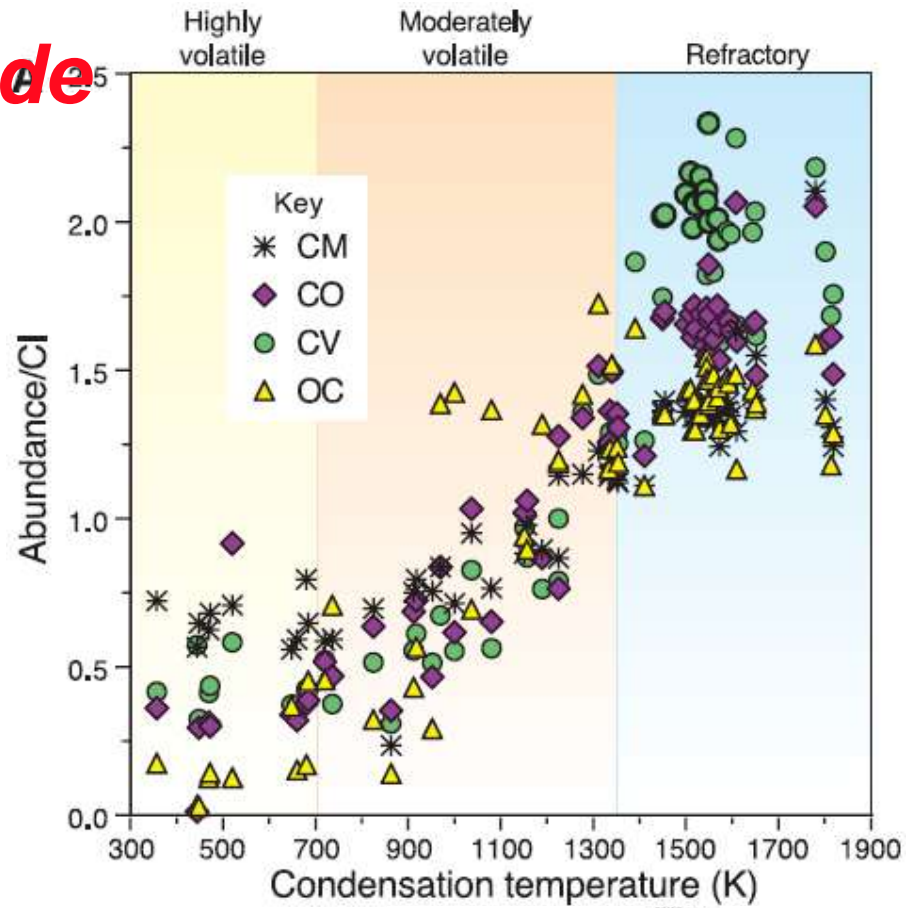
O Sol é deficiente em refratarios porque esses elementos foram usados para formar os planetas terrestres!



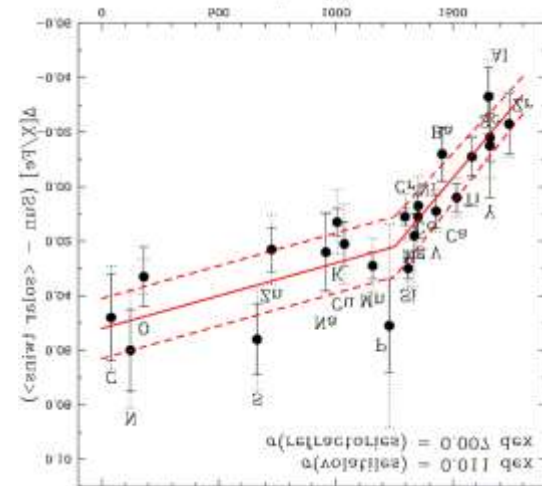
# Relação com formação de planetas terrestres: meteoritos

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

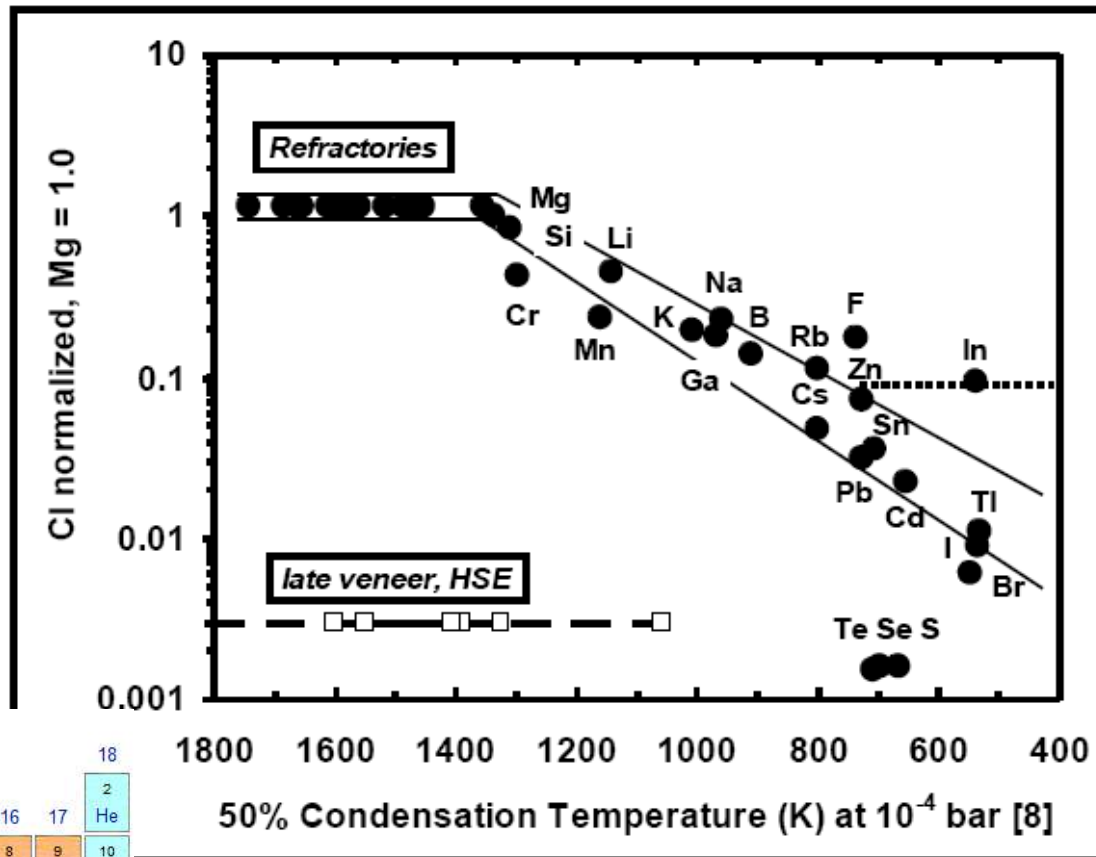
**Refractories depleted in the Sun:  $\sim 2 \cdot 10^{28} \text{ g} \approx 4 M_{\oplus}$**

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



# O manto terrestre também mostra abundâncias compatíveis com o nosso cenário

volatile elements in Earth's mantle are depleted !



Goldschmidt classification in the Periodic Table

1	2											18					
1	2											2					
3	4											10					
11	12	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
37	38	39	40	41	42	(43)	44	45	46	47	48	49	50	51	52	53	54
55	56	57-71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
87	88	89-103	(104)	(105)	(106)	(107)	(108)	(109)	(110)	(111)	(112)	(113)	(114)	(115)	(116)	(117)	(118)
Lanthanides		57	58	59	60	(61)	62	63	64	65	66	67	68	69	70	71	
Actinides		89	90	91	92	(93)	(94)	(95)	(96)	(97)	(98)	(99)	(100)	(101)	(102)	(103)	

Lithophile:  
silicate loving

Legend:

Lithophile	Siderophile	Chalcophile	Atmophile	very rare
------------	-------------	-------------	-----------	-----------

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

IOP A website from the Institute of Physics

physicsworld.com

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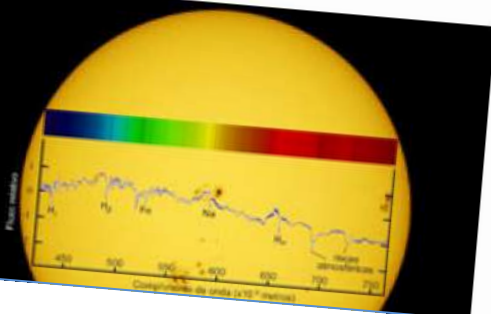
Centro de Astrofísica  
da Universidade do Porto

## Composição do Sol fornece pistas para a descoberta de outras Terras

Astronotícias

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

Subscribe

## RARE SOLAR SYSTEM, RARE SUN

Print this  Share This

12/14/2009  
by Dr. Hugh Ross

The [first discovered extrasolar planet](#) was found in 1995 in the constellation Pegasus. 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.”

# DISCOVER

Science, Technology, and The Future

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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.<sup>2</sup>  
er Jorge Meléndez, has  
<sup>3</sup> Meléndez has devoted much  
the Sun, in the sense that the  
ne existence of advanced life on  
[carried out in the last few decades.](#)



# Solar twins @ IAG/USP

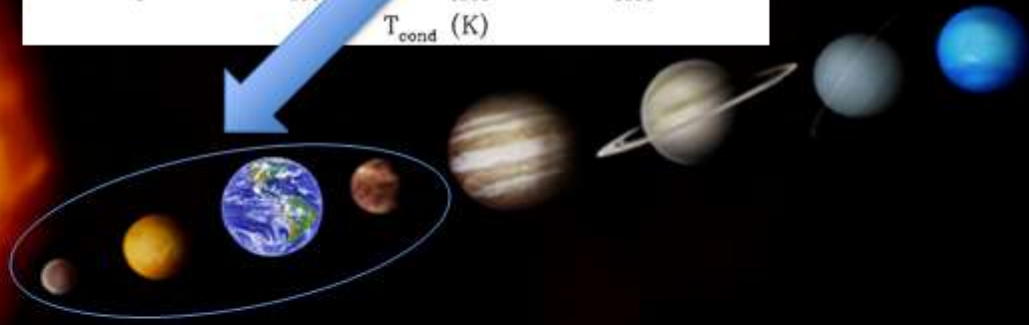
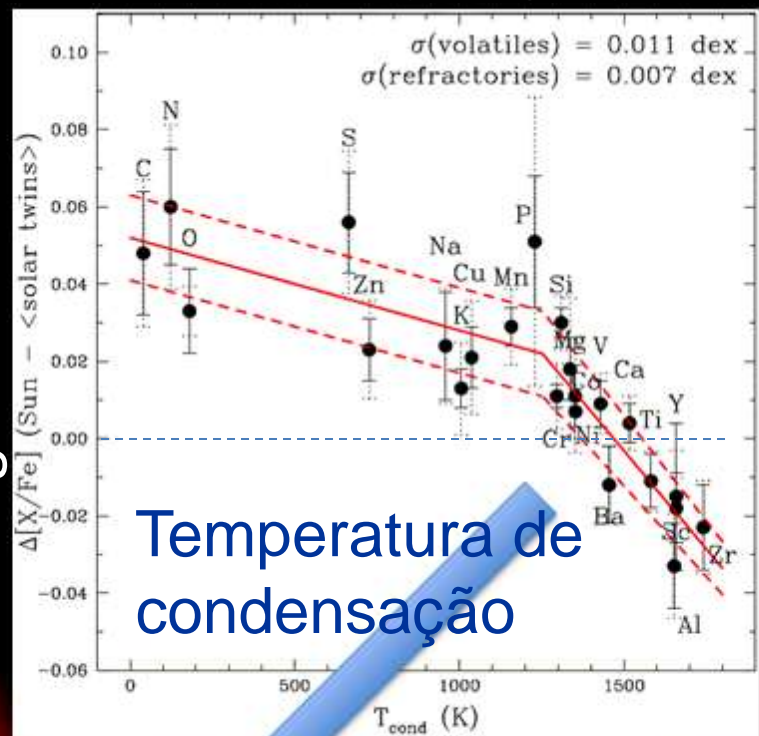
*Extremely high precision abundance analysis*

*using Keck and VLT data to study signatures of planet formation*

*Tala Monroe*

*(new postdoc @ IAG/USP)*

Sol – gêmeas solares



Planetas rochosos

Meléndez,  
Asplund,  
Gustafsson,  
Yong 2009,  
ApJ letters

# Solar twins @ IAG/USP

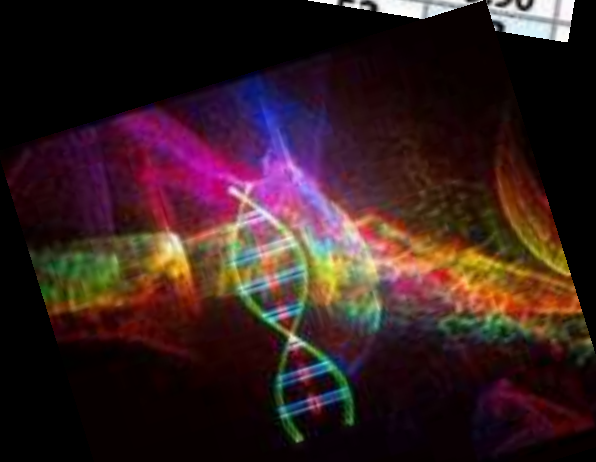
Biogenic elements :

C, O, N, P, S

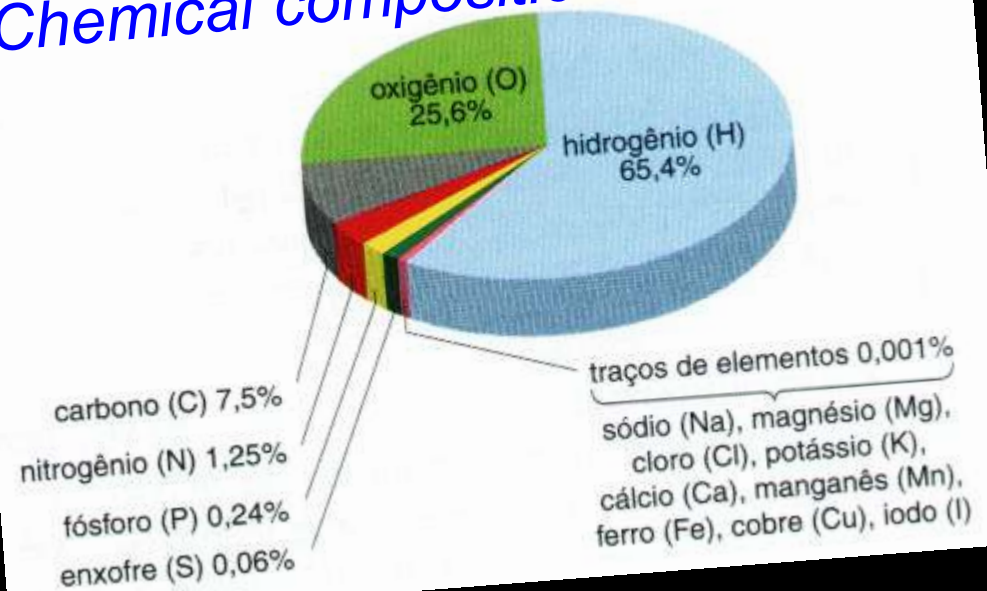
(Basic building blocks of life)

using VLT CRIFRES data

IIIA	IVA	VA	VIA	VIIA
5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00
13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45
31 Ga 69.72	32 Ge 72.61	33 As 74.92	34 Se 78.96	35 Br 79.90



## Chemical composition of humans



# Procura de planetas ao redor de gêmeas solares: 88 noites no HARPS/ESO

FOLHA.com

29 DE SETEMBRO DE 2011 - 02:34 SP  
VEJA O TEMPO EM MAIS CIDADES 14°C

NOTÍCIAS PODER MUNDO MERCADO COTIDIANO ESPORTE ILUSTRADA F5 CIÊNCIA TEC FOLHA D

AMBIENTE BICHOS BLOGS CELEBRIDADES COLUNISTAS COMIDA EQUILÍBRIO E SAÚDE FOLHATEEN FOLHINHA

HORÓSCOPO TRÂNSITO FOLHAINVEST INDICADORES GUIA E-MAIL FOLHA ASSINANTES ERRAMOS TV F

EM CIMA DA HORA PUBLICIDADE: Bluetec5. Conheça a nova tecnologia Mercedes-Benz para motores de ônibus

ciência

AA Maior | Menor Enviar por e-mail Comunicar erros Link <http://folha.com/no95E>

15/08/2011 - 09h02

## Brasil participará de monitoramento de planetas 'gêmeos' da Terra

SALVADOR NOGUEIRA  
COLABORAÇÃO PARA A FOLHA

Recomendar 114 +1 5

Atualizado às 14h15.

Um grupo liderado por um astrônomo do Brasil pode desvendar o que leva certas estrelas, como o Sol, a abrigar planetas como o nosso, rochosos e pequenos. De quebra, trata-se da primeira grande investida brasileira na busca por mundos extrassolares com telescópios em solo.

Help  
most  
welcome

O estudo se viabilizou graças ao acesso recém-obtido pelo Brasil às instalações do ESO (Observatório Europeu do Sul). O governo assinou no fim do ano passado o acordo que torna o país o mais novo membro do consórcio. Embora o acerto ainda careça de aprovação do Congresso para entrar em vigor, o ESO já trata o Brasil como parceiro, concedendo o direito de solicitar tempo de observação nos telescópios da organização.

Foi por conta disso que a equipe de **Jorge Meléndez**, peruano que trabalha no IAG (Instituto de Astronomia, Geofísica e Ciências Atmosféricas) da USP, conseguiu aprovação num projeto que pode finalmente revelar alguns dos segredos mais bem guardados sobre os exoplanetas.

# CONCLUSIONS

Very exciting research @ IAG/USP related to the chemical composition of stars:

- Big Bang nucleosynthesis
- Galaxy formation and evolution
- Stellar evolution
- Planet formation
- Uniqueness of our Sun and our solar system
- *Others: M dwarfs, isotopic ratios, stellar clusters, molecular spectroscopy, giant stars with planets, stellar parameters, interstellar extinction, archaeoastronomy...*