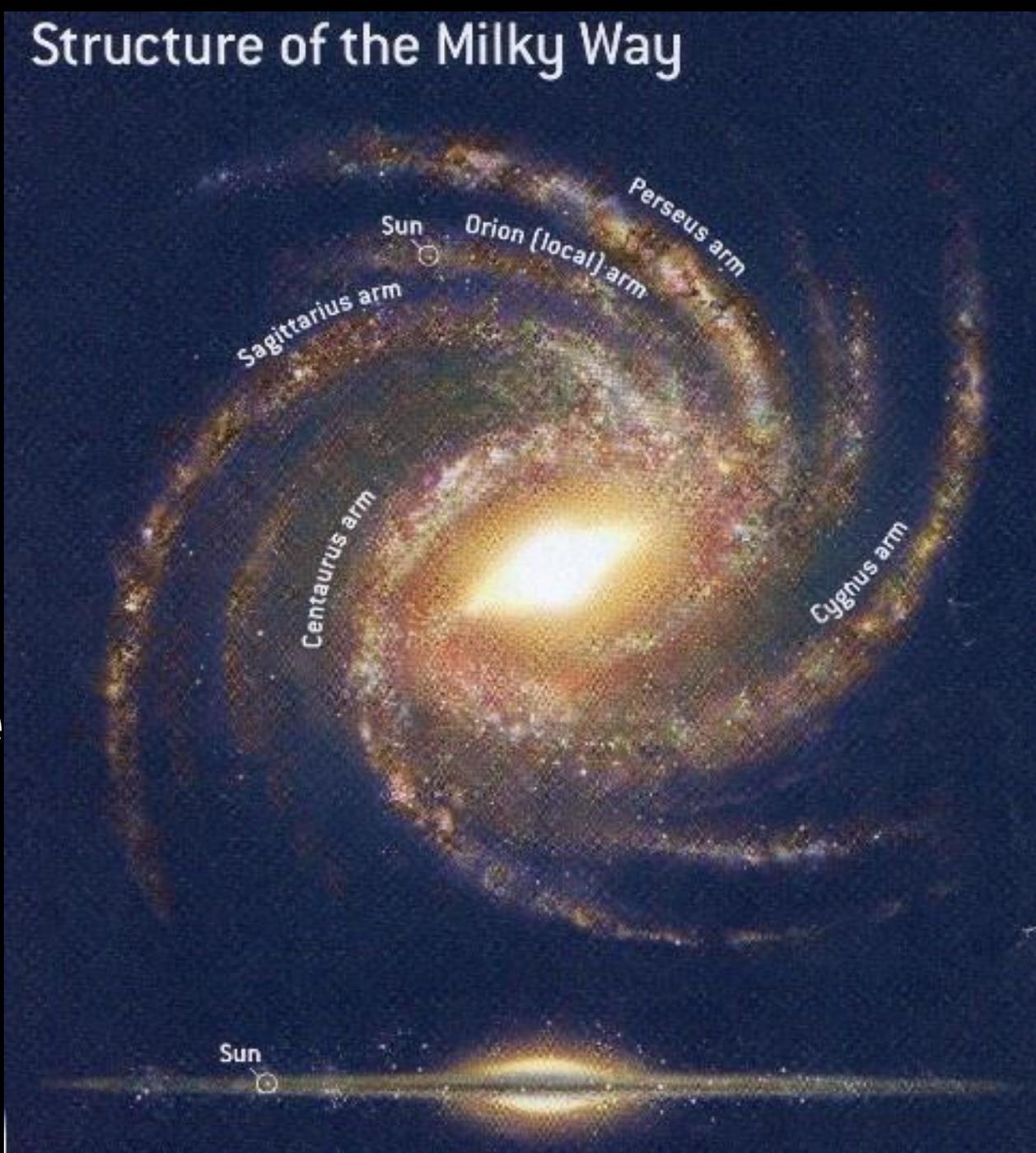




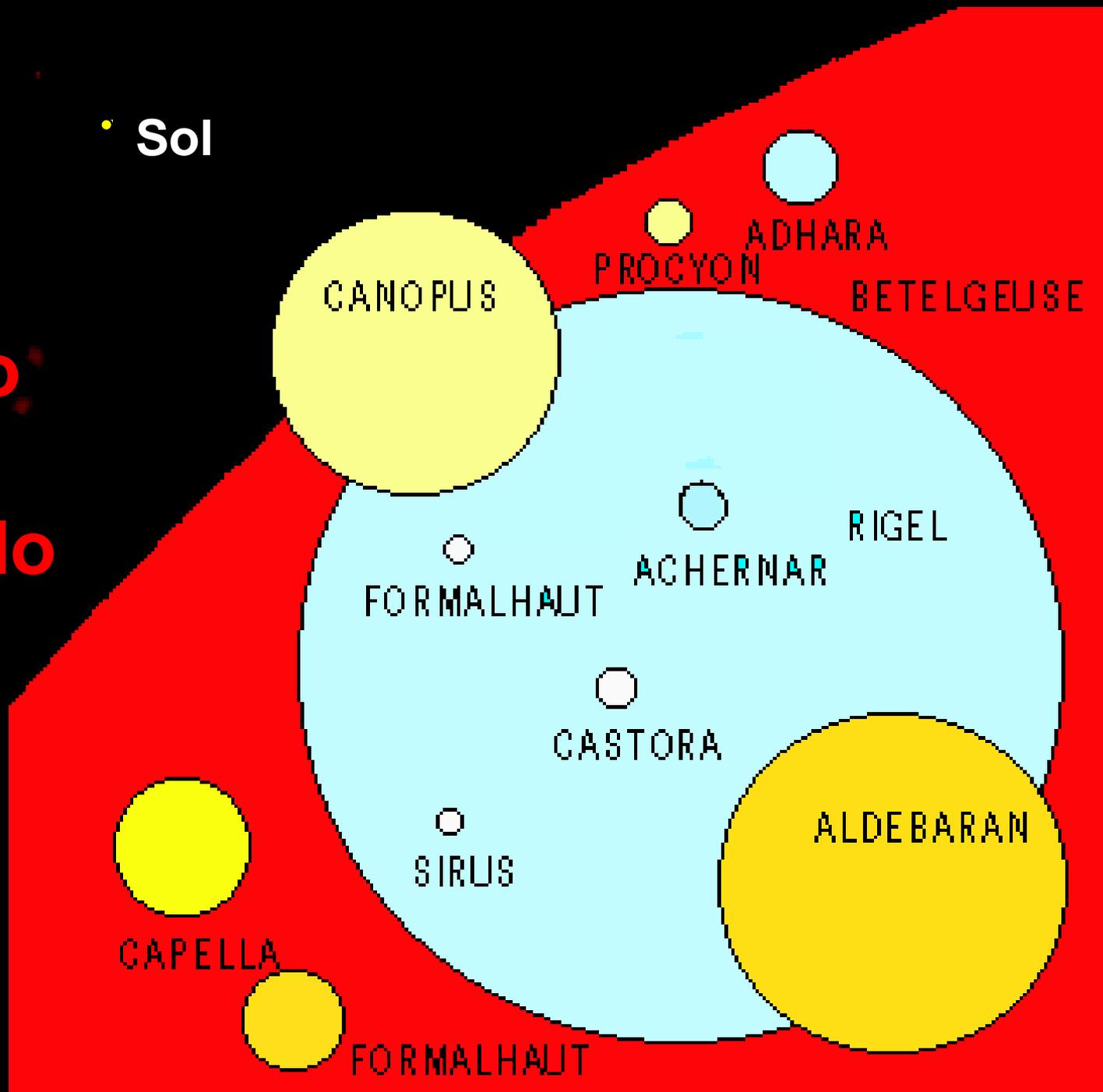
**Jorge Meléndez, baseado nas
aulas do Prof. R. Boczko**

O Sol é apenas uma entre ~ 300 mil milhões de estrelas

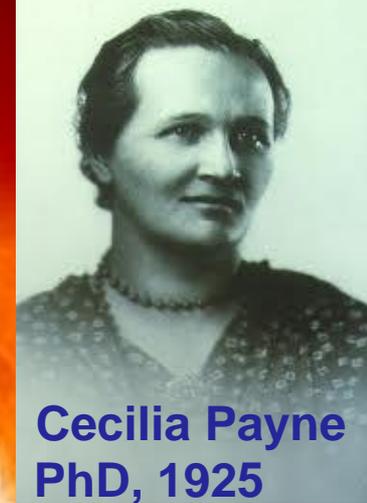
Structure of the Milky Way



Tamanho do Sol comparado a outras estrelas



Sol



Elemento	Abundância do elemento	
	Por número de átomos	Por massa total
H	91,2 %	71,0 %
He	8,7	27,1
O, C, N, Si, Mn, Ne, Fe, S etc.	0,1	1,9

Sol

Massa

$1,9891 \times 10^{27}$ ton
(330 000 Terra)

Luminosidade

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



Visão da
fotosfera

Distância
(sem escala)

Terra •
(em escala)

Raio

696 mil km
(109 Terra)

Observação
na região
visível do
espectro

Mudanças na superfície do Sol



2000.10.09 13:12:11

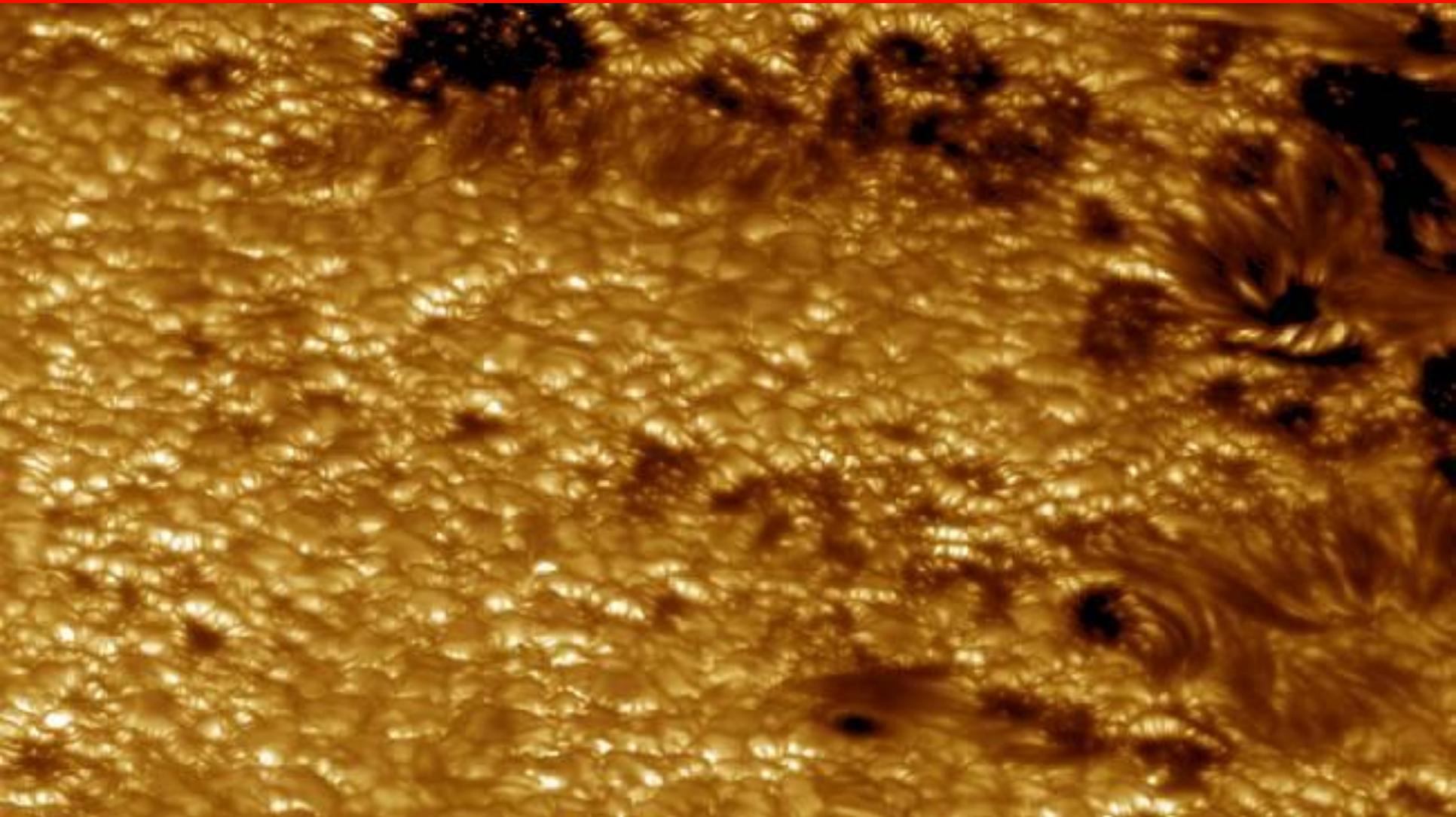


Solar Max

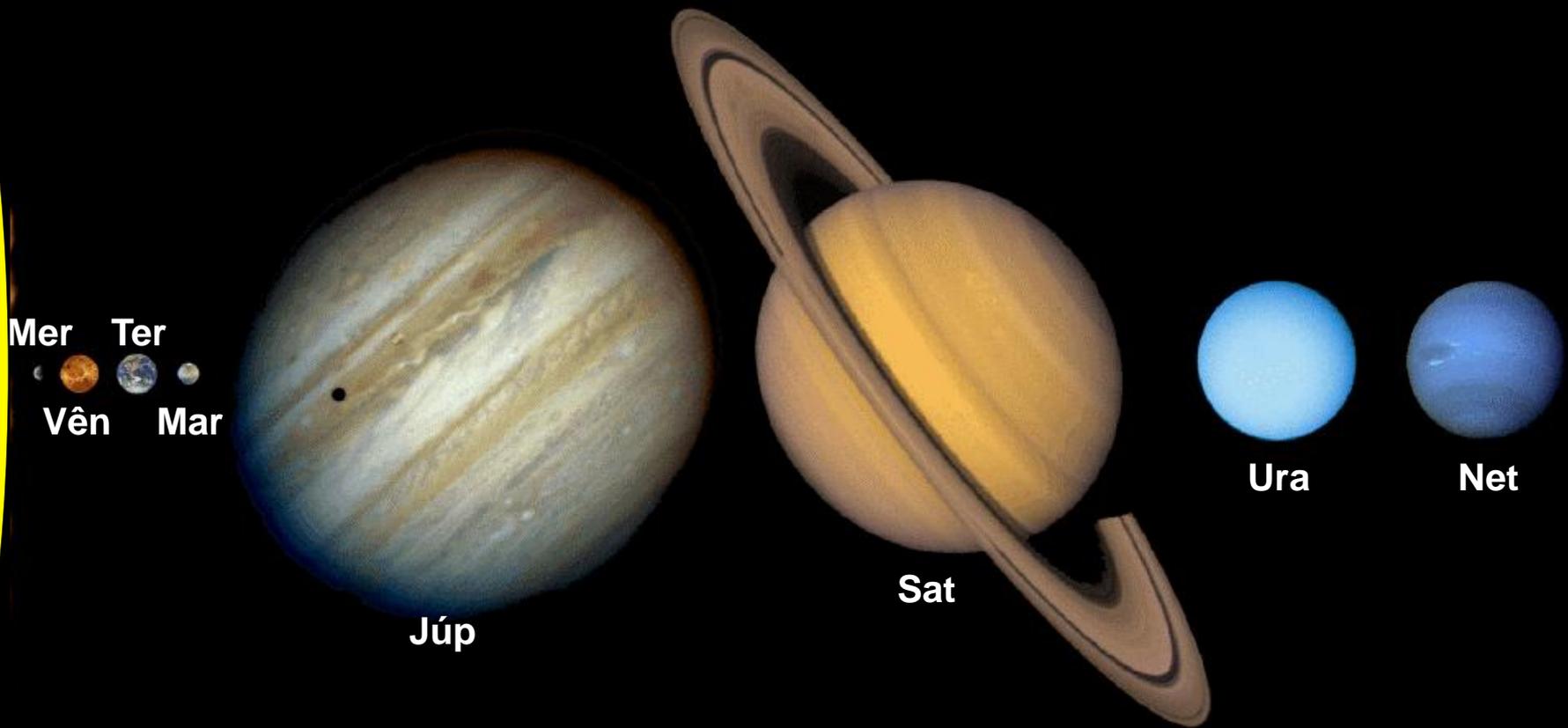
Solar Min



Superfície do Sol



Sol e Planetas



Raio Solar = 109 Raios Terrestres

Evolução do Universo e do Sol

Big-Bang



Formação do Sol



Sol Atual



Pré-seqüência principal

... e a vida do Sol!

Estágios finais

Proto Sol



T Tauri

Seqüência principal



Gigante vermelha

Anã Branca



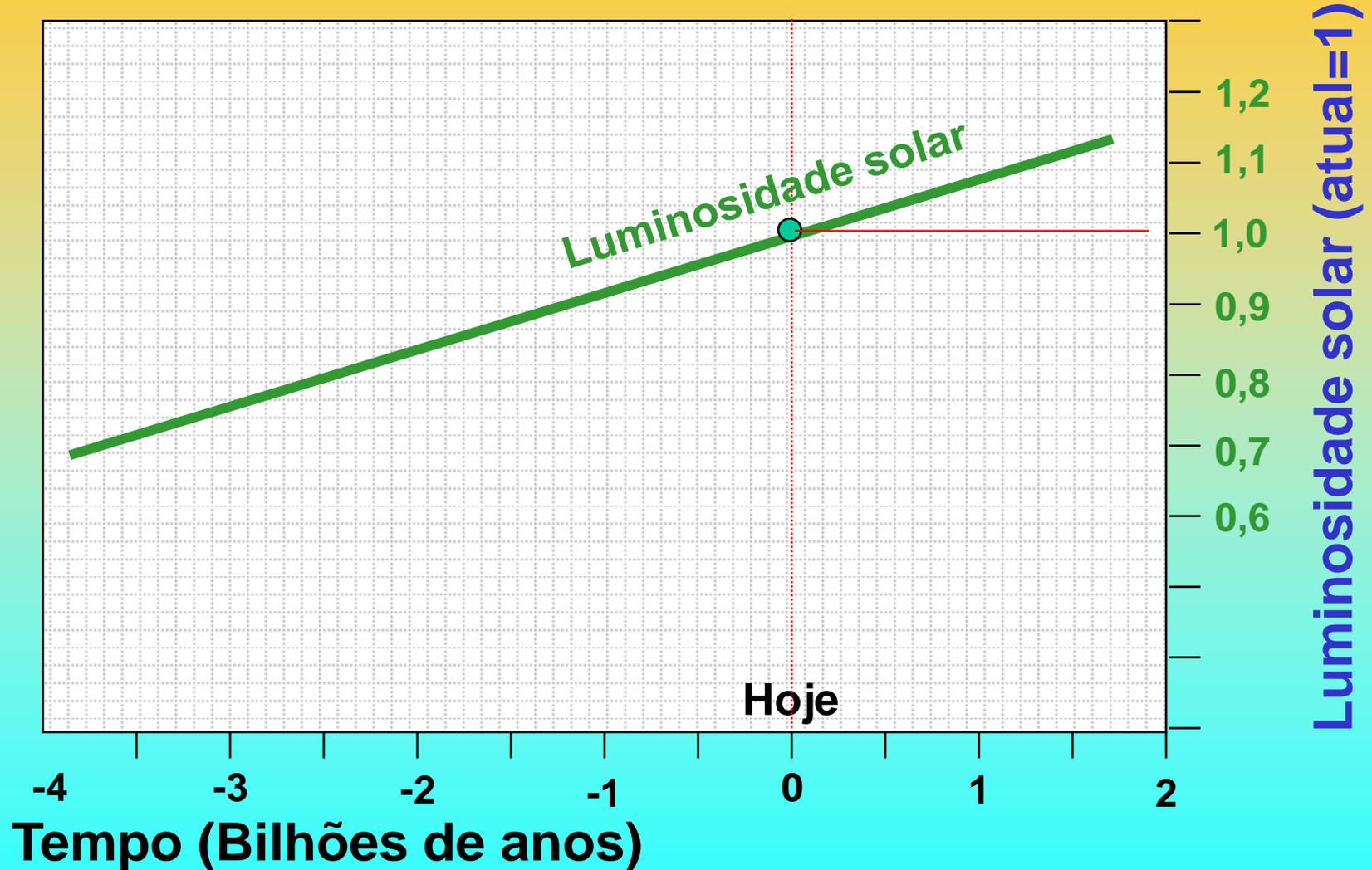
Nasceu o Sol!

Massa escura

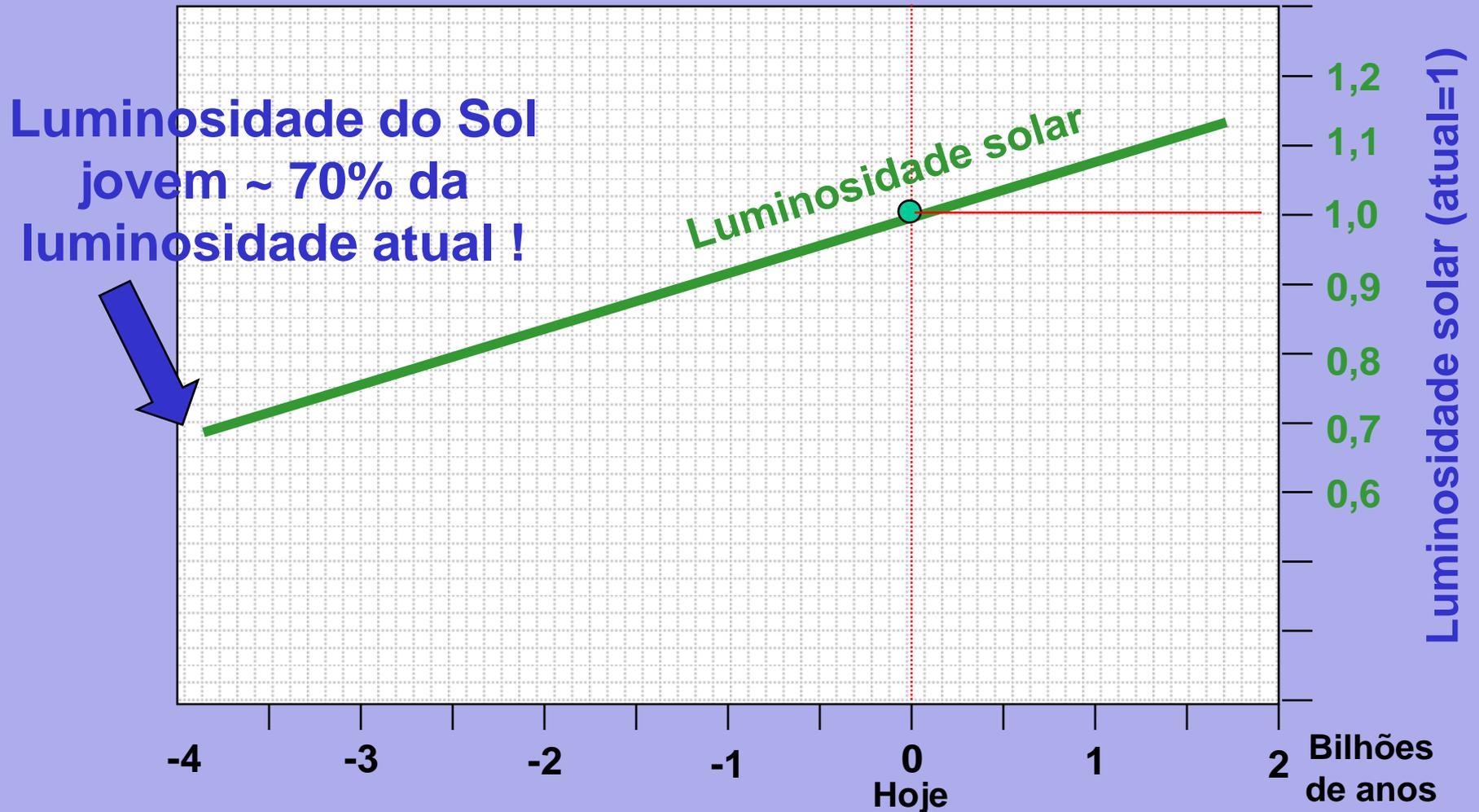
A Luminosidade do Sol é constante ou variável ?



Variação da Luminosidade vinda do Sol



Variação da Luminosidade vinda do Sol



Faint young Sun paradox

Paradoxo do jovem Sol fraco

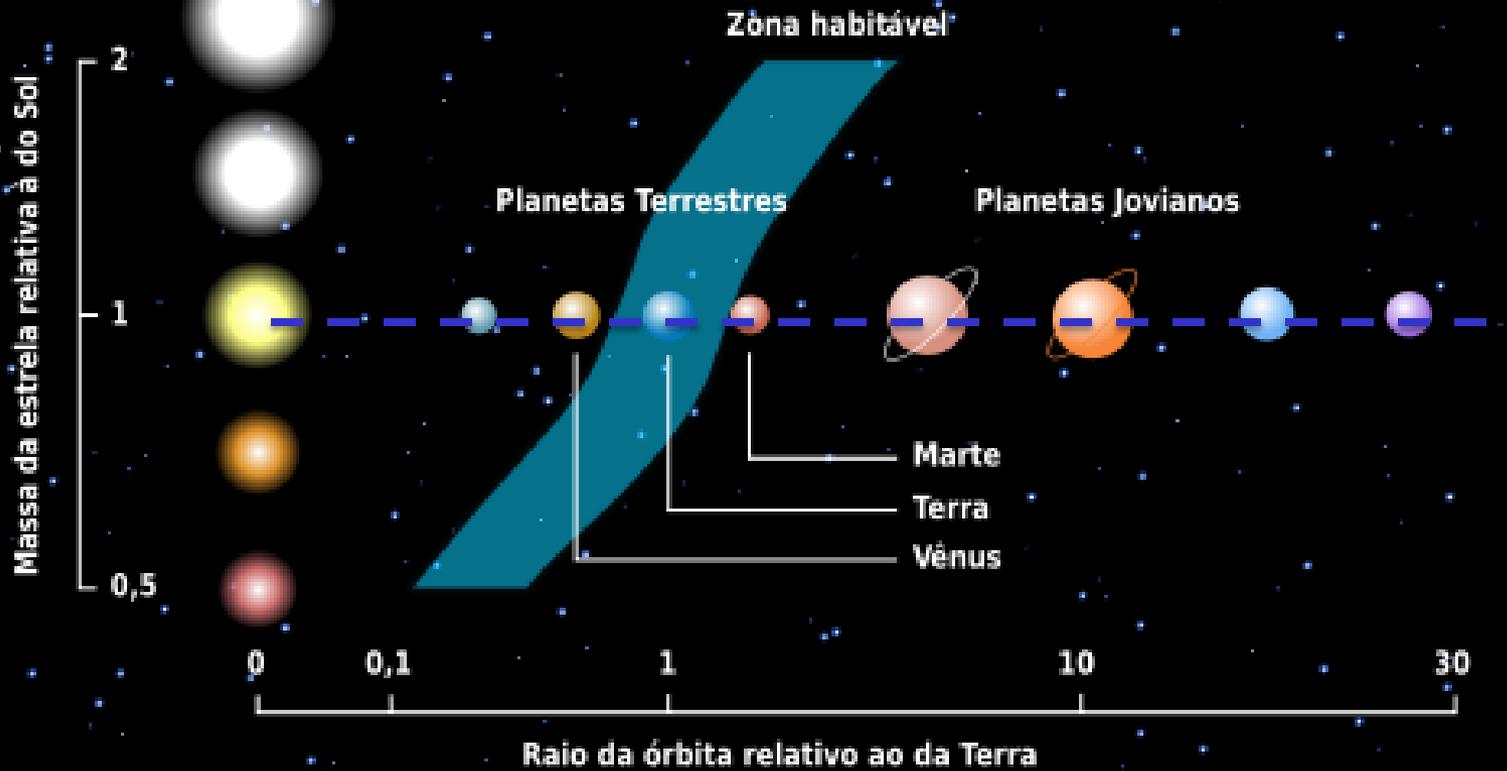
O problema do jovem Sol fraco é a contradição aparente entre observações de água líquida no início da história da Terra, e a predição astrofísica de que o brilho do Sol na época era de apenas 70% em relação ao presente, insuficiente para manter água no estado líquido



SNOWBALL: Terra nos seus primórdios?

Zona habitável em sistemas planetários: região onde pode existir água líquida

Massa da estrela (M Sol)



Distância ao Sol (U.A.)



Influencia de evolução do Sol na vida na Terra

temos ainda 500 milhões de anos)

The life span of the biosphere revisited

Ken Caldeira & James F. Kasting

Earth System Science Center & Department of Geosciences,
The Pennsylvania State University, University Park,
Pennsylvania 16802, USA

A DECADE ago, Lovelock and Whitfield¹ raised the question of how much longer the biosphere can survive on Earth. They pointed out that, despite the current fossil-fuel induced increase in the atmospheric CO₂ concentration, the long-term trend should be in the opposite direction: as increased solar luminosity warms the Earth, silicate rocks should weather more readily, causing atmospheric CO₂ to decrease. In their model¹, atmospheric CO₂ falls below the critical level for C3 photosynthesis, 150 parts per million (p.p.m.), in only 100 Myr, and this is assumed to mark the demise of the biosphere as a whole. Here, we re-examine this problem using a more elaborate model that includes a more accurate treatment of the greenhouse effect of CO₂ (refs 2–4), a biologically mediated weathering parameterization, and the realization that

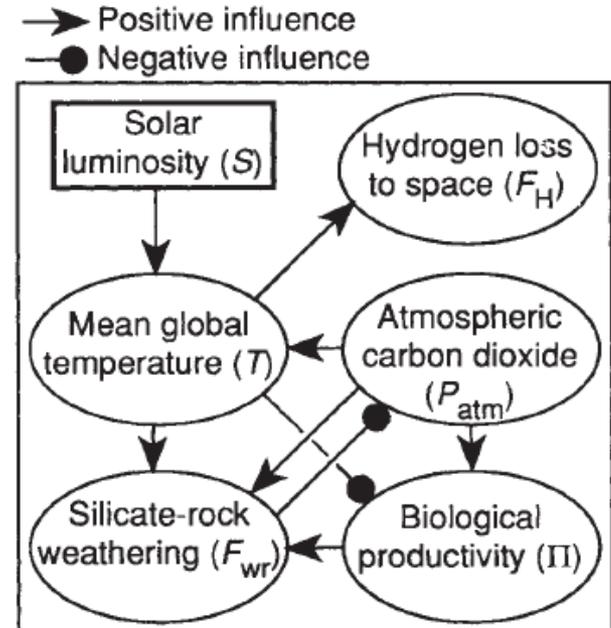
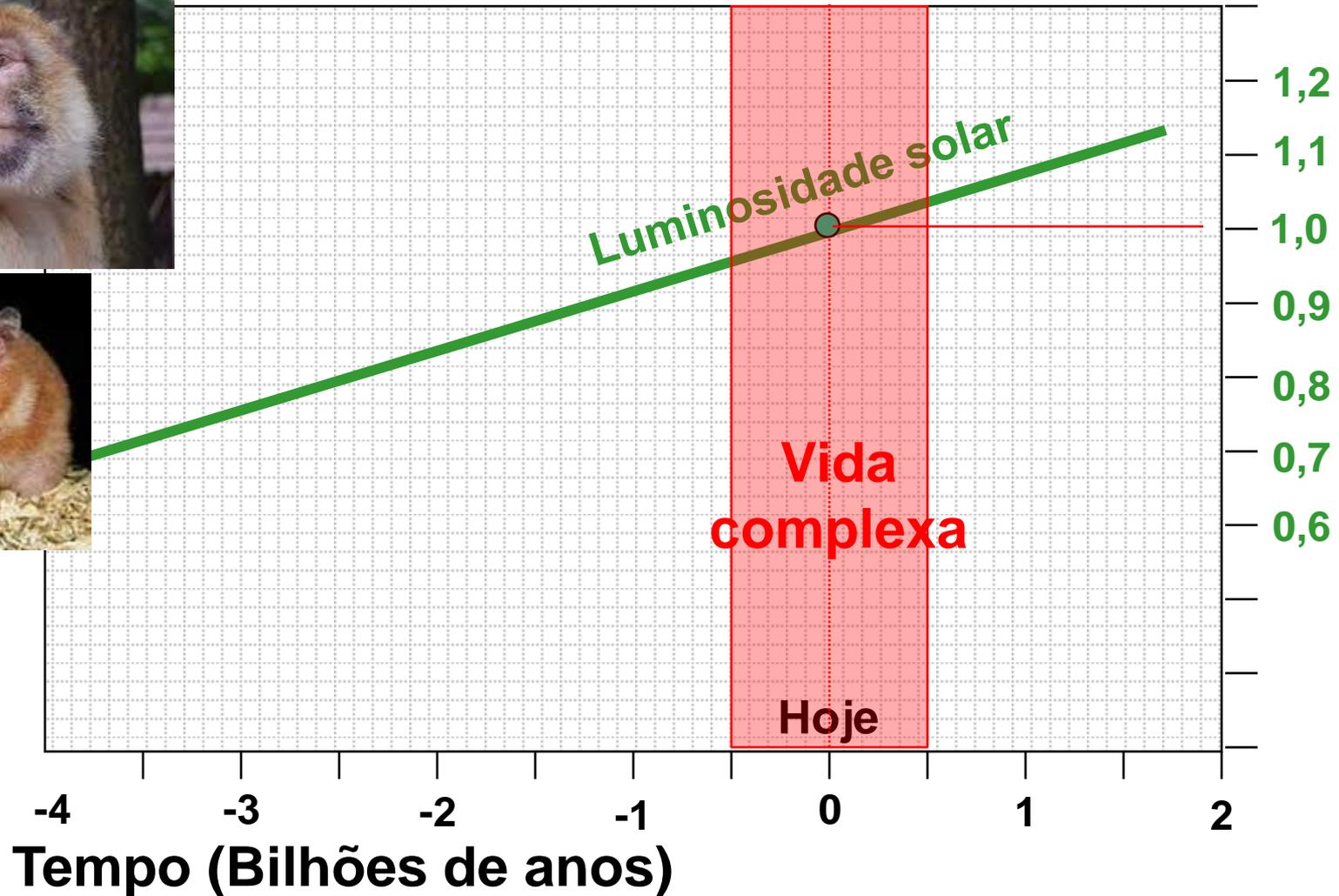


FIG. 1 Diagram illustrating the positive and negative influences represented in our model. System behaviour may be understood by examining the response to an increase in solar luminosity (S). Increasing S warms the Earth, increasing T . This enhances both the weatherability of silicate rocks (F_{wr}) and the rate of hydrogen escape to space (F_H). At temperatures approaching 50 °C, temperature increases have a negative influence on biological productivity (II). Enhanced silicate-rock weatherability draws down the atmospheric CO₂ concentration (P_{atm}). The lower CO₂ concentration tends to buffer T and F_{wr} and to reduce II . Eventually, either lack of CO₂, high temperatures, or the loss of water will limit the life span of the biosphere.

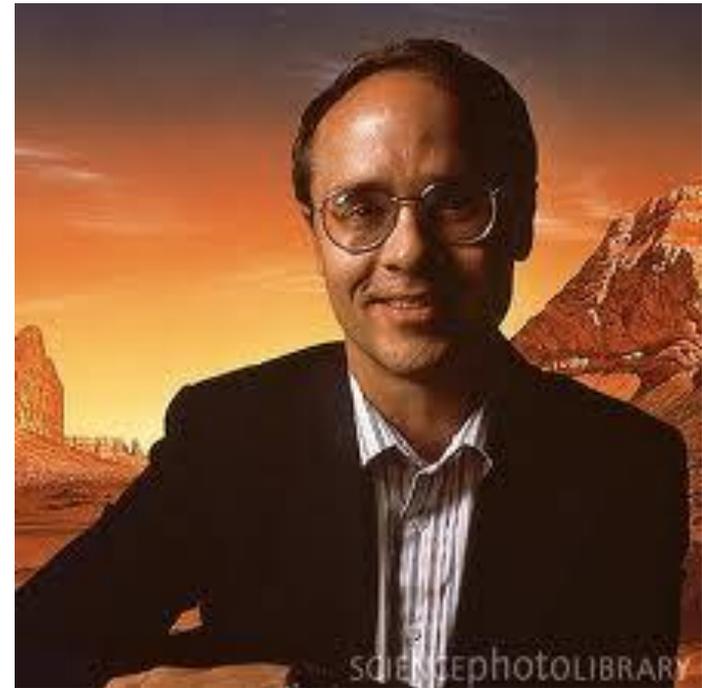
Variação da Luminosidade vinda do Sol



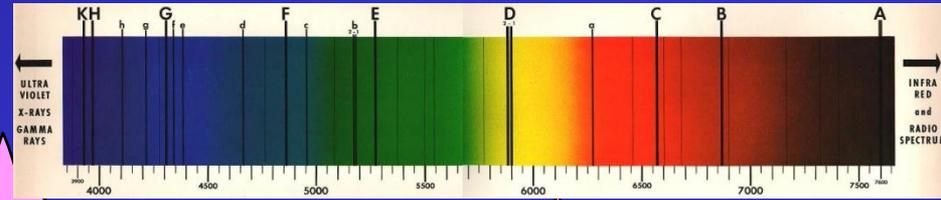
Luminosidade solar (atual=1)

Prof. James Kasting (1953 - ...)

Pioneiro no estudo de habitabilidade planetária



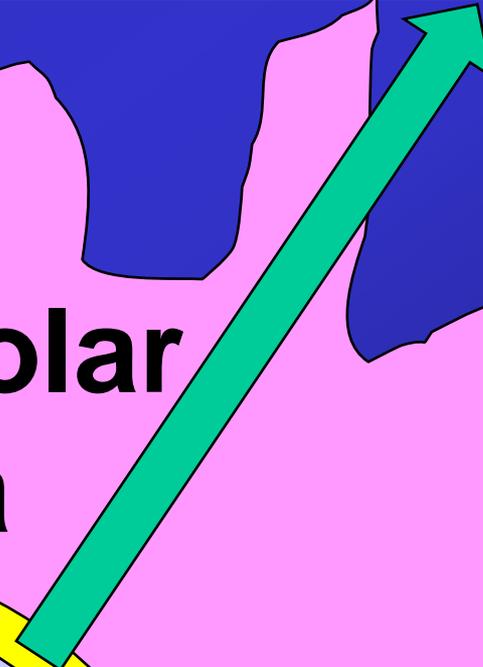
Estrutura básica do Sol



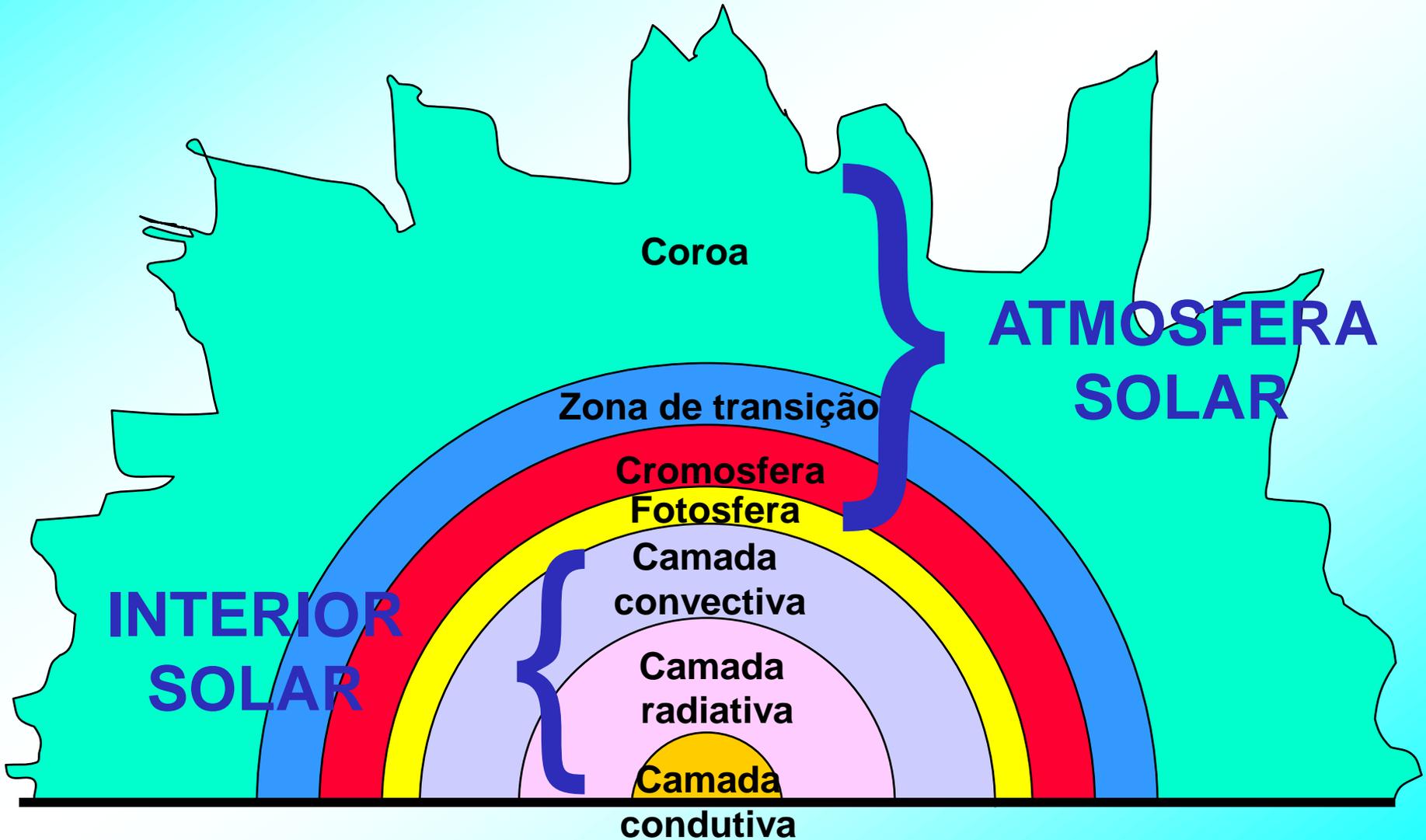
**Atmosfera solar
extendida**

Atmosfera solar: Fotosfera

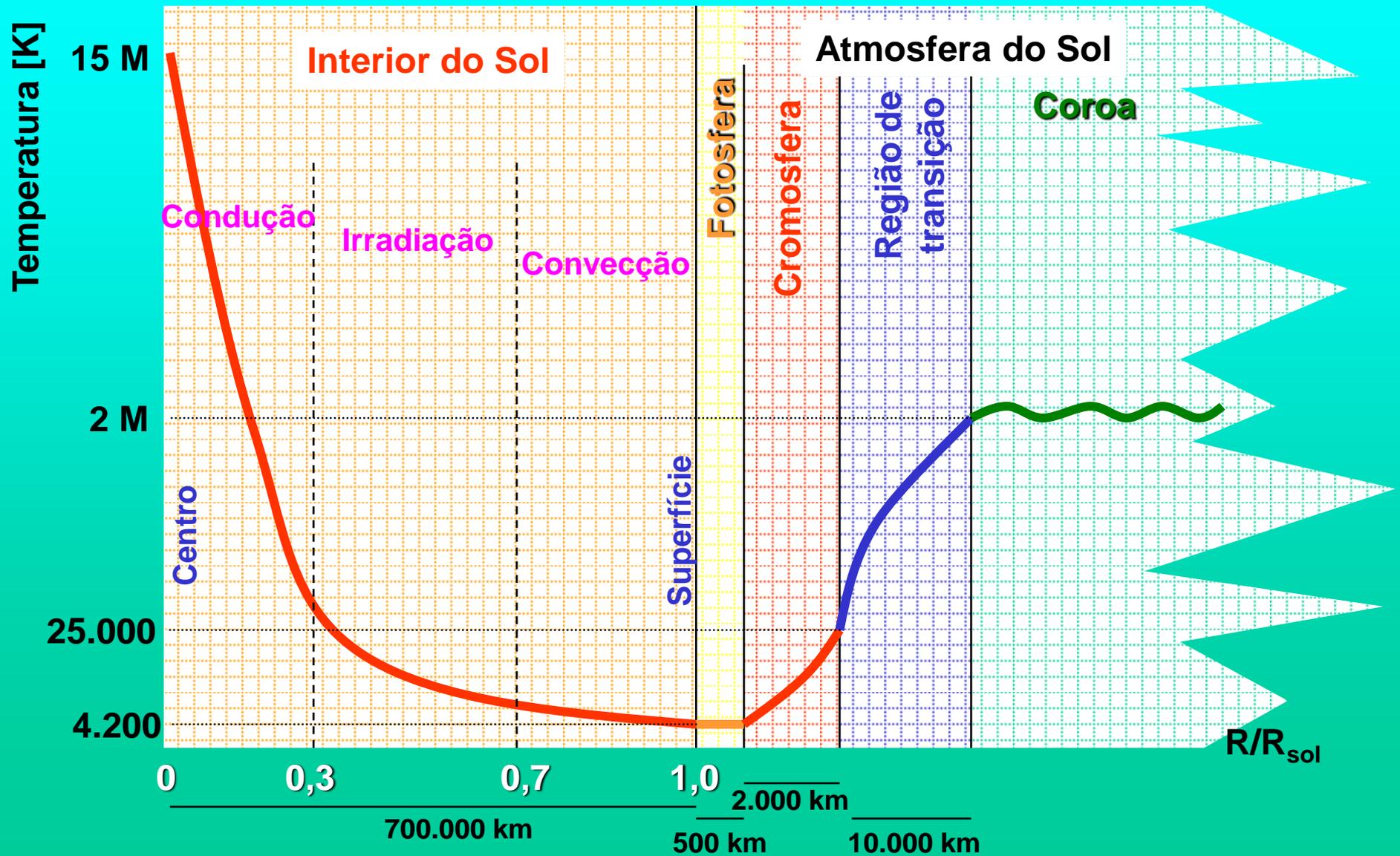
**Interior
Solar**



Estrutura mais fina do Sol



Temperatura nas camadas do Sol



Densidade das camadas do Sol

Densidades [g/cm³]

Atmosfera

da Terra 0,001

Água 1

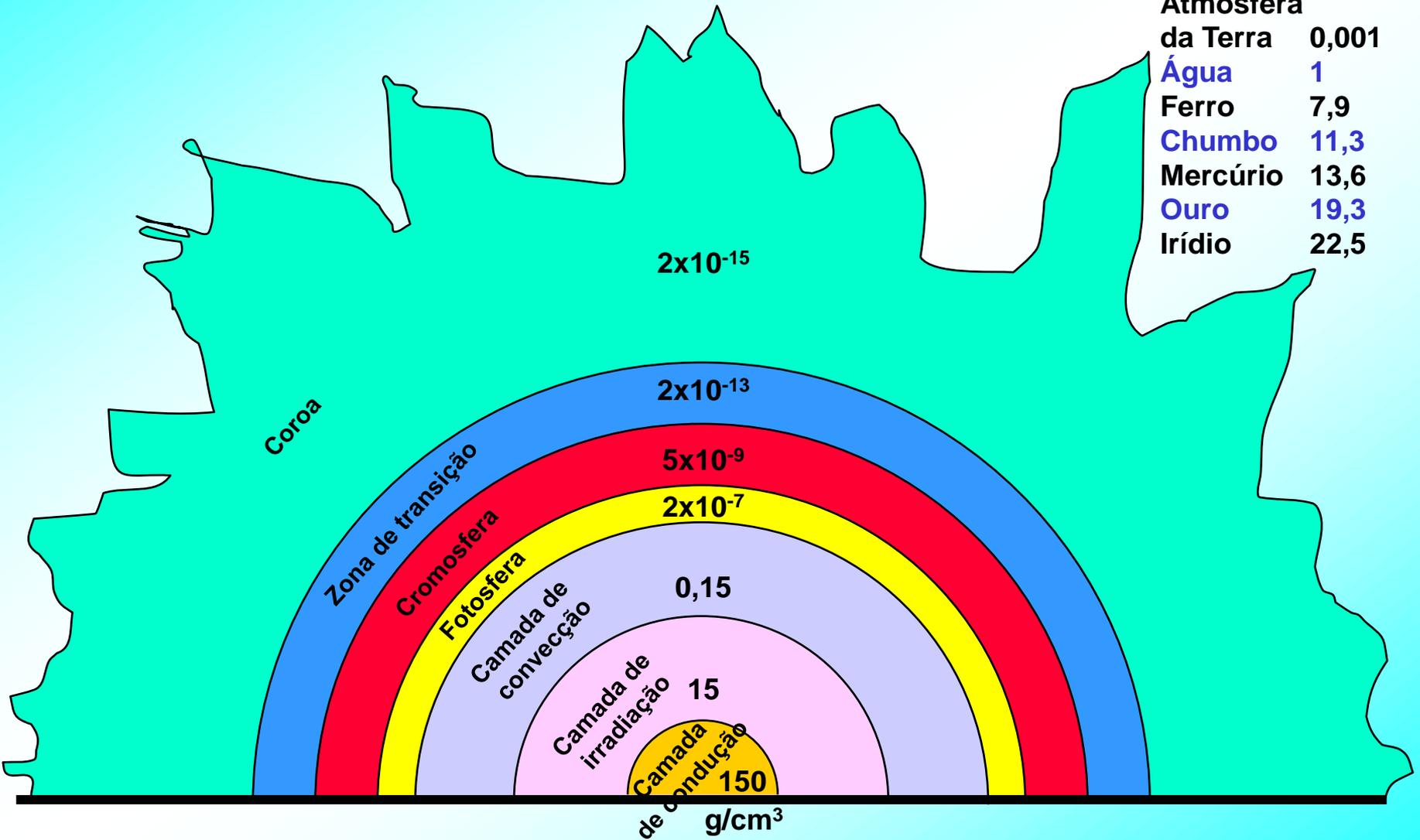
Ferro 7,9

Chumbo 11,3

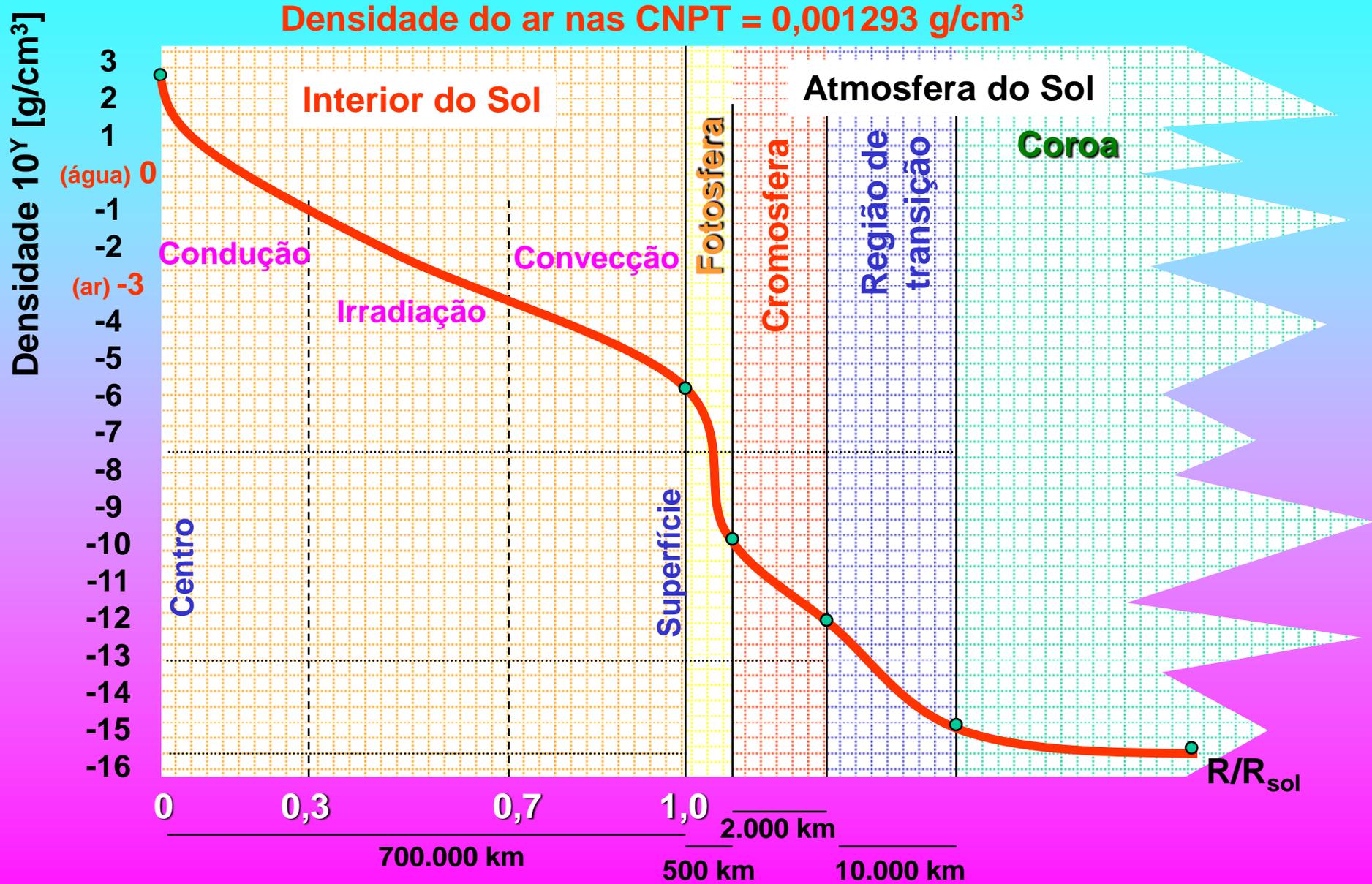
Mercúrio 13,6

Ouro 19,3

Írídio 22,5

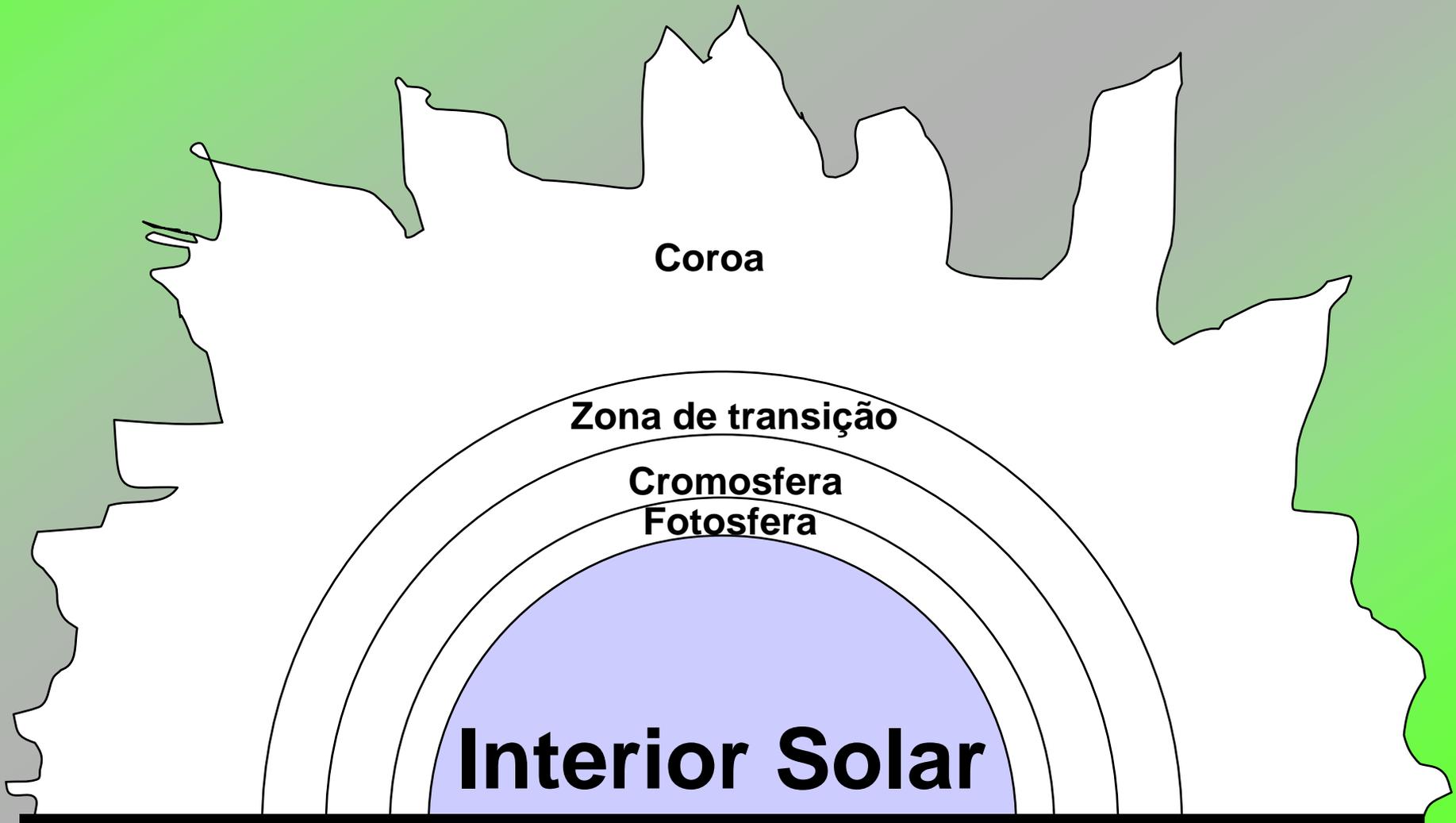


Densidade nas camadas do Sol



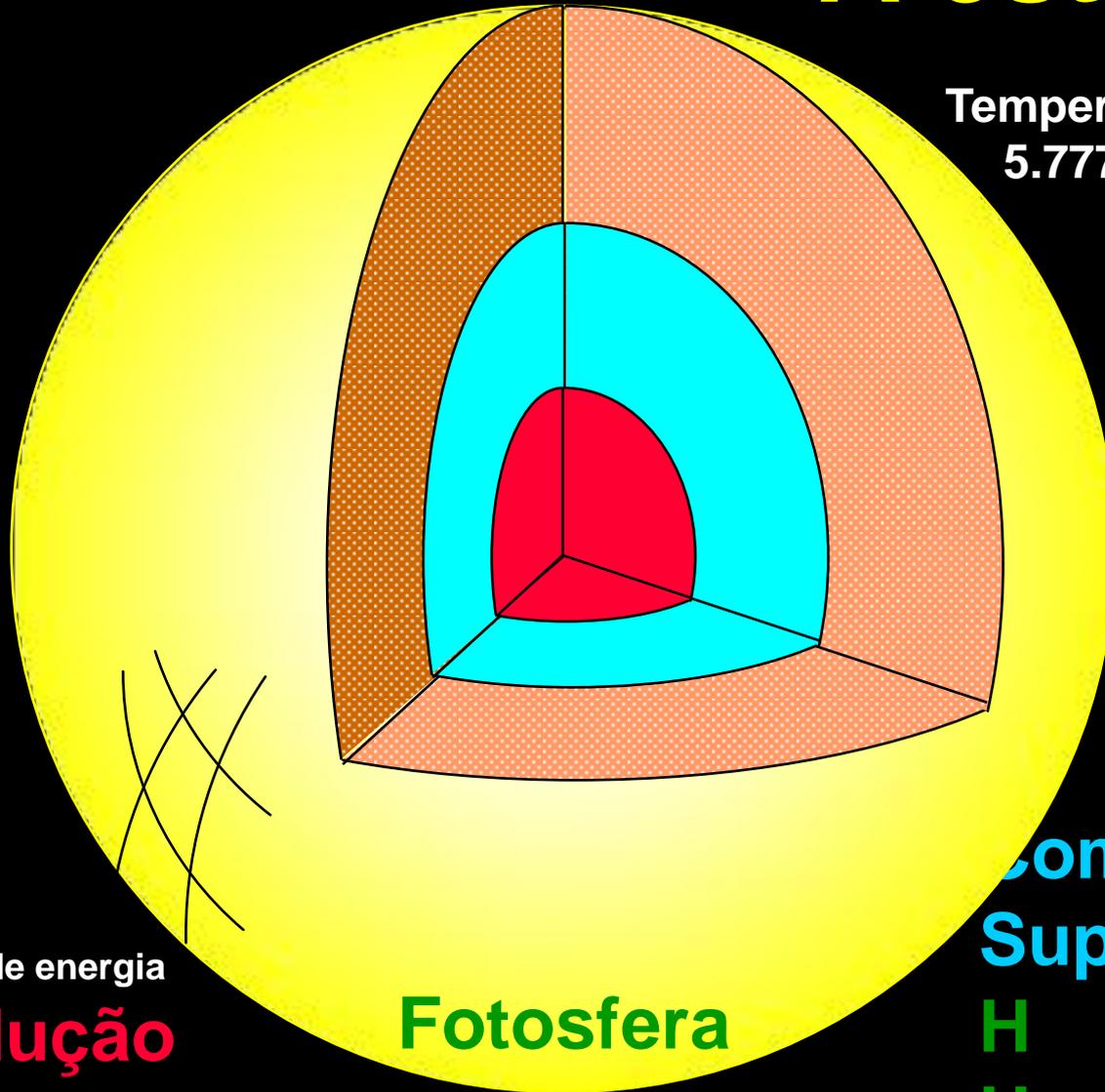
Interior do Sol

Interior do Sol



A estrela Sol

Temperatura
5.777 K



Transporte de energia

- **Condução**
- **Radiação**
- **Convecção**

Fotosfera

Composição Superficial (massa)

H	= 73,0%
He	= 24,5%
Outros	= 2,5%

Propagação do calor

(transferência de energia devido à diferença de temperatura)

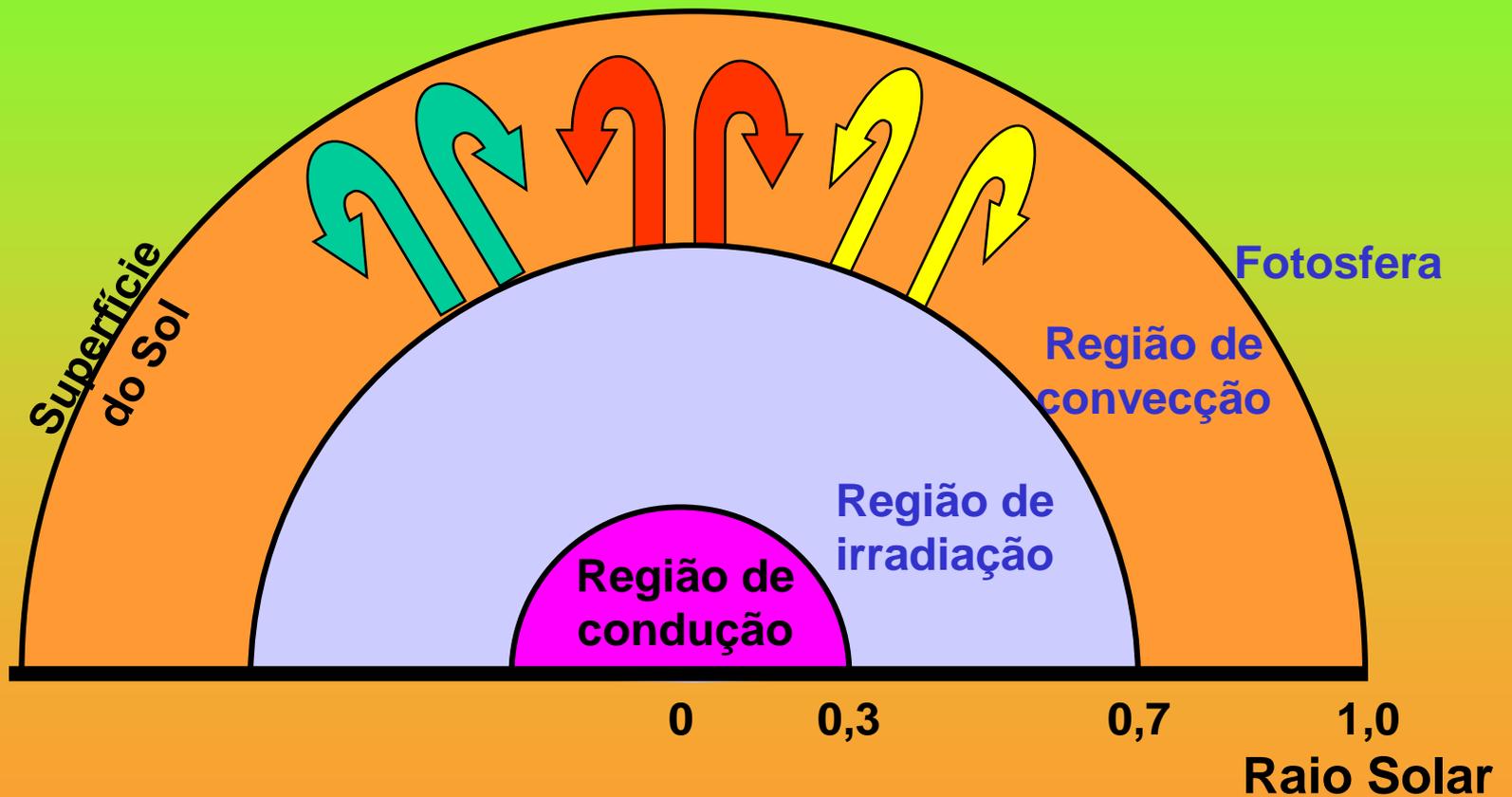
Convecção: movimento de material duma região para outra



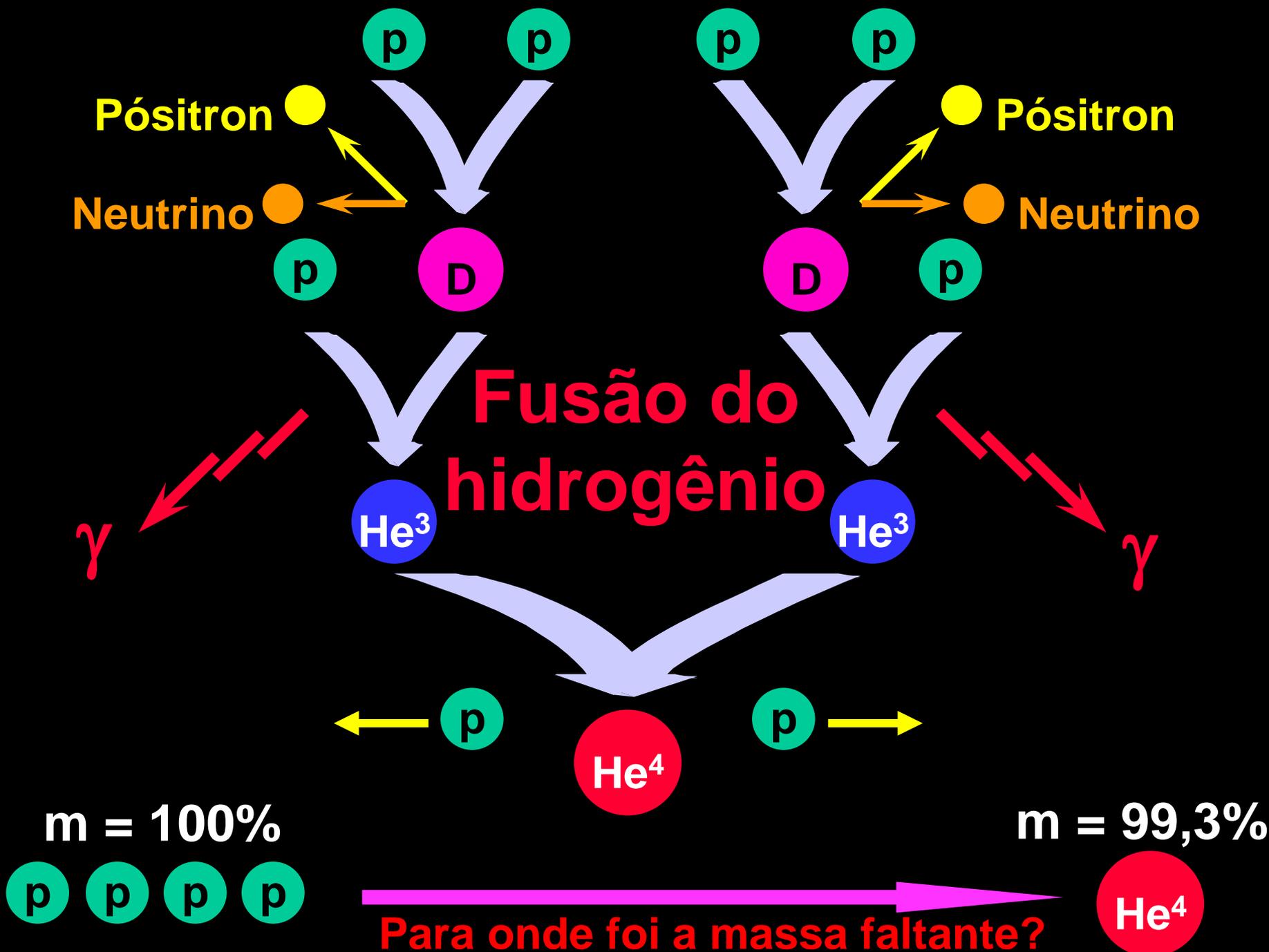
Condução:
Contato direto

Radiação:
Ondas
electromagnéticas

Camadas do interior do sol

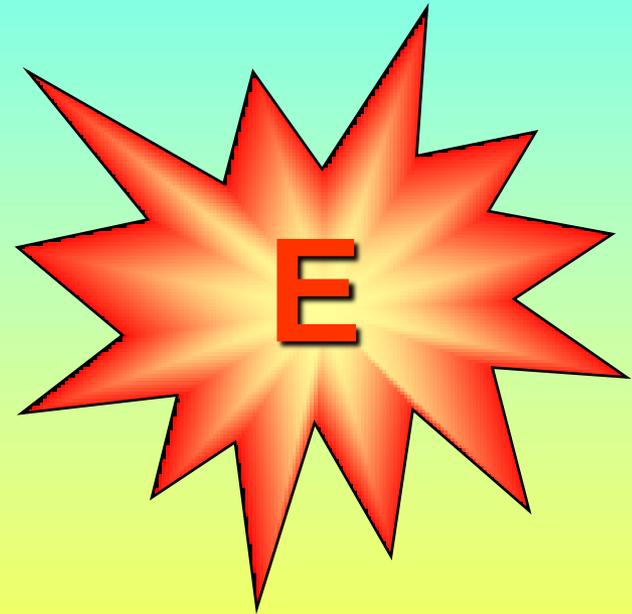
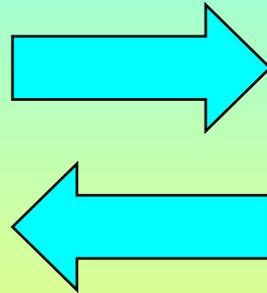


Reações de nucleossíntese solar



Relação entre massa e energia

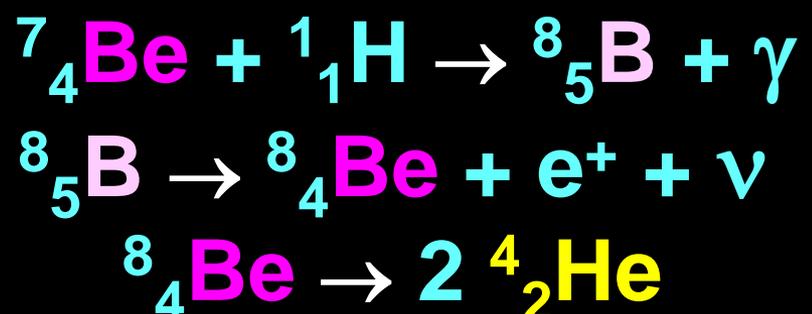
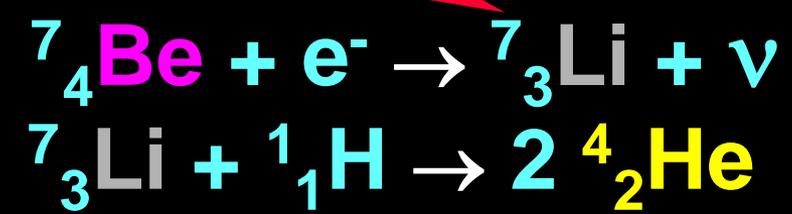
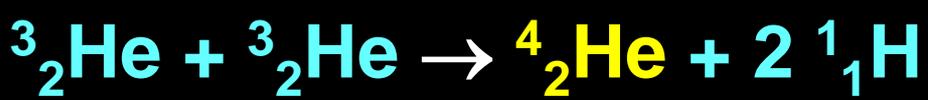
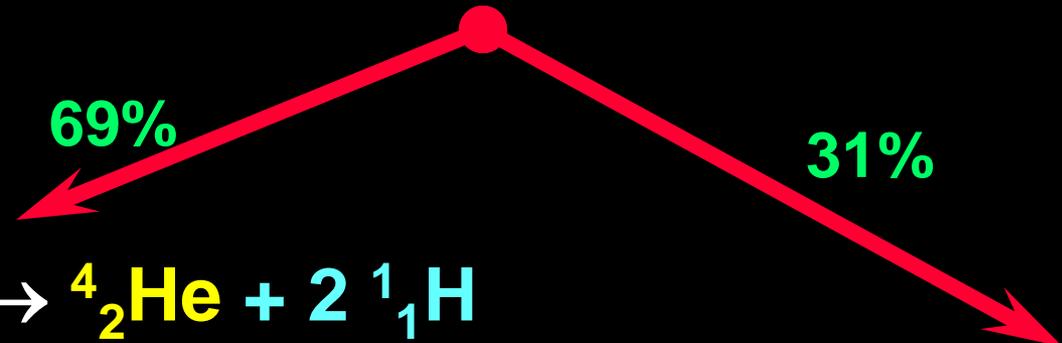
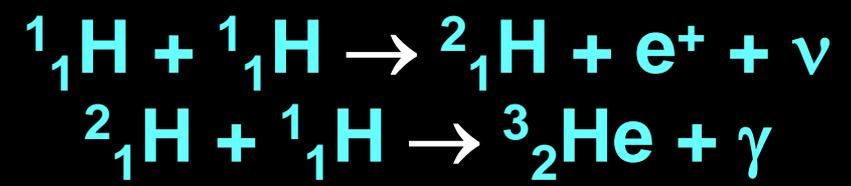
m



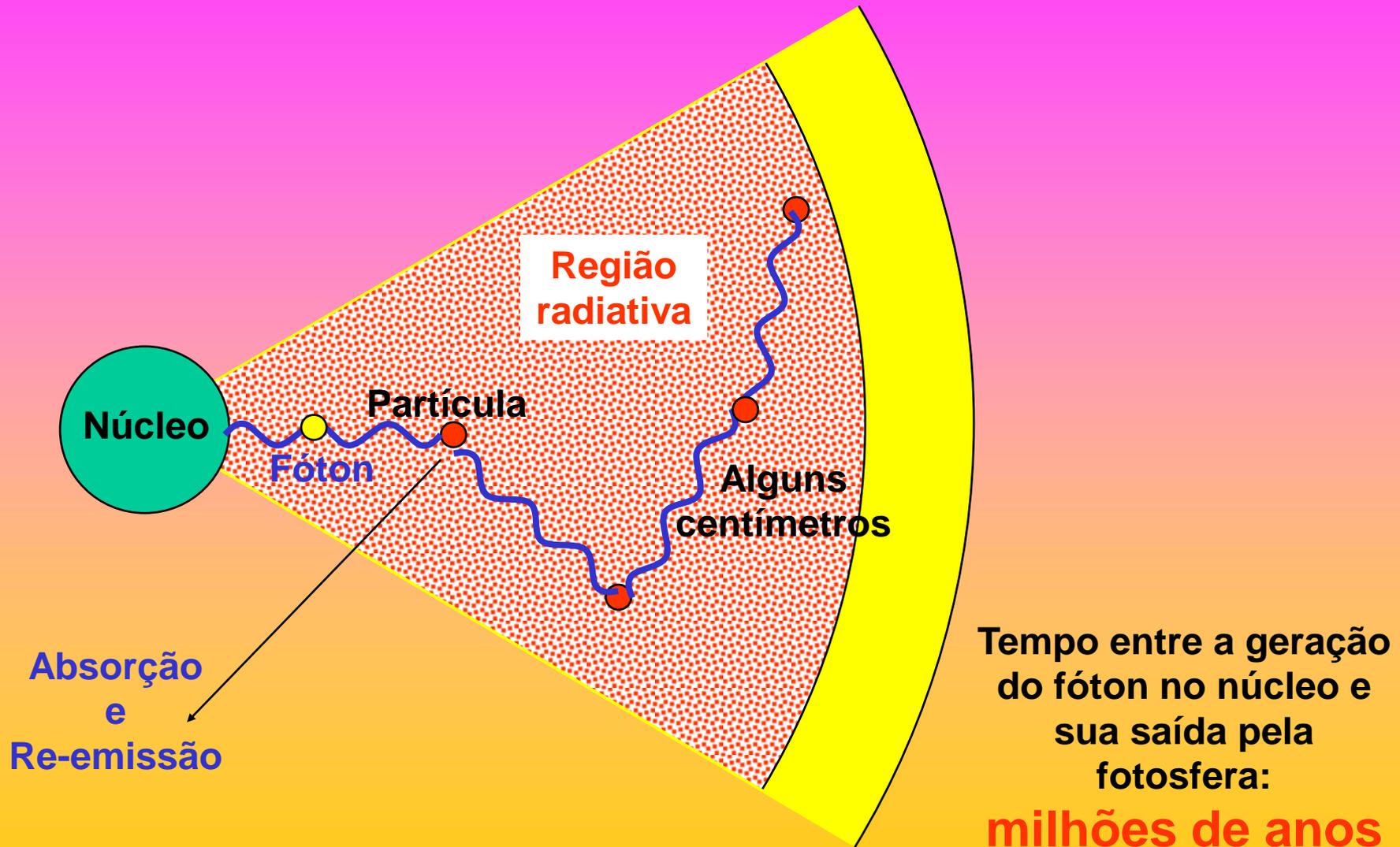
$$E = m c^2$$

c = velocidade da luz no vácuo

Cadeia próton-próton gerando He



Livre caminho médio dos fótons na camada radiativa



Dados do interior do Sol

Densidade solar

Densidade [g/cm³]

180

160

140

120

100

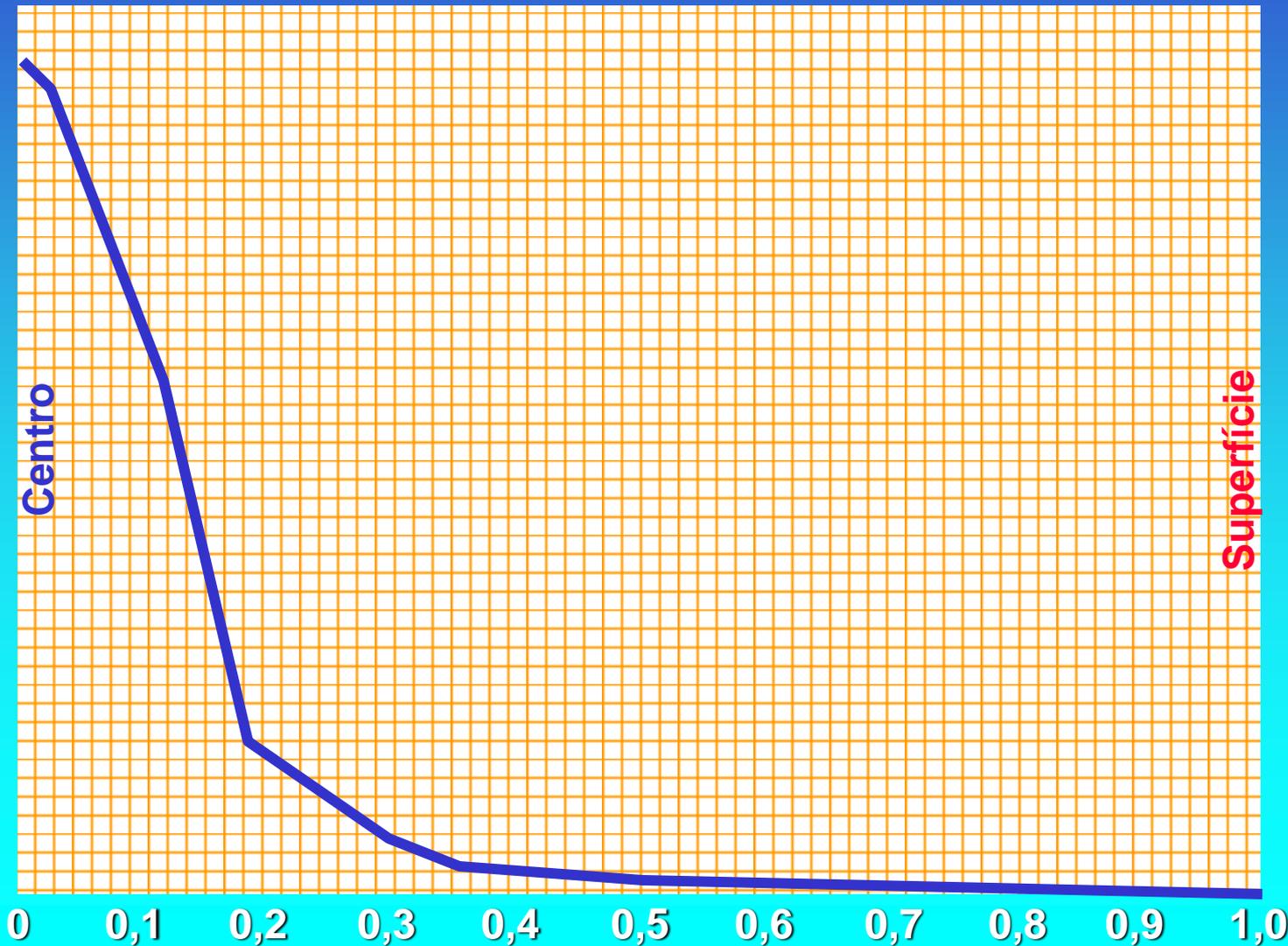
80

60

40

20

00



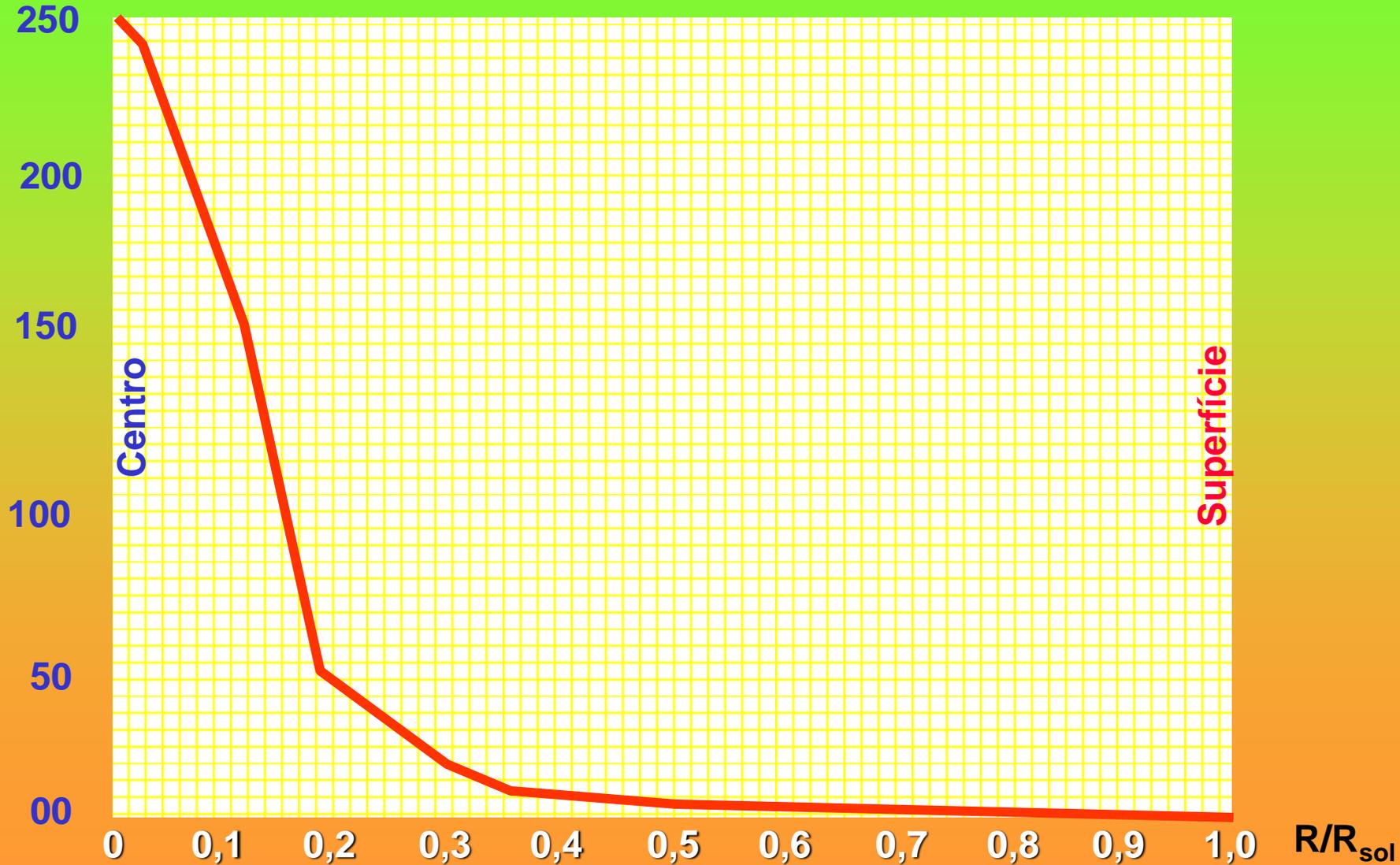
Centro

Superfície

R/R_{sol}

Pressão no interior solar

Pressão
[Bilhões de atm]



Temperatura no interior solar

Temperatura
Milhões de [K]

16

14

12

10

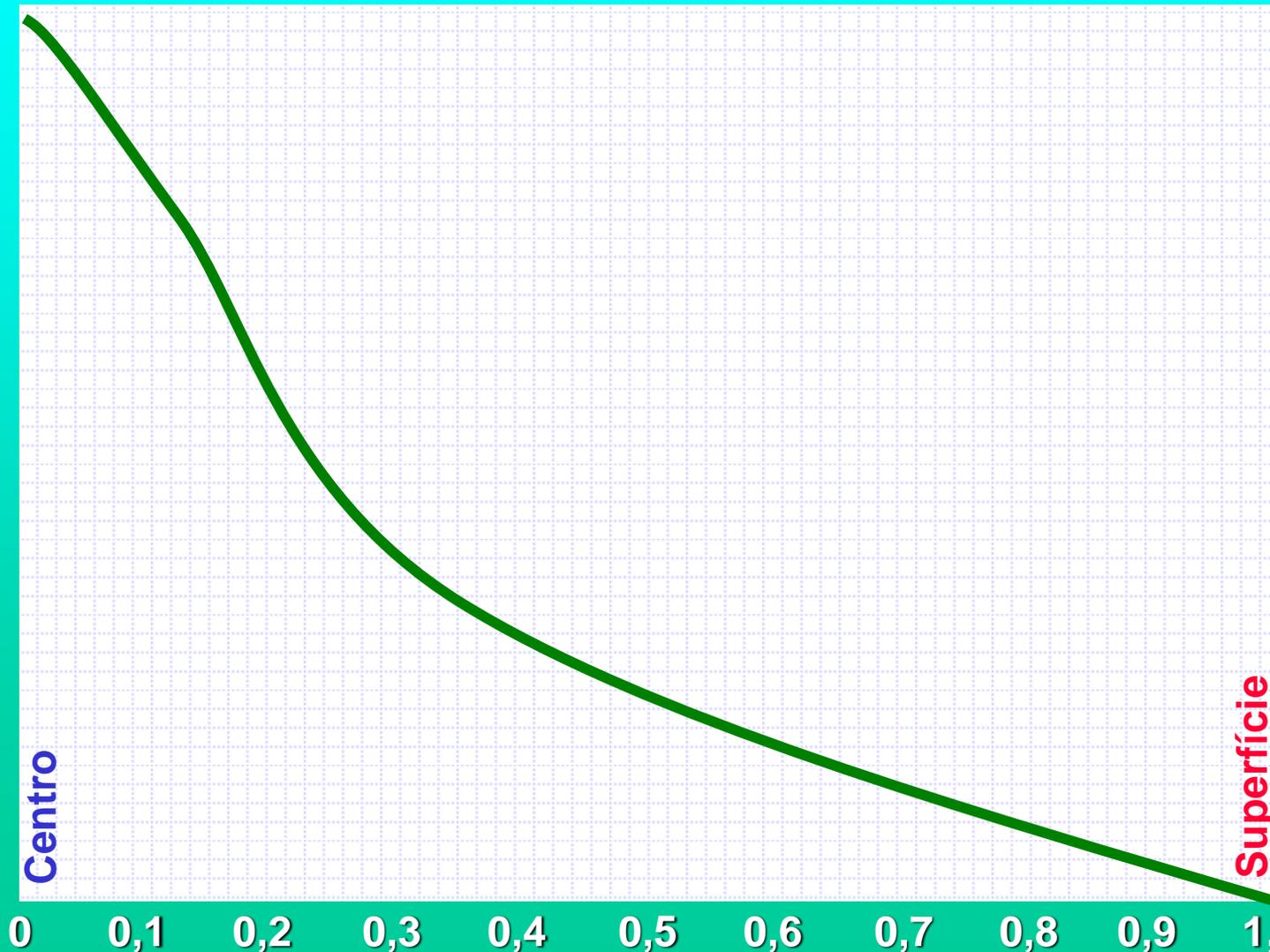
8

6

4

2

00

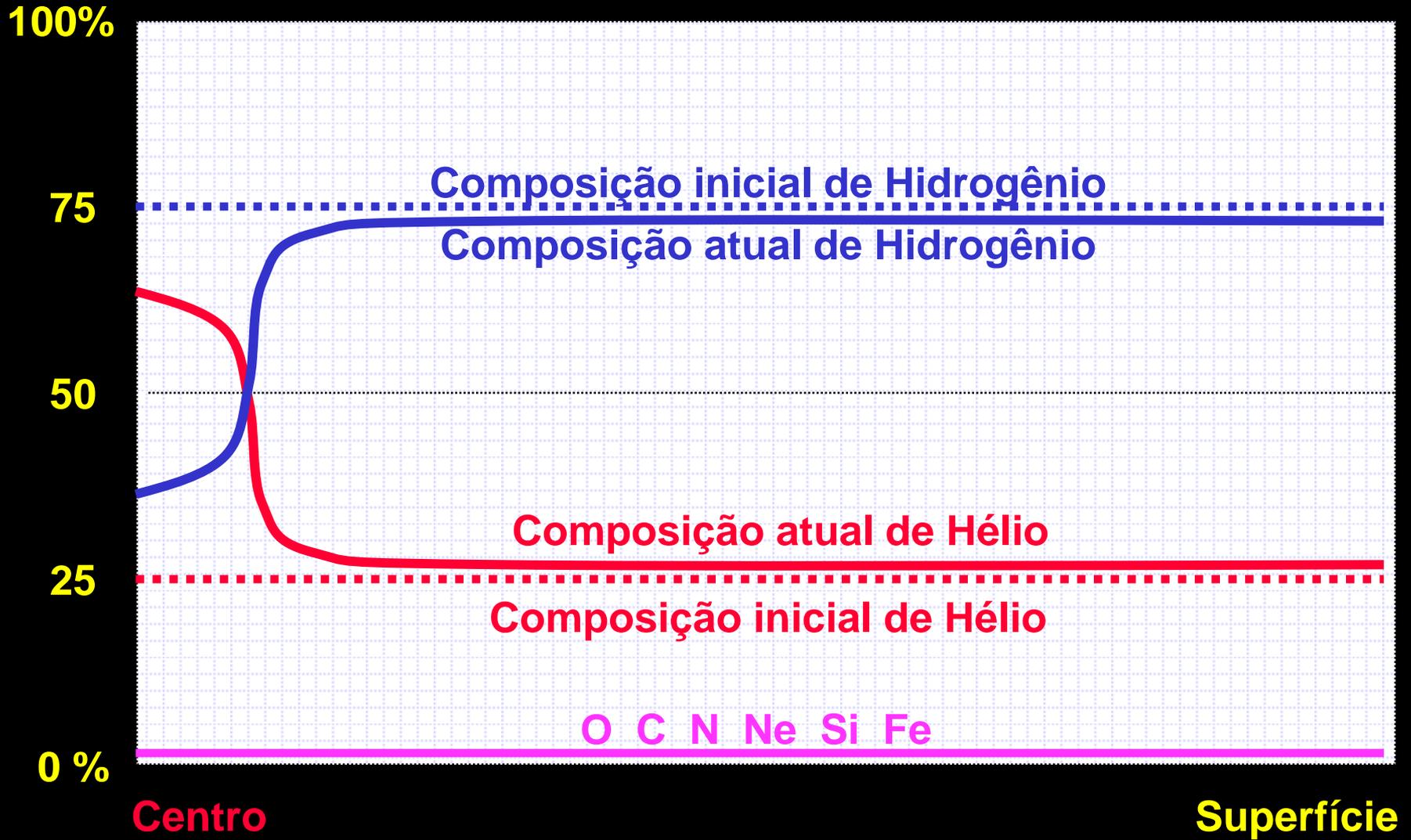


Centro

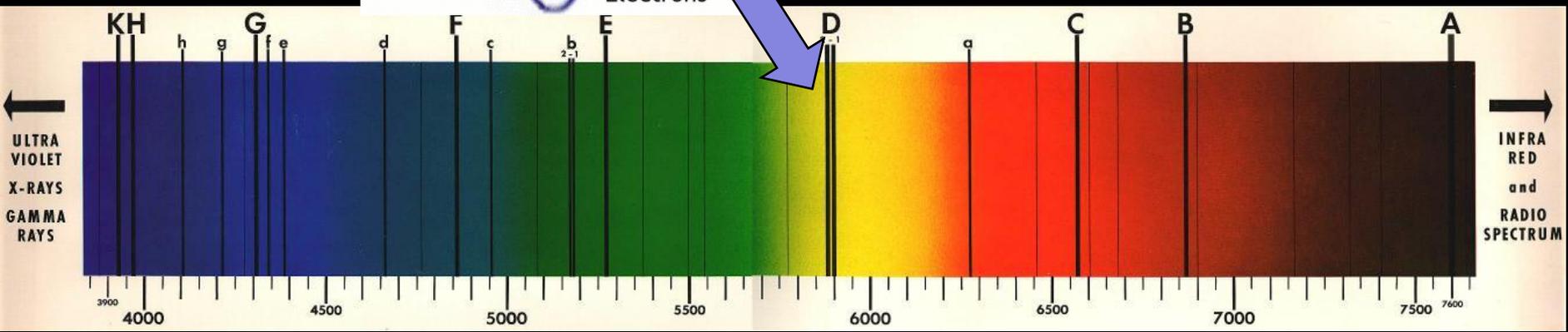
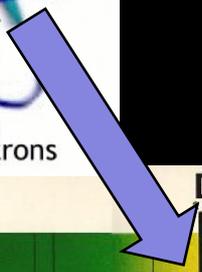
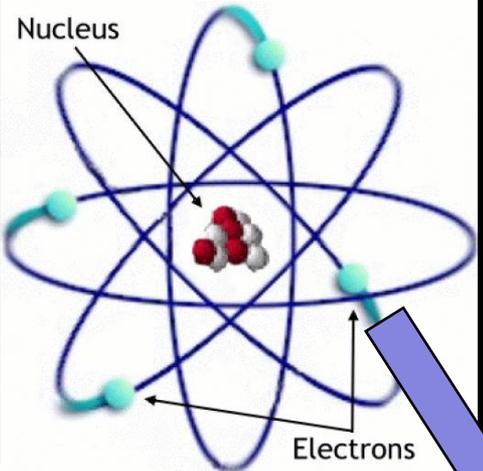
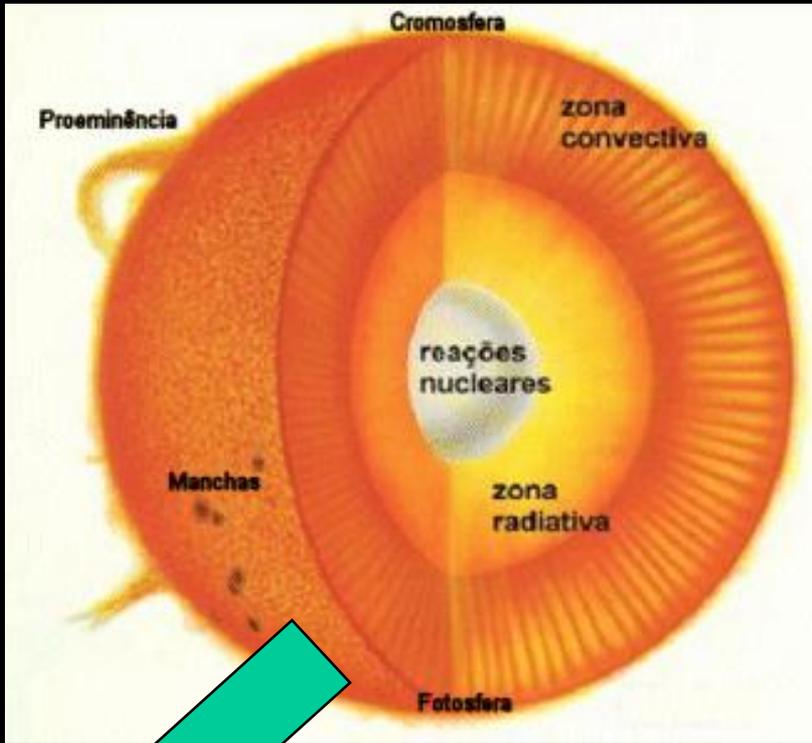
Superfície

R/R_{sol}

Mudanças na composição química do Sol

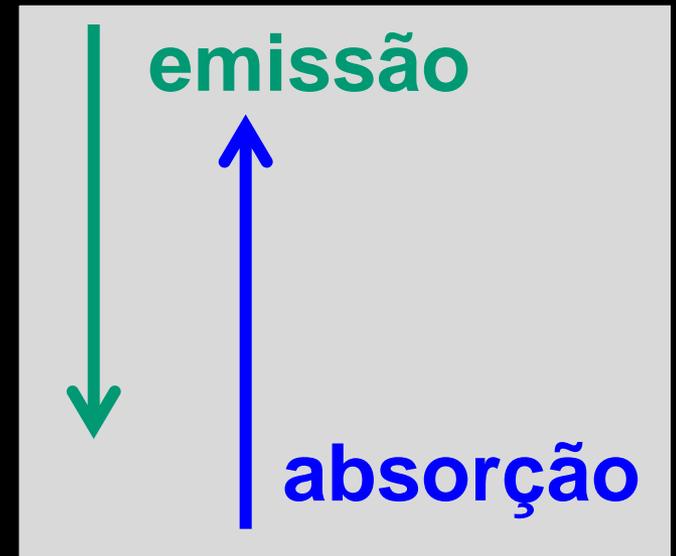
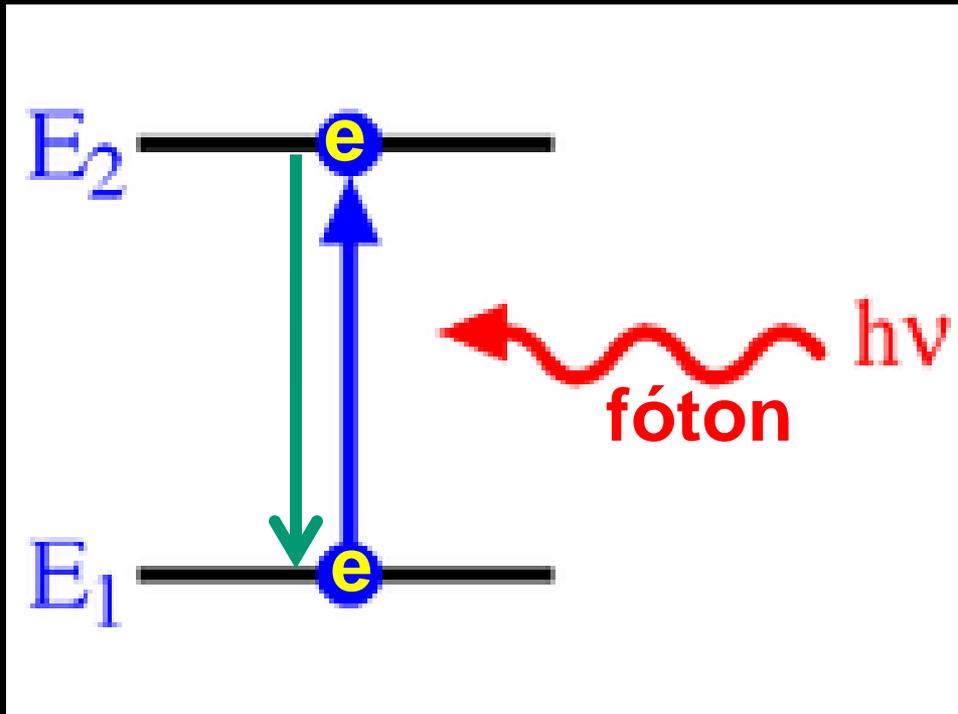


A composição química “observada” no Sol é maiormente aquela da fotosfera

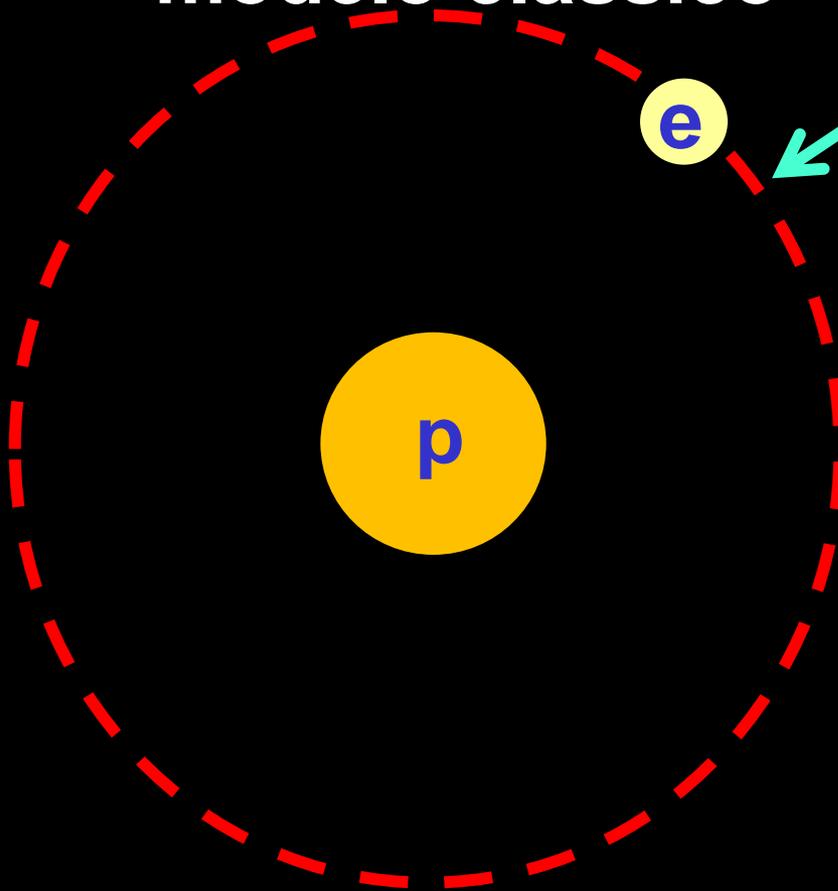


Formação de Linhas da Fotosfera

A linha é formada quando o elétron muda de uma órbita (nível de energia E) para outra devido à emissão ou absorção de um fóton

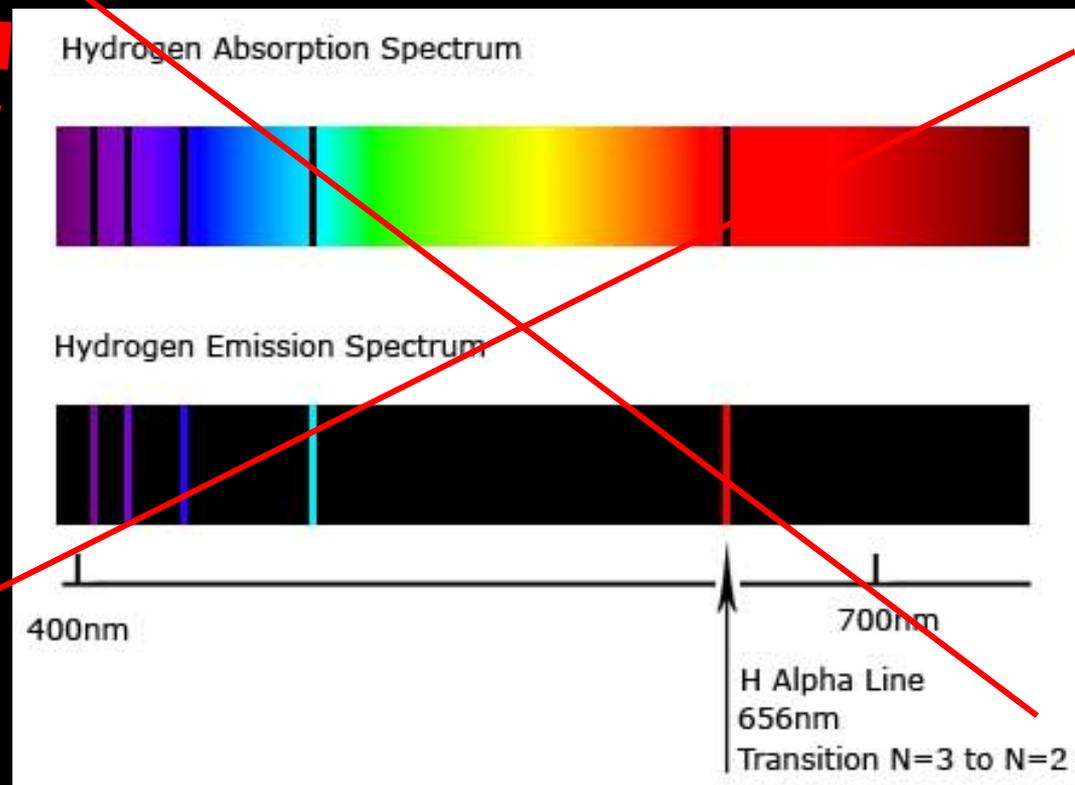


Átomo de hidrogênio : modelo clássico

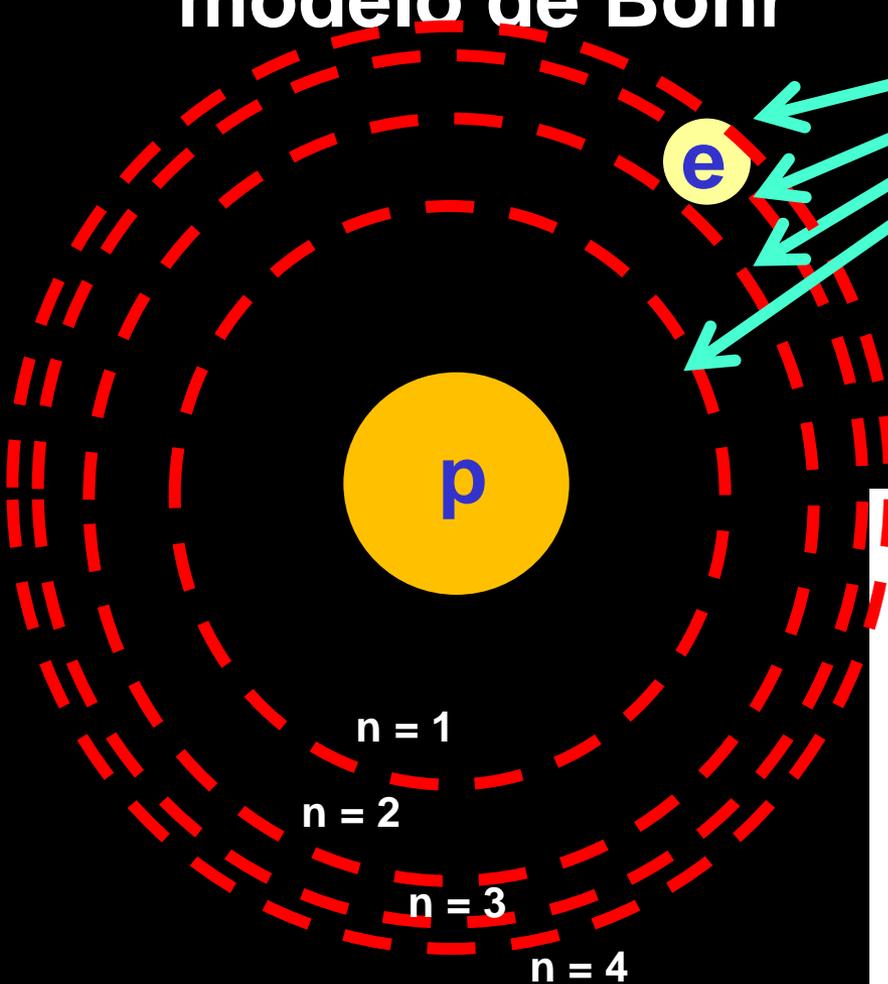


Só um nível de
energia
(só uma órbita)

Não é possível
formar linhas ...

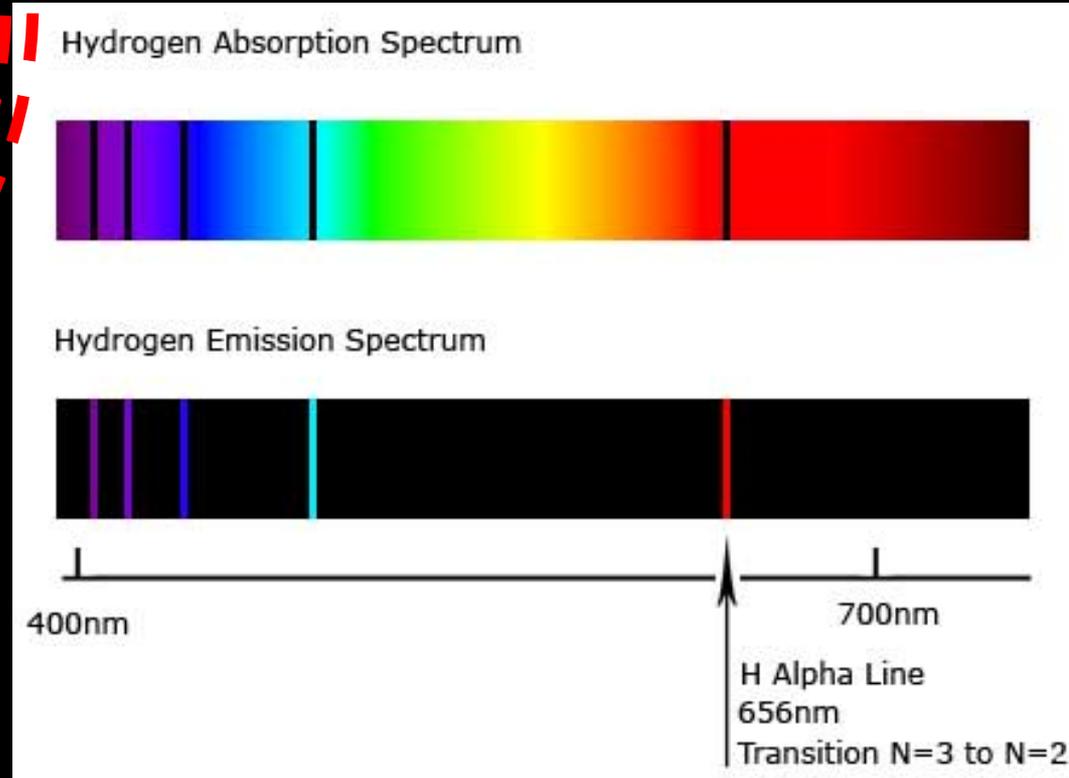


Átomo de hidrogênio : modelo de Bohr

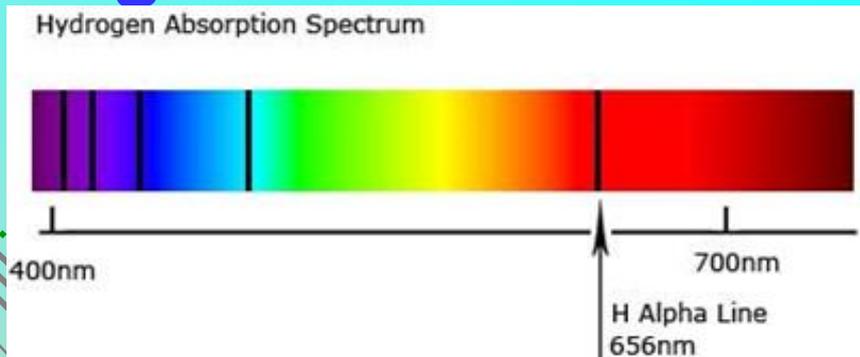
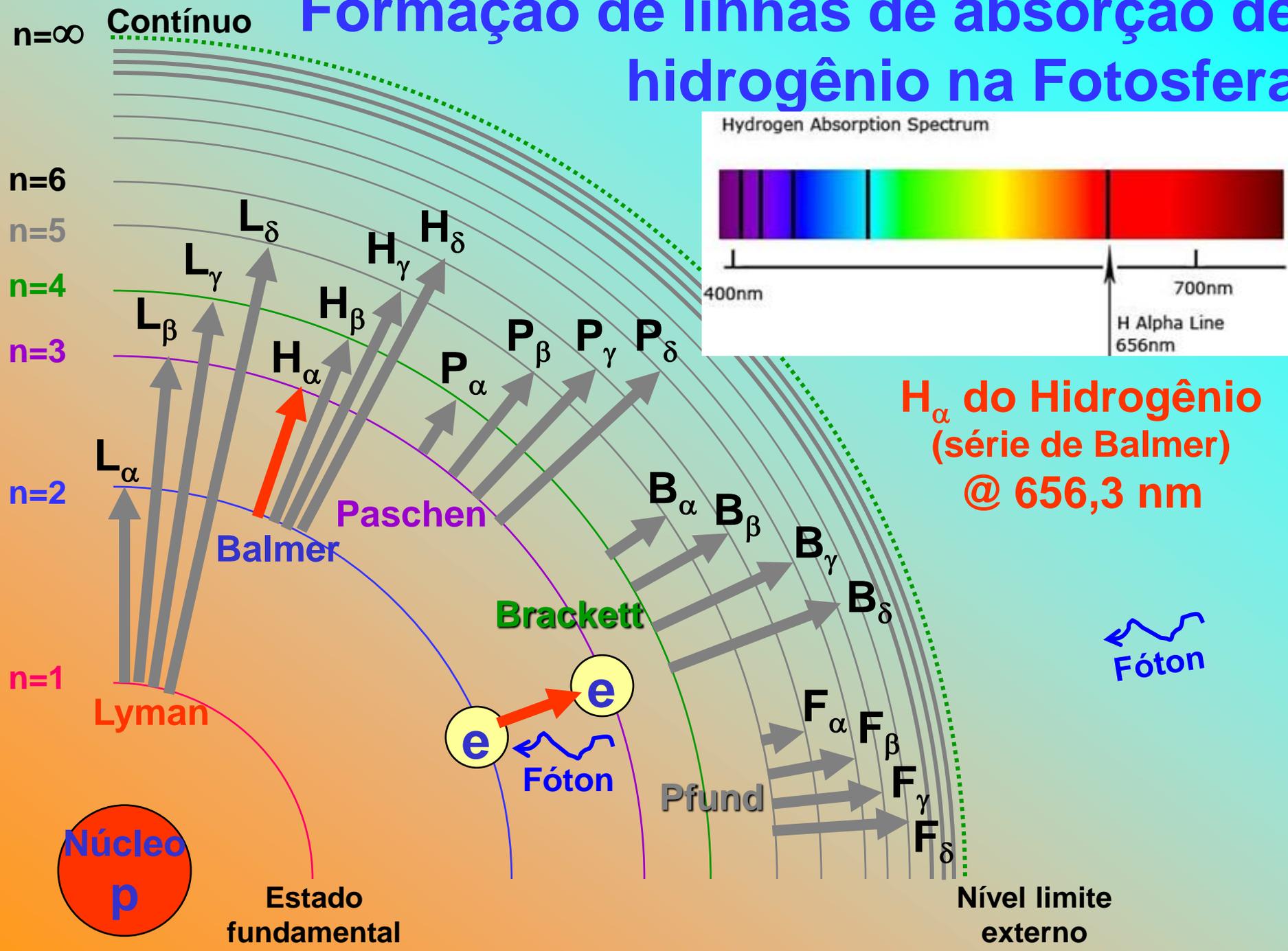


O elétron pode mudar
de nível de energia,
 $n = 1, 2, 3, 4, \dots$

É possível formar
linhas ...



Formação de linhas de absorção de hidrogênio na Fotosfera



H_α do Hidrogênio
(série de Balmer)
@ 656,3 nm

Fóton

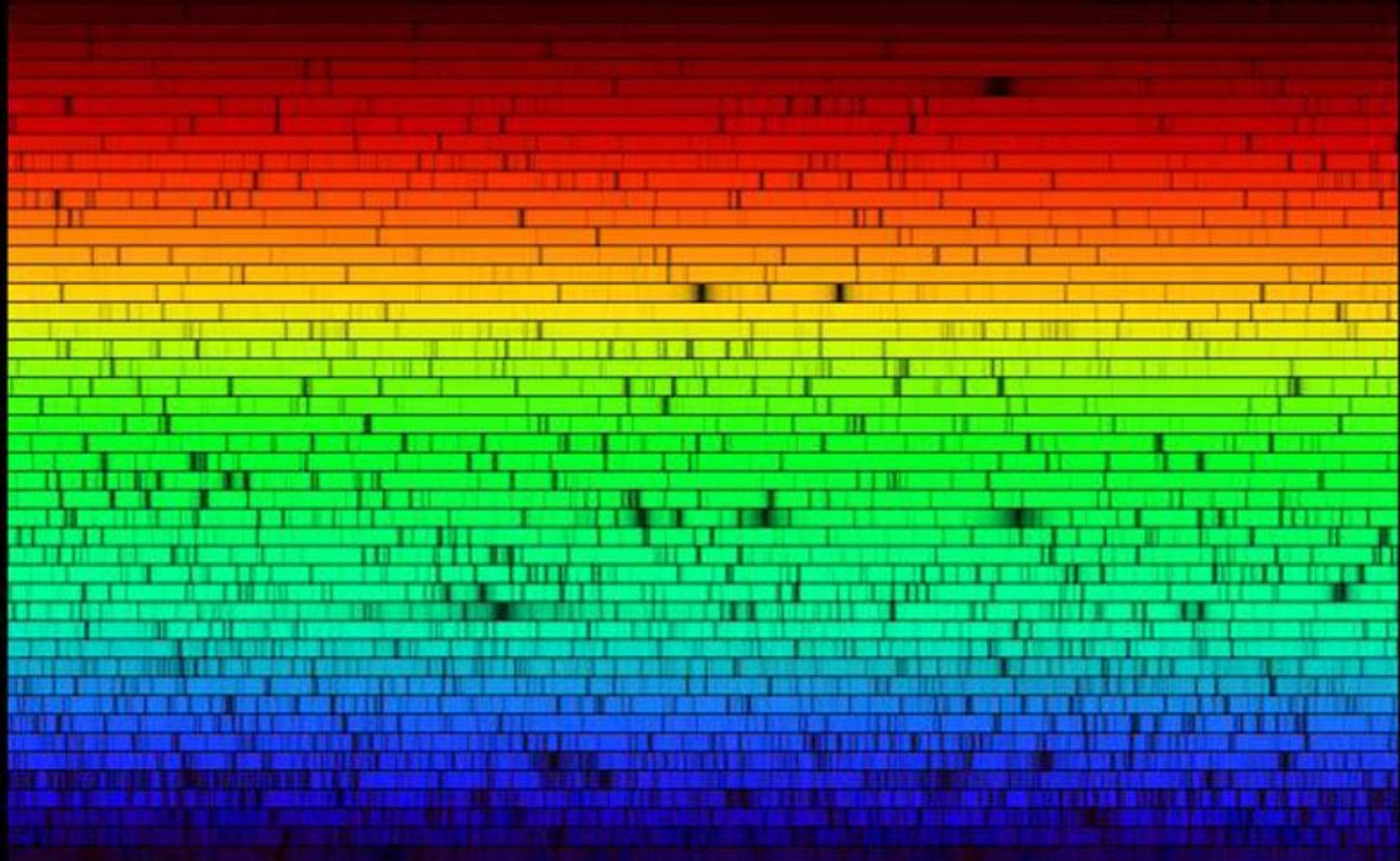
Núcleo
 p

Estado fundamental

Nível limite externo

Espectro solar (empilhado)

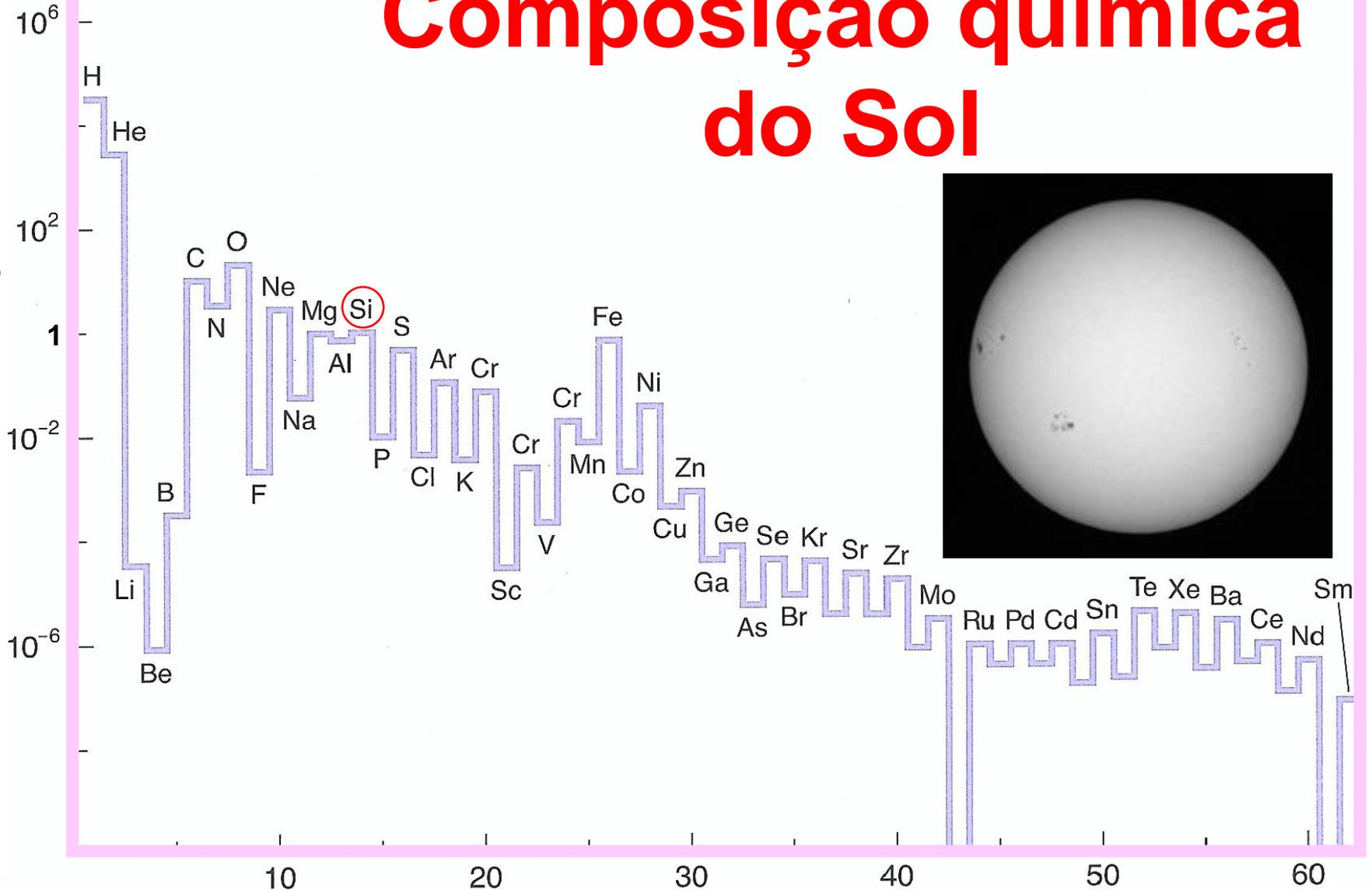
↑ Infravermelho



Ultravioleta ↓

Composição química do Sol

Abundância elementar com relação ao Silício Si



Número atômico = Número de prótons no núcleo do elemento químico

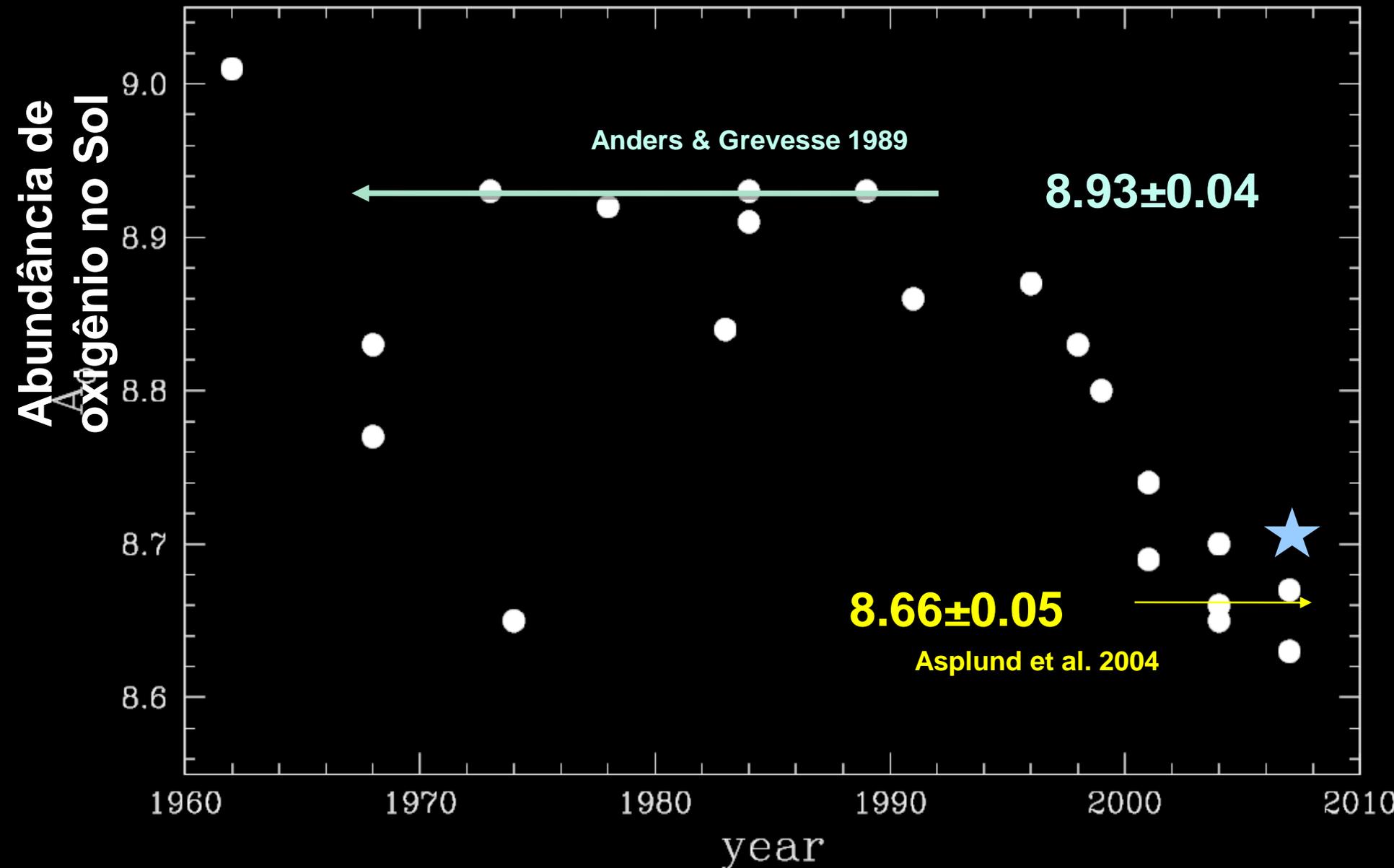
Composição química solar

						<i>Abundance</i>	<i>Abundance</i>
						<i>(% do numero total de atomos)</i>	<i>(% da massa total)</i>
<i>Elements</i>							
					Hydrogen	91.2	71.0
					Helium	8.7	27.1
					Oxygen	0.078	0.97
					Carbon	0.043	0.40
					Nitrogen	0.0088	0.096
					Silicon	0.0045	0.099
					Magnesium	0.0038	0.076
					Neon	0.0035	0.058
					Iron	0.0030	0.14
					Sulfur	0.0015	0.040

?

Embora o Sol seja a estrela mais próxima a sua abundância de oxigênio ainda não é muito bem conhecida ...

What is the solar oxygen abundance?



Another forbidden solar oxygen abundance: the [OI] 5577 Å line

J. Meléndez^{1,2} and M. Asplund³

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e-mail: jorge@astro.up.pt

² Research School of Astronomy & Astrophysics, Australian National University, Mt. Stromlo Observatory, Weston ACT 2611, Australia

³ Max Planck Institute for Astrophysics, Postfach 1317, 85741 Garching, Germany

Received 8 June 2008 /

A&A 508, 1403–1416 (2009)
DOI: [10.1051/0004-6361/200912840](https://doi.org/10.1051/0004-6361/200912840)
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Oxygen lines in solar granulation

II. Centre-to-limb variation, NLTE line formation, blends, and the solar oxygen abundance^{*}

T. M. D. Pereira^{1,2}, M. Asplund³, and D. Kiselman²

¹ Research School of Astronomy and Astrophysics, Australian National University, Cotter Rd., Weston, ACT 2611, Australia
e-mail: tiago@mso.anu.edu.au

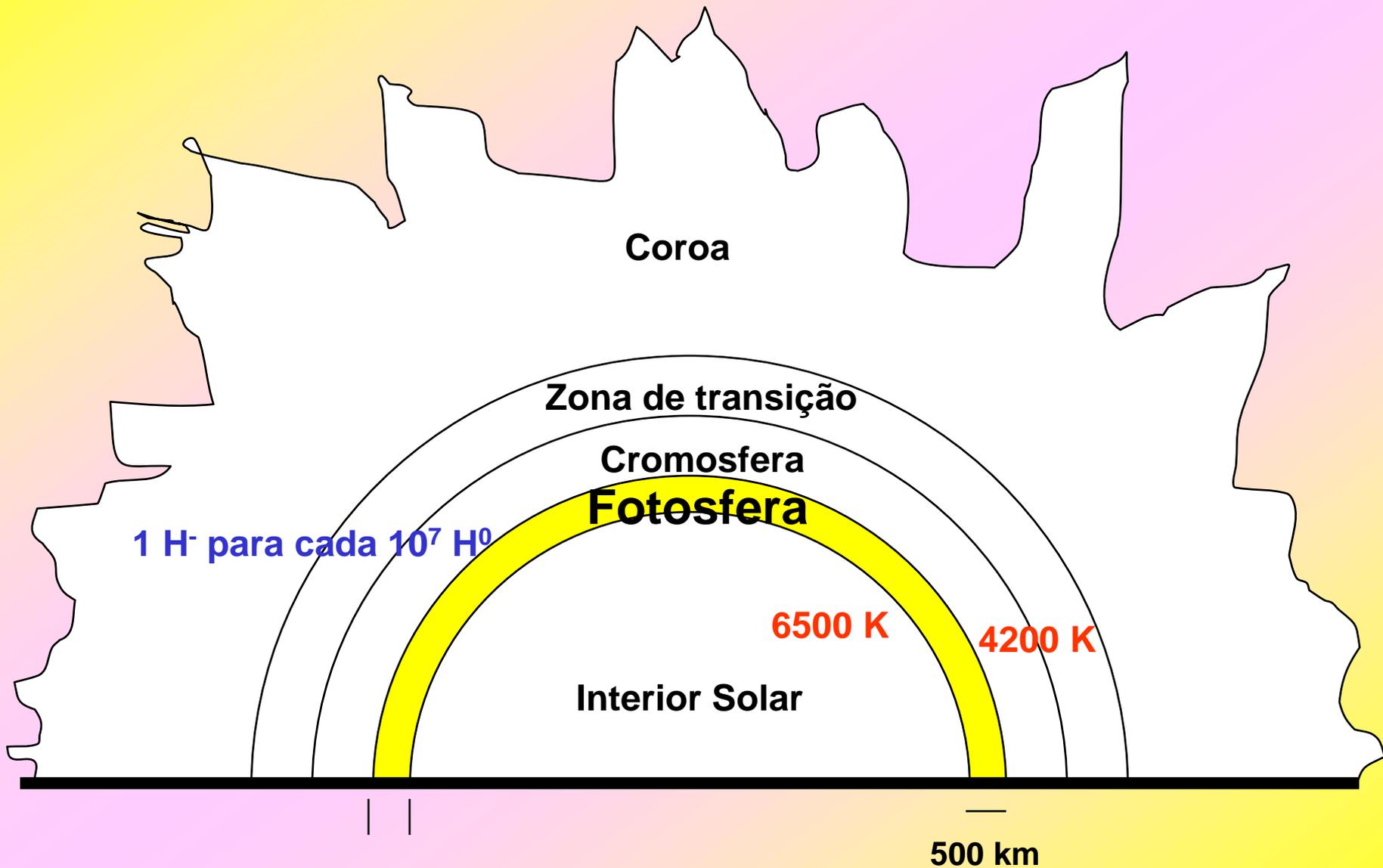
² The Institute for Solar Physics of the Royal Swedish Academy of Sciences, AlbaNova University Center, 106 91 Stockholm, Sweden

³ Max-Planck-Institut für Astrophysik, Postfach 1317, 85741 Garching b. München, Germany

Received 7 July 2009 / Accepted 9 September 2009

**“Superfície”
do Sol:
fotosfera**

Fotosfera do Sol



Fotosfera do Sol



Espessura óptica (τ)

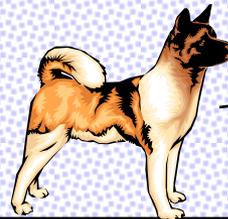
(ou profundidade óptica)

Neblina

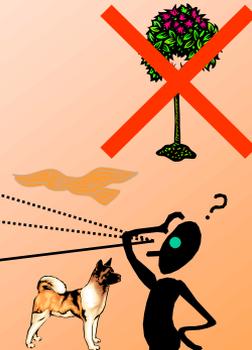
$$I/I_0 = e^{-\tau}.$$



$\tau = 1$



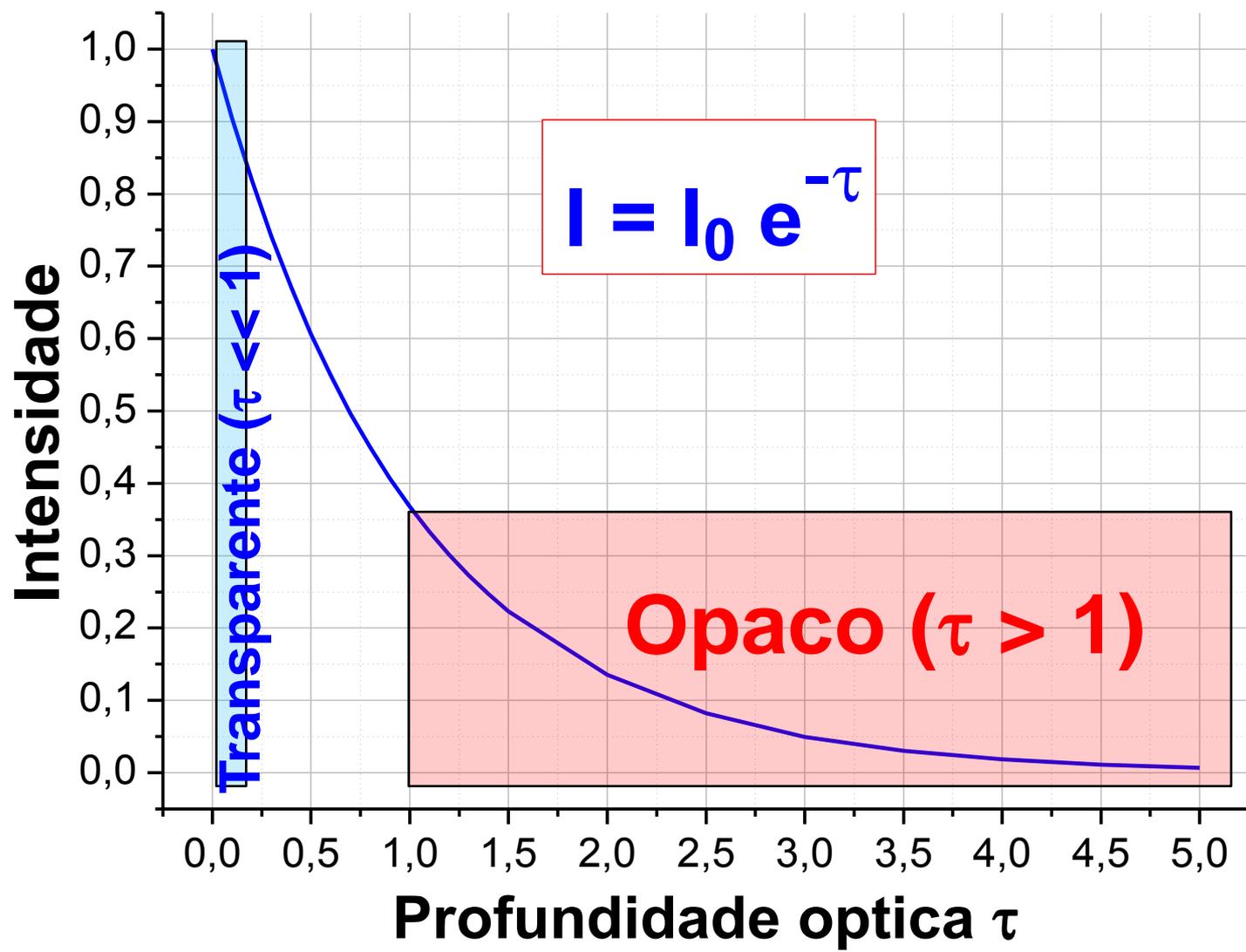
Opaco
 $\tau > 1$



Transparente
 $\tau < 1$



τ : medida da transparência

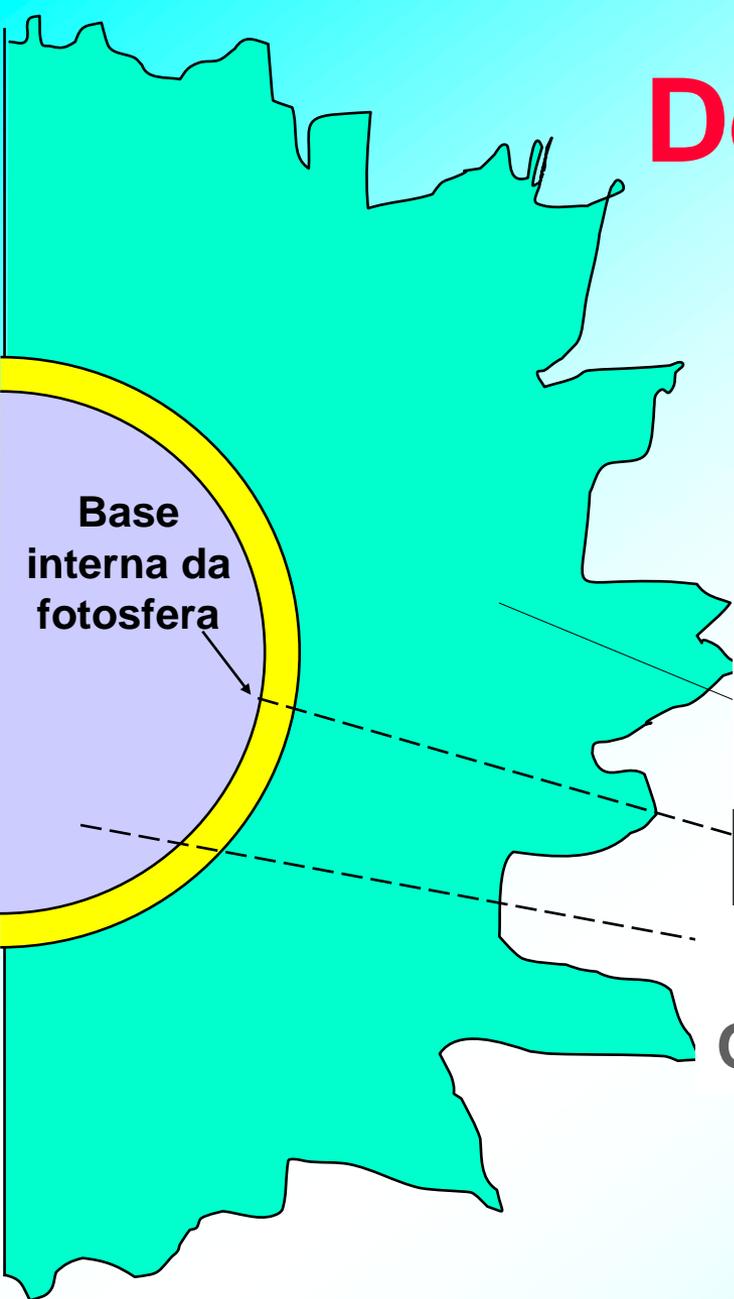


Definição da fotosfera

τ = Espessura óptica

Temperatura superficial:

$$T_{\text{Efetiva}} = T_{(\tau \sim 2/3)} = 5.777 \text{ K}$$



Transparente

$$\tau \ll 1$$

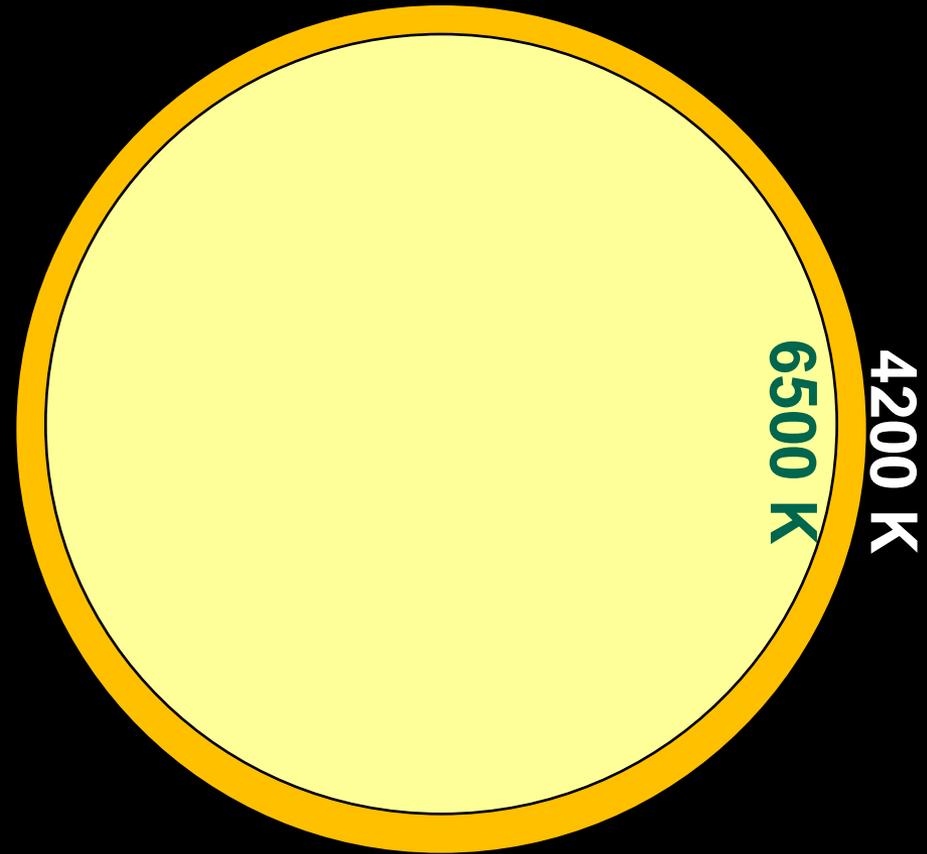
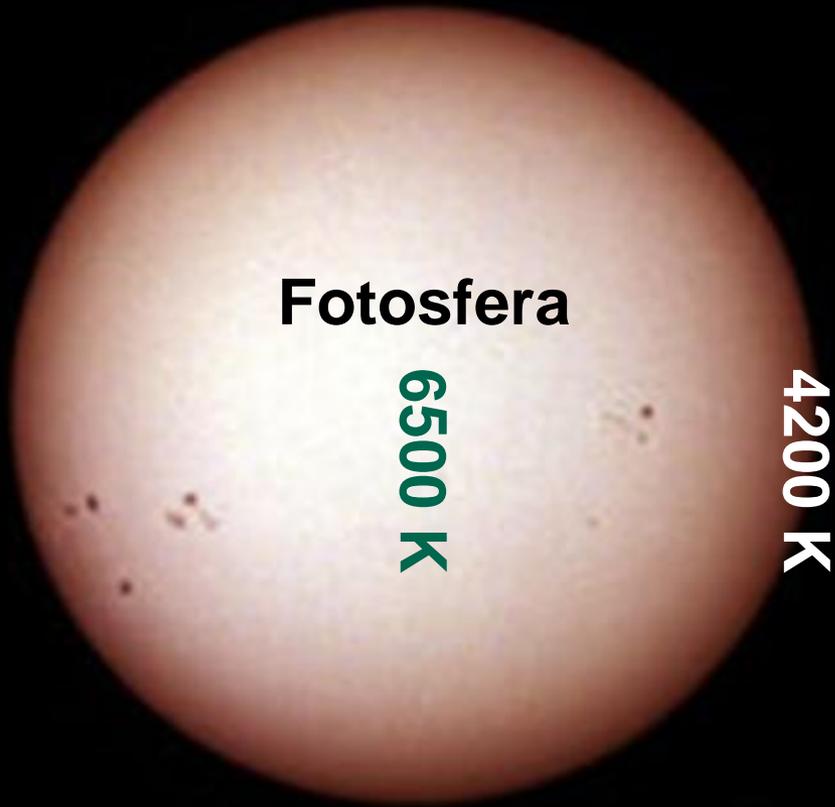
$$\tau = 1$$

$$\tau > 1$$

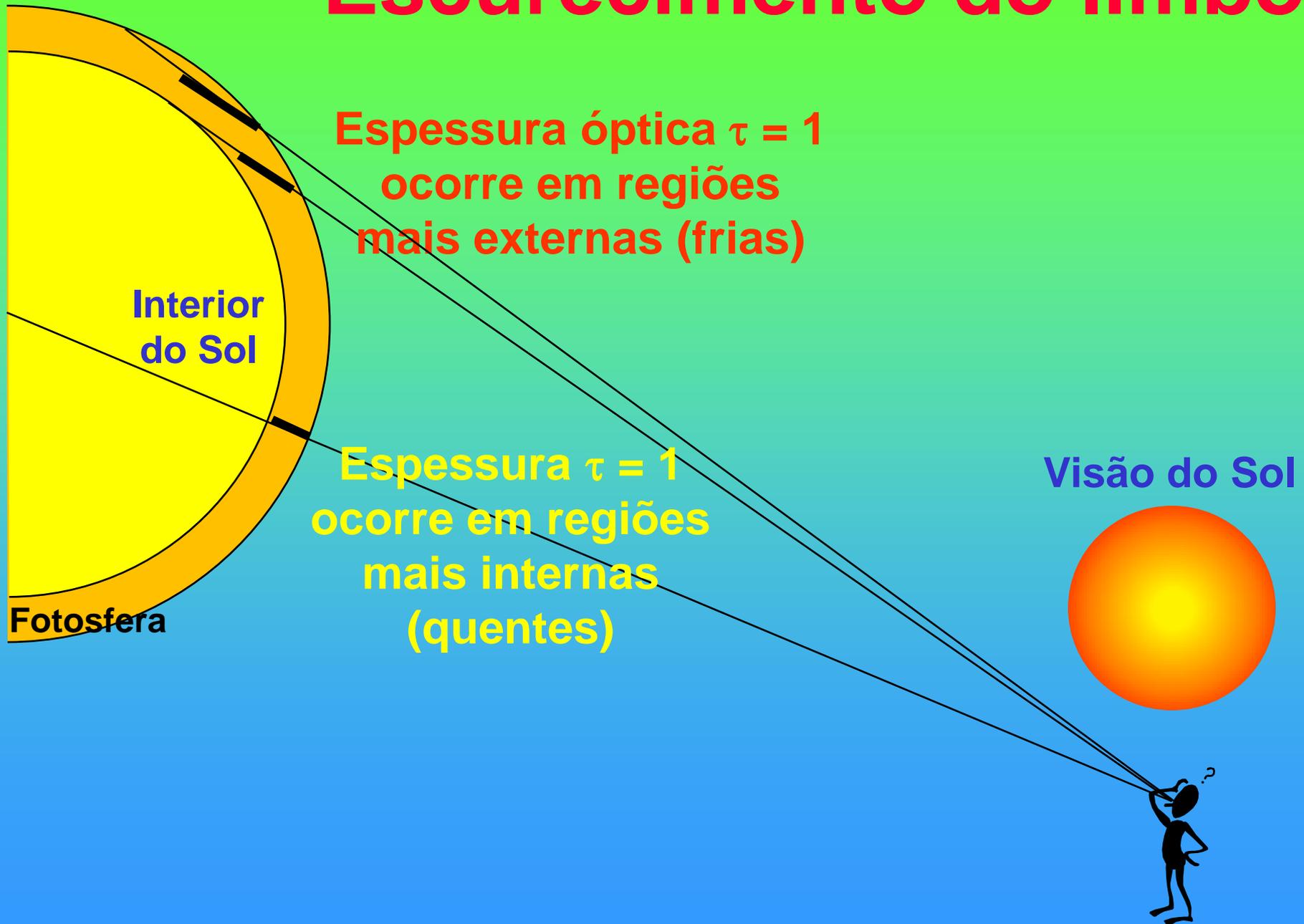
Opaco



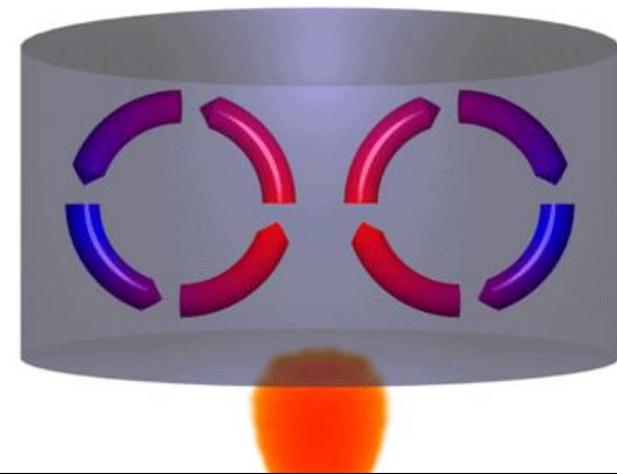
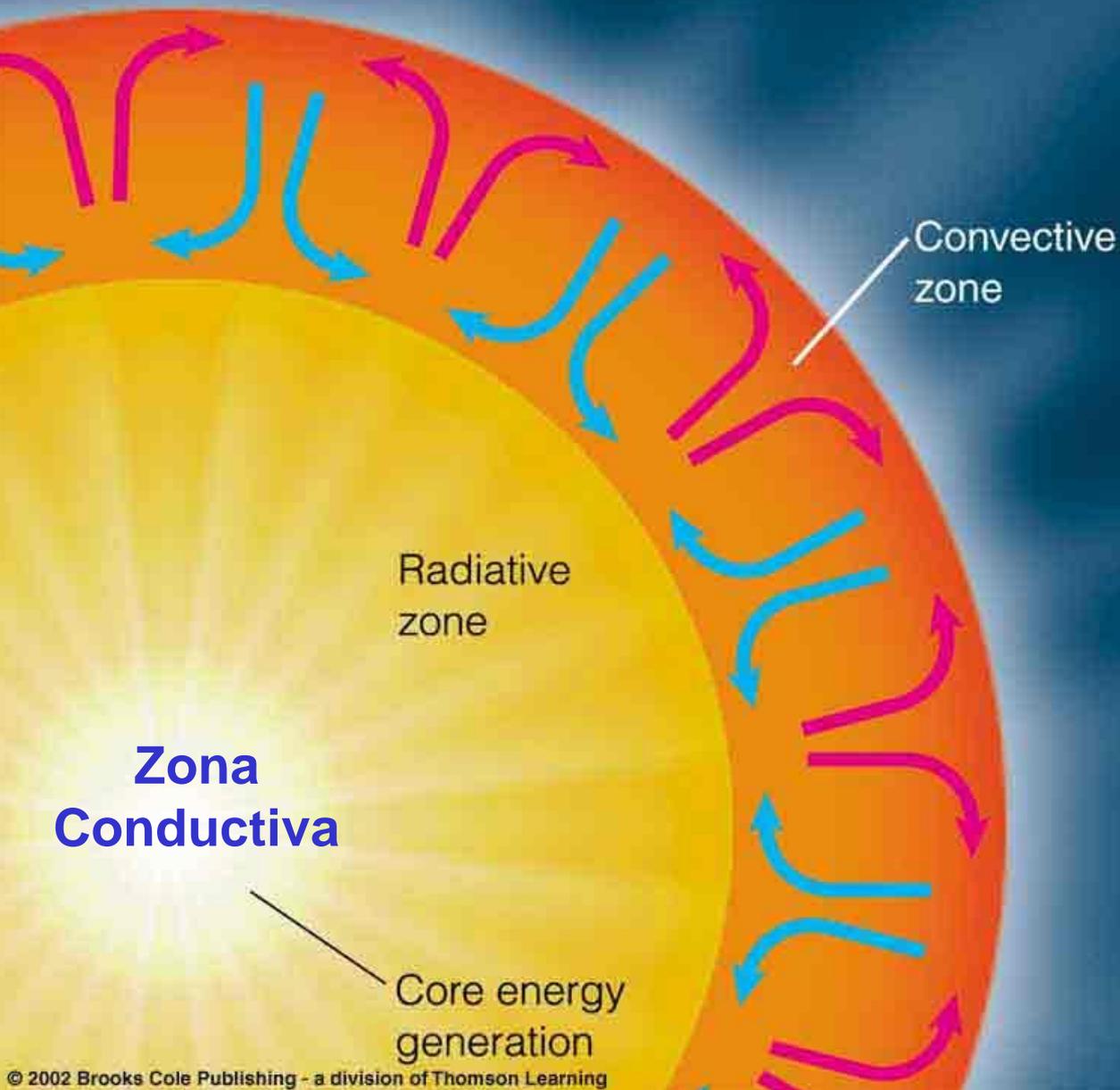
Escurecimento do limbo: prova da descida da temperatura em direção ao exterior da fotosfera



Escurecimento do limbo

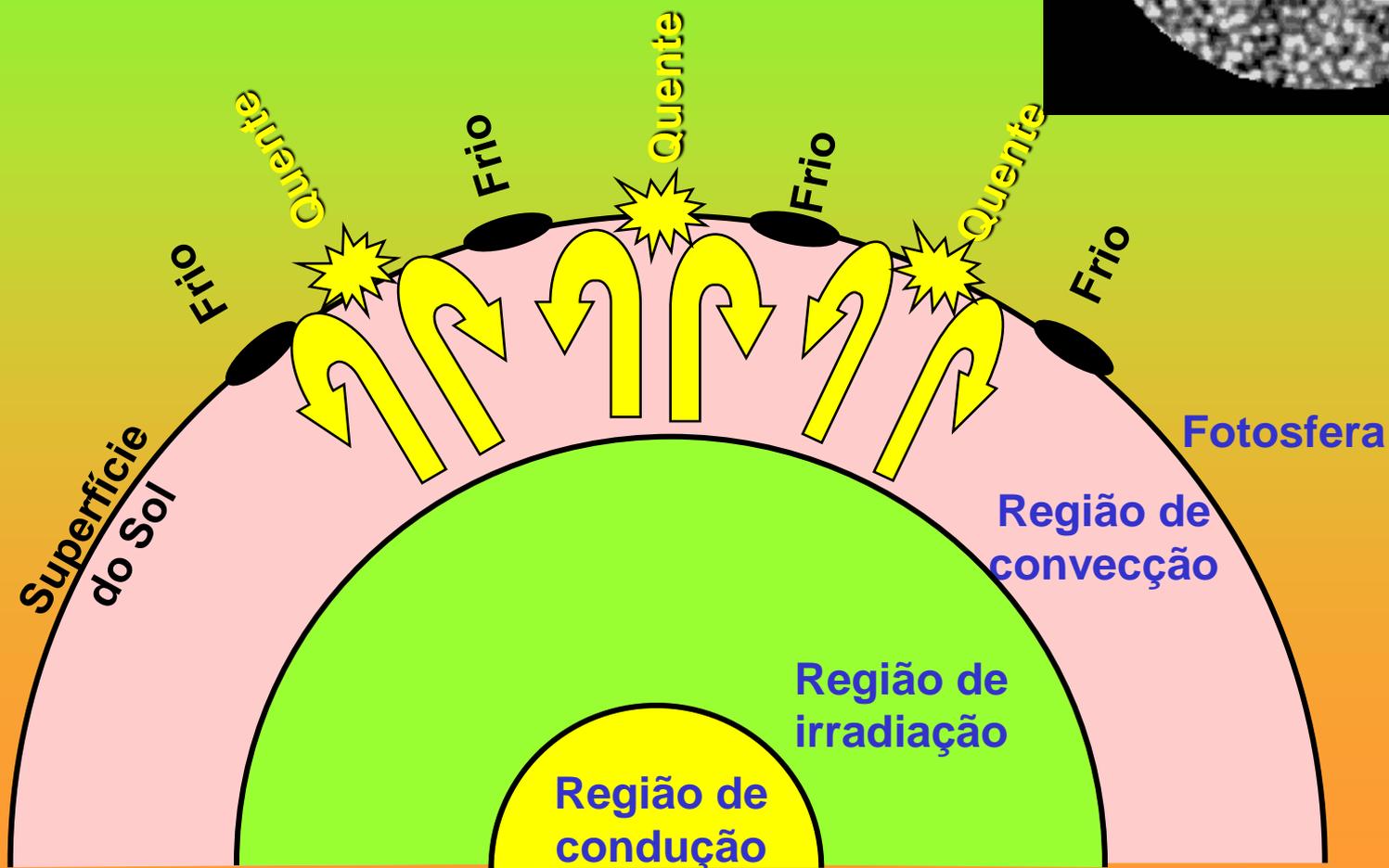
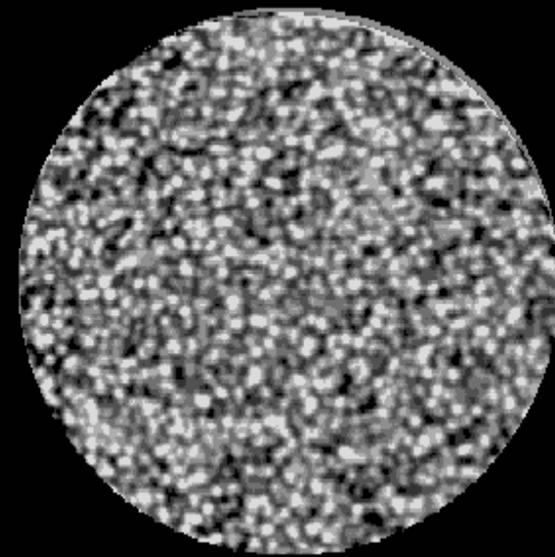


Convecção



Movimento por convecção

Convecção abaixo da fotosfera

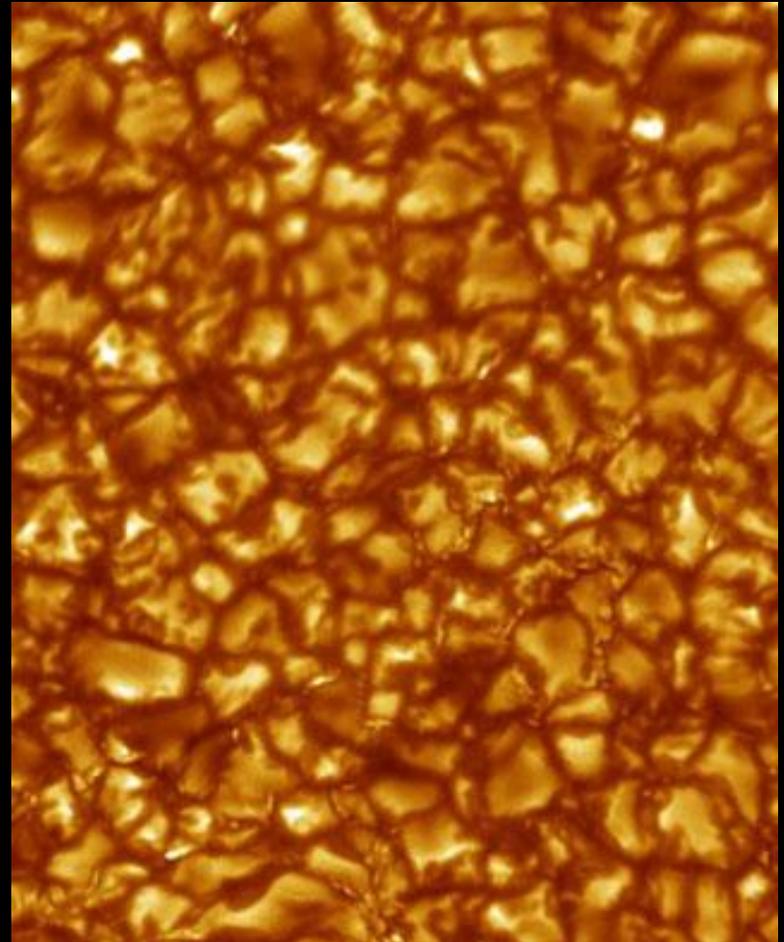


Estrutura Alveolar (Granular) do Sol

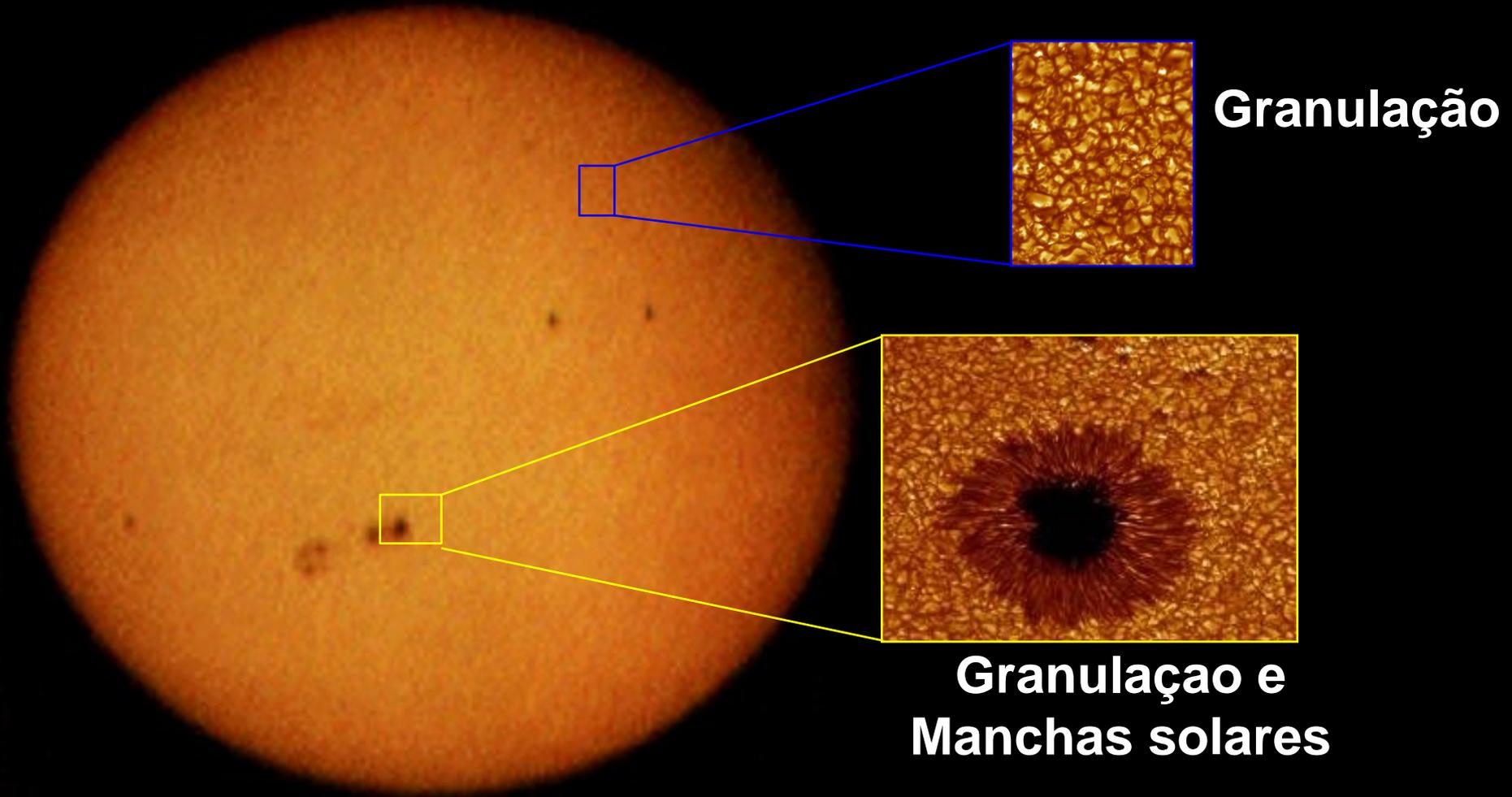
- **Regiões Claras**
 - Subida de gás quente
- **Regiões Escuras**
 - Descida de gás frio

Diâmetro típico de
um grânulo (alvéolo):
1000 km

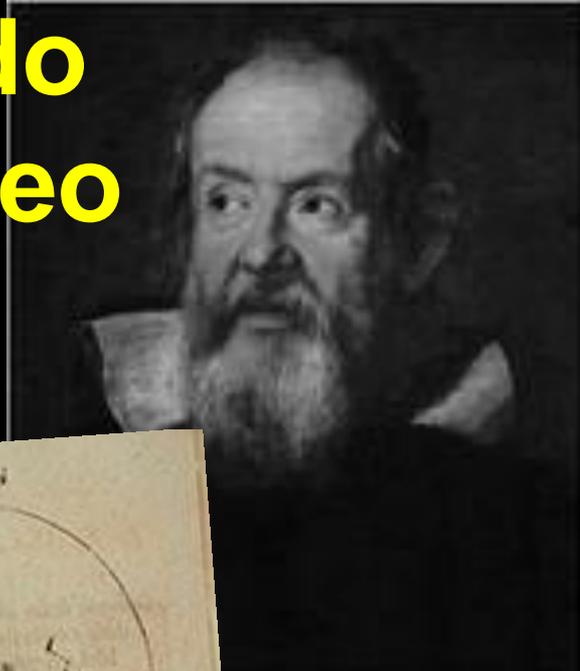
Vida de um grânulo (alvéolo):
5 a 10 minutos



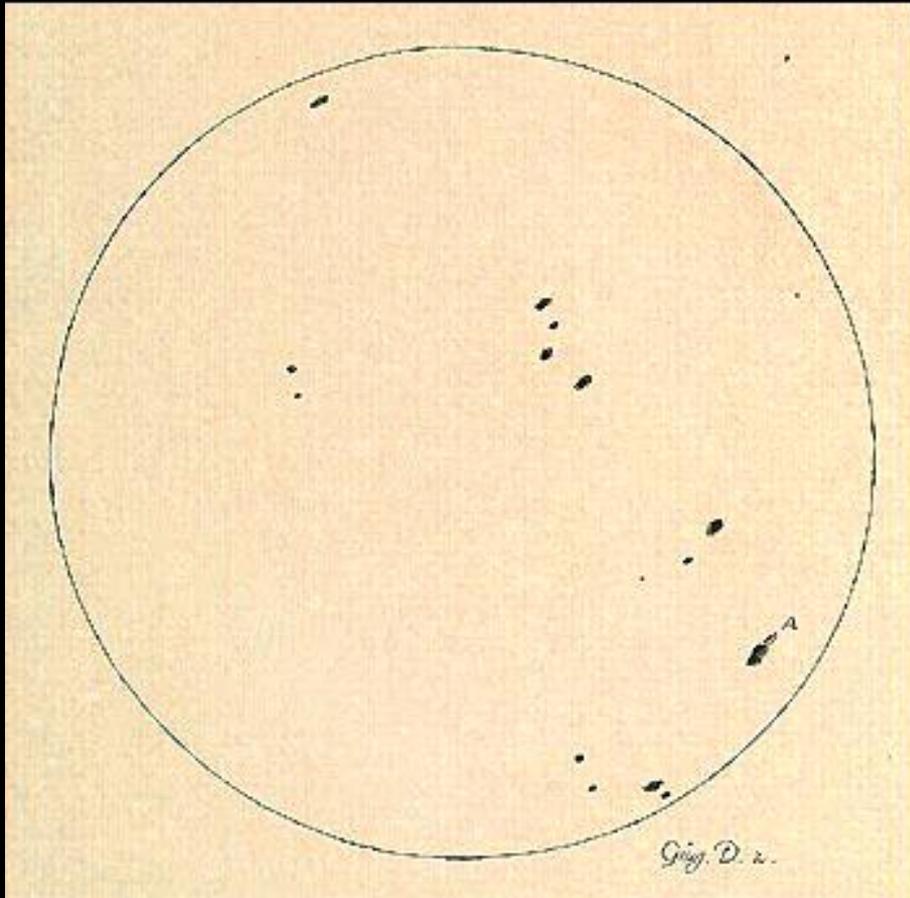
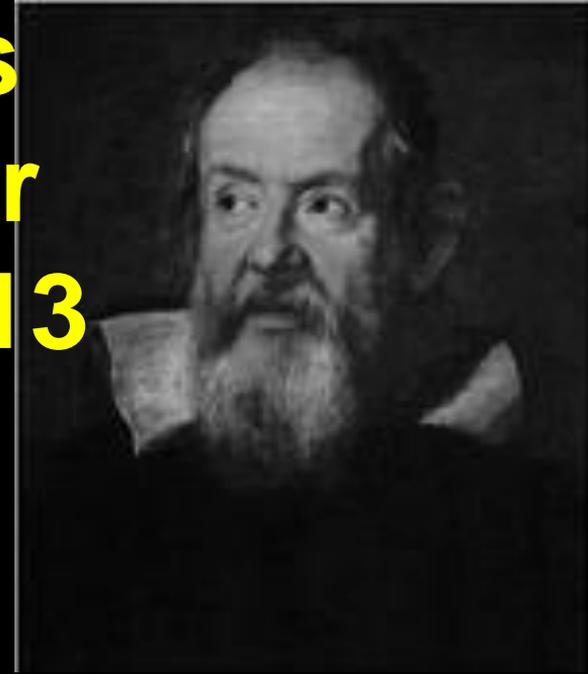
Manchas solares



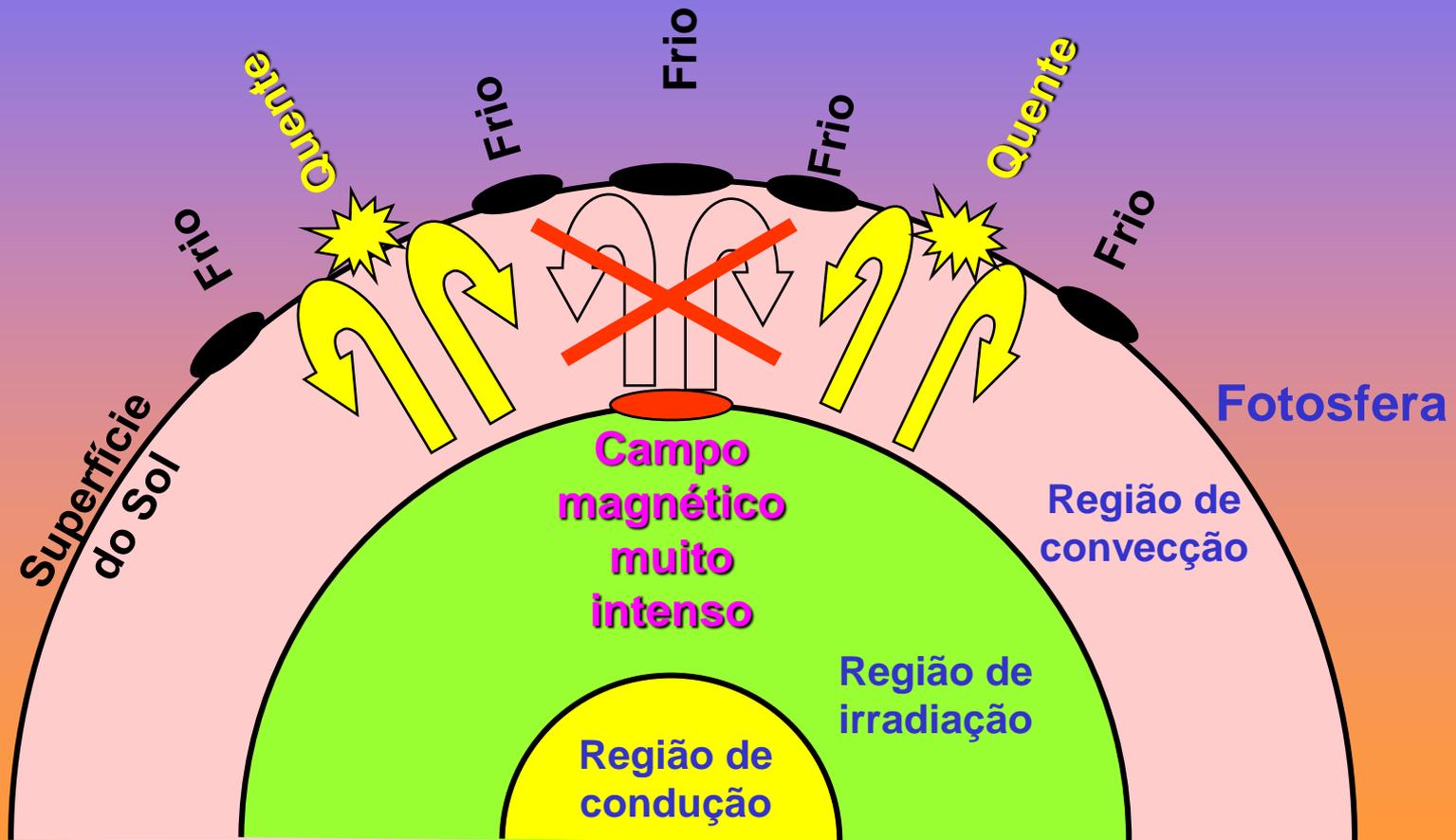
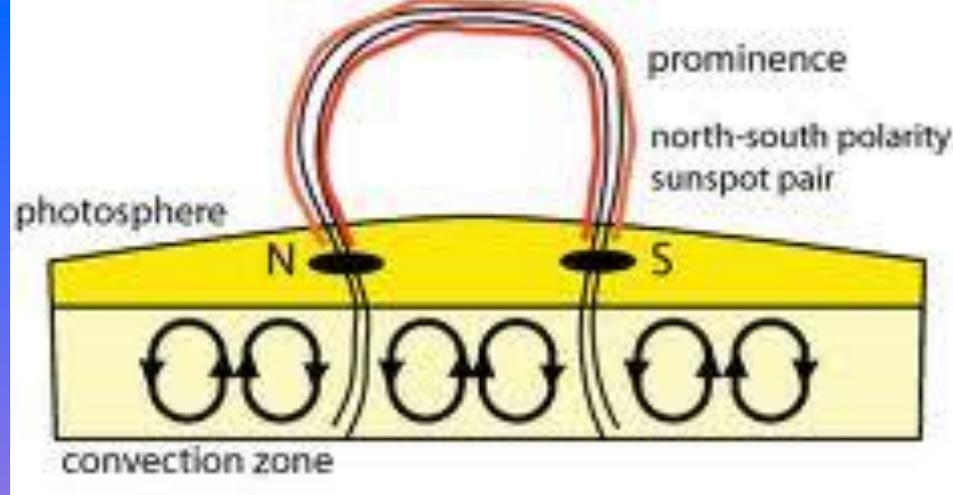
Manchas na superfície do Sol observadas por Galileo 1612-1613

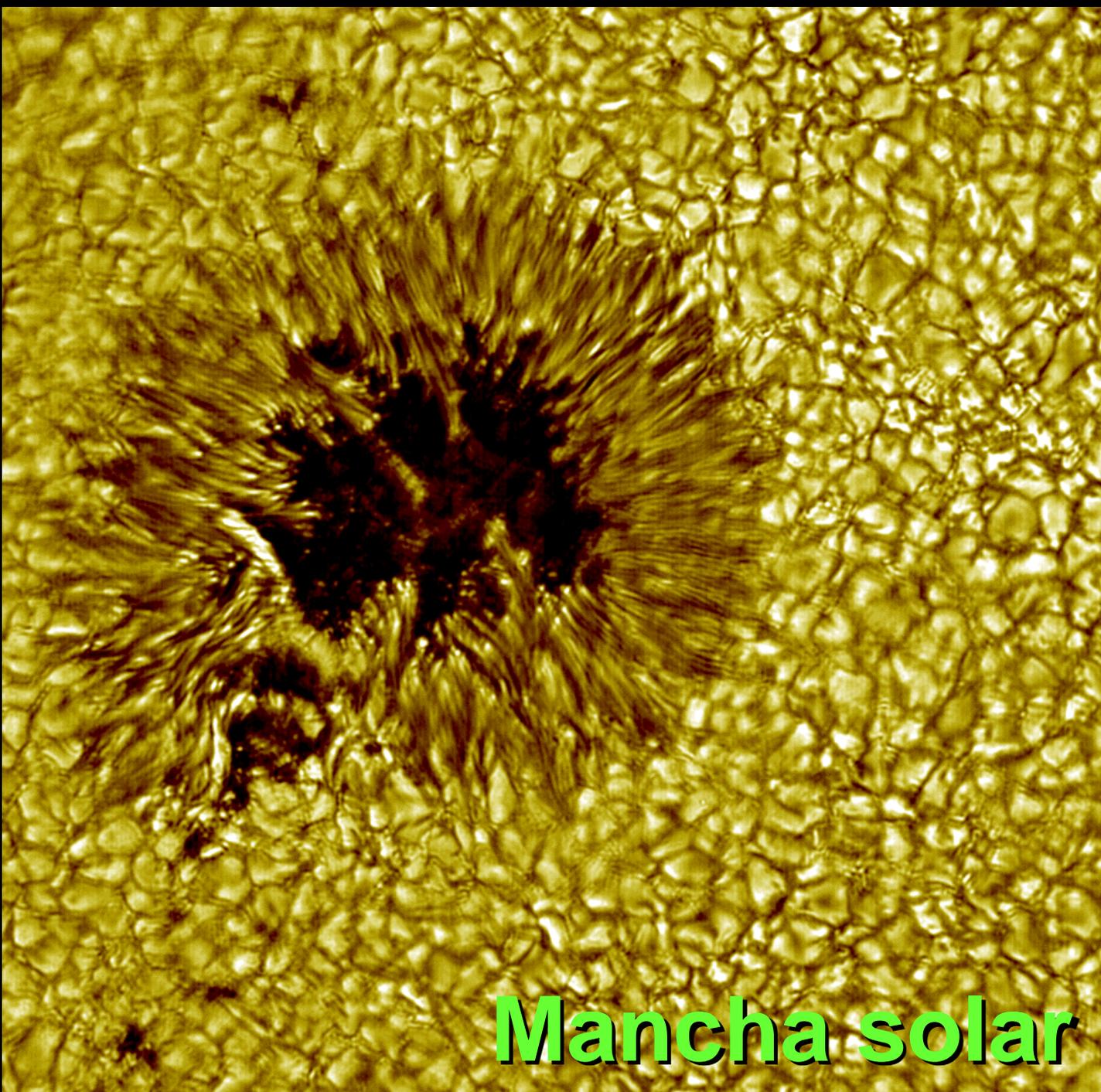


Animação de manchas solares observadas por Galileo 2 Jun – 8 Jul 1613

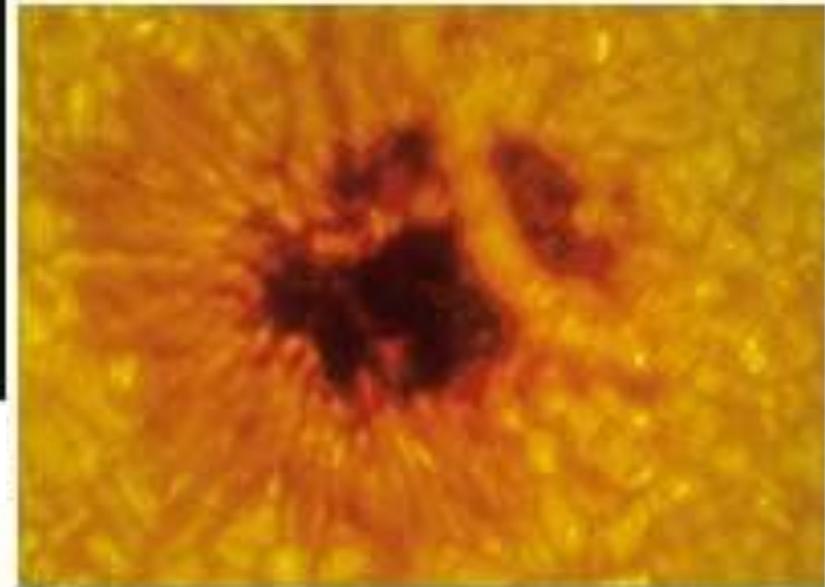
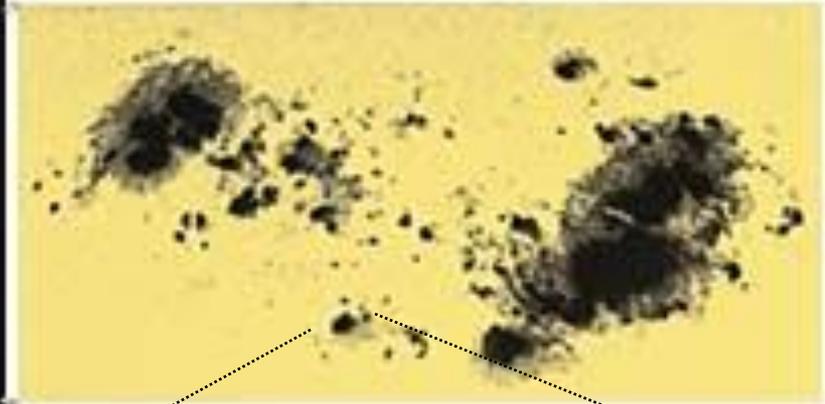
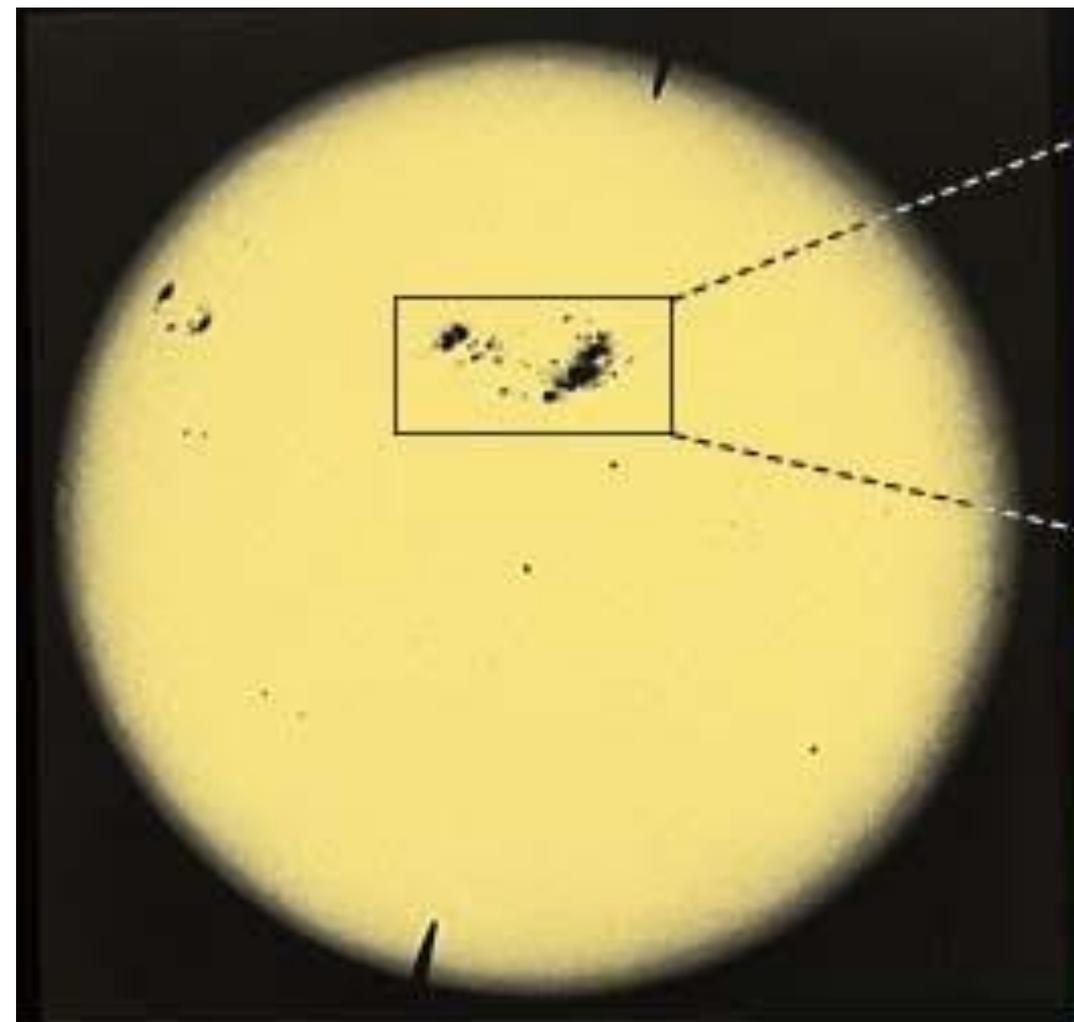


Formação de “uma” mancha solar



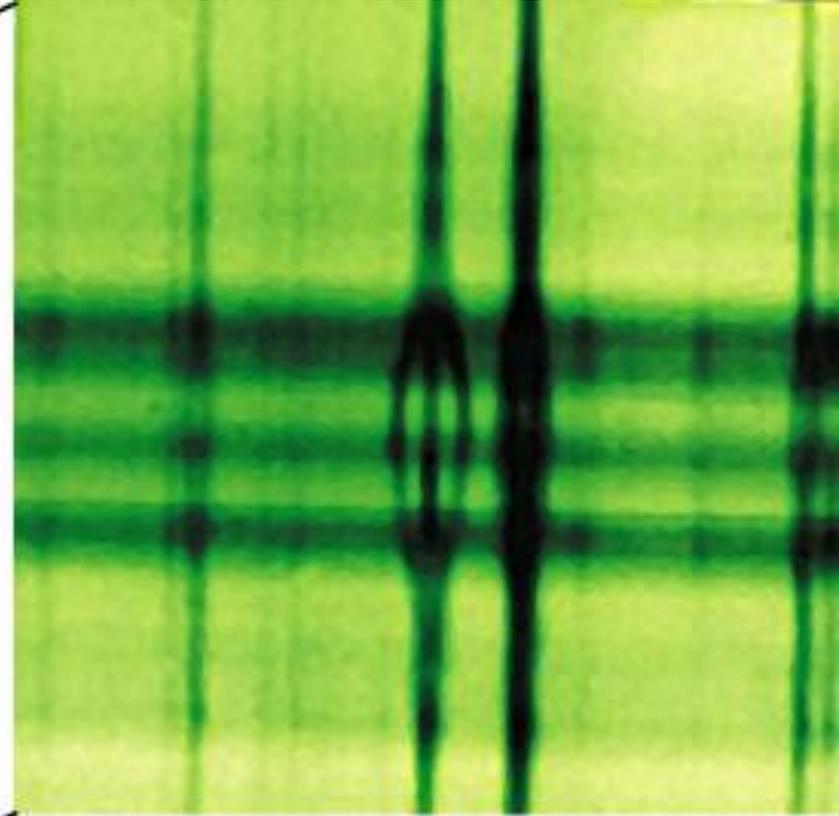
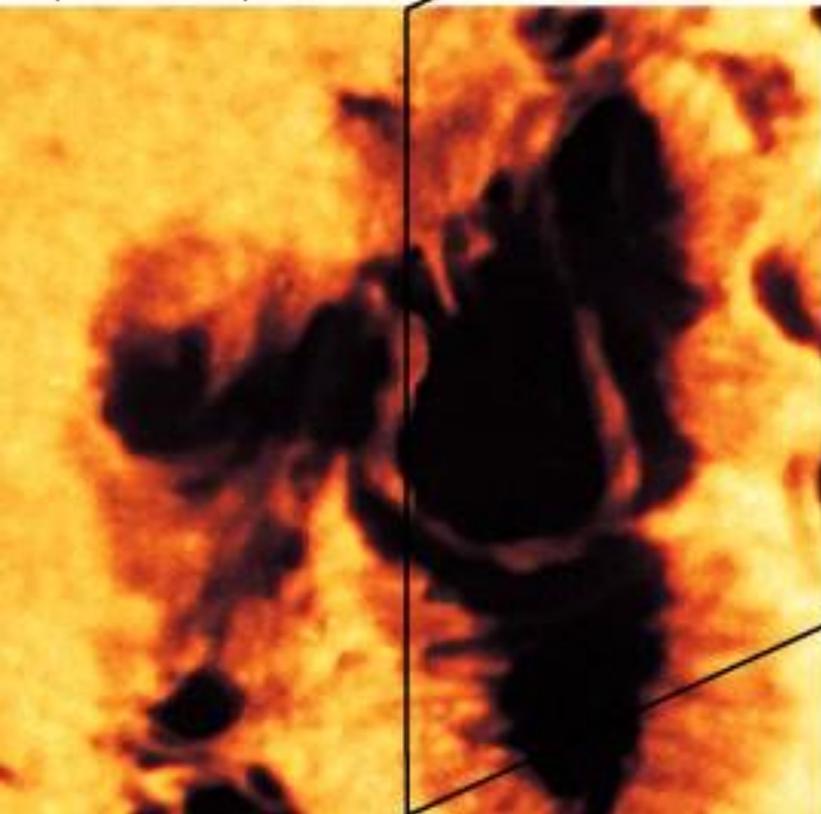
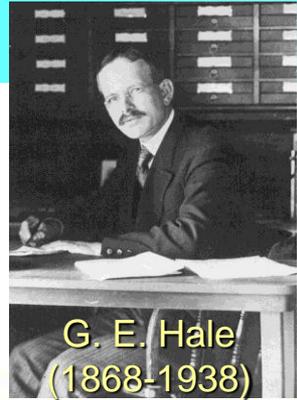


Mancha solar



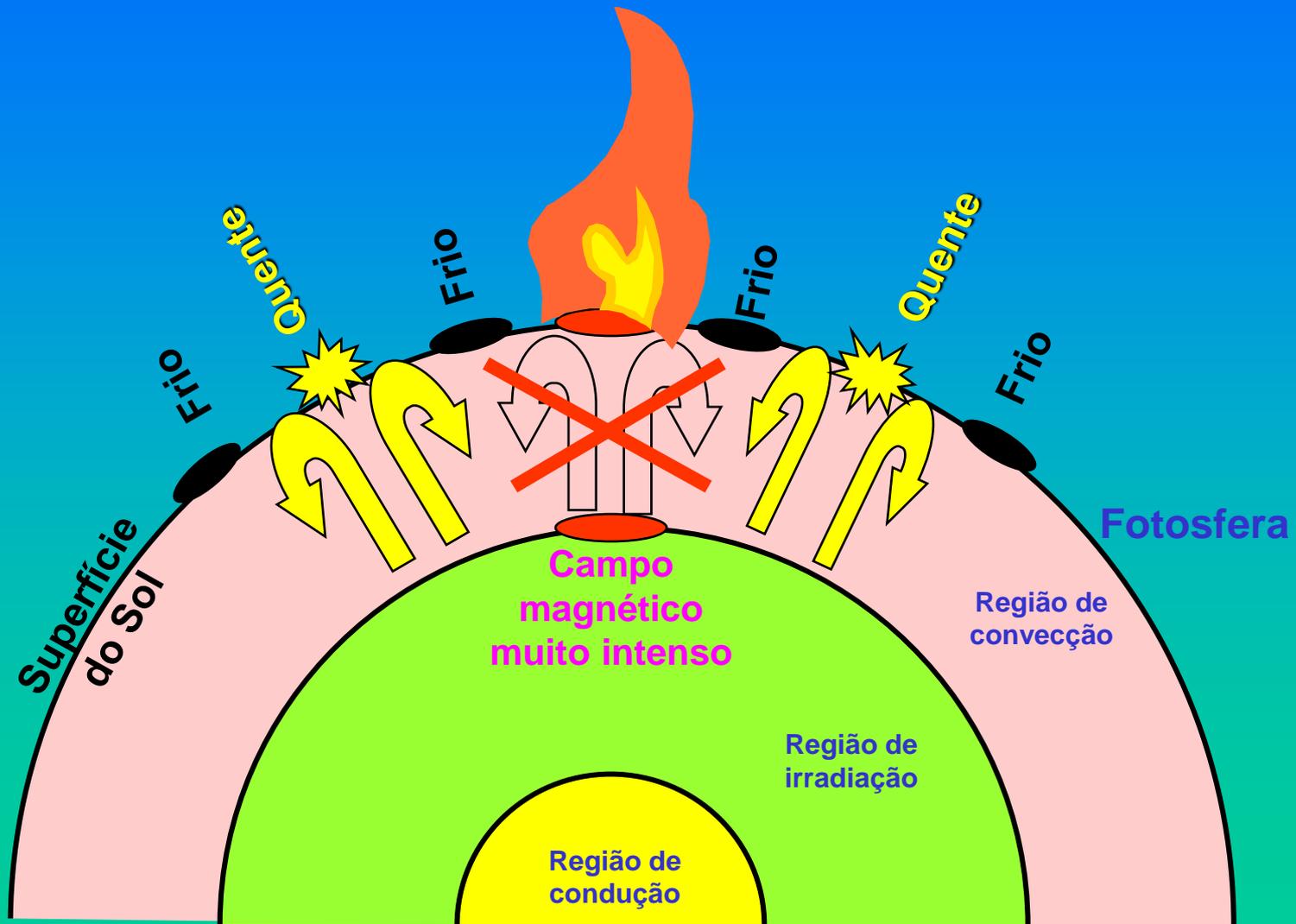
**Manchas
solares**

Efeito Zeemann numa mancha solar

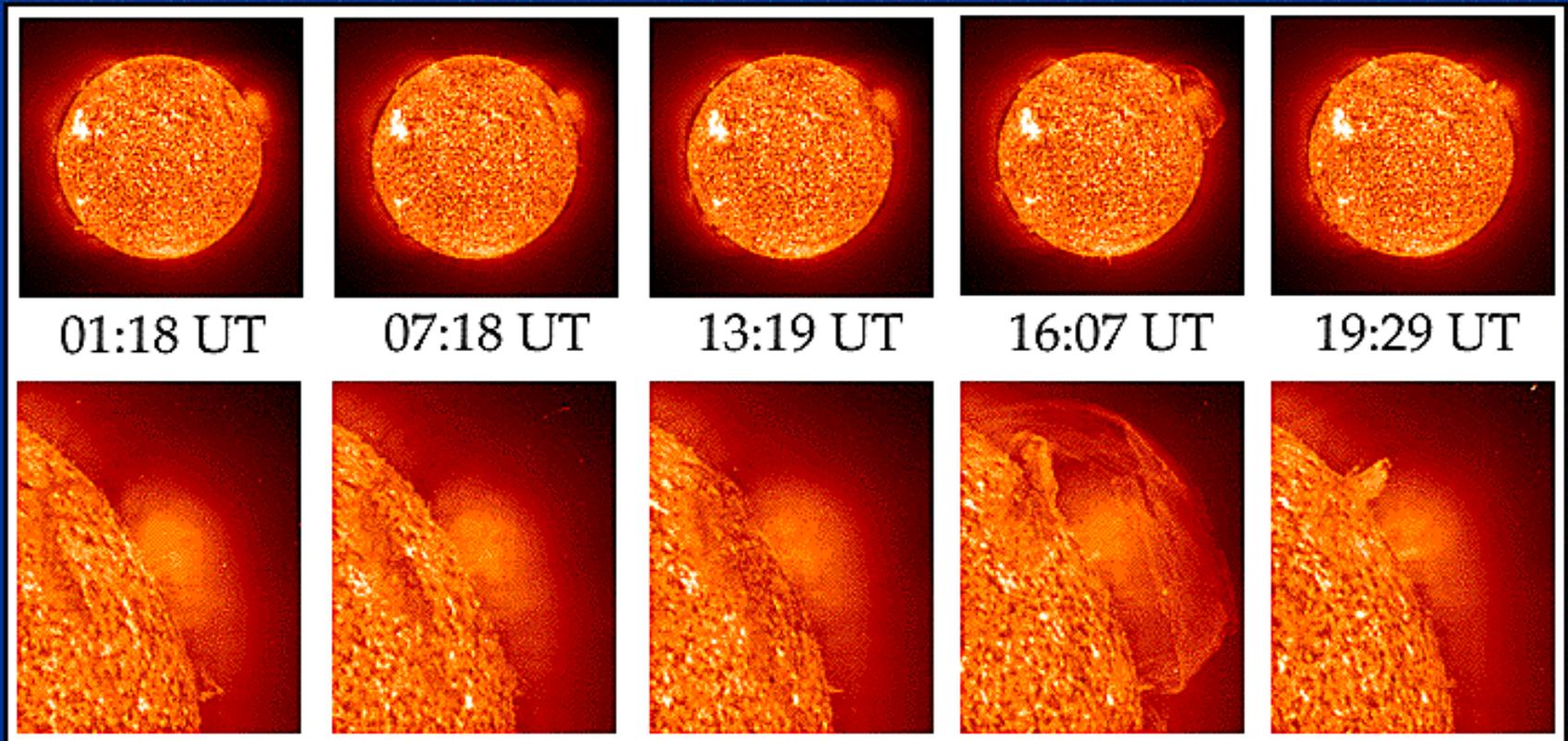


**Desdobramento das
linhas espectrais**

Erupção solar

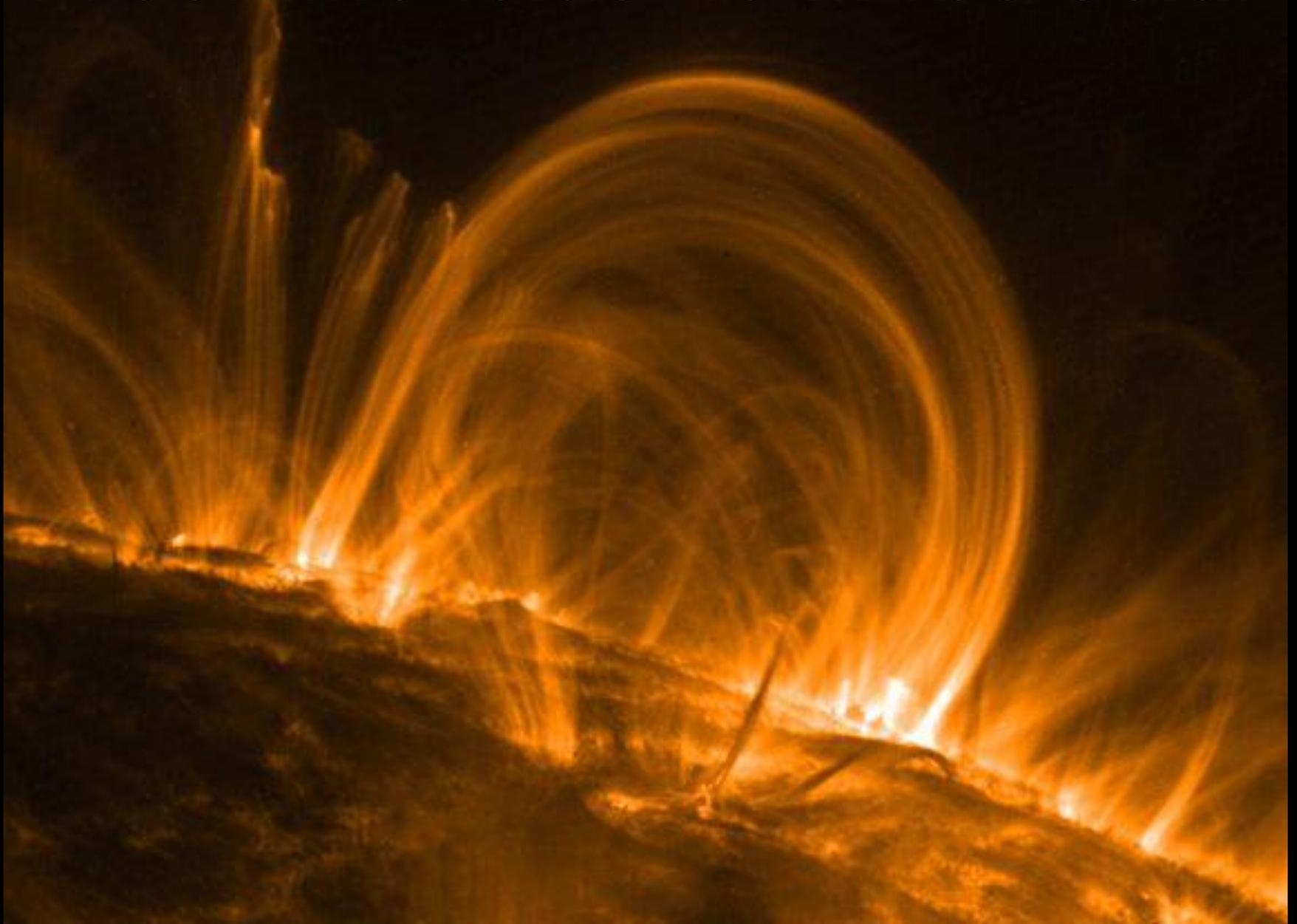


Seqüência de uma Erupção Solar



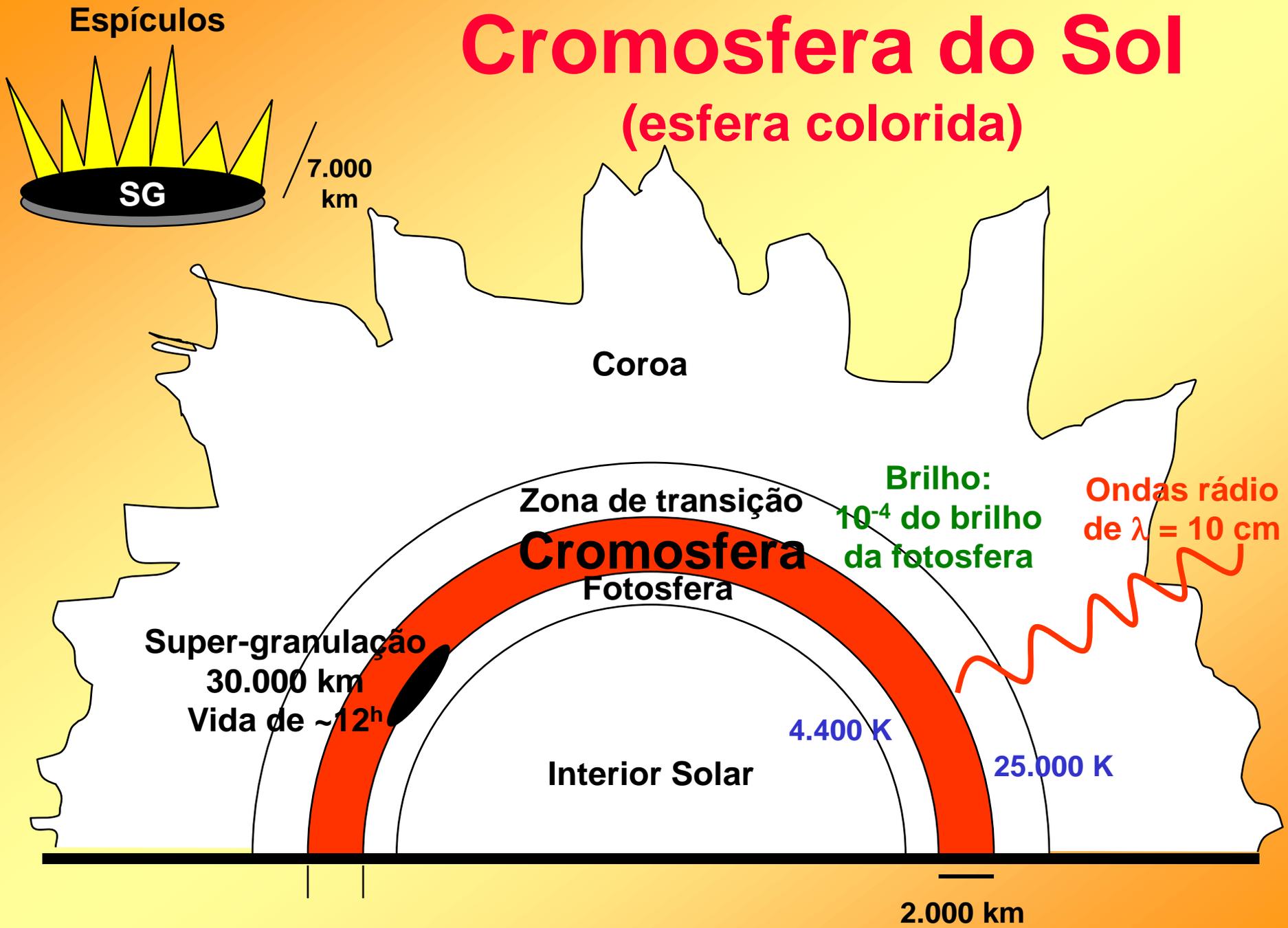
Grande erupção solar atingindo uma altura de 28 raios terrestres

Proeminências no limbo solar



Atmosfera do Sol

Cromosfera do Sol (esfera colorida)



Espículos

SG

7.000
km

Coroa

Zona de transição

Cromosfera

Fotosfera

Brilho:
 10^{-4} do brilho
da fotosfera

Ondas rádio
de $\lambda = 10$ cm

Super-granulação
30.000 km
Vida de ~12^h

4.400 K

25.000 K

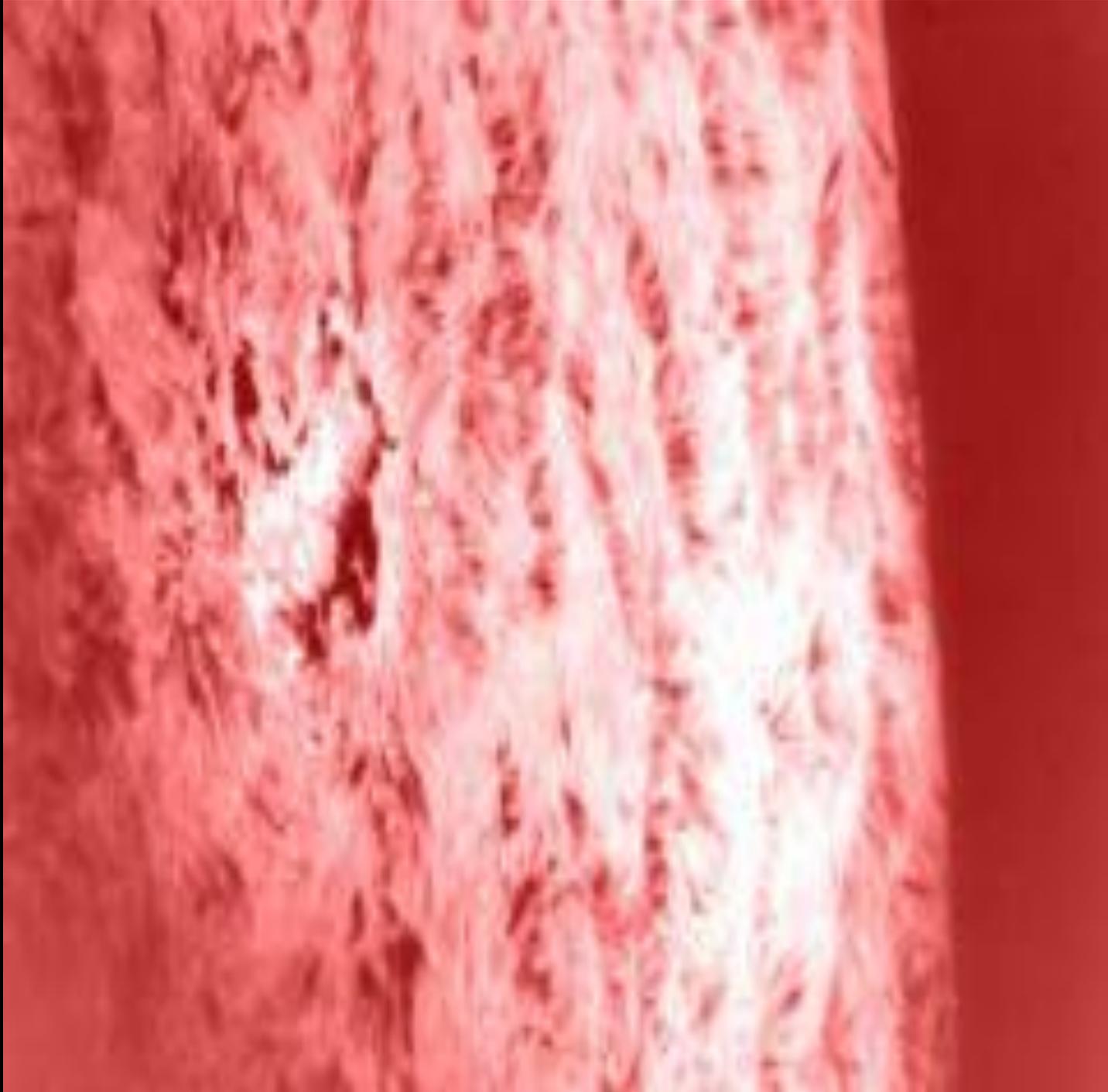
Interior Solar

2.000 km

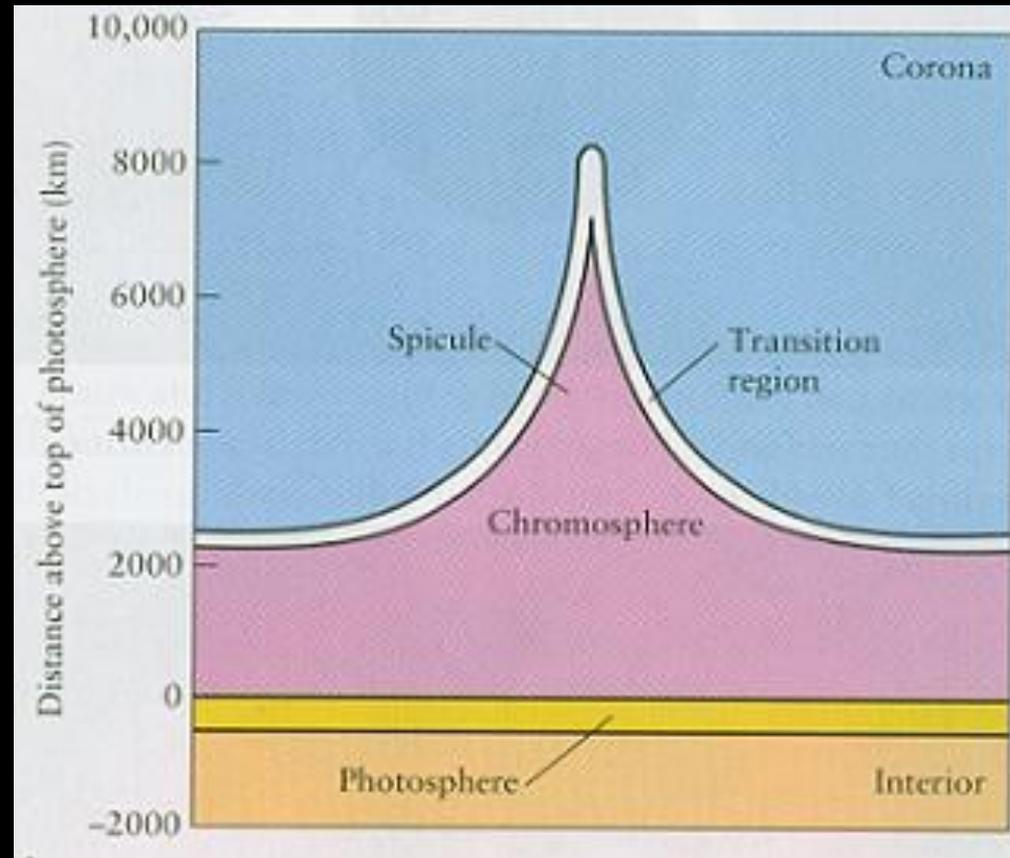
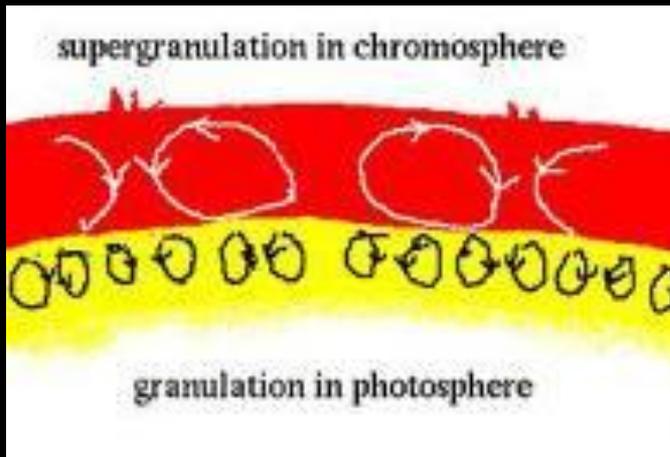
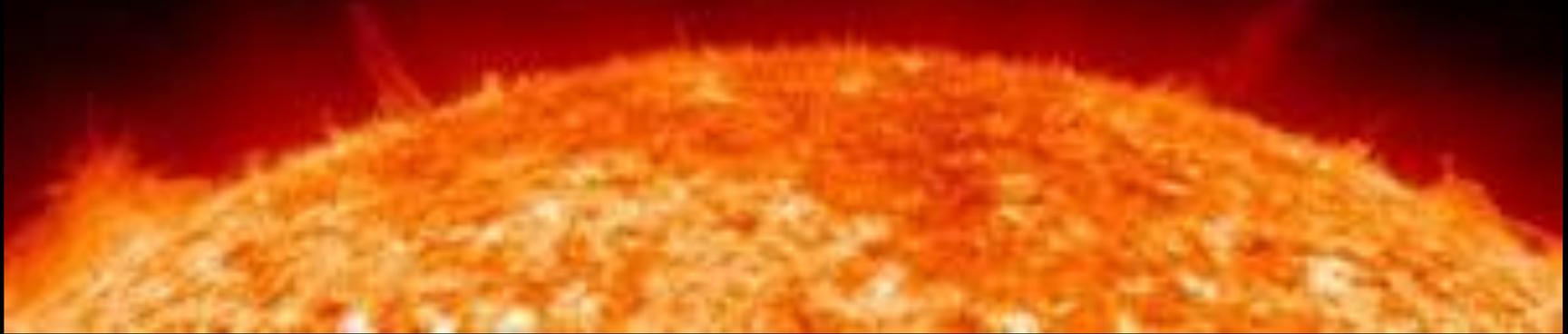
A photograph of a total solar eclipse. The sun is completely obscured by the moon, leaving a dark circular disk in the center. A thin, glowing ring of light, the solar chromosphere, is visible around the edge of the moon. The chromosphere has a reddish-pink hue. The background is black.

Cromosfera do Sol

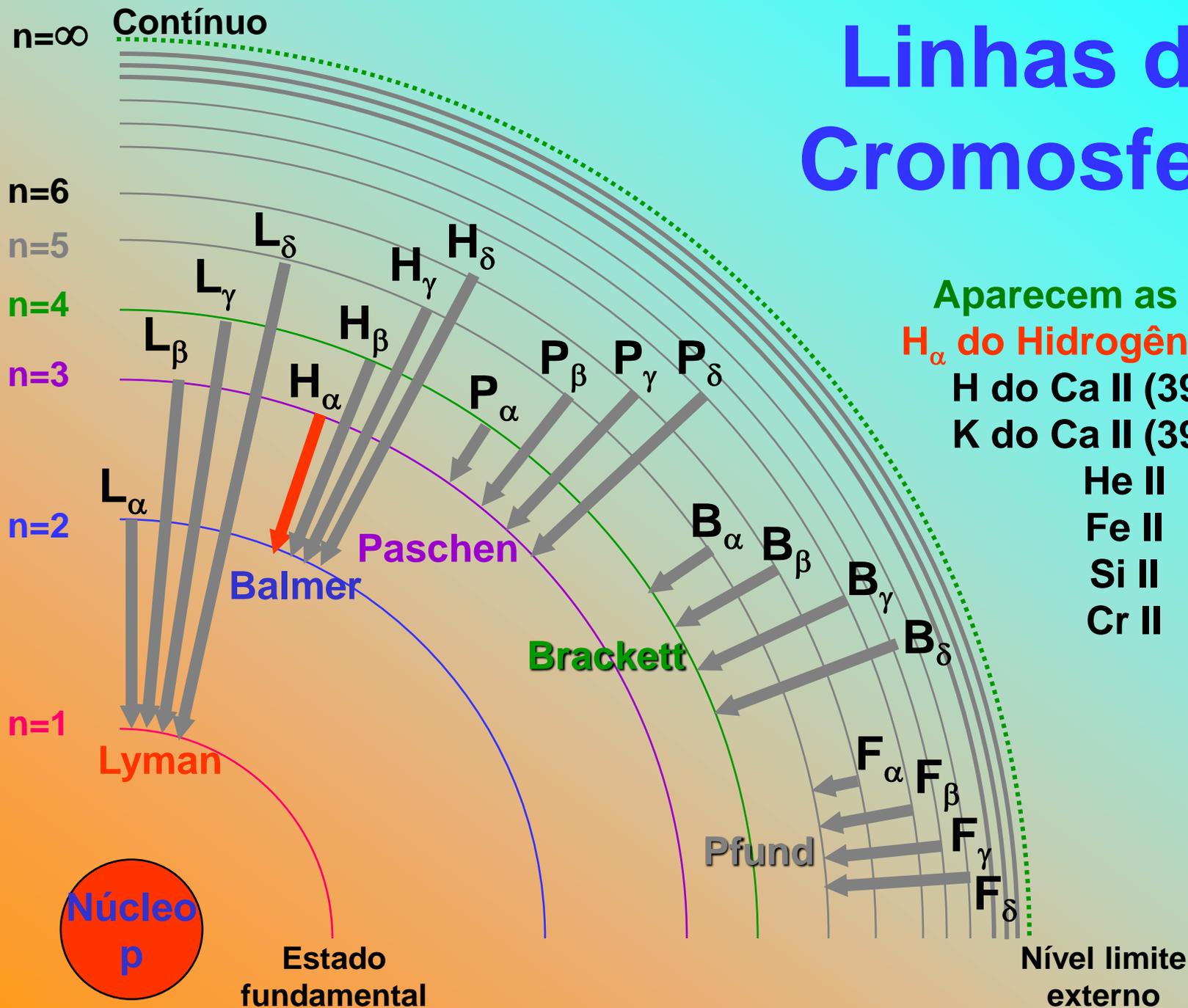
Cromosfera solar



Espículos



Linhas da Cromosfera



Aparecem as linhas:

H_α do Hidrogênio (Balmer)

H do Ca II (3968 Å)

K do Ca II (3933 Å)

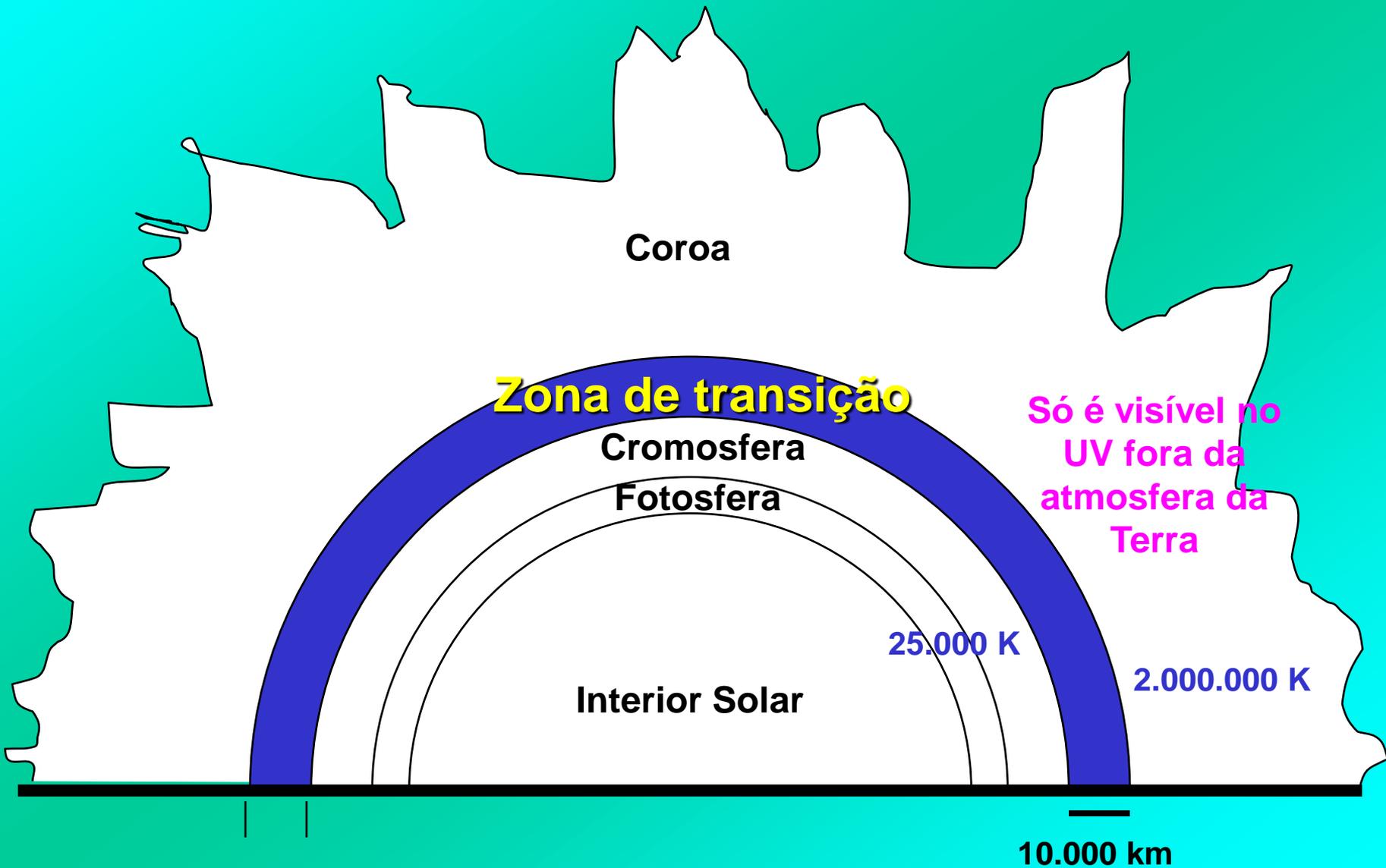
He II

Fe II

Si II

Cr II

Zona de Transição do Sol

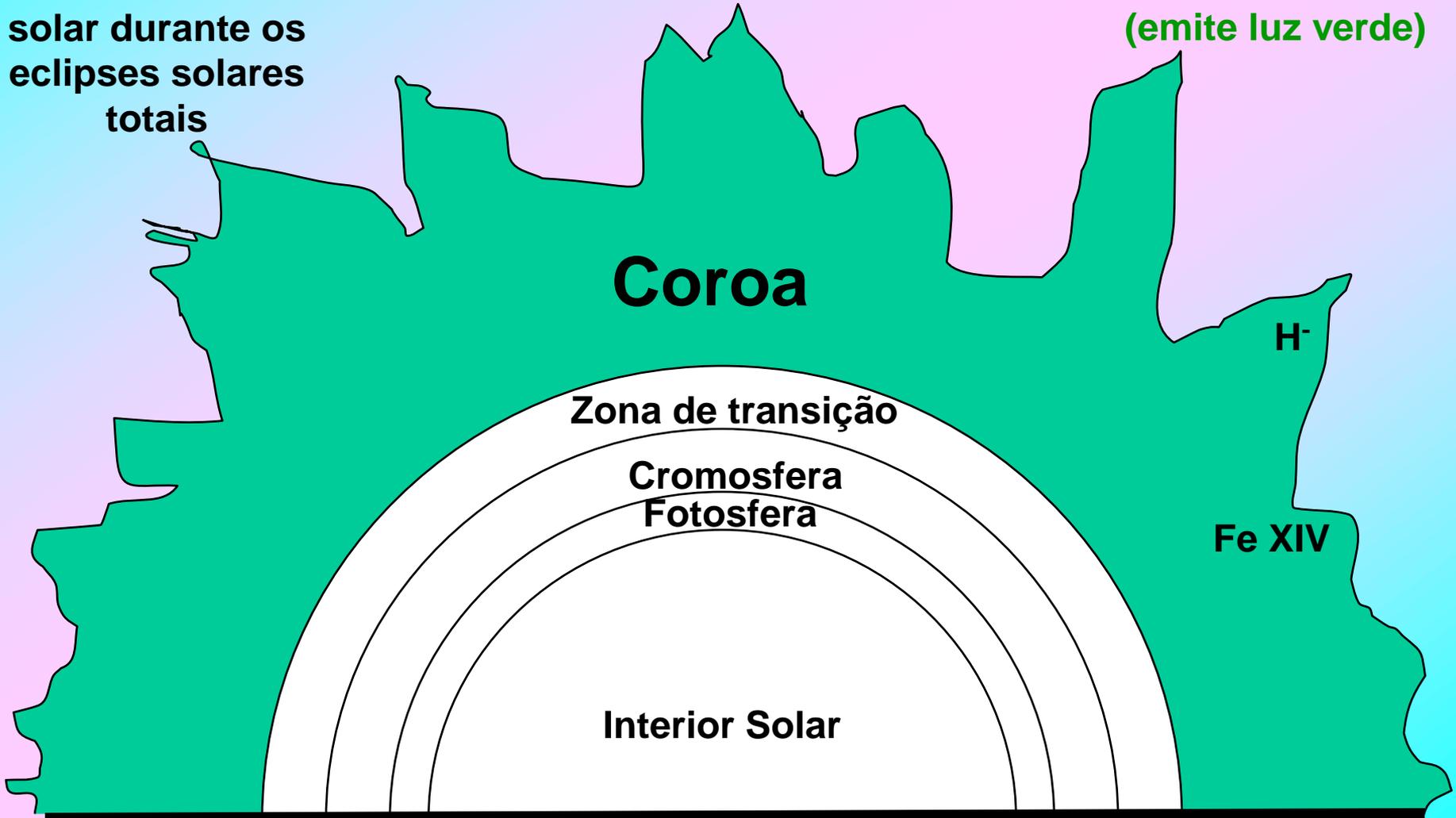


Coroa do Sol

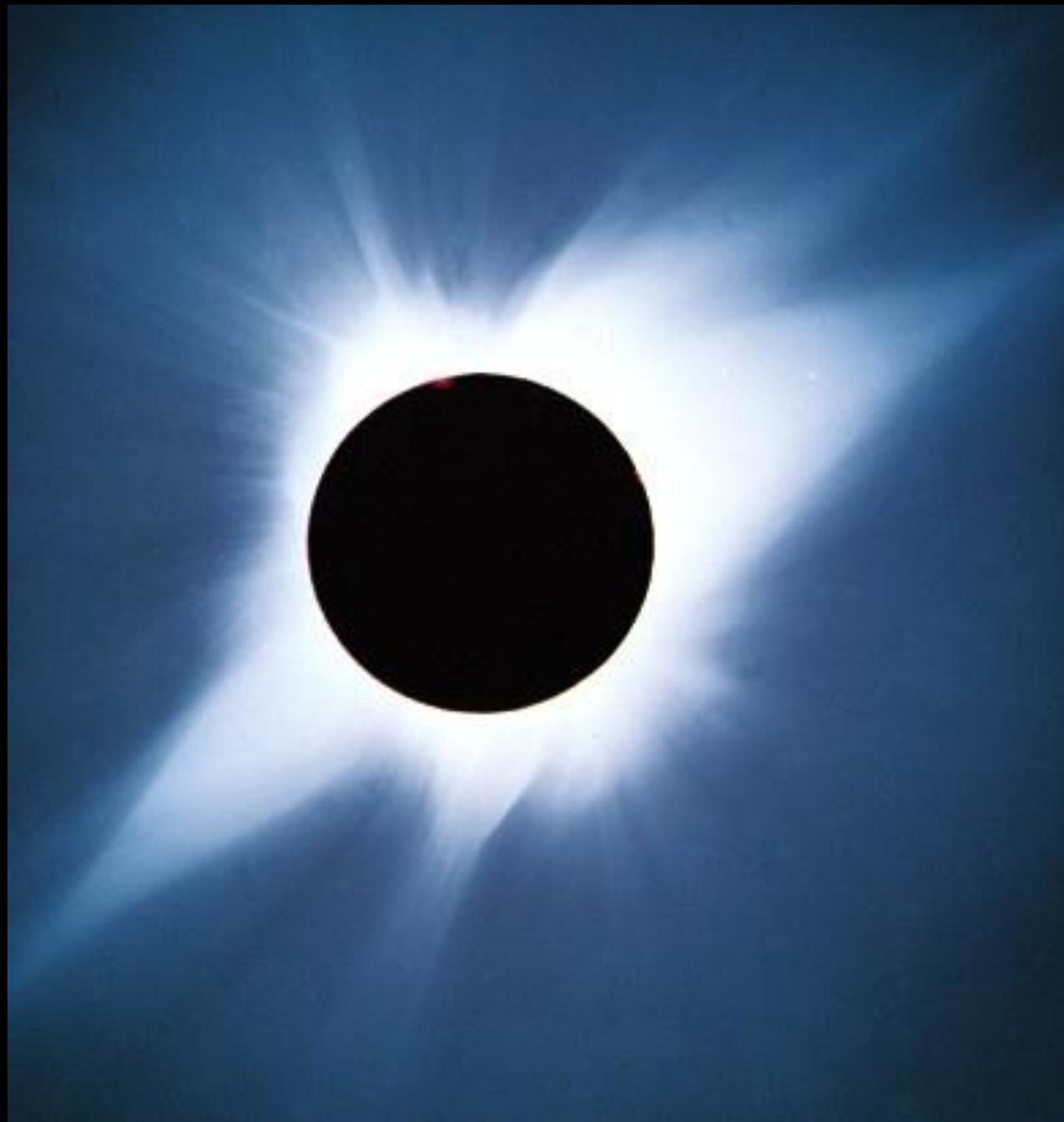
Coronógrafo

Instrumento para observar a coroa solar durante os eclipses solares totais

Fe XIV
Ferro que "perdeu"
13 dos seus 26
elétrons
(emite luz verde)



Coroa solar



Coroa solar

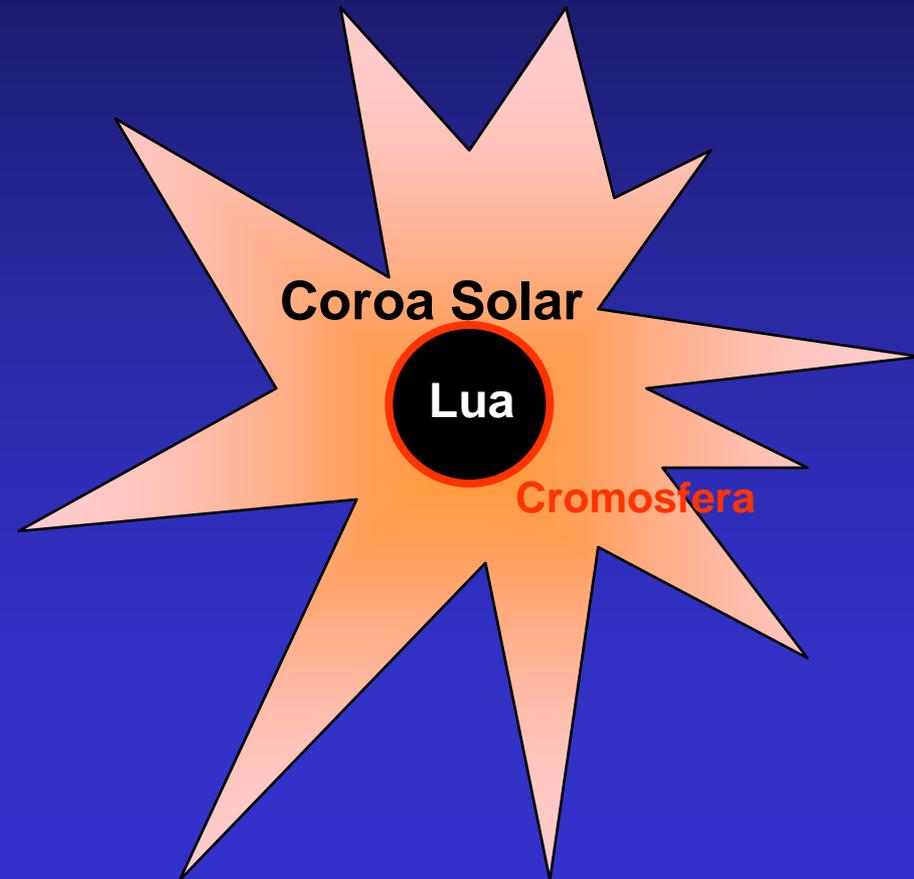


Para que observar o Sol durante o eclipse total?

Sol não eclipsado



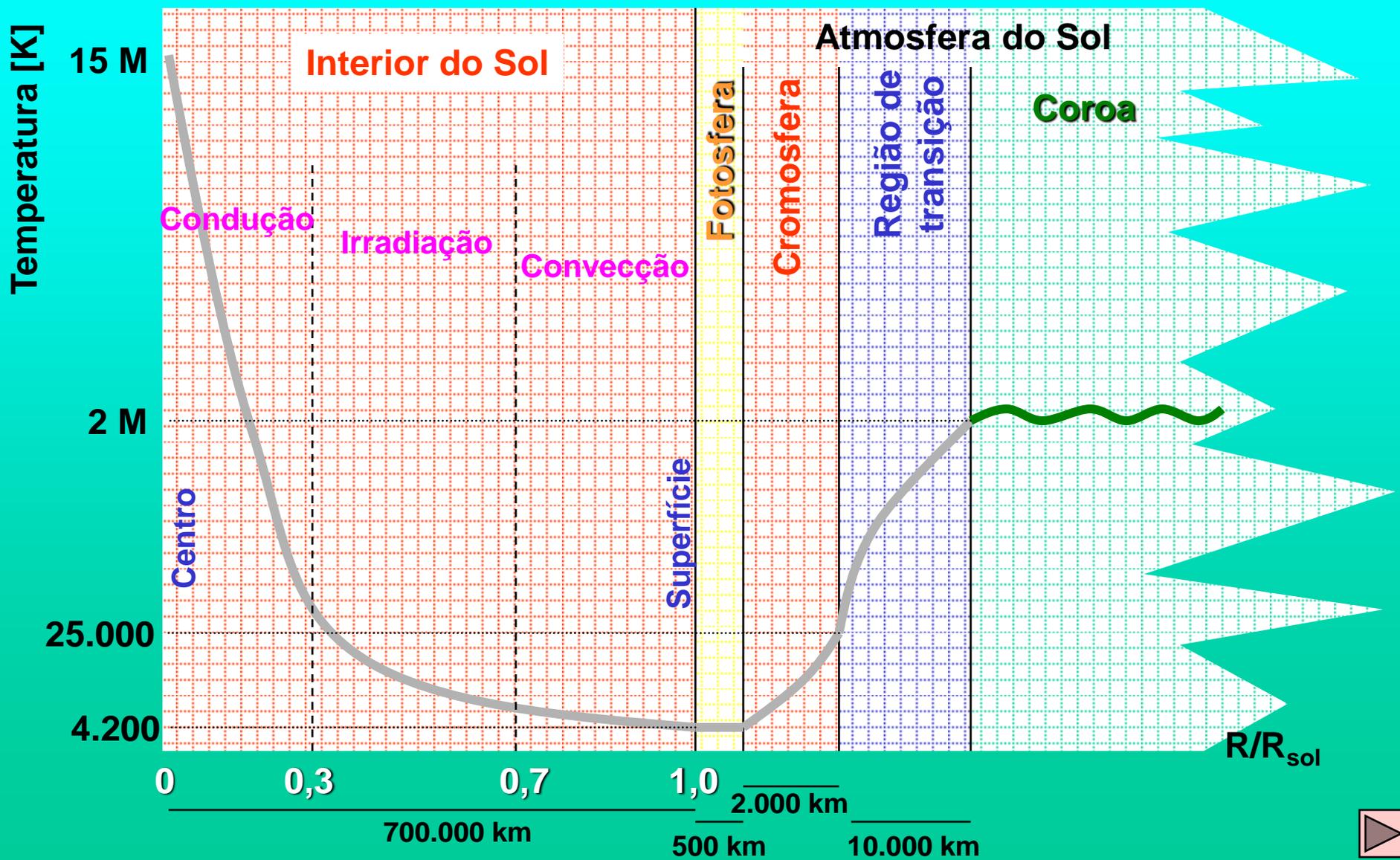
Sol eclipsado totalmente



Coroa solar em diferentes ocasiões



Coroa Solar



Cargas elétricas em campos magnéticos

Cargas elétricas em campos magnéticos

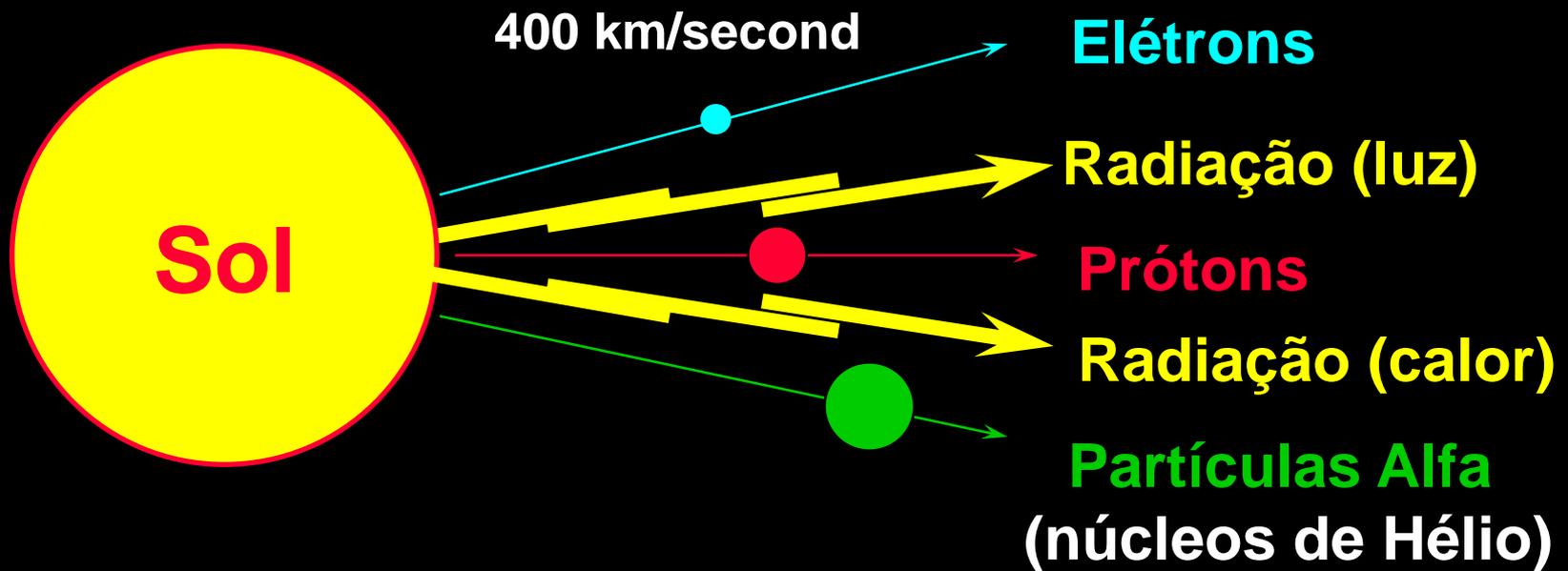


Carga elétrica em movimento num campo magnético é acelerada e emite luz

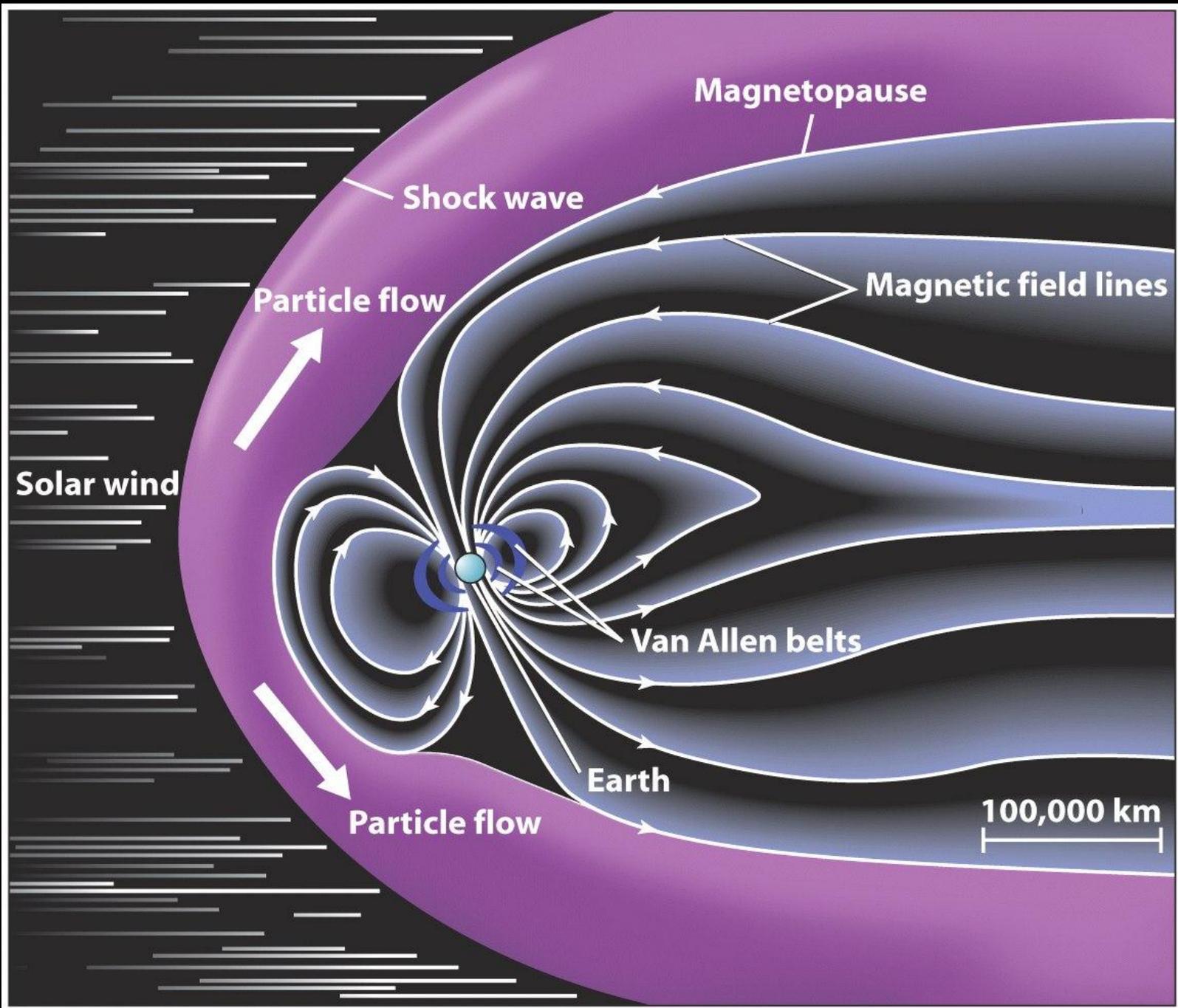
Vento Solar

Vento Solar

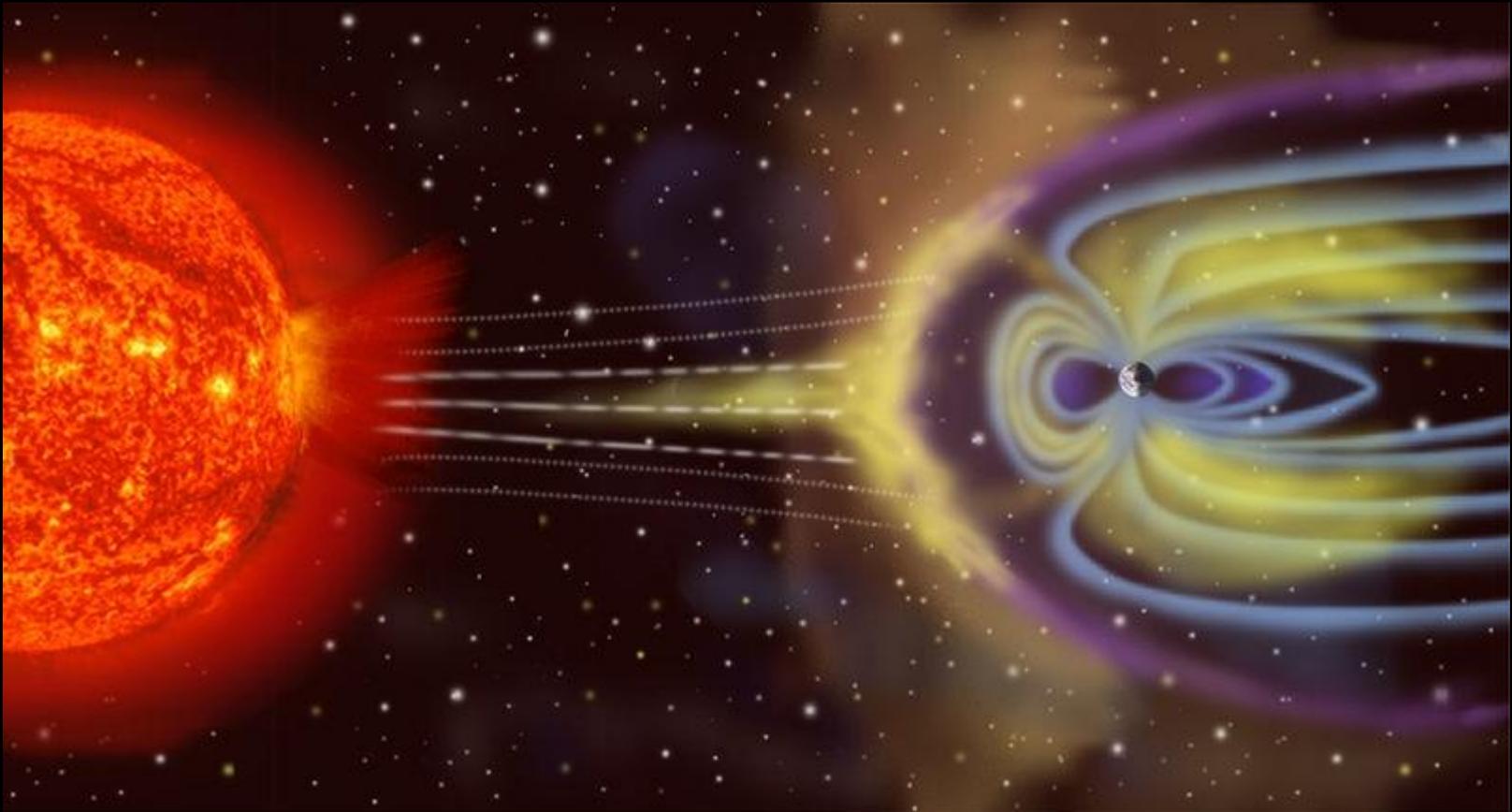
Perda de massa pelo vento solar = 1 milhão de ton por segundo



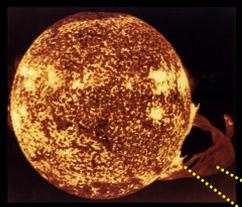
Efeito do vento solar sobre a magnetosfera



Efeitos de explosões solares e de ejeções de massa coronal



Interação do Sol com a Terra



Partícula
alfa



Próton



Nêutron



Elétron



α^{++}
(dias)



n^0
(horas)



p^+
(horas)



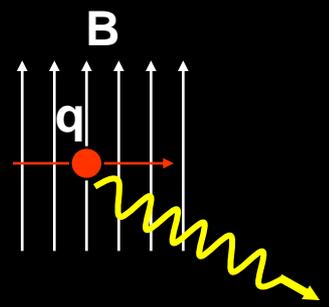
e^-
(horas)

08^m15^s

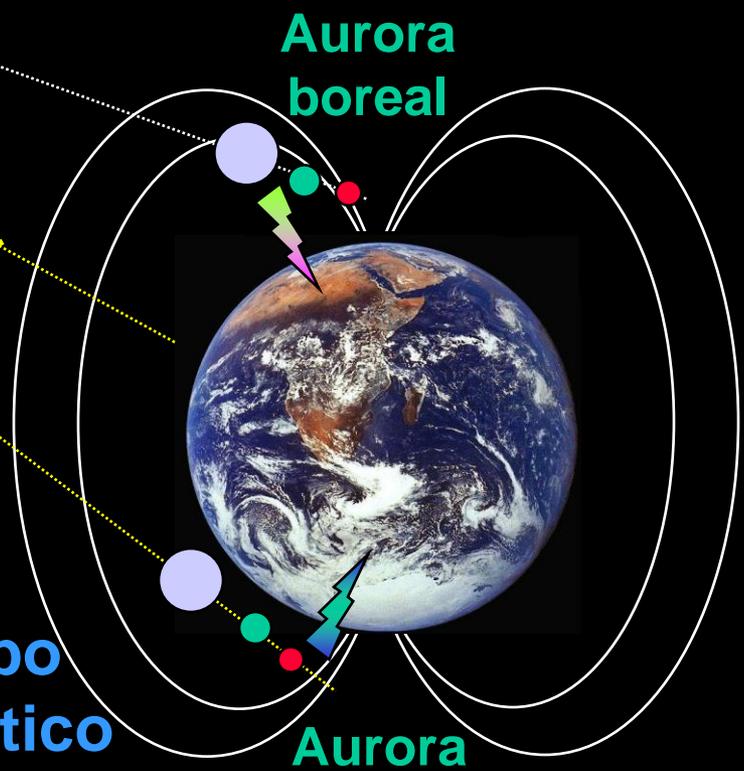


Luz

Interação entre
carga e campo
magnético



Campo
magnético
terrestre



Aurora
boreal

Aurora
austral

Aurora em Iowa



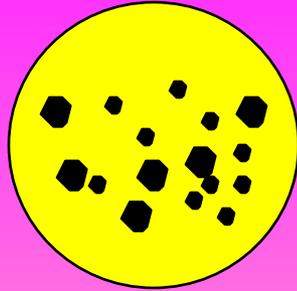
Aurora no Alasca

2005
jan

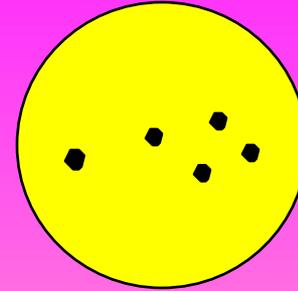


Ciclo Solar

Ciclo solar de 11 anos

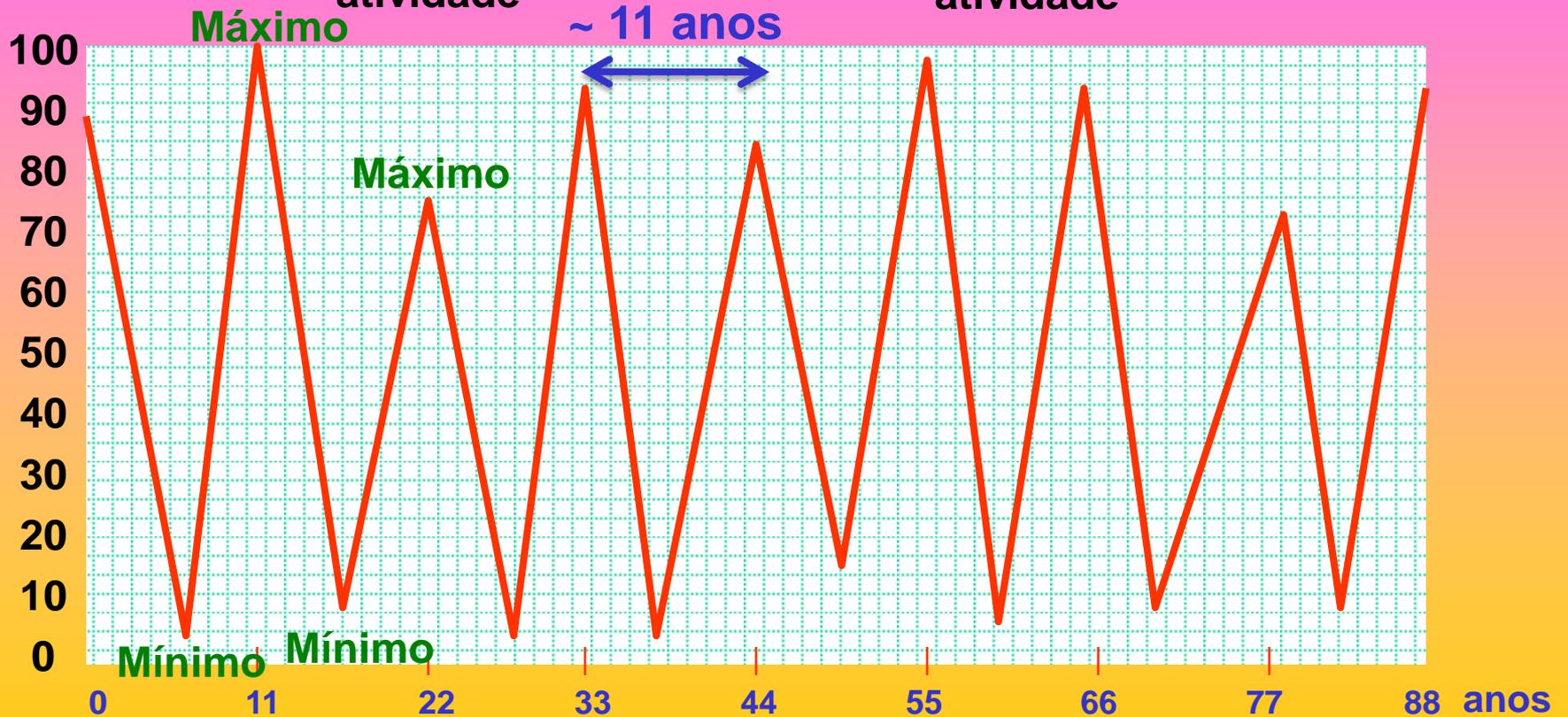


Máxima atividade



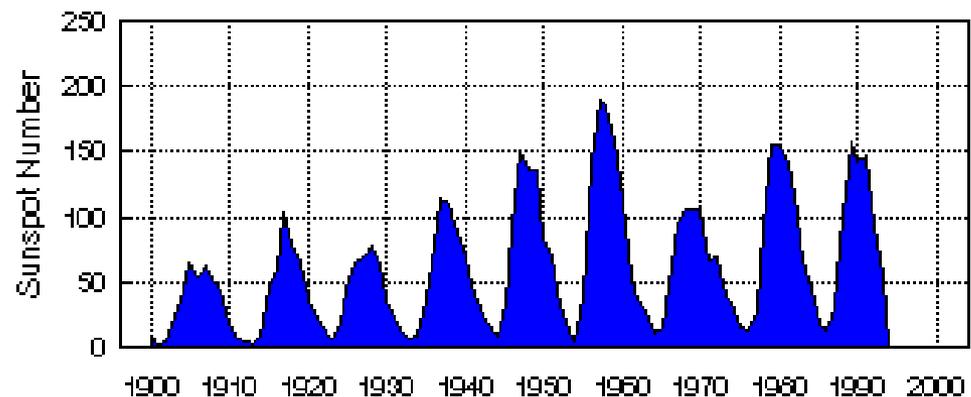
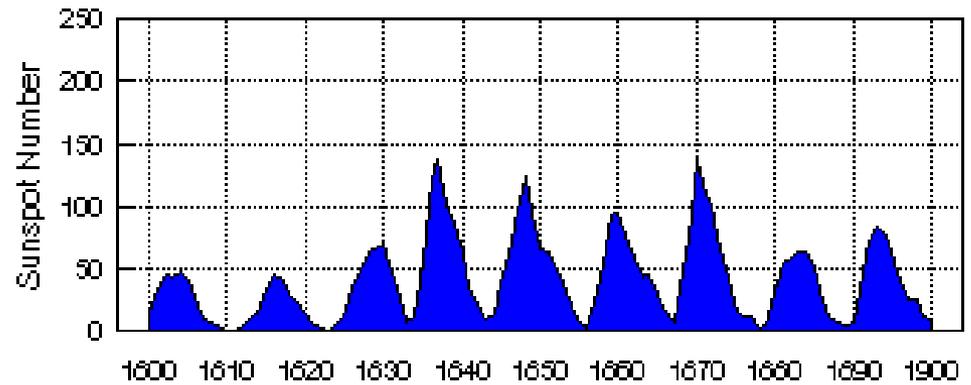
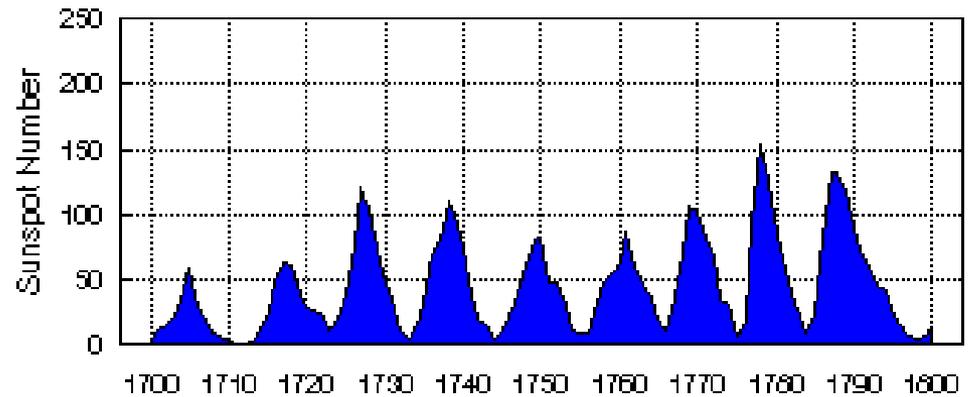
Mínima atividade

Número de manchas

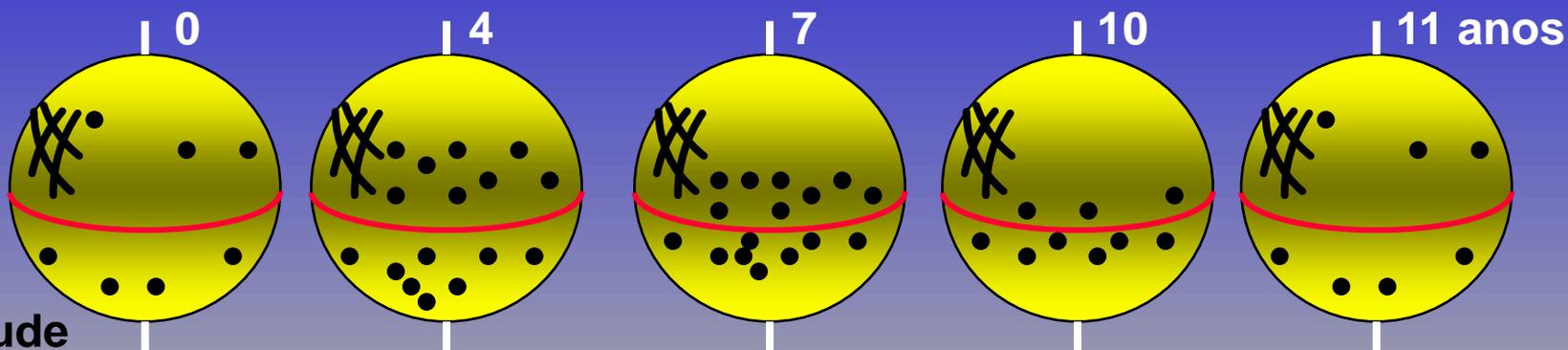


Número de manchas solares ao longo do tempo

Annual Sunspot Numbers: 1700-1993



Local de nascimento das manchas



Latitude solar

45°

30

15

0°

-15

-30

-45°

0

11

22

33

44

55

66

77

88 anos

Equador

Gráfico "asa de borboleta" dos locais de nascimento das manchas solares ao longo do ciclo de 11 anos

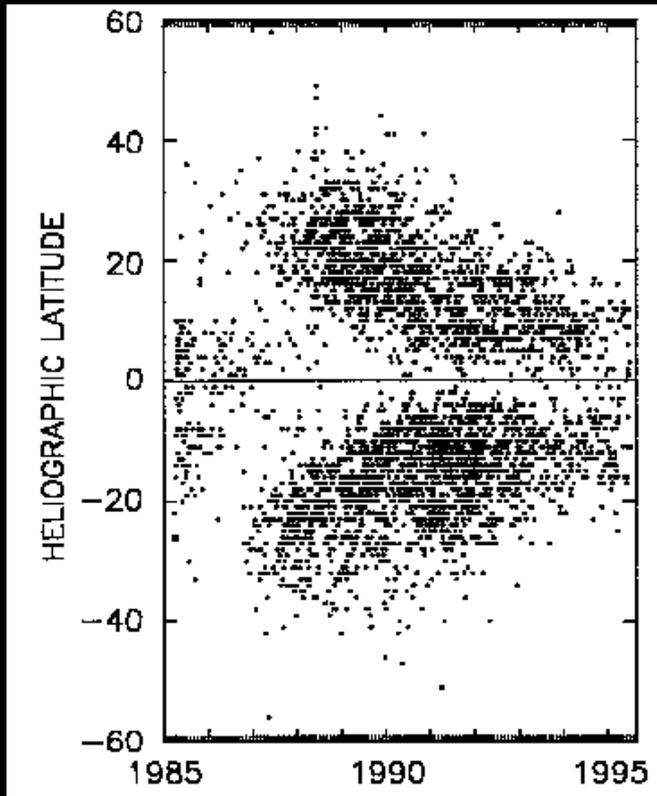
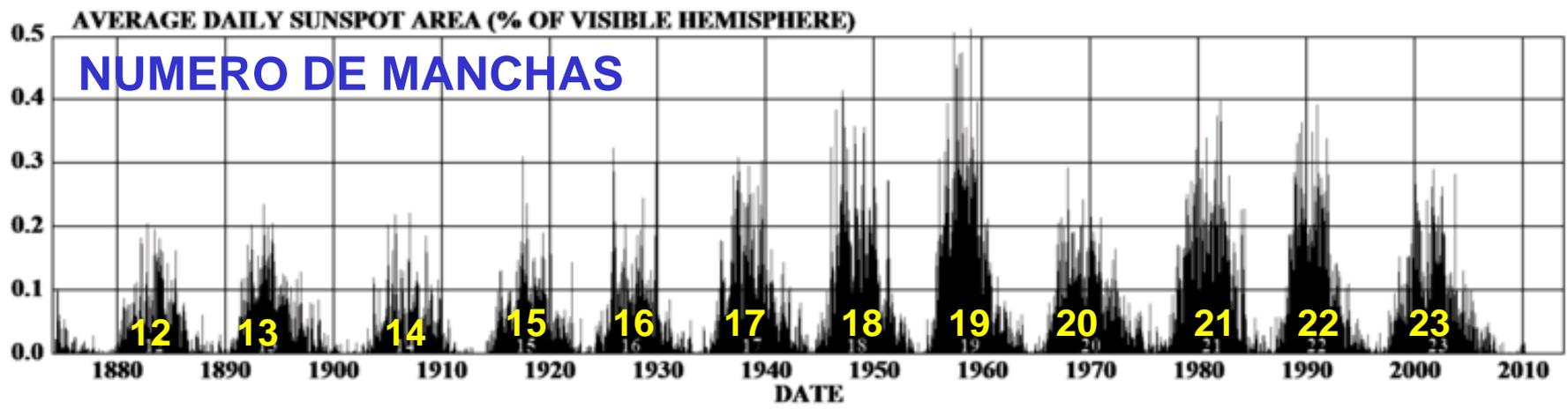
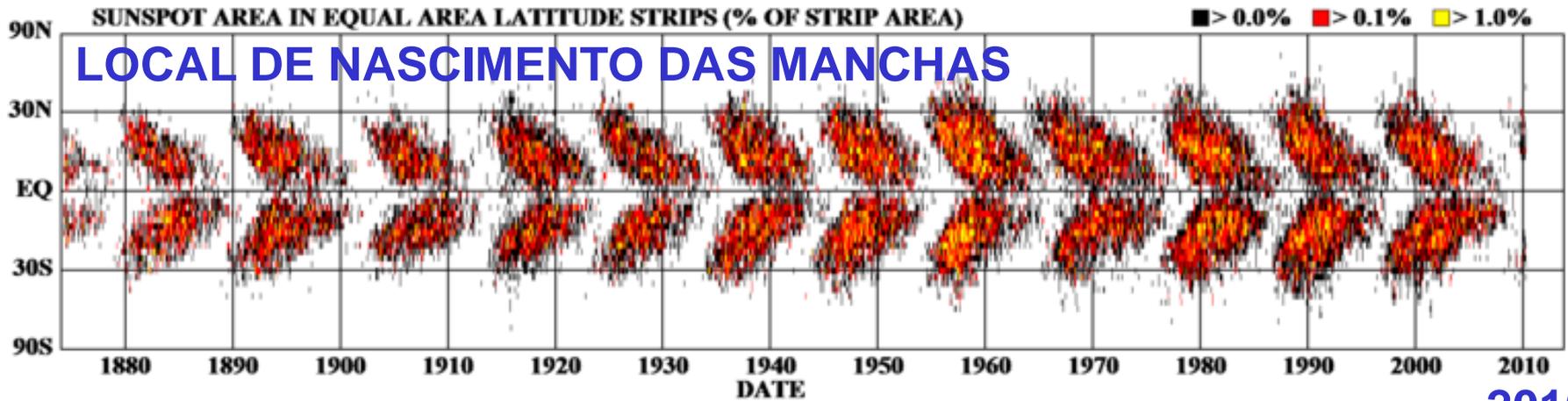


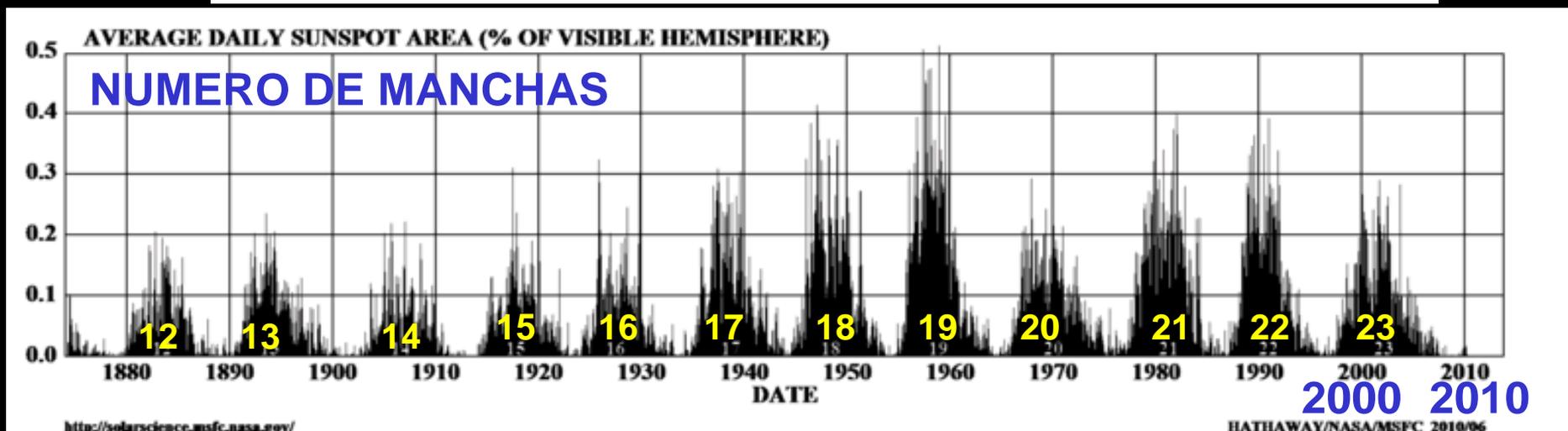
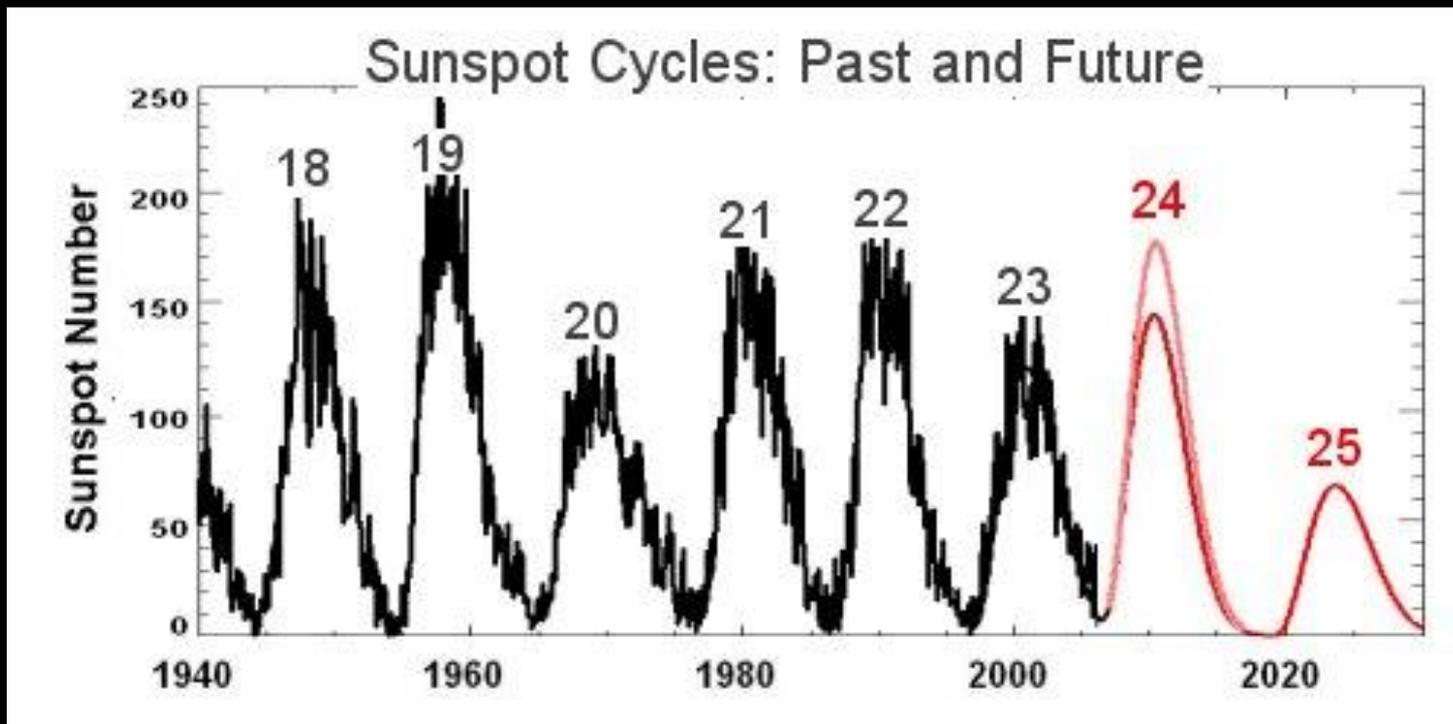
Gráfico "asa de borboleta" dos locais de nascimento das manchas solares ao longo do ciclo de 11 anos

DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS



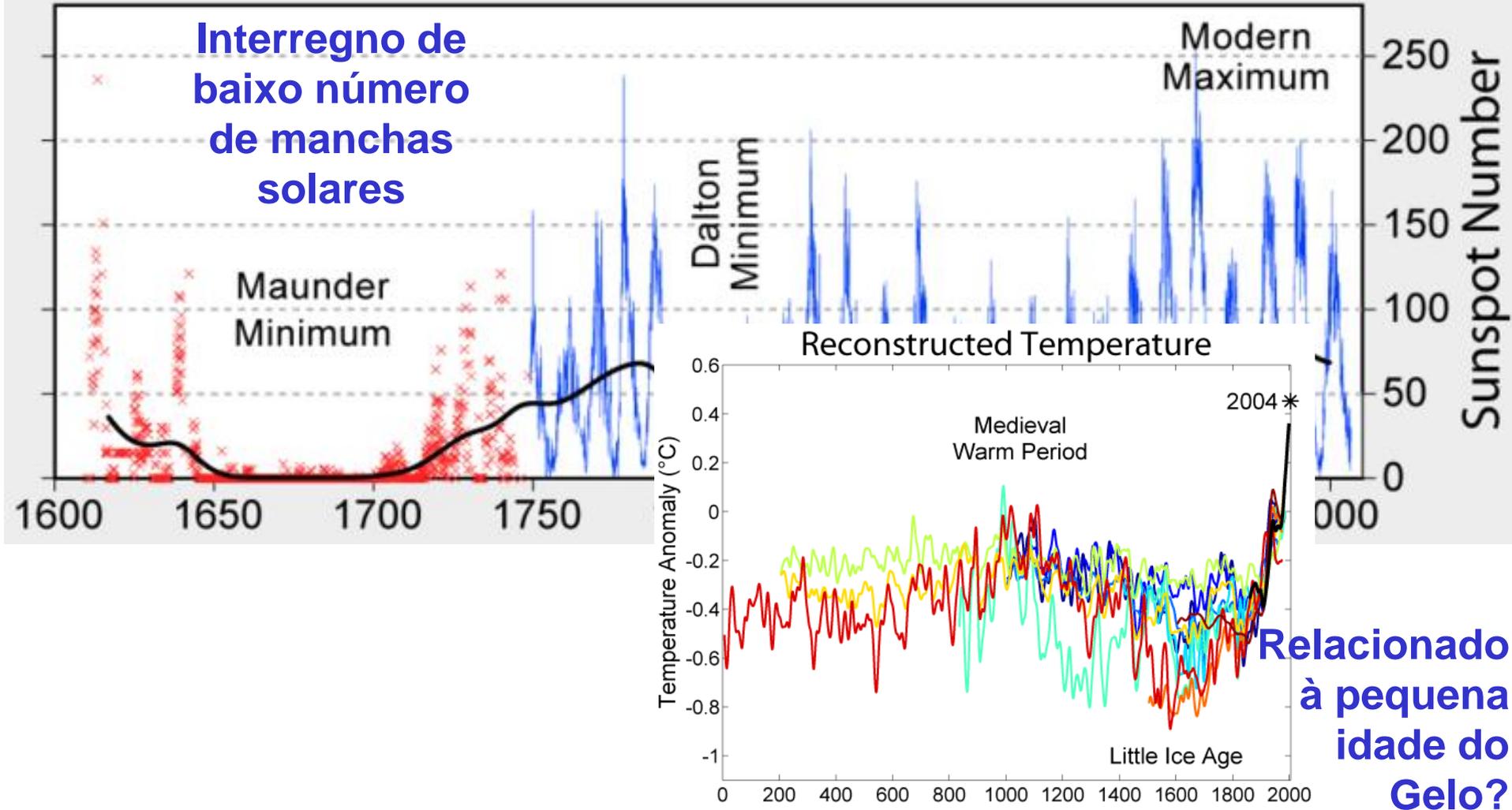
Previsão de manchas solares

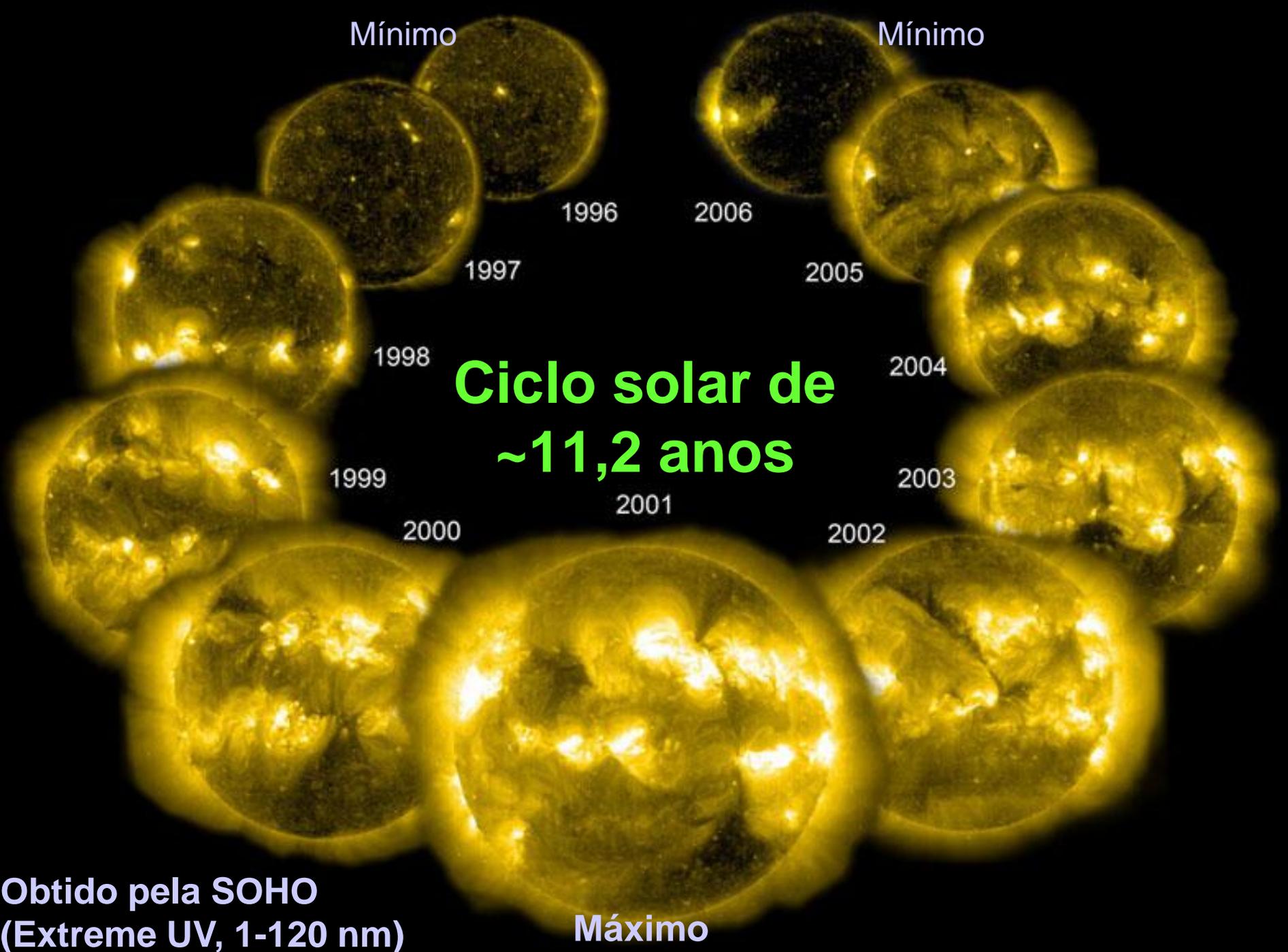
Em 2006 foi predito máximo de atividade em 2010-2011 (!)



Mínimo de Maunder no número de manchas solares

400 Years of Sunspot Observations





Mínimo

Mínimo

1996

2006

1997

2005

1998

2004

**Ciclo solar de
~11,2 anos**

1999

2003

2001

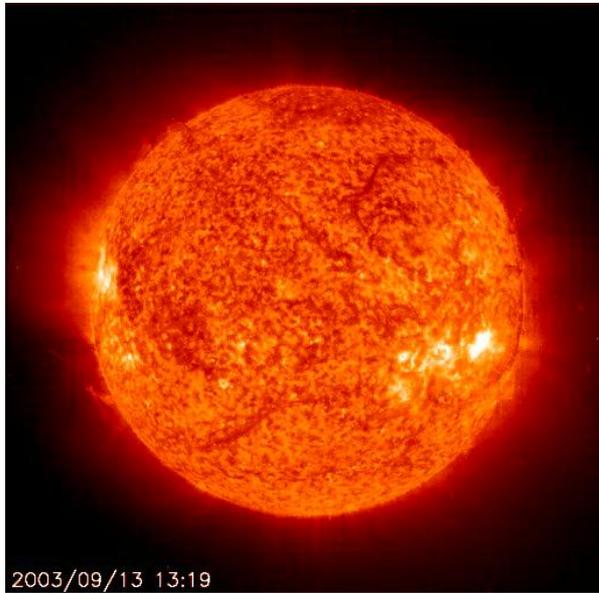
2000

2002

Máximo

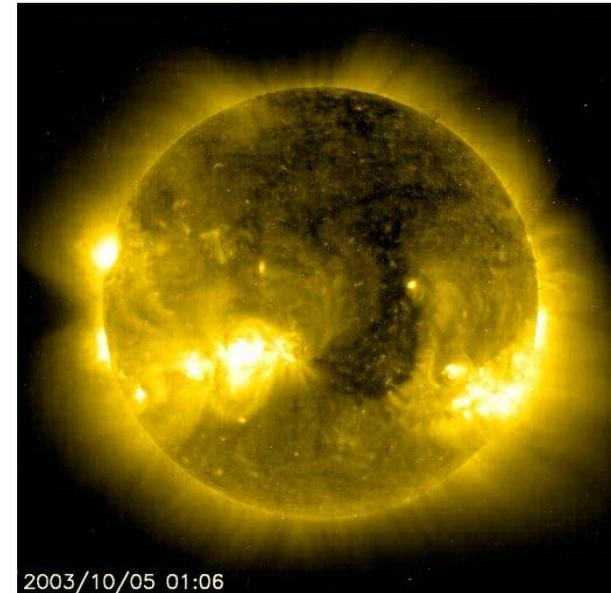
Obtido pela SOHO
(Extreme UV, 1-120 nm)

Sol visto em diversas cores



2003/09/13 13:19

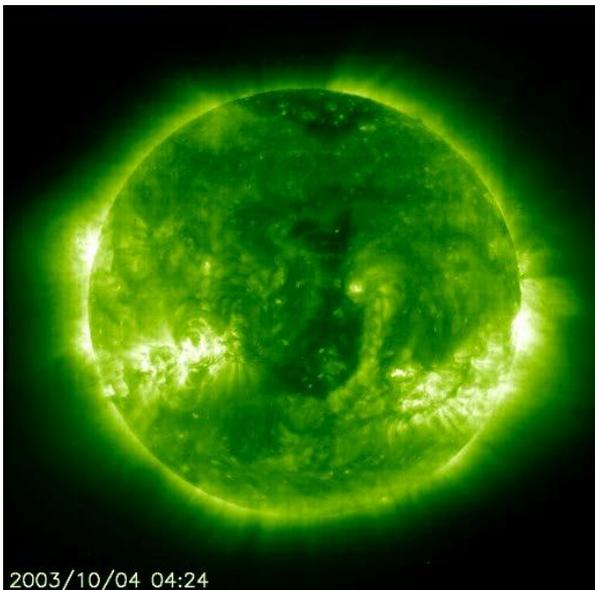
Ultravioleta 304 nm



2003/10/05 01:06

Ultravioleta 284 nm

Ultravioleta 195 nm



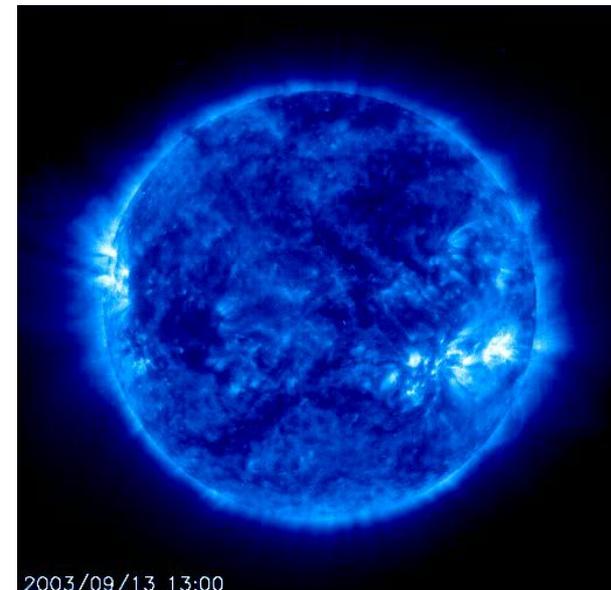
2003/10/04 04:24



2003/09/07 00:00

Visível

Ultravioleta 174 nm

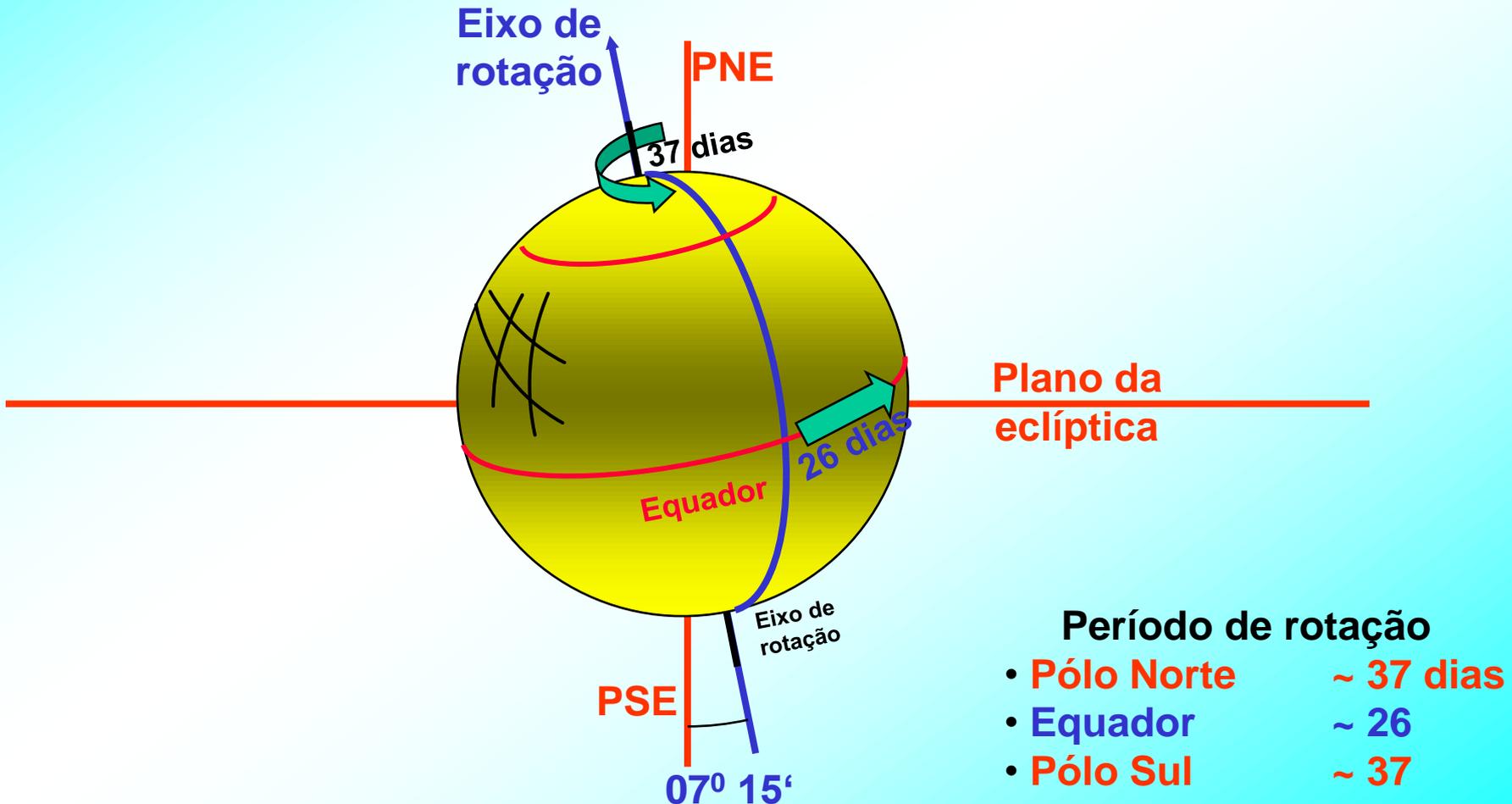


2003/09/13 13:00

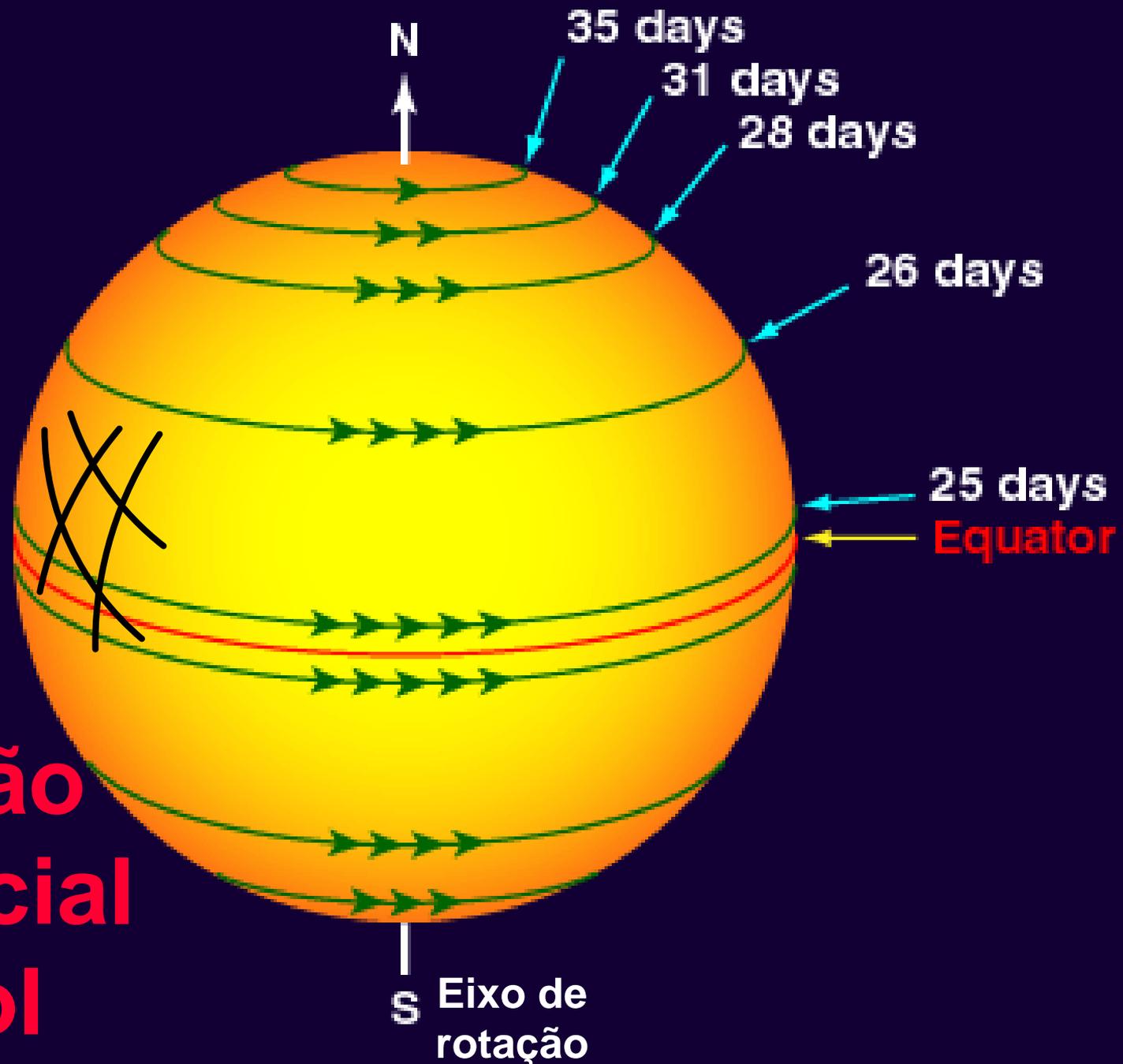
Rotação do Sol

Massa do Sol = 99,866% Massa Sistema Solar

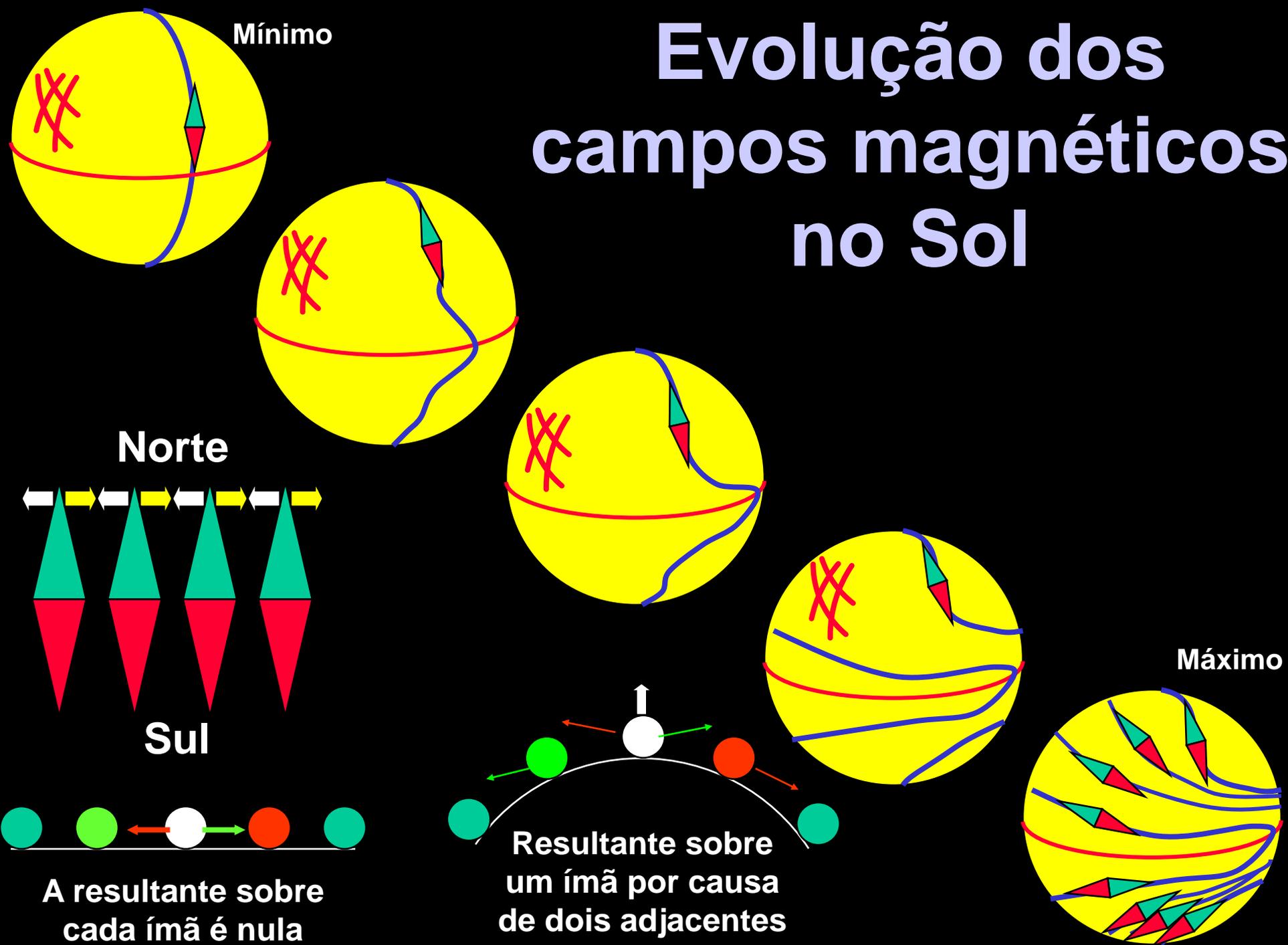
Momento angular do Sol = 1% Momento angular dos planetas



Rotação diferencial do Sol

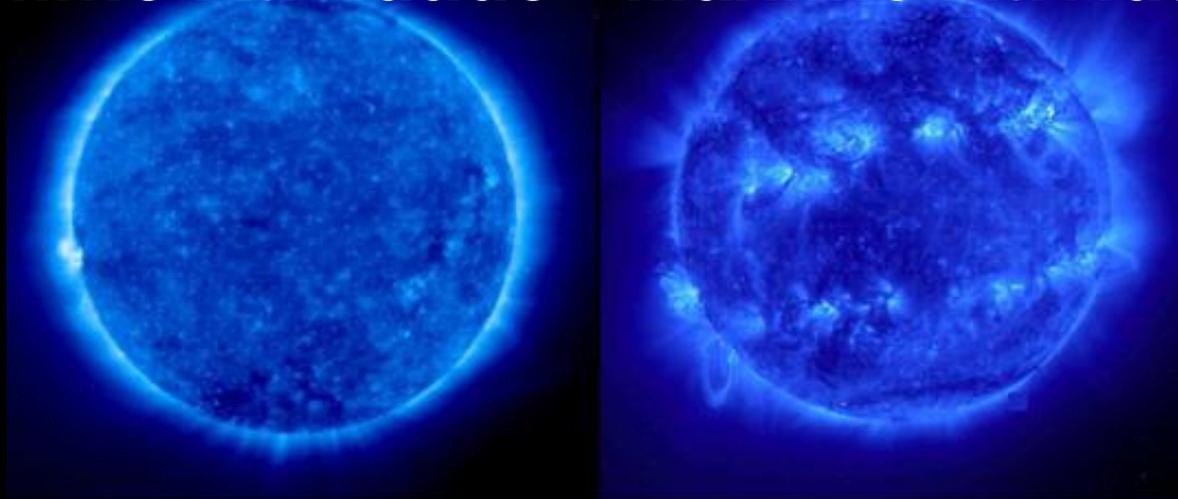


Evolução dos campos magnéticos no Sol

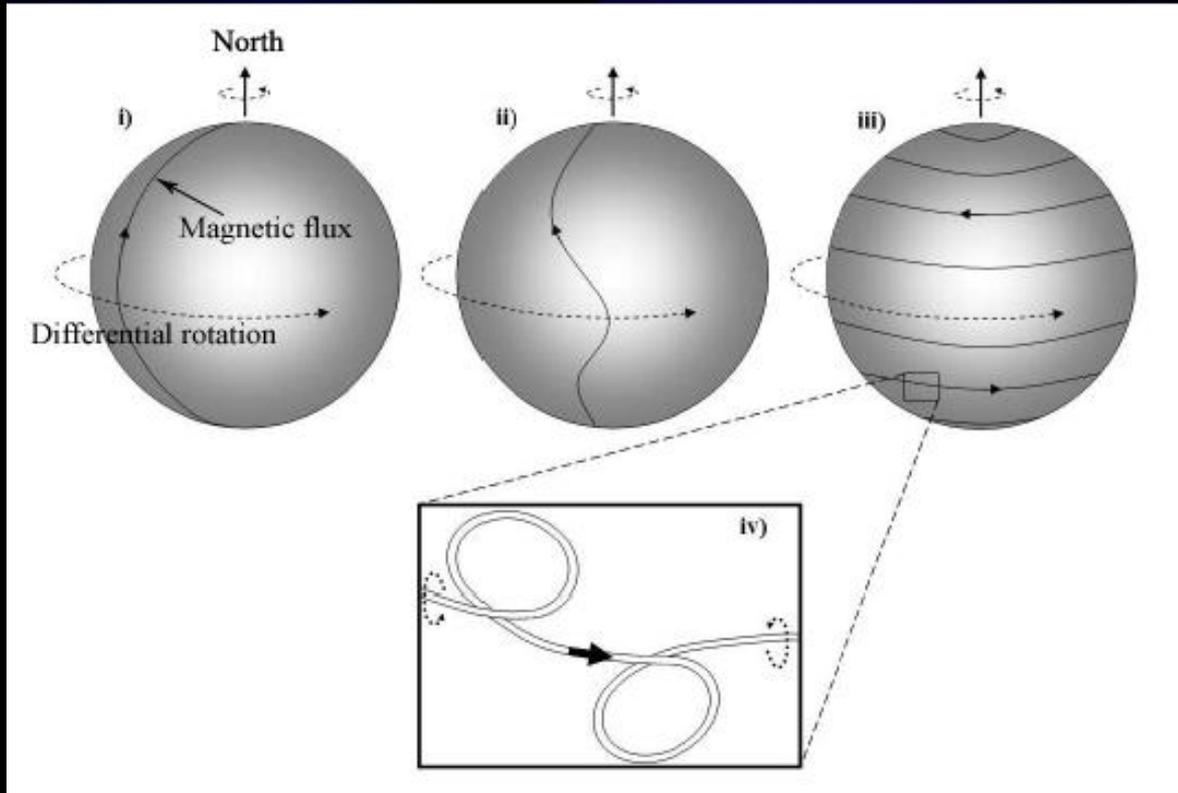


Mínimo Atividade

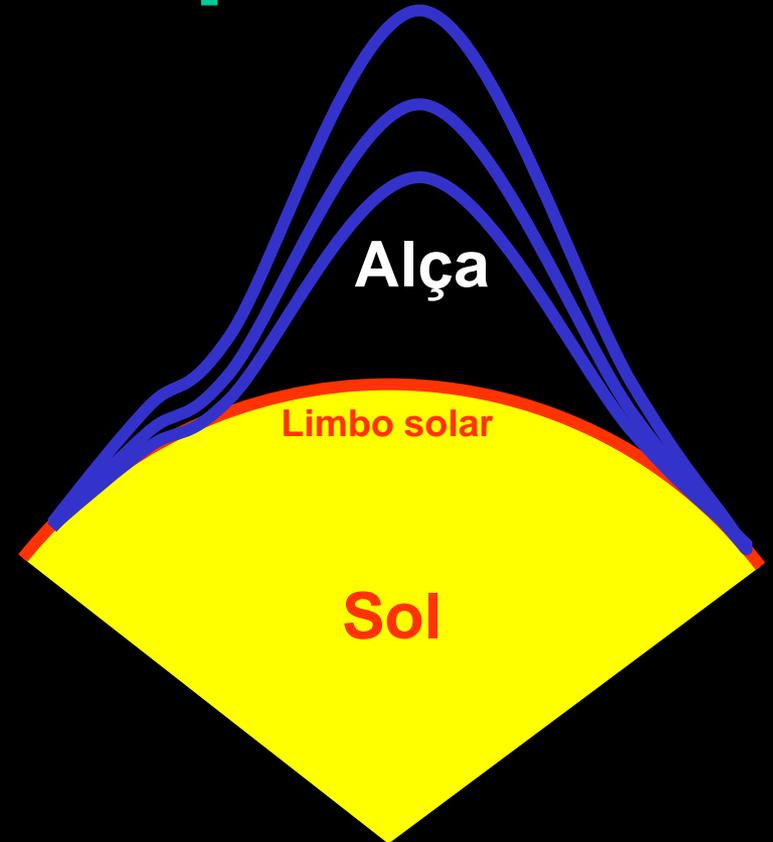
Máximo Atividade



Efeito da rotação diferencial no ciclo de atividade do Sol



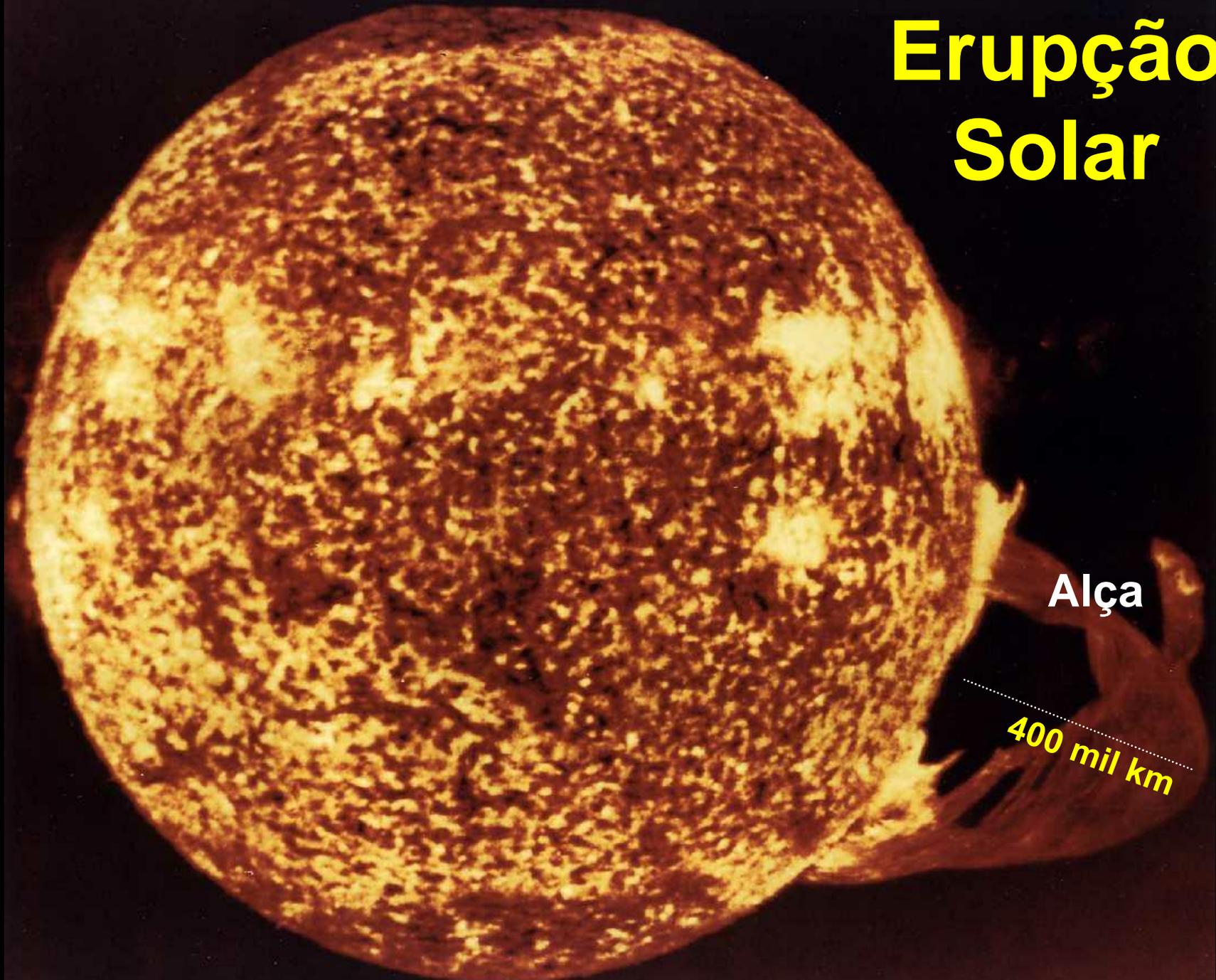
Despreendimento das linhas de campo



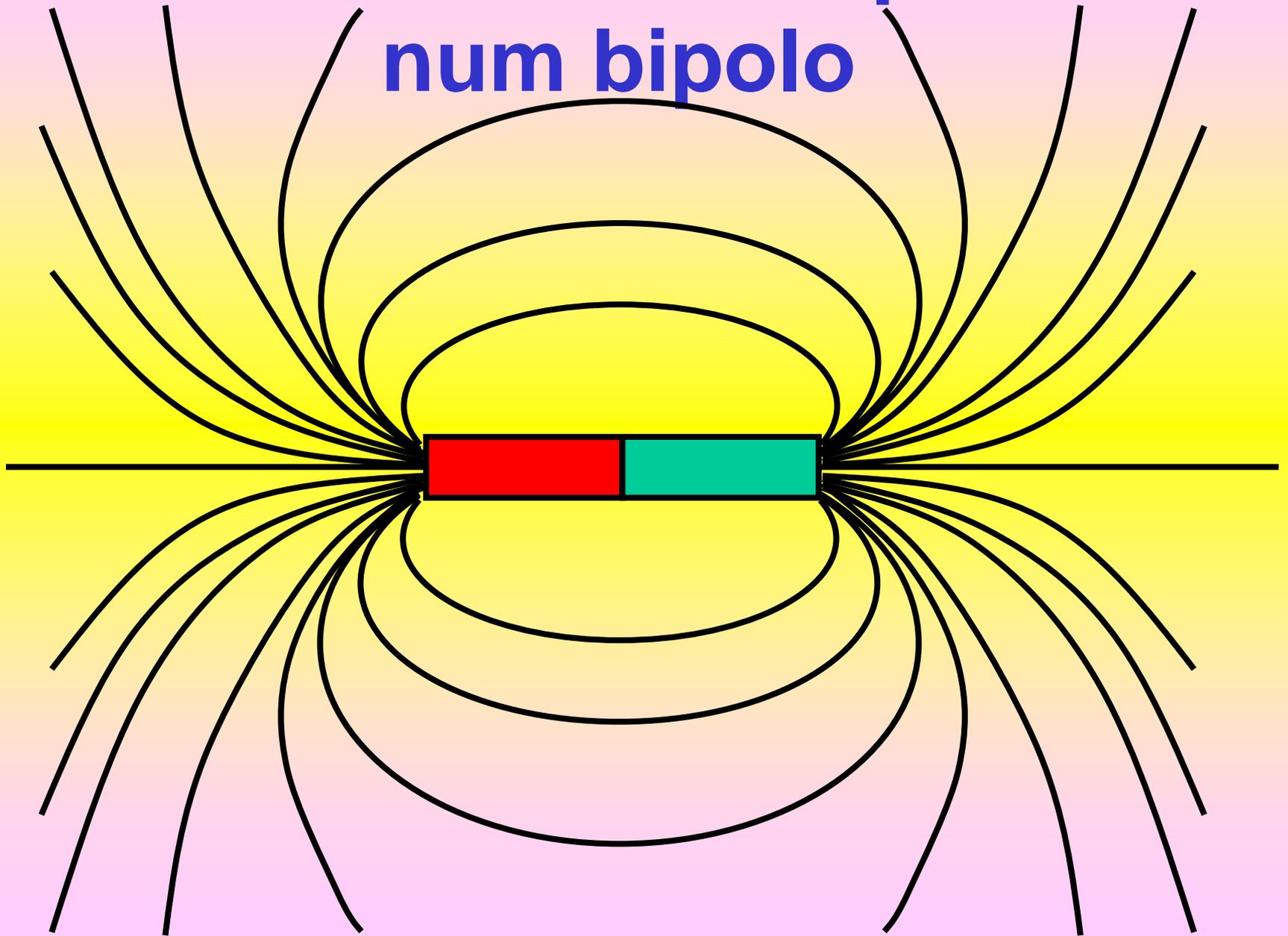
Erupção Solar

Alça

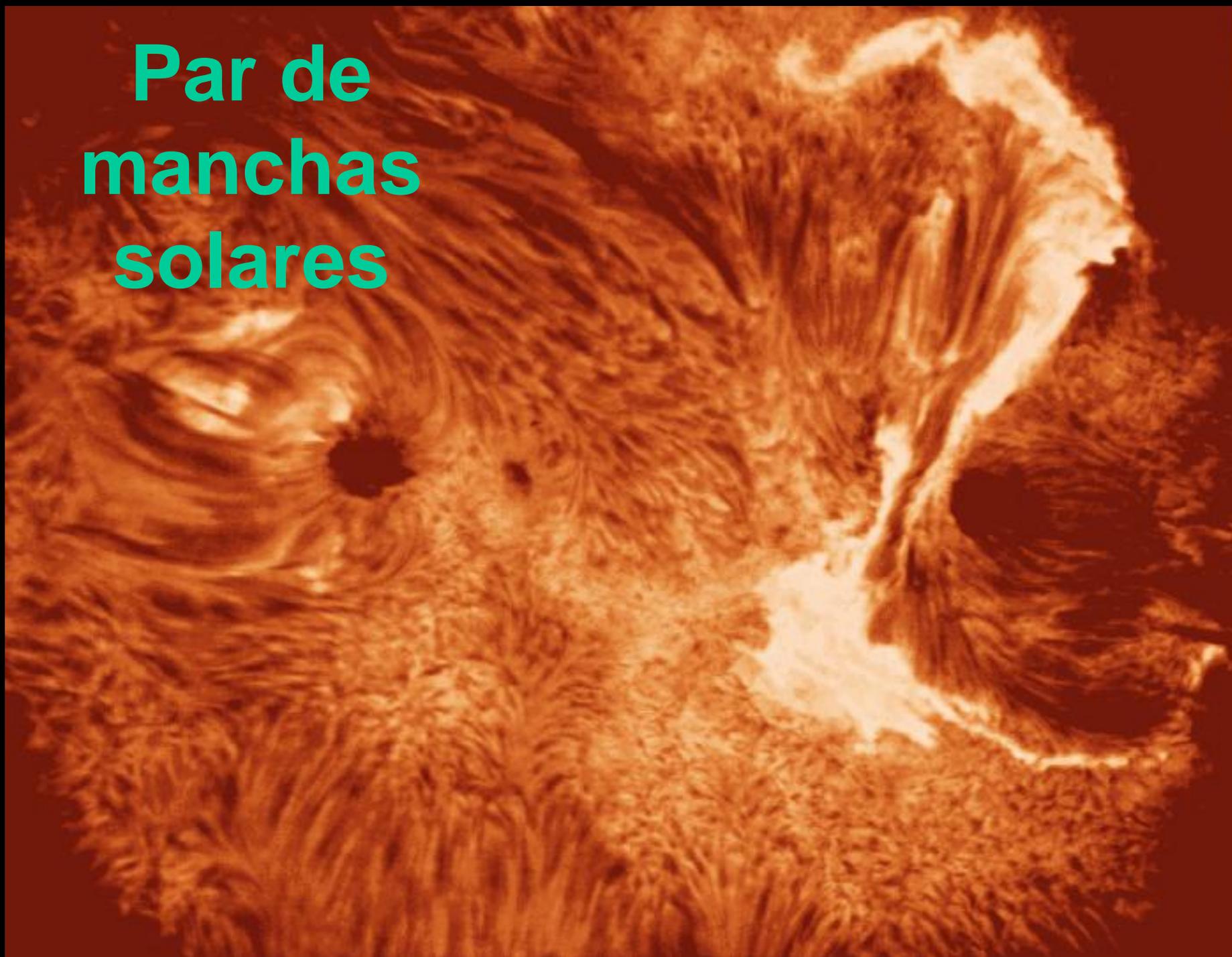
400 mil km



Linhas de campo num bipolo

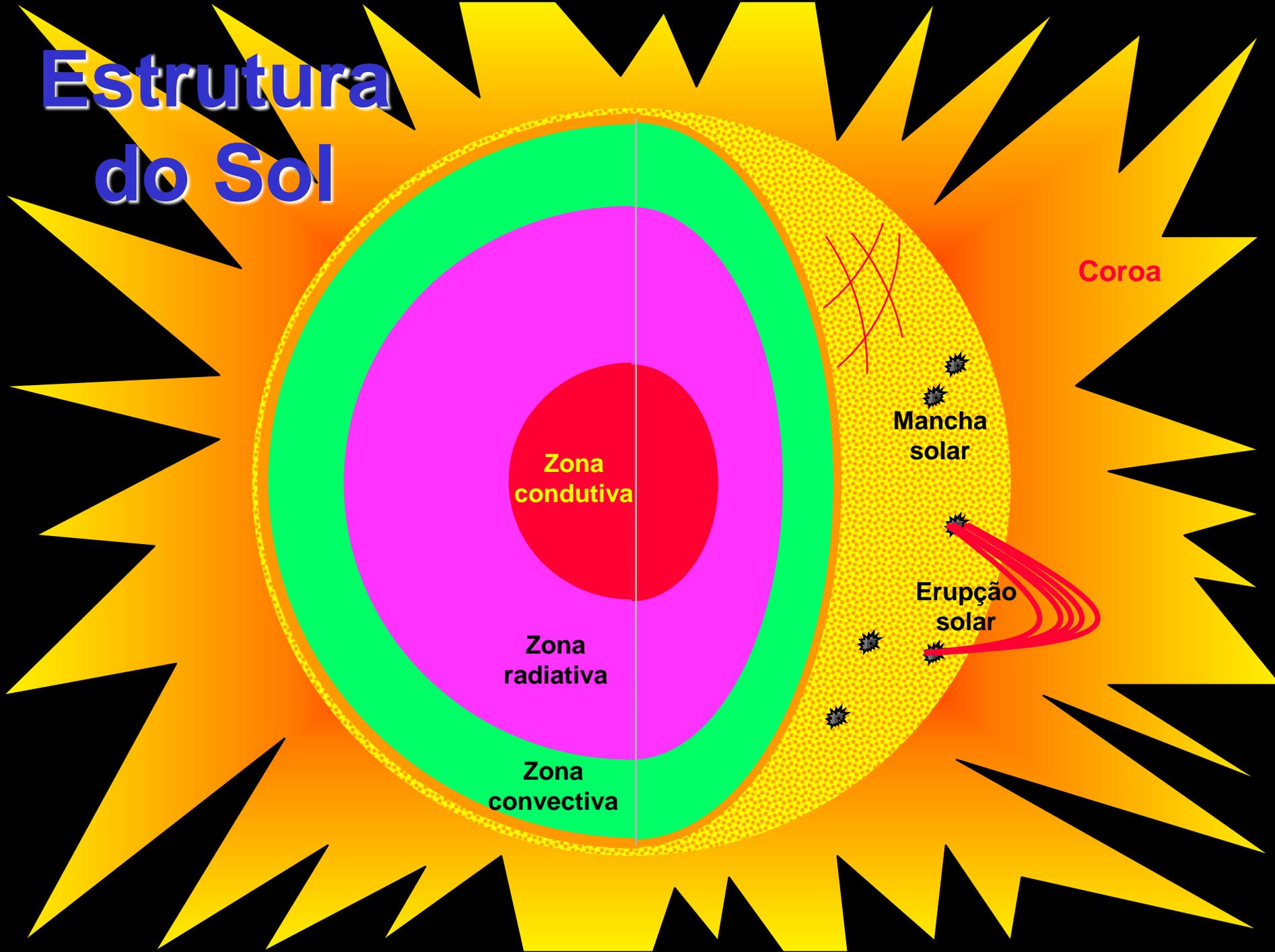


Par de manchas solares

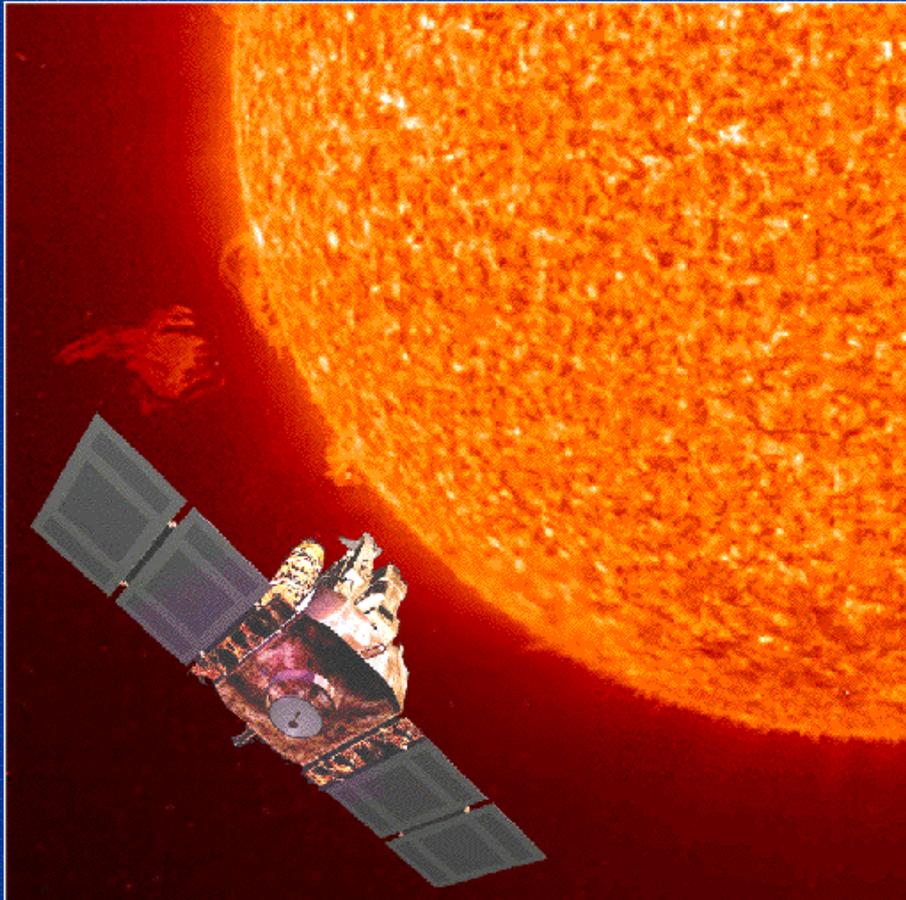


Esquema geral da estrutura do Sol

Estrutura do Sol



Observações Solares com Sondas



SOHO

Solar and Heliospheric Observatory

Proeminência solar

Foto: SOHO (UV)
Hélio ionizado

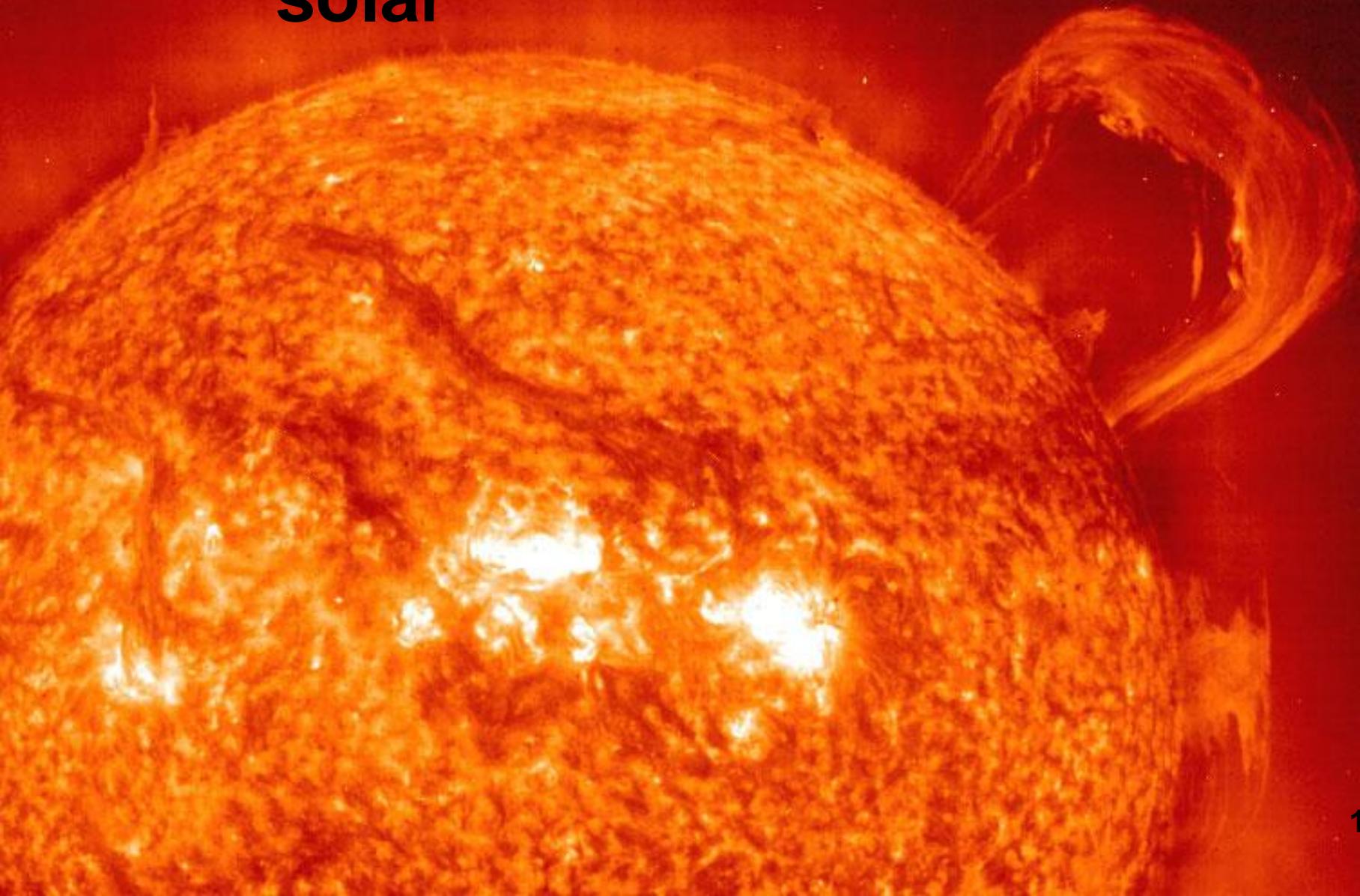
2000
Ano do Máximo de Atividade Solar



Tamanho aproximado da Terra na mesma escala

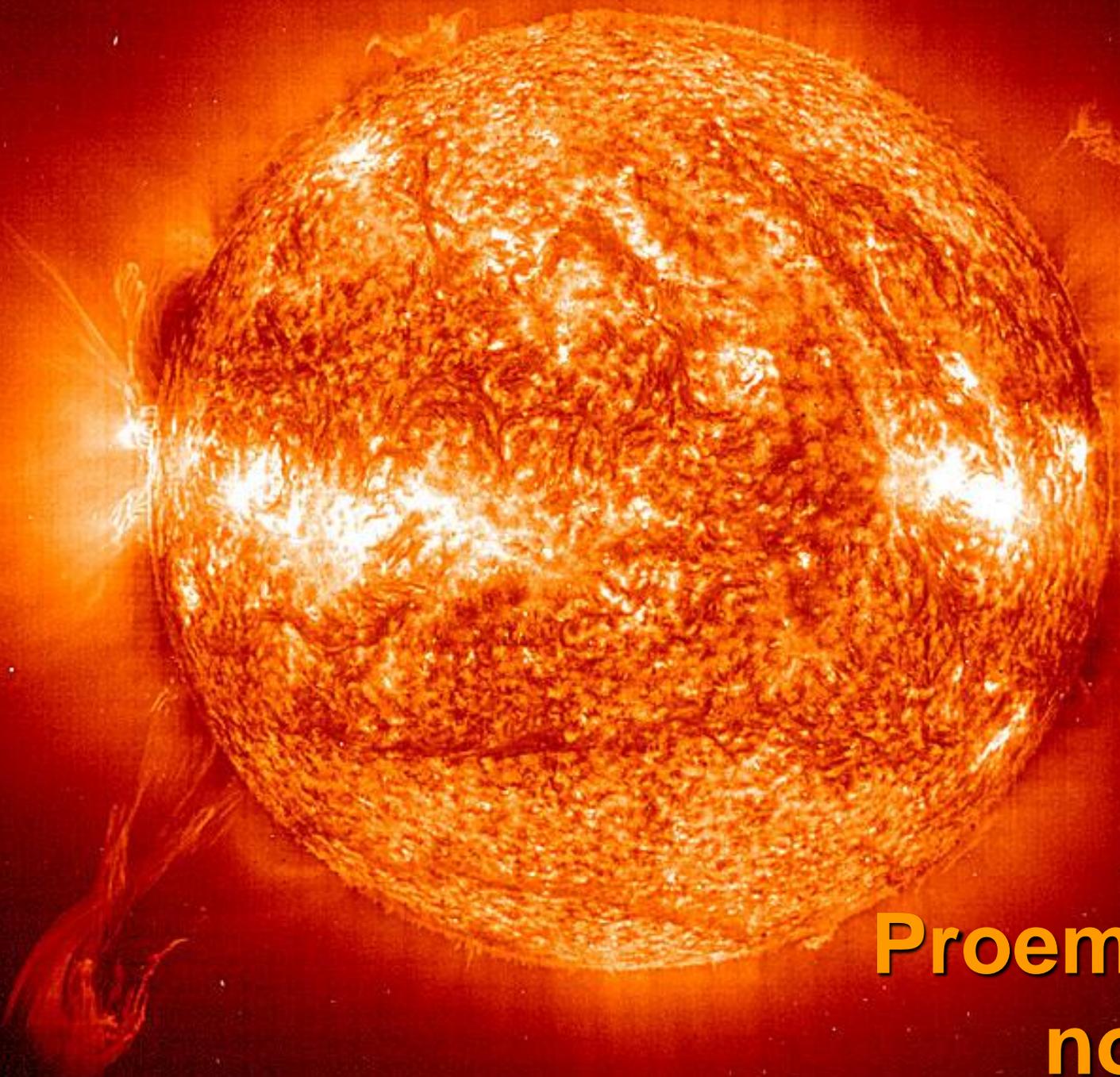
Proeminência solar

Gerado por
Hélio ionizado



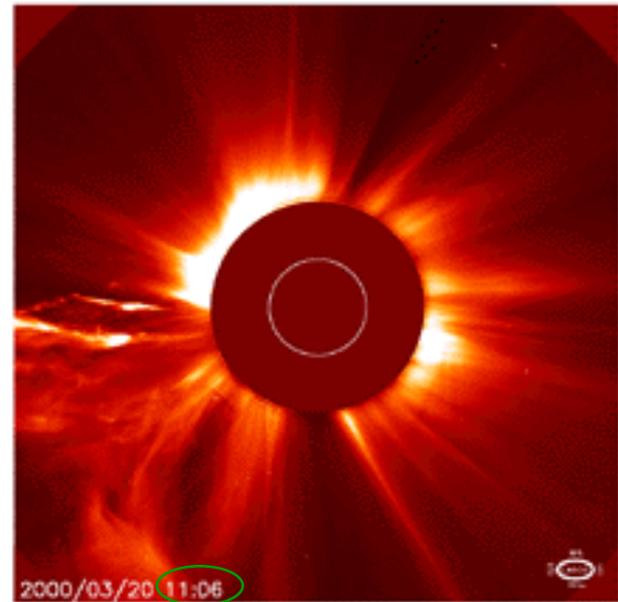
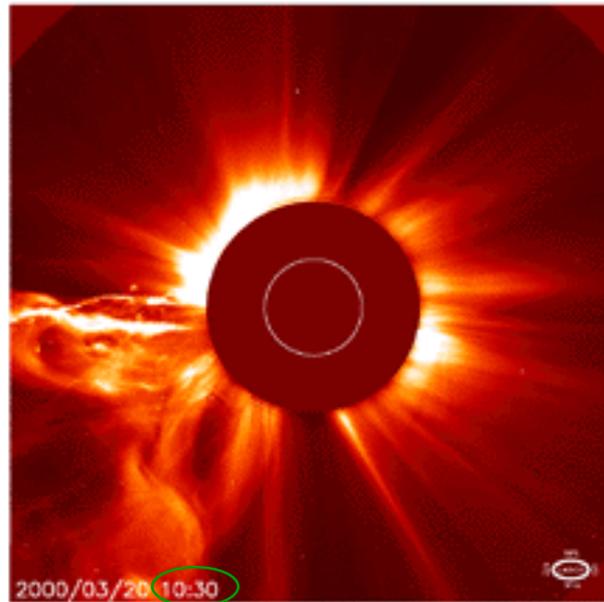
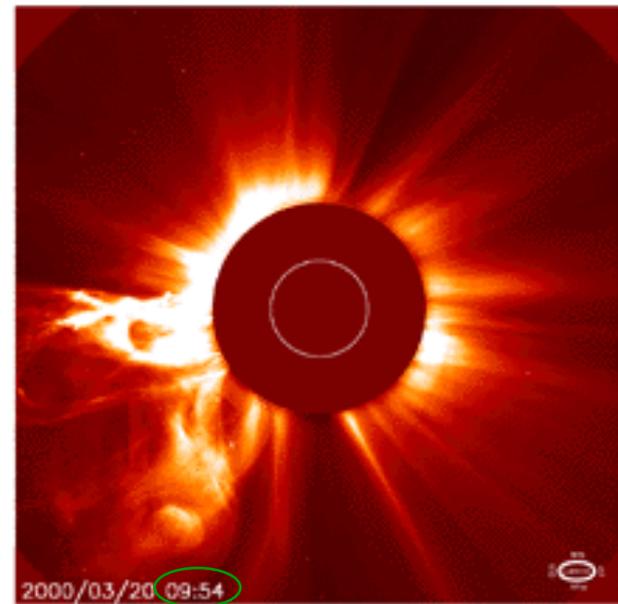
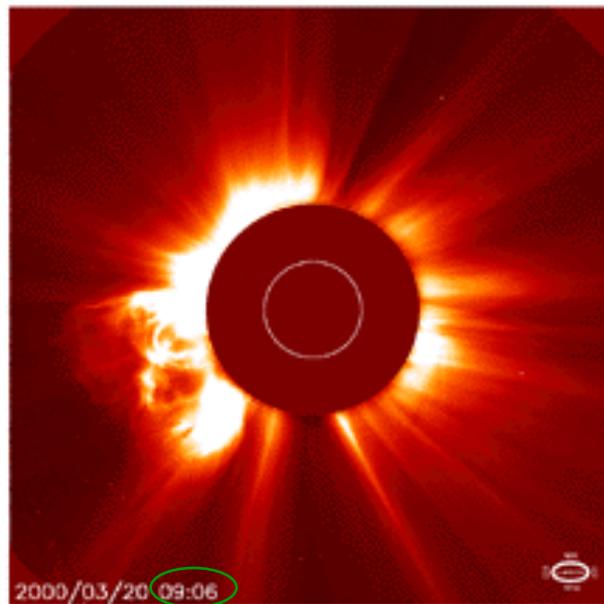
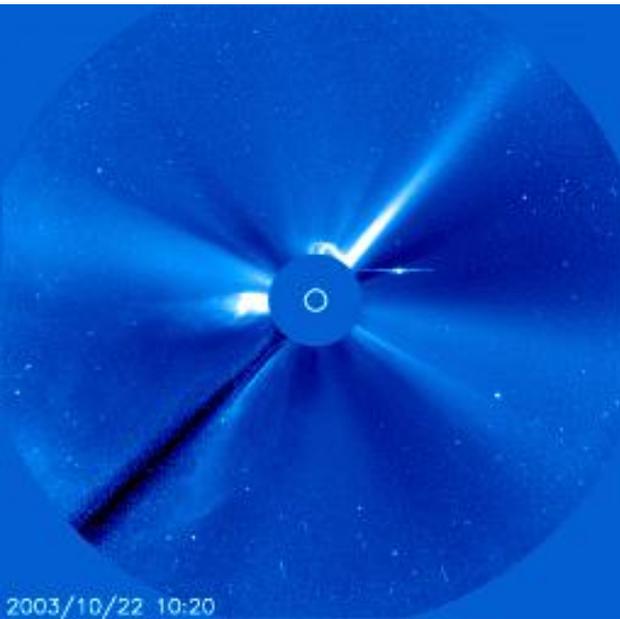
1999
set

Foto com o SOHO
(2000)



**Proeminências
no Sol**

Ejeção de massa do Sol



A large coronal mass ejection (CME) as observed by SOHO's LASCO C2 instrument over a two-hour period

20/03/2000

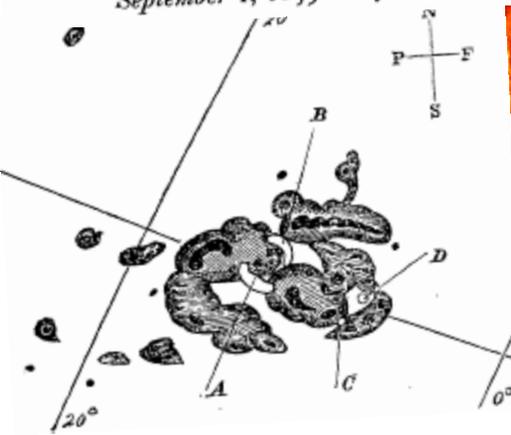
22/10/2003

01/1997

Sun 'ejection' killed TV satellite

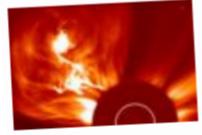
January 21, 1997
Web posted at: 10:10 am EST

Description of a Singular Appearance seen in the Sun on September 1, 1859. By R. C. Carrington, Esq.



overactive imagination,
orbiting 22,000 miles
the United States, when

09/1859



The Great Storm of 1859 Revealed
By **Robert Roy Britt**
Senior Science Writer
posted: 08:00 am ET
27 October 2003

A pair of strong solar storms that hit Earth late last year, a torrent of electrons that rained down in the "perfect storm" later, experts warn, the Sun will again conspire in a bout of space weather.

In Sept 1859, telegraph wires suddenly ignited fires. Colorful aurora were seen as far south as Hawaii.

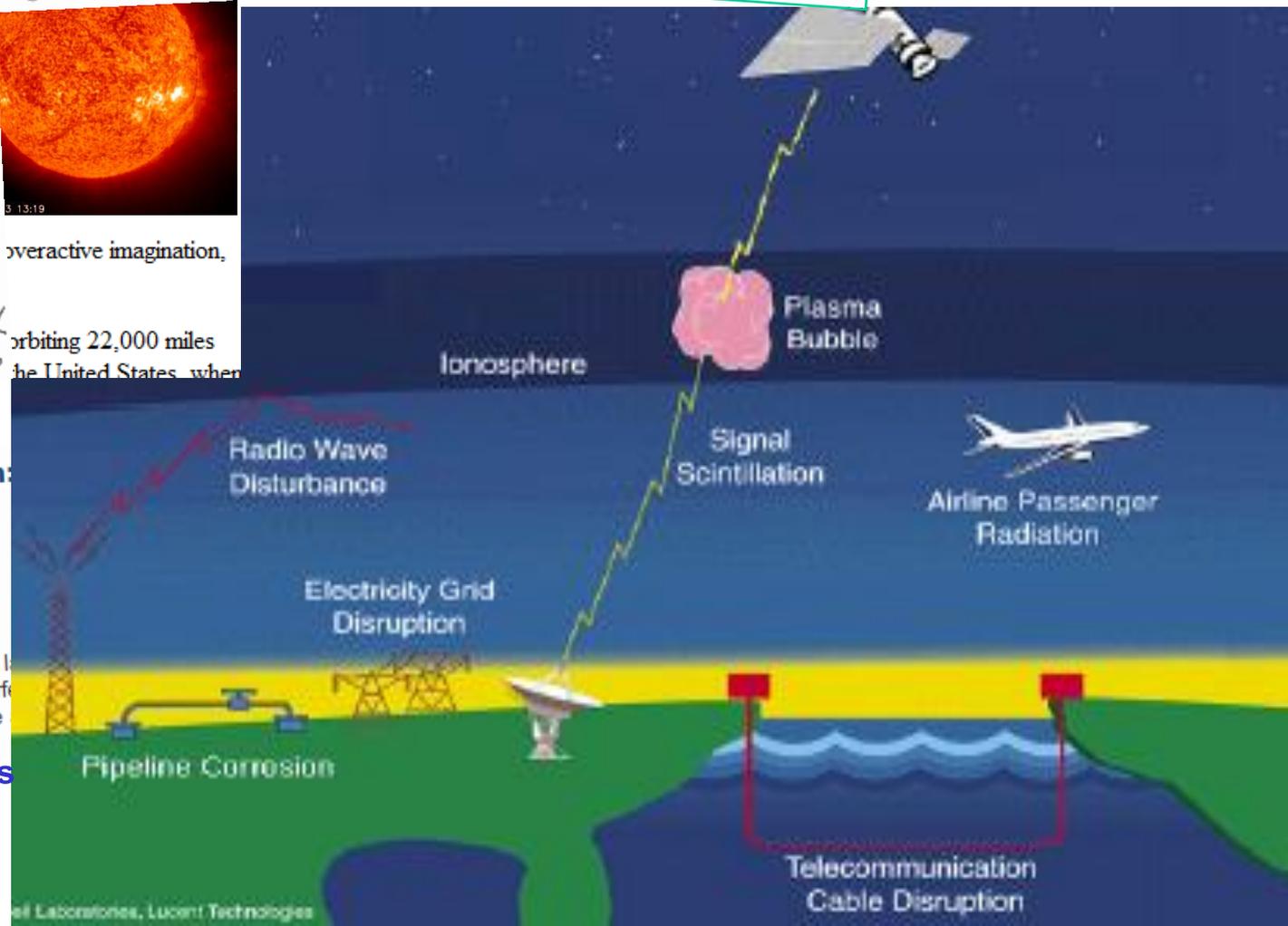
Science News

03/1989

The Day The Sun Brought Darkness

ScienceDaily (Mar. 19, 2009) — On March 13, 1989 the entire province of Quebec, Canada suffered an electrical power blackout. Hundreds of blackouts occur in some part of North America every year. The Quebec Blackout was different, because this one was caused by a solar storm.

Efeitos de tormentas solares



Fim