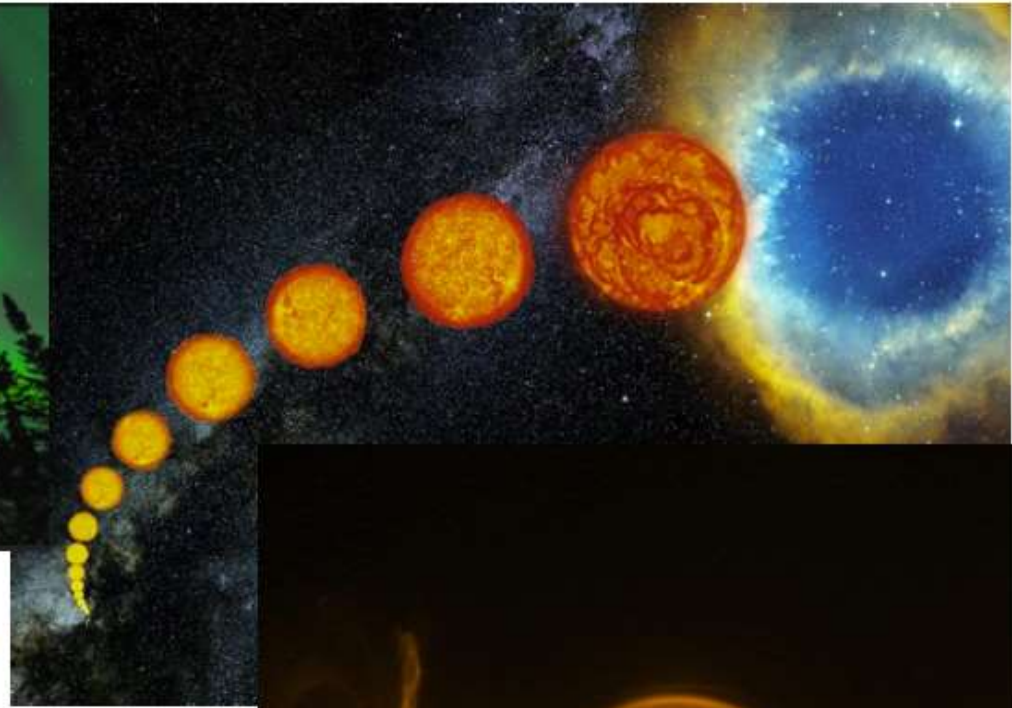


Sol



Prof. Jorge Meléndez
AGA205

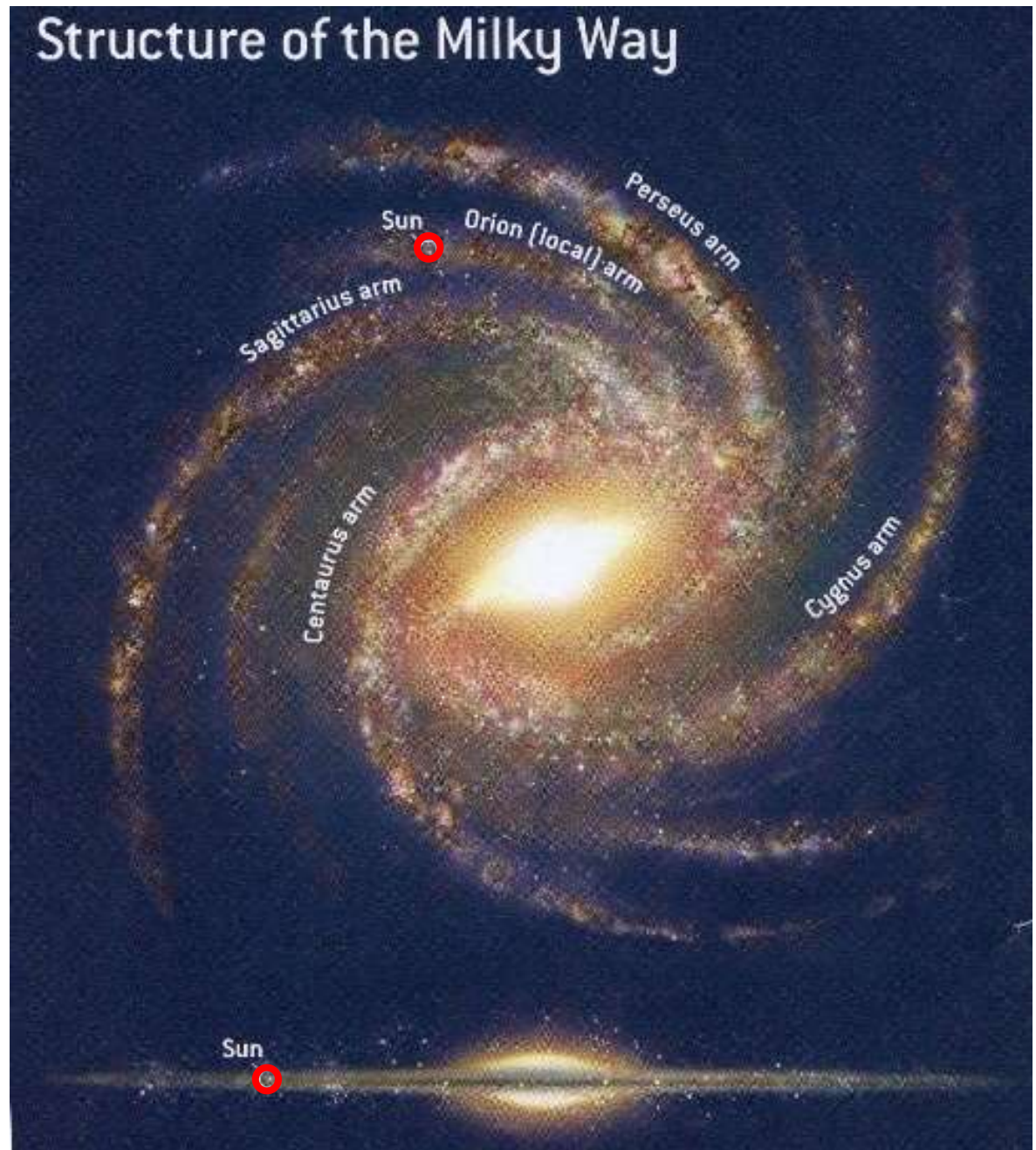
Por que estudar o Sol?

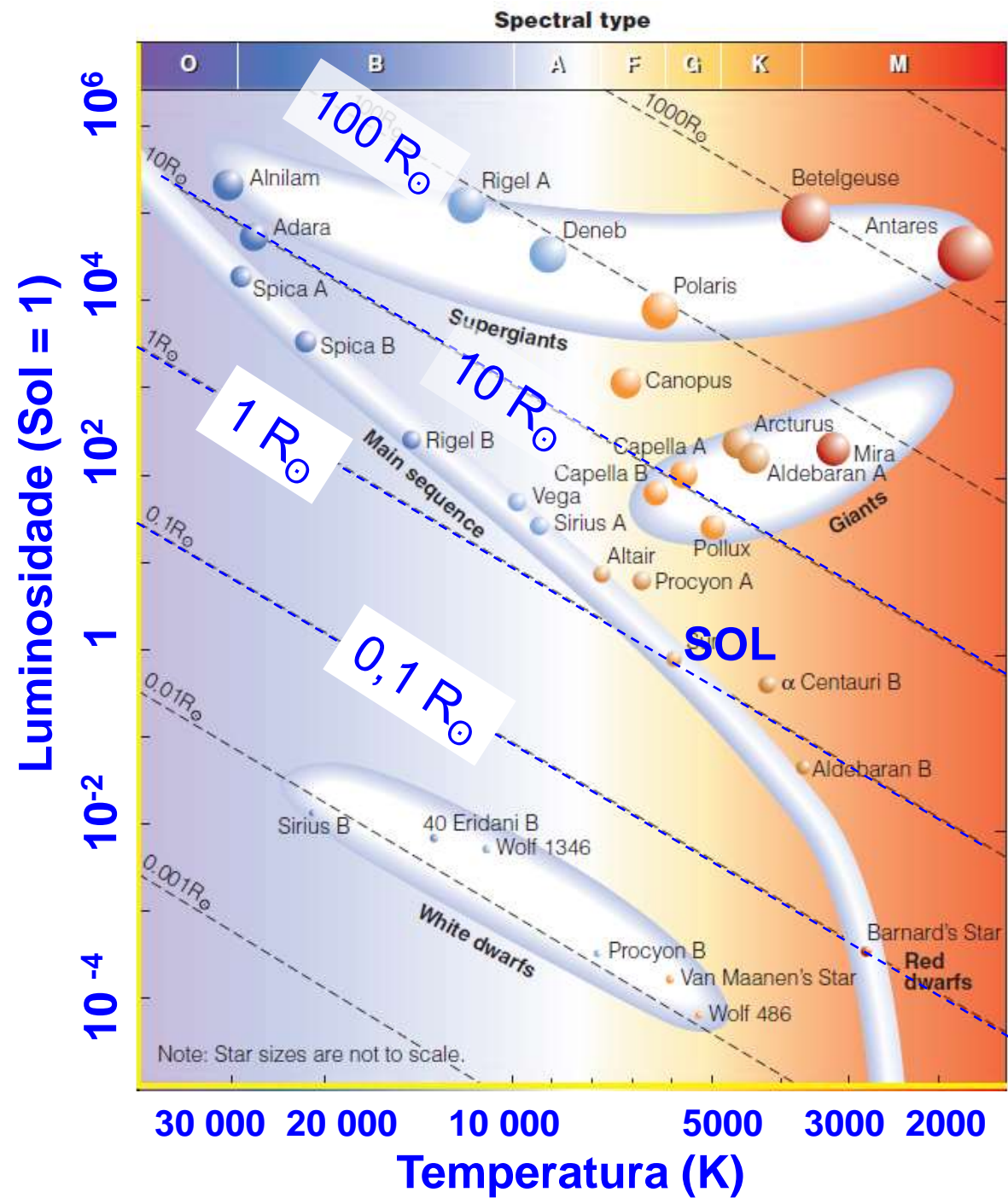


- Impacto em tecnologia e economia: uma tempestade solar causa 12 horas de blackout em Quebec (março 1989)
- Implicações no clima: queda no número de manchas solares (mínimo de Maunder) corresponde à mini era do gelo
- Aspectos astrofísicos: testar nossas idéias sobre evolução estelar



**O Sol é
apenas
uma entre
~ 300
bilhões de
estrelas na
Galáxia**





**Tamanho e
luminosidade
do Sol
comparado a
outras
estrelas**

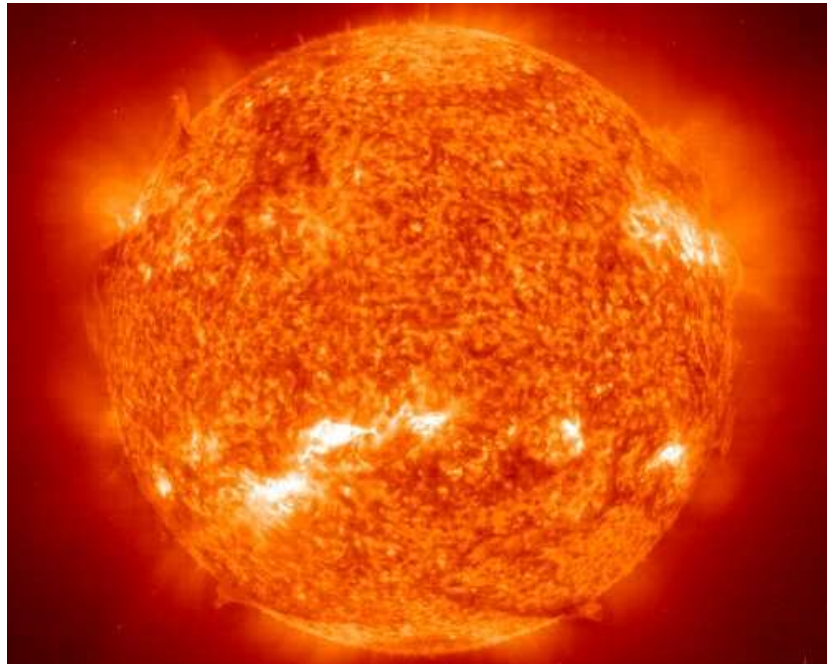
Magnitude Absoluta M_V (Sol = 4.83)

-5
0
5
10

$1 R_{\odot} = 696\,000 \text{ km}$
 $1 L_{\odot} = 3.84 \times 10^{26} \text{ W}$

Composição química do Sol

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

Sol

Massa

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

Luminosidade

$3,84 \times 10^{26}$ W

~4 septilhões de lâmpadas de 100 W



Visão da
fotosfera

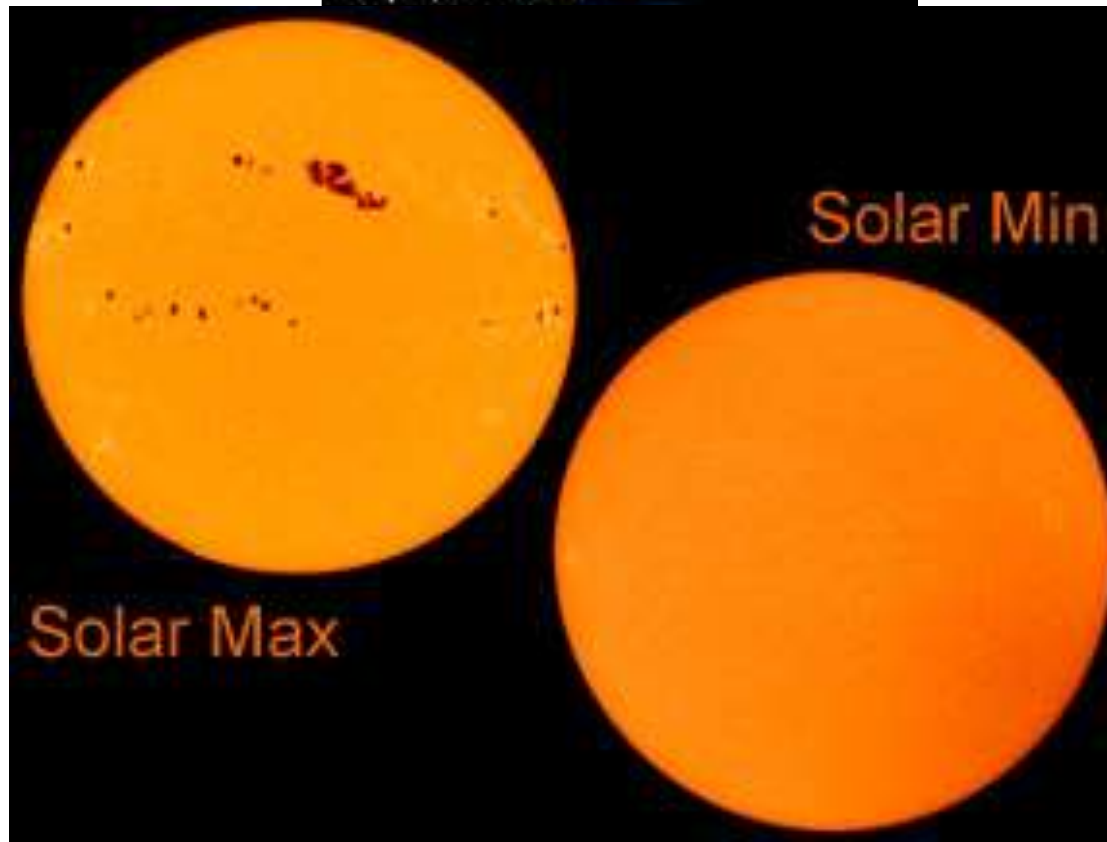
Distância
(sem escala)

Raio

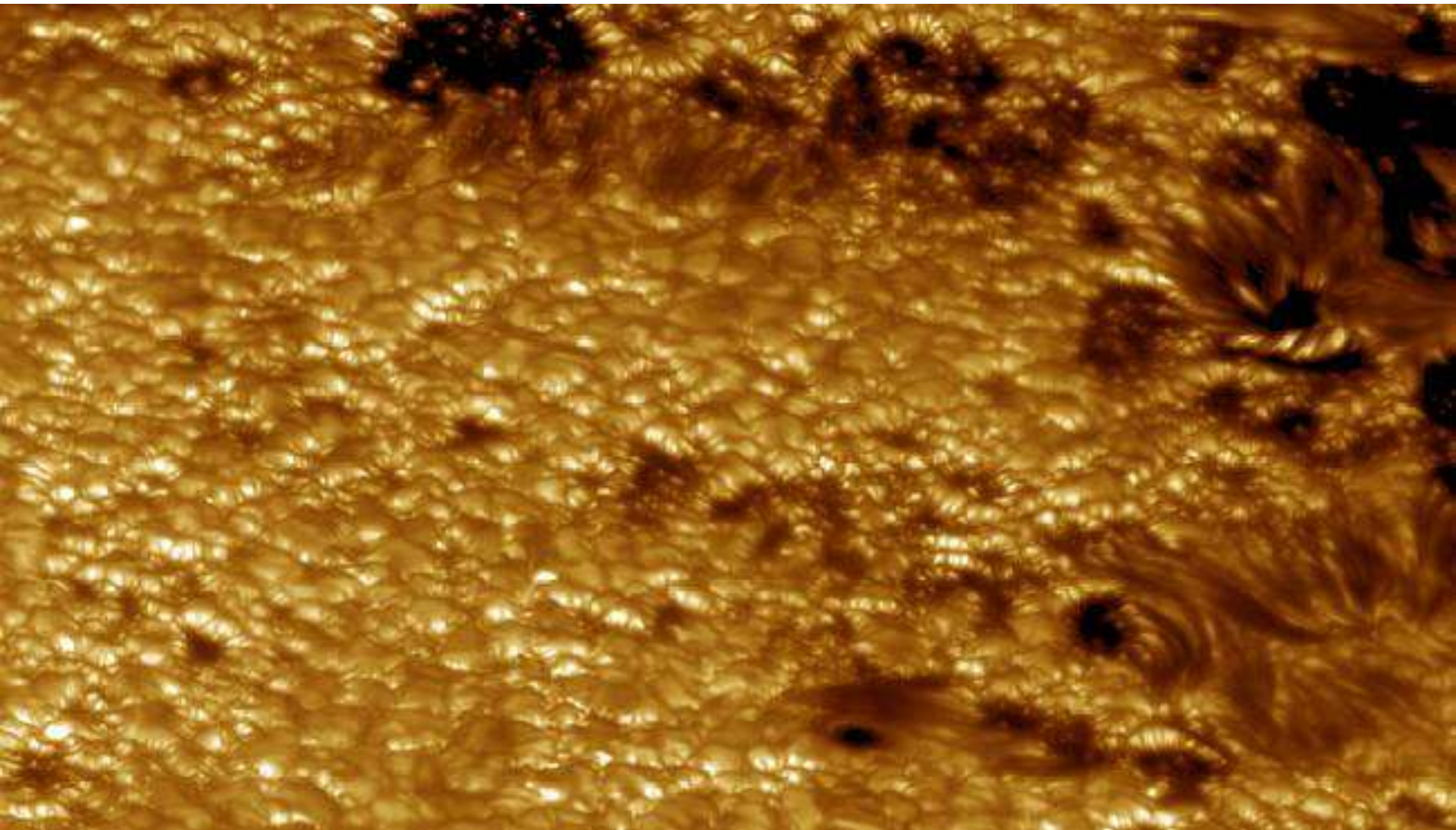
696 mil km
(109 Terra)

Observação
na região
visível do
espectro

Mudanças na superfície do Sol



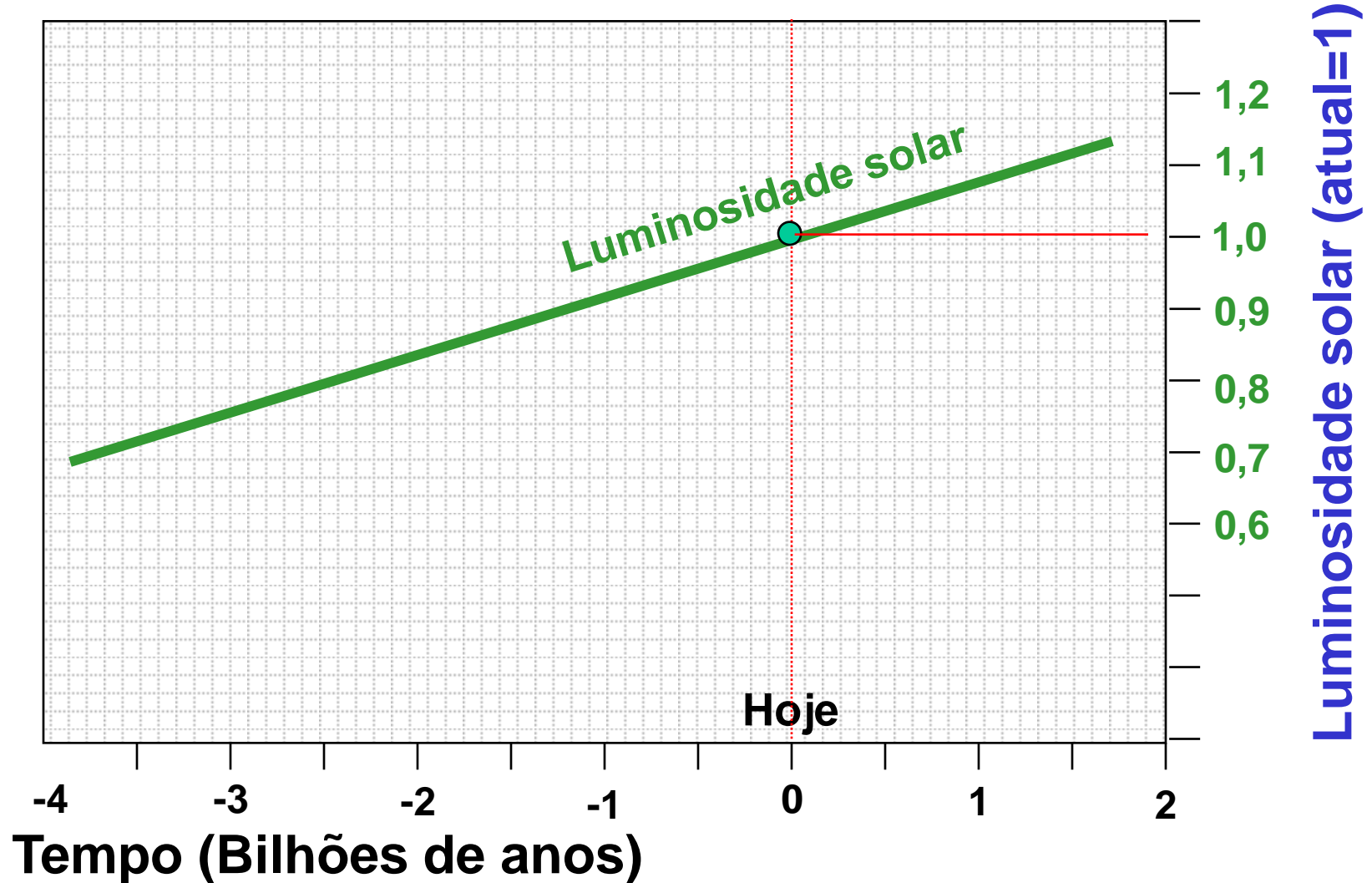
“Superfície” do Sol



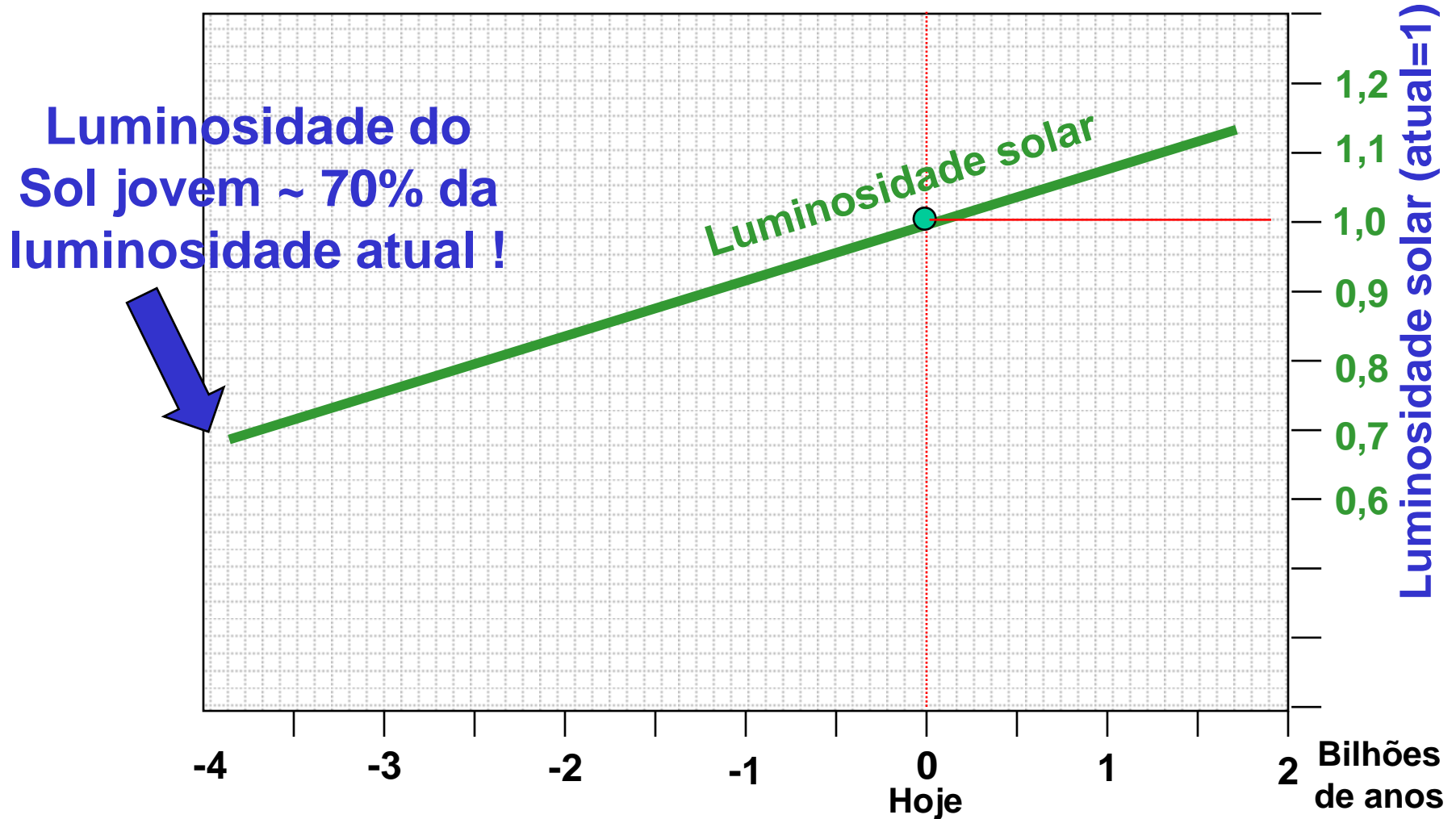
A Luminosidade do Sol é constante ou variável ?



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 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?

EXPLORING THE FAINT YOUNG SUN PROBLEM AND THE POSSIBLE CLIMATES OF THE ARCHEAN EARTH WITH A 3D GCM

B. Charnay¹, F. Forget¹, R. Wordsworth², J. Leconte¹, E. Millour¹, F. Codron¹, and A. Spiga¹

Abstract.

Different solutions have been proposed to solve the 'faint young Sun problem', defined by the fact that the Earth was not fully frozen during the Archean despite the fainter Sun. Most previous studies were performed with simple 1D radiative convective models and did not account well for the clouds and ice-albedo feedback or the atmospheric and oceanic transport of energy. We apply a Global Climate Model (GCM) to test the different solutions to the faint young Sun problem. We explore the effect of greenhouse gases (CO₂ and CH₄), atmospheric pressure, cloud droplet size, land distribution and Earth's rotation rate. We show that, neglecting organic haze, 100 mbars of CO₂ with 2 mbars of CH₄ at 3.8 Ga and 10 mbars of CO₂ with 2 mbars of CH₄ at 2.5 Ga allow a temperate climate (mean surface temperature between 10°C and 20°C). Such amounts of greenhouse gases remain consistent with the geological data. Removing continents produces a warming lower than +4°C. The effect of rotation rate is even more limited. Larger droplets (radii of 17 μm versus 12 μm) and a doubling of the atmospheric pressure produce a similar warming of around +7°C. In our model, ice-free waterbelts can be maintained up to 25° N/S with less than 1 mbar of CO₂ and no methane. An interesting cloud feedback appears above cold oceans, stopping the glaciation. Such a resistance against full glaciation tends to strongly mitigate the faint young Sun problem.

Zona habitável em sistemas planetários:

região onde pode existir água líquida



Influencia de evolução do Sol na vida na Terra

temos só 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

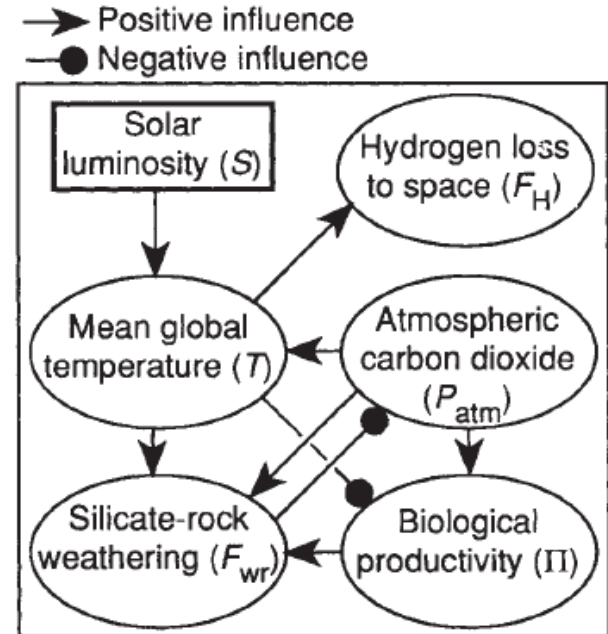
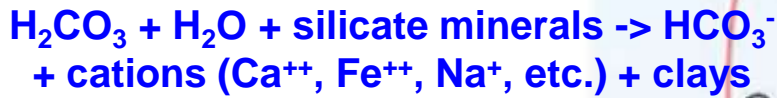


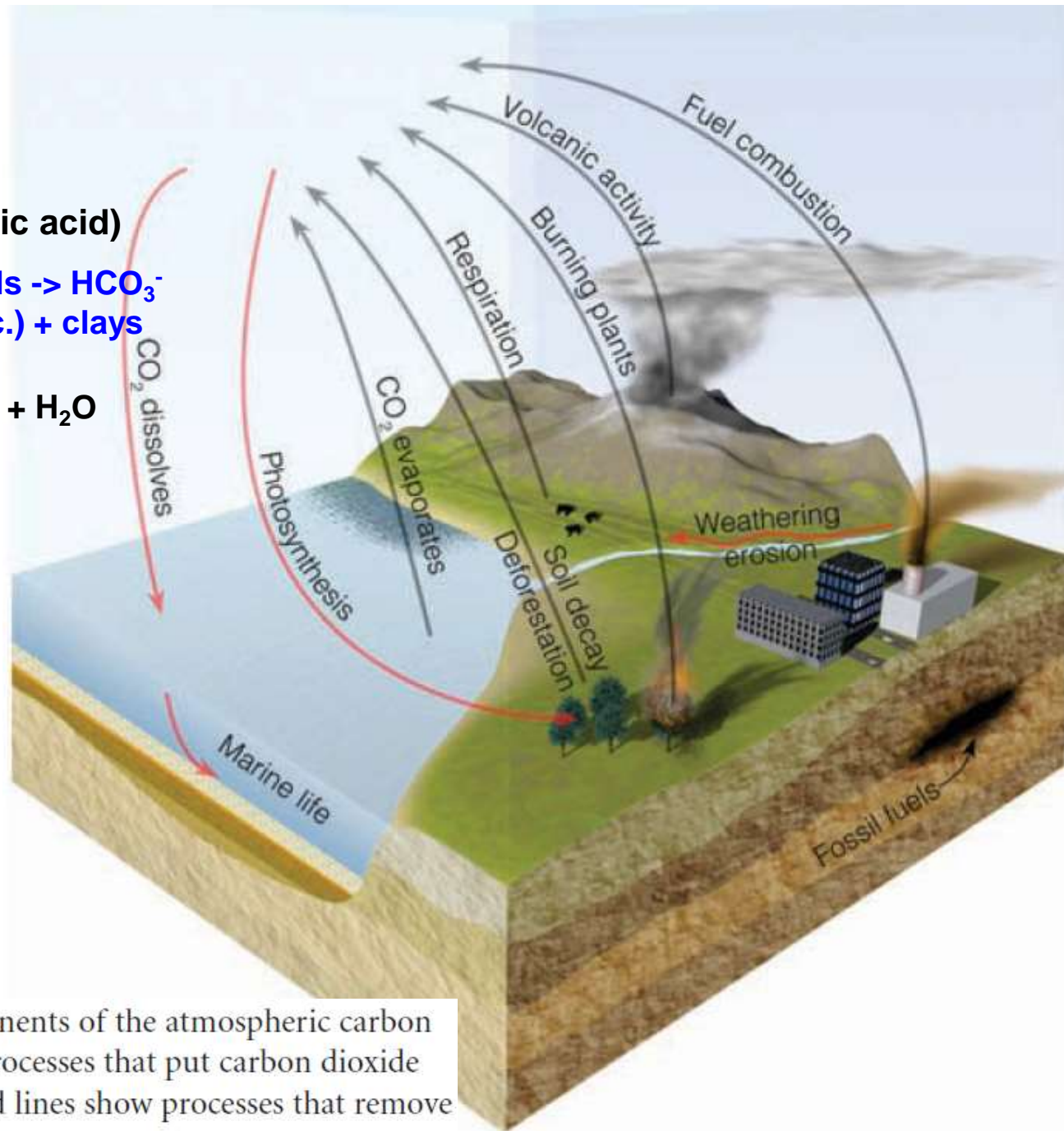
FIG. 1 Diagram illustrating the positive and negative influences represented in our model. System behaviour may be understood by examining the response to an increase in solar luminosity (S). Increasing S warms the Earth, increasing T . This enhances both the weatherability of silicate rocks (F_{wr}) 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.

CO₂ cycle



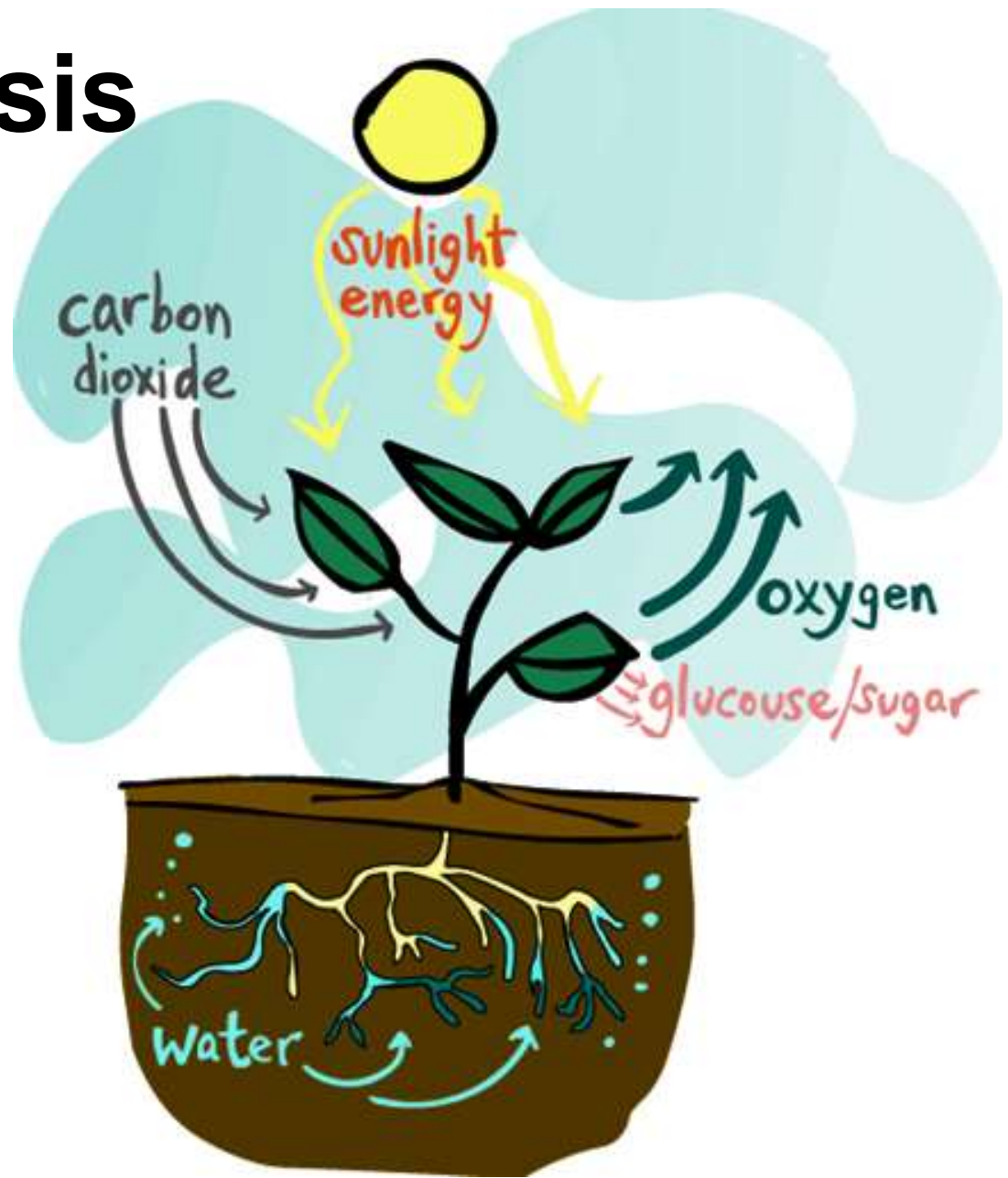
**Calcita
e calcáreos**

Parte do CO₂ é retornado:



● **FIGURE 1.4** The main components of the atmospheric carbon dioxide cycle. The gray lines show processes that put carbon dioxide into the atmosphere, whereas the red lines show processes that remove carbon dioxide from the atmosphere.

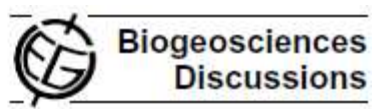
Photosynthesis



Influencia de evolução do Sol na vida na Terra

temos só 1500 milhões de anos?

Biogeosciences Discussions, 2, 1665–1679, 2005
www.biogeosciences.net/bgd/2/1665/
SRef-ID: 1810-6285/bgd/2005-2-1665
European Geosciences Union



Causes and timing of future biosphere extinction

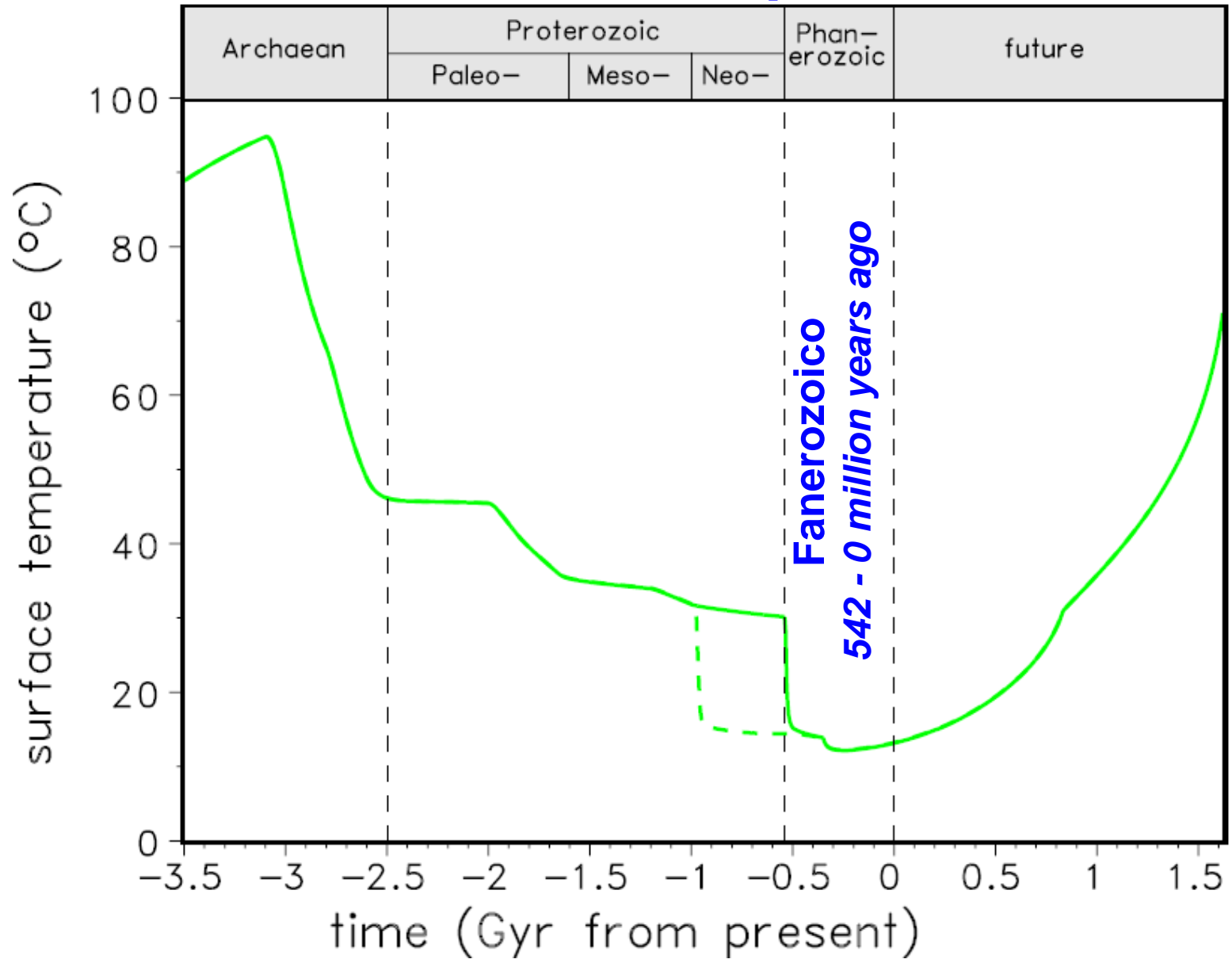
S. Franck, C. Bounama, and W. von Bloh

Correspondence to: C. Bounama (bounama@pik-potsdam.de)

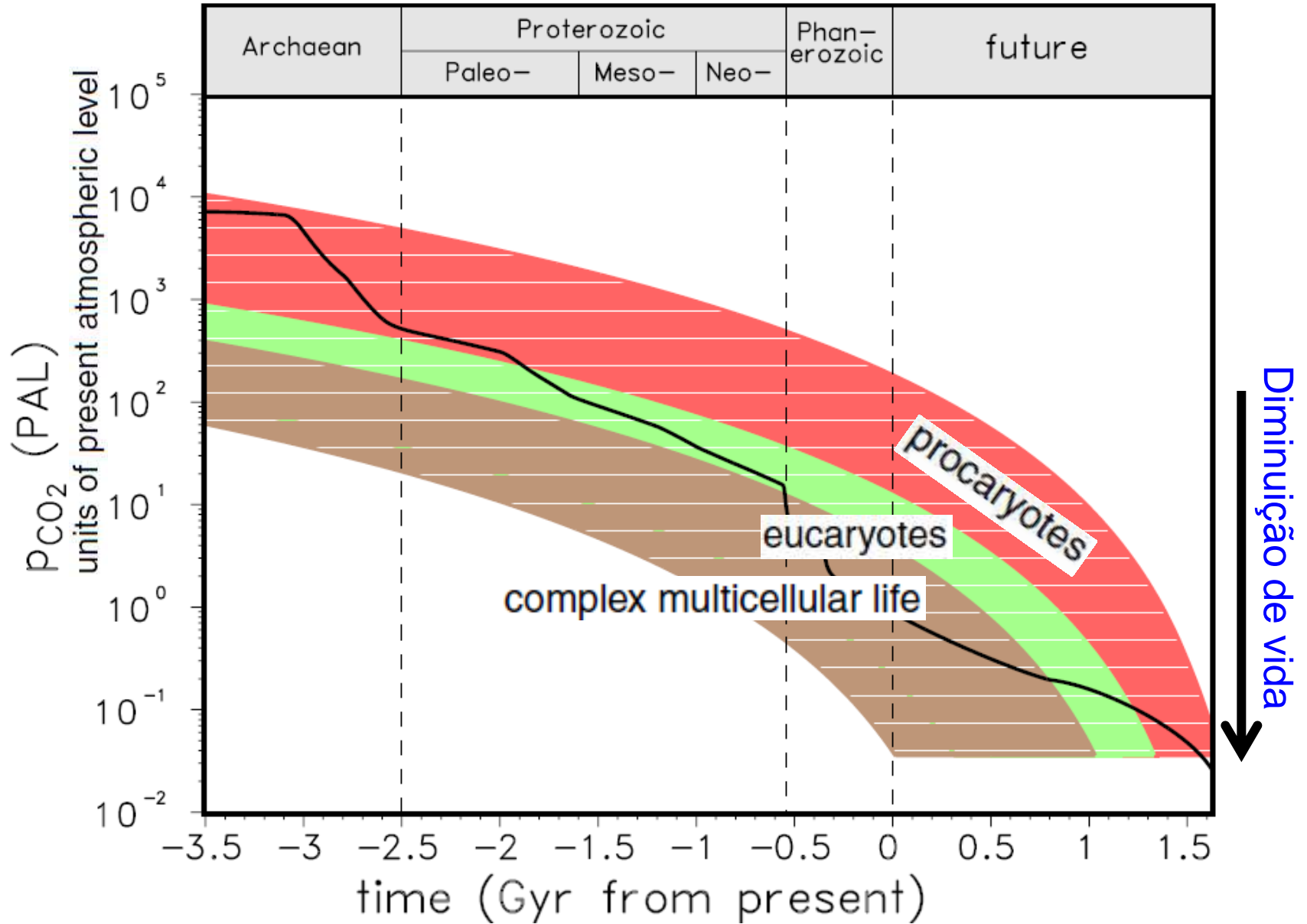
Potsdam Institute for Climate Impact Research, Potsdam, Germany

We present a minimal model for the global carbon cycle of the Earth containing the reservoirs mantle, ocean floor, continental crust, biosphere, and the kerogen, as well as the aggregated reservoir ocean and atmosphere. The model is specified by introducing three different types of biosphere: procaryotes, eucaryotes, and complex multicellular life. We find that from the Archaean to the future a procaryotic biosphere always exists. 2 Gyr ago eucaryotic life first appears. The emergence of complex multicellular life is connected with an explosive increase in biomass and a strong decrease in Cambrian global surface temperature at about 0.54 Gyr ago. In the long-term future the three types of biosphere will die out in reverse sequence of their appearance. We show that there is no evidence for an implosion-like extinction in contrast to the Cambrian explosion. The ultimate life span of the biosphere is defined by the extinction of procaryotes in about 1.6 Gyr.

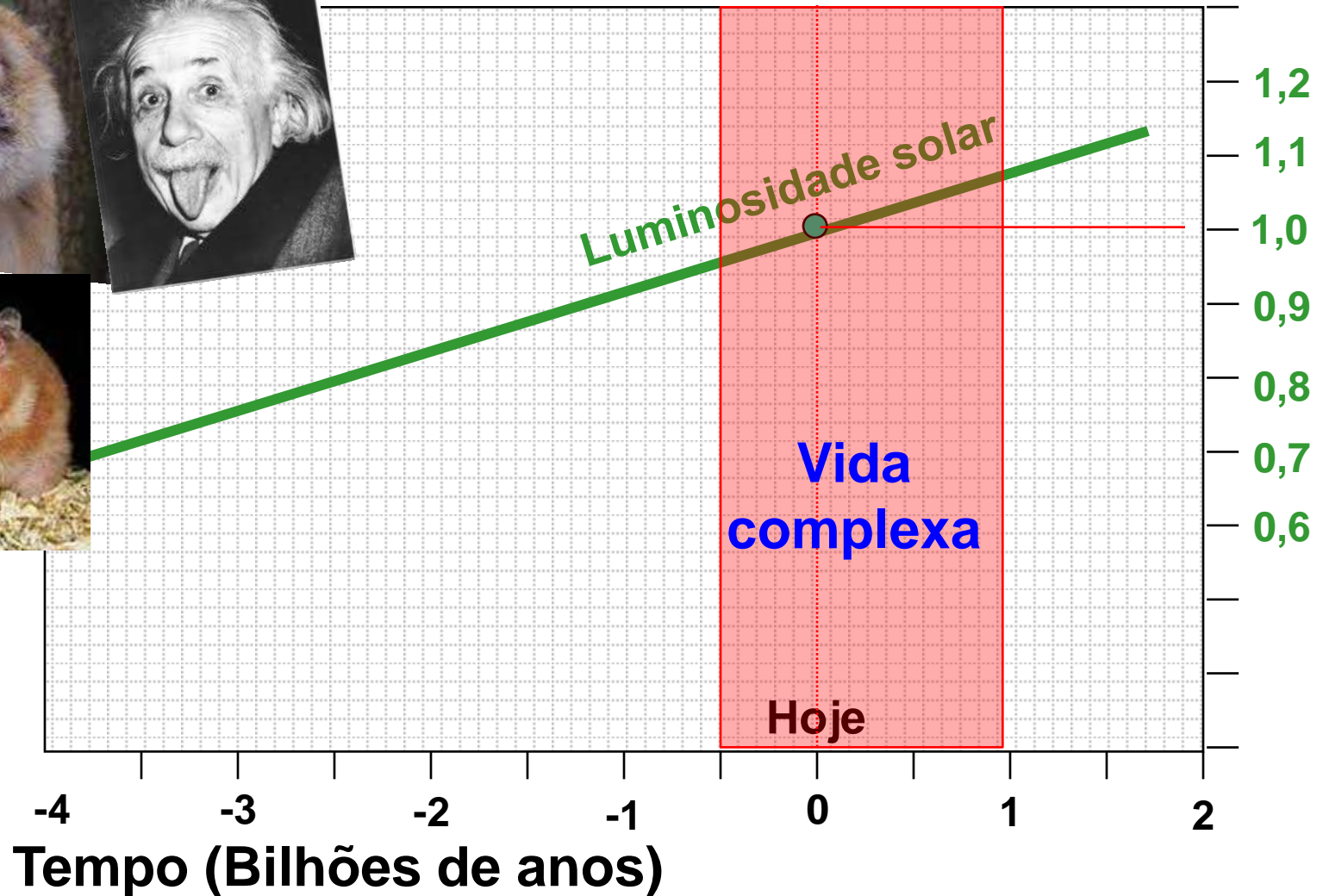
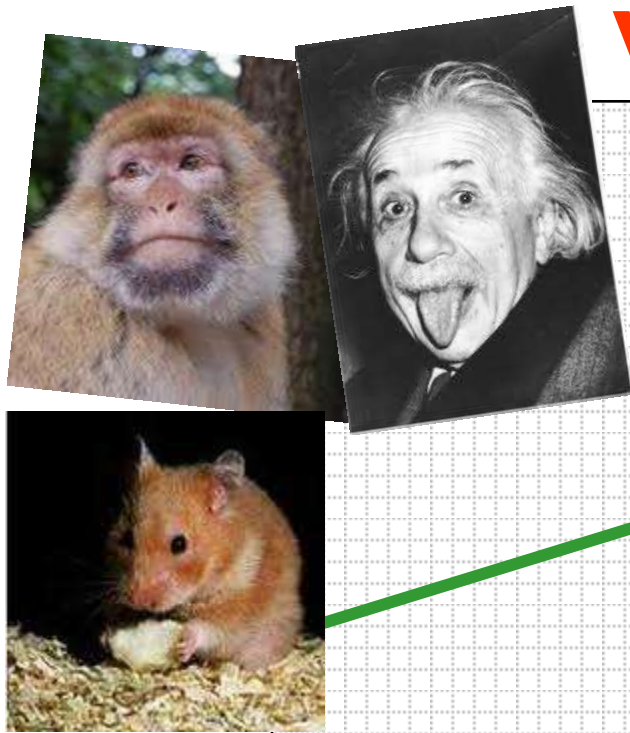
Earth surface temperature



The evolution of atmospheric CO₂ concentration



Variação da Luminosidade vinda do Sol



Luminosidade solar (atual=1)



POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH



Massachusetts Institute of Technology

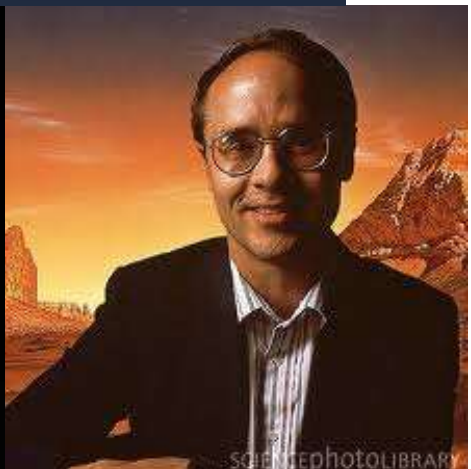
Profa. Sara Seager, pioneira no estudo de atmosferas de júpiteres quentes



<http://seagerexoplanets.mit.edu/>



Prof. James Kasting (1953 - ...). Pioneiro no estudo de habitabilidade planetária



Swansong Biospheres II: The final signs of life on terrestrial planets
near the end of their habitable lifetimes

<http://arxiv.org/abs/1310.4841>

Jack T. O'Malley-James

School of Physics and Astronomy, University of St Andrews, North Haugh, St
Andrews, Fife, UK.

Charles S. Cockell

UK Centre for Astrobiology, School of Physics and Astronomy, James Clerk Maxwell
Building, The King's Buildings, University of Edinburgh, Edinburgh, UK.

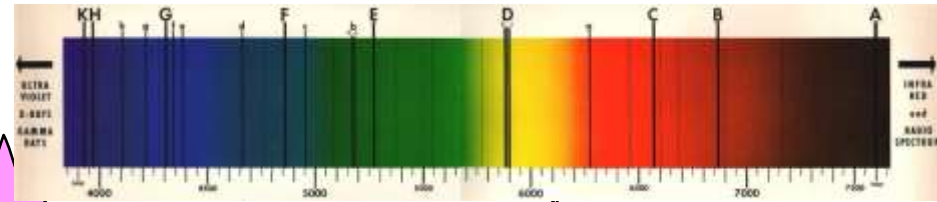
Jane S. Greaves

School of Physics and Astronomy, University of St Andrews, North Haugh, St
Andrews, Fife, UK.

John A. Raven

Division of Plant Sciences, University of Dundee at TJHI, The James Hutton Institute,
Invergowrie, Dundee, UK.

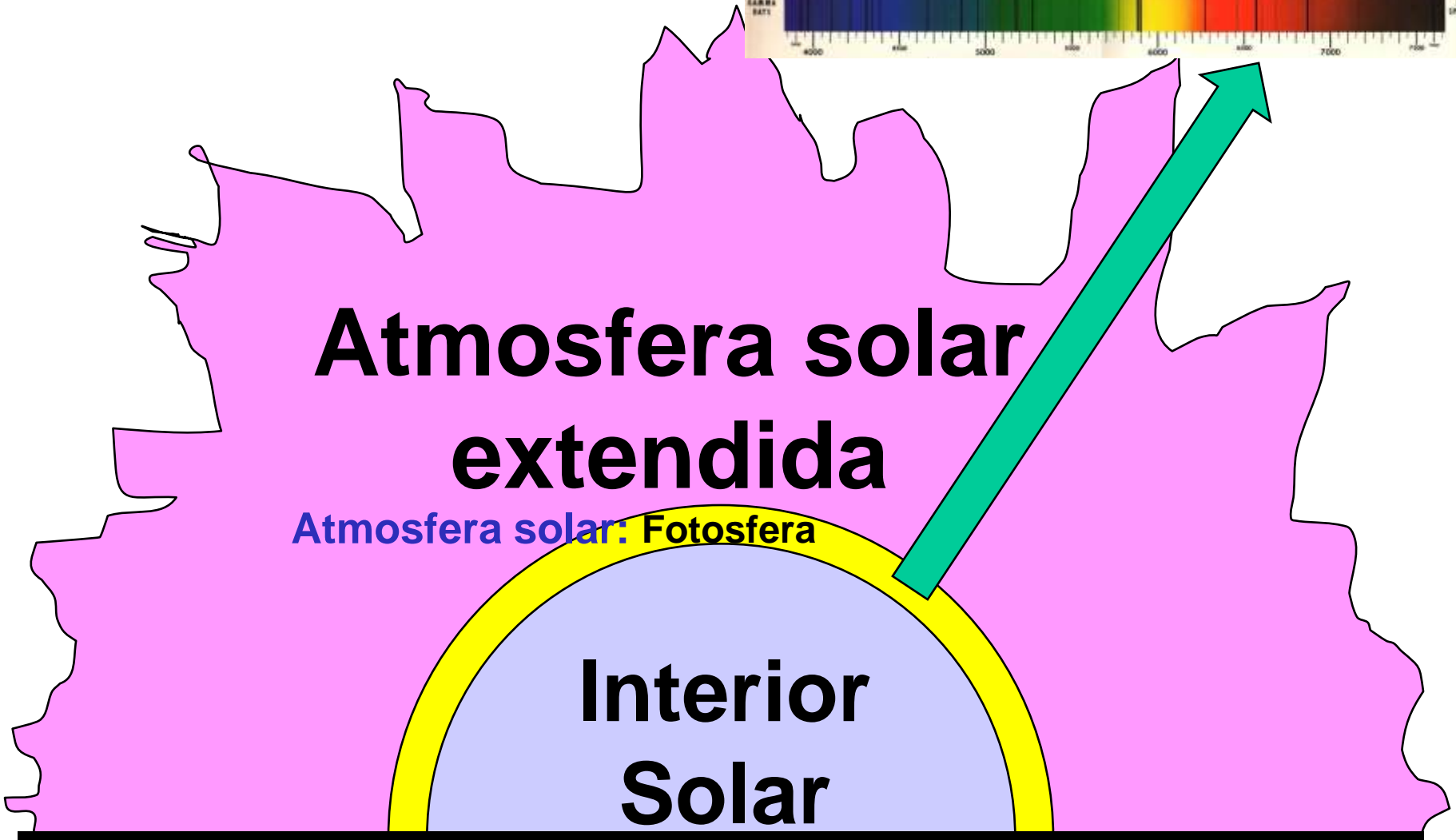
Estrutura básica do Sol



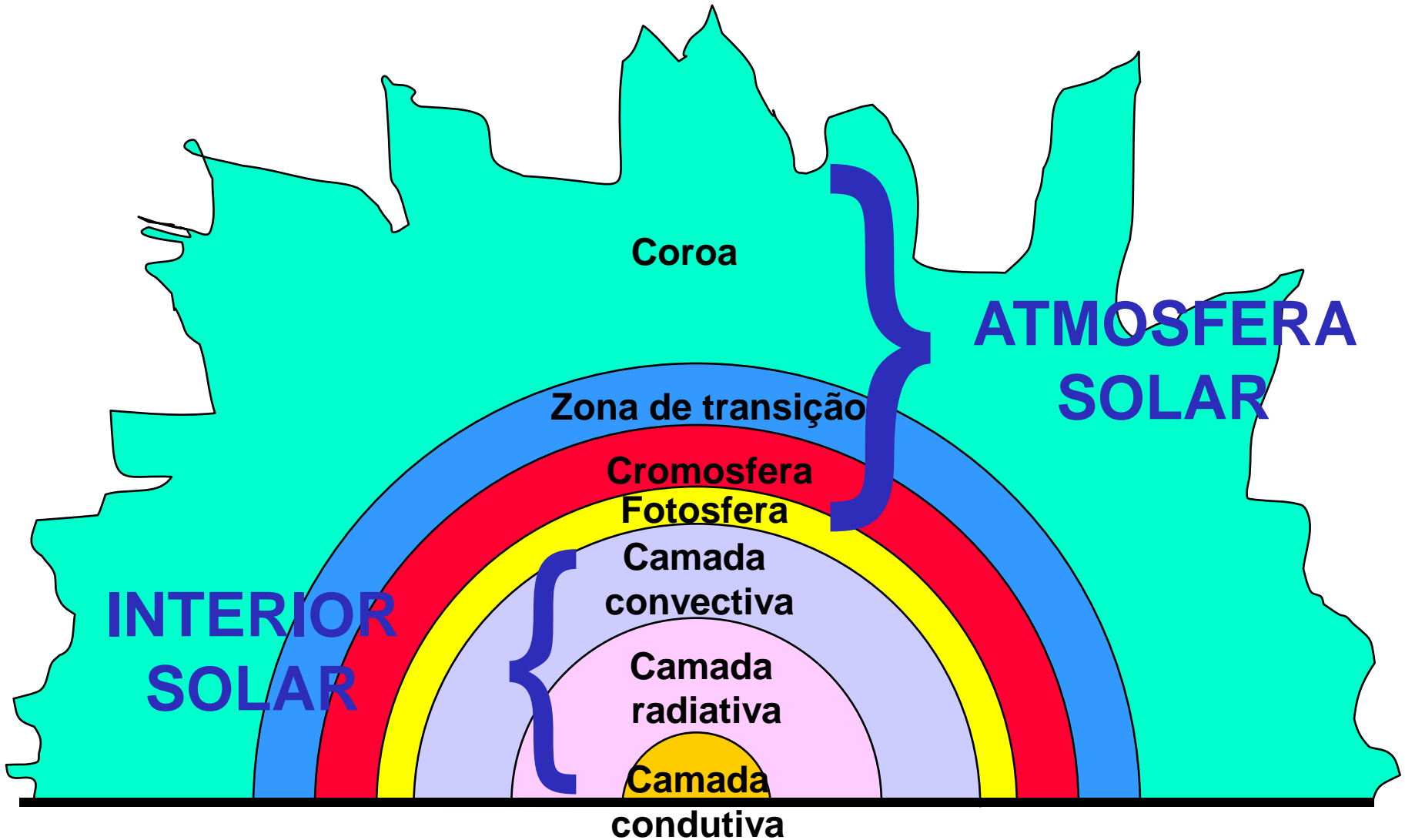
**Atmosfera solar
extendida**

Atmosfera solar: Fotosfera

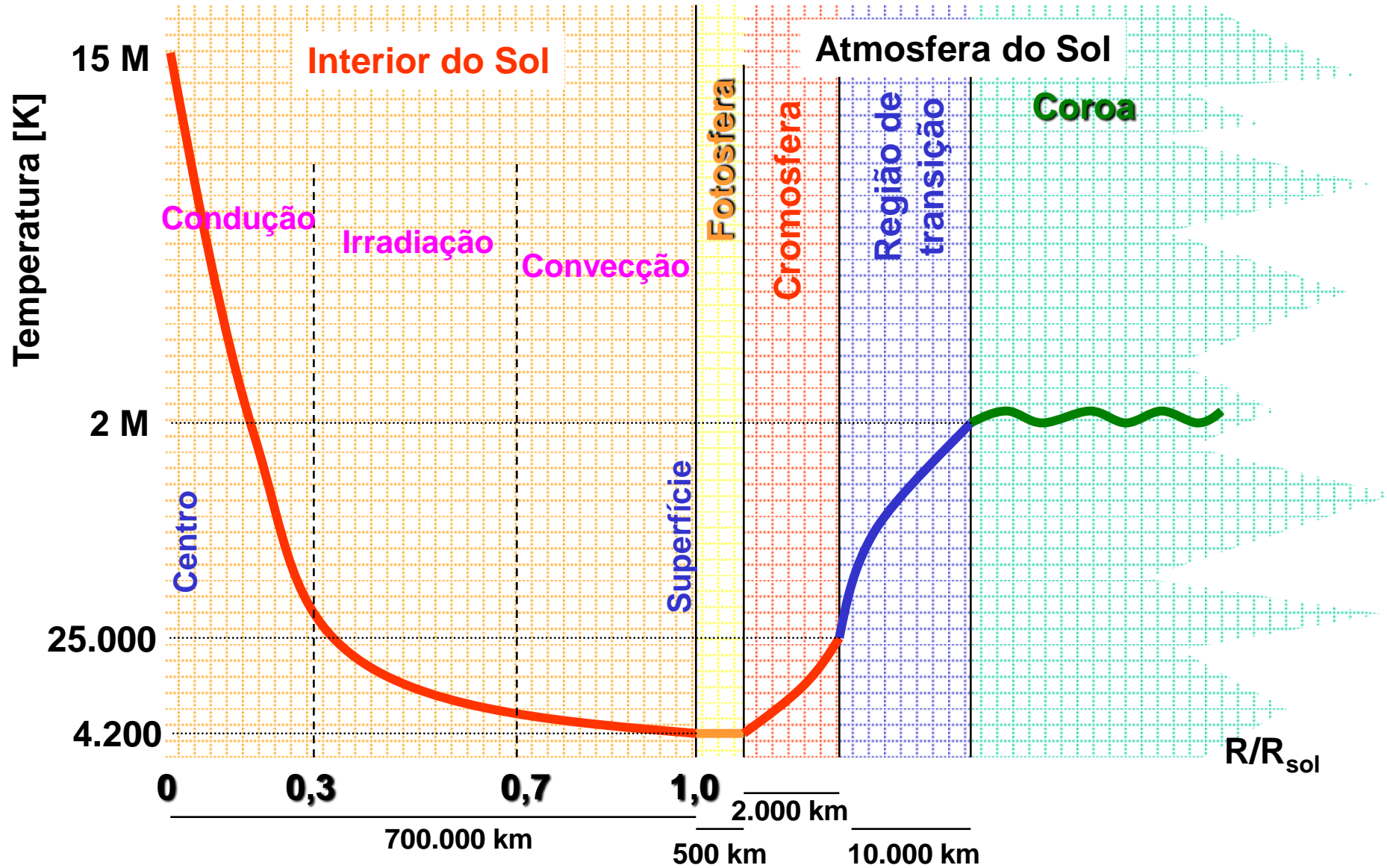
**Interior
Solar**



Estrutura mais fina do Sol



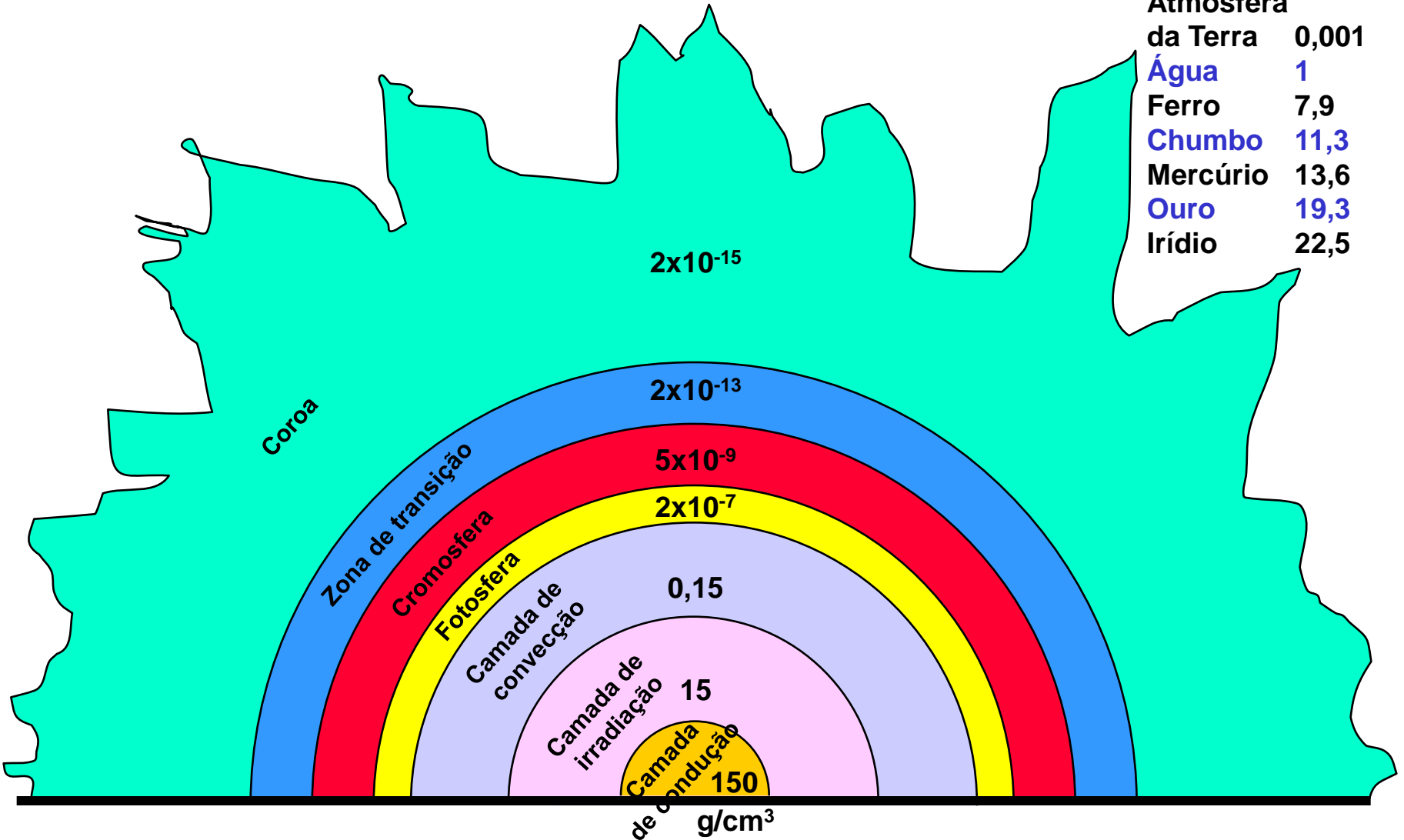
Temperatura nas camadas do Sol



Densidade das camadas do Sol

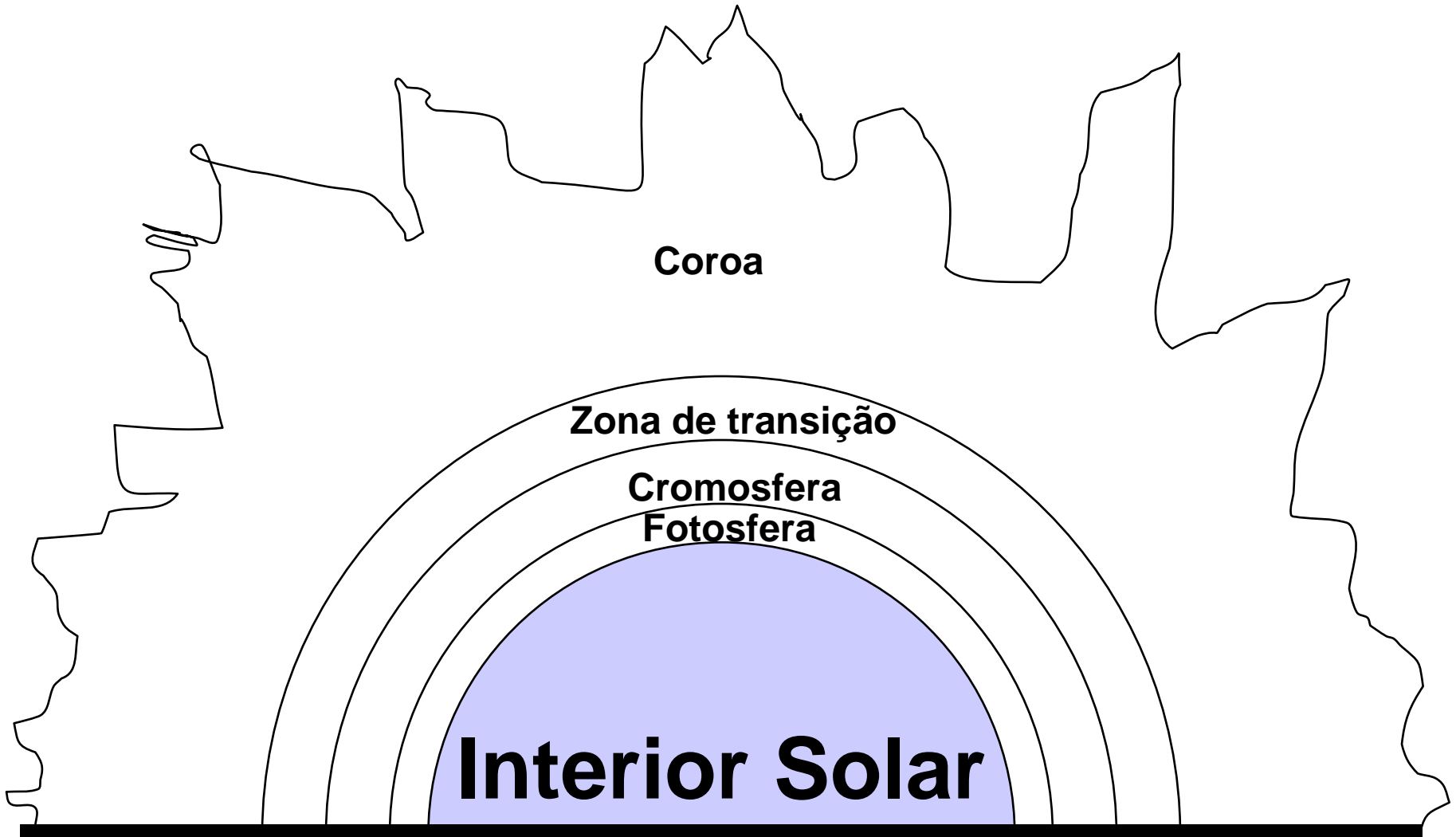
Densidades [g/cm³]

Atmosfera da Terra	0,001
Água	1
Ferro	7,9
Chumbo	11,3
Mercúrio	13,6
Ouro	19,3
Íridio	22,5



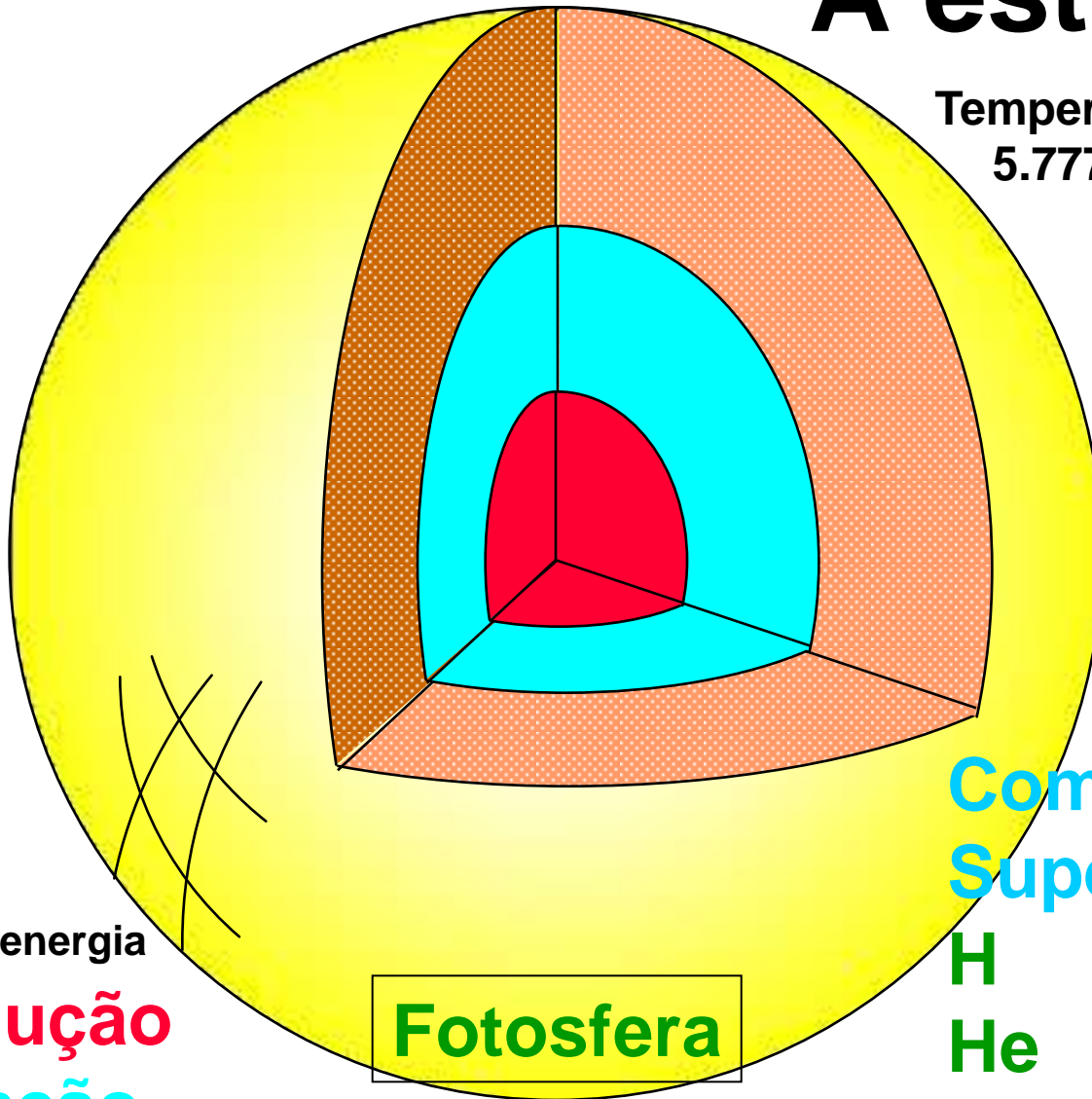
Interior do Sol

Interior do Sol



A estrela Sol




Temperatura
5.777 K



Composição
Superficial (massa)

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

Transporte de energia

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

Fotosfera

Propagação do calor

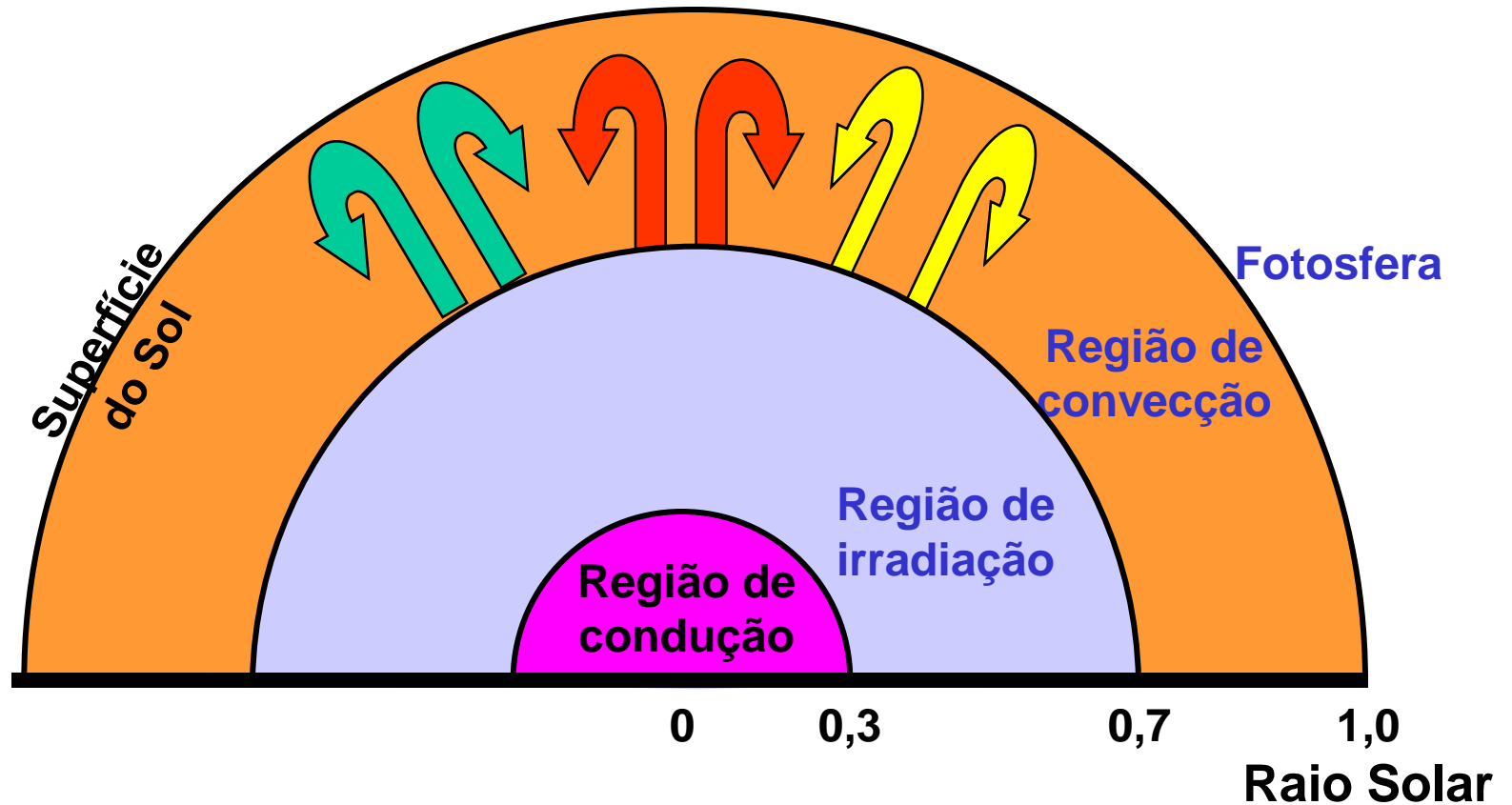
(transferência de energia devido à diferença de temperatura)

Convecção: movimento de material duma região para outra

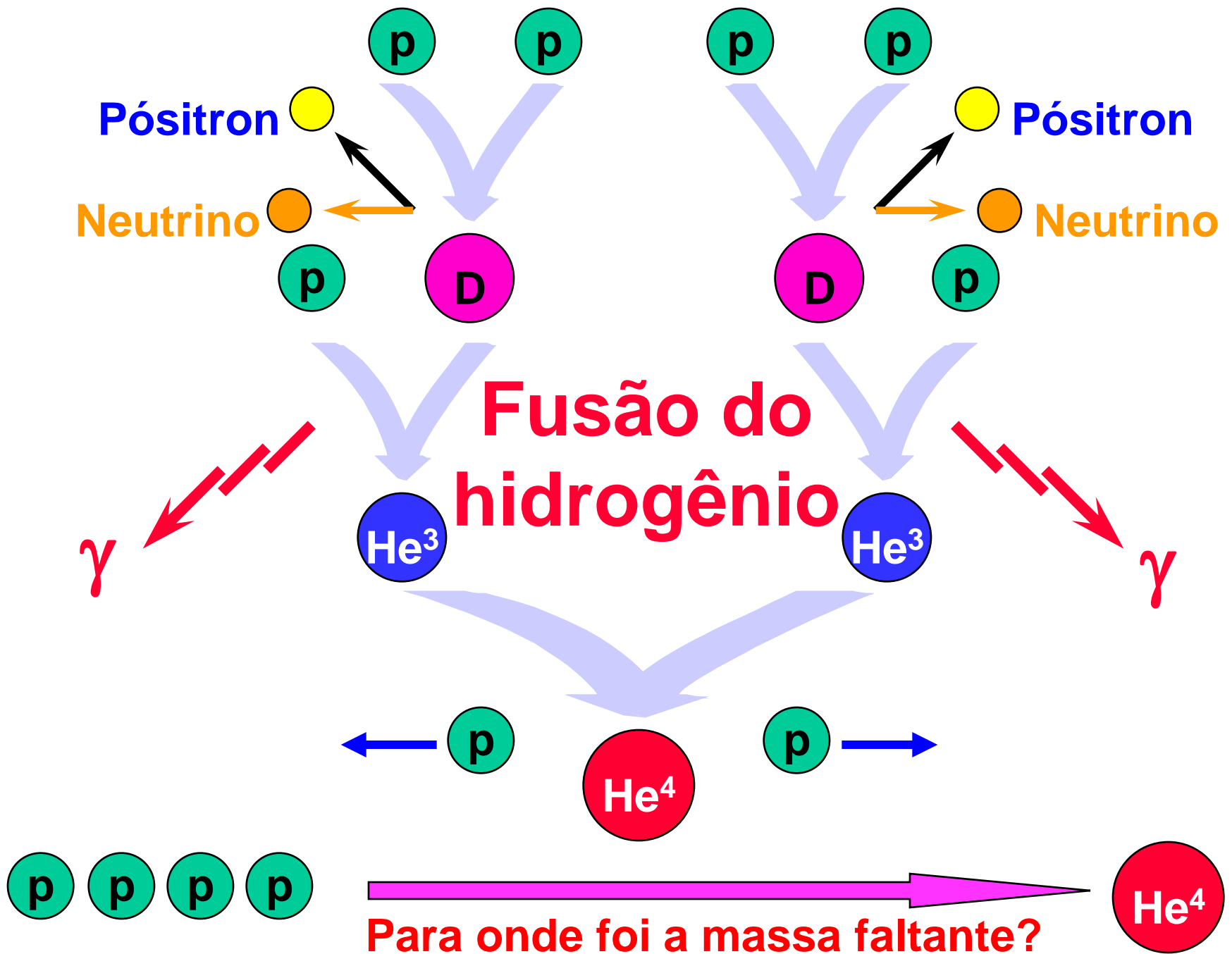


Condução:
Contato direto

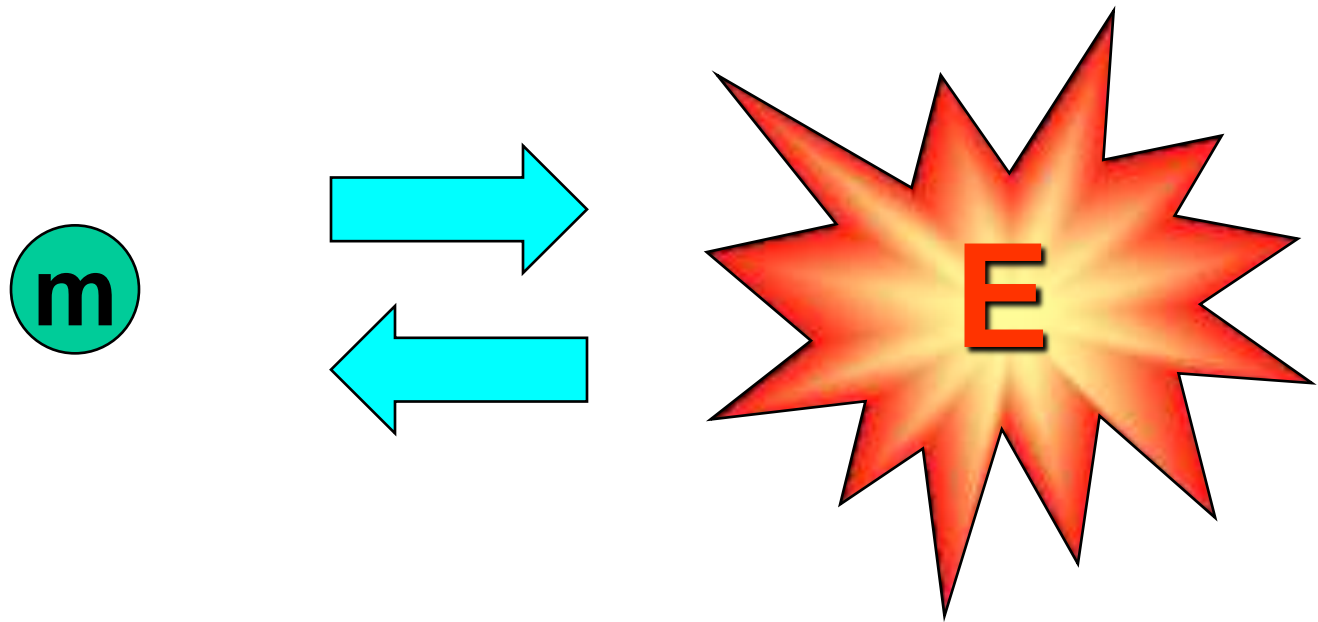
Camadas do interior do sol



Reações de nucleossíntese solar



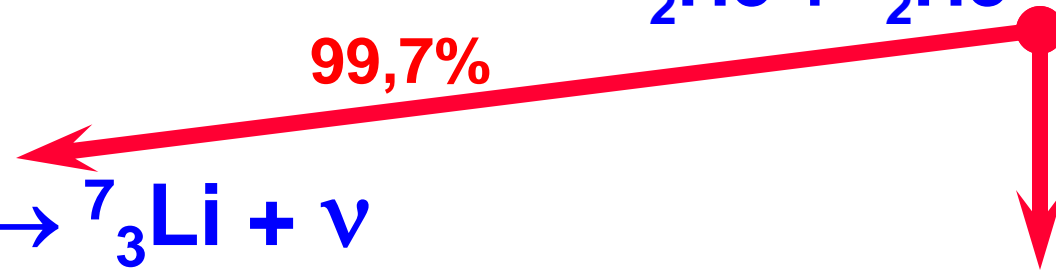
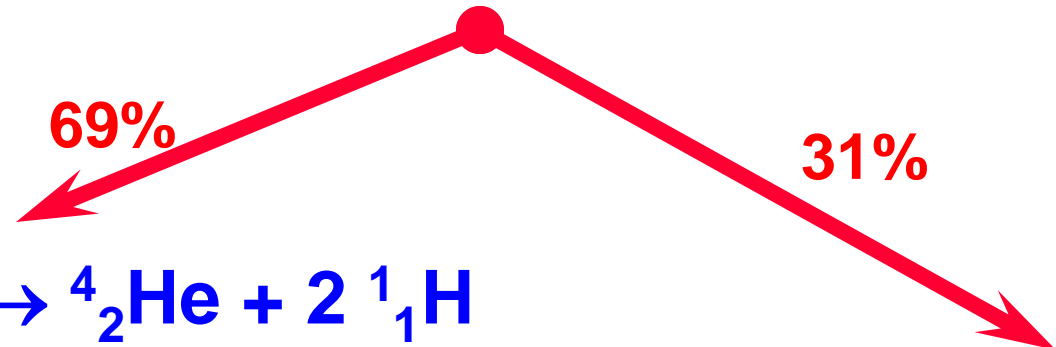
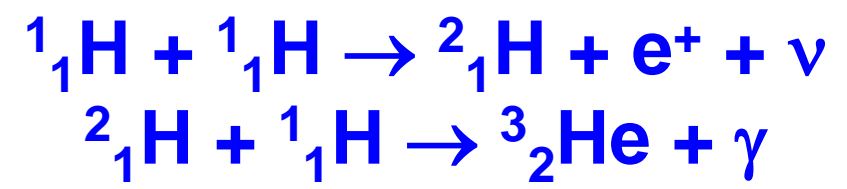
Relação entre massa e energia



$$E = m c^2$$

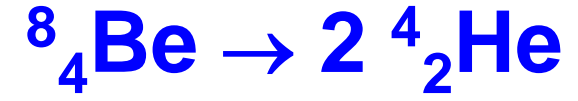
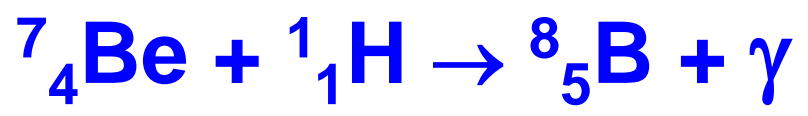
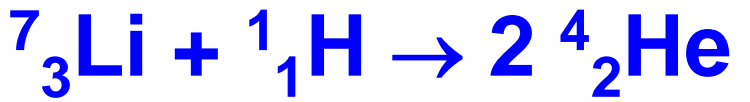
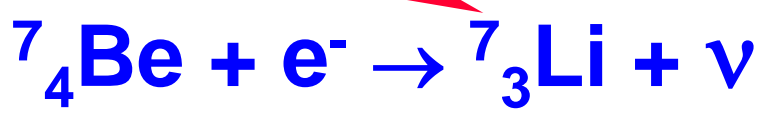
c = velocidade da luz no vácuo

Cadeia próton-próton gerando He

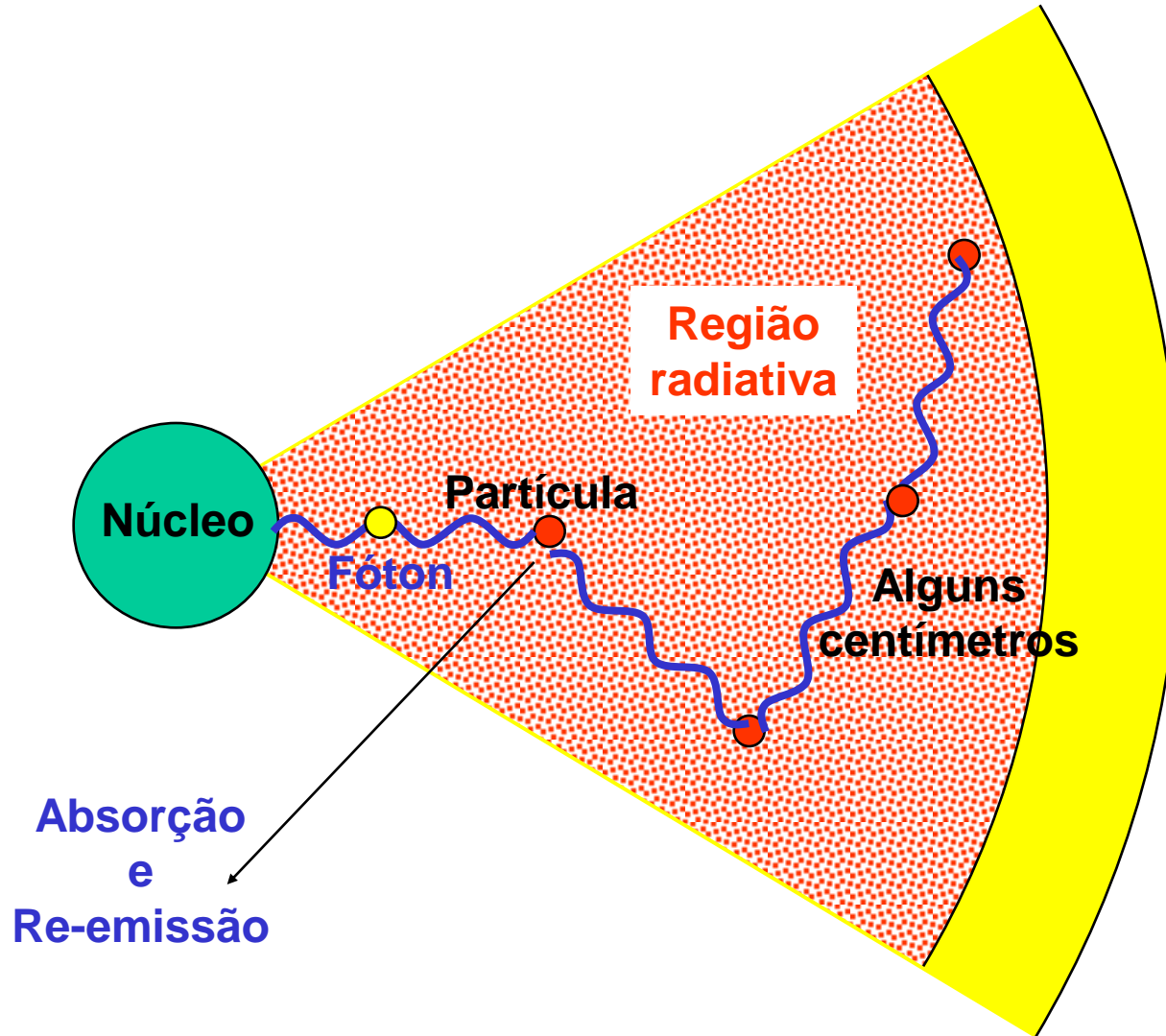


99,7%

0,3%



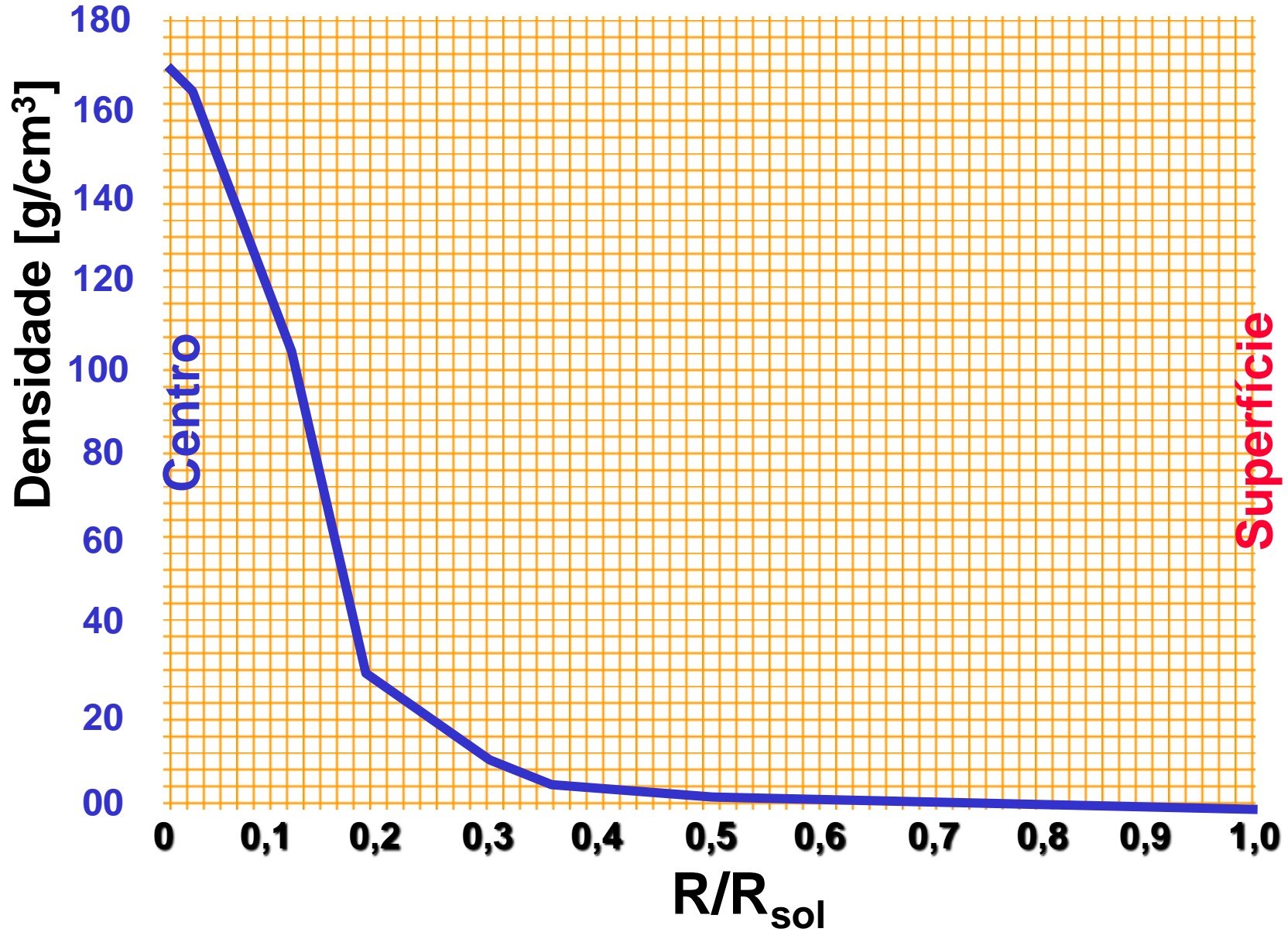
Livre caminho médio dos fótons na camada radiativa



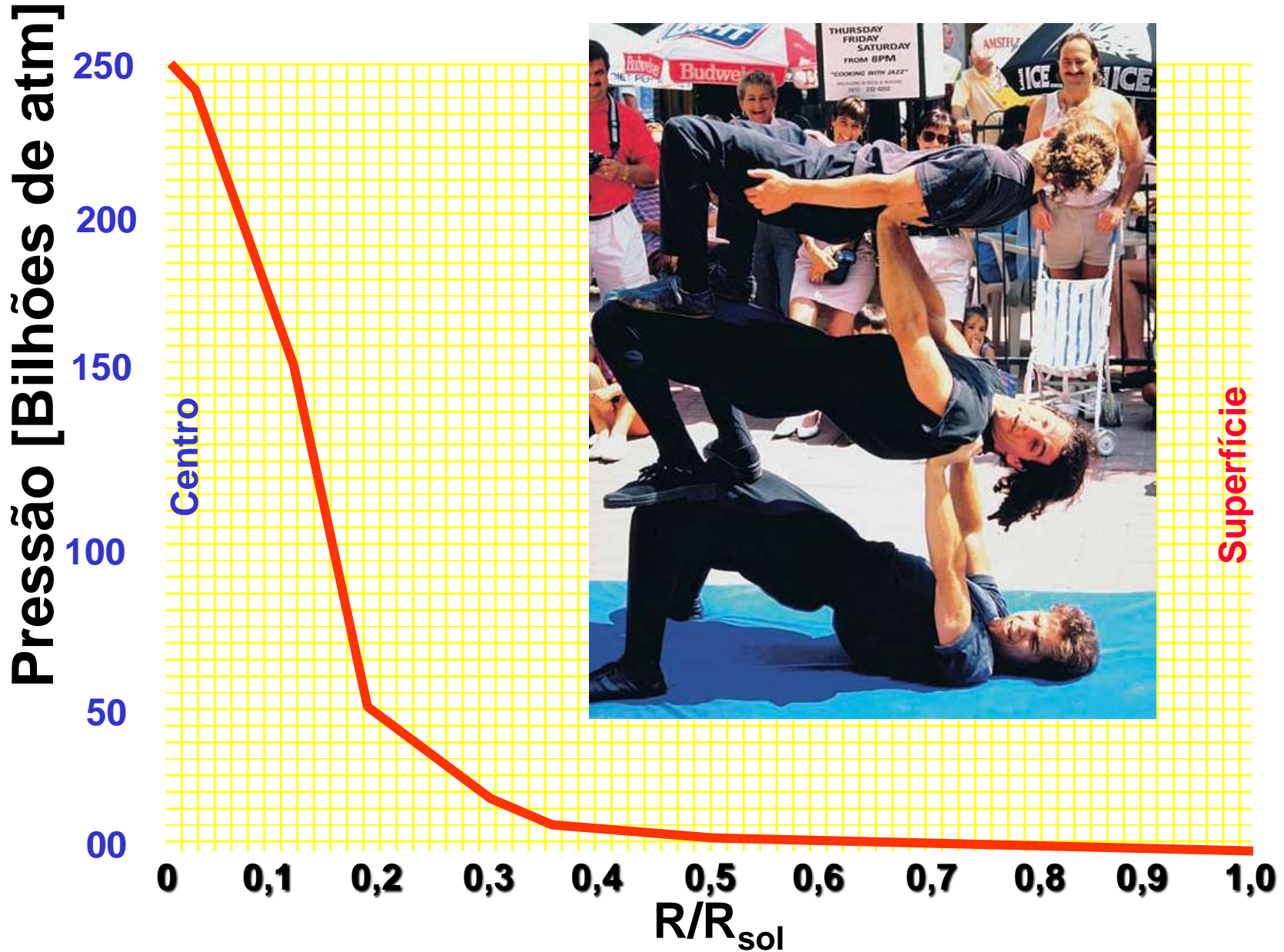
Tempo entre a geração do fóton no núcleo e sua saída pela fotosfera:
milhões de anos

Dados do interior do Sol

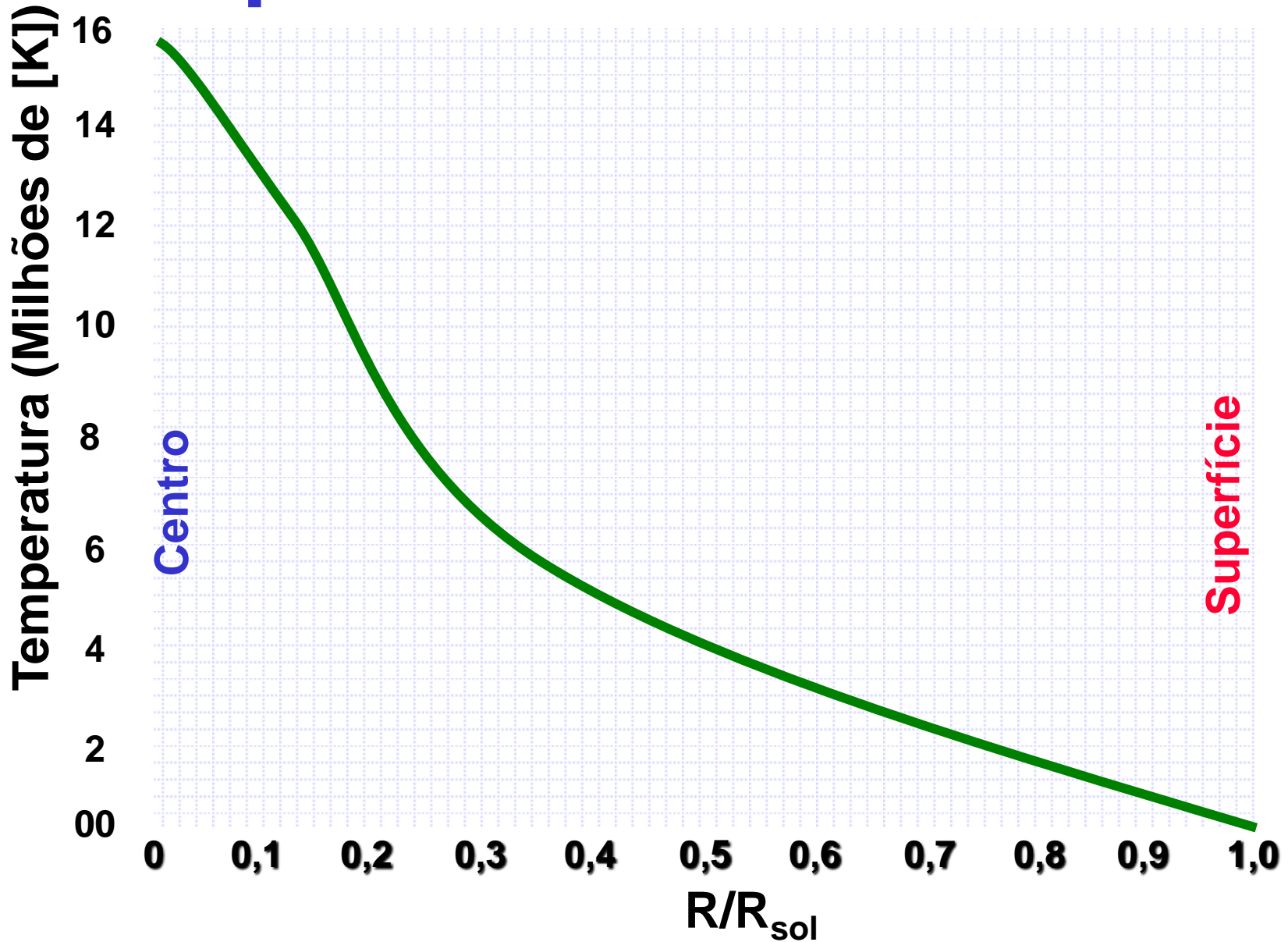
Densidade solar



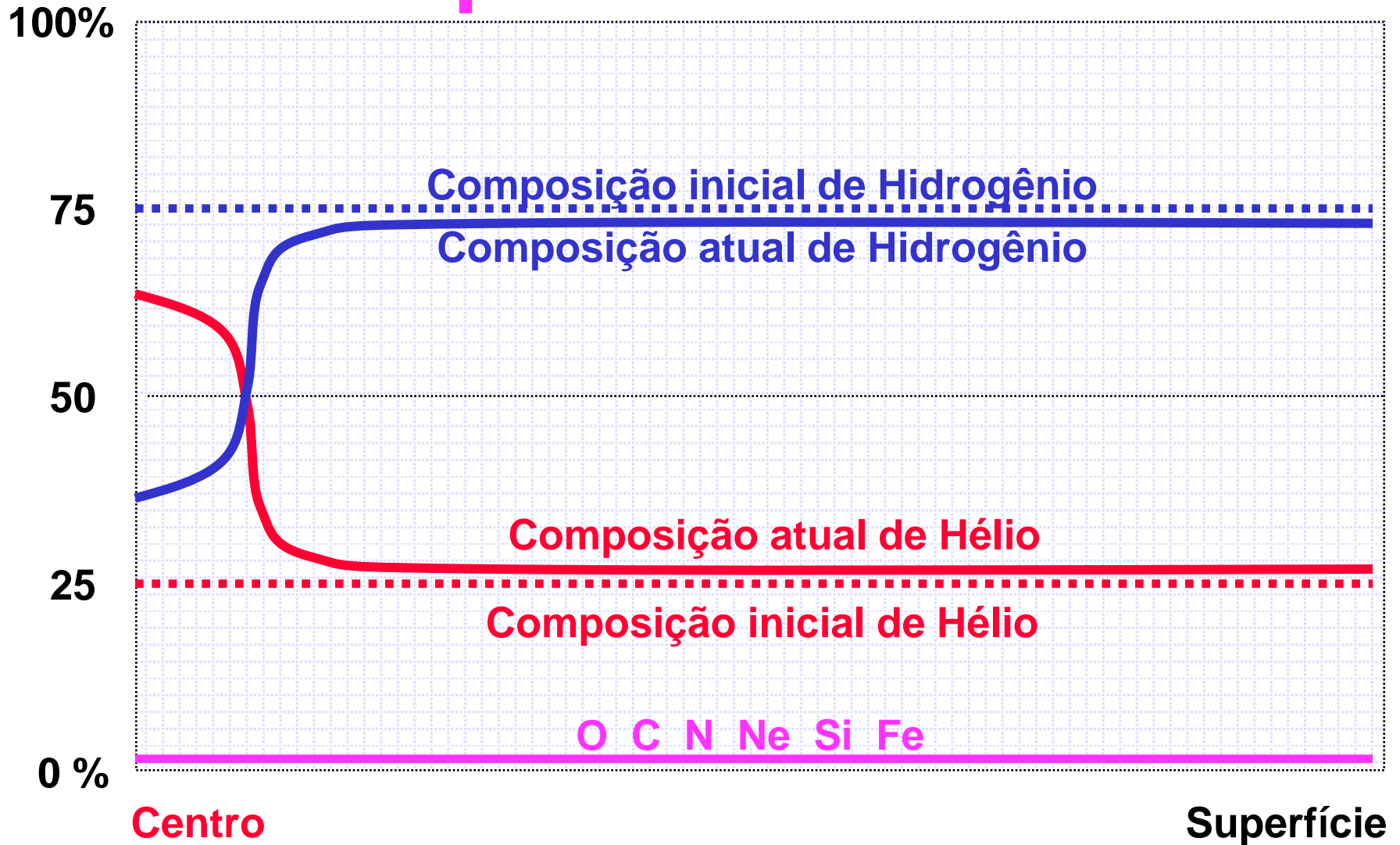
Pressão no interior solar

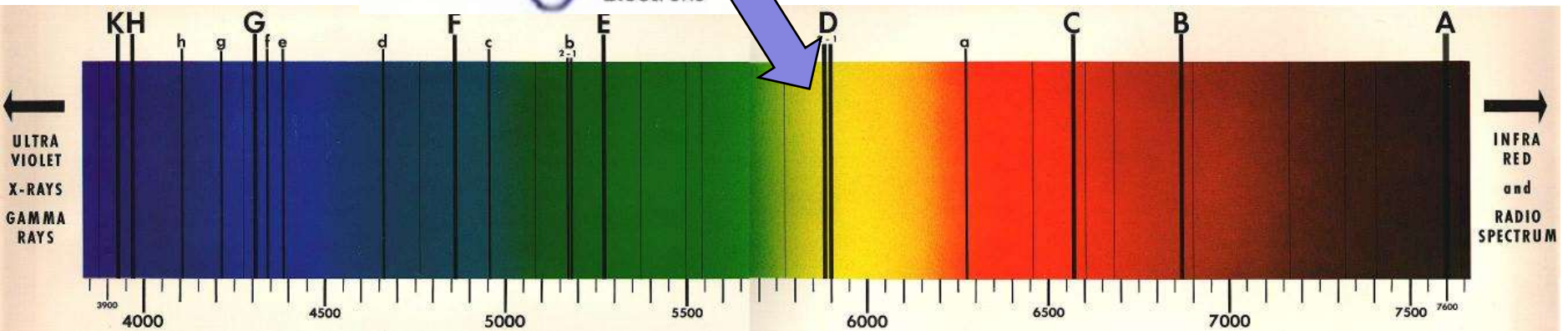
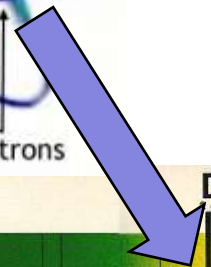
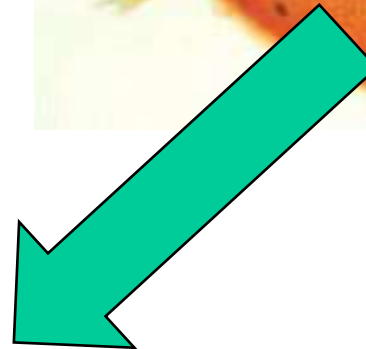
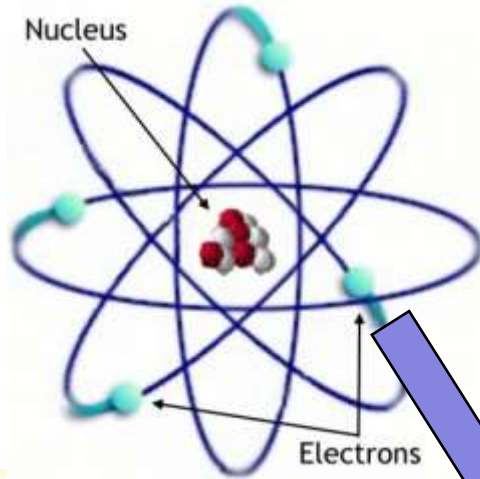
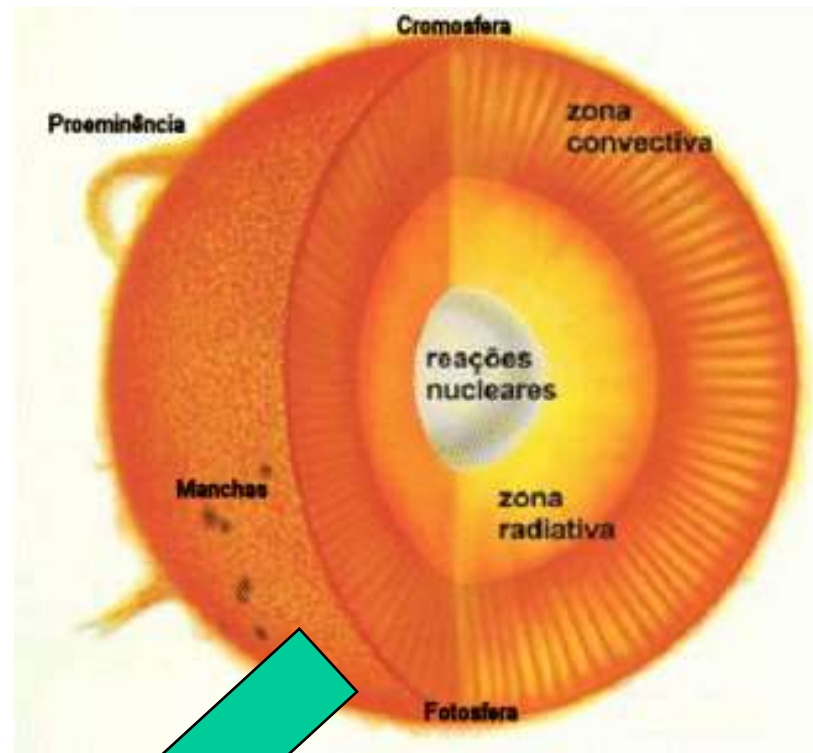


Temperatura no interior solar

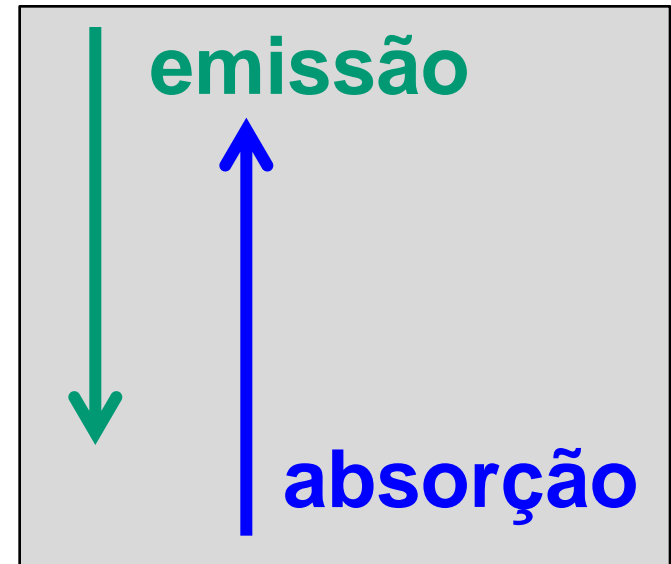
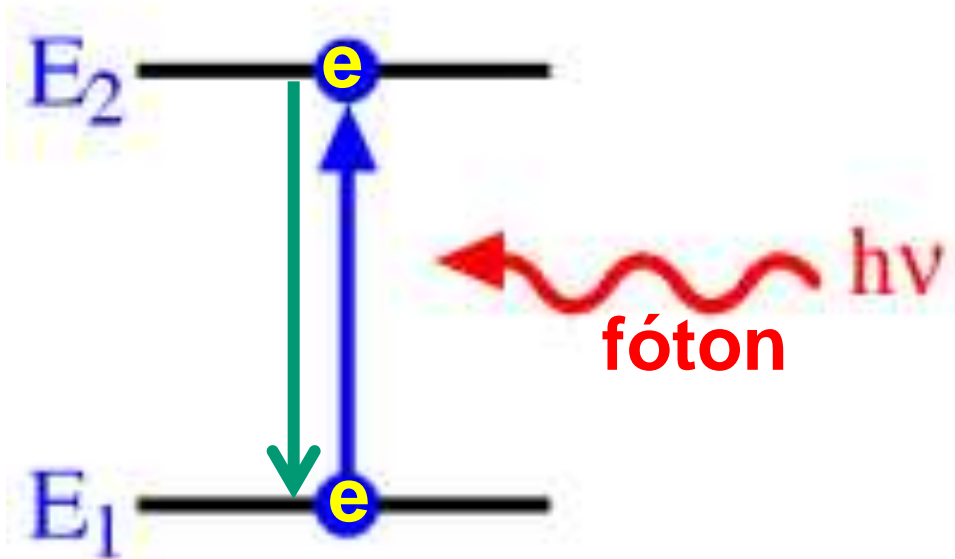


Mudanças na composição química do Sol

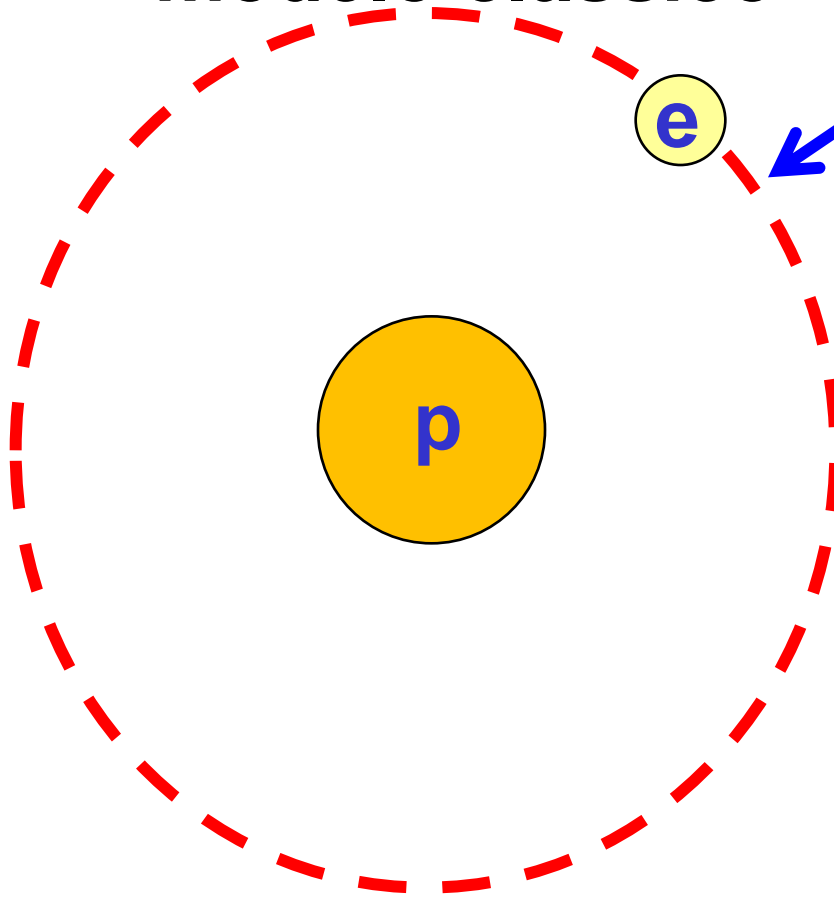




Formação de Linhas da Fotosfera

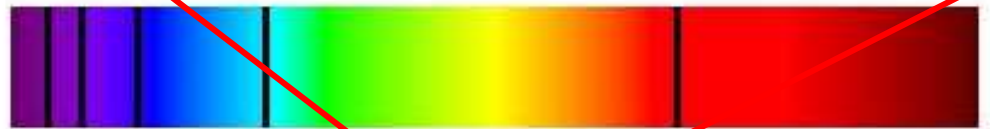


Átomo de hidrogênio : modelo clássico



**Não é possível
formar linhas ...**

Hydrogen Absorption Spectrum



Hydrogen Emission Spectrum



400nm

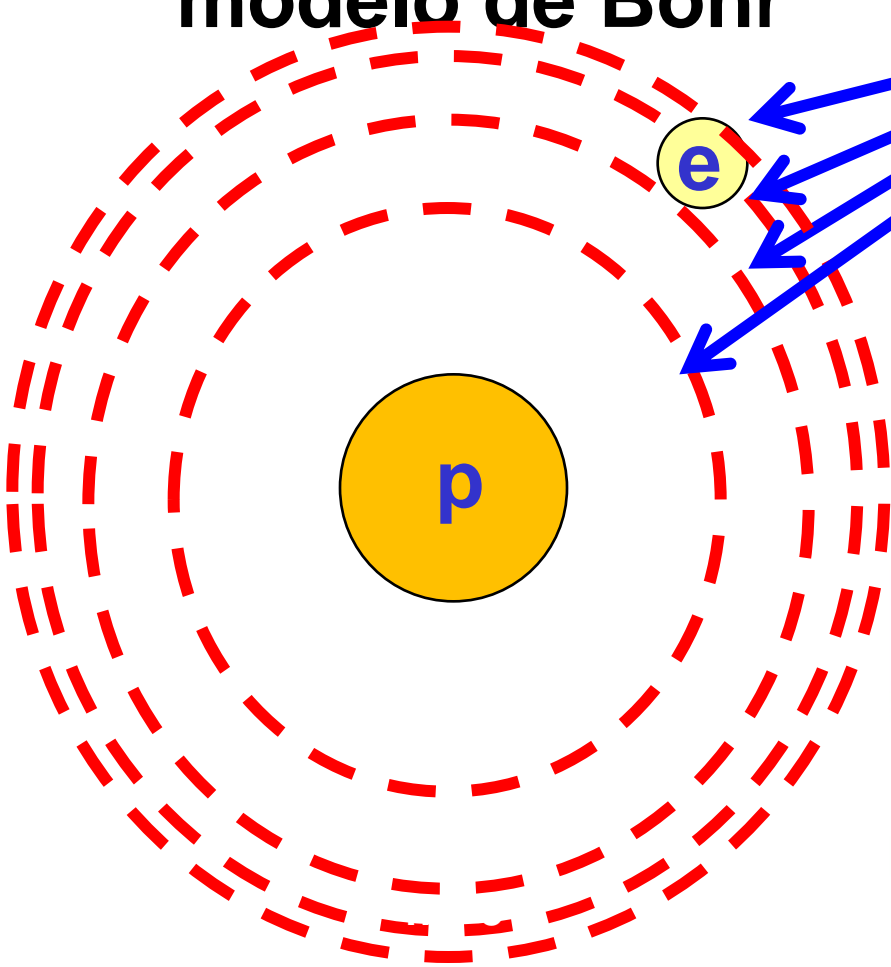
700nm

H Alpha Line
656nm
Transition N=3 to N=2

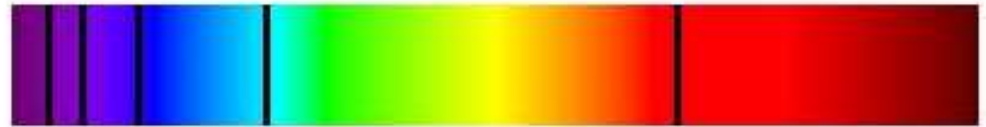
Átomo de hidrogênio : modelo de Bohr

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

É possível formar
linhas ...



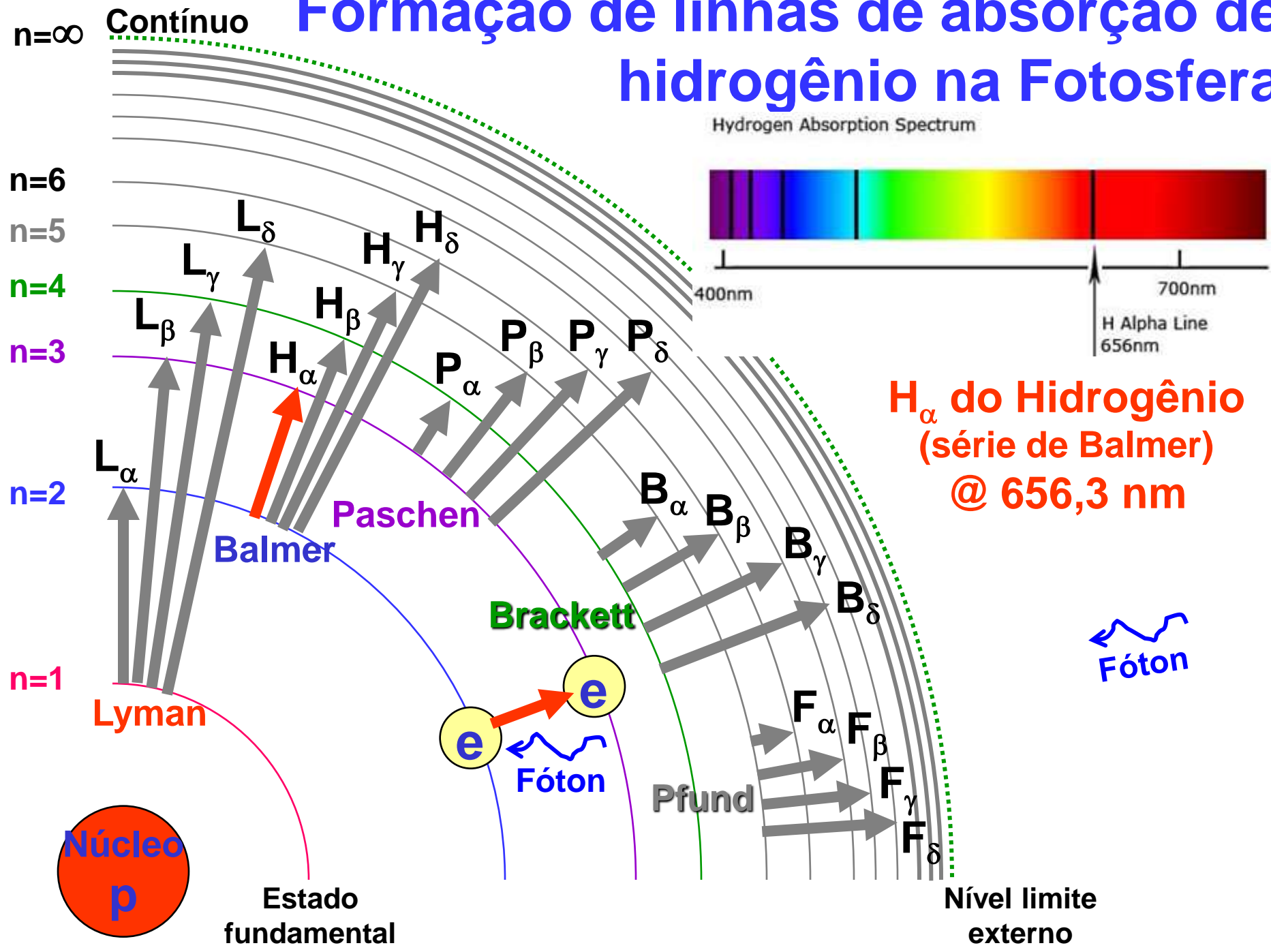
Hydrogen Absorption Spectrum



Hydrogen Emission Spectrum



Formação de linhas de absorção de hidrogênio na Fotosfera



Hydrogen Absorption Spectrum



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

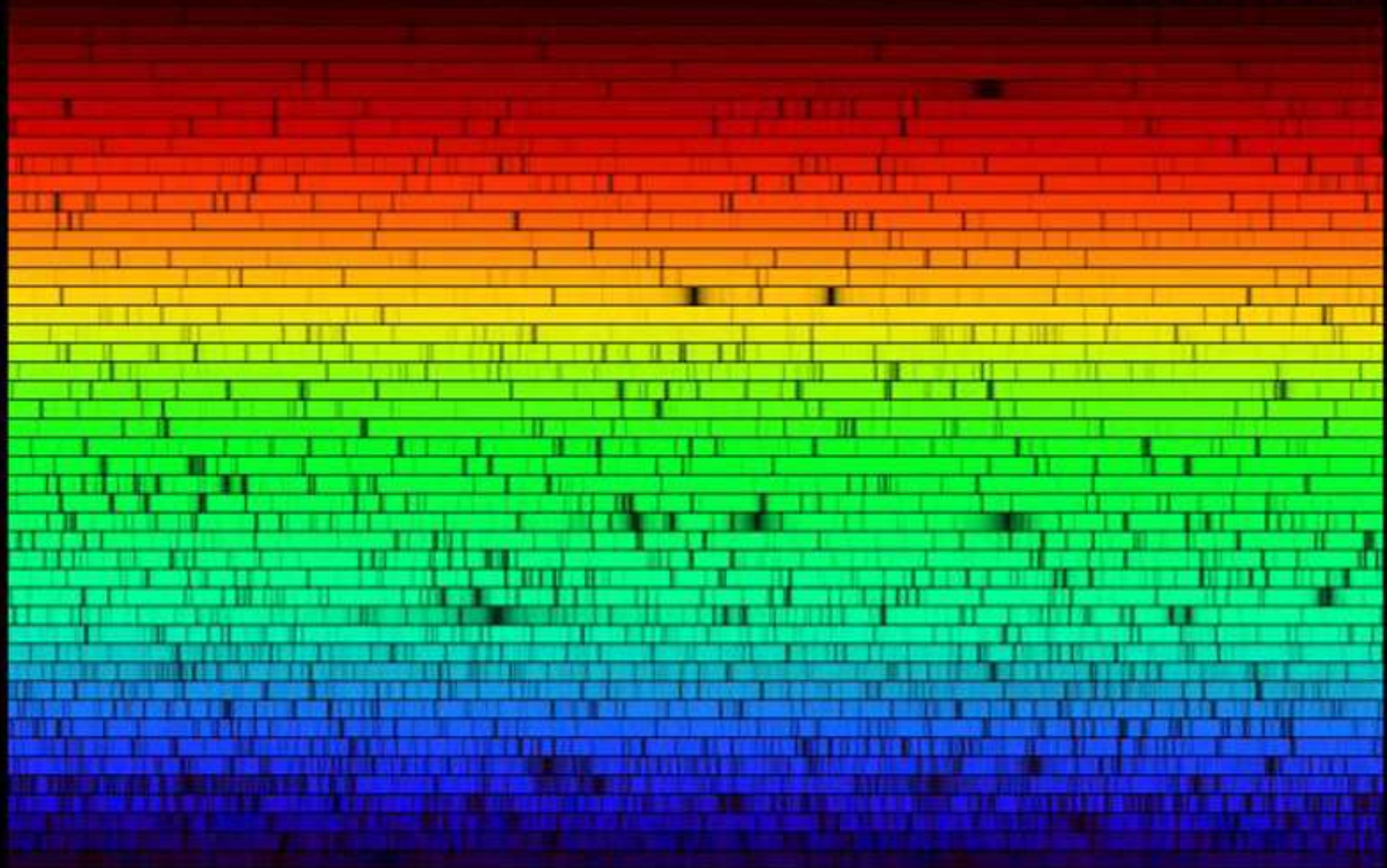
Fóton

Estado fundamental

Nível limite externo

Espectro solar (empilhado)

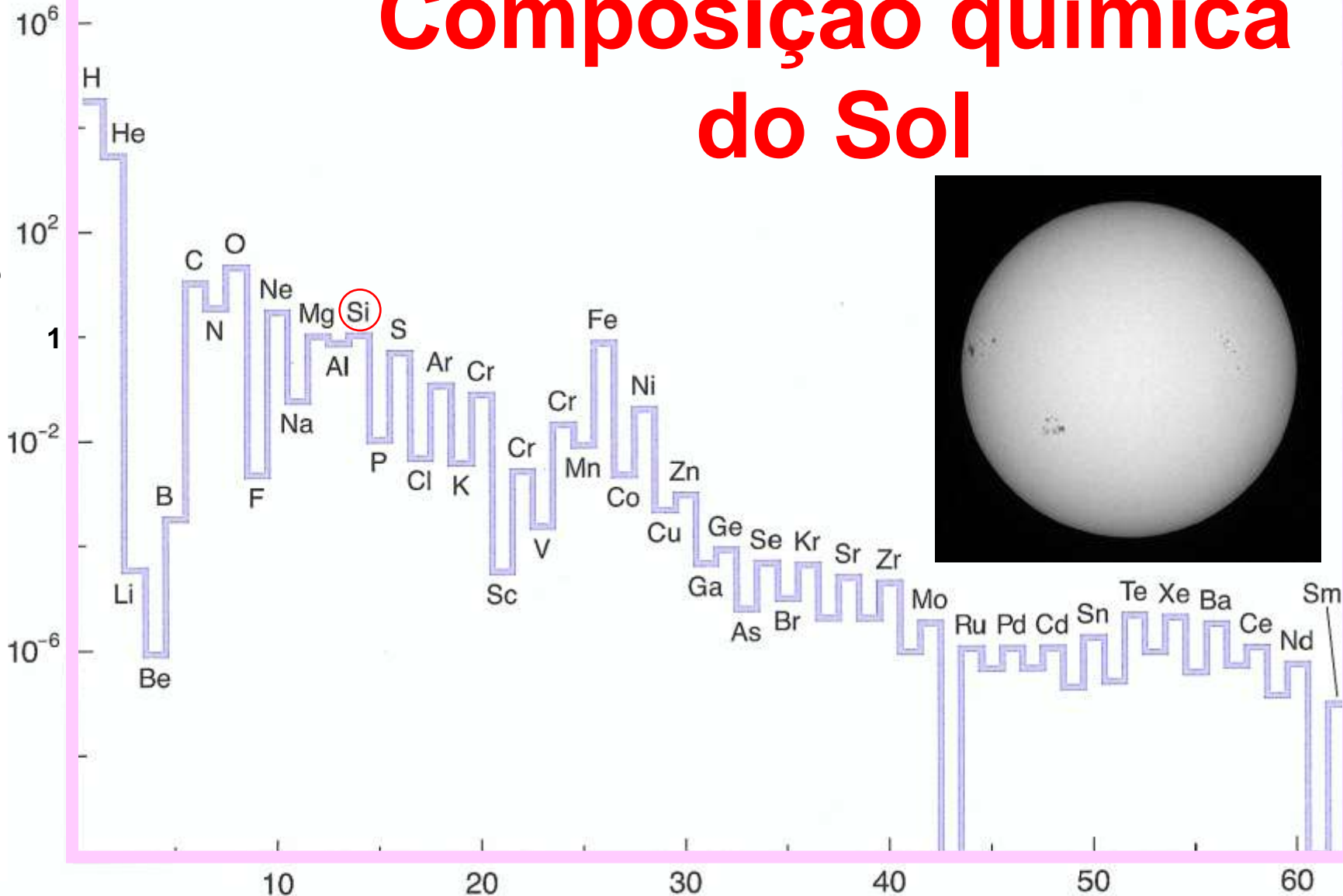
↑ Infravermelho



Ultravioleta ↓

Composição química do Sol

Abundância elemental 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

?

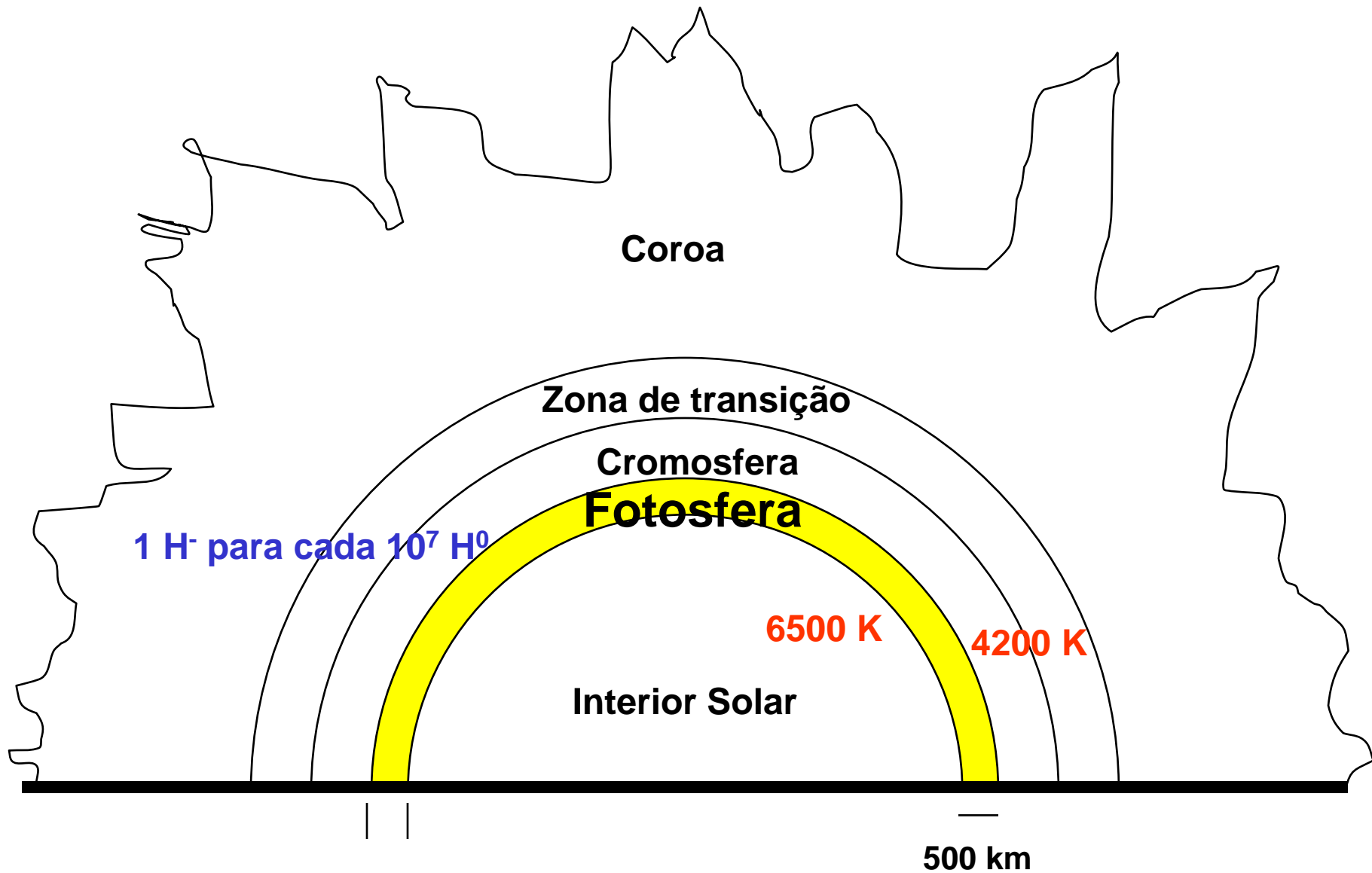
Embora o Sol seja a estrela mais próxima a sua abundância de oxigênio ainda não é muito bem conhecida ...

“Superfície”

do Sol:

fotosfera

Fotosfera do Sol



Fotosfera do Sol



Espessura óptica (τ)

(ou profundidade óptica)

τ : medida da transparência

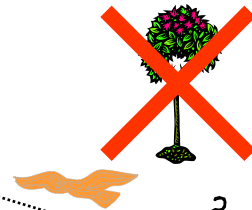
$$I/I_0 = e^{-\tau}.$$

Neblina

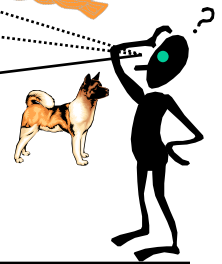
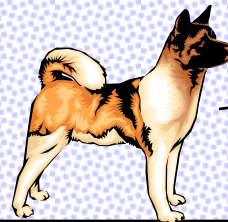


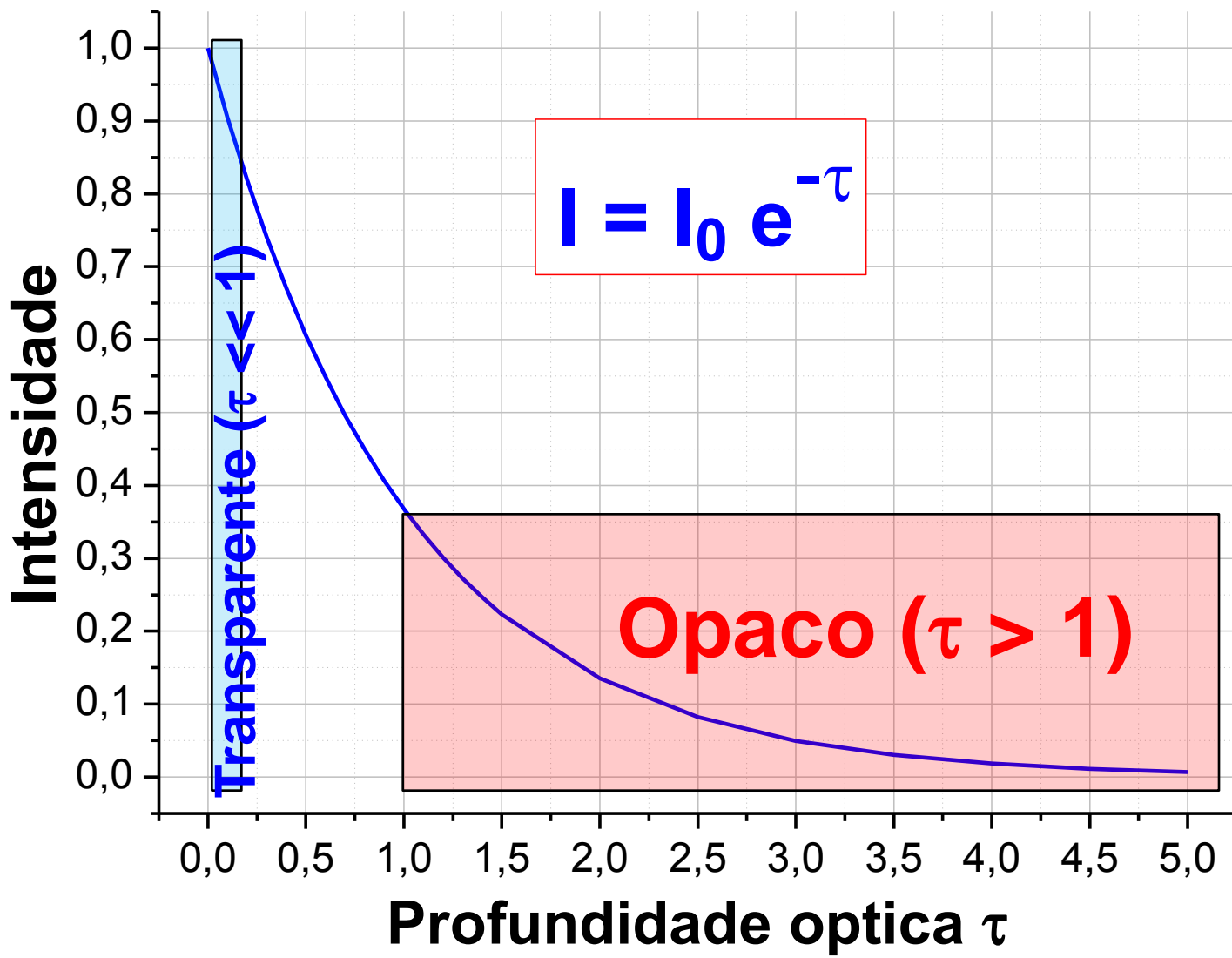
$\tau = 1$

Opaco
 $\tau > 1$



Transparente
 $\tau < 1$



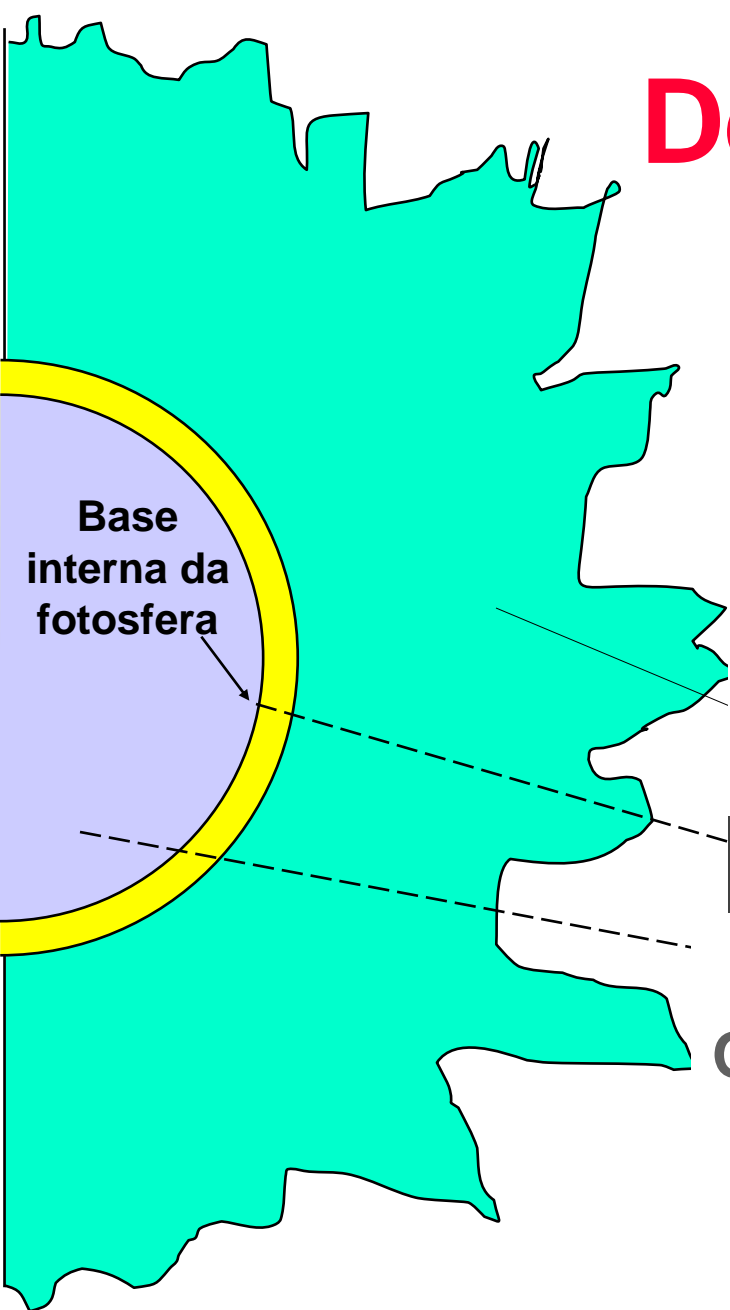


Definição da fotosfera

τ = Espessura óptica

Temperatura superficial:

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



Transparente

$$\tau \ll 1$$

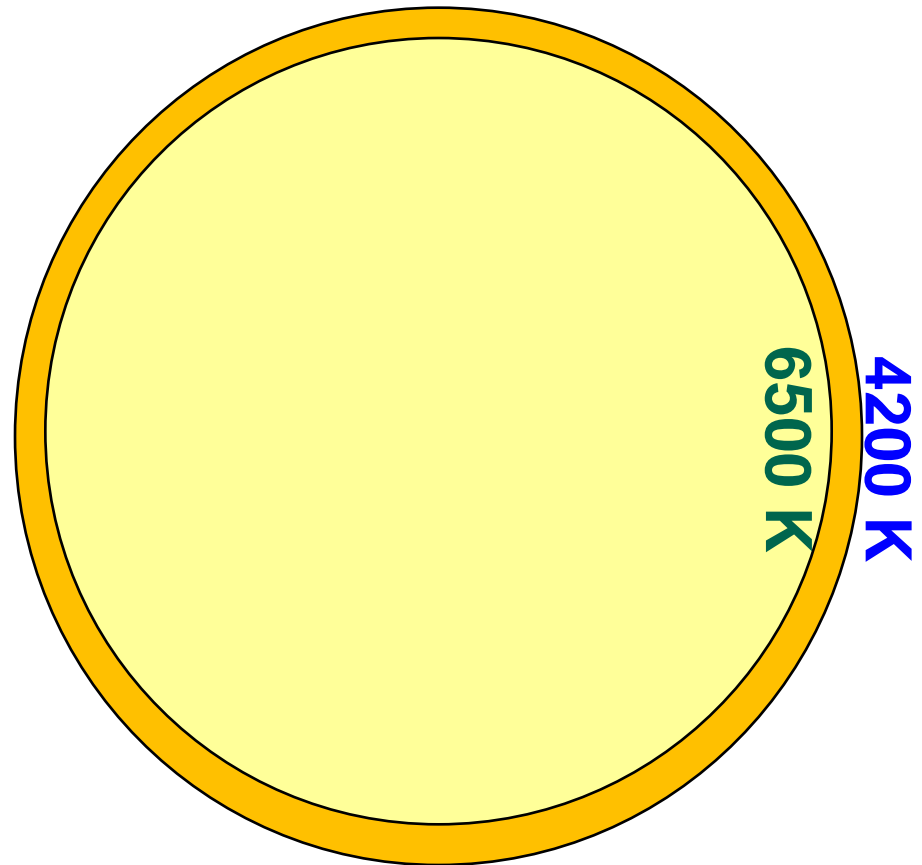
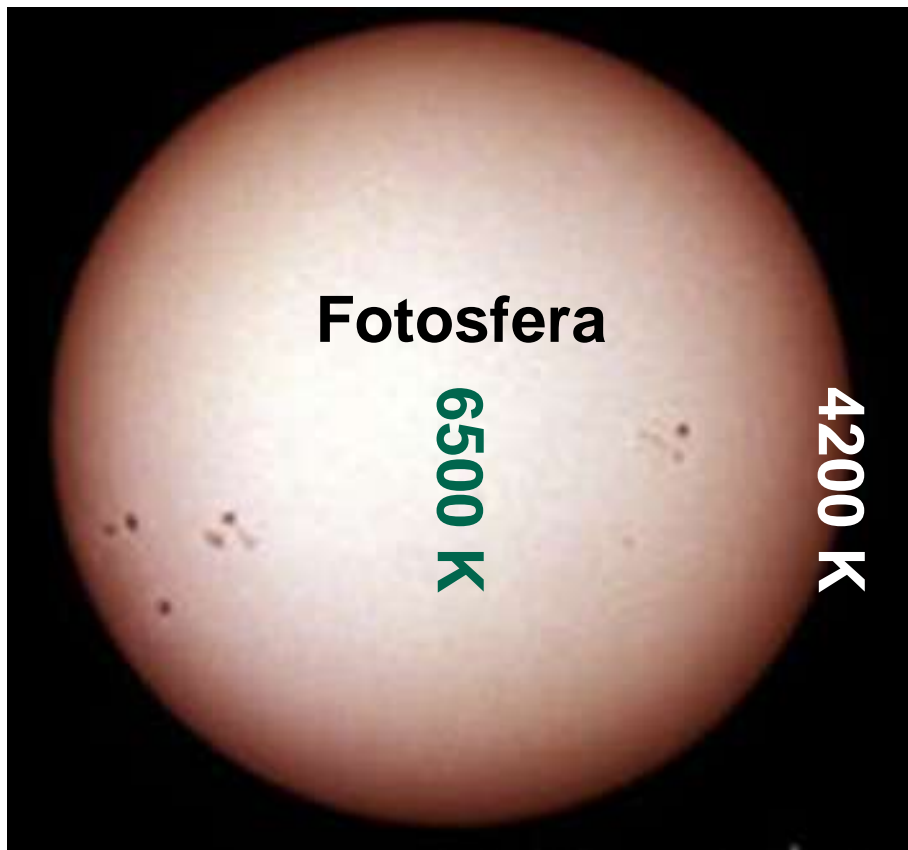
$$\tau = 1$$

$$\tau > 1$$

Opaco



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



Escurecimento do limbo



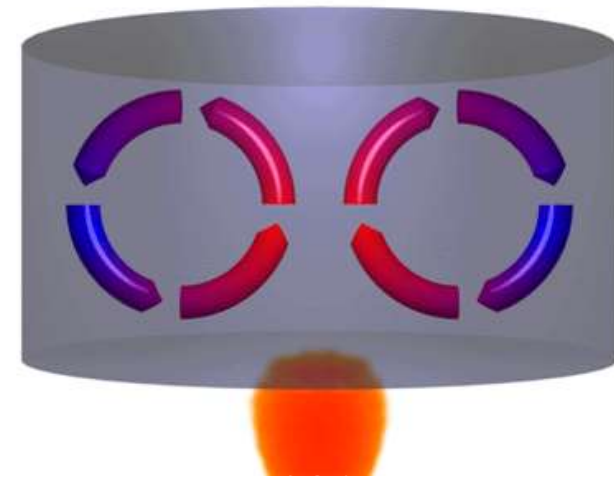
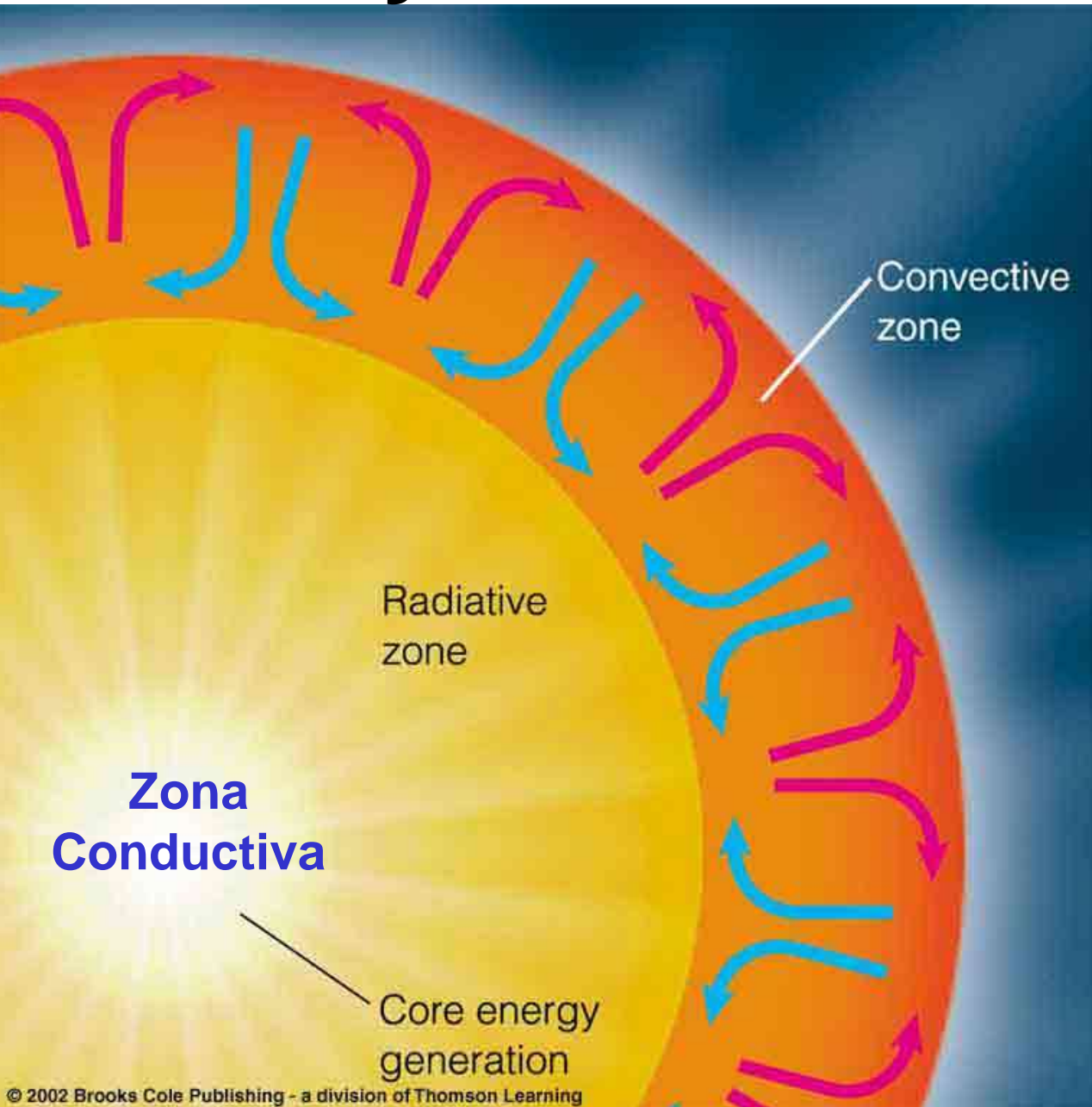
**Espessura óptica $\tau = 1$
ocorre em regiões
mais externas (frias)**

**Espessura $\tau = 1$
ocorre em regiões
mais internas
(quentes)**

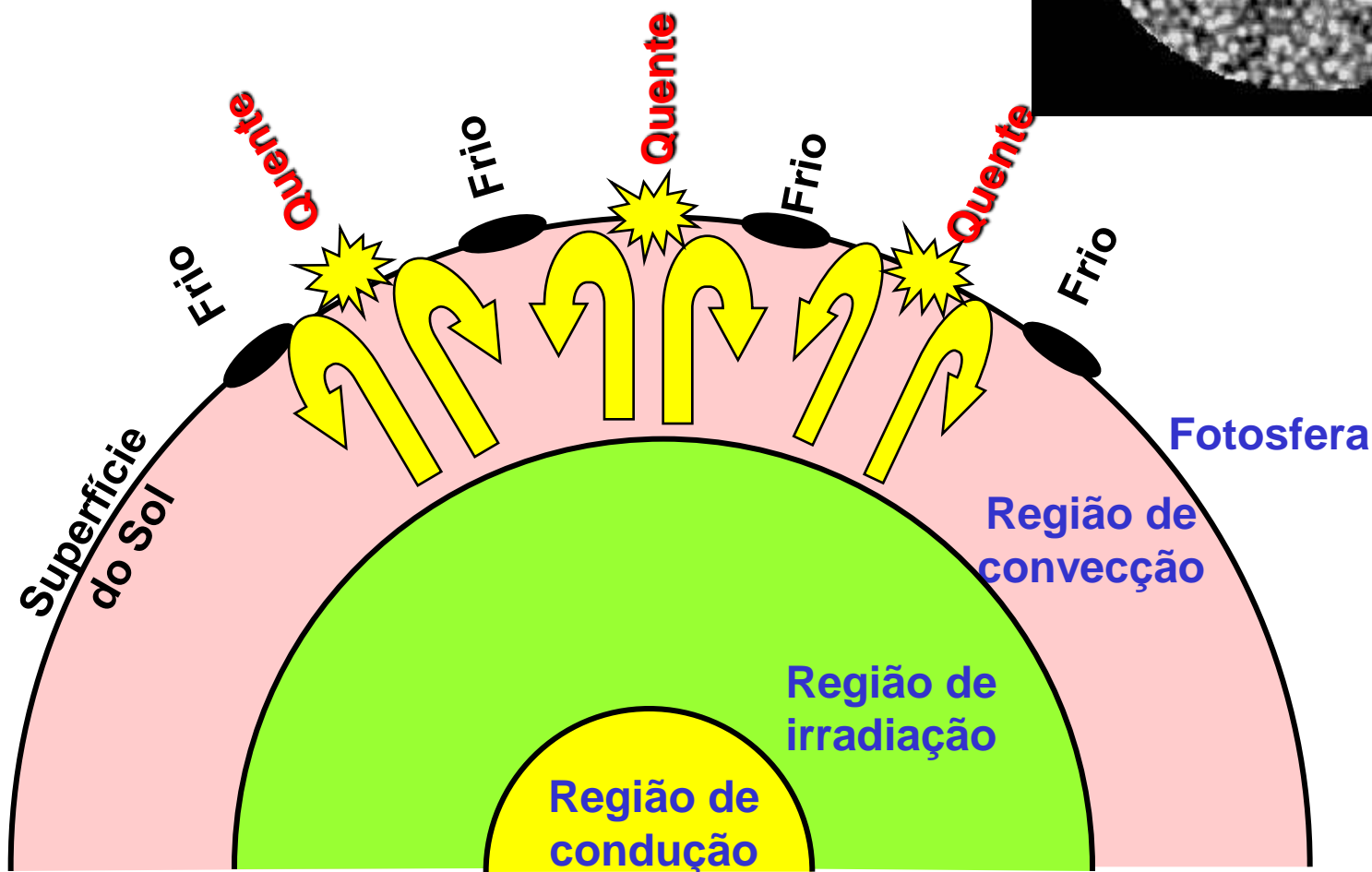
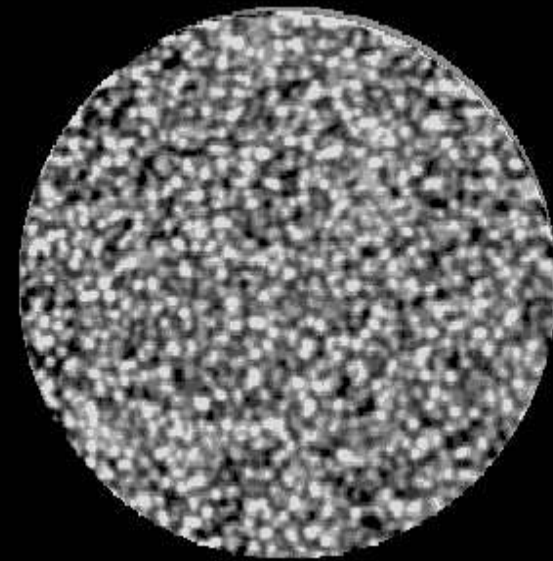
Visão do Sol



Convecção



Convecção abaixo da fotosfera

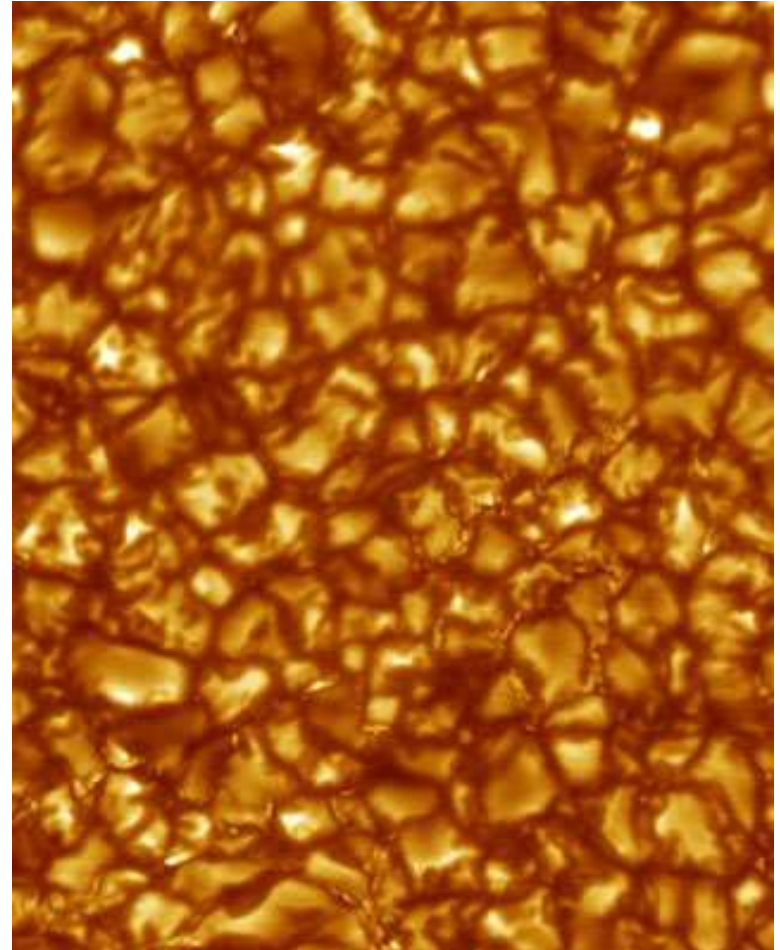


Estrutura Alveolar (Granular) do Sol

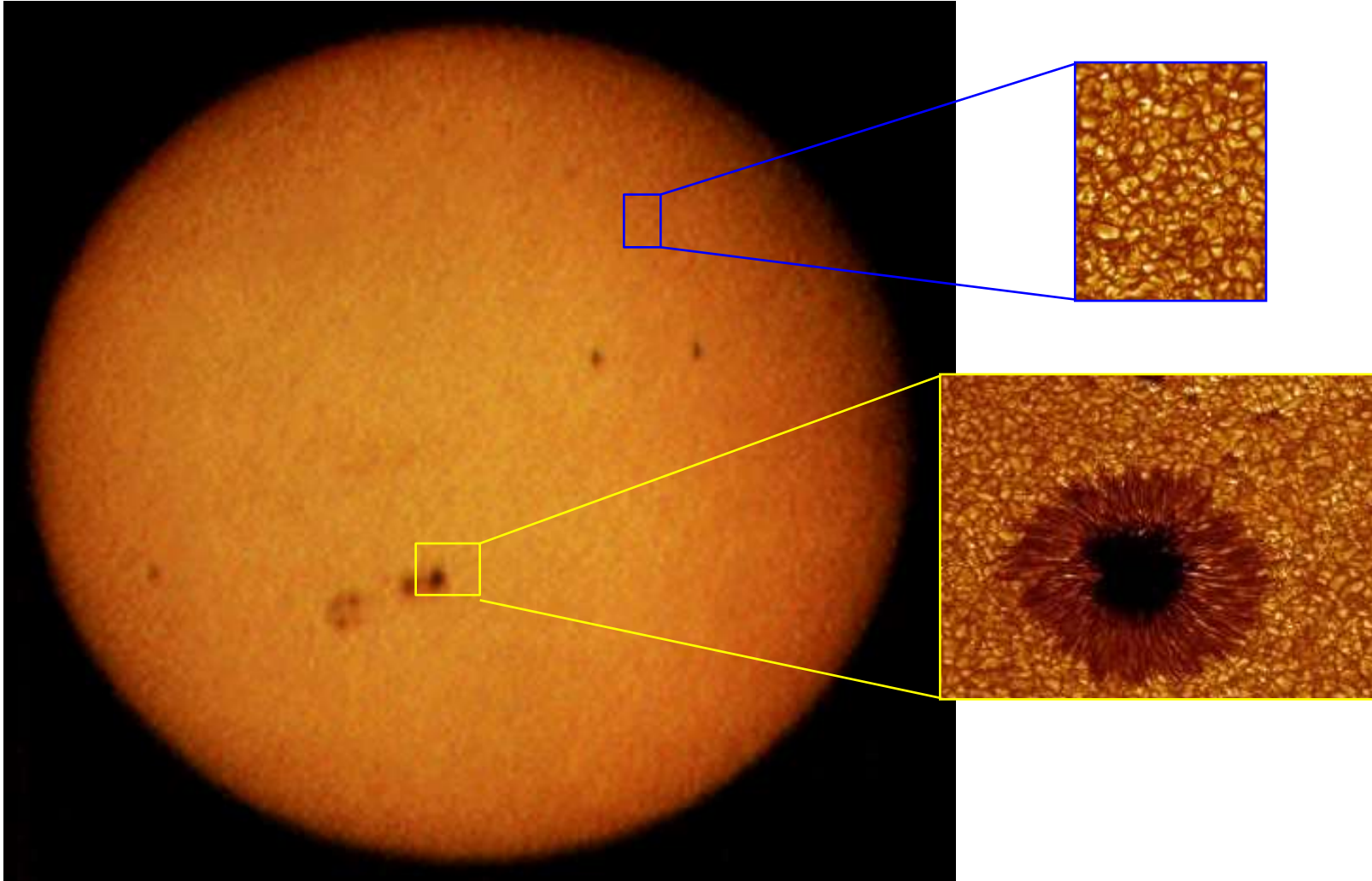
- **Regiões Claras**
 - Subida de gás quente
- **Regiões Escuras**
 - Descida de gás frio

**Diâmetro típico de
um grânulo (alvéolo):
1000 km**

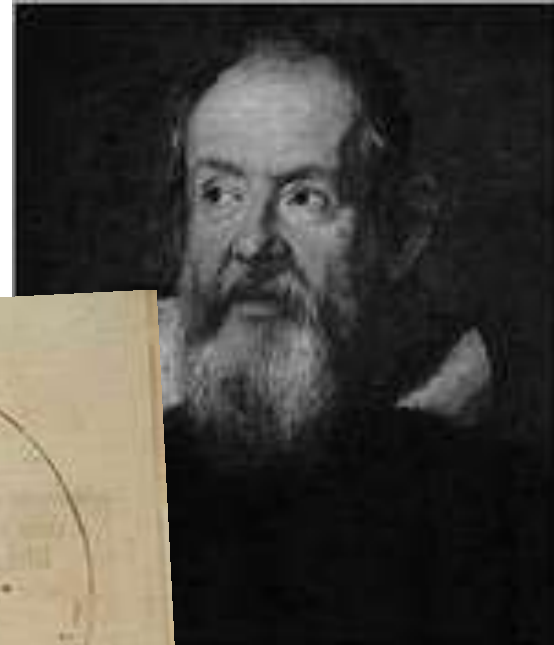
**Vida de um grânulo (alvéolo):
5 a 10 minutos**



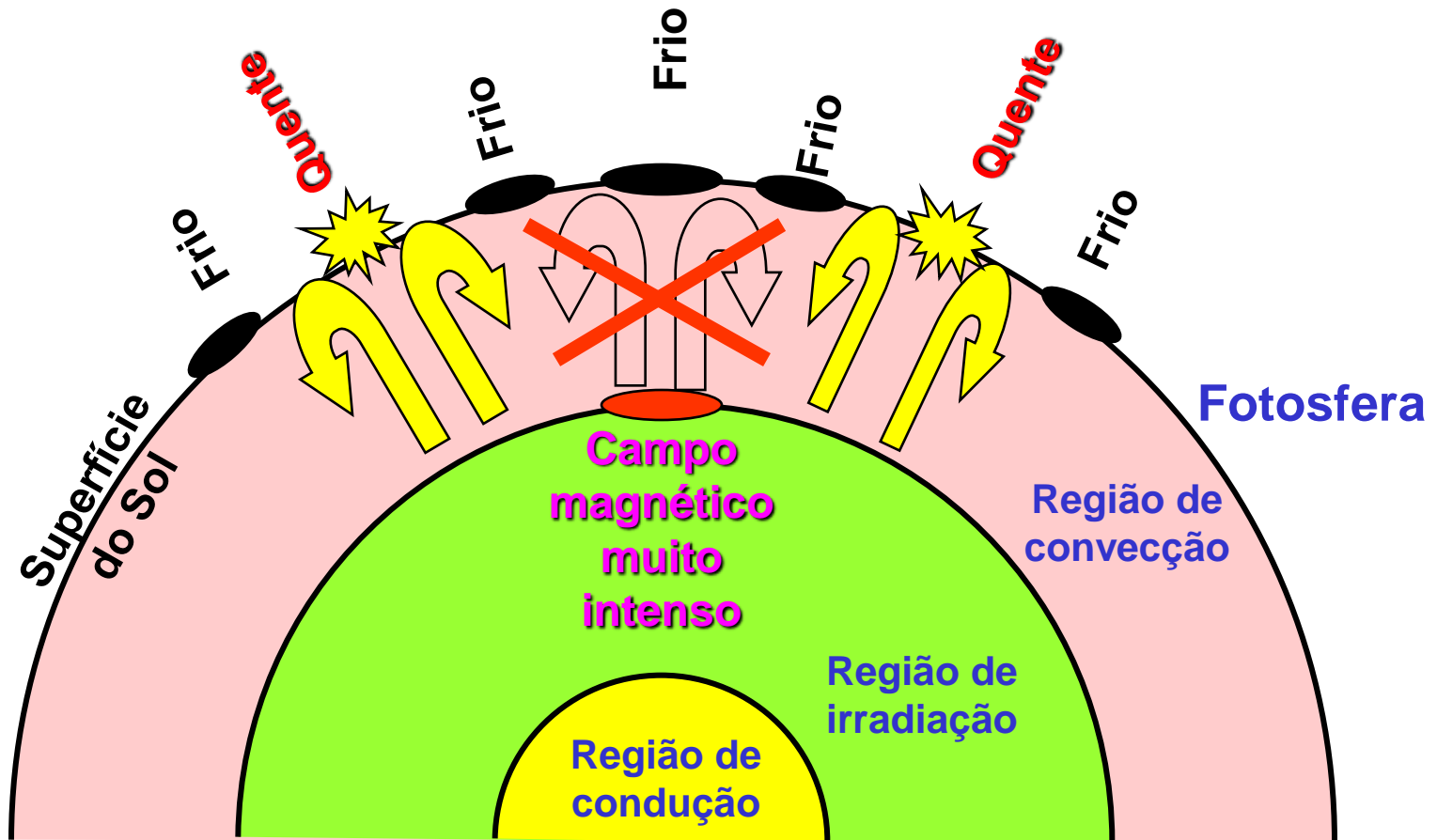
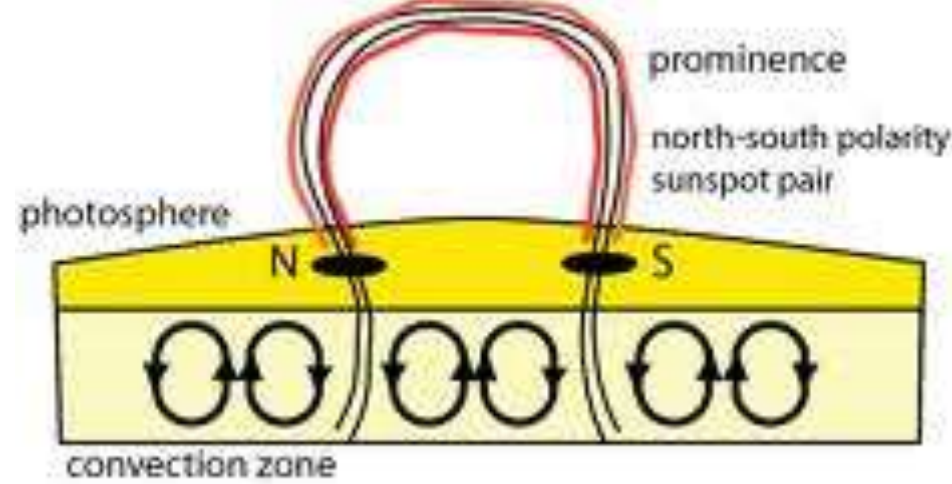
Manchas solares

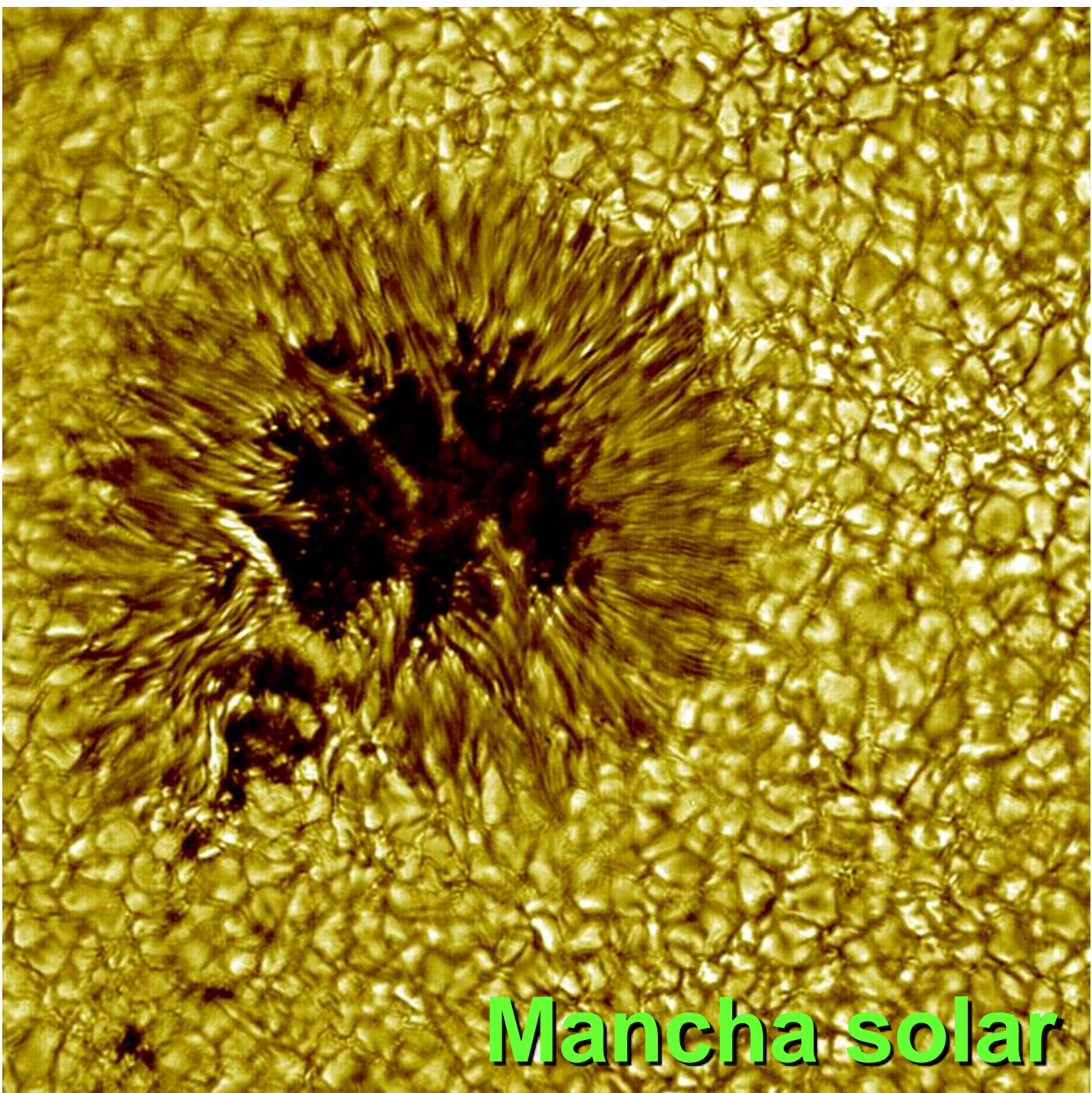


Manchas na superfície do Sol observadas por Galileo em 1612-1613

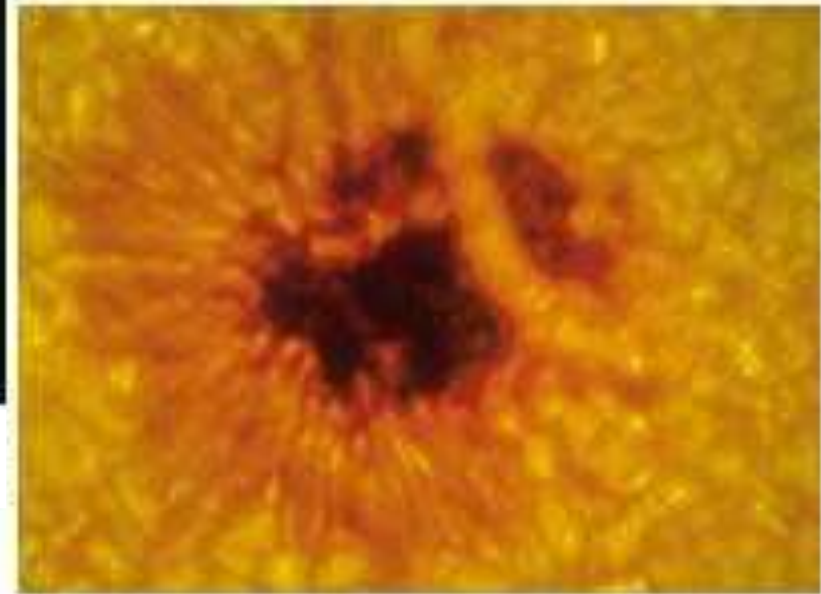
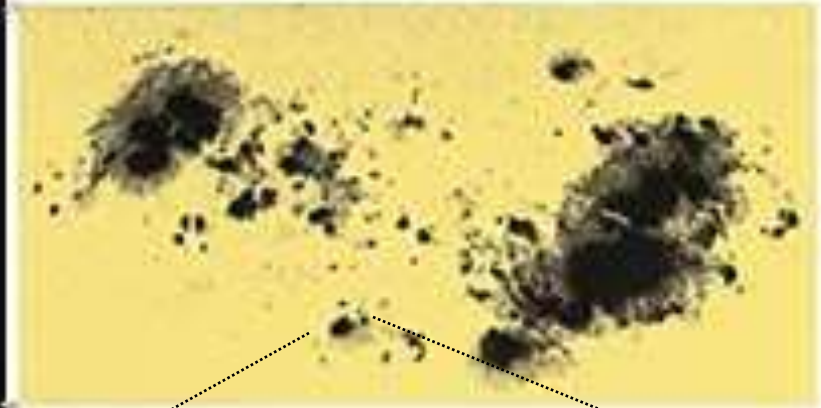
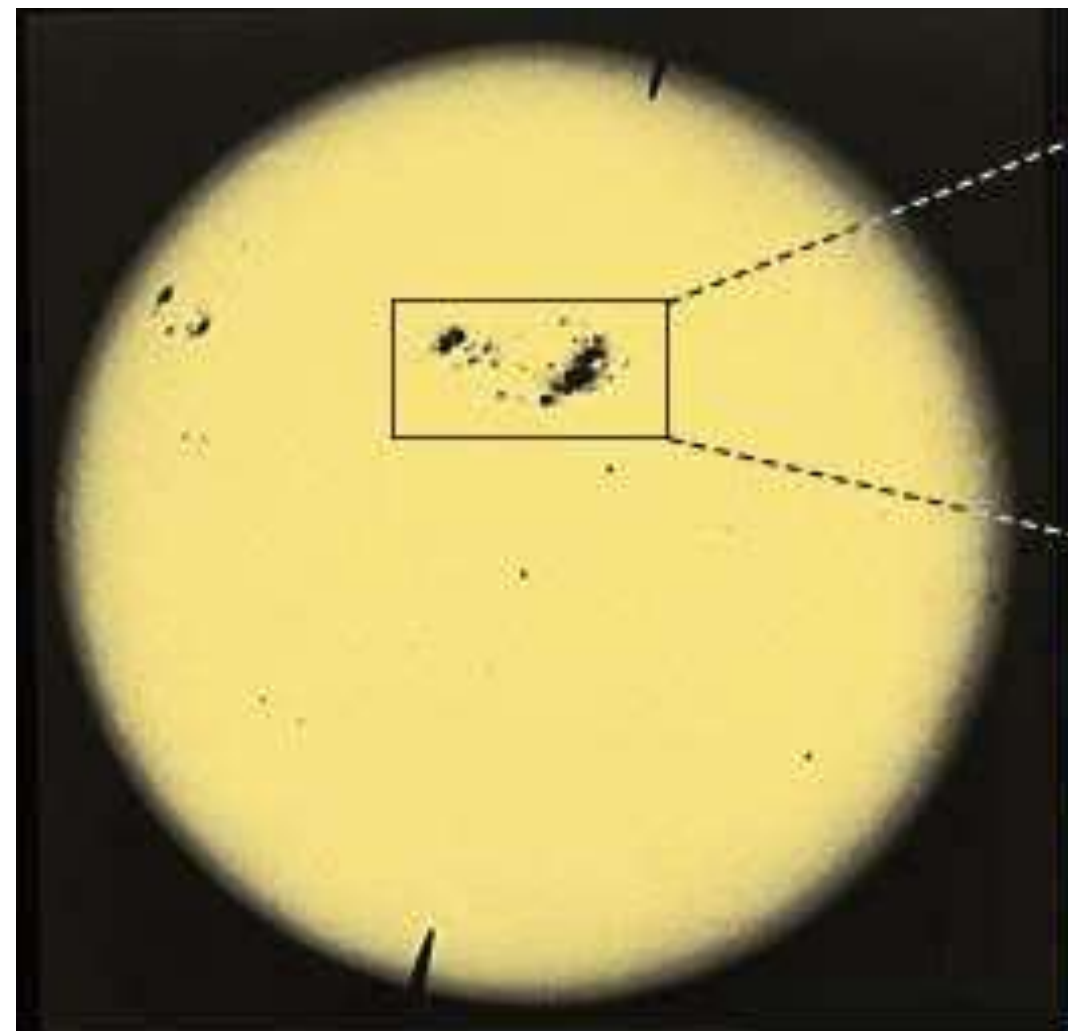


Formação de “uma” mancha solar



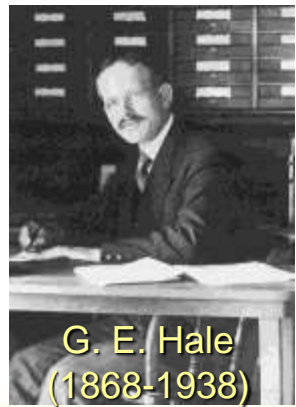


Mancha solar

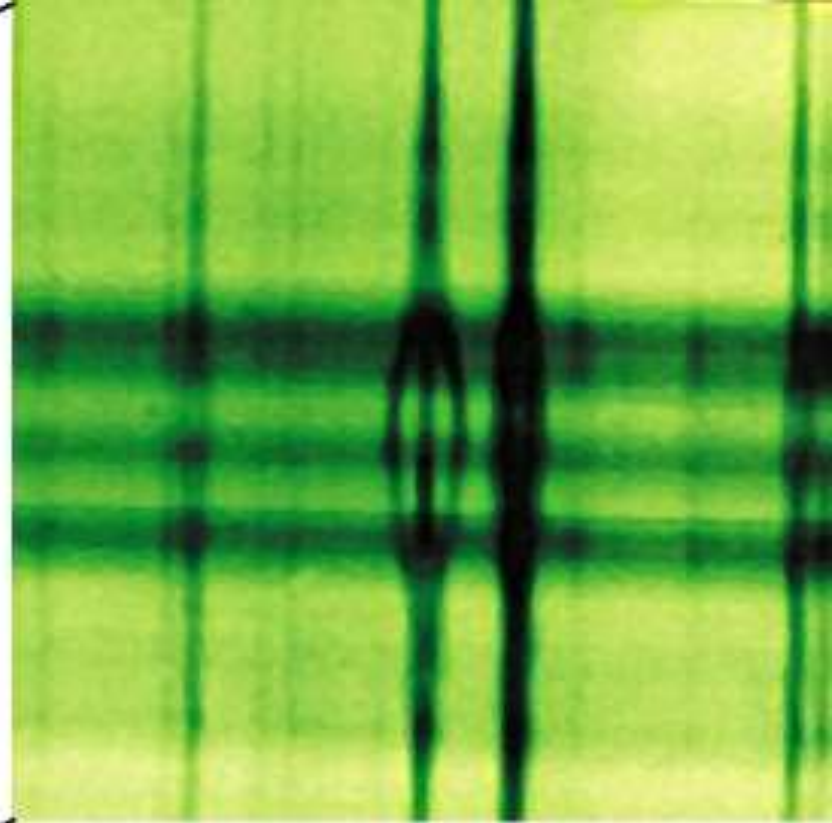
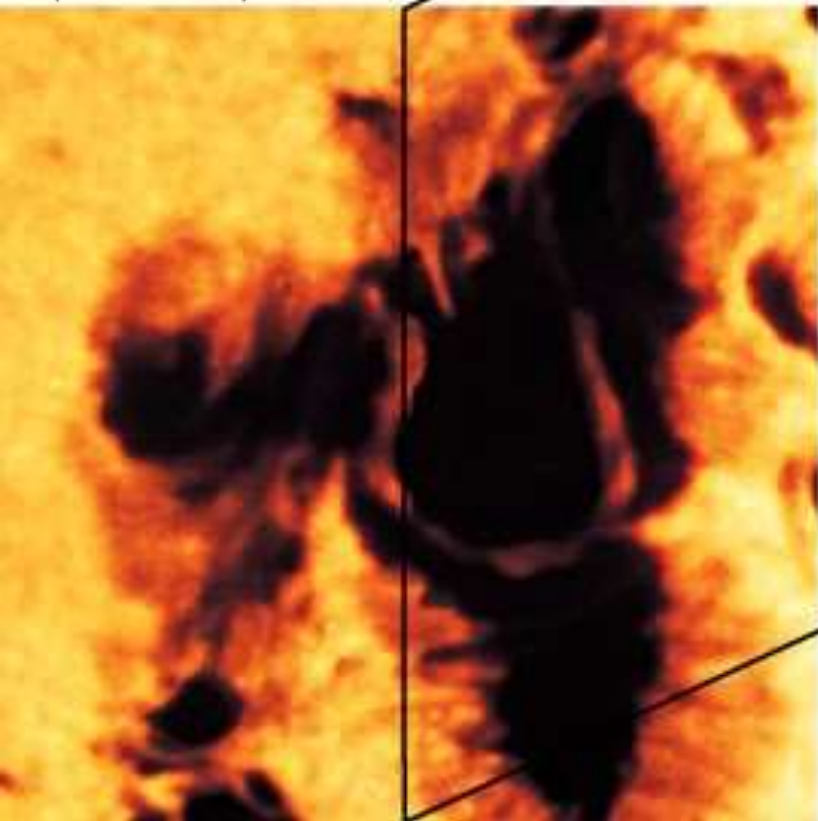


**Manchas
solares**

Efeito Zeemann numa mancha solar

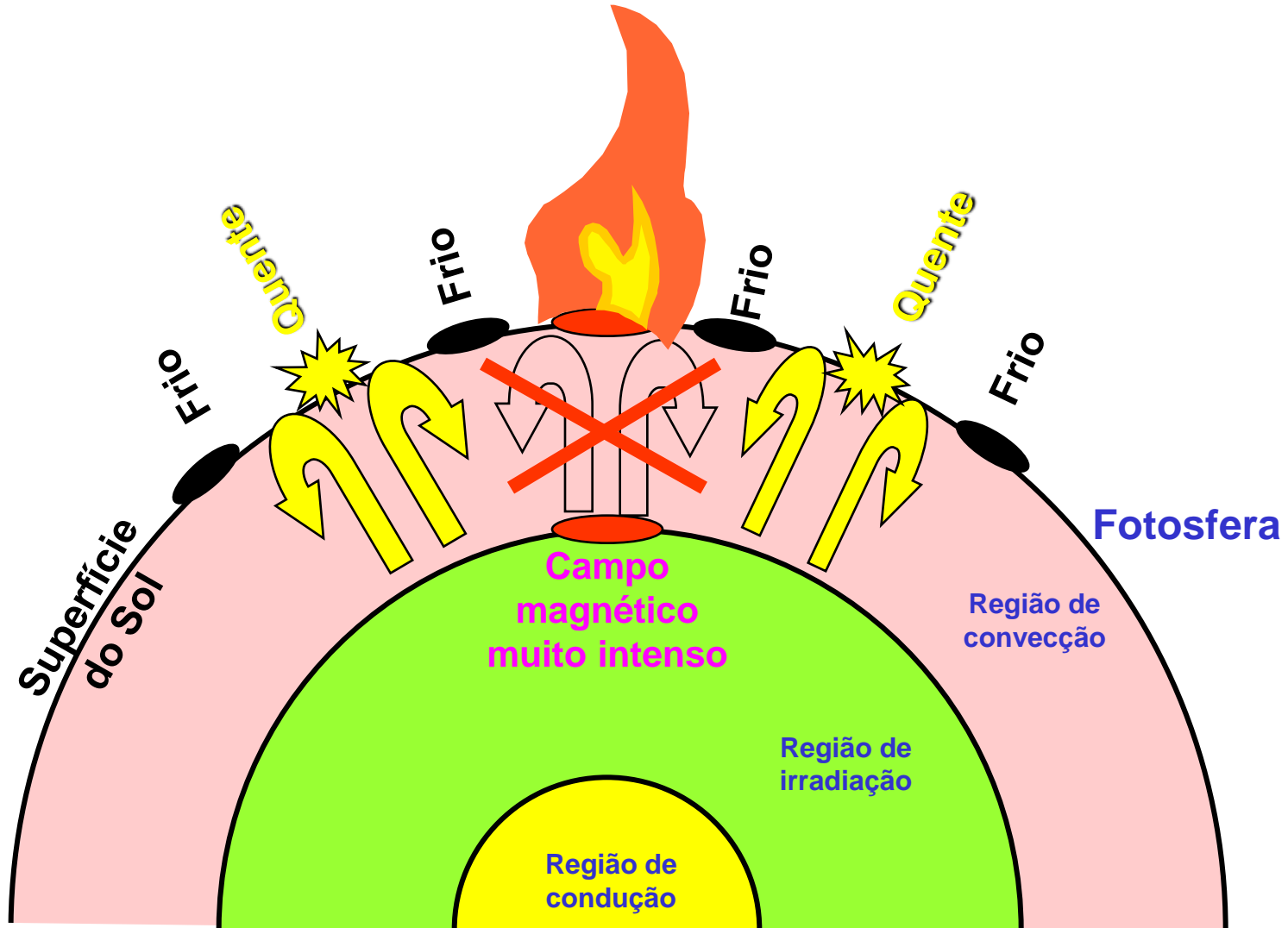


G. E. Hale
(1868-1938)

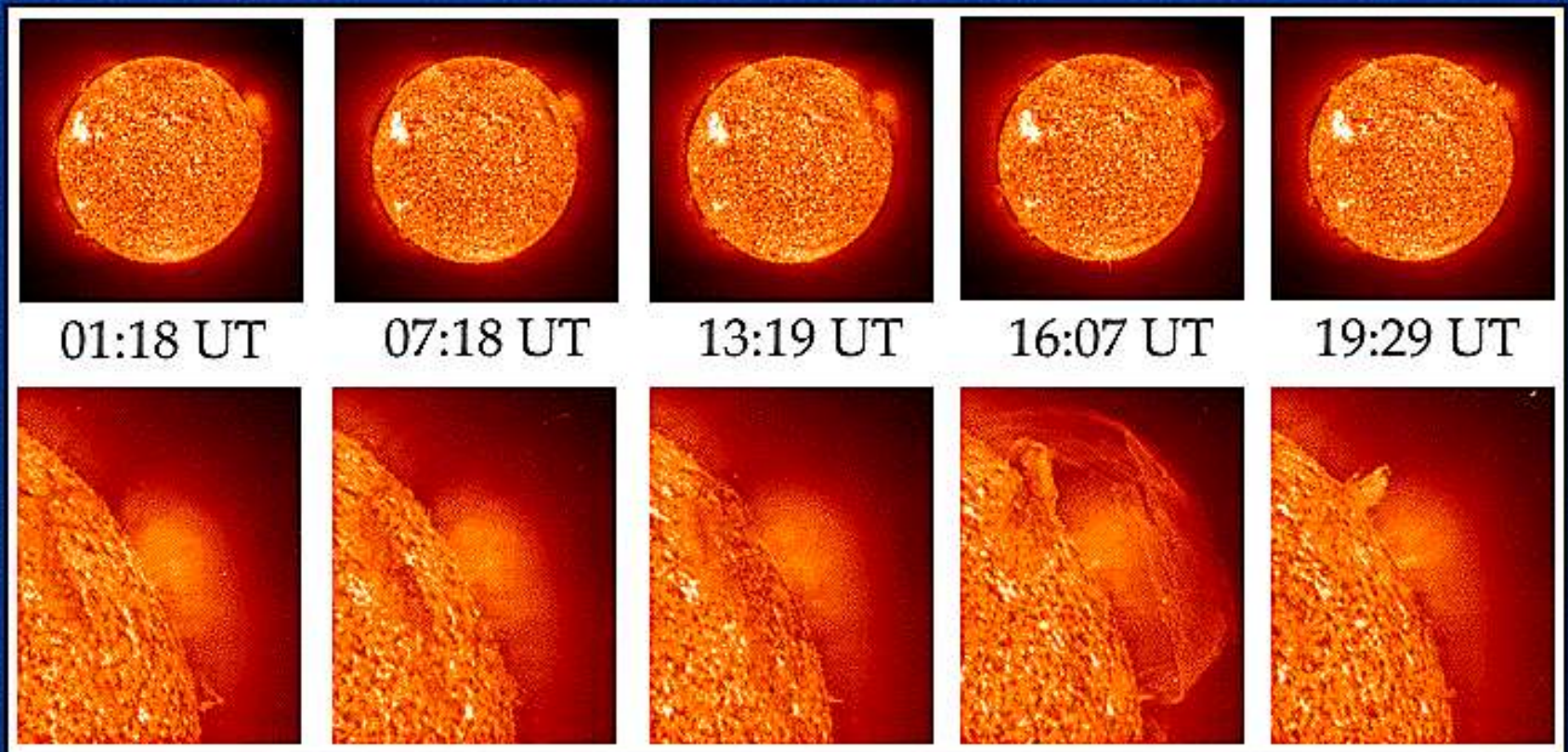


**Desdobramento das
linhas espectrais**

Erupção solar

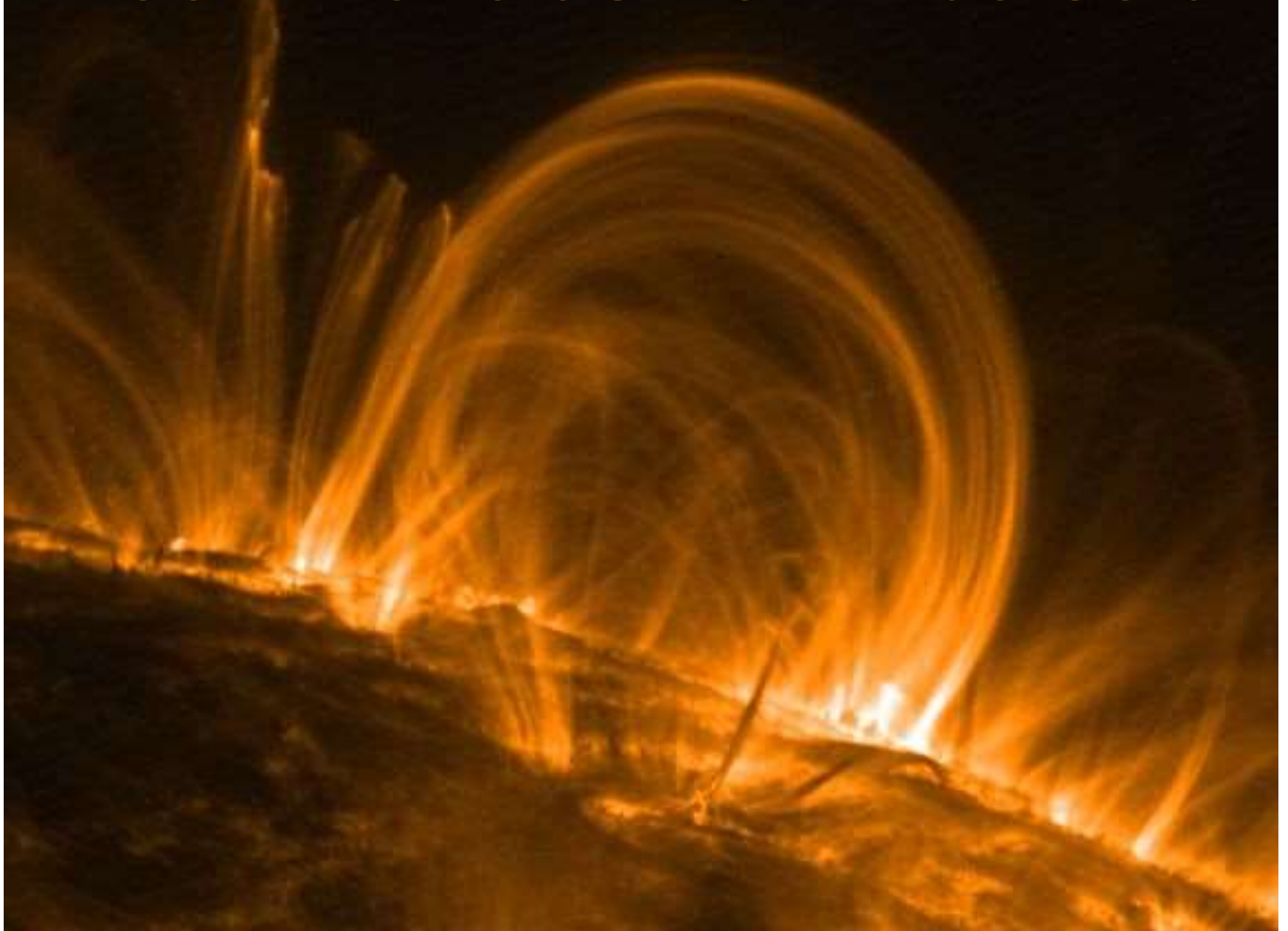


Seqüência de uma Erupção Solar



Grande erupção solar atingindo uma altura de 28 raios terrestres

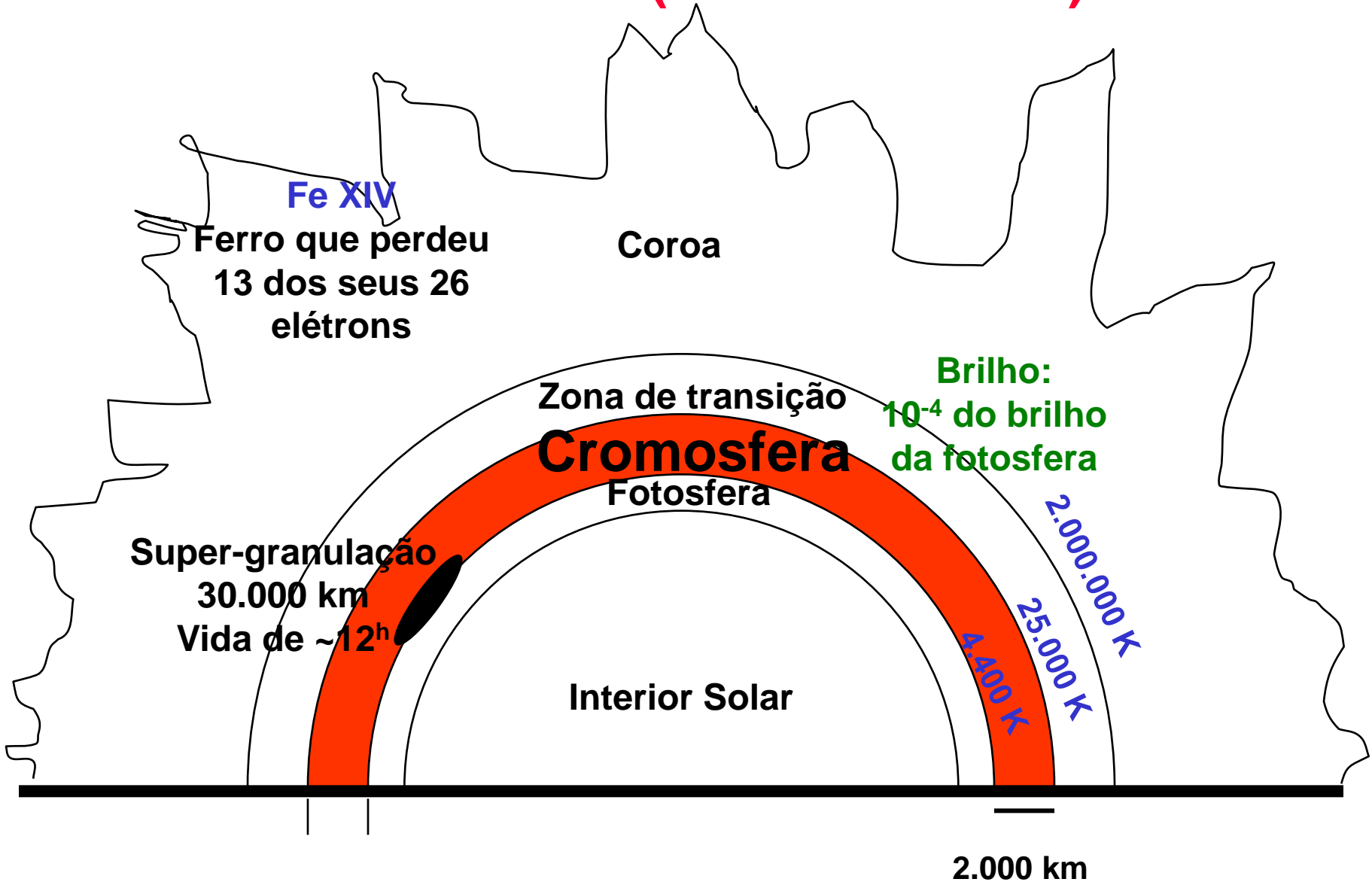
Proeminências no limbo solar



Atmosfera do Sol

Cromosfera do Sol

(esfera colorida)



A photograph of a total solar eclipse. The Sun's chromosphere is visible as a thin, glowing red ring against a black background. The text "Cromosfera do Sol durante eclipse" is overlaid in red.

**Cromosfera
do Sol
durante
eclipse**

**Coroa
solar
durante
eclipse**



Coroa solar



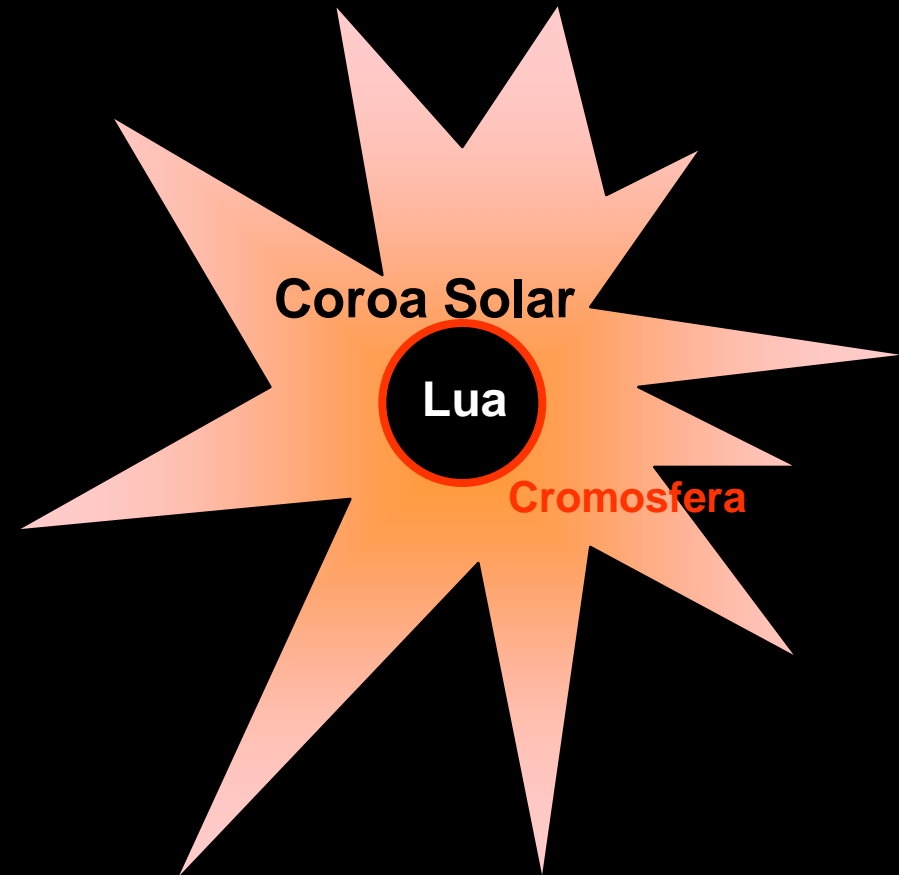
Para que observar o Sol durante o eclipse total?

Sol não eclipsado



Fotosfera
do Sol

Sol eclipsado totalmente

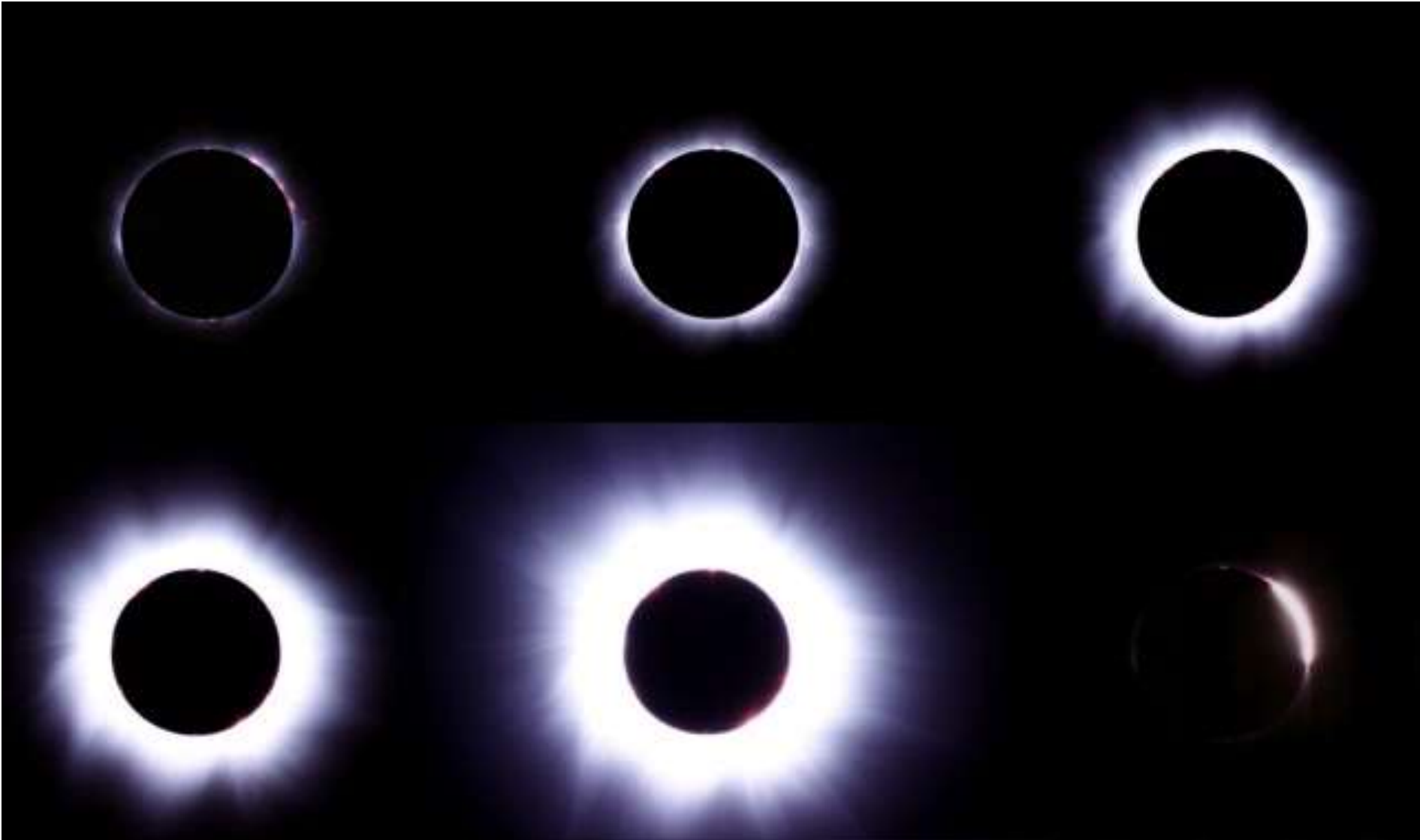


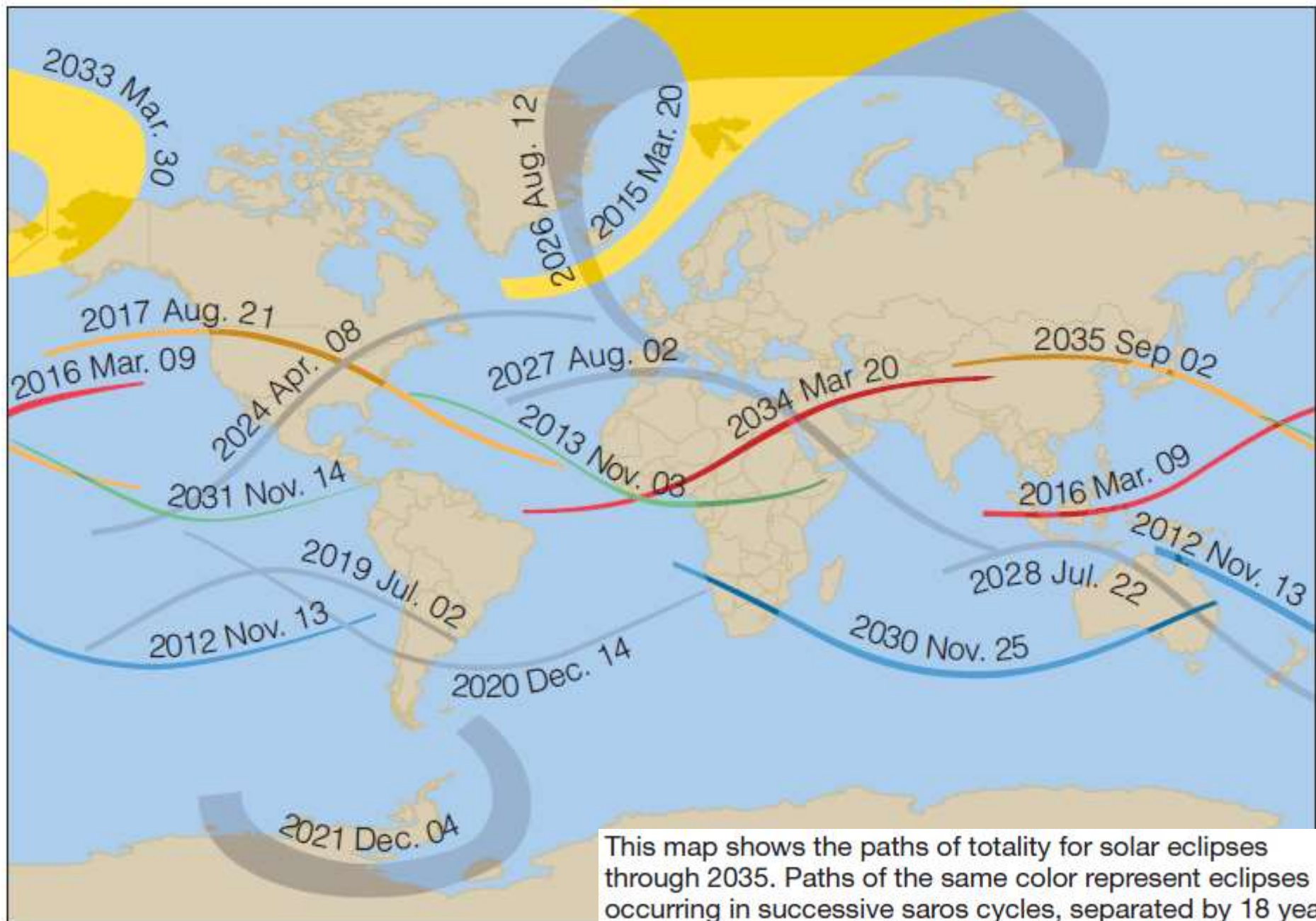
Coroa Solar

Lua

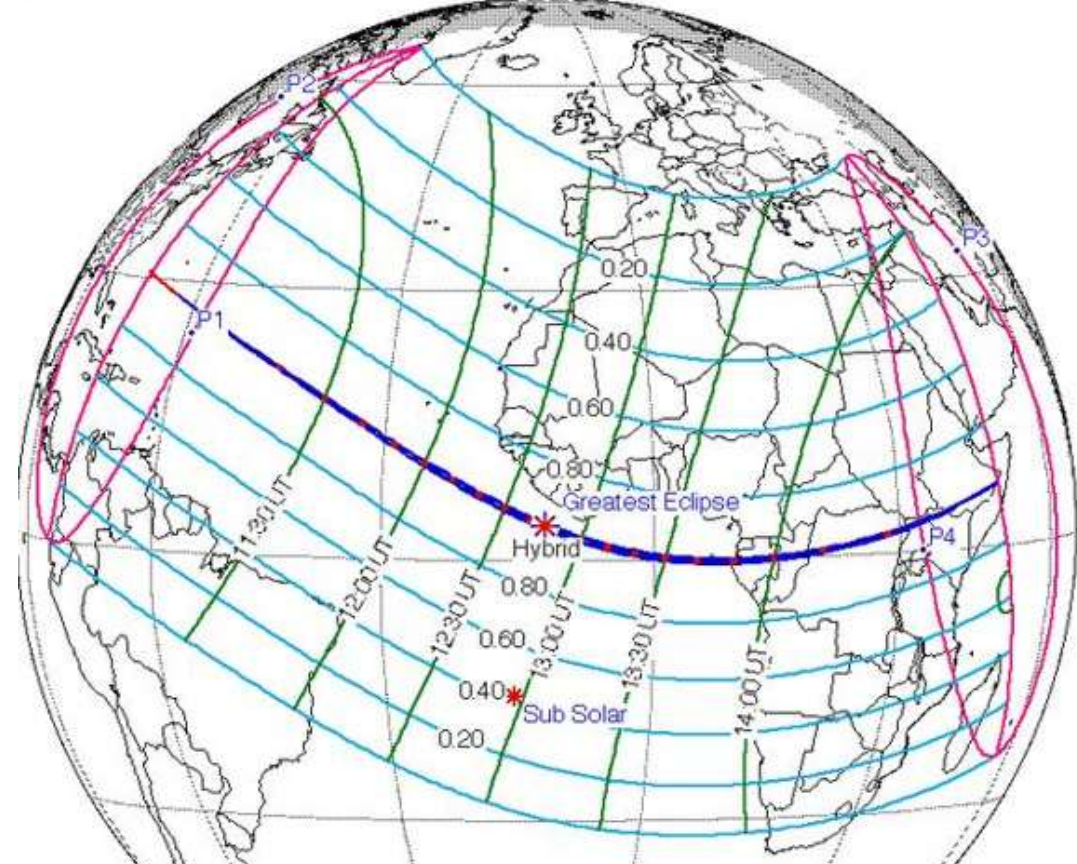
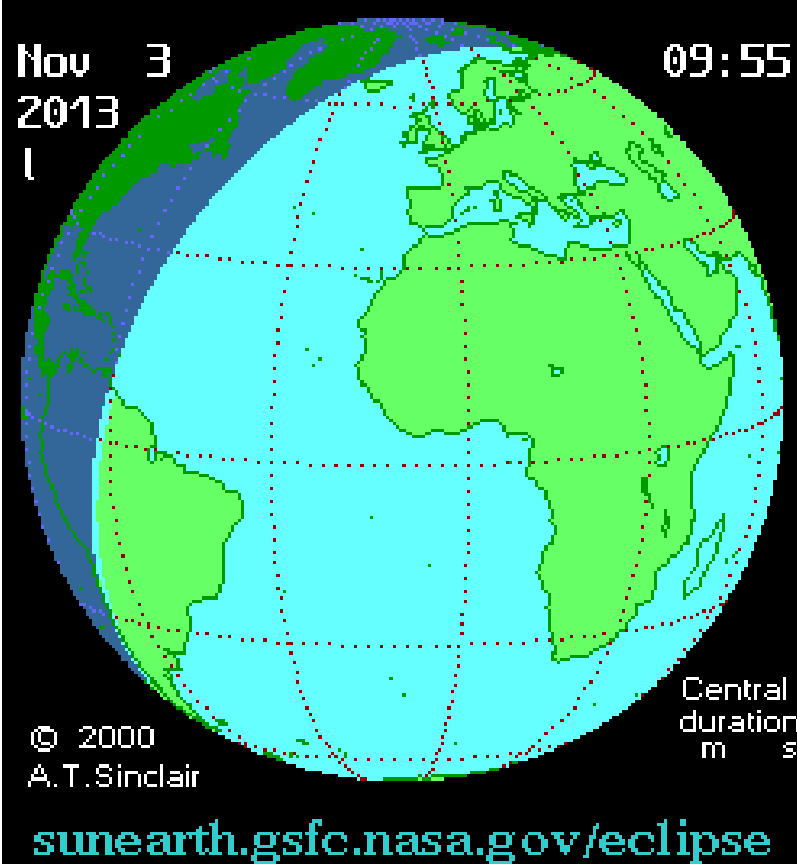
Cromosfera

Coroa solar em diferentes ocasiões

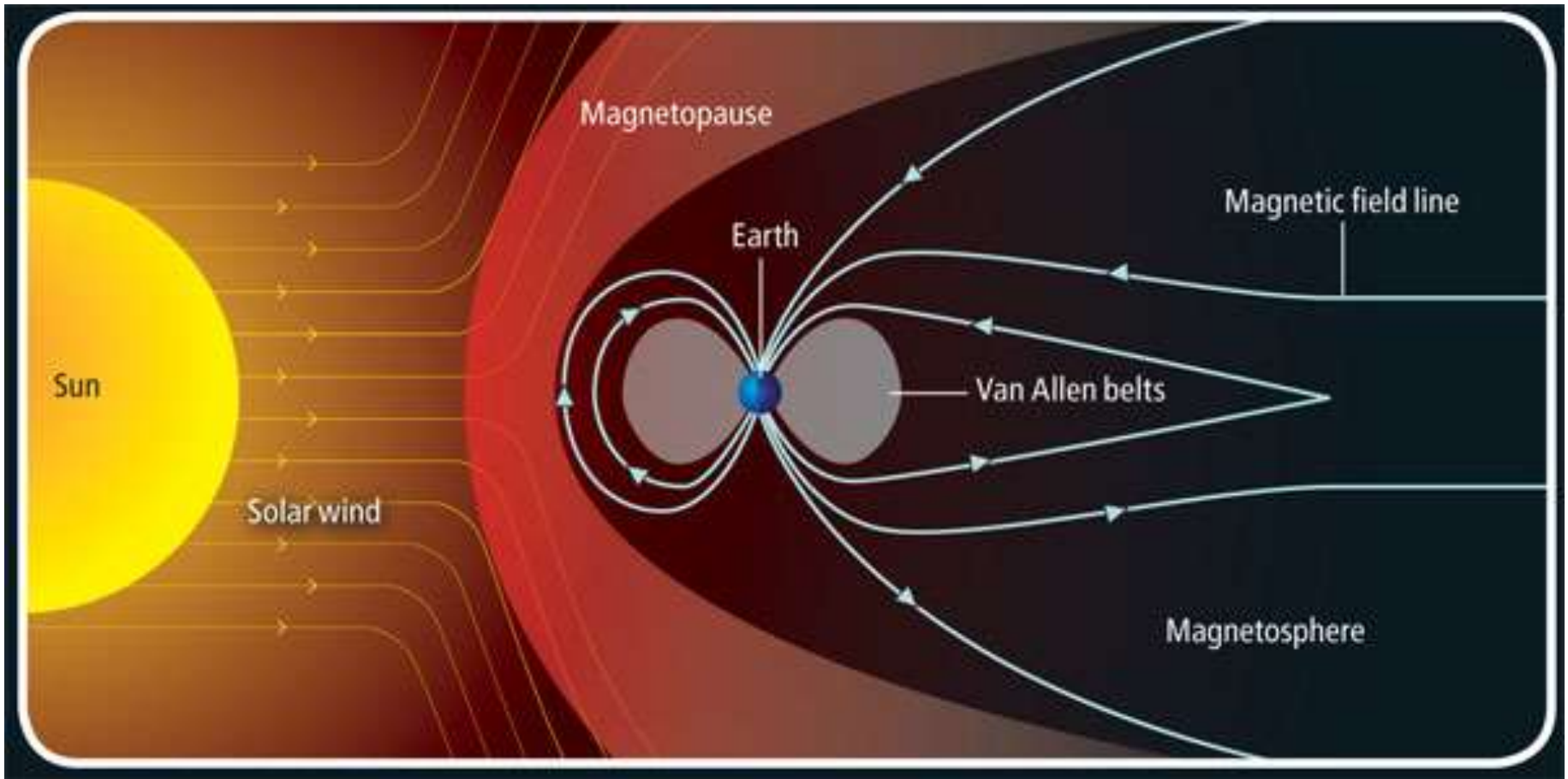




This map shows the paths of totality for solar eclipses through 2035. Paths of the same color represent eclipses occurring in successive saros cycles, separated by 18 years 11 days. For example, the 2034 eclipse occurs 18 years 11 days after the 2016 eclipse, both shown in red. (Eclipse predictions by Fred Espenak; see NASA's Eclipse Web site.)

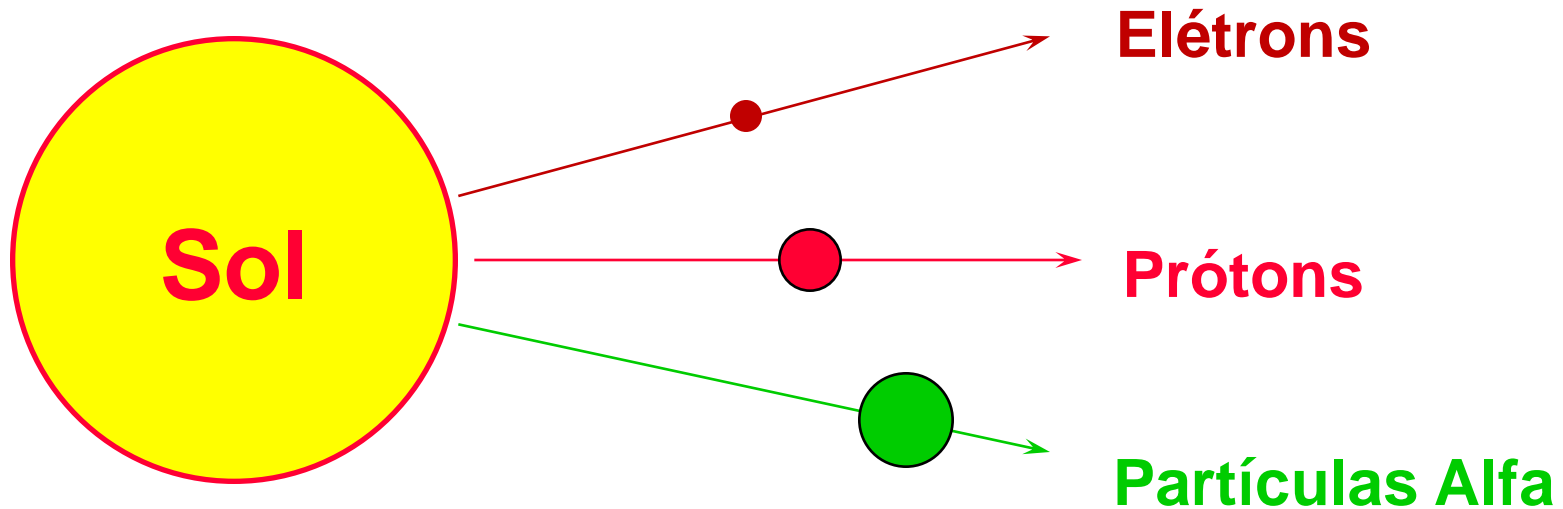


Vento Solar

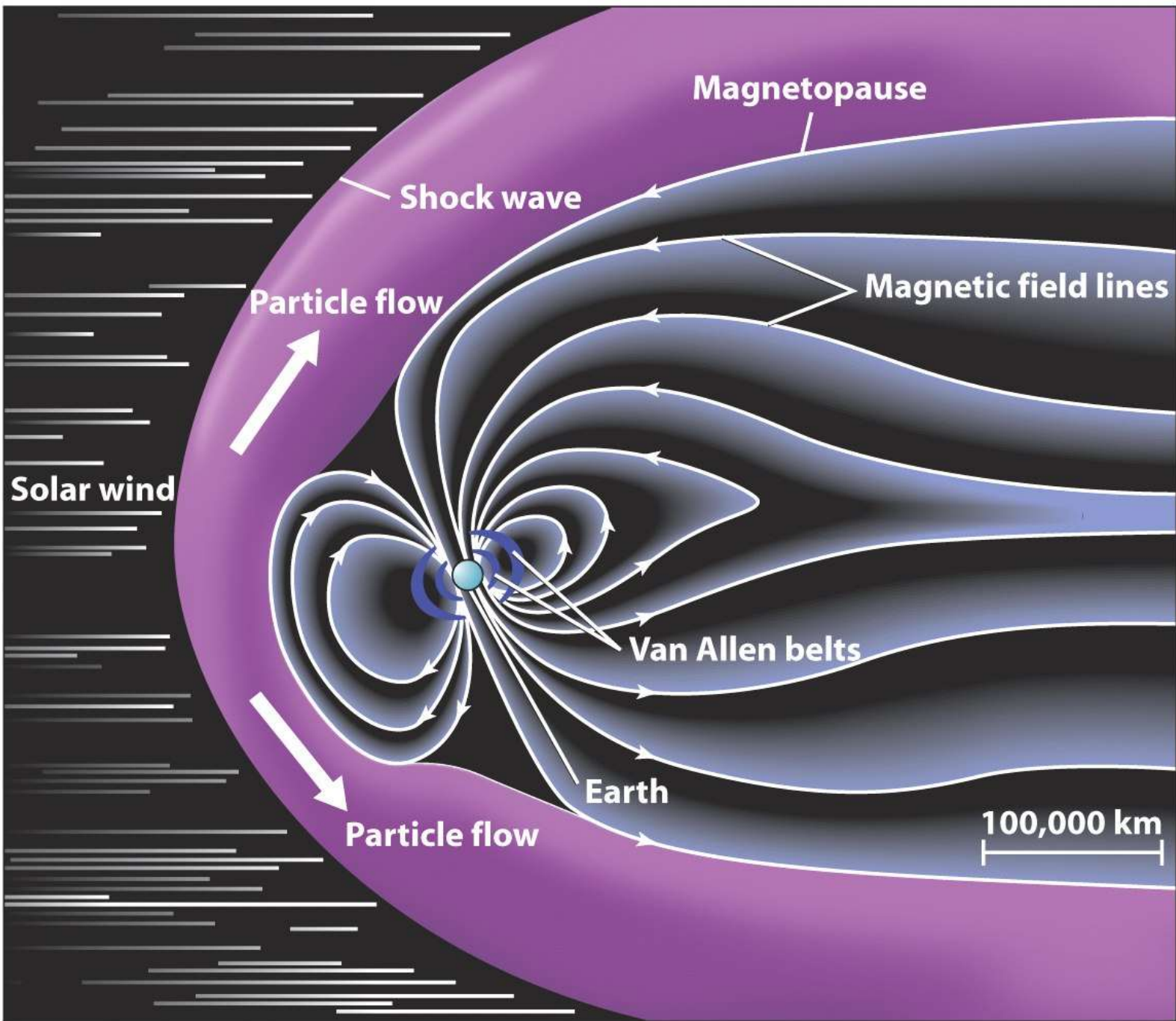


Vento Solar

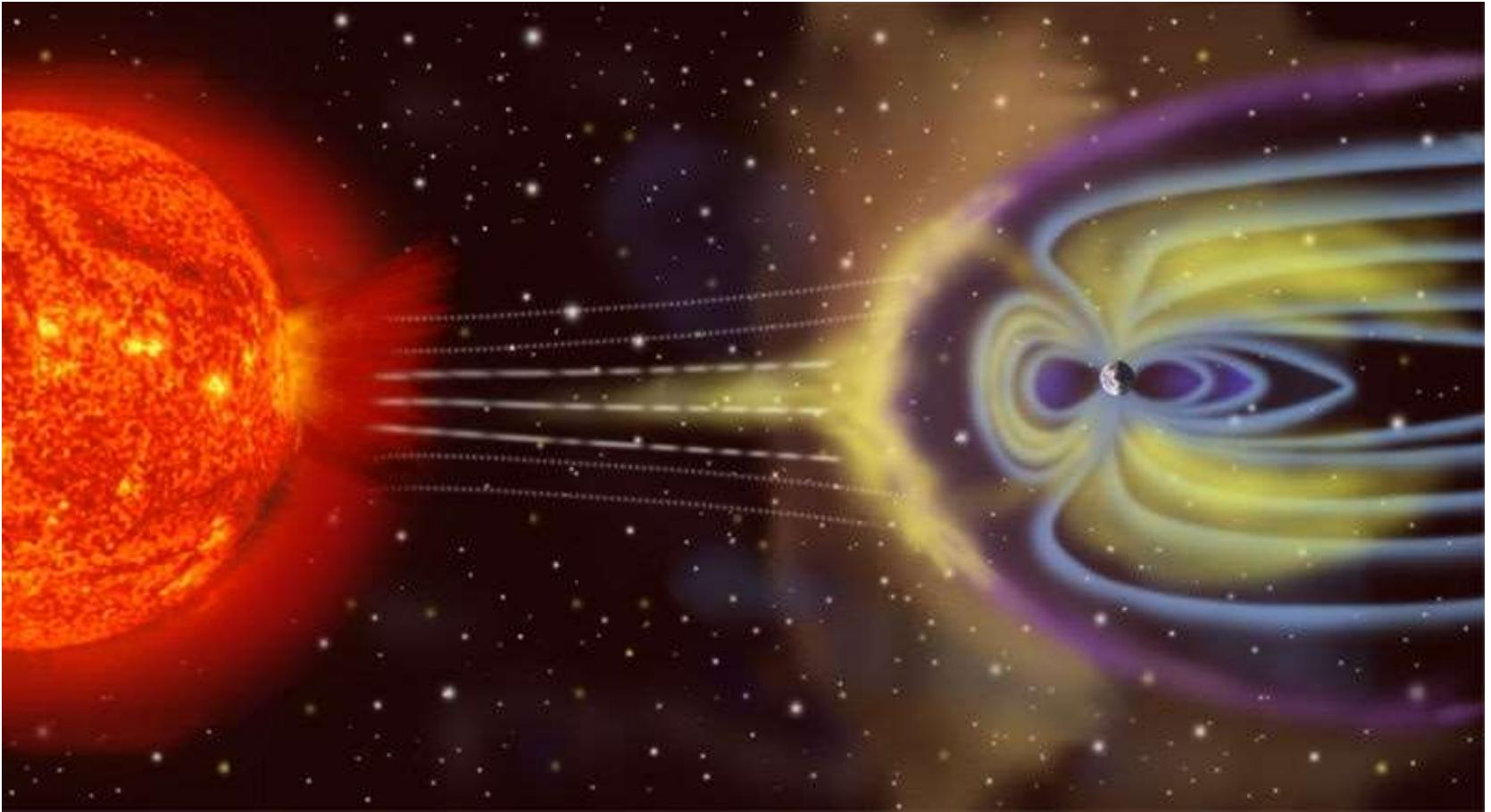
Perda de massa pelo vento solar = 1 milhão de ton por segundo



Efeito do vento solar sobre a magnetosfera



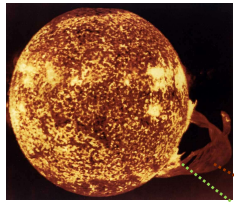
Efeitos de explosões solares e de ejeções de massa coronal



Ver vídeo de explosão real no site da NASA:

http://www.nasa.gov/multimedia/videogallery/index.html?collection_id=17320&media_id=151653121

Interação do Sol com a Terra



Partícula
alfa



Próton



Nêutron



Elétron



Elétron



Luz

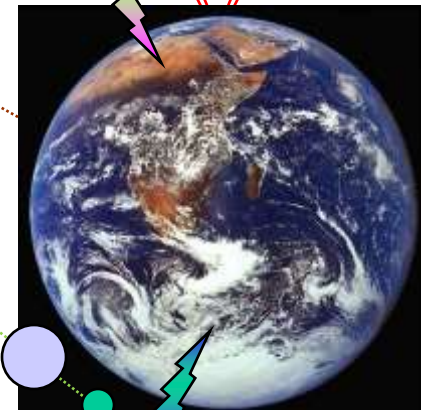


Choque com ions e átomos da alta atmosfera terrestre (> 80 km) causa excitação e ionização.

Ao voltar aos estados menos excitados ou na recombinação é emitida luz

Campo magnético terrestre

Aurora boreal



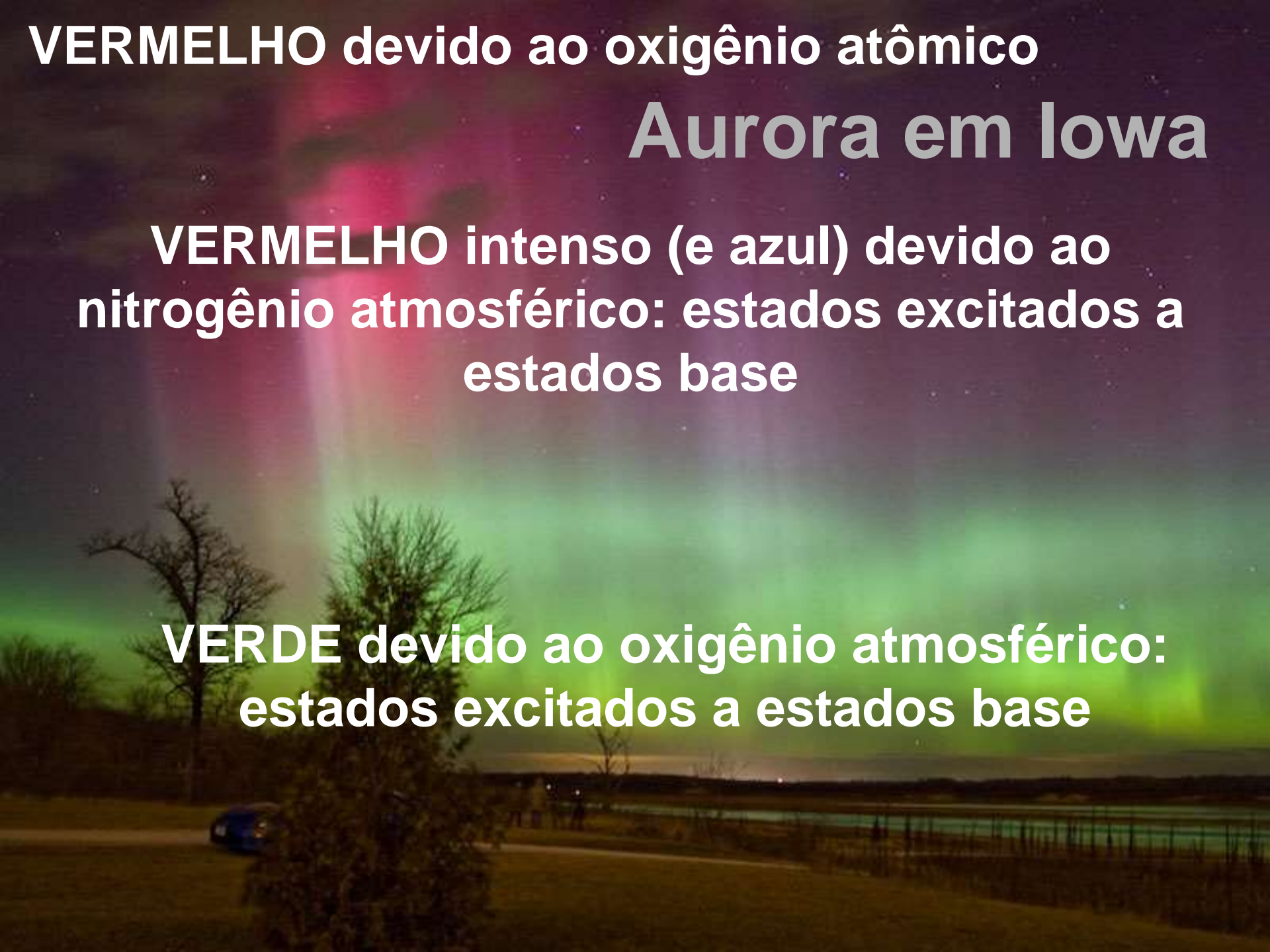
Aurora austral

VERMELHO devido ao oxigênio atômico

Aurora em Iowa

VERMELHO intenso (e azul) devido ao nitrogênio atmosférico: estados excitados a estados base

VERDE devido ao oxigênio atmosférico: estados excitados a estados base



Aurora no Alasca

A photograph capturing the Aurora Borealis in Alaska. The sky is filled with vibrant, flowing curtains of green and purple light, set against a dark, starry night sky. Below, a snowy landscape features a road with tracks, a few snow-covered evergreen trees, and a distant building illuminated by warm lights. The overall scene is serene and awe-inspiring.

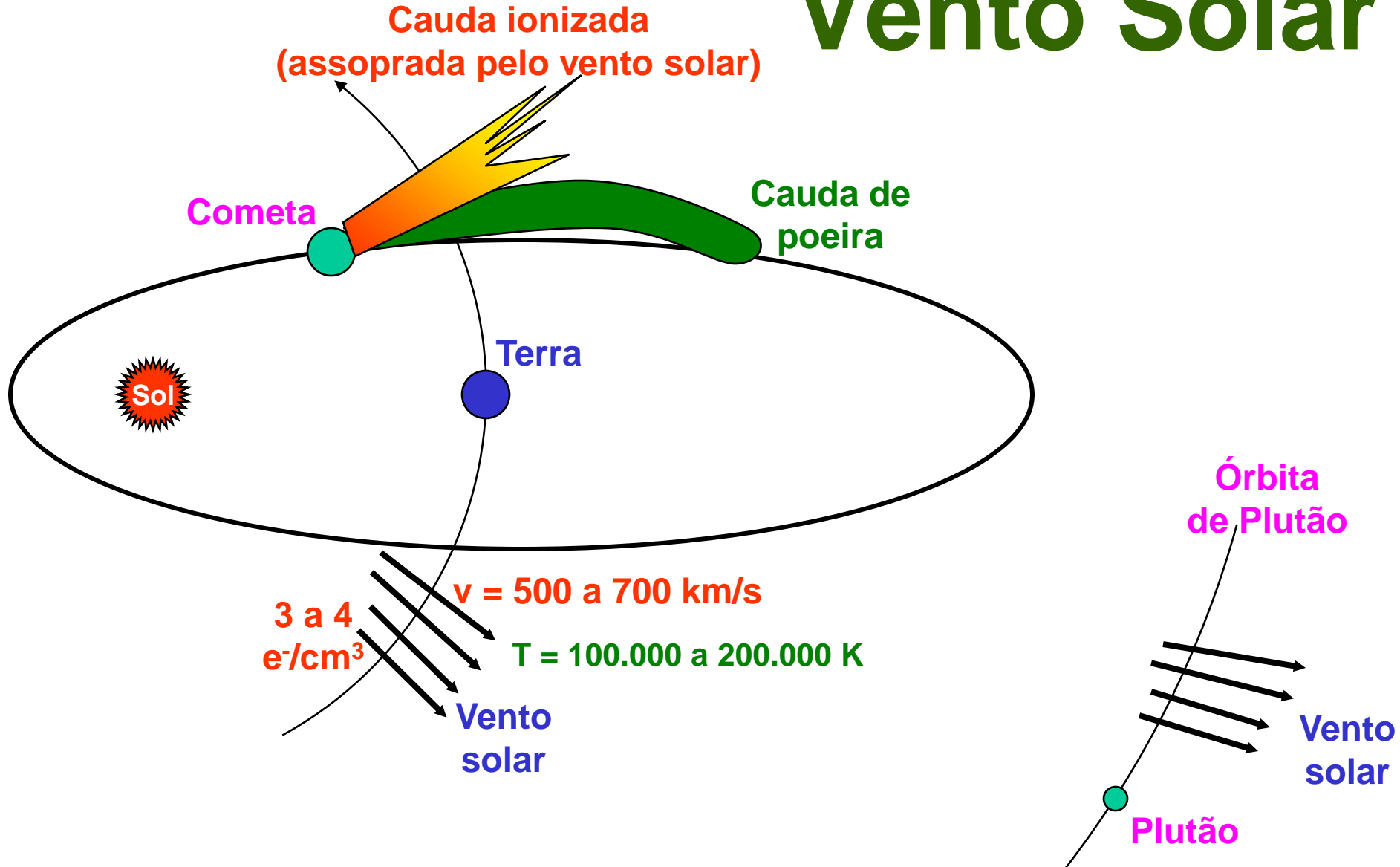
2005
jan

Aurora boreal em 2010

AZUL e VERMELHO devidos ao nitrogênio

VERDE devido ao oxigênio

Características do Vento Solar

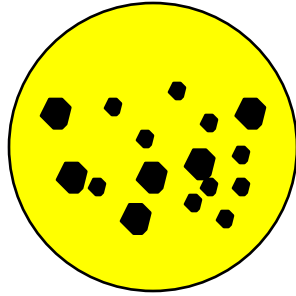


Cometa Hale-Bopp (1997)

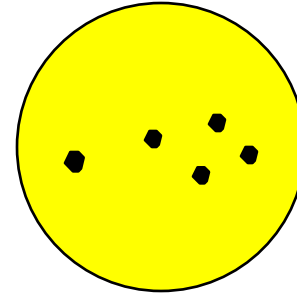
Comet Hale-Bopp (1997), which possessed two distinct tails - a dust tail (white) and an ion tail (blue)

Ciclo Solar

Ciclo solar de 11 anos

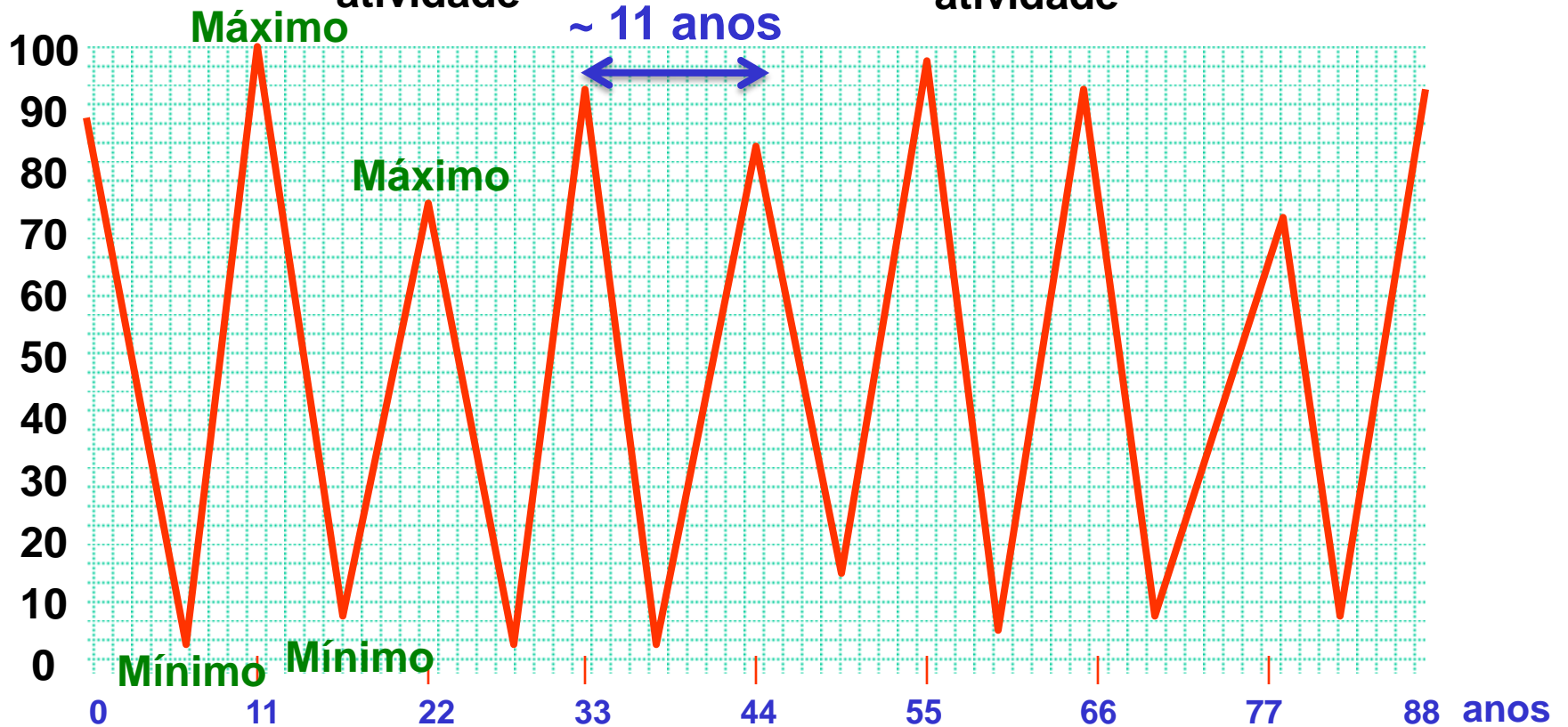


Máxima atividade



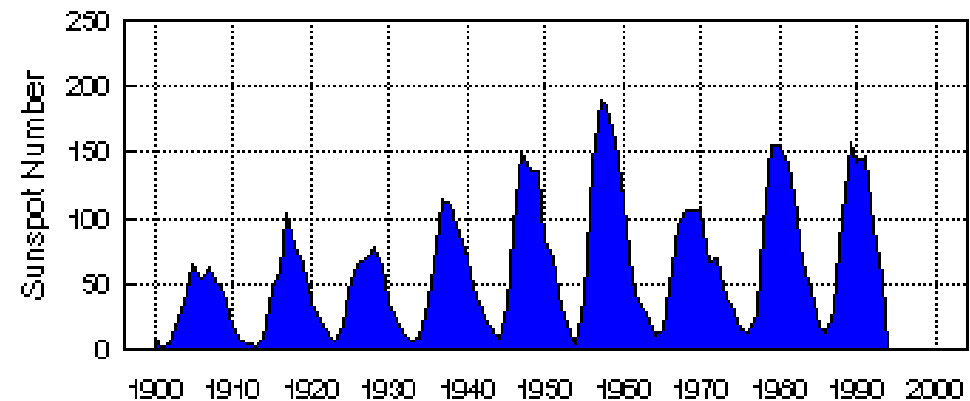
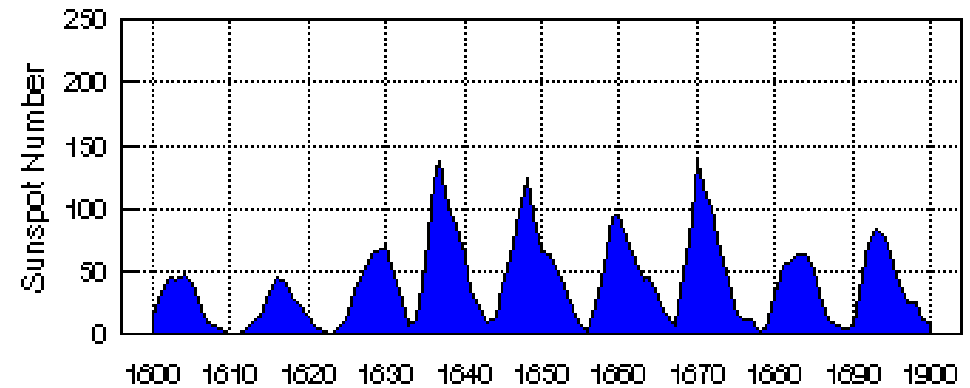
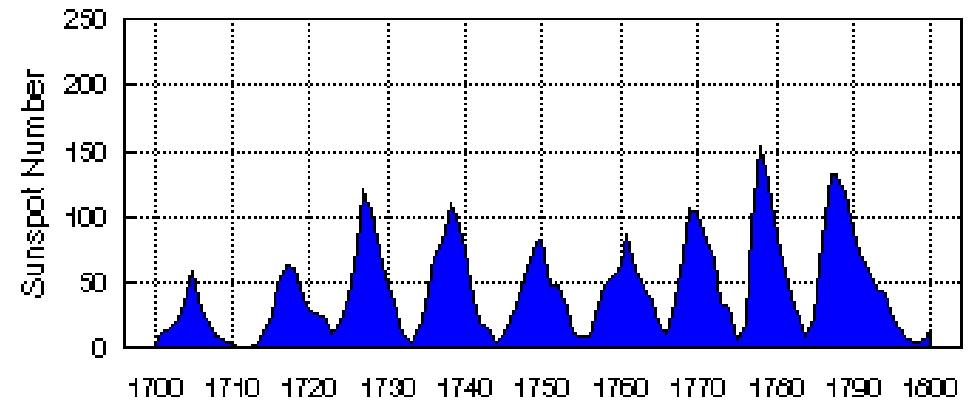
Mínima atividade

Número de manchas

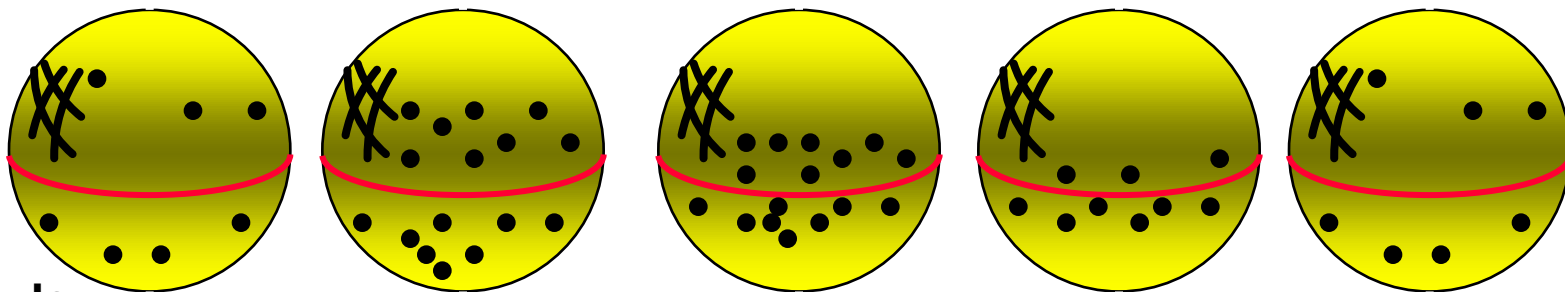


Número de manchas solares ao longo do tempo

Annual Sunspot Numbers: 1700-1998



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

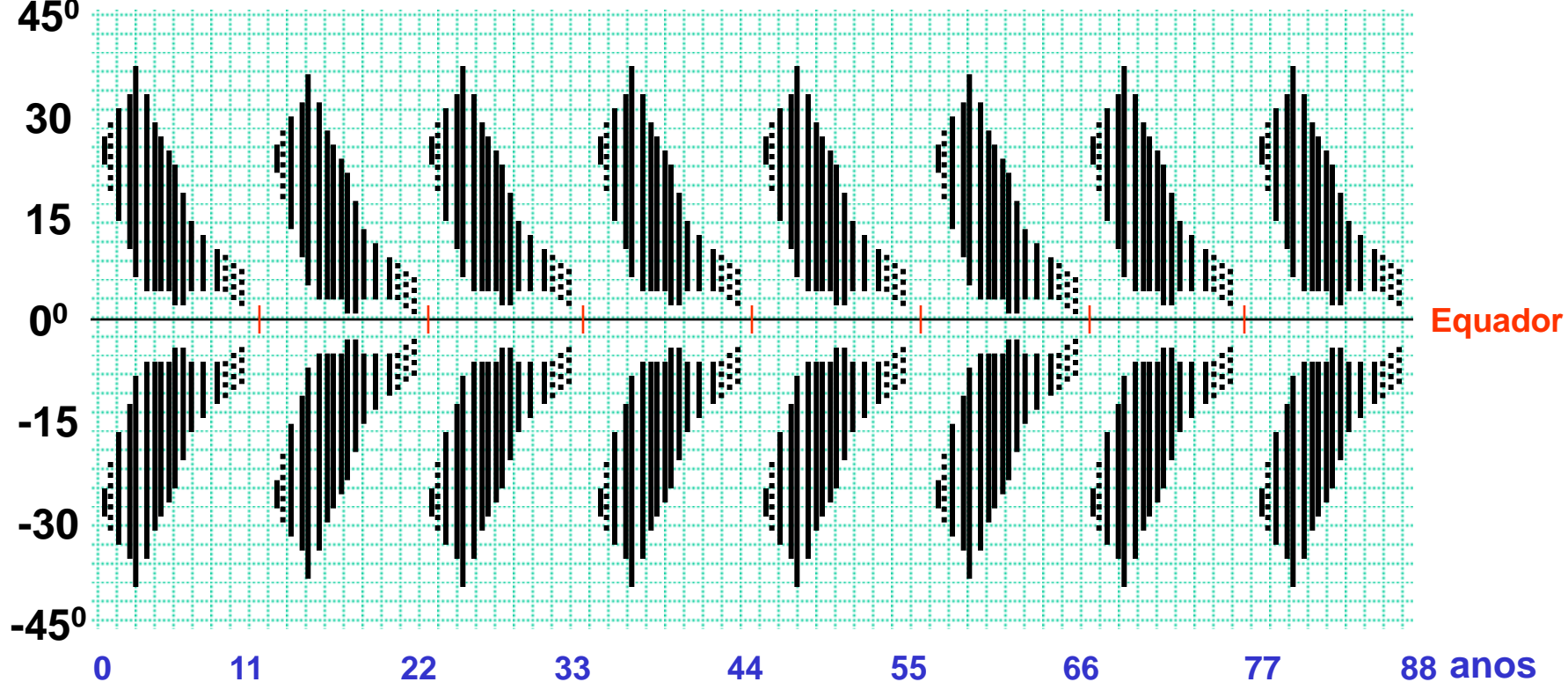


Gráfico "asa de borboleta" dos locais de nascimento das manchas solares ao longo do ciclo de 11 anos

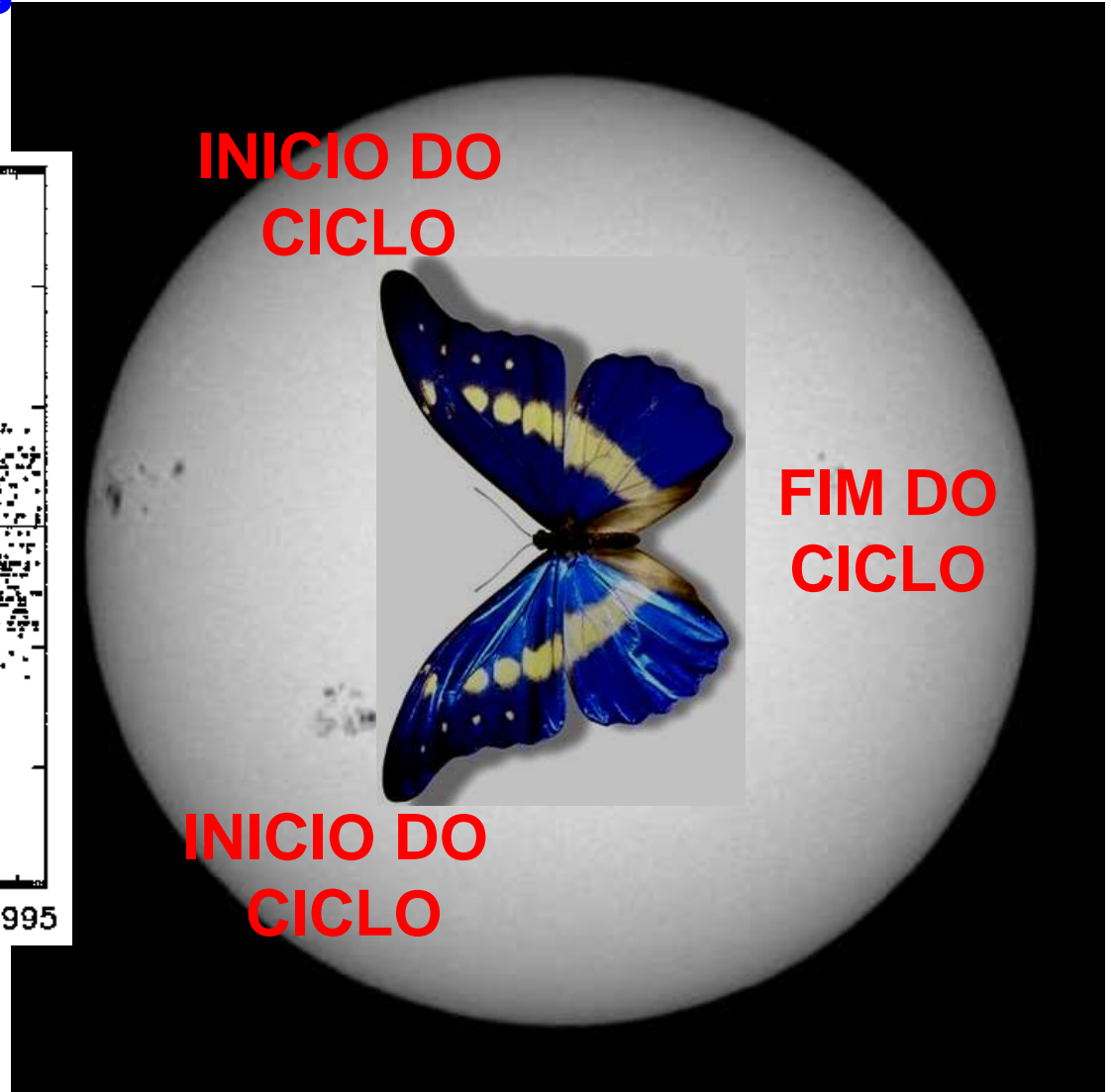
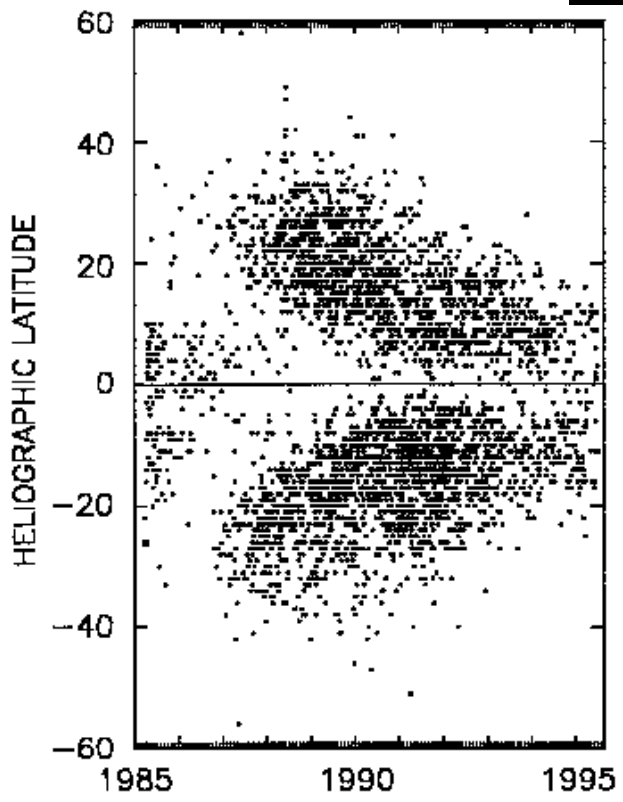
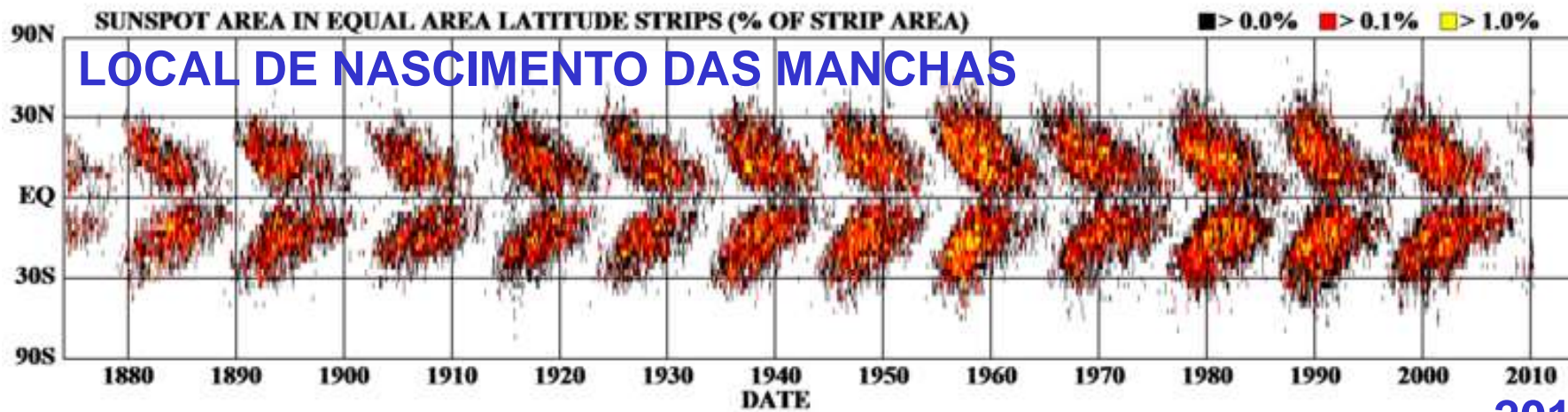
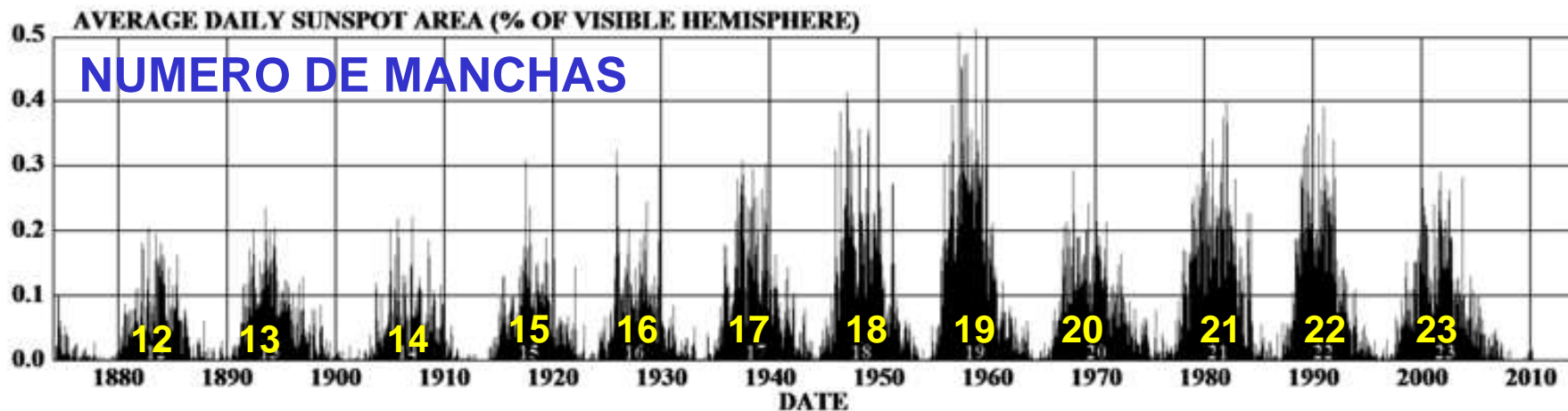


Gráfico "asa de borboleta" dos locais de nascimento das manchas solares ao longo do ciclo de 11 anos

DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS

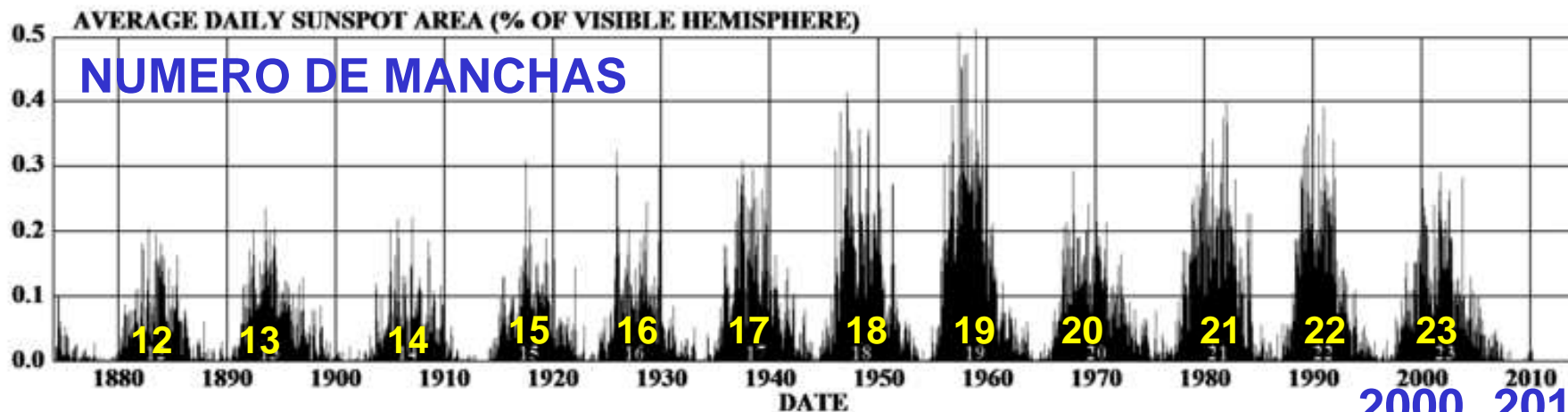
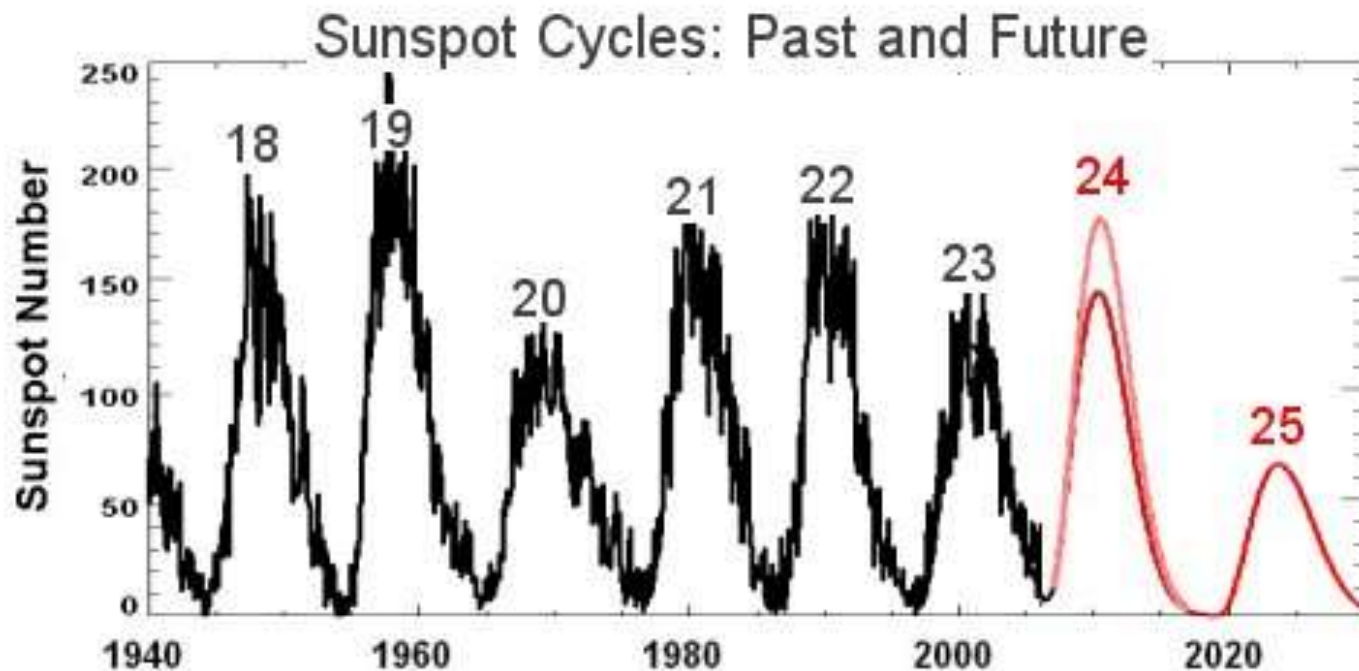


2010

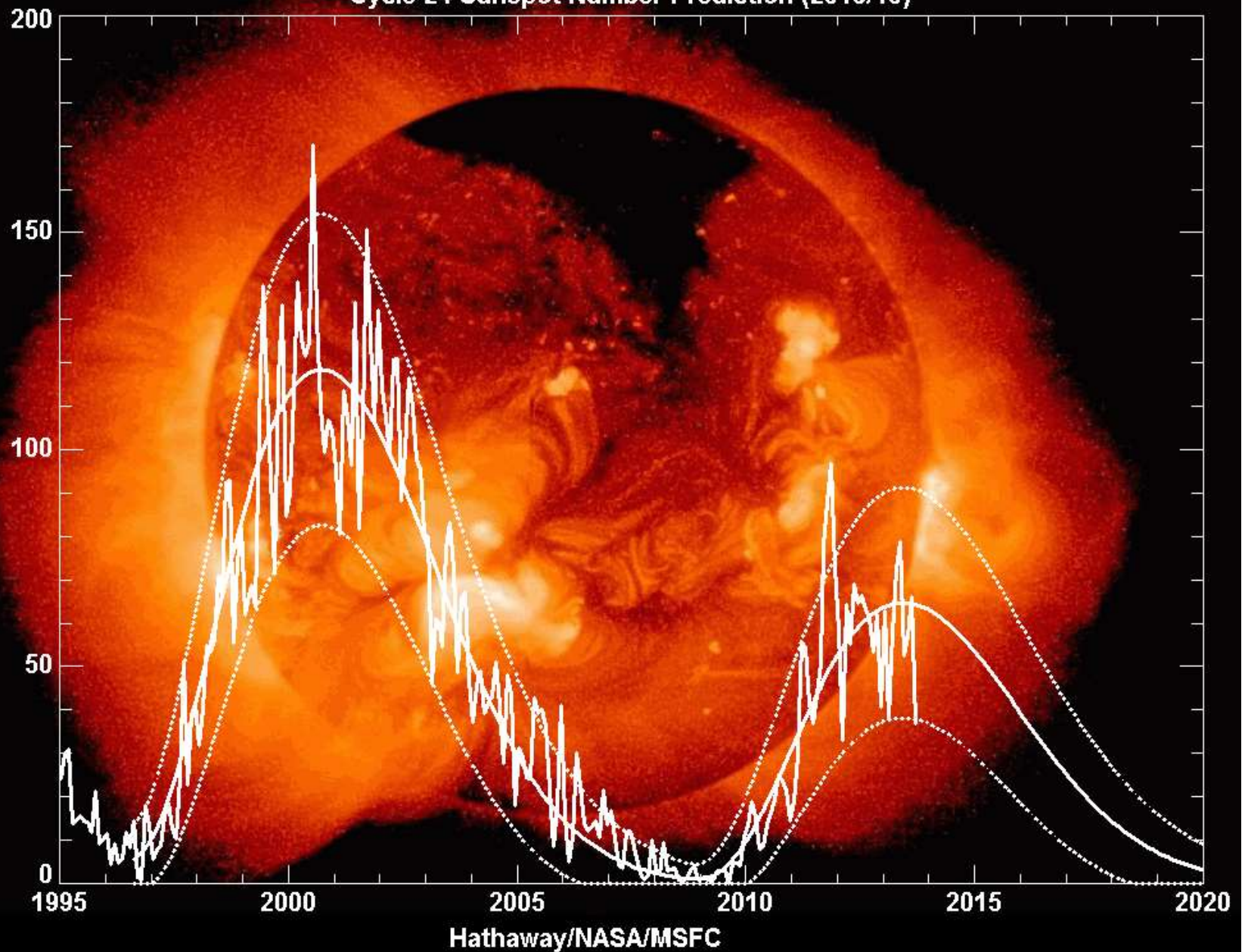


Previsão de manchas solares

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



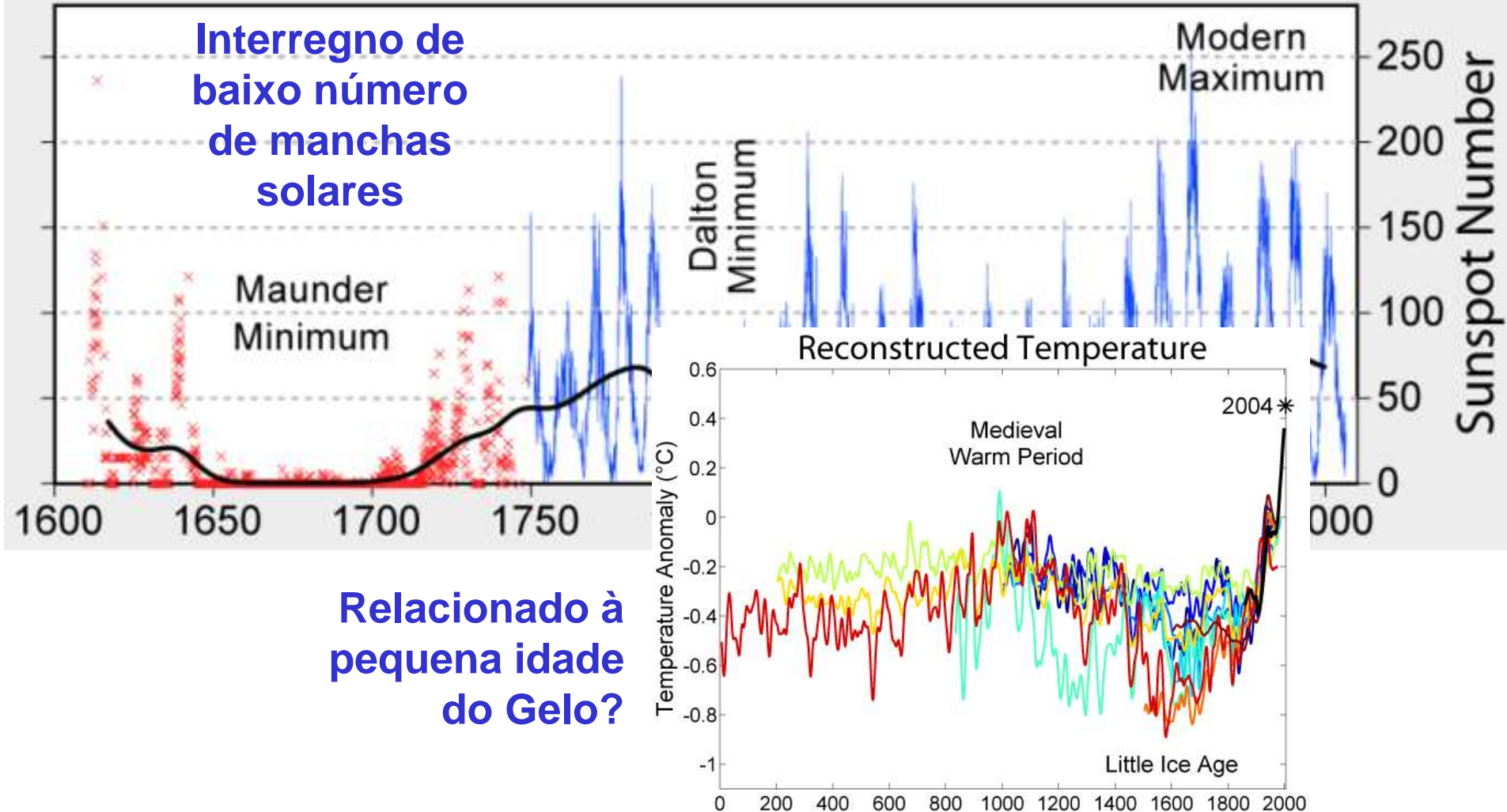
Cycle 24 Sunspot Number Prediction (2013/10)



http://solarscience.msfc.nasa.gov/images/ssn_predict_1.gif

Mínimo de Maunder no número de manchas solares

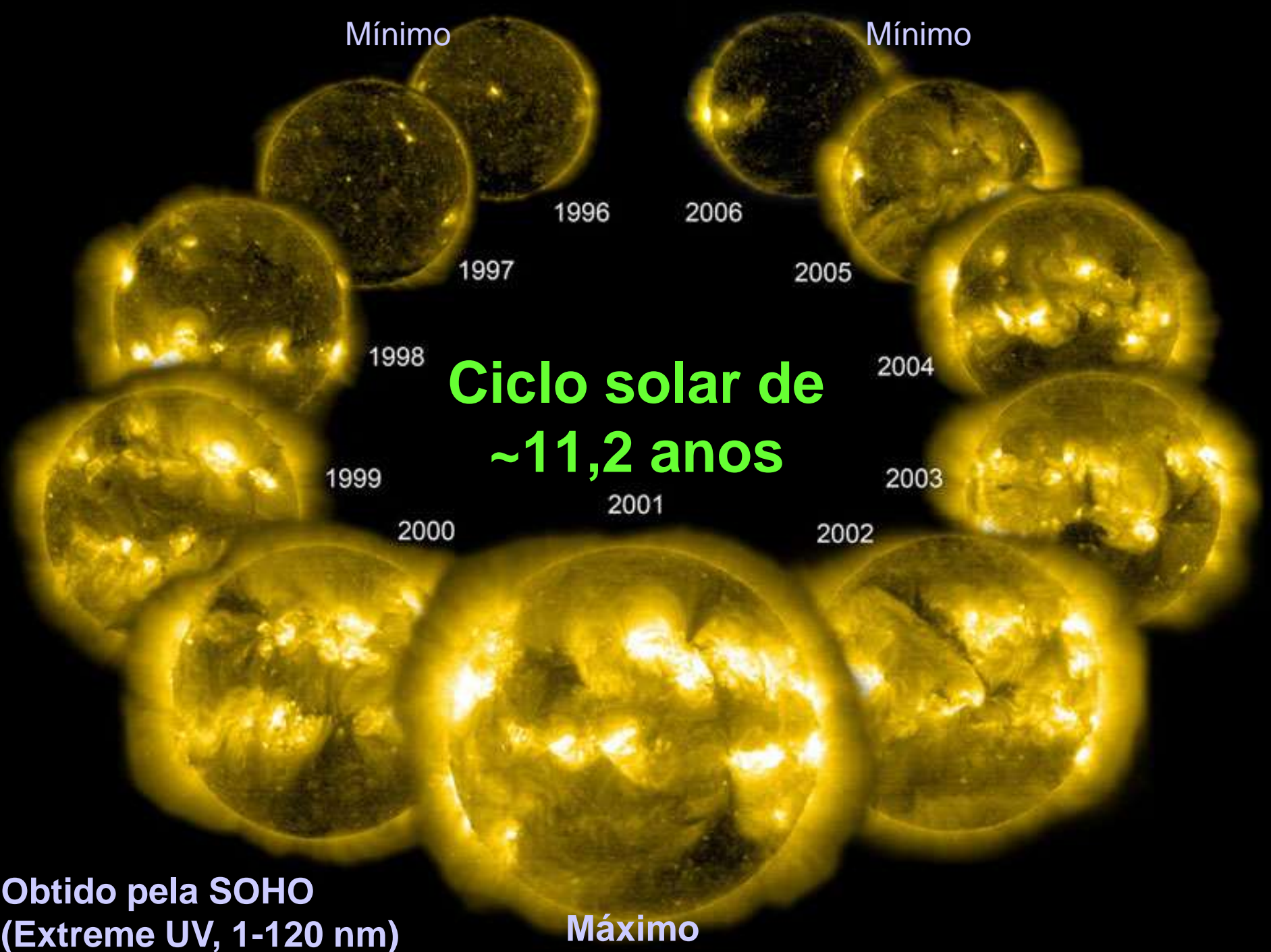
400 Years of Sunspot Observations



Relacionado à
pequena idade
do Gelo?

Congelamento do rio Tâmesa durante a pequena idade de gelo





Mínimo

Mínimo

1996

2006

1997

2005

1998

2004

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

1999

2003

2001

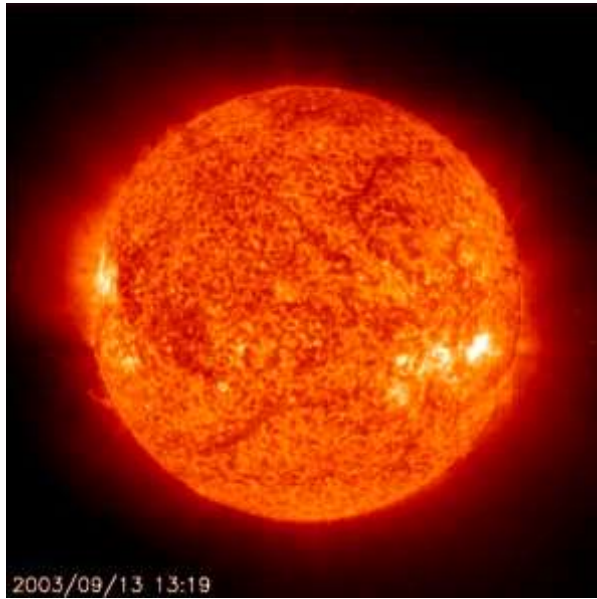
2000

2002

Máximo

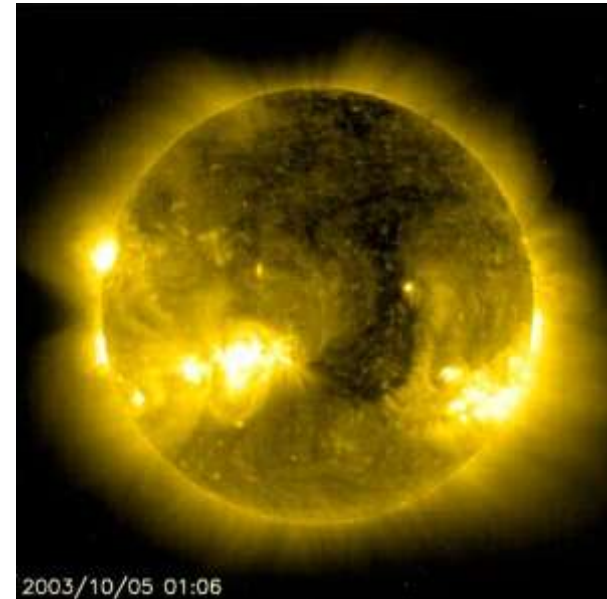
Obtido pela SOHO
(Extreme UV, 1-120 nm)

Sol visto em diversas cores



2003/09/13 13:19

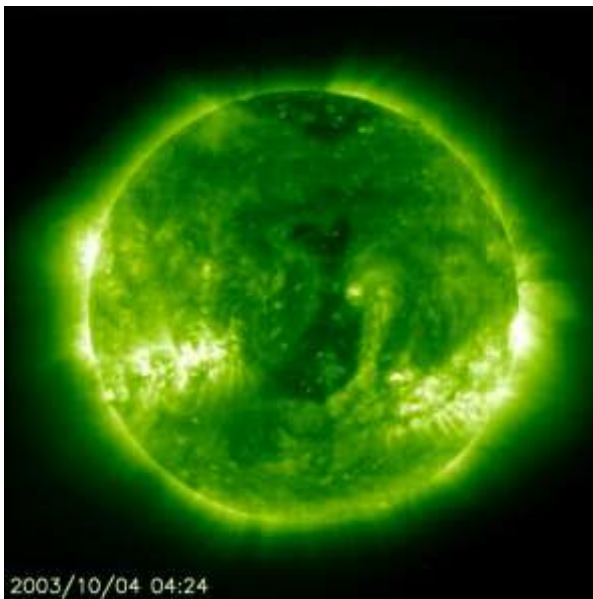
Ultravioleta 304 nm



2003/10/05 01:06

Ultravioleta 284 nm

Ultravioleta 195 nm



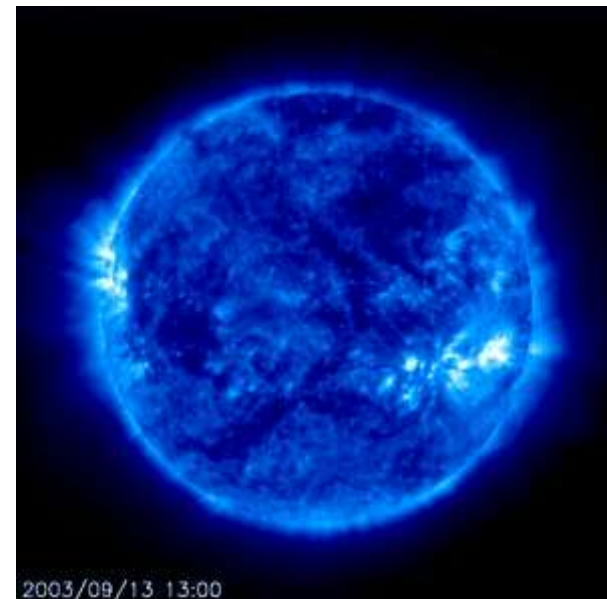
2003/10/04 04:24



2003/09/07 00:00

Visível

Ultravioleta 174 nm

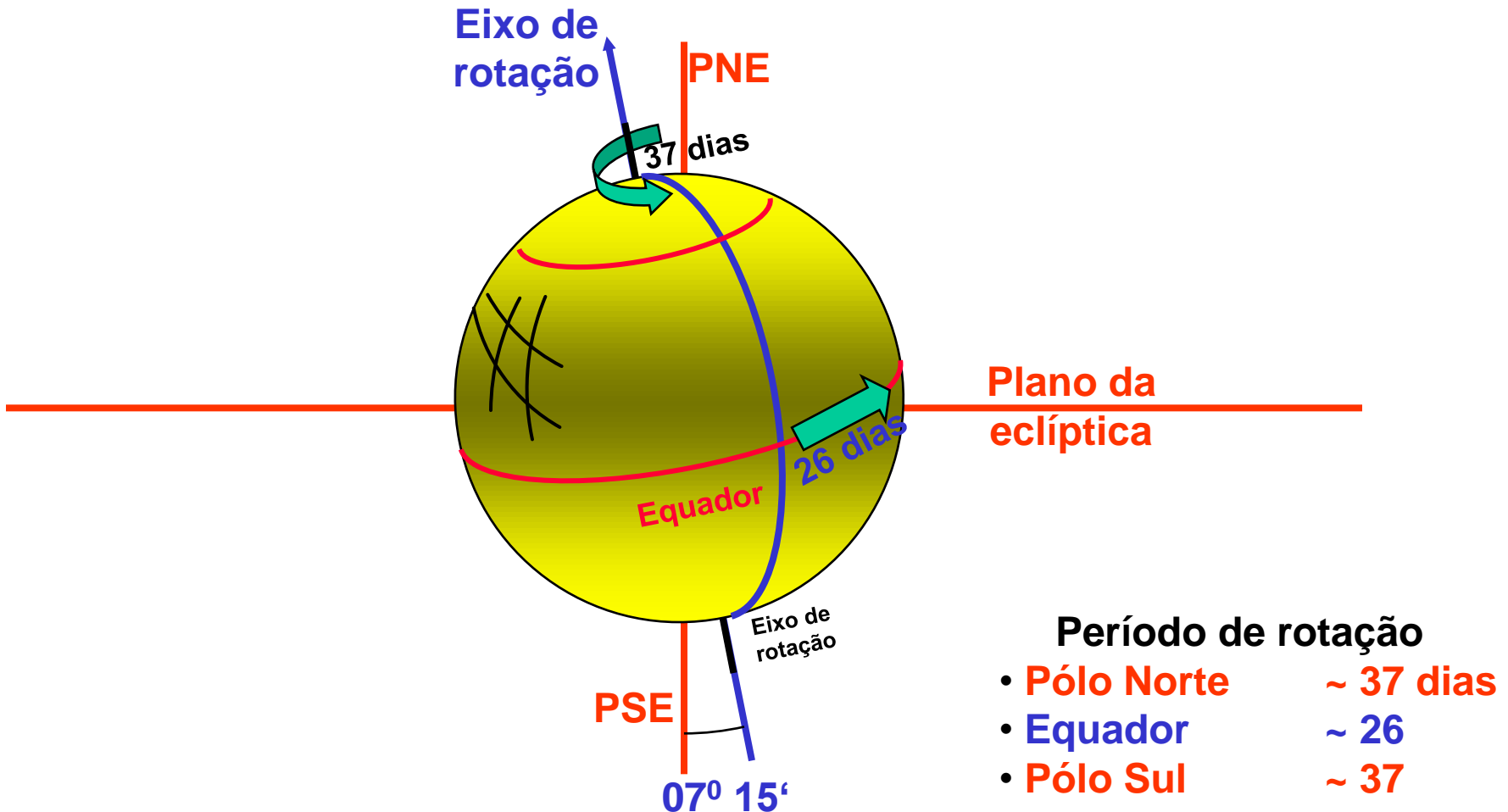


2003/09/13 13:00

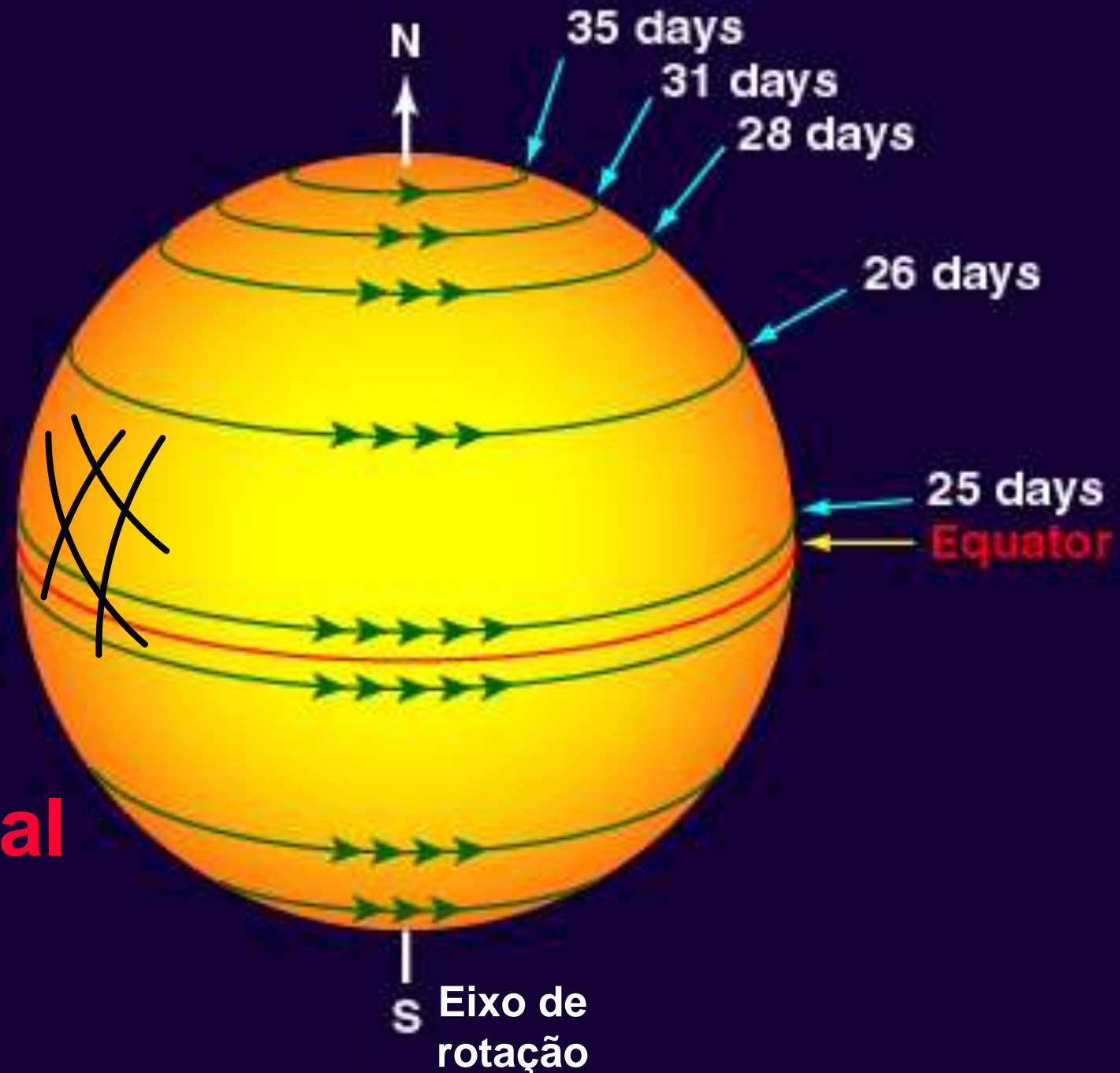
Rotação do Sol

Massa do Sol = 99,866% Massa Sistema Solar

Momento angular do Sol = 1% Momento angular dos planetas



Rotação diferencial do Sol



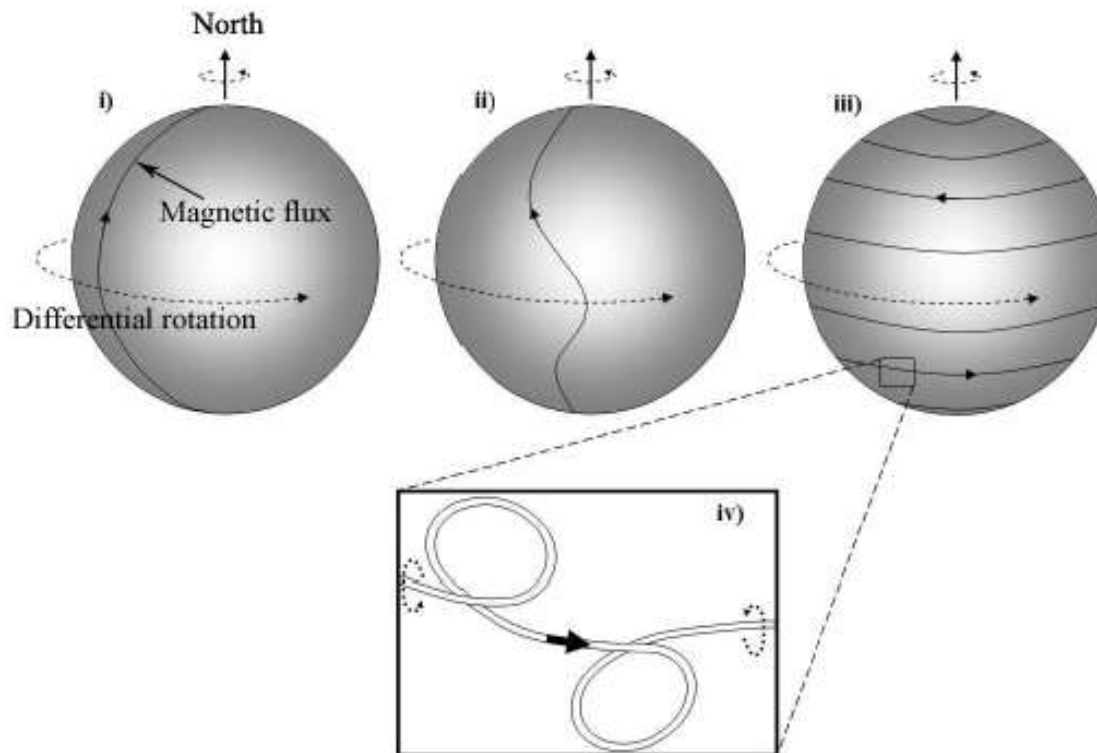
Evolução dos campos magnéticos no Sol



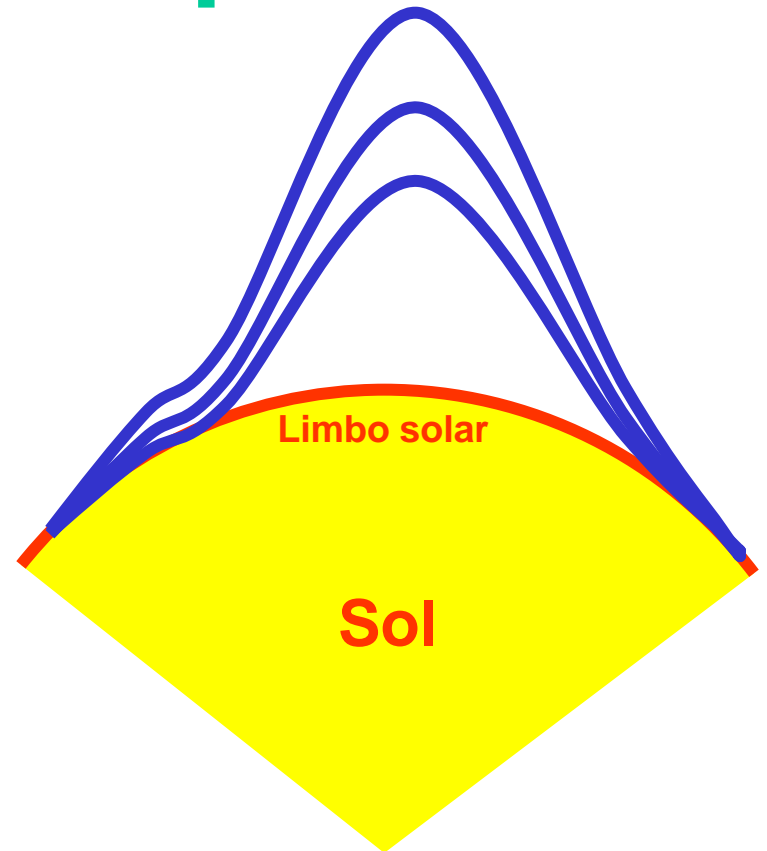
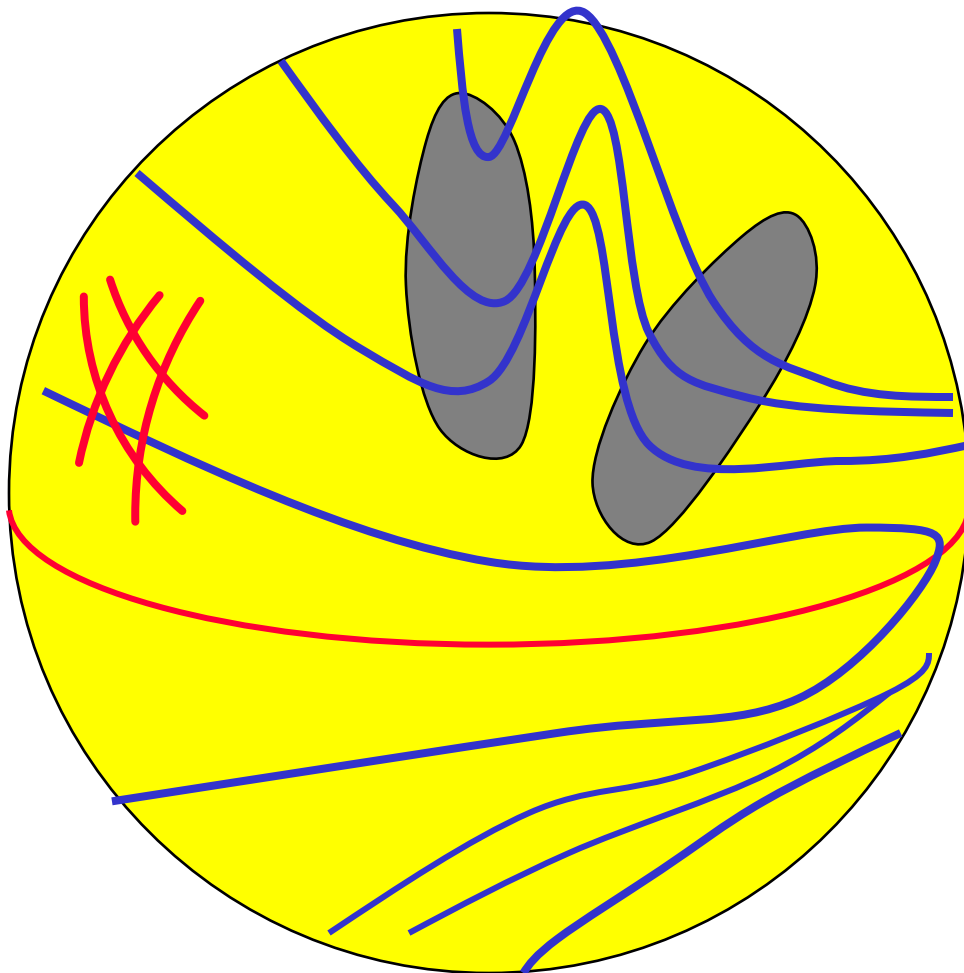
Mínimo Atividade Máximo Atividade



**Efeito da
rotação
diferencial
no ciclo de
atividade
do Sol**



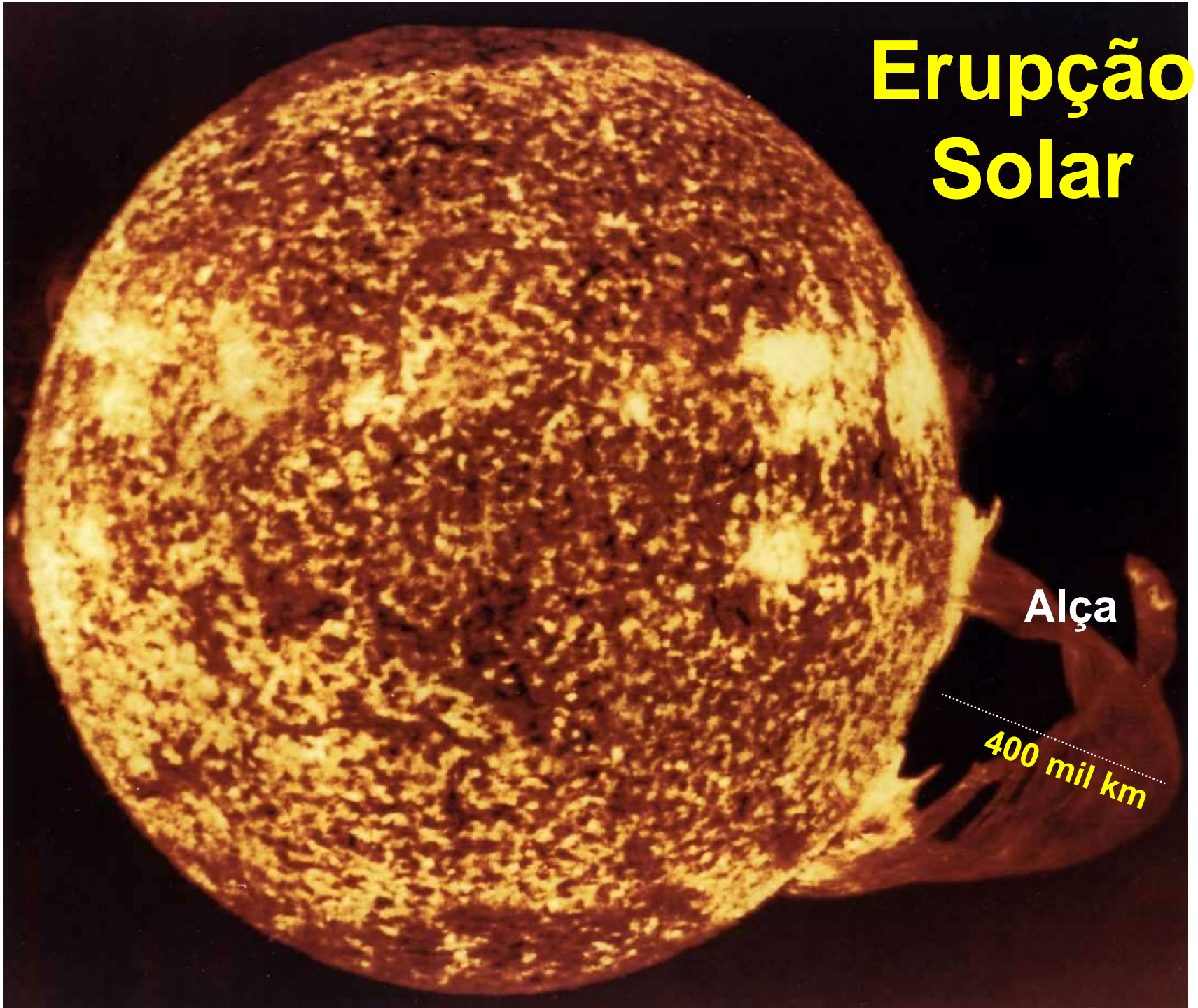
Despreendimento das linhas de campo



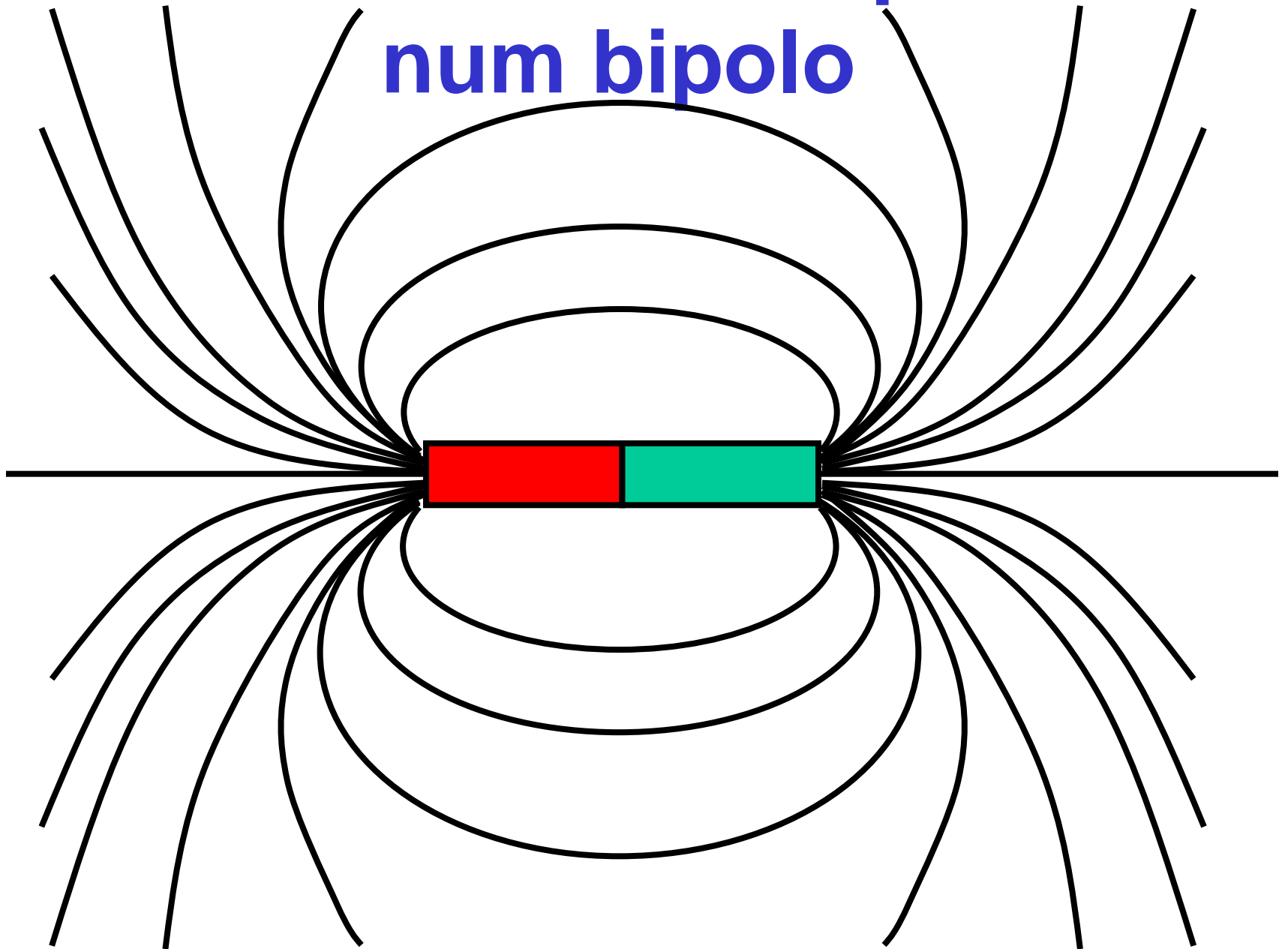
Erupção Solar

Alça

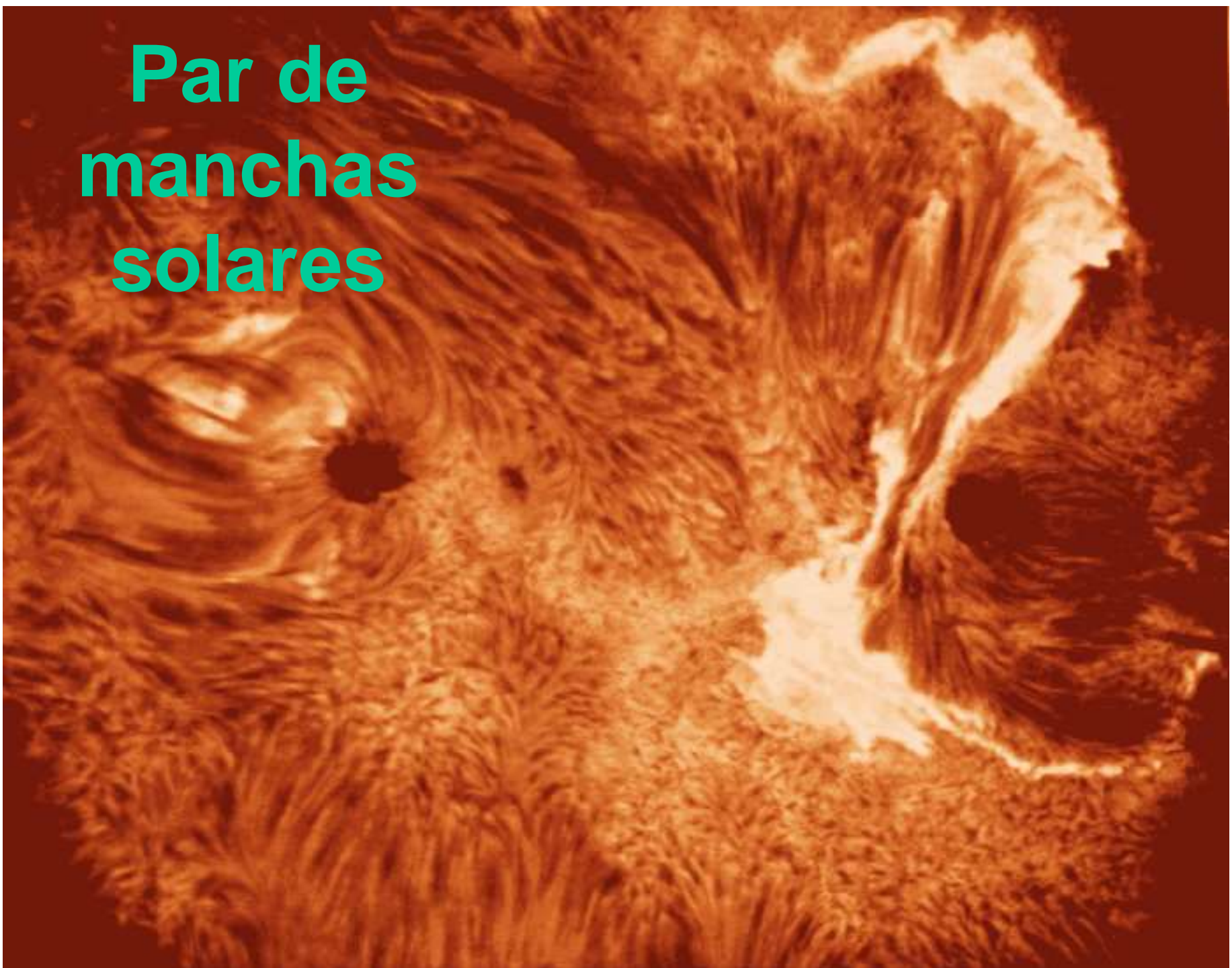
400 mil km



Linhas de campo num bipolo

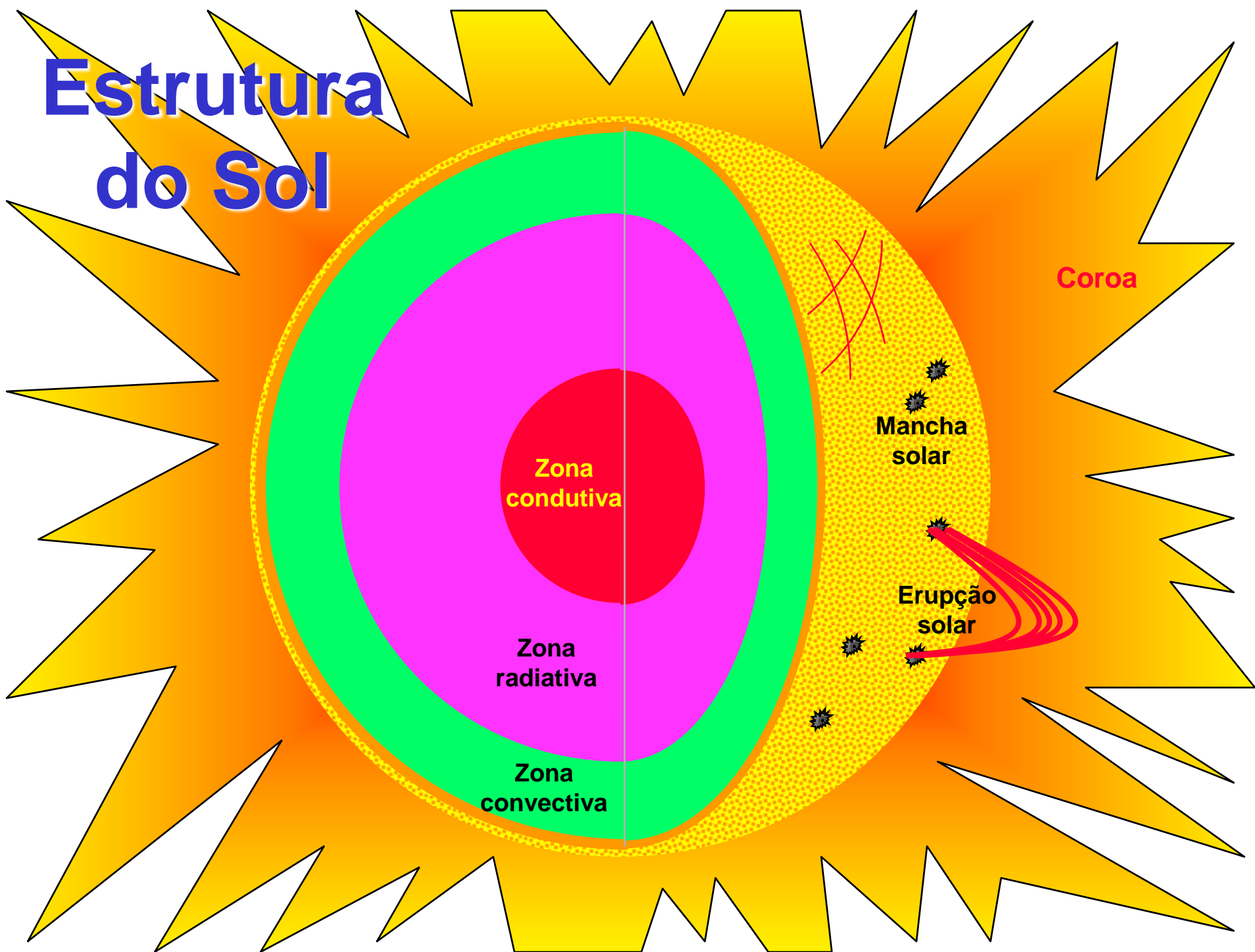


Par de manchas solares



Esquema geral da estrutura do Sol

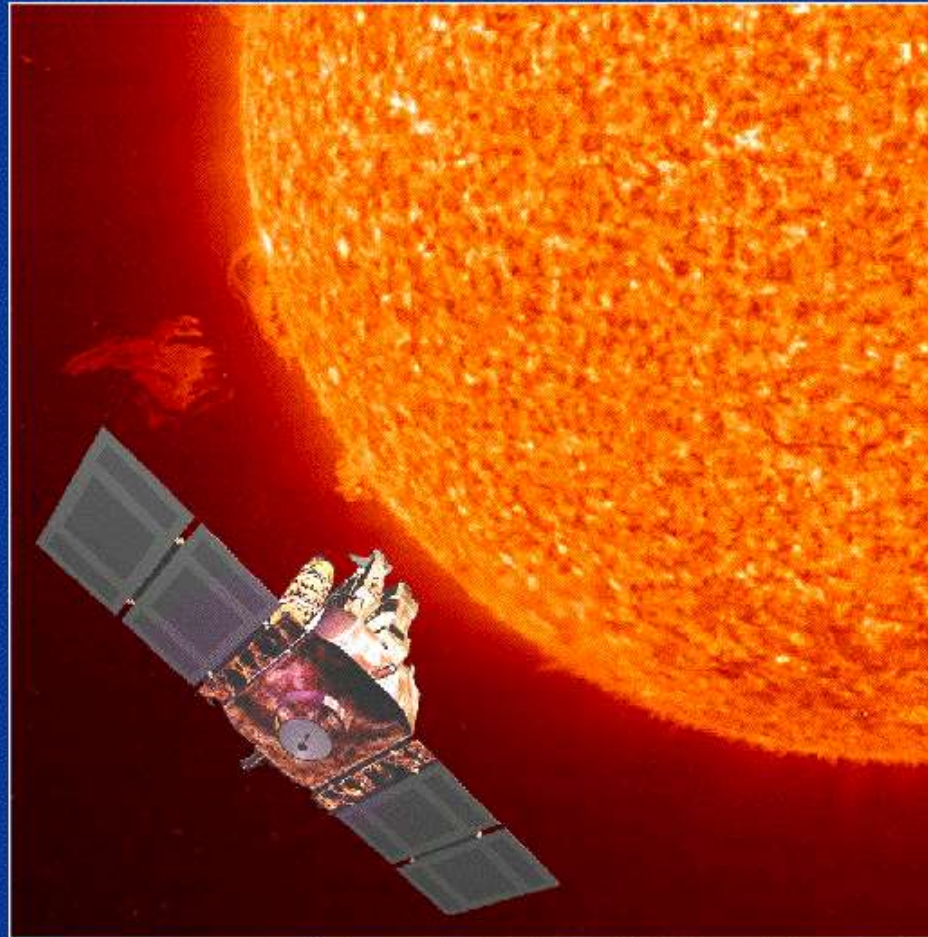
Estrutura do Sol



Observações Solares com Sondas



SOHO is an ESA/NASA mission of international cooperation



SOHO

■ ■ ■ SOLAR AND HELIOSPHERIC OBSERVATORY

Proeminência solar

Foto: SOHO (UV)
Hélio ionizado

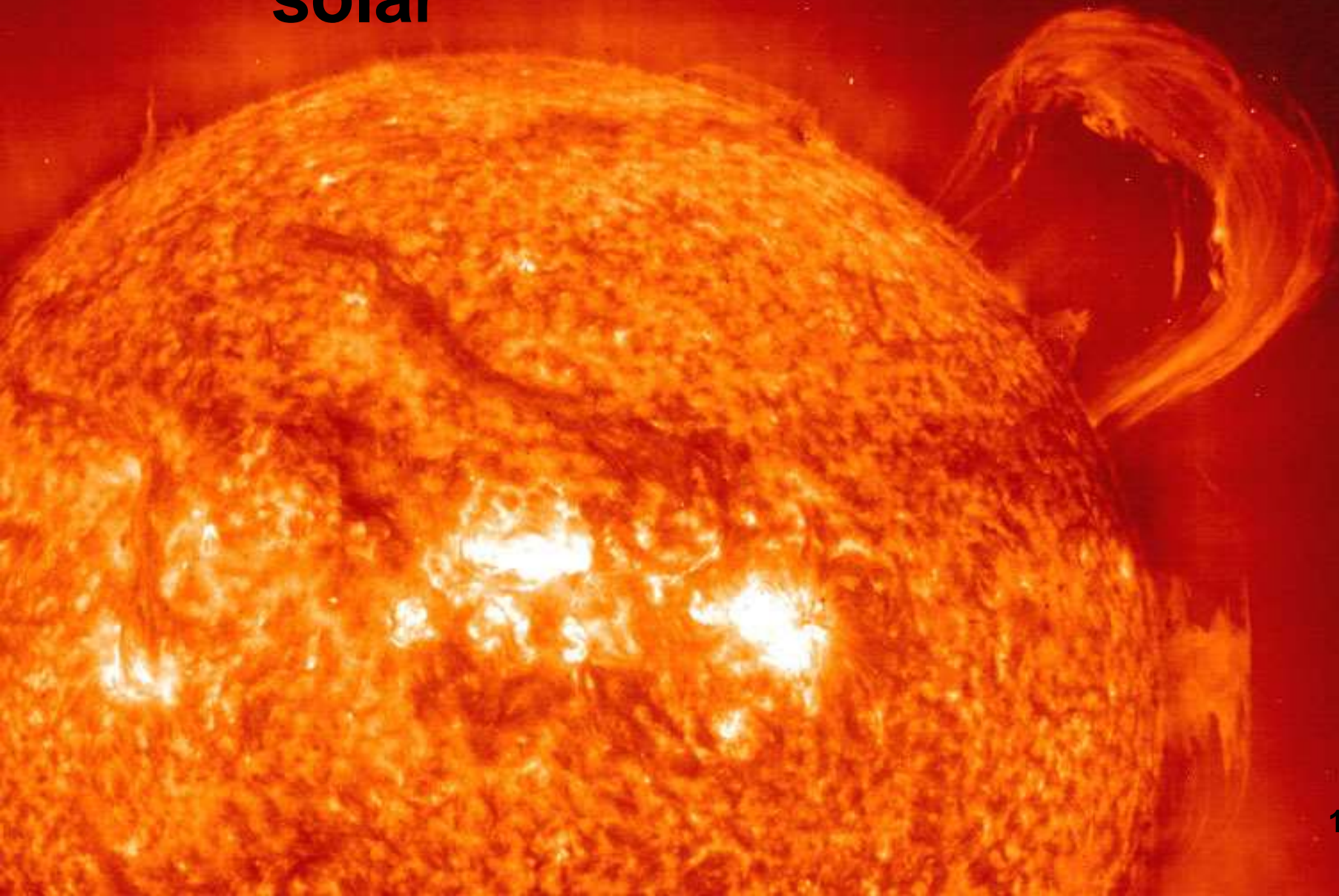
2000
Ano do Máximo de Atividade Solar



Tamanho aproximado da Terra na mesma escala

Proeminência solar

Gerado por
Hélio ionizado



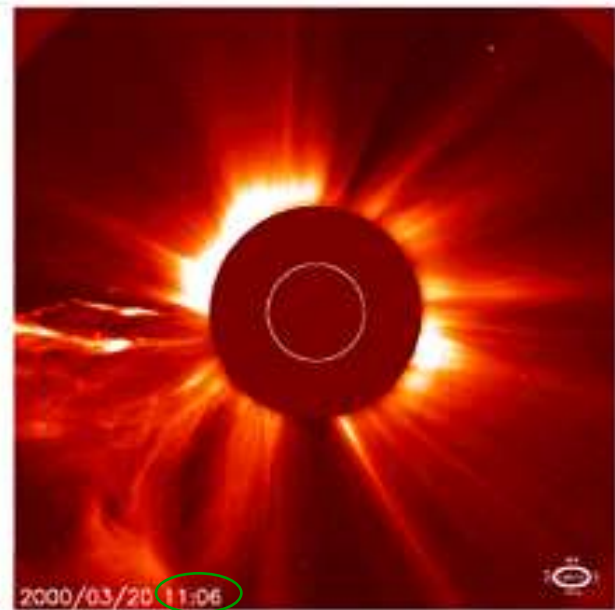
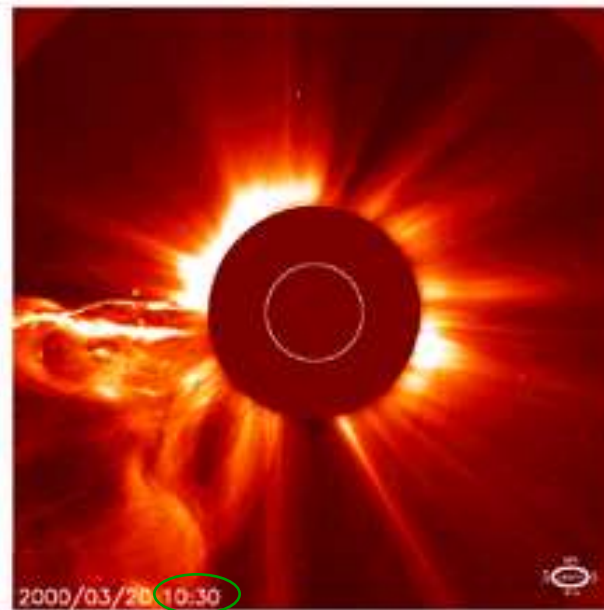
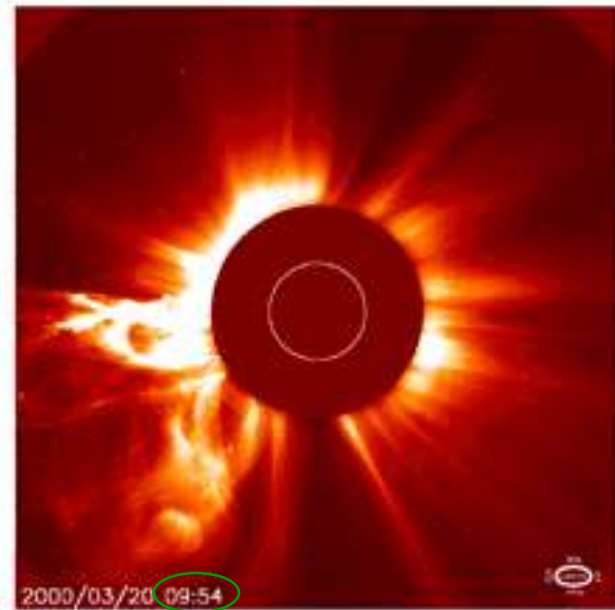
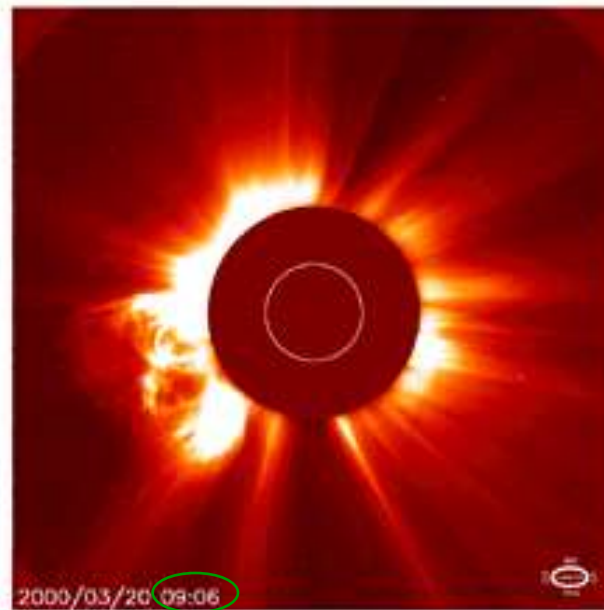
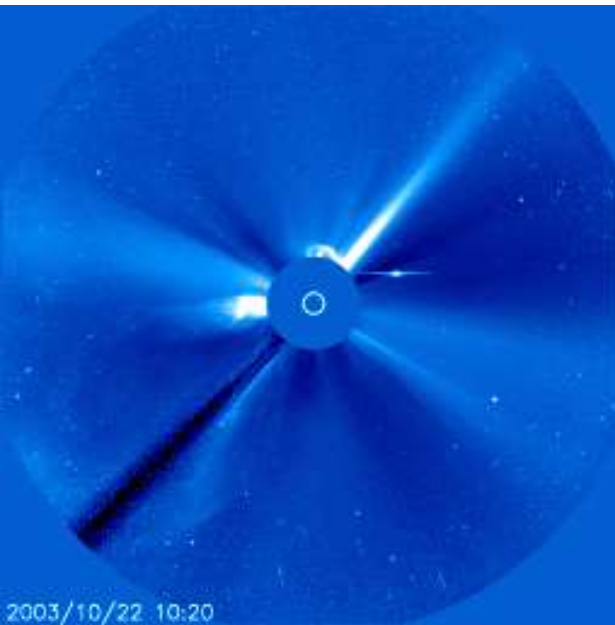
1999
set

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

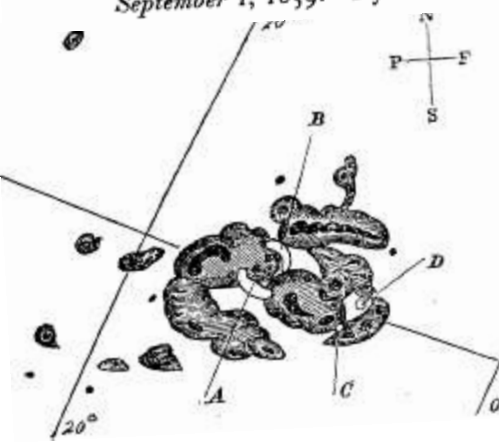
22/10/2003

01/1997

Sun 'ejection' killed TV satellite

January 21, 1997
Web posted at: 10:10 a.m. 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 above 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 in the 19th century, a torrent of electrons that rained down in the "perfect storm" later, experts warn, the Sun will again conspire to bring about 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

