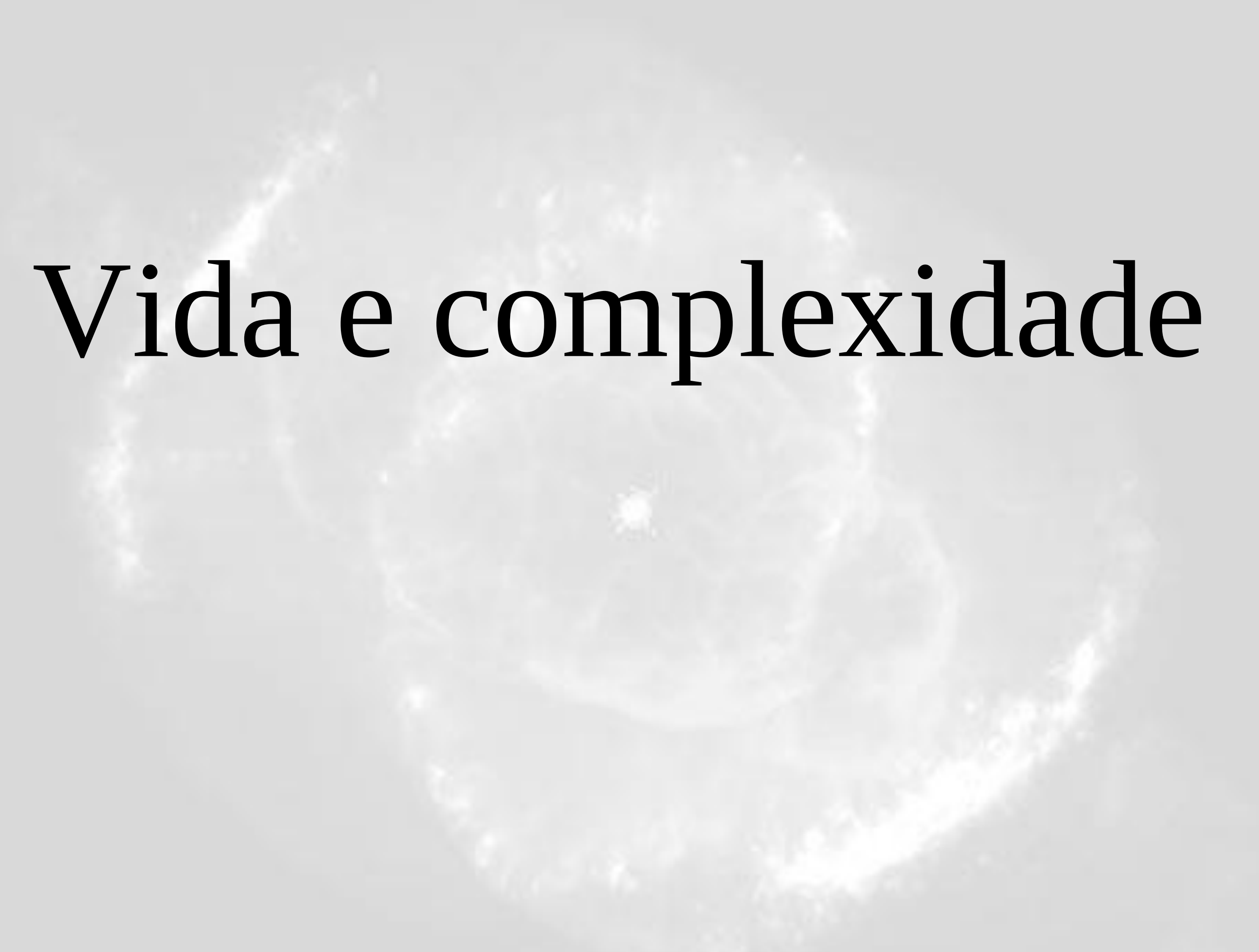
Evolução da Complexidade no Universo

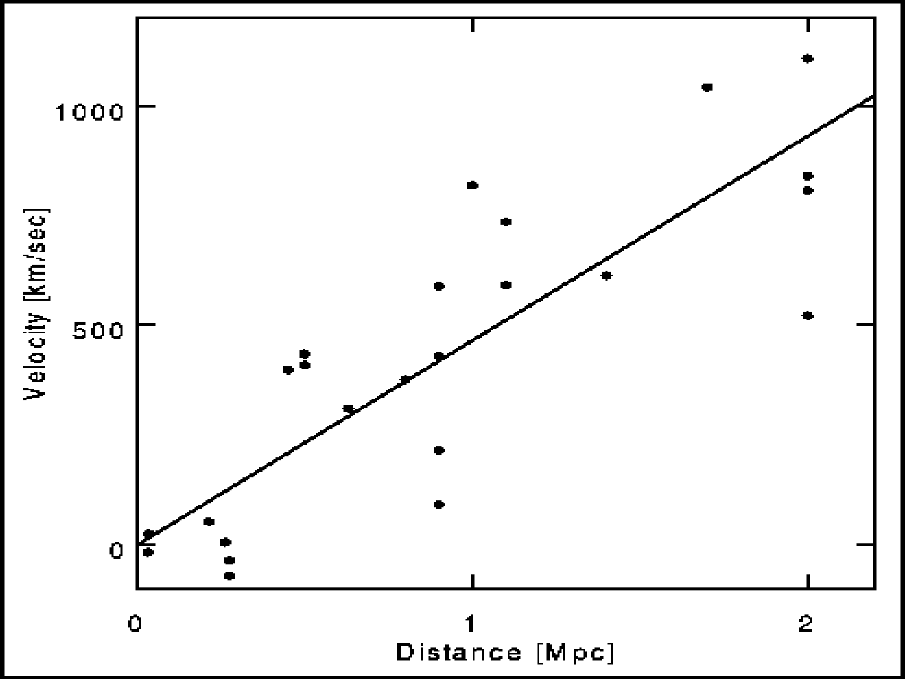
Vida e complexidade



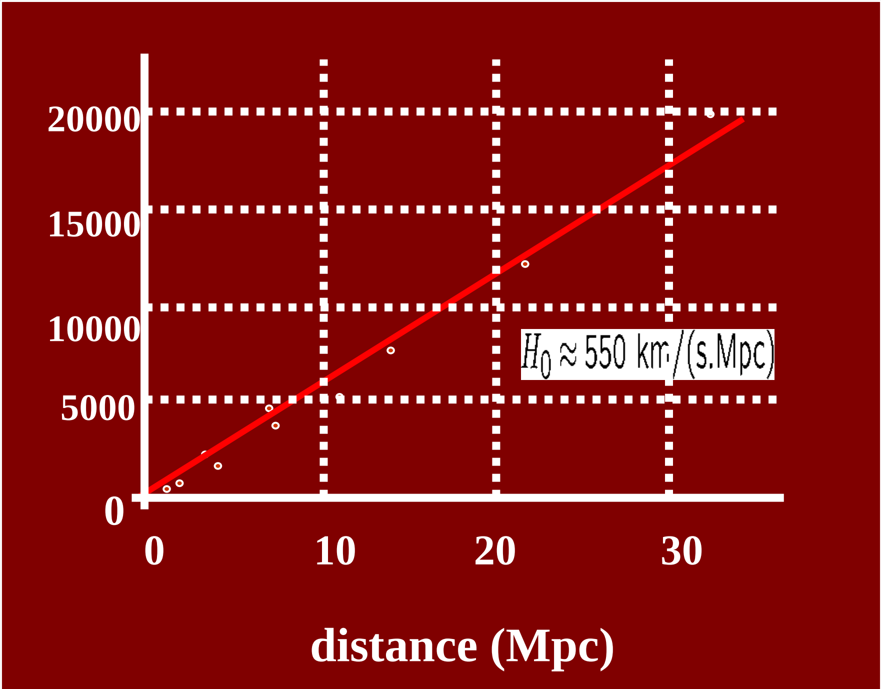
A lei de Hubble.

$$\text{desvio para o vermelho} = \frac{H_0}{c} \times \text{distância}$$

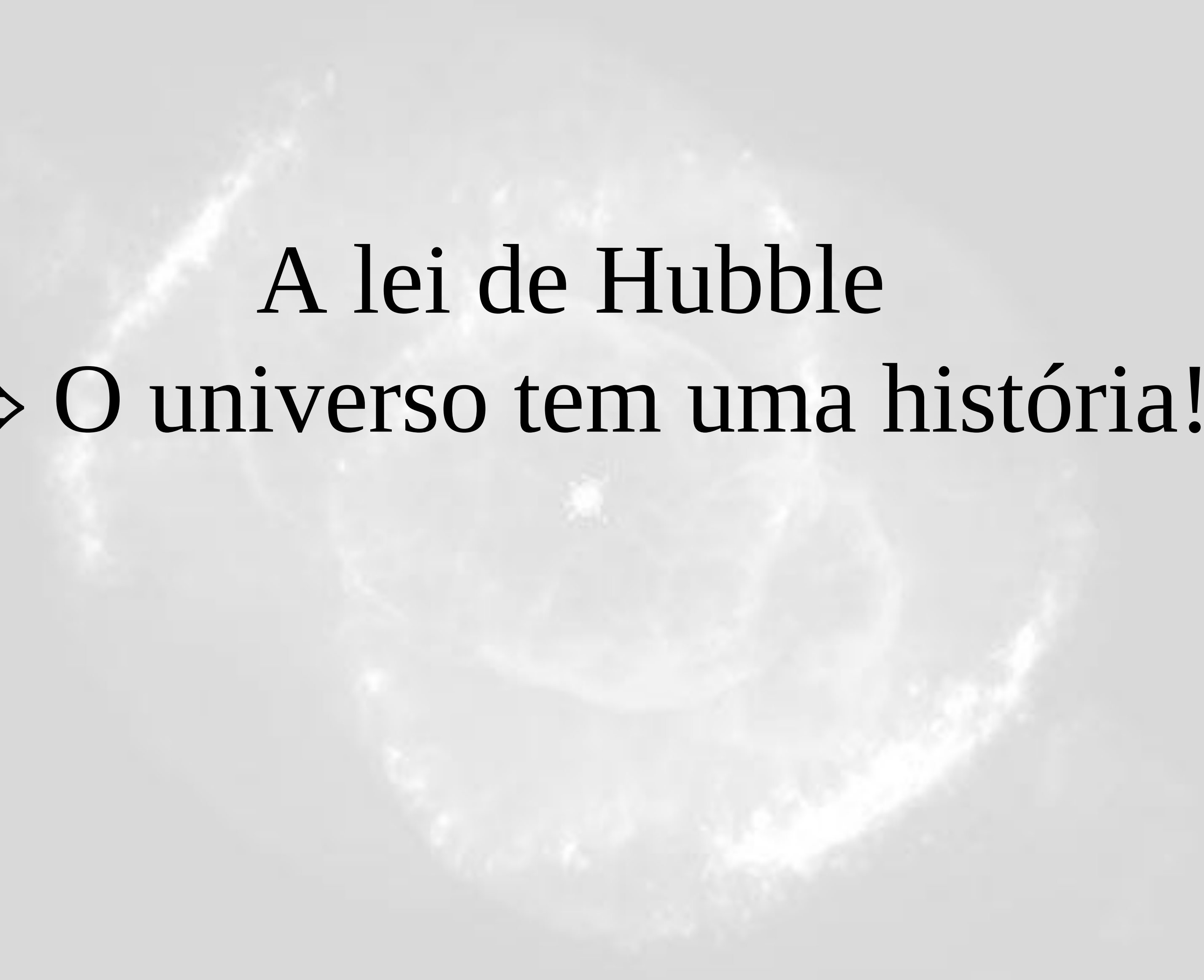
$$c\,z = v = H_0\,d \Rightarrow \text{(lei de Hubble dos astrônomos)}$$



[Hubble (1929)]

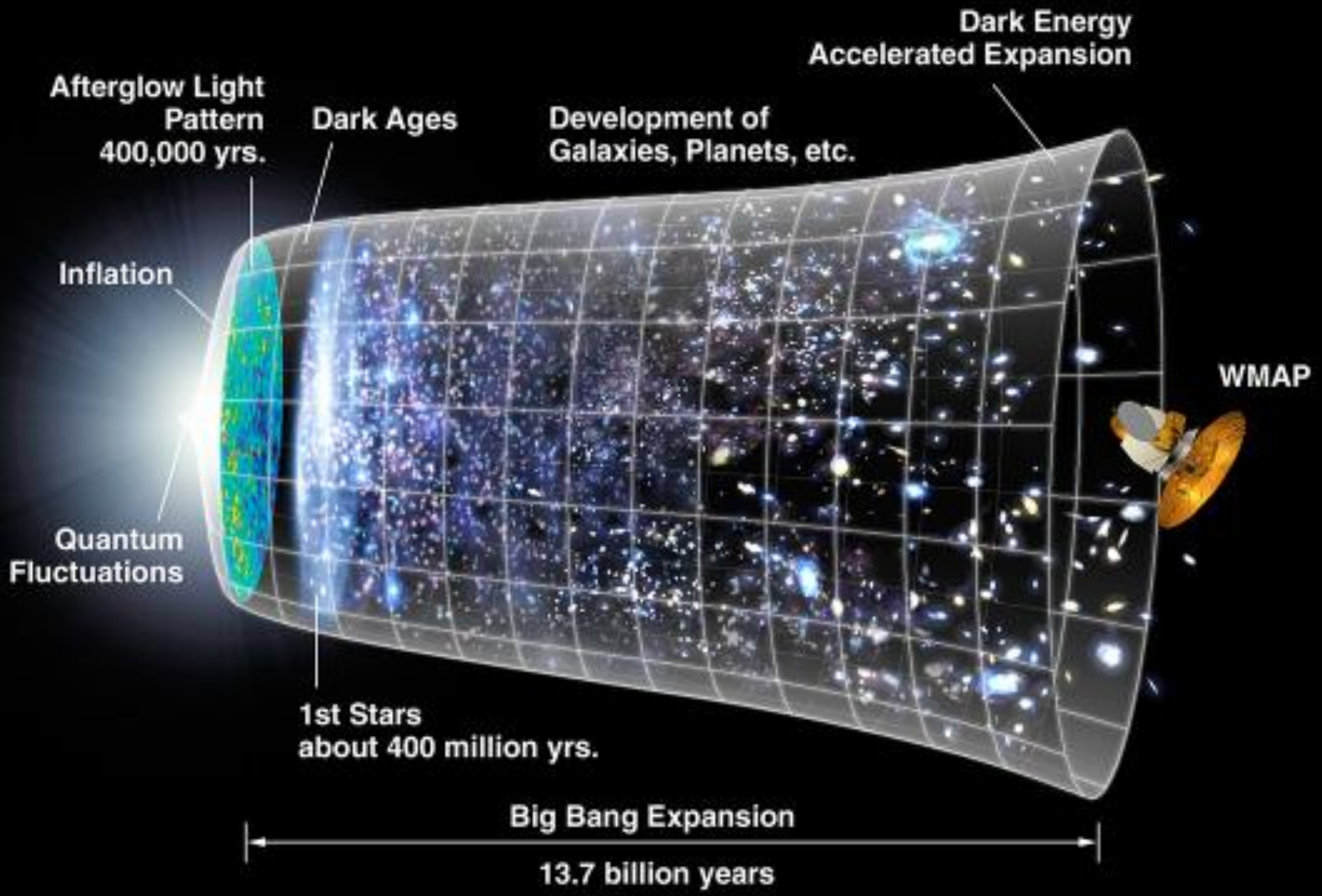


[Hubble & Humason (1931)]



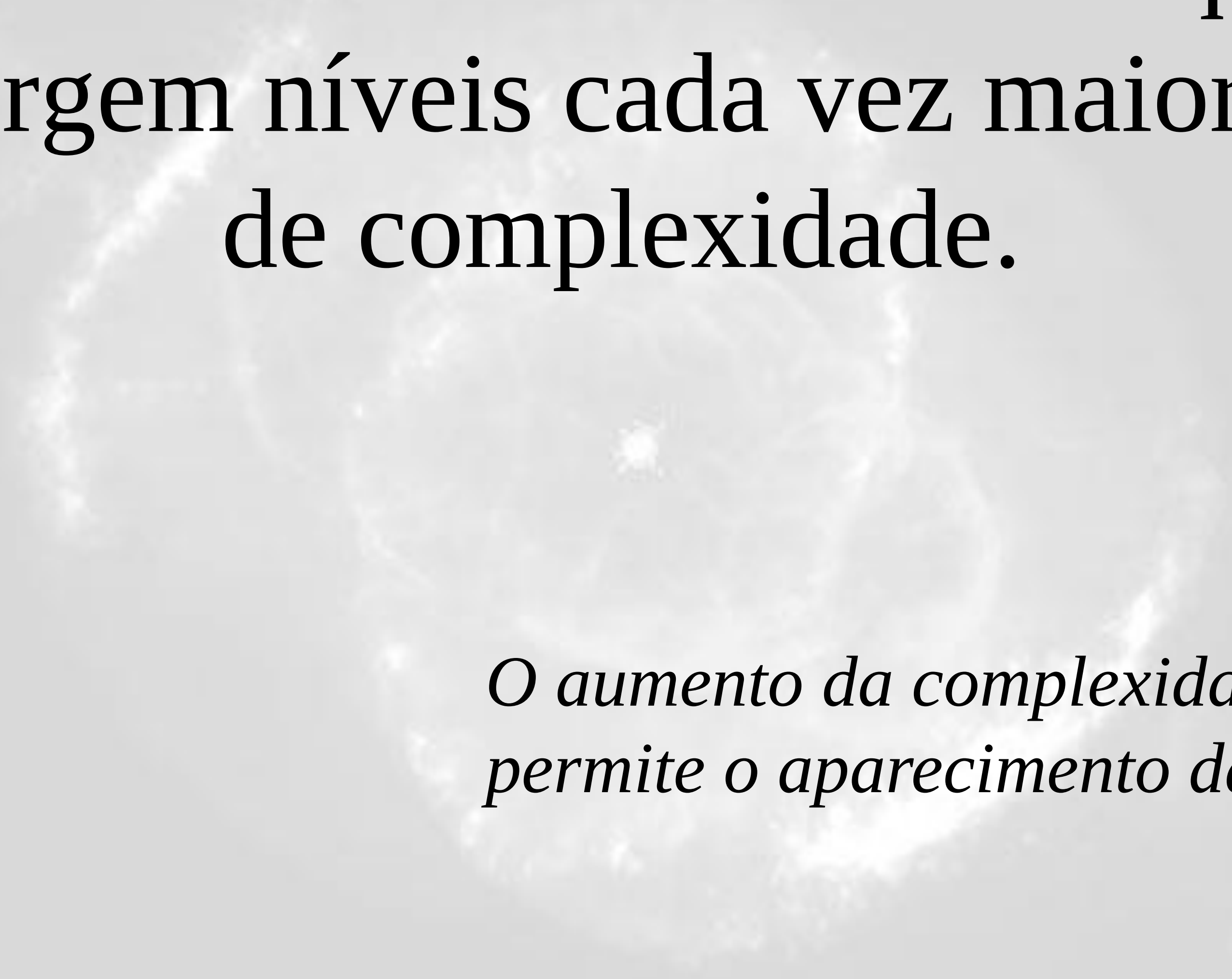
A lei de Hubble

⇒ O universo tem uma história!


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

NASA/WMAP Science Team

A história do universo é tal que surgem níveis cada vez maiores de complexidade.



O aumento da complexidade
permite o aparecimento da vida

História da Complexidade no Universo

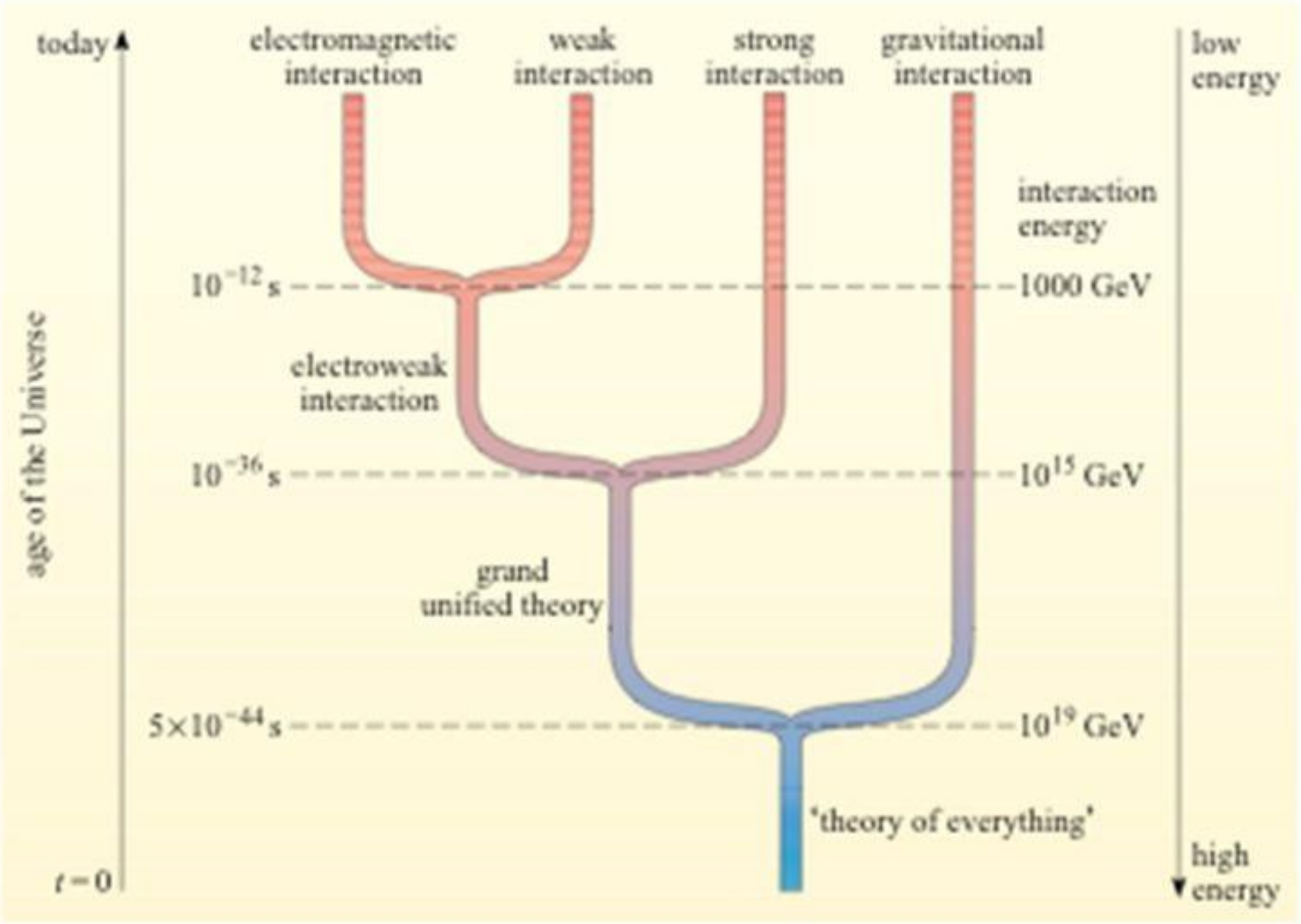
• 10^{-43} s	1. Nasce o espaço (4 dimensões estendidas)
• 10^{-33} s	2. Nasce a matéria (quarks e léptons)
• 10^{-4} s	3. Nascem os prótons (quarks confinados)
• 1 minuto	4. Nascem os núcleos (^{4}He ^{2}H ^{3}He ^{7}Li)
• 300.000 anos	5. Nascem os átomos (reunião elétrons-núcleos)
• ~300 Manos	6. Nascem os elementos pesados (C em diante)
• ~300 Manos	7. Nascem as heteromoléculas (OH, CO, H_2O)
• ~10 Ganos	8. Nasce a vida ($\oplus$: ao menos 3.85 Ganos atrás)

$$m_{pl} = \sqrt{\frac{\hbar c}{G}} = 10^{19} GeV$$

$$\ell_{pl} = \sqrt{\frac{\hbar G}{c^{3}}} = 10^{-35} m$$

$$t_{pl} = \sqrt{\frac{\hbar G}{c^{5}}} = 10^{-43} s$$

Evolution of fundamental interactions with time


today
electromagnetic interaction
weak interaction
strong interaction
gravitational interaction
low energy
interaction energy
10^{-12} s
1000 GeV
electroweak interaction
10^{-36} s
10^{15} GeV
age of the Universe
grand unified theory
5×10^{-44} s
10^{19} GeV
'theory of everything'
high energy
$t=0$

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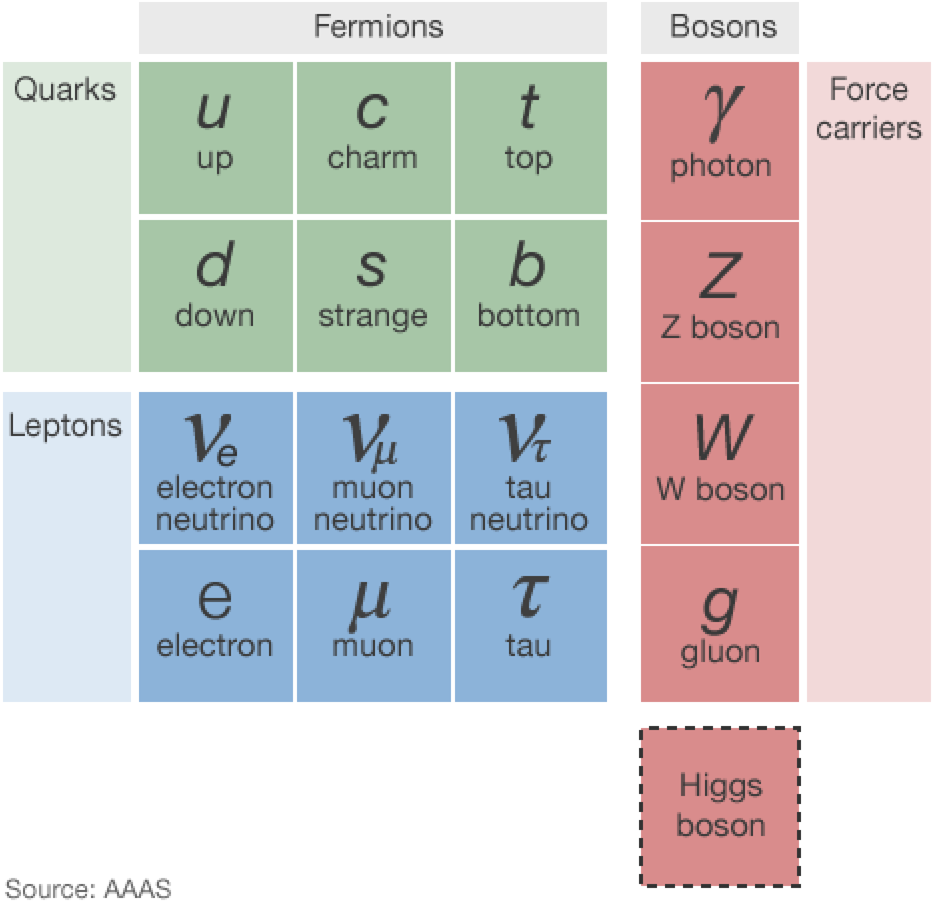
← inflation

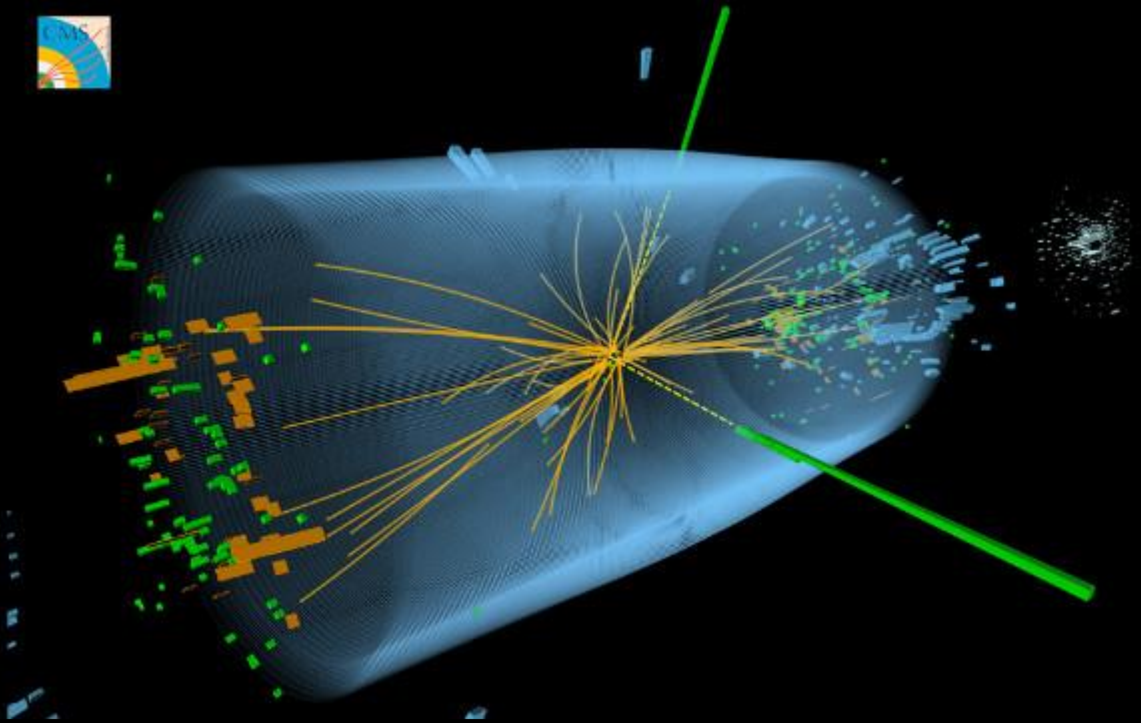


	Fermions			Bosons	
Quarks	u up	c charm	t top	γ photon	Force carriers
	d down	s strange	b bottom	Z Z boson	
Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
	e electron	μ muon	τ tau	g gluon	
				Higgs boson	

Source: AAAS

Scientists more certain that particle is Higgs boson

(CNN, March 14, 2013 -1919 GMT)



(CNN) -- Just in time for Albert Einstein's birthday Thursday, scientists delivered exciting news about how the universe works.

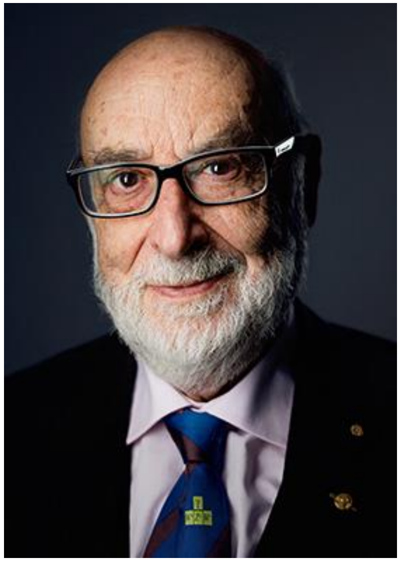
Last summer, physicists announced that they had identified a particle with characteristics of the elusive Higgs boson, the so-called "God particle." But, as often the case in science, they needed to do more research to be more certain.

On Thursday, scientists announced that the particle, detected at the Large Hadron Collider, the world's most powerful particle-smasher, looks even more like the Higgs boson.

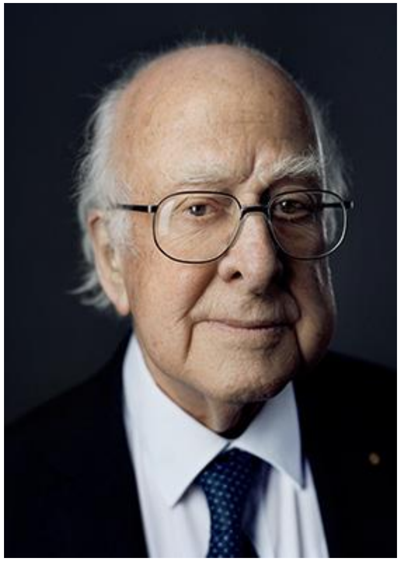
The news came at the Moriond Conference in La Thuile, Italy, from ATLAS and Compact Muon Solenoid experiments.

The Nobel Prize in Physics 2013

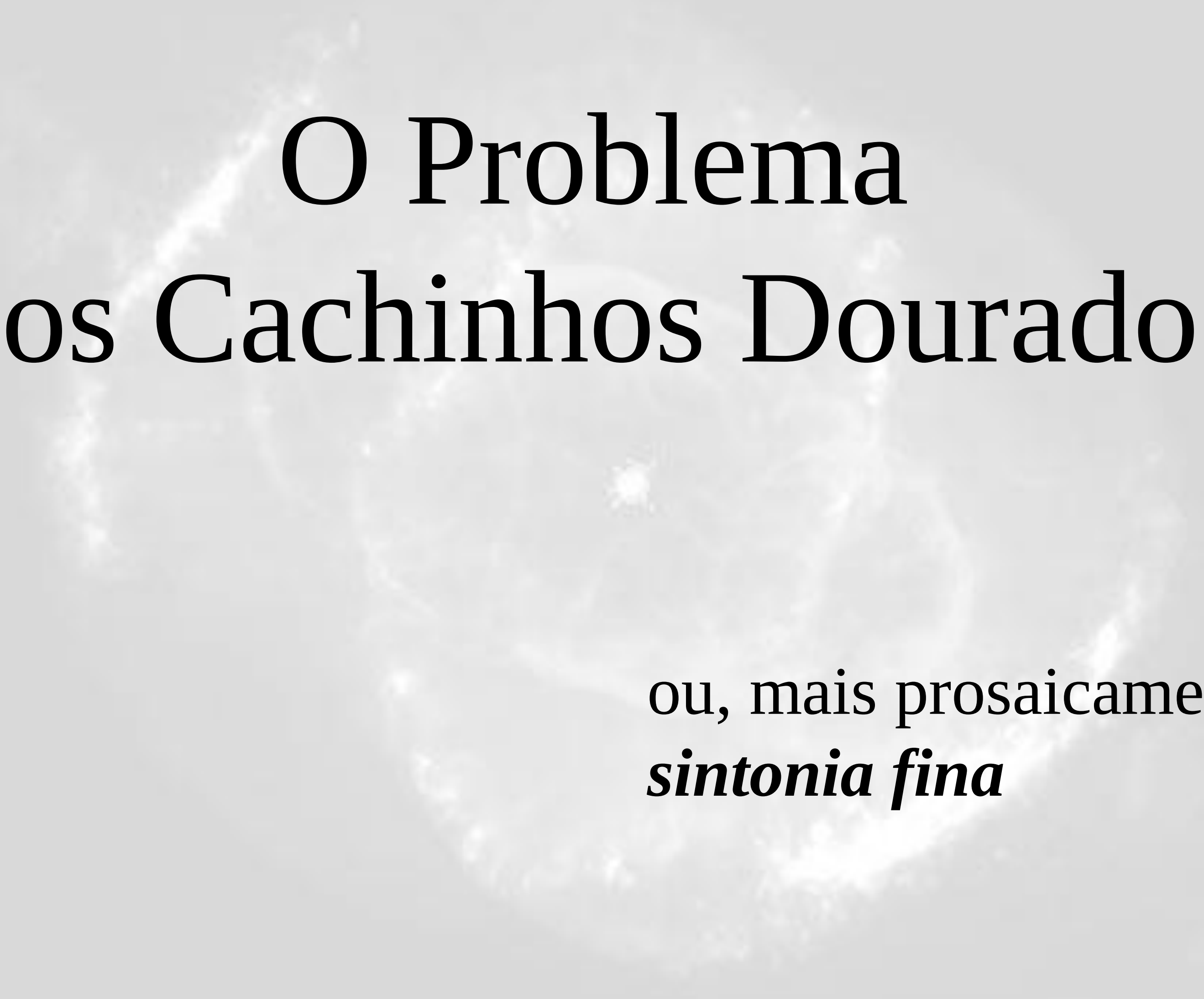
"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"



François Englert
Prize share: 1/2
Born: 6 November 1932, Etterbeek, Belgium
Affiliation at the time of the award: Université Libre de Bruxelles, Brussels, Belgium

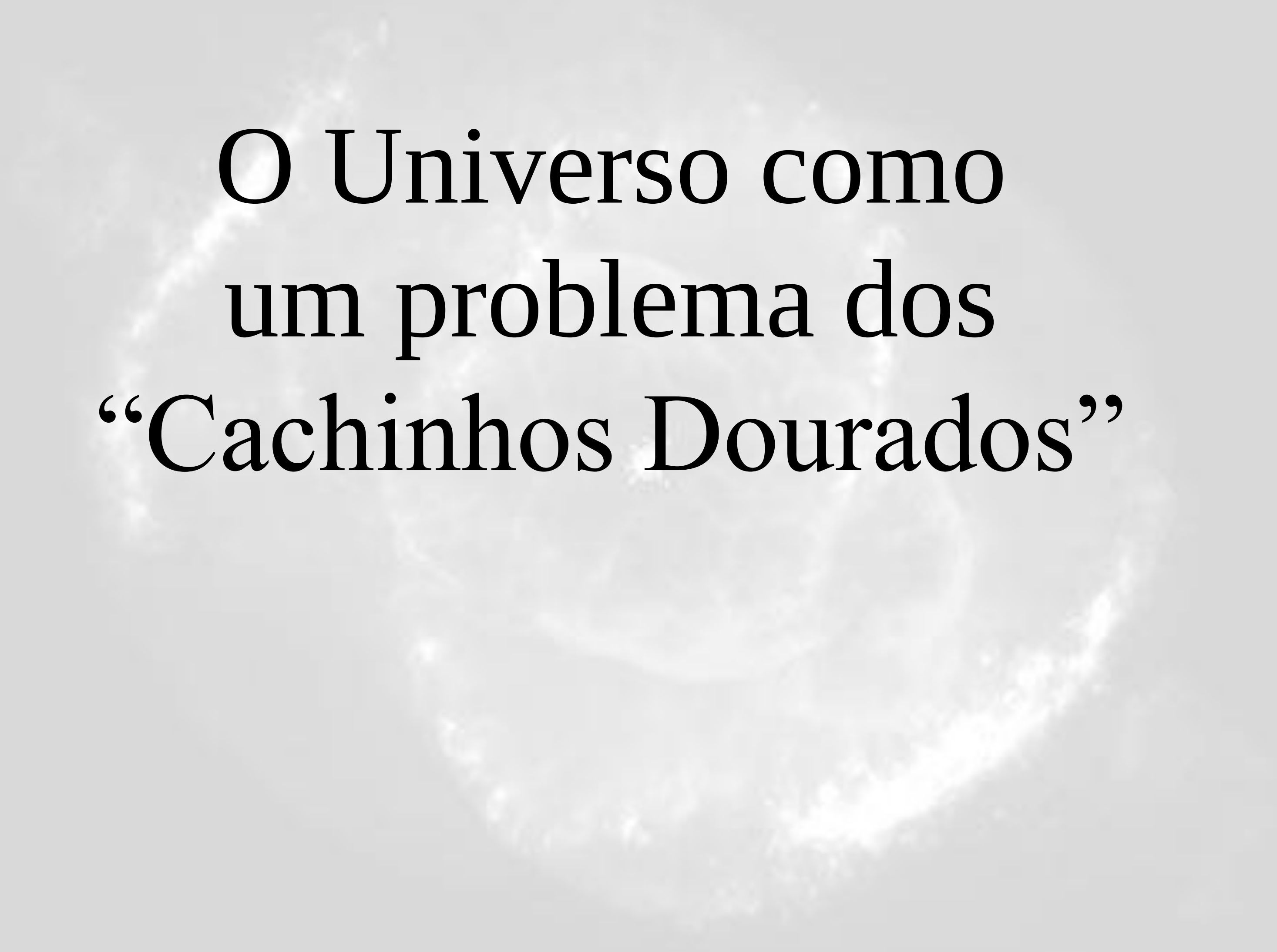


Peter W. Higgs
Prize share: 1/2
Born: 29 May 1929, Newcastle upon Tyne, United Kingdom
Affiliation at the time of the award: University of Edinburgh, Edinburgh, United Kingdom



O Problema dos Cachinhos Dourados

ou, mais prosaicamente,
sintonia fina



O Universo como
um problema dos
“Cachinhos Dourados”

Um Universo Biofílico

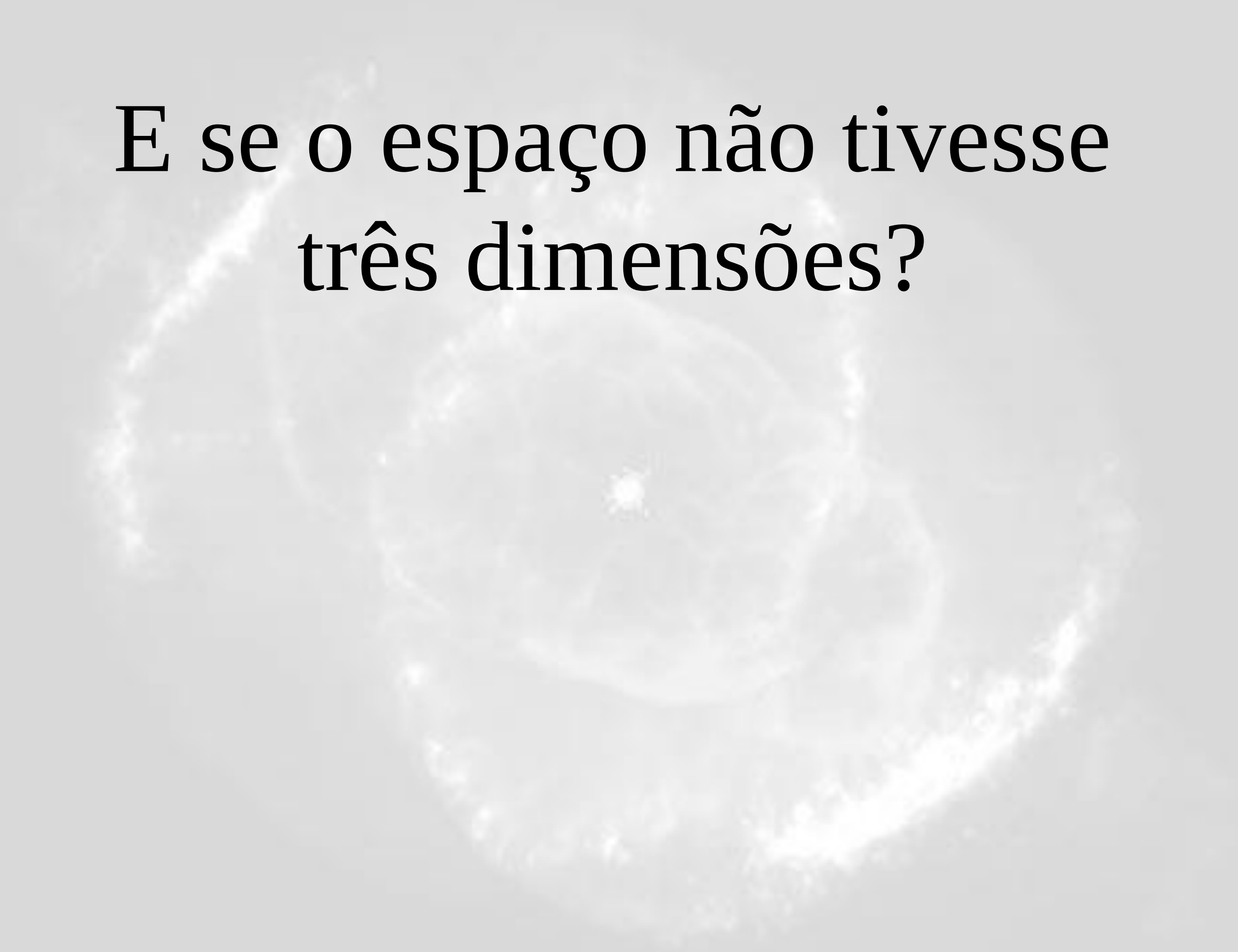
Um universo hospitaleiro à vida – o que podemos chamar de um universo biofílico – tem que ser muito especial de diversos modos.
Os pré-requisitos para qualquer vida – **estrelas de vida longa, uma tabela periódica de elementos com química complexa etc.** – são sensíveis às leis físicas e não poderiam ter emergido de um Big Bang com uma receita que fosse mesmo ligeiramente diferente.

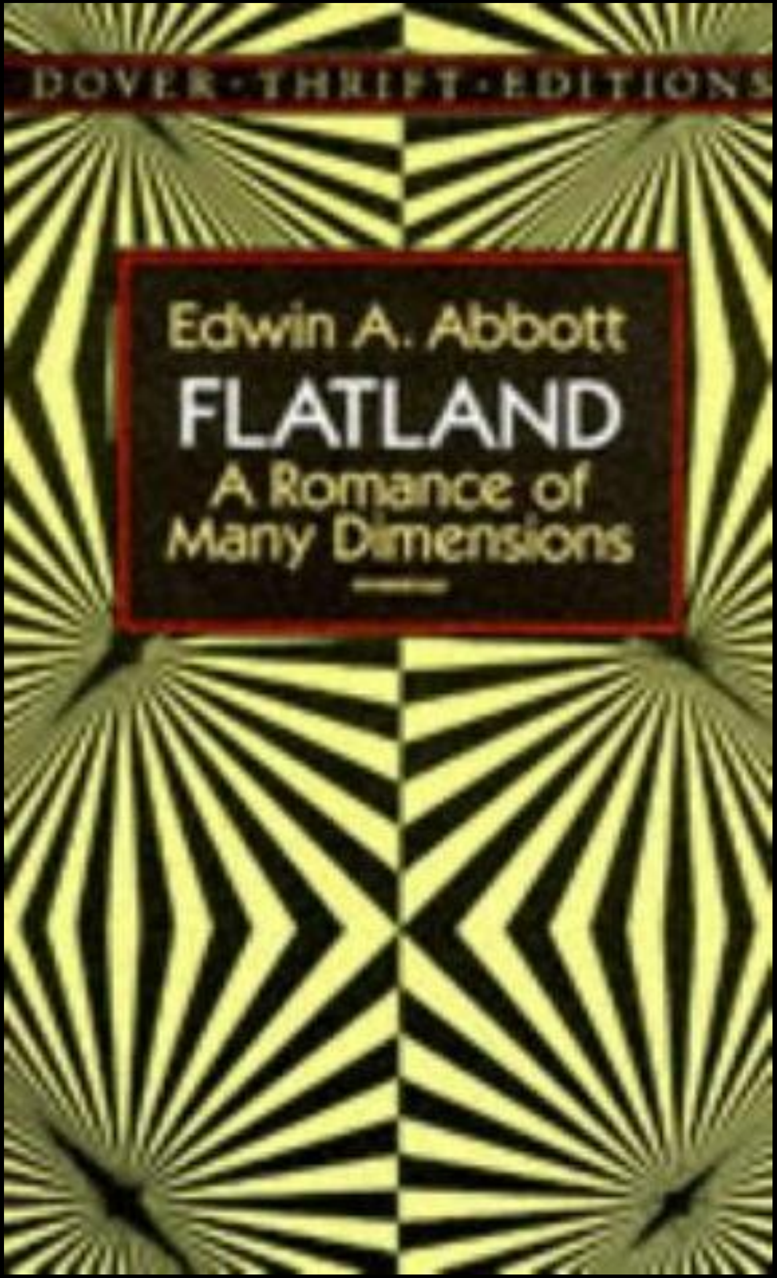
Martin Rees
Our Cosmic Habitat

APENAS SEIS NÚMEROS

- N = 10^{36}, a razão da força eletromagnética para a força gravitacional entre dois prótons.
- ε = 0.007, medida da intensidade da energia de ligação entre os nêutrons e prótons dentro do núcleo atômico.
- Ω = 0.3, quantidade de matéria no Universo
- λ = 0.7, quantidade de energia em vácuo no Universo
- Q = 1/100 000, medida da profundidade média das flutuações de densidade do Universo
- D = 3, número de dimensões do espaço

E se o espaço não tivesse três dimensões?



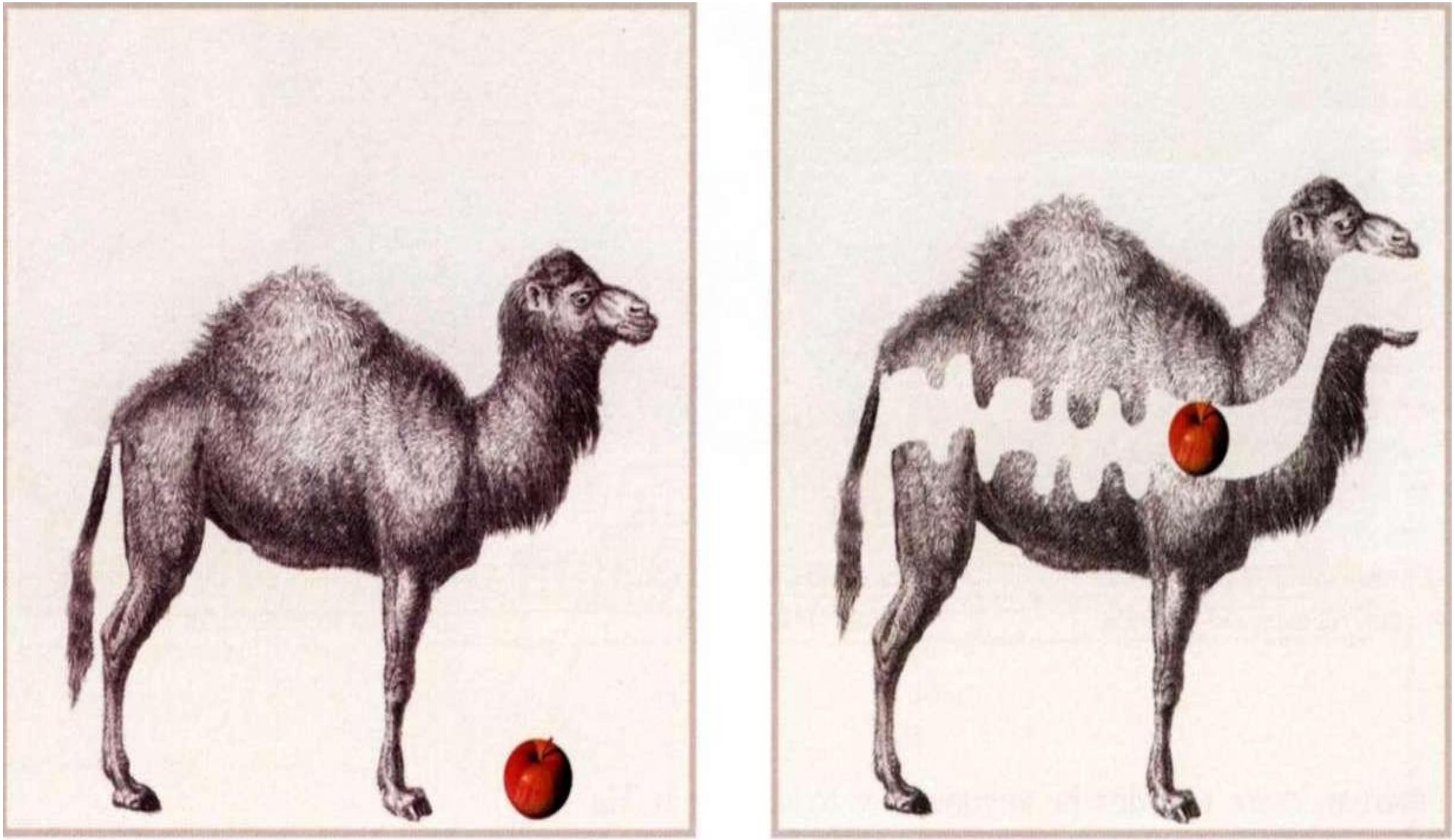

DOVER · THRIFT · EDITIONS
Edwin A. Abbott
FLATLAND
A Romance of
Many Dimensions

Ficção matemática, 1884

Autor: padre anglicano

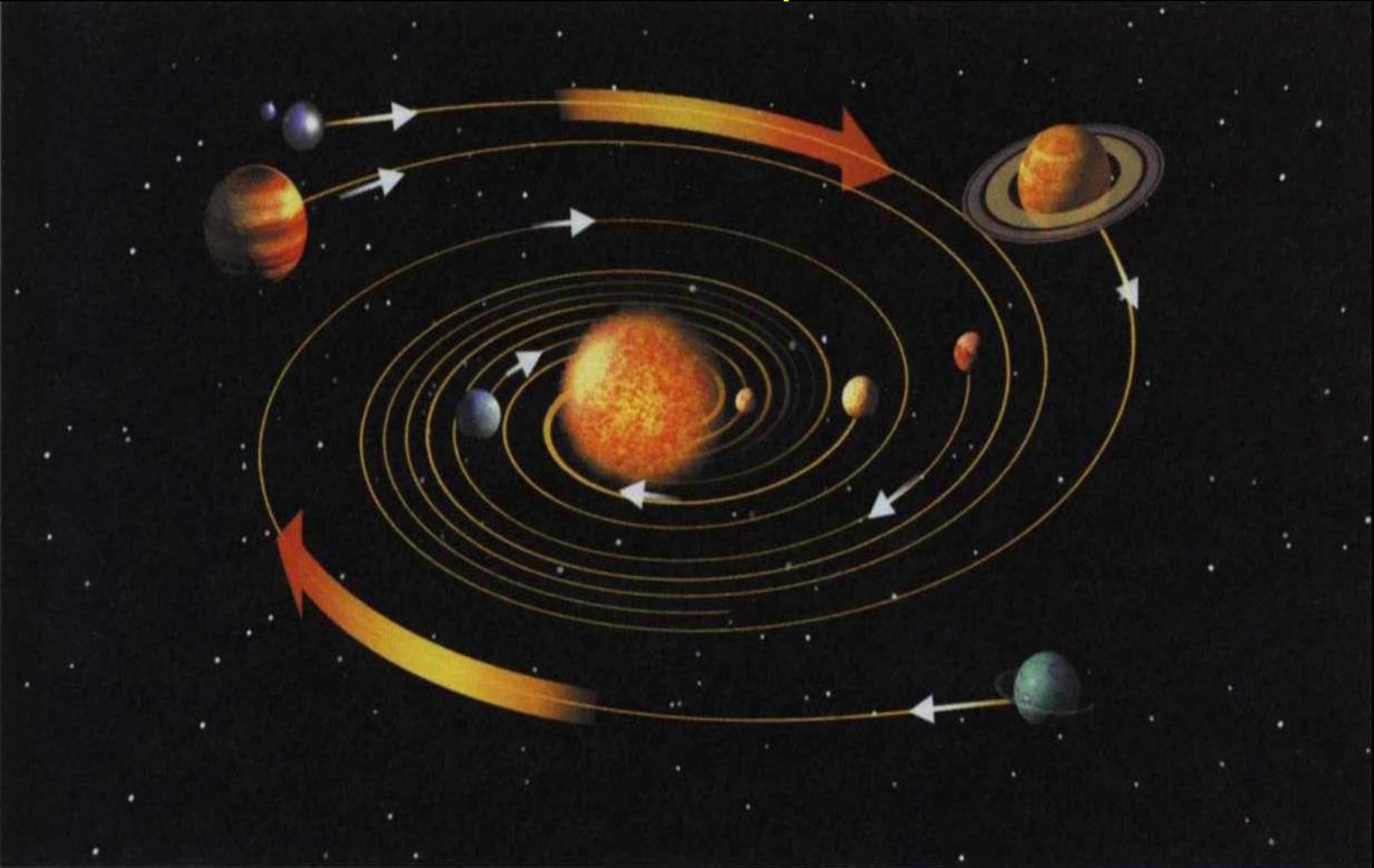
(Círculos, mulheres...)

Animais bidimensionais
$\Rightarrow$ sistema digestivo disjunto

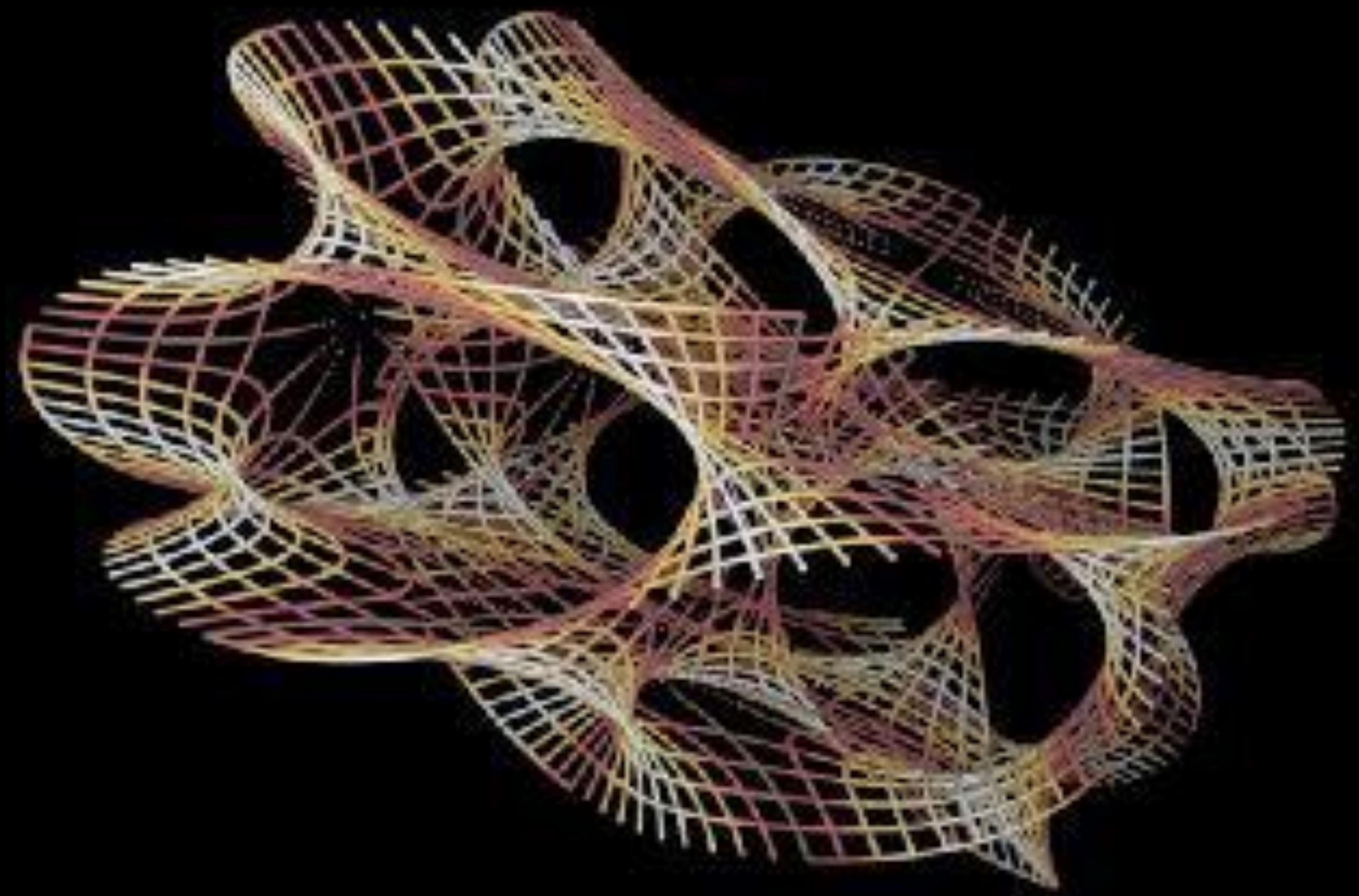


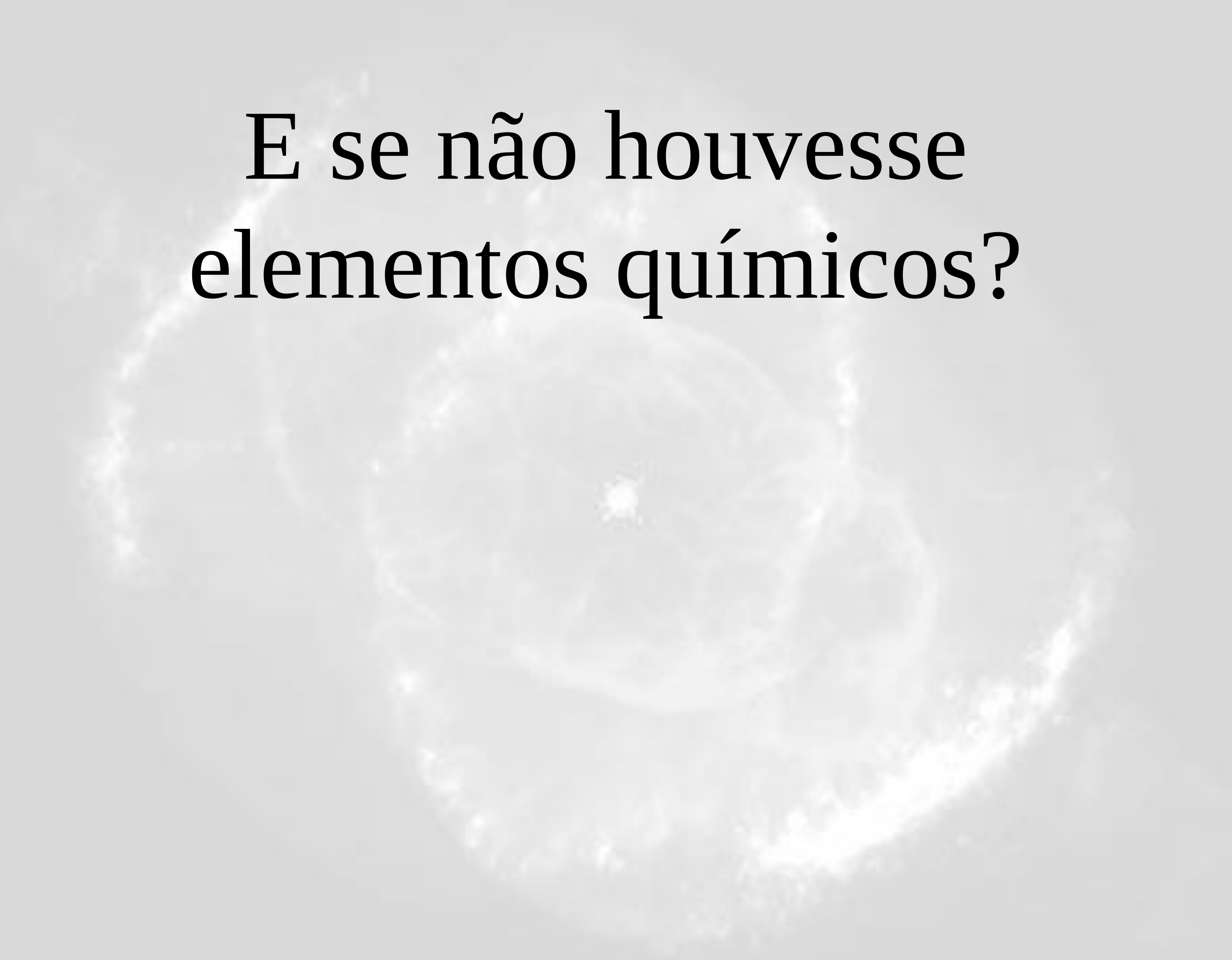
Quinta Dimensão

⇒ instabilidade de sistemas planetários e átomos



A Origem do Espaço...





E se não houvesse elementos químicos?

Um Universo Biofílico

Um universo hospitaleiro à vida – o que podemos chamar de um universo biofílico – tem que ser muito especial de diversos modos.

Os pré-requisitos para qualquer vida – estrelas de vida longa, **uma tabela periódica de elementos com química complexa** etc. – são sensíveis às leis físicas e não poderiam ter emergido de um Big Bang com uma receita que fosse mesmo ligeiramente diferente.

Martin Rees
Our Cosmic Habitat

PERIODIC TABLE OF THE ELEMENTS

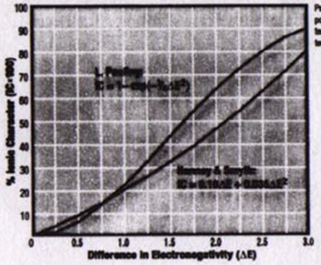
▼ Elementary Subatomic Particles

	Electron	Proton	Neutron	Photon	Neutrino
Symbol	e	P	n	γ	ν
Rest mass (kg)	9.1093897(54) x 10^{-31}	1.6726231(10) x 10^{-27}	1.6749286(10) x 10^{-27}	0	≈0
Molar mass (kg/mol)	5.48579903(13) x 10^{-7}	1.007276470(12) x 10^{-3}	1.008664904(14) x 10^{-3}	0	≈0
Particle-electron mass ratio	1	1836.152701(37)	1838.683662(40)	0	≈0
Particle-proton mass ratio	5.44617013(11) x 10^{-4}	1	1.001378404(9)	0	≈0
Particle-neutron mass ratio	5.438673x10^{-4}	0.998624	1	0	≈0
Specific charge (C/kg)	-1.75881962(53) x 10^{+11}	9.5788309(29) x 10^{+7}	0	0	0
Radius (m)	<1 x 10^{-16}	8 x 10^{-16}	8 x 10^{-16}	0	≈0
Spin quantum number	1/2	1/2	1/2	1	1/2
Compton wavelength (m)	2.42631058(22) x 10^{-12}	1.32141002(12) x 10^{-15}	1.31959110(12) x 10^{-5}	–	–
Magnetic moment (J/T); μ	928.47701(31) x 10^{-26}	1.41060761(47) x 10^{-26}	0.96623707(40) x 10^{-26}	0	0
In Bohr magnetons; μ/μ_B	1.001159652193(10)	1.521032202(15) x 10^{-3}	1.04187563(25) x 10^{-3}	0	0
In nuclear magnetons; μ/μ_N	1838.282000(37)	2.792847386(63)	1.91304275(45)	0	0

Elementary particles are the fundamental constituents of energy and matter. The positron (e^+) is a positive-energy particle which has the same mass as an ordinary electron. The antineutrino ($\bar{\nu}$) has similar properties as that of a neutrino (ν) except its spin is directed along its direction of motion, whereas the neutrino's spin is always opposite to the direction of motion. Negative beta decay is the transformation of a neutron into a proton, a beta particle (negative electron) and a antineutrino ($n \rightarrow p + e^- + \bar{\nu}$). Positive beta decay involves the transformation of a proton into a neutron, a positron and a neutrino ($p \rightarrow n + \beta^+ + \nu$). The magnetic moment (μ) of a particle can also be expressed as a dimensionless quantity by dividing it with either the Bohr magneton (μ_B = 9.2740154(31) x 10^{-24} J/T) or the nuclear magneton (μ_N = 5.0507866(17) x 10^{-27} J/T).

▼ % Ionic Character of a Single Chemical Bond

Difference in Electronegativity	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2
%IC (by L. Pauling)	0.2	1.0	2.2	3.9	6.1	8.6	12	15	18	22	26	30	34	39	43	47	51	56	59	63	67	70	73	76	79	82	84	86	88	89	91	92
%IC (by Hannay & Smyth)	1.6	3.3	5.1	7.0	8.9	11	13	15	17	20	22	24	27	29	32	35	37	40	43	46	49	52	55	59	62	65	69	72	76	80	83	87

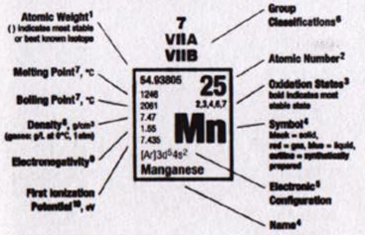


Percent ionic character describes the nature of a bond. Bonds possessing 50% or greater ionic character are commonly termed ionic; bonds with less than 50% ionic character are termed covalent. Pauling's equation was modified by Hannay & Smyth in order to achieve better agreement between experimental and calculated values. Transition from ionic to covalent binding is usually accompanied by a reduction in electrical conductance, melting point and boiling point.

1 IA IA	2 IIA IIA	3 IIIA IIIB	4 IVA IVB	5 VA VB	6 VIA VIB	7 VIIA VIIB	8 VIIIA VIII	9 VIIIA VIII	10 VIIIA VIII	11 IB IB	12 IIB IIB	13 IIIB IIIA	14 IVB IVA	15 VB VA	16 VIB VIA	17 VIIB VIIA	18 VIII 0
1.00794 **1** -259.34 -252.87 0.0899 2.20 13.598 1 **H** $1s^1$ Hydrogen																	4.002602 **2** -272.2$^{26 atm}$ -268.93 0.1785 – 24.587 **He** $1s^2$ Helium
6.941 **3** 180.5 1342 0.534 0.98 5.392 1 **Li** $[He]2s^1$ Lithium	9.012182 **4** 1287 2471 1.8477 1.57 9.322 2 **Be** $[He]2s^2$ Beryllium											10.811 **5** 2075 4000 2.31 2.04 8.298 3 **B** $[He]2s^2p^1$ Boron	12.011 **6** 4492* 3825* 2.25 2.55 11.260 2,±4 **C** $[He]2s^2p^2$ Carbon	14.00674 **7** -210.00 -195.79 1.25046 3.04 14.534 2,±3,4,5 **N** $[He]2s^2p^3$ Nitrogen	15.9994 **8** -218.79 -182.95 1.429 3.44 13.618 -2 **O** $[He]2s^2p^4$ Oxygen	18.9984032 **9** -219.62 -188.12 1.69 3.98 17.422 -1 **F** $[He]2s^2p^5$ Fluorine	20.1797 **10** -248.59 -246.08 0.9002 – 21.564 **Ne** $[He]2s^2p^6$ Neon
22.989768 **11** 97.72 883 0.97 0.93 5.139 1 **Na** $[Ne]3s^1$ Sodium	24.3050 **12** 650 1090 1.74 1.31 7.646 2 **Mg** $[Ne]3s^2$ Magnesium											26.981539 **13** 660.32 2519 2.702 1.61 5.986 3 **Al** $[Ne]3s^2p^1$ Aluminum	28.0855 **14** 1414 3265 2.33 1.90 8.151 4 **Si** $[Ne]3s^2p^2$ Silicon	30.973762 **15** 44.15 277 1.82 2.19 10.486 ±3,4,5 **P** $[Ne]3s^2p^3$ Phosphorus	32.066 **16** 115.21 444.60 2.07 2.58 10.360 ±2,4,6 **S** $[Ne]3s^2p^4$ Sulfur	35.4527 **17** -101.5 -34.04 3.214 3.16 12.967 ±1,3,5,7 **Cl** $[Ne]3s^2p^5$ Chlorine	39.948 **18** -189.35 -185.85 1.784 – 15.759 **Ar** $[Ne]3s^2p^6$ Argon
39.0983 **19** 63.38 759 0.86 0.82 4.341 1 **K** $[Ar]4s^1$ Potassium	40.078 **20** 842 1484 1.54 1.00 6.113 2 **Ca** $[Ar]4s^2$ Calcium	44.955910 **21** 1541 2830 2.989 1.36 6.54 3 **Sc** $[Ar]3d^14s^2$ Scandium	47.88 **22** 1668 3287 4.5 1.54 6.82 3,4 **Ti** $[Ar]3d^24s^2$ Titanium	50.9415 **23** 1910 3407 5.96 1.63 6.74 2,3,4,5 **V** $[Ar]3d^34s^2$ Vanadium	51.9961 **24** 1907 2671 7.20 1.66 6.766 2,3,6 **Cr** $[Ar]3d^54s^1$ Chromium	54.93805 **25** 1246 2061 7.47 1.55 7.435 2,3,4,6,7 **Mn** $[Ar]3d^54s^2$ Manganese	55.847 **26** 1538 2861 7.86 1.83 7.870 2,3 **Fe** $[Ar]3d^64s^2$ Iron	58.93320 **27** 1495 2927 8.92 1.88 7.86 2,3 **Co** $[Ar]3d^74s^2$ Cobalt	58.6934 **28** 1455 2913 8.90 1.91 7.635 2,3 **Ni** $[Ar]3d^84s^2$ Nickel	63.546 **29** 1084.62 2562 8.94 1.90 7.726 1,2 **Cu** $[Ar]3d^{10}4s^1$ Copper	65.39 **30** 419.53 907 7.14$^{25°C}$ 1.65 9.394 2 **Zn** $[Ar]3d^{10}4s^2$ Zinc	69.723 **31** 29.76 2204 6.095 1.81 5.999 3 **Ga** $[Ar]3d^{10}4s^2p^1$ Gallium	72.61 **32** 938.25 2833 5.35 2.01 7.899 4 **Ge** $[Ar]3d^{10}4s^2p^2$ Germanium	74.92159 **33** 817* 614* 5.727$^{25°C}$ 2.18 9.81 ±3,5 **As** $[Ar]3d^{10}4s^2p^3$ Arsenic	78.96 **34** 221 685 4.81 2.55 9.752 -2,4,6 **Se** $[Ar]3d^{10}4s^2p^4$ Selenium	79.904 **35** -7.2 58.8 3.119 2.96 11.814 ±1,5 **Br** $[Ar]3d^{10}4s^2p^5$ Bromine	83.80 **36** -157.36 -153.22 3.74 – 13.999 **Kr** $[Ar]3d^{10}4s^2p^6$ Krypton
85.4678 **37** 39.31 688 1.532 0.82 4.177 1 **Rb** $[Kr]5s^1$ Rubidium	87.62 **38** 777 1382 2.6 0.95 5.695 2 **Sr** $[Kr]5s^2$ Strontium	88.90585 **39** 1526 3336 4.469 1.22 6.38 3 **Y** $[Kr]4d^15s^2$ Yttrium	91.224 **40** 1855 4409 6.49 1.33 6.84 4 **Zr** $[Kr]4d^25s^2$ Zirconium	92.90638 **41** 2477 4744 8.57 1.6 6.9 3,5 **Nb** $[Kr]4d^45s^1$ Niobium	95.94 **42** 2623 4639 10.2 2.16 7.099 2,3,4,5,6 **Mo** $[Kr]4d^55s^1$ Molybdenum	(97.9072) **43** 2157 4265 11.5 1.9 7.28 7 **Tc** $[Kr]4d^55s^2$ Technetium	101.07 **44** 2334 4150 12.3 2.2 7.37 2,3,4,6,8 **Ru** $[Kr]4d^75s^1$ Ruthenium	102.90550 **45** 1964 3695 12.4 2.28 7.46 2,3,4 **Rh** $[Kr]4d^85s^1$ Rhodium	106.42 **46** 1554.9 2963 12.02 2.20 8.34 2,4 **Pd** $[Kr]4d^{10}$ Palladium	107.8682 **47** 961.78 2162 10.5 1.93 7.576 1 **Ag** $[Kr]4d^{10}5s^1$ Silver	112.411 **48** 321.07 767 8.642 1.69 8.993 2 **Cd** $[Kr]4d^{10}5s^2$ Cadmium	114.818 **49** 156.60 2072 7.30 1.78 5.786 3 **In** $[Kr]4d^{10}5s^2p^1$ Indium	118.710 **50** 231.93 2602 7.28 1.96 7.344 2,4 **Sn** $[Kr]4d^{10}5s^2p^2$ Tin	121.757 **51** 630.63 1587 6.684$^{25°C}$ 2.05 8.641 ±3,5 **Sb** $[Kr]4d^{10}5s^2p^3$ Antimony	127.60 **52** 449.51 988 6.25 2.1 9.009 -2,4,6 **Te** $[Kr]4d^{10}5s^2p^4$ Tellurium	126.90447 **53** 113.7 184.4 4.93 2.66 10.451 ±1,5,7 **I** $[Kr]4d^{10}5s^2p^5$ Iodine	131.29 **54** -111.75 -108.04 5.89 – 12.130 **Xe** $[Kr]4d^{10}5s^2p^6$ Xenon
132.90543 **55** 28.44 671 1.879 0.79 3.894 1 **Cs** $[Xe]6s^1$ Cesium	137.327 **56** 727 1897 3.594 0.89 5.212 2 **Ba** $[Xe]6s^2$ Barium	138.9055 **57** 920 3455 6.146 1.10 5.577 3 • **La** $[Xe]5d^16s^2$ Lanthanum	178.49 **72** 2233 4603 13.31 1.3 7.0 4 **Hf** $[Xe]4f^{14}5d^26s^2$ Hafnium	180.9479 **73** 3017 5458 16.6 1.5 7.89 5 **Ta** $[Xe]4f^{14}5d^36s^2$ Tantalum	183.84 **74** 3422 5555 19.35 2.36 7.98 2,3,4,5,6 **W** $[Xe]4f^{14}5d^46s^2$ Tungsten	186.207 **75** 3186 5596 20.5 1.9 7.88 -1,2,4,6,7 **Re** $[Xe]4f^{14}5d^56s^2$ Rhenium	190.23 **76** 3033 5012 22.61 2.2 8.7 2,3,4,6,8 **Os** $[Xe]4f^{14}5d^66s^2$ Osmium	192.22 **77** 2446 4428 22.65 2.20 9.1 2,3,4,6 **Ir** $[Xe]4f^{14}5d^76s^2$ Iridium	195.08 **78** 1768.4 3825 21.45 2.28 9.0 2,4 **Pt** $[Xe]4f^{14}5d^96s^1$ Platinum	196.96654 **79** 1064.18 2856 19.31 2.54 9.225 1,3 **Au** $[Xe]4f^{14}5d^{10}6s^1$ Gold	200.59 **80** -38.83 356.73 13.546 2.00 10.437 1,2 **Hg** $[Xe]4f^{14}5d^{10}6s^2$ Mercury	204.3833 **81** 304 1473 11.85 2.04 6.108 1,3 **Tl** $[Xe]4f^{14}5d^{10}6s^2p^1$ Thallium	207.2 **82** 327.46 1749 11.34 2.33 7.416 2,4 **Pb** $[Xe]4f^{14}5d^{10}6s^2p^2$ Lead	208.98037 **83** 271.40 1564 9.78 2.02 7.289 3,5 **Bi** $[Xe]4f^{14}5d^{10}6s^2p^3$ Bismuth	(208.9824) **84** 254 962 9.196 2.0 8.42 2,4 **Po** $[Xe]4f^{14}5d^{10}6s^2p^4$ Polonium	(209.9871) **85** 302 337 – 2.2 – ±1,3,5,7 **At** $[Xe]4f^{14}5d^{10}6s^2p^5$ Astatine	(222.0176) **86** -71 -61.7 9.73 – 10.748 **Rn** $[Xe]4f^{14}5d^{10}6s^2p^6$ Radon
(223.0197) **87** 27 677 – 0.7 – 1 **Fr** $[Rn]7s^1$ Francium	(226.0254) **88** 700 <1140 5.8 0.9 5.279 2 **Ra** $[Rn]7s^2$ Radium	(227.0278) **89** 1051 3198 10.07 1.1 6.9 3 •• **Ac** $[Rn]6d^17s^2$ Actinium	(261.11) **104** – – – – – 4 **Unq** $[Rn]5f^{14}6d^27s^2$ Unnilquadium	(262.114) **105** – – – – – – **Unp** $[Rn]5f^{14}6d^37s^2$ Unnilpentium	(263.118) **106** – – – – – – **Unh** $[Rn]5f^{14}6d^47s^2$ Unnilhexium	(262.12) **107** – – – – – – **Uns** $[Rn]5f^{14}6d^57s^2$ Unnilseptium	(265) **108** – – – – – – **Uno** $[Rn]5f^{14}6d^67s^2$ Unniloctium	(266) **109** – – – – – – **Une** $[Rn]5f^{14}6d^77s^2$ Unnilennium	(272) **110** – – – – – – **Uun** Ununnium								

*indicates approximate values and/or inconsistent literature data.

•	140.115 **58** 799 3424 6.770 1.12 5.466 3,4 **Ce** $[Xe]4f^15d^16s^2$ Cerium	140.90765 **59** 931 3510 6.773 1.13 5.422 3,4 **Pr** $[Xe]4f^36s^2$ Praseodymium	144.24 **60** 1016 3066 7.00 1.14 5.489 3 **Nd** $[Xe]4f^46s^2$ Neodymium	(144.9127) **61** 1042 3000 7.264 1.13 5.554 3 **Pm** $[Xe]4f^56s^2$ Promethium	150.36 **62** 1072 1790 7.536 1.17 5.631 2,3 **Sm** $[Xe]4f^66s^2$ Samarium	151.965 **63** 822 1596 5.244 1.2 5.666 2,3 **Eu** $[Xe]4f^76s^2$ Europium	157.25 **64** 1314 3264 7.901 1.20 6.141 3 **Gd** $[Xe]4f^75d^16s^2$ Gadolinium	158.92534 **65** 1359 3221 8.230 1.2 5.842 3,4 **Tb** $[Xe]4f^96s^2$ Terbium	162.50 **66** 1411 2561 8.551 1.22 5.927 3 **Dy** $[Xe]4f^{10}6s^2$ Dysprosium	164.93032 **67** 1472 2694 8.80 1.23 6.018 3 **Ho** $[Xe]4f^{11}6s^2$ Holmium	167.26 **68** 1529 2862 9.066 1.24 6.101 3 **Er** $[Xe]4f^{12}6s^2$ Erbium	168.93421 **69** 1545 1946 9.321 1.25 6.18436 2,3 **Tm** $[Xe]4f^{13}6s^2$ Thulium	173.04 **70** 824 1194 6.966 1.1 6.25394 2,3 **Yb** $[Xe]4f^{14}6s^2$ Ytterbium	174.967 **71** 1663 3393 9.84 1.27 5.42589 3 **Lu** $[Xe]4f^{14}5d^16s^2$ Lutetium
••	232.0381 **90** 1750 4788 11.72 1.3 6.08 4 **Th** $[Rn]6d^27s^2$ Thorium	231.03588 **91** 1572 – 15.37 1.5 5.89 4,5 **Pa** $[Rn]5f^26d^17s^2$ Protactinium	238.0289 **92** 1135 4131 19.05±0.02 1.38 6.05 3,4,5,6 **U** $[Rn]5f^36d^17s^2$ Uranium	(237.0482) **93** 644 – 20.45 1.36 6.19 3,4,5,6 **Np** $[Rn]5f^46d^17s^2$ Neptunium	(244.0642) **94** 640 3228 19.816 1.28 5.8 3,4,5,6 **Pu** $[Rn]5f^67s^2$ Plutonium	(243.0614) **95** 1176 2607 13.67 1.3 5.993 3,4,5,6 **Am** $[Rn]5f^77s^2$ Americium	(247.0703) **96** 1345 – 13.51 1.3 6.02 3 **Cm** $[Rn]5f^76d^17s^2$ Curium	(247.0703) **97** 1050 – 14.78 1.3 6.23 3,4 **Bk** $[Rn]5f^97s^2$ Berkelium	(251.0796) **98** 900 – – 1.3 6.30 3 **Cf** $[Rn]5f^{10}7s^2$ Californium	(252.083) **99** 860 – – 1.3 6.42 3 **Es** $[Rn]5f^{11}7s^2$ Einsteinium	(257.0951) **100** 1527 – – 1.3 6.50 3 **Fm** $[Rn]5f^{12}7s^2$ Fermium	(258.10) **101** 827 – – 1.3 6.58 2,3 **Md** $[Rn]5f^{13}7s^2$ Mendelevium	(259.1009) **102** 827 – – 1.3 6.65 2,3 **No** $[Rn]5f^{14}7s^2$ Nobelium	(262.11) **103** 1627 – – – – 3 **Lr** $[Rn]5f^{14}6d^17s^2$ Lawrencium


Atomic Weight[1]
() indicates most stable or best known isotope
Melting Point[7], °C
Boiling Point[7], °C
Density[8], g/cm³ (gases: g/L at 0°C, 1 atm)
Electronegativity[9]
First Ionization Potential[10], eV
7
VIIA
VIIB
54.93805
25
1246
2061
2,3,4,6,7
7.47
1.55
7.435
Mn
[Ar]3d⁵4s²
Manganese
Group Classifications[6]
Atomic Number[2]
Oxidation States[3]
bold indicates most stable state
Symbol[4]
black = solid, red = gas, blue = liquid, outline = synthetically prepared
Electronic[5] Configuration
Name[4]

The data for this reference guide were obtained from the latest scientific and government sources (IUPAC, CODATA, National Bureau of Standards, etc.). Estimated values and/or inconsistent data are marked with an asterisk (*).
1. Ratio of the average mass per atom of the element to 1/12 of the mass of an atom of ^{12}C. Round brackets indicate atomic weight of the most stable or best known isotope. **2.** Number of protons in the nucleus of each atom of an element. **3.** Number of charges an atom would have in a molecule (or an ionic compound) if electrons were transferred completely. **4.** Names and symbols of elements 104-110 are those recommended by the International Union of Pure and Applied Chemistry (IUPAC)—alternative names have been proposed by other groups. **5.** Distribution of electrons among the various atomic orbitals. **6.** Two older group classifications systems still in use today rely on an A/B coding scheme to categorize periodic properties. Because of the potential for confusion between these two systems (i.e., VIIA in one scheme is equal to VIIB in the other), IUPAC recommends the use of an unambiguous 1-18 group classification system. **7.** Melting point: temperature at which solid and liquid phases coexist in equilibrium. Boiling point: temperature at which the vapor pressure of a liquid is equal to the external atmospheric pressure. Unless otherwise stated values are at 1 atm; SP = sublimation point at 1 atm; TP = triple point. **8.** Mass of the substance divided by its volume (g/cm³ at 20°C; for gases: g/L at 0°C, 1 atm). **9.** Relative measure of the attraction of an atom in a chemical bond for the shared electrons. **10.** Minimum energy to remove an electron from an isolated atom in its ground state (1eV = 96.487 kJ/mol).

PAPERTECH

Editors: T. K. Varga, M.A.Sc. & C. Bello, M.A.Sc.
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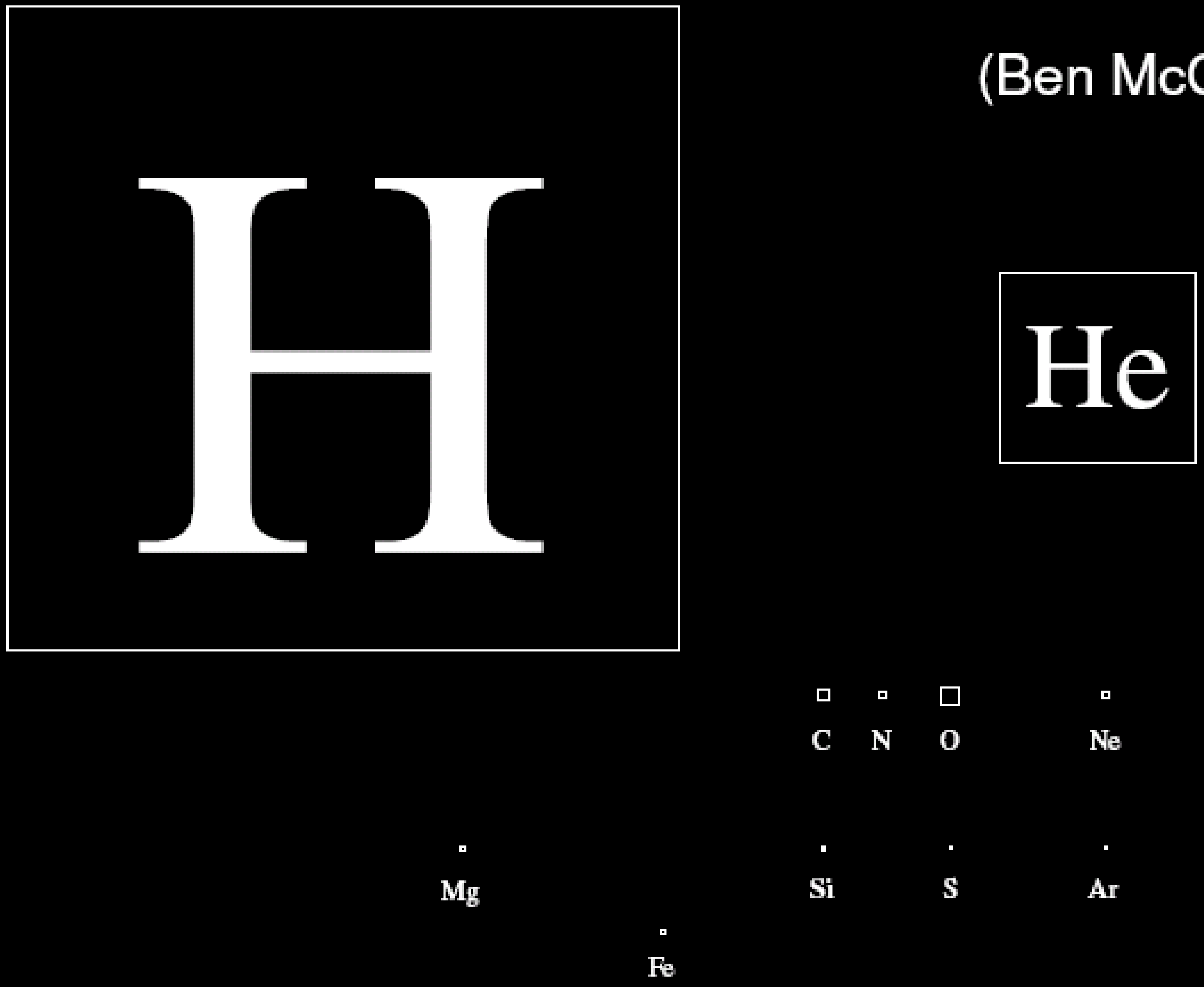
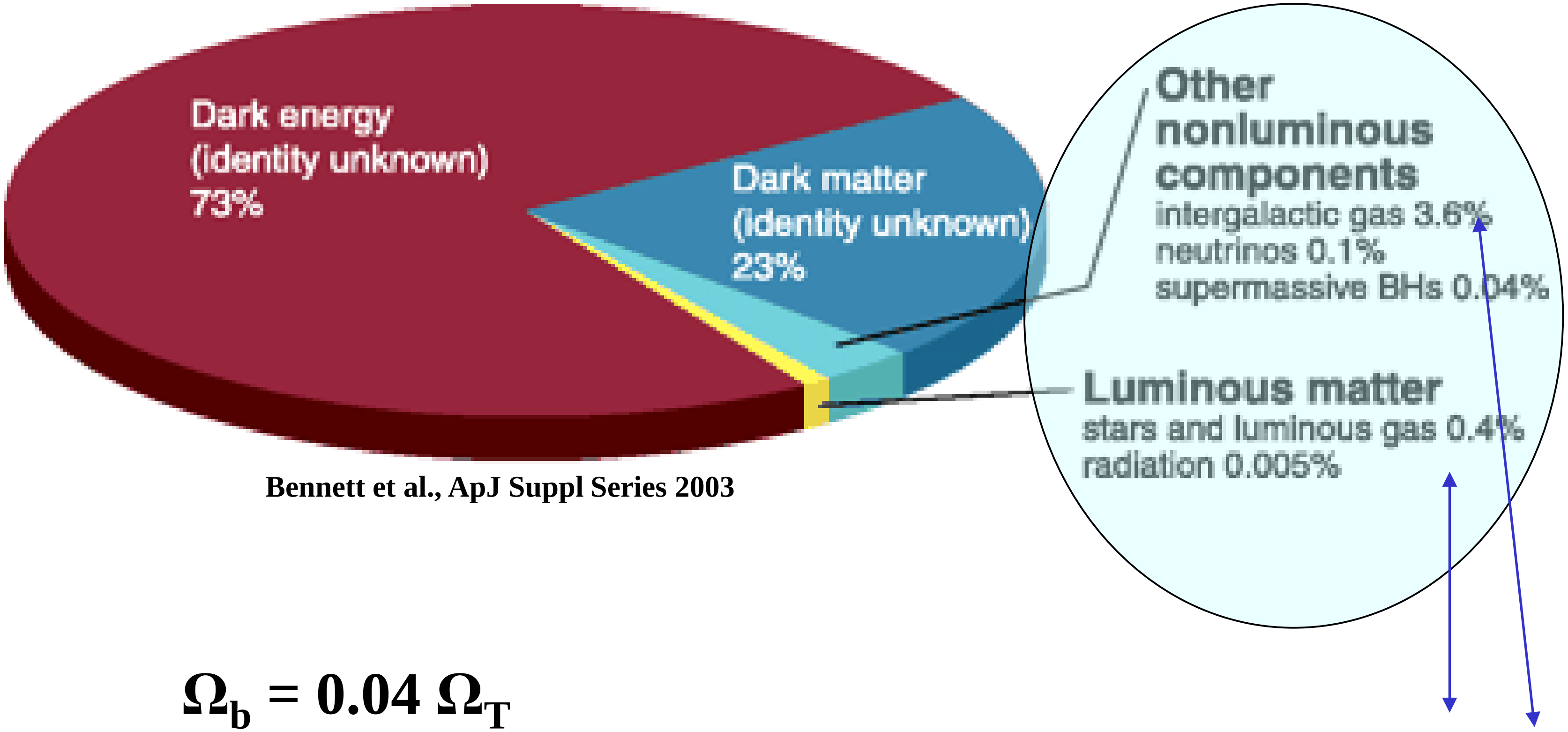
The Astronomer's Periodic Table

(Ben McCall)


H
He
C
N
O
Ne
Mg
Si
S
Ar
Fe

Courtesy Ben Mc Call

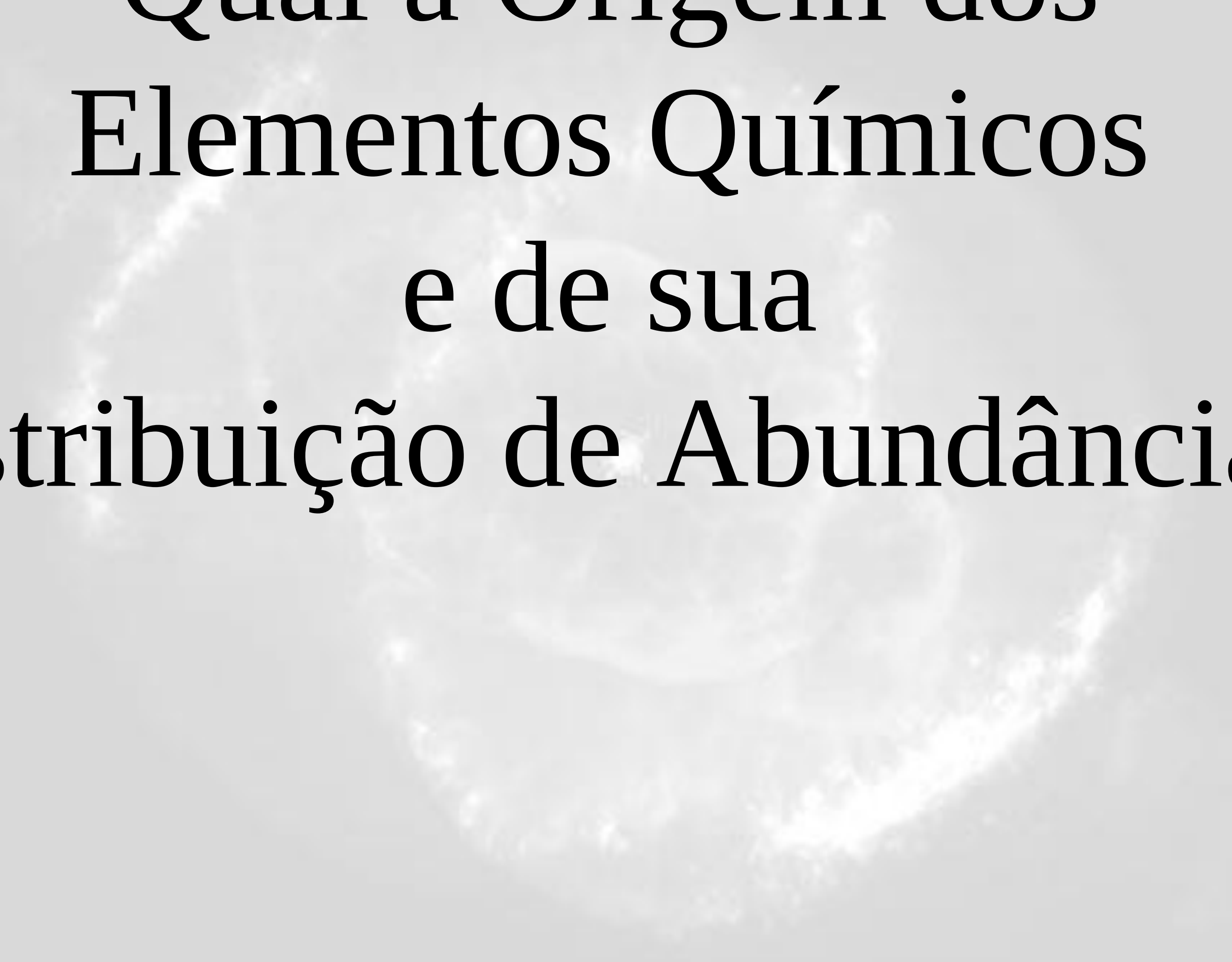
Lembrando o lugar da vida no universo ...somos minoria



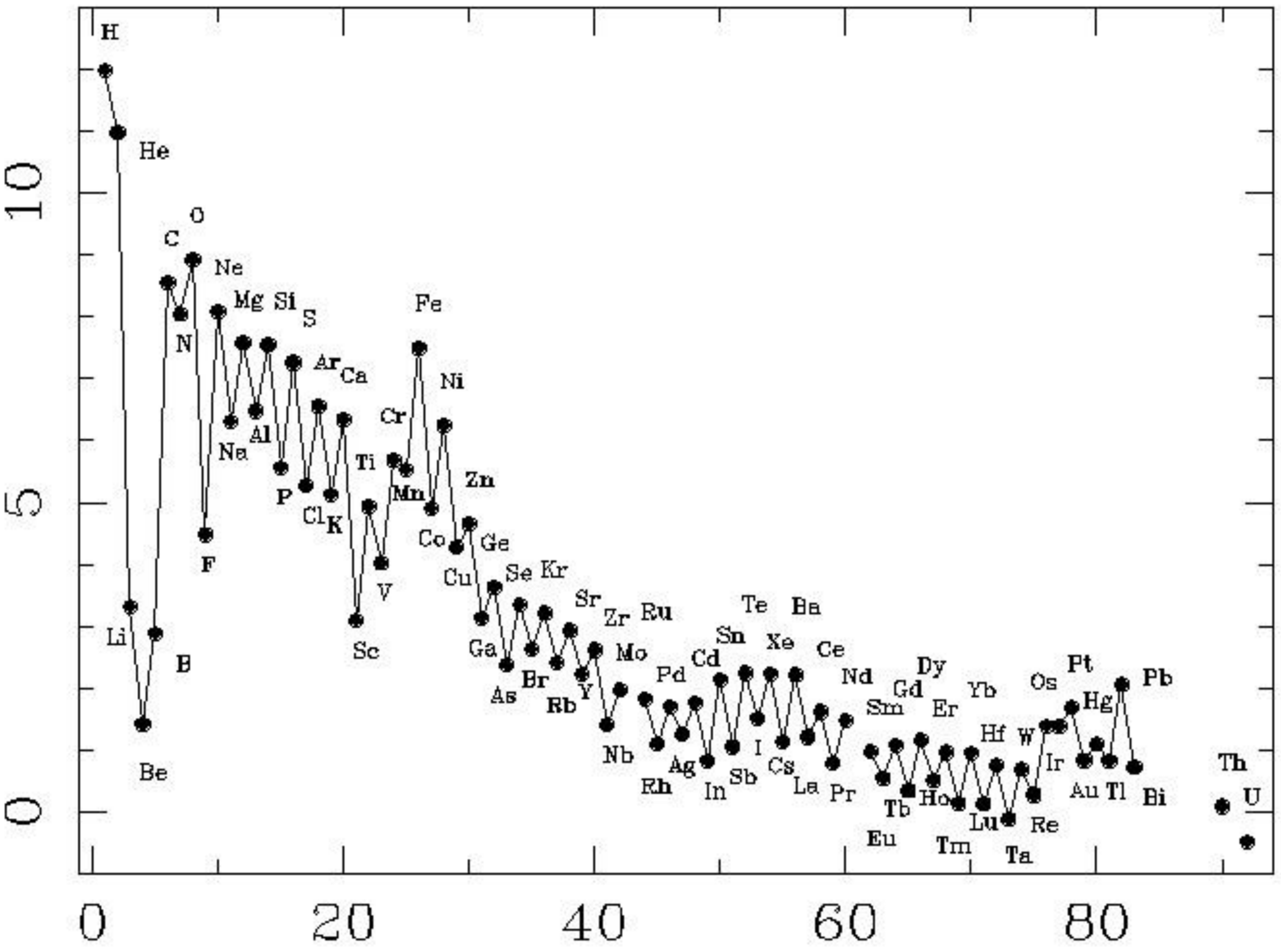
Bennett et al., ApJ Suppl Series 2003

$$\Omega_b = 0.04\ \Omega_T$$

Life building blocks come from these components...

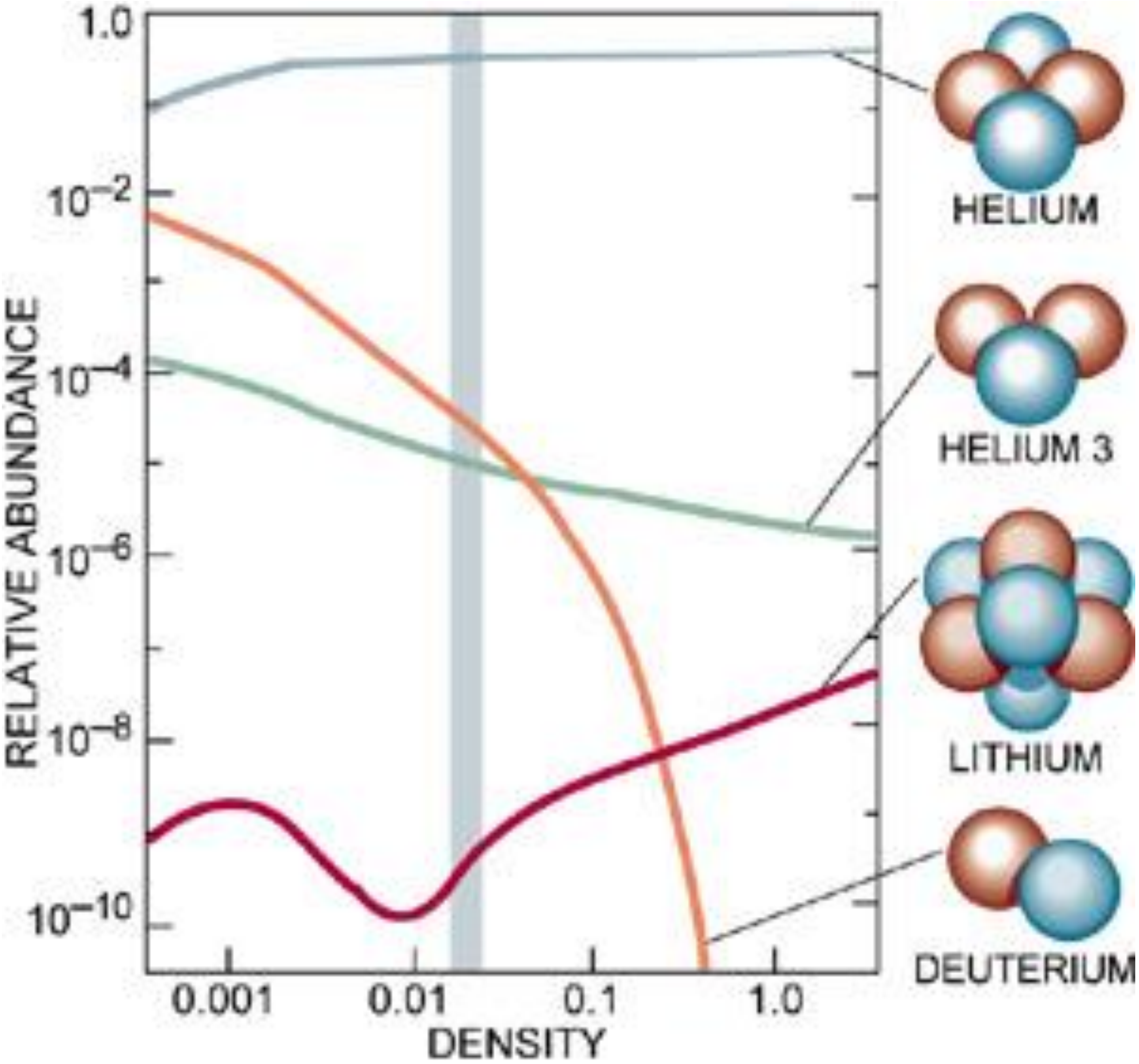


Qual a Origem dos Elementos Químicos e de sua Distribuição de Abundâncias?

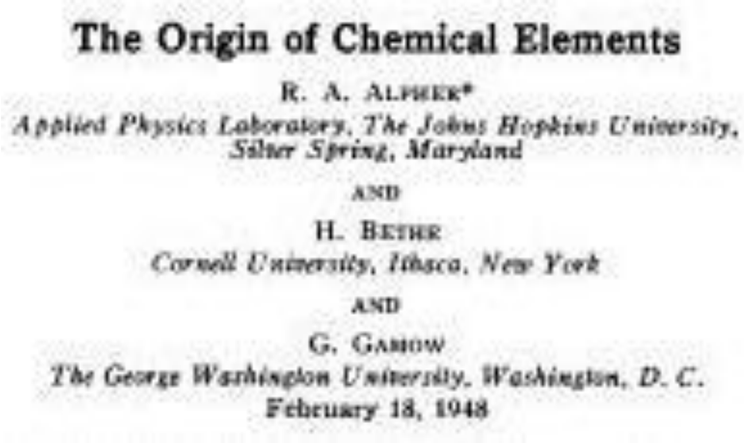


Abundâncias dos elementos químicos no Sistema Solar. Na abcissa está o número atômico e na ordenada, a abundância do número de átomos em relação ao hidrogênio, medida numa escala logarítmica $\log(N/N_H)+12$ (assim o H vale 12). Observe as lacunas devidas aos elementos radioativos artificiais tecnécio (Z=43) e promécio (Z=61)

NUCLEOSSÍNTESE PRIMORDIAL
(Big Bang Nucleosynthesis)



αβγ paper



The Origin of Chemical Elements

R. A. ALPHER*
Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Maryland

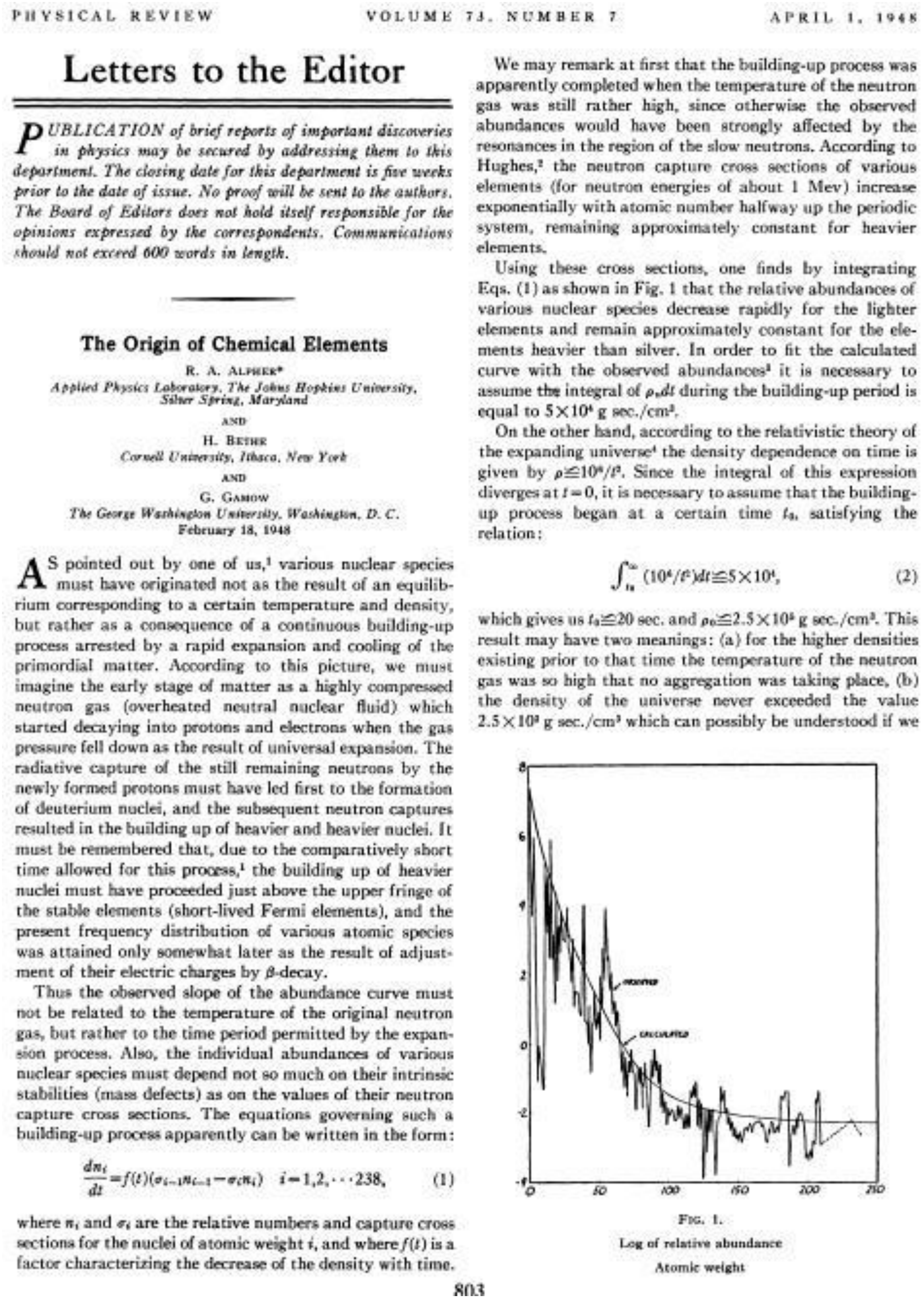
AND

H. BETHE
Cornell University, Ithaca, New York

AND

G. GAMOW
The George Washington University, Washington, D. C.

February 18, 1948



Letters to the Editor

PUBLICATION of brief reports of important discoveries in physics may be secured by addressing them to this department. The closing date for this department is five weeks prior to the date of issue. No proof will be sent to the authors. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents. Communications should not exceed 600 words in length.

The Origin of Chemical Elements

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Cornell University, Ithaca, New York

AND

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The George Washington University, Washington, D. C.

February 18, 1948

AS pointed out by one of us,[1] various nuclear species must have originated not as the result of an equilibrium corresponding to a certain temperature and density, but rather as a consequence of a continuous building-up process arrested by a rapid expansion and cooling of the primordial matter. According to this picture, we must imagine the early stage of matter as a highly compressed neutron gas (overheated neutral nuclear fluid) which started decaying into protons and electrons when the gas pressure fell down as the result of universal expansion. The radiative capture of the still remaining neutrons by the newly formed protons must have led first to the formation of deuterium nuclei, and the subsequent neutron captures resulted in the building up of heavier and heavier nuclei. It must be remembered that, due to the comparatively short time allowed for this process,[1] the building up of heavier nuclei must have proceeded just above the upper fringe of the stable elements (short-lived Fermi elements), and the present frequency distribution of various atomic species was attained only somewhat later as the result of adjustment of their electric charges by β-decay.

Thus the observed slope of the abundance curve must not be related to the temperature of the original neutron gas, but rather to the time period permitted by the expansion process. Also, the individual abundances of various nuclear species must depend not so much on their intrinsic stabilities (mass defects) as on the values of their neutron capture cross sections. The equations governing such a building-up process apparently can be written in the form:

$$\frac{dn_i}{dt}=f(t)(\sigma_{i-1}n_{i-1}-\sigma_i n_i) \quad i=1,2,\cdots 238, \tag{1}$$

where n_i and σ_i are the relative numbers and capture cross sections for the nuclei of atomic weight i, and where $f(t)$ is a factor characterizing the decrease of the density with time.

We may remark at first that the building-up process was apparently completed when the temperature of the neutron gas was still rather high, since otherwise the observed abundances would have been strongly affected by the resonances in the region of the slow neutrons. According to Hughes,[2] the neutron capture cross sections of various elements (for neutron energies of about 1 Mev) increase exponentially with atomic number halfway up the periodic system, remaining approximately constant for heavier elements.

Using these cross sections, one finds by integrating Eqs. (1) as shown in Fig. 1 that the relative abundances of various nuclear species decrease rapidly for the lighter elements and remain approximately constant for the elements heavier than silver. In order to fit the calculated curve with the observed abundances[3] it is necessary to assume the integral of $\rho_n dt$ during the building-up period is equal to 5×10^6 g sec./cm^3.

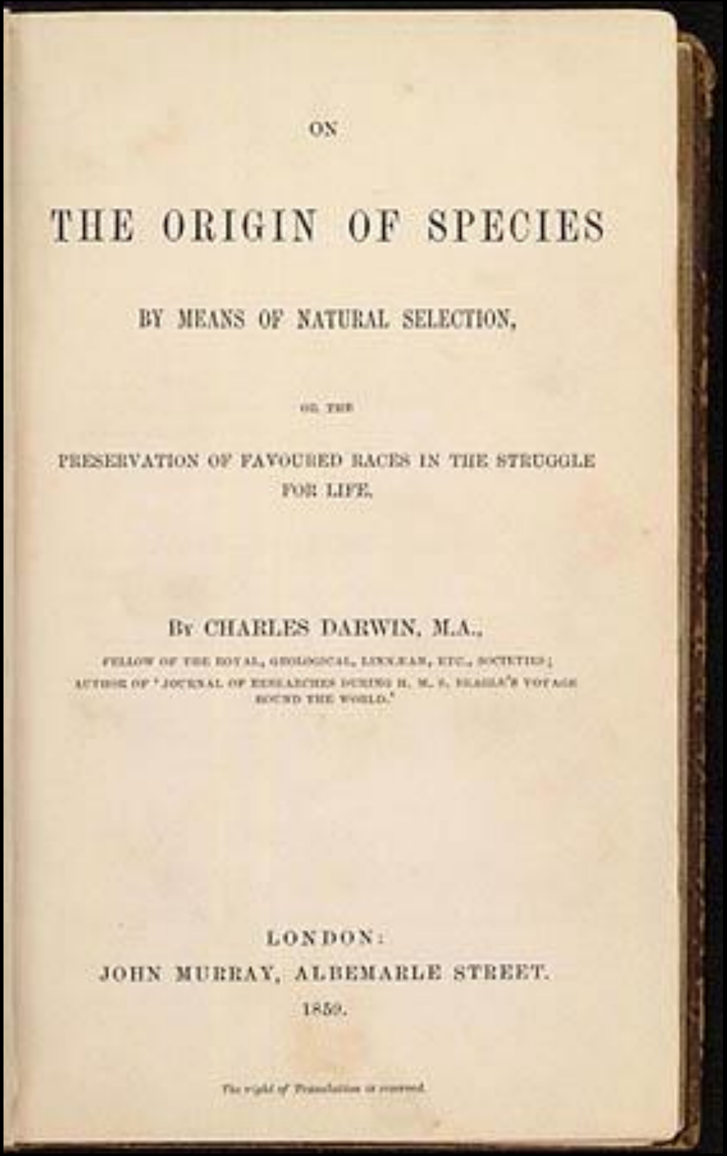
On the other hand, according to the relativistic theory of the expanding universe[4] the density dependence on time is given by $\rho\cong10^6/t^2$. Since the integral of this expression diverges at $t=0$, it is necessary to assume that the building-up process began at a certain time t_0, satisfying the relation:

$$\int_{t_0}^{\infty}(10^6/t^2)dt\cong5\times10^6, \tag{2}$$

which gives us $t_0\cong20$ sec. and $\rho_0\cong2.5\times10^5$ g sec./cm^3. This result may have two meanings: (a) for the higher densities existing prior to that time the temperature of the neutron gas was so high that no aggregation was taking place, (b) the density of the universe never exceeded the value 2.5×10^5 g sec./cm^3 which can possibly be understood if we

FIG. 1.
Log of relative abundance
Atomic weight

“Origem das Espécies” (1859)



ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE
FOR LIFE.

By CHARLES DARWIN, M.A.,

FELLOW OF THE ROYAL, GEOLOGICAL, LINNÆAN, ETC., SOCIETIES;
AUTHOR OF ‘JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE’S VOYAGE
ROUND THE WORLD.’

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

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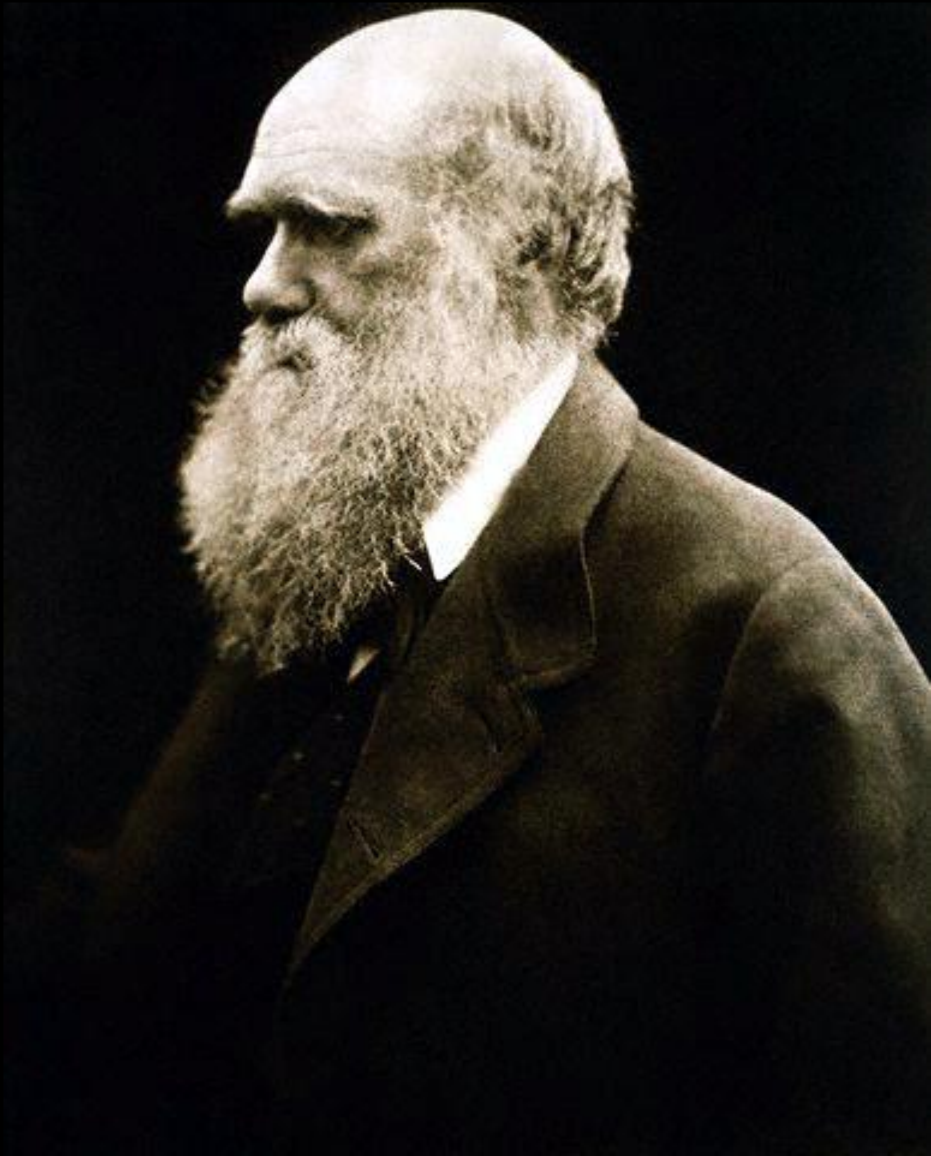
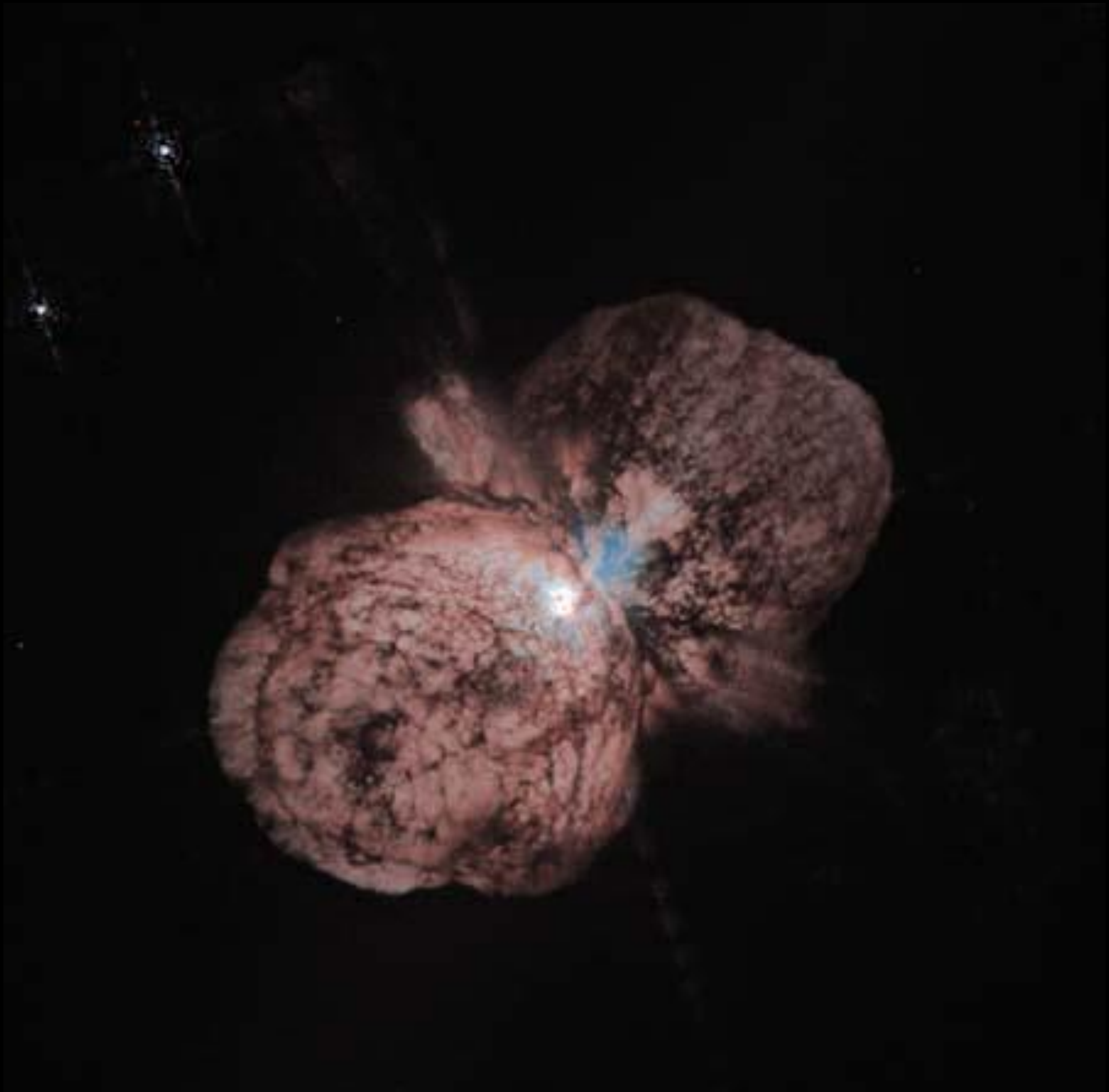


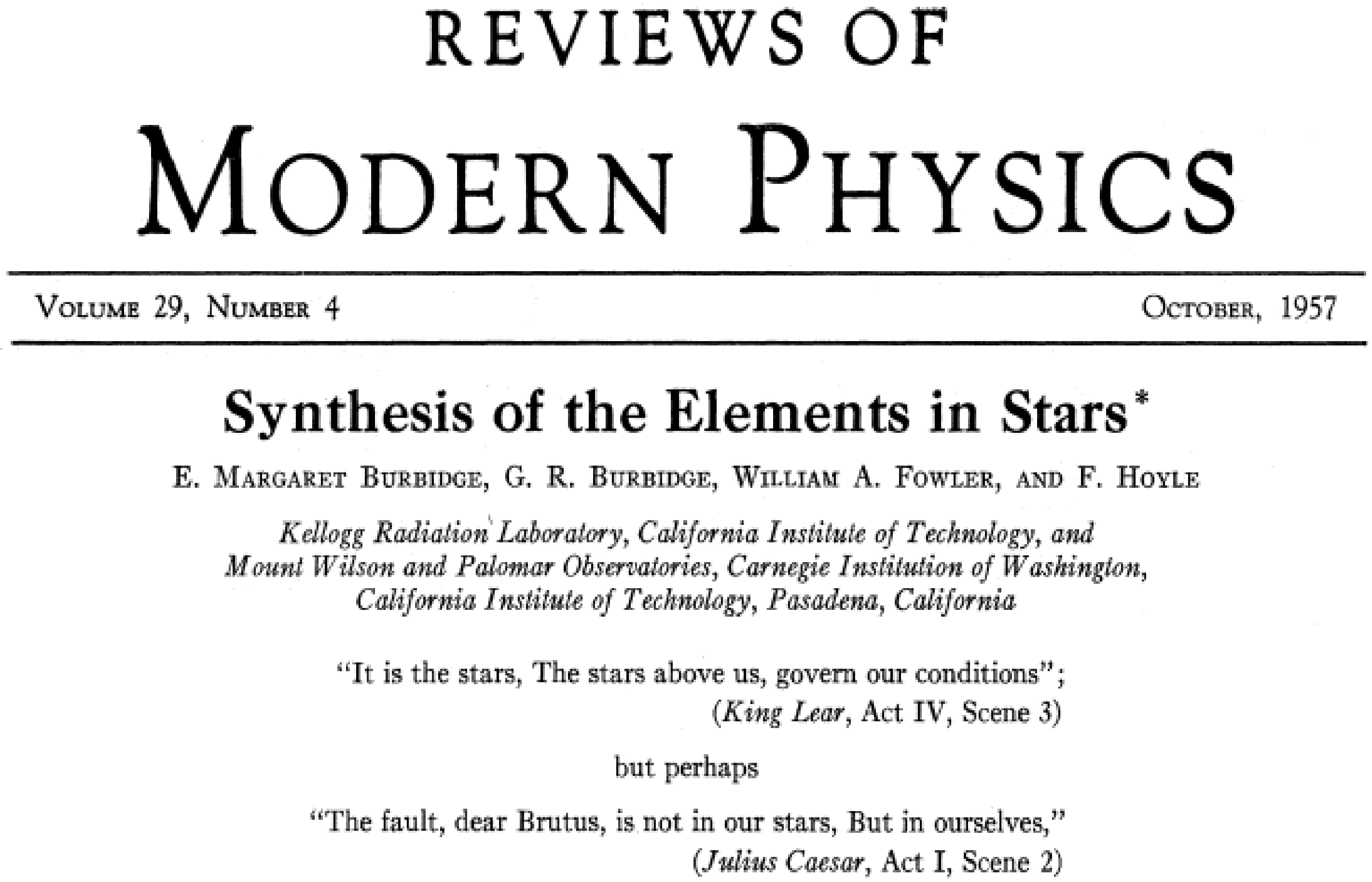
Além da Nucleossíntese Primordial

- Nucleossíntese primordial é insuficiente
- Produz apenas Hélio, Deutério e Lítio
- Não ultrapassa o numero de massa 8 (^{8}Be é uma ressonância com $\tau_{1/2} = 6.7\times 10^{-17}$ s)
- Do Carbono em diante, é necessária a nucleossíntese estelar!
- O nascimento das estrelas é essencial para o surgimento do C e da química necessária à vida!!!

NUCLEOSSÍNTESE ESTELAR



B^{2}FH paper



REVIEWS OF
MODERN PHYSICS

VOLUME 29, NUMBER 4 OCTOBER, 1957

Synthesis of the Elements in Stars*

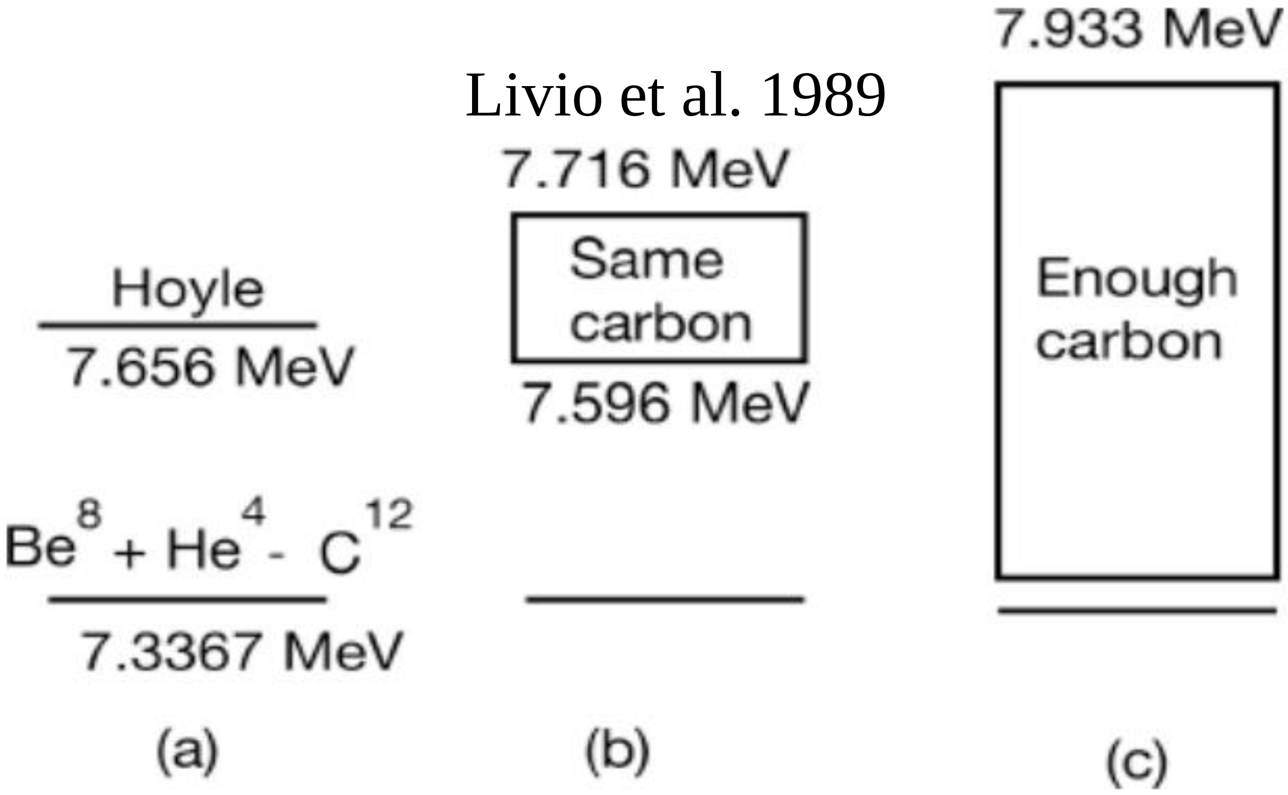
E. MARGARET BURBIDGE, G. R. BURBIDGE, WILLIAM A. FOWLER, AND F. HOYLE

Kellogg Radiation Laboratory, California Institute of Technology, and
Mount Wilson and Palomar Observatories, Carnegie Institution of Washington,
California Institute of Technology, Pasadena, California

> "It is the stars, The stars above us, govern our conditions";
> (*King Lear*, Act IV, Scene 3)
>
> but perhaps
>
> "The fault, dear Brutus, is not in our stars, But in ourselves,"
> (*Julius Caesar*, Act I, Scene 2)

Nucleossíntese Estelar x Nucleossíntese Primordial
Embate de duas Cosmologias
Estado Estacionário x Big Bang

Fred Hoyle (1915-2001) X George Gamow (1904-1968)

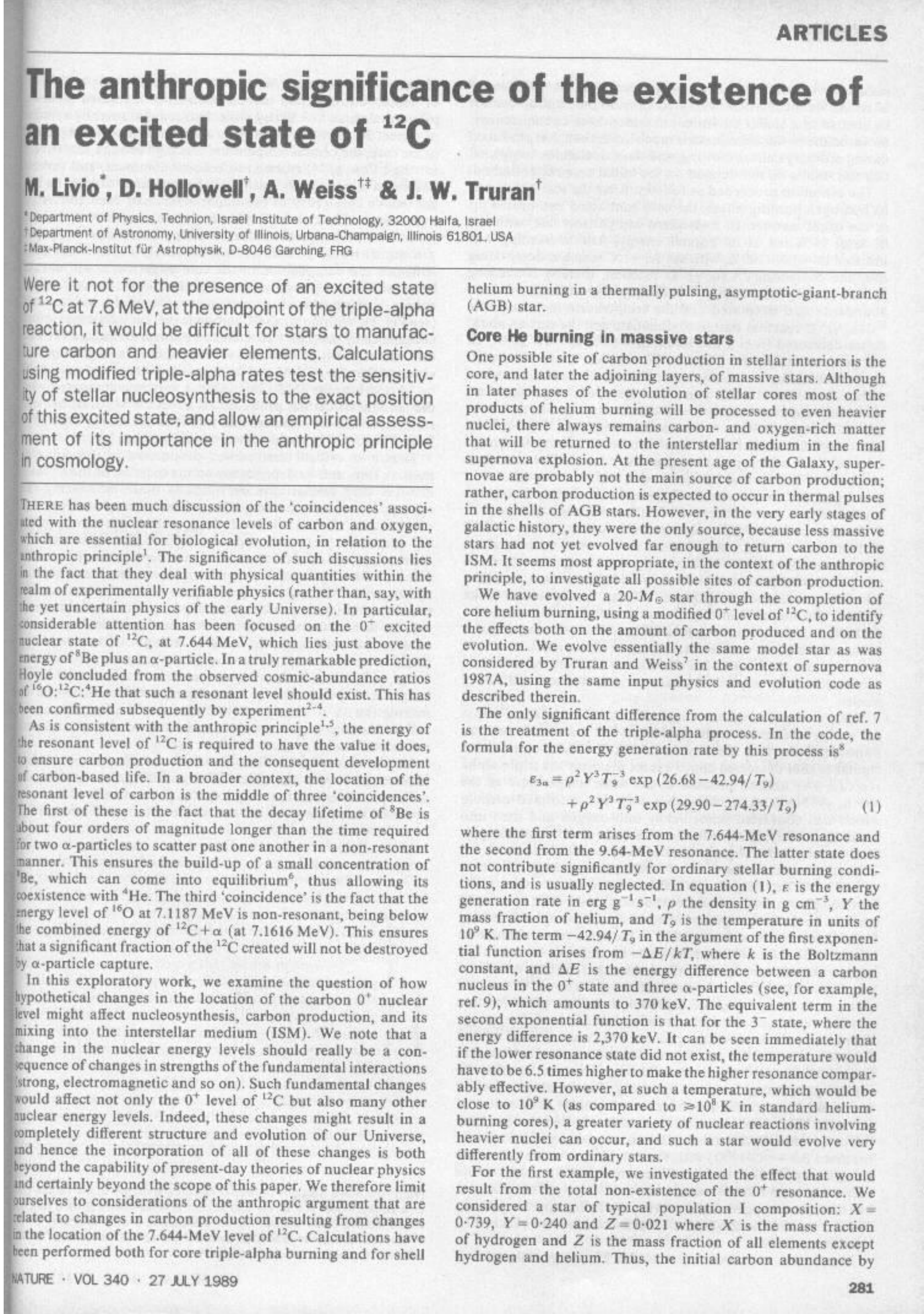

7.933 MeV
7.716 MeV
Hoyle
Same
carbon
Enough
carbon
7.656 MeV
7.596 MeV
$Be^{8} + He^{4} - C^{12}$
7.3367 MeV
(a)
(b)
(c)

Livio et al. 1989

Fig. 1 (a) energy levels of carbon showing the, and the excited state predicted by Hoyle; (b) the allowed range of the excited state that would yield the same amount of carbon, (c) the range of energy for an excited state that would produce carbon adequate for life.

Também na nucleossíntese estelar, temos, no nosso universo, uma sintonia fina das constantes físicas.

Poderíamos ter um universo com pouquíssimo Carbono.



The anthropic significance of the existence of an excited state of ^{12}C

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Were it not for the presence of an excited state of ^{12}C at 7.6 MeV, at the endpoint of the triple-alpha reaction, it would be difficult for stars to manufacture carbon and heavier elements. Calculations using modified triple-alpha rates test the sensitivity of stellar nucleosynthesis to the exact position of this excited state, and allow an empirical assessment of its importance in the anthropic principle in cosmology.

THERE has been much discussion of the 'coincidences' associated with the nuclear resonance levels of carbon and oxygen, which are essential for biological evolution, in relation to the anthropic principle[1]. The significance of such discussions lies in the fact that they deal with physical quantities within the realm of experimentally verifiable physics (rather than, say, with the yet uncertain physics of the early Universe). In particular, considerable attention has been focused on the 0^+ excited nuclear state of ^{12}C, at 7.644 MeV, which lies just above the energy of ^{8}Be plus an α-particle. In a truly remarkable prediction, Hoyle concluded from the observed cosmic-abundance ratios of ^{16}O:^{12}C:^4He that such a resonant level should exist. This has been confirmed subsequently by experiment[2-4].

As is consistent with the anthropic principle[1,5], the energy of the resonant level of ^{12}C is required to have the value it does, to ensure carbon production and the consequent development of carbon-based life. In a broader context, the location of the resonant level of carbon is the middle of three 'coincidences'. The first of these is the fact that the decay lifetime of ^{8}Be is about four orders of magnitude longer than the time required for two α-particles to scatter past one another in a non-resonant manner. This ensures the build-up of a small concentration of ^{8}Be, which can come into equilibrium[6], thus allowing its coexistence with ^{4}He. The third 'coincidence' is the fact that the energy level of ^{16}O at 7.1187 MeV is non-resonant, being below the combined energy of $^{12}C+\alpha$ (at 7.1616 MeV). This ensures that a significant fraction of the ^{12}C created will not be destroyed by α-particle capture.

In this exploratory work, we examine the question of how hypothetical changes in the location of the carbon 0^+ nuclear level might affect nucleosynthesis, carbon production, and its mixing into the interstellar medium (ISM). We note that a change in the nuclear energy levels should really be a consequence of changes in strengths of the fundamental interactions (strong, electromagnetic and so on). Such fundamental changes would affect not only the 0^+ level of ^{12}C but also many other nuclear energy levels. Indeed, these changes might result in a completely different structure and evolution of our Universe, and hence the incorporation of all of these changes is both beyond the capability of present-day theories of nuclear physics and certainly beyond the scope of this paper. We therefore limit ourselves to considerations of the anthropic argument that are related to changes in carbon production resulting from changes in the location of the 7.644-MeV level of ^{12}C. Calculations have been performed both for core triple-alpha burning and for shell helium burning in a thermally pulsing, asymptotic-giant-branch (AGB) star.

Core He burning in massive stars

One possible site of carbon production in stellar interiors is the core, and later the adjoining layers, of massive stars. Although in later phases of the evolution of stellar cores most of the products of helium burning will be processed to even heavier nuclei, there always remains carbon- and oxygen-rich matter that will be returned to the interstellar medium in the final supernova explosion. At the present age of the Galaxy, supernovae are probably not the main source of carbon production; rather, carbon production is expected to occur in thermal pulses in the shells of AGB stars. However, in the very early stages of galactic history, they were the only source, because less massive stars had not yet evolved far enough to return carbon to the ISM. It seems most appropriate, in the context of the anthropic principle, to investigate all possible sites of carbon production.

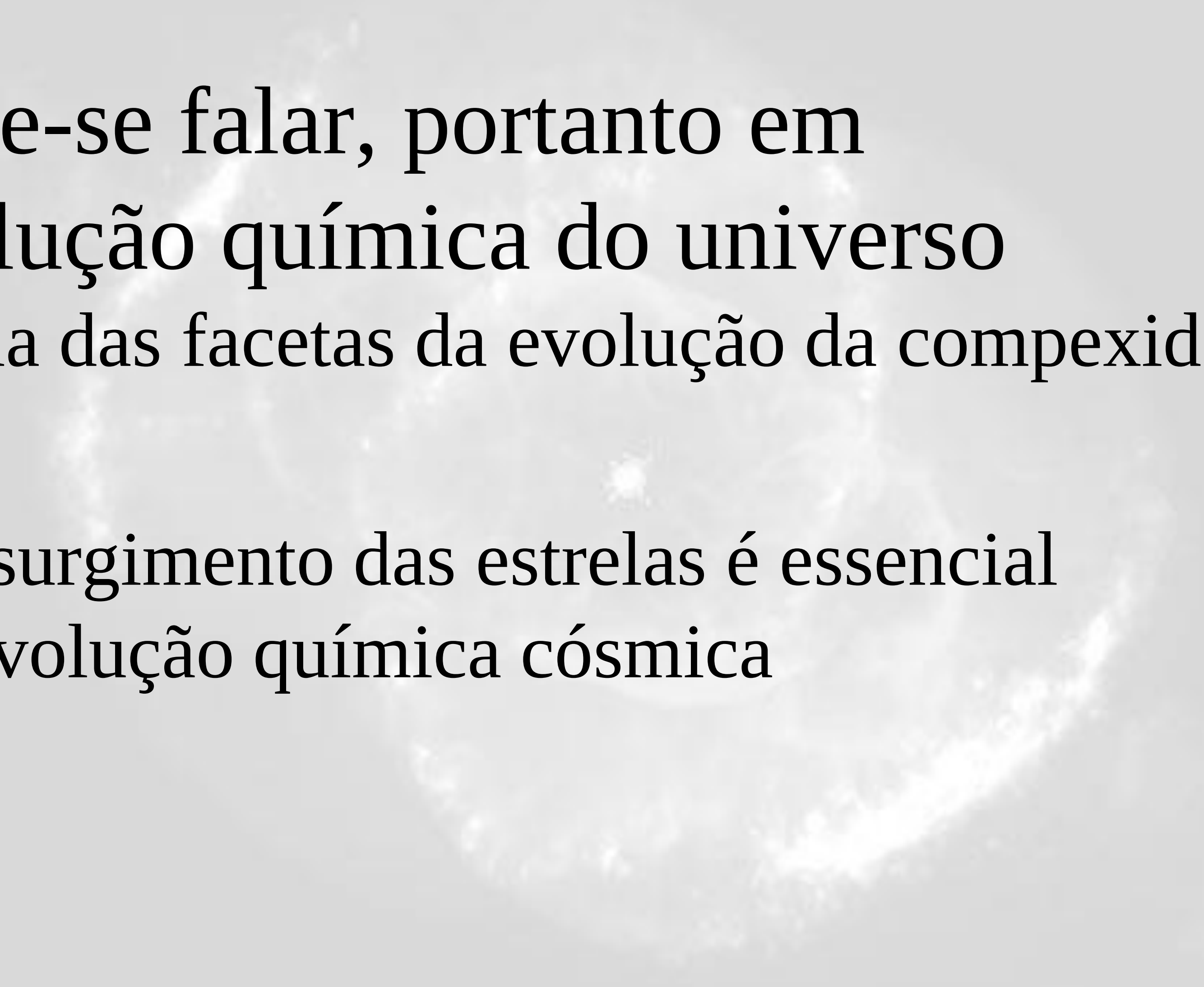
We have evolved a 20-$M_\odot$ star through the completion of core helium burning, using a modified 0^+ level of ^{12}C, to identify the effects both on the amount of carbon produced and on the evolution. We evolve essentially the same model star as was considered by Truran and Weiss[7] in the context of supernova 1987A, using the same input physics and evolution code as described therein.

The only significant difference from the calculation of ref. 7 is the treatment of the triple-alpha process. In the code, the formula for the energy generation rate by this process is[8]

$$\begin{aligned}\varepsilon_{3\alpha} &= \rho^2 Y^3 T_9^{-3} \exp(26.68 - 42.94/T_9)\\ &\quad + \rho^2 Y^3 T_9^{-3} \exp(29.90 - 274.33/T_9) \qquad (1)\end{aligned}$$

where the first term arises from the 7.644-MeV resonance and the second from the 9.64-MeV resonance. The latter state does not contribute significantly for ordinary stellar burning conditions, and is usually neglected. In equation (1), ε is the energy generation rate in erg g^{-1} s^{-1}, ρ the density in g cm^{-3}, Y the mass fraction of helium, and T_9 is the temperature in units of 10^9 K. The term $-42.94/T_9$ in the argument of the first exponential function arises from $-\Delta E/kT$, where k is the Boltzmann constant, and ΔE is the energy difference between a carbon nucleus in the 0^+ state and three α-particles (see, for example, ref. 9), which amounts to 370 keV. The equivalent term in the second exponential function is that for the 3^- state, where the energy difference is 2,370 keV. It can be seen immediately that if the lower resonance state did not exist, the temperature would have to be 6.5 times higher to make the higher resonance comparably effective. However, at such a temperature, which would be close to 10^9 K (as compared to $\geq 10^8$ K in standard helium-burning cores), a greater variety of nuclear reactions involving heavier nuclei can occur, and such a star would evolve very differently from ordinary stars.

For the first example, we investigated the effect that would result from the total non-existence of the 0^+ resonance. We considered a star of typical population I composition: $X = 0{\cdot}739$, $Y = 0{\cdot}240$ and $Z = 0{\cdot}021$ where X is the mass fraction of hydrogen and Z is the mass fraction of all elements except hydrogen and helium. Thus, the initial carbon abundance by



Pode-se falar, portanto em evolução química do universo

– uma das facetas da evolução da compexidade

E o surgimento das estrelas é essencial
na evolução química cósmica

Princípio Antrópico (B. Carter, 1973)

Argumento filosófico segundo o qual observações do universo físico devem ser compatíveis com uma VIDA CONSCIENTE que o observe.

Alguns defensores do argumento sustentam que ele explica porque o Universo tem a idade e as **constantes fundamentais** necessárias para acomodar vida consciente.

Em consequência, acreditam que não é extraordinário o fato das constantes fundamentais do Universo estarem dentro de uma **faixa estreita** exigida para permitir a vida.

PRINCÍPIOS ANTRÓPICOS “FRACO” E “FORTE”

FRACO:
Há localizações privilegiadas do espaço-tempo no Universo (ajuste fino local na nossa época)

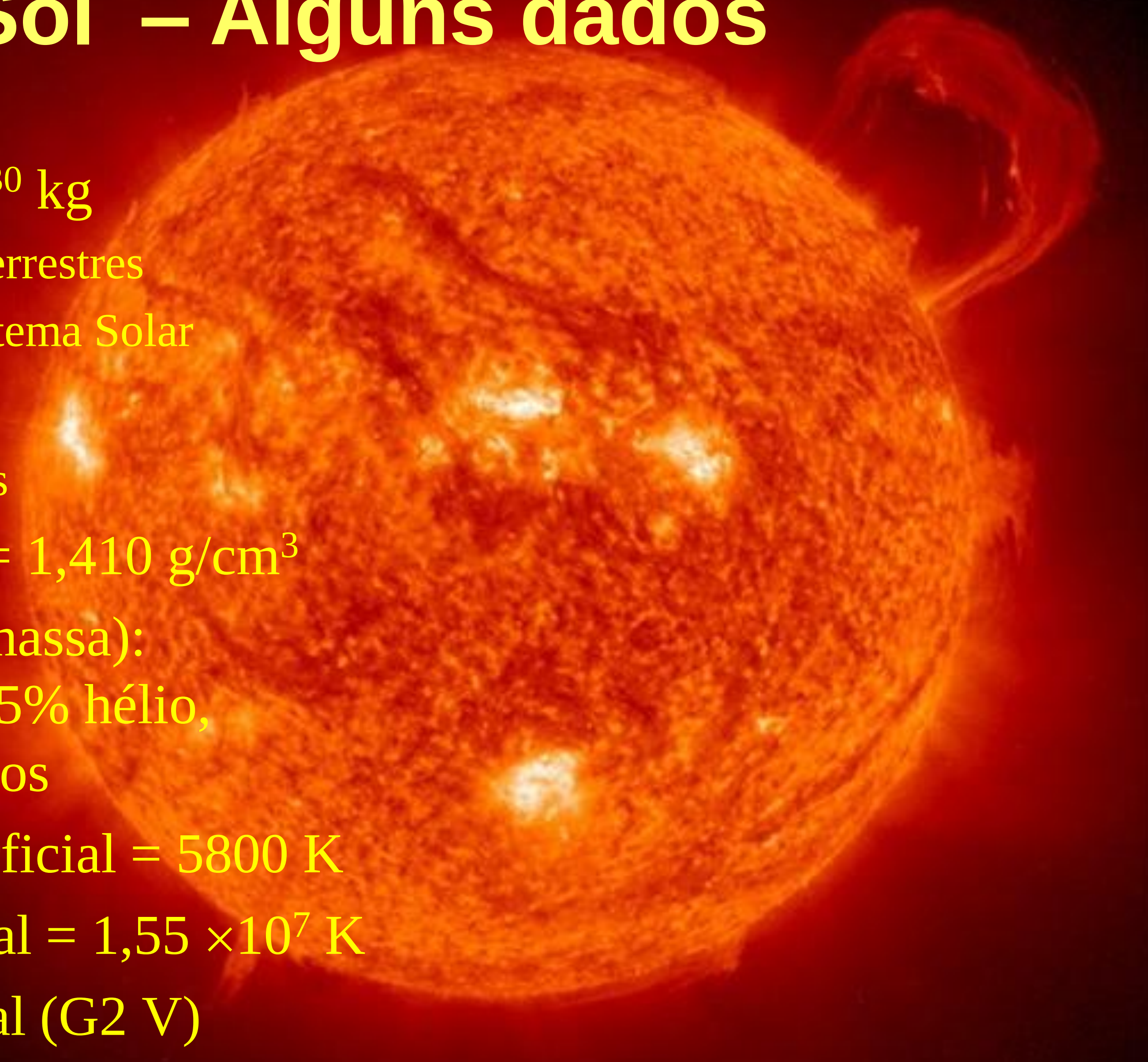
FORTE:
Os valores das **constantes fundamentais** da física têm um ajuste fino em toda parte

(Barrow & Tipler: “The Anthropic Cosmological Principle”, Oxford University Press, 1988)

Nucleossíntese estelar

– O Sol como ilustração

O Sol – Alguns dados

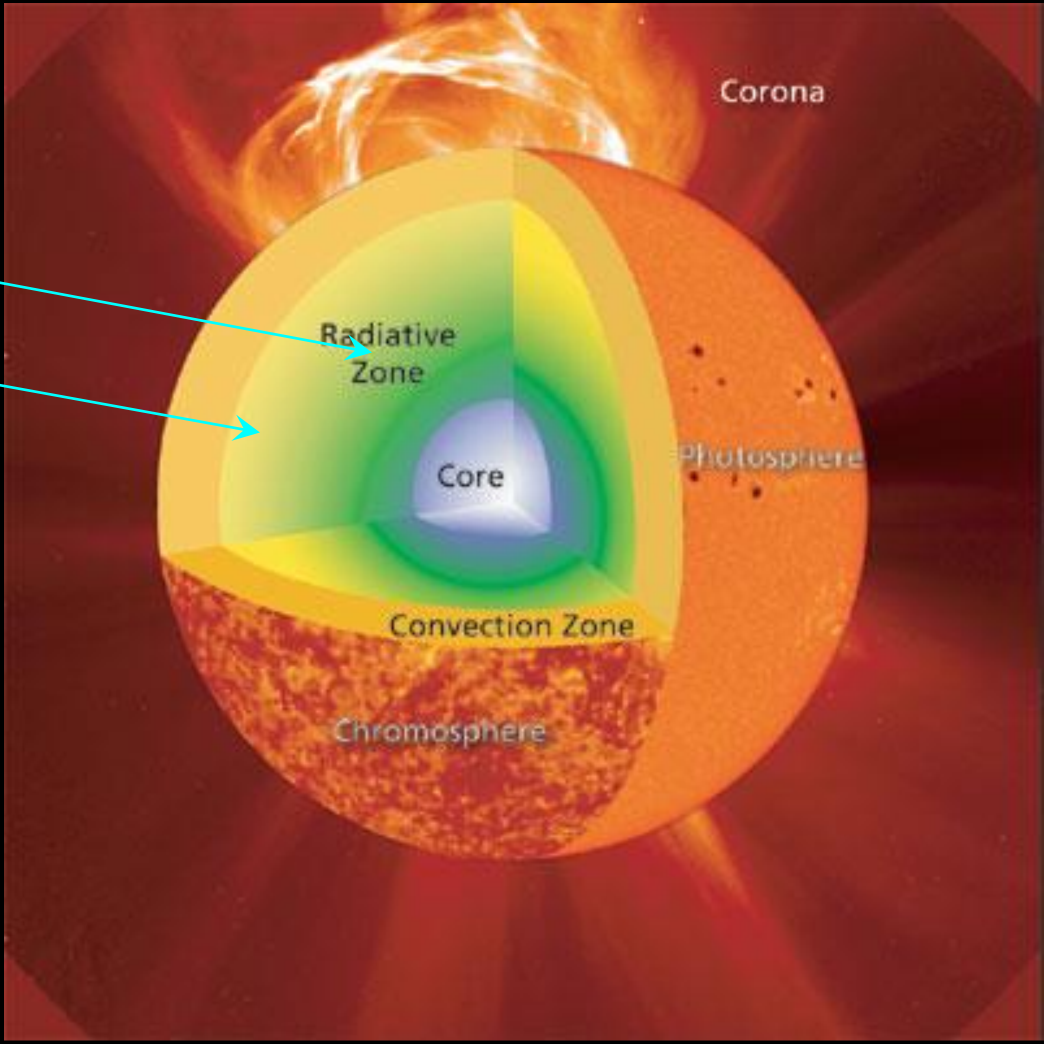


- $M_\odot = 1{,}989 \times 10^{30}$ kg
  - 333.000 massas terrestres
  - 99% massa do Sistema Solar
- $R_\odot = 6{,}96 \times 10^{8}$ m
  - 103 raios terrestres
- Densidade média = 1,410 g/cm^3
- Composição (em massa):
  74% hidrogênio, 25% hélio,
  1% outros elementos
- Temperatura superficial = 5800 K
- Temperatura central = $1{,}55 \times 10^{7}$ K
- Sequência Principal (G2 V)

A Estrutura do Sol

- O Interior
  - Região central (0.2 raio solar)
  - Zona radiativa (0.2-0.7 raio solar)
  - Zona convectiva (0.7-1 raio solar)

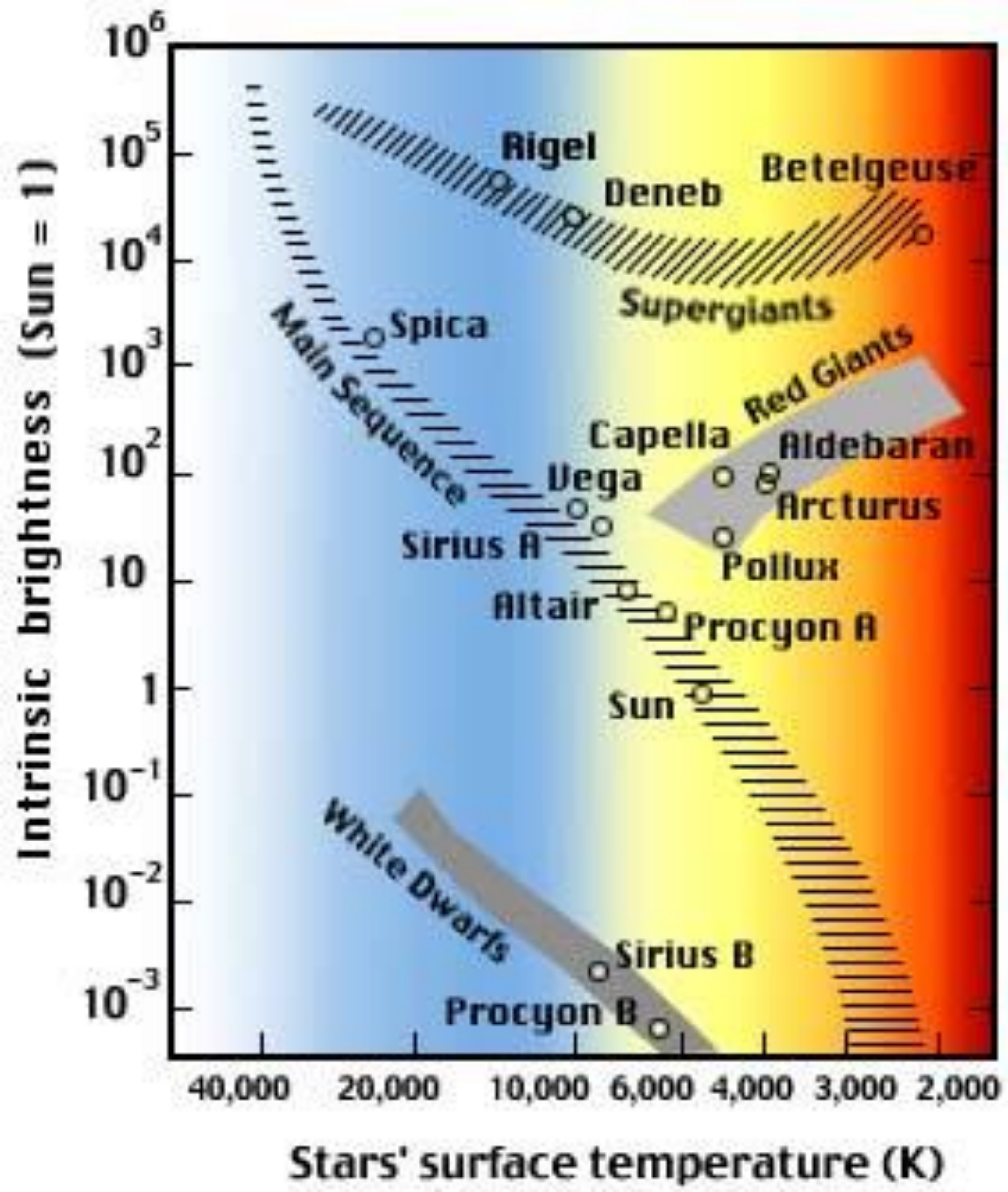
- A Superfície e a Atmosfera
  - Fotosfera
  - Cromosfera
  - Corona


Corona
Radiative Zone
Photosphere
Core
Convection Zone
Chromosphere

A fonte de energia do Sol é fusão nuclear de H em He no seu centro

- Cadeia próton-próton (na etapa atual da evolução solar)
  - 4 átomos de hidrogênio se fundem para formar um núcleo de hélio
- A fusão nuclear ocorre somente às temperaturas muito altas do centro do Sol
- Continuará a aquecer o Sol por mais 5,5 bilhões de anos
- Enquanto produz energia, a fusão nuclear também faz nucleossíntese (He)

Diagrama HR (Hertzsprung-Russell)

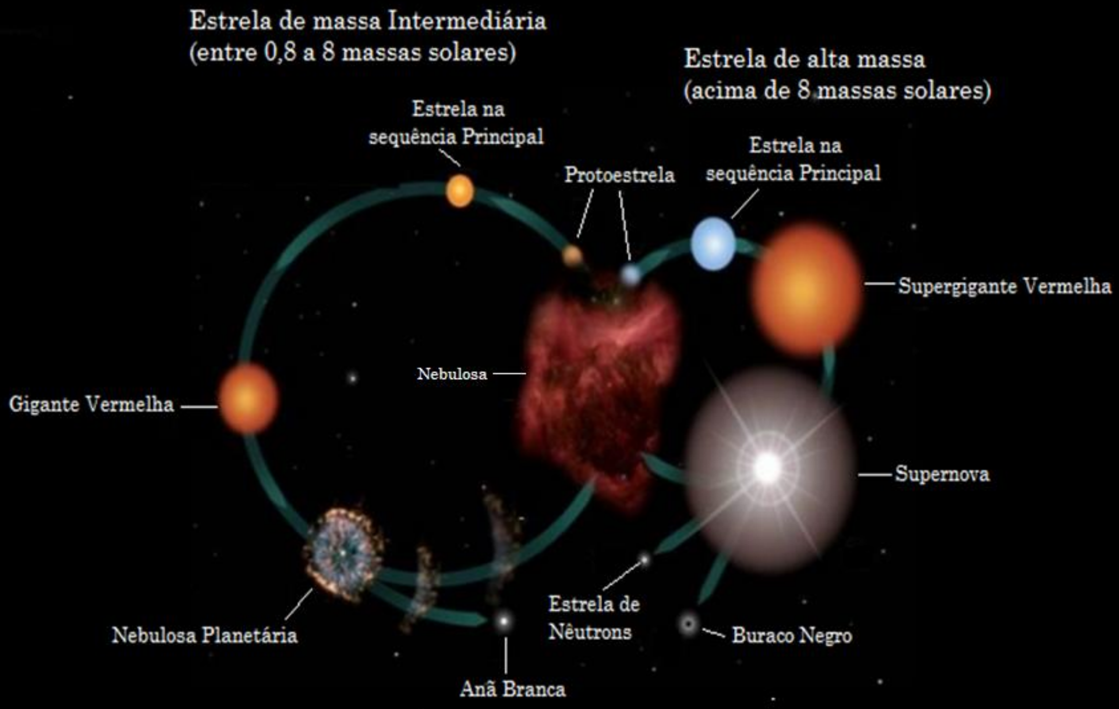


Estrelas de Sequência Principal (SP) (como o Sol, tipo G2 V; a classe de luminosidade “V” indica que é da SP) representam o estágio mais longo e mais estável na evolução de uma estrela, durante o qual a estrela está queimando hidrogênio em hélio em seu núcleo. Durante o estágio de SP, a estrela se encontra aproximadamente em equilíbrio hidrostático com condições relativamente constantes. Em contraste, os estágios finais da evolução estelar (por exemplo, o estágio de gigante vermelha) estão em rápida evolução. (o Sol passará 90% de sua vida na SP).

A EVOLUÇÃO ESTELAR DEPENDE DA MASSA

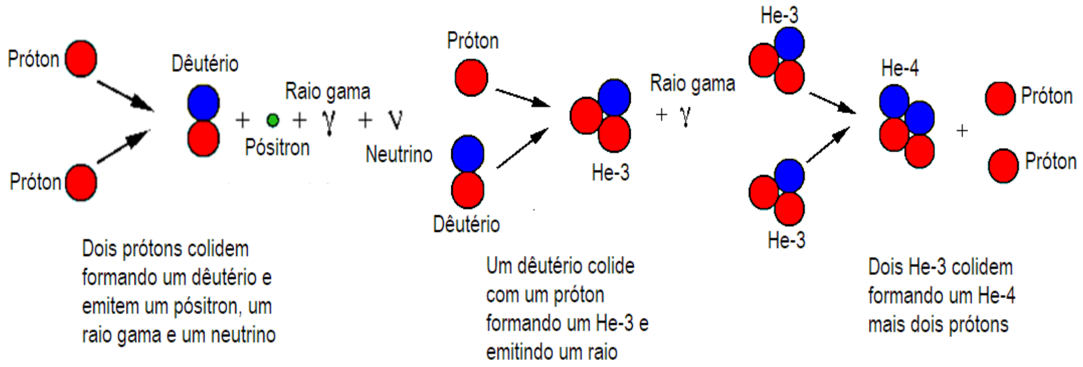
Massa intermediária (0,8* a 8 $M_\odot$) vs. alta massa (> 8 $M_\odot$)

- Massa intermediária
  “morte”: Nebulosa Planetária
  resto: anã branca
- Alta massa
  “morte”: Supernova
  resto: estrela de nêutrons
  buraco negro
- Nucleossíntese quiescente
  (equiíbrio hidrostático)
  – durante a vida da estrela
- Nucleossíntese explosiva
  Supernova


Estrela de massa Intermediária
(entre 0,8 a 8 massas solares)
Estrela de alta massa
(acima de 8 massas solares)
Estrela na sequência Principal
Protoestrela
Estrela na sequência Principal
Supergigante Vermelha
Nebulosa
Gigante Vermelha
Supernova
Estrela de Nêutrons
Nebulosa Planetária
Buraco Negro
Anã Branca

*O tempo de vida de estrelas com $M<0,8M_\odot$ é maior do que a idade do Universo:
não contribuem à evolução química cósmica

NUCLEOSSÍNTESE ESTELAR
Fusão do H em He

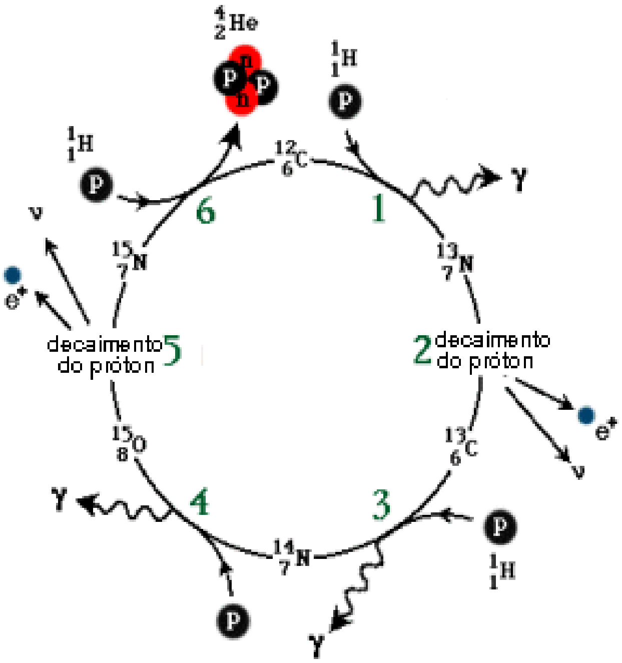

Próton
Próton
Dêutério
Raio gama
+ ● + γ + ν
Pósitron
Neutrino
Próton
Dêutério
He-3
Raio gama
+ γ
He-3
He-3
He-4
Próton
+
Próton

Dois prótons colidem formando um dêutério e emitem um pósitron, um raio gama e um neutrino

Um dêutério colide com um próton formando um He-3 e emitindo um raio

Dois He-3 colidem formando um He-4 mais dois prótons

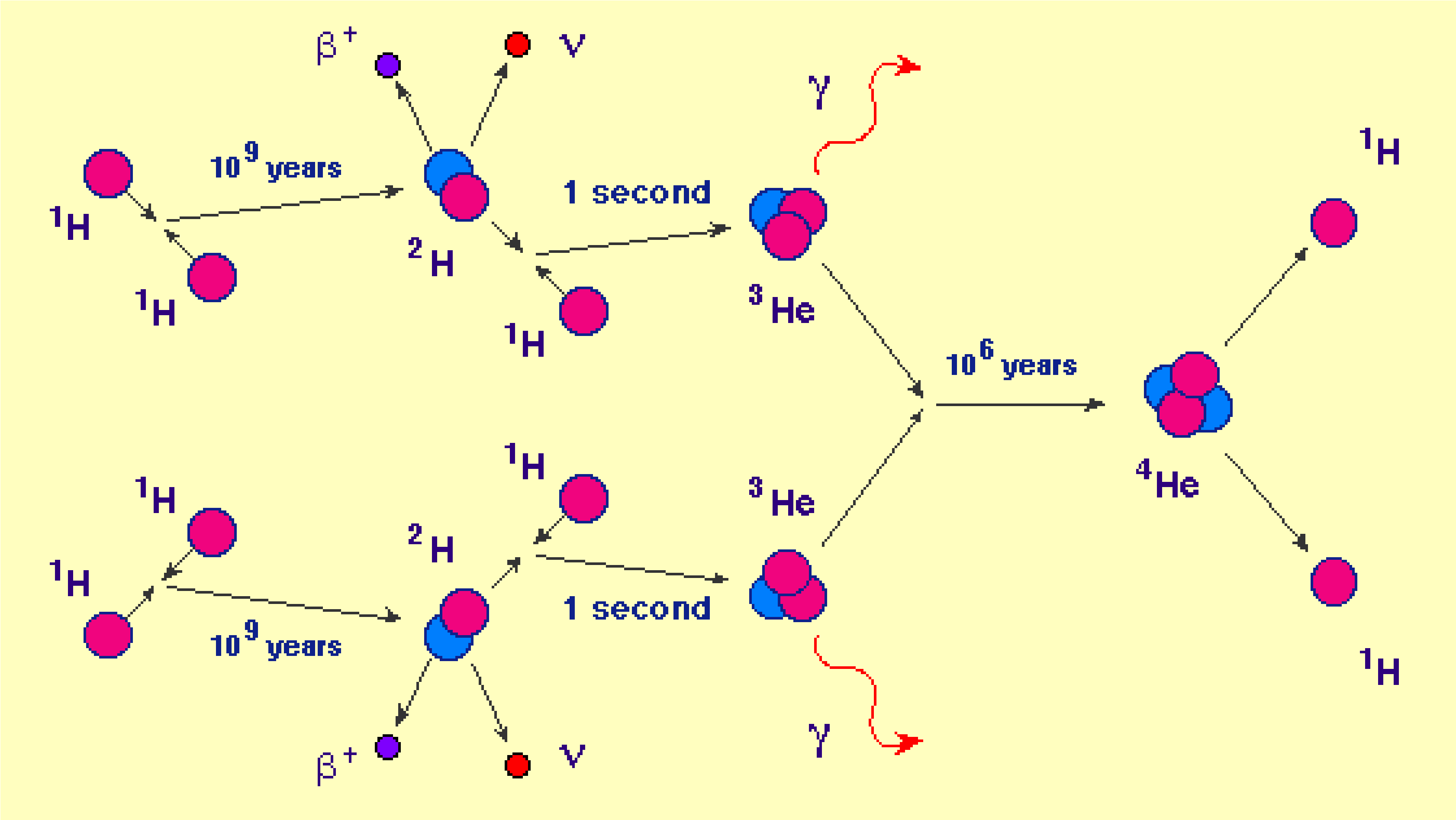
Cadeia próton-próton
M> 0,08 $M_\odot$


$^{4}_{2}He$
p
n
$^{1}_{1}H$
p
$^{12}_{6}C$
1
γ
$^{13}_{7}N$
2 decaimento do próton
e+
ν
$^{13}_{6}C$
3
p
$^{1}_{1}H$
$^{14}_{7}N$
γ
p
4
γ
$^{15}_{8}O$
5 decaimento do próton
e+
ν
$^{15}_{7}N$
6
$^{1}_{1}H$
p

Ciclo Carbono-Nitrogênio-Oxigênio (CNO)

Mais eficiente que p-p para M> 1,4 $M_{\odot 1}$

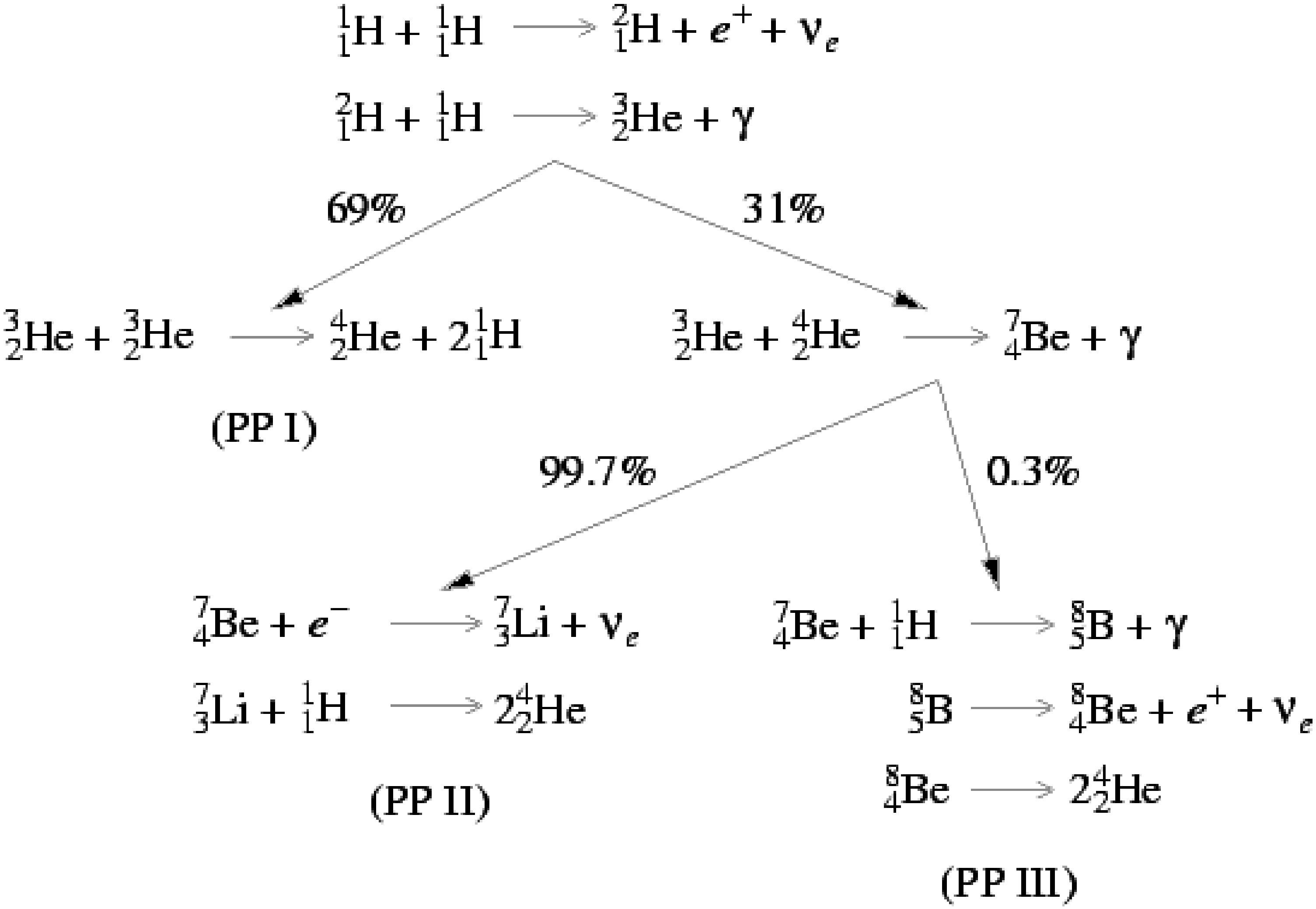
Cadeia Próton-Próton


β^+
ν
γ
^1H
10^9 years
^1H
^1H
^2H
1 second
^1H
^3He
10^6 years
^4He
^1H
^1H
^1H
^2H
^1H
^3He
^1H
1 second
10^9 years
^1H
β^+
ν
γ

The Proton-Proton Chain

Weak Nuclear Interaction	$p + p \rightarrow d + e^{+} + \upsilon_e$	t_{Mean} ~ 5 000 000 000 years
Electromagnetic	$p + d \rightarrow {}^{3}He + \gamma$	t_{Mean} ~ 1sec
Strong Nuclear Interaction	${}^{3}He + {}^{3}He \rightarrow {}^{4}He + p + p$	t_{Mean} ~ 3 000 000 years

Cadeia p-p (em detalhe)



$${}^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \longrightarrow {}^{2}_{1}\mathrm{H} + e^{+} + \nu_e$$

$${}^{2}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \longrightarrow {}^{3}_{2}\mathrm{He} + \gamma$$

69%

31%

$${}^{3}_{2}\mathrm{He} + {}^{3}_{2}\mathrm{He} \longrightarrow {}^{4}_{2}\mathrm{He} + 2\,{}^{1}_{1}\mathrm{H}$$

(PP I)

$${}^{3}_{2}\mathrm{He} + {}^{4}_{2}\mathrm{He} \longrightarrow {}^{7}_{4}\mathrm{Be} + \gamma$$

99.7%

0.3%

$${}^{7}_{4}\mathrm{Be} + e^{-} \longrightarrow {}^{7}_{3}\mathrm{Li} + \nu_e$$

$${}^{7}_{3}\mathrm{Li} + {}^{1}_{1}\mathrm{H} \longrightarrow 2\,{}^{4}_{2}\mathrm{He}$$

(PP II)

$${}^{7}_{4}\mathrm{Be} + {}^{1}_{1}\mathrm{H} \longrightarrow {}^{8}_{5}\mathrm{B} + \gamma$$

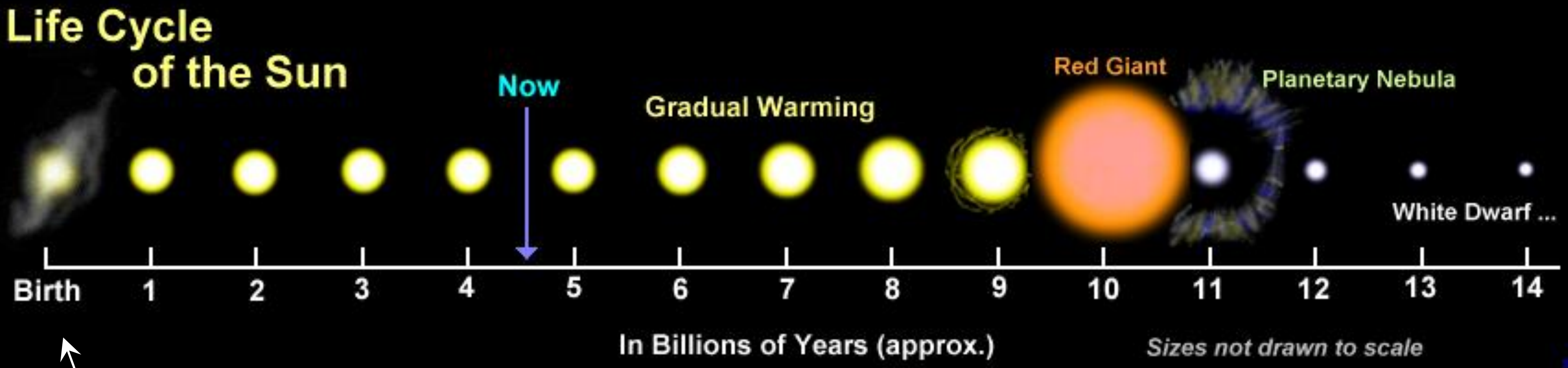
$${}^{8}_{5}\mathrm{B} \longrightarrow {}^{8}_{4}\mathrm{Be} + e^{+} + \nu_e$$

$${}^{8}_{4}\mathrm{Be} \longrightarrow 2\,{}^{4}_{2}\mathrm{He}$$

(PP III)

- O Sol está em equilíbrio hidrostático – nem se expande e nem se contrai
- A força gravitacional é balanceada pela pressão interna devida à geração de energia por reações nucleares
- ...contudo, o equilíbrio não é estritamente exato ⇒ há uma lenta (sobre escalas de tempo de bilhões de anos) evolução da estrutura do Sol

Evolução do Sol


Life Cycle
of the Sun
Now
Gradual Warming
Red Giant
Planetary Nebula
White Dwarf ...
Birth
1
2
3
4
5
6
7
8
9
10
11
12
13
14
In Billions of Years (approx.)
Sizes not drawn to scale

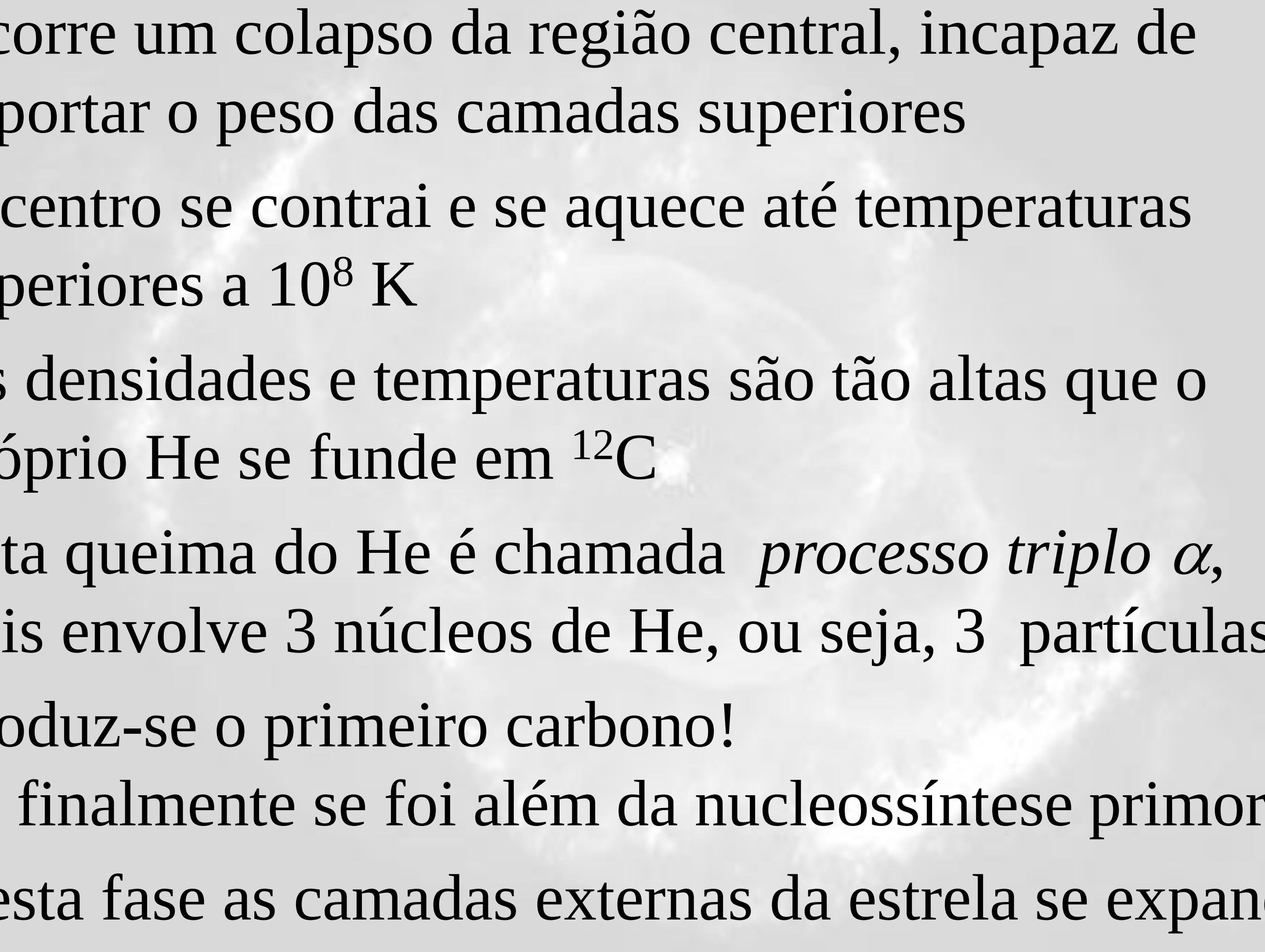
Colapso da nuvem molecular

A Terra provavelmente será destruída

Por que o Sol fica mais luminoso com o tempo?

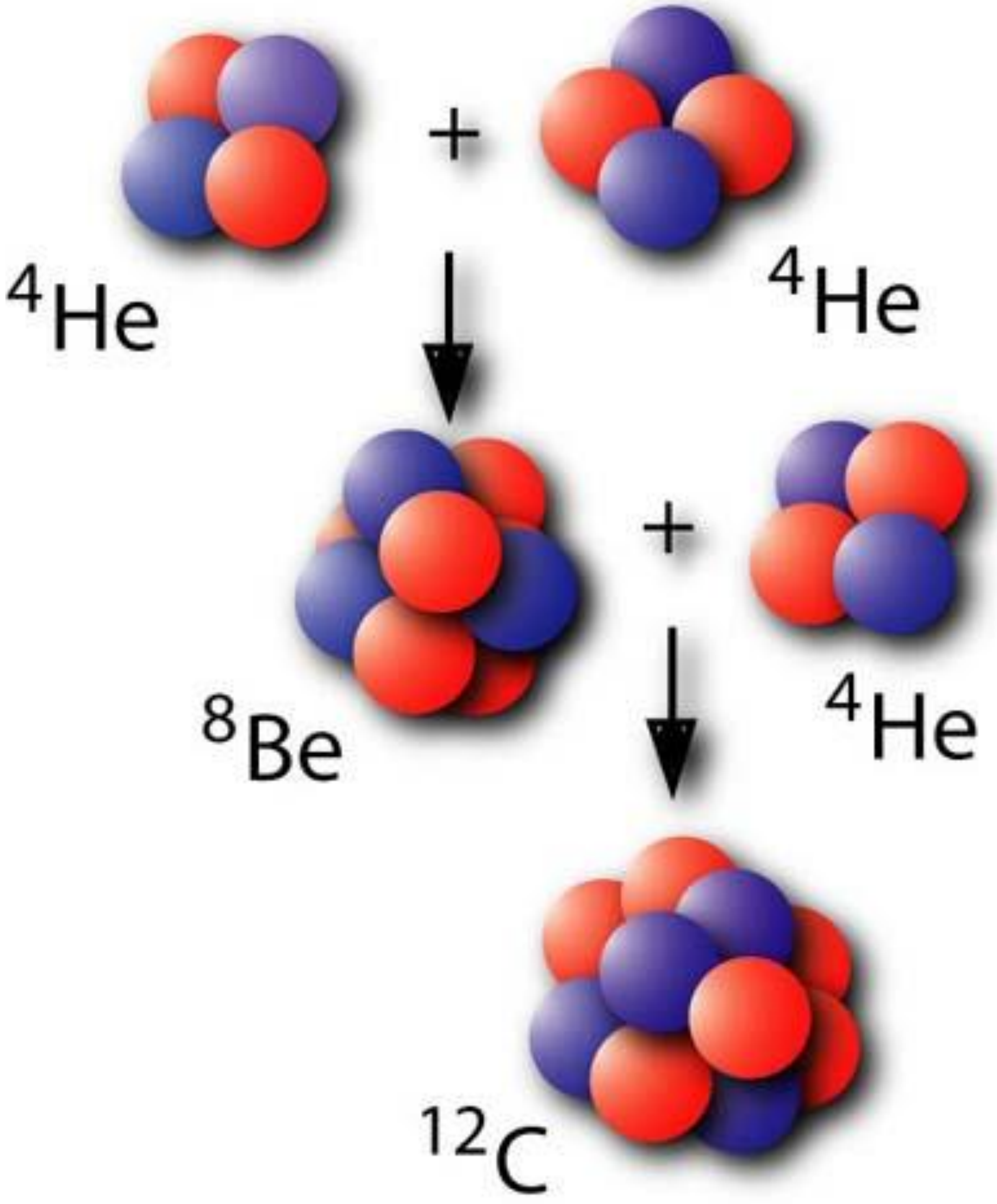
- H se funde em He no centro
- O centro torna-se mais denso
- O centro se contrai e se aquece
- Com o aumento da densidade e da temperatura, as reações nucleares ocorrem a uma taxa mais rápida
- Mais energia é produzida no centro ⇒ mais energia é irradiada na superfície

Quando o Sol exaurir o hidrogênio no centro ⇒ Produção do Carbono



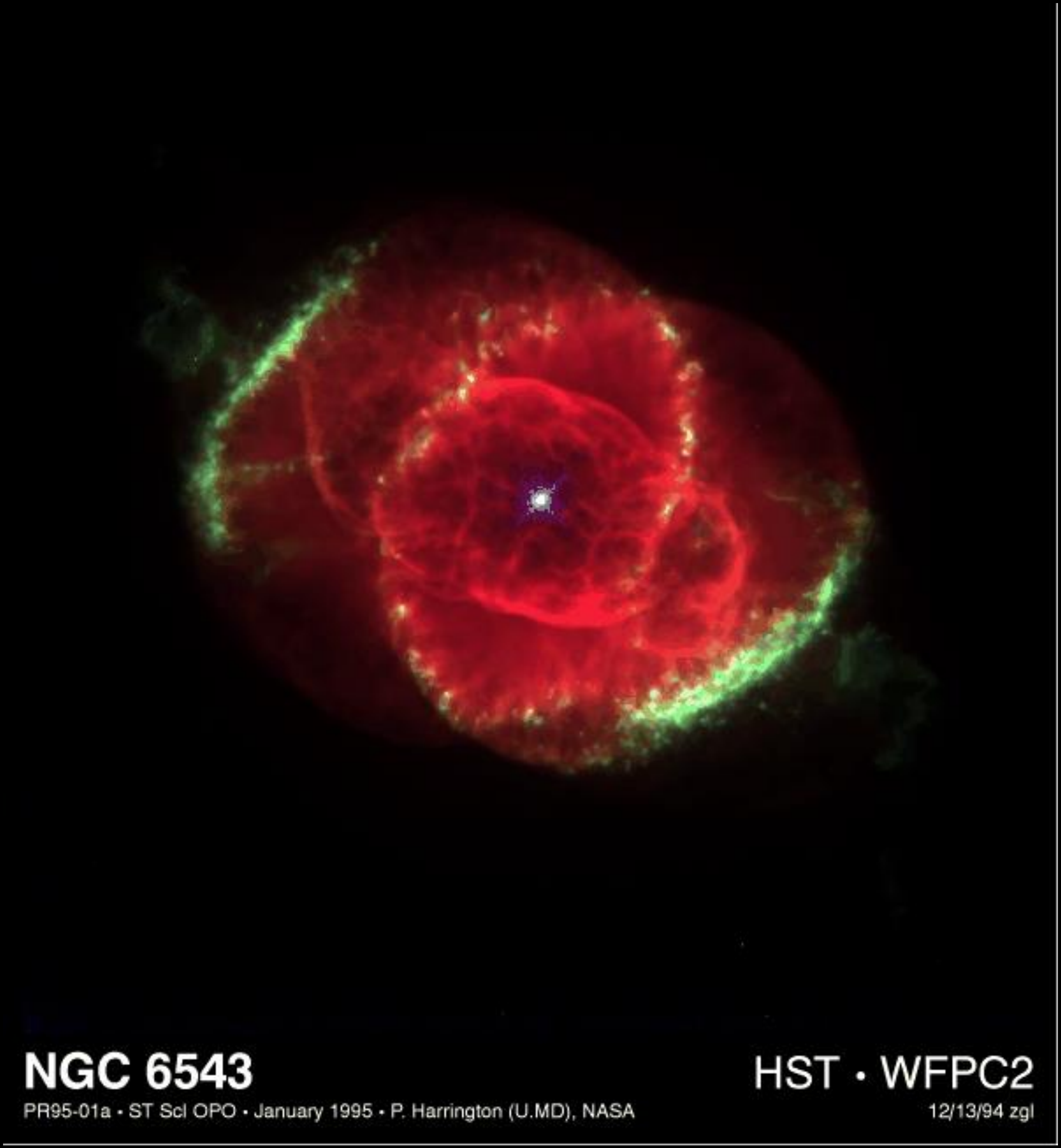
- Ocorre um colapso da região central, incapaz de suportar o peso das camadas superiores
- O centro se contrai e se aquece até temperaturas superiores a 10^8 K
- As densidades e temperaturas são tão altas que o próprio He se funde em ^{12}C
- Esta queima do He é chamada *processo triplo* α, pois envolve 3 núcleos de He, ou seja, 3 partículas α
- Produz-se o primeiro carbono!
  ⇒ finalmente se foi além da nucleossíntese primordial
- Nesta fase as camadas externas da estrela se expandem e resfriam, e a estrela torna-se uma gigante vermelha

Processo Triplo Alfa


^{4}He
+
^{4}He
^{8}Be
+
^{4}He
^{12}C

E além da fusão do hélio em carbono?

- Dependendo de sua massa, as estrelas podem desenvolver regiões com múltiplas camadas em que há reações nucleares, como por exemplo a queima de ^{4}He em ^{12}C no núcleo e a queima simultânea de H em ^{4}He em uma camada adjacente ao núcleo e um pouco mais fria do que este.
- Parte do carbono formado pode também se converter em ^{16}O, se a temperatura central for suficientemente alta.
- Estrelas com massas semelhantes à do Sol ou maiores, até um limite da ordem de 8 massas solares geralmente não conseguem ir além deste estágio, isto é, não podem formar elementos químicos mais pesados
- Estas estrelas terminam sua vida como uma ***nebulosa planetária***
  $\Rightarrow$ será o caso do Sol



NGC 6543

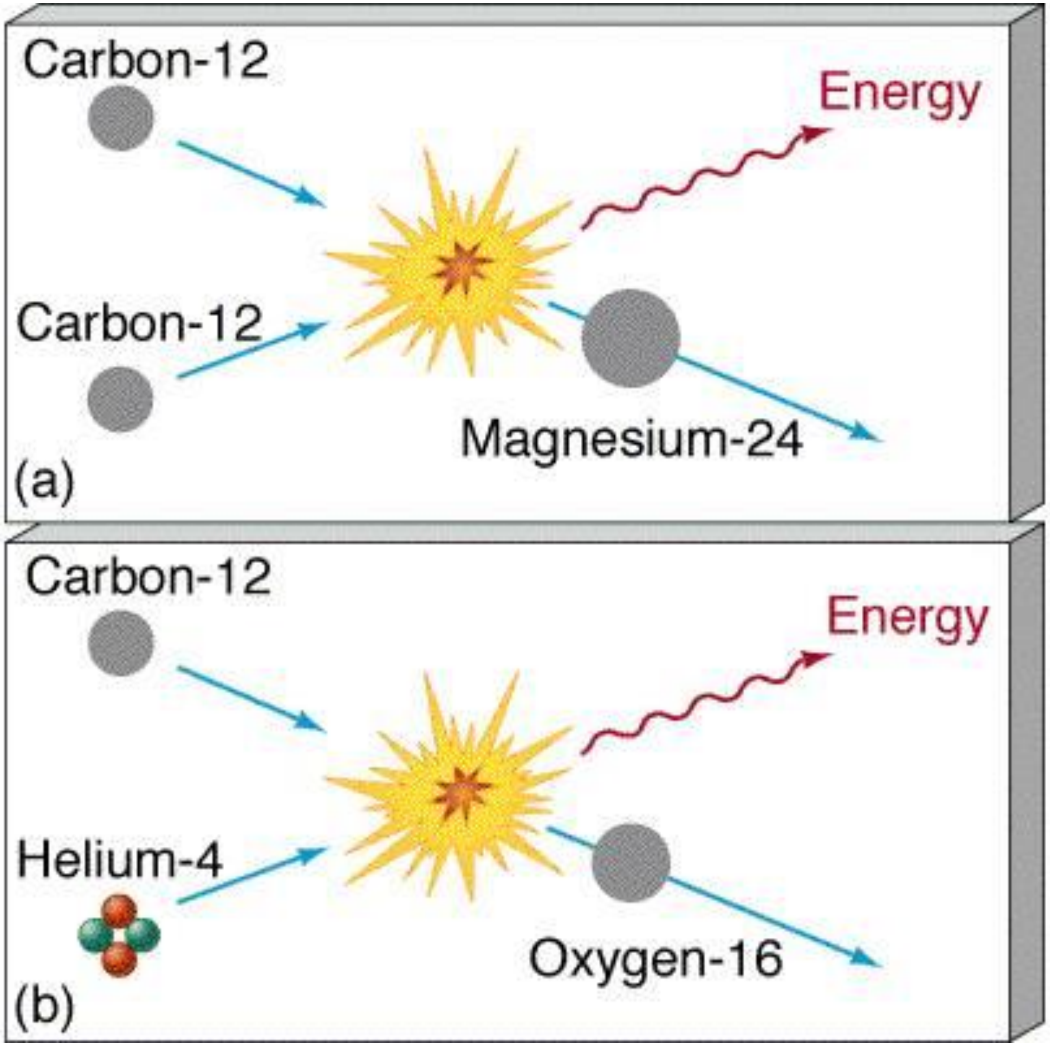
PR95-01a • ST ScI OPO • January 1995 • P. Harrington (U.MD), NASA

HST • WFPC2

12/13/94 zgl

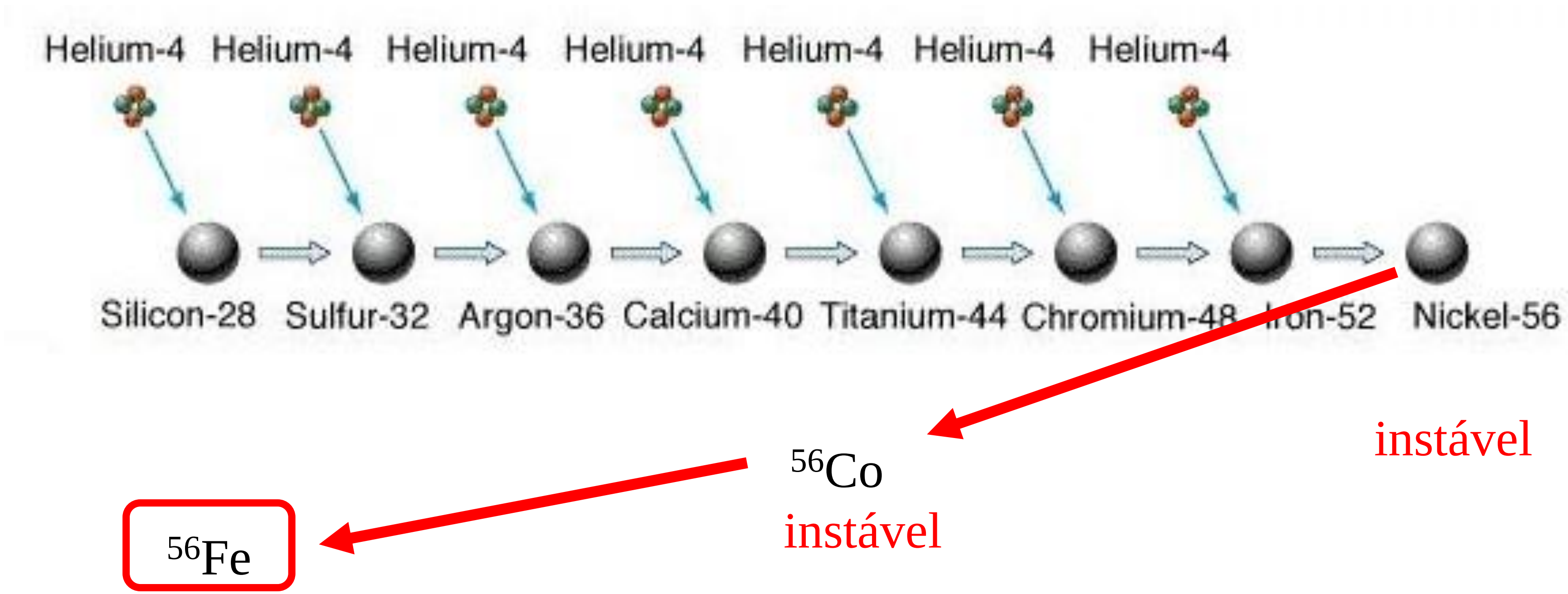
Elementos alfa

- Acima do limite de aproximadamente 8 massas solares, as temperaturas centrais atingem valores acima de 10^9 K e, em seus estágios finais de evolução, essas estrelas possibilitam a formação dos elementos mais pesados ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si, ^{32}S, ^{36}Ar, ^{40}Ca e alguns de seus isótopos.
- Esses são chamados elementos alfa, pois sua formação dá-se pela captura de um núcleo de ^{4}He (uma partícula alfa) por um núcleo mais leves
- Alguns destes elementos podem também ser formados na queima de carbono (^{12}C+^{12}C) e oxigênio (^{16}O+^{16}O)
- Essa sequência de reações é eficiente até o ^{56}Fe
- Além do ^{56}Fe, as reações nucleares passam a sequestrar energia em vez de fornecer, e a região central colapsa
- Estas estrelas terminam sua vida como uma ***supernova de tipo II***


Carbon-12
Energy
Carbon-12
Magnesium-24
(a)
Carbon-12
Energy
Helium-4
Oxygen-16
(b)

NUCLEOSSÍNTESE ESTELAR

Processos Alfa


Helium-4
Helium-4
Helium-4
Helium-4
Helium-4
Helium-4
Helium-4
Silicon-28
Sulfur-32
Argon-36
Calcium-40
Titanium-44
Chromium-48
Iron-52
Nickel-56

instável

^{56}Co

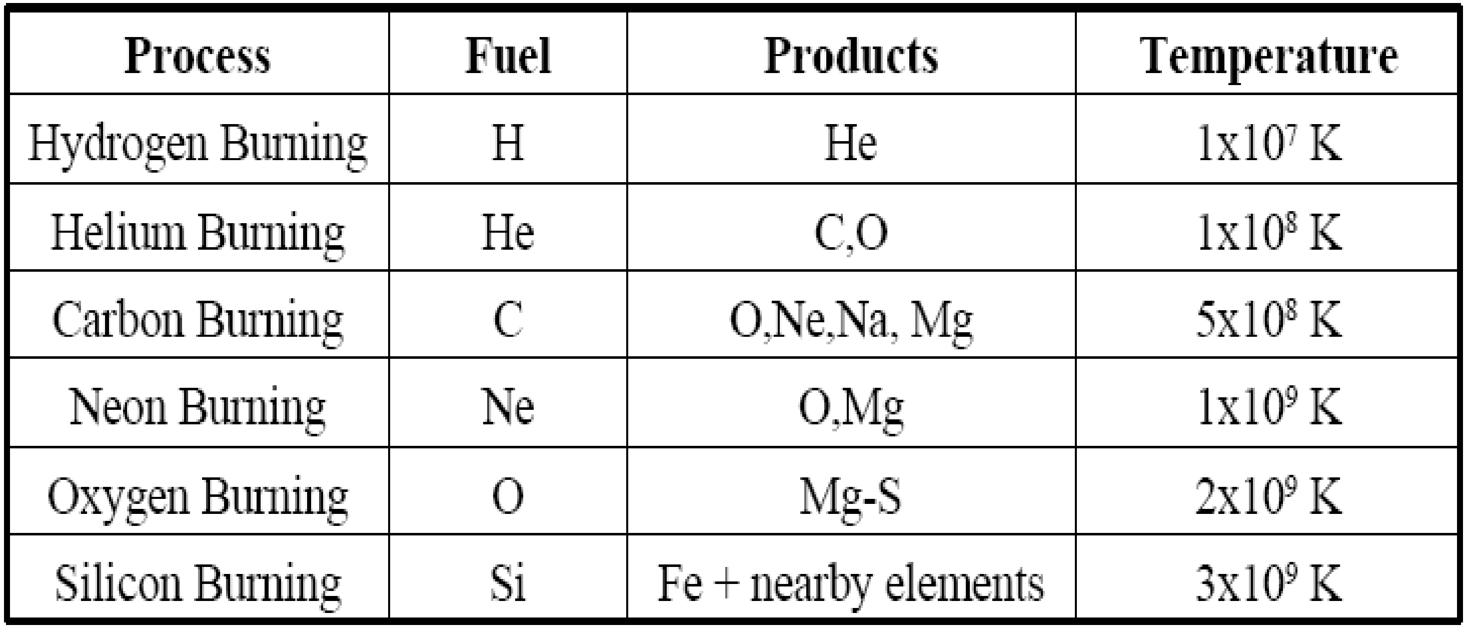
instável

^{56}Fe

O ^{56}Fe é o elemento mais estável

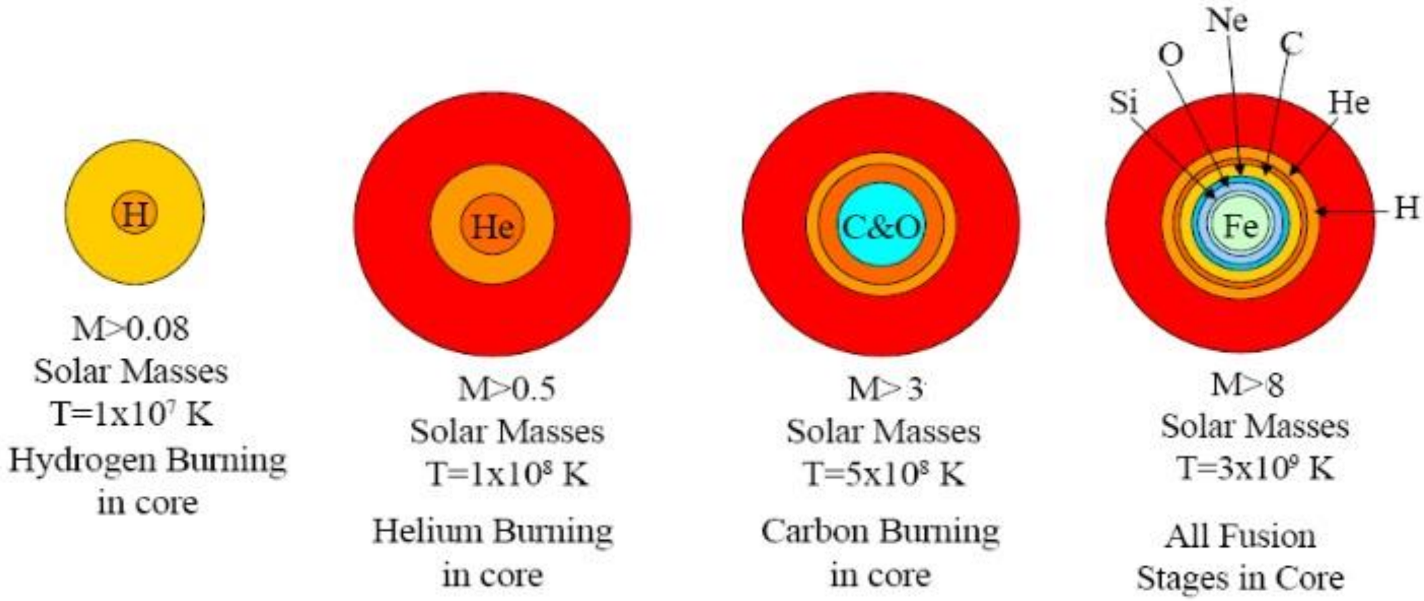
Após ele as reações são endotérmicas (“roubam” energia)

O ***Pico do Fe*** – Cr, Mn, Fe, Co, Ni – é um “pico” de abundância



Process	**Fuel**	**Products**	**Temperature**
Hydrogen Burning	H	He	$1x10^{7}$ K
Helium Burning	He	C,O	$1x10^{8}$ K
Carbon Burning	C	O,Ne,Na, Mg	$5x10^{8}$ K
Neon Burning	Ne	O,Mg	$1x10^{9}$ K
Oxygen Burning	O	Mg-S	$2x10^{9}$ K
Silicon Burning	Si	Fe + nearby elements	$3x10^{9}$ K

NUCLEOSSÍNTESE ESTELAR
Dependência com a massa estelar



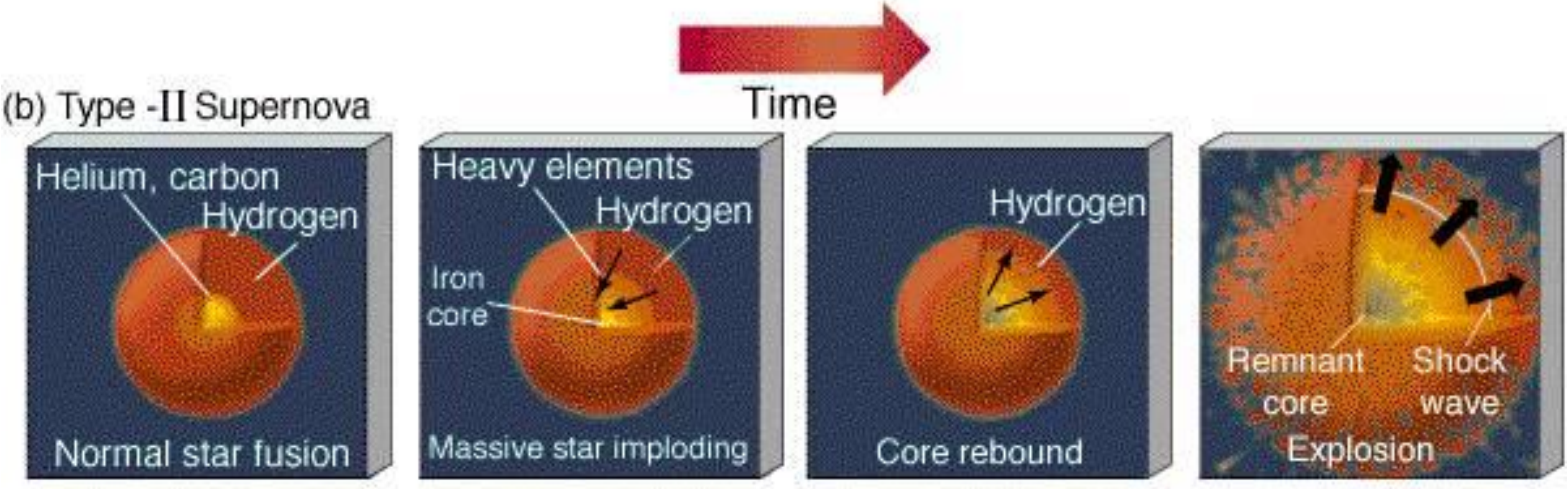
M>0.08
Solar Masses
T=1x10^7 K
Hydrogen Burning
in core

M>0.5
Solar Masses
T=1x10^8 K
Helium Burning
in core

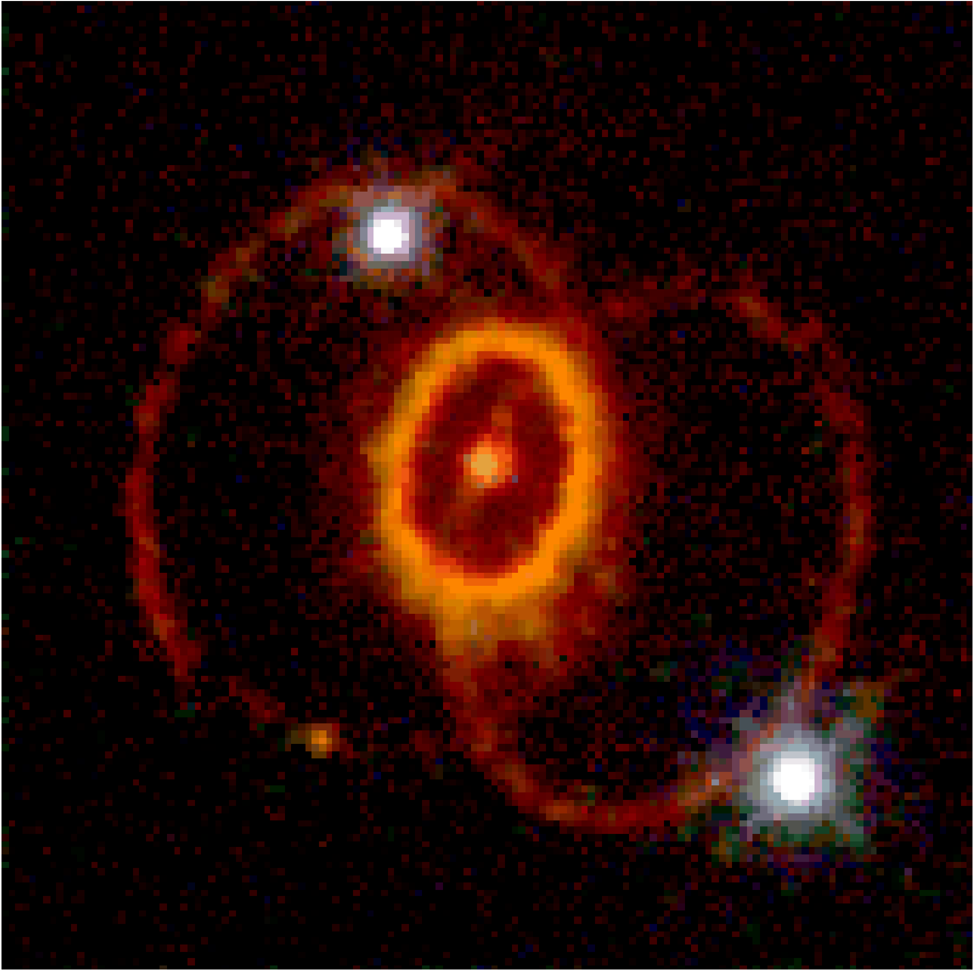
M>3
Solar Masses
T=5x10^8 K
Carbon Burning
in core

M>8
Solar Masses
T=3x10^9 K
All Fusion
Stages in Core

Produção de uma Supernova de Tipo II (estrela acima de 8 massas solares)


(b) Type -II Supernova
Time
Helium, carbon
Hydrogen
Normal star fusion
Heavy elements
Hydrogen
Iron core
Massive star imploding
Hydrogen
Core rebound
Remnant core
Shock wave
Explosion

Supernova 1987A Rings



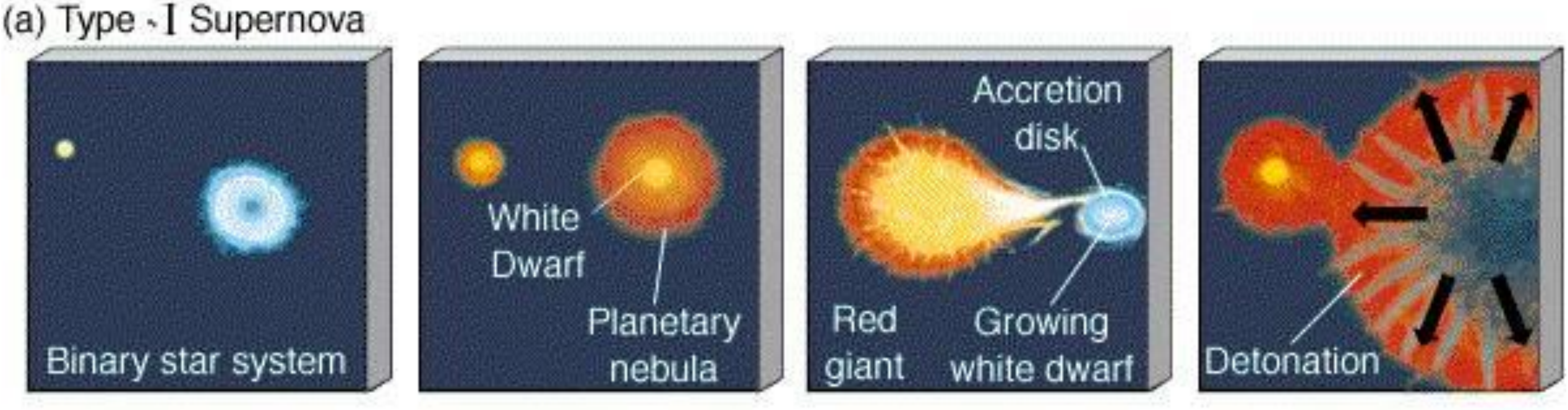
Hubble Space Telescope

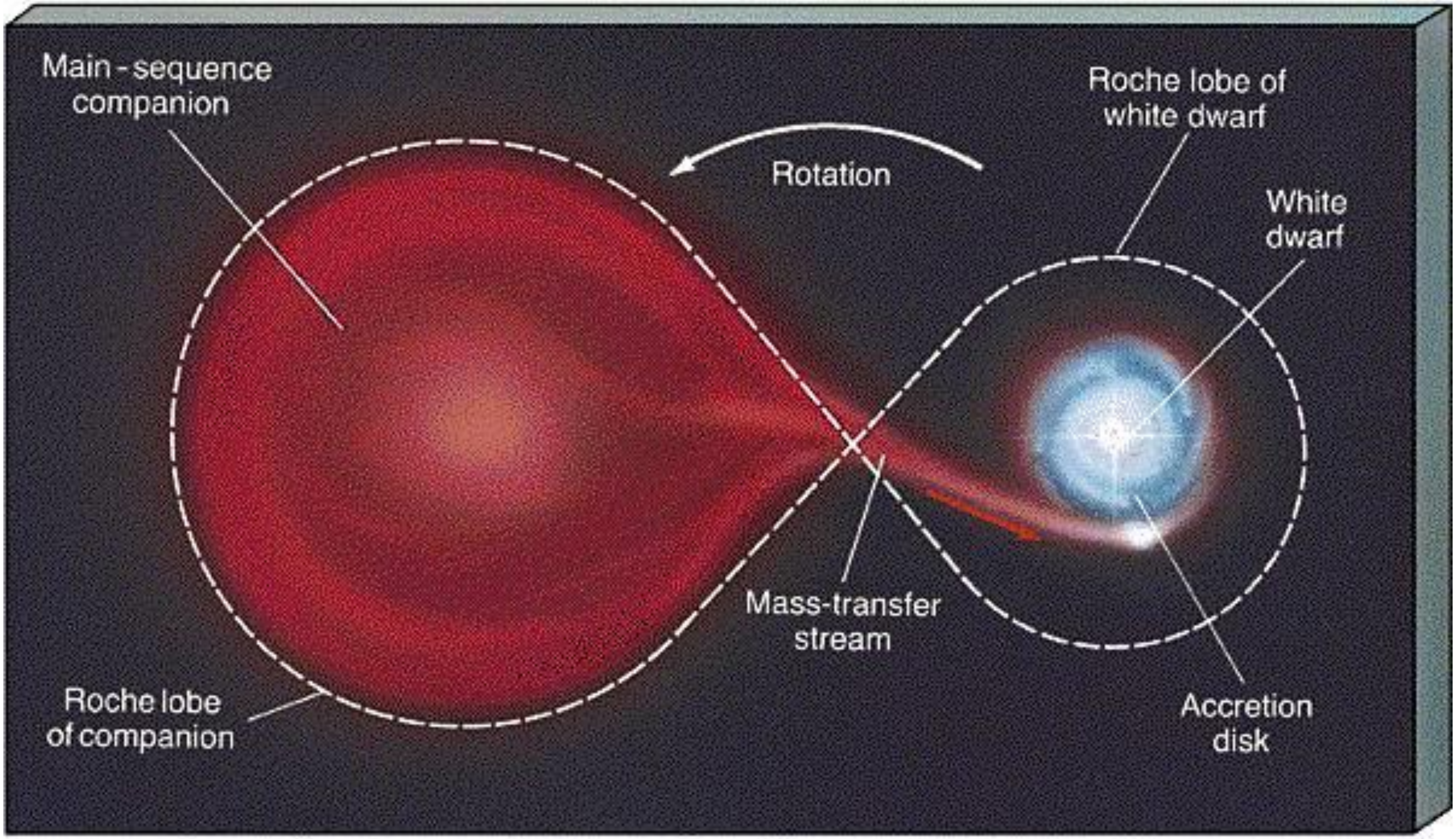
Wide Field Planetary Camera 2

SPACE TELESCOPE SCIENCE INSTITUTE

Produção de uma Supernova de Tipo Ia

(Sistema binário com ambas estrelas tendo menos de 8 massas solares)


(a) Type - I Supernova
Binary star system
White Dwarf
Planetary nebula
Accretion disk
Red giant
Growing white dwarf
Detonation

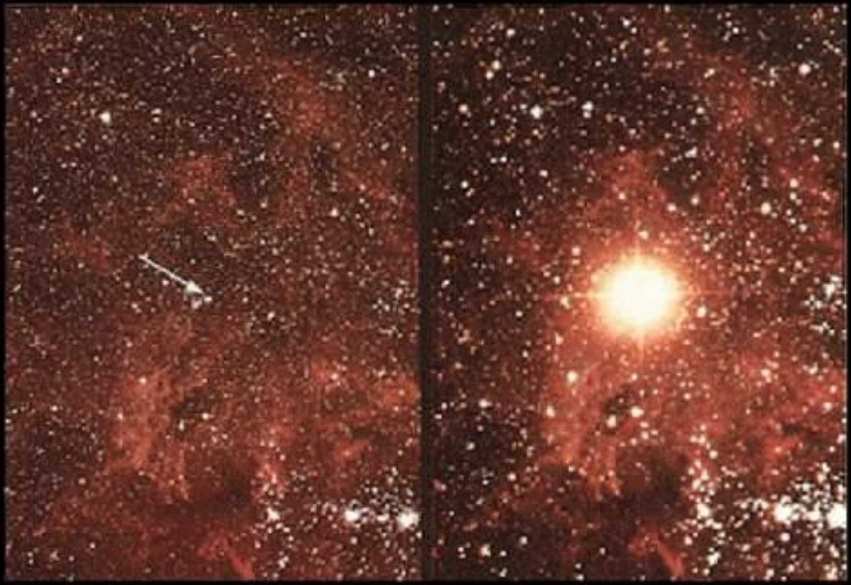

Main - sequence
companion
Roche lobe of
white dwarf
Rotation
White
dwarf
Mass-transfer
stream
Roche lobe
of companion
Accretion
disk

Sintetizando

Supernovas

- Morte Violenta!
- Mais de um tipo:
  - – Ia: sistemas binários
  - – II: estrelas de alta massa

Supernova!



SN1987A (David Malin and the Anglo Australian Observa

Supernovas II

SNII: queima nuclear até Fe

- Colapso gravitacional
- Núcleo ⇒ estrela de nêutrons ou buraco negro
- Camadas exteriores ⇒ supernova
- Produção de O, elementos α, C, (Fe), (N)
- Tempos: Manos (ou anos para as hipernovas primevas)

SN1987A (David Malin and the Anglo Australian Observa

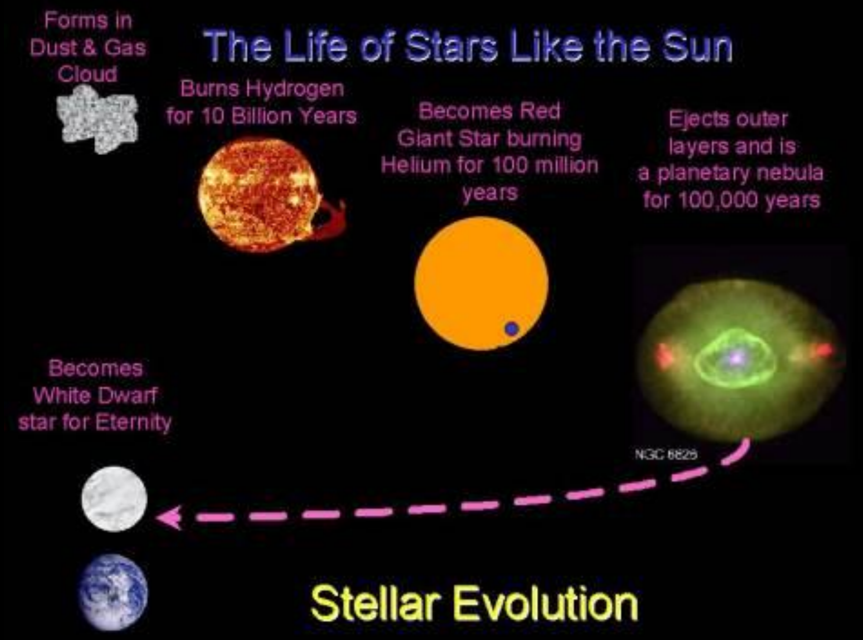
Supernovas Ia

- SN Ia: anãs brancas em sistemas binários
- Incertezas quanto a companheira:
  - anã branca,
  - gigante vermelha,
  - degenerada,
  - não degenerada
- $L \sim 10 - 100 \times L_{SNII}$
- Produção de Fe
- Tempos: 0.1-1 Ganos

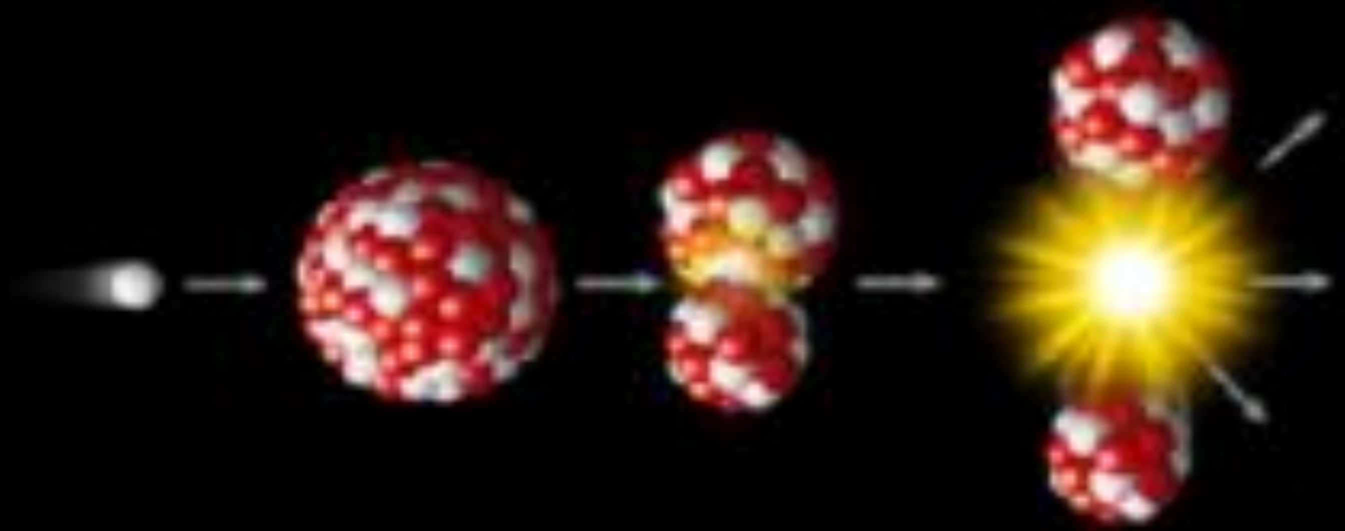
SN1994D - Hubble Space Telescope

Nebulosas Planetárias

- O Sol vai morrer assim!
- Estrelas com massas menores que 8 vezes a massa do Sol
- Núcleo ⇒ anã branca
- Camadas exteriores ⇒ nebulosa planetária
- Produção de C, N
- Tempos: até vários Ganos
- Promovem as condições pré-bióticas.


The Life of Stars Like the Sun
Forms in Dust & Gas Cloud
Burns Hydrogen for 10 Billion Years
Becomes Red Giant Star burning Helium for 100 million years
Ejects outer layers and is a planetary nebula for 100,000 years
NGC 6826
Becomes White Dwarf star for Eternity
Stellar Evolution

Li, Be, B (bem pouco abundantes)
⇐ NUCLEOSSÍNTESE NO MEIO INTERESTELAR
Espalação por raios cósmicos



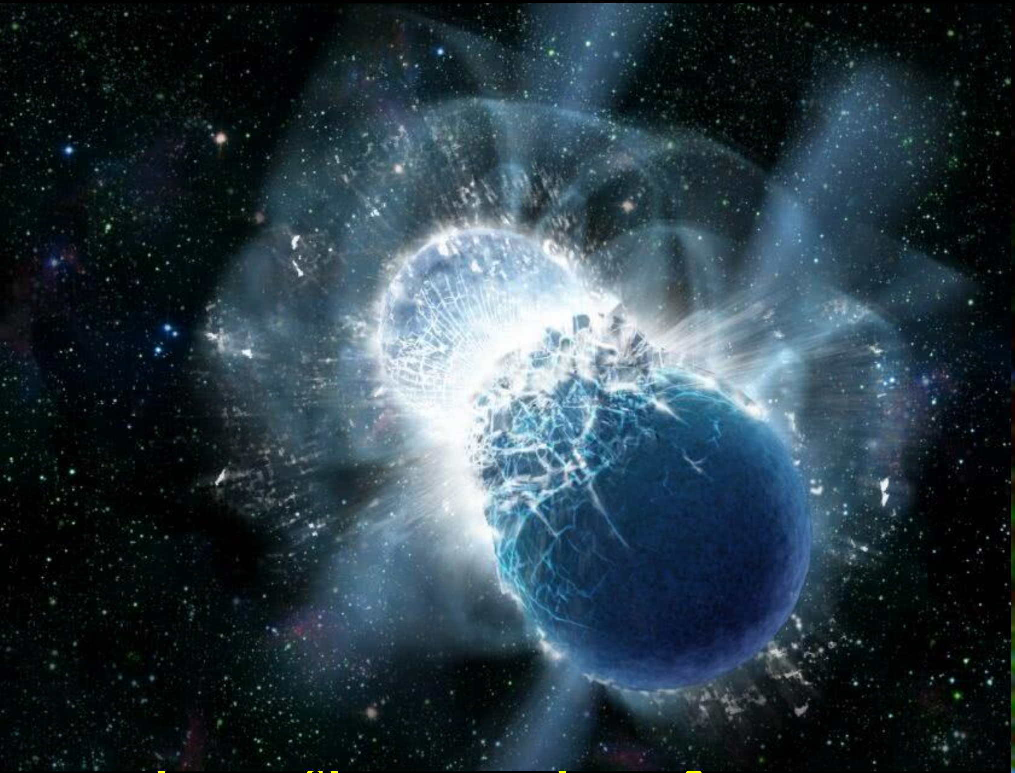
^{6}Li (o isótopo mais leve do lítio)*, Be (berílio) e B (boro)

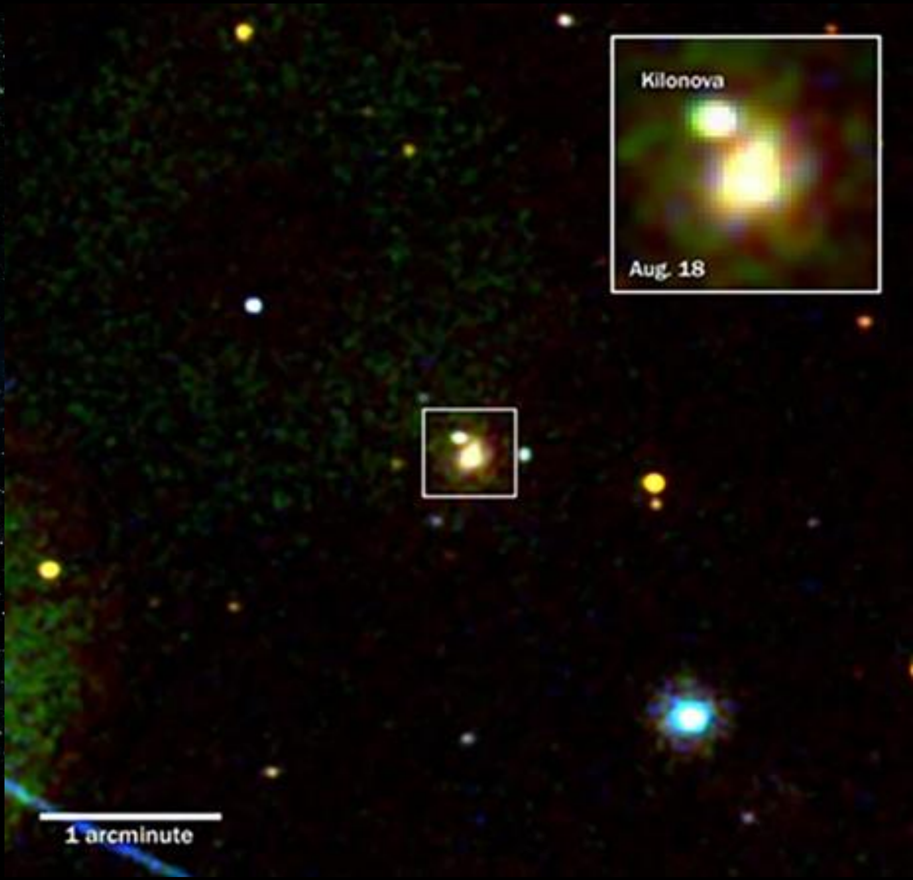
*^{7}Li é produzido no Big Bang, por espalação e em estrelas

Nucleossíntese além do Fe

- Além do Fe, a energia de ligação por núcleon diminuiu com a massa atômica e a nucleossíntese passa a exigir energia em vez de produzir.
- Além do Fe, pode ocorrer a captura de prótons, *processo-p*, que é pouco importante , só acontece em altíssimas temperaturas porque o próton tem que vencer a força repulsiva do núcleo positivo
- A síntese de núcleos mais pesados que o ferro se dá principalmente por *captura de nêutrons*, que é de dois tipos: *processo-s* e *processo-r*
- O processo-s (“s” de *slow*) ocorre em fluxos moderados de nêutrons, e envolve isótopos intermediários radioativos de vida longa (milhares de anos), que depois decaem no núcleo final estável. Seus sítios são estágios avançados de evolução estelar de estrelas tanto de massa intermediária como de alta massa. Produzem até o Bi.
- O processo-r (“r” de *rapid*) se dá em fluxos de nêutrons altíssimos, e envolve isótopos radioativos de vida curta (menos de 1 segundo). Ocorre em supernovas tipo II e em *fusões de estrelas de nêutrons*.

Fusões de Estrelas de Nêutrons





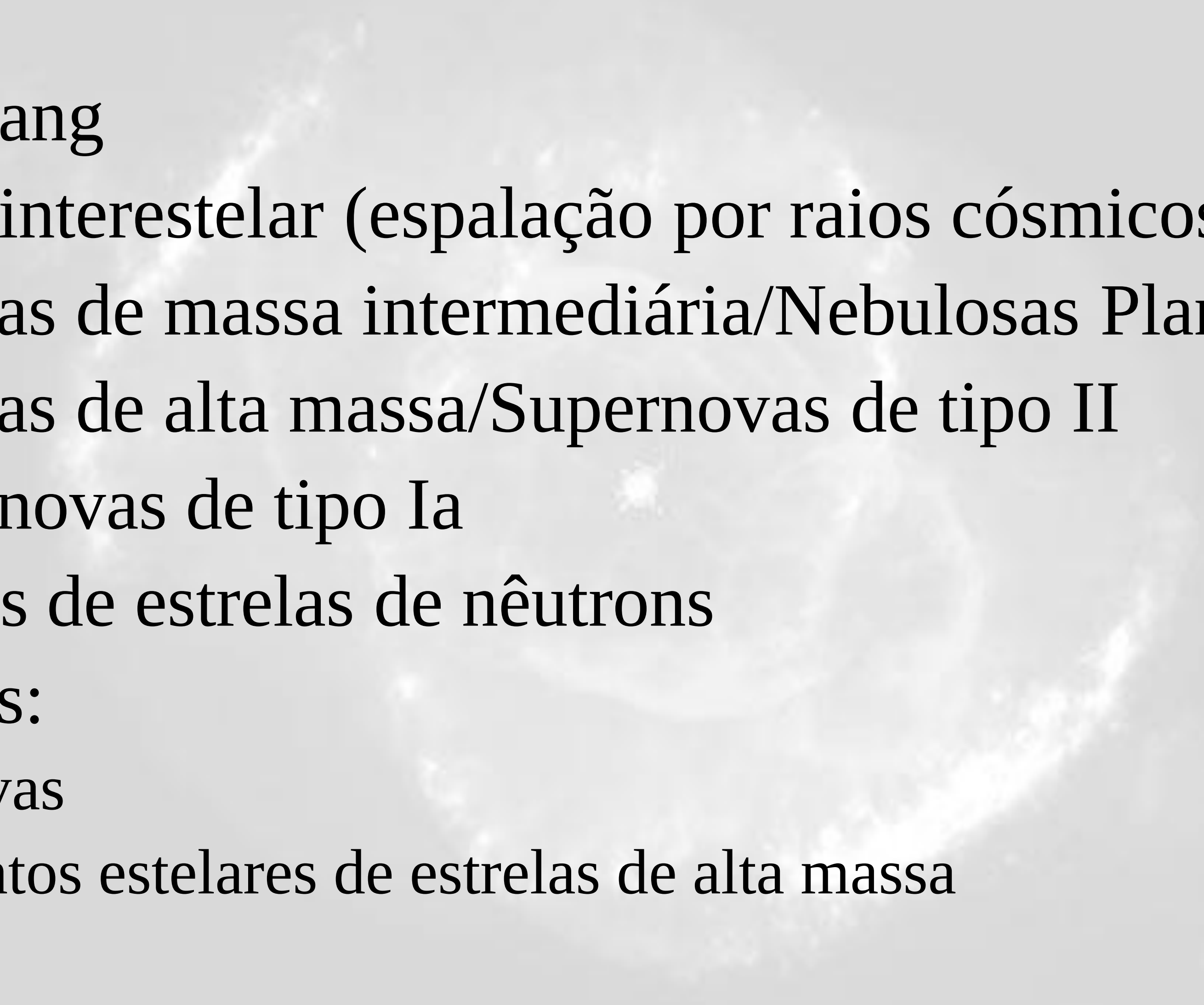
- altos fluxos de nêutrons

$\Rightarrow$ processo-r

- Produção de lantanídeos (ex. Eu), Os-Ir-Pt-Au, actinídeos (Th, U)

Kilova detectada em 2017 pelo Swift após o evento de ondas gravitacionais GW170817 . Produziu-se 1-5 $M_\oplus$ de Eu e 3-13 $M_\oplus$ de Au, e > 100 $M_\oplus$ de Pt.

Sítios de Nucleossíntese

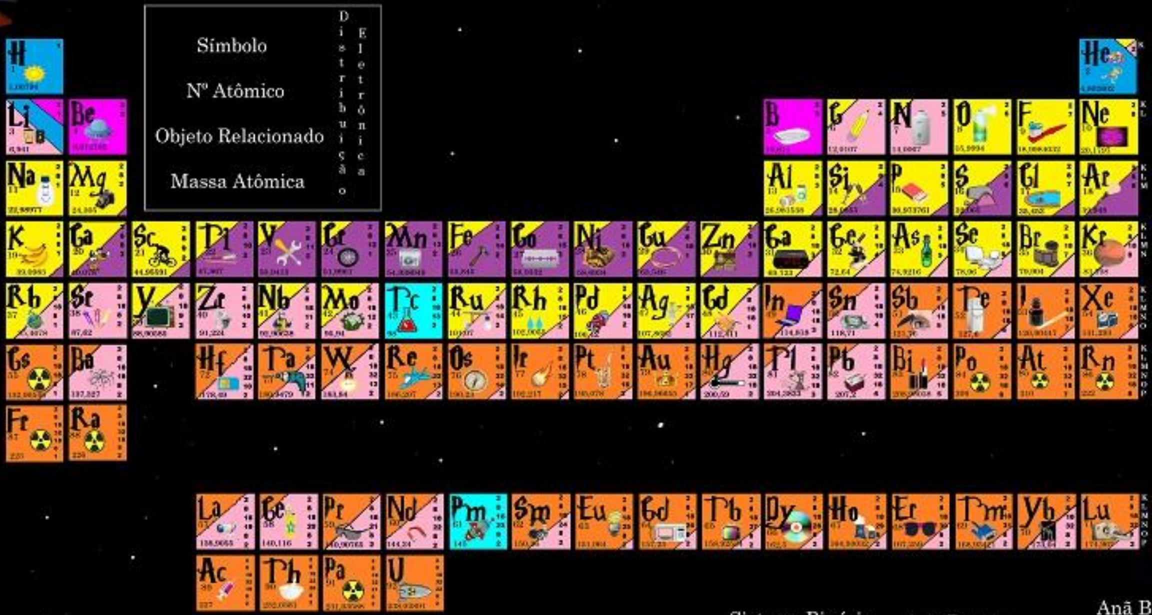


- Big Bang
- Meio interestelar (espalação por raios cósmicos)
- Estrelas de massa intermediária/Nebulosas Planetárias
- Estrelas de alta massa/Supernovas de tipo II
- Supernovas de tipo Ia
- Fusões de estrelas de nêutrons
- Outros:
  - Novas
  - Ventos estelares de estrelas de alta massa

TABELA
ORIGEM DOS ELEMENTOS QUÍMICOS

🟦 Big Bang

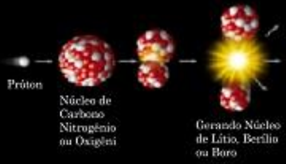
■ Estrela de massa intermediária (entre 0,8 e 8 massas solares), que termina sua vida como Nebulosa Planetária.



Símbolo
Nº Atômico
Objeto Relacionado
Massa Atômica
Distribuição Eletrônica
H
He
Li
Be
B
C
N
O
F
Ne
Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
Br
Kr
Rb
Sr
Y
Zr
Nb
Mo
Tc
Ru
Rh
Pd
Ag
Cd
In
Sn
Sb
Te
I
Xe
Cs
Ba
Hf
Ta
W
Re
Os
Ir
Pt
Au
Hg
Tl
Pb
Bi
Po
At
Rn
Fr
Ra
La
Ce
Pr
Nd
Pm
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Ac
Th
Pa
U

🟨 Estrela de alta massa (acima de 8 massas solares), que termina sua vida como Supernova de tipo II

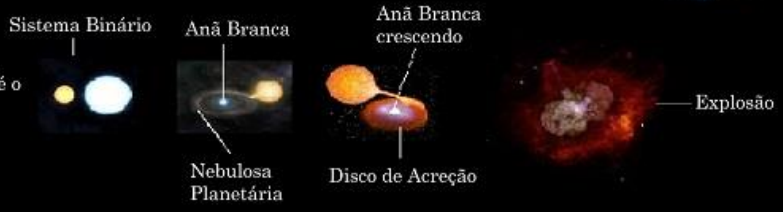
🟧 Fusão de estrelas de nêutrons.



Próton
Núcleo de Carbono Nitrogênio ou Oxigêni
Gerando Núcleo de Lítio, Berílio ou Boro

■ Espalação
Processo de colisão entre raios cósmicos (partículas de alta energia) e núcleos atômicos do meio interestelar

🟪 Supernova de tipo Ia, que é o resultado da evolução de um sistema de duas estrelas, cada uma de massa intermediária



Sistema Binário
Anã Branca
Anã Branca crescendo
Explosão
Nebulosa Planetária
Disco de Acreção

■ Elementos produzidos artificialmente

Tabela adaptada por Karline Brandão