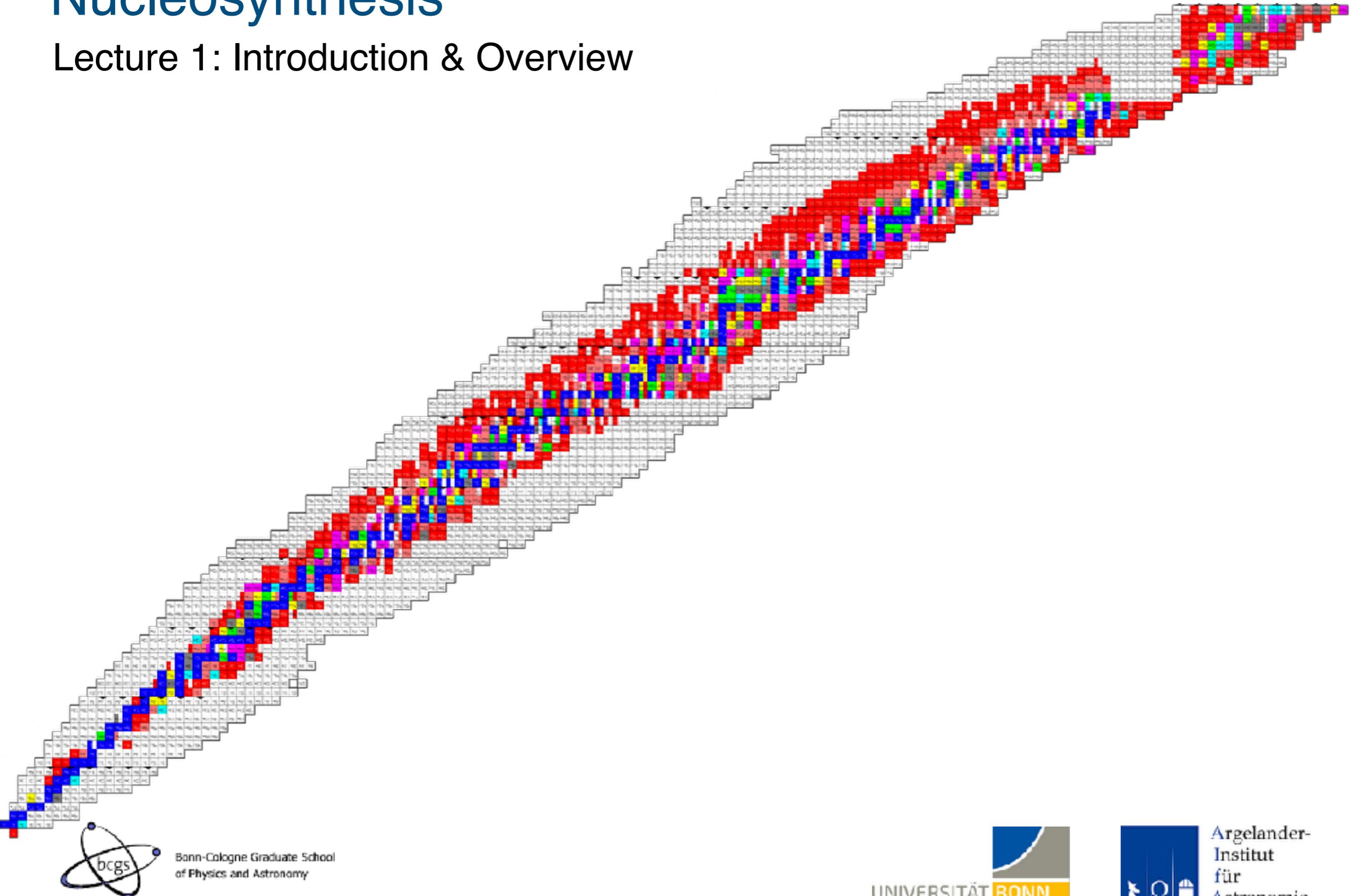


Nucleosynthesis

Lecture 1: Introduction & Overview



Bonn-Cologne Graduate School
of Physics and Astronomy



Nucleosynthesis

Lectures
Lab

John Antoniadis — office 3.015; janton@mpifr.de
Name A
Name B

Lectures
Exercises

Thursdays @ 11:15 — 12:45 April 11 to July 11 Room 0.008
Fridays @ 9:00 — 10:00 April 19 to July 12 Room 0.006/0.008
11:00 — 12:00

Course Language

English [...with a greek accent]

Course website

www.astro.uni-bonn.de/~janton/nuc.html
antoniadisjohn.com/nuc.html

Notes, presentations, papers...

Nucleosynthesis

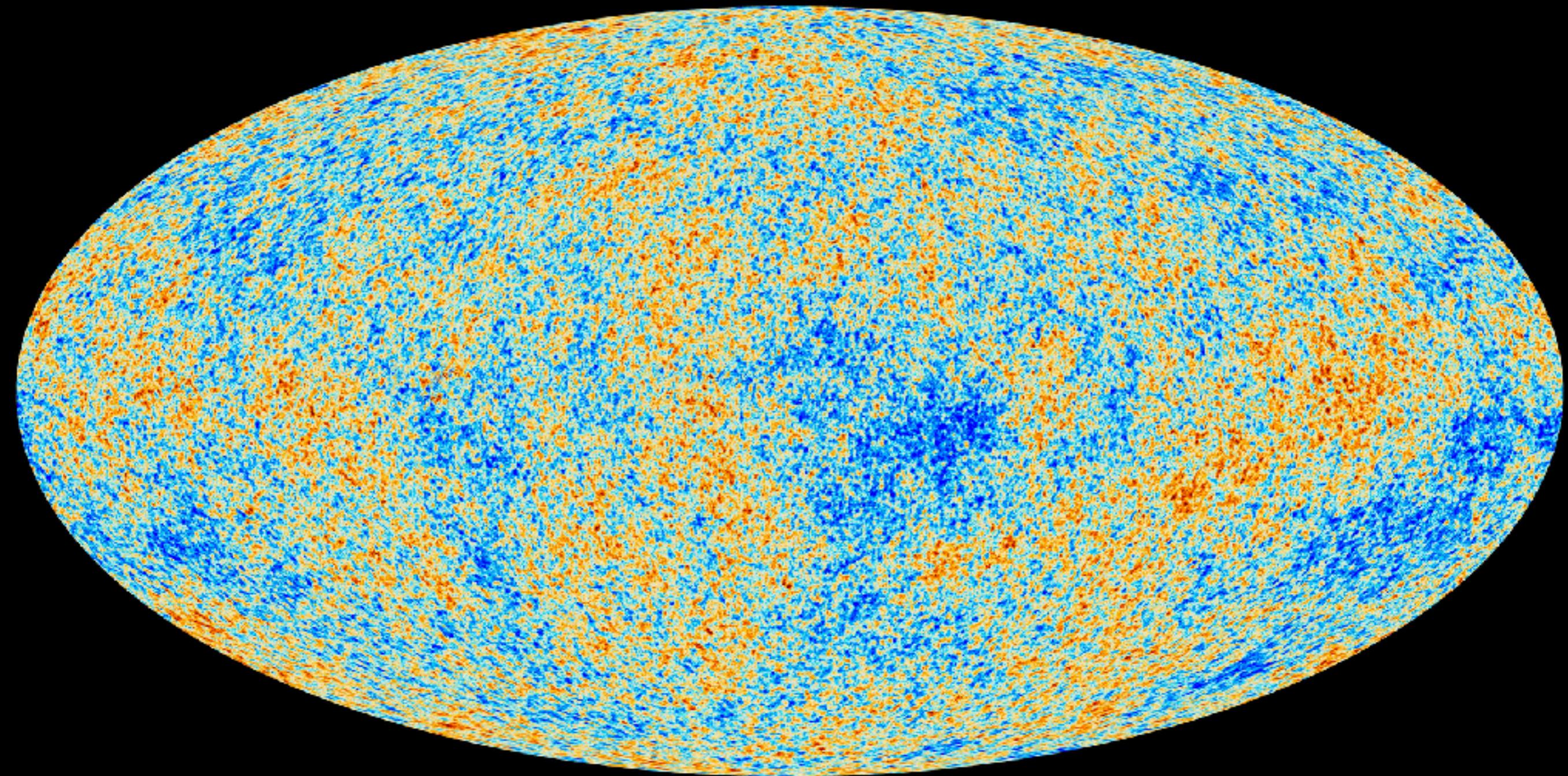
Course Material	<p>Presentations (uploaded beforehand)</p> <p>Lecture Notes by Prof. Norbert Langer (see website)</p> <p>B. E. J. Pagel <i>Nucleosynthesis and Chemical Evolution of Galaxies</i> 1997, University Press, ISBN 0 521 55958 8</p> <p>D. D. Clayton <i>Principles of Stellar Evolution and Nucleosynthesis</i> 1968, University of Chicago Press, ISBN 0 226 10953 4</p> <p>C. Iliadis <i>Nuclear Physics of Stars</i> 2015, Wiley, ISBN 978 3 527 33648 7</p>
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Evaluation

1. comprehension of material
2. ability to follow literature
3. presentation skills

- Read material beforehand and e-mail at least 3 non-trivial questions before **Wednesday @ 13:00** **email to janton@mpifr.de; use subject heading [Nuc] - Lecture N** **25%**
- Lectures and Exercise (compulsory attendance) **25%**
- Student presentations on nucleosynthesis papers
List of papers can be found @ www.astro.uni-bonn.de/~janton/nuc.html **50%**
10' presentations; more details to follow from tutors

Overview



Overview



Overview

Goal: explain the distribution of isotopic abundances in the Universe

• Lecture 1: Introduction & overview	April 11
• Lecture 2: Thermonuclear reactions	April 18
• Lecture 3: Big-bang nucleosynthesis	April 25
• Lecture 4: Hydrostatic nucleosynthesis inside stars – I (H-burning)	May 2
• Lecture 5: Thermonuclear reactions inside stars – II (advanced burning)	May 9
• Lecture 6: Neutron-capture and supernovae – I (s–process)	May 16
• Lecture 7: Neutron-capture and supernovae – II (r– and p–process)	May 23
• Lecture 8: Thermonuclear supernovae	May 30
• Lecture 9: Li, Be and B	June 6
• Lecture 10: Galactic chemical evolution and relation to astrobiology	June 13
Paper presentations I	June 20
Paper presentations II	July 4

Chemical elements

1 IA 1A	H Hydrogen 1.001	2 IIA 2A	3 Li Lithium 6.941	4 Be Beryllium 9.032	5 VB 5B	6 VIB 6B	7 VIIIB 7B	8	9 VIII 8	10	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
11 Na Sodium 22.990	12 Mg Magnesium 24.305	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIIB 7B	8	9 VIII 8	10	11 IB 1B	12 IIB 2B	13 Al Aluminum 26.982	14 Si Silicon 28.095	15 P Phosphorus 30.974	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.949	
19 K Potassium 39.090	20 Ca Calcium 40.070	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.980	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.720	32 Ge Germanium 72.031	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798	
37 Rb Rubidium 64.466	38 Sr Strontium 69.983	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.925	43 Tc Technetium 96.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.866	48 Cd Cadmium 112.414	49 In Indium 114.016	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.296	
55 Cs Cesium 132.905	56 Ba Barium 137.329	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.949	74 W Tungsten 183.84	75 Re Rhenium 186.217	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.065	79 Au Gold 196.967	80 Hg Mercury 204.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.900	84 Po Polonium 209.903	85 At Astatine 216.907	86 Rn Radon 222.010	
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (265)	107 Bh Bohrium (264)	108 Hs Hassium (269)	109 Mt Mertensium (266)	110 Ds Darmstadtium (268)	111 Rg Roentgenium (270)	112 Cn Copernicium (272)	113 Uut Ununtrium unknown	114 Fl Florium unknown	115 Uup Ununpentium unknown	116 Lv Livermorium unknown	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown	

Periodic Table of the Elements

Atomic Number	Valence Charge
Symbol	Name
Atomic Mass	

Lanthanide Series

57 La Lanthanum 130.905	58 Ce Cerium 140.119	59 Pr Praseodymium 140.909	60 Nd Neodymium 144.243	61 Pm Promethium 147.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 159.265	66 Dy Dysprosium 162.500	67 Ho Holmium 164.920	68 Er Erbium 167.259	69 Tm Thulium 169.924	70 Yb Ytterbium 173.052	71 Lu Lutetium 174.967
89 Ac Actinium 227.020	90 Th Thorium 232.039	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 239.029	94 Pu Plutonium 244.036	95 Am Americium 243.031	96 Cm Curium 247.370	97 Bk Berkelium 247.370	98 Cf Californium 251.360	99 Es Lingensium 257.024	100 Fm Fermium 257.025	101 Md Mendelevium 259.1	102 No Nobelium 259.101	103 Lr Lawrencium (260)

Alkali Metal

Alkaline Earth

Transition Metal

Basic Metal

Semimetal

Nonmetal

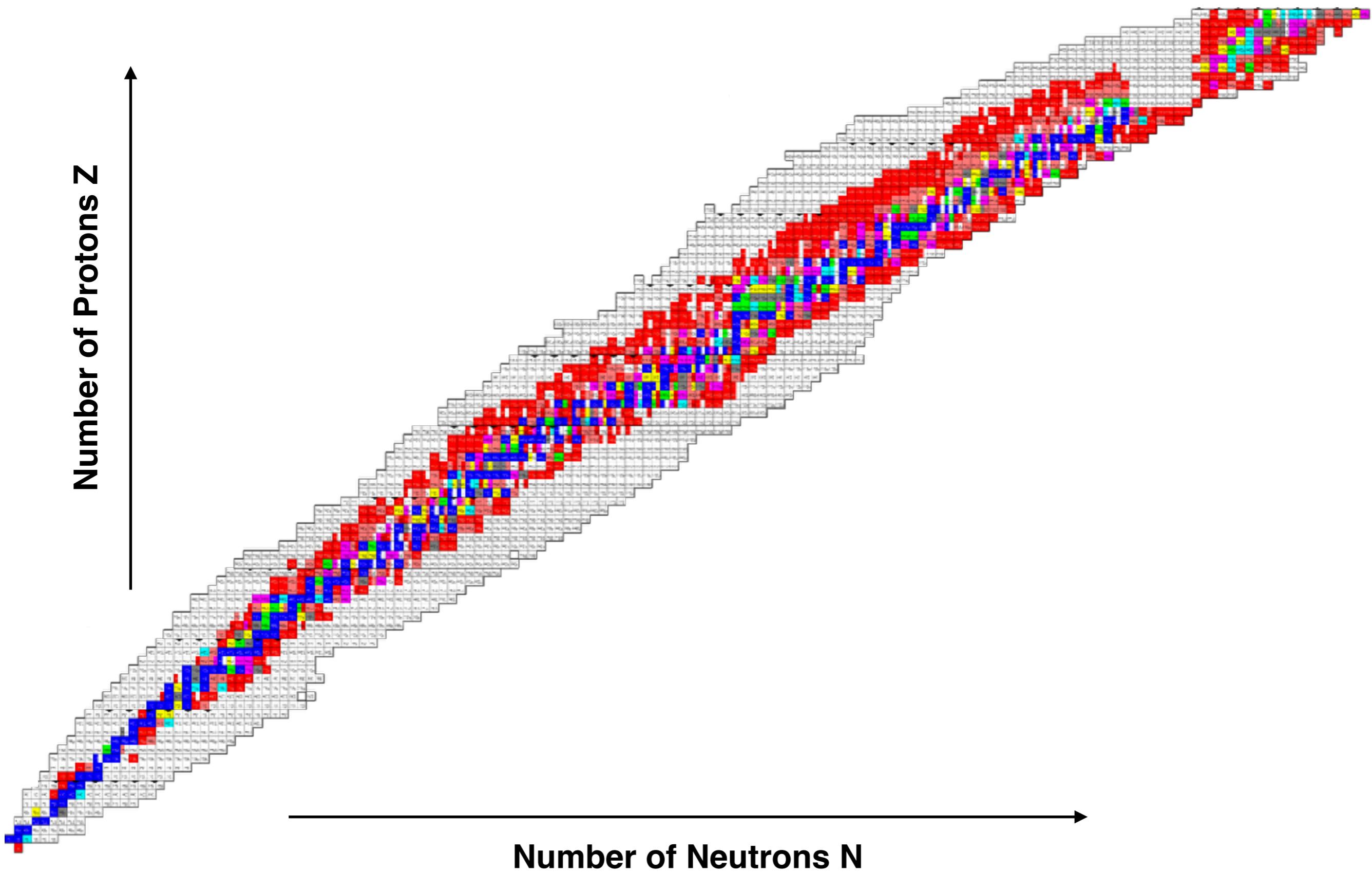
Halogen

Noble Gas

Lanthanide

Actinide

Isotopes



Nuclear abundances

Definitions

$$\text{He} \rightarrow Y \quad X + Y + Z = 1$$

$$\text{Metals } (A > 4) \rightarrow Z \quad \sum X_i = 1$$

$$\textbf{By number} \quad N_i = X_i/A_i$$

$$N_{\mathrm{H}} = 10^{12}$$

$$A_{\mathrm{H}} = \log(N_{\mathrm{H}}) = 12$$

$$E_X = A_X - A_H = \log(N_X/N_H)$$

Relative to solar $(X_i/X_j)_\odot$

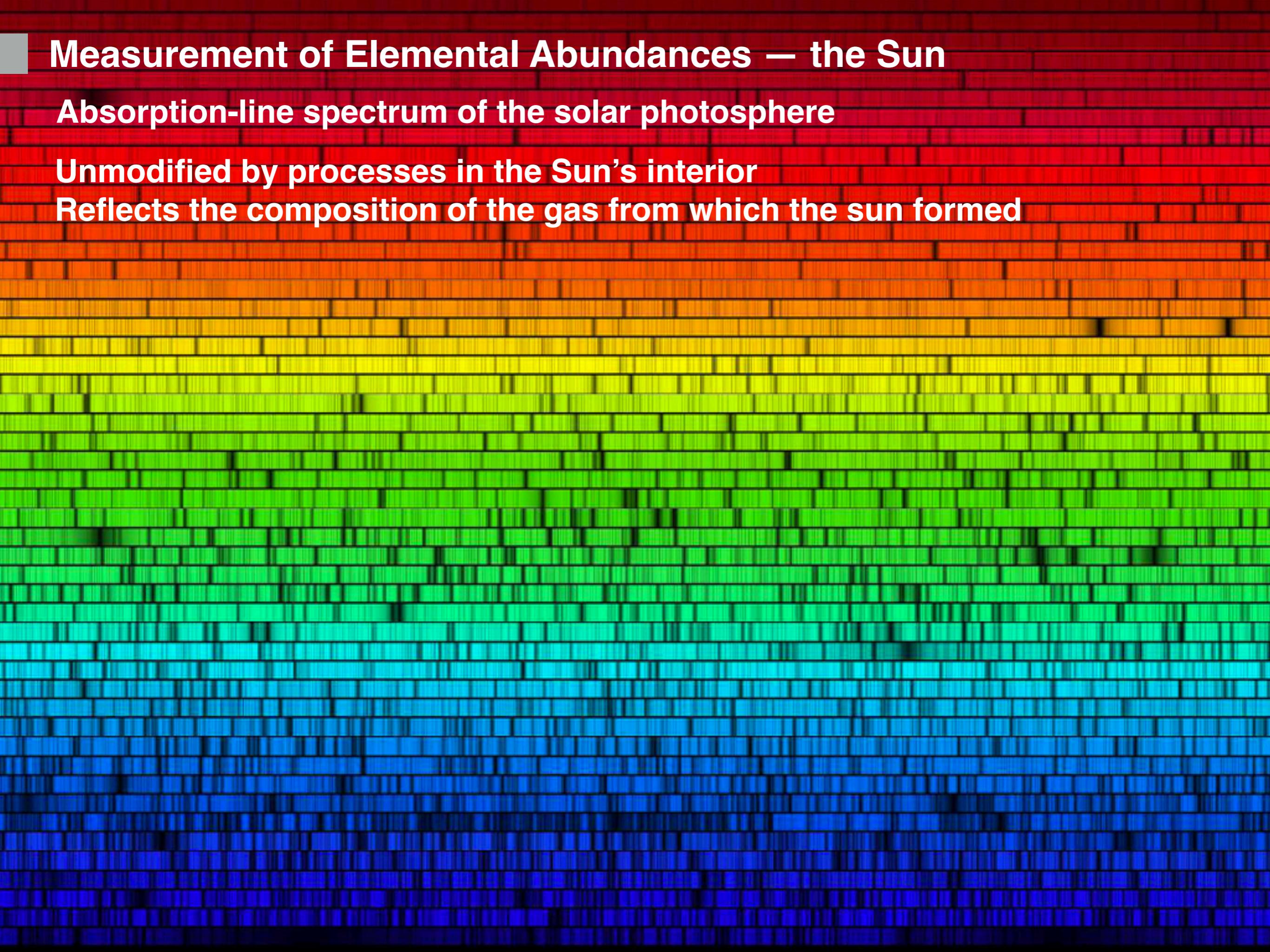
$$[X_i/X_j] = \log(X_i/X_j) - \log(X_i/X_j)_\odot \rightarrow [X_i/X_j]_\odot = 0$$

Measurement of Elemental Abundances – the Sun

Absorption-line spectrum of the solar photosphere

Unmodified by processes in the Sun's interior

Reflects the composition of the gas from which the sun formed



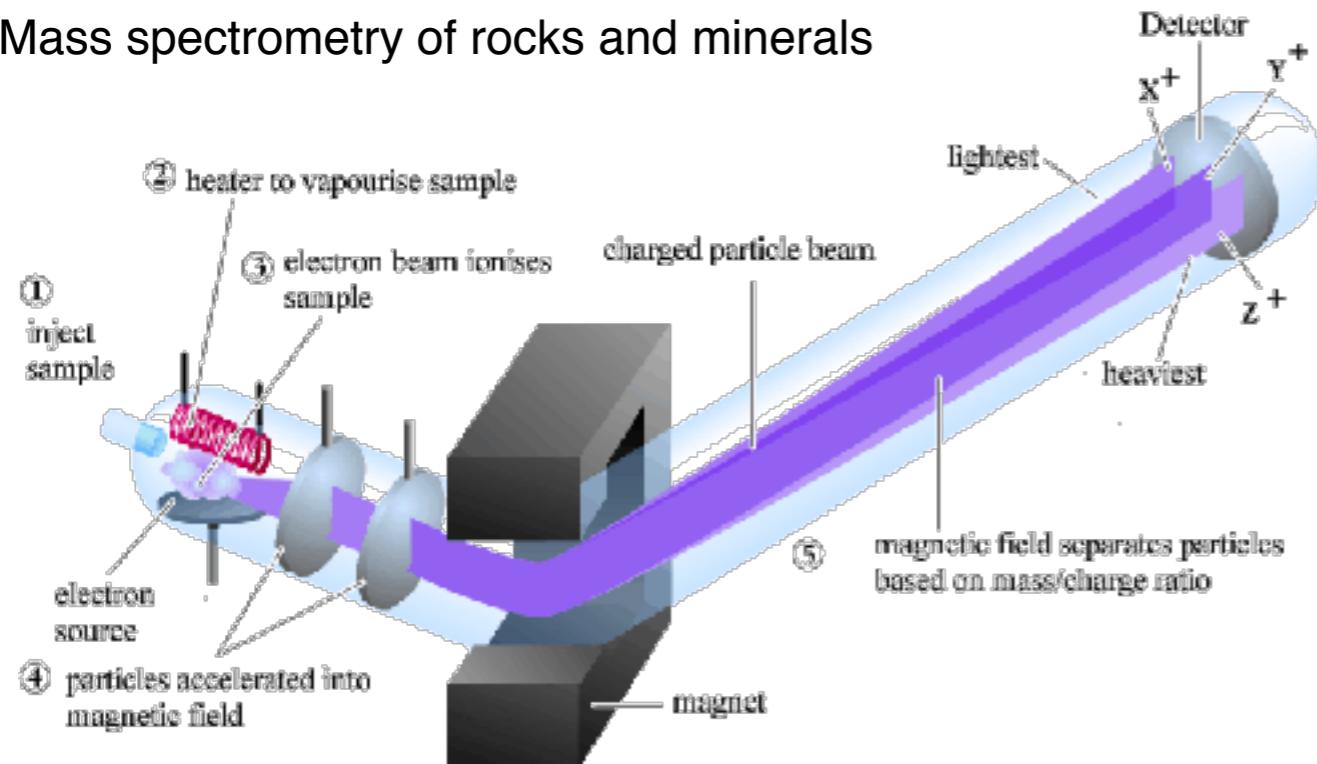
Measurement of Elemental Abundances — the Sun

“Metals”

Element	Abundance (pct. of total number of atoms)	Abundance (pct. of total mass)
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	0.030	0.014
Sulfur	0.015	0.040

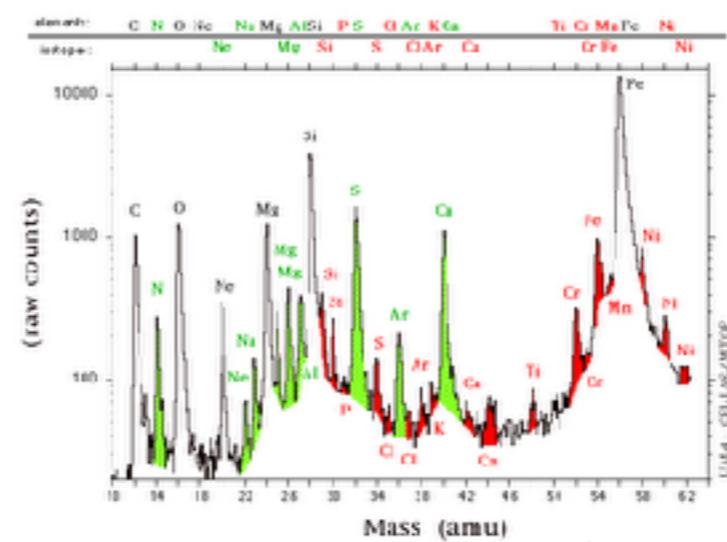
Measurement of Elemental Abundances — Isotopes

Mass spectrometry of rocks and minerals



Solar wind

Solar Wind Elements/Isotopes Observed by CELIAS MTOP



Elemental Abundances — Meteorites

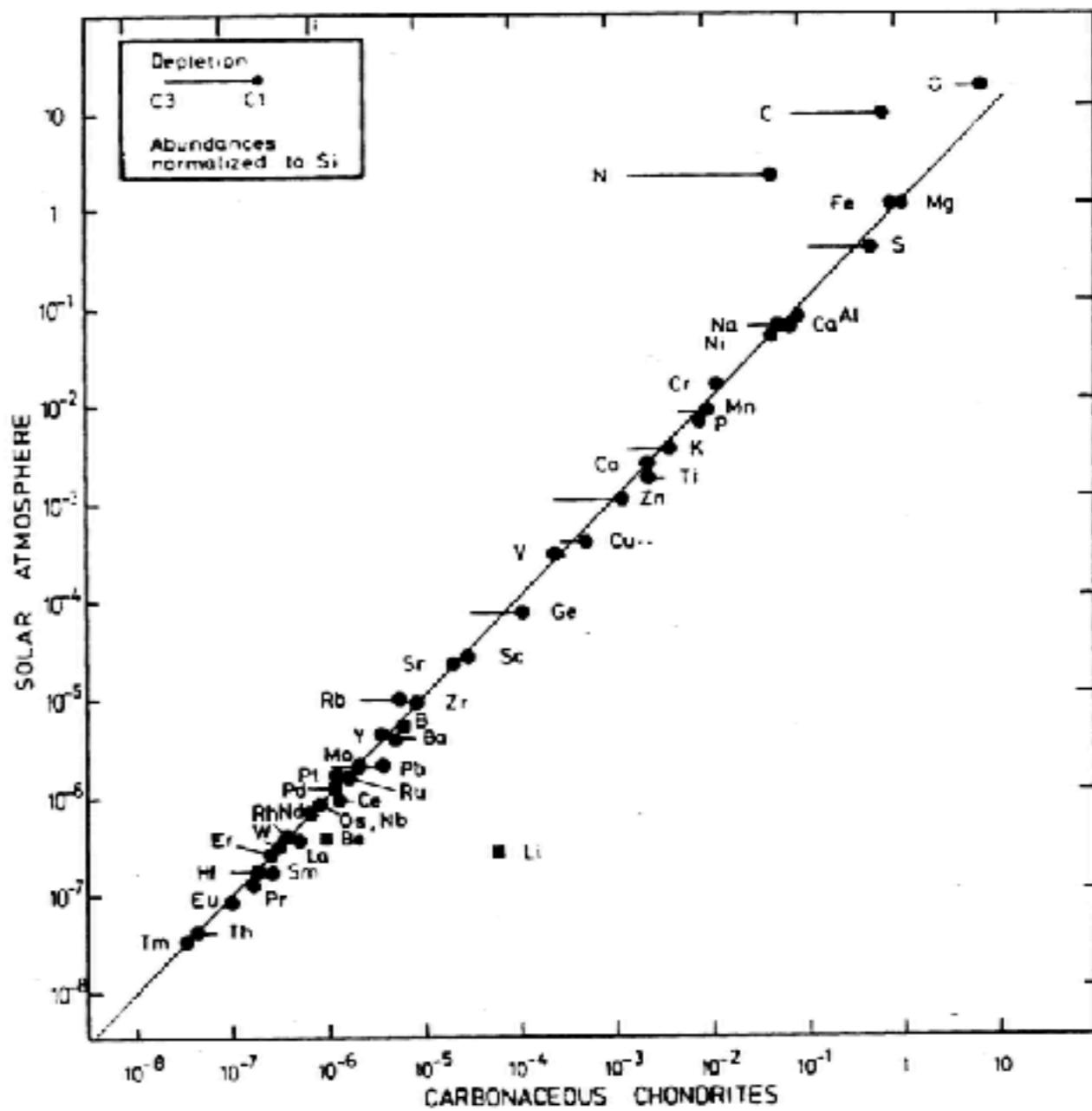
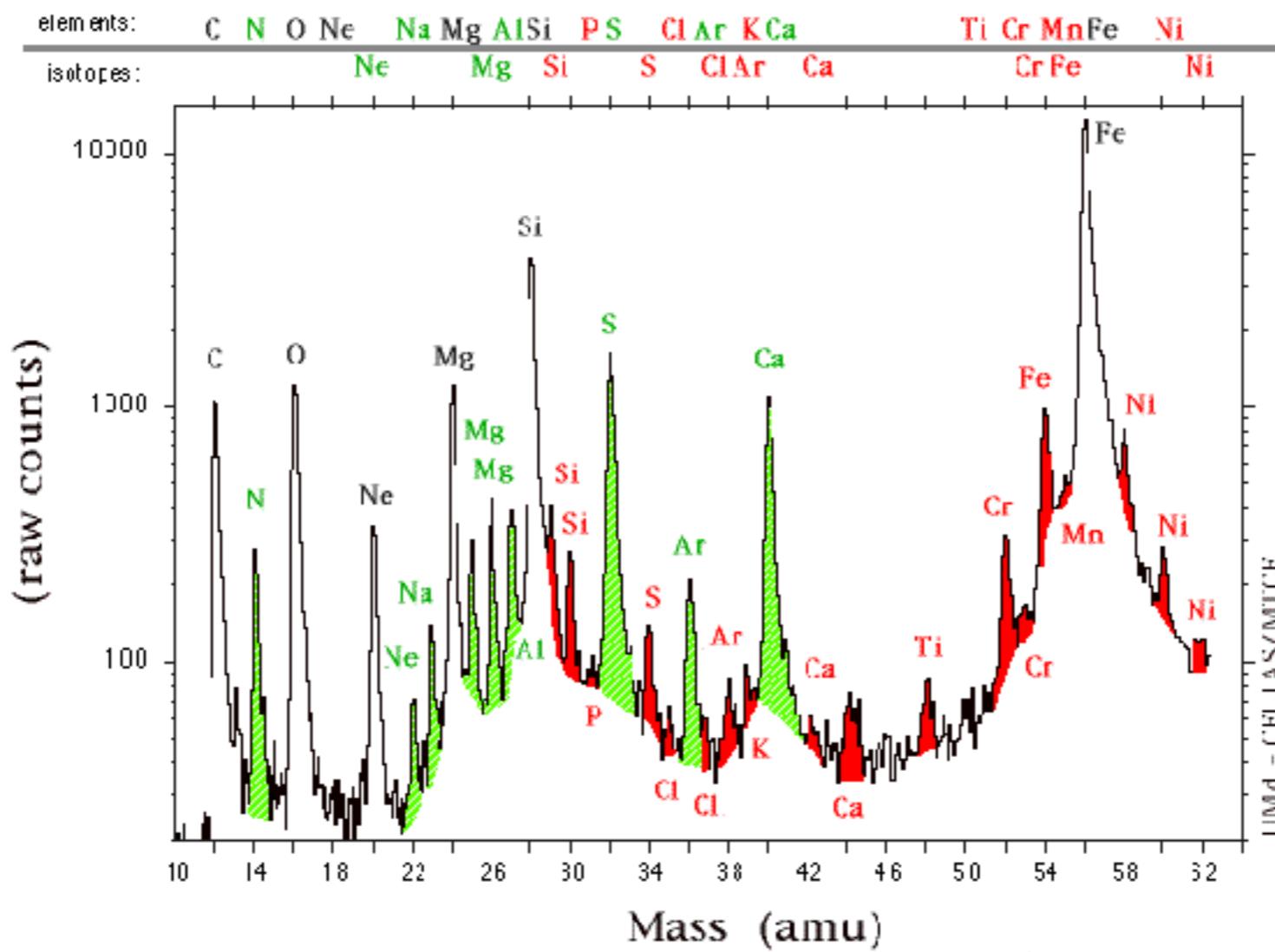


Figure 7.7. Abundances in the Solar Atmosphere Compared with those in C1 and C3 Carbonaceous Chondrites. Courtesy H. Holweger and International Astronomical Union.

Cosmic Abundances

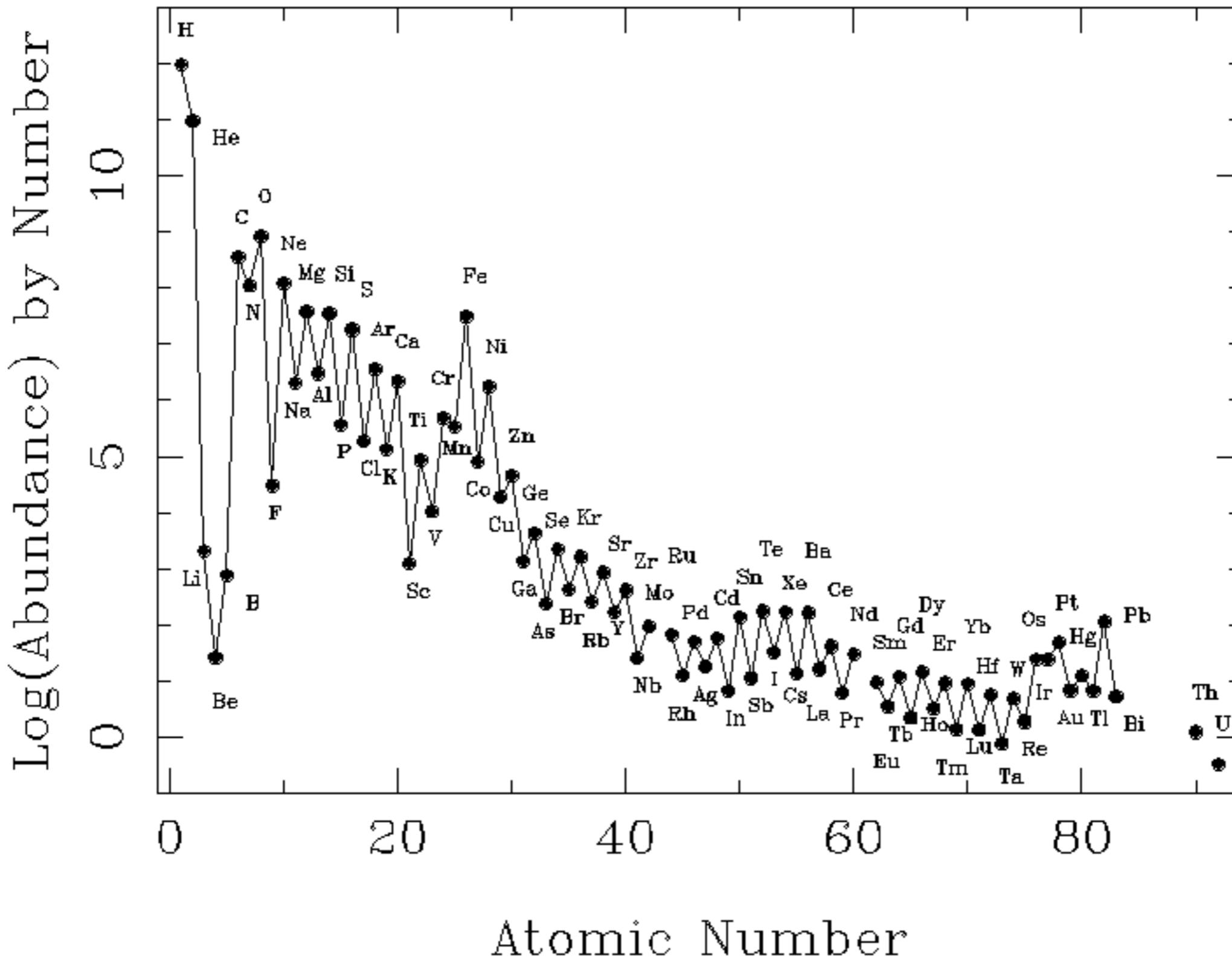
Homogeneous solar system composition

Solar Wind Elements/Isotopes Observed by CELIAS MTOF

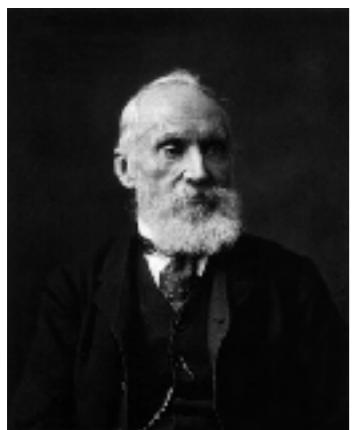


Cosmic abundances

Logarithmic SAD Abundances: $\text{Log}(\text{H}) = 12.0$

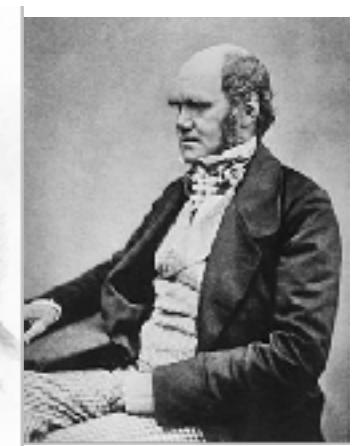


Early insights



William Thomson, 1st Baron Kelvin

Age of the Sun and Earth: 20 million years (cooling / gravitational contraction)



Charles Darwin, Charles Lyell, Arthur Holme
Geology and evolution require billions of years

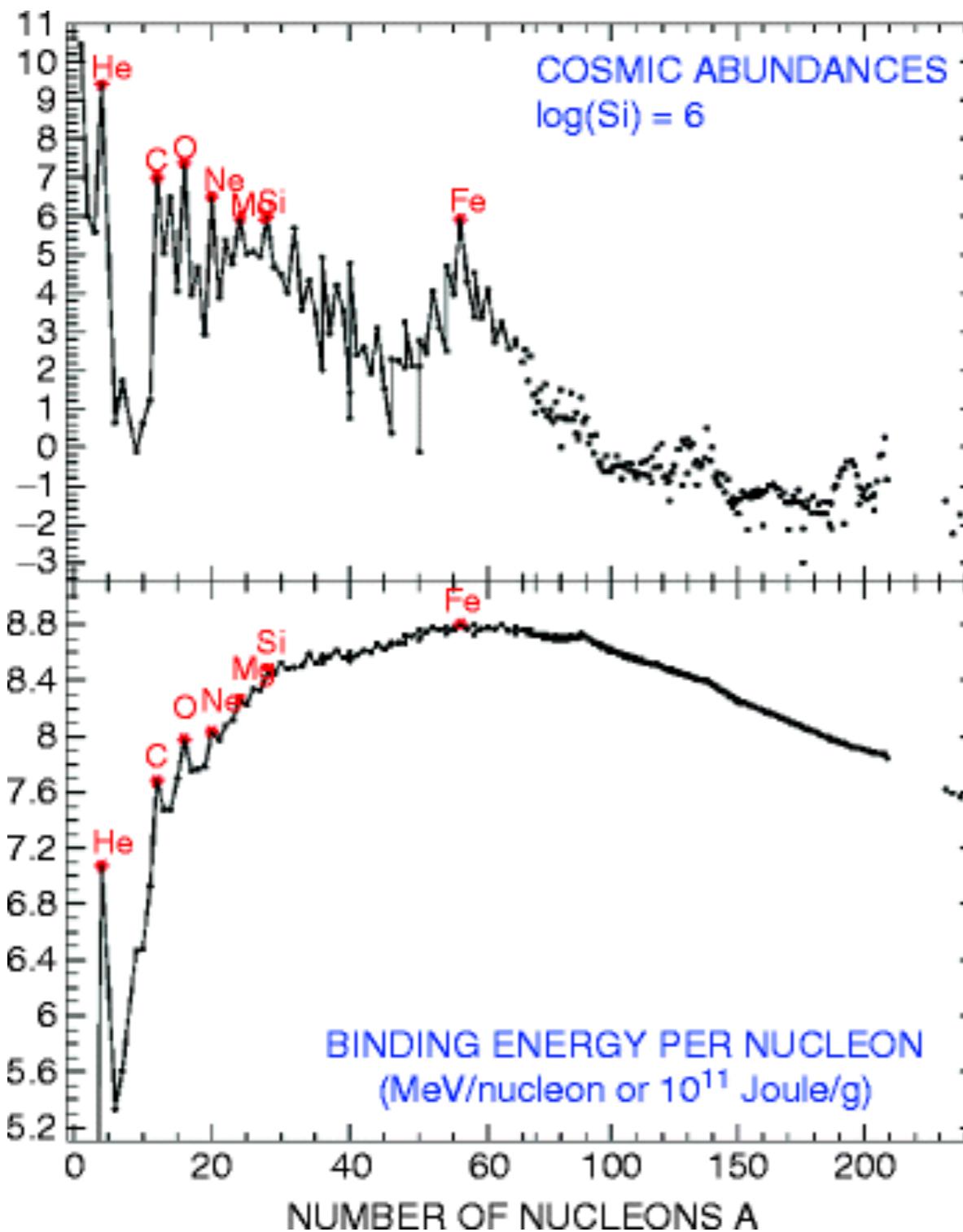


Albert Einstein, Arthur Eddington, Marie Curie (et al.)
energy/mass equivalence, radioactivity, fusion in stars

Friedrich Hund, Robert Atkinson, Fritz Houtermans (et al.)
Quantum tunnelling, energy release from fusion can provide energy source for stars



Abundances and nuclear processes



Elemental abundances are correlated with a fundamental property of the nucleus

“Magic” nuclei (A : multiple of 4) or α -nuclei are locally more stable and more abundant than neighbours

Conclusion

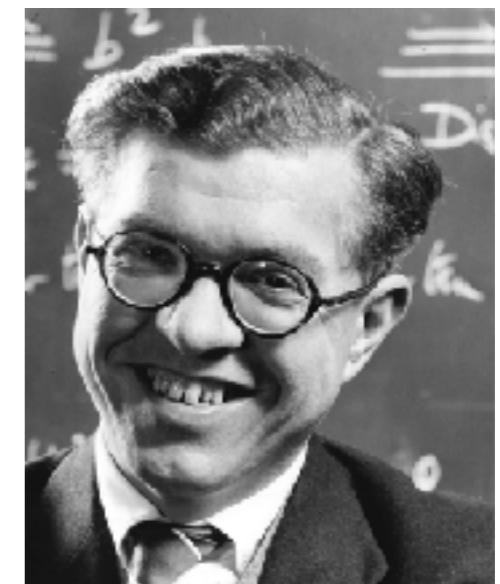
Abundances of chemical elements depend on nuclear processes

Where does nucleosynthesis take place?

Nuclei need to overcome the Coulomb barrier to interact → High temperatures (MKelvin)

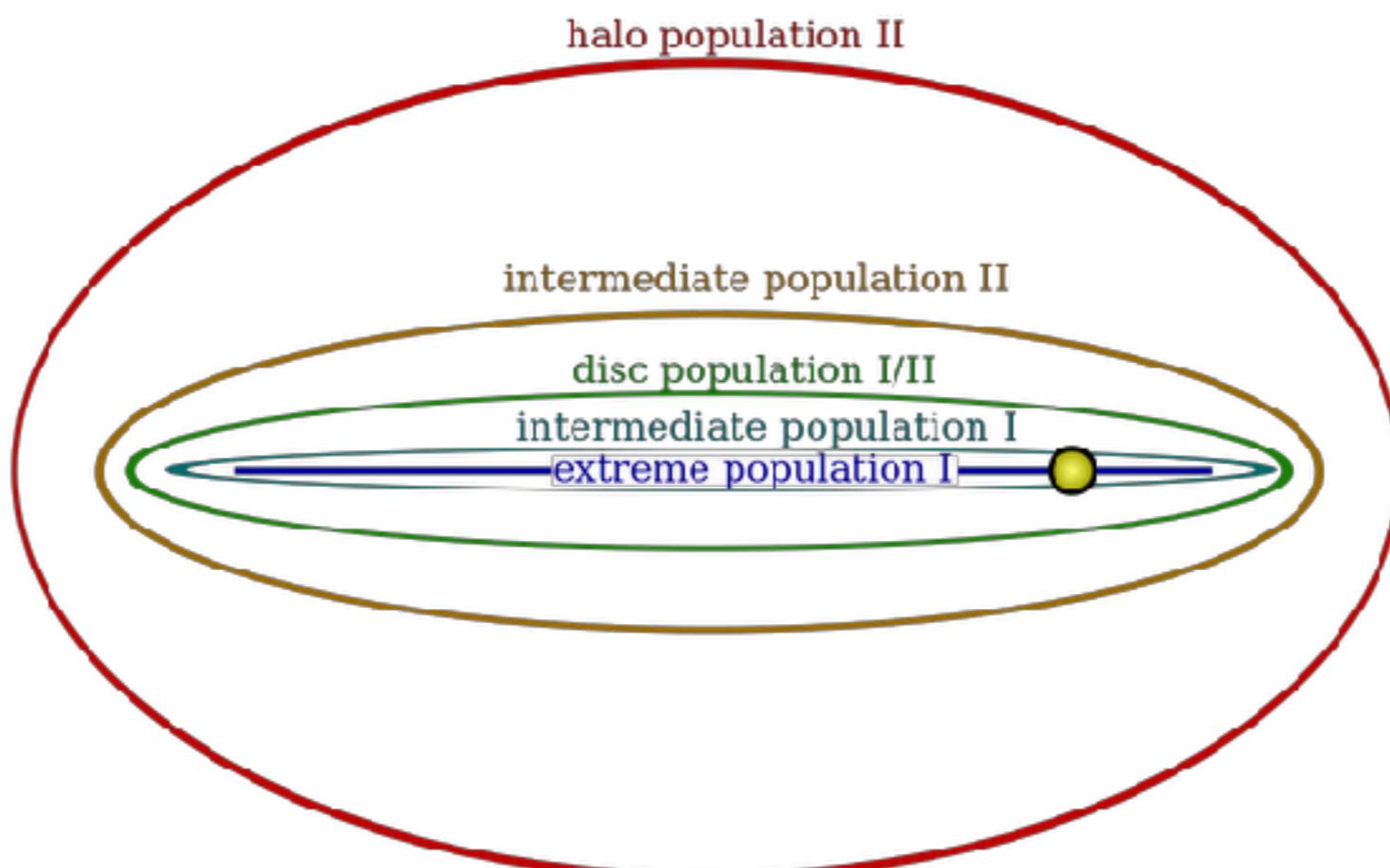


George Gamow (1904–1968)
Elements formed during the Big Bang

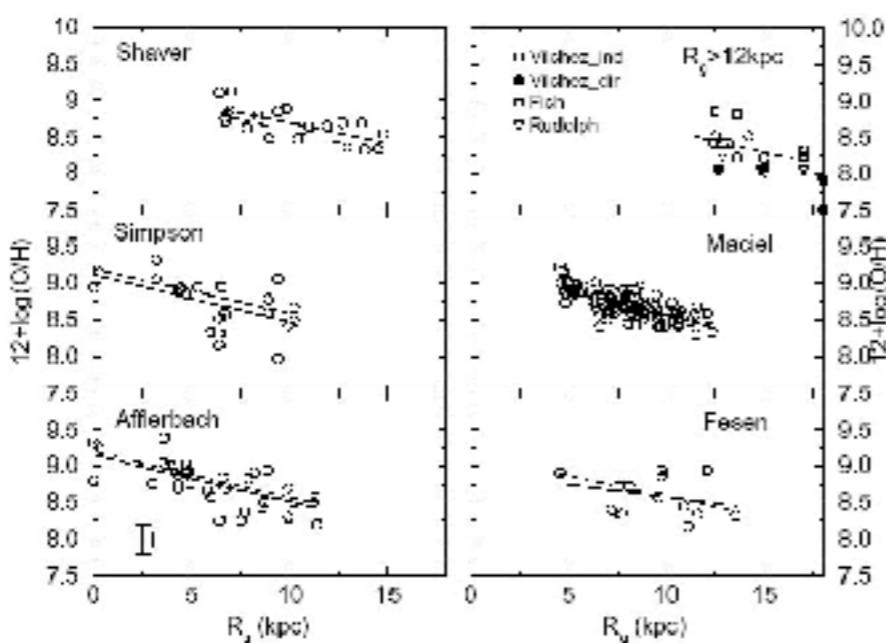


Fred Hoyle (1915–2001)
Elements form inside stars and in supernovae

Observational evidence



Distribution of Star Populations
in Milky Way



Evidence for evolution with time
Stars near the galactic disk have higher metallicities than stars in the halo

Nucleosynthesis inside stars



Hans Albrecht Bethe (1906 – 2005)
pp-chains and CNO cycle inside stars

Thermonuclear reactions



REVIEWS OF
MODERN PHYSICS

VOLUME 29, NUMBER 4

OCTOBER, 1957

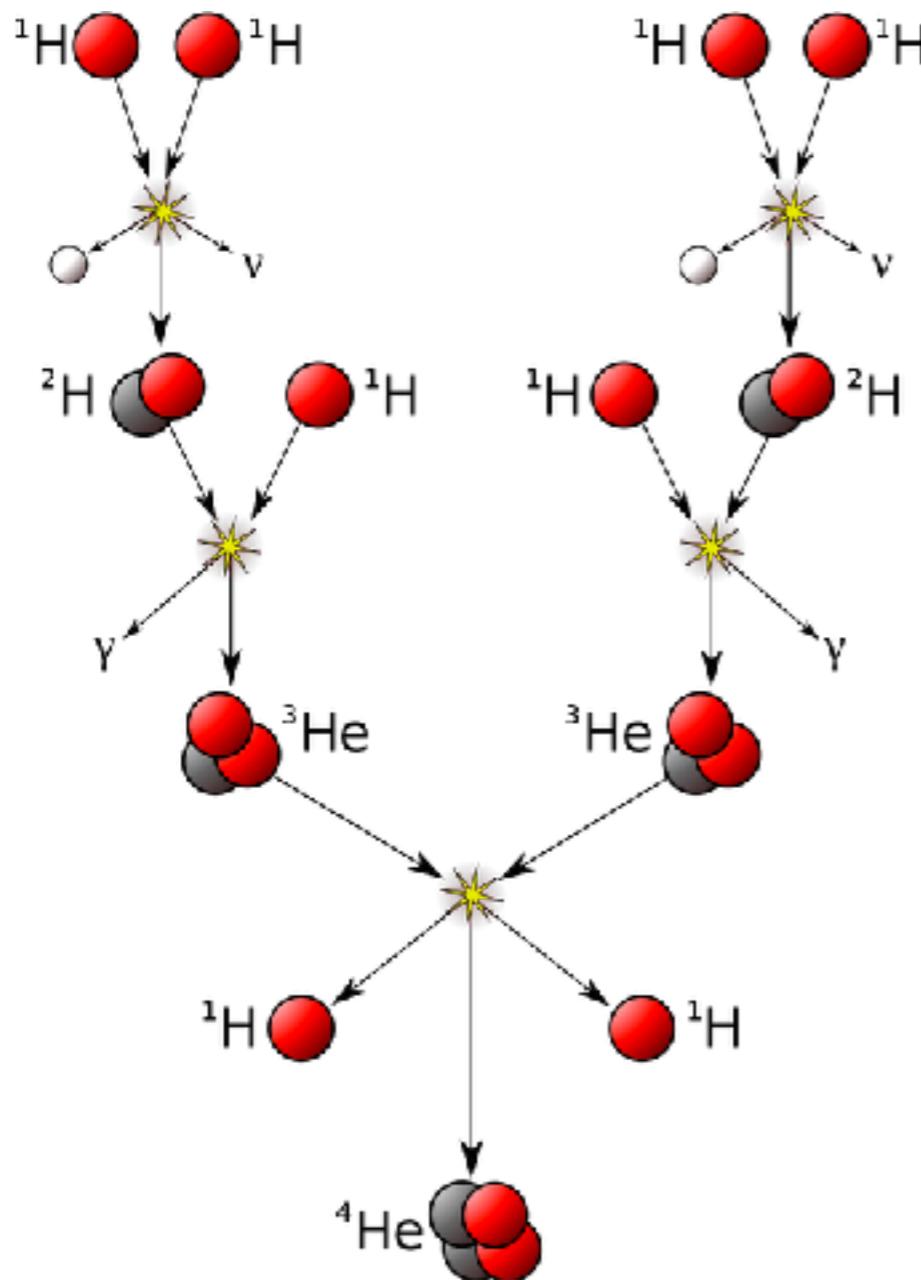
Synthesis of the Elements in Stars *

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

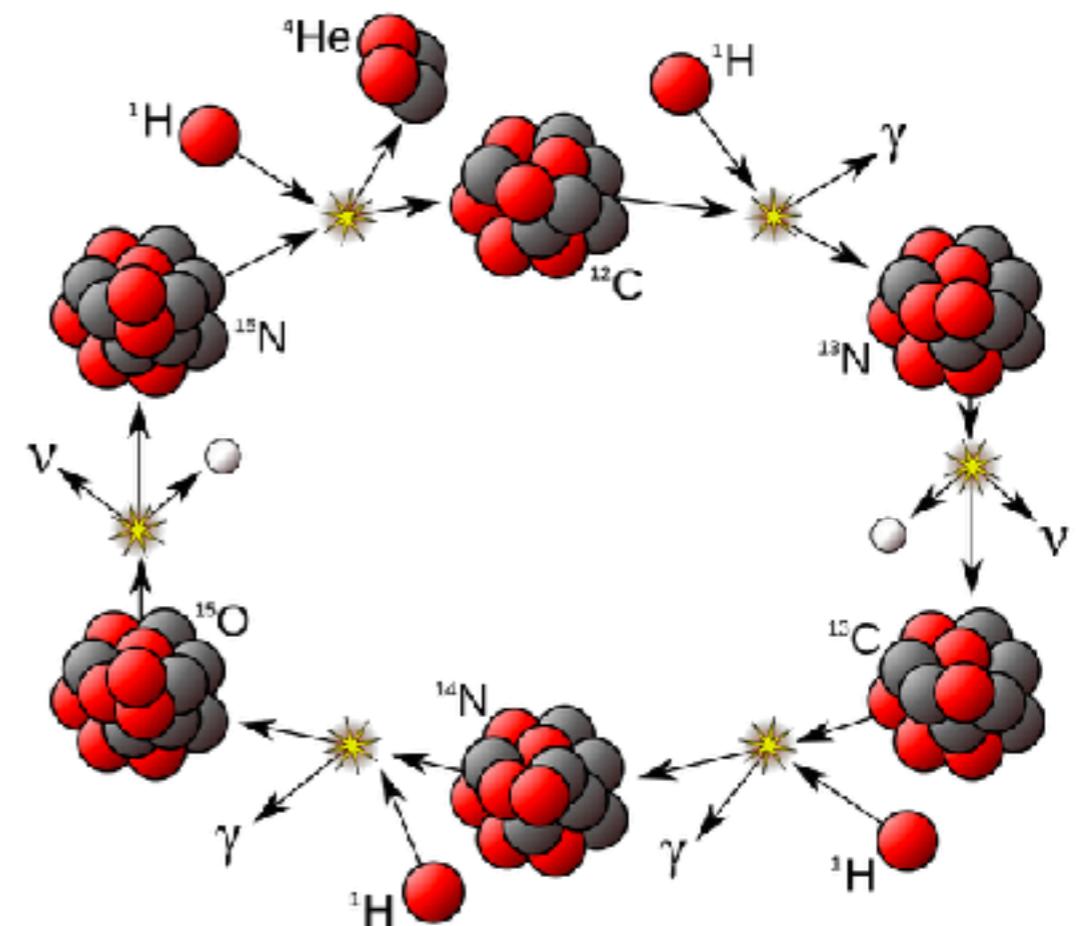


Hydrogen burning

proton-proton chains



CNO-I cycle



	Proton	γ	Gamma Ray
	Neutron	ν	Neutrino
	Positron		

Logistics

Course Overview

