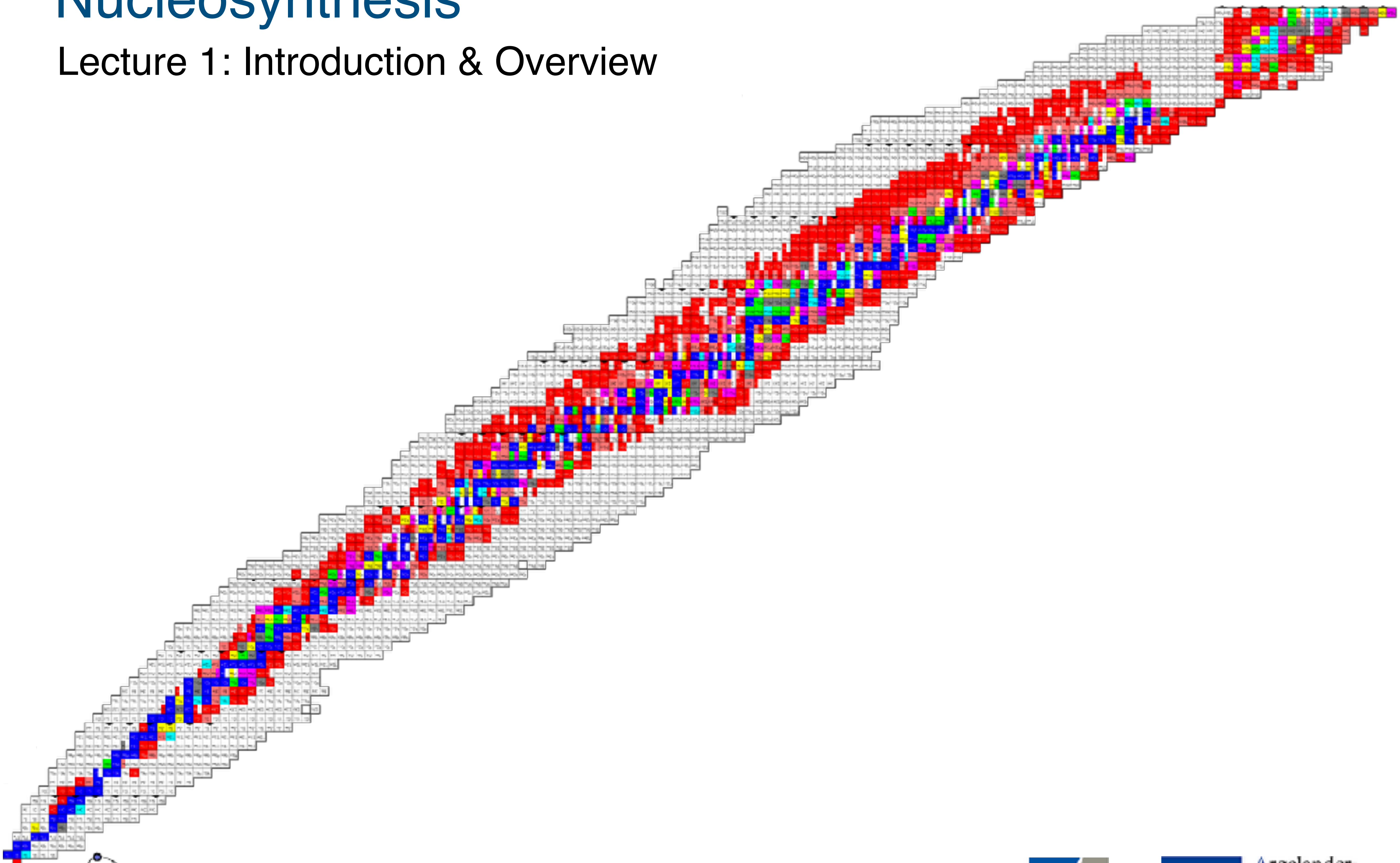
Nucleosynthesis

Lecture 1: Introduction & Overview



Bonn-Cologne Graduate School of Physics and Astronomy

UNIVERSITÄT BONN

Argelander-Institut für Astronomie

Logistics

Nucleosynthesis

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

Lectures	Thursdays	@ 11:15 — 12:45	April 11 to July 11	Room	0.008
Exercises	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…

Logistics

Nucleosynthesis

Course Material

Presentations (uploaded beforehand)

Lecture Notes by Prof. Norbert Langer (see website)

B. E. J. Pagel *Nucleosynthesis and Chemical Evolution of Galaxies*
1997, University Press, ISBN 0 521 55958 8

D. D. Clayton *Principles of Stellar Evolution and Nucleosynthesis*
1968, University of Chicago Press, ISBN 0 226 10953 4

C. Iliadis *Nuclear Physics of Stars*
2015, Wiley, ISBN 978 3 527 33648 7

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Evaluation

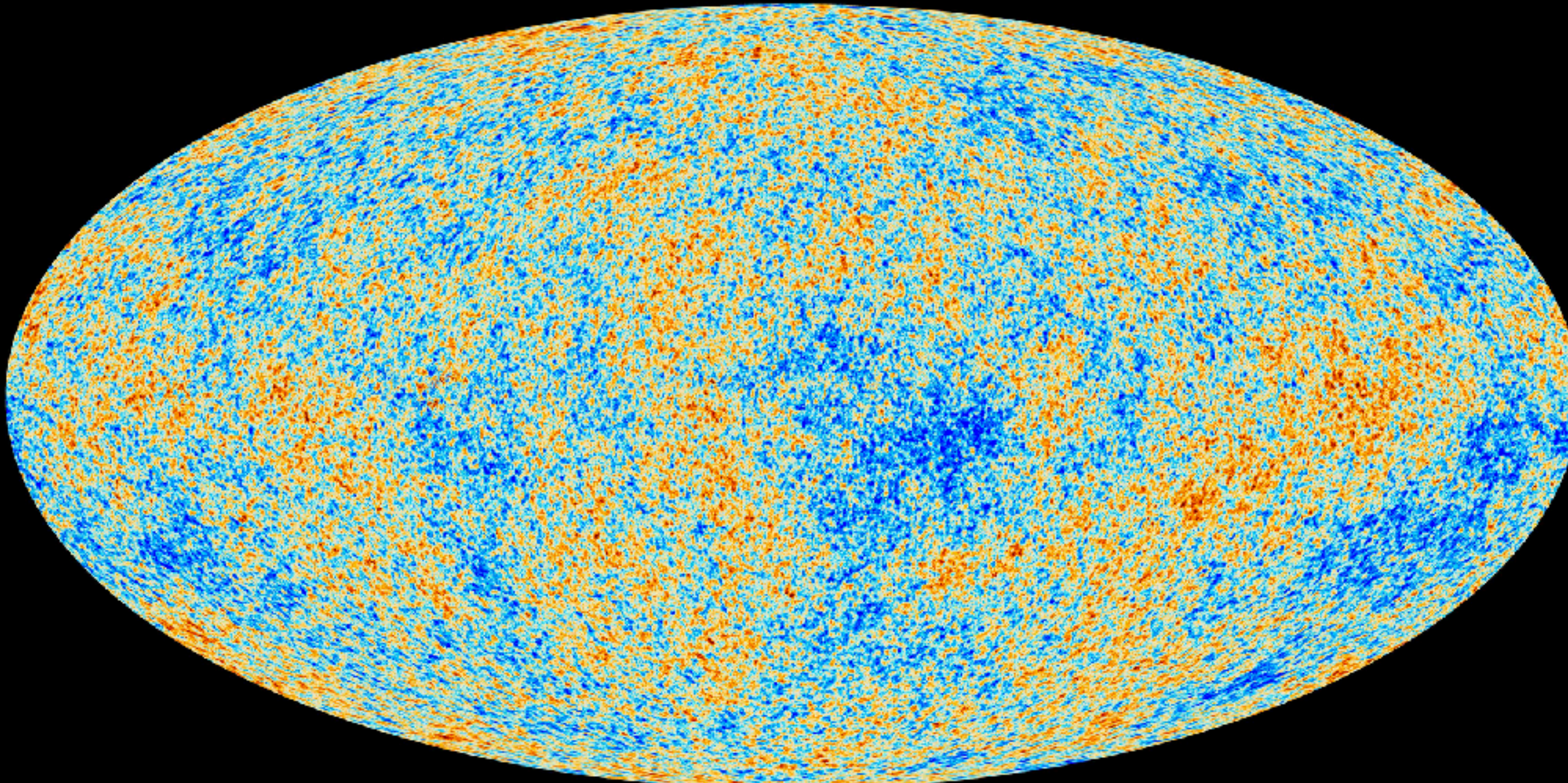
1. **comprehension of material**
2. **ability to follow literature**
3. **presentation skills**

- Read material beforehand and e-mail at least 3 non-trivial questions before **Wednesday @ 13:00** **25%**
  email to janton@mpifr.de; use subject heading [Nuc] - Lecture N

- 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

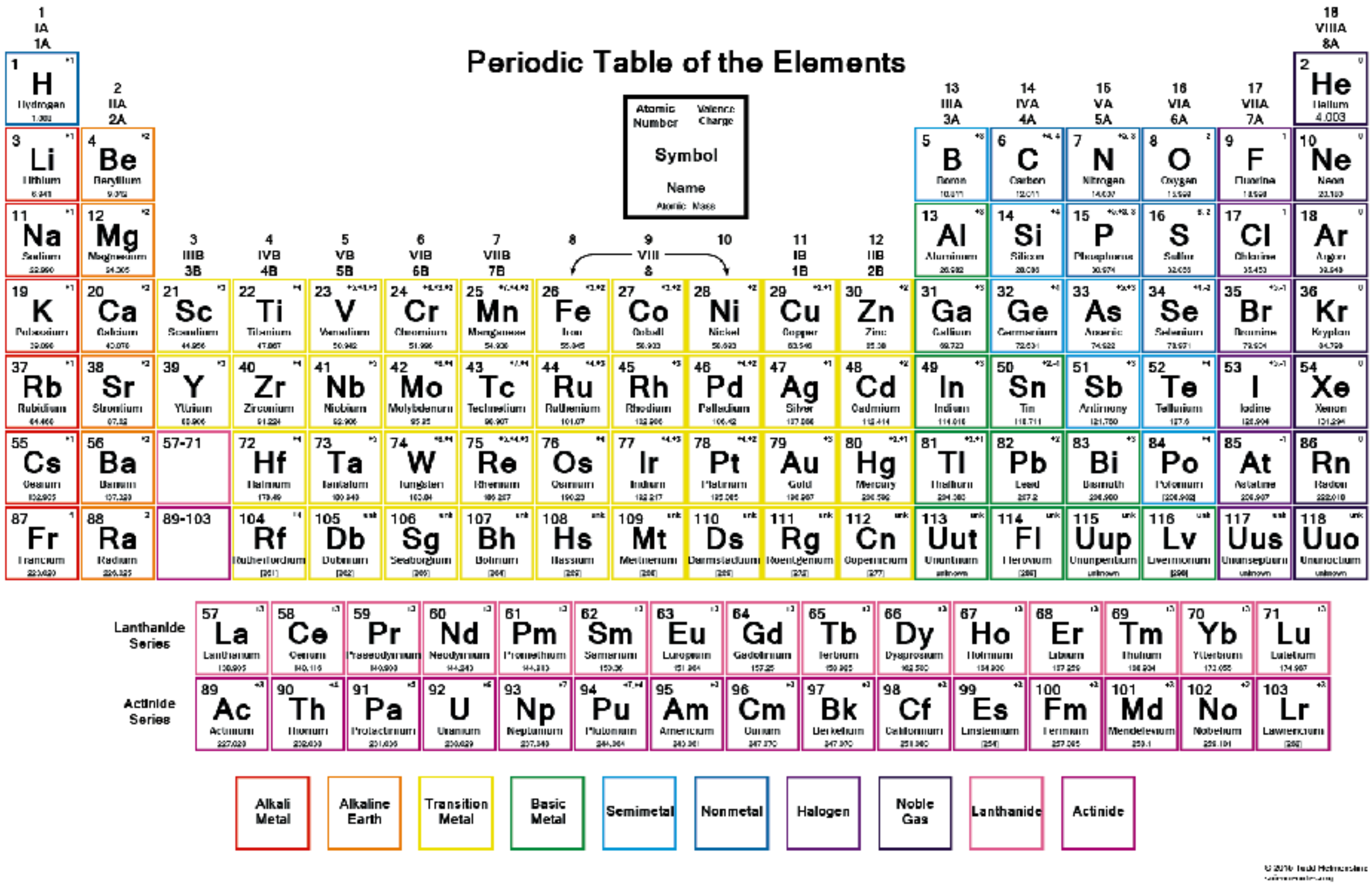
Goal: explain the distribution of isotopic abundances in the Universe

- **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**

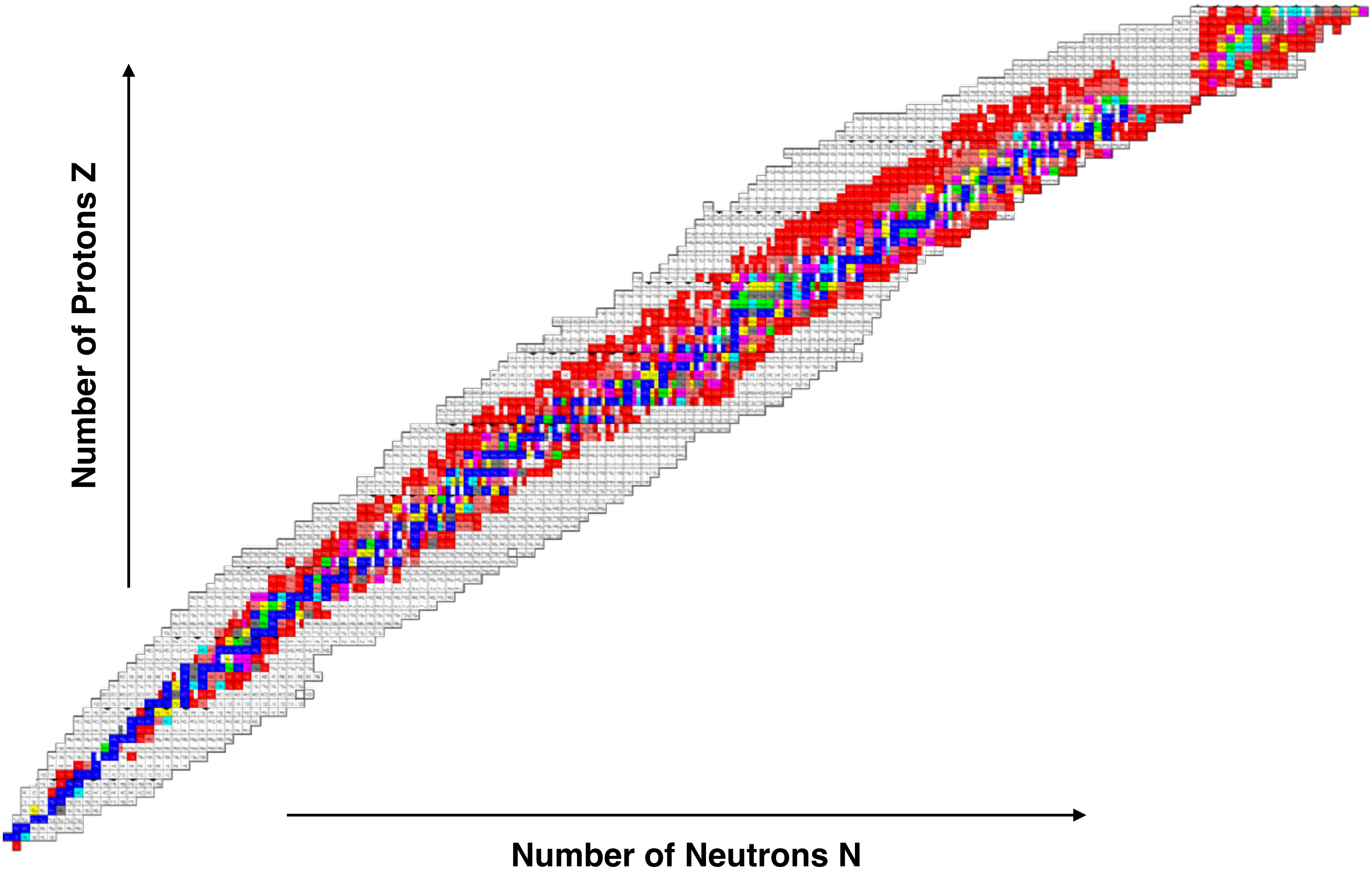
Paper presentations I **June 20**

Paper presentations II **July 4**

Chemical elements



Isotopes



Nuclear abundances

Definitions

By mass fraction

$\mathrm{H} \rightarrow X$

$\mathrm{He} \rightarrow Y$

$\mathrm{Metals}\,(\mathrm{A} > 4) \rightarrow Z$

$\mathrm{Sun}: X_\odot = 0.71;\ Y_\odot = 0.275;\ Z_\odot = 0.015$

$X + Y + Z = 1$

$\sum X_i = 1$

By number

$N_i = X_i / A_i$

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

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

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

Relative to solar

$(X_i/X_j)_\odot$

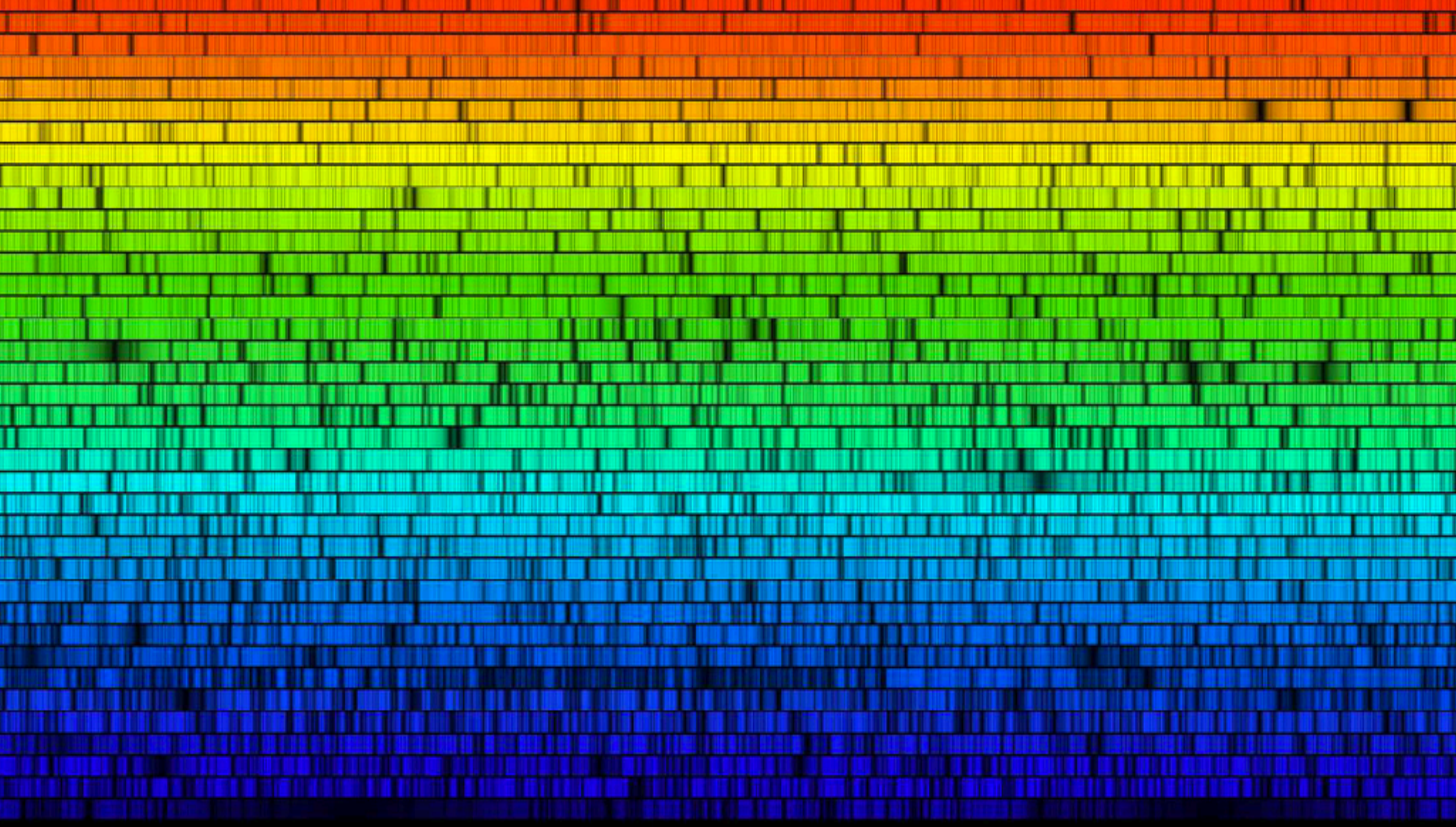
$[X_i/X_j] = log(X_i/X_j) - log(X_i/X_j)_\odot \rightarrow [X_i/X_j]_\odot = 0$

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



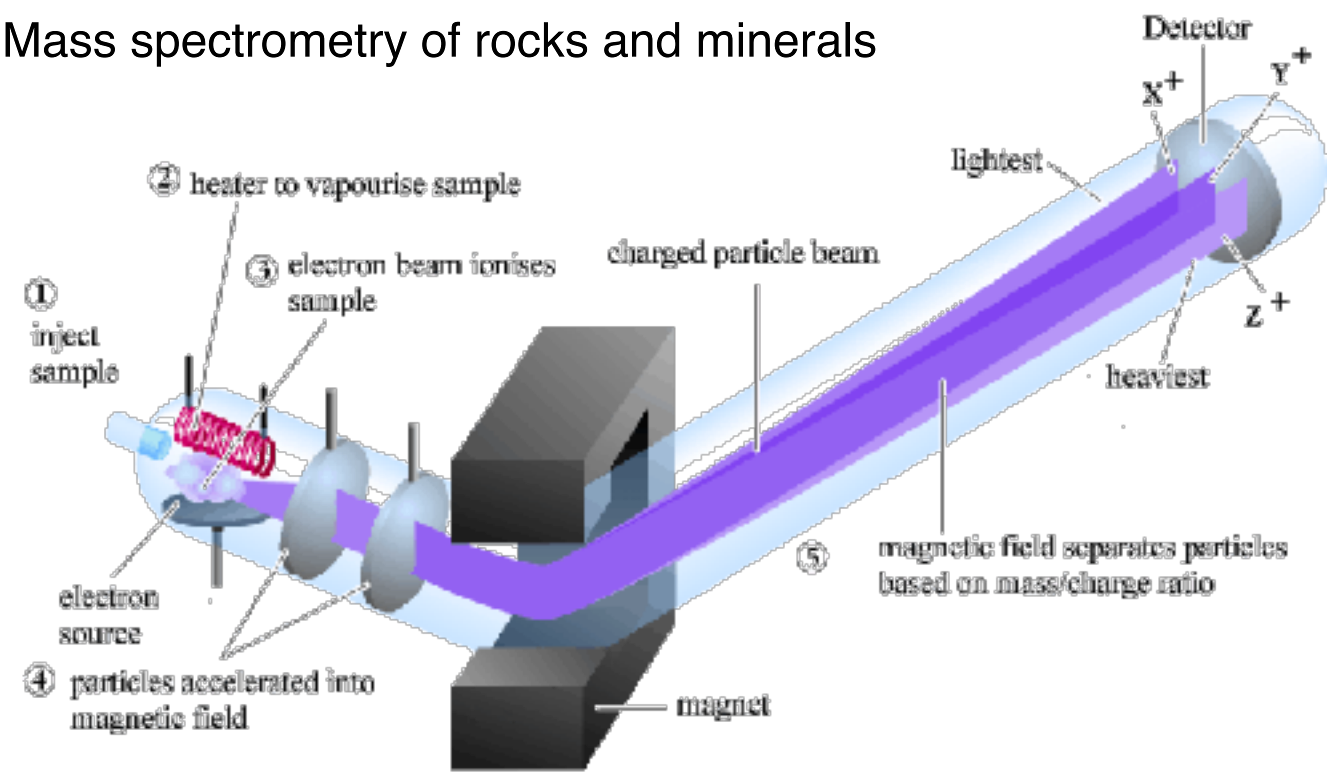
Measurement of Elemental Abundances — the Sun

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

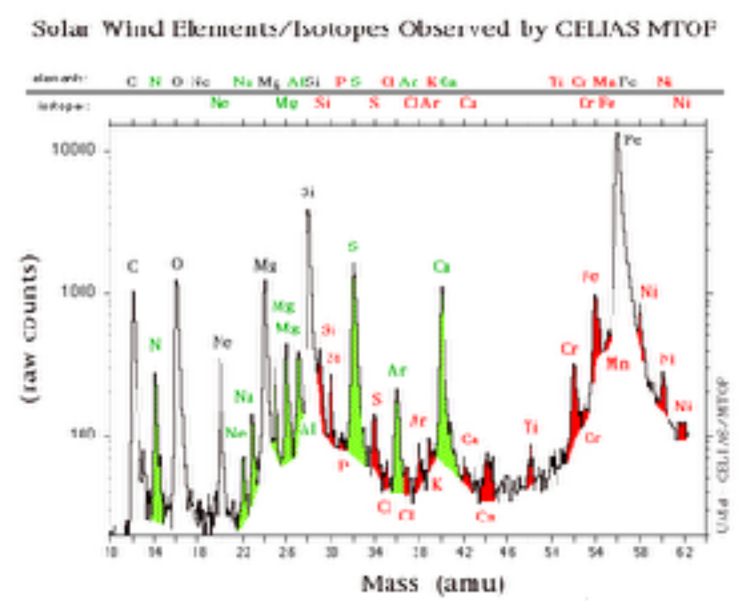
"Metals"

Measurement of Elemental Abundances — Isotopes

Mass spectrometry of rocks and minerals



Solar wind



Elemental Abundances — Meteorites

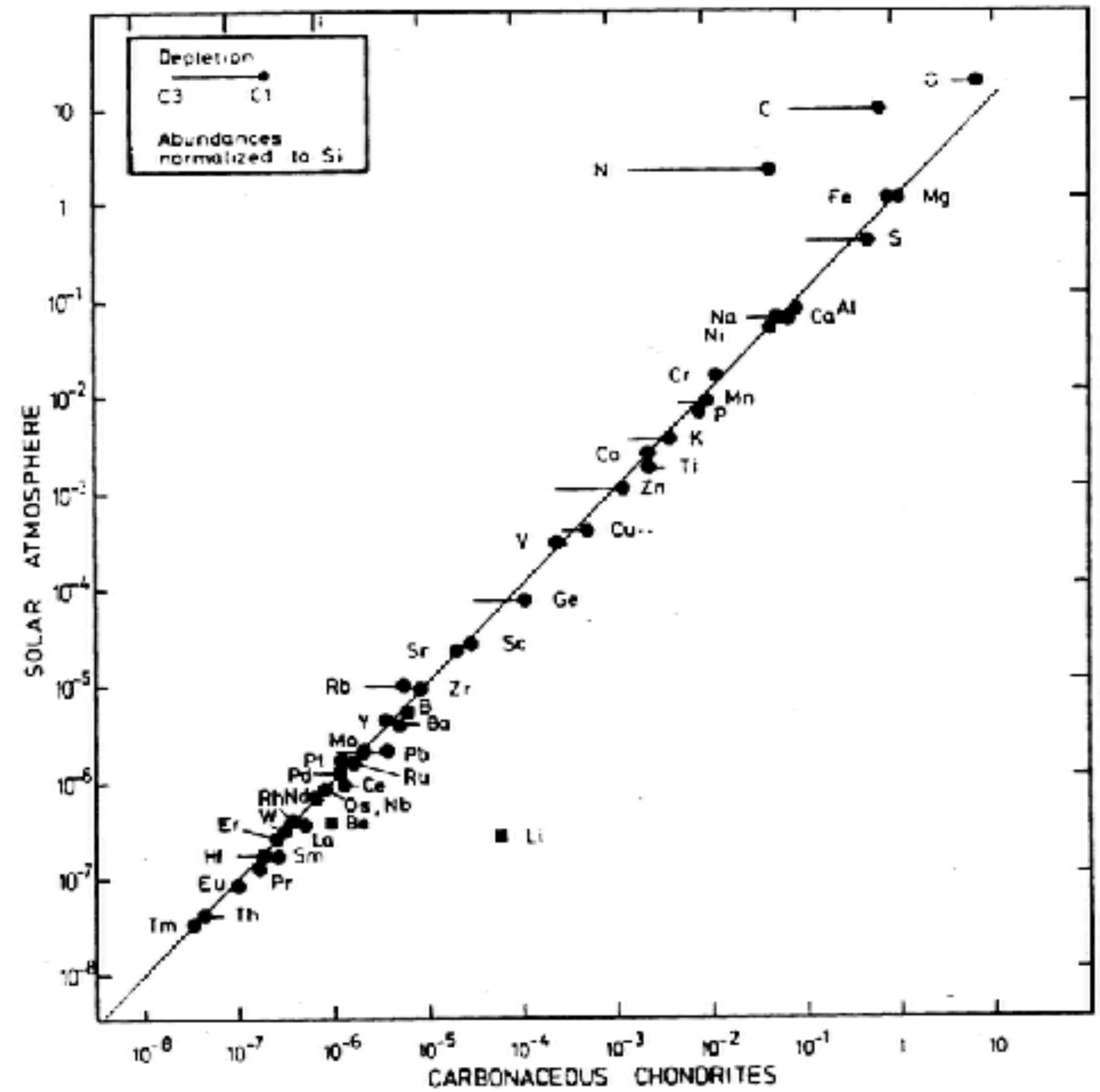
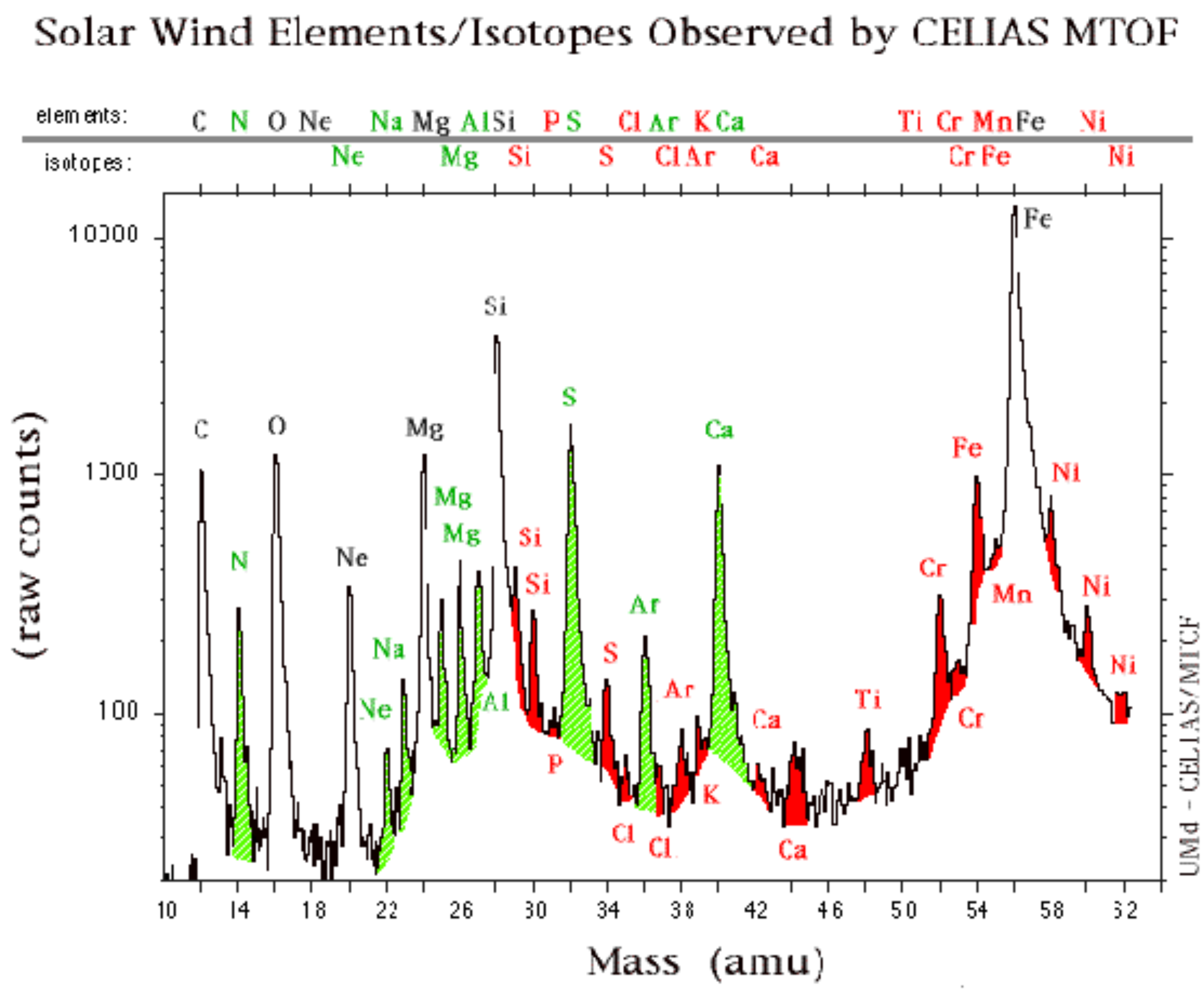


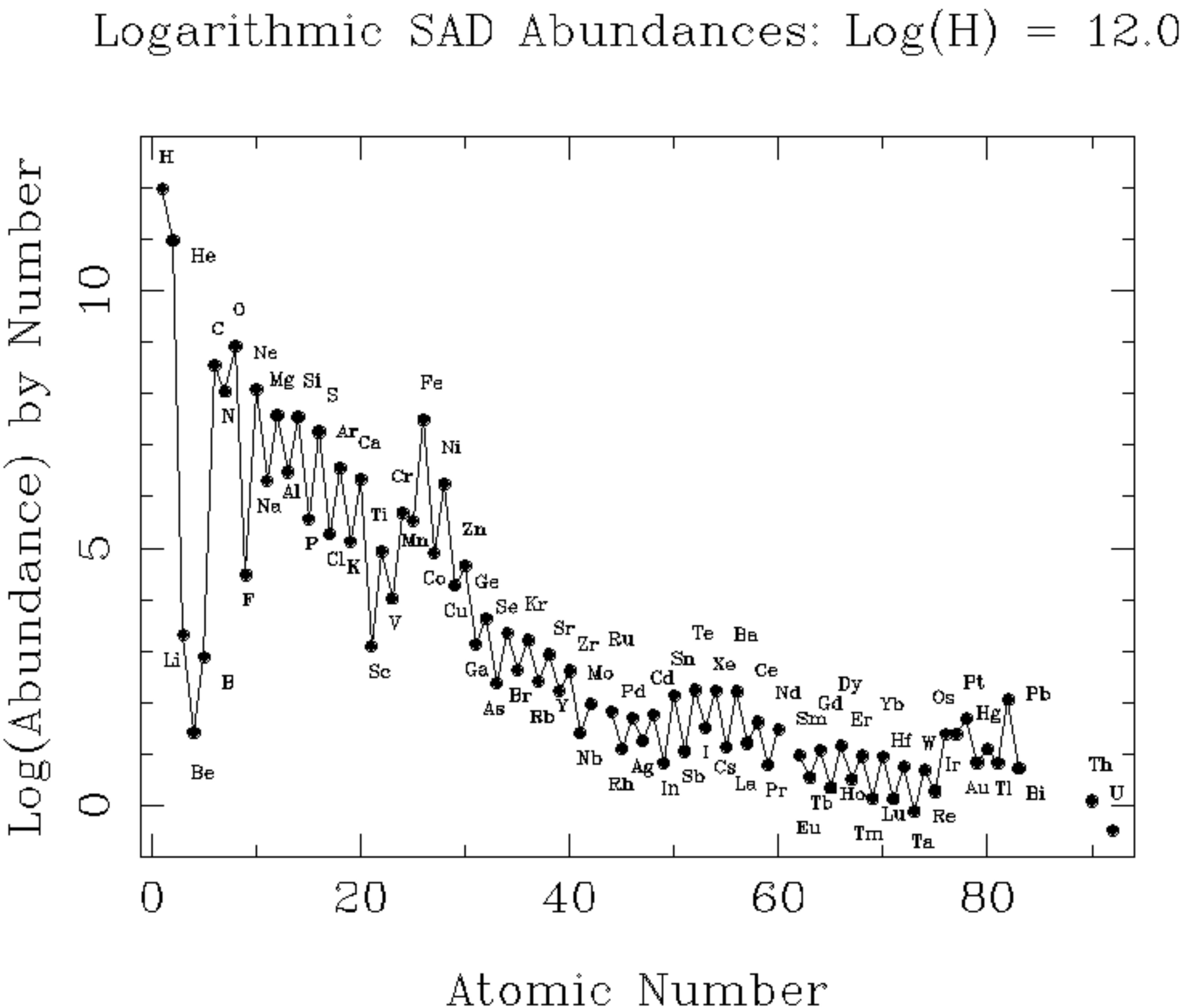
Figure 7.7. Abundances in the Solar Atmosphere Compared with those in C1 and C3 Carbonaceous Chondrites. Courtesy H. Holweger and International Astronomical Union.

Cosmic Abundances

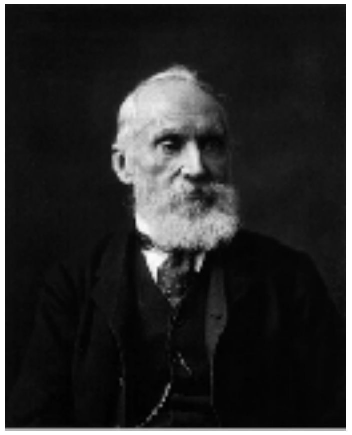
Homogeneous solar system composition



Cosmic abundances

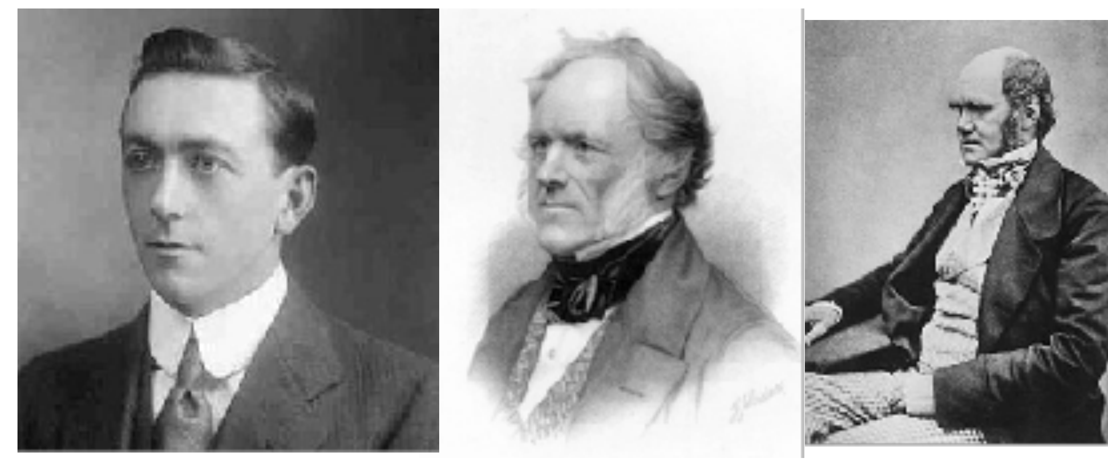


Early insights



William Thomson, 1st Baron Kelvin
Age of the Sun and Earth: 20 million years (cooling / gravitational contraction)

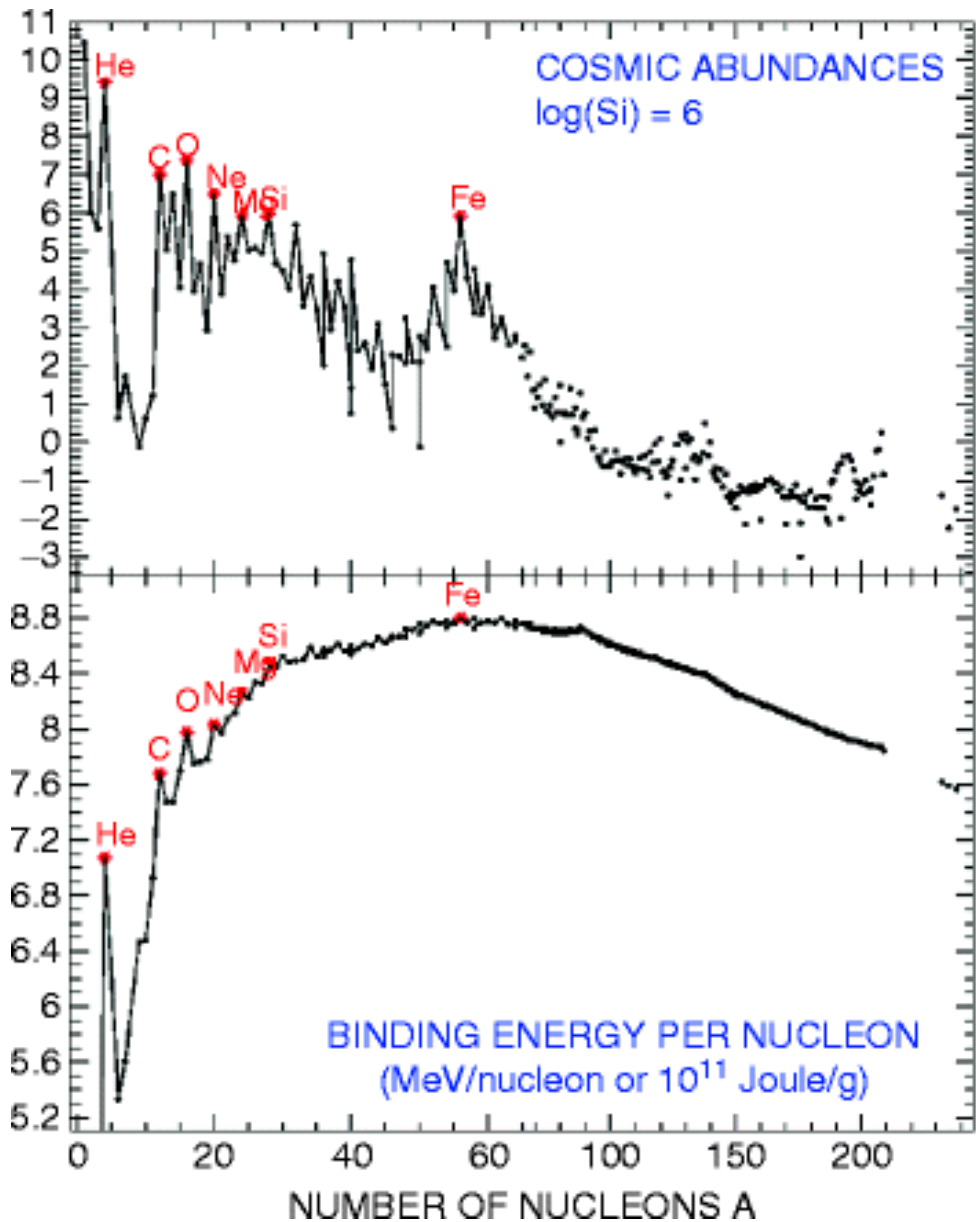
Charles Darwin, Charles Lyell, Arthur Holme
Geology and evolution require billions of years



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

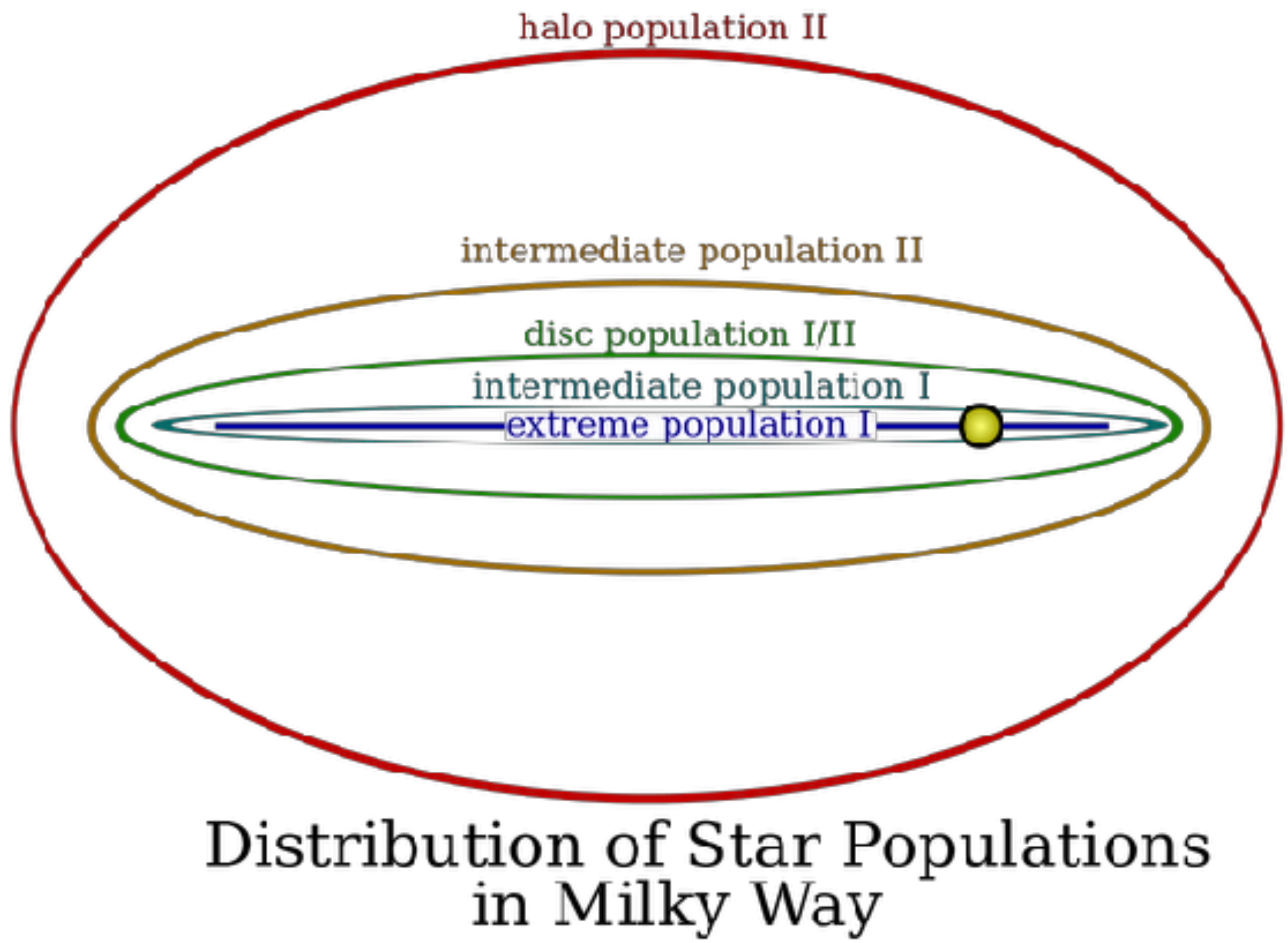
Where does nucleosynthesis take place?

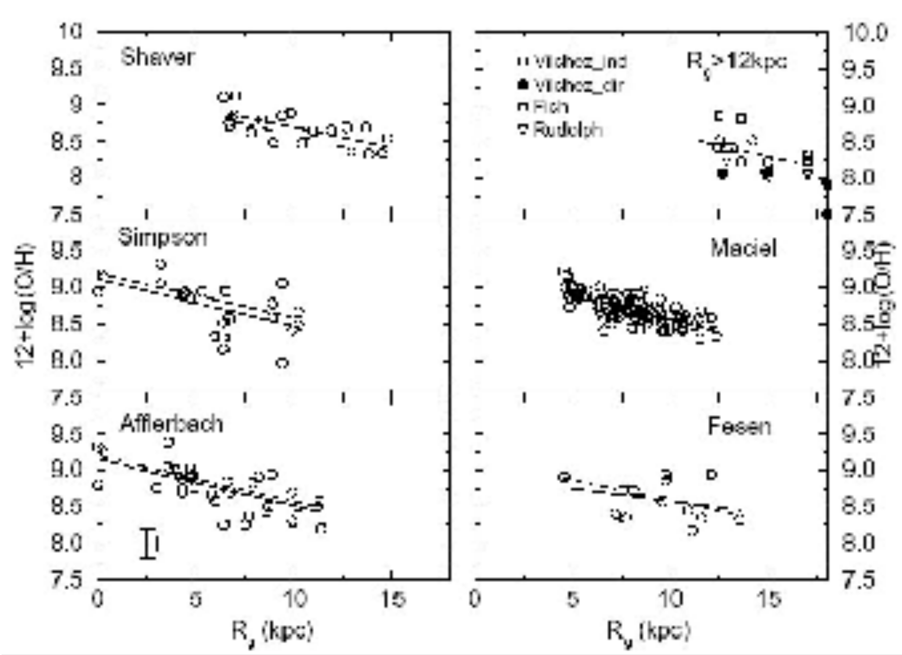
Nuclei need to overcome the Coulomb barrier to interact —> High temperatures (MKelvin)

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

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

Observational evidence





Evidence for evolution with time

Stars near the galactic disk have higher metallicities that 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

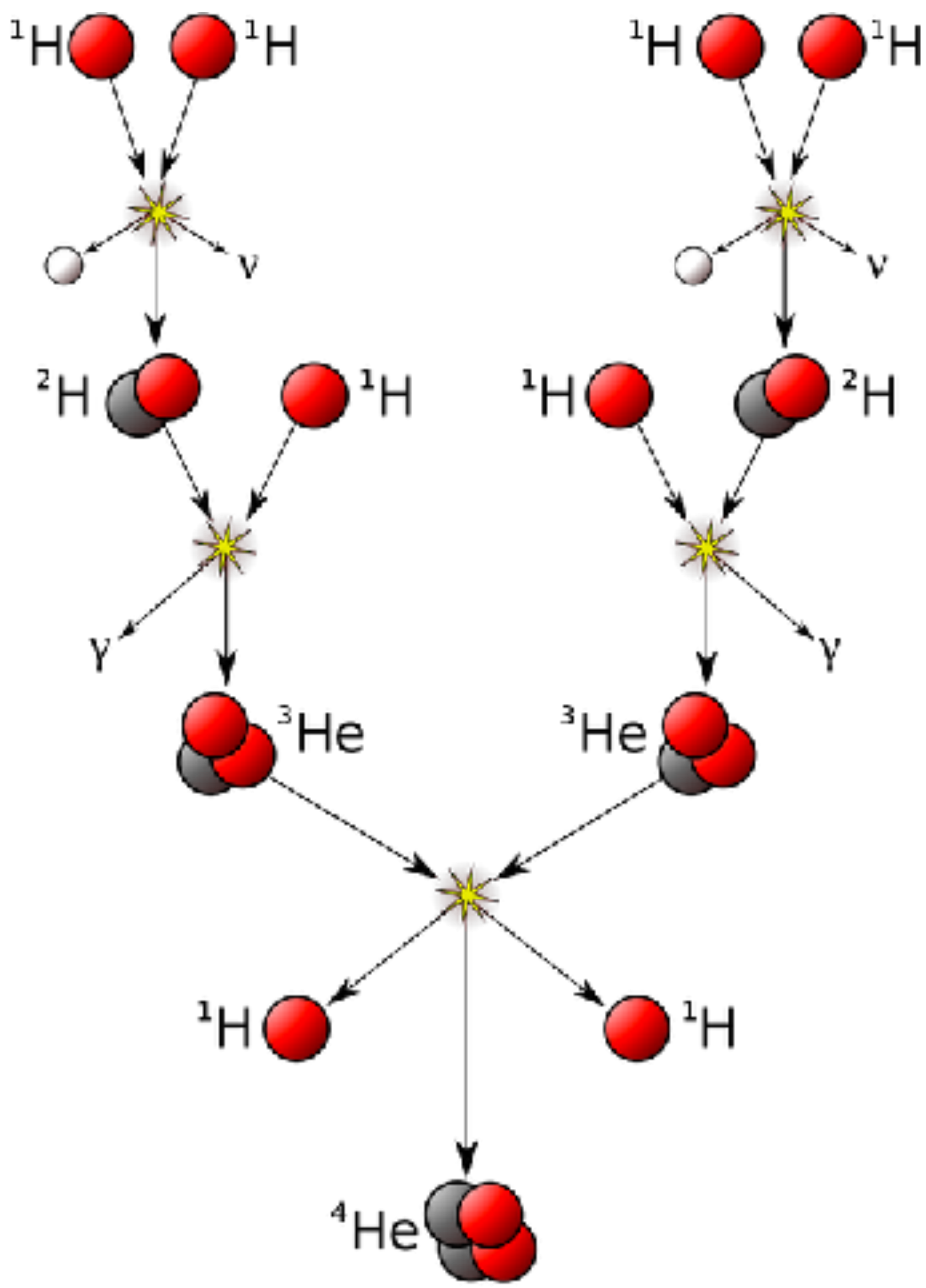
VOLUME 29, NUMBER 4 OCTOBER, 1957

Synthesis of the Elements in Stars*

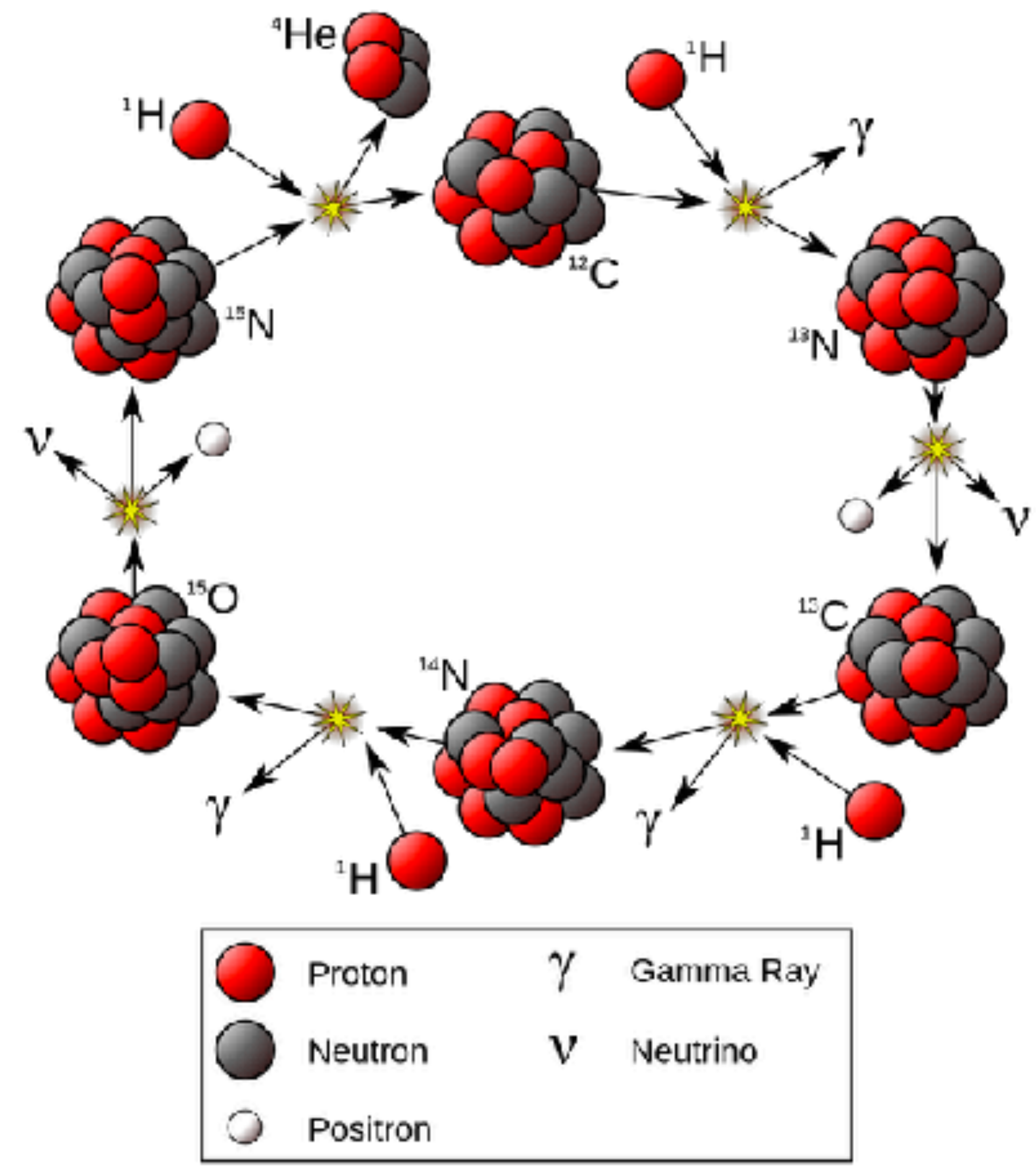
E. MARGARET BURBIDGE, G. R. BURBIDGE, WILLIAM A. FOWLER, AND F. HOYLE

Hydrogen burning

proton-proton chains



CNO-I cycle



from *Wikipedia*

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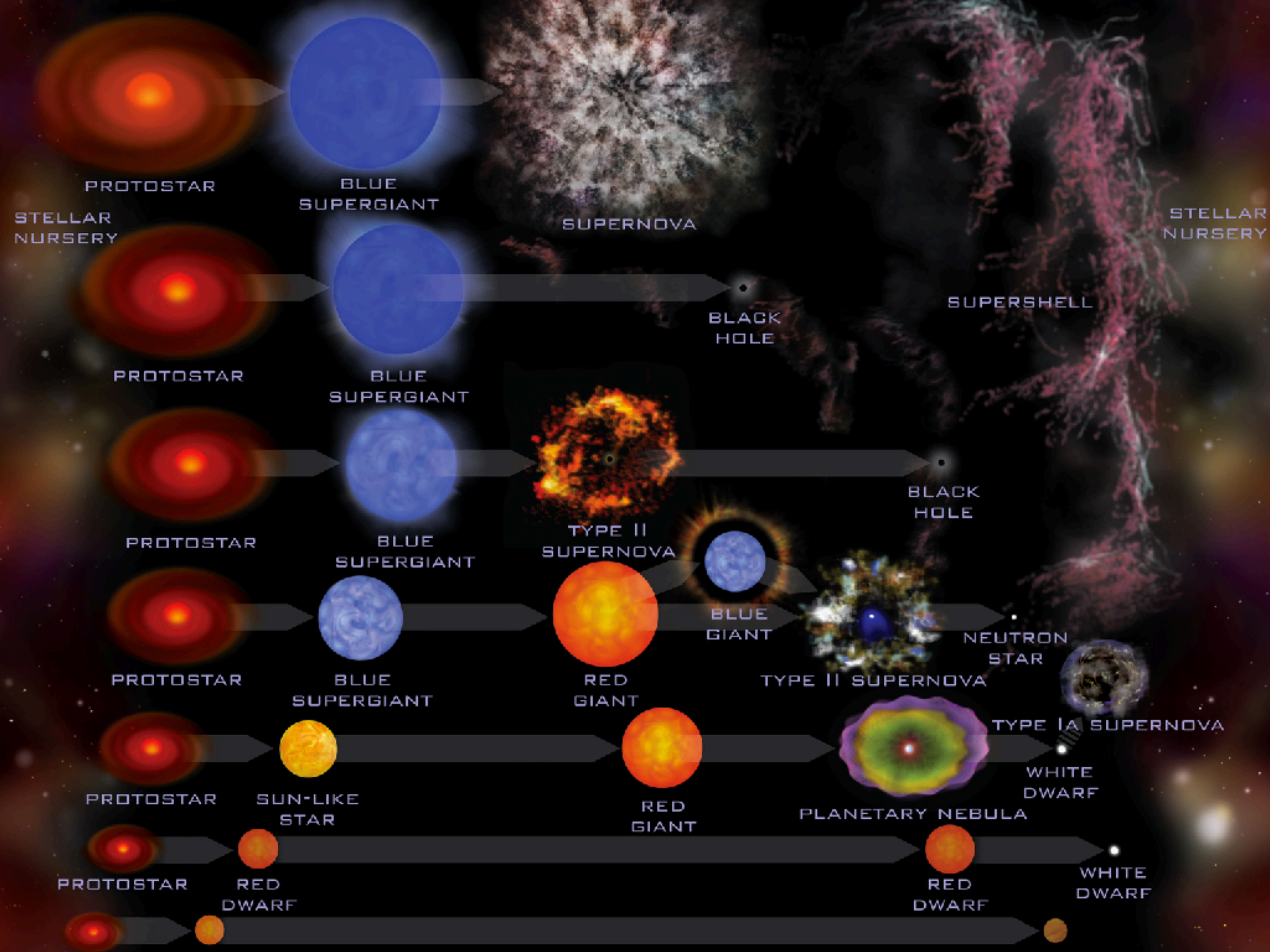
Course Overview


STELLAR NURSERY
PROTOSTAR
BLUE SUPERGIANT
SUPERNOVA
STELLAR NURSERY
PROTOSTAR
BLUE SUPERGIANT
BLACK HOLE
SUPERSHELL
PROTOSTAR
BLUE SUPERGIANT
TYPE II SUPERNOVA
BLACK HOLE
PROTOSTAR
BLUE SUPERGIANT
RED GIANT
BLUE GIANT
TYPE II SUPERNOVA
NEUTRON STAR
TYPE IA SUPERNOVA
PROTOSTAR
SUN-LIKE STAR
RED GIANT
PLANETARY NEBULA
WHITE DWARF
PROTOSTAR
RED DWARF
RED DWARF
WHITE DWARF