Finish chapter 4

(nuclear cosmology, cosmic background)

Start chapter 5

(cosmic structure, cosmic inflation)

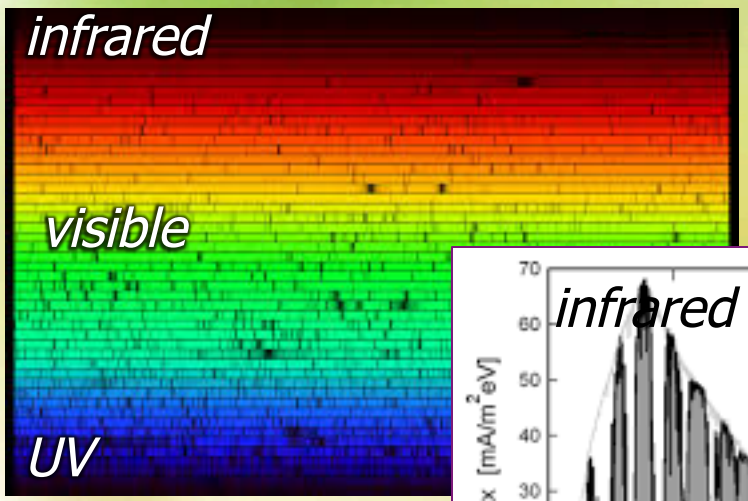
## Course grades (let's be clear!)

- 50% Homeworks
  - HWs replace exams.
  - Late HW's now penalized.
- 25% Term paper: "what's really new"
  - 5-10 pages. Due Feb 22 or so (stay tuned)
- 15% Term paper: "what's wrong with BB?"
  - 5-10 pages. Due March 3

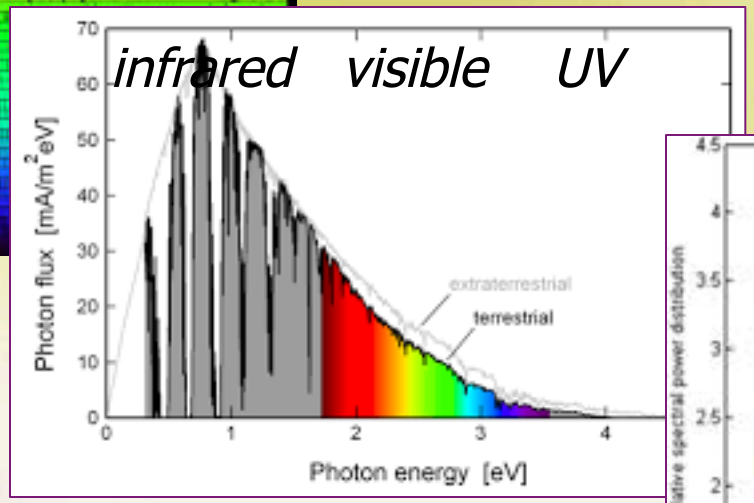
# Start planning final term paper:

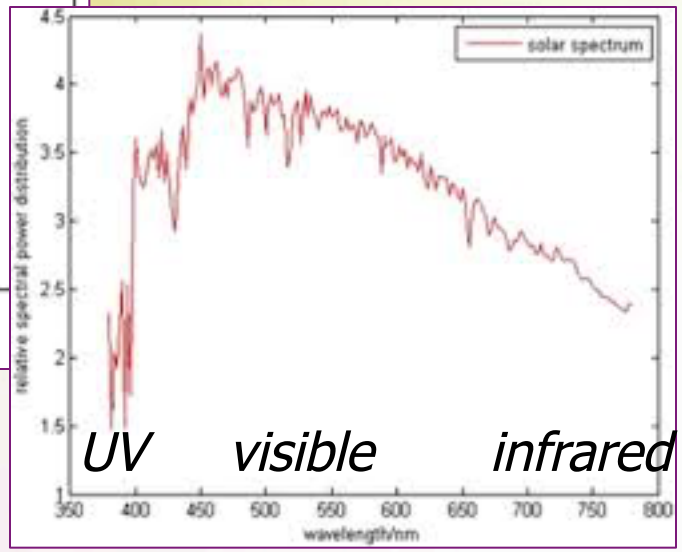
- "What's really New in the Big Bang Story of Creation?"
- Identify some of the fundamental elements of the Big Bang story, select any 3 cultural stories and compare their most closely corresponding elements
- 5-10 pages.  Due date Monday of final exams.
- 25% of course grade

# 1930s-40s: Abundances from Spectroscopic Observations




"Absorption Line" spectrum of the Sun



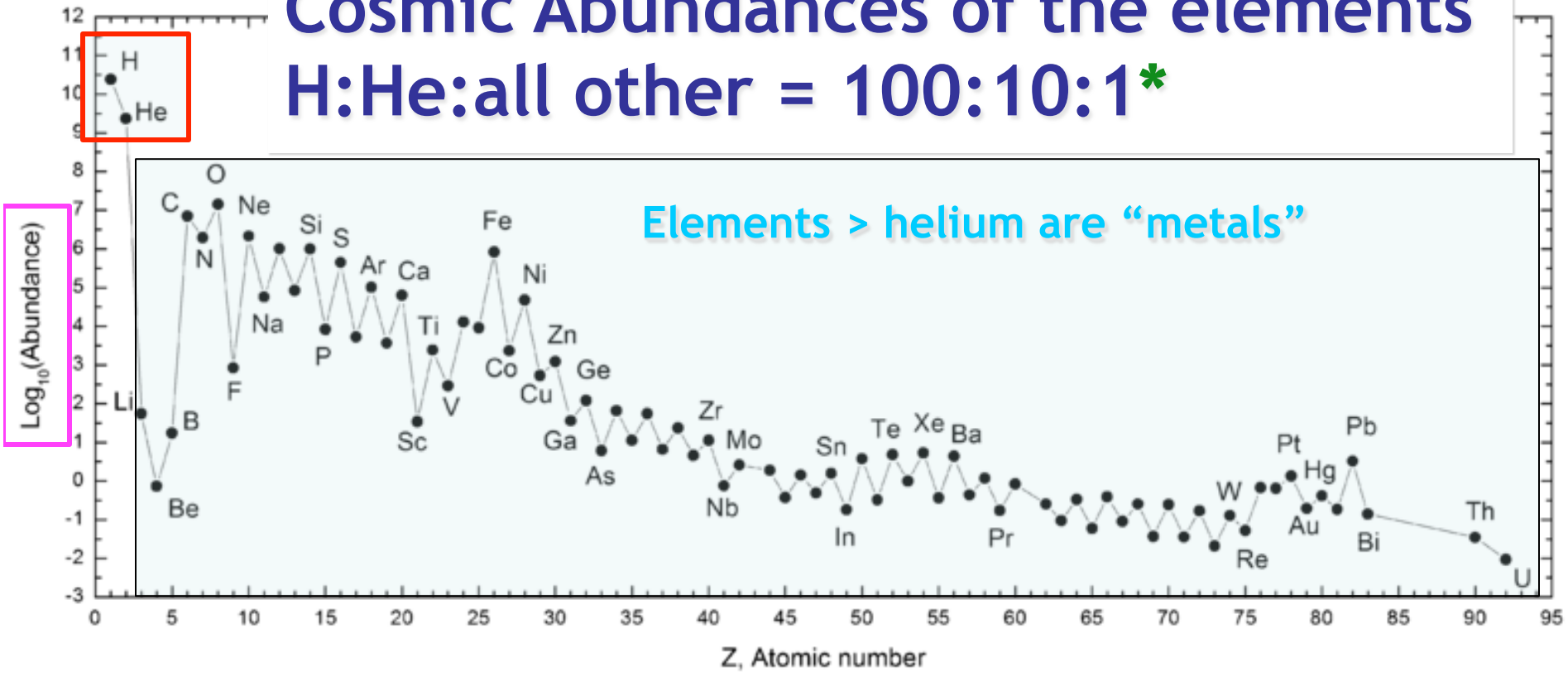




Each "line" comes from a different element

**Careful analysis reveals element abundances**

# 1930s-40s: Abundances from Spectroscopic Observations

## Cosmic Abundances of the elements
## H:He:all other = 100:10:1*



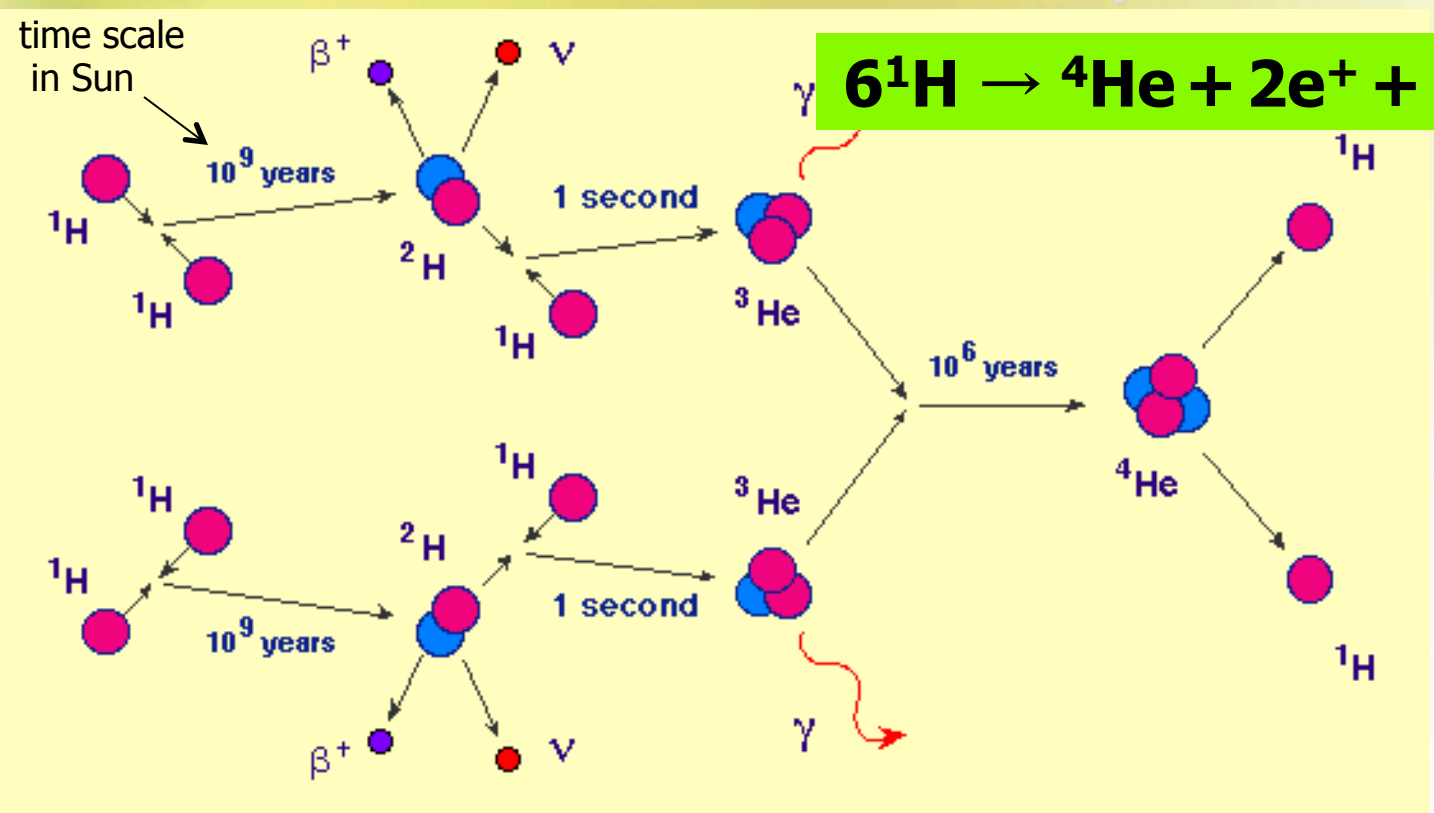

All stars exhibit He/H abundance ≈ 10%.
Abundances of metals vary from star to star.

# EXIT THE 1930s

- Hubble continues work on the Diagram, but his distance measurement method is flawed, even with Baade's help
  - e.g., $T_{Universe} = 1/H_o$ is way too small: 4 Gy
- Zwicky and Oort proposed dark matter
  - ***Their results seem like mere curiosities.***
- Studies of distant galaxies and their spectra continue
  - Zwicky recognizes clusters of galaxies
  - Assumed that galaxies have not changed
- Quantum physics explores atomic nuclei and opens our understanding of matter at high densities and temperatures.

# EXIT THE 1930s

- Huge advances in nuclear physics
  - Hans Bethe figures out how stars make energy as four protons "fuse" to produce helium and heat
  - Fermi and many others figure our how to make an A bomb when the nuclei of heavy elements "fission"




$$6\,^1\mathrm{H} \rightarrow {}^4\mathrm{He} + 2e^+ + 2\nu + 2\gamma + 2\,^1\mathrm{H}$$

$^1$H proton
$e^+$ antielectron
$\nu$ neutrino
$\gamma$ $\gamma$–photon
$^2$H deuterium
$^3$He helium3
$^4$He helium4

Net energy yield = 0.7% $4m_pc^2$

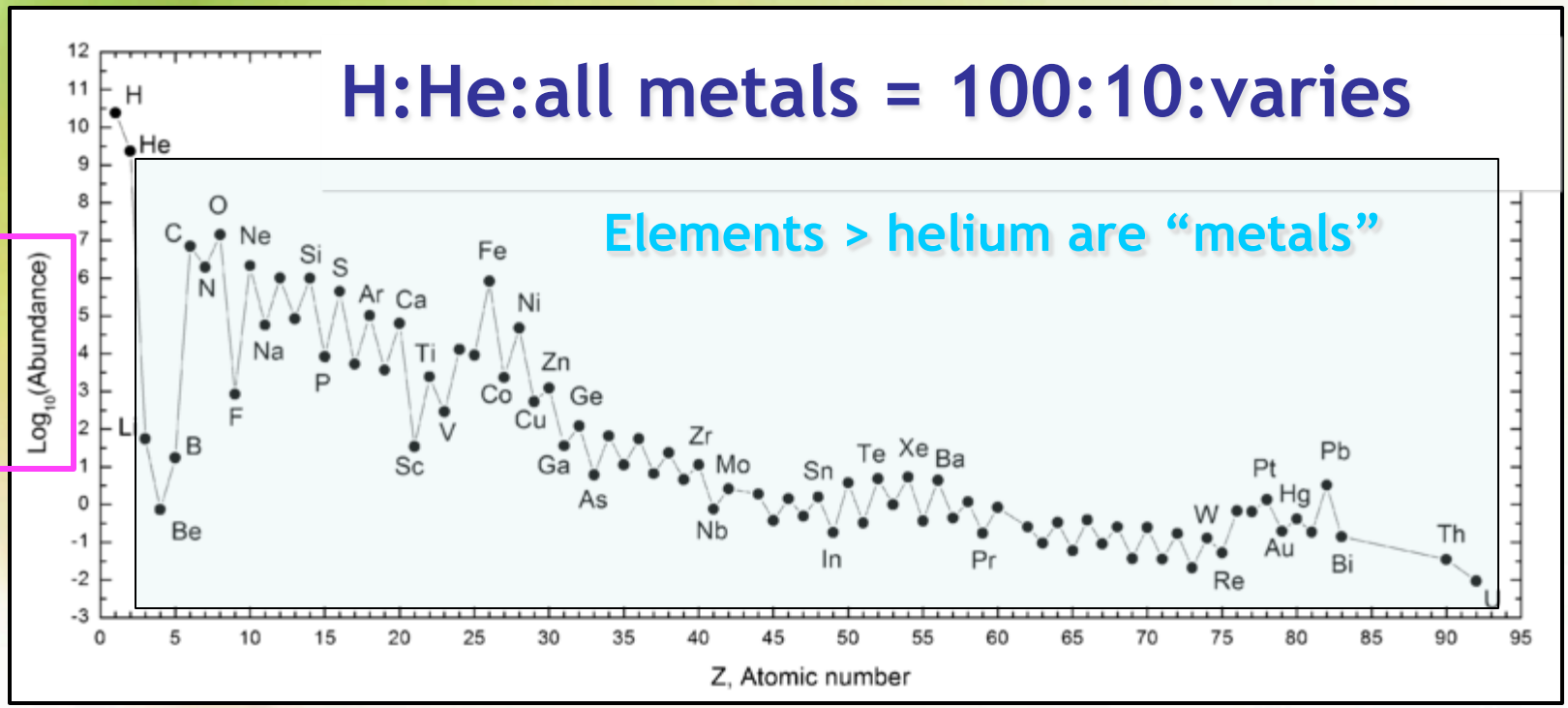
# EXIT THE 1930s

- No one is thinking about what came before stars and galaxies
- No sensational new observational breakthroughs to inspire theoretical studies of the very early Universe.
- New science and technology developed during WWII was about to change that.
  - Nuclear physics
  - Radar

# EXIT WORLD WAR II

- Optical spectra of stars and nebulae
  - Details of the spectra enable comparison of the chemical abundances
- A "crop" of aspiring young nuclear physicists enters the story
  - Gamow, Bethe, Fowler, Hoyle, Burbidges
- By 1948 the cosmic abundance of He/H leads to the necessity of a very hot early Universe
- **Theoretical progress comes quickly.**

# Nuclear Astrophysics Revolutionizes Cosmology

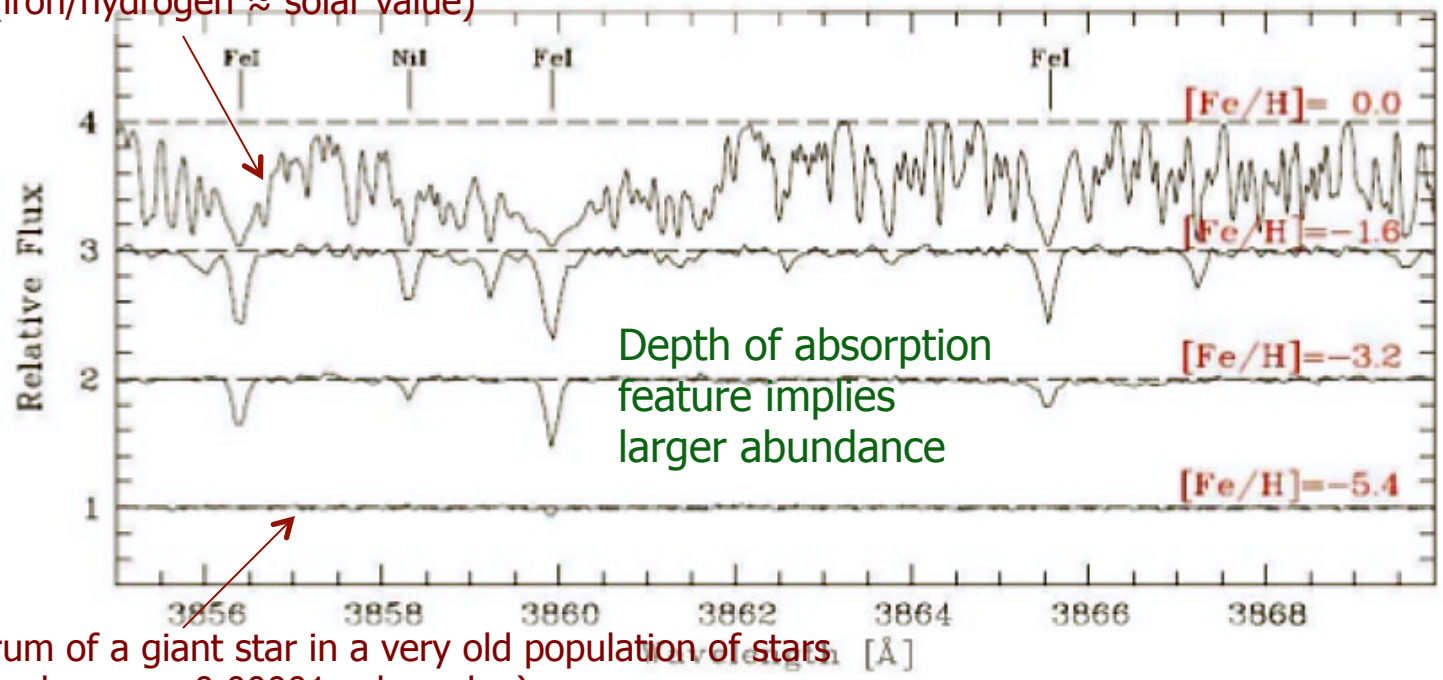



Helium: stellar He/H must be universally 10% in the gas from which all stars form

**Gamow and Alpher: He is made in Big Bang while all matter @ $10^9$ degrees**

# Nuclear Astrophysics Revolutionizes Cosmology

Spectrum of a giant star in a young population of stars (iron/hydrogen ≈ solar value)




Depth of absorption feature implies larger abundance

Spectrum of a giant star in a very old population of stars (iron/hydrogen ≈ 0.00001 solar value)

[Fe/H] = iron/hydrogen

*increases with time as stars enrich it in the interstellar medium*

- Heavier elements: Smallest abundances in oldest starts. **(unlike helium)**
- Assembled from H and He at even higher temperatures from He and protons
- "Forged" during later stellar core explosions and neutron star mergers.
- Accumulates in the interstellar medium from which new generations stars form