

Lecture Notes: Introduction to Astrophysics and Cosmology

Based on lectures by **Dr. Shmuel Bialy** in 2025-26
Notes created by Daniel Haim Breger

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These notes were typed in the 2026 winter semester *Introduction to Astrophysics and Cosmology* course taught by **Dr. Shmuel Bialy** at the Technion.

The lectures were given in Hebrew and were live-translated by me to English. The document is provided as is and likely contains many errors.

If you find any mistakes or typos please let me know at danielbreger@campus.technion.ac.il.

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Lecture 1.

Thu, October 30, 2025

1 introduction

Since astrophysics is a very wide subject we won't be able to dive deep on each subject. The course is introductory so we'll be skipping some things like full solutions to integrals and the such.

1.1 So what is astrophysics?

Astrophysics and Cosmology could be broken down into:

Physics of stars

Solar systems planets, comets...

ISM Inter-Stellar Medium, Inter-Galactic Medium

Cosmology development, the big bang, dark energy/matter

Exotic objects black holes, neutron stars, white dwarfs...

Relativity gravitational waves, gravitational lensing

Galaxies types, development, active galactic nuclei, quasars

Explosions novas, supernovas, gamma ray bursts

and the methods used to research those things include

Observations Telescopes IR, radio, xray, gamma rays...

Gravitational waves

Neutrinos

Other particles (via probes)

Labs

Computer simulations hydrodynamics, N-body simulations...

Analytical theory

We'll focus mostly on the analytical theory, but we'll mention the others too.

Lecture 2.

Mon, November 3rd, 2025

1.2 Regular (Baryonic) Matter

In our normal day to day life we meet protons, neutrons, and electrons. There are also other particles we come across, such as neutrinos, muons, taus, etc. Another particle we meet often is the photon, and some others we won't get into.

When the universe came into being in the big bang quarks and photons were created. those quarks then combined into protons and neutrons. protons are basically hydrogen nuclei, so hydrogen was created in the big bang. For a short period of time after the big bang there were conditions for nuclear fusion across the early universe, so about 10% of the matter created from the big bang ended up being helium, and in terms of mass it was about 25% (Because Helium is heavier than hydrogen). Elements heavier than helium weren't created at any significant quantities in the big bang. If we plot this on a graph:

The portion of mass of hydrogen of the total mass is denoted by X , hydrogen by Y , and metals, which are all the elements heavier than helium and are denoted by $Z = \frac{M_{metals}}{M}$. For our sun:

$$X_{\odot} = 0.7381 \quad (2.1)$$

$$Y_{\odot} = 0.2485 \quad (2.2)$$

$$Z_{\odot} = 0.0134 \quad (2.3)$$

The above was a discussion for gas and plasma. There is another kind of matter in space called dust. Dust is similar to the dust we know. It's particles about a micrometer in diameter made of water, carbon, silica, etc. Why do we mention this? In terms of the mass of the metals in the universe, about half of it is dust. Moreover, dust is a significant factor in observations of the universe, either in interfering in our ability to see things or in creating conditions that allow us to infer information. Dust also aids the creation of molecules by speeding up processes which are very slow in gasses.

An important definition for us will be the "average mass" which we'll use in many formulas. Assume we have a box filled with hydrogen and some helium and some metals, all with the relative quantities that are in the sun. What would the average mass per particle be? approximately a proton mass. And if the gas in the box is ionized? 0.5 proton masses. This is because we doubled the number of particles by freeing the electrons, which have approximately 0 mass relatively to the protons. This was a back of the napkin approximation just for sanity check and to have an idea of what we're expecting. The exact calculations is:

$$\bar{m} = \frac{\sum_j N_j m_j}{\sum_j N_j} \quad (2.4)$$

where j is each element type, N is their number, and m their mass. Rewriting in terms of X, Y, Z :

$$\frac{1}{\bar{m}} = \frac{\sum N_j M_j}{\sum N_j m_j M_j} \quad (2.5)$$

$$= \frac{M_j}{M_{tot}} \cdot \sum \frac{N_j}{M_j} \quad (2.6)$$

$$= \frac{1}{m_H} \left(X + \frac{1}{4}Y + \frac{1}{A_Z}Z \right) \quad (2.7)$$

where

$$M_j = \begin{cases} N_H m_H & H \\ N_{He} \cdot 4m_H & He \\ N_Z A_Z & else \end{cases} \quad (2.8)$$

Sometimes the following definition is used:

$$\mu = \frac{\bar{m}}{m_H} \quad (2.9)$$

and if we plug in the numbers for the sun we indeed find that it's very close to 1. We won't do this explicitly because there's a correction for the formula for a non-neutral gas, which our sun is not. For a completely ionized gas, i.e all the electrons are free, we just need to change N_j :

$$N_j = \begin{cases} 1 \rightarrow 2 & H \\ 1 \rightarrow 3 & He \\ 1 \rightarrow \langle \frac{A_Z}{2} \rangle & Else \end{cases} \quad (2.10)$$

Which gives us, for a completely ionized gas:

$$\mu = \left[2X + \frac{3}{4}Y + \frac{1}{2}Z \right]^{-1} \quad (2.11)$$

and if you insert the numbers for our sun we find

$$\langle A \rangle = 15 - 16 \quad (2.12)$$

$$\mu_\odot \simeq 0.6 \quad (2.13)$$

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