PYTHON FOR ASTROPHYSICS

Lecture 3

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Lecture 3 goals:

1. Plotting tools for astronomy and astrophysics

2. Master Plotting on Google Colab

3. Hydrostatic Equilibrium of isothermal gas slabs (**stratified atmospheres**)

What do you need for the practicals?

- A PC/laptop with any OS.

- Internet access.

- A Google/gmail account.

- A GitHub account (desirable, not strictly needed).

Plotting in Python: Matplotlib

Matplotlib Resources

We will use mainly Matplotlib for plotting: https://matplotlib.org/

Some examples on how to use Matplotlib for plotting cane be found here:

https://matplotlib.org/tutorials/introductory/sample_plots.html
https://matplotlib.org/gallery/index.html

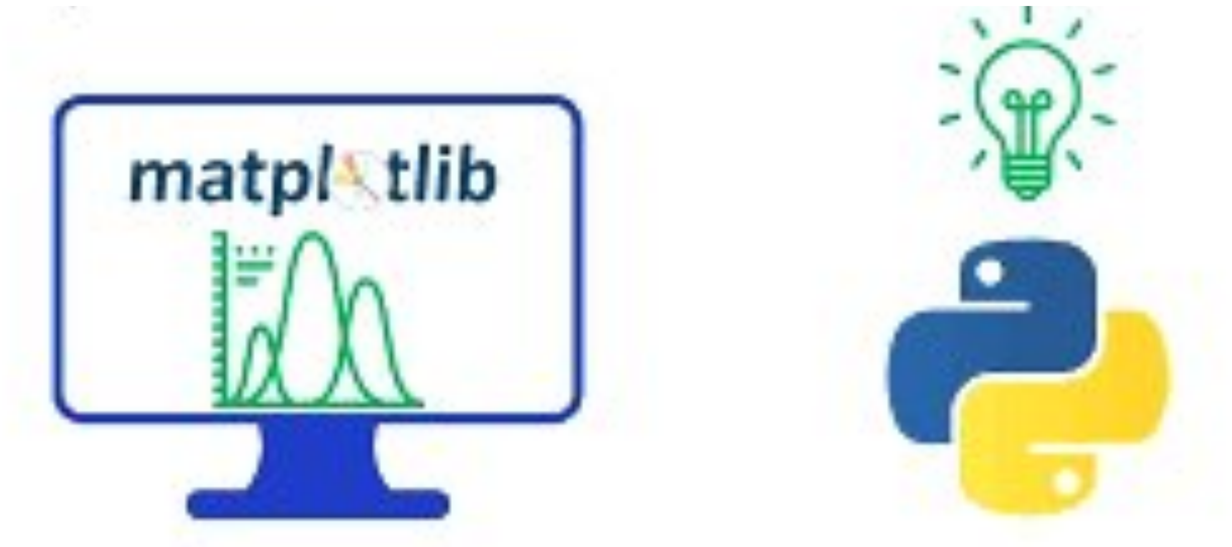
Other examples can be found on forums, e.g. StackOverflow:
https://stackoverflow.com/

Asking questions on Google/AI chatbots is also helpful as there are many links, examples, solutions to problems, etc.

Python is a community-developed language, so you are also welcome to report bugs:
https://bugs.python.org

Pyplot and Plotly

pyplot():



Pyplot is an interface to plot using Matlab- and Mathematica-like plotting sequences.

It facilitates plotting and it is widely used.

Website: https://matplotlib.org/stable/tutorials/pyplot.html

Pyplot and Plotly

Plotly: 3D interactive plotting

Plotly is an open-source graphing library used to create interactive visualisations directly in web browsers.

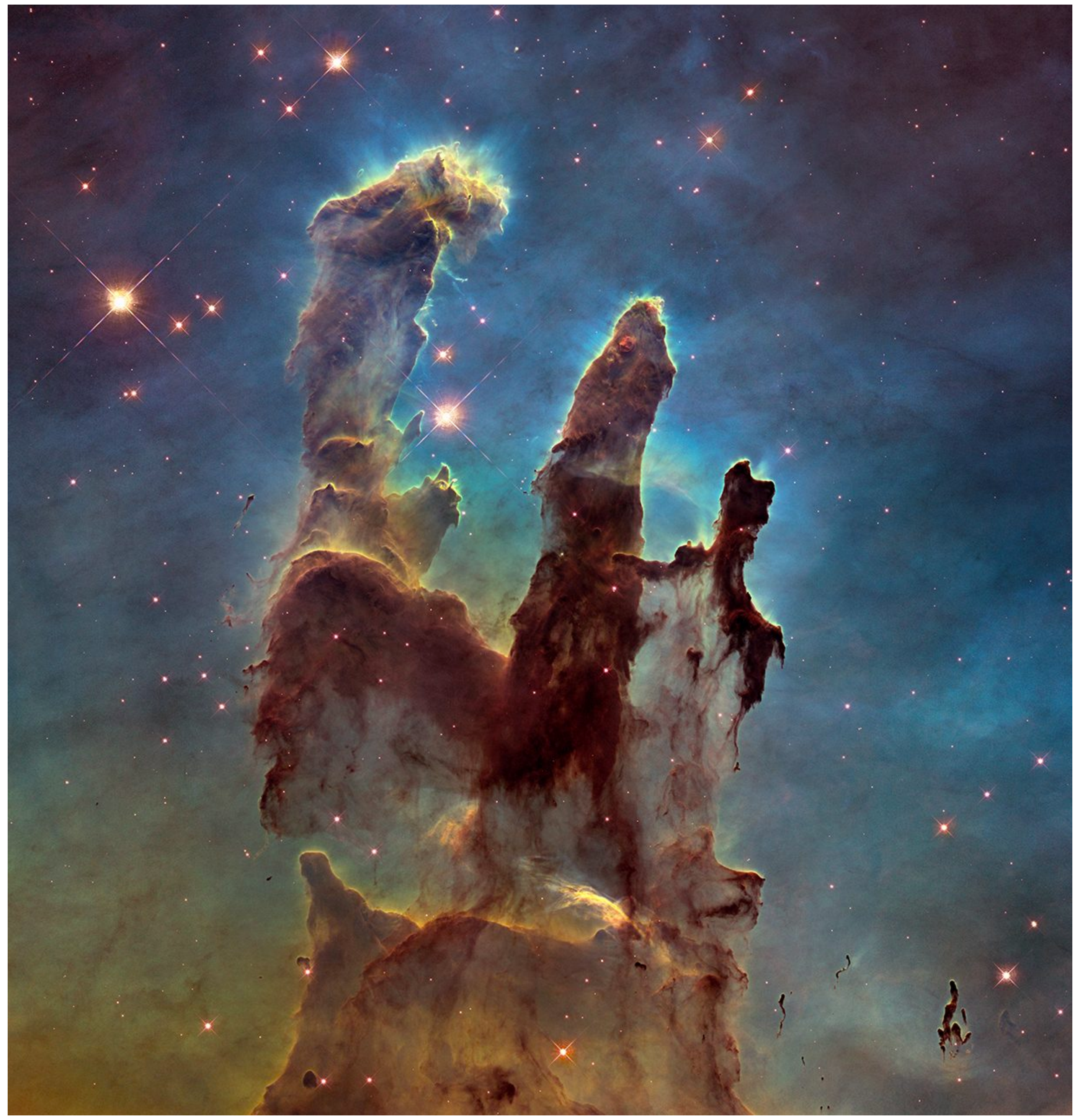
It can be integrated with jupyter notebooks.

Plotly is highly versatile, with APIs available in Python, R, JavaScript, HTML.

Website: https://plotly.com

Interstellar Medium Clouds

Galactic discs



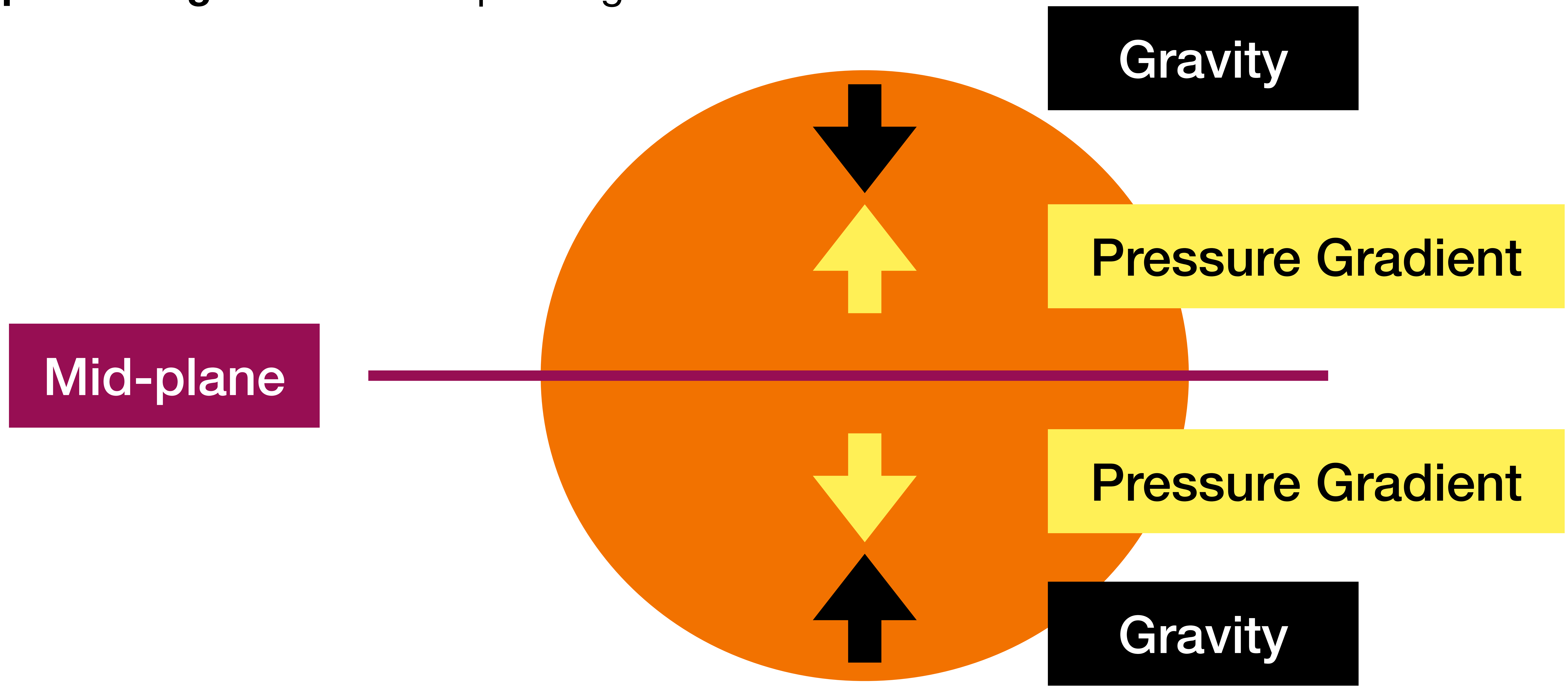
Stratified Astrophysical Atmospheres

Molecular Pillars in the Eagle Nebula (7000 light-years).
Credits: http://hubblesite.org/

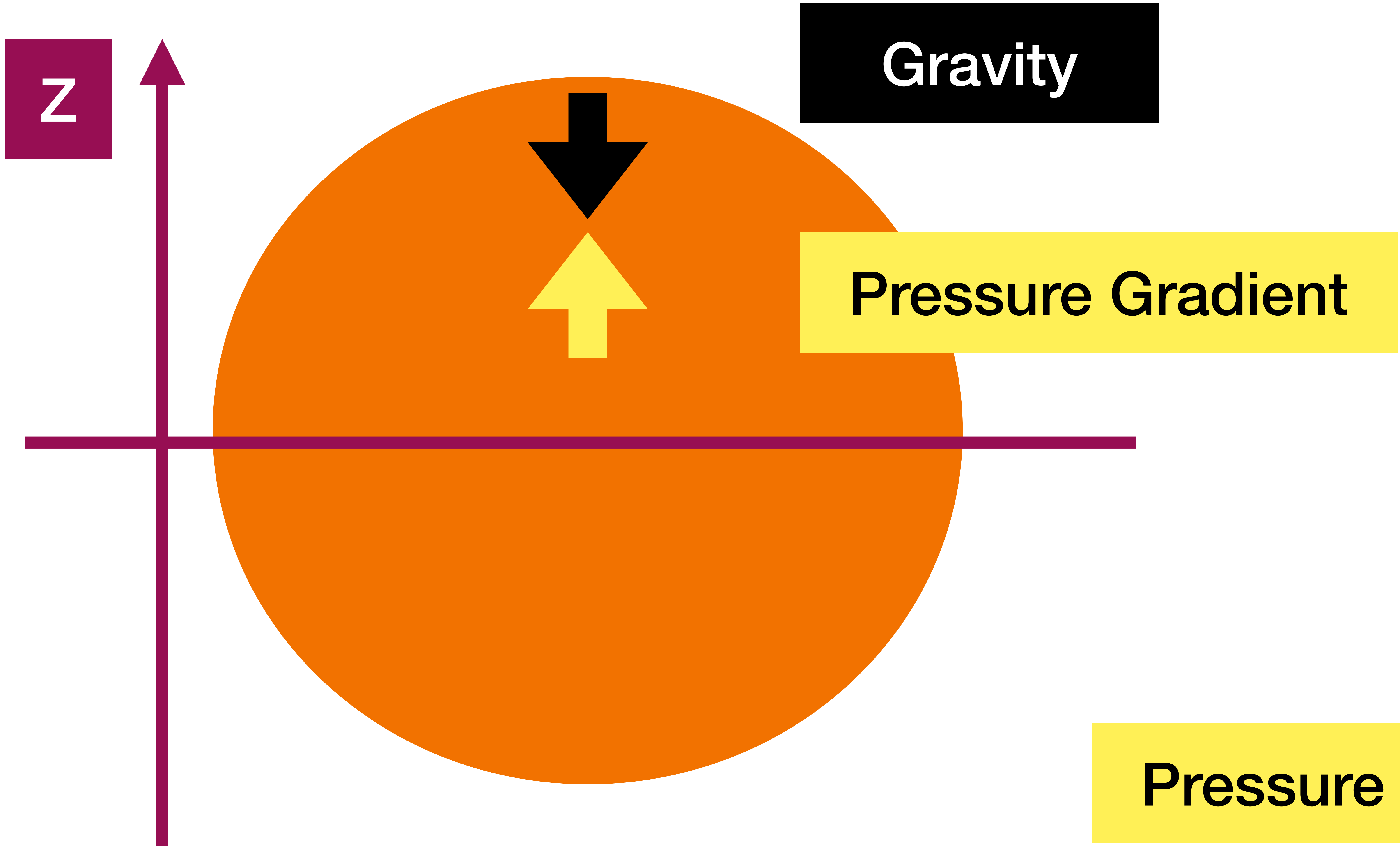
A Hubble image of the spiral disc galaxy NGC3972.
Credits: NASA/Hubble

Hydrostatic equilibrium

The **gravitational force** pulling gas towards the mid-plane is balanced with the **pressure gradient force** pushing outward.



Self-gravitating atmosphere (gas slab)



Vertical gradient of the gravitational potential

$$\frac{dP}{dz} = -\,\rho(z)\frac{d\Phi}{dz}$$

Pressure Gradient

Mass density

1D self-gravitating atmosphere (gas slab)

The gravitational potential, Φ, is sourced by the gas itself, so we need to solve the Poisson equation:

$$\frac{d^2\Phi}{dz^2} = 4\pi G\rho(z)$$

In addition, we need an equation of state that determines the thermodynamical properties of the gas. The simplest case is to assume the gas is isothermal.

$$P = \rho\, c_s^2$$

These equations combined with the hydrostatic equilibrium equation:

$$\frac{dP}{dz} = -\rho(z)\frac{d\Phi}{dz}$$

Give us in 1D, the following solution:

$$\rho(z) = \rho_0\,\mathrm{sech}^2\left(\frac{z}{H}\right)$$

with: $H = \dfrac{c_s}{\sqrt{2\pi G\rho_0}}$ (scale height)

Reference: https://ui.adsabs.harvard.edu/abs/1942ApJ....95..329S

2D/3D self-gravitating atmosphere (gas slab)

In 2D cylindrical symmetry (e.g., interstellar filaments), the equilibrium density profile is:

$$\rho(r) = \frac{\rho_0}{\left(1 + \frac{r^2}{8H^2}\right)^2} \qquad \text{with:} \qquad H = \frac{c_s}{\sqrt{4\pi G\rho 0}} \qquad \text{(scale height)}$$

Reference: https://ui.adsabs.harvard.edu/abs/1964ApJ...140.1056O

In 3D solutions require numerical integration. A commonly used analytic approximation to the solution of the isothermal Lane-Emden equation reads:

$$\rho(r) = \frac{\rho_0}{\left(1 + \frac{r^2}{r_c^2}\right)^{3/2}}$$

(~ 7% accurate wrt to the numerical isothermal sphere solution for $r \lesssim 4r_c$, where ρ_0 is the central density and r_c is a characteristic core radius.

Reference: https://ui.adsabs.harvard.edu/abs/2008gady.book.....B

Tutorial Time

1. Please log into your gmail accounts:

2. Open this lecture on GitHub:

   https://github.com/Astronomia-Ecuador/ISYA2025/blob/main/Python_for_Astrophysics/01_programming_essentials.ipynb

3. Click on the "**Open in Colab**" icon and you are ready to code!