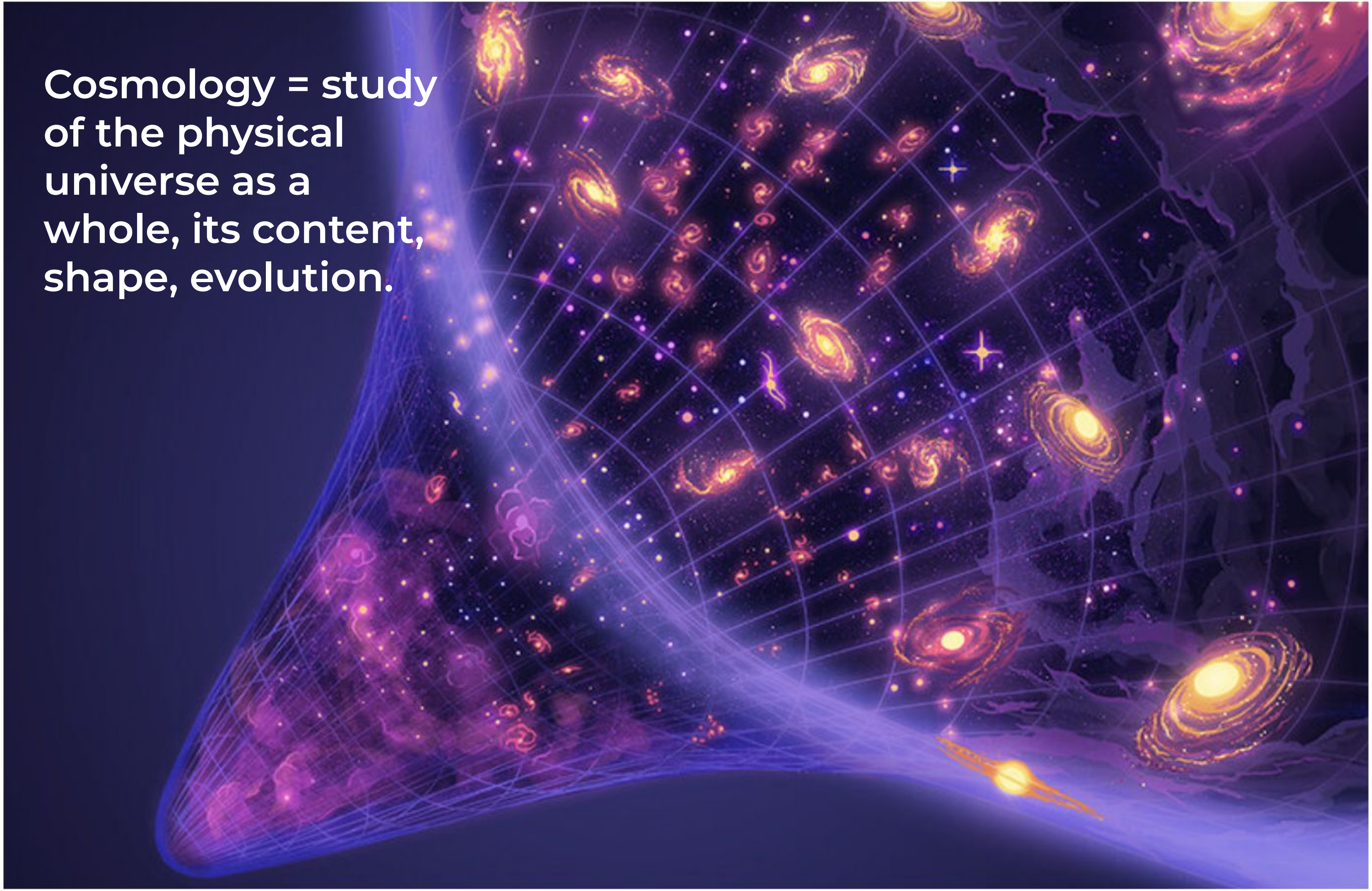
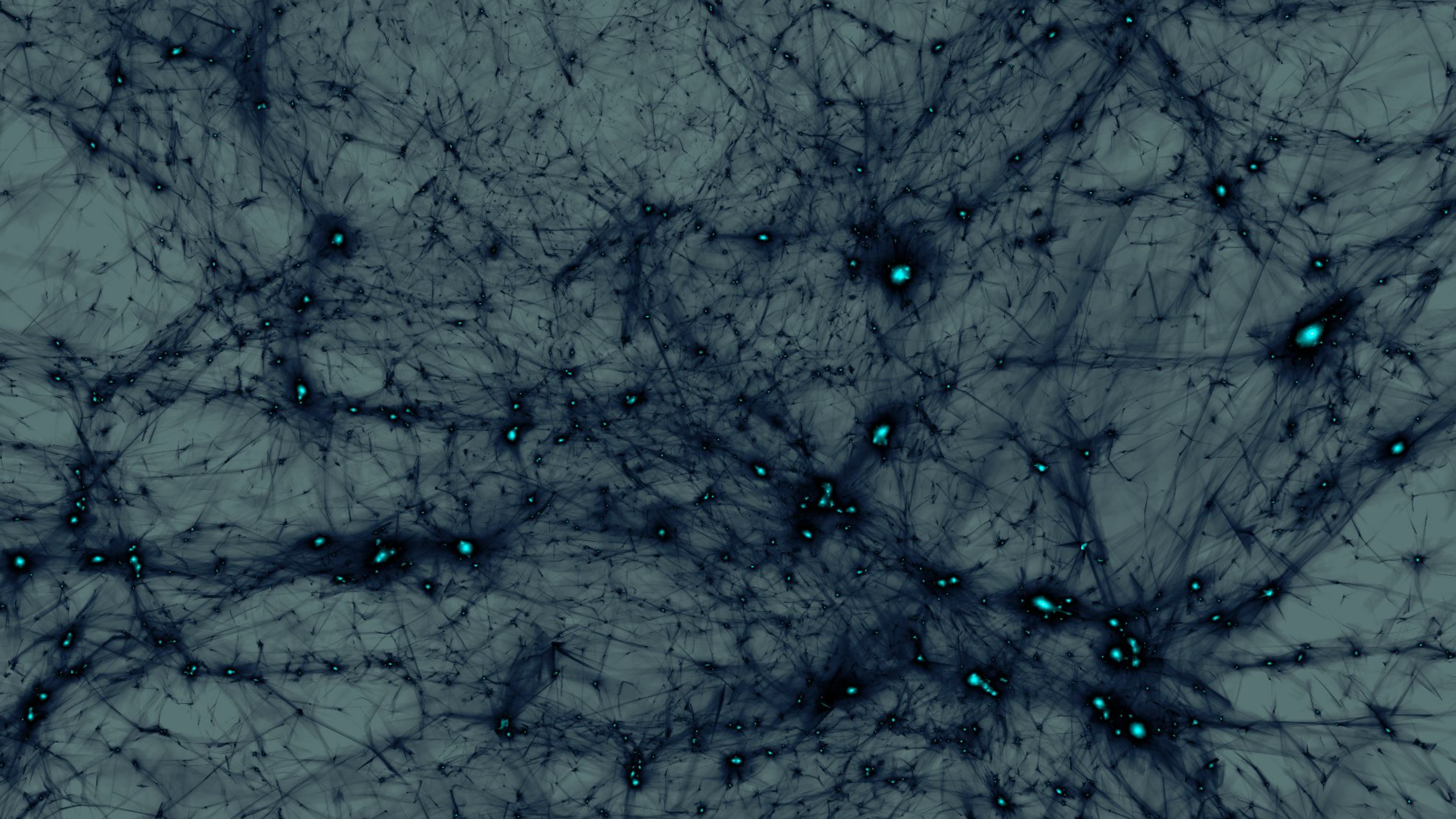
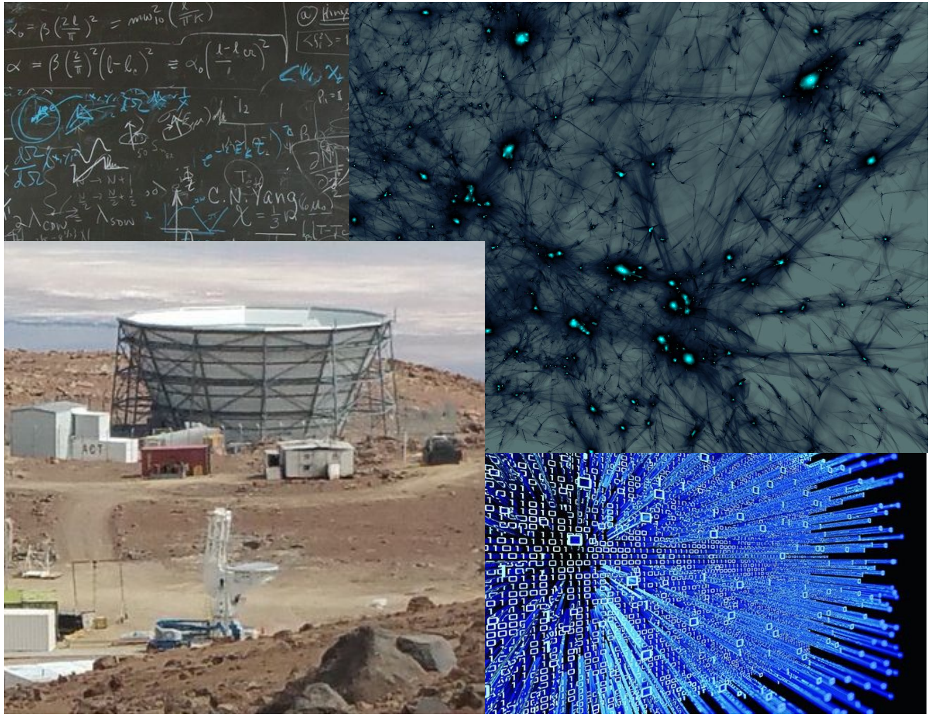
Cosmolab Open House 2023

Cosmology = study of the physical universe as a whole, its content, shape, evolution.





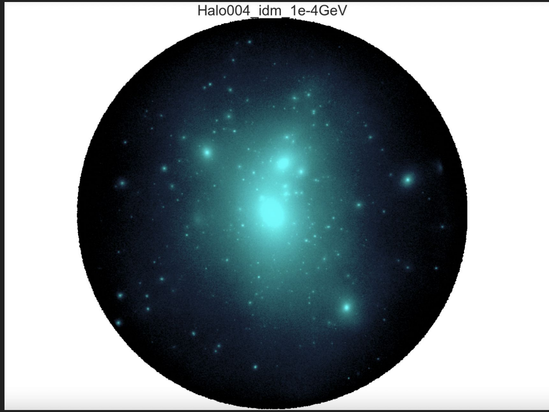
What we really do @ USC



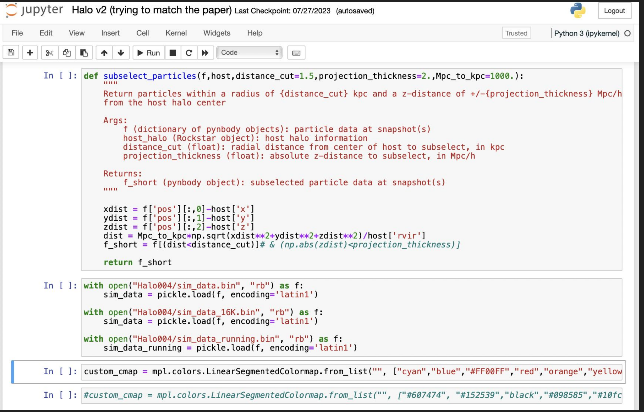
- Paper and pen
- Programming
Computer simulations
- Statistics and data analysis
- Instrumentation

Summer 2023 Research:

Custom colormaps for a Jupyter Notebook file of a visualization of a dark matter halo



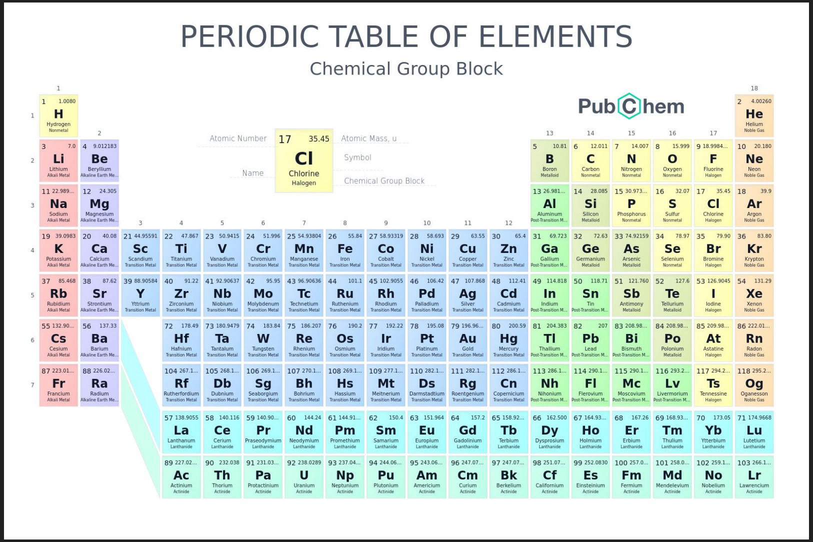
L Retterer



Overview

1) Terms to Know
2) Color mapping
    a) To previous image density & velocity
    b) To a paper’s image
3) SSH Key sidetrack

Baryons



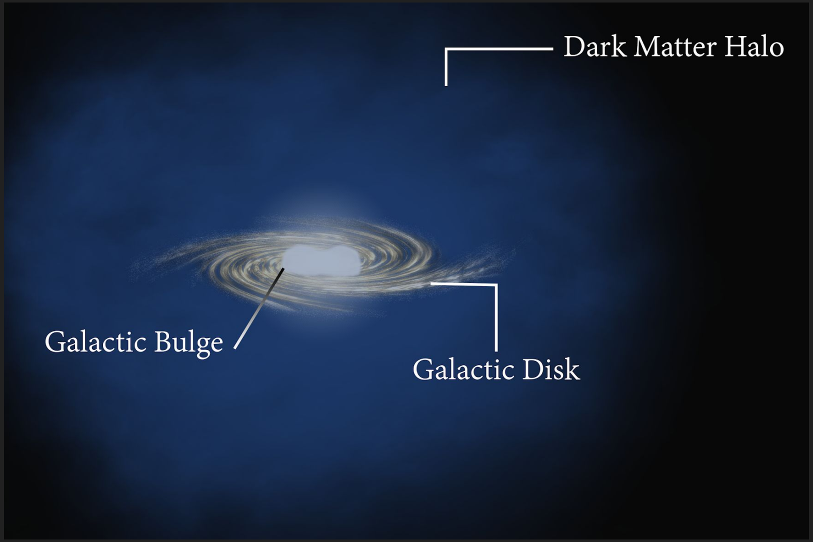
What we often talk about in cosmology as the "normal matter" we interact with on a day-to-day basis

(5%)

Dark Matter

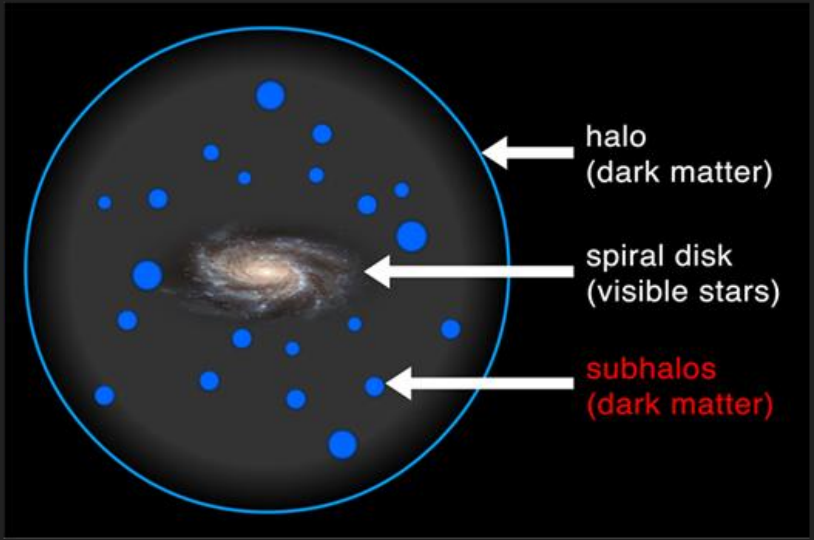
What scientists discovered *must* exist, as there wasn't enough baryonic matter present in galaxies for the them to rotate at the speeds they were found to move at (95%).

Dark Matter Halo



Concentration of dark matter surrounding a galaxy

Subhalo



Smaller clumps of dark matter found within the halo

Jupyter Notebook

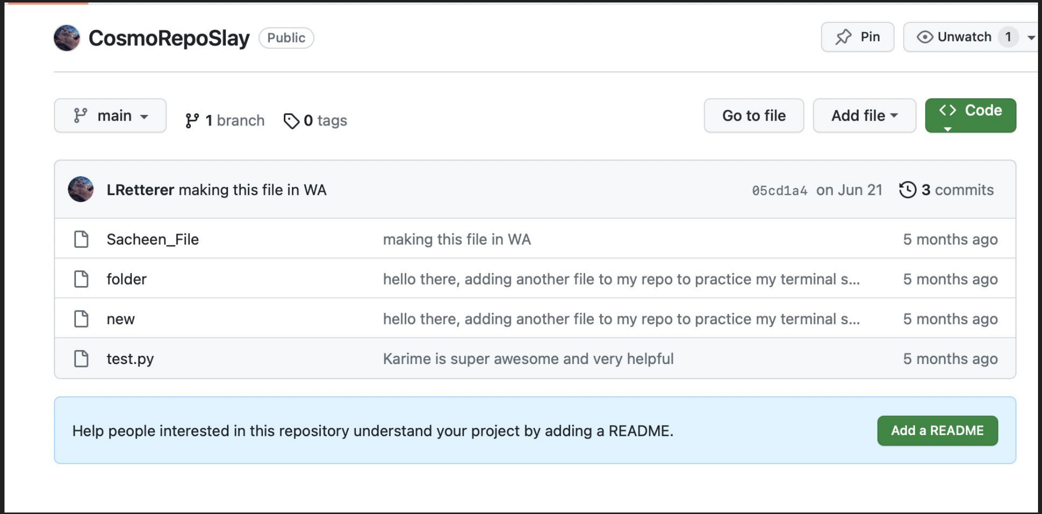
Coding interactive platform that uses python

Able to house code, visualizations, equations, and live text all in one file

Terminal

Refers to a computer's terminal window that a user can open to directly communicate with the device
Used to avoid going through all the steps of the usual computer interface

Repository



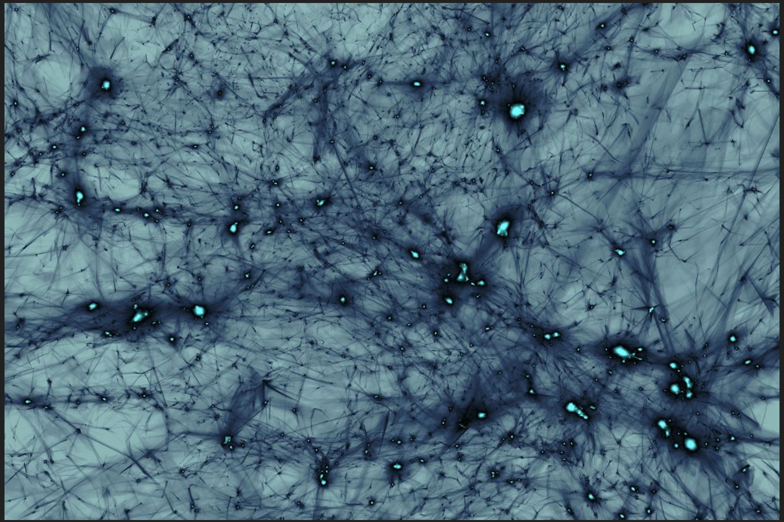
A place to store code
Often a file that contains multiple files within it

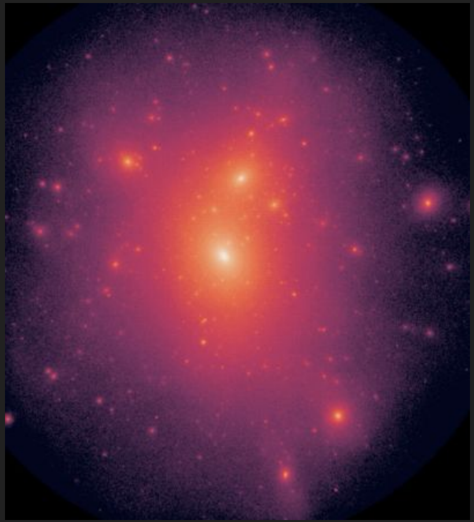
Github

Website/platform that houses code
Cosmologists often use it to access repositories

Colormap: density

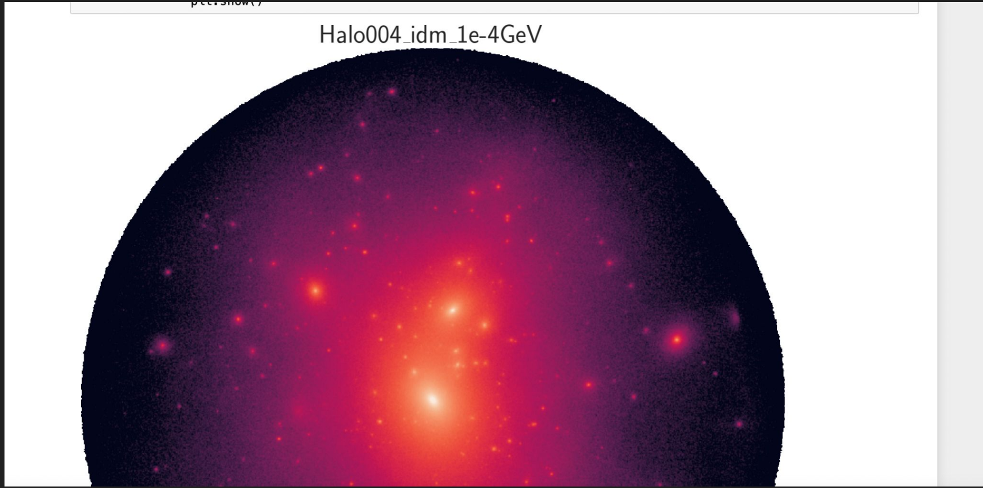
- Task: Create a colormap to match a simulation of a dark matter halo
- Goal: Match the visualization on the right to the colors on the left:





Colormap

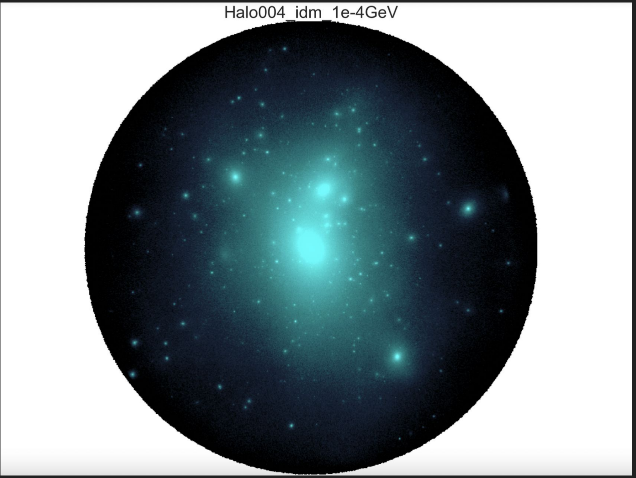
- This is the original visualization:



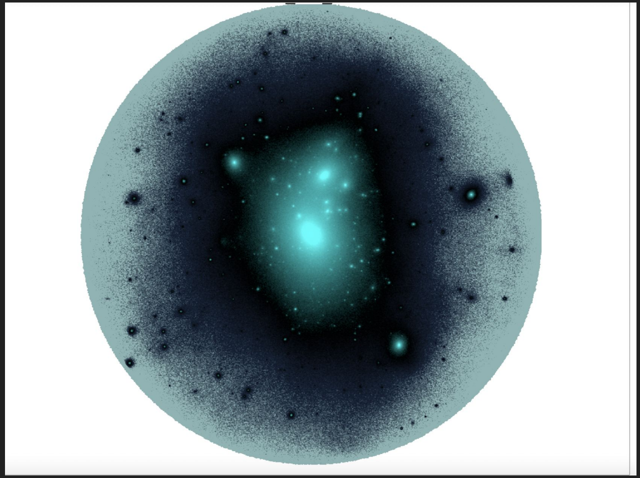
- Here is the custom colormap code:
- import matplotlib as mpl
  custom_cmap = mpl.colors.LinearSegmentedColormap.from_list("", ["cyan","#10fcfc","black", "#152539","#88b4b4"])

Colormap: density

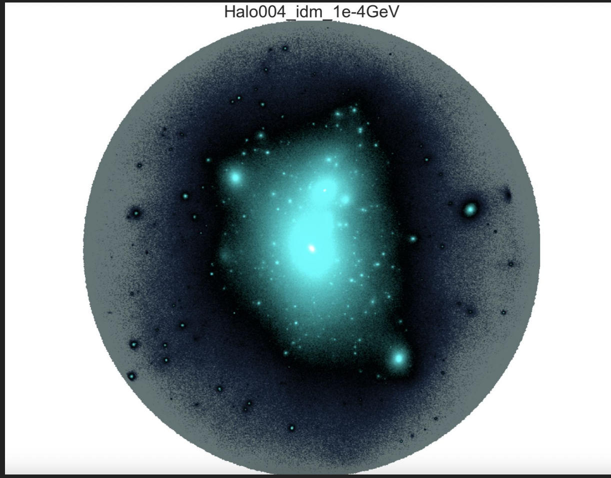
Version 1:
Good cohesion, but no light blue!!!!



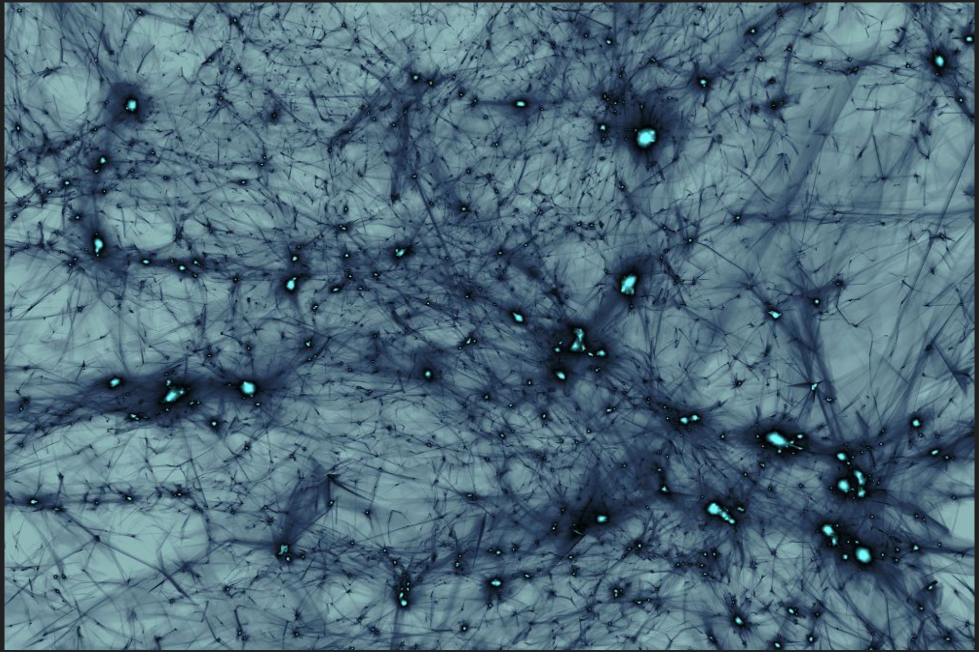
Version 2:
Light blue present, but now too grainy

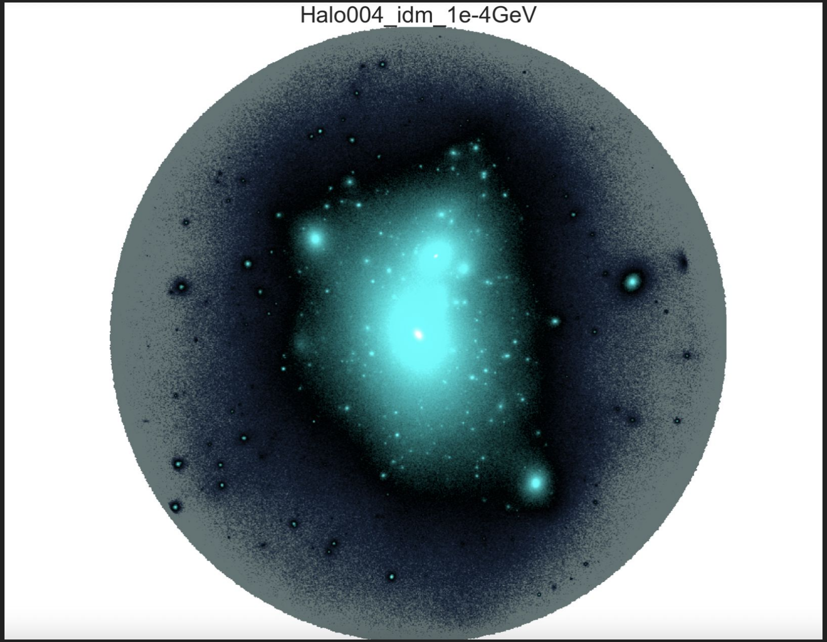


Version 3:
Better



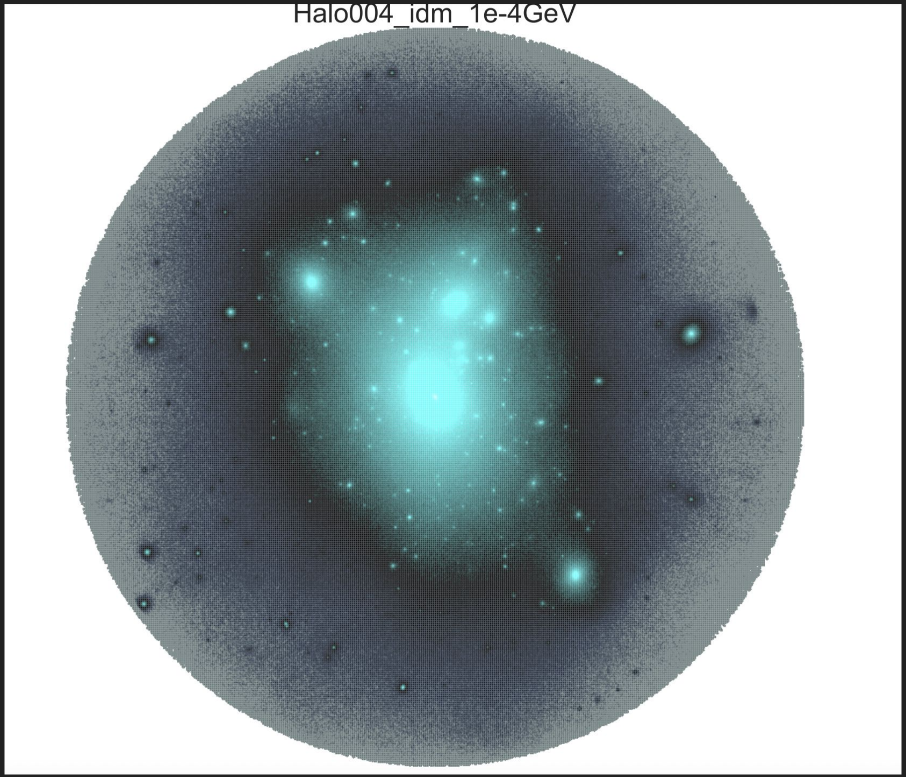
Colormap: density





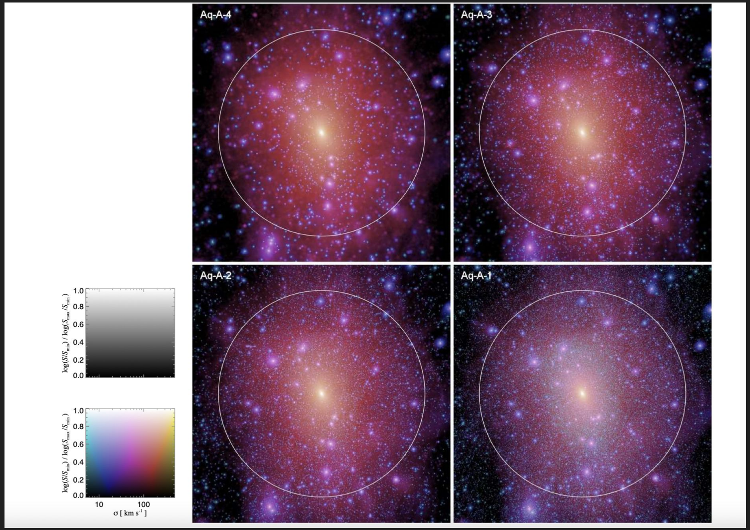
Colormap: velocity dispersion

- I changed the visualization to show velocity dispersion instead of density
  - the dispersion/distribution of the velocity of the dark matter particles)
- I had to create a new variable and substitute it in the code for where the code previously used the density variable
- It looked quite similar to the density visualization, which was expected due to the way the density was already spread out in the visualization.

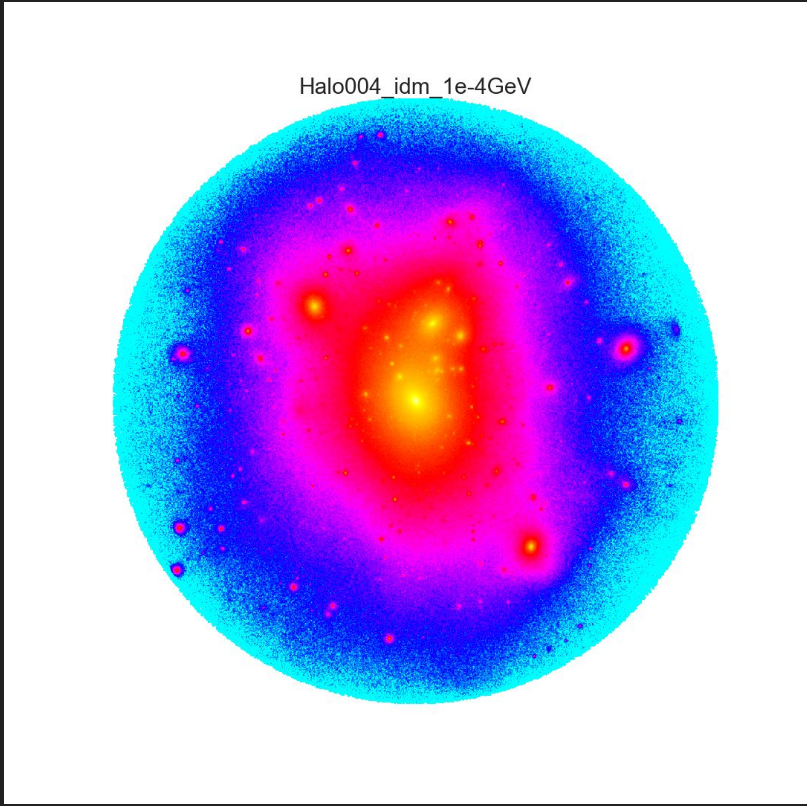


Colormap: velocity dispersion

- I combined the two different types of visualizations (density and velocity dispersion) and to match the color of a specific paper that did a similar analysis:



arXiv:0809.0898



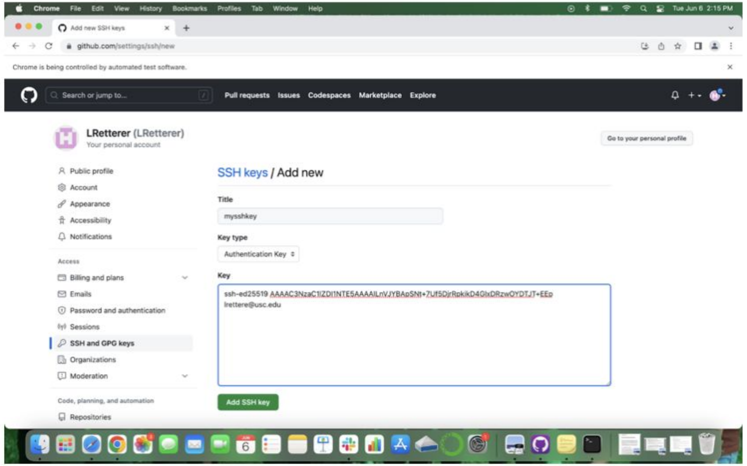
SSH Key Access

- Trouble with the data- opening repos
- Wanted to get an SSH key to make it easier
- Then I made a doc for anyone in the future to follow along for how to get an SSH Key

Main steps include

1) Ensure you can access Github through terminal
2) Put something from a repo into terminal
3) Use ghsu, gsussh, follow instructions and tada!

    - Type git clone <paste link you just copied>
    - Be sure to not use “<” or “>” , for example if the code is github.com, you would type *git clone github.com*
    - Next hit enter, and terminal will spit out some text mentioning your repo you are trying to get into terminal, and it will ask if you are sure you want to continue connecting→ type yes
- Does terminal then say you don’t have access rights? If so, we need to get you access, so follow the steps below. (If you <u>don’t</u> get this message, you already have access to github, so you can skip the following steps to the next pink header)
- Type pip install ghsu
- After your terminal finishes and says it downloaded, then type ghsussh and follow the instructions it gives you
    - It most likely will ask for your email, and then after you enter that it will open up a new page on github, something like this:



    - Click the green button that says add SSH key

Thank you!

BSAVI: Visualizing the connection between Bayesian Posteriors and Cosmological Observables

Jimmy Wen

What is Bayesian Inference?

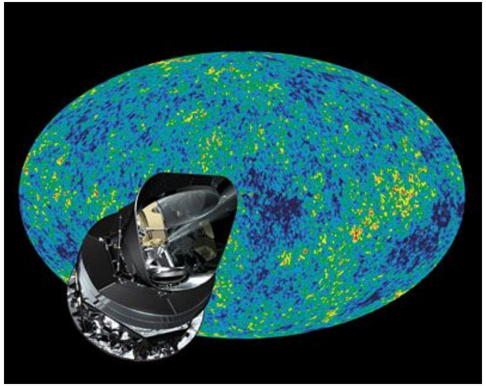
- As you learn more about your subject, you update your beliefs about it using Bayes' Theorem

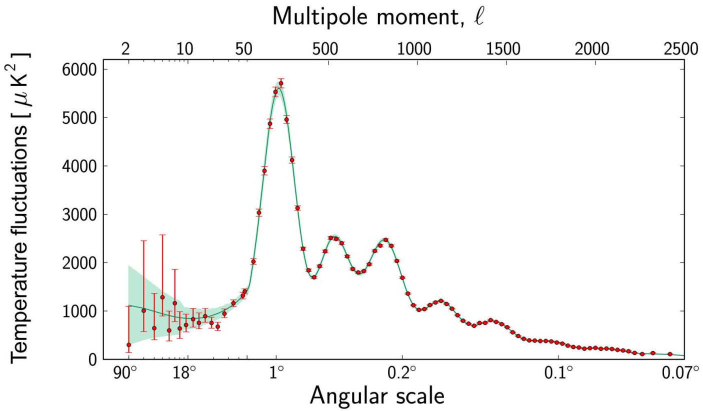
$$P(H|E) = \frac{P(E|H) \cdot P(H)}{P(E)}$$

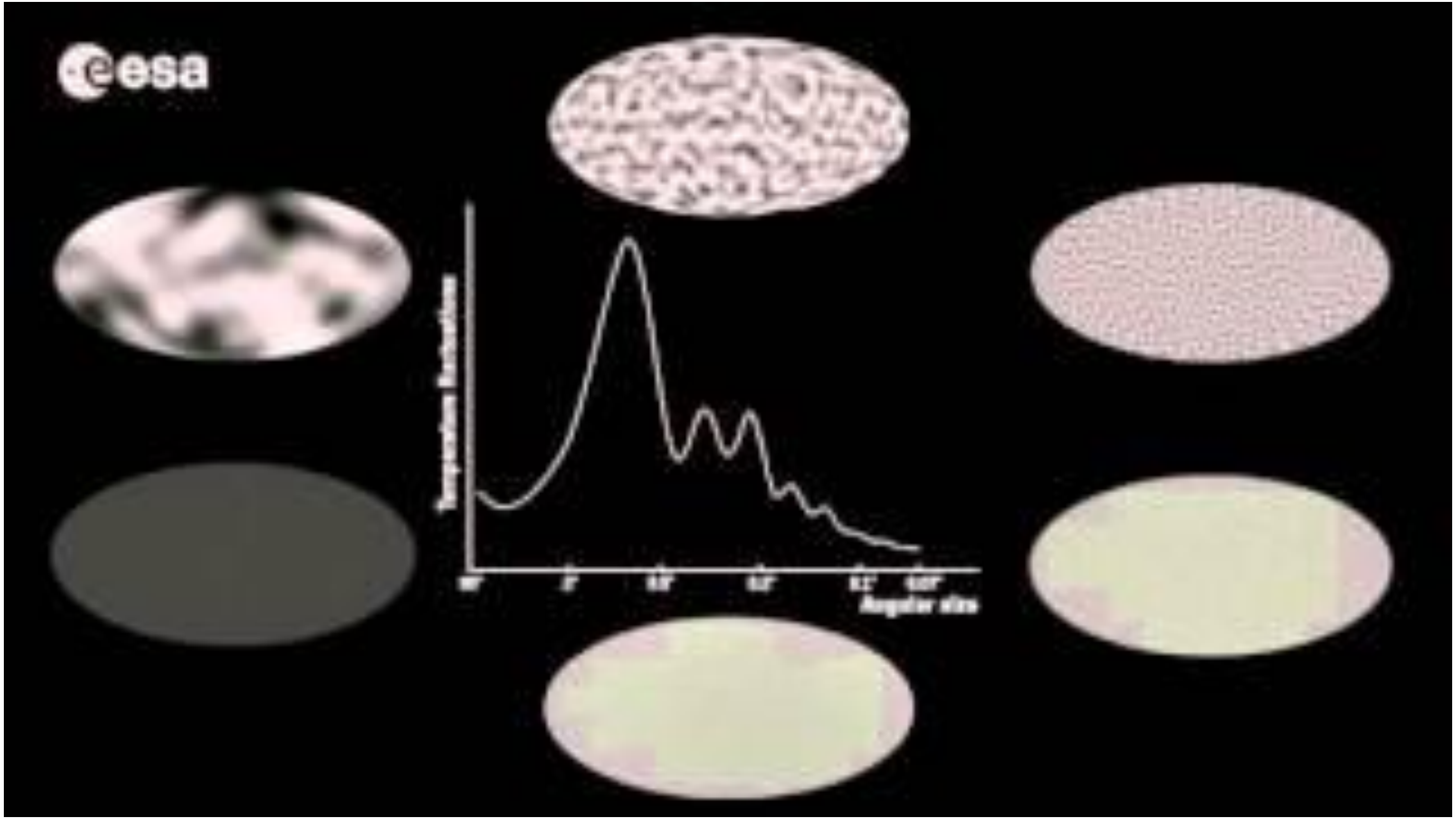
- Posterior = Likelihood * Prior / Evidence
- Posterior = probability of hypothesis being true given the observed evidence

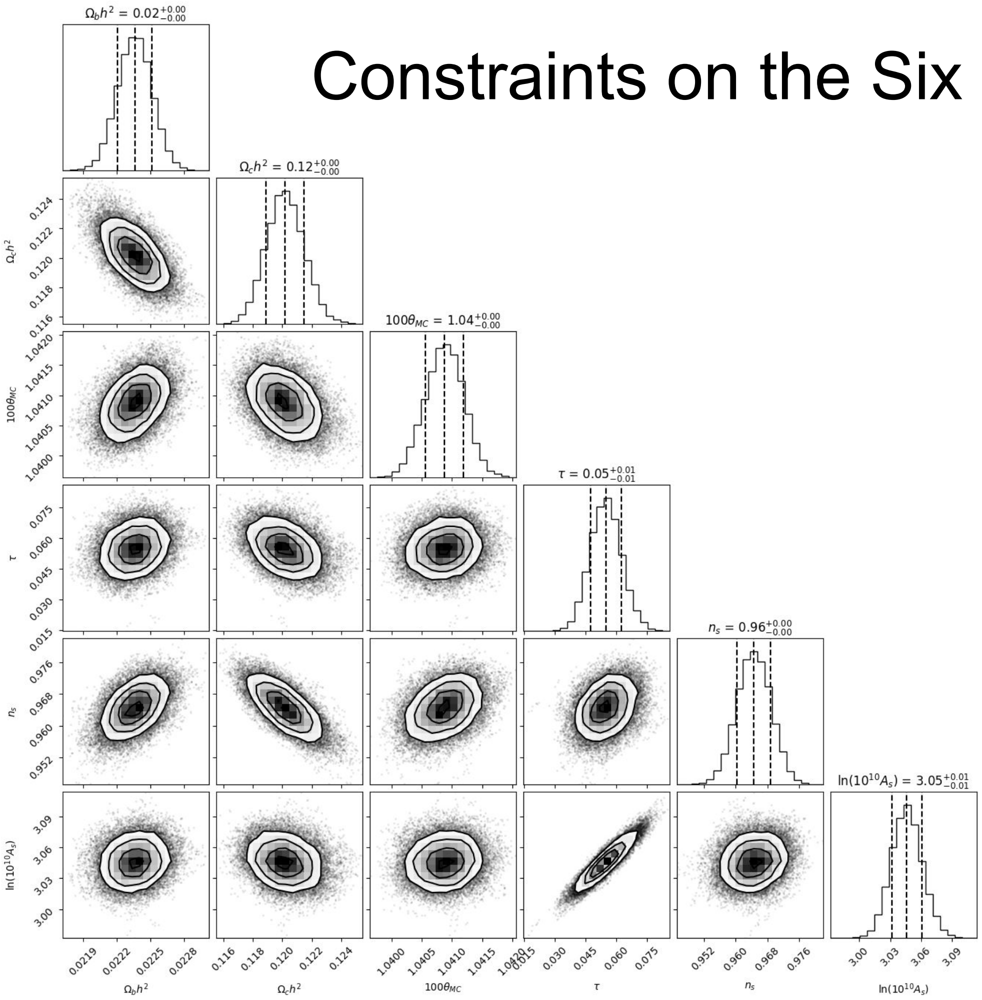
Why Use Bayesian Inference in Cosmology?

- In Lambda CDM, there are six numbers that describe the universe
  - Baryon density, dark matter density, age of the universe, scalar spectral index, curvature fluctuation amplitude, and reionization optical depth
- We would like to know what values of these numbers describe *our* universe
- If we search for them in the parameter space using Bayesian methods, we'll find a region of values corresponding to real life observations.





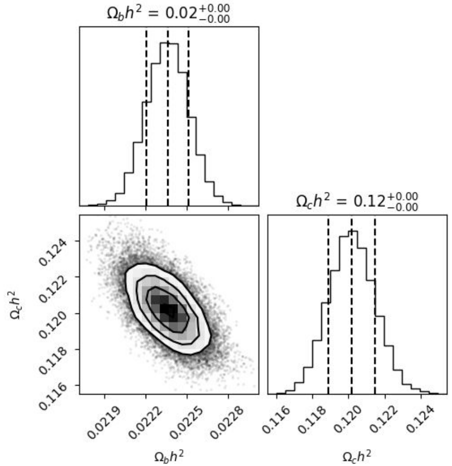
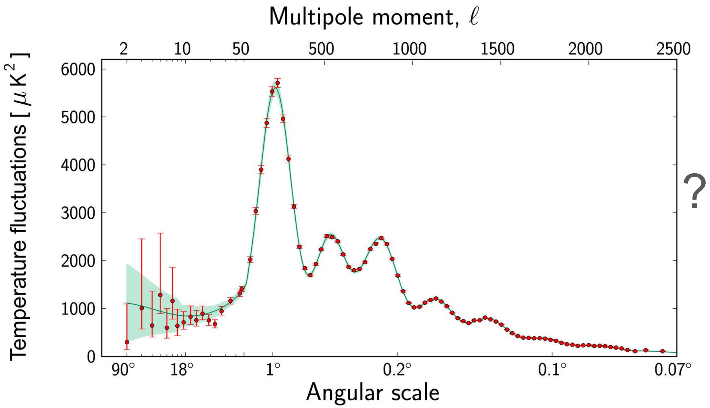




Constraints on the Six LCDM Parameters

Each blob represents a posterior probability distribution. The individual points were sampled from this continuous distribution using Monte Carlo Markov Chain (MCMC).

This data was released by the Planck Collaboration in 2018

But how does  relate to  ?

Each point in the posterior sample distribution is a set of parameter values which will produce a slightly different CMB anisotropy.

As we traverse the parameter space, the CMB power spectrum will change.

Exploring the Parameter Space Interactively with BSAVI

- We want to quickly, easily and intuitively see how some Observable changes with different model parameters
- Current method:
  - Plot the samples. Find one that seems interesting
  - Look for it in your data table
  - Feed it into a program which calculates the observable
- Problems:
  - Several steps involving multiple packages
  - Static plotting backend (matplotlib)
- Solution: BSAVI (**B**ayesian **Sa**mple **Vi**sualizer)
  - A dashboard tying multiple plots together
  - Interactive plotting backend (bokeh)
    - zoom in/out, change plot axes, etc.
  - Linking selections made on the sample distribution directly to their corresponding observables

Exploring the Parameter Space Interactively with BSAVI

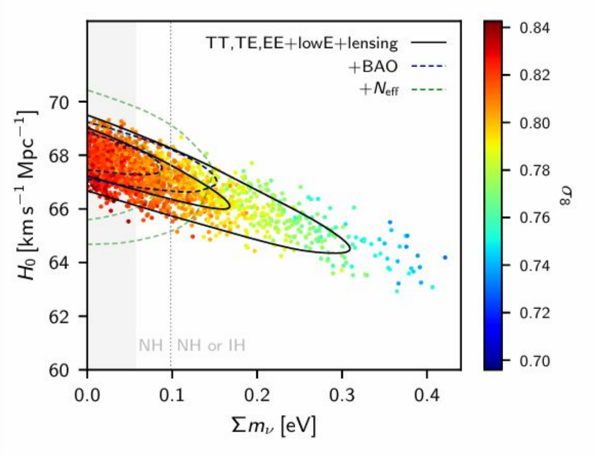
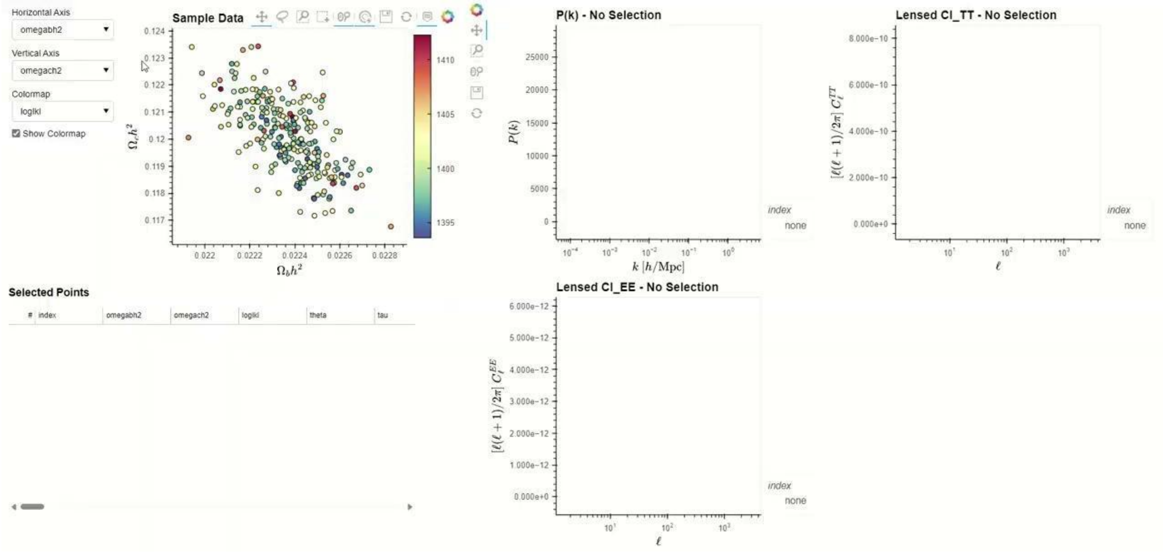


Fig. 34. Samples from *Planck* TT,TE,EE+lowE chains in the $\sum m_\nu$–H_0 plane, colour-coded by σ_8. Solid black contours show the constraints from *Planck* TT,TE,EE+lowE+lensing, while dashed blue lines show the joint constraint from *Planck* TT,TE,EE+lowE+lensing+BAO, and the dashed green lines additionally marginalize over $N_{\rm eff}$. The grey band on the left shows the region with $\sum m_\nu < 0.056$ eV ruled out by neutrino oscillation experiments. Mass splittings observed in neutrino oscillation experiments also imply that the region left of the dotted vertical line can only be a normal hierarchy (NH), while the region to the right could be either the normal hierarchy or an inverted hierarchy (IH).



Low Code, but lots of options if you need them

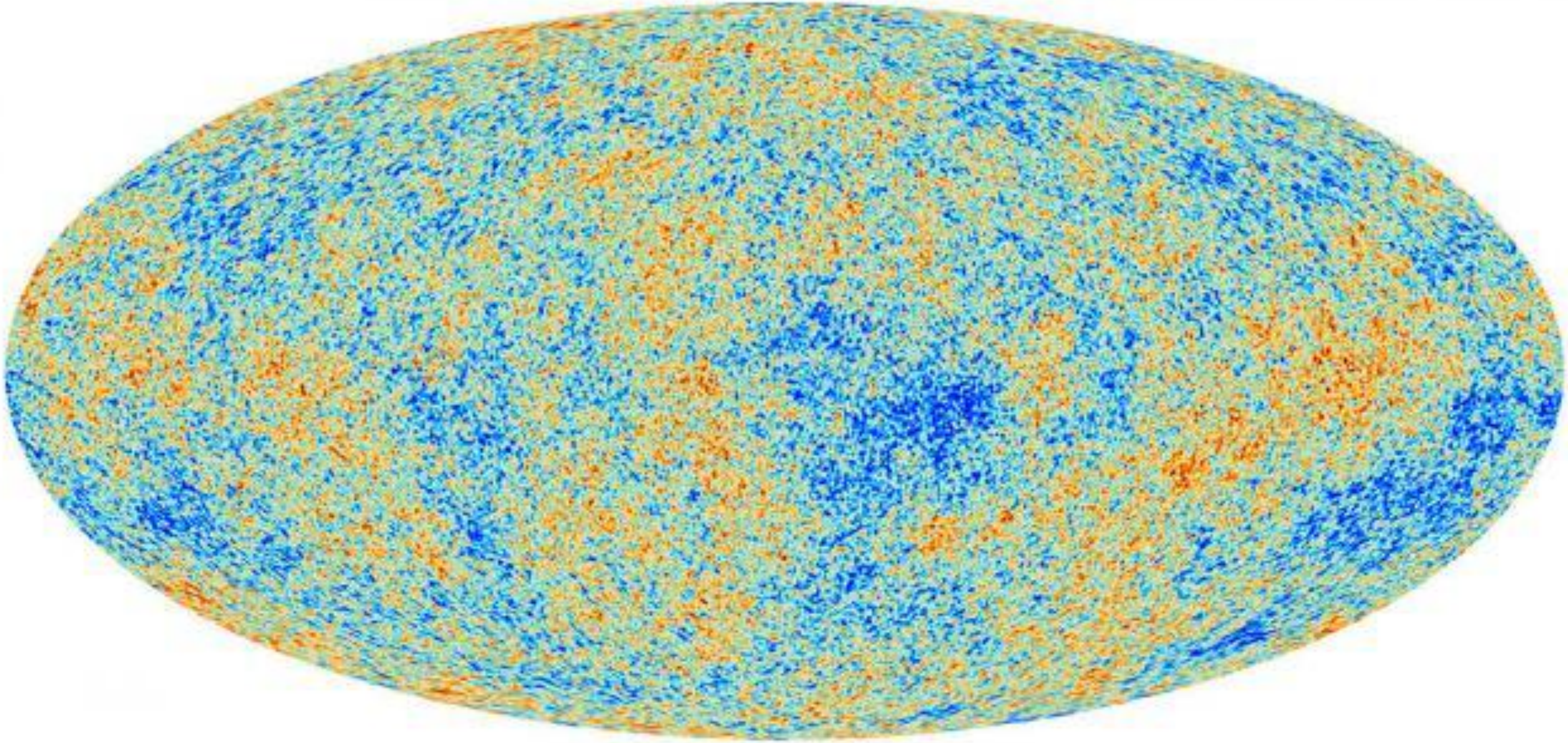
```
GNU nano 6.2                                              planck_mnu.py *
import pandas as pd
from holoviews import opts
import bsavi as bsv
from bsavi.loaders import load_params

mycosmo = pd.read_json('../data/planck2018/power_spectra_small.json')
chains = mycosmo.drop(columns=['p(k)', 'cl_tt', 'cl_ee'])
class_results = mycosmo[['p(k)', 'cl_tt', 'cl_ee']]


params_with_latex = load_params('../data/planck2018/base_mnu_plikHM_TTTEEE_lowl_lowE_lensing.paramnames')


curve_opts = opts.Curve(logx=True)

ps_latex = {
    'k': 'k~[h/\mathrm{Mpc}]',
    'Pk': 'P(k)',
    'l': '\ell',
    'Cl_tt': '[{\ell(\ell+1)}/{2\pi}]~C_{\ell}^{TT}',
    'Cl_ee': '[{\ell(\ell+1)}/{2\pi}]~C_{\ell}^{EE}',
}

power_spectra = bsv.Observable(
    name=['P(k)', 'Lensed Cl_TT', 'Lensed Cl_EE'],
    data=class_results,
    plot_type='Curve',
    plot_opts=curve_opts,
    latex_labels=ps_latex
)

bsv.viz(chains, [power_spectra], latex_dict=params_with_latex).servable()
```

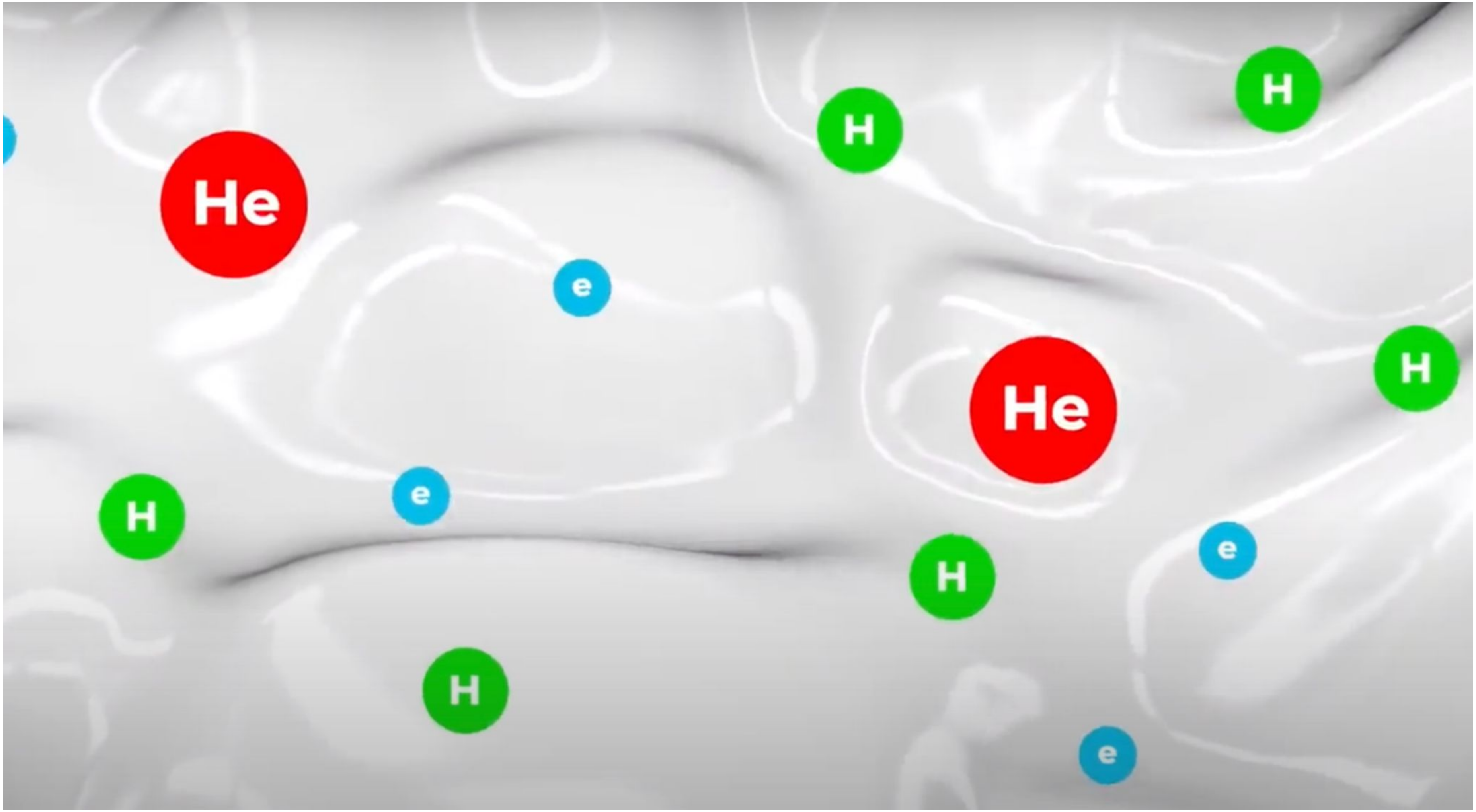
Thank You😎

Cosmic Microwave Background (CMB)

Adam He


15

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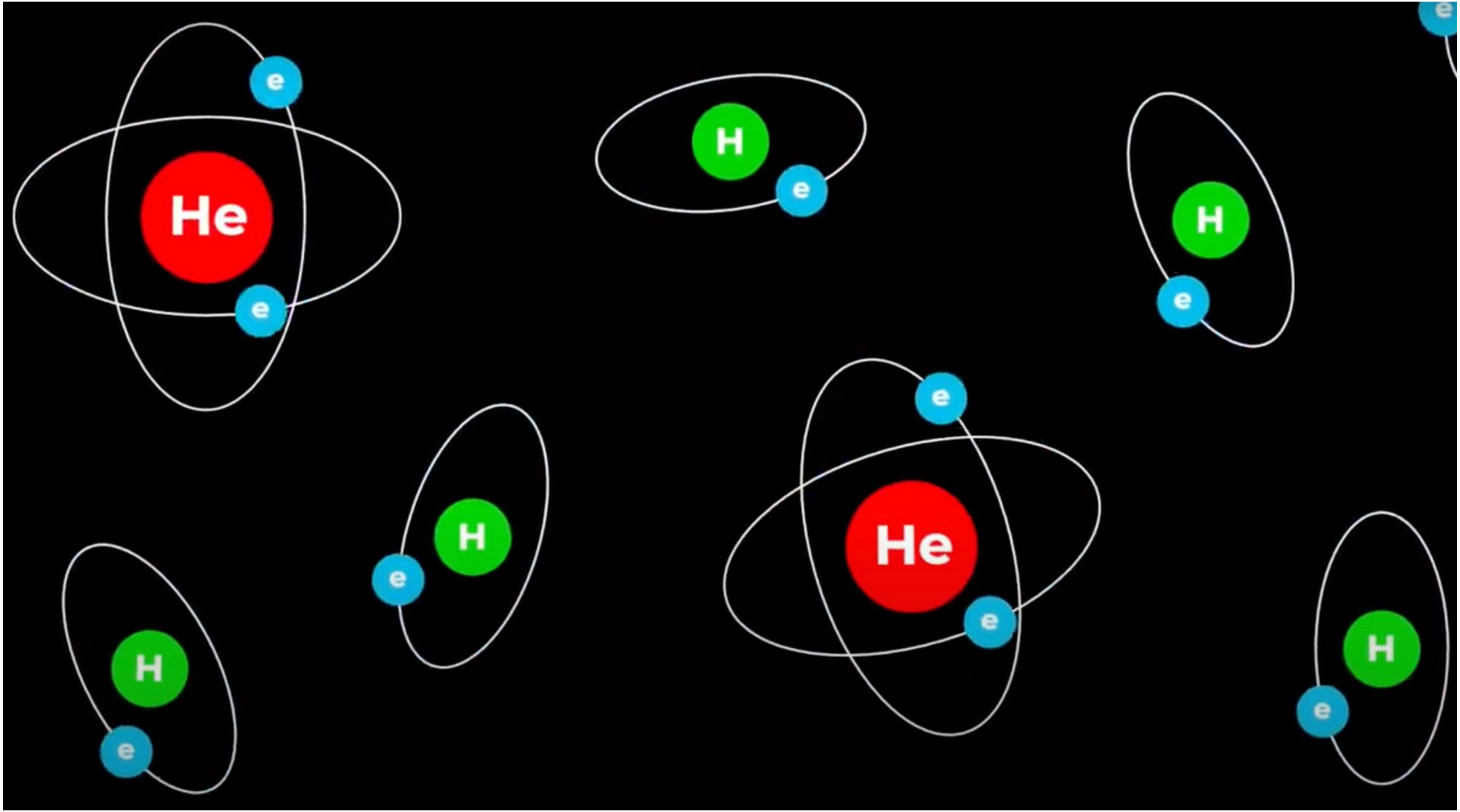
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DM research

To test a particular dark matter model,

- Simulate the evolution of the universe under this particular scenario
- Generate the distribution of matter at the time of recombination
- Compare this expected distribution with what we actually observe in the CMB

Thank you

Hunting for Dark Matter

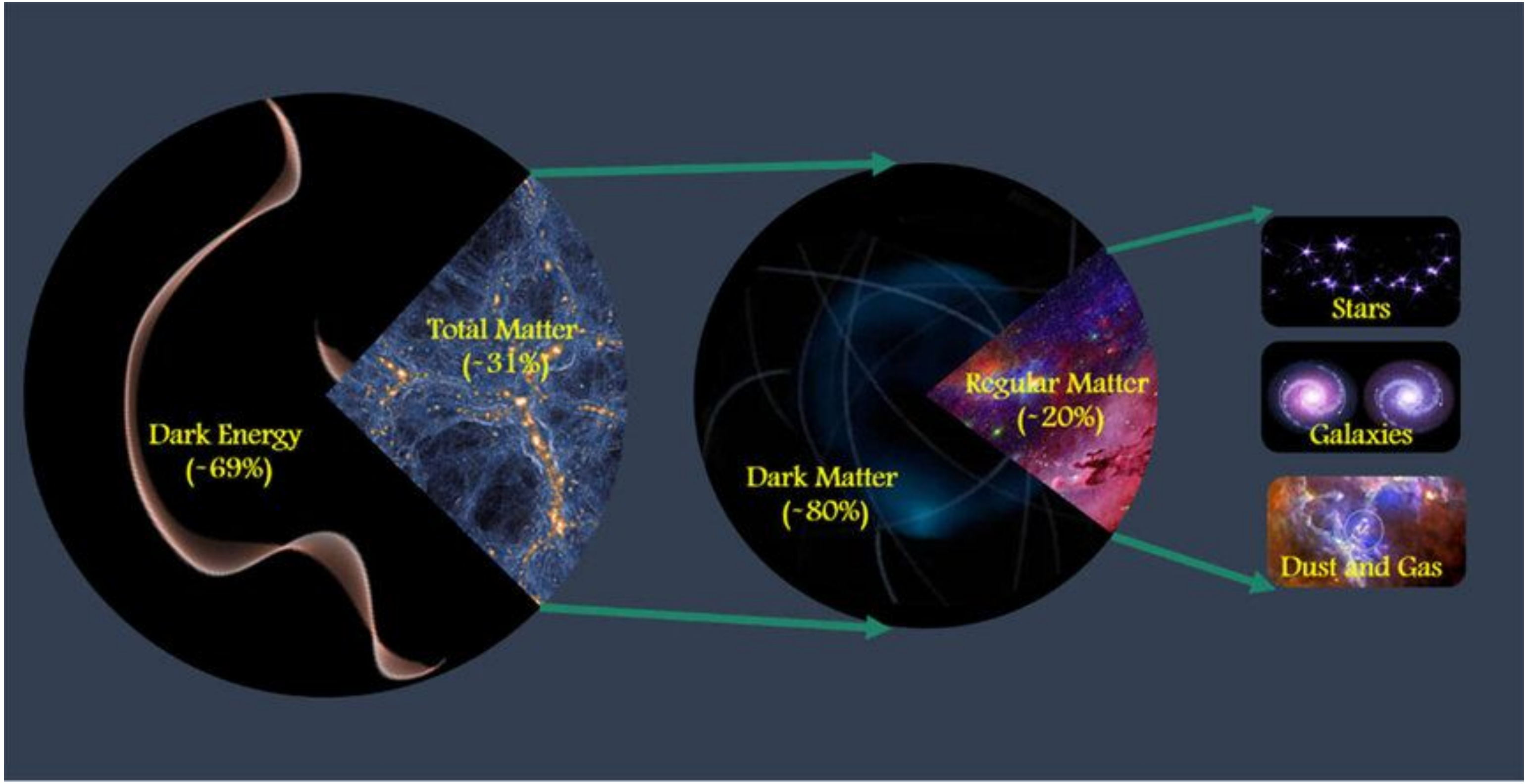
Cosmolab Open House

Dimple Sarnaaik

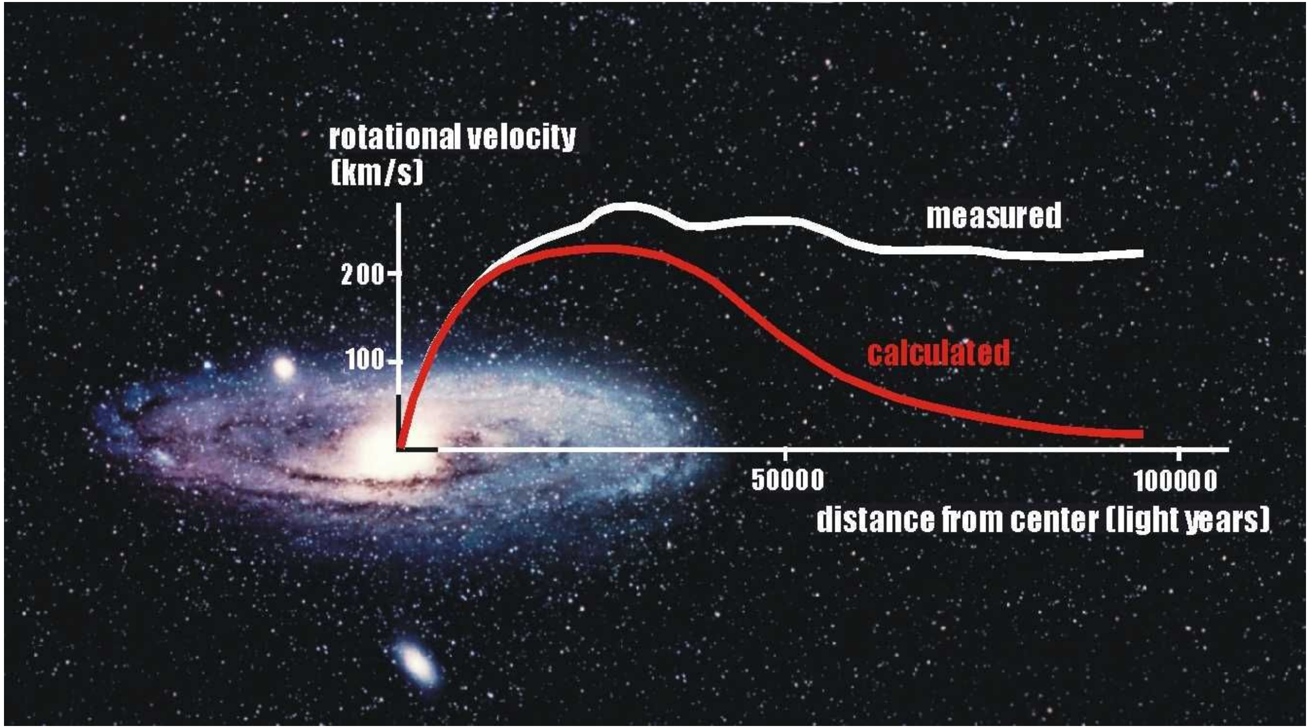
Outline

- What is DM and how to look for it?
- Gravitational Lensing
- Simulations

What is DM?


Dark Energy
(~69%)
Total Matter
(~31%)
Dark Matter
(~80%)
Regular Matter
(~20%)
Stars
Galaxies
Dust and Gas

How do I know it's there?

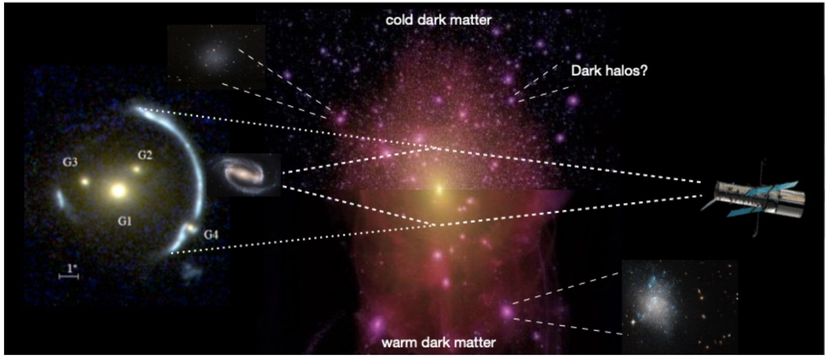


But also..

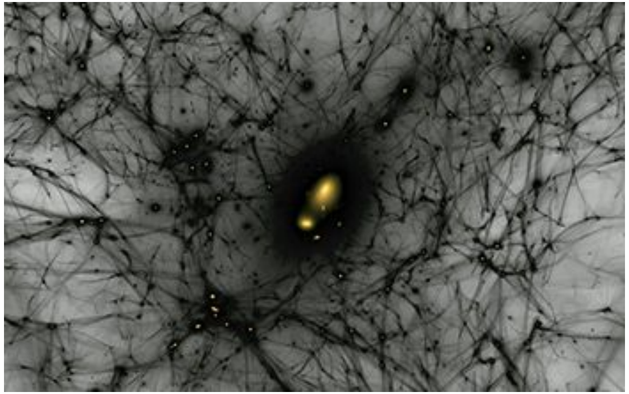
1. Gravitational Lensing
2. Mass of observed galaxies
3. CMB

How to hunt for DM

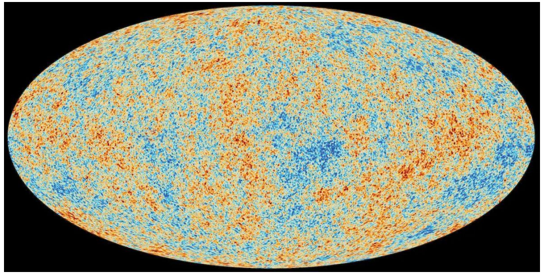
Gravitational Lensing



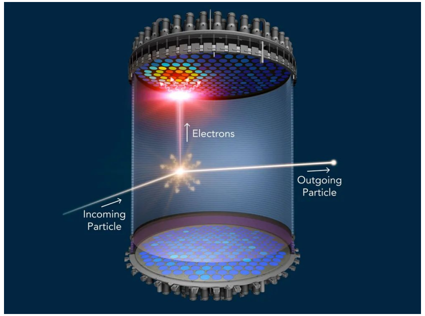
Simulations



Cosmic Microwave Background



Direct Detection & more..

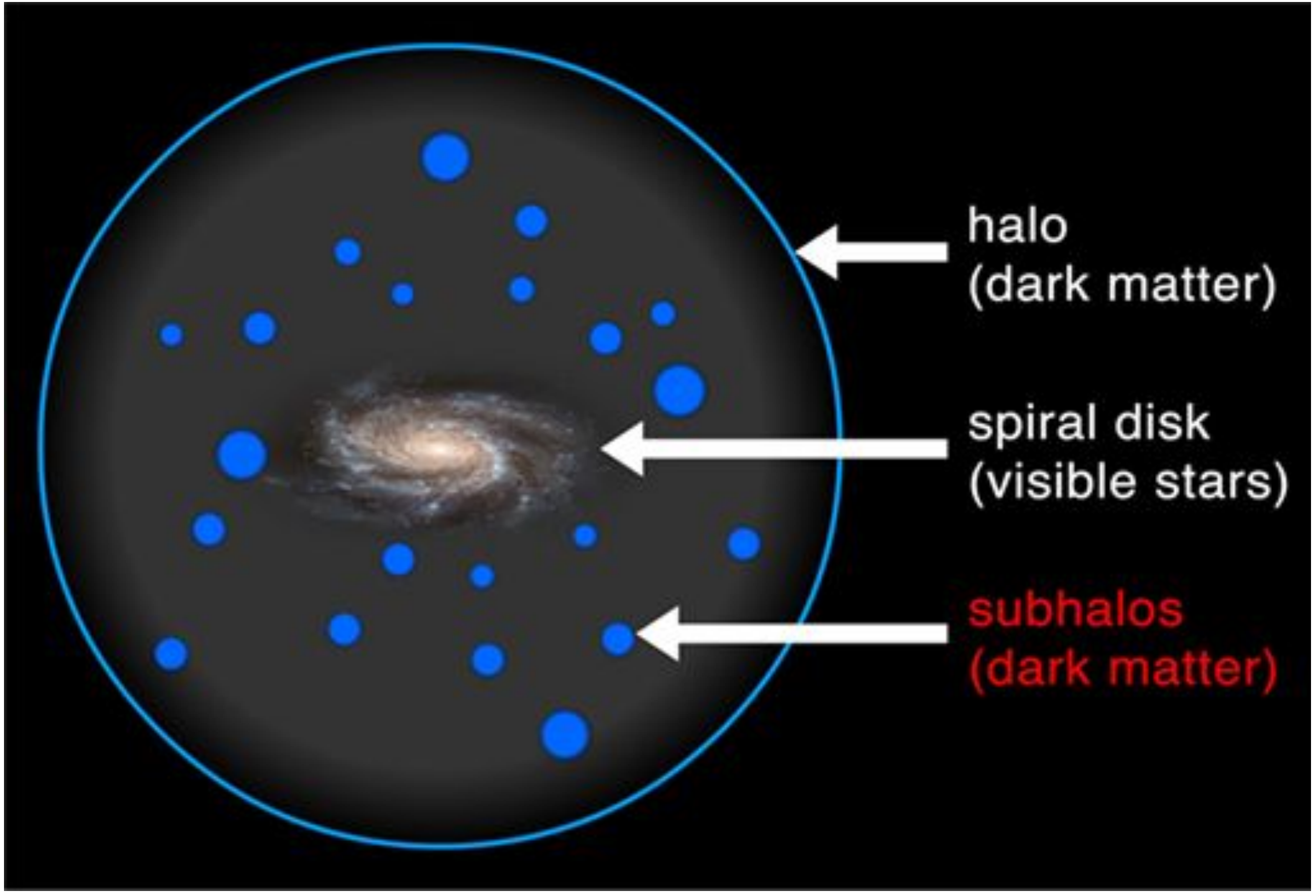


Credit: Fig.1:NASA/ESA HST (strong lens, dwarf galaxies), M. Lovell (CDM/WDM simulations), Fig.2: Ethan Nadler, Vera Gluscevic, Fig3: Planck Collaboration, Fig 4: SLAC National Accelerator Lab

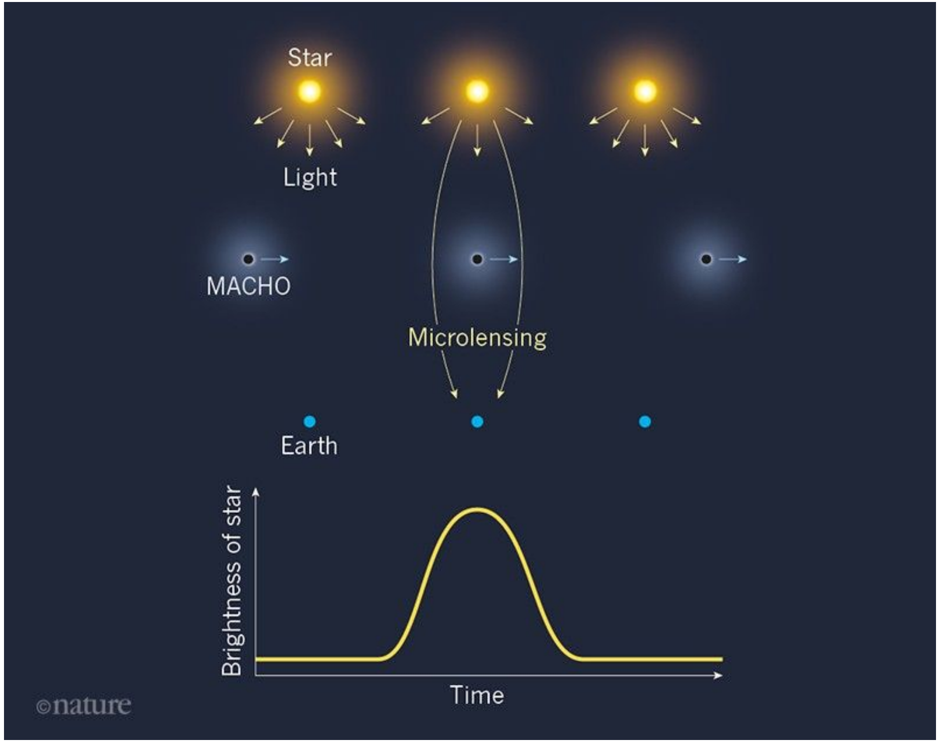
Outline

- What is DM and how to look for it?
- Gravitational Lensing
- Simulations

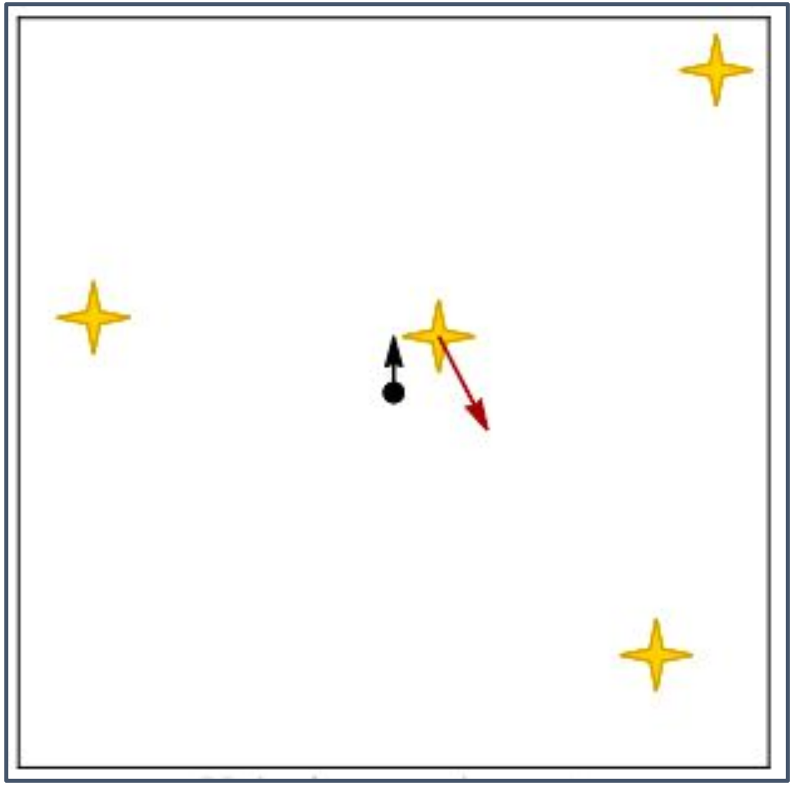
Probing DM subhalo populations



Galaxies embedded in DM Halos

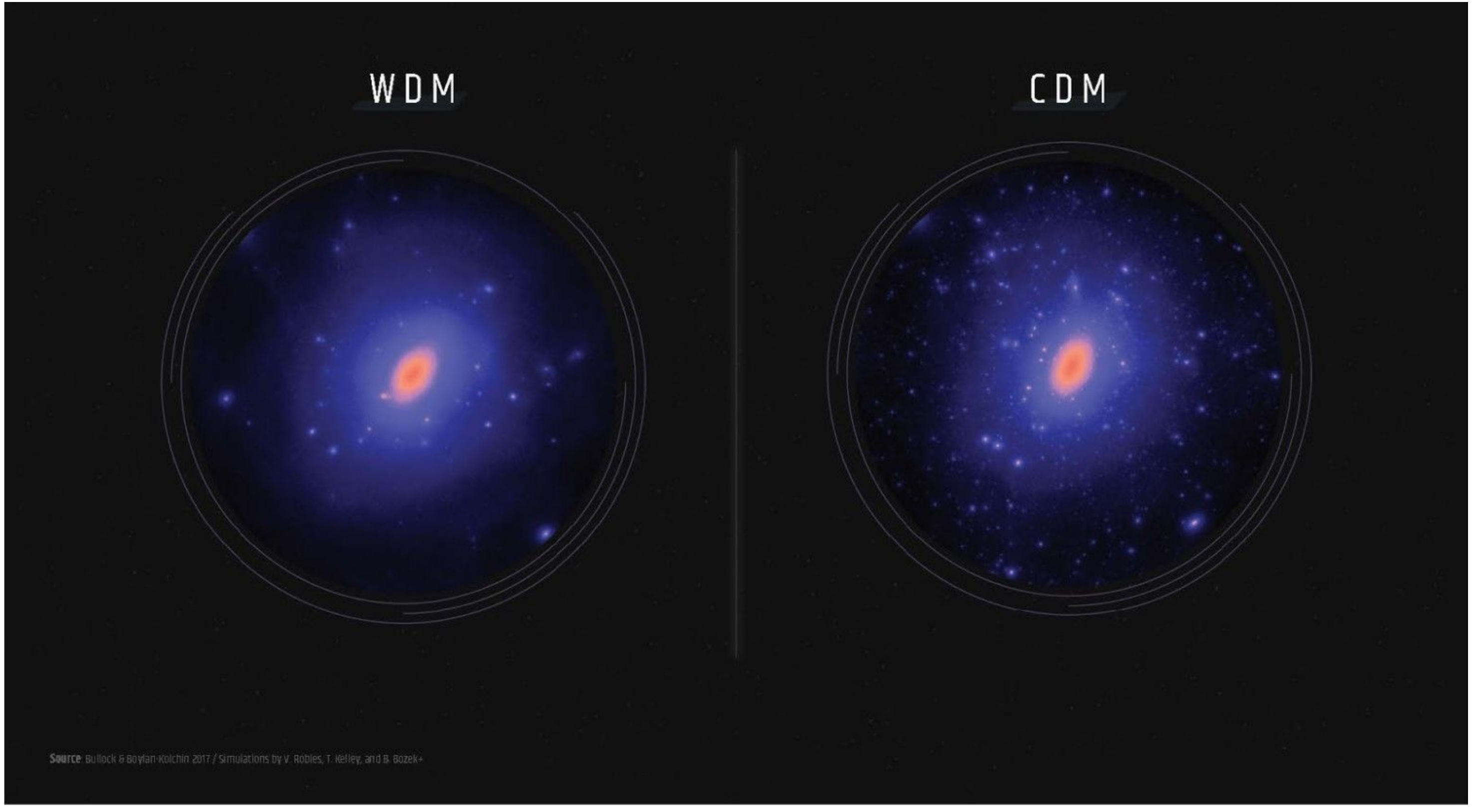


Microlensing



Using Astrometry

Different Subhalos



Mass functions

Cold Dark Matter

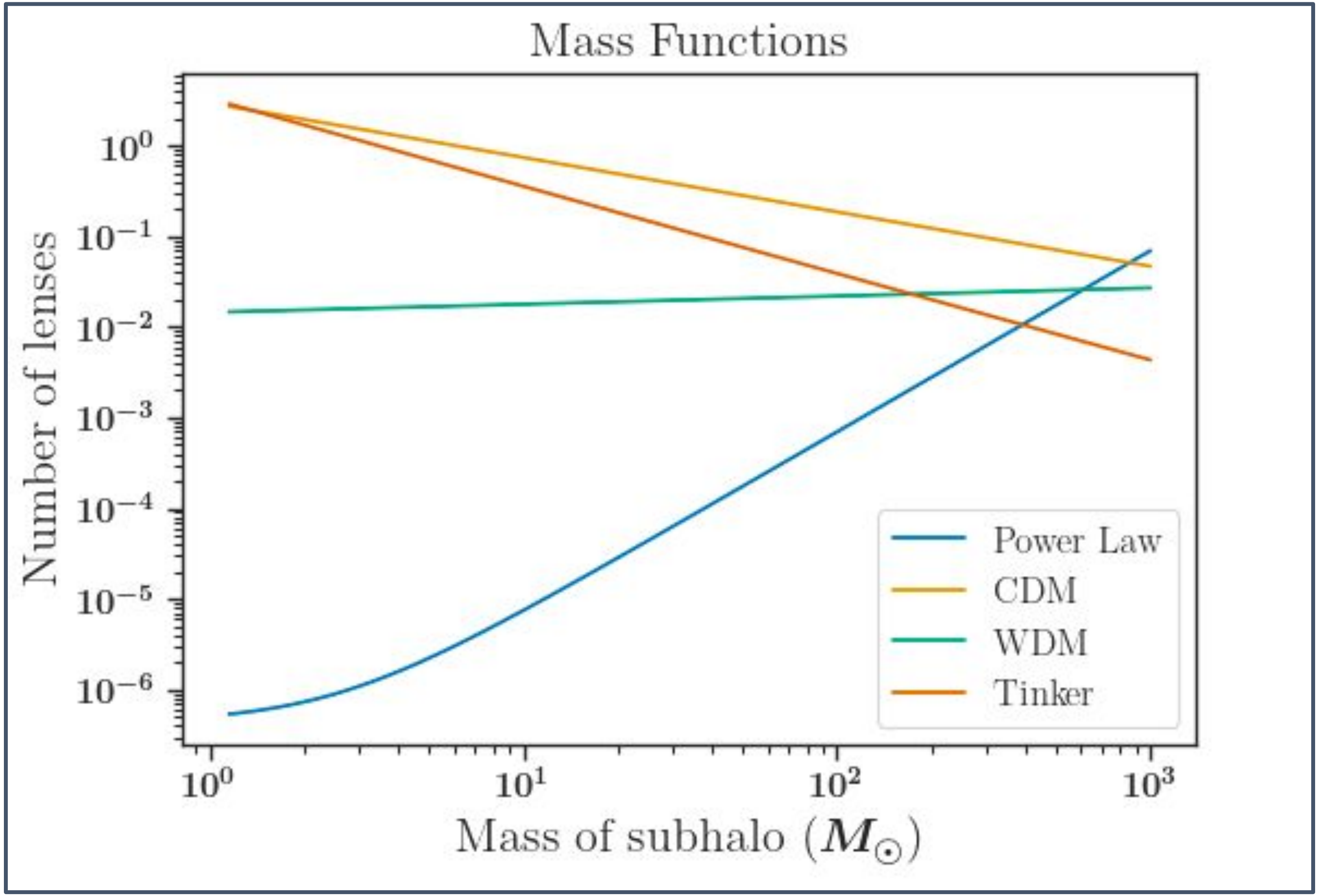
$$\left(\frac{dN}{dM}\right)_{\mathrm{CDM}} = 3.26 \times 10^{-5} \left(\frac{M}{2.57 \times 10^{7} M_{\odot}}\right)^{-1.9} M_{\odot}^{-1}.$$

Warm Dark Matter

$$\left(\frac{dN}{d\ln M}\right)_{\mathrm{WDM}}^{\mathrm{stream}} = \left(1 + \gamma \frac{M_{\mathrm{hm}}}{M}\right)^{-\beta} \left(\frac{dN}{d\ln M}\right)_{\mathrm{CDM}}$$

Tinker

$$\frac{\mathrm{d}n}{\mathrm{d}M} = f(\sigma) \frac{\bar{\rho}_{\mathrm{m}}}{M} \frac{\mathrm{d}\ln \sigma^{-1}}{\mathrm{d}M}$$



Number of Subhalos in Roman’s field of view acc. to massfunction

Outline

- What is DM and how to look for it?
- Gravitational Lensing
- Simulations

Matching Galacticus and Simulations

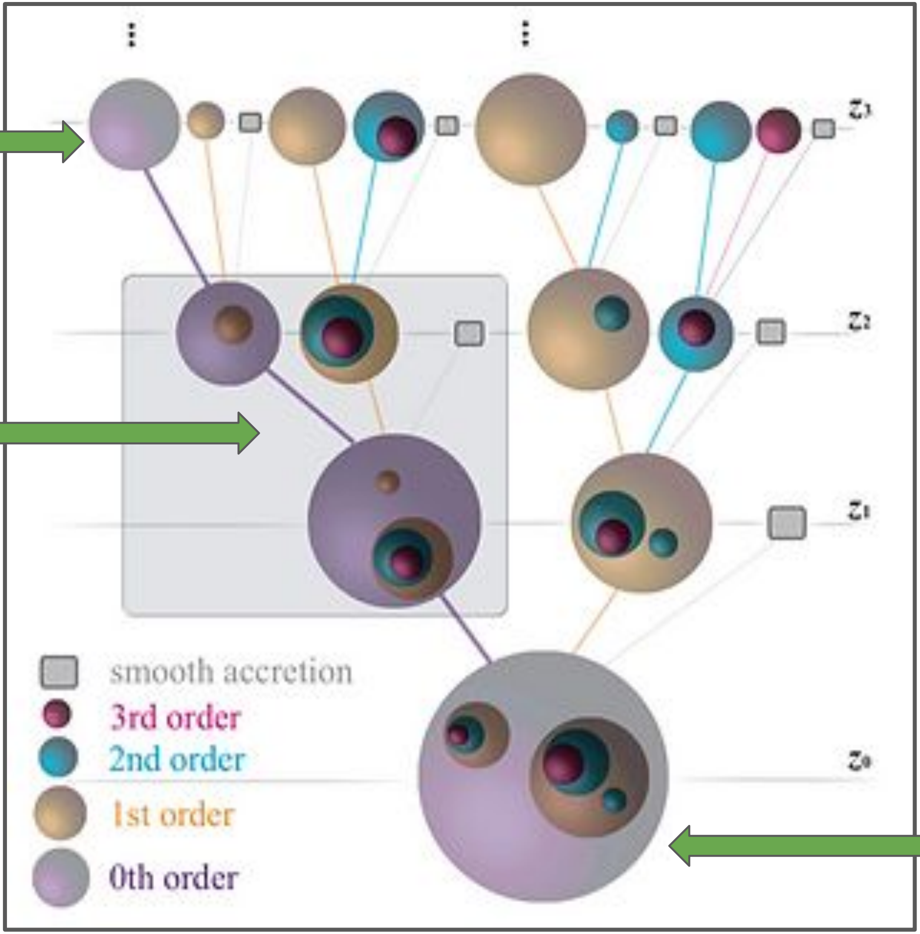
CARNEGIE SCIENCE


FPS: 002.00 | Bodies: 50000 | Theta: 0.7 | Dt: 0.5 | Softening: 25

Galacticus: A Semi-Analytic Model of Galaxy Formation

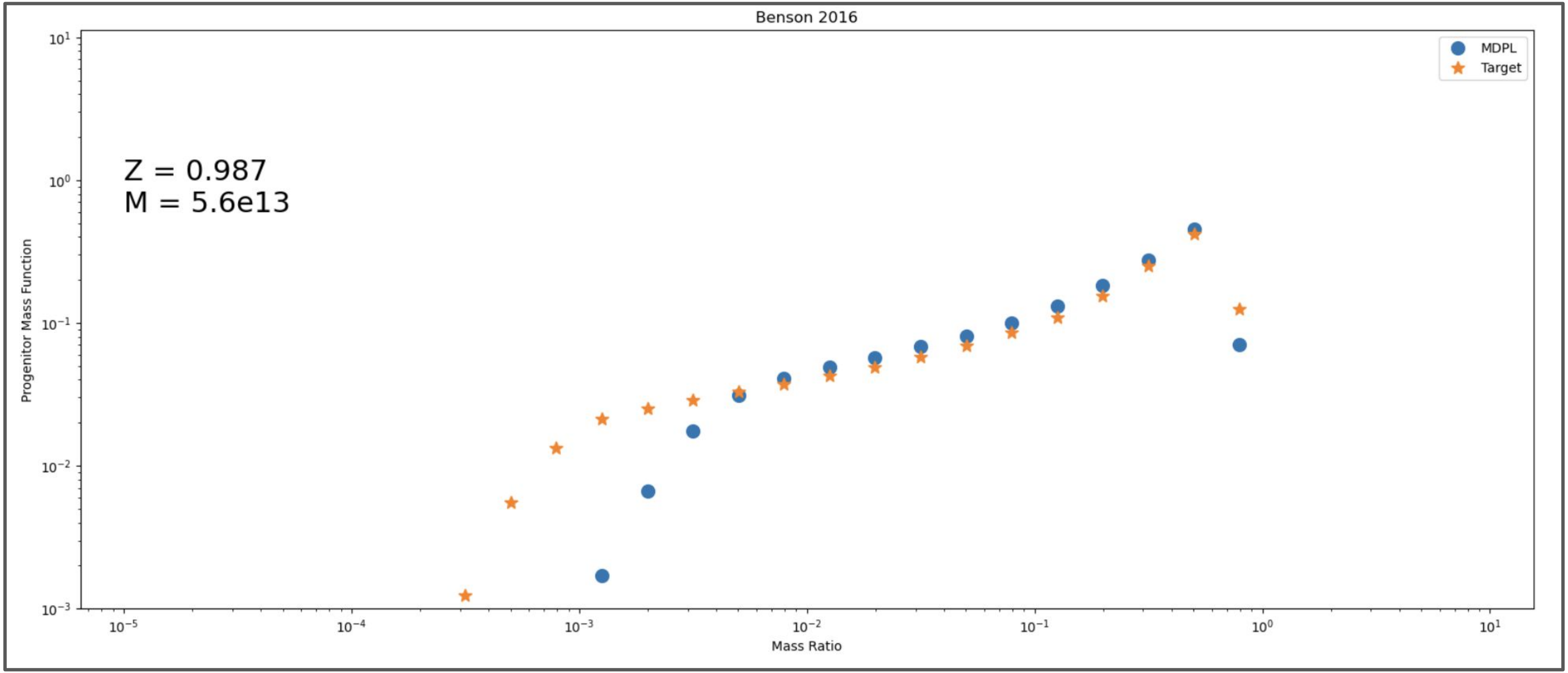
Progenitors

Merger

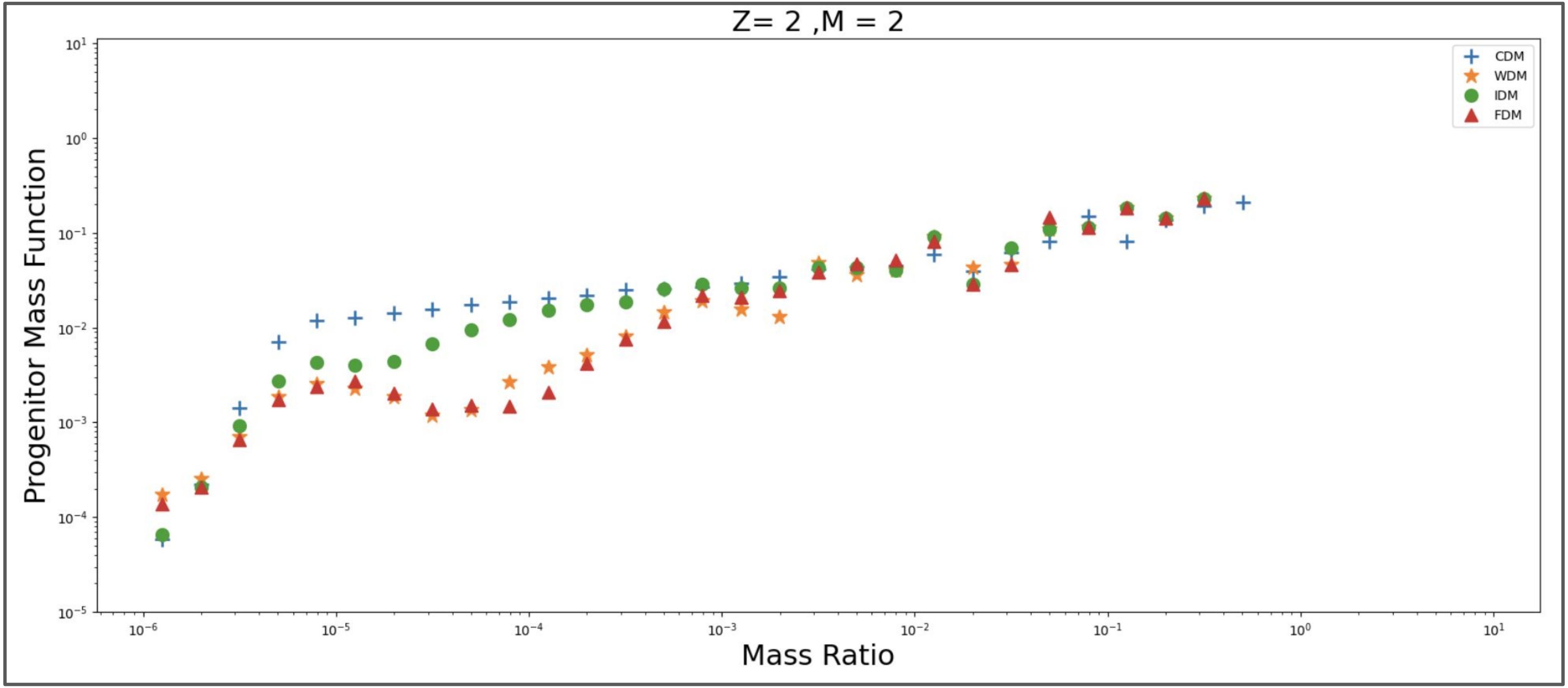


Main Halo

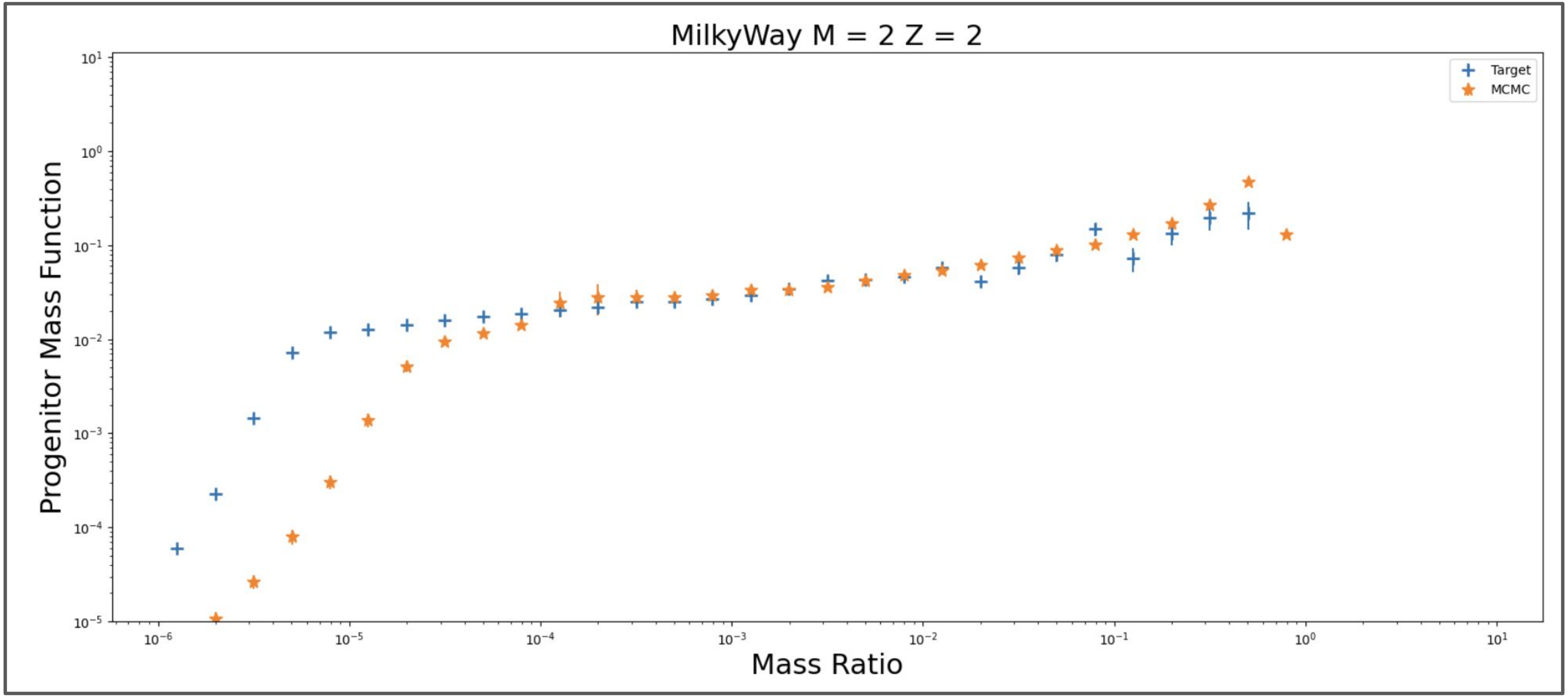
Fangzhou



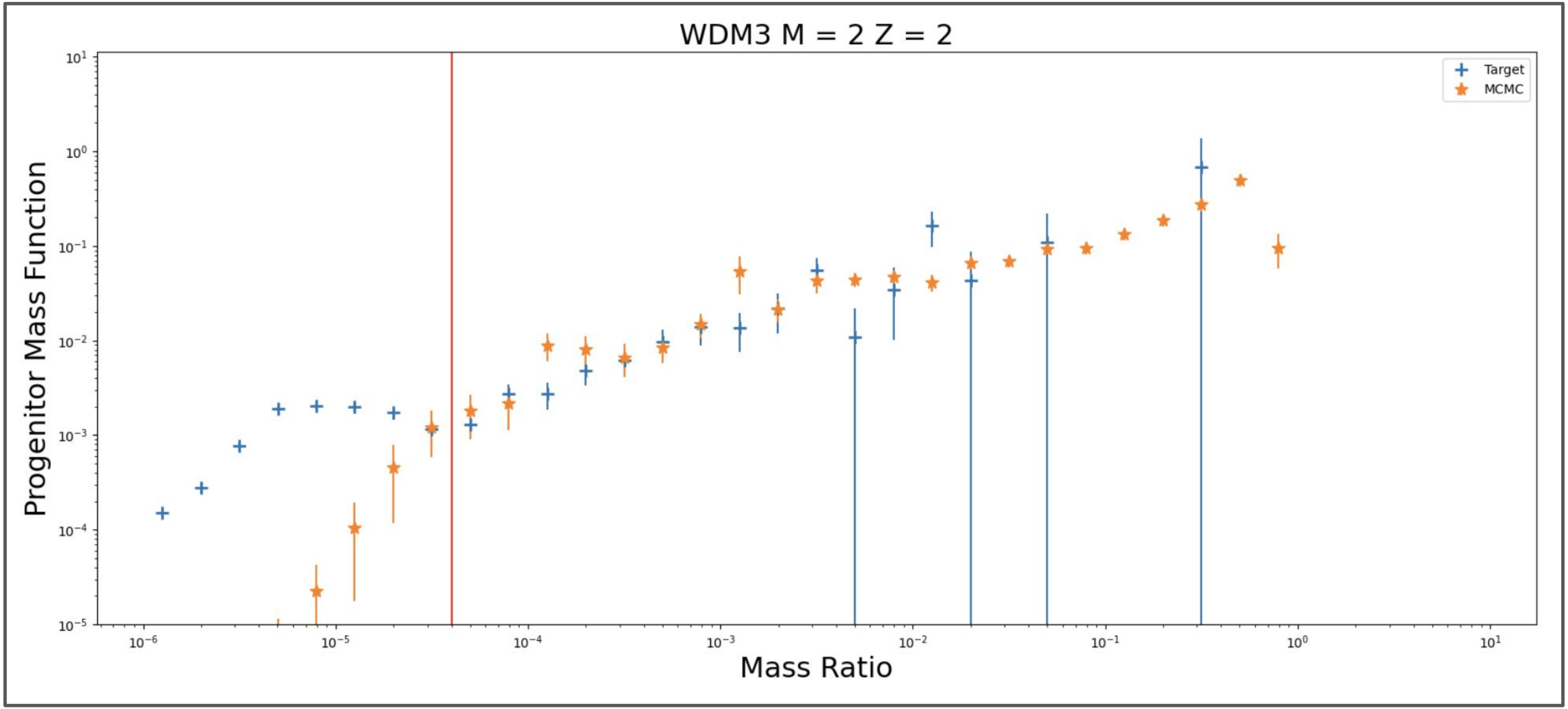
MDPL 2 simulation vs Galacticus



Comparing models for Symphony simulation



Symphony Milkyway after running MCMC



Symphony WDM 3 keV after running MCMC


Thank you!

Tips for starting on research

- Take your core physics courses
- Come to cosmolab weekly
- Learn to code in python
- Read some astrophysics and cosmology!
- **Get in touch (best in 3rd of 4th year).**

How to get involved

Github Project Database: https://github.com/usc-cosmolab/cosmovizlab

Email: kmpardo@usc.edu, vera.gluscevic@usc.edu

Slack: **cosmolabusc.slack.com**
usc-physics.slack.com

Website: https://cosmolab.usc.edu/

Meetings: Thursdays, ACB 5th floor conference room.