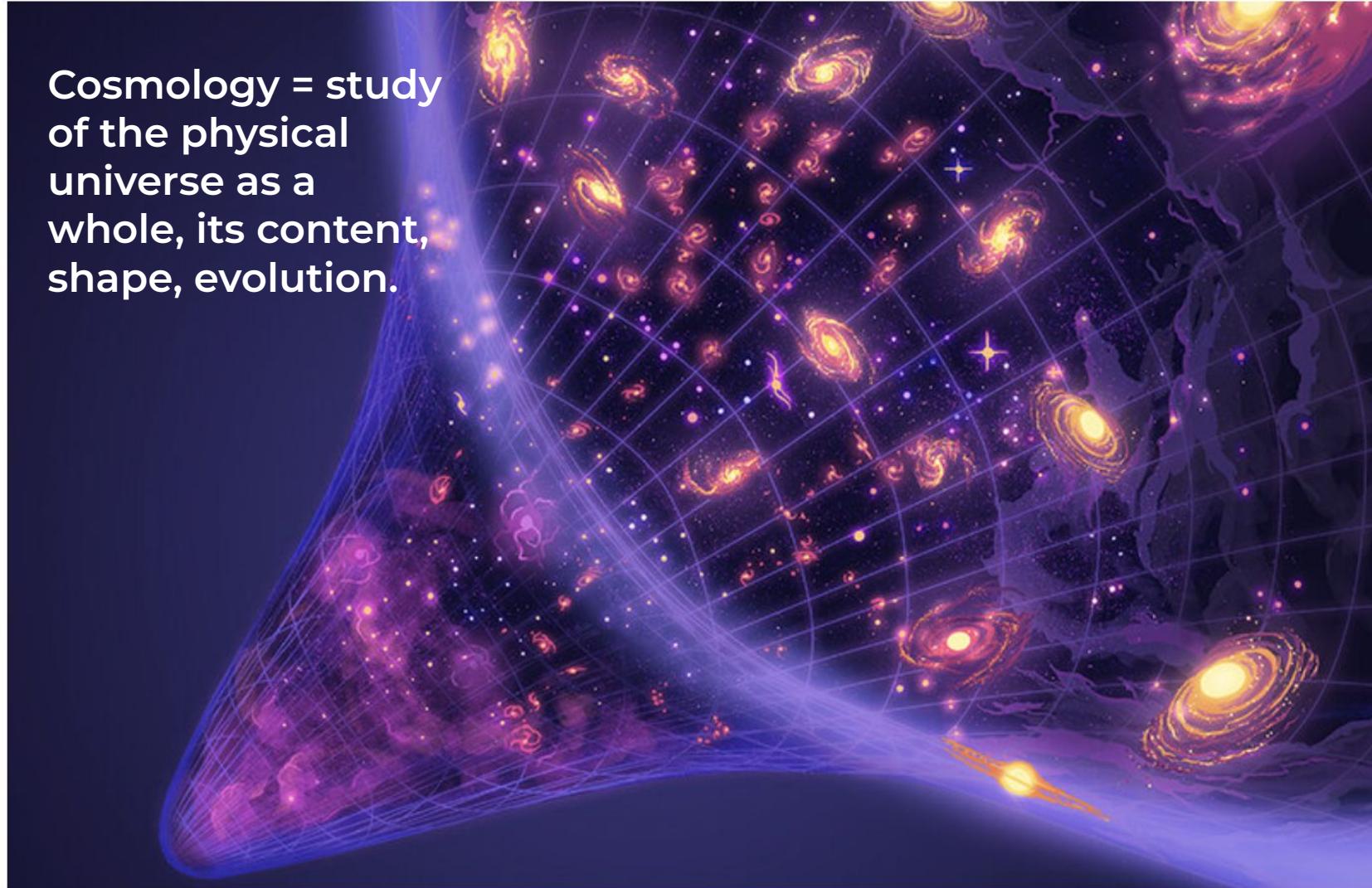
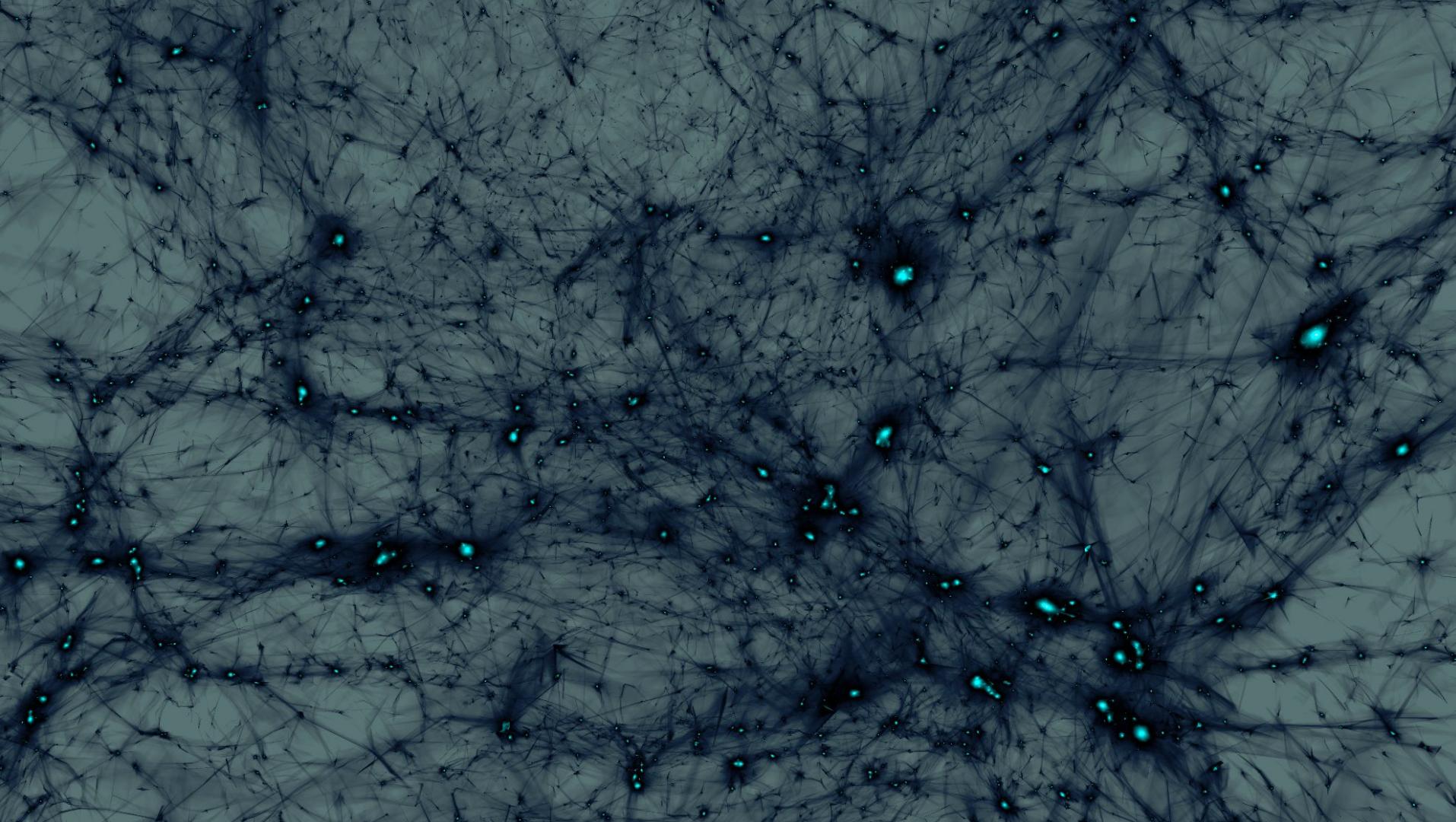


Cosmolab Open House 2023

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



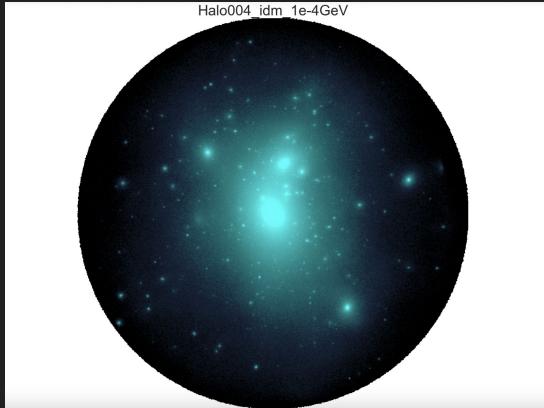


What we really do @ USC



- 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

jupyter Halo v2 (trying to match the paper) Last Checkpoint: 07/27/2023 (autosaved)

File Edit View Insert Cell Kernel Widgets Help

In [1]: `def subselect_particles(f,host,distance_cut=1.5,projection_thickness=0.,Mpc_to_kpc=1000.):`

 Return particles within a radius of `{distance_cut}` kpc and a z-distance of `+/-{projection_thickness}` Mpc/h from the host halo center.

Args:

- (dictionary of pyndbody objects): particle data at snapshot(s)
- host_halo (Rockstar object): host halo information
- distance_cut (float): radial distance from center of host to subselect, in kpc
- projection_thickness (float): absolute z-distance to subselect, in Mpc/h

Returns:

- `f_short` (pyndbody object): subselected particle data at snapshot(s)

`odist = f['pos'][0]-host['x']`
 `vdist = f['pos'][1]-host['y']`
 `zdist = f['pos'][2]-host['z']`
 `Mpc_to_kpc=Mpc_to_kpc*(np.sqrt(odist**2+vdist**2+zdist**2))/host['rvir']`
 `f_short = f[(dist-distance_cut)>> (np.abs(zdist)-projection_thickness)]`

 return `f_short`

In [1]: `with open("Halo004/sim_data.bin", "rb") as f:`
 `sim_data = pickle.load(f, encoding="latin1")`
 `with open("Halo004/sim_data_10K.bin", "rb") as f:`
 `sim_data = pickle.load(f, encoding="latin1")`
 `with open("Halo004/sim_data_running.bin", "rb") as f:`
 `sim_data_running = pickle.load(f, encoding="latin1")`

In [1]: `custom_cmap = mpl.colors.LinearSegmentedColormap.from_list("", ["cyan","blue","#FF00FF","red","orange"], 100)`

In [1]: `#custom_cmap = mpl.colors.LinearSegmentedColormap.from_list("", ["#607474", "#152539","black","#096585","#10f0`

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

PERIODIC TABLE OF ELEMENTS
Chemical Group Block

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
	H	He	Li	Be	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Al	Si	P	S	Cl	Ar	
1	1.0080	4.012383	7.0	9.012383	20.495993	23.503943	24.513946	25.543934	27.583933	28.58639	29.635393	30.654.9	13.26.981...	14.28.085	15.30.973...	16.32.07	17.35.45	18.39.9	
2	Hydrogen Neutral	Helium Neutral	Lithium Metal	Boron Metal	Titanium Metal	Vanadium Metal	Chromium Metal	Manganese Metal	Iron Metal	Nickel Metal	Copper Metal	Zinc Metal	Aluminum Metal	Silicon Metal	Phosphorus Metal	Sulfur Metal	Chlorine Metal	Argon Metal	
3	3.008913	12.24.355	Na	Mg	Ca	Sc	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Al	Si	P	Ne	
4	11.008913	20.49.08	K	Potassium Metal	Ca	Scandium Metal	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Al	Si	P	Ne	
5	37.95.448	38.01.42	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Pd	Rh	Cd	In	Sb	As	Se	Br	Kr
6	55.132.33	56.137.33	Cs	Ba	Yttrium Metal	Hf	Ta	Ta	Tc	Ru	Pd	Rh	In	Sn	Te	I	Xe		
7	87.223.02	88.228.02	Fr	Ra	Rhenium Metal	104.281.3...	105.286.1...	106.286.1...	107.271.3...	108.288.1...	109.307.3...	110.302.1...	111.302.1...	112.348.1...	113.348.1...	114.296.1...	115.295.2...	117.294.2...	118.295.2...
8	137.138.055	138.140.126	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dysprosium	Ho	Er	Tm	Yb	Lu		
9	143.127.02	143.130.03	Ac	Th	Pa	U	Np	Pu	Am	Cm	Dy	Terbium	Europium	Thulium	Yterbium	Neptunium	Lutetium		

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

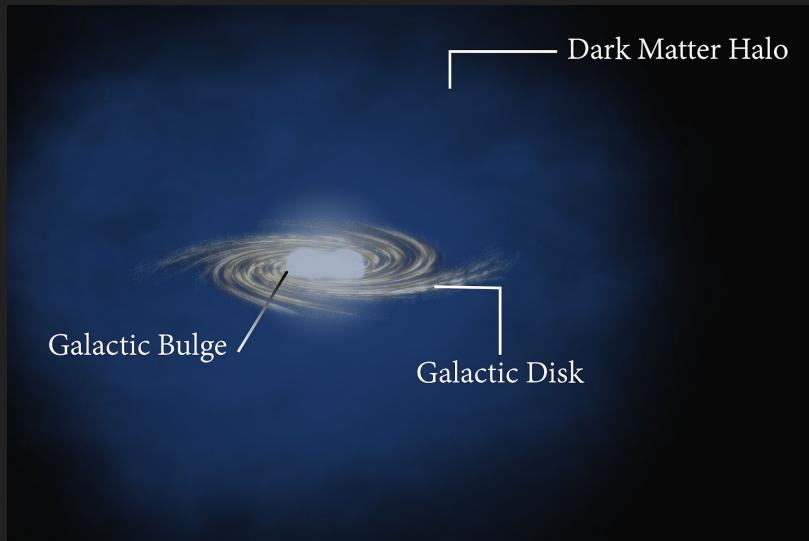
(5%)

Dark Matter



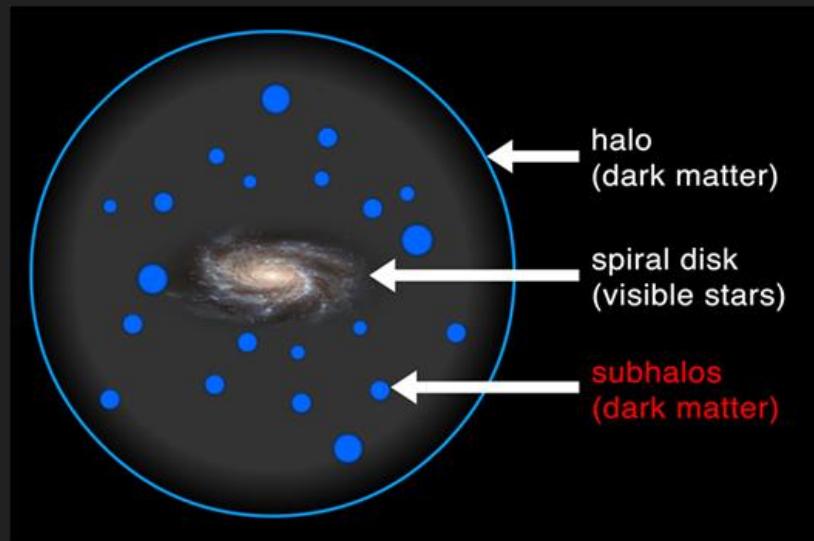
What scientists discovered *must* exist, as there wasn't enough baryonic matter present in galaxies for them to rotate at the speeds they were found to move at (95%).

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

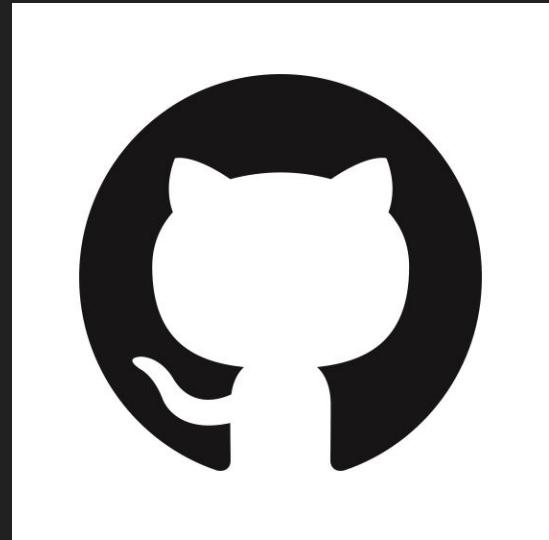
The screenshot shows a GitHub repository page for a public repository named 'CosmoRepoSlay'. The page displays basic repository statistics: 1 branch and 0 tags. It features a list of recent commits from user 'LRetterer' with messages like 'making this file in WA' and 'hello there, adding another file to my repo to practice my terminal s...'. A message at the bottom encourages adding a README, with a 'Add a README' button.

File/Folder	Message	Date
Sacheen_File	making this file in WA	5 months ago
folder	hello there, adding another file to my repo to practice my terminal s...	5 months ago
new	hello there, adding another file to my repo to practice my terminal s...	5 months ago
test.py	Karime is super awesome and very helpful	5 months ago

A place to store code

Often a file that contains multiple files within it

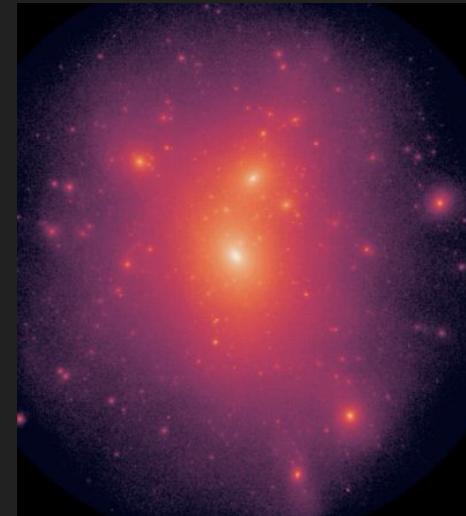
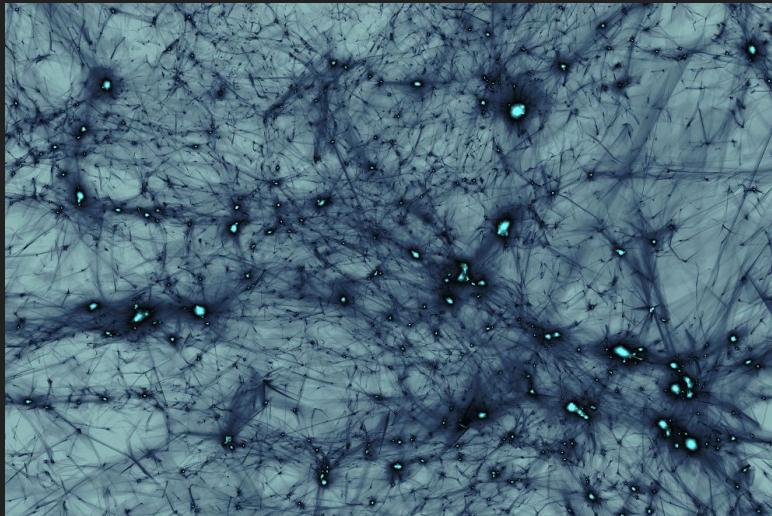
Github



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

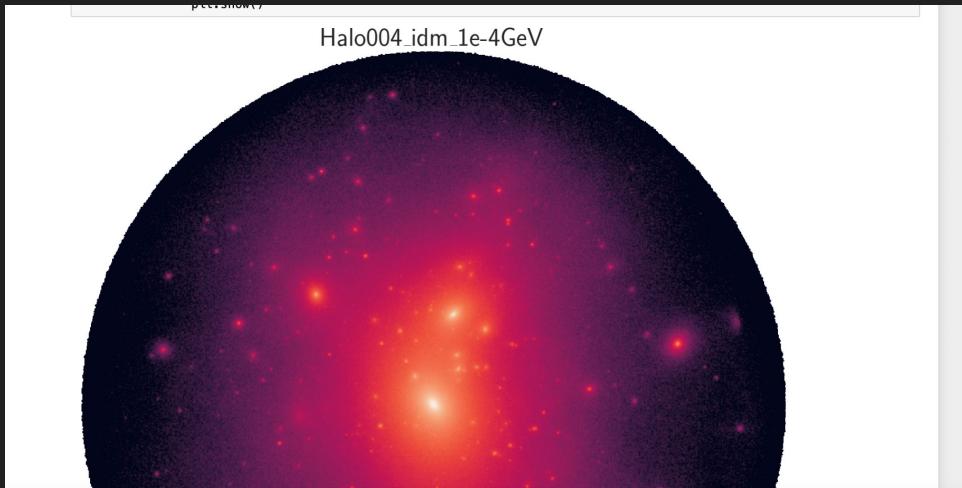
Colormap: density

- 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:

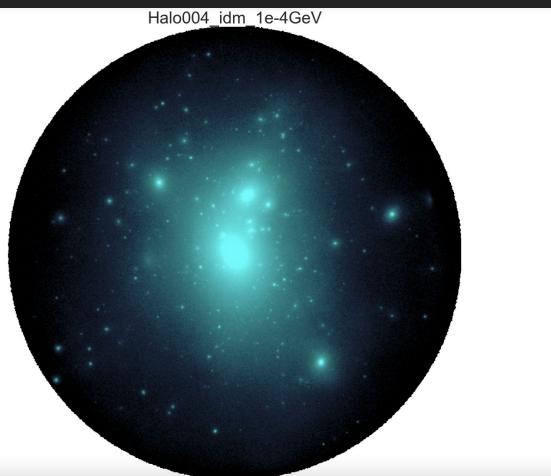


- Here is the custom colormap code:
- ```
import matplotlib as mpl
custom_cmap = mpl.colors.LinearSegmentedColormap.from_list("", ["cyan","#10fcfc","black",
"#152539","#88b4b4"])
```

# Colormap: density

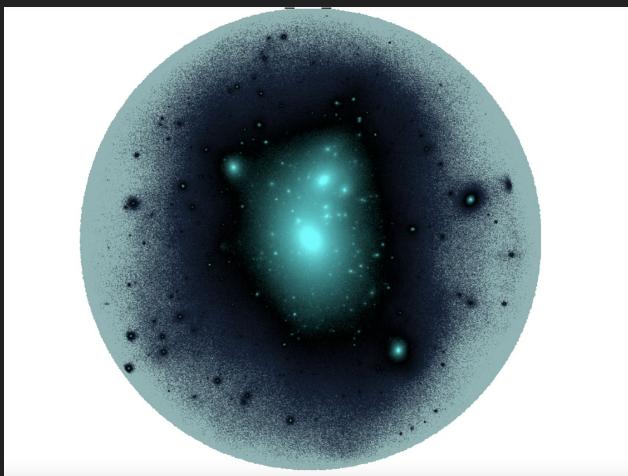
Version 1:

Good cohesion, but no light blue!!!!



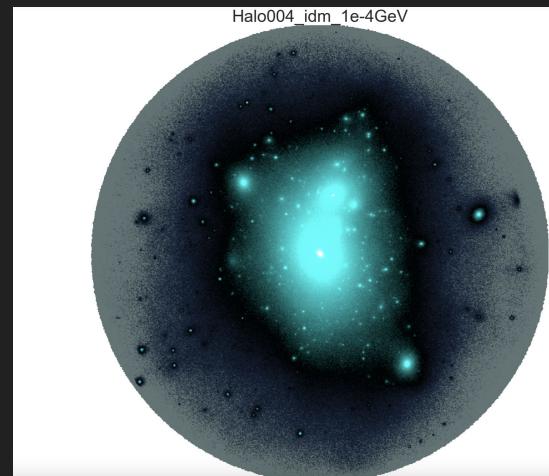
Version 2:

Light blue present, but now too grainy

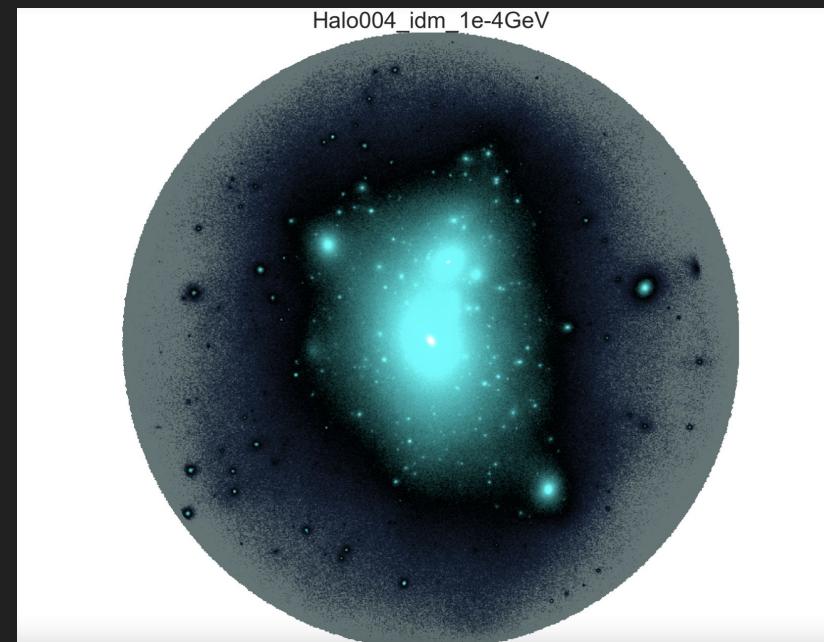
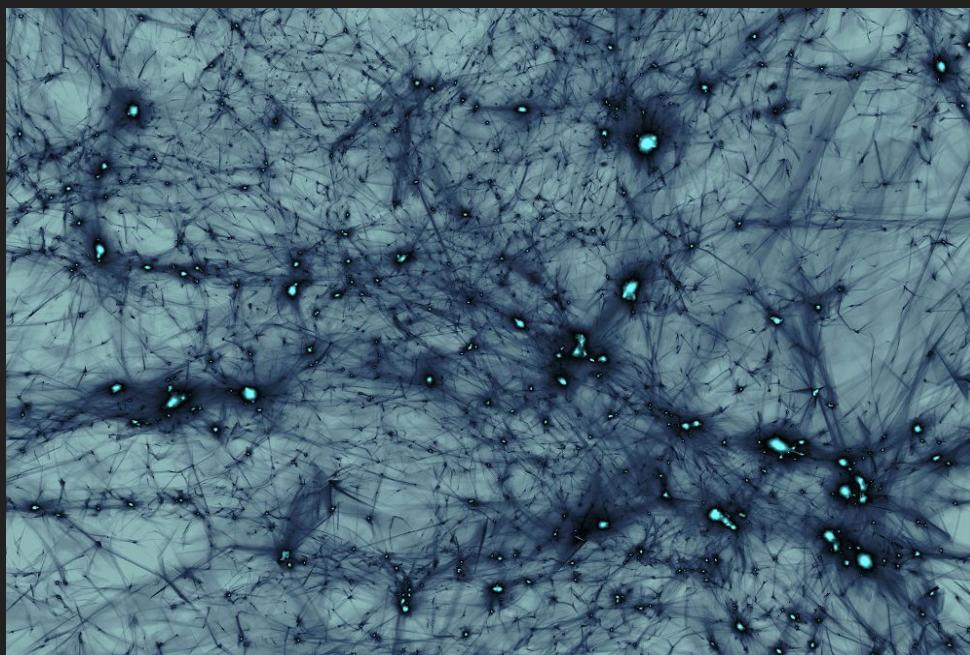


Version 3:

Better

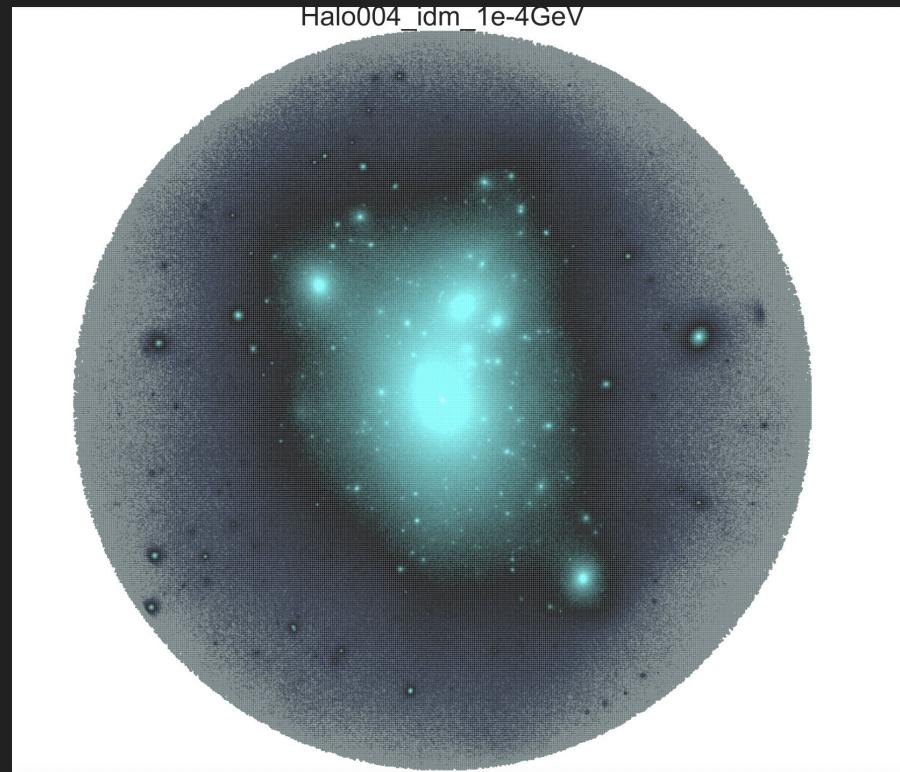


# Colormap: density



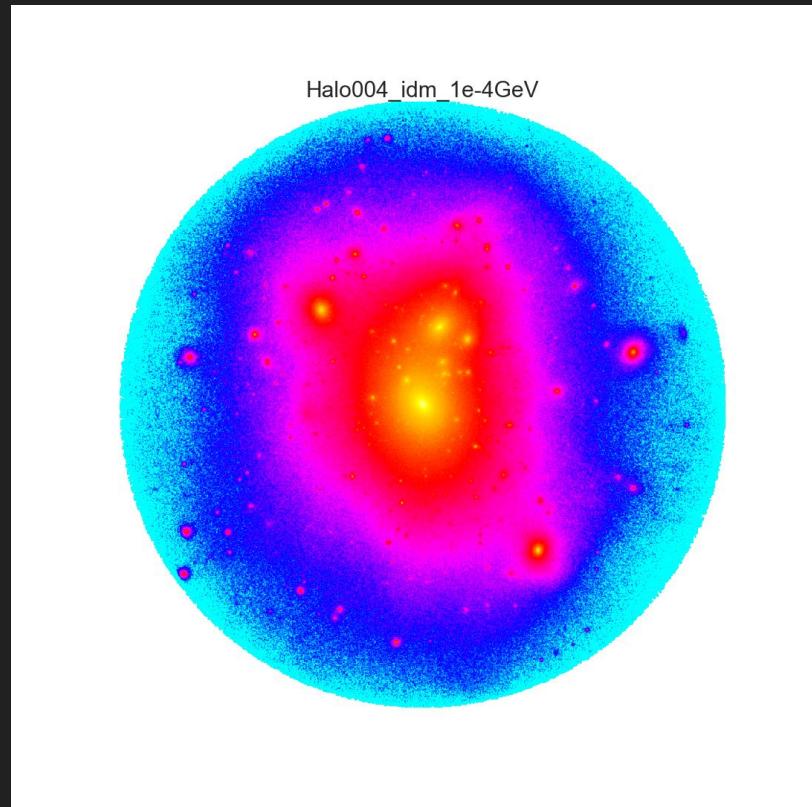
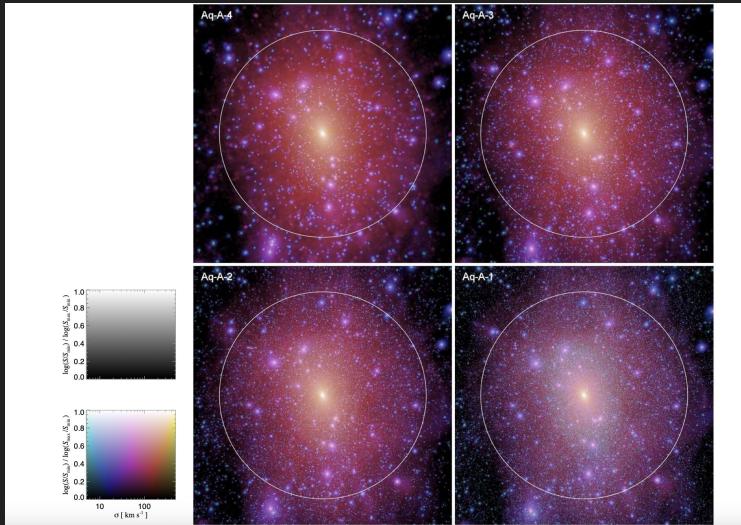
# Colormap: velocity dispersion

- 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:



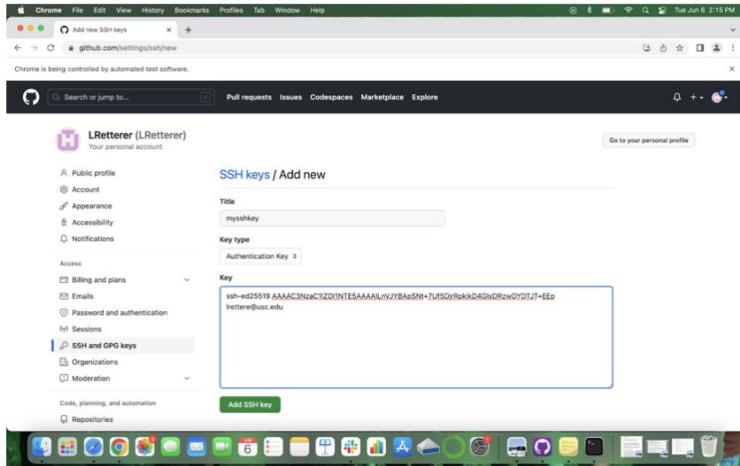
# SSH Key Access

- 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 don't 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 `ghsuss` 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?

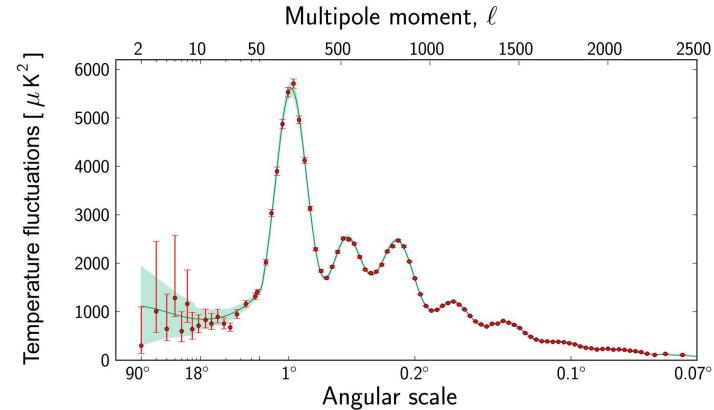
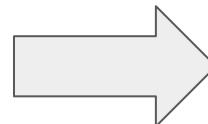
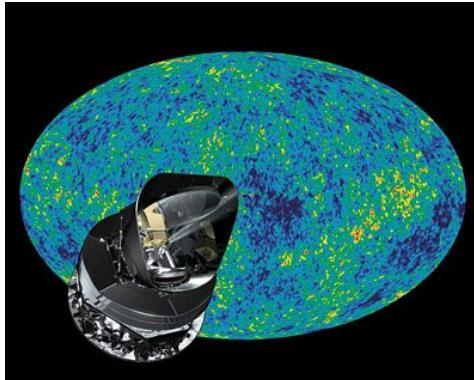
- As you learn more about your subject, you update your beliefs about it using Bayes' Theorem

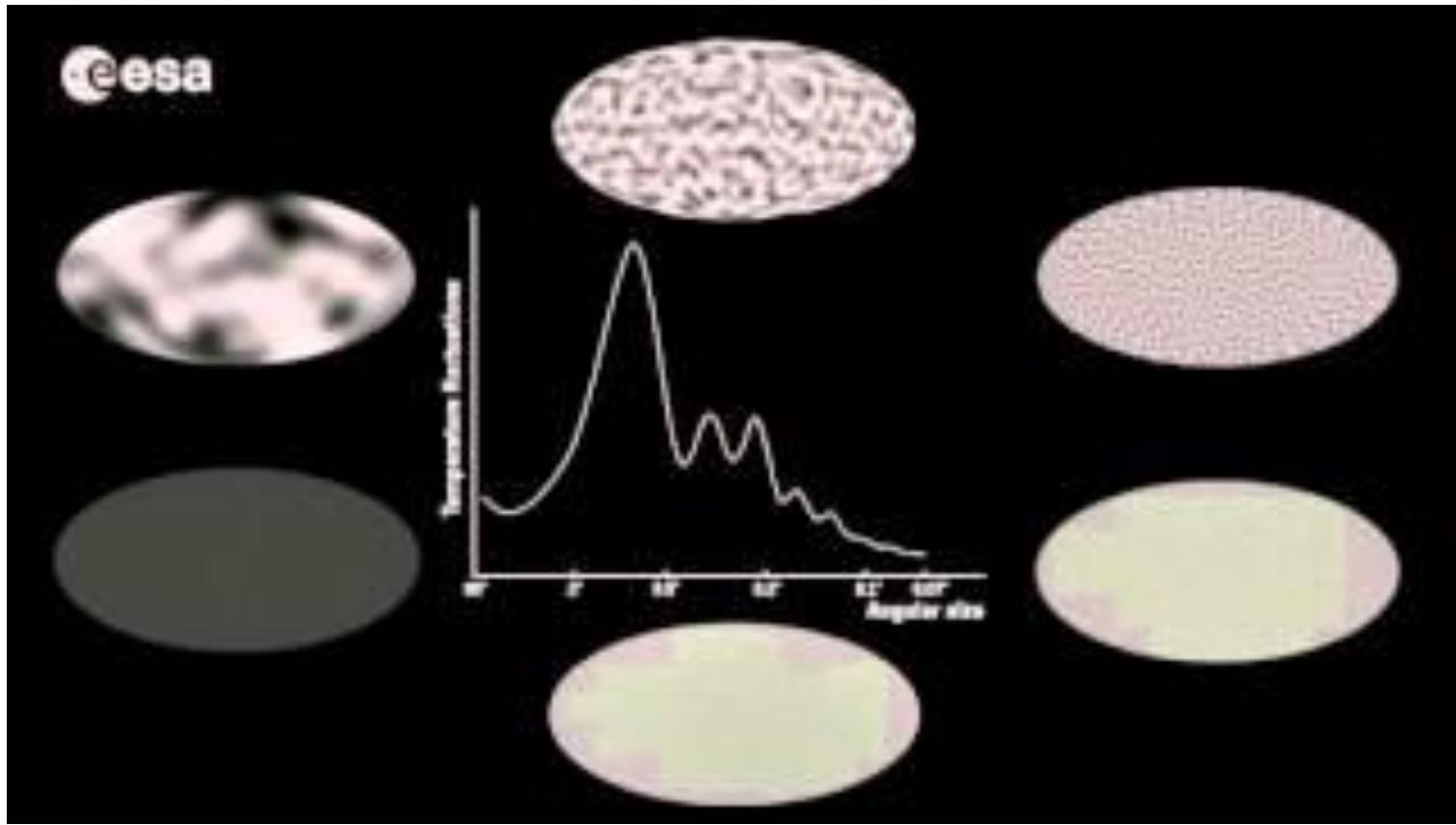
$$P(H|E) = \frac{P(E|H) \cdot P(H)}{P(E)}$$

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

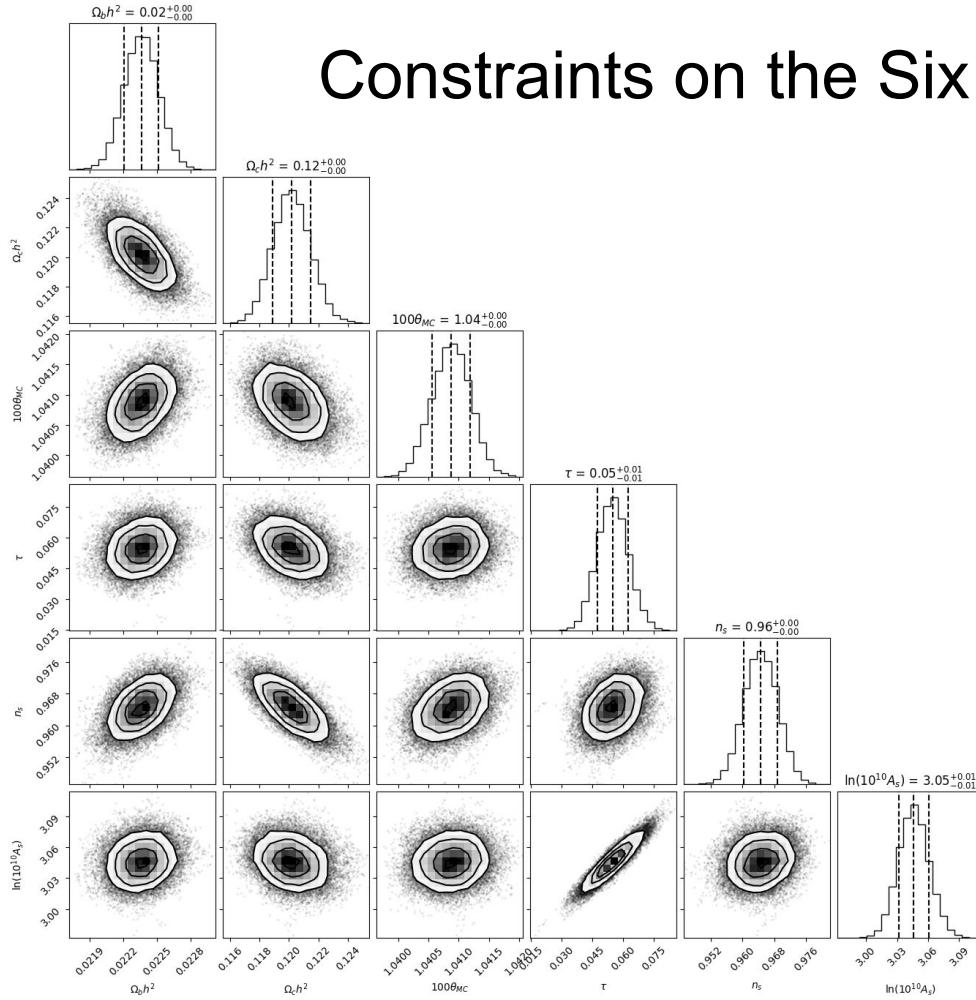
# Why Use Bayesian Inference in Cosmology?

- 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.





esa

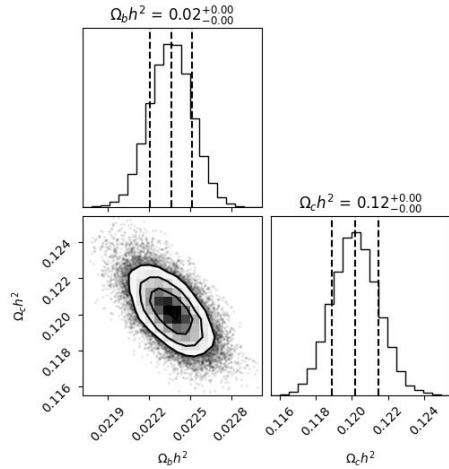


# Constraints on the Six LCDM Parameters

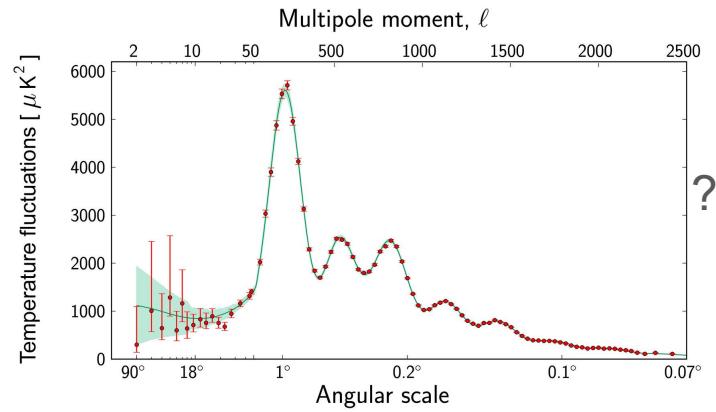
Each blob represents a posterior probability distribution. The individual points were sampled from this continuous distribution using Monte Carlo Markov Chain (MCMC).

This data was released by the Planck Collaboration in 2018

But how does



relate to



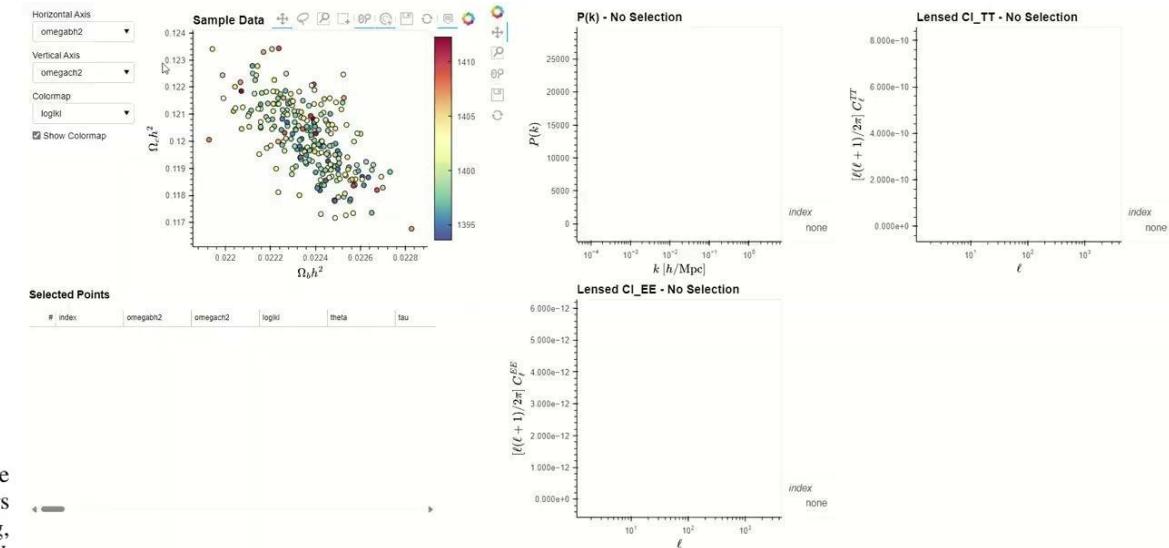
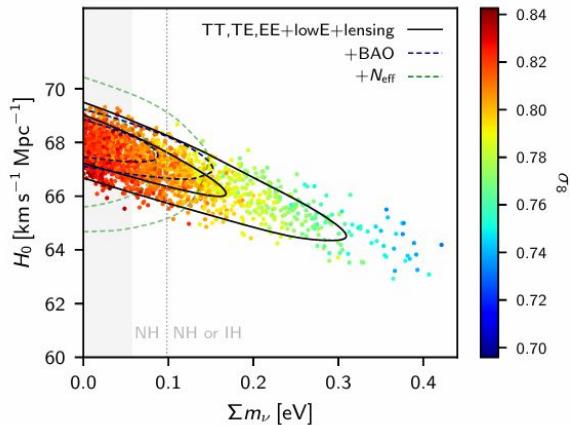
Each point in the posterior sample distribution is a set of parameter values which will produce a slightly different CMB anisotropy.

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 **S**ample **V**isualizer)
  - 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  $\sigma_8$ . 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  $N_{\text{eff}}$ . 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 bsvi as bsv
from bsvi.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\}]\sim C_{\ell}^{TT}',
 'Cl_ee': '[\{\ell(\ell+1)\}/\{2\pi\}]\sim 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
)

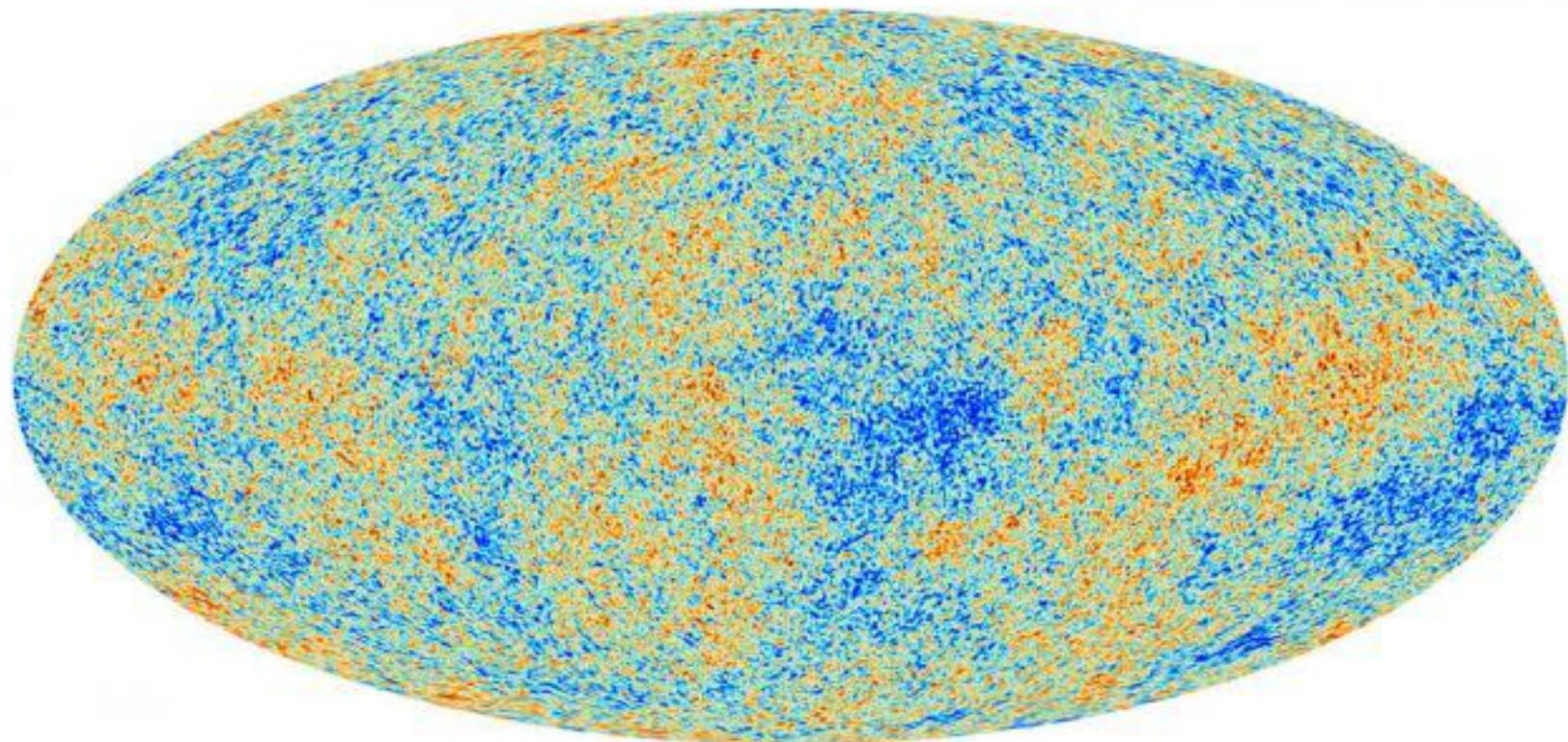
bsv.viz(chains, [power_spectra], latex_dict=params_with_latex).servable()
```

Thank You

# Cosmic Microwave Background (CMB)

Adam He





**He**

**He**

**H**

**H**

**H**

**H**

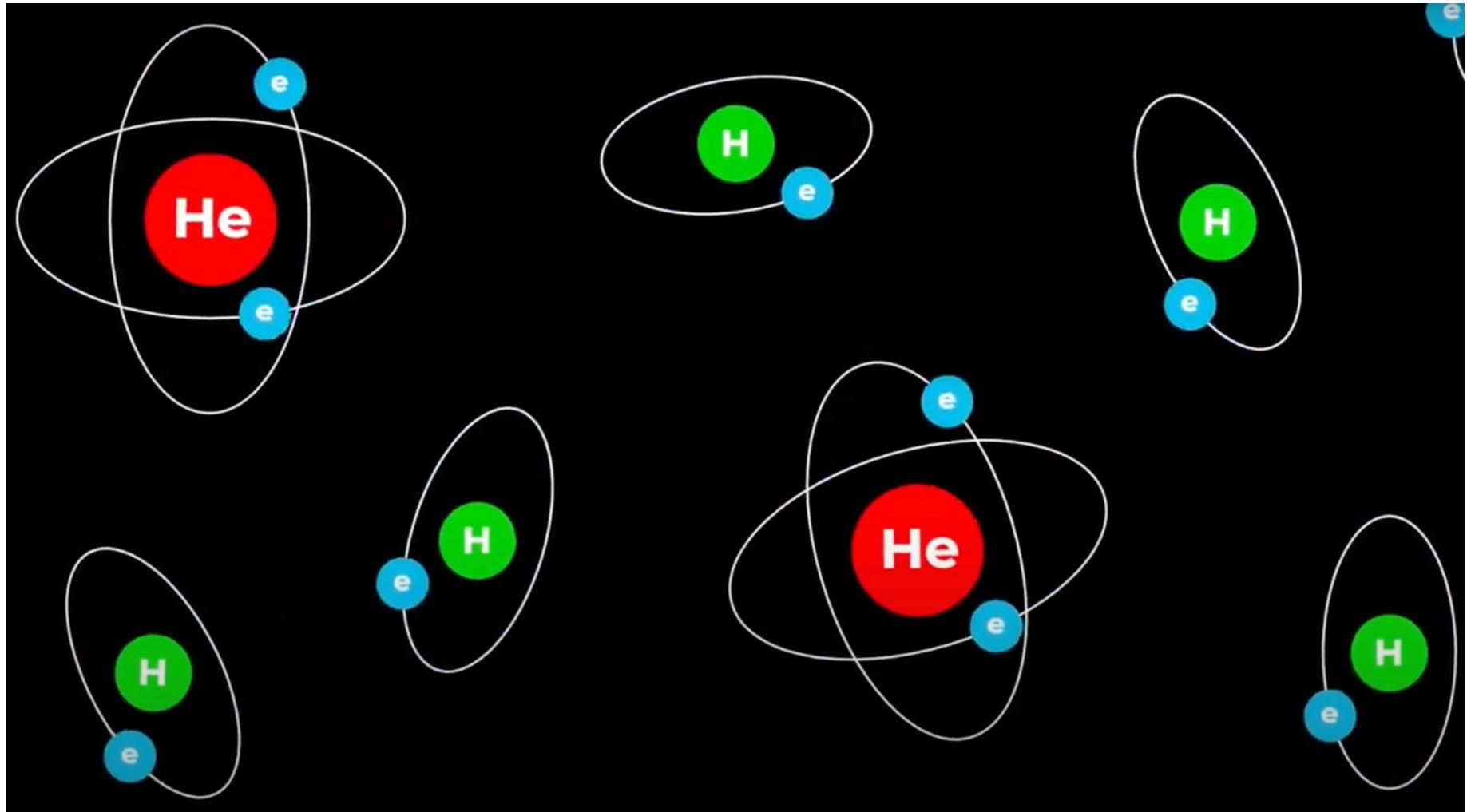
**e**

**e**

**H**

**e**

**e**







# 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

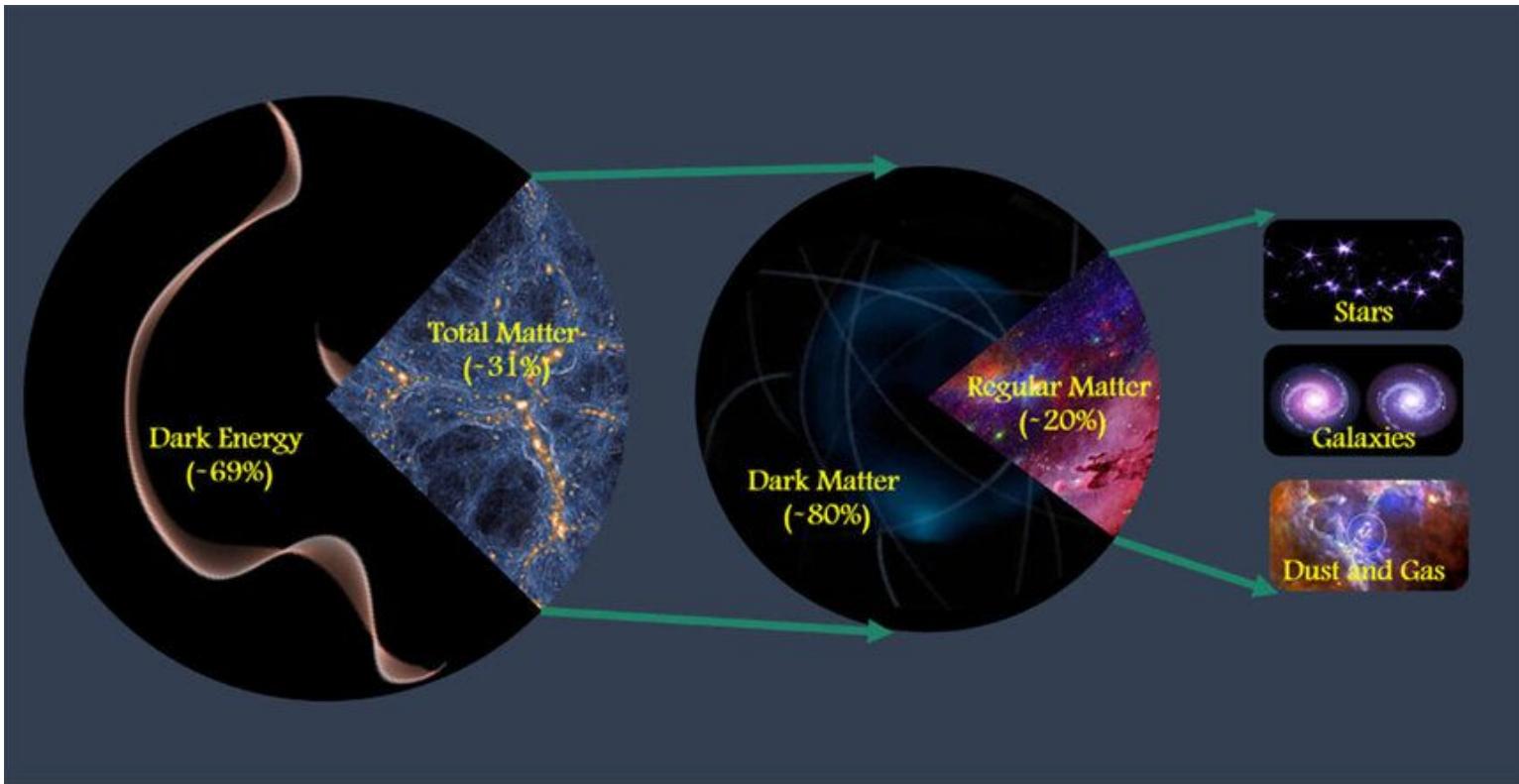
Cosmolab Open House

Dimple Sarnaik

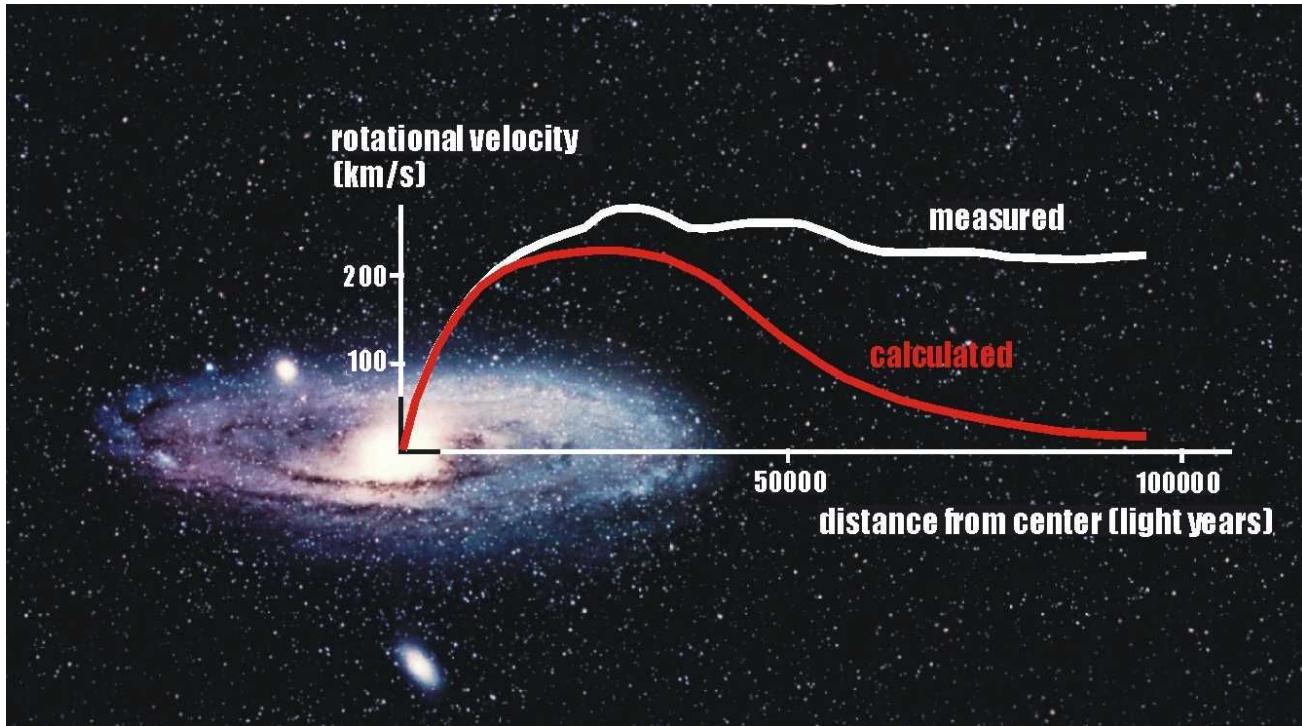
# Outline

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

# What is DM?



# How do I know it's there?

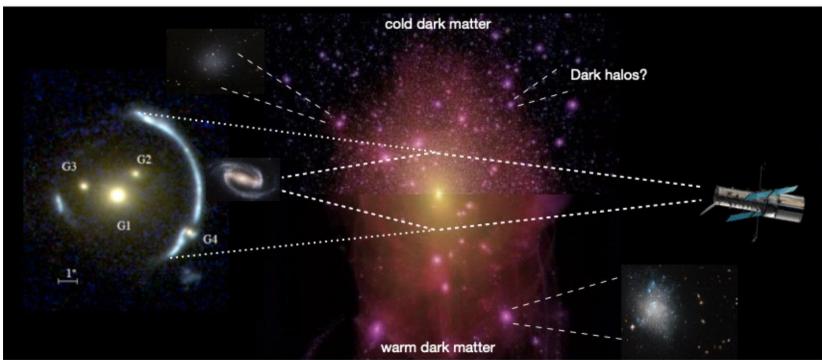


But also..

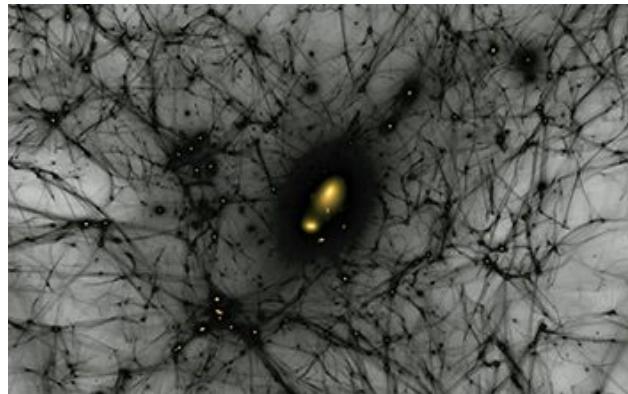
1. Gravitational Lensing
2. Mass of observed galaxies
3. CMB

# How to hunt for DM

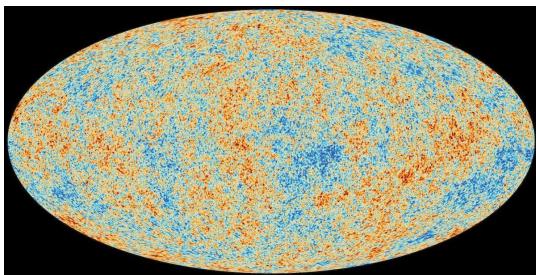
Gravitational Lensing



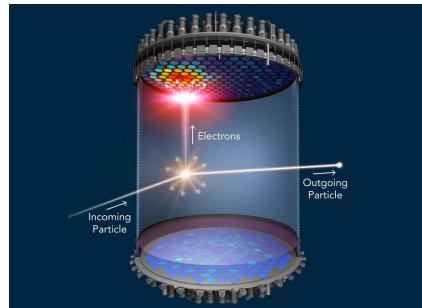
Simulations



Cosmic Microwave Background



Direct Detection & more..

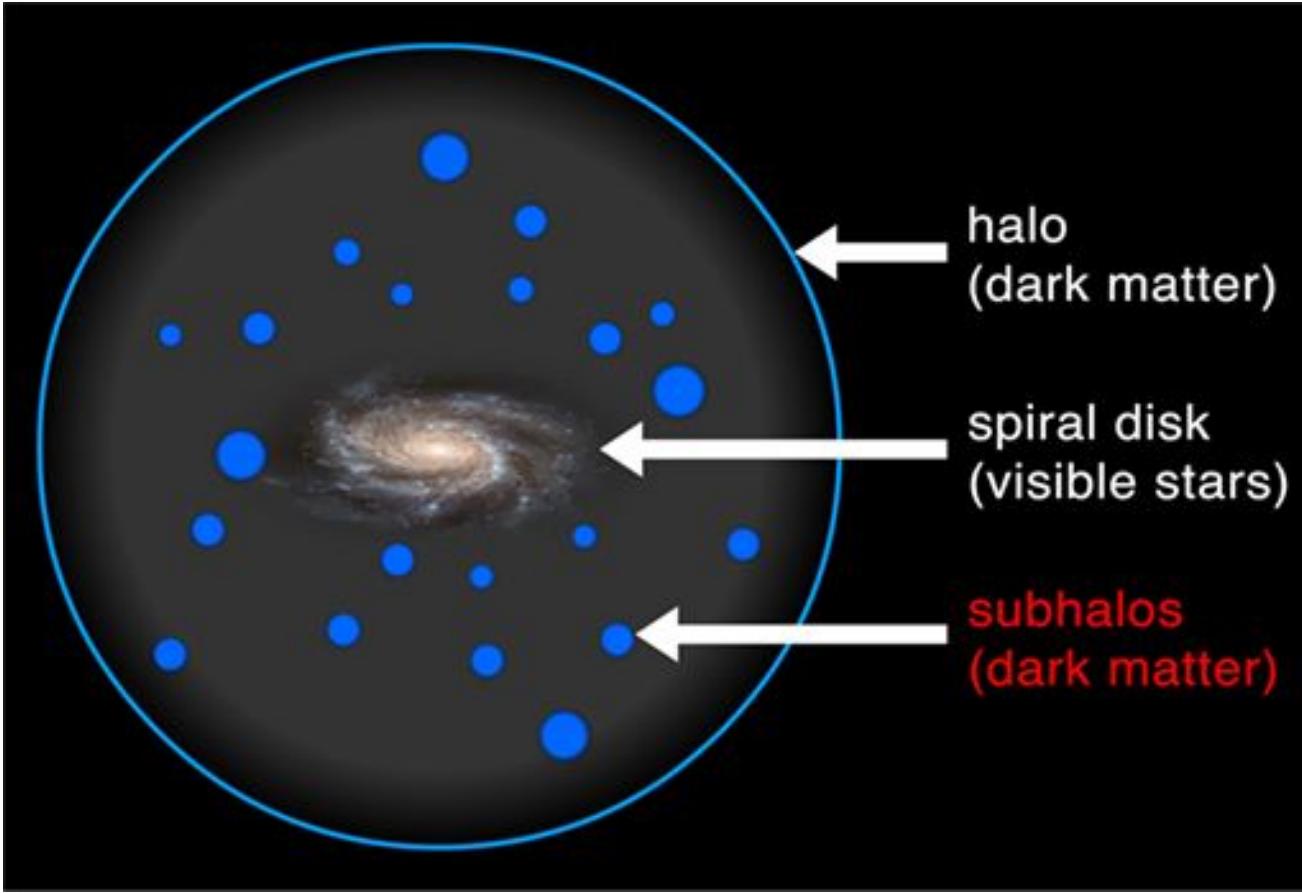


Credit: Fig.1:NASA/ESA HST (strong lens, dwarf galaxies), M. Lovell (CDM/WDM simulations), Fig.2: Ethan Nadler, Vera Gluscevic, Fig3: Planck Collaboration, Fig 4: SLAC National Accelerator Lab

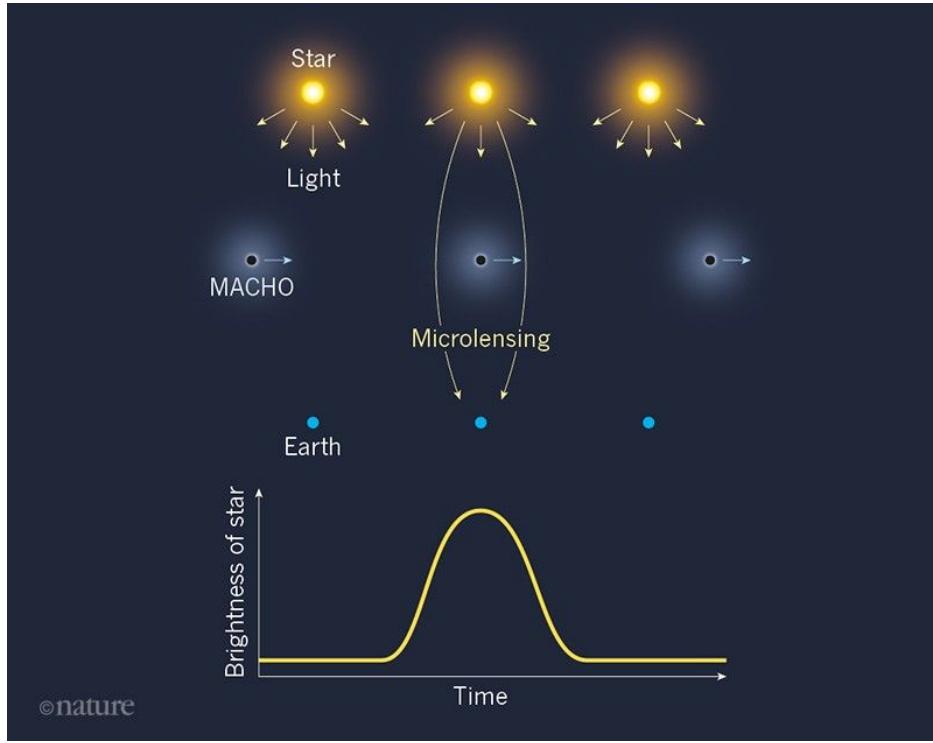
# Outline

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

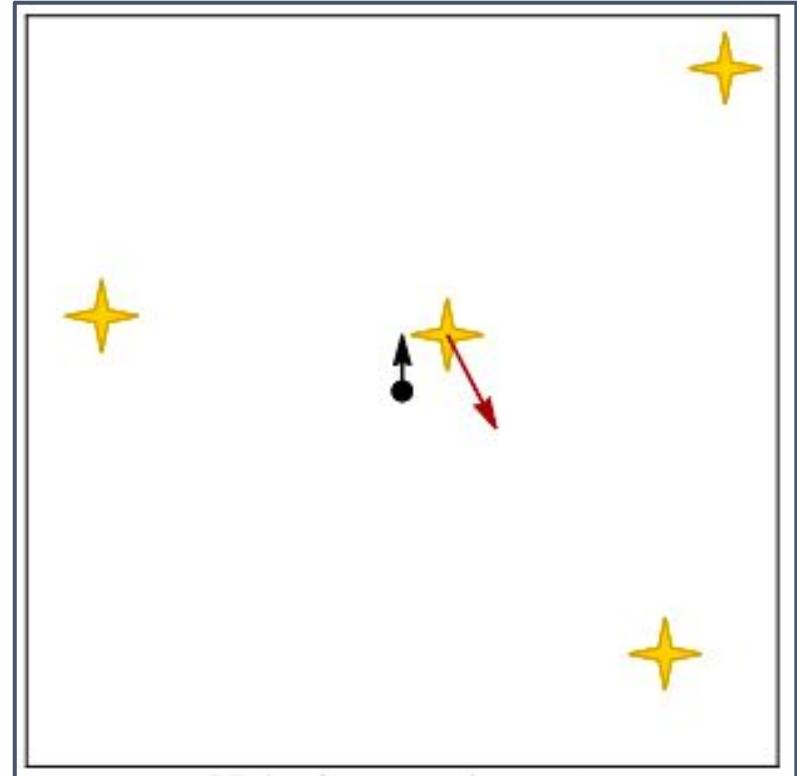
# Probing DM subhalo populations



Galaxies embedded in DM Halos



Microlensing



Using Astrometry

# Different Subhalos



# Mass functions

Cold Dark Matter

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

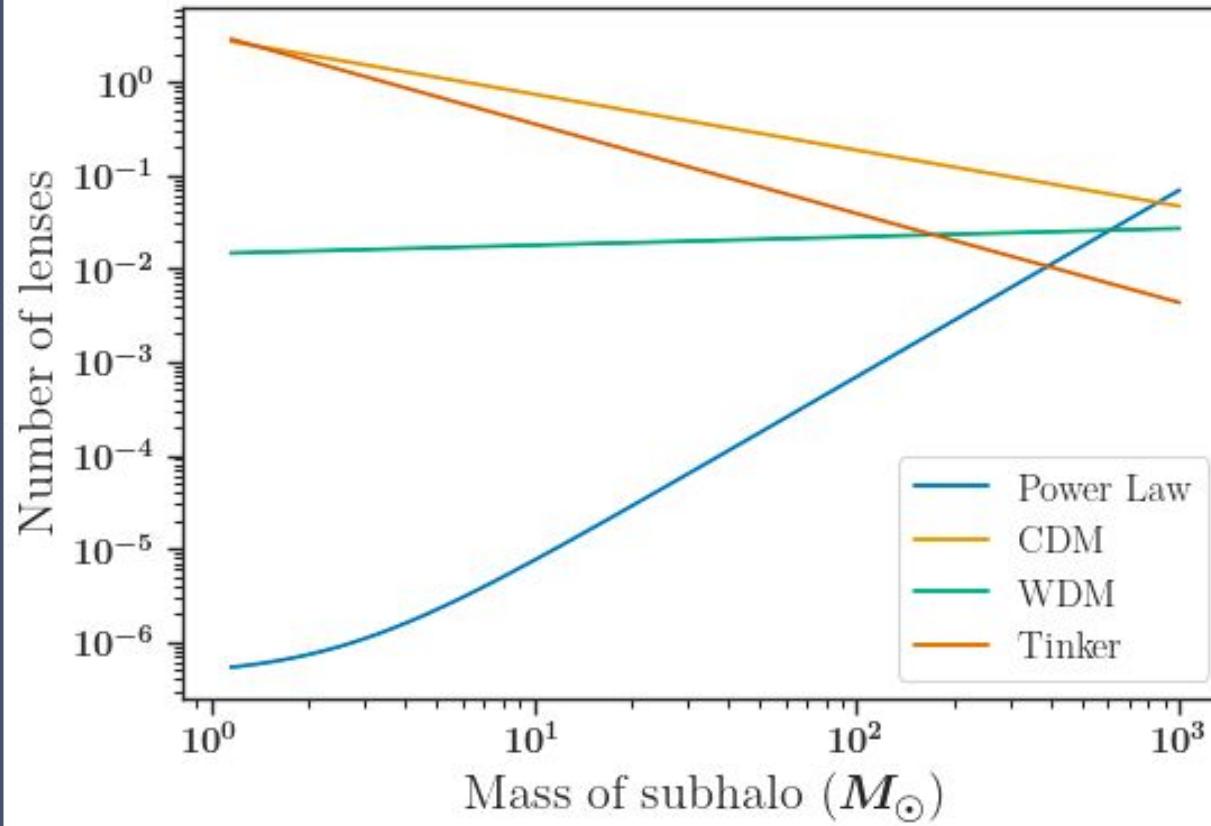
Warm Dark Matter

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

Tinker

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

## Mass Functions



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

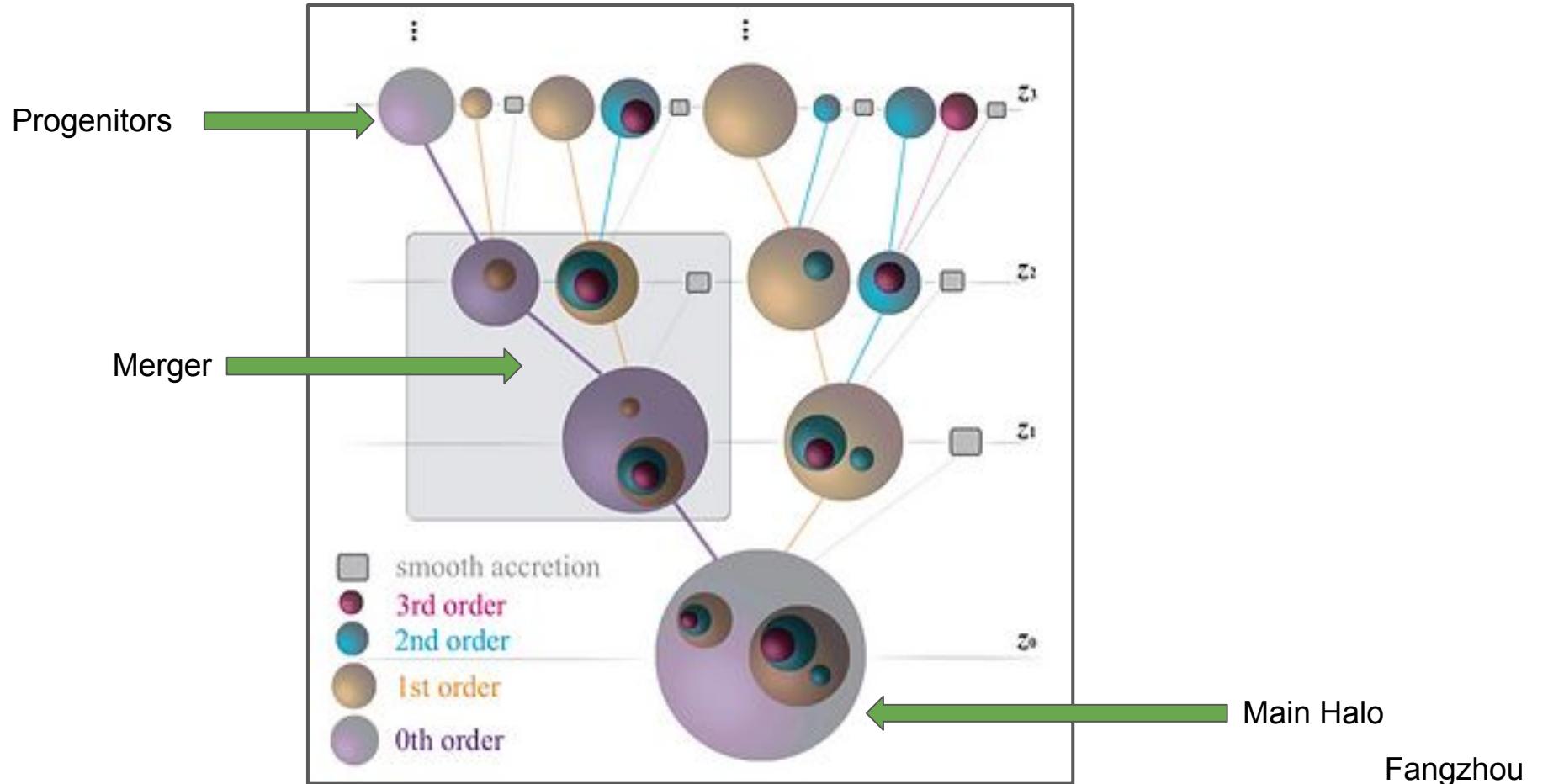


CARNEGIE  
SCIENCE

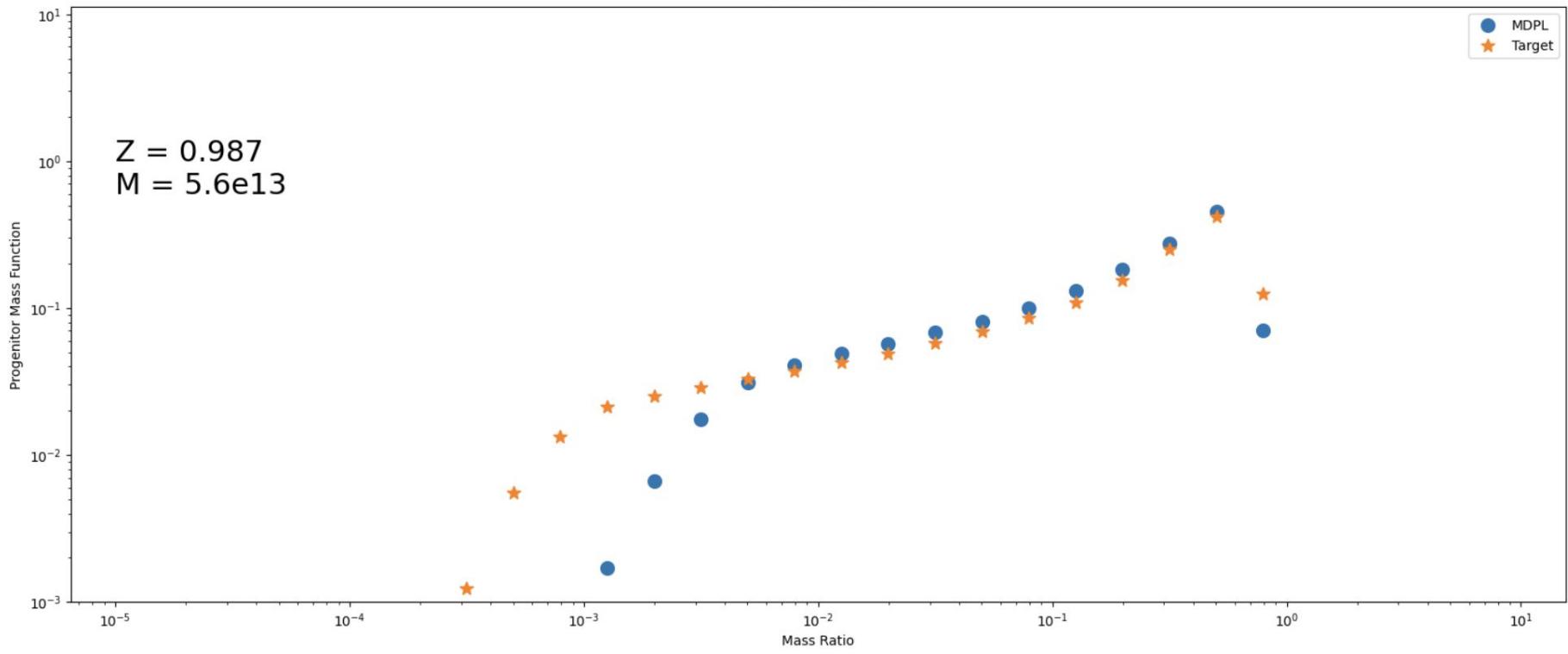
FPS: 002.00 | Bodies: 50000 | Theta: 0.7 | Dt: 0.5 | Softening: 25



# Galacticus: A Semi-Analytic Model of Galaxy Formation

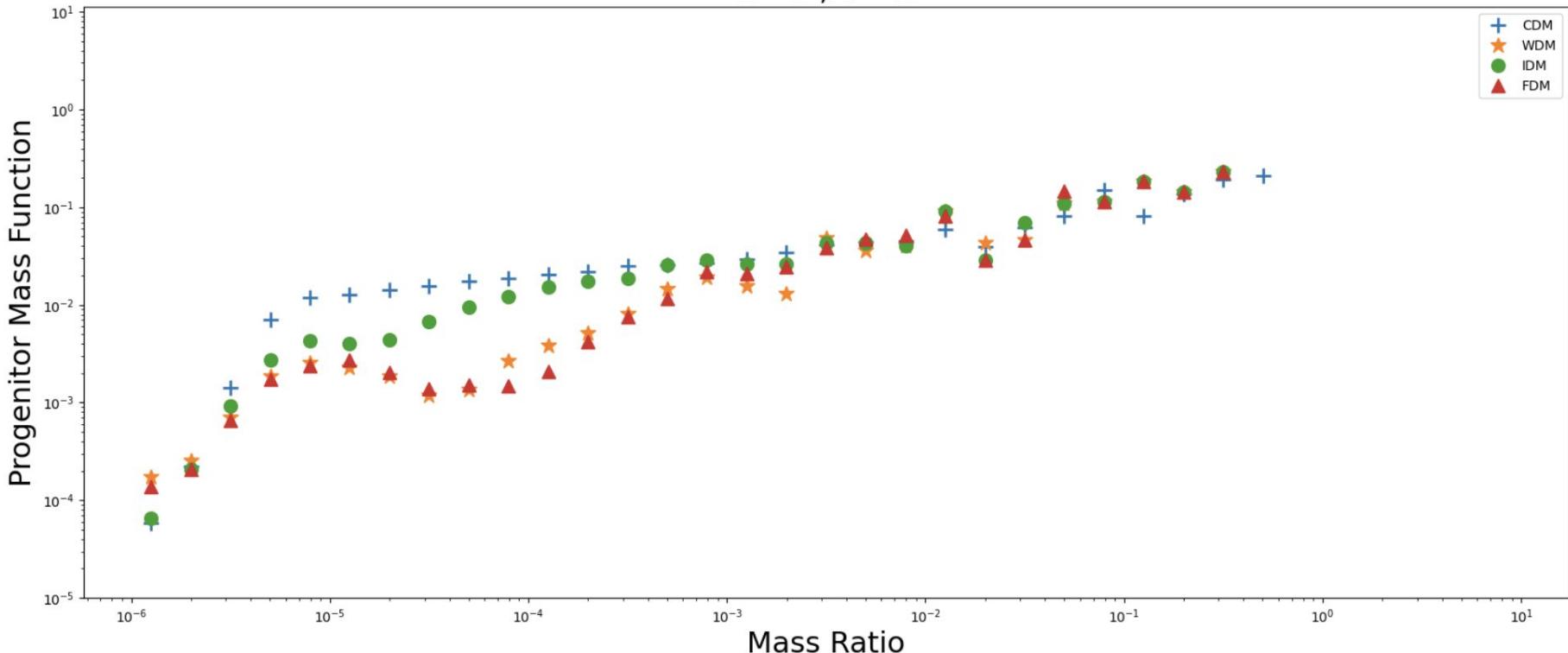


Benson 2016



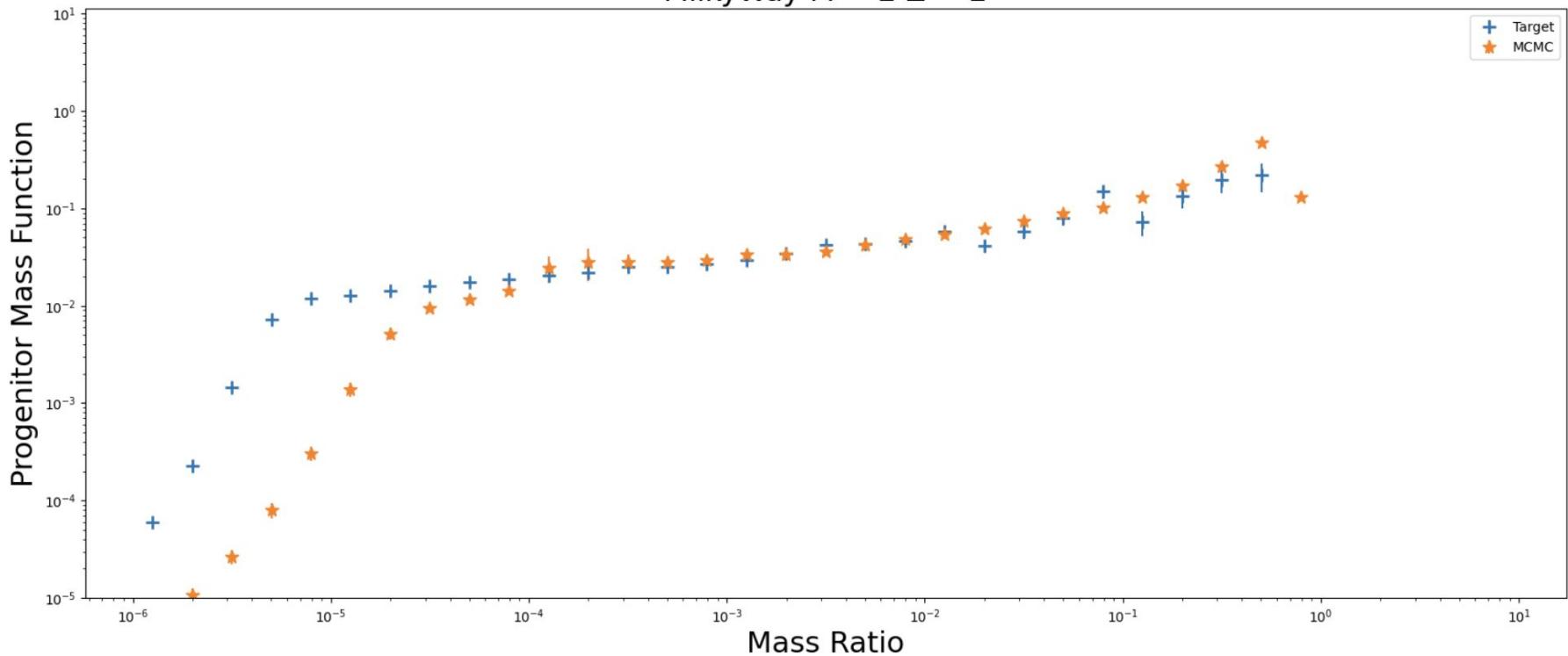
MDPL 2 simulation vs Galacticus

$Z=2, M=2$



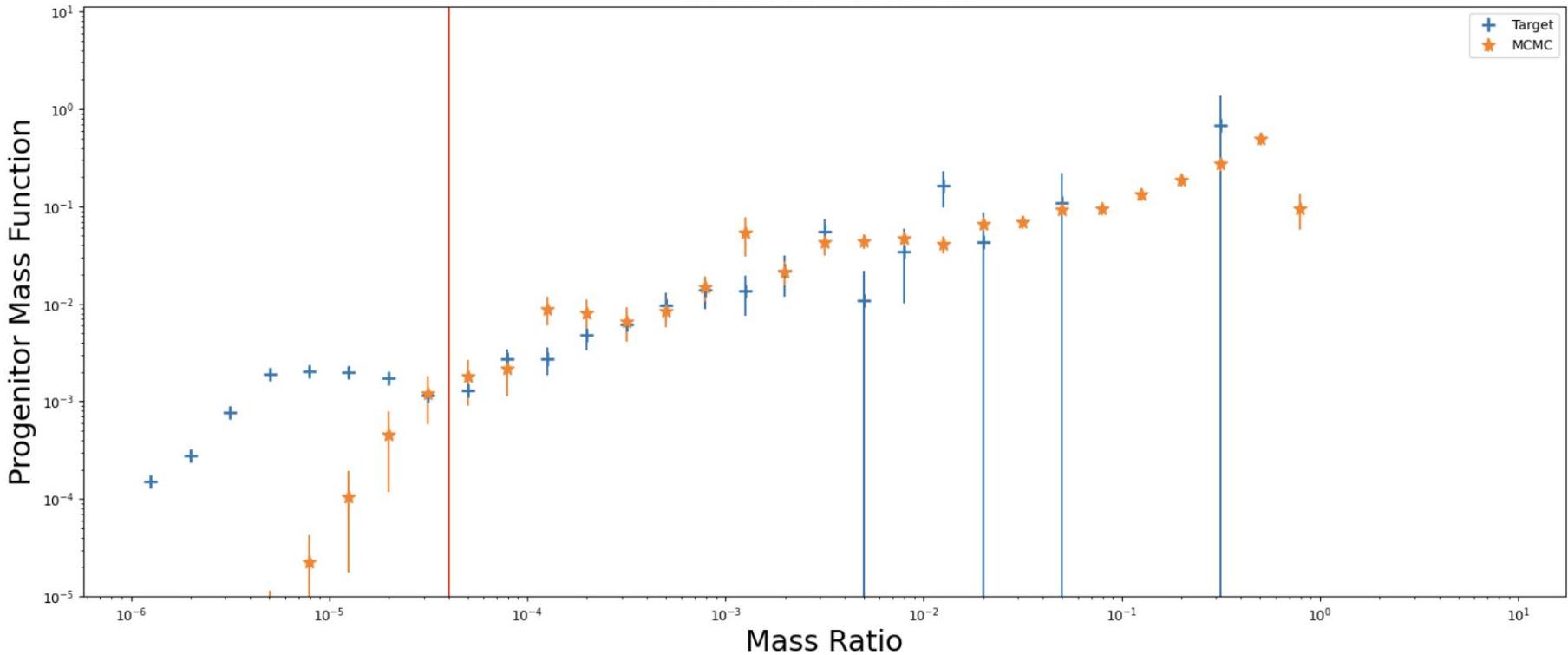
Comparing models for Symphony simulation

MilkyWay  $M = 2$   $Z = 2$



Symphony Milkyway after running MCMC

WDM3 M = 2 Z = 2



Symphony WDM 3 keV after running MCMC

The background of the image is a dark, almost black, space. Overlaid on this are numerous thin, branching lines in shades of blue and orange. These lines form a complex, organic network that resembles a microscopic view of a biological tissue or a network of neurons. The lines are more concentrated in the center and spread out towards the edges.

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 or 4th year).**

# How to get involved

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

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Meetings: Thursdays, ACB 5th floor conference room.