# Scale:
## our place in the Universe

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# Introduction

Here is a brief tour through our universe. My purpose is to introduce its different scales of structure. Through a backyard telescope you can see planets in our own solar system. Beyond the neighborhood, you can see other stars and dust and glowing gases in our Milky Way Galaxy. On a really dark and clear night you can even see a few other galaxies. Those are the kernels of structure in our universe – the galaxies. What we cannot see without much more sophisticated instruments is the large-scale distribution of the galaxies and the footprints of their evolution over time. The slides that follow provide an introduction to that vast Cosmic Web.

## Key concepts:

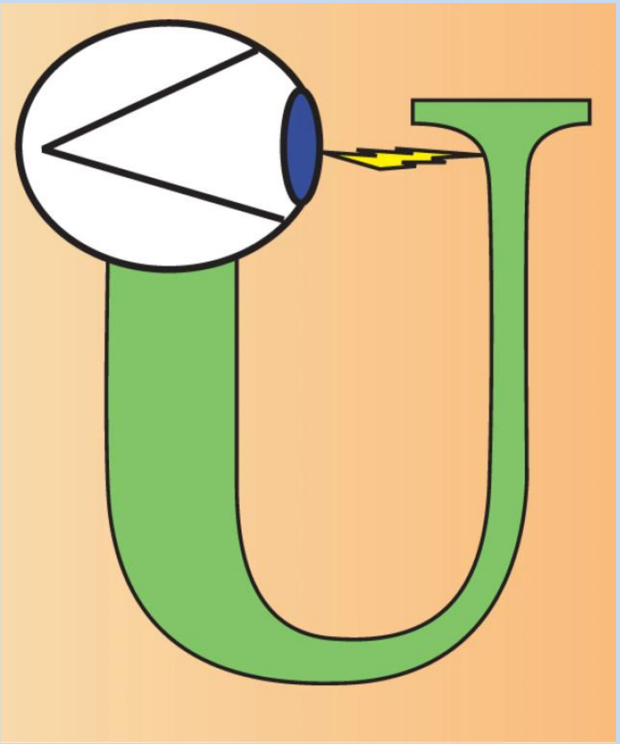
- astronomical observations reveal a hierarchy of structures in our universe
- the speed of light provides the constant with which to measure distance: the light year (Ly)
- telescopes are time machines
- backyard telescopes can see objects out to a few million light years
- our current generation of great telescopes can see out to about 13.8 billion light years

# Key concepts (cont'd):

- from the largest structures (~10^9 light years diameter) to our solar system (~20 light hours diameter) we see, in descending order of scale, a vast cosmic foam of galaxy clusters and voids, individual galaxies comprising gas and dust and billions of stars, planets orbiting those stars.

# Key concepts (cont'd):

- but there's a whole lot more stuff out there that we can't see with any telescope. In fact, about 95% of the composition of the universe is invisible to us. We're just beginning to figure out what most of the universe is made of.



Misner, Thorne, Zurek. 2006. Wheeler's Participatory Universe. *Physics Today*.

# What the Universe is made of

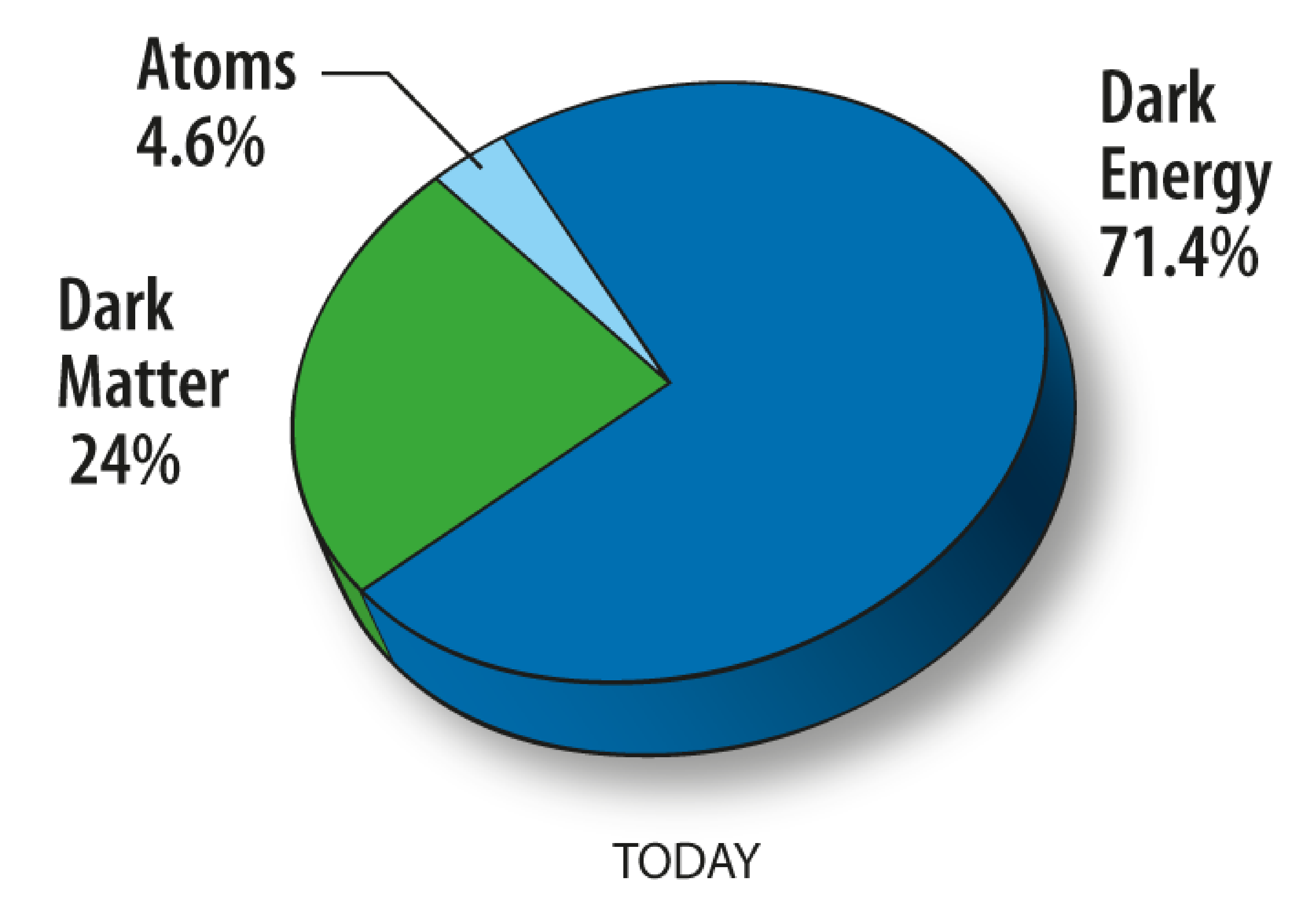



Image: NASA / ESA

## The time scale of the universe

Our universe originated about 13.8 billion years ago. Its origins are a story for another time. For now what’s important is some appreciation of the vast scale of time over which the universe has evolved, from a hot, dense soup of primordial particles (e.g. quarks, electrons, neutrinos, photons) to the ever expanding, enormous volume of cold spacetime seeded with clumps of matter (galaxies) that we observe today. To get an impression of that time scale, imagine 14 billion years compressed into two weeks. Our species, *Homo sapiens*, has been around for about ten seconds. Advanced (so-called) civilization has been here for about one second. One second out of fourteen days.


image by Dorsett with ChatGPT

# Then and now

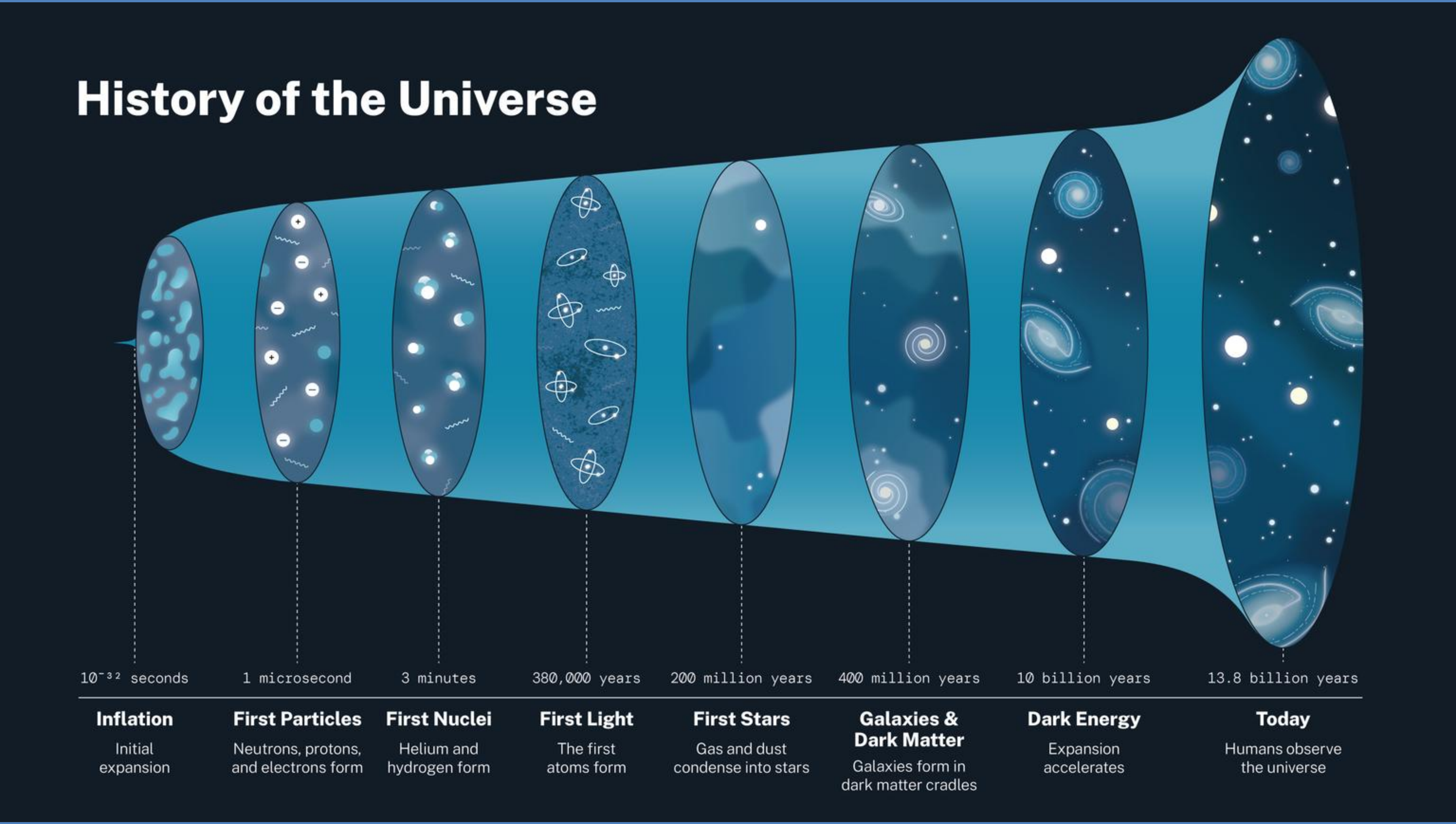


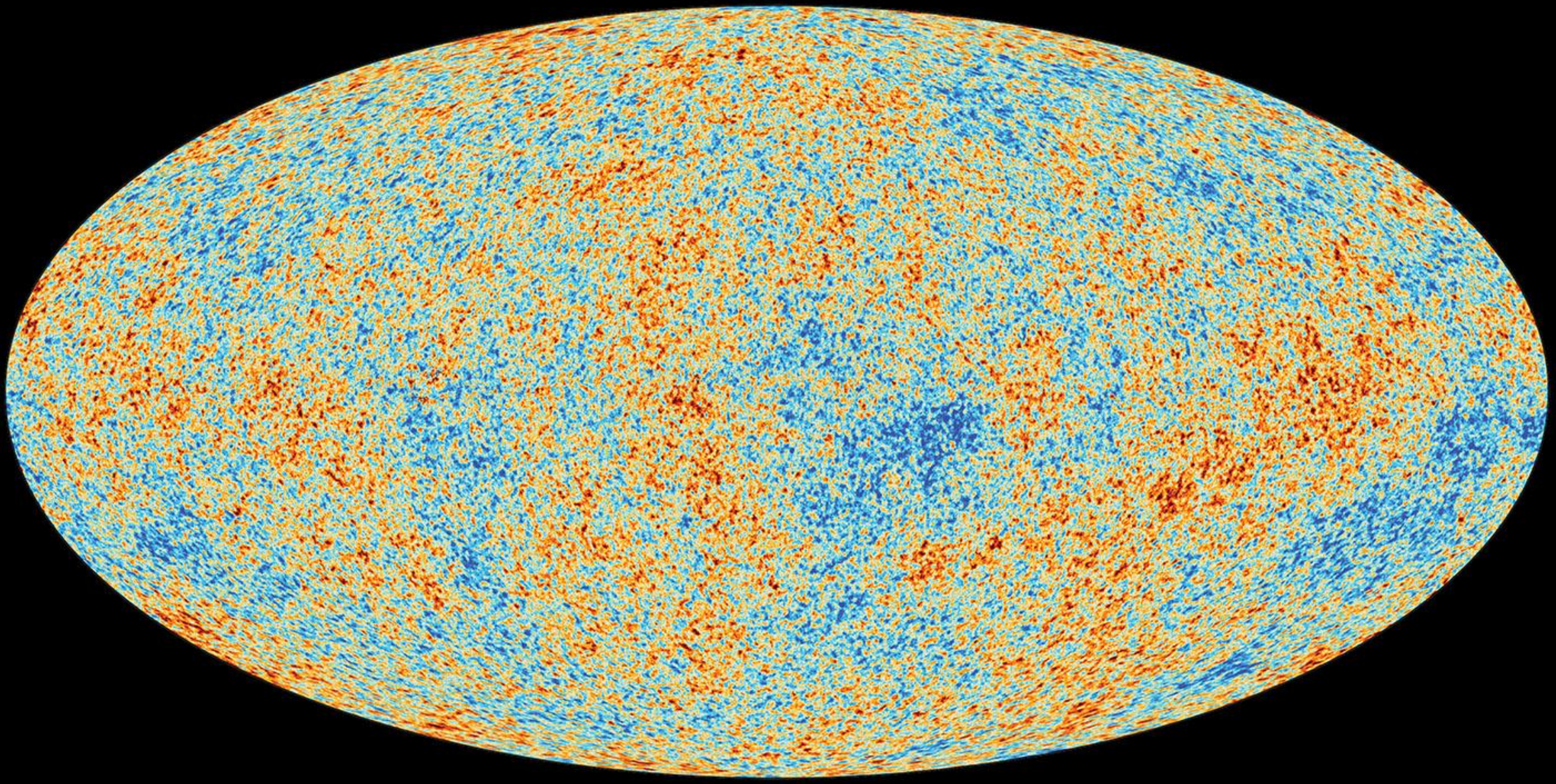

image: science.nasa.gov

## The Cosmic Microwave Background

The structure of our universe 13.8 billion years ago is imprinted on the cosmic microwave background radiation (CMB). The CMB is a baby picture of our universe, at age 380,000 years, when the early universe became transparent to light. All other structure lies in the foreground of the CMB. Behind the CMB lies information about the Big Bang. We are just beginning to probe beyond that curtain with gravitational wave detectors.

# → THE COSMIC MICROWAVE BACKGROUND

Planck Legacy Release 2018



Credit: ESA/Planck Collaboration

www.esa.int

European Space Agency

# The Large Scale Structure

The next image shows a slice spanning about one third of the sky and out to about 11 billion light years (GLy). Each dot is a galaxy. There are over 15 million galaxies in this image, accumulated by the Dark Energy Spectroscopic Instrument (DESI), Kitt Peak Observatory. Note the bubble and void structure. The voids between webs of galaxies are on the order 100 million light years across. And consider – everything in this image is expanding, bubbles pushing galaxies ever farther away from each other.

# DESI map of ~ 15 million galaxies extending out to about 11 GLy.

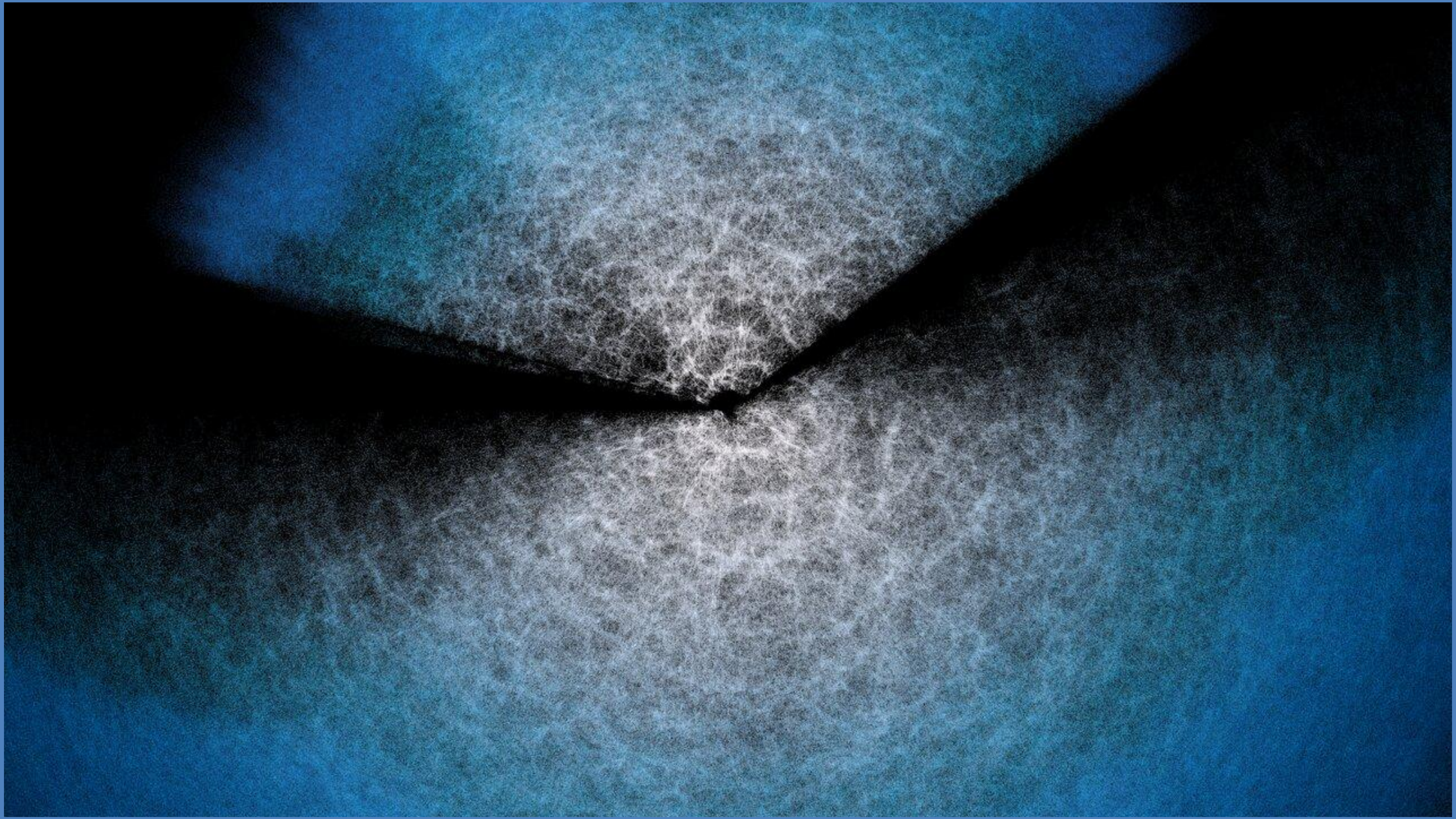


image: DESI collaboration 2025, Kitt Peak Observatory

# The Cosmic Web

The following image shows a computer simulation of the large scale structure of the universe, based on the “lambda, cold dark matter” (LCDM) model. LCDM is a mathematical model using Einstein’s equations for gravity and the known proportions of ordinary matter, dark matter, and dark energy. Note the bubble and void pattern as in the DESI image – bright clusters of galaxies distributed as if in a foam of bubbles with empty space in between bubble walls.

# Computer LCDM simulation of the cosmic web.

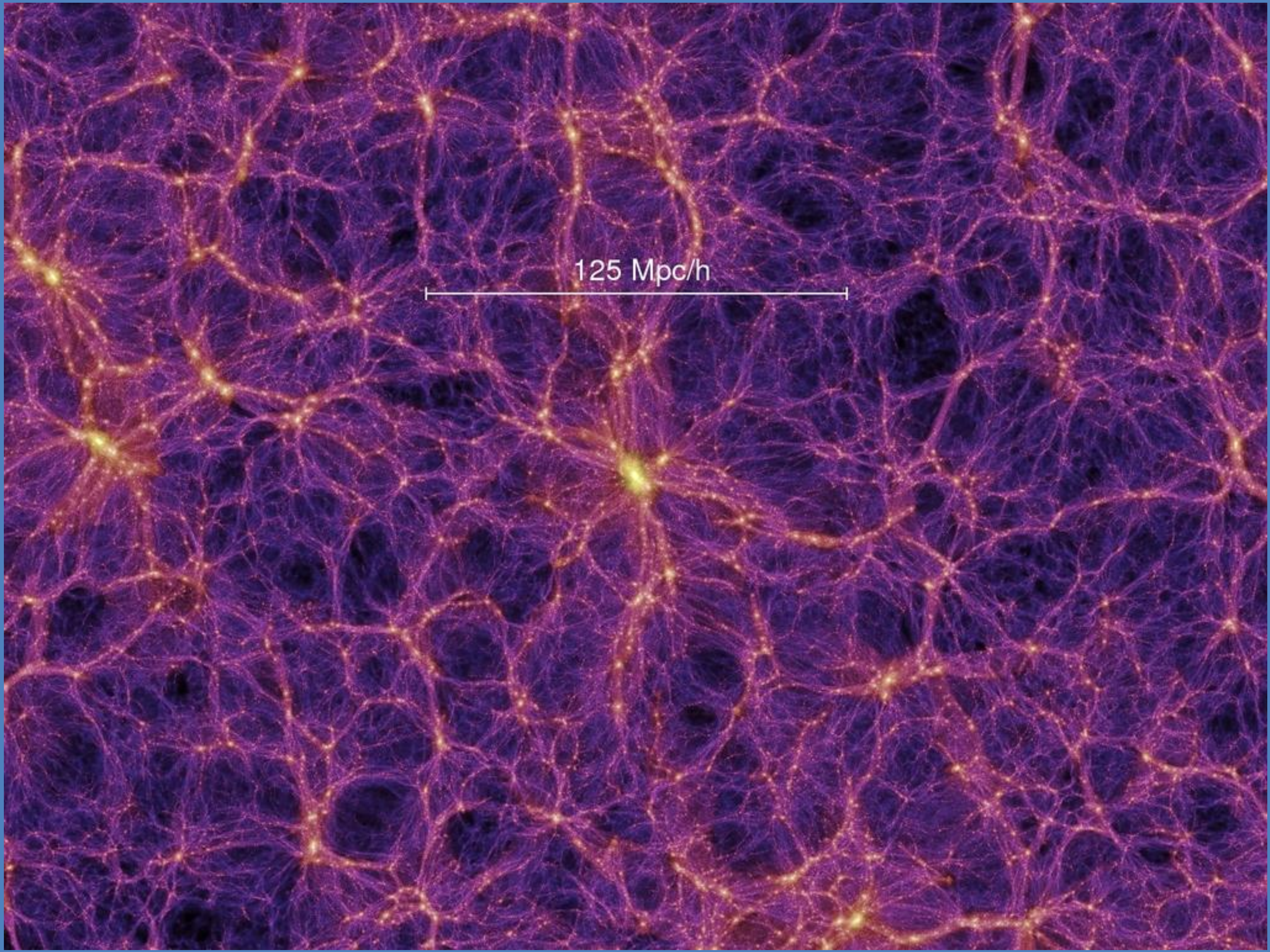
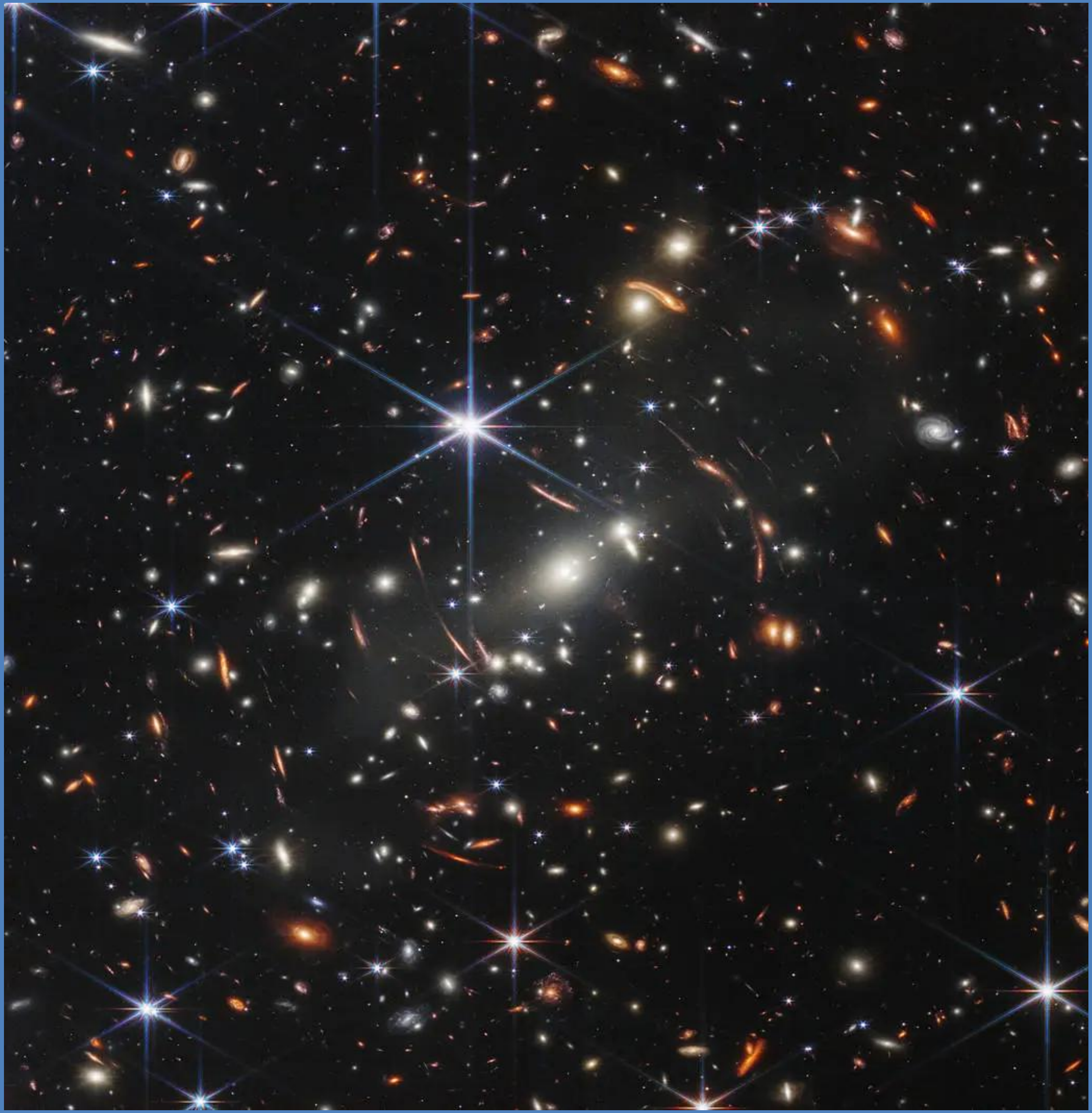



image: Springel et al 2005. Scale bar units are megaparsecs. 1 Mpc = 3.25 Ly.

# Into the cosmic web

Next is the Deep Field image from the James Webb Space Telescope. Like a searchlight peering through the foam of the cosmic web, it reveals galaxies all the way back as far as we can see, almost 13.8 billion light years. This image and subsequent images from the Webb telescope have revealed surprising structures and events near the very beginning of the universe. Bright spots with rays are stars in our own Milky Way galaxy. All the other structures are galaxies, the redder in color the farther away. Arcs are distant galaxies whose images have been distorted by the gravitational effects of other, nearer galaxies.



JWST Deep Field

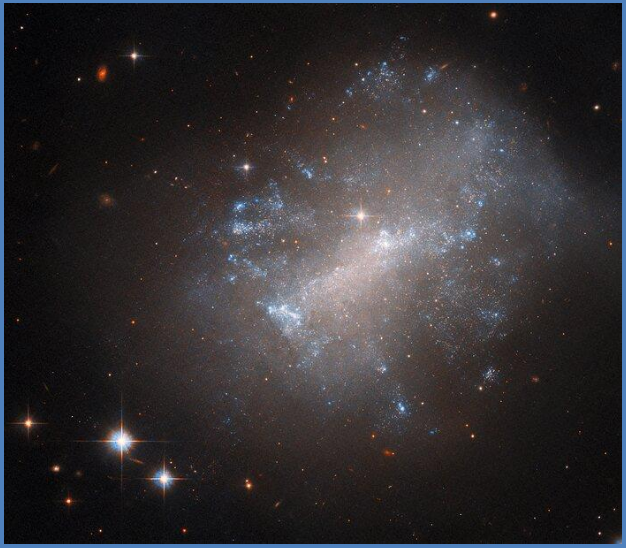
# Galactic scale

Next rung down the ladder of structure we find individual galaxies. There are uncounted billions of galaxies scattered throughout the universe, distributed mostly along the bubble walls of the cosmic web. Galaxies generally appear in three basic forms: spirals, ellipticals, and irregulars. They all have the same essential ingredients – gas (mostly hydrogen), dust, stars and their planetary systems. Most stars have planets. What we cannot see is the galactic halo of dark matter, which comprises about 80% of a galaxy's mass. Every galaxy also harbors a black hole at its center, some of them with masses hundreds of millions times the mass of our sun.

# Galaxies evolve

Spirals are mature configurations emerging from early galaxy formation.

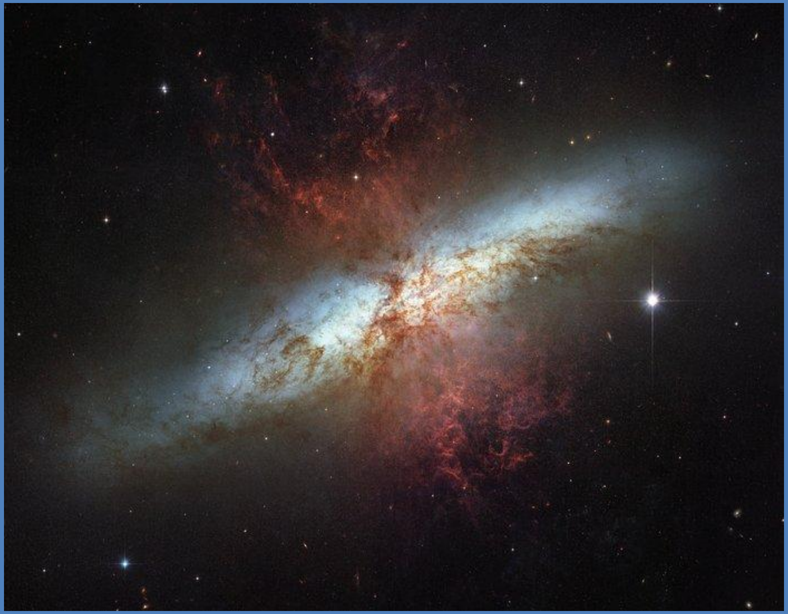
Ellipticals result from multiple spiral collisions over the eons.



Irregulars are galaxies that have recently collided or experienced disruptive internal events like black hole burps or runaway supernova explosions.

Things that go bump in the night:  Galaxies are dynamic.  They collide and belch and do-se-doe with their neighbors.

A colliding spiral and elliptical.

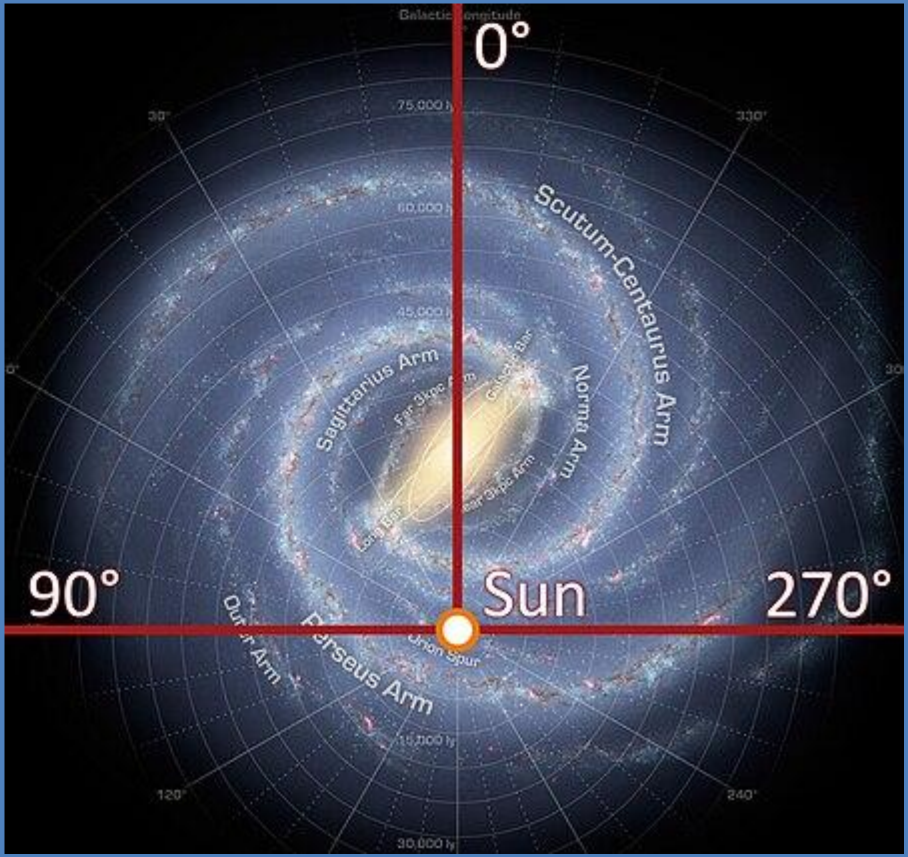


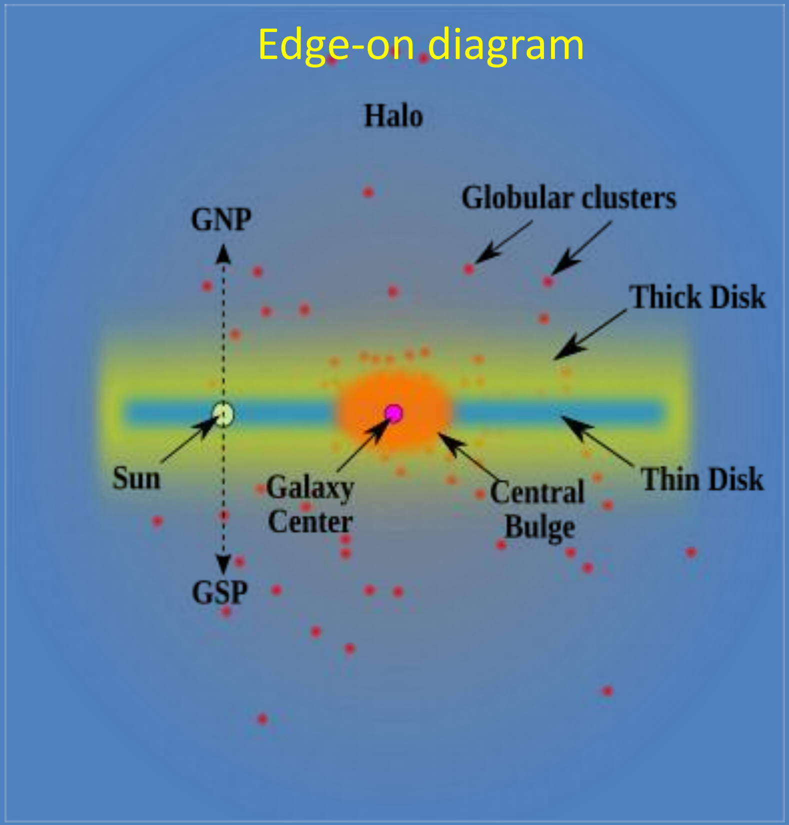
Spiral with active galactic center, probably winds from an accreting black hole or supernovae.

images:  Hubble Space Telescope

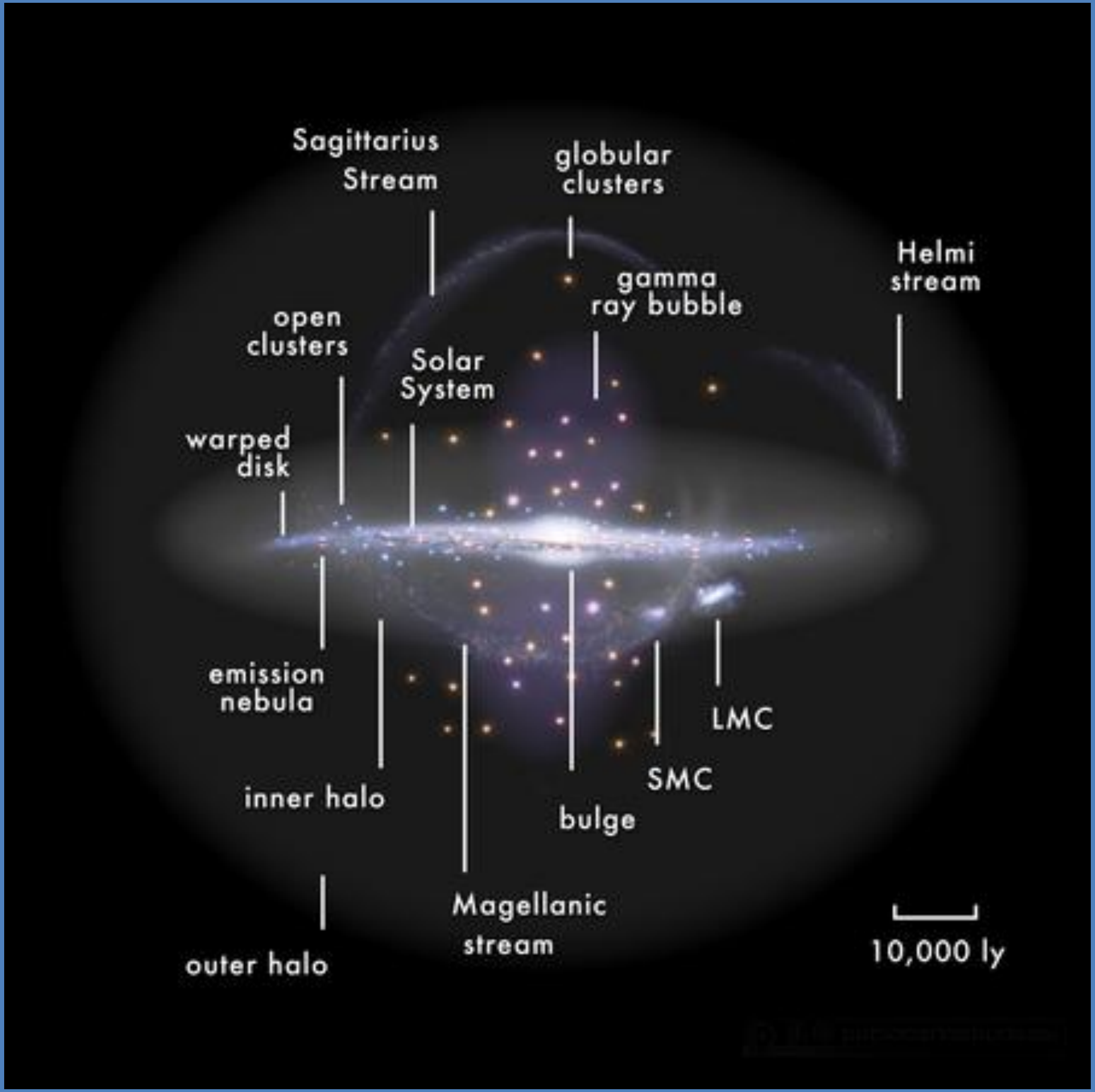
Scale of our home galaxy, the Milky Way. The Andromeda Galaxy (pictured below) is essentially the twin of our Milky Way. Andromeda is two million light years away and includes a couple hundred billion stars. A telescope in Andromeda looking our way would see our Milky Way as a very similar image.

Maps of the structure of the Milky Way Galaxy, about 100,000 Ly in diameter with about 300 billion stars. It includes visible mass in the form of gas (mostly primordial hydrogen) and dust (mostly debris from supernovae), plus much more dark matter, invisible to our telescopes.  Our solar system sits about 25,000 Ly from the galactic center.  Note the many companion globular clusters surrounding the main galaxy.



Another edge-on diagram of Milky Way structure, this one showing the dark matter halo and axial gamma ray bubbles probably remnant from past activity of the supermassive black hole at the galactic center.



Globular cluster M3, one of the many globular cluster companions to the Milky Way. M3 contains about 500,000 stars and is about 180 Ly diameter. Some of these stars are among the oldest in the Milky Way system. The origin of the globulars remains a mystery.

The Milky Way viewed from the southern Hemisphere (Atacama desert, Chile). We're looking through the disk of the Galaxy toward its center in Sagittarius. Note the central bulge and dark dust lanes. Note also the glow of dust in the ecliptic (the plane of earth's orbit) illuminated by the setting sun.

image: Yuri Beletsky

Here's what we see here in Meeker, looking toward Sagittarius in the Fall. Dust lanes and central bulge thin out as you move away (upward in this photo) from the galactic center.

Scale of our solar system, one of billions of planetary systems in our Milky Way Galaxy.  Our system is about twenty-two light hours across. More than 4200 other planetary systems have been observed so far (2026), including about 6,000 planets. (Planet orbit distances are not to scale, but sizes are ~ true proportions.)

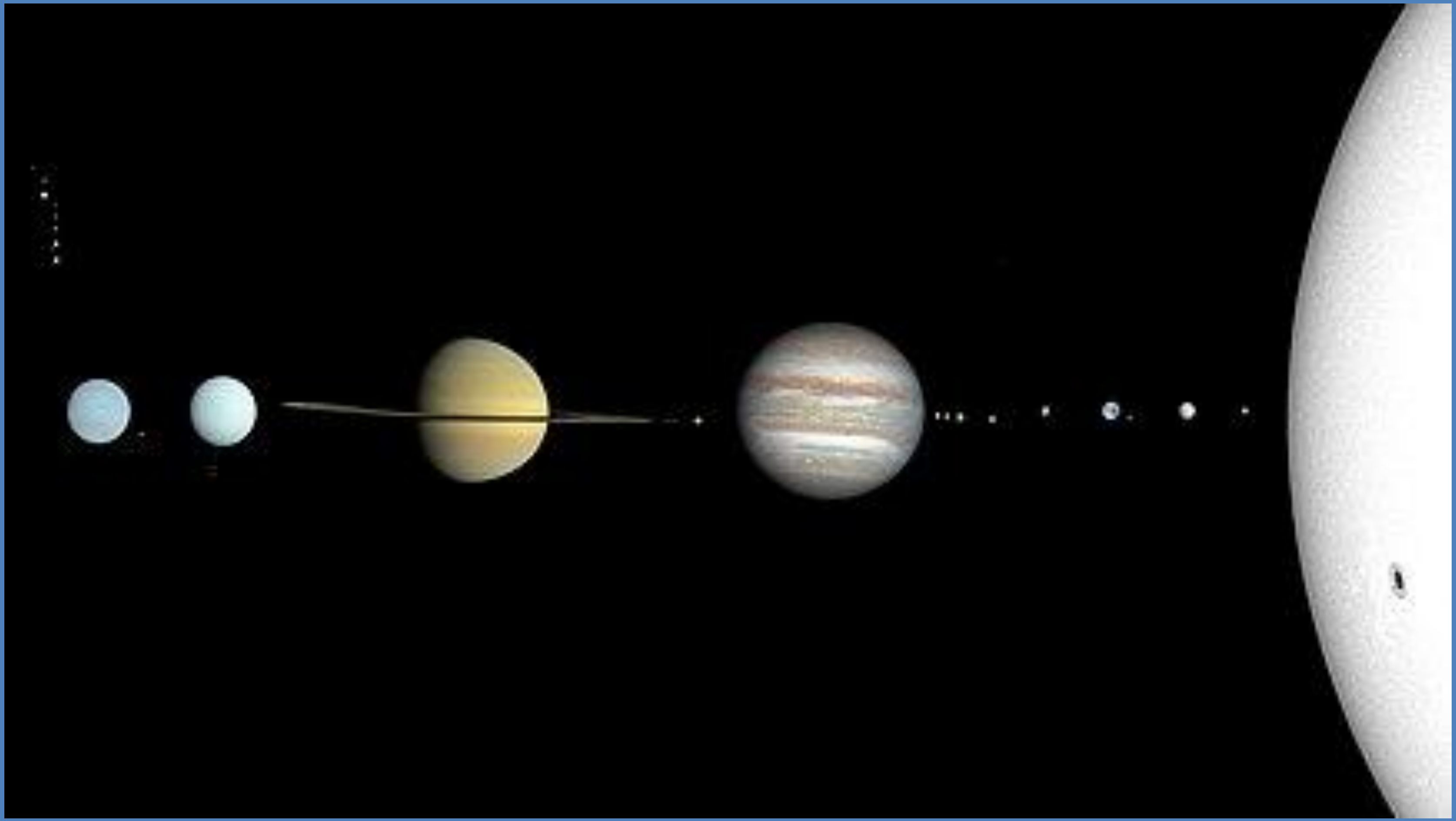
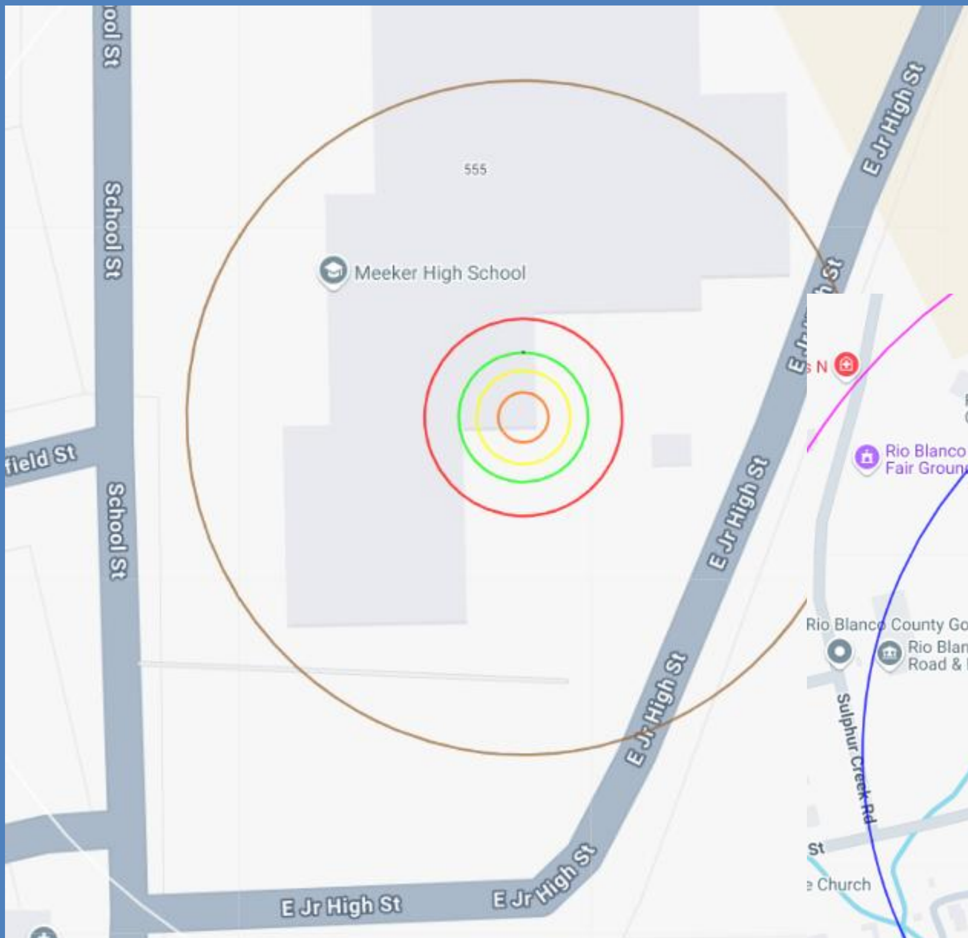
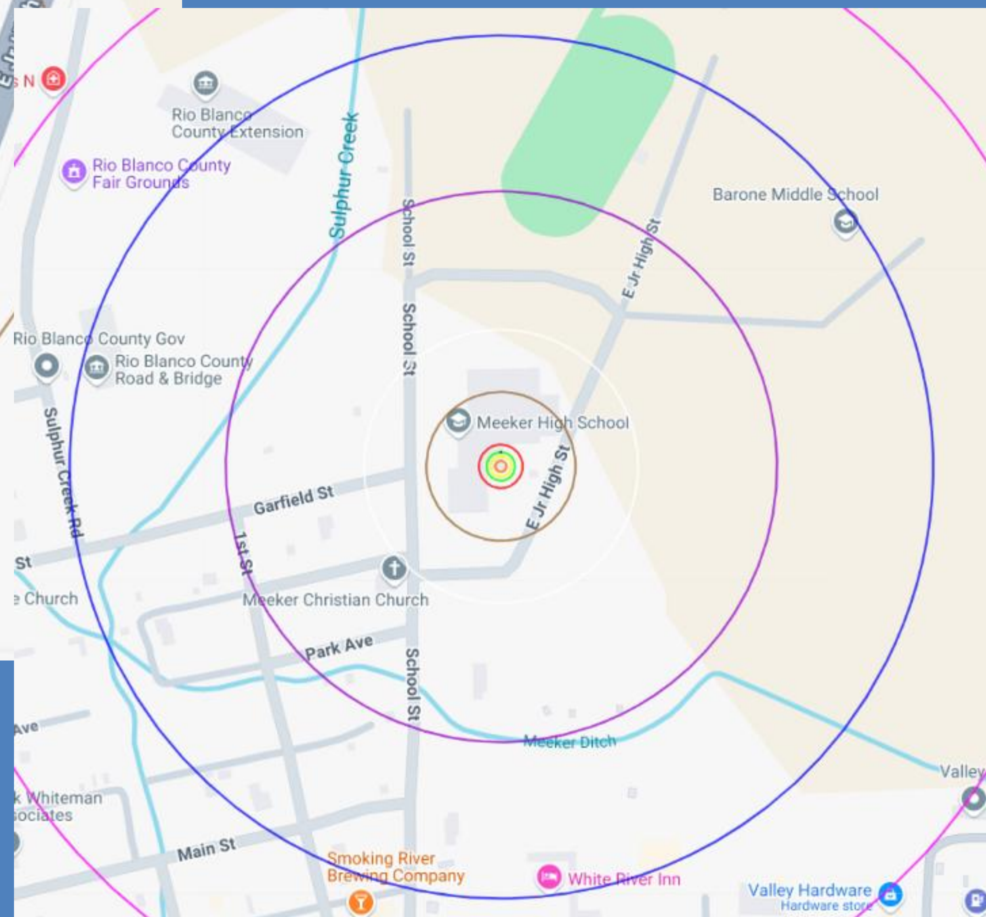


image:  NASA and CactiStaccingCrane, Wikipedia

# Solar system to scale if sun is 10 cm diameter in MHS Art Room.




. . . on out to Neptune (blue). Saturn orbit is white, hard to see. Magenta is the Kuiper Belt.




Inner planets, Mercury (orange) out to Jupiter (brown) . . .

source: https://www.dunlap.utoronto.ca/~du/solarsystem.html

The pale blue dot, Earth is visible in the dust lane of the ecliptic.  Voyager 2, outbound after its Neptune fly-by, turned its camera to snap this one last picture of its home planet, 4 light hours away.

"Look again at that dot. That's here. That's home. That's us. On it everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives."
Carl Sagan.

image:  NASA, JPL

# How many little blue dots are out there?

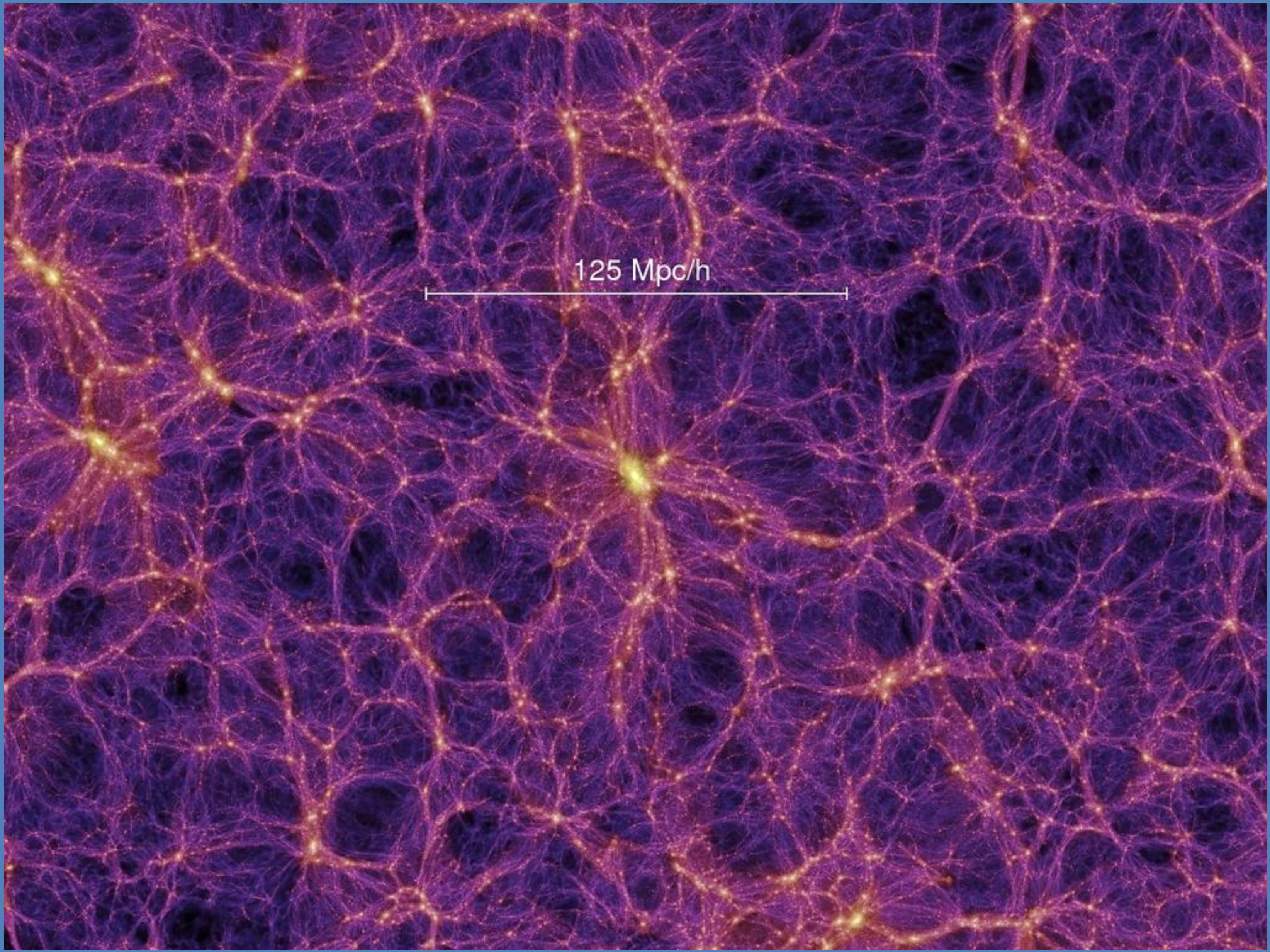



image: Springel et al 2005

It’s a REALLY BIG Universe (and maybe just one of zillions in a Multiverse). We have a whole lot left to learn. I hope you join the endeavor.