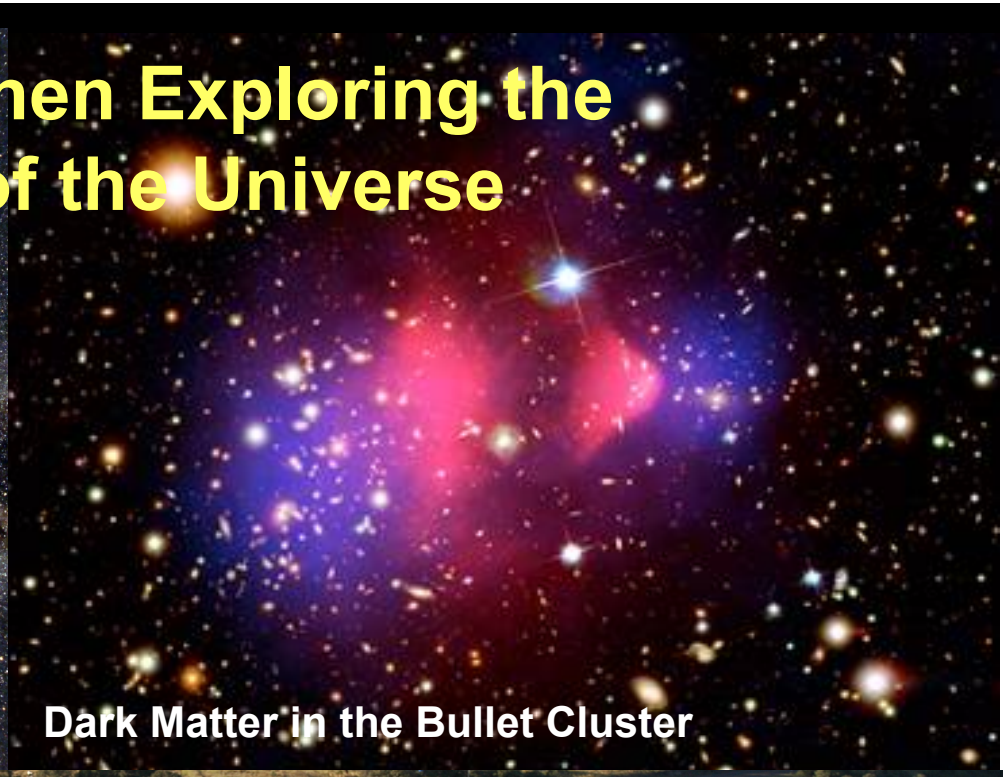
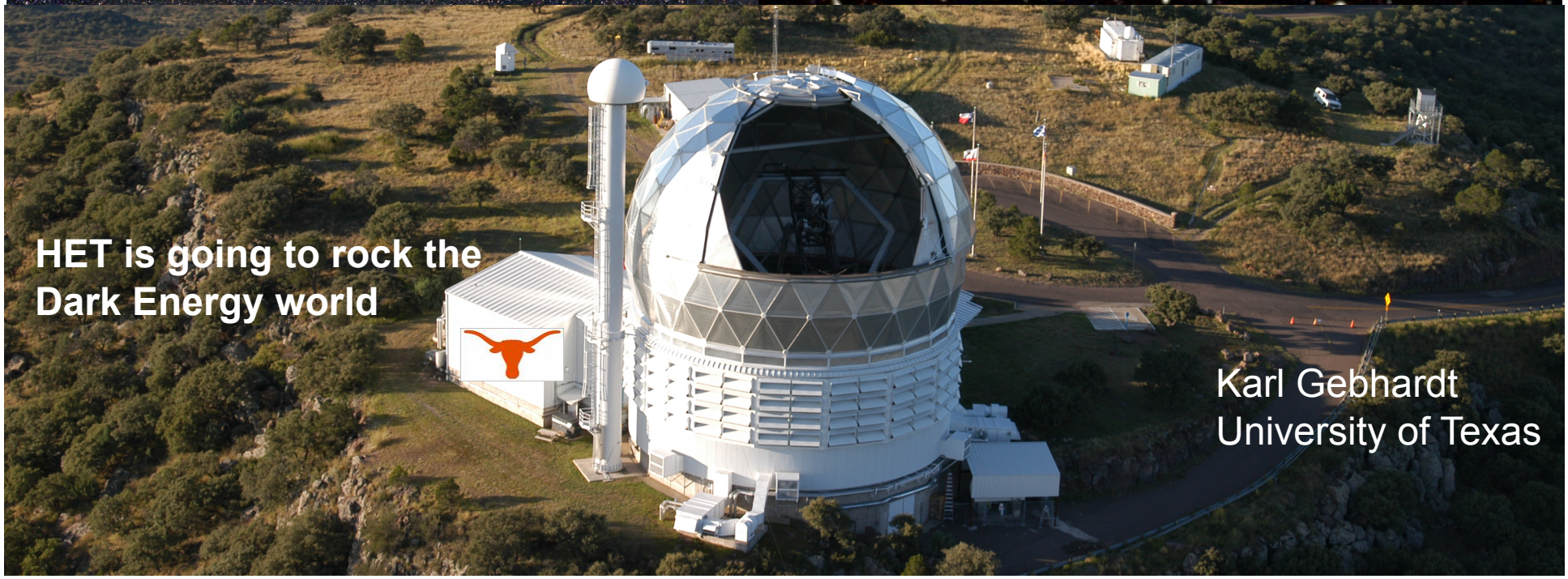
Walk Softly When Exploring the Dark Side of the Universe

Black Hole close encounter



Dark Matter in the Bullet Cluster



HET is going to rock the Dark Energy world

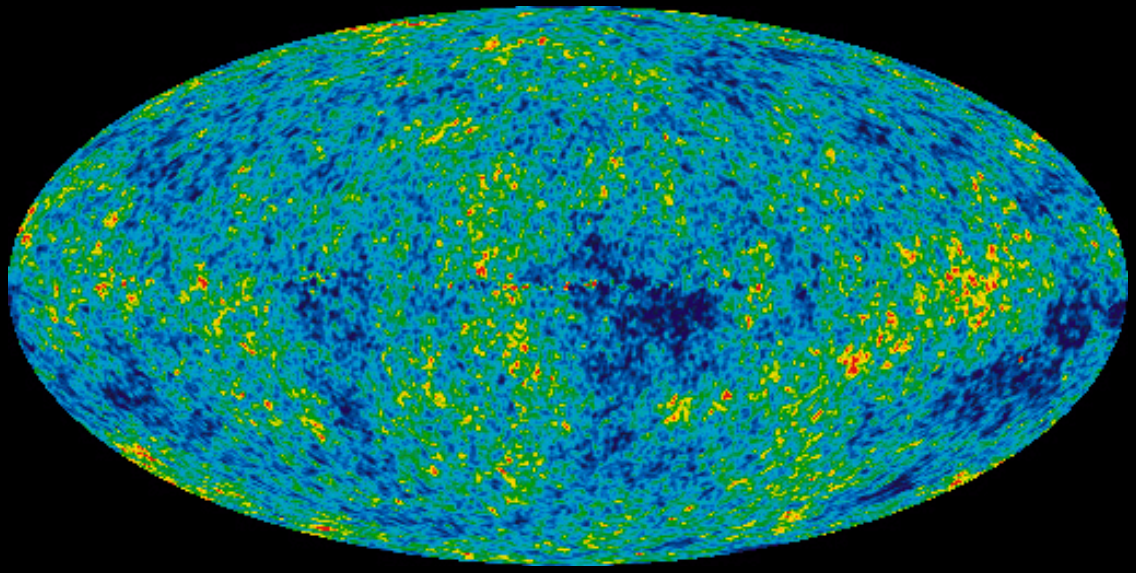
Karl Gebhardt
University of Texas

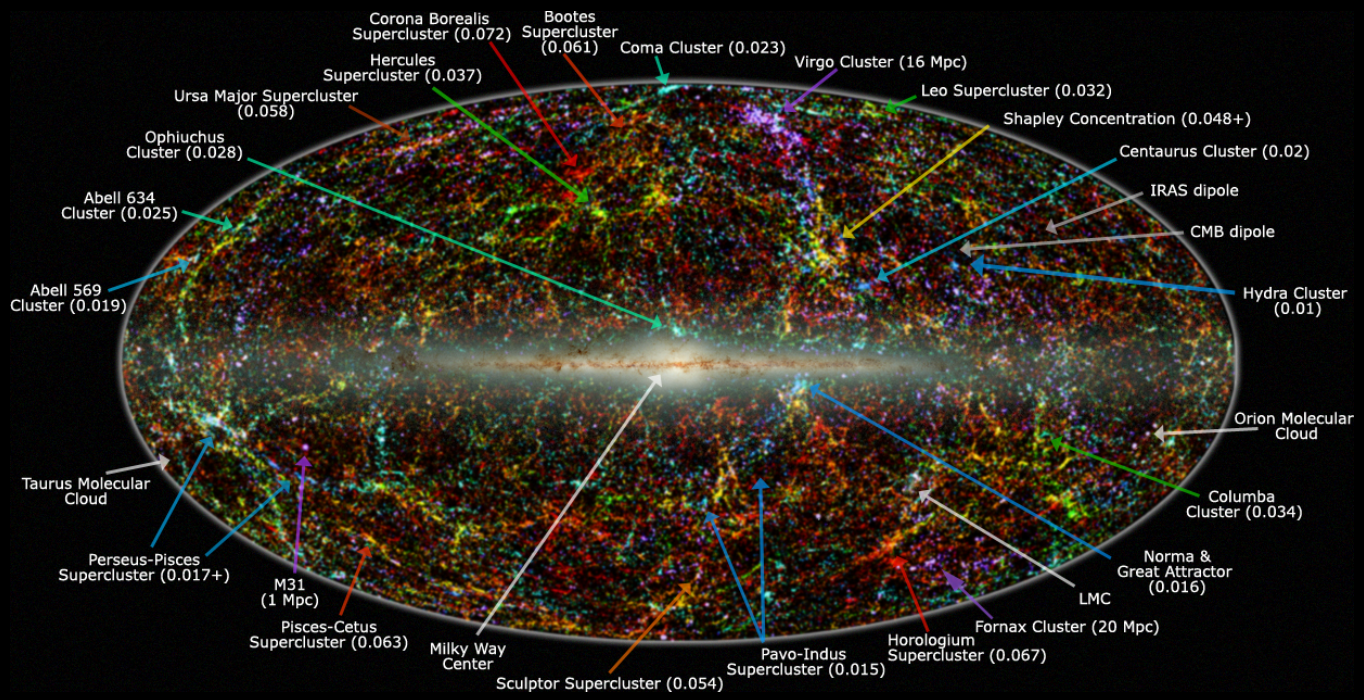
We're just trying to get from Point A to Point B

Universe as it appeared 13.5 billion years ago

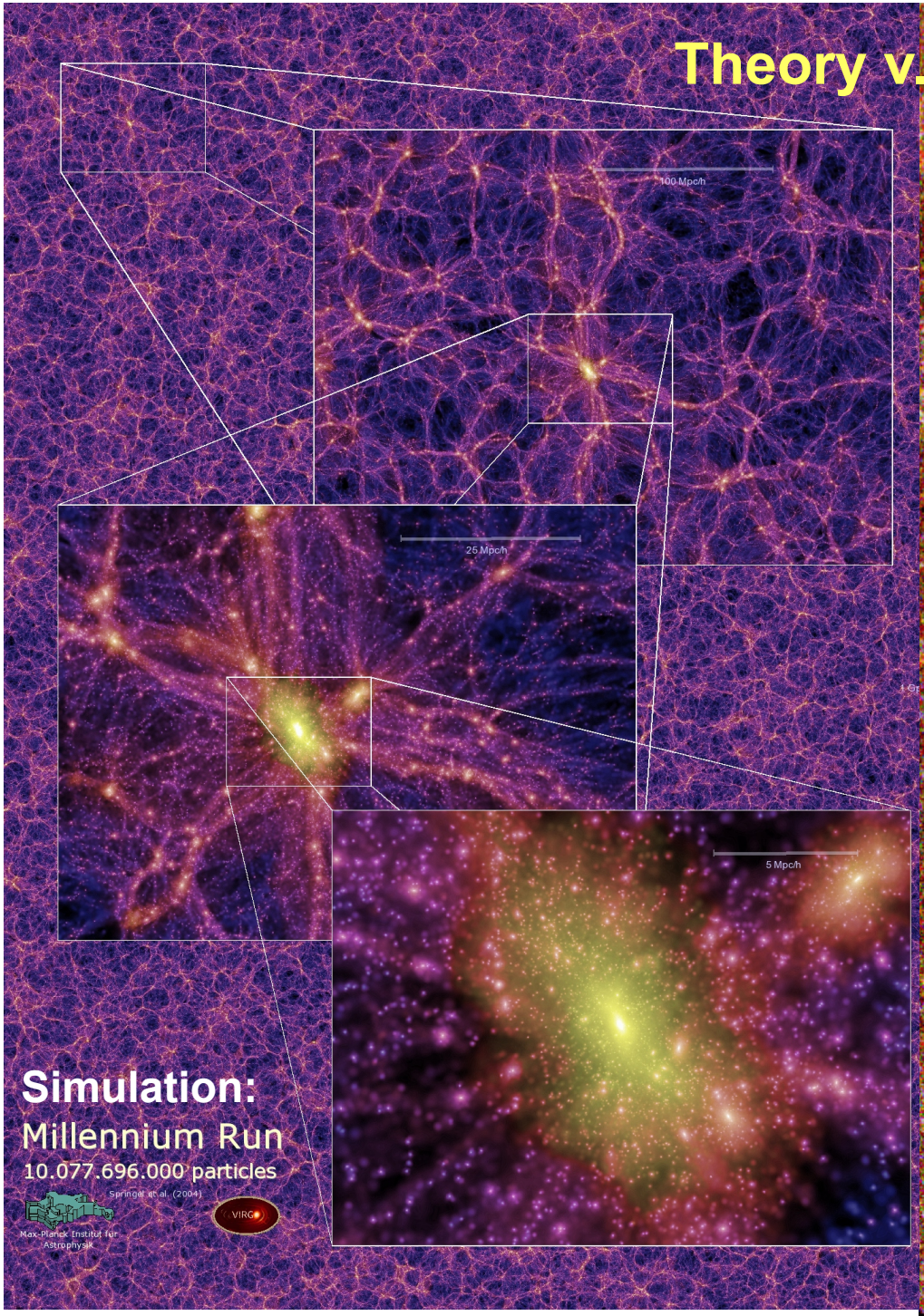
Time

Today

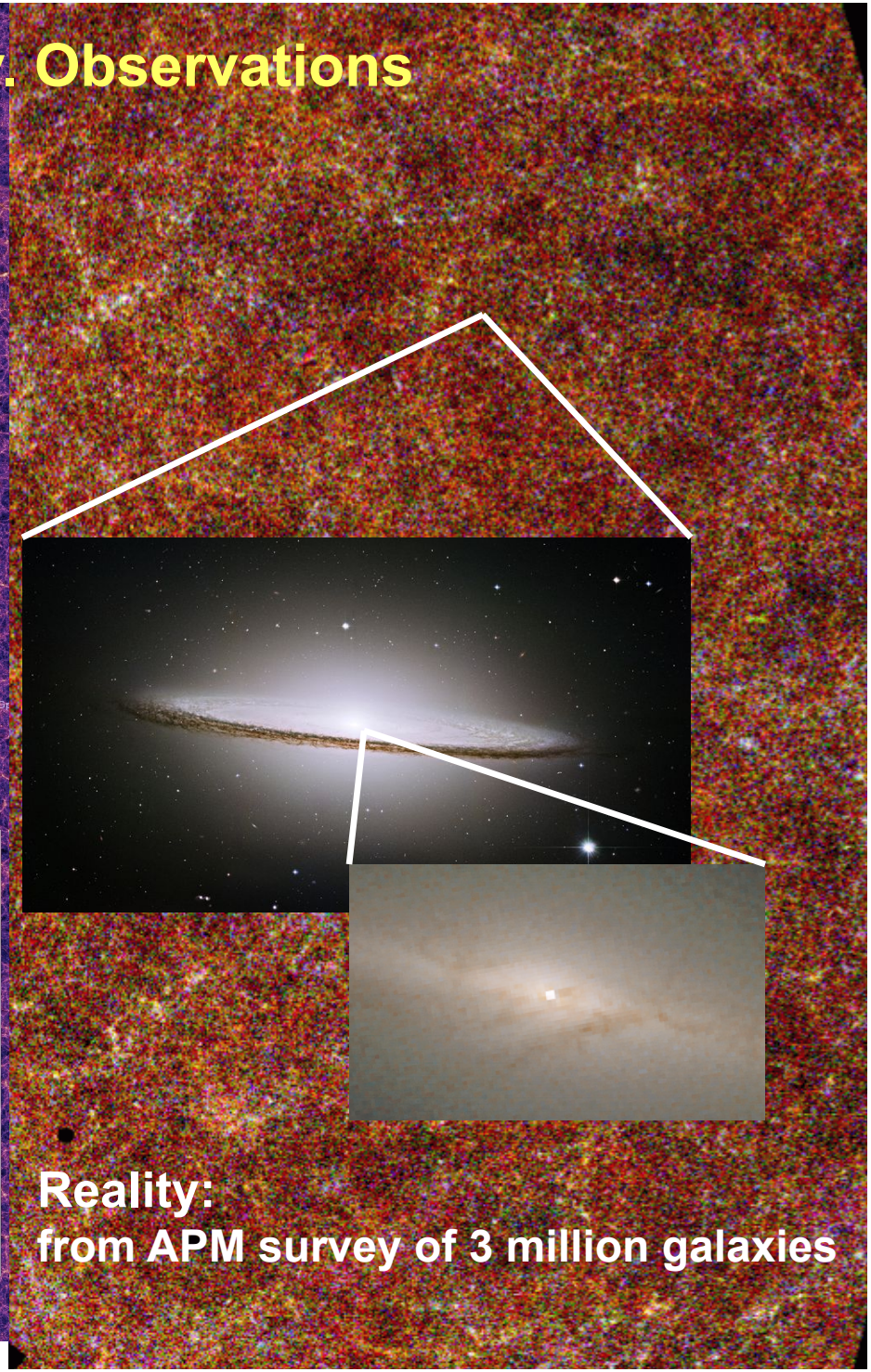




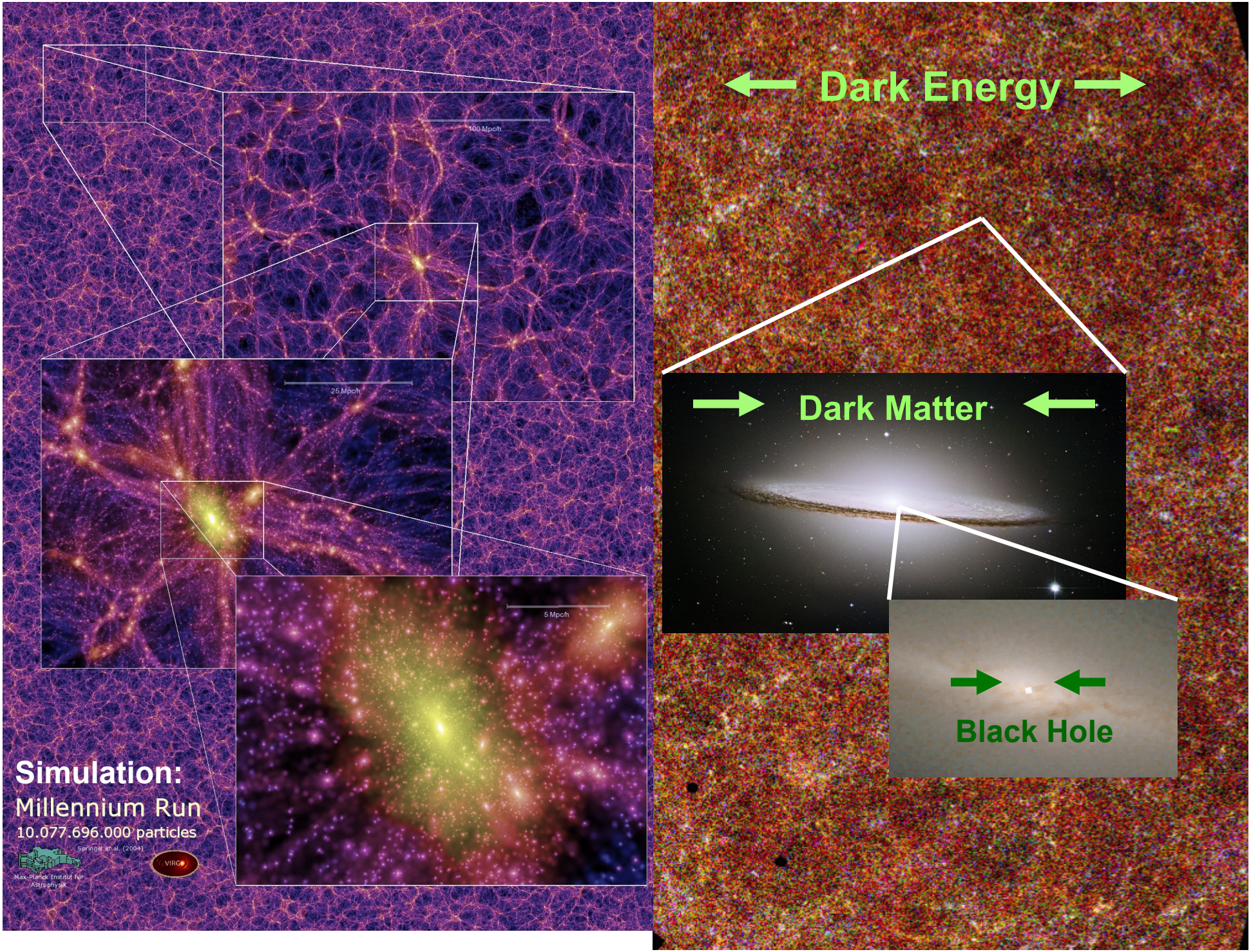
Theory v. Observations



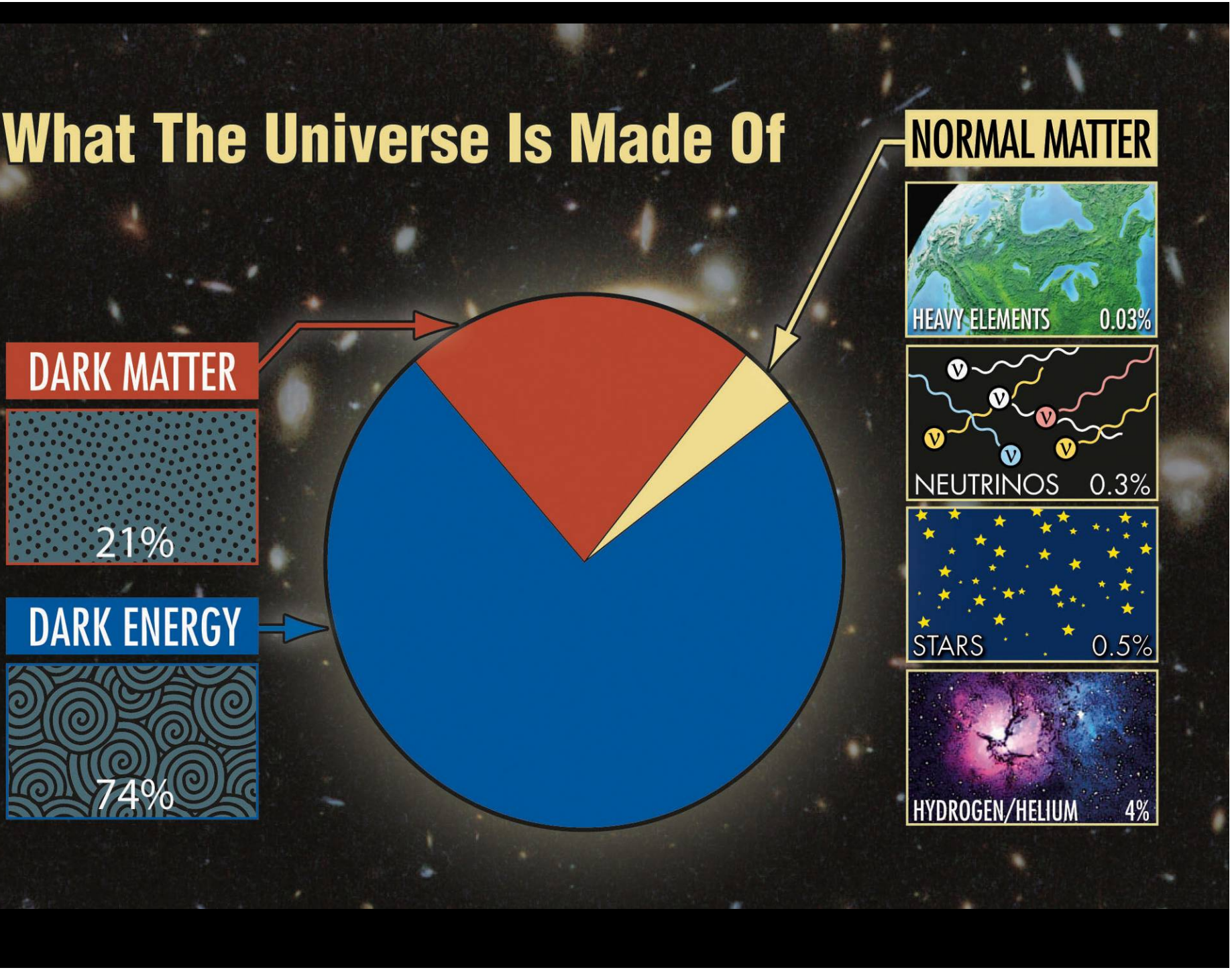
Simulation:
Millennium Run
10.077.696.000 particles
Springel et al. (2004)
Max-Planck Institut für Astrophysik
VIRGO



Reality:
from APM survey of 3 million galaxies


Dark Energy
Dark Matter
Black Hole
100 Mpc/h
25 Mpc/h
5 Mpc/h
Simulation:
Millennium Run
10.077.696.000 particles
Springel et al. (2004)
Max-Planck Institut für Astrophysik
VIRGO

What The Universe Is Made Of



Best Explanations

Black Holes

- Mass is so concentrated that gravity wins all (nothing can escape)
- Theory breaks down at these high densities
- Likely a new state of matter and energy that we cannot understand yet
- Lots of fun to theorize that it is a porthole to another dimension

Dark Matter

- Been around for 70 years as an extra inward pull in galaxies
- Strong consensus that it is a new particle
- Theory and observations specify some properties of it
- We are very close to finding the dark matter particle!

Dark Energy

- Been around for 10 years as an outward push between galaxies
- Strong consensus that we have a problem
- Property of space; gravity not understood; modify the Big Bang
- Theory is struggling. Observations to the rescue!

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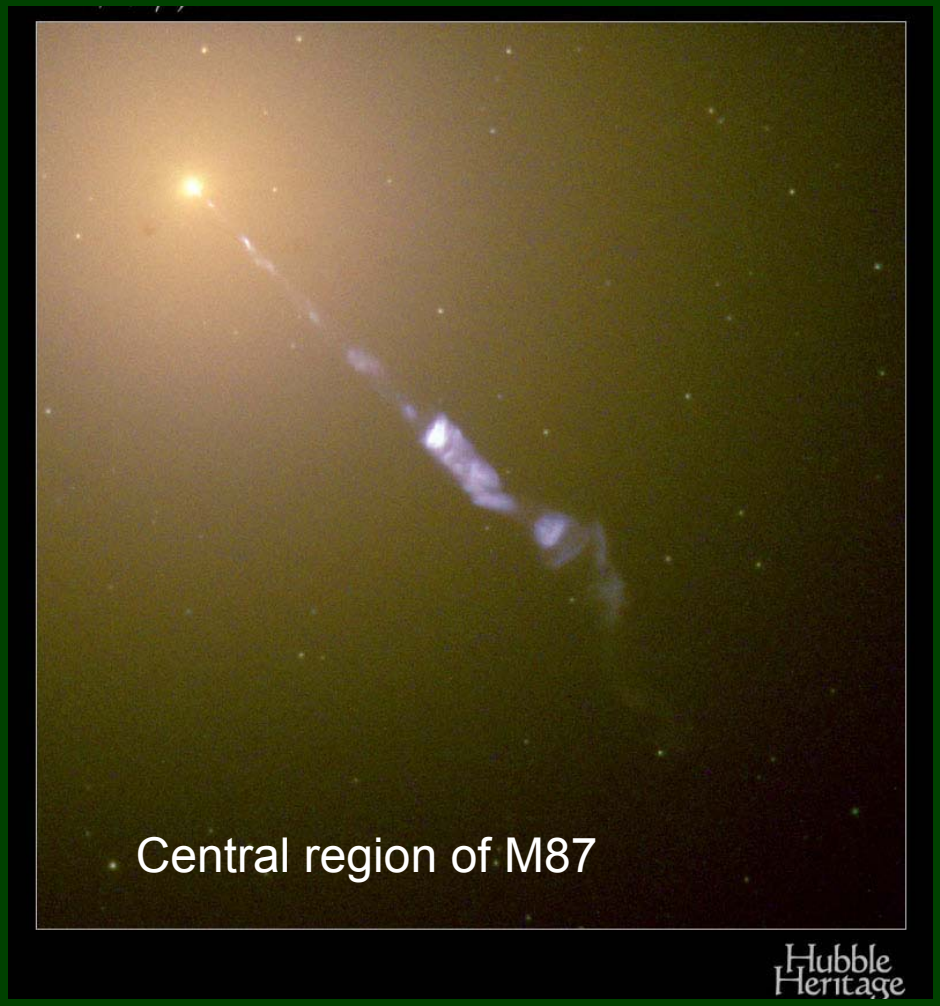
Their understanding is fundamental for quantifying how the universe formed, how matter and energy are distributed, how galaxies form, and how stars form within galaxies.

It's all about the motion

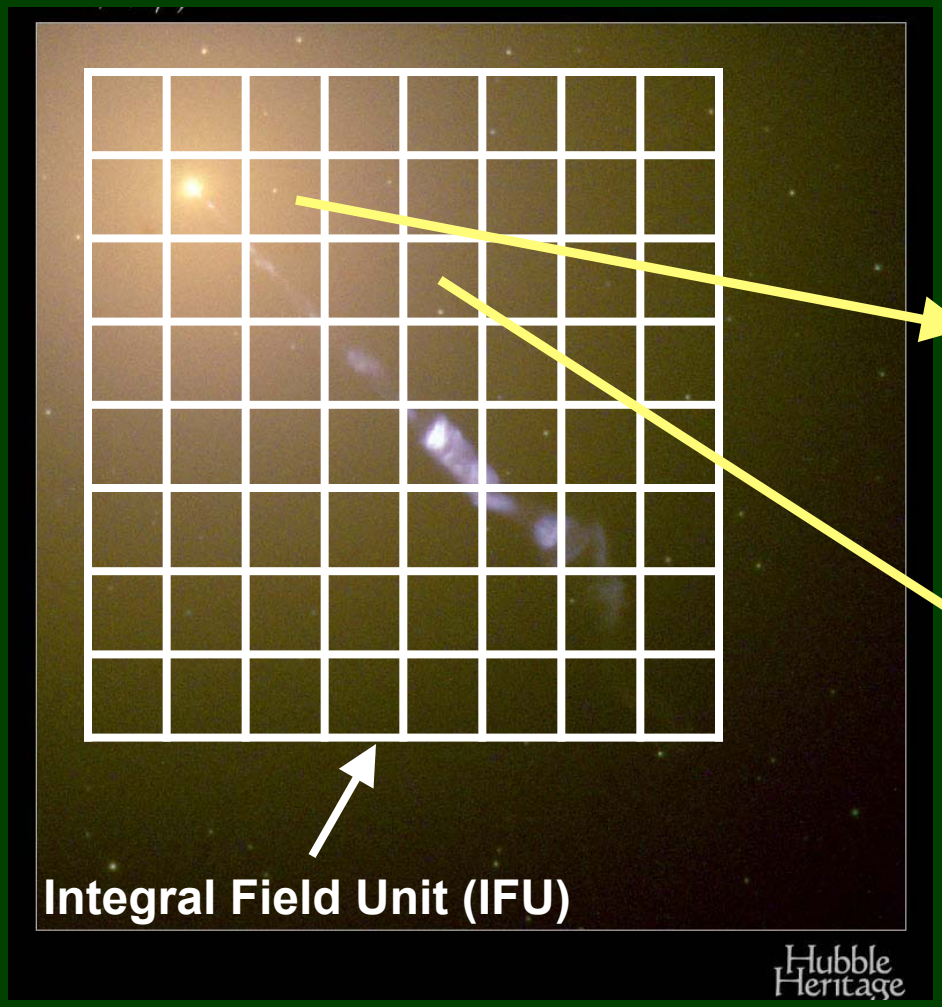
How to measure a black hole



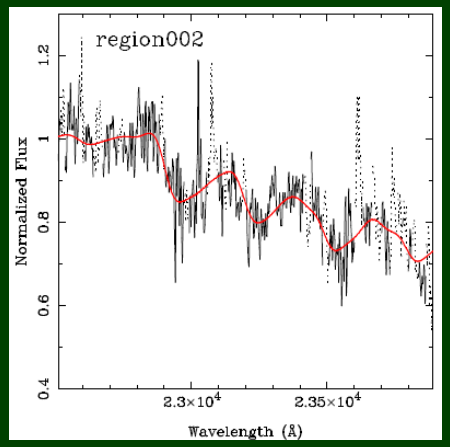
- Take a spectrum of individual locations in the center of a galaxy.
- Measure how fast the stars are moving.
- Use Newton to tell us the enclosed mass.
- Mass = Radius x Velocity^2 / G

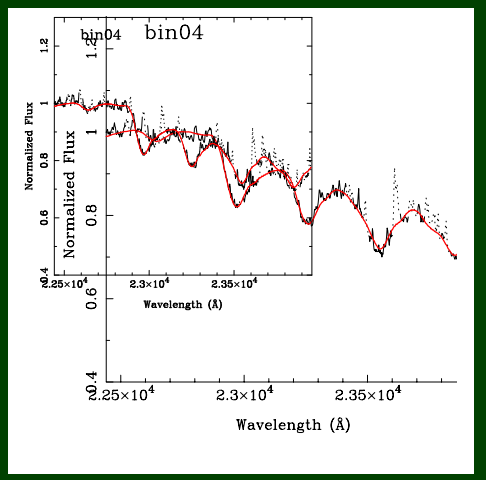
It's all about the motion

How to measure a black hole



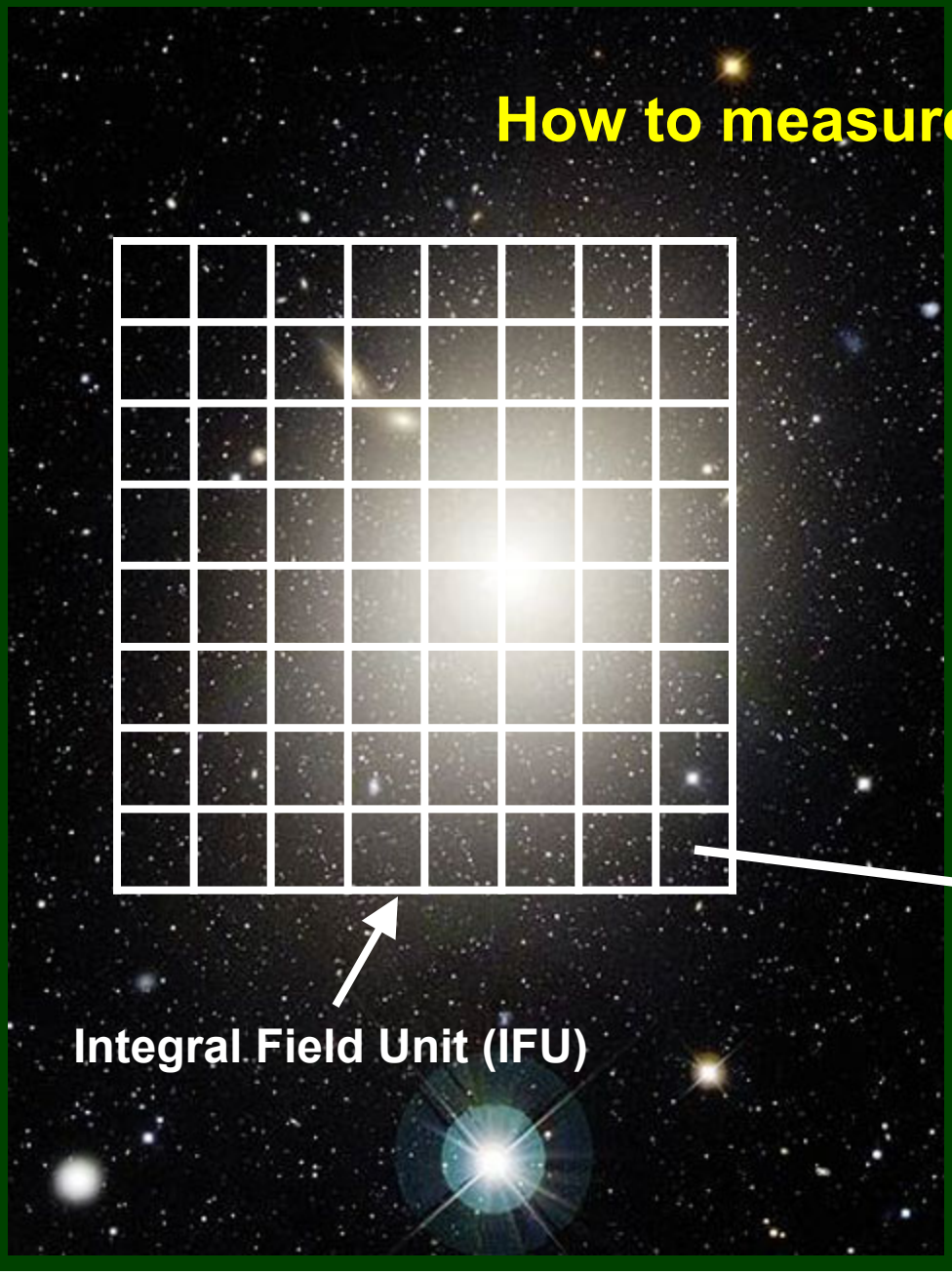
Build up a model for how the stars move based on their Doppler shift



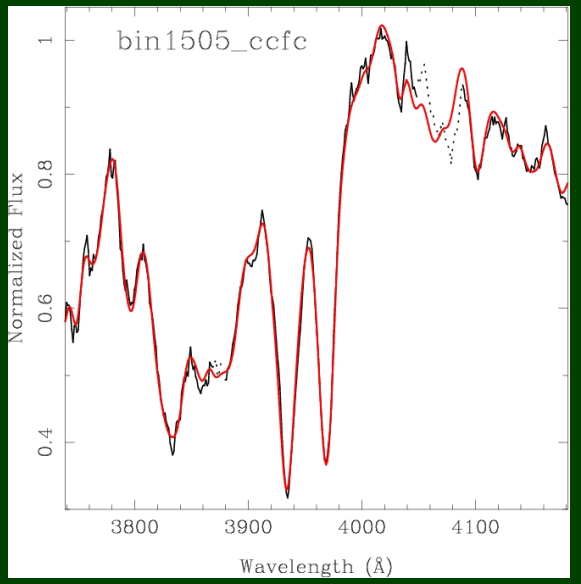


What you get is what you don't see

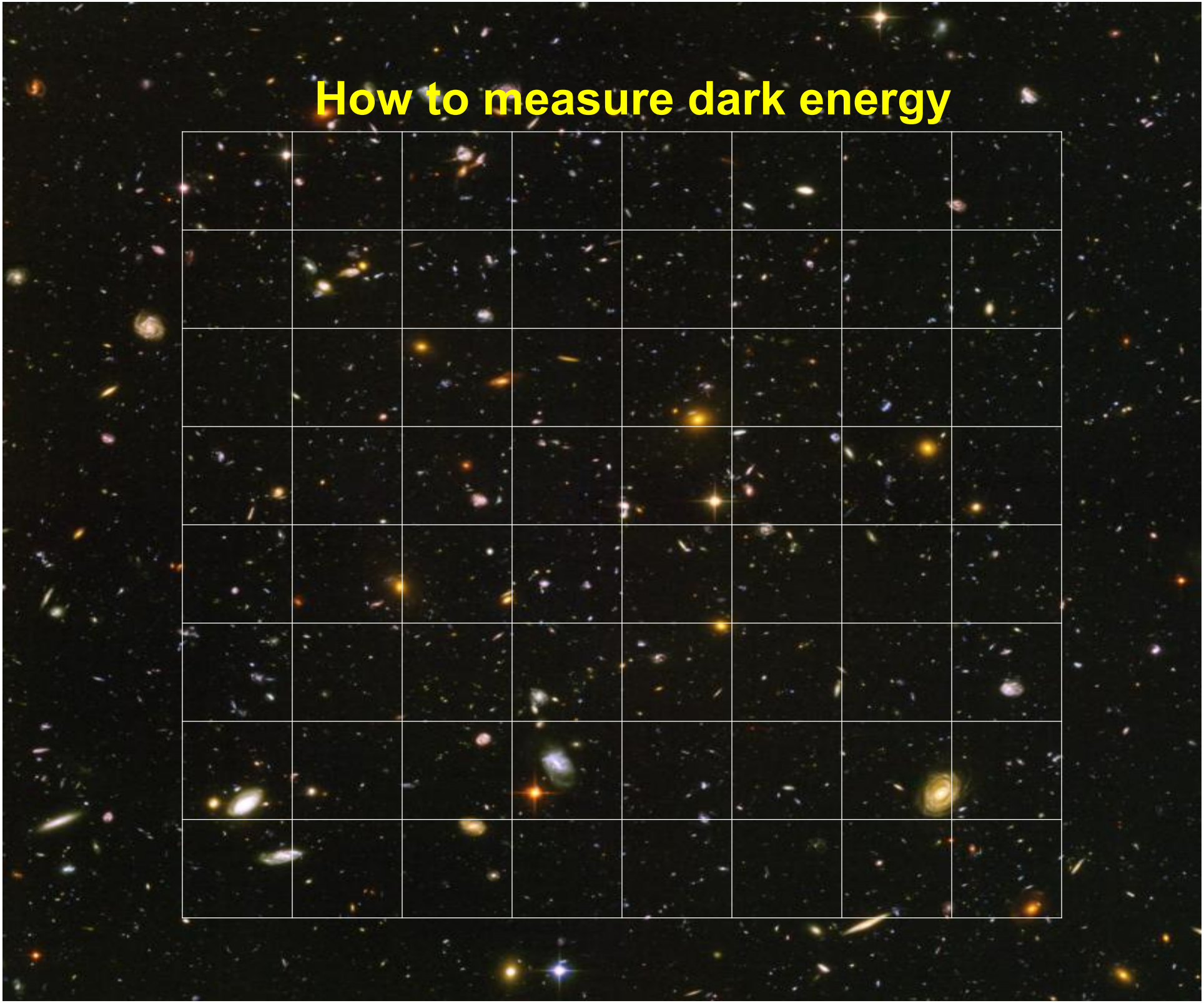
How to measure dark matter

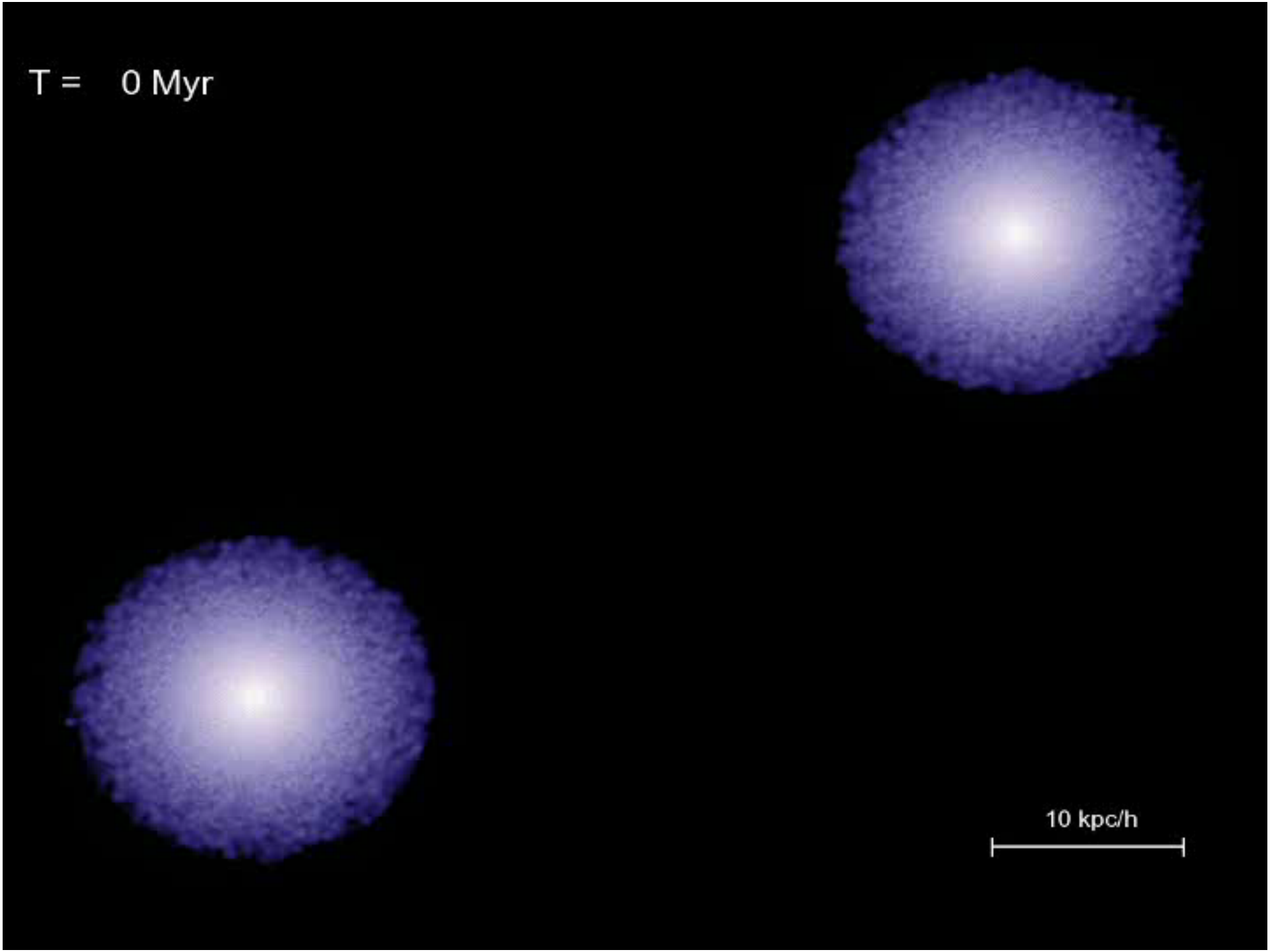


Need to measure how stars move at the outer edge of a galaxy, where the dark matter lives.



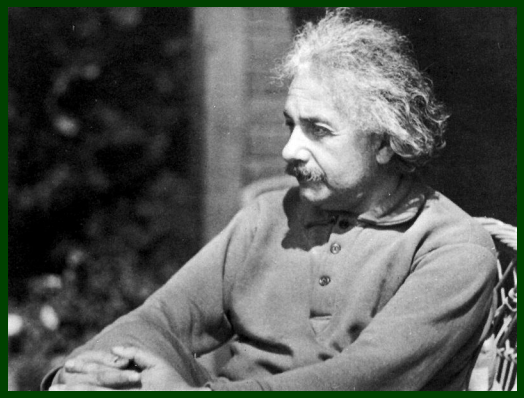
How to measure dark energy




T = 0 Myr
10 kpc/h

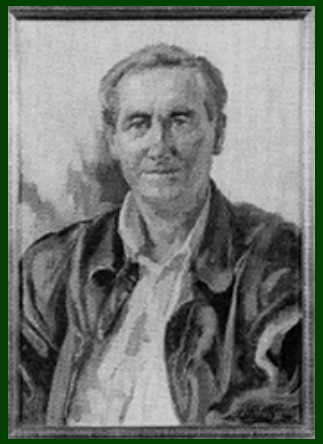
A Brief History of Black Holes (theory-side)

Laplace and Michell discuss “dark stars” in 1700’s



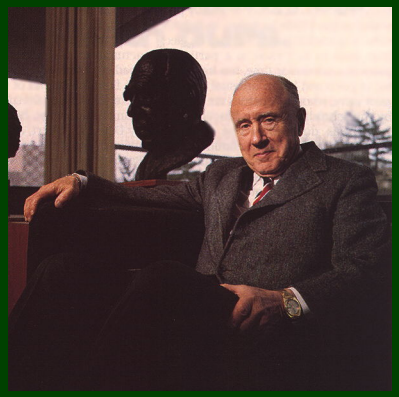
In early 1900’s, Einstein develops General Relativity

Schwarzchild solves equations to discover the central singularity



Kerr solves equations for rotating black holes in 1960’s

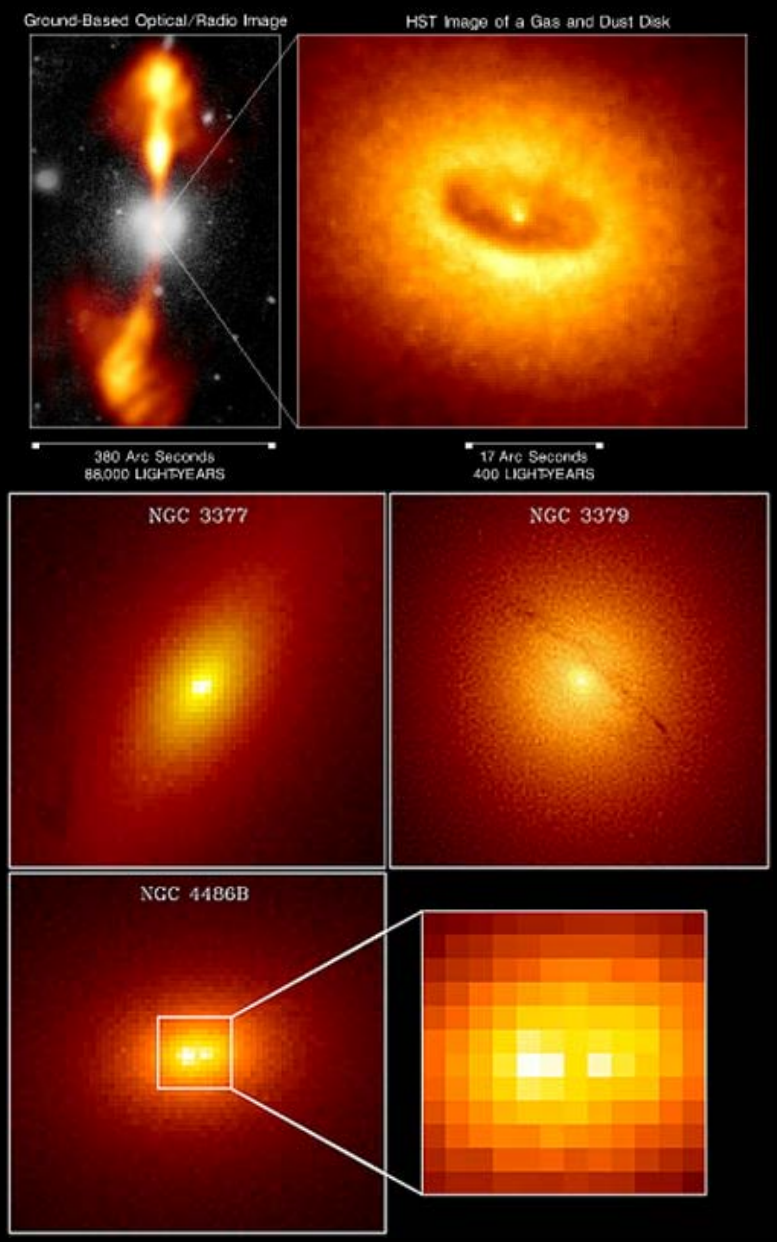
Stephan Hawking studies what happens in a black hole



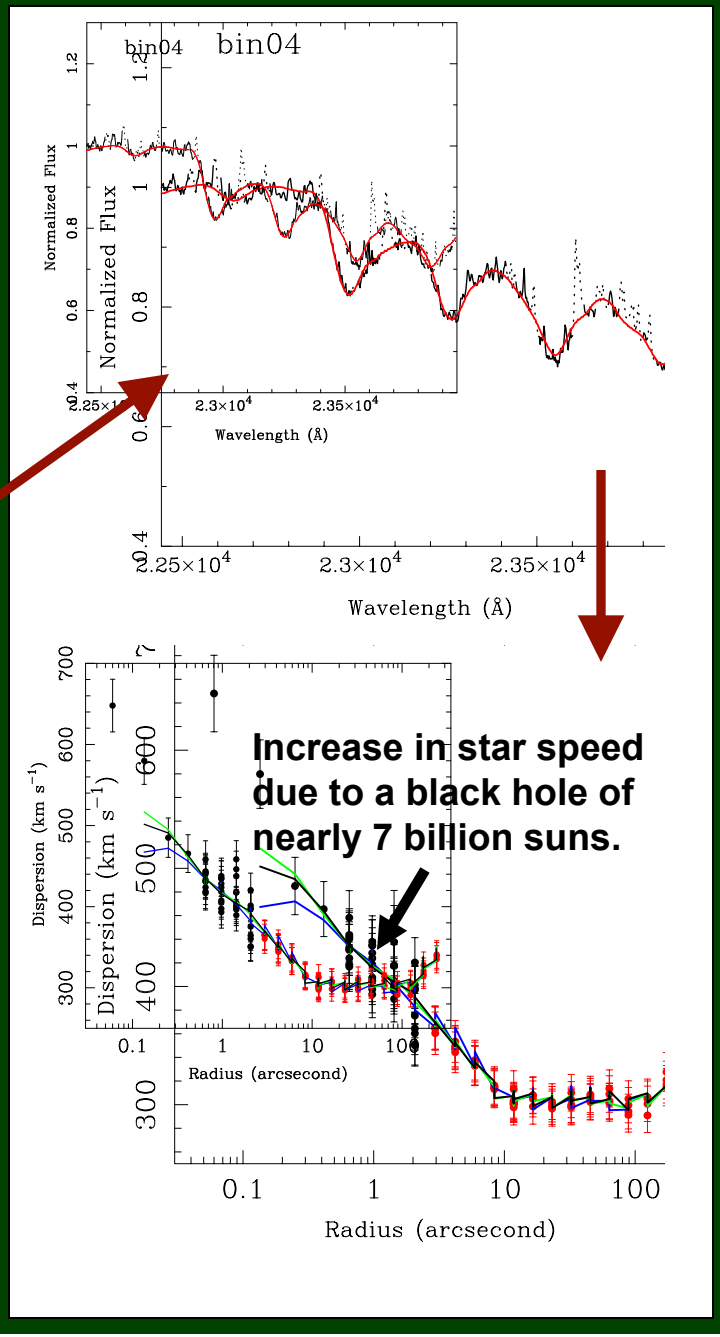
Wheeler coins the phrase “black hole” at a public talk in1968

Reality check: HST

Hubble Space Telescope revolutionized our thinking of Black Holes



Even Greater Reality Check: Adaptive Optics

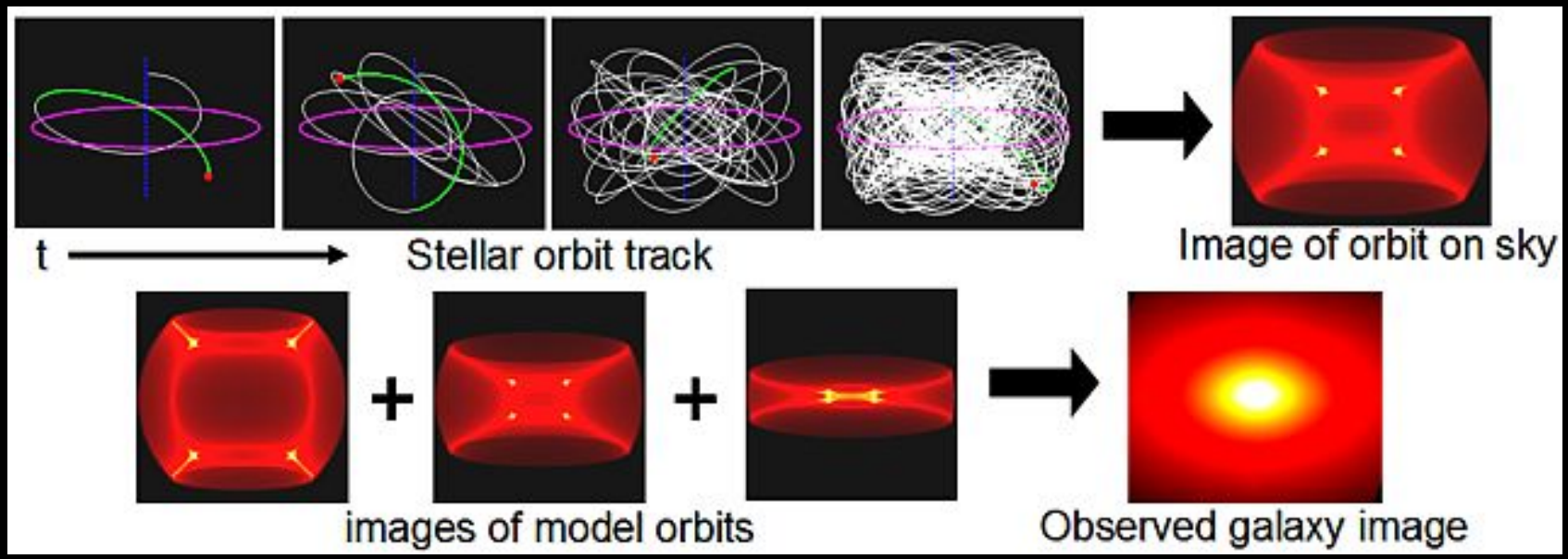


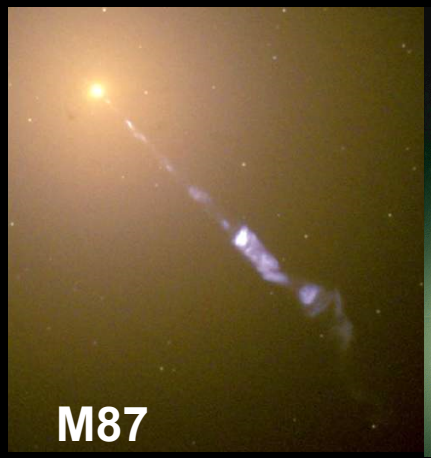
Gemini Telescope Adaptive Optics data show a dramatic increase in speed of stars in the center of M87. These data provide a robust measure of the black hole mass.

Why is it so hard to measure a black hole mass

How I view a galaxy

(There are just too many stars!)





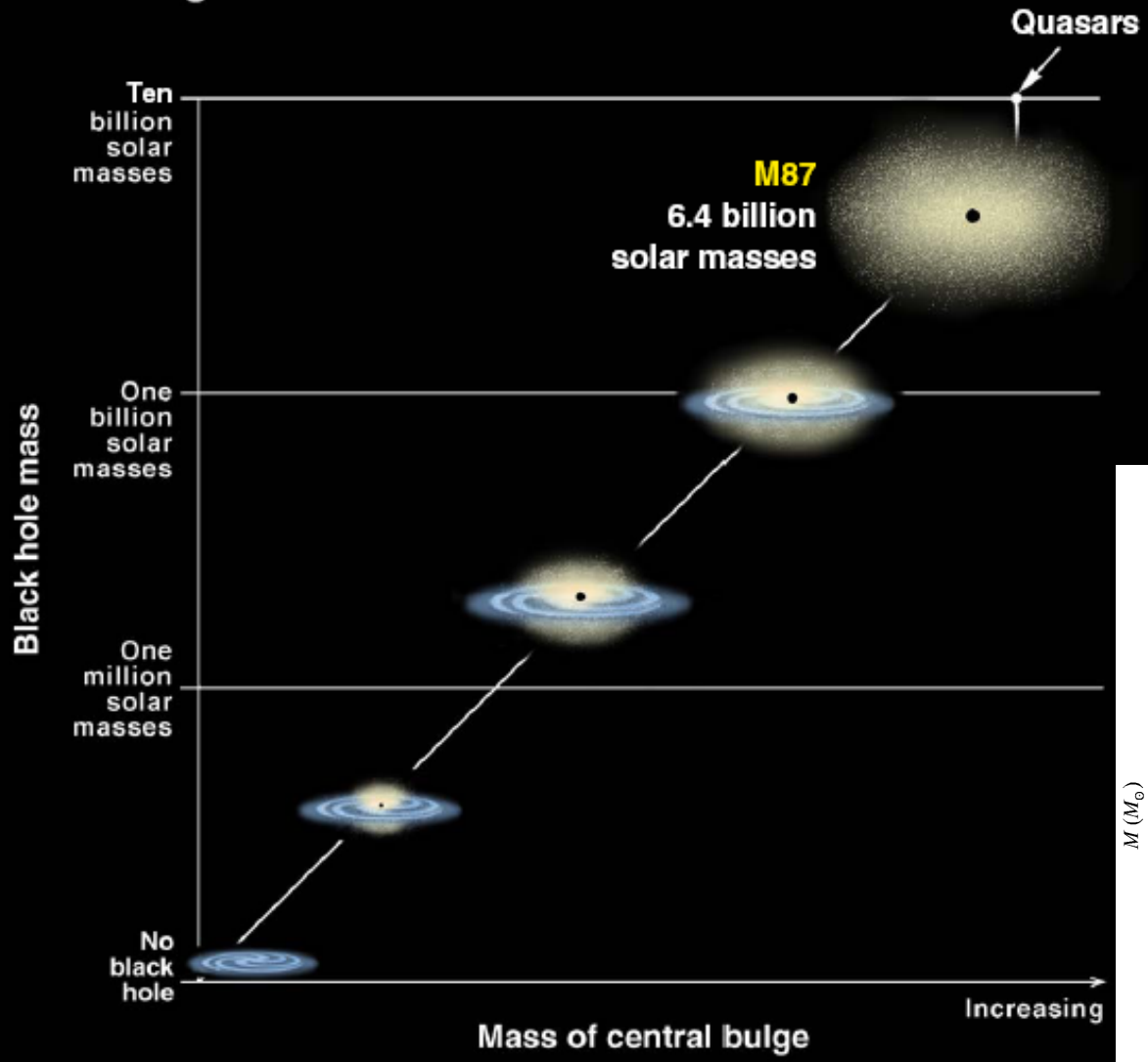
Lonestar to the rescue!

- The problem is that we need very complicated models to include both black hole and the dark matter. This would take 10 years in the old mode.
- This would not be possible without supercomputers. I use the TACC (Texas Advanced Computing Center) and the 5800 (called Lonestar) and 60,000 (Ranger) node systems.

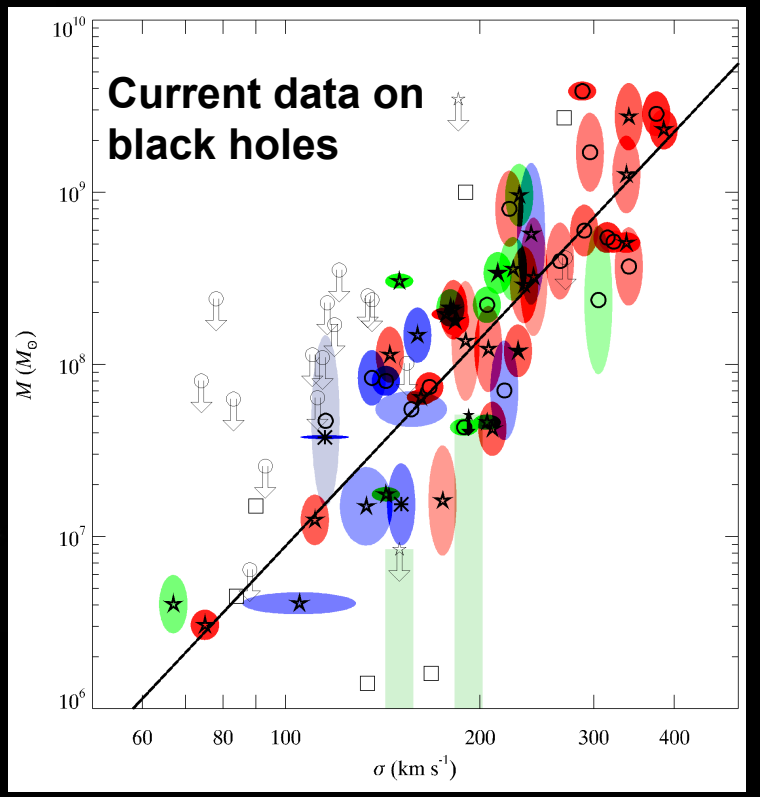
Lonestar at the Texas Advanced Computing Center

- M87 is the largest galaxy in the nearby universe, with a trillion solar masses in its stars. Sits in the center of the Virgo Cluster.
- Black Hole Mass measured to be nearly 7 billion Suns, which is 2.5 times larger than previously thought.

Black Holes trace the Galaxy Mass



Tight correlation implies an intimate link between the galaxy and black hole.



History of Dark Matter

Fritz Zwicky suggested dark matter in the 1930s by looking at how fast galaxies move around each other. No one believed him.

Vera Rubin studied how stars and gas moved in a galaxy to infer dark matter in the 1970s. Her work was the bedrock for dark matter.

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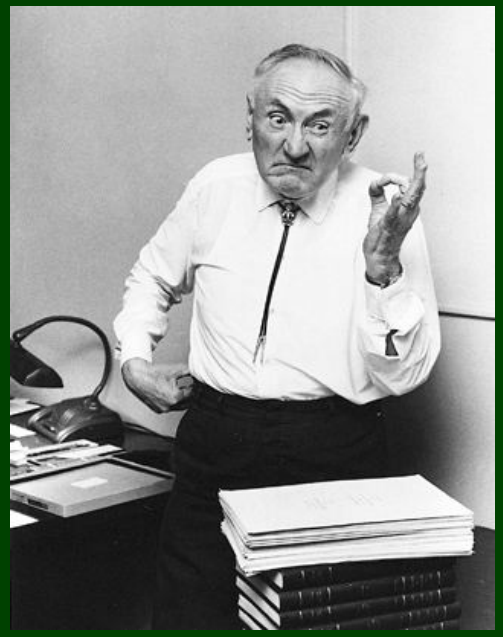

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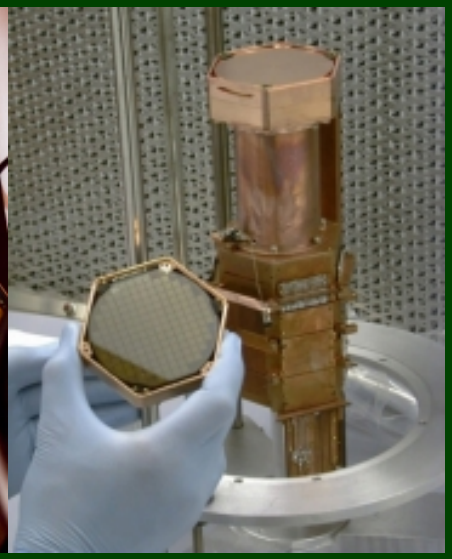
Who would you believe?

Existence of Dark Matter is now well established

Gravitational lensing (bending of starlight) studies show that galaxies are dominated by dark matter.

The Bullet Cluster is our best proof of dark matter; the mass (in blue) is not at the same place as normal matter (in red).

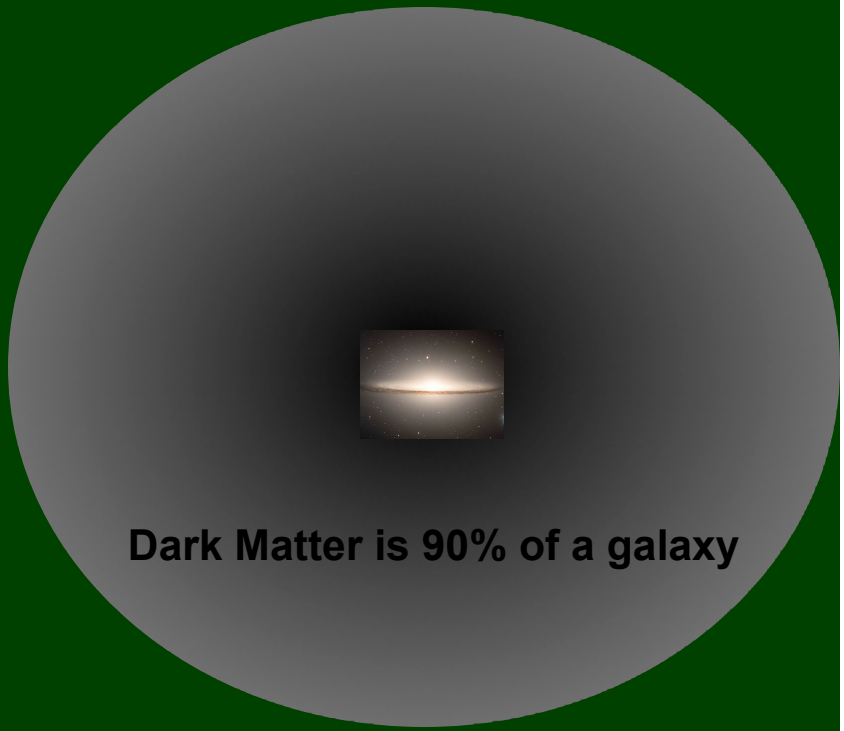


We may have a detection!? CDMS used 5 stacks of germanium to try to measure the interaction of a dark matter particle with normal matter.

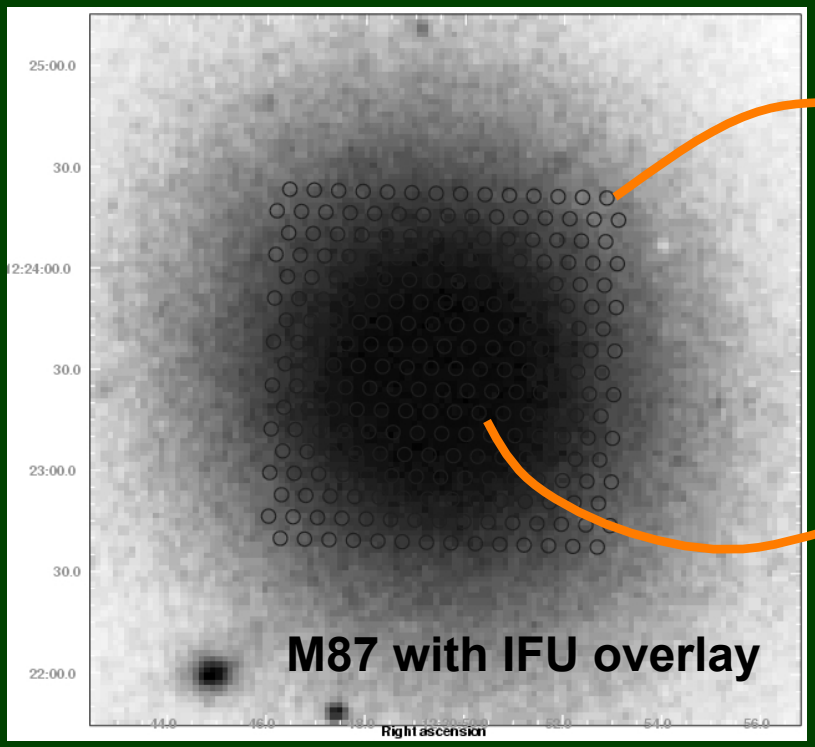
BUT….

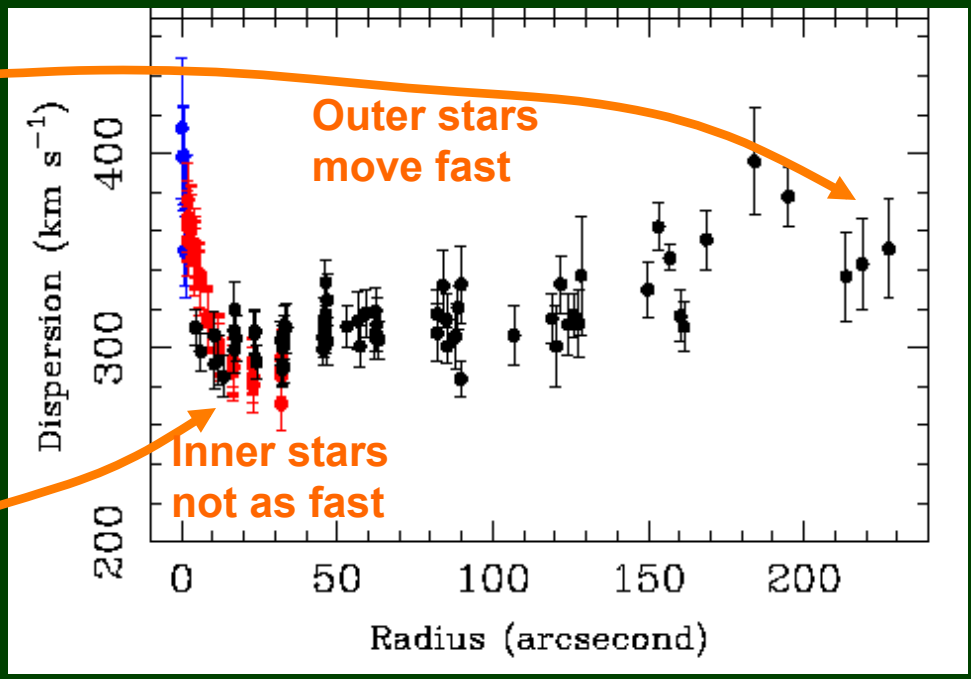
We need to Understand how to make a Galaxy

- What we see in a galaxy (the stars) is not necessarily the controlling factor.
- Black Holes were postulated to exist over 40 years ago and now we think we understand their important role.
- Dark Matter has been more of a mystery, but is also the most important aspect.



Dark Matter is hard to measure since it only dominates at the edges of galaxies. However, new technology is making this feasible.





- Current results show that we require dark matter, however the distribution of dark matter around the galaxy is not what theorists predict (observations are more extended).
- Thus, we have a lot to learn about how dark matter interacts with normal matter.

HETDEX
Hobby-Eberly Telescope Dark Energy Experiment

THE UNIVERSITY OF TEXAS AT AUSTIN
Department of Astronomy
1 University Station, C1400 • Austin, Texas 78712-0259

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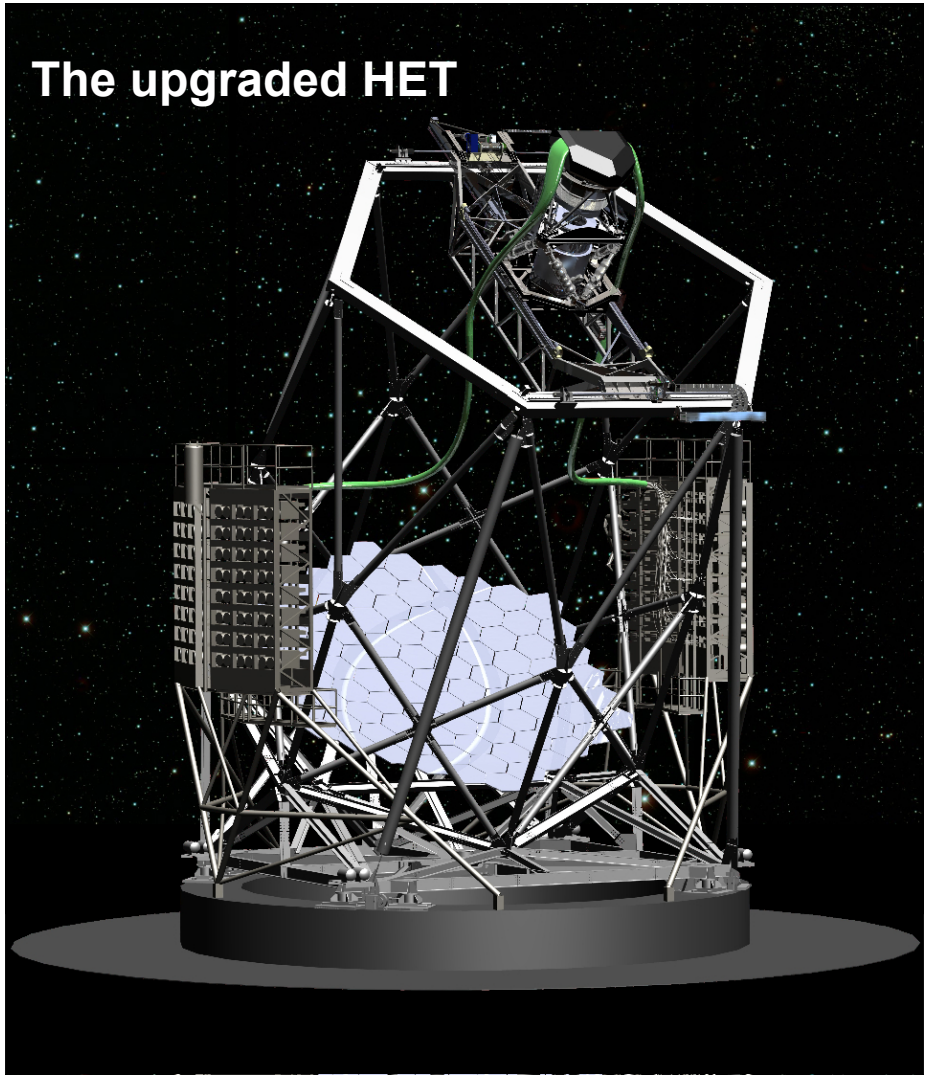
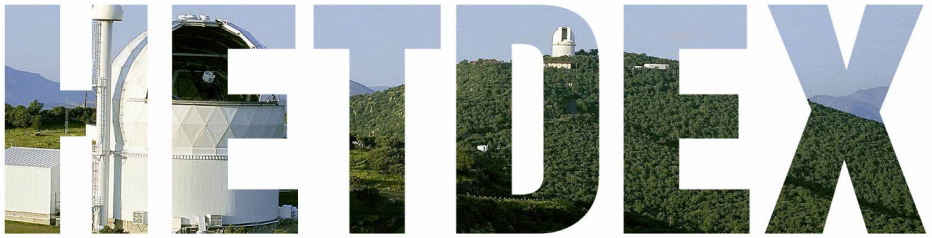




Hobby-Eberly Telescope
Dark Energy Experiment

MPE

PENNSTATE
1855

AIP

LMU
USM

HETDEX
Hobby-Eberly Telescope Dark Energy Experiment

The Universe is accelerating!

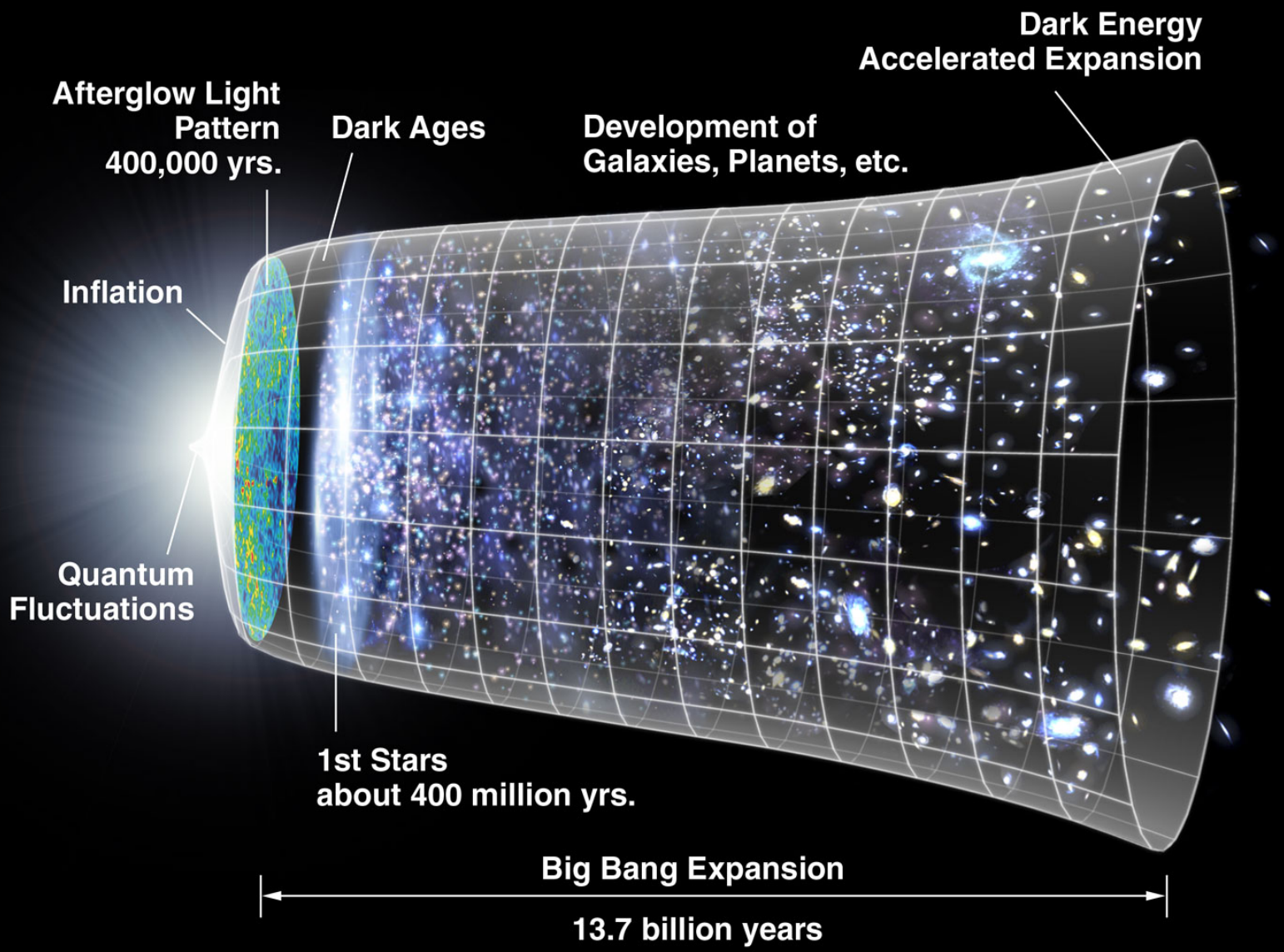
McDONALD OBSERVATORY
THE UNIVERSITY OF TEXAS AT AUSTIN

- The Universe is expanding due to the Big Bang
- Matter in the Universe should slow down the expansion over time
- But the expansion of the Universe is actually increasing
- Dark Energy is the biggest mystery in all of science right now

$$\left(\frac{H(z)}{H_{100}}\right)^2 = \omega_m(1+z)^3 + \omega_k(1+z)^2 + \omega_\Lambda(z)$$

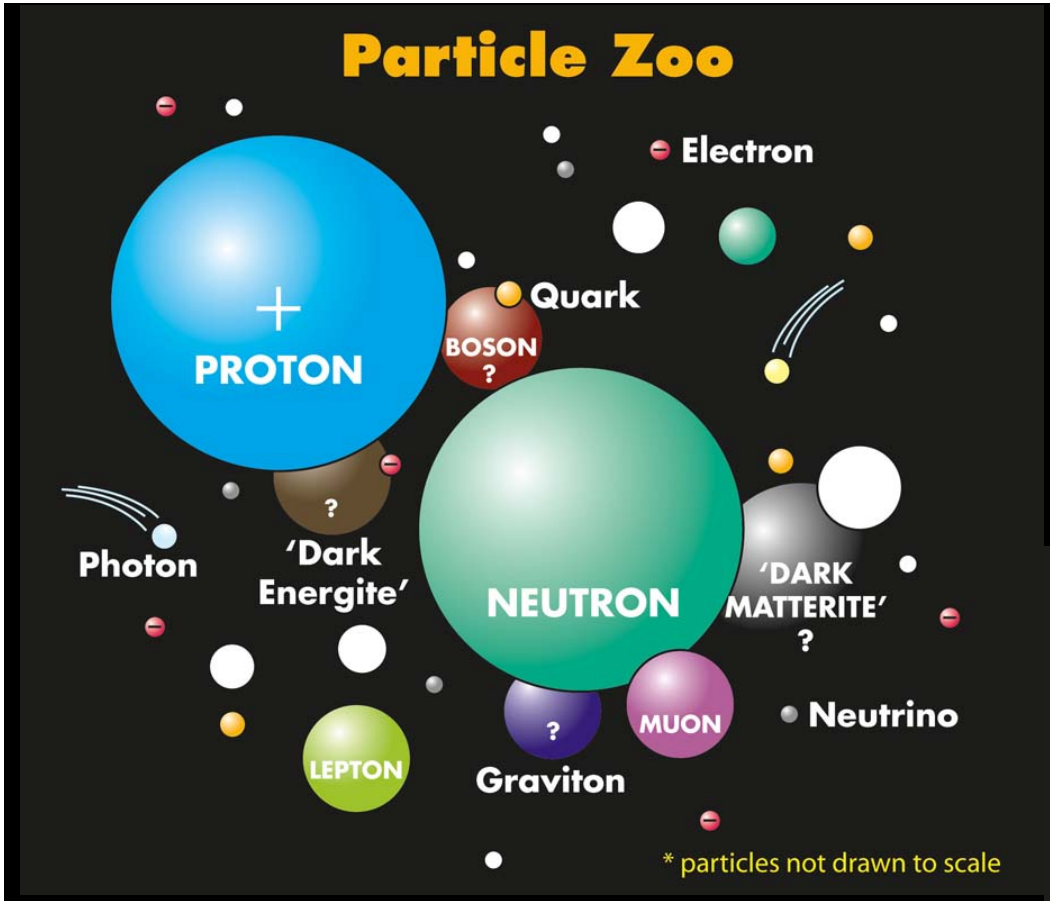
Expansion Rate **Matter** **Universe Shape** **Dark Energy**

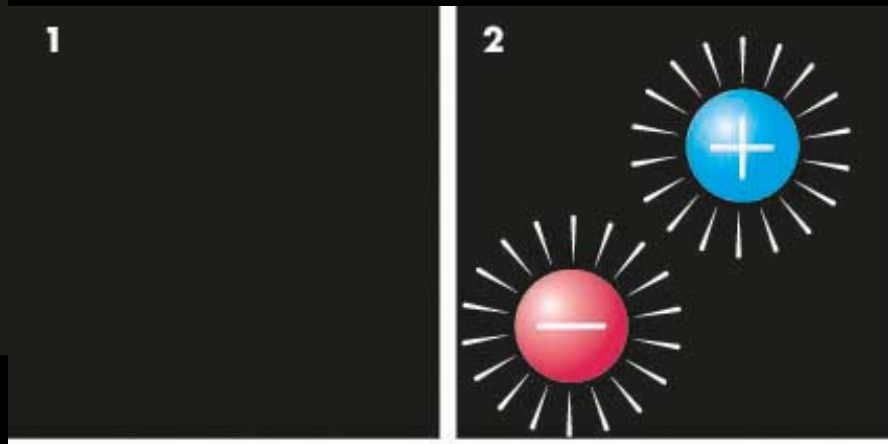
It's all a Matter of Time

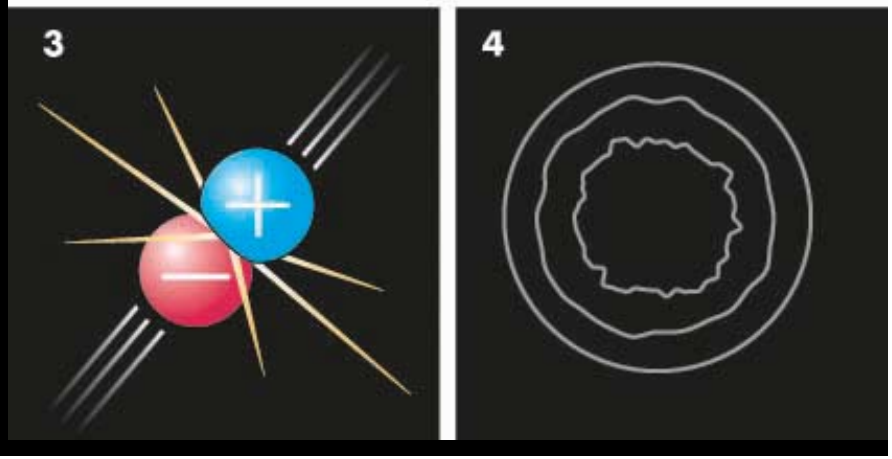


It could be: 1) That we don't understand gravity, or…..

NASA/WMAP Science Team







2) a new type of particle, or….

3) Einstein's Cosmological Constant (energy of empty space) or ????

HETDEX
Hobby-Eberly Telescope Dark Energy Experiment

ESSENCE of HETDEX

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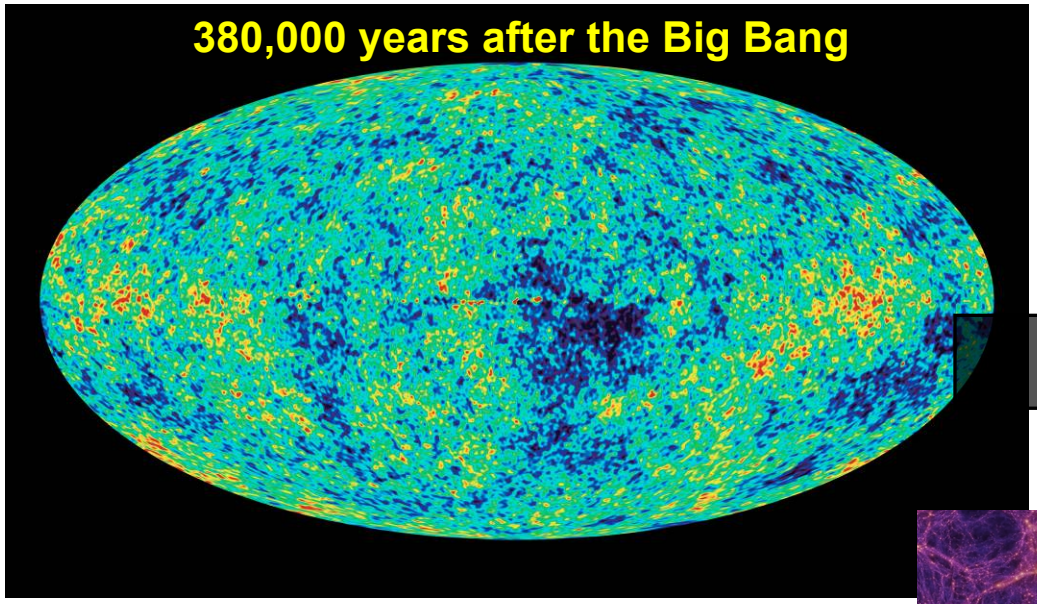
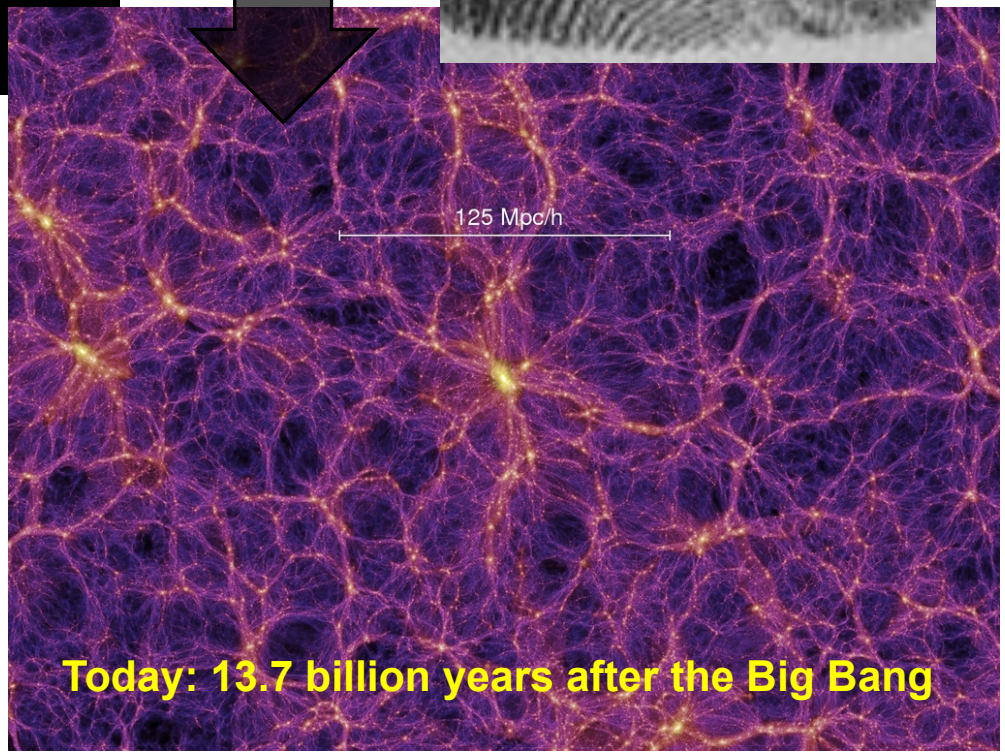




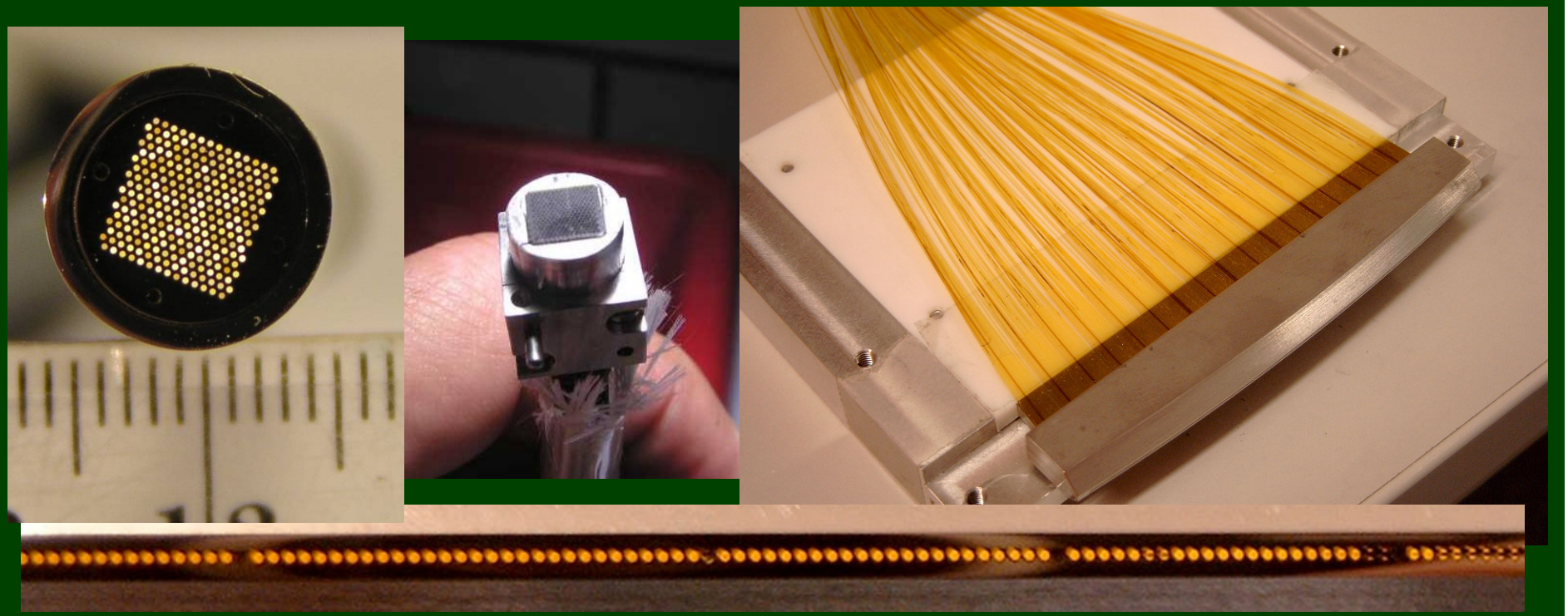
- There is a characteristic scale imprinted in the distribution of matter.
- It acts like a fingerprint that we use to trace over cosmic time.
- Requires about one million galaxies in order to see it.

The Instrument for HETDEX: VIRUS

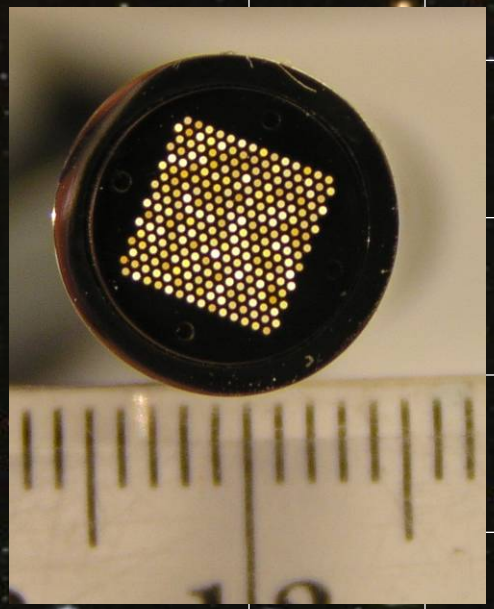
- Visible Integral-field Replicable Unit Spectrograph
- Uses idea of industrial replication
  - 150 copies of a simple spectrograph
  - We're the only ones doing this
- Huge advantages
  - Cost savings, schedule, low risk
- Build a prototype

VIRUS Integral Field Unit

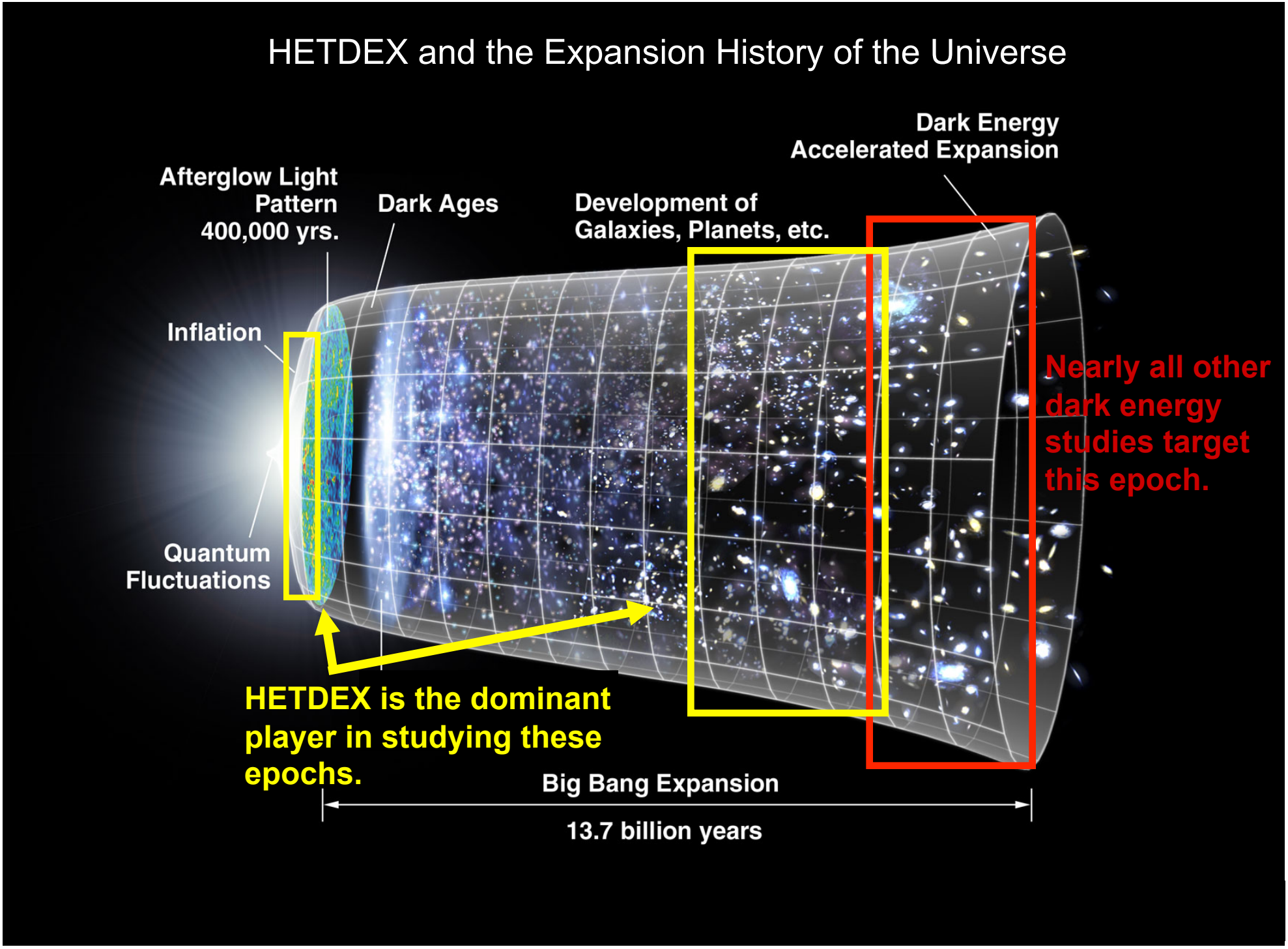
- An Integral Field Unit (IFU) reformats the sky to feed into the spectrograph
  - Bundle of 246 fibers
  - In a square array at the input
  - spread out into a slit at the output
- The light from any star or galaxy that falls on the fibers will be spread out into a spectrum and analyzed



How to measure dark energy



HETDEX and the Expansion History of the Universe



Example Science from Dark Energy Experiments

- Detection of dark energy
- Shape of Universe (curvature) to 0.1%
- Best measure of shape of matter distribution early in the Universe.
- Best measure of total neutrino mass
- Detection of cosmic web in emission
- Nature of early galaxies
- Black Hole-Galaxy correlations
- Star formation at late times
- Dark matter in nearby galaxies
- Stellar populations at large radii
- Map nearby clusters
- Galactic structure from stellar kinematics
- Study of the first stars

The Goal has been and will continue to be Dark Energy, yet we realize the remarkable potential of the powerful instrument and telescope combination. We see this in the science, student training, technology development, and engaging the public.

Walk Softly but Carry a Huge Number of Spectrographs (when exploring the dark side)