A Digital Color Image of the Universe

Felipe Menanteau,
(NCSA & Astronomy, University of Illinois)

"The Mice" (NGC 4676), ACS Science Team, Johns Hopkins Univ.

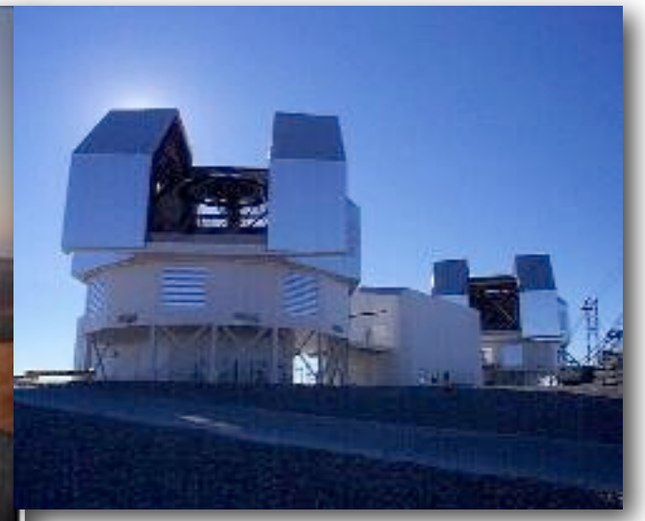
Main Ideas,

- **The Great Debate,** the “discovery” of galaxies and our expanding Universe.
- **Galaxy Types,** the morphology of galaxies after Hubble.
- **Galaxies are not randomly distributed,** The Large Scale Structure of the Universe.
- **Dark Matter and Dark Energy dominates the growth of structure,** The Dark Energy Survey and the Large Synoptic Survey Telescope

Optical Astronomer's Toolbox

Hubble Space Telescope (~380mi)

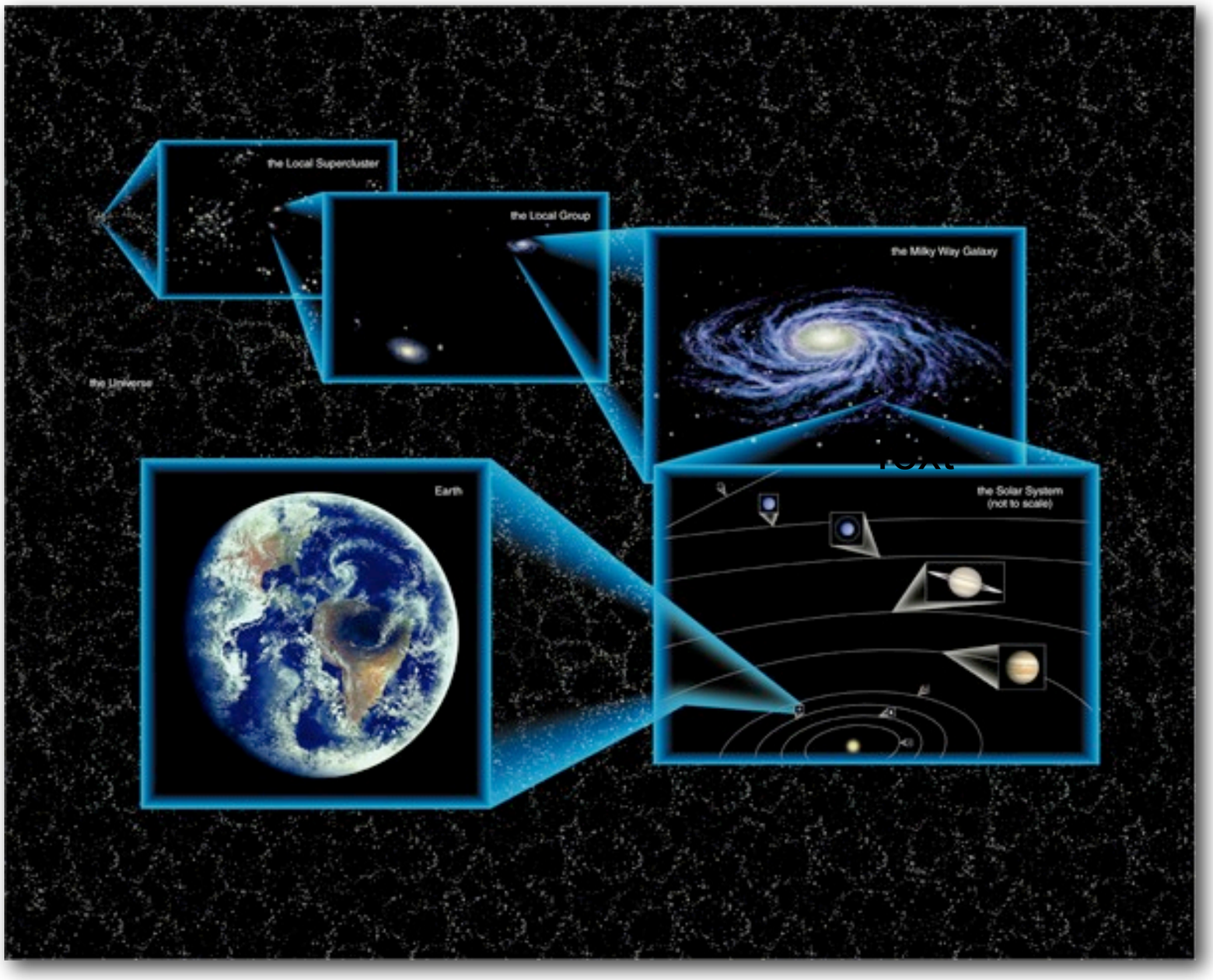
DECam on CTIO, Chile



VLT and Magellan,
Atacama Desert, Chile

W.M. Keck, Mauna Kea,Hawaii

Our place in the Universe



Our Address is:

Pittsburg, Kansas
USA,
Planet Earth
Solar System
Milky Way
Local Galaxy Group
The Universe

The Nature of the Milky Way

Ancient Greeks: "Galaxias Kyklos (Milky Circle)“, from the Greek root γαλαξίας, meaning "milky".

Romans: "Via Lactea (Milky Way)"

Galileo resolved it into numerous stars with telescope

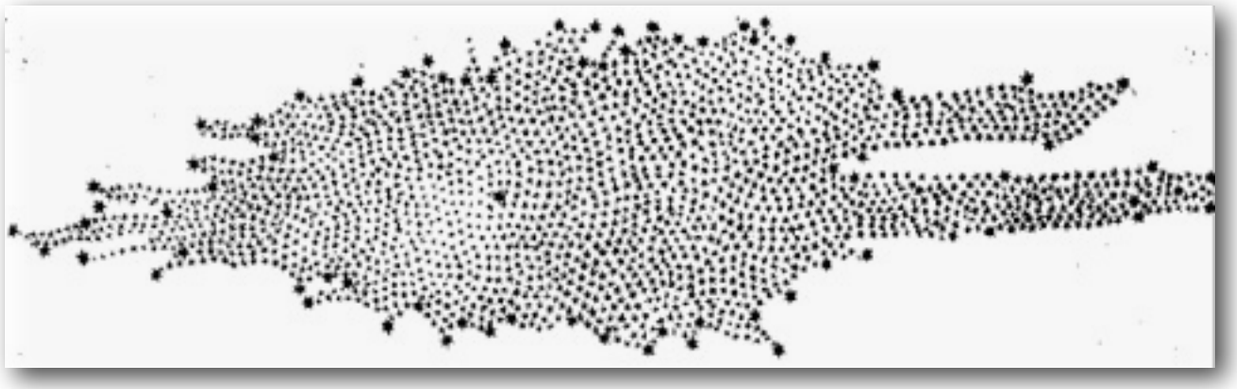
Herschel (1784) counted stars in several sample regions, established this picture:

- Disk of stars with the sun near the center
- 1500 light years top to bottom, 8000 light years across
- Contained 300,000,000 stars

Modern view (Kapteyn, Shapley)

- Disk of 400,000,000,000 stars
- 100,000 light years in diameter

•Sun is 27,000 light years from center



The shape of the Milky Way Galaxy by William Herschel in 1785; the solar system was assumed near center.

Dust absorbs the light from distant stars - Herschel’s model of the Milky Way ignored this effect

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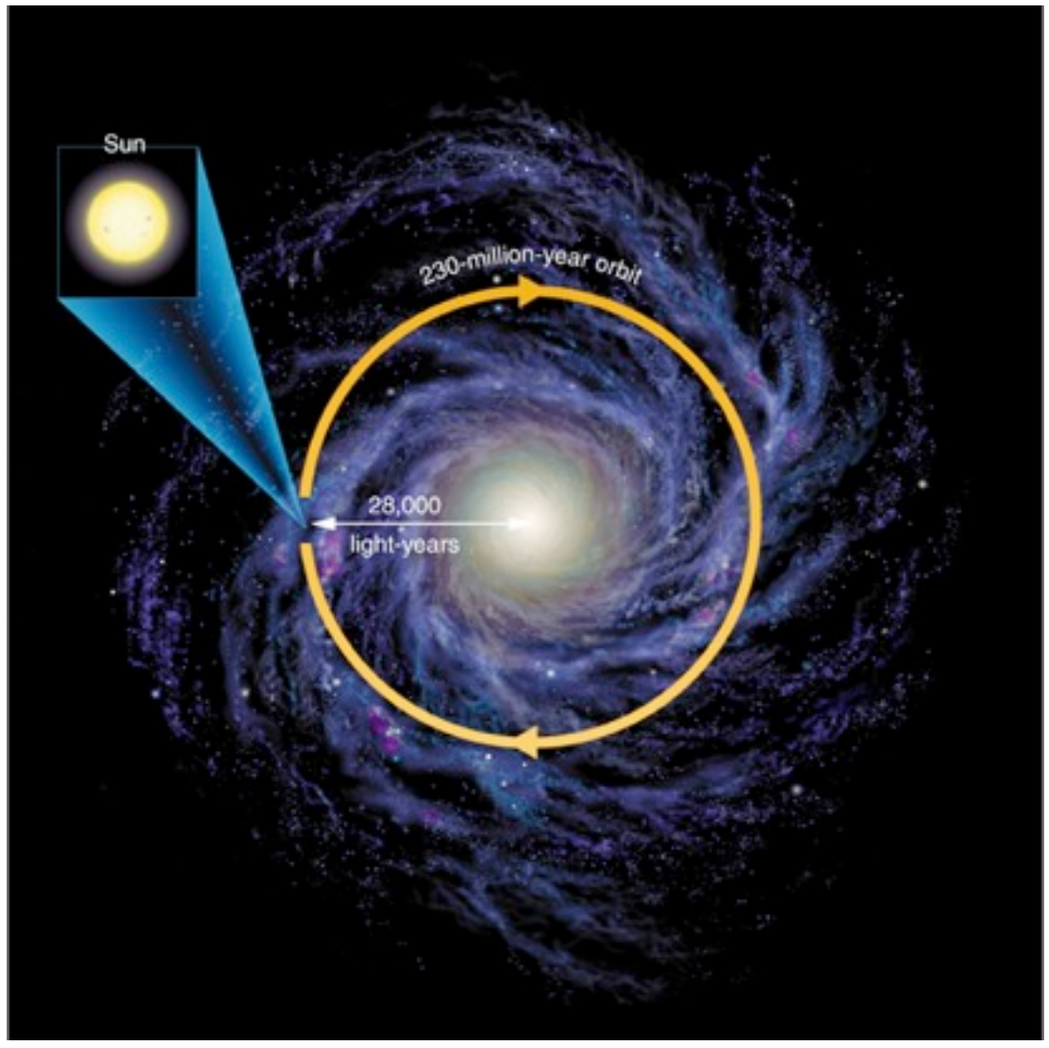
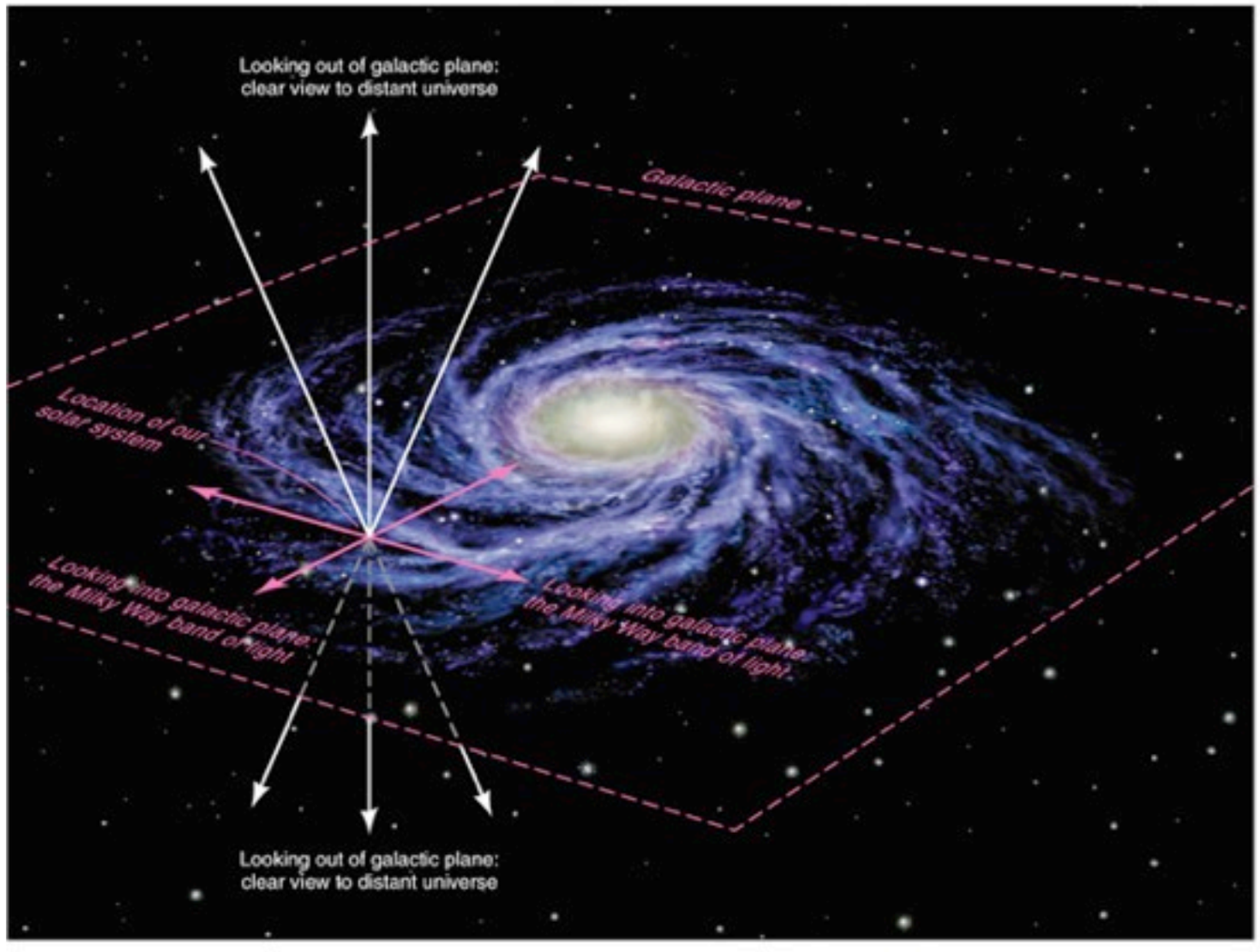
Schematic of the Milky Way





Schematic model of the Milky Way Galaxy showing its main features: nucleus, halo and disk

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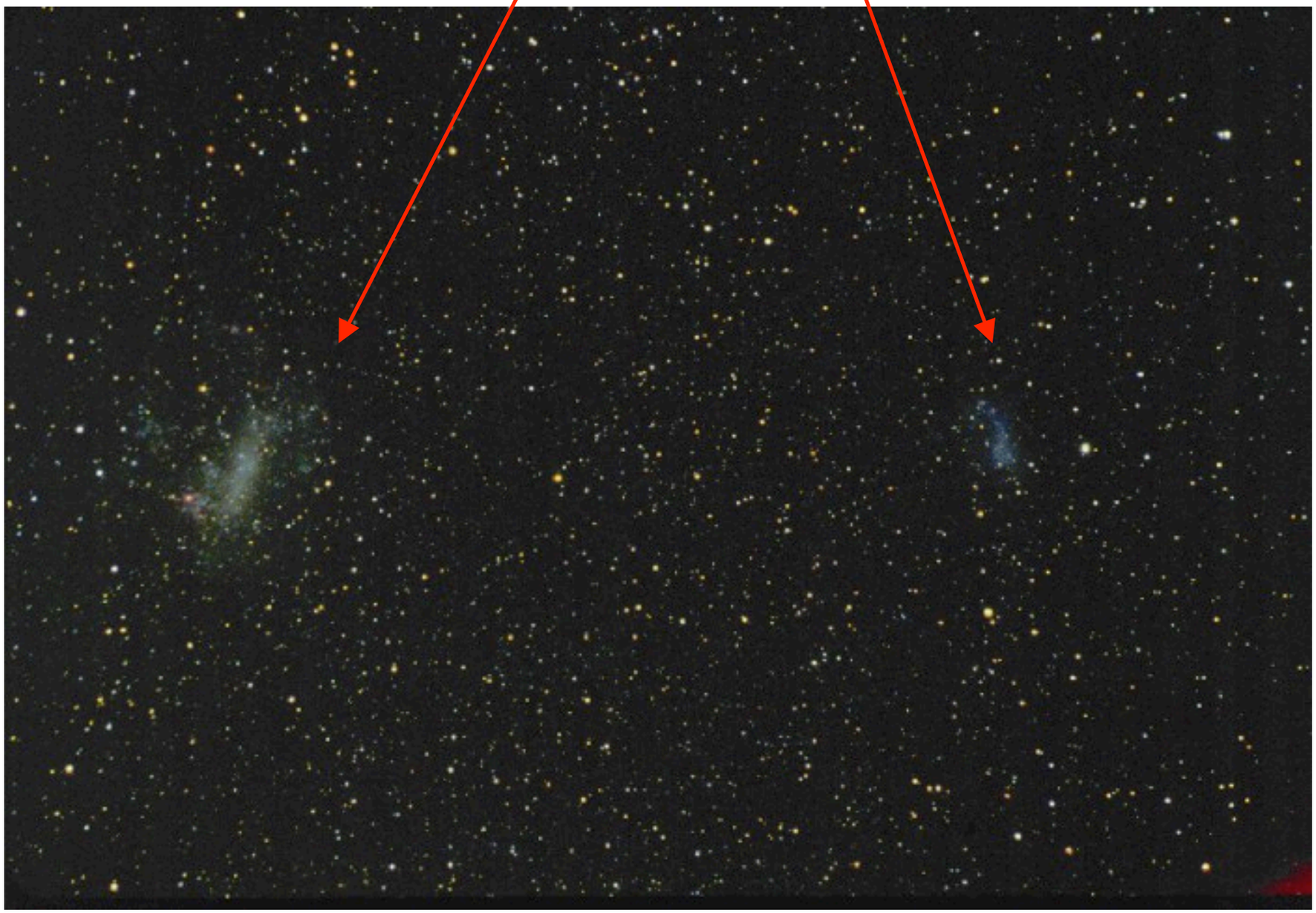
Other “Nebulae”

Naked eye objects: Large and Small Magellanic Clouds (visible only from south), Andromeda Galaxy



(telescope view)

By the 1920’s thousands of such “extragalactic nebulae” (Hubble’s term) were known

The Discovery of the Spiral Nebulae

M51 (Messier Catalog), The Whirlpool Galaxy

M51 seen by the "Leviathan" in Ireland (1845), drawn by William Parsons, Earl of Rosse. (72-in telescope)

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M51 seen by the "Leviathan" in Ireland (1845), drawn by William Parsons, Earl of Rosse. (72-in telescope)

M51 as seen by ACS on the Hubble Space Telescope about 160 years later (2005)

How to make a color picture with Hubble?

- Combine filters and assign weights
- Example: M51, observed with ACS/HST

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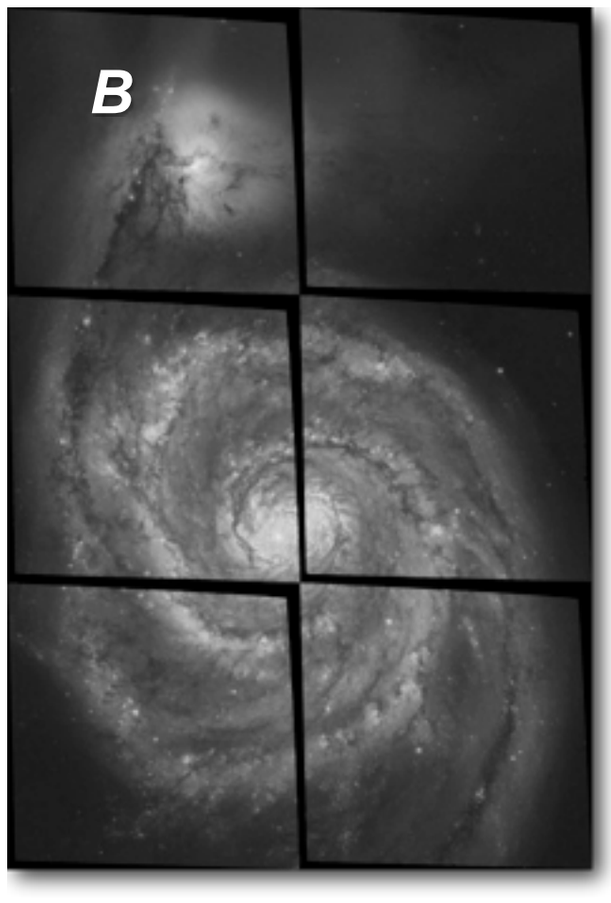

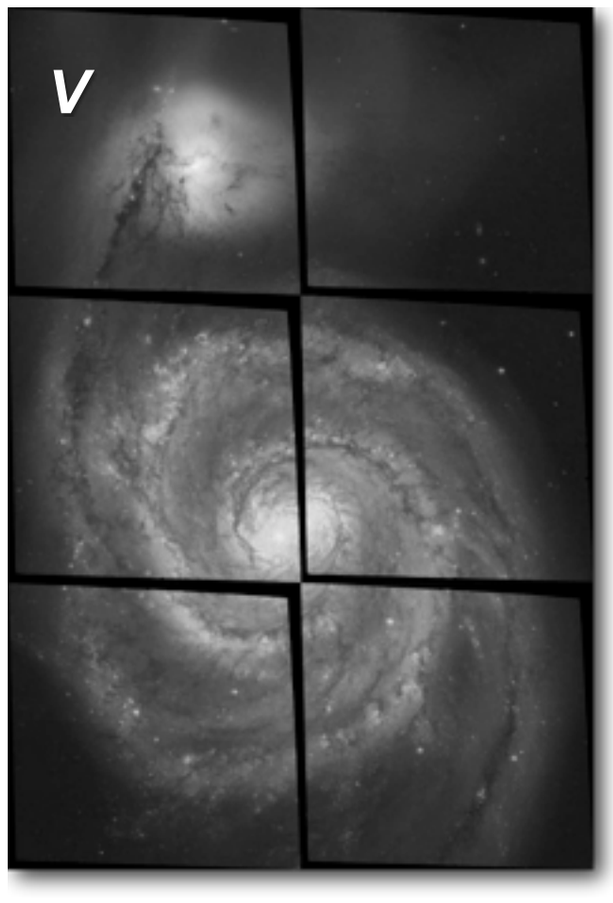

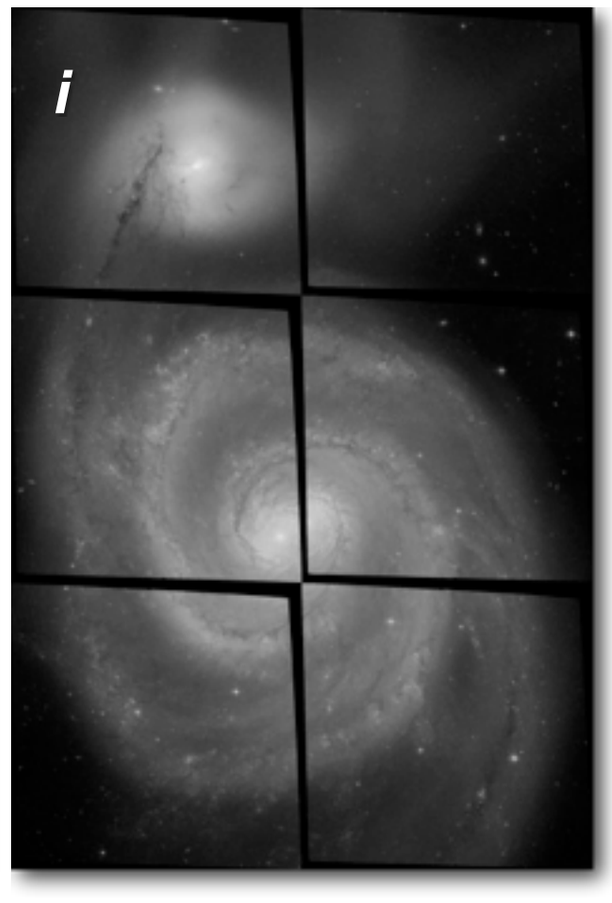

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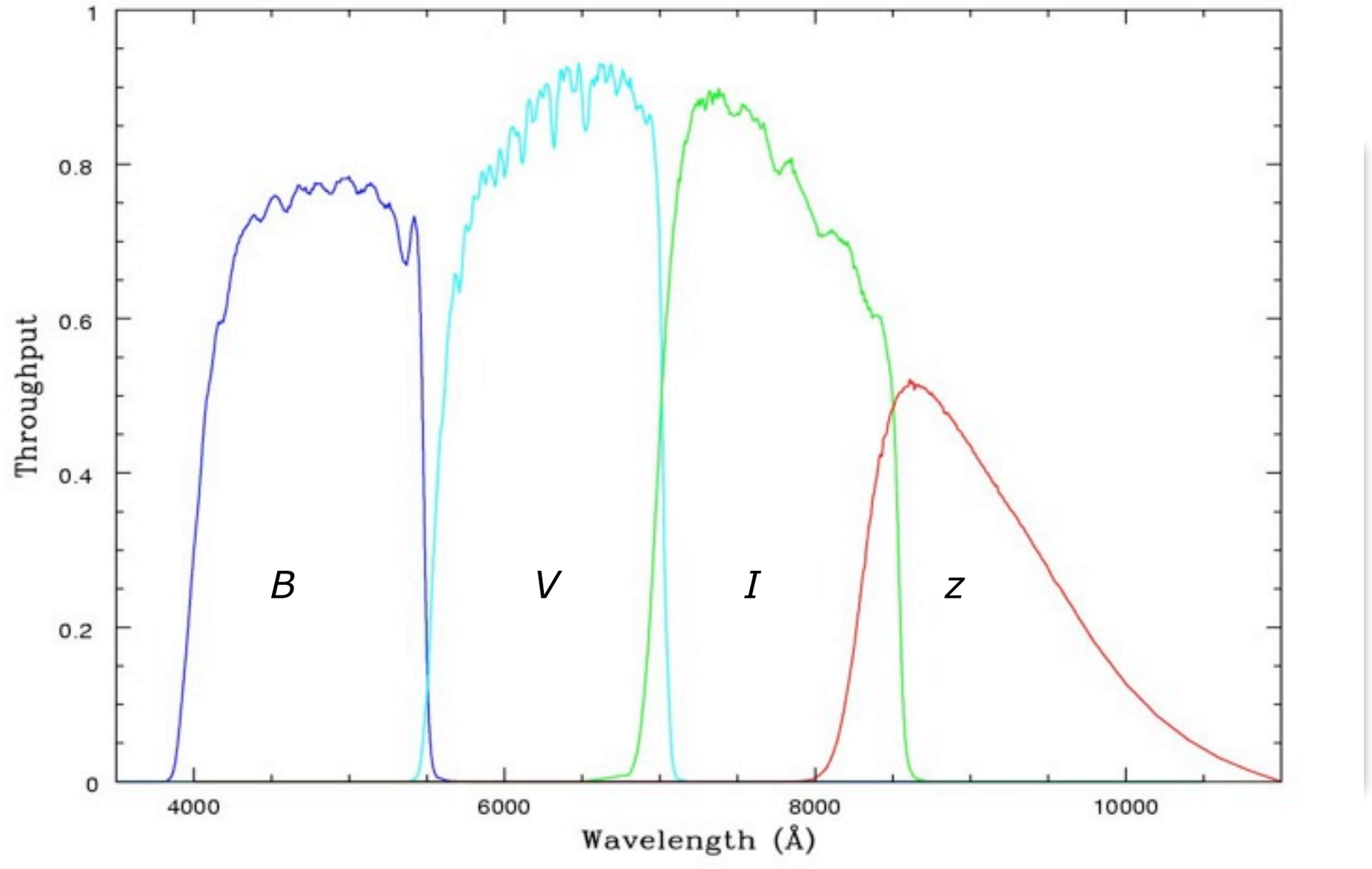

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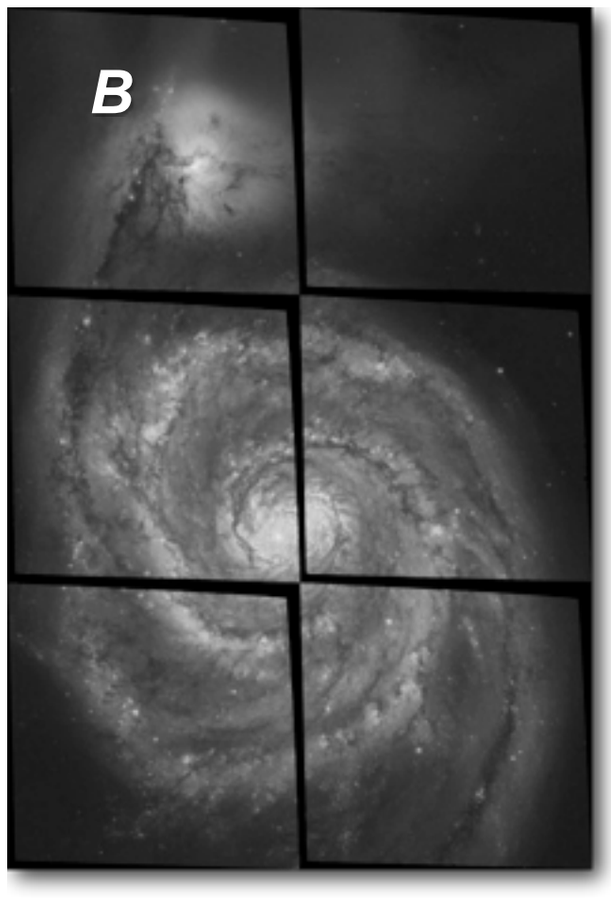

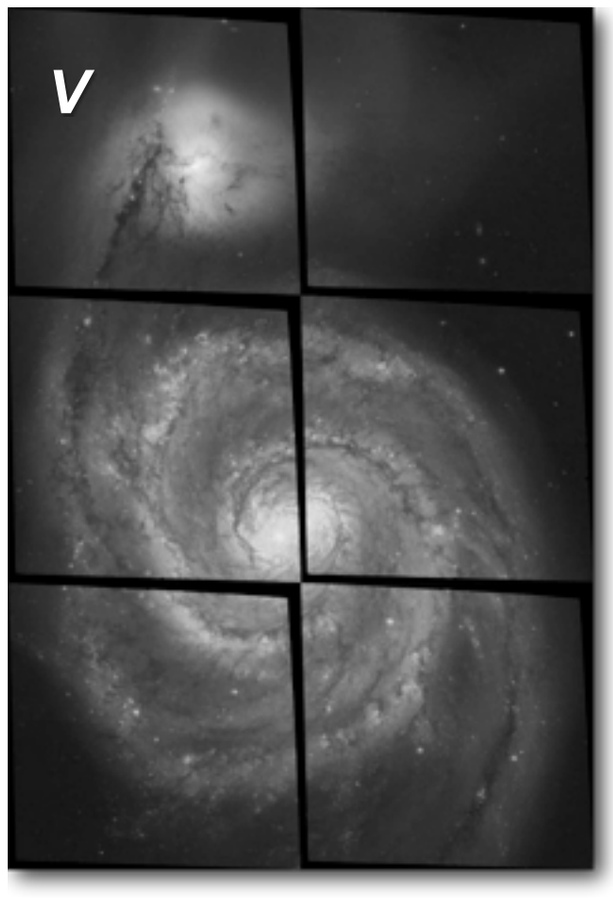

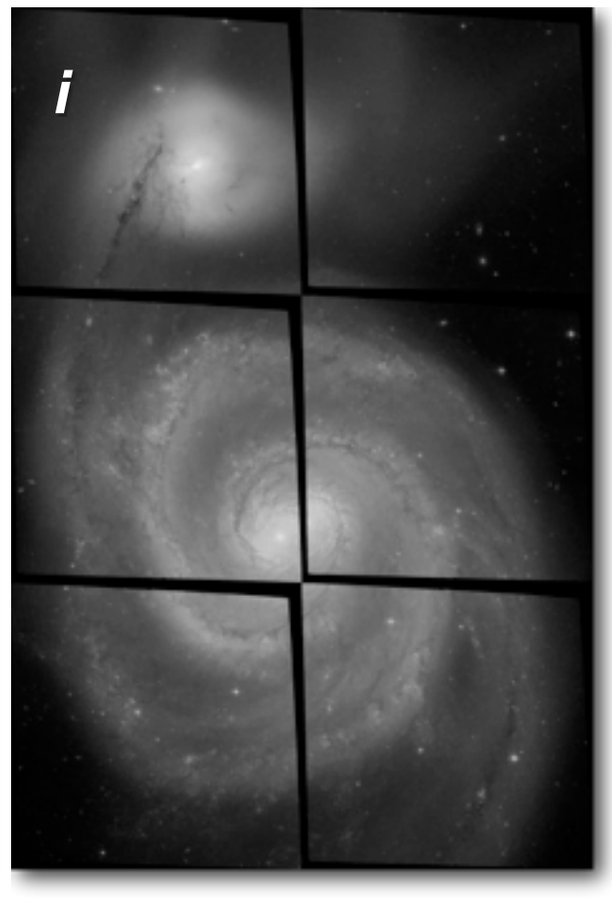

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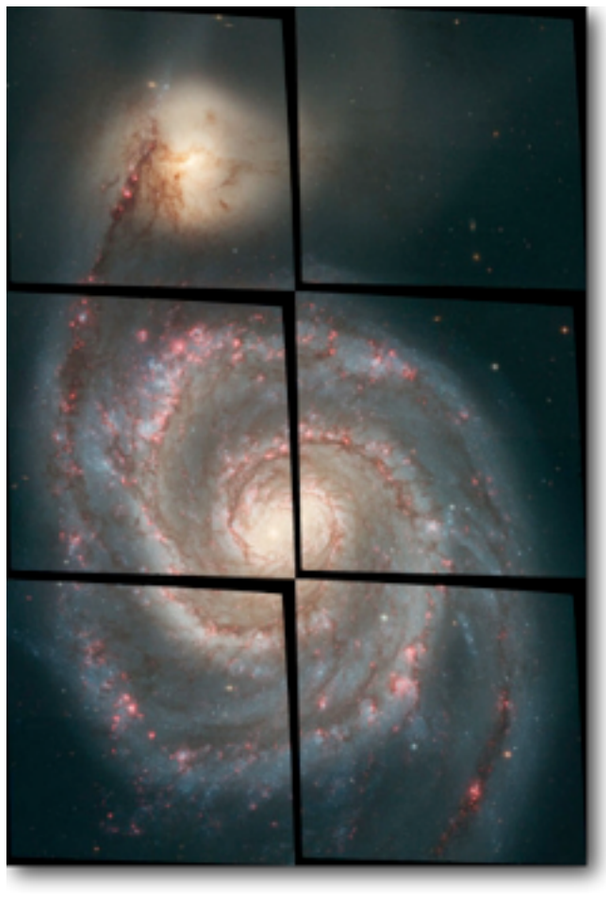

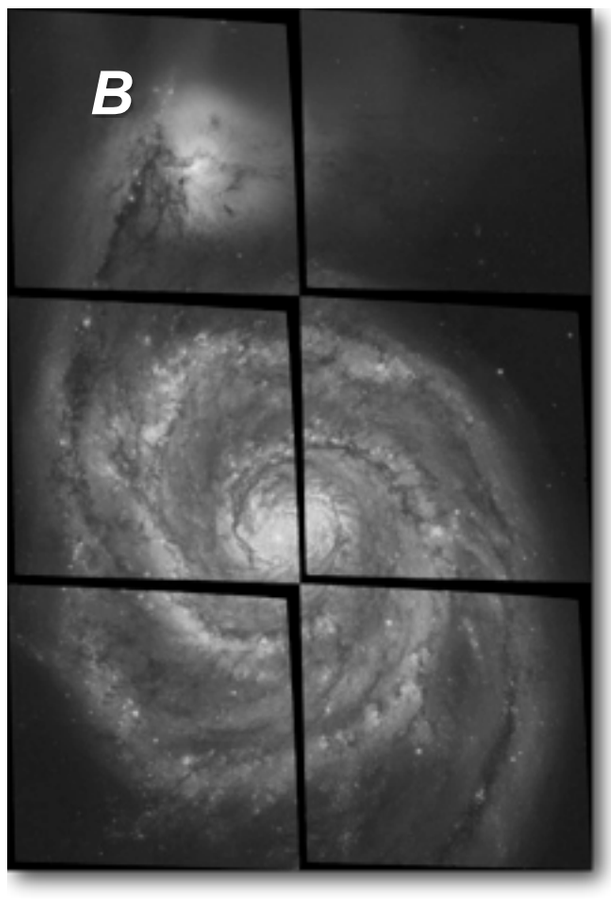

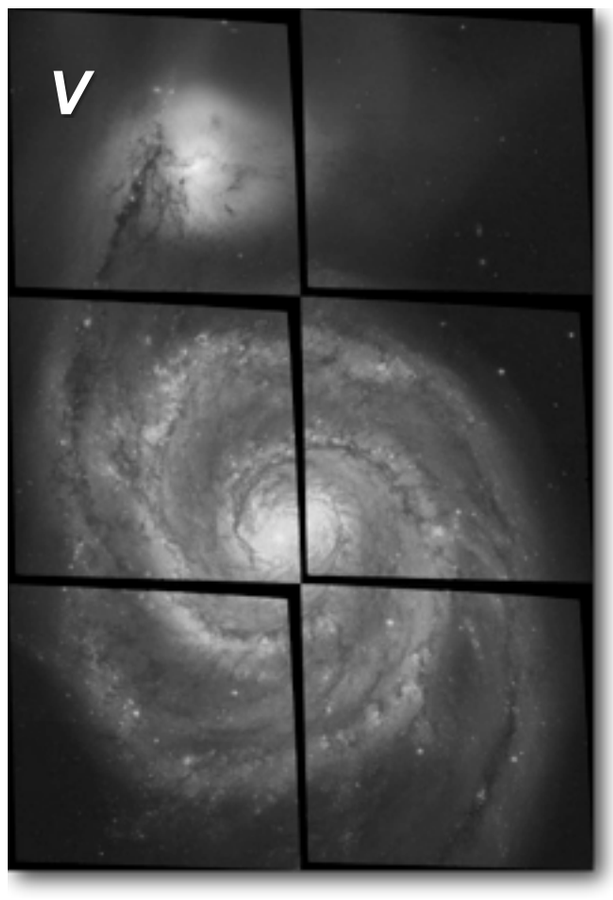

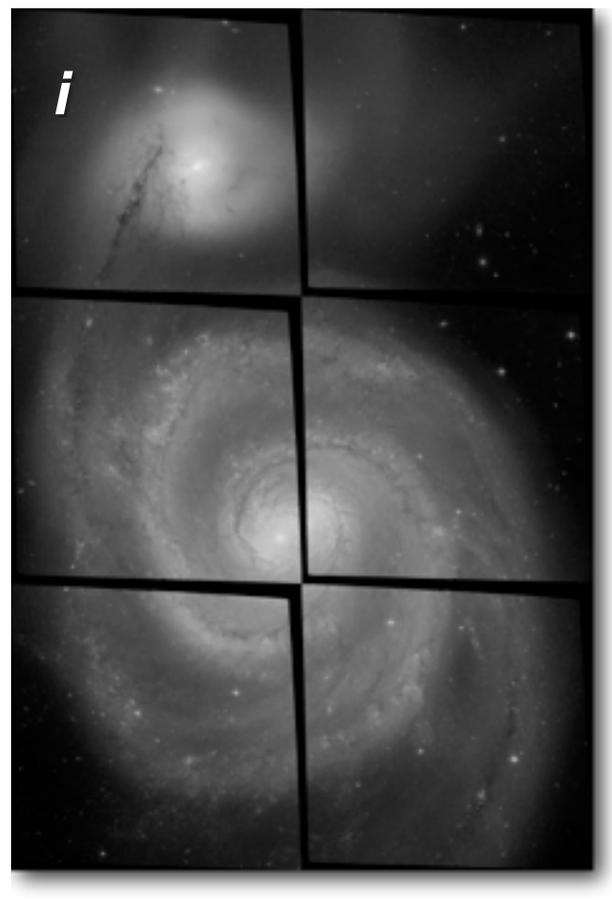


Harlow Shapley

The Great Debate (1920),

the discovery of galaxies, and the new order in the Universe.


Heber Curtis

Between Harlow Shapley and Heber Curtis, focused on the *nature of spiral Nebulae* and the *size of the Universe*.

- Whether Spiral Nebulae are :
  - Some sort of spinning gas at short distance *within* our own Galaxy
  - Distant *Island Universes* (philosopher I. Kant) like our own Milky Way;
- The Universe is :
  - Just our own Galaxy, The Milky Way
  - Comprised of billions of *Island Universes*, Islands of Stars

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Edwin Hubble made a fabulous revelation in 1924. He measured the distance to the Andromeda galaxy, using Cepheid's stars in it. The distance put Andromeda much further away than any object in the Milky Way. Debate was over.

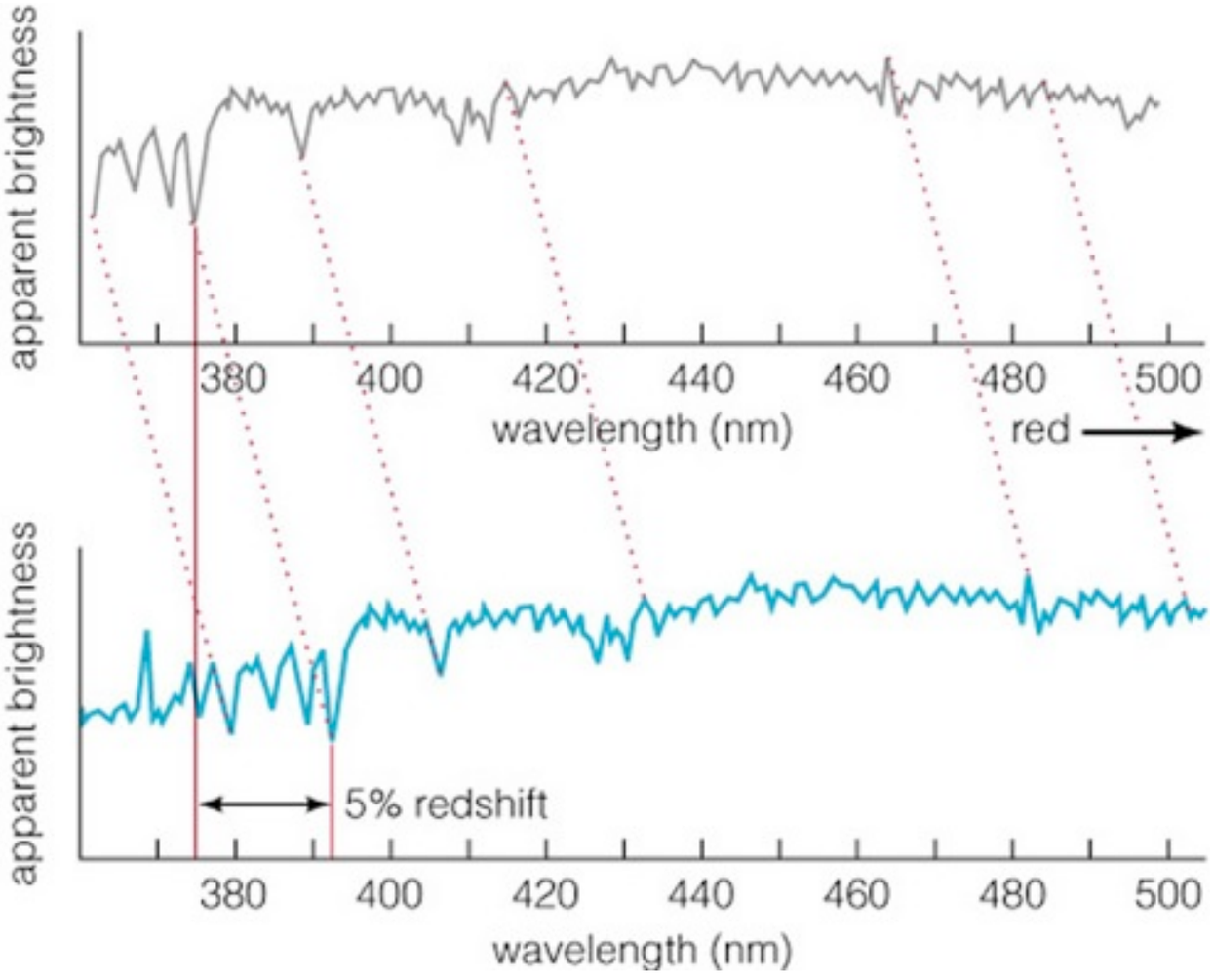
A New Era in Astronomy was born!

Galaxy ≠ Universe

The Redshift (z)

- Between 1910 - 1920: Vesto Slipher laid the foundation for the theory of the expansion of the Universe.
- Found that most galaxies (Spiral Nebulae) spectra were redshifted. They were observed at longer wavelengths than expected. It wasn't clear why.
- Preceded Hubble's discovery.

Vesto Slipher
(1875-1969)



$$\text{redshift} = z = \frac{\lambda_{observed} - \lambda_{rest}}{\lambda_{rest}}$$

Where λ is the observed wavelength, λ_0 is the rest-frame wavelength.

For ***small*** *z (i.e. z<<1)*:

$$V = C \times Z$$

Where *v* is the recession velocity and *c* is the speed of light $c=3x10^5$ km/s

Hubble's Law (1929) and the Expanding Universe

Hubble found that the more distant a galaxy is, the greater its redshift, and hence the faster it is moving away from us…

→ *the Universe is expanding!*

The speed of expansion ***v*** is proportional to its distance ***d*.**

where,

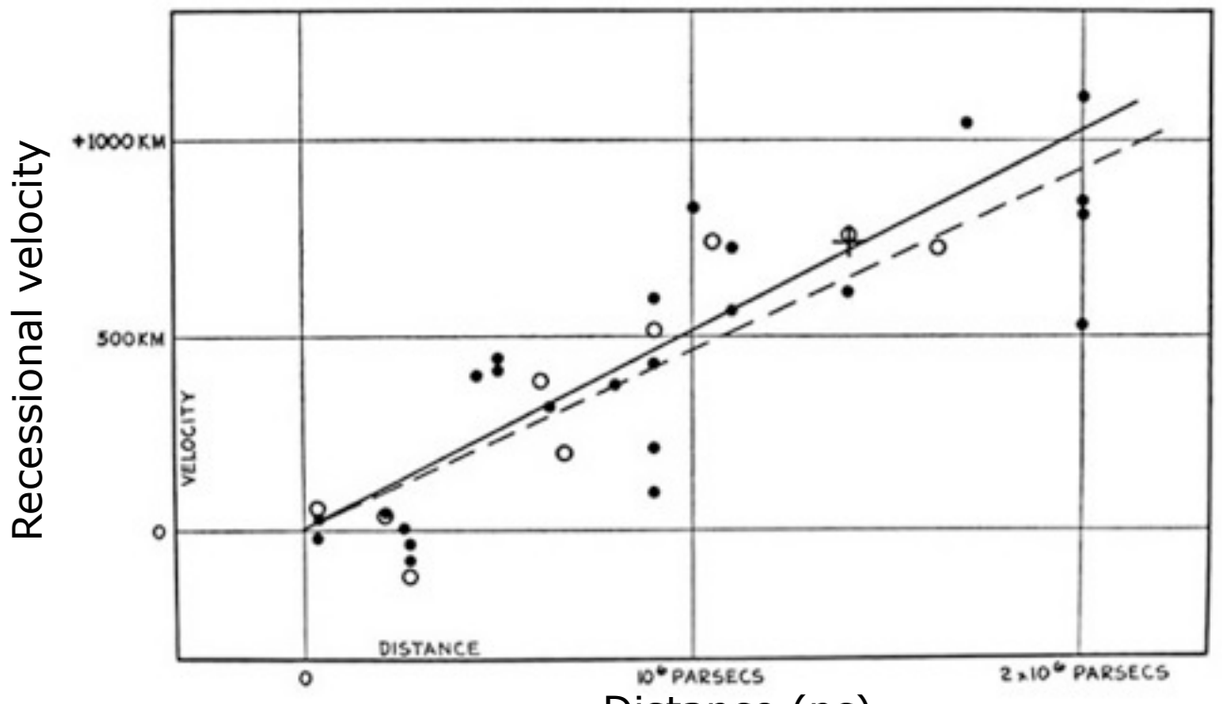
$$v = H_0 \times d$$

d = distance in parsec (pc)

H_0 is the slope and called the Hubble constant, the current estimate:

$H_0 \approx 70$ [km/s/Mpc]

Hubble's original data



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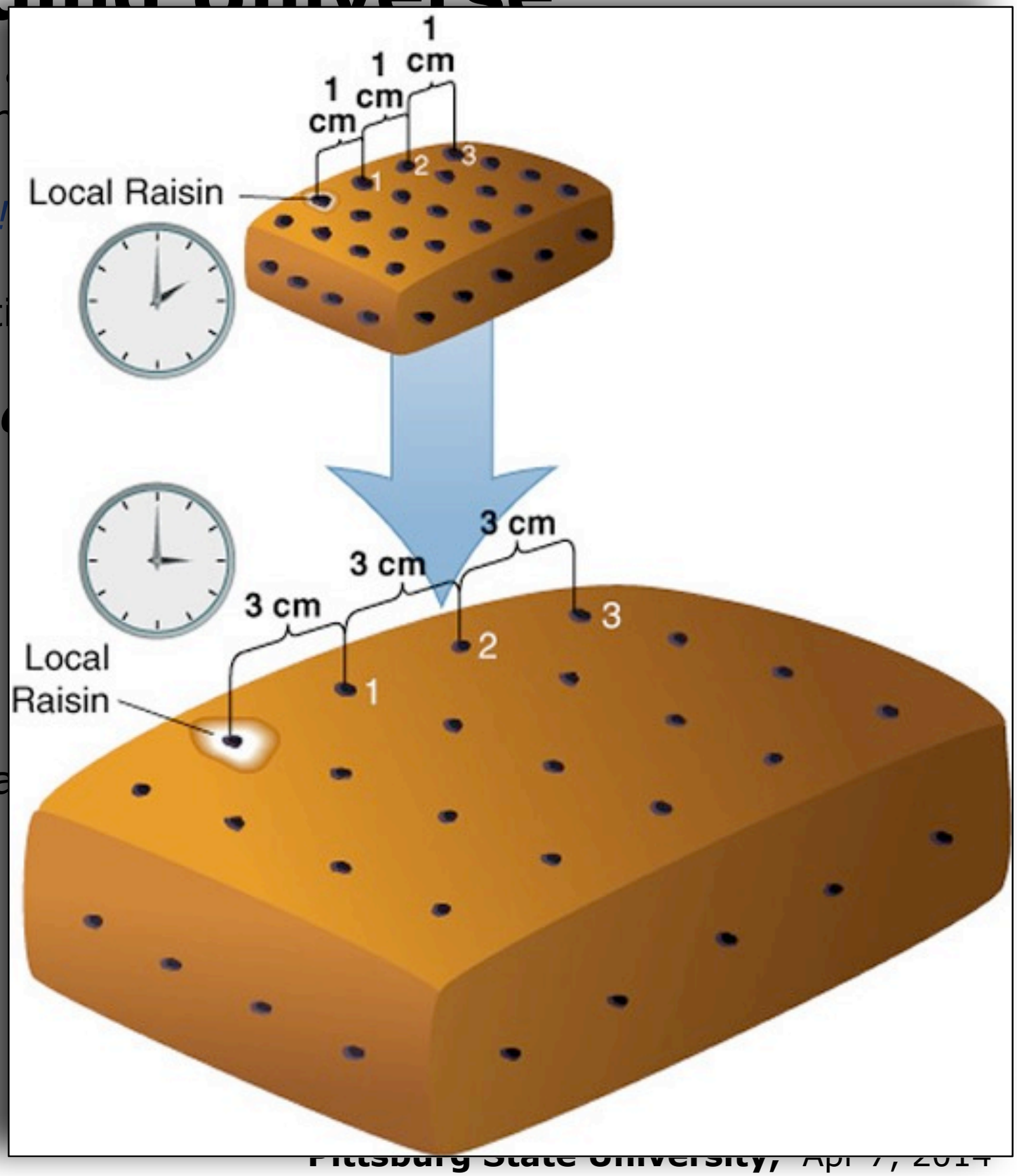


Summary I,

- **We live in an expanding Universe full of galaxies**

Main Ideas,

- **The Great Debate,** the "discovery" of galaxies and our expanding Universe.
- **Galaxy Types,** the morphology of galaxies after Hubble.
- **Galaxies are not randomly distributed,** The Large Scale Structure of the Universe.
- **Dark Matter dominates the growth of structure**
- **The Quest to Understand our Dark Universe,** The Dark Energy Survey and the Large Synoptic Survey Telescope.

The Zoology of Galaxies

Galaxies can classified into three basic types:

-Ellipticals -Spirals -Irregulars

Ellipticals (E) and Lenticulars (S0)

- Very similar to bulge component of spirals
- Es have no structure, no arms, featureless.

M87, Giant Elliptical – Virgo Cluster

- Just a big elliptical blob
- Lenticulars have a disk but no arms.
- In general, no star formation – changing view for more distant ellipticals.
- E/S0s are used to study galaxy evolution.
- Also called early-type galaxies (E/S0s).
- Es dominate the population of clusters of galaxies.
- Large range of masses, Giant Es to Dwarf Es.

NGC 2787 (HST/ACS), Lenticular

Types of Spiral Galaxies

- A flat disk shape
- Have flat *disk* with *spiral* arms, a *bulge* (usually redder than arms), and halo
- They rotate in the direction we would expect from the trailing arms
- Arms are so visible because star-formation happens there, hot gas from new stars and HII regions lights them up.

a) Normal Spirals (S)

NGC 4414 (HST/WFPC2), Normal Spiral

M101 Pinwheel Galaxy (ACS/HST), Normal Spiral

b) Barred Spirals (SBs)

- Same structure as regular Spirals (S), bulge+disk+halo
- They have a sometimes smaller, but stretched-out bulge
- The spiral arms start at the end of the bar.
- Bars are believed to be the result of galaxy interactions/mergers.
- We believe that the Milky Way is a barred spiral.

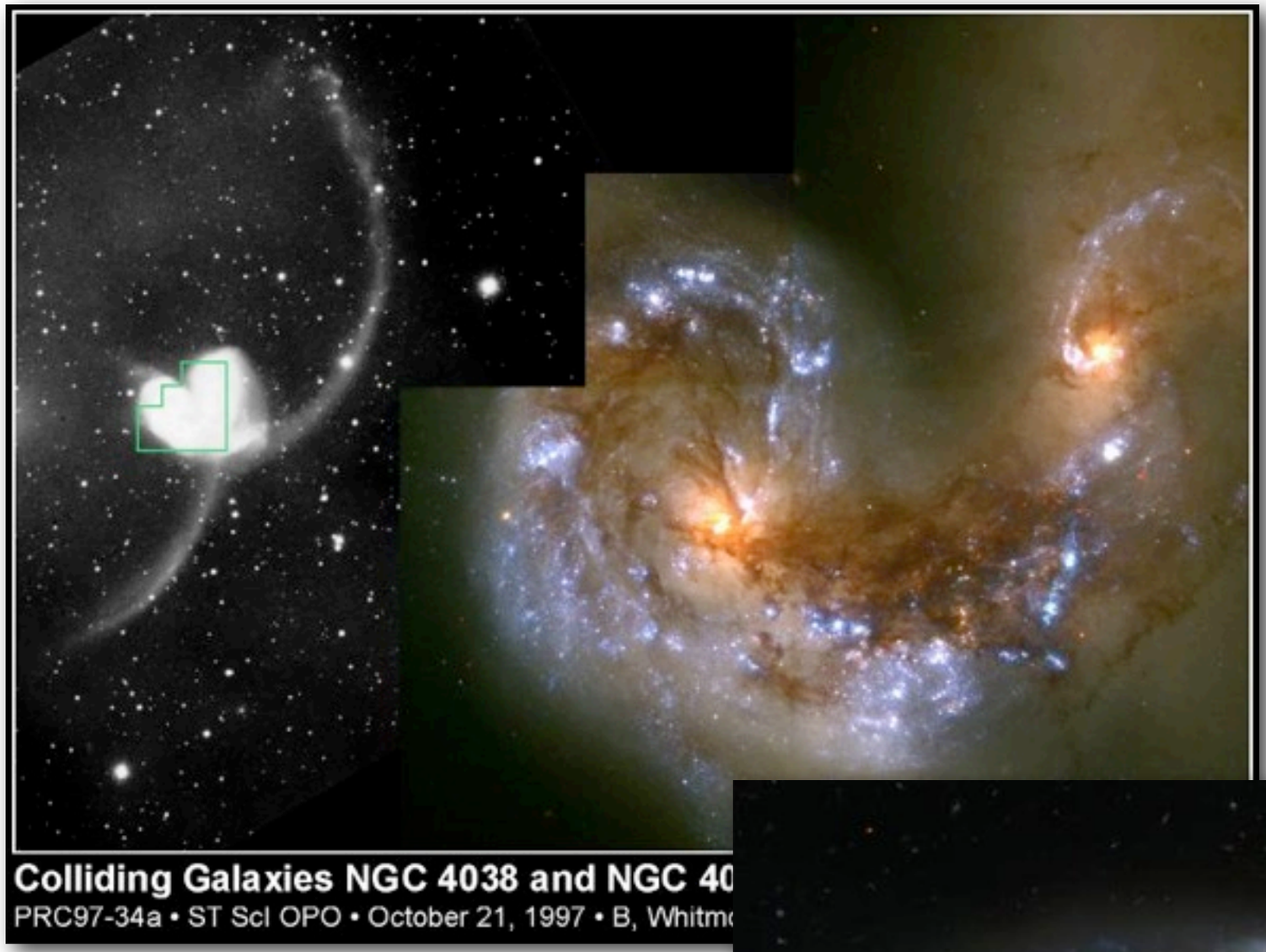
NGC 1365 (ESO/VLT), Barred Spiral

NGC 1300 (HST/WFPC2), Barred Spiral

Irregular Galaxies (Irr)

- They don’t have a well defined shape.
- The result of violent collision or merger
- Smaller than normal Spirals and Ellipticals.
- Active star formation, triggered by collisions.

Galaxy Mergers/Collisions



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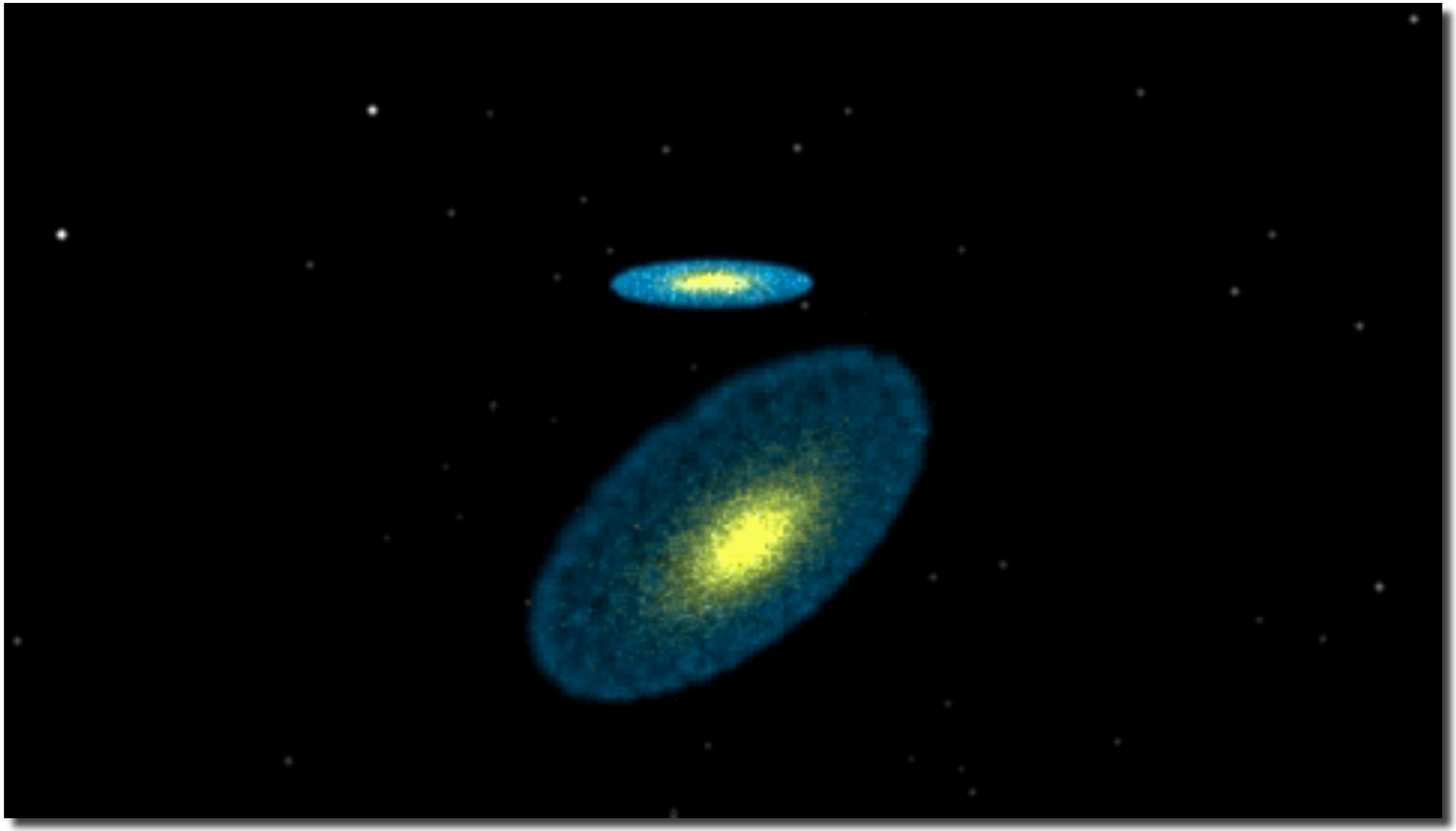
Simulations/Mergers



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Summary II,

- We live in an expanding Universe full of galaxies
- **Galaxies have distinct morphologies**

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Scale of a (typical) Galaxy

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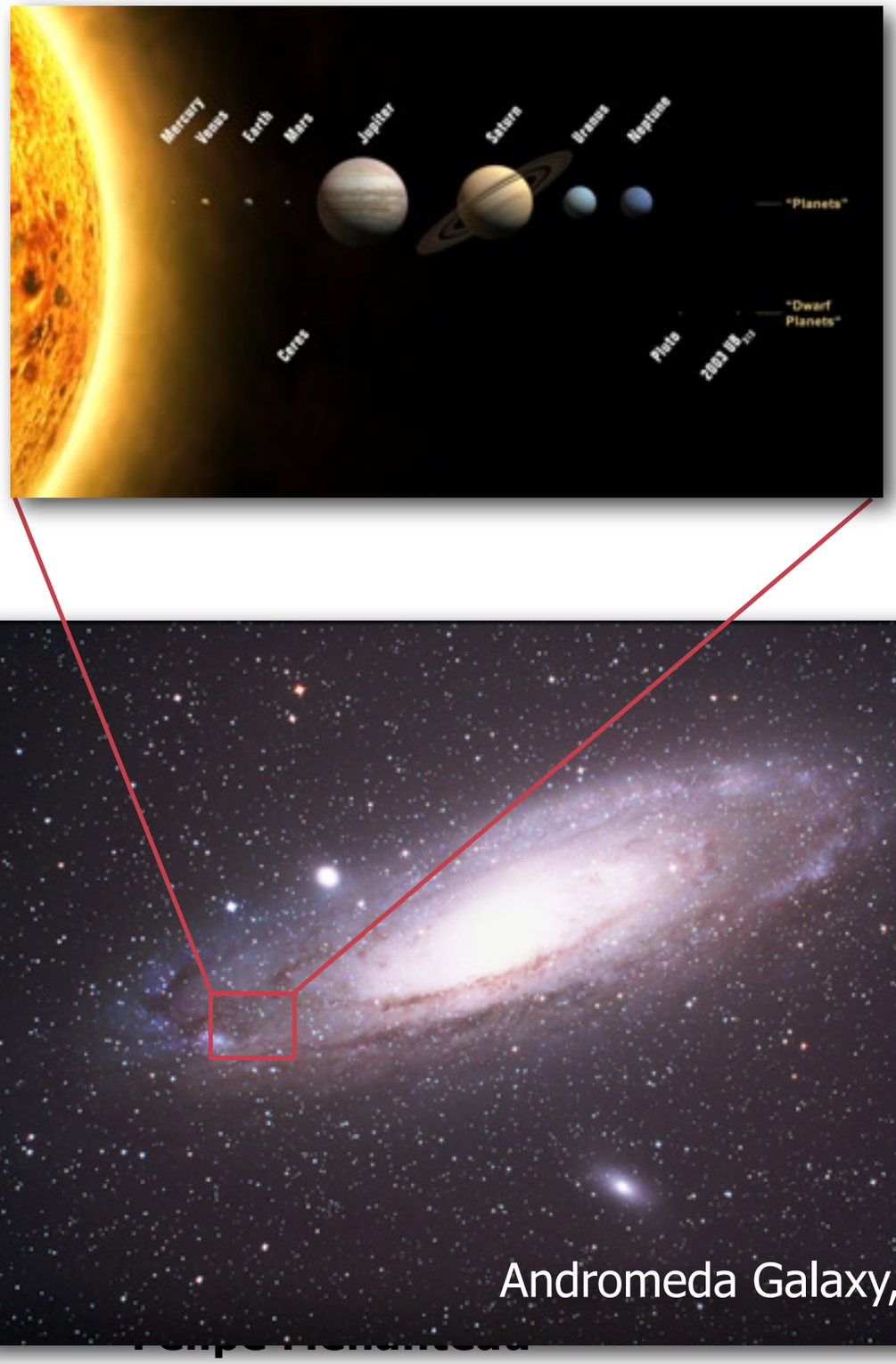

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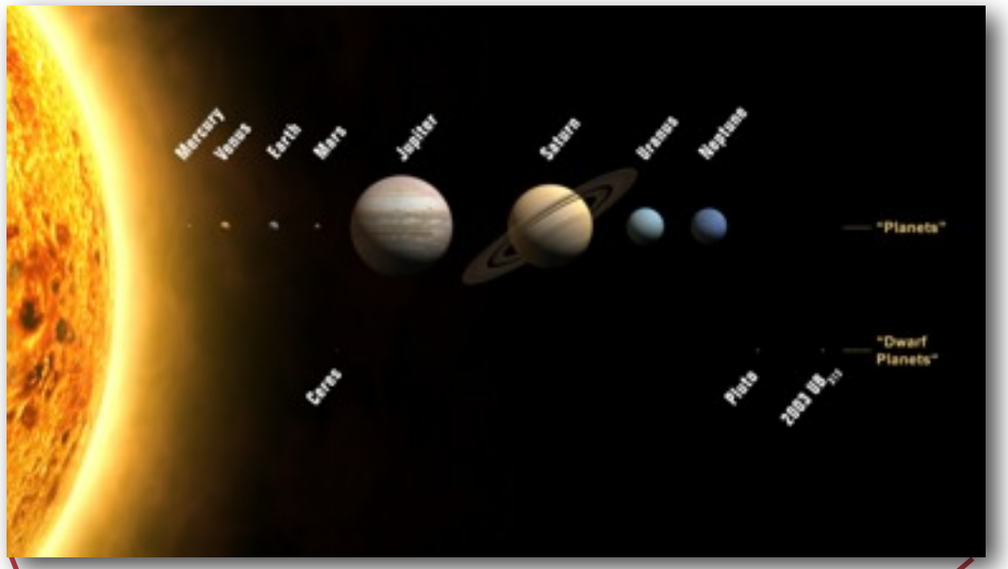

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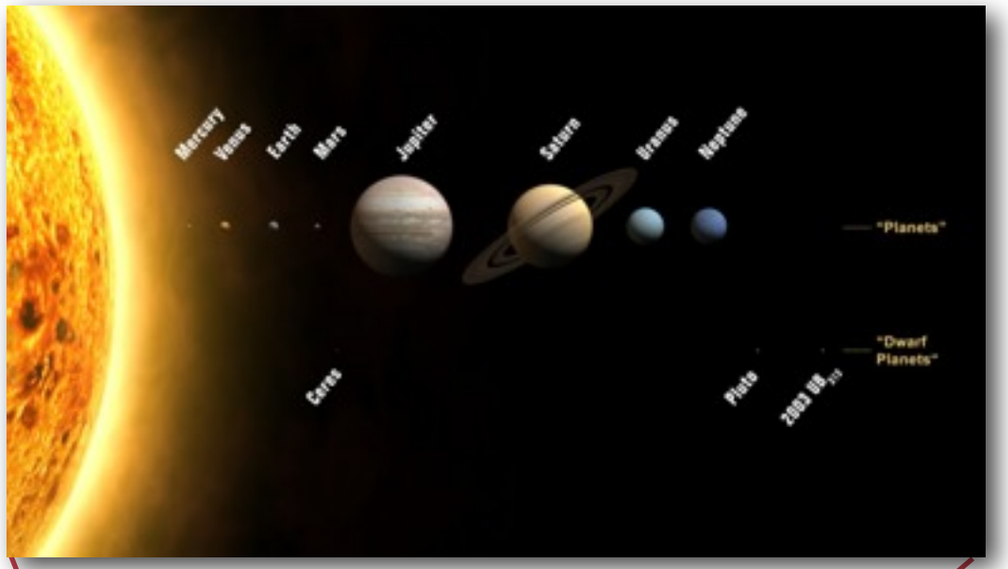

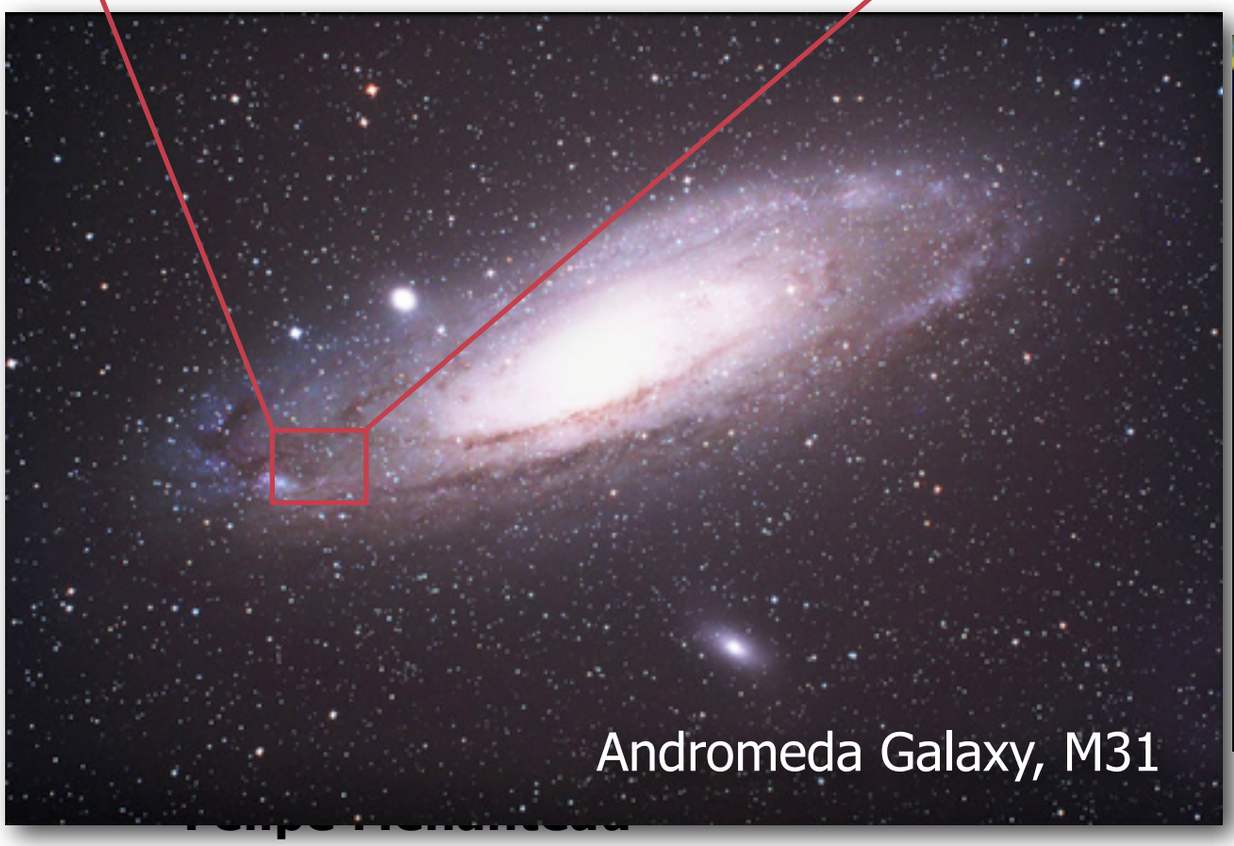

Where do galaxies live?

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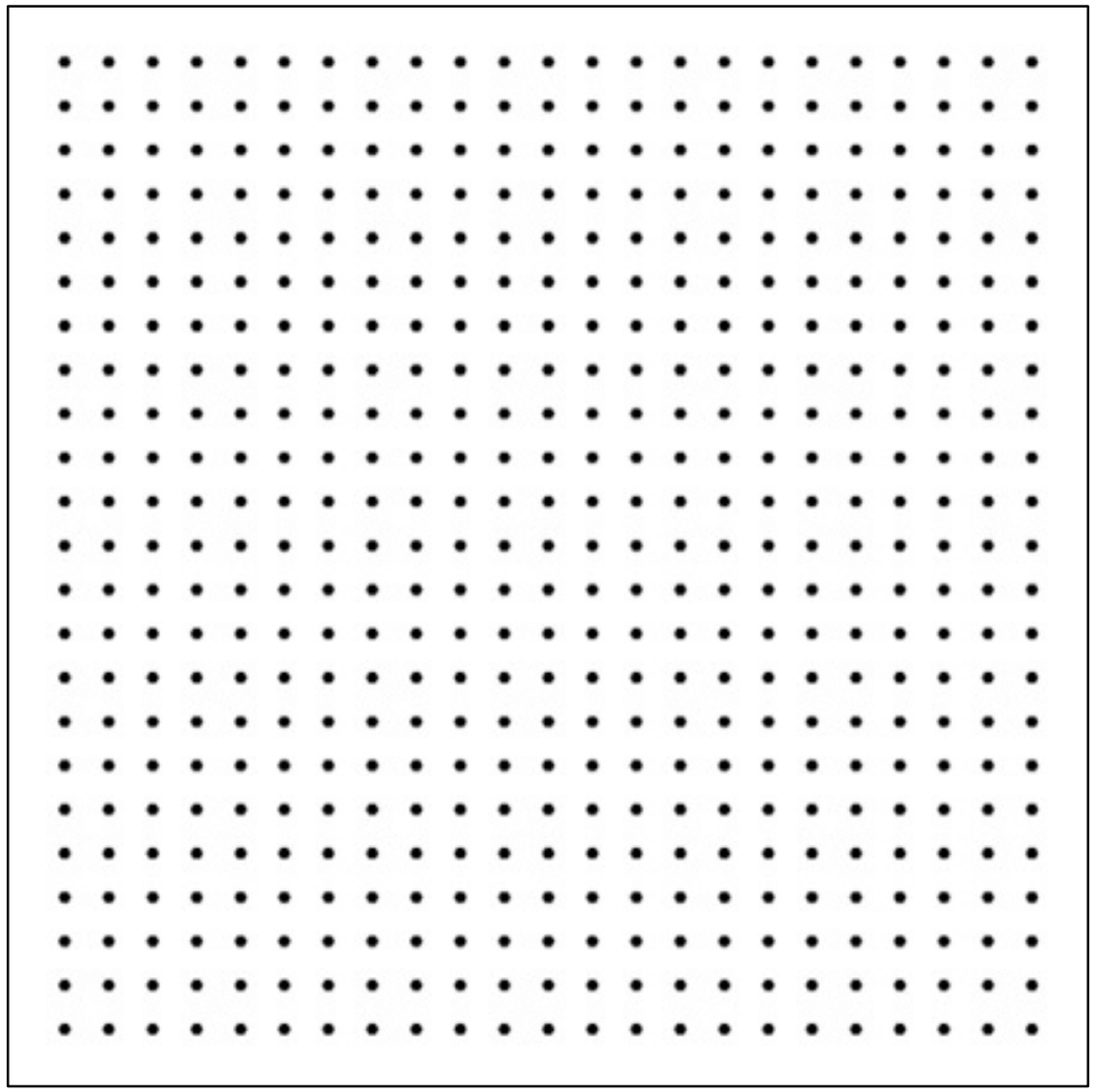
Where do galaxies live?

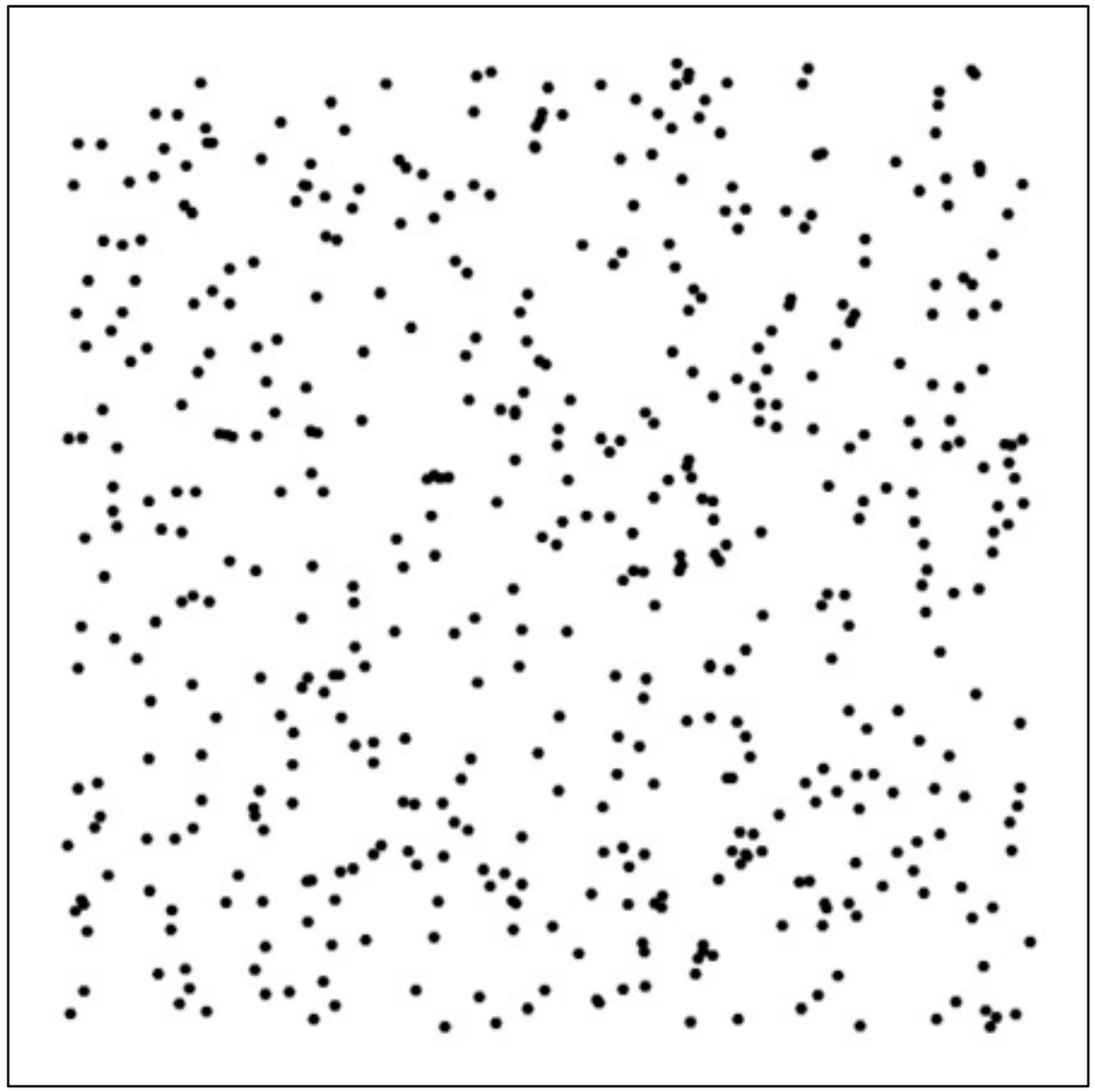
- **Galaxies are not randomly distributed**

Spatial Distributions

Uniform



Random



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Spatial Distributions

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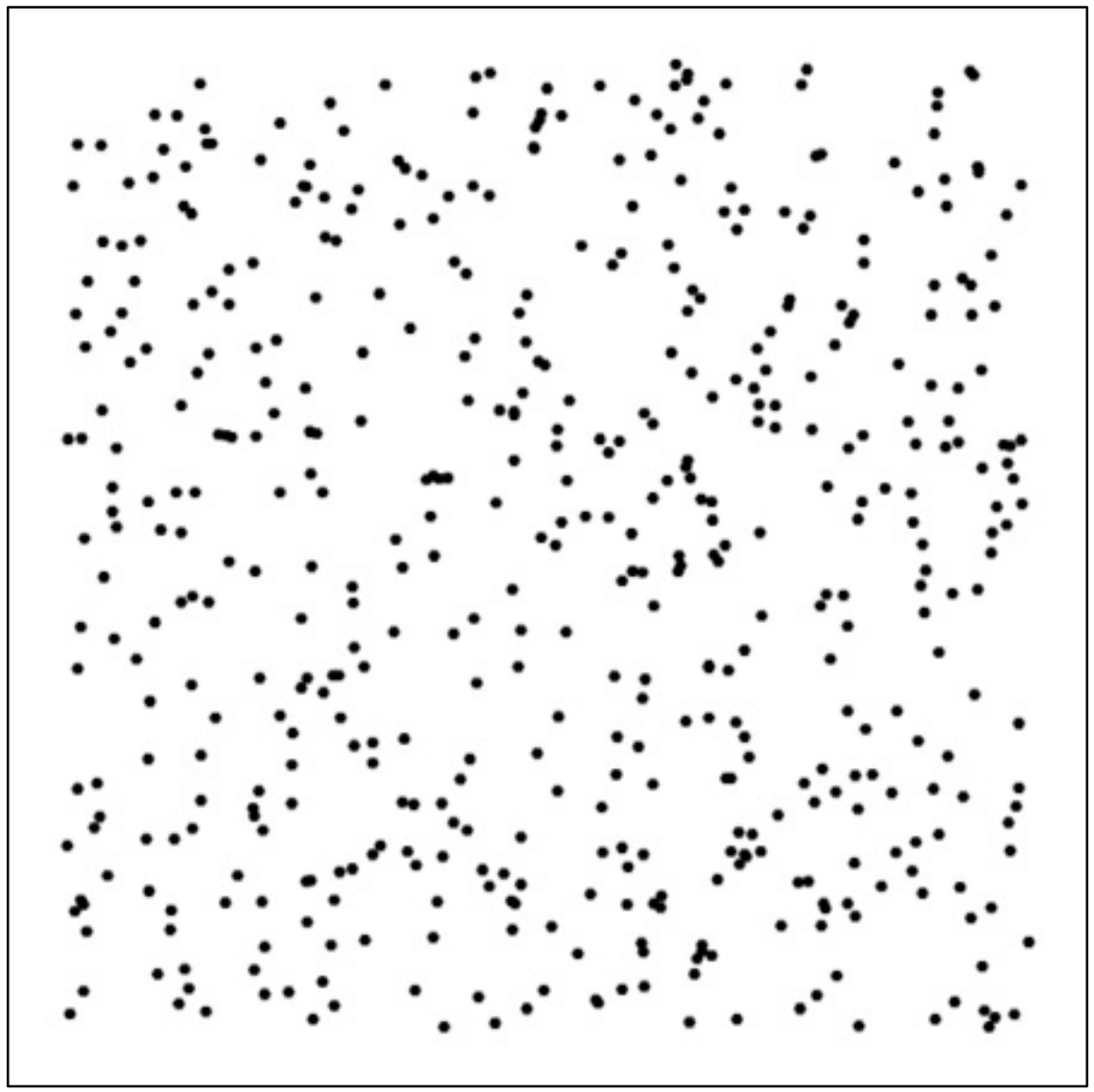
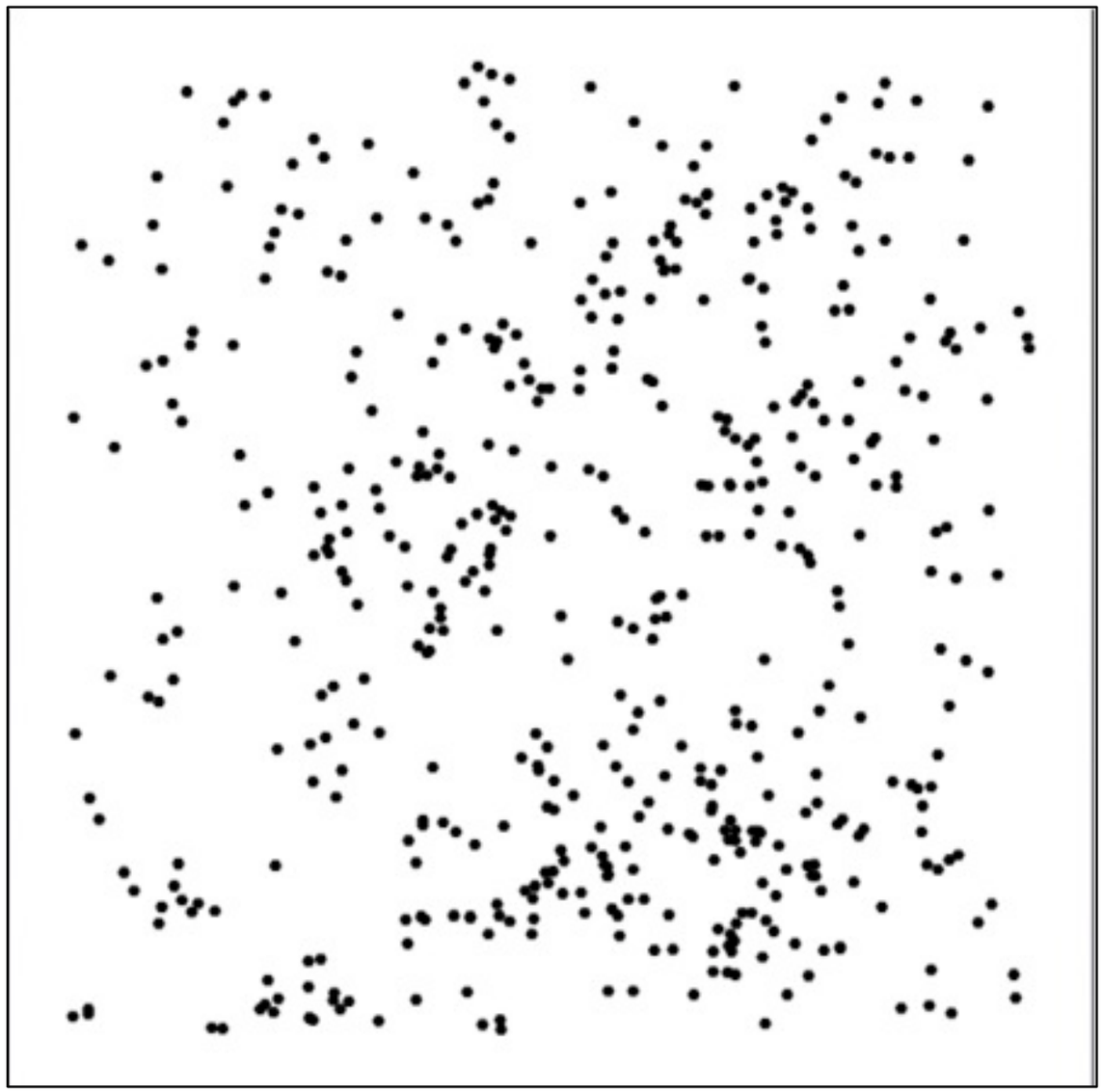


Clustered



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Where do we live?

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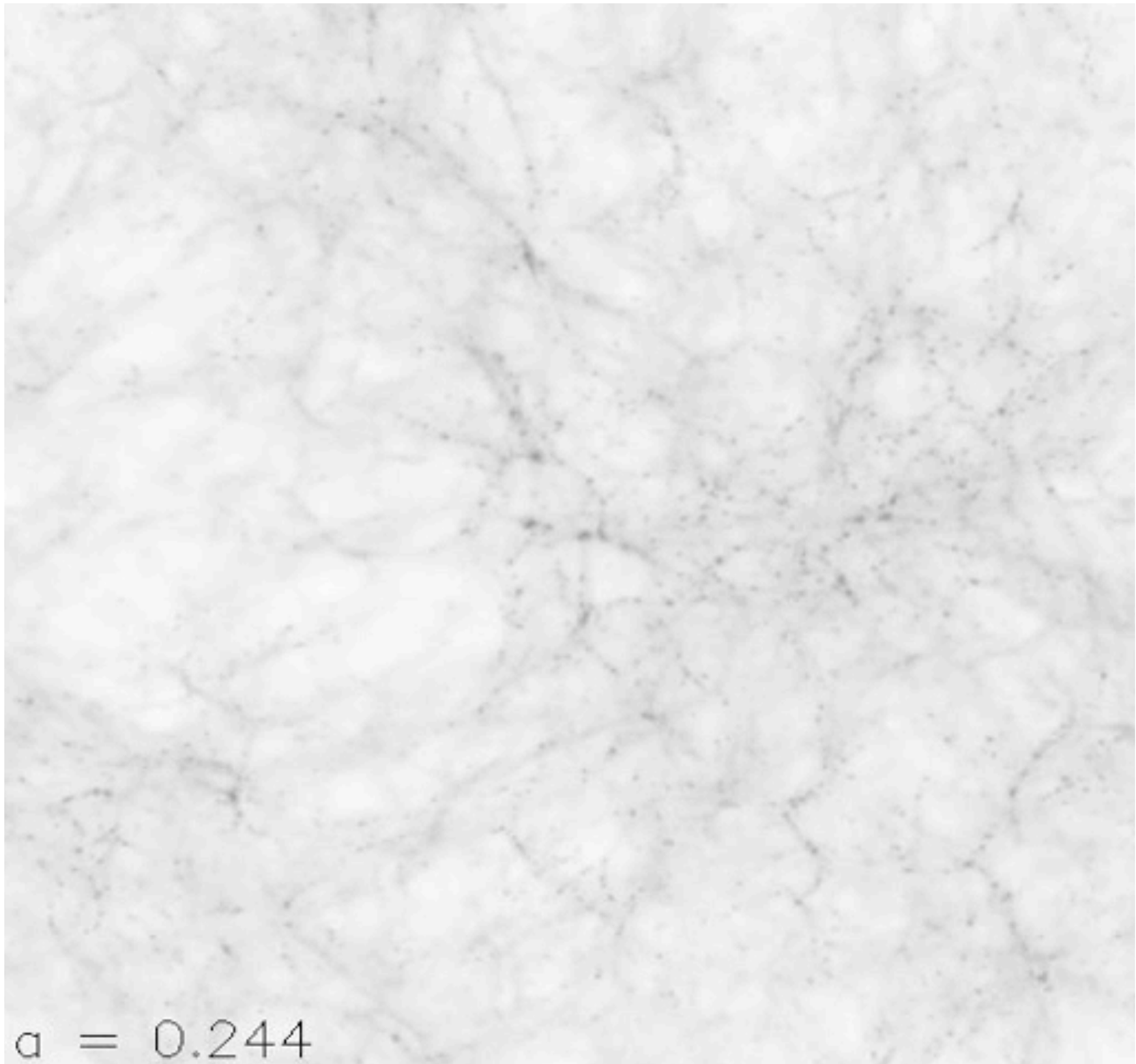
Where do we live?

Courtesy Michael Busha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Summary III,

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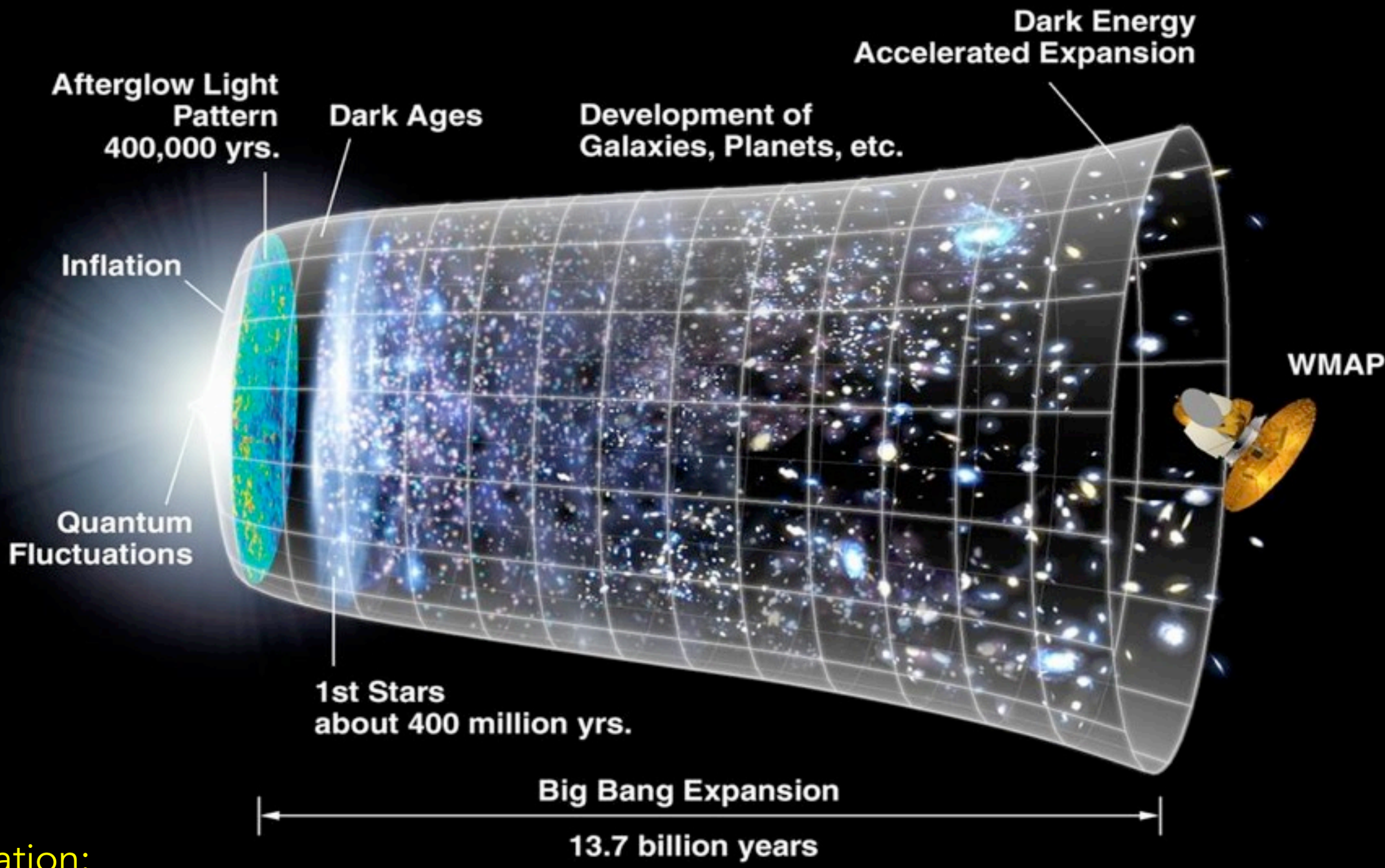
- Galaxies have distinct morphologies
- Galaxies are not randomly distributed
- **Dark Matter and Dark Energy dominate growth of structures.**

Brief History of the Universe



Inflation:

burst of rapid expansion a tiny fraction of a second after the Big Bang

Does the expansion of the Universe change over time?

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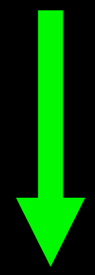
Gravity:

everything in the Universe attracts everything else

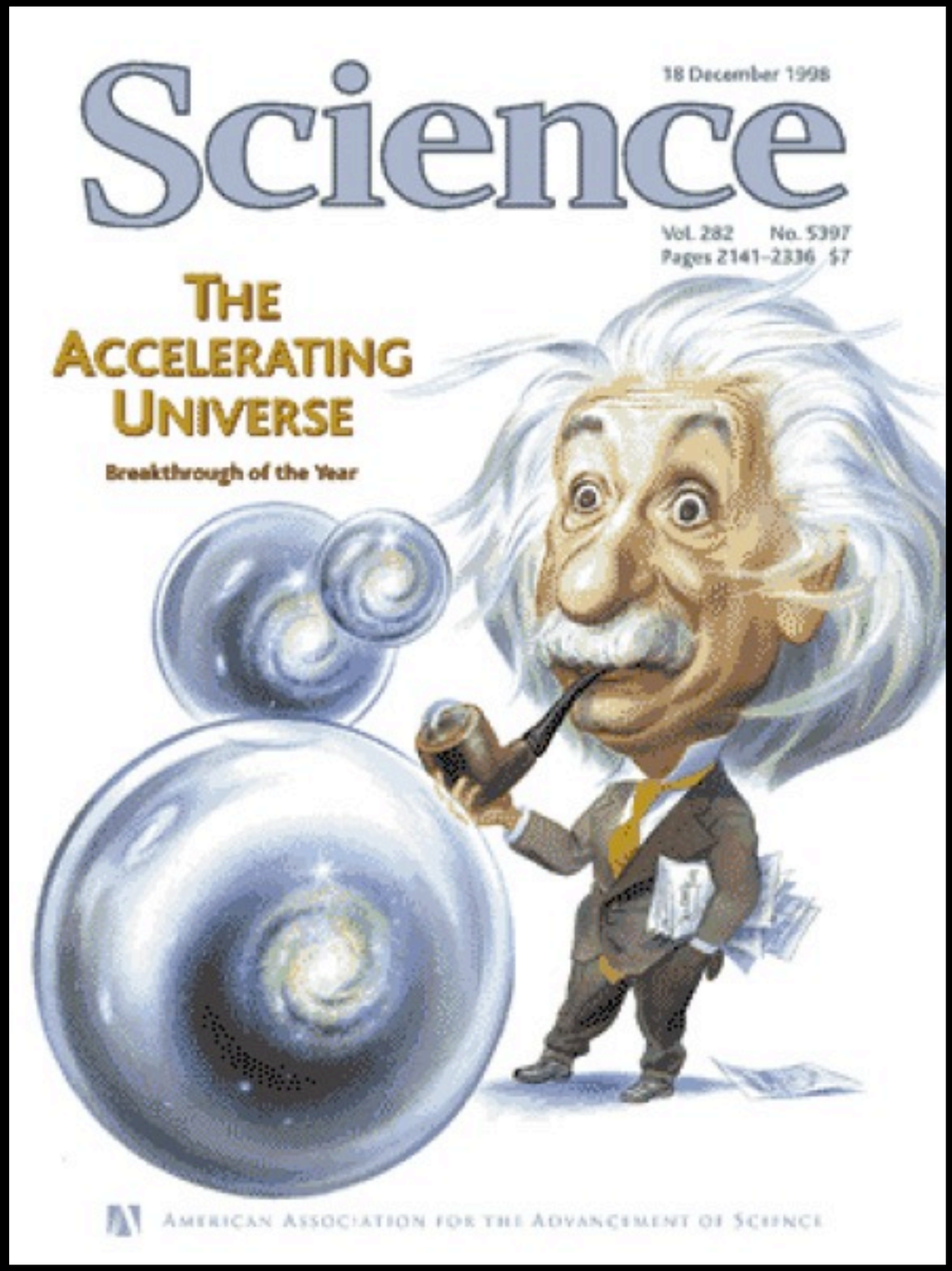


the expansion of the Universe should slow down over time

The Expansion is Speeding Up

Discovered in 1998 by 2 teams of astronomers.

They won the Nobel Prize in 2011 for this discovery.



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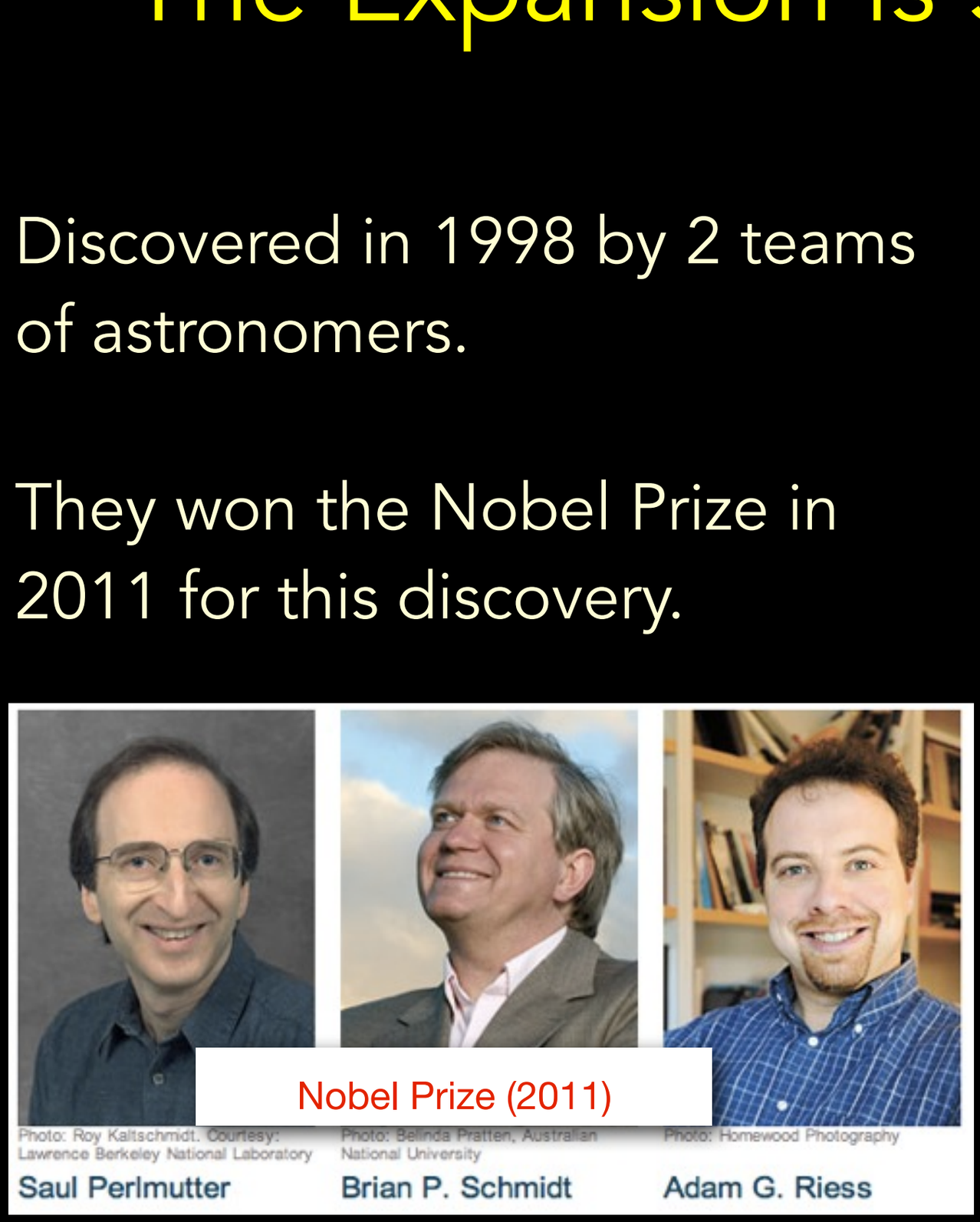
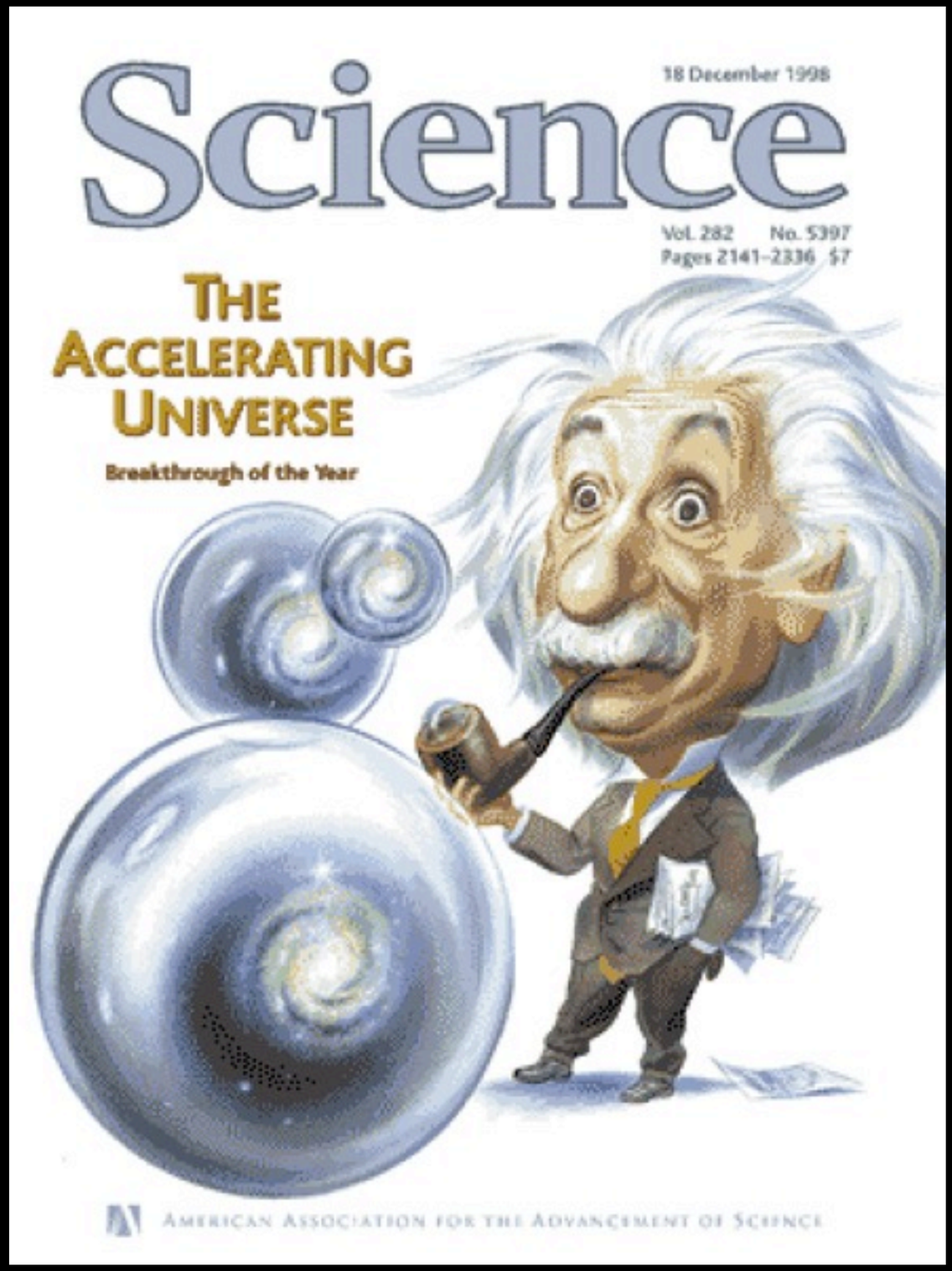


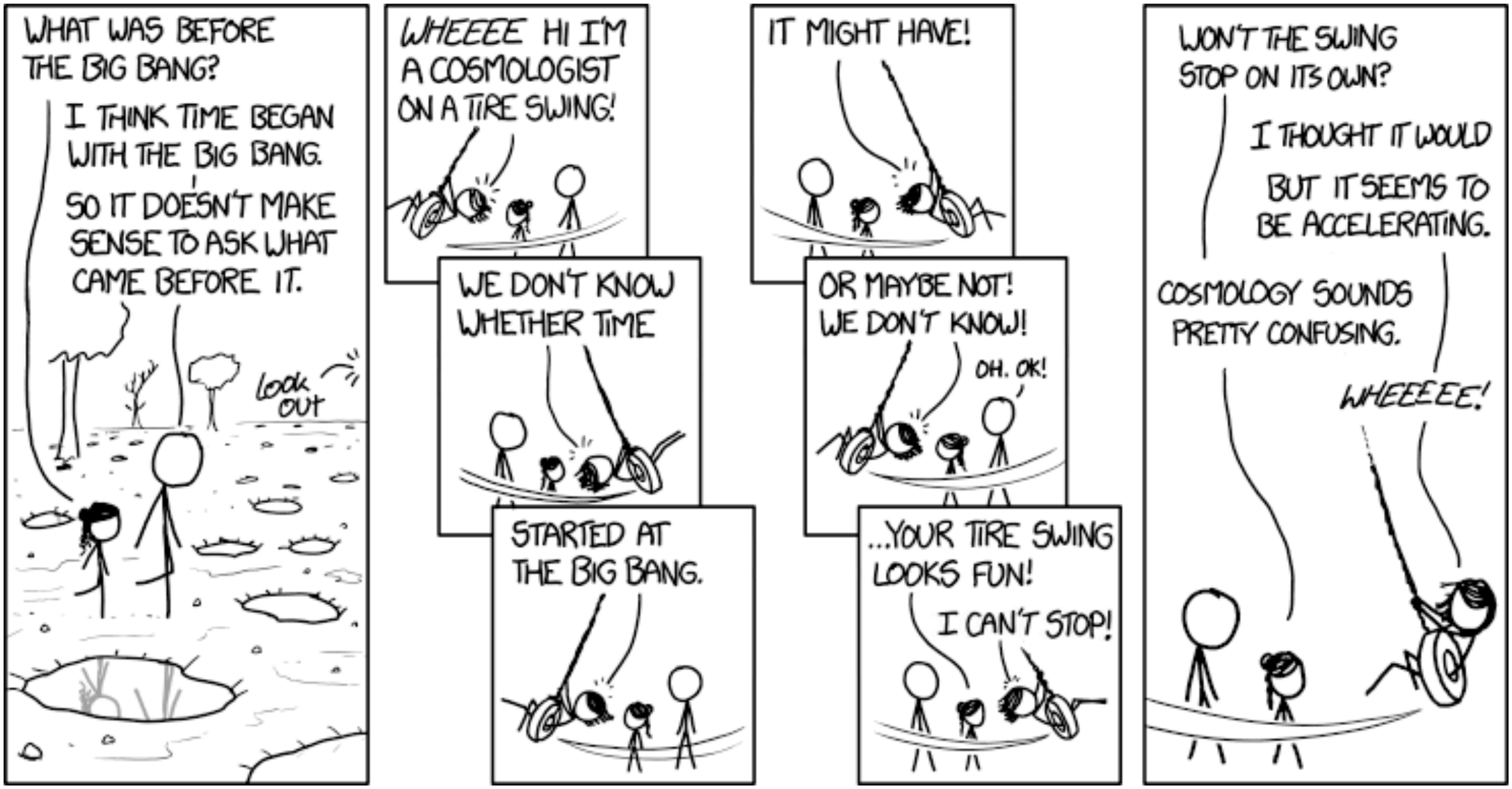


Supernova: an exploding star. The brightness of distant supernovae showed that expansion is speeding up.

Why is this a mystery?

When you throw a ball straight up in the air, imagine it first slows down but then, instead of falling back to Earth, it starts speeding up and rockets out of the atmosphere. That's what the Universe appears to be doing.

Why is this a mystery?



http://xkcd.com/1352/

What causes Cosmic Speed-up?

Two possibilities:

1. The Universe is filled with stuff that gives rise to `anti-gravity'. We now call this

Dark Energy

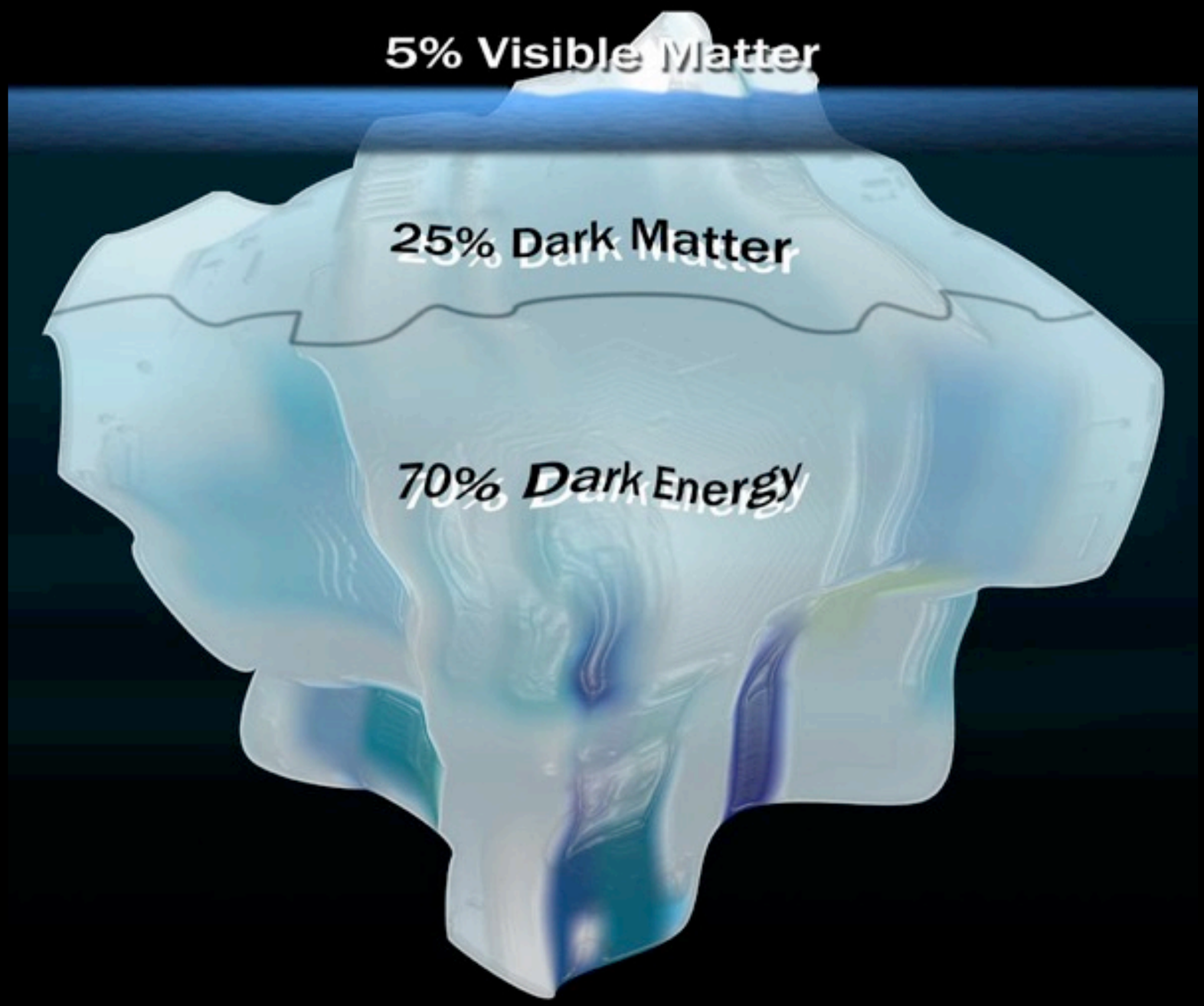
2. Our understanding of gravity (which comes from Einstein) is wrong.

95% of the Universe is “Dark”

Ordinary Matter:
atoms

Dark Matter:
holds galaxies together, helps them form

Dark Energy:
`gravitationally repulsive’ stuff that speeds up cosmic expansion



What is Dark Energy?

- We don't know.
- Most conservative hypothesis is that it's the energy of empty space.
- Quantum theory predicts that energy should be infinite.
- Other ideas even more speculative.

Why is Dark Energy important?

- Nature of Dark Energy will determine the future evolution of the Universe (but its effects on Earth or in our galaxy are now extremely tiny).

- It's 70% of the Universe.

- Mapping the Universe can give us clues to what Dark Energy is:

Dark Energy Survey

From Expansion to Acceleration

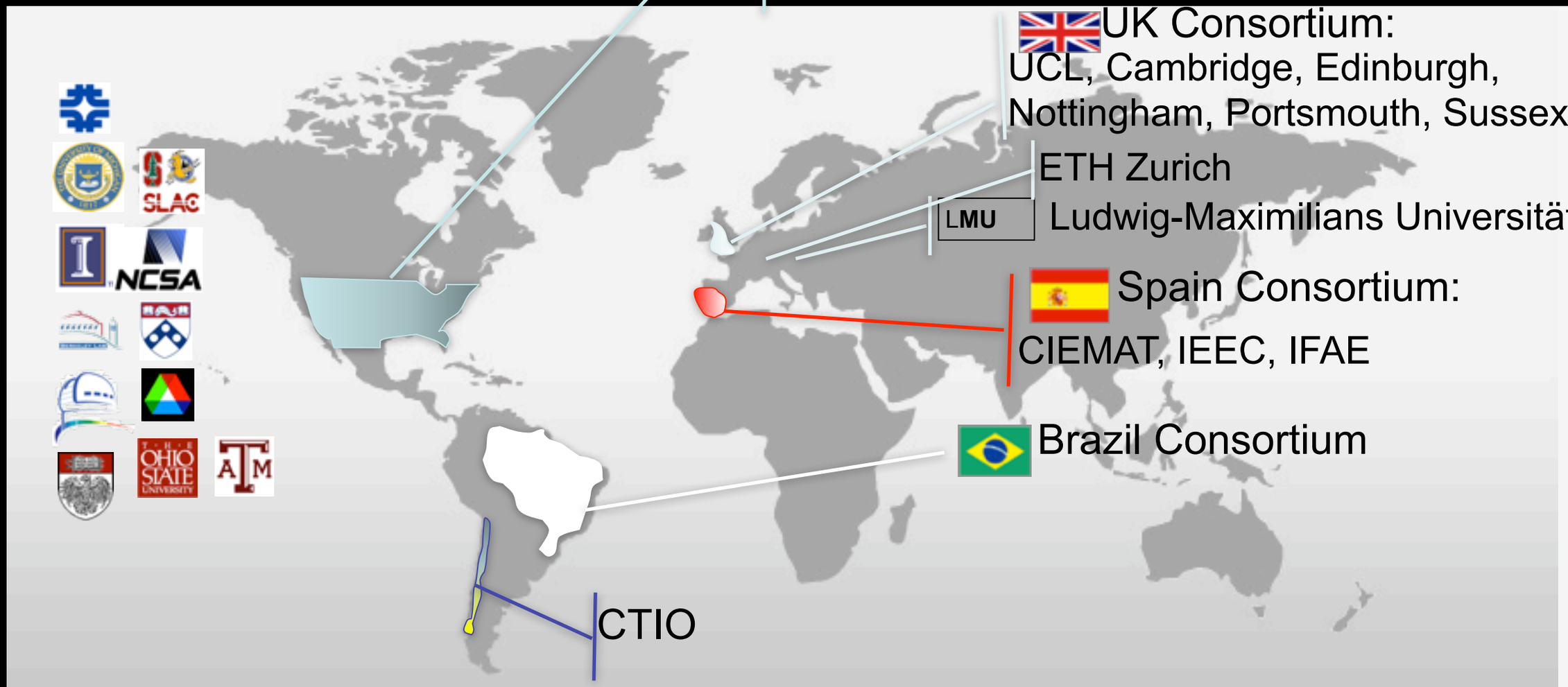
... from Mount Wilson to Cerro Tololo

Cerro Tololo Inter-American Observatory
in the Andes mountains of Chile

Dark Energy Survey Collaboration

~300 scientists from around the world

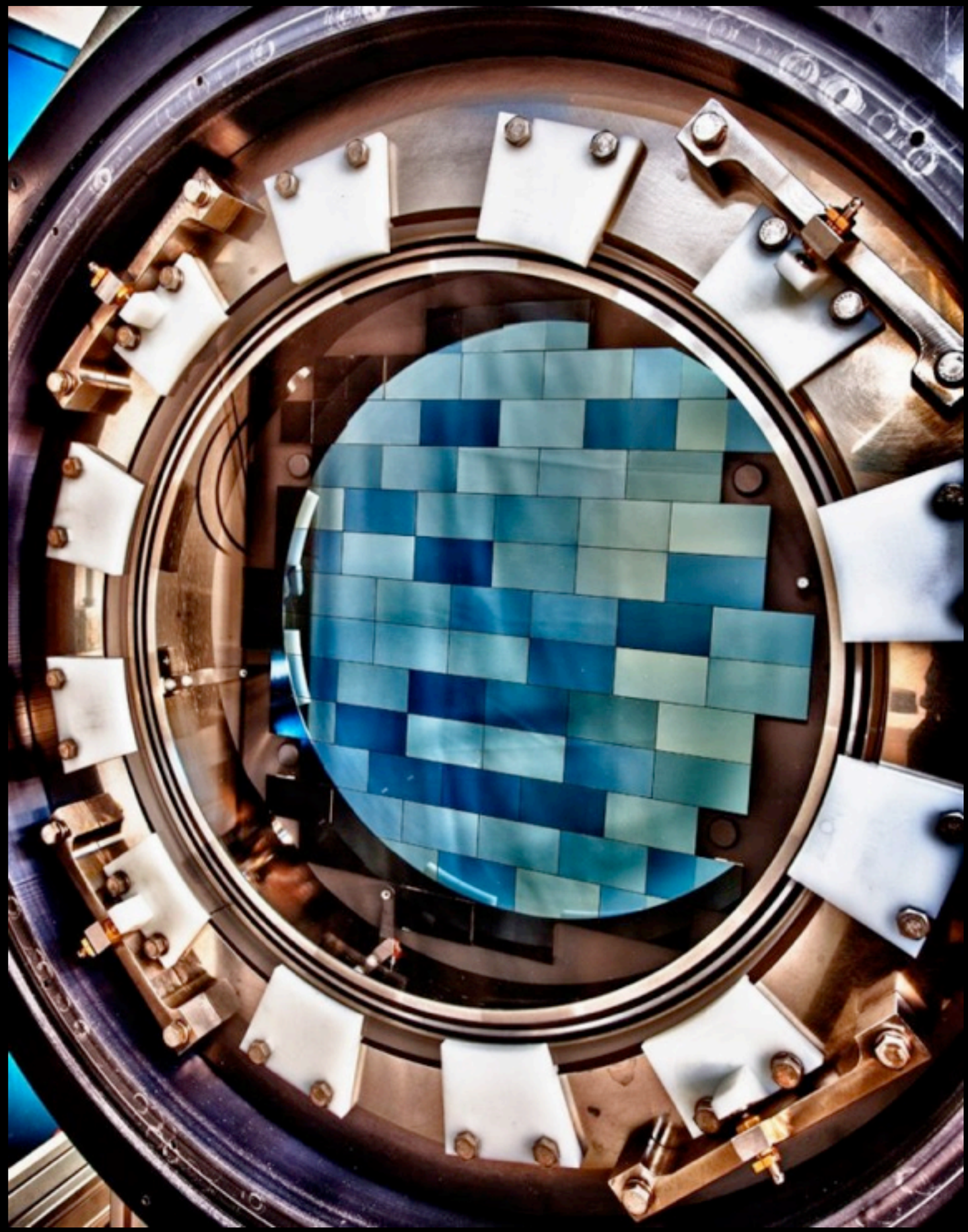
Fermilab, UIUC/NCSA, University of Chicago, LBNL, NOAO, University of Michigan, University of Pennsylvania, Argonne National Lab, Ohio State University, Santa-Cruz/SLAC/Stanford, Texas A&M



570-Million pixel
Dark Energy Camera

installed on the Blanco telescope Sept. 2012

Dark Energy Survey over 5 years will map 300 million galaxies and thousands of supernovae to study Dark Energy and why the Universe is speeding up



DECam at work Cerro Tololo Inter-American Observatory
in the Andes mountains of Chile

Credit: Brian Nord

DECam at work Cerro Tololo Inter-American Observatory in the Andes mountains of Chile

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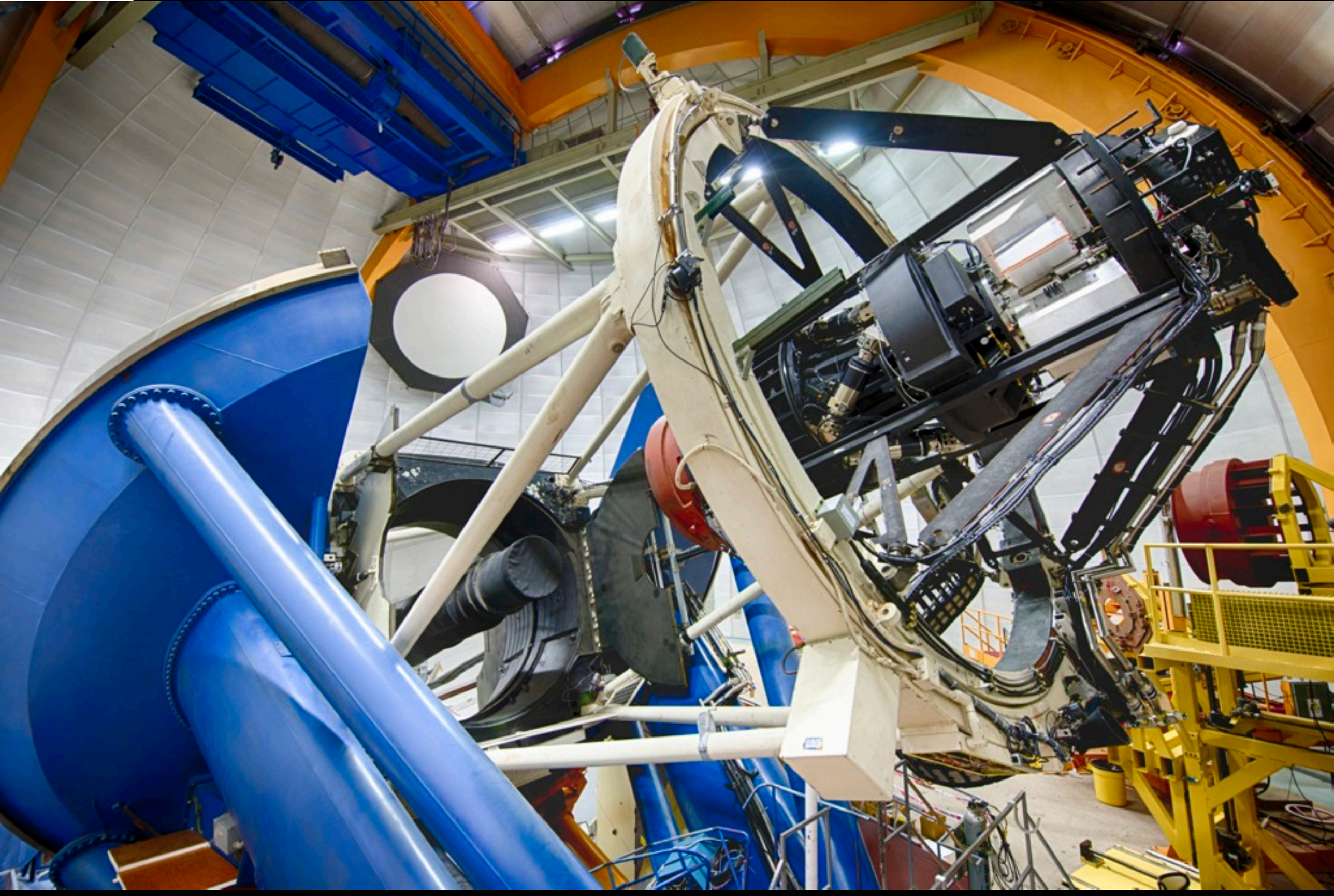


Dark Energy Camera on the Blanco Telescope

DECam at a Glance:

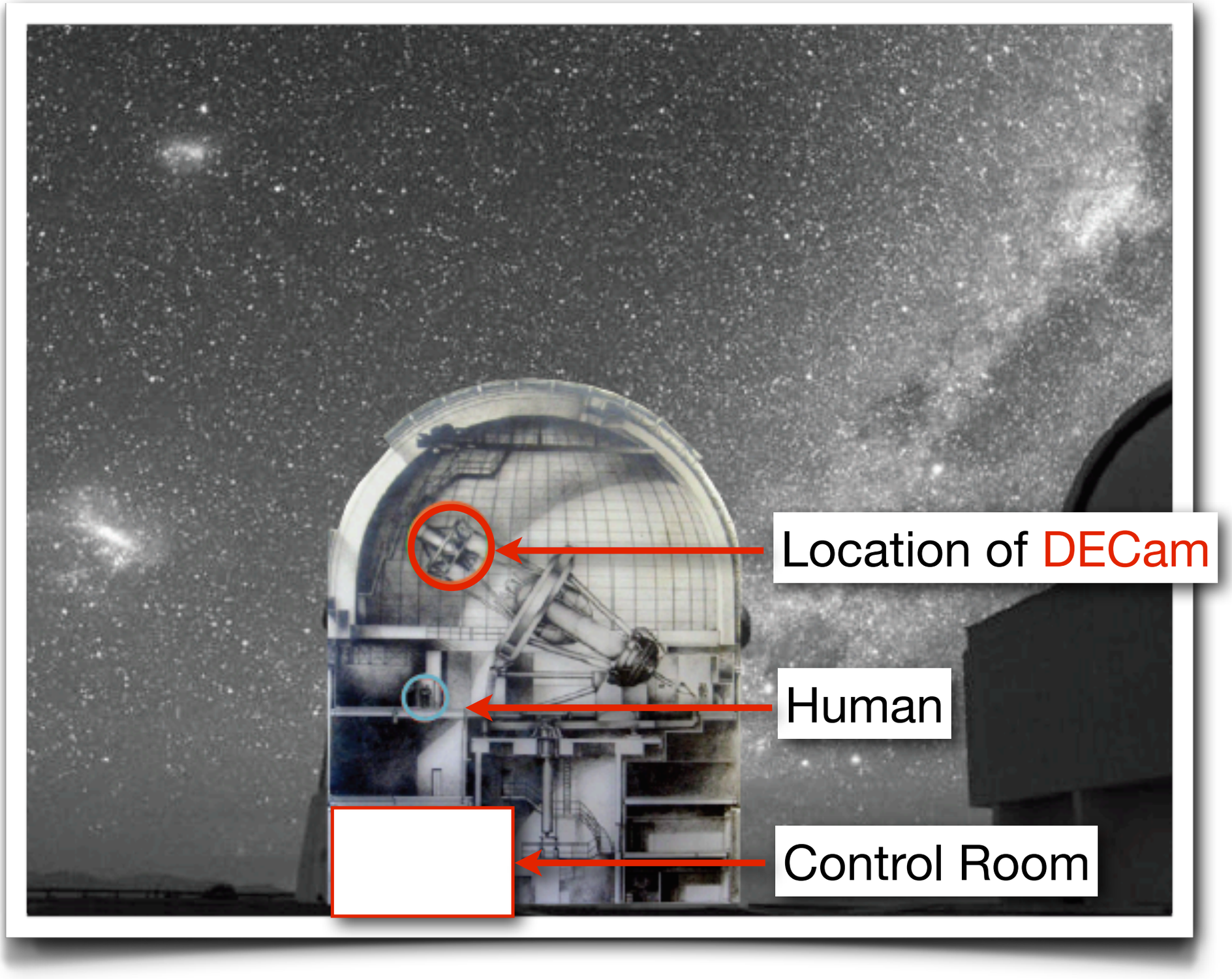
At home inside the Blanco

DECam at a Glance:

At home inside the Blanco

DECam at a Glance:

At home inside the Blanco



DARK ENERGY SURVEY

First Images

Fornax Cluster of Galaxies

First Light on Sept. 12, 2012

DARK ENERGY SURVEY

First Images

Fornax Cluster of Galaxies

First Light on Sept. 12, 2012

DARK ENERGY SURVEY

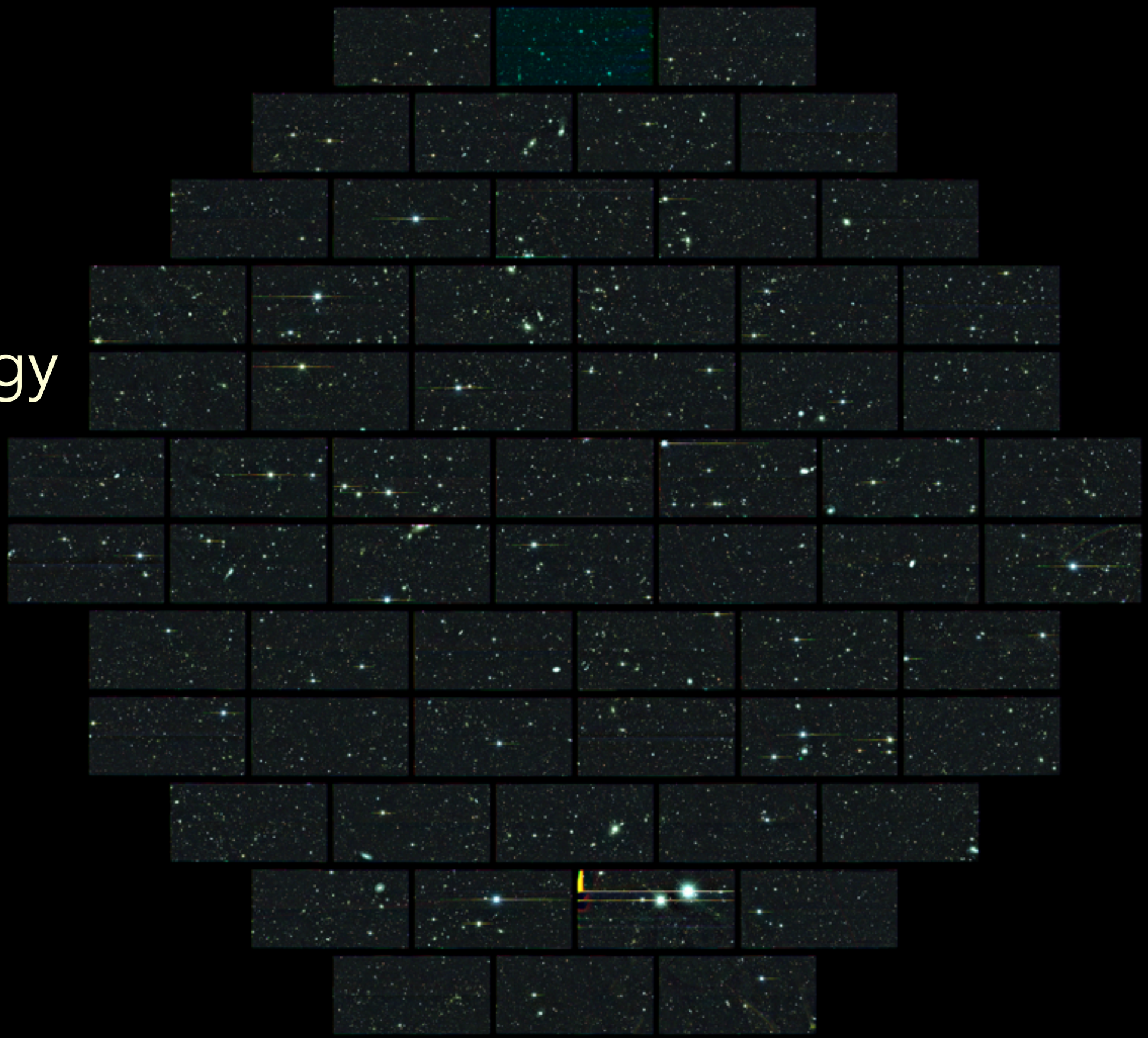
First Images

Galaxy NGC 1365 in Fornax

image from a single CCD

DARK ENERGY SURVEY

Dark Energy Camera image



DARK ENERGY SURVEY

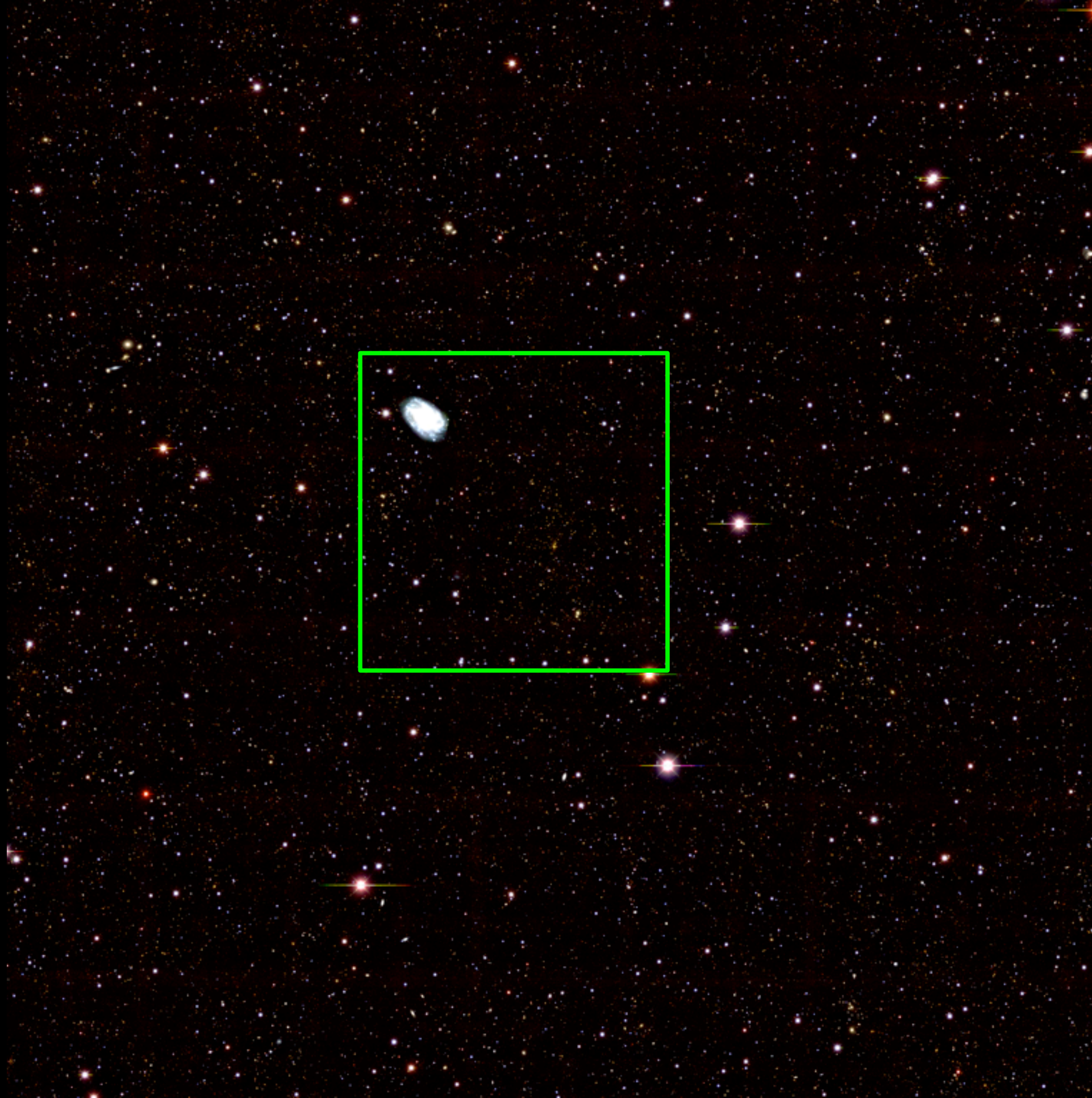
Dark Energy Camera image

DARK ENERGY SURVEY

50,000 galaxies in this image

DARK ENERGY SURVEY

50,000 galaxies in this image



DARK ENERGY SURVEY

Distant Cluster of Galaxies

DARK ENERGY SURVEY

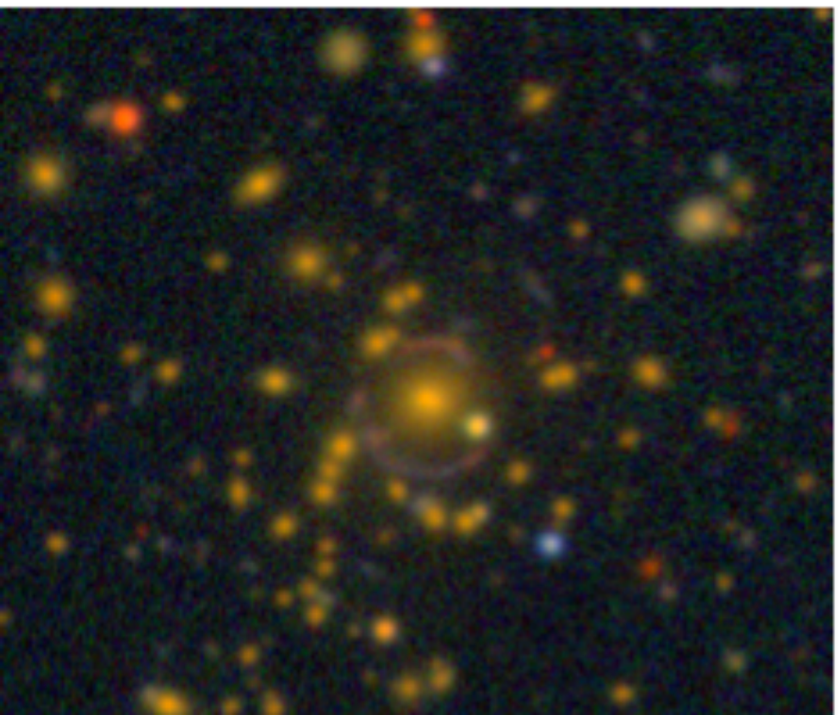
Distant Cluster of Galaxies

Another Cluster of Galaxies

Gravitational Lensing

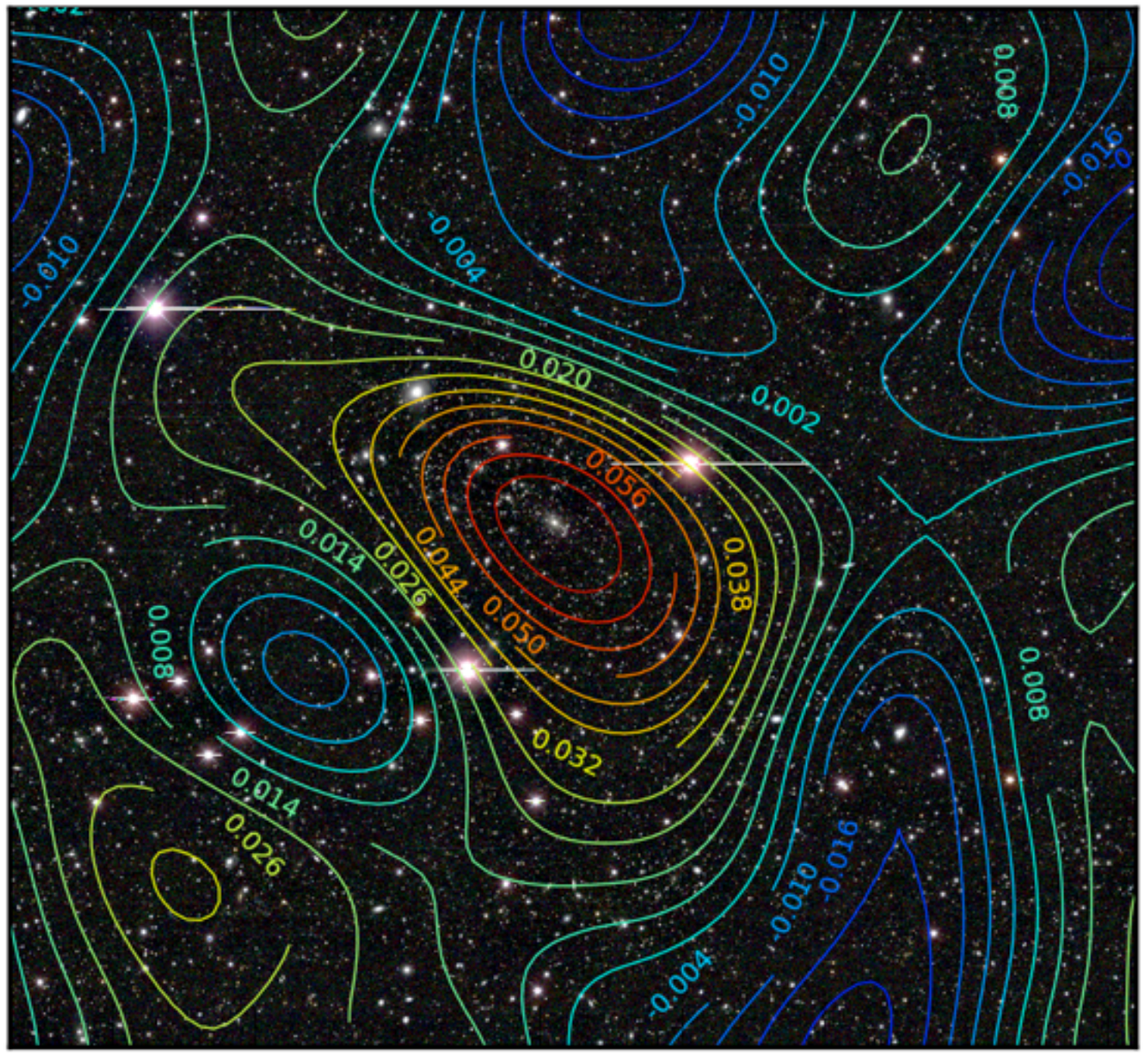
foreground mass bends light from distant galaxies



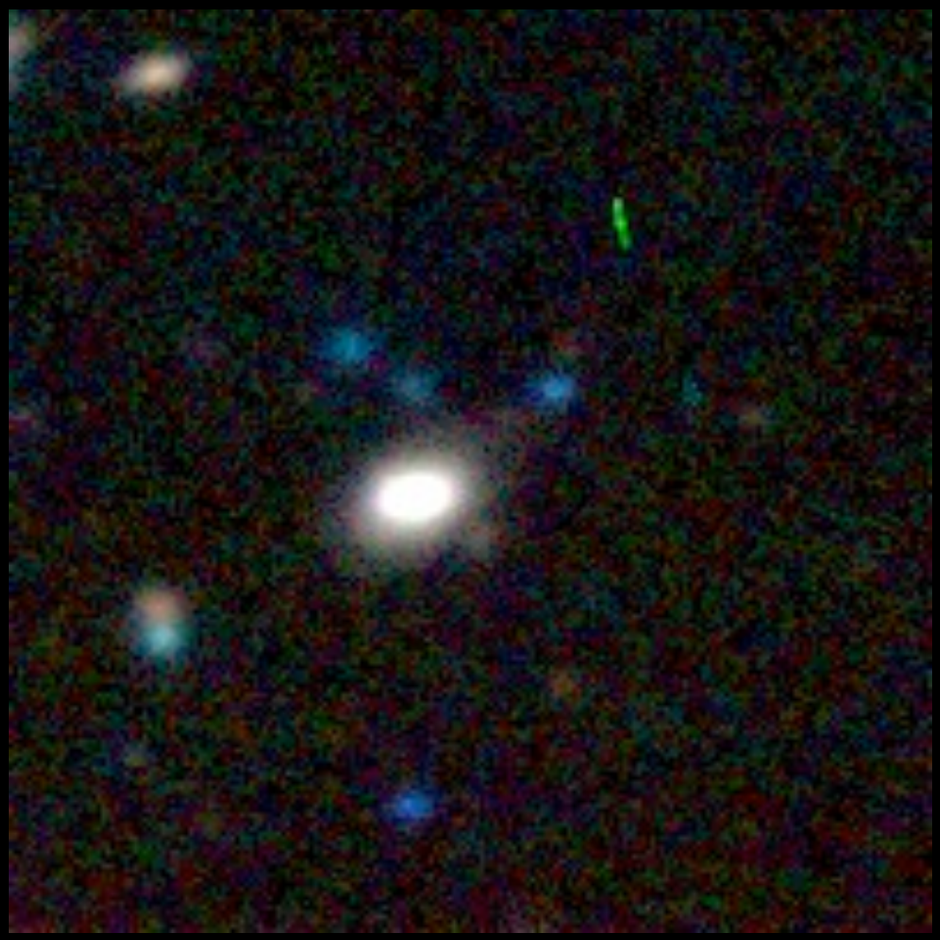



`Seeing' Dark Matter

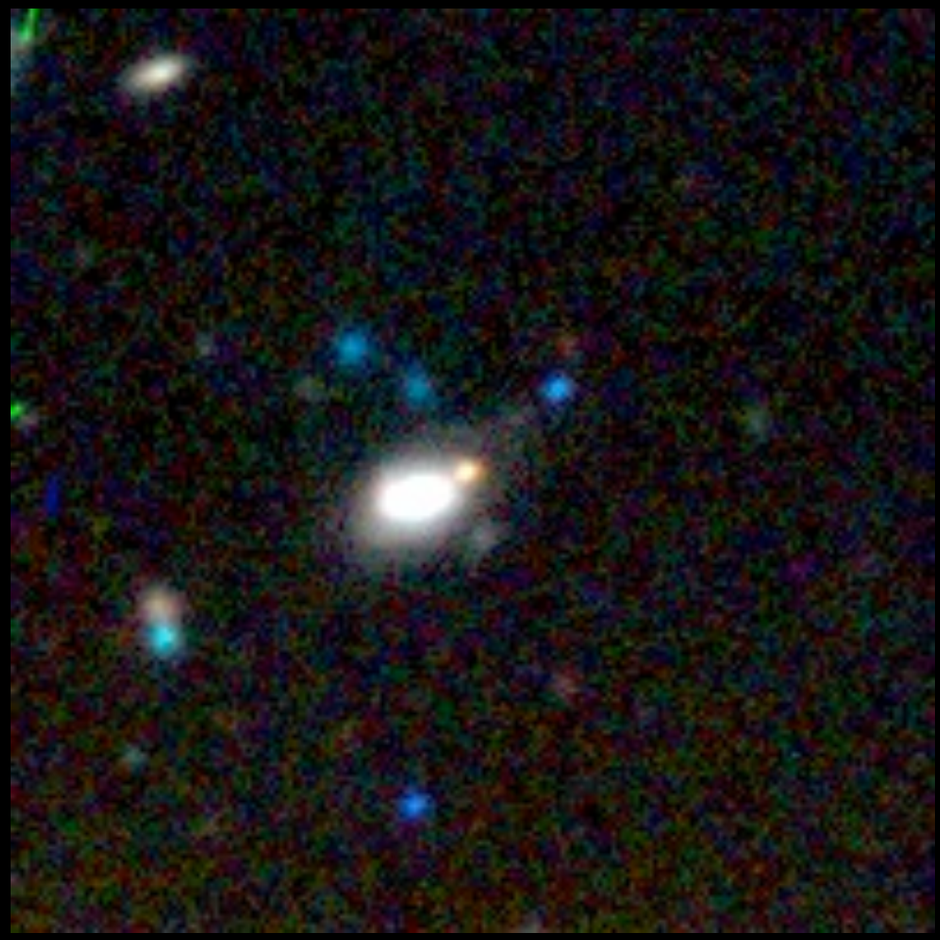
- Image: light from a cluster of galaxies
- Contours: inferred dark matter distribution in the cluster from gravitational lensing



Discovering Supernovae

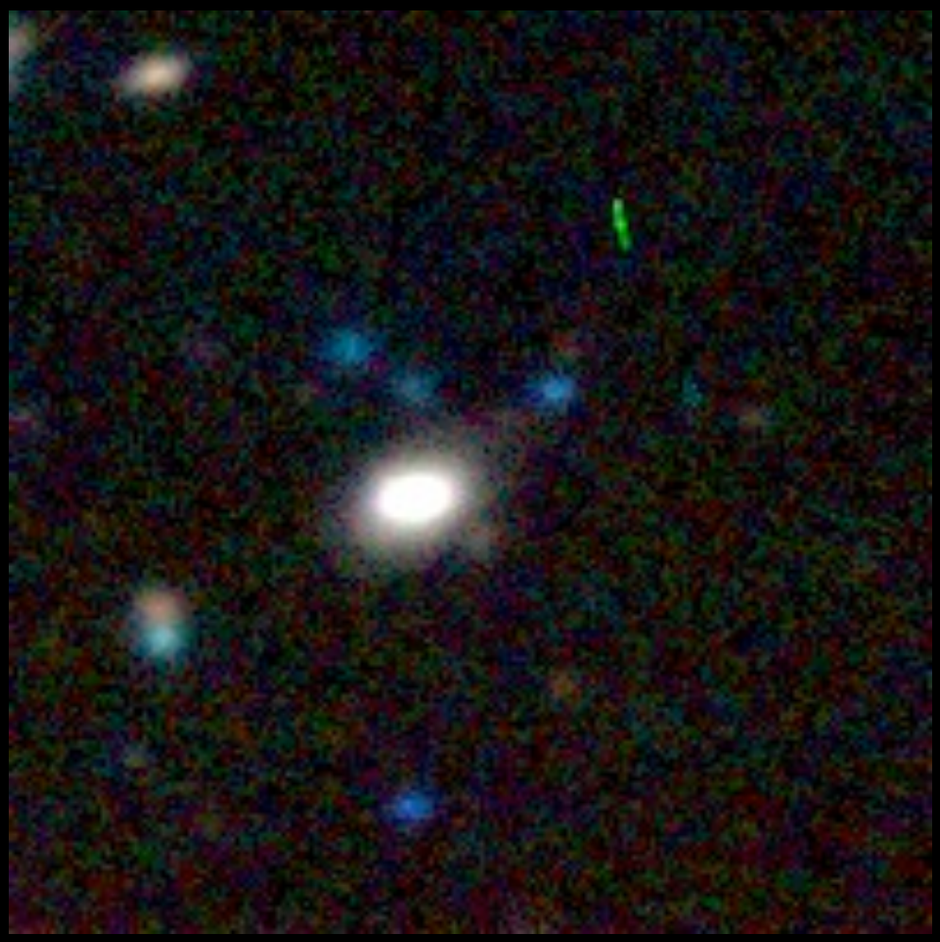


Nov. 7

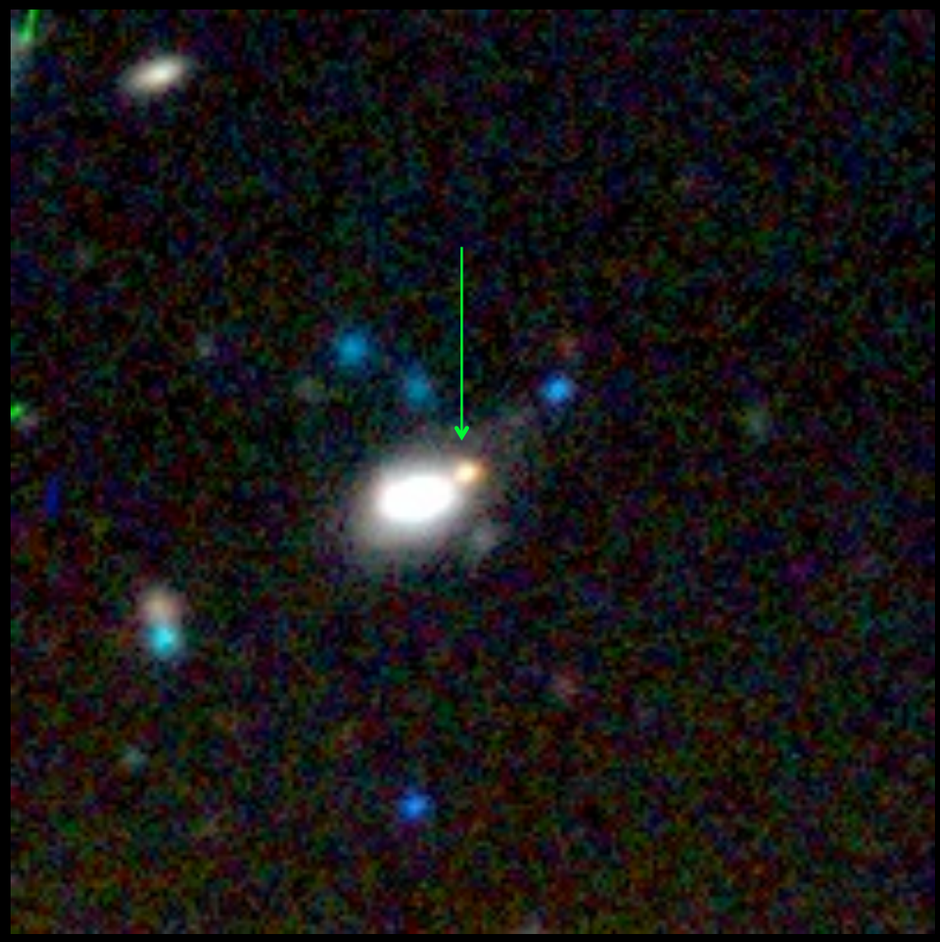


Dec. 15

Discovering Supernovae



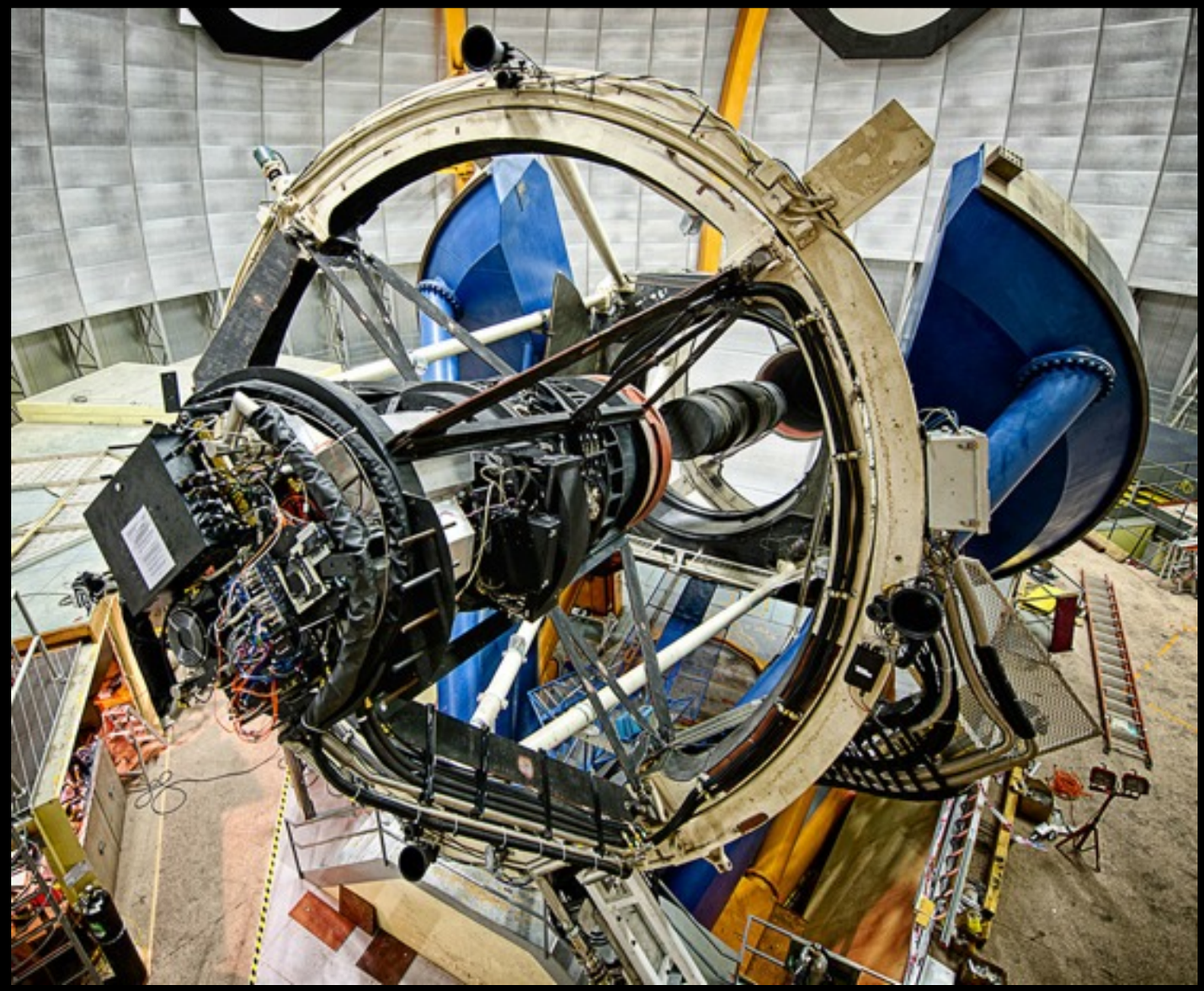
Nov. 7



Dec. 15

The Dark Energy Survey

- Probe Dark Energy and the origin of Cosmic Acceleration:
  - History of cosmic expansion
  - Growth of structure
- Two multicolor surveys:
  - 300 M galaxies over 1/8 sky
  - 4000 supernovae
- Five-year Survey started Aug. 31, 2013



www.darkenergysurvey.org

www.darkenergydetectives.org

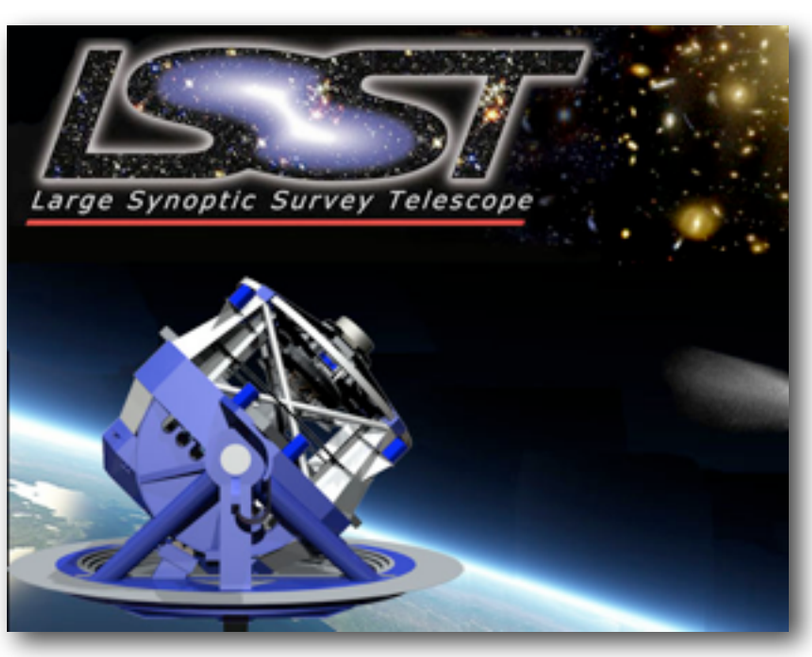
What we know:

- The Universe is:
  - old
  - big
  - filled with galaxies that are mostly dark matter
  - expanding from a Big Bang
  - speeding up, perhaps due to Dark Energy
- With the Dark Energy Survey, we are embarked on a 5-year journey to address this mystery and learn more about the evolution of the cosmos.

DES and LSST in Context:

Past, Current and Future Large Optical Surveys

SDSS I-II	DES	LSST
[Stage I/II]	[Stage III]	[Stage IV]
2000-08	2013-18	2022-32
2.5-meter mirror	4-meter	8.4 -meter
$O(10^8)$ Galaxies	$O(10^8)$ Galaxies	$O(10^9)$ Galaxies
10k sq. deg.	5k sq. deg.	20k sq. deg.
200 Gb/Night	500 Gb/Night	1,500 Gb/Night



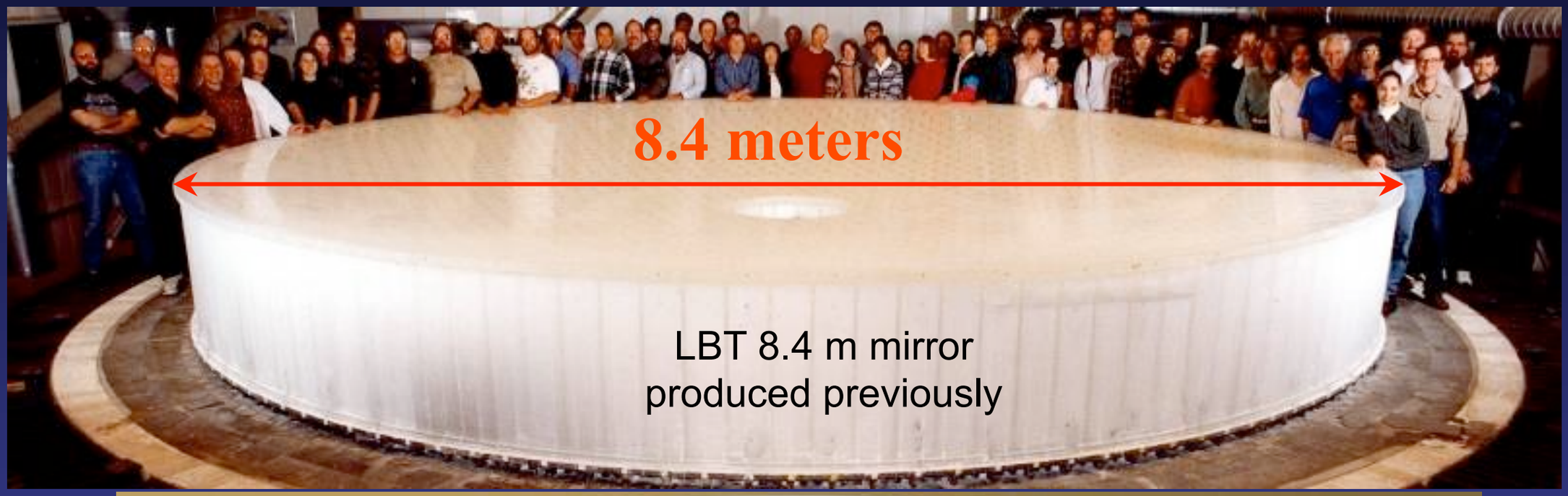
The LSST is a comprehensive Project to address today's compelling science in a single data set

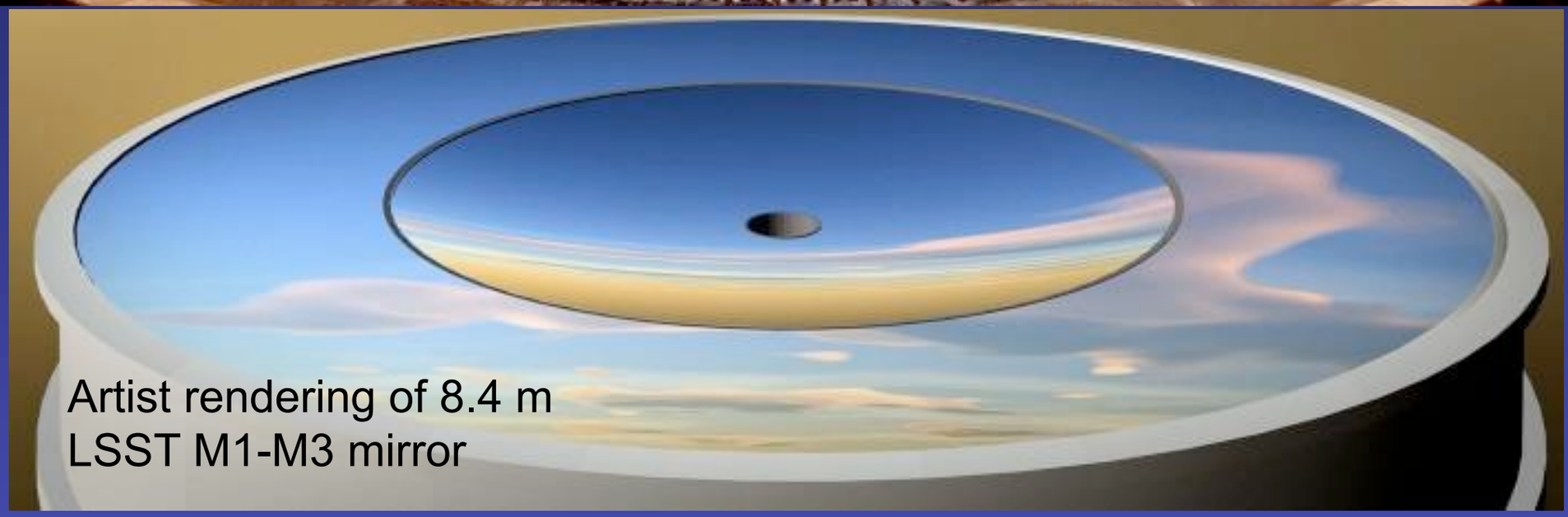
- **~40 Second Cadence**
  - Two 15 second exposures
  - Full sky coverage every few nights
- **Public Data**
  - Alerts of new events
  - Catalogs of object
  - Archives of images
- **Education and Public Outreach is provided**

LSST is designed to image the whole sky every few nights for 10 years, giving us a movie like window into our dynamic Universe.

Primary-Tertiary mirror construction has started at University of Arizona

Very unique monolithic primary mirror has both M1 and M3 surfaces in single borosilicate substrate





LSST's 15 TB of nightly data is sent by fiber link from Cerro Pachón to the data system for analysis.

The LSST produces transient alerts within 60 seconds, catalogs all objects, and serves the data to the public immediately.

LSST (2020-2032)

LSST (2020-2032)