Seeing the Invisible Universe with Gravitational Lensing and SNAP

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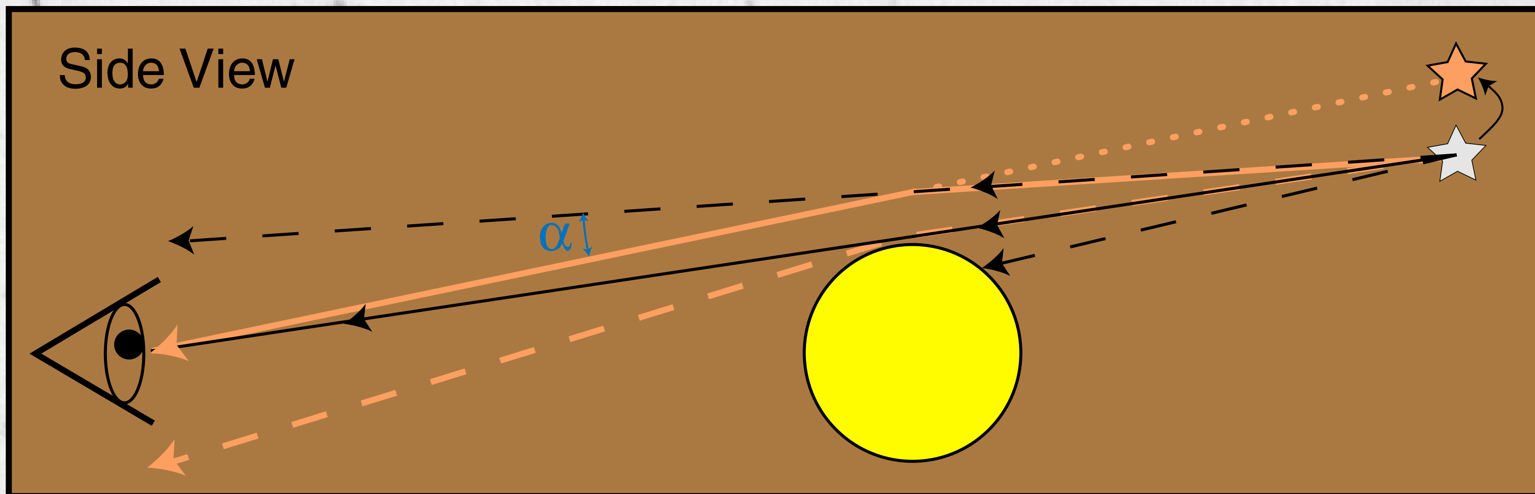
Questions for this presentation:

1. Why is the Universe like a shower stall?
2. What is the Universe made of?
3. Was Albert Einstein right about General Relativity? Wrong? Wrong about being wrong?
4. Why do we want to spend nearly $1B to measure the shape of little blots on the sky?

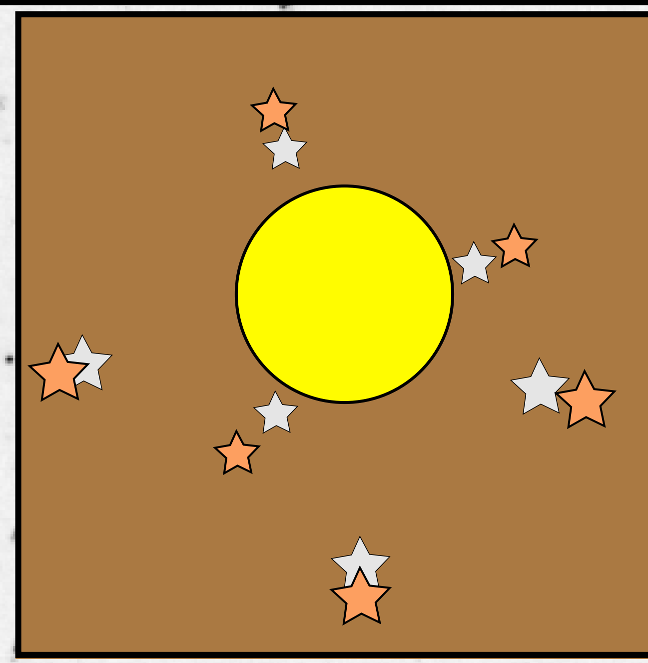
General Relativity & Gravitational Lensing

Einstein:

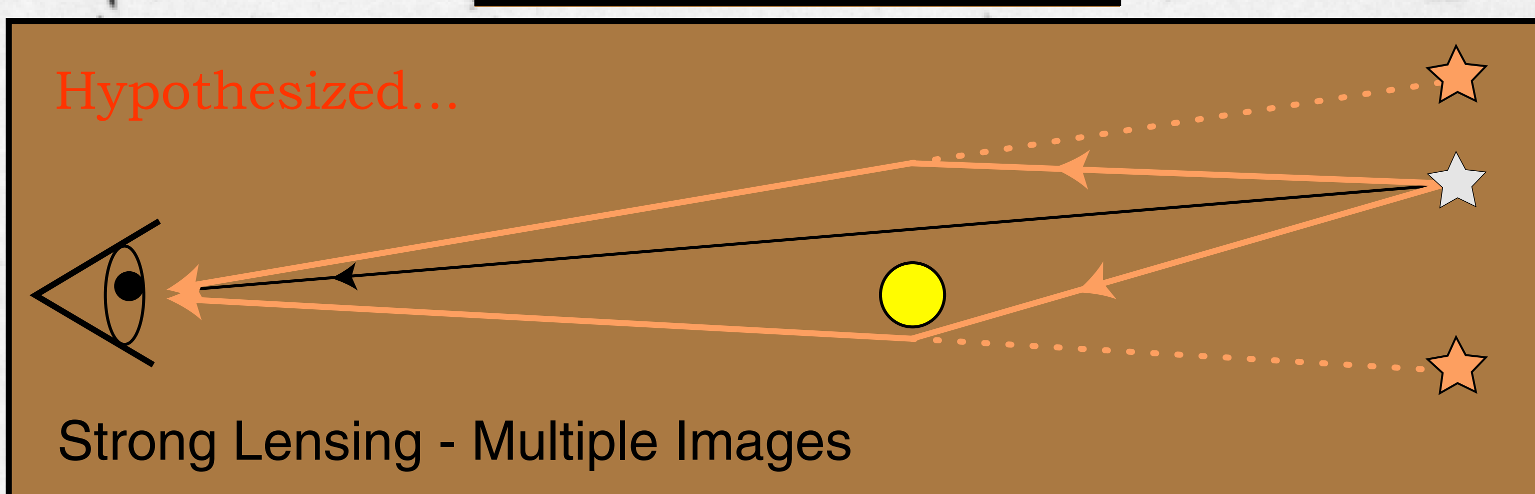
$$\alpha = \frac{4GM}{bc^2}$$



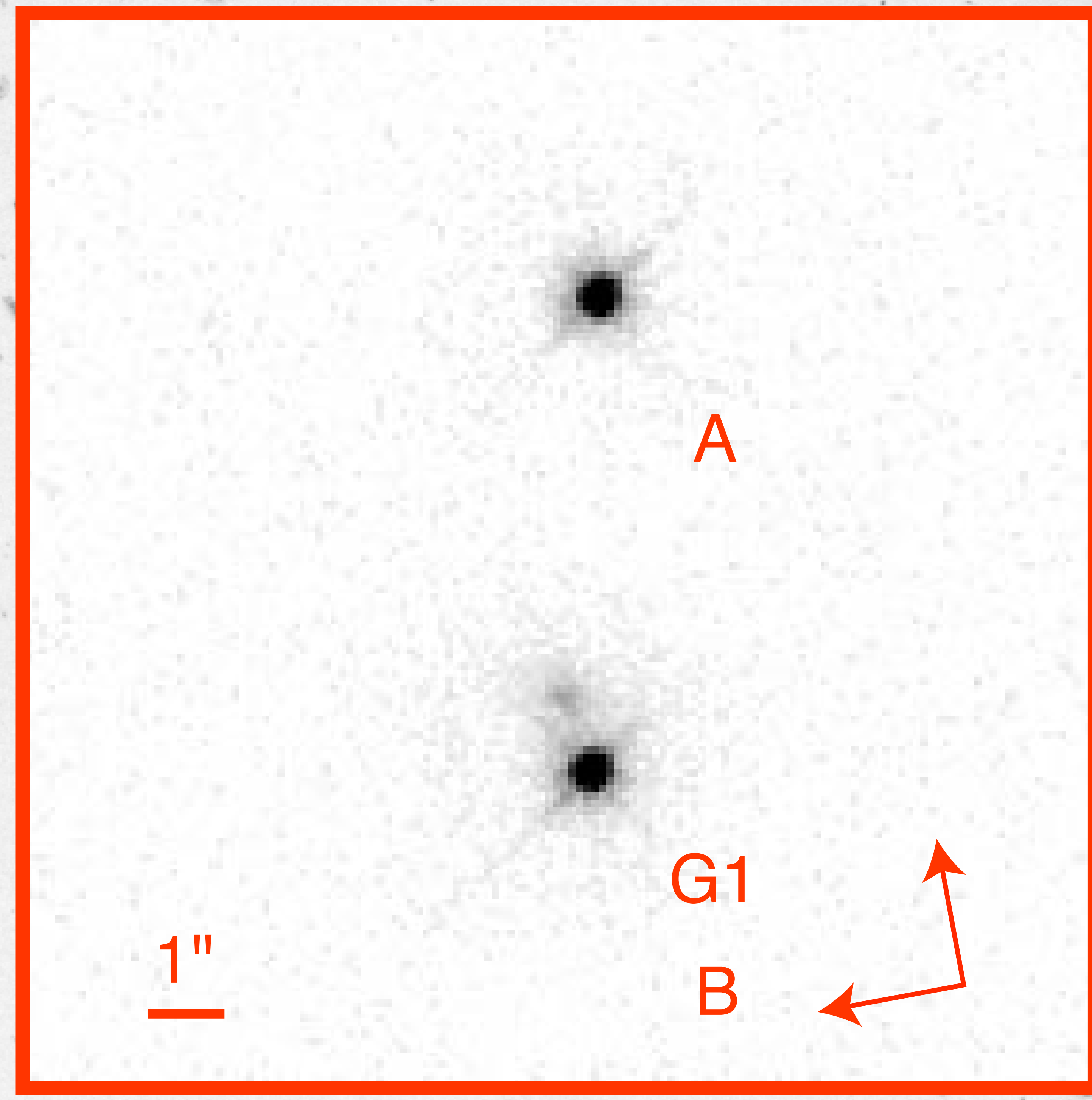
View from Earth



Verified 1919



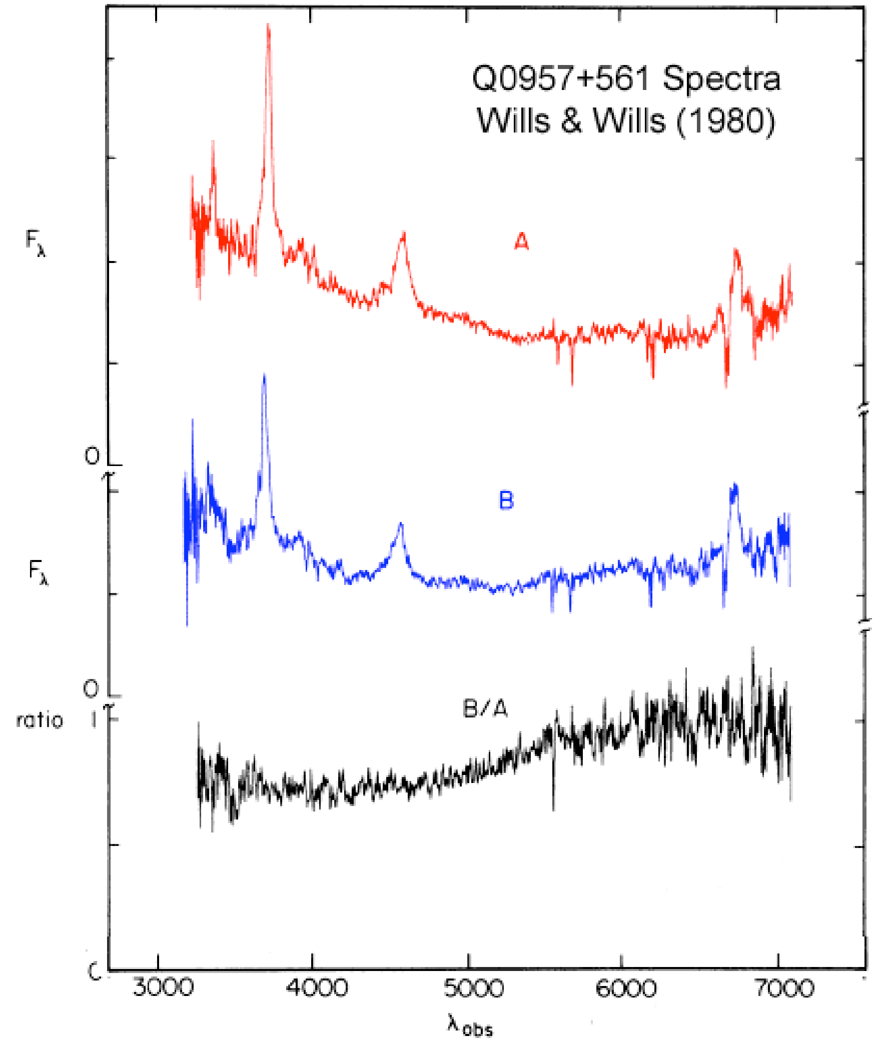
1979: A real gravitational lens?



Double quasar discovered by Walsh, Carswell, & Weymann 1979
Image from Hubble Space Telescope (Bernstein et al 1997)

A double image, or just two similar objects?

But this is clearly a lens...



Global VLBI observations of the gravitational lens system 0957+561 A,B

Garrett et al (1996)

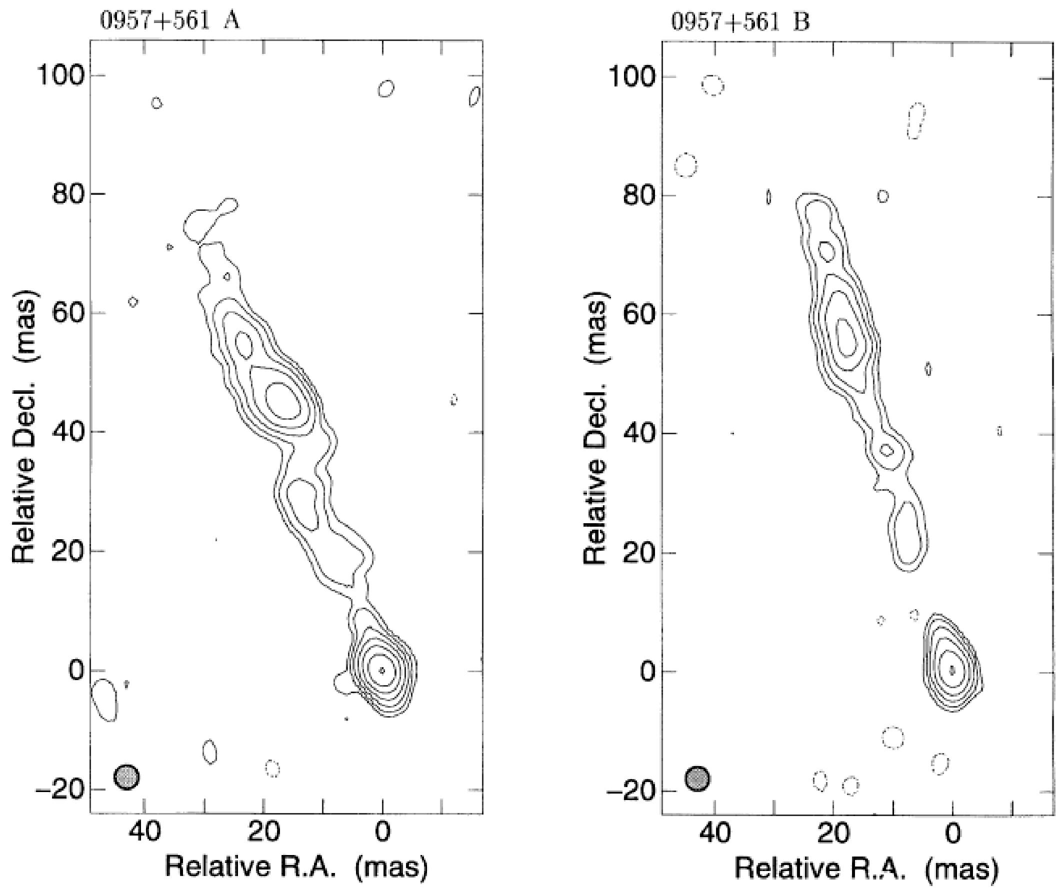


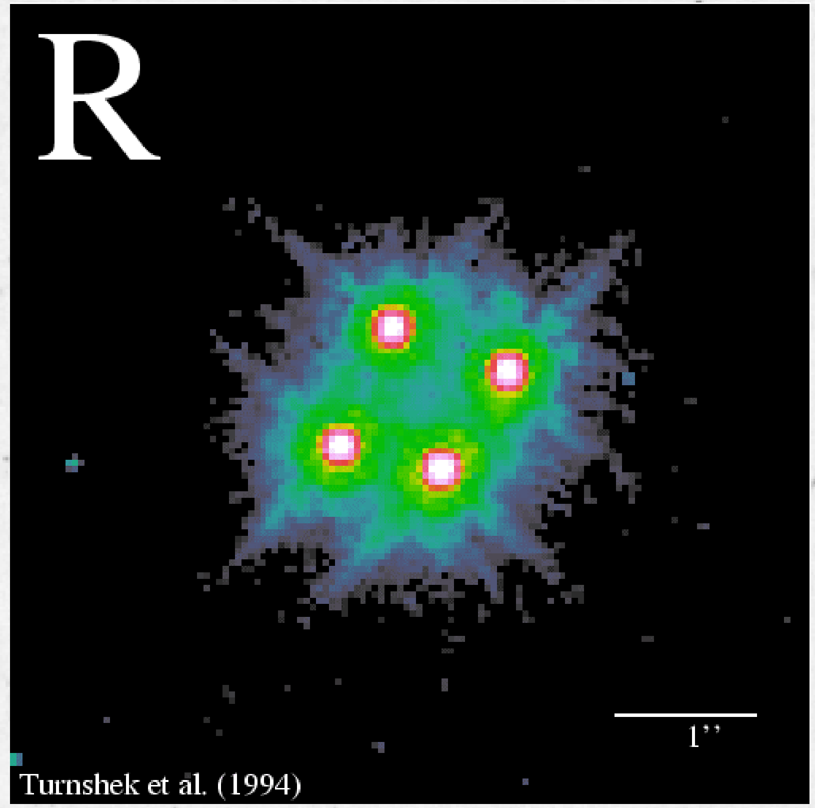
Figure 2. The λ18-cm global VLBI hybrid maps of 0957+561 A,B. The contours are plotted at intervals of −0.15, 0.15, 0.3, 0.6, 1.2, 2.4, 4.8, 9.6 mJy beam^{-1}. The maps were restored with a 4-mas (FWHM) circular Gaussian beam (as shown in the bottom left corner) and have an off-source rms noise of ~ 65 μJy beam^{-1}. Note that each component that is identified in one image has a counterpart in the other.

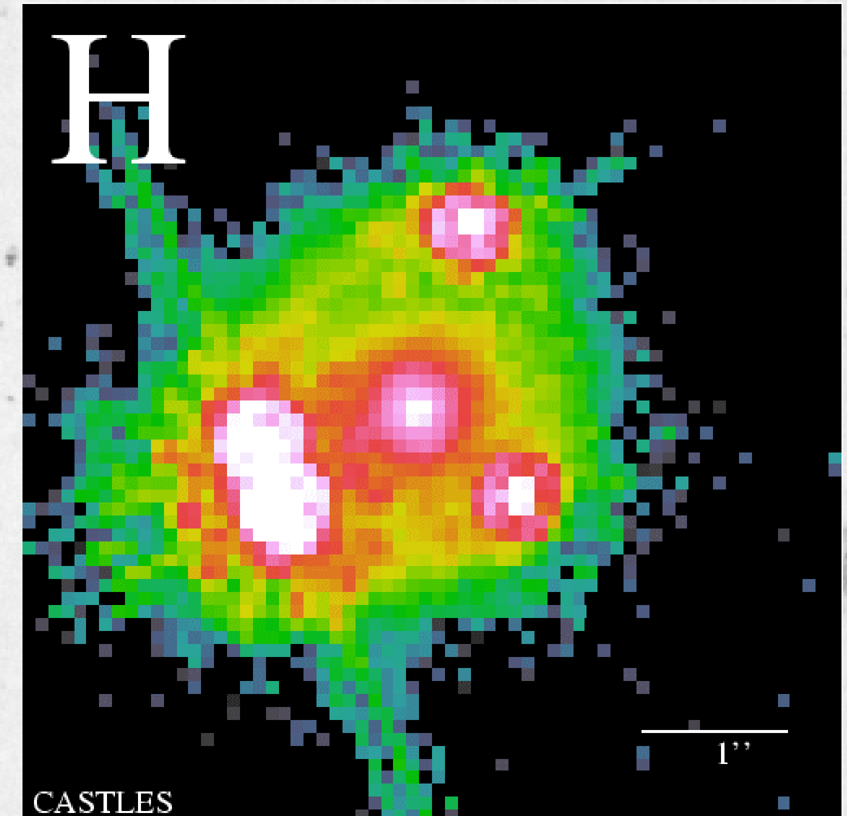
Same color/spectra...

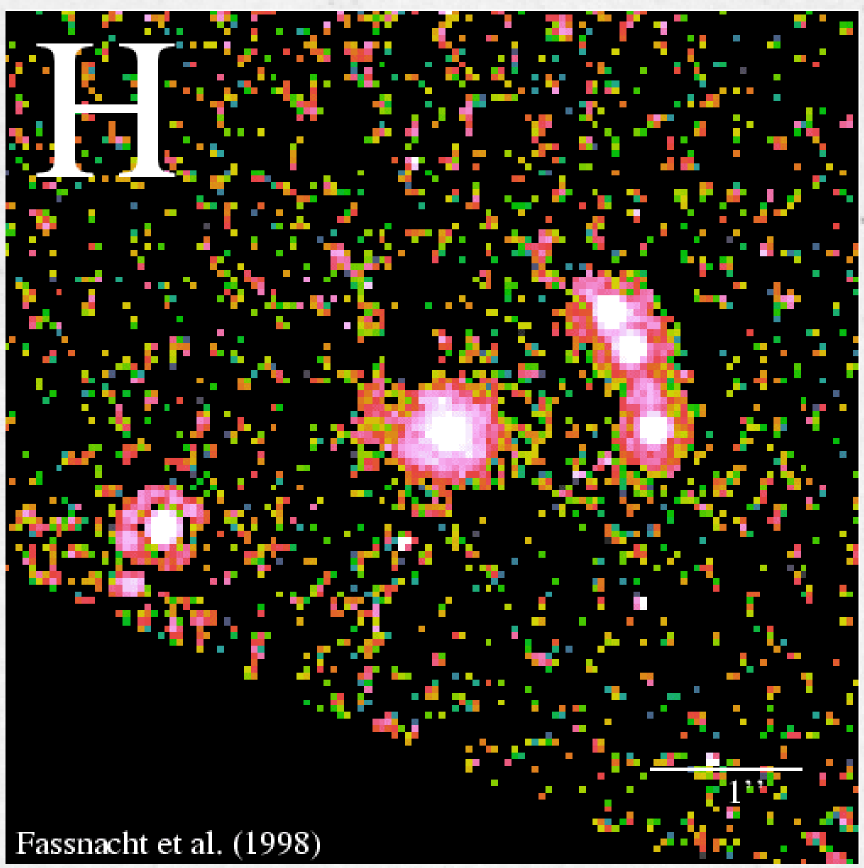
Same through radio telescope...

...and when image A gets brighter, image B does 1 year later!

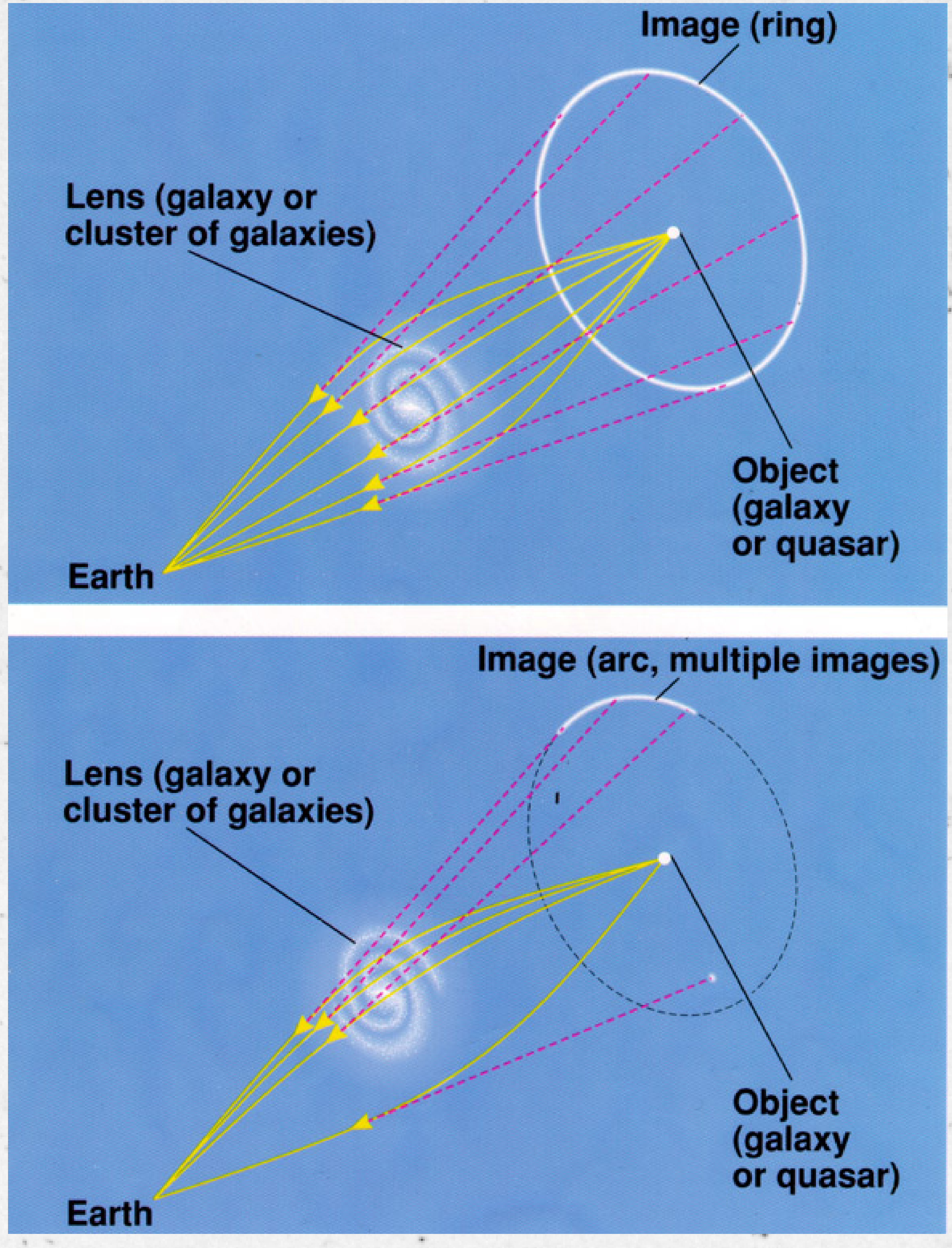
50-100 cases of multiple imaging by galaxies now known:



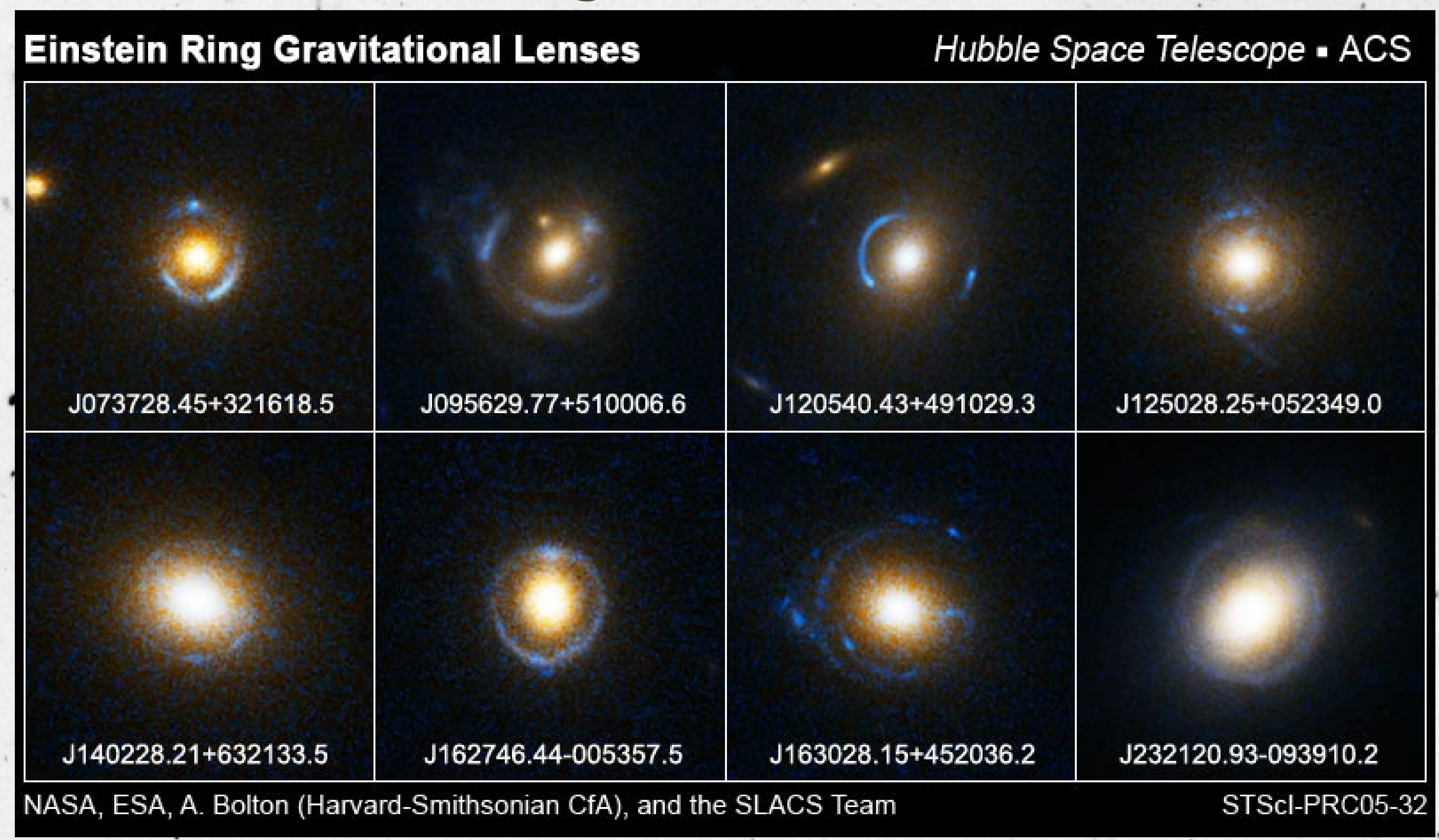


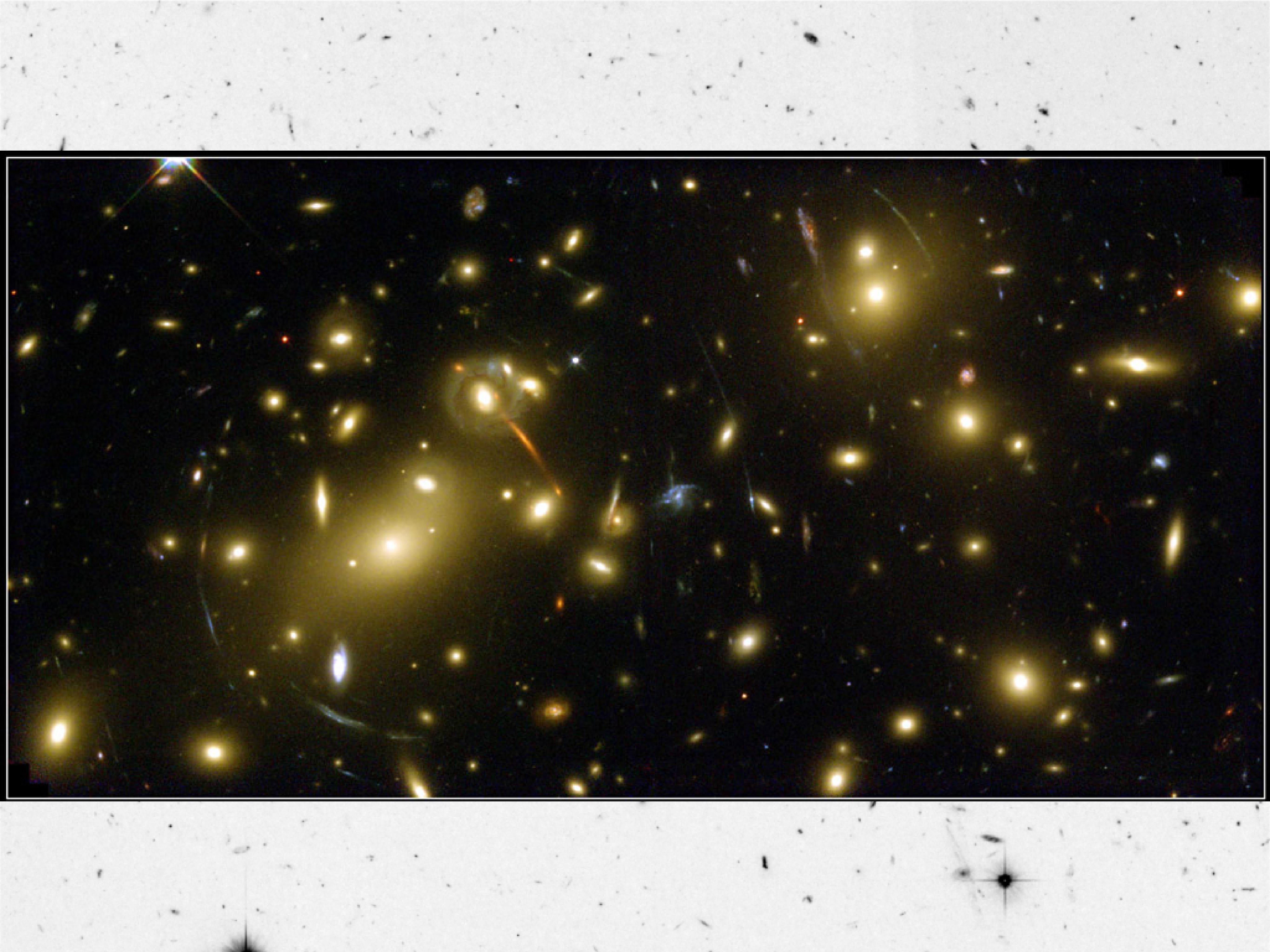


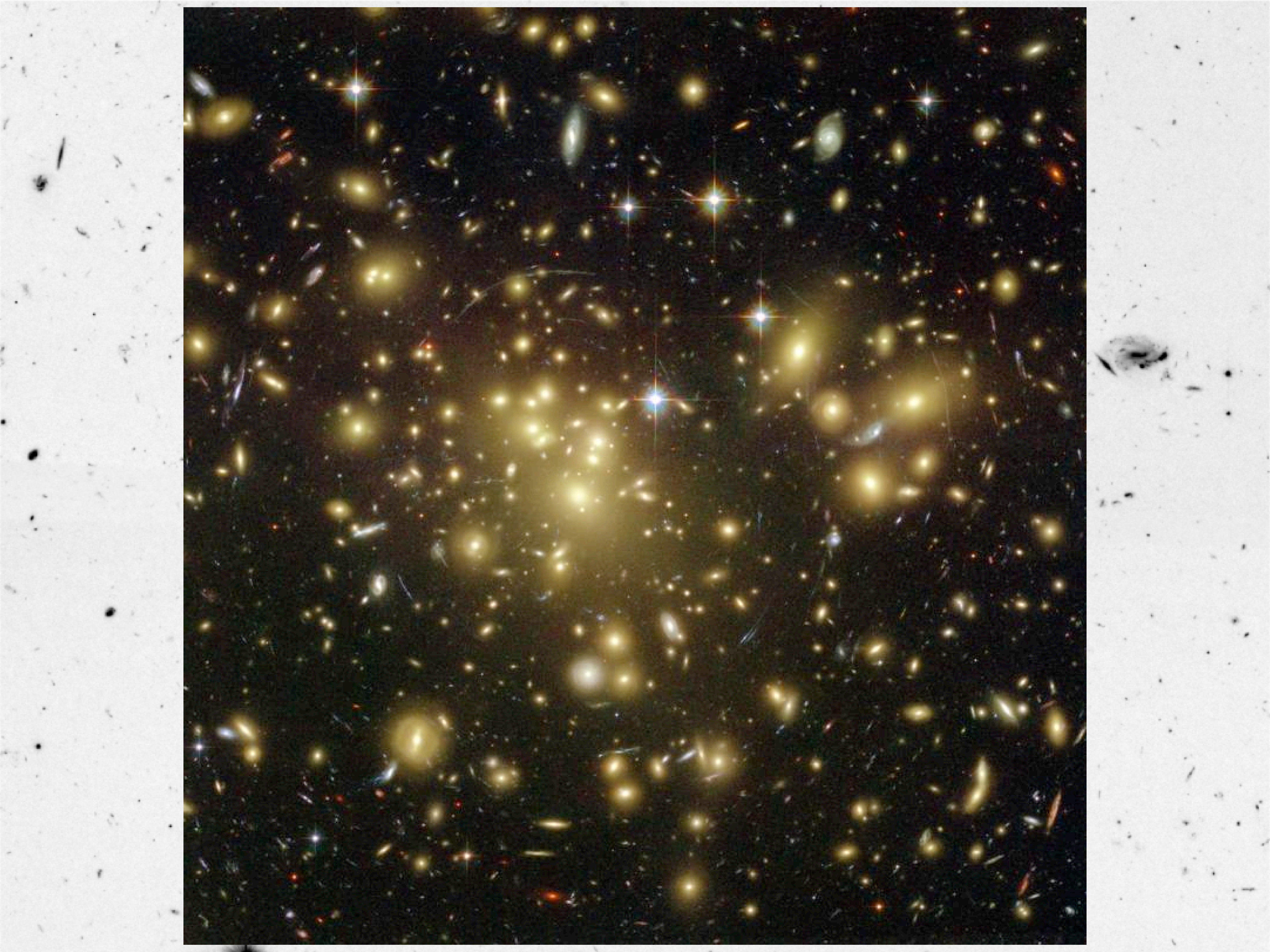
“Einstein rings”



Real Einstein Rings & Arcs







The recent history of the Universe:

- *<1917: Assumed that Universe is basically unchanging.*
- *~1920: Einstein & others realize that if GR is correct, it is very difficult to make the Universe stay still.*

Λ

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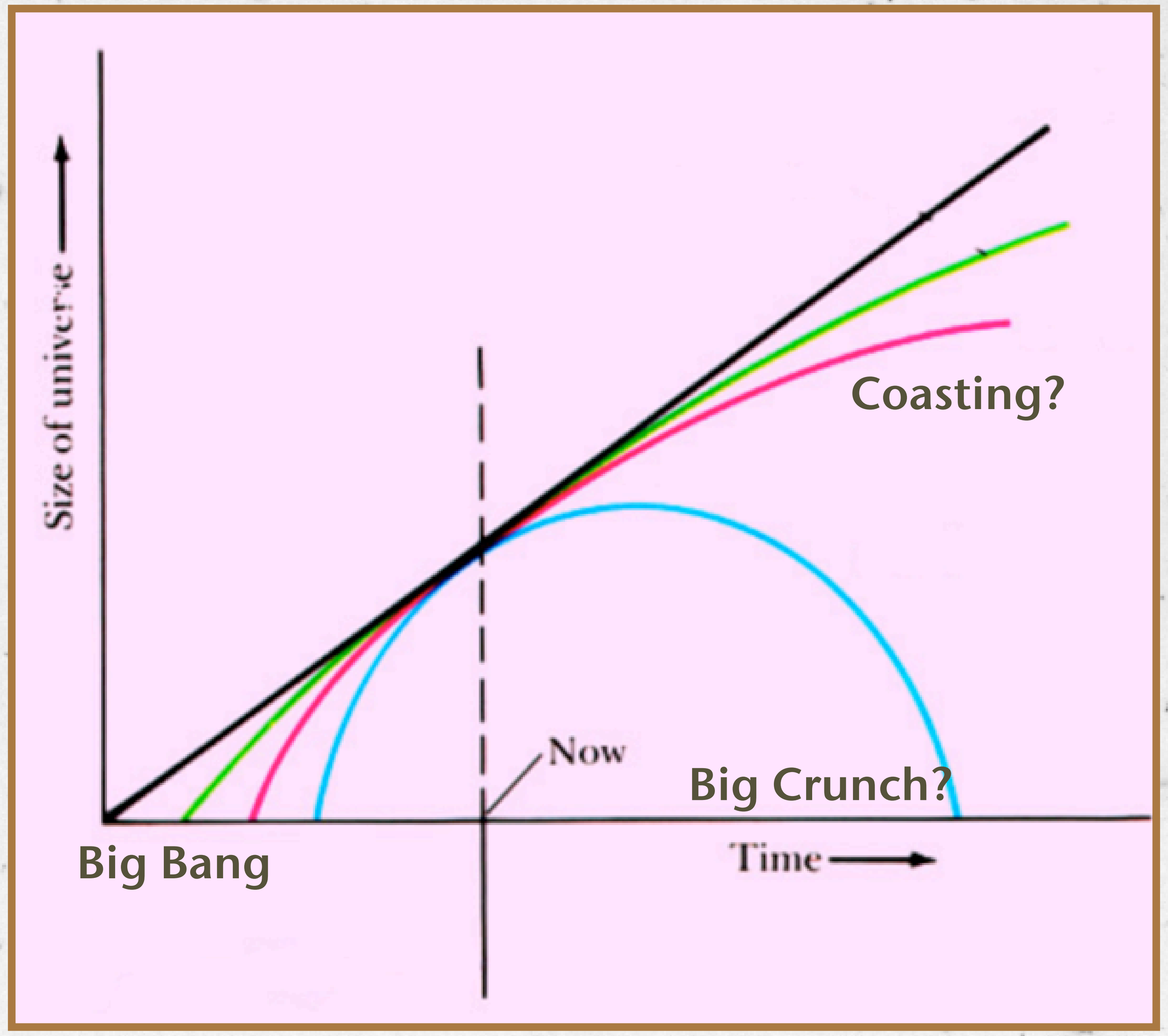
- *~1930: Edwin Hubble shows Universe is expanding, not standing still!*

Will the Universe Recollapse?

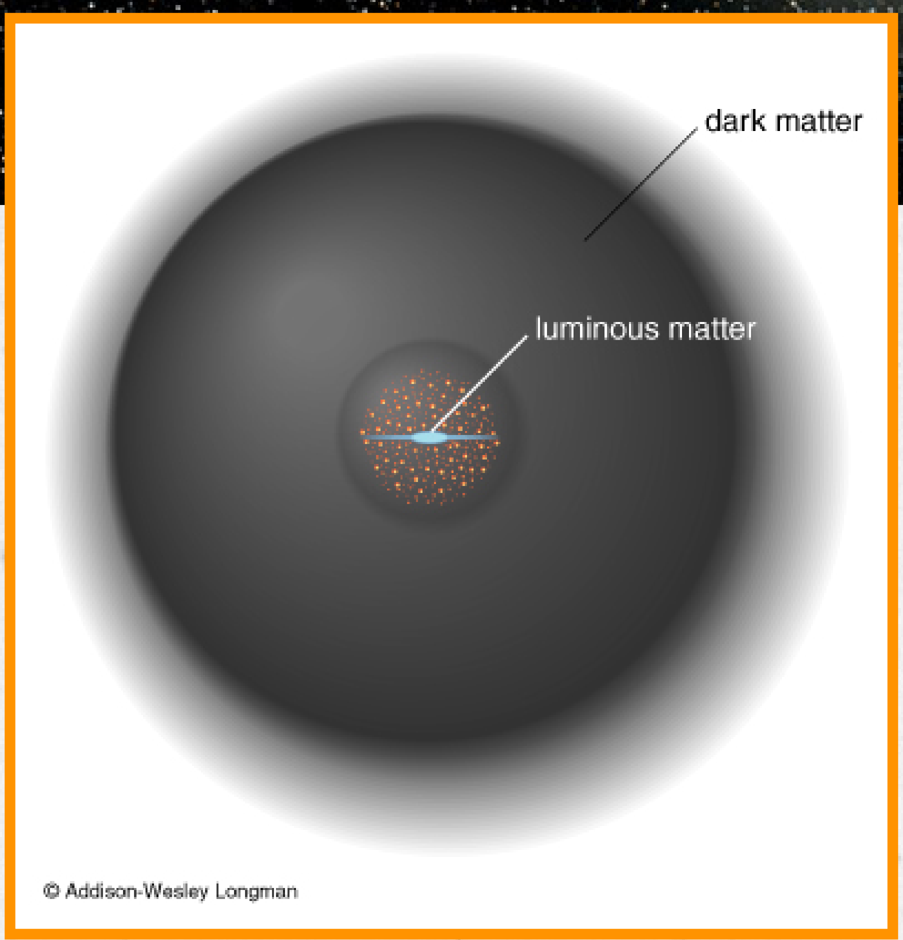


…depends how much matter (gravity) there is

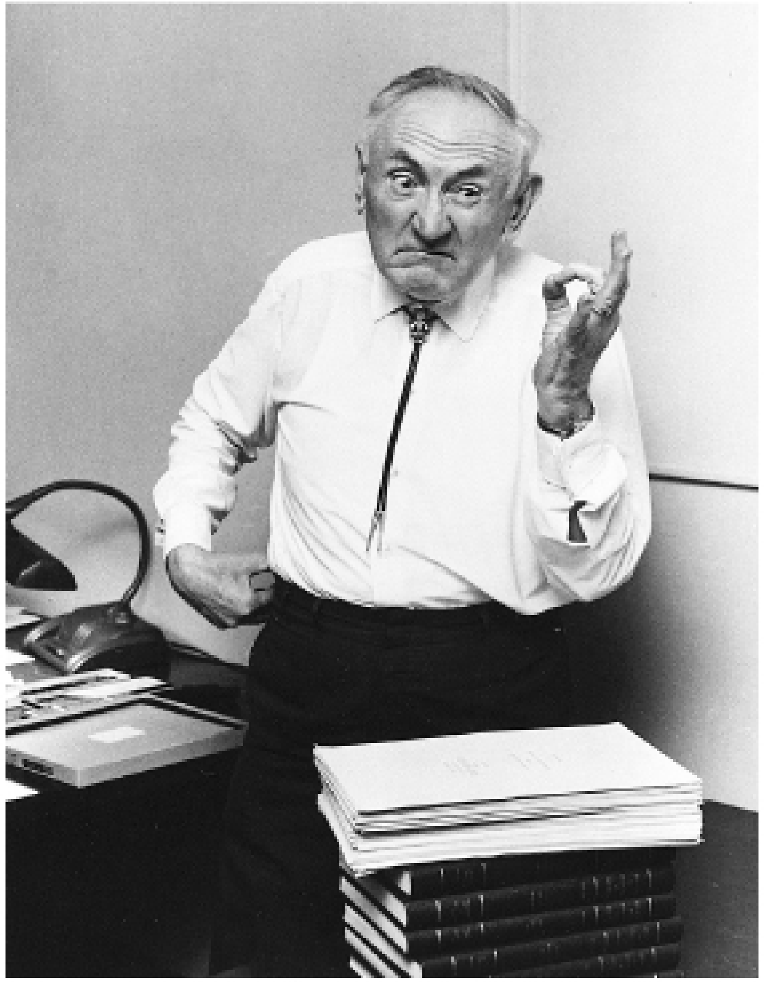
The recent history of the Universe:

- *<1917: Assumed that Universe is basically unchanging.*
- *~1920: Einstein & others realize that if GR is correct, it is very difficult to make the Universe stay still.*
- *~1930: Edwin Hubble shows Universe is expanding, not standing still!*
- *1930-2000: Astronomers debate whether Universe has enough matter to halt expansion and recollapse.*
- *1980's: Strong evidence that most of the matter in the Universe is invisible!*

Signs of Dark Matter



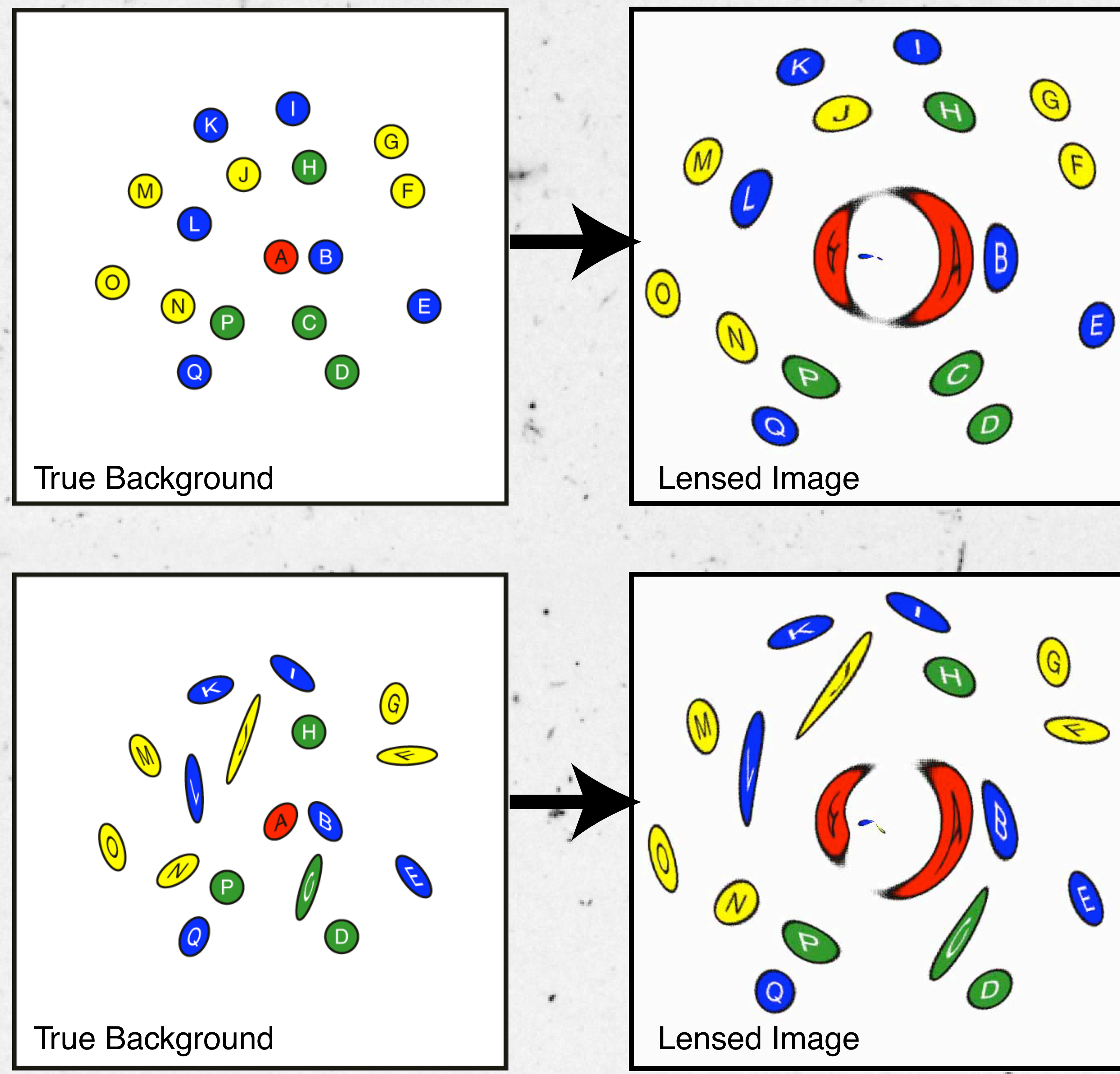
More signs of dark matter:



Fritz Zwicky 1932: Galaxies in clusters should be flying apart. Need extra mass to hold together?

- Gravitational multiple images, rings, and arcs confirm the presence of large quantities of dark matter.
- Can we look for dark matter in directions that do not have lucky alignments with bright background objects?

Seeing the invisible with gravitational lensing:

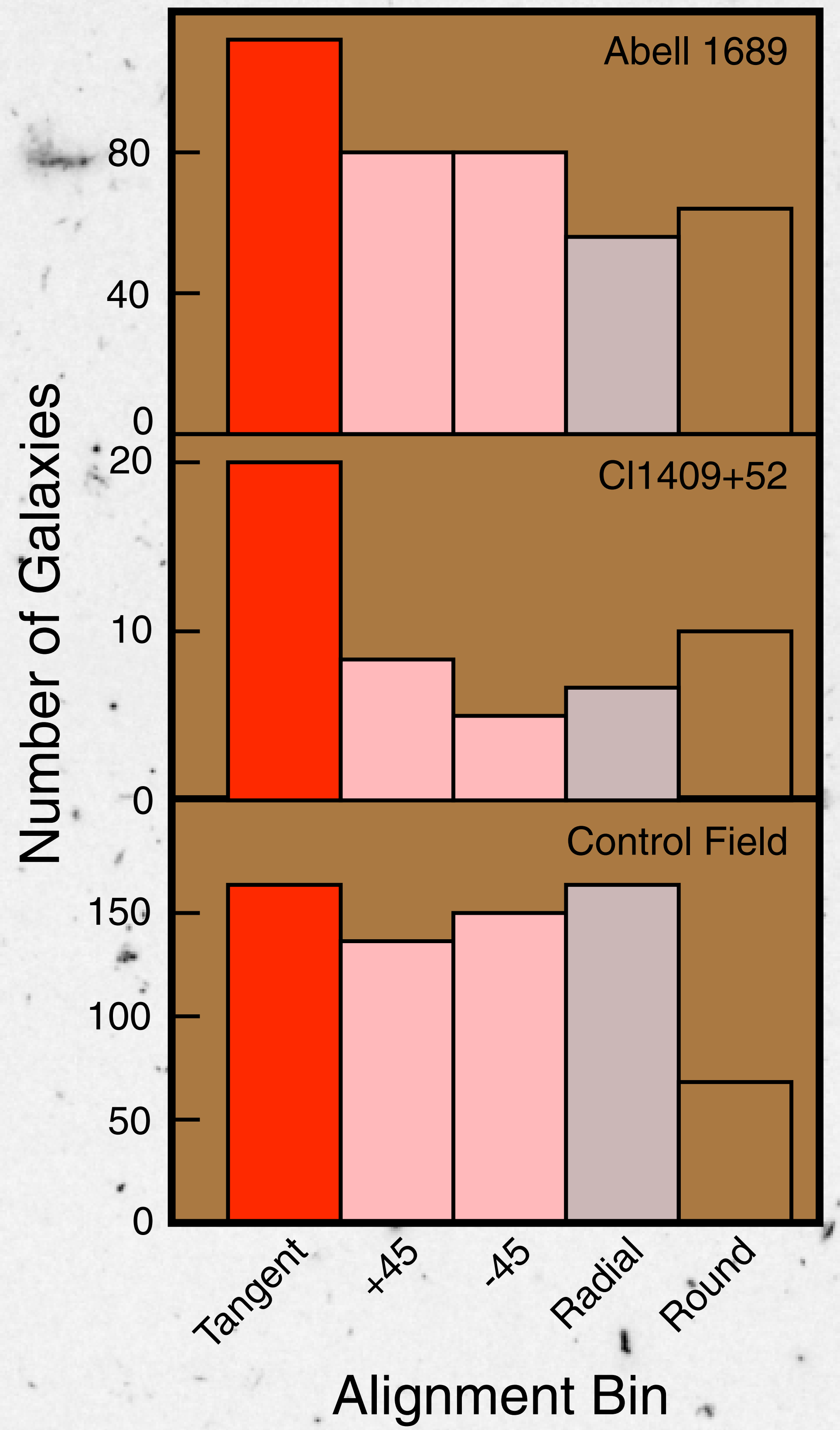


"Weak gravitational lensing"

Effect of cluster dark matter on the wallpaper:

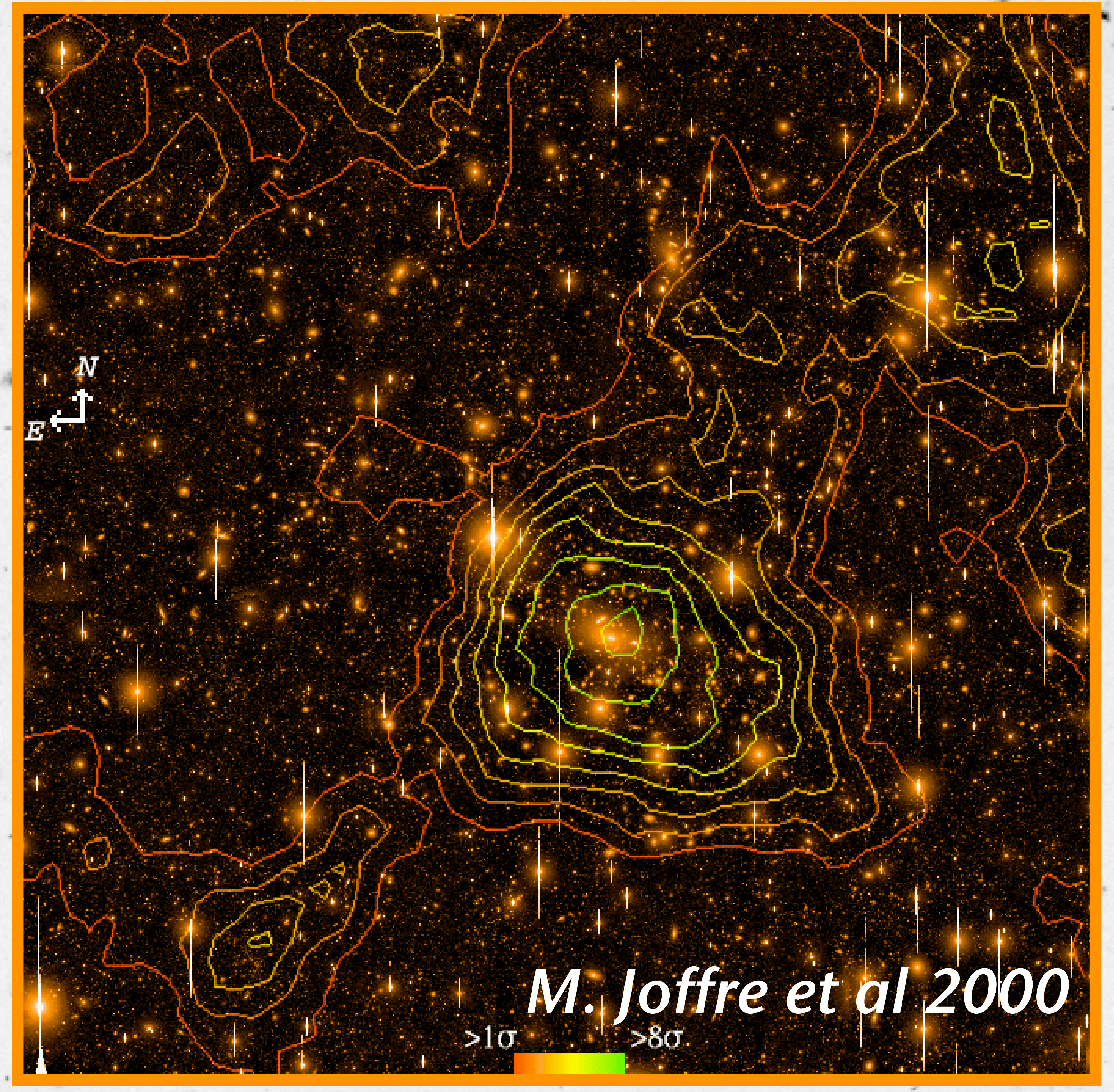
animation by J. A. Tyson et al, Bell Labs

First detection of weak gravitational lensing
Tyson, Wenk, & Valdes (1990)




Galaxy cluster CL0024+1624
J. P. Kneib et al 2003

Dark Matter Revealed:



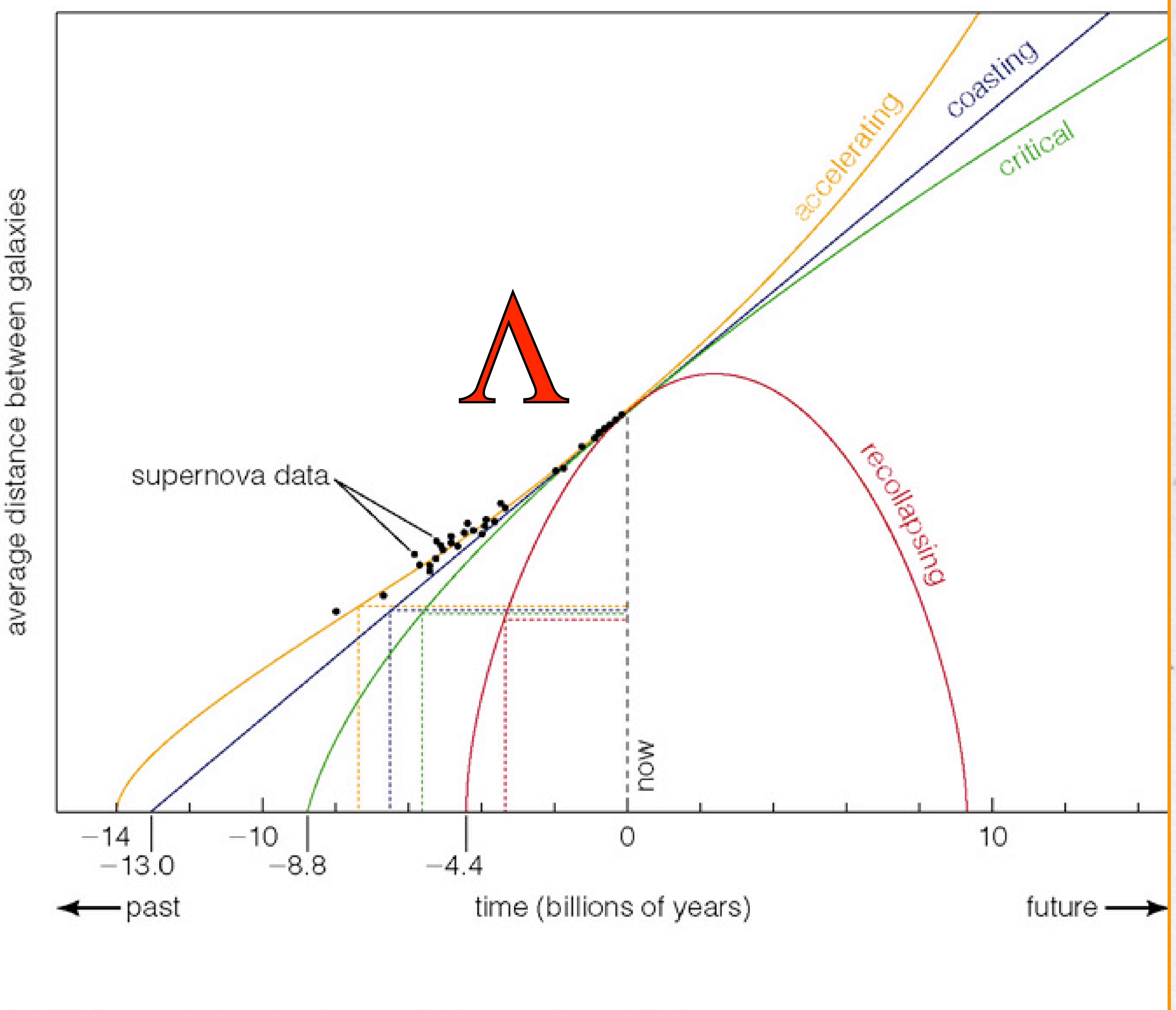
History of the Universe (cont’d)

- History of size of Universe = contents of the Universe
- Astronomers can look into the past
  - Mars signals are a few minutes old
  - Cassini signals are a few hours old
  - Light from distant galaxies is a few BILLION years old
- How far away = how long ago.

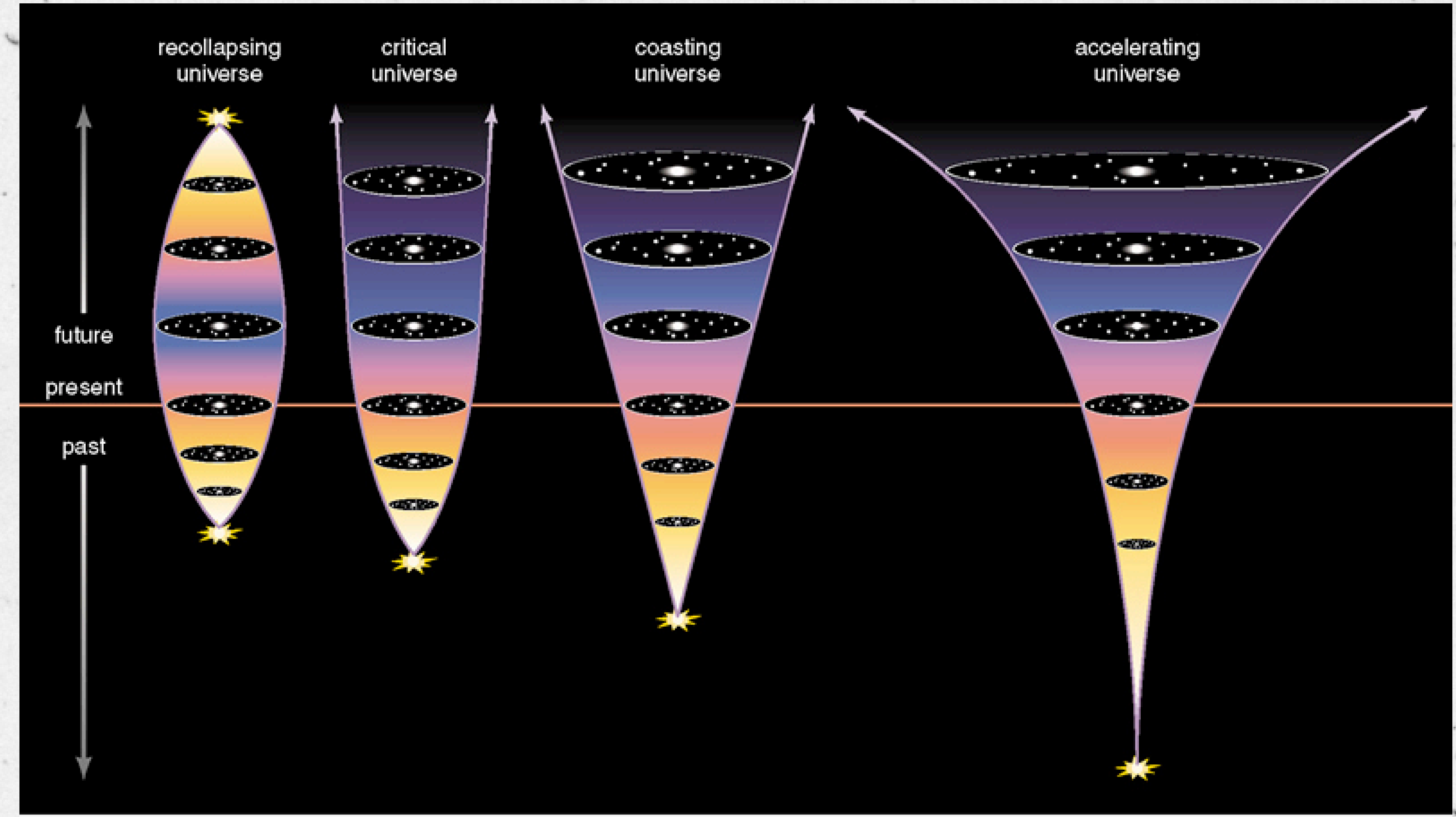
Mapping the History of Universe

- Supernovae = exploding stars.
- Brightness = distance = how long ago
- Hard part: find an exploding star 5 billion light-years away!
- 1998: two experiments to determine the expansion history of the Universe. "Big Crunch" or "coasting" in the future?

Surprise!

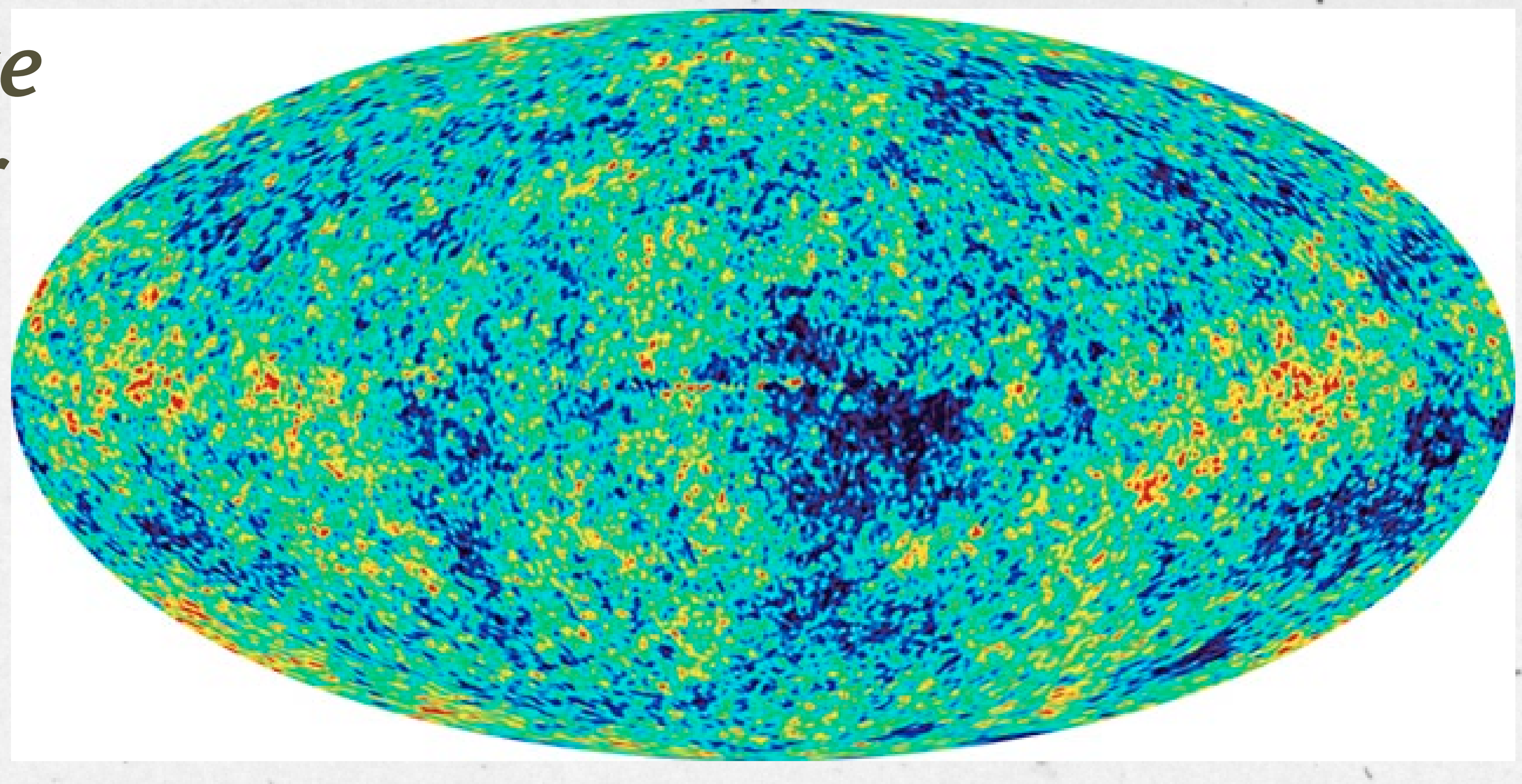

Λ
average distance between galaxies
accelerating
coasting
critical
recollapsing
supernova data
now
−14
−10
0
10
−13.0
−8.8
−4.4
past
time (billions of years)
future

An accelerating Universe?

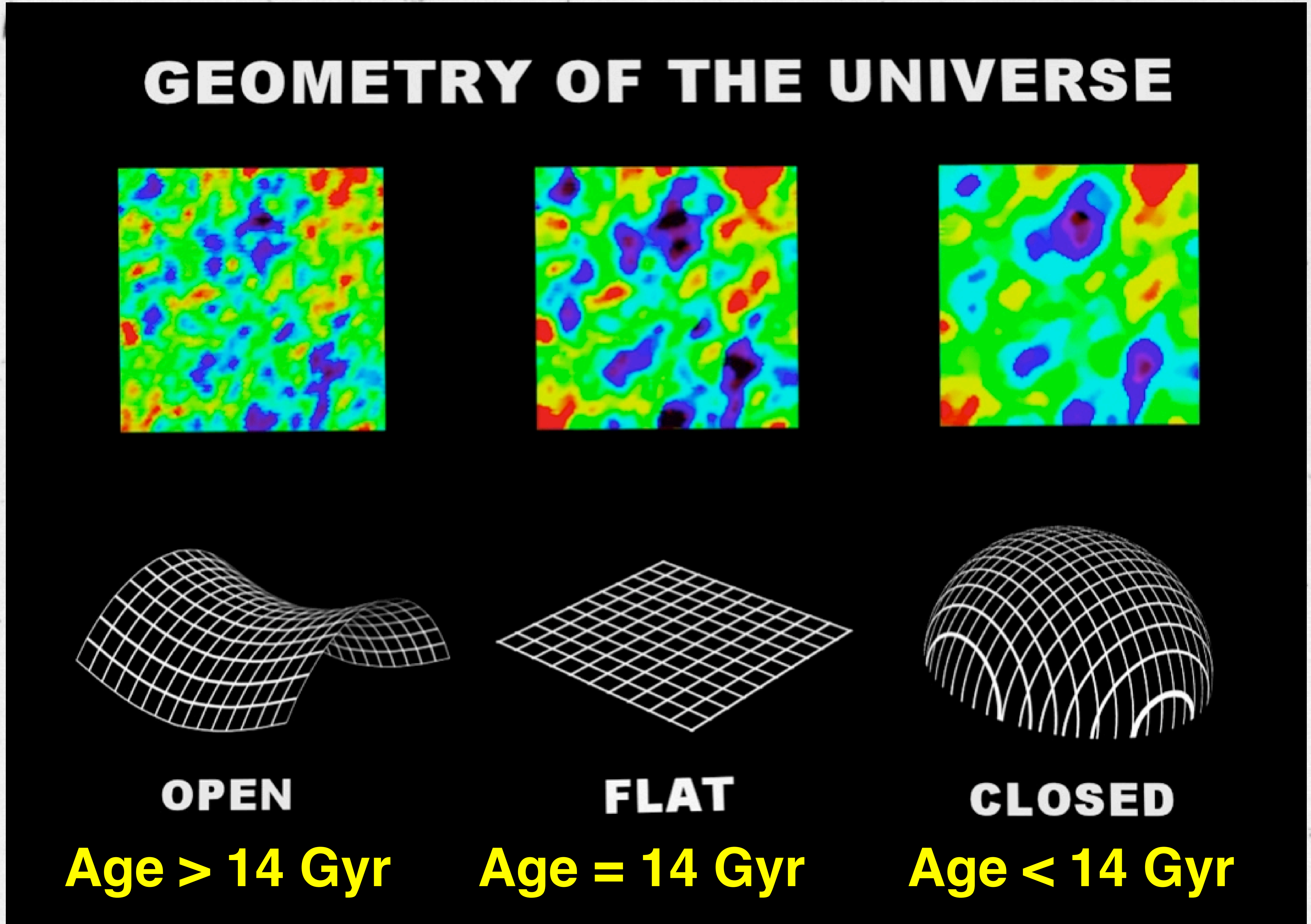


Looking at the Big Bang:

Wilkinson Microwave Anisotropy Explorer

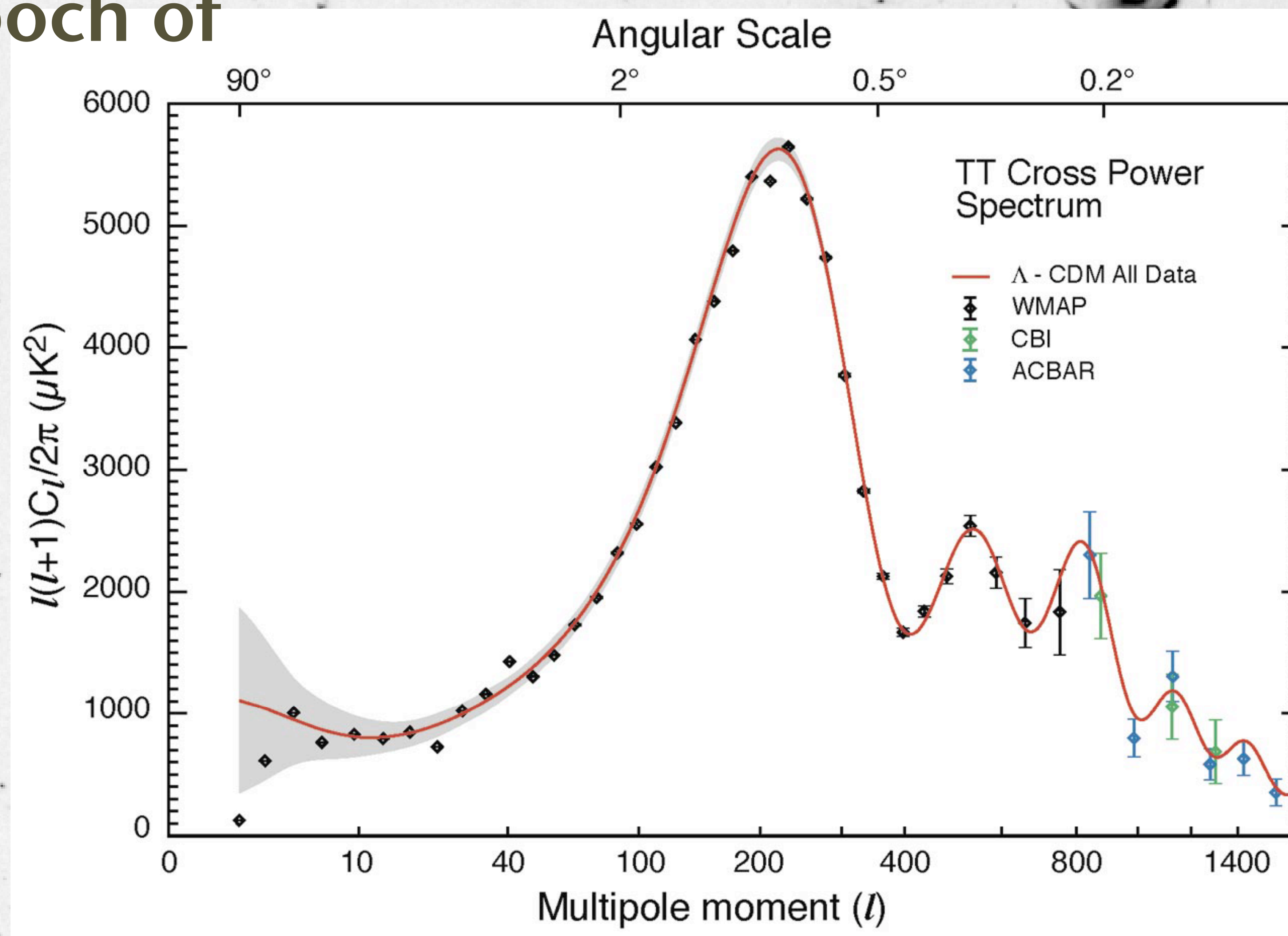


WMAP's distance to the Big Bang:

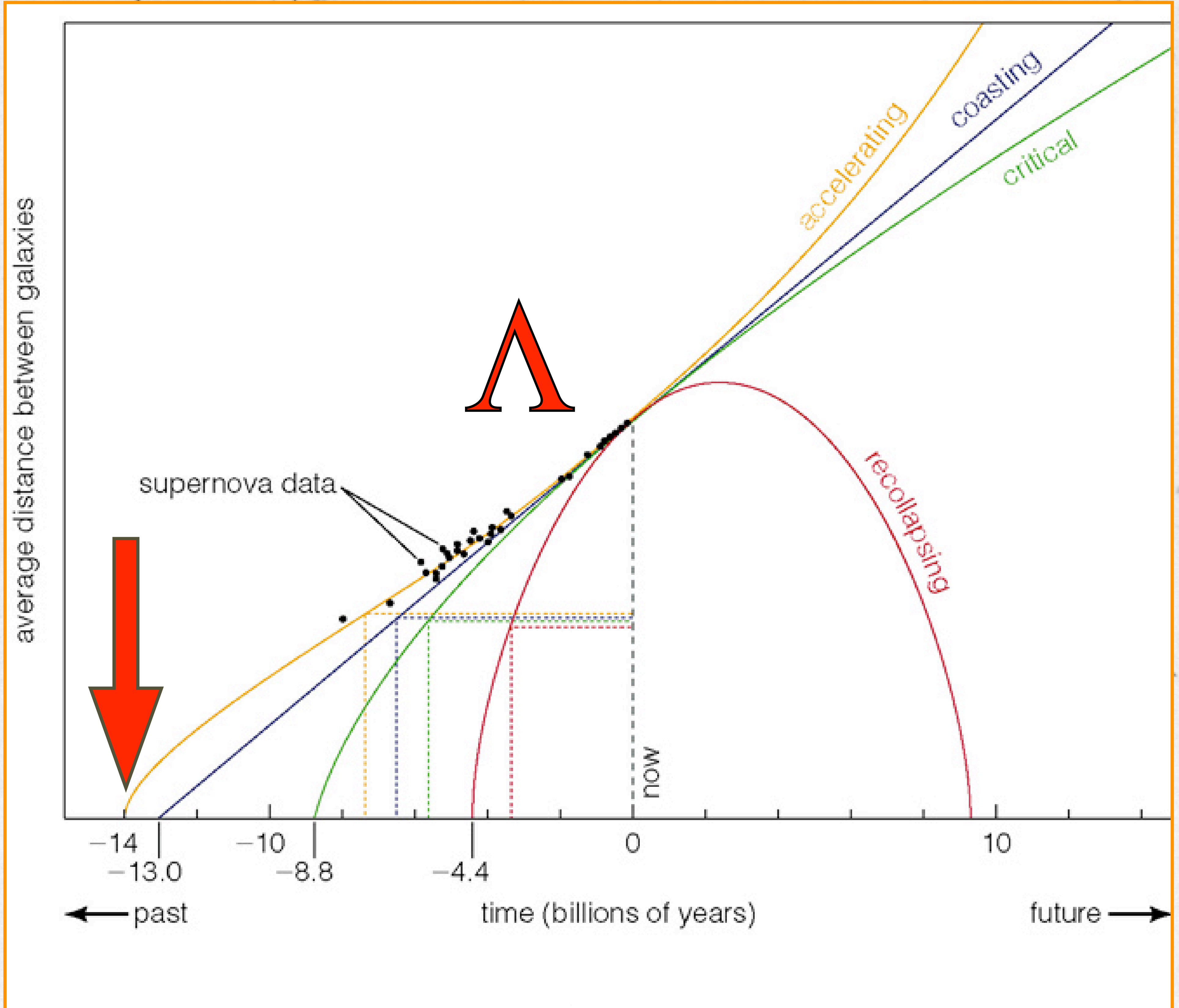


Cosmic Background Fluctuations:

More precisely: the peak of the power spectrum of CMB sky determines distance to the plasma epoch of Universe.



Surprise!



Λ
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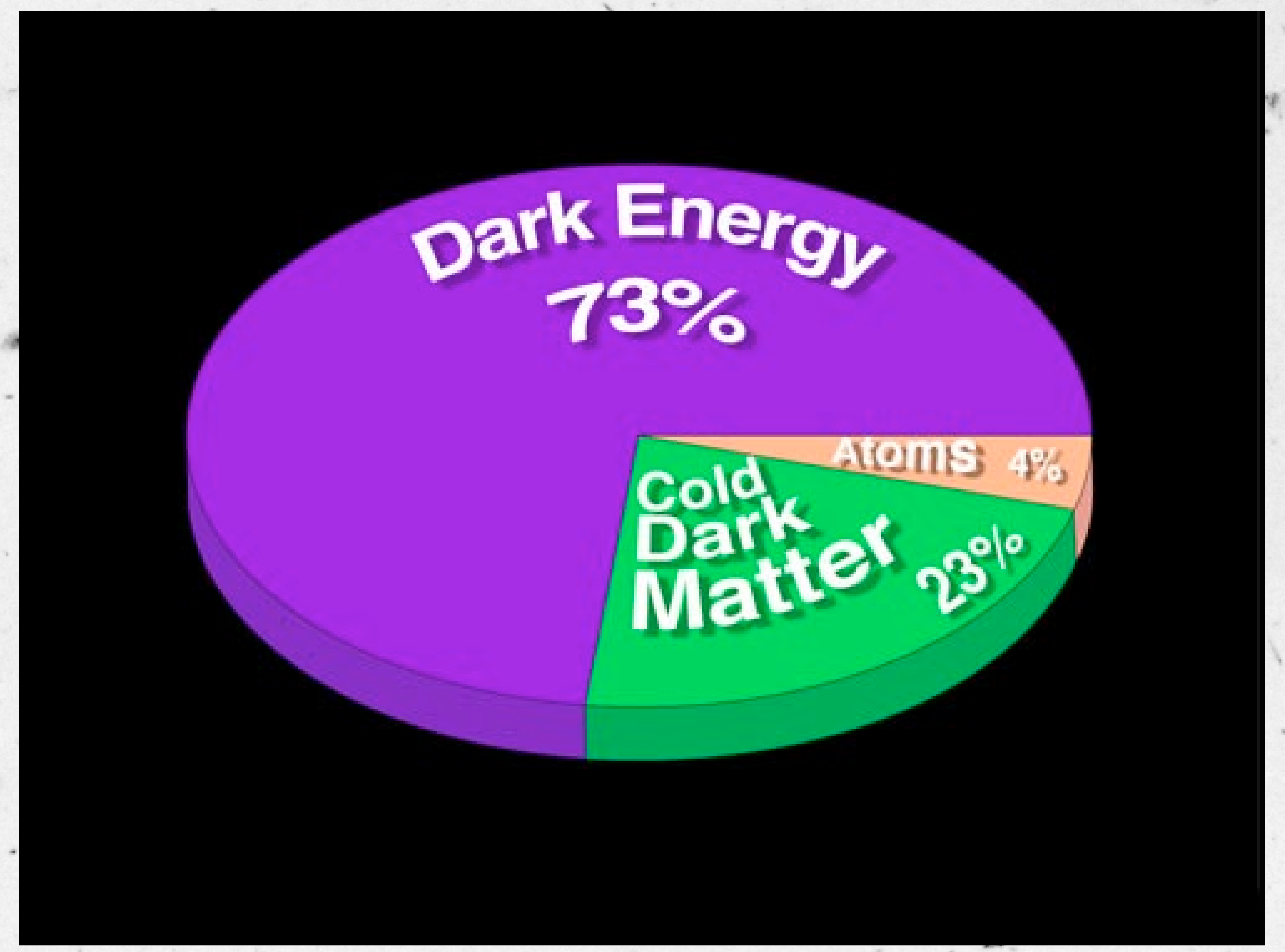
10
past
time (billions of years)
future

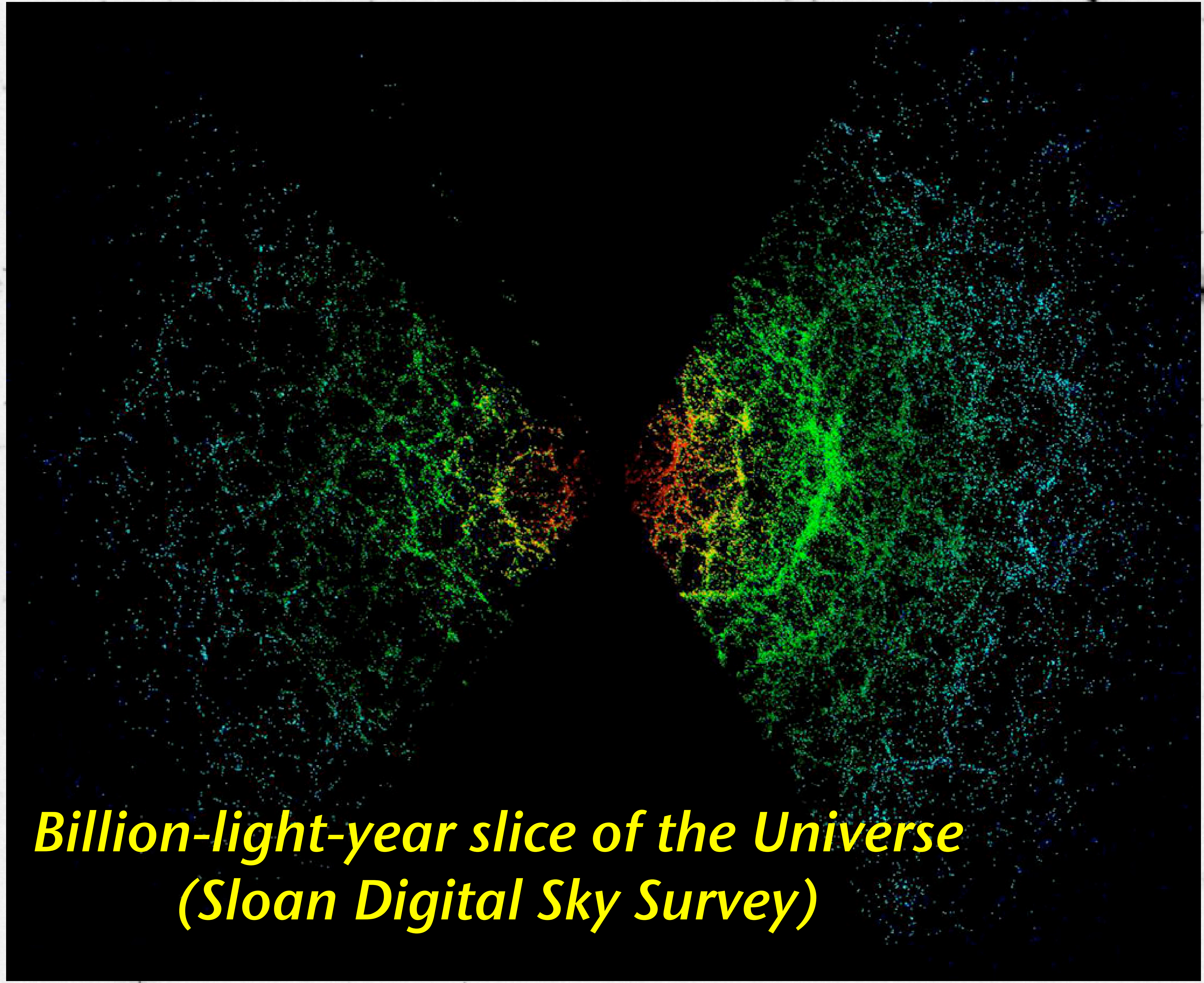
What is the Universe made of?



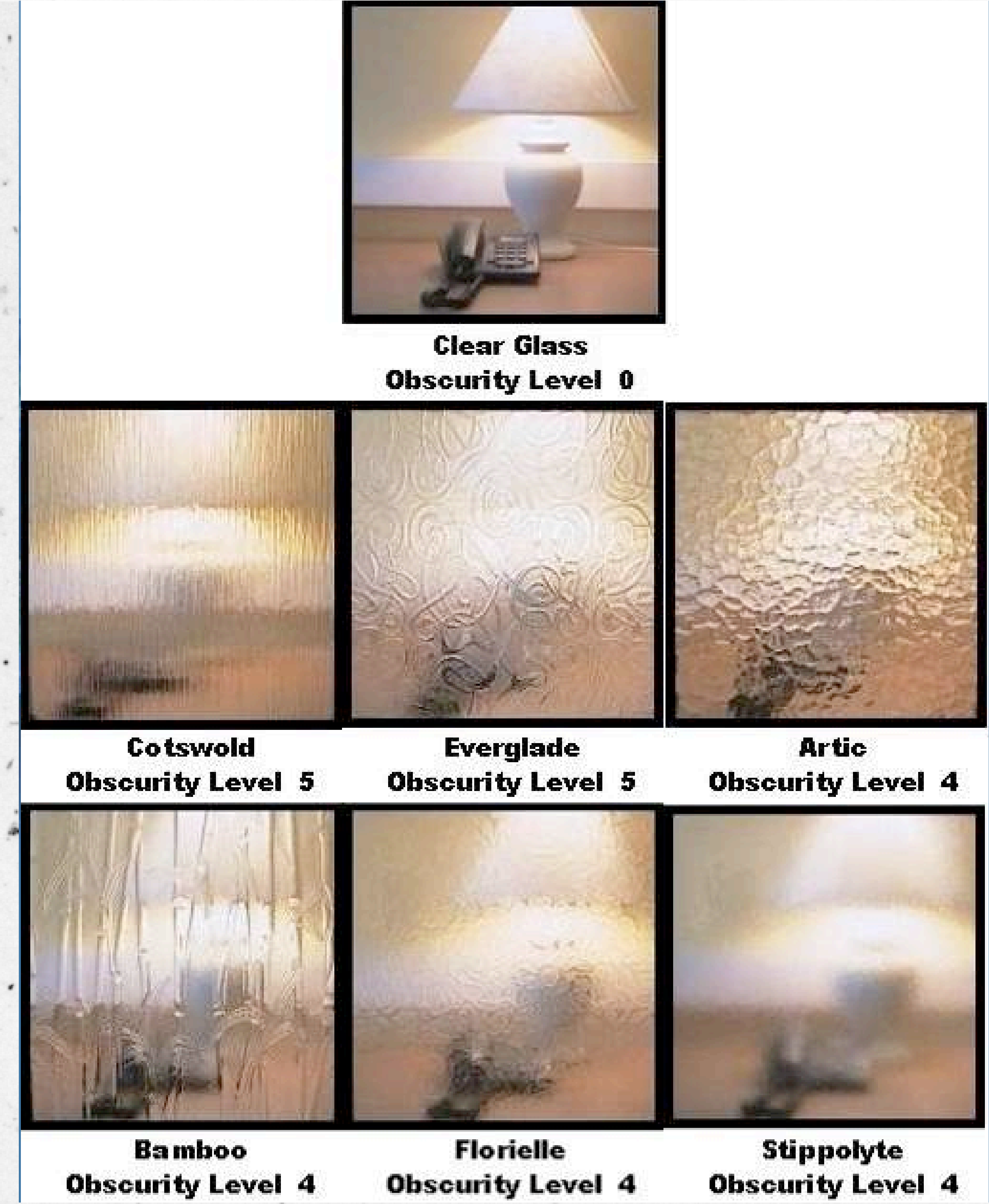
Learning more about dark energy:

- The cosmic background tells us relatively little about what has happened **since** 14 Gyr ago.
- Determine the expansion history of Universe to greater accuracy using supernovae observed from ground and **SPACE**.
- Is it consistent with the cosmological constant?
- If not: is there some new "dark energy" field, or is General Relativity wrong? Can't tell which from supernovae alone.

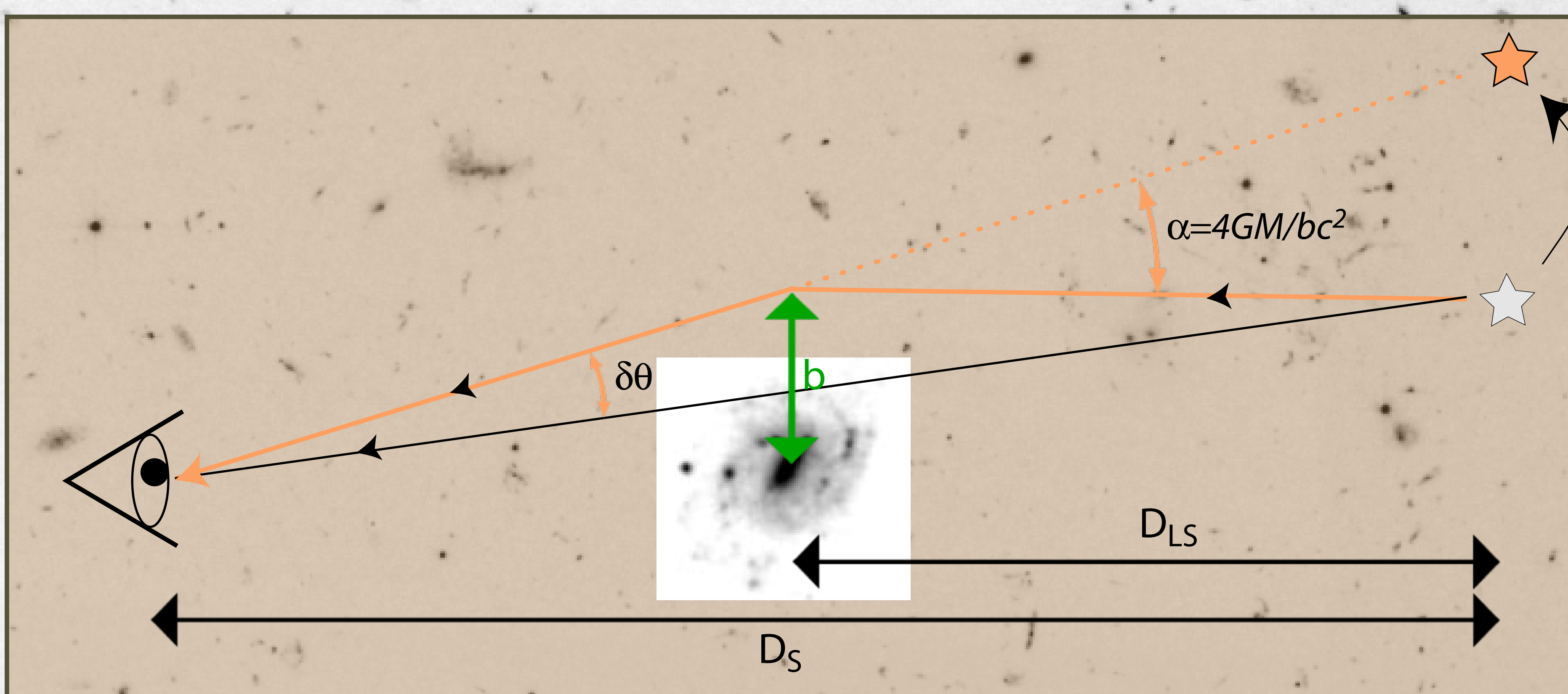
The frothy Universe:



A view through the Universe



The obscurity level of the Universe:



$$\delta\theta = \frac{4GM}{bc^2} \quad \frac{D_{LS}}{D_S}$$

We observe this deflection angle (more precisely, gradients of the deflection angle).

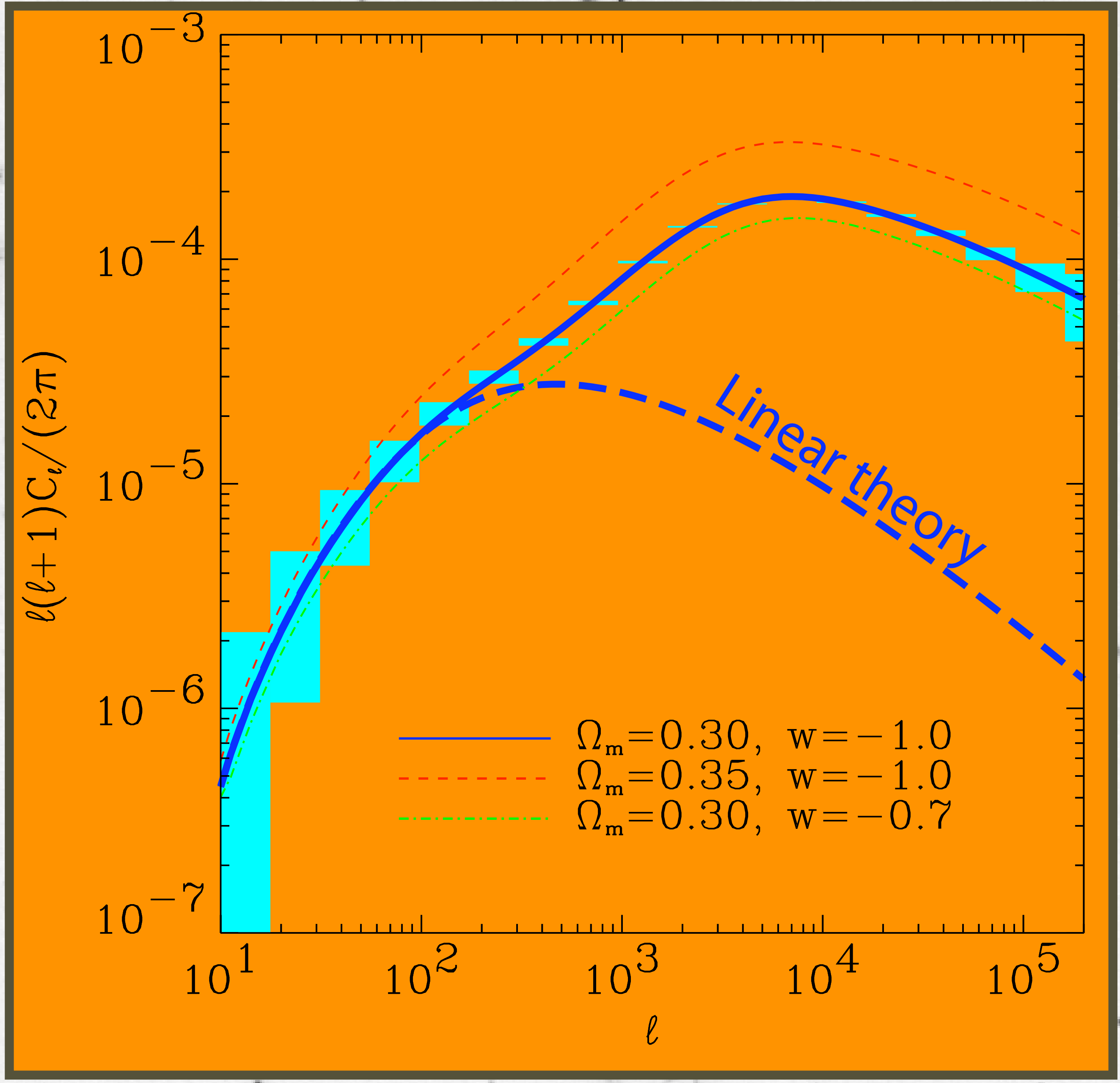
Cosmology changes growth rate of mass structures in the Universe.

Cosmology changes the geometric distance factors.

...tells us the history of dark matter AND dark energy!

What does weak lensing add?

- We can measure a power spectrum, just like for CMB, but it measures things more **recently** than 14 Gyr ago.
- WL can divide source galaxies into many distance slices and measure **many power spectra.** Combine them to determine the **history** of dark energy.
- WL sees non-linear, **non-Gaussian** growth and collapse of mass structures.
- WL can measure and use the relation between **visible** matter and **dark** matter.
- WL can measure the growth of Universe's size **and** growth of structure within it. *This allows us to test whether GR is correct!*



To measure the dark energy, just:

1. Take pictures of roughly 1 billion galaxies

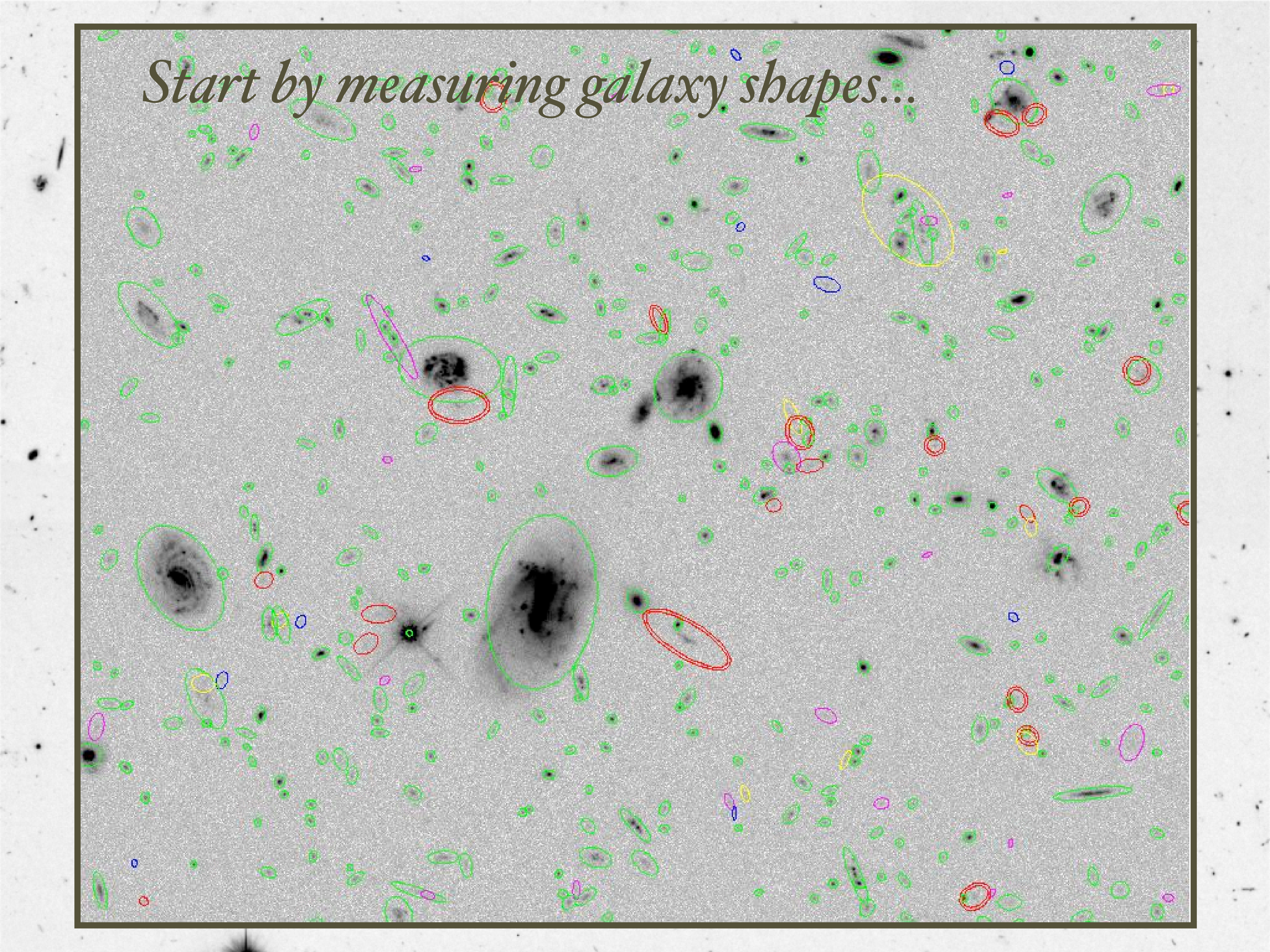
2. Carefully measure the shape of each one

3. Determine the lensing distortion to an accuracy of about 0.0001

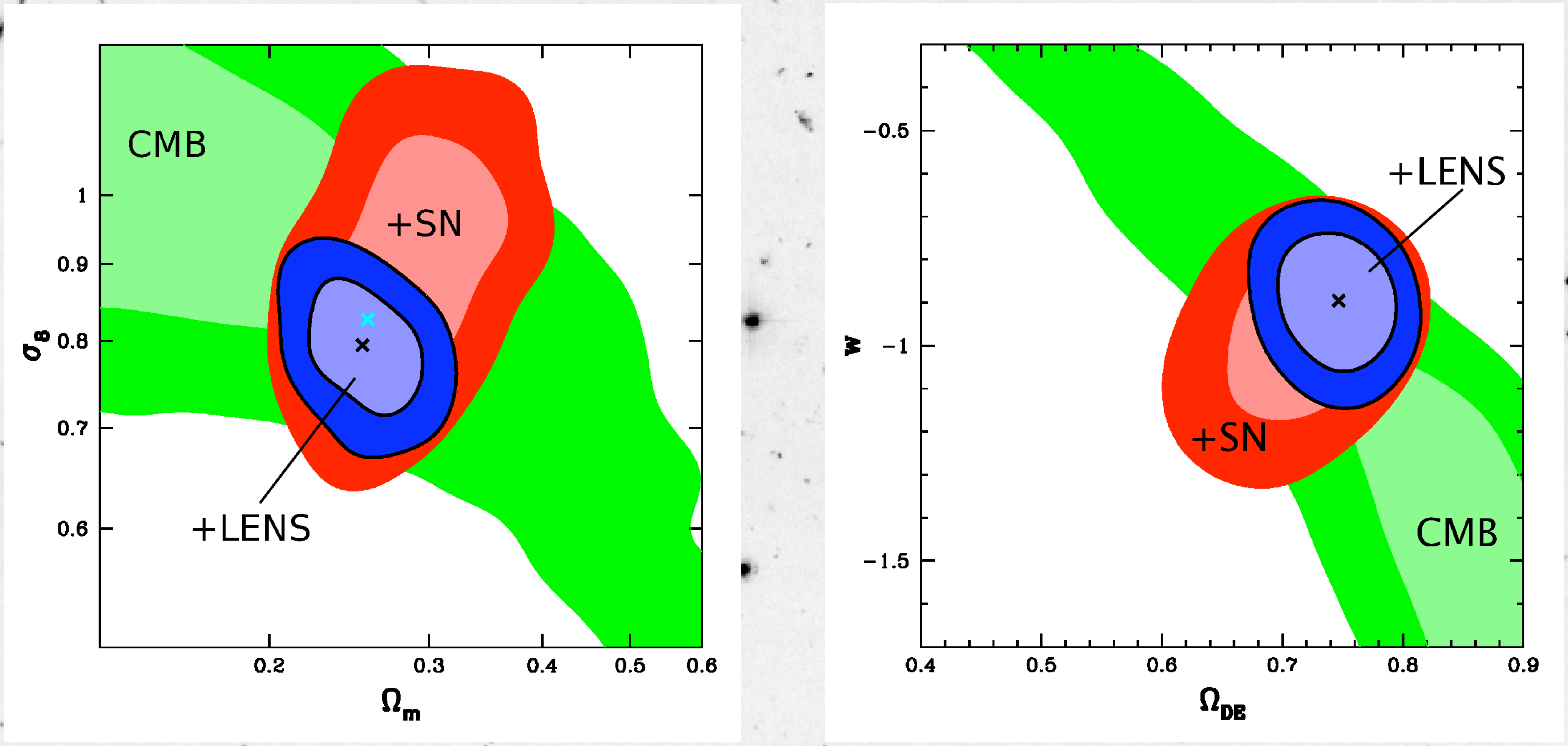
4. Then use General Relativity formulae to determine history of Universe size and lumpiness

5. (...or maybe find that GR is incorrect)

Start by measuring galaxy shapes...



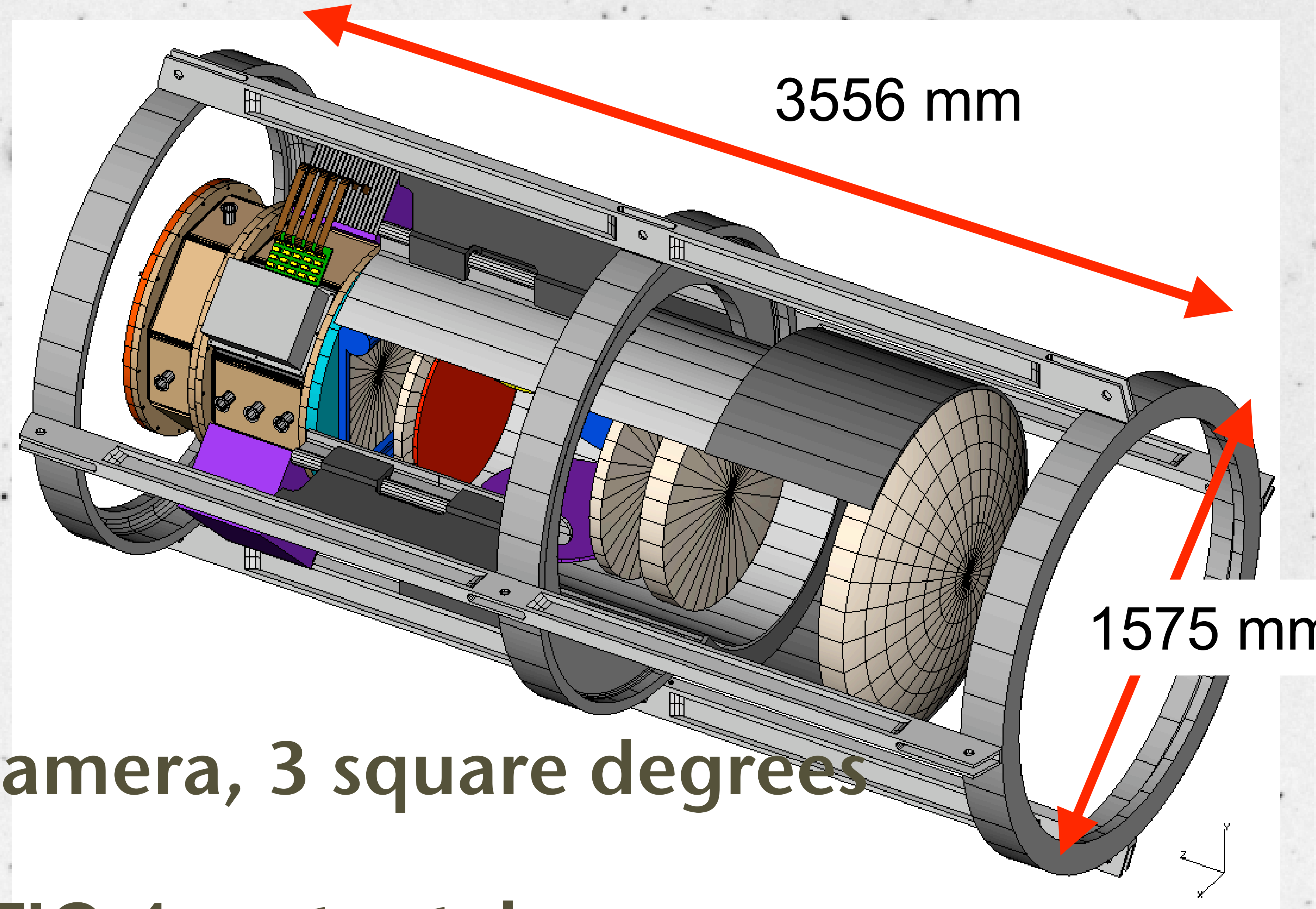
End up with measurements of dark energy!



Results for constant-w models from Jarvis, Jain, & Bernstein (2005) from the 75-square-degree CTIO lensing survey: 2 million galaxy shapes

The Dark Energy Survey

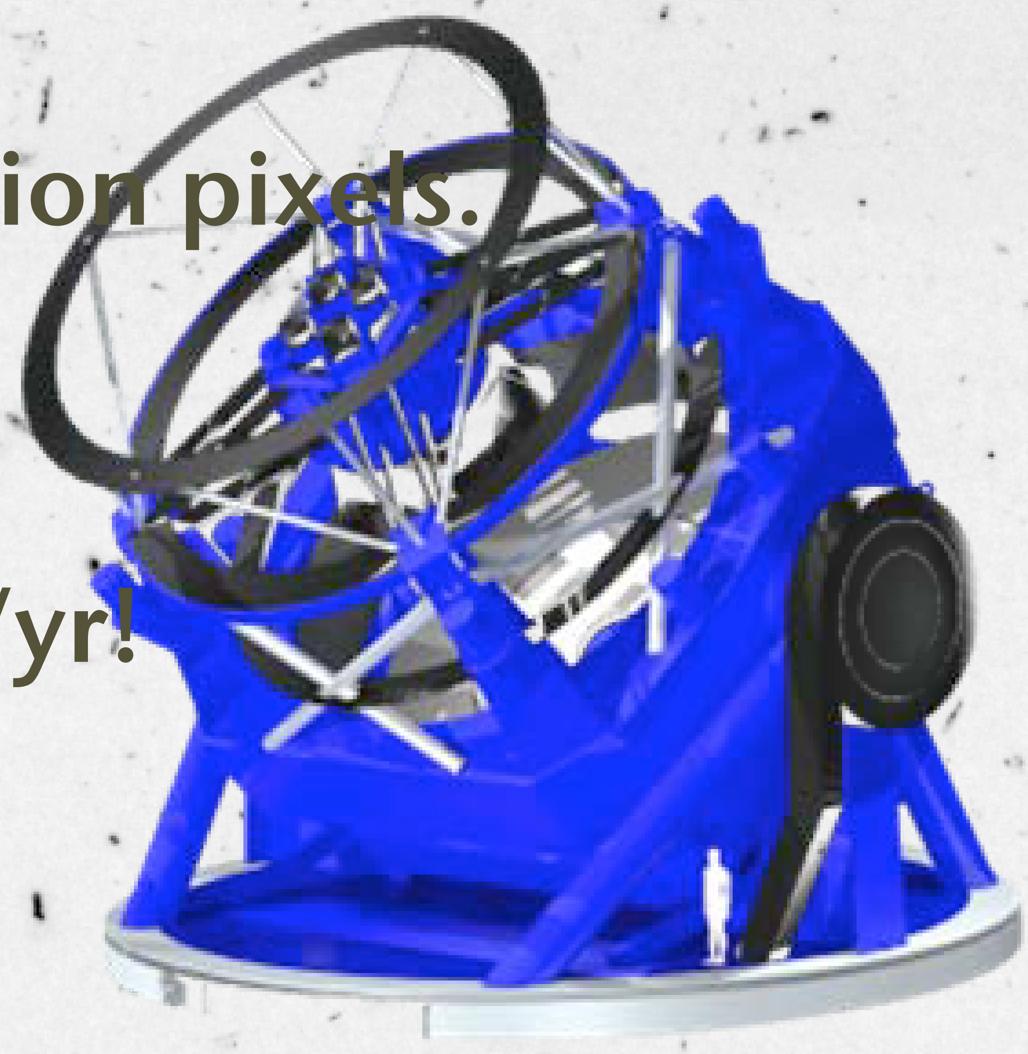
DARK ENERGY
SURVEY



- 500 Megapixel camera, 3 square degrees
- 500 nights on CTIO 4-meter telescope
- Shapes of 300 million galaxies over 5000 square degrees of Southern sky 2009 -2013

The LSST Project

- Ground-based 8-meter telescope to survey the entire visible sky every 4 days.
- Measure several billion galaxy shapes over a full hemisphere
- A single camera with >2 billion pixels.
- 4 GB image every 15 s
- 1 TB/hr, 8 TB/night, 2-3 PB/yr!
- Yours for only $300M!



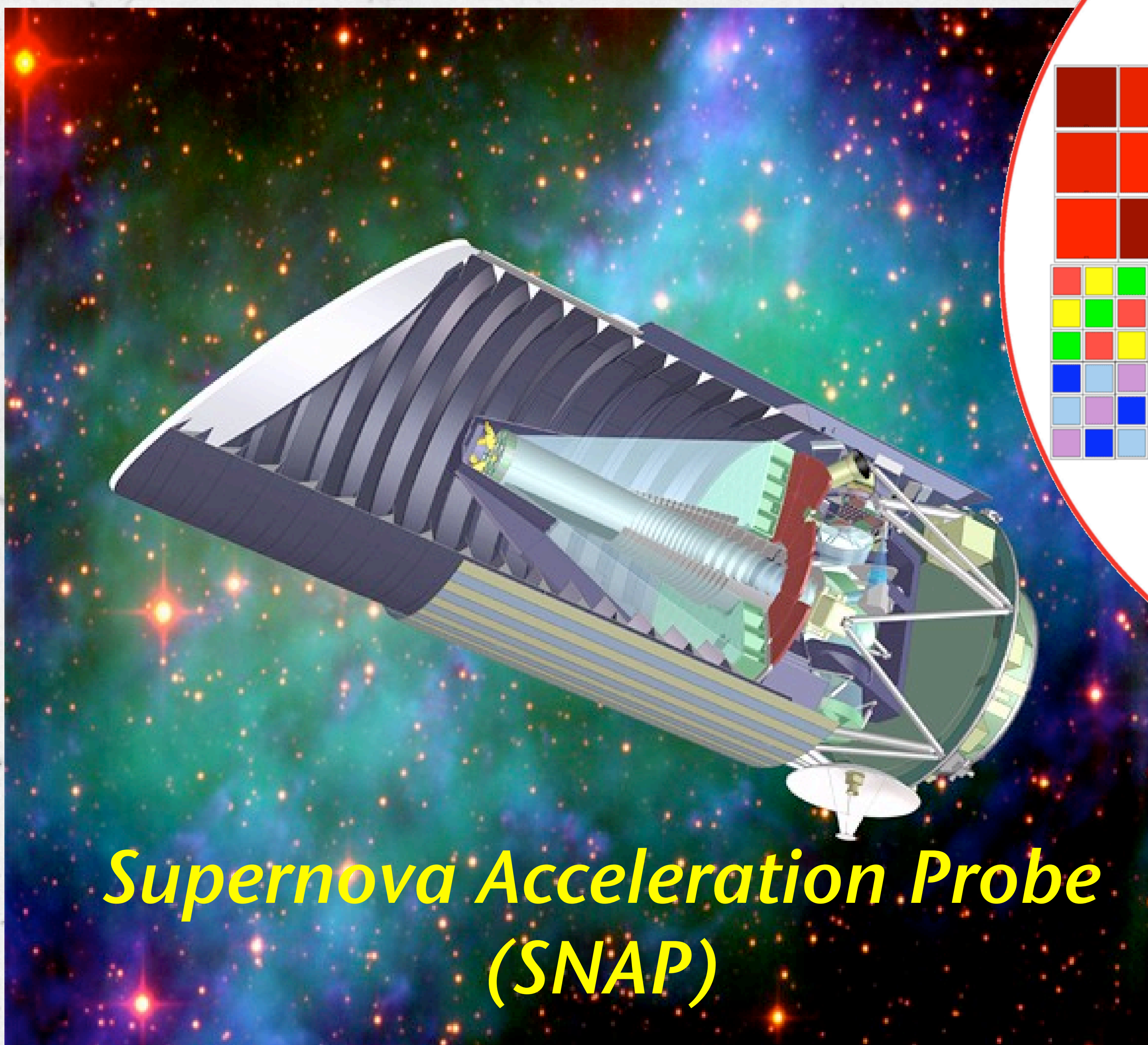
What I want for my science project

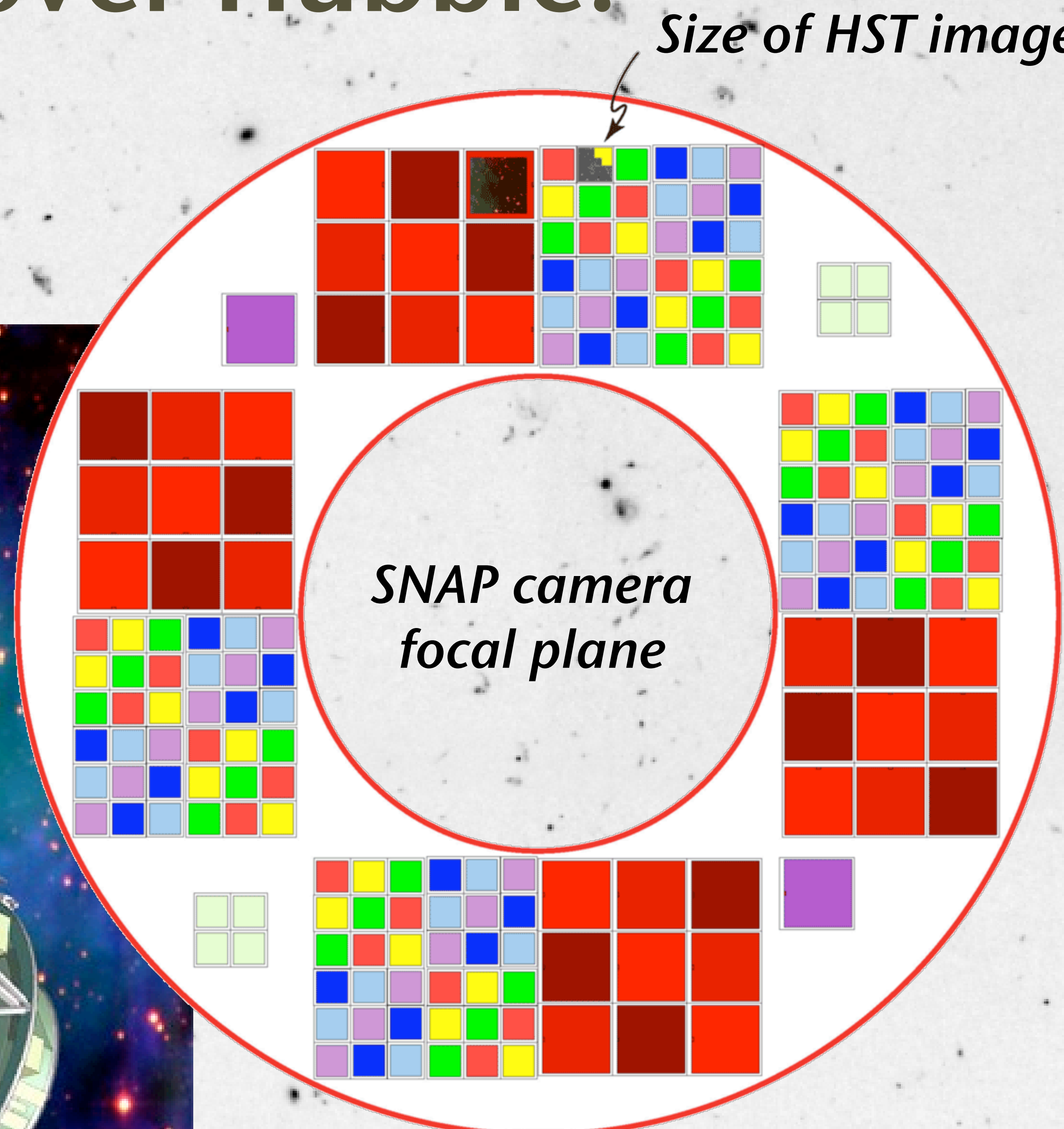
- The "cosmic distortions" have been detected and measured starting in 2000.
- Advancing rapidly using ground telescopes
- What we'd really like:
  - A space telescope is above the distorting affects of Earth's atmosphere.
  - But Hubble has tunnel vision, not enough galaxies.

Wide Area Space Telescope (WASTe)

A huge advance over Hubble:

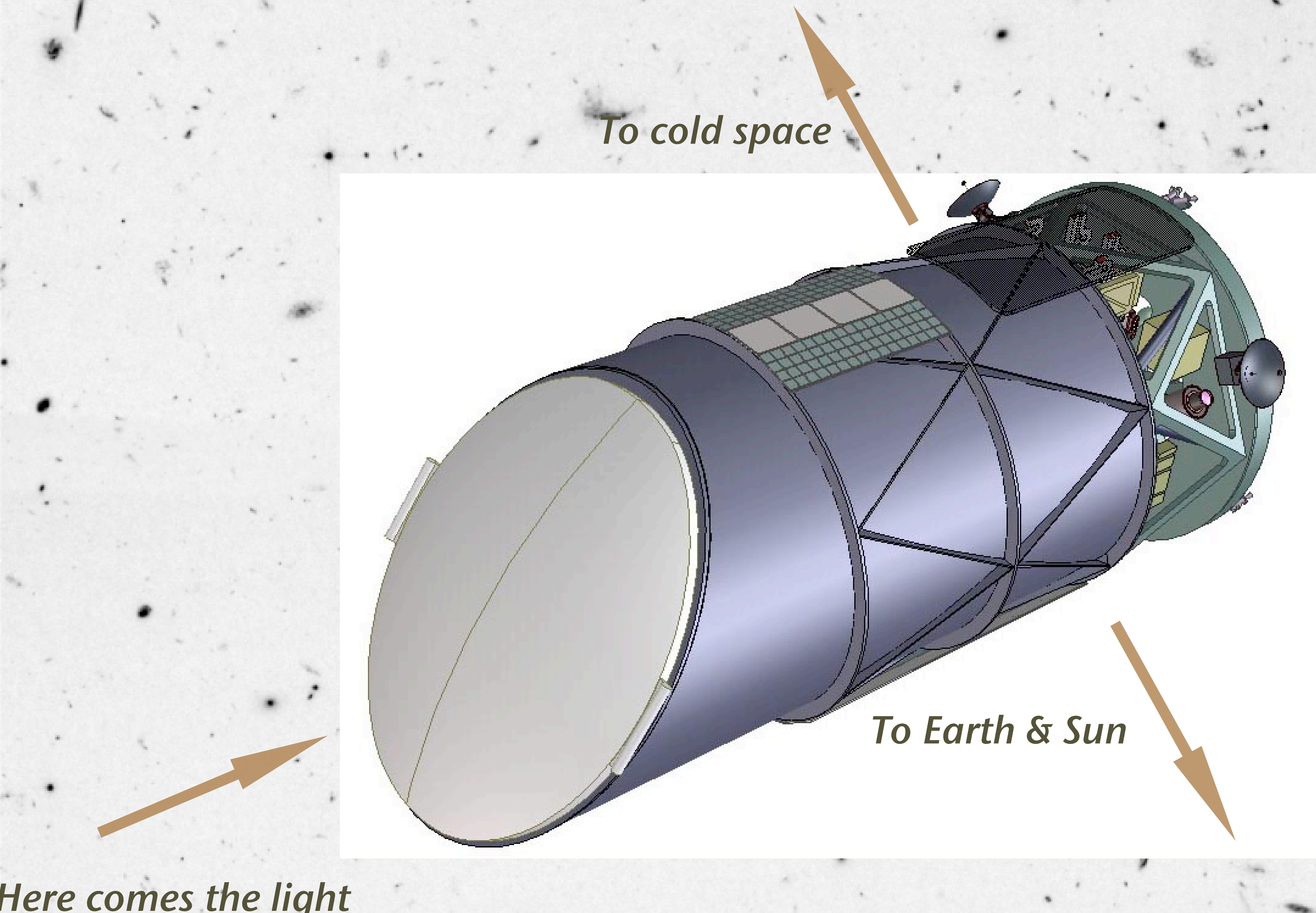
600 Megapixel Camera
on HST-sized Space Telescope



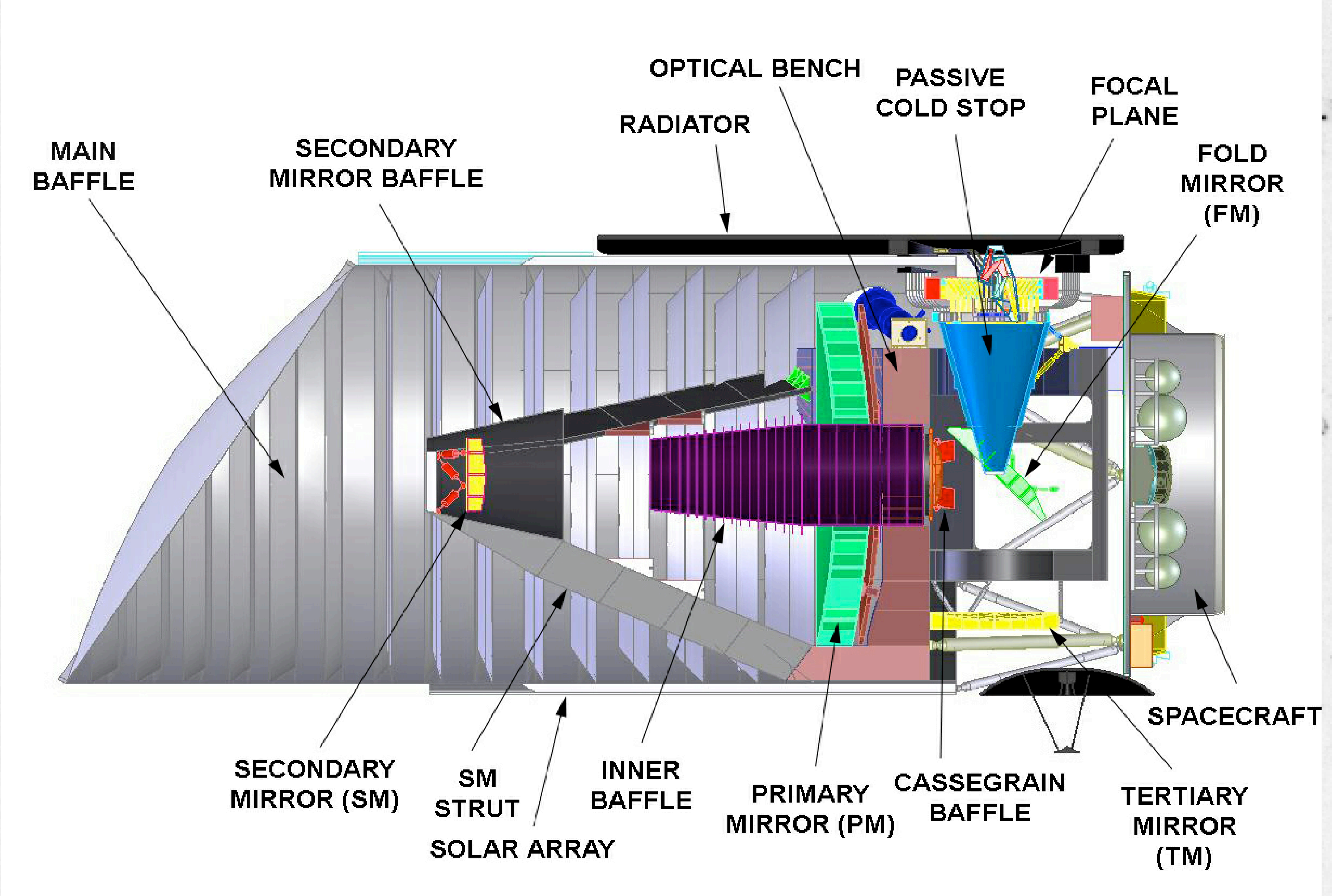


SNAP could harvest galaxy shapes hundreds of times faster than the HST or JWST

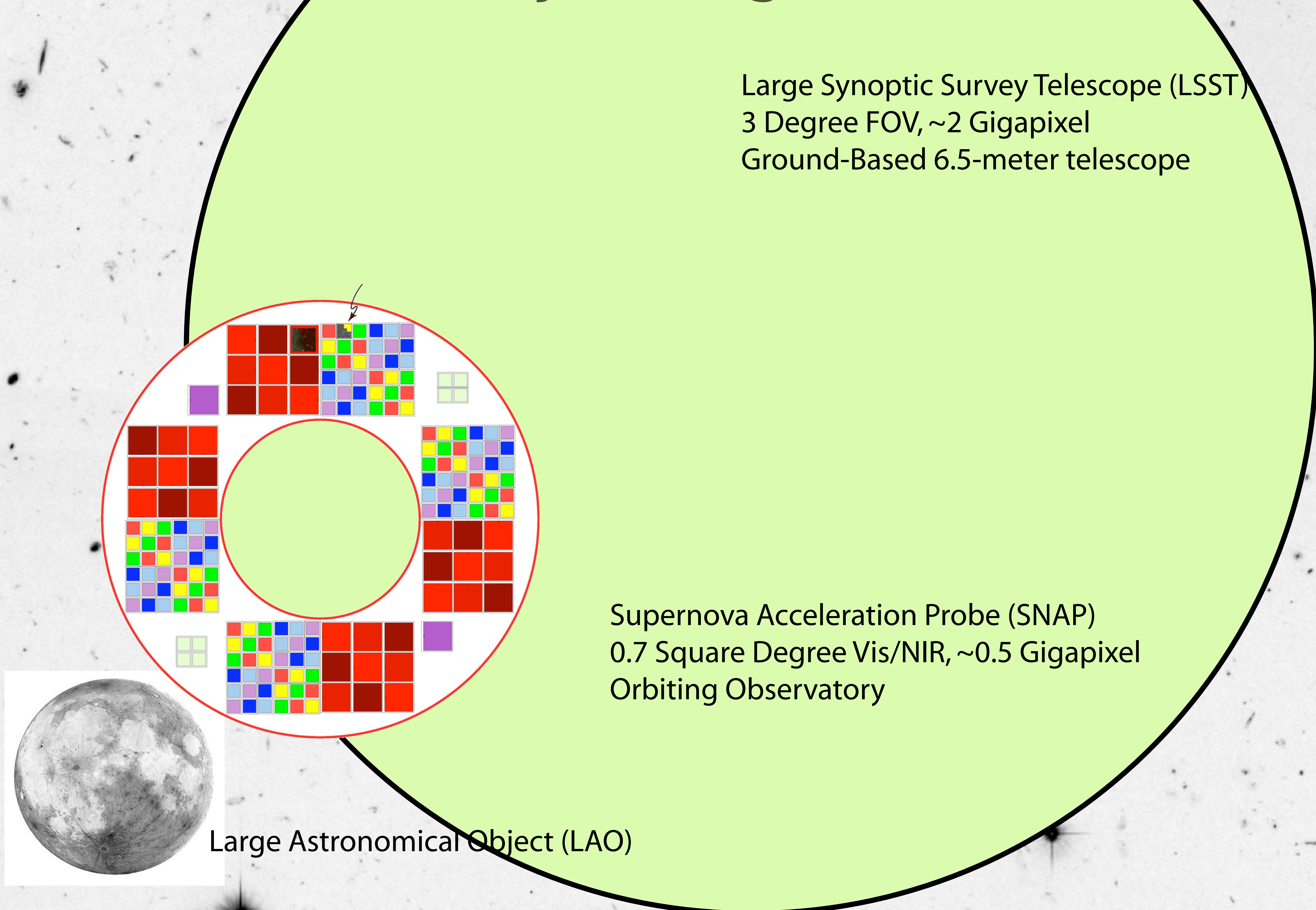
The SNAP spacecraft



More SNAP pictures



Next decade's sky-eating monsters



The future of cosmic distortions

- DES and then LSST will measure lensing over 5000 -20,000 square degrees.
- The Joint Dark Energy Mission will survey thousands of square degrees with the high quality available from space.
- The Universe's "obscurity level" will be determined to a fraction of a percent
- We will infer the properties of dark energy to high accuracy, combining WL with supernovae and other observations.
- What will we have to add to Einstein's Universe to explain what we discover?

Thanks to...

- The SNAP collaboration for designing (and building!) an incredibly powerful and efficient experiment.
- FNAL for hosting our meeting and this talk.
- The Dept of Energy, NASA, and the National Science Foundation for supporting our research in weak lensing and dark energy.
- You, (and the US Congress, we hope) for your interest in obscure but fascinating questions about the Universe.