

Large Scale Structure & Cosmology

Vikram Khaire
IIT Tirupati

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Workshop of Introduction to Astronomy and Astrophysics

IF PEOPLE SAT OUTSIDE
AND LOOKED AT THE STARS
EACH NIGHT, I'LL BET THEY'D
LIVE A LOT DIFFERENTLY.

WELL, WHEN YOU LOOK
INTO INFINITY, YOU
REALIZE THAT THERE
ARE MORE IMPORTANT
THINGS THAN WHAT
PEOPLE DO ALL DAY.

HOW
SO?



Our galaxy - The Milky-Way



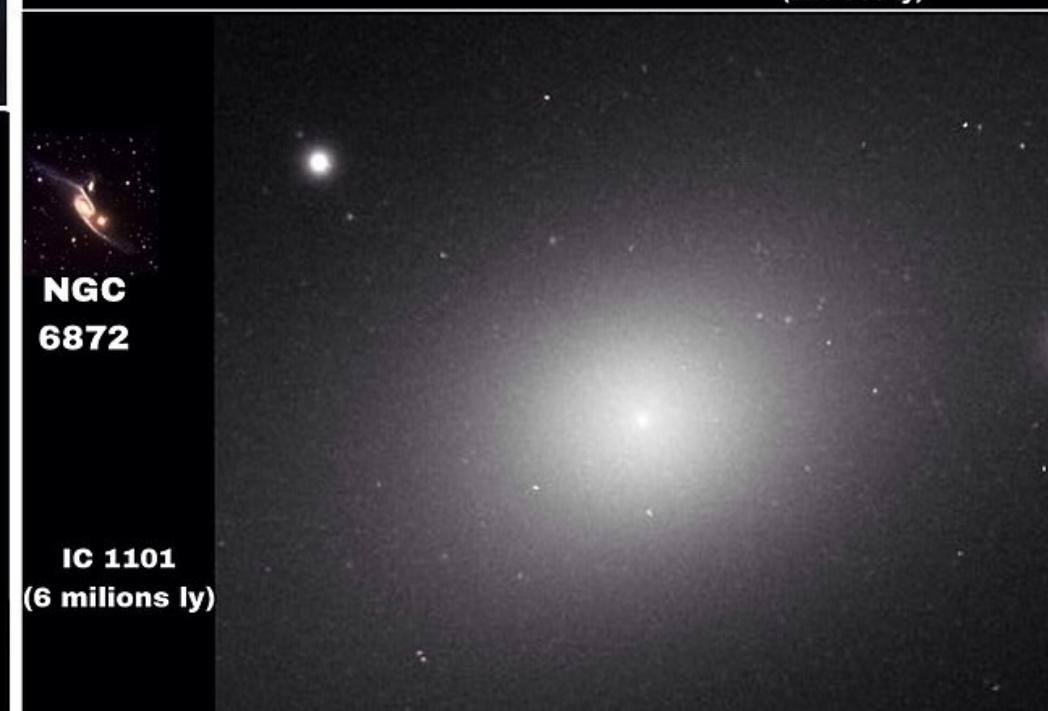
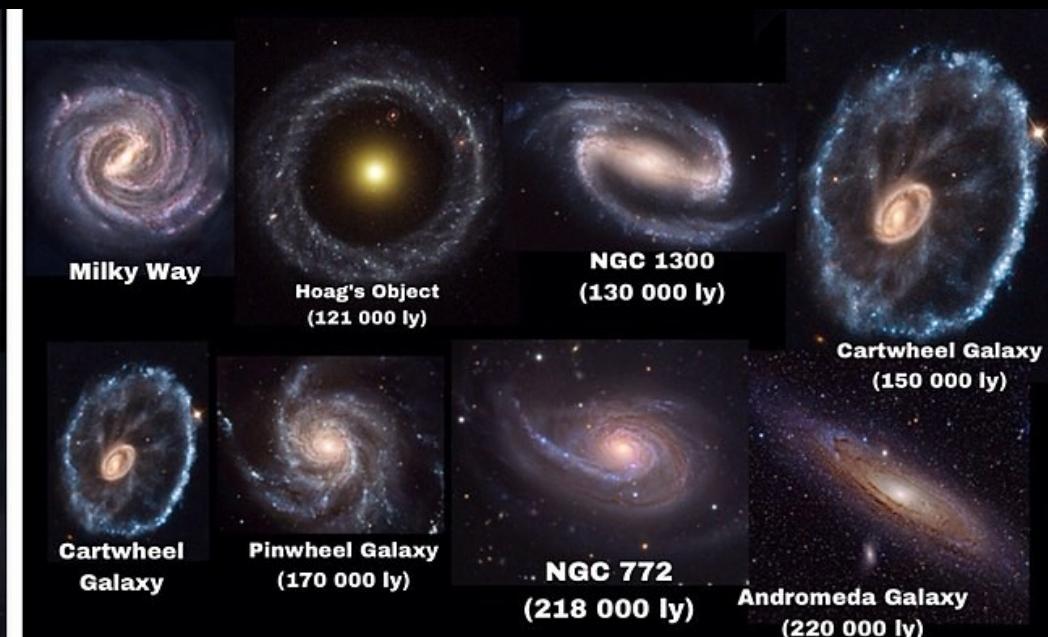
Our galaxy - The Milky-Way



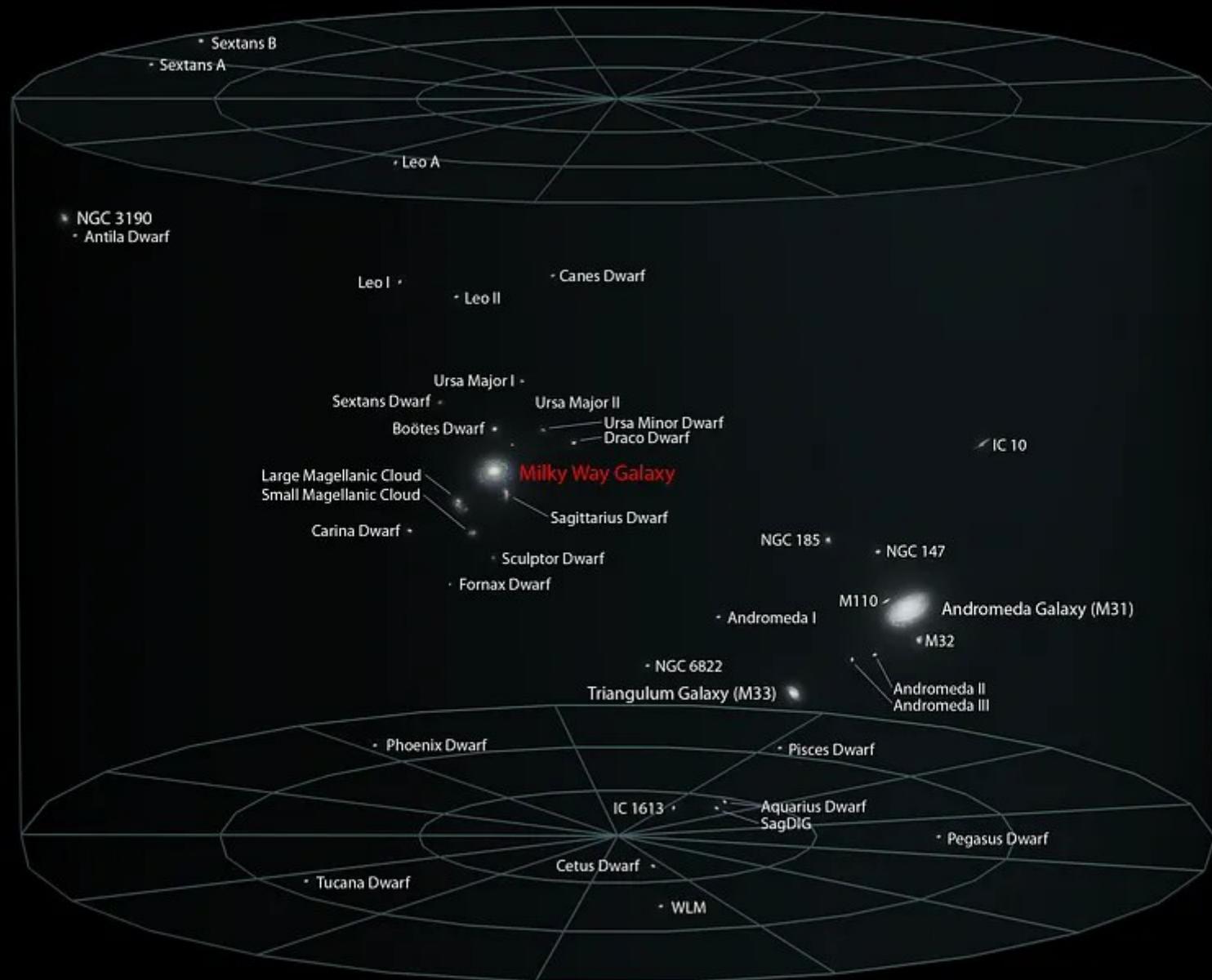
Diameter ~ 100,000 Light years

Contains ~ 100 billion stars (10^{11})

Galaxies



Local Galactic Group

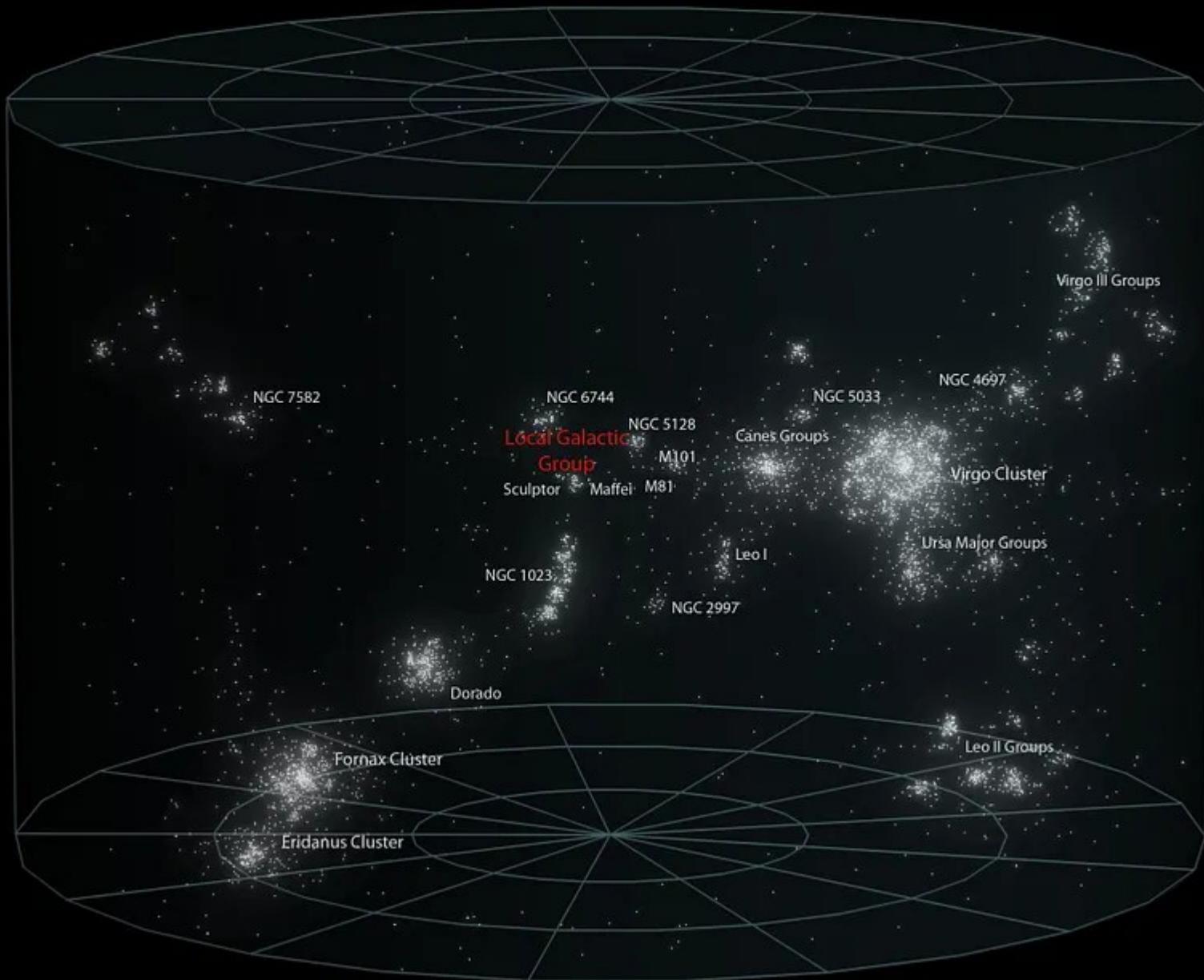


Abell 2029 Cluster



Supercluster

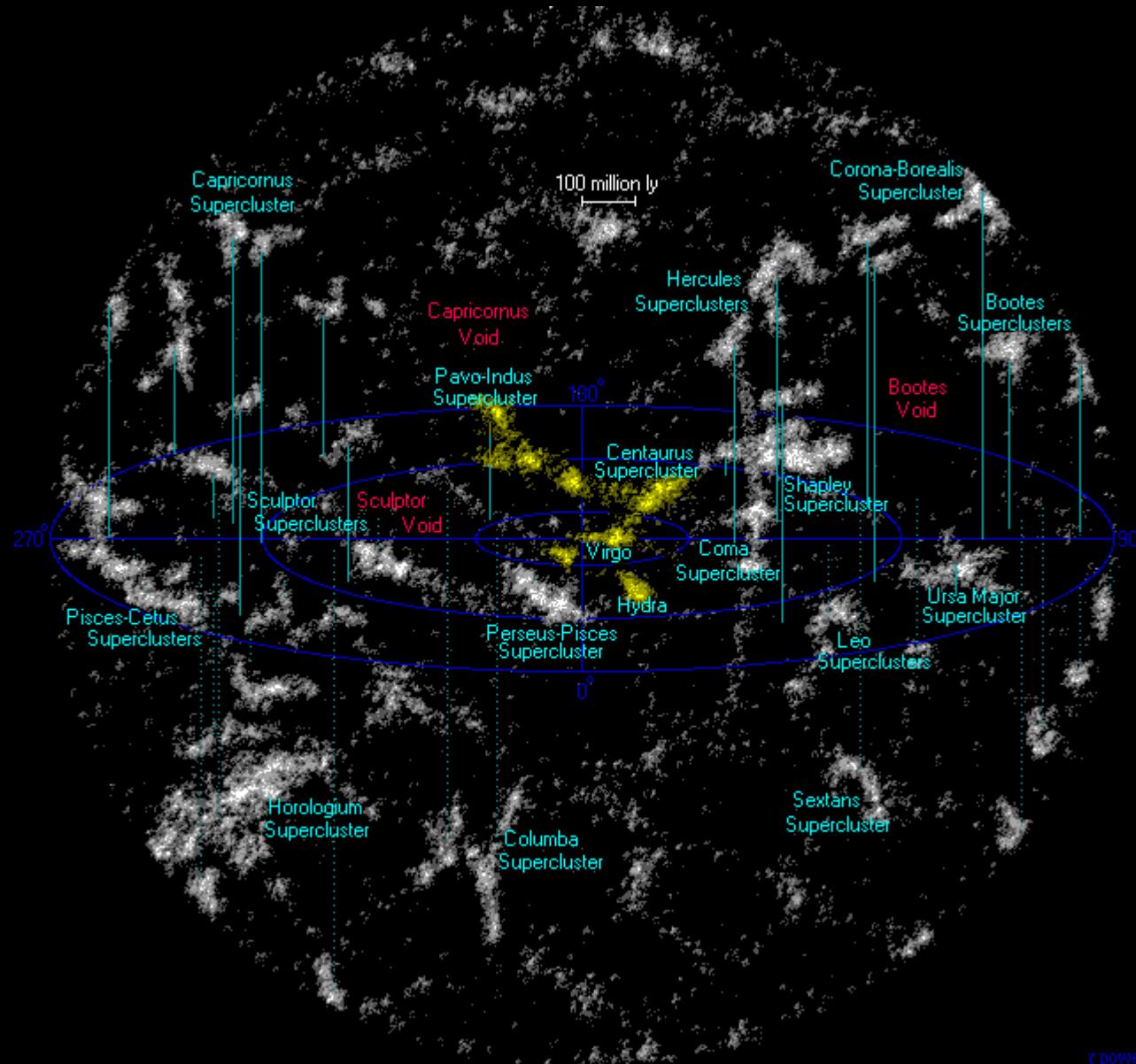
Virgo Supercluster



Supercluster

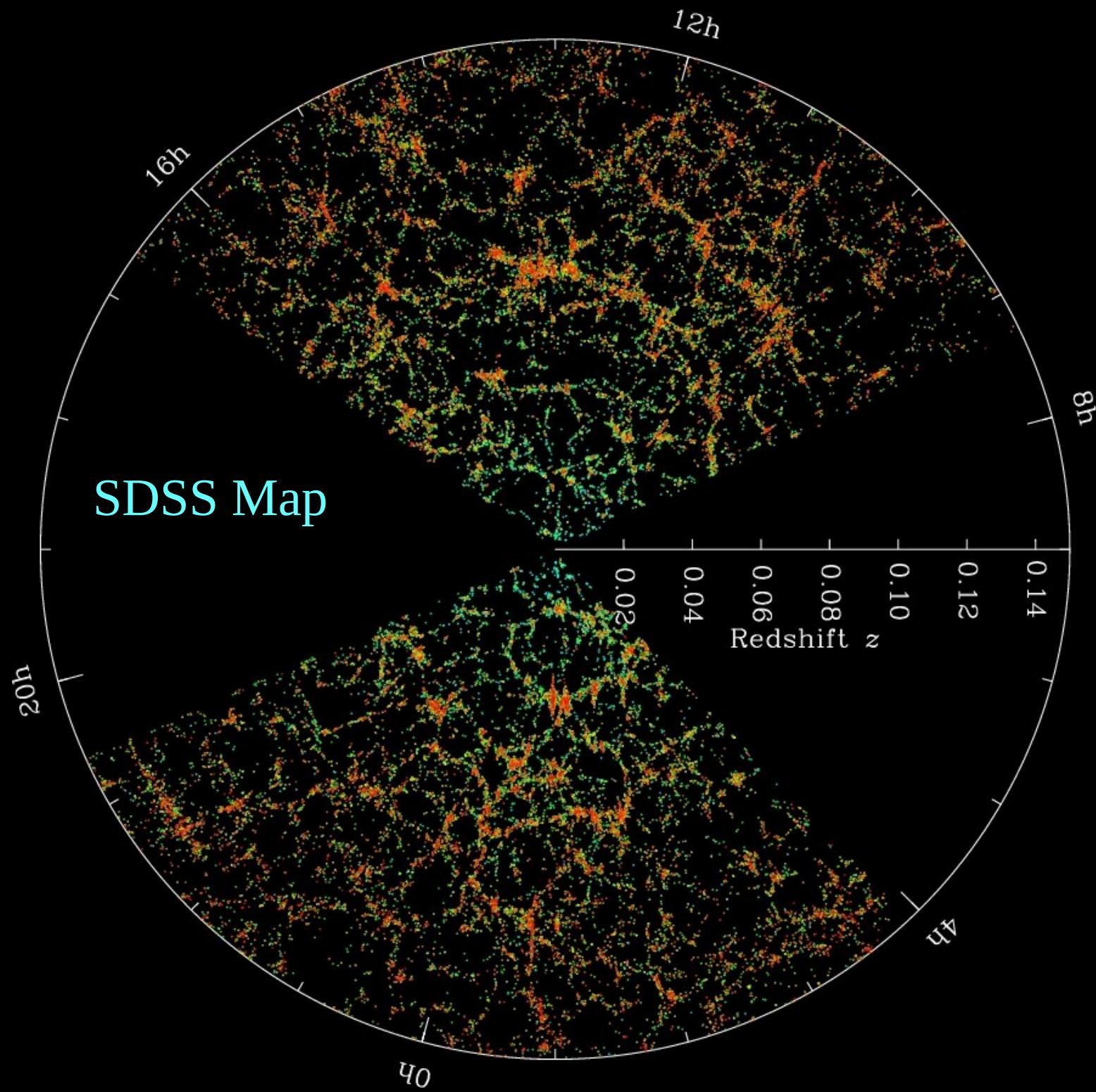
LANI AKEA

Superclusters everywhere!



rpowell

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Galaxies



The area of the sky observed in the Hubble Ultra Deep Field view has been compared to the area you would see through an eight foot soda straw! The viewing area contained about 10,000 detectable galaxies.



The Hubble
Ultra-deep Field



The Hubble
Ultra-deep Field
(JWST version)

100,000 galaxies



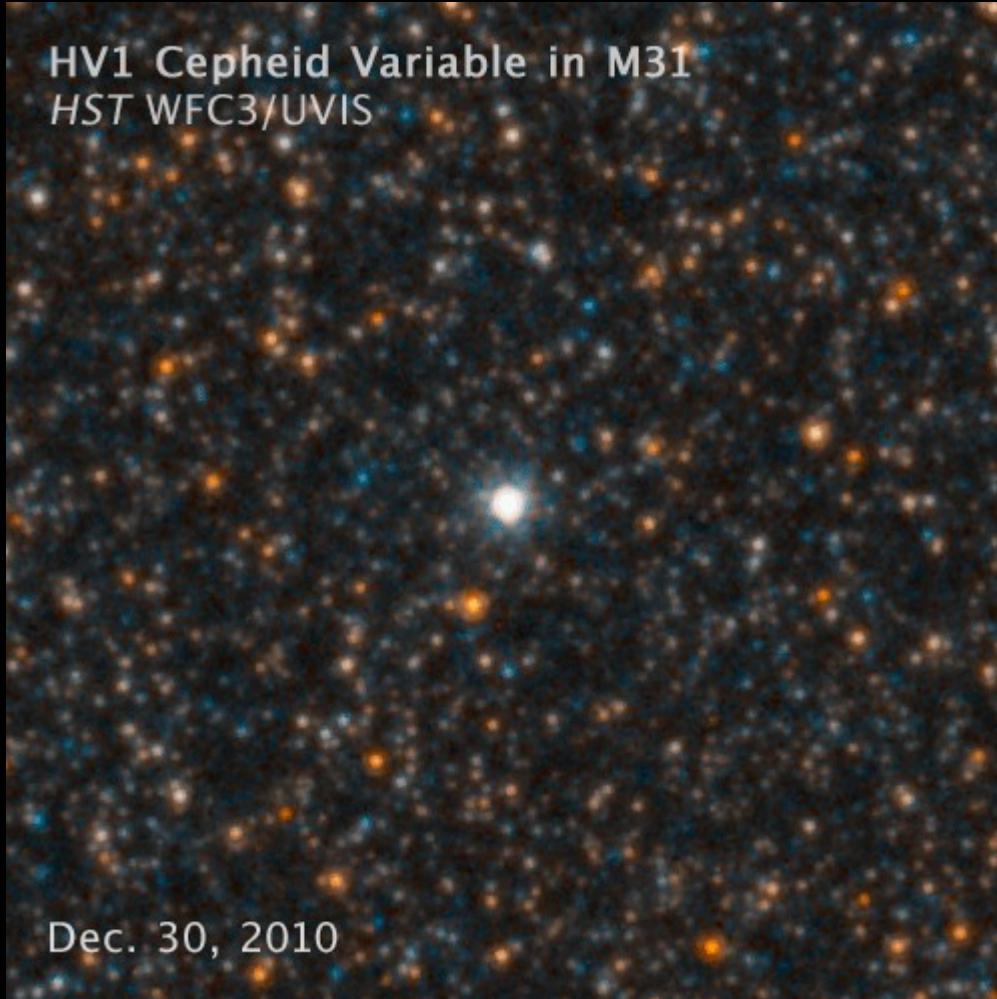
1 Trillion galaxies
each with 100
billion stars

= 10^{23} stars in the
Universe

The beginnings of cosmology

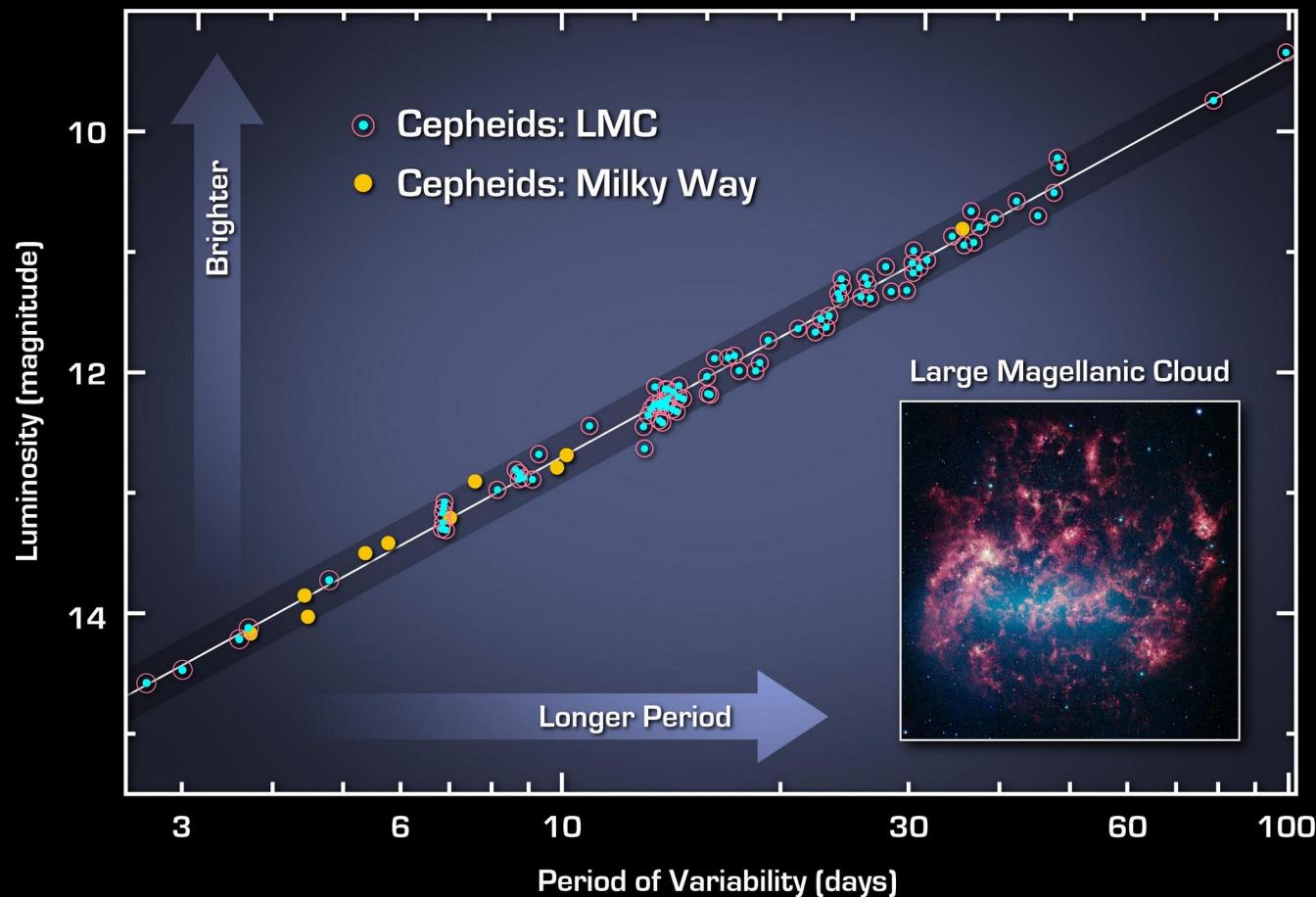
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Pulsating Cepheid variable stars as a standard candles



Henrietta Swan Leavitt
(1868 - 1921)

Pulsating Cepheid variable stars as a standard candles

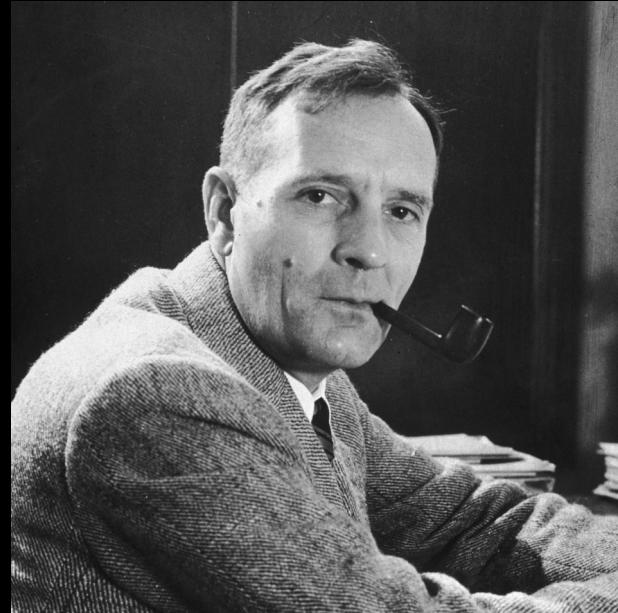


Henrietta Swan Leavitt
(1868 - 1921)

Calibrated Period-luminosity Relationship for Cepheids
NASA / JPL-Caltech / W. Freedman (Carnegie)

Spitzer Space Telescope • IRAC
ssc2012-13a

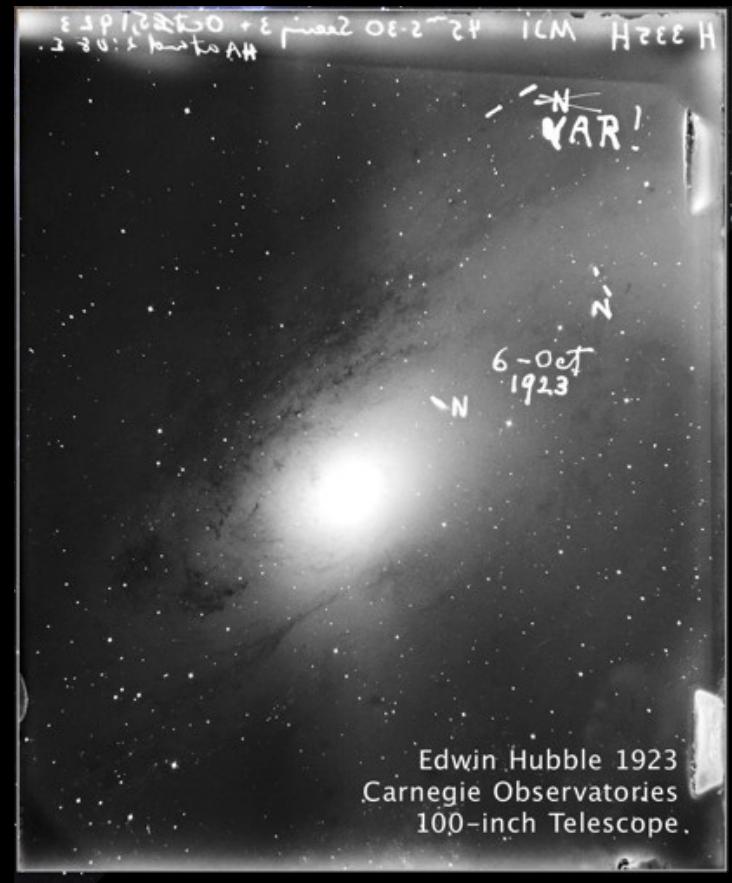
Edwin Hubble



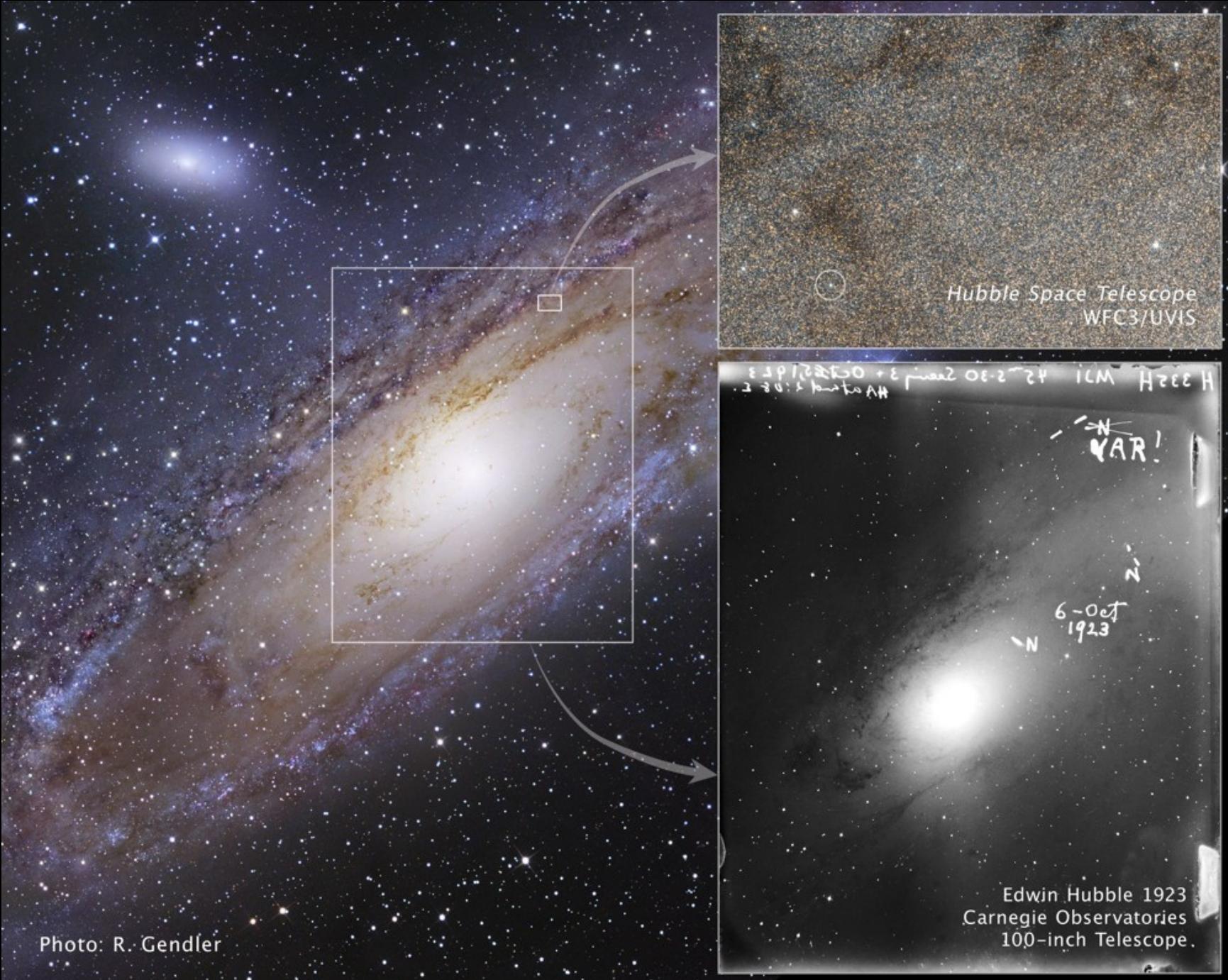
In 1923: Edwin Hubble found a Cepheid in Andromeda galaxy!

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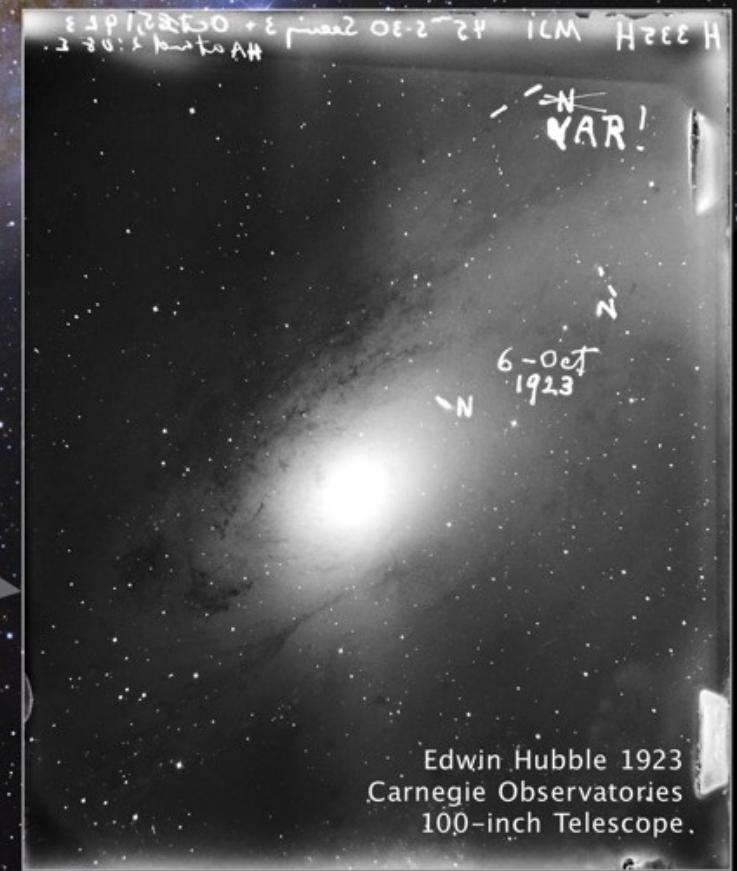
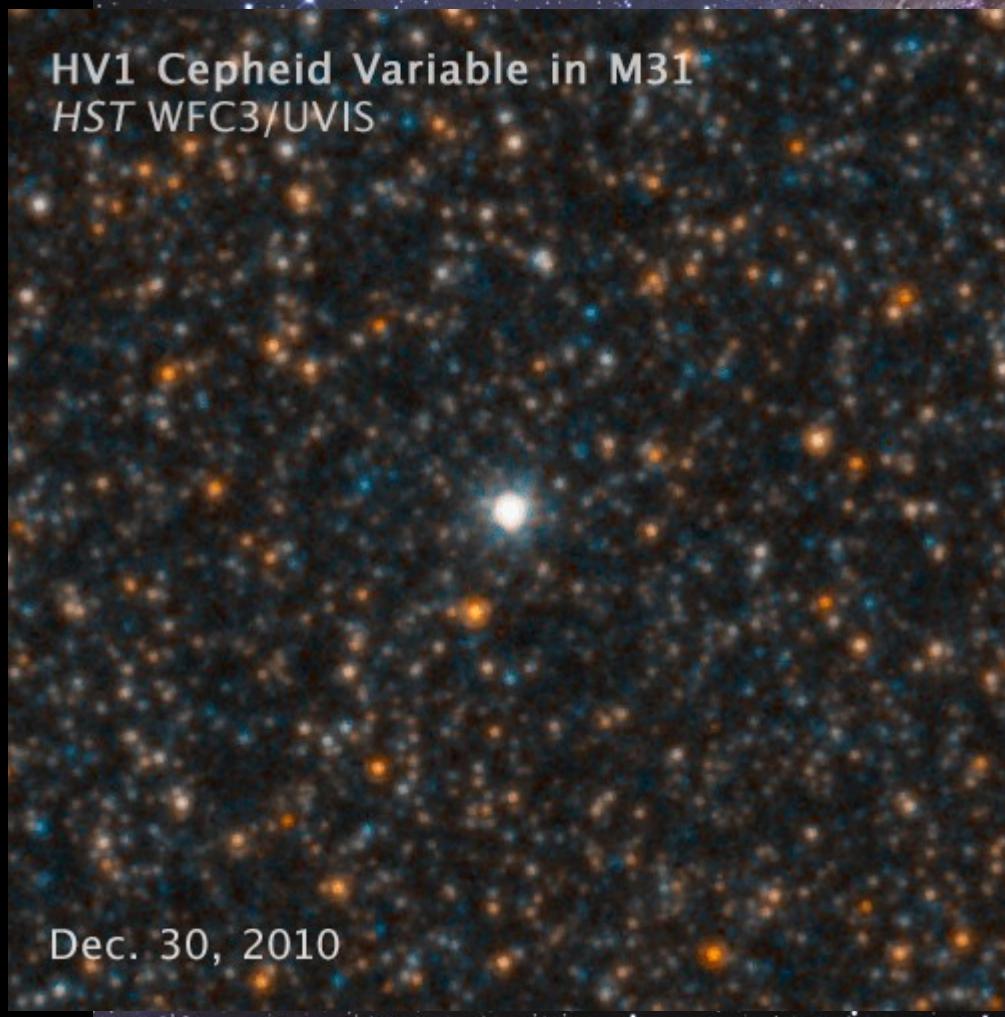
First Cepheid variable star in a nearby nebula



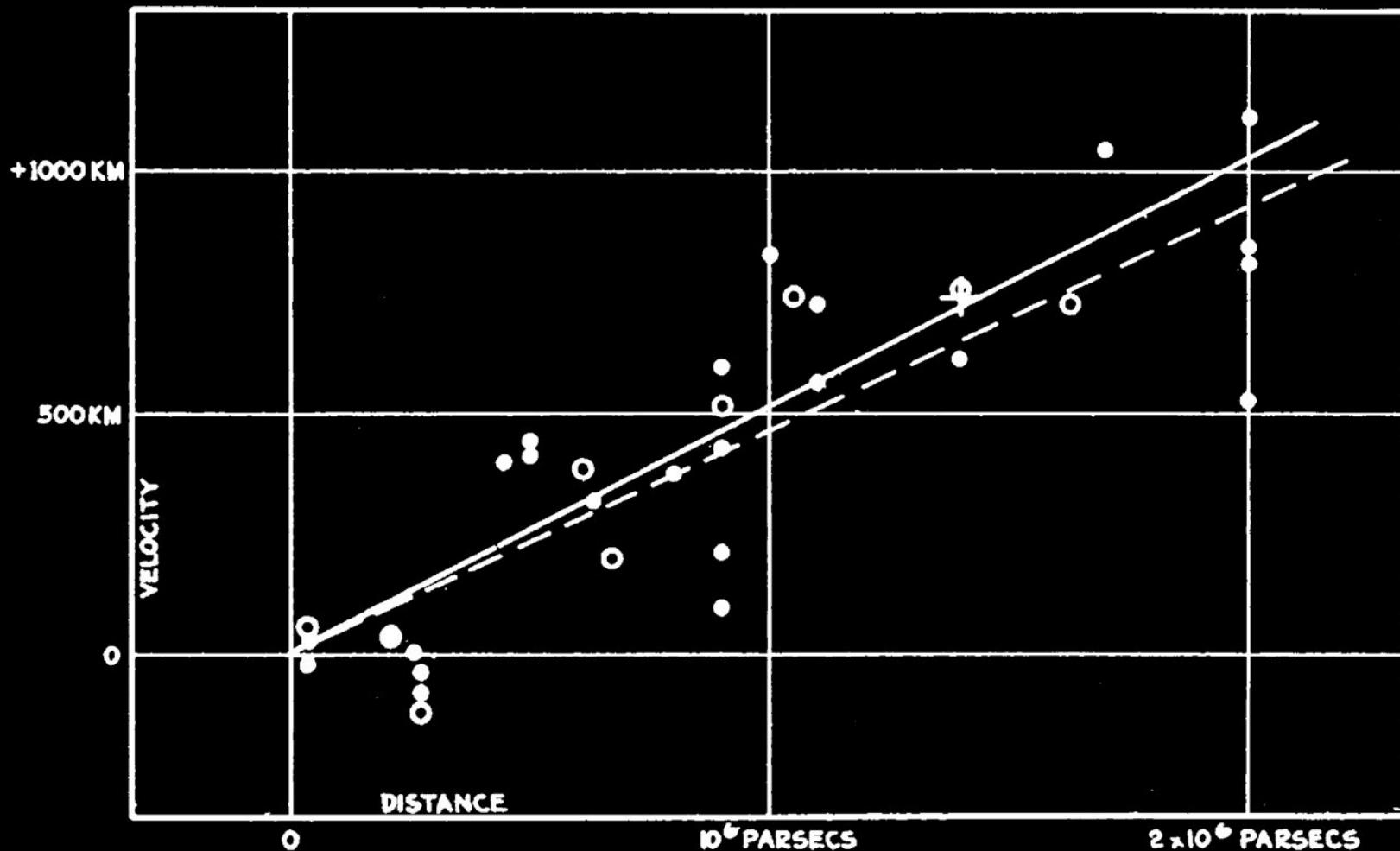
First Cepheid variable star in a nearby galaxy



First Cepheid variable star in a nearby nebula



Hubble's discovery of expansion of the space



"A relation between distance and radial velocity among extra-galactic nebulae"

Edwin Hubble - PNAS March 15, 1929 15 (3) 168-173

Note: 1 parsecs = 3.26 Light years

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Hubble's discovery of expansion of the space

Speed of galaxies is proportional to distance → Hubble's law

$V = H D$ where H is Hubble's constant

“The outstanding feature, however, is the possibility that the velocity-distance relation may represent the de Sitter effect...”

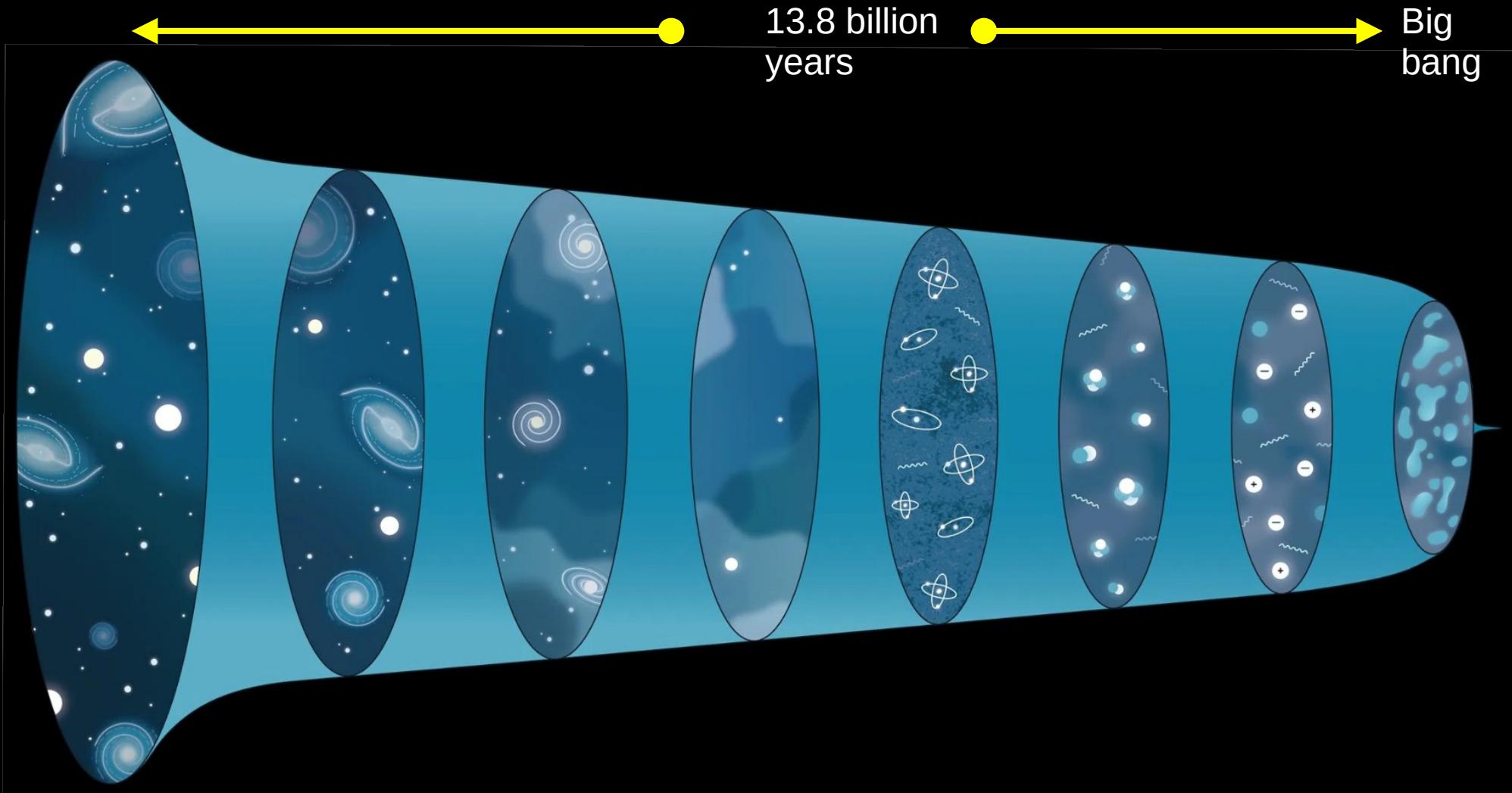
- Edwin Hubble

De Sitter (in 1917) solved Einstein's field equations in General Relativity and for a special case he found a solution where space in the universe expands

→ De Sitter got the same speed and distance relation!

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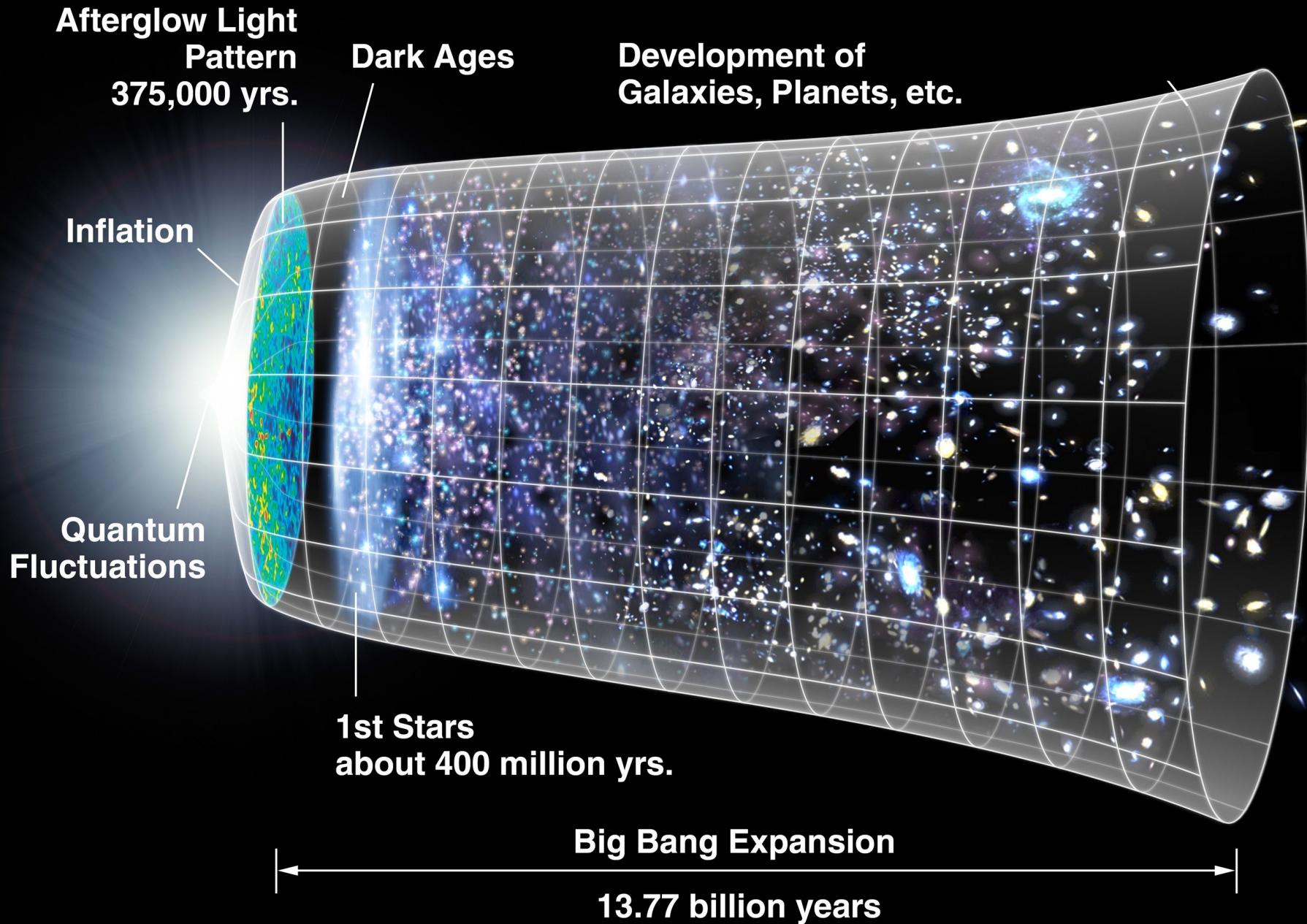
Backtracking the origin of the Universe



Backtracking the origin of the Universe

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Current picture of the Universe?



Discovery of relics of Big bang – Cosmic Microwave Radiation



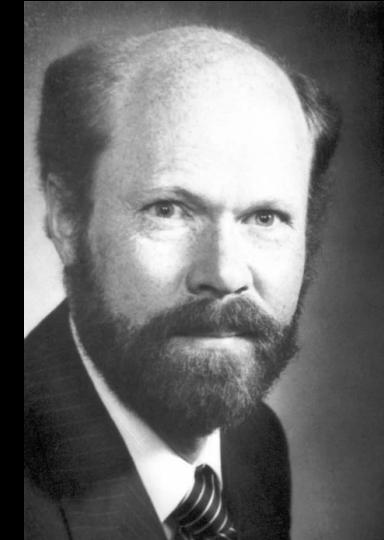
CMB radiation discovered in 1964

Wavelength was larger by factor 2 from the Gamow's prediction

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Arno Penzias



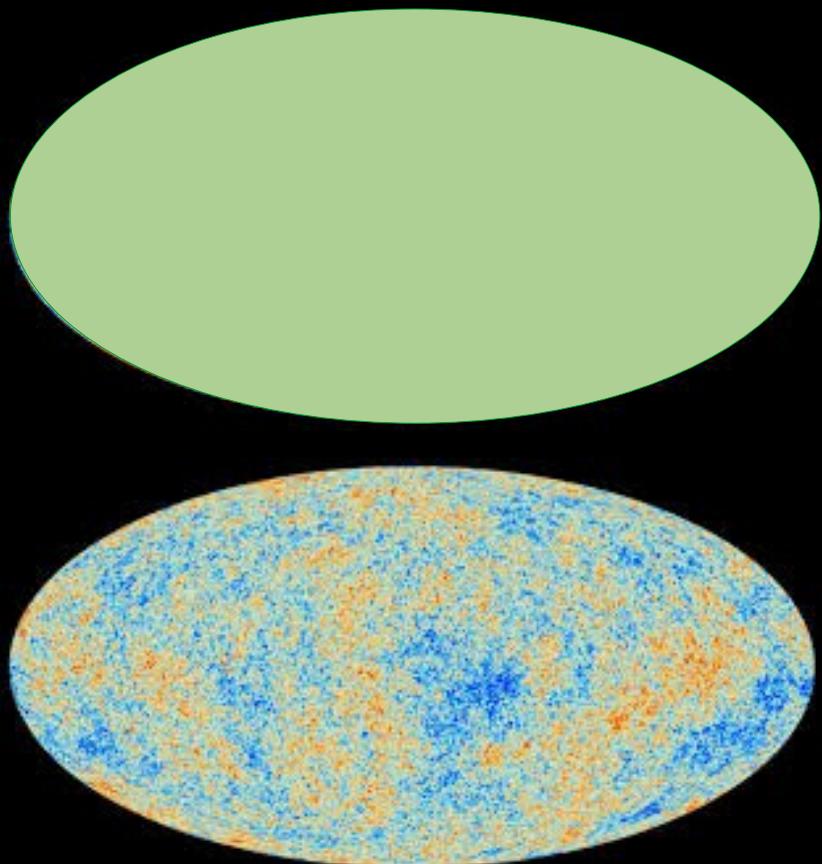
Robert Wilson

Two Nobel prizes for CMB:

1978 – Penzias & Wilson for the CMB discovery

2006 – Smoot & Mather (COBE satellite's principal investigators to map the CMB)

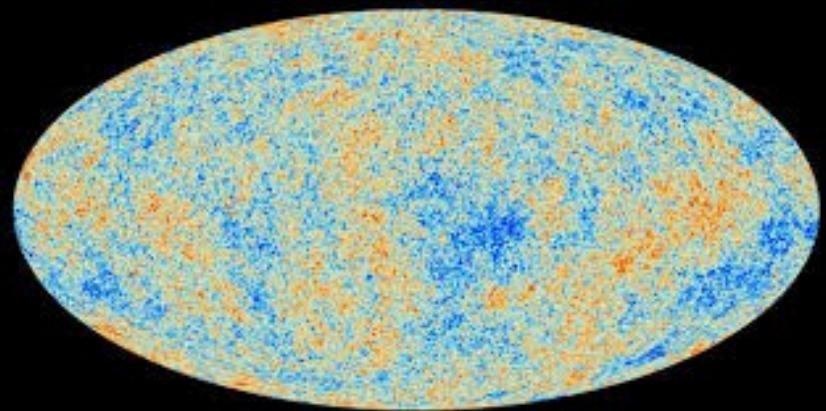
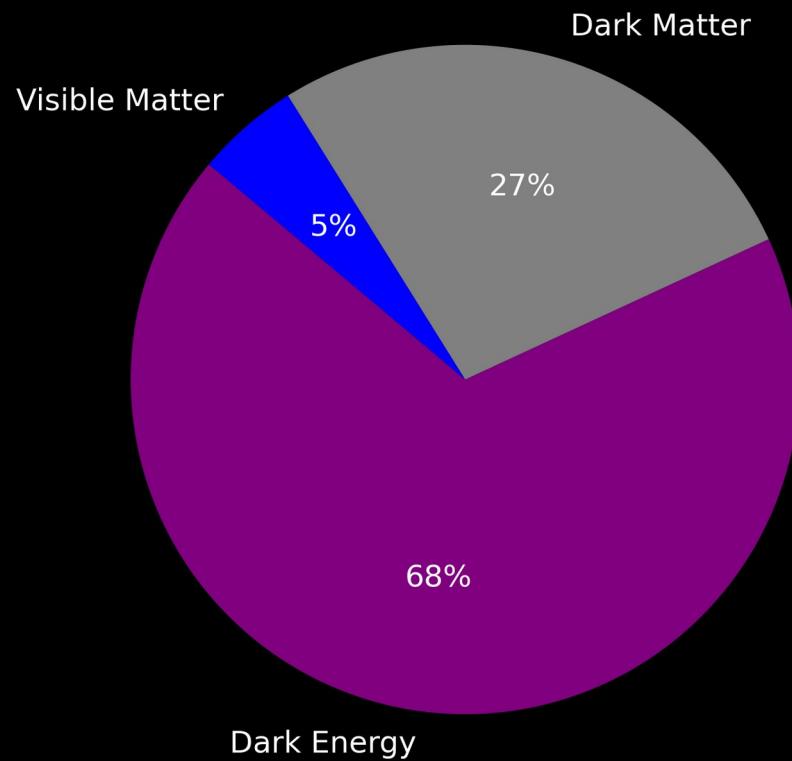
Earliest picture of the Universe!



Cosmic Microwave Background
Temperature = 2.725 K

Cosmic Microwave Background
Temperature Fluctuations – μ K
(Planck Satellite)

One picture summary of the Universe!



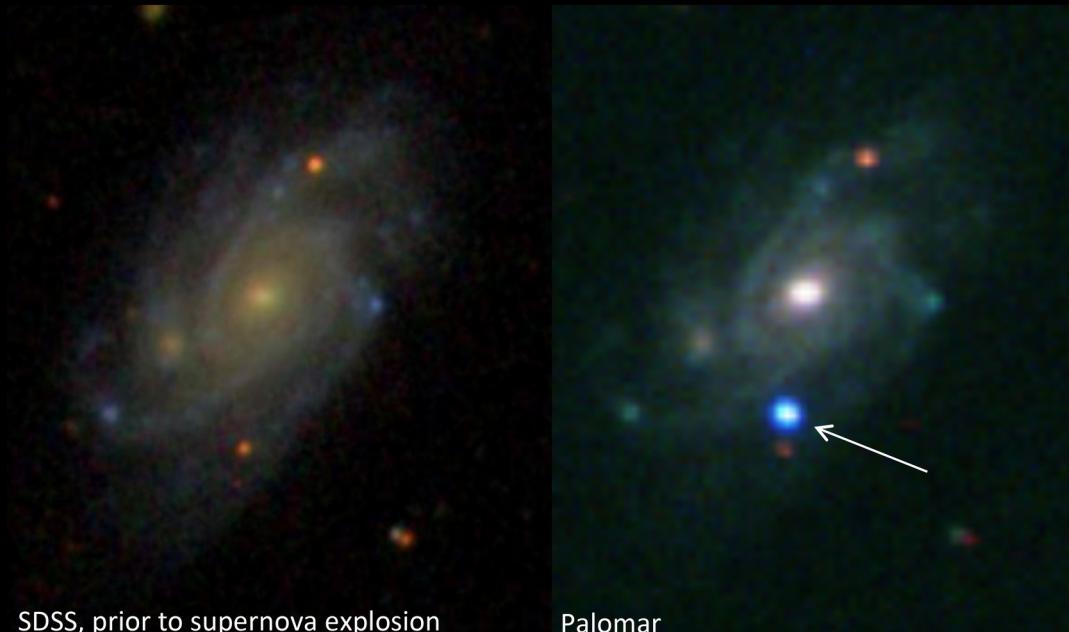
Cosmic Microwave Background
Temperature Fluctuations
(Planck Satellite)

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Race to measure the speed of expansion ...

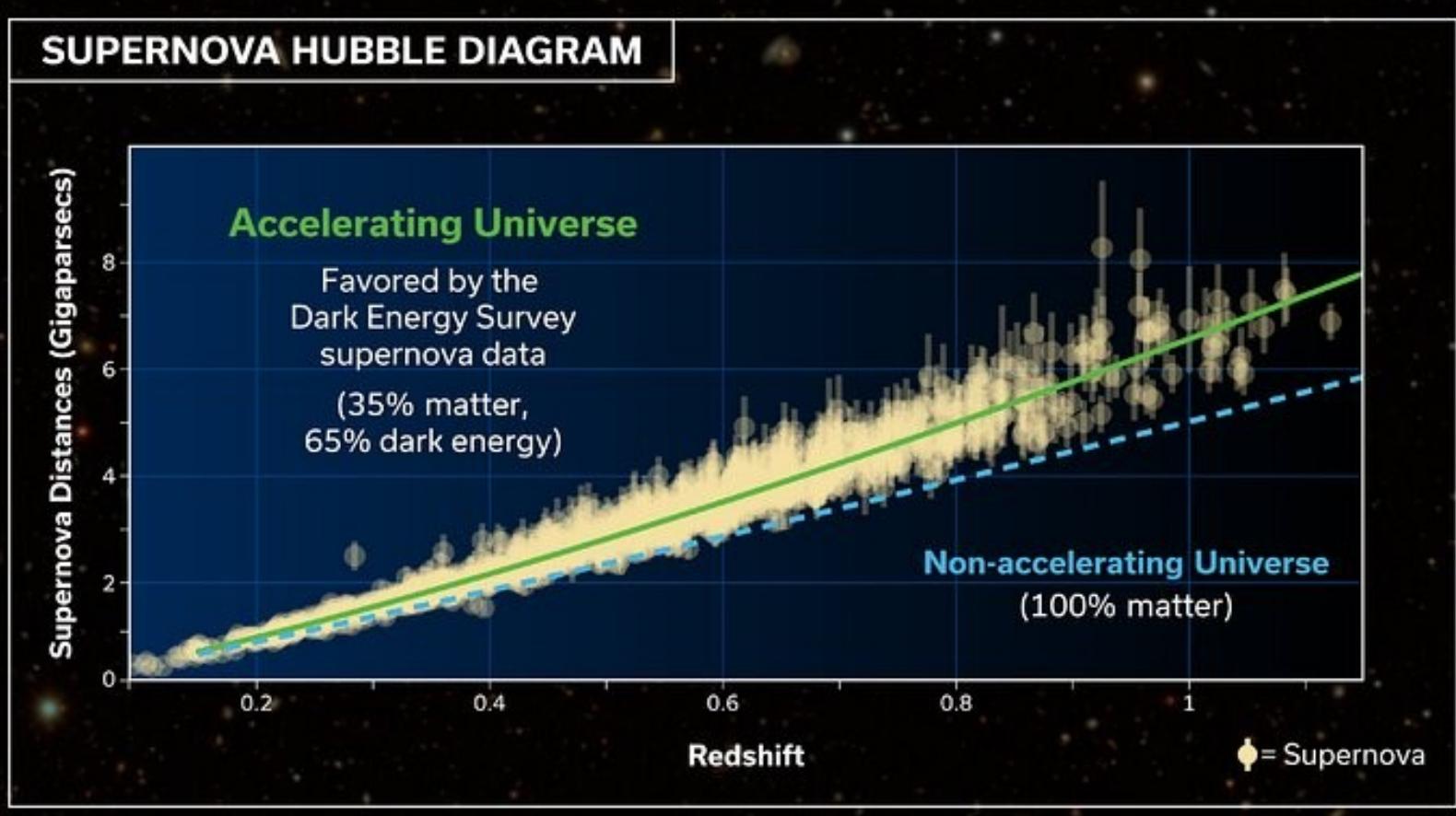
Type 1a Supernovae

SN 2013cu (iPTF13ast)

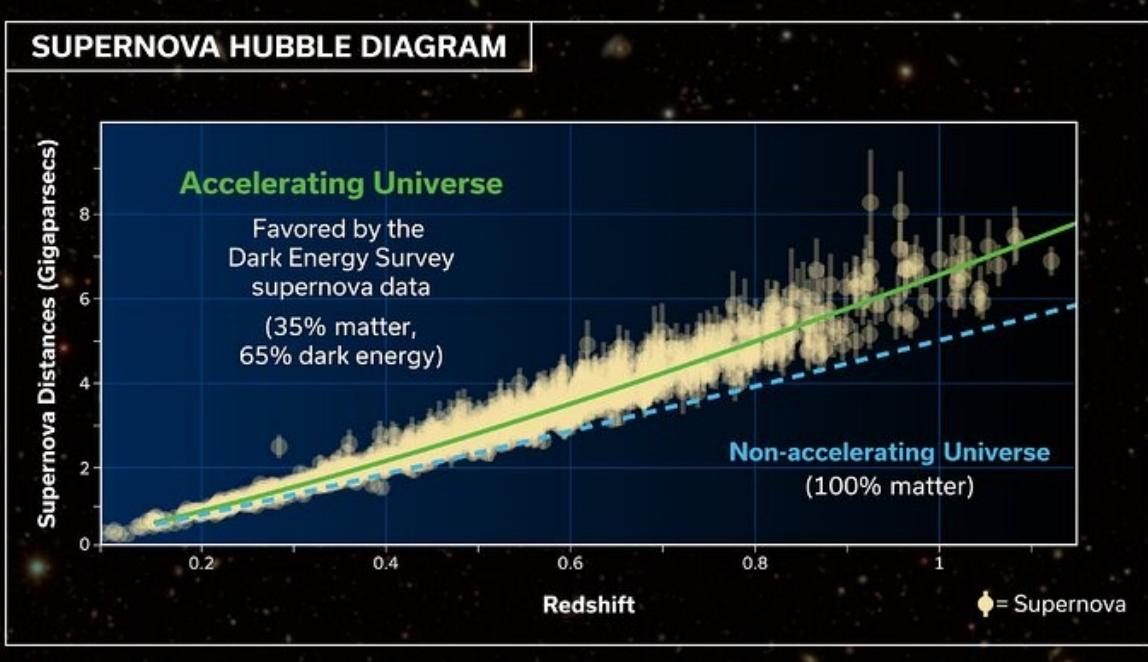


Gal-Yam et al. 2014; Nature, May 22, 2014

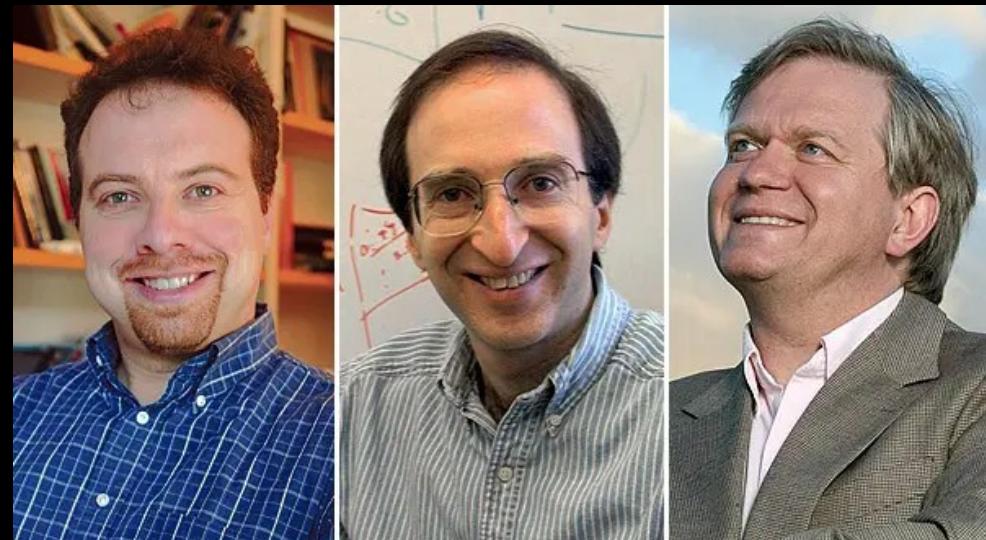
Type 1a Supernovae



Type 1a Supernovae

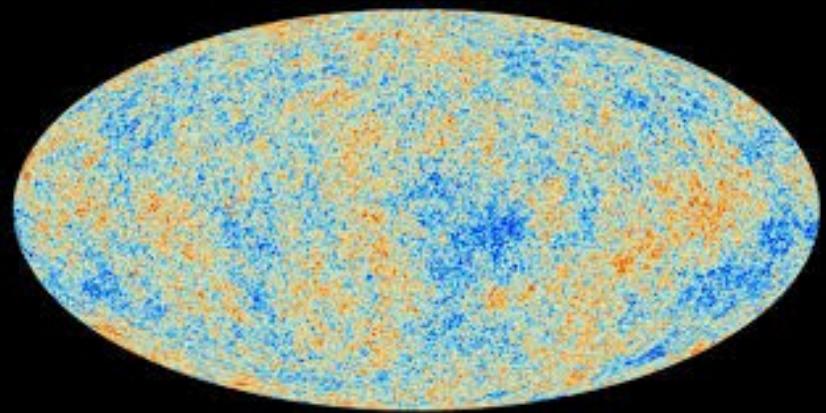
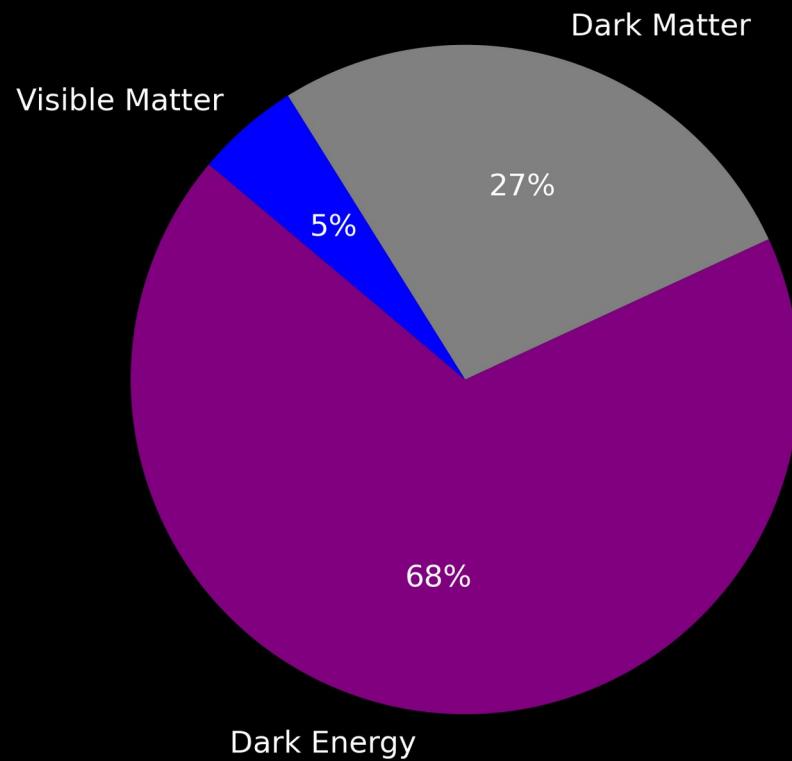


Adam Riess, Saul Perlmutter and Brian Schmidt shared the 2011 Nobel Prize in physics



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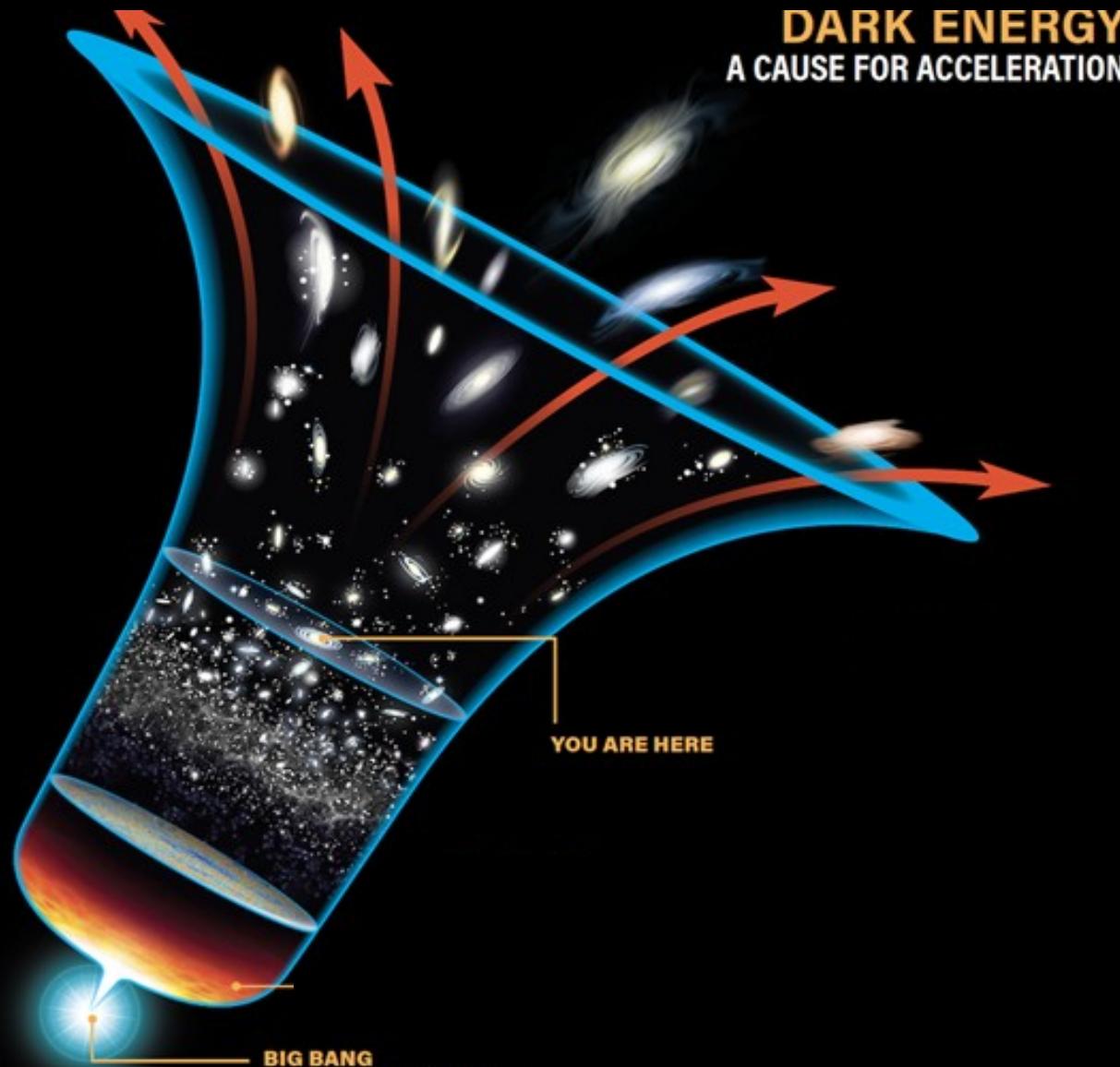
One picture summary of the Universe!



Cosmic Microwave Background
Temperature Fluctuations
(Planck Satellite)

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Dark Energy



Problems with Lambda-CDM cosmology

Dark Matter – What is it?

Dark Energy – What is it?

Inflation? – Observational evidence

Hubble Tension

Growth of Supermassive Blackholes

Galaxy Formation Feedback

...

THANK YOU

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"Look again at that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every "superstar," every "supreme leader," every saint and sinner in the history of our species lived there – on a mote of dust suspended in a sunbeam.

The Earth is a very small stage in a vast cosmic arena. Think of the rivers of blood spilled by all those generals and emperors so that, in glory and triumph, they could become the momentary masters of a fraction of a dot. Think of the endless cruelties visited by the inhabitants of one corner of this pixel on the scarcely distinguishable inhabitants of some other corner, how frequent their misunderstandings, how eager they are to kill one another, how fervent their hatreds.

Our posturings, our imagined self-importance, the delusion that we have some privileged position in the Universe, are challenged by this point of pale light. Our planet is a lonely speck in the great enveloping cosmic dark. In our obscurity, in all this vastness, there is no hint that help will come from elsewhere to save us from ourselves.

The Earth is the only world known so far to harbor life. There is nowhere else, at least in the near future, to which our species could migrate. Visit, yes. Settle, not yet. Like it or not, for the moment the Earth is where we make our stand.

It has been said that astronomy is a humbling and character-building experience. There is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the pale blue dot, the only home we've ever known."

