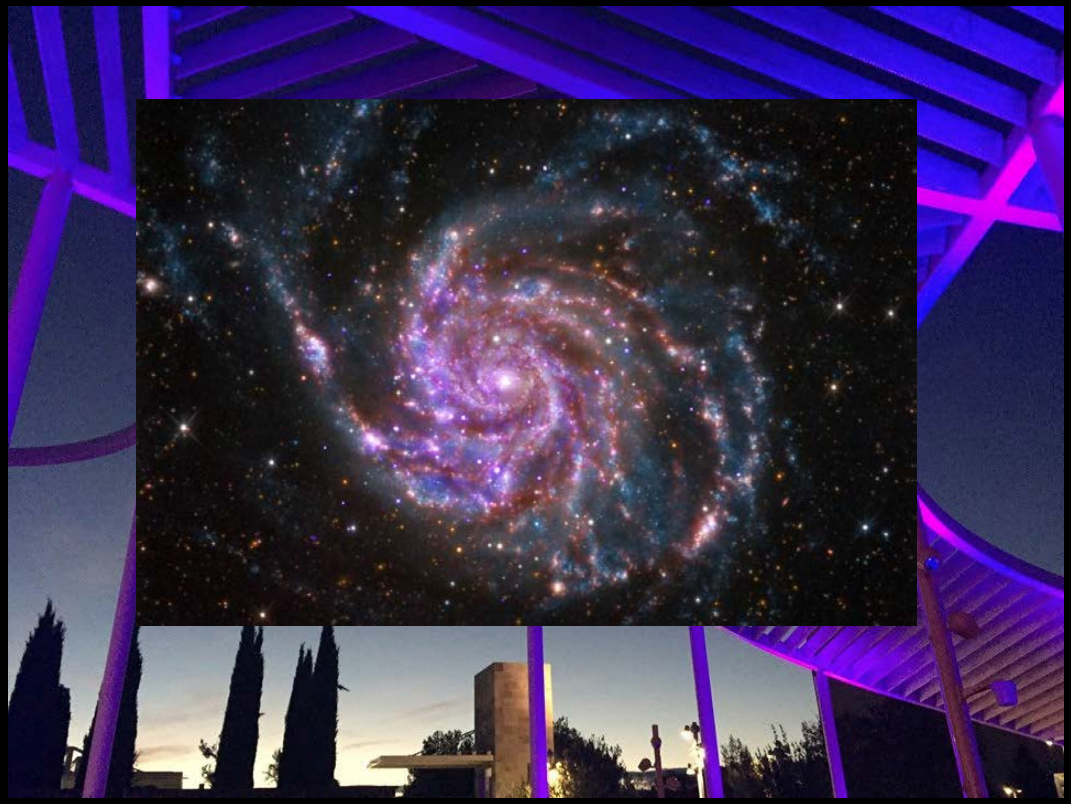
Shadows and Light in the Universe



Andreas Albrecht
UC Davis dept. of Physics
Public Talk at Manetti Shrem Museum
December 1, 2016

https://www.nasa.gov/mission_pages/chandra/multimedia/spiral-galaxy-m101.html

Cornell, c.1976

Cornell, c.1976

Physicist Robert Wilson

(Cornell Arts & Architecture Colloquium 1979)

Physicist Robert Wilson

(Cornell Arts & Architecture Colloquium 1979)

The Fermilab architects did not know what they were doing so I had to step in!

Physicist Robert Wilson

Fermilab (Batavia IL)

(Cornell Arts & Architecture Colloquium 1979)

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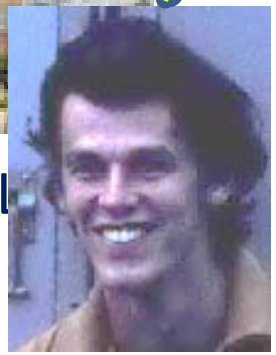
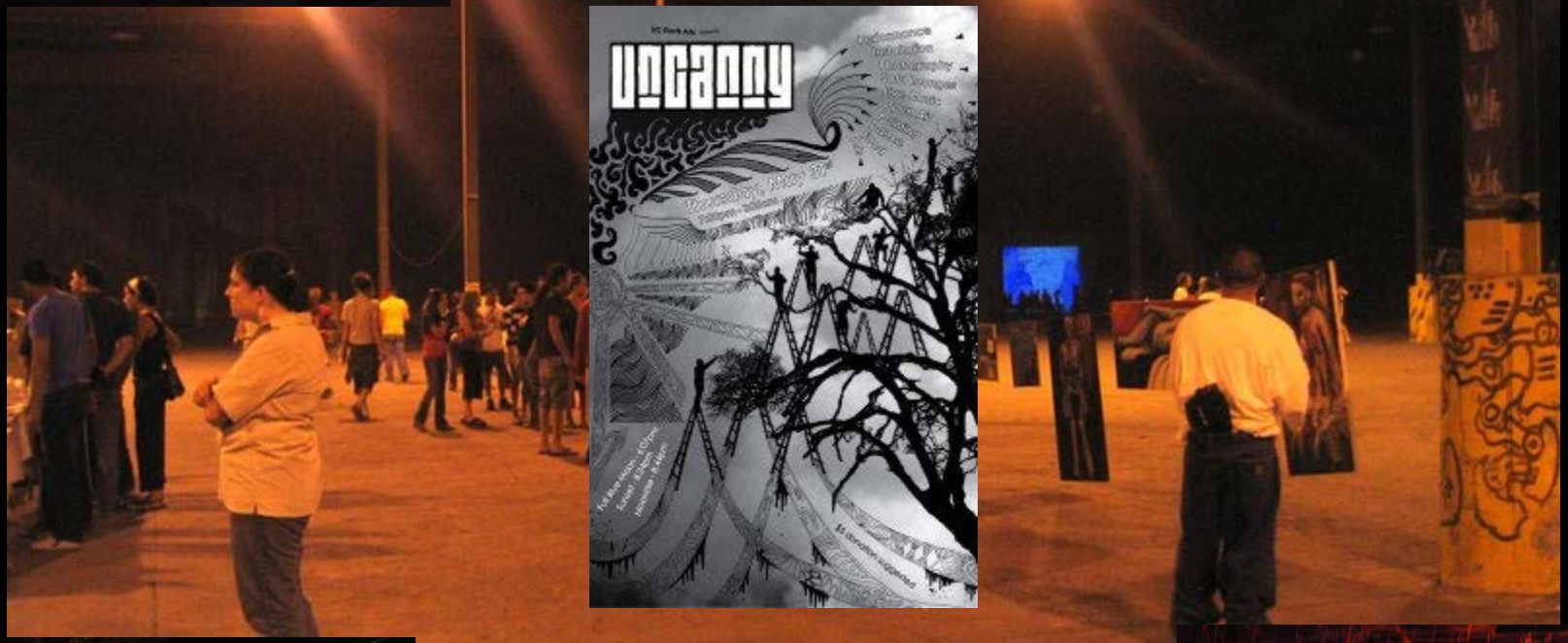
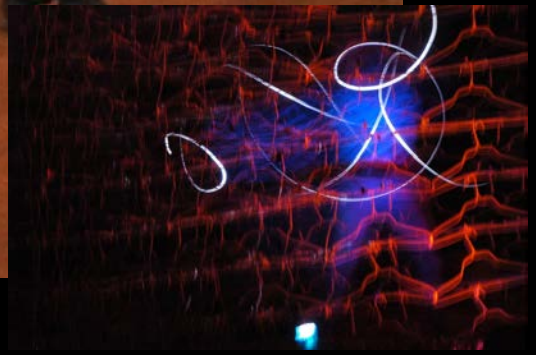
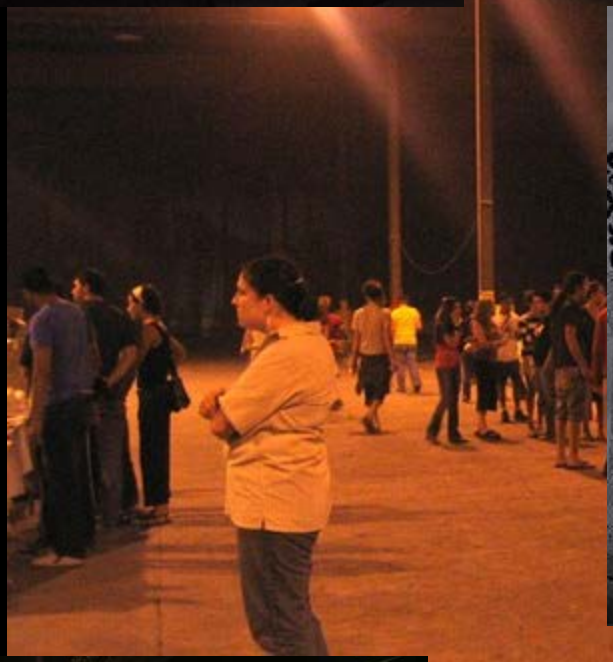
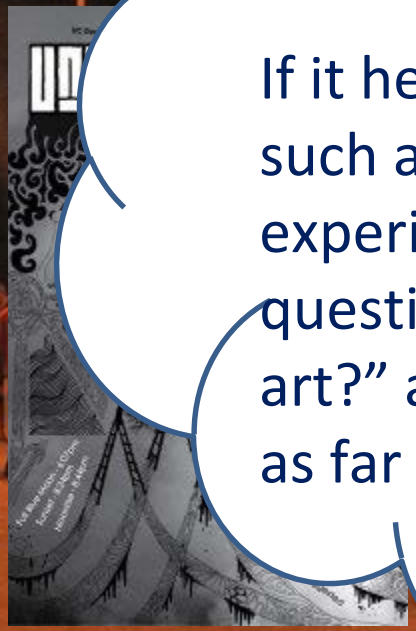




uncanny



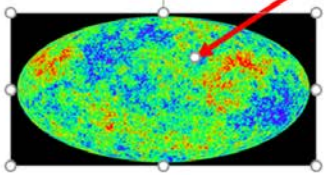


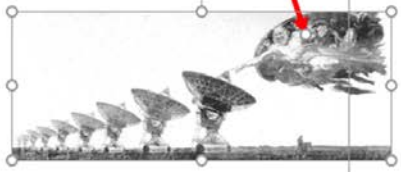


If it helps them create such a powerful experience, they can ask questions like “what is art?” as much as they like, as far as I am concerned!

The UCD Cosmology Group:

- **Faculty** A. Albrecht & B. Becker





- **Grad Students** R. Garavuso, A. Lewin, T. Price, C. Skordis, J. Weller

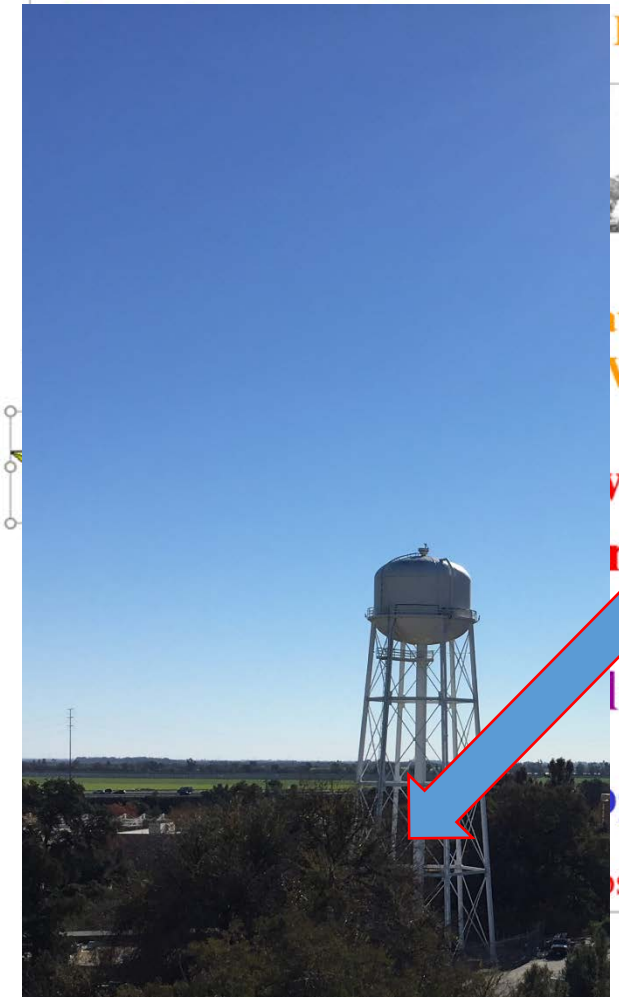
Future: Three new cosmology hires in the next three years (two offers out right now). + more in dept plan

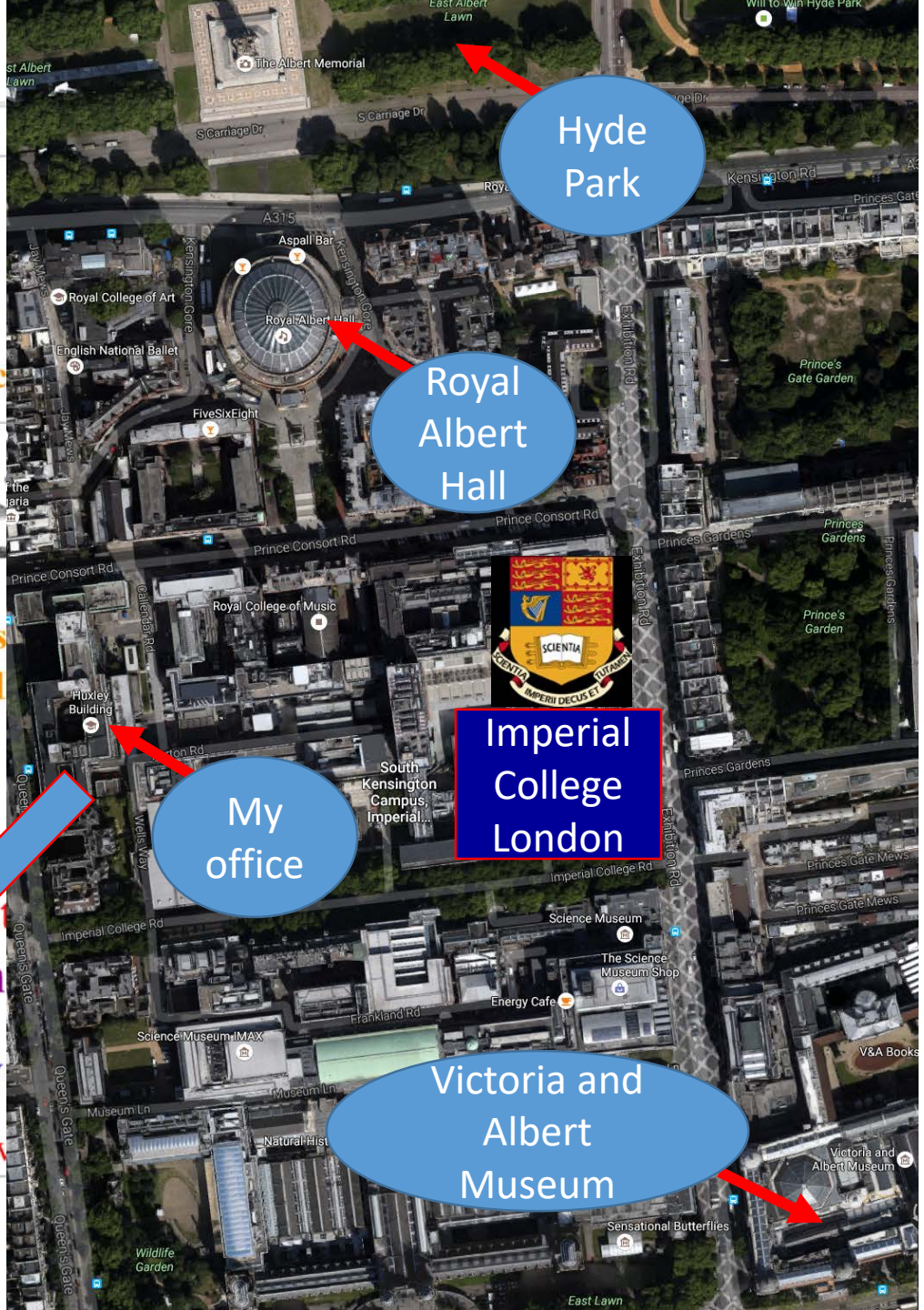
- **Golden age of cosmology:**

Rapid advances in Theory & Observation

From a 1999 presentation to prospective graduate students

The UCD Cosmology Group:





OUT OUR WAY

Soon after its founding in 1958, the Department of Art at UC Davis achieved international acclaim, and its first generation faculty became known as a wildly inventive community of artists. The twelve artists recruited by founding chair Richard L. Nelson fostered a complex creative community rife with jocular exchange as well as competitive jockeying.

In this gallery a singular work by each artist represents the power of their collective achievement. As you progress through the exhibition you will encounter what we call "pivotal moments" when the artists were exploring new directions, taking chances, and consistently defying the conventional wisdom coming out of New York. Projected images from the archive offer glimpses of each artist's studio practice and teaching style.

Inspired by colleagues from across the university, our first generation faculty enjoyed a provocative and open environment. "We had continual challenges, knocking us off our feet, making us mad and instigating the whole process of creative germination," explained Wayne Thiebaud. Exhibited together with a focus on work made at Davis during this formative period, their remarkably open flow of ideas becomes apparent again.

Because they were unafraid to pursue their own vision, our artists were once condemned for sharing "a defiant provincialism." Now we celebrate their maverick spirit. The audacity of their ideas and the boldness of their reach have become core values of the Manetti Shrem Museum. Always pursuing the new and open to challenging ideas, we are a contemporary art museum with a future inspired by our past.

Rachel Teagle, Founding Director
Jessica Hough, Guest Curator
Randy Roberts, Deputy Director
Francesca Wilmott, Associate Curator
Arielle Hardy, Curatorial Assistant

MA Grads, 1967

Top row: Harold Schlotzhauer, Dick Nelson, Bob Morrison, Ralph Johnson, Gary Molitor, Dick Cramer, Roland Peterson, David Gilhooly. Next row: Ruth Horsting, Robyn Winters, Dan Shapiro, Jeannie Martin, Tio Giambruni, Manuel Neri. Bottom row: Peter Saul, Robert Bechtle, (bottom row between Robyn and Roy), Roy DeForest

(From the wall text of the current "Out Our Way" exhibit)

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Jochen Weller

Alex Lewin

Andy Albrecht

Bob Becker

Constantinos Skordis

Ben Gold

Adam Amara

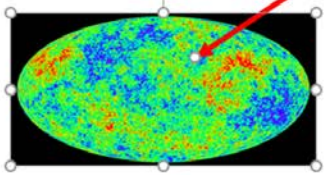
Yong-Seon Song

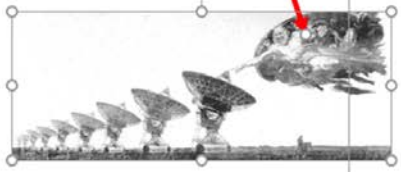
Alan Peel

Some members of the UCD Cosmology Group, July 2000

The UCD Cosmology Group:

- **Faculty** A. Albrecht & B. Becker





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From a 1999 presentation to prospective graduate students

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Department of Physics
UC Davis
One Shields Avenue
Davis, CA 95616
Ph: (530) 752-1500
Fax: (530) 752-4717

Safety
Make a Gift

People

Faculty
- Andreas Albrecht
- Bob Becker
- Pat Boeshaar
- Marusa Bradac
- Chris Fassnacht
- Nemanja Kaloper
- Lloyd Knox
- Lori Lubin
- Tony Tyson
- David Wittman

+2 New hires = 12 faculty!

Visiting Faculty and Researchers
- Eric Gawiser
- Kirk Gilmore
- Michael Wood-Vasey

Senior Fellow of Mathematical and Physical Sciences
- Wayne Rosing

Research Physicists
- Michael Cregg
- Myungkook James Jee
- Matt Richter
- Michael Schneider
- Sam Schmidt
- Ryan Scranton
- Adam Stanford

Postdocs
- Will Dawson
- Craig Lage
- Pedro Mora
- Edward Rusu
- George Zahariade

Specialists
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- Alison Mansheim
- Marius Millea
- (Karen) Yin Yee Ng
- Zhen Pan
- Daniel Phillips
- Nick Rumbaugh

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Center for Quantum Mathematics and Physics (QMAP)

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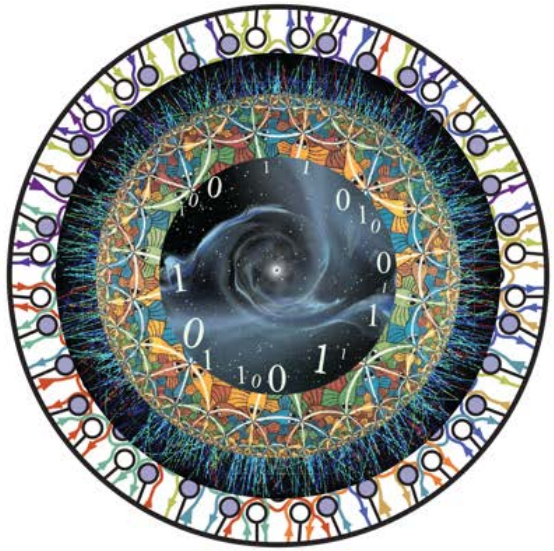

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s (QMAP)

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itors

THE WINSTON KO FRONTIERS OF MATHEMATICAL AND PHYSICAL SCIENCES PUBLIC LECTURE SERIES

Illuminating Black Holes

May 9, 2016, 5 p.m.
UC Davis Conference Center

QMAP

Black holes are among the most remarkable objects present in our universe. Intriguingly, they have also proved to be incredibly fascinating and useful theoretical laboratories for exploring our deepest questions in fundamental physics. This talk, aimed at a broad audience, will reveal the multifaceted nature of black holes by describing our modern understanding of them as well as some of the profound mysteries which remain.

Speaker
VERONIKA HUBENY, professor of physics

Veronika Hubeny, a leader in theoretical physics, joined the Department of Physics as a professor in 2015. Hubeny's interests include string theory, black holes, and reconciling quantum mechanics with the classical model of gravity. She earned her doctorate at UC Santa Barbara and most recently was a professor at Durham University in the United Kingdom. She is a key member of the Center for Quantum Mathematics and Physics (QMAP), a new initiative aimed at addressing questions at the forefront of modern theoretical and mathematical physics. QMAP was founded in 2015 with five new faculty in physics and mathematics.

ls.ucdavis.edu/our-college/mps

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RALPH JOHNSON

"My definition of art is to remain as open as possible. I don't think there are any rules. Shouldn't be."

(From the wall text of the current "Out Our Way" exhibit)

RALPH JOHNSON

"My definition of art is to remain as open as possible. I don't think there are any rules. Shouldn't be."

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PIVOTAL MOMENT

Like ceramics, carpentry was an unconventional choice in the 1960s, and risked being characterized as mere craft. Johnson embraced this challenge, and never returned to painting and drawing in the same way again. With a combination of academic and artistic interest, Johnson labored over nuance of form and unequivocal craftsmanship, even traveling to Europe to study joinery at the Victoria and Albert Museum. Working in wood, he balanced precision and whimsy in lively sculptures that dance between artistic form and furniture function.

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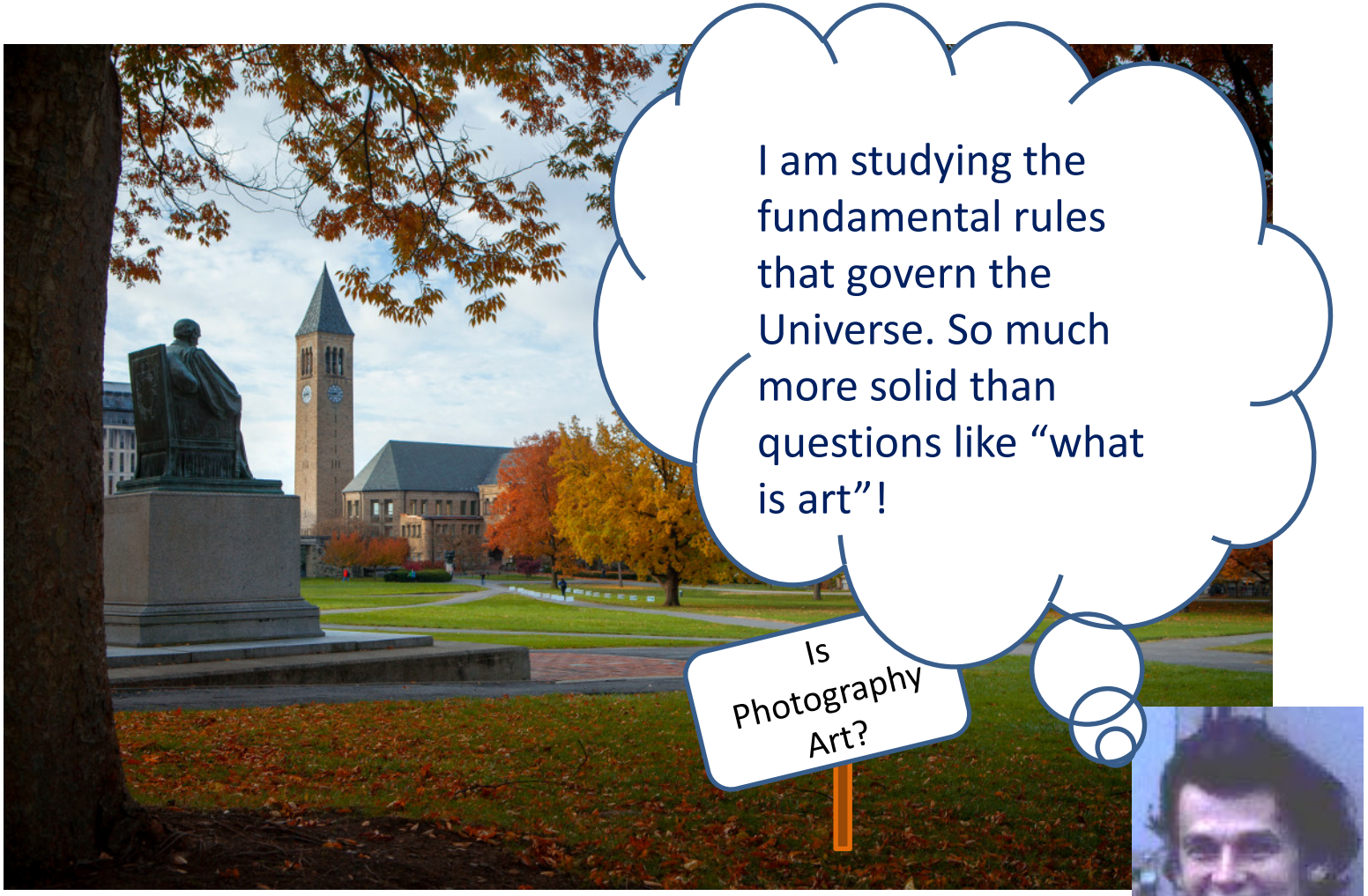
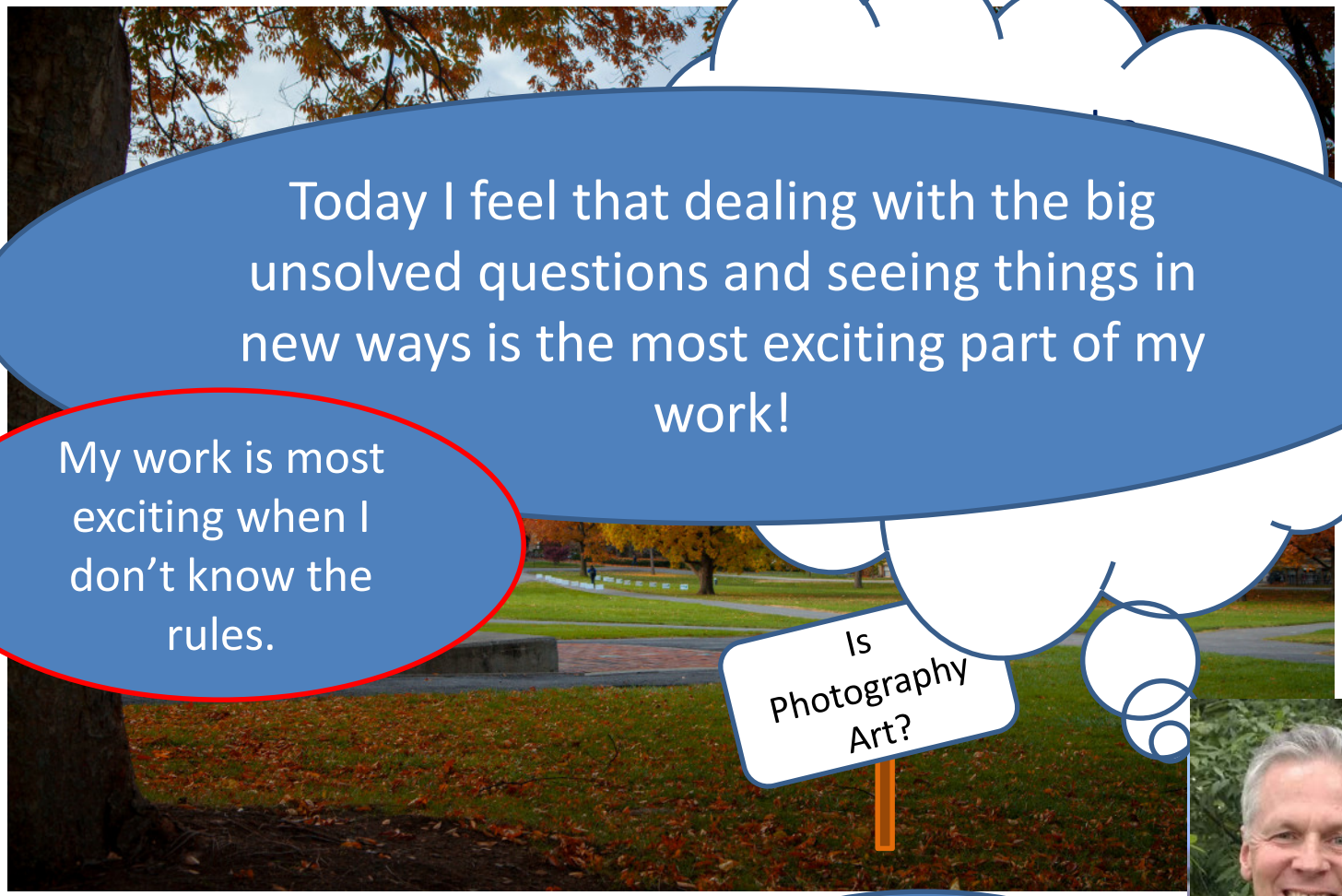


Cornell, c.1976


Today I feel that dealing with the big unsolved questions and seeing things in new ways is the most exciting part of my work!
Is Photography Art?
UCD 2016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My work is most exciting when I don't know the rules.
Is Photography Art?
UCD 2016

Ralph Johnson

Ralph Johnson
Hello Chair, c. 1967
Enamel on wood
Approx. 35" x 21" x 21"
Private Collection of Clay Johnson

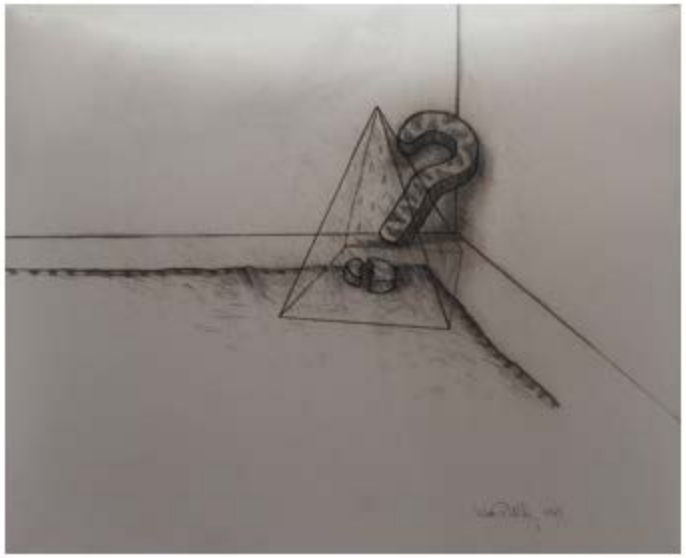
Ralph Johnson with "Family Reu[illegible] late 1960's

What is a chair?

jan shrem and maria manetti shrem museum of art

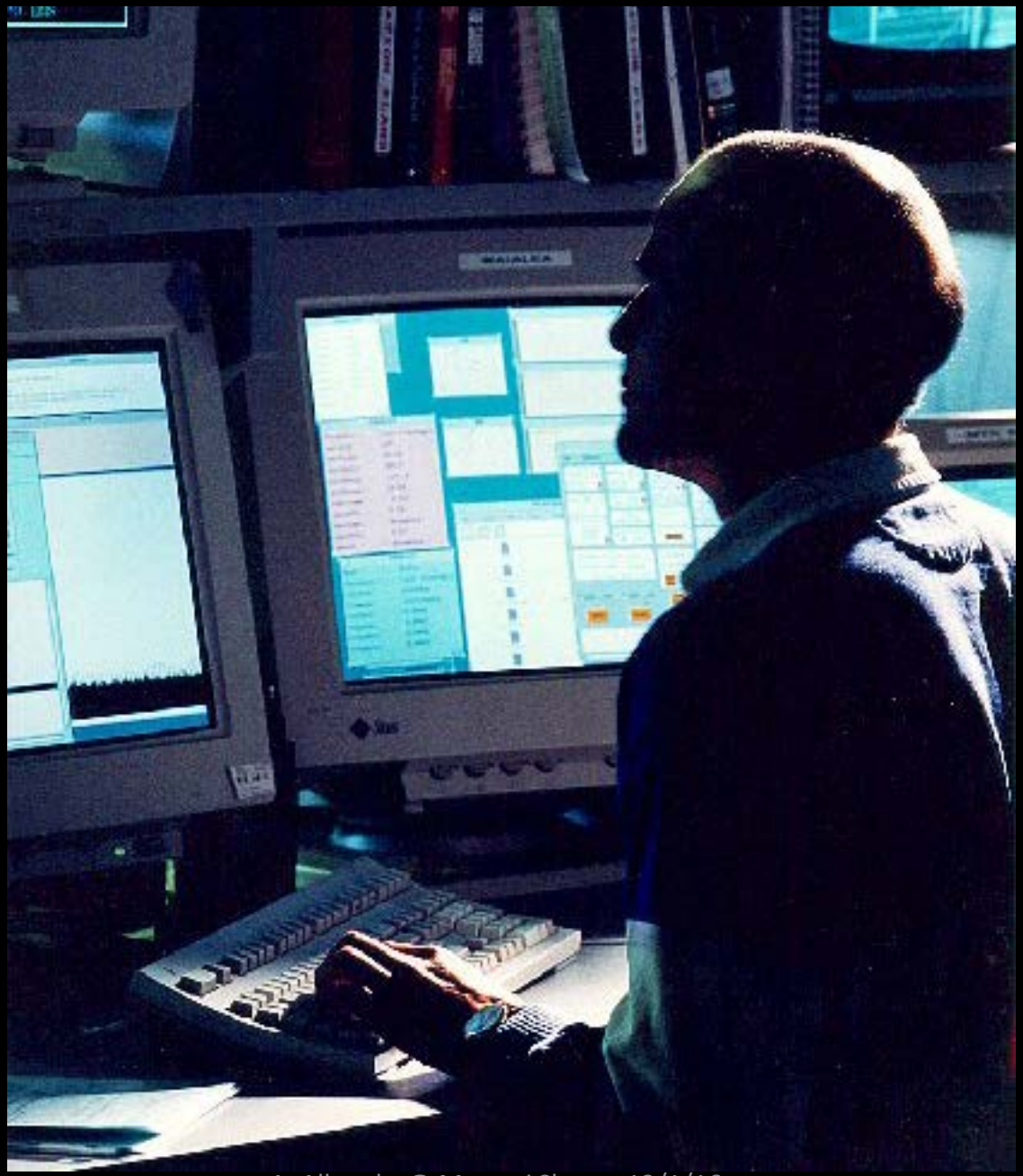
UCDAVIS

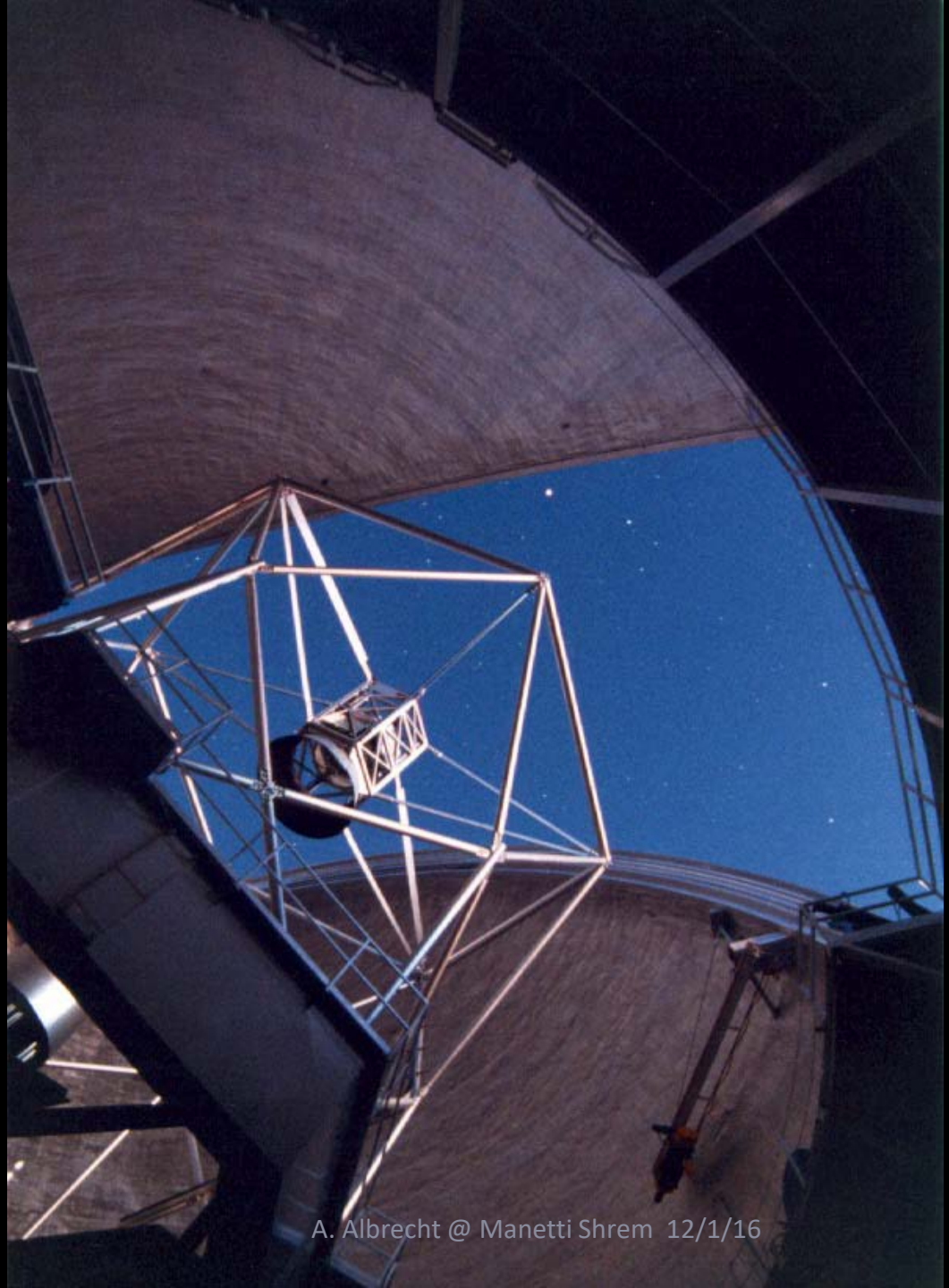
William T. Wiley



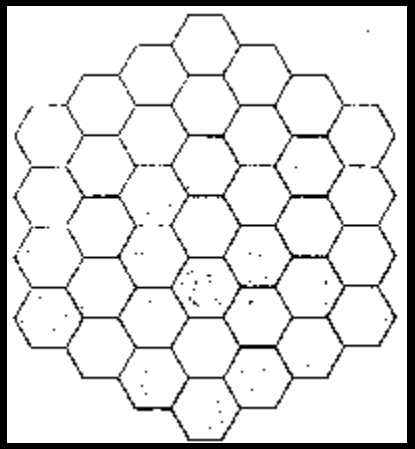
William T. Wiley
Untitled, 1965
Ink on aluminum
14 ½" x 17 ½"
Gift of Fay Nelson
The Fine Arts Collection at UC Davis. 1987.03.20D

What is the question?





The Keck 10m Telescopes on Mauna Kea, Hawaii



Segments of the Keck 10m Telescope Mirror

Outline

1. Introduction (The “Golden age of cosmology”)
2. The Big Picture
3. Some Big ideas
   - Cosmic Inflation
   - The String theory landscape

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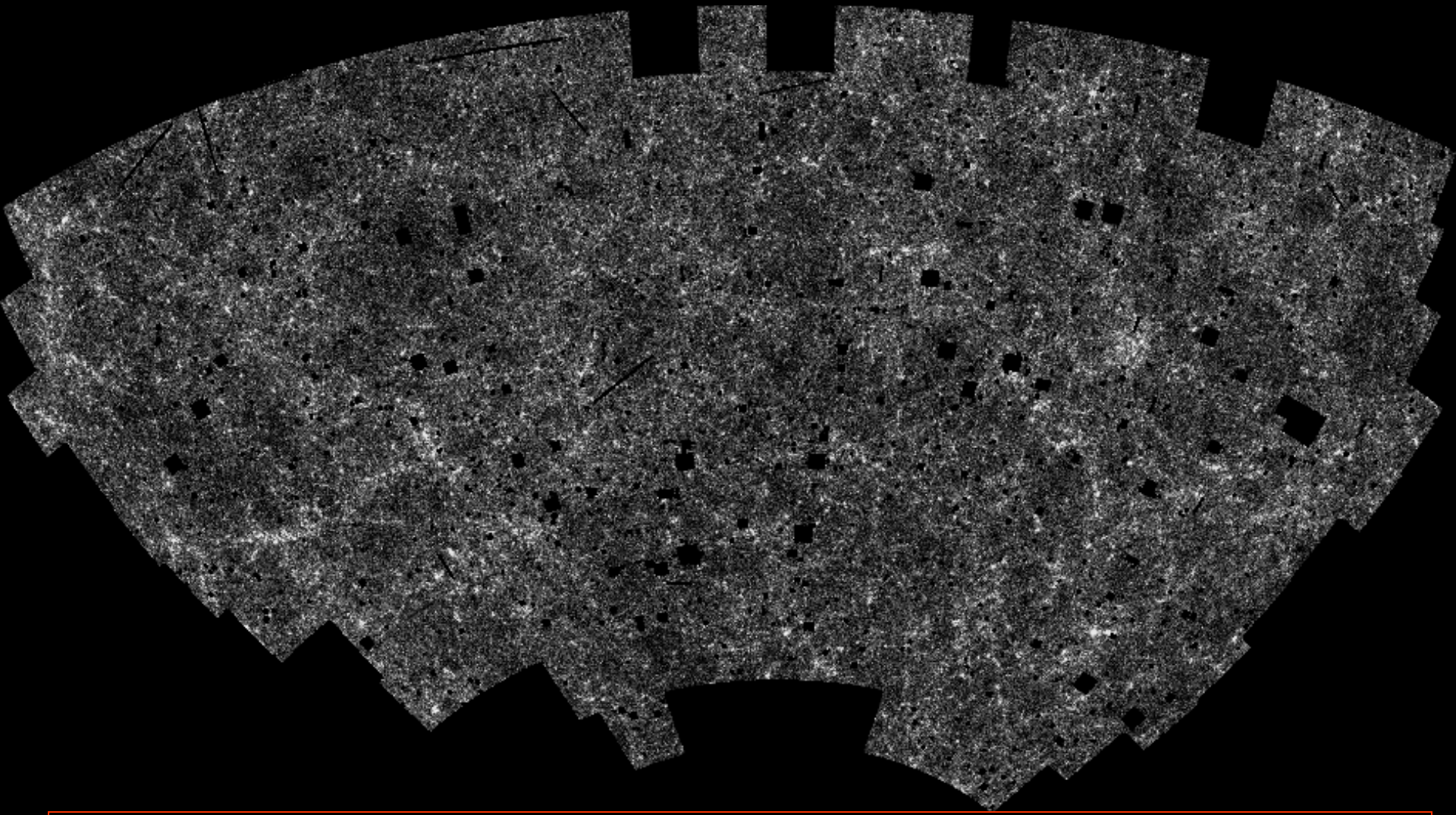
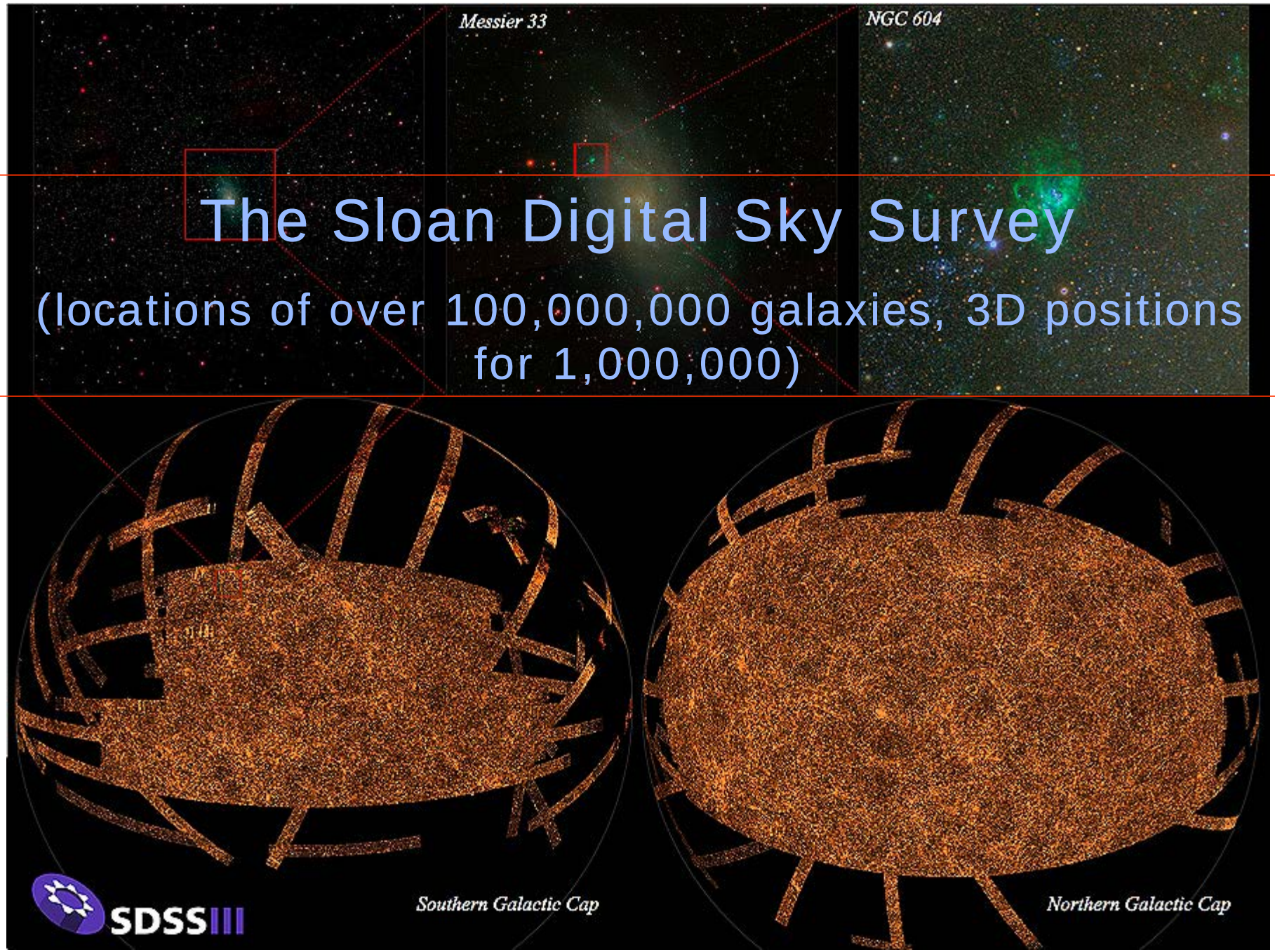


The APM (Automatic Plate Machine) Survey (1992)

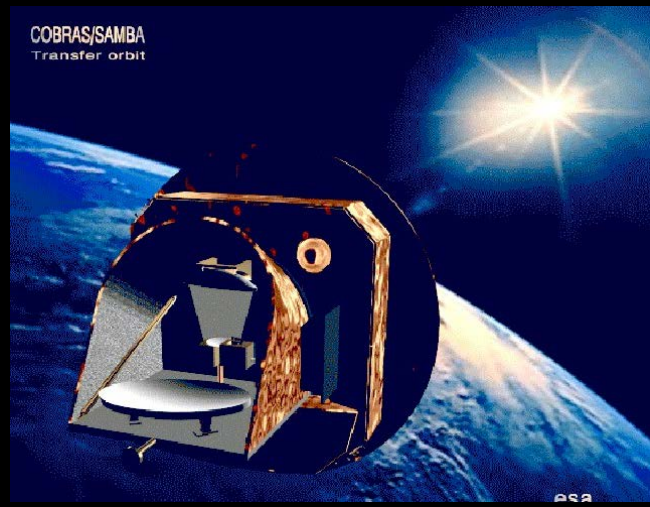
Sky positions of 2,000,000 Galaxies



The Sloan Digital Sky Survey

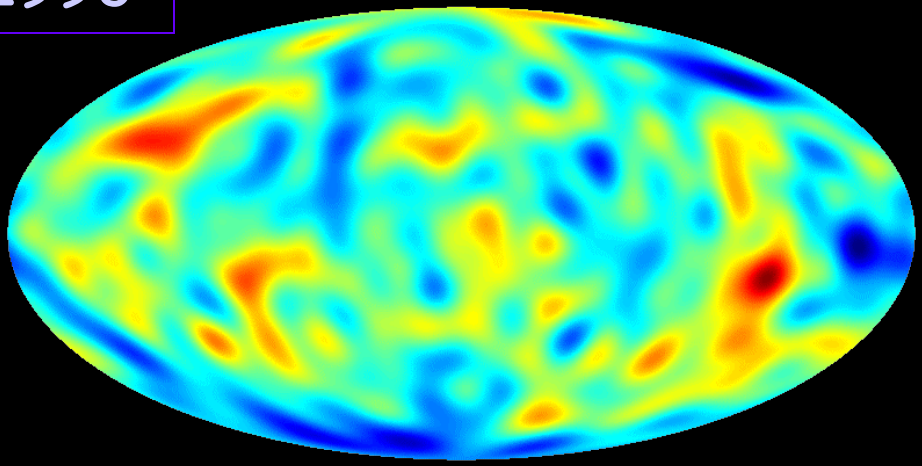
(locations of over 100,000,000 galaxies, 3D positions for 1,000,000)

Maps of the microwave sky (the "edge of the observable universe")



1993

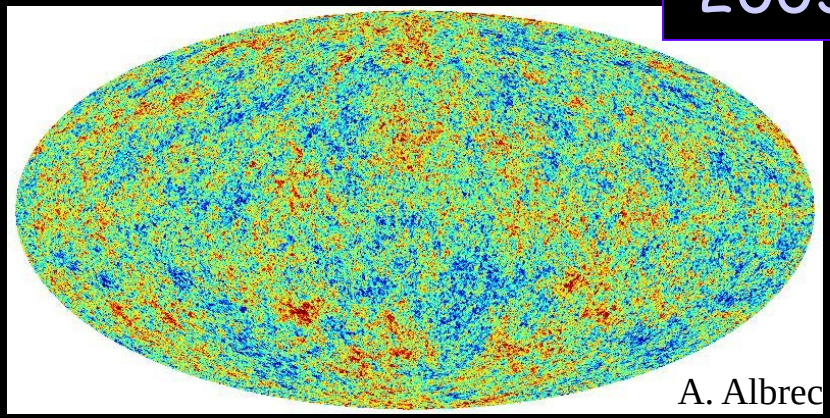
Real

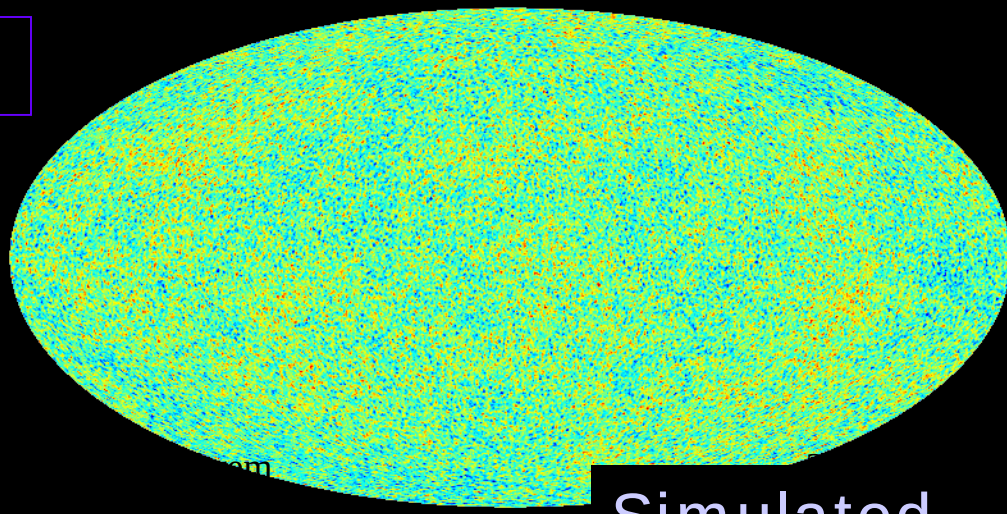


2009

Simulated

2003





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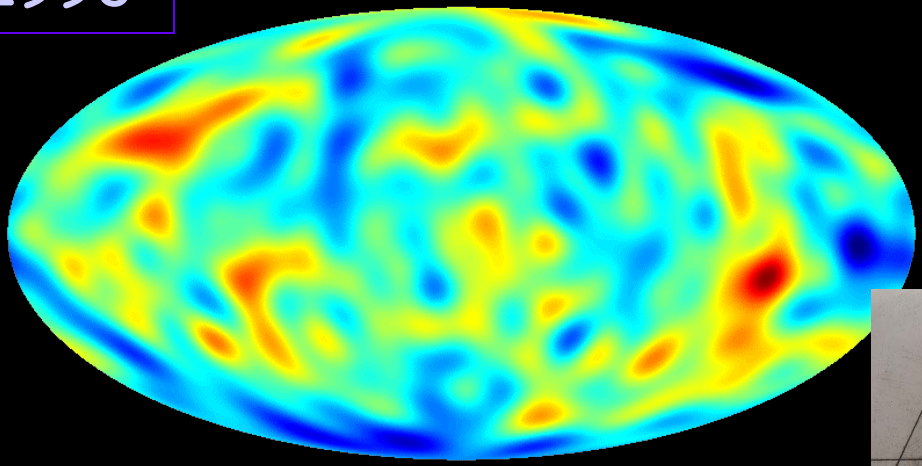
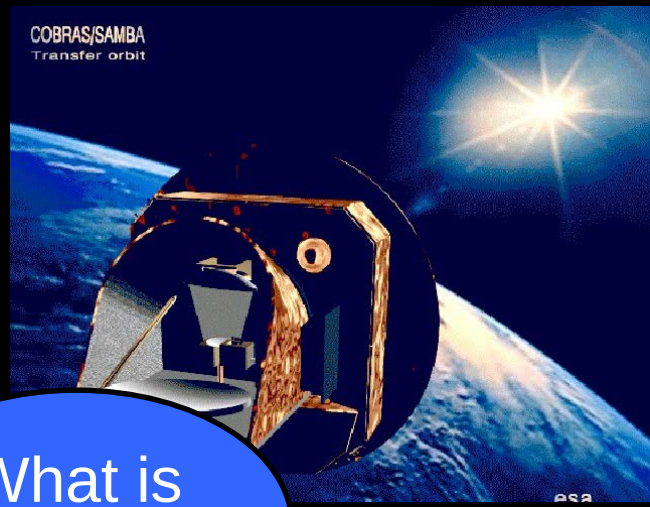
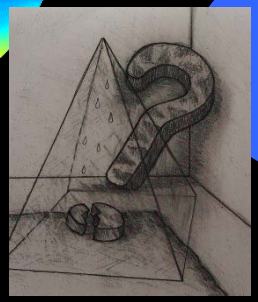




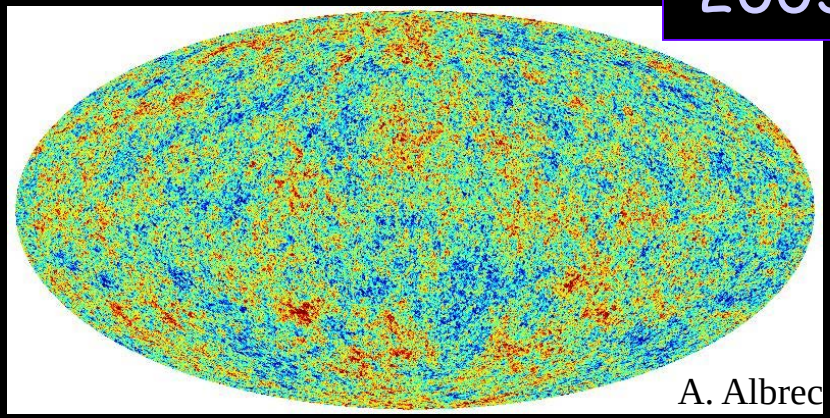


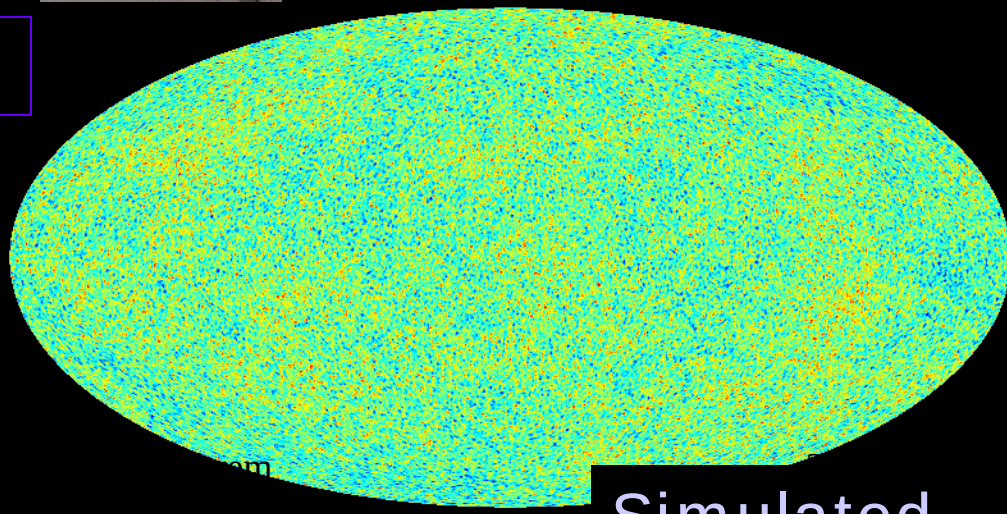
What is light?

2009

Simulated

2003



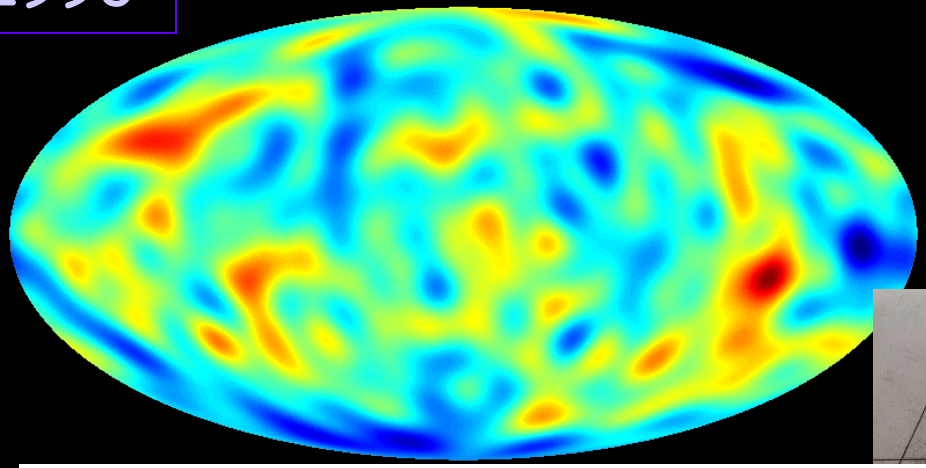


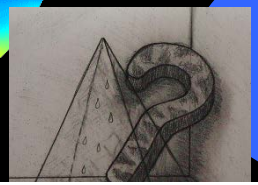
Simulated

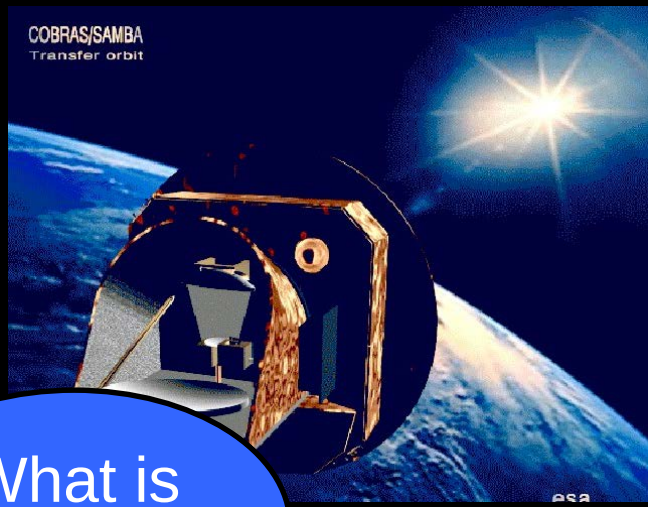
Maps of the microwave sky (the “edge of the observable universe”)

1993

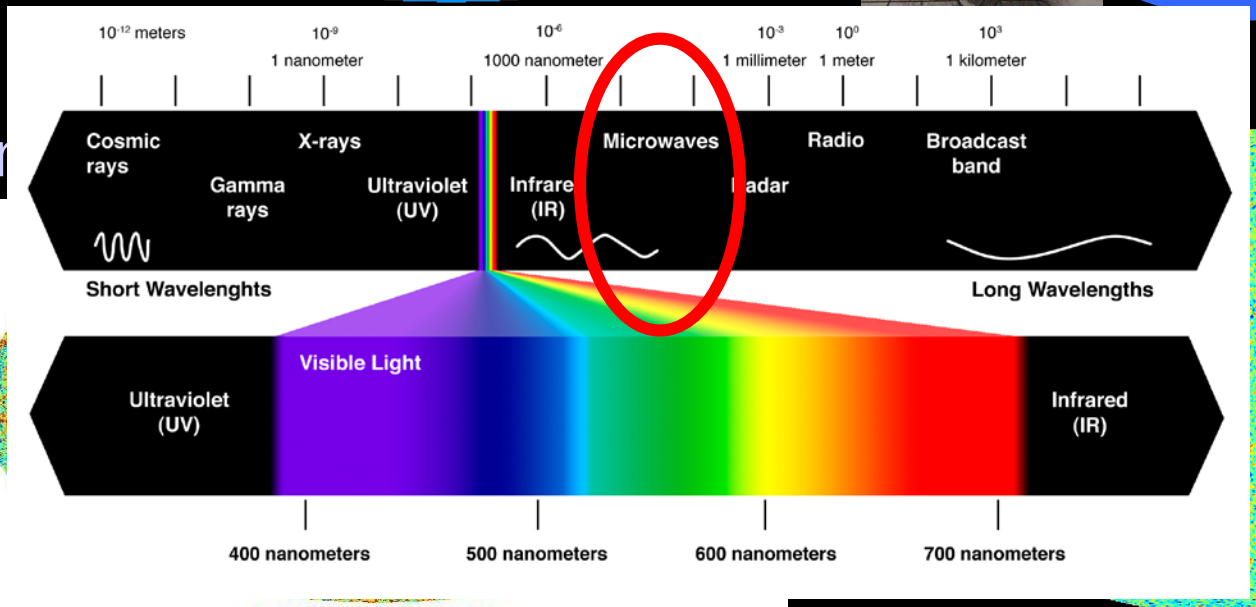
Real







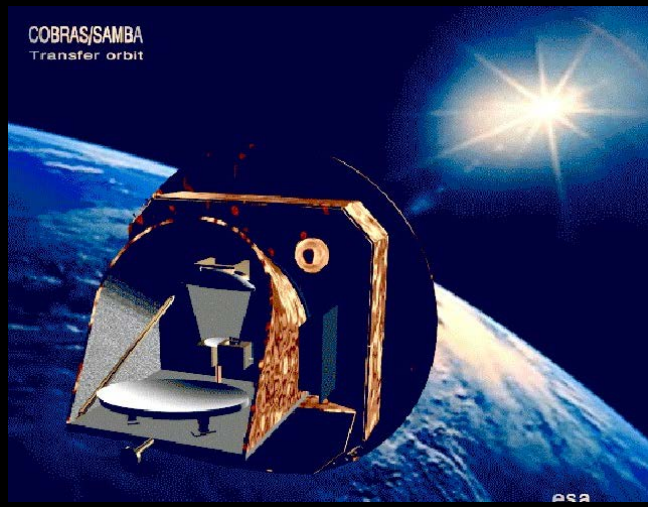
What is light?



2009

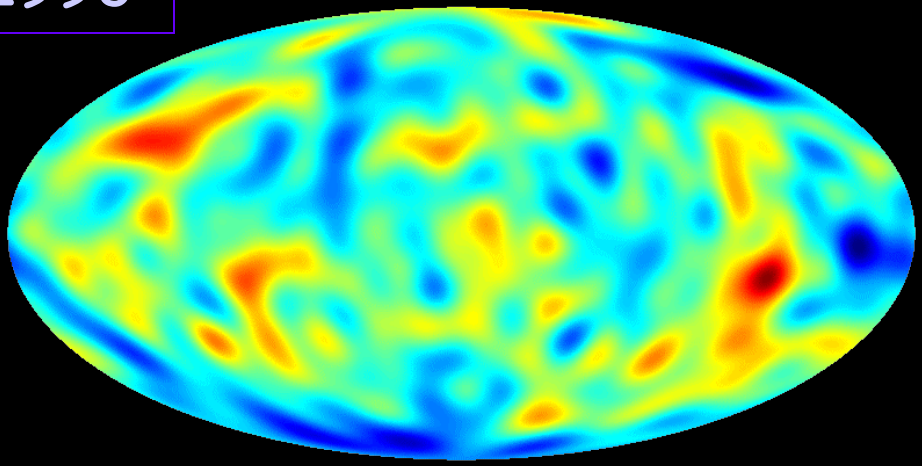
Simulated

Maps of the microwave sky (the "edge of the observable universe")



1993

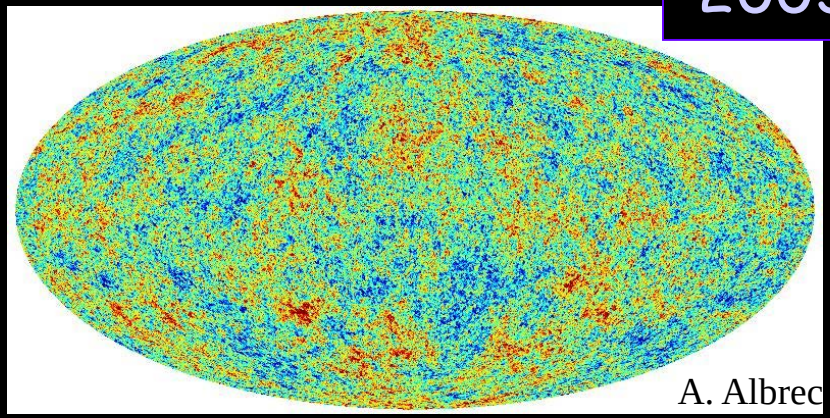
Real

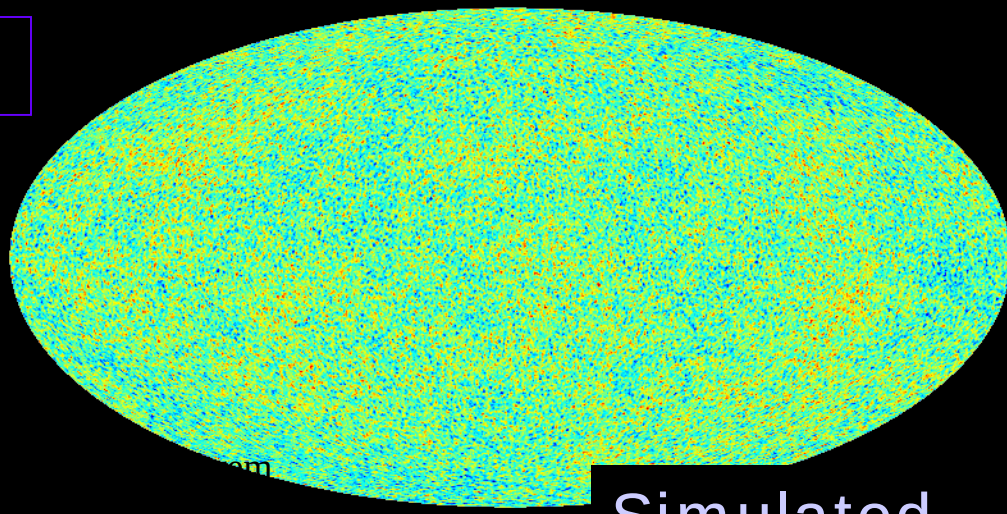


2009

Simulated

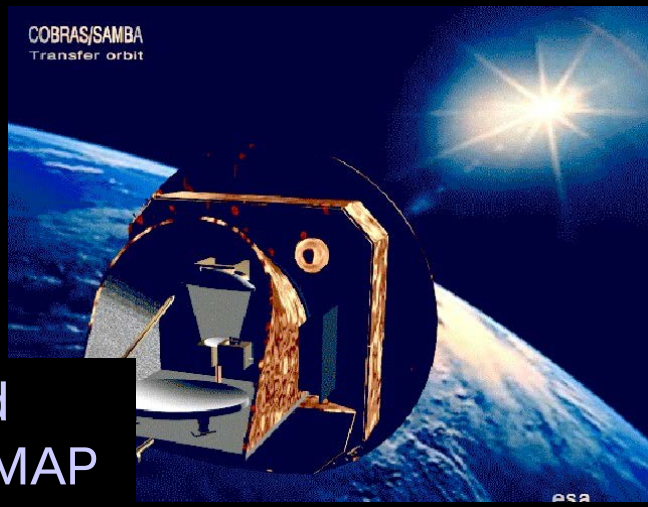
2003





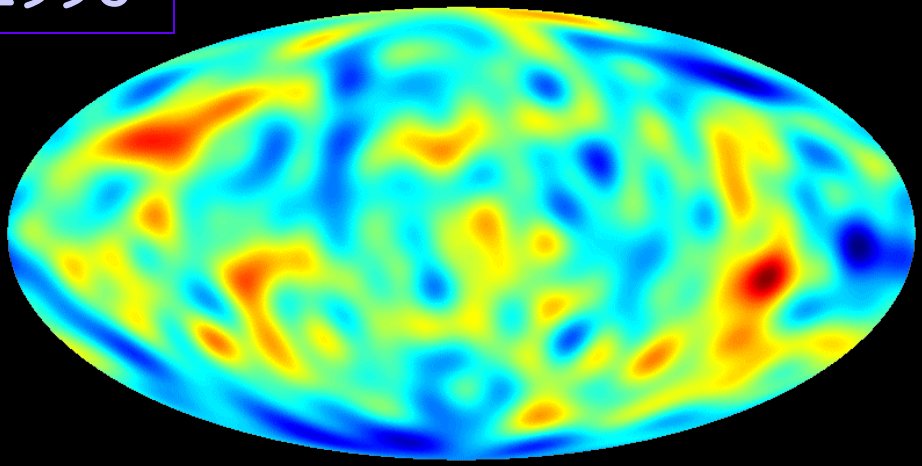
Simulated

Maps of the microwave sky (the "edge of the observable universe")



1993

Real

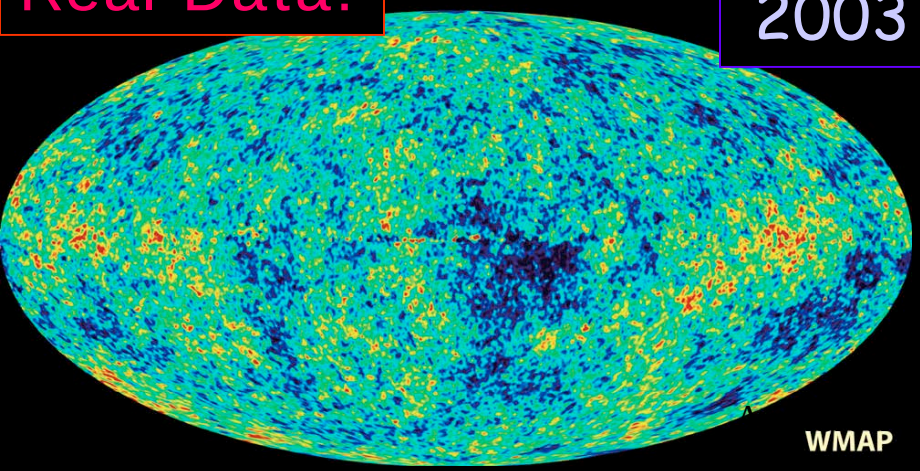


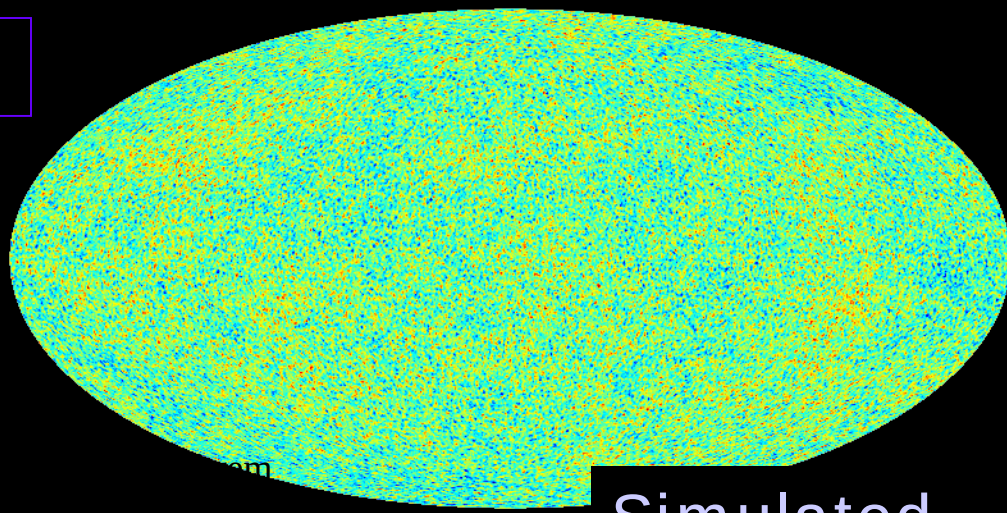
Updated after WMAP announcement, Feb 2003

2009

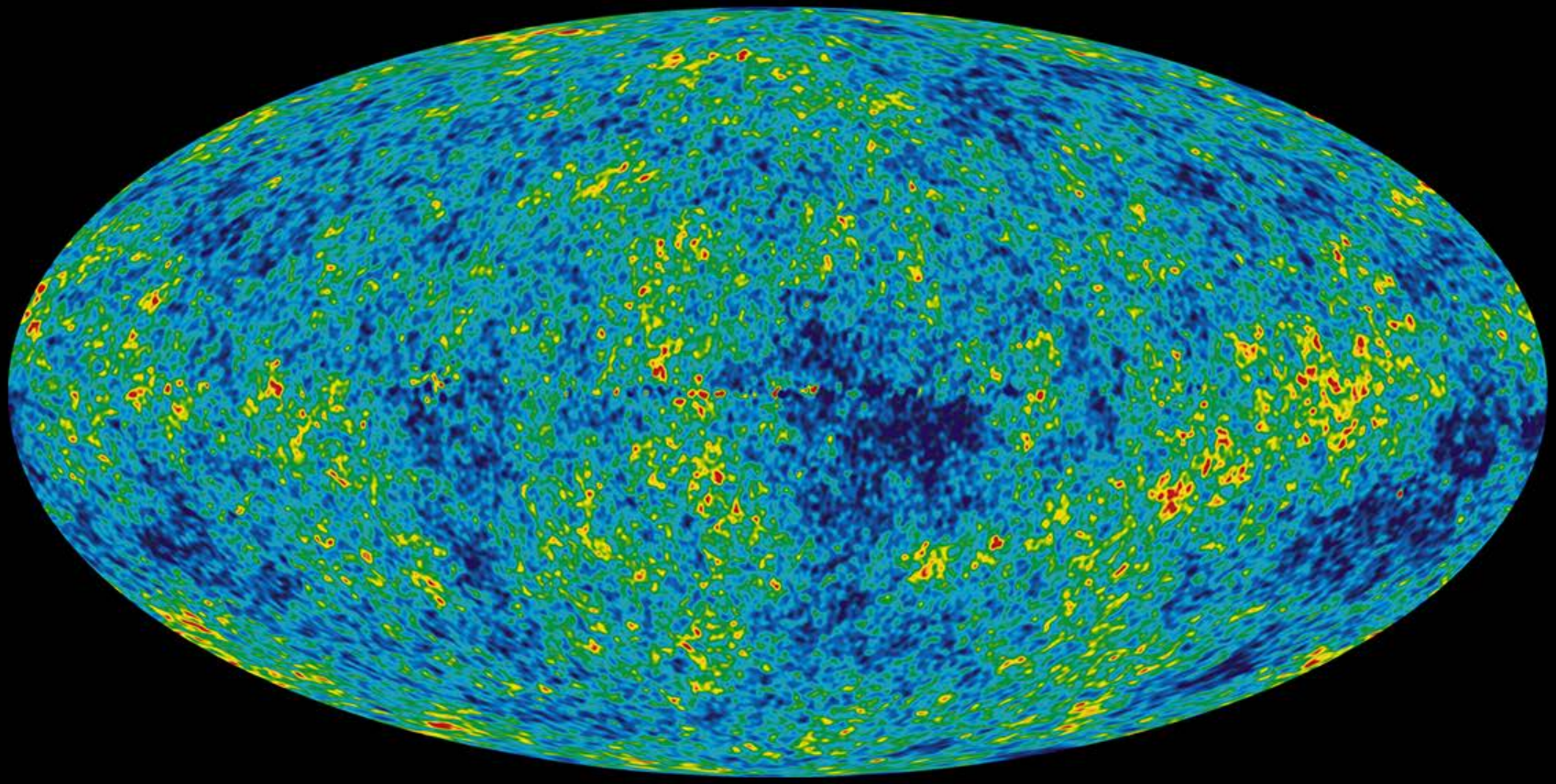
Real Data!

2003

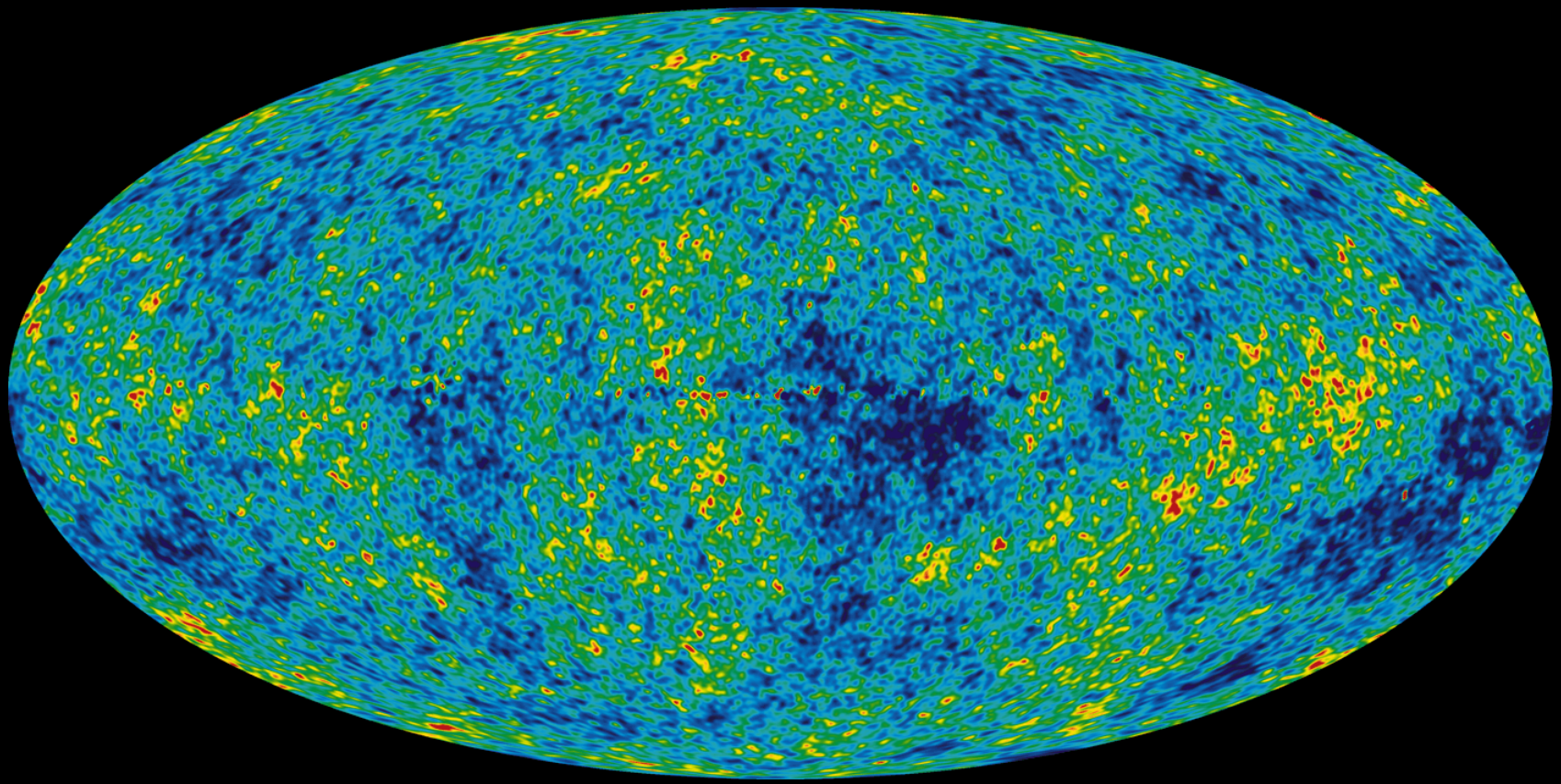




Simulated



WMAP 3-yr map

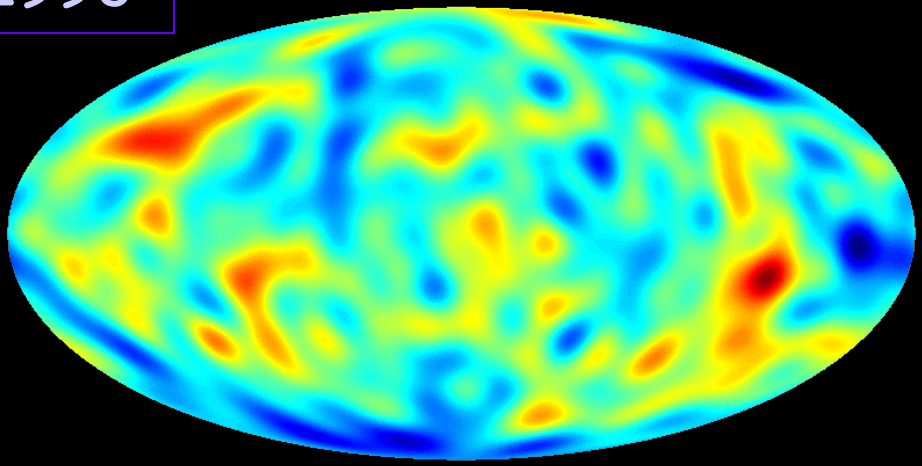


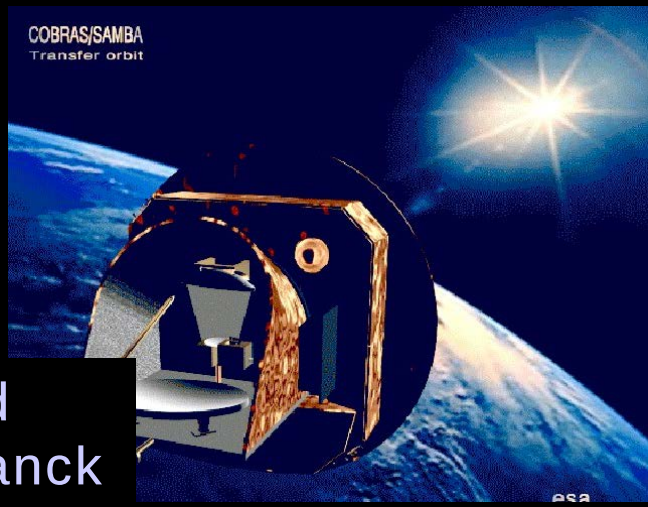
WMAP 5-yr map

Maps of the microwave sky (the "edge of the observable universe")

1993

Real



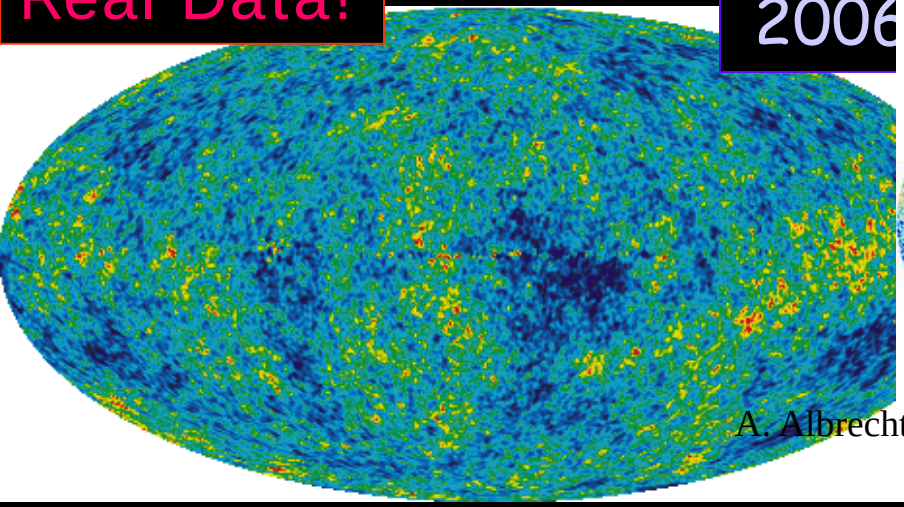


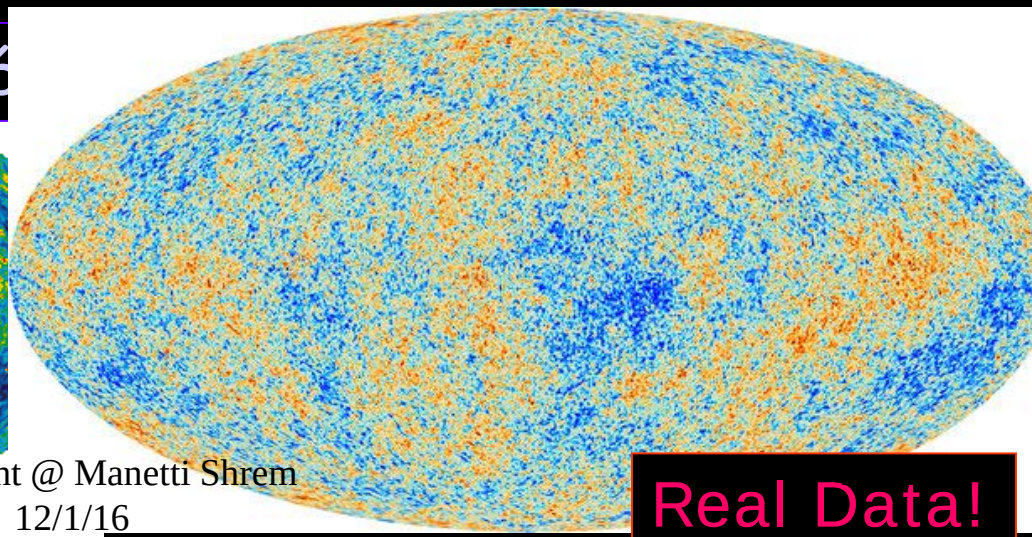
Updated after Planck announcement, 2013

2013

Real Data!

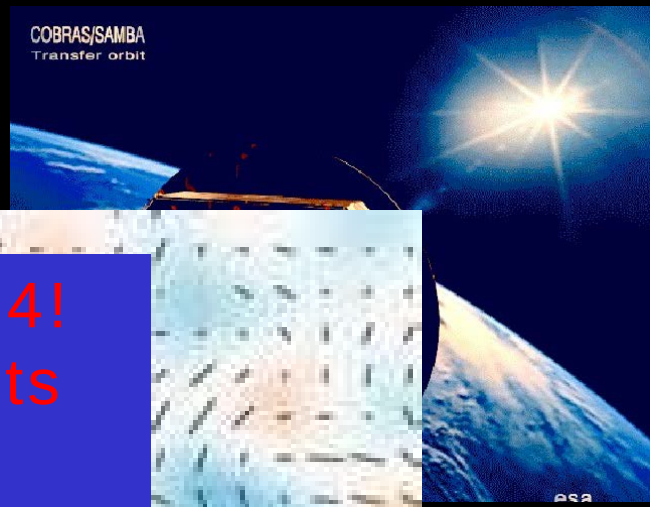
2006





Real Data!

Maps of the microwave sky (the "edge of the observable universe")



1993

Real

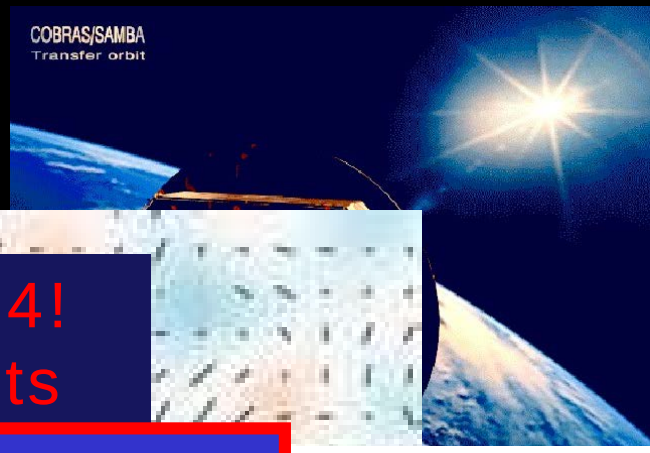
March 17 2014!
BICEP2 reports
signal from
primordial
gravitation waves
in microwave
"polarization"

013

Real Dat

Real Data!

Maps of the microwave sky (the "edge of the observable universe")



1993

Real

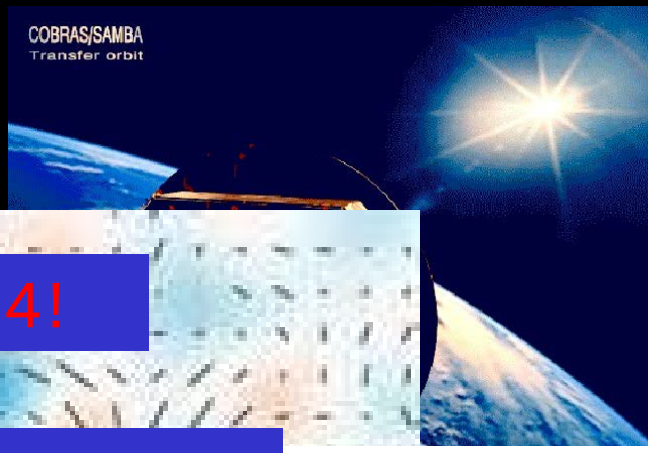
March 17 2014!
BICEP2 reports

May 2 2015 Planck reports better polarization data most likely due to nearby dust

Real Dat

Real Data!

Maps of the microwave sky (the "edge of the observable universe")



1993

Real

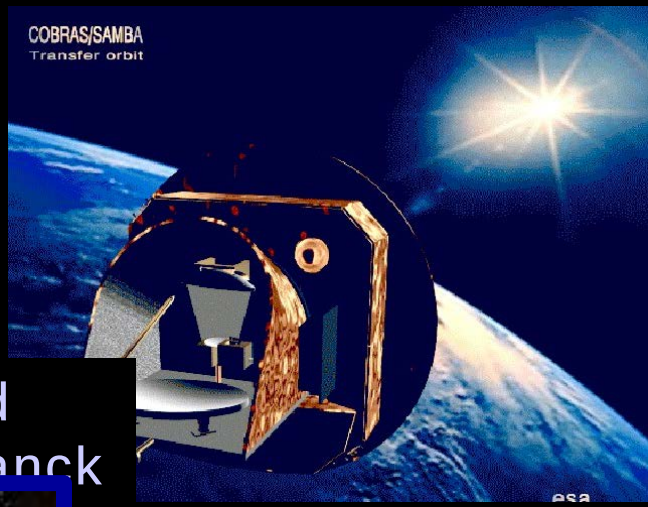
March 17 2014!

May 2 2015

Real Dat

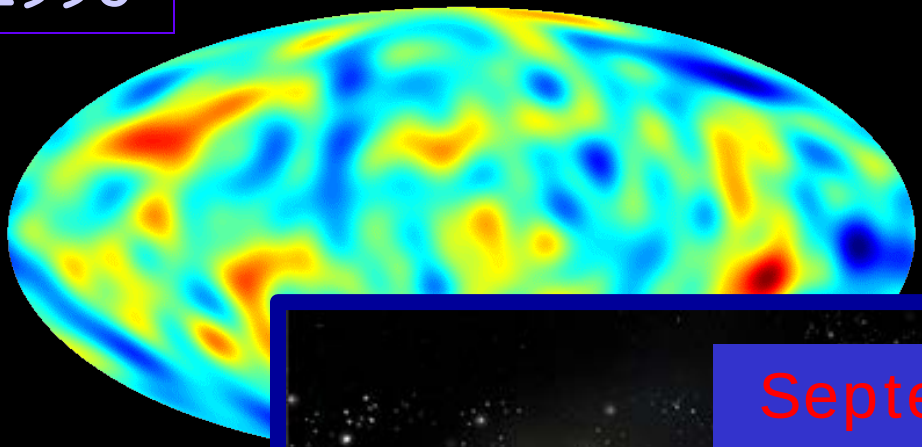
Real Data!

Maps of the microwave sky (the "edge of the observable universe")



1993

Real

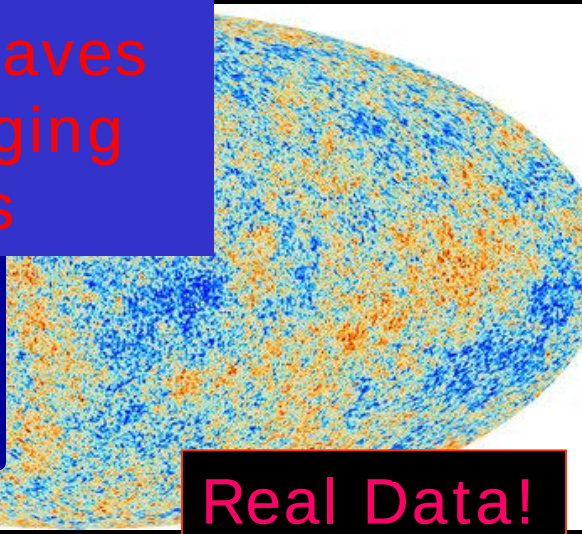


Updated after Planck

September 14 2015! LIGO reports direct detection of gravitational waves from two merging black holes

2013

Real Data!

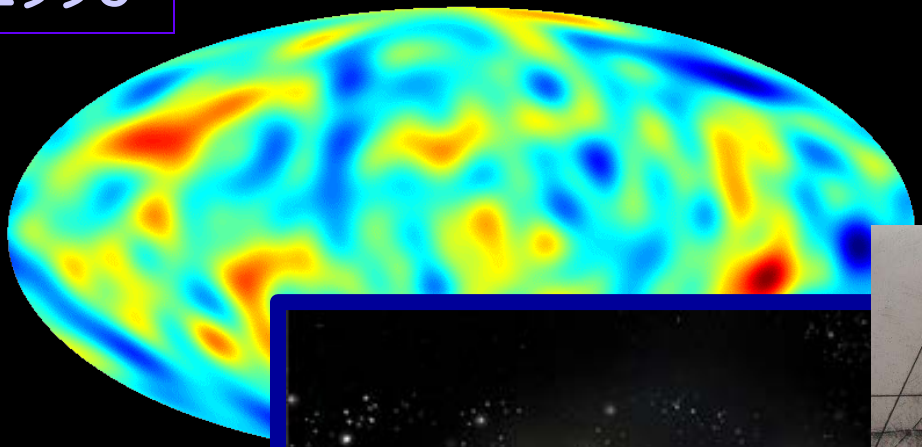


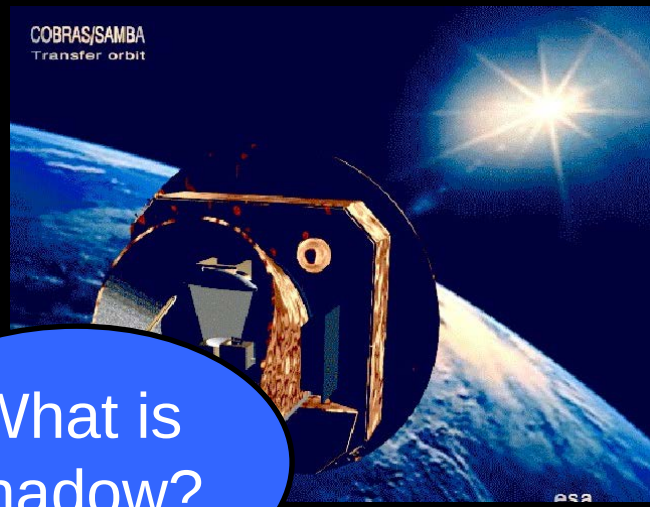
Real Data!

Maps of the microwave sky (the "edge of the observable universe")

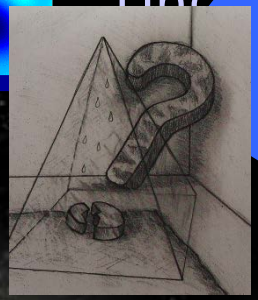
1993

Real



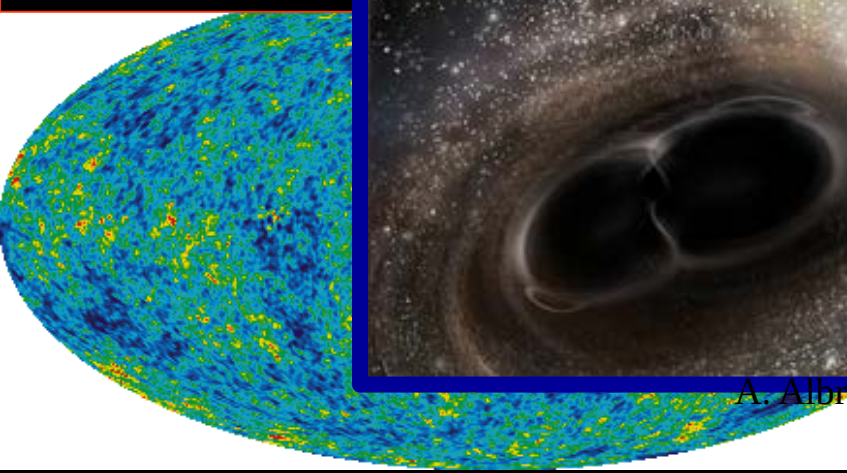


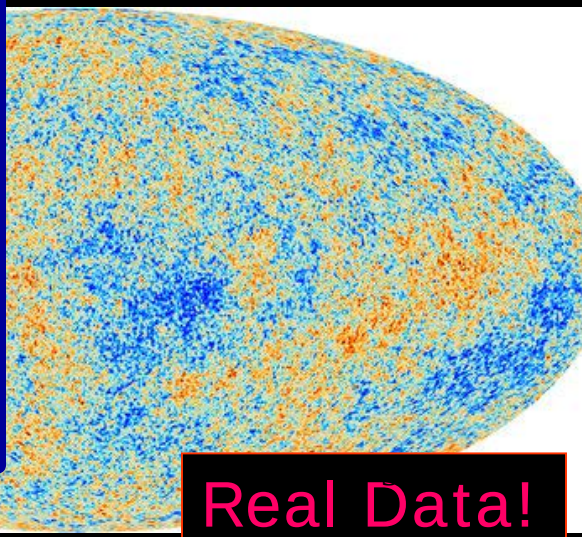
What is shadow?



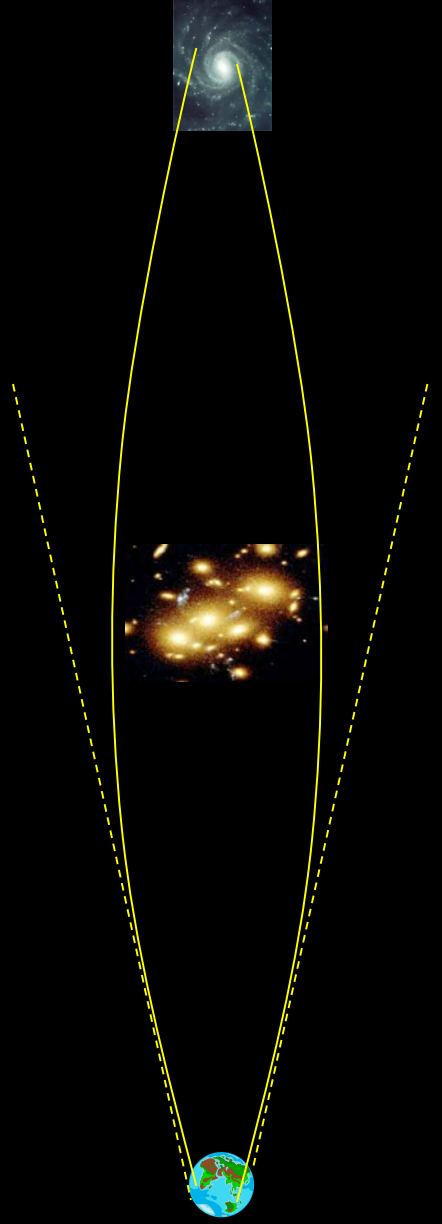
2013

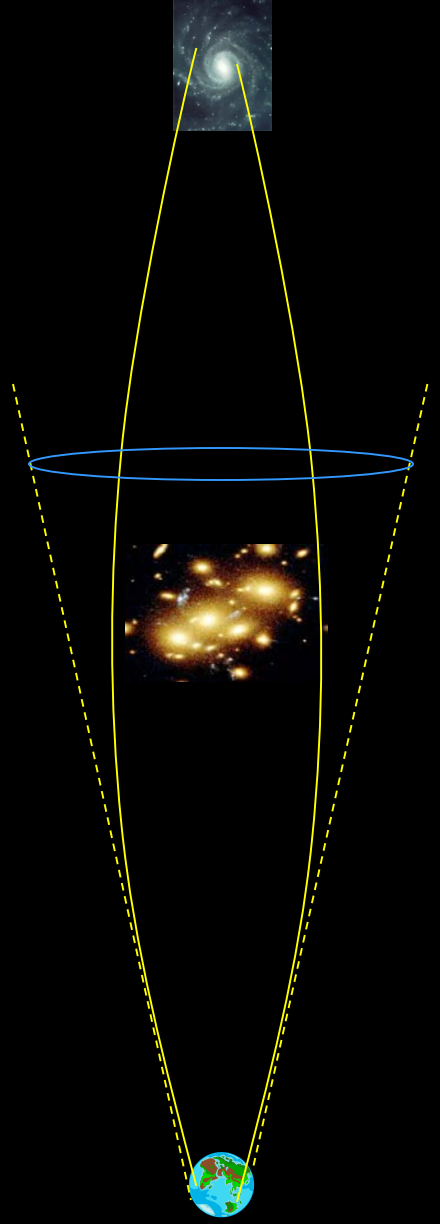
Real Data!



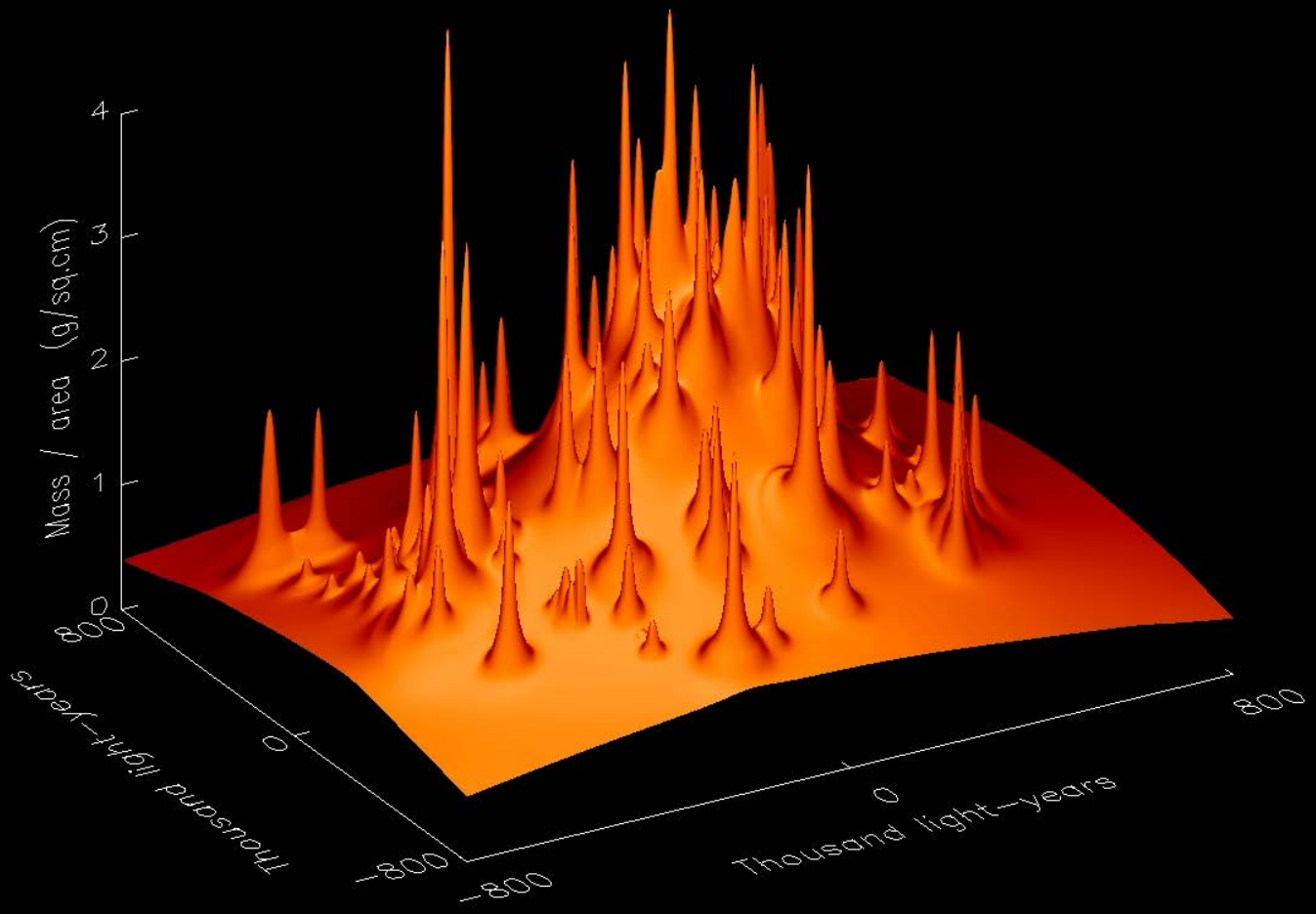


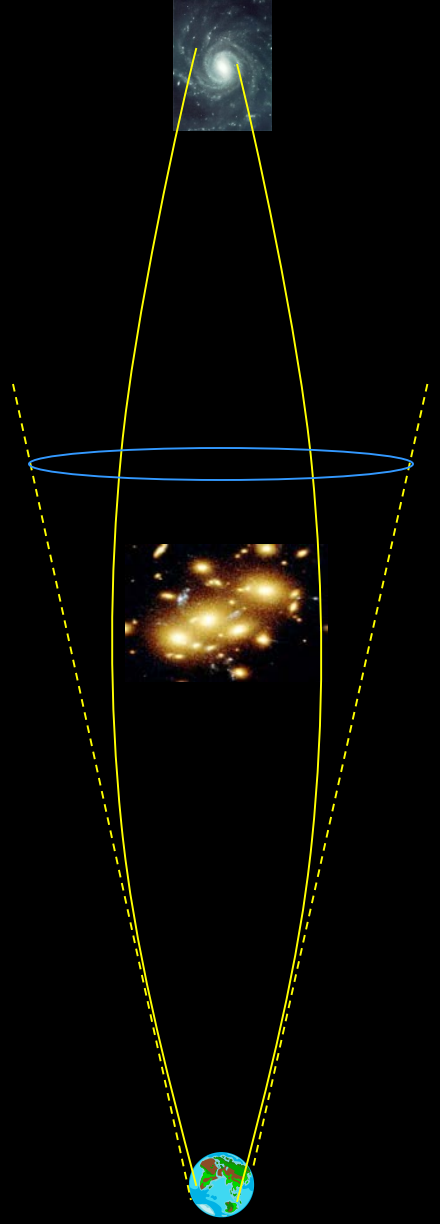
Real Data!

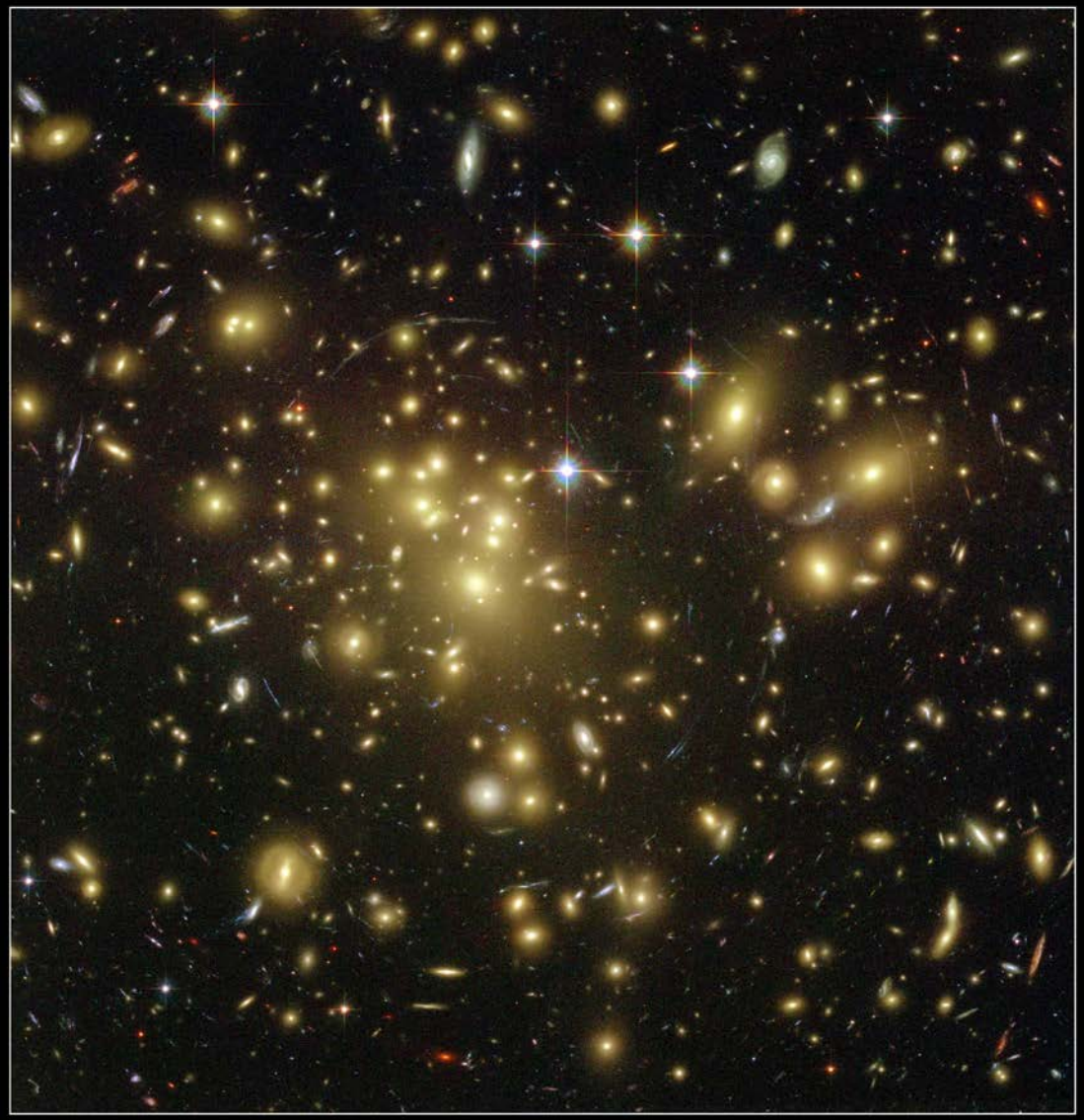




Mass inferred from lensing: Must have dark matter





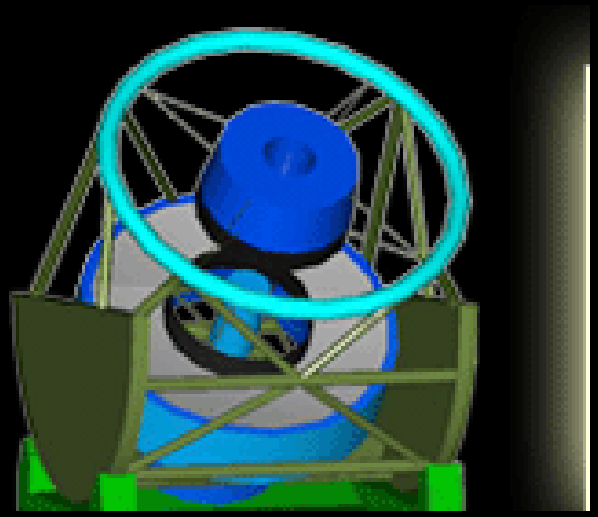


Galaxy Cluster Abell 1689
Hubble Space Telescope • Advanced Camera for Surveys

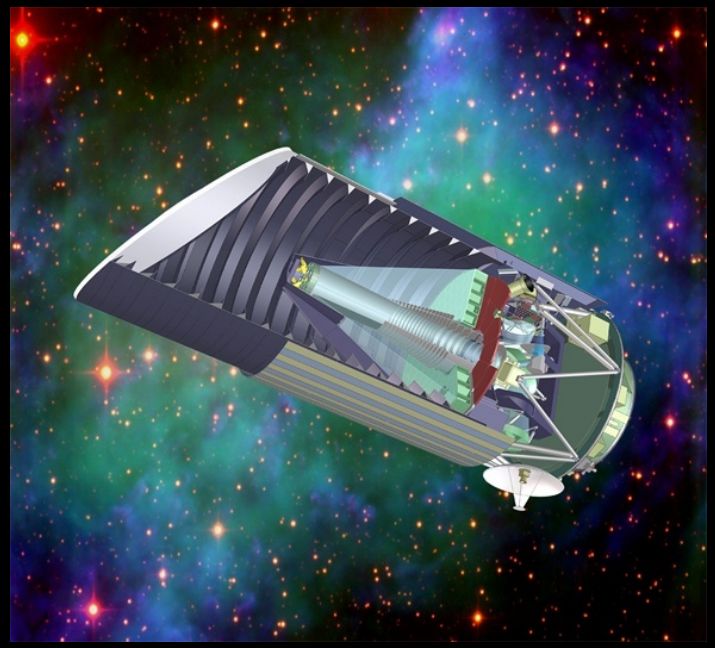
NASA, N. Benitez (JHU), T. Broadhurst (The Hebrew University), H. Ford (JHU), M. Clampin(STScI), G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory), the ACS Science Team and ESA
STScI-PRC03-01a

Using Hubble's "advanced camera for surveys" installed June 2002

Some Future Plans



LSST (Large-aperture Synoptic Survey Telescope)

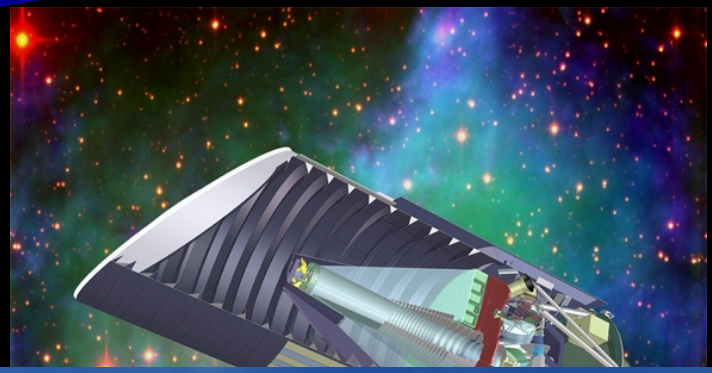


WFIRST

James Webb Space Telescope

Some Fut

New facilities being built



LSST (Large-aperture Synoptic Survey Telescope)

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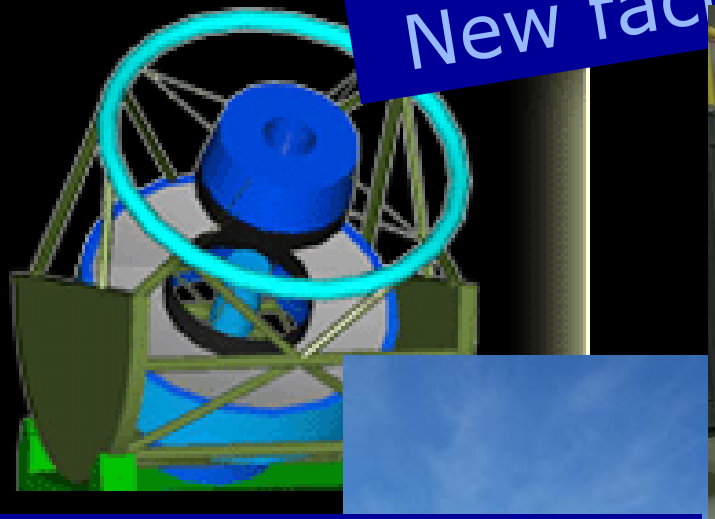

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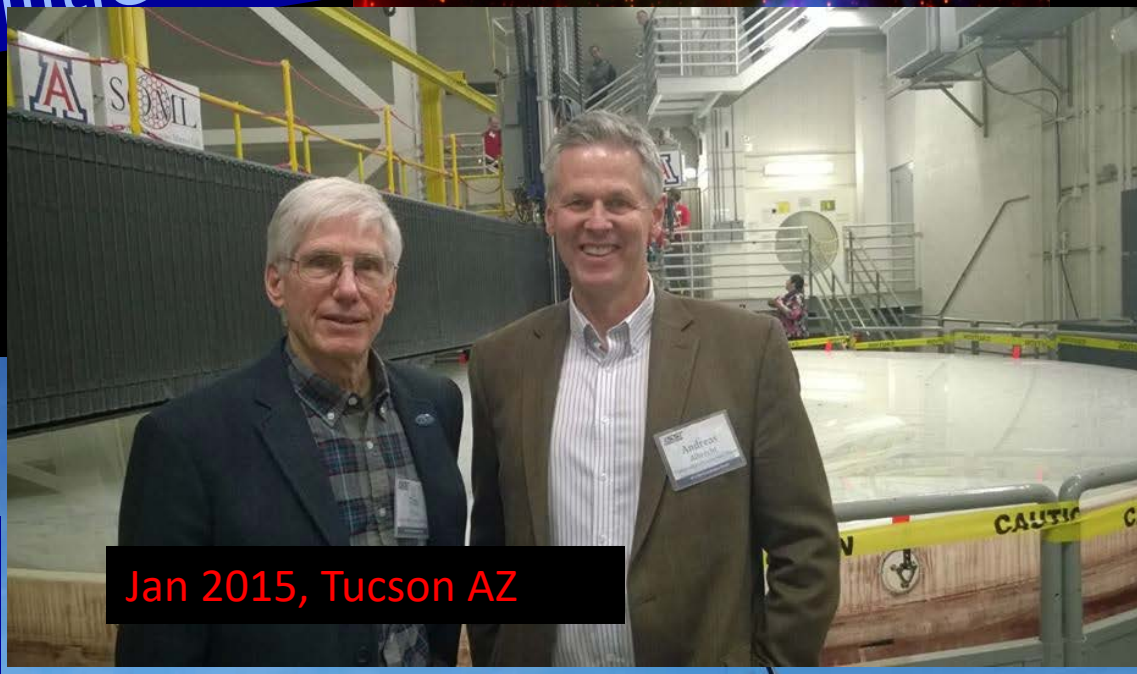
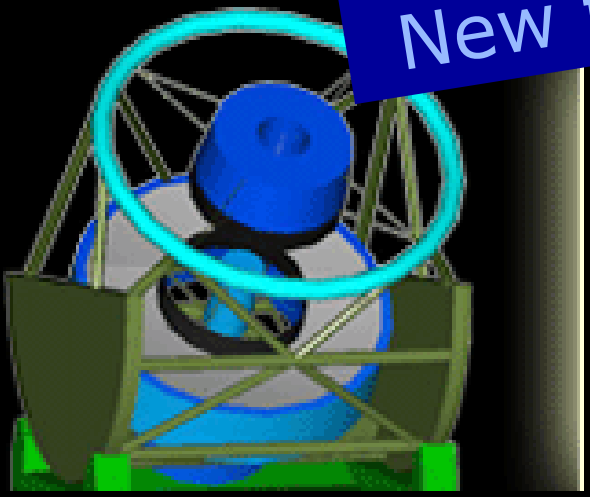
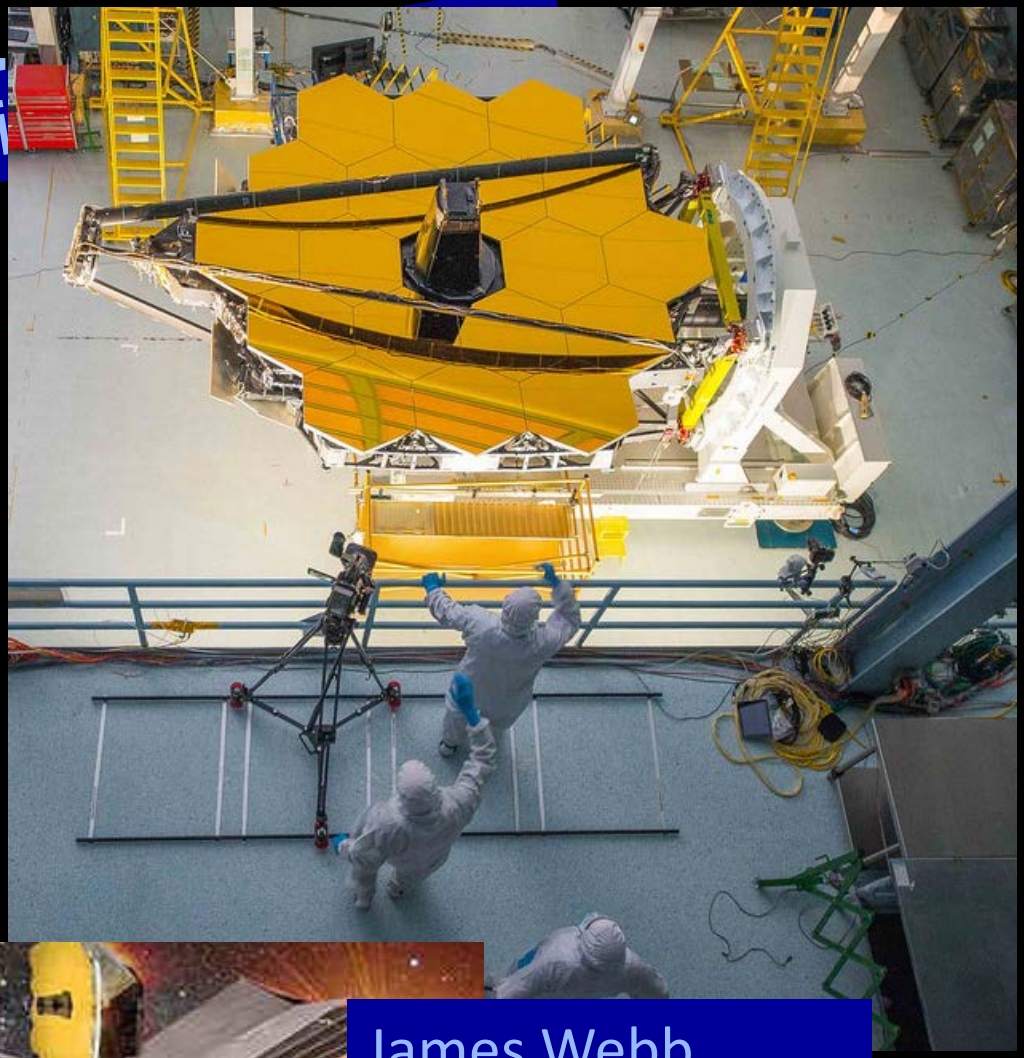


Some F

New faciliti



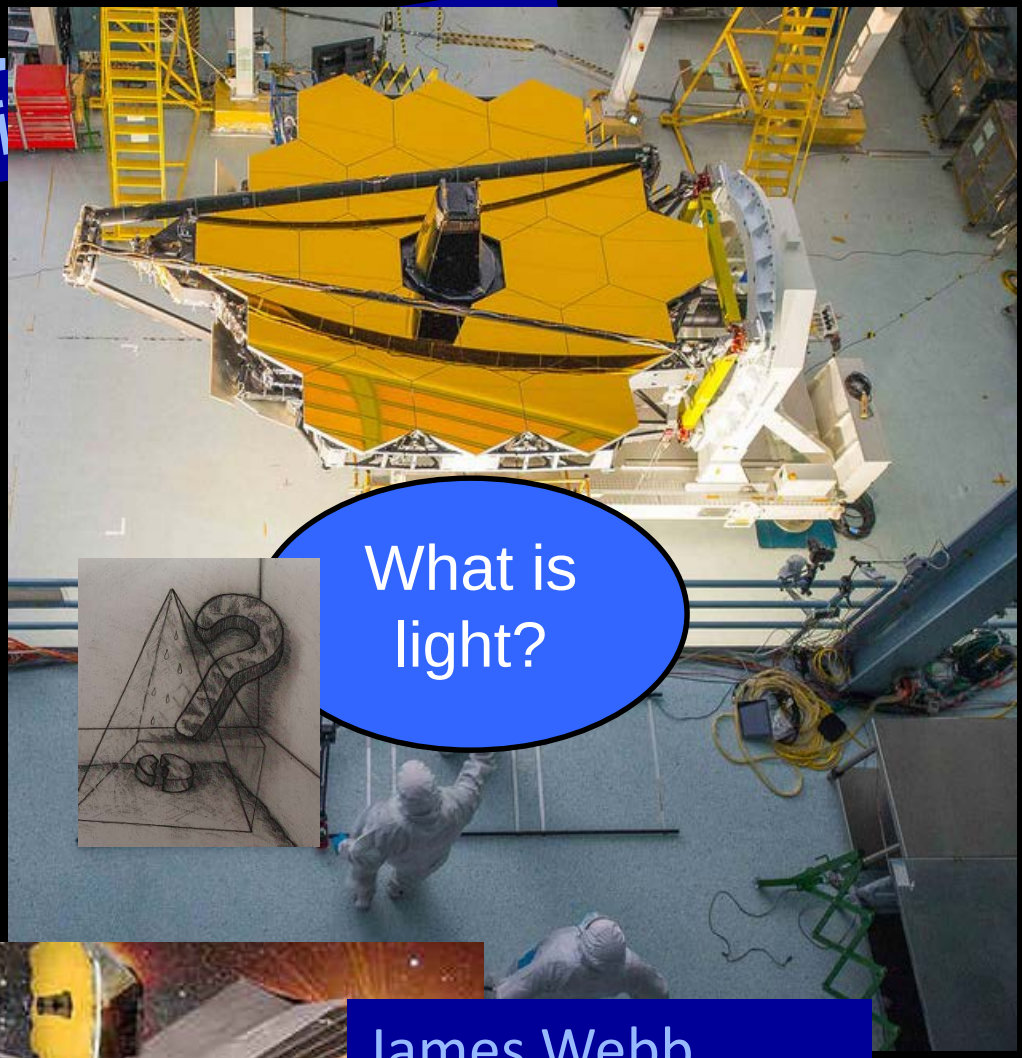
LSST (Large-aperture Synoptic Survey Telescope)



James Webb Space Telescope (2018 Launch)

Some F
New faciliti

LSST (Large-aperture Synoptic Survey Telescope)

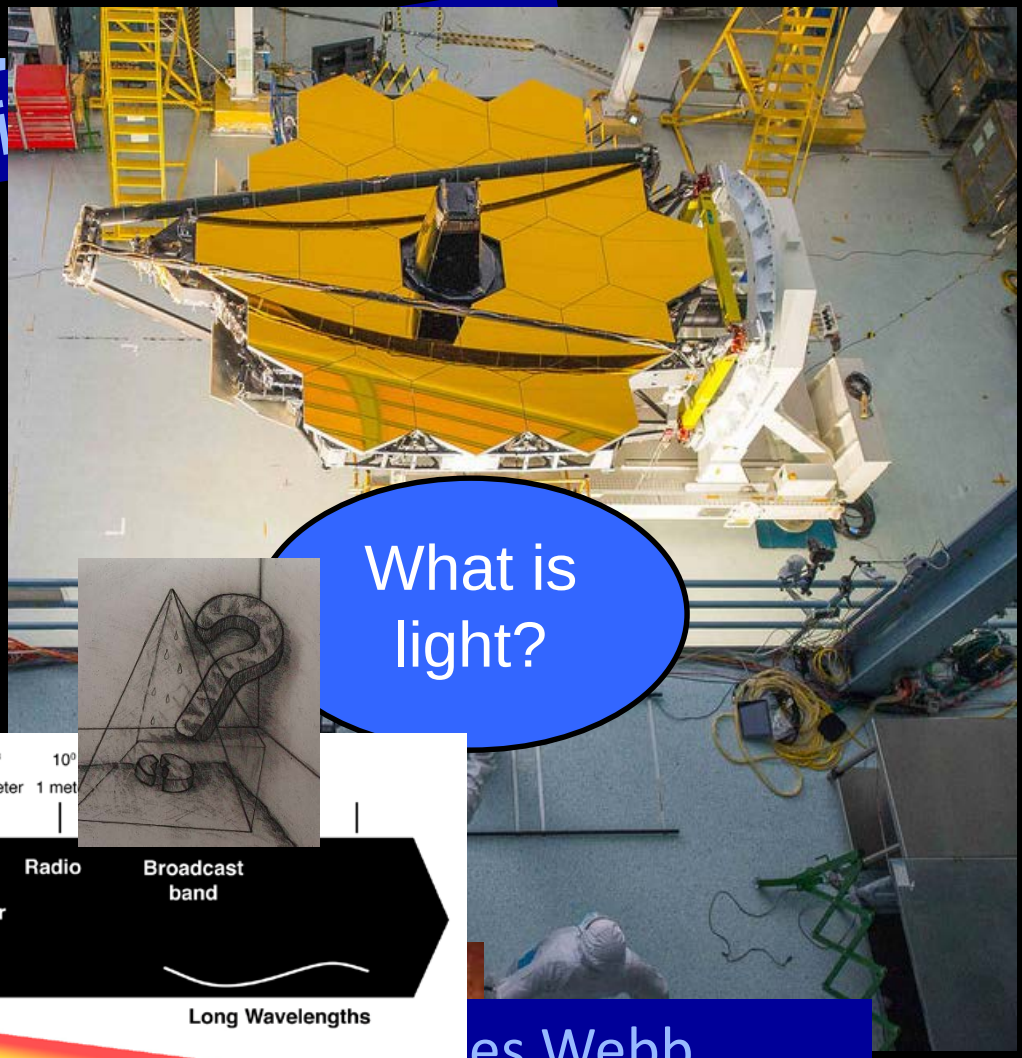


What is light?

James Webb Space Telescope (2018 Launch)

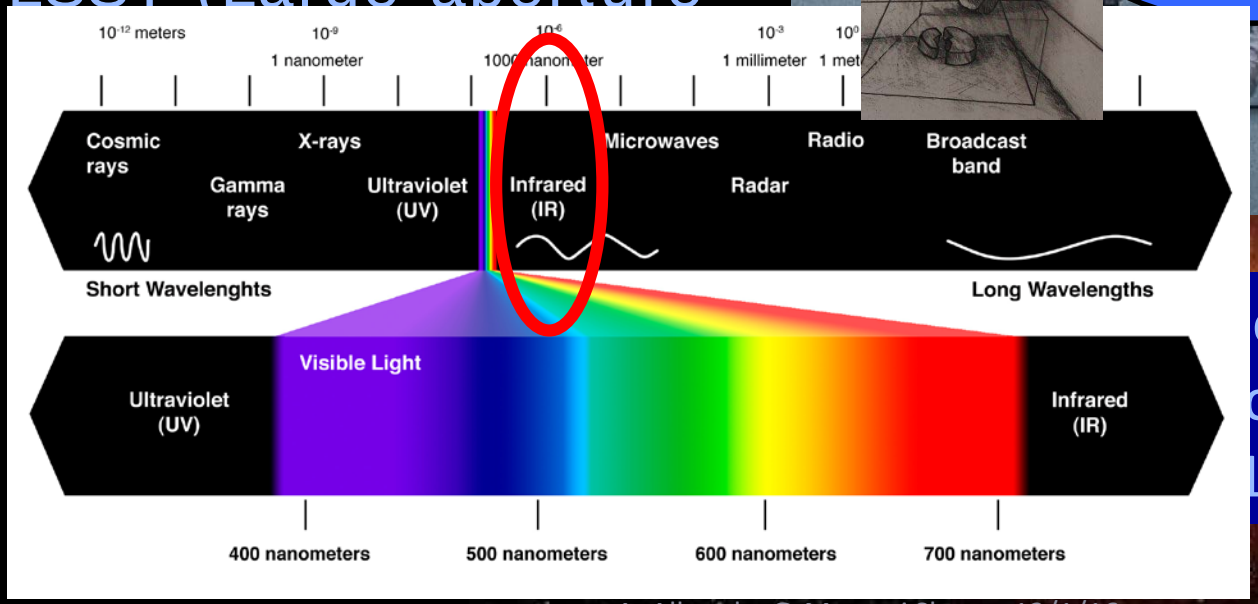
Some F
New faciliti

LSST (Large-aperture



What is light?

es Webb
ce Telescope
18 Launch)



Some Fut

New facilities being built

NASA

WFIRST WIDE FIELD INFRARED SURVEY TELESCOPE

Home | About | Science | Observatory | Resources | FAQ

Frequently Asked Questions

1. Will the WFIRST mission be a breakthrough in the search for dark matter?

WFIRST will survey large areas of the sky measuring the effects of dark matter on the distribution of galaxies in the universe. It will also observe distant Type Ia supernovae to use them as tracers of dark matter and dark energy. It will provide a huge step forward in our understanding of dark matter and dark energy.

2. In what phase of development is currently the WFIRST spacecraft?

WFIRST is currently in Phase A.The purpose of Phase A is to develop the mission requirements and architecture necessary to meet the programmatic requirements and constraints on the Project and to develop the plans for the Preliminary Design phase.

3. Are the preparations on track for the mid-2020 launch?

Yes, the preparations are on track for a mid-2020 launch.

WFIRST

Outline

1. Introduction (The "Golden age of cosmology")
2. The Big Picture
3. Some Big ideas
   - Cosmic Inflation
   - The String theory landscape

Outline

1. Introduction (The “Golden age of cosmology”)
2. The Big Picture
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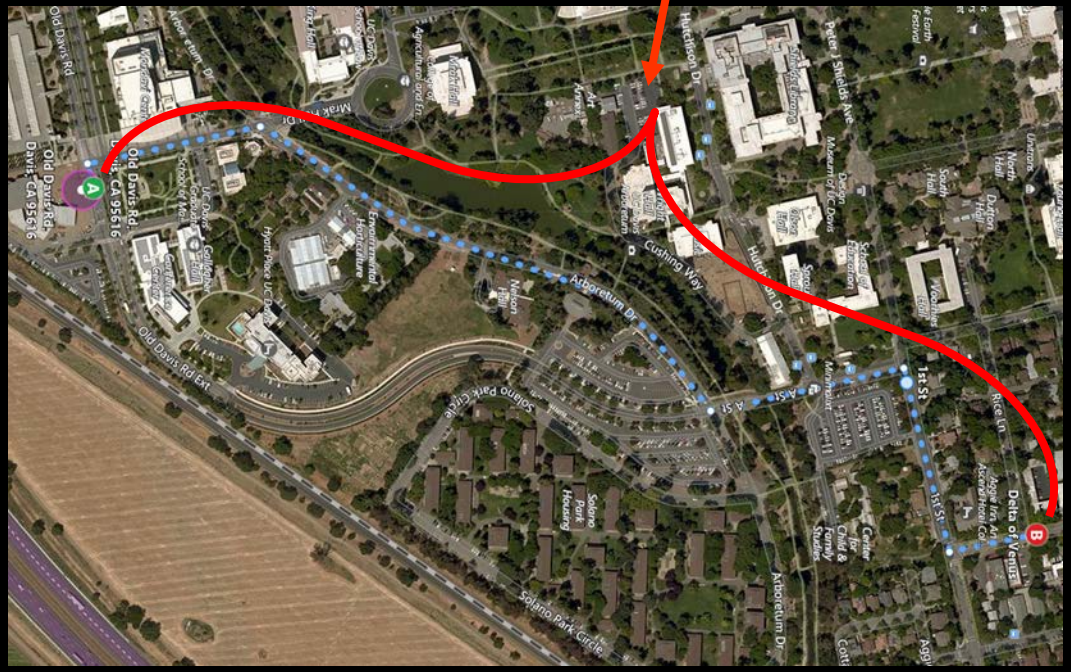
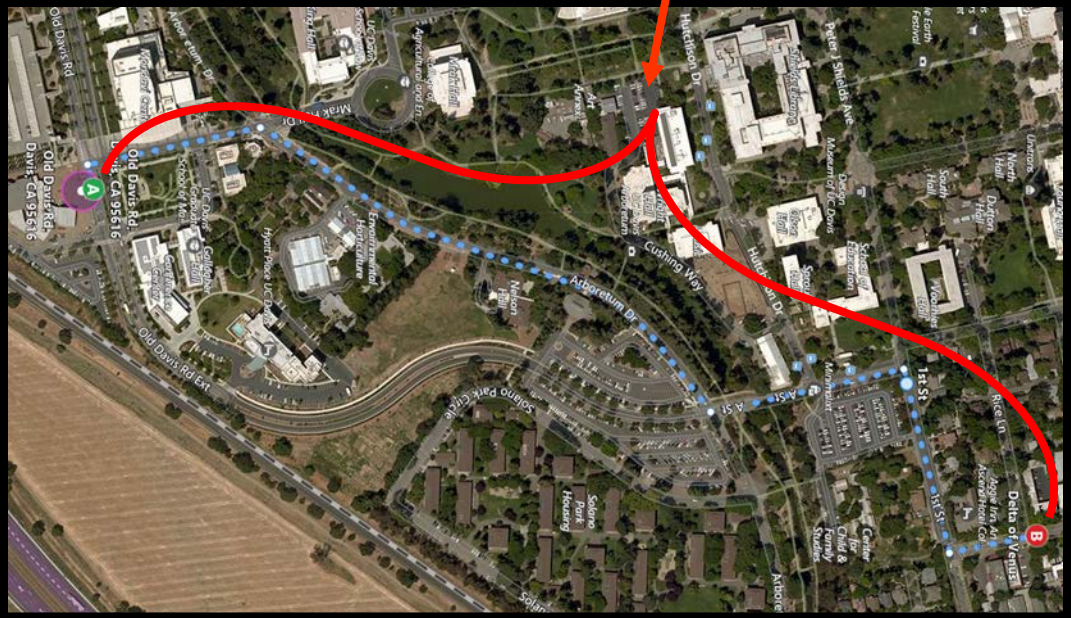
Distances in the Universe

Measure of distance: One Kilometer ≈ Walk from the *Manetti Shrem* to *Delta of Venus*



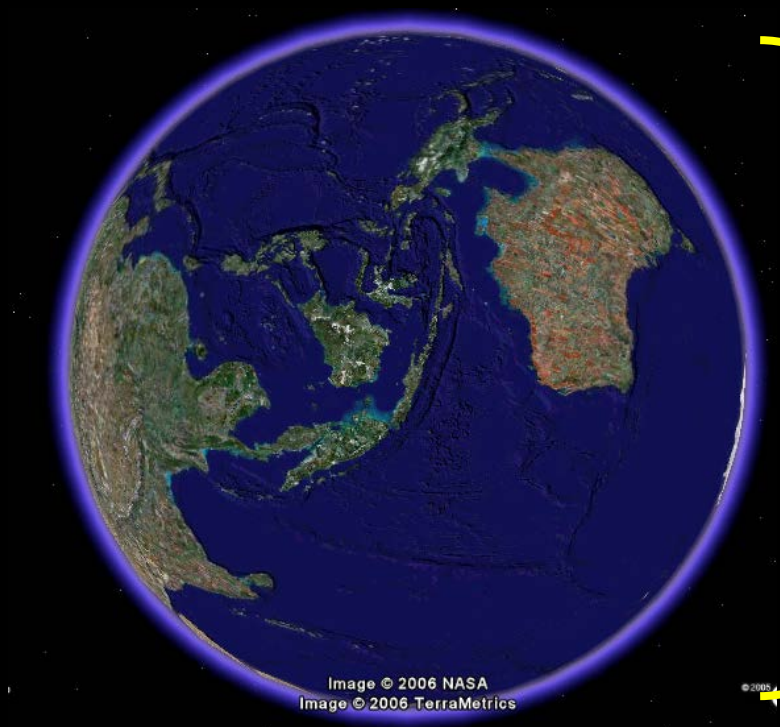
Measure of distance: One Kilometer ≈ Walk from the *Manetti Shrem* to *Delta of Venus*



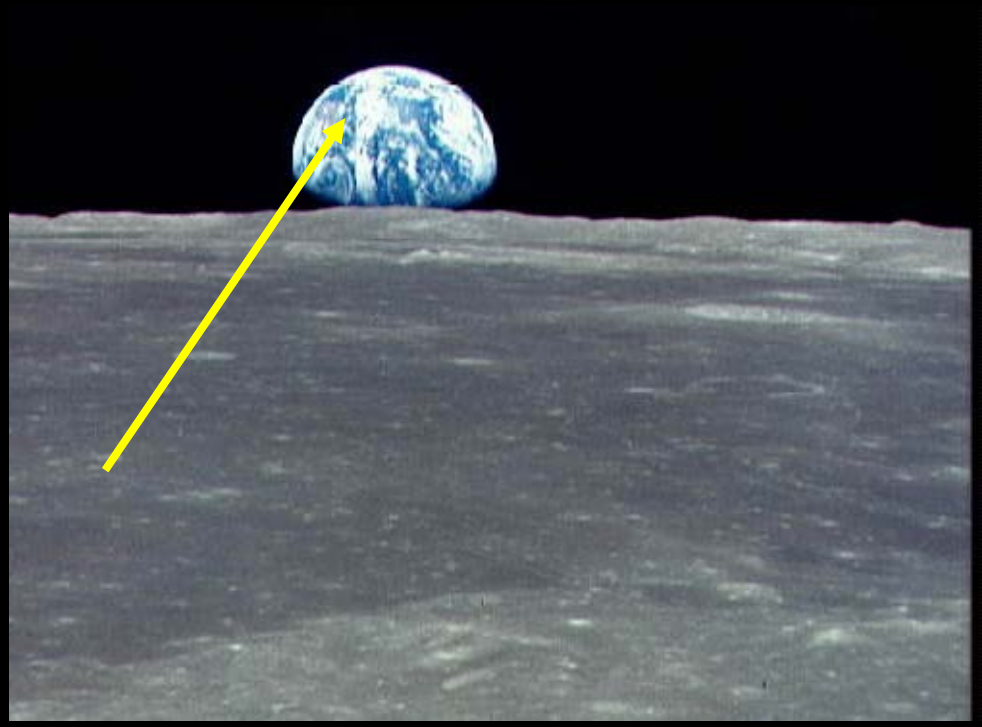
Count cosmic distances as grains of sand:
One grain of sand per kilometer.

Grain of sand
(enlarged)

Diameter of earth = 12,760 kilometers ←→
1 Teaspoon of sand

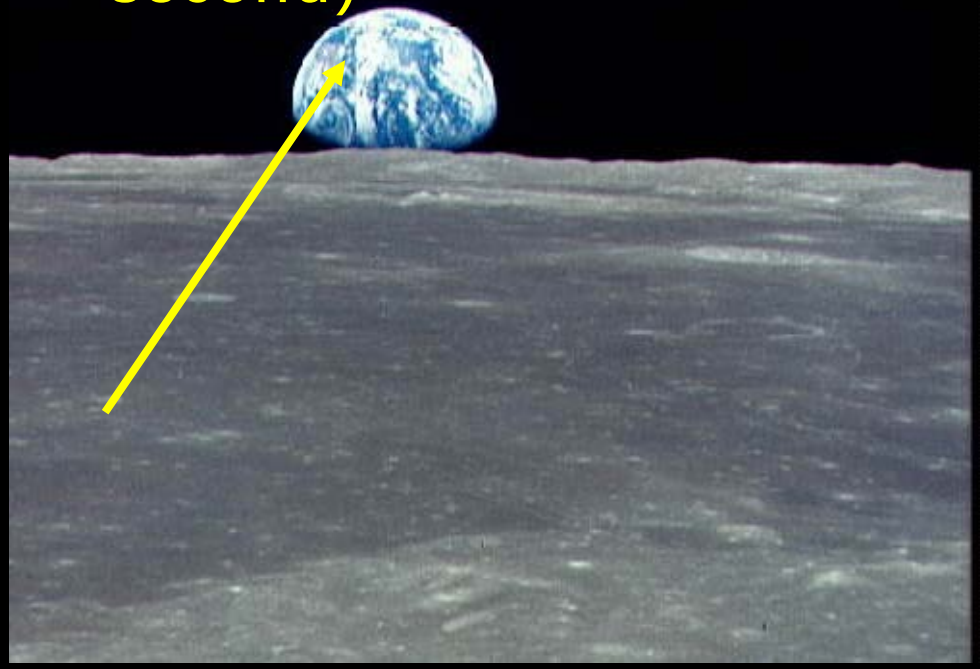


Distance to Moon = 356,410 kilometers ←→
1 Handful of sand

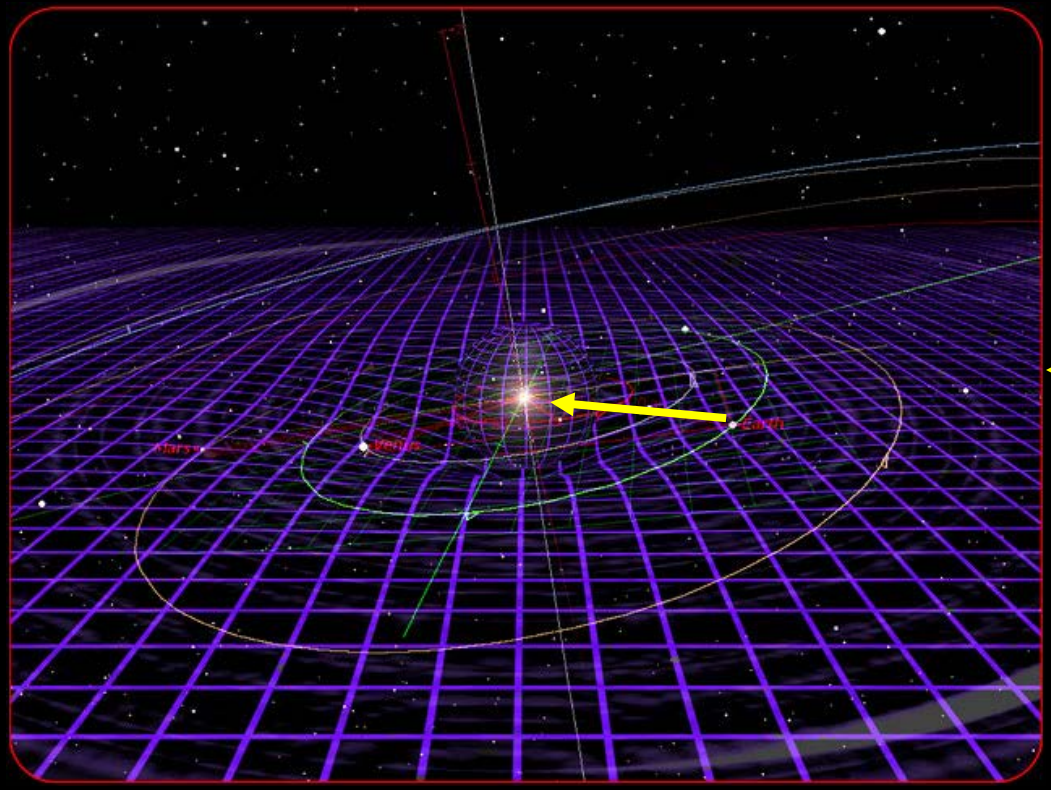


Distance to Moon = 356,410 kilometers ←→
1 Handful of sand

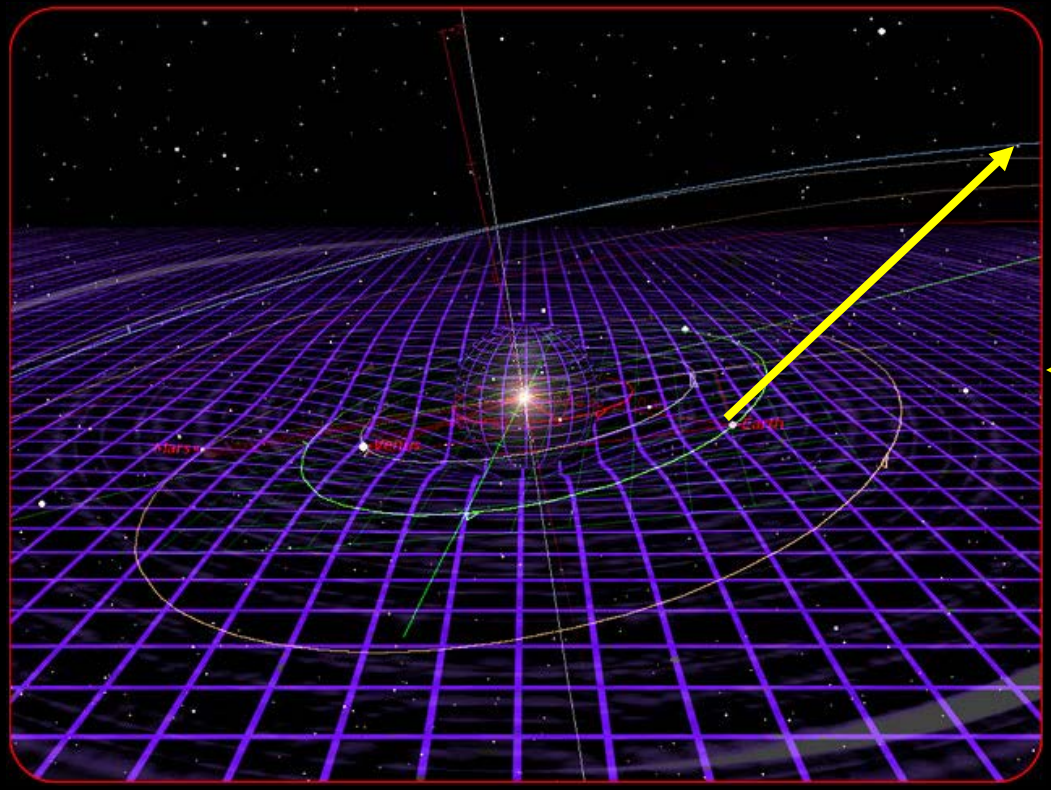
(Also roughly the distance light travels in one second)



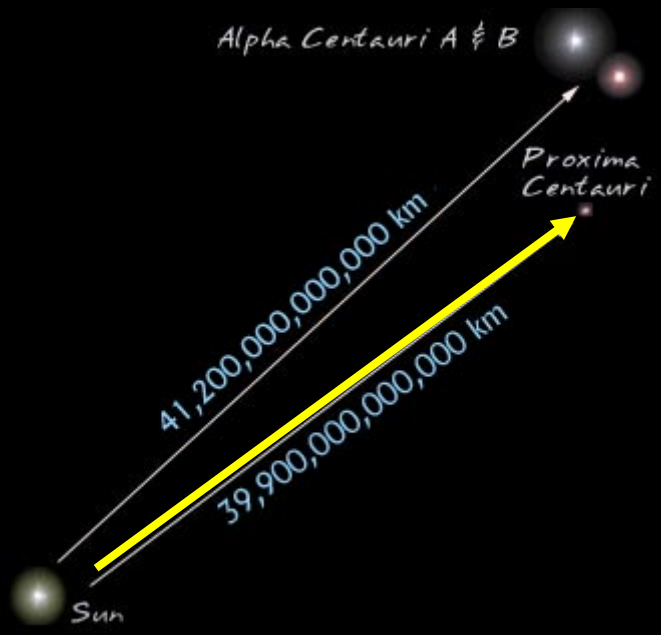
Distance from Earth to Sun = 149,600,000 kilometers (8 light minutes) ←→ 1 Milkshake cup of sand



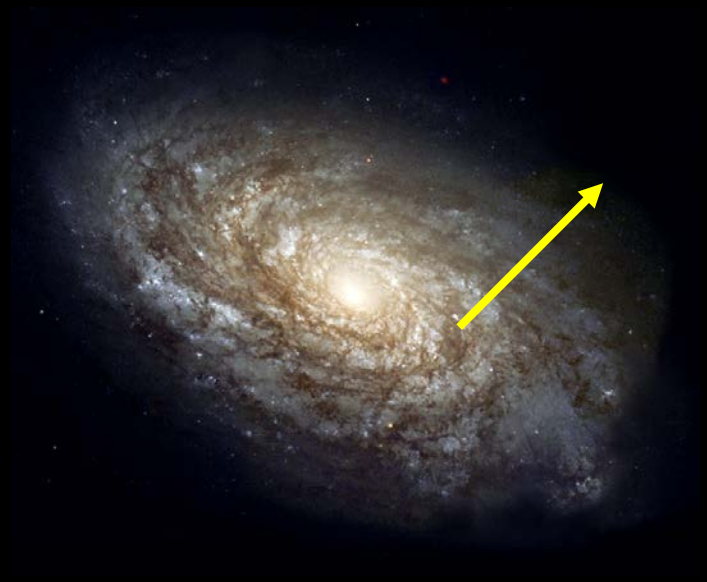
Distance from Earth to Pluto = 6,000,000,000 kilometers ⬅➡ 1 wheelbarrow of sand



Distance from Earth to Nearest Star = 40,000,000,000,000 kilometers ⟷ 1 dumpster of sand



Distance from Earth to Edge of our galaxy = 1,000,000,000,000,000,000 kilometers ⟷ 1 Physics/Geology Bulidng full of sand



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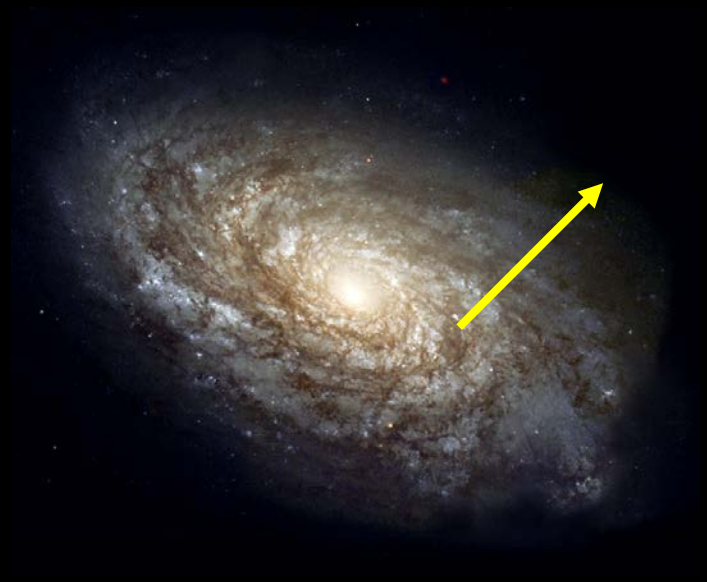
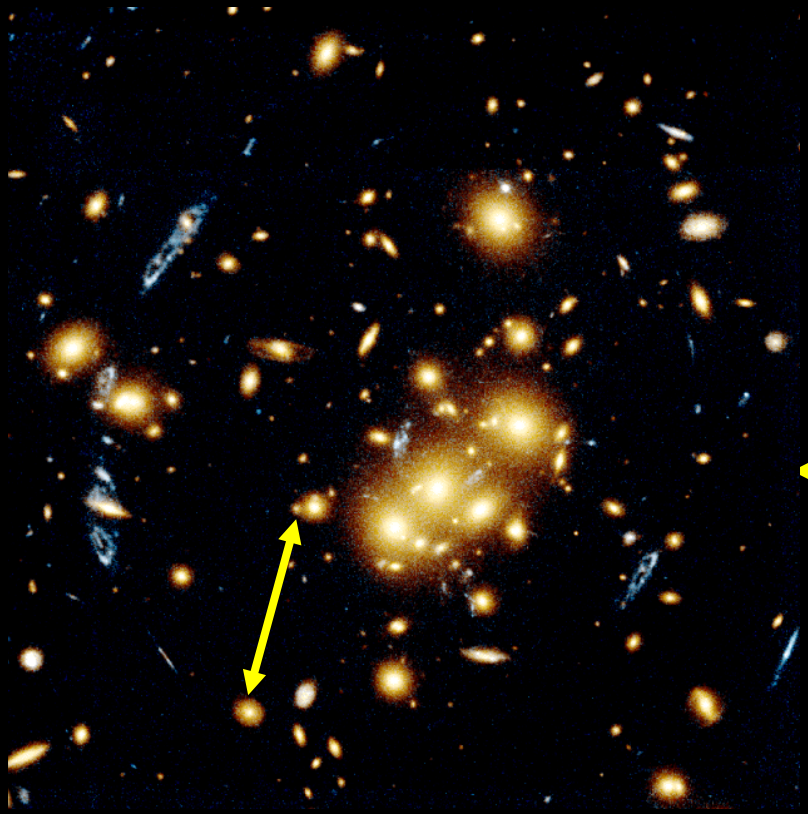
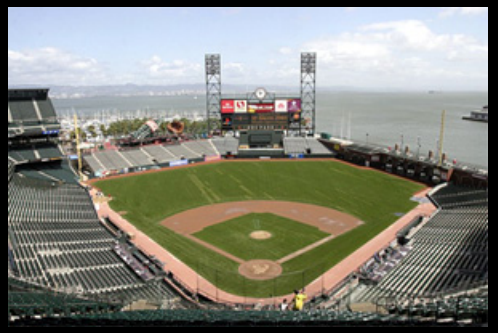
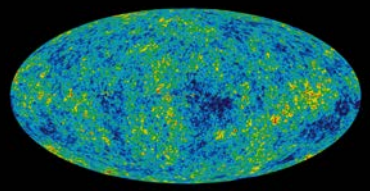


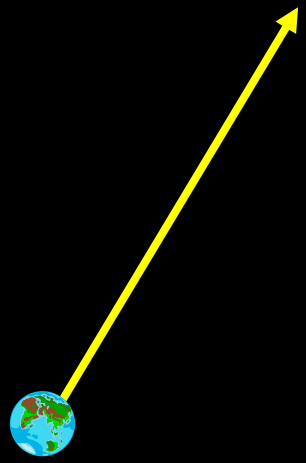
Average distance between galaxies = 3×10^{19} kilometers ⟷ 1 baseball stadium full of sand

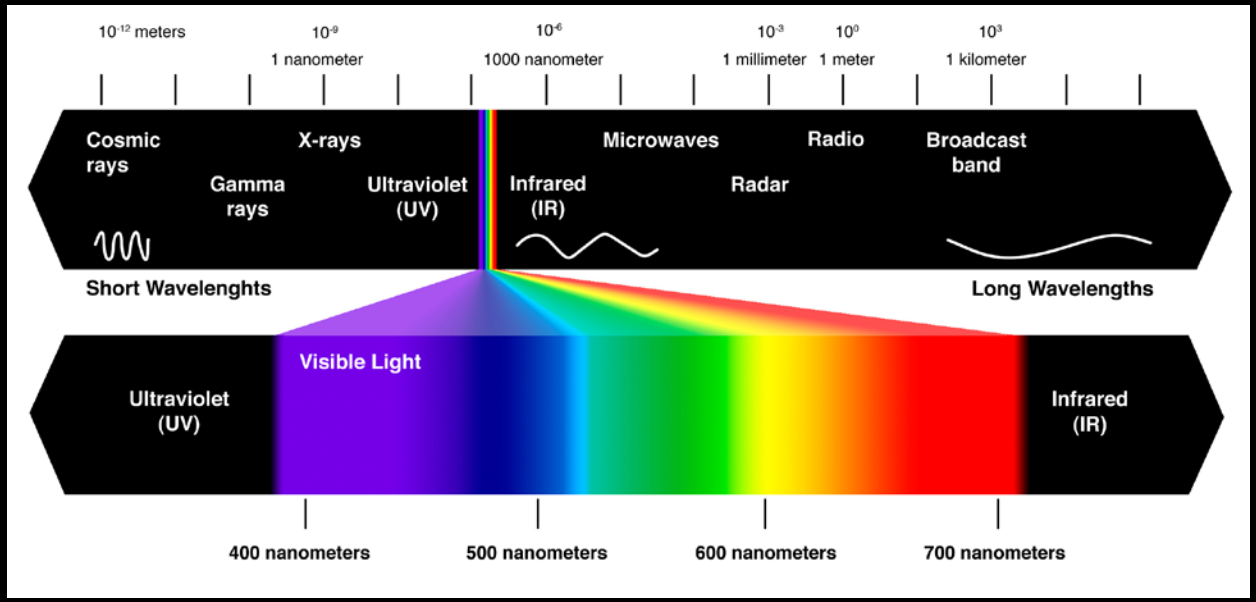




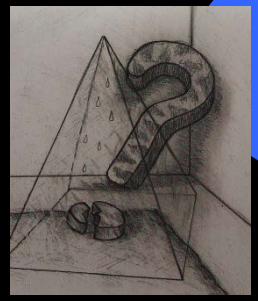
Farthest visible "object" in the universe: 1×10^{23} kilometers ⟷ mountain range of sand



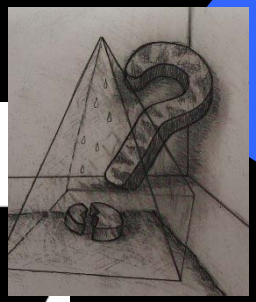



10^{-12} meters
10^{-9}
1 nanometer
10^{-6}
1000 nanometer
10^{-3}
1 millimeter
10^{0}
1 meter
10^{3}
1 kilometer
Cosmic rays
Gamma rays
X-rays
Ultraviolet (UV)
Infrared (IR)
Microwaves
Radar
Radio
Broadcast band
Short Wavelenghts
Long Wavelengths
Ultraviolet (UV)
Visible Light
Infrared (IR)
400 nanometers
500 nanometers
600 nanometers
700 nanometers

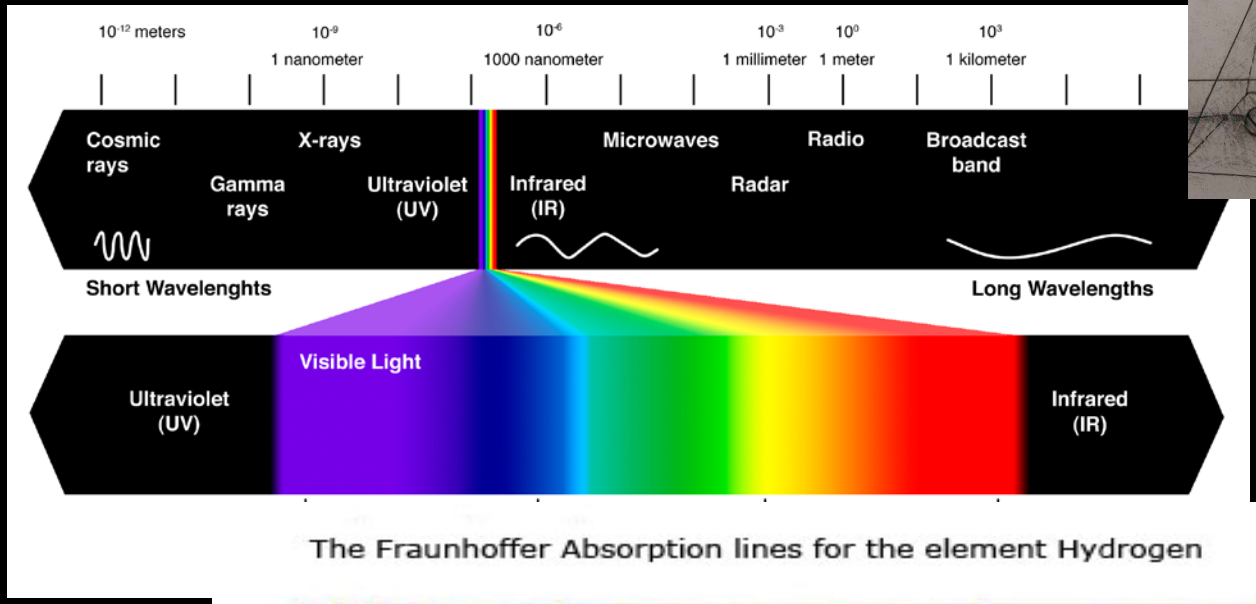
The physics of “absorption spectra” (**shadows** affecting only specific colors of light) is key to much of the information we have about the Universe

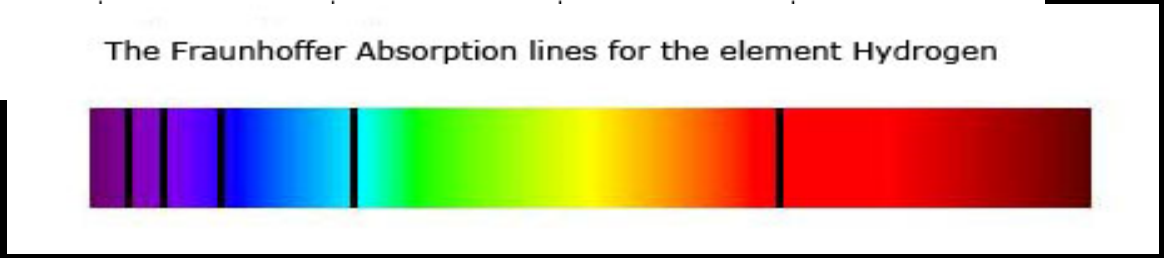


What is light?

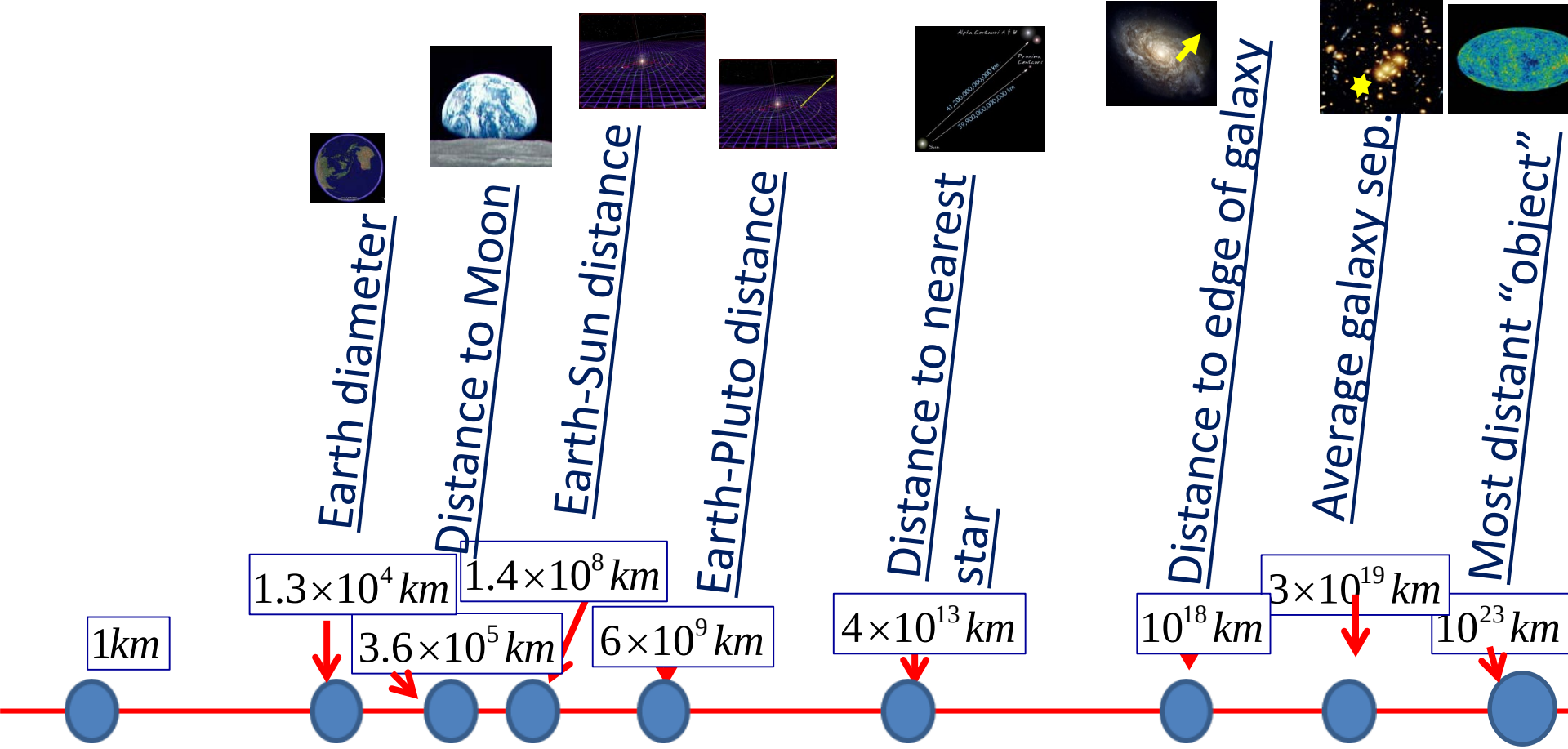


What is shadow?





Thanks Prof. Knox!


Earth diameter
Distance to Moon
Earth-Sun distance
Earth-Pluto distance
Distance to nearest star
Distance to edge of galaxy
Average galaxy sep.
Most distant "object"
$1km$
$1.3\times10^{4}\,km$
$3.6\times10^{5}\,km$
$1.4\times10^{8}\,km$
$6\times10^{9}\,km$
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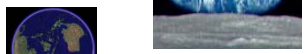
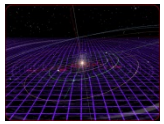
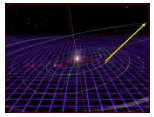
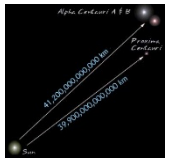
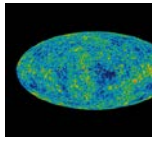
$3\times10^{19}\,km$
$10^{23}\,km$











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$4\times10^{13}\,km$

$10^{18}\,km$

$3\times10^{19}\,km$

$10^{23}\,km$

0 4.1 5.6 8.1 9.8 13.6 18 19.5 23

$\log(d\,/\,km)$

What we know about the big picture

1) On large scales the matter in the Universe is spread out very smoothly ("Homogeneous")

Mean density: $10^{-29}\, gram/cm^3$

2) The Universe is expanding

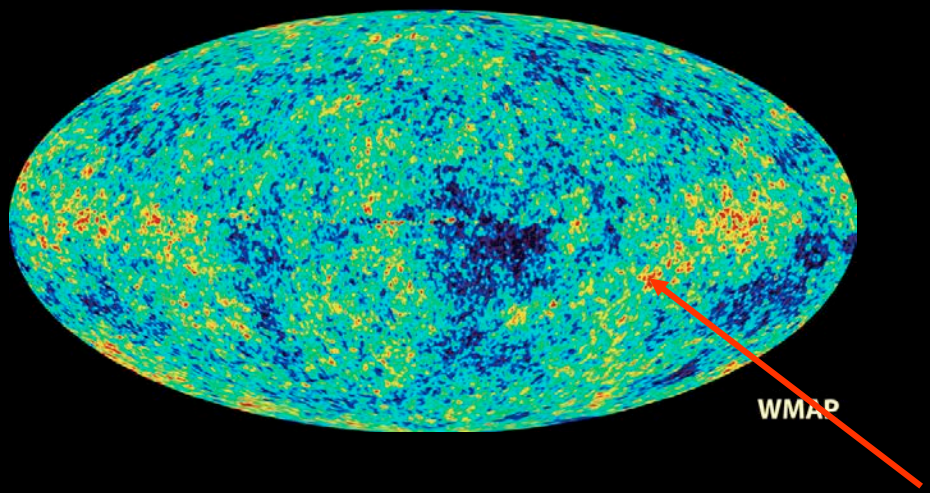
Hubble law: $v = Hr$

Distance

Expansion Speed

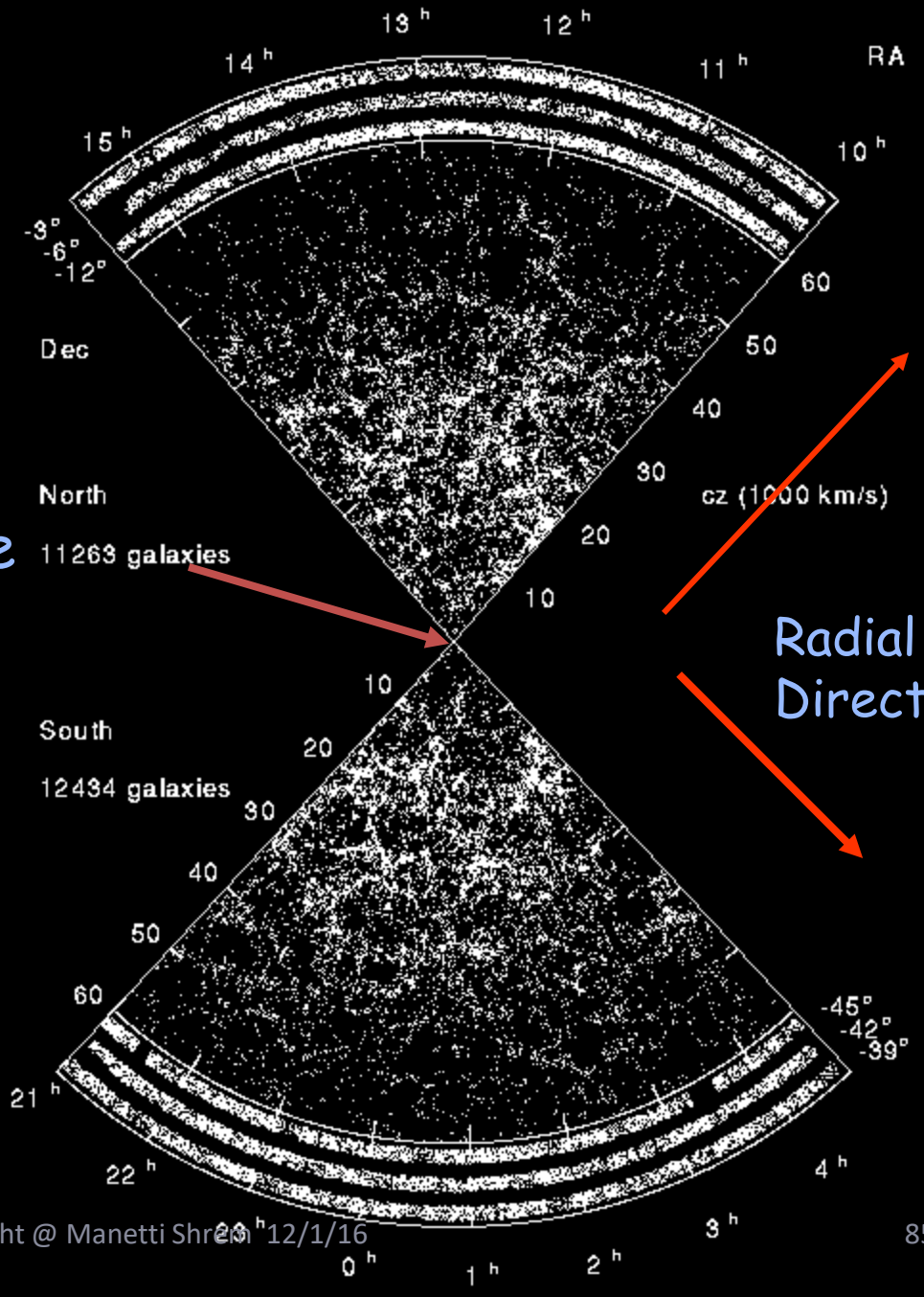
$$H = \left(\frac{3m/\sec}{100 lightyears} \right)$$

The homogeneity of the Universe



Isotropy of the microwave background (from the “edge of the observable universe”) to one part in 100,000

The homogeneity of the universe

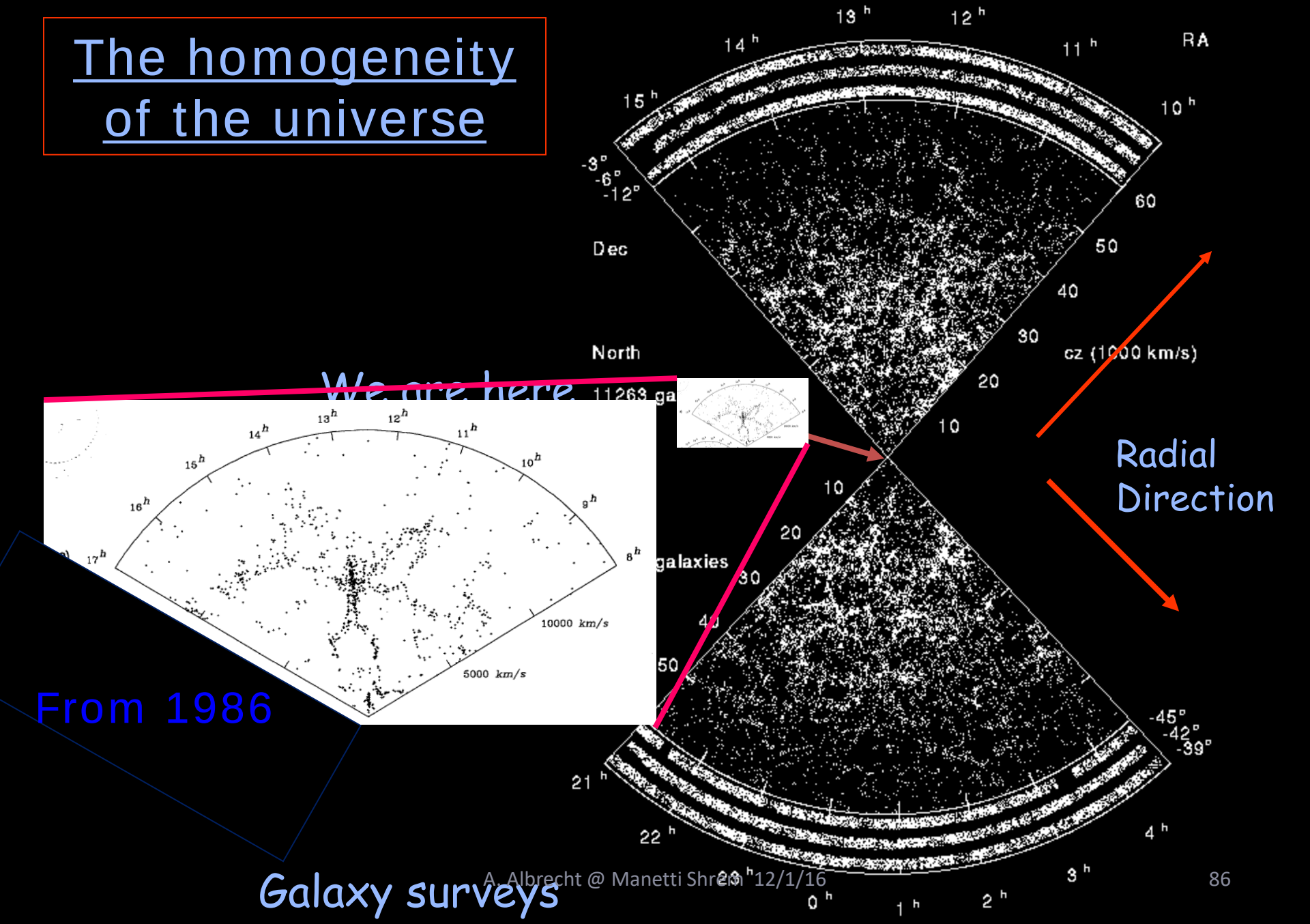


We are here

Radial Direction

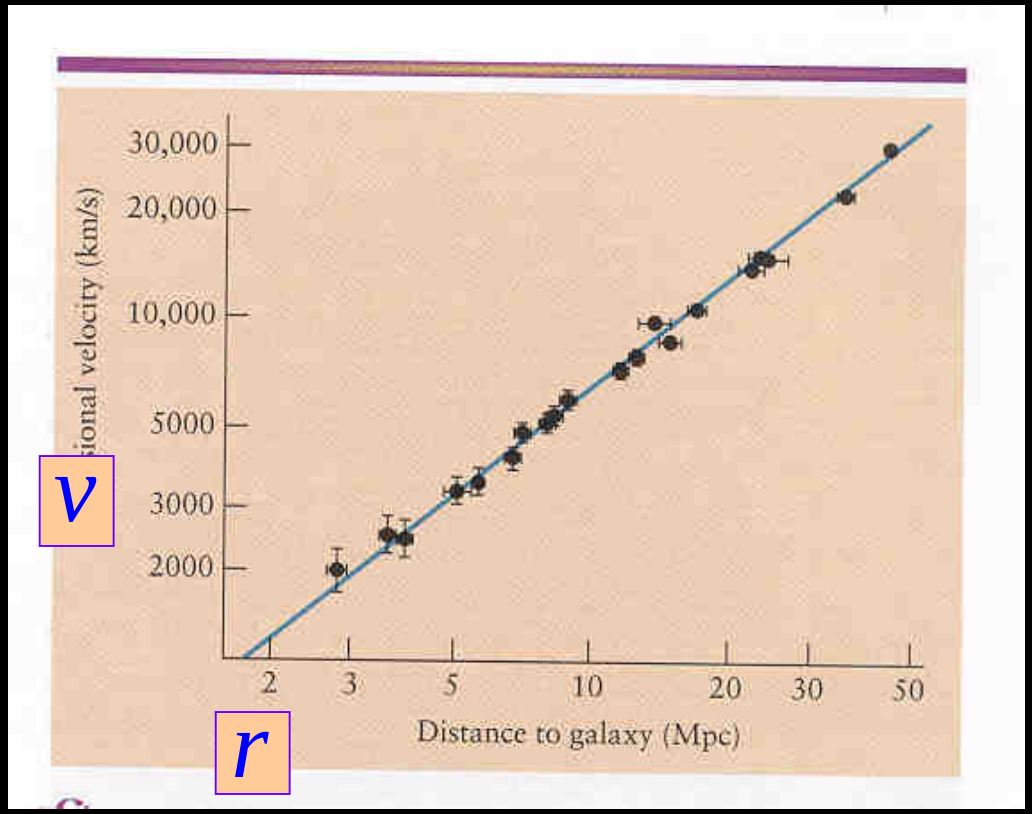
Galaxy surveys

The homogeneity of the universe



Galaxy surveys

The Hubble law

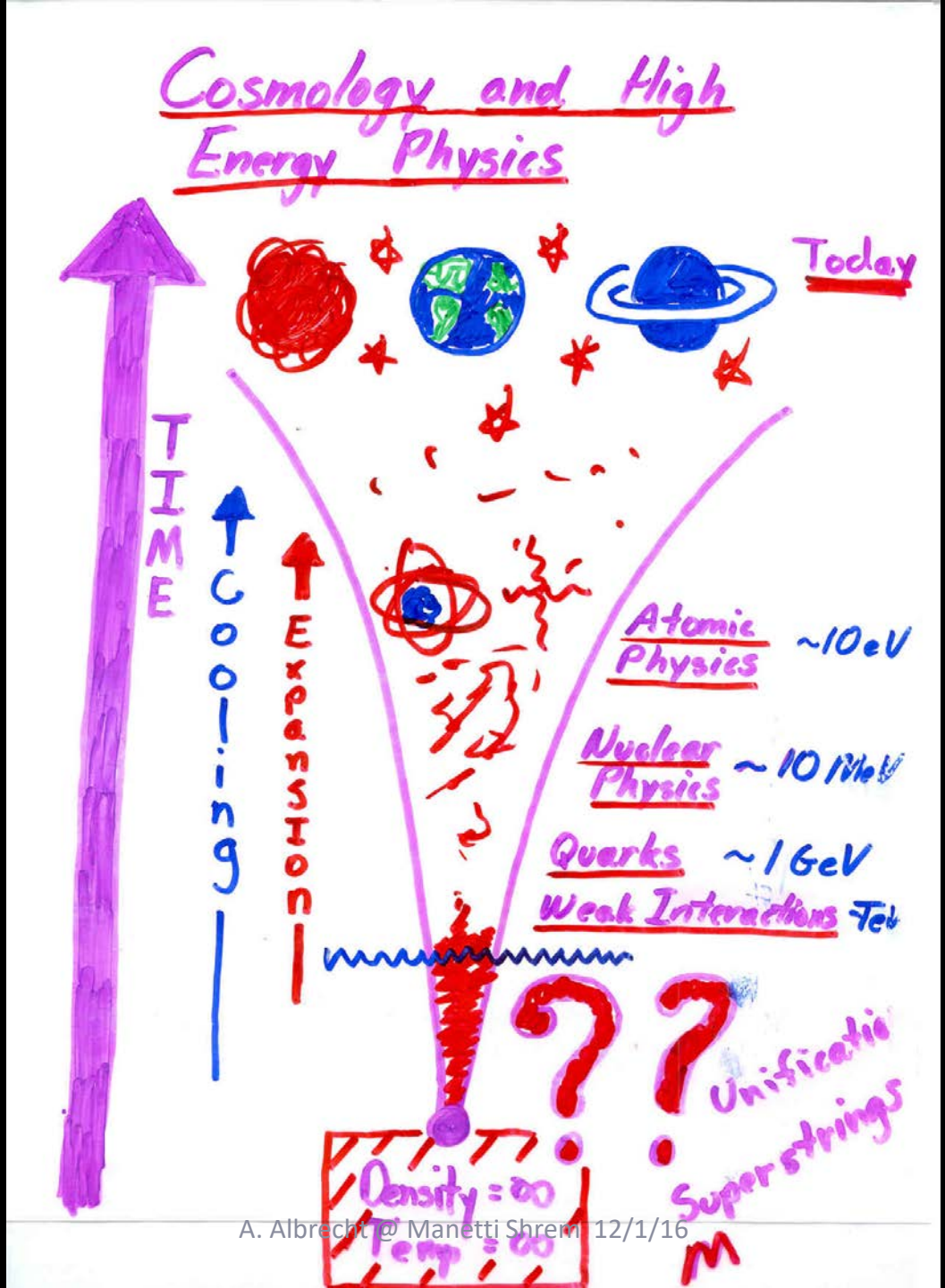


$$v = Hr$$

$$H = \left(\frac{3m/\sec}{100 lightyears} \right)$$

Hubble Expansion

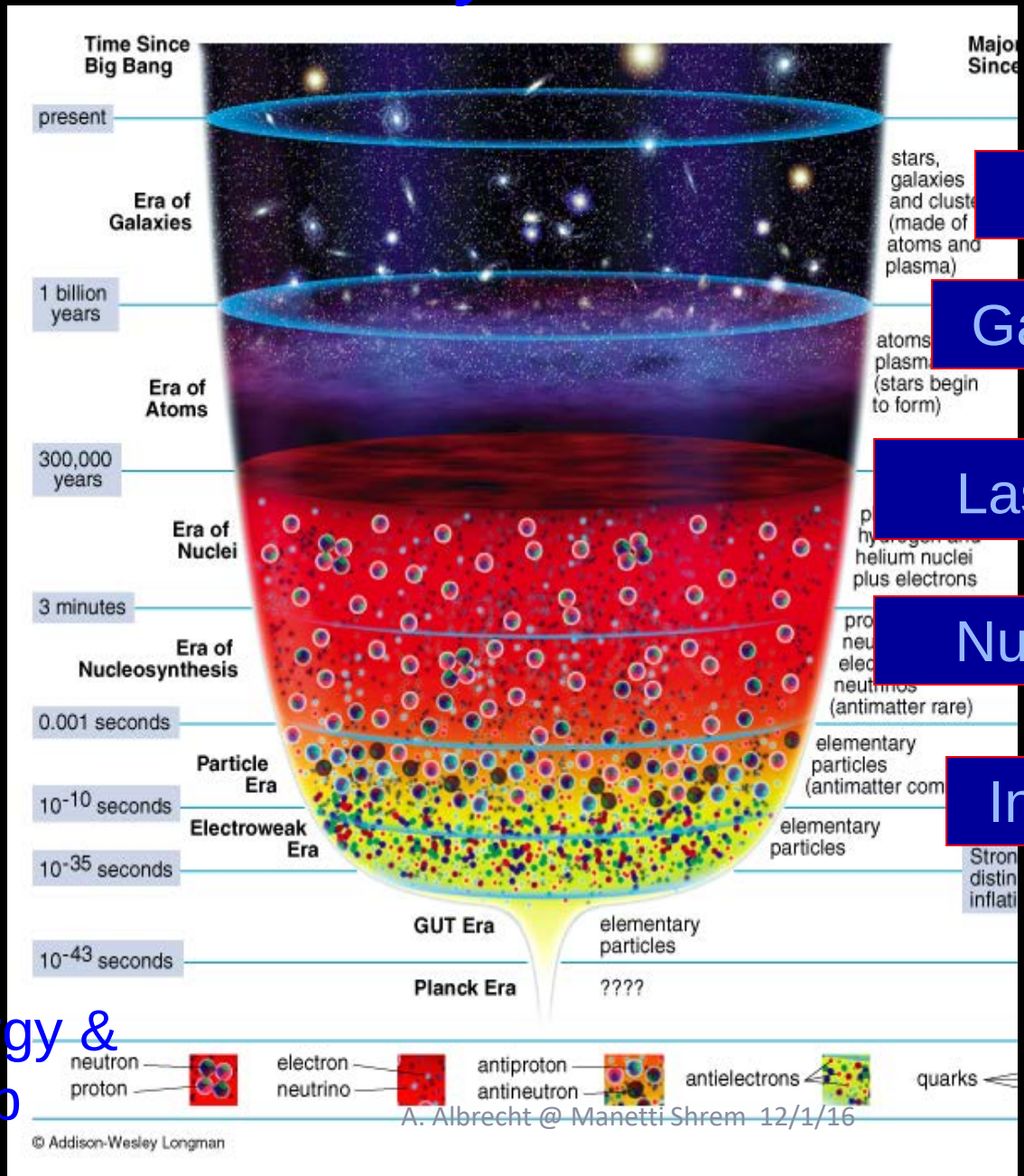
Hot, Dense past


Cosmology and High Energy Physics
Today
TIME
Cooling
Expansion
Atomic Physics ~10eV
Nuclear Physics ~10 MeV
Quarks ~1GeV
Weak Interactions Tev
??
Unificatio
Superstrings
Density = ∞
Temp = ∞
M

The History of the Universe

Time

High Energy & Temp



Today

Dark Energy

Galaxy Formation

Last Scattering

Nuclear & HEP

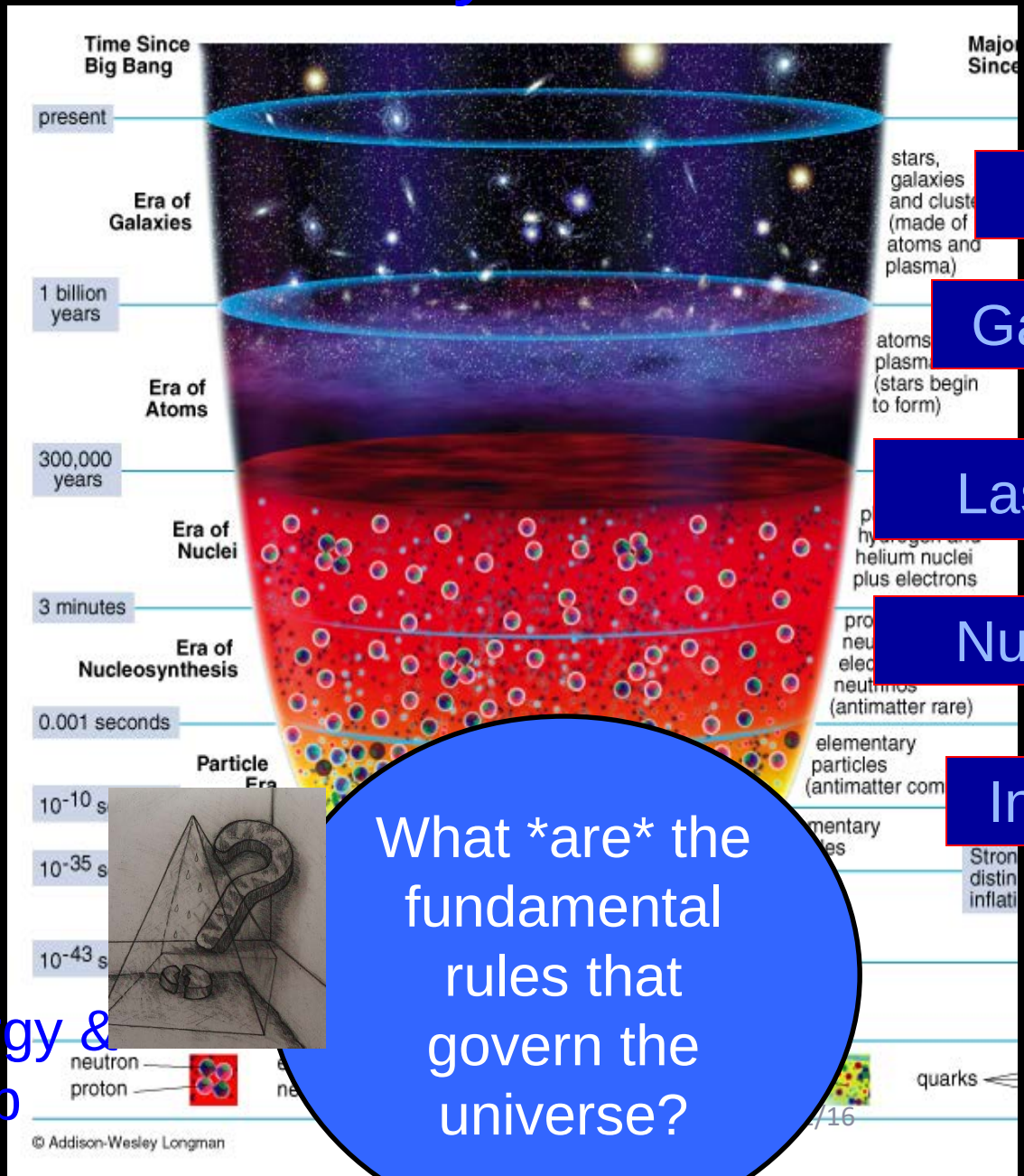
Inflation?

Extra Dimensions?

The History of the Universe

Time

High Energy & Temp



What *are* the fundamental rules that govern the universe?

Today

Dark Energy

Galaxy Formation

Last Scattering

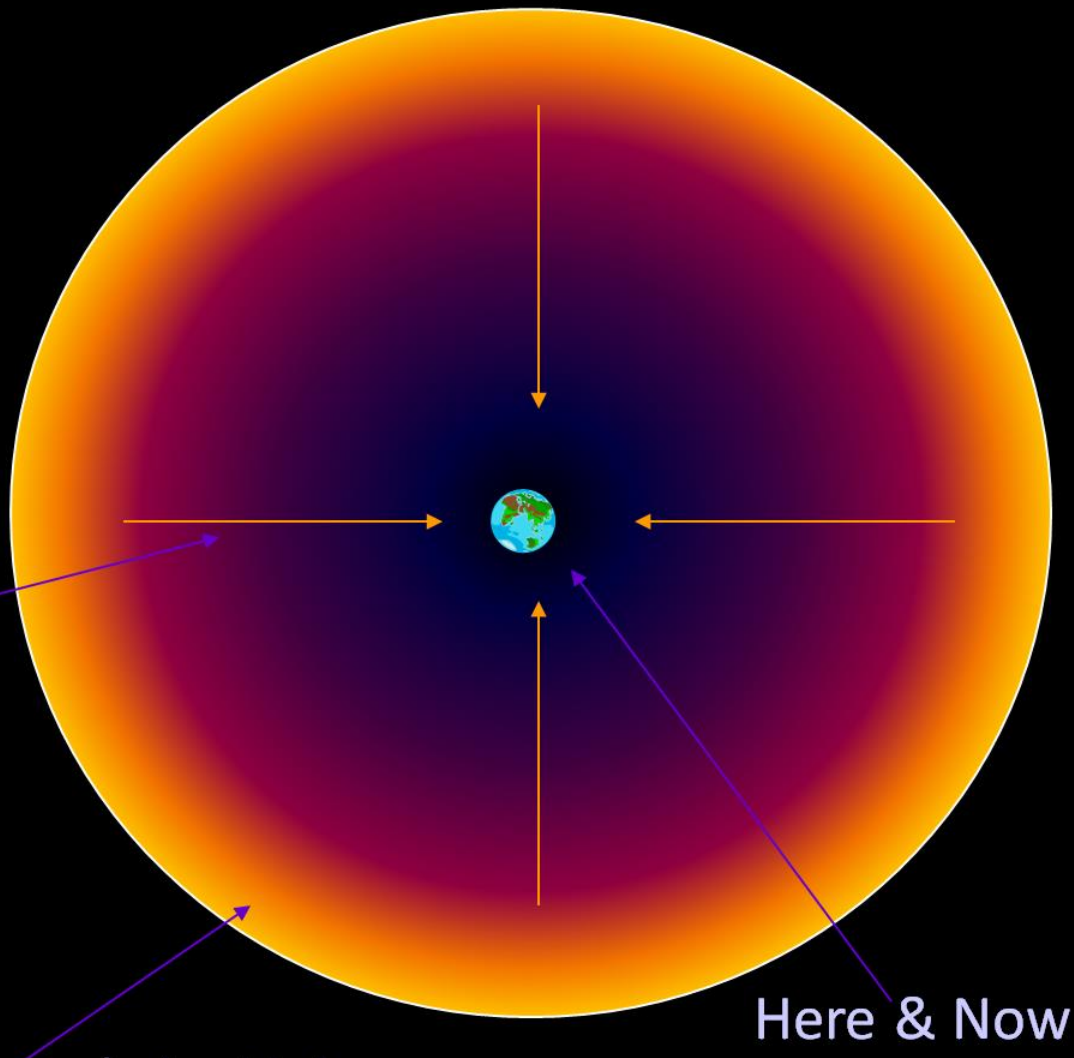
Nuclear & HEP

Inflation?

Extra Dimensions?

The Edge of the Observable Universe:

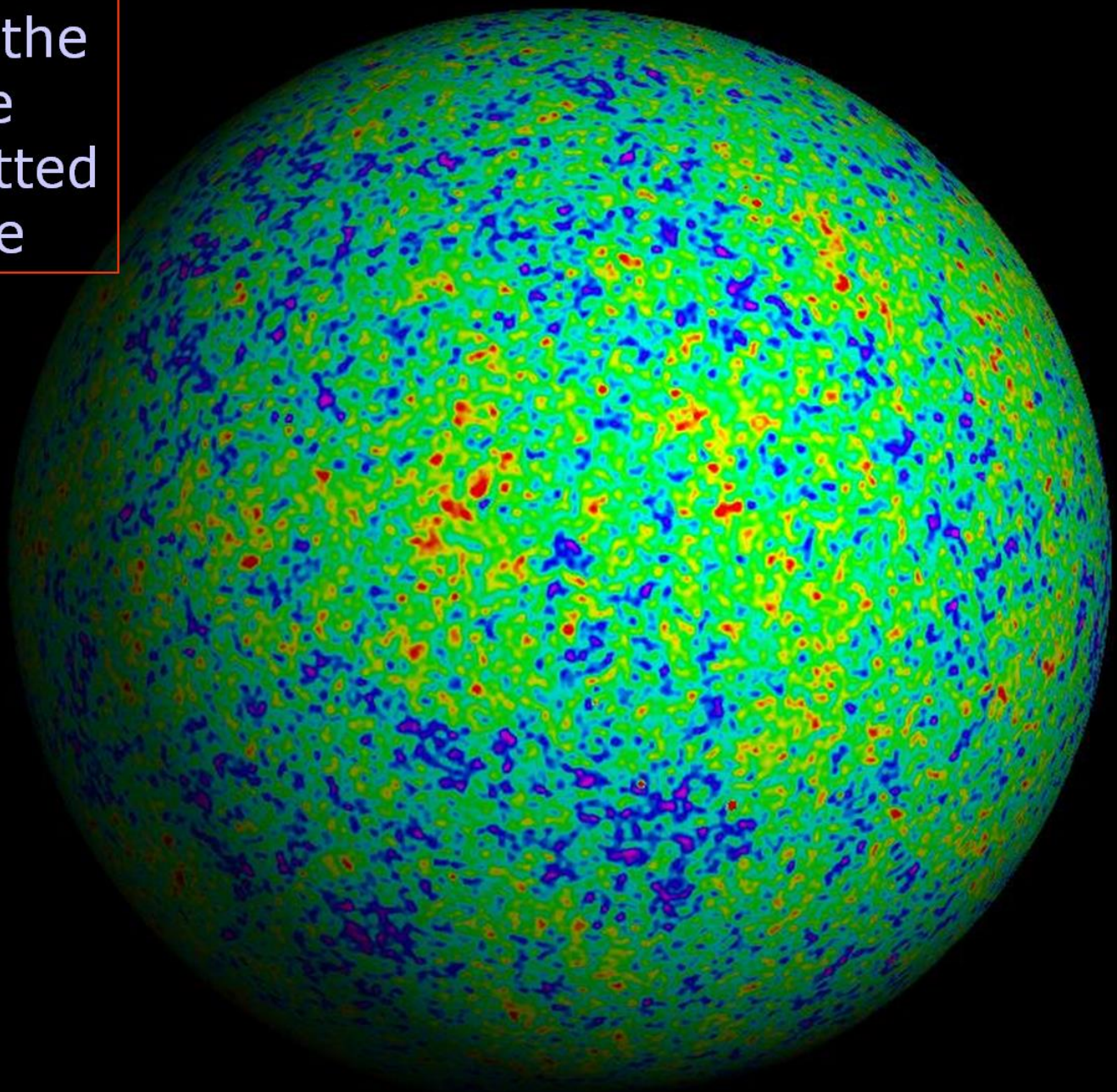
As we look back in space we look back in time. We see:



Light traveling from far away = from distant past

Long ago (about 14 Billion years) the Universe was so hot and dense it was opaque: The edge of the observable universe

WMAP map of the "edge of the observable universe" plotted as a sphere



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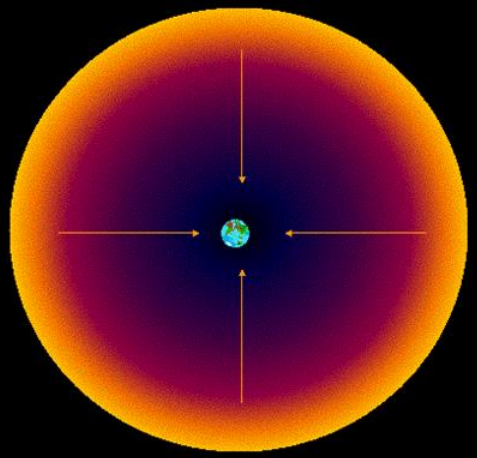
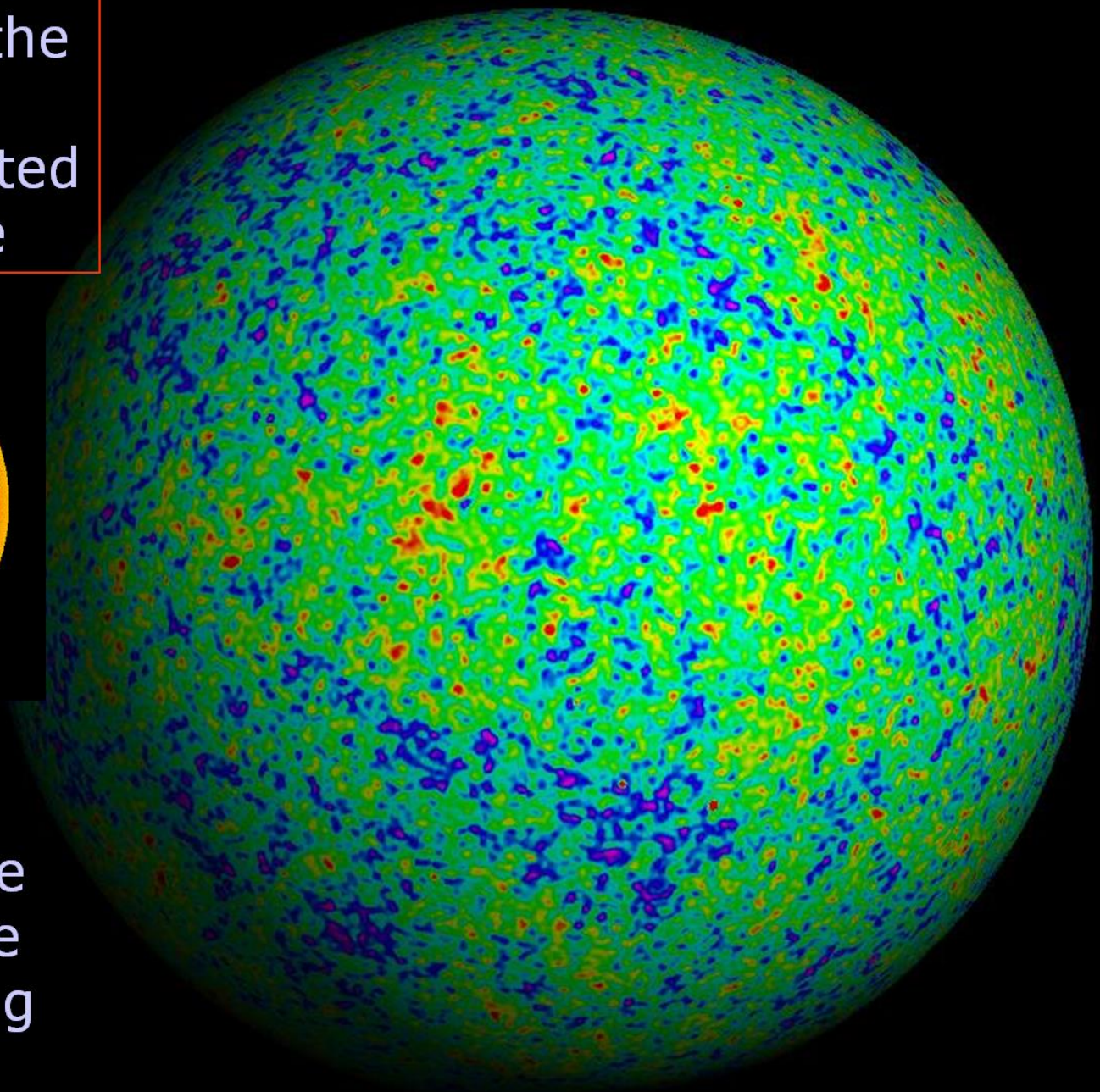




Note: we are really on the inside looking out

The History of the Universe

Time

High Energy & Temp

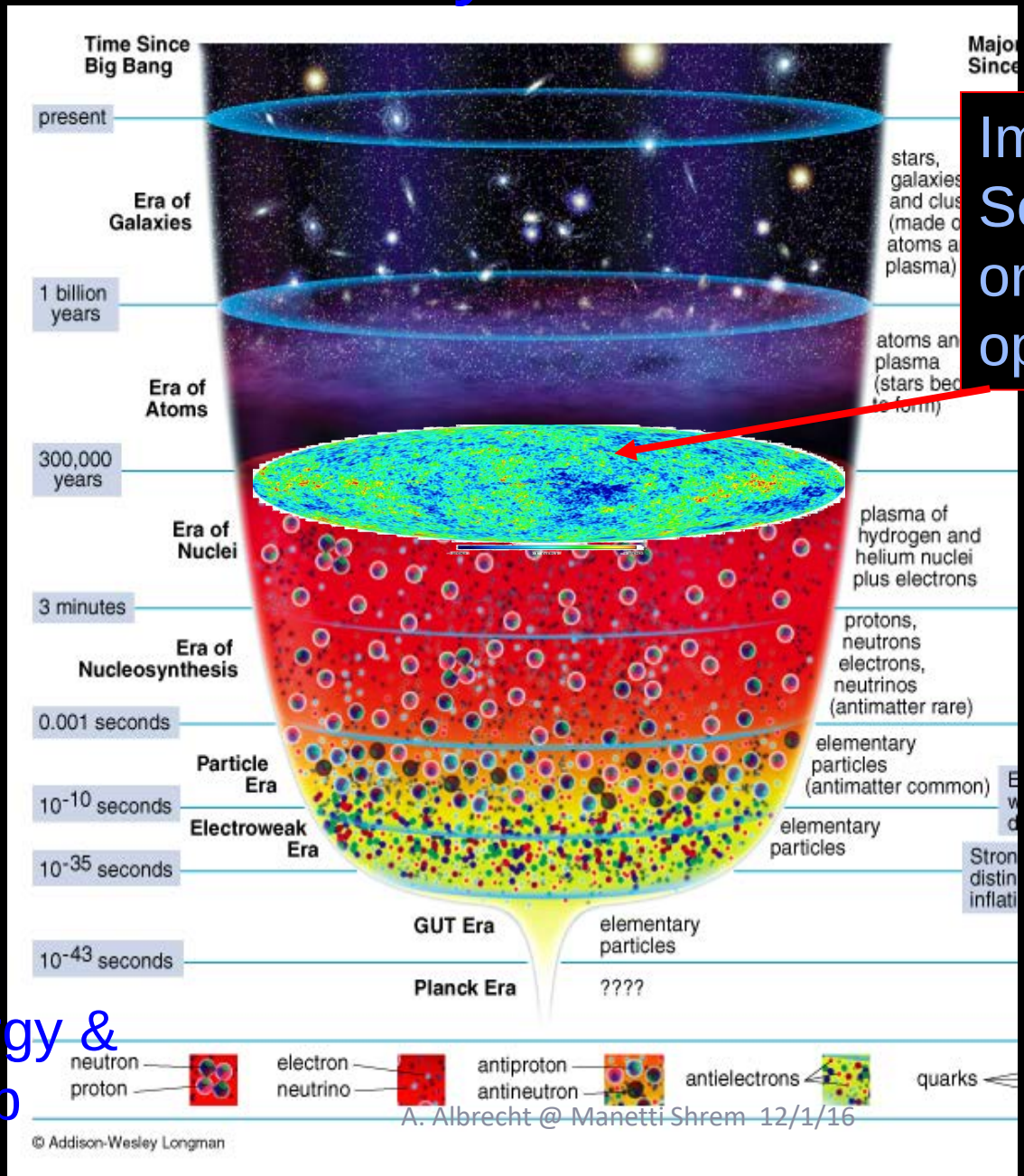


Image of the "Last Scattering Surface" or "edge of opaqueness"

The History of the Universe

Time

High Energy & Temp

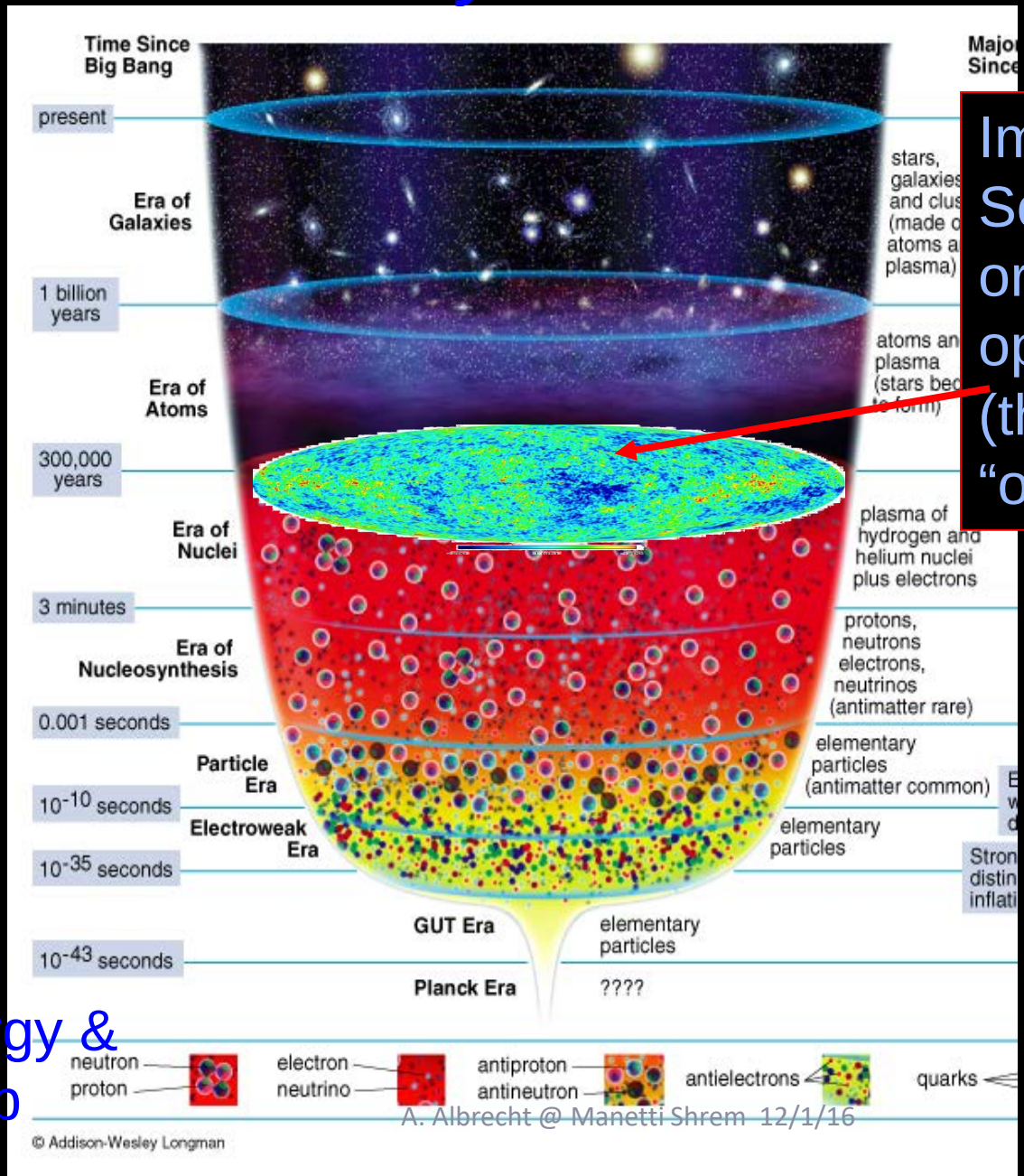


Image of the "Last Scattering Surface" or "edge of opaqueness" (the most distant "object")

The History of the Universe

Time

High Energy & Temp

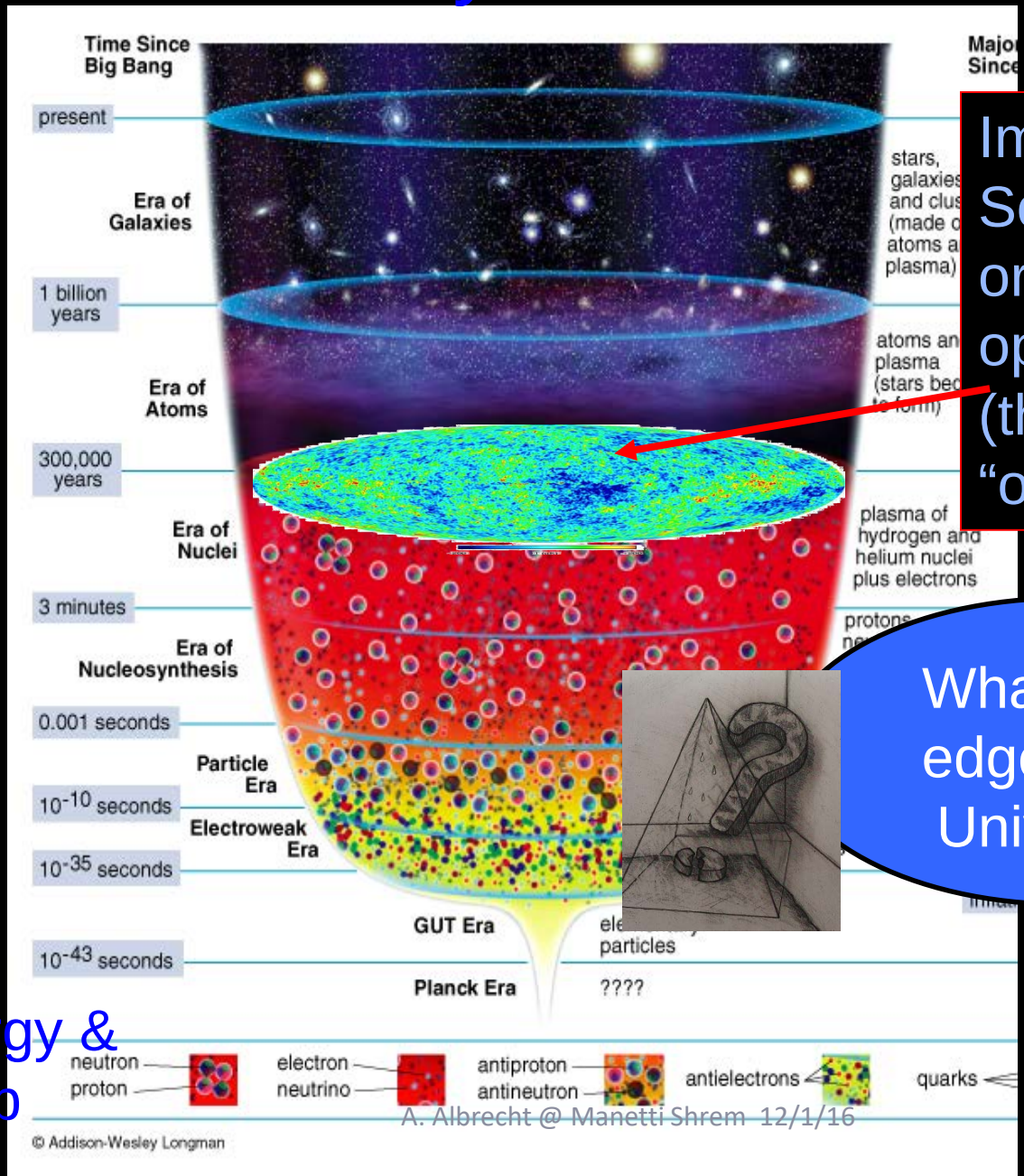
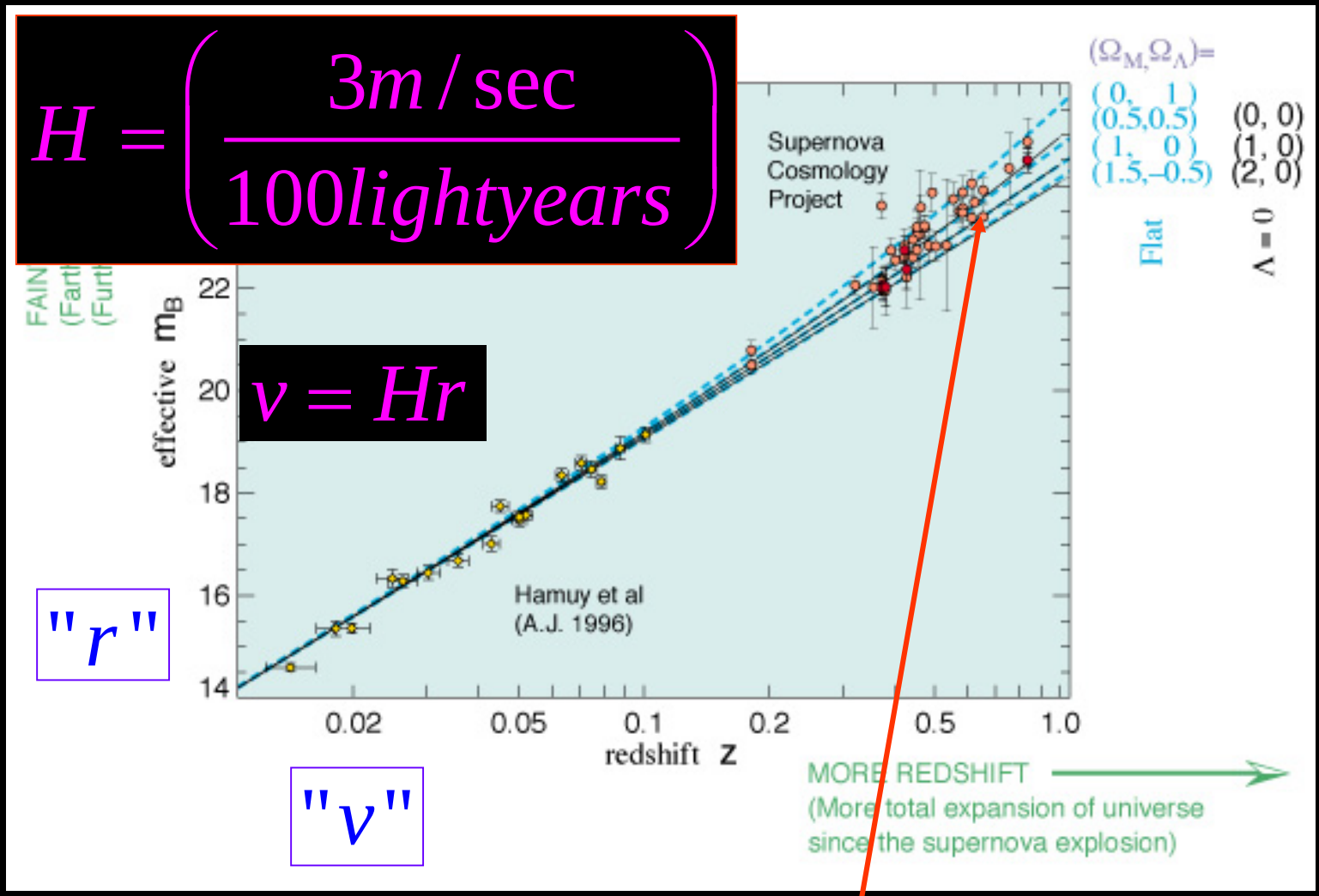


Image of the "Last Scattering Surface" or "edge of opaqueness" (the most distant "object")

What is the edge of the Universe?

Acceleration of the universe

$$H = \left(\frac{3m/\sec}{100 lightyears} \right)$$



$v = Hr$

"r"

"v"

The Hubble law at great distances depends on the variations of the Hubble "constant" H with time.

Acceleration of the universe

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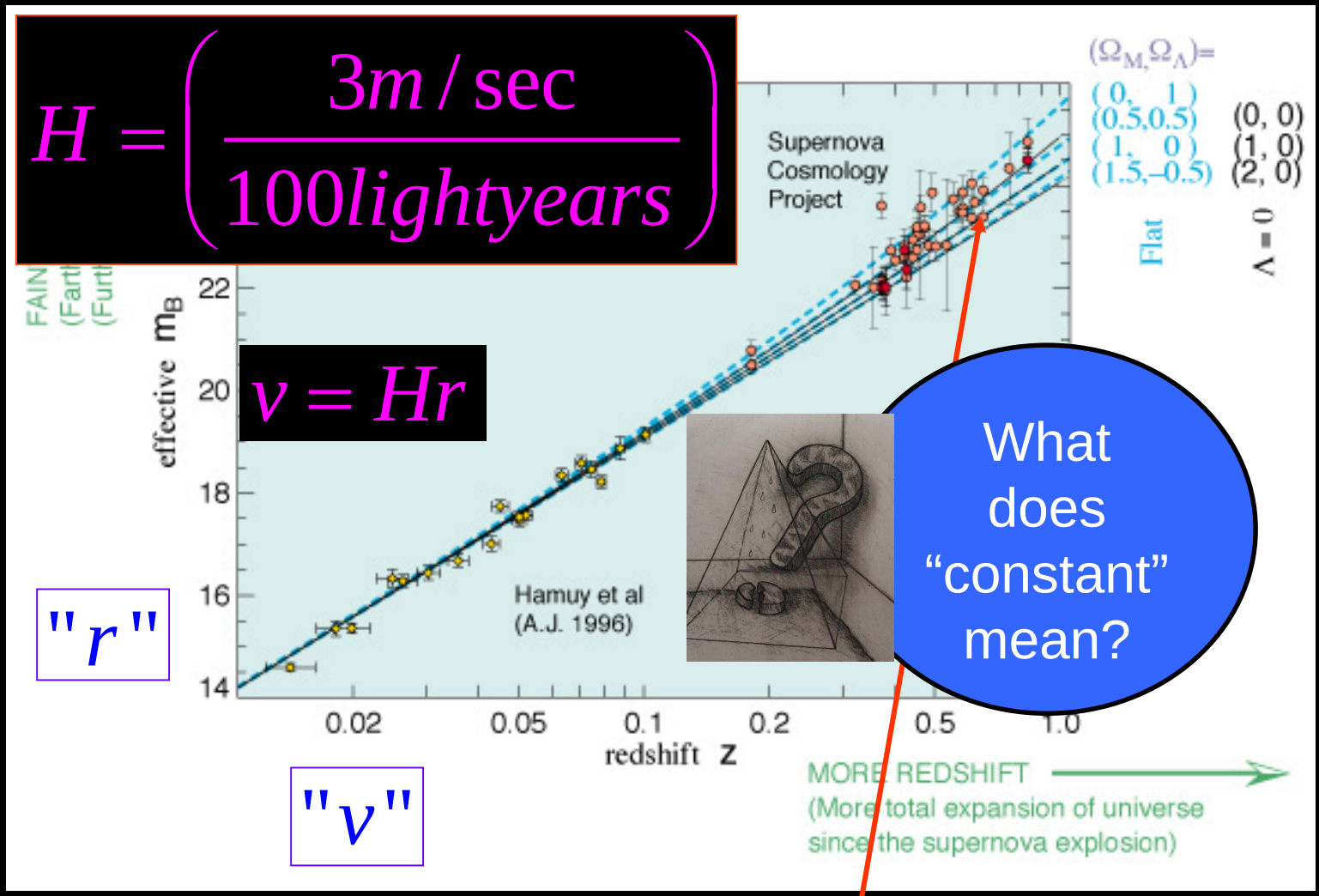

$v = Hr$

"r"

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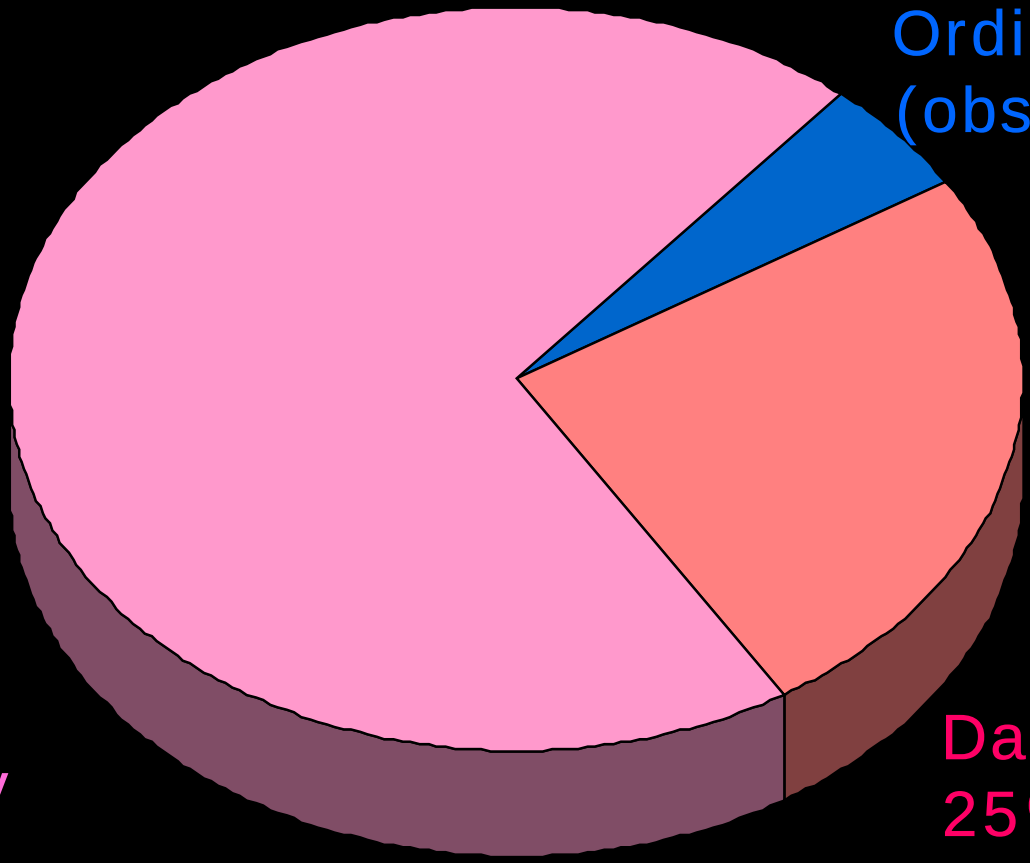
What does "constant" mean?

The Hubble law at great distances depends on the variations of the Hubble "constant" H with time.

95% of the cosmic matter/energy is a mystery. It has never been observed even in our best laboratories



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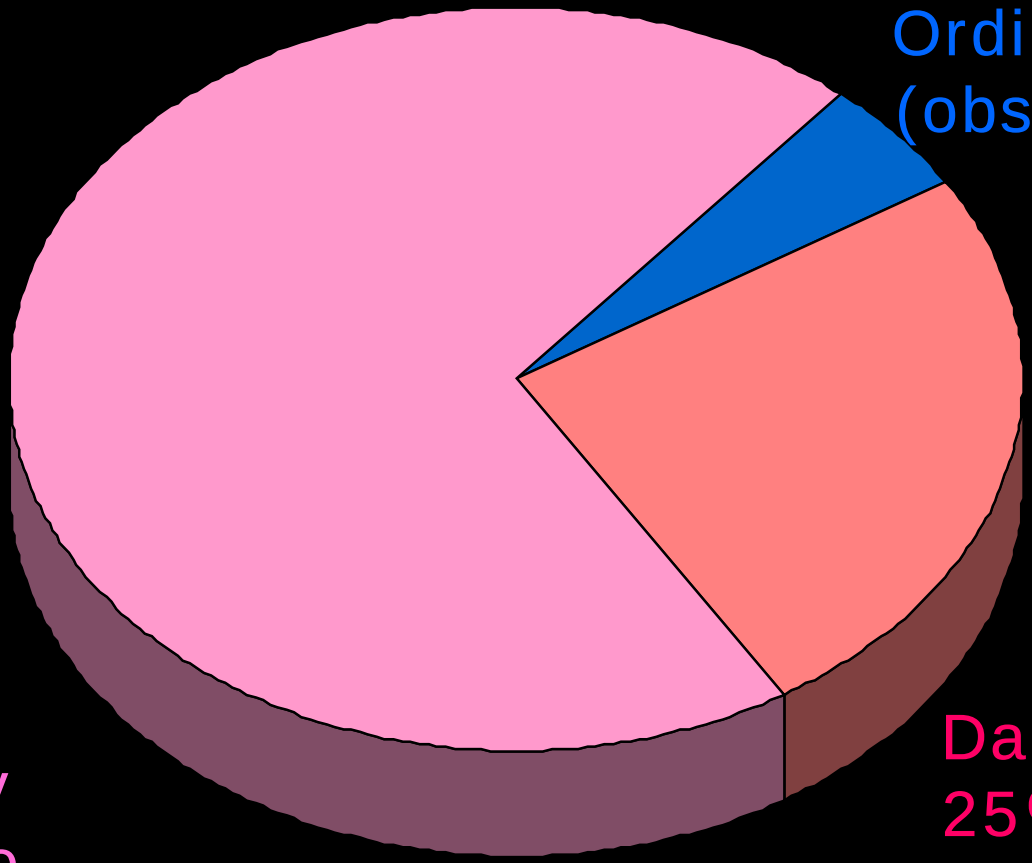


Ordinary Matter (observed in labs)

5%

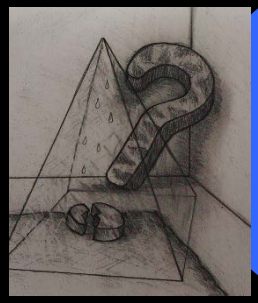
Pulled together by gravity

Dark Matter 25%

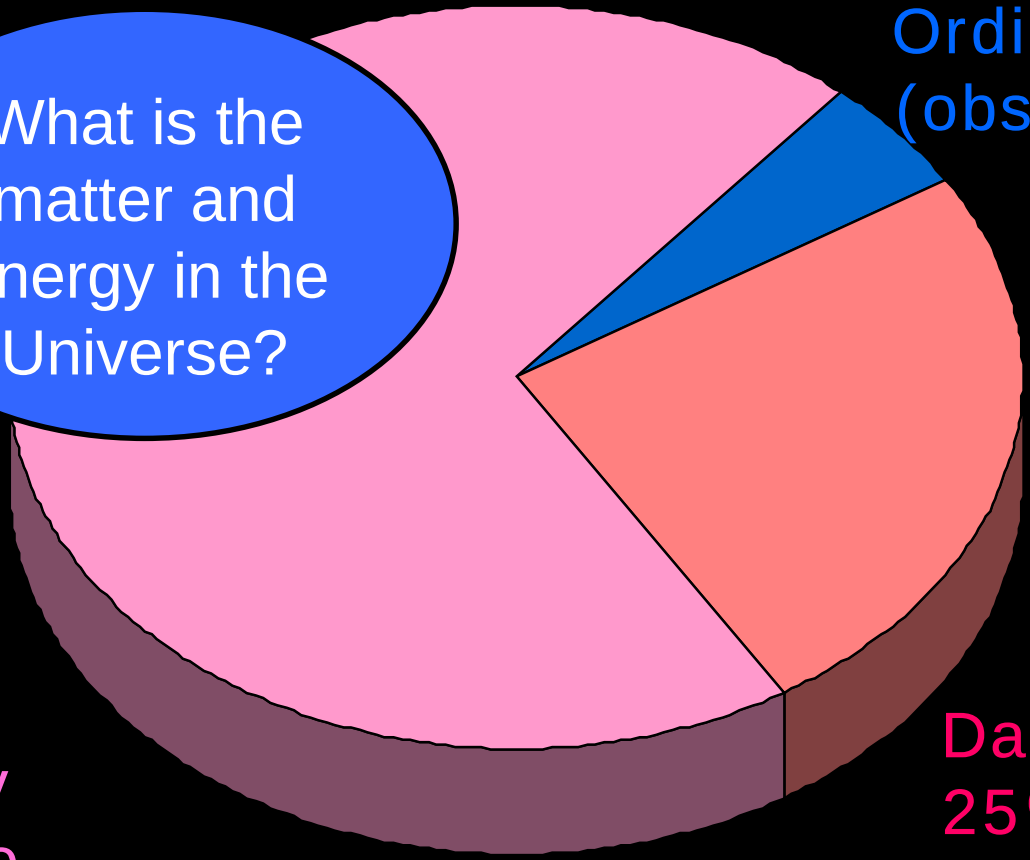
Dark Energy (pushing the Universe apart…accelerating)

70%

95% of the cosmic matter/energy is a mystery. It has never been observed even in our best laboratories



What is the matter and energy in the Universe?



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Outline

1. Introduction (The "Golden age of cosmology")
2. The Big Picture
3. Some Big ideas
   - Cosmic Inflation
   - The String theory landscape

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2. The Big Picture
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   - Cosmic Inflation
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Cosmic Inflation

- A period of accelerated expansion in the very early universe

- Motivated by particle physics (related to the recently discovered Higgs particle).
- In most models inflation operates when the temperature was 10^{25} times greater than today!

- Conceptually similar in some ways to the acceleration observed today (interesting relationship between the two)

The History of the Universe

Time

High Energy & Temp

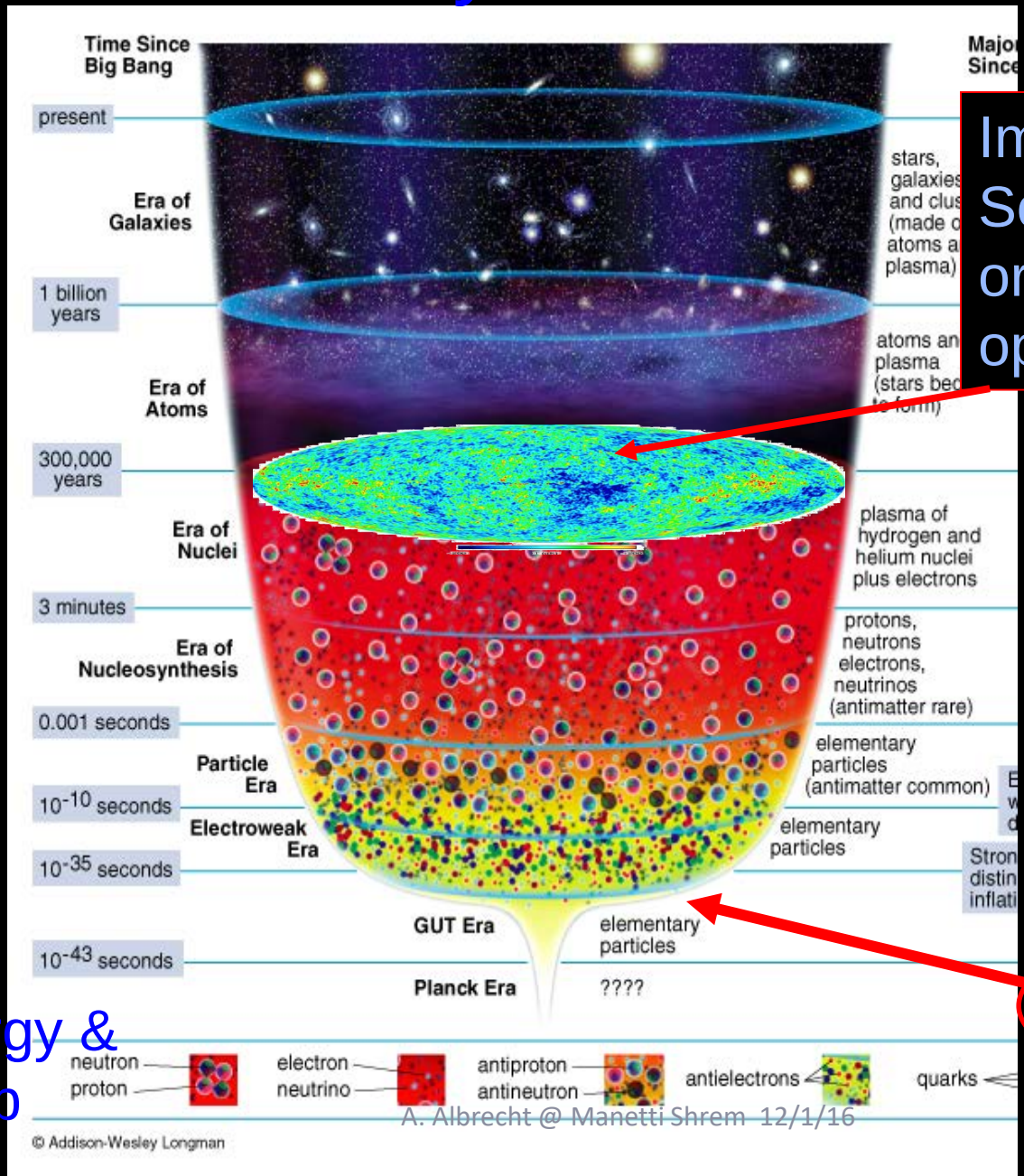


Image of the "Last Scattering Surface" or "edge of opaqueness"

Cosmic Inflation here

The History of the Universe

Time

High Energy & Temp

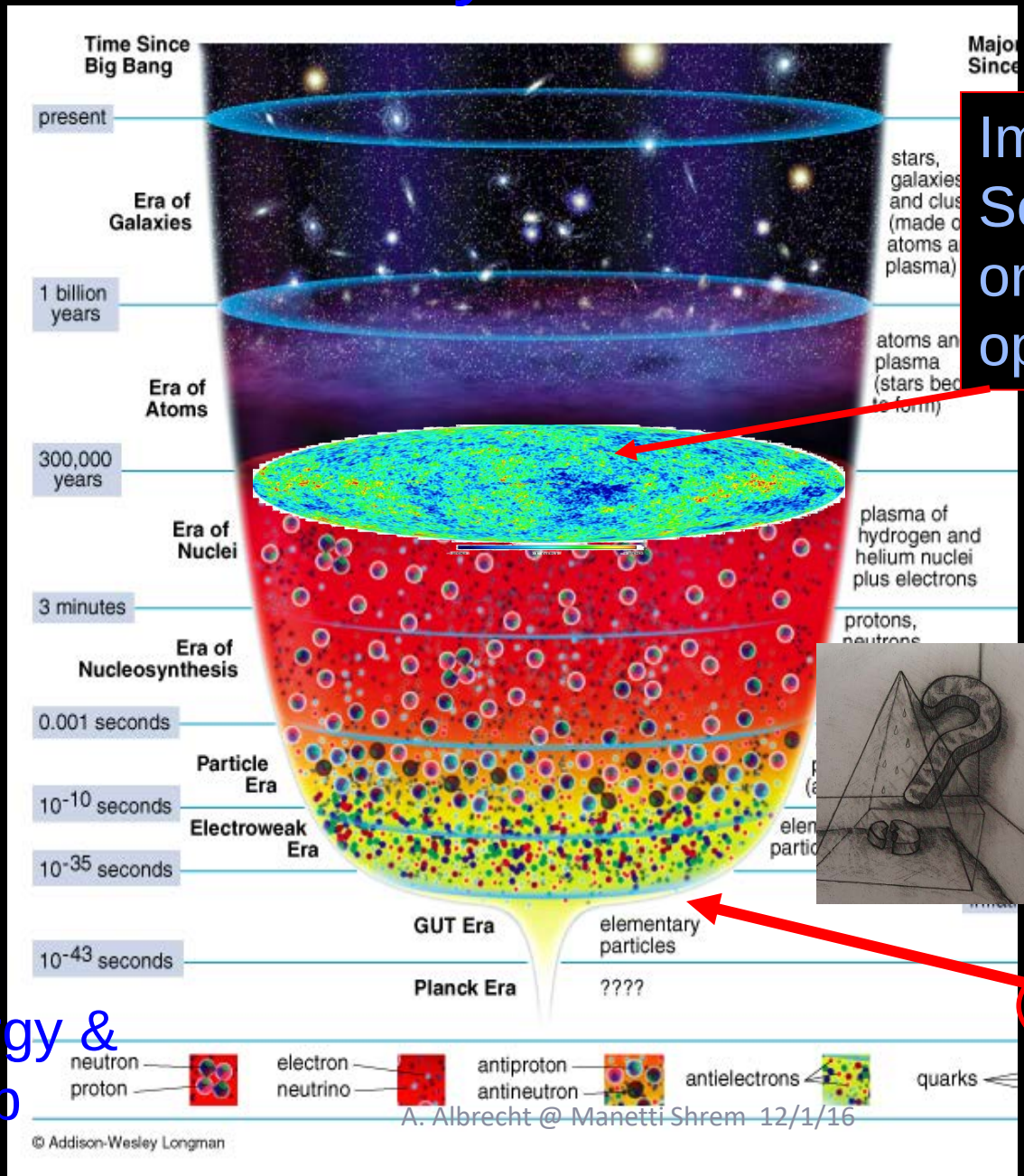
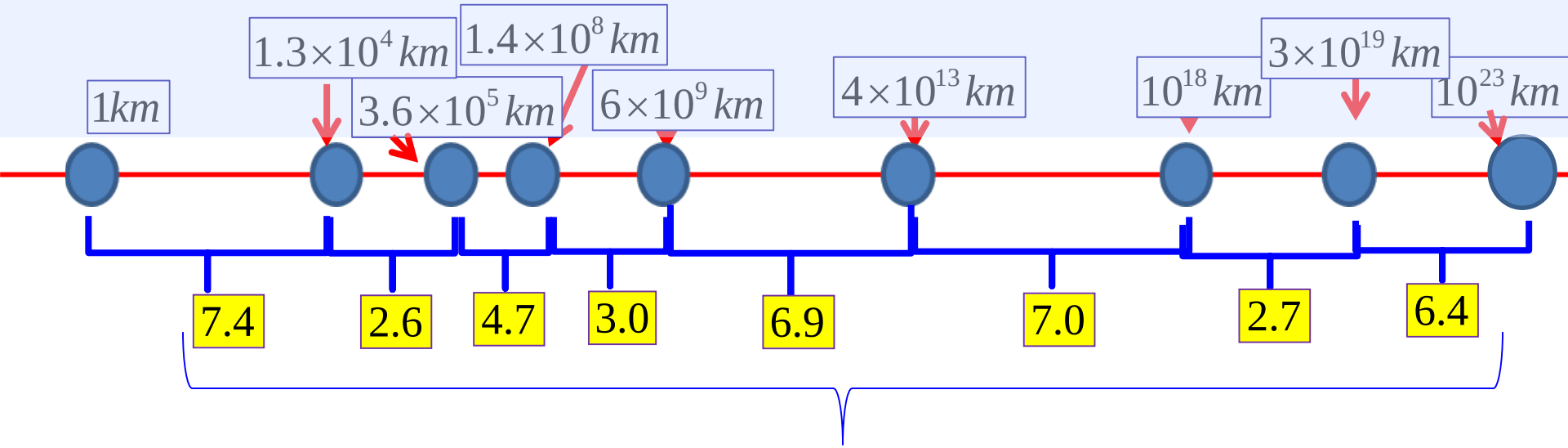


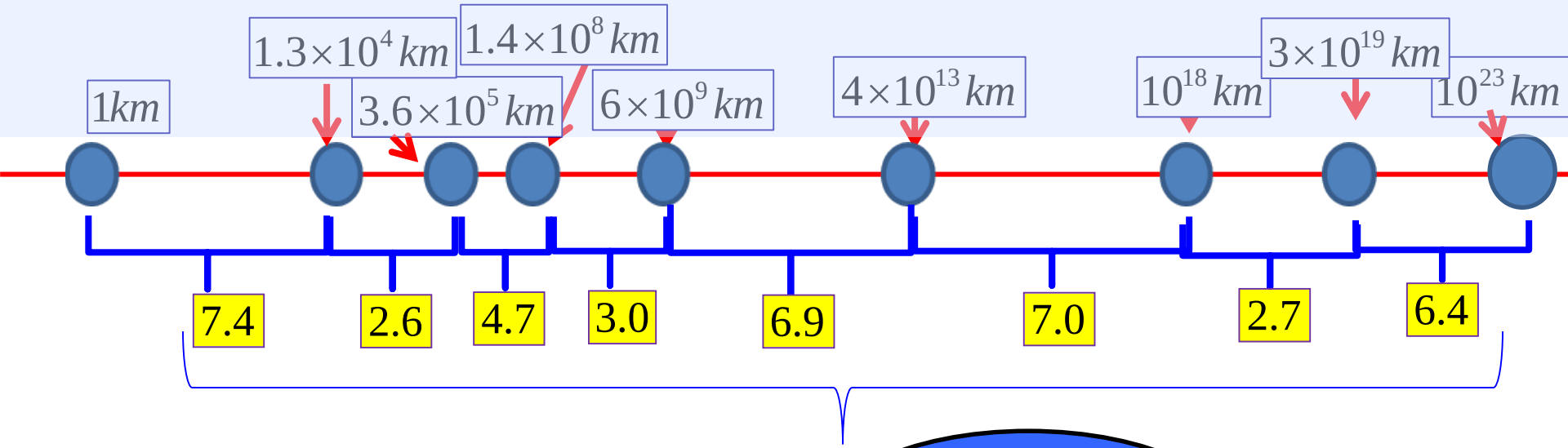
Image of the "Last Scattering Surface" or "edge of opaqueness"

What happened at the beginning?

Cosmic Inflation here



- Cosmic inflation creates features in the universe on all these different lengths.
- The yellow boxes give the time between "feature creation" in units of seconds! 10^{-40}



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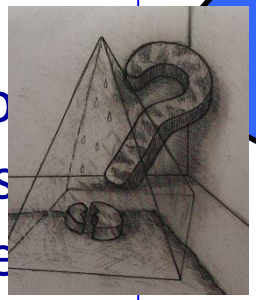
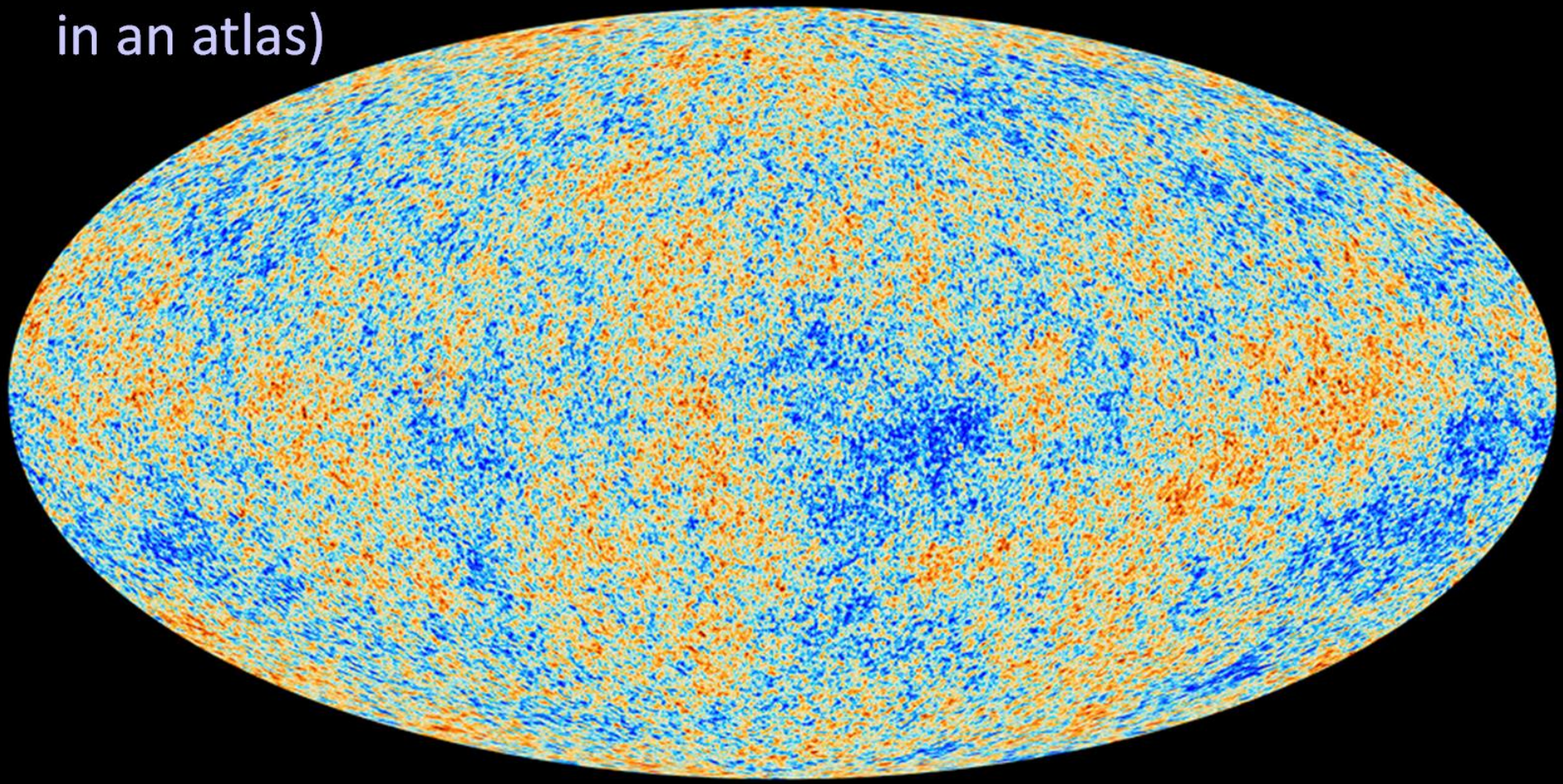
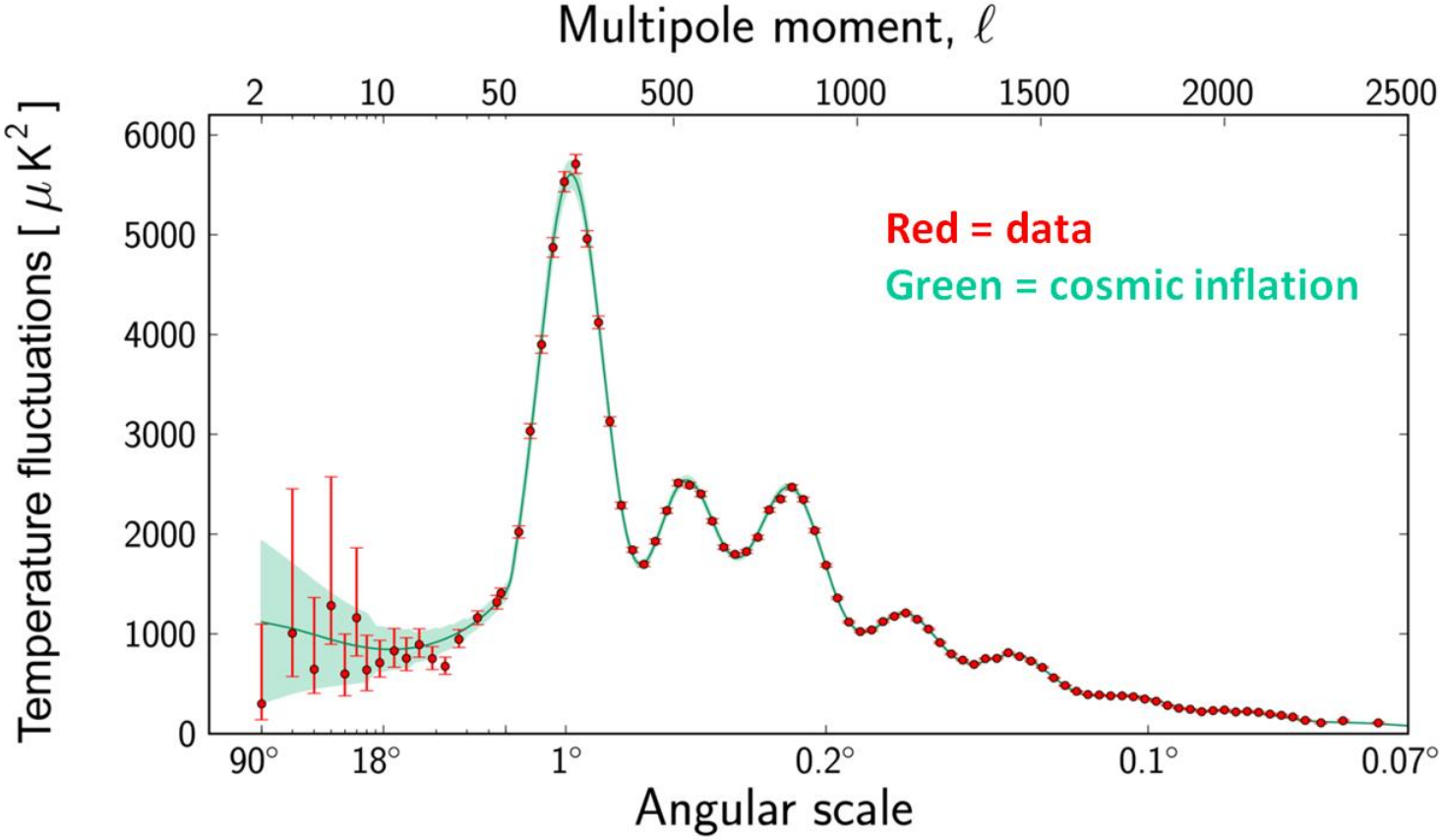


What is time?

Cosmic Microwave Background (CMB) map produced by the Planck satellite (sphere shown using a projection, like in an atlas)

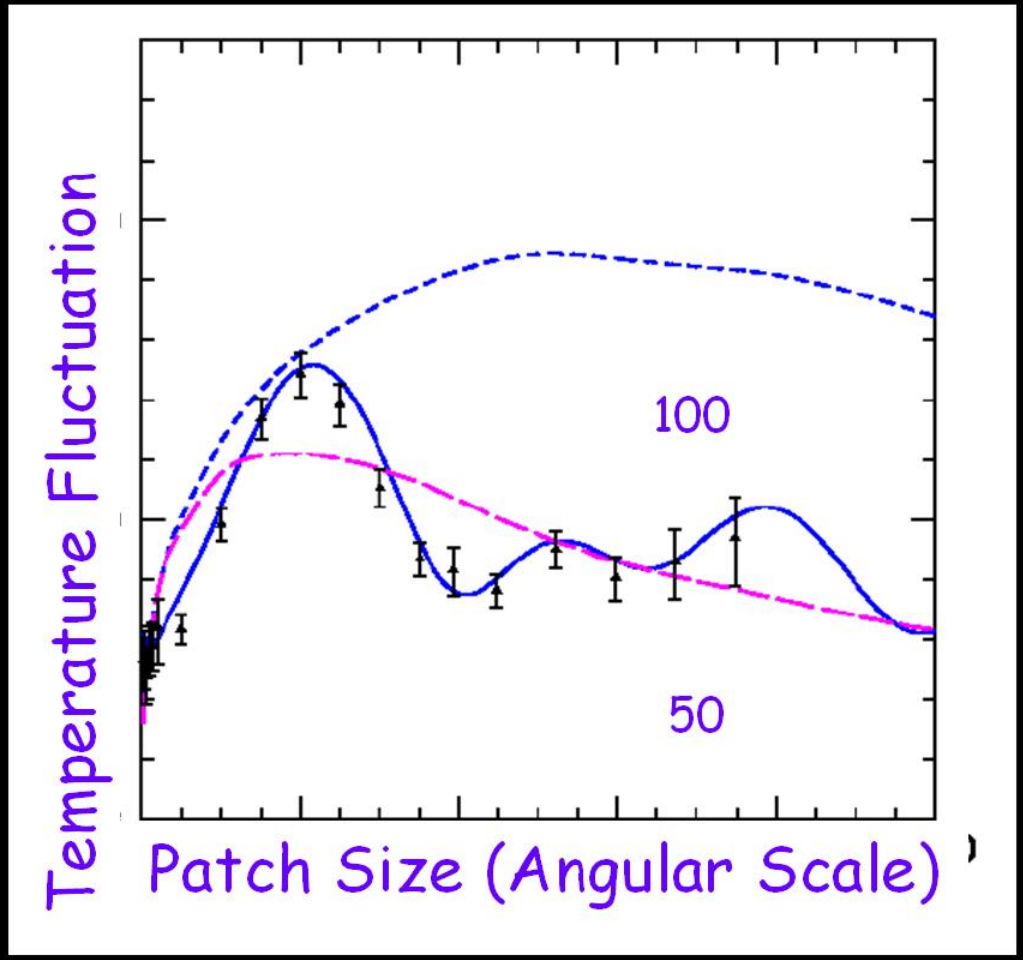


The map shows minute variations in the temperature (just 1 part in 100,000, or in the 5^{th} decimal place).



This plot shows one way to quantify the feature in the CMB map. Roughly, the x-axis labels patch size, and the y-axis show how strongly the temperature typically varies among patches of that size.

Using the CMB to learn about the Universe



solid=inflation model

dashed=defect models

(magenta=desperate)

Cosmic Inflation

- A period of accelerated expansion in the very early universe
- Motivated by particle physics (related to the recently discovered Higgs particle)
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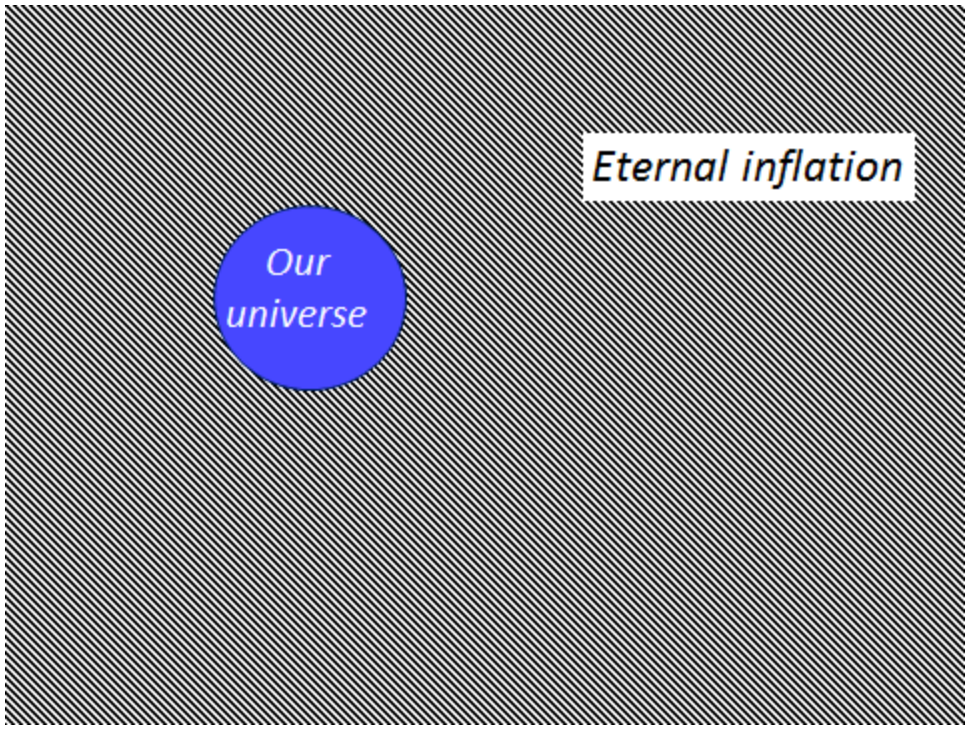

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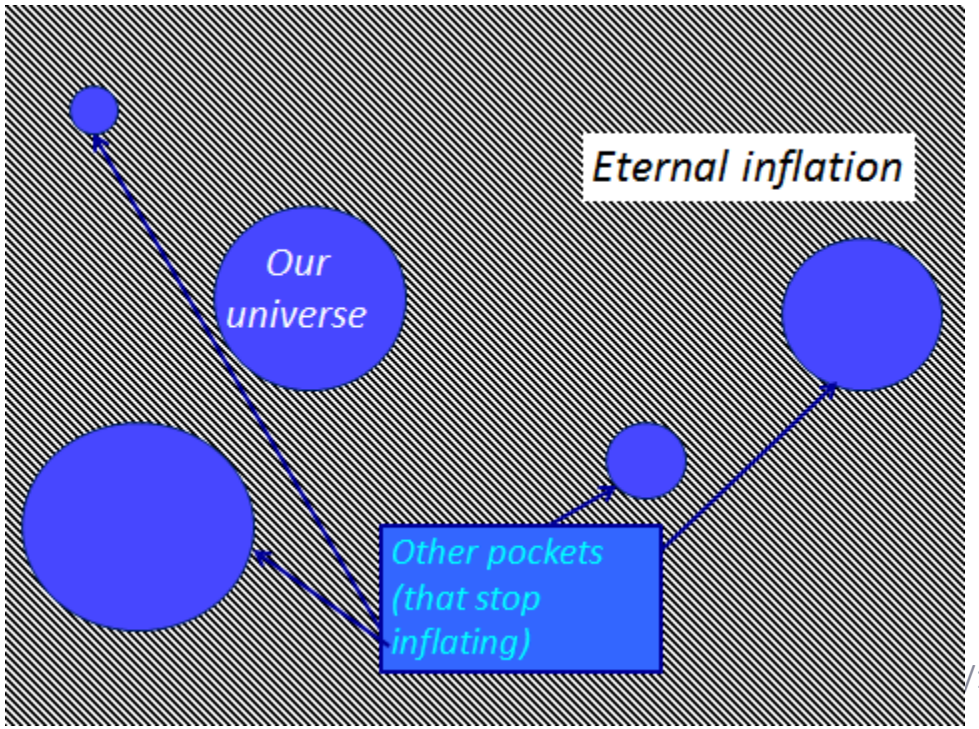

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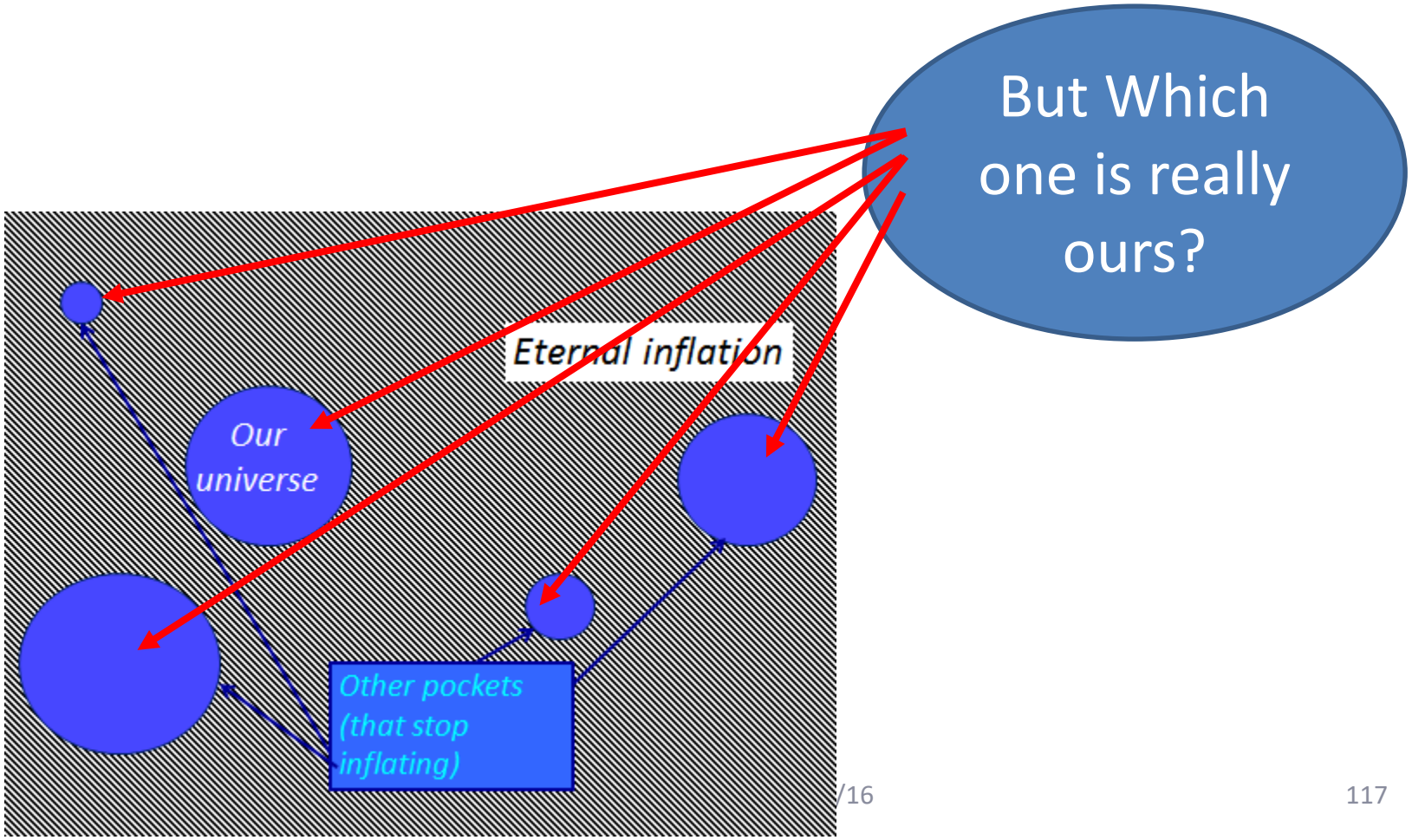

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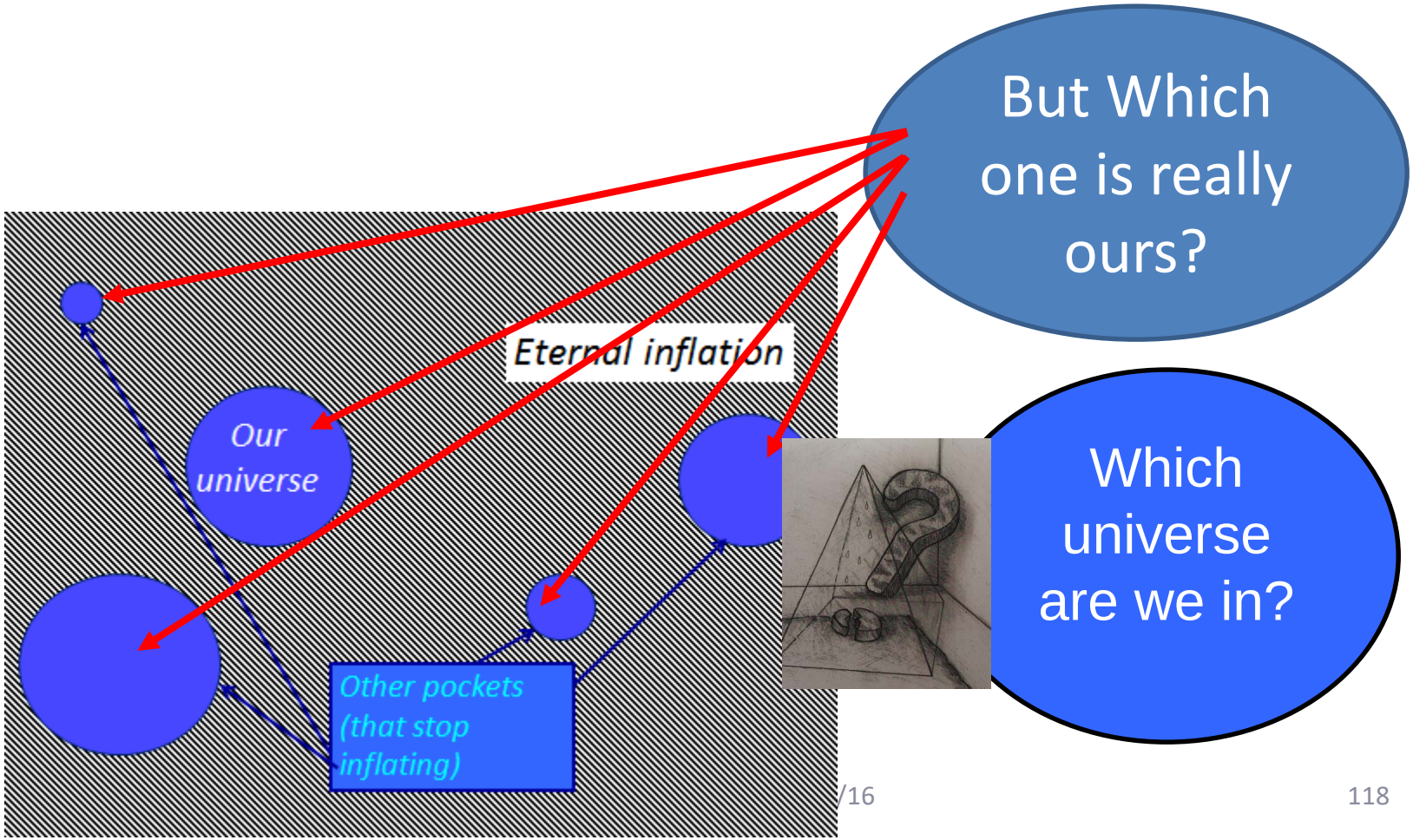

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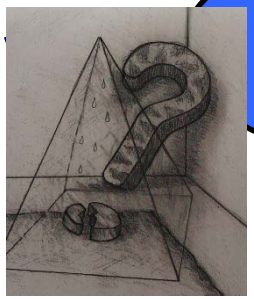
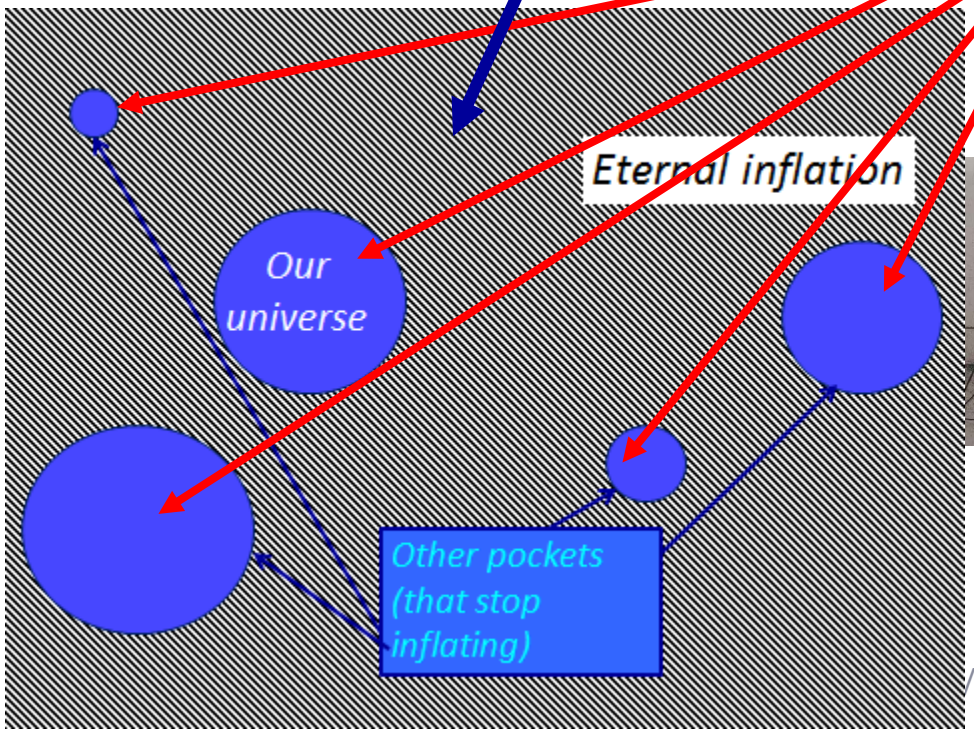
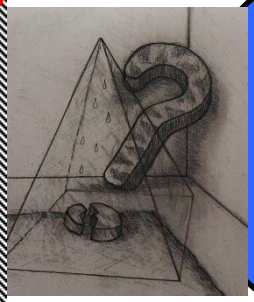


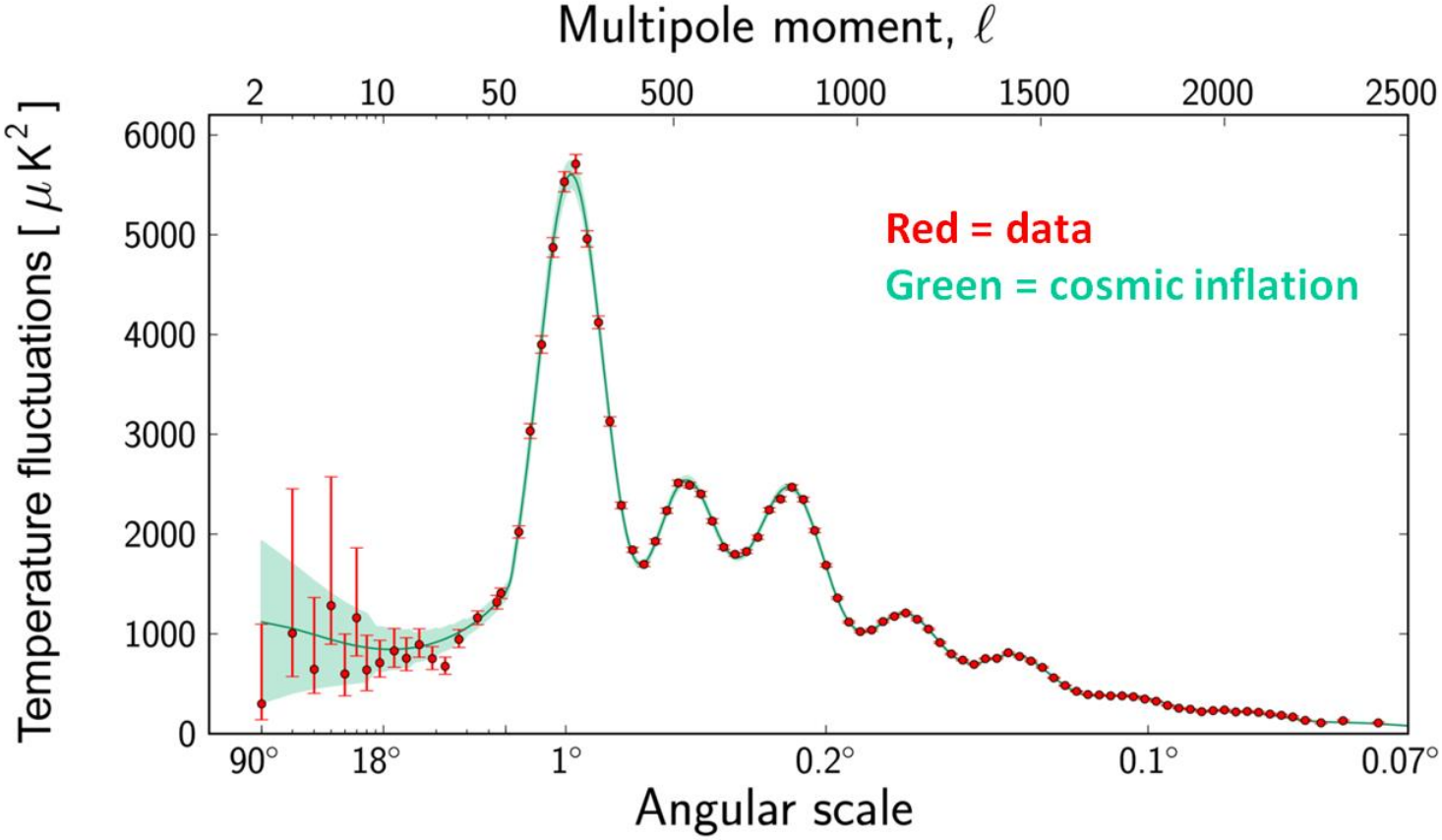
What’s all this stuff?

But Which one is really ours?





Which universe are we in?



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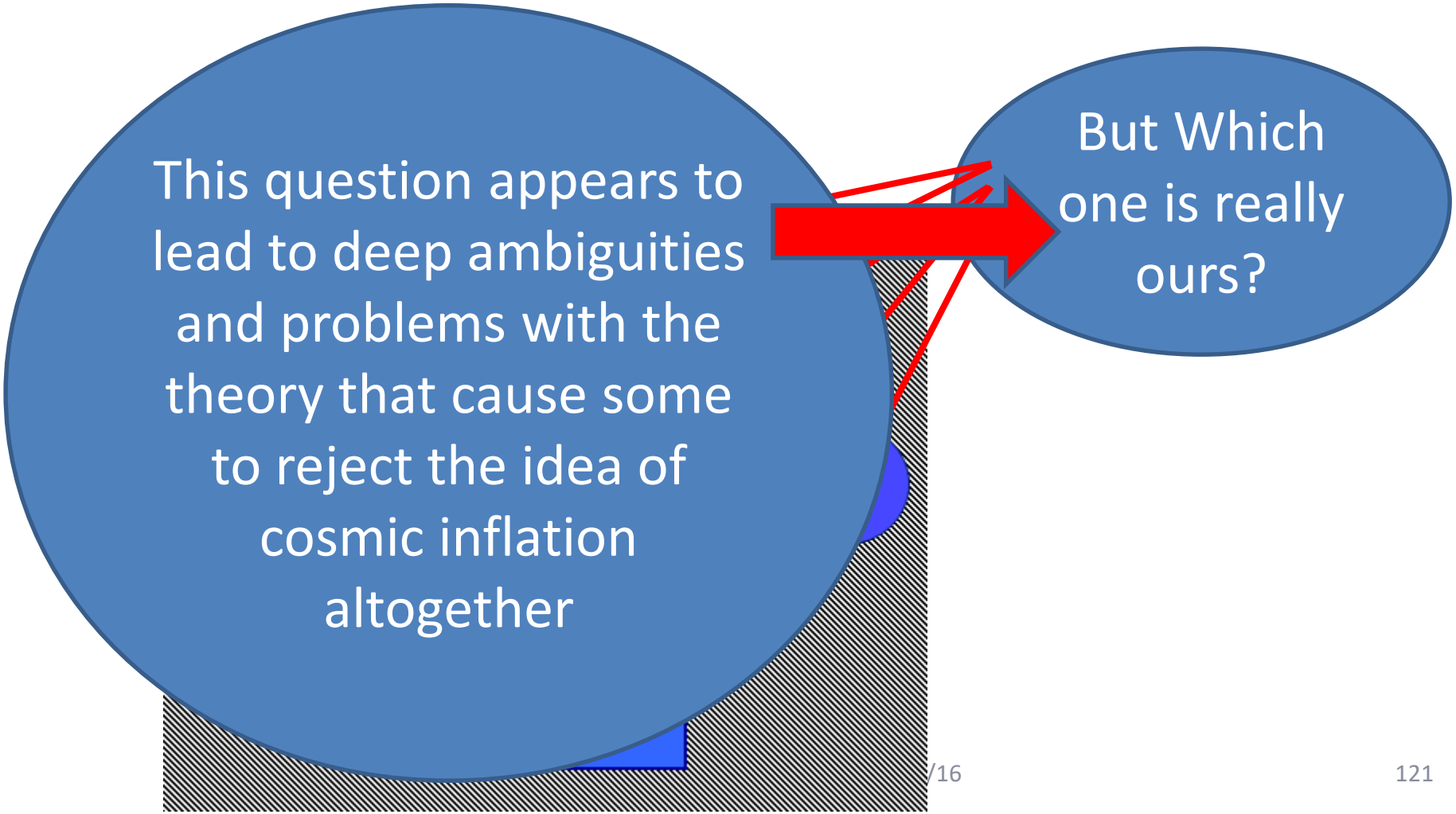

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What is time?

What is probability?

Is the universe infinite?

What happened at the beginning?

What exists?

Outline

1. Introduction (The "Golden age of cosmology")
2. The Big Picture
3. Some Big ideas
   - Cosmic Inflation
   - The String theory landscape

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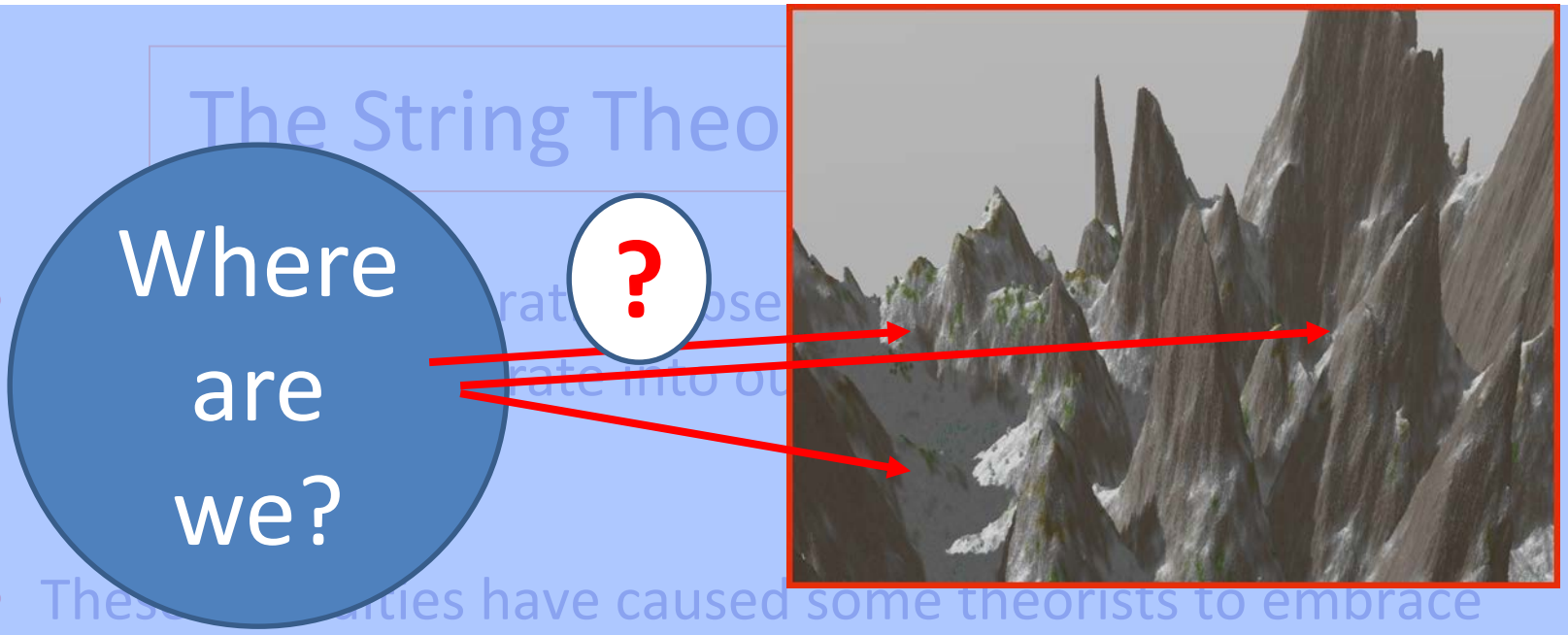

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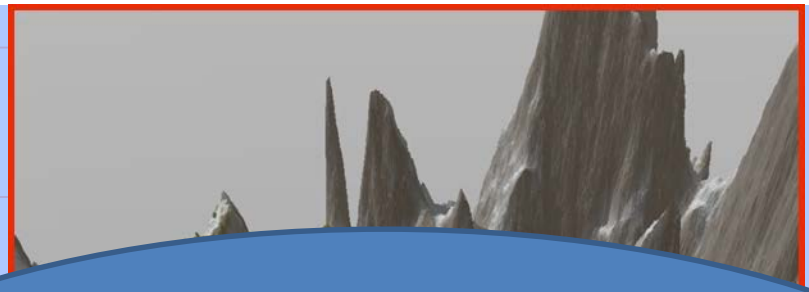

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A radical change from how we thought we should be doing physics

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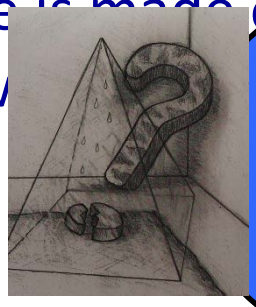

Which version of the "laws of physics do we experience?

Cosmic Inflation

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