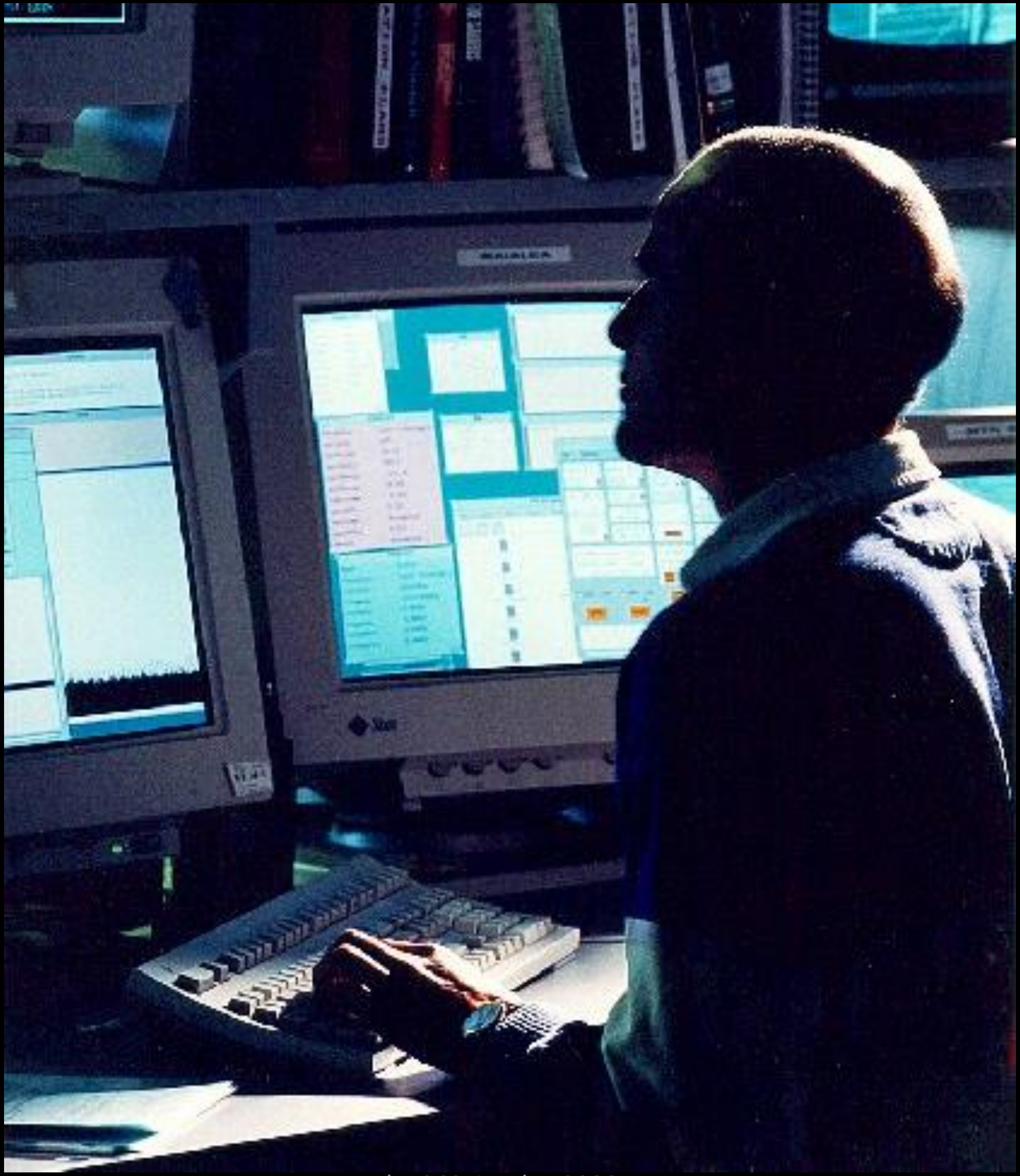
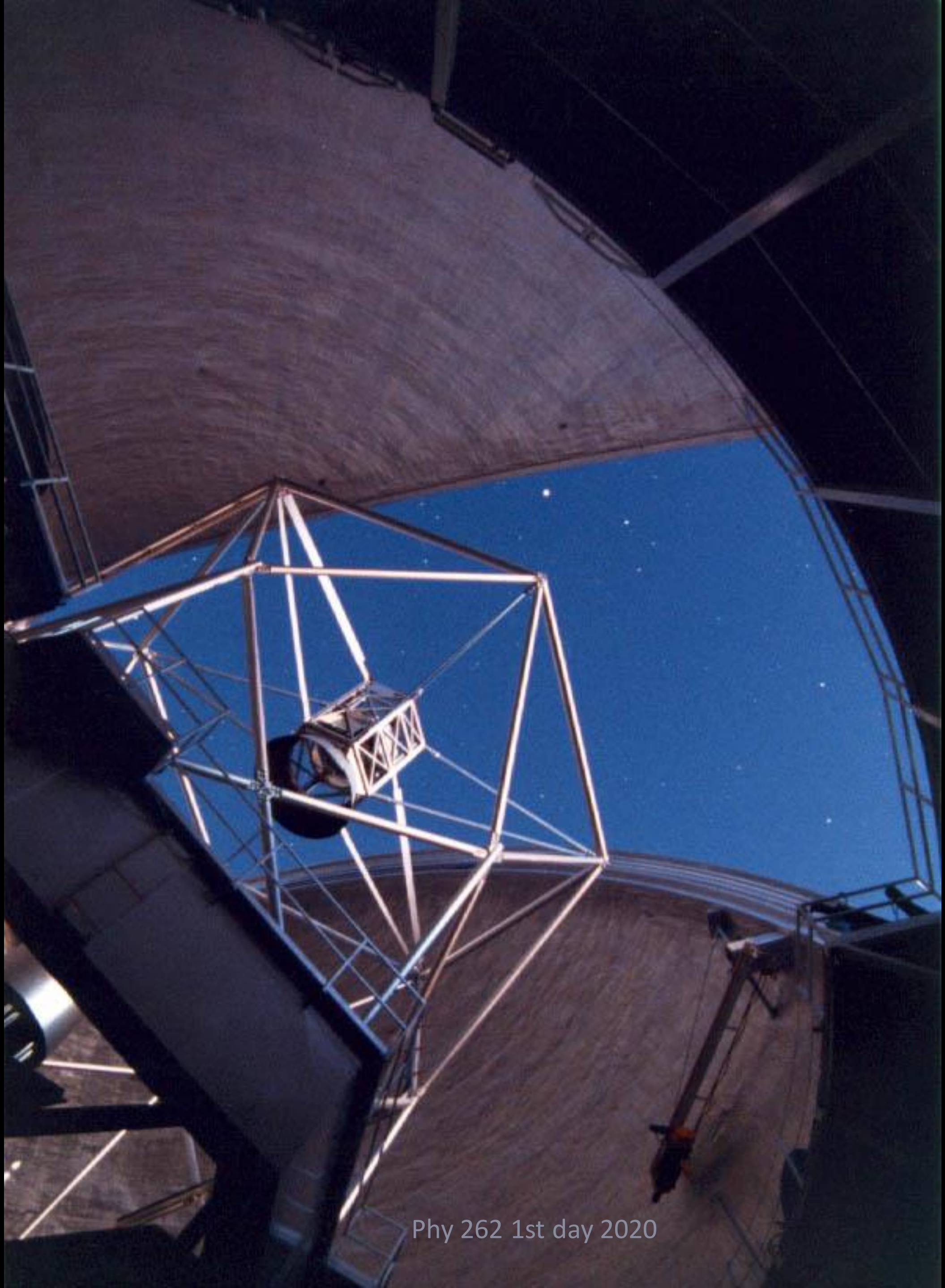
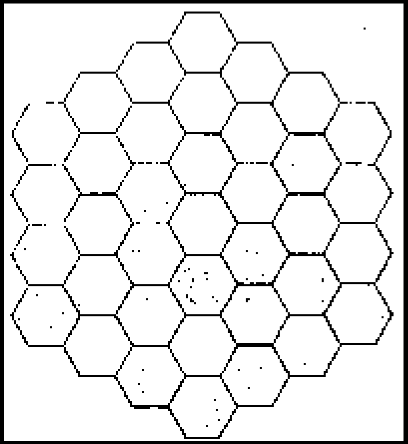
Phy 262 1st day slides

Andreas Albrecht

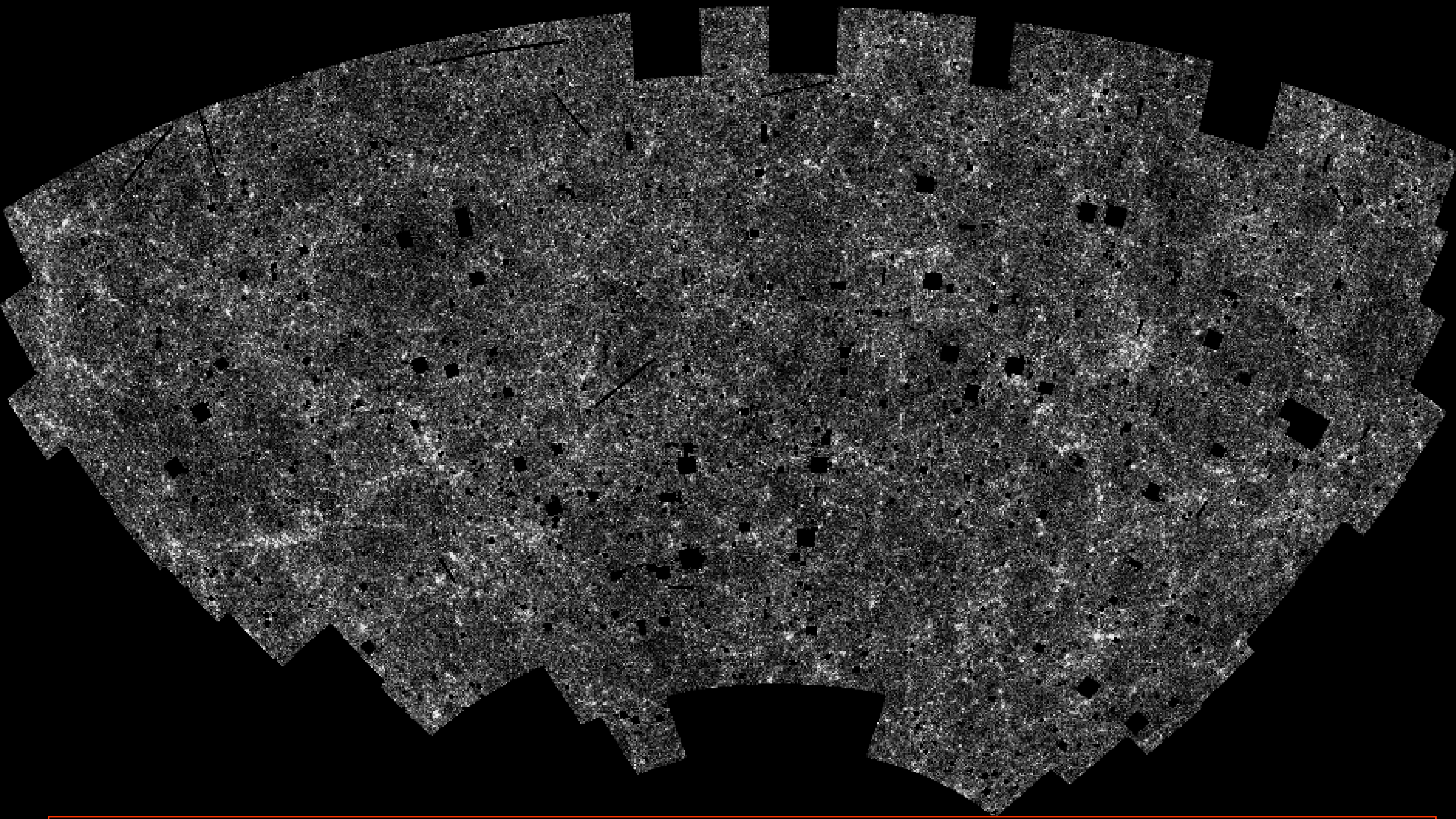




The Keck 10m Telescopes on Mauna Kea, Hawaii



Segments of the Keck 10m Telescope Mirror

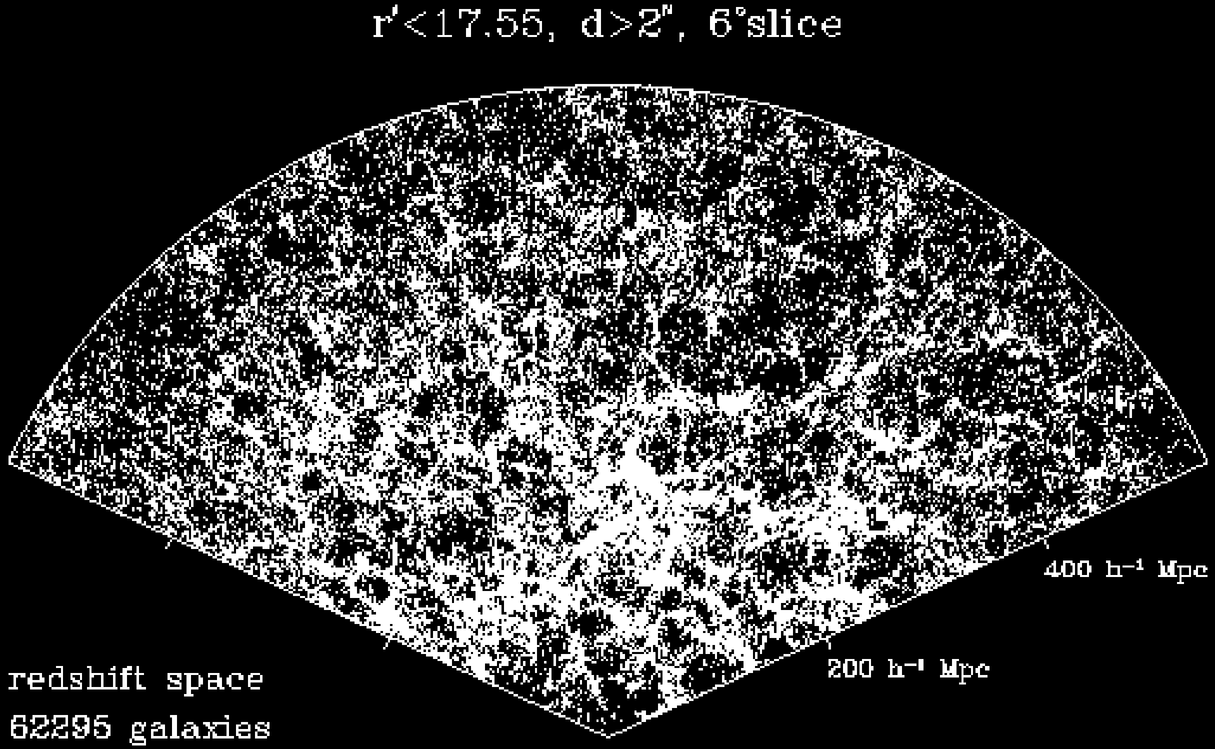


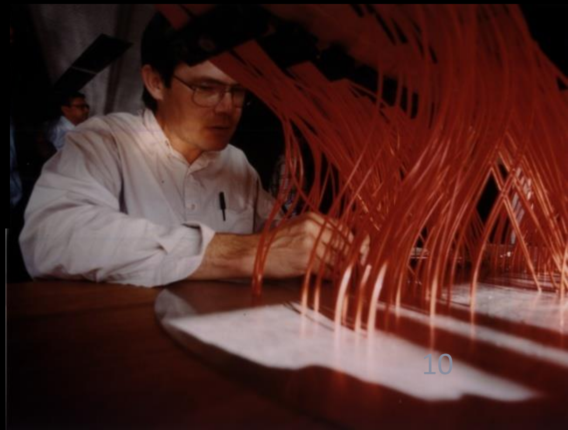
The APM (Automatic Plate Machine) Survey (1992)

Sky positions of 2,000,000 Galaxies

The Sloan Digital Sky Survey

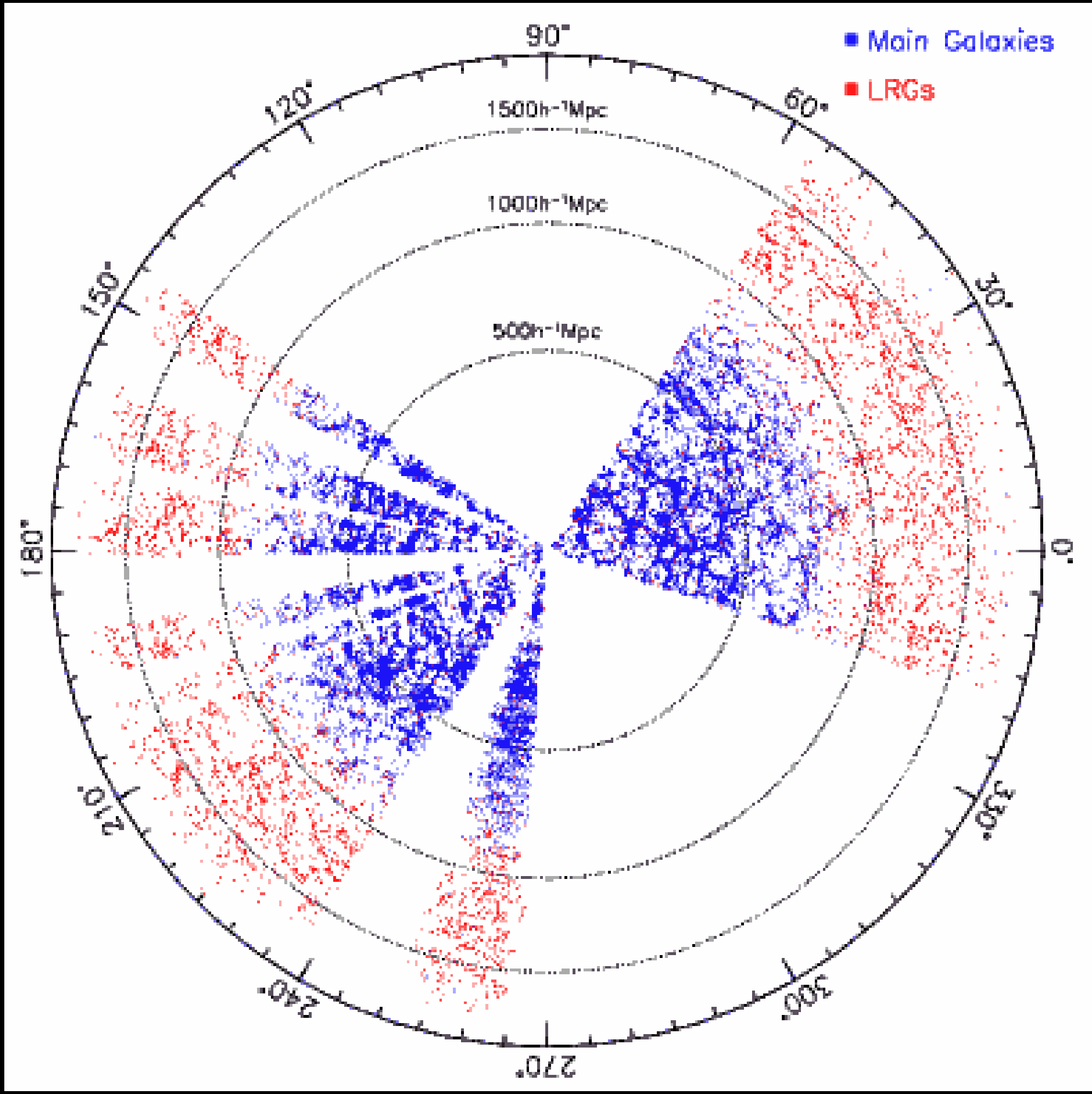
(to locate over 100,000,000 galaxies, 3D positions for 1,000,000)





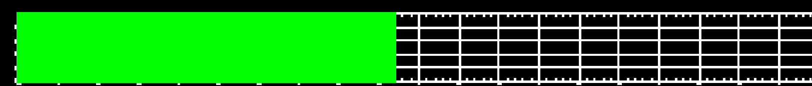
A simulation of just 65,000 Sloan galaxies

June 5 2001: First release of Sloan data (50,000 galaxies)



Sloan Survey Status

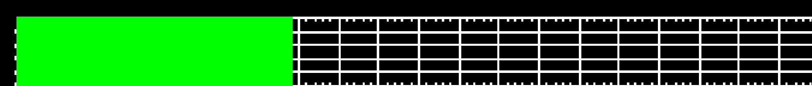
Imaging (Galaxy positions on the sky)



47% Complete Jun 21 2002

➔ 47,000,000 galaxy positions

Spectroscopy (3D galaxy positions)

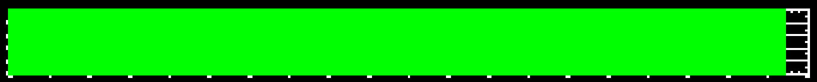


34% Complete Jul 15 2002

➔ 340,000 galaxy positions

Sloan Survey Status

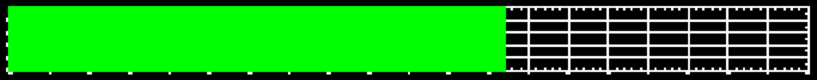
Imaging (Galaxy positions on the sky)



97% Complete Jun 27 2004

➔ 97,000,000 galaxy positions

Spectroscopy (3D galaxy positions)



67% Complete Jun 27 2004

➔ 670,000 galaxy positions

Sloan Survey Status

Imaging (Galaxy positions on the sky)

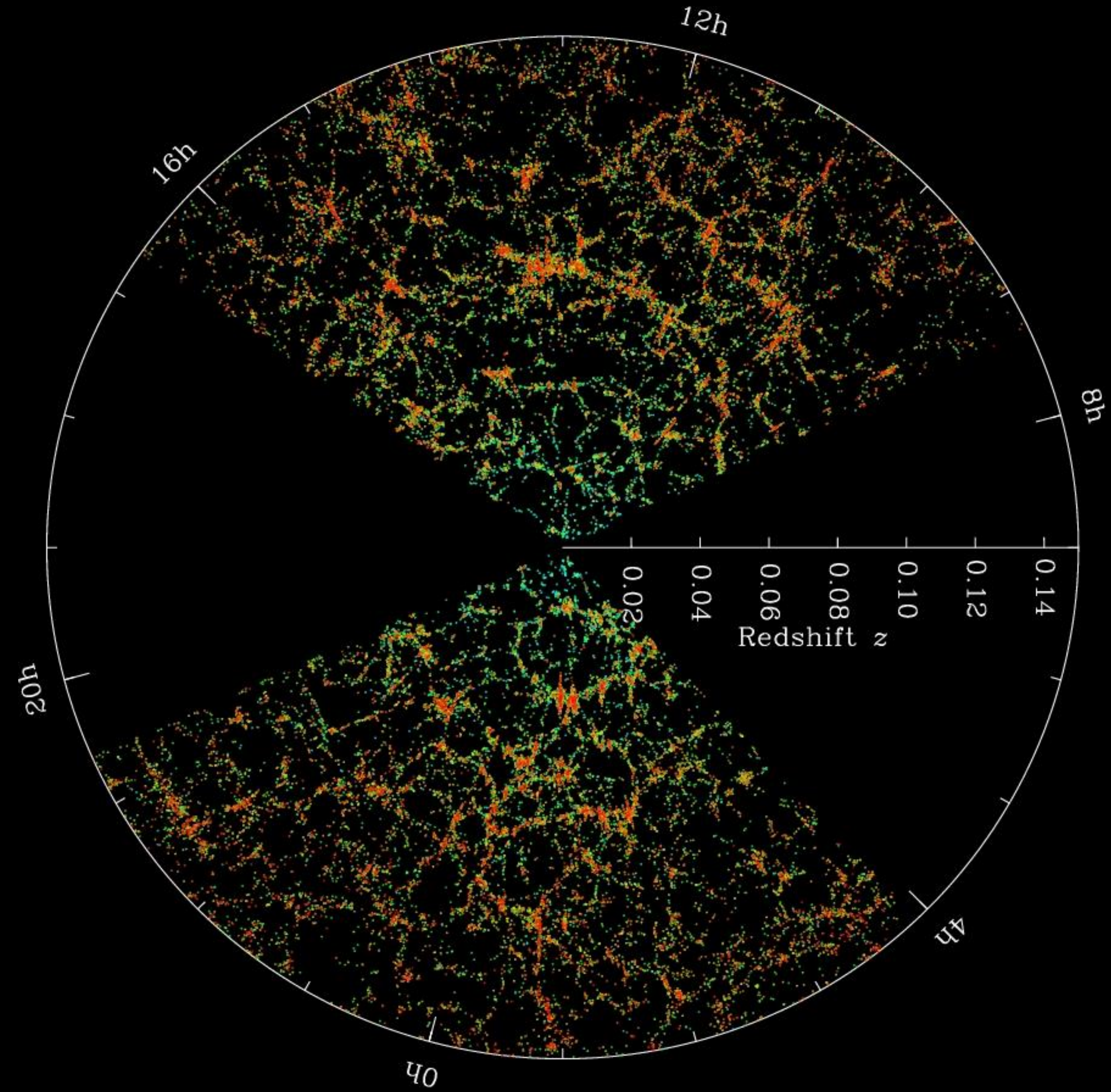
107% Complete Mar 13 2005

➔ 107,000,000 galaxy positions

Spectroscopy (3D galaxy positions)

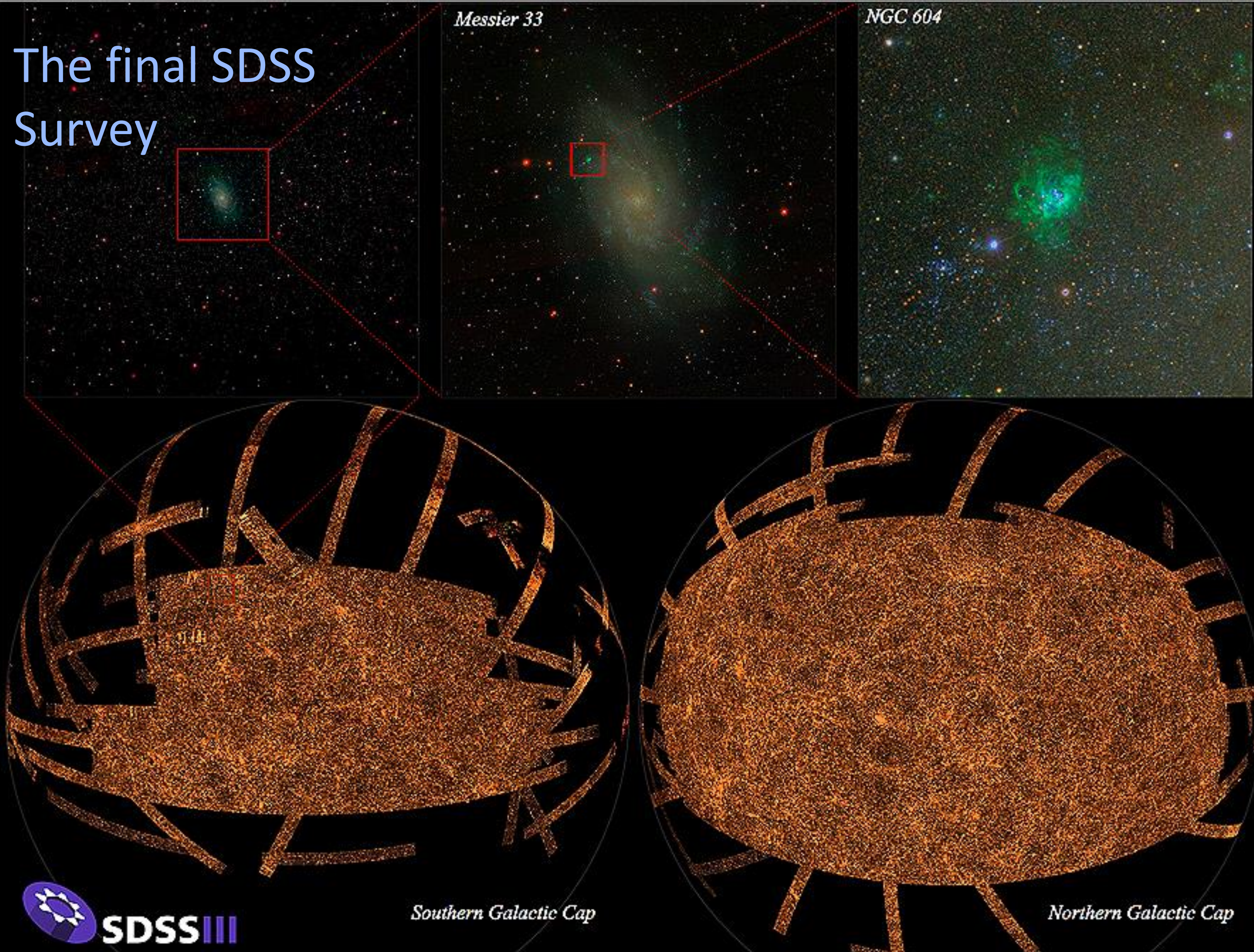
68% Complete Mar 15 2005

➔ 680,000 galaxy positions



Plot of a slice of SDSS galaxies

The final SDSS Survey



SDSS

This is Data Release 16.

Data | Surveys | Instruments | Collaboration | Results | Education | The Future | Contact

Search www.sdss.org | Search

The Future: SDSS-V | Join the Collaboration | Science | MWM | BHM | LVM | Technology

https://www.sdss.org/future/

SDSS-V: Pioneering Panoptic Spectroscopy

Multi-Object Spectroscopy: optical & near-IR, all-sky, multi-epoch

Integral Field Spectroscopy: optical, 2500 deg^2, ultra wide-field

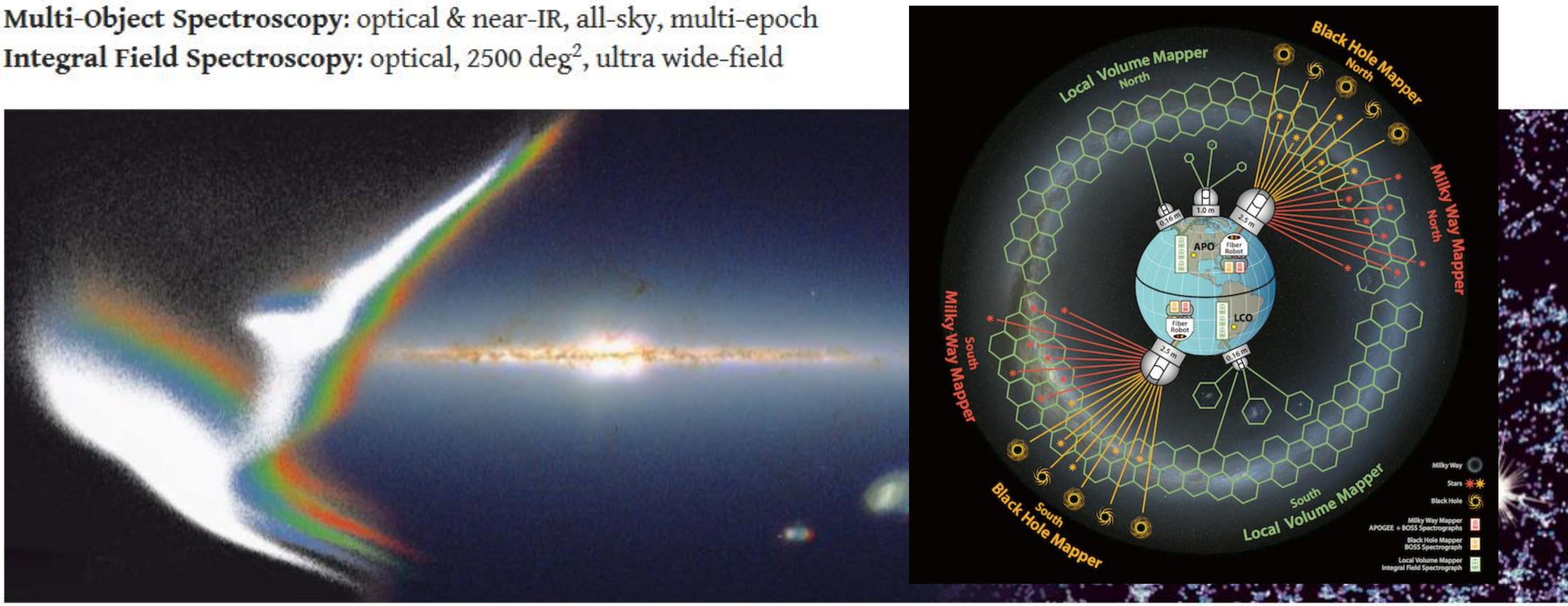
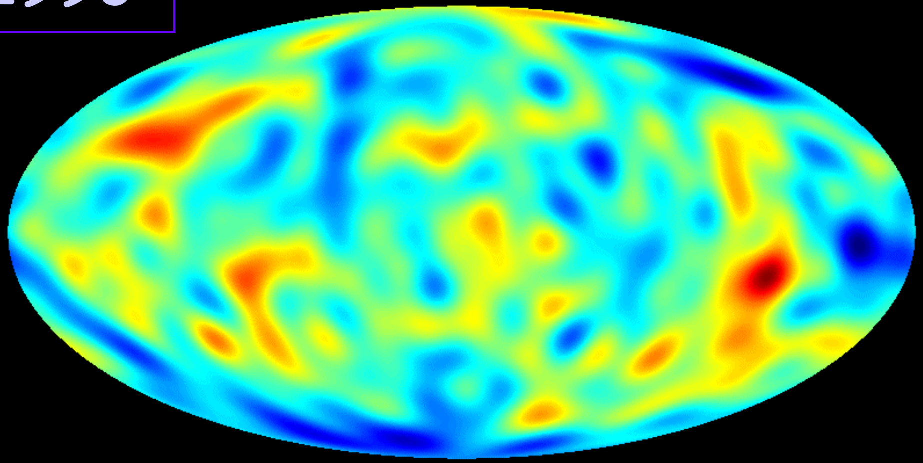


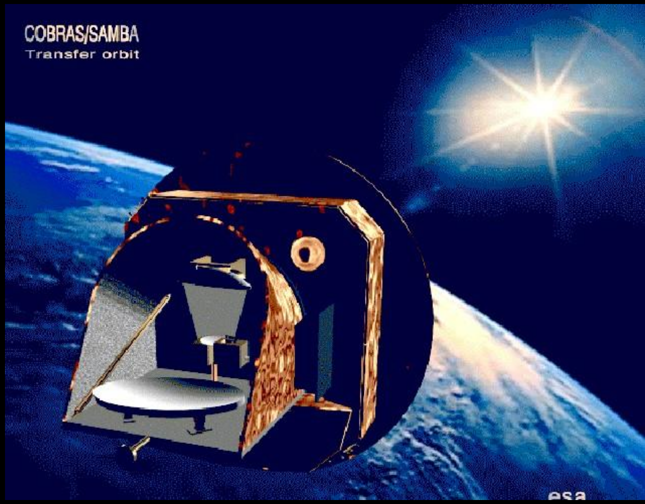
Image Credit: Juna A. Kollmeier and Hans-Walter Rix http://sdss.org

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

1993

Real

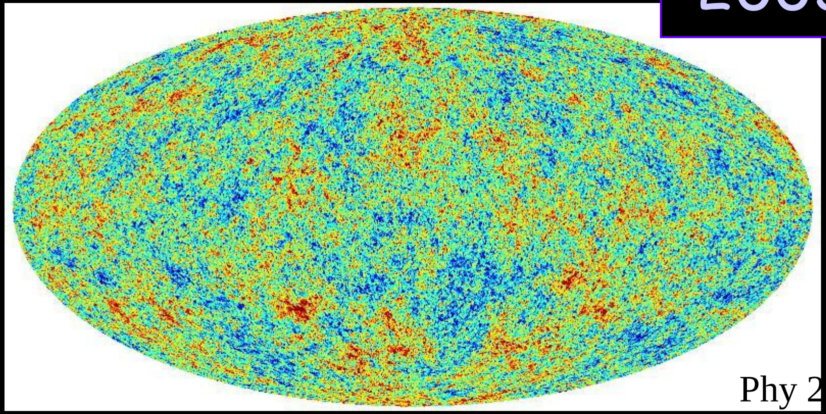


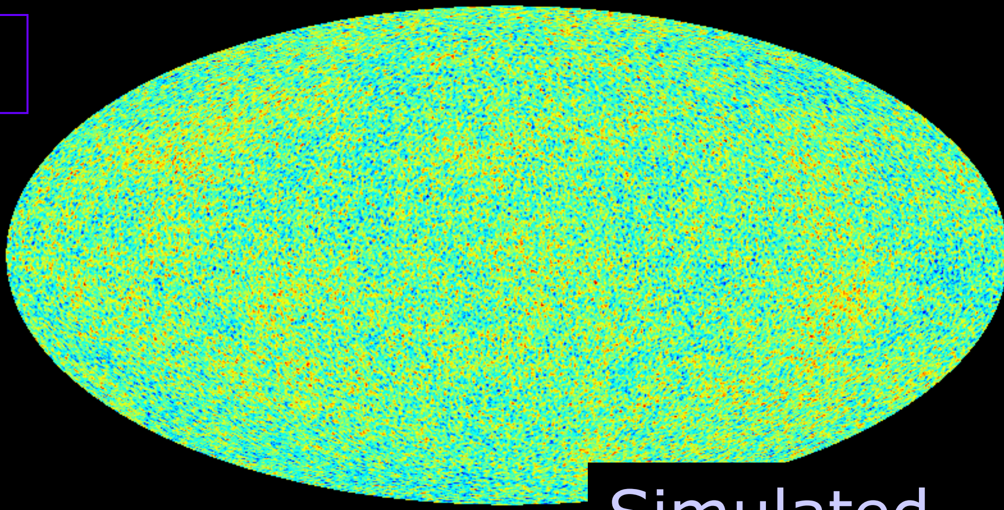


2009

Simulated

2003



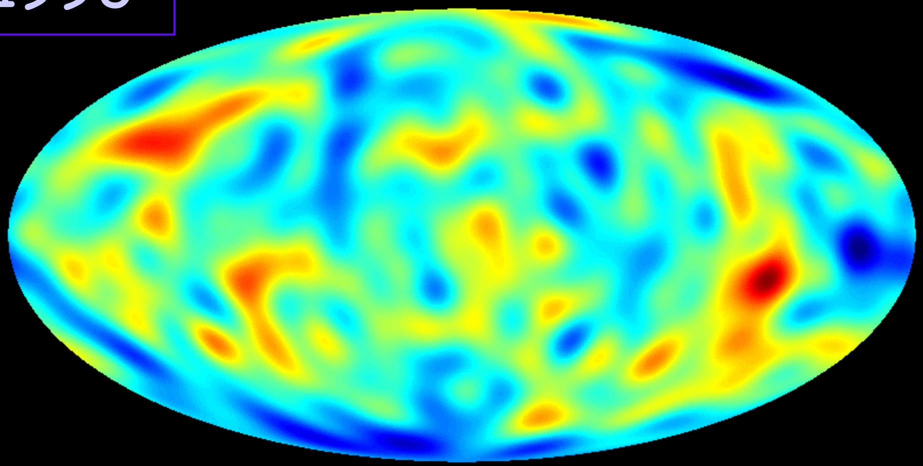


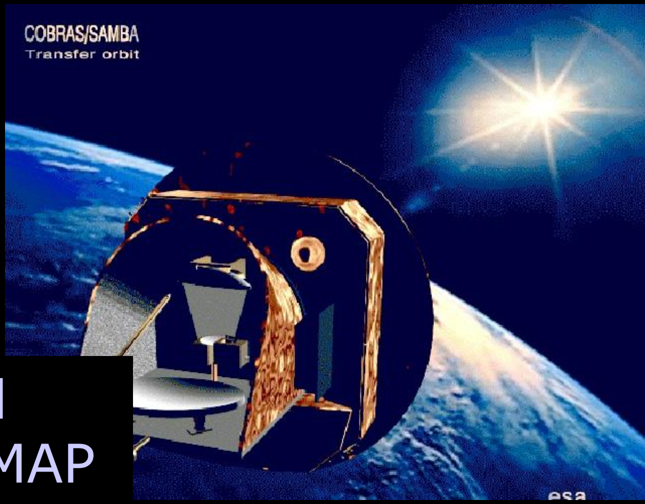
Simulated

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

1993

Real



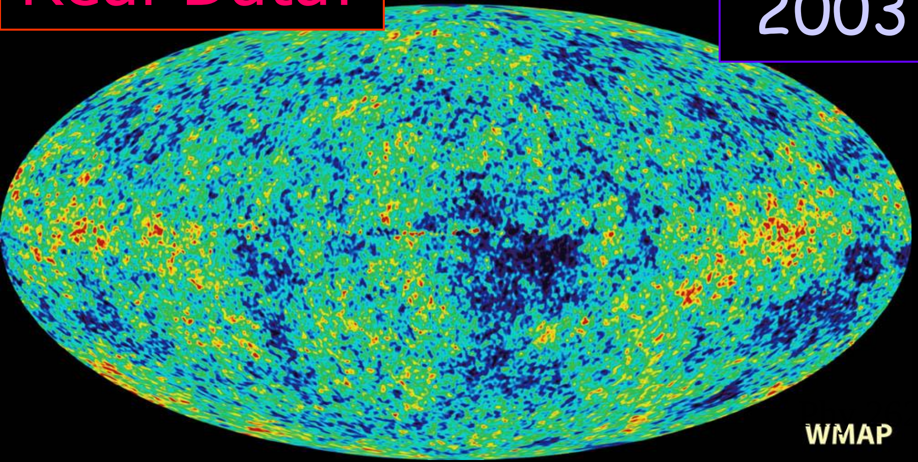


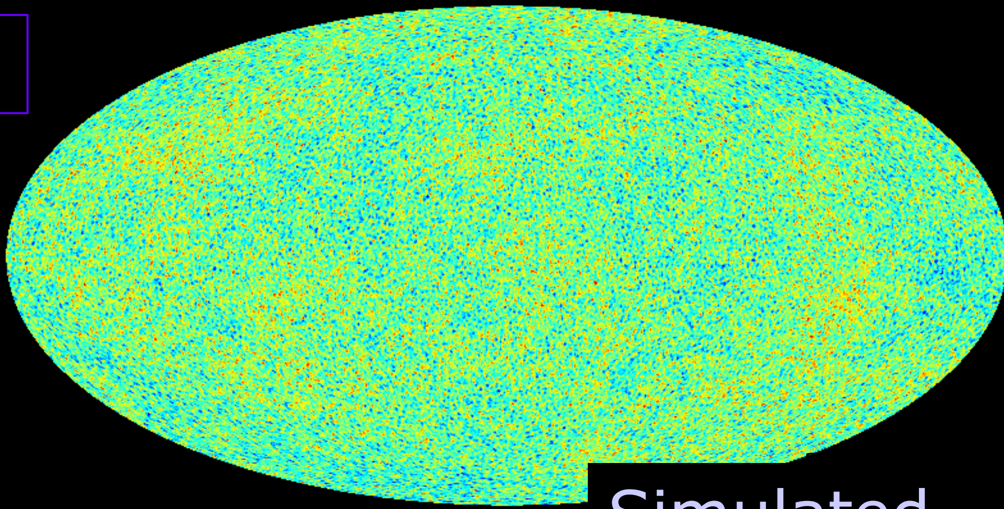
Updated after WMAP announcement, Feb 2003

2009

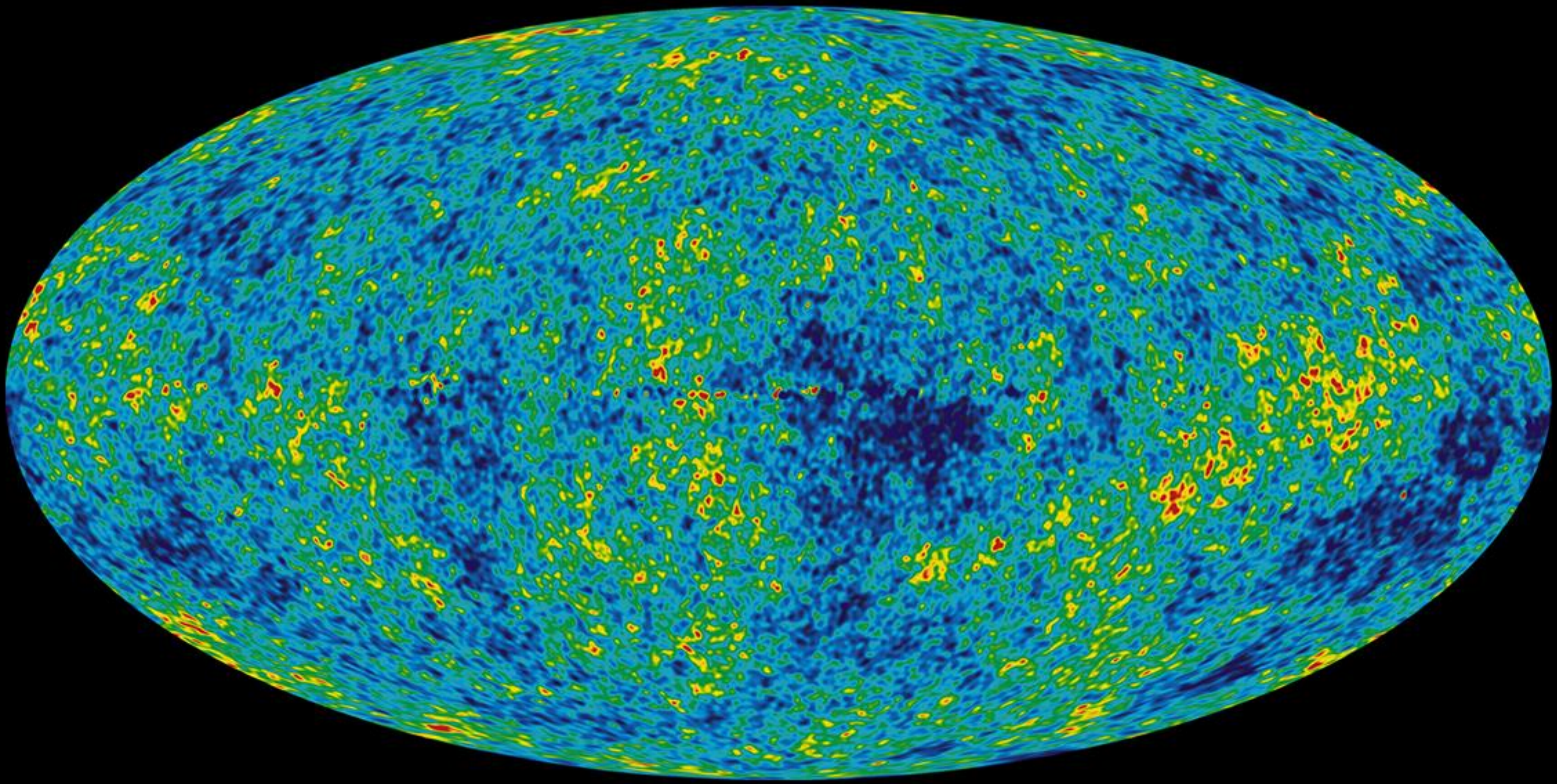
Real Data!

2003

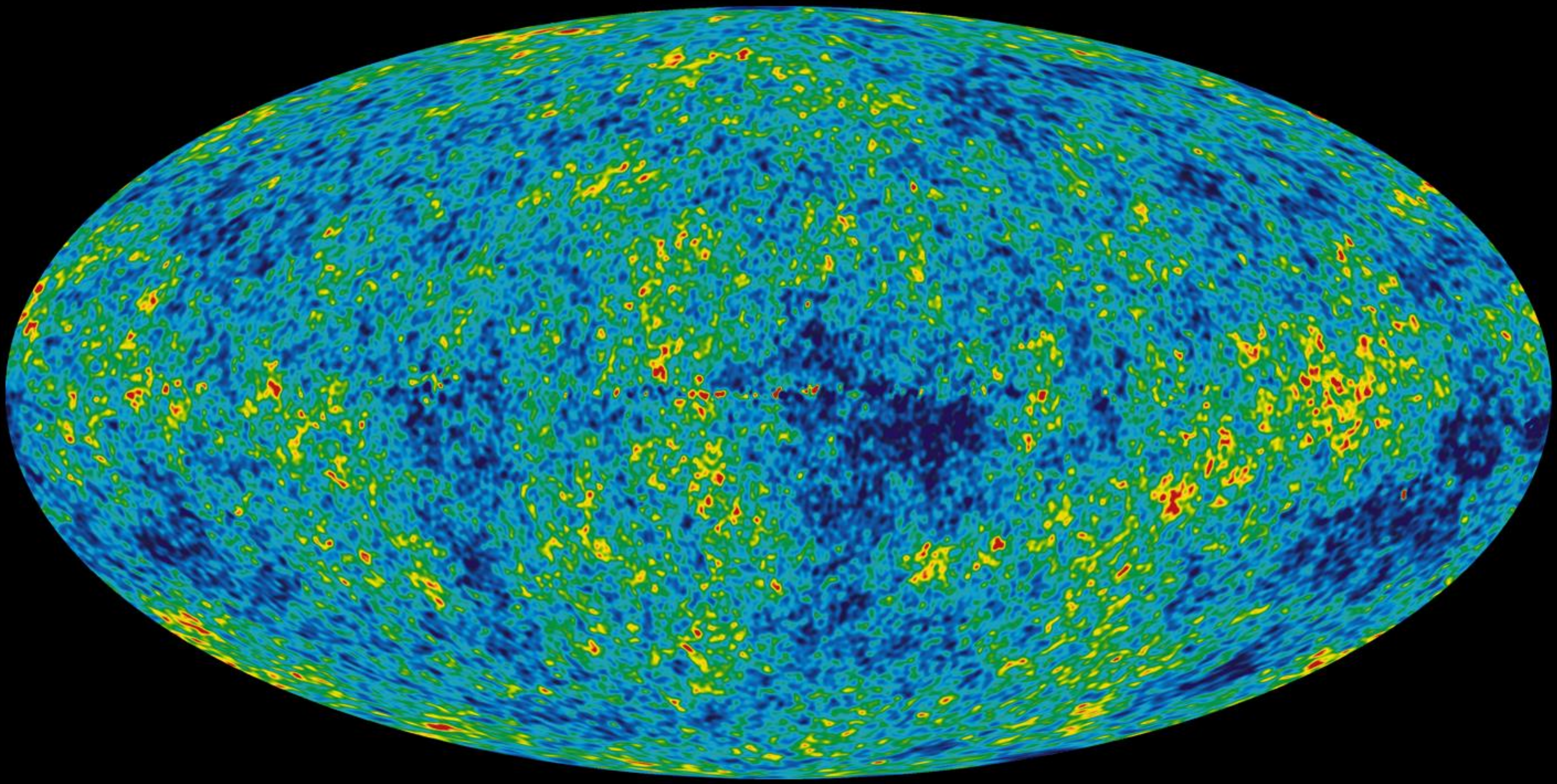




Simulated



WMAP 3-yr map

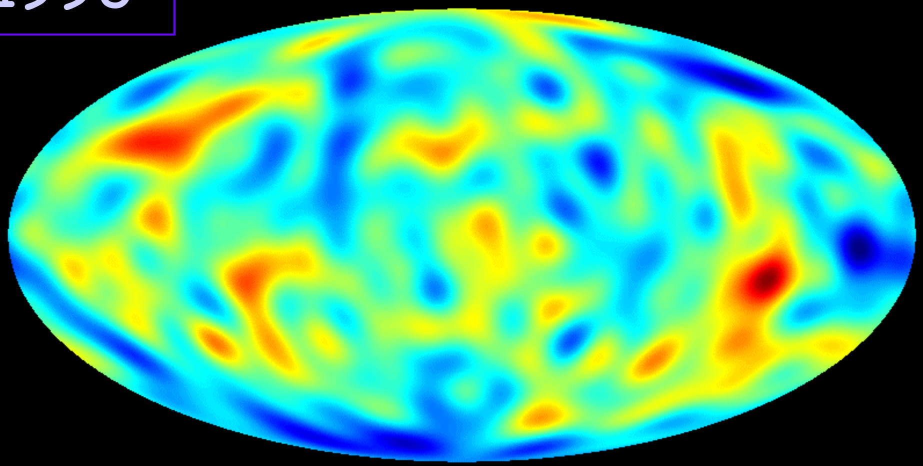


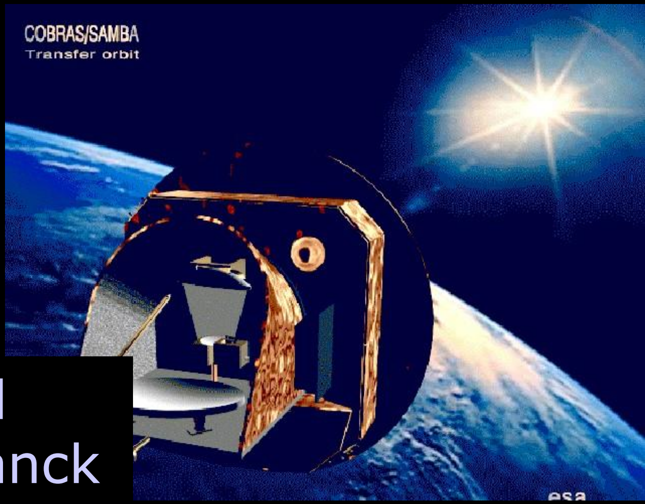
WMAP 5-yr map

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

1993

Real



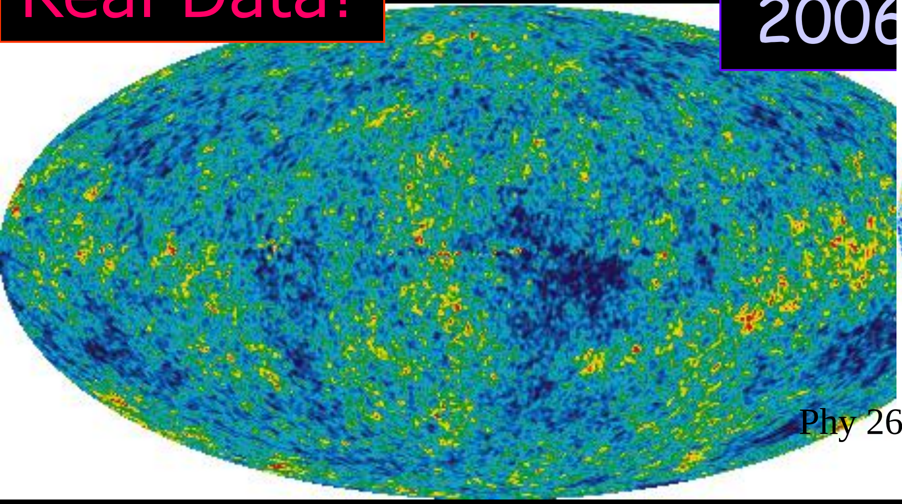


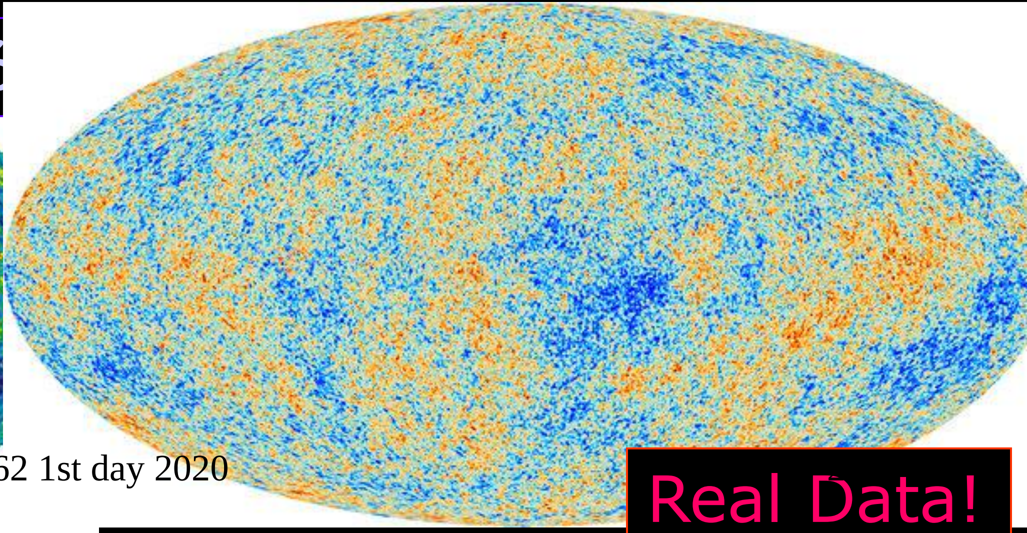
Updated after Planck announcem ent, 2013

2013

Real Data!

2006





Real Data!

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

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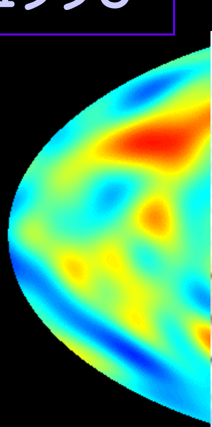
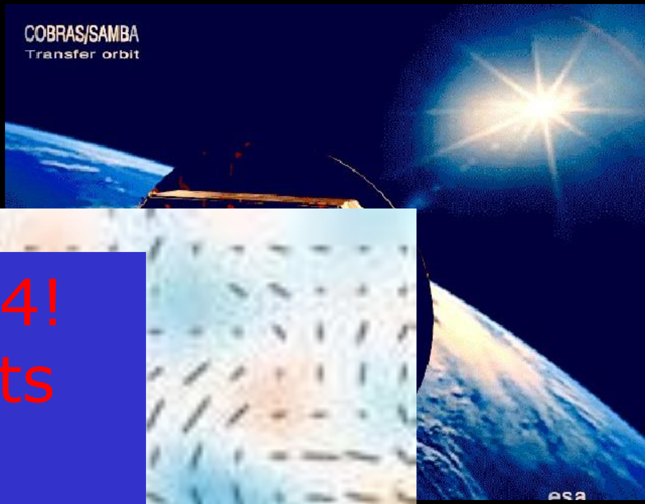
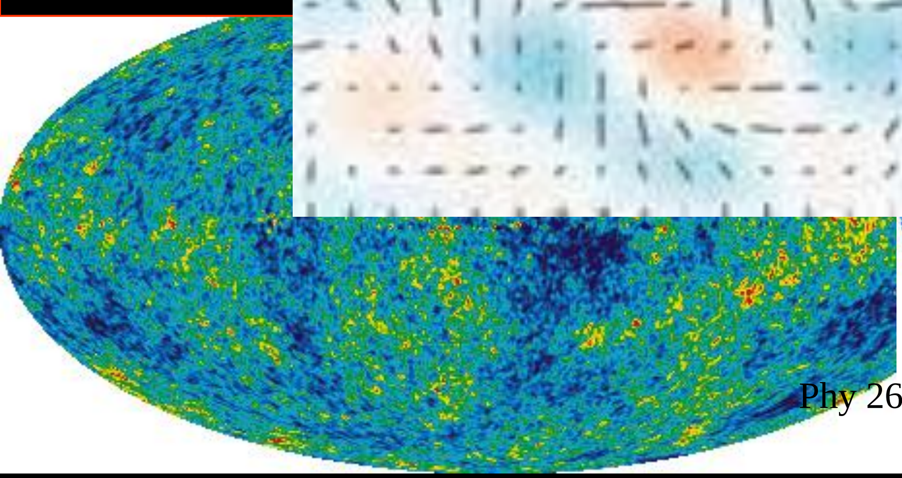


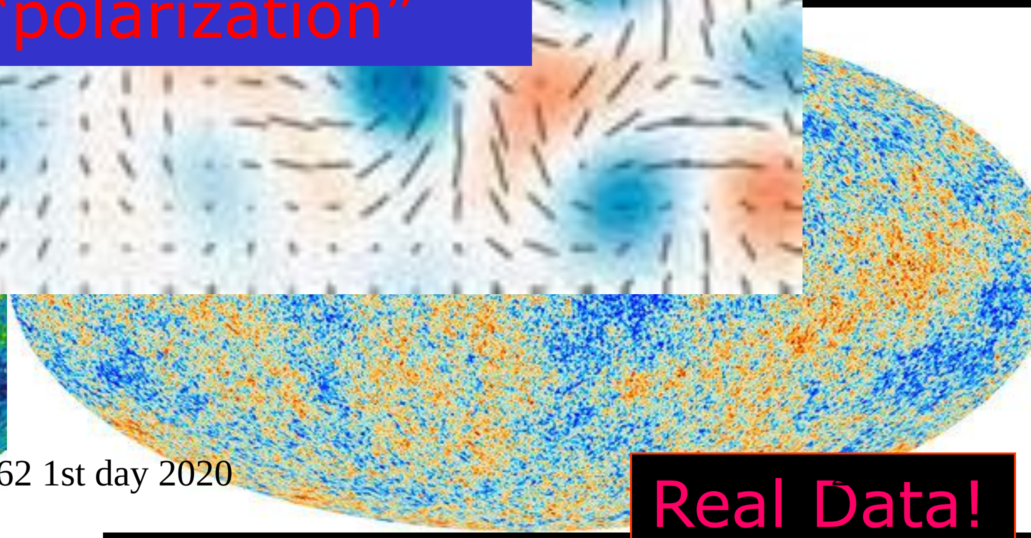


March 17 2014!
BICEP2 reports signal from primordial gravitation waves in microwave "polarization"

013

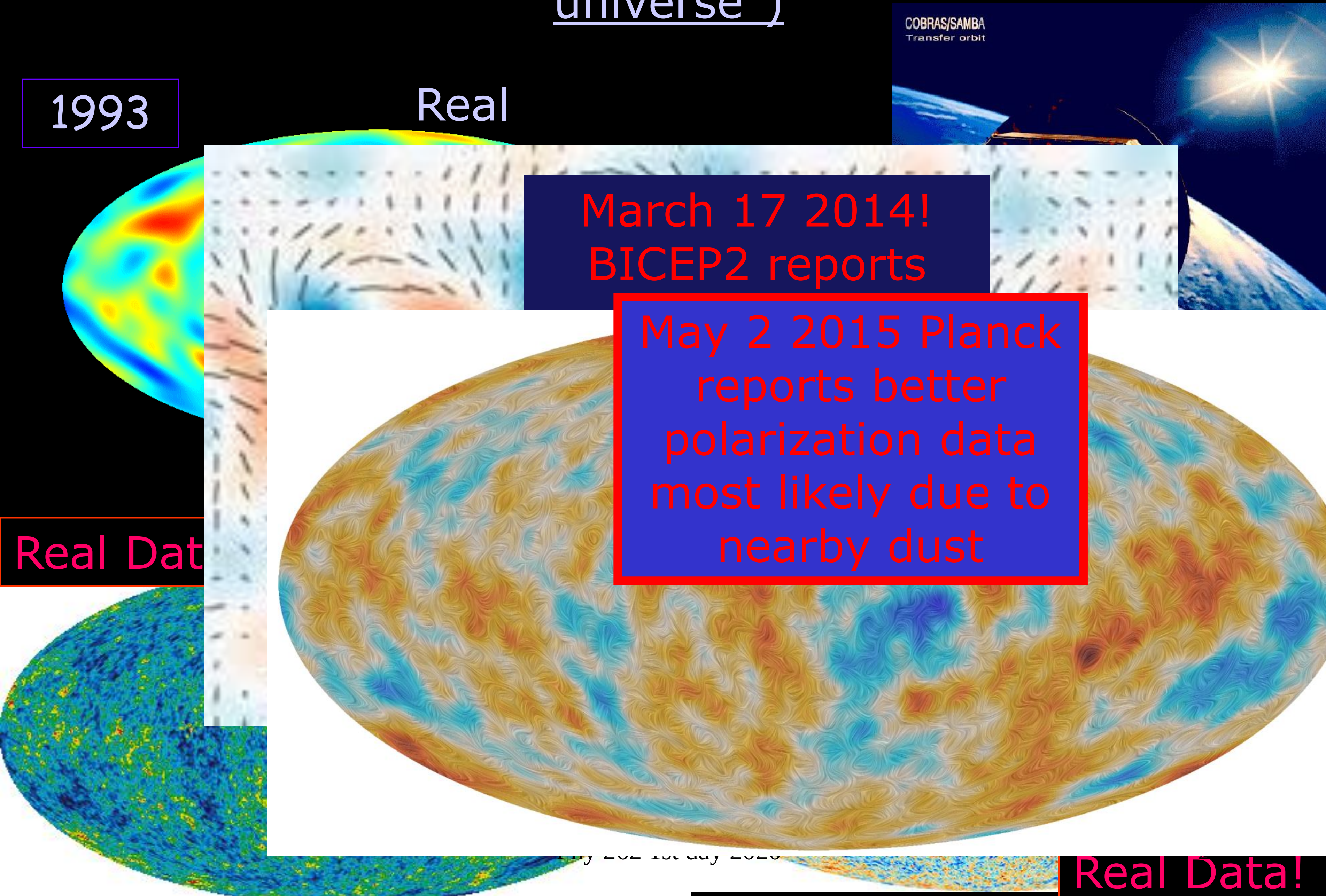
Real Dat





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

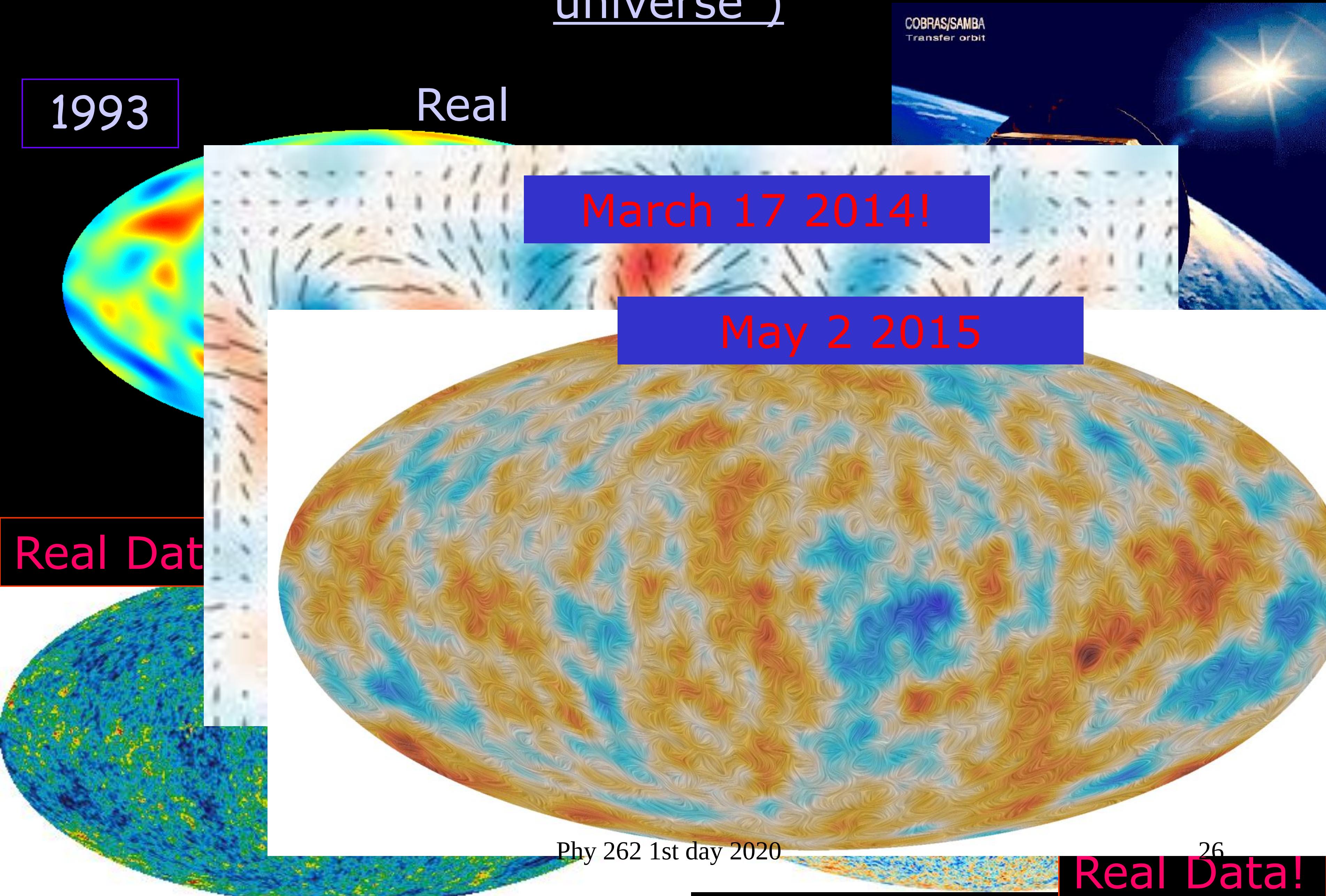
Real Dat

Real Data!

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

1993

Real



March 17 2014!

May 2 2015

Real Dat

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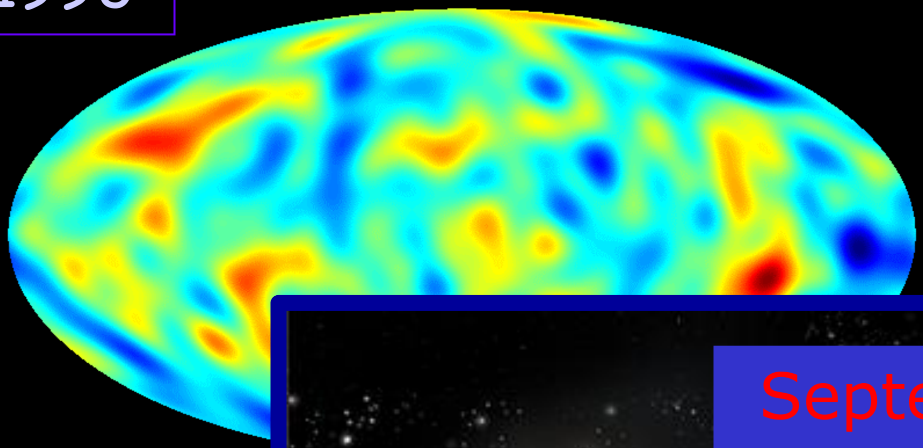
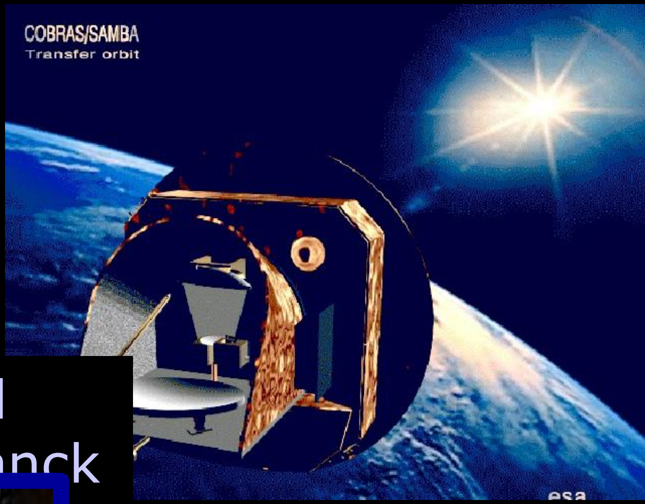


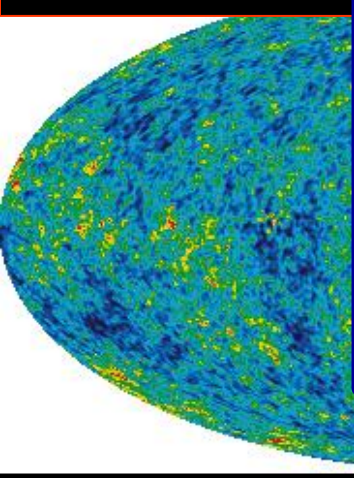


Updated
after Planck

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

2013

Real Data!



Real Data!

Links related to previous slides

http://www.esa.int/esaSC/120398_index_0_m.html

http://www.rssd.esa.int/index.php?project=planck

http://bicepkeck.org/

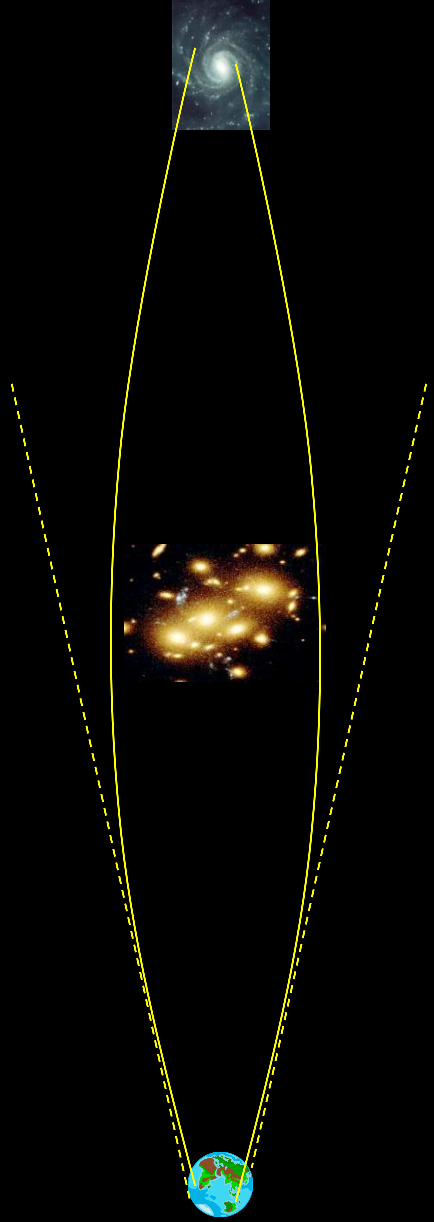
http://www.esa.int/spaceinimages/Images/2015/02/Polarisation_of_the_Cosmic_Microwave_Background

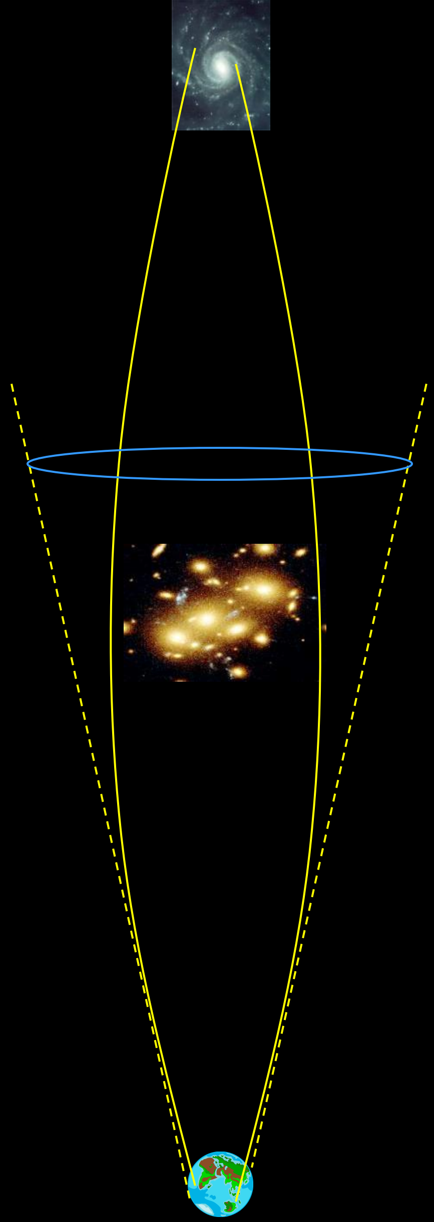
http://www.esa.int/esaSC/120398_index_0_m.html

http://www.rssd.esa.int/index.php?project=planck

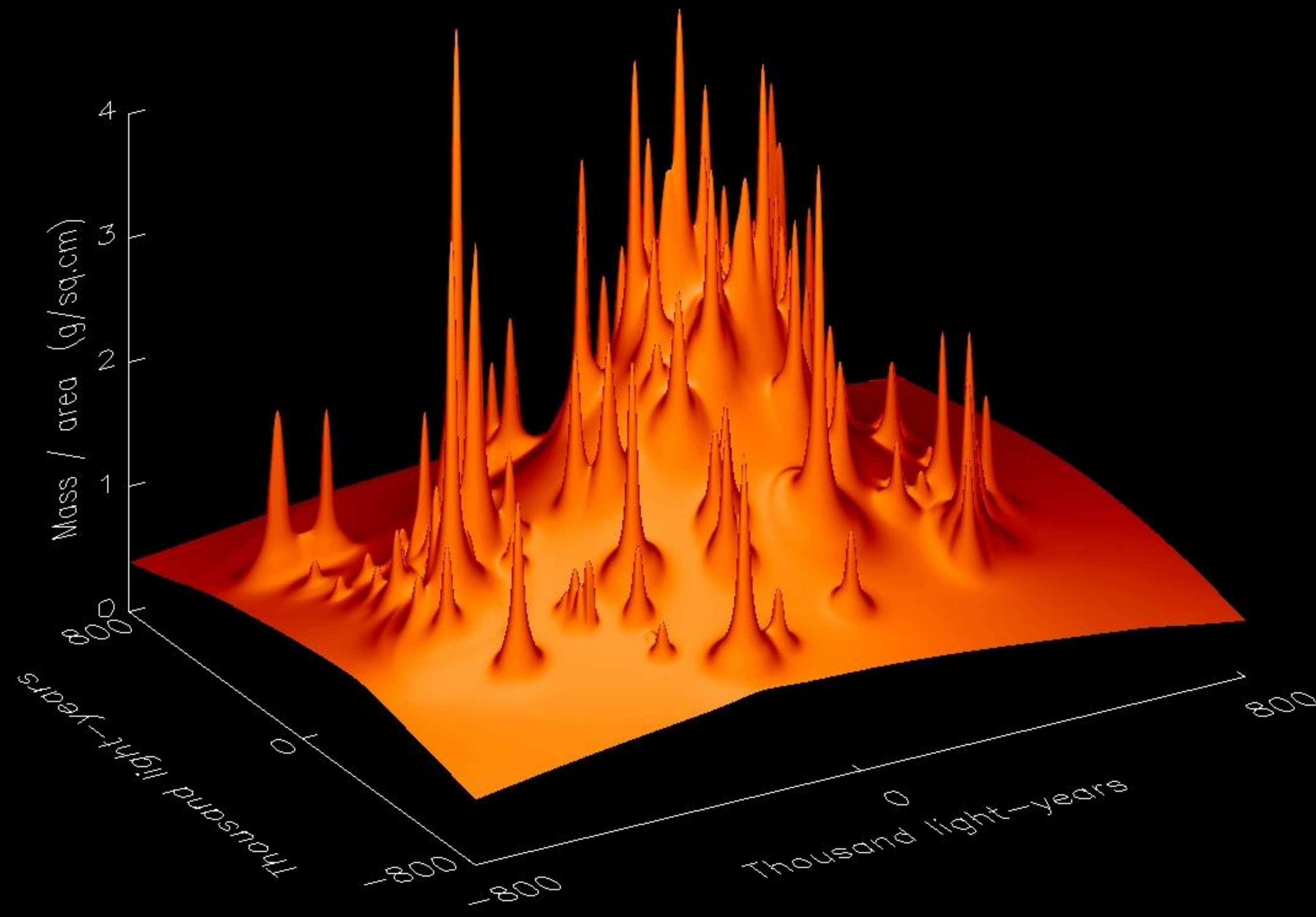
http://albrecht.ucdavis.edu/special-topics/bicep2-story

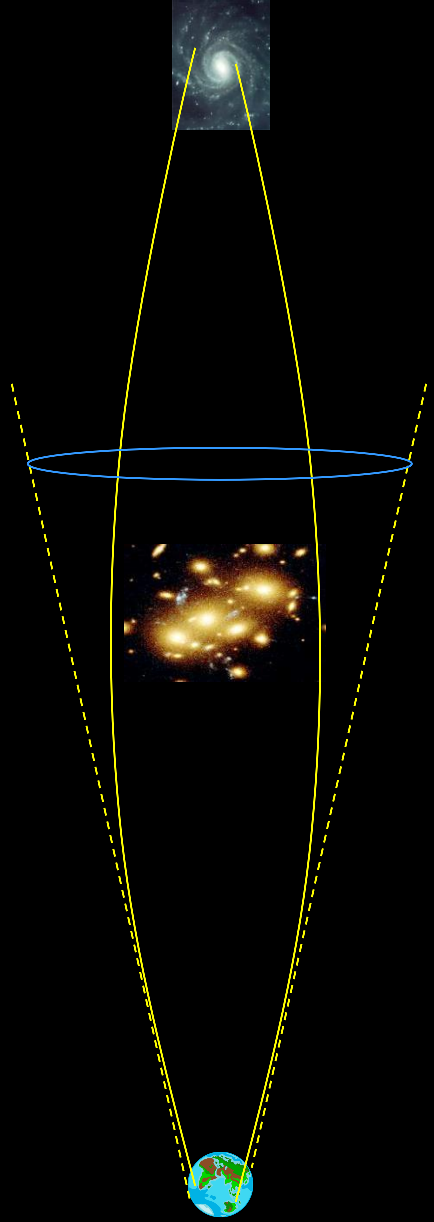
https://www.ligo.caltech.edu/news



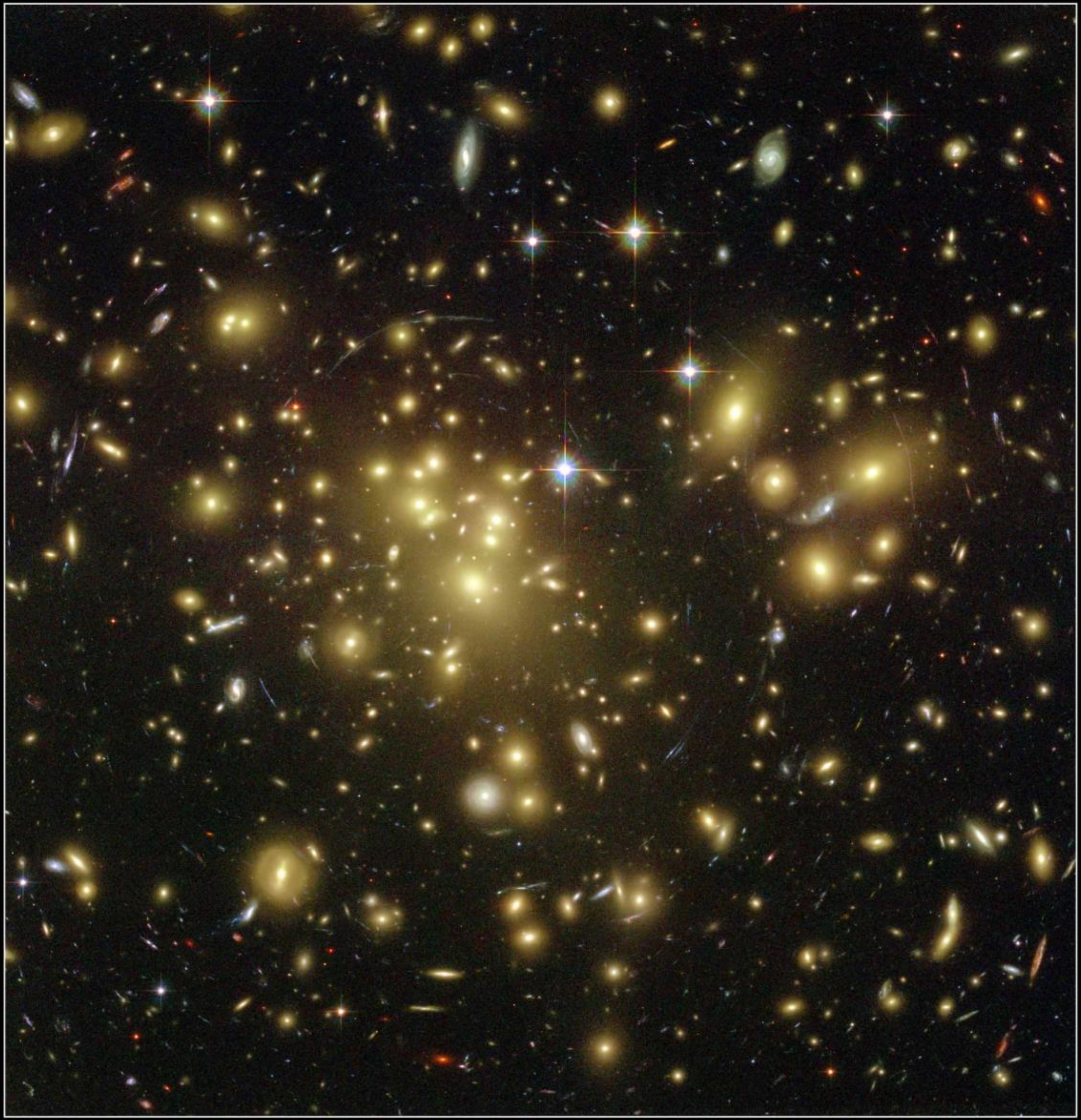


Mass inferred from lensing:
Must have dark matter





1996



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

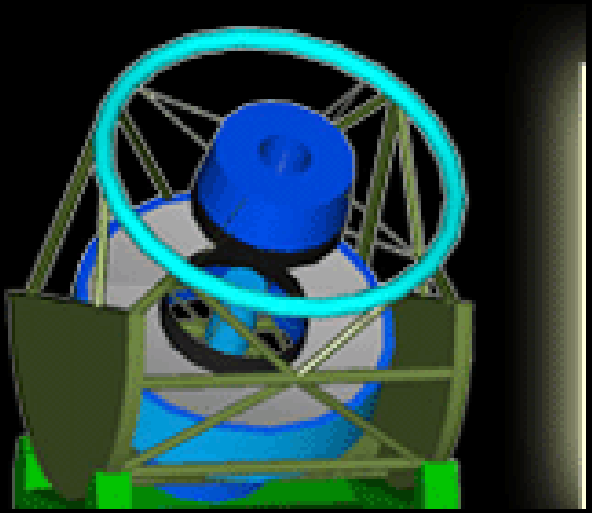
NASA, N. Benitez (JHU), T. Broadhurst (The Hebrew University), H. Ford (JHU), M. Clampin(STScI), G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory), the ACS Science Team and ESA
STScI-PRC03-01a

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

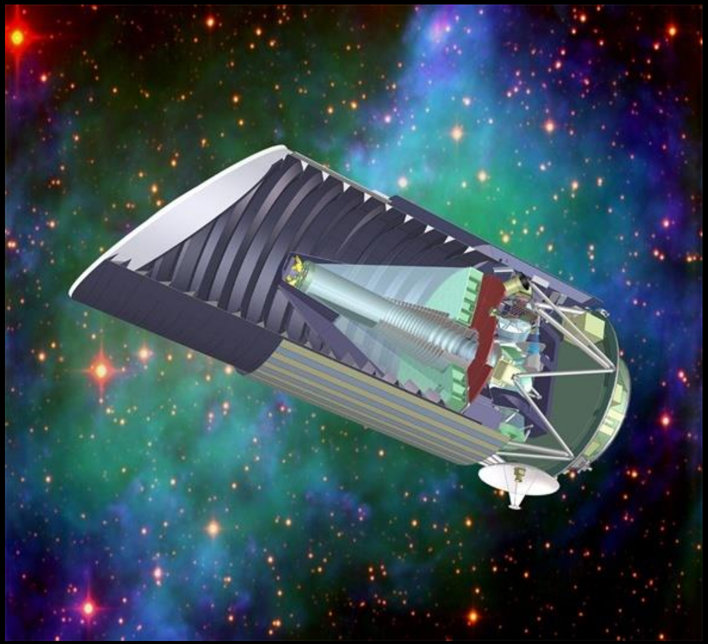
http://hubblesite.org/

http://www.nasa.gov/mission_pages/hubble/main/index.html

Some Future Plans



LSST (Large-aperture Synoptic Survey Telescope)

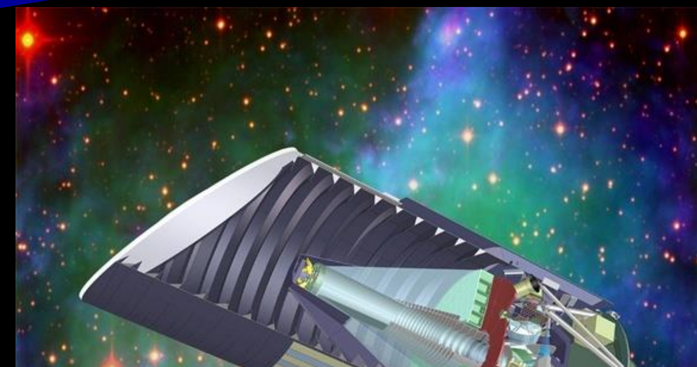


WFIRST

James Webb Space Telescope

Some Fut

New facilities being built



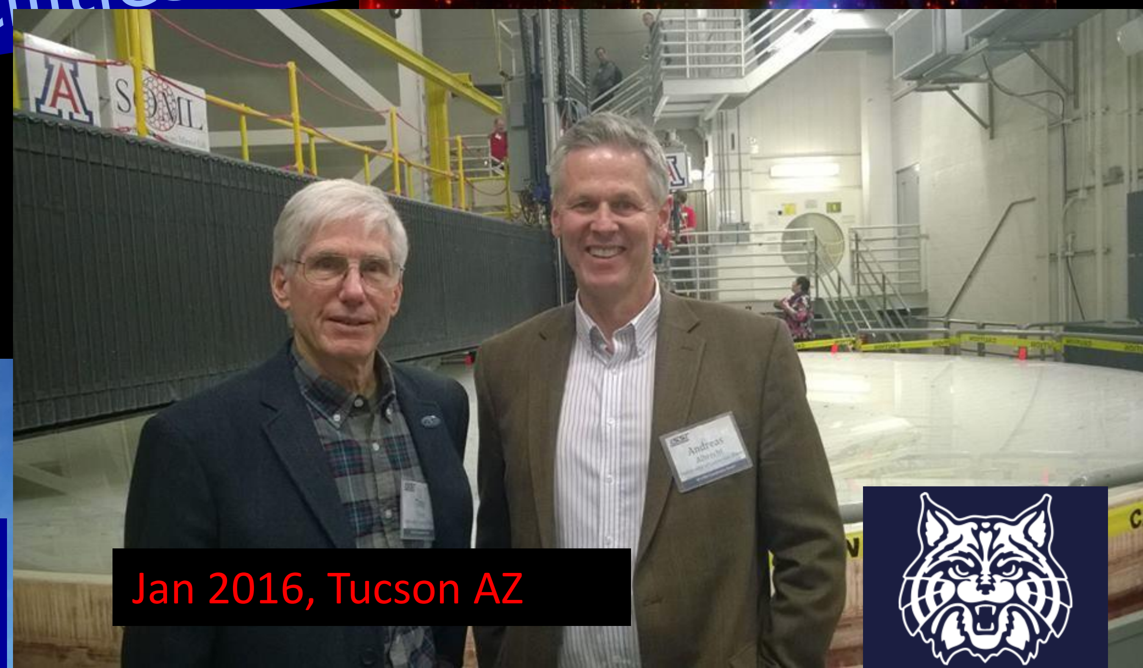
LSST (Large-aperture Synoptic Survey Telescope)

2018

Some Fut

New facilities being built

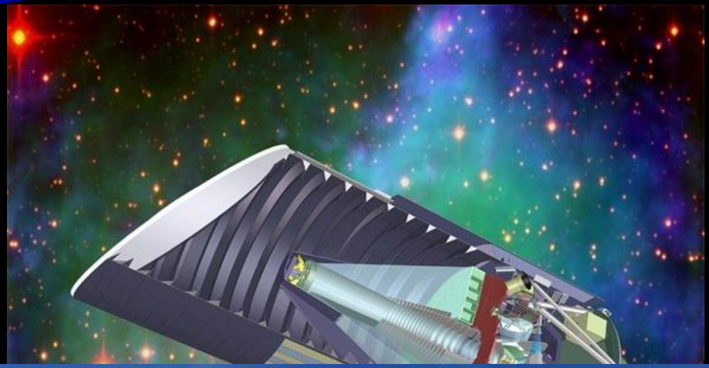
LSST (Large-aperture Synoptic Survey Telescope)



Jan 2016, Tucson AZ

Some Fut

New facilities being built

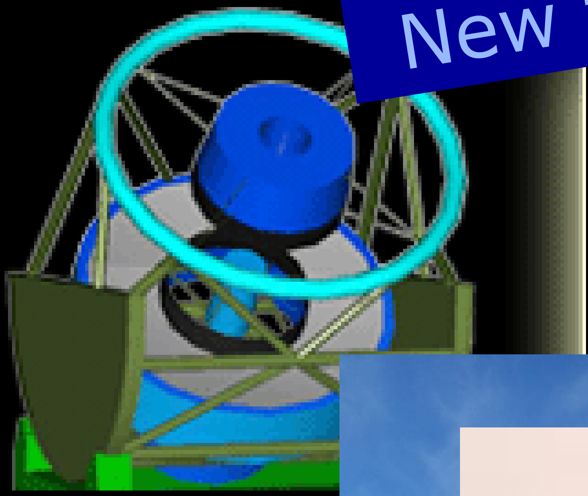


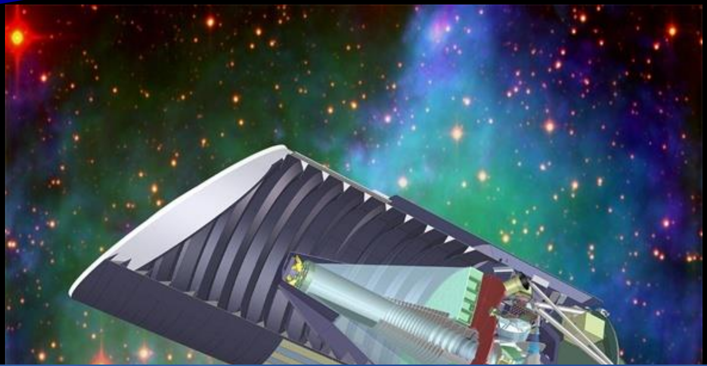
LSST (Large-
aperture Sync
Survey Telesc

2019

Some Futu

New facilities being built





LSST (Large-aperture Syno… Su…

Monday, January 6, 2020

It was announced today that the upcoming Large Synoptic Survey Telescope (LSST), which will conduct a vast astronomical survey for unprecedented discovery of the deep and dynamic Universe, will now be named the NSF (National Science Foundation) Vera C. Rubin Observatory (Rubin Observatory or VRO). The announcement was made today by Ralph Gaume, Director of the NSF Division of Astronomical Sciences; Kathy Turner, DOE (Department of Energy) Office of High … program manager; and Steve Kahn, LSST Director during the LSST … the 235th American Astronomical Society meeting in Honolulu, Hawai'i, USA. The construction and operations of the Rubin Observatory and the DOE LSST Camera is a U.S. federal partnership of the NSF and DOE, with private

Vera Rubin operated the 2.1-meter telescope at Kitt Peak National Observatory, Kent Ford's spectrograph is attached. Image credit:

2020

WIDE FIELD INFRARED SURVEY TELESCOPE
GODDARD SPACE FLIGHT CENTER

Scheduled to launch in the mid-2020s

James Webb Space Telescope on Track for March 2021 Launch, NASA Says

Despite numerous setbacks, the $9.7-billion observatory is still on schedule to revolutionize our view of the universe

By Meghan Bartels, SPACE.com on January 7, 2020

The James Webb Space Telescope, seen here fully assembled in a clean room, is set to launch in March 2021. Credit: Chris Gunn *NASA*

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December 9, 2019

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9 hours ago — Thomas Frank and E&E News

SPACE

NASA's TESS Planet Hunter Finds Its First Earth-Size World in "Habitable Zone"

https://www.lsst.org/

http://jwst.nasa.gov/index.html

http://wfirst.gsfc.nasa.gov/

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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   - Cosmic Inflation
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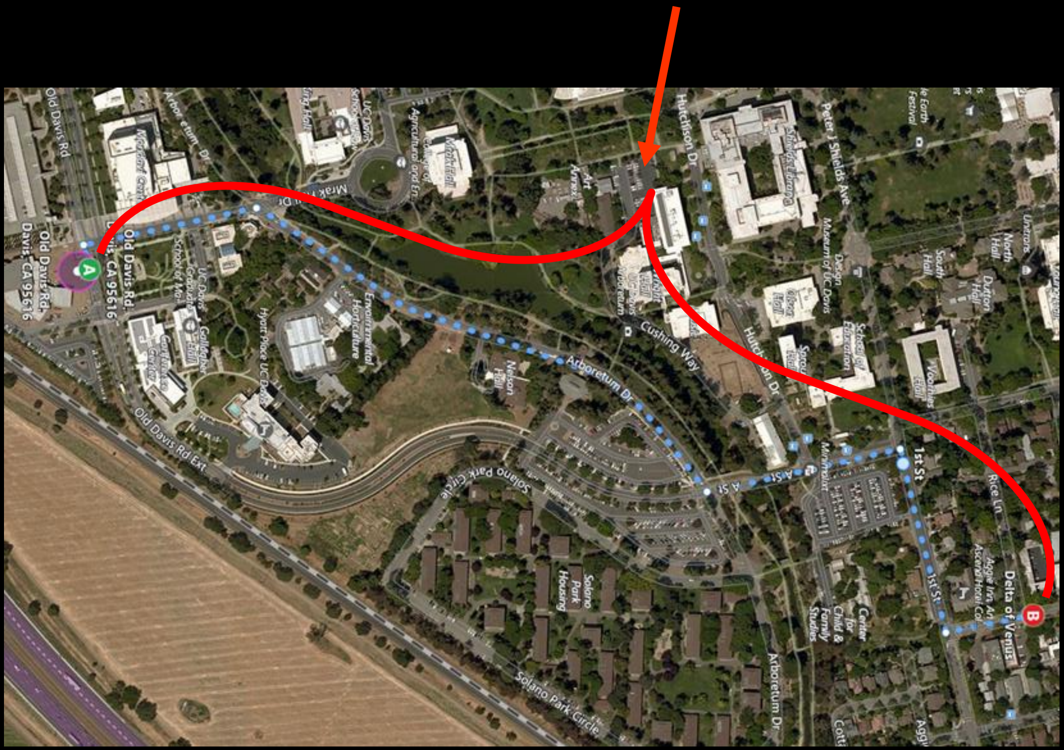
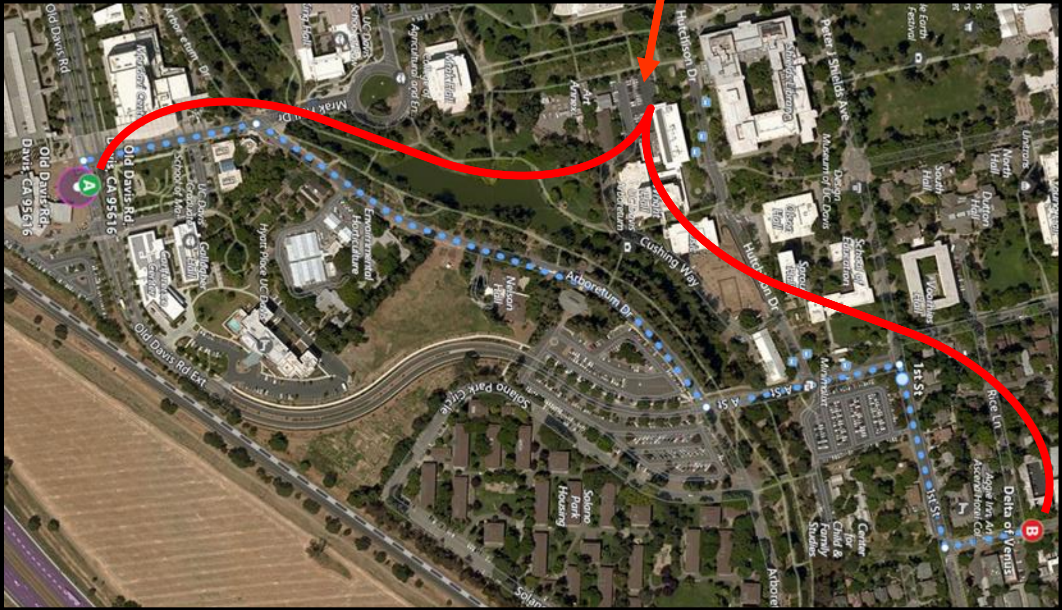
Distances in the Universe

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



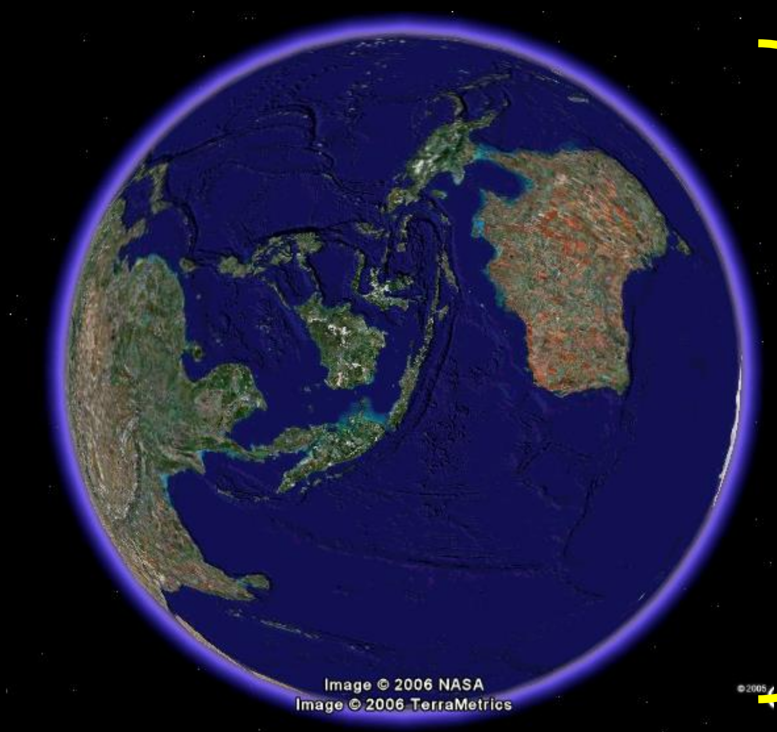
Measure of distance: One Kilometer ≈ Walk from the *Manetti Shrem* to *Delta of Venus*



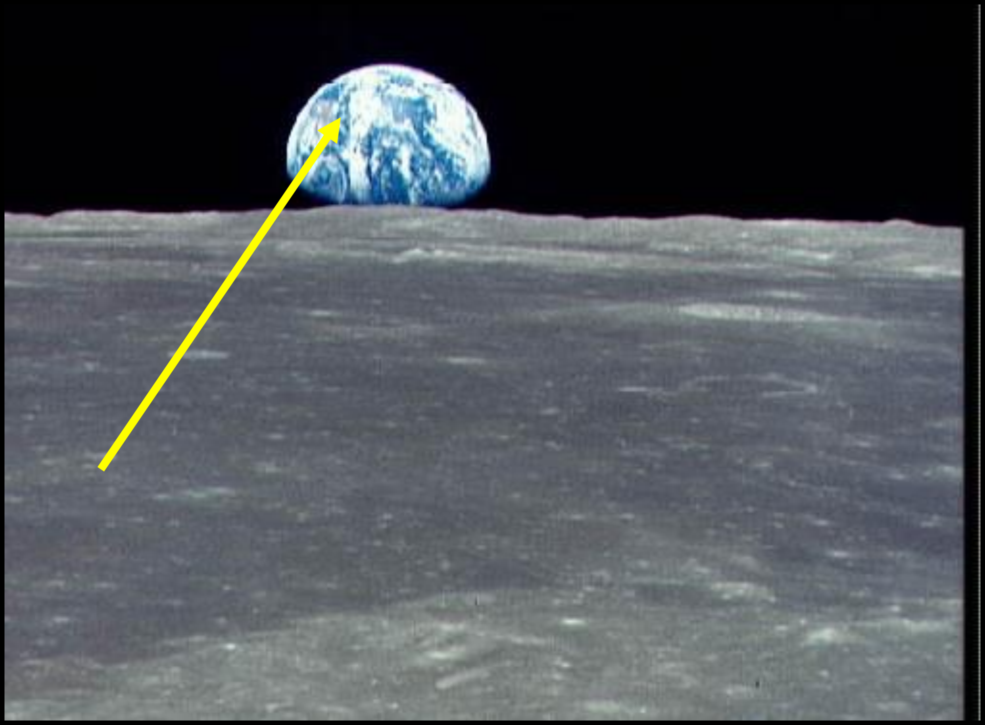
Count cosmic distances as grains of sand: One grain of sand per kilometer.

Grain of sand (enlarged)

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

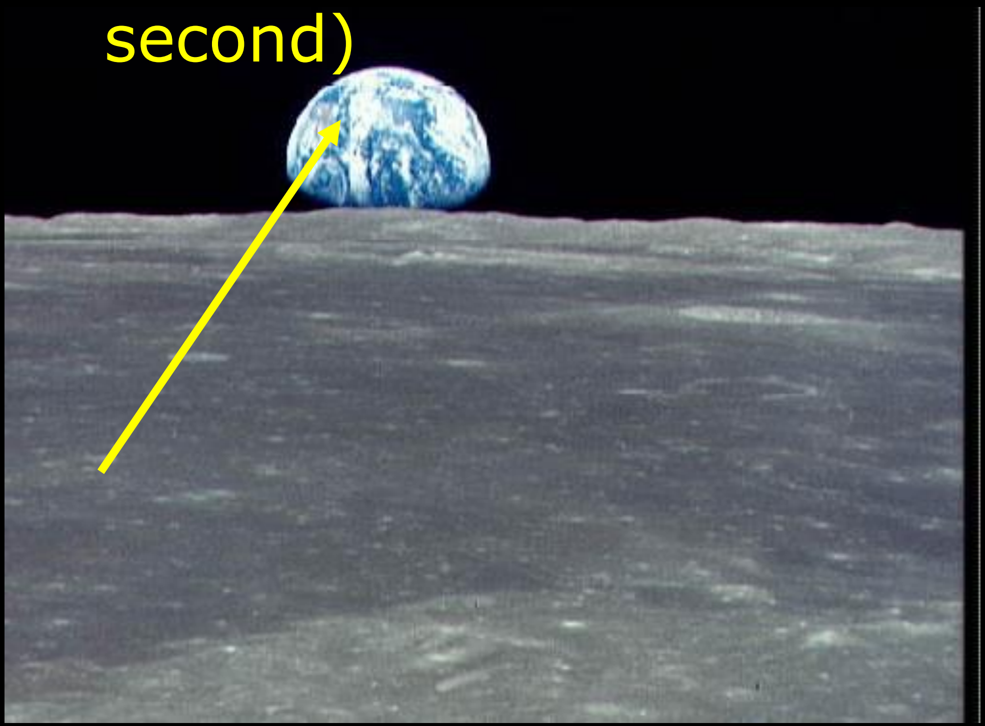


Distance to Moon = 356,410 kilometers ←→
1 Handful of sand

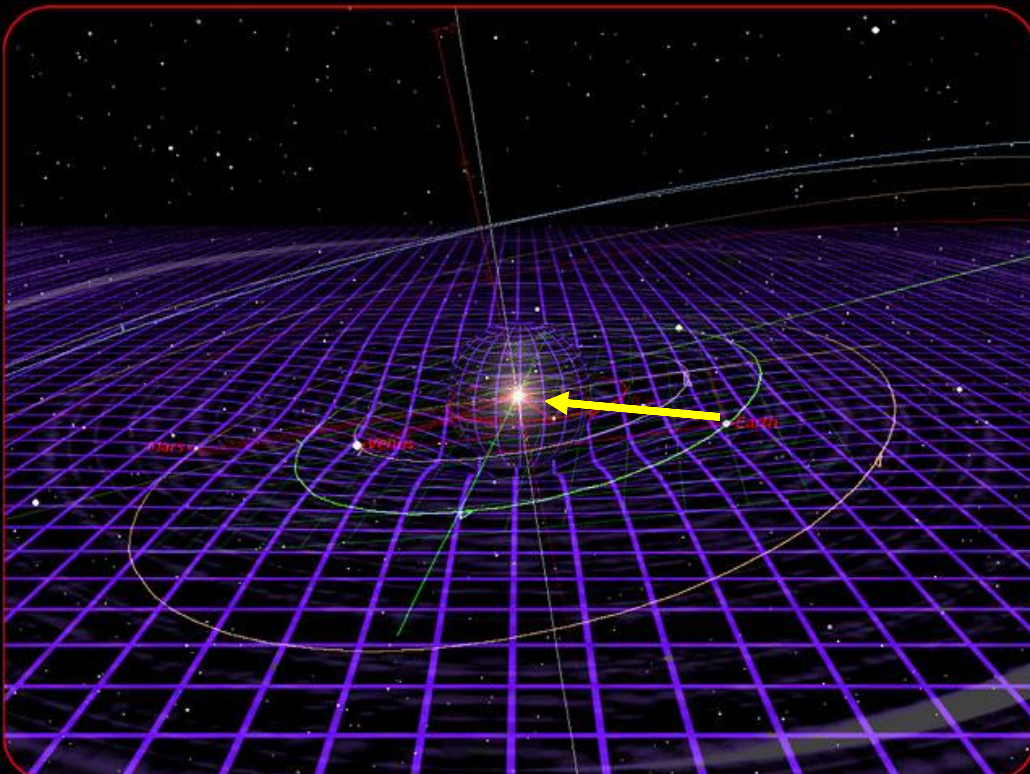


Distance to Moon = 356,410 kilometers ←→
1 Handful of sand

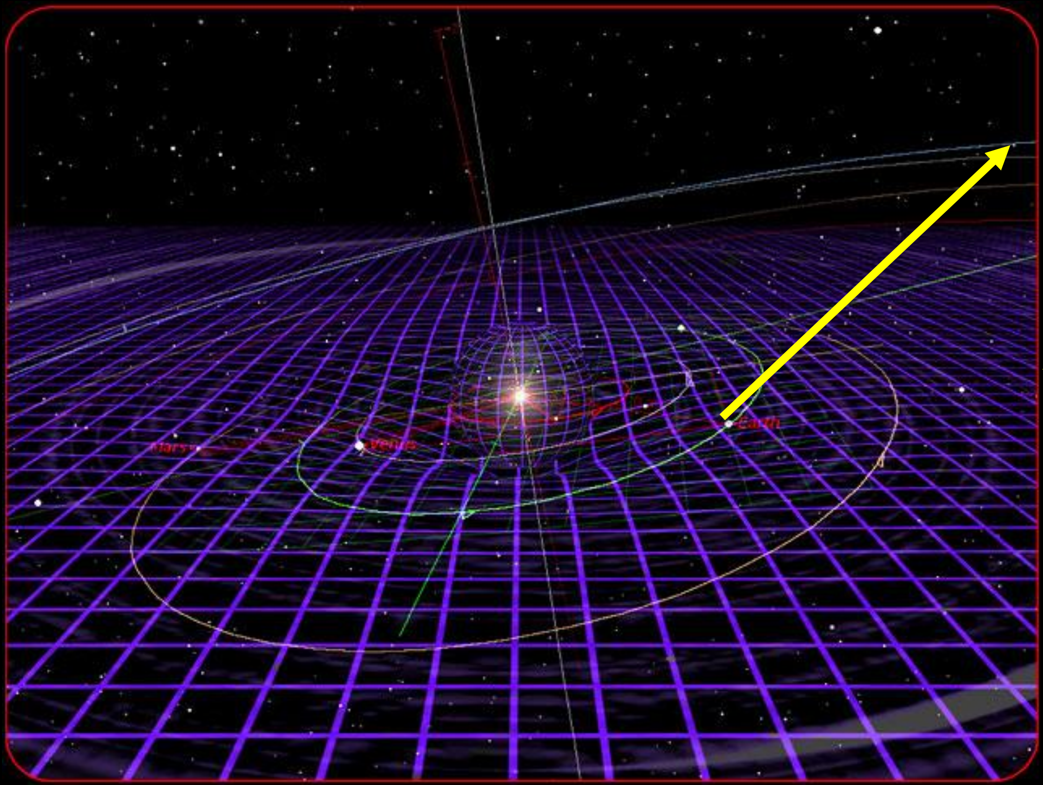
(Also roughly the distance light travels in one second)



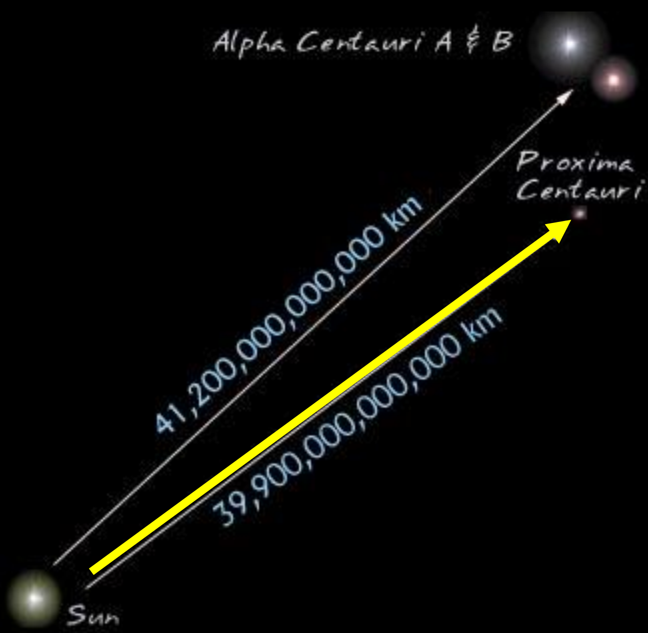
Distance from Earth to Sun = 149,600,000 kilometers (8 light minutes) ←→ 1 Milkshake cup of sand



Distance from Earth to Pluto = 6,000,000,000 kilometers ←→ 1 wheelbarrow of sand



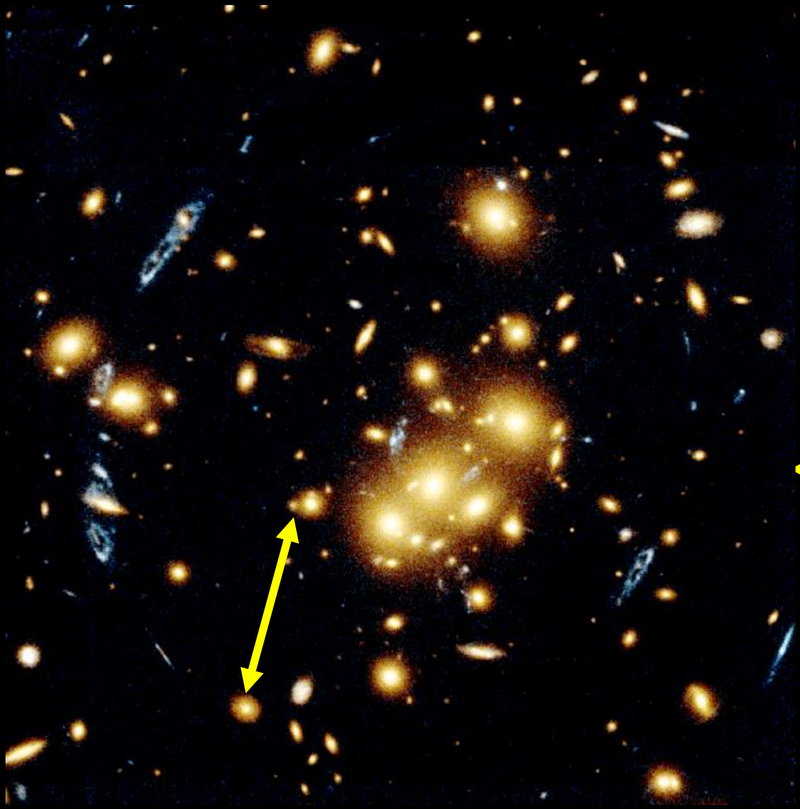
Distance from Earth to Nearest Star = 40,000,000,000,000 kilometers ←→ 1 dumpster of sand



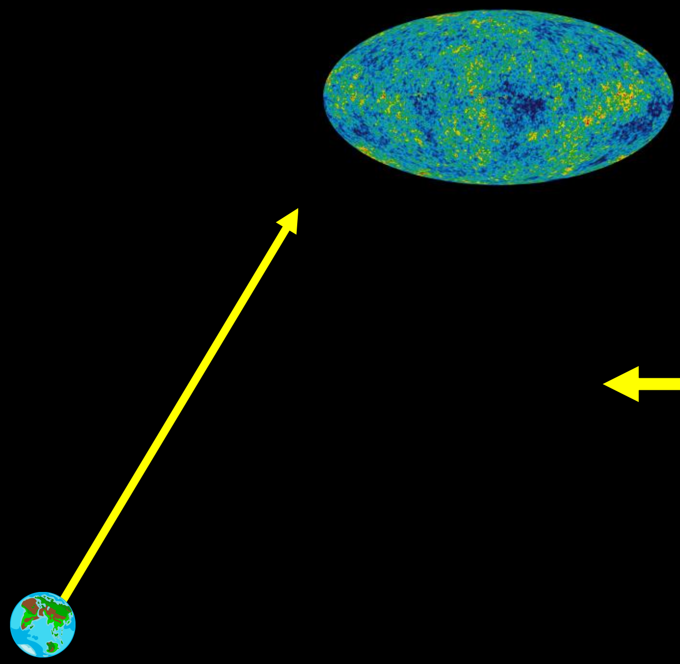
Distance from Earth to Edge of our galaxy = 1,000,000,000,000,000,000 kilometers ←→ 1 Physics/Geology Bulidng full of sand

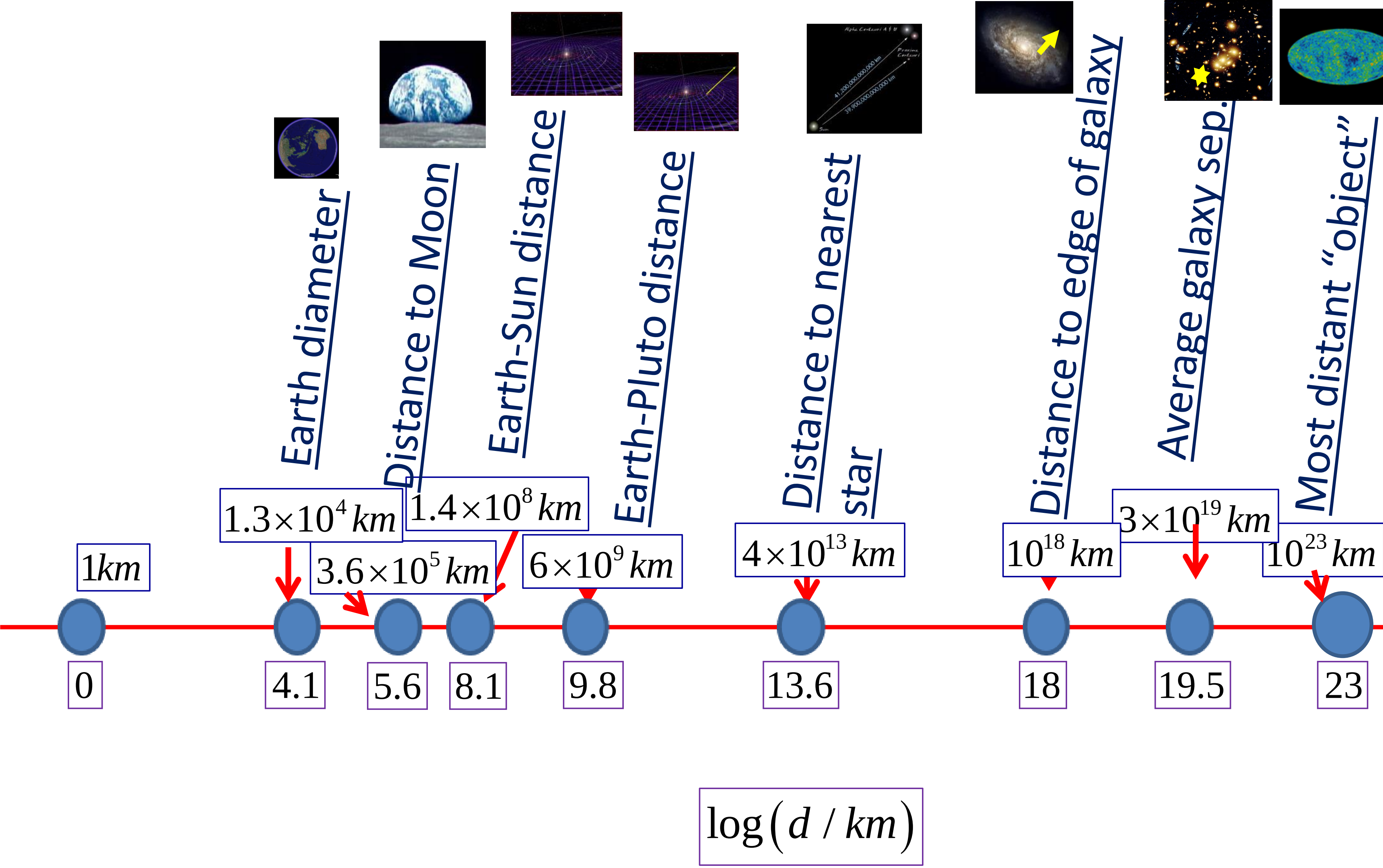
Distance from Earth to Edge of our galaxy = 1,000,000,000,000,000,000 kilometers ←→ 1 Physics/Geology Bulidng full of sand

Average distance between galaxies = 3×10^{19} kilometers $\leftarrow\rightarrow$ 1 baseball stadium full of sand



Farthest visible “object” in the universe: 1×10^{23} kilometers ←→ mountain range of sand




1km
0
Earth diameter
1.3×10^4 km
4.1
Distance to Moon
3.6×10^5 km
5.6
Earth-Sun distance
1.4×10^8 km
8.1
Earth-Pluto distance
6×10^9 km
9.8
Distance to nearest star
4×10^13 km
13.6
Distance to edge of galaxy
10^18 km
18
Average galaxy sep.
3×10^19 km
19.5
Most distant "object"
10^23 km
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

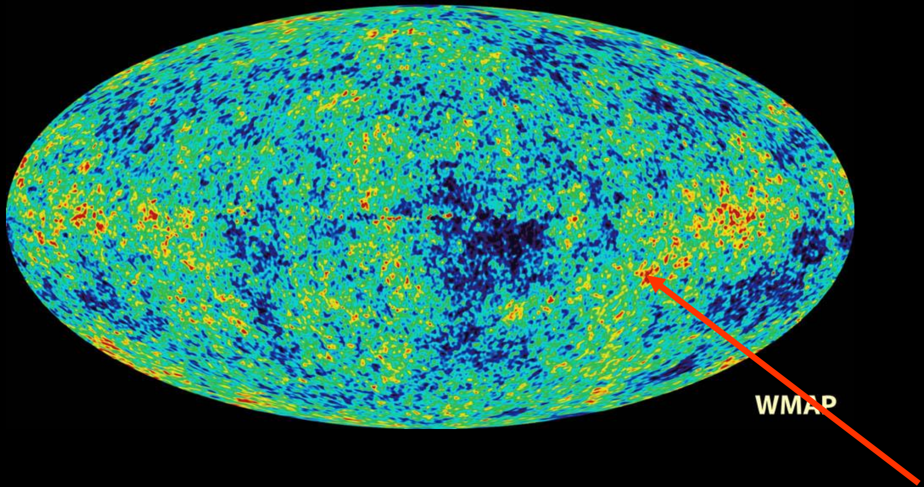
Hubble law: $v = Hr$

Distance

Expansion Speed

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

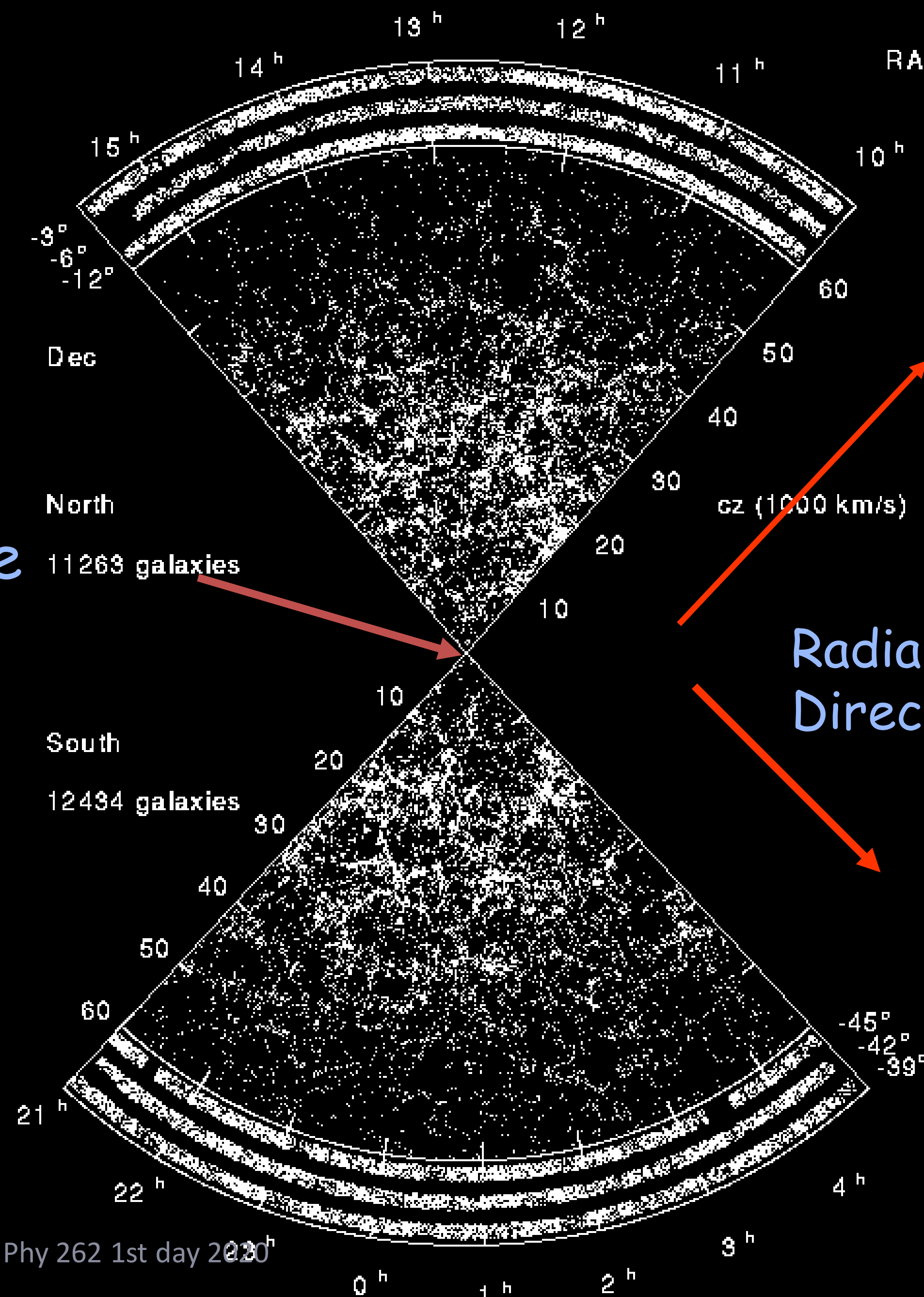
The homogeneity of the Universe



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

The homogeneity of the universe

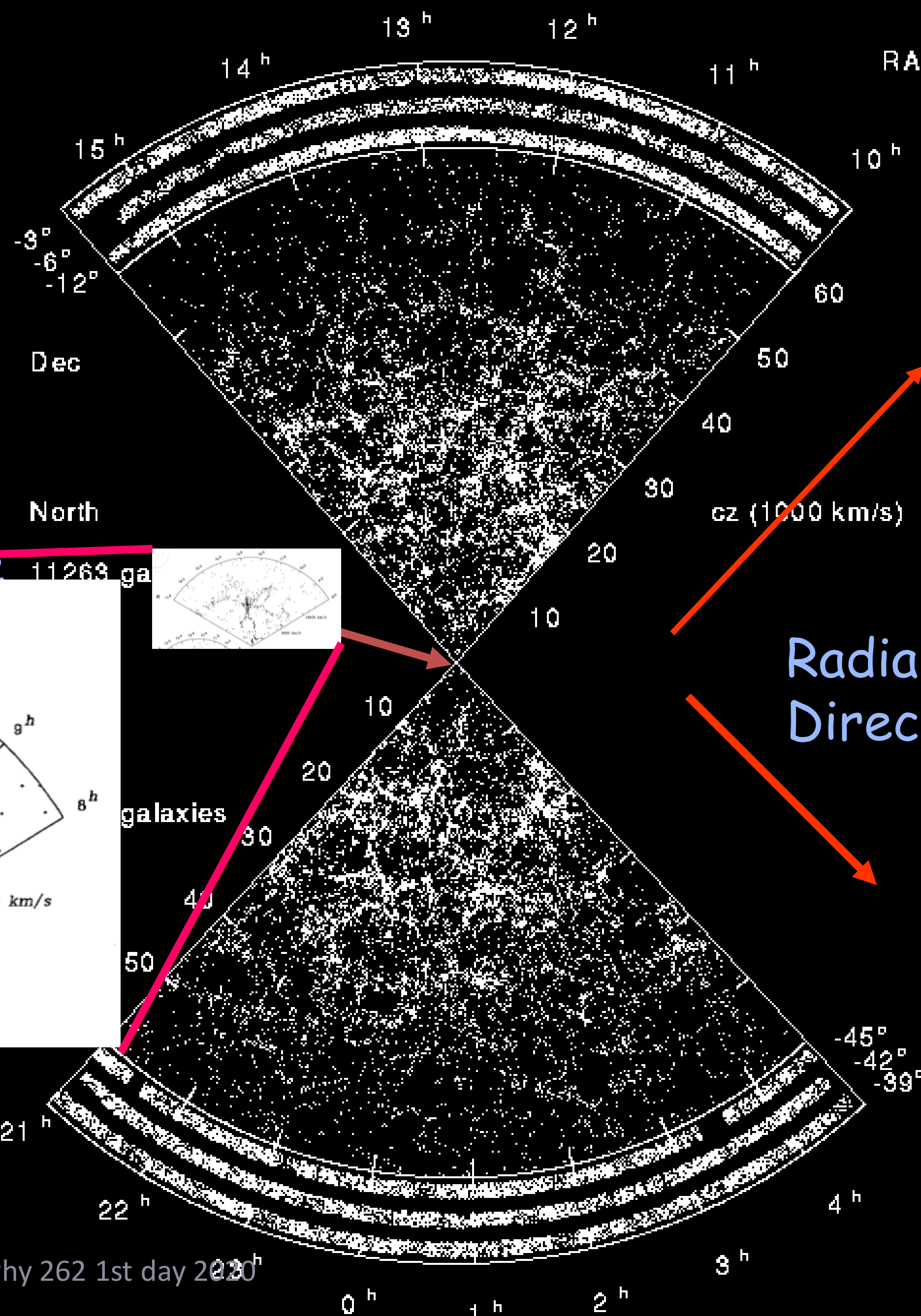
We are here



Radial Direction

Galaxy surveys

The homogeneity of the universe



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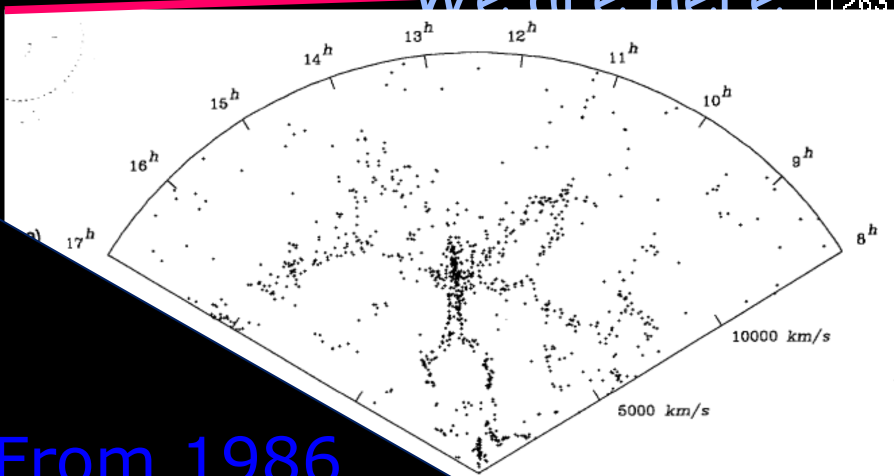
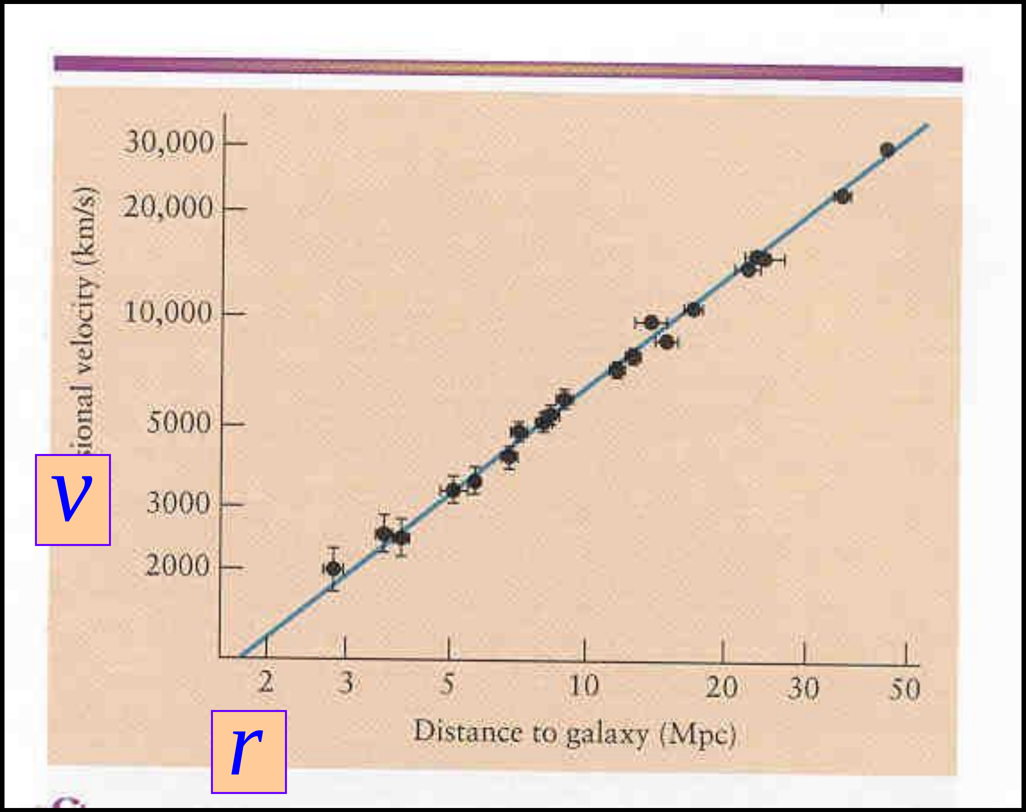


From 1986

Radial Direction

Galaxy surveys

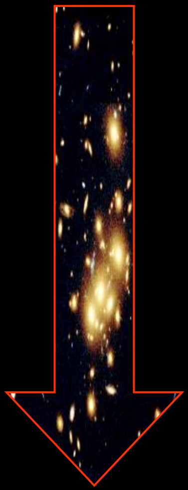
The Hubble law



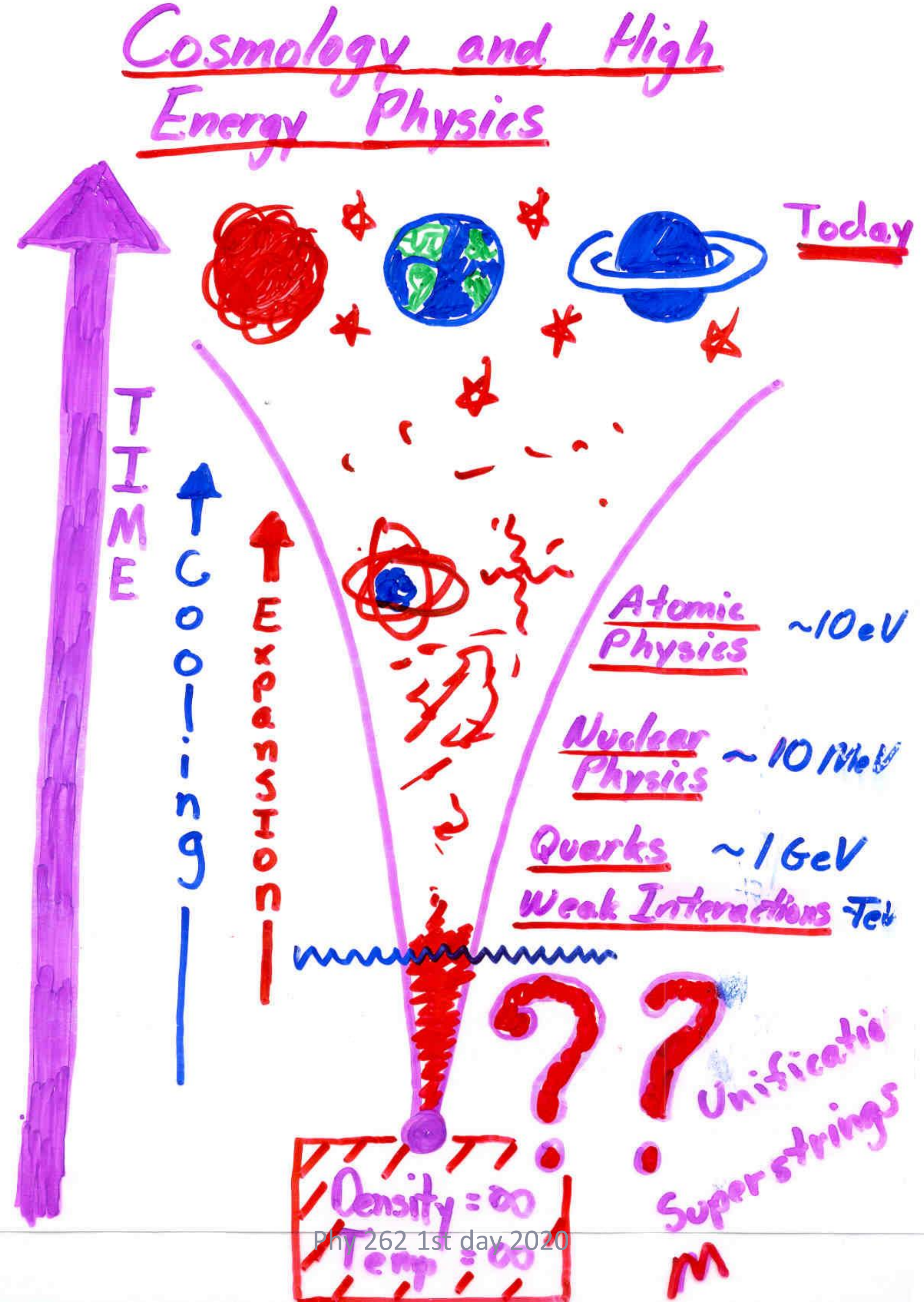
$$v = Hr$$

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

Hubble Expansion



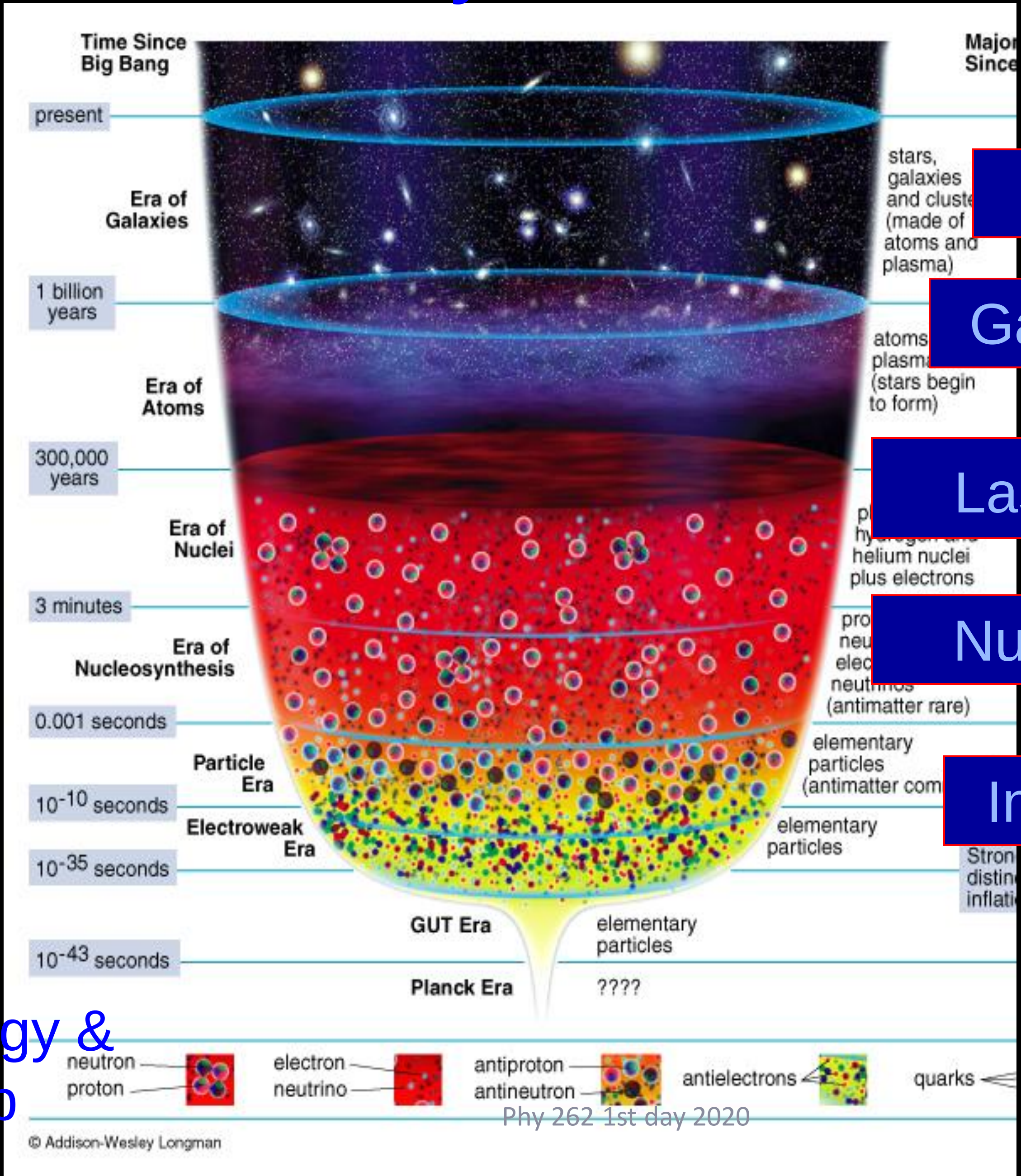
Hot, Dense past



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

The History of the Universe

Time



Today

Dark Energy

Galaxy Formation

Last Scattering

Nuclear & HEP

Inflation?

Extra Dimensions?

High Energy & Temp

The History of the Universe

Time

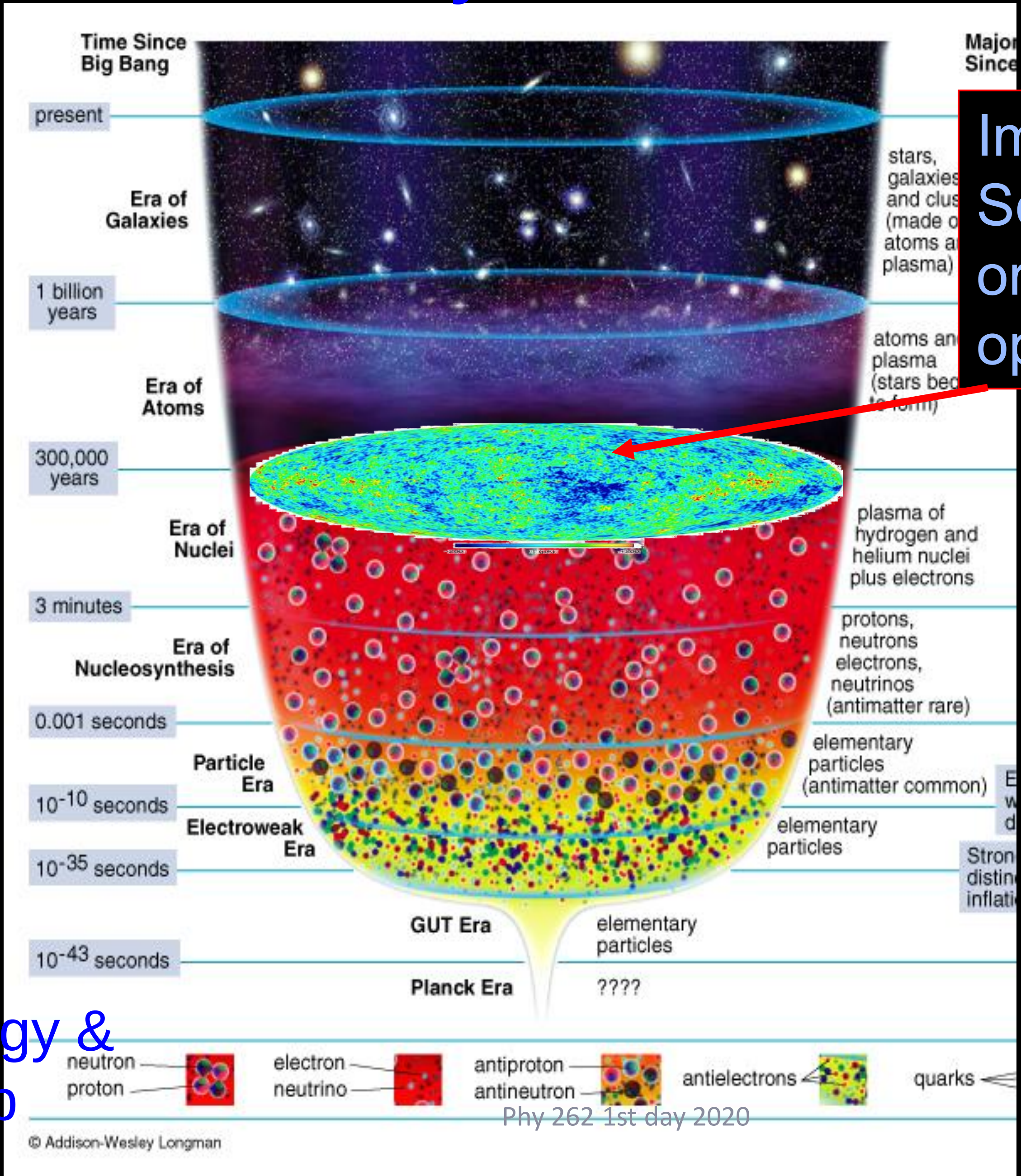


Image of the "Last Scattering Surface" or "edge of opaqueness"

High Energy & Temp

The History of the Universe

Time

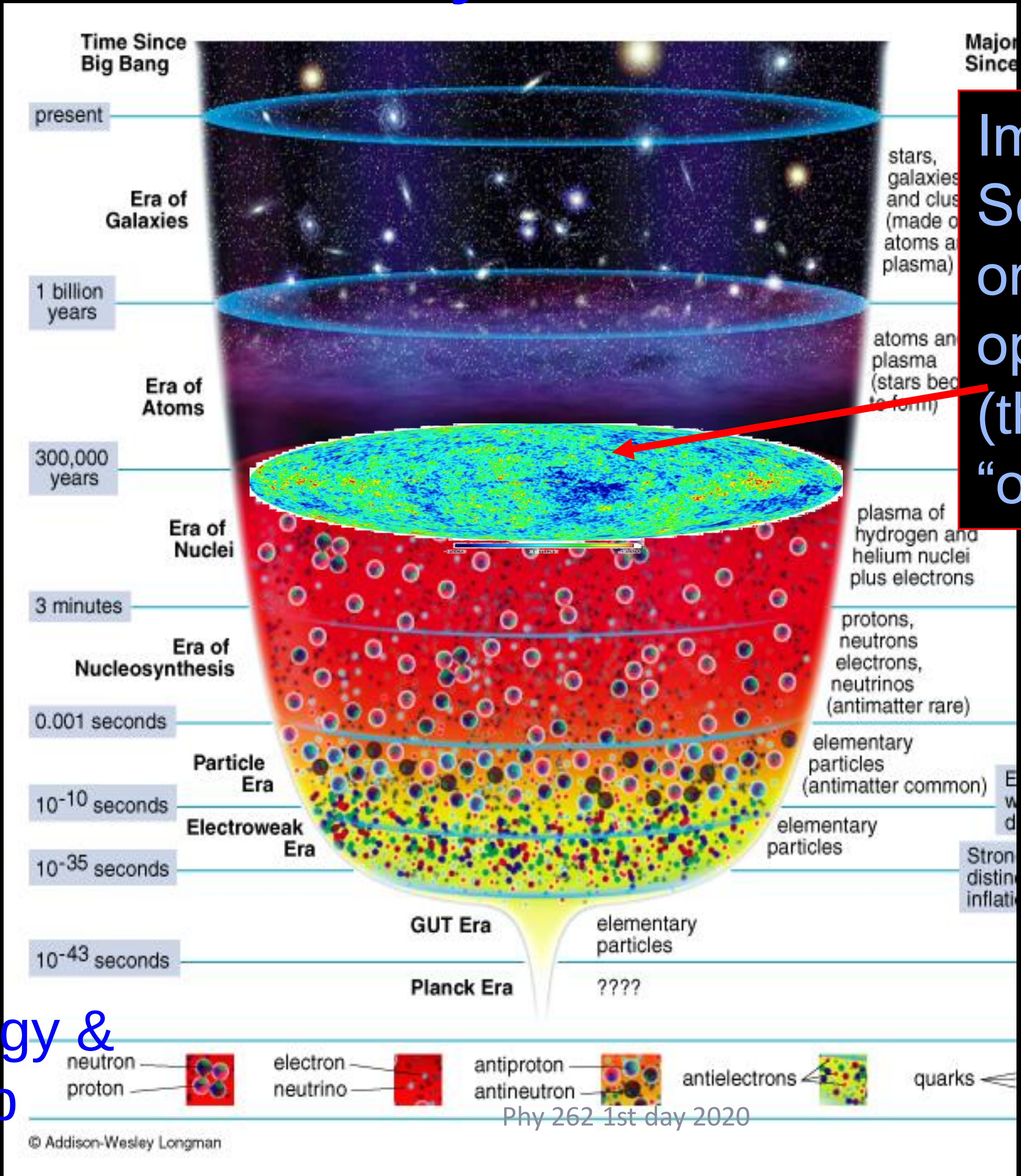
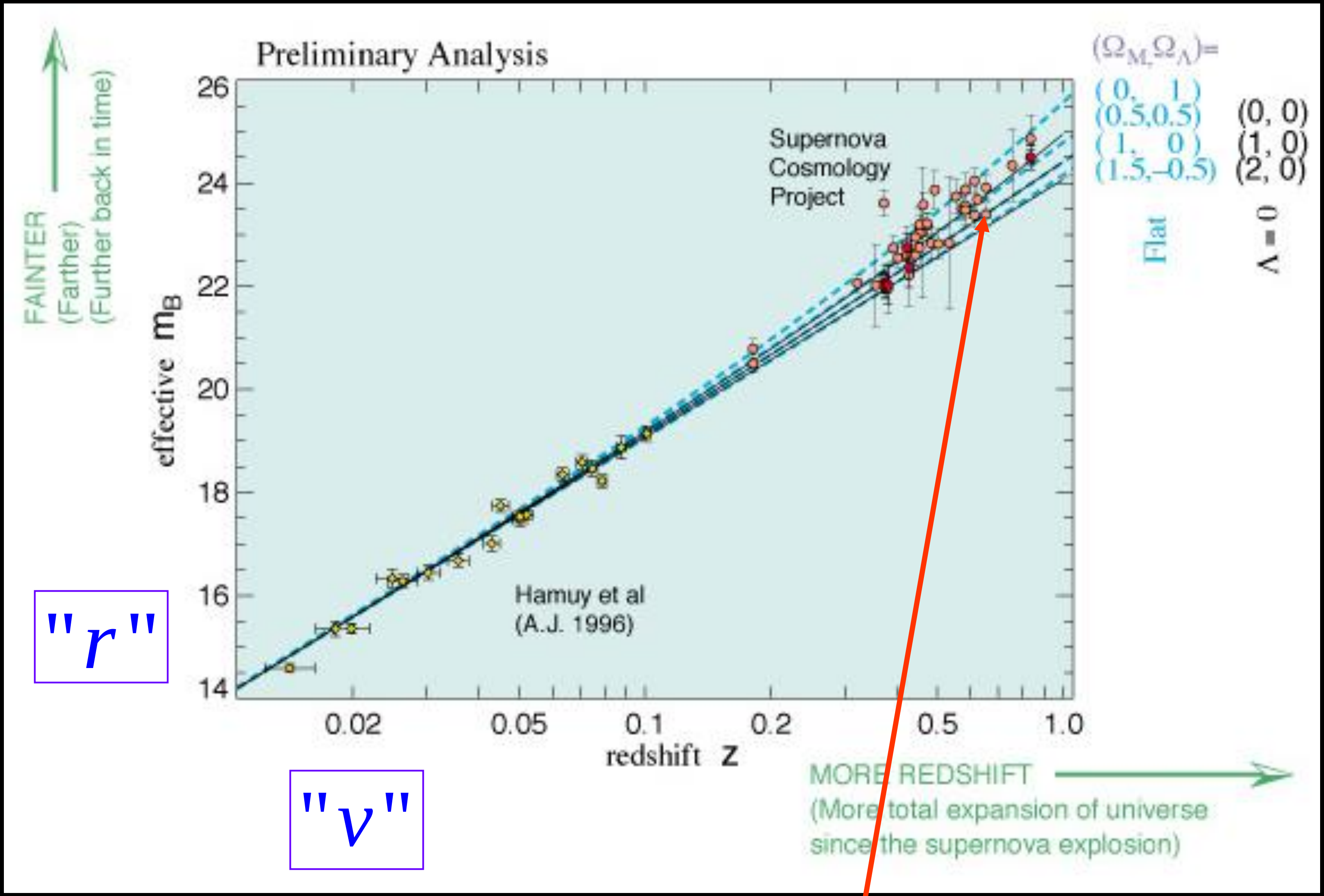


Image of the "Last Scattering Surface" or "edge of opaqueness" (the most distant "object")

High Energy & Temp

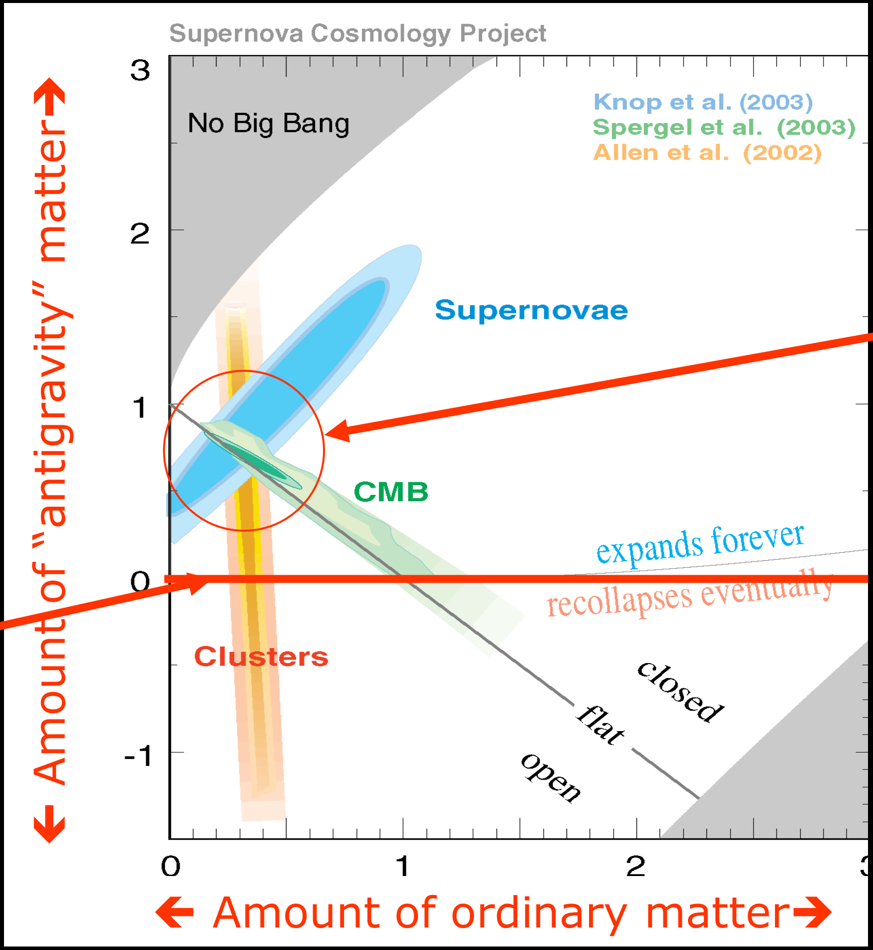
Acceleration of the universe



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

Cosmic acceleration

Using supernovae (exploding stars) as cosmic "mileposts", *acceleration* of the Universe has been detected.

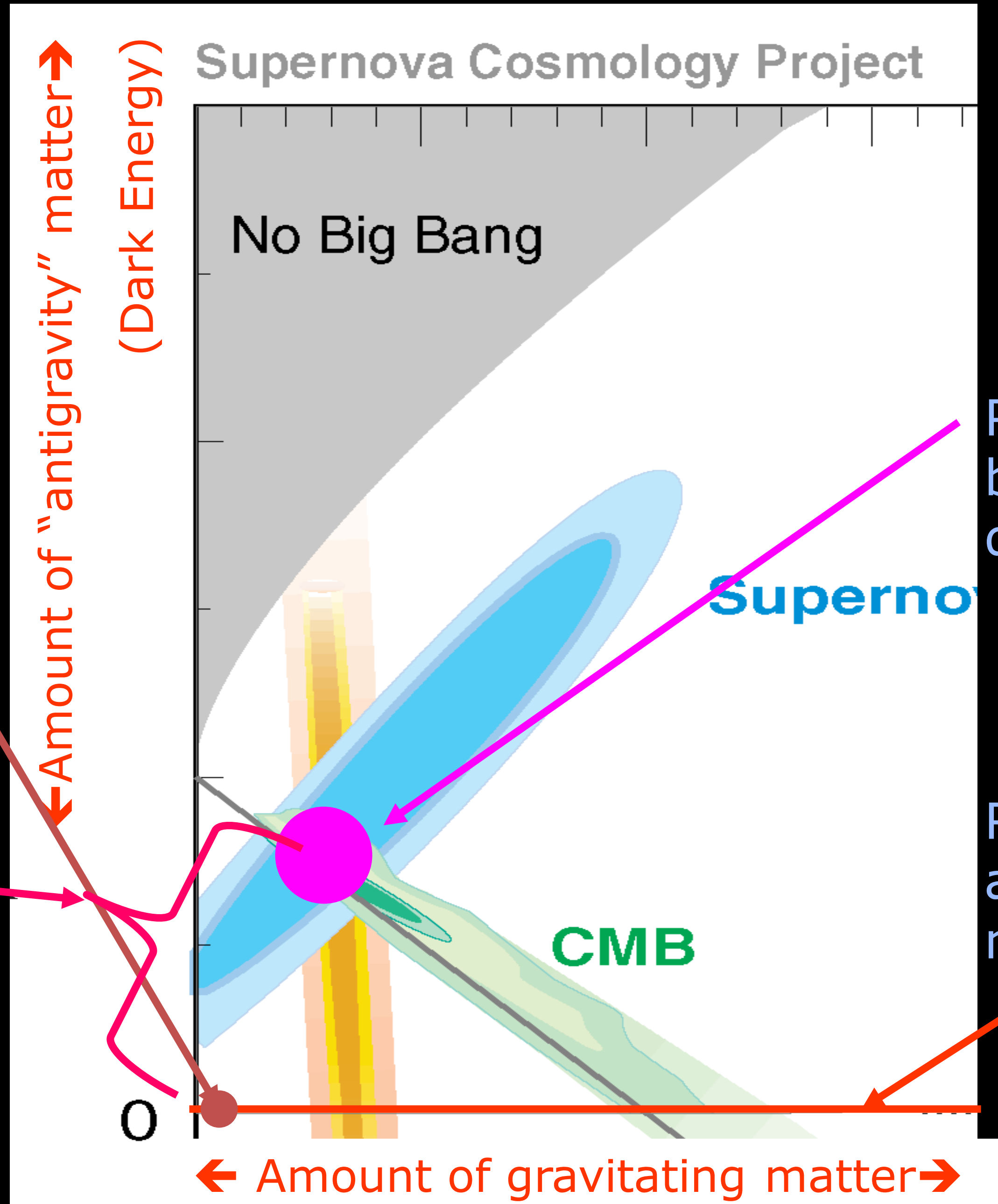


Preferred by modern data

"Ordinary" non accelerating matter

Mass-Energy of the a Universe made *only* out of standard model matter

Surprise factor



Preferred by modern data

Red line: No anti-gravity matter

Need to add dark matter here

Preferred by modern data

Mass-Energy of the a Universe made *only* out of standard model matter

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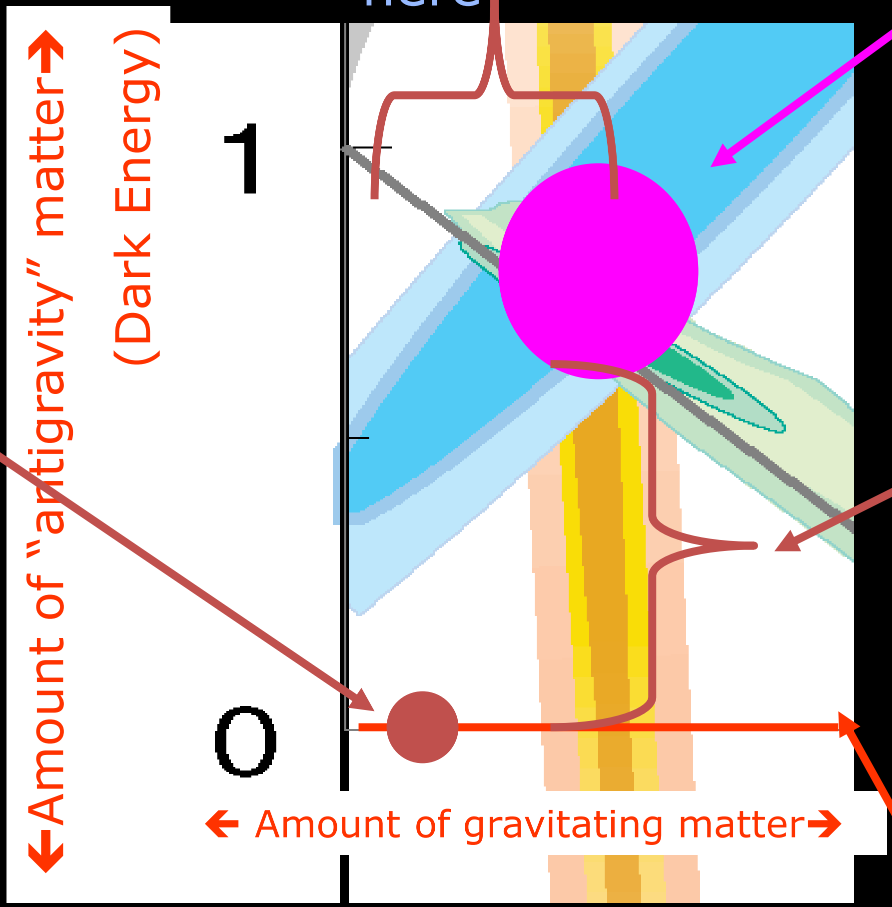
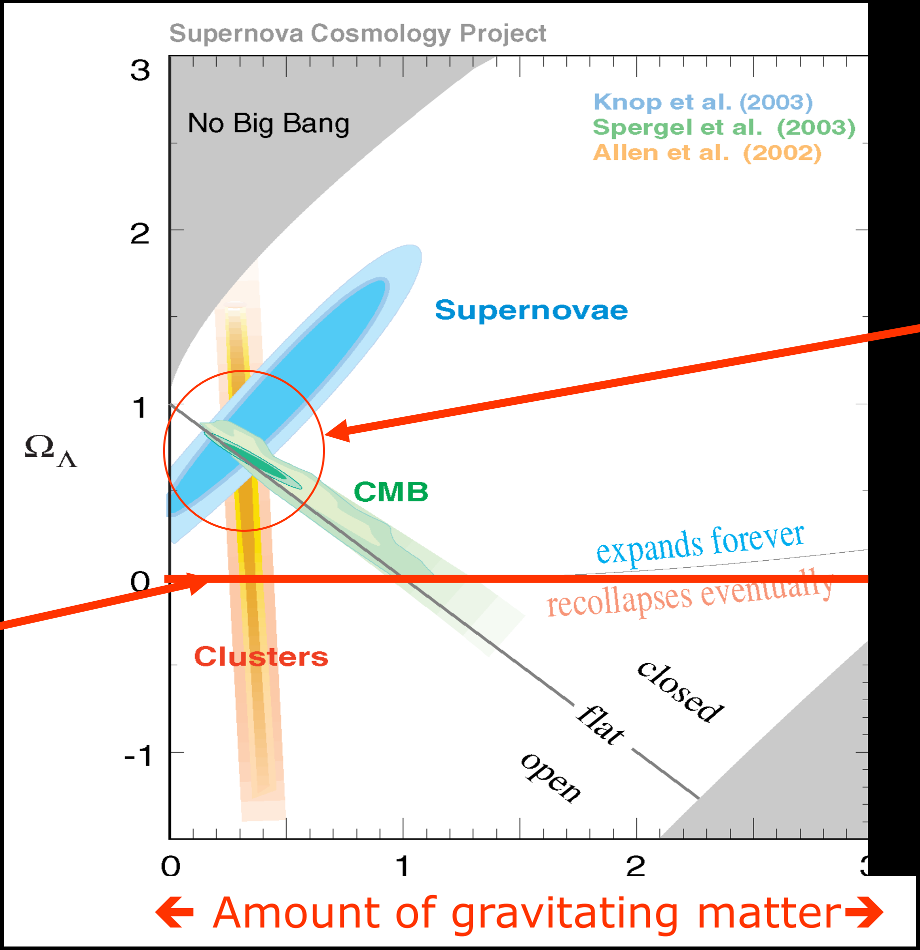


Cosmic acceleration (newest data)

Using supernovae (exploding stars) as cosmic "mileposts", *acceleration* of the Universe has been detected.

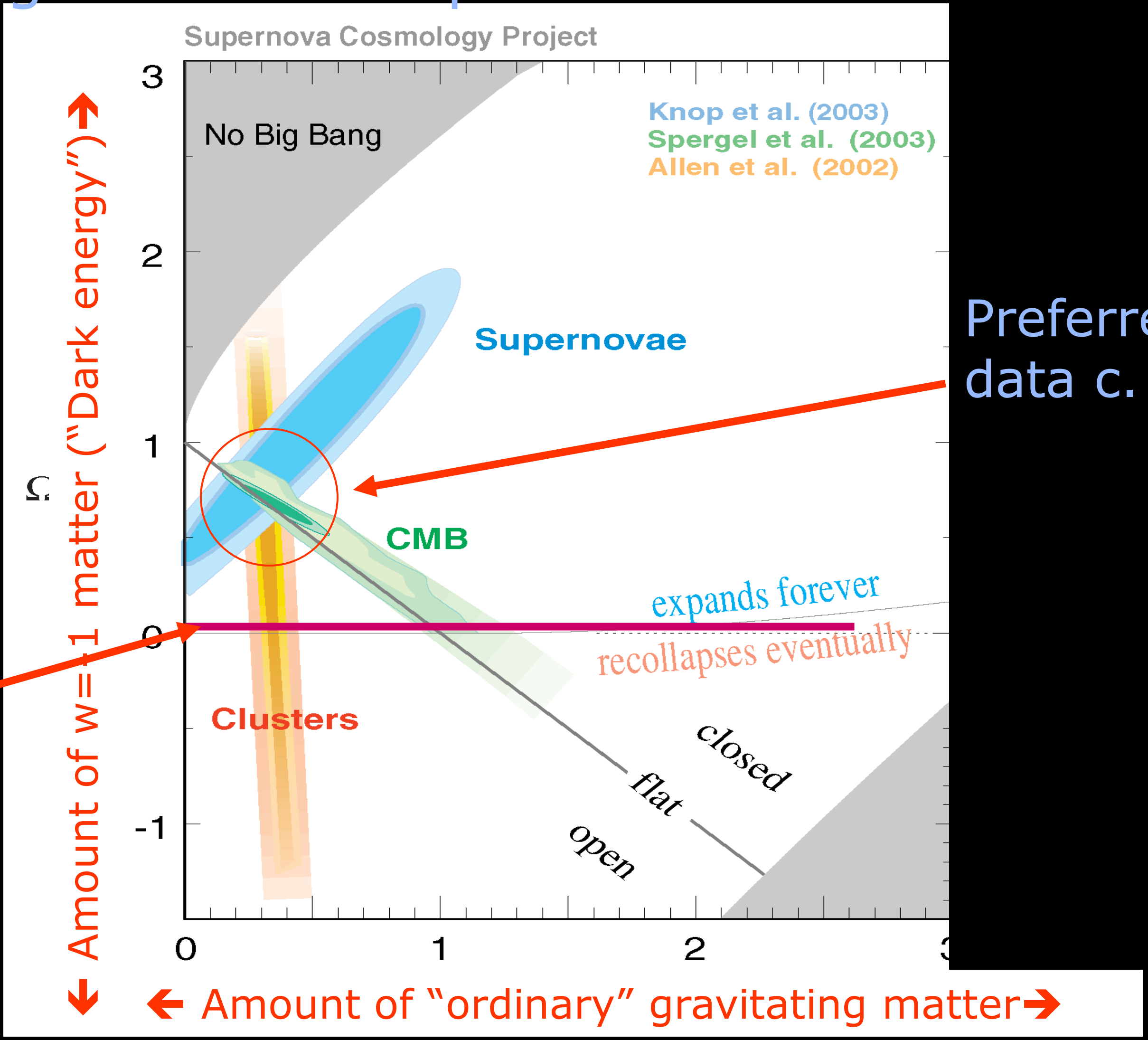


Preferred by modern data

"Gravitating" non accelerating matter

Cosmic acceleration

Accelerating matter is required to fit current data

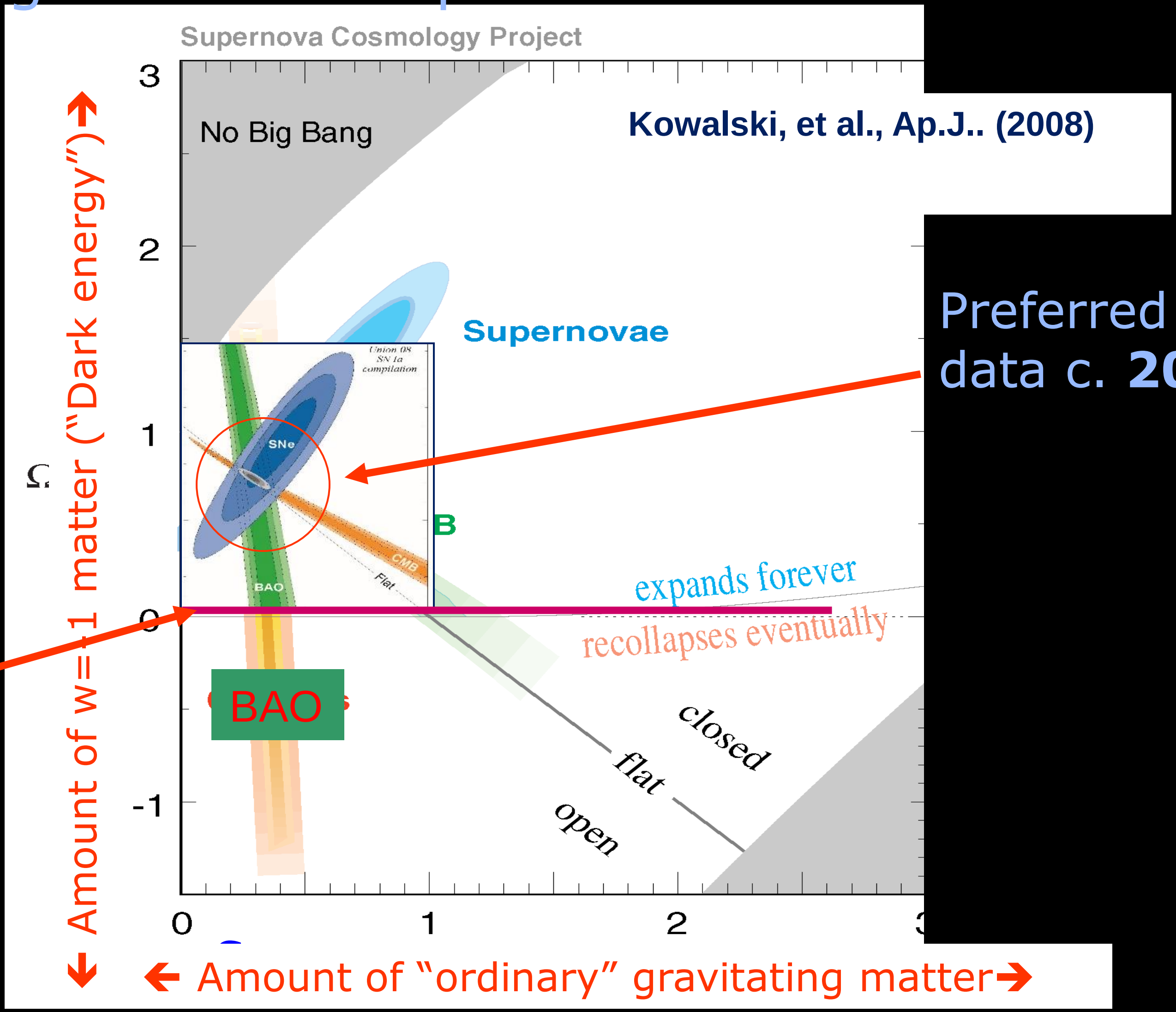


Preferred by data c. 2003

"Ordinary" non accelerating matter

Cosmic acceleration

Accelerating matter is required to fit current data



Preferred by data c. **2008**

"Ordinary" non accelerating matter

Cosmic acceleration

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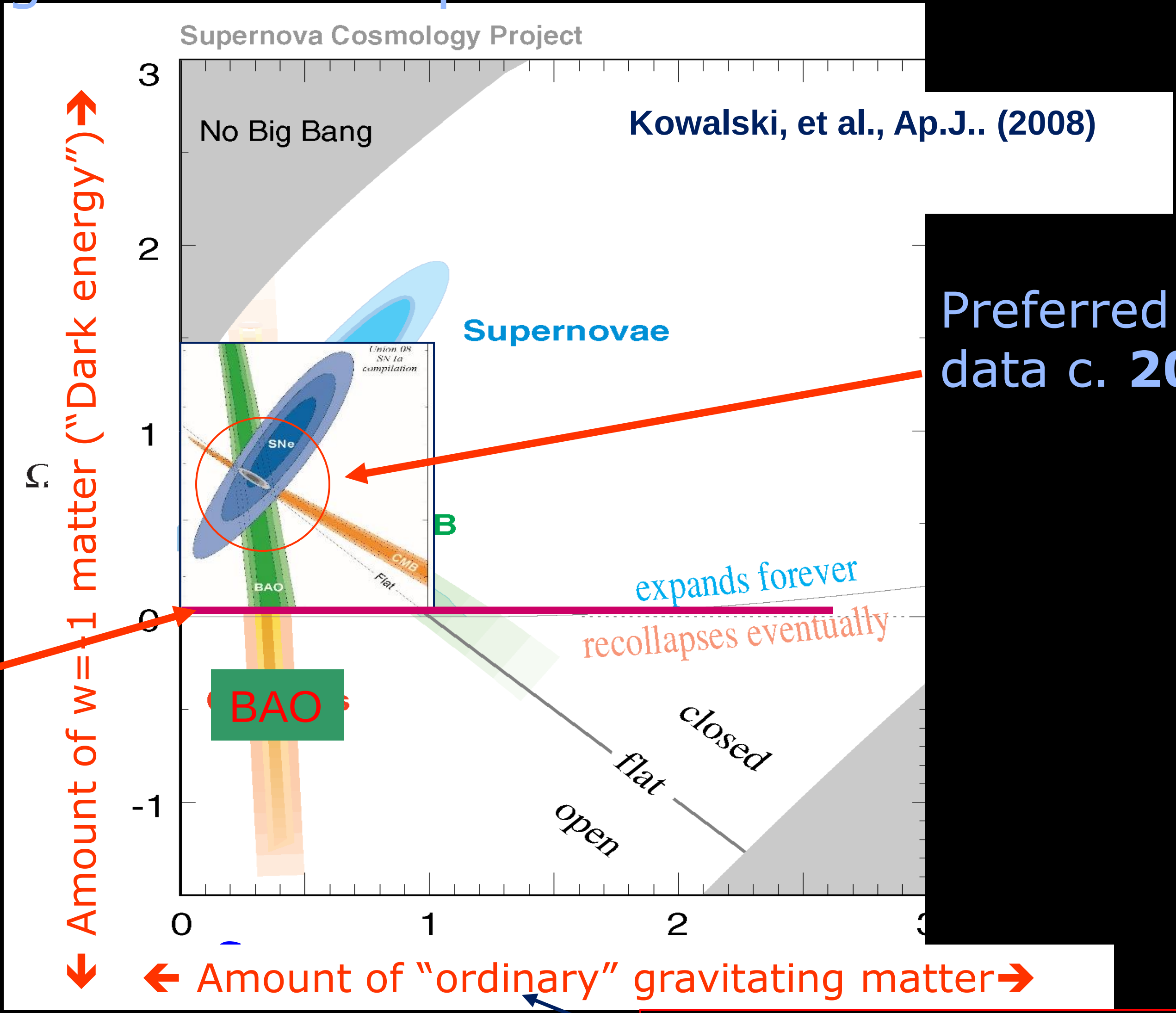
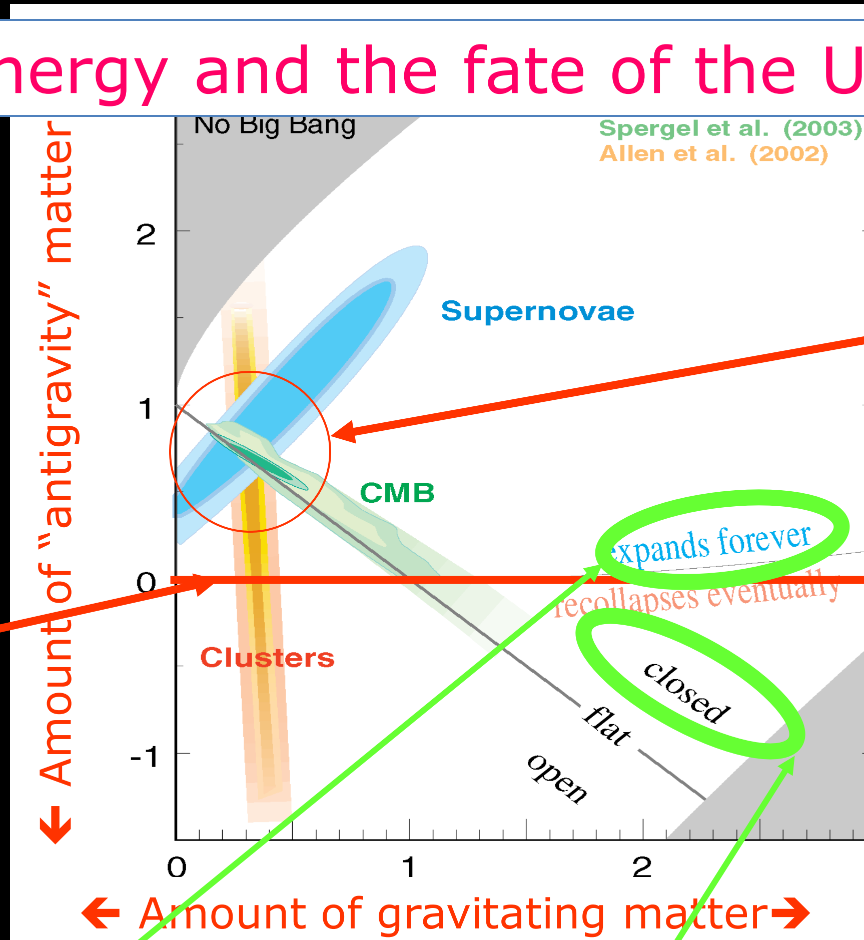


Preferred by data c. **2008**

"Ordinary" non accelerating matter

(Includes dark matter)

Dark Energy and the fate of the Universe

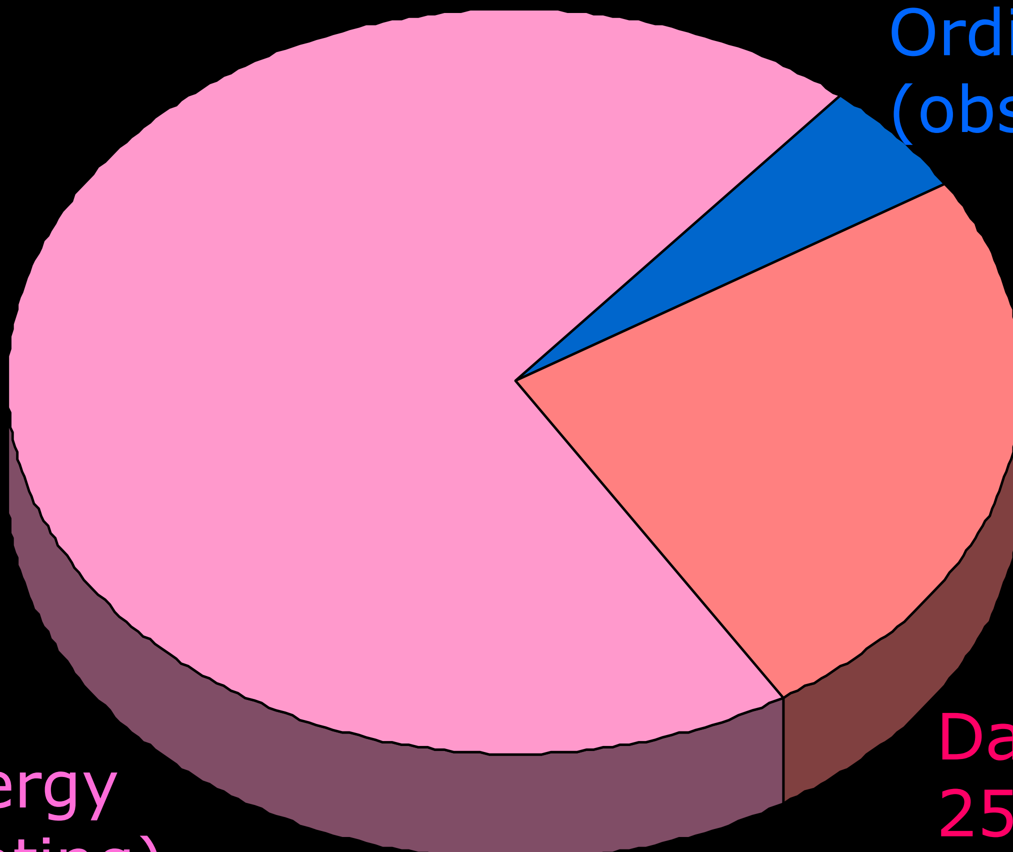


Preferred by modern data

"Gravitating" non accelerating matter

In the presence of dark energy, the simple connection between open/closed/flat and the future of the universe no longer holds

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



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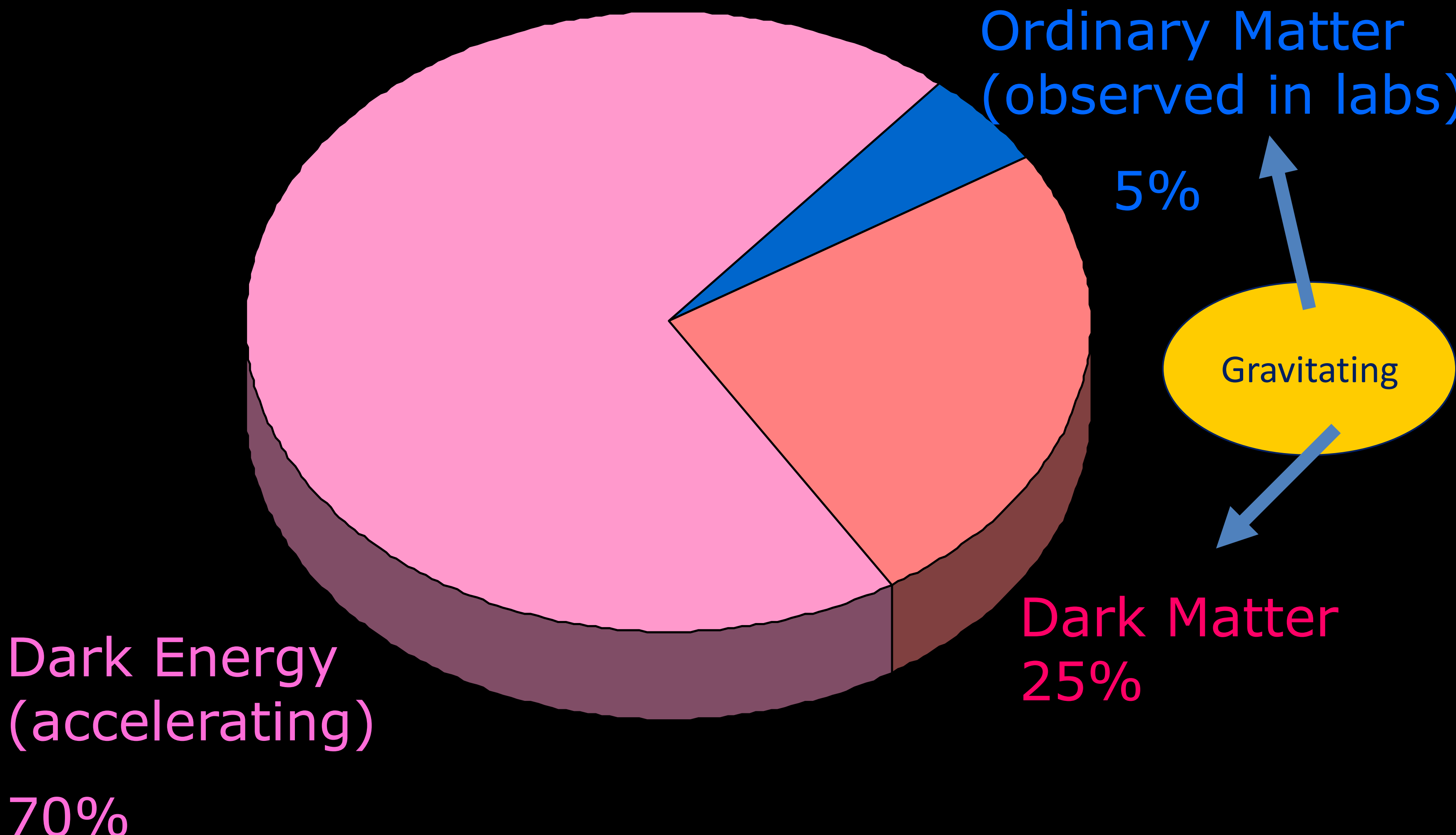

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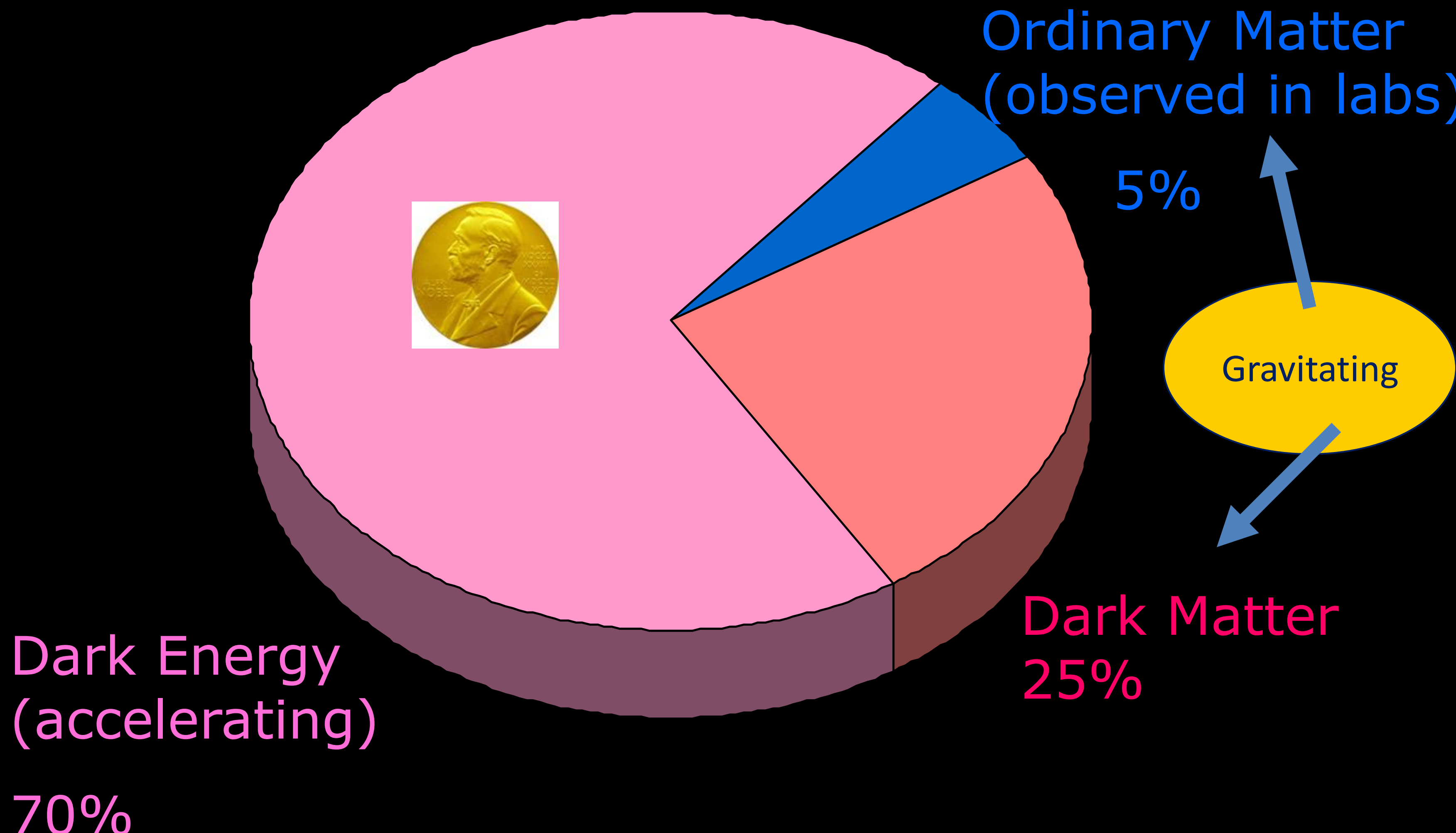

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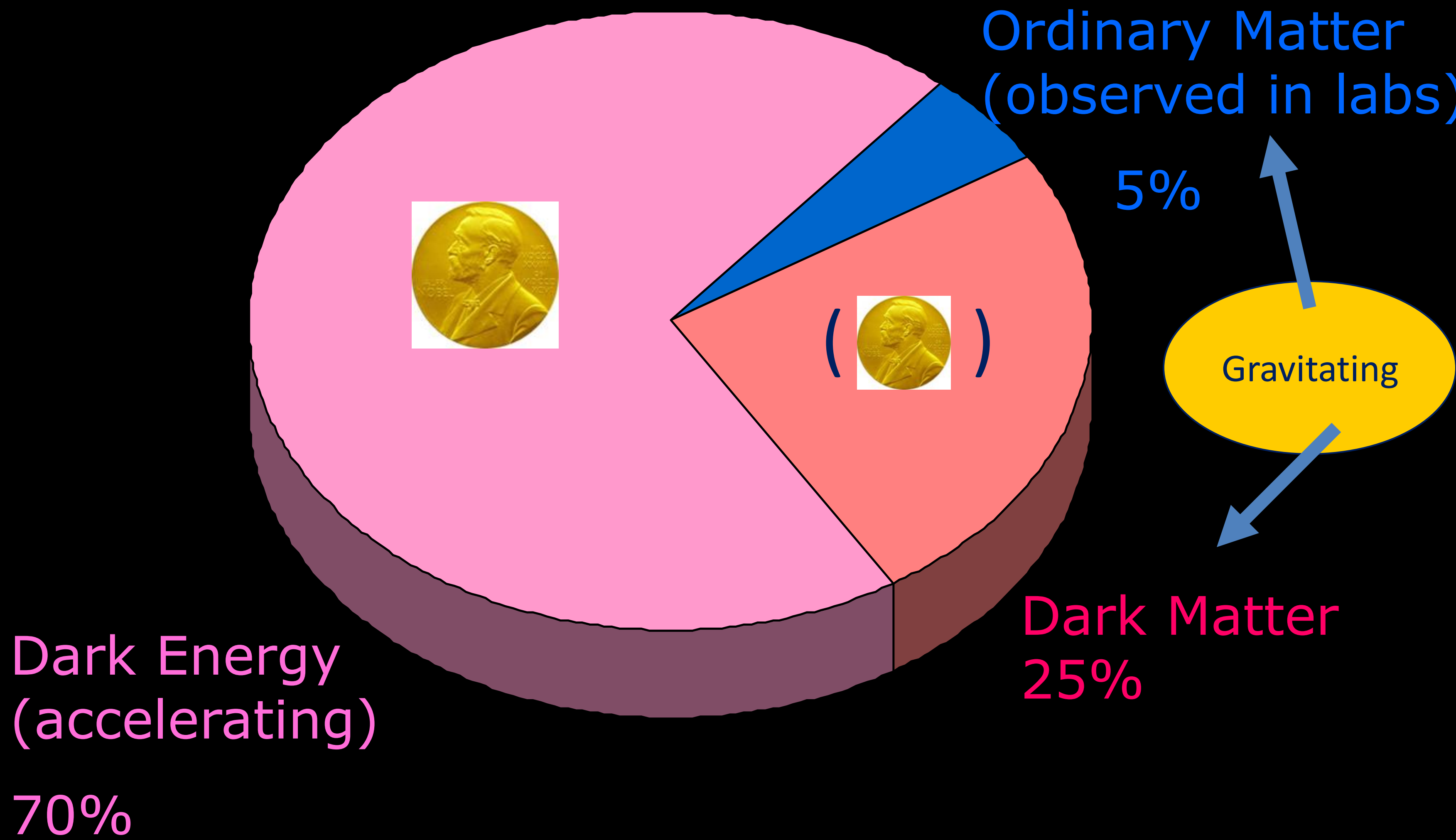


Cosmic Controversies

A conference organized by the
Kavli Institute for Cosmological Physics
Saturday October 5 – Tuesday October
UChicago Gleacher Center, Chicago, IL

Home | Overview | Participants | **Program** | Presentations | KICP

Program

- October 5, 2019 - Saturday
- October 6, 2019 - Sunday
- October 7, 2019 - Monday
- October 8, 2019 - Tuesday

OCTOBER 5, 2019 - SATURDAY

7:30 AM - 8:30 AM	Registration and Continental Breakfast
8:30 AM - 9:00 AM	**Conference opening** ***Chair: Rocky Kolb*** **Simon White**, Max-Planck-Institut fuer Astrophysik *Cosmic controversies: boon or bane?* [PDF, 17.79 MB]
9:00 AM - 12:35 PM	PARALLEL SESSIONS **H0 Tension (Room 621)** ***Chair: Kimmy Wu*** **Lloyd Knox**, UC Davis *The Hubble Hunter's Guide* [PDF, 4.08 MB]

The Hubble Hunter's Guide*

Lloyd Knox
UC Davis

https://arxiv.org/abs/1908.03663

*with apologies to J. Gunion et al.

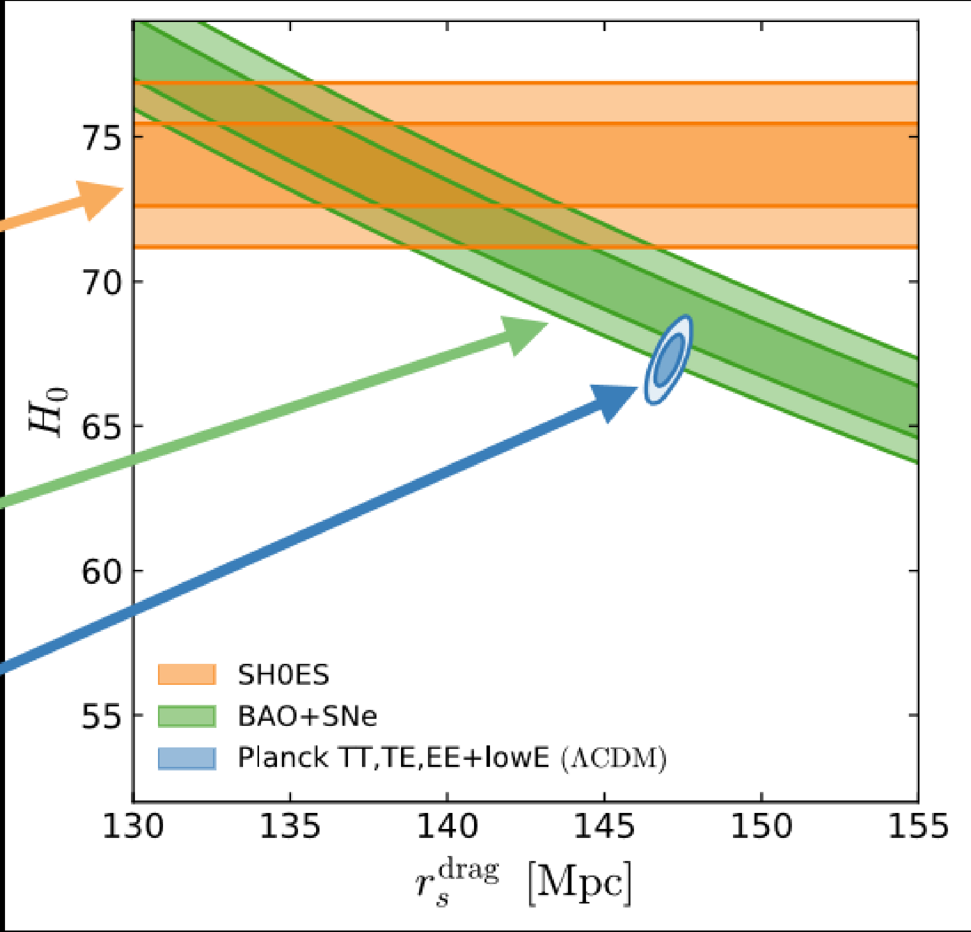
The Hubble constant / sound horizon problem

From "The Hubble Hunter's Guide" (LK+Millea 2019)
Also see Bernal, Verde & Riess (2016), and Arendse et al. (2019)

SH0ES 2019 (Cepheids + Supernovae)
(no assumption of LCDM)

BOSS BAO + Pantheon SNe
(no assumption of LCDM*)

Planck (Assumes LCDM)



Sound Horizon

*assumes 5-parameter spline model for H(z) and zero mean curvature. Also see Raveri et al. (2019).

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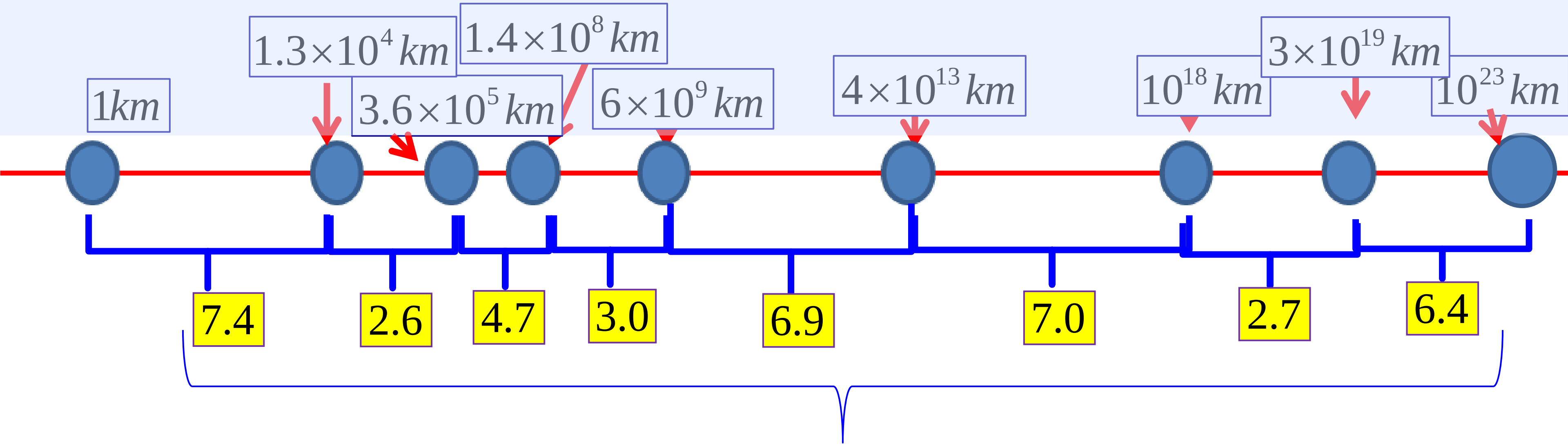
Cosmic Inflation

- A period of accelerated expansion in the very early universe

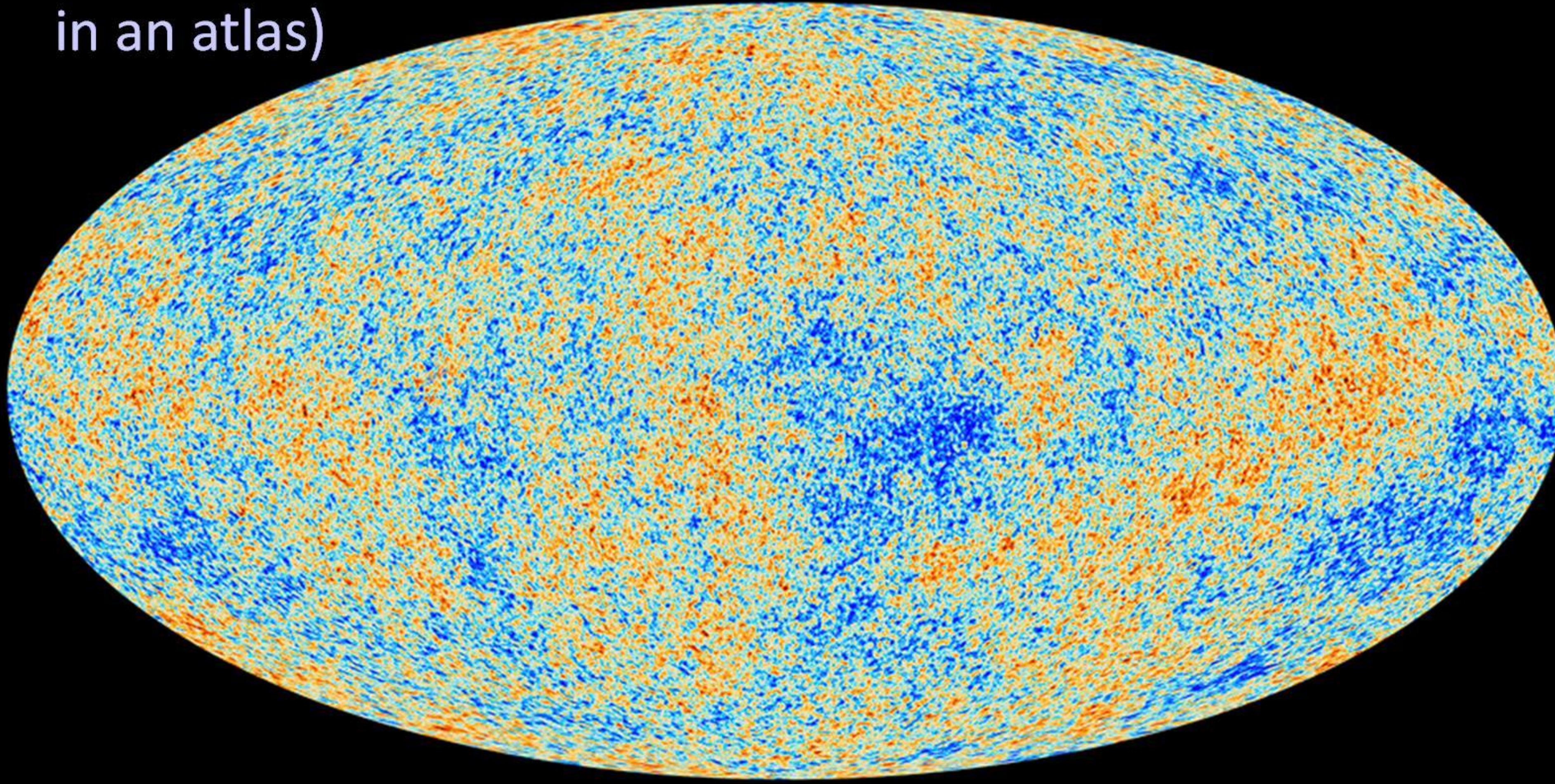
- Motivated by particle physics (related to the recently discovered Higgs particle).
- In most models inflation operates when the temperature was 10^{25} times greater than today!

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

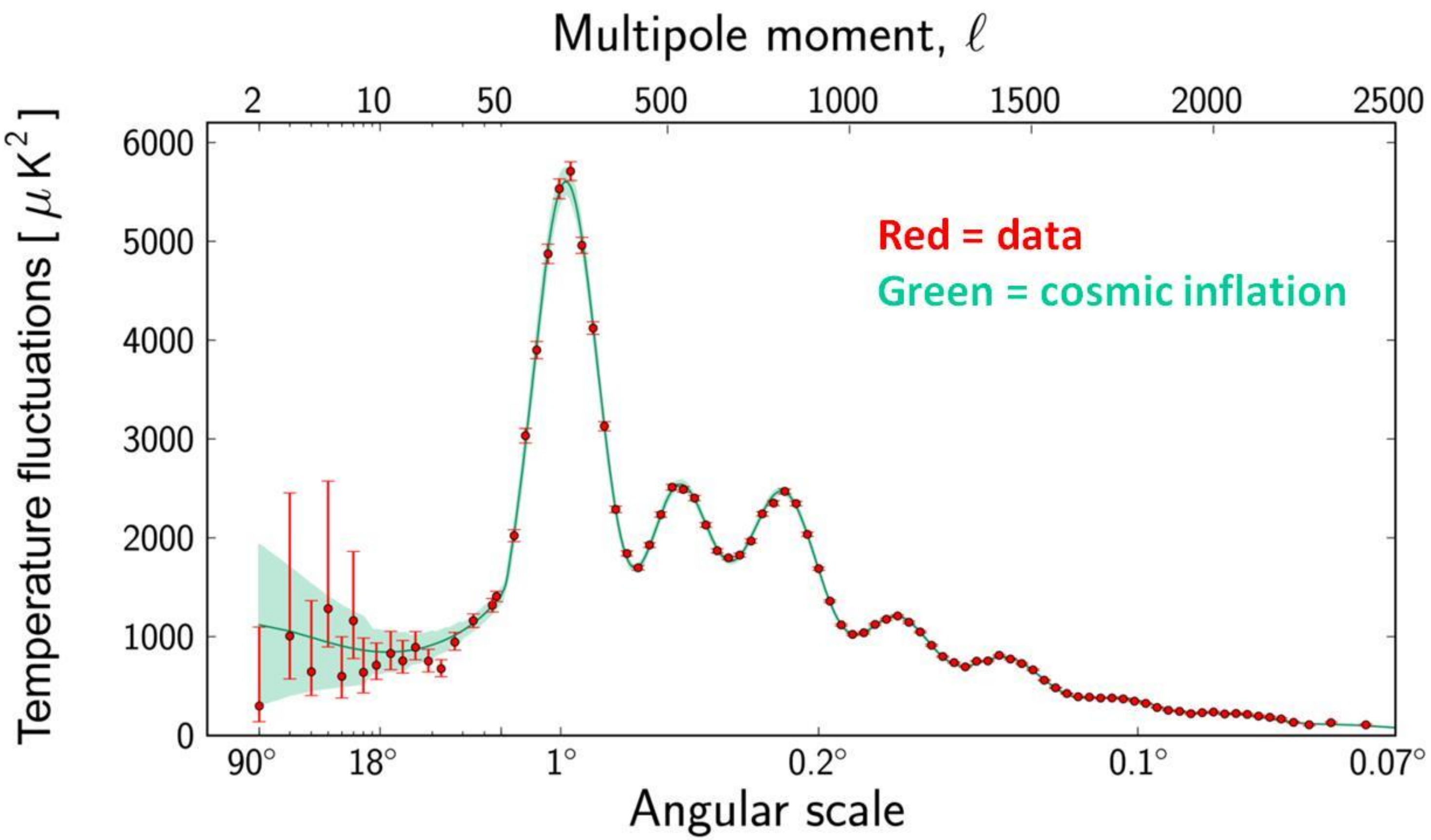


- Cosmic inflation creates features in the universe on all these different lengths.
- The yellow boxes give the time between "feature creation" in units of 10^{-40} seconds!

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

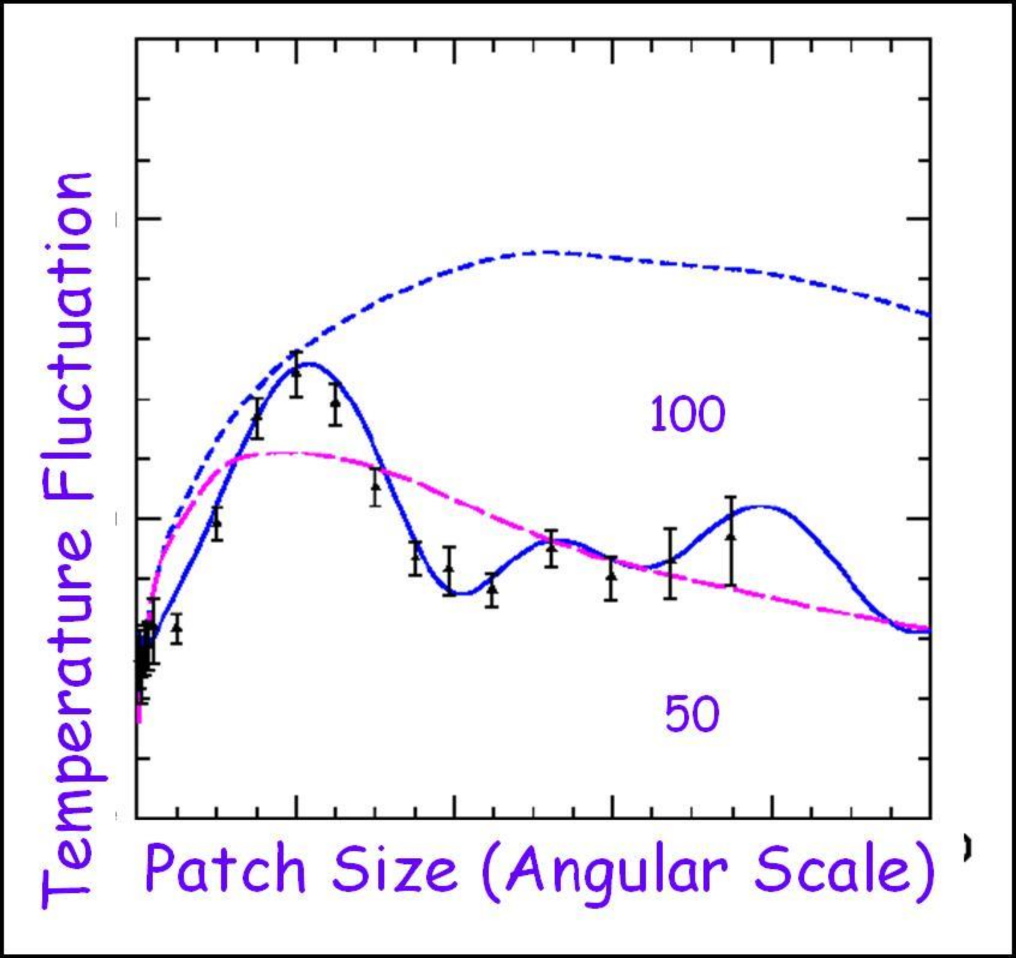


The map shows minute variations in the temperature (just 1 part in 100,000, or in the 5th decimal place).



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)

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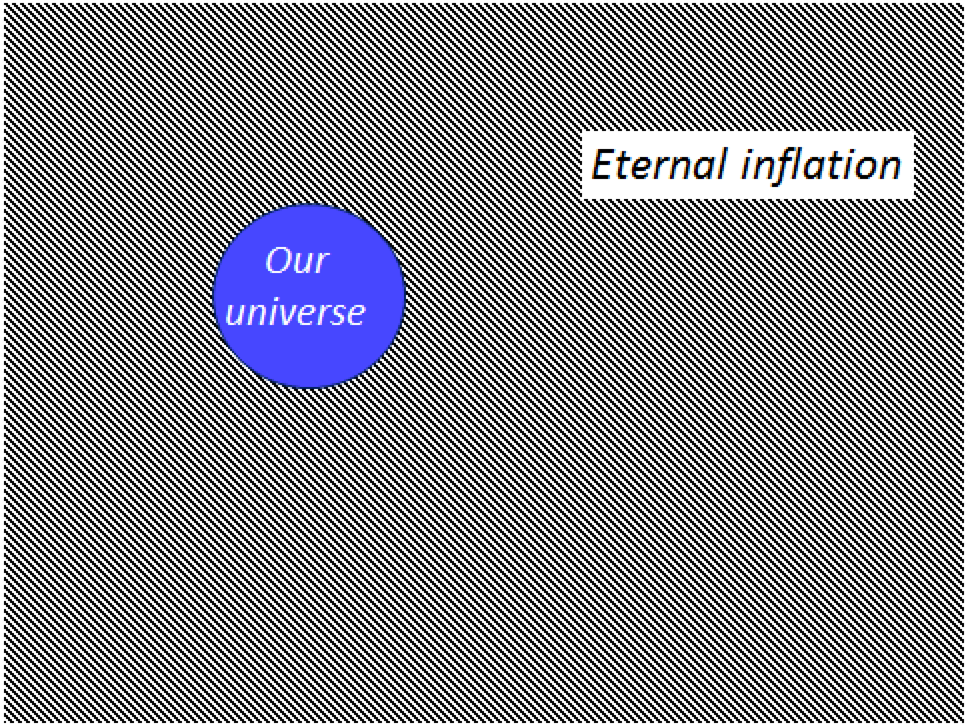
- Very problematic aspects emerge when we attempt to complete the picture. (The cause of intensive research and debate among the experts.)

- May cosmologists believe in “eternal inflation” (our universe exists in a “pocket” with eternal inflation all around us).



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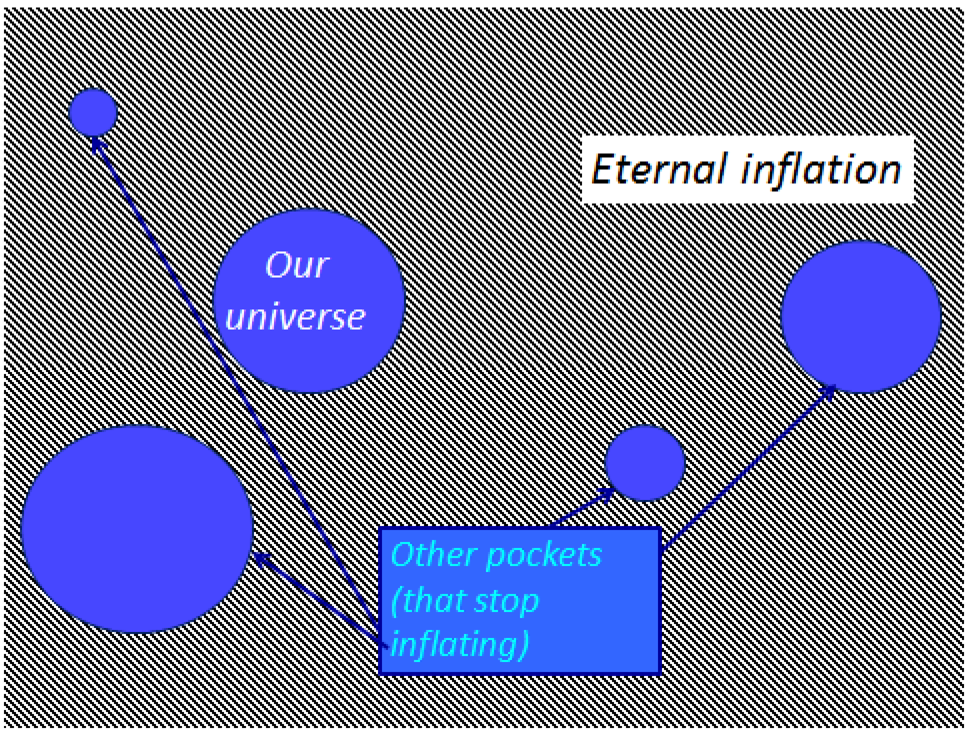
- Eternal inflation theory predicts infinitely many pocket universes, some like ours, some different



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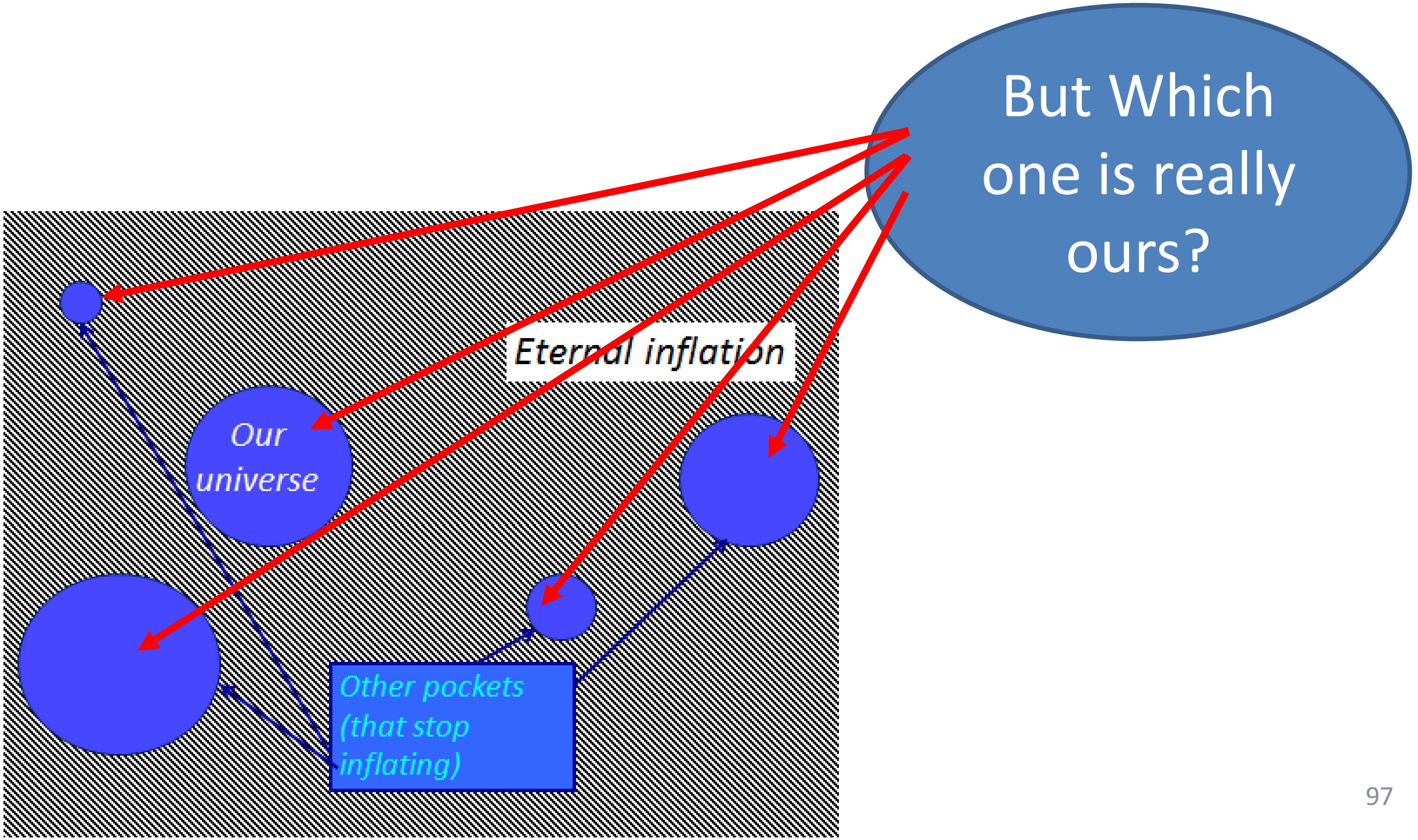

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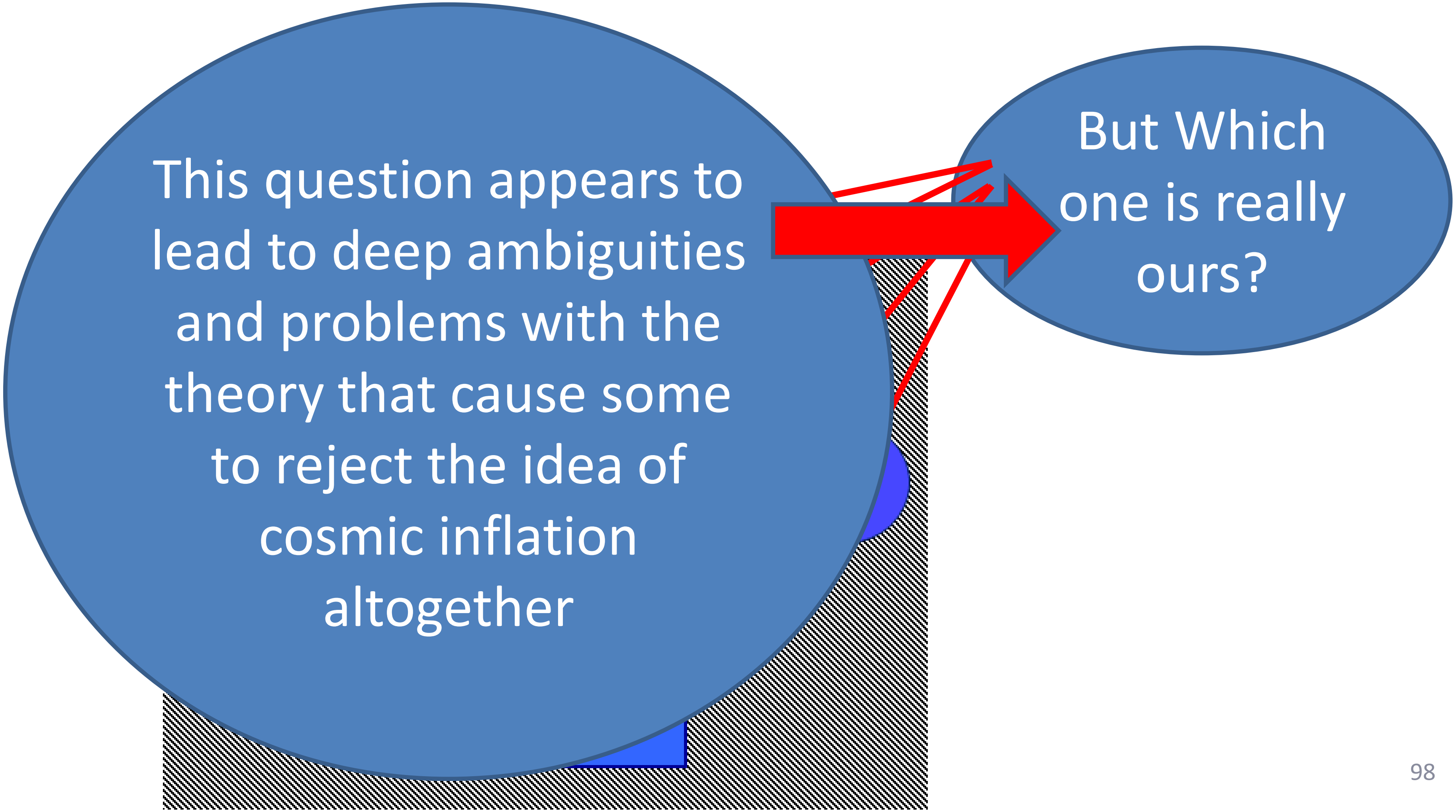

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A very exciting place to be!

Cosmic Inflation

Multiverse debate, World Science Festival 2013

- rly
- ently
- observed today (interesting relationship

https://www.youtube.com/watch?v=2Qt-eGKa34M

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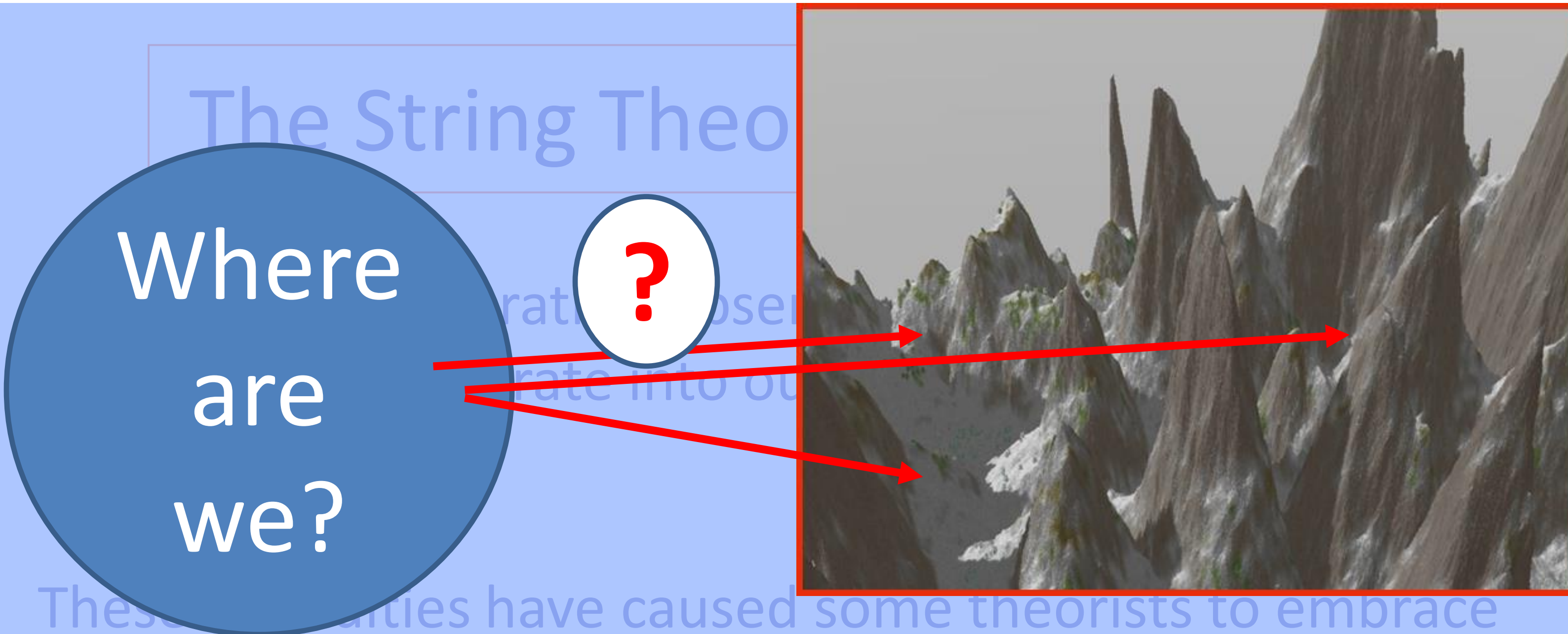

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The String Theo

Where are we?

?

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

- Instead of the physical world around us exhibiting “the fundamental laws”, according to the STL picture the universe is made of a landscape of different “worlds” which with their own laws of physics.

Conclusions

- The search for a “big picture” of the Universe that explains why the region we observe should take this form has proven challenging, but has generated exciting ideas.

- We know we can do science with the Universe

- It appears that there is something right about cosmic inflation

- dSE cosmology offers a finite alternative to the extravagant (and problematic) infinities of eternal inflation

- Predictions of observable levels of cosmic curvature from dSE cosmology will give an important future test

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Conclusions

Amazing data and facilities

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We have learned a huge amount about the Universe

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Our theories are both remarkably successful and provocative/confusing

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