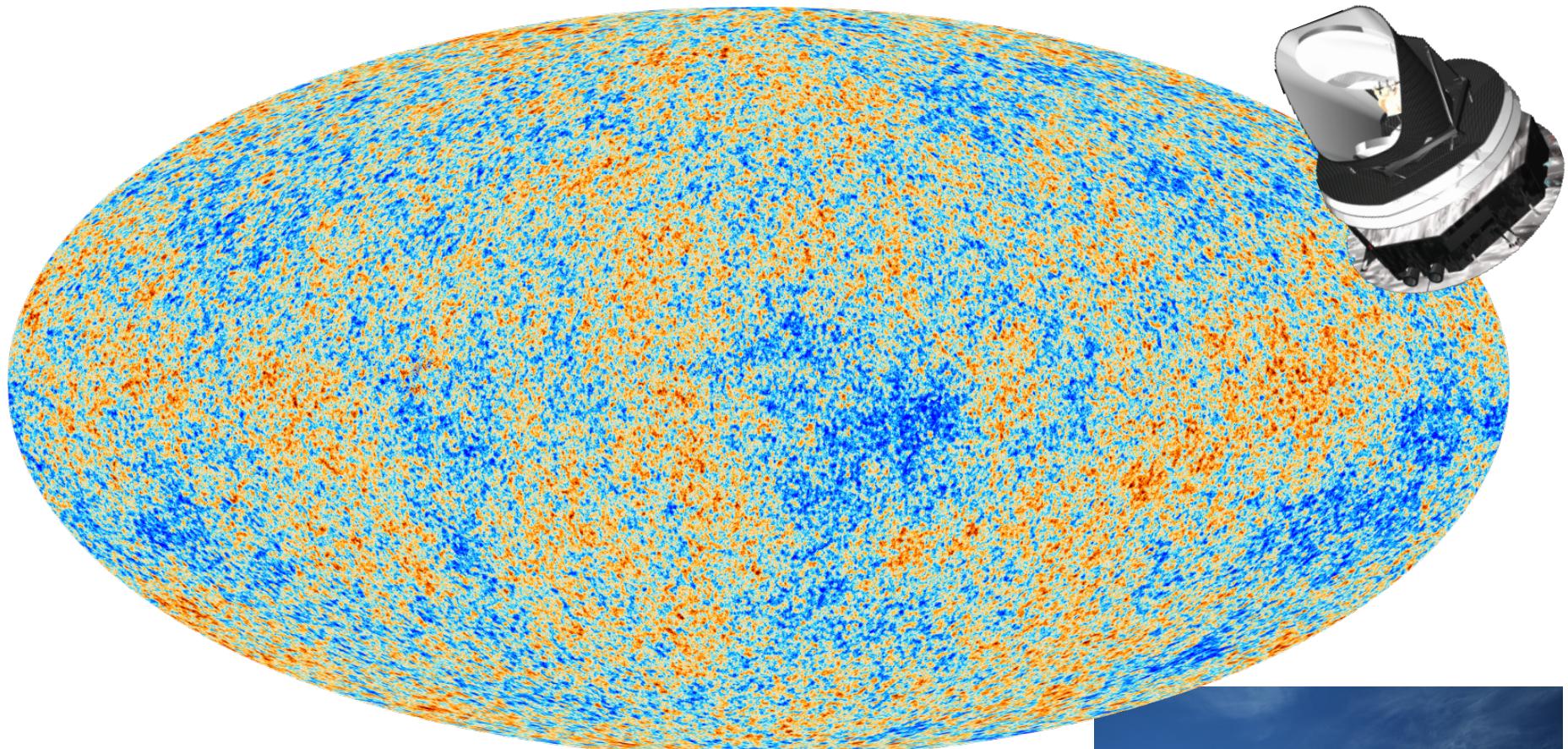
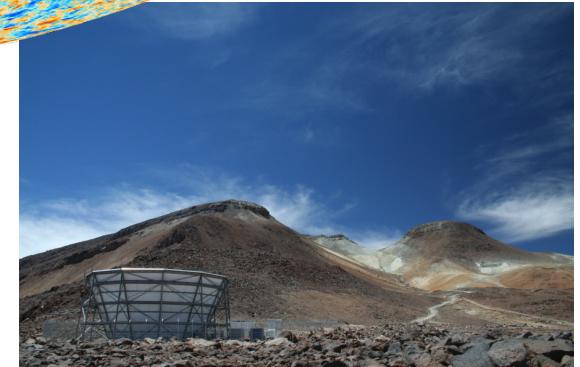


The Cosmic Microwave Background

Physics, Astrophysics, and Cosmology



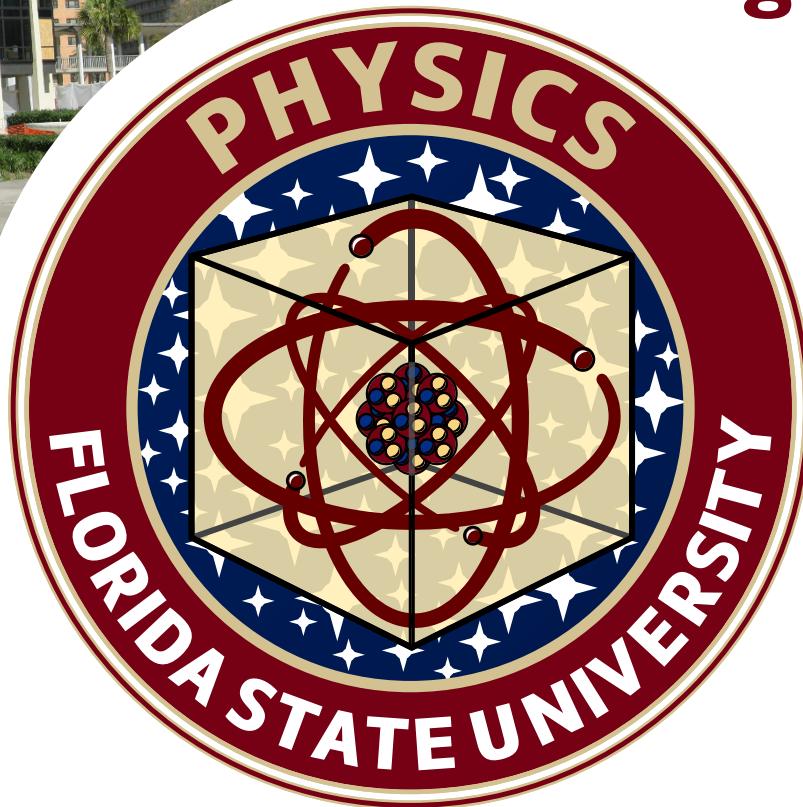
Kevin Huffenberger
Assoc. Prof., Dept. of Physics
Florida State University





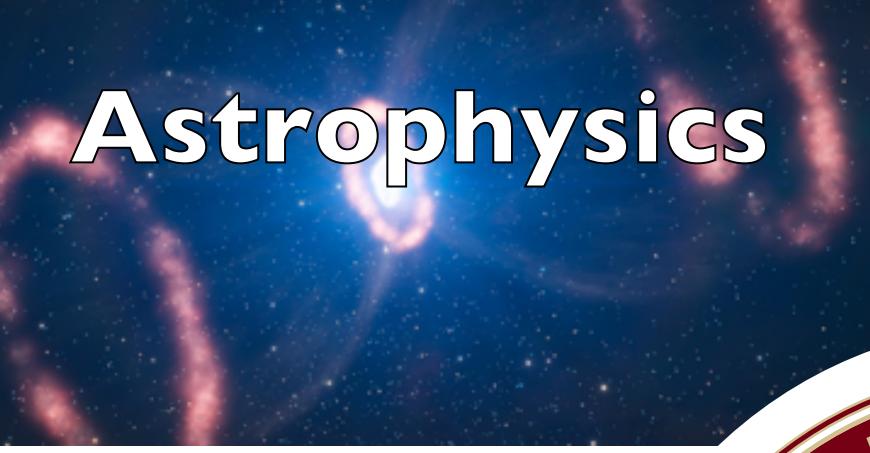
Keen building
Ugrad Phys Lab
Nuclear Res. Bldg
Maglab

WIMSE
SPS

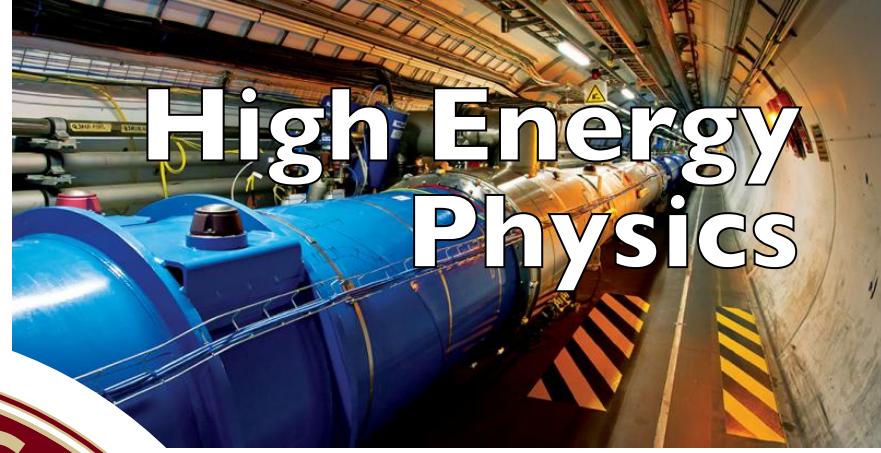


~45 Tenured / T. Track Faculty
~200 undergraduate majors
~150 graduate students

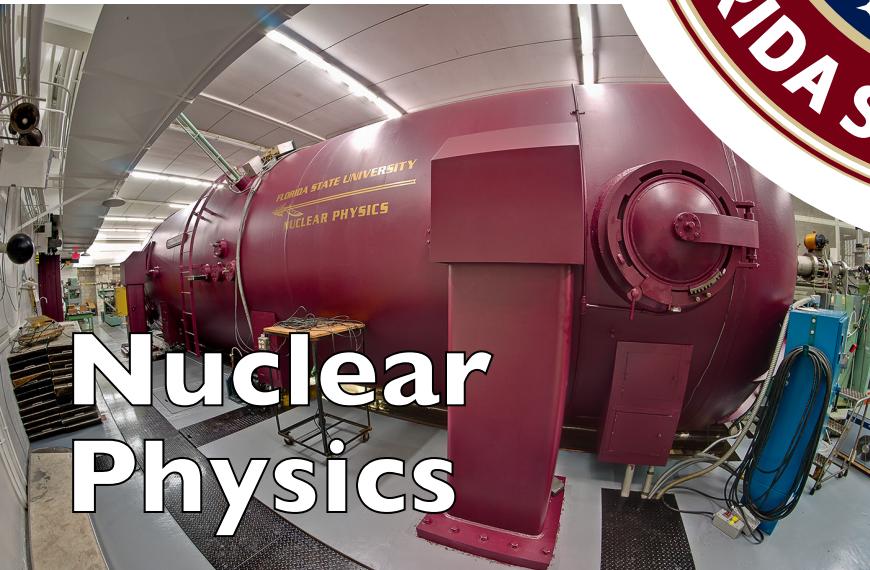
Astrophysics



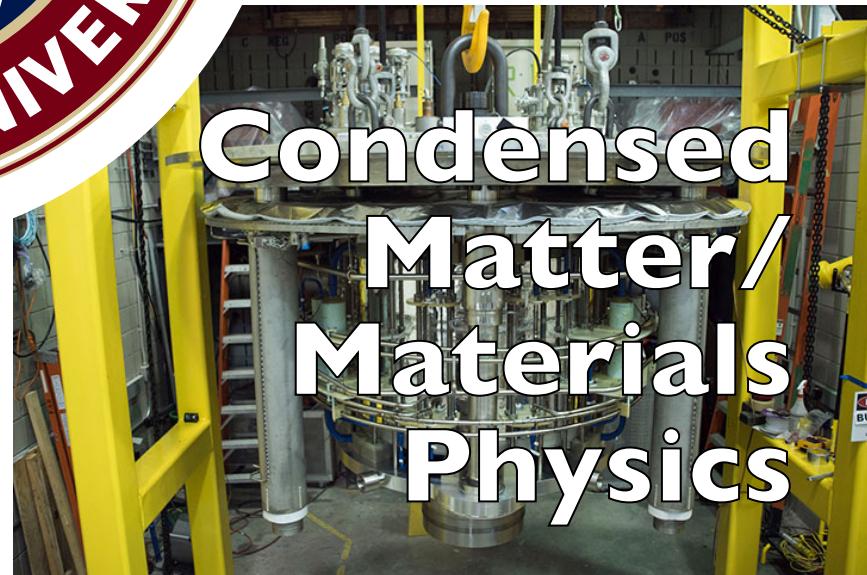
High Energy Physics

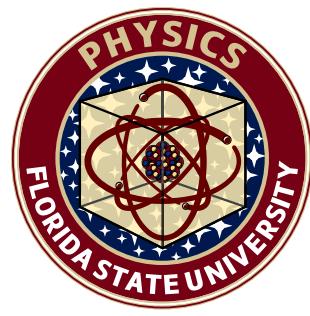


Nuclear Physics



Condensed Matter / Materials Physics





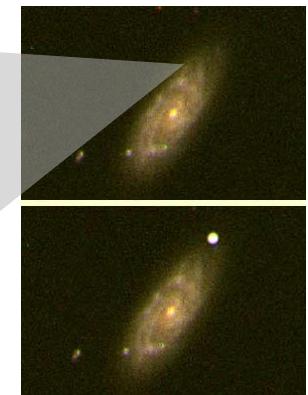
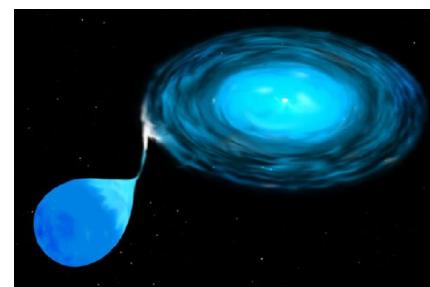
Astrophysics

Founded 2007... 2 T / 3 TT Faculty

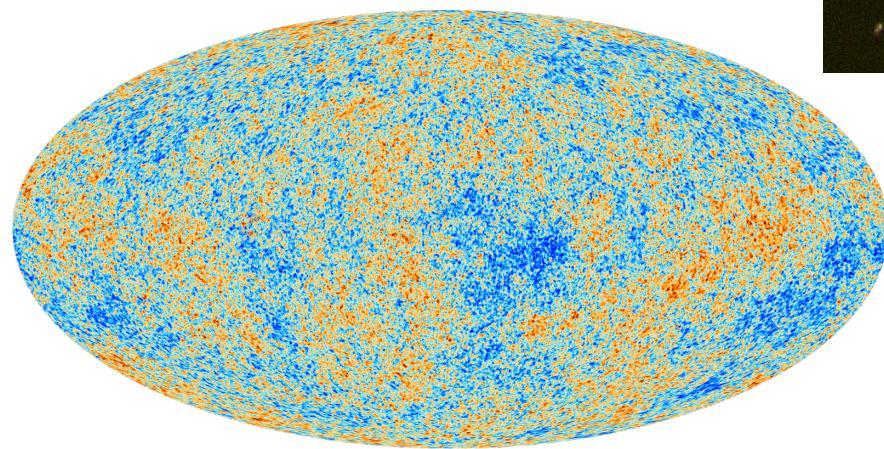
Star formation



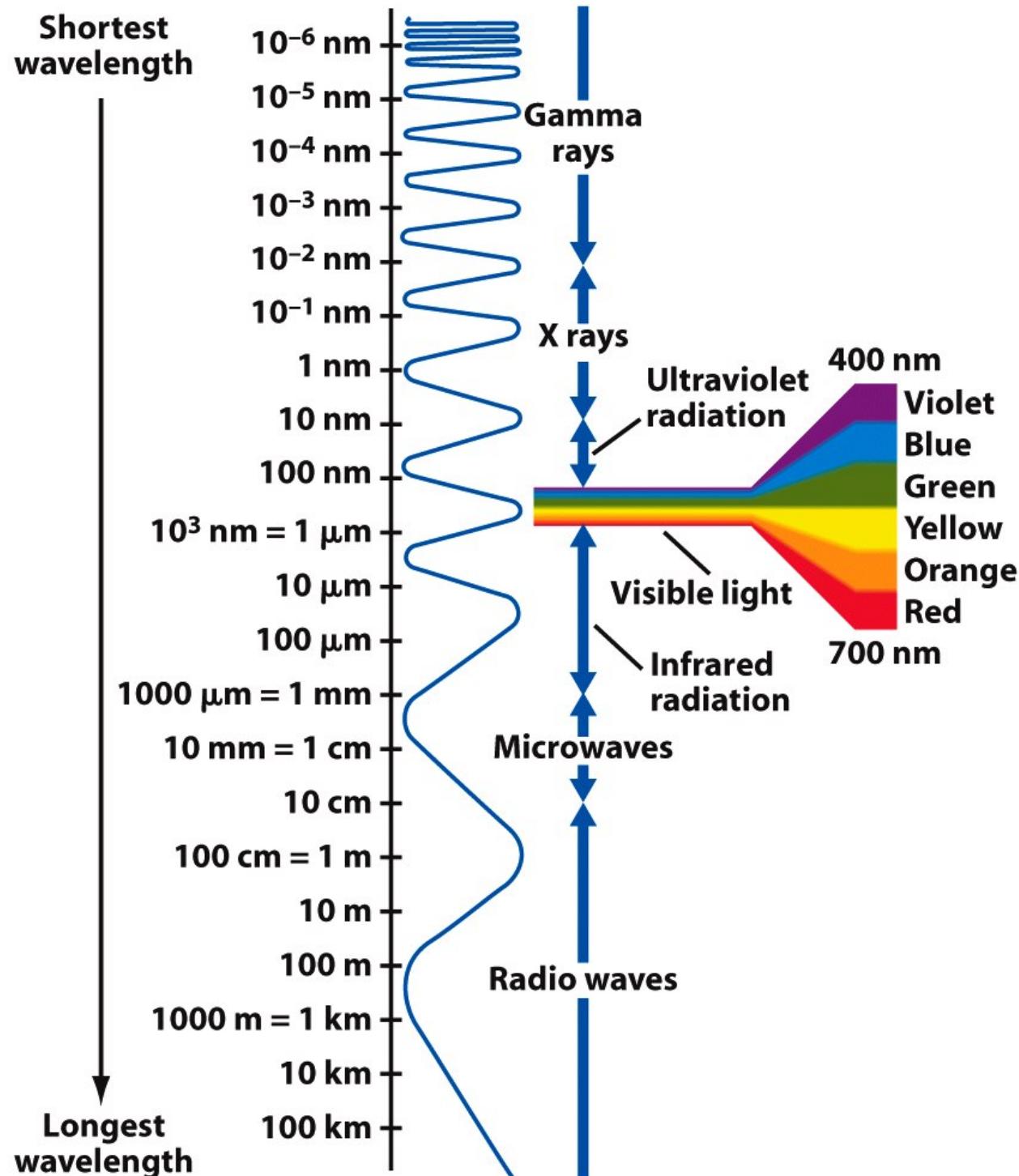
Stellar explosions



Cosmology



EM radiation characterized by wavelength



Practical uses of EM radiation



(a) Mobile phone:
radio waves



(b) Microwave oven:
microwaves



(c) TV remote:
infrared light



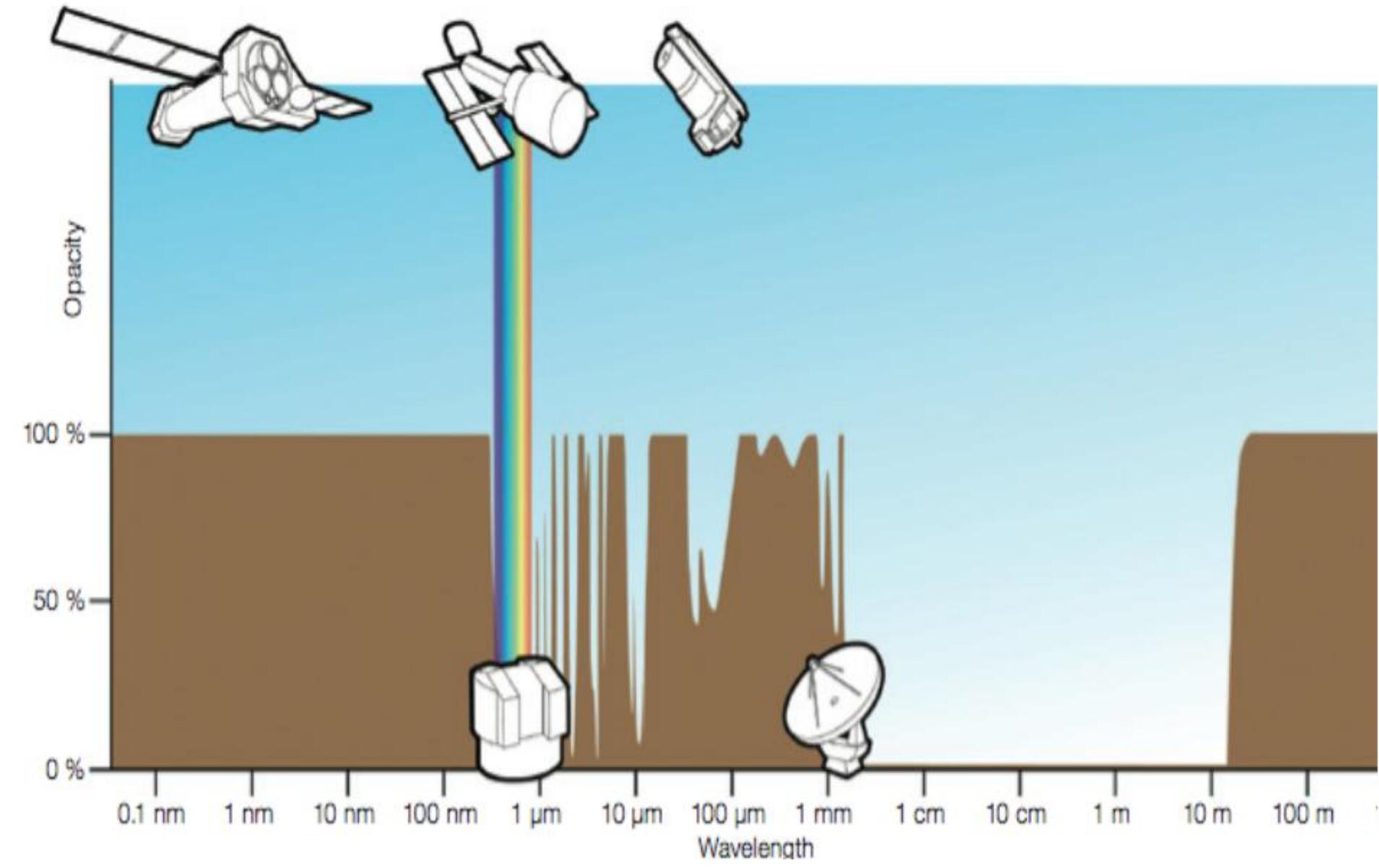
(d) Tanning booth:
ultraviolet light

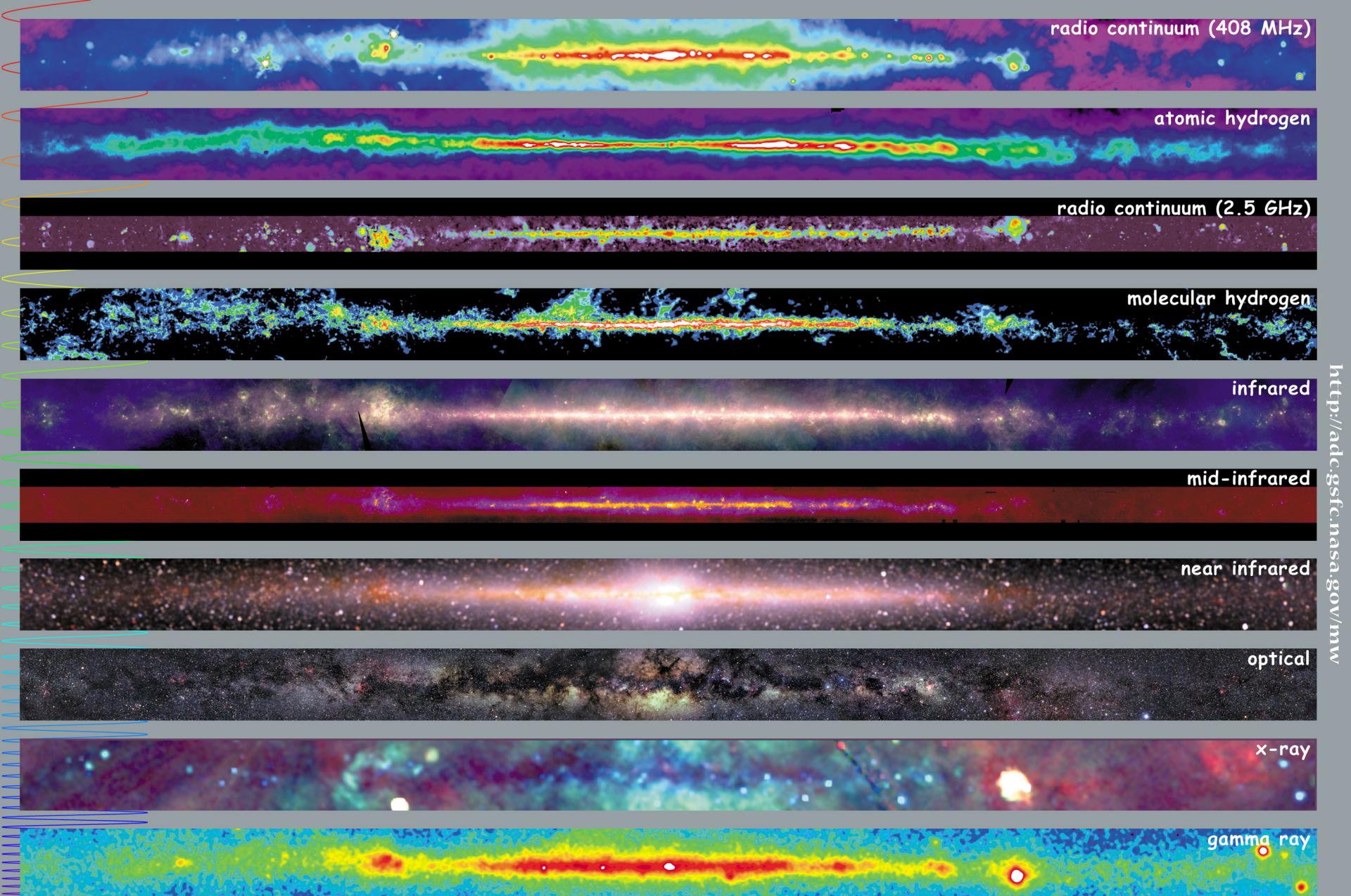


(e) Medical imaging:
X rays.



(f) Cancer
radiotherapy:
gamma rays





radio continuum (408 MHz)

atomic hydrogen

radio continuum (2.5 GHz)

molecular hydrogen

infrared

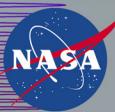
mid-infrared

near infrared

optical

x-ray

gamma ray



Multiwavelength Milky Way

Hubble Ultra Deep Field

HST • ACS



NASA, ESA, S. Beckwith (STScI) and The HUDF Team

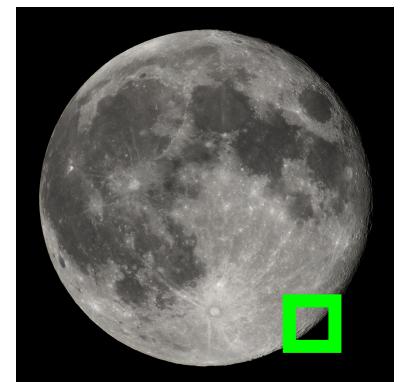
STScI-PRC04-07a



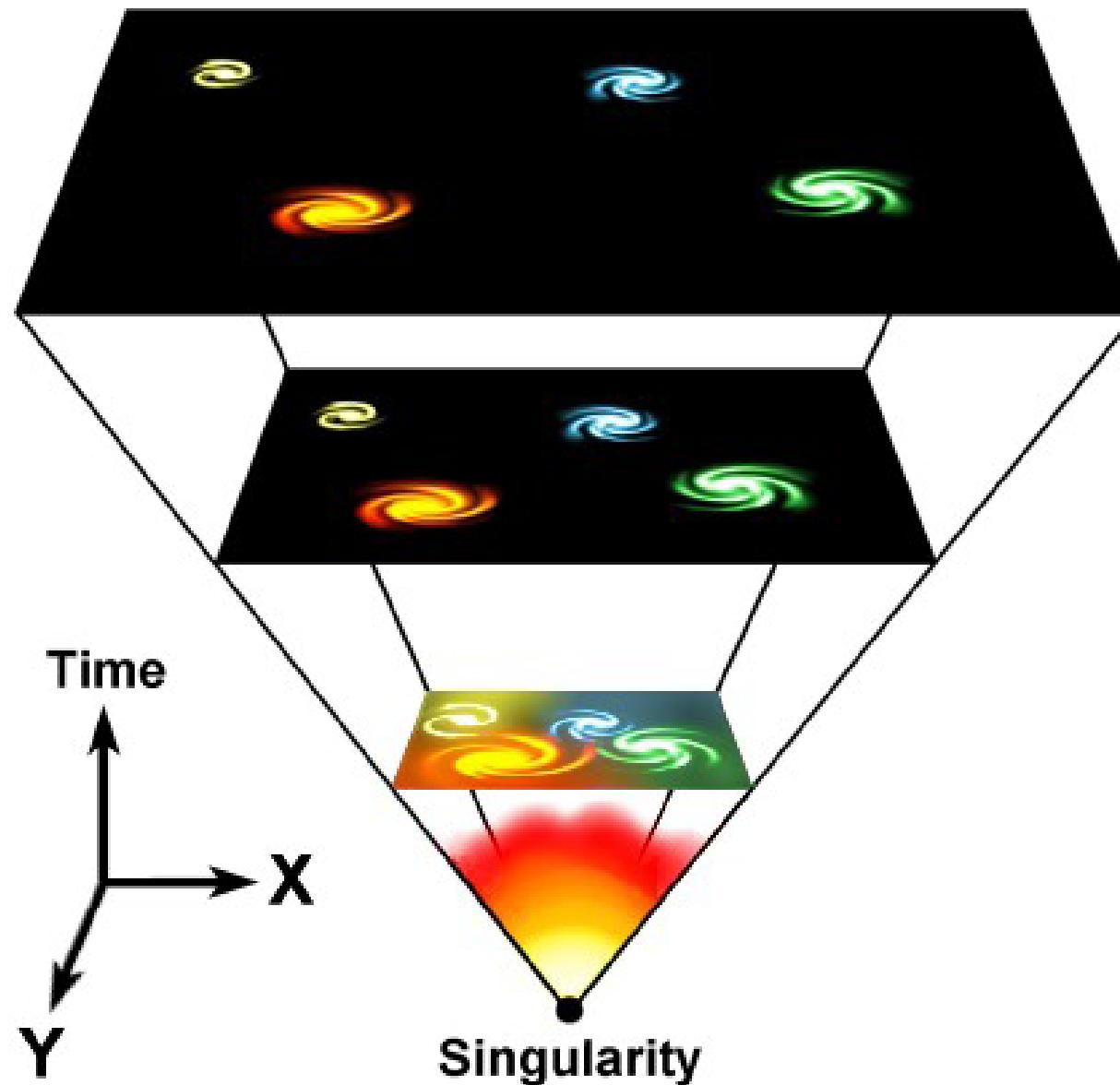
In Fornax,
11.0 arcmin²

1 mm² @ 1 m

13 million such
patches to cover
sky.



Expanding universe & the Big Bang





Opaque

last scattering

Transparent

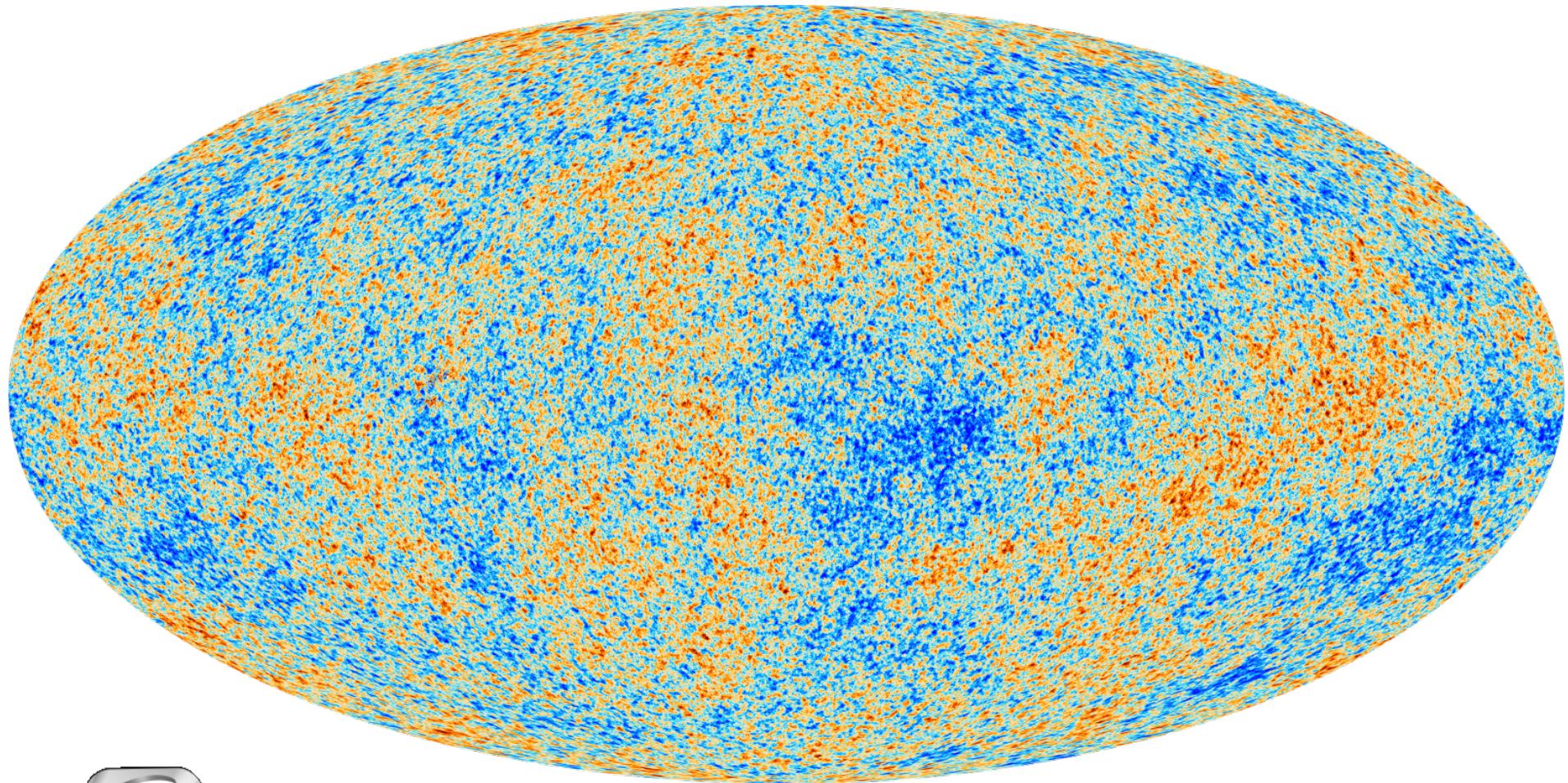
dark ages,
structure formation proceeds

Increasing distance,
lookback time,
mean density,
temperature

reionization,
1st stars



Cosmic Microwave Background



~ few hundred μK around mean T

"All the News
That's Fit to Print"

The New York Times

National Edition

Florida. A mix of sun and clouds. Afternoon showers. Highs 70s to near 80. Showers central and north tonight. Partly cloudy south. Lows 50s to 70s. Weather map, Page B10.

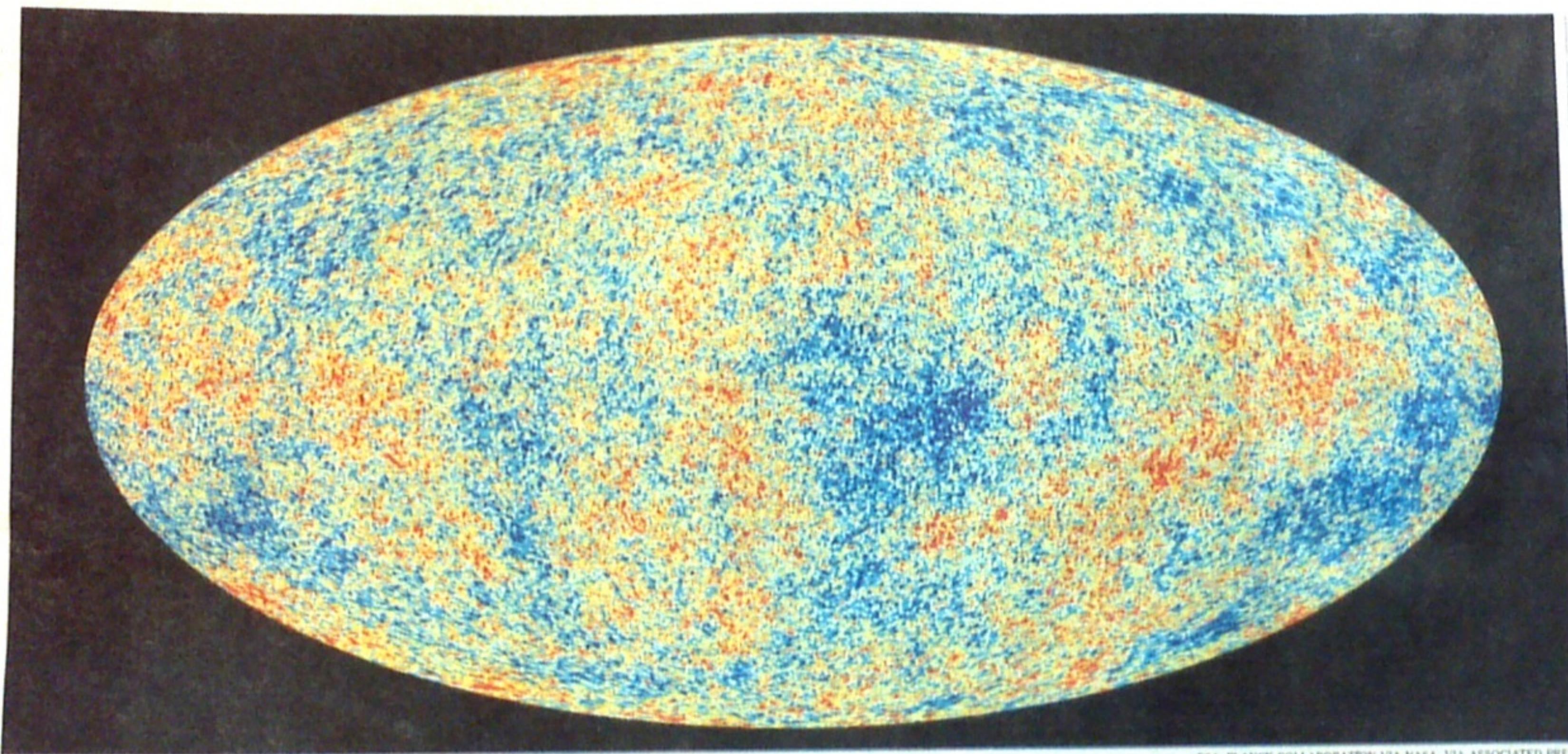
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Printed in Deerfield Beach

\$2.50



ESA, PLANCK COLLABORATION VIA NASA, VIA ASSOCIATED PRESS

The Cosmos, Back in the Day

An image from data recorded by a European Space Agency satellite shows a heat map of the universe as it appeared 370,000 years after the Big Bang. Page A10.

As Pollution Worsens in China,

Once Few, Women Hold More Power in Senate

PRESIDENT URGES ISRAELIS TO PUSH EFFORT FOR PEACE

APPEAL AIMED AT YOUNG

In Jerusalem, He Eases Stance on Settlement Halt Before Talks

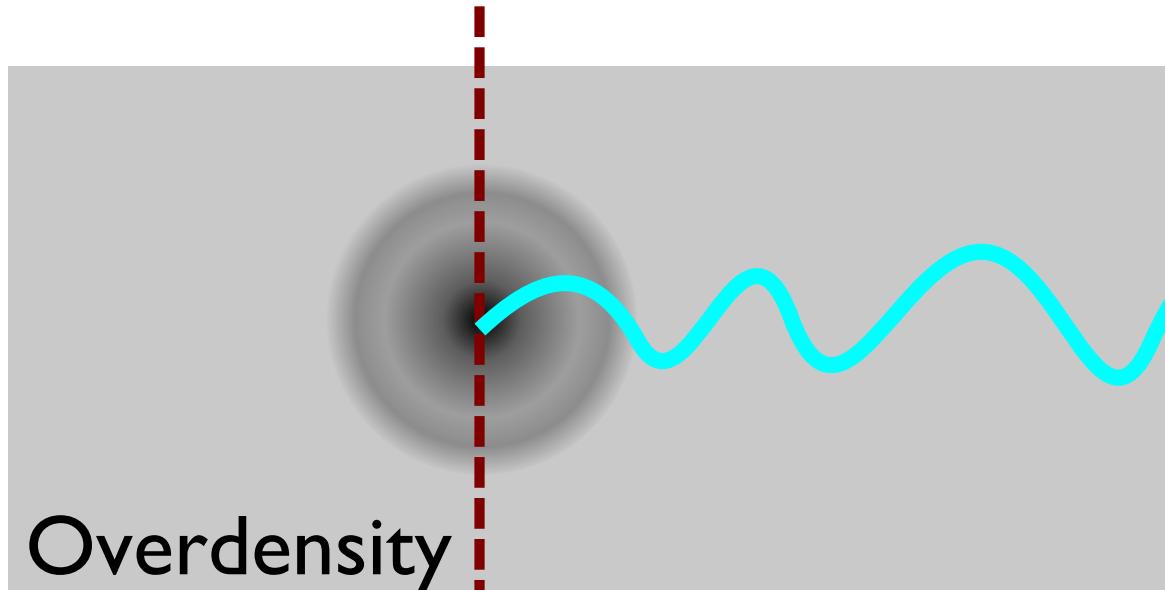
By MARK LANDLER

JERUSALEM — President Obama, appealing to very disparate audiences to solve one of the world's thorniest problems, moved closer on Thursday to the Israeli government's position on resuming long-stalled peace talks with the Palestinians, even as he passionately implored young Israelis to get ahead of their own leaders in the push for peace.

Addressing an enthusiastic crowd of more than 2,000, Mr. Obama offered a fervent, unsparing case for why a peace agreement was both morally just and in Israel's self-interest. Younger Israelis, Mr. Obama said, should empathize with their Palestinian neighbors living under occupation — or, as he put it, "look at the world through their eyes."

Probing gravitational potential

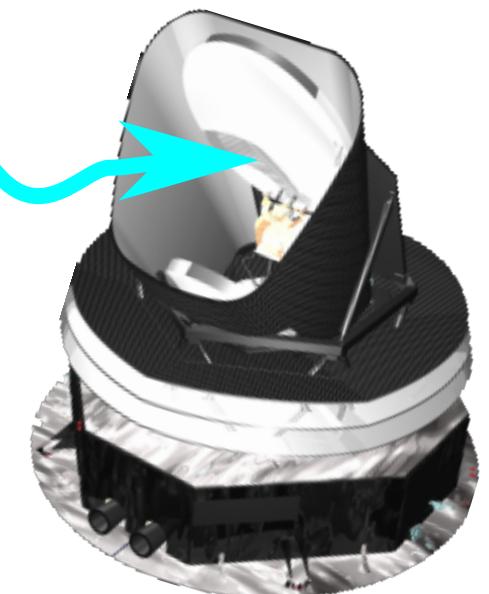
Recombination



Overdensity

Potential

cold photon!



Universe's contents

3 components cosmologically relevant:

1. **baryons, atoms, "normal matter".**
2. **cold dark matter, normal gravity, no pressure, no interactions.**
3. **dark "energy", $\Lambda = \text{Lambda}$, anti-gravity, cosmological constant, acceleration.**

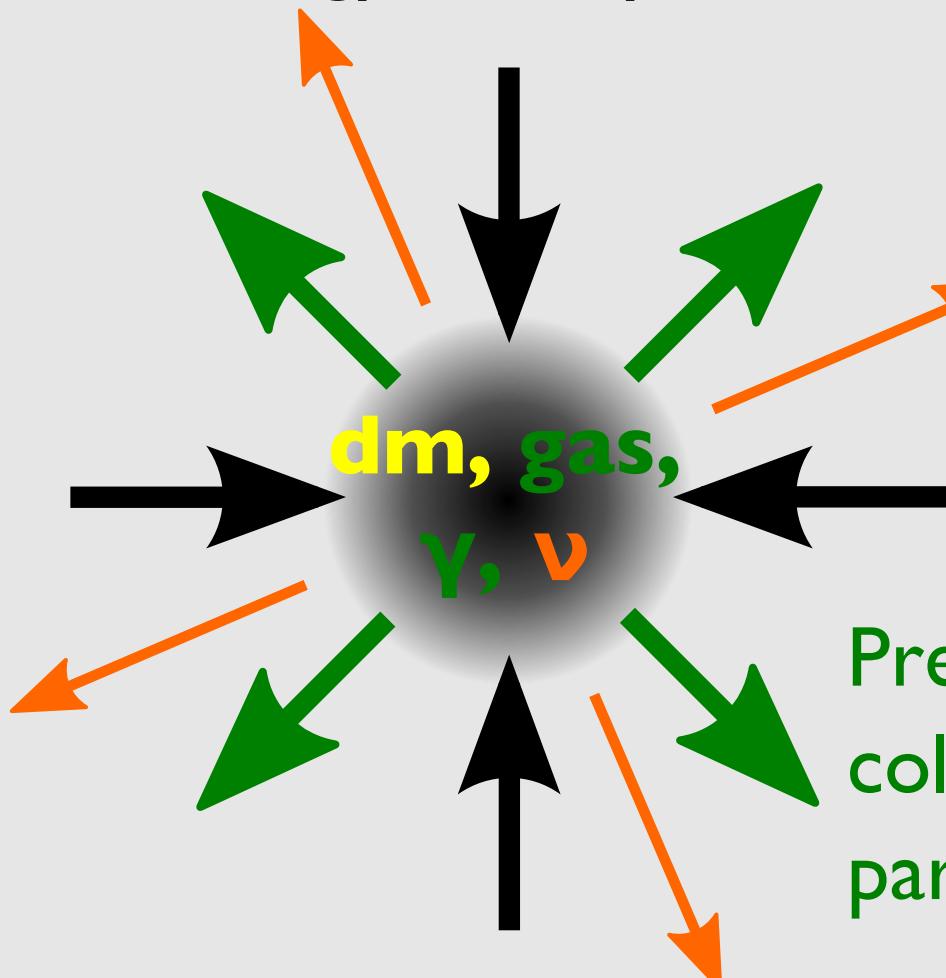
Evolution of overdensity

Expansion of
the universe

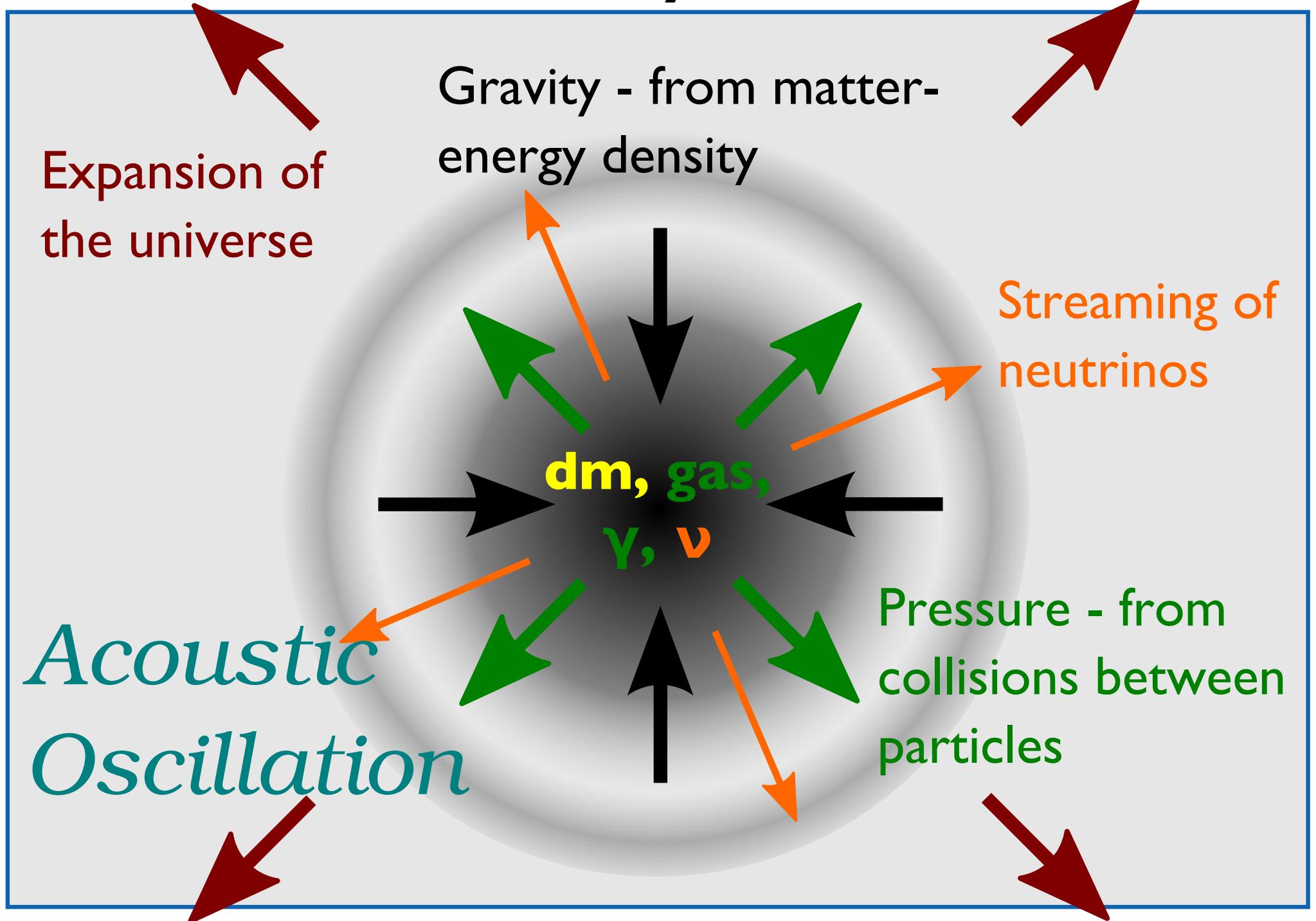
Gravity - from matter-
energy density

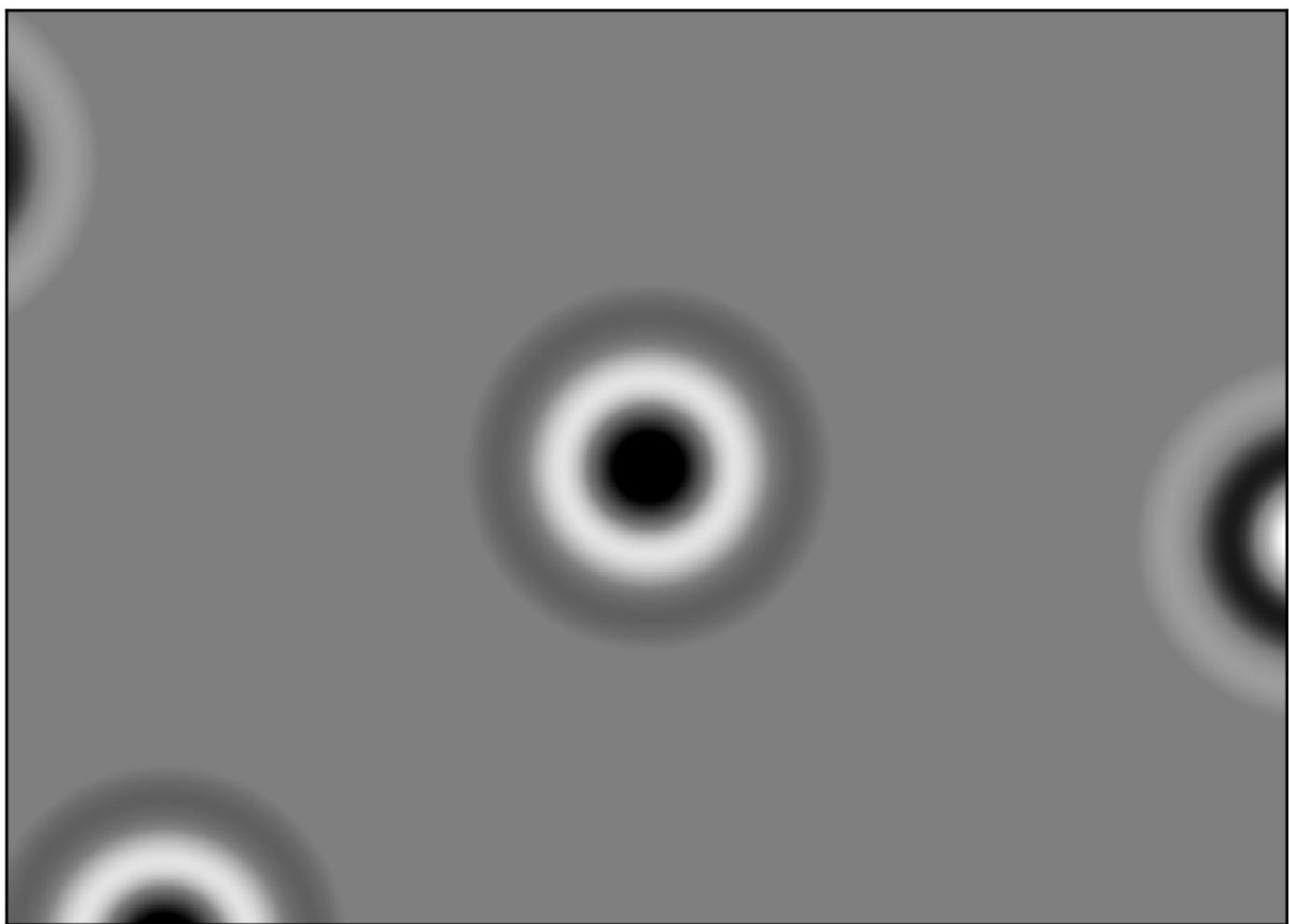
Streaming of
neutrinos

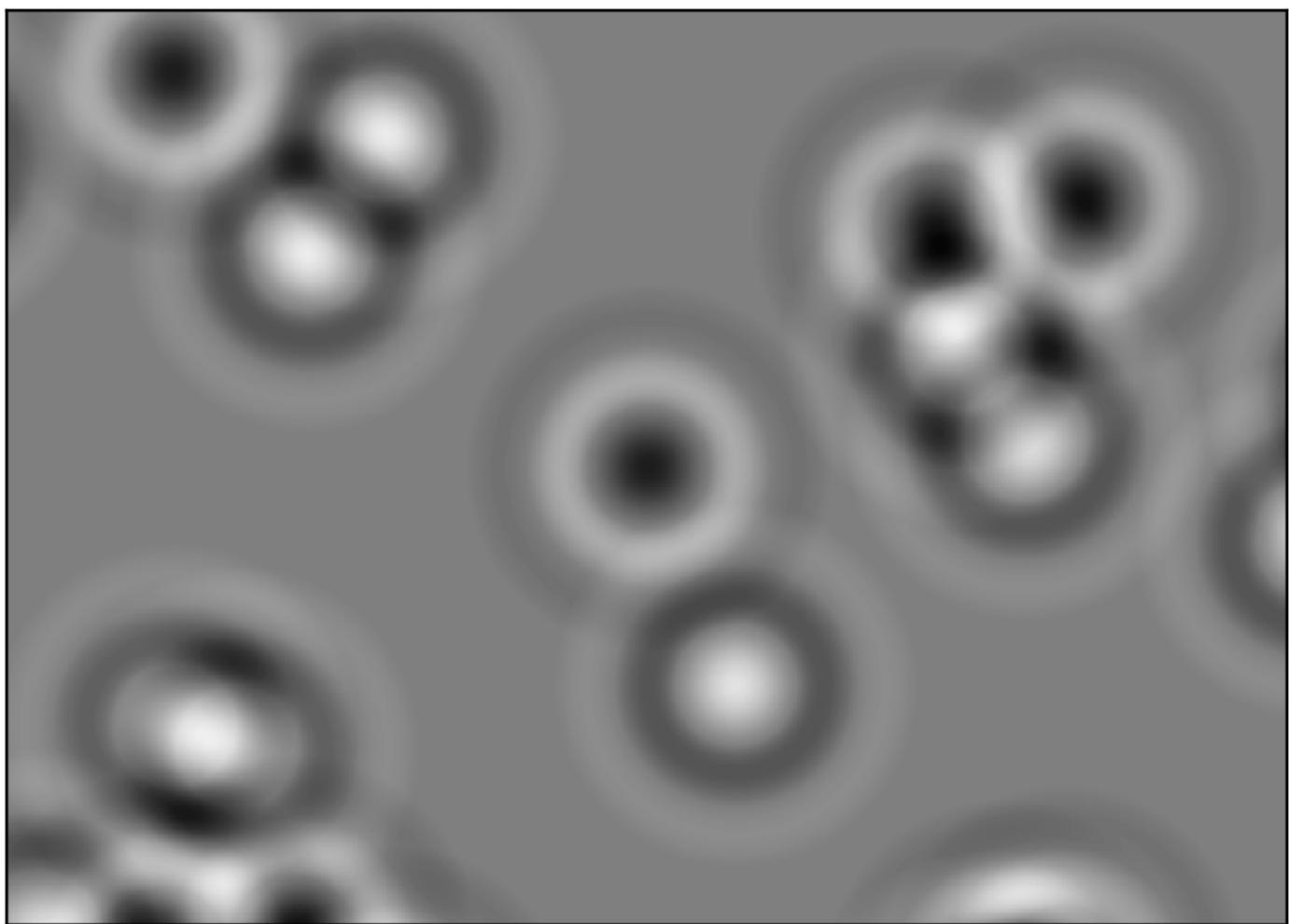
Pressure - from
collisions between
particles

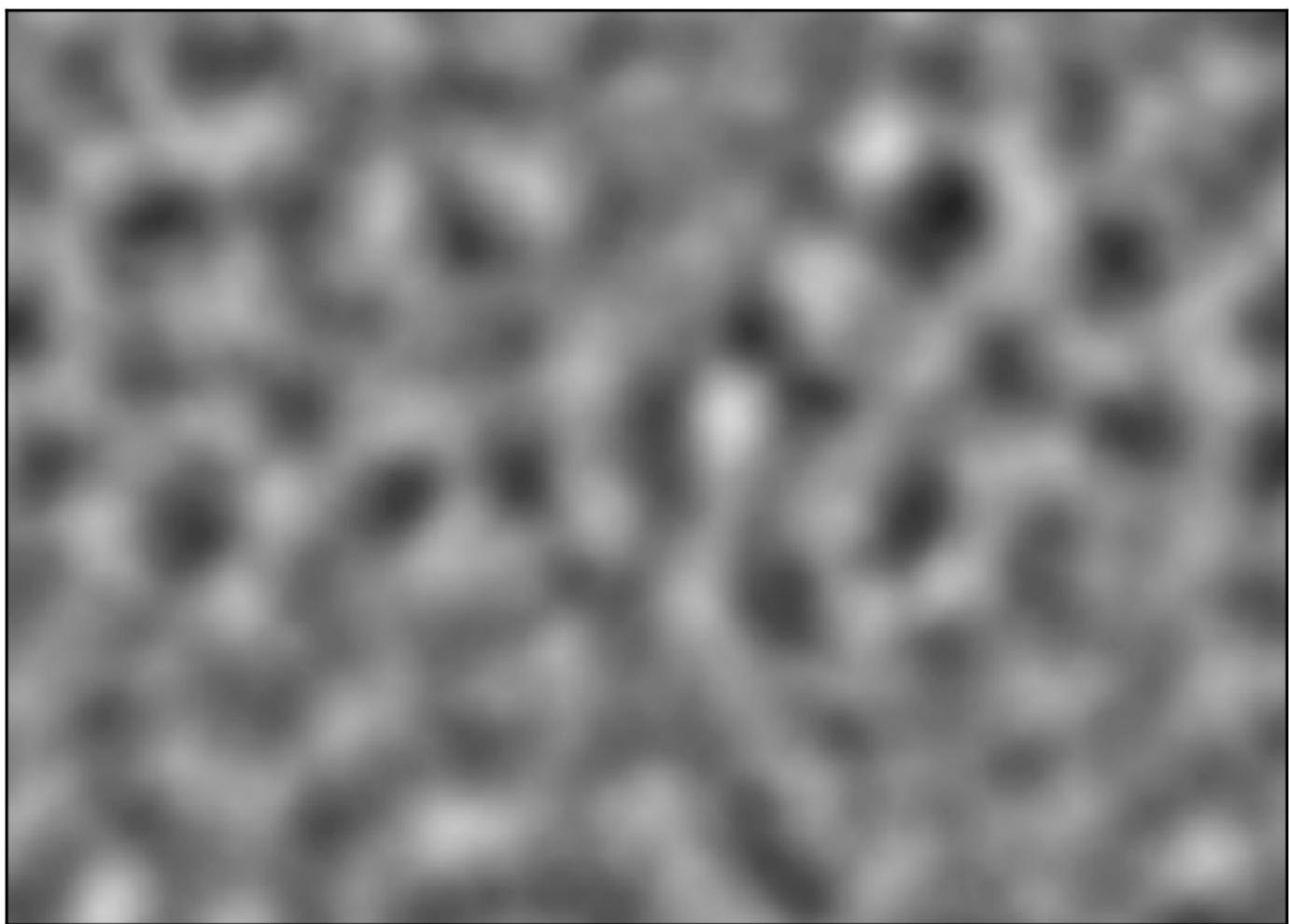


Evolution of overdensity

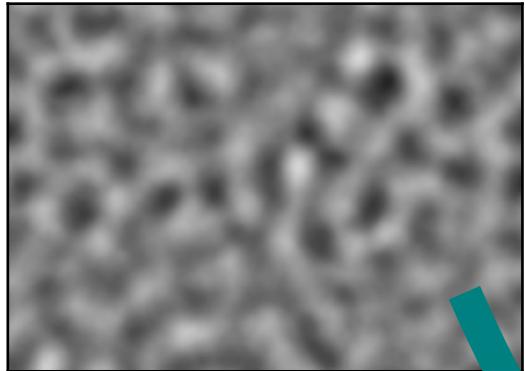




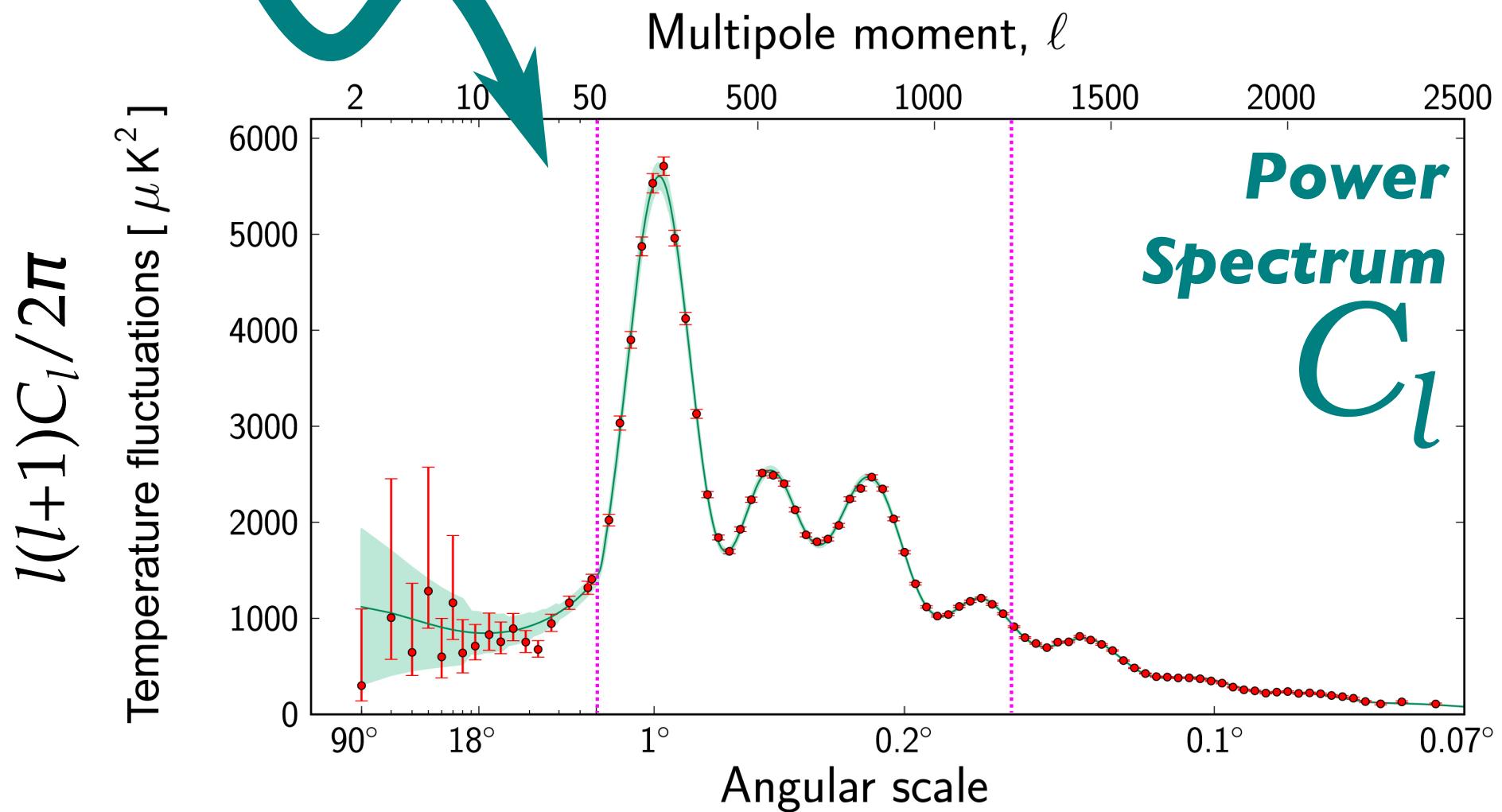


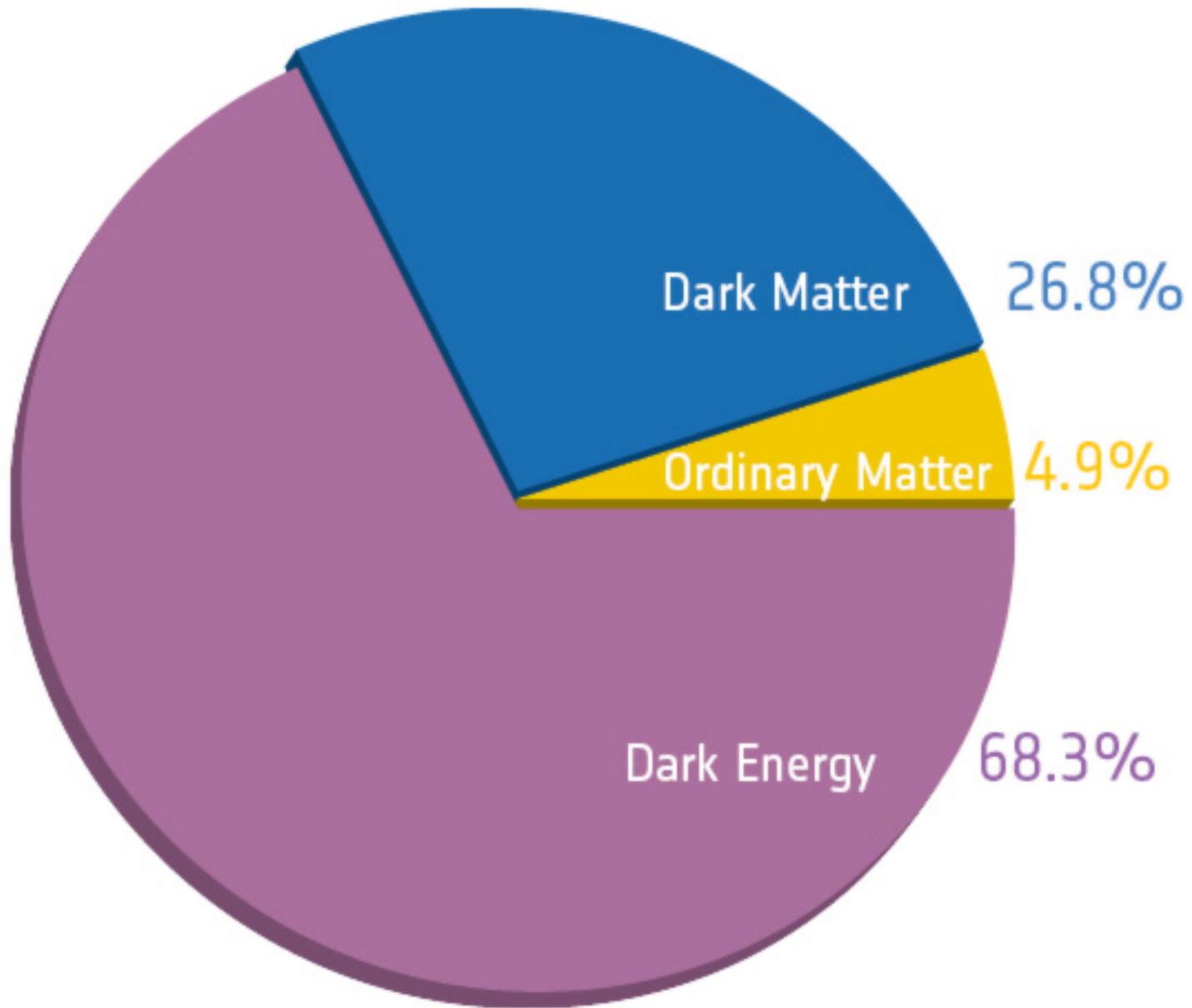


Correlations in harmonic space

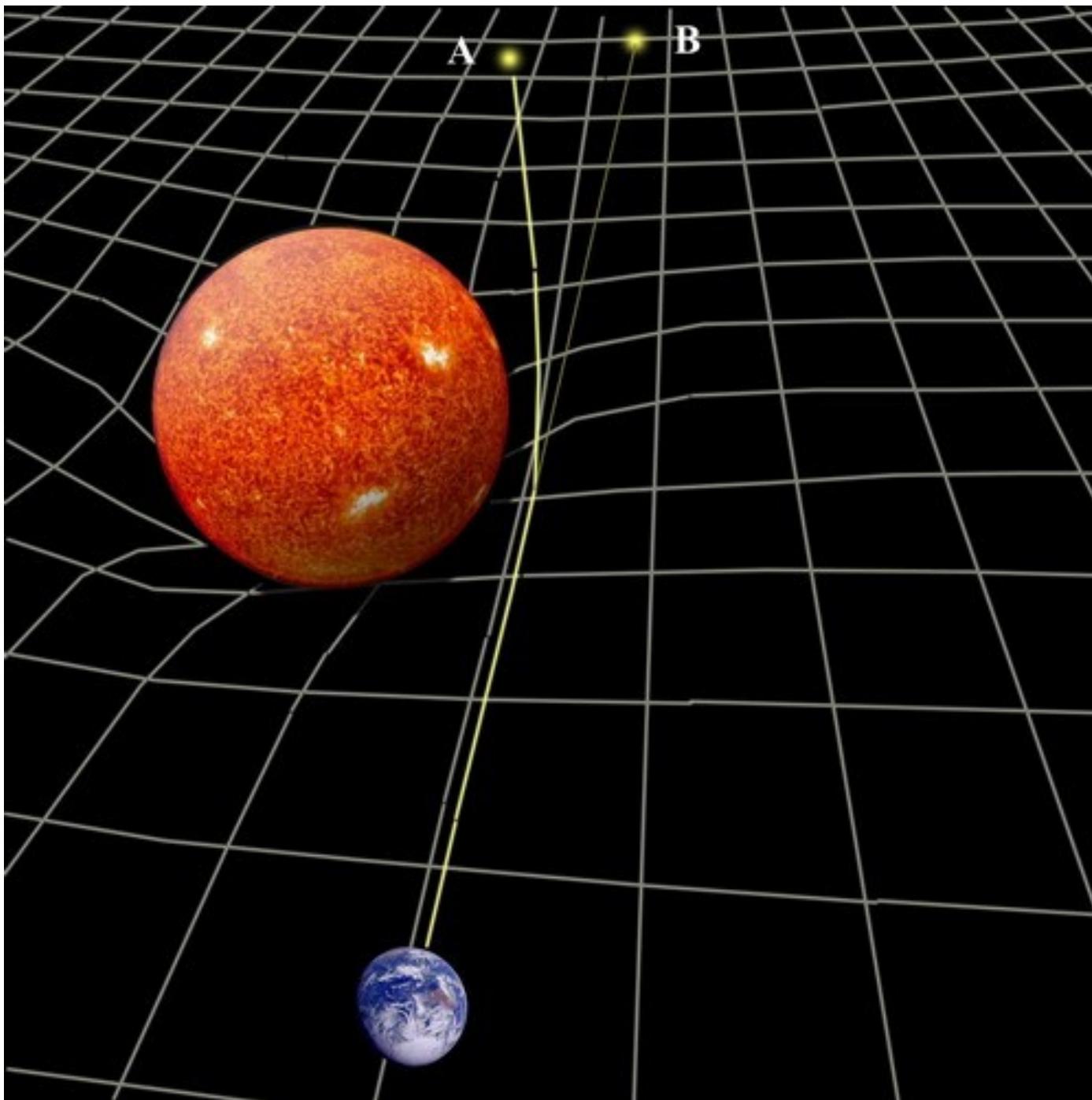


$$a_{lm} = \int d\Omega T(\theta, \phi) Y_{lm}^*(\theta, \phi)$$
$$\langle a_{lm} a_{l'm'}^* \rangle = C_l \delta_{ll'} \delta_{mm'}$$



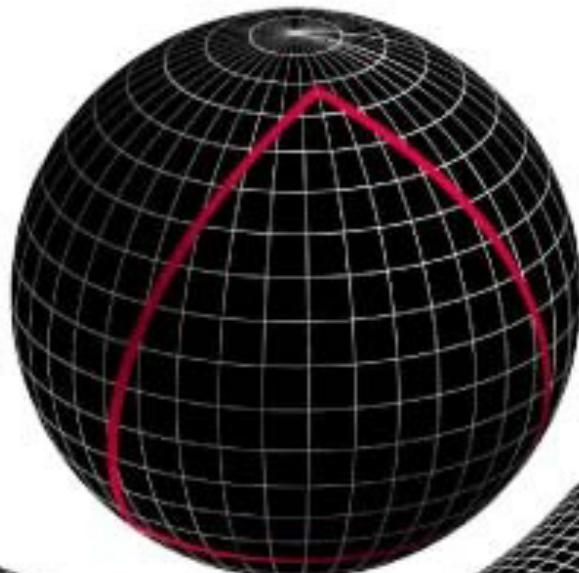


Gravity = curvature of spacetime.



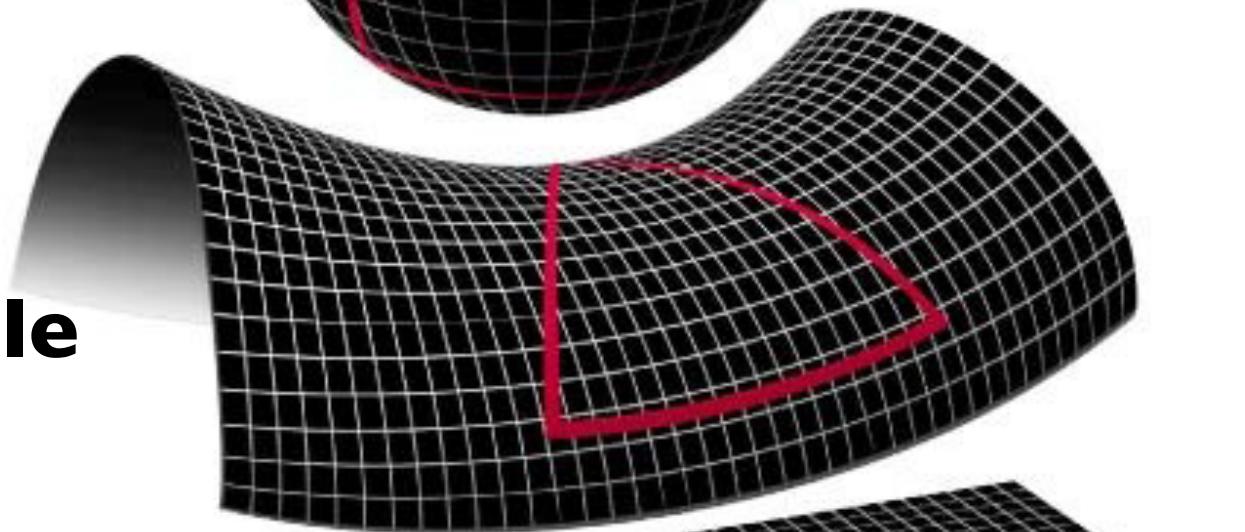
Gravity = curvature of spacetime.

ball

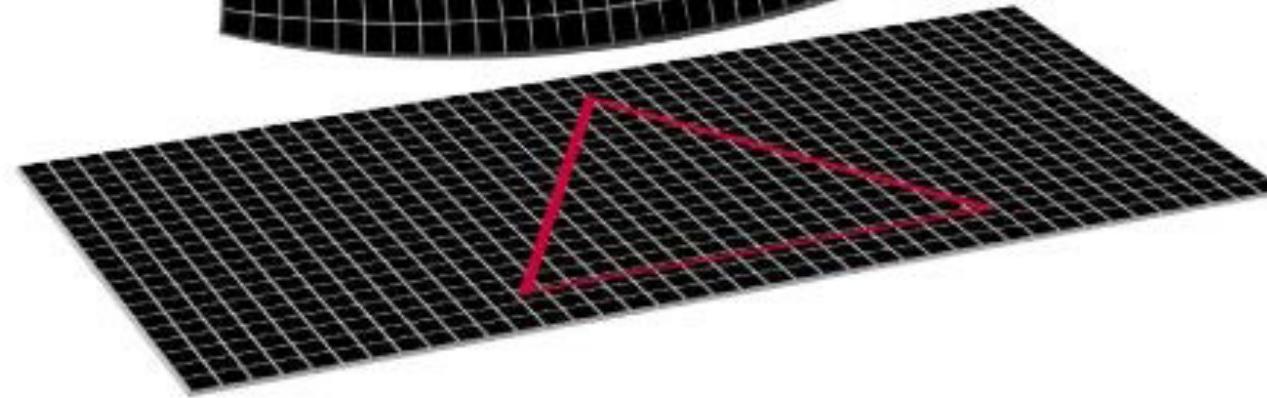


**2-d analogs for
3-d curved spaces
we can't visualize.**

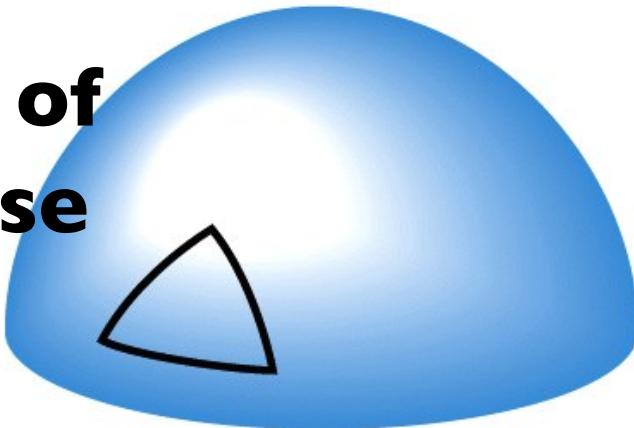
saddle



flat

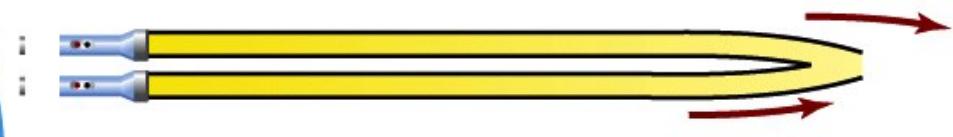


Geometry of the universe

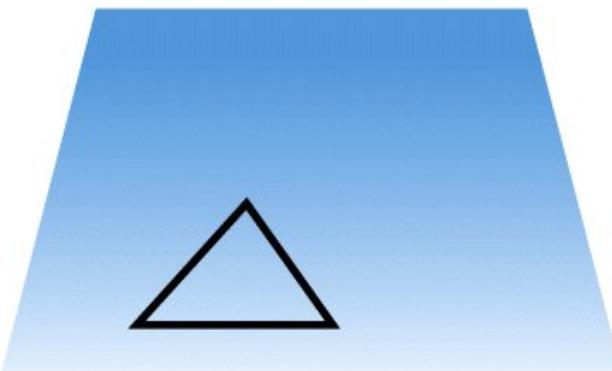


(a) Spherical space

$$\rho_0 > \rho_c, \Omega_0 > 1$$

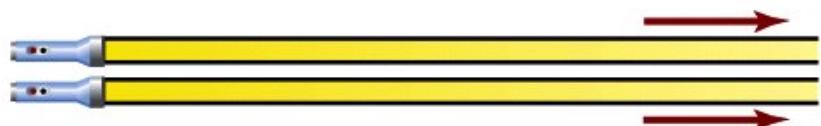


Parallel light beams converge

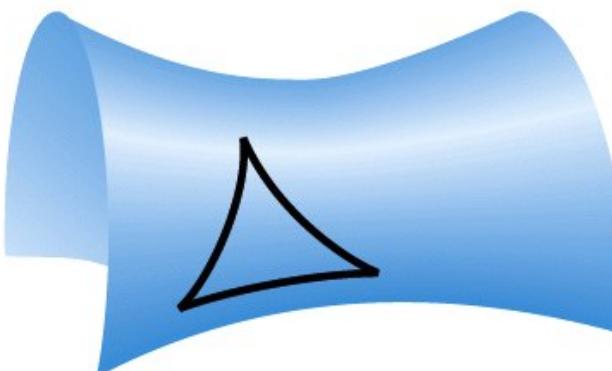


(b) Flat space

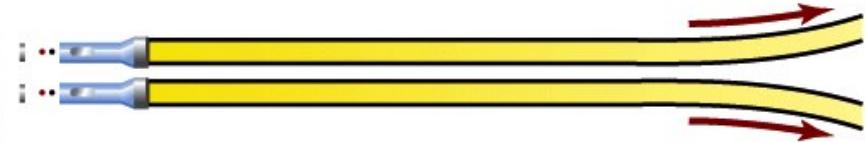
$$\rho_0 = \rho_c, \Omega_0 = 1$$



Parallel light beams remain parallel



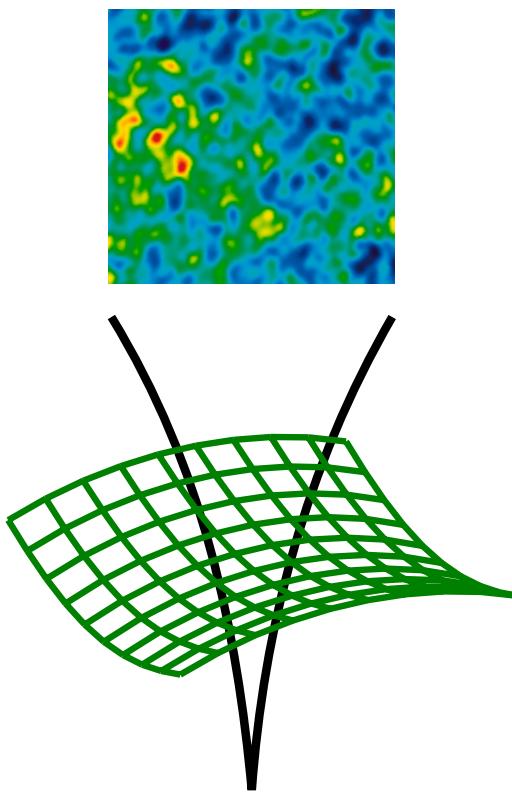
(c) Hyperbolic space



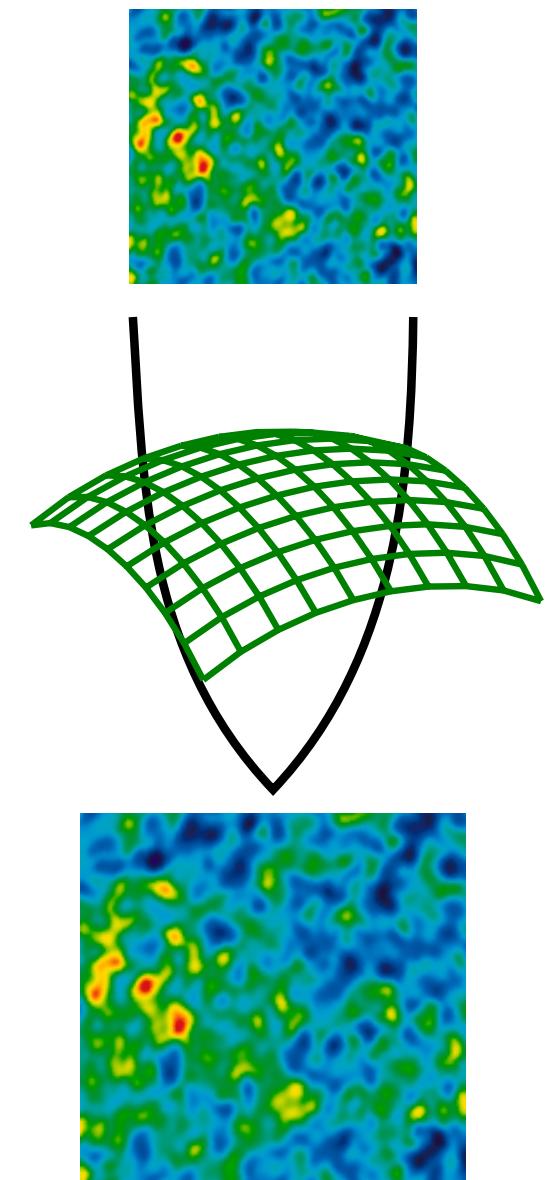
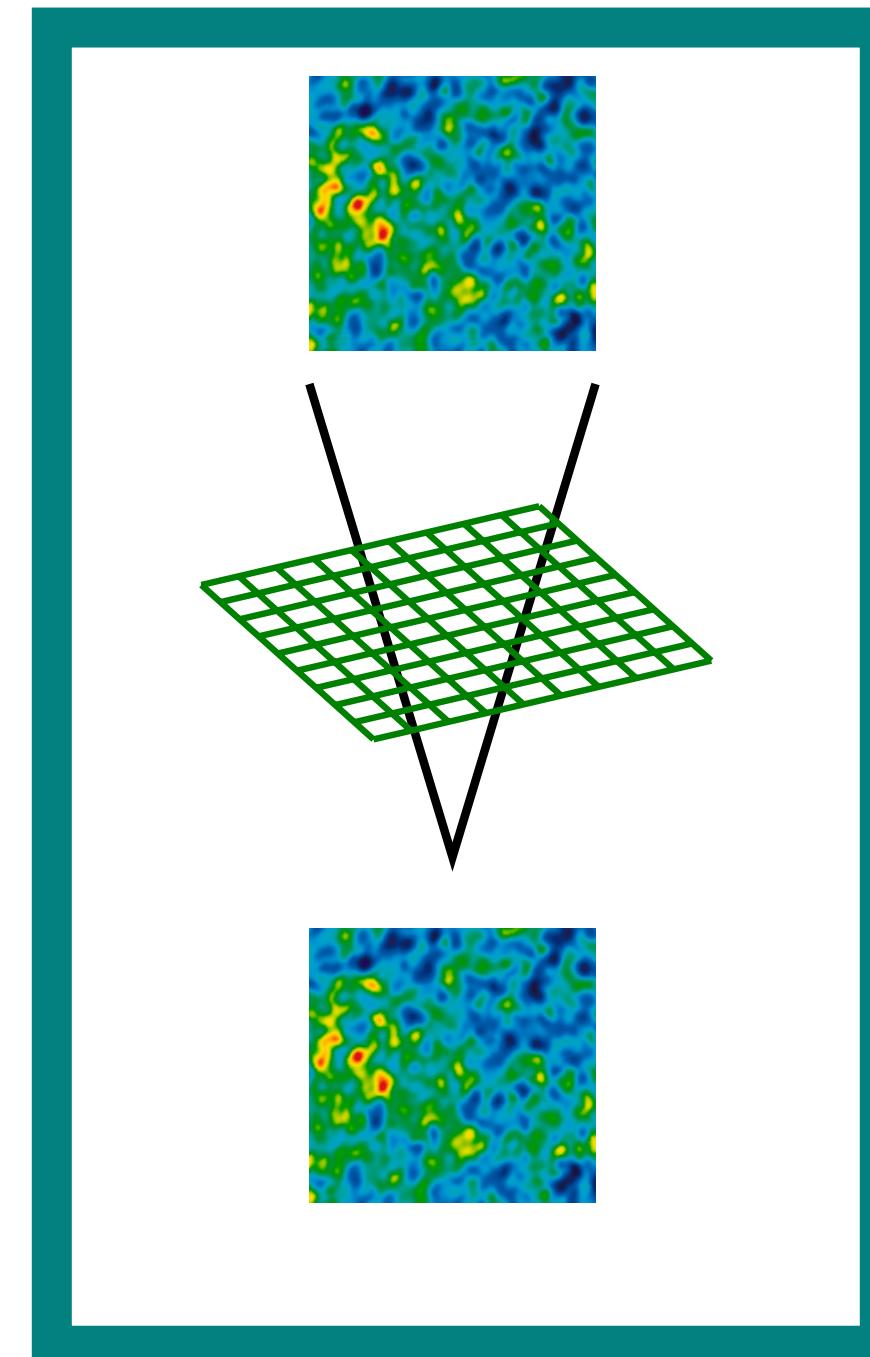
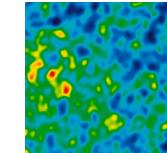
Parallel light beams diverge

Measuring curvature

**CMB
surface**

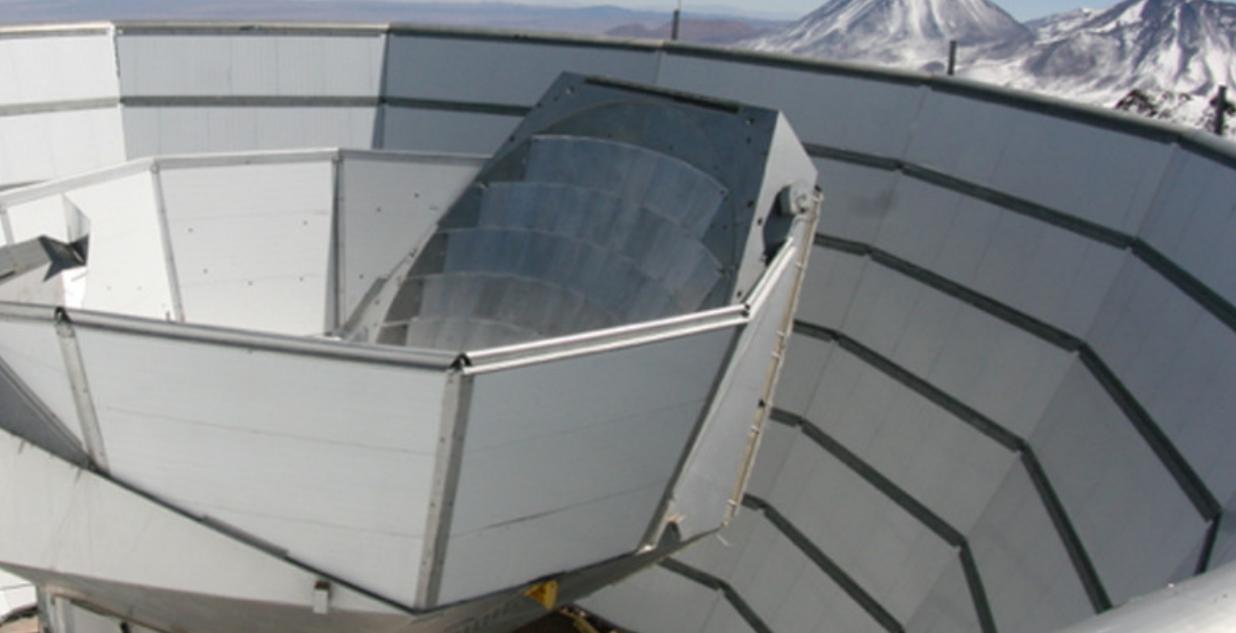


**CMB
observed**



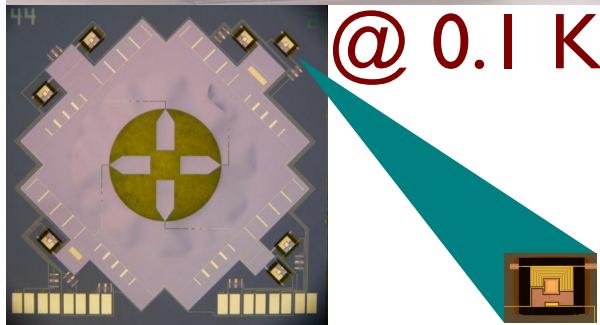
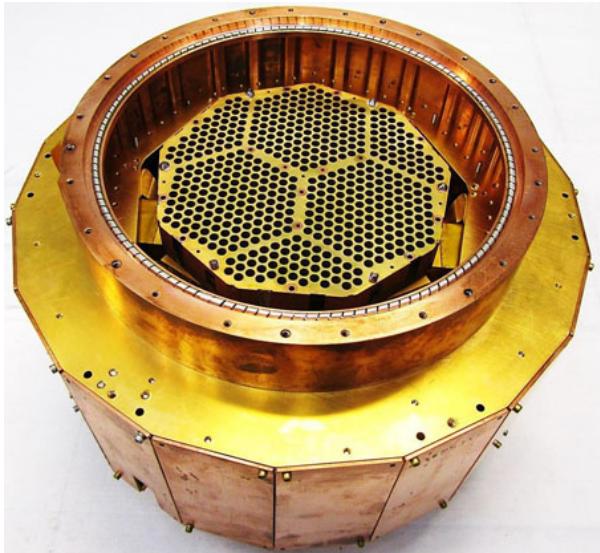
**Viewing standard ruler through
flat or curved spacetime.**

Atacama Cosmology Telescope and Simons Observatory





CMB Detector Technology



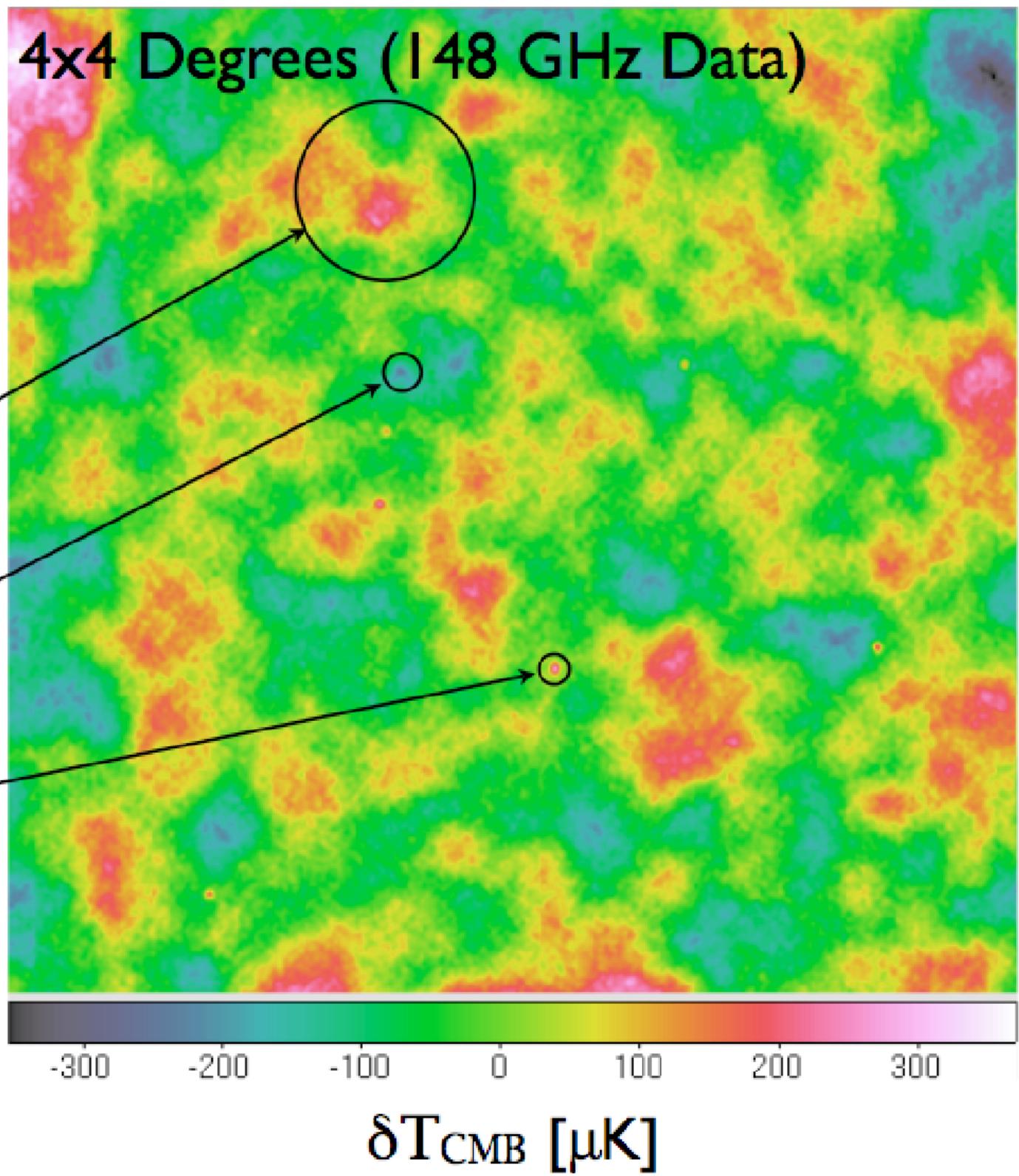
~ 7 mm

O Langley invented the **bolometer**,
Which is really a kind of thermometer.
You can measure the heat
Of a polar bear's seat
At a distance of half a kilometer.



ACT Map

CMB fluctuation
Cluster
Active Galactic Nucleus





[HOME](#)

Research Group

Postdocs



Aditya Rotti

Research projects: Isotropy statistics of the CMB; B-mode foregrounds; clustering of large scale structure.

Graduate students



Brittany Fuzia

Research projects: Stacking analysis of SZ clusters.



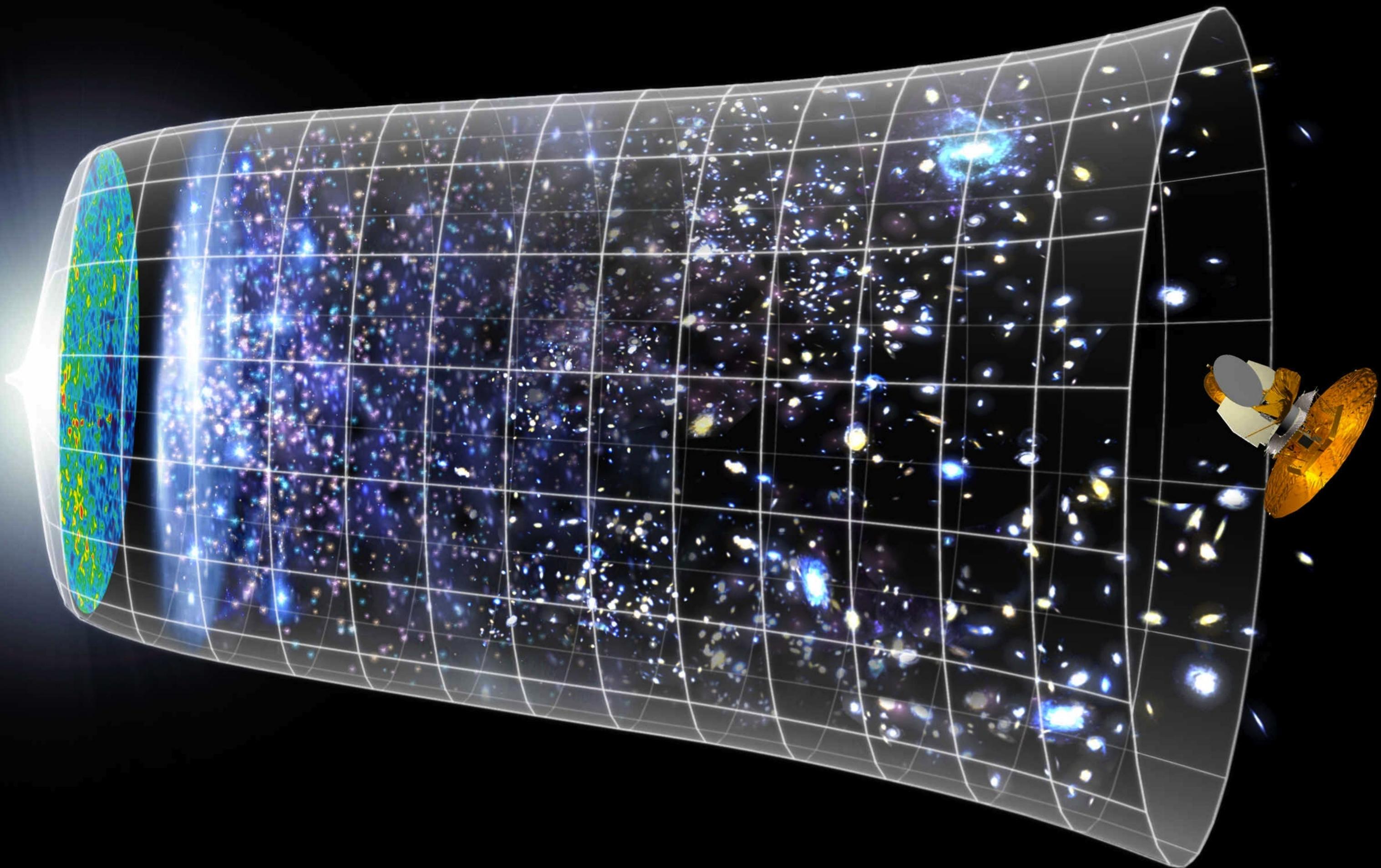
Vincent Lakey

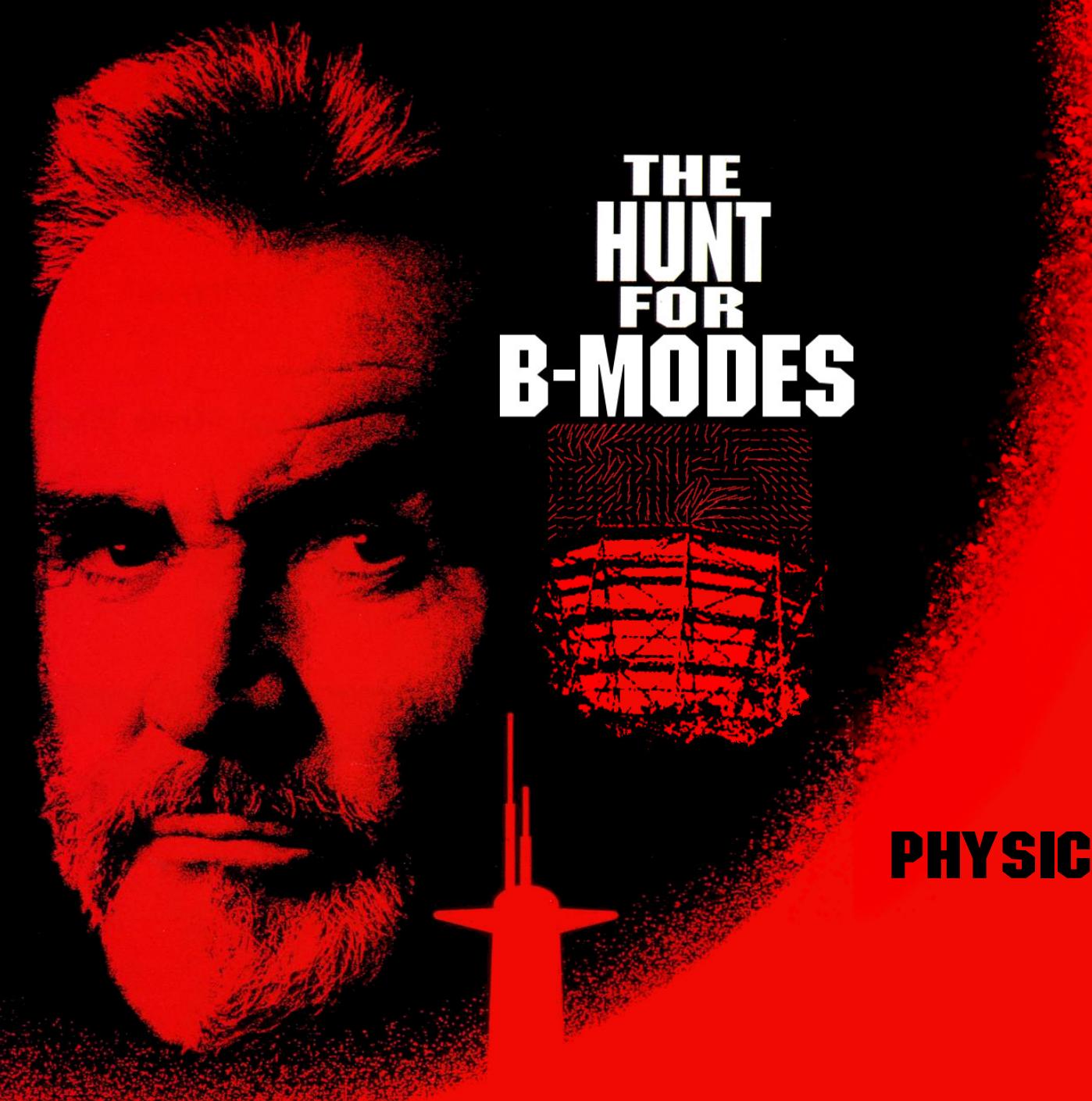
Research projects: CMB/X-ray background cross-correlations.



Felipe Maldonado

Research projects: Joint analysis of CMB lensing and large scale structure.





THE HUNT FOR B-MODES

**POLARIZATION
SIGNATURE OF
GRAVITY WAVES**

**DISTINCTIVE OF
INFLATION IN EARLY
UNIVERSE**

**PHYSICS AT GRAND-UNIFIED-
SCALE ENERGIES**

ACT, SIMONS OBSERVATORY, CMB-S4, MANY OTHERS

The Simons Observatory

United States

- Arizona State University
- Carnegie Mellon University
- Columbia University
- Cornell University
- Florida State
- Haverford College
- Johns Hopkins University
- Lawrence Berkeley National Laboratory
- NASA/GSFC
- NIST
- Princeton University
- Rutgers University
- Stanford University/SLAC
- Stony Brook
- University of California - Berkeley
- University of California – San Diego
- University of Illinois at Urbana-Champaign
- University of Michigan
- University of Pennsylvania
- University of Pittsburgh
- University of Southern California
- West Chester University

- 8 Countries
- 35+ Institutions
- 160+ Researchers

Canada

- CITA/Toronto
- Dalhousie University
- Dunlap Institute/Toronto
- McGill University
- University of British Columbia

Chile

- Pontificia Universidad Catolica
- University of Chile

Europe

- APC - France
- Cardiff University
- Imperial College
- Manchester University
- Oxford University
- SISSA – Italy

Japan

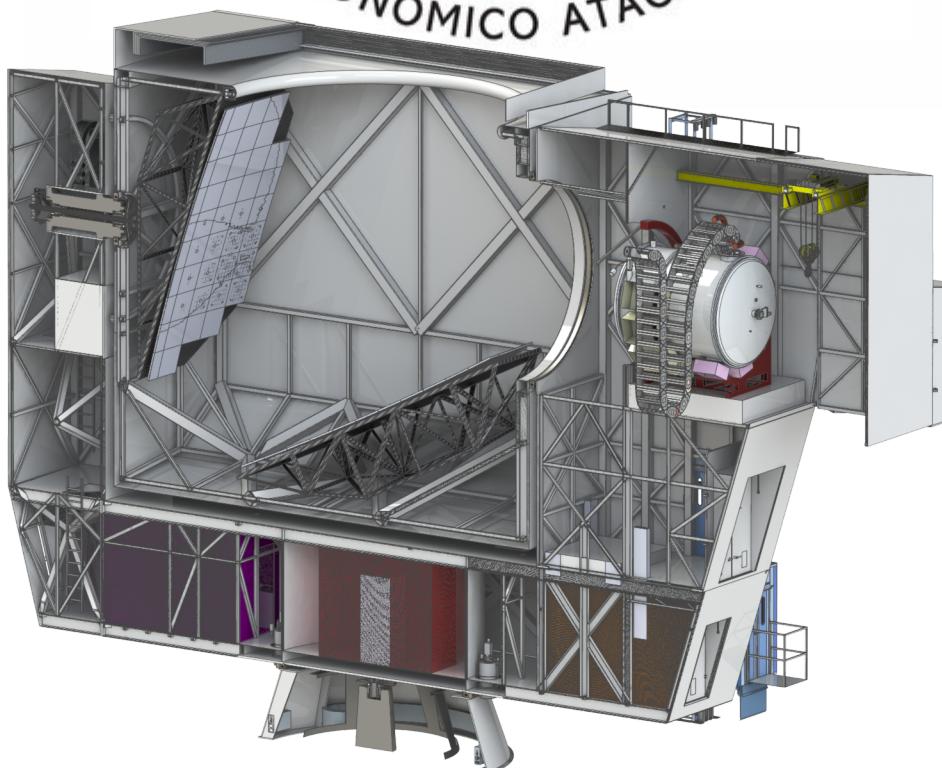
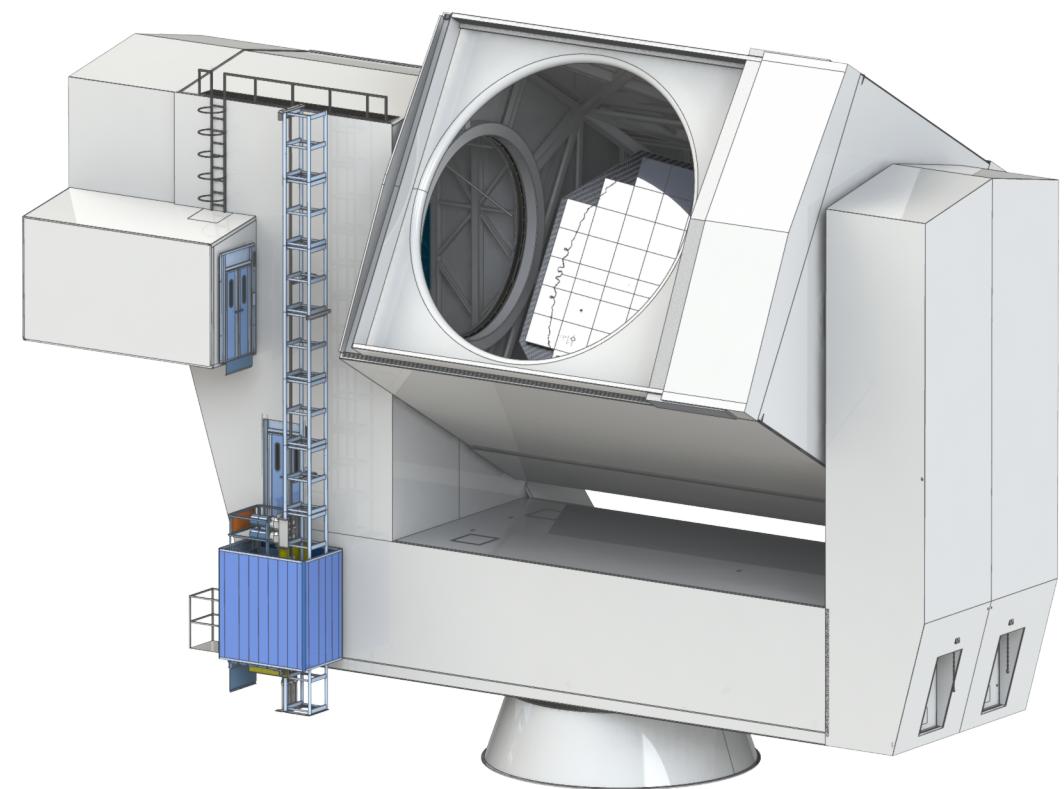
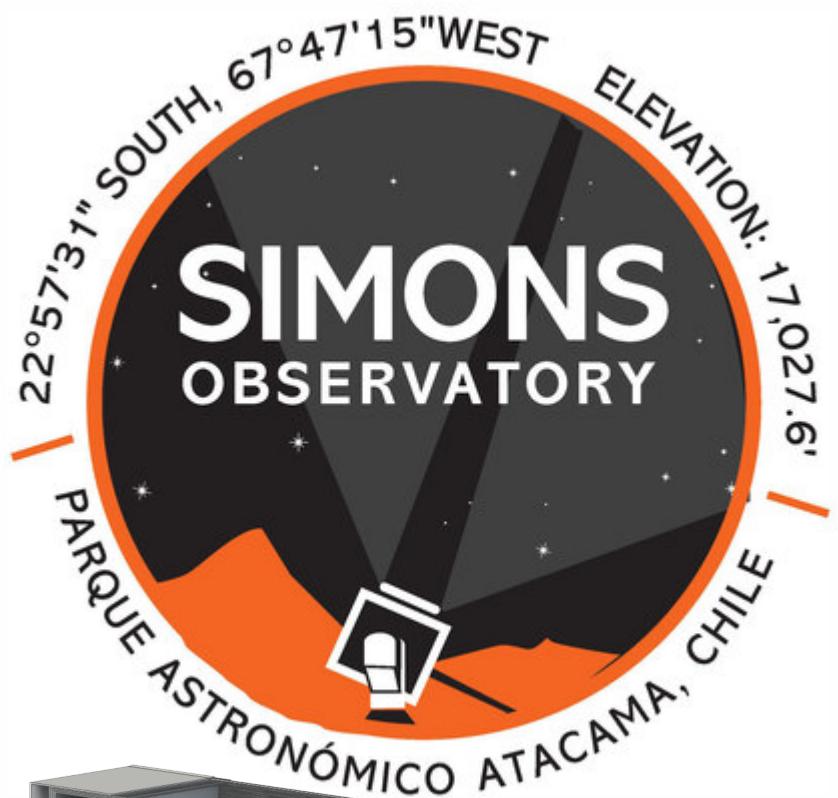
- KEK
- IPMU

South Africa

- Kwazulu-Natal, SA

Simons Observatory

First light 2020



Conclusions

What are the contents?

Mostly dark energy, with some dark matter, and a small fraction of normal atoms.

But what are dark energy and dark matter?

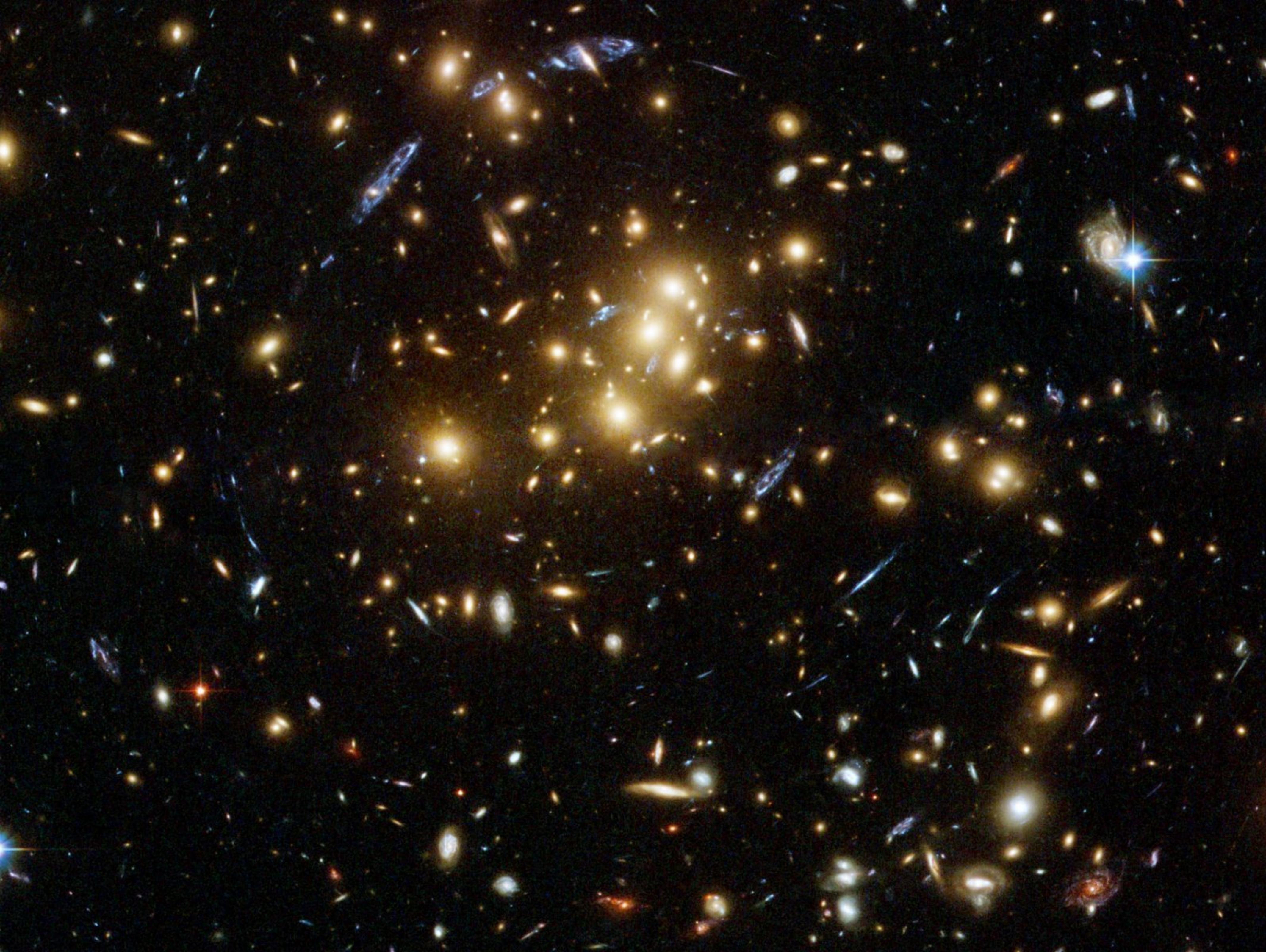
What's the space-time like?

Measurements are consistent with flat.

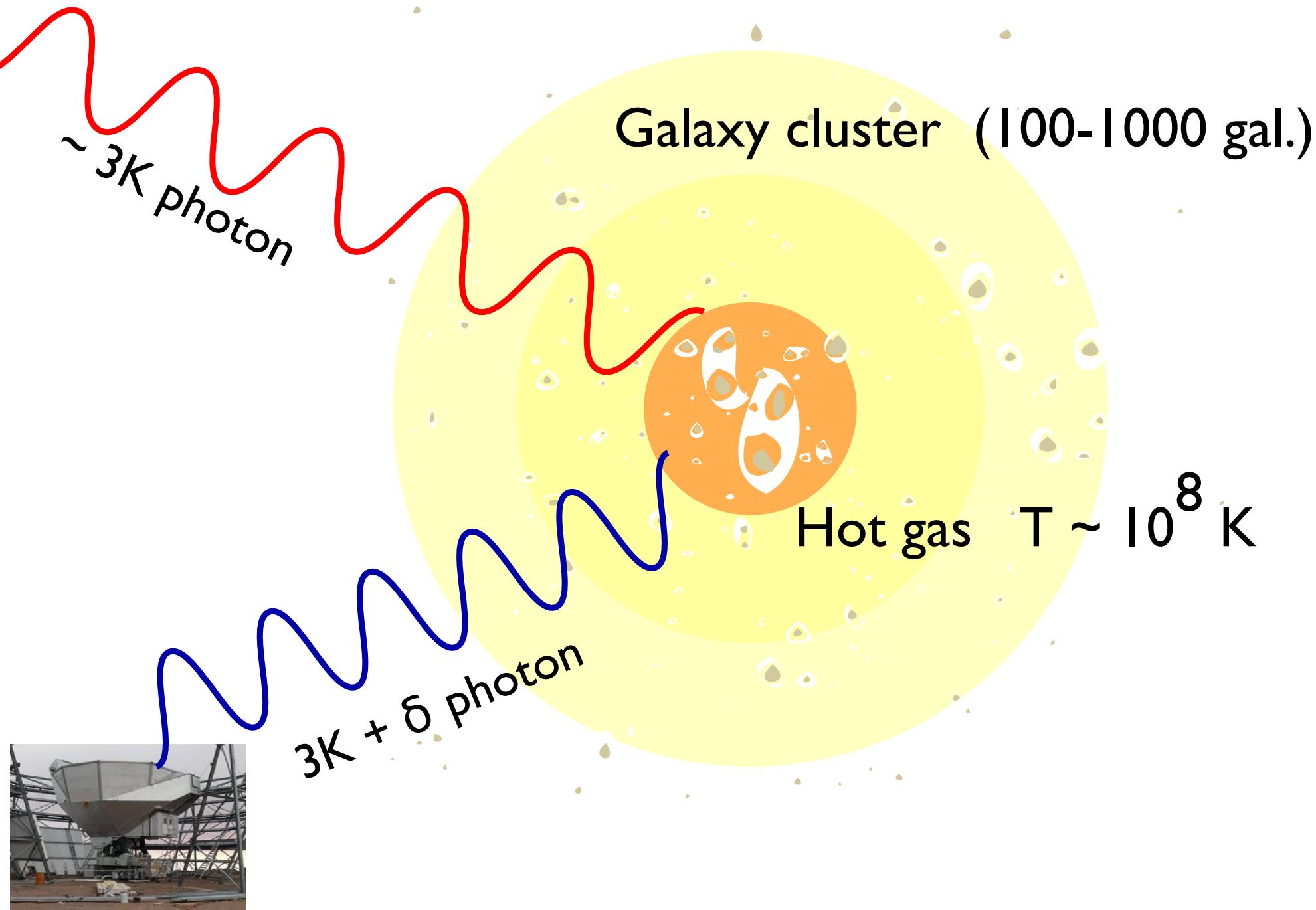
What happened at the very beginning?

Many exciting efforts!

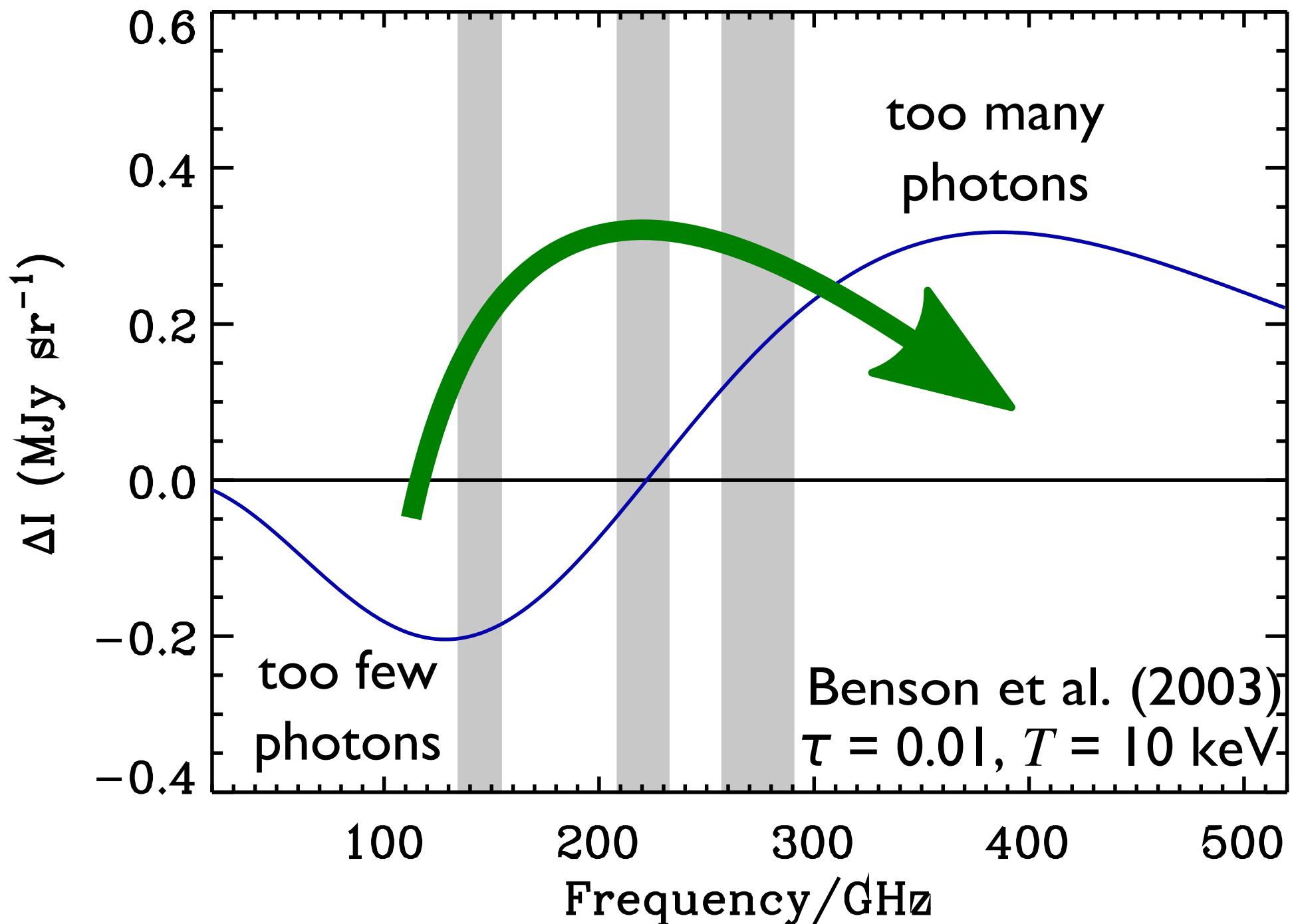
It will all our skills in advanced engineering, microwave detector development, software design, image processing, etc. to find out!

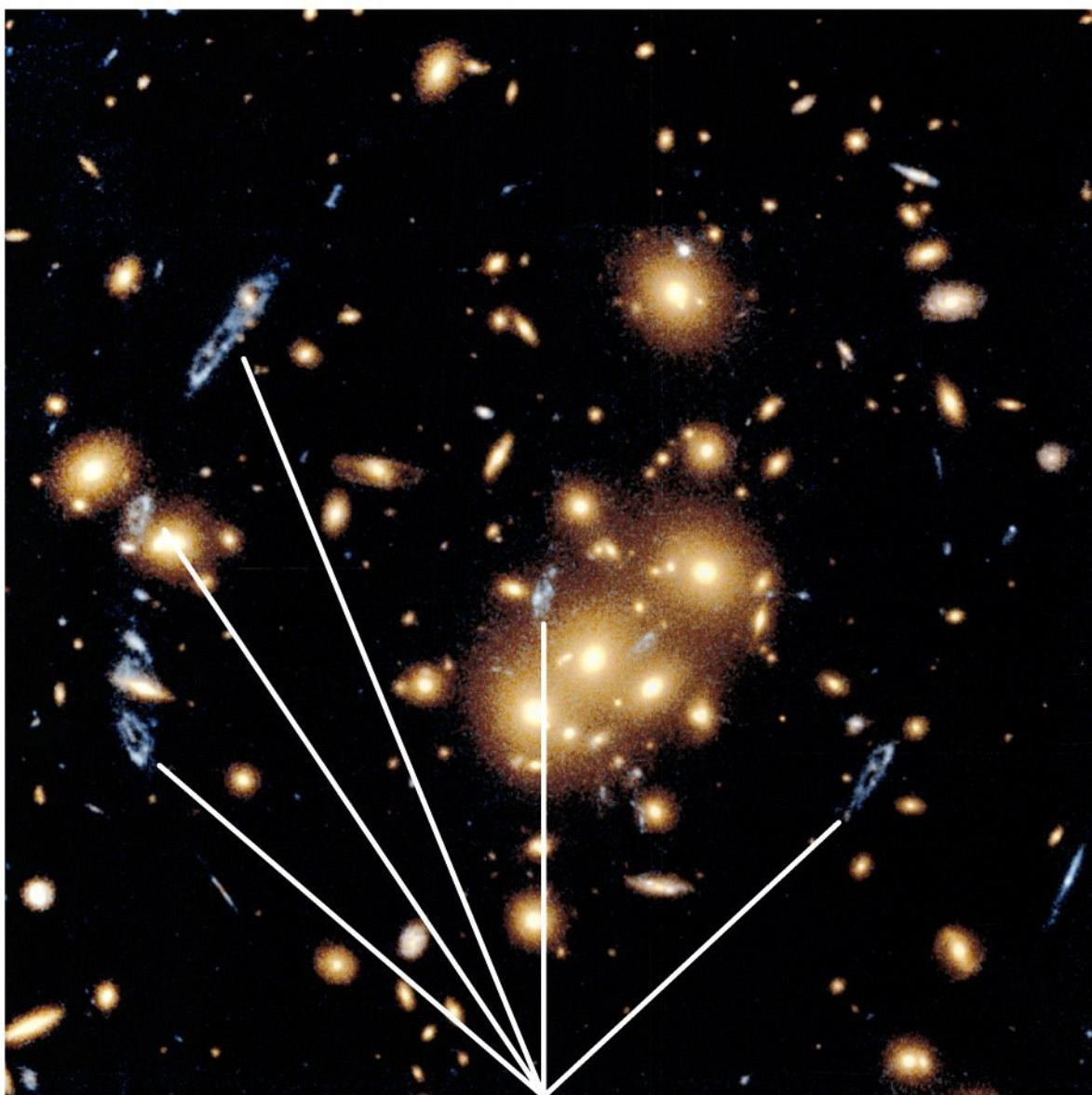


Sunyaev-Zeldovich effect



SZ distorts CMB blackbody



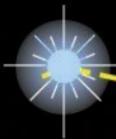


All of these blue arcs are images of the same distant galaxy.

Figure 24-31
Universe, Eighth Edition

© 2008 W.H. Freeman and Company

Image 1 of distant galaxy



Distant galaxy

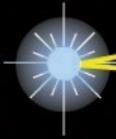


Image 2 of distant galaxy



gravitational lens



How gravitational lensing happens

Figure 24-30a
Universe, Eighth Edition

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