



CITA  ICAT

Beyond Einstein

the universe is comprehensible!!!

Gravity=Geometry=Mass-Energy

cosmological constant 1917

1998/2007+: dark energy

Ω_{Λ} (space, time)?

Ω_{dm} = dark matter (in labs?)

Ω_b = ordinary matter
Gravitational waves – 1917
(known)

ripples in spacetime moving at the speed of light. we will "see" it from black holes

Ω_{BH} & neutron stars ~2011, from the

quantum early Universe ~2010? Ω_{GW}



ClfAR Cosmology & Gravity Program

12 fellows (all but 3 new/repatriated Cdns)

1 institute fellow

6 scholars (all new/repatriated Cdns)

all in Canada (UVic, UBC, UofA, McMaster, PI, UofT, CITA, Queens, McGill)

22 Associates

US, UK (4), Canada (3, incl 2 ex-fellows)

7 Board Members (treated as associates for interaction)

To 04/07 US (4), Germany (1), Canada (2)

Now US (5), Germany (1), Canada (1), UK(0)

+ 47 PDFs, 51 grad students (+ undergrads) in Canada

Review Committee, Jun 06, Part 1 and 2; Bibliometric Assessment of CIAR's Cosmology & Gravity Program


ClfAR YES decisions Research Council Oct 06, ClfAR Board Nov 06

String theory

branes & compactified extra dimensions

the landscape

“environmental selection”
anthropic

emergence of space/time

Strong Gravity

Strings

Early Universe

Black holes

HEA

Physical cosmology

Early universe physics & Inflation

Dark matter, Dark Energy probes

Cosmic Microwave Background

Redshifted 21 cm

Galaxy formation & properties

Large scale structure

Weak lensing, z-surveys

Supernovae

Clusters in CMB, optical, X

Gravity Waves

Particle Astrophysics

Experiment

SNOlab, LHC

High Energy Astrophysics

neutron stars

Black holes

High energy cosmic rays

Magnetars, double pulsars

Numerical relativity

colliding black holes in 3D

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PERSON OF THE CENTURY

TIME

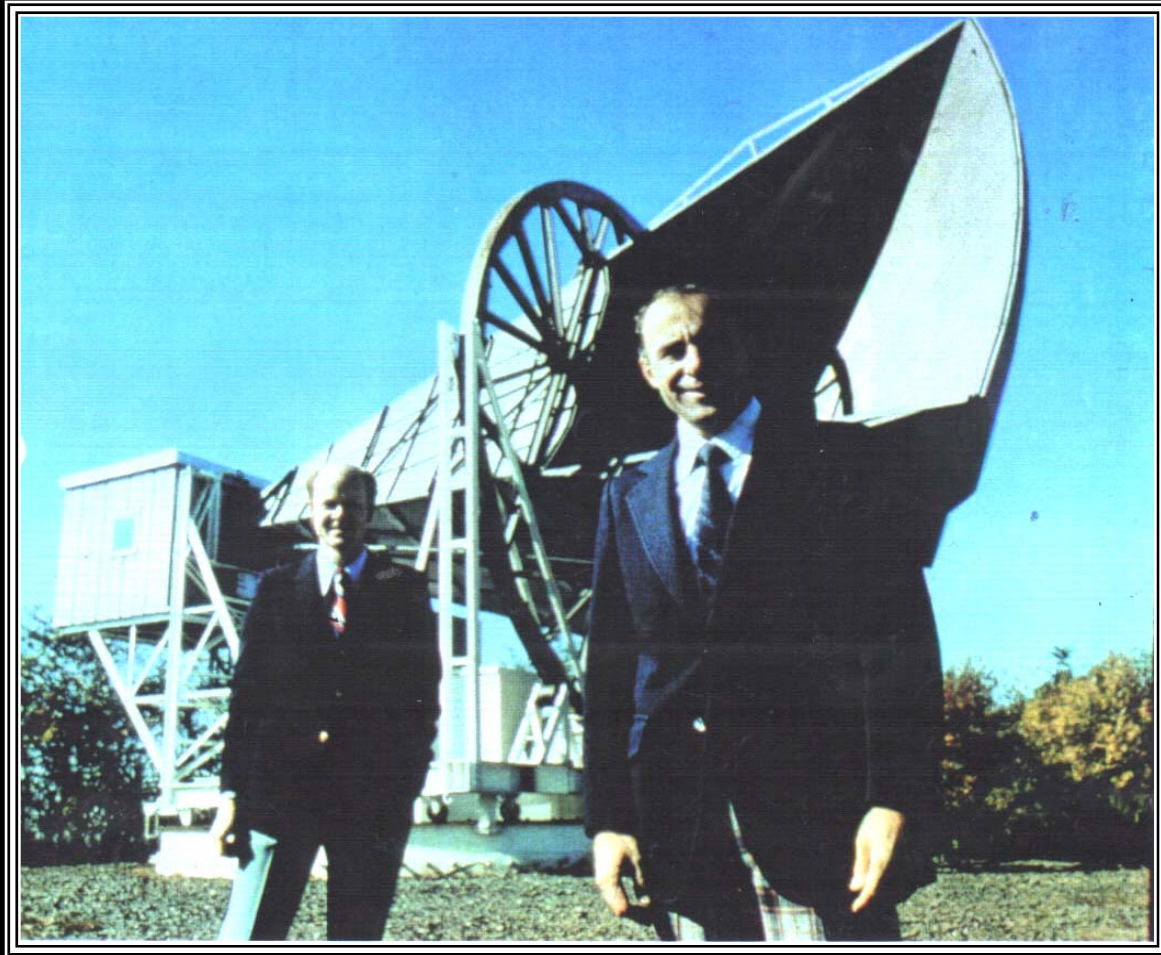
ALBERT
EINSTEIN

“The most beautiful thing we can experience is the mysterious. It is the source of all true art and all science. Those to whom this emotion is a stranger, who can no longer pause to wonder and stand rapt in awe, are as good as dead: their eyes are closed.”

Albert Einstein

***The
Universe
Is Radiant***

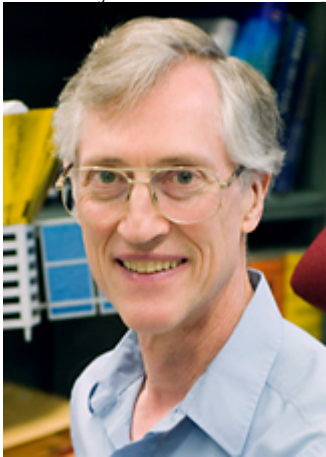
**Arno Penzias
Robert Wilson
1965**



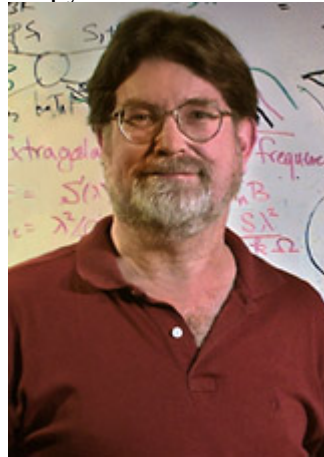
The Nobel Prize in Physics 2006

(also Gruber Prize in Cosmology 2006 for Mather + the COBE team)

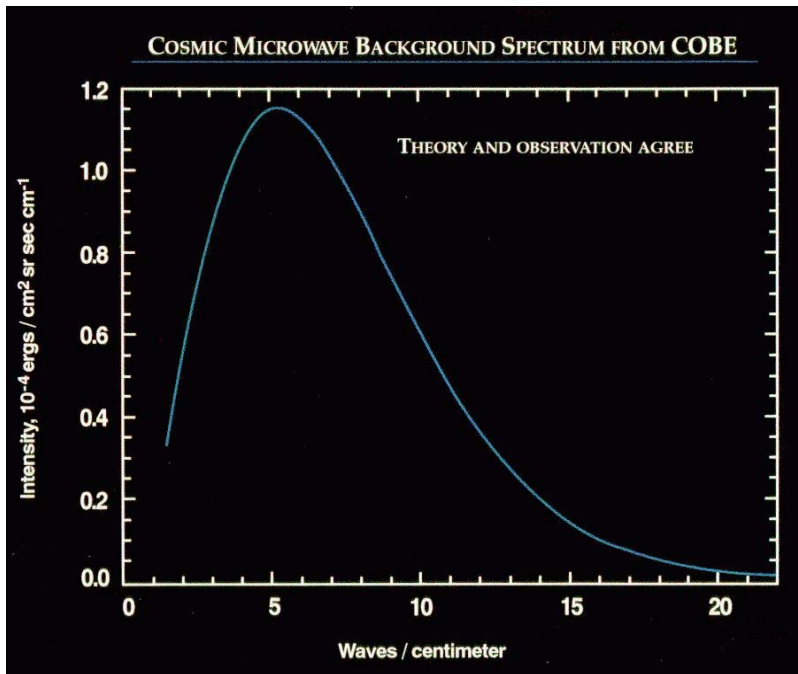
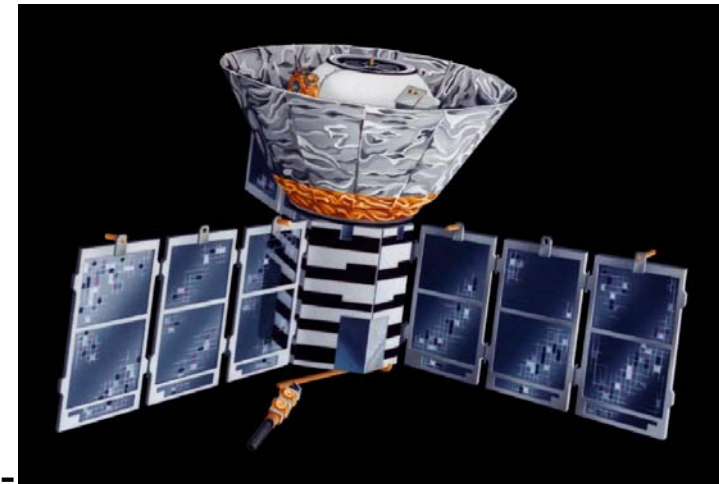
"for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation"



John C. Mather 1946-



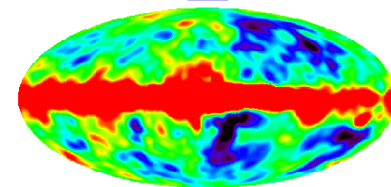
George F. Smoot 1945-



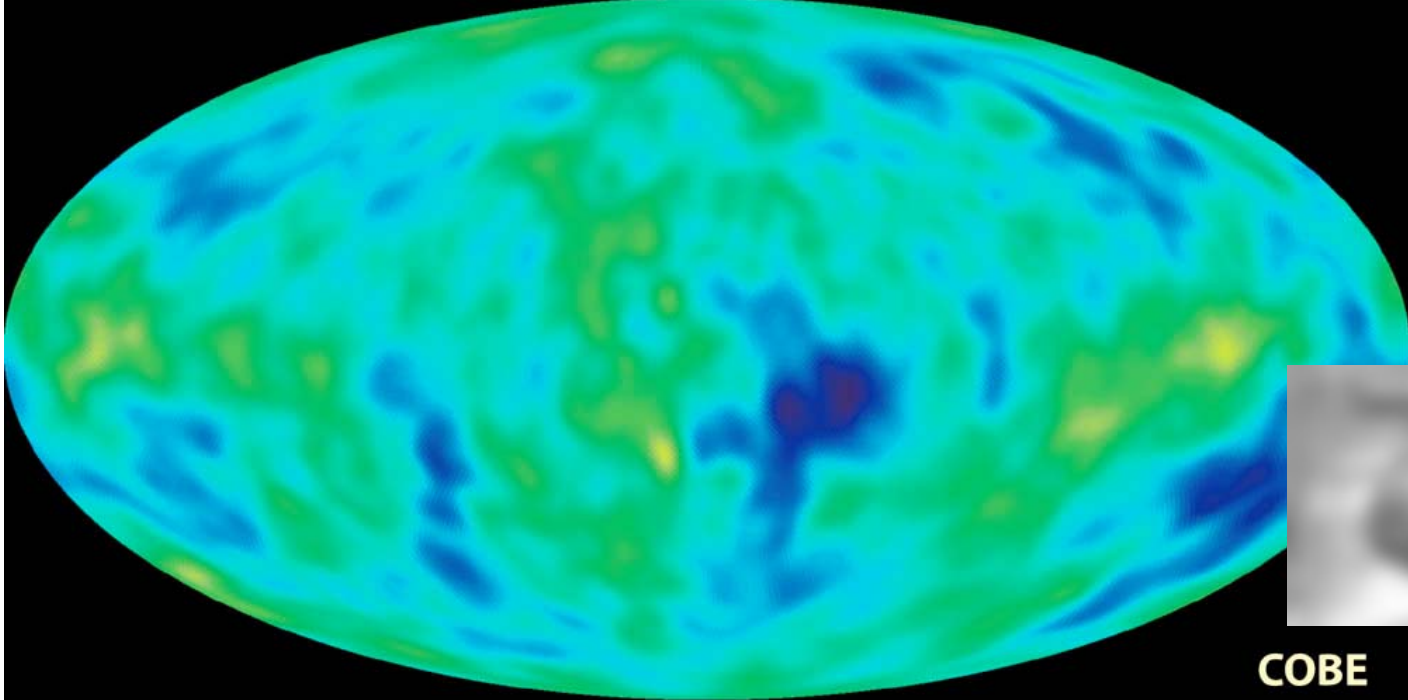
CMB

Nearly Perfect Blackbody
 $T = 2.725 \pm 0.001$ K COBE/FIRAS

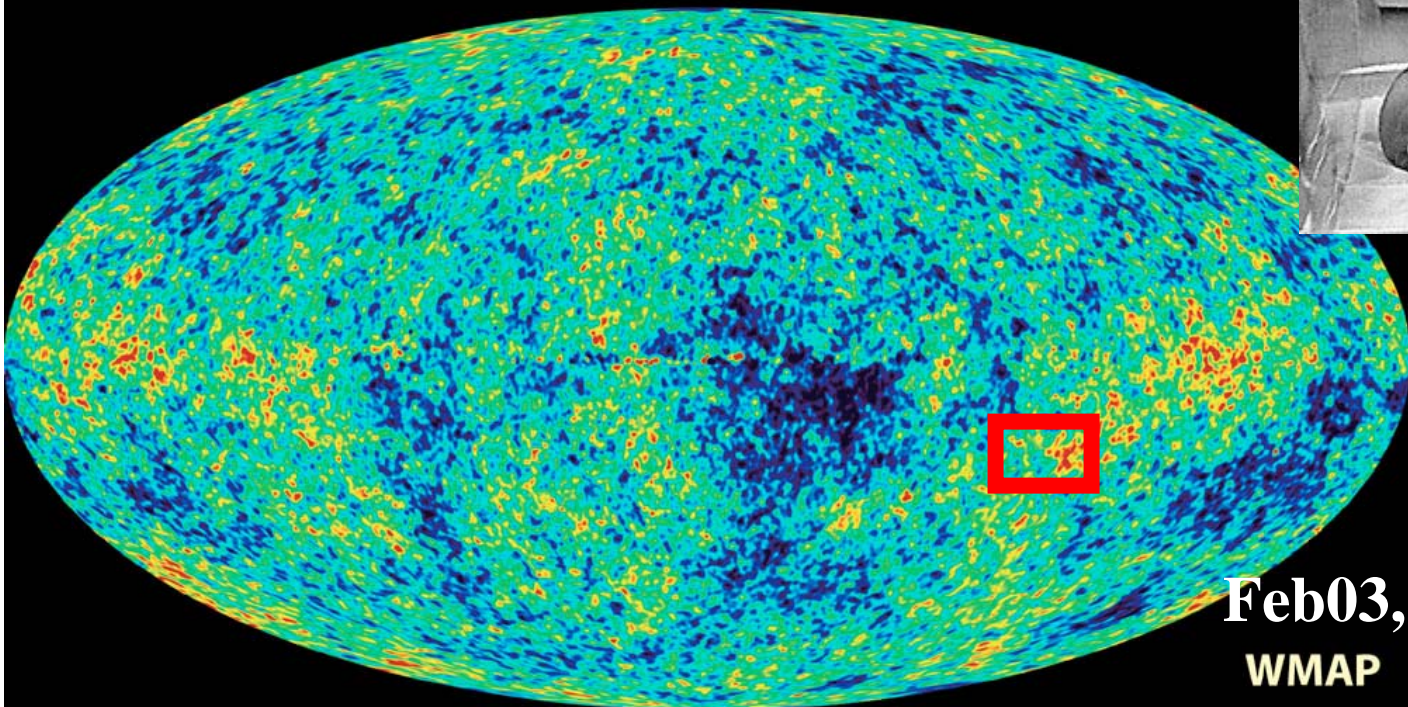
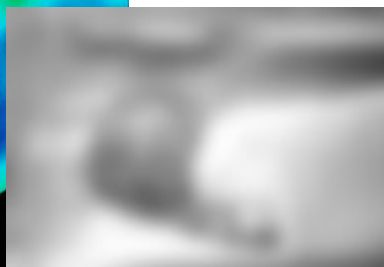
Dipole: flow of the earth in the CMB



COBE/DMR:
CMB + Galactic @ 7°

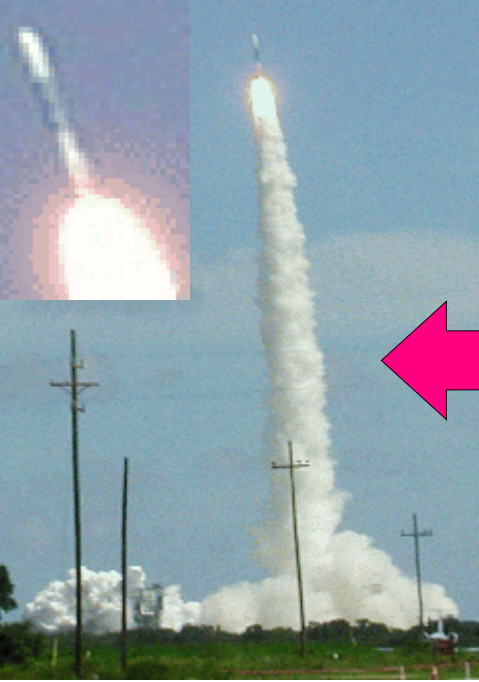


COBE



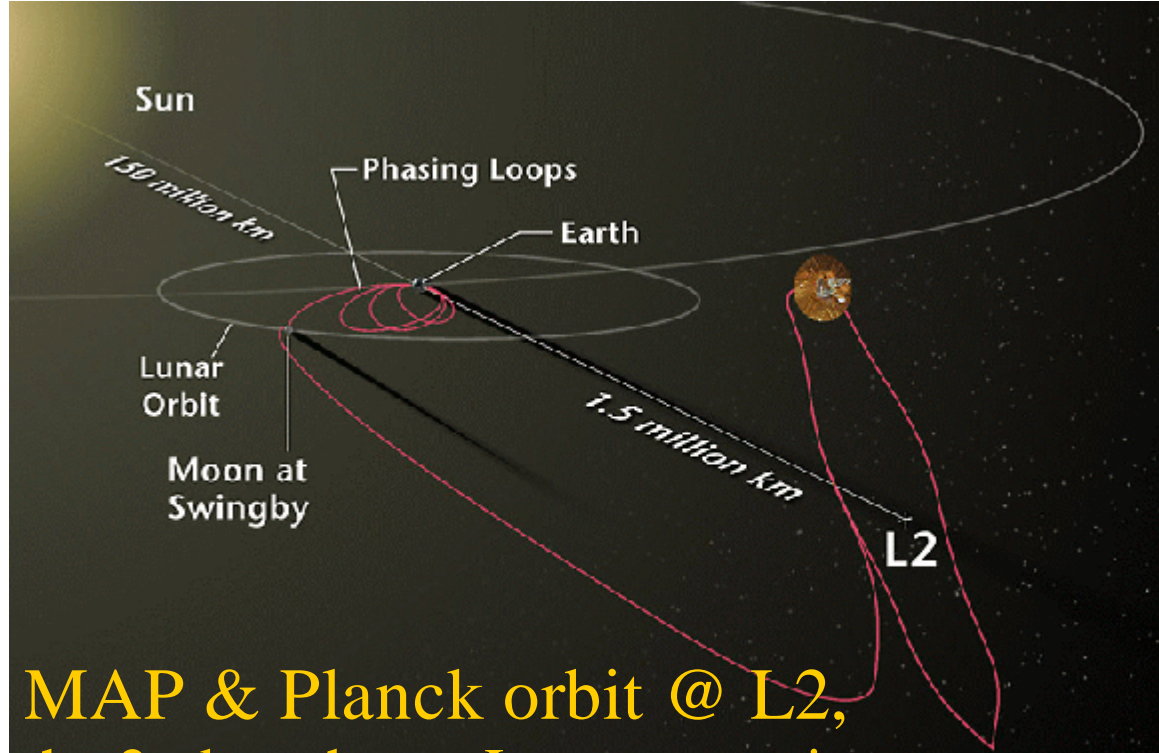
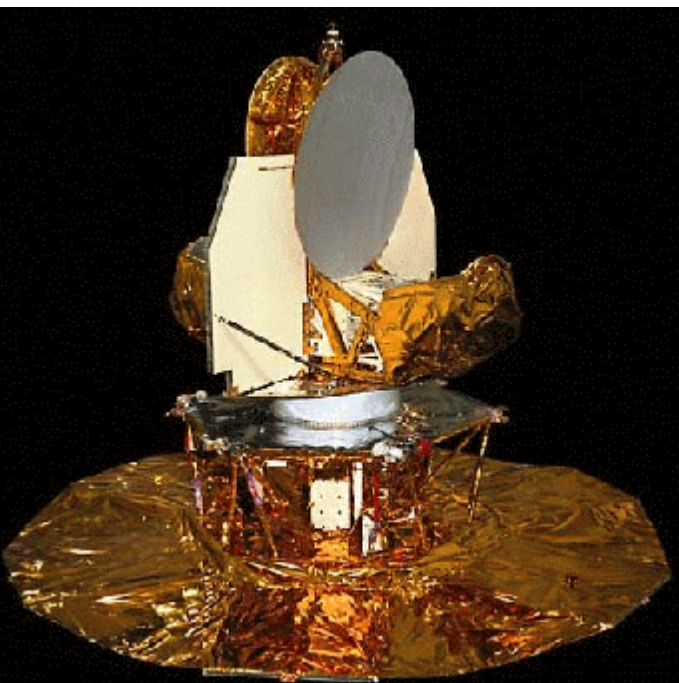
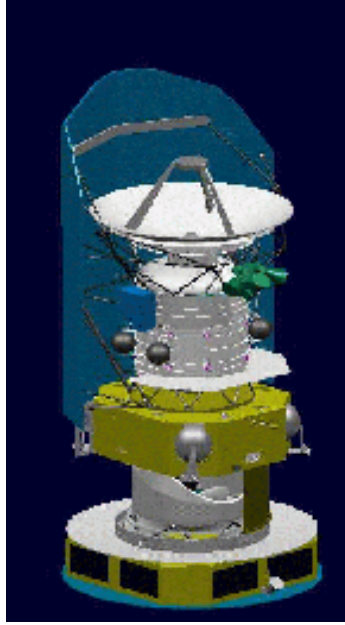
Feb03, Mar06
WMAP



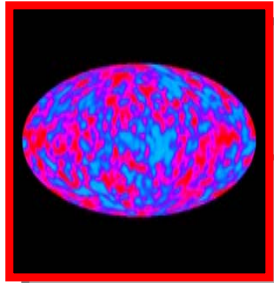


Nasa's WMAP satellite @ L2: launch 2001.5, 1yr data 2003.2, 3yr 2006.3

**Planck satellite @ L2: launch 2008.7
ESA+NASA+ Cdn Space Agency**



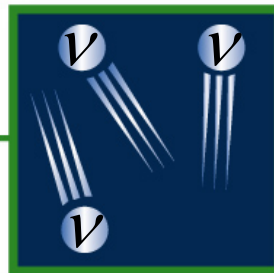
**MAP & Planck orbit @ L2,
the 2nd earth-sun Lagrange point**



Radiation:
0.005%



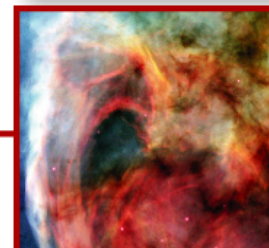
Chemical Elements:
(other than H & He) 0.025%



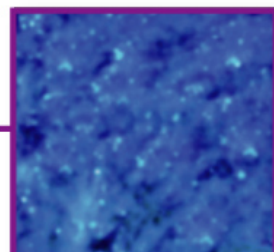
Neutrinos:
0.47%



Stars:
0.5%

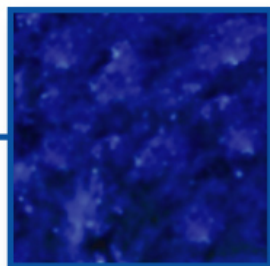


**Free
H & He:**
4%



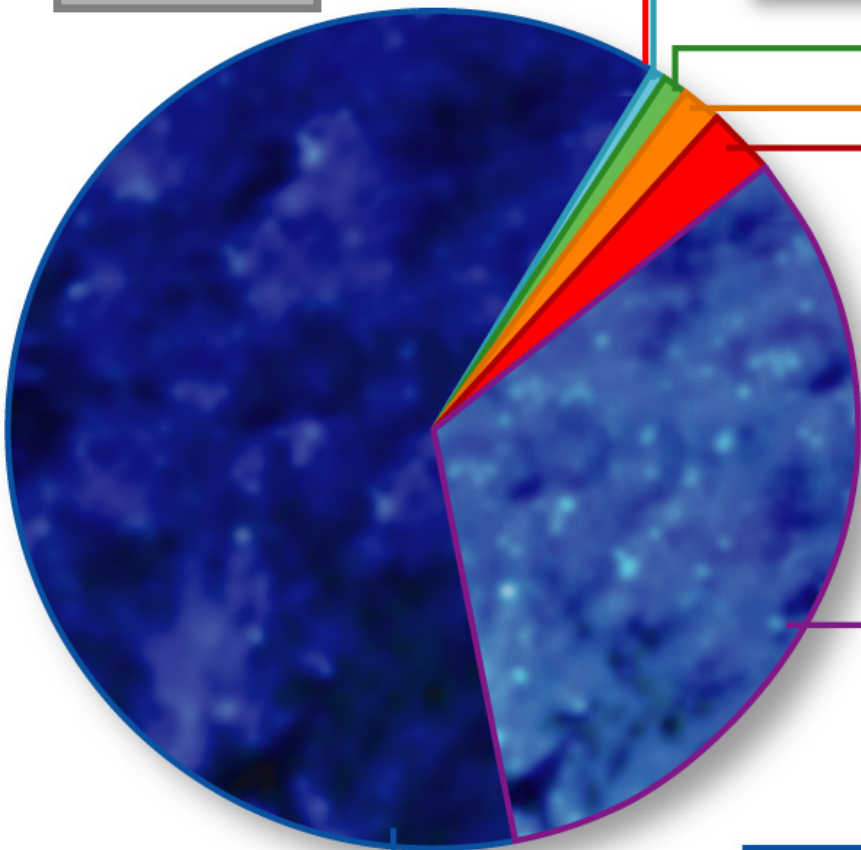
Dark Matter:

$$\Omega_{\text{cdm}} = 22.5 \pm 3\%$$



Dark Energy:

$$\Omega_{\Lambda} = 73 \pm 3\%$$



Gravity Waves

$$\Omega_{\text{GW}} \sim 10^{-14} - 10^{-10} \text{ LIGO}$$

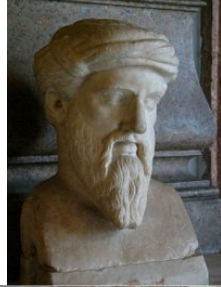
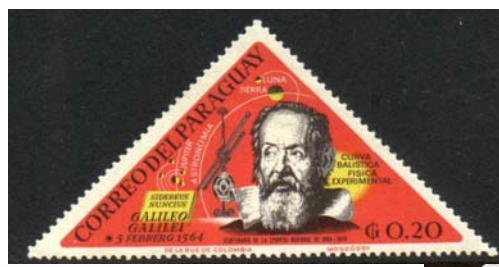
$$\Omega_{\text{BlackHoles}} \sim 10^{-7}$$

*large halo of dark matter
70s/80s around galaxies;
30s around clusters.*

relics or remnants?

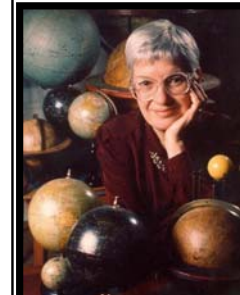


Milky Way 1953-55



Sombrero Galaxy • M104

Hubble Heritage

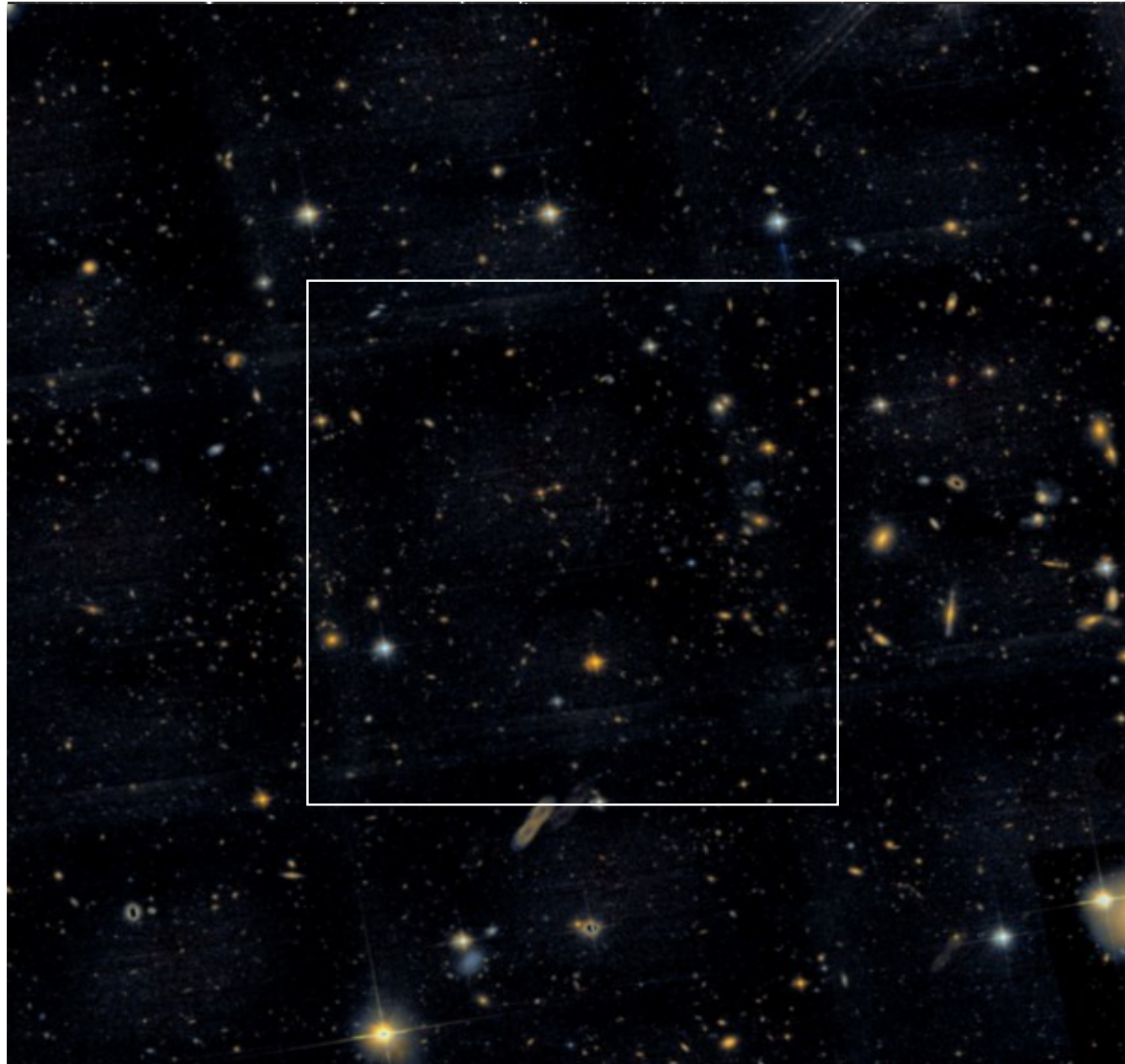


Hubble “Cosmic Evolution Survey”

- 2 deg² Hubble Space Telescope data (largest ever Hubble program)
- > 2 million faint galaxies with measurable shapes

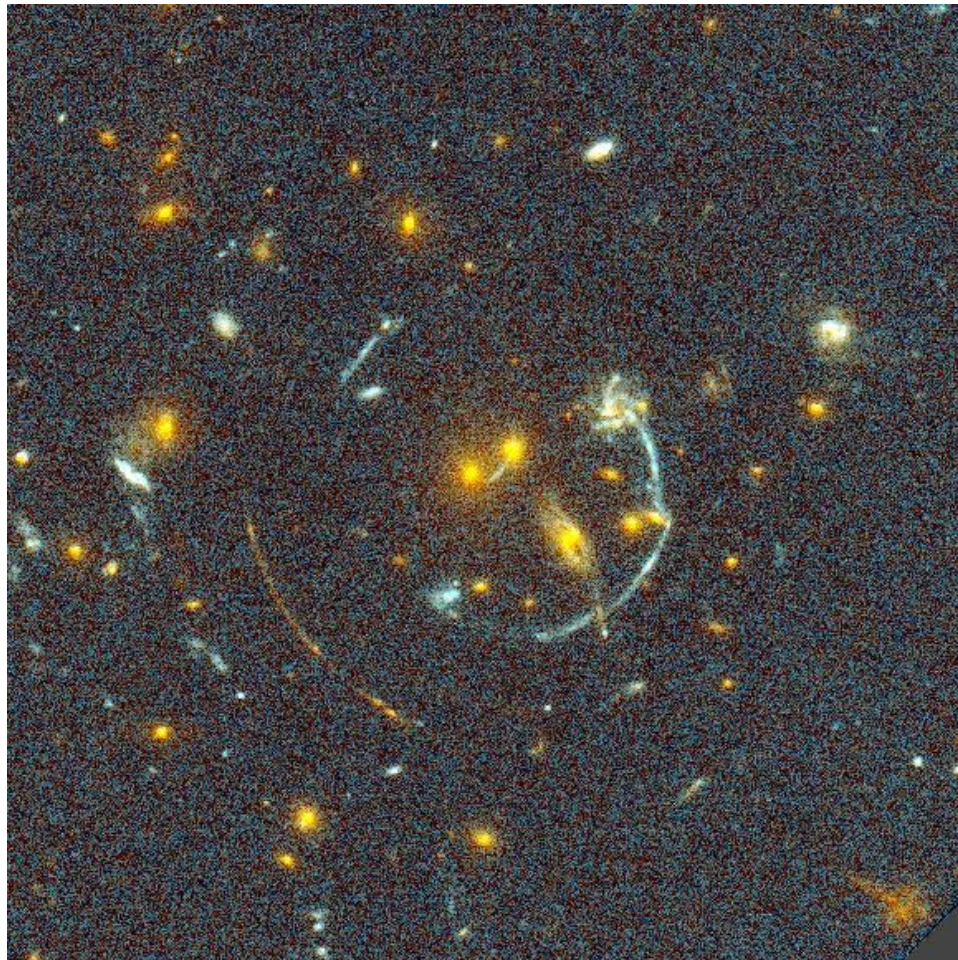
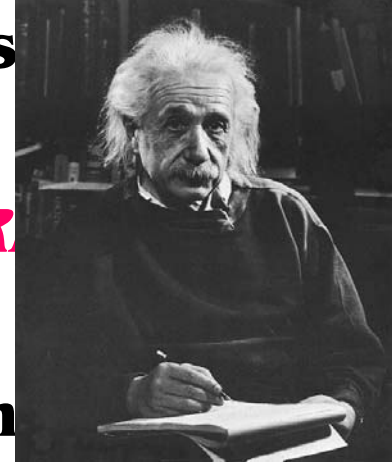


**& Beyond
Hubble: JWST
(+TMT+)**



EINSTEIN ... 1905 international year of physics

- ✓ **NEW LAW OF GRAVITATION (1916)**
- ✓ **speed of light is the ultimate speed (*HOR*)**
- ✓ **Space is curved by mass**
- ✓ **Lightwaves bend, wavelengths change, un**



*Gravitational lensing of
deep galaxies by
clusters*

 *CIAR to RCS 2001;
RCS2 now*

*Weak lensing via Canada
Hoekstra, Gladders, Yee
France Hawaii Telescope
Legacy Survey 2002-08*



Hoekstra, van
Waerbeke

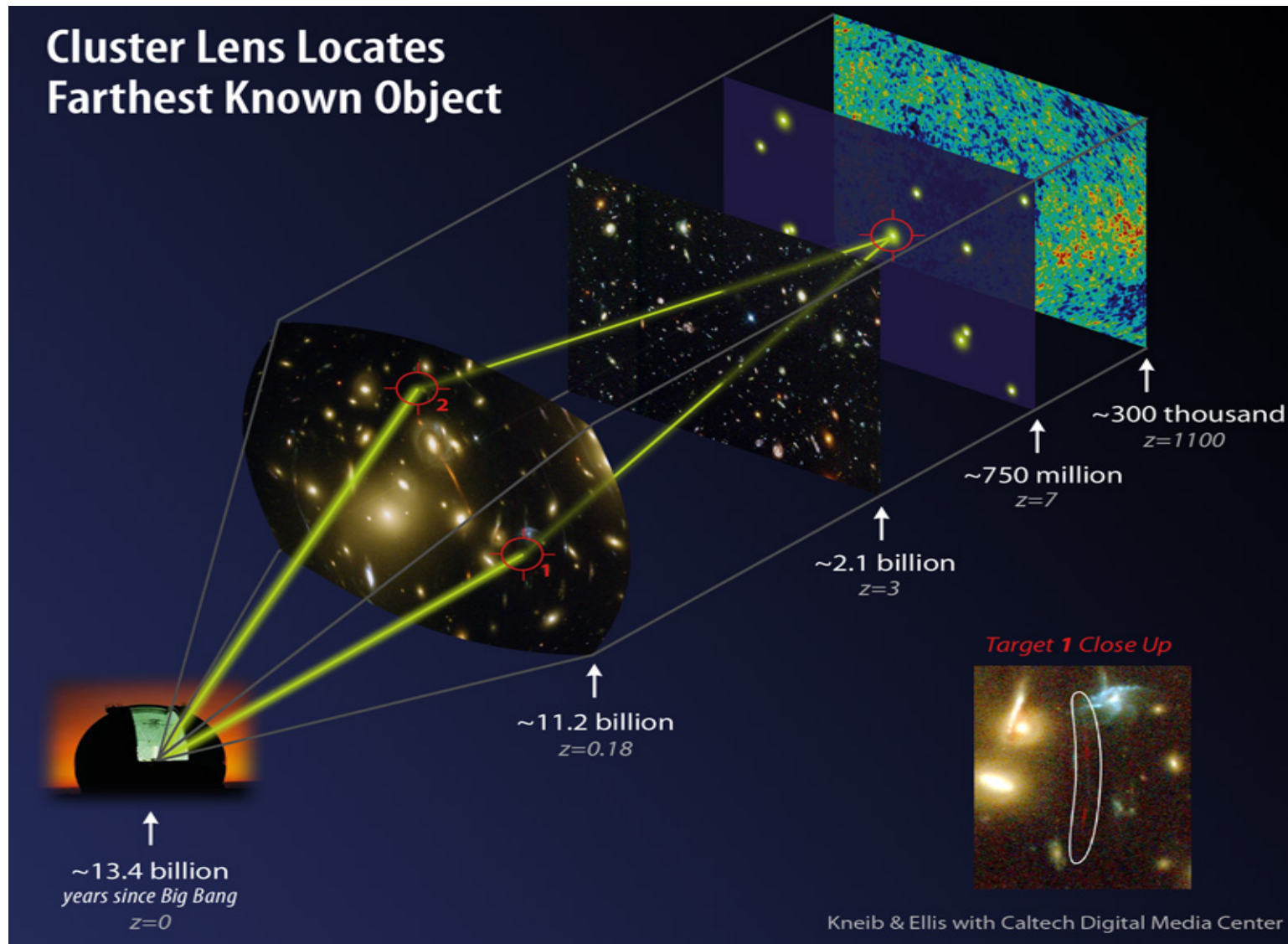
 CIAR

a **starless**
"dark age"
before the
most distant
galaxies

dwarflets &
the 1st stars
form at
compression 13

1st light:
Cosmic
Microwave
Background

released at
compression
1100; formed at
 $\sim 10^{30}$



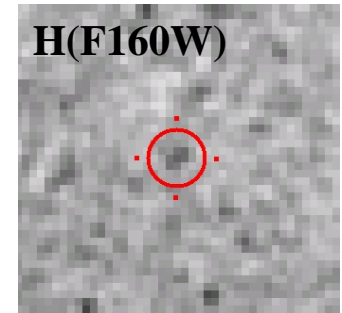
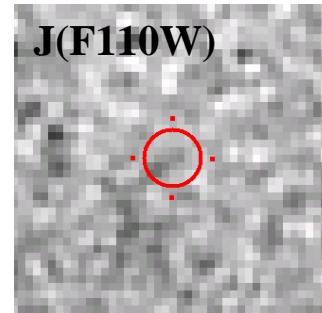
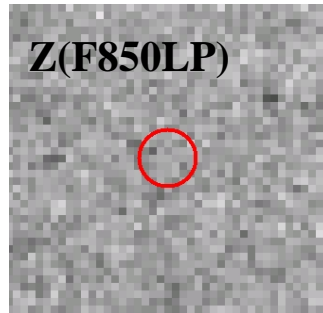
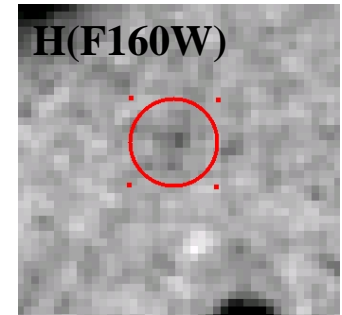
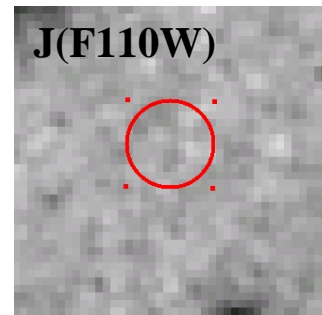
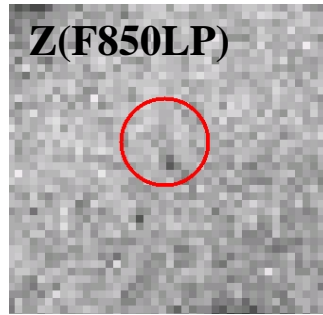


DAVE BARRY

Over the years I have been harshly critical of the scientific community for wasting time researching things nobody cares about, such as the universe. I don't know about you, but I'm tired of reading newspaper stories like this:

“Using a giant telescope, astronomers at the prestigious Crudwinkle Observatory have observed a teensy light smudge that they say is a humongous galaxy cluster 17 jillion light years away, which would make it the farthest-away thing that astronomers have discovered this week. However, astronomers at the rival Fendleman Observatory charged that what the Crudwinkle scientists discovered is actually mayonnaise on the lens. Both groups of astronomers say they plan to use these new findings to obtain even larger telescopes.”

Galaxies at compression 10



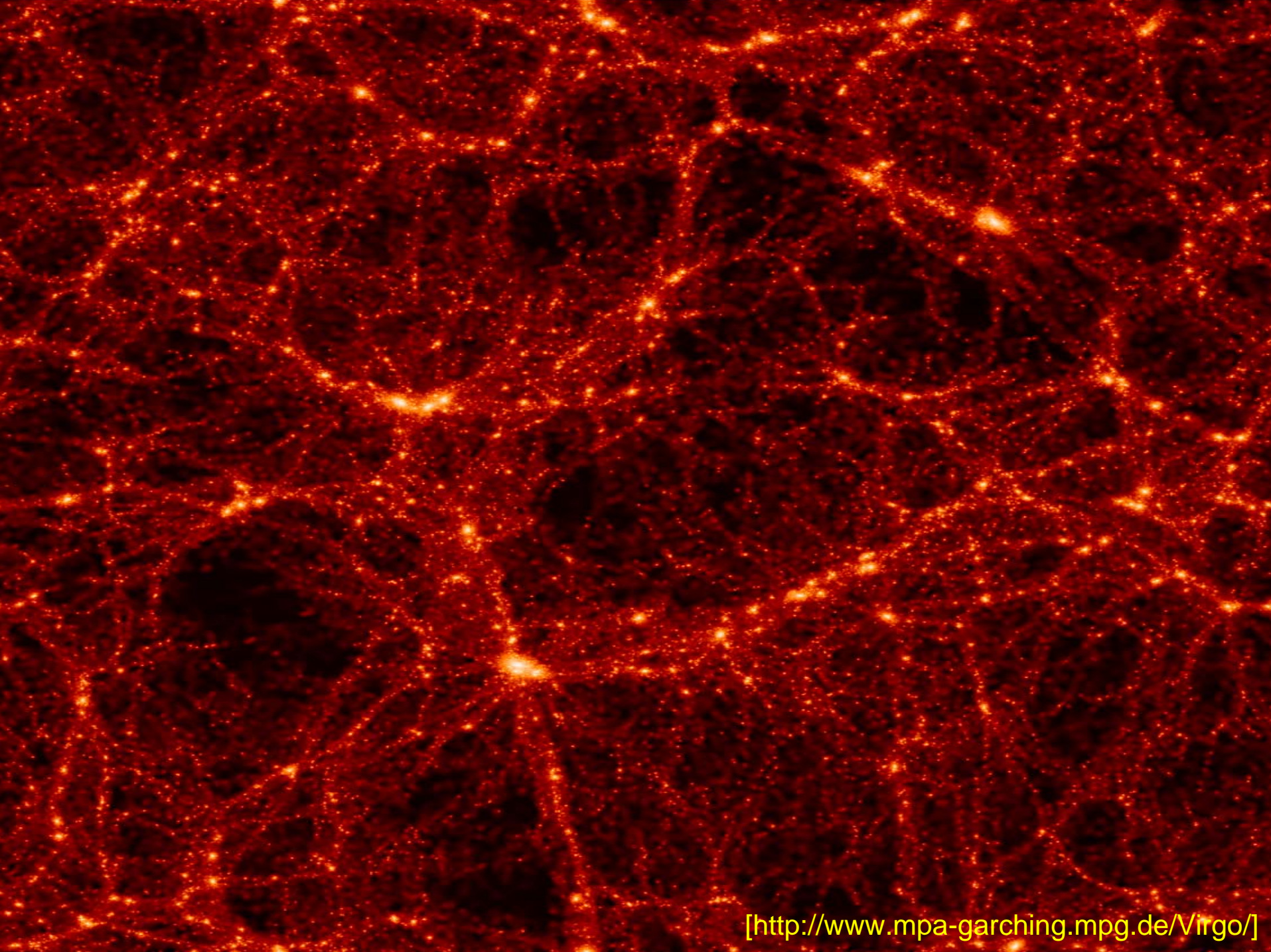
“UltraDeep” work of Richard Ellis et al. CifAR Associate

TMT: Thirty Metre Telescope

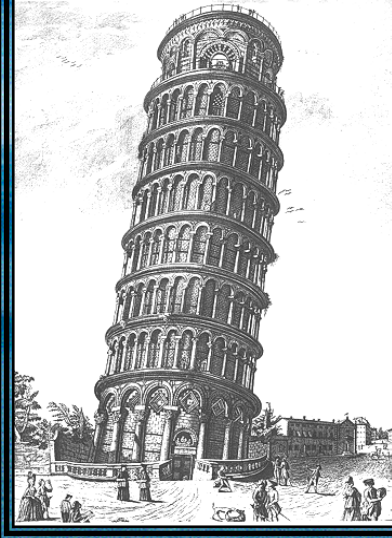
JWST: James Webb Space Telescope

SKA: Square Kilometre Array





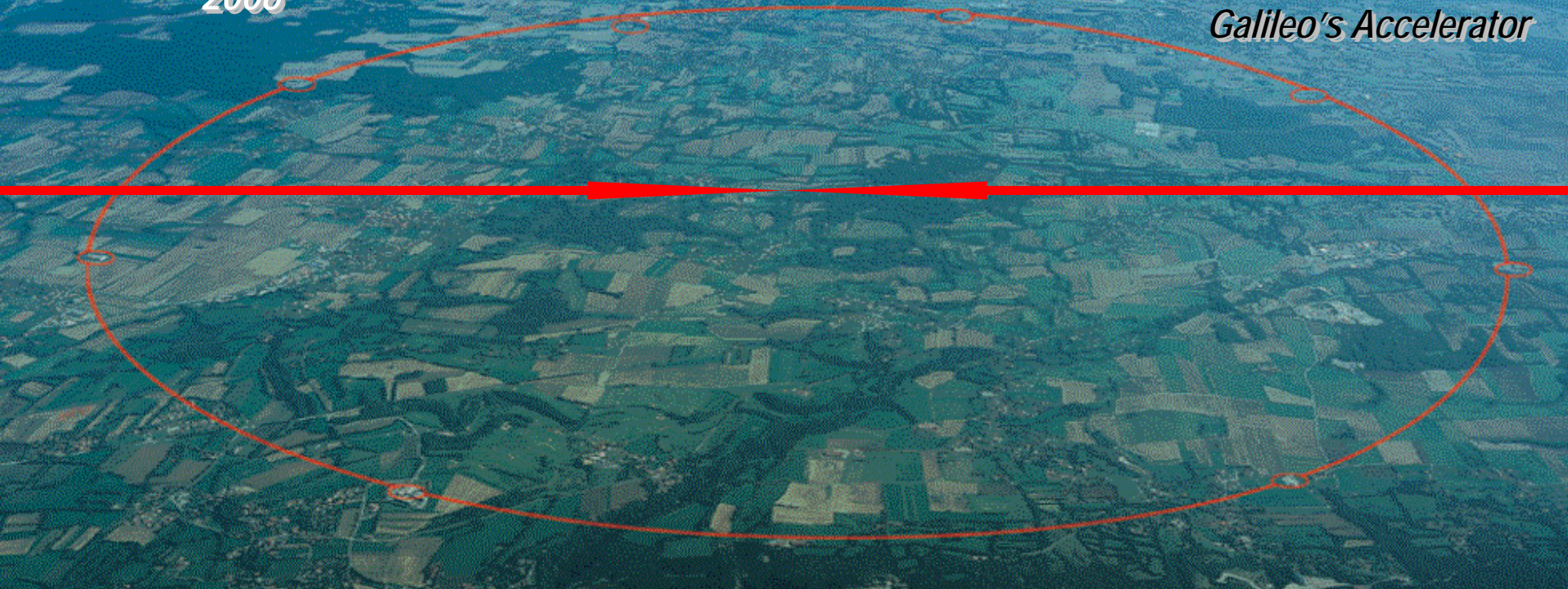
How will Accelerators cast Light on the Dark Side of the Universe?



Galileo's Accelerator

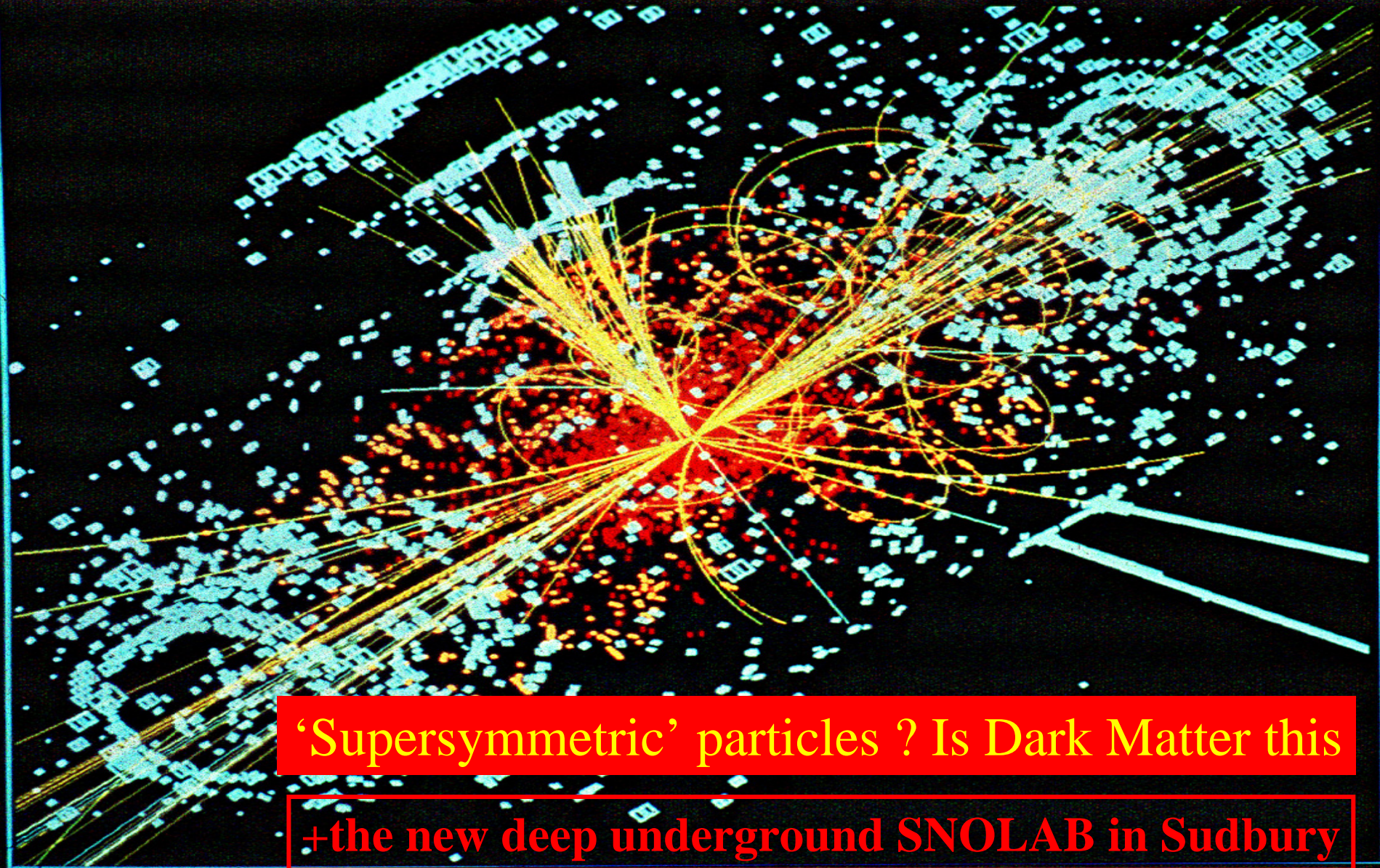
Cern's Accelerator

2008



If Dark Matter interacts with ordinary matter by more than gravity, we may "see" it at the Large Hadronic Collider 2008+ or at SNOlab 2008+ in Sudbury

A Simulated Higgs Event in CMS: LHC Origin of Mass Cern2008



‘Supersymmetric’ particles ? Is Dark Matter this

+the new deep underground SNOLAB in Sudbury

Science

18 December 1998

Vol. 282 No. 5397
Pages 2141-2336 \$7

THE ACCELERATING UNIVERSE

Breakthrough of the Year



AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE



CFHT

SN

Survey

Carlberg,
Pritchett,

et al.

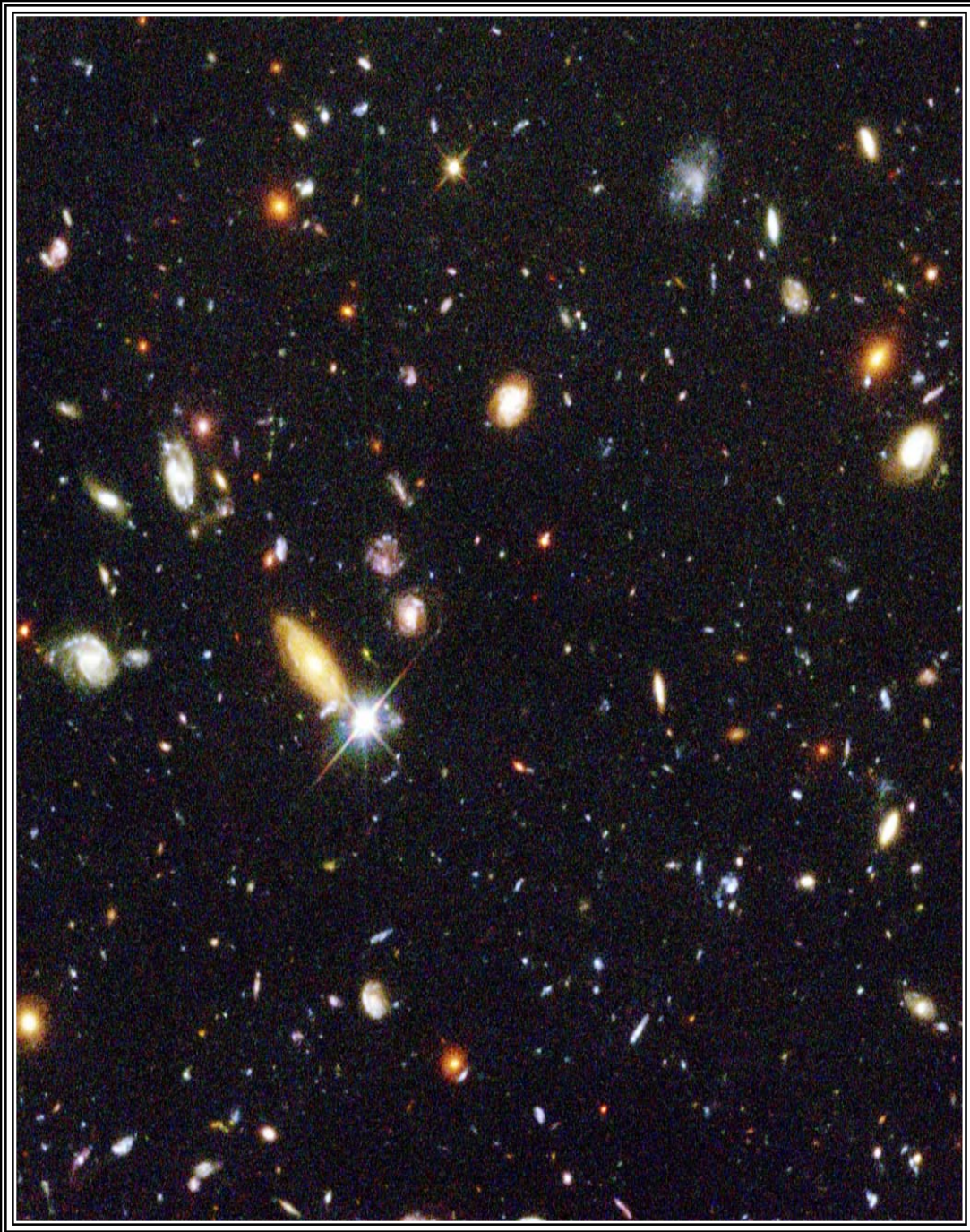


3yr now
300 SN1a

5yr

500





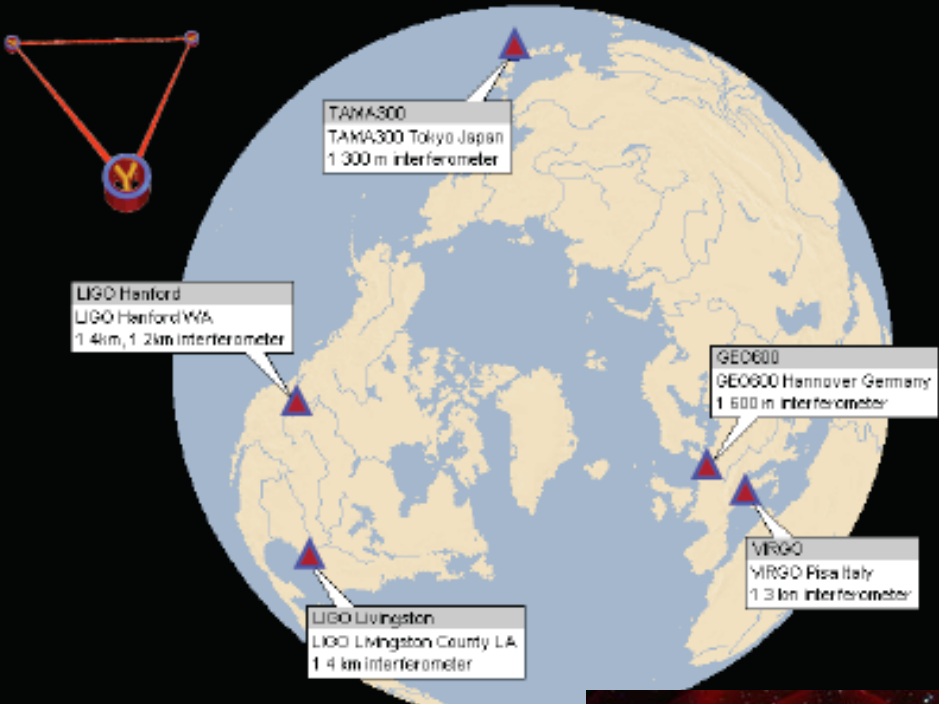
“To me every hour of the light and dark is a miracle. Every cubic inch of space is a miracle.”

– Walt Whitman

Every cubic inch of space is a miracle!

- **cosmic radiation**
- **dark matter**
- **dark energy**
- **neutrinos**
- **gravity waves**
- **virtual particles**
- **Higgs potential**
- **extra dimensions**

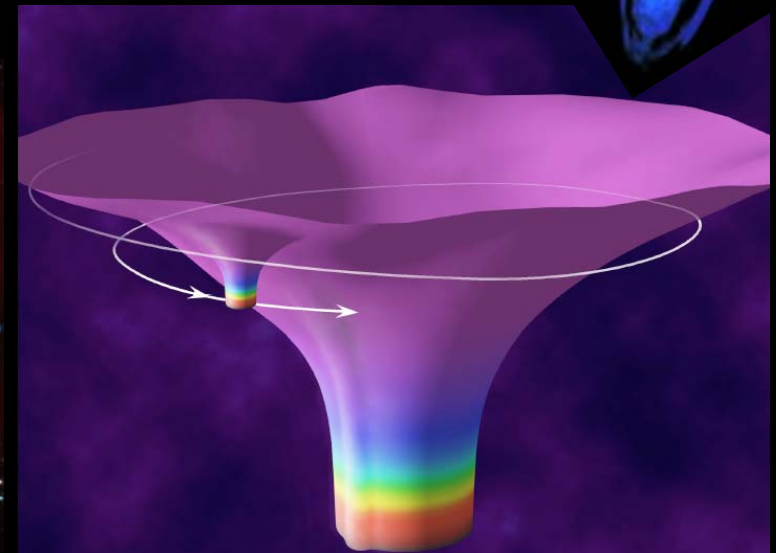
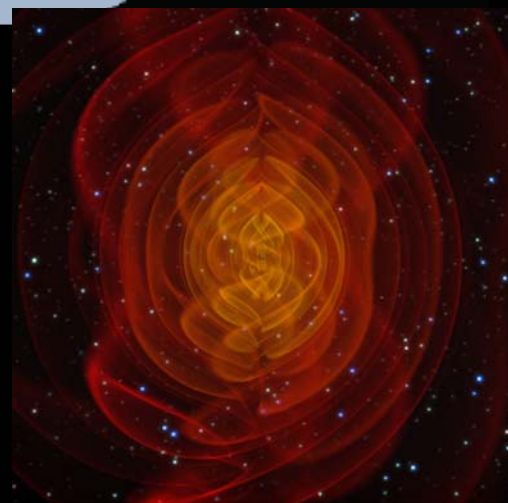
Worldwide Interferometer Network



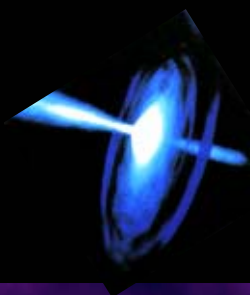
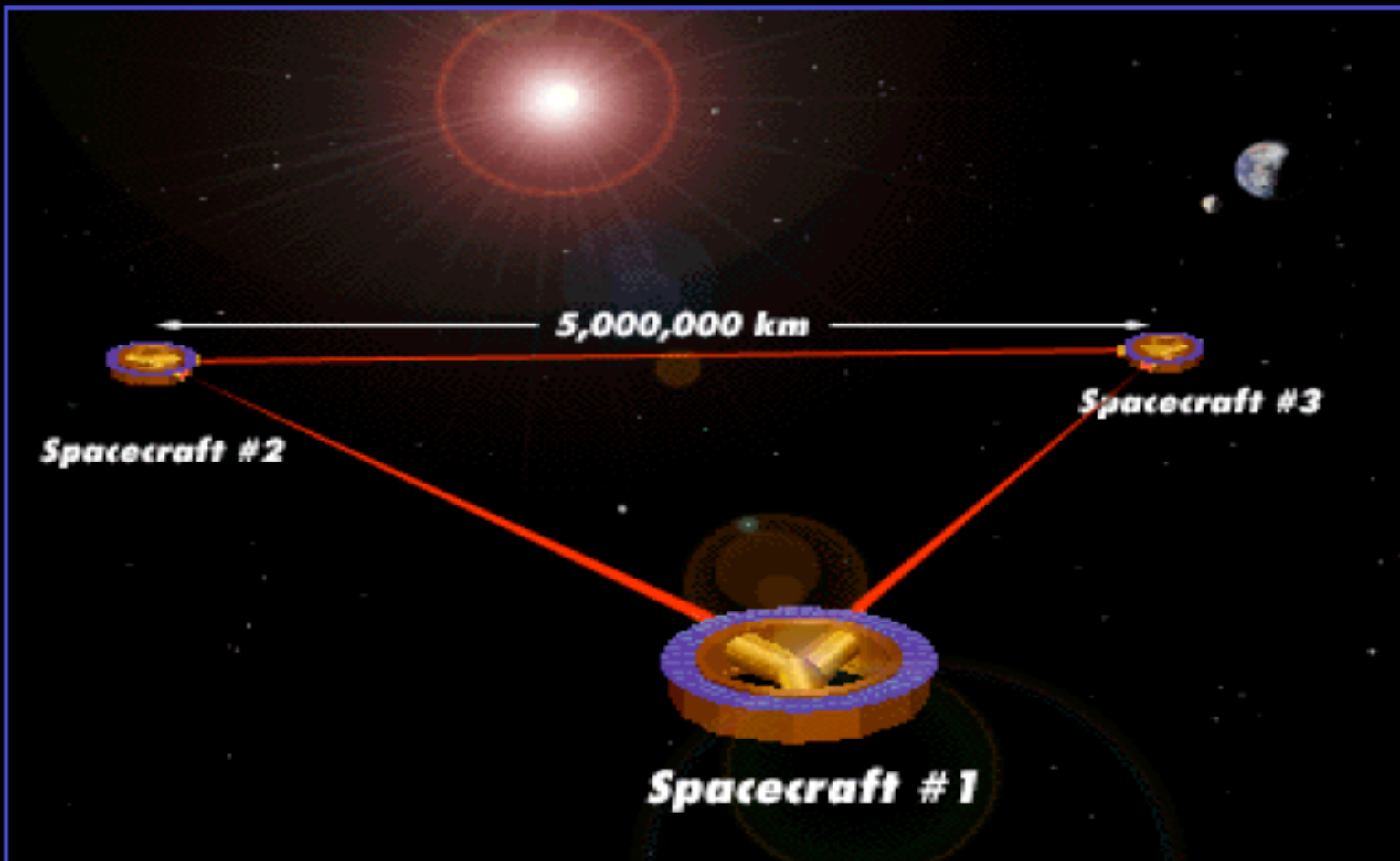
DANGER:
BLACK HOLES
MERGING



Now-2013+
~km scale
detect .001 nuclear
radius



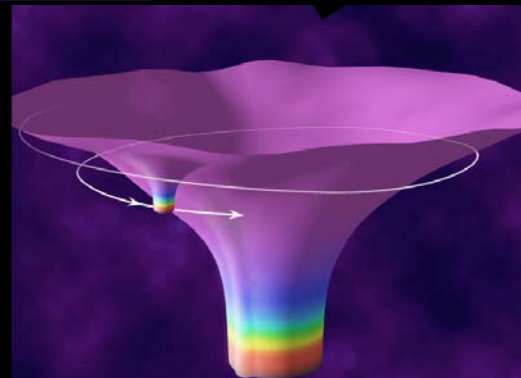
LISA



2017??

~5 million km scale
detect .001 atomic radius

DANGER:
SuperMassive
BLACK HOLES
MERGING

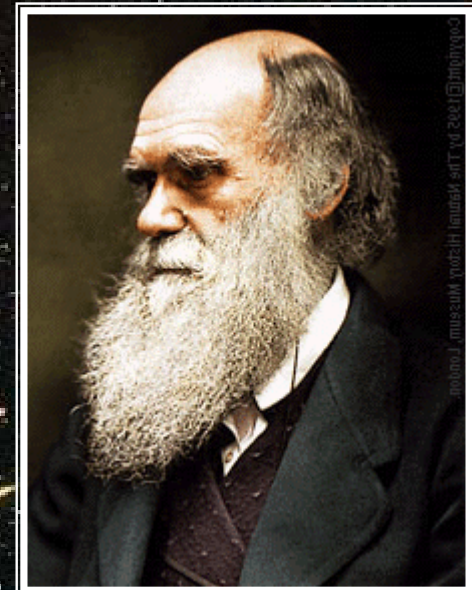


Cosmology today

- 1) Space and time: geometry shaped by mass-energy
- 2) Origin: “big bang” 13.7 aeons ago
- 3) Evolution: expanding, cooling, accelerating
- 4) Arrangement: galaxies in the cosmic web
- 5) Composition: dark matter and dark energy & us

There is grandeur in this view ... from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved.

Charles Darwin
The Origin of Species



detect Ω_{cdm} in lab; detect primordial Ω_{GW}

Ω_{Λ} (time, space)

Then (10^{-37}s) inflation &

Now ($13.7 \times 10^9 \text{ yr}$)

dark energy mystery

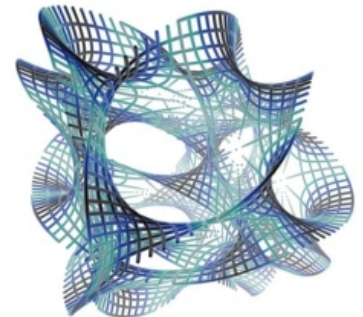
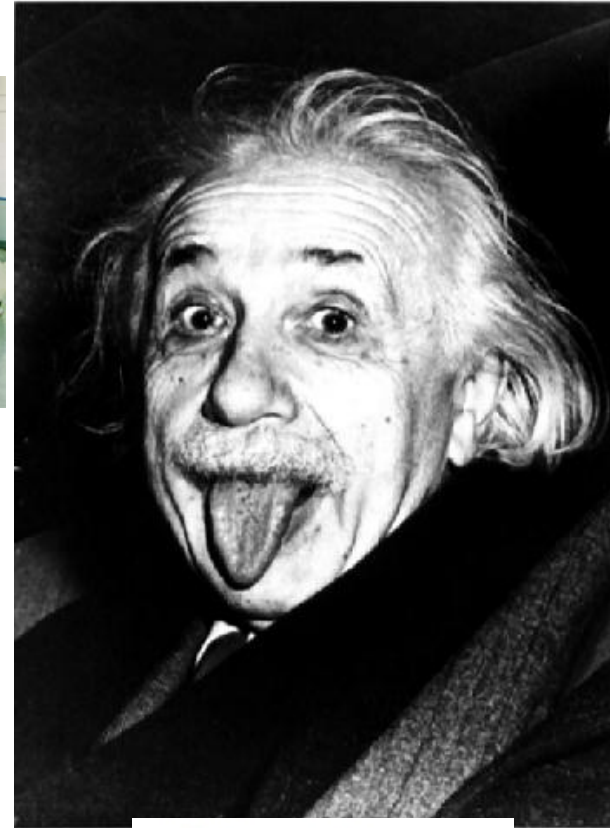
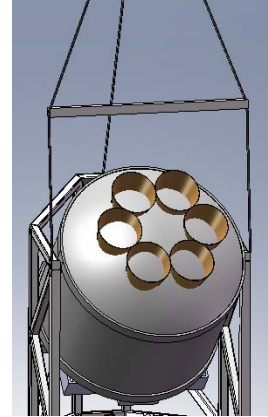
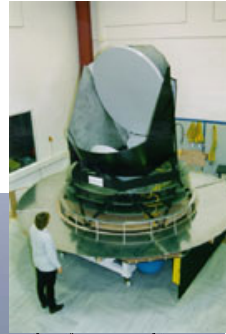
our CfAR future: to the
early & late Universe thru

Experiment + Theory

(CMB+Lens+SN+clusters +

LIGO/LISA/BBO for gravity waves +

SNOlab/CERN/ILC for dark matter)



**We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.**

– T. S. Eliot

**it is primarily for
this knowing & its
inspiration to young
minds that the world
is spending tens of
billions of dollars on
the cosmic quest for
fundamental physics**

The world wide web,
technological space
spinoffs, amazing detector
& computational advances,
are (important) asides



"IT from BIT"

FATE U inflate (again)

a cold death? reheat/rebirth?

NOW 14 Gyr 1

Pythagoras formed

Galaxies Cluster
Cosmic "web" of
vast filaments +
membranes

Life forms on
earth

9 Gyr 1.4

Carbon/oxygen/etc
form

Galaxies form

2 Gyr 4

The 'Meaning' may change
But the facts will remain

Inflation fluctuations
form: quantum jitter

10^{-37} sec 10^{29}

Protons/Neutrons
form

Helium forms
 100 sec 10^9

Cosmic background
radiation released from
matter
carries imprint of
fluctuations in matter which
grow to generate galaxies etc.

0.4 Myr 1100

