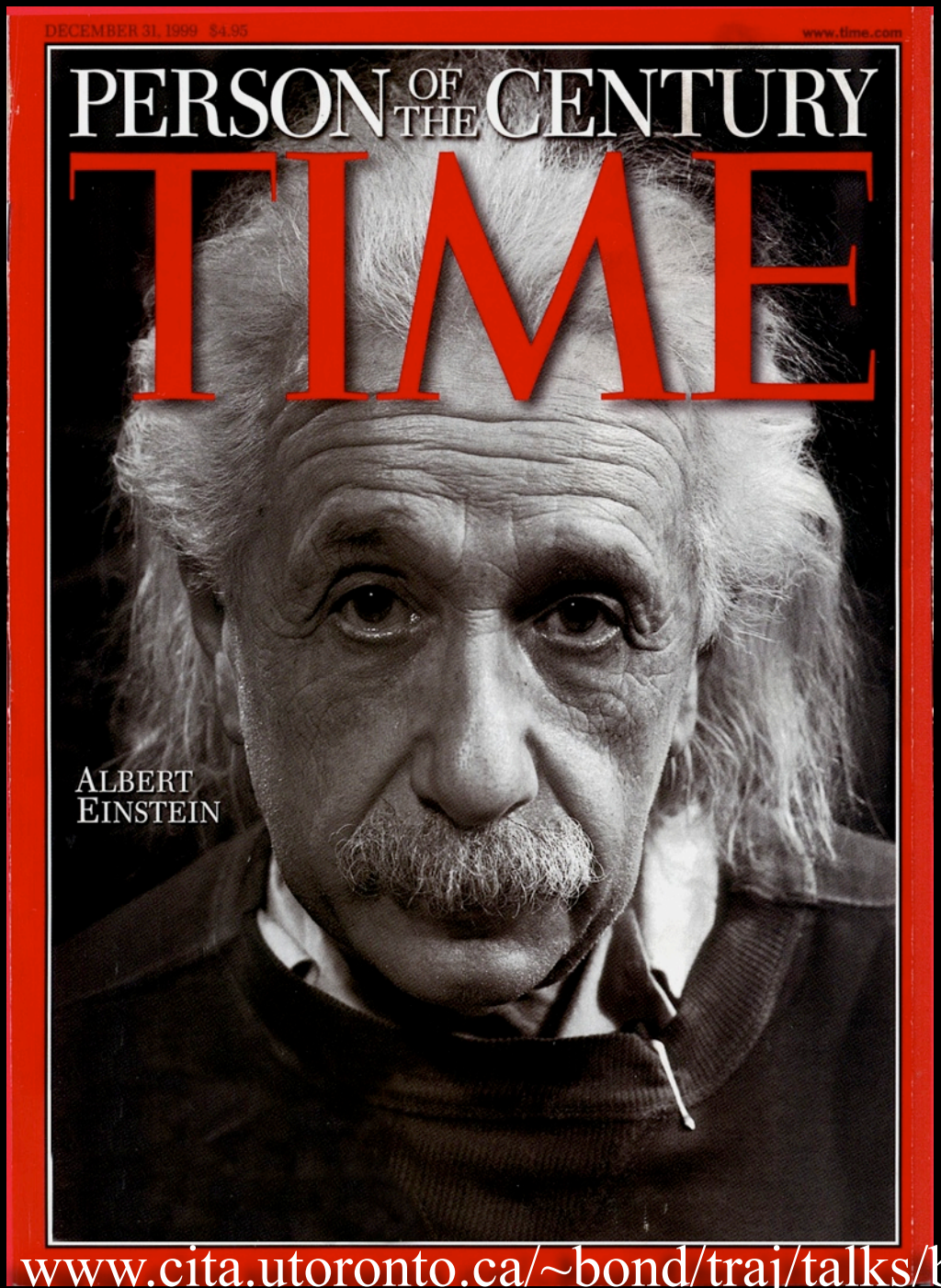


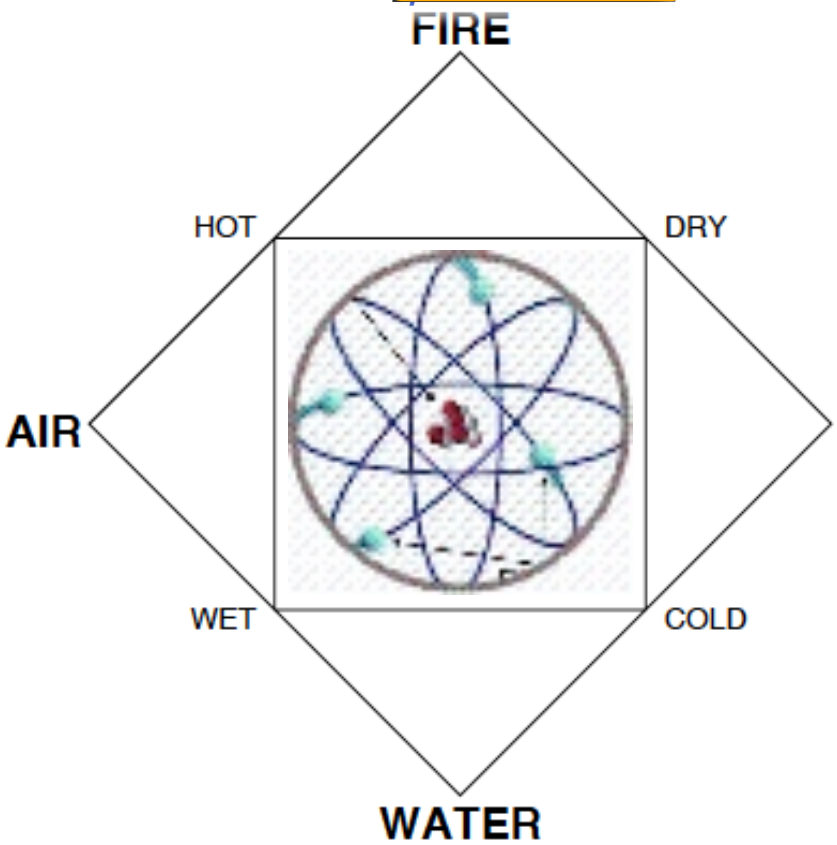
"The most beautiful thing we can experience is the mysterious. It is the source of all true art and all science. Those to whom this emotion is a stranger, who can no longer pause to wonder and stand rapt in awe, are as good as dead: their eyes are closed."

Albert Einstein

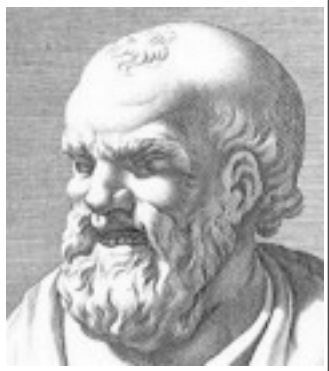
www.cita.utoronto.ca/~bond/traj/talks/bond_rci_public_09_11_01.pdf

the Weighty Matter of the Cosmos: *what is the Universe made of?*

4 elements/ 4 qualities
+ 5th element: quintessence aether

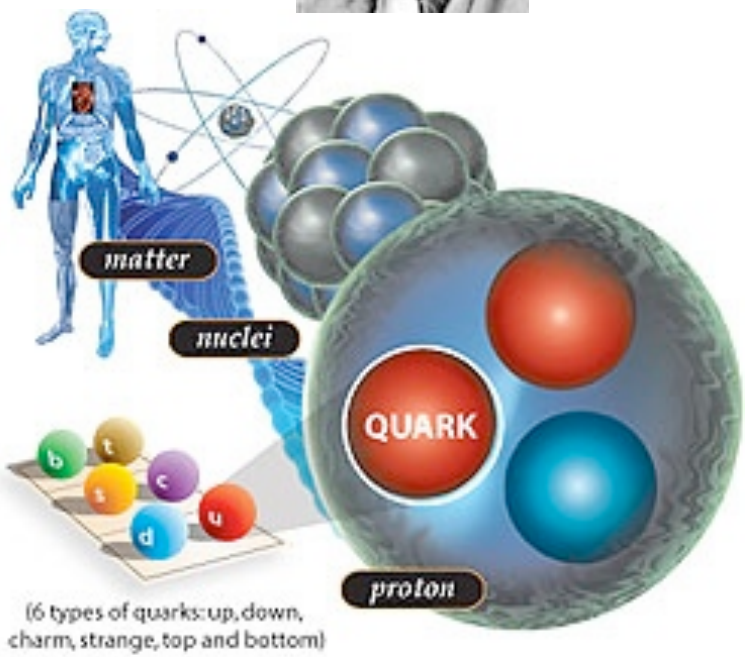


Leucippus, *Big Cosmology*
& Democritus, *Little Cosmology*
460-370BC 2 elements: atoms & the void; *eternal U, matter conserved*

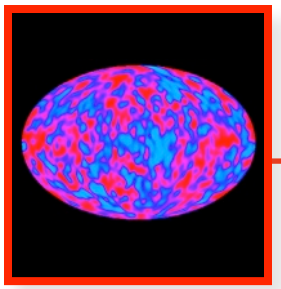


Dalton
1766
-1844

Rutherford
1911 nucleus
+electrons

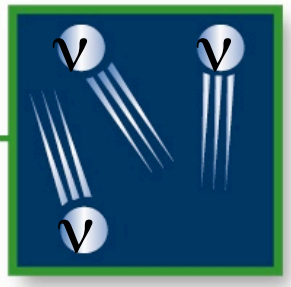


water (Thales), air (Anaximenes), earth (Xenophanes), and fire (Heraclitus). Empedocles unified theory of all 4. Plato 4 of 5 geometrical crystal-like solids as atoms. Aristotle prevailed: elements as combinations of qualities



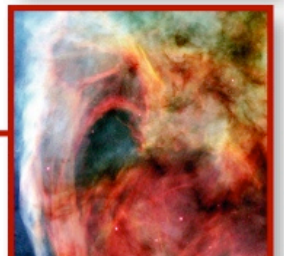
Radiation:

Chemical Elements:
(other than H & He)

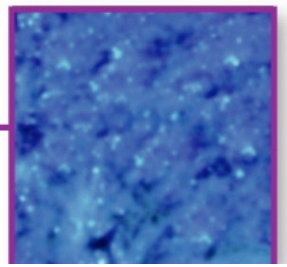


Neutrinos:

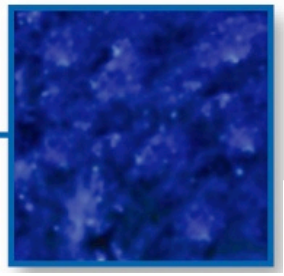
Stars:



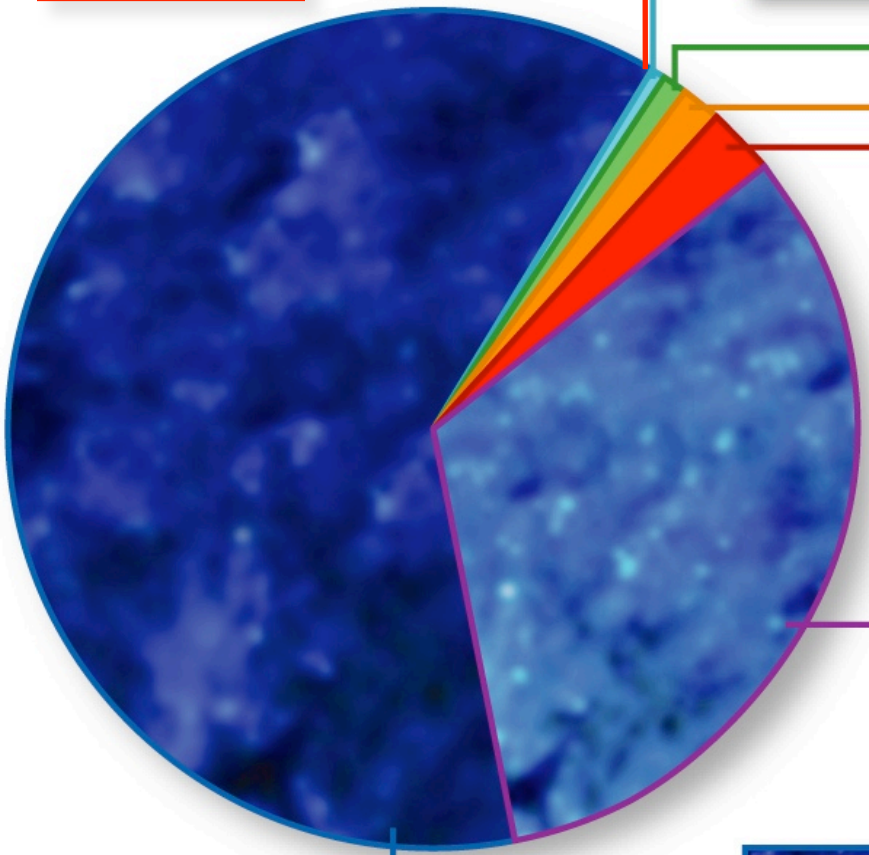
Free
H & He:



Dark Matter:



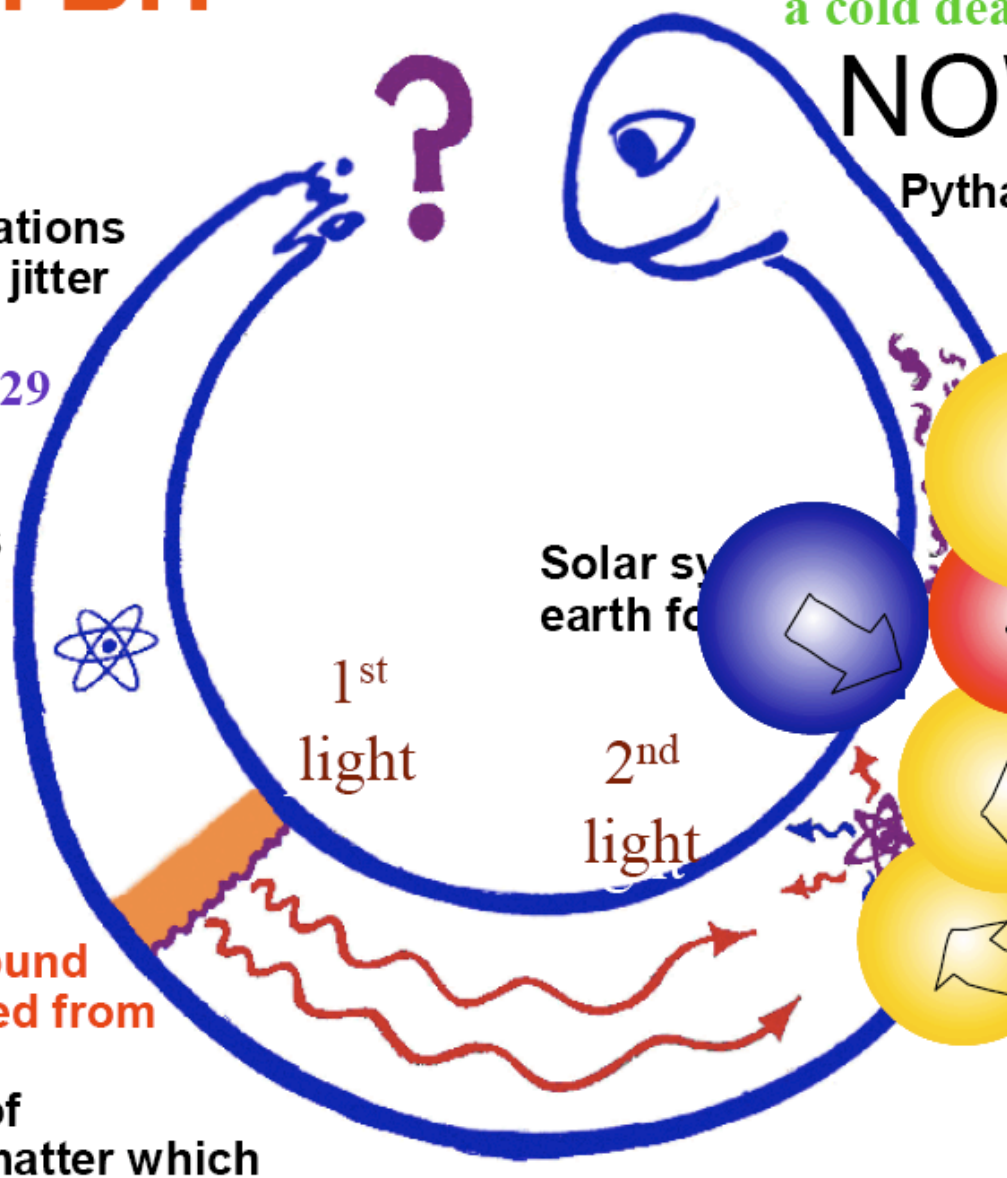
Dark Energy:



Gravity Waves

Black Holes

"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

Inflation fluctuations form: quantum jitter

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

Protons/Neutrons form

Helium forms

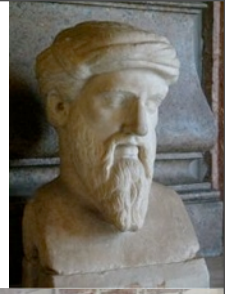
100 sec 10^{9}

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

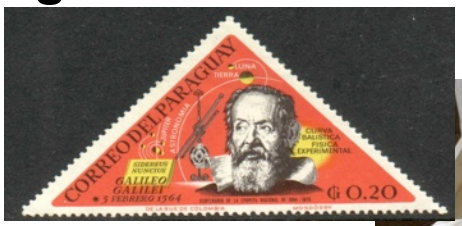
0.4 Myr 1100

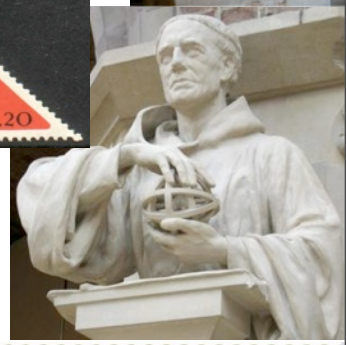
The 'Meaning' may change
But the facts will remain

PYTHAGORAS ~ 550 BCE *The THEORIST*



- ✓ Cosmos - The Universe as a Mathematical Entity
- ✓ Music of the Heavens – Frequency/Wavelength





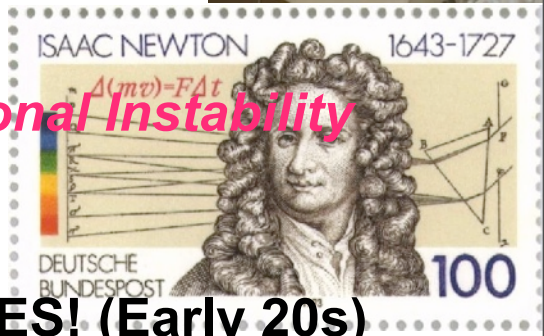
ROGER BACON ~ 1260 AD

MARRIAGE: of Experiment to Theory

COPERNICUS/KEPLER/GALILEO et al. ~1600 AD

NEWTON ~ 1660 - 1690 AD *The PHYSICIST*

- ✓ LAW OF GRAVITATION - Mass Attraction
- ✓ Heavenly Objects Arise via Clumping .. *Gravitational Instability*
- ✓ Thus: the Universe is Infinite



KANT ~ 1755 AD **Galaxies - 'Island Universes'** **YES! (Early 20s)**

Newton's Death Mask @ROE

Crawford collection

Beyond Einstein

the universe is comprehensible!!!

Gravity as Geometry=Mass-Energy

Beyond Einstein

the universe is comprehensible!!!

Gravity as Geometry=Mass-Energy

cosmological constant 1917 Λ

Beyond Einstein

the universe is comprehensible!!!

Gravity as Geometry=Mass-Energy

cosmological constant 1917 Λ

G-Λg=Energy-density x $8\pi G_{Newton}$

Beyond Einstein

the universe is comprehensible!!!

Gravity as Geometry=Mass-Energy

cosmological constant 1917 Λ

G-Λg=Energy-density x $8\pi G_{Newton}$

Gravitational waves – 1917

Beyond Einstein

the universe is comprehensible!!!

Gravity as Geometry=Mass-Energy

cosmological constant 1917 Λ

G-Λg=Energy-density x $8\pi G_{Newton}$

Gravitational waves – 1917

ripples in spacetime moving at the speed of light

Beyond Einstein

the universe is comprehensible!!!

Gravity as Geometry=Mass-Energy

cosmological constant 1917 Λ

G-Λg=Energy-density x $8\pi G_{Newton}$

Gravitational waves – 1917

ripples in spacetime moving at the speed of light c

Beyond Einstein

the universe is comprehensible!!!

Gravity as Geometry=Mass-Energy

cosmological constant 1917 Λ

G-Λg=Energy-density x $8\pi G_{Newton}$

Einstein: Mass = Energy /c^2

Planck's Quantum:

Energy= h x frequency

Quantum + Gravity $\Rightarrow$ Planck Mass

Gravitational waves – 1917

ripples in spacetime moving at the speed of light c

Beyond Einstein

the universe is comprehensible!!!

Gravity as Geometry=Mass-Energy

cosmological constant 1917 Λ

G-Λg=Energy-density x $8\pi G_{Newton}$

Einstein: Mass = Energy /c^2

Planck's Quantum:

Energy= h x frequency

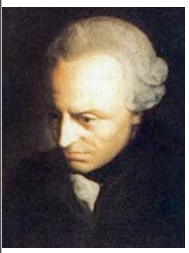
Quantum + Gravity $\Rightarrow$ Planck Mass

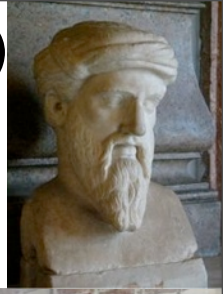
$$M_P = (ch/G_{Newton})^{1/2} /4\pi$$

Gravitational waves – 1917

ripples in spacetime moving at the speed of light c

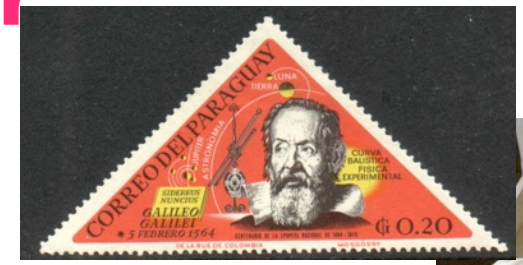
KANT ~ 1755 AD Galaxies - 'Island Universes' **YES! (Early 20s)**

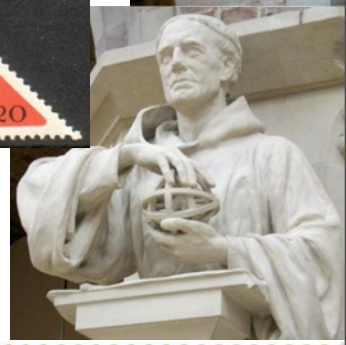




large **halo** of **dark matter**
70s/80s around galaxies;
30s around clusters.

relics or remnants?





Milky Way 1953-55

EINSTEIN: SCIENTIFIC COSMOLOGY(1917)

- ✓ Finite universe without a boundary
- ✓ "Cosmological Constant" (~ 1895) Λ

Make the Universe Finite via A Repulsive Force

"My greatest blunder"

EINSTEIN: SCIENTIFIC COSMOLOGY(1917)

- ✓ Finite universe without a boundary
- ✓ "Cosmological Constant" (~ 1895) Λ

Make the Universe Finite via A Repulsive Force

"My greatest blunder"

EINSTEIN: SCIENTIFIC COSMOLOGY(1917)

- ✓ Finite universe without a boundary
- ✓ "Cosmological Constant" (~ 1895) Λ

Make the Universe Finite via A Repulsive Force

"My greatest blunder"

FRIEDMANN (1922) Evolving (Expanding) Universe

- ✓ **YES! Hubble (late 20s) rate**
- ✓ **the SINGULARITY (30s,60s), infinite density (!!!???)**

EINSTEIN: SCIENTIFIC COSMOLOGY(1917)

- ✓ Finite universe without a boundary
- ✓ "Cosmological Constant" (~ 1895) Λ

Make the Universe Finite via A Repulsive Force

"My greatest blunder"

FRIEDMANN (1922) Evolving (Expanding) Universe

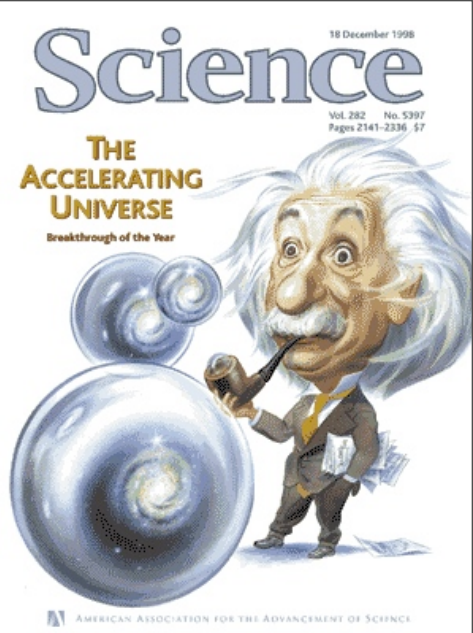
- ✓ **YES! Hubble (late 20s) rate H**
- ✓ **the SINGULARITY (30s,60s), infinite density (!!!???)**

EINSTEIN: SCIENTIFIC COSMOLOGY(1917)

- ✓ Finite universe without a boundary
- ✓ "Cosmological Constant" (~ 1895) Λ

Make the Universe Finite via A Repulsive Force

"My greatest blunder"



FRIEDMANN (1922) Evolving (Expanding) Universe

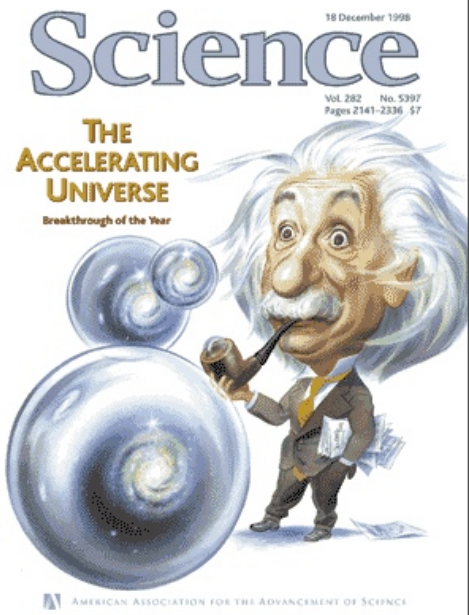
- ✓ **YES! Hubble (late 20s) rate H**
- ✓ **the SINGULARITY (30s,60s), infinite density (!!!???)**

EINSTEIN: SCIENTIFIC COSMOLOGY(1917)

- ✓ Finite universe without a boundary
- ✓ "Cosmological Constant" (~ 1895) Λ

Make the Universe Finite via A Repulsive Force

"My greatest blunder"



FRIEDMANN (1922) Evolving (Expanding) Universe

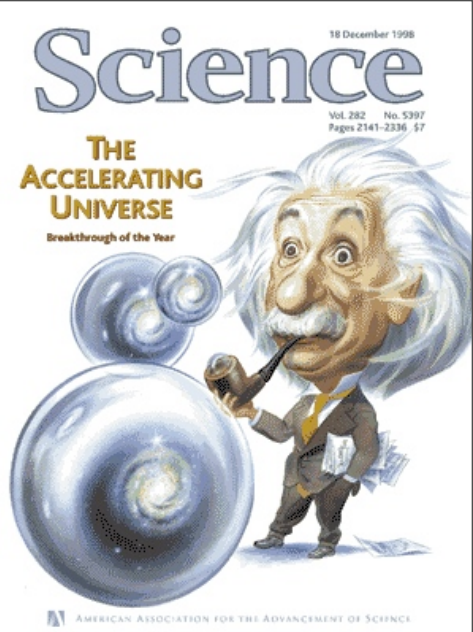
- ✓ **YES! Hubble (late 20s) rate** H
- ✓ **the SINGULARITY (30s,60s), infinite density (!!!???)**

EINSTEIN: SCIENTIFIC COSMOLOGY(1917)

- ✓ Finite universe without a boundary
- ✓ "Cosmological Constant" (~ 1895) Λ

Make the Universe Finite via A Repulsive Force

"My greatest blunder"



ρ_Λ =vacuum energy density

Sakharov~67

FRIEDMANN (1922) Evolving (Expanding) Universe

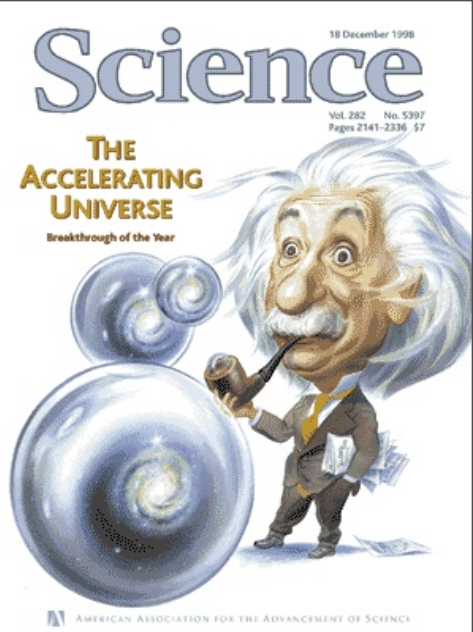
- ✓ **YES! Hubble (late 20s) rate H**
- ✓ **the SINGULARITY (30s,60s), infinite density (!!!???)**

EINSTEIN: SCIENTIFIC COSMOLOGY(1917)

- ✓ Finite universe without a boundary
- ✓ "Cosmological Constant" (~ 1895) Λ

Make the Universe Finite via A Repulsive Force

"My greatest blunder"



ρ_Λ = vacuum energy density

Sakharov~67

FRIEDMANN (1922) Evolving (Expanding) Universe

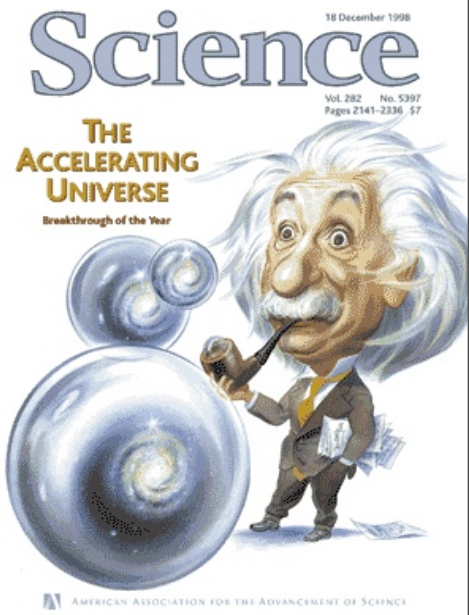
- ✓ **YES! Hubble (late 20s) rate H**
- ✓ **the SINGULARITY (30s,60s), infinite density (!!!???)**

EINSTEIN: SCIENTIFIC COSMOLOGY(1917)

- ✓ Finite universe without a boundary
- ✓ "Cosmological Constant" (~ 1895) Λ

Make the Universe Finite via A Repulsive Force

"My greatest blunder"



ρ_Λ = vacuum energy density

Sakharov~67

$V=\Lambda/8\pi G_{Newton}$
vacuum potential

FRIEDMANN (1922) Evolving (Expanding) Universe

- ✓ **YES! Hubble (late 20s) rate H**
- ✓ **the SINGULARITY (30s,60s), infinite density (!!!???)**

Beyond Einstein

the universe is comprehensible!!!

Gravity=Geometry=Mass-Energy

cosmological constant 1917 Λ

Gravitational waves – 1917

ripples in spacetime moving at the speed of light c

Beyond Einstein

the universe is comprehensible!!!

Gravity=Geometry=Mass-Energy

cosmological constant 1917 Λ

1998/2009+: dark energy

ρ_Λ(space,time)?

Gravitational waves – 1917

ripples in spacetime moving at the speed of light c

Beyond Einstein

the universe is comprehensible!!!

Gravity=Geometry=Mass-Energy

cosmological constant 1917 Λ

1998/2009+: dark energy

ρ_Λ(space,time)? $\Lambda / 8\pi G_{Newton}$

Gravitational waves – 1917

ripples in spacetime moving at the speed of light c

Beyond Einstein

the universe is comprehensible!!!

Gravity=Geometry=Mass-Energy

cosmological constant 1917 Λ

1998/2009+: dark energy

ρ_Λ(space,time)? $\Lambda / 8\pi G_{Newton}$

ρ_b = ordinary matter (known)

Gravitational waves – 1917

ripples in spacetime moving at the speed of light c

Beyond Einstein

the universe is comprehensible!!!

Gravity=Geometry=Mass-Energy

cosmological constant 1917 Λ

1998/2009+: dark energy

ρ_Λ(space,time)? $\Lambda / 8\pi G_{Newton}$

ρ_{dm} = dark matter (in labs?)

ρ_b = ordinary matter (known)

Gravitational waves – 1917

ripples in spacetime moving at the speed of light c

Beyond Einstein

the universe is comprehensible!!!

Gravity=Geometry=Mass-Energy

cosmological constant 1917 Λ

1998/2009+: dark energy

ρ_Λ(space,time)? $\Lambda/ 8\pi G_{Newton}$

ρ_{dm} = dark matter (in labs?)

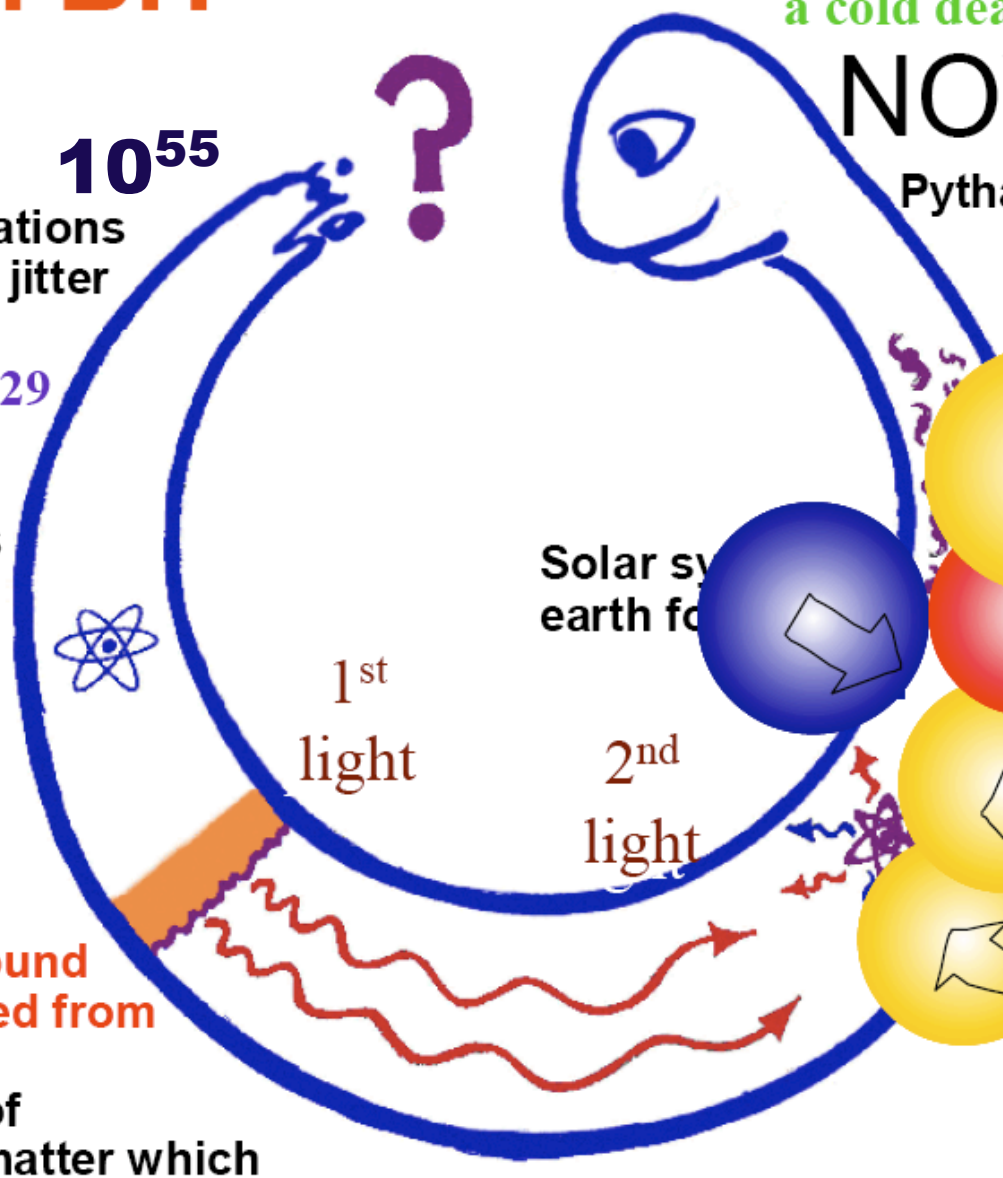
ρ_b = ordinary matter (known)

Gravitational waves – 1917

ripples in spacetime moving at the speed of light c

to be "observed": from black holes ρ_{BH} & neutron stars ~2012, from the quantum early Universe ~2011? ρ_{GW}

"IT from BIT"



The 'Meaning' may change
But the facts will remain

- ✓ **GAMOW (40s, early 50s) HOT BIG BANG**
  Hydrogen (75%) & Helium (25%) Deuterium/Lithium from the first minutes ; Carbon, Oxygen, Iron,..from exploding stars 40s-80s

IOTA 1967, Cambridge **B^2FH 57, WFH 67, sn**

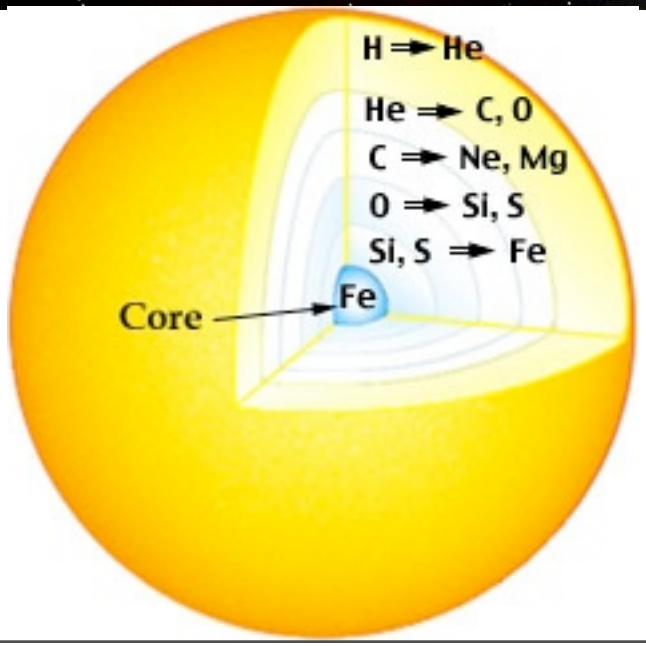
Crab 1054 AD SN + pulsar
i.e. neutron star remnant

SN1987a @LMC

collapse neutrinos,

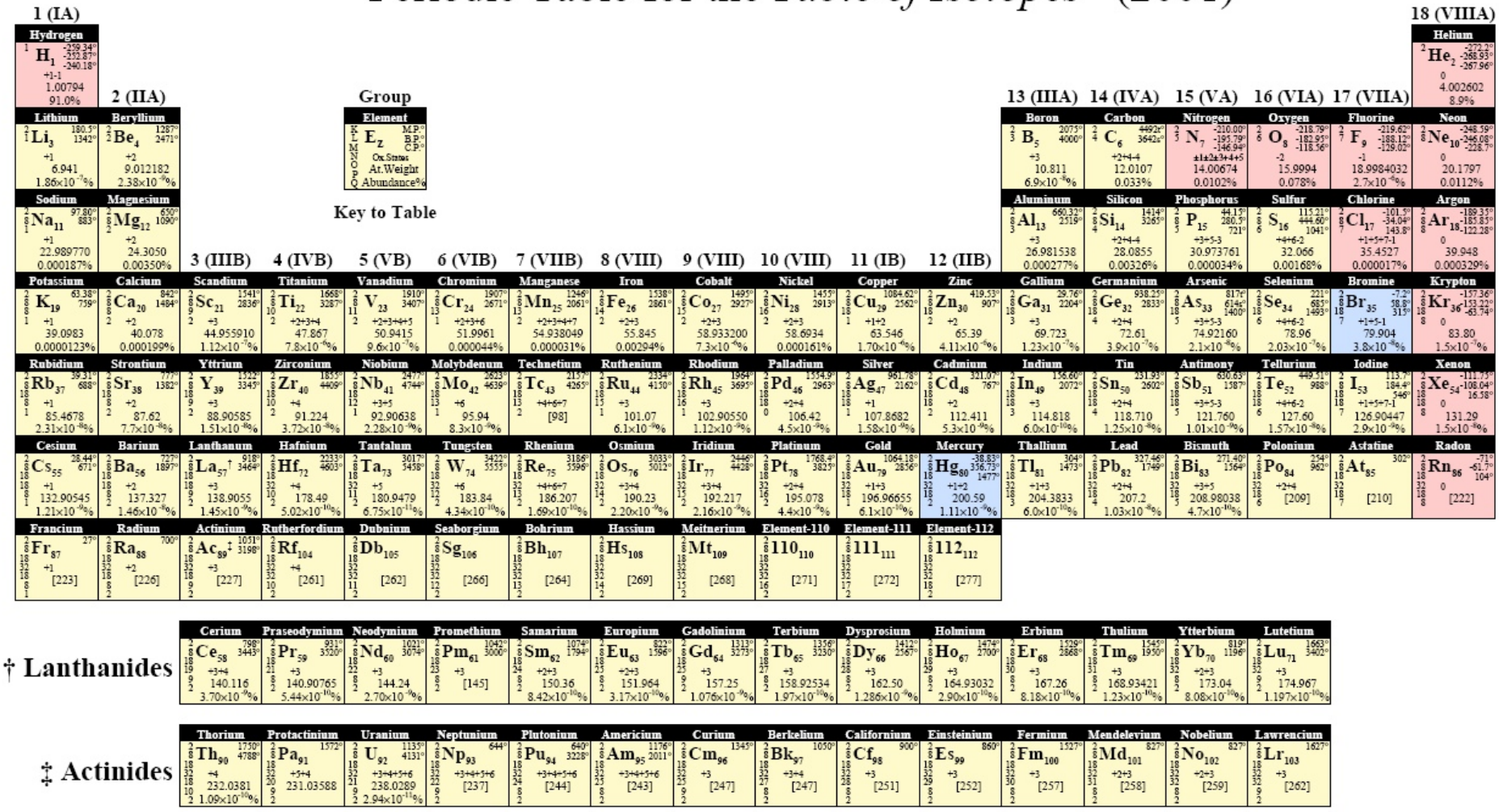
no neutron star yet

SN1987a + 17 yrs



Nobel Prize 84 Willy Fowler + Chandra -sekhar

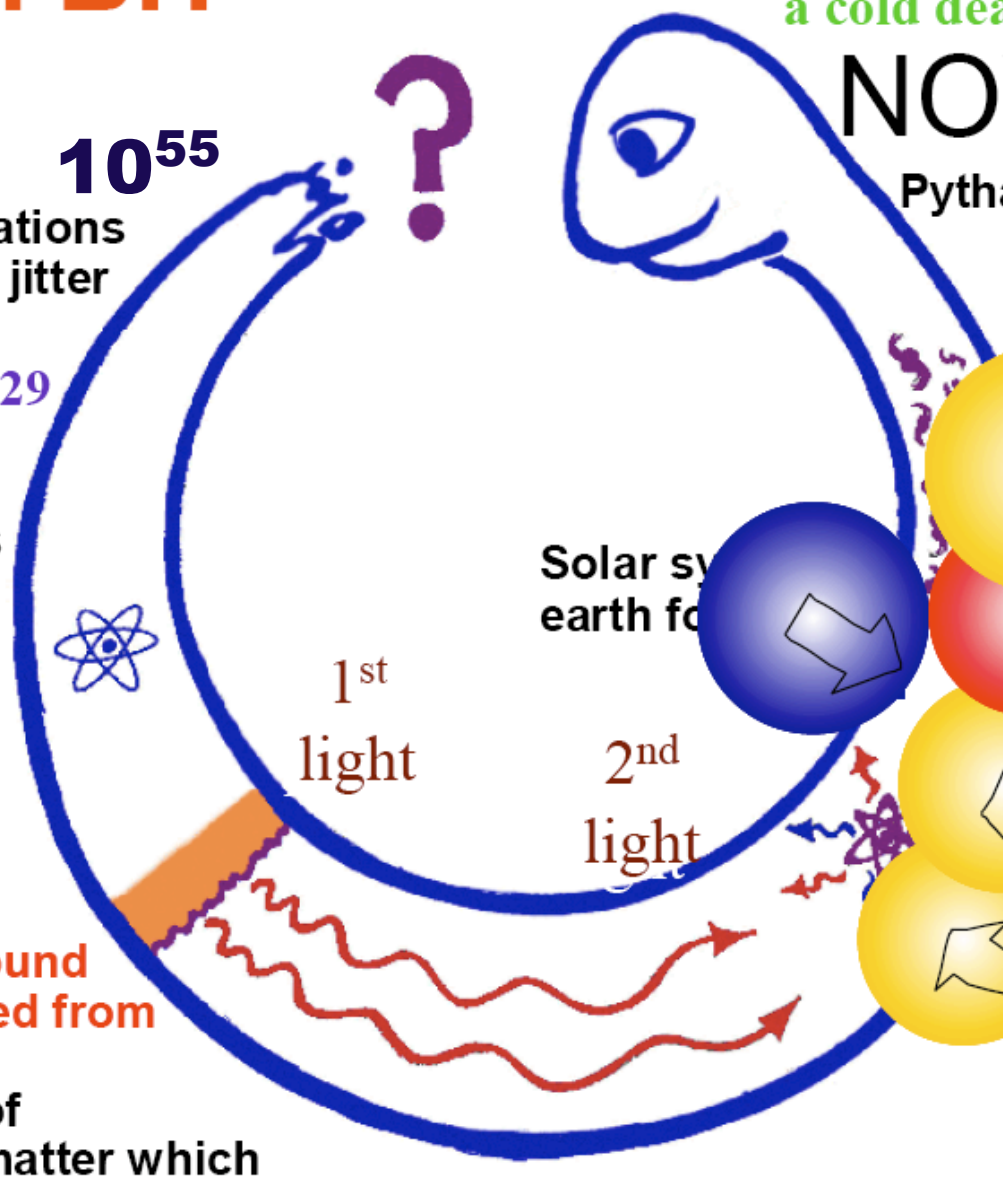
Periodic Table for the *Table of Isotopes** (2001)



cosmic baryon number n_b=0.261 +-.005 /m^3

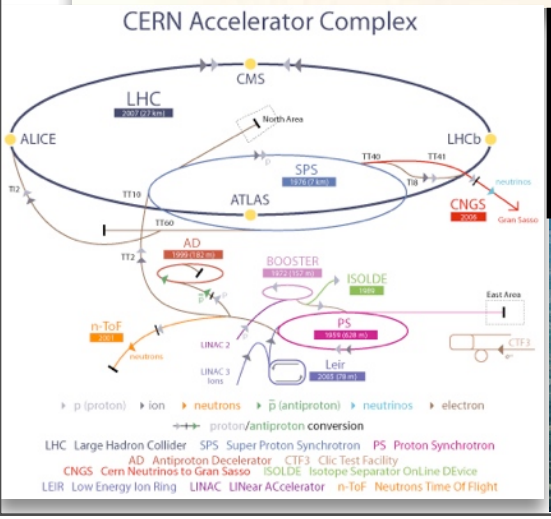
from the latest data: wmap5+acbar+cbi+b03+.+WL+LSS+SN1+Lya

"IT from BIT"



The 'Meaning' may change
But the facts will remain

extra-“ordinary” matter



what is **mass?**

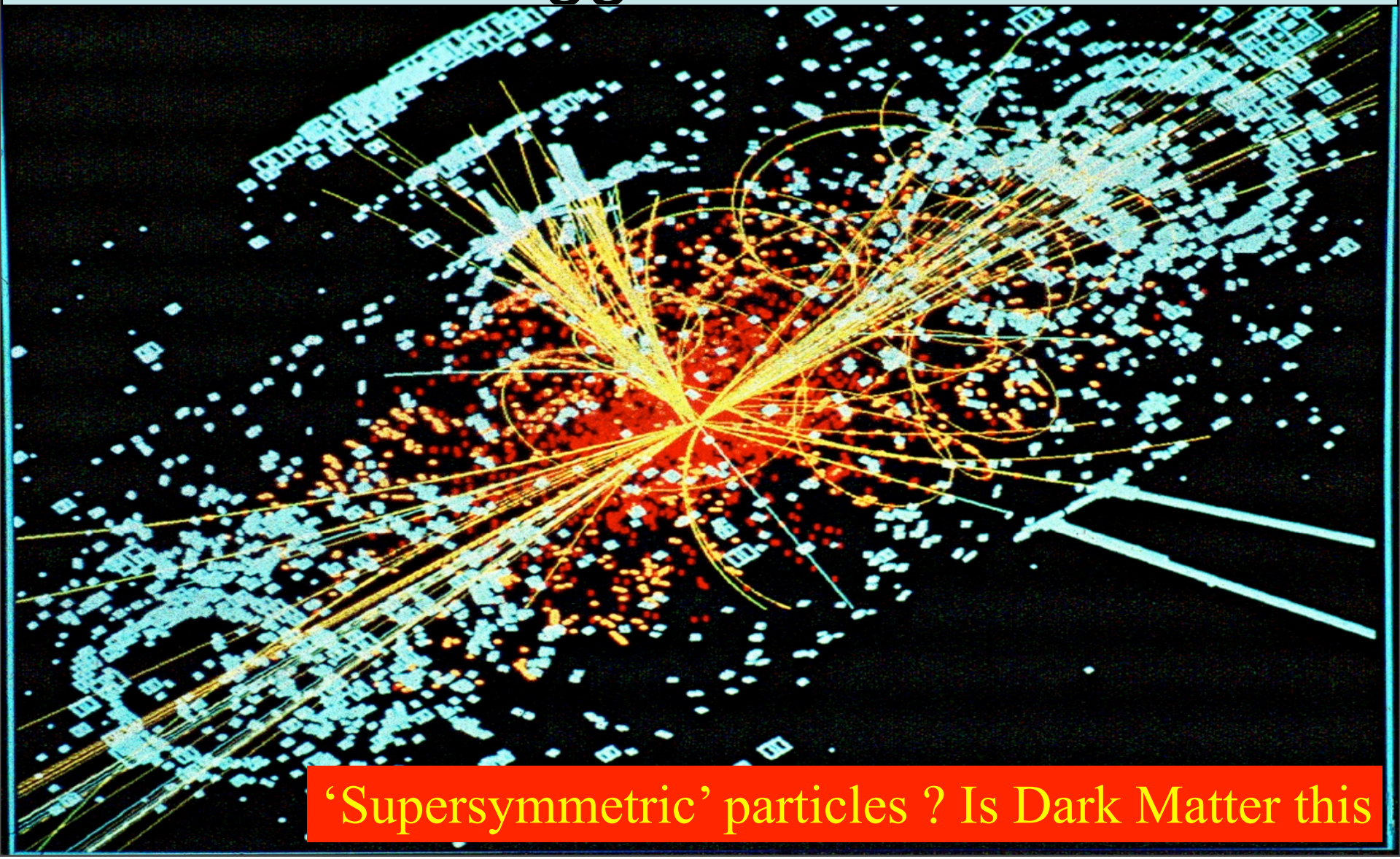
vacuum potential

dark matter

antimatter asymmetry

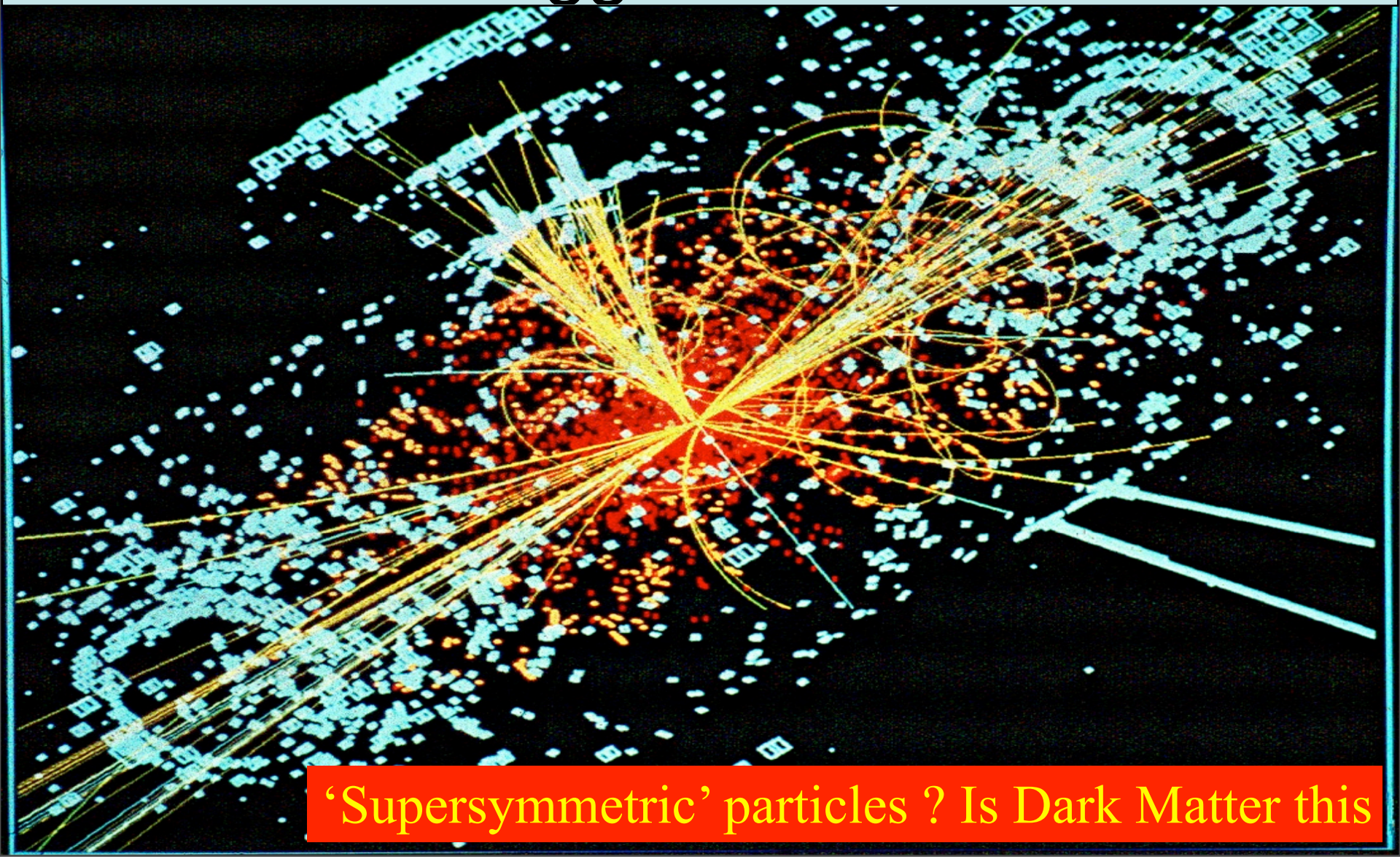
extra dimensions

A Simulated Higgs Event in CMS: LHC

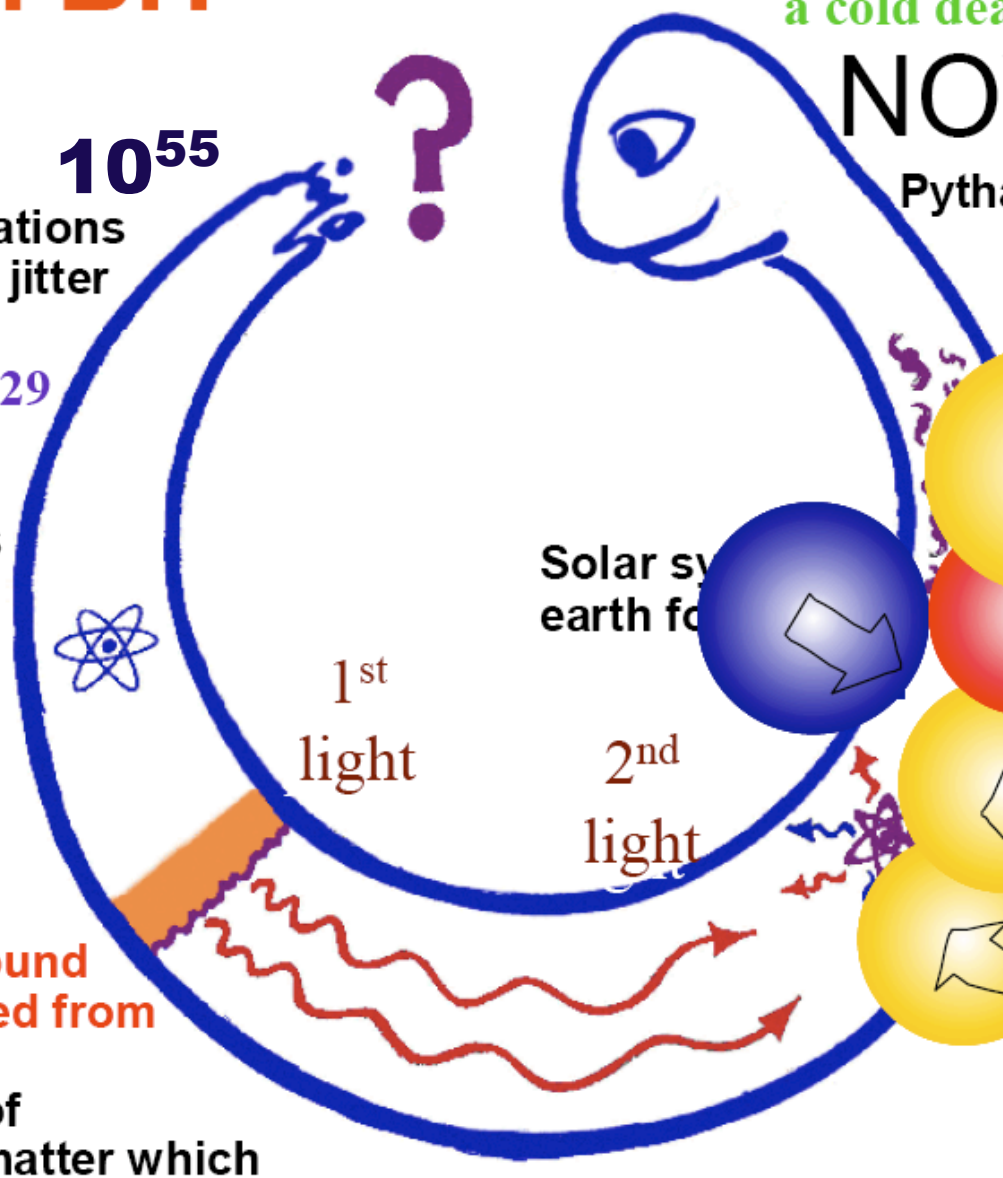


If Dark Matter interacts with ordinary matter by more than gravity, we may "see" it at the Large Hadronic Collider 2009+ or at SNOlab 2010+ in Sudbury

A Simulated Higgs Event in CMS: LHC

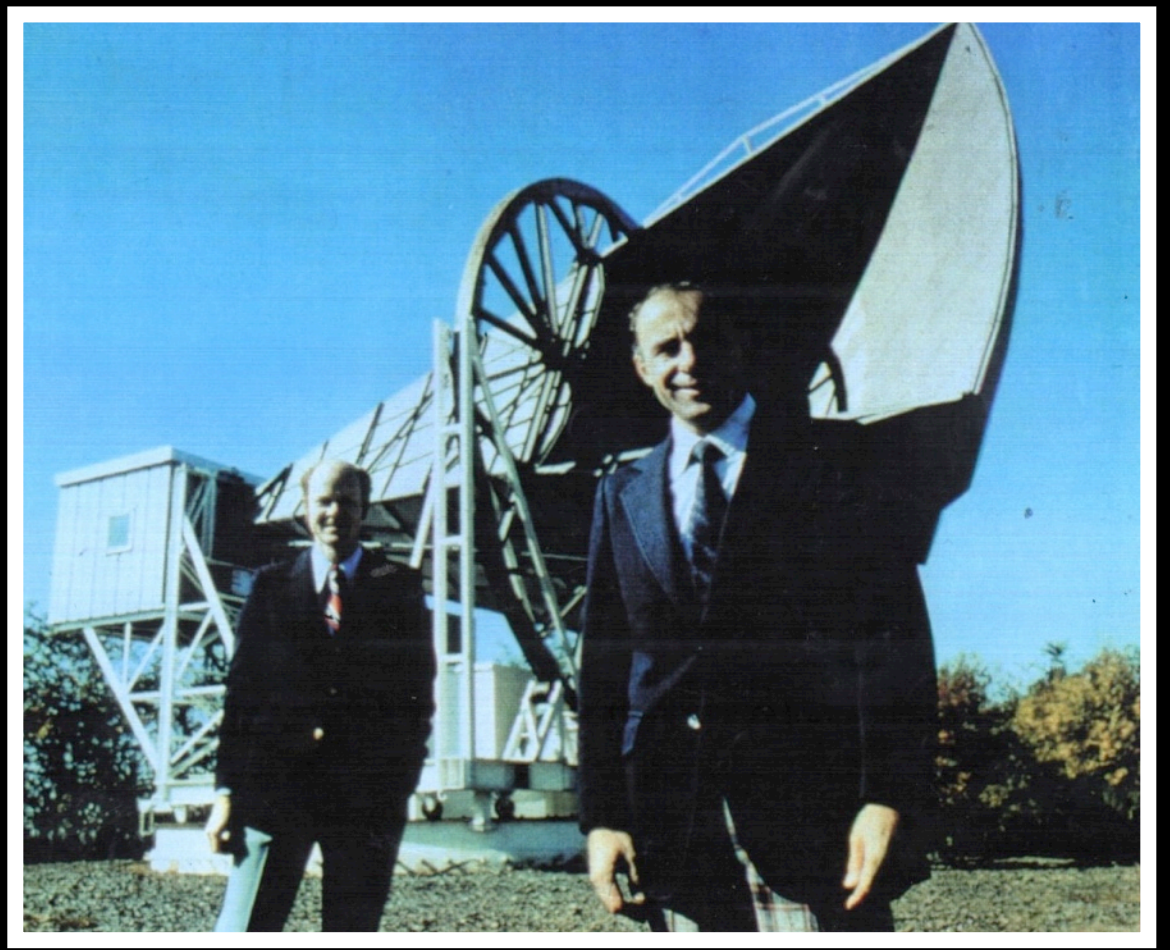


"IT from BIT"



The 'Meaning' may change
But the facts will remain

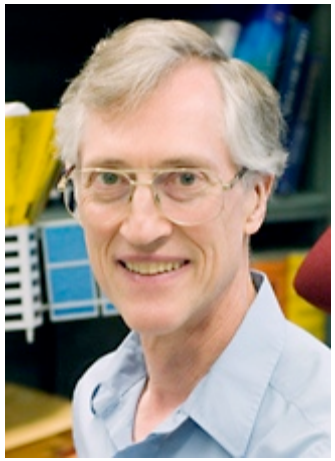
The Universe Is Radiant



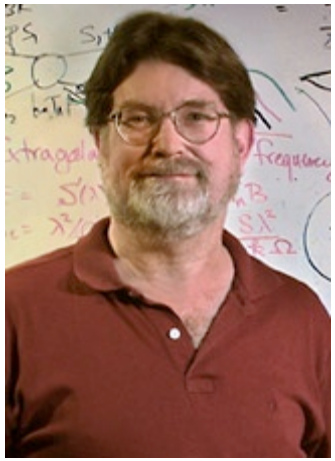
Arno Penzias
Robert Wilson
1965

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

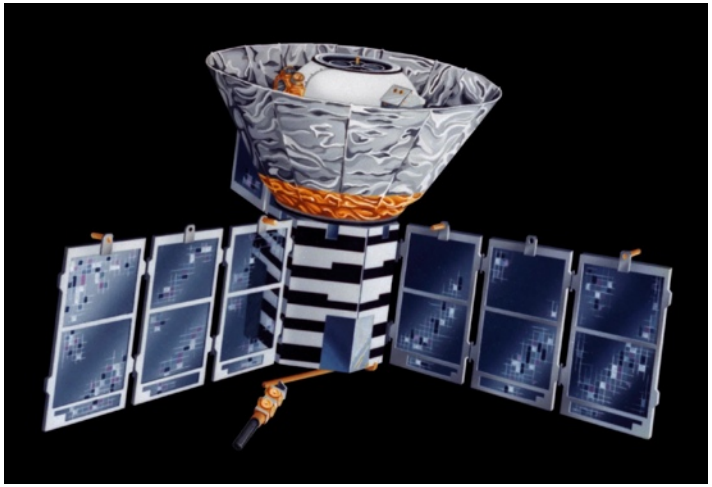
"for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation"

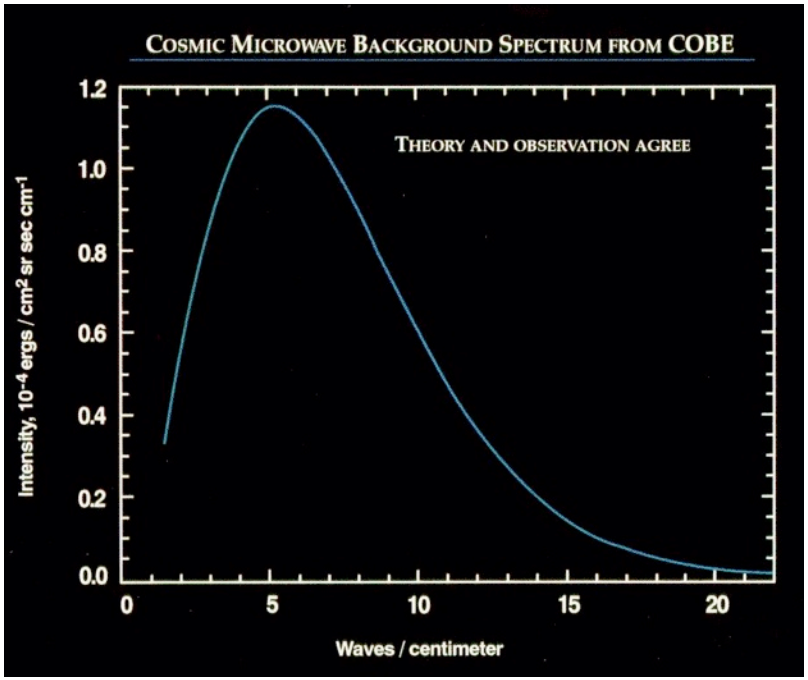


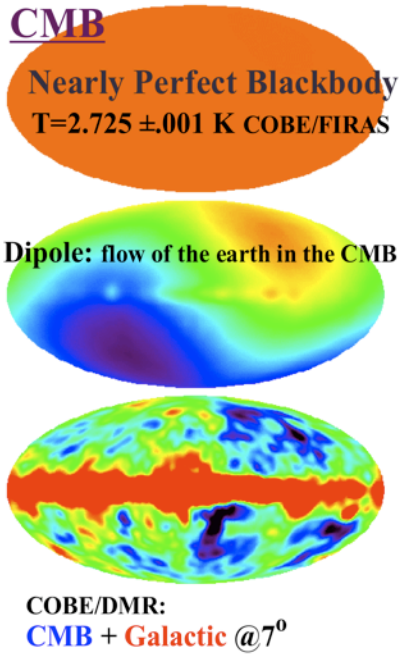
John C. Mather 1946-

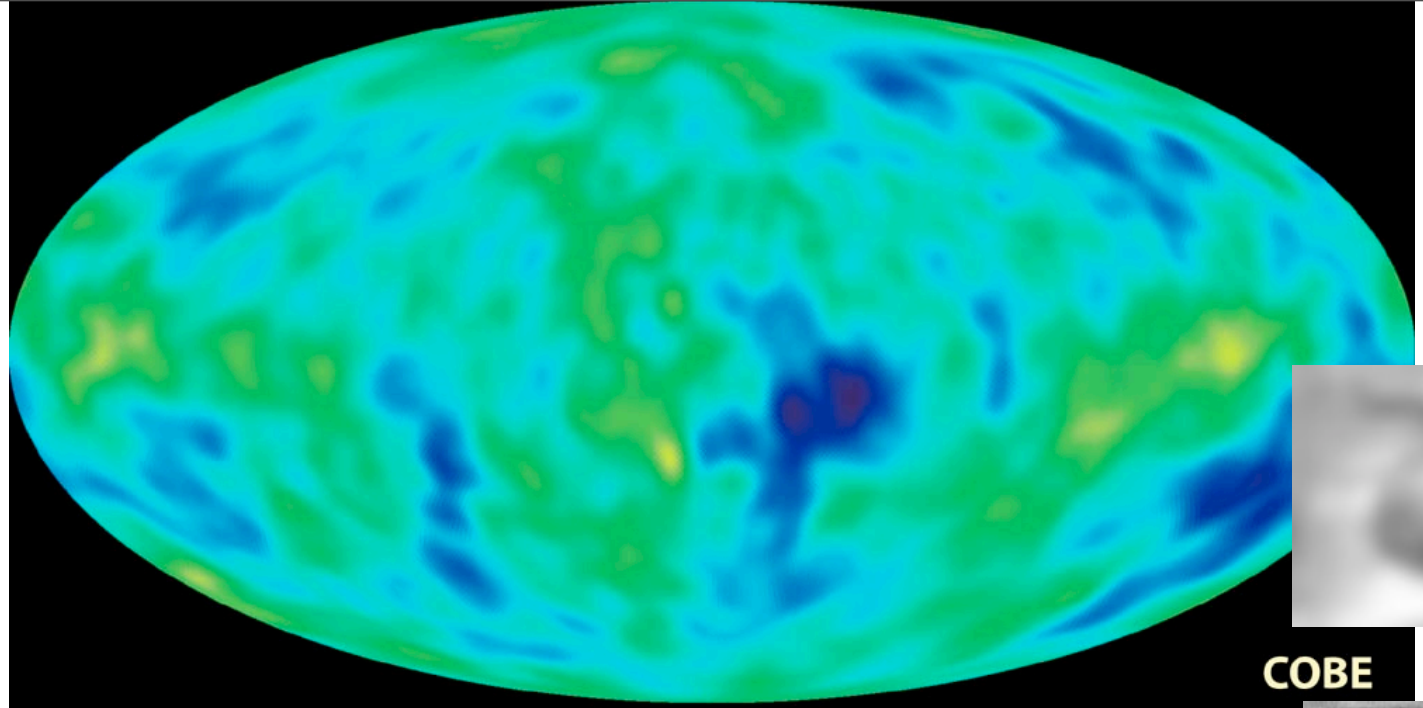


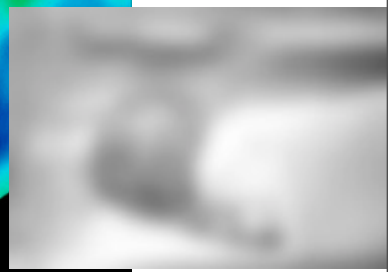
George F. Smoot 1945-



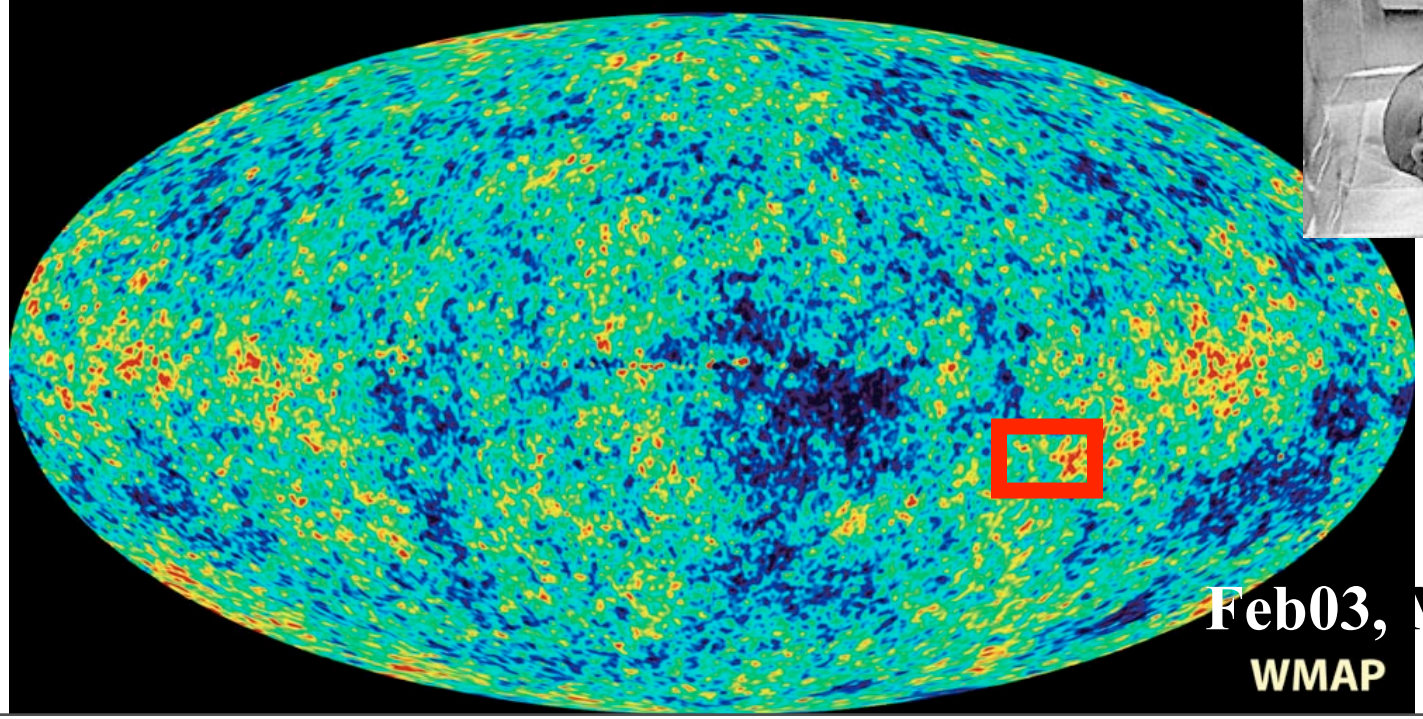






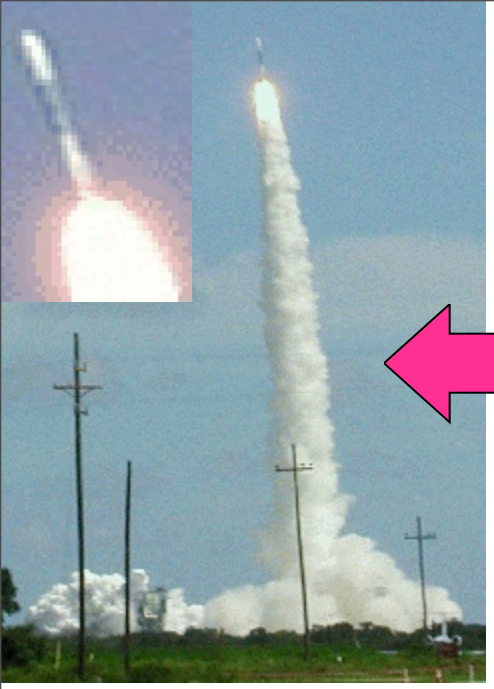


COBE



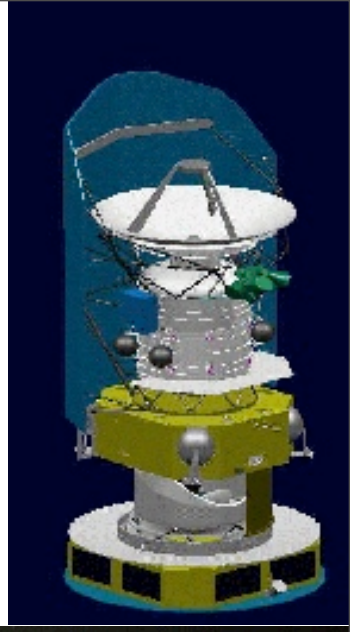
Feb03, Mar06,08

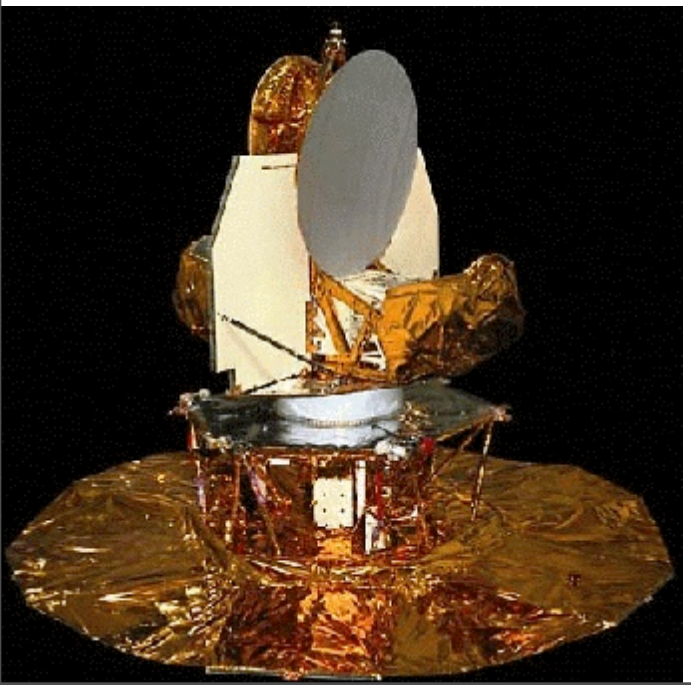
WMAP

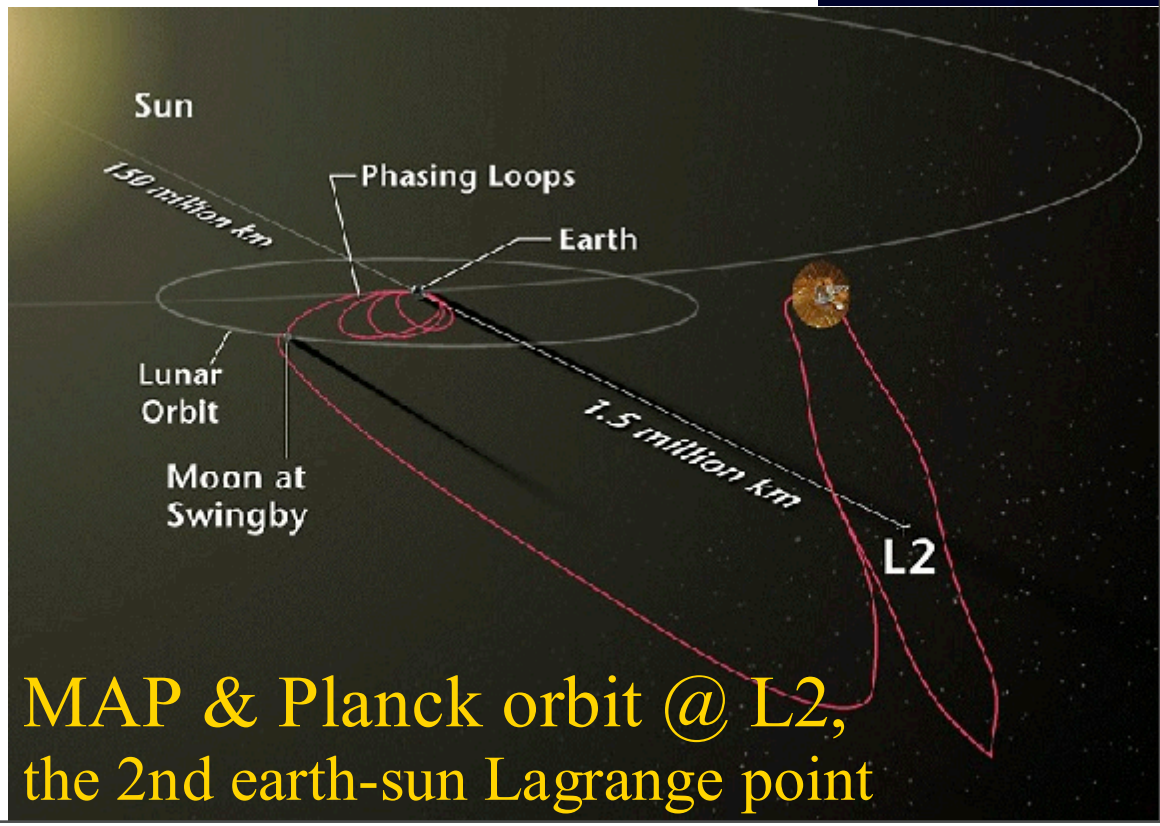


Nasa's WMAP satellite @ L2: launch 2001.5, 1yr data 2003.2, 3yr 2006.3, 5yr 2008.3, funded for 9 years

Planck satellite @ L2: launch 2009.5
ESA+NASA+ Cdn Space Agency





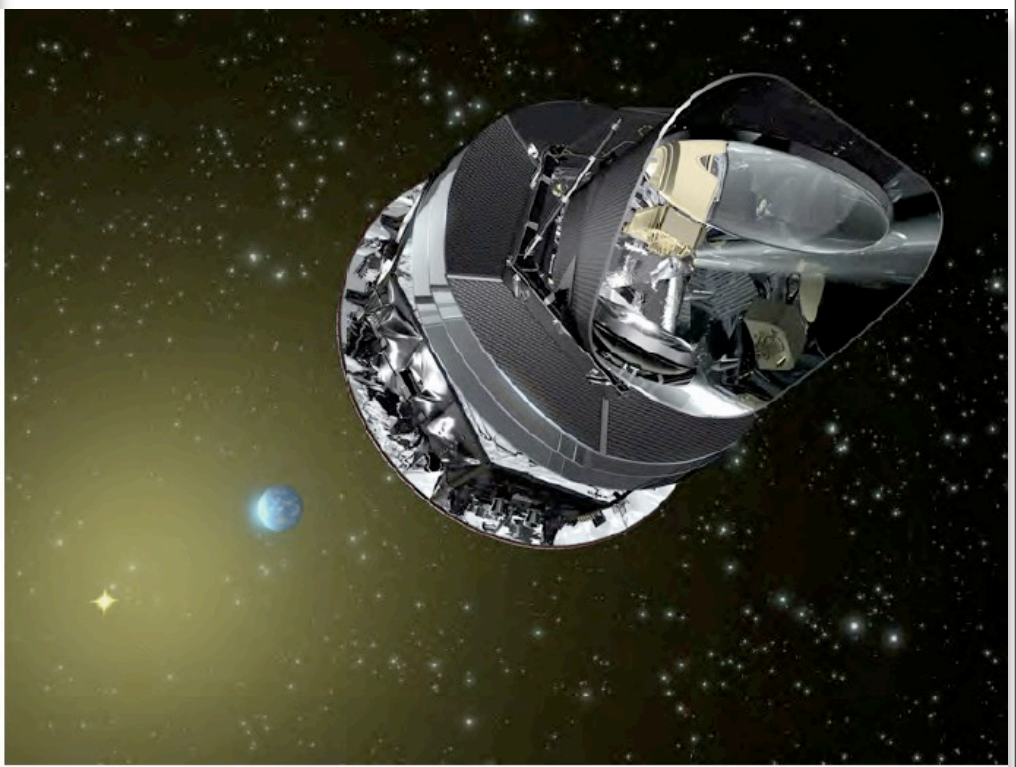


MAP & Planck orbit @ L2,
the 2nd earth-sun Lagrange point

Entering the Planck Era > May 14, 2009

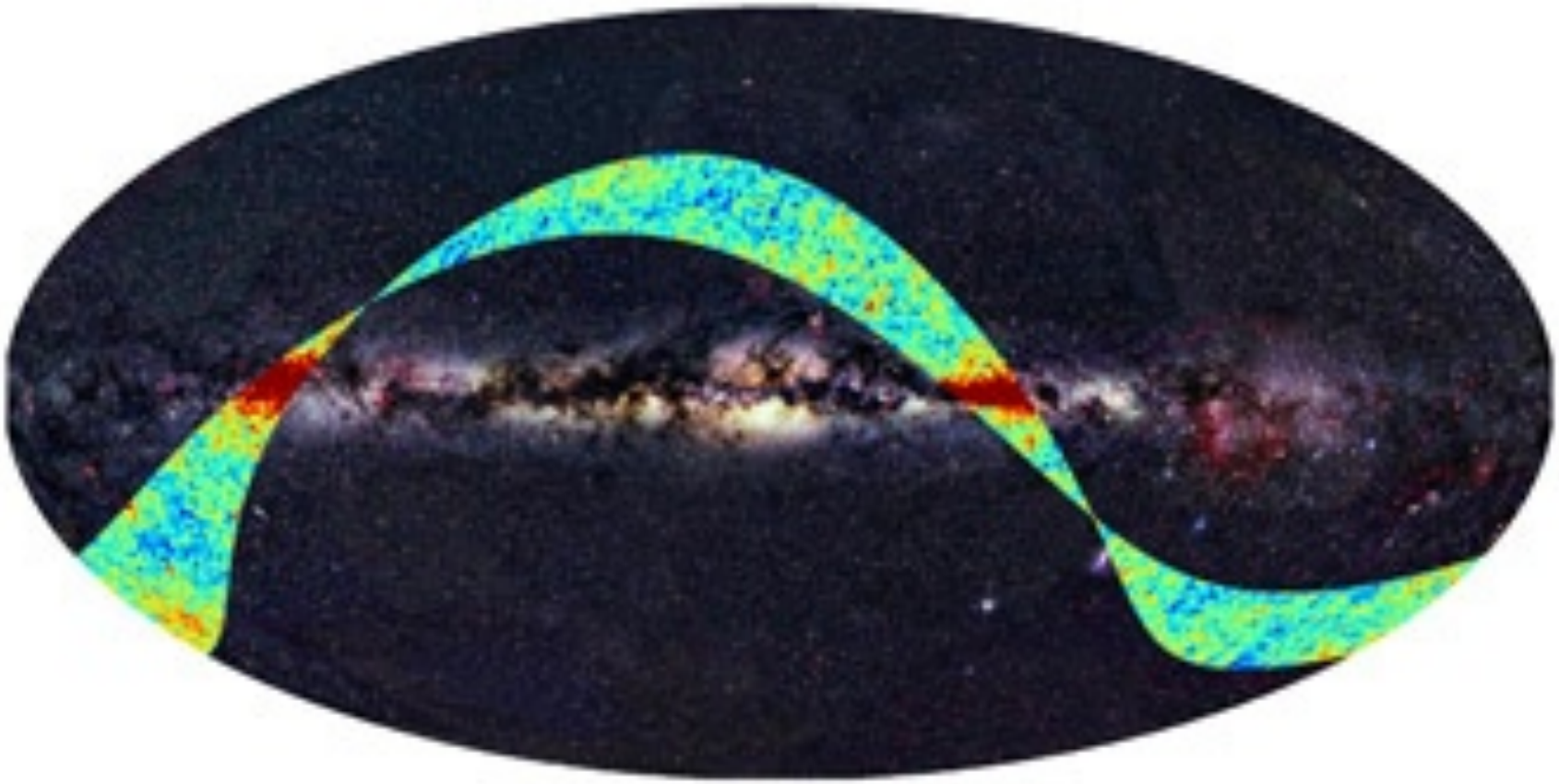
status A-OK, first all sky survey finishes Feb 2010; 5 in all

huge impact of Planck on Planck era physics **(early inflation)** ***& on late inflation (Dark Energy)***

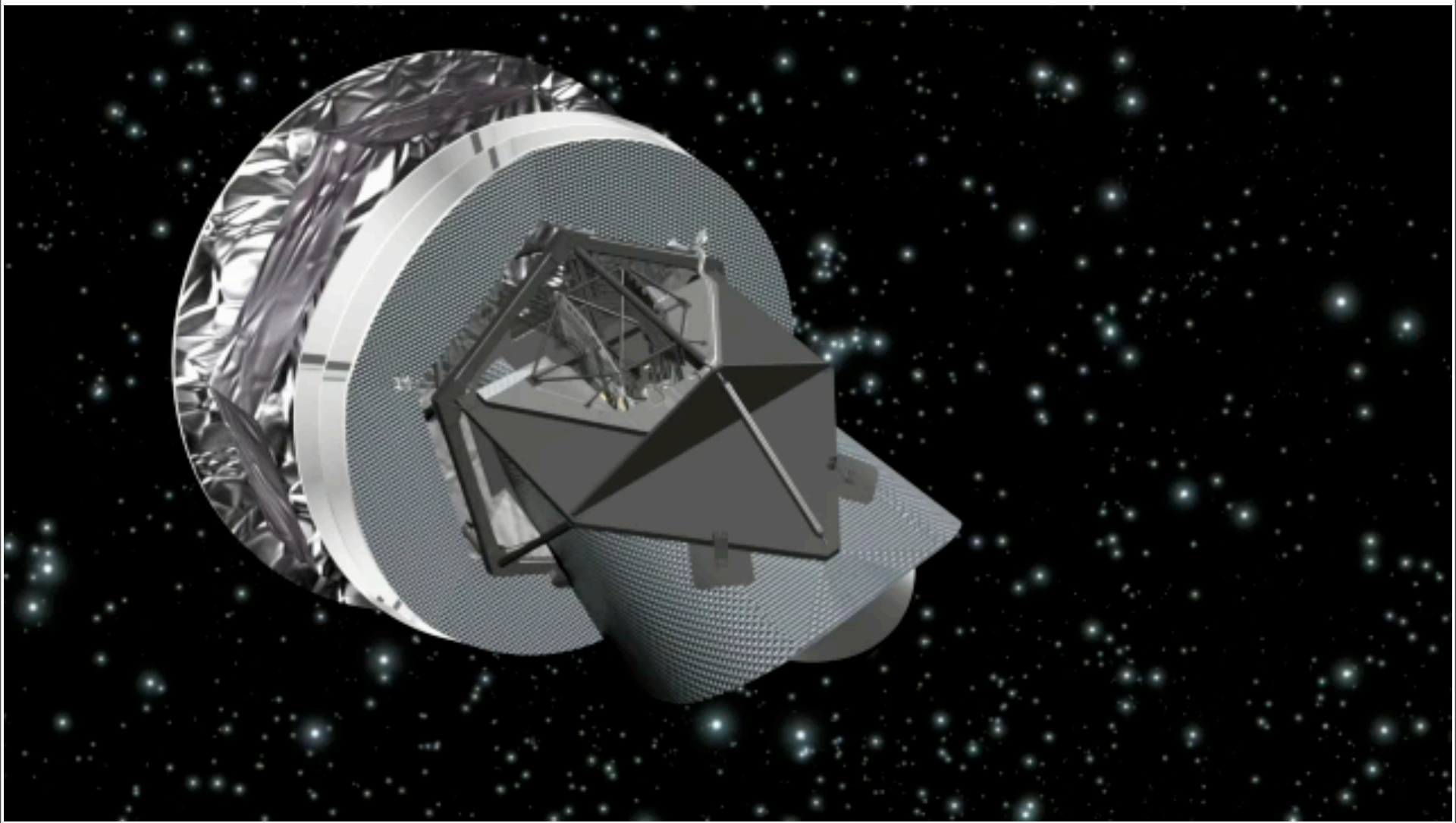


ESA /NASA /CSA Toronto HFI QLA/KST, TA, … *Barth & Dick, Marc-Antoine Miville-Deschenes, Carrie MacTavish, Brendan Crill, Olivier Dore, Carlo Contaldi, Mike Nolta, Peter Martin, Francine Marleau,* UBC LFI

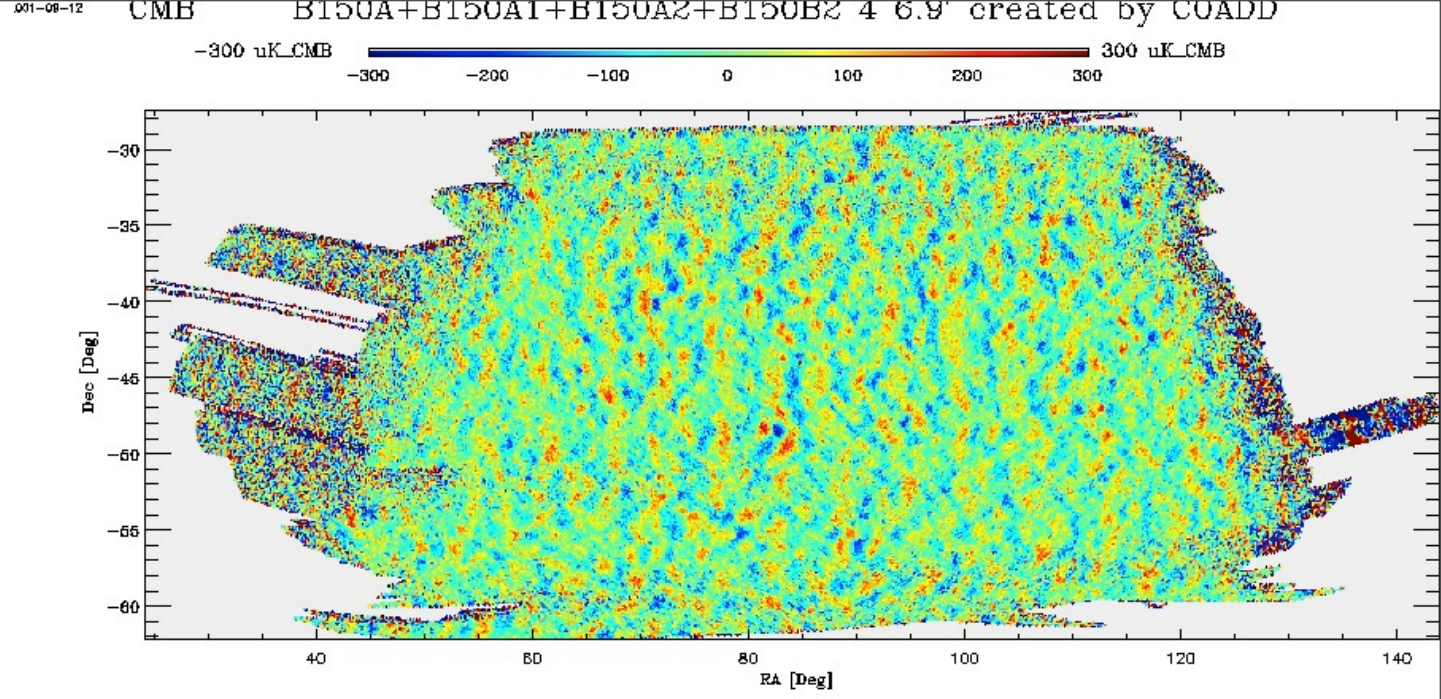
Planck “First Light” Survey Aug 2009



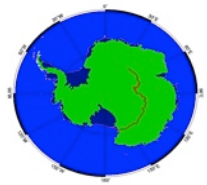
Planck 1st of 5 all Sky Surveys 09.7-10.1

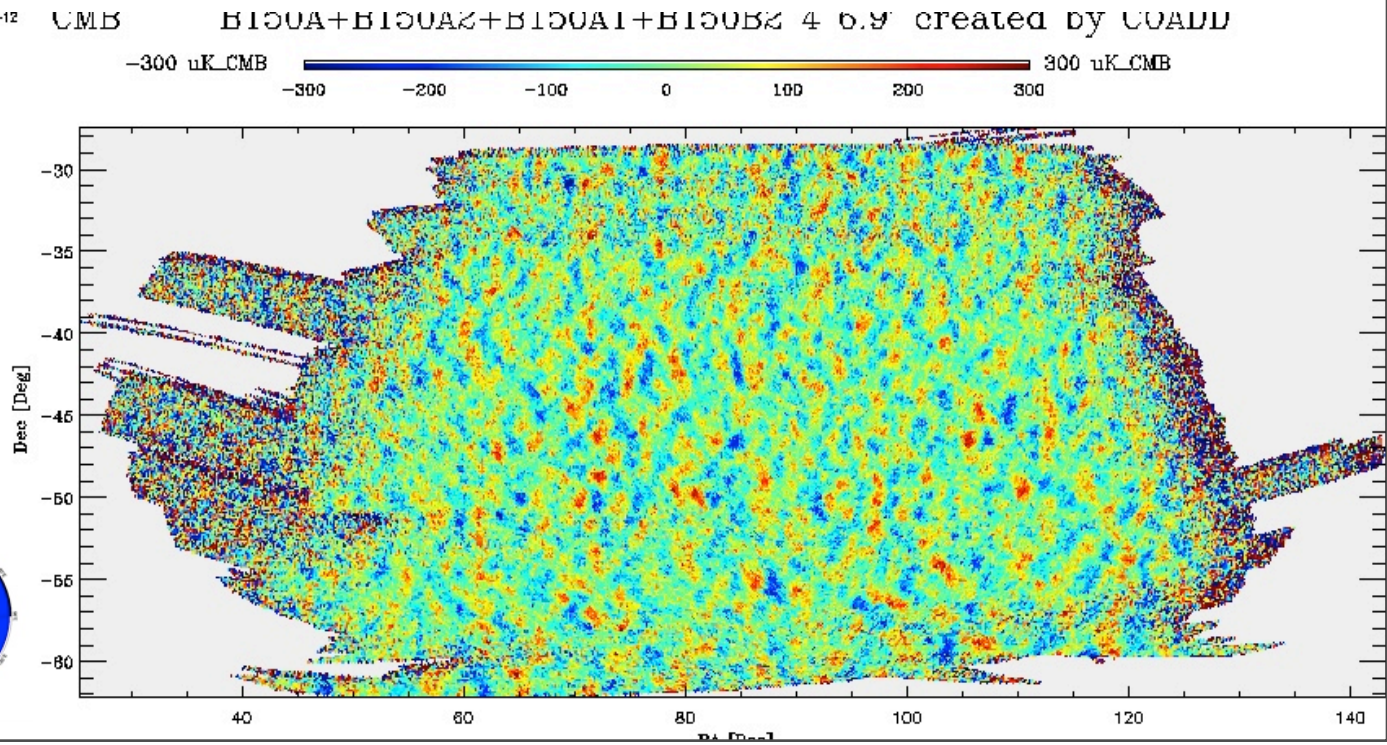


Boomerang @150GHz is (nearly) Gaussian: **Simulated vs Real** ***looks the same***

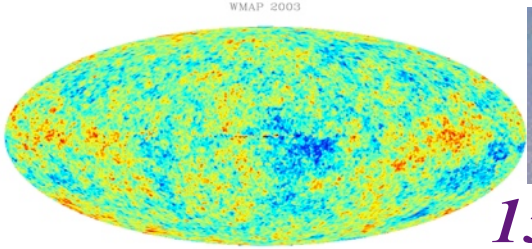


thermodynamic CMB temperature fluctuations 2.9% of sky $\Delta T \sim 30$ ppm



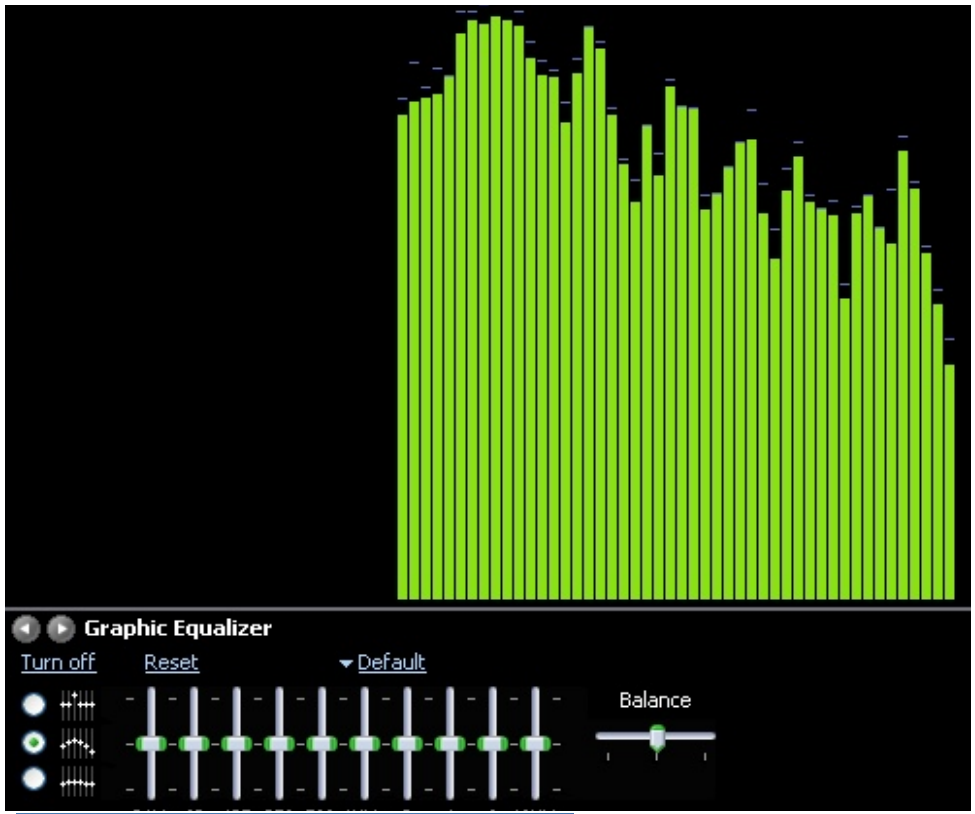


CITA ICAT
Canadian Institute for Theoretical Astrophysics
L'institut canadien d'astrophysique theorique

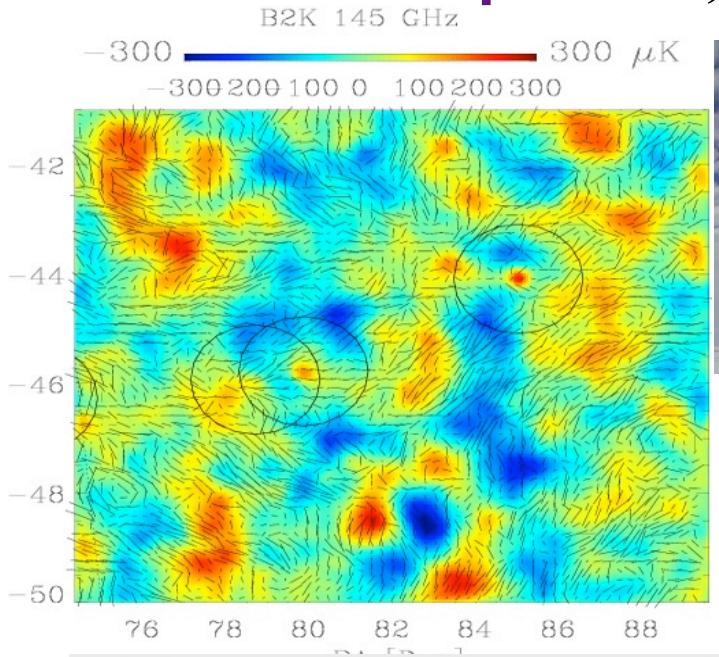


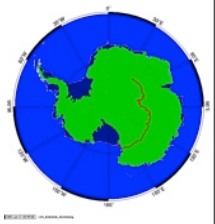
CIAR 25 years cifar

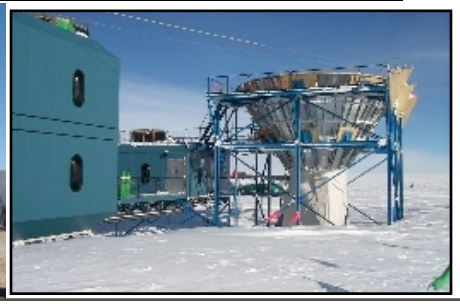
13.65 -0.00038 billion years ago

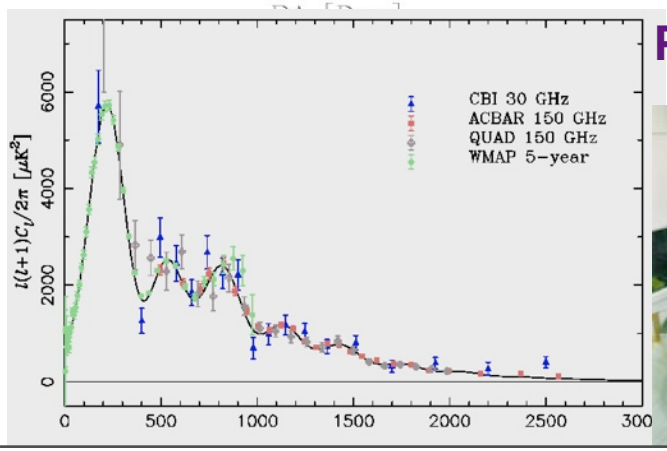


Boom05 deep **Jul05, Sept08**



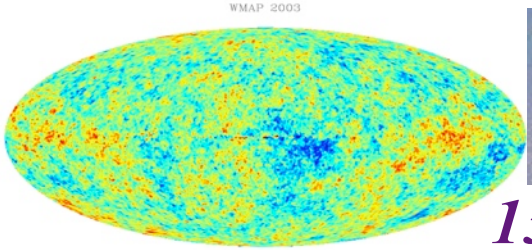






Planck09 as deep

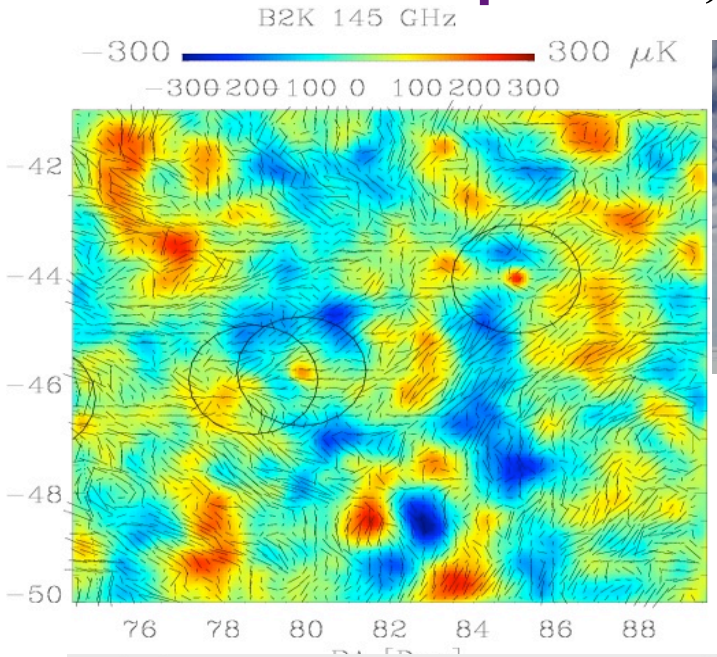
CITA ICAT
Canadian Institute for Theoretical Astrophysics
L'institut canadien d'astrophysique theorique

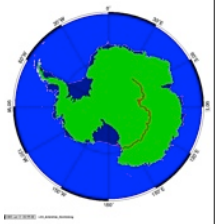


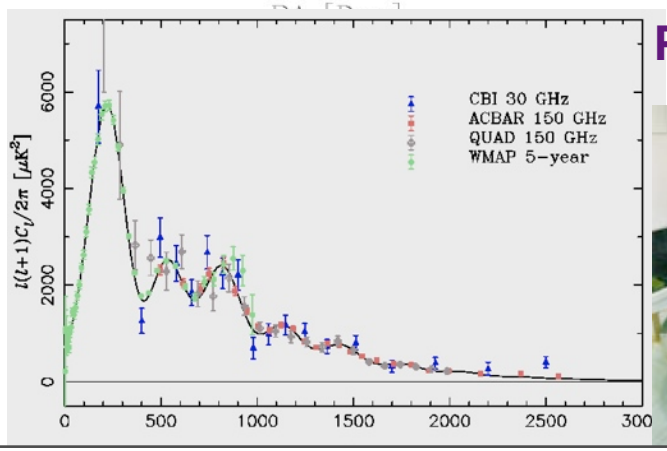
CIAR 25 years cifar

13.65 -0.00038 billion years ago

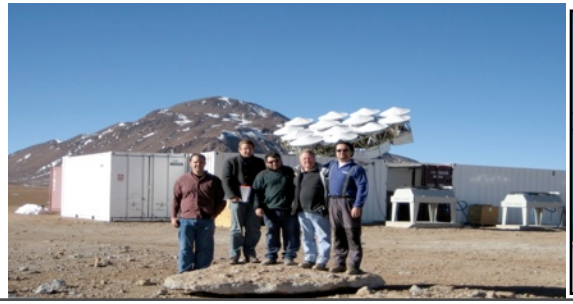
Boom05 deep **Jul05, Sept08**

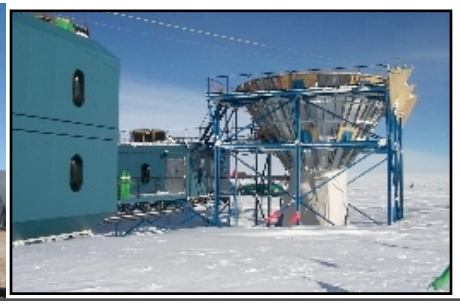




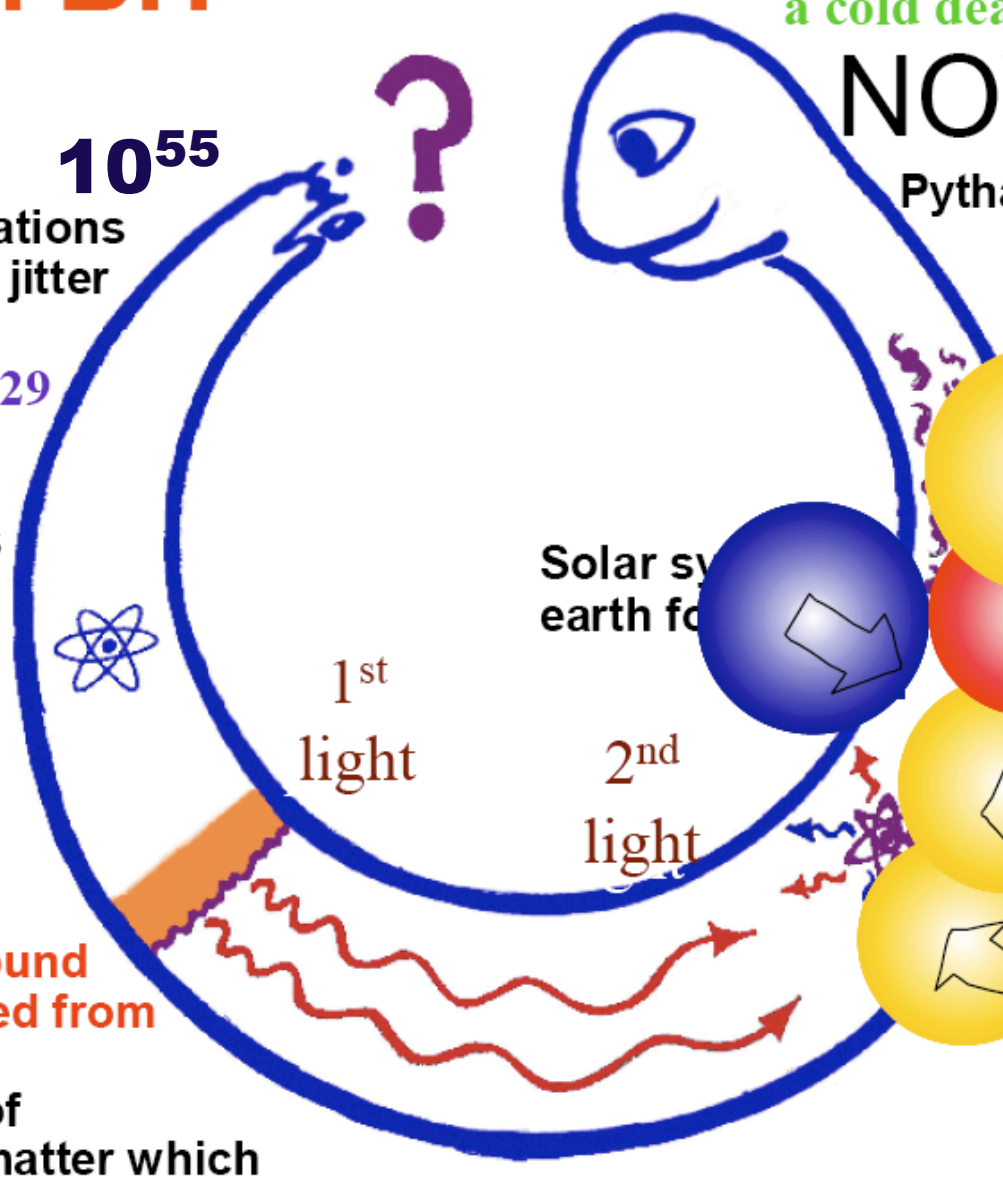


Planck09 as deep





"IT from BIT"

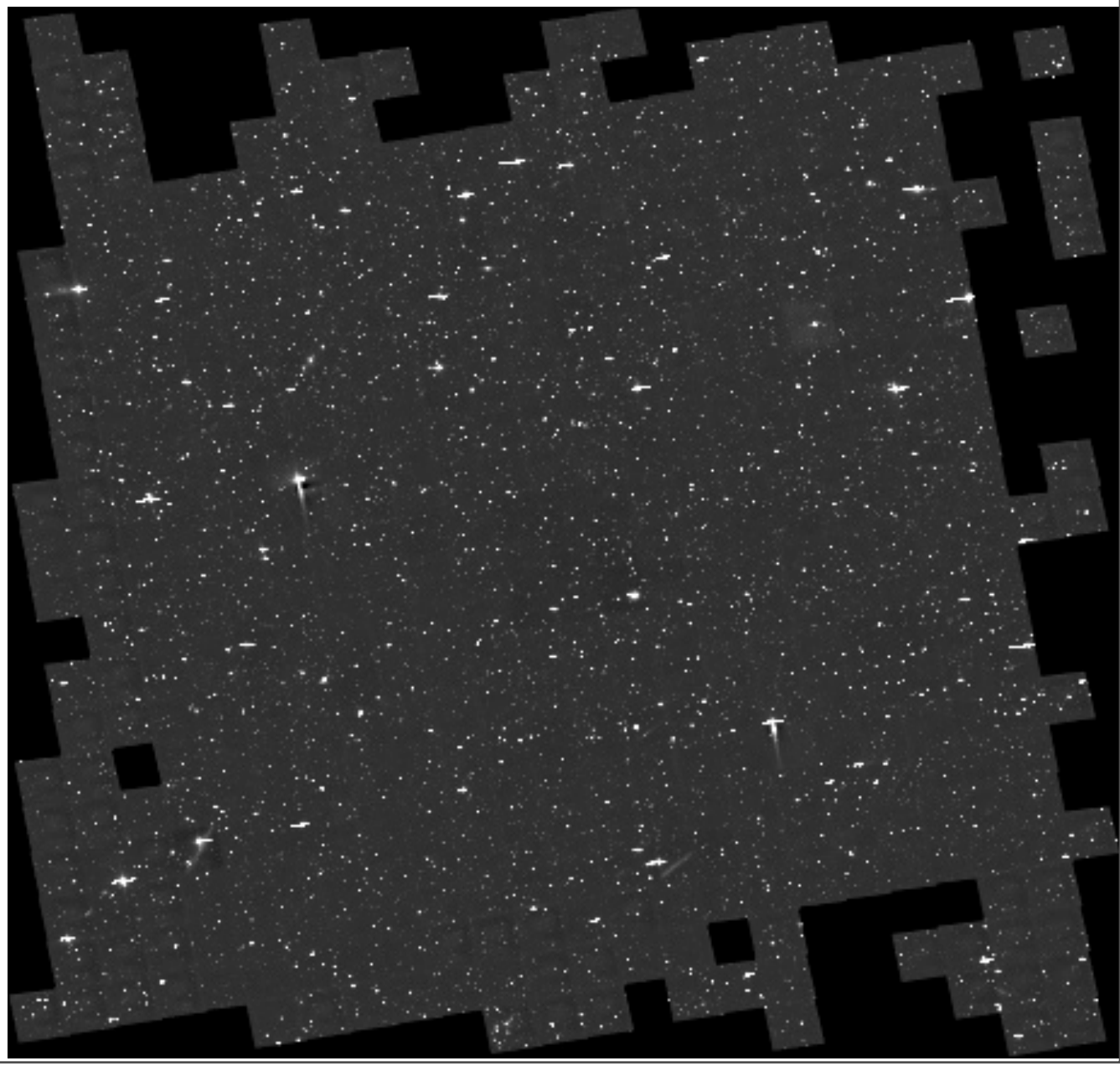


The 'Meaning' may change
But the facts will remain

Hubble "Cosmic Evolution Survey"

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

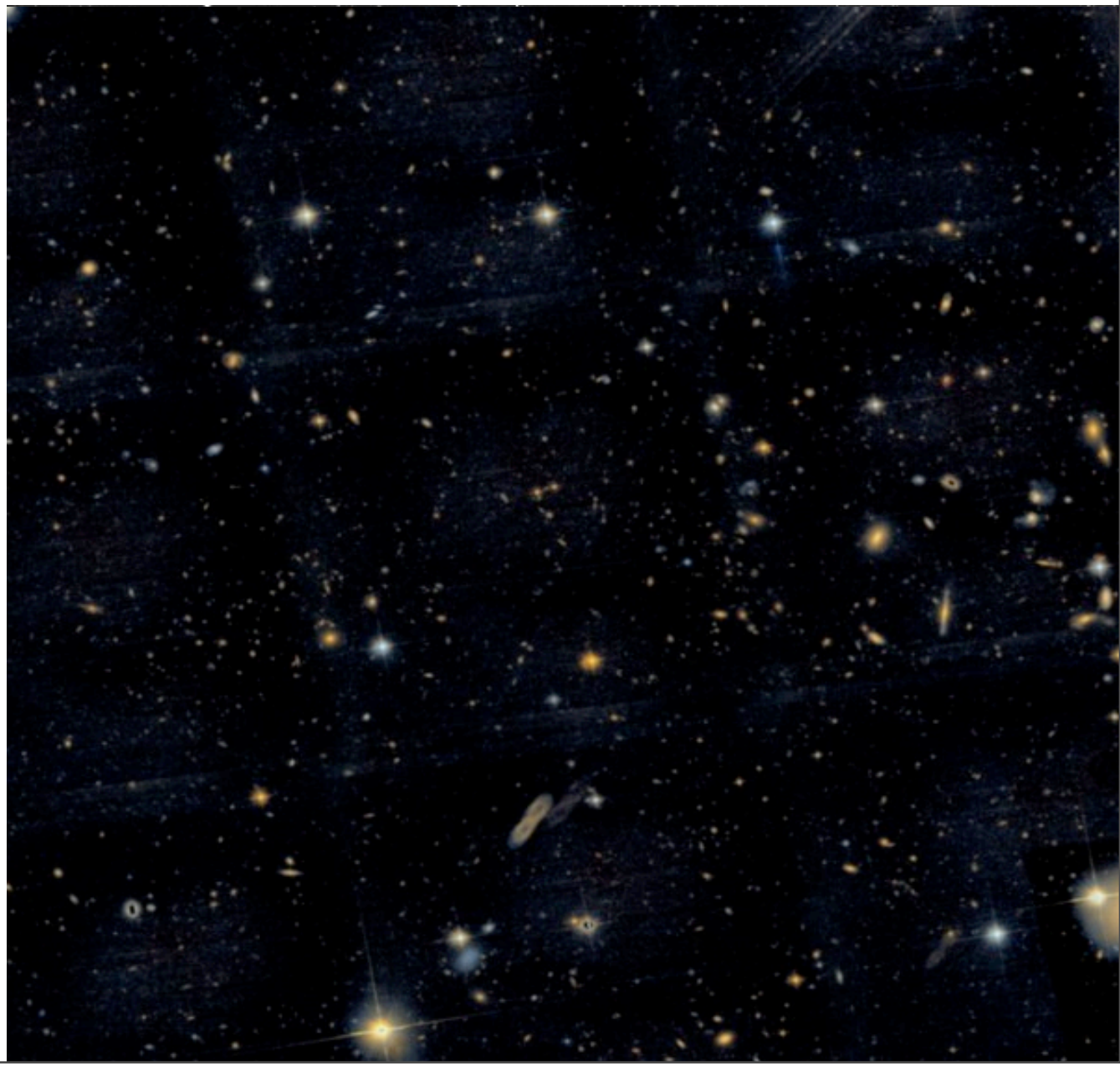
& Beyond Hubble: JWST (+TMT+)



Hubble "Cosmic Evolution Survey"

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

& Beyond Hubble: JWST (+TMT+)



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

dwarflets & the 1st stars

form at compression 13

1st light: Cosmic Microwave Background

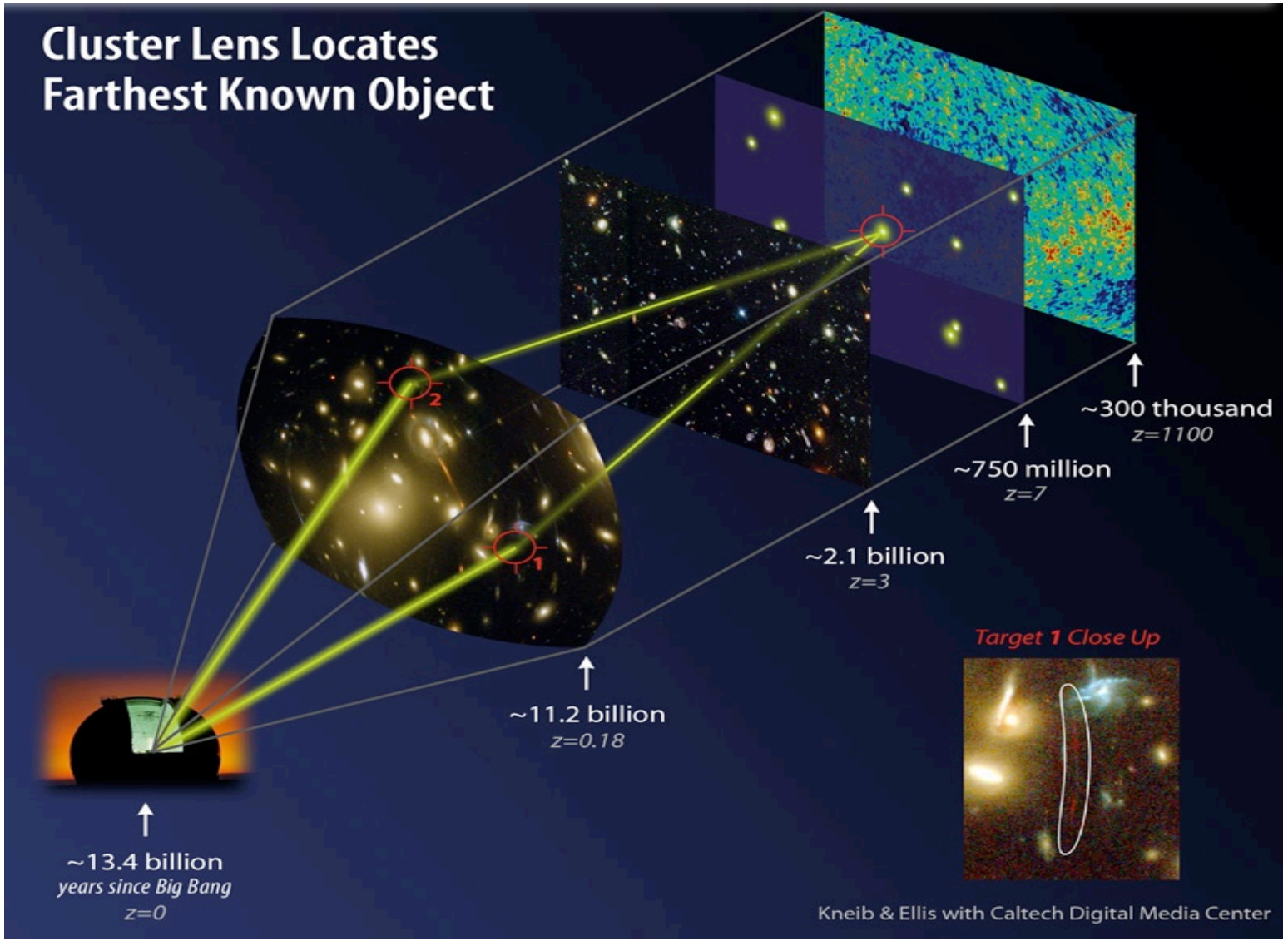
released at compression 1100; formed at ~10^{30}

EINSTEIN …1905 ***international year of physics 2005***

international year of astronomy 2009

NEW LAW OF GRAVITATION (1916); speed of light is the ultimate speed ***HORIZONs***;

Space is curved by mass; **Light bends, wavelengths change, under gravity**

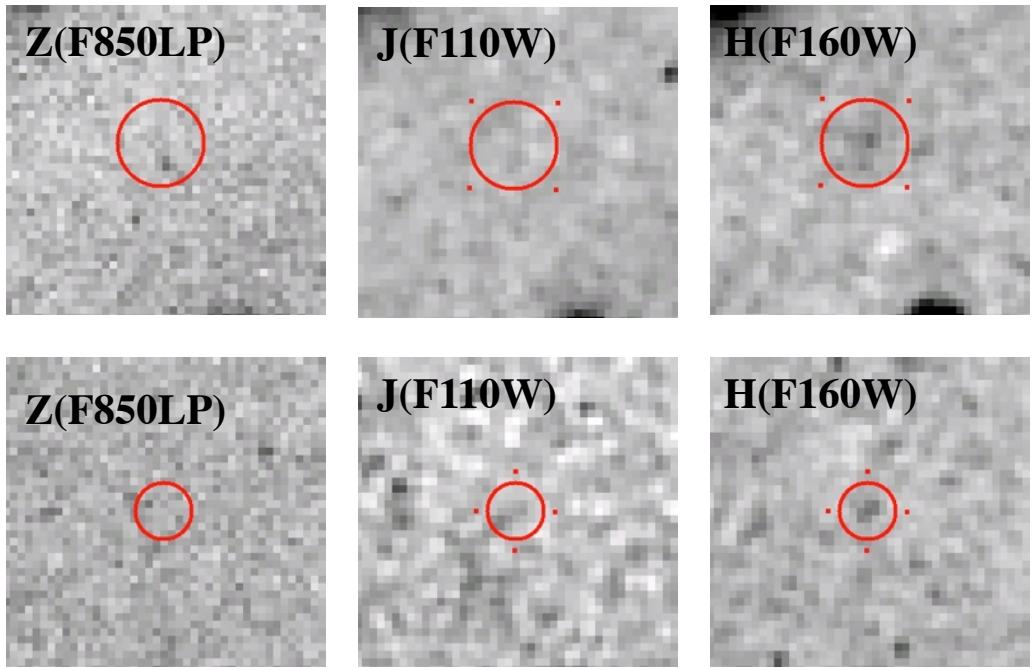


DAVE BARRY

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



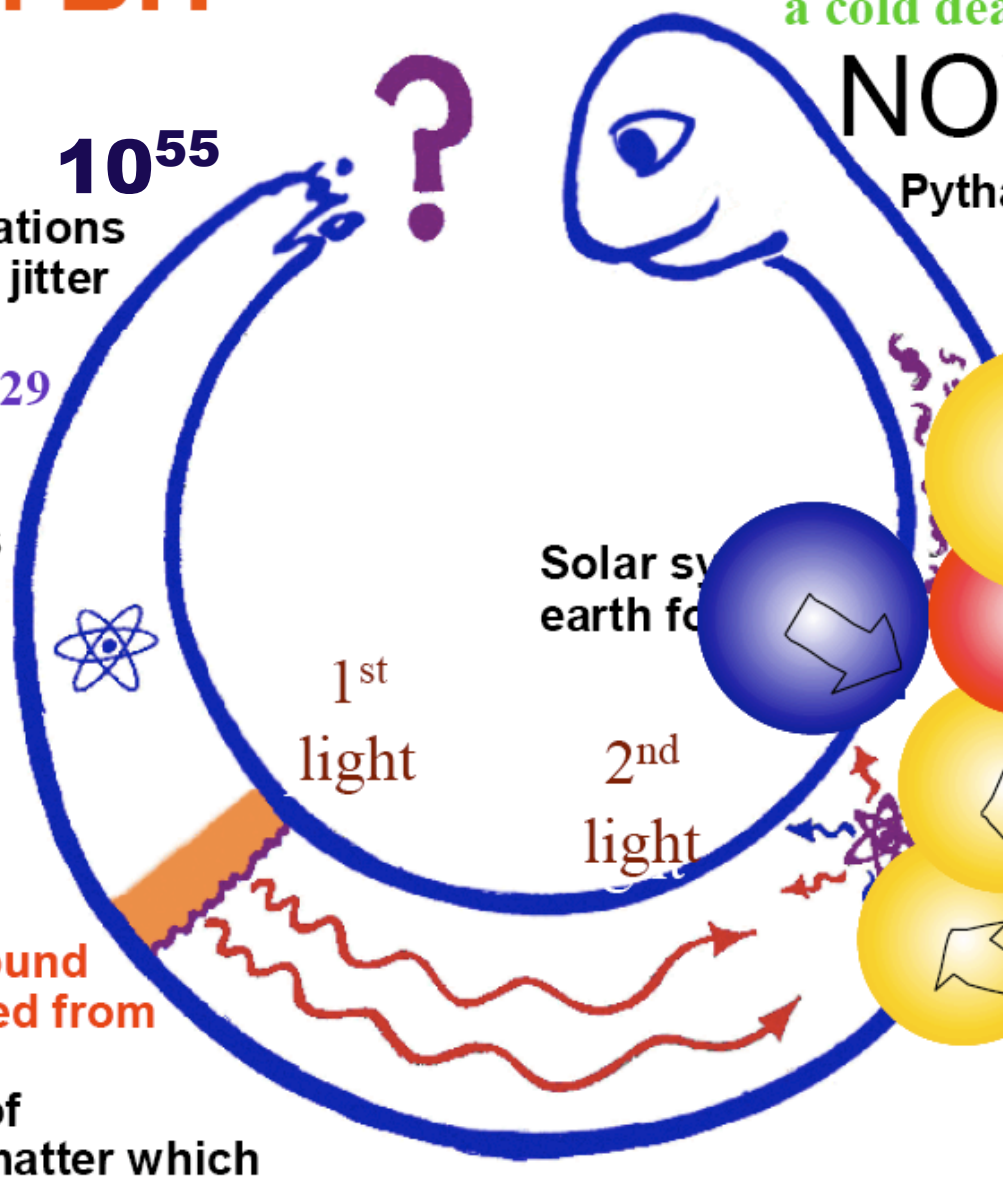
"UltraDeep" work of Richard Ellis et al.CIfAR Associate

TMT: Thirty Metre Telescope

JWST: James Webb Space Telescope

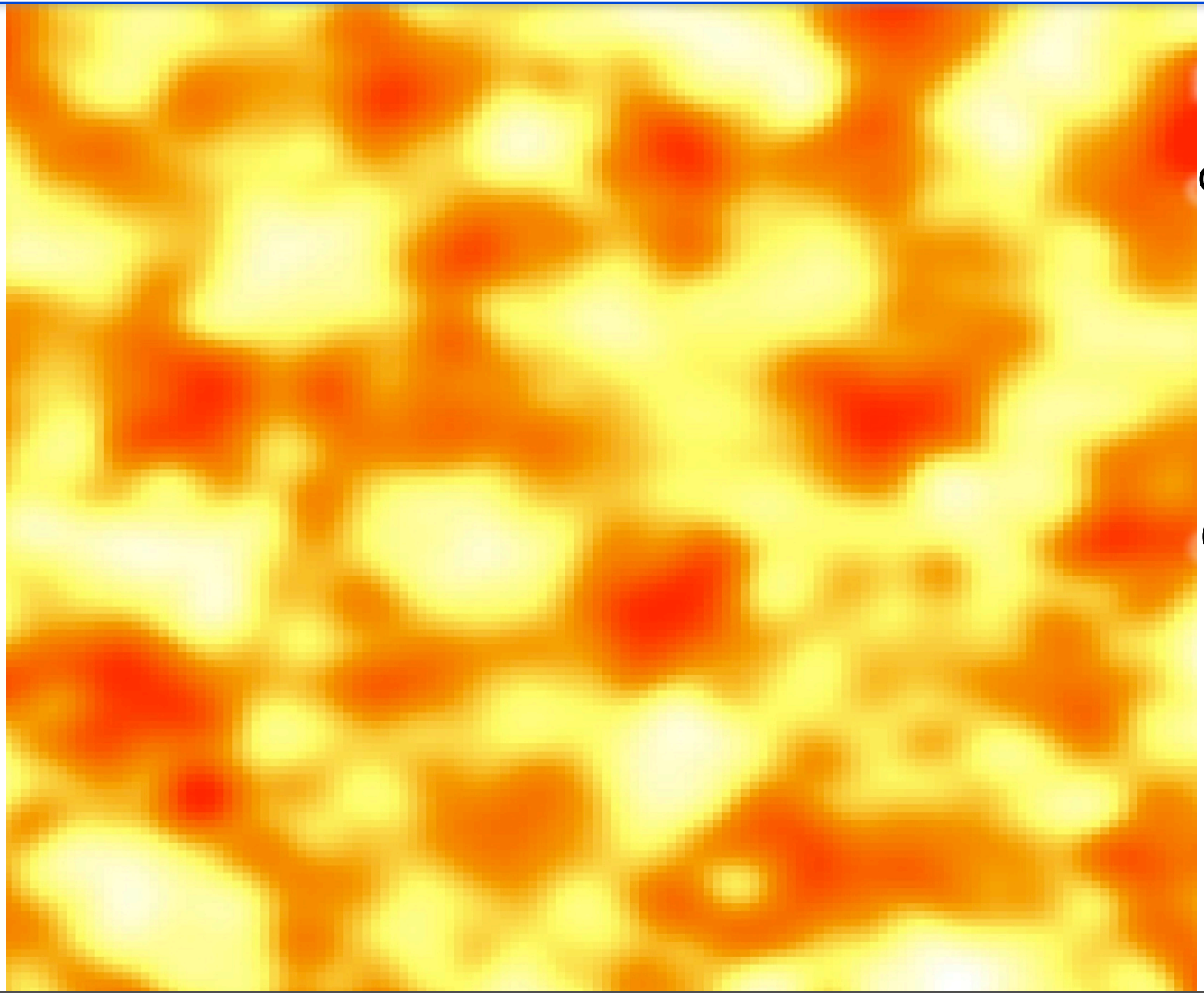
SKA: Square Kilometre Array

"IT from BIT"



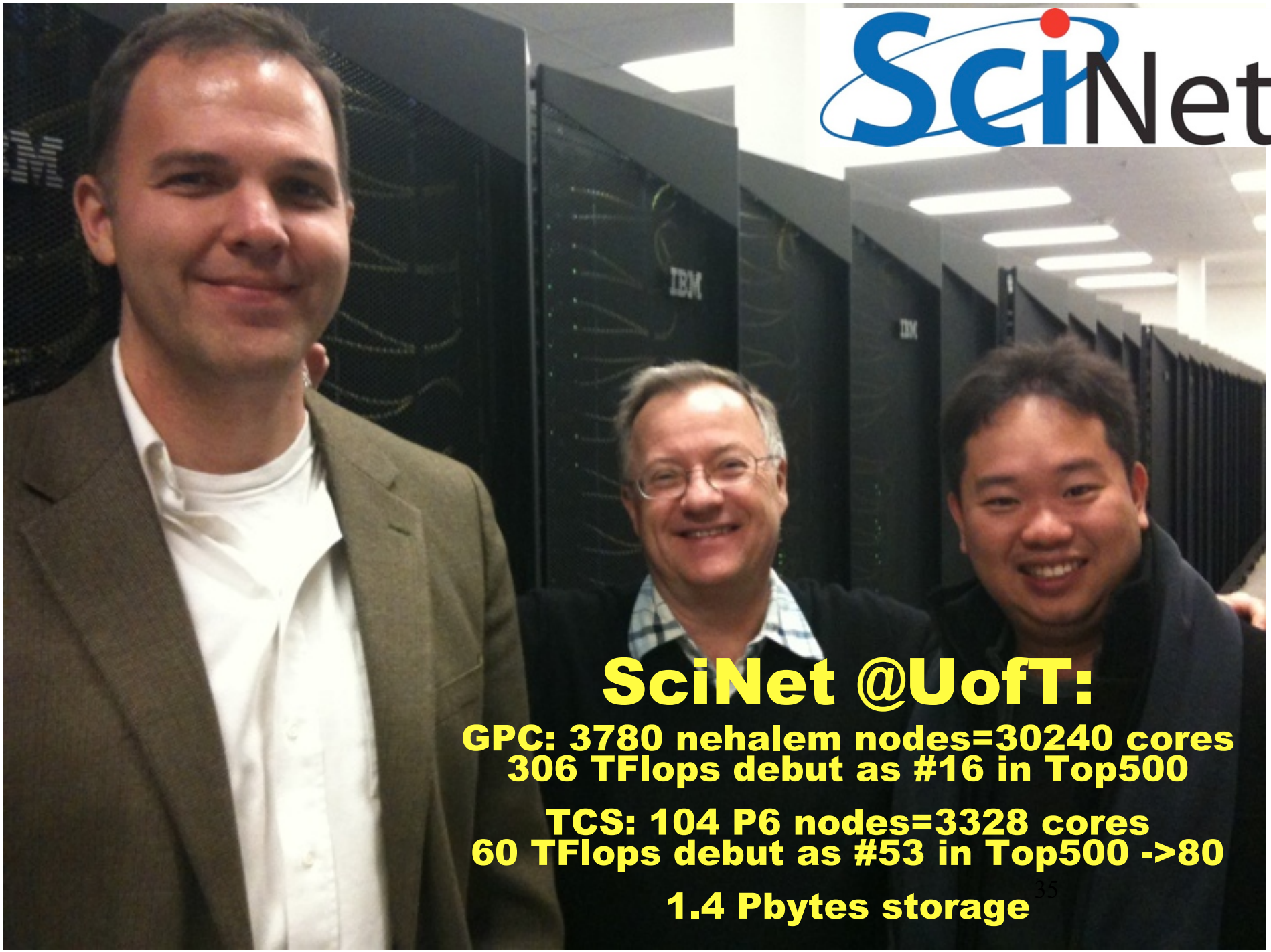
The 'Meaning' may change
But the facts will remain

fluctuations in the **early universe "vacuum" grow** to ***all*** **structure**

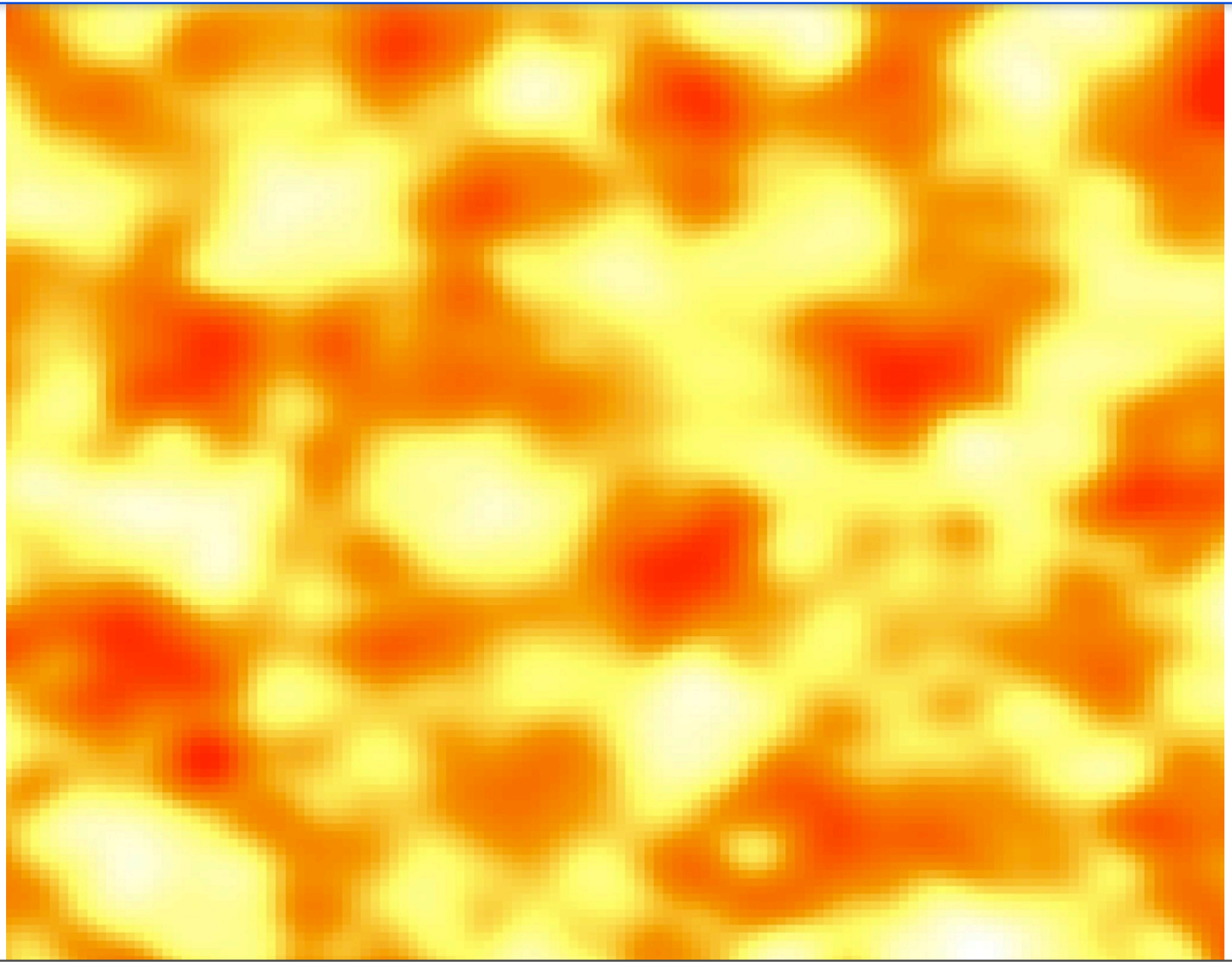


patterns in the quantum jitter evolve under gravity

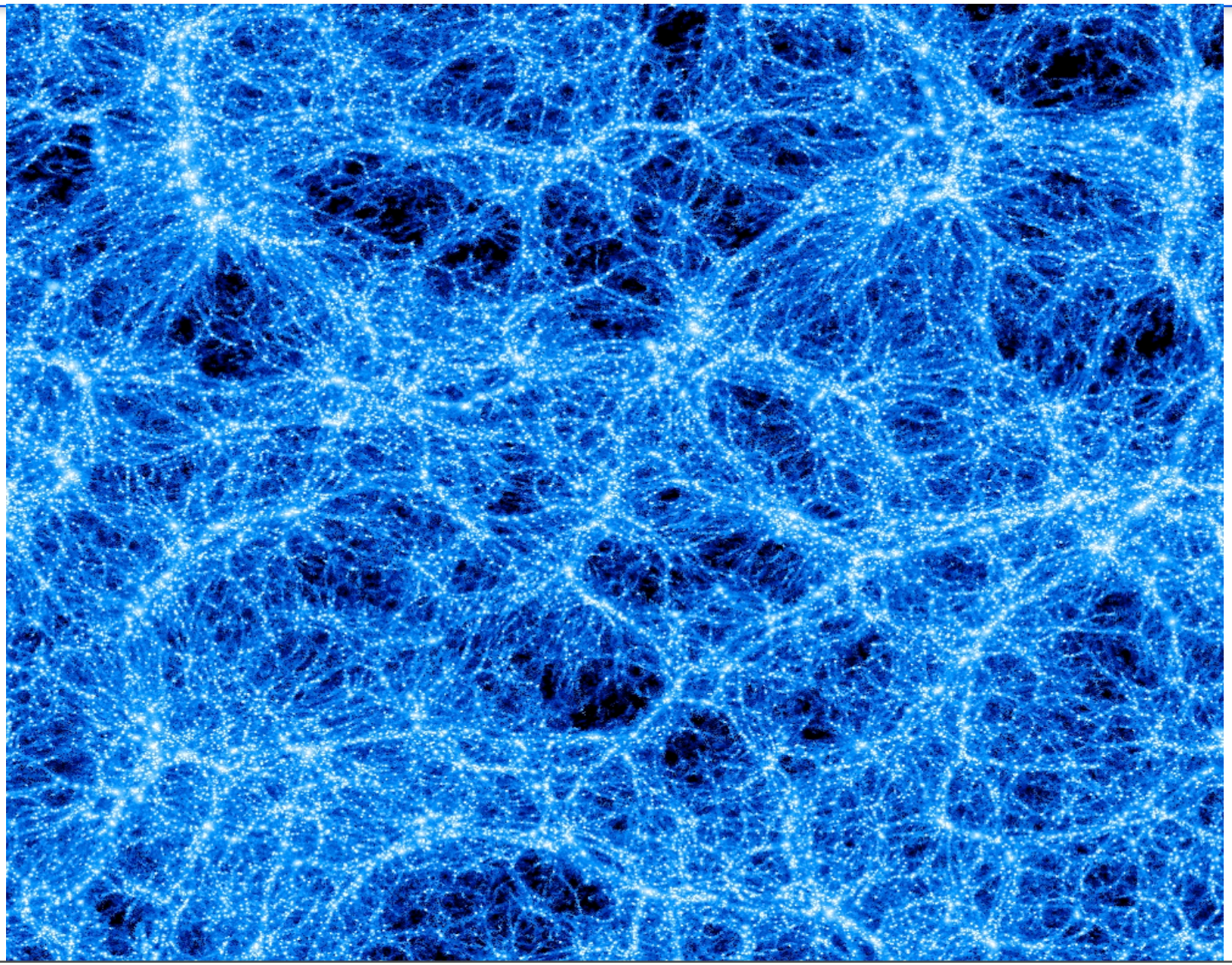
(& gas dynamics)


SciNet
SciNet @UofT:
GPC: 3780 nehalem nodes=30240 cores
306 TFlops debut as #16 in Top500
TCS: 104 P6 nodes=3328 cores
60 TFlops debut as #53 in Top500 ->80
1.4 Pbytes storage

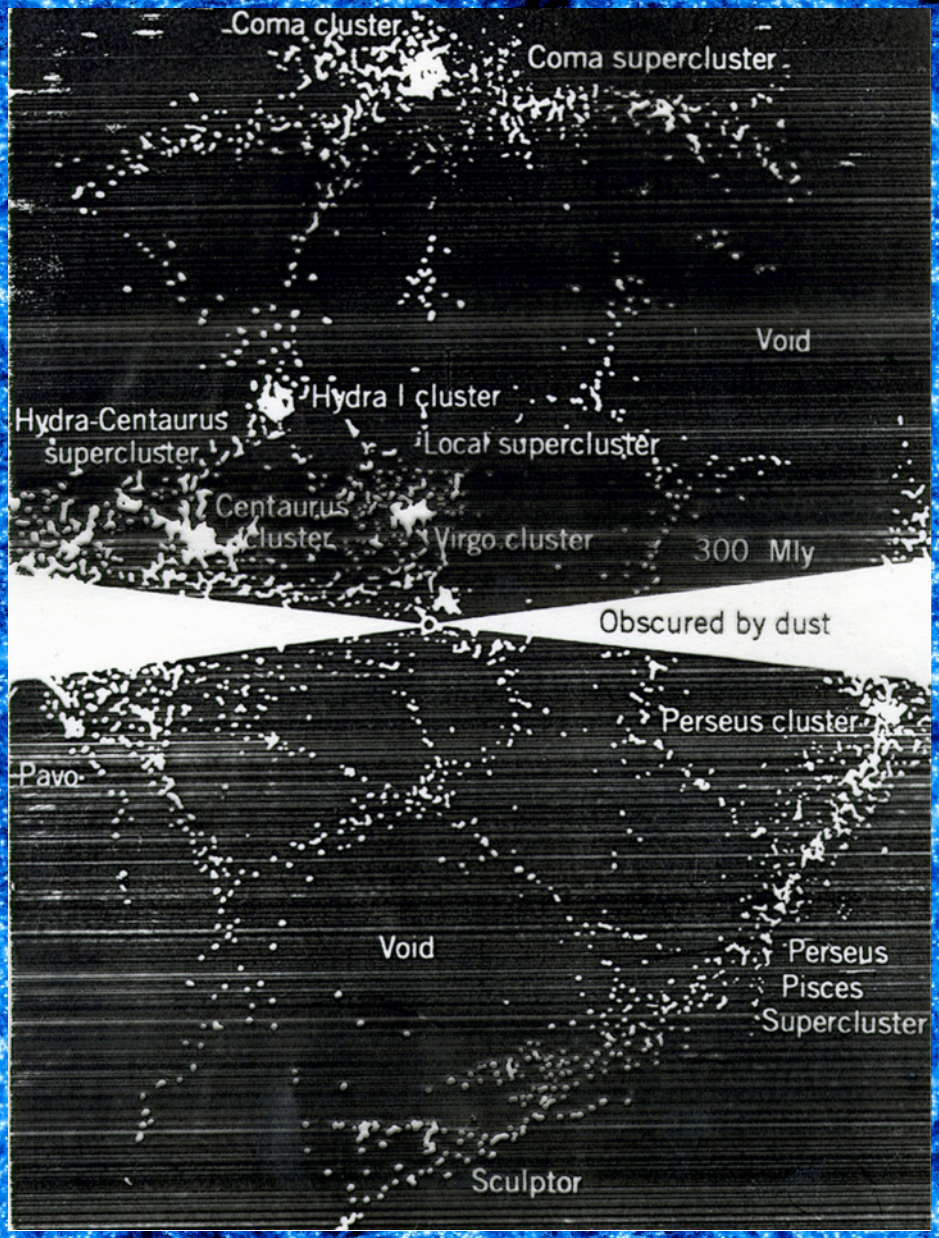
nonlinear Gas & Dark Matter Structure in the Cosmic Web the cluster/gp web “now”, the galaxy/dwarf system “then”



nonlinear Gas & Dark Matter Structure in the Cosmic Web the cluster/gp web “now”, the galaxy/dwarf system “then”



nonlinear Gas & Dark Matter Structure in the Cosmic Web the cluster/gp web "now", the galaxy/dwarf system "then"



all this can

evolve from early U vacuum potential and vacuum noise

in the presence of late U vacuum potential

aetherial!

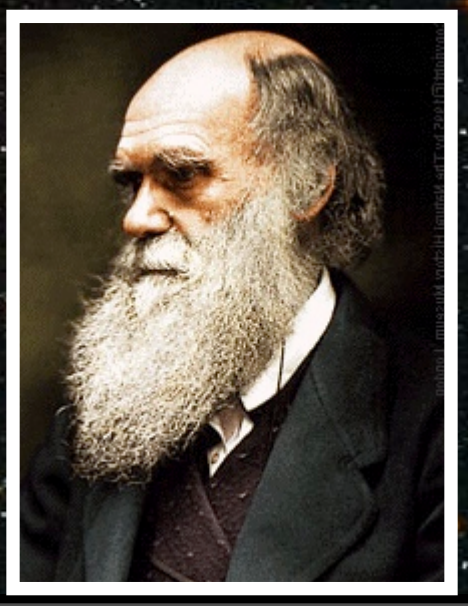
Cosmology today

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



Beyond Einstein

the universe is comprehensible!!!

Gravity=Geometry=Mass-Energy

cosmological constant 1917 Λ

1998/2009+: dark energy

Ω_Λ(space,time)? $\Omega=\rho/3M_P^2H^2$

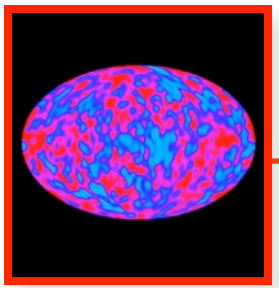
Ω_{dm}= dark matter (in labs?)

Ω_b= ordinary matter (known)

Gravitational waves – 1917

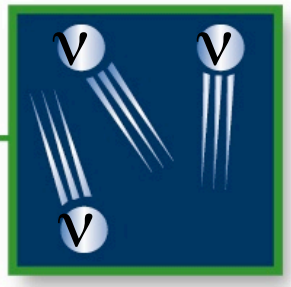
ripples in spacetime moving at the speed of light c

to be "observed": from black holes Ω_{BH} & neutron stars ~2012, from the quantum early Universe ~2011? Ω_{GW}



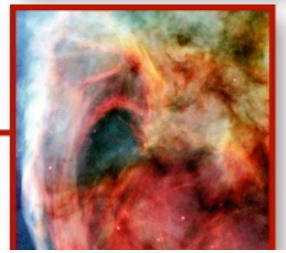
Radiation:
0.005%

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

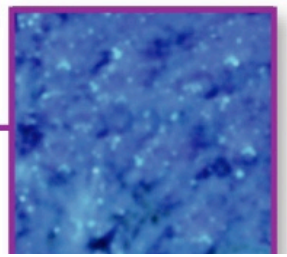


Neutrinos:
0.47%

Stars:
0.5%

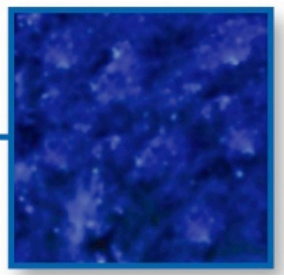


Free
H & He:
4.3%



Dark Matter:

$\Omega_{dm}=20.7 \pm 5\%$



Dark Energy:

$\Omega_{\Lambda} = 75 \pm 3\%$

Gravity Waves

Ω_{GW} ~10^{-14} - 10^{-10} LIGO

$\Omega_{BlackHoles}$ ~10^{-7}

detect Ω_{dm} in lab; annihilation in space; early U Ω_{GW} via CMB

ρ_Λ(time,space) vacuum E

Then (10^{-37}s) inflation

Now (13.7×10^9 yr)

=dark energy mysteries

in a landscape of

different vacuua

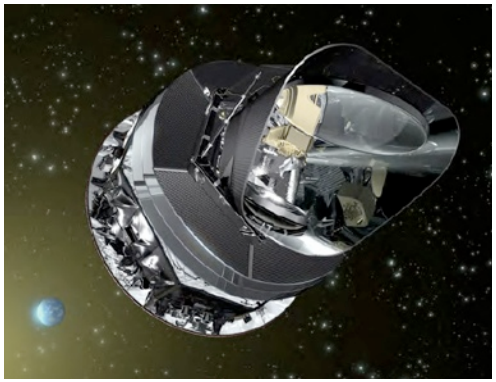
our ClfAR future: to the early & late Universe thru

Theory+Experiment (CMB+Lens+SN+clusters

+ LIGO,LISA,BBO for gravity waves +

SNOlab,CERN,..,Planck,Fermi,.. for dark matter)

detect Ω_{dm} in lab; annihilation in space; early U Ω_{GW} via CMB



ρ_Λ(time,space) vacuum E

Then (10^{-37}s) inflation

Now (13.7×10^9 yr)

=dark energy mysteries

in a landscape of

different vacuua

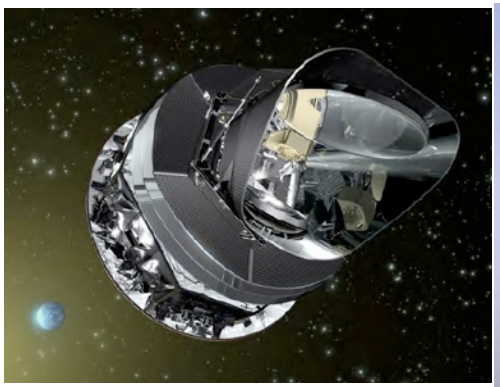
our CIfAR future: to the early & late Universe thru

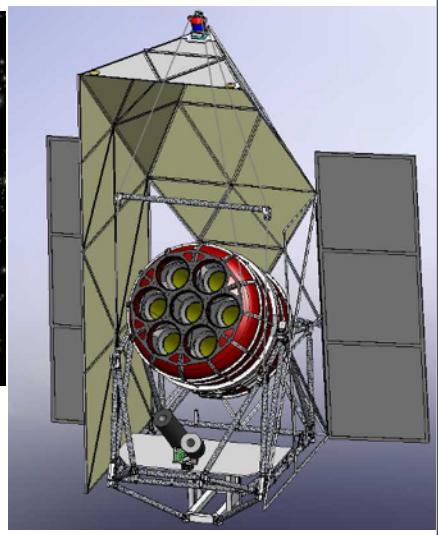
Theory+Experiment (CMB+Lens+SN+clusters

+ LIGO,LISA,BBO for gravity waves +

SNOlab,CERN,..,Planck,Fermi,.. for dark matter)

detect Ω_{dm} in lab; annihilation in space; early U Ω_{GW} via CMB





ρ_Λ(time,space) vacuum E

Then (10^{-37}s) inflation

Now (13.7×10^9 yr)

=dark energy mysteries

in a landscape of

different vacuua

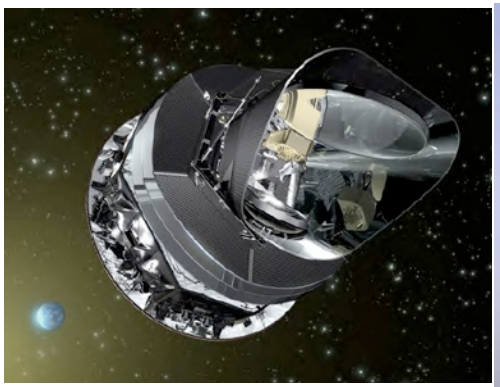
our CIfAR future: to the early & late Universe thru

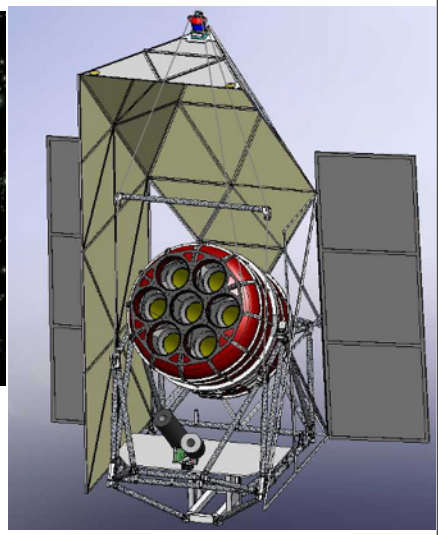
Theory+Experiment (CMB+Lens+SN+clusters

+ LIGO,LISA,BBO for gravity waves +

SNOlab,CERN,..,Planck,Fermi,.. for dark matter)

detect Ω_{dm} in lab; annihilation in space; early U Ω_{GW} via CMB





ρ_Λ(time,space) vacuum E

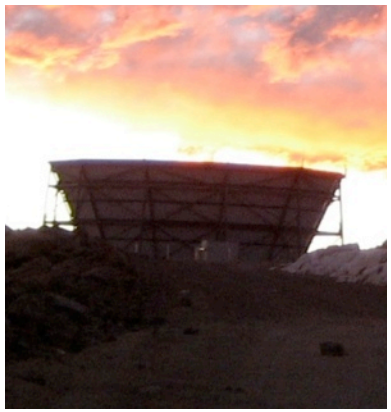
Then (10^{-37}s) inflation

Now (13.7×10^9 yr)

=dark energy mysteries

in a landscape of

different vacuua



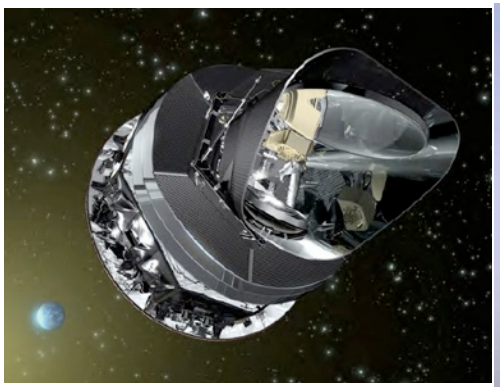
our ClfAR future: to the early & late Universe thru

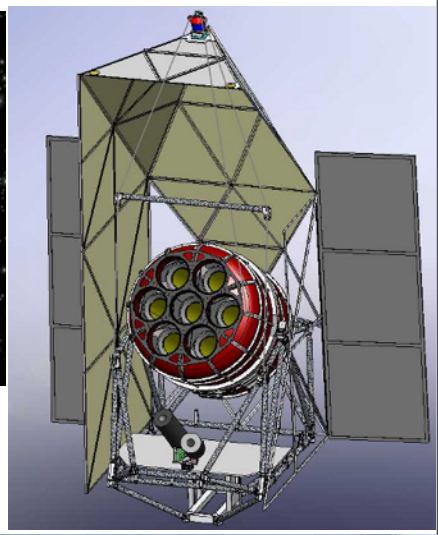
Theory+Experiment (CMB+Lens+SN+clusters

+ LIGO,LISA,BBO for gravity waves +

SNOlab,CERN,..,Planck,Fermi,.. for dark matter)

detect Ω_{dm} in lab; annihilation in space; early U Ω_{GW} via CMB





ρ_Λ(time,space) vacuum E

Then (10^{-37}s) inflation

Now (13.7×10^9 yr)

=dark energy mysteries

in a landscape of

different vacuua

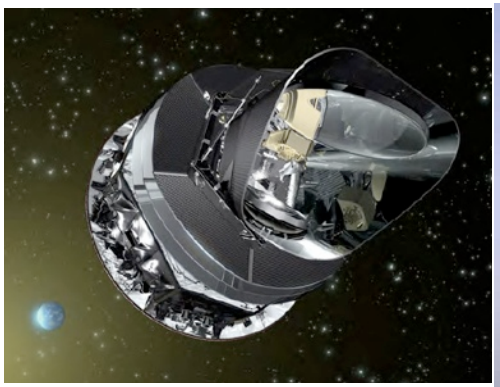
our ClfAR future: to the early & late Universe thru

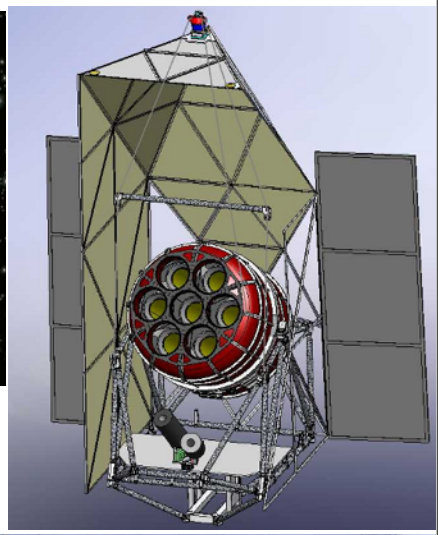
Theory+Experiment (CMB+Lens+SN+clusters

+ LIGO,LISA,BBO for gravity waves +

SNOlab,CERN,..,Planck,Fermi,.. for dark matter)

detect Ω_{dm} in lab; annihilation in space; early U Ω_{GW} via CMB





ρ_Λ(time,space) vacuum E

Then (10^{-37}s) inflation

Now (13.7×10^9 yr)

=dark energy mysteries

in a landscape of

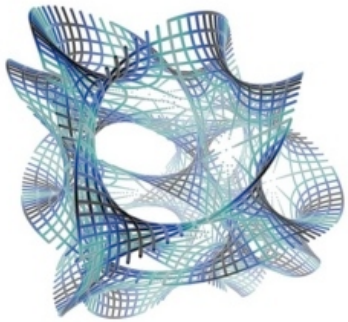
different vacuua

our CIfAR future: to the early & late Universe thru

Theory+Experiment (CMB+Lens+SN+clusters

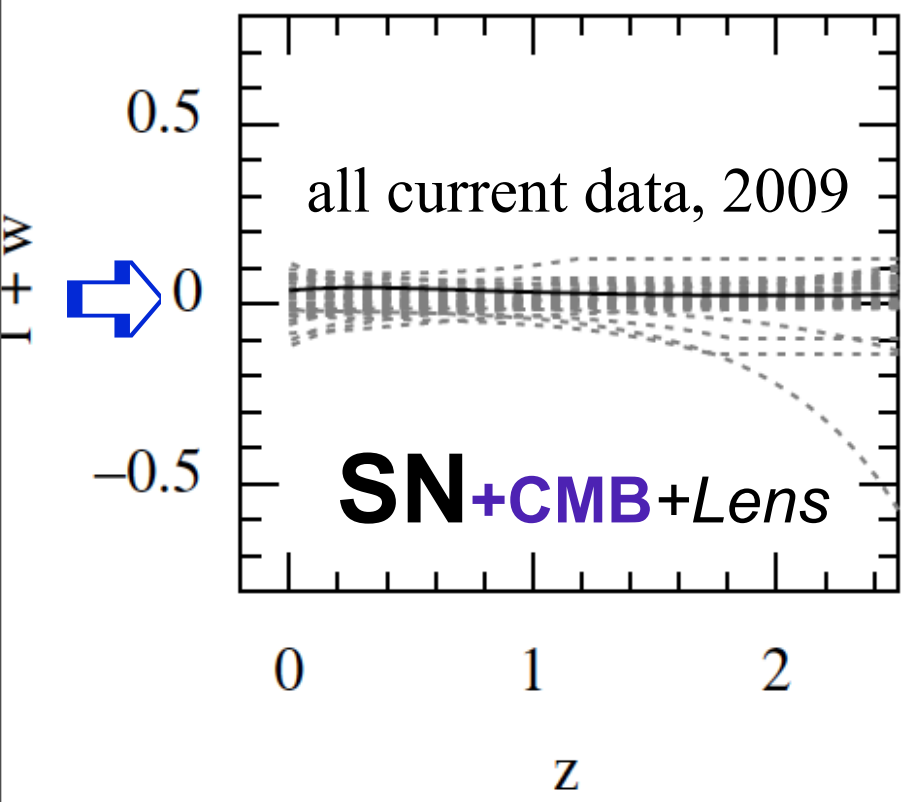
+ LIGO,LISA,BBO for gravity waves +

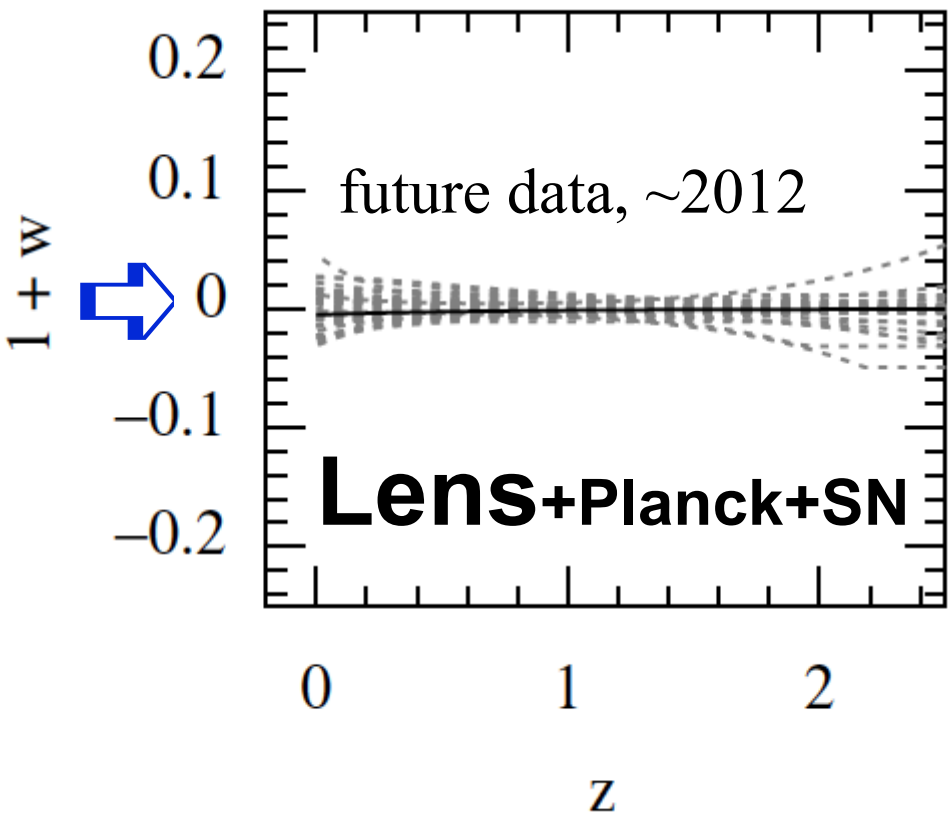
SNOlab,CERN,..,Planck,Fermi,.. for dark matter)



ρ_Λ(time,space) ?

is the dark energy "vacuum potential energy" ?

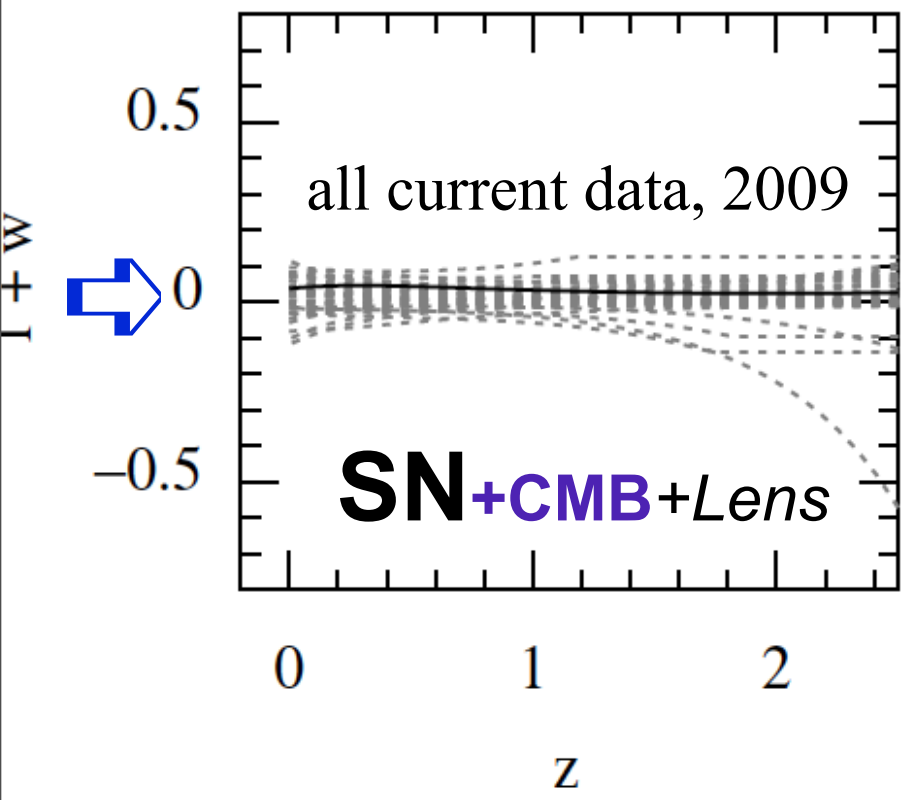


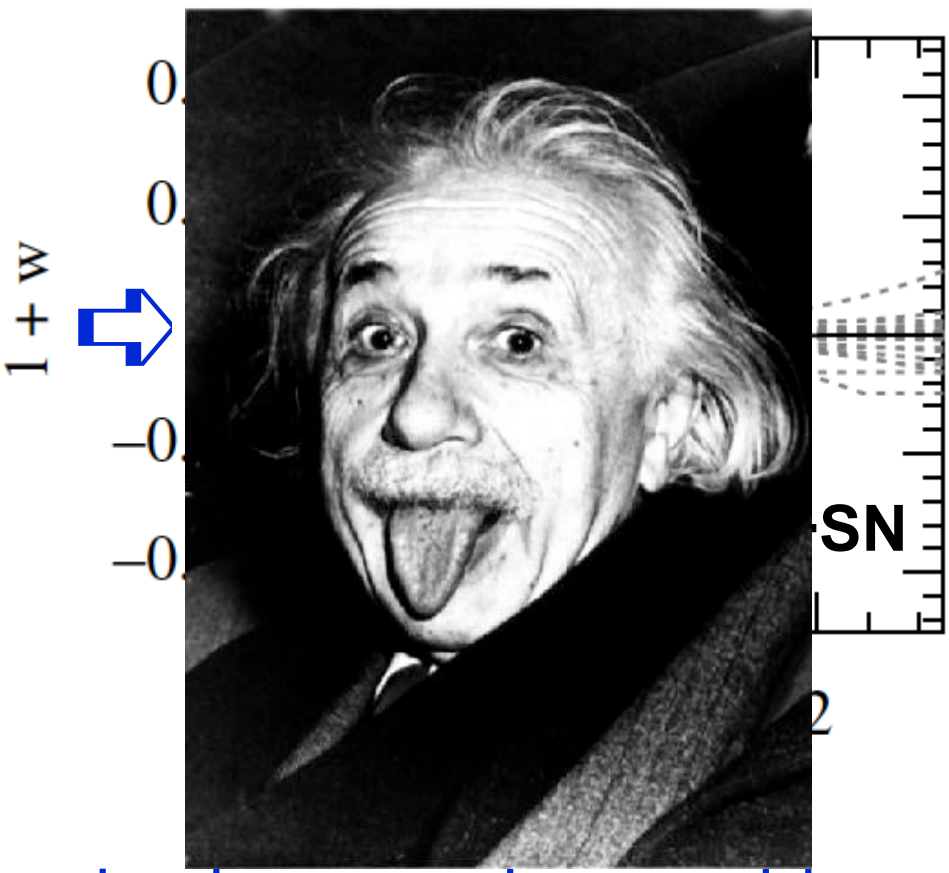


TEST: within errors, energy-density does not change with expansion ⇨Einstein's cosmological constant is best fit so far

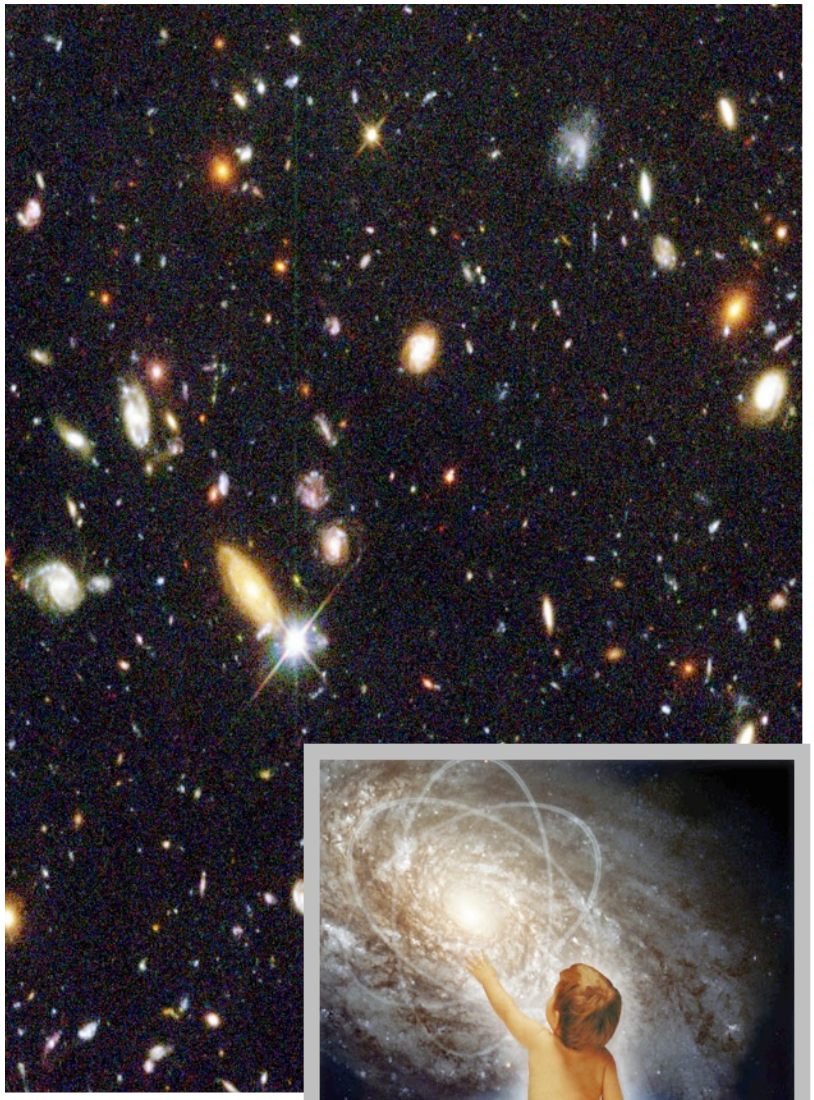
ρ_Λ(time,space) ?

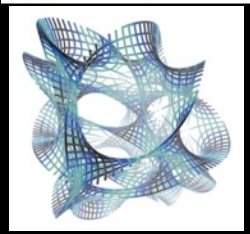
is the dark energy "vacuum potential energy" ?





TEST: within errors, energy-density does not change with expansion ⇨Einstein's cosmological constant is best fit so far





"To me every hour of the light and dark is a miracle. Every cubic inch of space is a miracle."
– Walt Whitman

In every cubic centimetre

- cosmic radiation 412 cm^{-3}
- dark matter ~amu m^{-3} ~

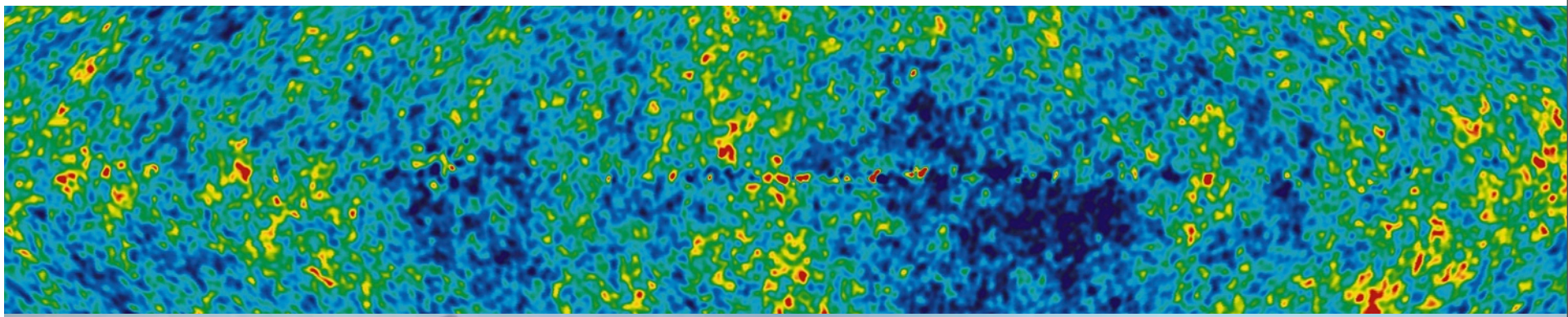
compressed in MW to ~0.1 amu cm^{-3} for LHC-type DM, ~ 1 every 10 cm

- dark energy ~4 keV cm^{-3} ~ $(milli\text{-}eV)^4$
- neutrinos ~ CMB photons
- gravity waves
- virtual particles - vacuum fluctuations
- Higgs potential - origin of mass
- extra dimensions here, now?

www.cita.utoronto.ca/~bond/traj/talks/bond_rci_public_09_11_01.pdf

end

Mapping the Birth of the Universe with ACT and SciNet



SciNet

ACT@5170m

why Atacama? driest desert in the world. thus: cbi, toco, apex, asti, act, alma, quiet, clover

CBI2@5040m

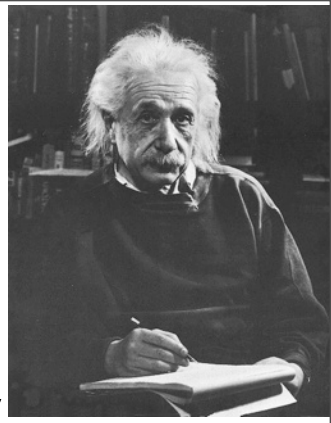
We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time. – T. S. Eliot

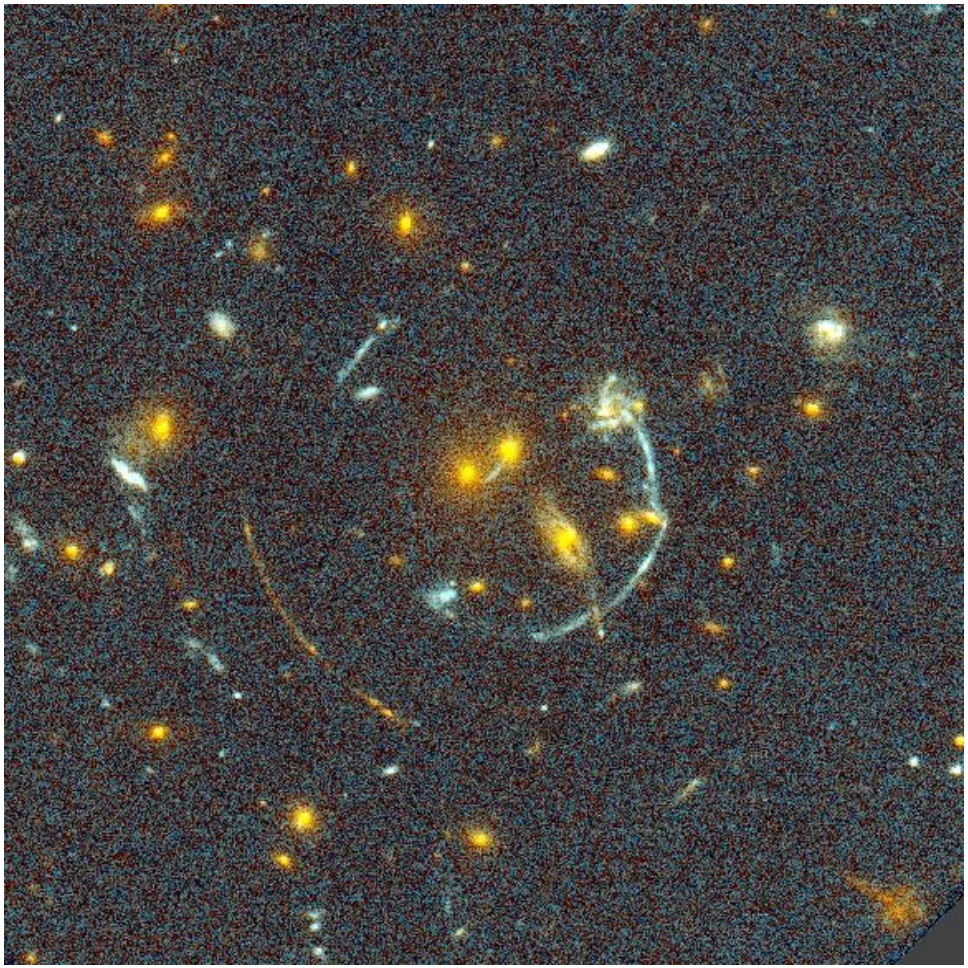
it is primarily for this knowing & its inspiration to young minds that the world is spending tens of billions of dollars on the cosmic quest for fundamental physics

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

EINSTEIN … 1905 international year of physics 2005

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





Gravitational lensing of deep galaxies by clusters

Toronto RCS 2001; RCS2

CIAR

Hoekstra, Gladders, Yee

Weak lensing via Canada France Hawaii Telescope Legacy Survey 2002-08

Hoekstra, van Waerbeke

CIAR

CFHT

SN

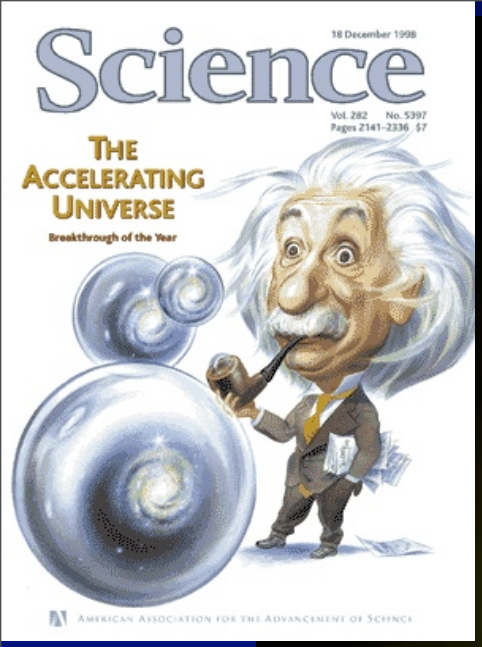
Survey

Carlberg, Pritchet, et al.

3yr now
300 SN1a

5yr

500



CFHT

SN

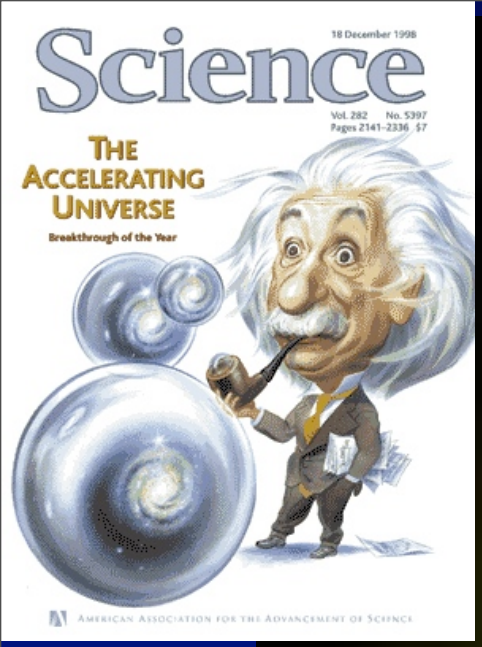
Survey

Carlberg, Pritchet, et al.

3yr now
300 SN1a

5yr

500



CFHT

SN

Survey

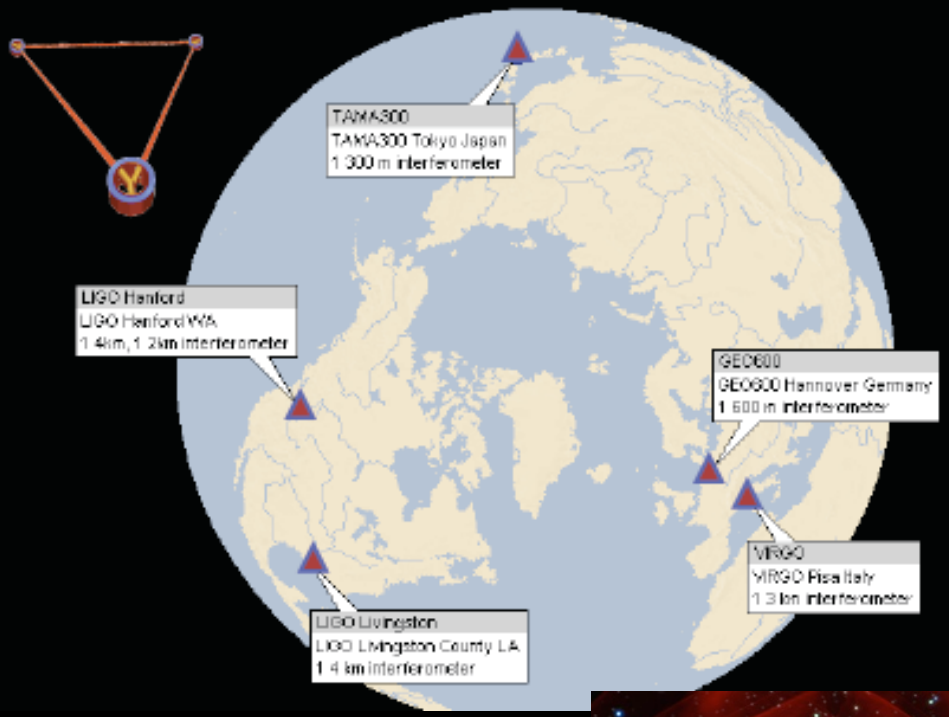
Carlberg, Pritchet, et al.

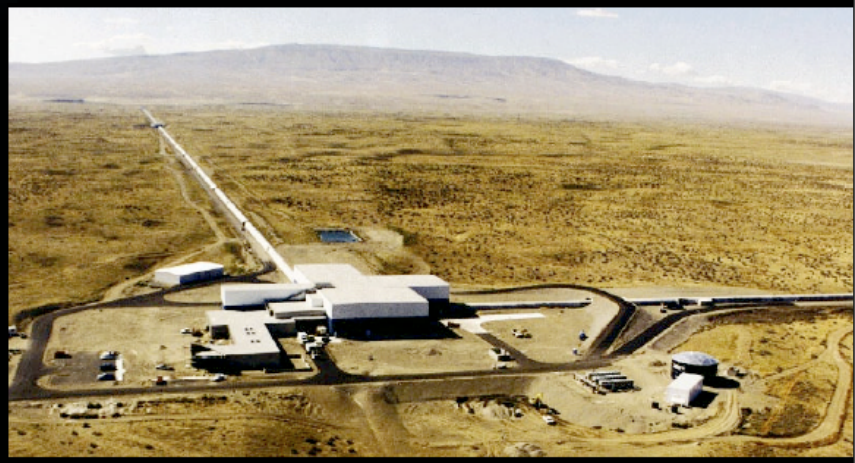
3yr now
300 SN1a

5yr

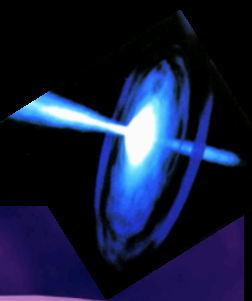
500

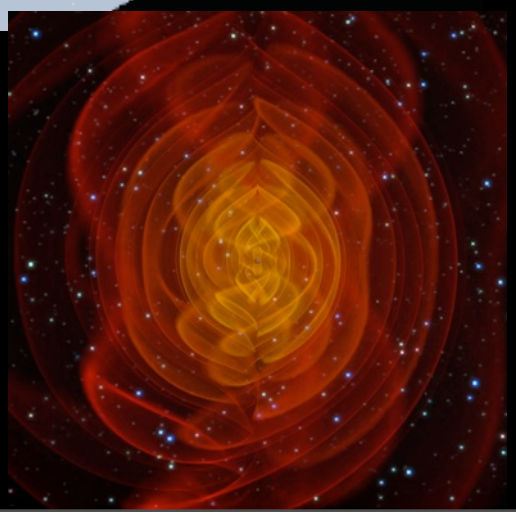
Worldwide Interferometer Network

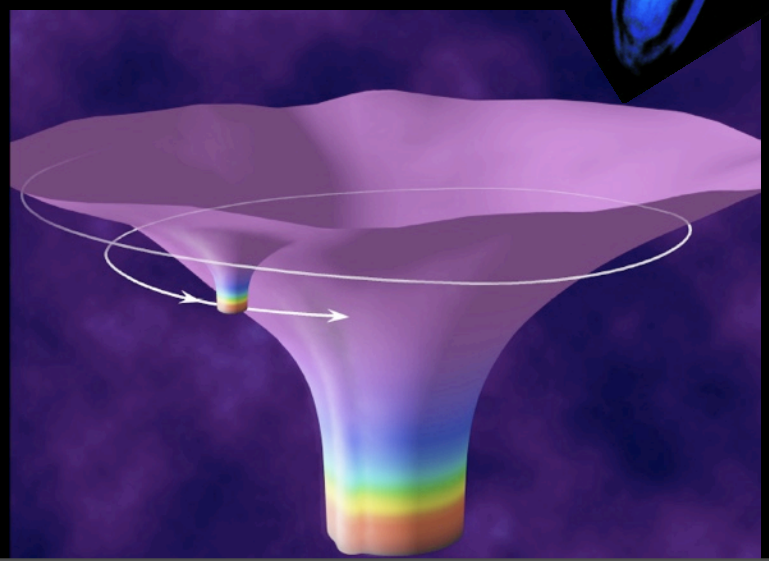




DANGER:
BLACK HOLES MERGING





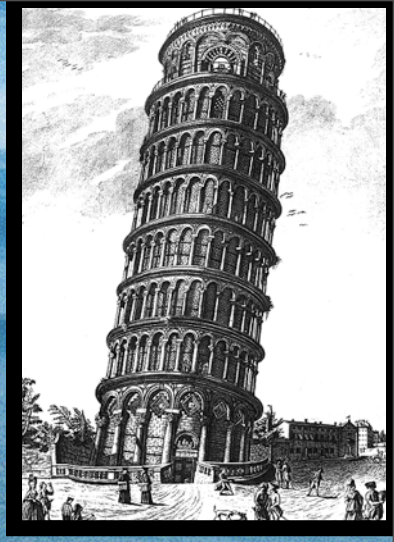


Now-2013+

~km scale

detect .001 nuclear radius

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

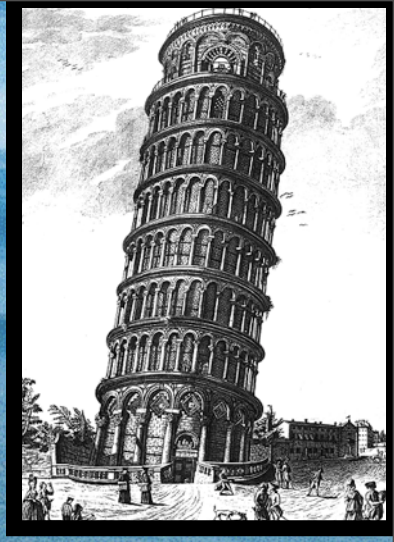


Galileo's Accelerator

Cern's Accelerator

2008

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

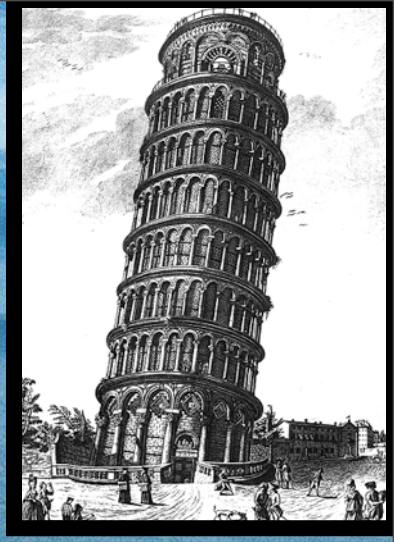


Galileo's Accelerator

Cern's Accelerator

2008

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



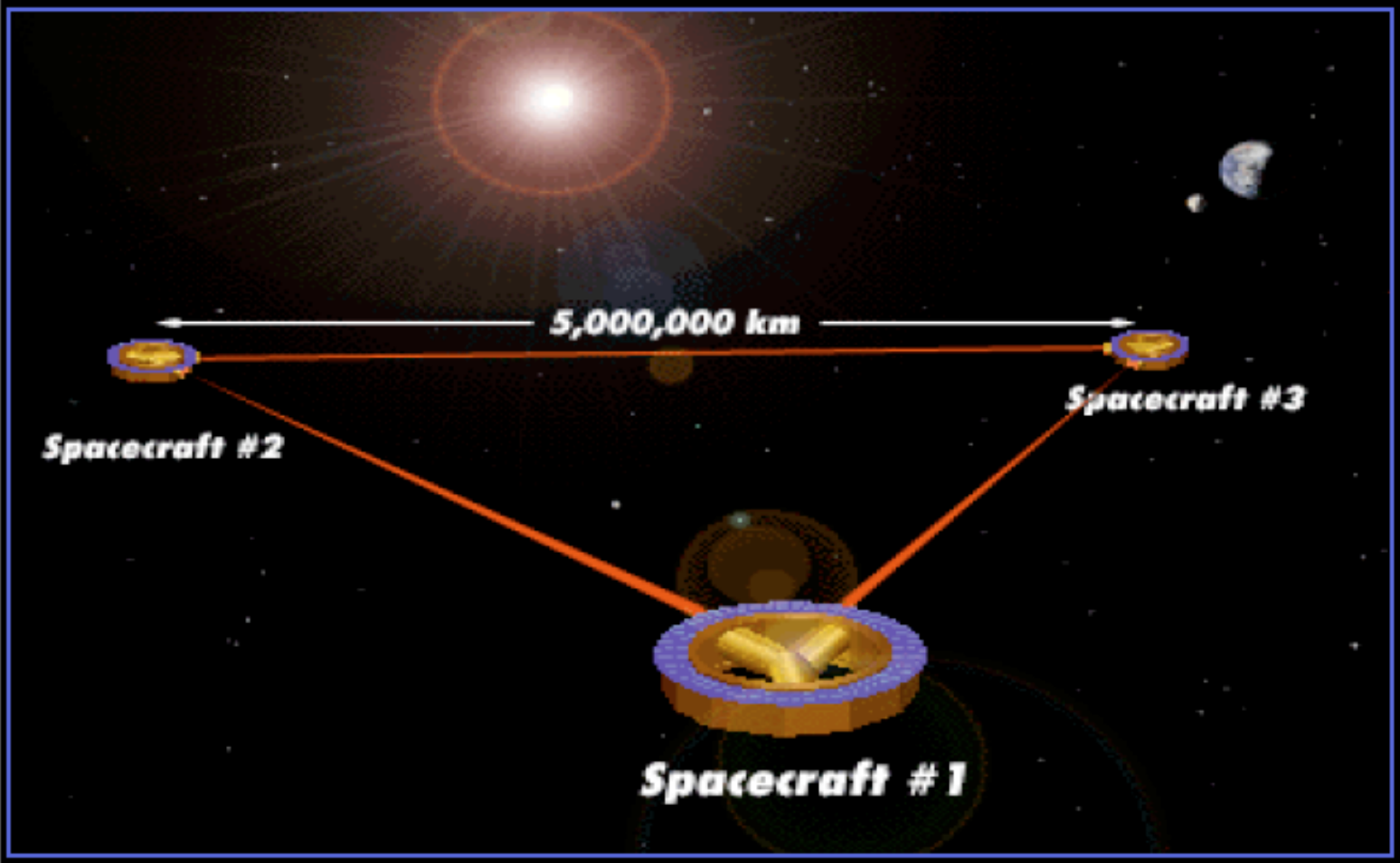
Galileo's Accelerator

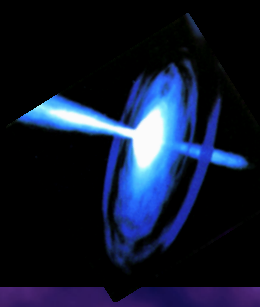
Cern's Accelerator

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

LISA

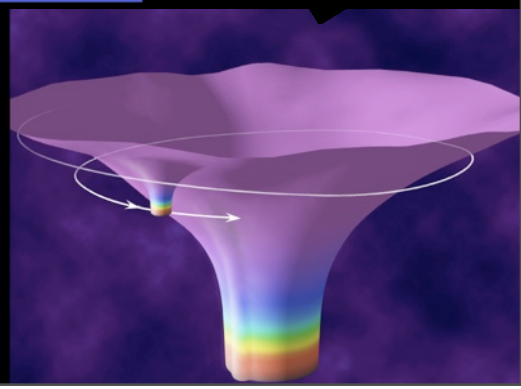




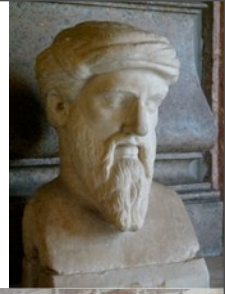
2017??

~5 million km scale
detect .001 atomic radius

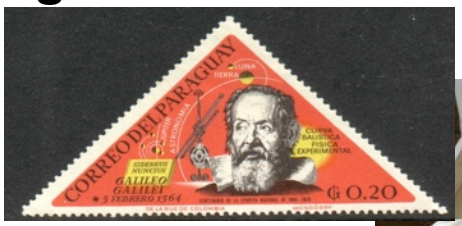
DANGER:
SuperMassive
BLACK HOLES
MERGING

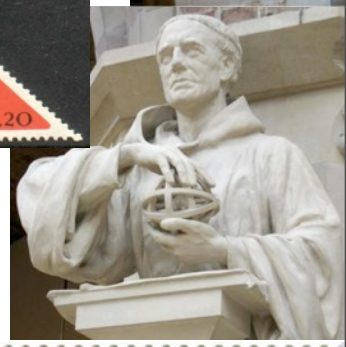


PYTHAGORAS ~ 550 BCE *The THEORIST*



- ✓ Cosmos - The Universe as a Mathematical Entity
- ✓ Music of the Heavens – Frequency/Wavelength





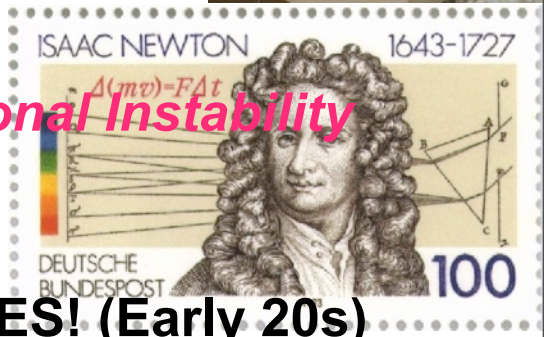
ROGER BACON ~ 1260 AD

MARRIAGE: of Experiment to Theory

COPERNICUS/KEPLER/GALILEO et al. ~1600 AD

NEWTON ~ 1660 - 1690 AD *The PHYSICIST*

- ✓ LAW OF GRAVITATION - Mass Attraction
- ✓ Heavenly Objects Arise via Clumping .. *Gravitational Instability*
- ✓ Thus: the Universe is Infinite



KANT ~ 1755 AD **Galaxies - 'Island Universes'** **YES! (Early 20s)**

large halo of dark matter 70s/80s relics or remnants?

EINSTEIN: SCIENTIFIC COSMOLOGY(1917)

✓ Finite universe without a boundary

✓ "Cosmological Constant" (~ 1895) Λ

Make the Universe Finite via A Repulsive Force

"My greatest blunder"

$\Lambda / 8\pi G_{Newton}$

FRIEDMANN (1922) Evolving (Expanding) Universe

- ✓ **YES! Hubble (late 20s) rate H**
- ✓ **the SINGULARITY (30s,60s), infinite density (!!!???)**

EINSTEIN: SCIENTIFIC COSMOLOGY(1917)

✓ Finite universe without a boundary

✓ "Cosmological Constant" (~ 1895) Λ

Make the Universe Finite via A Repulsive Force

"My greatest blunder"

$\Lambda / 8\pi G_{Newton}$

FRIEDMANN (1922) Evolving (Expanding) Universe

- ✓ **YES! Hubble (late 20s) rate H**
- ✓ **the SINGULARITY (30s,60s), infinite density (!!!???)**

EINSTEIN: SCIENTIFIC COSMOLOGY(1917)

✓ Finite universe without a boundary

✓ "Cosmological Constant" (~ 1895) Λ

Make the Universe Finite via A Repulsive Force

"My greatest blunder"

Ω_Λ = vacuum energy

Sakharov~67

$\Lambda / 8\pi G_{Newton}$

FRIEDMANN (1922) Evolving (Expanding) Universe

- ✓ **YES! Hubble (late 20s) rate H**
- ✓ **the SINGULARITY (30s,60s), infinite density (!!!???)**

EINSTEIN: SCIENTIFIC COSMOLOGY(1917)

✓ Finite universe without a boundary

✓ "Cosmological Constant" (~ 1895) Λ

Make the Universe Finite via A Repulsive Force

"My greatest blunder"

Ω_Λ = vacuum energy

Sakharov~67

$\Lambda / 8\pi G_{Newton}$

FRIEDMANN (1922) Evolving (Expanding) Universe

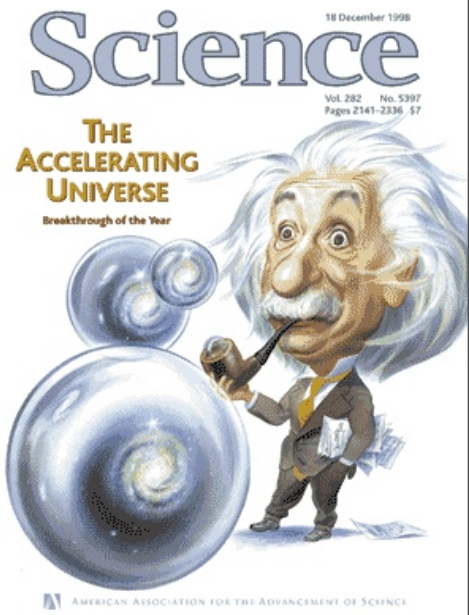
- ✓ **YES! Hubble (late 20s) rate H**
- ✓ **the SINGULARITY (30s,60s), infinite density (!!!???)**

EINSTEIN: SCIENTIFIC COSMOLOGY(1917)

- ✓ Finite universe without a boundary
- ✓ "Cosmological Constant" (~ 1895) Λ

Make the Universe Finite via A Repulsive Force

"My greatest blunder"



Ω_Λ = vacuum energy

Sakharov~67

$\Lambda / 8\pi G_{Newton}$

FRIEDMANN (1922) Evolving (Expanding) Universe

- ✓ **YES! Hubble (late 20s) rate H**
- ✓ **the SINGULARITY (30s,60s), infinite density (!!!???)**