

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.”

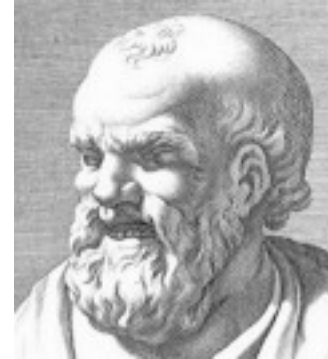
Albert Einstein

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

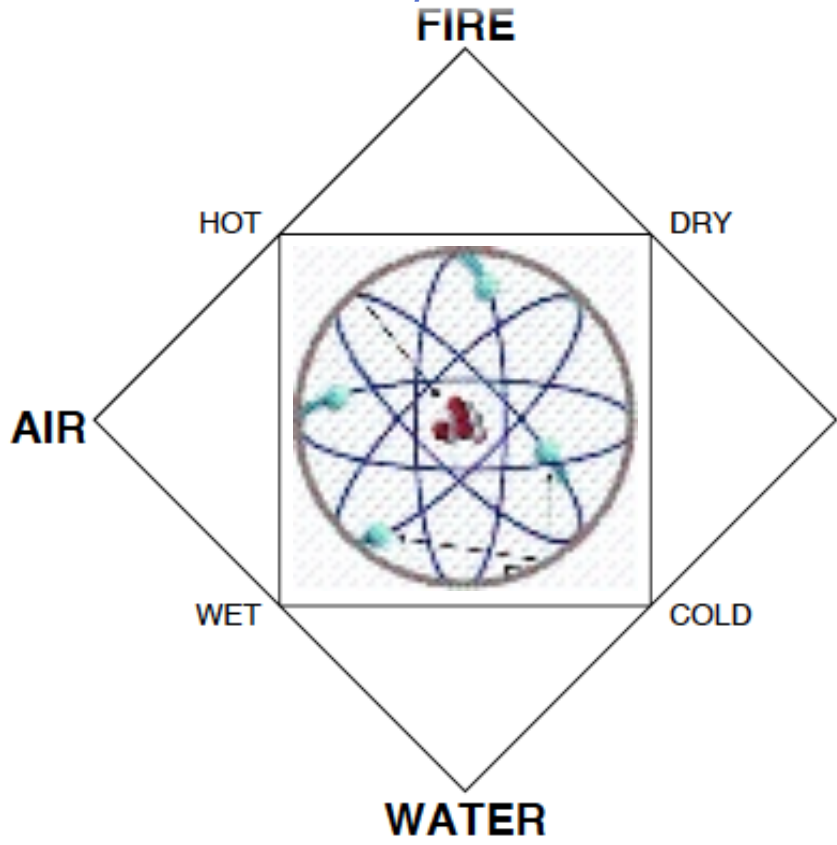
Leucippus, Big Cosmology
& **Democritus, Little Cosmology**
460-370BC 2 elements: **atoms** &
the **void**; eternal U, matter conserved



Rutherford
1911 nucleus
+electrons

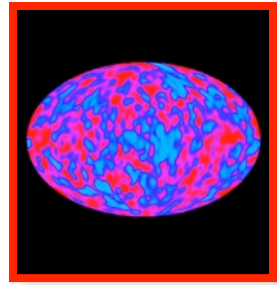


Dalton
1766
-1844



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

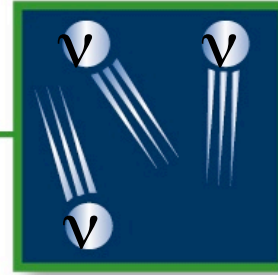




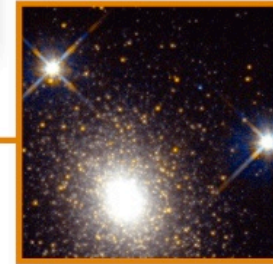
Radiation:



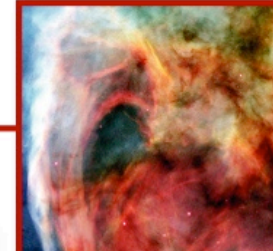
**Chemical Elements:
(other than H & He)**



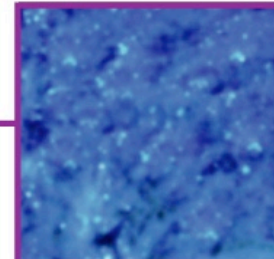
Neutrinos:



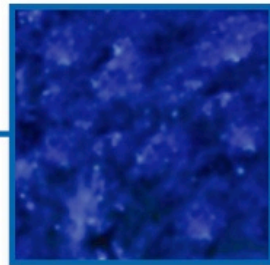
Stars:



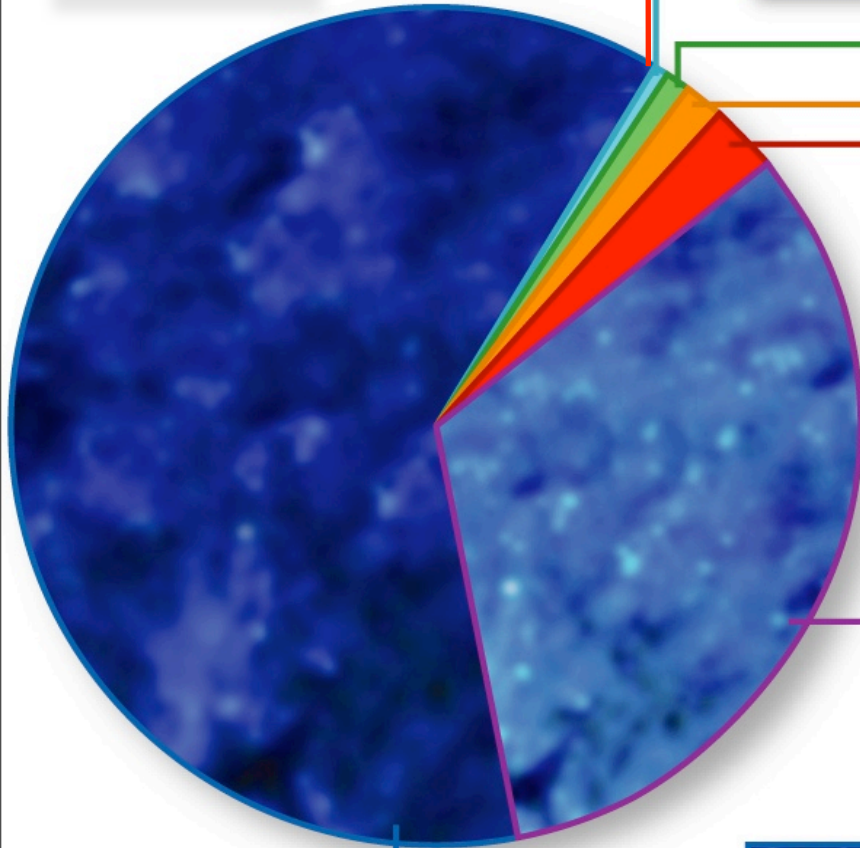
**Free
H & He:**



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

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.

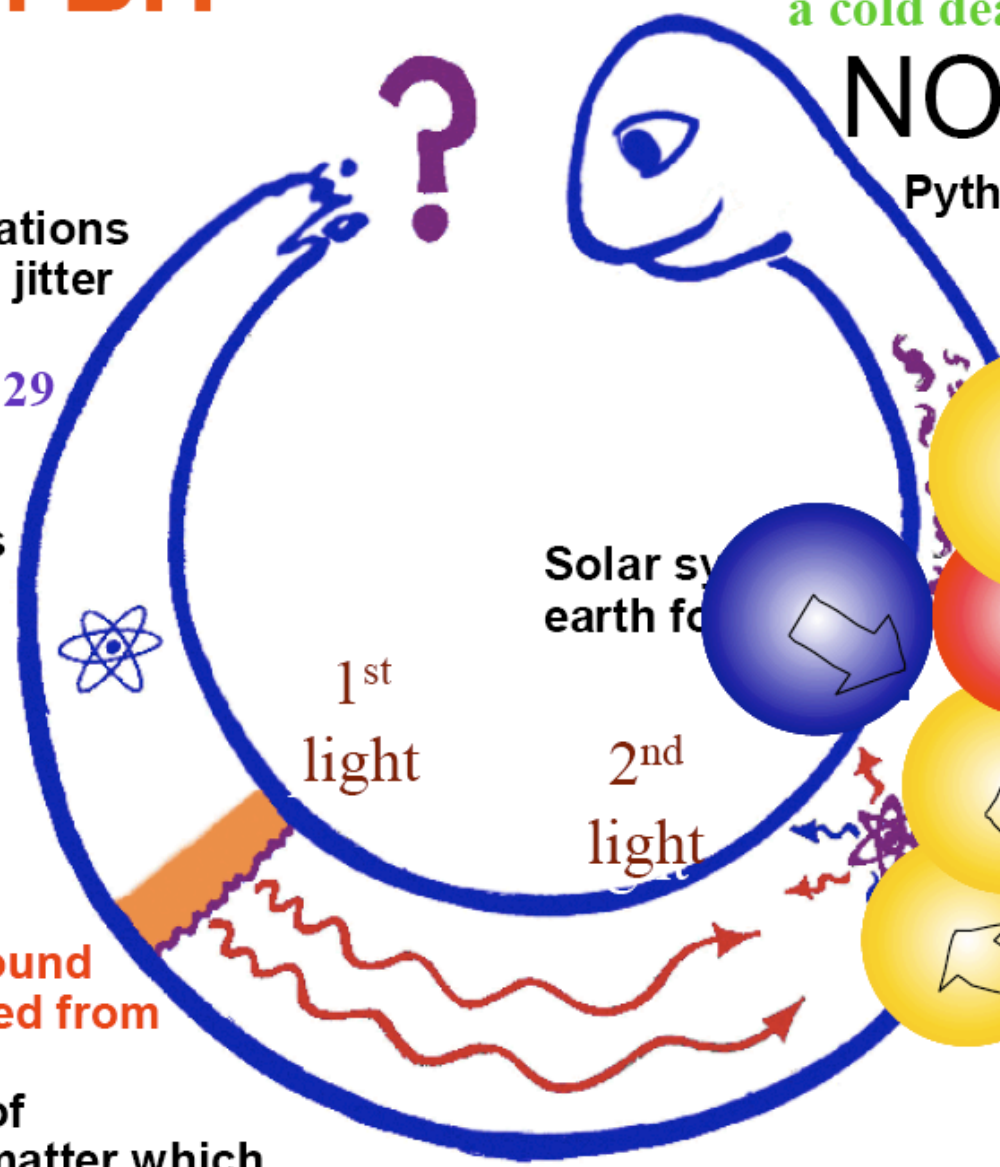
0.4 Myr 1100



1st
light

2nd
light

Solar system
earth forms



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

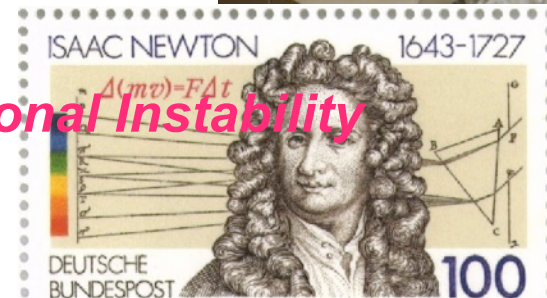
NEWTON ~ 1660 - 1690 AD

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)



Milky Way 1953-55

Newton's Death Mask @ROE

Crawford collection





Beyond Einstein

the universe is comprehensible!!!

Gravity as Geometry=Mass-Energy



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cosmological constant 1917 Λ



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$G - \Lambda g = \text{Energy-density} \times 8\pi G_{\text{Newton}}$



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ripples in spacetime moving at the speed of light



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Einstein: Mass = Energy / c^2

Planck's Quantum:

Energy = $h \times \text{frequency}$

Quantum + Gravity \Rightarrow Planck Mass

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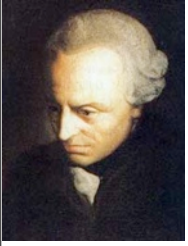
Einstein: Mass = Energy / c^2
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 Quantum + Gravity \Rightarrow Planck Mass
 $M_P = (ch/G_{\text{Newton}})^{1/2} / 4\pi$

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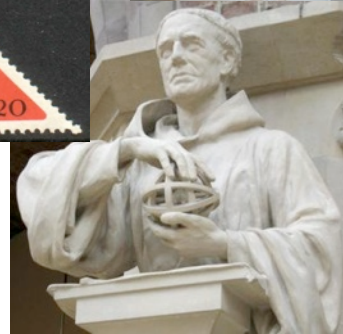
ripples in spacetime moving at the speed of light C

KANT ~ 1755 AD Galaxies - 'Island Universes'

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

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FRIEDMANN (1922) Evolving (Expanding) Universe

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

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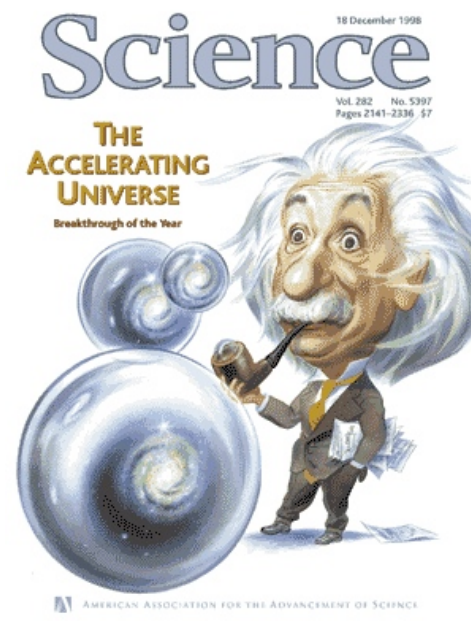
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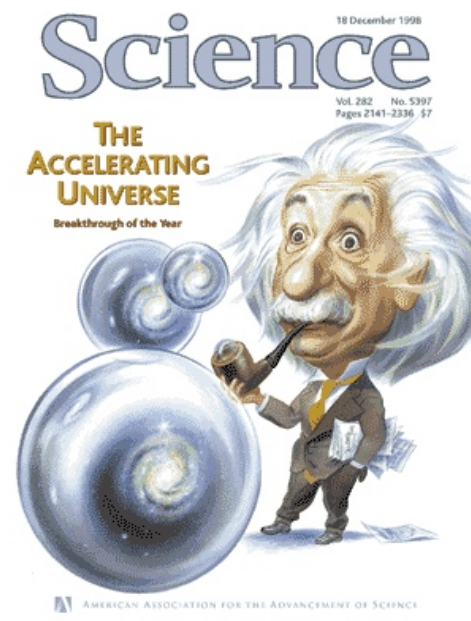
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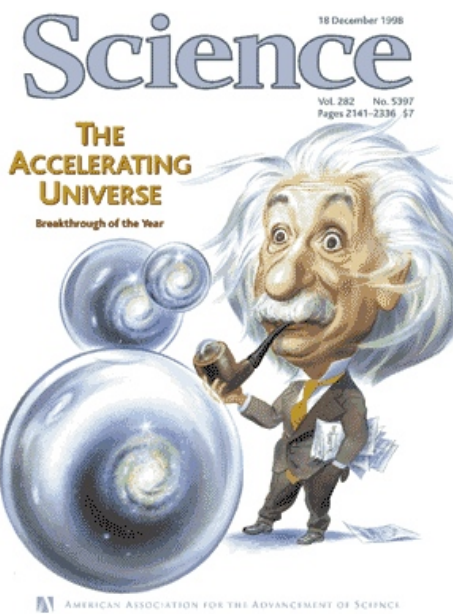
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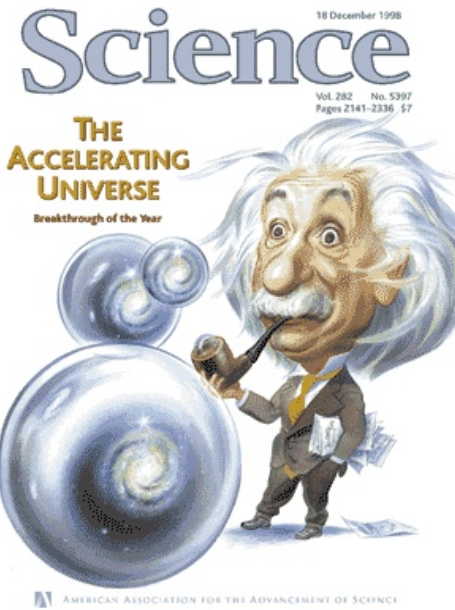
ρ_{Λ} = vacuum energy density

Sakharov~67



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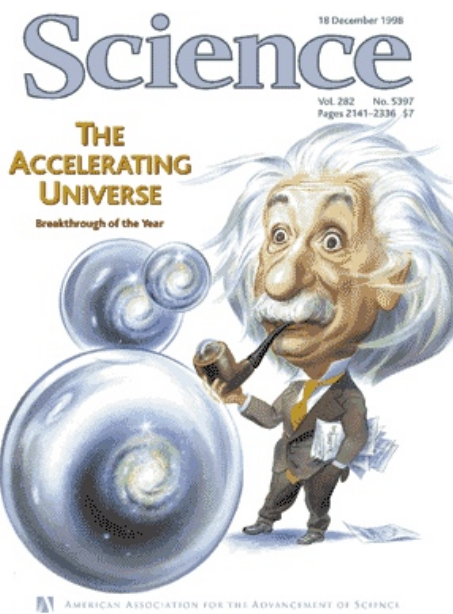
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$V = \Lambda / 8\pi G$ Newton
 vacuum potential



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cosmological constant 1917 Λ

Gravitational waves – 1917
ripples in spacetime moving at the speed of
light **C**



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1998/2009+: dark energy

ρ_{Λ} (space,time)?

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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”

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

10^{55}

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.

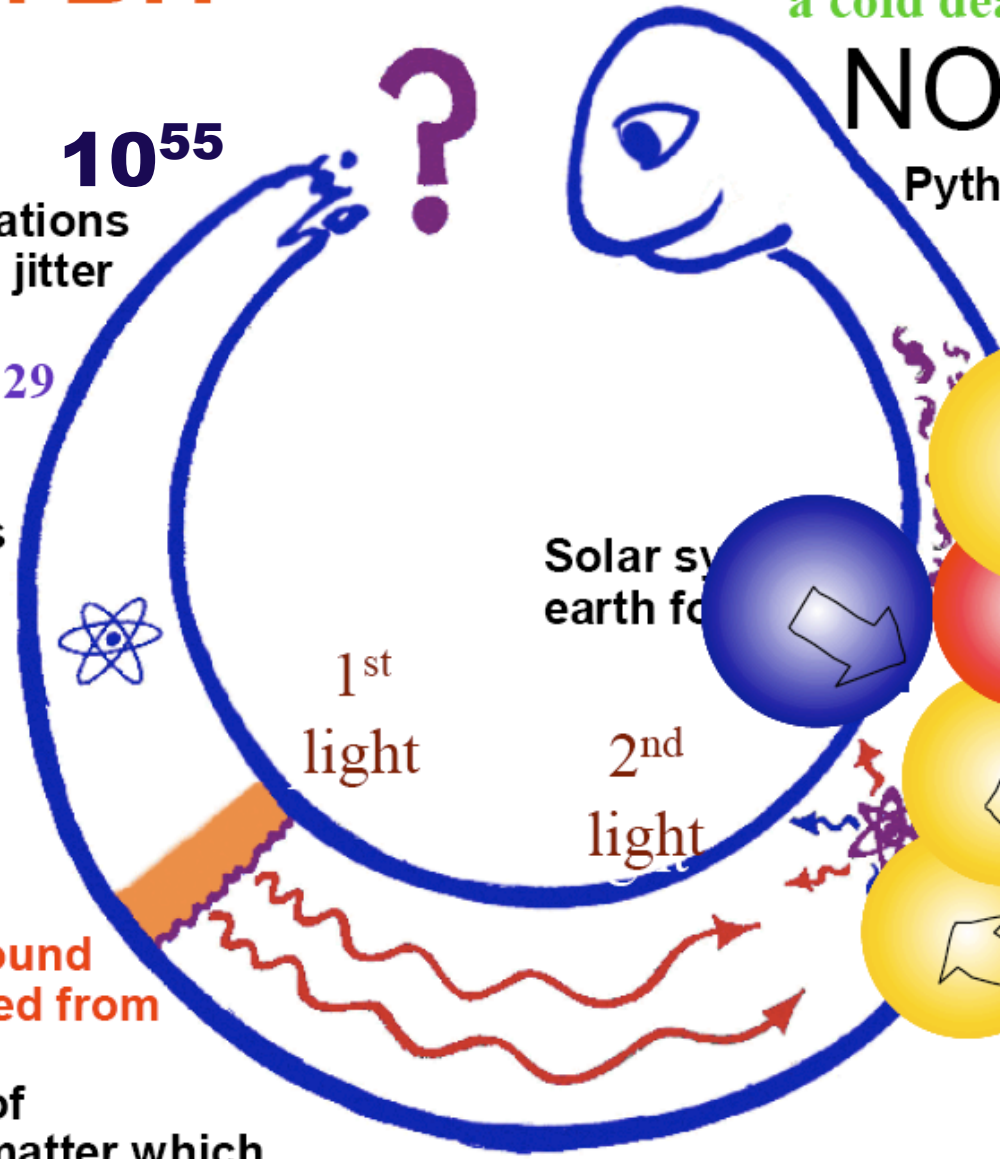
0.4 Myr 1100



1st light

2nd light

Solar system earth form



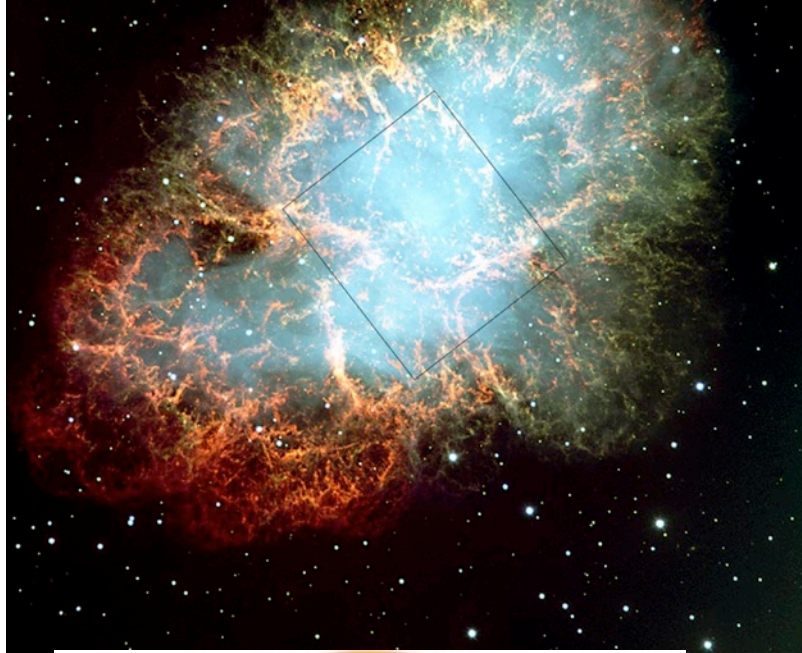


✓ **GAMOW (40s, early 50s) HOT BIG BANG**
 Hydrogen (75%) & Helium (25%) Deuterium/Lithium
 from the first minutes ; Carbon, Oxygen, Iron,..from
 exploding stars 40s-80s



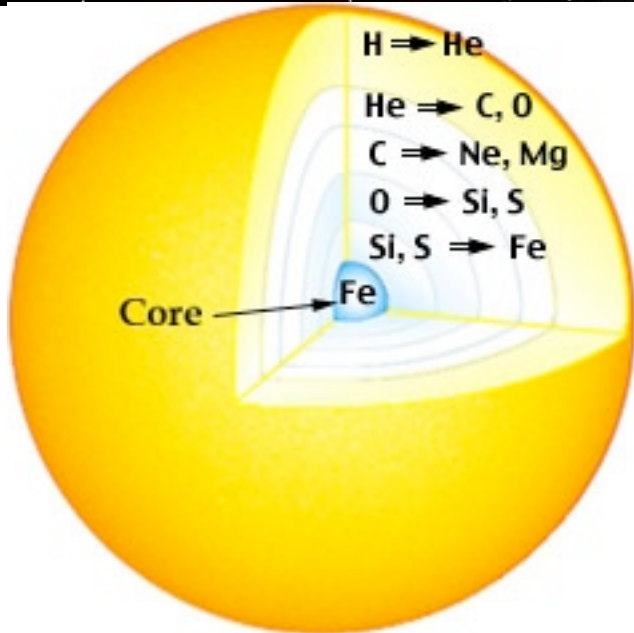
IOTA 1967, Cambridge **B²FH 57, WFH 67, sn**

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



SN1987a @LMC

collapse neutrinos,
no neutron star yet



**Nobel
Prize 84
Willy
Fowler +
Chandra
-sekhar**

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

1 (IA)										18 (VIIIA)																																											
Hydrogen										Helium																																											
${}^1_1\text{H}$ 1.00794 91.0%										${}^4_2\text{He}$ 4.002602 8.9%																																											
2 (IIA)		Group																																																			
Lithium		Beryllium		Element		M		E _Z		M.P. ^o		B.P. ^o		Ox.States		At.Weight		Abundance ^o %																																			
${}^7_3\text{Li}$ 7.016003 9.999999999999999		${}^9_4\text{Be}$ 9.012182 2.38x10 ⁻⁶ %																																																			
Sodium		Magnesium		Key to Table																																																	
${}^{23}_{11}\text{Na}$ 22.989770 0.000187%		${}^{24}_{12}\text{Mg}$ 24.3050 0.00350%																																																			
3 (IIIB)			4 (IVB)			5 (VB)			6 (VIB)			7 (VIIB)			8 (VIII)			9 (VIII)			10 (VIII)			11 (IB)			12 (IIB)																										
Potassium			Calcium			Scandium			Titanium			Vanadium			Chromium			Manganese			Iron			Cobalt			Nickel			Copper			Zinc																				
${}^{39}_{19}\text{K}$ 39.0983 0.0000123%			${}^{40}_{20}\text{Ca}$ 40.078 0.000199%			${}^{45}_{21}\text{Sc}$ 44.955910 1.12x10 ⁻⁶ %			${}^{48}_{22}\text{Ti}$ 47.867 7.8x10 ⁻⁶ %			${}^{51}_{23}\text{V}$ 50.9415 9.6x10 ⁻⁶ %			${}^{52}_{24}\text{Cr}$ 51.9961 0.000044%			${}^{55}_{25}\text{Mn}$ 54.938049 0.000031%			${}^{56}_{26}\text{Fe}$ 55.845 0.00294%			${}^{59}_{27}\text{Co}$ 58.933200 7.3x10 ⁻⁶ %			${}^{58}_{28}\text{Ni}$ 58.6934 0.000161%			${}^{63}_{29}\text{Cu}$ 63.546 1.70x10 ⁻⁶ %			${}^{65}_{30}\text{Zn}$ 65.39 4.11x10 ⁻⁶ %																				
Rubidium			Strontium			Yttrium			Zirconium			Niobium			Molybdenum			Technetium			Ruthenium			Rhodium			Palladium			Silver			Cadmium			Indium			Tin			Antimony			Tellurium			Iodine			Xenon		
${}^{85}_{37}\text{Rb}$ 85.4678 2.31x10 ⁻⁶ %			${}^{88}_{38}\text{Sr}$ 87.62 7.7x10 ⁻⁶ %			${}^{89}_{39}\text{Y}$ 88.90585 1.51x10 ⁻⁶ %			${}^{90}_{40}\text{Zr}$ 91.224 3.72x10 ⁻⁶ %			${}^{93}_{41}\text{Nb}$ 92.90638 2.28x10 ⁻⁶ %			${}^{98}_{42}\text{Mo}$ 95.94 8.3x10 ⁻⁶ %			${}^{98}_{43}\text{Tc}$ [98]			${}^{101}_{44}\text{Ru}$ 101.07 6.1x10 ⁻⁶ %			${}^{103}_{45}\text{Rh}$ 102.90550 1.12x10 ⁻⁶ %			${}^{106}_{46}\text{Pd}$ 106.42 4.5x10 ⁻⁶ %			${}^{107}_{47}\text{Ag}$ 107.8682 1.58x10 ⁻⁶ %			${}^{112}_{48}\text{Cd}$ 112.411 5.3x10 ⁻⁶ %			${}^{115}_{49}\text{In}$ 114.818 6.0x10 ⁻⁶ %			${}^{118}_{50}\text{Sn}$ 118.710 1.25x10 ⁻⁶ %			${}^{121}_{51}\text{Sb}$ 121.760 1.01x10 ⁻⁶ %			${}^{127}_{52}\text{Te}$ 127.60 1.57x10 ⁻⁶ %			${}^{127}_{53}\text{I}$ 126.90447 2.9x10 ⁻⁶ %			${}^{131}_{54}\text{Xe}$ 131.29 1.5x10 ⁻⁶ %		
Cesium			Barium			Lanthanum			Hafnium			Tantalum			Tungsten			Rhenium			Osmium			Iridium			Platinum			Gold			Mercury			Thallium			Lead			Bismuth			Polonium			Astatine			Radon		
${}^{133}_{55}\text{Cs}$ 132.90545 1.21x10 ⁻⁶ %			${}^{137}_{56}\text{Ba}$ 137.327 1.46x10 ⁻⁶ %			${}^{139}_{57}\text{La}$ 138.9055 5.02x10 ⁻⁶ %			${}^{178}_{72}\text{Hf}$ 178.49 6.75x10 ⁻⁶ %			${}^{181}_{73}\text{Ta}$ 180.9479 4.34x10 ⁻⁶ %			${}^{184}_{74}\text{W}$ 183.84 1.69x10 ⁻⁶ %			${}^{186}_{75}\text{Re}$ 186.207 1.59x10 ⁻⁶ %			${}^{190}_{76}\text{Os}$ 190.23 2.20x10 ⁻⁶ %			${}^{192}_{77}\text{Ir}$ 192.217 2.16x10 ⁻⁶ %			${}^{195}_{78}\text{Pt}$ 195.078 4.4x10 ⁻⁶ %			${}^{197}_{79}\text{Au}$ 196.96655 1.11x10 ⁻⁶ %			${}^{200}_{80}\text{Hg}$ 200.59 1.11x10 ⁻⁶ %			${}^{204}_{81}\text{Tl}$ 204.3833 6.0x10 ⁻⁶ %			${}^{207}_{82}\text{Pb}$ 207.2 1.03x10 ⁻⁶ %			${}^{208}_{83}\text{Bi}$ 208.98038 4.7x10 ⁻⁶ %			${}^{209}_{84}\text{Po}$ [209]			${}^{210}_{85}\text{At}$ [210]			${}^{222}_{86}\text{Rn}$ [222]		
Francium			Radium			Actinium			Rutherfordium			Dubnium			Seaborgium			Bohrium			Hassium			Meitnerium			Element-110			Element-111			Element-112																				
${}^{223}_{87}\text{Fr}$ [223]			${}^{226}_{88}\text{Ra}$ [226]			${}^{227}_{89}\text{Ac}$ [227]			${}^{261}_{104}\text{Rf}$ [261]			${}^{262}_{105}\text{Db}$ [262]			${}^{266}_{106}\text{Sg}$ [266]			${}^{264}_{107}\text{Bh}$ [264]			${}^{269}_{108}\text{Hs}$ [269]			${}^{268}_{109}\text{Mt}$ [268]			${}^{271}_{110}$ [271]			${}^{272}_{111}$ [272]			${}^{277}_{112}$ [277]																				

† Lanthanides

Cerium	Praseodymium	Neodymium	Promethium	Samarium	Europium	Gadolinium	Terbium	Dysprosium	Holmium	Erbium	Thulium	Ytterbium	Lutetium
${}^{140}_{58}\text{Ce}$	${}^{141}_{59}\text{Pr}$	${}^{142}_{60}\text{Nd}$	${}^{145}_{61}\text{Pm}$	${}^{150}_{62}\text{Sm}$	${}^{152}_{63}\text{Eu}$	${}^{157}_{64}\text{Gd}$	${}^{159}_{65}\text{Tb}$	${}^{163}_{66}\text{Dy}$	${}^{165}_{67}\text{Ho}$	${}^{167}_{68}\text{Er}$	${}^{169}_{69}\text{Tm}$	${}^{173}_{70}\text{Yb}$	${}^{175}_{71}\text{Lu}$
140.116	140.90765	144.24	[145]	150.36	151.964	157.25	158.92534	162.50	164.93032	167.26	168.93421	173.04	174.967
3.70x10 ⁻⁶ %	5.44x10 ⁻⁶ %	2.70x10 ⁻⁶ %		8.42x10 ⁻⁶ %	3.17x10 ⁻⁶ %	1.076x10 ⁻⁶ %	1.97x10 ⁻⁶ %	1.286x10 ⁻⁶ %	2.90x10 ⁻⁶ %	8.18x10 ⁻⁶ %	1.23x10 ⁻⁶ %	8.08x10 ⁻⁶ %	1.197x10 ⁻⁶ %

‡ Actinides

Thorium	Protactinium	Uranium	Neptunium	Plutonium	Americium	Curium	Berkelium	Californium	Einsteinium	Fermium	Mendelevium	Nobelium	Lawrencium
${}^{232}_{90}\text{Th}$	${}^{231}_{91}\text{Pa}$	${}^{238}_{92}\text{U}$	${}^{237}_{93}\text{Np}$	${}^{244}_{94}\text{Pu}$	${}^{243}_{95}\text{Am}$	${}^{247}_{96}\text{Cm}$	${}^{247}_{97}\text{Bk}$	${}^{251}_{98}\text{Cf}$	${}^{252}_{99}\text{Es}$	${}^{257}_{100}\text{Fm}$	${}^{258}_{101}\text{Md}$	${}^{259}_{102}\text{No}$	${}^{262}_{103}\text{Lr}$
232.0381	231.03588	238.0289	237.04817	244.06422	243.06138	247.0703	247.0703	251.0795	252.08322	257.10528	258.10645	259.10854	262.10987
1.09x10 ⁻¹⁰ %		2.94x10 ⁻¹¹ %											

cosmic baryon number $n_b = 0.261 \pm 0.005 / m^3$

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

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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.

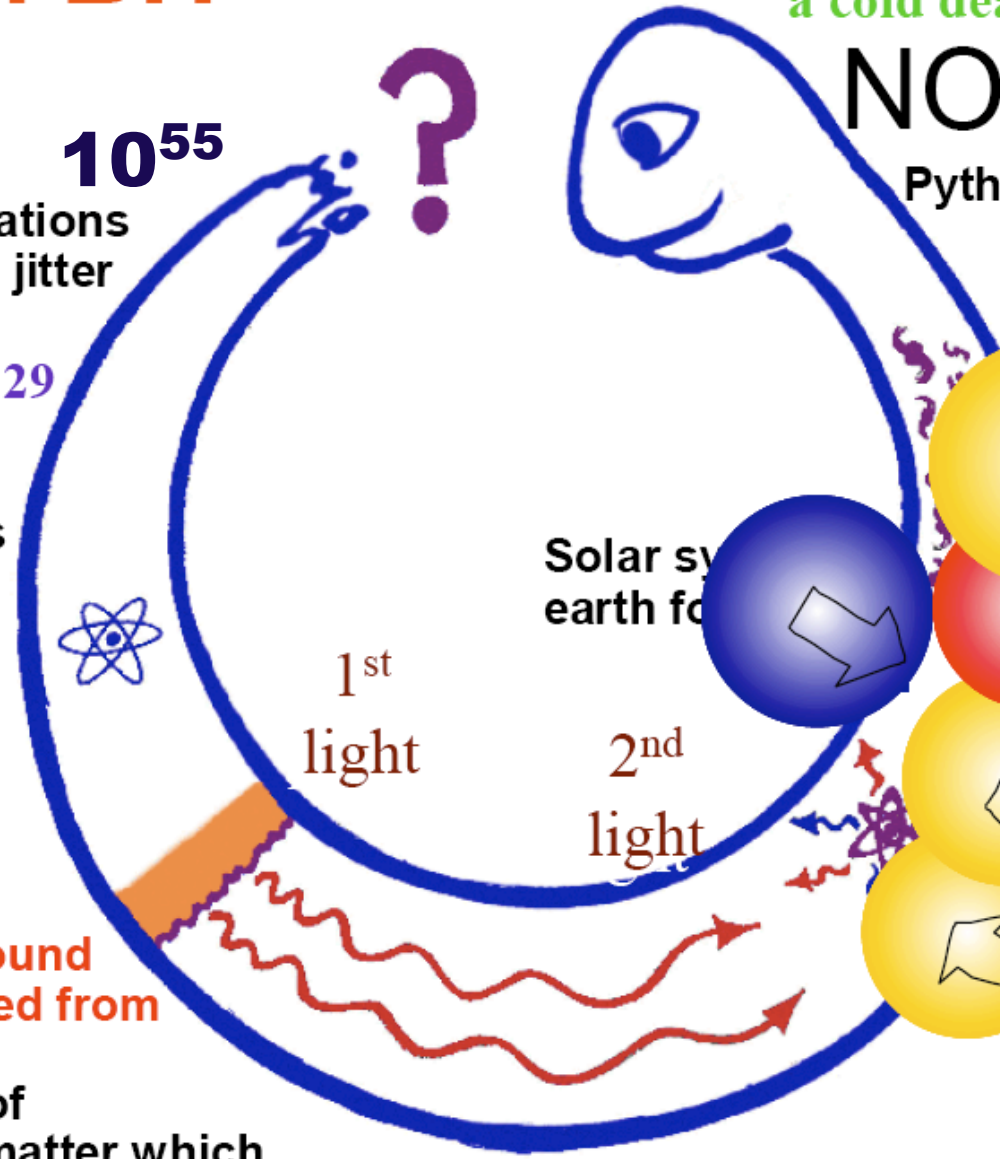
0.4 Myr 1100



1st light

2nd light

Solar system earth form



extra-“ordinary” matter

Fermilab's

vacuum potential

Primordial SOUP

DIRECTIONS
Heat ingredients to 3,000,000,000,000,000 degrees, stirring occasionally if you wish.

If allowed to cool for 14 billion years, this product will become the atoms that make up our known universe.

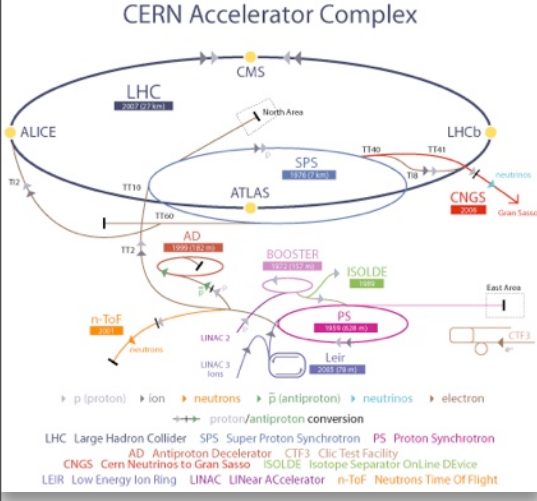
CAUTION:
Contents are extremely dense and are under enormous pressure.

INGREDIENTS

Quarks.....	56%
Force Carriers.....	29%
Electron-like Particles.....	9%
Neutrinos.....	5%
Higgs Bosons.....	1%

INSPECTED BY U.S. Department of Energy

Provides 100% of the minimum daily requirements for a healthy developing and expanding known universe.



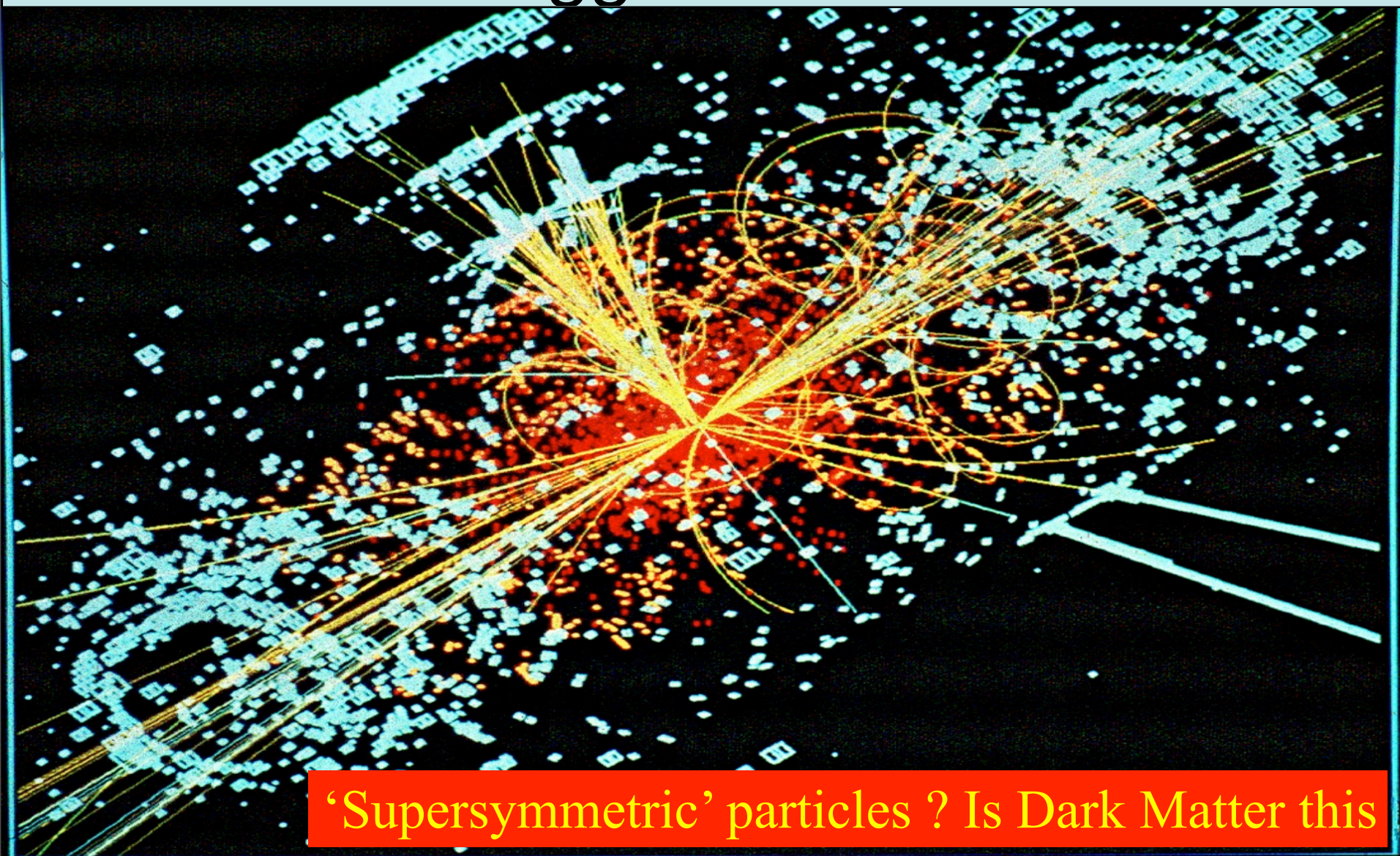
Galileo's Accelerator

LHC “new first light” Dec09
 @CERN “cosmic” accelerator



what is mass?
 vacuum potential
 dark matter
 antimatter
 asymmetry
 extra
 dimensions

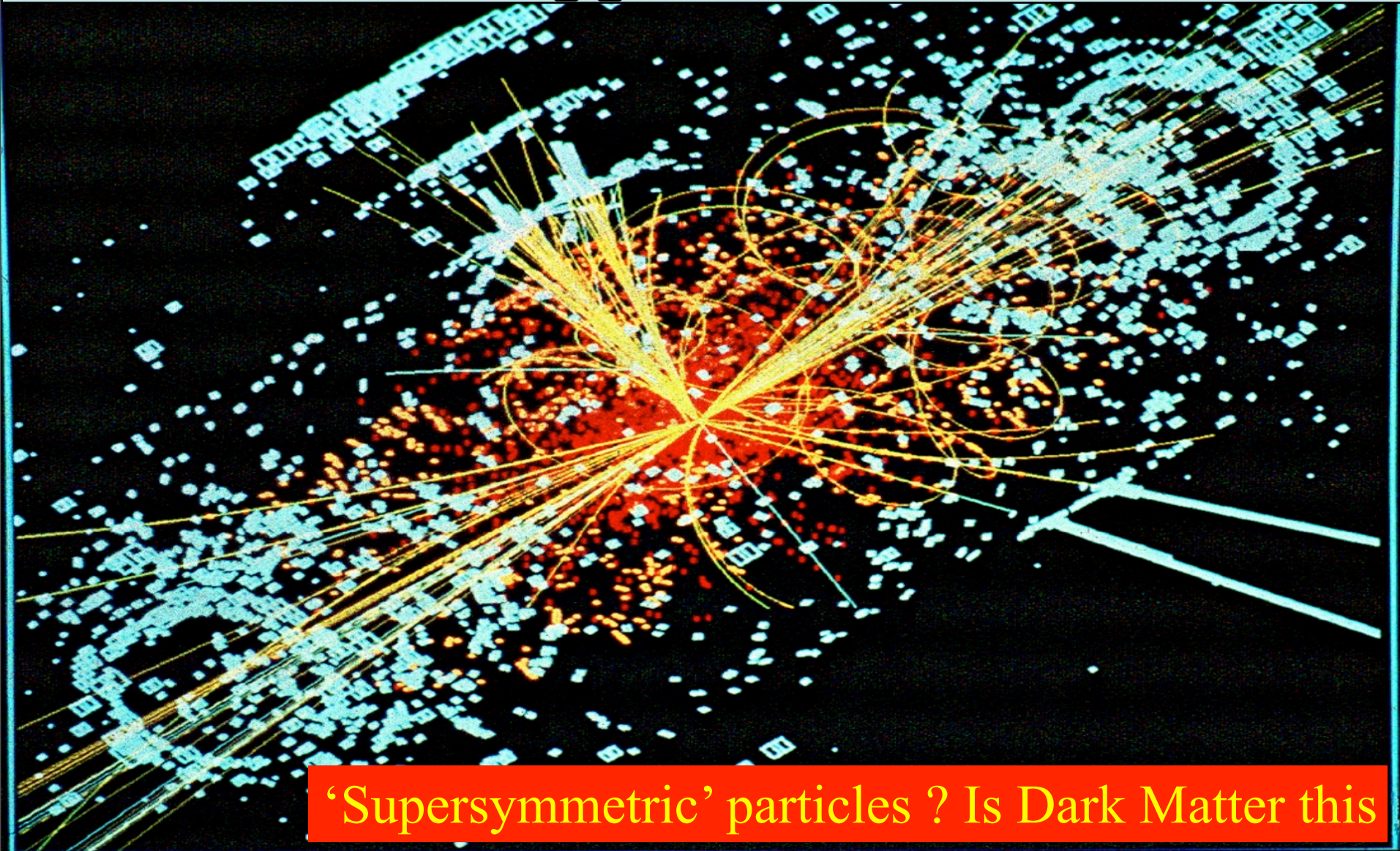
A Simulated Higgs Event in CMS: LHC



‘Supersymmetric’ particles ? Is Dark Matter this

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



‘Supersymmetric’ particles ? Is Dark Matter this

“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

10^{55}

Inflation fluctuations
form: quantum jitter

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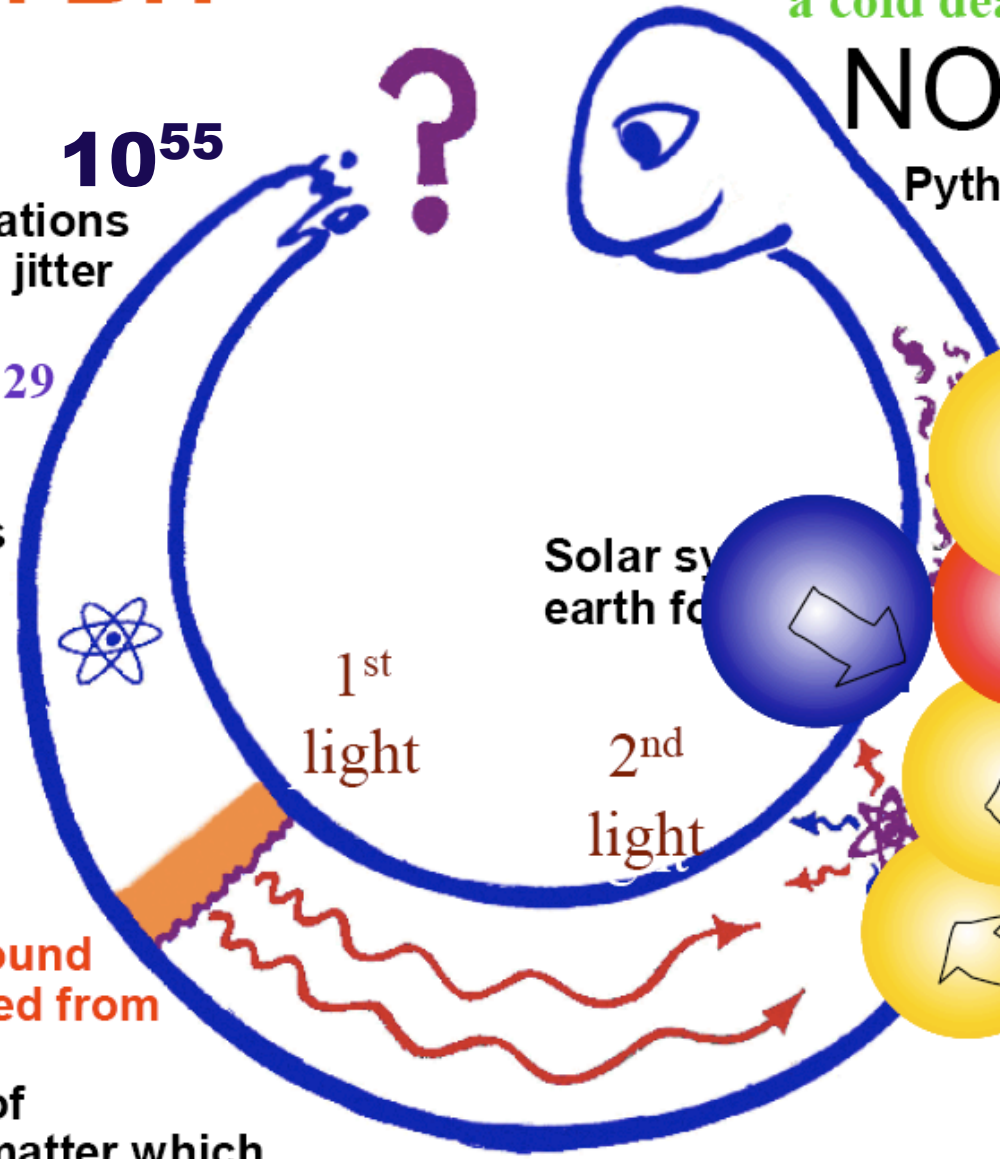
0.4 Myr 1100



1st
light

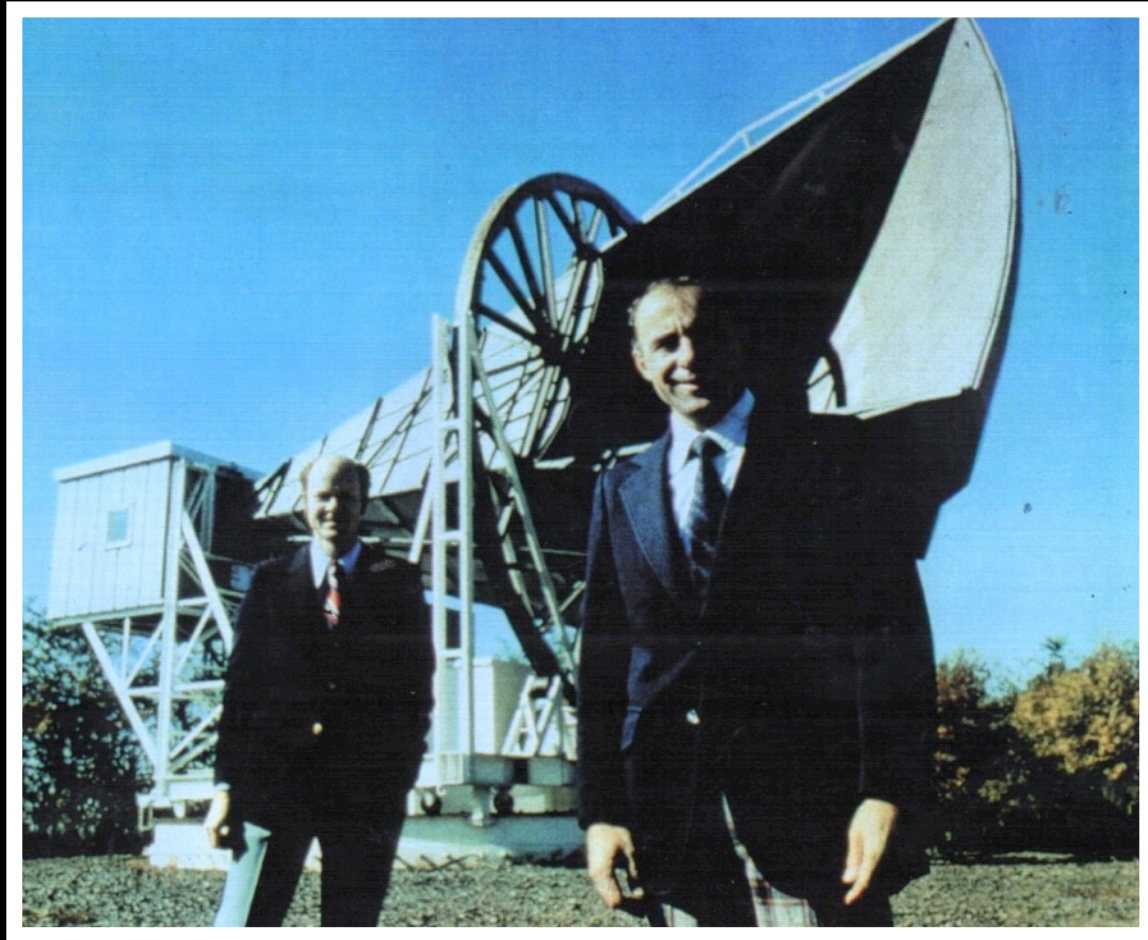
2nd
light

Solar sy
earth fo



***The
Universe
Is Radiant***

**Arno Penzias
Robert Wilson
1965**



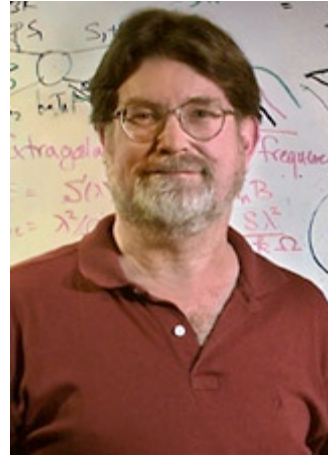
The Nobel Prize in Physics 2006

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

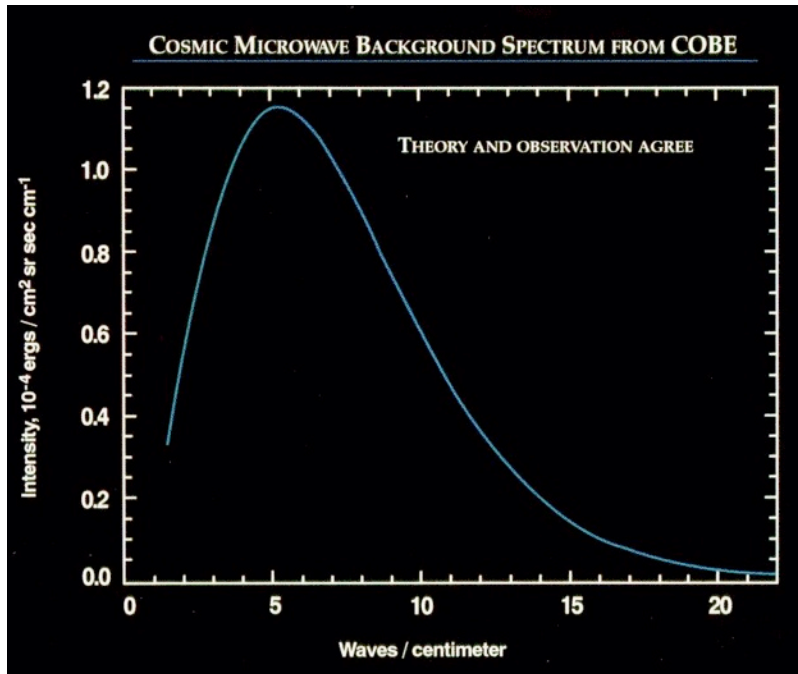
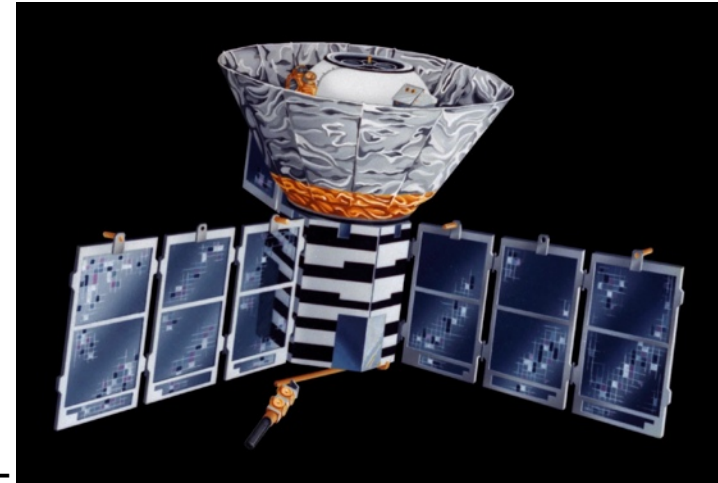
"for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation"



John C. Mather 1946-



George F. Smoot 1945-

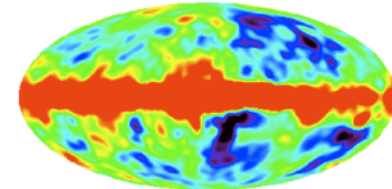
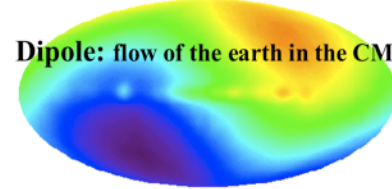


CMB

Nearly Perfect Blackbody

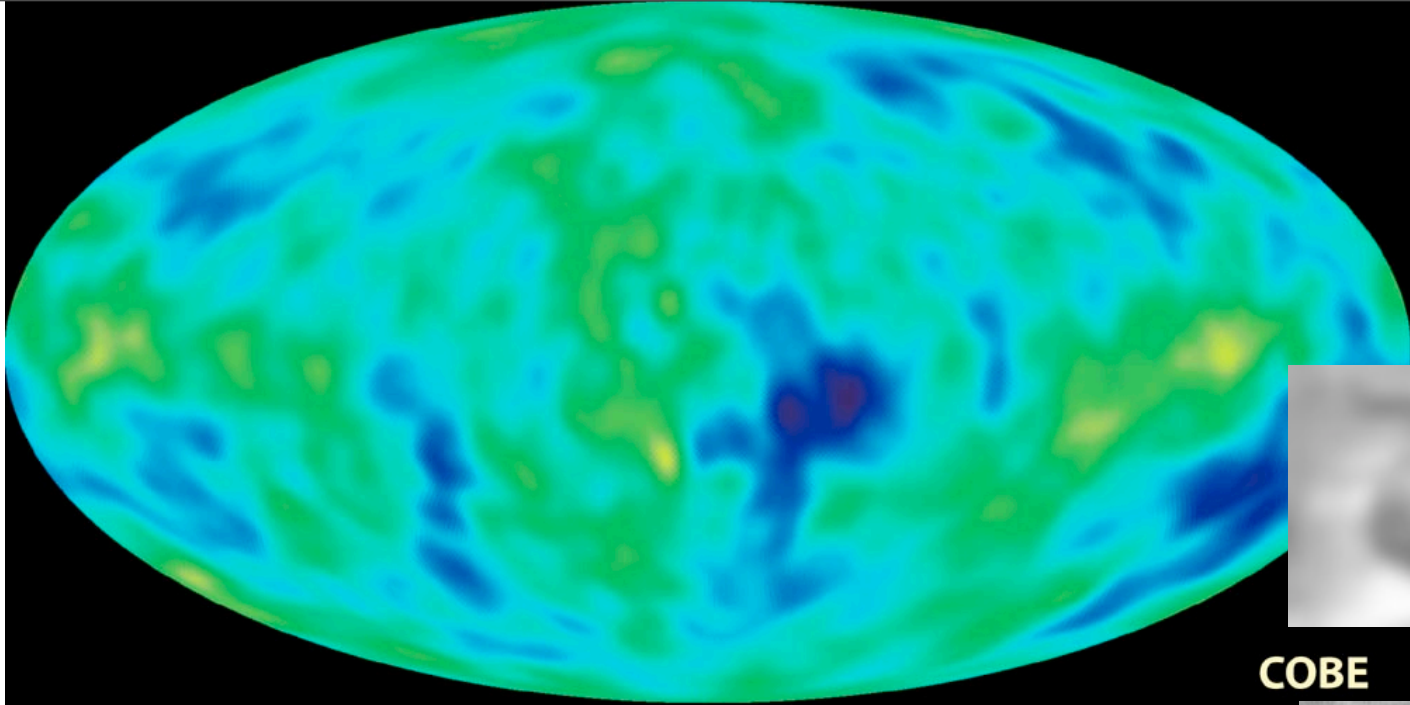
$T = 2.725 \pm 0.001$ K COBE/FIRAS

Dipole: flow of the earth in the CMB

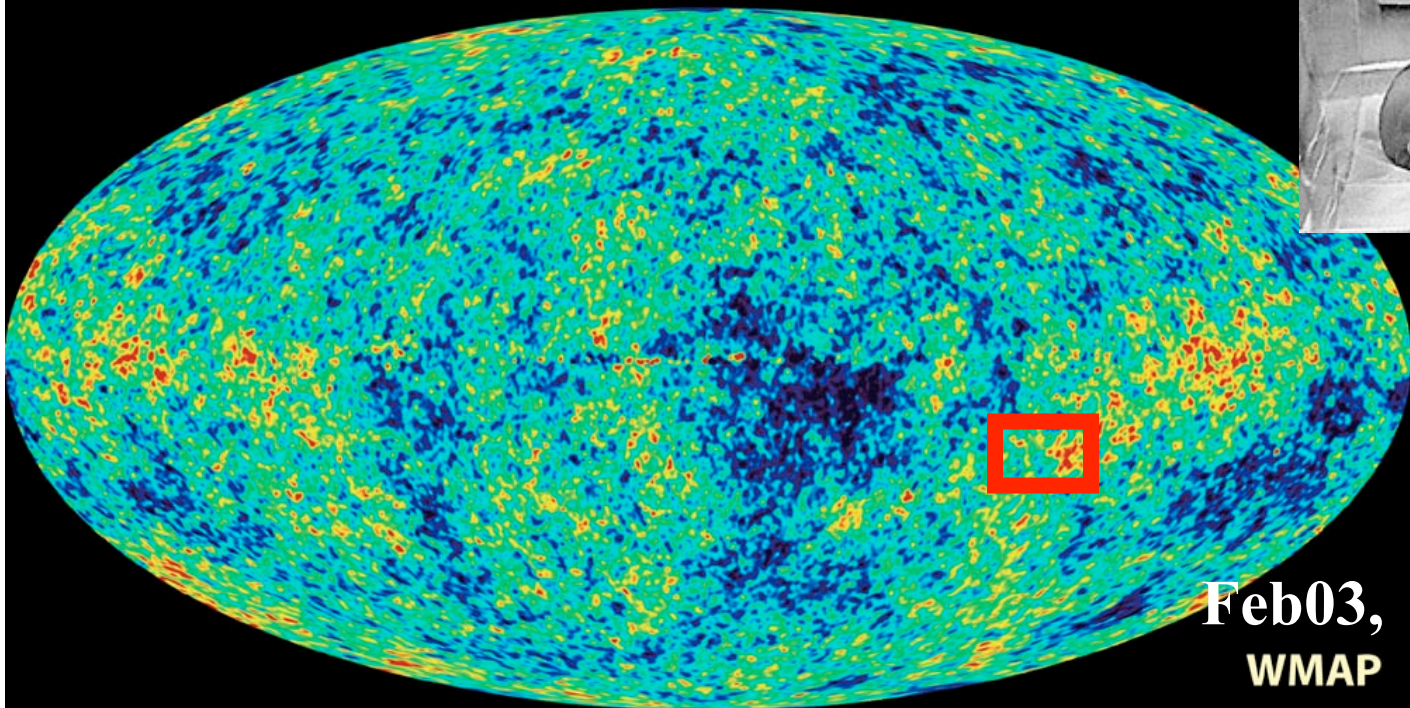


COBE/DMR:

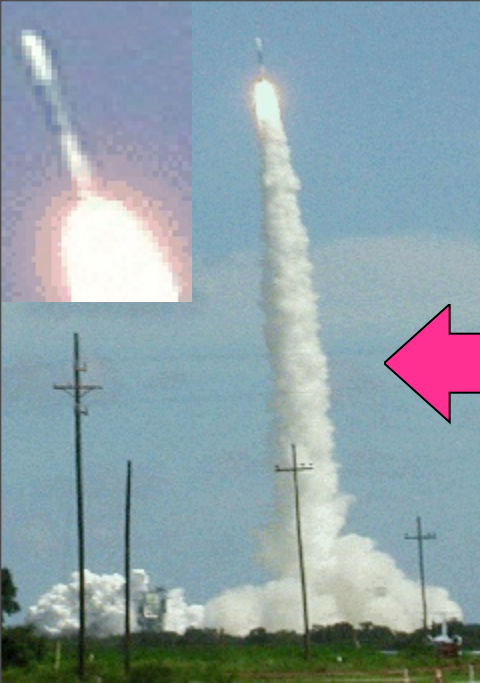
CMB + Galactic @ 7°



COBE

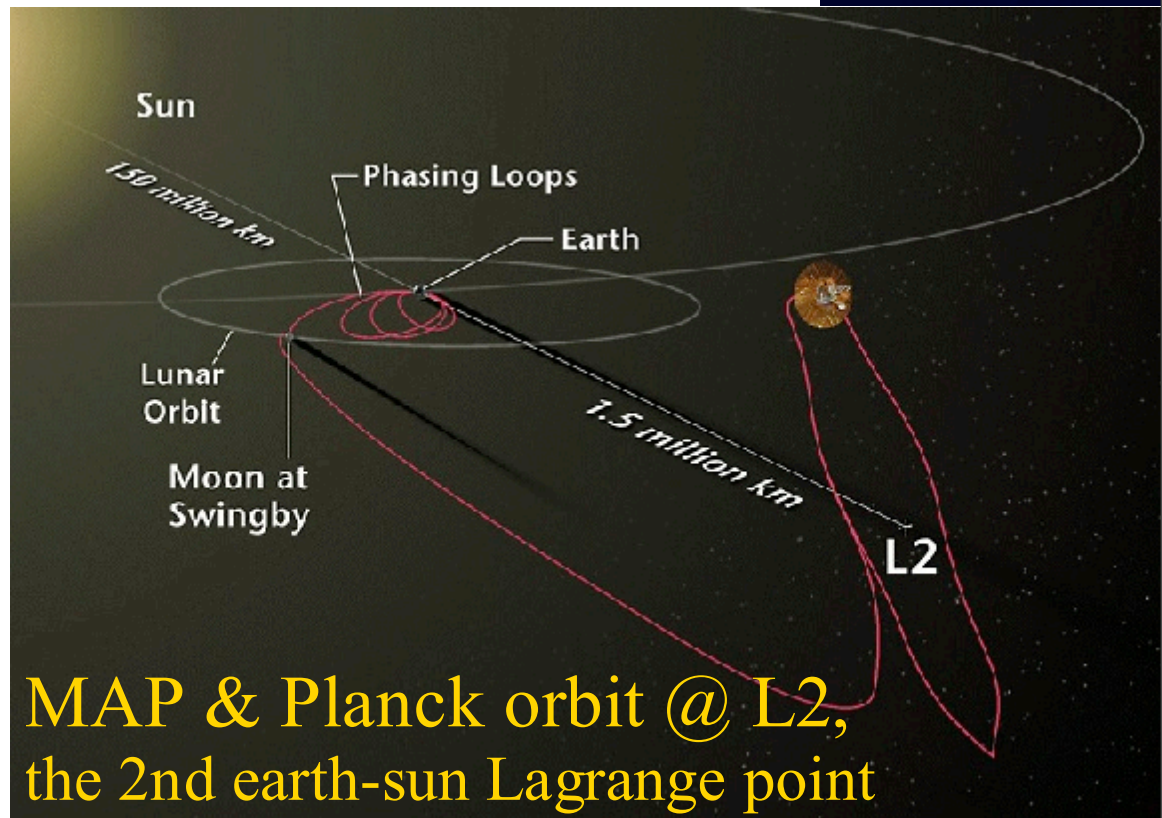
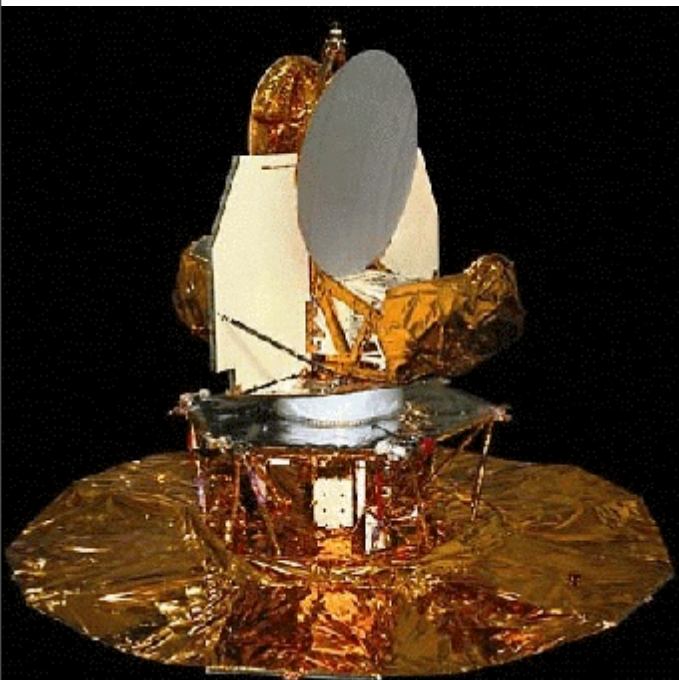
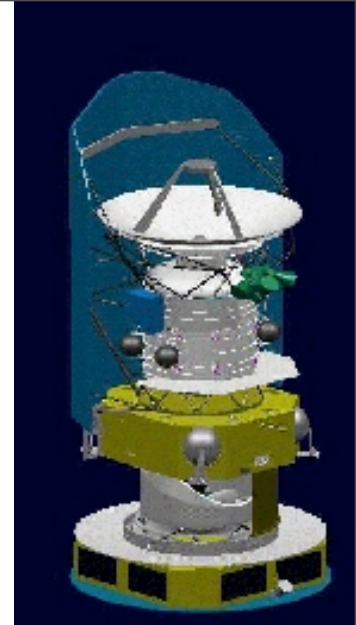
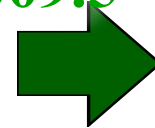


Feb03, Mar06,08
WMAP



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



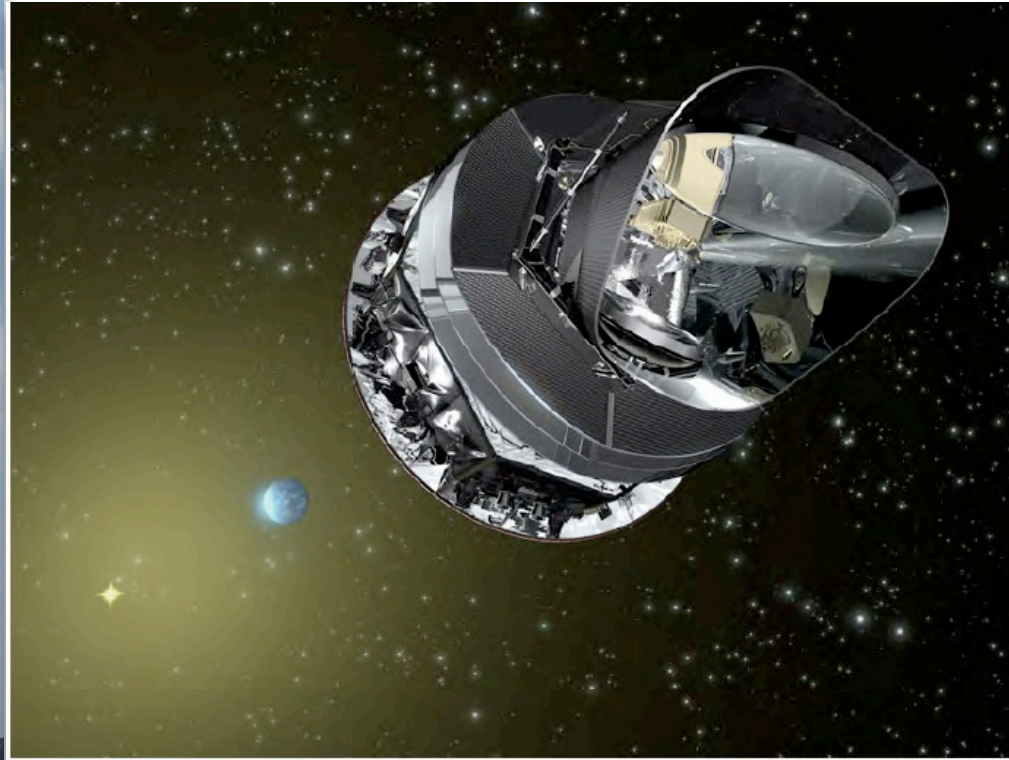
MAP & Planck orbit @ L2,
the 2nd earth-sun Lagrange point

Entering the Planck Era > May 14, 2009

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

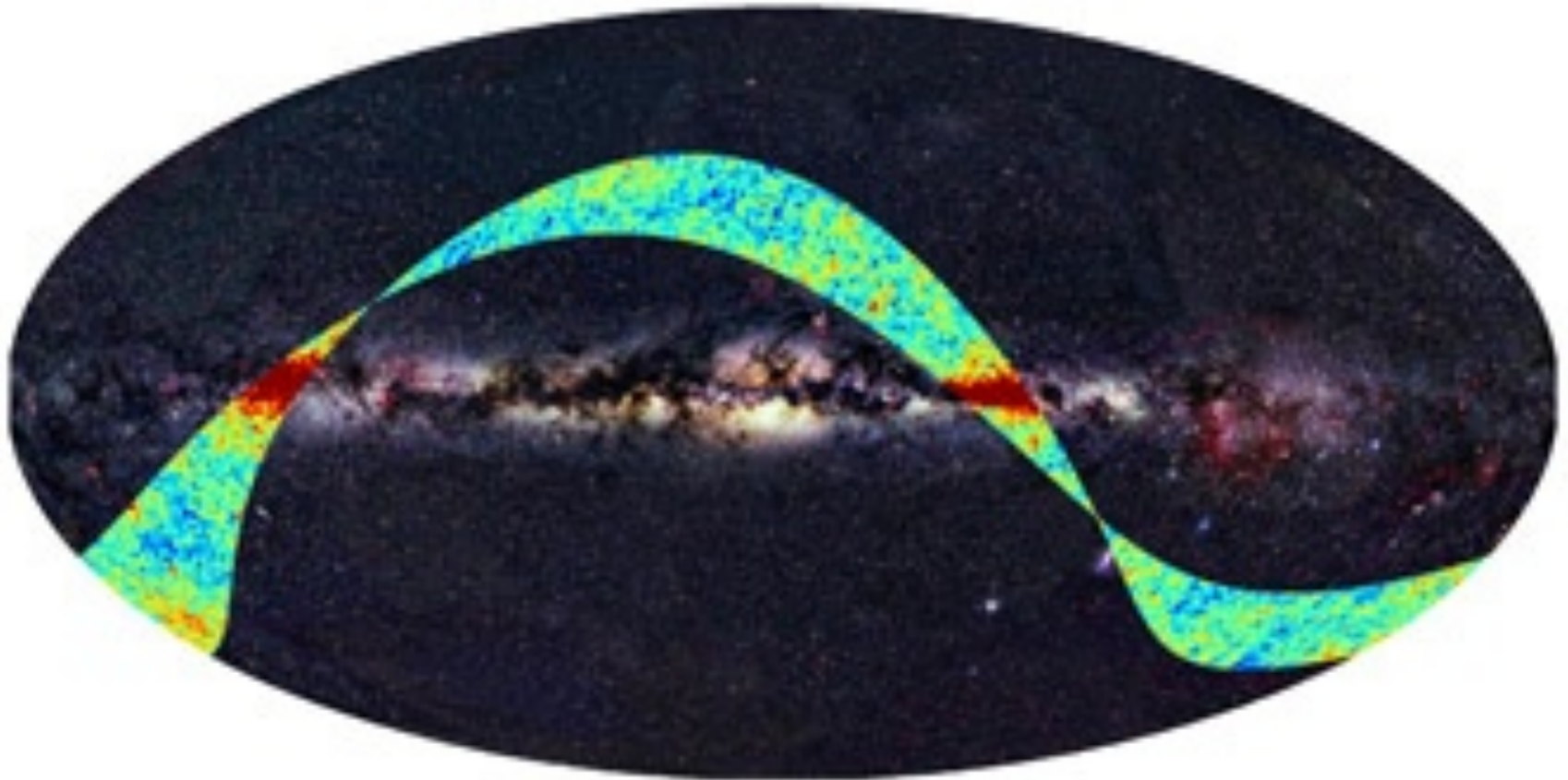
huge impact of Planck on Planck era physics (early inflation) & on late inflation (Dark Energy)

**Launch May 14, 2009
FrenchGuiana, @L2 early July,
Survey Began Aug 09**

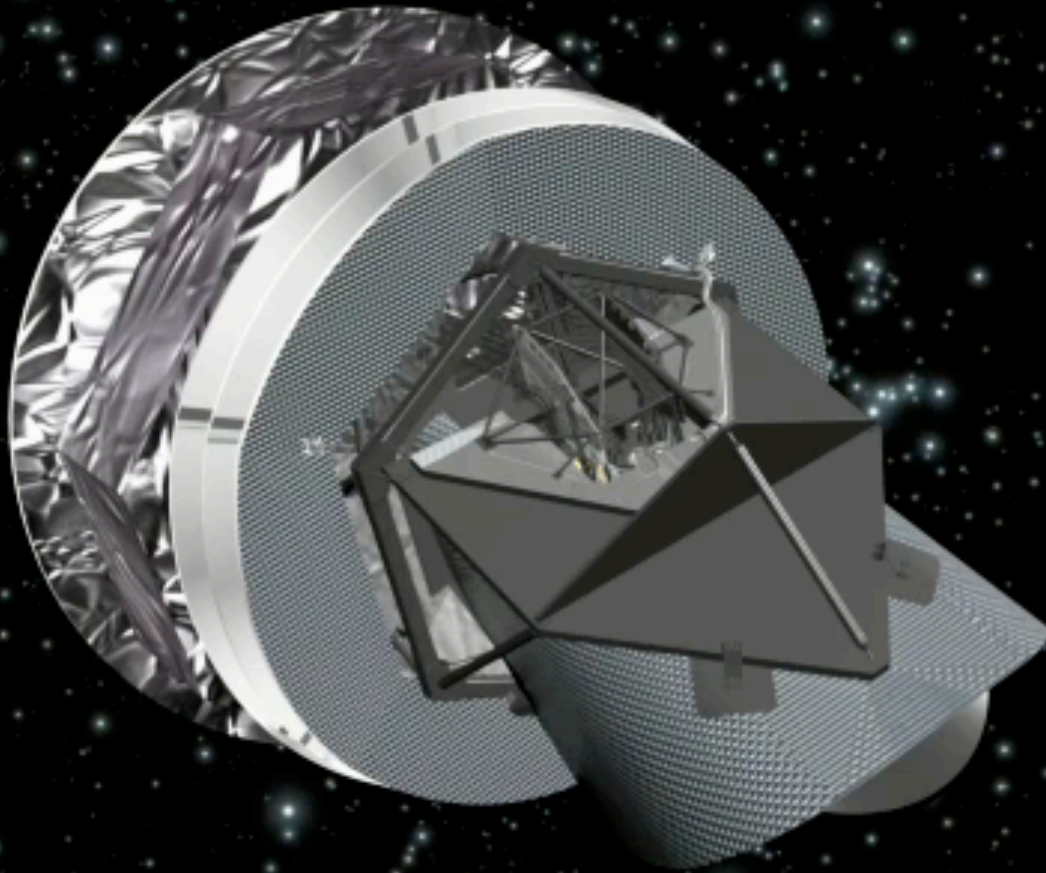


ESA /NASA /CSA Toronto HFI QLA/KST, TA, ... Barth & Dick, Marc-Antoine Miville-Deschenes, Carrie MacTavish, Brendan Crill, Olivier Dore, Carlo Contaldi, Mike Nolta, Peter Martin, Francine Marleau, UBC LFI

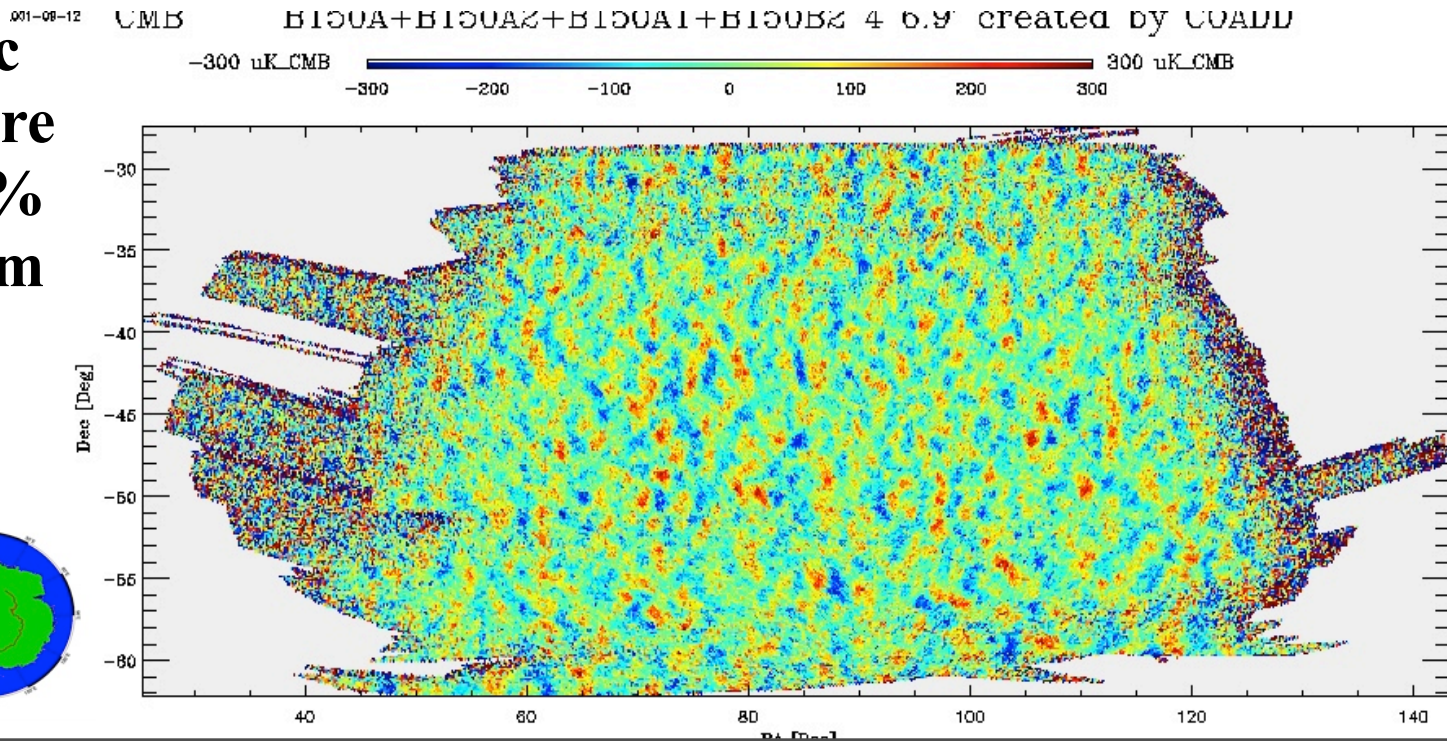
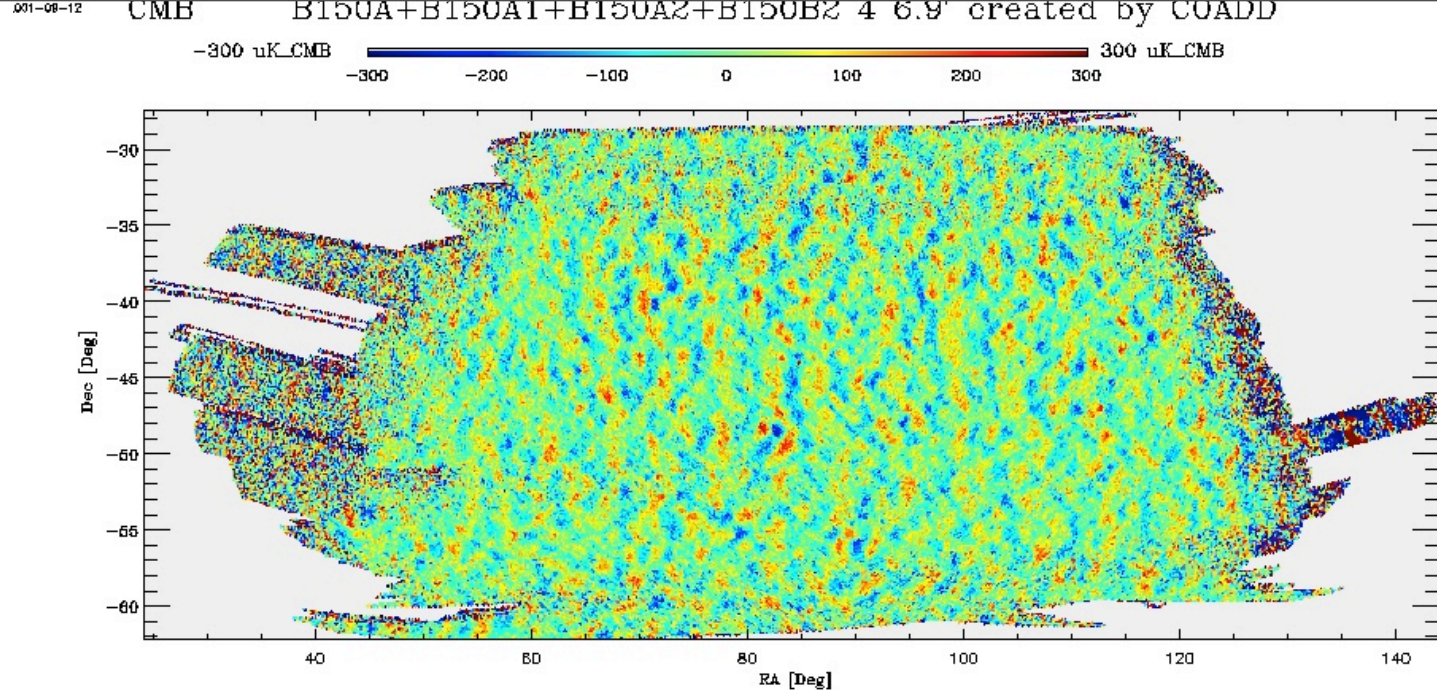
Planck “First Light” Survey Aug 2009



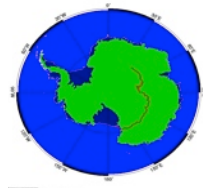
Planck 1st of 5 all Sky Surveys 09.7-10.1

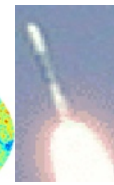
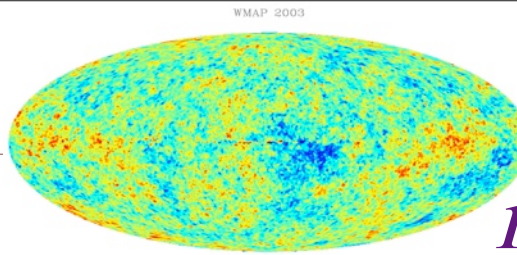


Boomerang
@150GHz is
(nearly)
Gaussian:
Simulated
vs Real
looks the
same



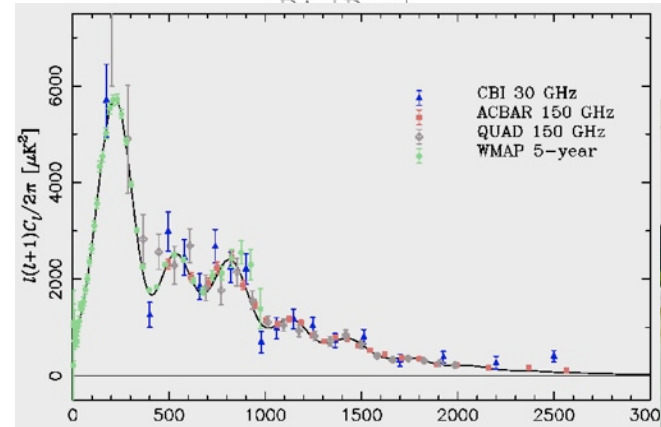
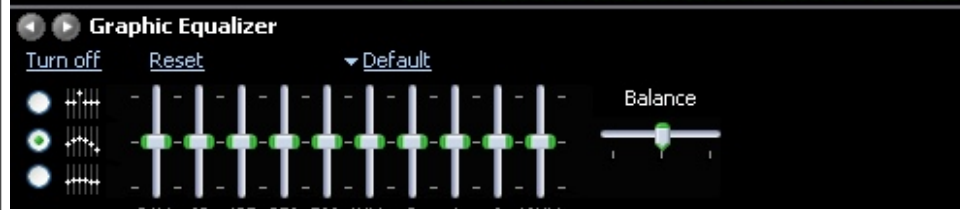
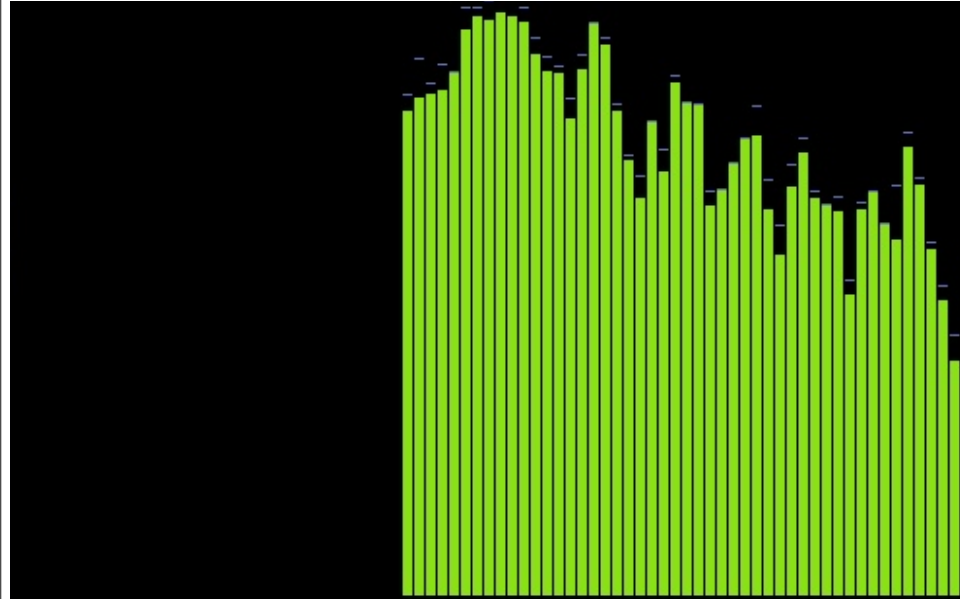
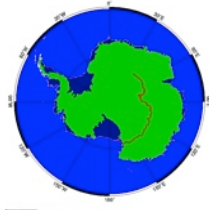
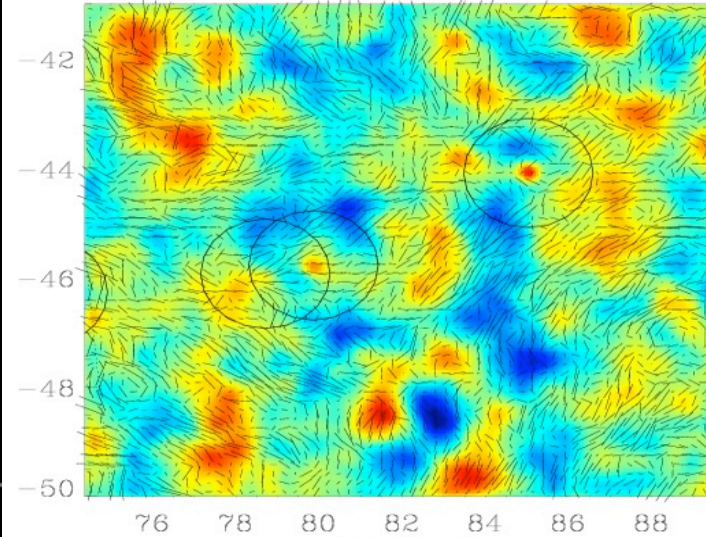
thermodynamic
CMB temperature
fluctuations 2.9%
of sky $\Delta T \sim 30$ ppm



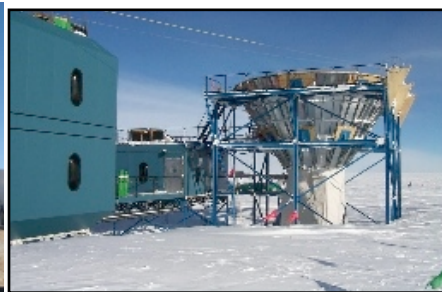
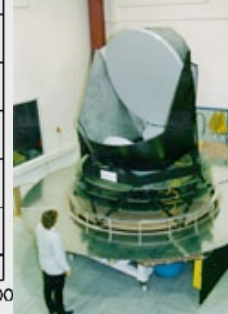


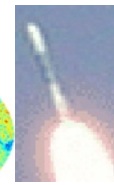
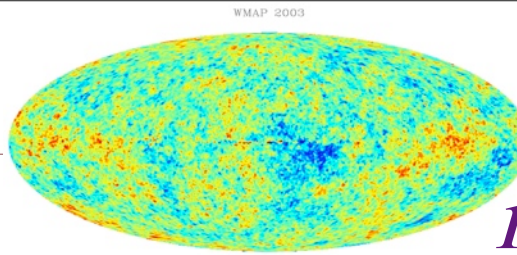
13.65 - 0.00038 billion years ago

Boom05 deep Jul05, Sept08



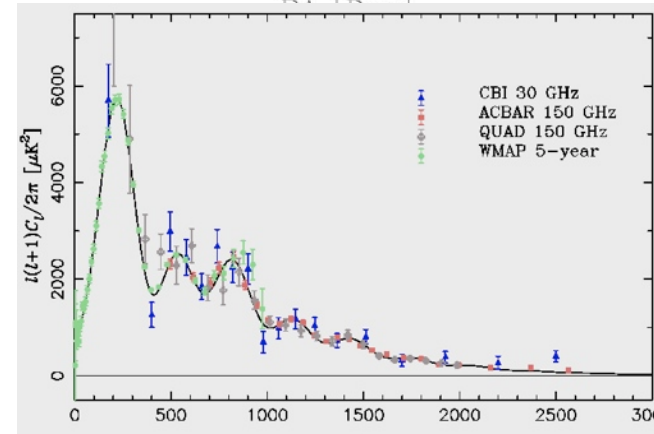
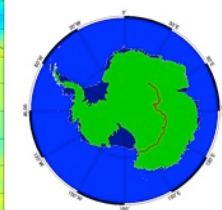
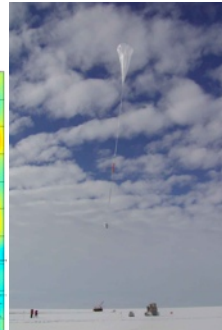
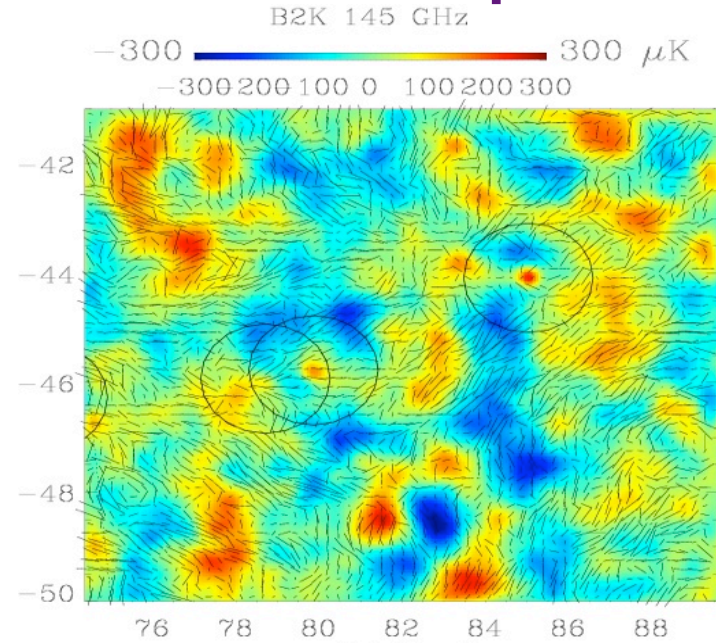
Planck09 as deep



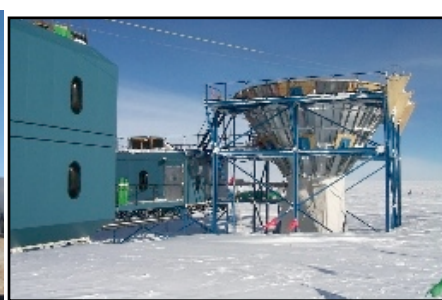
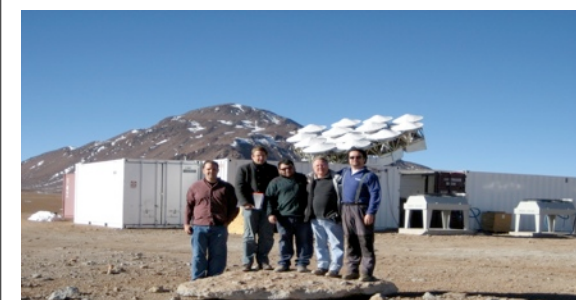


13.65 - 0.00038 billion years ago

Boom05 deep Jul05, Sept08



**Planck09
as deep**



“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

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2 Gyr 4

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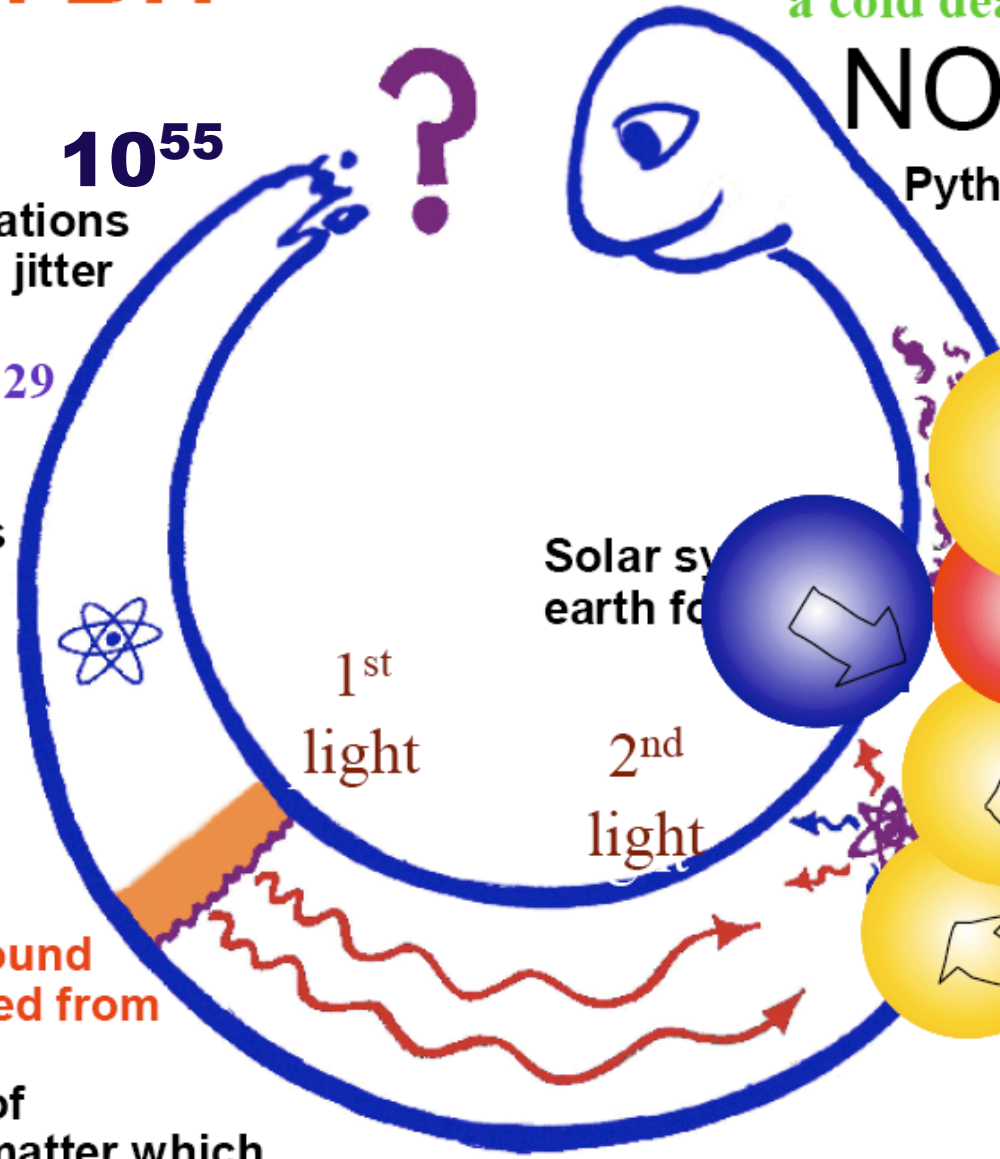
0.4 Myr 1100



1st light

2nd light

Solar system earth form

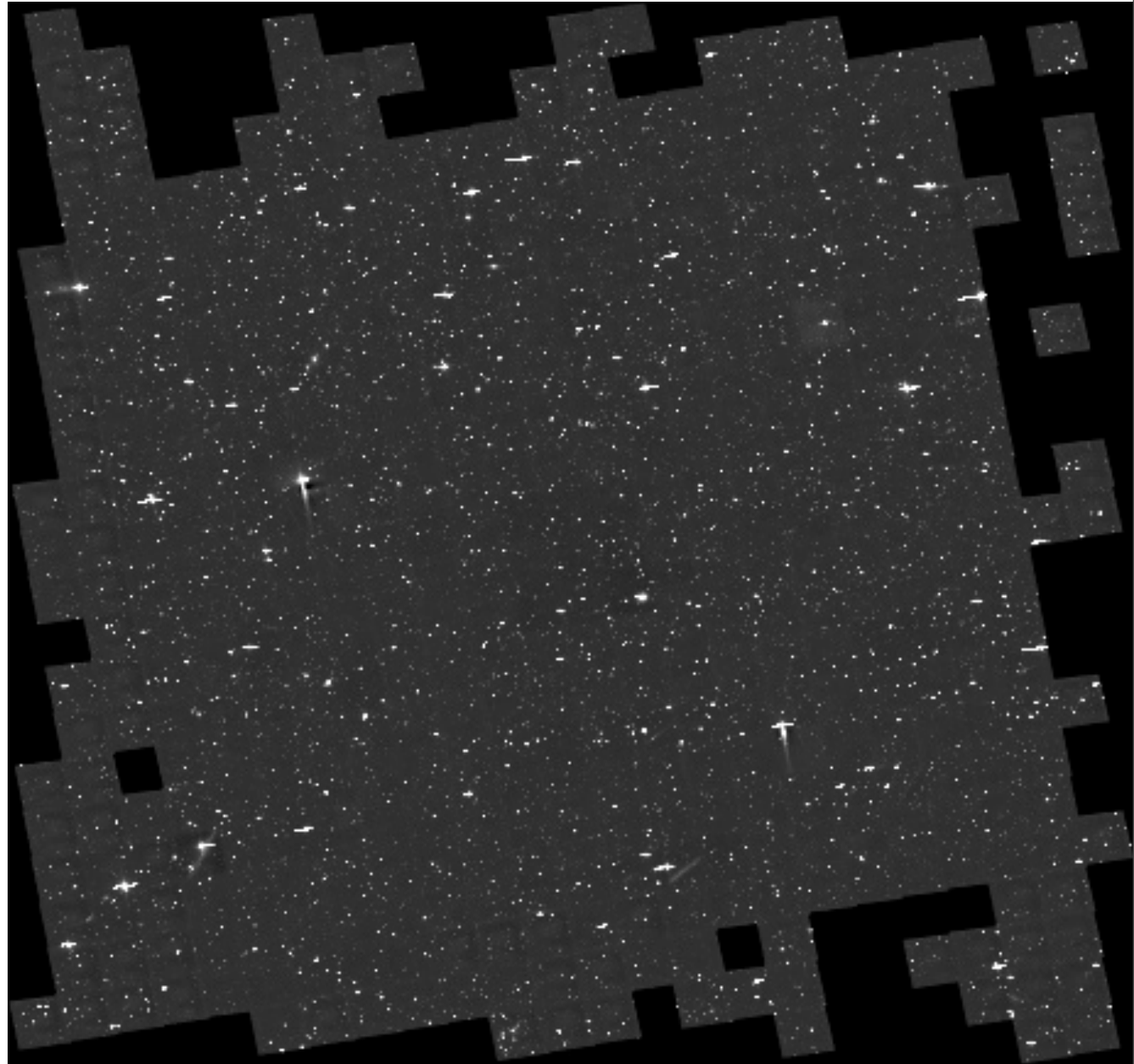


Hubble “Cosmic Evolution Survey”

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



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



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**& Beyond
Hubble: JWST
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a **starless**
“dark age”
before the
most
distant
galaxies

dwarflets &
the 1st stars

form at
compression 13

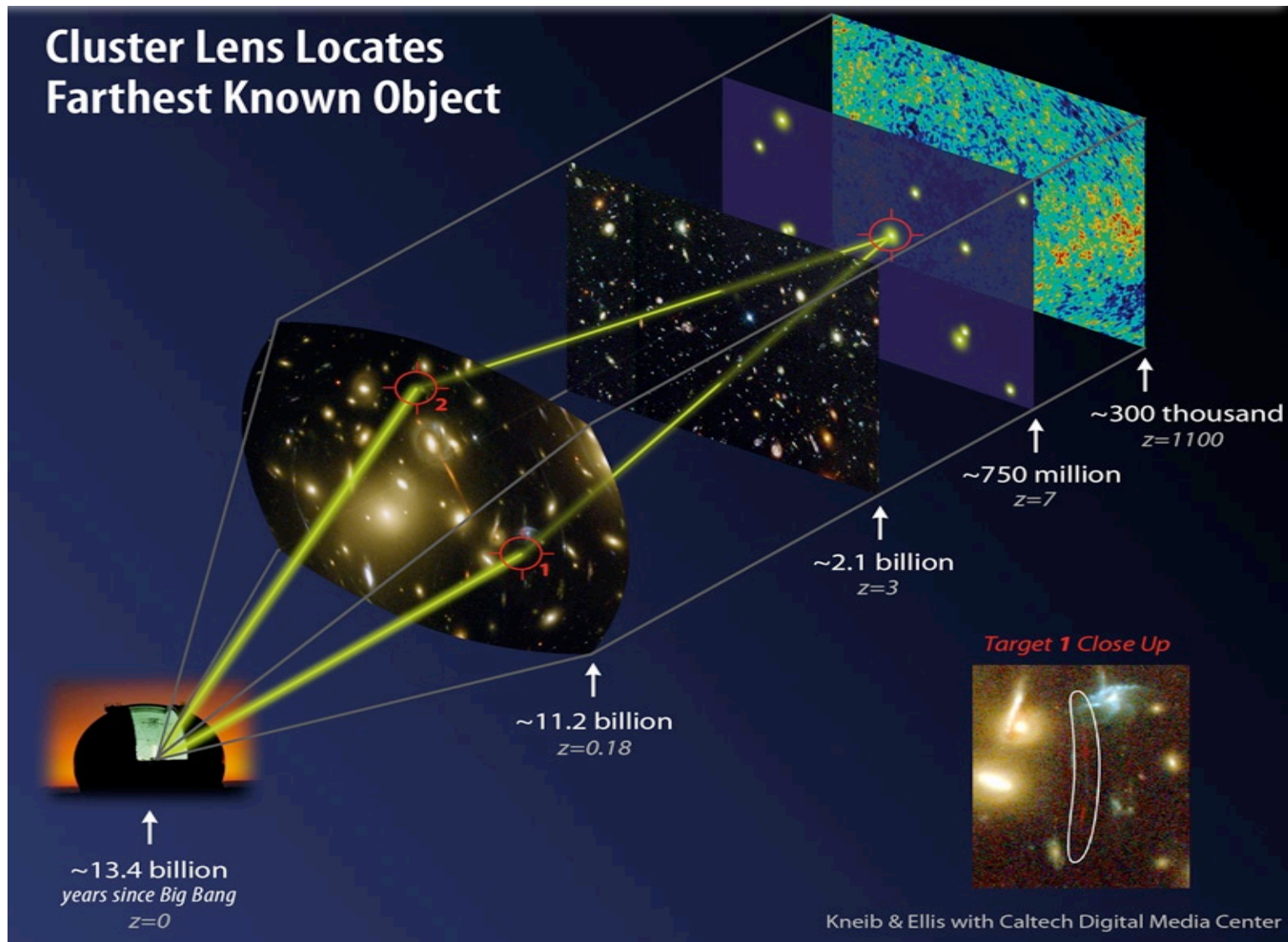
1st light:
Cosmic
Microwave
Background

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

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**



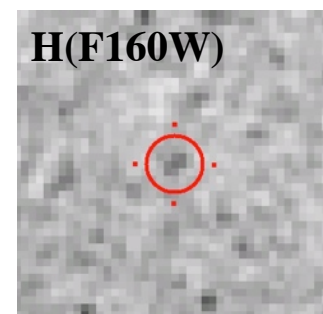
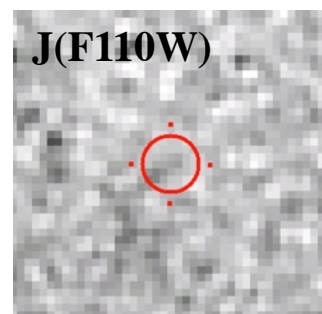
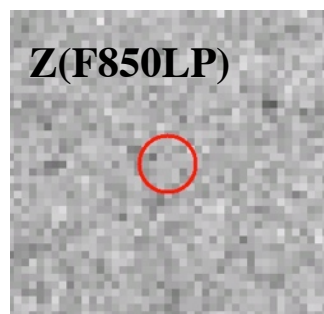
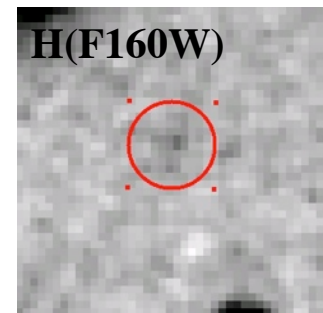
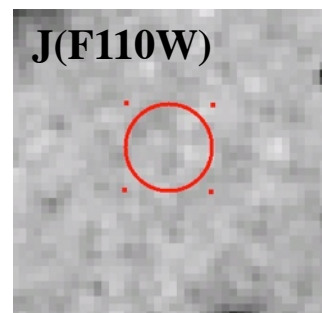
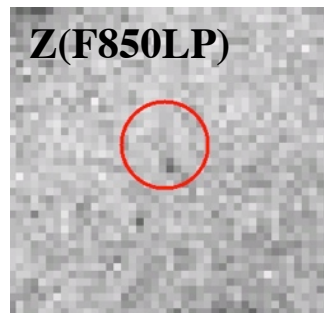


DAVE BARRY

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



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FATE U inflate (again)

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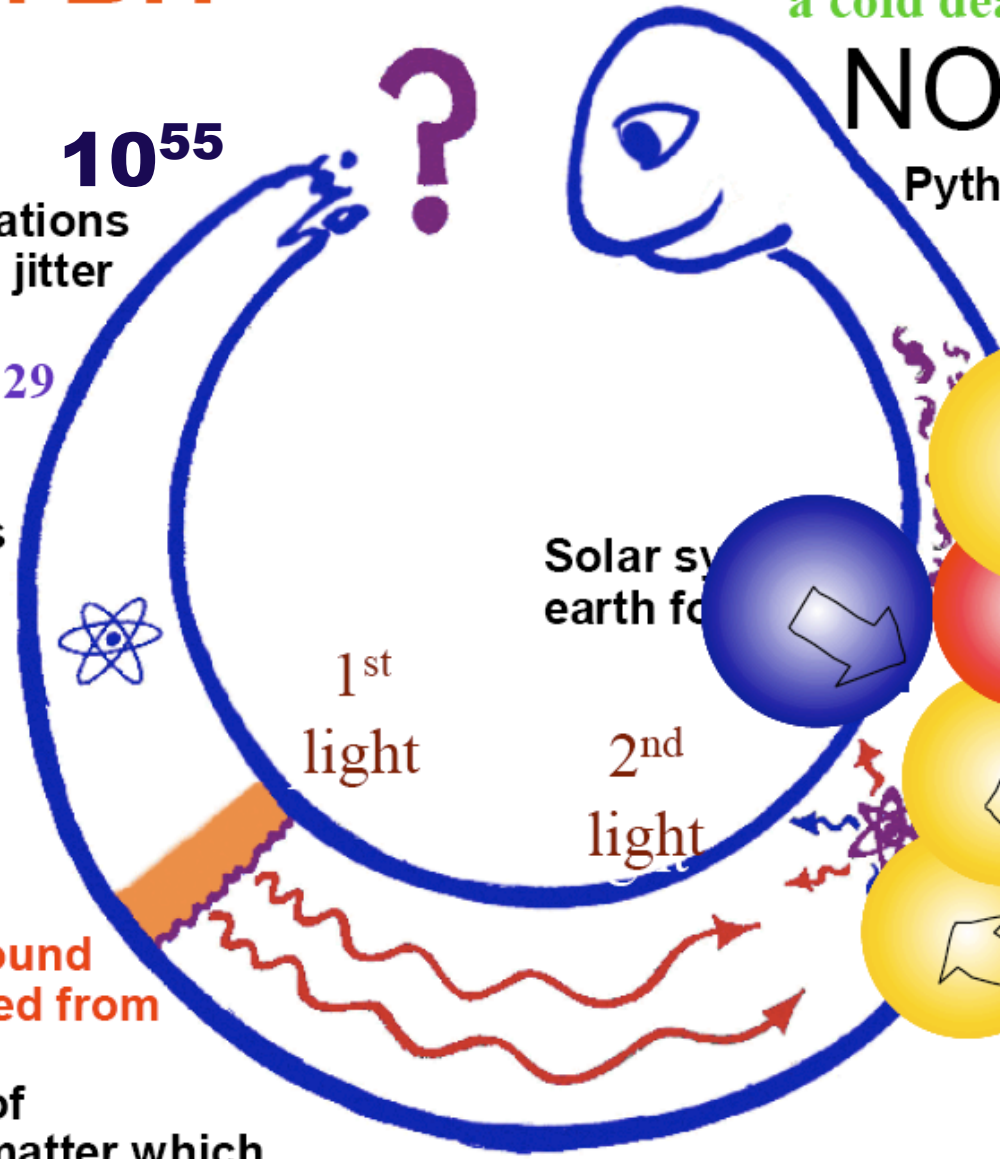
0.4 Myr 1100



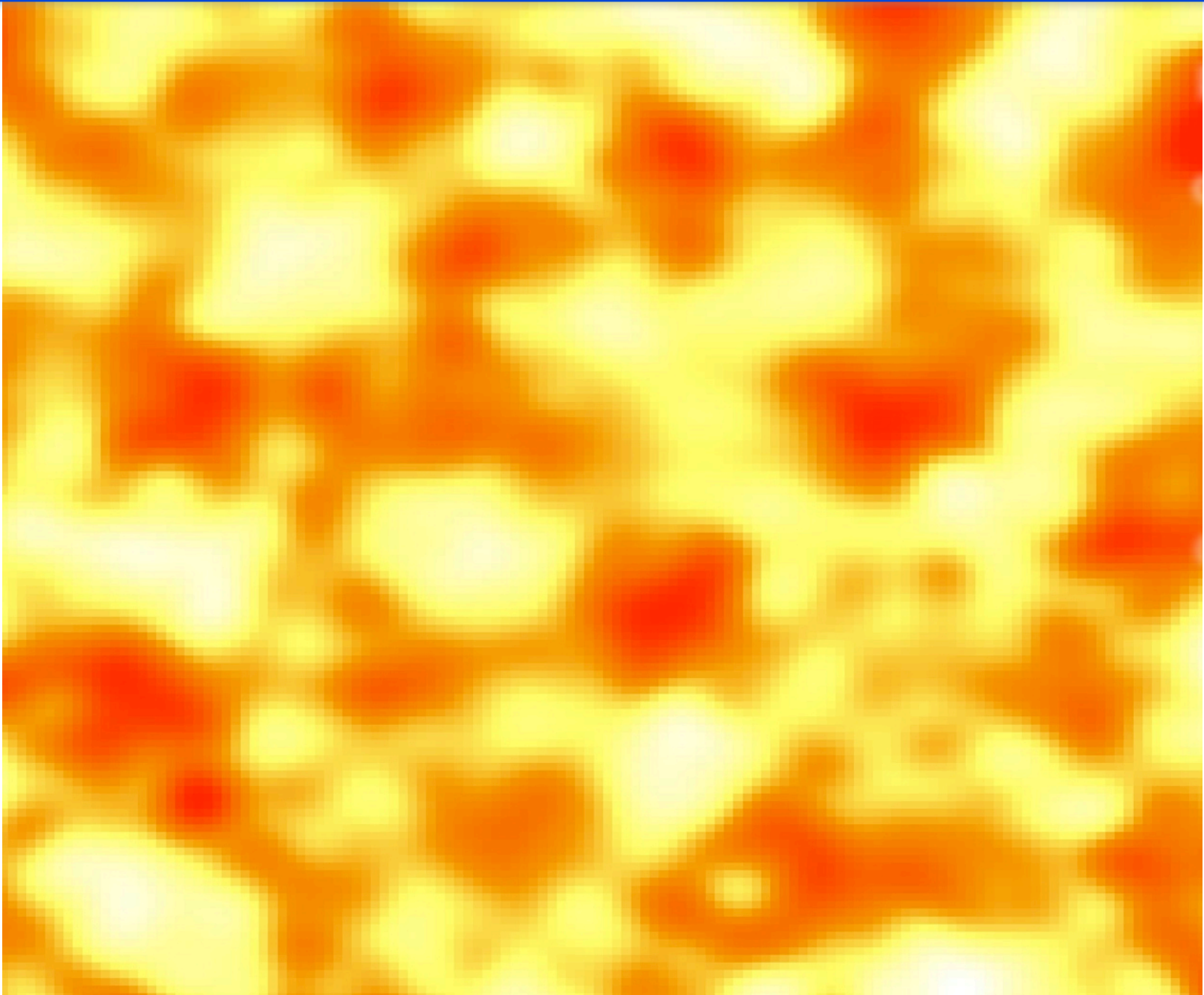
1st
light

2nd
light

Solar sy
earth fo



fluctuations in the **early universe** “**vacuum**” grow to *all* **structure**



patterns
in the
quantum
jitter
evolve
under
gravity

(& gas
dynamics)

A photograph of three men standing in a server room. The man on the left is wearing a brown blazer over a white t-shirt. The man in the middle is wearing glasses and a dark jacket over a plaid shirt. The man on the right is wearing a dark jacket. They are all smiling. In the background, there are rows of black server racks with "IBM" logos visible on them.

SciNet @UofT:

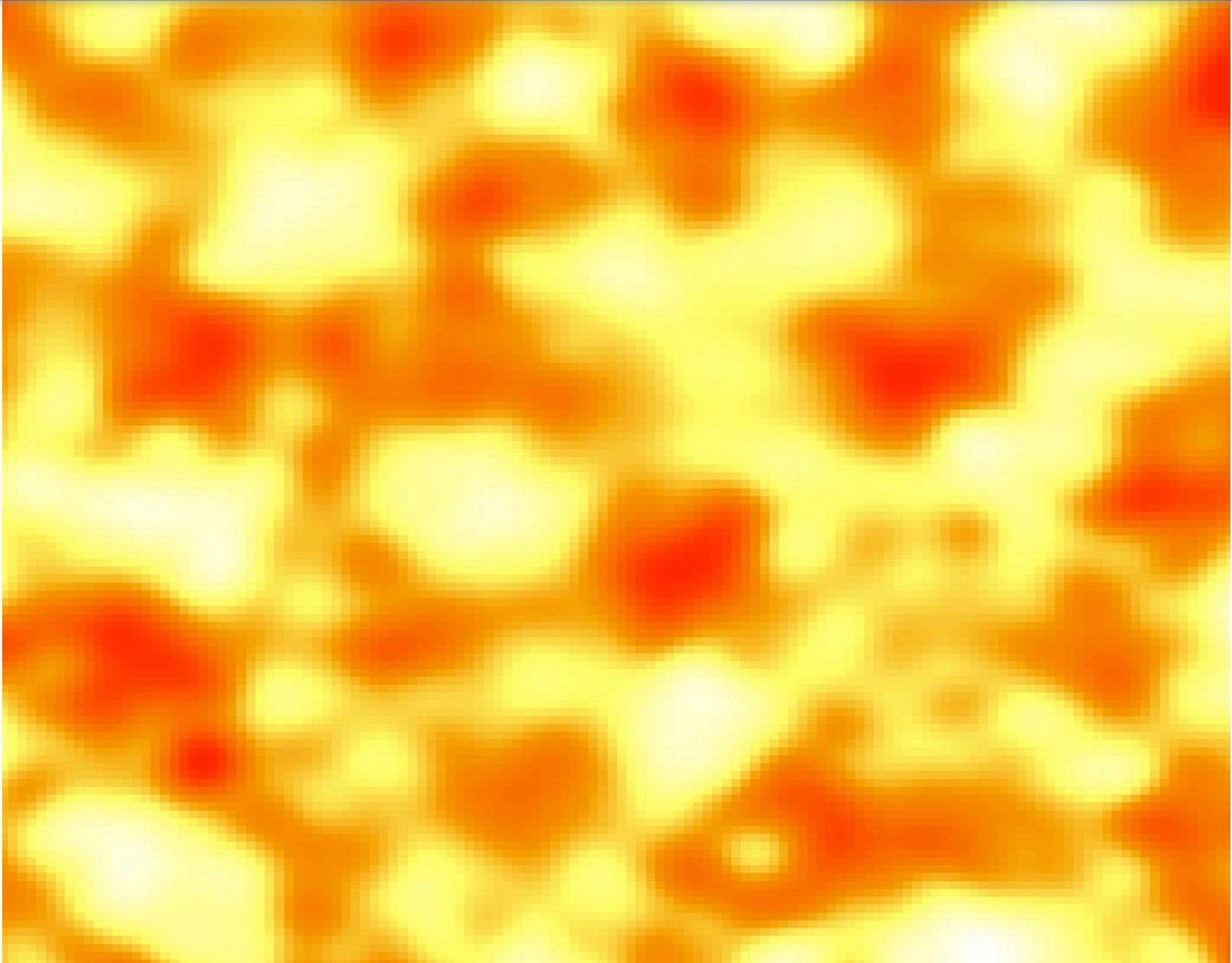
**GPC: 3780 nehalem nodes=30240 cores
306 TFlops debut as #16 in Top500**

**TCS: 104 P6 nodes=3328 cores
60 TFlops debut as #53 in Top500 ->80**

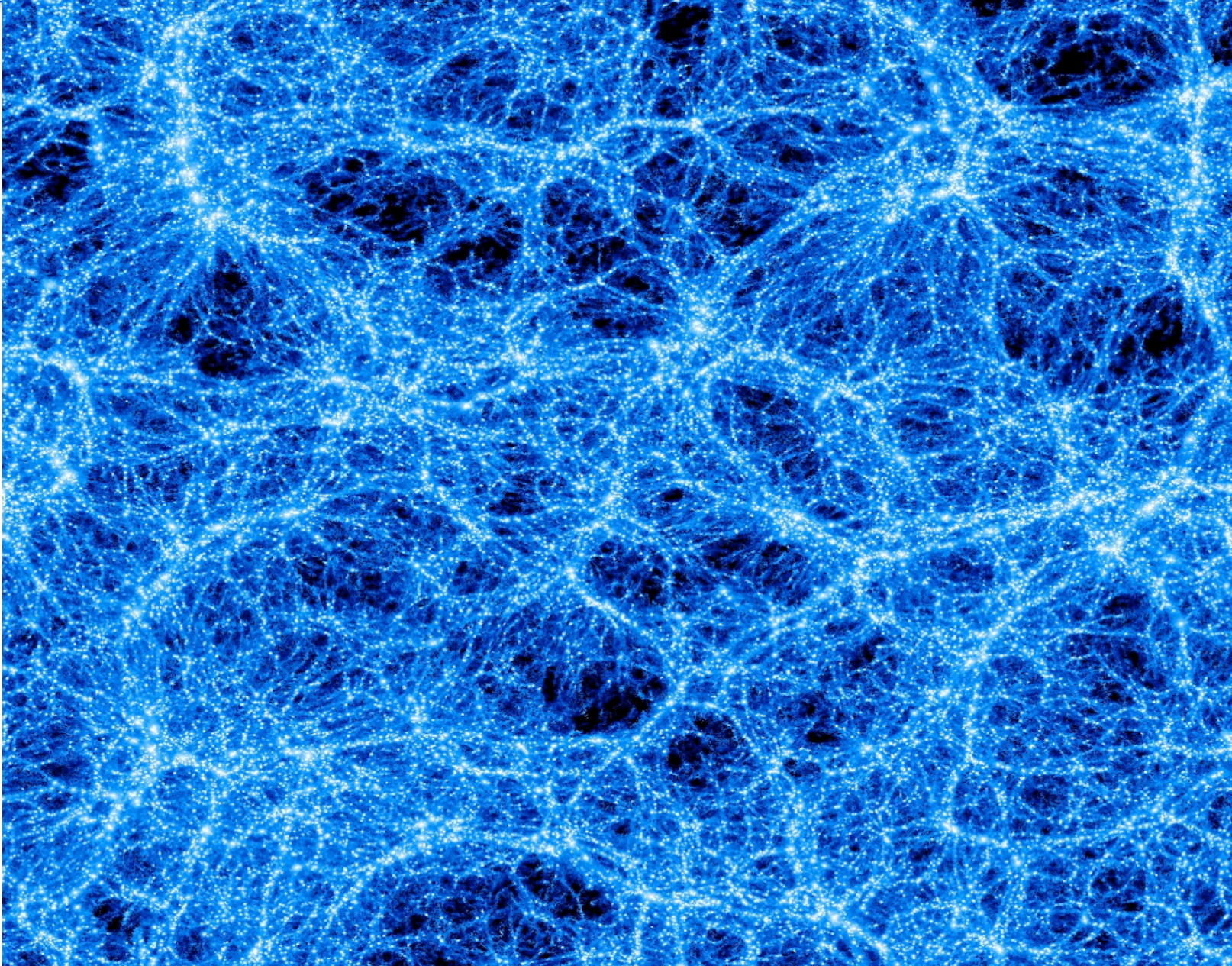
1.4 Pbytes storage

35

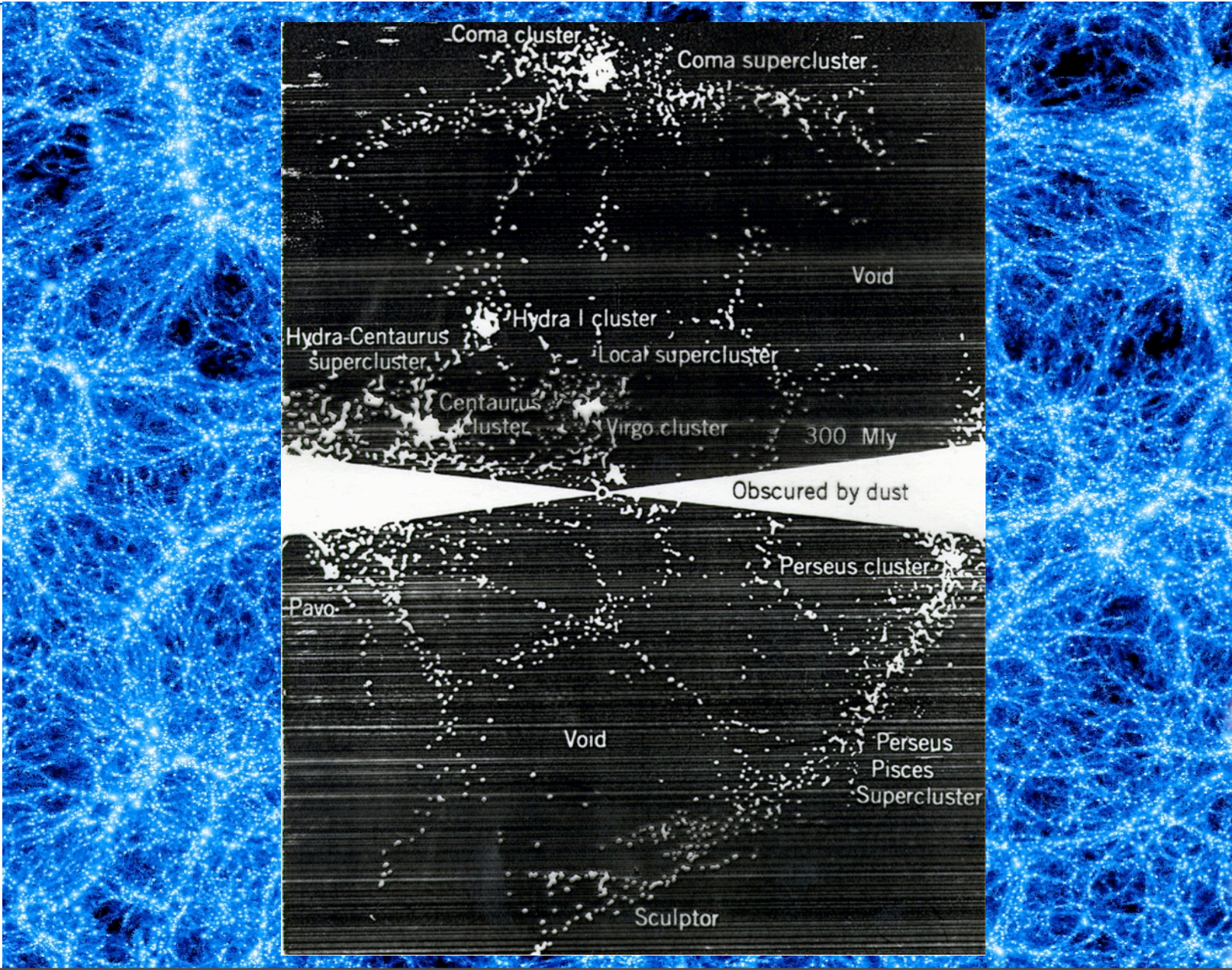
nonlinear Gas & Dark Matter Structure in the Cosmic Web the cluster/gp web “now”, the galaxy/dwarf system “then”



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”



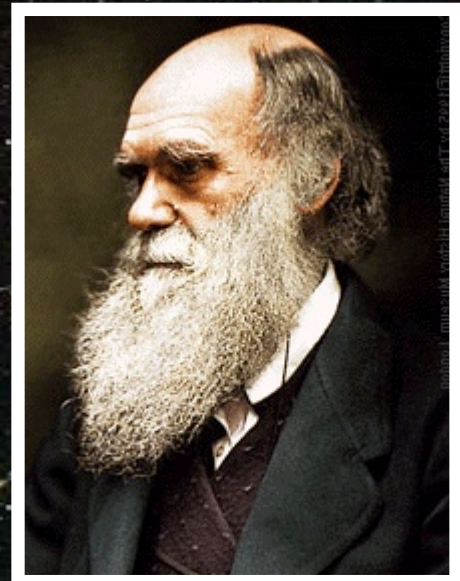
*all this
can
evolve
from
early U
vacuum
potential
and
vacuum
noise
in the
presence
of late U
vacuum
potential
aetherial!*

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)? $\Omega = \rho / 3M_P^2 H^2$

Ω_{dm} = dark matter (in labs?)

Ω_b = ordinary matter (known)

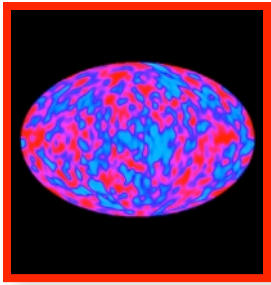
Gravitational waves – 1917

ripples in spacetime moving at the speed of

light **C** to be “observed”: from black holes

Ω_{BH} & neutron stars ~2012, from the

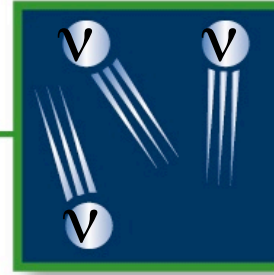
quantum early Universe ~2011? Ω_{GW}



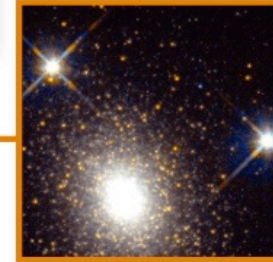
Radiation:
0.005%



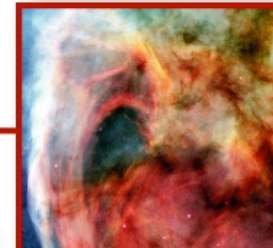
Chemical Elements:
(other than H & He) 0.025%



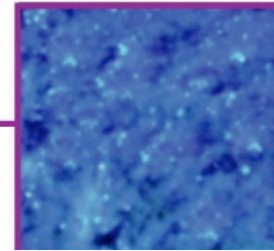
Neutrinos:
0.47%



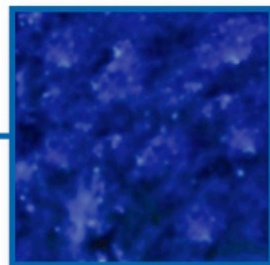
Stars:
0.5%



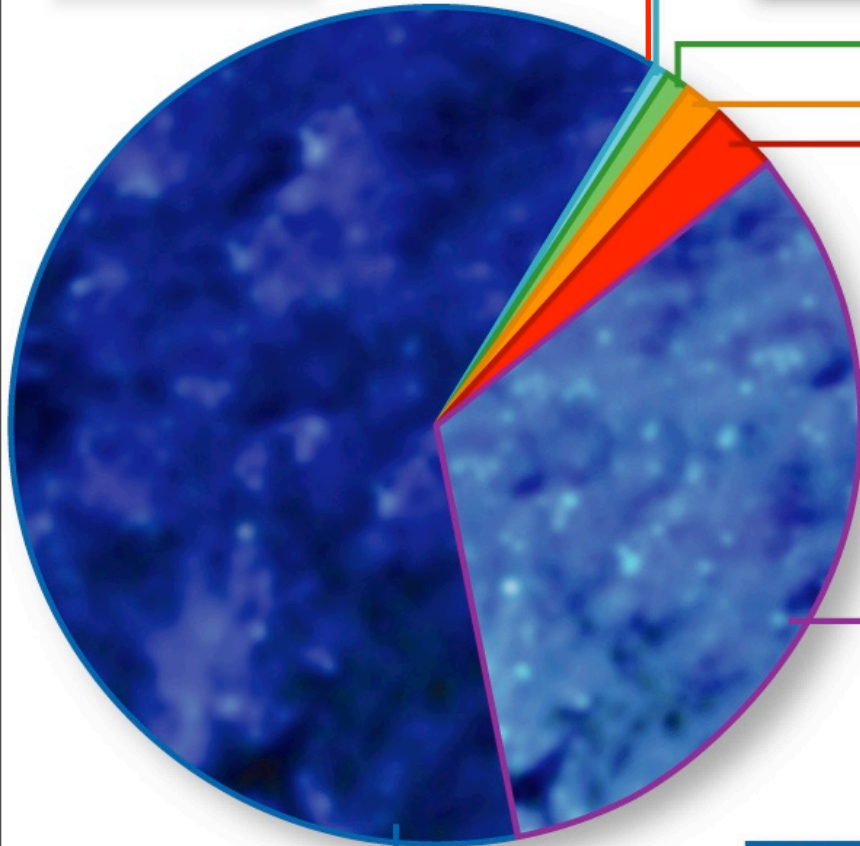
**Free
H & He:**
4.3%



Dark Matter:
 $\Omega_{\text{dm}} = 20.7 \pm 5\%$



Dark Energy:
 $\Omega_{\Lambda} = 75 \pm 3\%$



Gravity Waves
 $\Omega_{\text{GW}} \sim 10^{-14} - 10^{-10}$ LIGO
 $\Omega_{\text{BlackHoles}} \sim 10^{-7}$

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 CfAR future: to the
early & late Universe thru

Theory+Experiment (CMB+Lens+SN+clusters

+ LIGO,LISA,BBO for gravity waves +

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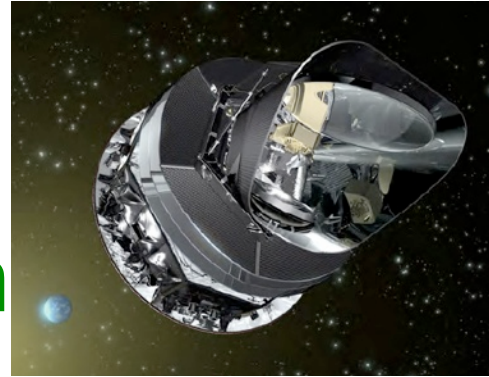
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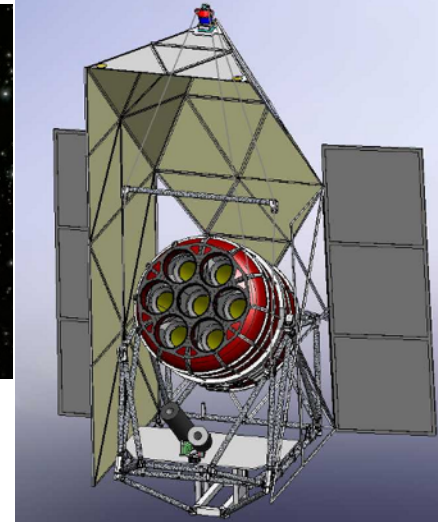
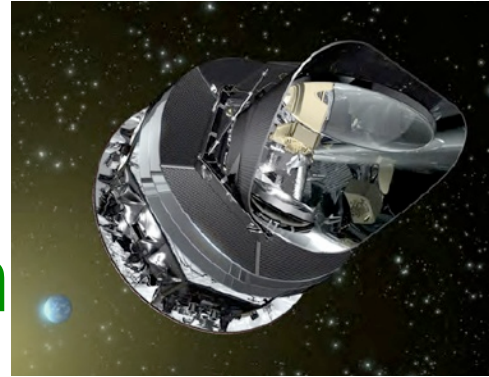
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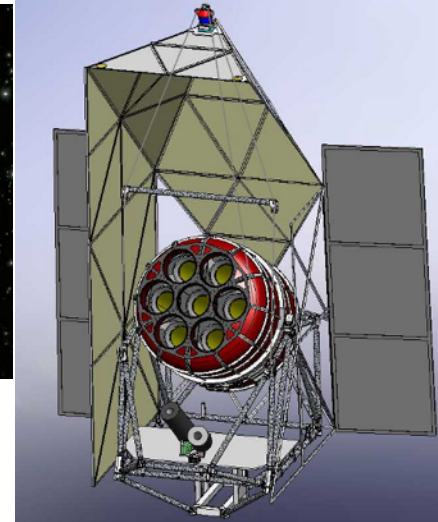
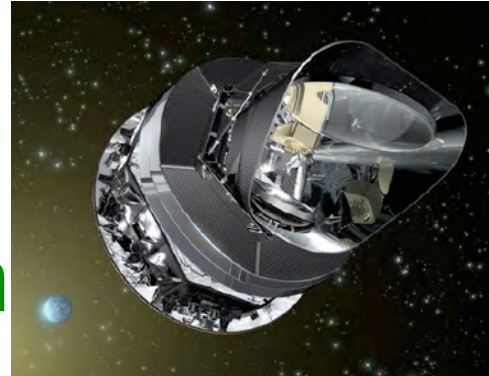


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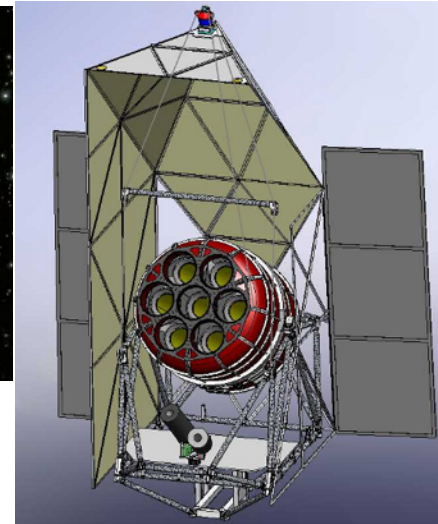
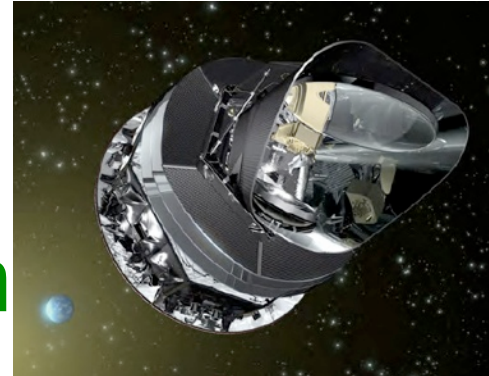
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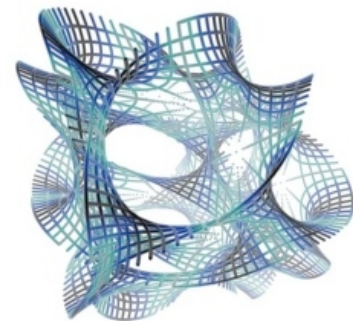
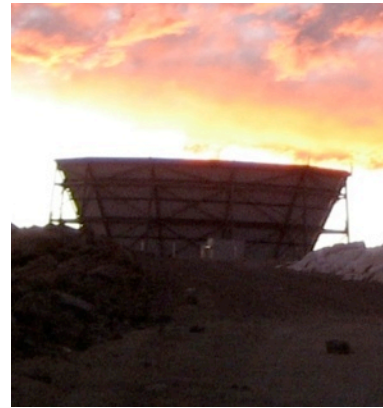
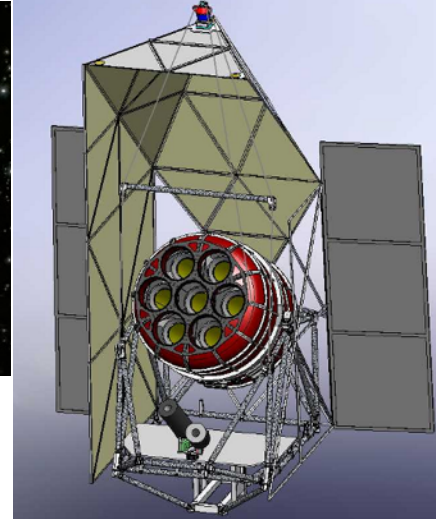
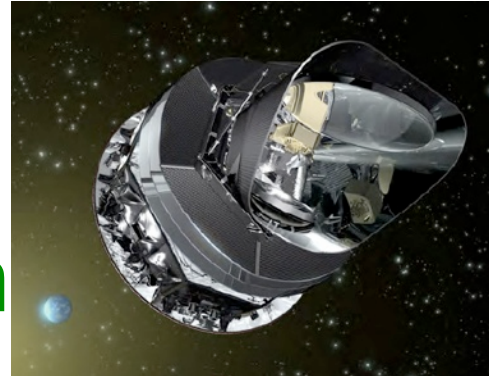
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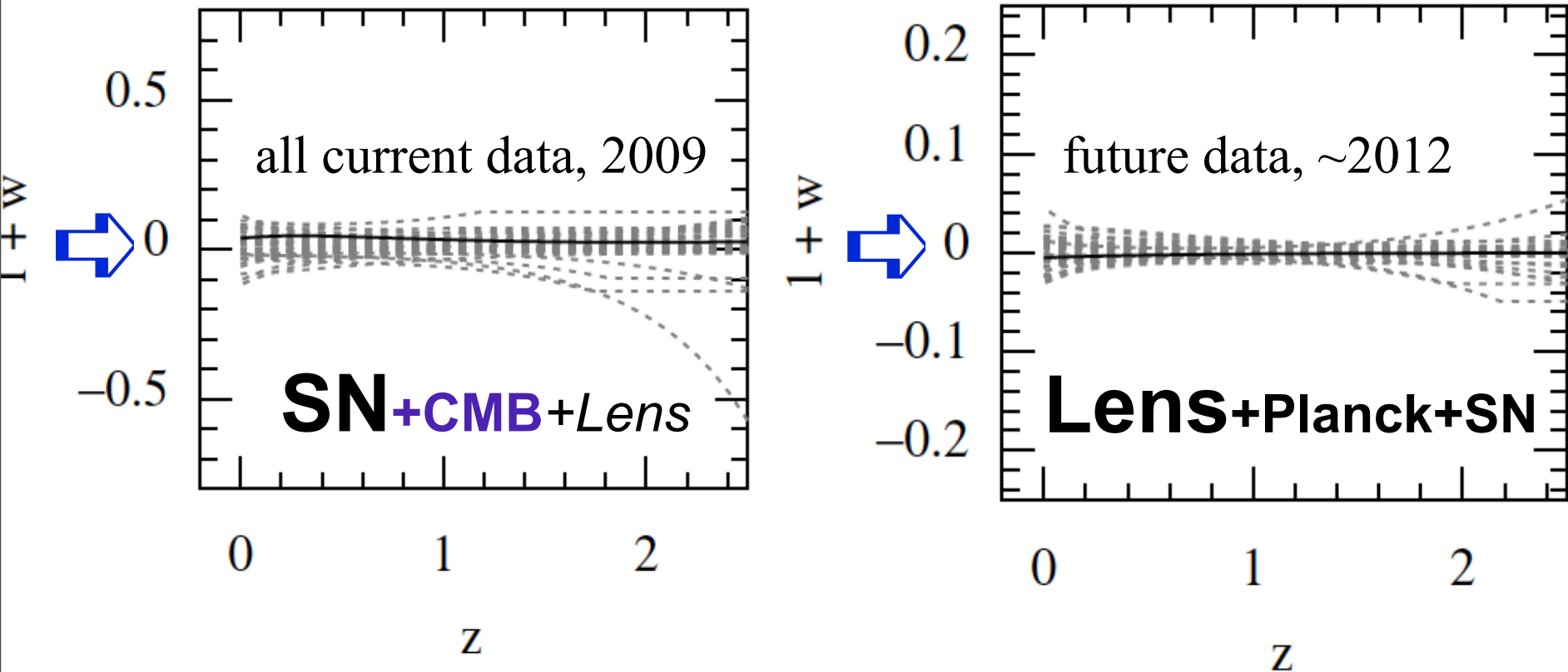
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ρ_{Λ} (time, space) ?

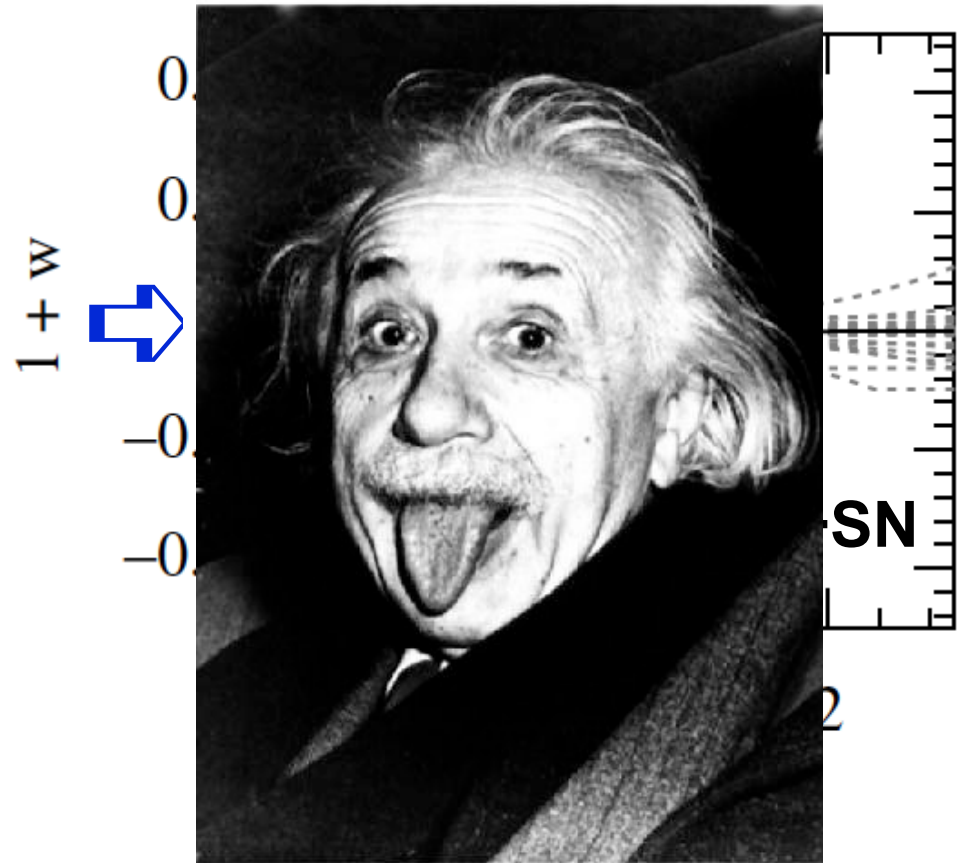
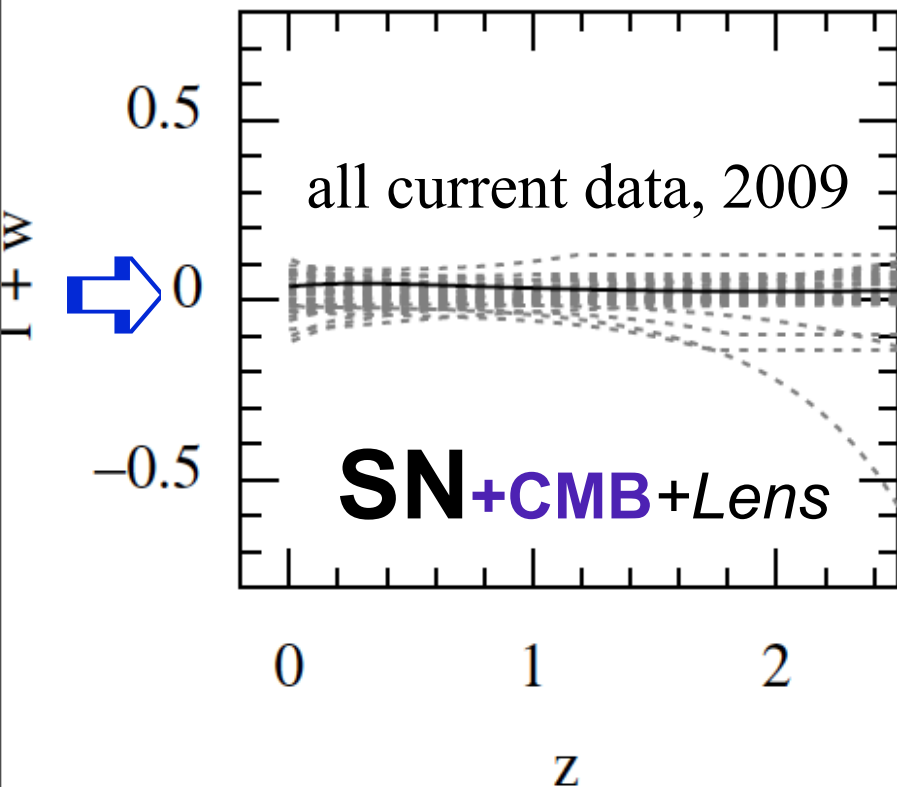
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TEST: within errors, energy-density does not change with expansion \Rightarrow Einstein's cosmological constant is best fit so far

ρ_{Λ} (time, space) ?

is the **dark energy** “vacuum potential energy” ?



TEST: within errors, energy-density does not change with expansion \Rightarrow 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** $\sim \text{amu m}^{-3} \sim$

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

- **dark energy** $\sim 4 \text{ keV cm}^{-3} \sim$
(milli-eV)⁴

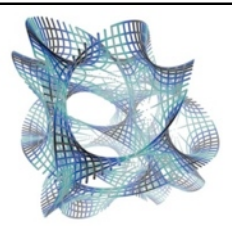
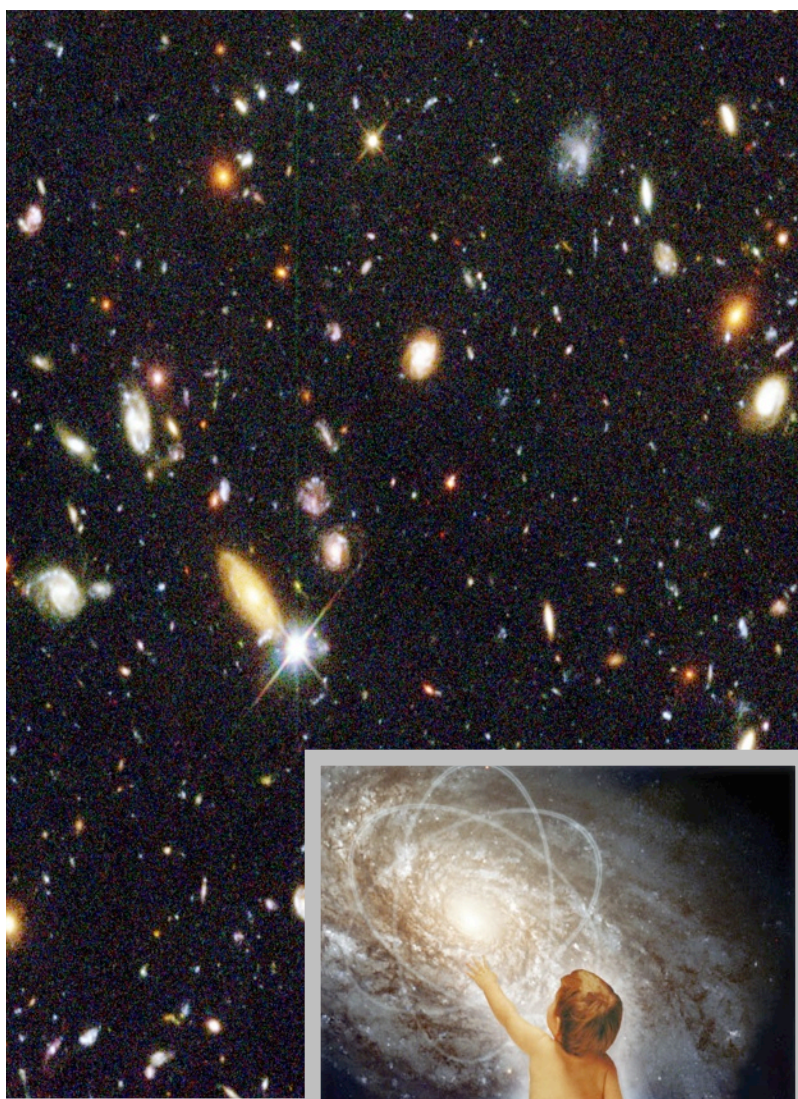
- neutrinos \sim CMB photons

- gravity waves

- virtual particles - vacuum fluctuations

- Higgs potential - origin of mass

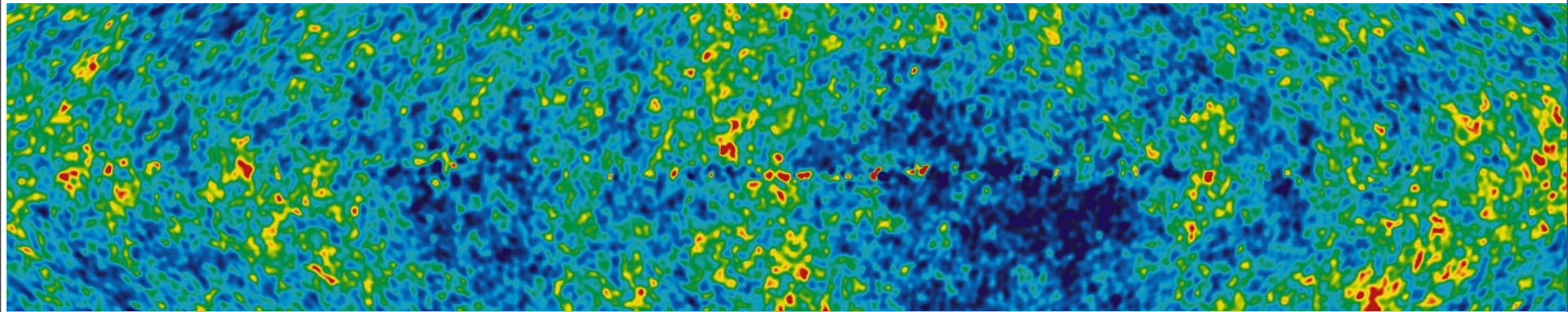
- **extra dimensions here, now?**



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



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

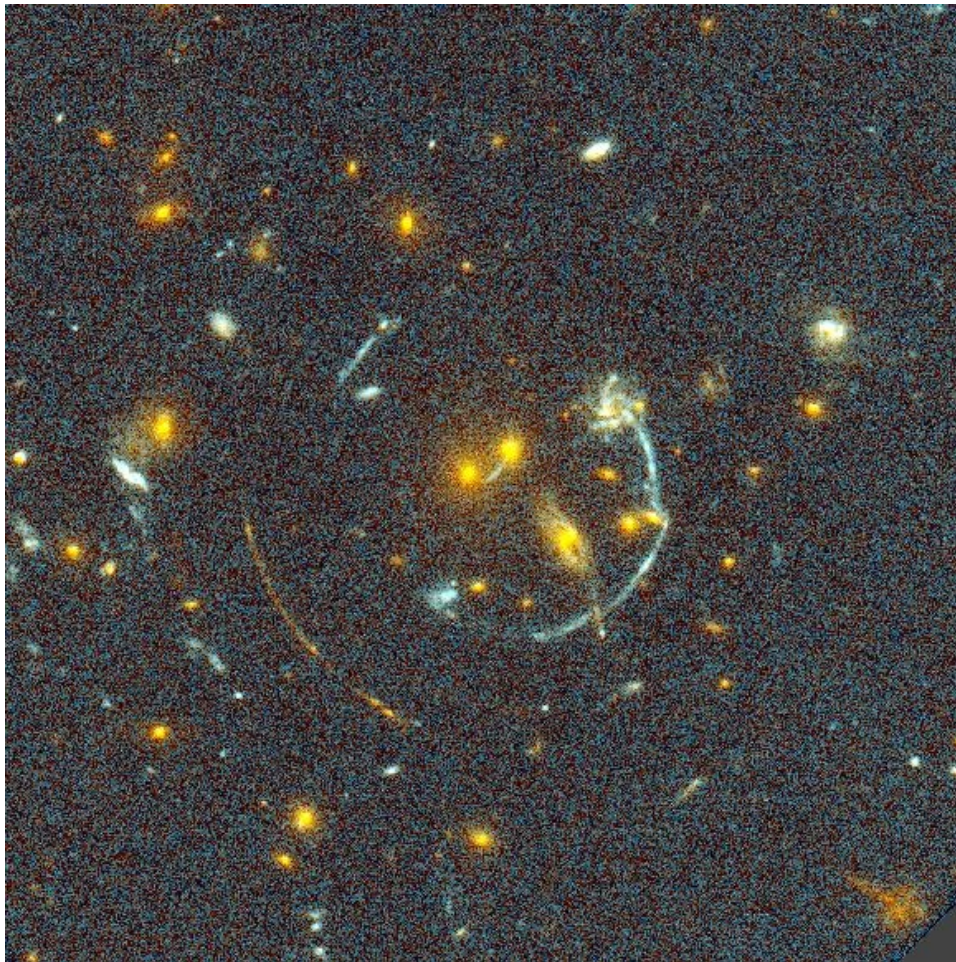
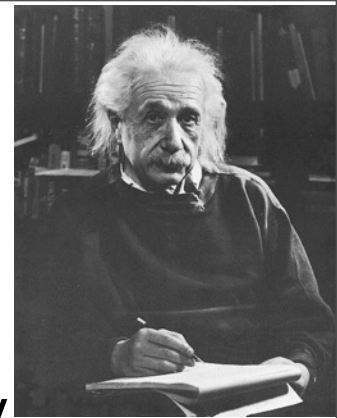


**it is primarily for
this knowing & its
inspiration to young
minds that the world
is spending tens of
billions of dollars on
the cosmic quest for
fundamental physics**

**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

 **Hoekstra, Gladders, Yee**

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



**Hoekstra, van
Waerbeke**





CFHT

SN

Survey

Carlberg,
Pritchard,

et al.



3yr now
300 SN1a

5yr

500

Science

18 December 1998

Vol. 282 No. 5397
Pages 2141-2336 57

THE ACCELERATING UNIVERSE

Breakthrough of the Year



AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE



CFHT

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Pritchett,

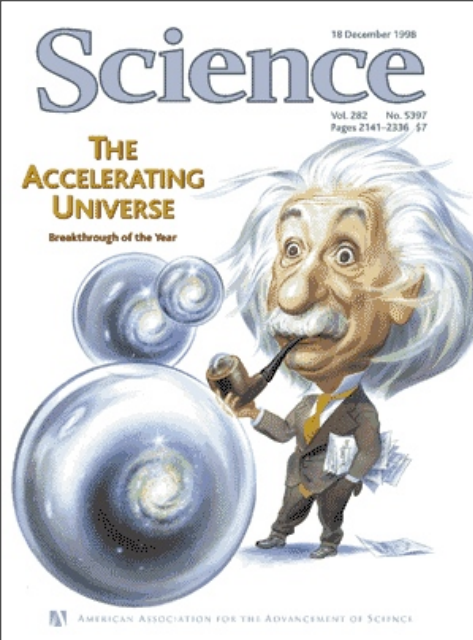
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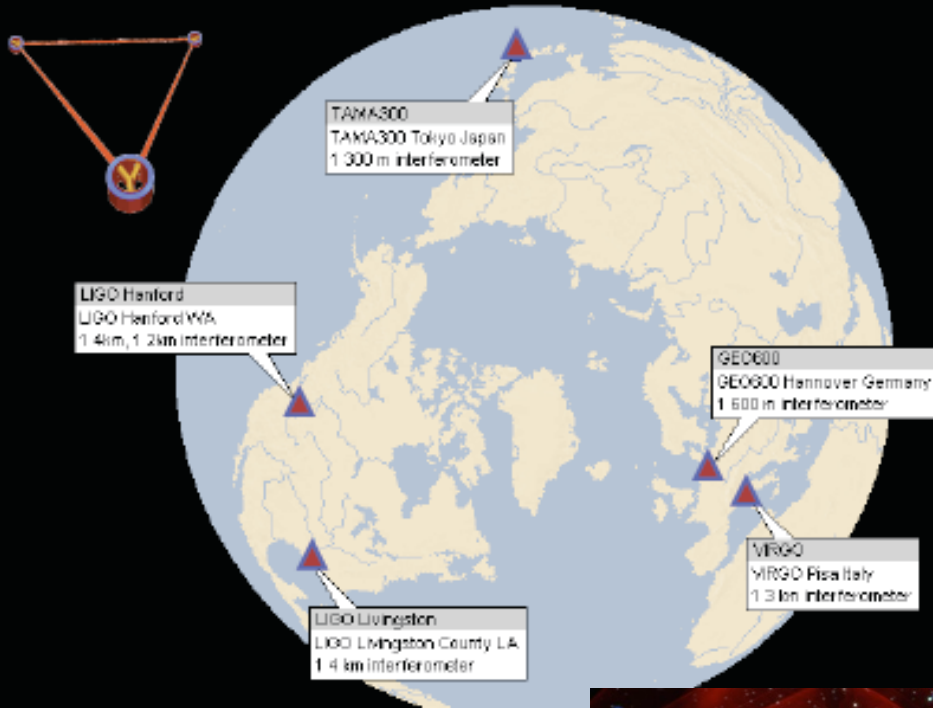
3yr now
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5yr

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Worldwide Interferometer Network



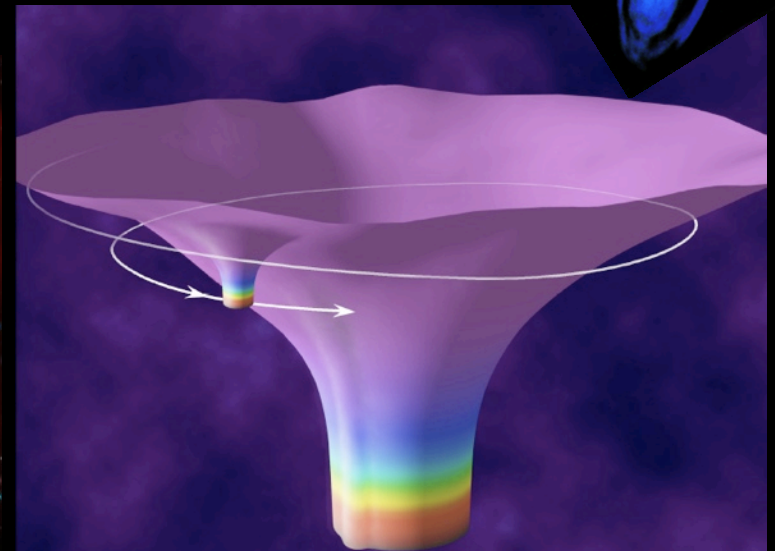
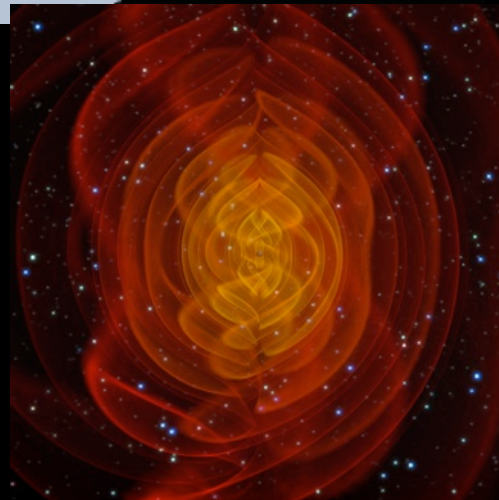
DANGER:
BLACK HOLES
MERGING



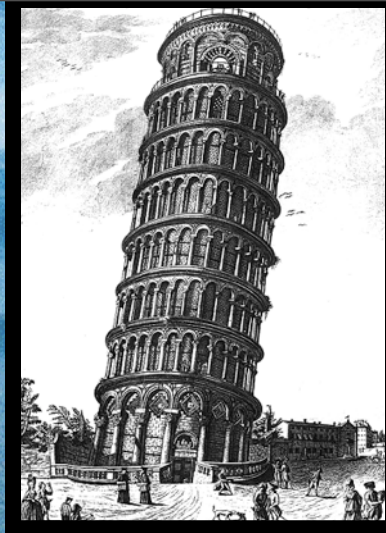
Now-2013+

~km scale

**detect .001 nuclear
radius**



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



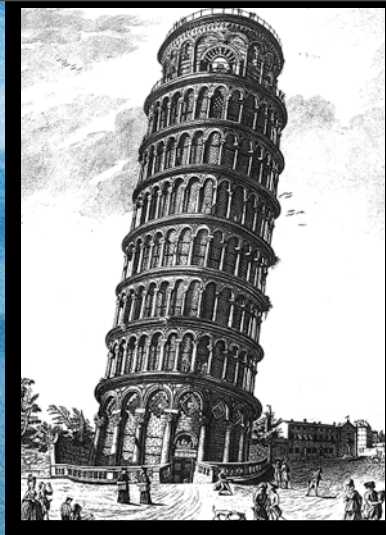
Cern's Accelerator

2008

Galileo's Accelerator



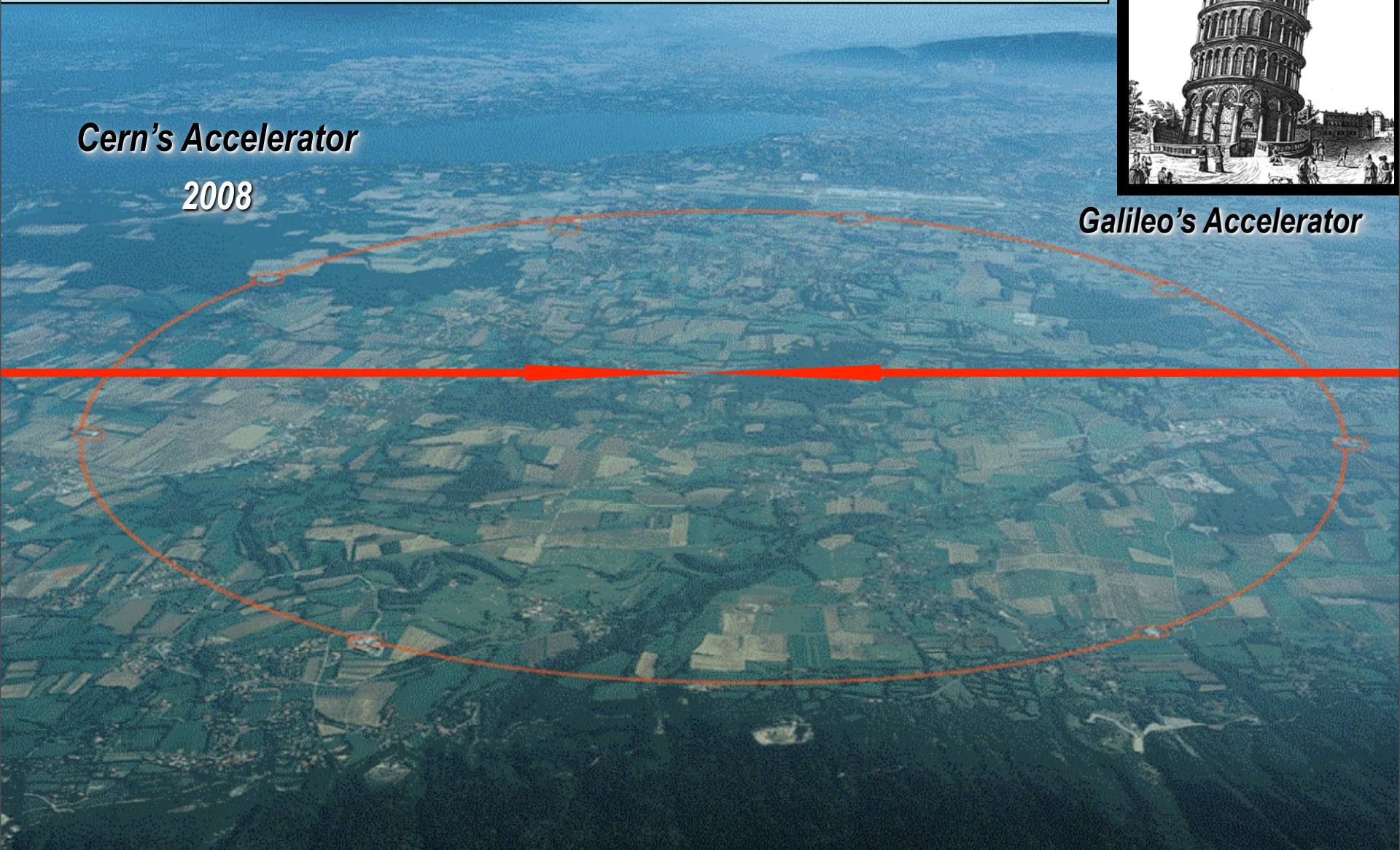
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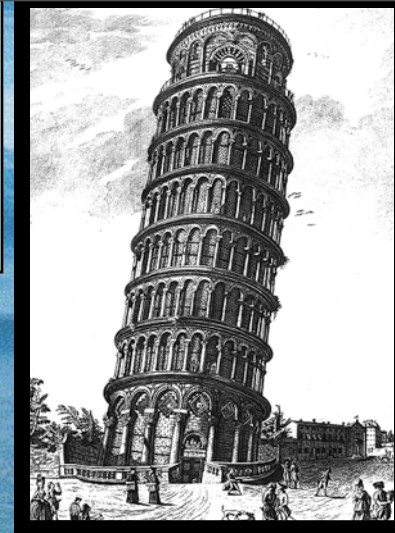
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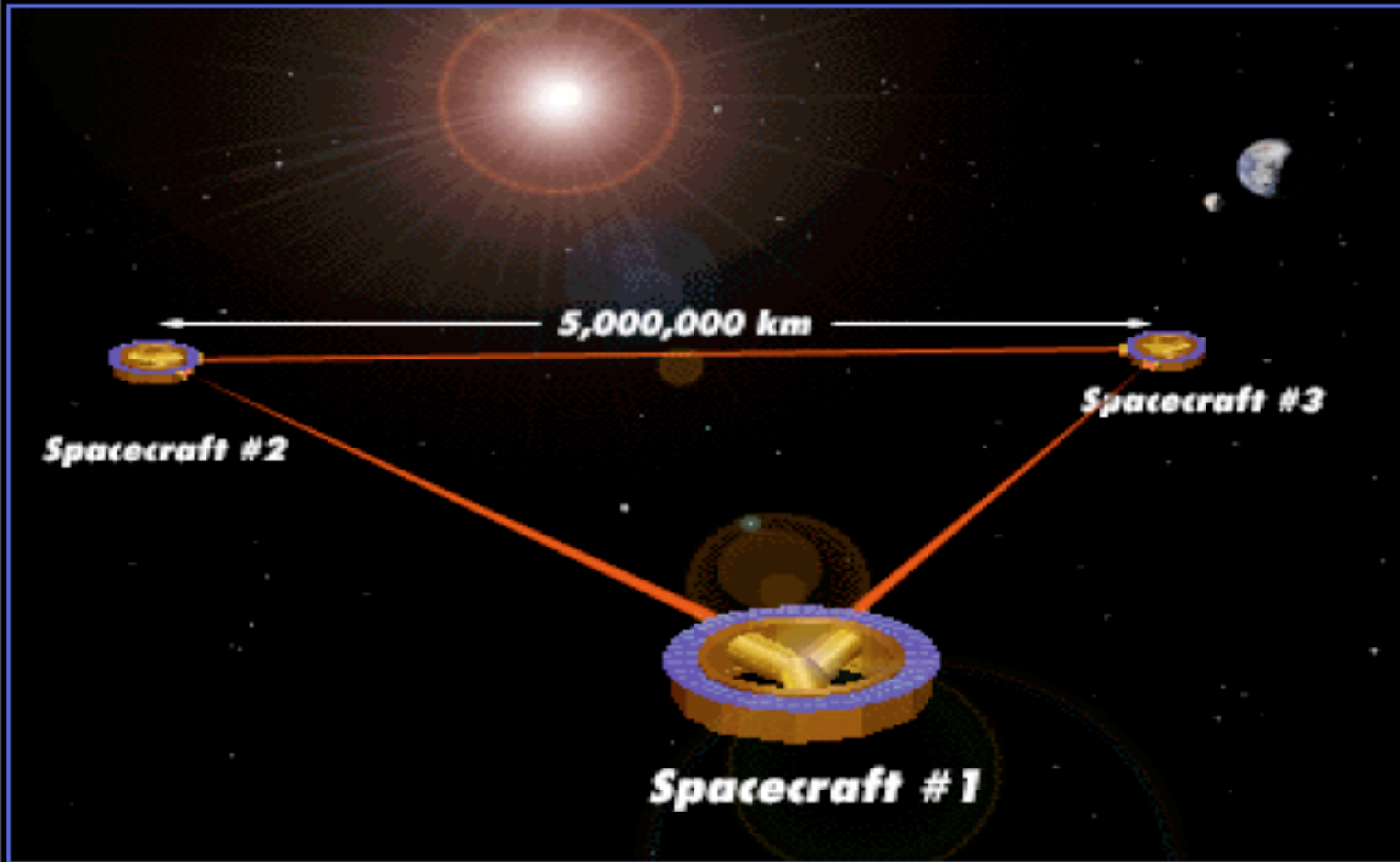
Cern's Accelerator

2008

Galileo's Accelerator

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

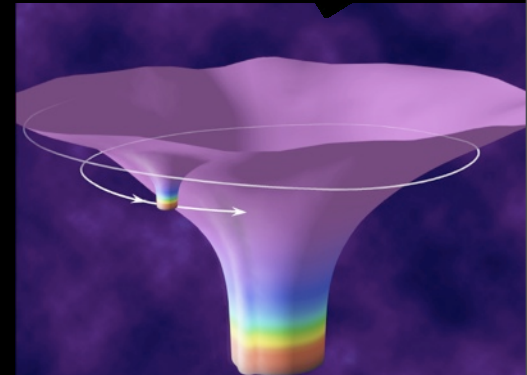
LISA



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

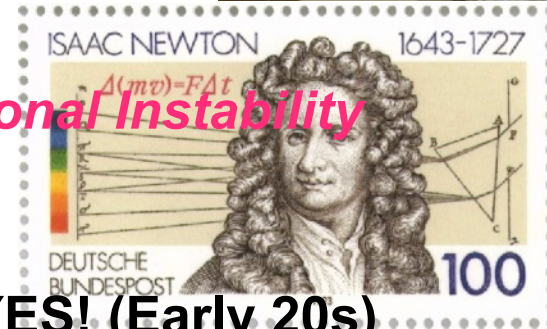
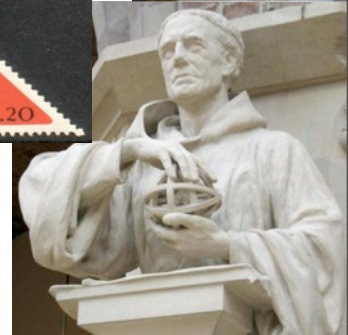
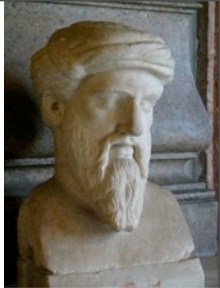
The PHYSICIST

- ✓ 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?*



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”



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

FRIEDMANN (1922) Evolving (Expanding) Universe

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

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Sakharov~67

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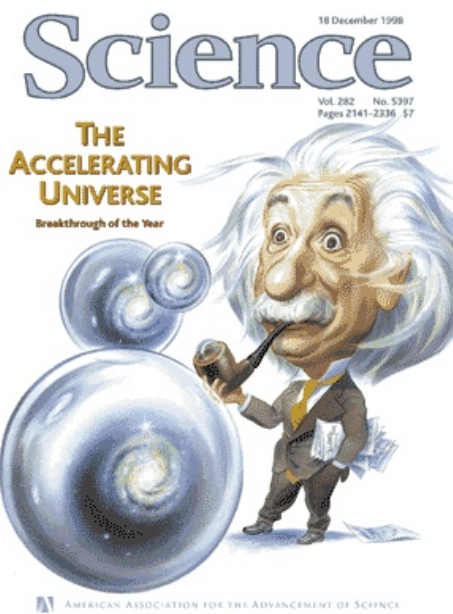
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