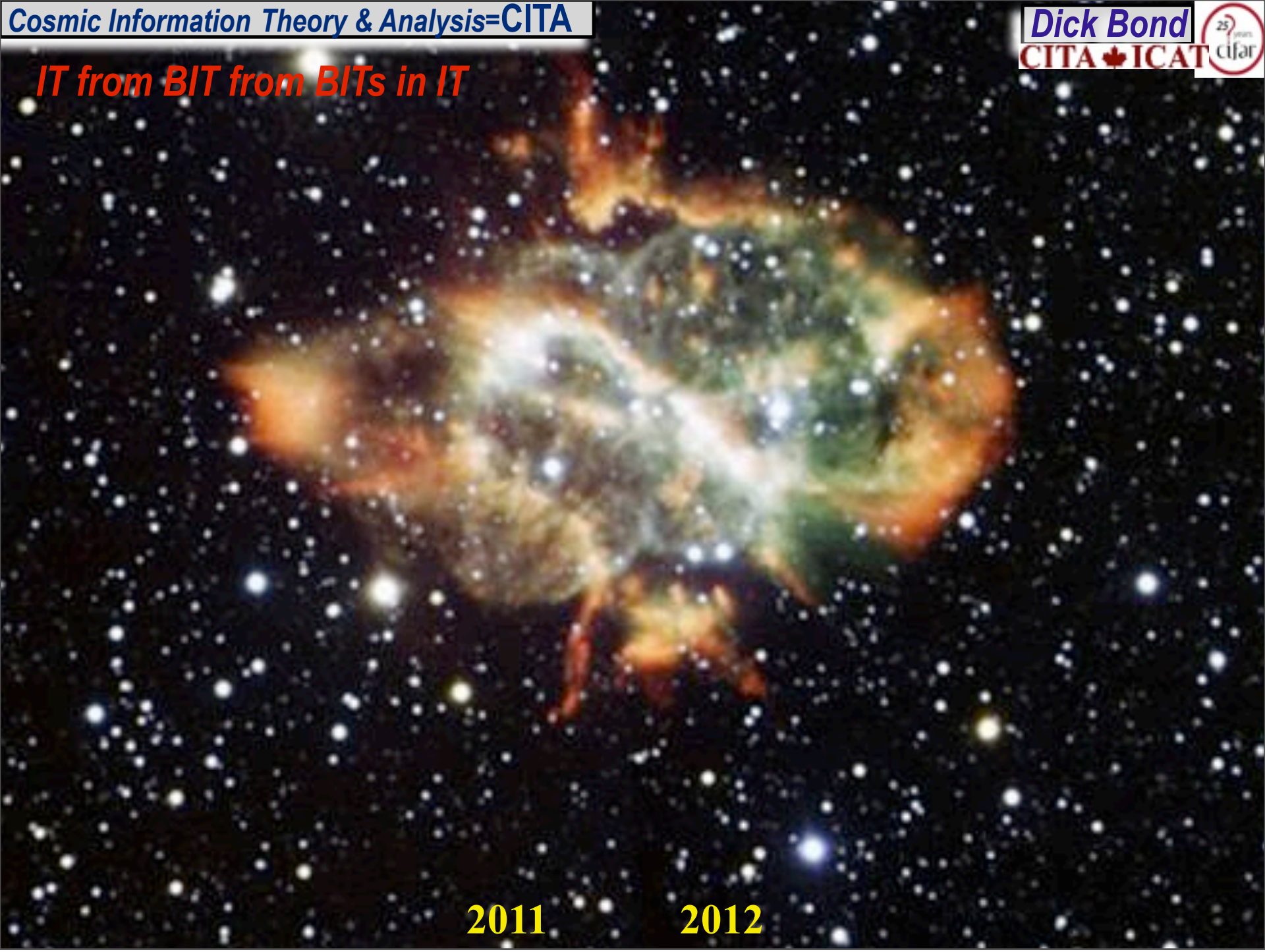
Cosmic Information Theory & Analysis=CITA

Dick Bond
CITA ICAT

IT from BIT from BITs in IT



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2011 2012

"IT from BIT" *from BITs in IT*

FATE U inflate (again a cold death? reheat/rebirth?

Dick Bond
CITA ICAT

Planck era 10^{-43} sec 10^{55+}

?

NOW 14 Gyr 1

$a(t,x)$

Pythagoras formed

Inflation fluctuations form: quantum jitter

Galaxies Cluster
Cosmic "web" of vast filaments + membranes

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

Protons/Neutrons form

Solar sy
earth fo

Life forms on earth

Helium forms

100 sec 10^{9}

1st light

2nd light

9 Gyr 1.4

Carbon/oxygen/etc form

Galaxies form

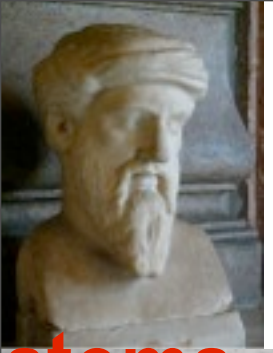
2 Gyr 4

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

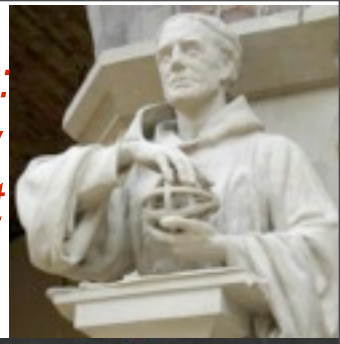
0.4 Myr 1100

what ***message*** *in the information* ***medium****?*

The 'Meaning' may change
But the facts will remain



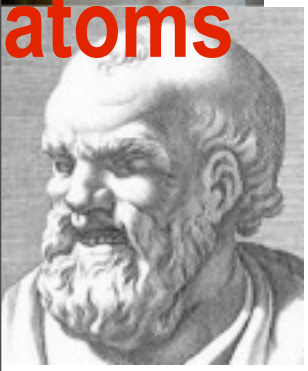
PYTHAGORAS 550 BCE ***THEORIST*** **Cosmos⊇ mathematics,**
digital "all is number", harmonic frequency/wavelength



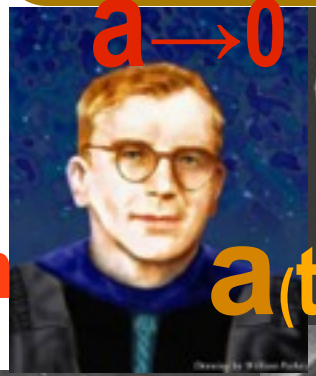
bacon: theory & expt

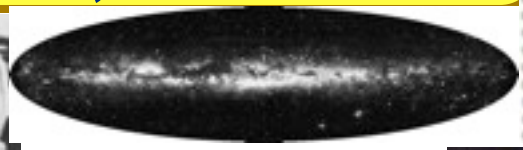
a very brief human history
of how
Cosmic Information
was generated by Us:
highly filtered, compressed,reduced

atoms



$a \to 0$



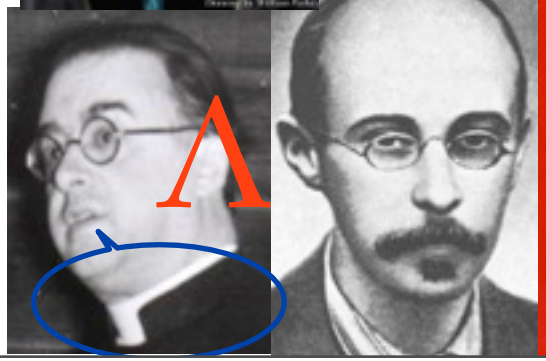


Milky Way 1953-55

PE vacuum

$a_{(t,x)}$ H

Λ

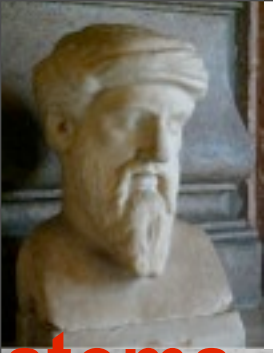


Λ

Λ

nuclei

atoms



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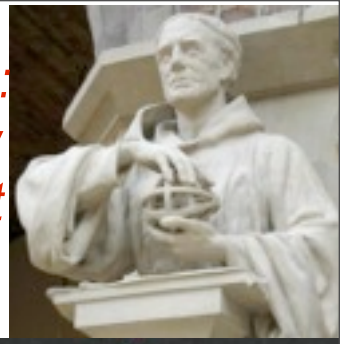

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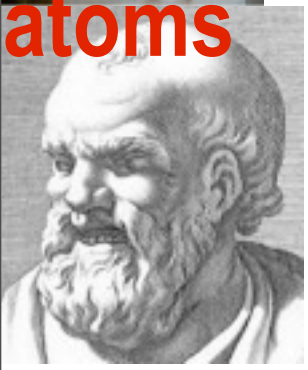

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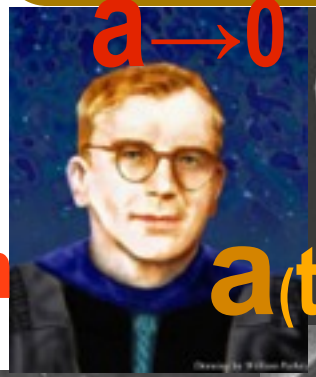

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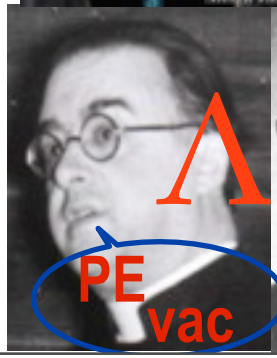

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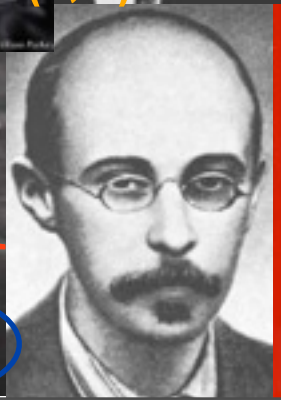
PE_{vac}



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nuclei

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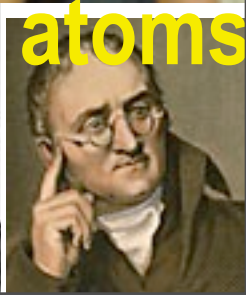

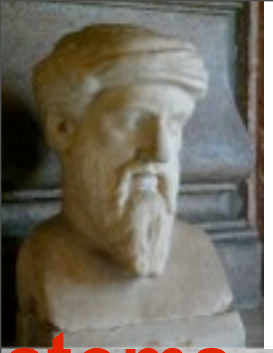

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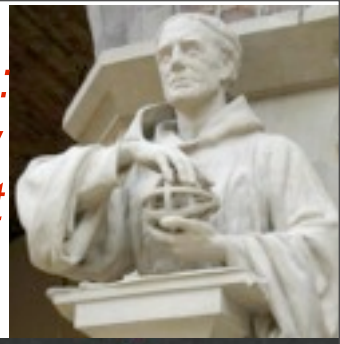

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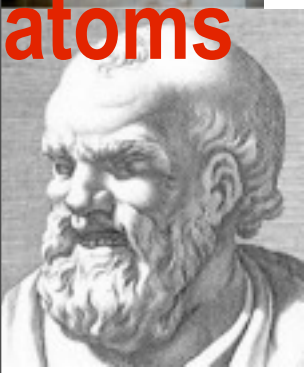

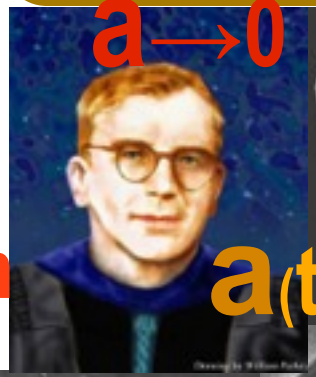

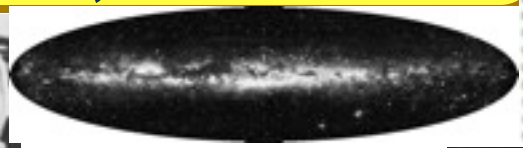

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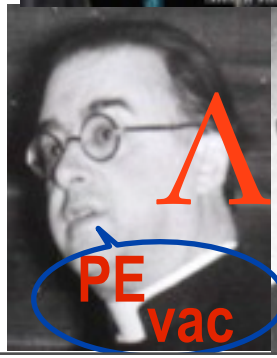
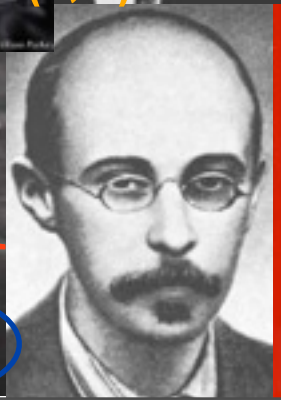
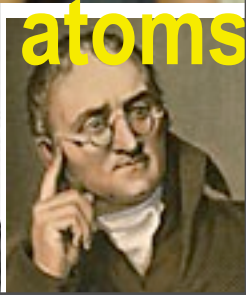
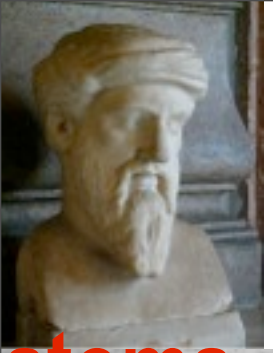




nuclei

atoms





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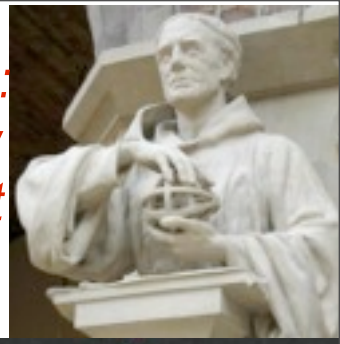

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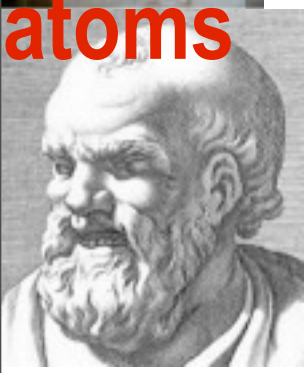


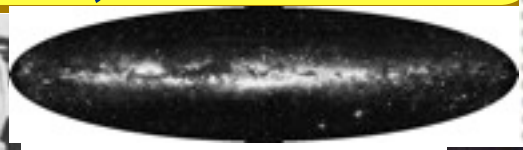
PE vacuum

a→0

ε(t)

a(t,x)

H



Milky Way 1953-55

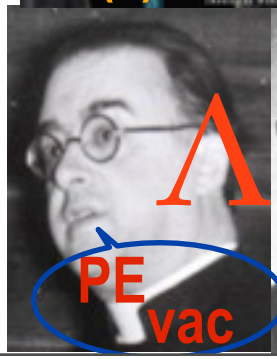
ISAAC NEWTON 1643-1727

$\Delta(mv)=F\Delta t$

G

DEUTSCHE BUNDESPOST 100

Λ



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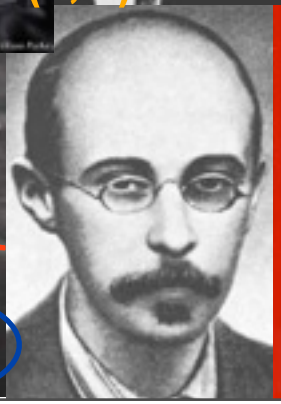
PE vac



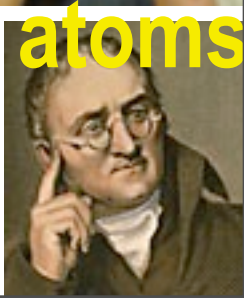
PERSON OF THE CENTURY TIME

ALBERT EINSTEIN

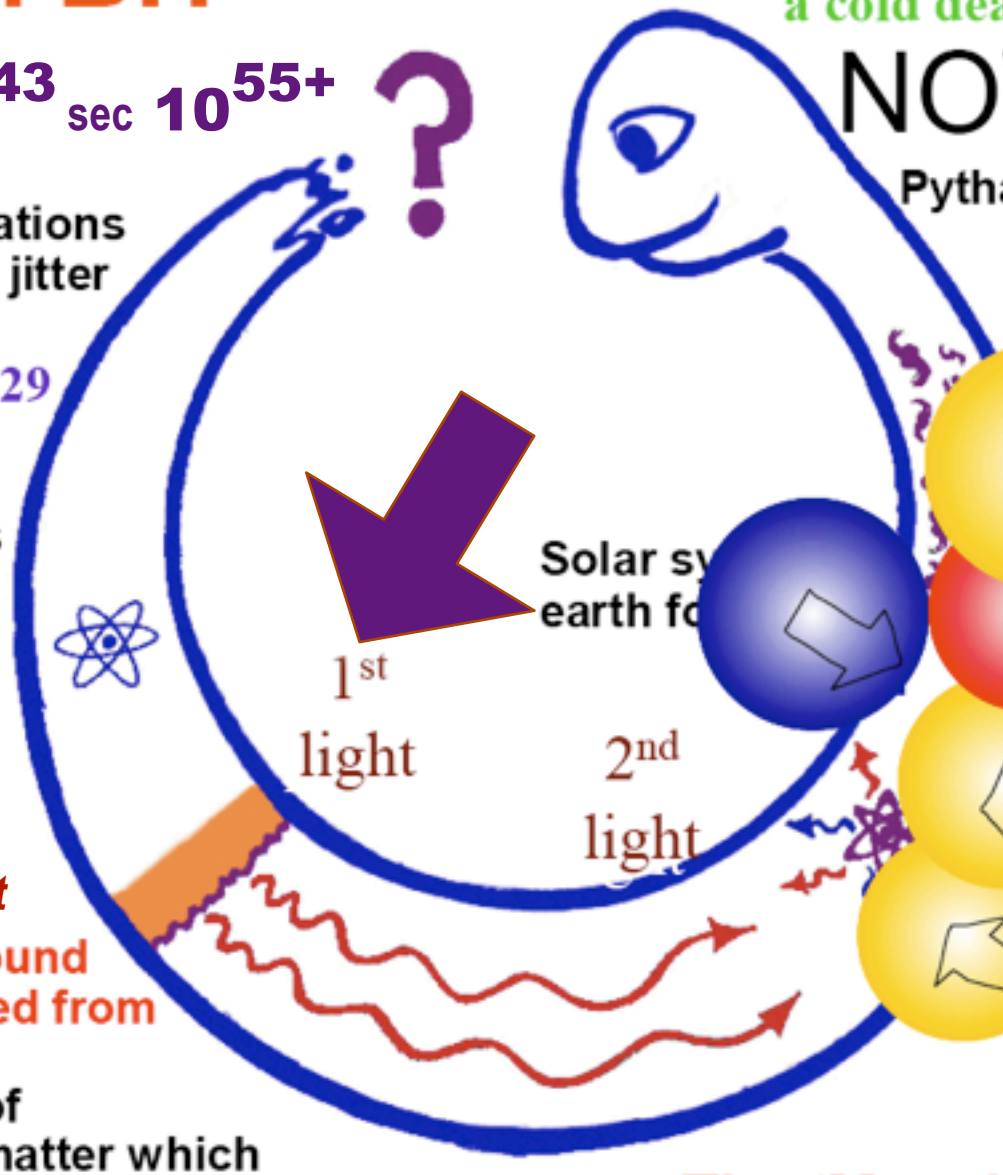
Λ

nuclei

atoms



"IT from BIT"



FATE U inflate (again)

a cold death? reheat/rebirth?

NOW 14 Gyr 1

Pythagoras formed $a(t,x)$

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

Planck era 10^{-43} sec 10^{55+}

Inflation fluctuations form: quantum jitter

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

Protons/Neutrons form

Helium forms

100 sec 10^{9}

Let there be Light

Cosmic background radiation released from matter

carries imprint of fluctuations in matter which grow to generate galaxies etc.

0.4 Myr 1100

Solar sy
earth fo

1st light

2nd light

The 'Meaning' may change
But the facts will remain

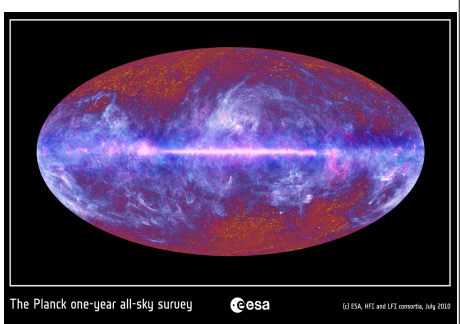
the gatherers of cosmic information

**Cosmic Microwave Background **+

Large Scale Structure experimental probes

then & now & then

Process Data *compressing the Petabit+ raw observed CMB+LSS information into high quality bits of information characterizing the standard model of cosmology* (***tilted*** ΛCDM). so far 7 parameters fit all data- we can simulate well the observed Universe! hopefully 7+x will be needed as experimental precision increases (PlanckEXT): *the more high Q information the better*



the gatherers of cosmic information

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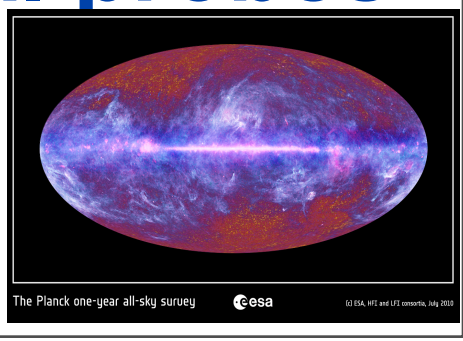

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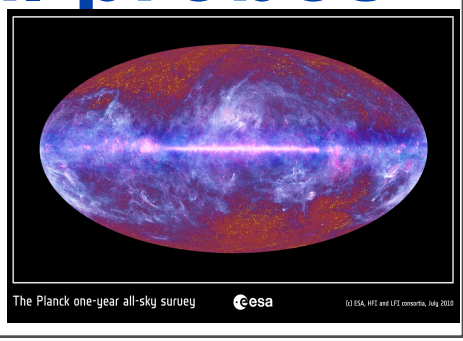
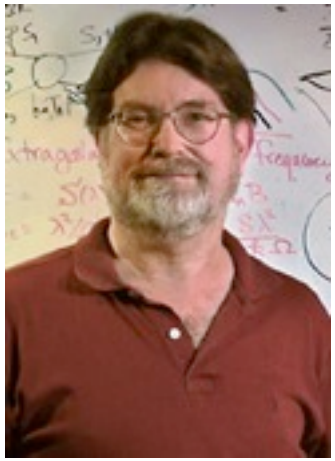


The Nobel Prize in Physics 2006
(also Gruber Prize in Cosmology 2006 for Mather + the COBE team)

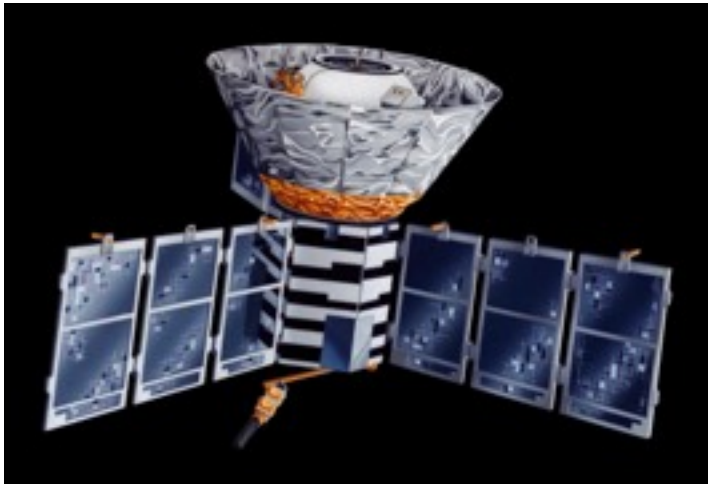
& SN Λ Nobel 2011

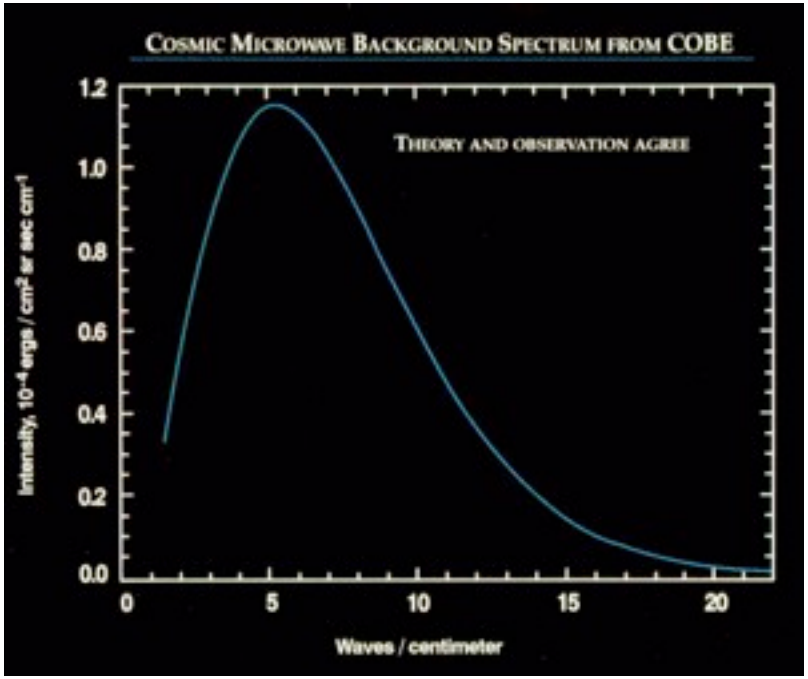
"for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation"

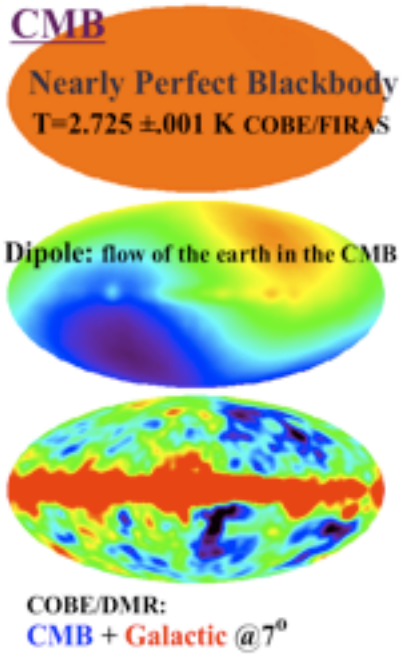
John C. Mather 1946-

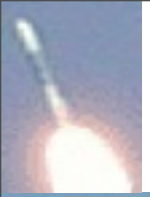


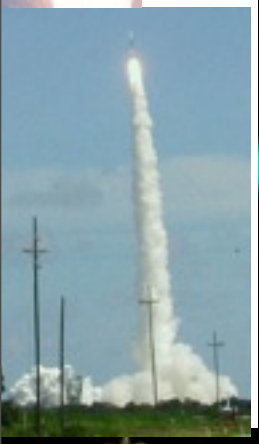
George F. Smoot 1945-



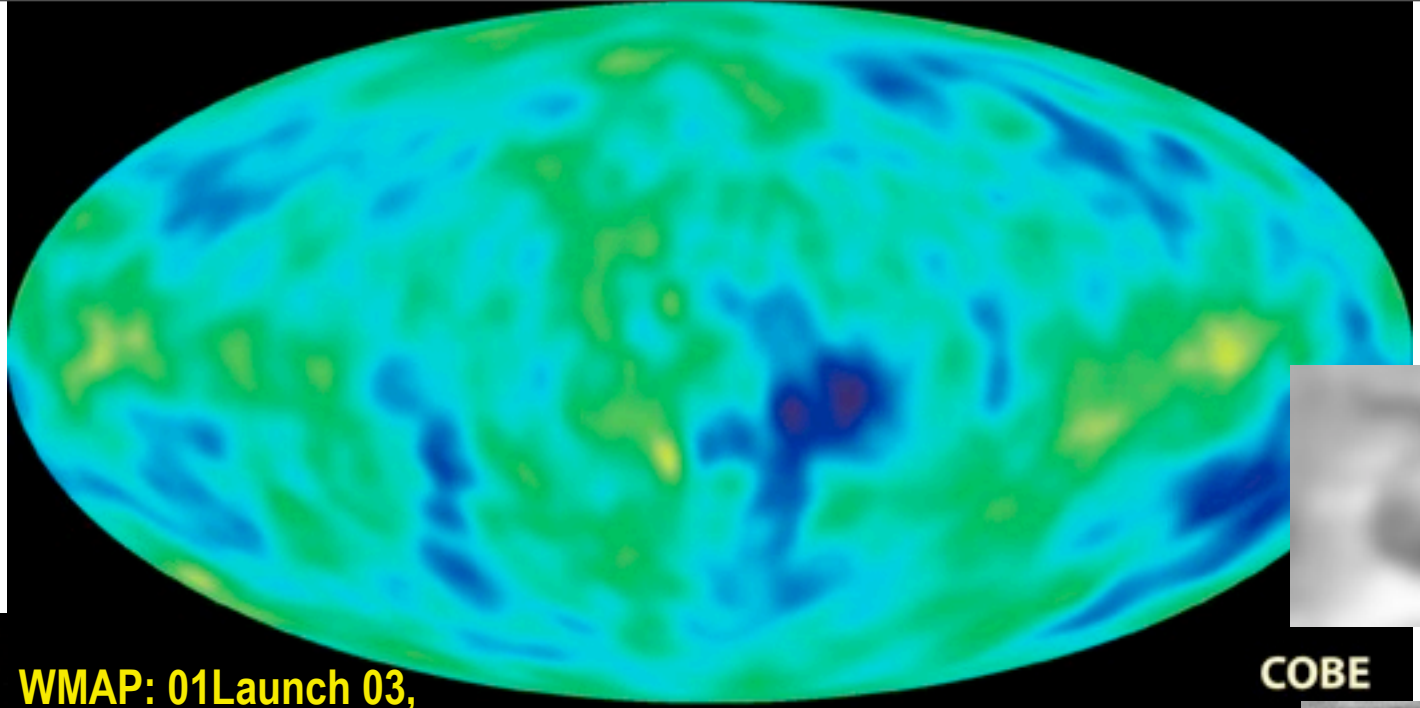


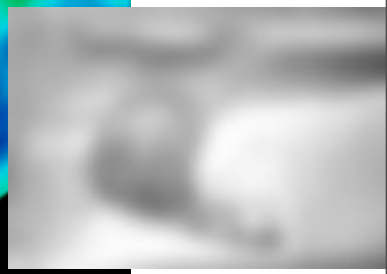




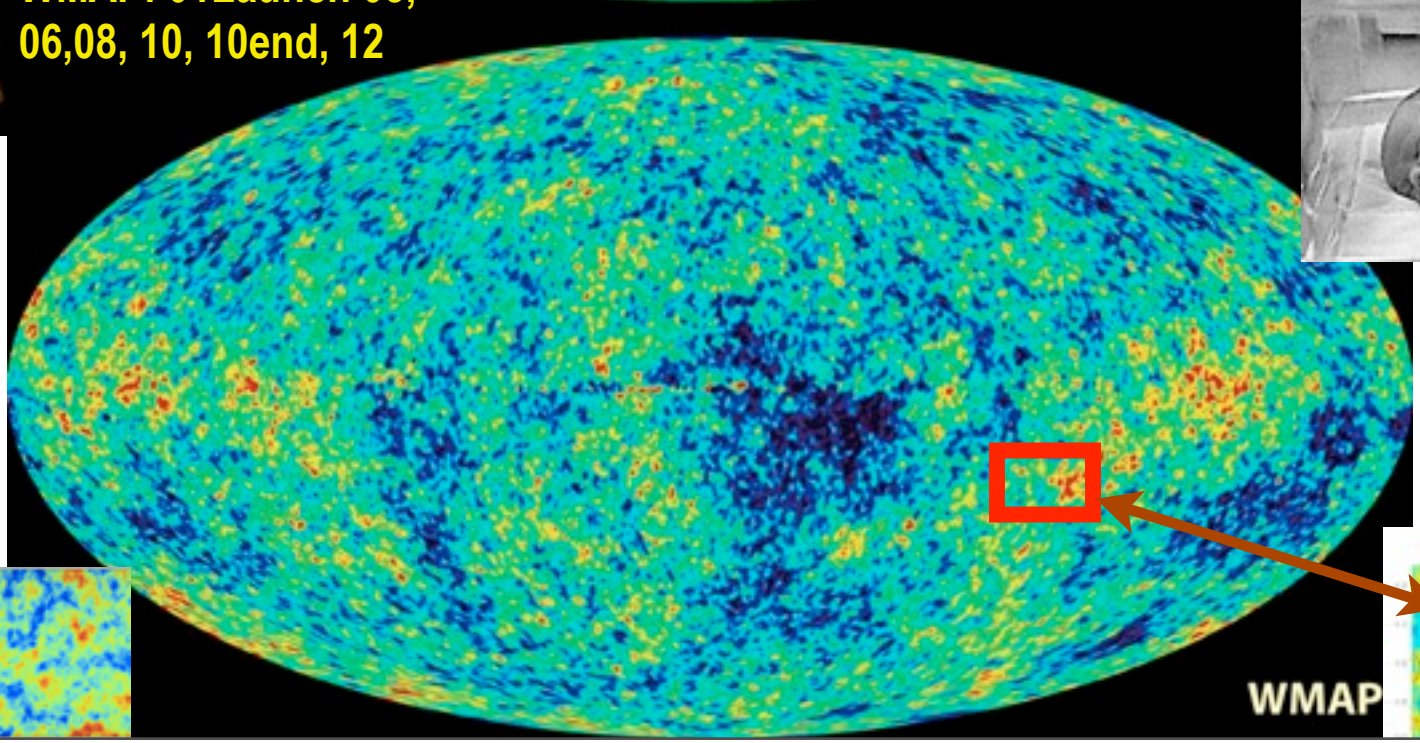


WMAP: 01Launch 03,
06,08, 10, 10end, 12



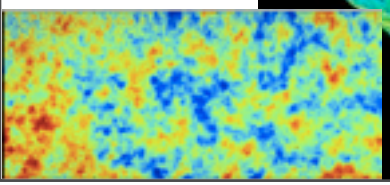


COBE

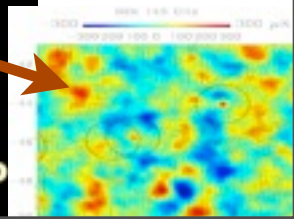


WMAP

ACT
+WMAP7
2011



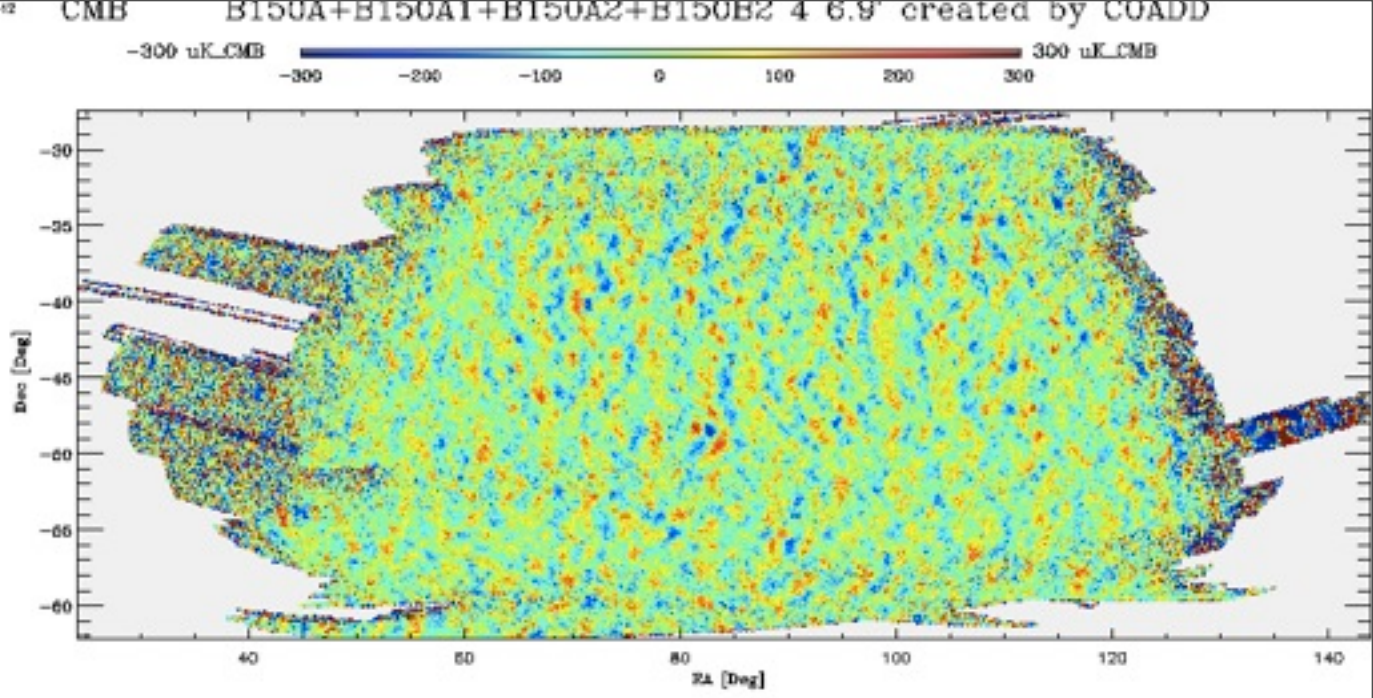
BOOM
2000
2005



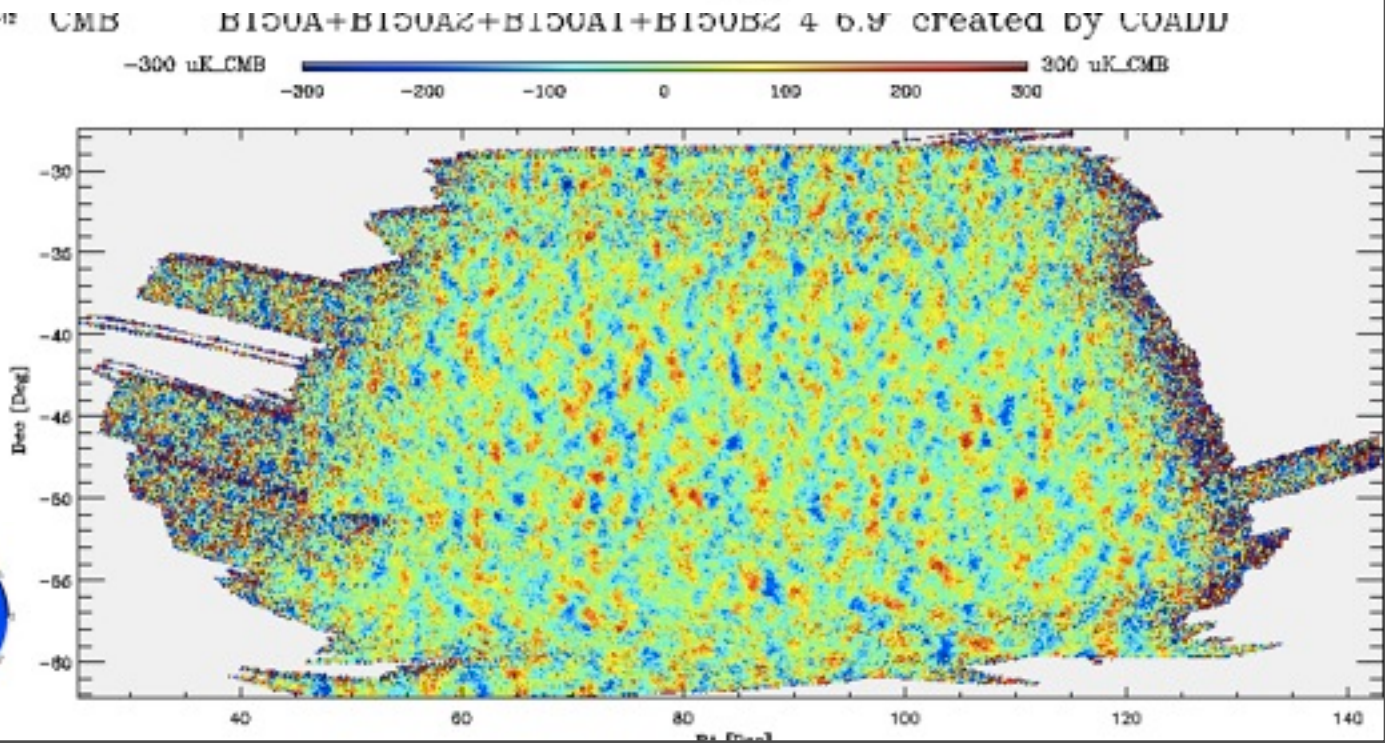
Boomerang98 @150GHz is (nearly) Gaussian: **Simulated vs Real**

looks the same

00,01,02 pre-WMAP



thermodynamic CMB temperature fluctuations 2.9% of sky ΔT~30 ppm



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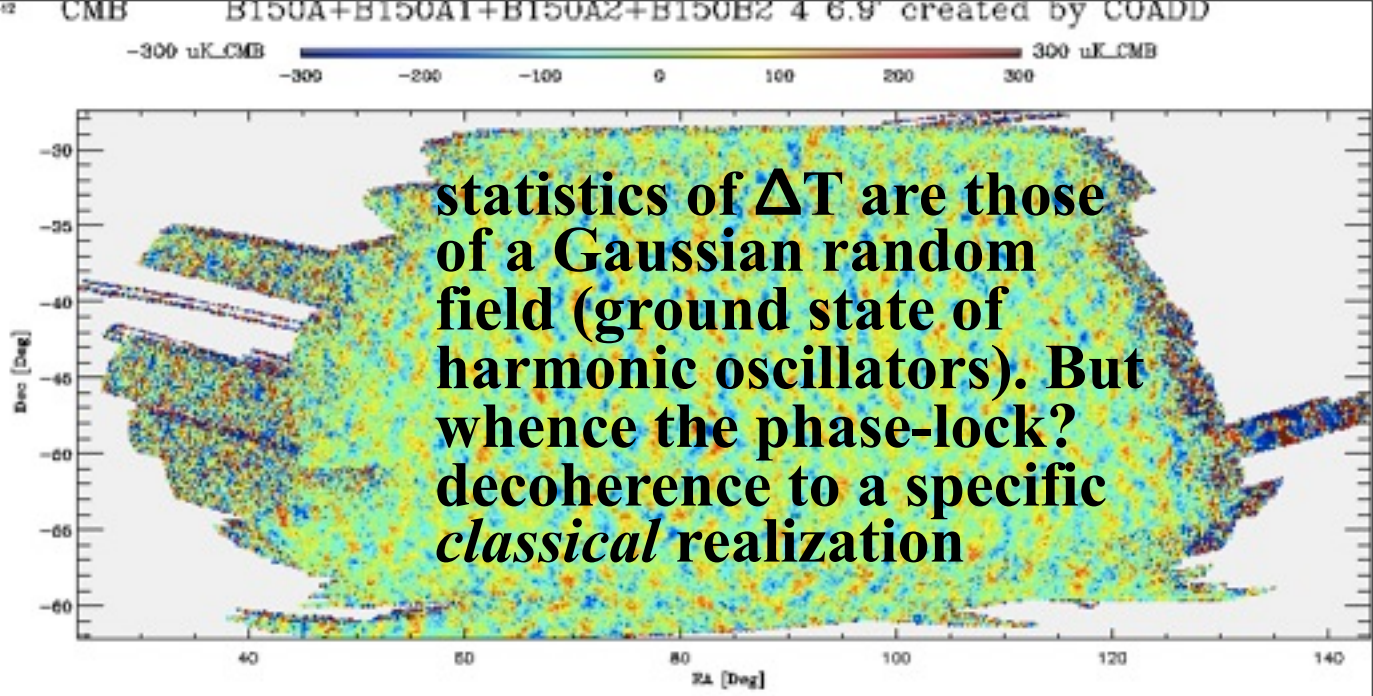

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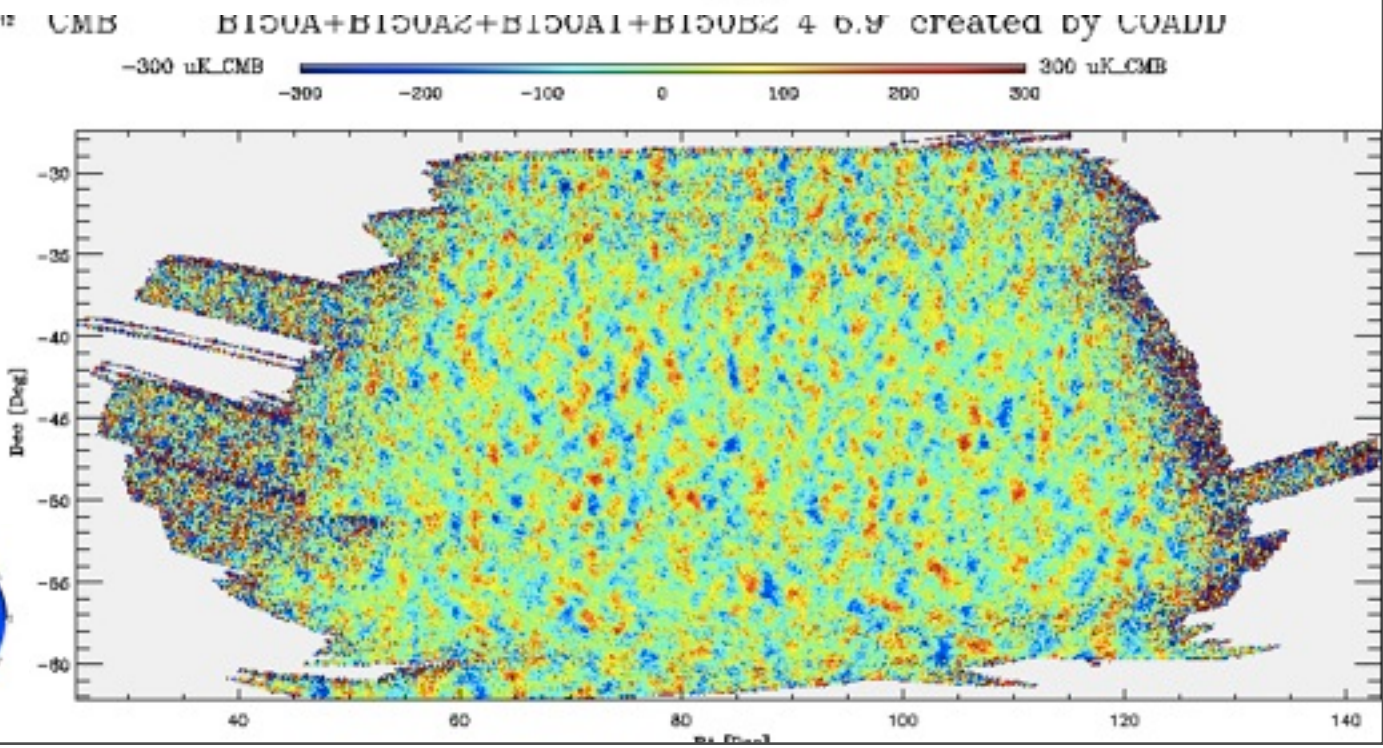
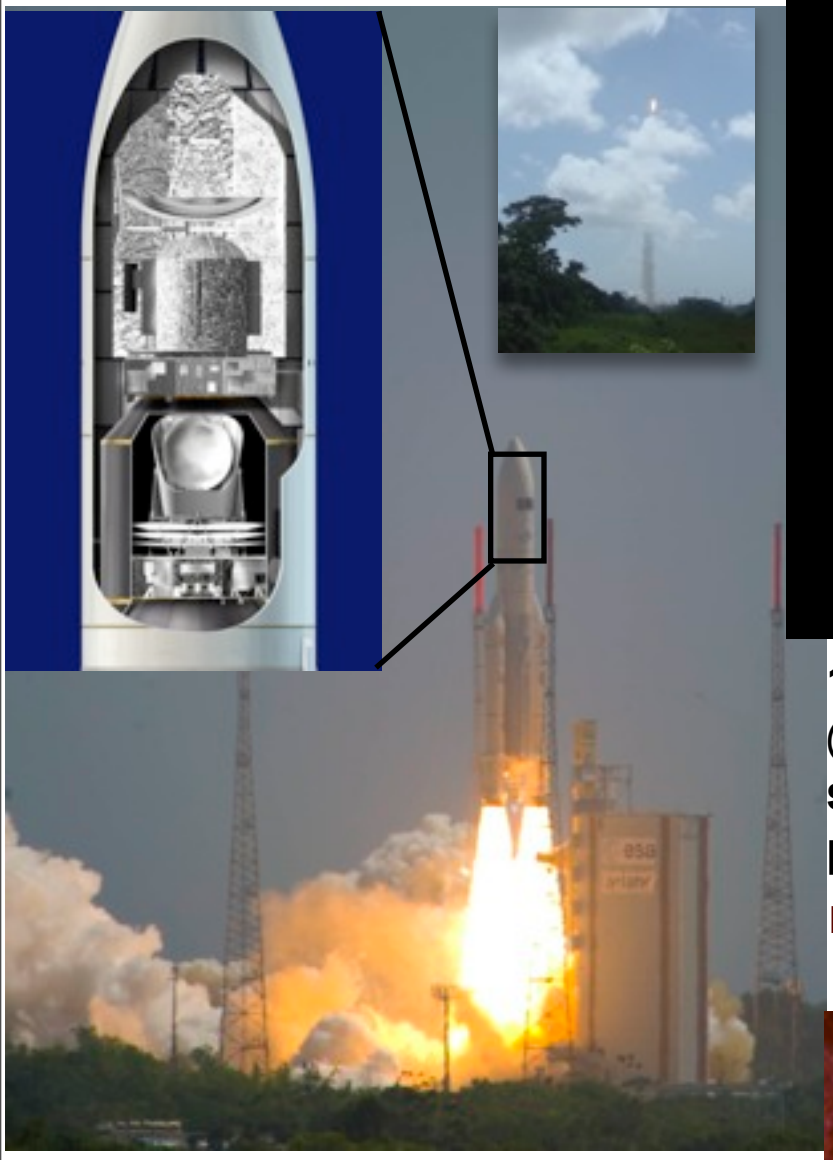


The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 50 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency -- ESA -- with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

Bond since 1993, Canada since 2001, 1st CSA pre-launch contract 2002-09, post-launch 2010-11, 2011-13

Planck+Herschel Launch May14 09 Fr. Guiana

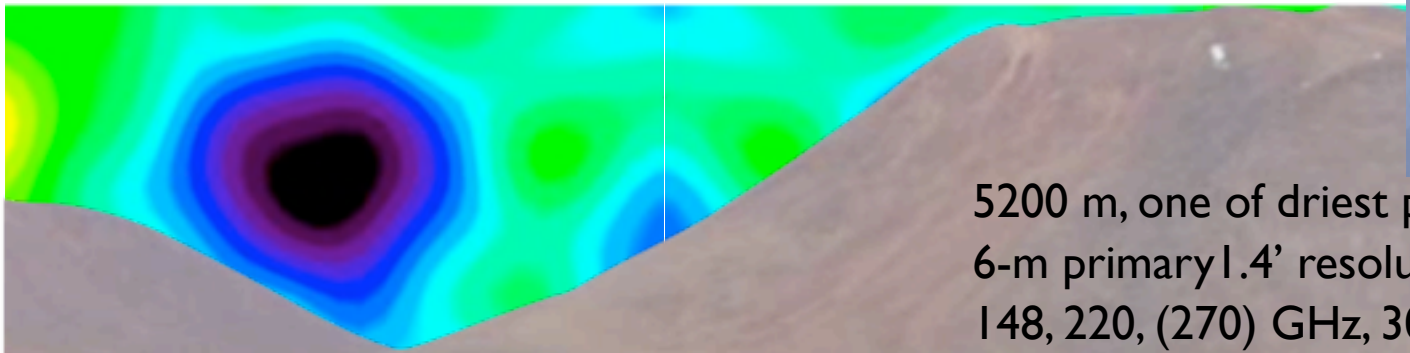


1.5m telescope, HFI bolometers @6freq <100mK, LFI HEMTs@3freq, some bolometers & all HEMTS are polarization sensitive

HFI+LFI **performance** to **spec** or better

Left earth at ~10 km/s, 1.5 million km in 45 days, cooling on the way (20K, 4K, 1.6K, 0.1K 4 stage). @L2 on July 2 09 -almost no trajectory correction @operational temp; Survey started on Aug 13 09 spin@1 rpm, 40-50 minutes on the same circle, covers all-sky in ~6 month, ~2.43 years to Jan14,2012

Cosmology From 5200 metres:
the Atacama Cosmology Telescope



5200 m, one of driest places on planet
6-m primary1.4' resolution
148, 220, (270) GHz, 3000 TES detectors!!
to Jan 2011 => ACTpol+ABS 2012

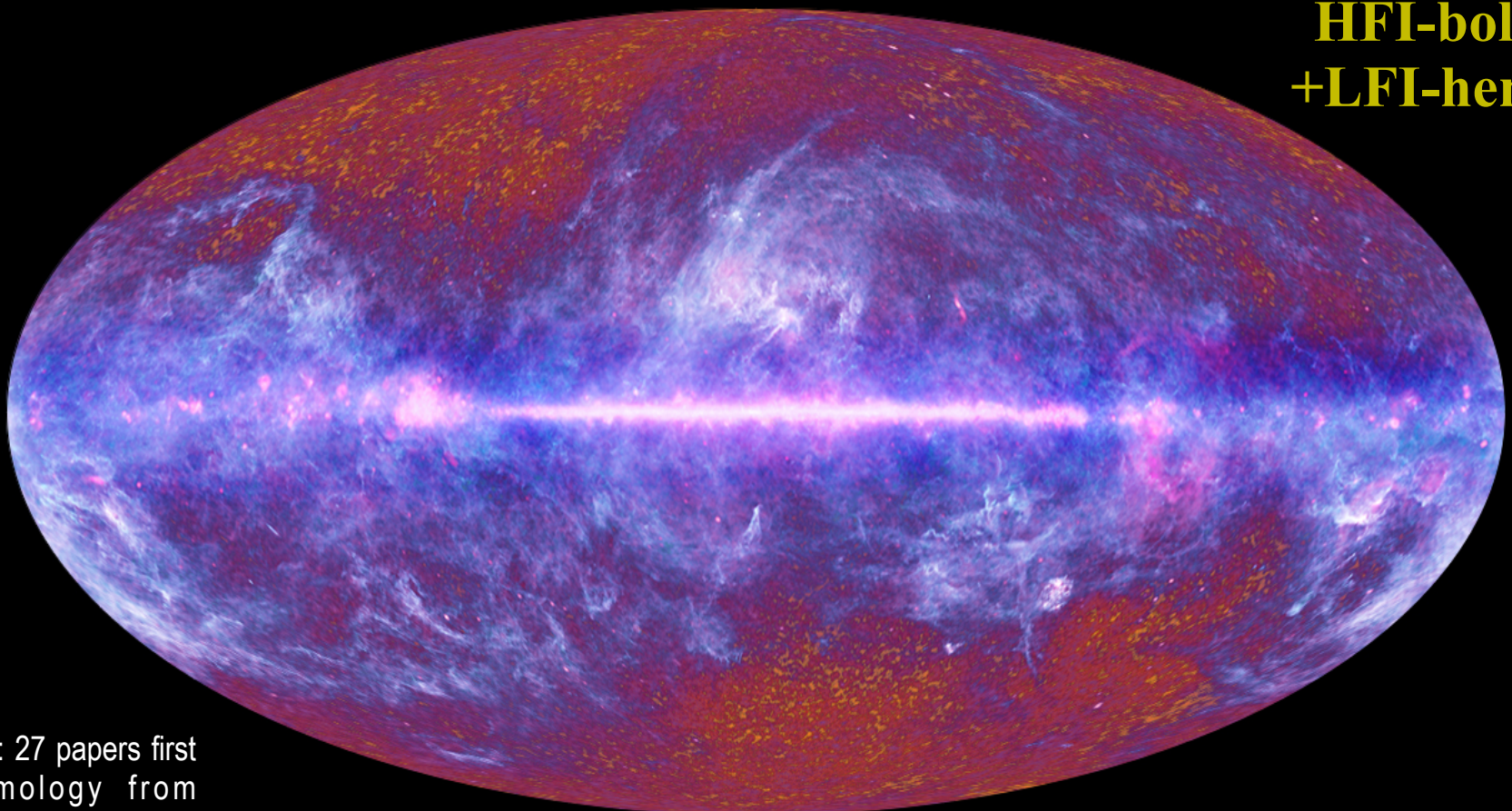
CMB@CITA: Boomerang, Acbar, CBI1,2, Planck, ACT, Spider, Blast, & ACTpol, ABS, QUIET90-2;
GBT-Mustang2, CARMA/SZA, SCUBA2, ALMA; *other CMB: QuAD, SPT/SPTpol, BICEP/KECK, EBEX, PolarBear, ...*

Planck & ACT

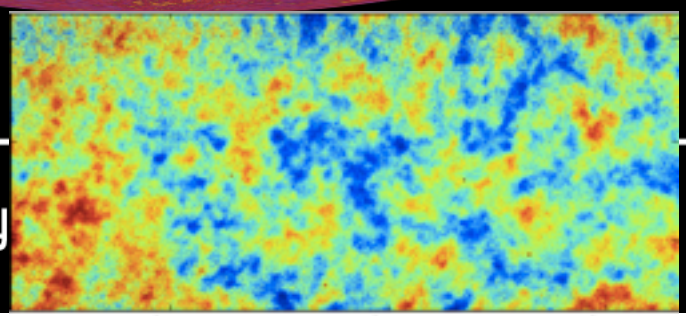
Dick Bond

7 veils(v)+CMB

9 v, pol, HFI-bolos +LFI-hemts



2011: 27 papers first cosmology from Planck early 2013, major polarization release early 2014



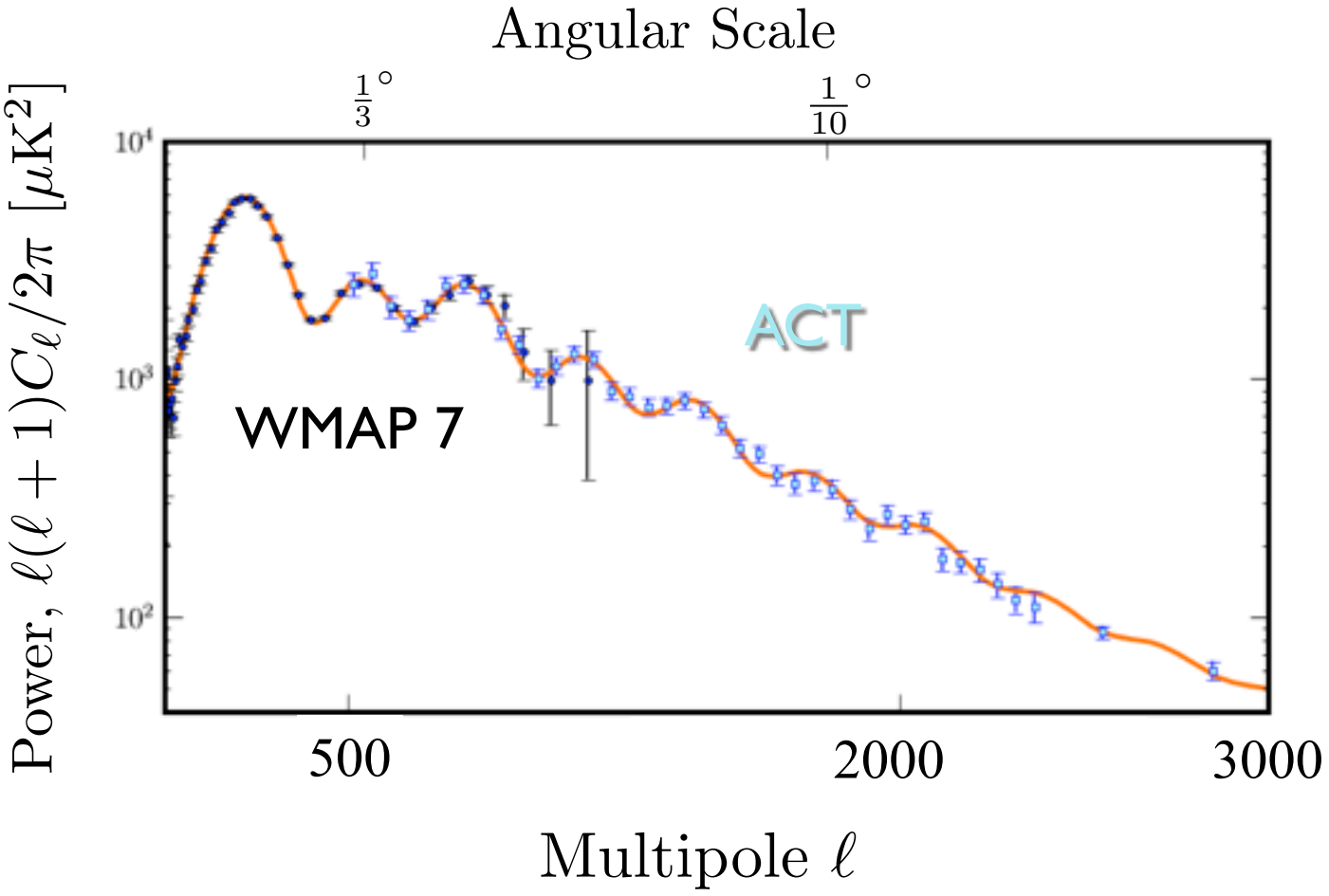
ACT+WMAP7 hajian+10

The Planck one-year all-sky survey

ESA, HFI and LFI consortia, July 2010

(radically) compress: ~0.3 PetaBits of the ~3000 detector timestreams from 3 years => 3 frequency maps, with noise variance, => isotropic Fourier/Y_{LM} -transformed temperature power spectra, ~8000 numbers + variances, => further bandpower compressed at high L

HIGH RESOLUTION POWER SPECTRUM from ACT: OLD



Das+ 2011, ApJ, 729:62, Hajian_2011, **Dunkley+.2011**, Hlozek+ 2011, Das+2011, Sherwin+2011, ..., **Sievers+2012**

tilted ΛCDM a very good fit (n_s constant); data are good enough to search for subdominant cosmic parameters N_ν, X_{He}, r, $dn_s/d\ln k$, $n_s(k)$ in bands, CMB lensing, .. & we have (strings, isocurvature,..)

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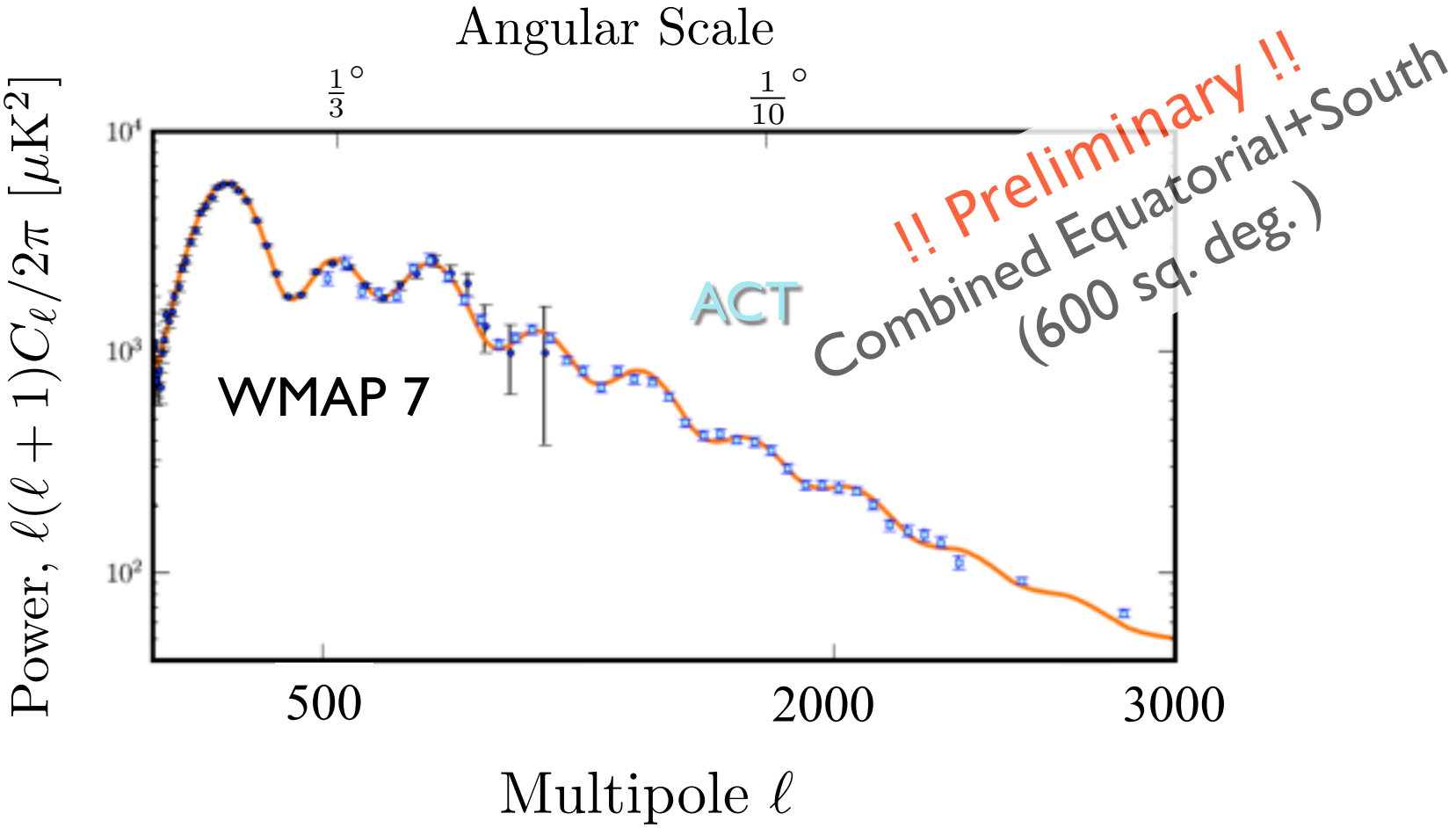

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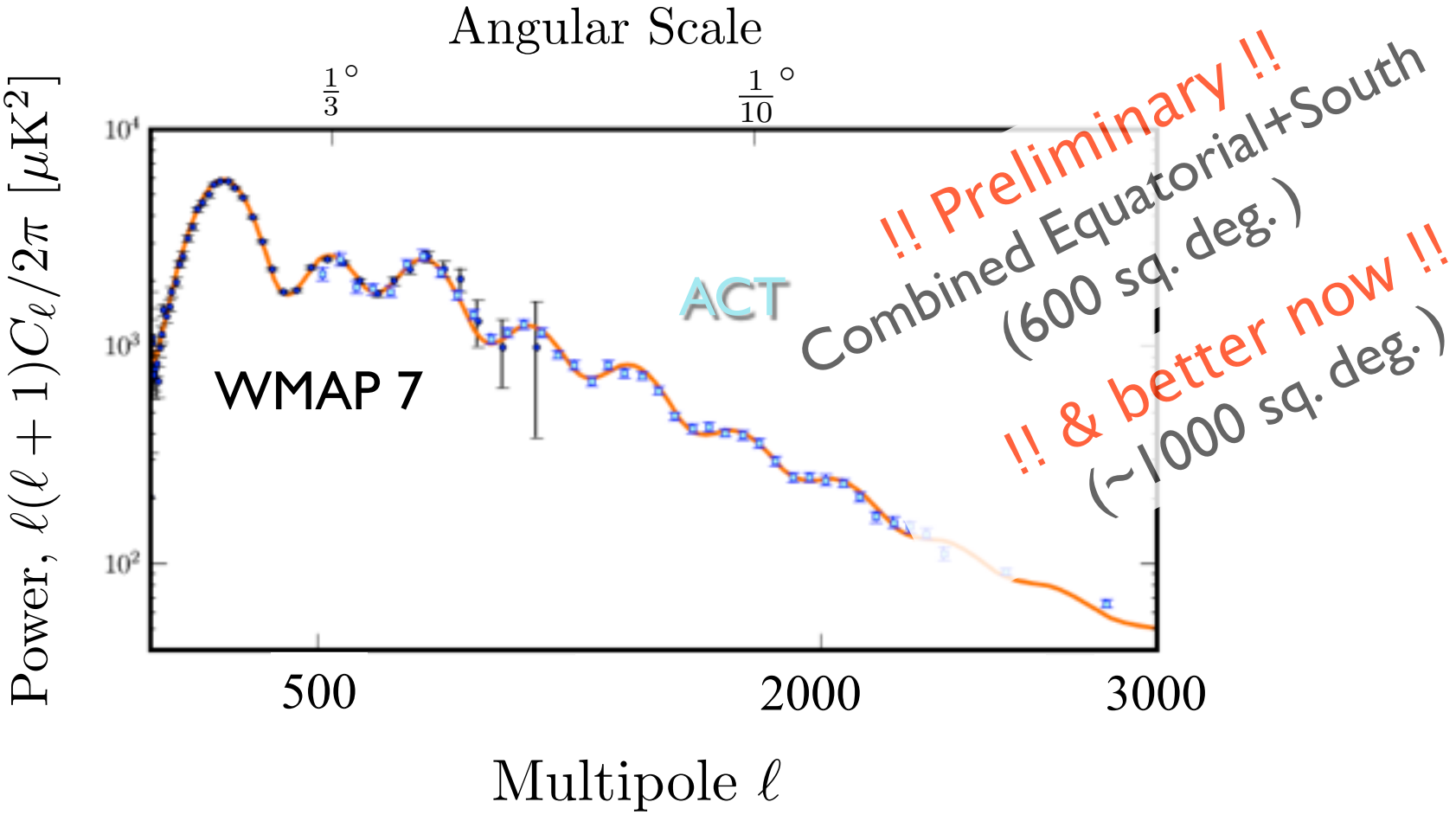

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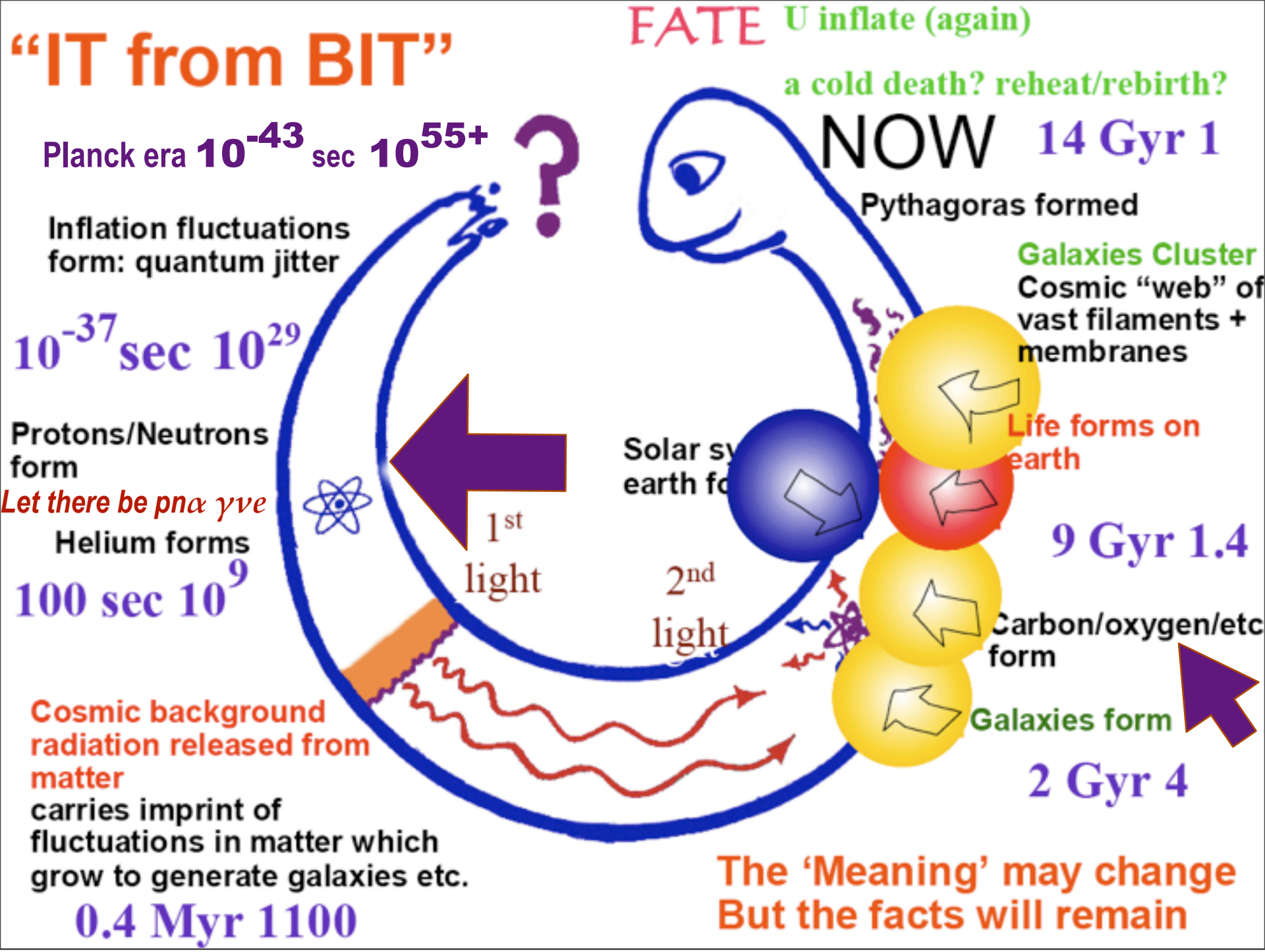
"IT from BIT"


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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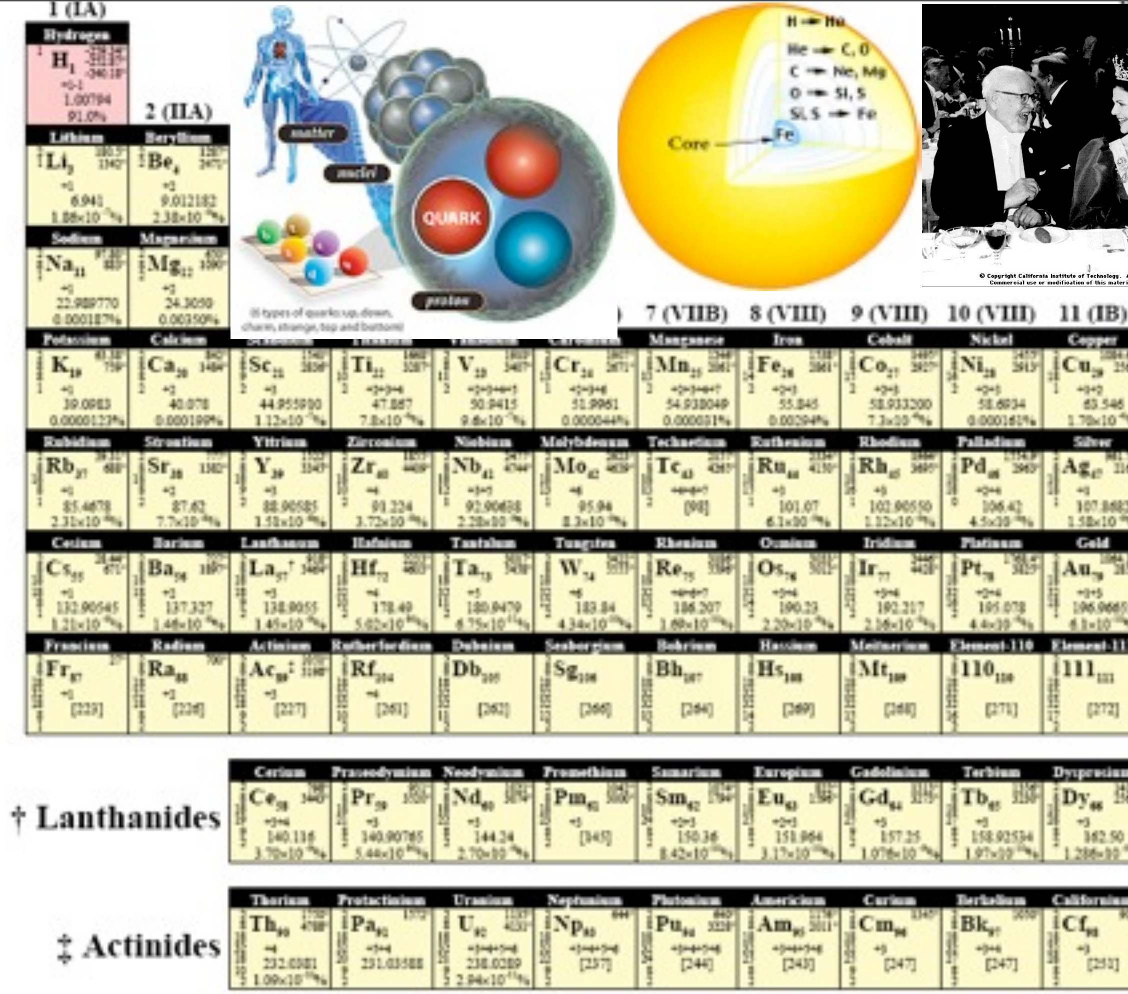
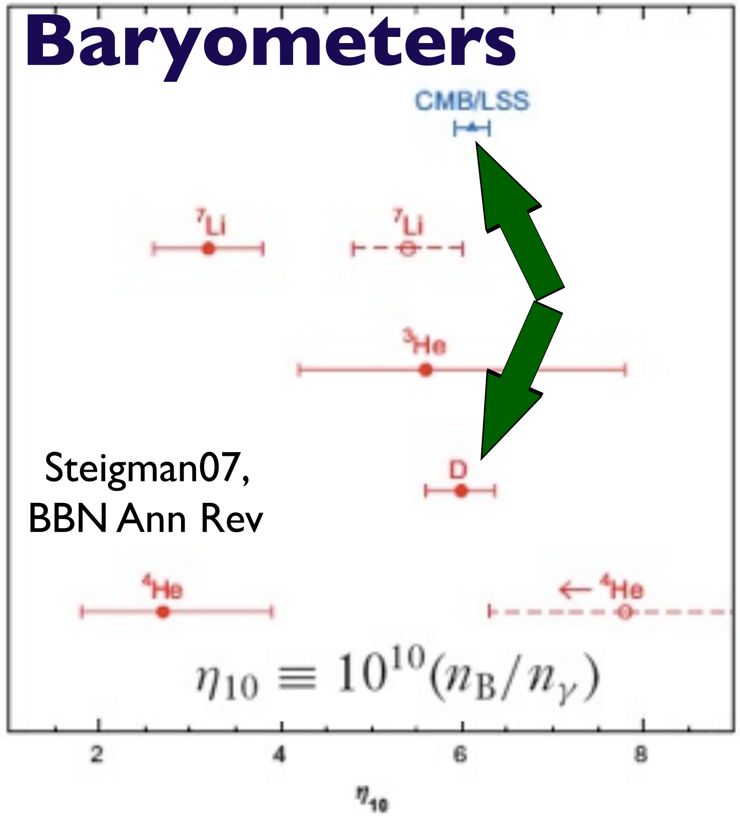
0.4 Myr 1100
The 'Meaning' may change
But the facts will remain

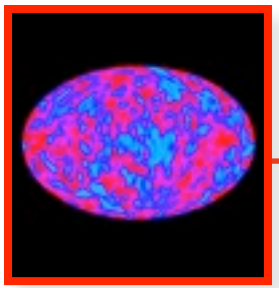


periodic table of the isotopes



cosmic baryon number
n_b=0.254 +-.005 /m^3

from the latest data: wmap7+acbar+cbi+b03+ACT+WL+LSS+SN1+Lya



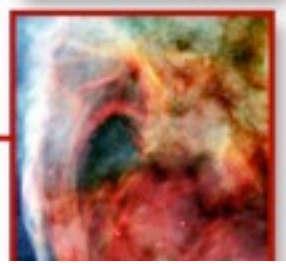
Radiation:

Chemical Elements:
(other than H & He)

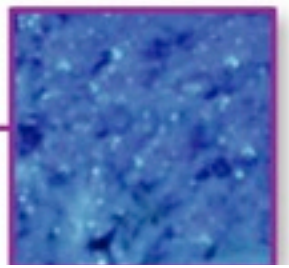
Neutrinos:

Stars:

$$\Omega_{total} = 1 = \varrho_{total} / 3H^2 M_P^{\,2}$$



Free
H & He:

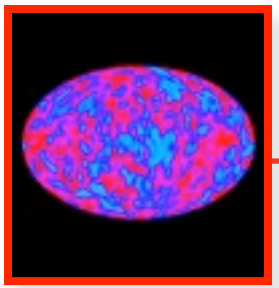


Dark Matter:

Dark Energy:

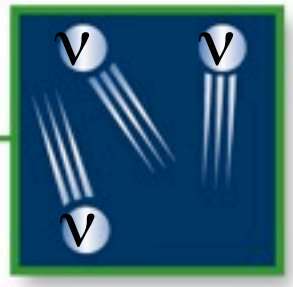
Gravity Waves

Black Holes



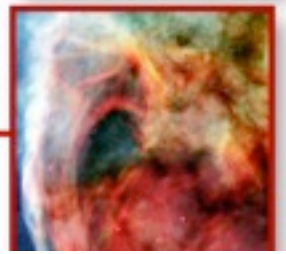
Radiation:
0.005%

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

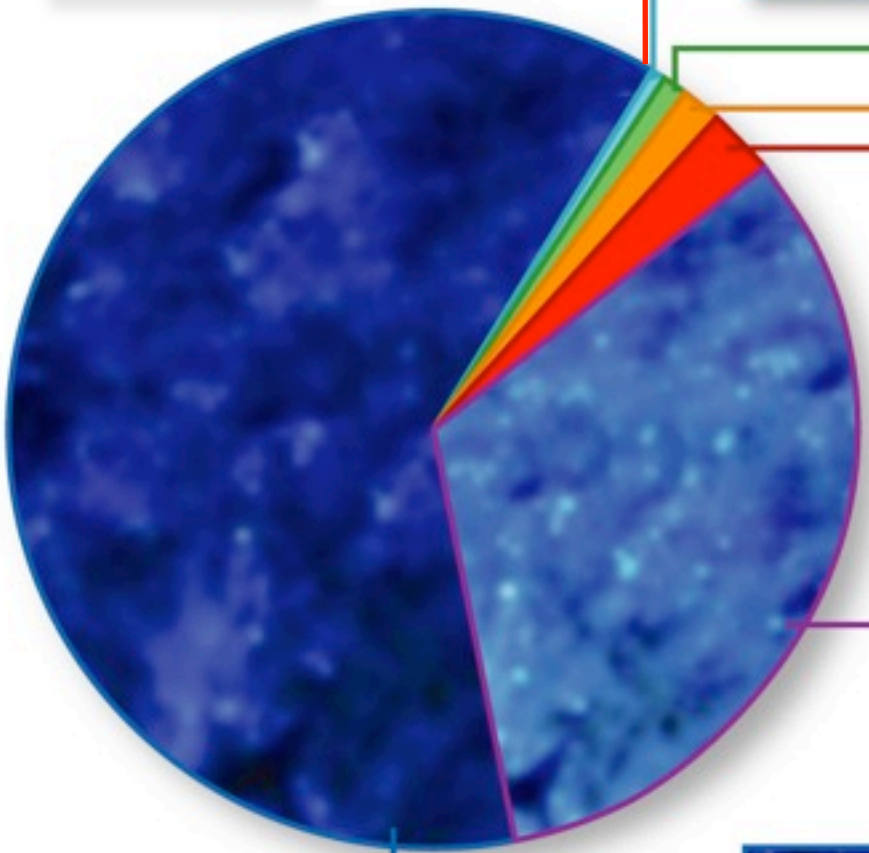


Neutrinos:
0.47%

Stars:
0.5%



Free
H & He:
3.9%



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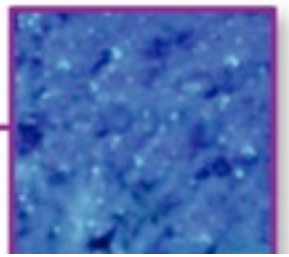


Dark Matter:

$$\Omega_{dm} = 22.4 \pm 2\%$$

Gravity Waves

Ω_{GW} ~10^{-14} - 10^{-10} LIGO

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

Dark Energy:

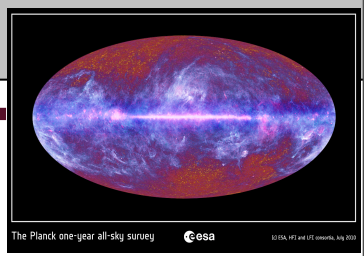
$$\Omega_\Lambda = 74 \pm 2\%$$

the gatherers of cosmic information

Cosmic Microwave Background +

Large Scale Structure experimental probes

then & now & then



near-future cosmology => PlanckEXT

EXT=many observatories & expts enabling the cosmology/astro

cosmology: **$n_s(k)$, GW $r(k)$, nonG f_{NL}++, $\rho_{de}(t)$, m_ν, strings, isocurvature,... $n_e(t)$**

ACTpol, SPTpol, ***ABS, Spider, Quiet-90,*** *EBEX, Keck,* **GBT**, **CCAT**,
eRosita, PanStarrs, DES, HSC, LSST, ***CHIME***, ***EUCLID***, ... ⊂ **EXT**

CITA = Cosmic Information Theory & Analysis: *IT from BIT, from BITs in IT*

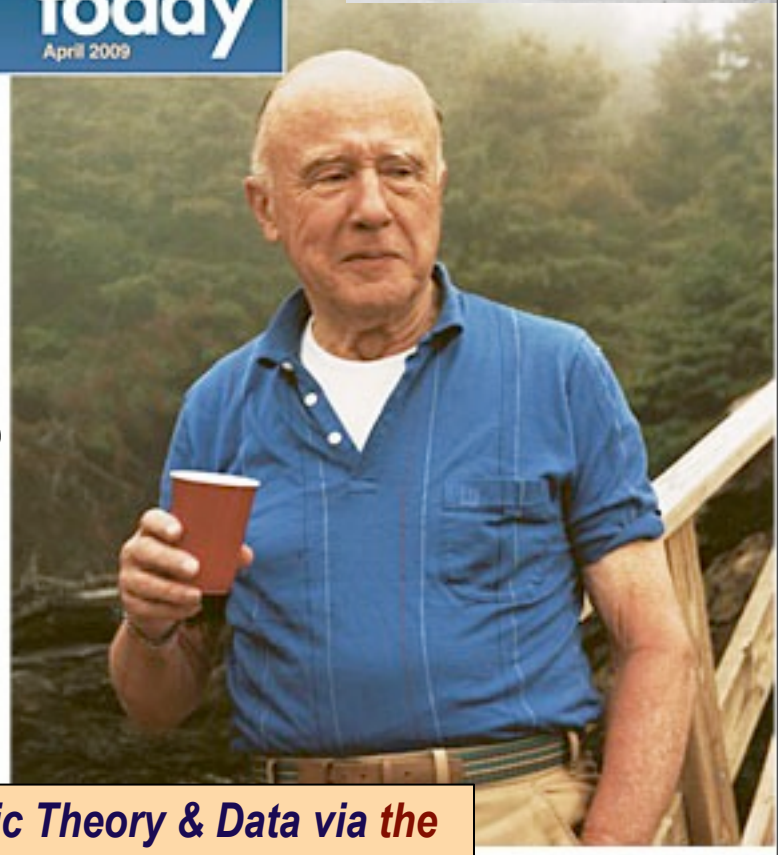
"black hole" =”gravitationally completely collapsed object"

measurement problem—the role of the observer in defining what "is."

What do we mean by 'reality' except the results of observations?

the observer confers "reality" on the past by observing it, and offered the Big Bang as an example

"Now I am in the grip of a new vision, that Everything Is Information. The more I have pondered the mystery of the quantum and our strange ability to comprehend this world in which we live, the more I see possible fundamental roles for logic and information as the bedrock of physical theory. ... I continue to search."



information-content =entropy **Shannon 1948**

S measures Quantity *not* Quality Q

filter, compress, reduce, marginalize information in quest of Q

IQ=information quality

IQ~{minimal length messages/codes | error tolerance}

Planck(E/T), genetic code, recipes, axioms, algorithms, IC/BC/evolution eq^{n}s

the medium is the message **McLuhan 1964 UofT**

our Cosmoticians' Agenda: Statistical Paths in Cosmic Theory & Data via the Bayesian chain (an entropy decreasing flow) drawing what we know of It from Its Bits

Special issue:
John Archibald Wheeler

CITA = Cosmic Information Theory & Analysis: *IT from BIT, from BITs in IT,*

Studying the Cosmic Tango en-TANGO-ment the dance of U=R∪S Universe =System(s)+Reservoir

=Signal(s)+Residual *noise* =Effective Theory+*Hidden variables,* =*Data+Theory,* observer(s)+observed

U=R∪S ruled by (information) entropy in bits, entangled. ***the fine grains in the coarse grains***

$S_{U,m+r} \sim 10^{88.6}$ in our Hubble∧Volume compressed onto $T_\gamma \approx 2.725$K &

$1/H_0 \approx 14$ Gyr

5.2 bits/ϒ

$S_G \sim 10^{121.9}$

$S_m \sim 1$ bits/baryon atmosphere

$S_{clusters} \sim 190$, in all~10^{76}

after CMB, most S in waste heat from dust re-emission of starlight CIB

WMAP9 $10^{12.1}$

Planck $10^{13.6}$

ACT $10^{14.5}$

Compress ~7 parameters

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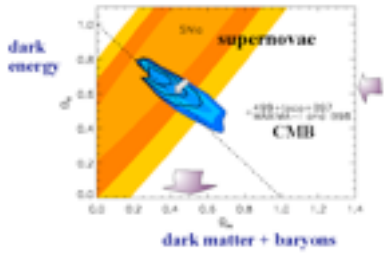


Dark Energy Histories
(SN+WL+BAO+CMB+cls)

future fate?

SN Nobel 2011

the **cold-death** of the **Universe** (cf. 1800s heat-death)

coherence (dark energy $\rho_{de}(t,x) \Rightarrow V_{de} \sim \Lambda$)

beats **incoherence** (Υ,ν,h_{+x},..p,n,e)

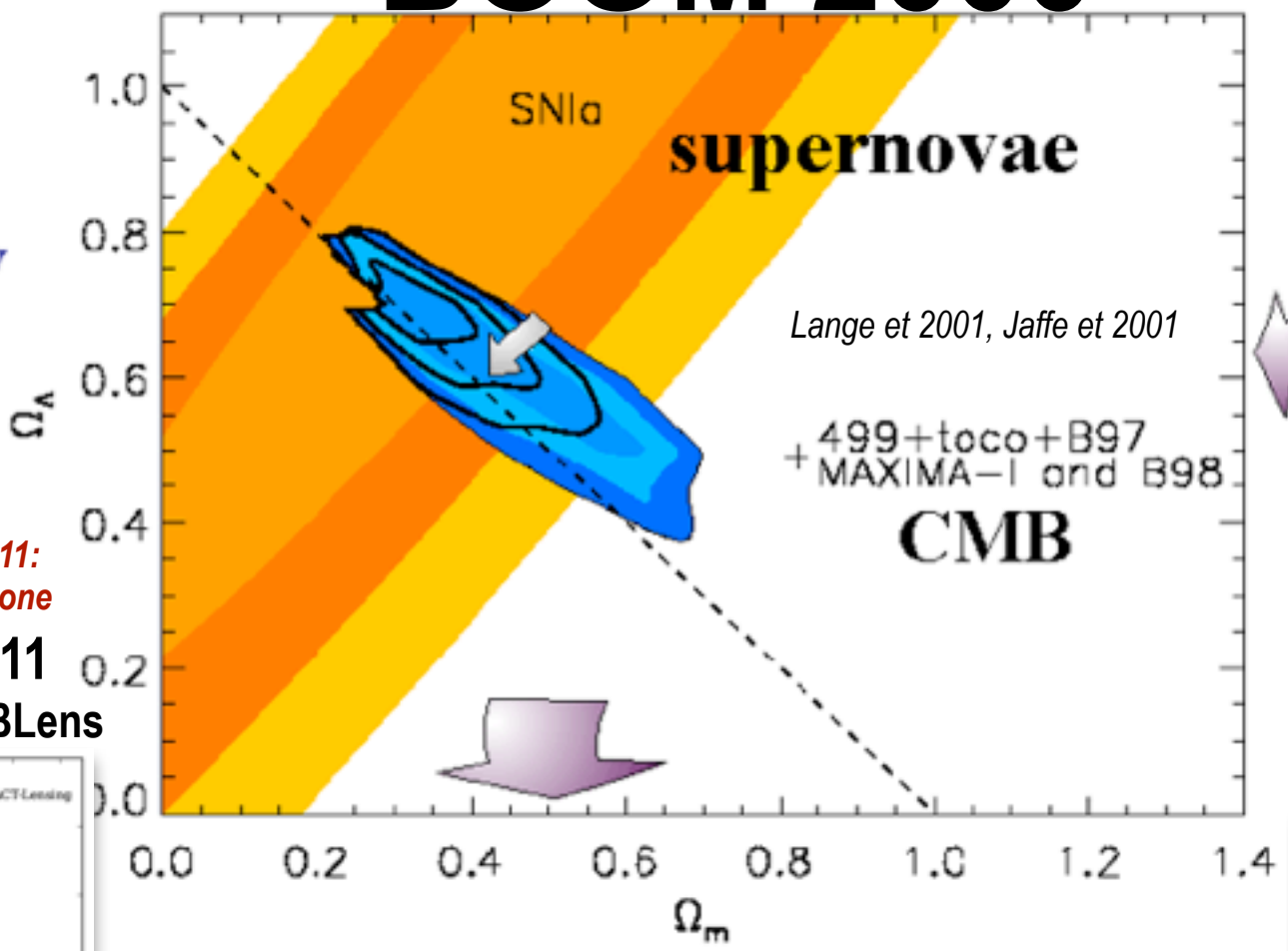
but **entropy/particle**

remains *(for those particles that survive)*

⇒evidence for "dark energy" aka the cosmological constant

BOOM 2000

dark energy



ΛCDM was the standard "concordance" model since ~1995;

much invoked since

Peebles 1985

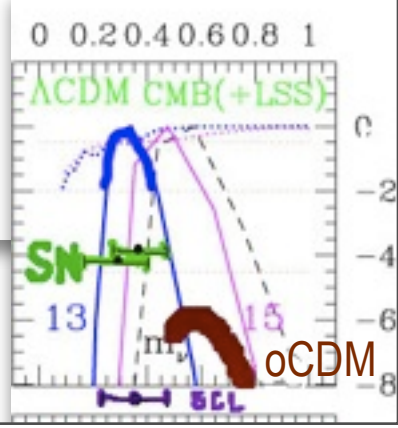
a neo-Lemaitrian

WYSIWYG

BBE87, PR88, Weinberg87, ...

CMB+LSS 1996/98

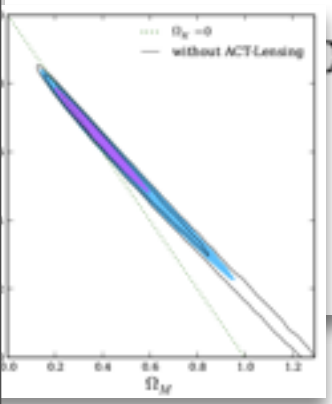
DE w/o SN



Sherwin et 2011: Λ from CMB alone

ACT 2011

DE from CMBLens



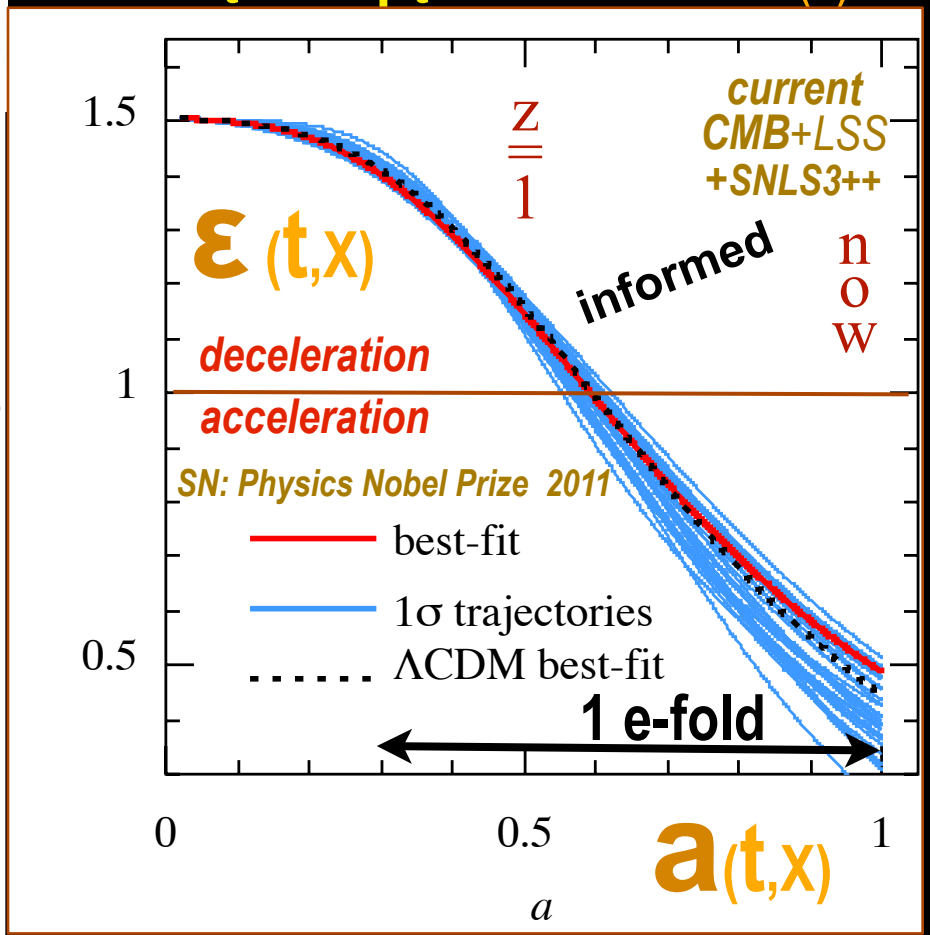
Dunkley et 2011 cosmic parameters

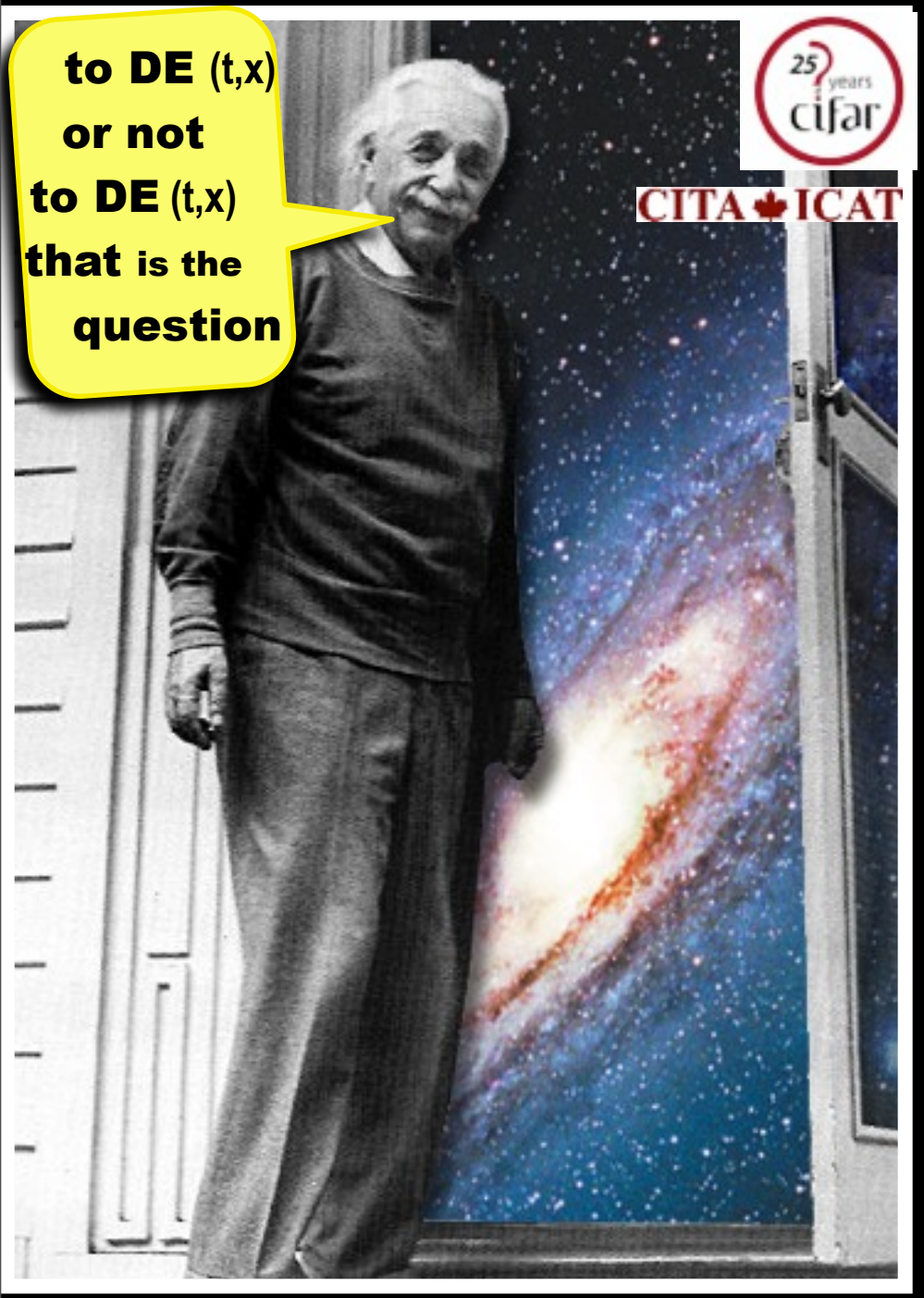
Ω_Λ=0.736 ±.012 =>± 0.001 (Pext) B+Huang 2011

2011: WMAP7+ACT+BAO+H0

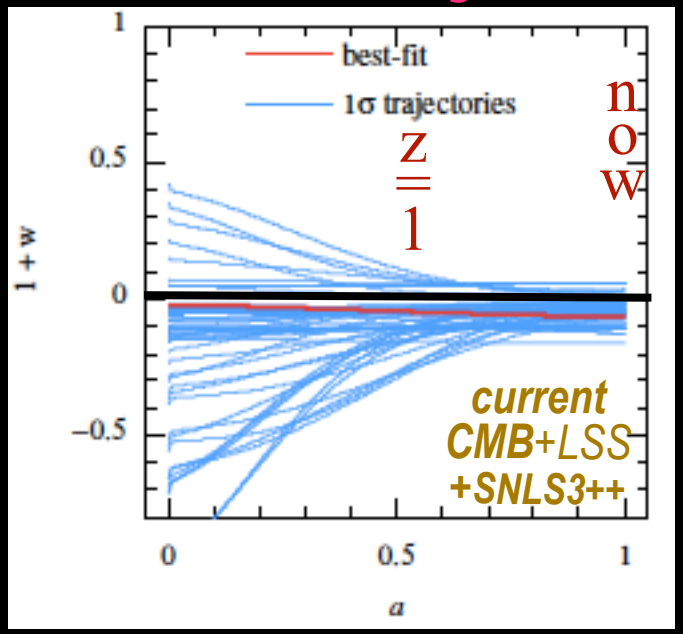
Dark Energy Histories (SN+WL+BAO+CMB+cls)

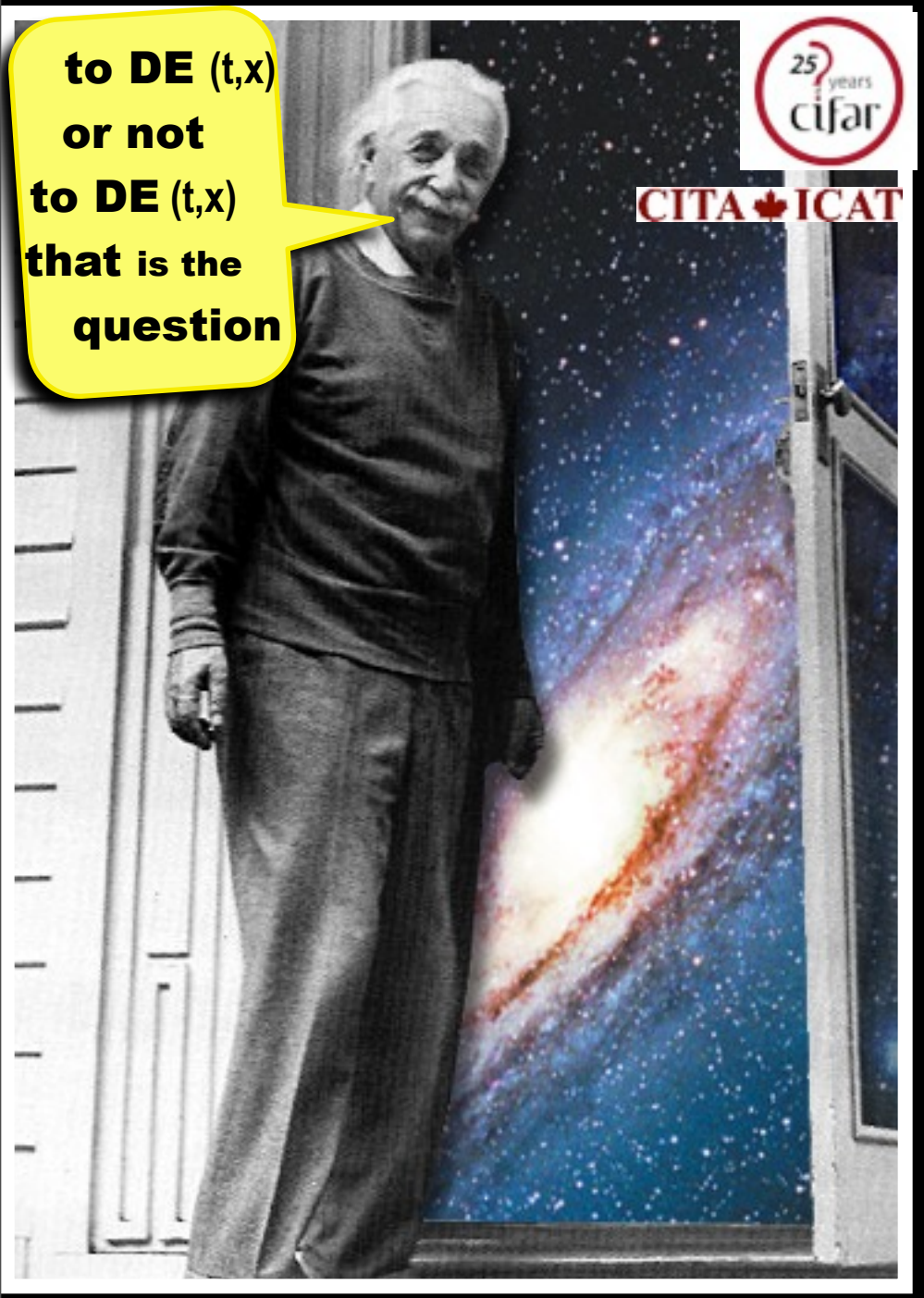
$1+W_t=-d\ln\rho_t / d\ln a^3=2/3\,\varepsilon(t)$





late-inflaton DE trajectories





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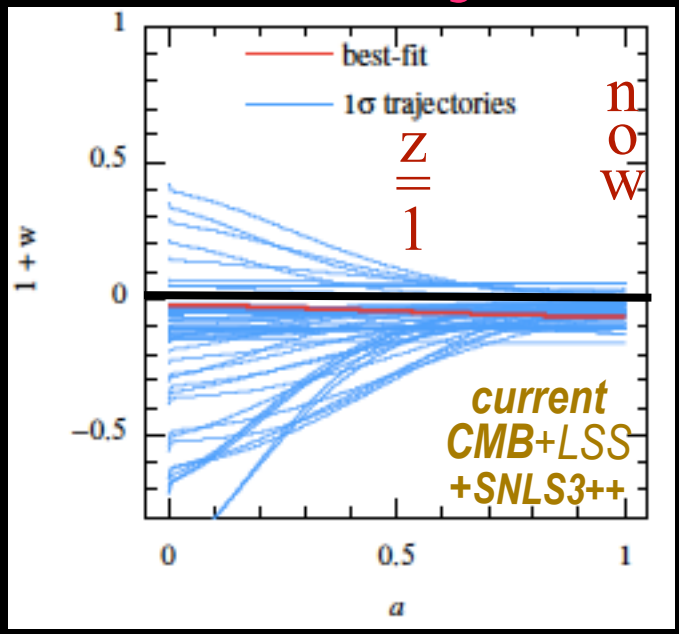
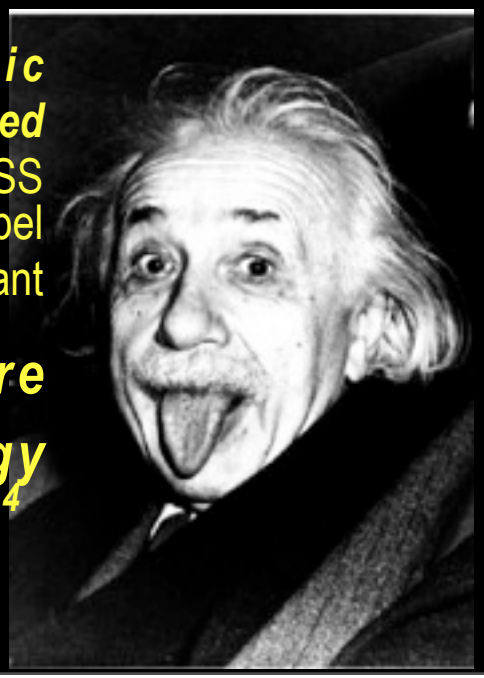


so far the cosmic standard model (***tilted*** ΛCDM) fits CMB+LSS +supernova (2011 Nobel Prize) data, with constant

ϱ_{vac} i.e., ***a pure potential energy density ~ 28 (meV)^4***



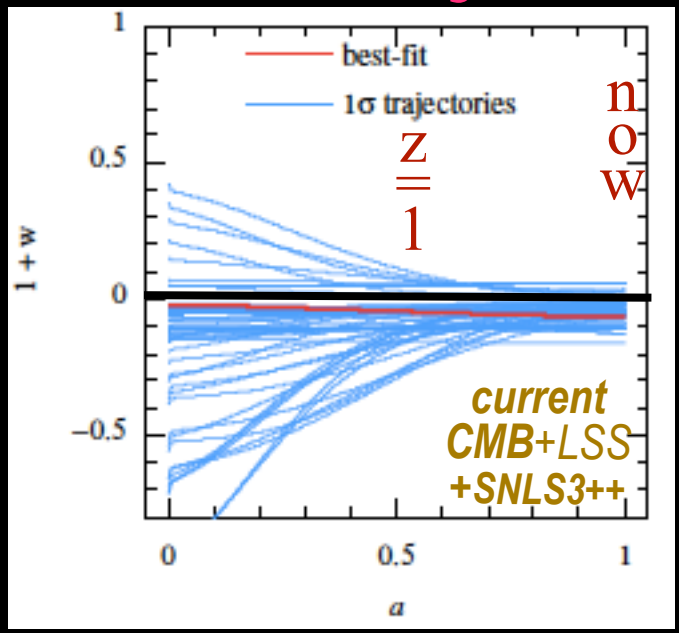
to DE (t,x)
or not
to DE (t,x)
that is the
question

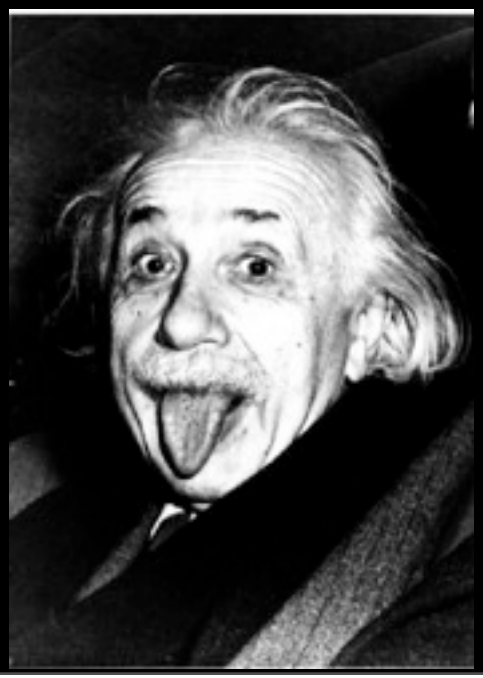
modify
Einstein
equations?!
nein

CITA ICAT

cifar 25 years

late-inflaton DE trajectories





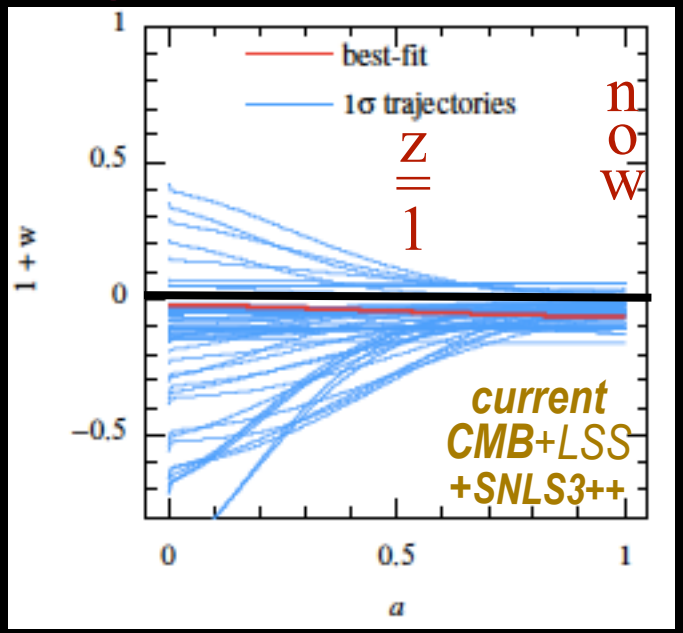
Beyond Einstein

to DE (t,x) or not to DE (t,x) that is the question

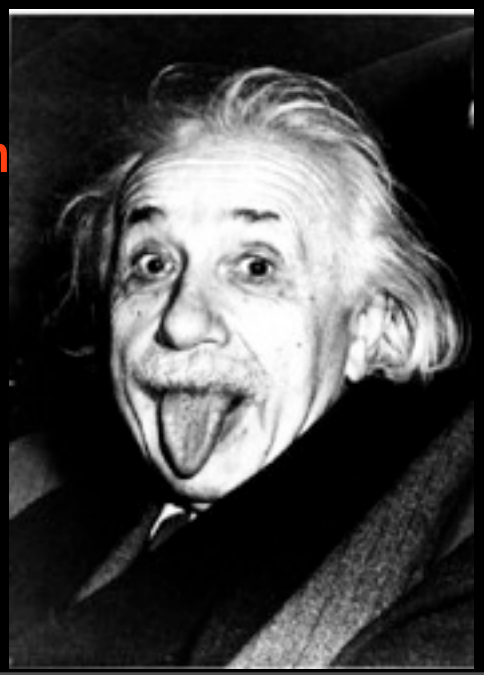
modify Einstein equations?!

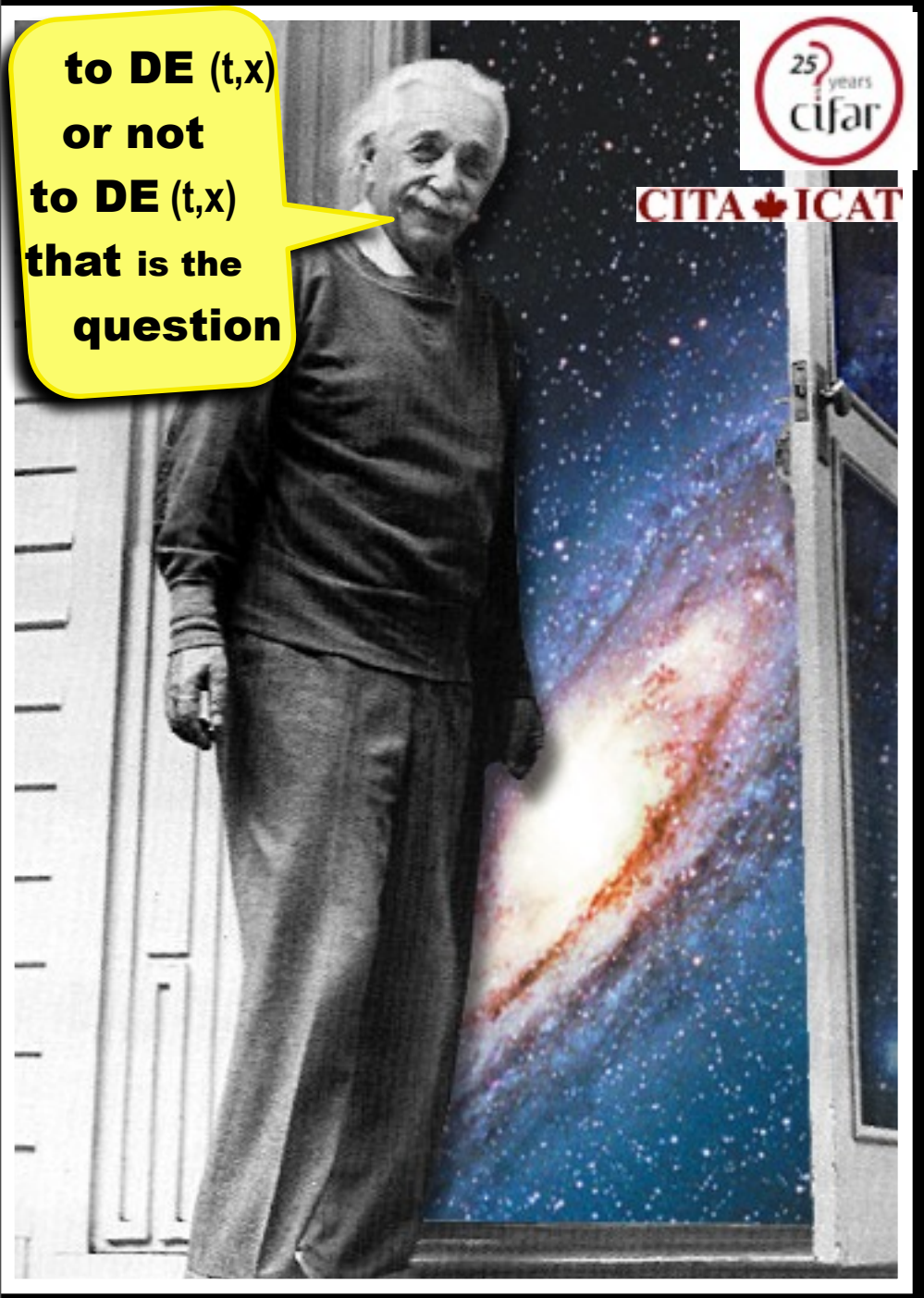
~~nein~~ ja

aha = Einstein + fifth force



DE-matter-interaction => exciting new window??!! *chameleon-ish*





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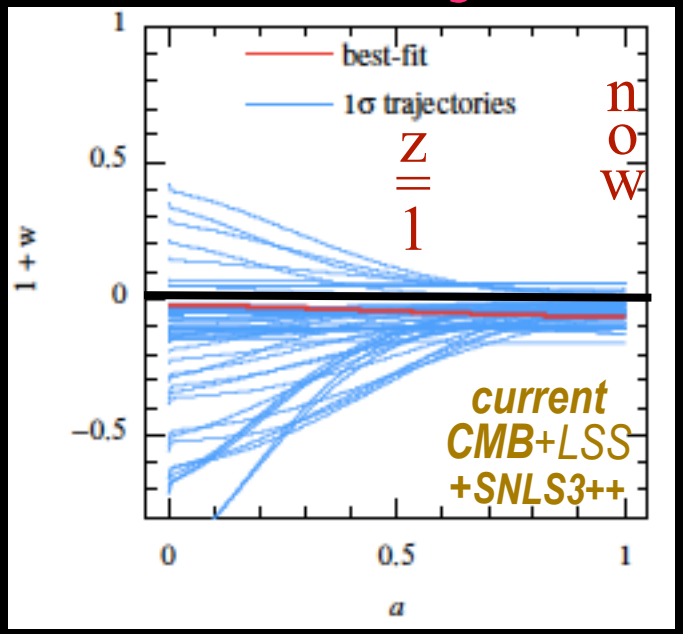
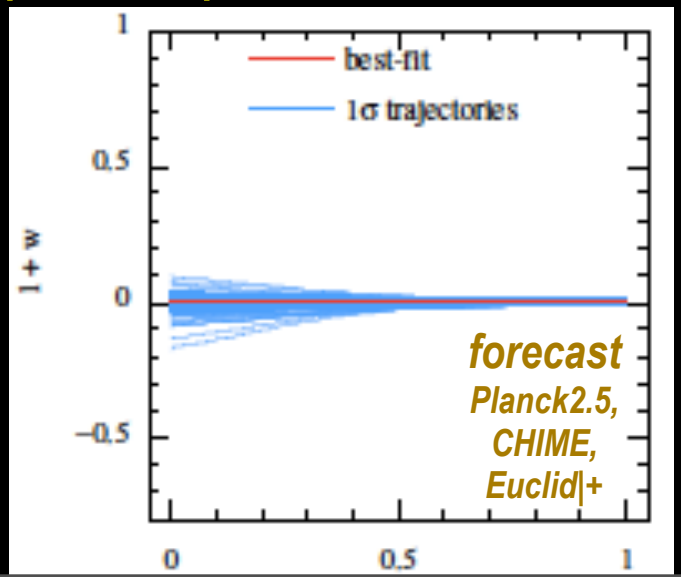


$$(1+W_{de}) = - d\ln\rho_{de} / d\ln a^3$$



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what ***message*** *in the information* ***medium****?*

The 'Meaning' may change

But the facts will remain

end

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

25 years cifar

CITA = Cosmic Information Theory & Analysis:
IT from BIT, from BITs in IT, Studying the Cosmic Tango

Universe=System+Res =Data+Theory en-TANGO-ment

Dick Bond CIAR

IAS Distinguished Lecture

Cosmic Information: IT from BIT, from BITs in IT

Prof J. Richard Bond, Canadian Institute for Theoretical Astrophysics, University of Toronto

Date 16 Jan 2012 (Monday)

Time 3:30- 5:00pm

Venue Room 5583 (5/F via Lifts 27-30), HKUST

Abstract:

We consider the Universe to be fundamentally quantum and statistical, the many-paths/many-worlds story. Cosmic Information Theory and Analysis, CITA, is a unifying theme underlying the vast sweep of our current ideas of the Universe and the experiments we use to probe them, ranging from the ultra-early beginnings to our far-future fate. The speaker will describe the intimate entanglement of theory with precision "first-light" and other cosmic data, in particular from the cosmic microwave background satellite Planck and the Andes-based Atacama Cosmology Telescope. Such data are the BITs in IT informing us of the physics that defines the BIT of the Universe accessible to us from which we hope to learn of that vast IT which encodes all Cosmic Information. The mysterious dark energy that drives the cosmic acceleration we observe happening now and its early universe counterpart, inflation, will be a focus.