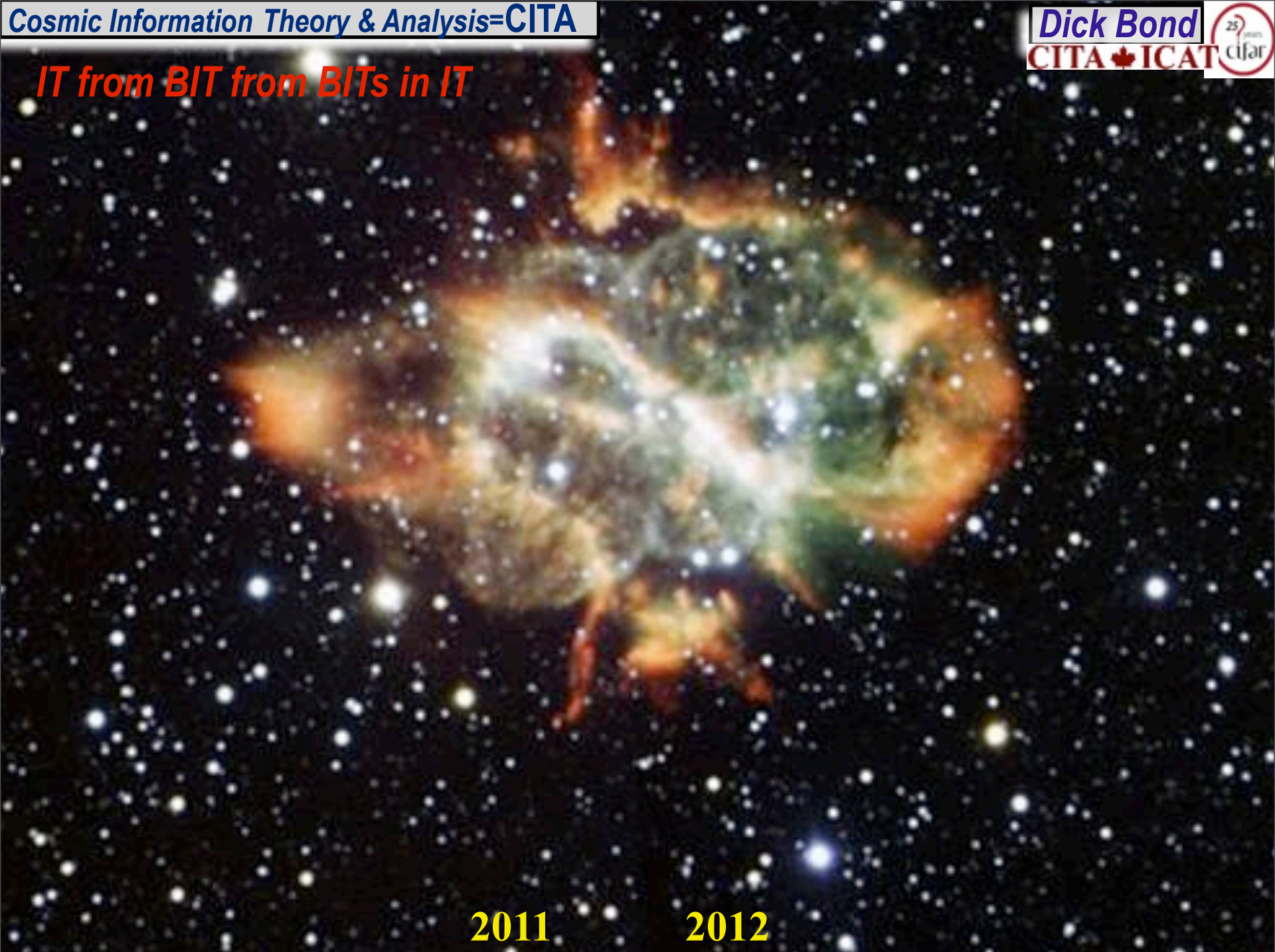


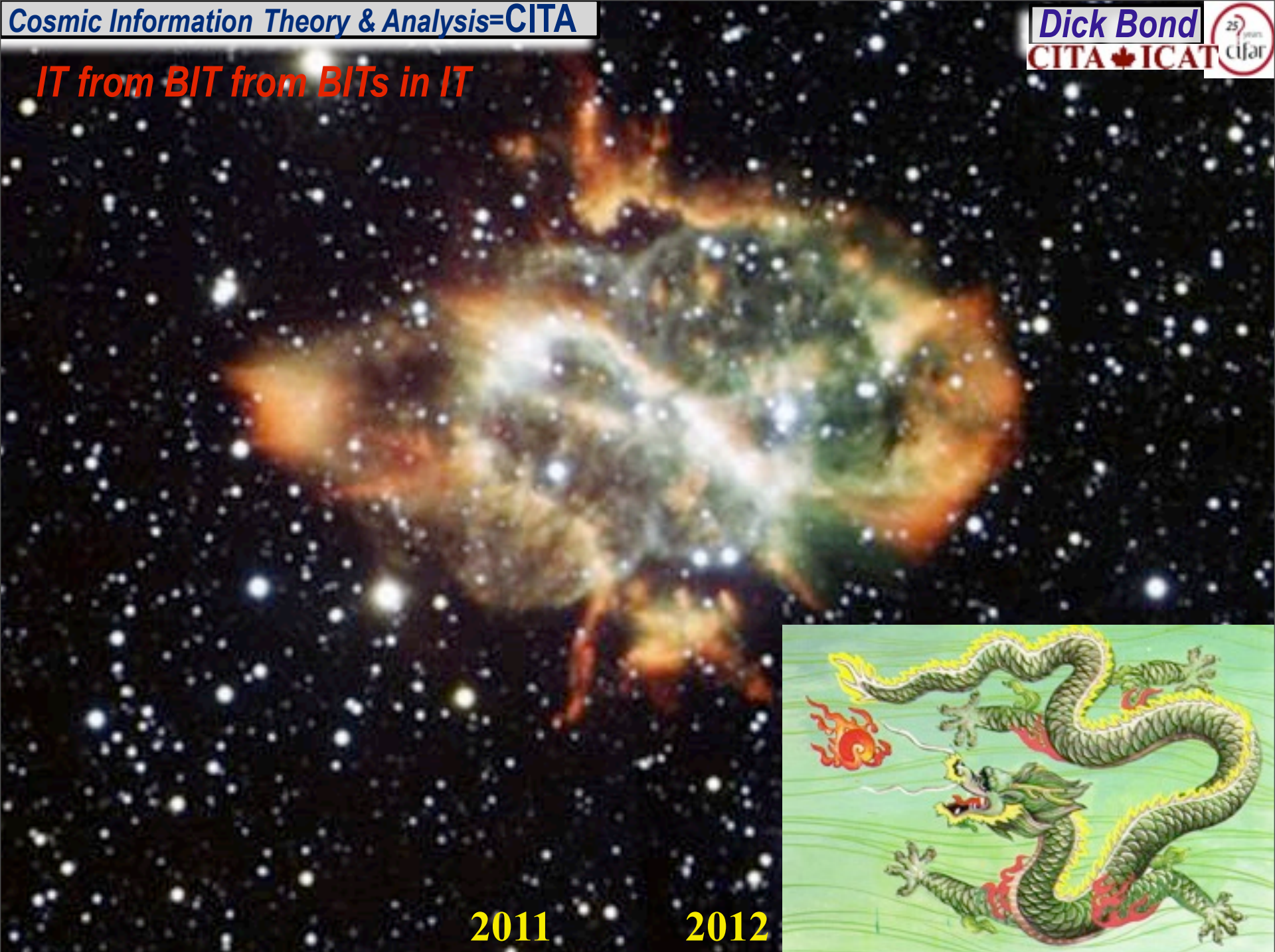
IT from BIT from BITs in IT



2011

2012

IT from BIT from BITS in IT



2011

2012



IT from BIT from BITS in IT



2011

2012



"IT from BIT" from BITs in IT

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

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

0.4 Myr 1100



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

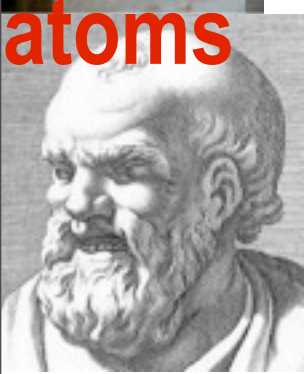
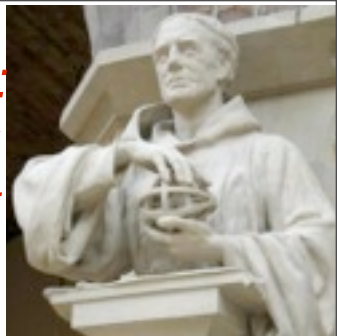
2 Gyr 4

what message in the information medium?

The 'Meaning' may change But the facts will remain

PYTHAGORAS 550 BCE THEORIST Cosmos \supset 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**

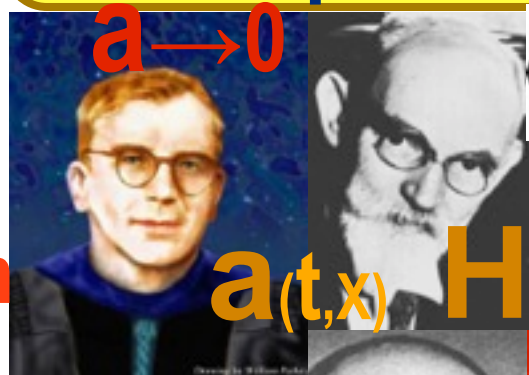


PE
vacuum

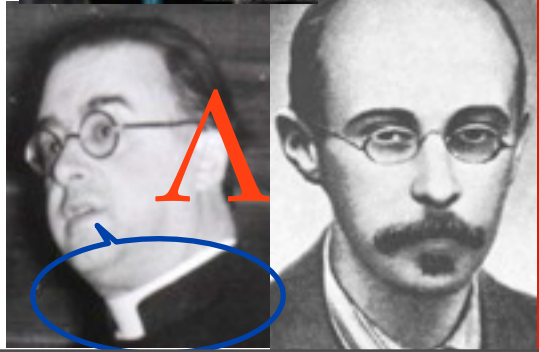
$a \rightarrow 0$



Milky Way 1953-55

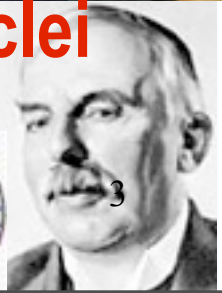


$a(t,x)$ H



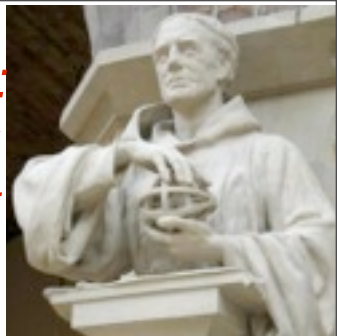
nuclei

atoms

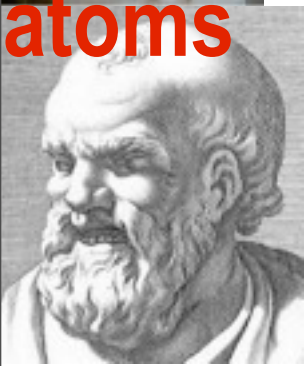


PYTHAGORAS 550 BCE THEORIST Cosmos \supset mathematics, digital "all is number", harmonic frequency/wavelength

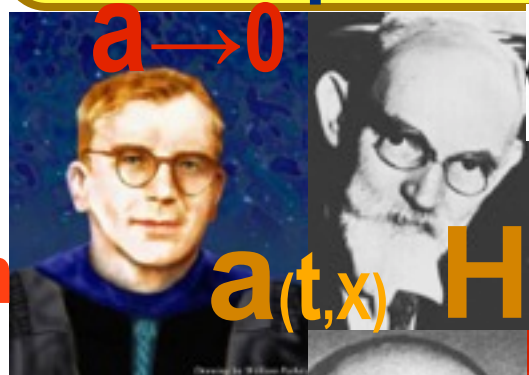
bacon:
theory
& expt



atoms



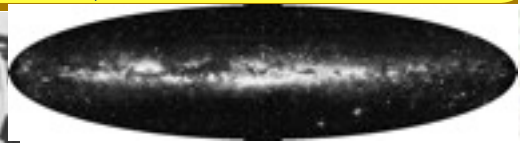
**a very brief human history
of how
Cosmic Information
was generated by Us:
highly filtered,
compressed, reduced**



$a \rightarrow 0$

PE vacuum

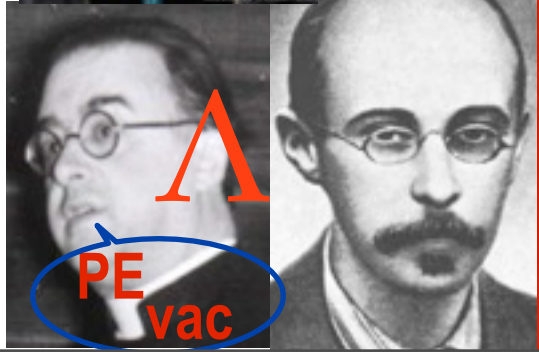
$a(t,x)$ H



Milky Way 1953-55



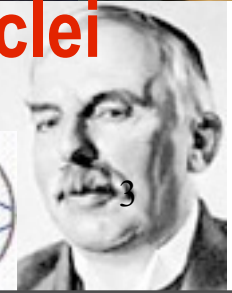
Δ



Δ

PE vac

nuclei

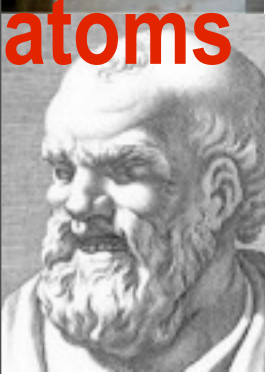
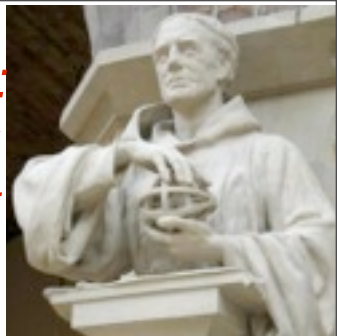


atoms



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

bacon:
theory
& expt



atoms

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



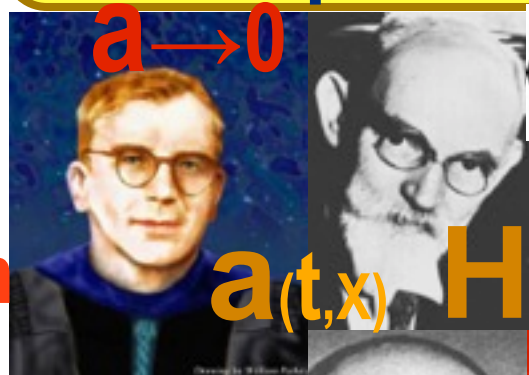
G



Milky Way 1953-55

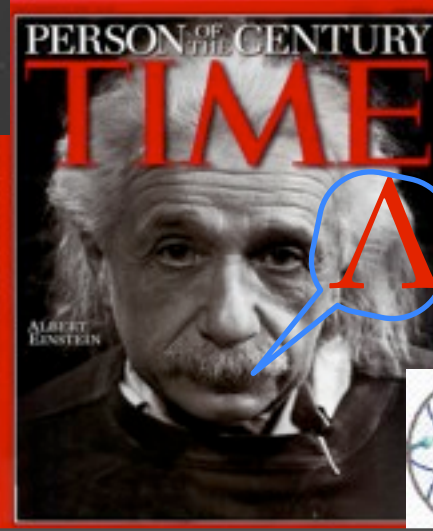


PE vacuum



$a \rightarrow 0$

$a(t,x)$ H

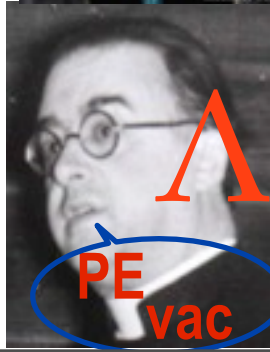


nuclei

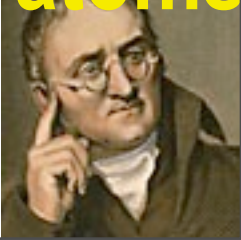
atoms



Λ

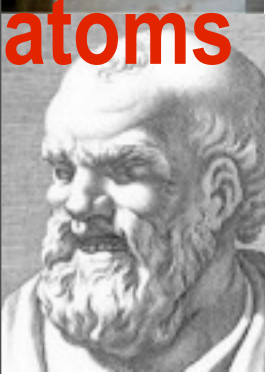
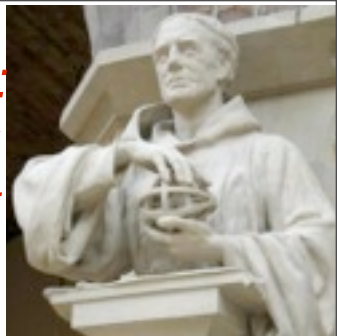


PE vac



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

bacon:
theory
& expt



atoms

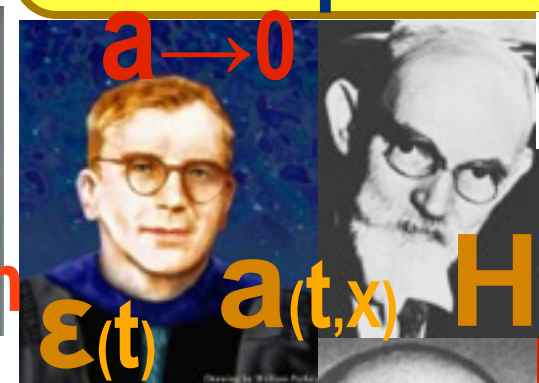
**a very brief human history
of how
Cosmic Information
was generated by Us:
highly filtered,
compressed, reduced**



G

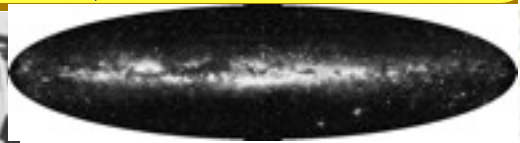


PE vacuum

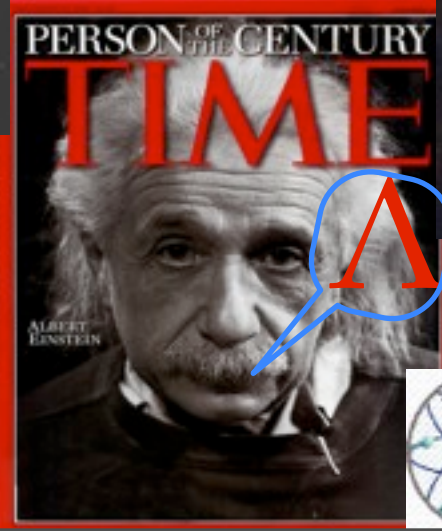


$a \rightarrow 0$

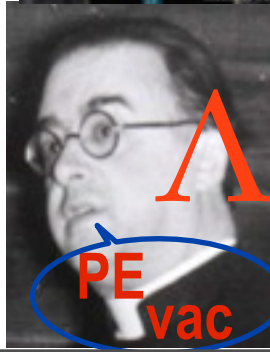
$\epsilon(t)$ $a(t,x)$ H



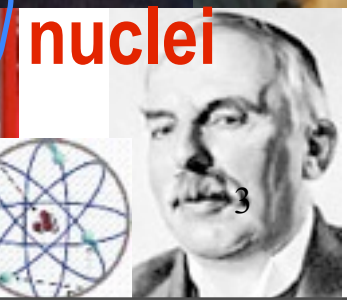
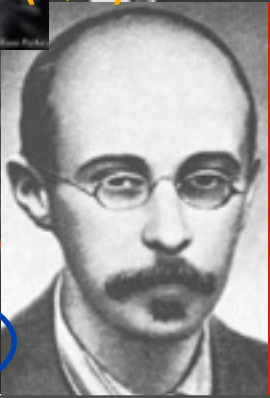
Milky Way 1953-55



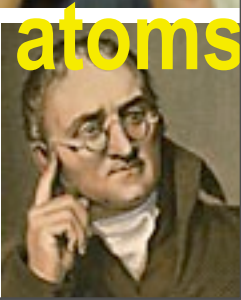
Δ



PE vac



nuclei



atoms

“IT from BIT”

FATE U inflate (again)

a cold death? reheat/rebirth?

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

Inflation fluctuations form: quantum jitter

NOW 14 Gyr 1

Pythagoras formed $a(t,x)$

Galaxies Cluster Cosmic “web” of vast filaments + membranes

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

Protons/Neutrons form

Solar system earth form

Life forms on earth

Helium forms

100 sec 10^9

1st light

2nd light

9 Gyr 1.4

Carbon/oxygen/etc form

Let there be Light

Cosmic background radiation released from matter

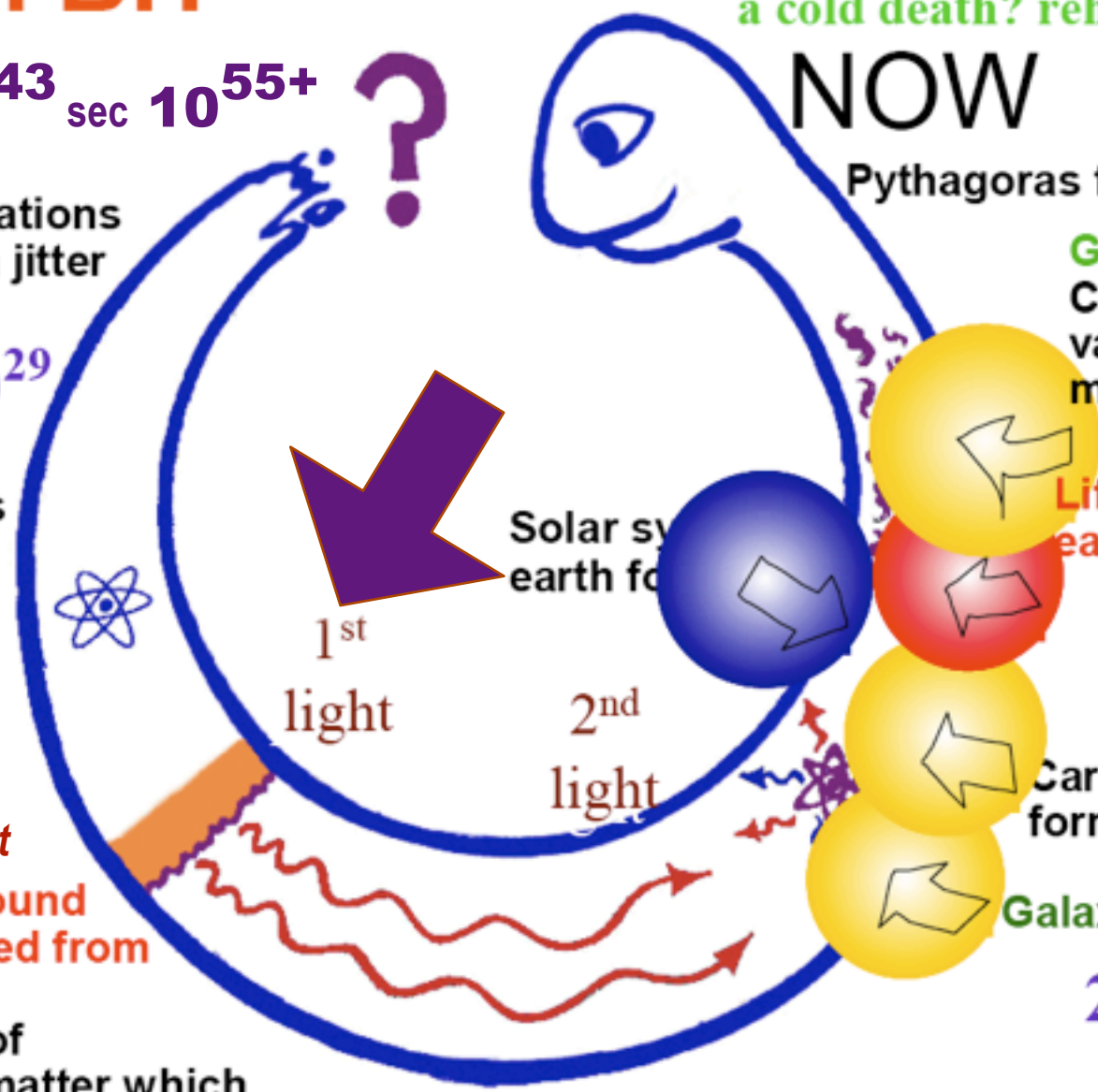
carries imprint of fluctuations in matter which grow to generate galaxies etc.

0.4 Myr 1100

Galaxies form

2 Gyr 4

The ‘Meaning’ may change But the facts will remain



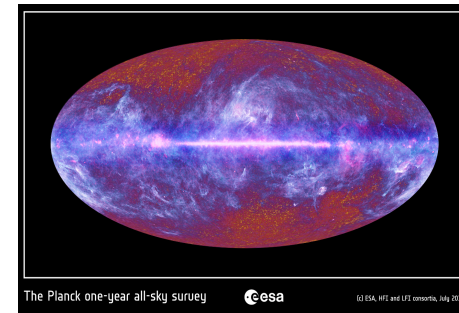
the gatherers of cosmic information

****C**osmic **M**icrowave **B**ackground ****+**

Large **S**cale **S**tructure 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 Λ CDM).* 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*



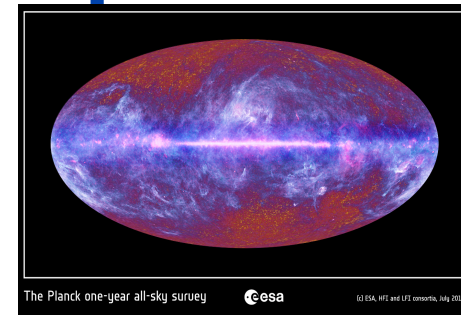


the gatherers of cosmic information

****C**osmic **M**icrowave **B**ackground ****+**

Large **S**cale **S**tructure experimental probes

then & now & then



The Planck one-year all-sky survey

esa

© ESA, IRT and UFR cosmetics, July 2010

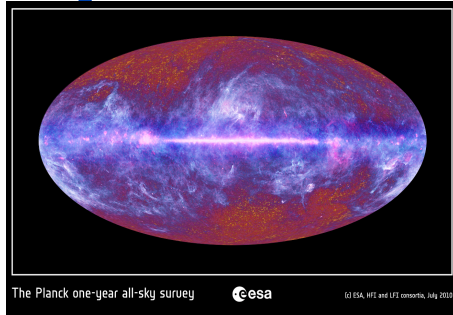


the gatherers of cosmic information

****C**osmic **M**icrowave **B**ackground ****+**

Large **S**cale **S**tructure experimental probes

then & now & then



The Nobel Prize in Physics 2006

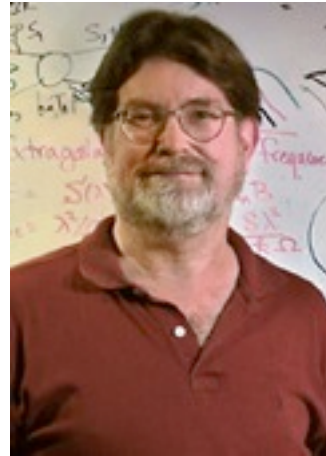
(also Gruber Prize in Cosmology 2006 for Mather + the COBE team)

& SN Λ Nobel 2011

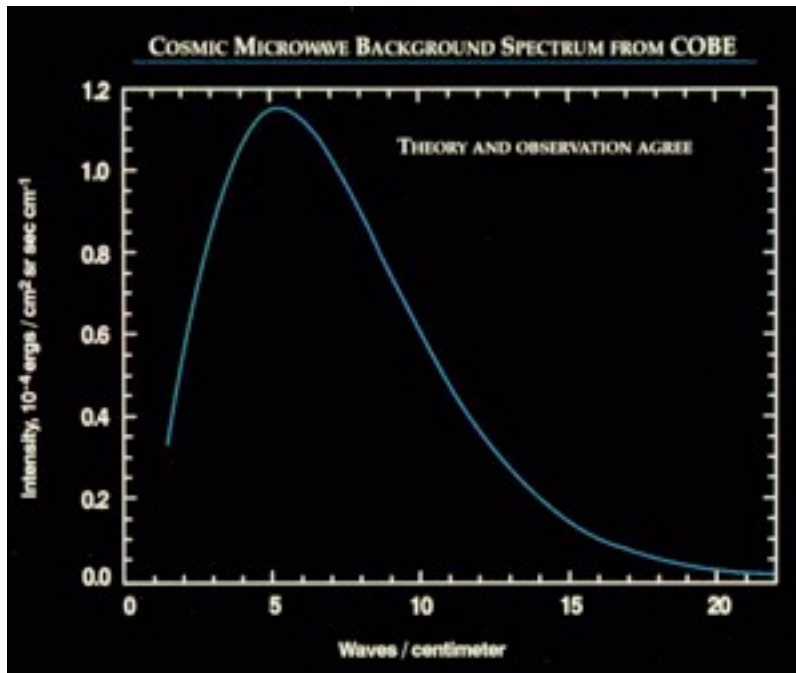
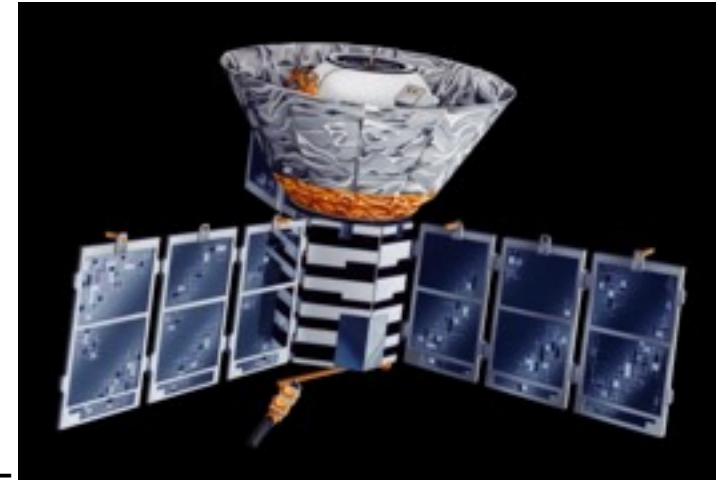
"for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation"



John C. Mather 1946-



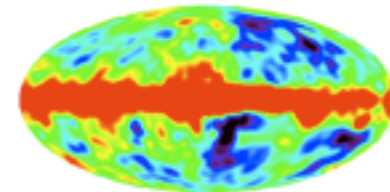
George F. Smoot 1945-



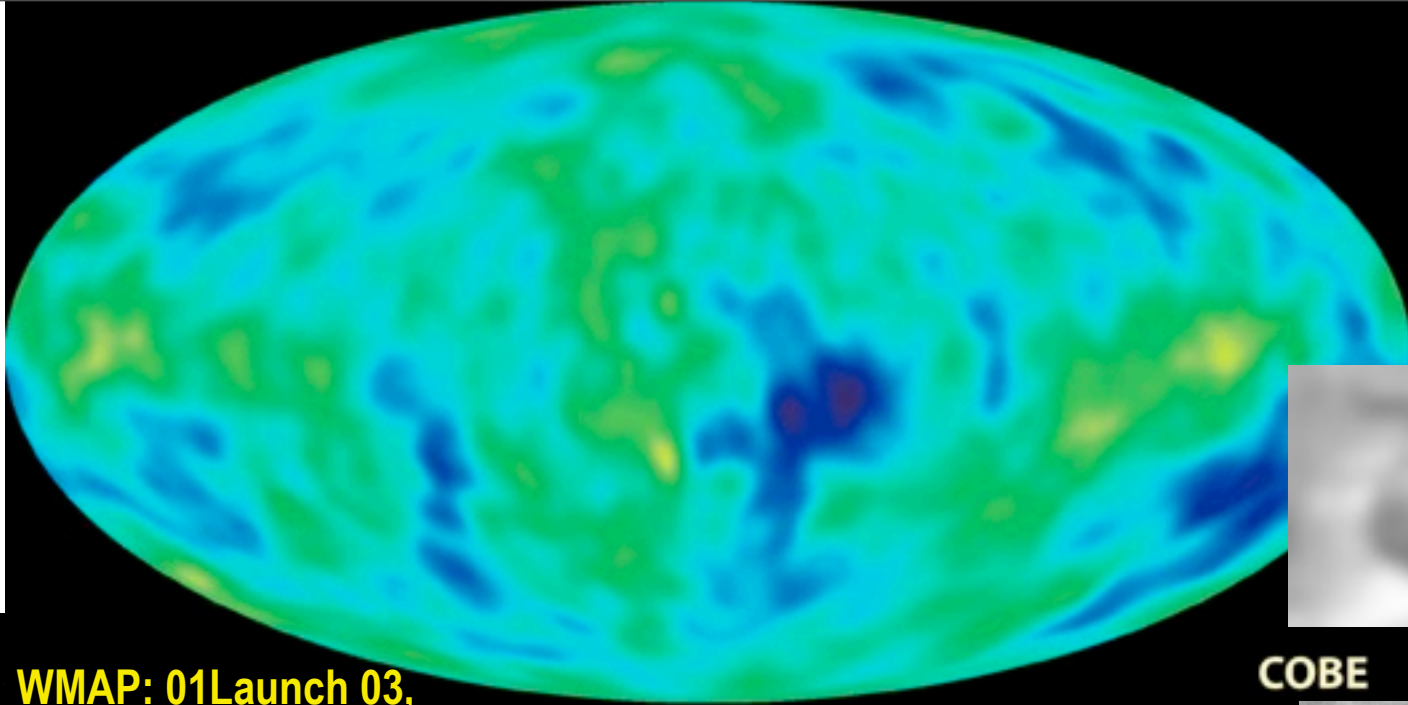
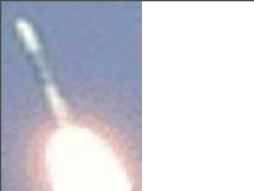
CMB

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°

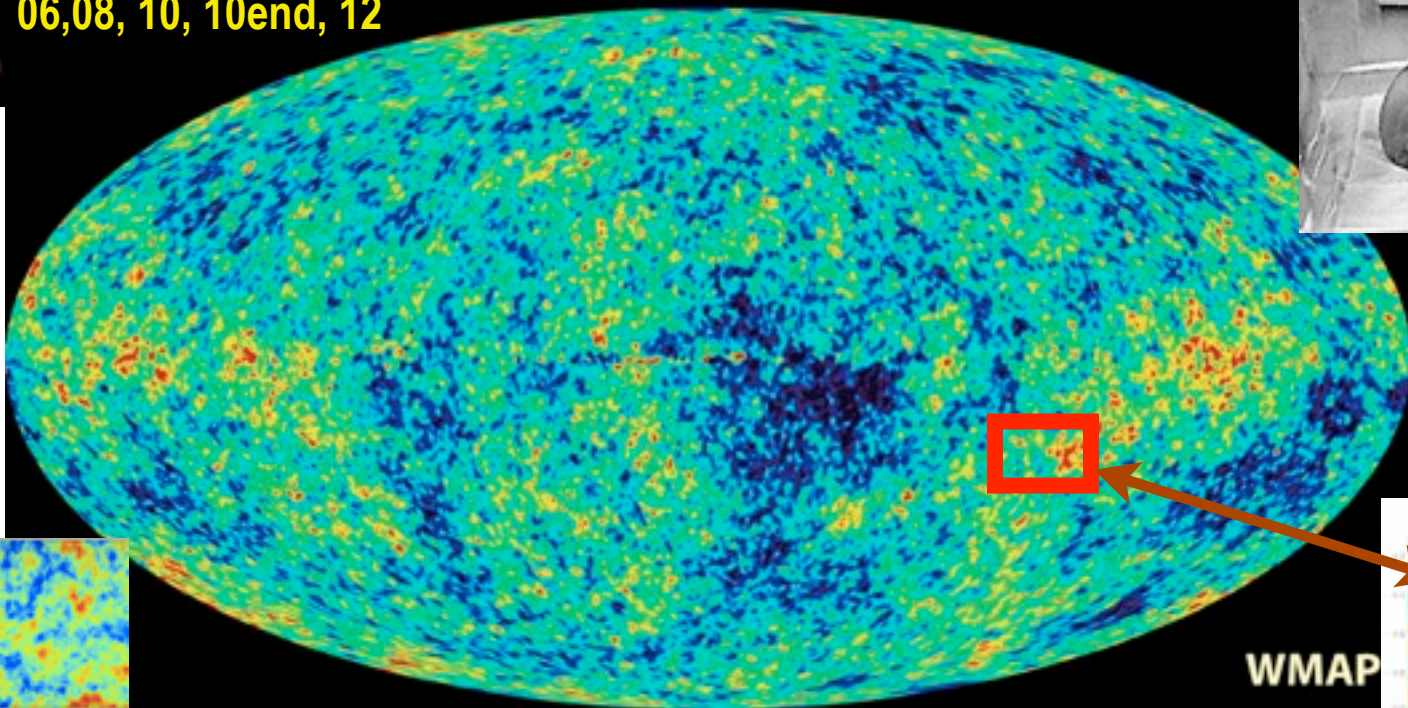


WMAP: 01 Launch 03, 06, 08, 10, 10end, 12

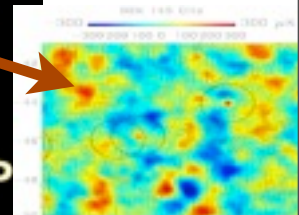
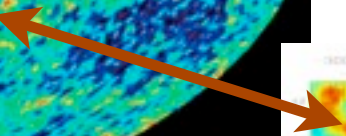
COBE



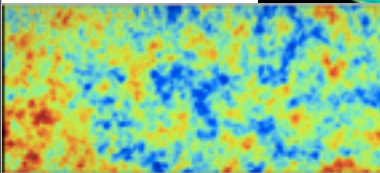
**ACT
+WMAP7
2011**



**BOOM
2000
2005**



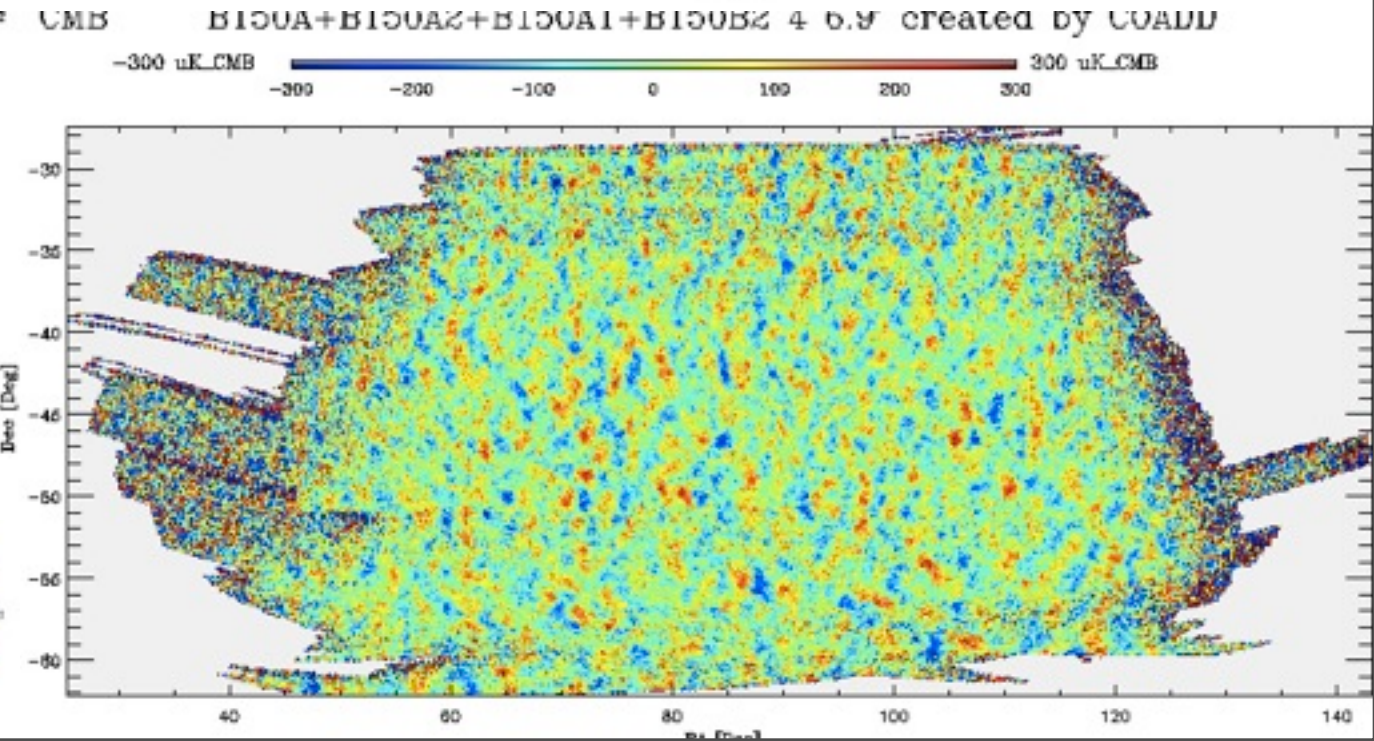
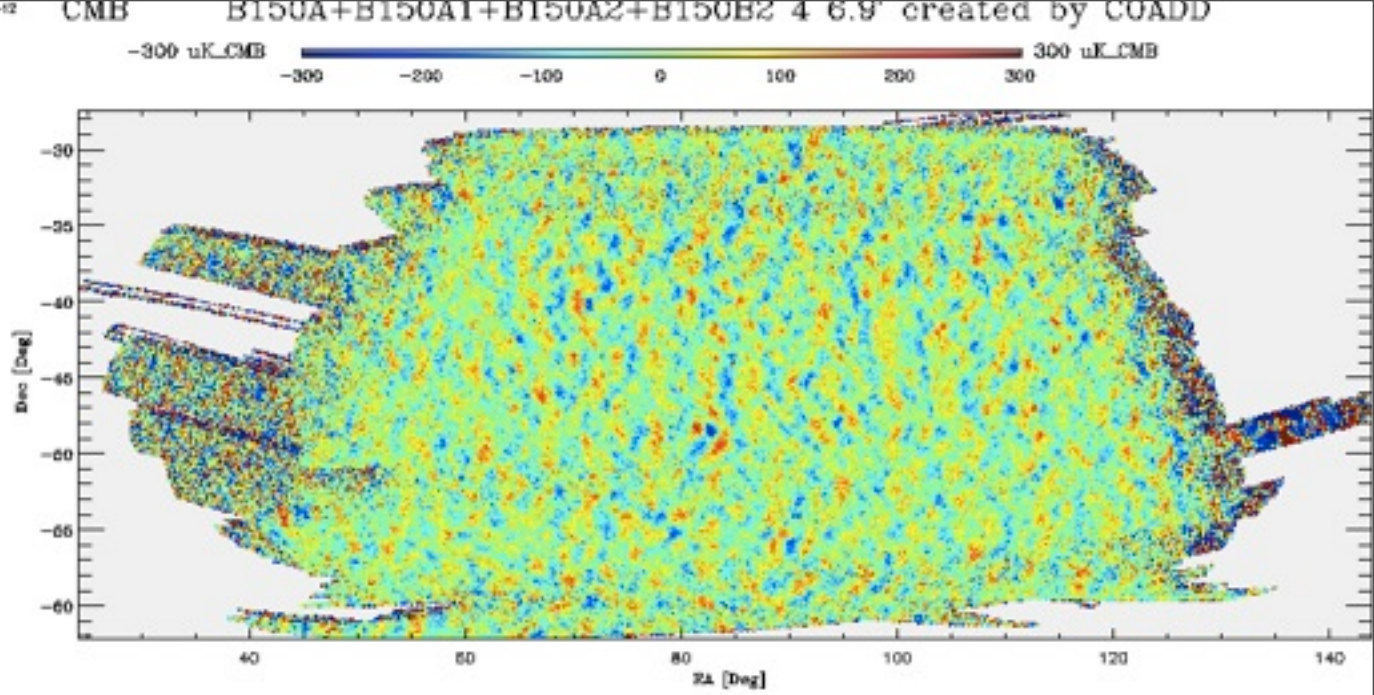
WMAP



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

looks the same
00,01,02 pre-WMAP

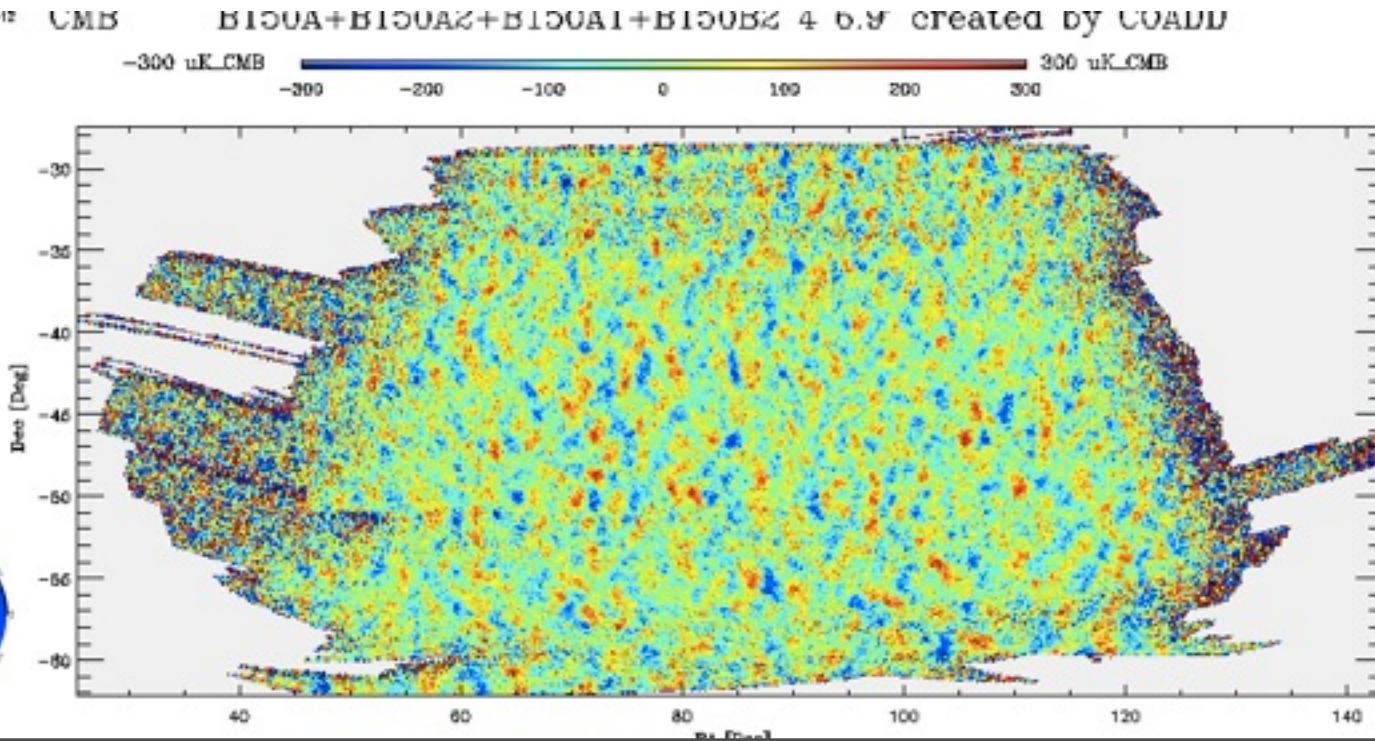
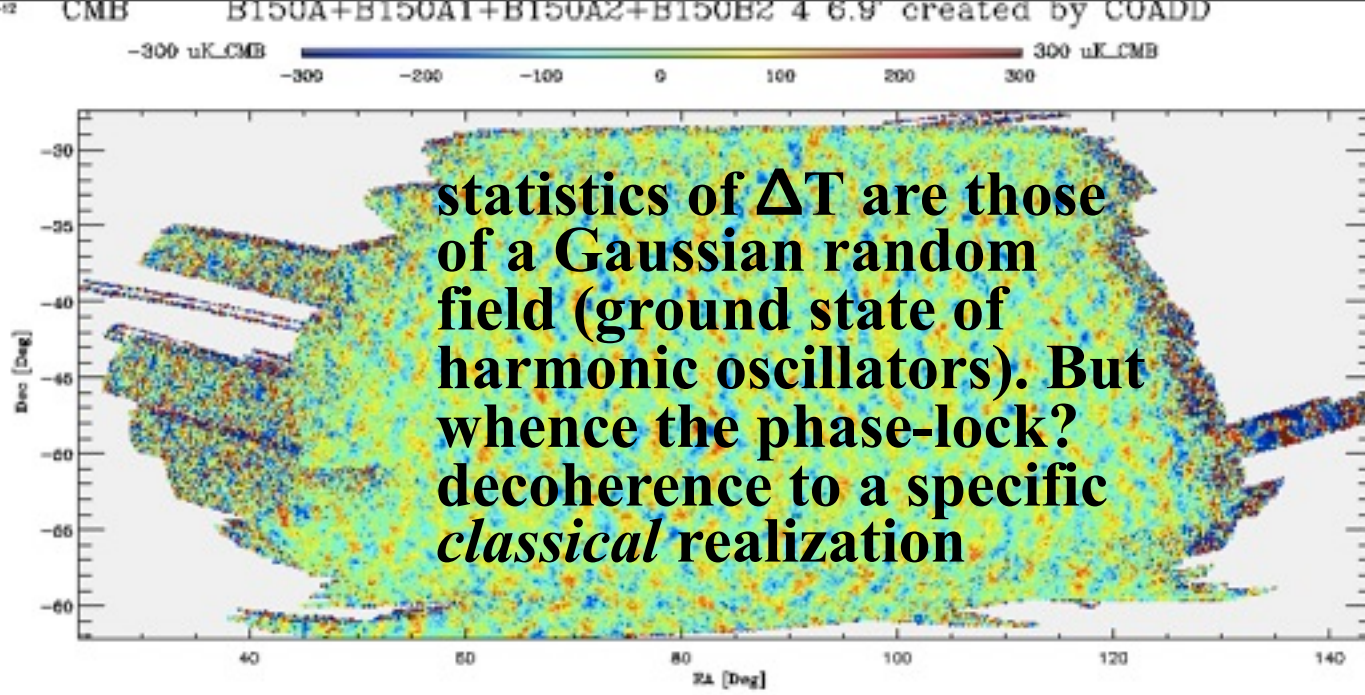
thermodynamic
CMB temperature
fluctuations 2.9%
of sky $\Delta T \sim 30$ ppm



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

looks the same
00,01,02 pre-WMAP

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

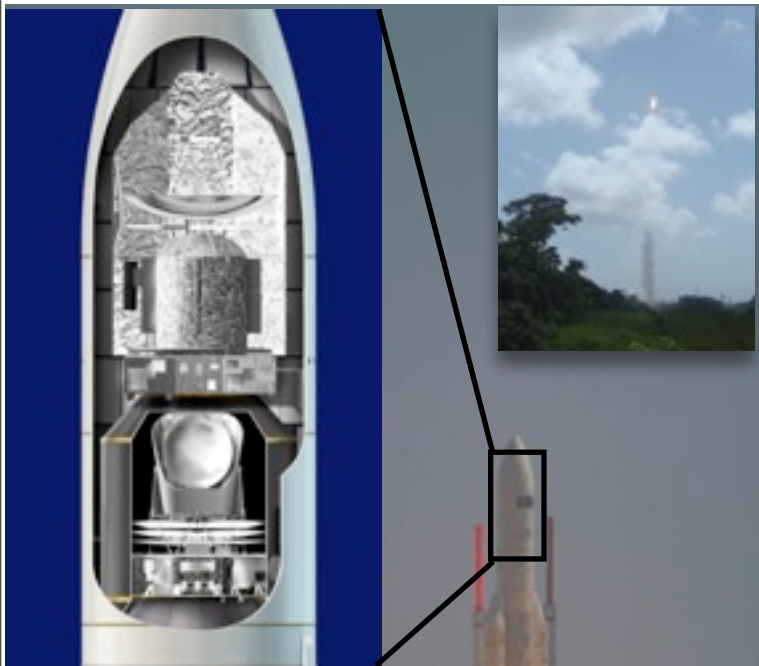


The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 50 scientific institutes in Europe, the USA and Canada



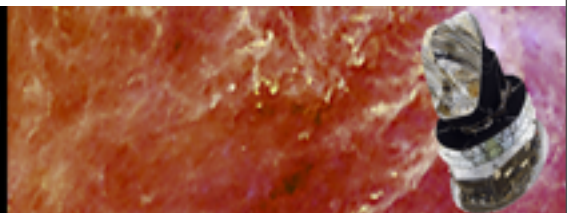
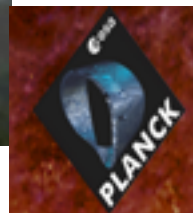
Planck is a project of the European Space Agency -- ESA -- with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a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



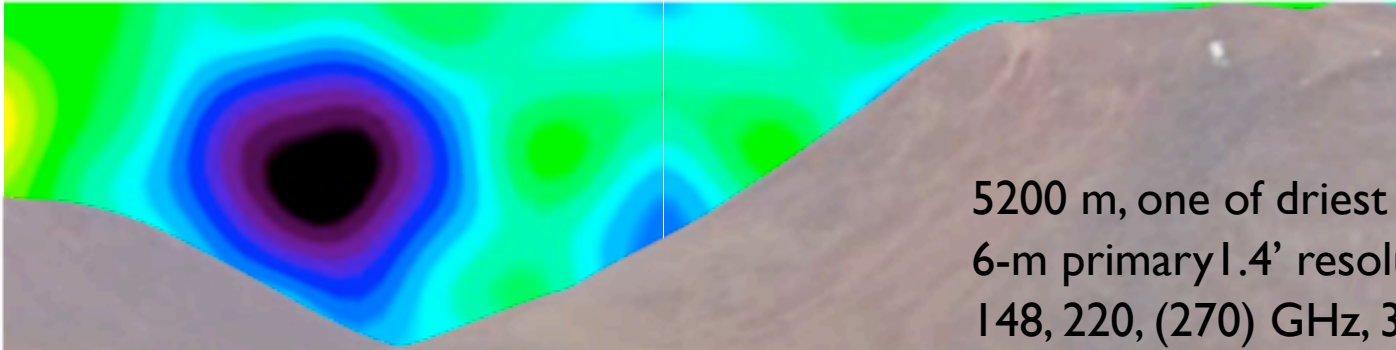
1.5m telescope, HFI bolometers
 @6freq <100mK, LFI HEMTs@3freq,
 some bolometers & all HEMTS are
 polarization sensitive

HFI+LFI performance to spec or better

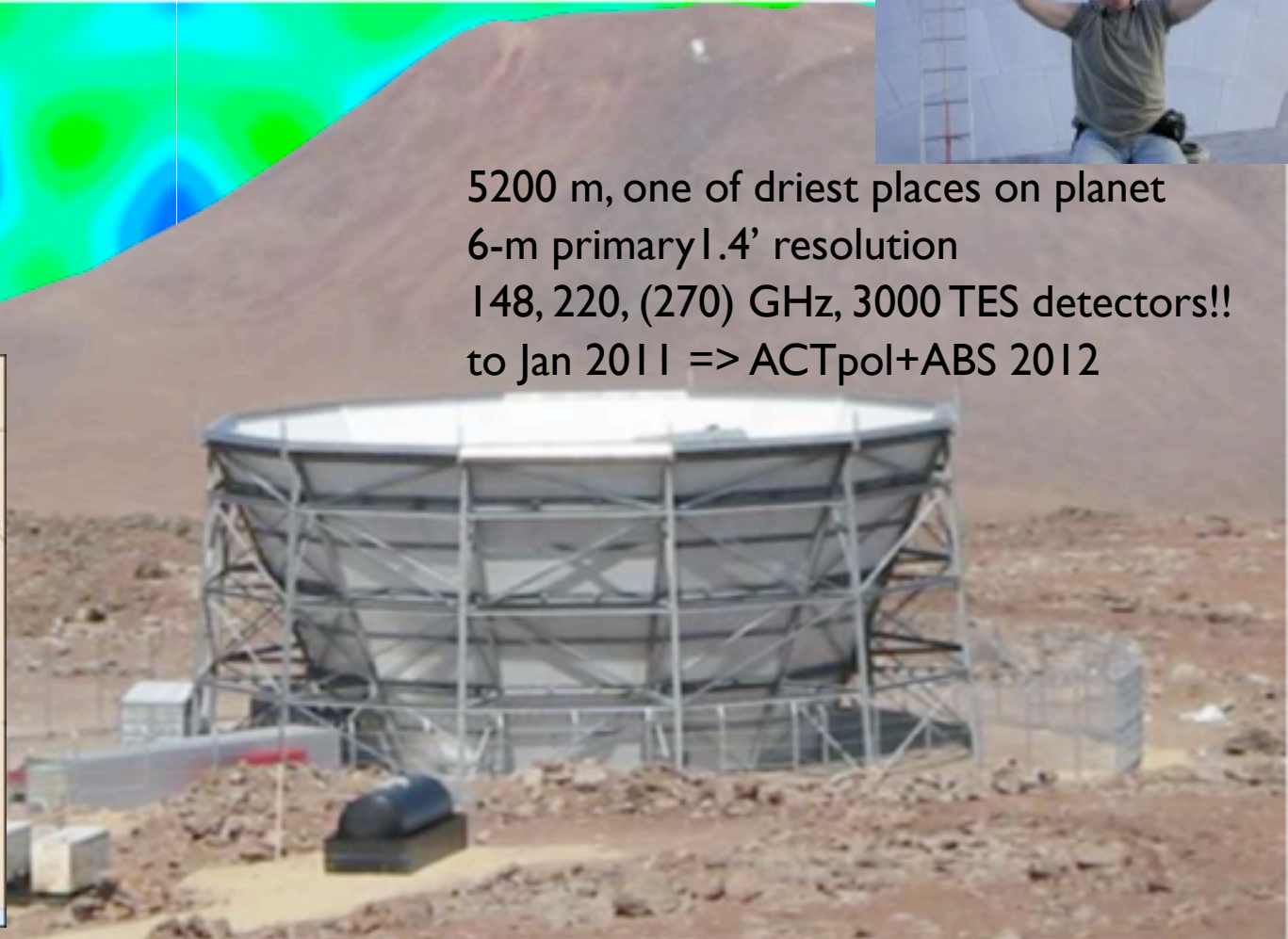


Left earth at ~10 km/s, 1.5 million km in 45 days, cooling on the way (20K, 4K, 1.6K, 0.1K 4 stage).
 @L2 on July 2 09 -almost no trajectory correction @operational temp; Survey started on Aug 13 09
 spin@1 rpm, 40-50 minutes on the same circle, covers all-sky in ~6 month, ~2.43 years to Jan14,2012

Cosmology From 5200 metres: the Atacama Cosmology Telescope



5200 m, one of driest places on planet
6-m primary 1.4' resolution
148, 220, (270) GHz, 3000 TES detectors!!
to Jan 2011 => ACTpol+ABS 2012



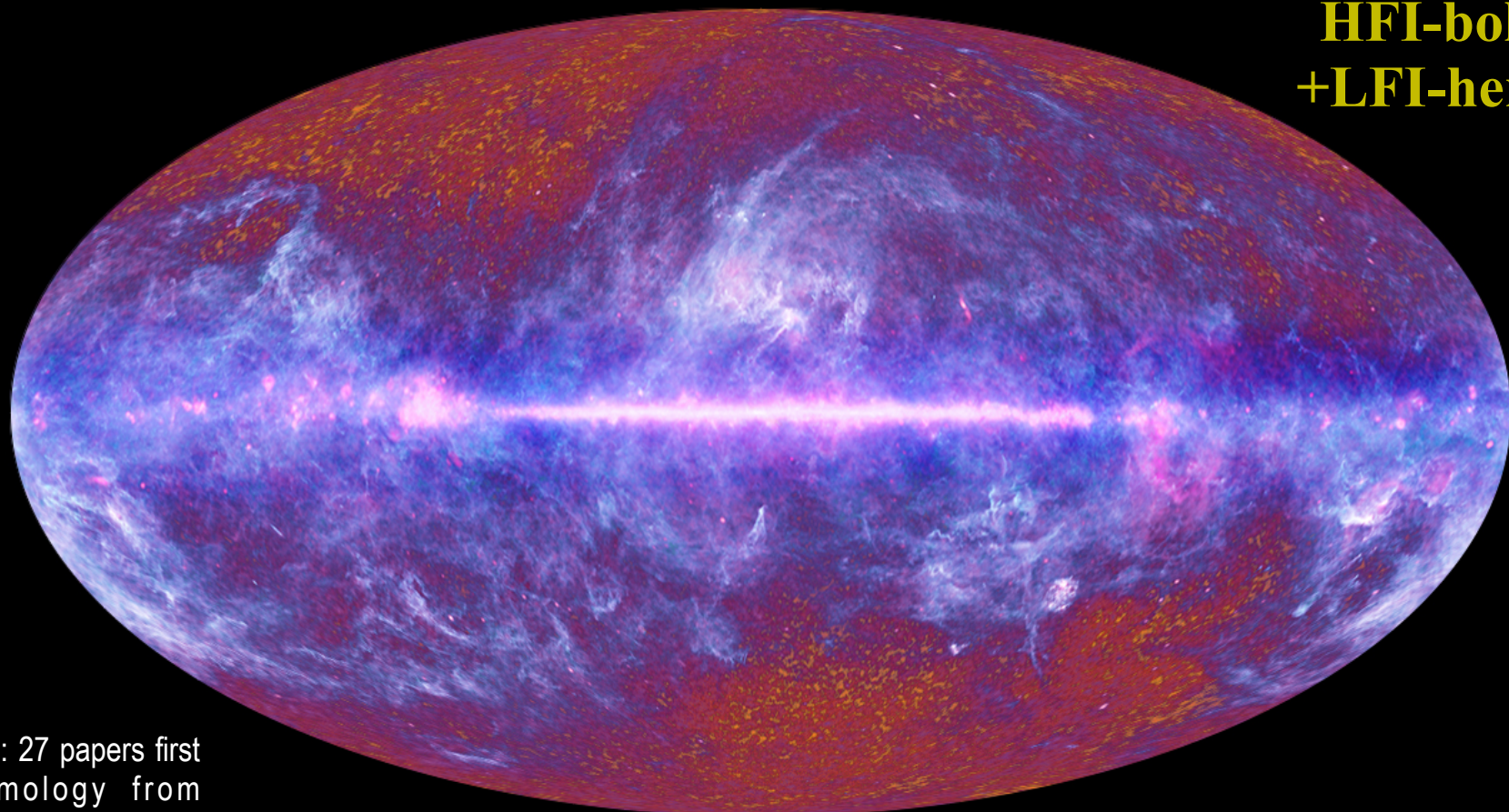
CMB@CITA: Boomerang, Acbar, CBI1,2, Planck, ACT, Spider, Blast, & ACTpol, ABS, QUIET90-2;
GBT-Mustang2, CARMA/SZA, SCUBA2, ALMA; other CMB: QuAD, SPT/SPTpol, BICEP/KECK, EBEX, PolarBear, ...

Planck & ACT

7 veils(v)+CMB

Dick Bond

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

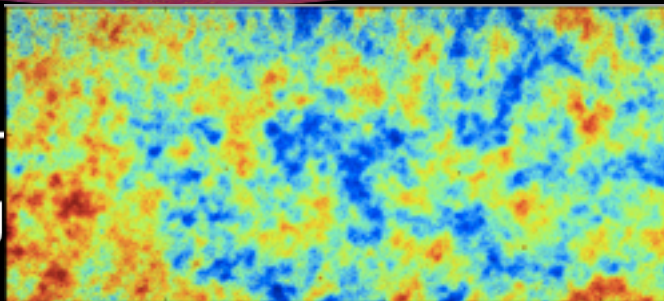


2011: 27 papers first
cosmology from
Planck early 2013,
major polarization
release early 2014

ACT+WMAP7 *hajian+10*

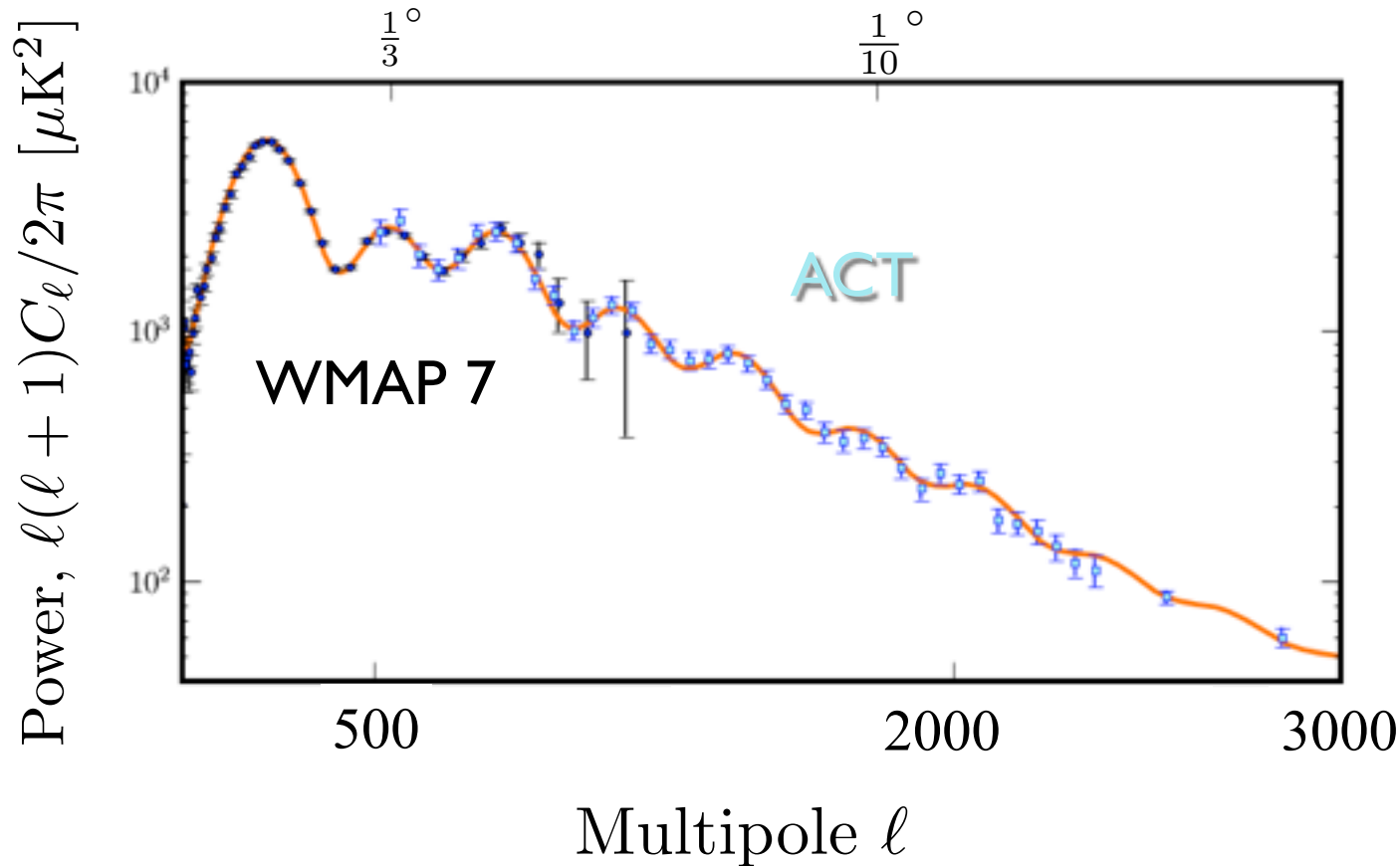
The Planck one-year all-sky survey

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

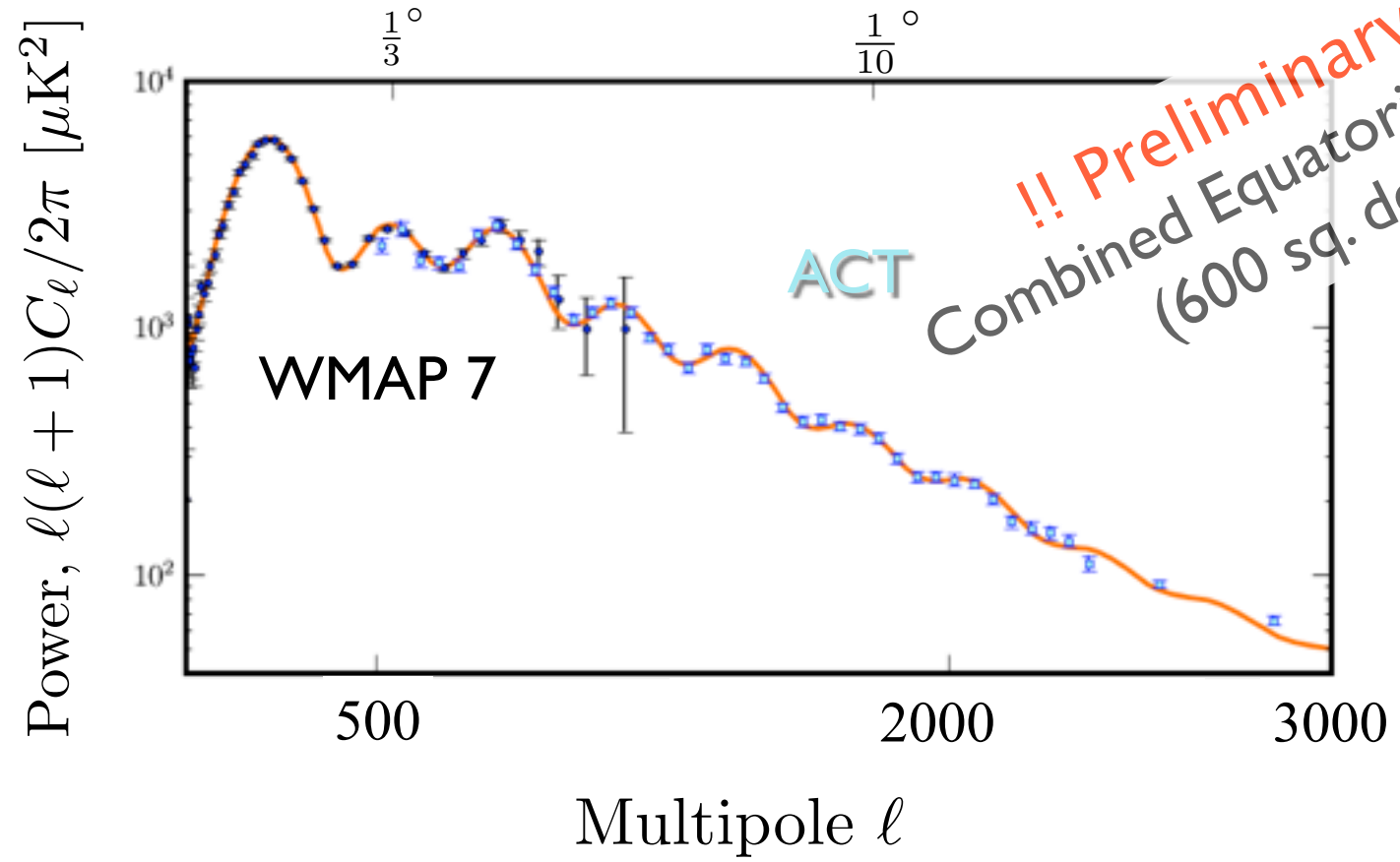
HIGH RESOLUTION POWER SPECTRUM from ACT: OLD Angular Scale



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

(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

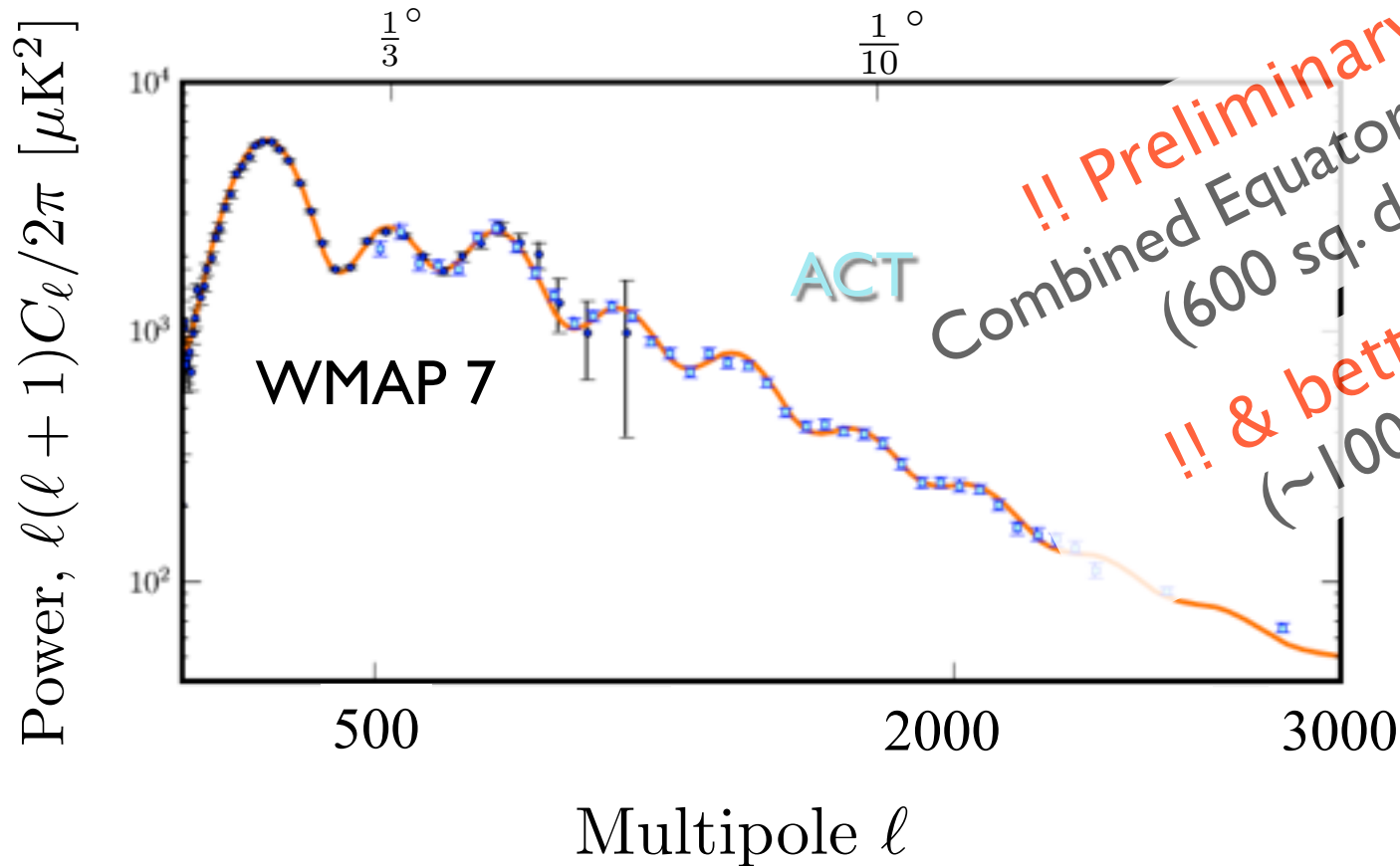
HIGH RESOLUTION POWER SPECTRUM from ACT: NEW Angular Scale



Das+ 2011, ApJ, 729:62, Hajian_2011, **Dunkley+.2011**, Hlozek+ 2011, Das+2011, Sherwin+2011, ..., **Sievers+2012**
tilted Λ CDM a very good fit (n_s constant); data are good enough to search for subdominant cosmic parameters N_v , X_{He} , r , $dn_s/dlnk$, $n_s(k)$ in bands, CMB lensing, .. & we have (strings, isocurvature,..)

(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: NEW Angular Scale



Das+ 2011, ApJ, 729:62, Hajian_2011, **Dunkley+.2011**, Hlozek+ 2011, Das+2011, Sherwin+2011, ..., **Sievers+2012**
tilted Λ CDM a very good fit (n_s constant); data are good enough to search for subdominant cosmic parameters N_ν , X_{He} , r , $dn_s/dlnk$, $n_s(k)$ in bands, CMB lensing, .. & we have (strings, isocurvature,..)

“IT from BIT”

FATE U inflate (again)

a cold death? reheat/rebirth?

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

Inflation fluctuations form: quantum jitter

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

Protons/Neutrons form

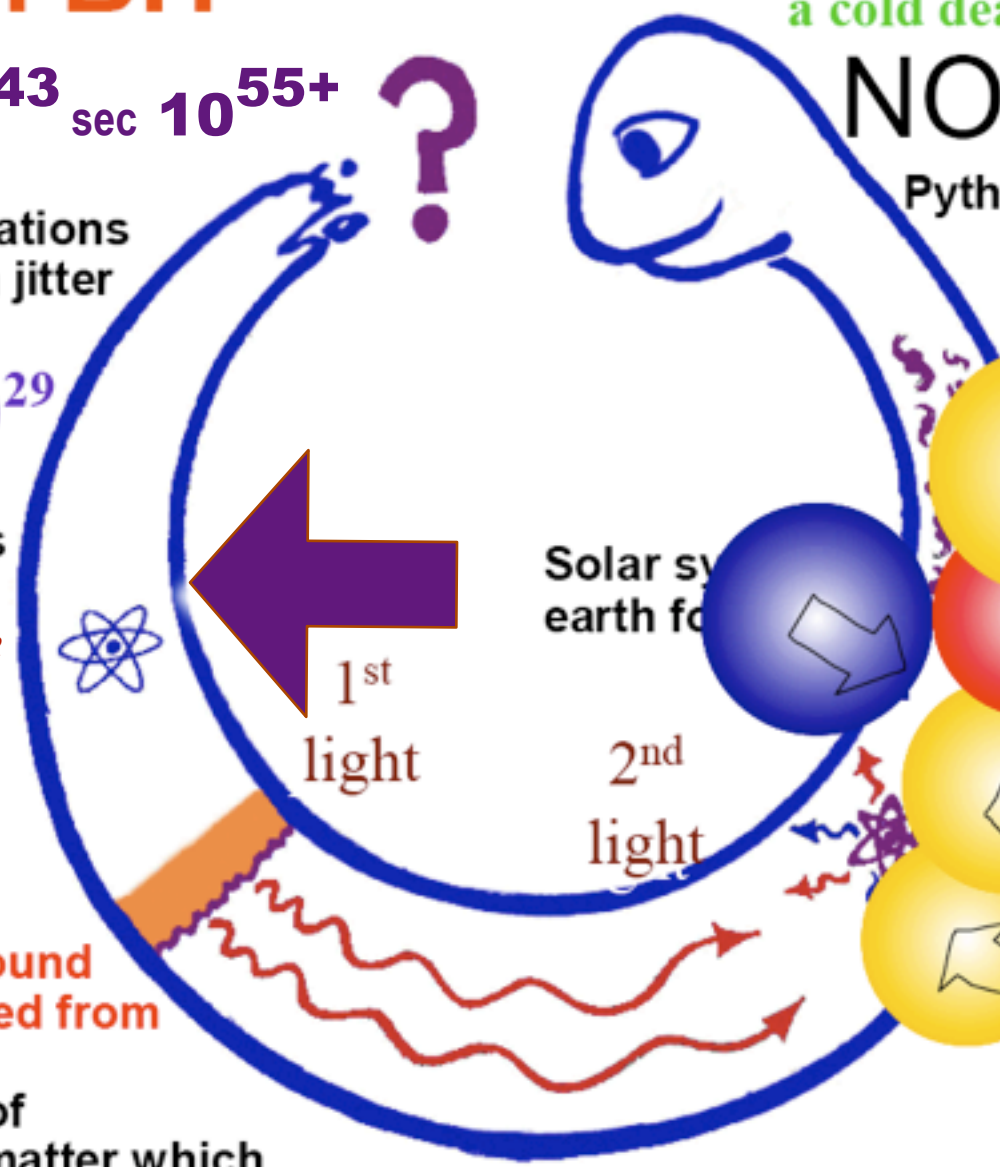
Let there be p n α γ ve

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



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

1 (IA) Hydrogen H ₁ 1.00794 91.0%	2 (IIA) Lithium Li ₃ 6.941 6.88×10 ⁻⁴ %	Beryllium Be ₄ 9.012182 2.38×10 ⁻⁴ %	Sodium Na ₁₁ 22.989770 0.000117%	Magnesium Mg ₁₂ 24.3050 0.000150%	Potassium K ₁₉ 39.0983 0.000117%	Calcium Ca ₂₀ 40.078 0.000189%	Manganese Mn ₂₅ 54.938044 0.000044%	Iron Fe ₂₆ 55.845 0.00024%	Cobalt Co ₂₇ 58.933200 7.3×10 ⁻⁵ %	Nickel Ni ₂₈ 58.6934 0.00016%	Copper Cu ₂₉ 63.546 1.70×10 ⁻⁴ %	Zinc Zn ₃₀ 65.38 4.12×10 ⁻⁴ %	Gallium Ga ₃₁ 69.723 1.23×10 ⁻⁴ %	Germanium Ge ₃₂ 72.61 1.9×10 ⁻⁵ %	Arsenic As ₃₃ 74.9216 2.1×10 ⁻⁵ %	Selenium Se ₃₄ 78.96 2.03×10 ⁻⁵ %	Bromine Br ₃₅ 79.904 1.5×10 ⁻⁵ %	Krypton Kr ₃₆ 83.80 1.5×10 ⁻⁶ %	Helium He ₂ 4.002602 8.9%
---	--	---	--	---	--	--	---	--	---	---	---	--	--	--	--	--	---	--	---

Rubidium Rb ₃₇ 85.4678 2.32×10 ⁻⁴ %	Strontium Sr ₃₈ 87.62 7.7×10 ⁻⁵ %	Yttrium Y ₃₉ 88.90585 1.46×10 ⁻⁵ %	Zirconium Zr ₄₀ 91.224 8.7×10 ⁻⁶ %	Niobium Nb ₄₁ 92.90638 2.28×10 ⁻⁶ %	Molybdenum Mo ₄₂ 95.94 4.3×10 ⁻⁶ %	Technetium Tc ₄₃ [98]	Ruthenium Ru ₄₄ 101.07 1.22×10 ⁻⁶ %	Rhodium Rh ₄₅ 102.90550 1.22×10 ⁻⁶ %	Palladium Pd ₄₆ 106.42 4.5×10 ⁻⁷ %	Silver Ag ₄₇ 107.8682 1.52×10 ⁻⁷ %	Cadmium Cd ₄₈ 112.411 [2]	Indium In ₄₉ 114.818 [2]	Tin Sn ₅₀ 118.710 [2]	Antimony Sb ₅₁ 121.760 [2]	Tellurium Te ₅₂ 127.60 [2]	Iodine I ₅₃ 126.90447 [2]	Xenon Xe ₅₄ 131.29 [2]
--	--	---	---	--	---	--	--	---	---	---	---	--	---	--	--	---	--

† Lanthanides

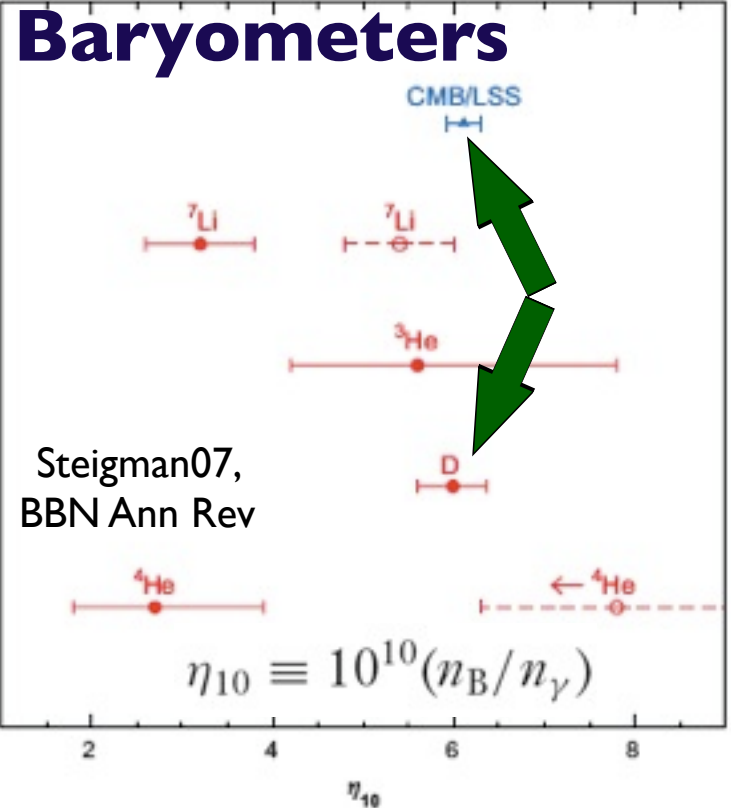
Cerium Ce ₅₈ 140.116 3.70×10 ⁻⁵ %	Praseodymium Pr ₅₉ 140.90765 5.44×10 ⁻⁶ %	Neodymium Nd ₆₀ 144.24 2.70×10 ⁻⁶ %	Promethium Pm ₆₁ [145]	Samarium Sm ₆₂ 150.36 8.42×10 ⁻⁷ %	Europium Eu ₆₃ 151.964 3.17×10 ⁻⁷ %	Gadolinium Gd ₆₄ 157.25 1.076×10 ⁻⁷ %	Terbium Tb ₆₅ 158.92534 1.97×10 ⁻⁸ %	Dysprosium Dy ₆₆ 162.50 1.286×10 ⁻⁸ %
--	--	--	---	---	--	--	---	--

‡ Actinides

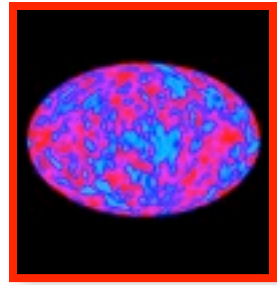
Thorium Th ₉₀ 232.0381 1.09×10 ⁻⁷ %	Protactinium Pa ₉₁ [231]	Uranium U ₉₂ 238.02891 2.84×10 ⁻⁷ %	Neptunium Np ₉₃ [237]	Plutonium Pu ₉₄ [244]	Americium Am ₉₅ [243]	Curium Cm ₉₆ [247]	Berkelium Bk ₉₇ [247]	Californium Cf ₉₈ [251]
--	---	--	--	--	--	-------------------------------------	--	--

periodic table of the isotopes

cosmic baryon number
 $n_b = 0.254 \pm 0.005 / m^3$



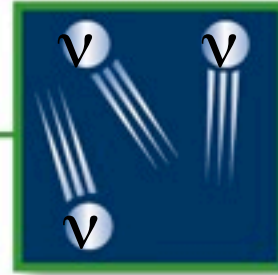
from the latest data: wmap7+acbar+cbi+b03+ACT+WL+LSS+SNI+Lya



Radiation:



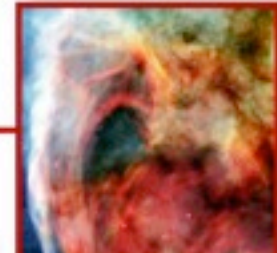
**Chemical Elements:
(other than H & He)**



Neutrinos:

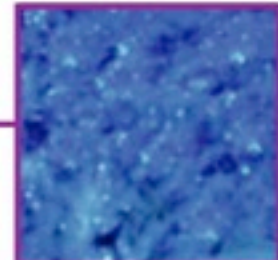


Stars:



**Free
H & He:**

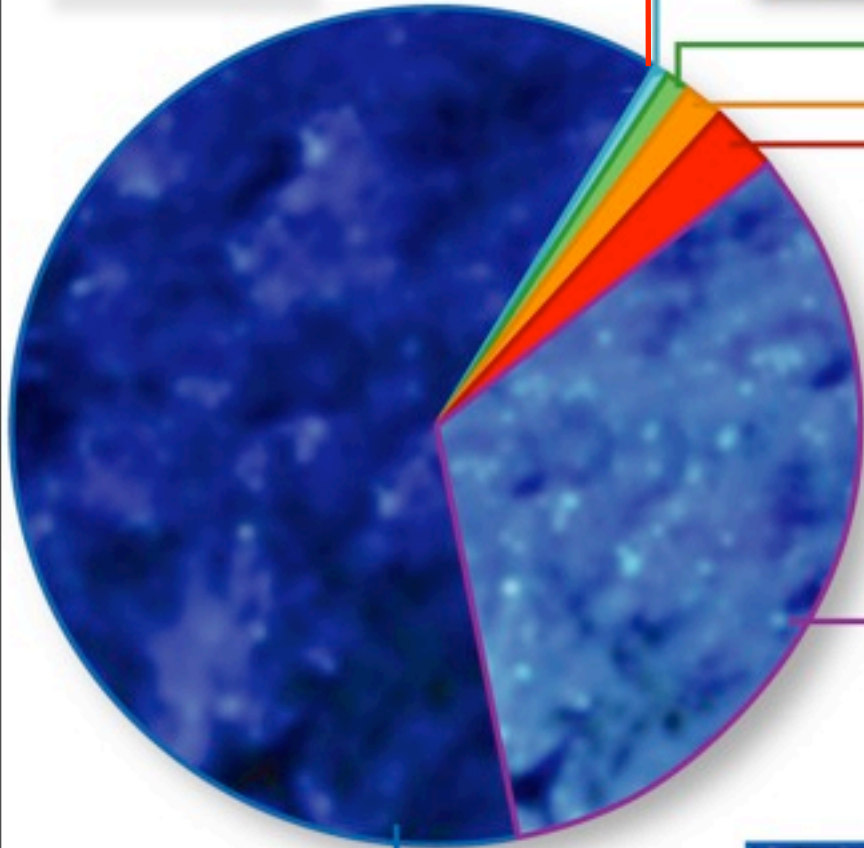
$$\Omega_{\text{total}} = 1 = \rho_{\text{total}} / 3H^2 M_p^2$$



Dark Matter:

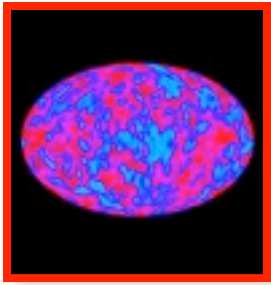


Dark Energy:



Gravity Waves

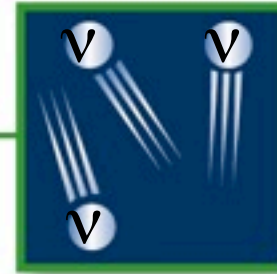
Black Holes



Radiation:
0.005%



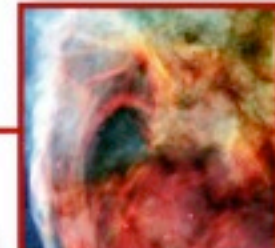
Chemical Elements:
(other than H & He) 0.025%



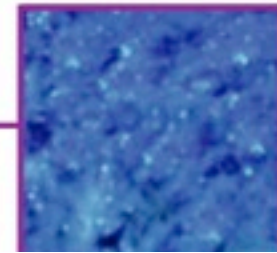
Neutrinos:
0.47%



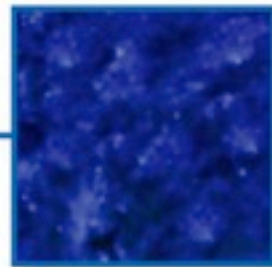
Stars:
0.5%



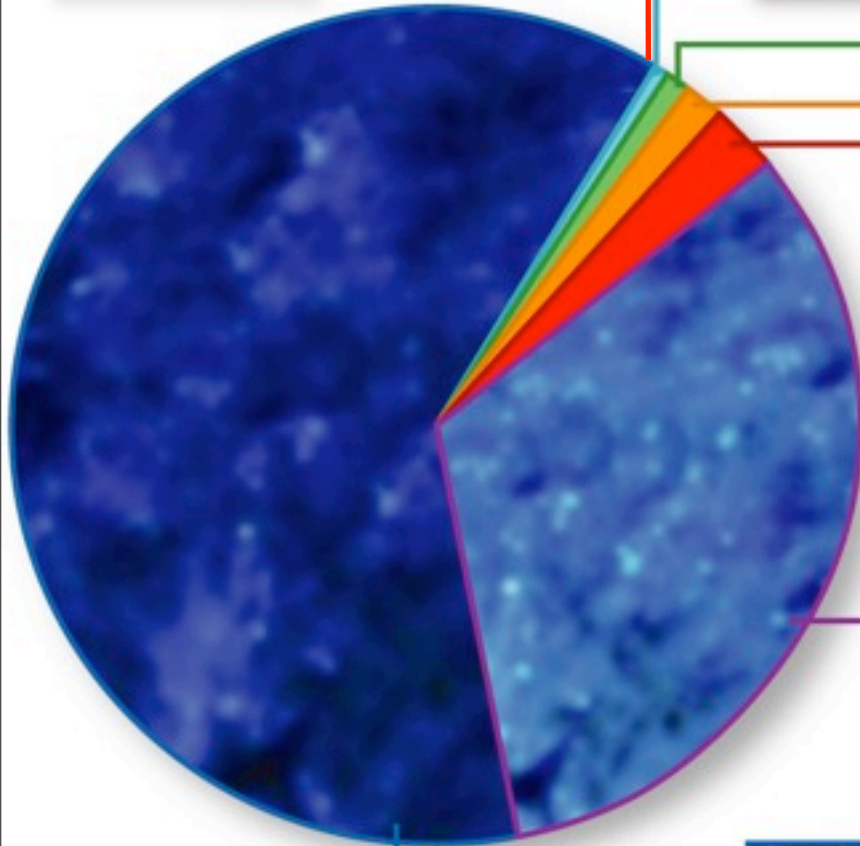
**Free
H & He:**
3.9%



Dark Matter:
 $\Omega_{dm} = 22.4 \pm 2\%$



Dark Energy:
 $\Omega_{\Lambda} = 74 \pm 2\%$



$$\Omega_{total} = 1 =$$

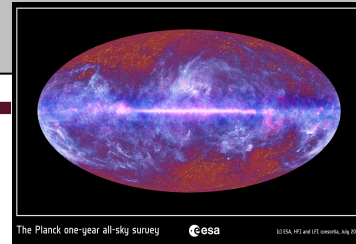
$$\rho_{total} / 3H^2 M_p^2$$

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

the gatherers of cosmic information

Cosmic **M**icrowave **B**ackground +
Large **S**cale **S**tructure 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**, ... **C****EXT**

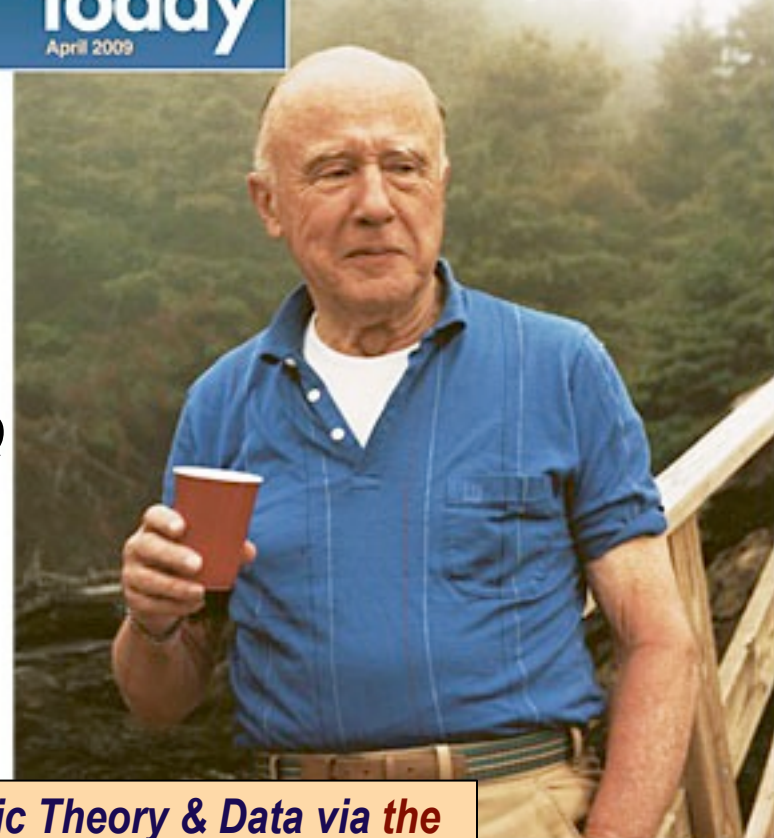
CITA = Cosmic Information Theory & Analysis: IT from BIT, from BITs in IT

"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."



Special issue:
John Archibald Wheeler

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 eqⁿs

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

CITA = Cosmic Information Theory & Analysis: IT from BIT, from BITs in IT, Studying the Cosmic Tango en-TANGO-ment the dance of U=R_US Universe =System(s)+Reservoir =Signal(s)+Residual noise =Effective Theory+Hidden variables, =Data+Theory, observer(s)+observed

U=R_US ruled by (information) entropy in bits, entangled. the fine grains in the coarse grains



S_{U,m+r} ~10^{88.6} in
 our Hubble_ΛVolume
 compressed onto
T_V ≈2.725K &
1/H₀≈14 Gyr
5.2 bits/γ
S_G ~10^{121.9}
S_m~1 bits/baryon
 atmosphere
S_{clusters}~190, in
 all~**10⁷⁶**
 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



CITA = Cosmic Information Theory & Analysis: IT from BIT, from BITs in IT, Studying the Cosmic Tango en-TANGO-ment the dance of $U=R_{U}S$ Universe =System(s)+Reservoir =Signal(s)+Residual noise =Effective Theory+Hidden variables, =Data+Theory, observer(s)+observed

$U=R_{U}S$ ruled by (information) entropy in bits, entangled. *the fine grains in the coarse grains*



COMPUTE the Universe

SciNet

Simulate Universes from ultra-early beginnings to the ultimate end, turning 6 parameter theories into Petabits

Process Data compressing the Petabit+ raw observed CMB +LSS information into high quality bits

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

27

“IT from BIT”

FATE U inflate (again)

a cold death? reheat/rebirth?

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

Inflation fluctuations form: quantum jitter

NOW 14 Gyr 1

Pythagoras formed

Galaxies Cluster
Cosmic “web” of vast filaments + membranes

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

Protons/Neutrons form

Solar system earth form

Life forms on earth

Helium forms

100 sec 10^9

1st light

2nd light

9 Gyr 1.4

Carbon/oxygen/etc form

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

Galaxies form

2 Gyr 4

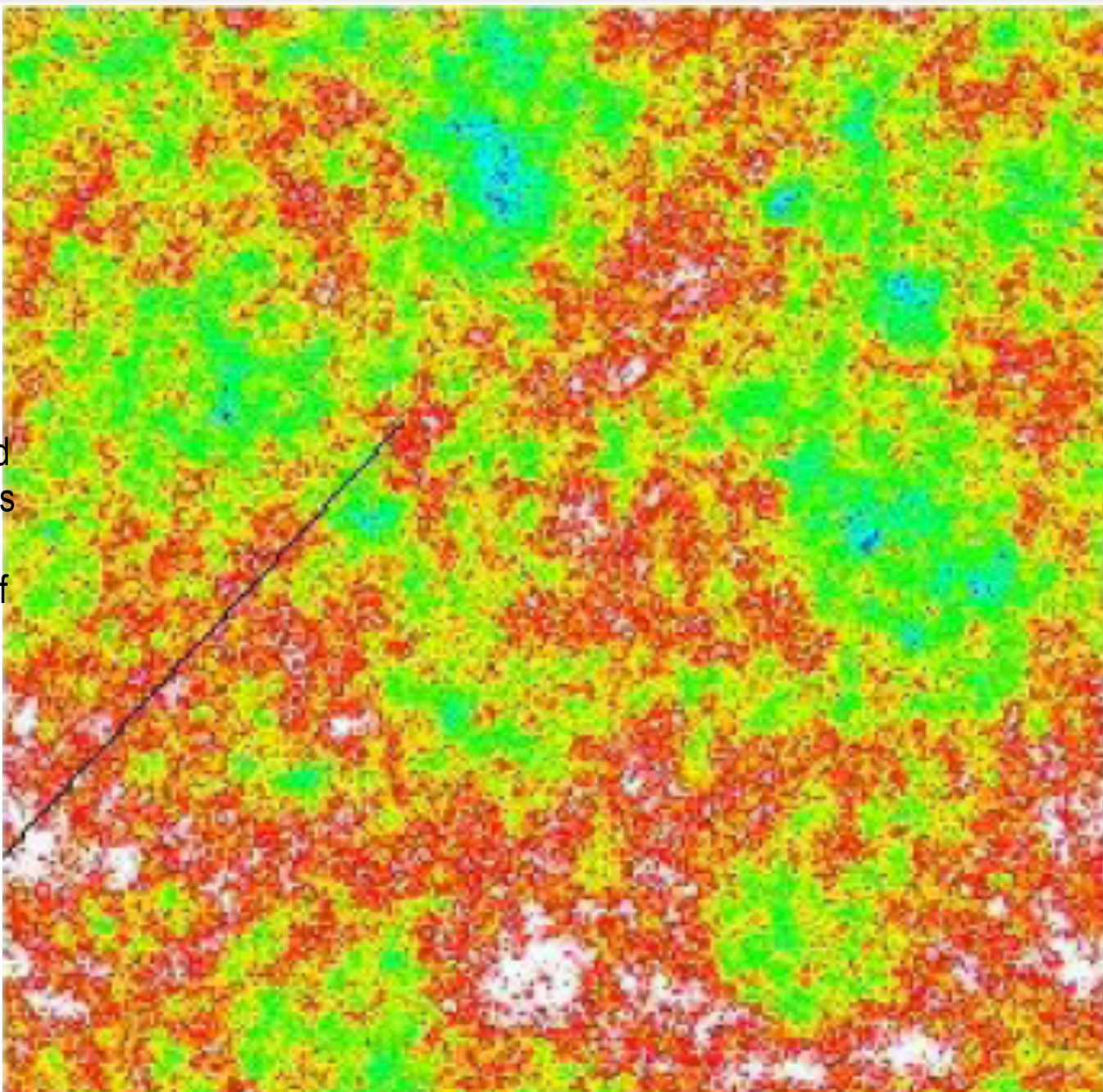
The ‘Meaning’ may change But the facts will remain

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

χ

scalar field
fluctuations
in the
vacuum of
the ultra-
early
Universe

pre-
heating
patch
(~1cm)



$$\chi(\mathbf{x}, \ln a)$$

$$\ln a(\mathbf{x}, \ln H)$$

evolve
from early
U vacuum
potential
and
vacuum
noise

10 Gpc

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

χ

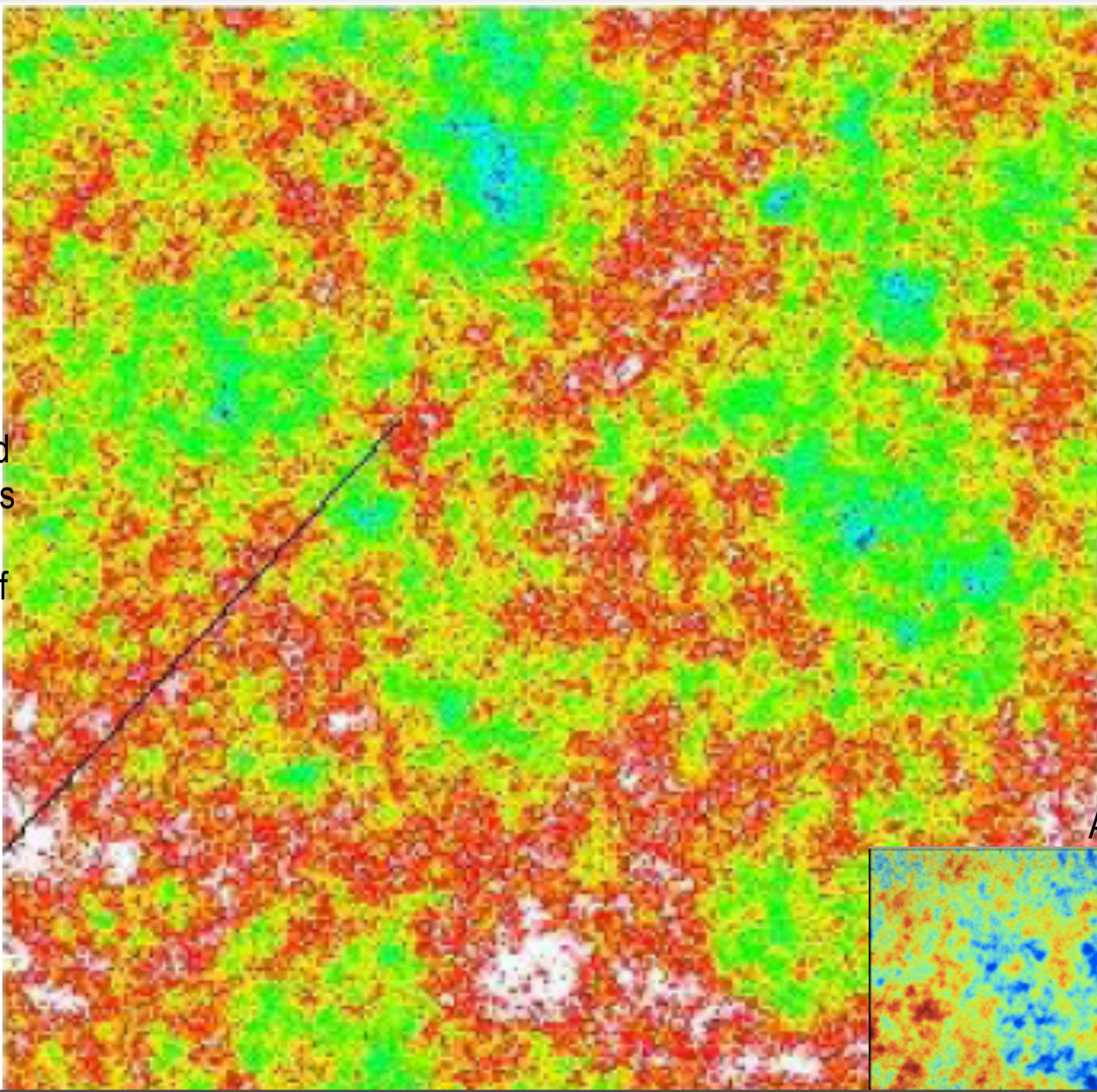
$$\ln a(\mathbf{x}, \ln H)$$

evolve
from early
U vacuum
potential
and
vacuum
noise

aetherial!

scalar field
fluctuations
in the
vacuum of
the ultra-
early
Universe

pre-
heating
patch
(~1cm)



ACT+WMAP7 hajian+10

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

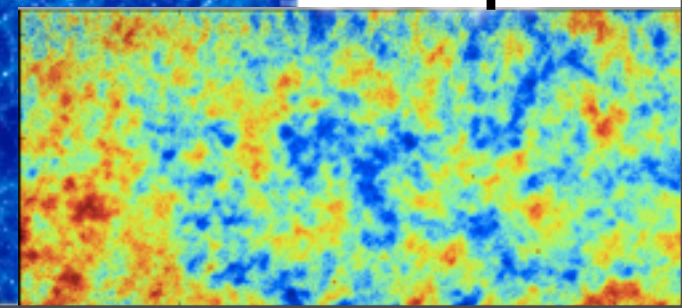
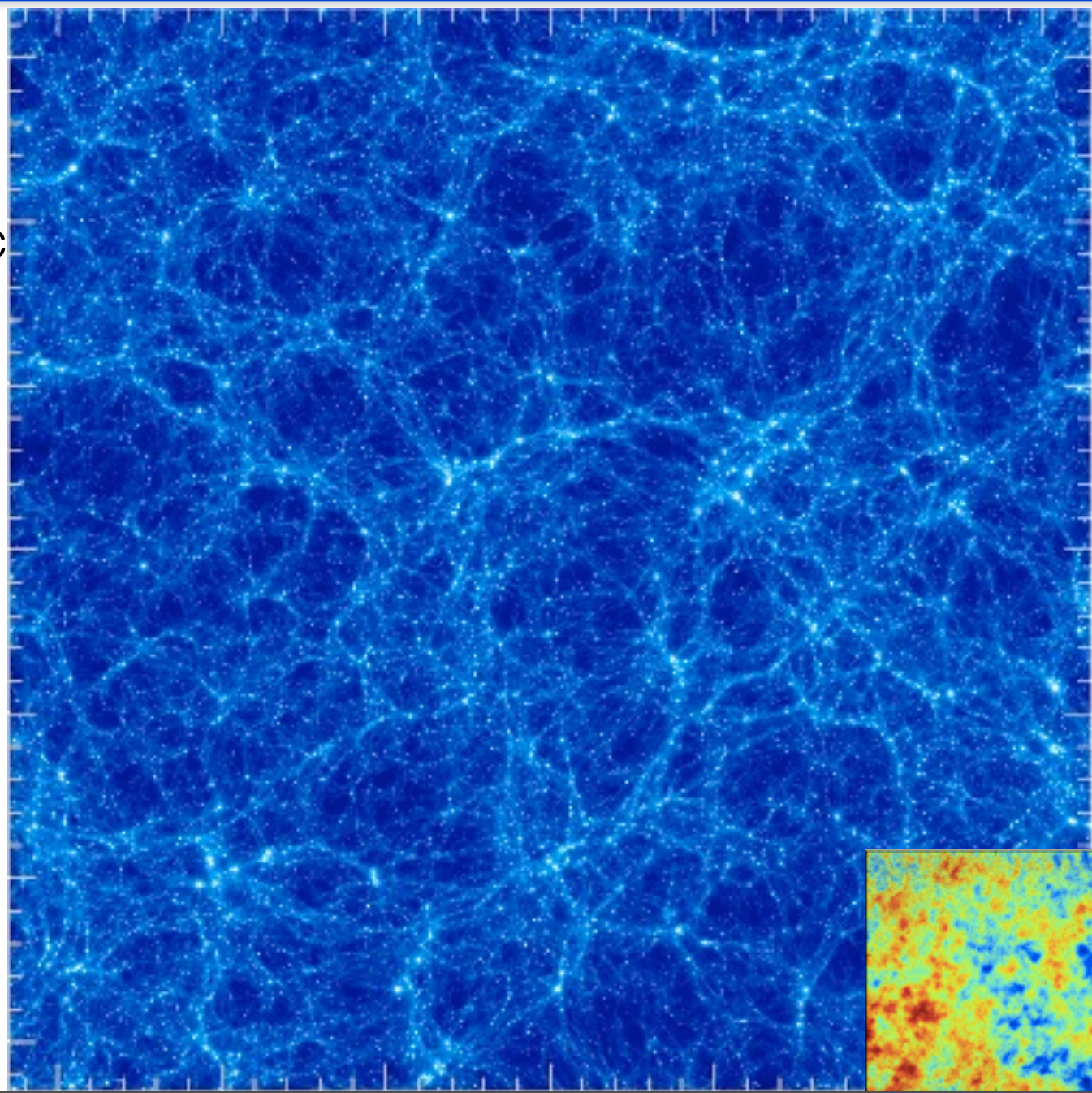
$$\rho_g(\mathbf{x}, t)$$

*evolve
from early
U vacuum
potential
and
vacuum
noise*

*in the
presence
of late U
vacuum
potential
aka dark
energy*

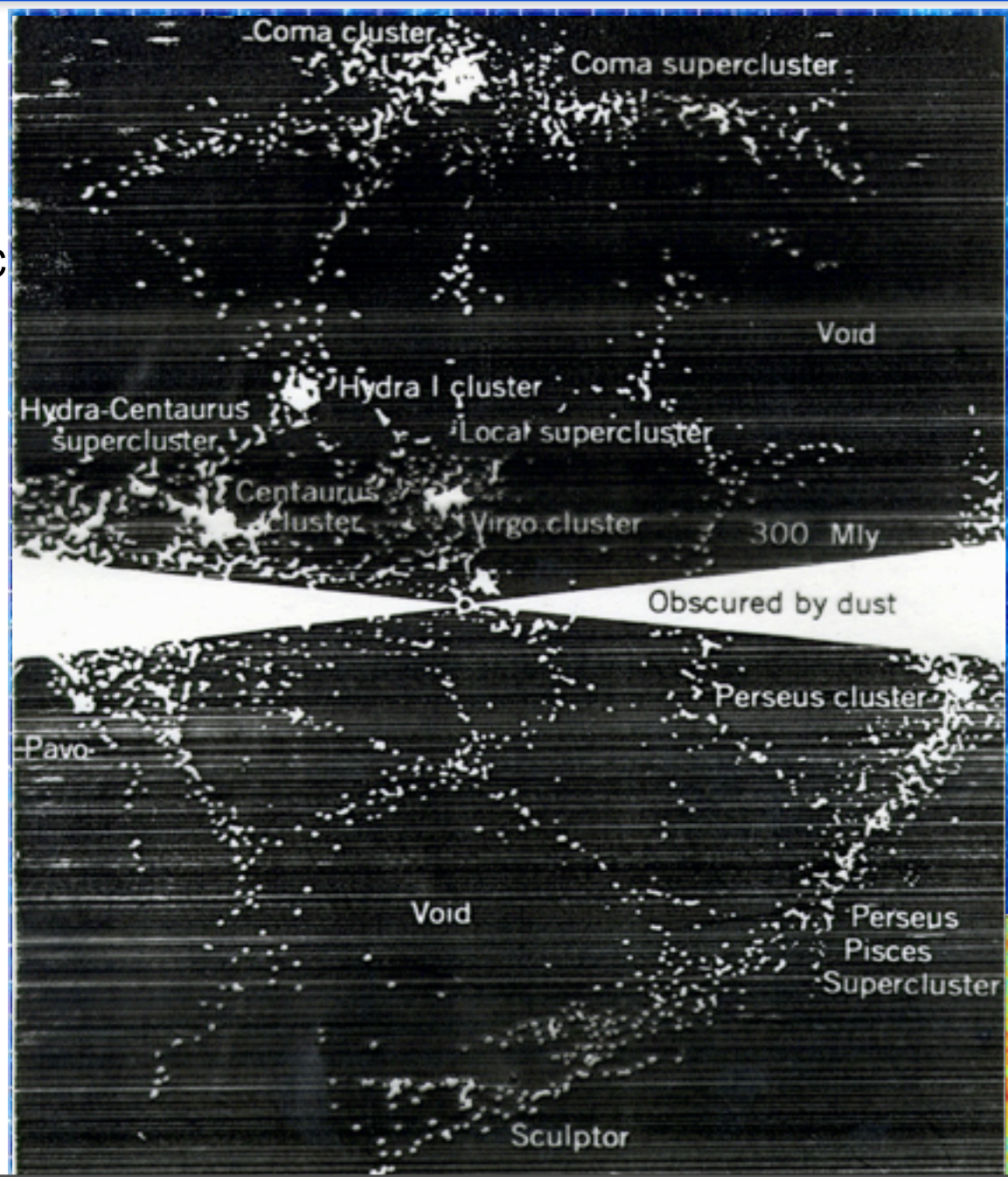
0.4 Gpc

400 Mpc
 Λ CDM
WMAP5
gas
density
Gadget-3
SF+ SN
E+
winds
+CRs
512³
BBPSS10
BBPS1,2,3,4



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

400 Mpc
 Λ CDM
 WMAP5
 gas density
 Gadget-3
 SF+ SN
 E+
 winds
 +CRs
 512³
 BBPSS10
 BBPS1,2,3,4

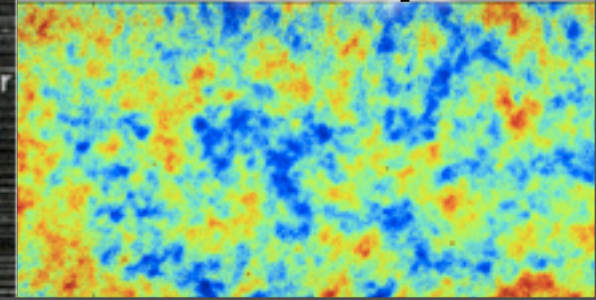
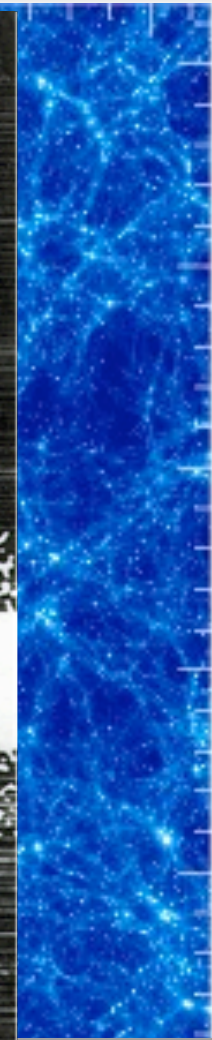


$$\rho_g(\mathbf{x}, t)$$

evolve from early U vacuum potential and vacuum noise

in the presence of late U vacuum potential aka dark energy

0.4 Gpc

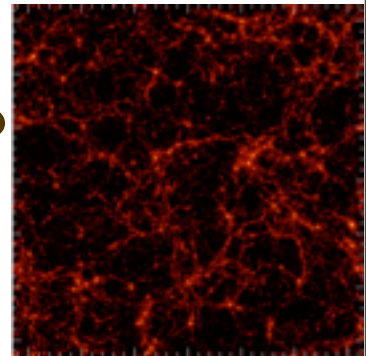


dS/dt 2

how most of the entropy in baryons & dark matter was generated

strain waves break => clusters/groups (galaxies/dwarfs) in the
cosmic web collapse => shocked gas & extreme nonlinear
phase space entanglement of dark matter / stars

then the baryons **feed back entropy**: exploding stars,
accreting black holes, dusty radiation,
... **who, what, where, when, why?**



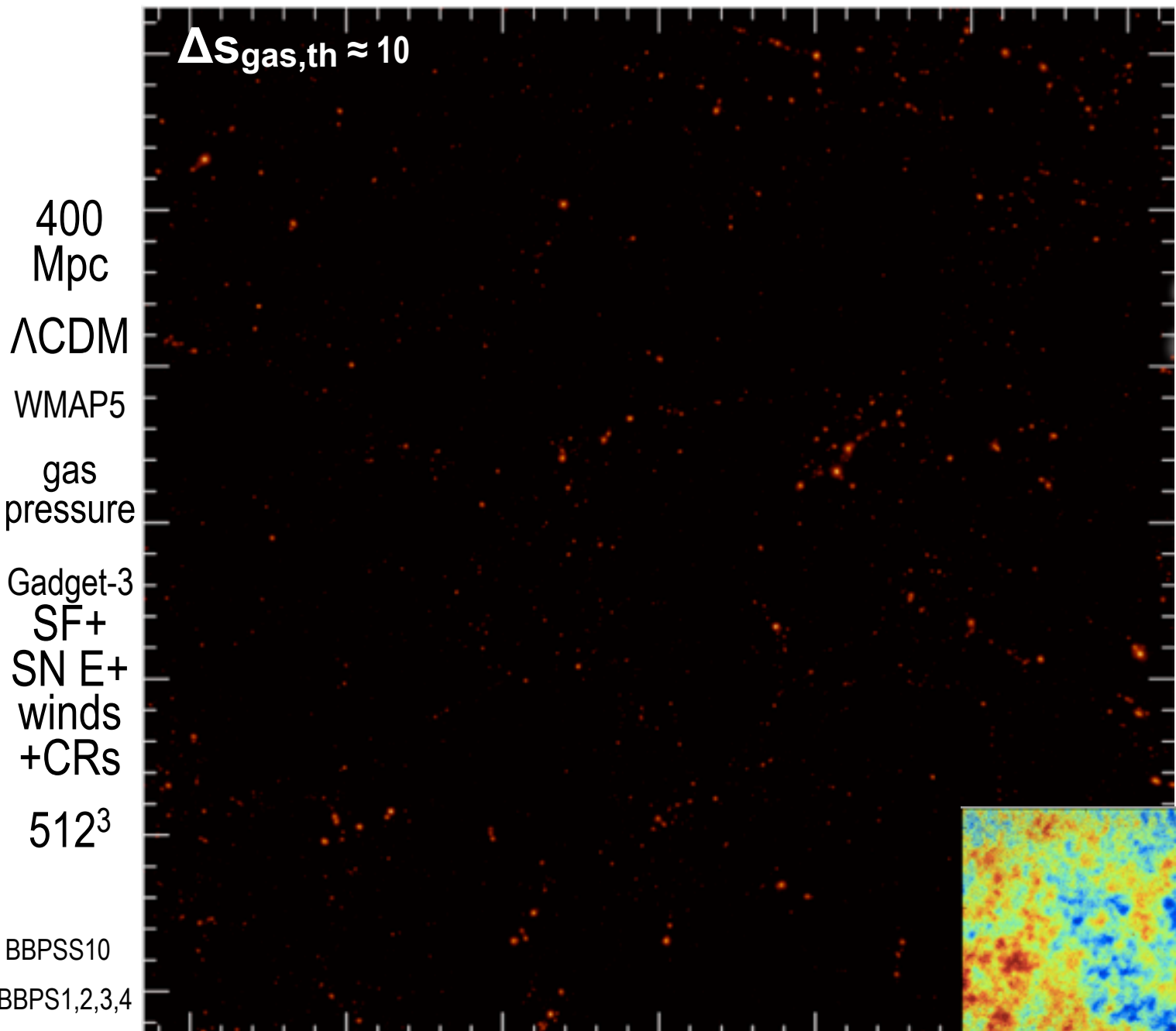
Secondary Anisotropies

(tSZ, kSZ, WL, reion, CIB; hydro)

*morphs into the nonlinear Cosmic Web: clusters, filaments, voids; galaxies (SZ)
gastrophysical simulations with feedback from AGN / starbursts / SN .. confront CMB+LSS data*

entropy intermittency in the cosmic web, via gravitation-induced shocks (then E/S-feedback)

Secondary Anisotropies
(tSZ, kSZ, WL, reion, CIB; hydro)

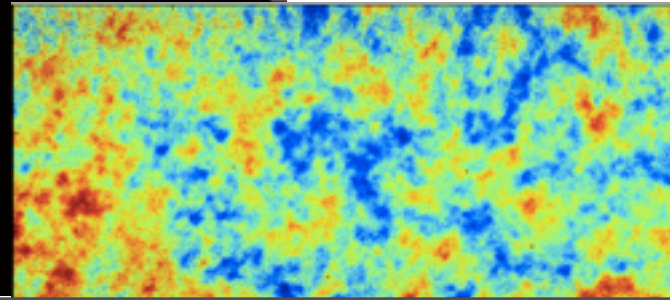


S_{b,th}(x,t)

CMB gets entangled in the cosmic web
descending into the real gas physics of cosmic weather

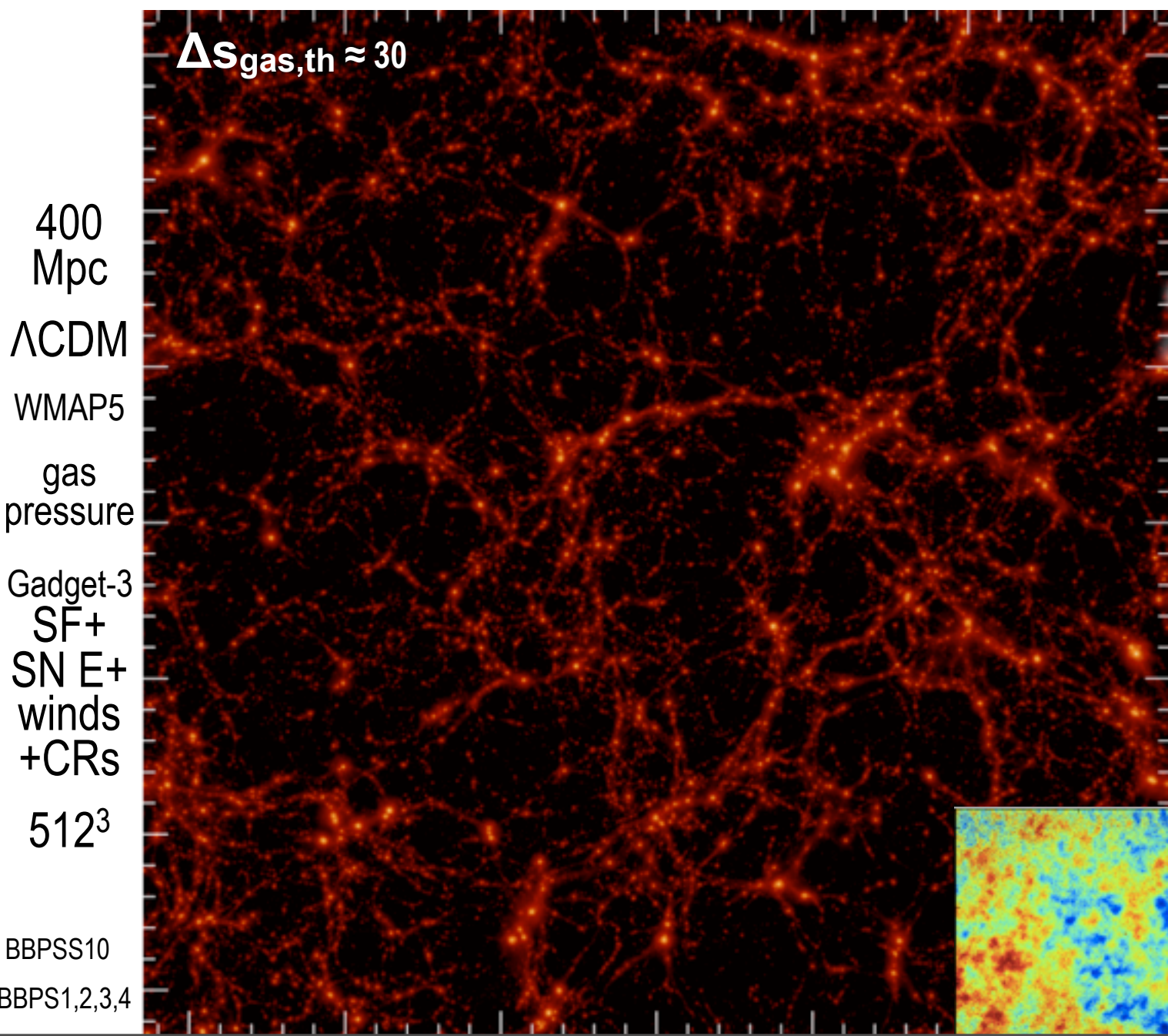
the energetic, turbulent, dissipative, compressive

life of the IGM/ICM/ISM



entropy intermittency in the cosmic web, via gravitation-induced shocks (then E/S-feedback)

Secondary Anisotropies
(tSZ, kSZ, WL, reion, CIB; hydro)

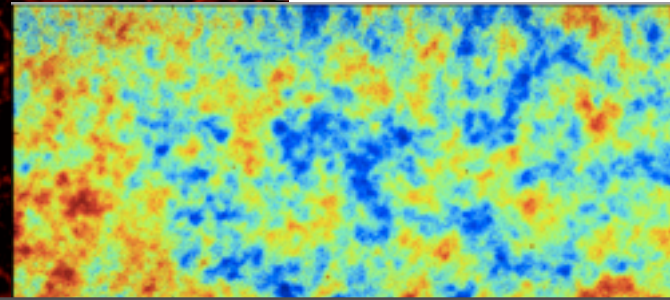


$S_{b,th}(\mathbf{x},t)$

CMB gets entangled in the cosmic web
descending into the real gas physics of cosmic weather

the energetic, turbulent, dissipative, compressive

life of the IGM/ICM/ISM



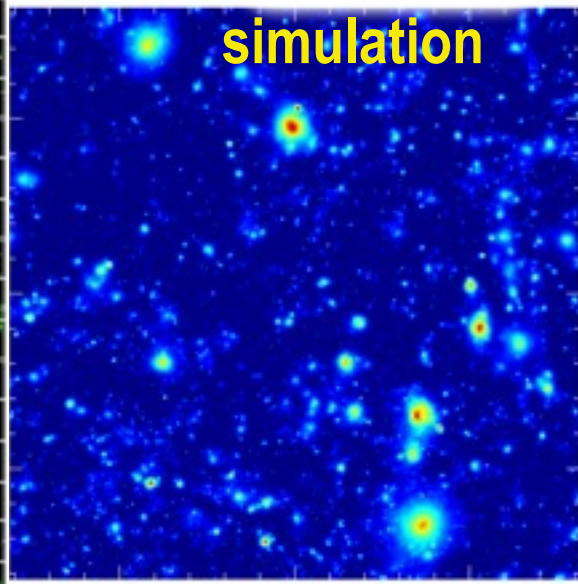
pressure intermittency in the cosmic web, in cluster-group concentrations probed by tSZ

Secondary Anisotropies
(tSZ, kSZ, WL, reion, CIB; hydro)

2011 Planck ~200 clusters, SPT ~50 cls, ACT ~50 cls; 2013 1000's

$$p_e(\mathbf{x}, t)$$

simulation



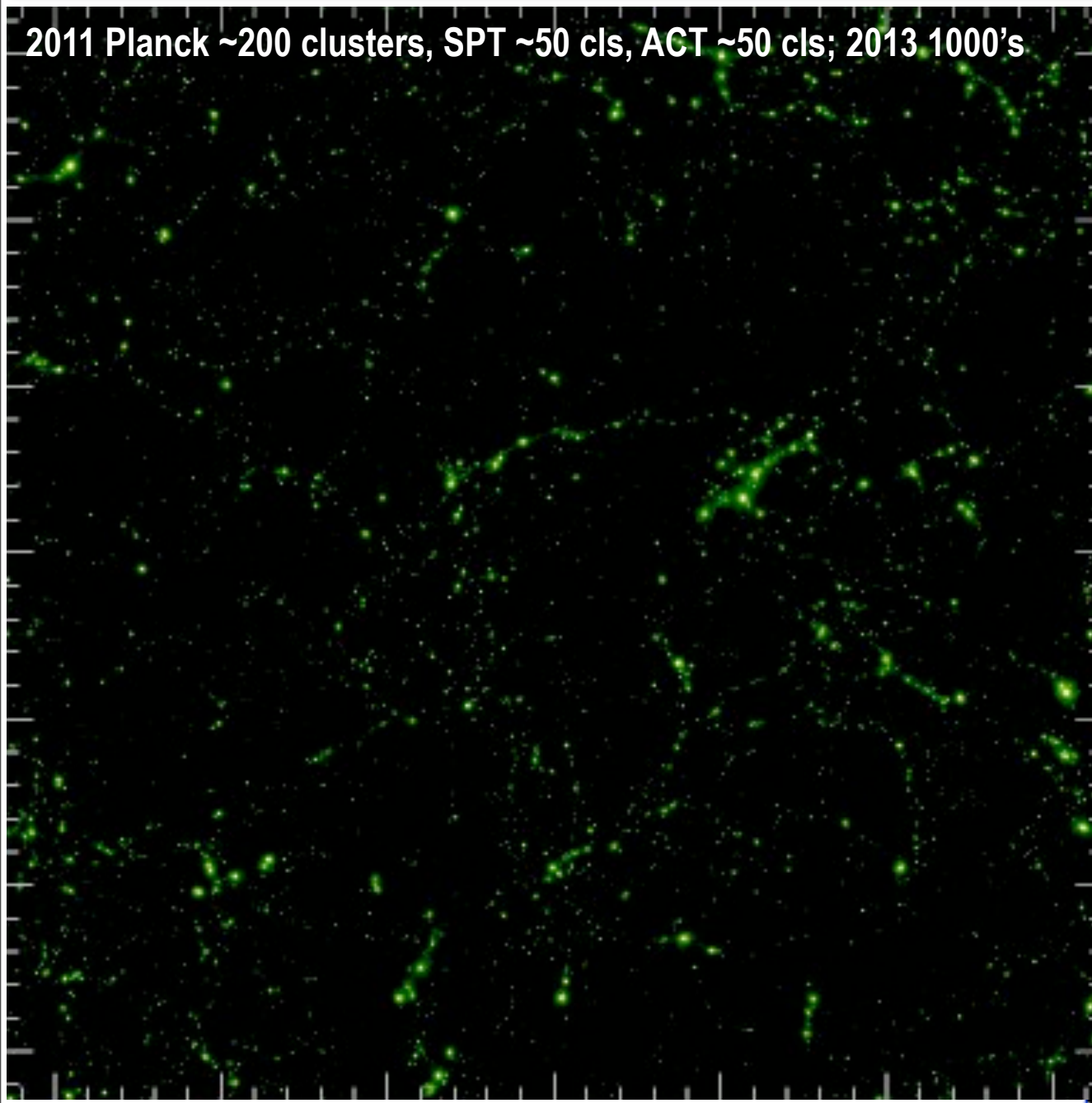
observed single cluster



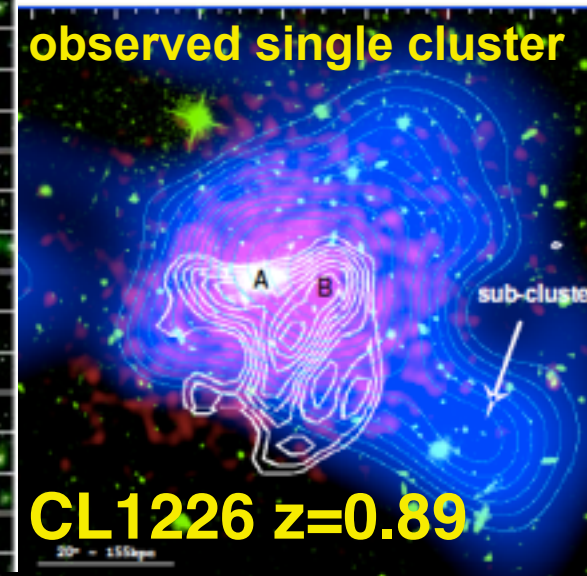
pressure intermittency in the cosmic web, in cluster-group concentrations probed by tSZ

Secondary Anisotropies
(tSZ, kSZ, WL, reion, CIB; hydro)

2011 Planck ~200 clusters, SPT ~50 cls, ACT ~50 cls; 2013 1000's



ACT's el Gordo z=0.87
 $2 \times 10^{15} M_{\text{sun}}, T_x = 14.5 \text{ keV}$



CL1226 z=0.89

“IT from BIT”

FATE U inflate (again)

a cold death? reheat/rebirth?

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

Inflation fluctuations form: quantum jitter

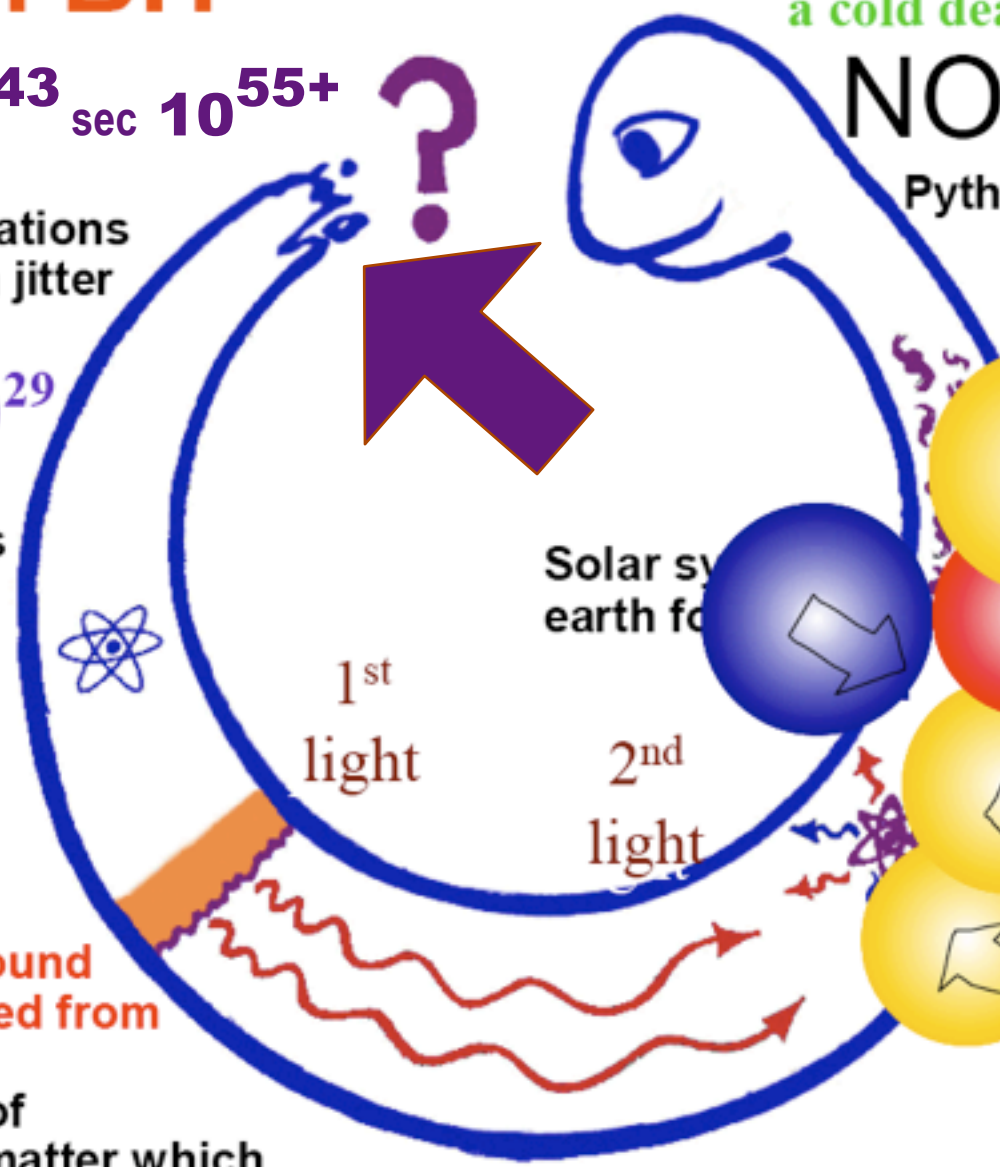
10^{-37} sec 10^{29}

Protons/Neutrons form

Helium forms
 100 sec 10^9

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

0.4 Myr 1100



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

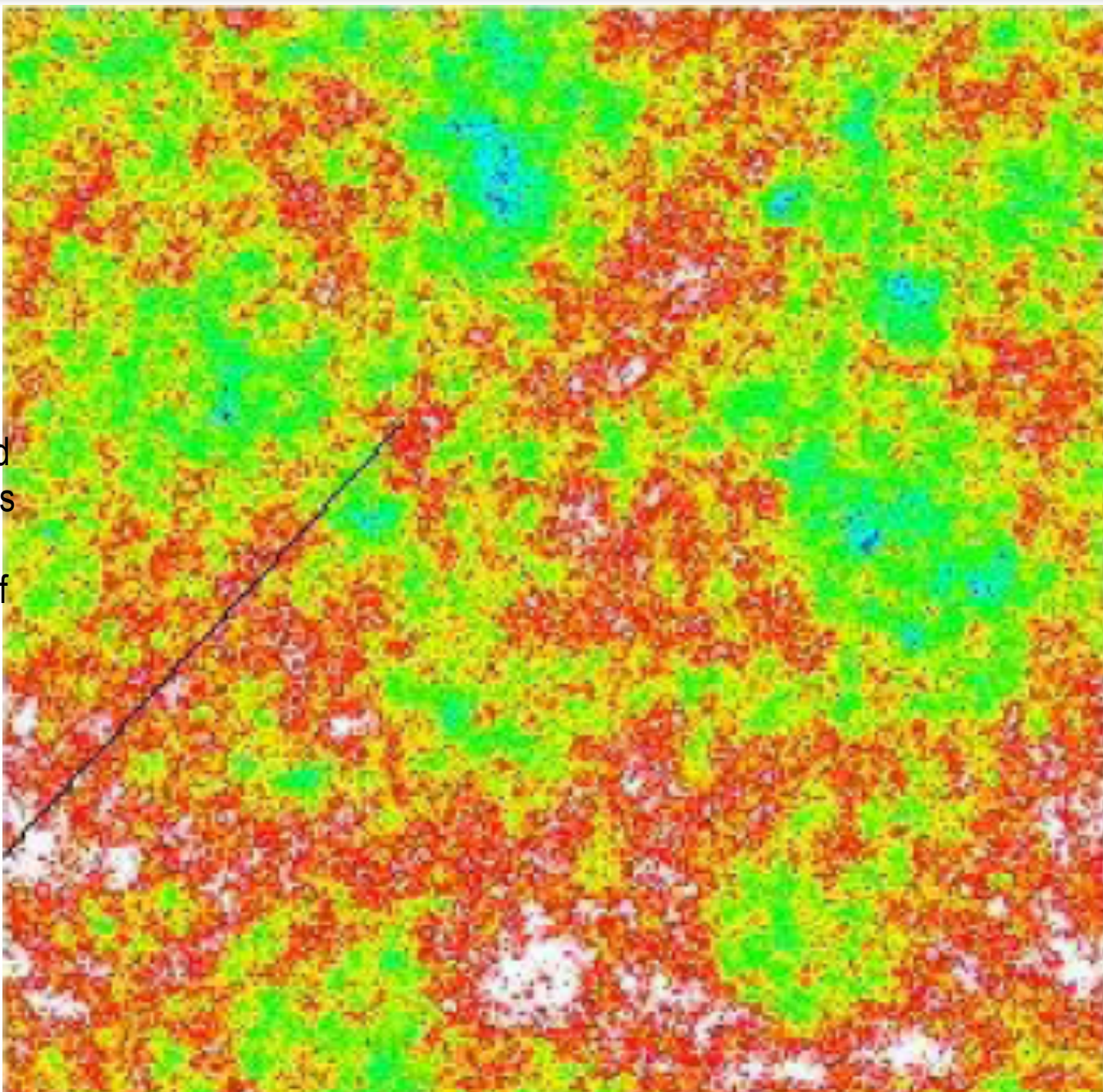
The ‘Meaning’ may change But the facts will remain

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

χ

scalar field
fluctuations
in the
vacuum of
the ultra-
early
Universe

pre-
heating
patch
(~1cm)



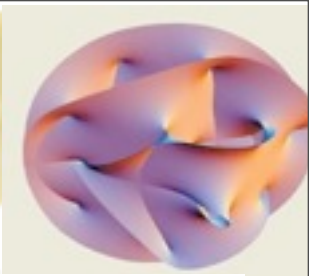
$$\chi(\mathbf{x}, \ln a)$$

$$\ln a(\mathbf{x}, \ln H)$$

*evolve
from early
U vacuum
potential
and
vacuum
noise*

10 Gpc

Roulette Inflation: *a statistical mini-landscape (one of very many) of the early U origins of observed cosmic structure:*



holey U: sizes/shapes of geometrical structures such as holes in a dynamical extra-dimensional (6-7D) space settling into a stable bit of extra-dim at each point in our 3D space;
braney U: motions of lower-dimension subspaces:

when quantum kicks

beat

classical drift

we are in the

semi-ETERNAL INFLATION regime

or thru tunnelling between potential minima

Preheating After
Roulette Inflation

$$\langle \tau \rangle =$$

quantum
diffusion
spatial jitter

drift

$$\ln a(\mathbf{x}, \ln H)$$

let there be
heat

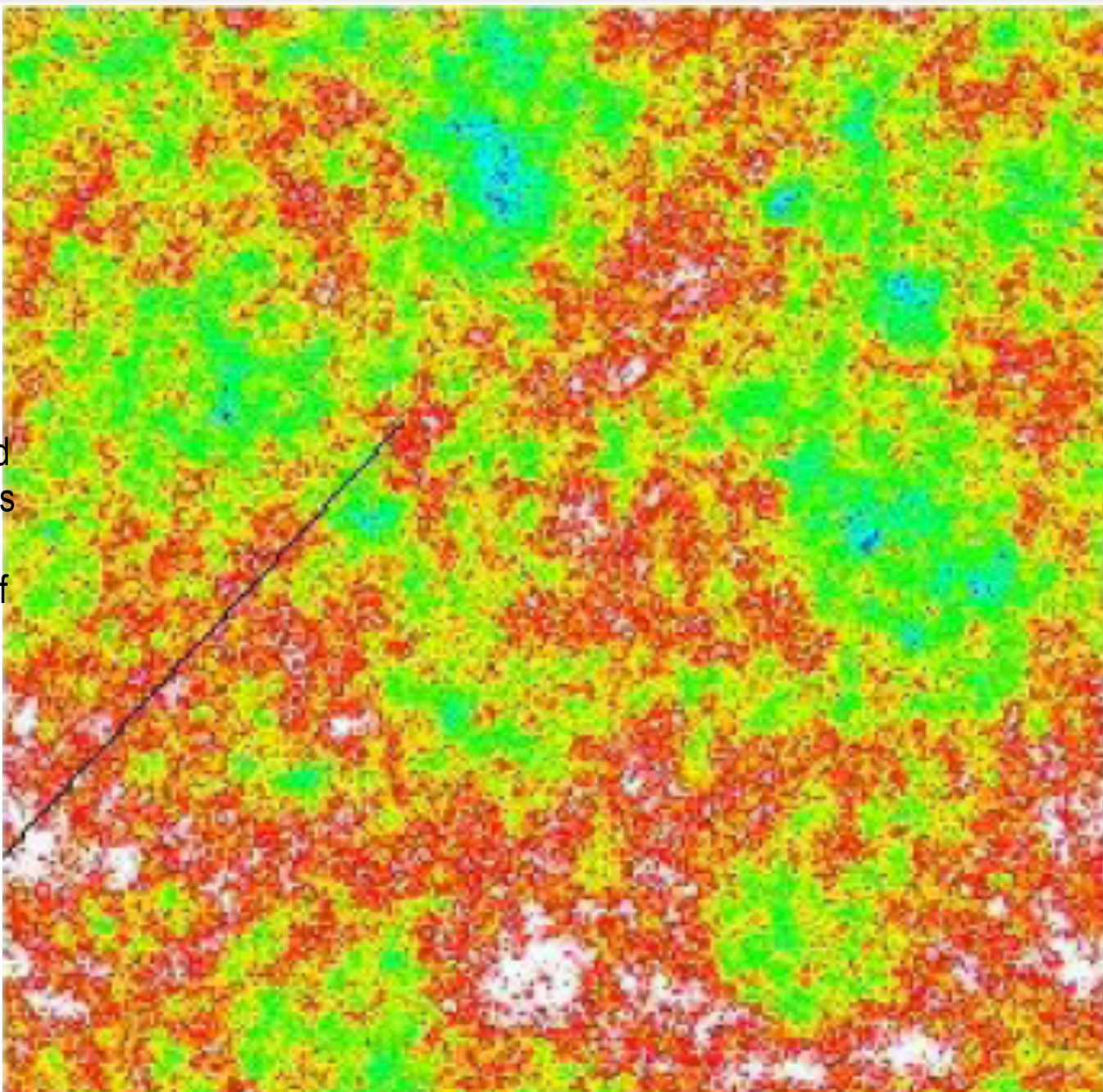
SEMI-ETERNAL INFLATION

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

χ

scalar field
fluctuations
in the
vacuum of
the ultra-
early
Universe

pre-
heating
patch
(~1cm)



$$\chi(\mathbf{x}, \ln a)$$

$$\ln a(\mathbf{x}, \ln H)$$

*evolve
from early
U vacuum
potential
and
vacuum
noise*

10 Gpc

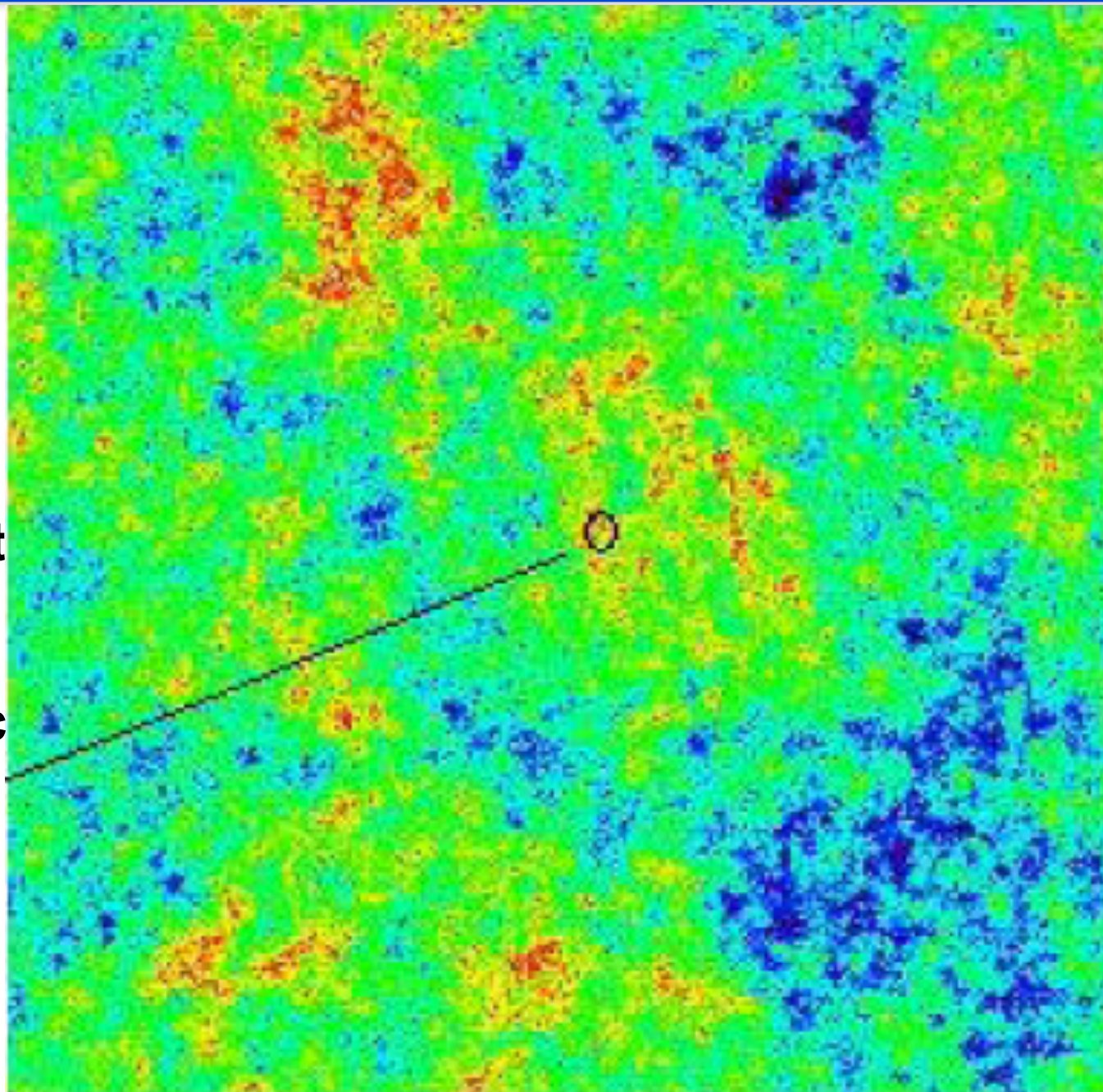
fluctuations in the early universe “vacuum” grow to *all* structure

χ

$\ln a(\mathbf{x}, \ln H)$

patterns
in the
quantum
jitter
evolve
under
gravity
(& gas
dynamics)

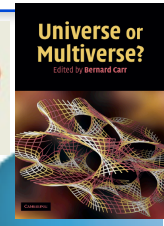
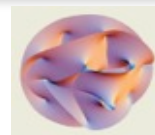
current
Hubble
patch
~10 Gpc
speed
limit
horizon



1000 Gpc

quantum stochastic *non-Gaussian* time landscape cf. stringy landscape

multiverse
 Starobinsky,
 Vilenkin,
 Linde, SB,
 Rees, ...,
 stringy:
 Susskind et al



$$\ln a(\mathbf{x}, \ln H)$$

a "natural" consequence of quantum mechanics of the U's
 uuUULSS on $\ln a(\mathbf{x}, \ln H)$

if quantum diffusion > 'classical' drift at high H

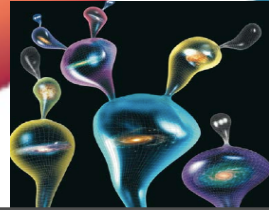
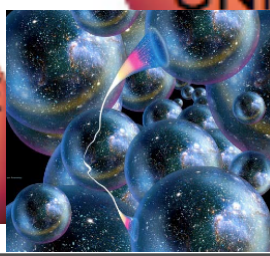
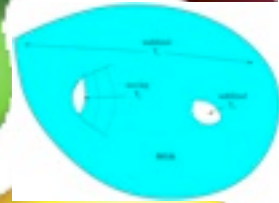
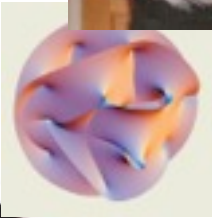
cf. our observable horizon (patch)

at low H

this eternal inflation can happen even at

low H

Salopek & Bond 1991



“IT from BIT”

FATE U inflate (again)

a cold death? reheat/rebirth?

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

Inflation fluctuations form: quantum jitter

Let there be Heat

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

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

NOW 14 Gyr 1

Pythagoras formed

Galaxies Cluster
Cosmic “web” of vast filaments + membranes

Life forms on earth

Solar system earth form

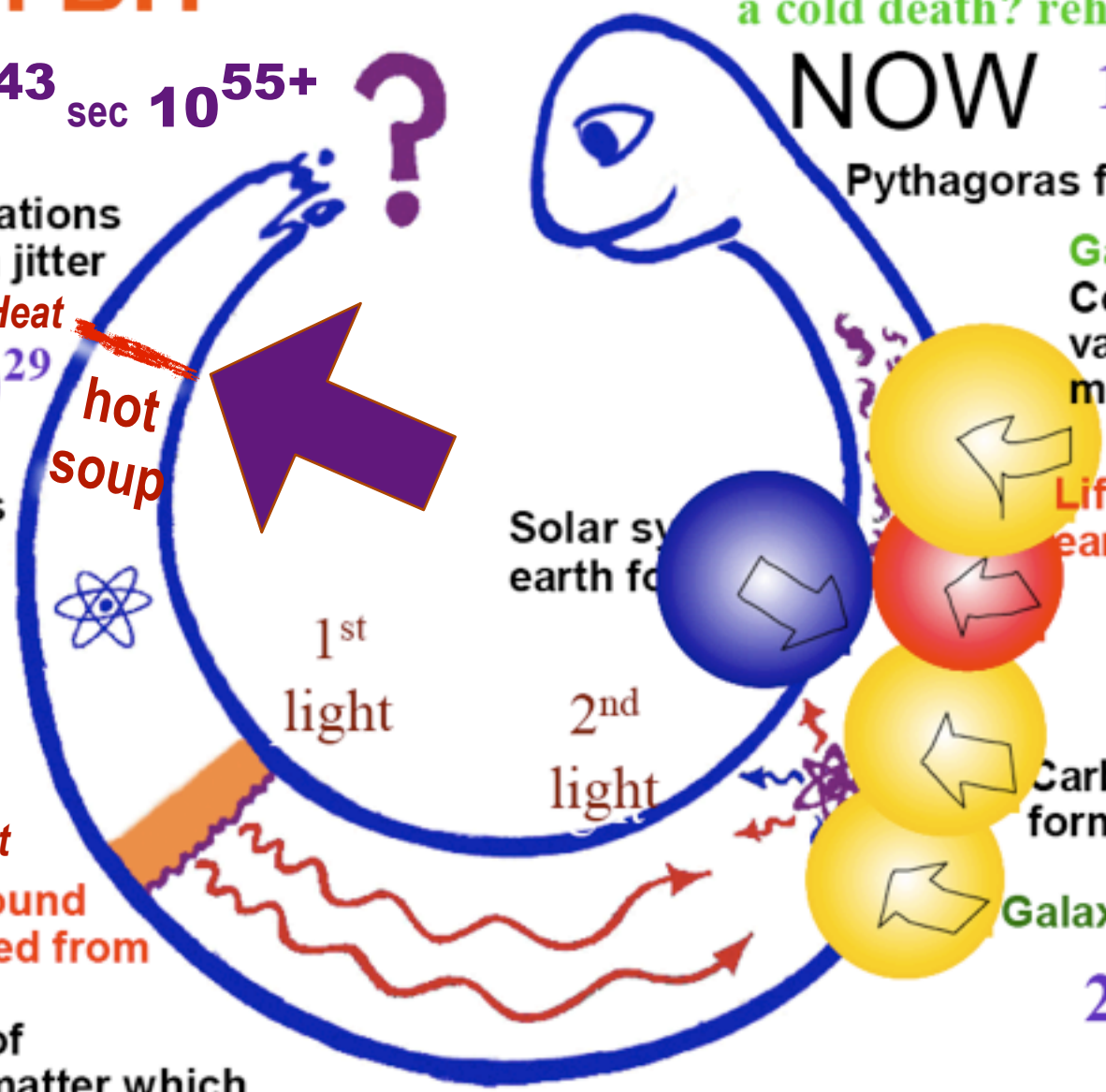
9 Gyr 1.4

Carbon/oxygen/etc form

Galaxies form

2 Gyr 4

**The ‘Meaning’ may change
But the facts will remain**



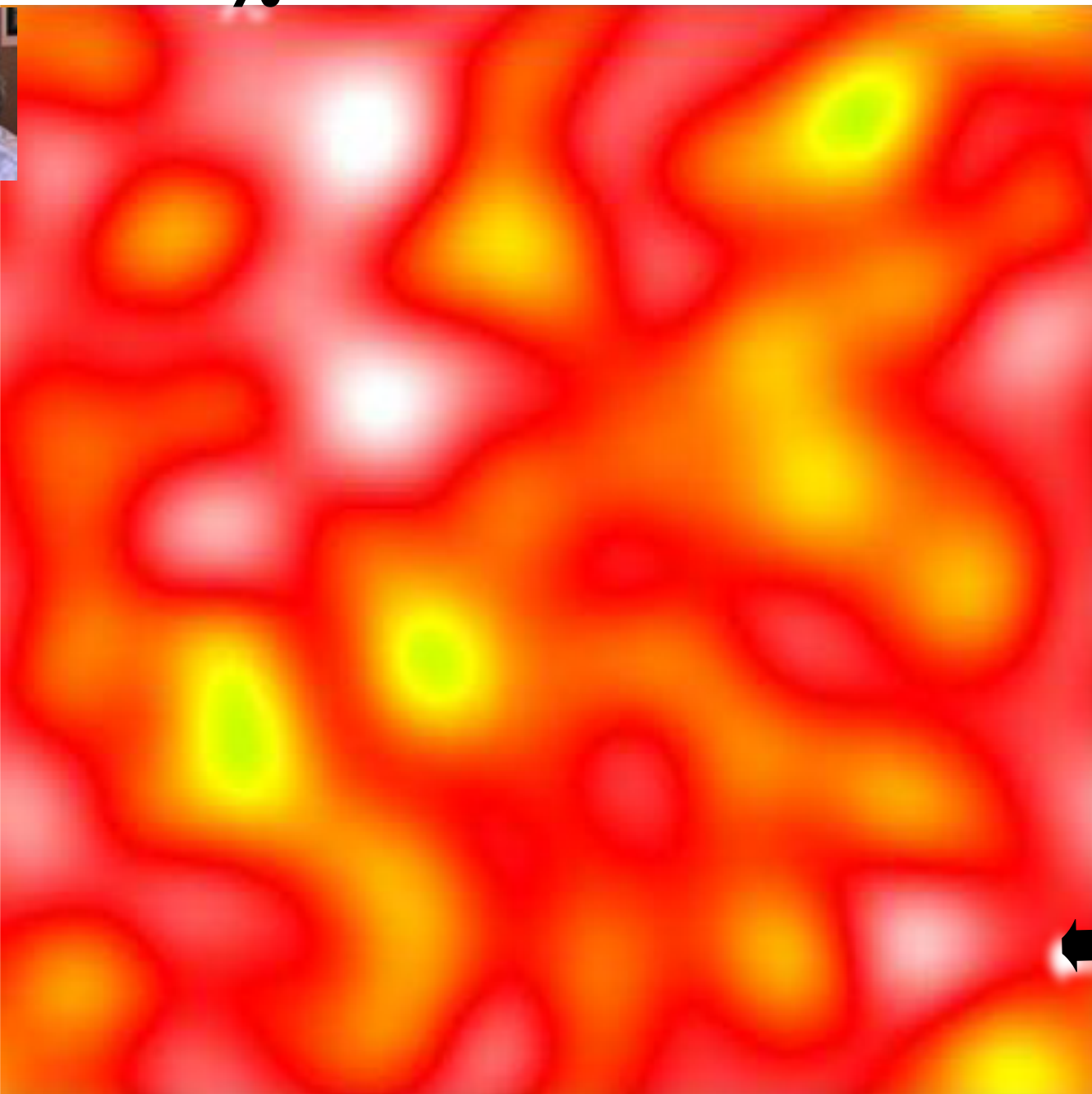
ϕ inflaton

χ isocon

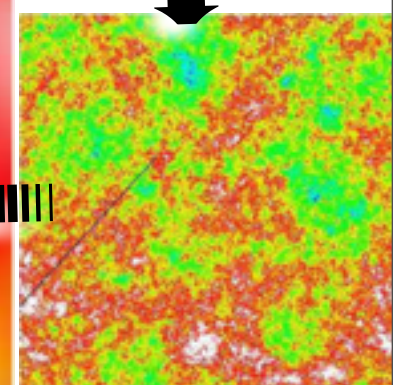
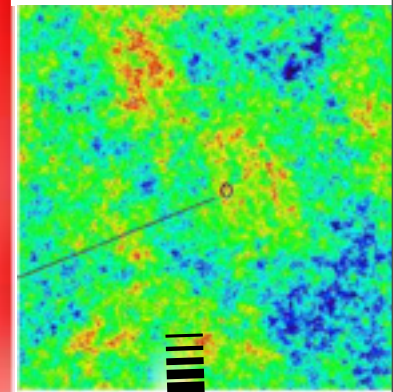
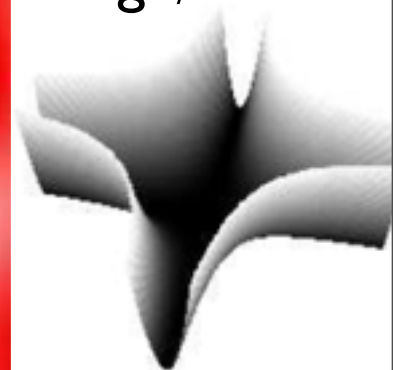
$$V(\phi, \chi) = 1/4 \lambda \phi^4 + 1/2 g^2 \phi^2 \chi^2$$

Parametric
Resonance

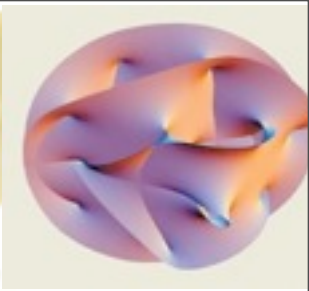
$$g^2 / \lambda \sim 1$$



pre-
heating
patch
(~1cm)



Roulette Inflation: *a statistical mini-landscape (one of very many) of the early U origins of observed cosmic structure:*



holey U: sizes/shapes of geometrical structures such as holes in a dynamical extra-dimensional (6-7D) space settling into a stable bit of extra-dim at each point in our 3D space;

braney U: motions of lower-dimension subspaces

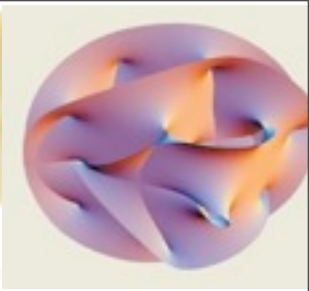
pre-heating patch (<1cm-now, 10^{-30} cm-then)

quantum
diffusion
spatial jitter

drift

let there be
heat

Roulette Inflation: *a statistical mini-landscape (one of very many) of the early U origins of observed cosmic structure:*

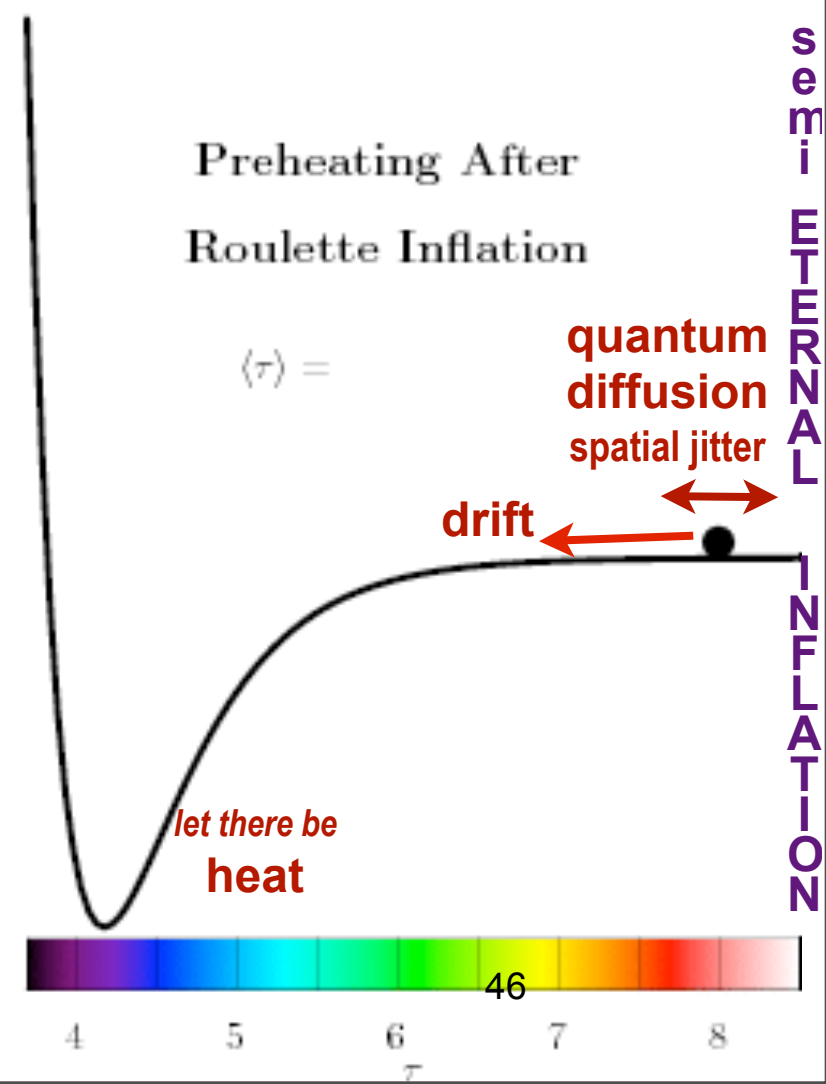


holey U: sizes/shapes of geometrical structures such as holes in a dynamical extra-dimensional (6-7D) space settling into a stable bit of extra-dim at each point in our 3D space;

braney U: motions of lower-dimension subspaces

pre-heating patch (<1cm-now, <10⁻³⁰ cm-then)

A visualized 2D slice in lattice simulation



www.youtube.com/watch?v=FW__su-W-ck&NR=1

how (most of) the **entropy** in matter

=> *GUT plasma/quark soup* => $S(\gamma, \nu)$ was

generated (through a *shock-in-time*)

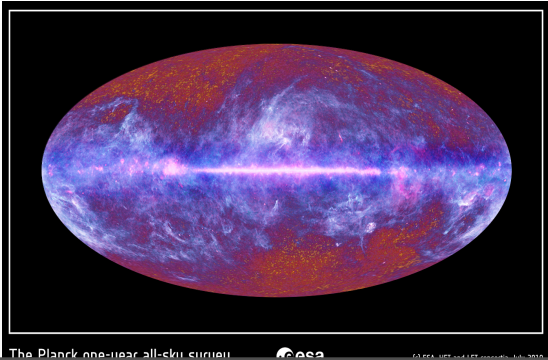
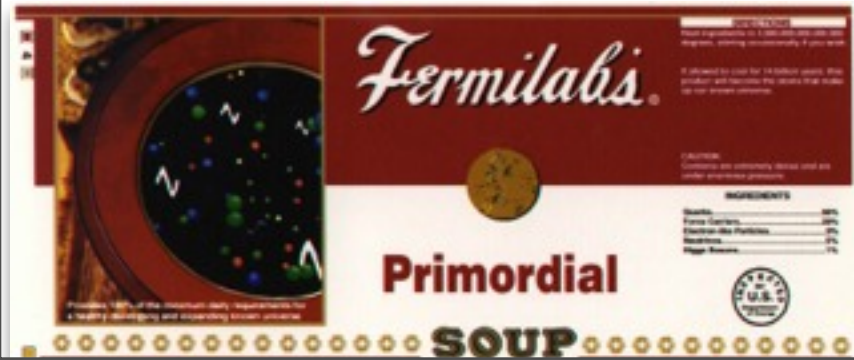
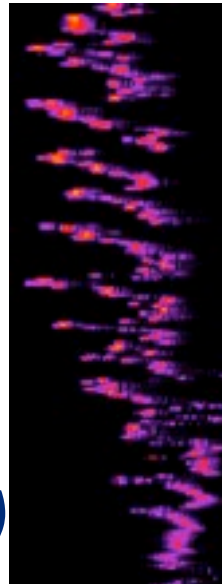
via *nonlinear coupling* of the *inflaton* to

new interaction channels g, χ_a ultimately to *standard model degrees of freedom*

∃ a role for *decaying particles, 1st order phase transitions?*

exactly who, what, where, when, why?

we search for fossil "non-Gaussian" structures from this period with Planck +WMAP9



$a_{shock}(g)$

non-Gaussianity (WMAP, Planck, LSS) spiky nG preheating

"IT from BIT"

FATE U inflate (again)
anthropic $U \in \{Us\}$
a cold death? reheat/rebirth?

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

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

0.4 Myr 1100



1st light

Solar system earth form

2nd light

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





SN Nobel 2011

future fate?

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

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

beats **incoherence** ($\Upsilon, v, h+x, \dots p, n, e$)

but **entropy/particle**

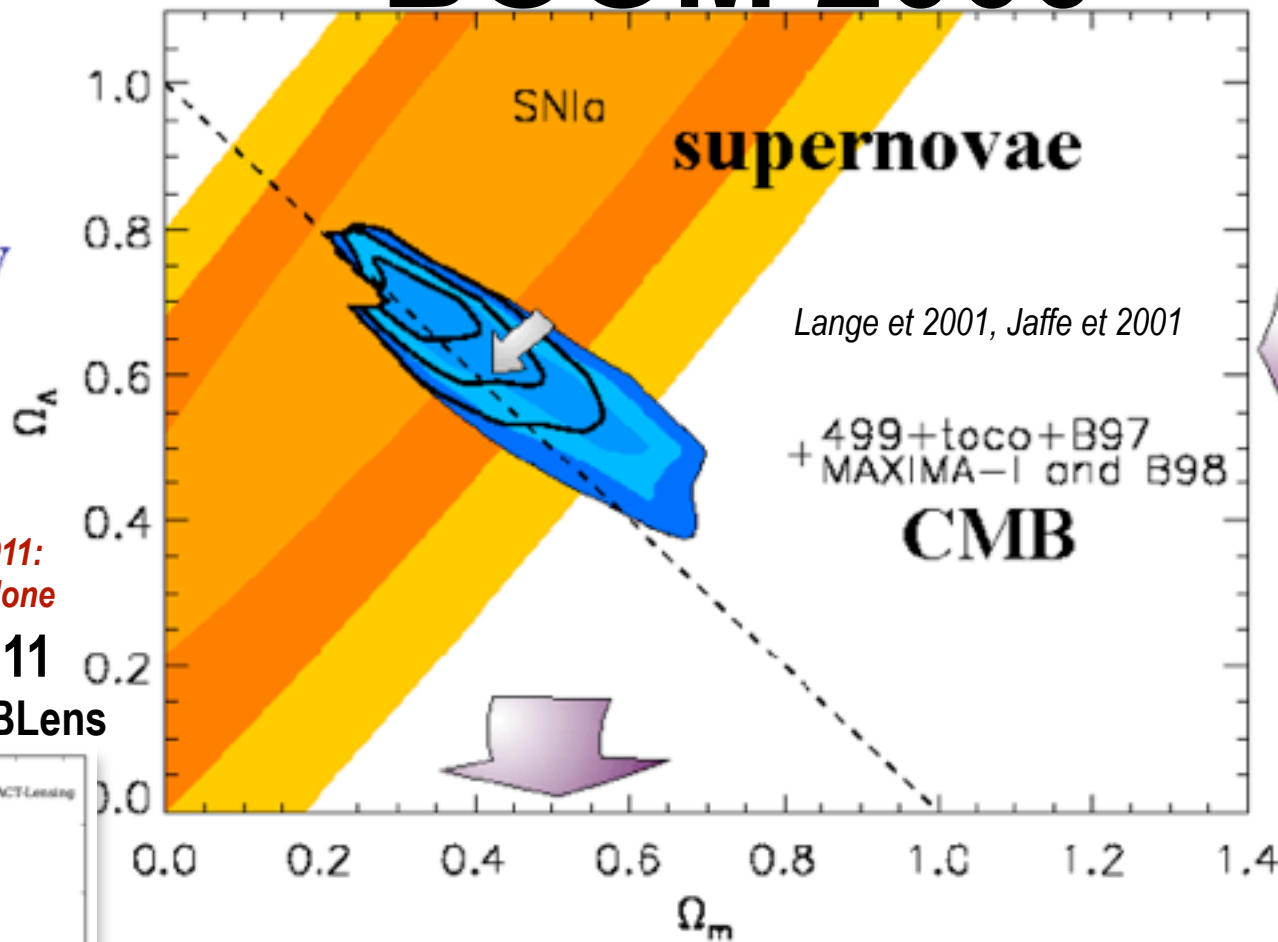
remains (*for those particles that survive*)

⇒ evidence for “dark energy” aka the cosmological constant

BOOM 2000



dark energy



Λ CDM was the standard “concordance” model since ~1995;

much invoked since

Peebles 1985 a neo-Lemaitrian WYSIWYG

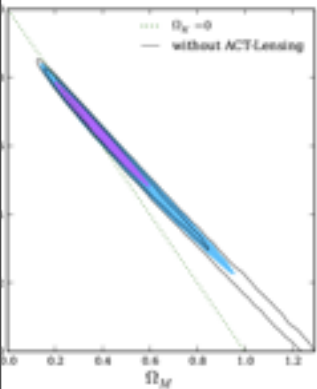
BBE87, PR88, Weinberg87, ...

CMB+LSS 1996/98

DE w/o SN

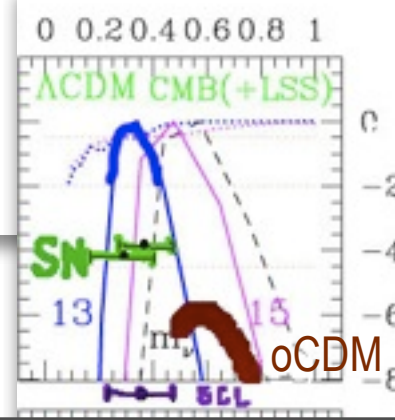
Sherwin et 2011: Λ from CMB alone

ACT 2011 DE from CMB Lens



Dunkley et 2011 cosmic parameters
 $\Omega_\Lambda = 0.736 \pm 0.012 \Rightarrow \pm 0.001$ (Pext)
 B+Huang 2011
 2011: WMAP7+ACT+BAO+H0

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

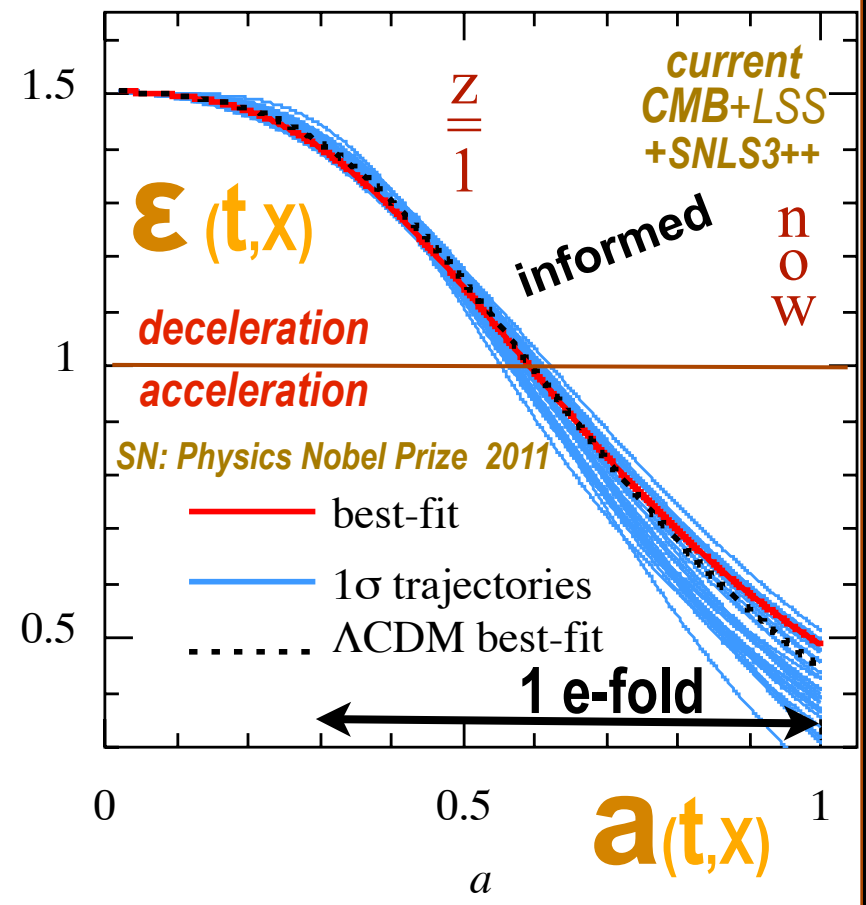


to DE (t,x)
or not
to DE (t,x)
that is the
question



CITA ICAT

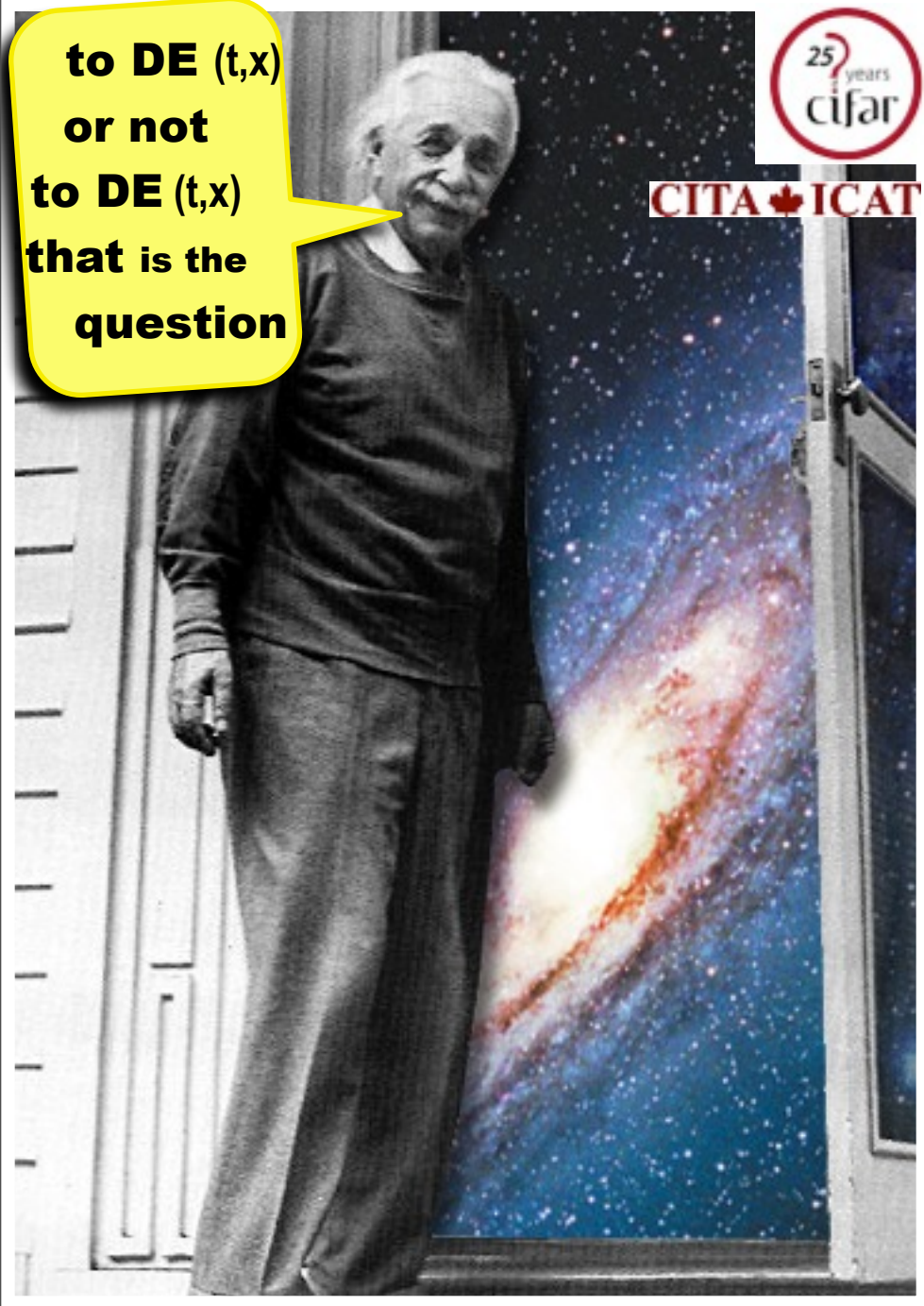
$$1+W_t = -d \ln p_t / d \ln a^3 = 2/3 \epsilon(t)$$



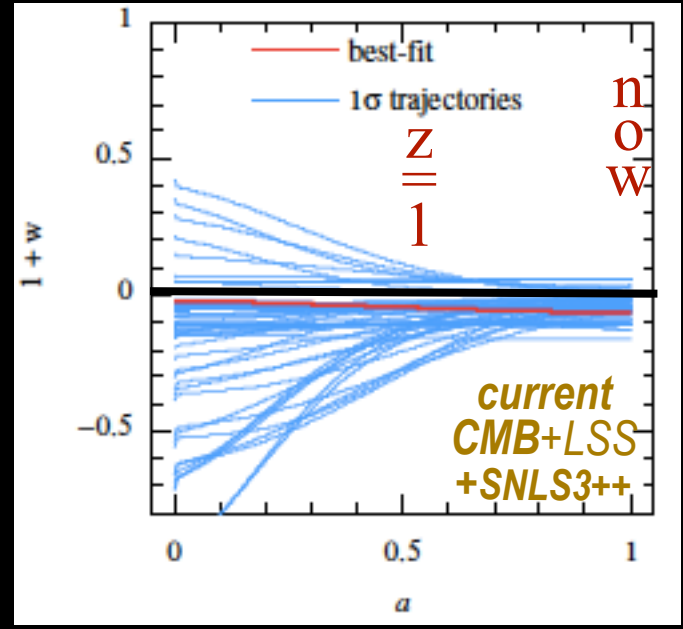
to DE (t,x)
or not
to DE (t,x)
that is the
question



CITA ICAT



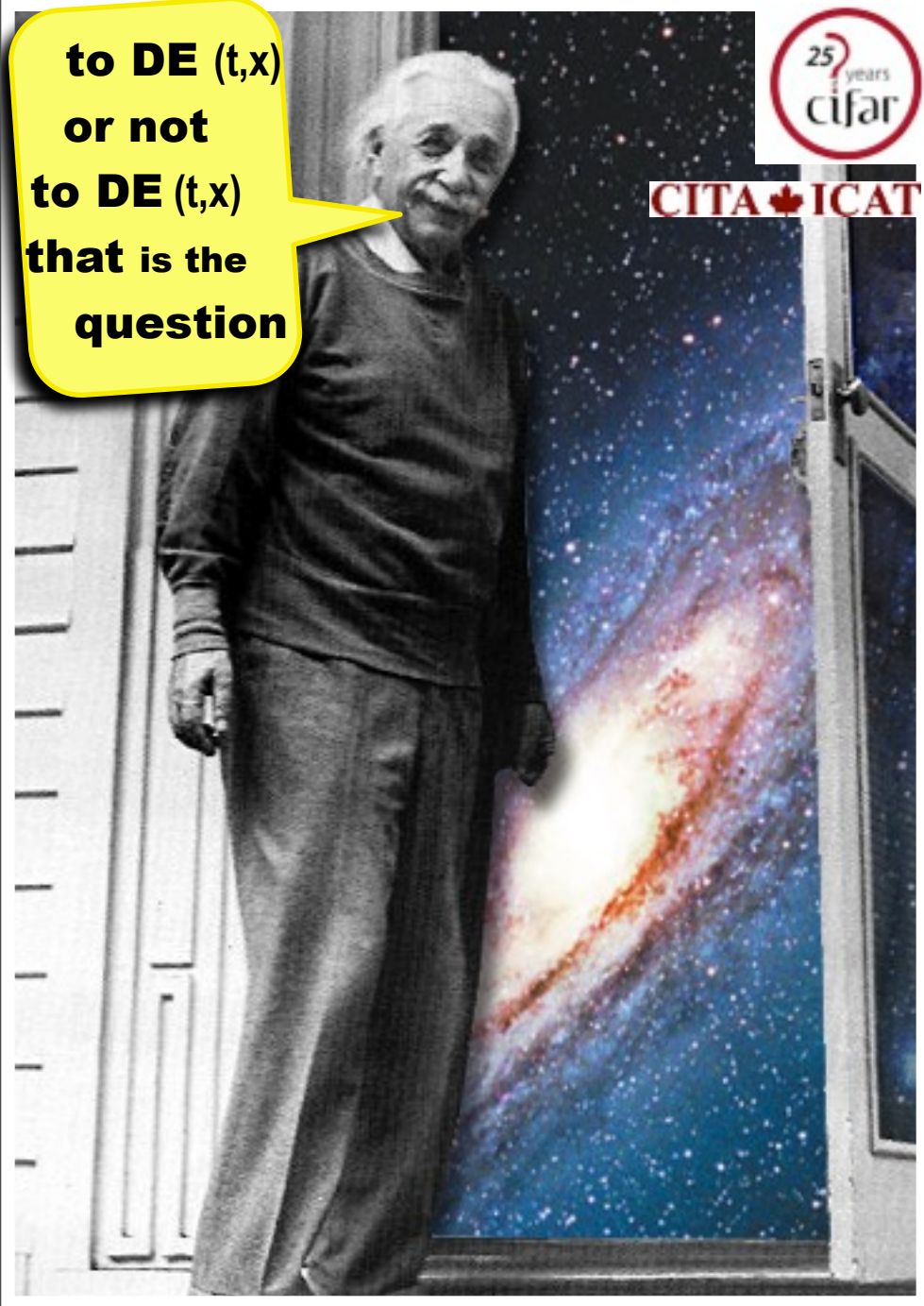
late-inflaton DE trajectories



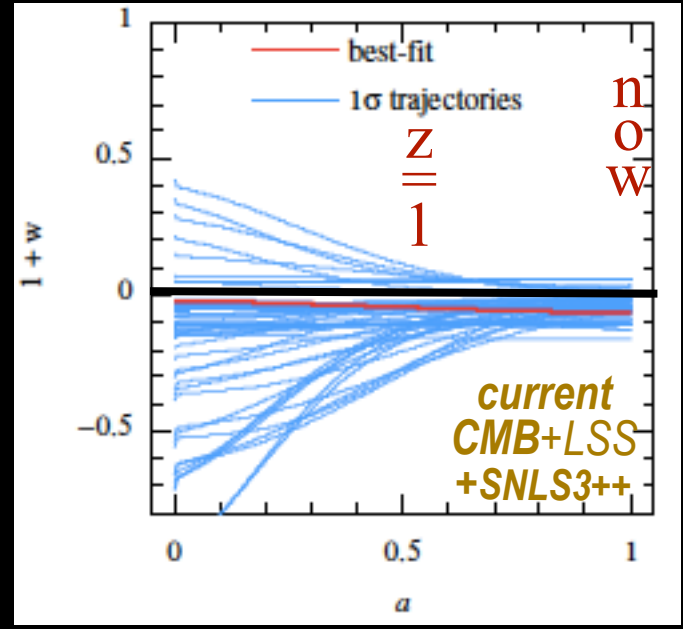
to DE (t,x)
or not
to DE (t,x)
that is the
question



CITA ICAT

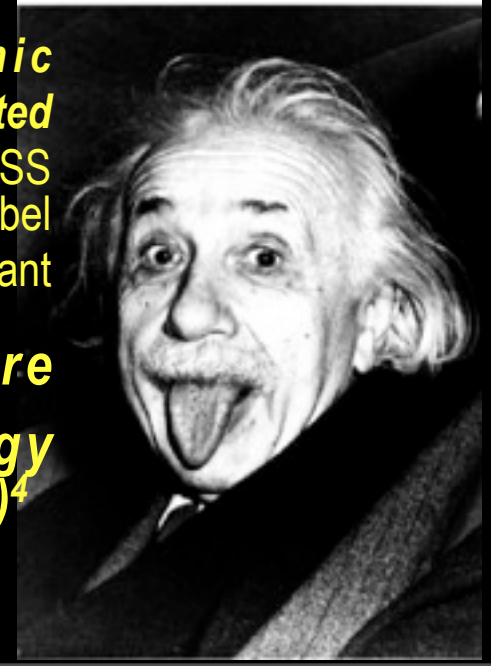


late-inflaton DE trajectories



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

Q_{vac} i.e., a pure potential energy density $\sim 28 \text{ (meV)}^4$



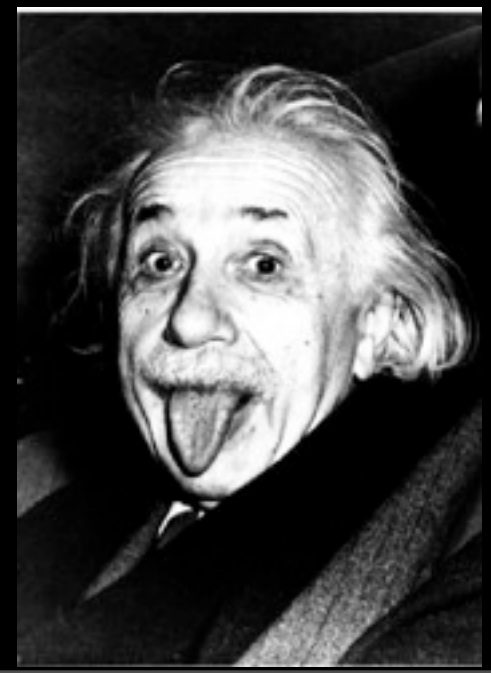
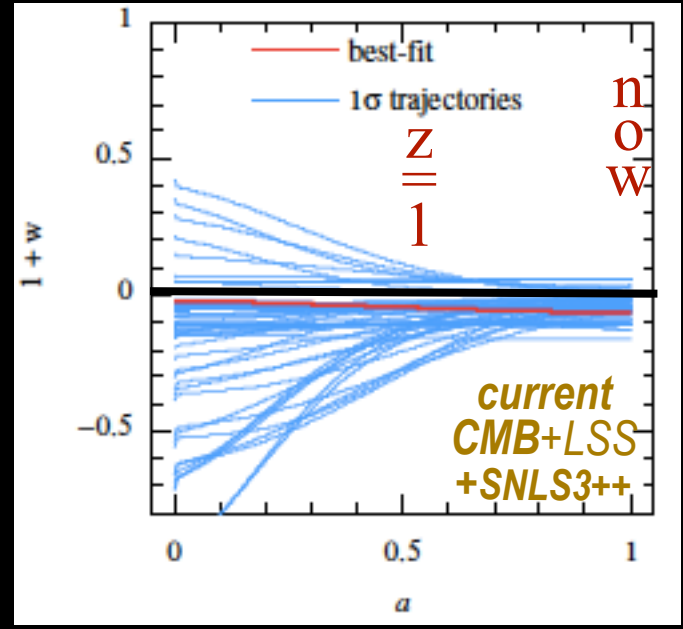
to DE (t,x)
or not
to DE (t,x)
that is the
question

modify
Einstein
equations?!
nein



CITA ICAT

late-inflaton DE trajectories



Beyond Einstein

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

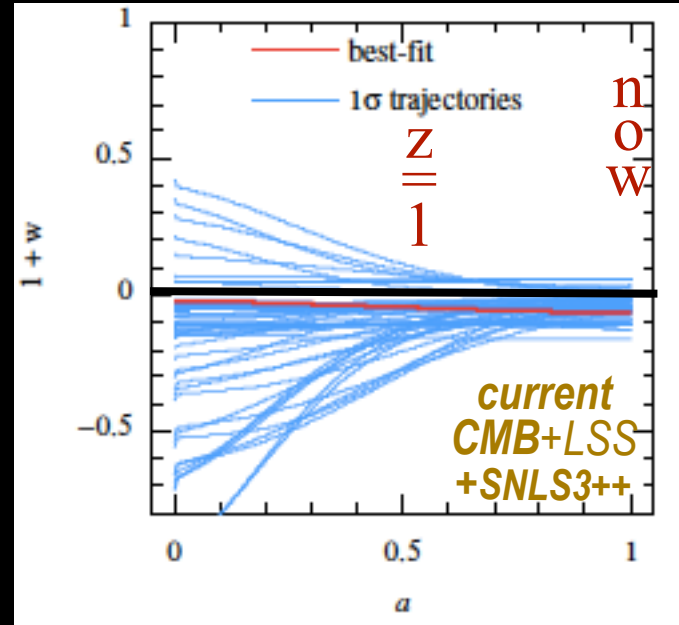
modify
Einstein
equations?!

~~nein ja~~

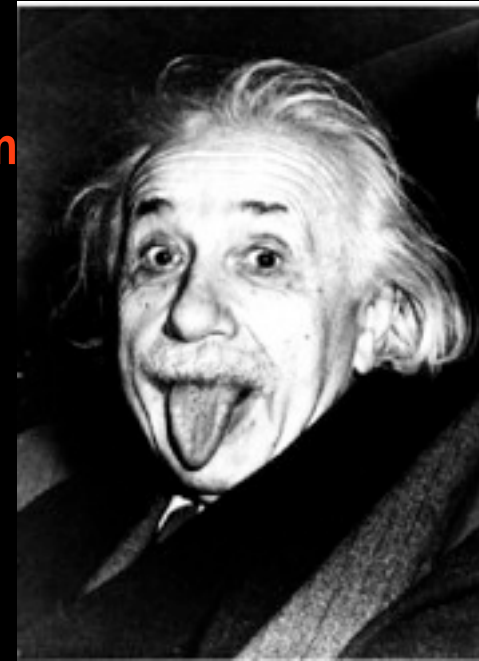
aha = Einstein
+ fifth
force



CITA ICAT



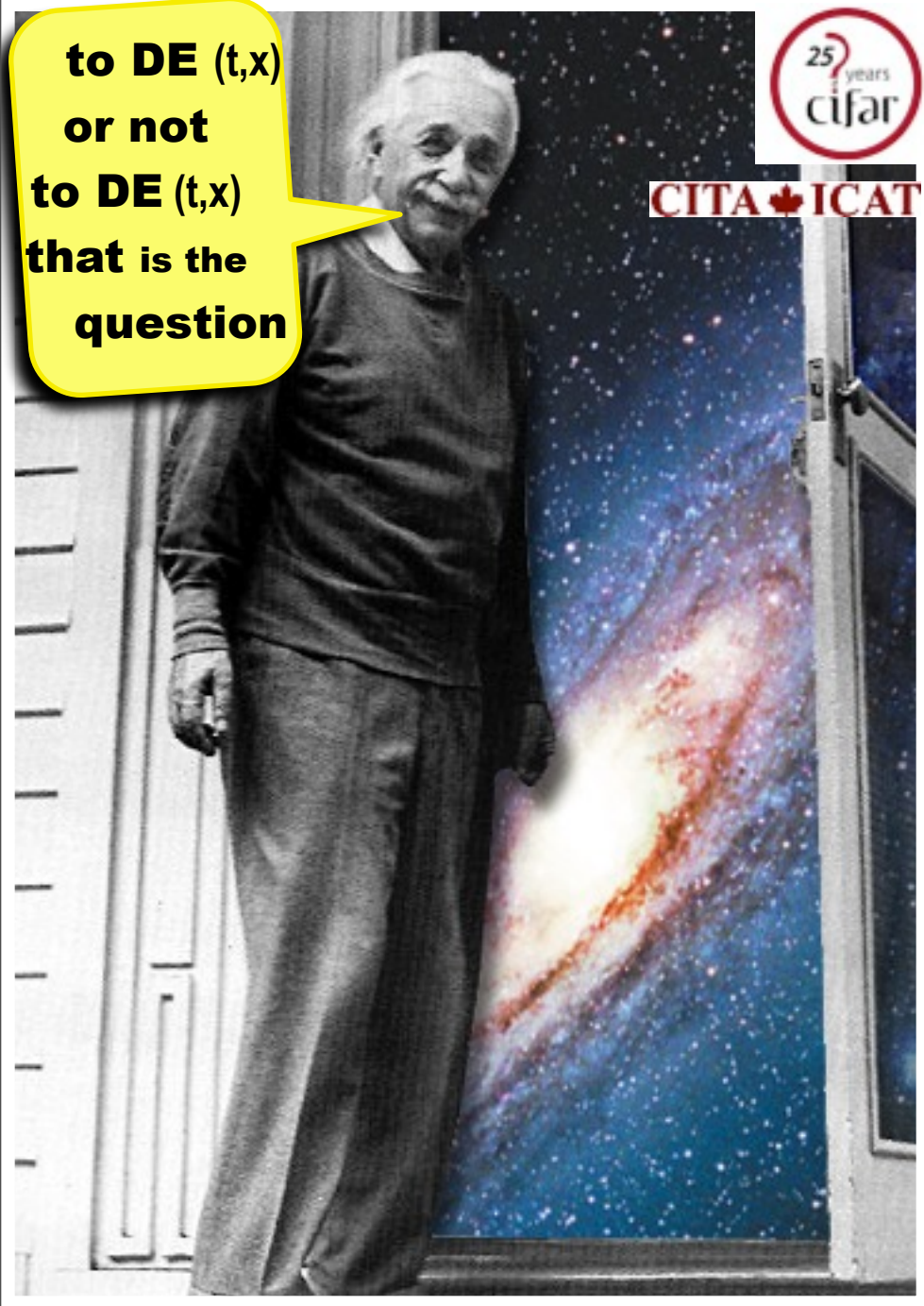
DE-matter-interaction
=> exciting new
window??!
chameleon-ish



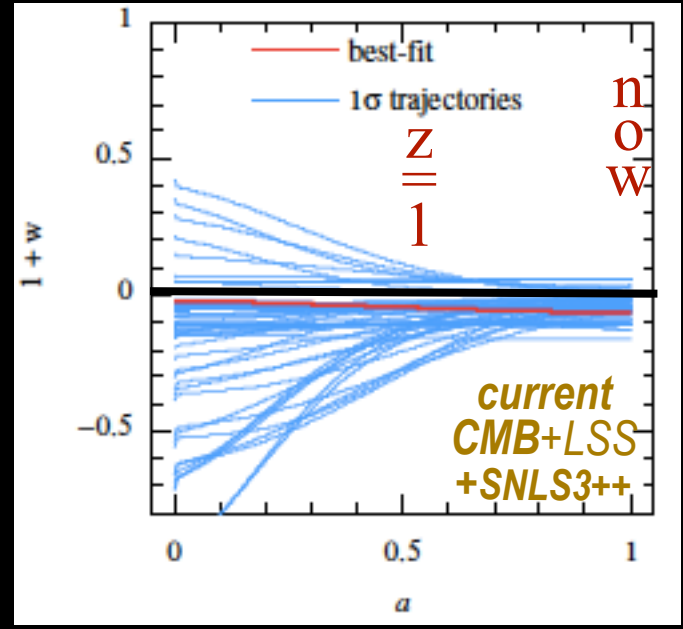
to DE (t,x)
or not
to DE (t,x)
that is the
question



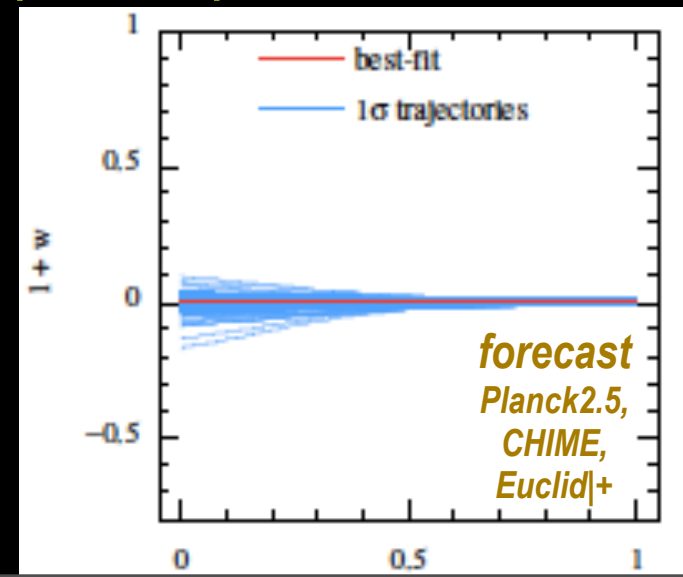
CITA ICAT



late-inflaton DE trajectories



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



"IT from BIT"

FATE U inflate (again) natural selection anthropic $U \in \{Us\}$

a cold death? reheat/rebirth?

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

NOW 14 Gyr 1

Inflation fluctuations form: quantum jitter

Pythagoras formed

Let there be Heat

Galaxies Cluster Cosmic "web" of vast filaments + membranes

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



Solar system earth formed

Life forms on earth

Protons/Neutrons form

Helium forms

9 Gyr 1.4

Let there be $\rho n \alpha \gamma$ ve

100 sec 10^9

1st light

2nd light

Carbon/oxygen/etc form

Let there be Light

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

Galaxies form

2 Gyr 4

what message in the information medium? The 'Meaning' may change But the facts will remain

end



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.