



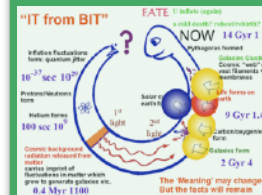
begin Bond's *imagine-ary* Time

Have *quantum* Transport will Travel:

Entropy in a Coherent Universe



bond @ ACT telescope under construction
1st light 2007
decommissioned nov 2022.
last big release march 18 2025



U-fusion

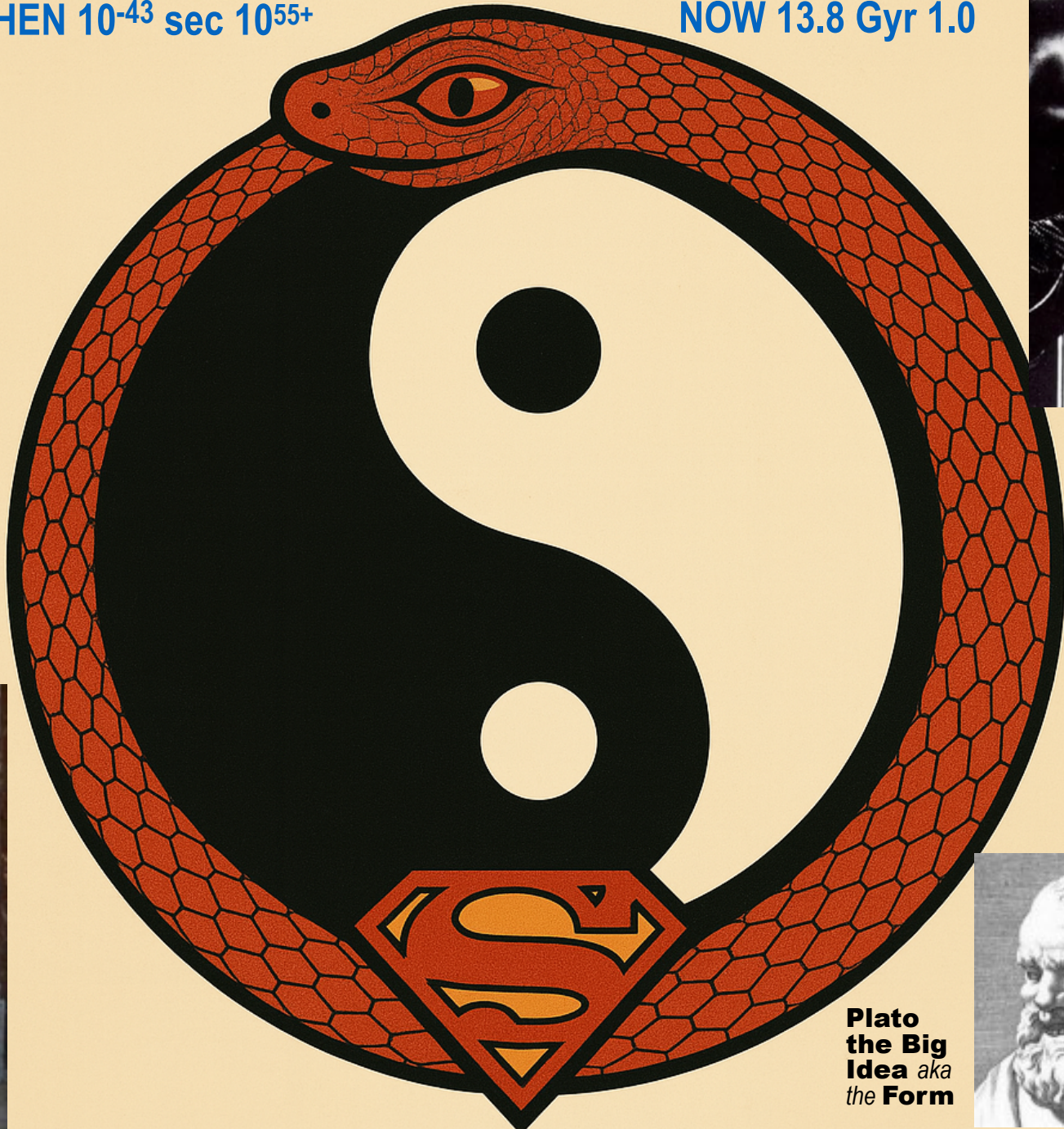
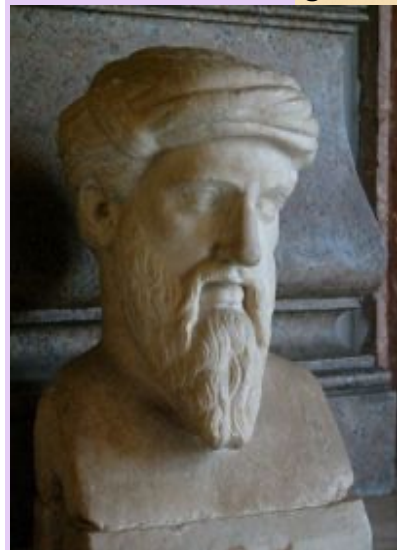
LaoTzu forms **Pythagoras** forms .. **Plato** forms => **Gamow** forms 123^∞
THEN 10^{-43} sec 10^{55+} **NOW** 13.8 Gyr 1.0



the **TAO**

$$\psi(U) = \exp(-\text{☯})$$

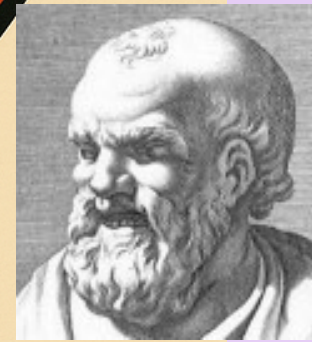
PYTHAGORAS
550 BCE THEORIST
 Cosmos $\supseteq$ math,
 harmonic ν/λ , digital



~1930

ylem =
 primordial stuff
 => **CMB@75**
 cf. bond@75
 forms
 efstathiou@70
 forms

Plato
 the Big
 Idea aka
 the **Form**



Let there be **TIME** Planck era 10^{-43} sec

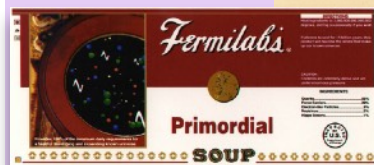
Let there be **Inflation (dE)** emergence!?!?
= **acceleration** (differential)



 **(U) condensate**
begets all cosmic structure
the **Cosmic SuperWeb**

LaoTse forms **Pythagoras** .. => Gamow 123^∞
NOW

Universe =
SignalUNoise
StimulusUResponse
SystemUReservoir
particleUhole
QuestionUAnswer
ChargeUField-gauge
StressUStrain



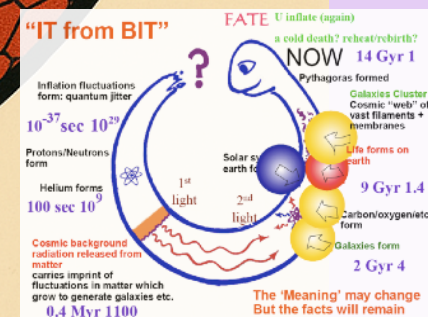
Let there be **CvB**
Let there be **pn α**
100 sec 10⁹

Let there be **Light**
 γ eN dm ν
0.38 Myr 1100

9 Gyr 1.4

cosmic web

0.4 Gyr 12





Bond's ToMe: ~~ancient wisdom~~ aphorisms

There is no ~~MetaPhysics~~, only Physics

of Life, the Universe, and Everything

**There is only Quantum Physics aka
Quantum Information aka
Quantum Cosmology**



$$\psi(U) = \exp(-\text{☯})$$

*classical physics and classical cosmology never were, except historical anomalies as human ideas grew.
we are still catching up to Einstein. relativity => gravity => wormholes (black hole / white hole with a bridge in
between) => quantum entanglement. bose-einstein condensates. reality of photons. stimulated emissions. quest
for a grand unified theory. one smart being!*

**Quantum is the physics of counting 'Things', of Quantities
Things are coherent in phase = en-tango-ed = correlated
the flow of quantum information is Quantum Mechanics**

**Quantum Wave Function of the universe ~ entropy (counting) - *i* action (phase)
~ complex entropy**

*We transport: the Quantum Occupation Number Matrix of things $N(f|i)$
from then & there (initial) to here & now (final)*

*the Quantum Entropy Matrix $\$(f|i)$ encodes ALL of the THINGS,
via (create *f*, things, particles) to (annihilate *i*, not-things, holes)*

$d\$(f|i)/dN(f|i) = s(f|i)$ *the specific entropy of things, new way to see the transport*

*$N(f|i)$ and $\$(f|i)$ are responses of *f* given *i*. Response functions = Transfer functions are key = industry@CITA*

there is no MetaVerse = MultiVerse, only UniVerse

there are many Realities, aka Realizations

Realities interact in the Quantum flow = information spreads

processes: quantum fission, fusion, tunneling, phase-locking = coherence & unlocking = decoherence

peak patch picture of cosmic catalogues = expansion in ordered prominences ~ AI?

Quantum Cosmology in the Planck Era & Beyond



Gamow $123\infty \alpha\beta\gamma$ + 5K CMB + QM tunnel

$\alpha_{ij}(t,x)$ $H_{ij}(t,x)$ $\epsilon_{Hij..}(t)$ *i, j over ALL dimensions*

the Cosmic SuperWeb

SuperGravity in 11 dimensions, 2 “time” (complex), 9 “space”, or ... >> more

SuperString Theory, a theory of everything?

‘tis the cosmic POV I embrace while others abandon

= Matrix theory = M-theory

emergent thought-dreams are so much fun! e.g.,

multi-dimensional (white hole + black hole) @ THmax QM fusion

< => white hole @ TH(time) expanding U + TBD QM fission

from bond no-thing to
entangled bond thing

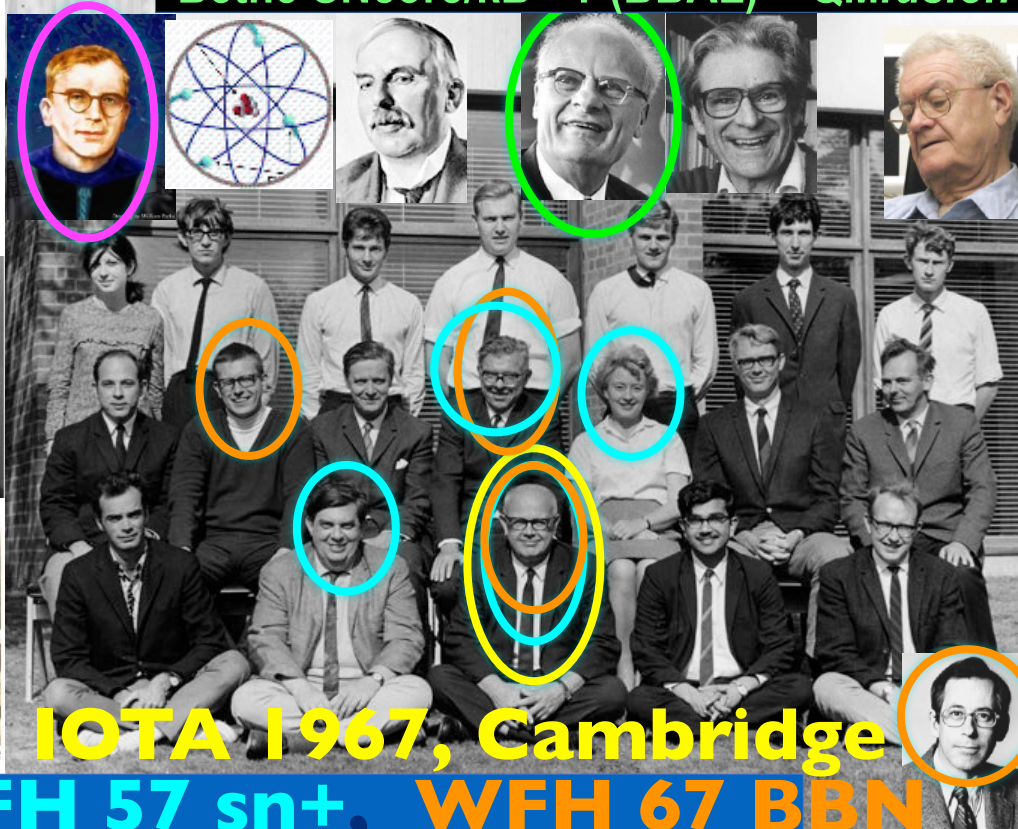
Entropy in a Coherent Universe: the Quantum Information in the Action of the Cosmic SuperWeb

Quantum Information Transport is what we do => 1980 Entropy, Neutrinos and Supernovae @1st KITP Bethe++
=> 2020 Entropy, Phonons and Phase Transitions @KITP

Gamow 123 ∞ $\alpha\beta\gamma$ + 5K CMB + QMtunnel

during and after inflation
=> Dick Bond @ APS 24 04 04 BetheTalk

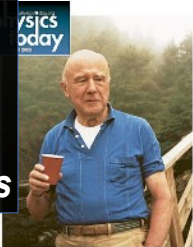
Bethe SNcore/kB ~1 (BBAL) + QMfusion



IOTA 1967, Cambridge

B²FH 57 sn+, WFH 67 BBN

QMfission
particles 30s
=> fields 50s
=> quantum
information 70s



Coat of arms adopted by Niels Bohr in 1947



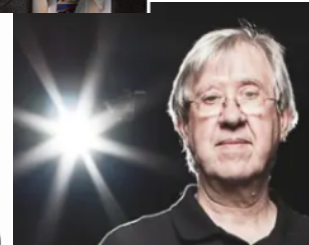
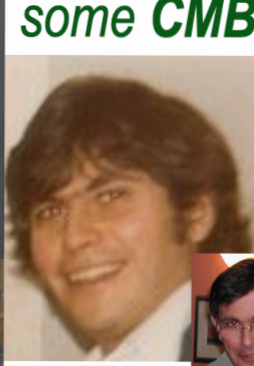
the ideas we had = the parties we had

Have Transport will Travel Collective Quest UofT73 SuperFluid+ => ManyBody ν N Caltech 73-78,
Bky 78-81, Cam 82-83, Stanford 81-87, SantaBarbara 84,..., **CITA 85-now**

NuclearAstro, Neutrinos & Supernovae @ Caltech Five decades of cosmic ν CvB **SM ν =>BSM ν ...**

4.5 decades of cosmic γ CMB **SM γ =>BSM γ** 4.5 decades of cosmic **dark matter CdmB**

=> Cosmic Neutrino Decoupling and its Observable Imprints: Insights from Entropic-Dual Transport BFGMW24



some **CMB** theorists

+ N Vittorio

test with **CMB+LSS**

~85-87 reconsider Λ , quintessence
“what you see is what you get”

CMB CdmB transport
with George E & Alex S
... & George F

~80-84: Hot (light ν), Warm, Cold DM
hot Big Bang collisionless relics
or
black holes from Very Massive Stars,
Jupiters, primordial black holes



anthropic matters with BJ Carr

vary **x** in **xCDM**: find x by the tests **x=tiltedHBA**

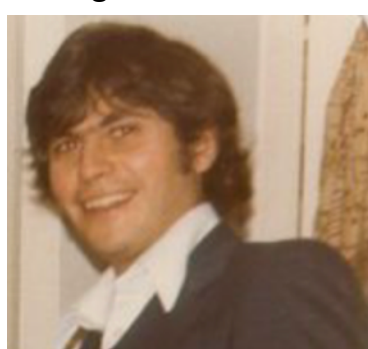
BBE87
SBB89
SB90, 91

theory of polarization of the CMB 60s 80s - 90s for GW

..
CBCHM25



party pix at the BBC house! begelman bond carr



'twas all entropic at its core

*bond szalay 81-83 collisionless damping, hot warm cold DM
bond, szalay, turner 82 warm DM as gravitinos



* BBKS 82-86, ITP84 and RandomField stats

Bond & Efstathiou 1984/1987 GUCMB $\Rightarrow$
Delta T over Tea 1987 @CITA bond + wilkinson = theory + expt = CMB community

Computing Cosmologies @ CITA 1989 gas + dark matter + bond+lm sph sims: filaments are fundamental in both

salopek bond bardeen 89 Higgs inflation & $n_s(k)$

* **salopek bond 90 91 stochastic inflation, nonGaussianity**

bond cole efstathiou kaiser 91 excursion sets

* **bond myers 91-96 peak patch picture of cosmic catalogues**

$\Rightarrow$ bond kofman pogosyan 97 = CosmicWeb @ITP96

bond, efstathiou, silk 80 hot dm

* bond efstathiou 84 on CMB@19, vittorio and silk 84

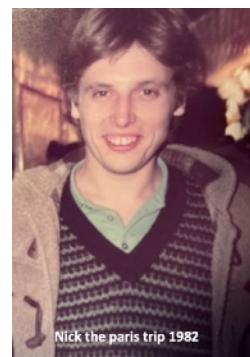
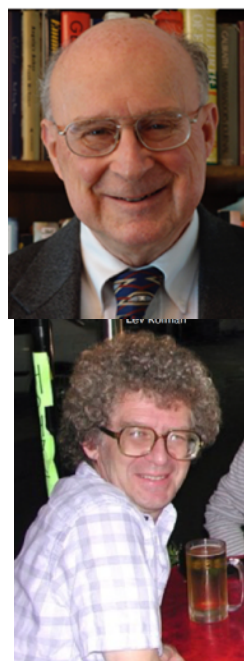
$\Rightarrow$ bond efstathiou 87 unified CMB + stats ... $\Rightarrow$ CMB@60



ITP santa barbara 1984



+ marc davis, simon white, carlos frenk DEFW
+ bernard carr BCA VMBH, 1st *, bbhGW, BCH CIB
+ **jim bardeen, nick kaiser, alex szalay BBKS**



'twas all entropic

Coat of arms adopted by Niels Bohr in 1947



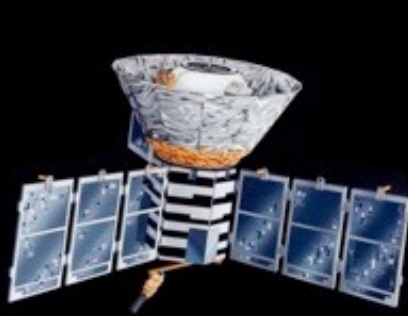
the ideas we had = the parties we had

Comparison of CMB Space Experiments: Resolution, 420', 12.5', ~5-7'

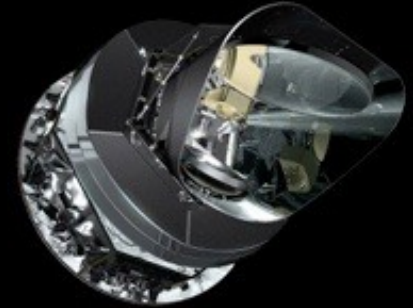
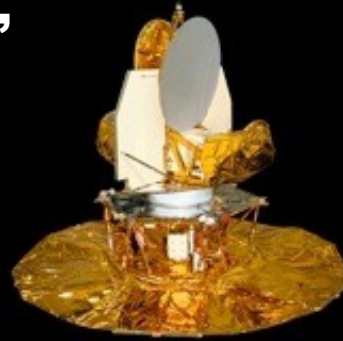
COBE 89 launch

WMAP 01 launch

Planck 09 launch



full moon **31'**



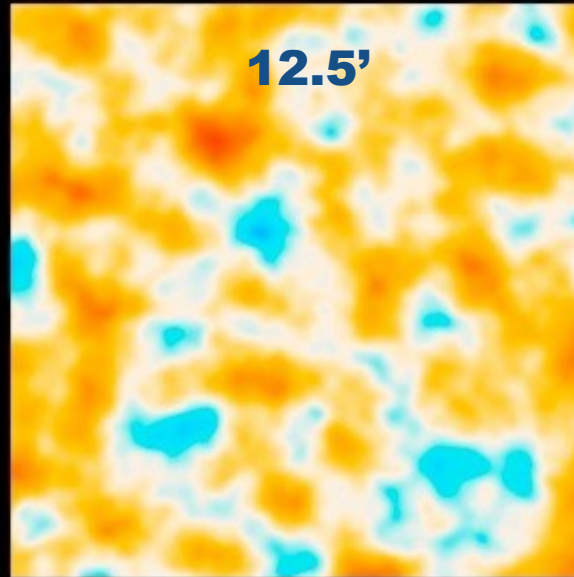
420'



Nobel 2006

COBE

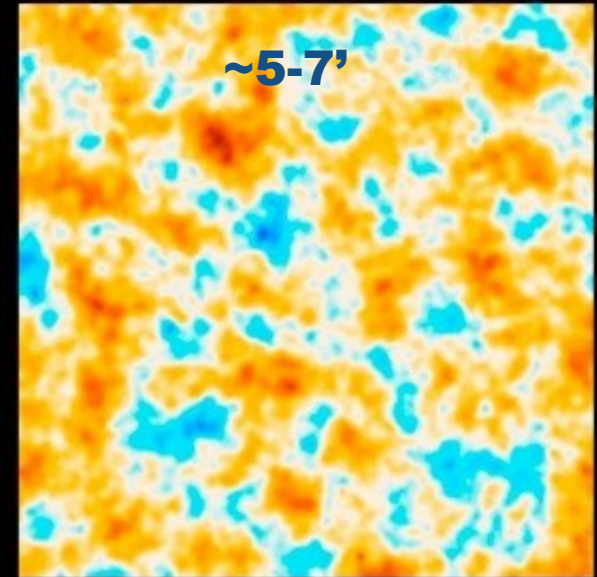
12.5'



Shaw 2010

WMAP

~5-7'



Shaw 2018 + CIB

Planck

space future => more ν ~2031 Litebird Japan, Europe, Canada res ~ 30' 12 ν ; > 2040 FOSSIL Europe

ground goal: plumb all cosmic info => hi res ACT (1.4'), SPoleT(1') => now SO (1') ~100K detectors, CCAT (1')

also target gravity waves: BICEP@SPole, balloon SPIDER ~40' + Litebird ~30' + SO

Planck's primordial light unveiled, Mar 2013 => Feb 2015 => pre-2016 => July 2018+ final

reveals the **SIMPLICITY** of primordial cosmic structure

7+ numbers, 3 densities, 2+1 early-Universe inflation

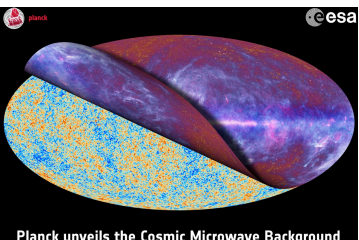
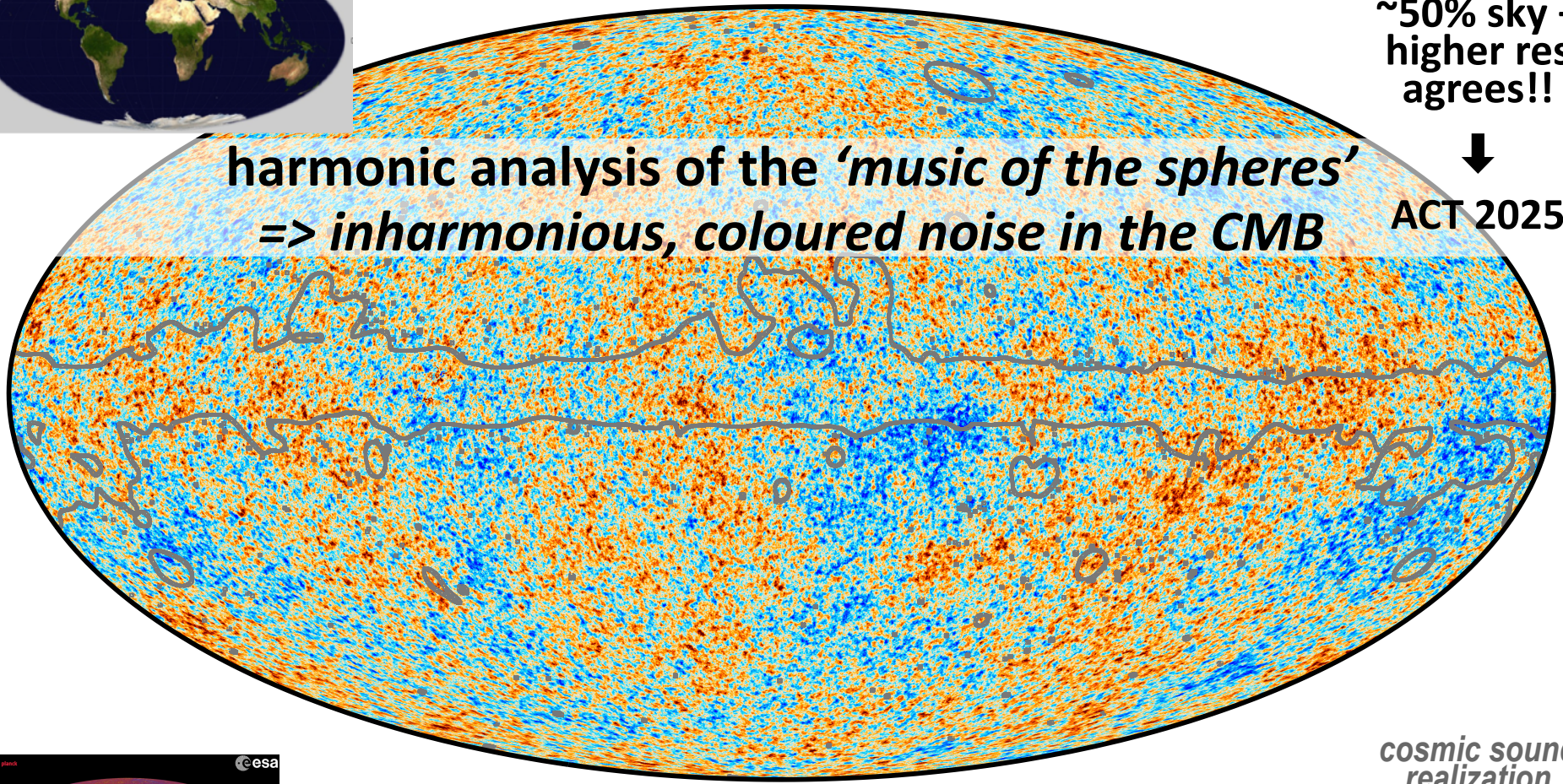


ACT 2022
~50% sky +
higher res
agrees!!



ACT 2025

harmonic analysis of the 'music of the spheres'
=> *inharmonious, coloured noise in the CMB*



-300



300 μ K

**Temperature changes
in micro-degrees**

cosmic sound
realization

phase incoherent,
but count coherent

Baryon Acoustic
Oscillation scale:

$r_{\text{sound}} = 144.6 \pm 0.22 \text{ Mpc}$

Atacama?
driest
desert in
the world.
thus: cbi,
toco,
apex, asti,
act, alma,
quiet,
polarbear,
CLASS,
Simons
Obs

ACT@5170m

Simons Observatory@5170m

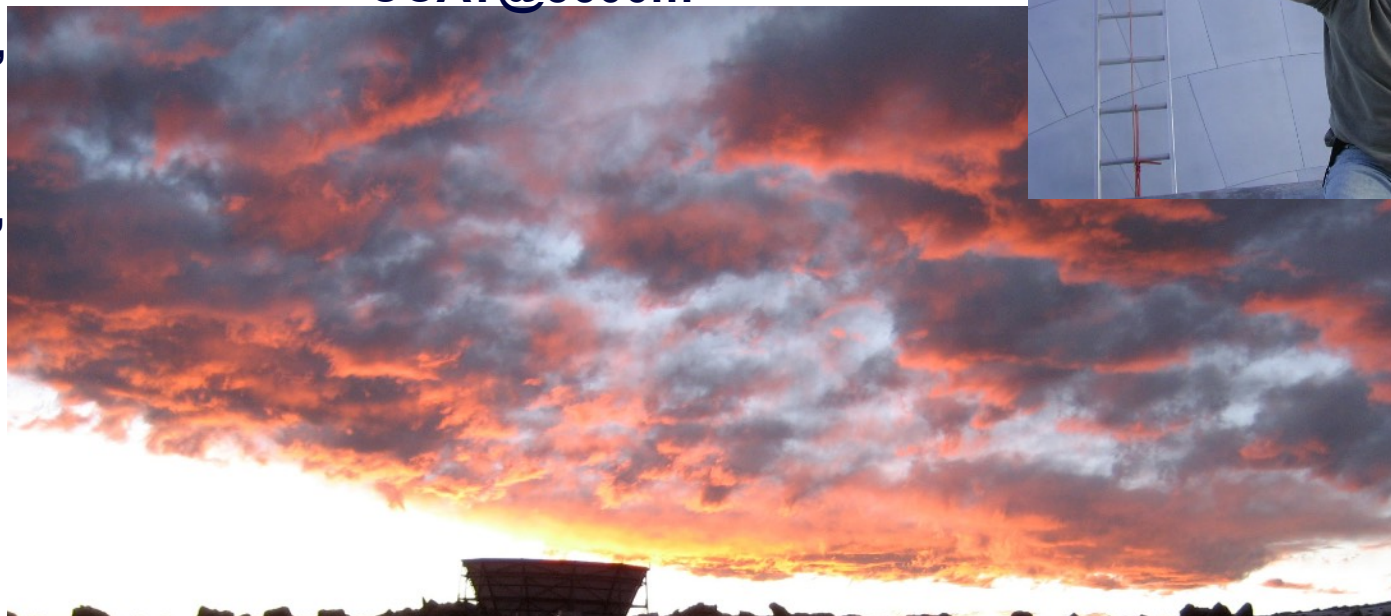
CCAT@5600m

birth of ACT

1st light 2007



RIP ACT 2022



ACT $\Rightarrow$ *ACTPol* $\Rightarrow$ *AdvancedACTPol* fsky=0.45 $\Rightarrow$ Simons Observatory

maps via
SciNet

ACT Mar 2025 release WOW cf. Planck

People: the joys &
constraints of
large teams

@Toronto
computers

Jon Sievers
+bond,nolta

Sigurd Naess+



Comparison of CMB Space Experiments: Resolution, 420', 12.5', ~5-7'

COBE 89 launch

ACT 1.4' + Planck

ACT+Planck

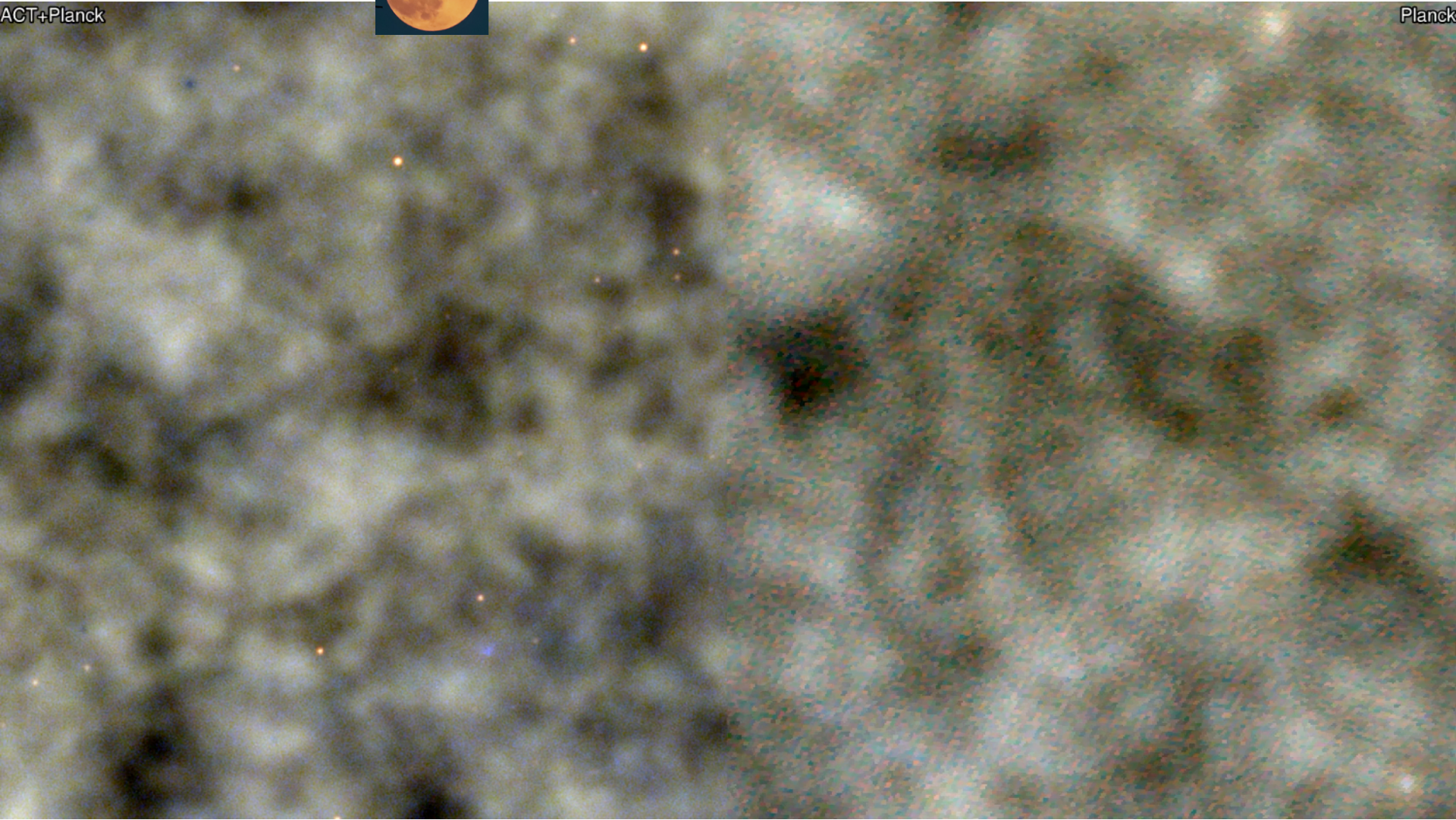


WMAP 01 launch

Planck 09 launch

Planck ~5-7'

Planck



Scan from lower res Planck to higher res ACT in temperature *bravo* Sigurd Naess

“point” sources emerge

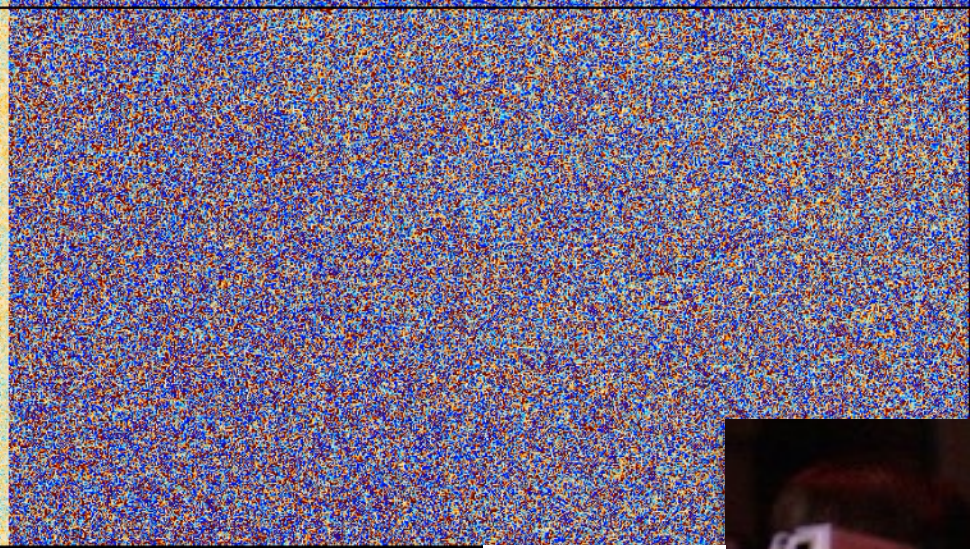
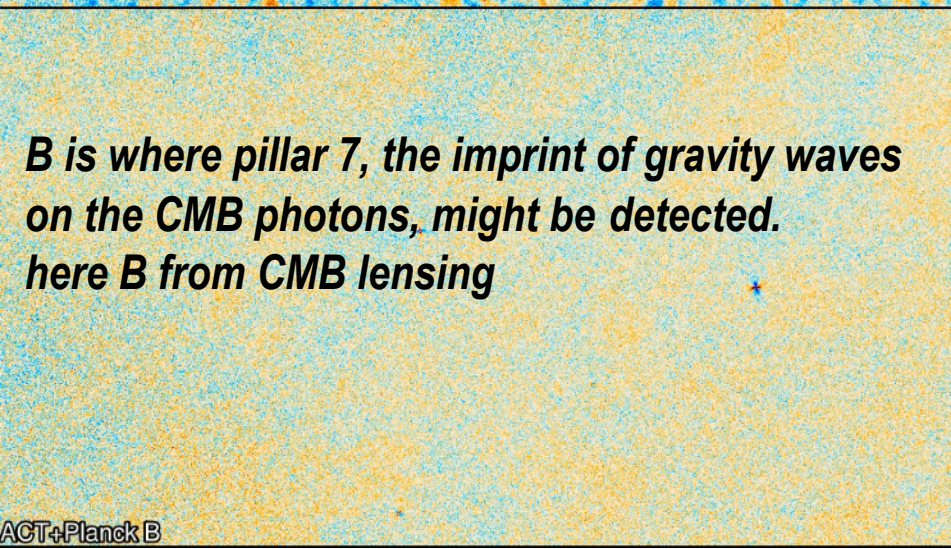
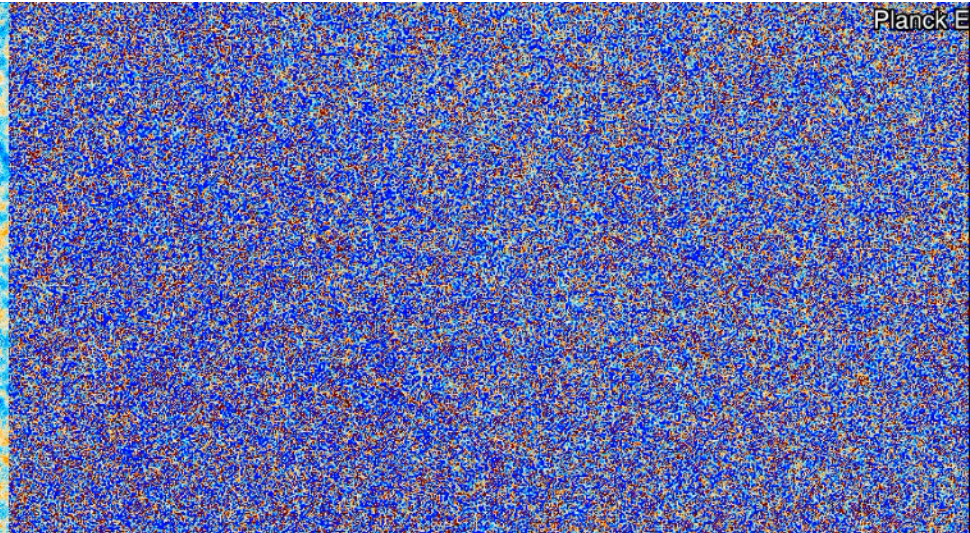
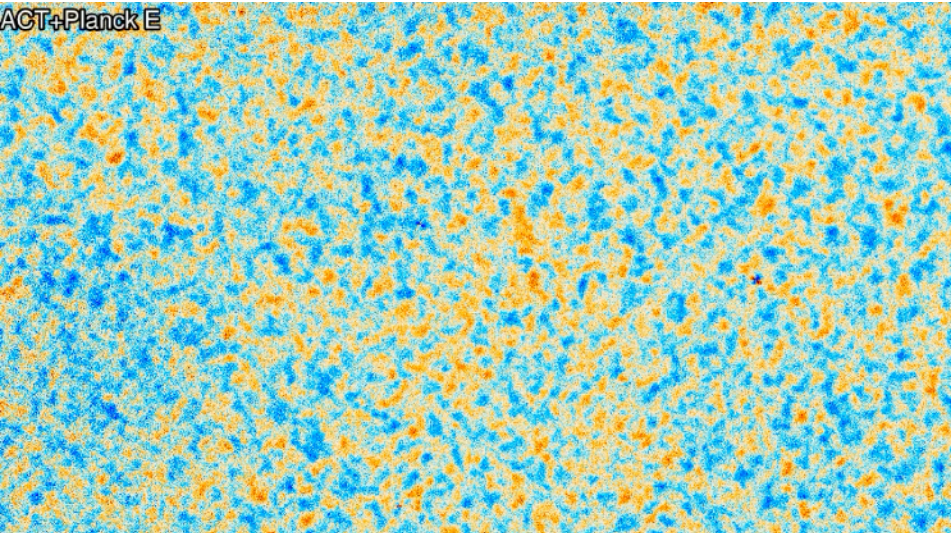
CMB in Polarization

ACT 1.4' + Planck

Planck ~5-7'

ACT+Planck E

Planck E



B is where pillar 7, the imprint of gravity waves on the CMB photons, might be detected. here B from CMB lensing

ACT+Planck B

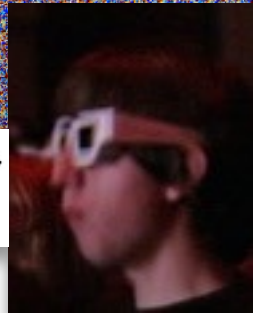
Planck B



Scan from lower res noisy Planck to higher res ACT in polarization, E mode & B mode



bravo Sigurd Naess



Dick Bond **CITA** *the summary talk*

CMB@50 THEN & NOW & THEN

a celebration Princeton June 2015

a Who's Who of the CMB world => CMB@60

**an extended CMB family
reunion & Peebles@80 => Peebles@90**

CMB prediction

Alpher, Gamow Herman 1950s Tcmb ~5K

CMB Discovery

Penzias & Wilson 65

@7cm

CMB dipole 70s $\Delta T/T \sim V/c$

360km/s

Delta T over Tea 87 @CITA theory+expt

COBE 1989 launch

Blackbody 1990 Tcmb = 2.725K -455°F

Anisotropies 1992 ΔT ... Boomerang 98

WMAP 2001 launch

Polarization Revealed >2002

DASI,CBI 2002 Boom Quad

Planck 2009 launch

.. Planck 2015-18 precision U parameters

ACT SPT higher resolution + polarization

BICEP/Keck +Planck B =dusty no GW Spider

=> future

.. CMB Stage 3 (now) => SO SPT3g CCAT

.. LiteBird 2031, other satellites Fossil??



Dick Bond **CITA** *the summary talk*

CMB@50 THEN & NOW & THEN **a celebration** *Princeton June 2015*

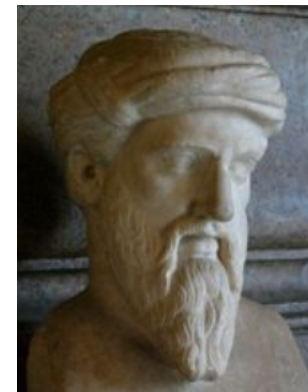
a Who's Who of the CMB world => CMB@60

an extended CMB family
reunion & *Peebles@80 => Peebles@90*



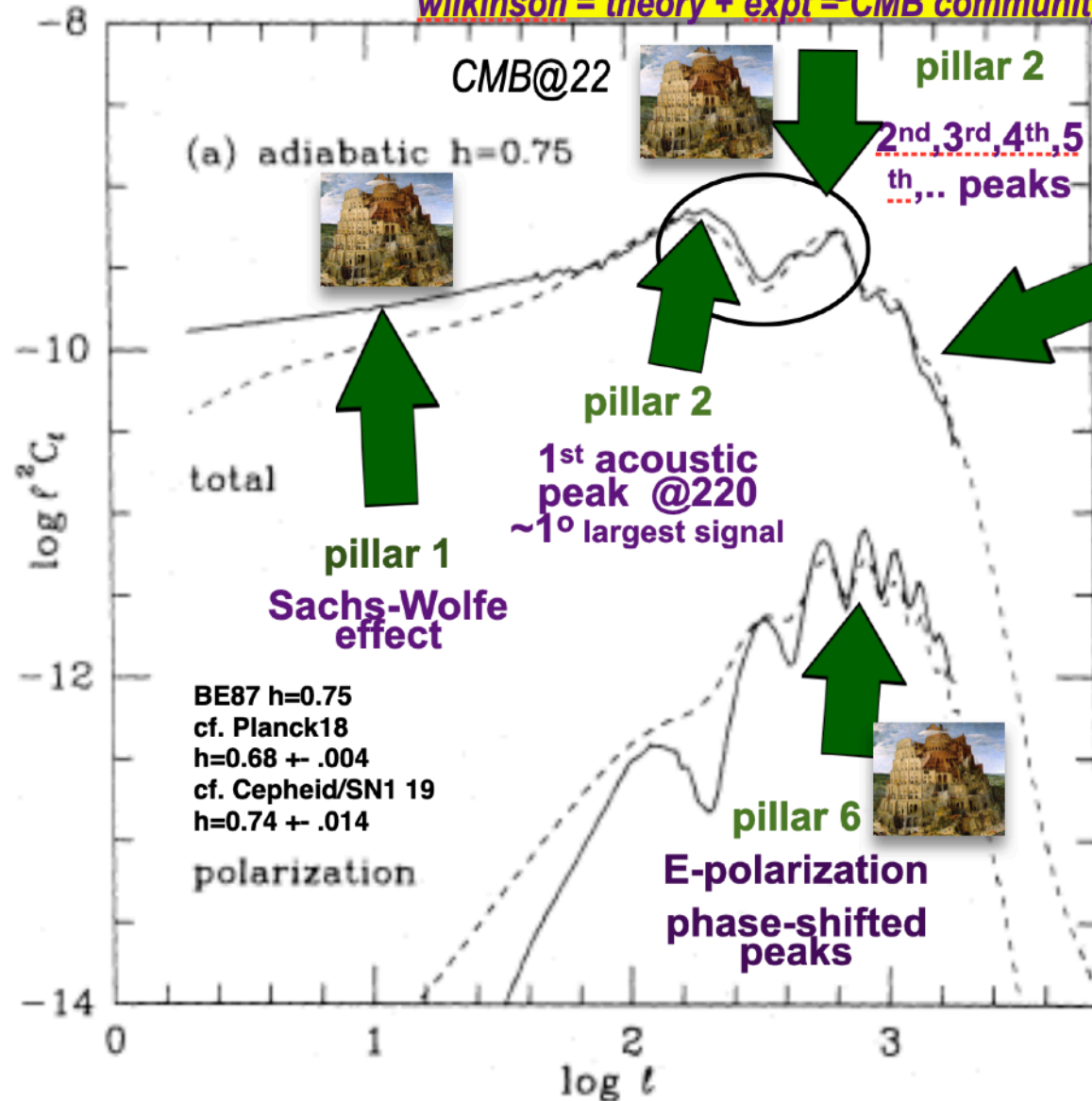
a Planck family reunion CMB@60

harmonic analysis of the 'music of the spheres' => inharmonious, coloured noise in the CMB

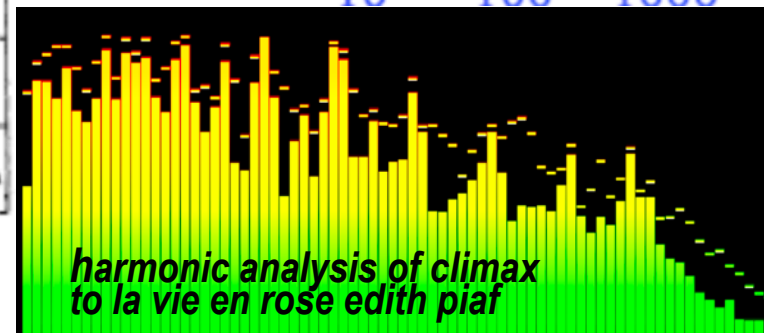
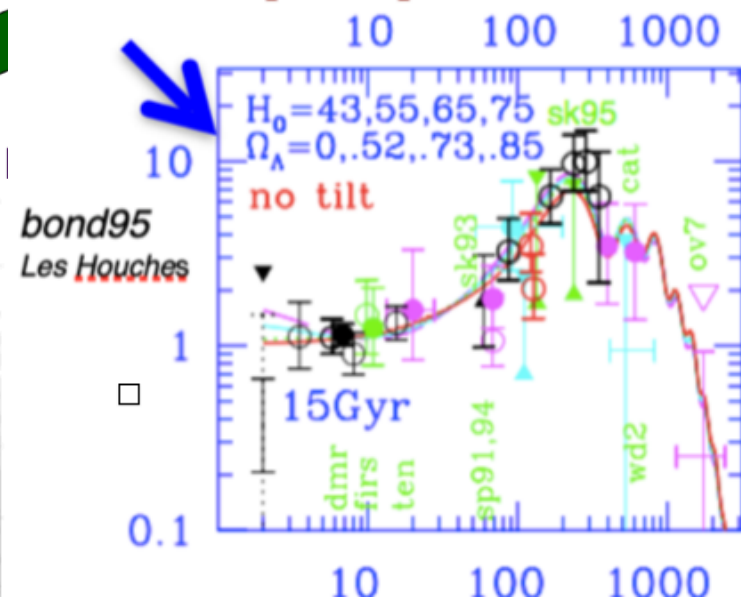


the Seven Pillars

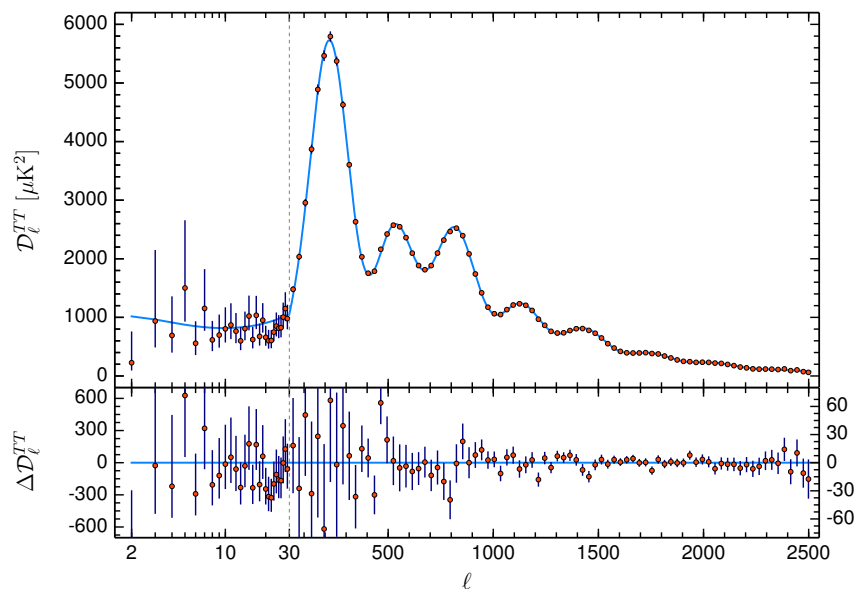
Bond & Efstathiou 1984/1987 GUCMB =>
Delta T over Tea 1987 @CITA bond + wilkinson = theory + expt = CMB community



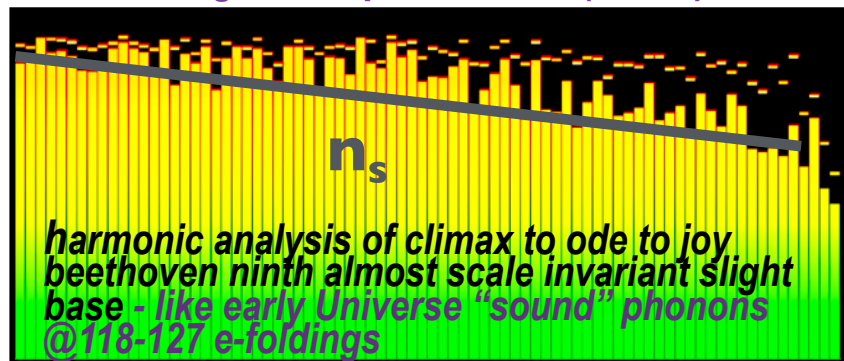
JRB@Capri 1993 Bandpowers cf. theoretical power spectra



Planck 2018 harmonic analysis of underlying 

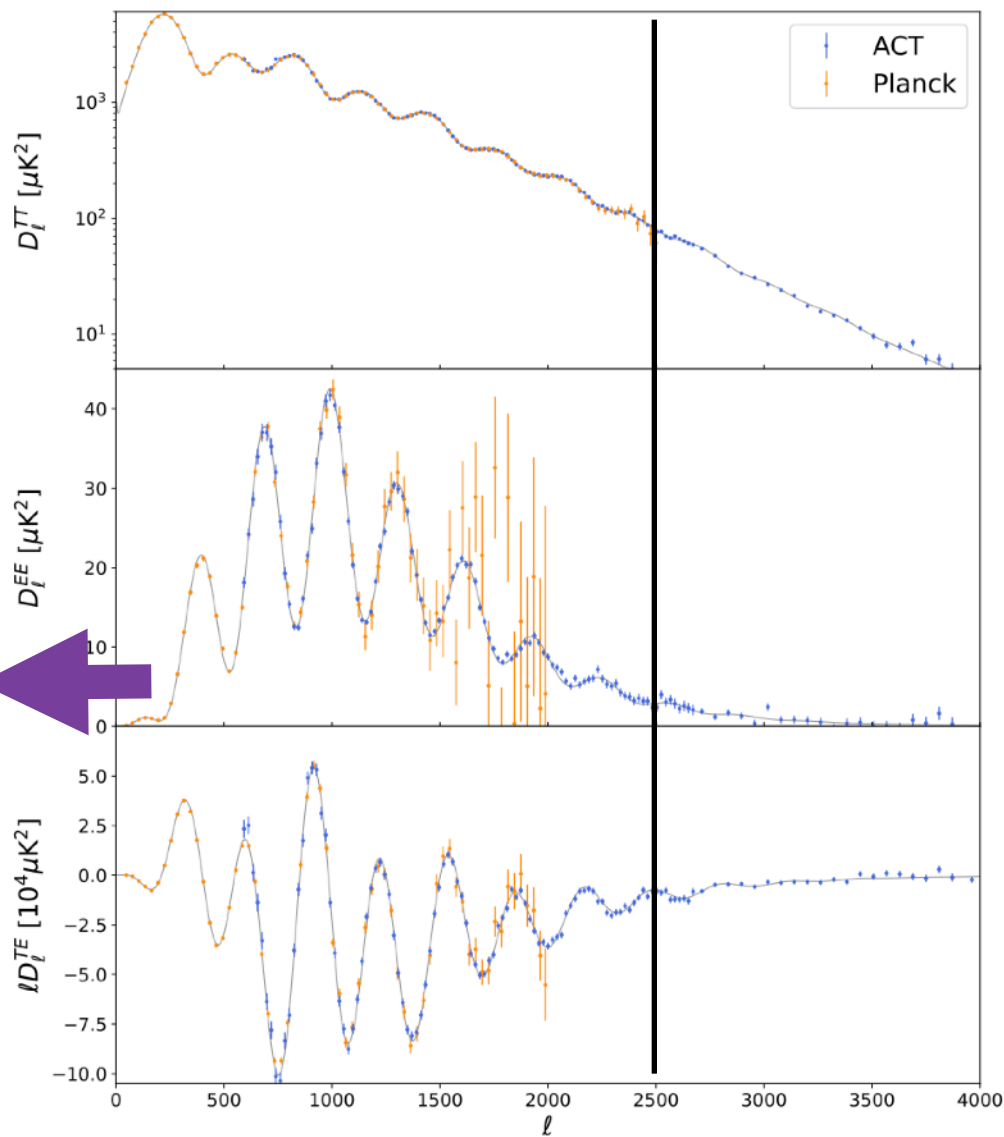


the highest impact Planck (&ACT) result



scale invariant - power all octaves equally - in 1D=1/f

ACT 2025 harmonic analysis

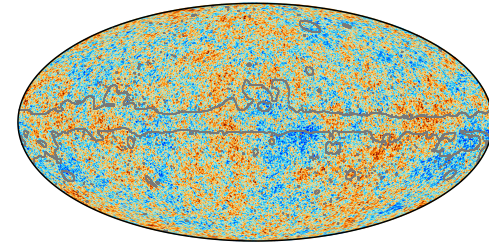




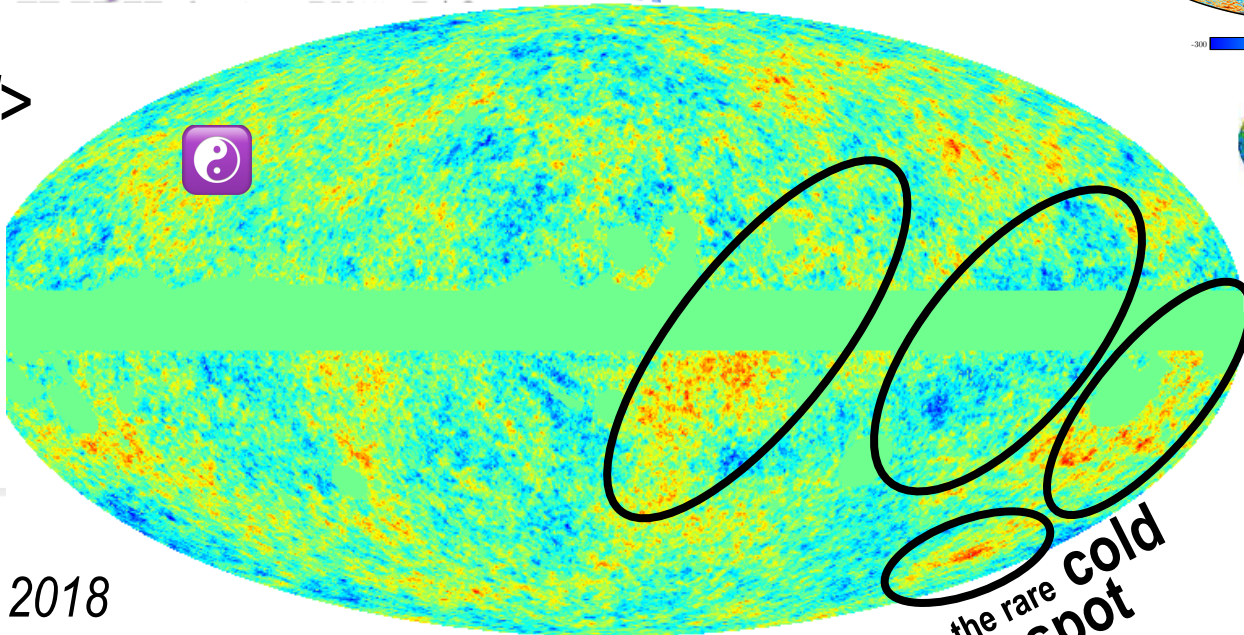
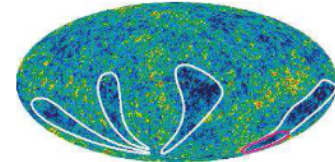
Primordial map: Beyond the Standard Model of cosmology?

$SM_c = \textit{tilted} \Lambda\text{CDM}$

IMAGE of the Beginning 10^{-33} seconds



$\langle \zeta | T, E\text{-pol} \rangle$



-35.0 +35.0

Bond + Huang 2018

random sound loudness $P_\zeta(k_p) + \text{bass/treble } n_s = 0.967 \pm 0.004$ **8.8 σ from 1**

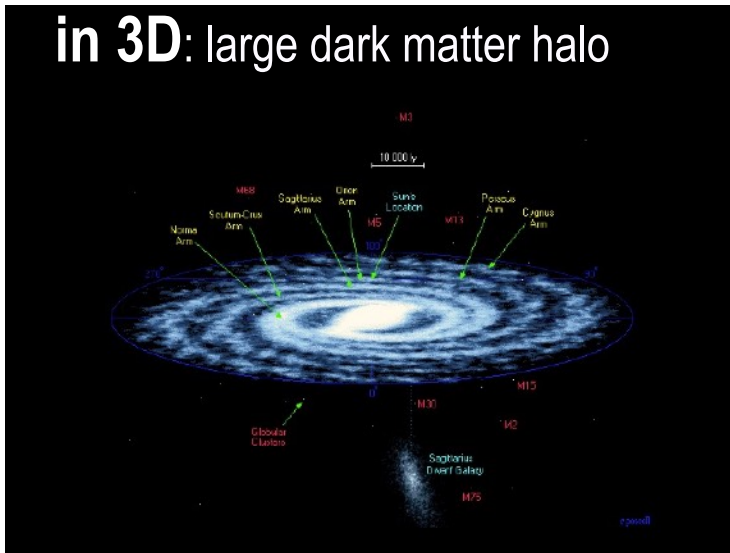


GUTA = Grand Unified Theory of Anomalies? not yet: pinGponG theory?

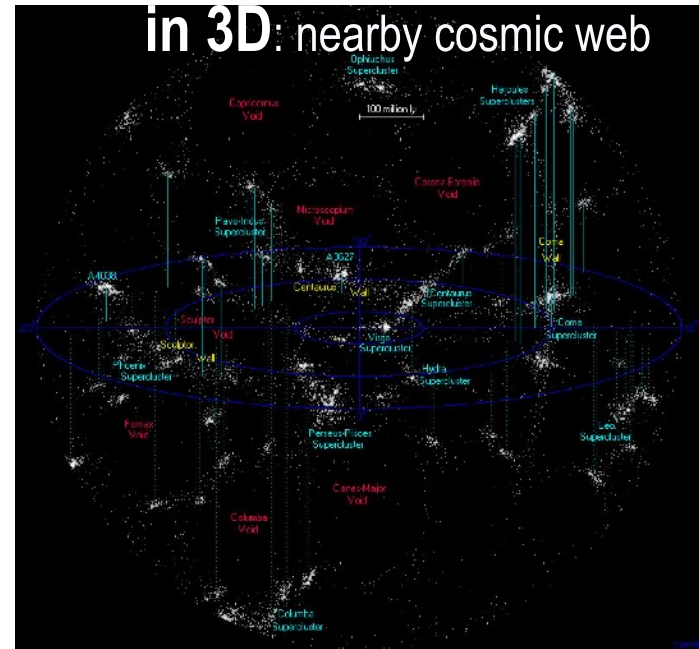
LightWaves, Gas and Dark Matter Entropy in the nonlinear Cosmic Web

Milky Way, a disk galaxy

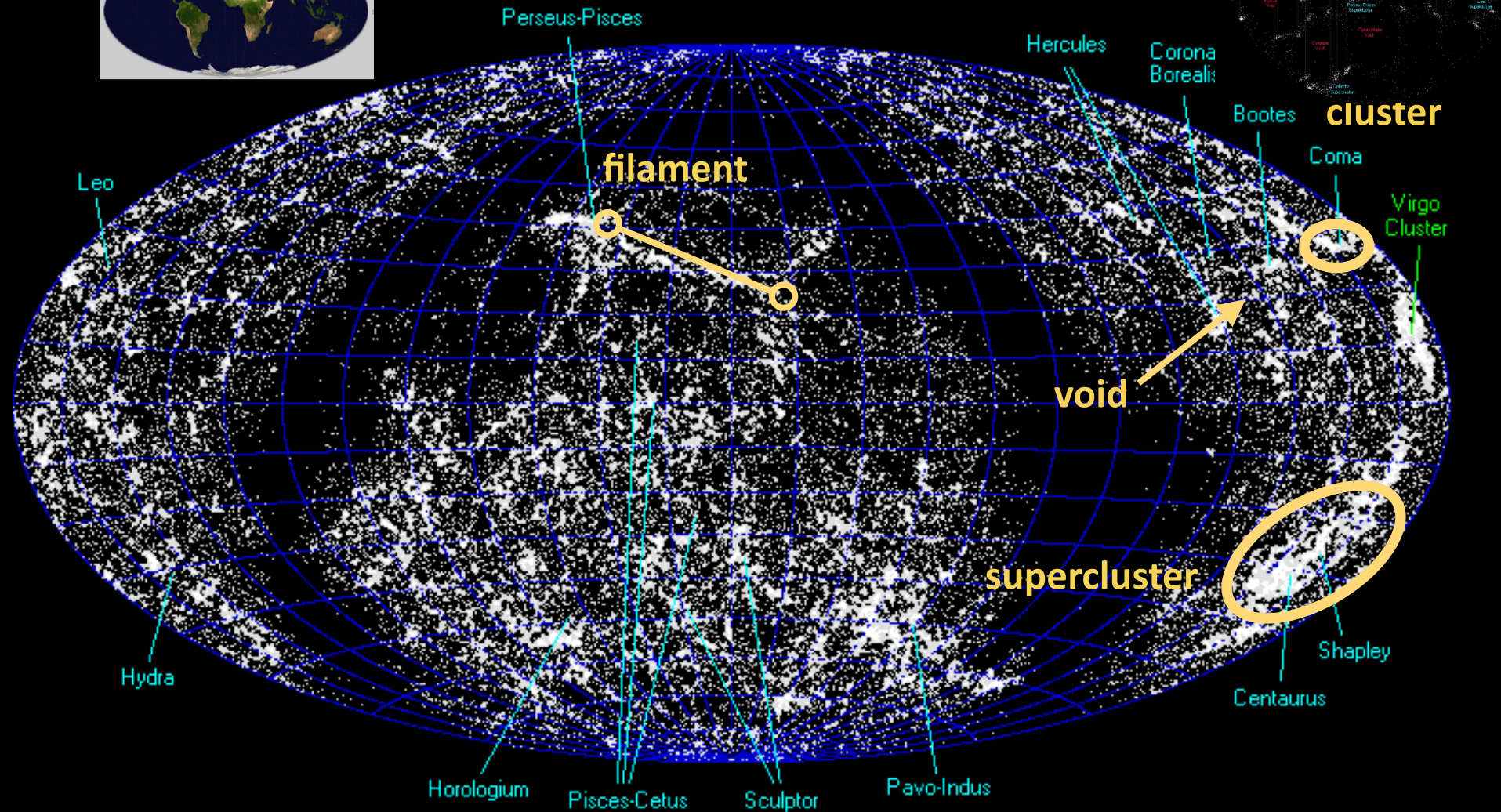
in 3D: large dark matter halo



in 3D: nearby cosmic web



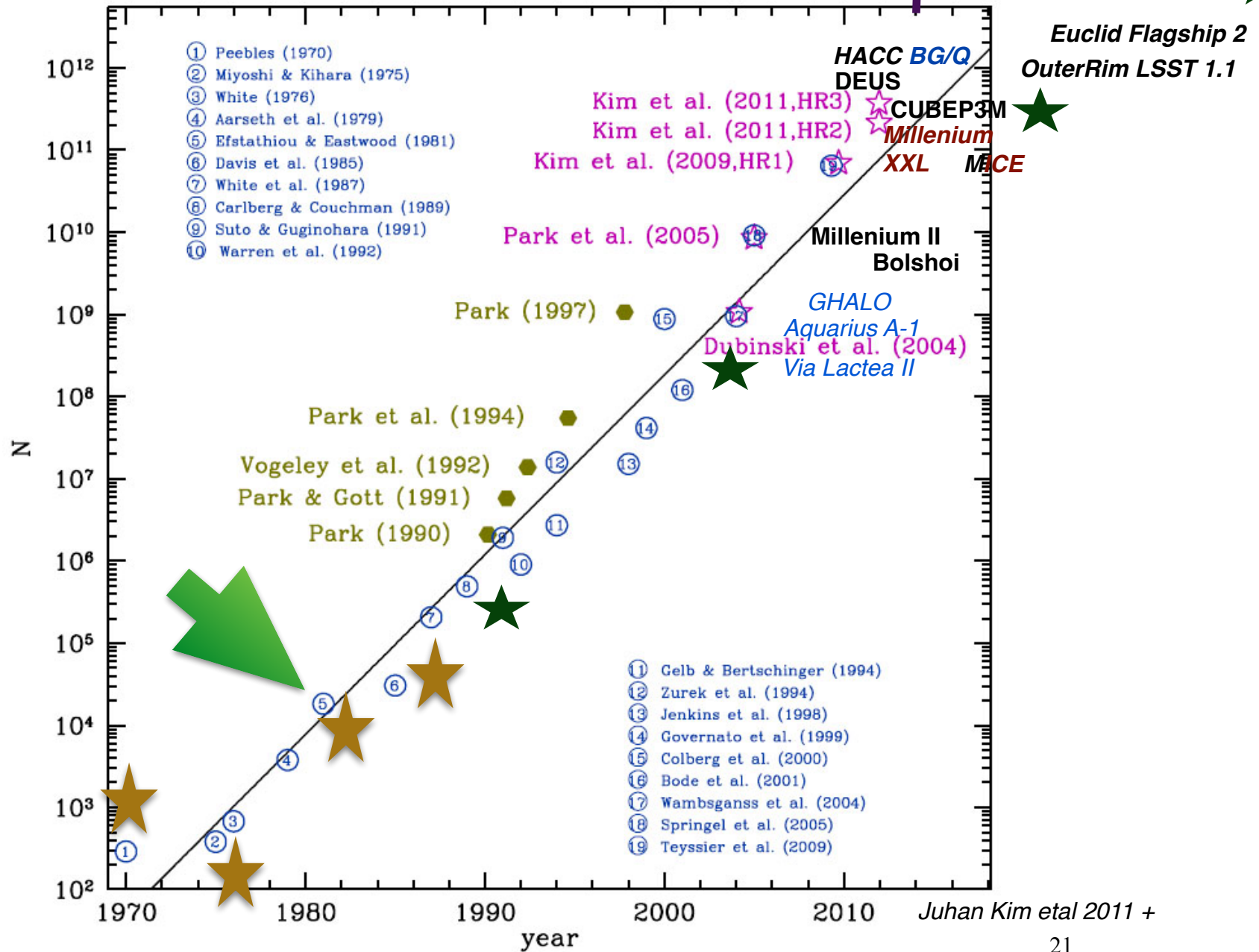
Cosmic Web of 60,000 nearby galaxies: exhibits “local” COMPLEXITY

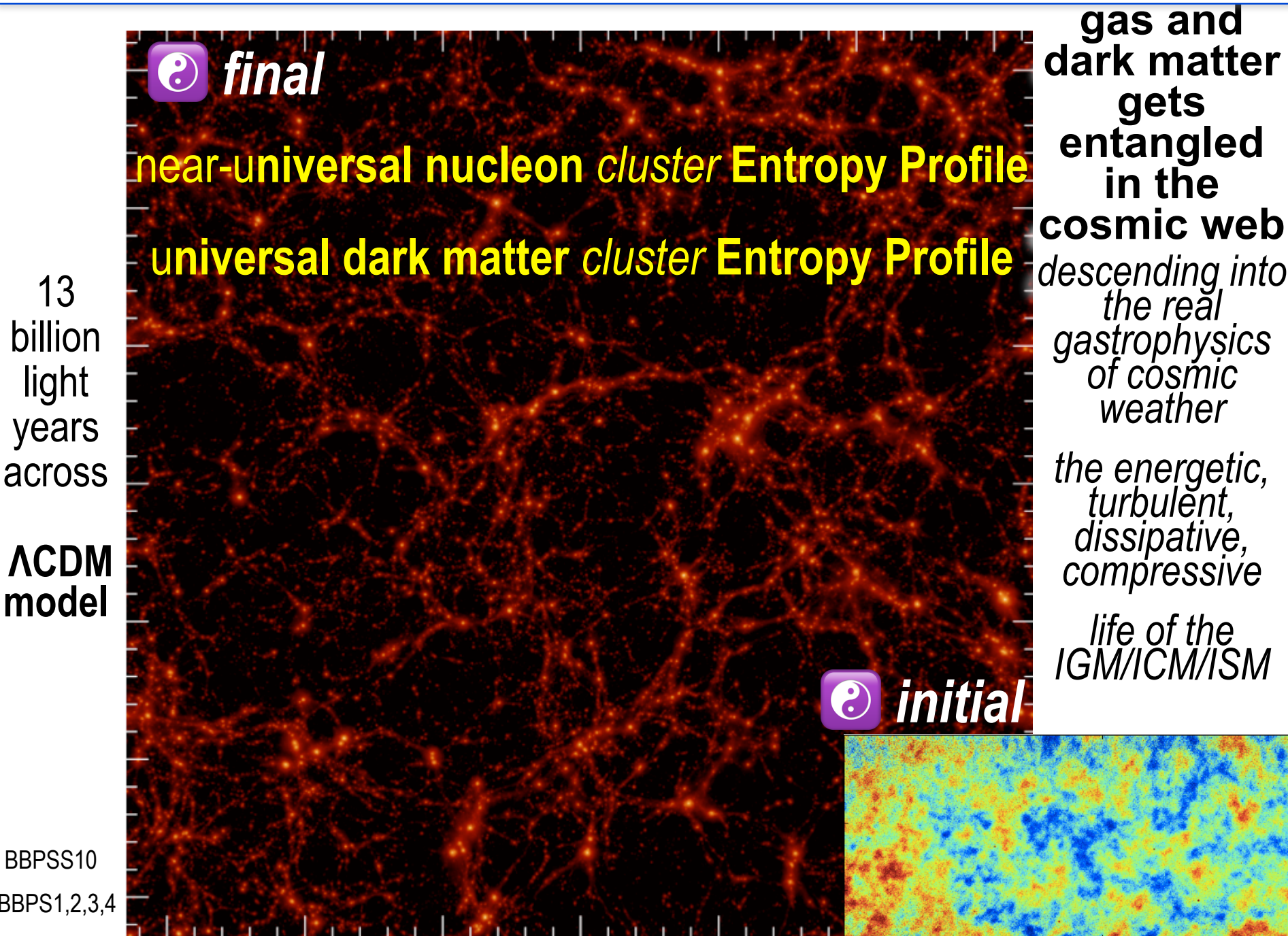


observational emergence of the web = ~80s tour de force, e.g., Coma supercluster ++. voids
interconnected structures from a Gaussian random adiabatic field under gravitational instability

NBody History + related story for gasdynamics

CUBEP3M HCDM in China





Dick Bond@CITA NOW 26 CITAzens in 2013 ... 2025++ .. and many generations of CITAzens before

webskying U: 1.0 => 2.0

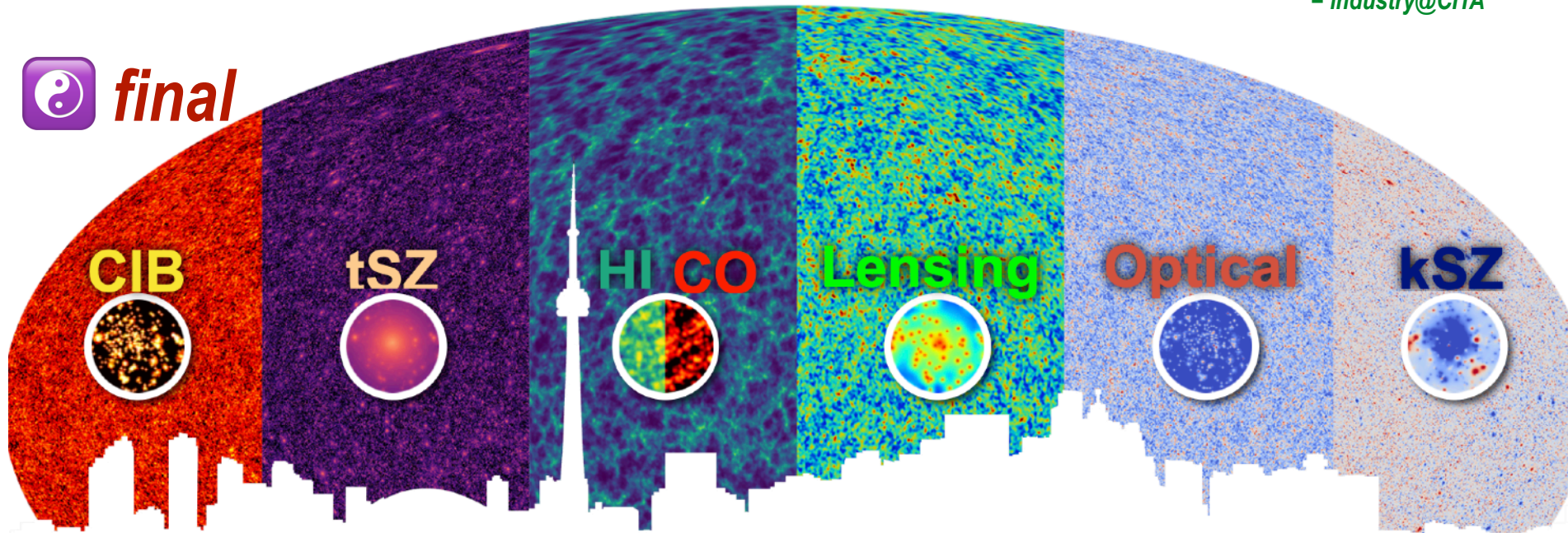
A toolkit for CMB+LSS experiments to test Beyond-the-Standard-Model theories

CMB+LSS+ = one single vast entangled multi-messenger experiment probing the underlying BSMc

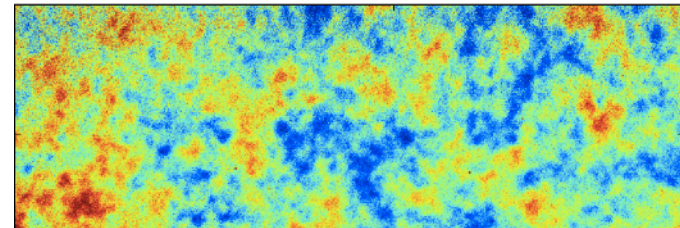
mocking heaven with **PeakPatches+(Hydro+eUsims+..)** response functions

= industry@CITA

 **final**



 **initial**



now back to my beginnings in nuclear astrophysics

Cosmic Neutrino Background and Light Element nucleosynthesis



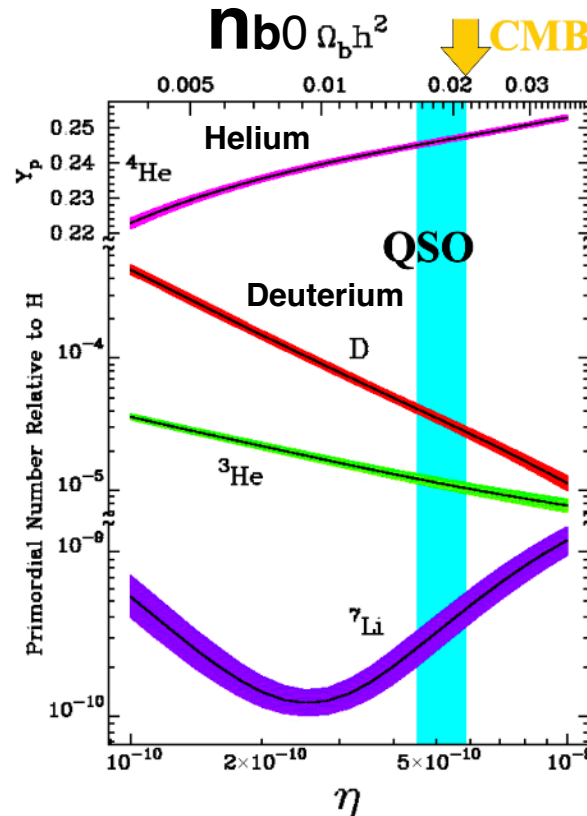
WOW Willy would be proud of us!!

slide from ~2000, Boomerang+

Big Bang Nucleosynthesis

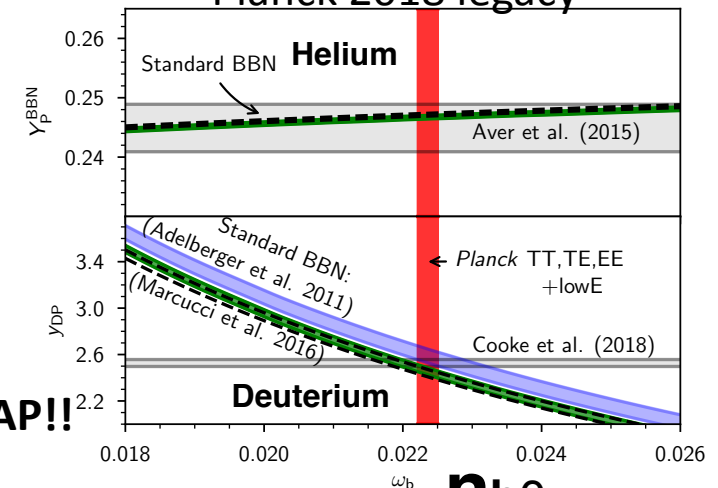
Light Element Abundances are cooked in the "first 3 minutes"

observations of deuterium lines in QSO absorption spectra allow D abundances to be estimated, hence the baryon abundance



WOW Willy would be proud of us!!

$\approx$ Planck 2018 legacy

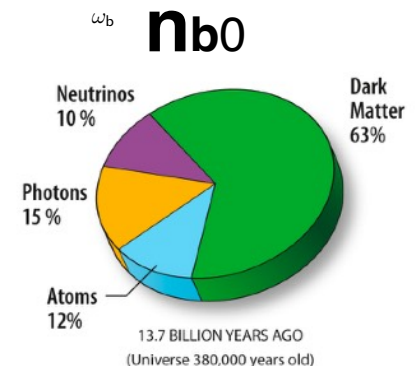


atomic density Ω_b from CMB very stable since pre-WMAP!!

recall the neutrino mass of ~1980 starting bond efstathiou szalay dark matter work

Nobel Prize 2015 $0.06 \text{ eV} < \Sigma m_{\nu} < 2.3 \text{ eV}$ (95%cl)

$\Sigma m_{\nu} < 0.120 \text{ eV}$ 95% Planck 18 $\Rightarrow$ measure with Simons Observatory
as much mass as all of the visible stars in the universe!
 $\Rightarrow$ cosmic web effect: suppress structure a bit



end Bond's *real* Time

eureka



bond's future TBD, e.g.,:

pave the sky with LIM

search for localized entropic forms aka pinGPonGs in CMB, LSS, LIM data.

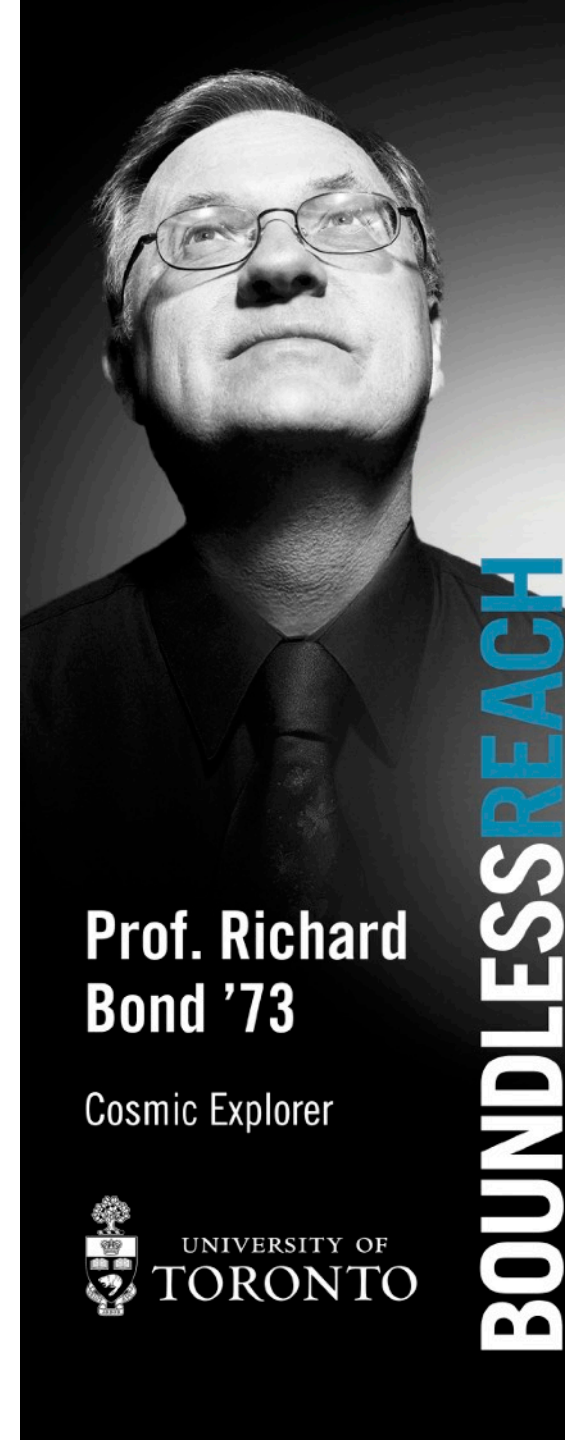
*and gravity wave signatures of pinGPonGs and
theory of Artificial Intelligence ~ theory of CosmicWeb (scale)*

prominence expansion of cosmology hierarchy

writeToMe: of Life the Universe and Everything as "Entropy in a Coherent Universe"

& on & on we shall go

neg-entropy



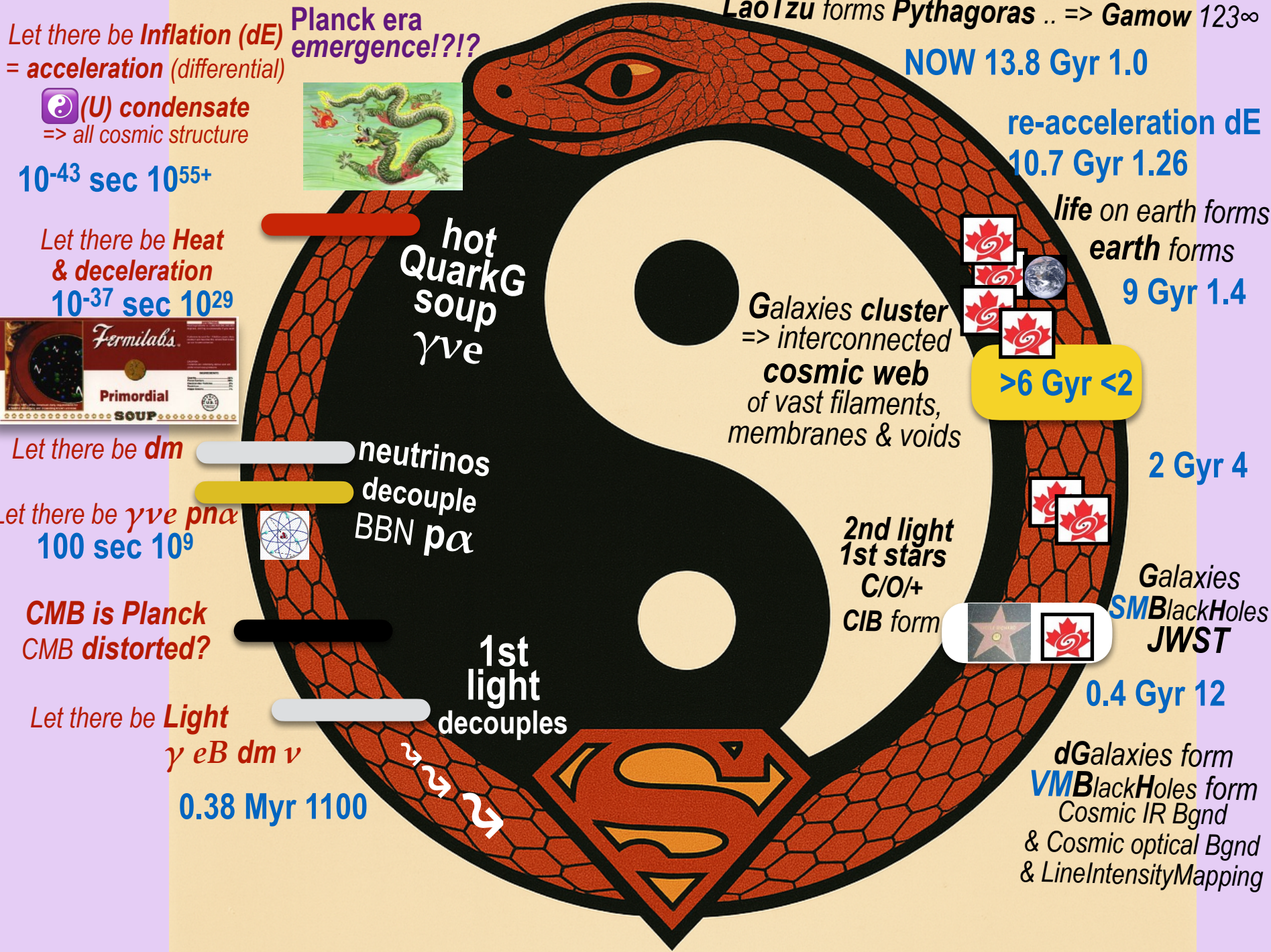
**Prof. Richard
Bond '73**

Cosmic Explorer



UNIVERSITY OF
TORONTO

BOUNDLESS REACH



end Bond's *real* Time

eureka **really**



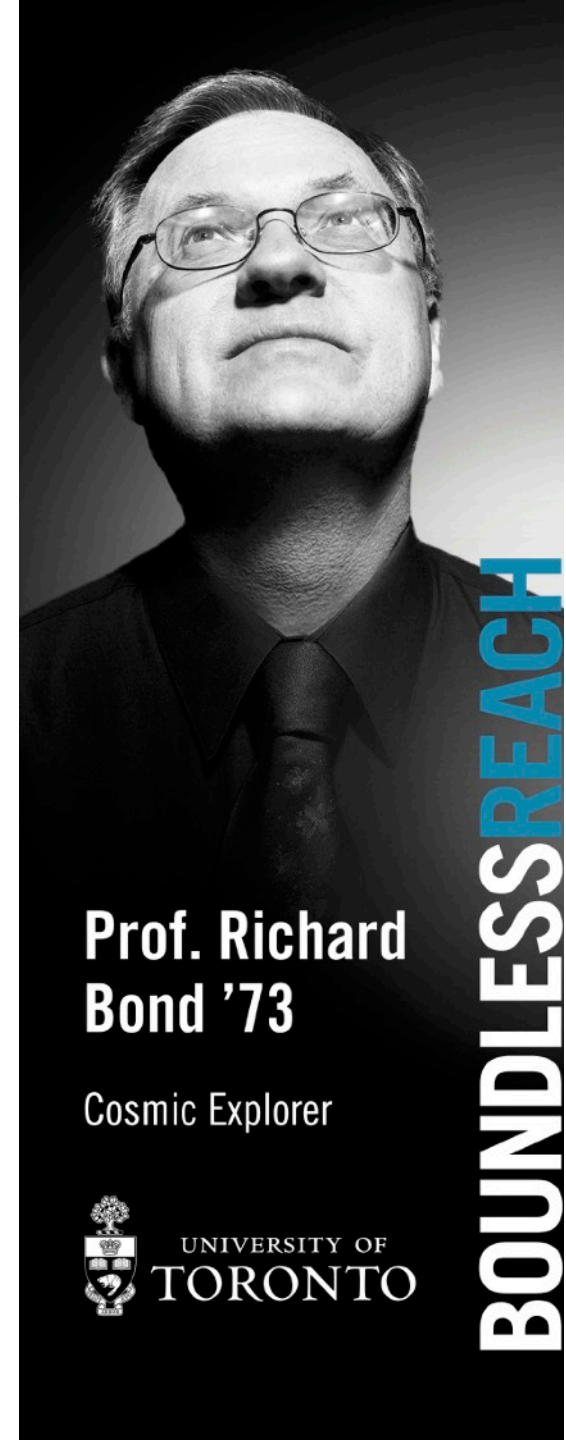
random advice: physics
= pyramid of knowledge
=> get technical aka compute

Artificial Intelligence = Reservoir
U-Man is the System

AI = processes what humans have learned
so be skeptical

aka **Question** authority but do learn AI and do use AI
you $\in$ **U** = **TAO** are the system

theory of Artificial Intelligence ~ theory of CosmicWeb (scale flow aka Rg flow)
ordered prominence expansion of cosmology hierarchy



**Prof. Richard
Bond '73**

Cosmic Explorer



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extra Q_{cosmic} information

what do we know about U: compressed information summary, **neg-entropy**
with each experiment the entropy of parameters gets smaller - Bayesian flow from prior to posterior

relic1:  ζ from *inflaton* -observable = all cosmic structure CMB&LSS & stars/humans & ..
amplitude & slope $\leftrightarrow$ acceleration history & V_{eff} simple over observable range

  generation $dS_I/d\alpha = \epsilon S_G$; $dS_R/d\alpha = -S_G (1-2\epsilon/3)$; $S_G = 2M_P^2 \beta_H^2$, $\epsilon = d\ln \beta_H / d\alpha$
relic2: entropy cooled remnant of particle/field plasma post-inflation $S_{\text{tot}} = S_{\text{CMB}} + S_{\text{CnuB}}$
 $10^{88.6}$

 relic3: baryon asymmetry of matter over antimatter $N_{\text{baryon}}/S_{\text{tot}}$
 $10^{-10.06}$

 relic4: dark matter from quark/gluon plasma - only seen gravitationally WIMPS, axions,..
 $26.6 \pm 0.7\%$

 relic5: big bang nucleosynthesis products H, He, D, Li (influenced by CnuB - weak physics)

 relic 6: CMB with all its fluctuations & polarization **CMB@60**

 relic 7: CWEB galaxies & large scale clustering, flows, gravitational lensing - tomography 3D

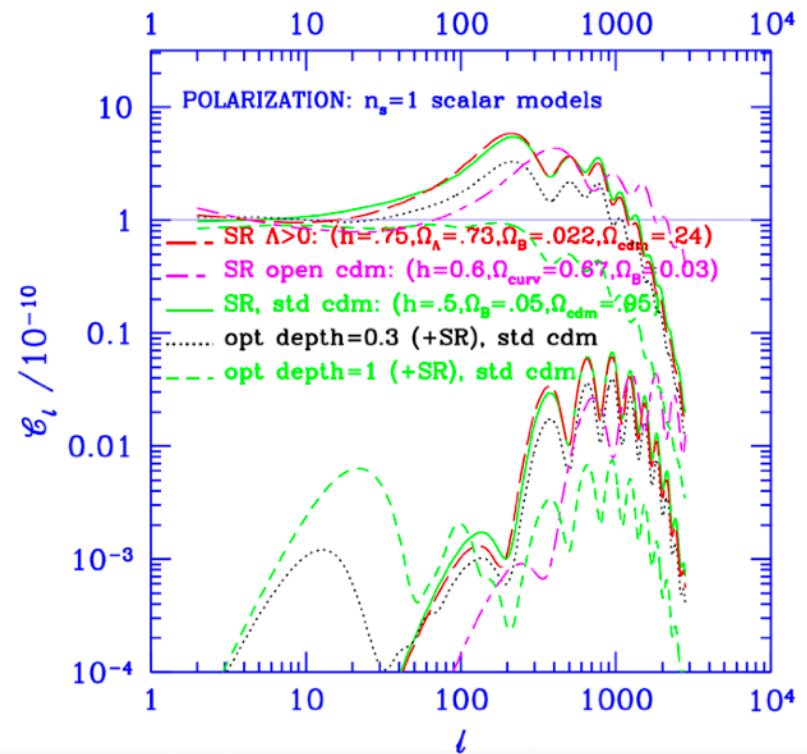
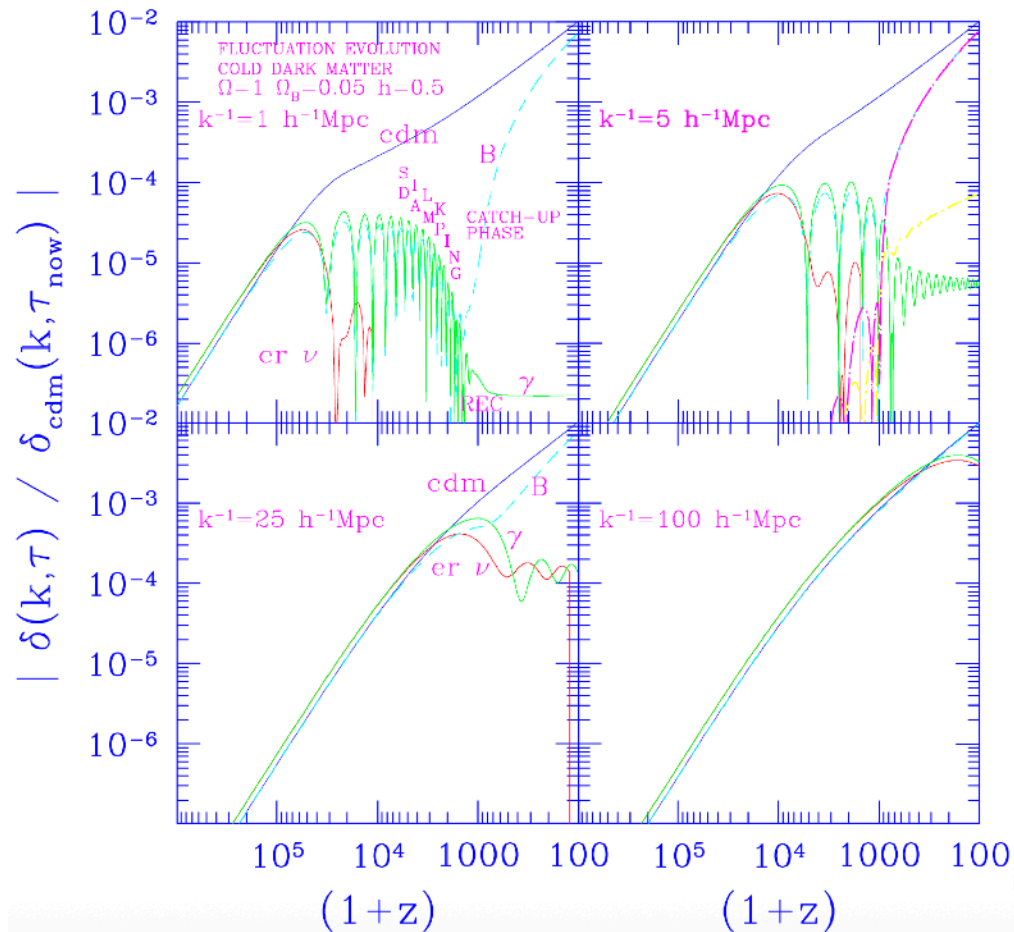
 relic 8: dark energy - let it be dynamical (few params) & coupled (more params)
 $68.5 \pm 0.7\%$

gravitational k-flow in to black holes, entropic x-flow out to freedom of the expanding void white holes

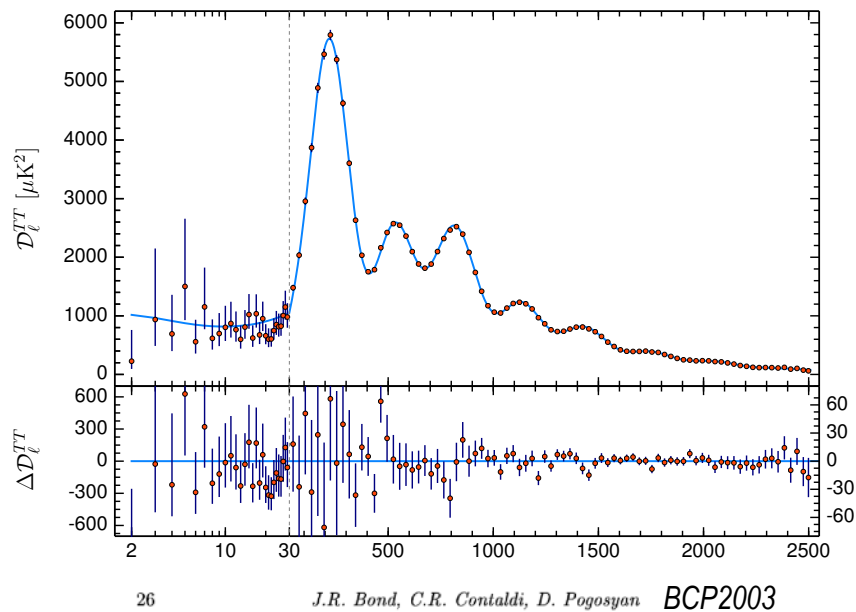
gravo-thermal catastrophe = negative specific heat - goal localize mass into BH & S in accelerating voids
aka straighten U out. gravitational entropy $S_{\text{GH}} = 2M_P^2 / (H/2\pi)^2$; $S_{\text{BH}} = M_P^2 / 2(g/2\pi)^2 = M_{\text{bh}}^2 / 2M_P^2$

harmonic (wave) analysis $\Rightarrow$ Response Functions of **CMB photons, CνB neutrinos, CdmB dark matter, CbB atomic nuclei** to the universal ☯ entropy input *a la bond95 les houches, & efstathiou, szalay*

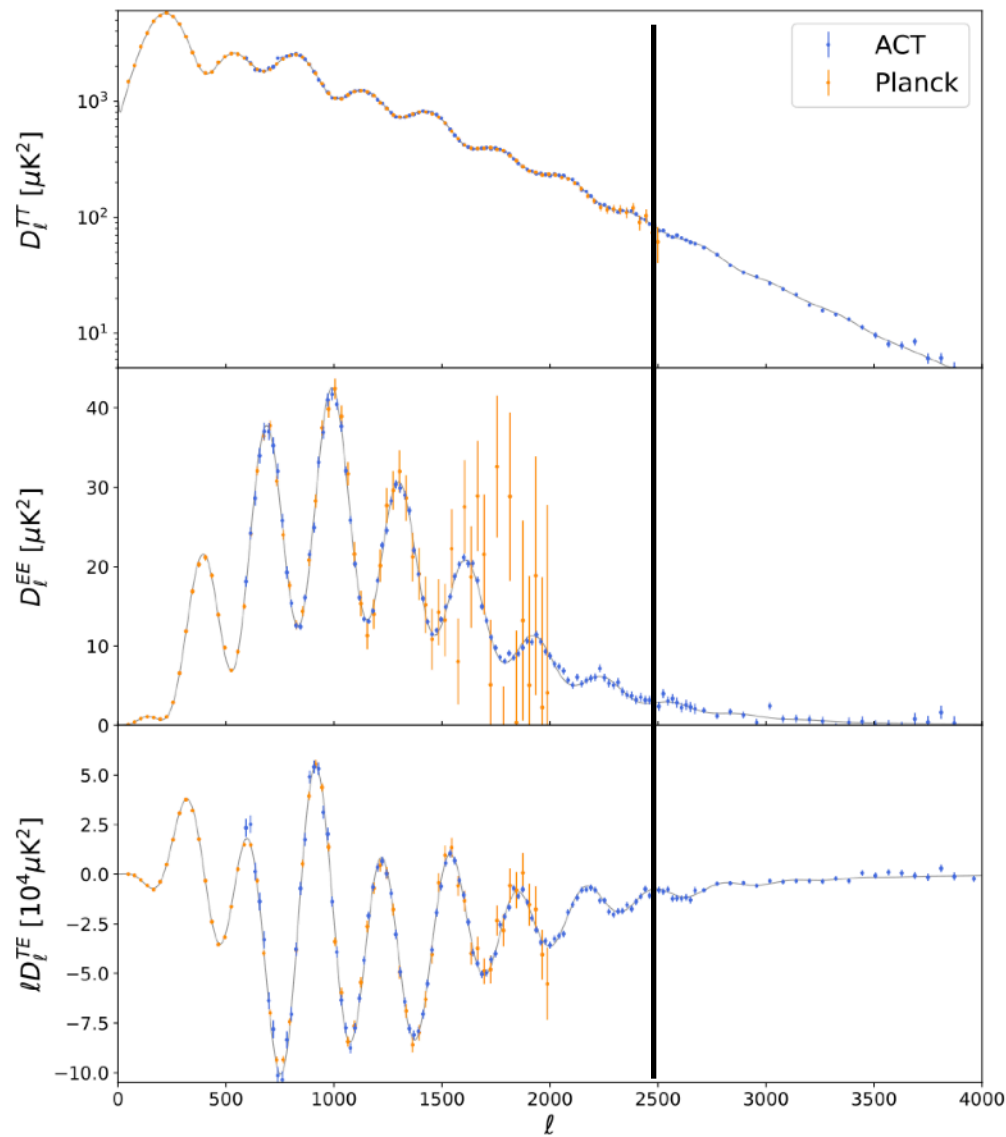
the components in the primordial entropy ☯ separate, fission into observable species
linear separation $\Rightarrow$ nonlinear separation into the interconnected/entangled cosmic web



Planck 2018 harmonic analysis



ACT 2025 harmonic analysis



pre-WMAP 2000-2003 cf. WMAP 2003

