

Quantum Cosmology in the Planck Era & Beyond



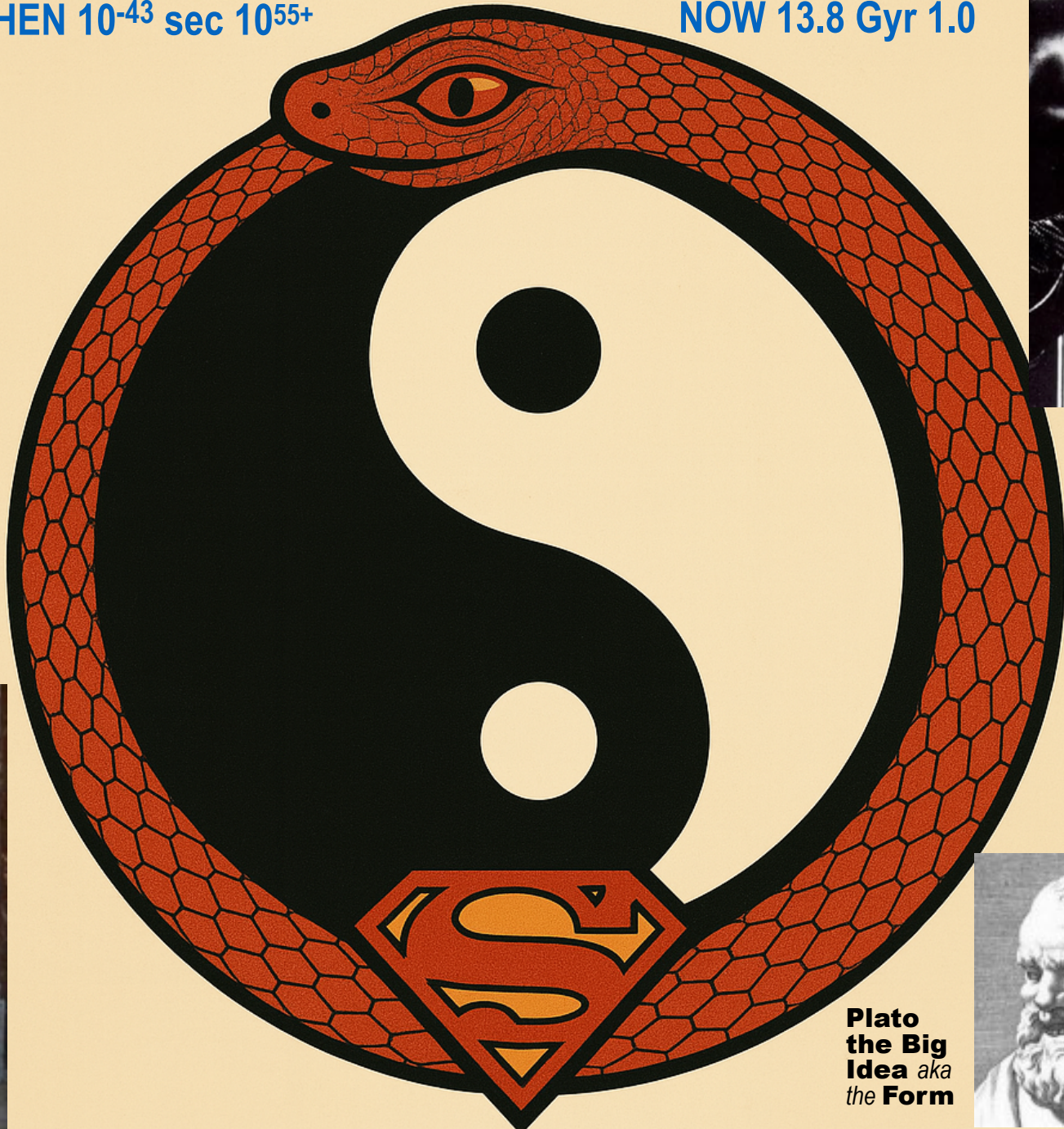
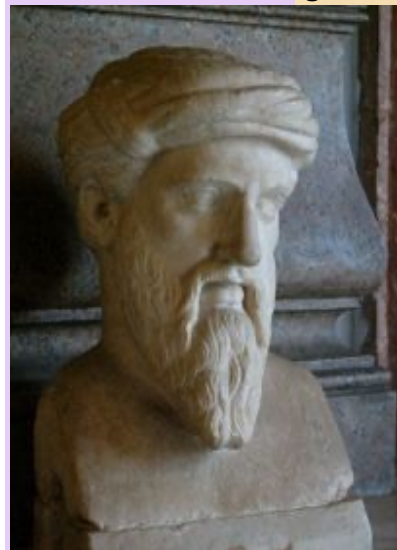
LaoTzu forms **Pythagoras** forms .. **Plato** forms => **Gamow** forms 123^∞
THEN 10^{-43} sec 10^{55+} **NOW** 13.8 Gyr 1.0



the **TAO**

$$\psi(U) = \exp(-\text{☯})$$

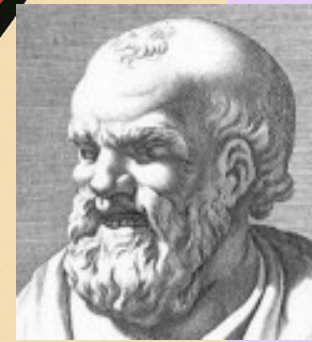
PYTHAGORAS
550 BCE THEORIST
 Cosmos $\supseteq$ math,
 harmonic ν/λ , digital



~1930

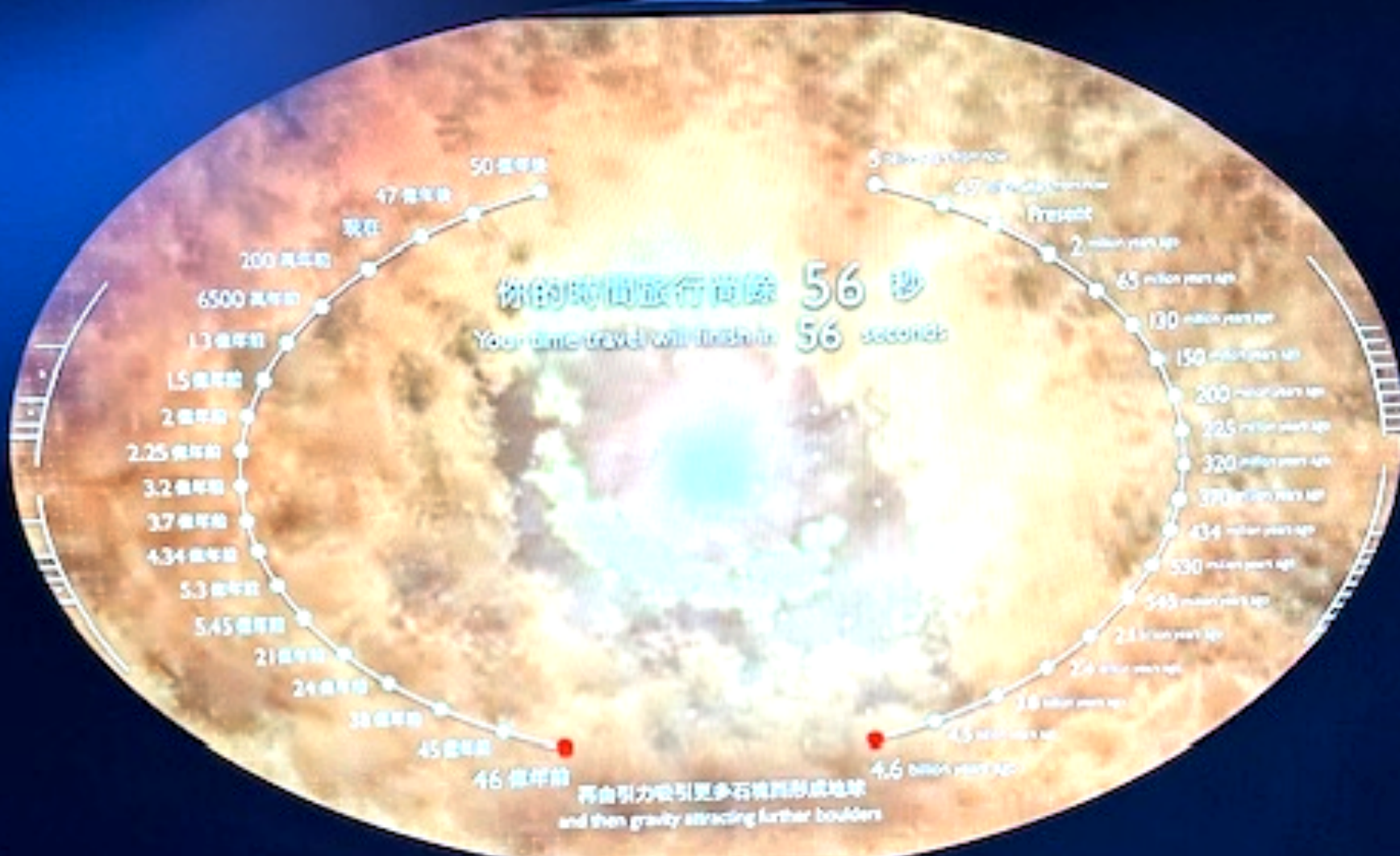
ylem =
 primordial stuff
 => **CMB@75**
 cf. bond@75
 forms
 efstathiou@70
 forms

Plato
 the Big
 Idea aka
 the **Form**



Hall of the Cosmos Hong Kong

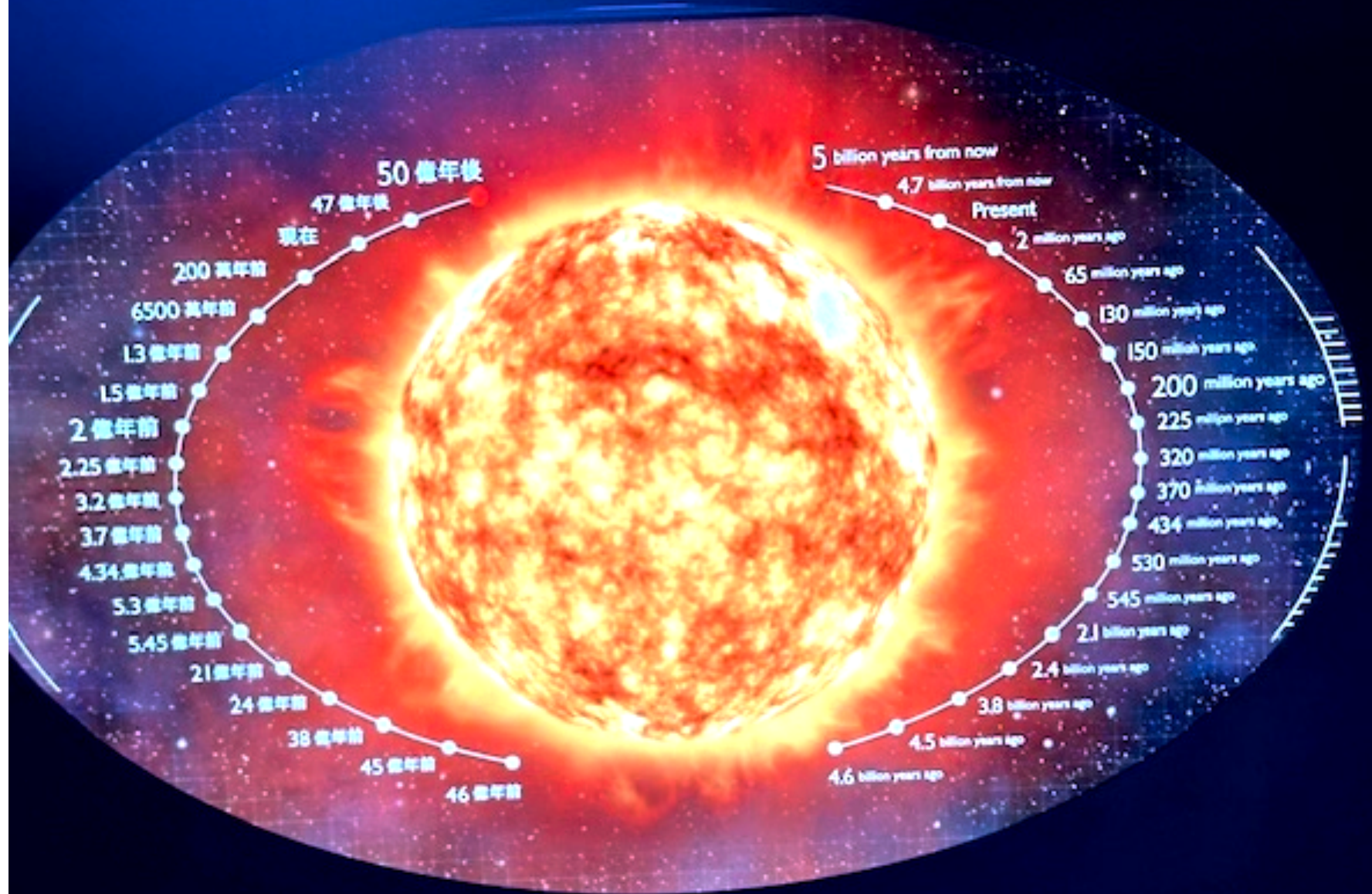
FORMation of Sun and Earth 4.5 billion years ago



the **RISE of hU-Man ~2 million years ago — to here & now**



the **END of Sun and Earth 5 billion years ahead**



hU-man engulfed in a red giant star
which will become a white dwarf remnant star then a black dwarf star

PYTHAGORAS 550 BCE THEORIST

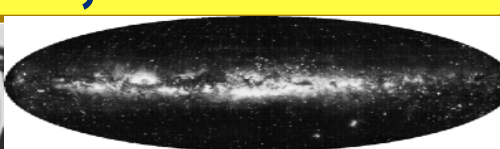
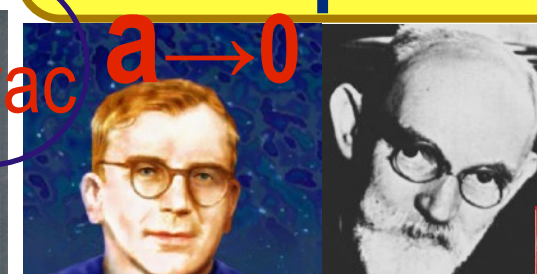
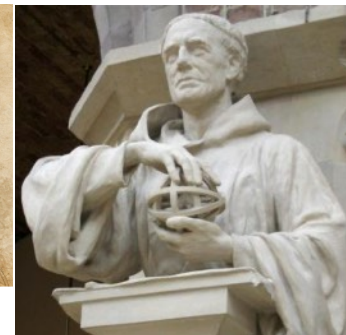
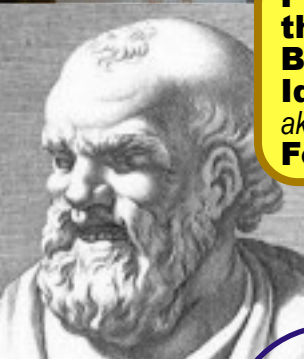
Cosmos $\supseteq$ math, harmonic v/λ , digital

the TAO

*a very brief human history
of how*

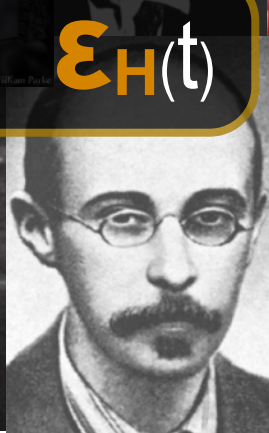
Cosmic Information
was processed by Us:
highly filtered,
compressed, reduced

Plato
the
Big
Idea
aka
Form



Milky Way 1953-55

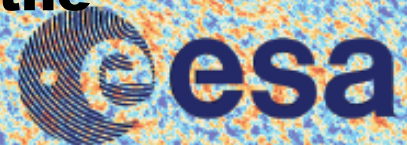
$\alpha(t,x)$ H $\epsilon_H(t)$





planck

Quantum Cosmology in the Planck Era & Beyond



Dick Bond @ Shaw 25 10 22 space museum

Unveiling Fundamental Physics
from the Cosmic First Light:

from COMPLEXITY
to SIMPLICITY
to COMPLEXITY
to SIMPLICITY,
the Universe at Large

the BOUNDED flow of information
the BOUNDless thought of man

my ToMe $\neq$ my ToMb

CMB past =>
CMB present

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

CMB+LSS future
SMc -> BSMc

Beyond the
Standard Model
of Cosmology

CITA Cosmic Information Theory & Analysis =>
qCITA Quantum Cosmic Information Theory & Analysis

wave function of the universe encodes life, the universe and everything

$$\psi(U) = \exp(-\text{🌀})$$



CITA
ICAT

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

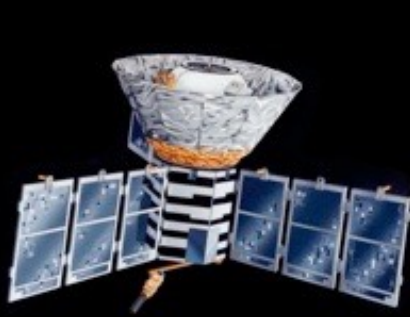
< => white hole @ TH(time) expanding U + TBD QM fission

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

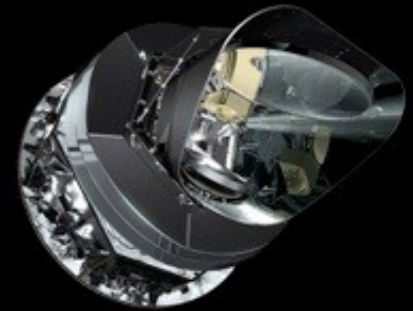
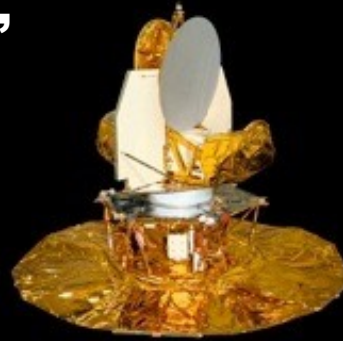
COBE 89 launch

WMAP 01 launch

Planck 09 launch



full moon **31'**



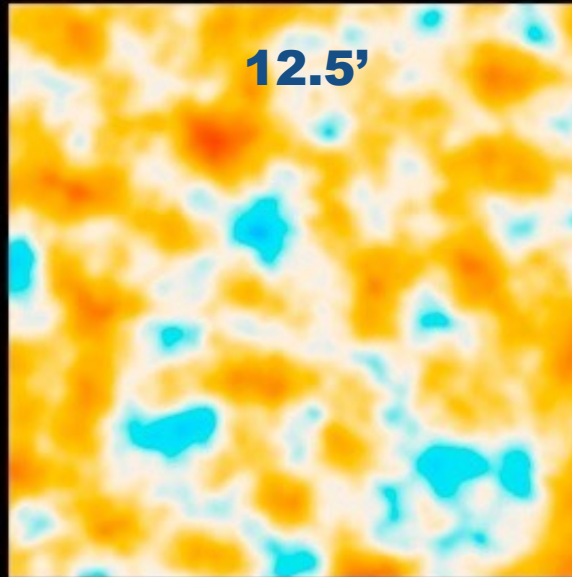
420'



Nobel 2006

COBE

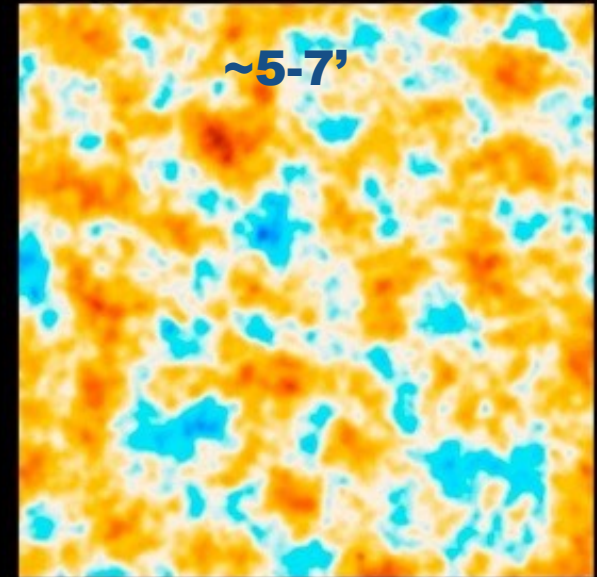
12.5'



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

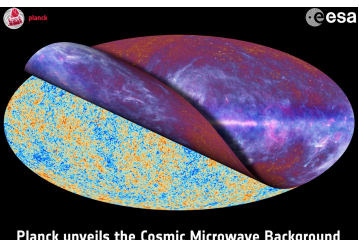
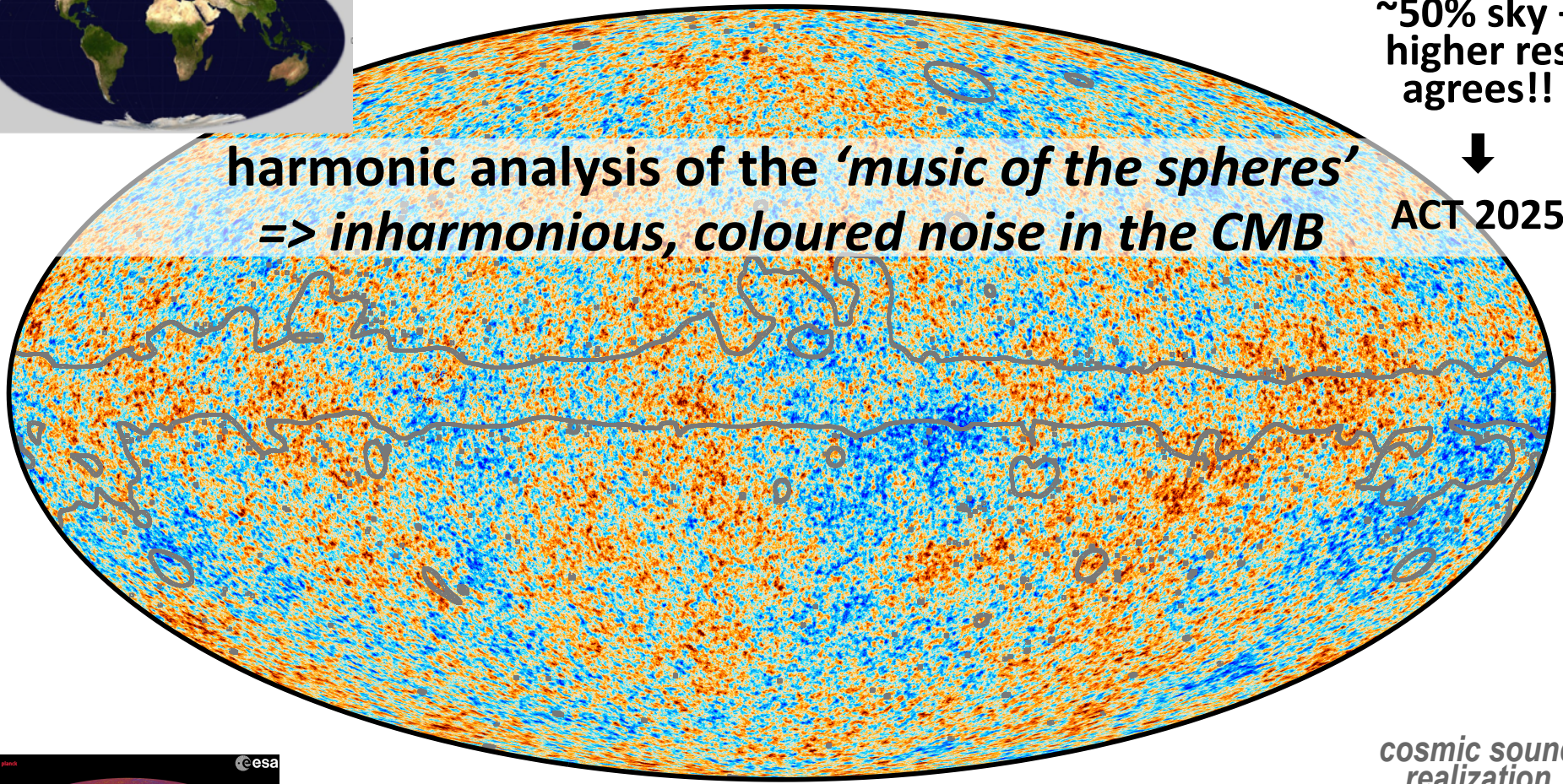


ACT 2022
~50% sky +
higher res
agrees!!



ACT 2025

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



-300



300 μK

**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

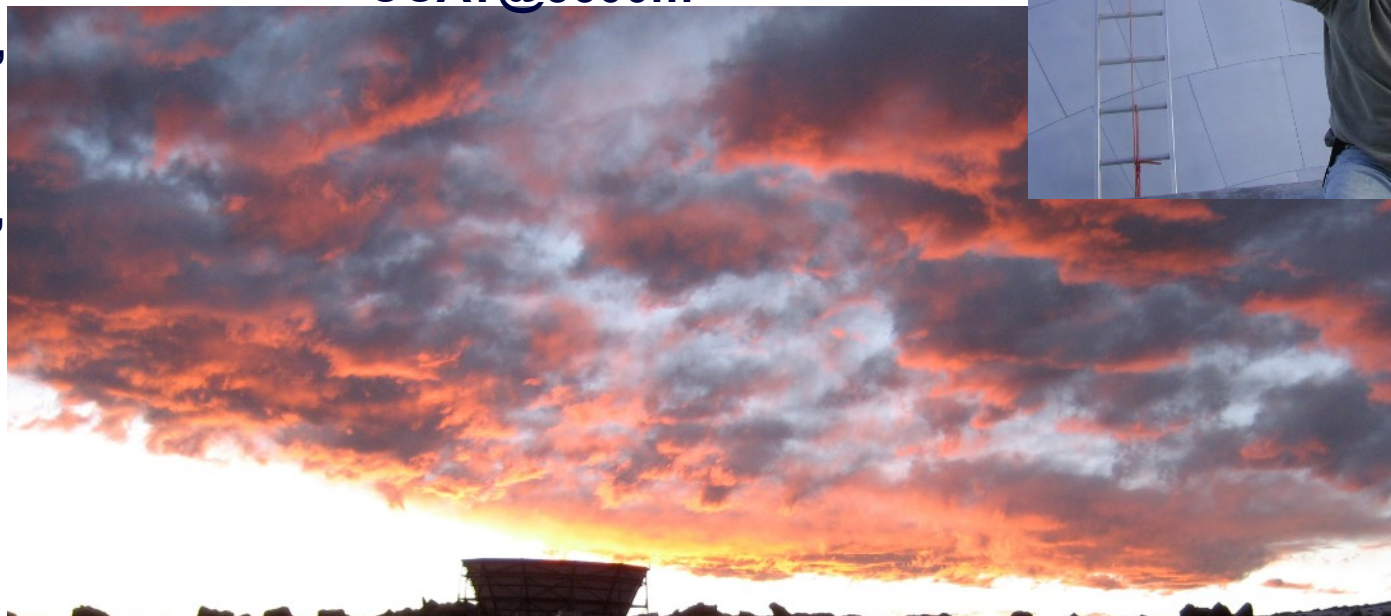
CCAT@5600m

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

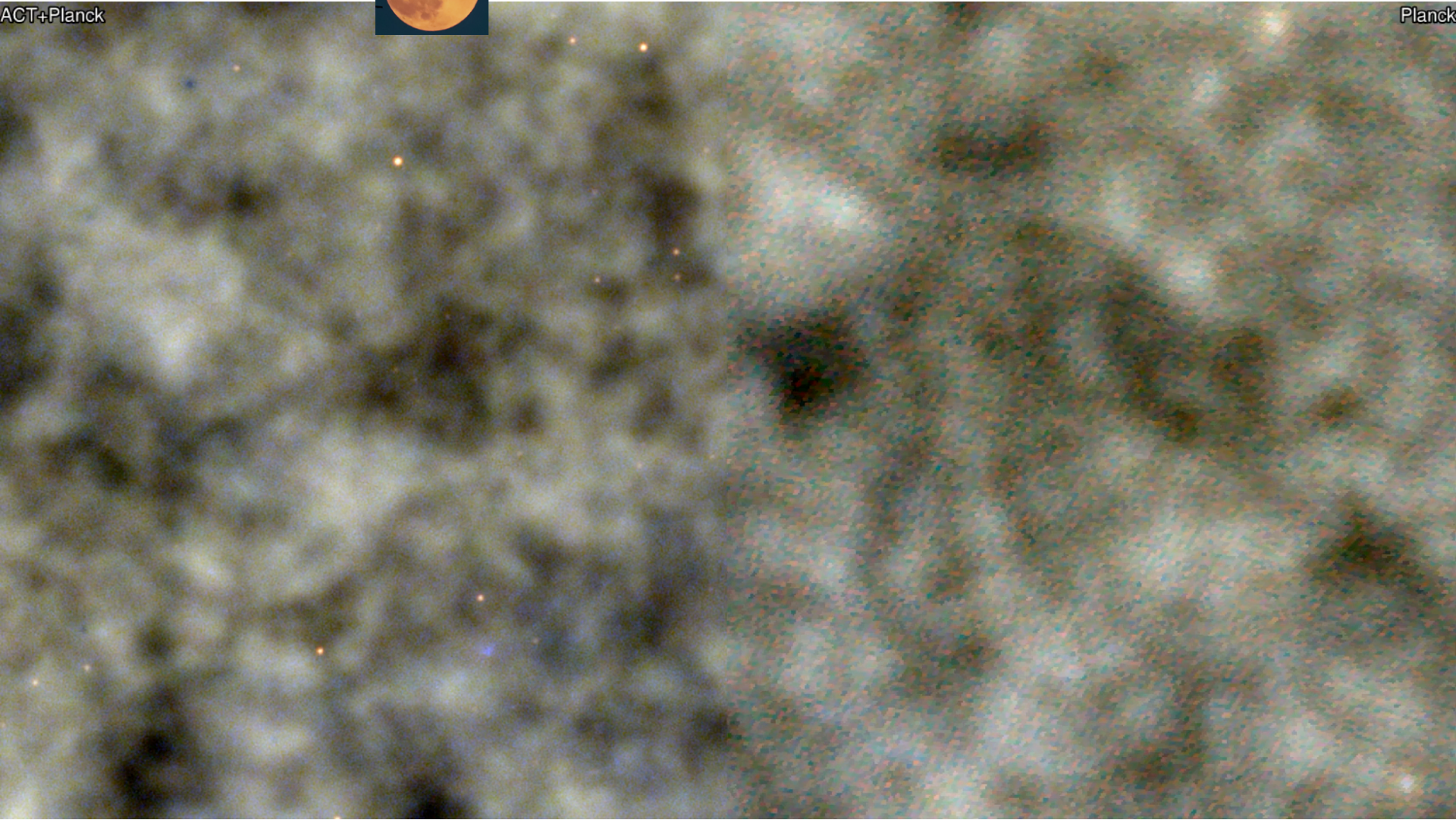


WMAP 01 launch

Planck 09 launch

Planck ~5-7'

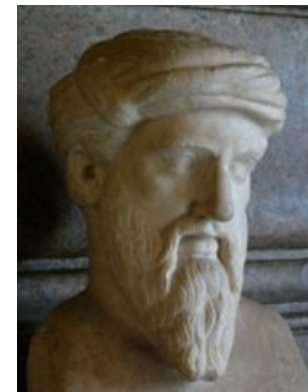
Planck



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

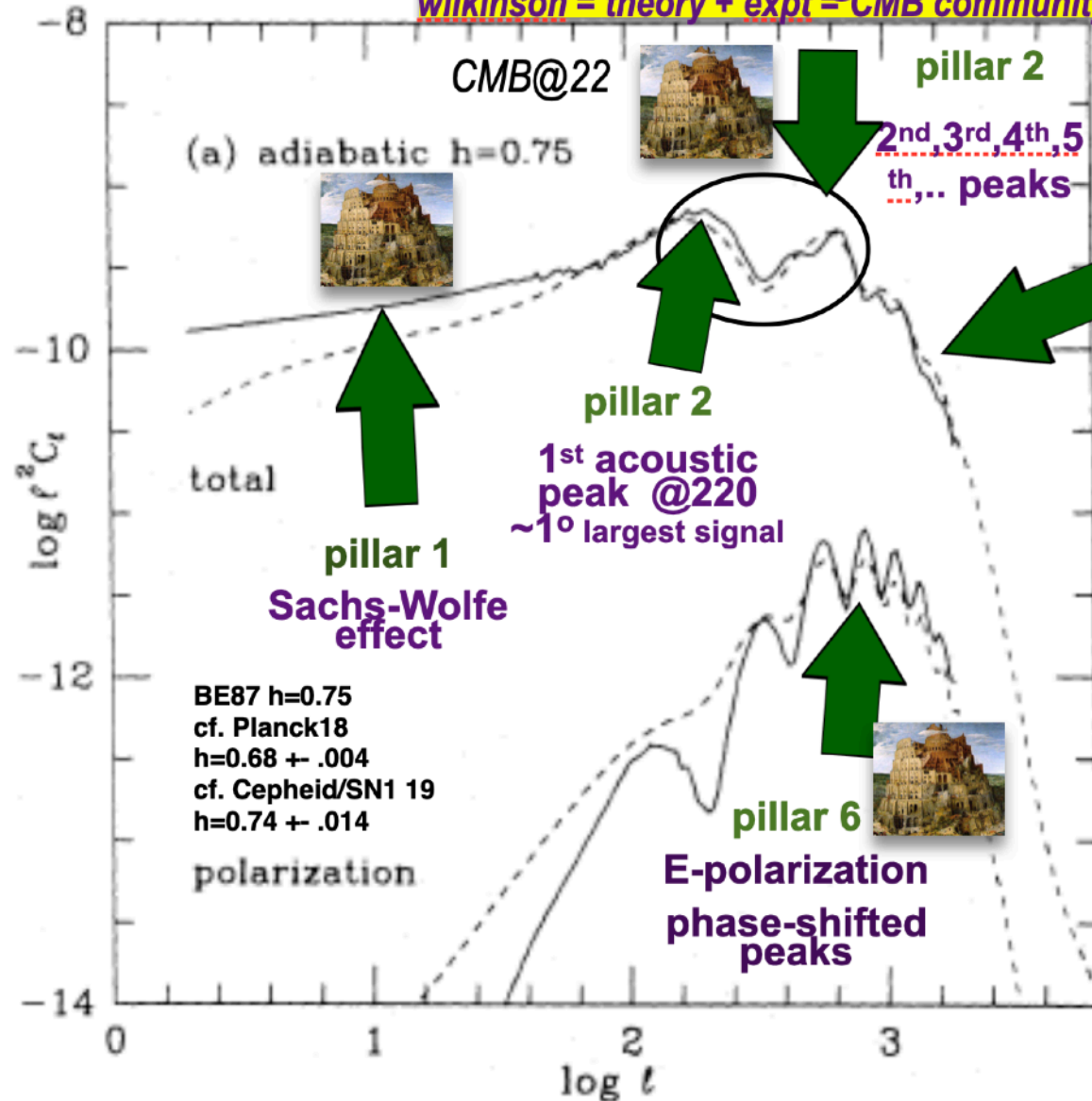
“point” sources emerge

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

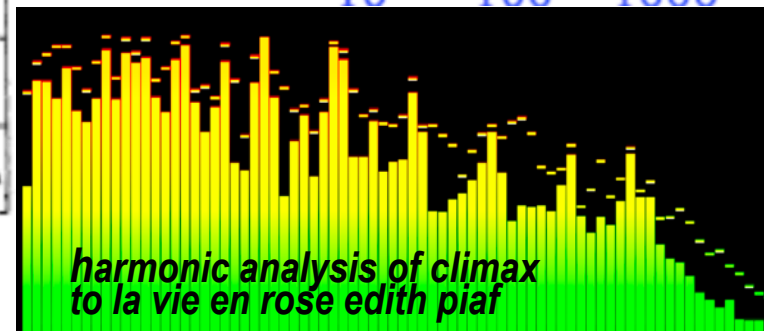
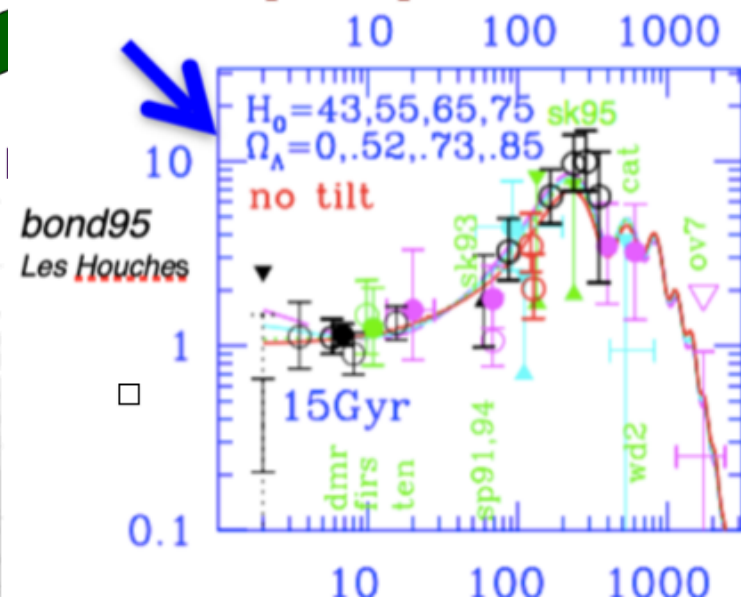


the Seven Pillars

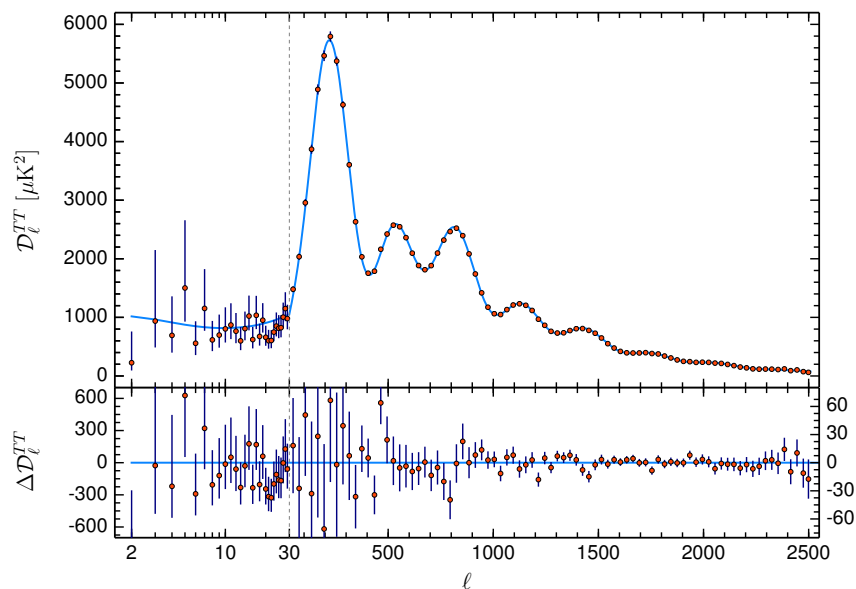
Bond & Efstathiou 1984/1987 GUCMB =>
Delta T over Tea 1987 @CITA bond + wilkinson = theory + expt = CMB community



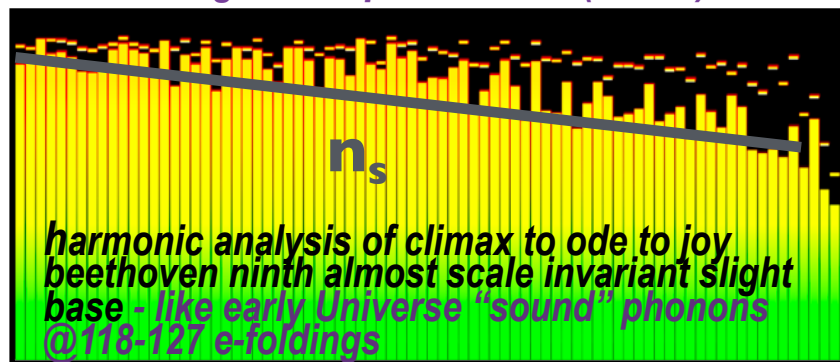
JRB@Capri 1993 Bandpowers cf. theoretical power spectra



Planck 2018 harmonic analysis of underlying 



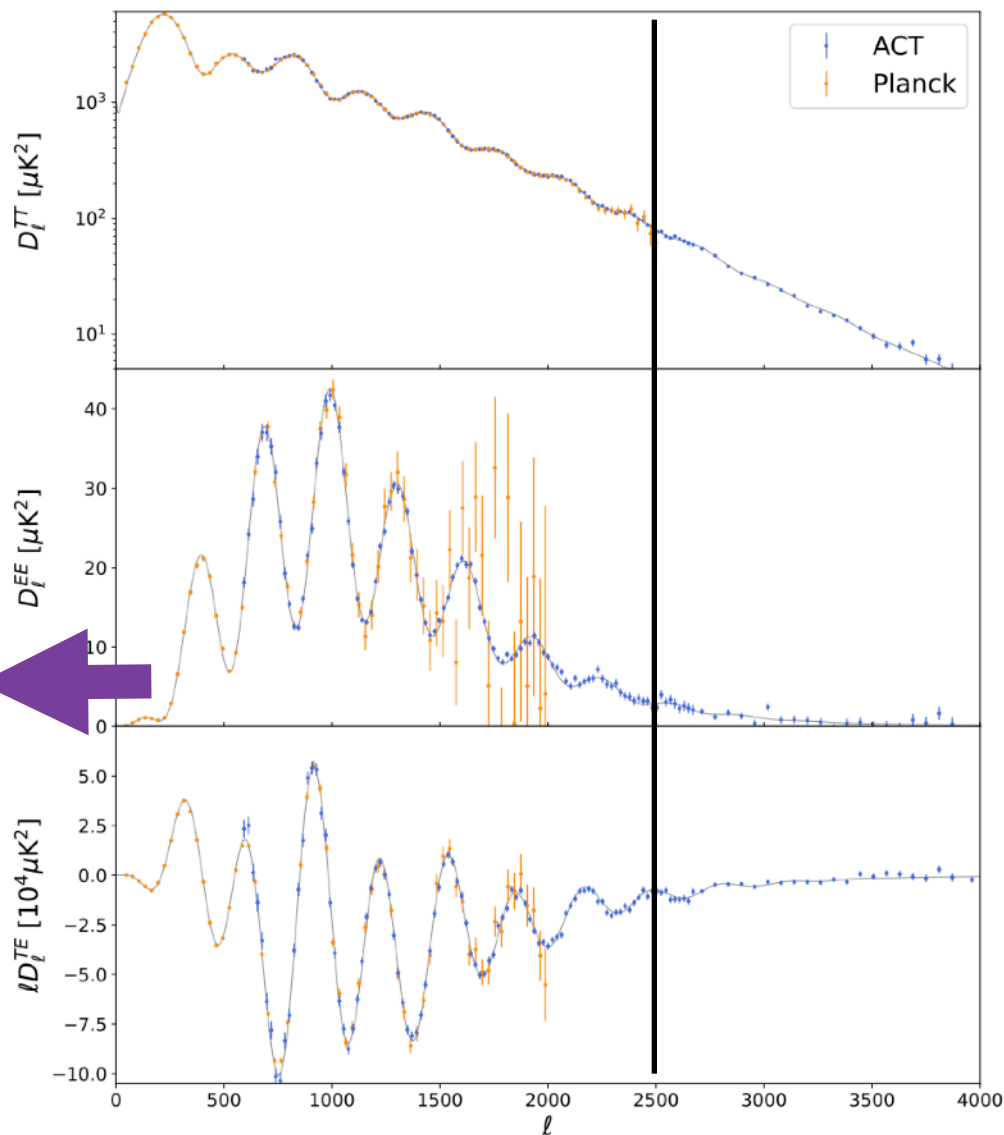
the highest impact Planck (&ACT) result



harmonic analysis of climax to ode to joy
beethoven ninth almost scale invariant slight
base - like early Universe "sound" phonons
@118-127 e-foldings

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

ACT 2025 harmonic analysis



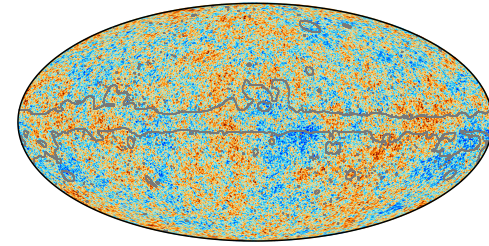
cosmic sound realization



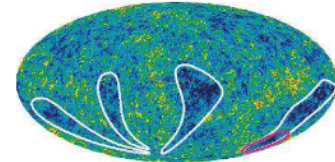
Primordial map: Beyond the Standard Model of cosmology?

SMc = *tilted* Λ CDM

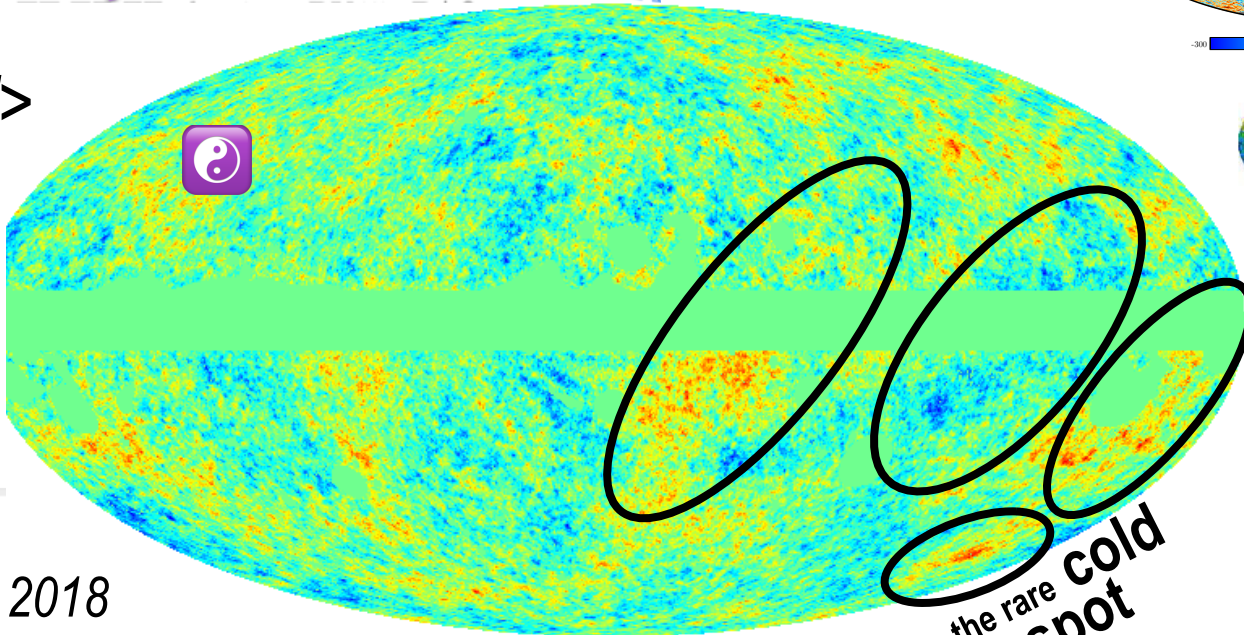
IMAGE of the Beginning 10^{-33} seconds



-300 300 μ K



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



the rare cold spot

-35.0 +35.0

Bond + Huang 2018

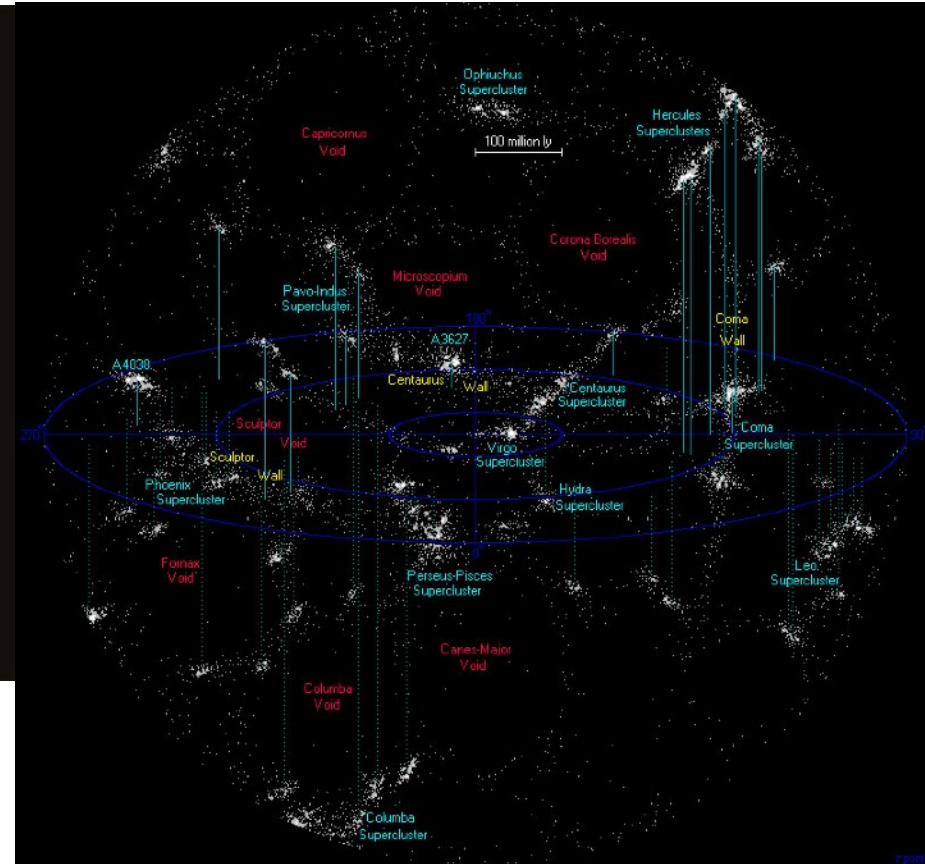
random sound loudness $P_\zeta(k_p)$ + bass/treble $n_s = 0.967 \pm 0.004$ **8.8 σ from 1**



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

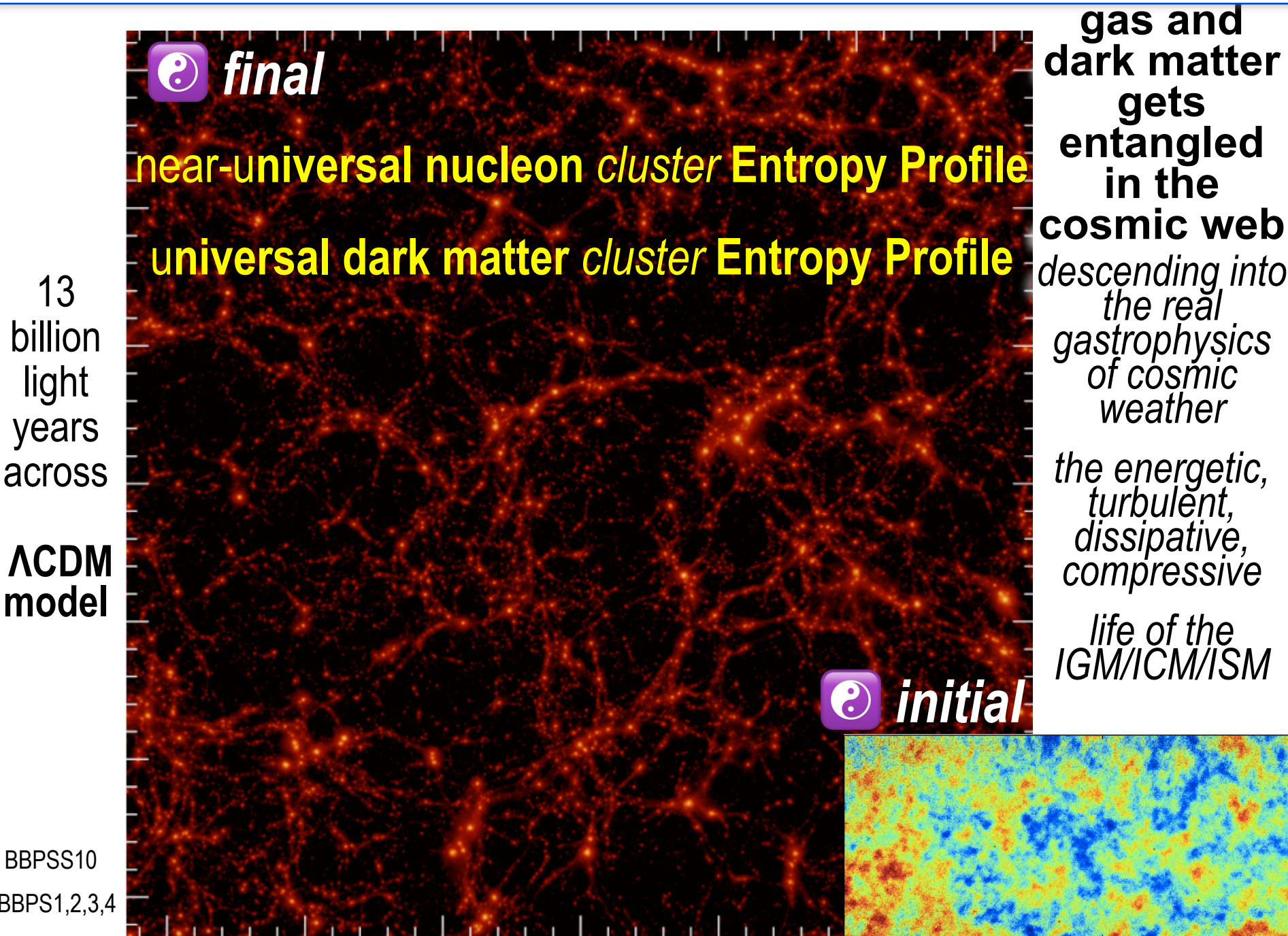
Cosmic Web of ~60,000 nearby galaxies: exhibits “local” **COMPLEXITY**

*observational emergence of the web = ~80s tour de force
now billions of galaxies in very large surveys*



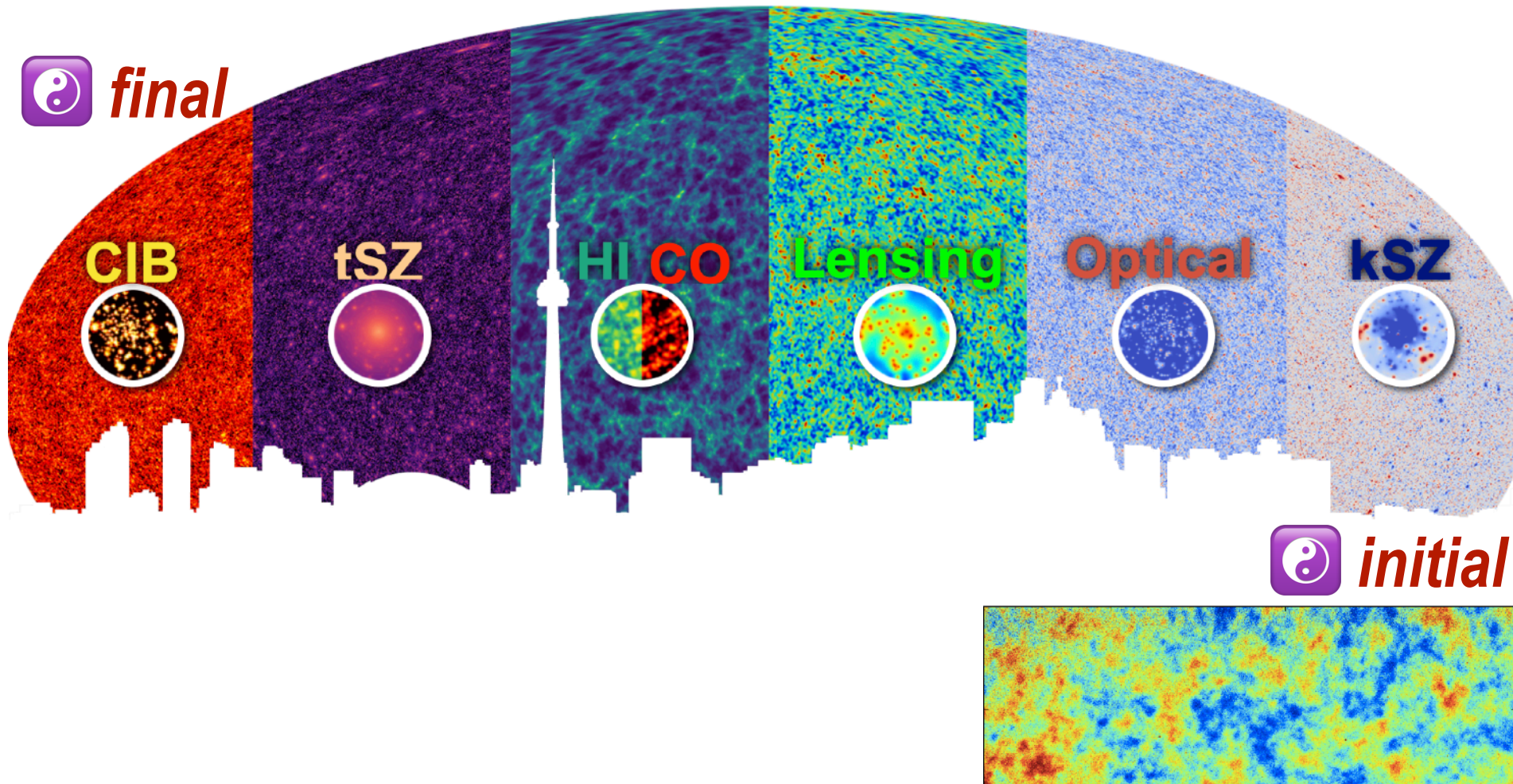
Brent Tully local U in 3D @KITP23





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

*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*

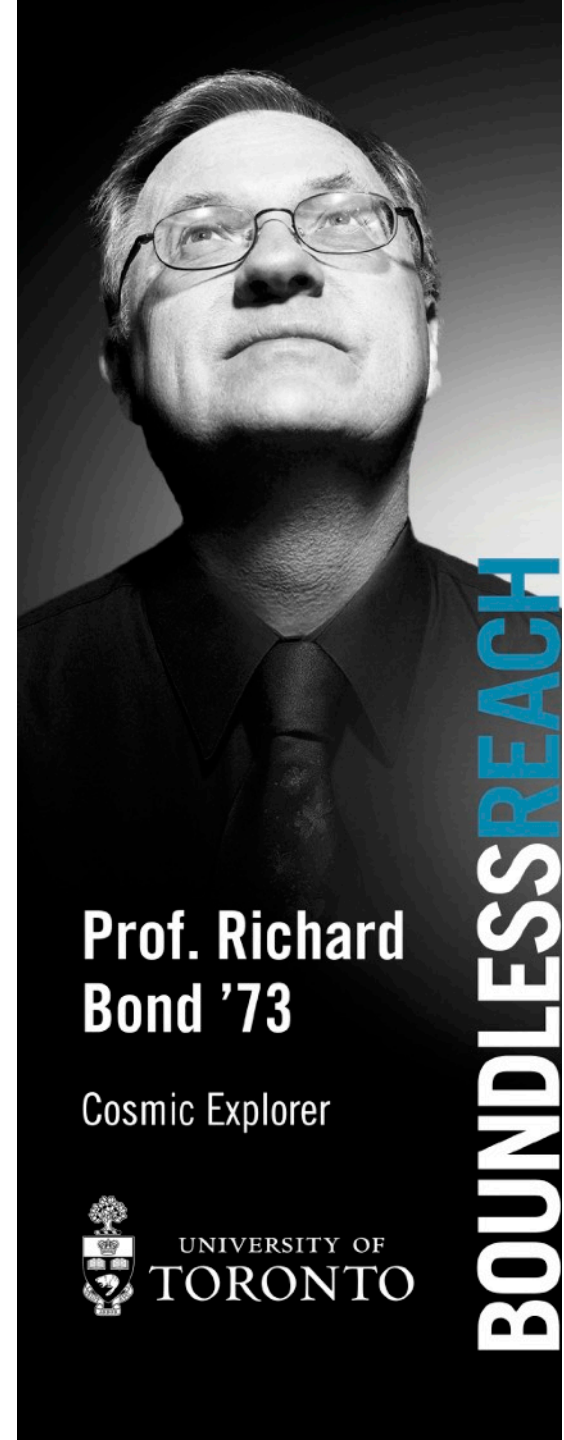


end Bond's *real* Time

eureka



begin Bond's *imagine-ary* Time



Prof. Richard
Bond '73

Cosmic Explorer



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BOUNDLESS REACH

Let there be **TIME**

Let there be **Inflation (dE)**
= **acceleration** (differential)

10^{-43} sec $10^{55}+$



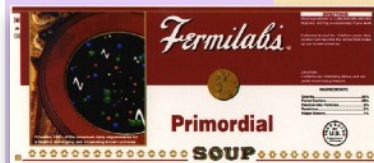
(U) condensate
begets all cosmic structure
the **Cosmic SuperWeb**

**Planck era
emergence!?!?**



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

Universe =
SignalUNoise
StimulusUResponse
SystemUReservoir
particleUhole
QuestionUAnswer
ChargeUField-gauge
StressUStrain



Let there be **dm**

Let there be **CvB**

Let there be **pn α**

100 sec 10^9

Let there be **Light**
 γ eN dm ν

0.38 Myr 1100

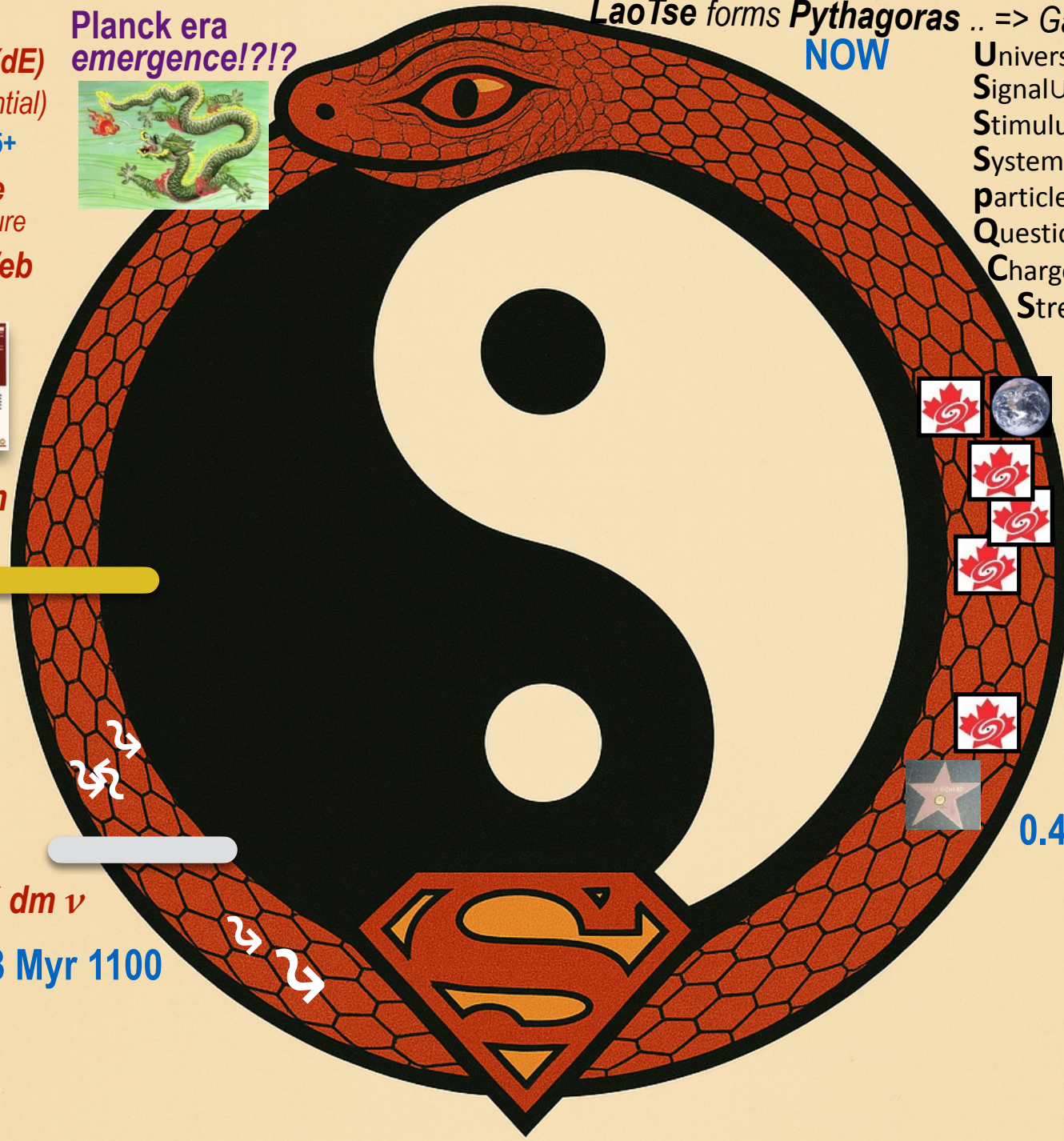
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NOW

Universe =
SignalUNoise
StimulusUResponse
SystemUReservoir
particleUhole
QuestionUAnswer
ChargeUField-gauge
StressUStrain

9 Gyr 1.4

**cosmic
web**

0.4 Gyr 12



end Bond's *real* Time *really* *eureka*

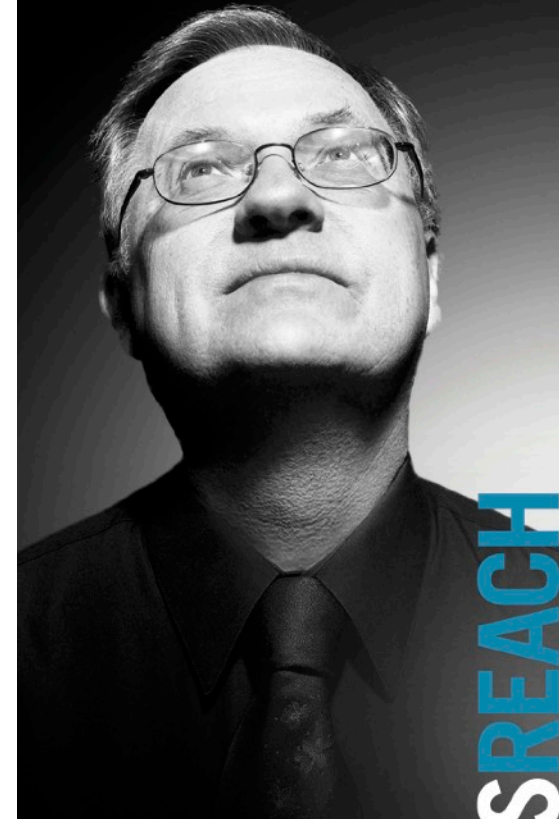


*random advice: physics
= pyramid of knowledge
=> get technical aka compute*

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*



**Prof. Richard
Bond '73**

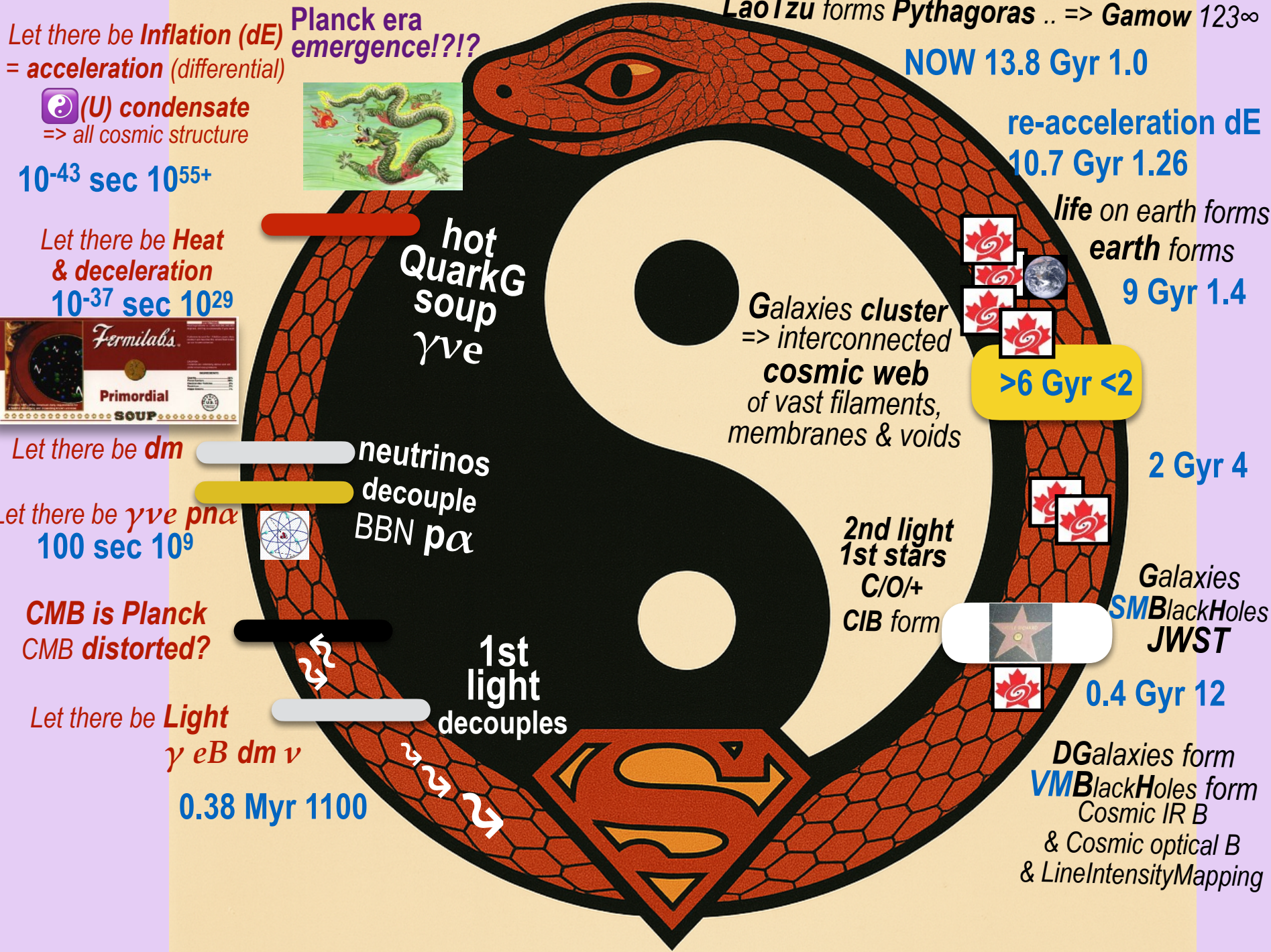
Cosmic Explorer



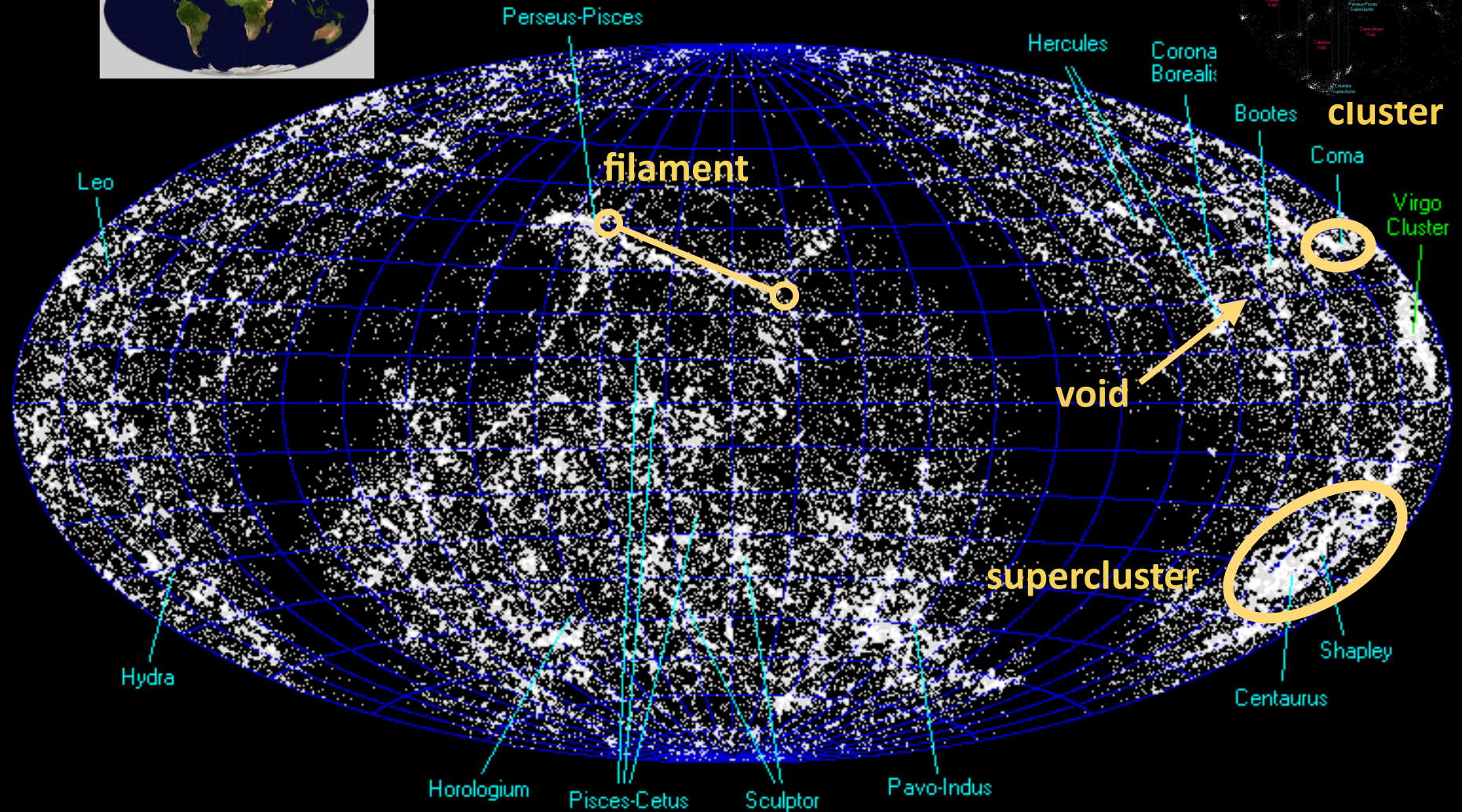
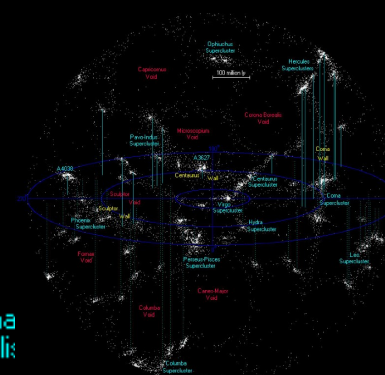
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BOUNDLESS REACH

extra Q_{cosmic} information



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