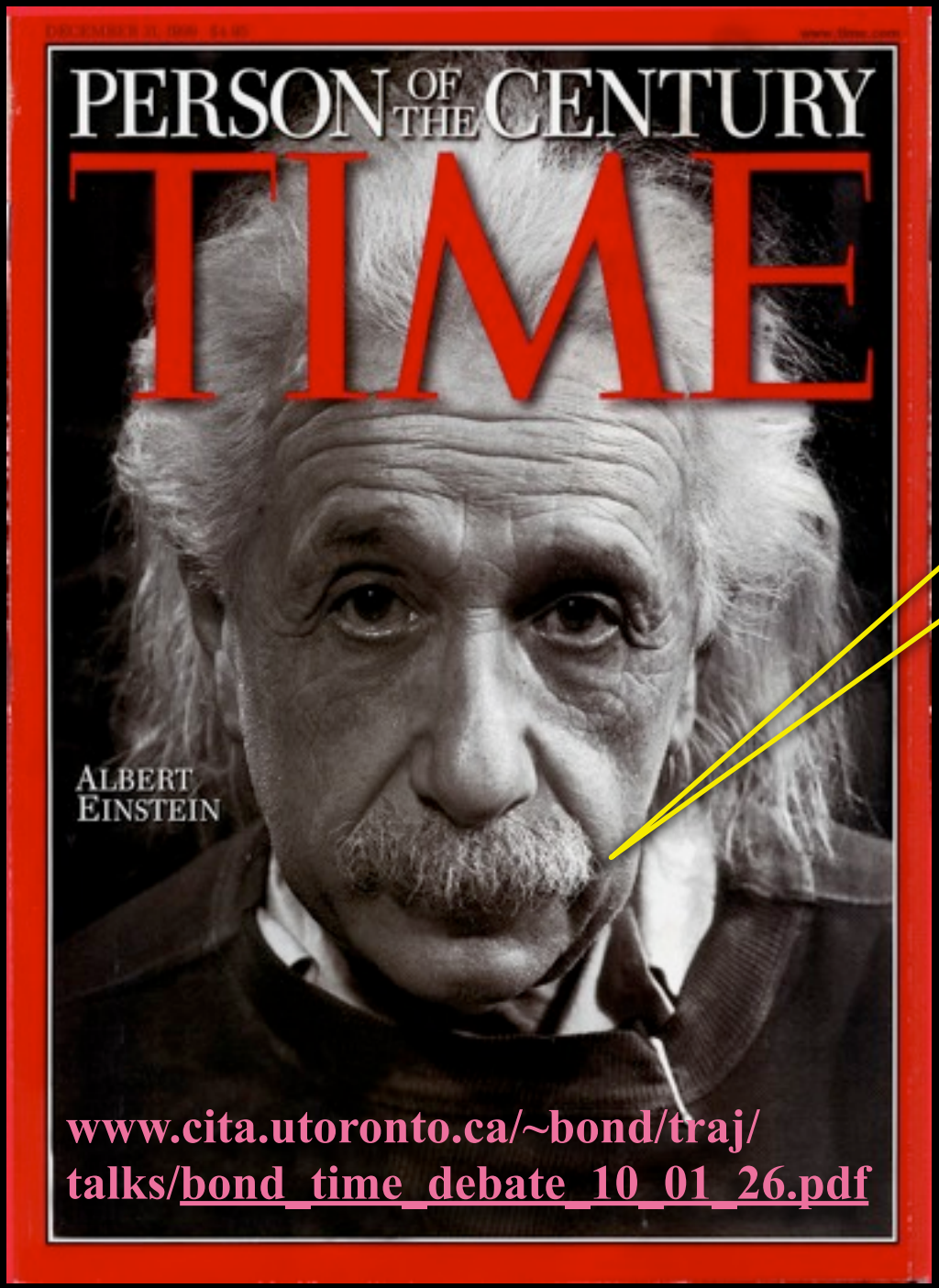
Dick Bond *Canadian Institute for Theoretical Astrophysics, University of Toronto*

THE GREAT TIME DEBATE

Tuesday, January 26, 2010



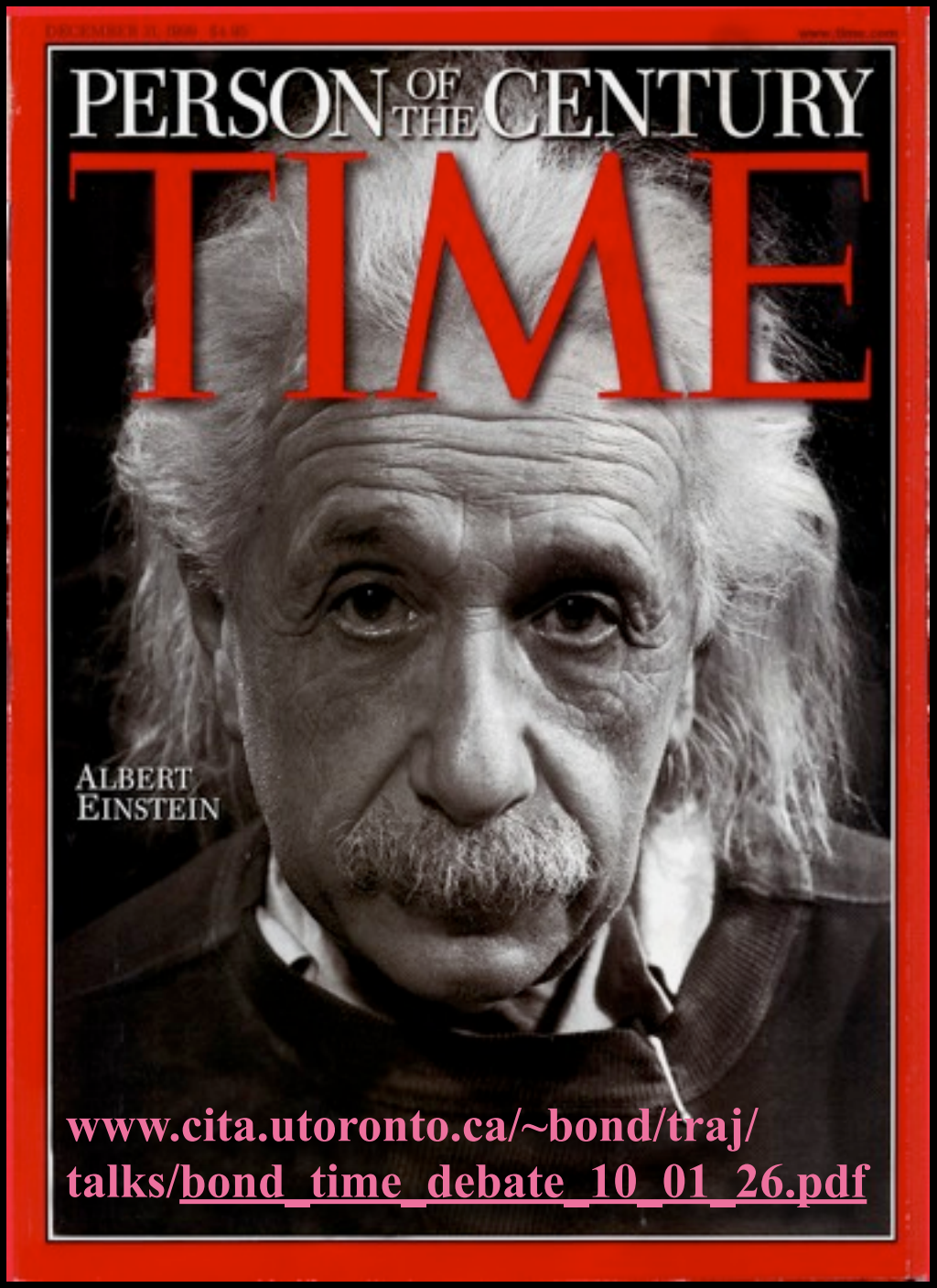
MY TIME **I**(t), me (t), you (t), **U**(t)

ASTRONOMICAL TIME

PHYSICS TIME

precision
COSMIC TIME!

www.cita.utoronto.ca/~bond/traj/talks/bond_time_debate_10_01_26.pdf



MY TIME **I(t), me(t), you(t), U(t)**

coherence of being; in the **NOW**

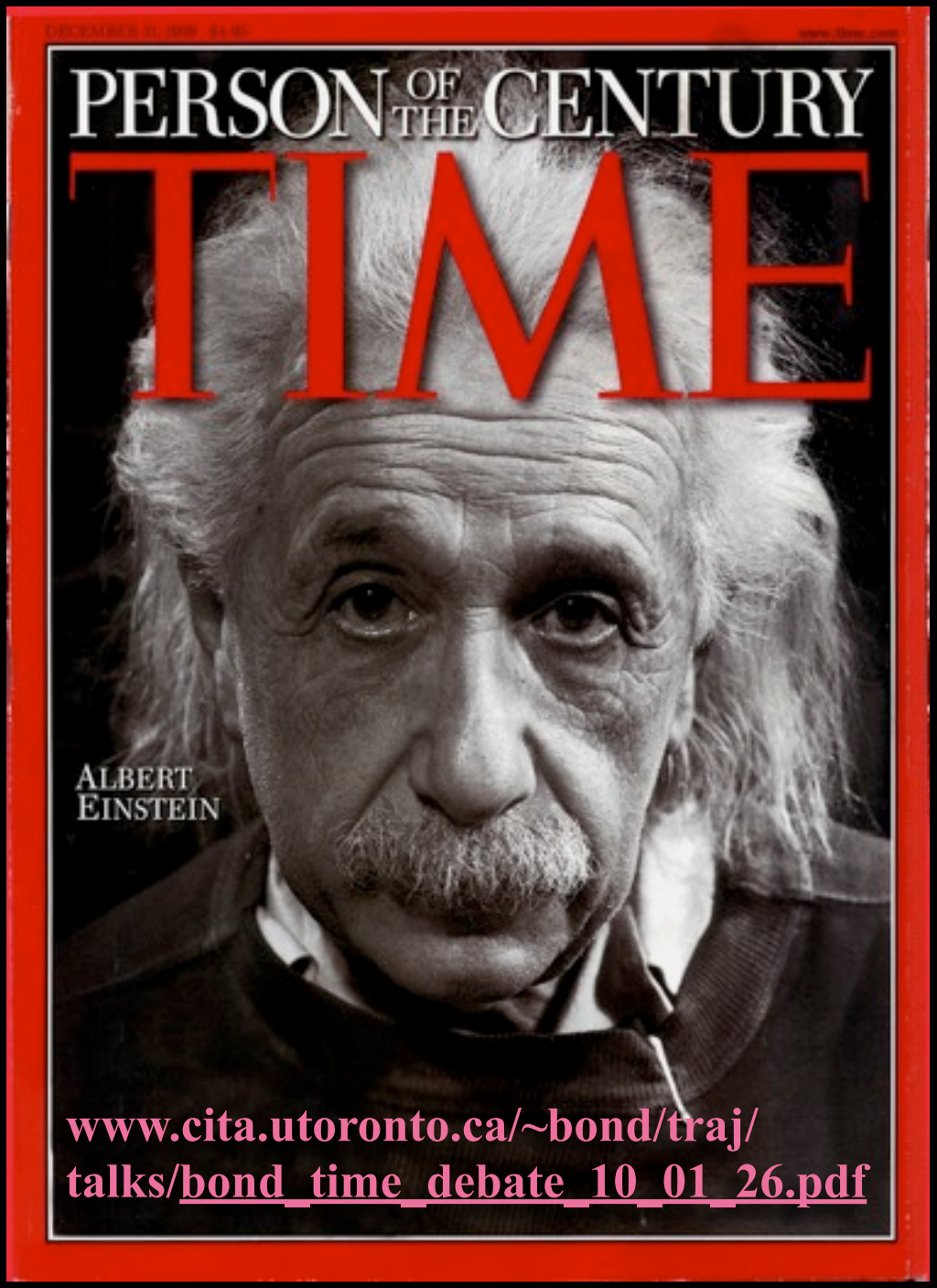
(∃ no NOW?); **past** & **future**,

history & forecasting ... $U \in \{Us\}$

ASTRONOMICAL TIME

PHYSICS TIME

COSMIC TIME

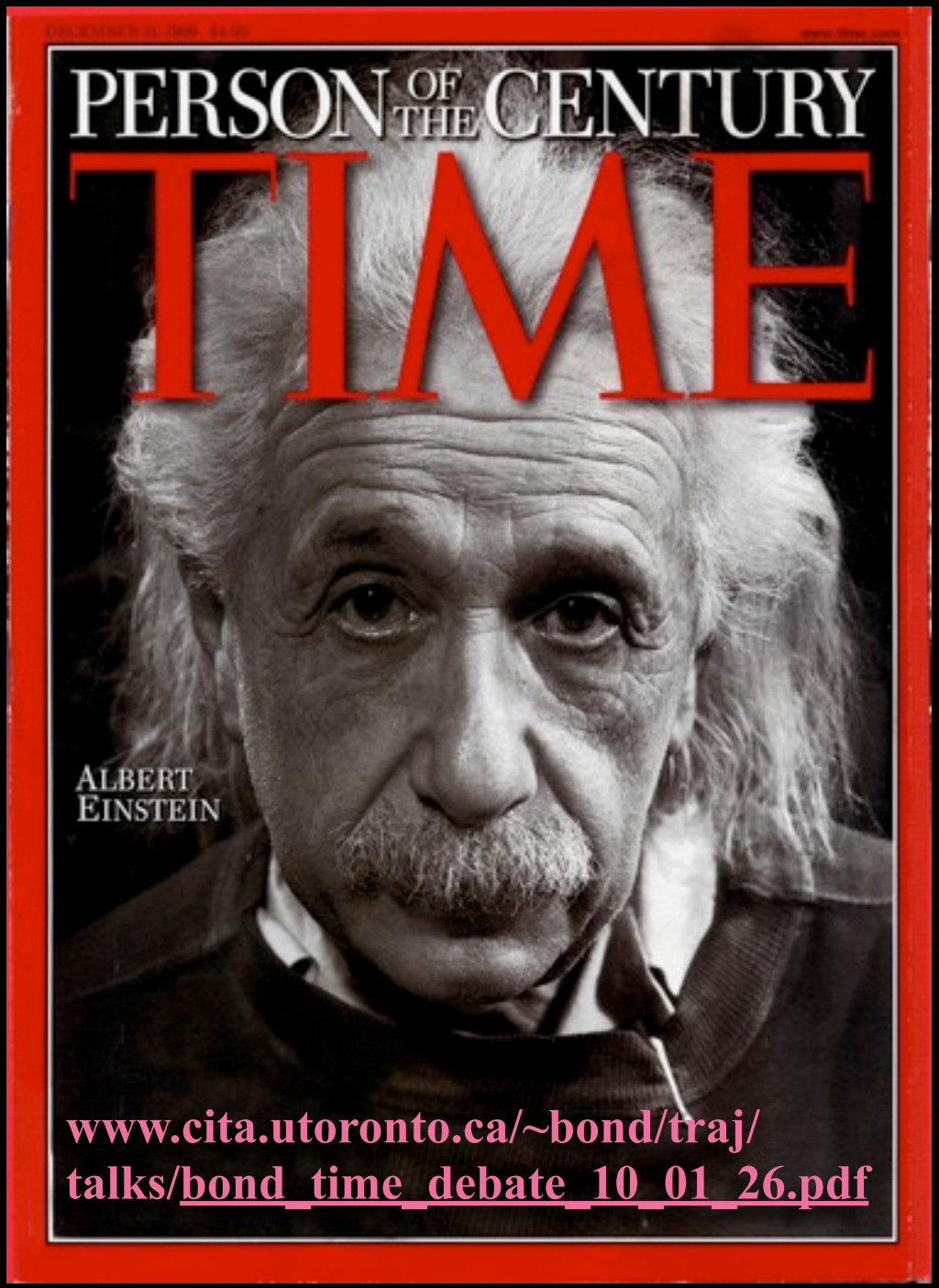


MY TIME I(t), me(t), you(t), U(t) coherence of being; NOW; past & future, history & forecasting

ASTRONOMICAL TIME counting cycles = clock: years *(seasons & agriculture)*, **moons** *(wax &wane)*, **days** *& nights*, **hours** *(medieval)*; **sundials,** ***water clocks*** **& calendars**

PHYSICS TIME

COSMIC TIME



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MY TIME I(t), me(t), you(t), U(t) coherence of being; NOW; past & future, history & forecasting
ASTRONOMICAL TIME counting cycles = clock: years *(seasons & agriculture)*, **moons** *(wax &wane)*, **days** & *nights*, **hours** *(medieval)*; *sundials, water clocks* ***& calendars***

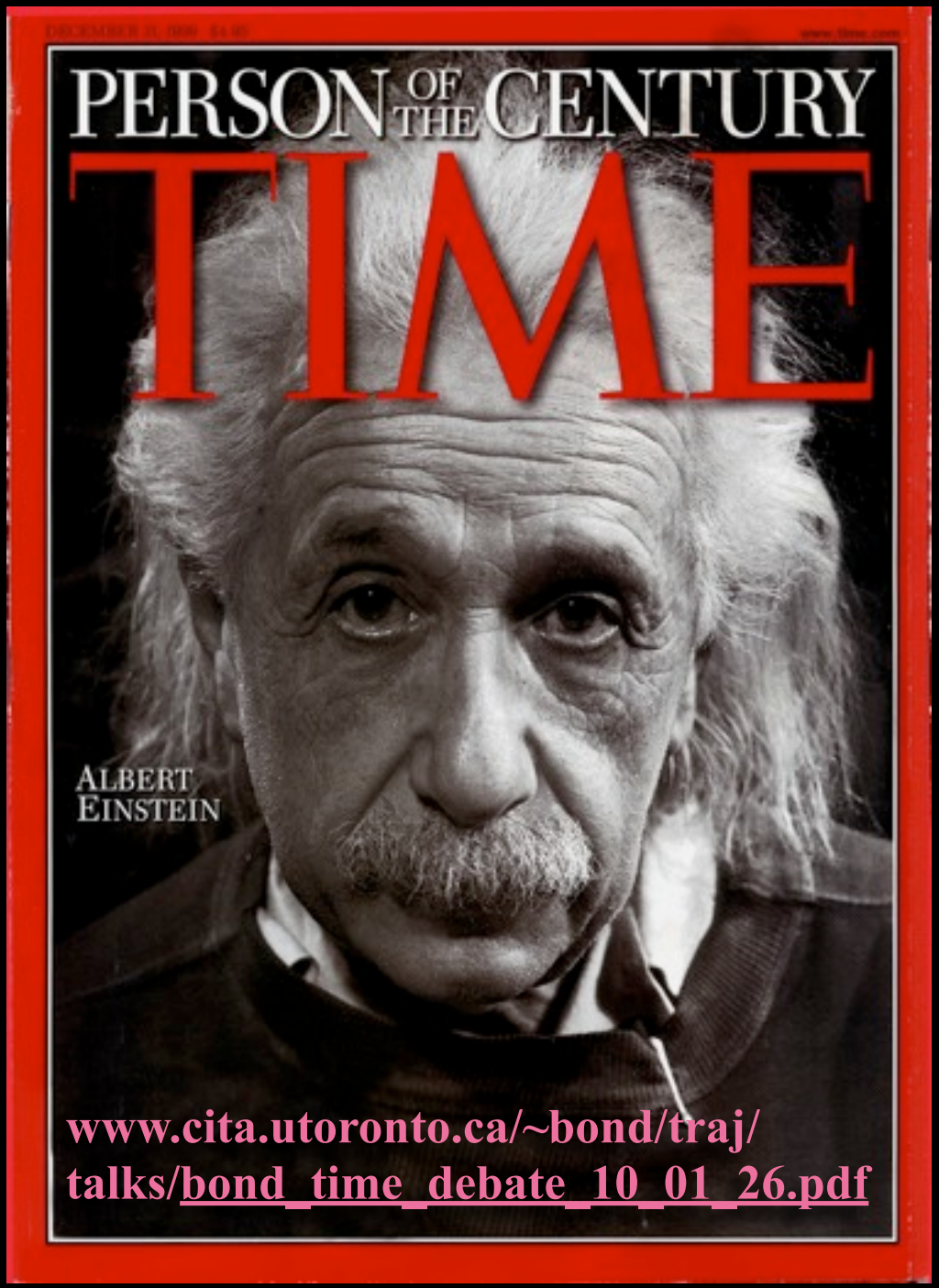
PHYSICS TIME pythagoras
frequency ν harmonics in music

cycles per minute, second; to millisec, microsec, nanosec, pico, femto; attosec;
***pendulum, spring & crystal clocks,* cesium atom standard to ± 30 nanosec** 1955-67 0.11 nsec

from string oscillations to the cosmic music of the spheres
frequency = conjugate to time
the quantum:
energy E=hν conjugate to time

(wavelength)$^{-1}$ & momentum conjugate of space, light & structure;
phase-space, spacetime & action

physics time⇒all of physics⇒COSMIC TIME



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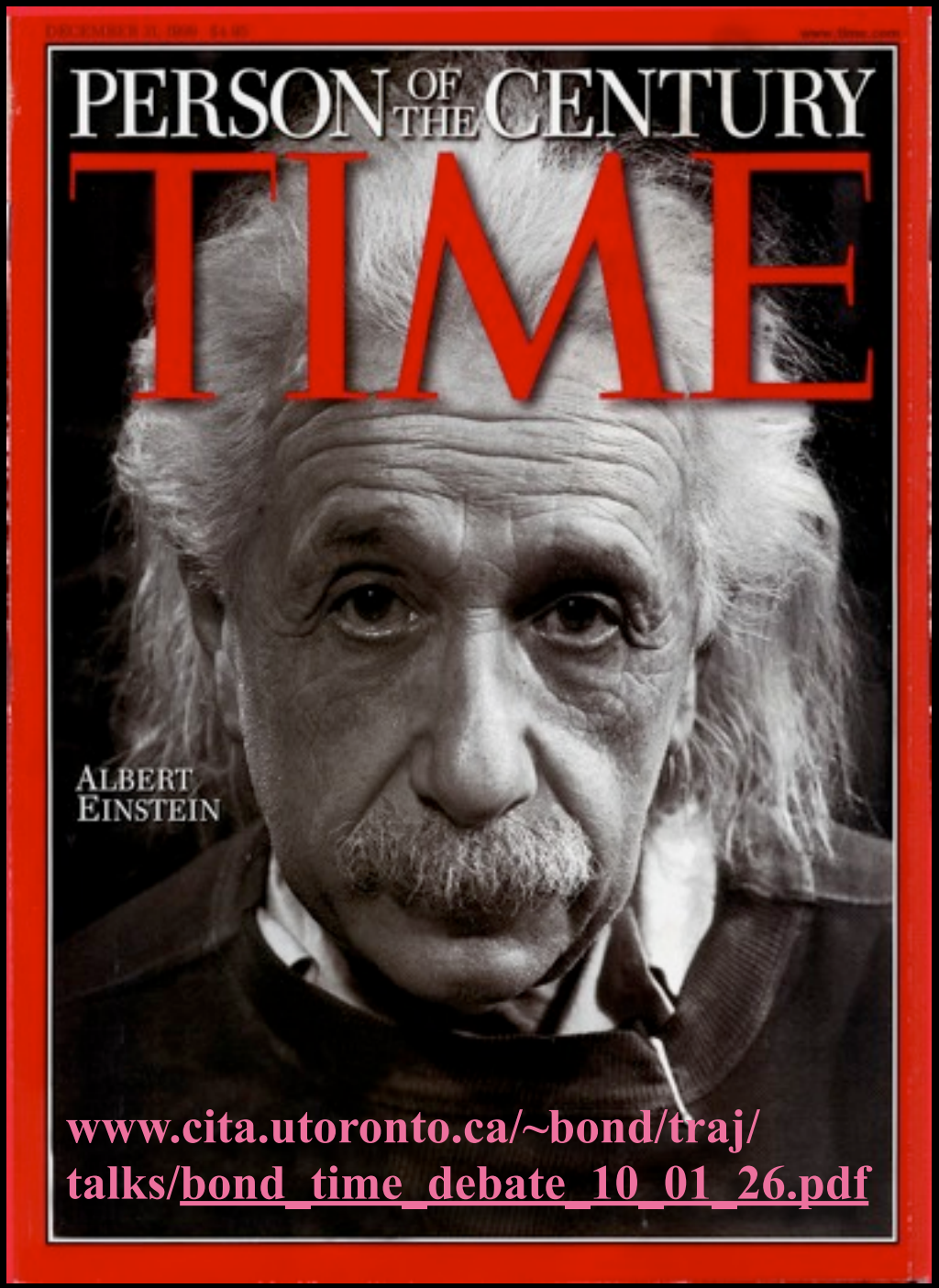
MY TIME I(t), me(t), you(t), U(t) coherence of being; NOW; past & future, history & forecasting
ASTRONOMICAL TIME **counting cycles = clock: years** *(seasons & agriculture)*, **moons** *(wax &wane)*, **days** *& nights*, **hours** *(medieval)*; **sundials & calendars**
PHYSICS TIME *pythagoras frequency* ν *harmonics in music cycles per minute, second; to* ***milli, micro, nano, pico, femtosec;*** *spring clocks, digital clocks, cesium standard from string oscillations to the cosmic music of the spheres frequency = conjugate to time the quantum: energy* $E=h\nu$ *conjugate to time* $(wavelength)^{-1}$ *& momentum conjugate of space, of light and structure; phase-space, phase & action*
shortest usable times: ultrafast lasers pulses femtosec ⇒ attosec (10^{-18})

CERN quark-gluon plasma light pulses **yoctosec (10^{-24}); LHC** collisions **(10^{-28})**

COSMIC AGE of U= 13.7 ±0.1 Gyr AB ($10^{17.6}$) + the time before matter/radiation creation, pre-BigBang ... pre-spacetime?



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PHYSICS TIME:
points move thru *phase*-space as time progresses worldline: x(t), p(t)

Special Relativity 1905
spacetime (x,t: p,E)
The views of space and time which I wish to lay before you have sprung from the soil of experimental physics, and therein lies their strength. They are ***radical.*** *Henceforth* ***space by itself, and time by itself, are doomed to fade away*** *into mere shadows, and* ***only a kind of union of the two will preserve an independent reality.*** *Minkowski 1908 after Einstein 1905*

the relativity of time and space t(x)⇒ so many times

BUT ***time IS fundamentally different*** *from space. 1 time dimension, 3 (⇒10) space dimensions, related by:*

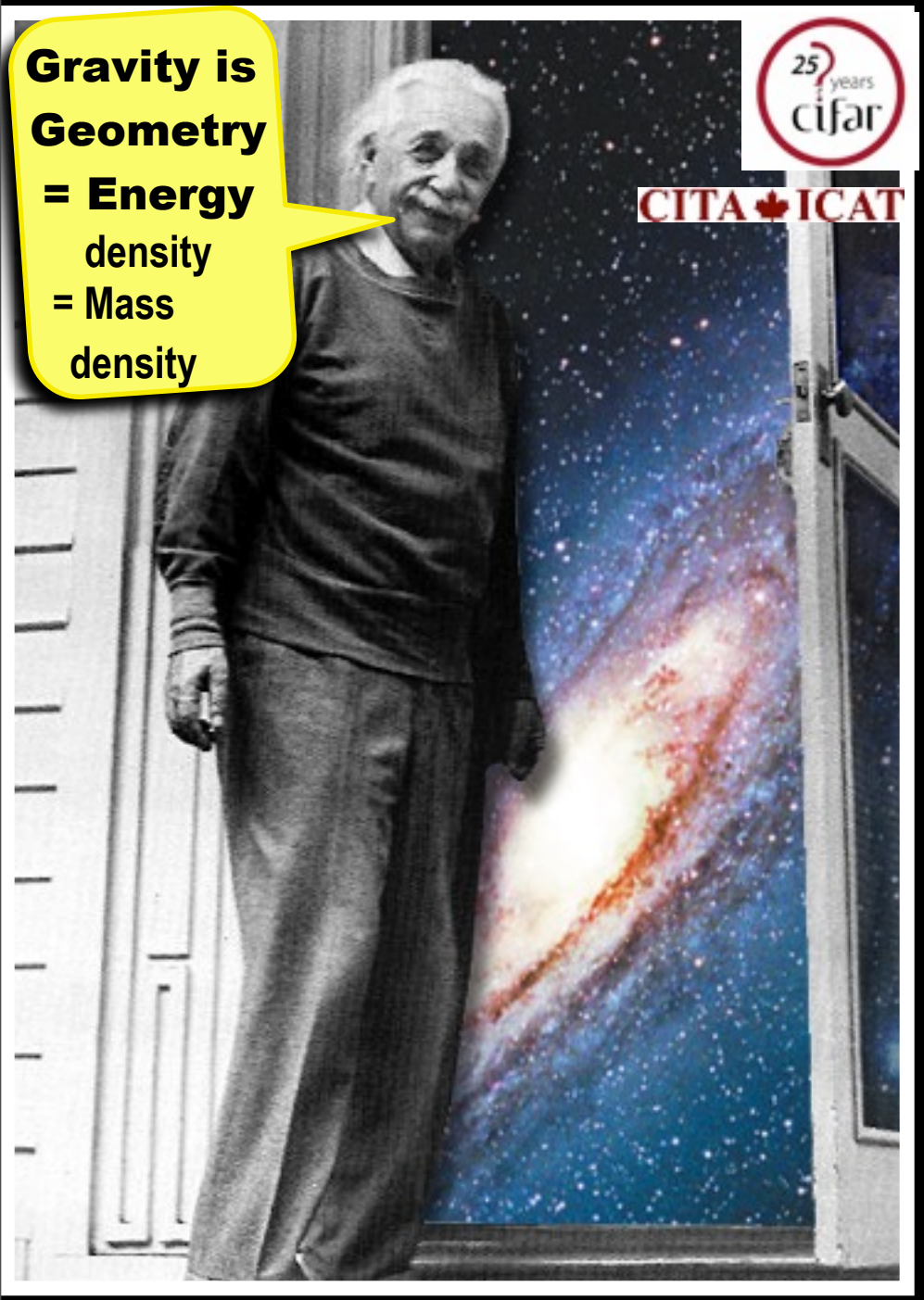
the ultimate speed limit: of light & other signals

way back is far out: *only events in our past light cone influence us, we can only influence our future light cone*

we cannot "see" beyond our past horizon

General Relativity 1916-17 cosmology
gravity warps time, time is curved

⇒ COSMIC TIME



ASTRONOMICAL TIME + PHYSICS TIME =

COSMIC TIMEs *(x,t)* *Gigayear = aeon* AB

Hubble expansion rate **H** = velocity/distance
1/H 13.5 ±0.7 Gyr HST⇒**13.7 ±0.5 Gyr** CMB

many **TIMEs(SPACE,t)**. dynamical cosmic clocks
expansion factor **a** = 1/compression = 1/ (1+redshift)
ln(a) (e-foldings) is better, **>130 ABang, 67 AMatter**

early Universe physical clocks *ln***a**, *ln***H**, *ln***Ha**
but they fluctuate by QUANTUM vacuum effects - this is the origin of all cosmic structure!!!!; quantum breakdown in the **ultra-early Universe** ***Time emerges?***

later Universe, no expansion in earth, star & galaxy gravity wells ⇒*bad clocks even reversing in collapse*

atomic, nuclear clocks OK but ticks vary with gravity: clocks speed up climbing out of gravity wells (redshift), slow down dropping into gravity wells (blueshift)

cosmic veil: the ***first light*** is released **13.7-.00038 Gyr**
CMB an effective ***horizon***, but ∃ ***beyond*** our horizon

cosmic ages Gigayear = aeon

Galactic year earth orbital period around the Milky Way centre **0.22 Gyr**; *centre* **25000 lyrs**

nuclear chronometers, radioactive elements

Uranium-lead for **earth** (hence sun) **4.54 ± 0.02 Gyr** (created **9.15 Gyr AB** After the Big Bang)

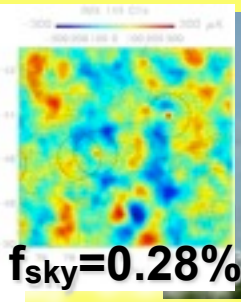
Uranium dating in old stars **12.5 ± 3 Gyr** 2001

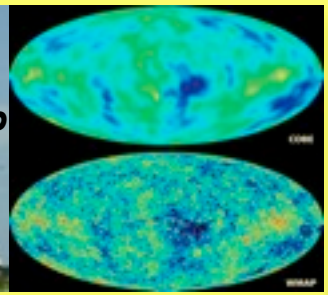
Uranium/Thorium dating of old stars **11.8 ± 3.7, 10.9 ± 2.9** and **13.5 ± 2.9 Gyr** 2009

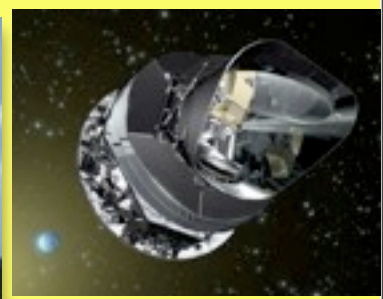
ages of oldest Milky Way (evolution of **globular cluster stars**) **~ 13.4 ± 0.9 Gyr** 2001

expansion of the universe, from stars 1/Hubble= **13.5 ± 0.7 Gyr** HST 2001, 09

CMB+ 13.7 ± 1.9 1999 ⇒**13.8 ± 0.3** 2002 ⇒**13.6 ± 0.2** 2005 ⇒**13.7 ± 0.1 AB** 2010







~350 boom-deeps

age when the "first stars" were created: **0.68 Gyr AB**

age when the **first light (CMB)** was released: **380081** (**± 1.5%) years AB**

Big Bang Nucleosynthesis age when hydrogen and helium were created **~1 minute AB**

Dark Matter synthesis age if dark matter are WIMPS **~ nanosecond ?** - microsecond

radiation/matter genesis, entropy genesis, baryogenesis: **~ 10^{-37} seconds???**

quantum gravity epoch: **2.8×10^{-43}** seconds **Planck time (quantum+gravity+light-speed)**

$$t_P = (hG_{Newton}^{9} c^{-5})^{1/2}_{2}$$

LHC@CERN proton collisions will soon probe **~10^{-28}** sec physics

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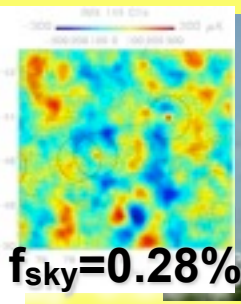

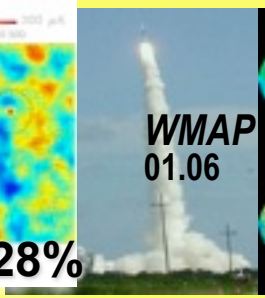

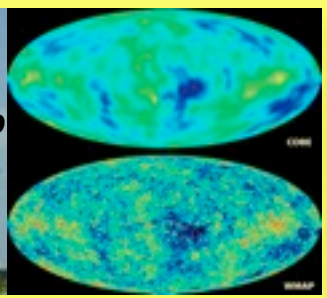

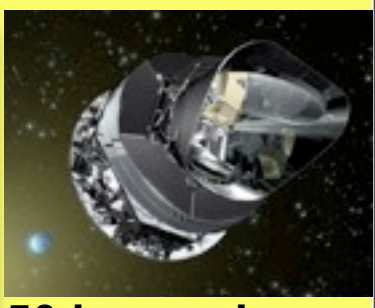

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$$t_P = (\hbar G_{Newton} c^{-5})^{1/2}$$

a **starless "dark age"** before the **most distant galaxies**

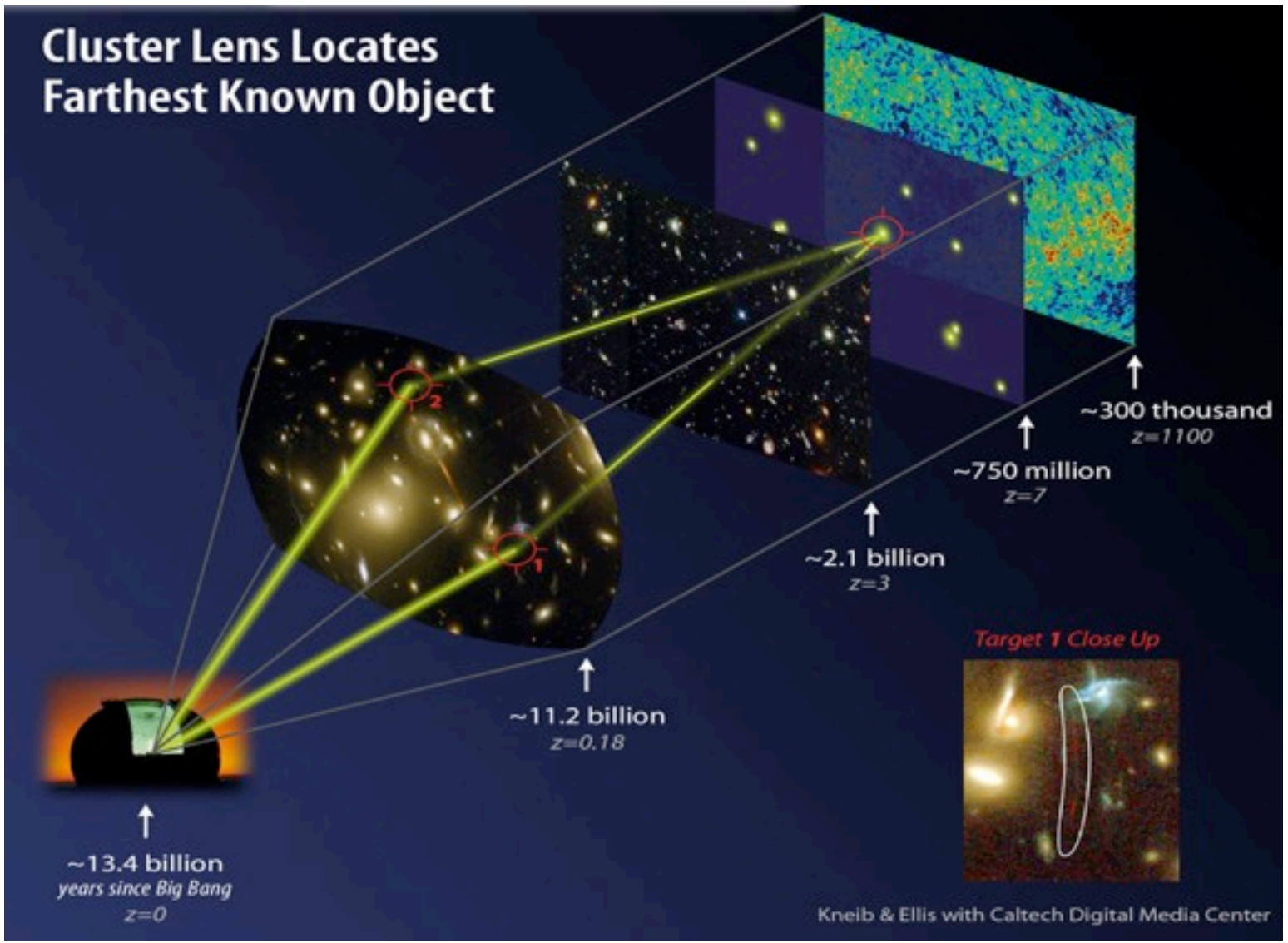
dwarf galaxies & the 1st stars

form ~13 compression **0.37 Gyr AB**

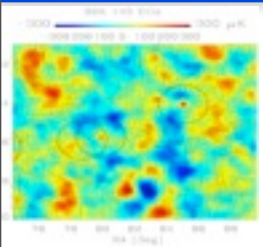
1st light: Cosmic Microwave Background

released **1100 compression** **38000 yr AB; ~10^{30} formed** **~10^{-37} sec AB**

most distant explosion (gamma ray burst) known, 0.63 Gyr AfterBang, 13.1 Gyr ago, @compression 9.2 *2009*



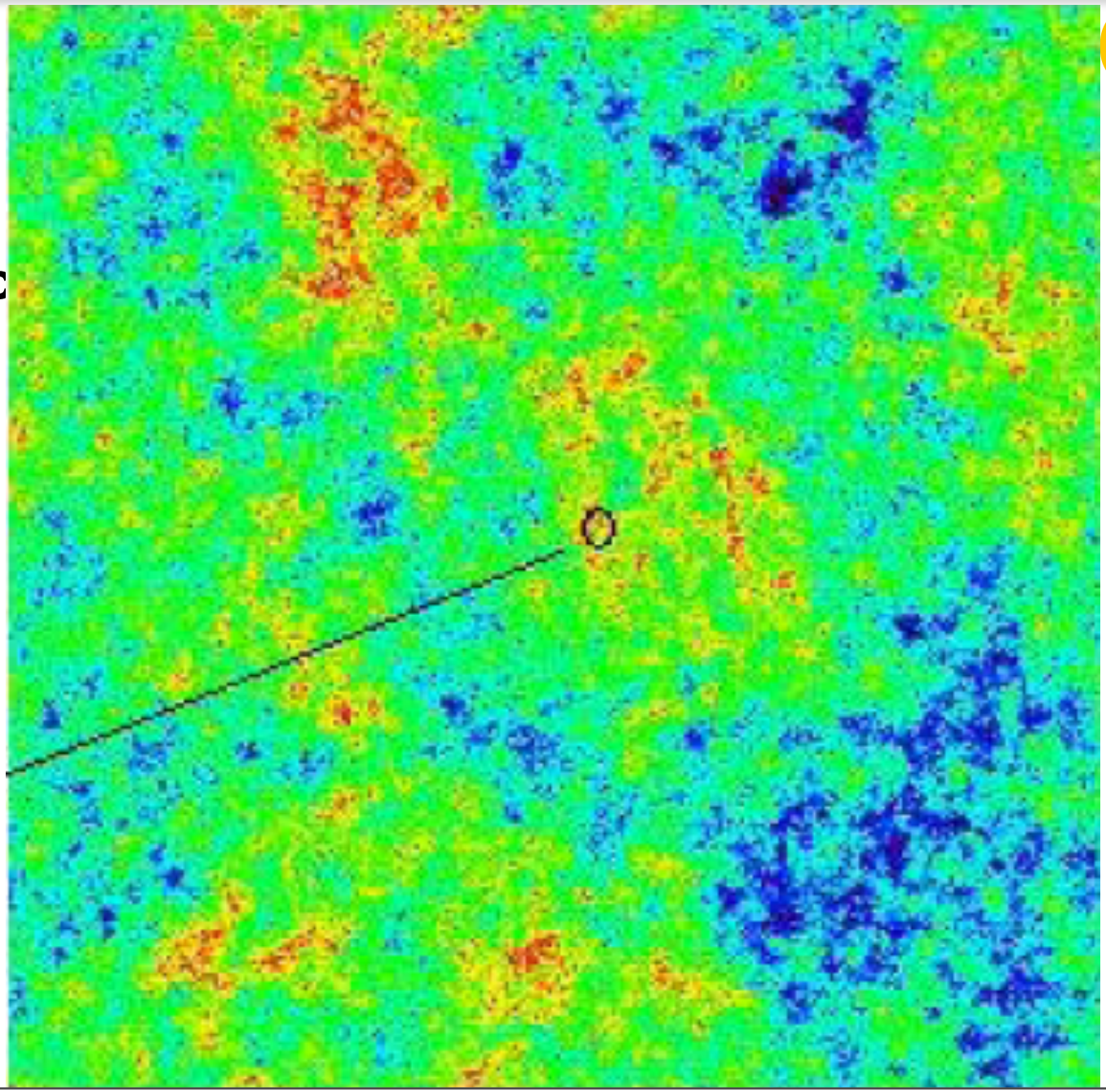
time **fluctuations** in the **early universe "vacuum" grow** to ***all*** **structure**



1000 Gpc

current Hubble patch (effective horizon) **14 Gpc**

speed limit horizon



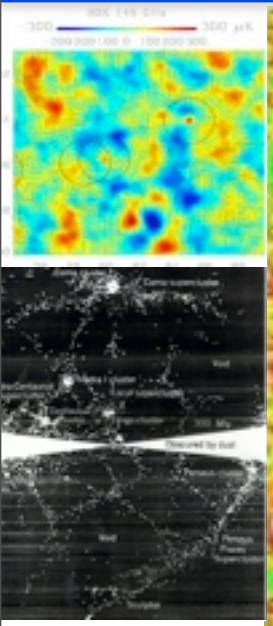
ln a(x, ln H)

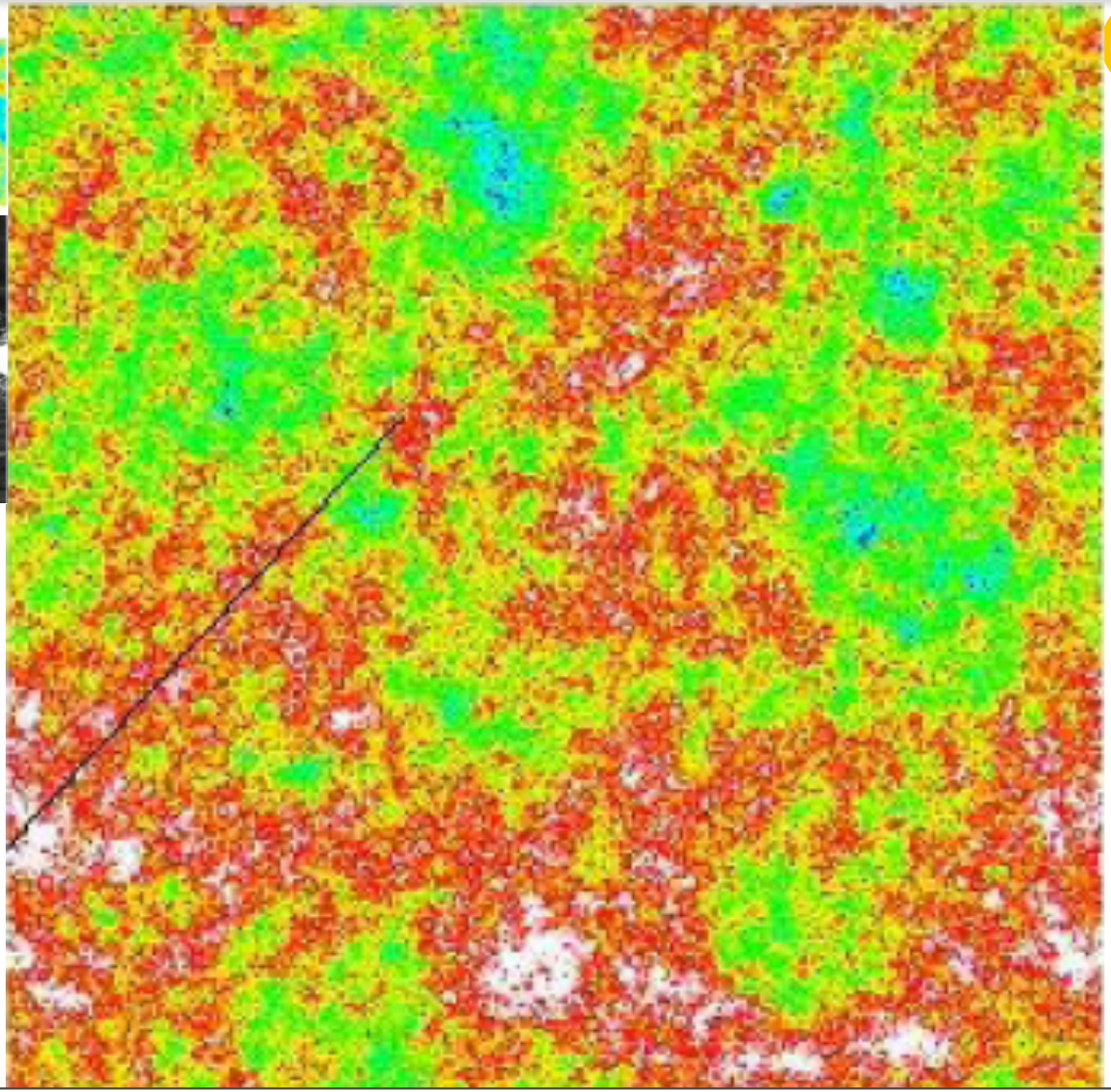
spatial patterns in the quantum jitter of time evolve under gravity

(& gas dynamics) to make all structure we can "see"

& stuff we cannot ever see

time **fluctuations** in the **early universe "vacuum" grow** to *all* **structure**





ln a(x,ln H)

all this can

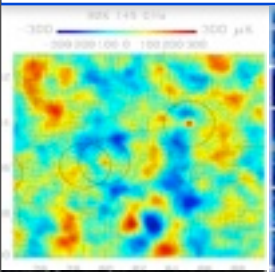
evolve from early U vacuum potential and vacuum noise

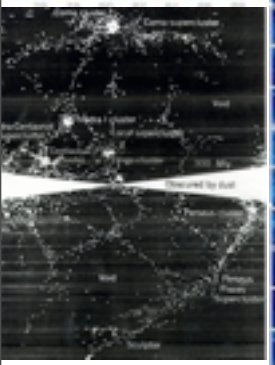
in the presence of late U vacuum potential

aetherial!

10 Gpc

time **fluctuations** in the **early universe "vacuum" grow** to *all* **structure**





400Mpc

ΛCDM

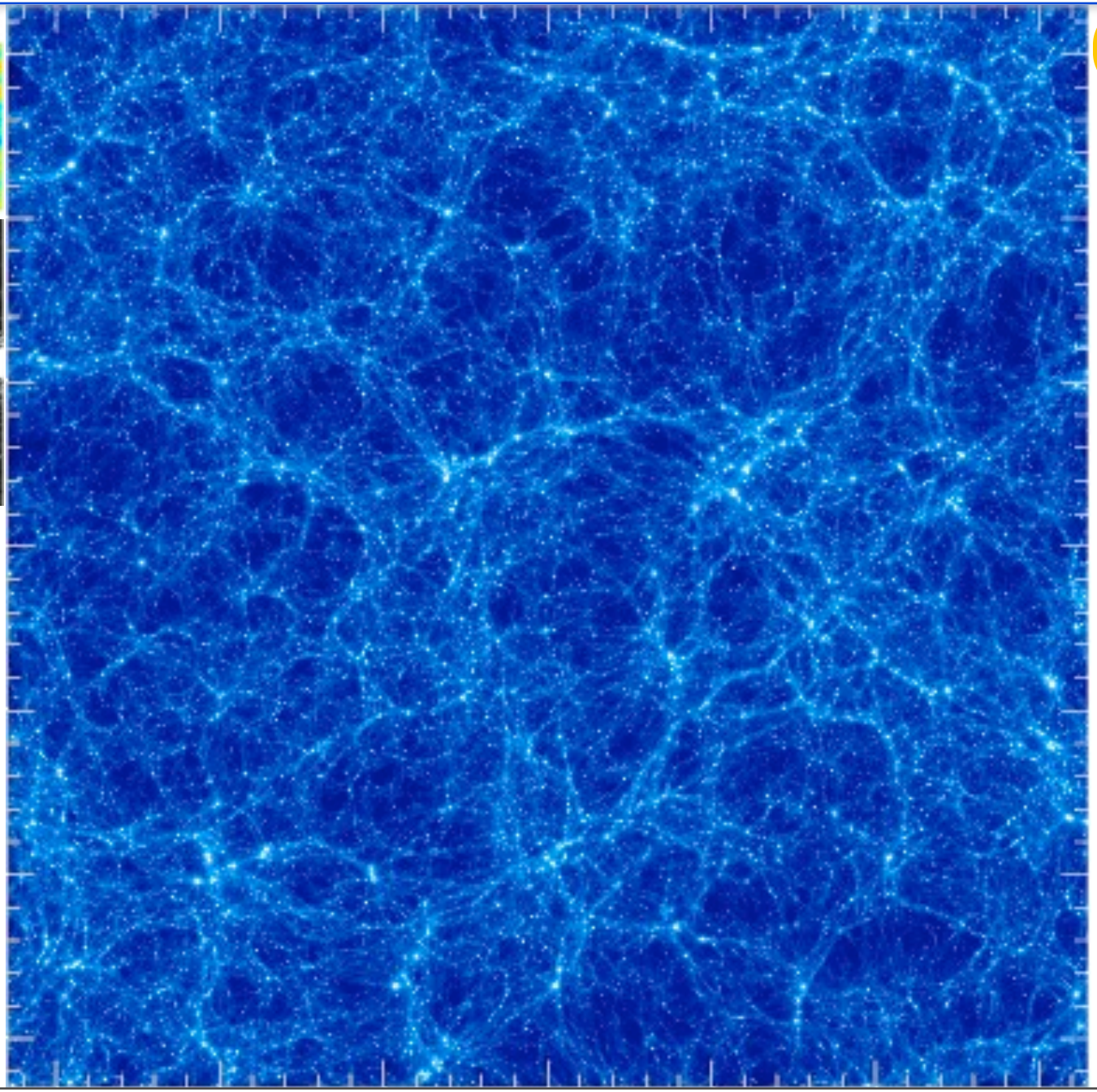
WMAP5

gas density

Gadget-3

SF+SN E +winds +CRs

512^3



ln**a(x,**ln**H)**

all this can

evolve from early U vacuum potential and vacuum noise

in the presence of late U vacuum potential

aetherial!

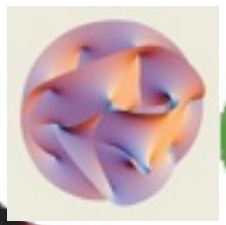
0.4 Gpc

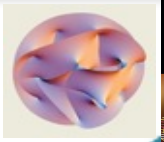
quantum stochastic *non-Gaussian* time landscape cf. stringy landscape

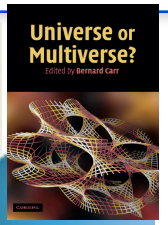
multiverse
Starobinsky, Vilenkin, ***Linde****, SB, Rees, ..., stringy: Susskind etal*

UNIVERSE

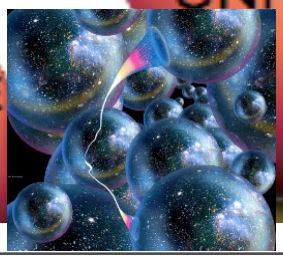
ln**a(x,**ln**H)**

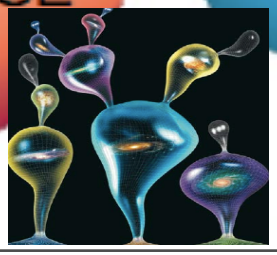






our horizon





ln**a(x,**ln**H)**

a "natural" consequence of quantum mechanics of the U's uuUULSS on ln**a(x,** ln**Ha)**

***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) *natural selection* *anthropic* $U \in \{Us\}$

a cold death? reheat/rebirth?

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

NOW 14 Gyr 1

Pythagoras formed

Inflation fluctuations form: quantum jitter

Galaxies Cluster

Cosmic "web" of vast filaments + membranes

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

Protons/Neutrons form

Solar sy… earth fo…

Life forms on earth

Helium forms

100 sec 10^{9}

1st light

2nd light

9 Gyr 1.4

Carbon/oxygen/etc form

Galaxies form

2 Gyr 4

Cosmic background radiation released from matter

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

0.4 Myr 1100

The 'Meaning' may change

But the facts will remain

end of Bond's TIME