Title: Secrets of the Universe â€“ Hiding in Plain Sight?

Speakers: Neil Turok

Collection: Perimeter Public Lectures

Date: October 25, 2023 - 7:00 PM

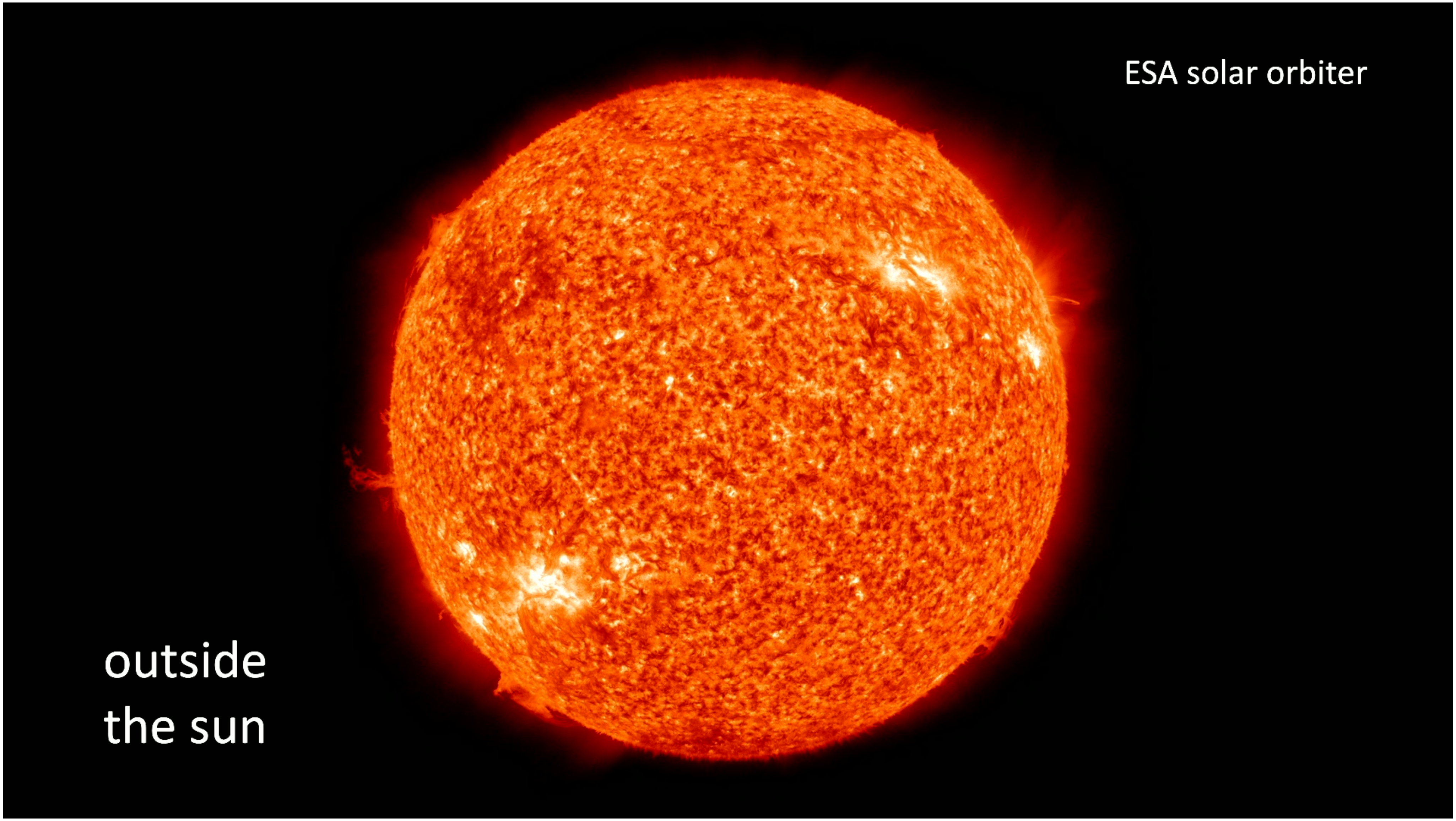
URL: https://pirsa.org/23100117

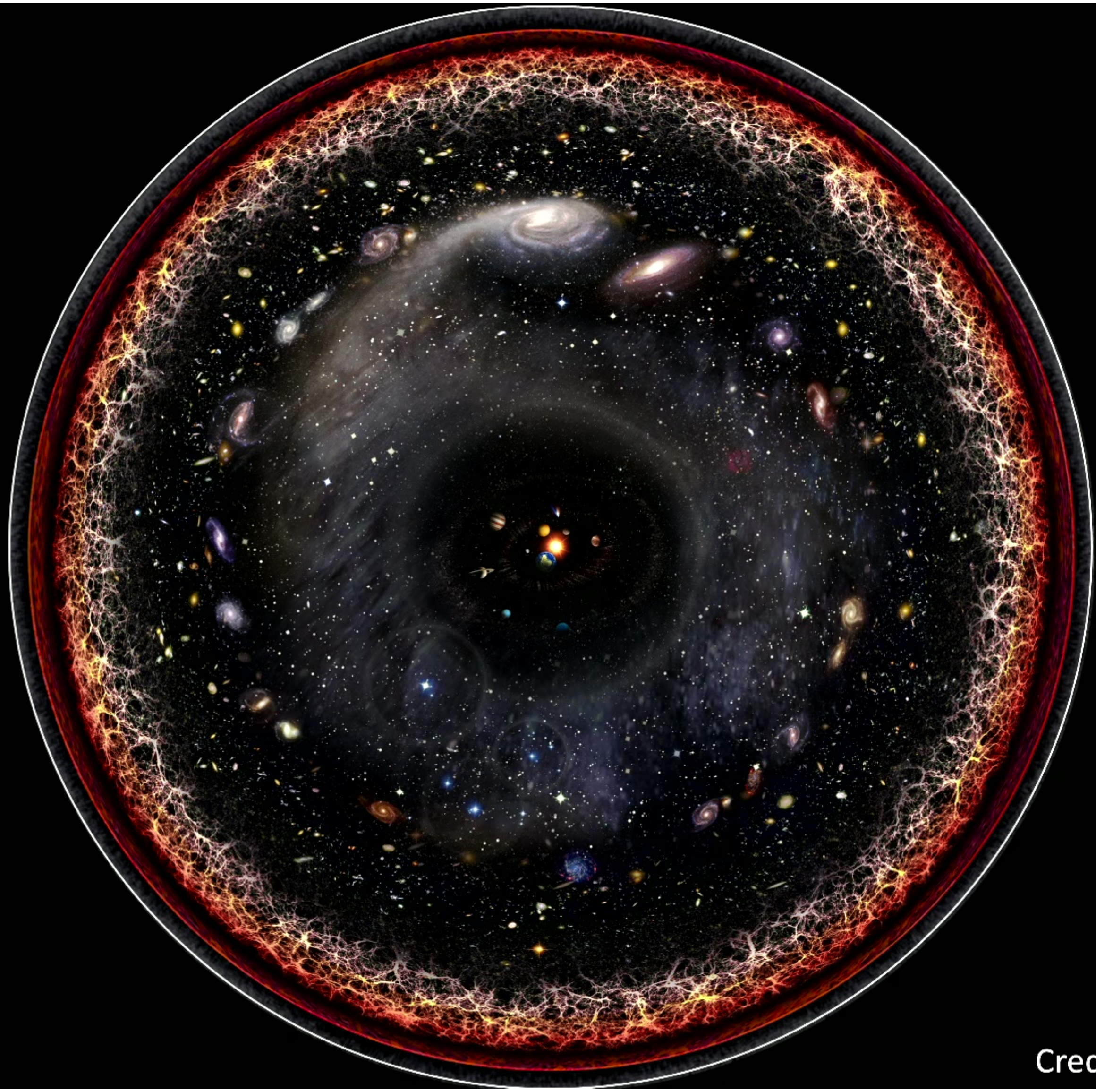
Abstract: How did the universe begin? How did it evolve to what we see now?

There was a time when few people believed such questions could even be posed in scientific terms. Now, as increasingly precise instruments deliver their treasure trove of data, the answers may be within reach.

On Wednesday, October 25, Perimeter Director Emeritus Neil Turok will tackle this intriguing topic in a Perimeter Institute Public Lecture, "Secrets of the Universe: Hiding in Plain Sight?"


Secrets of the universe: hiding in plain sight?

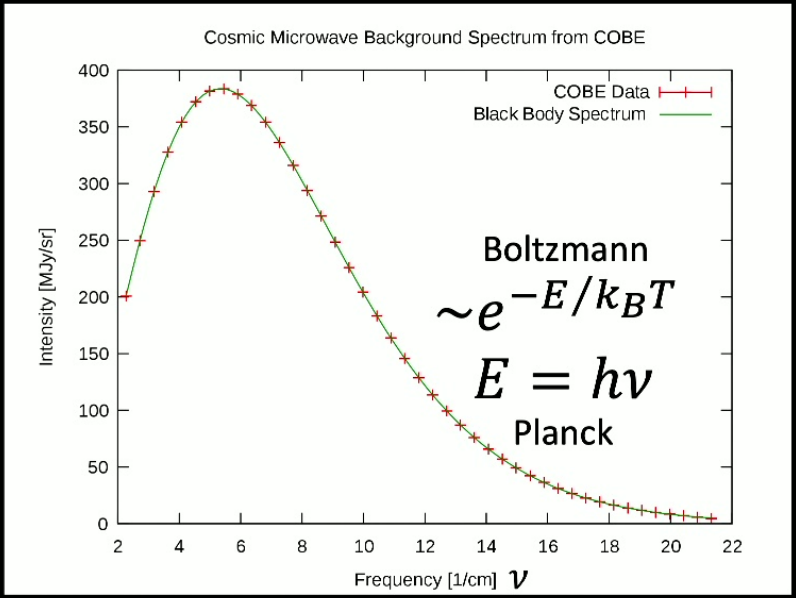

ESA solar orbiter
outside
the sun



inside
the bang

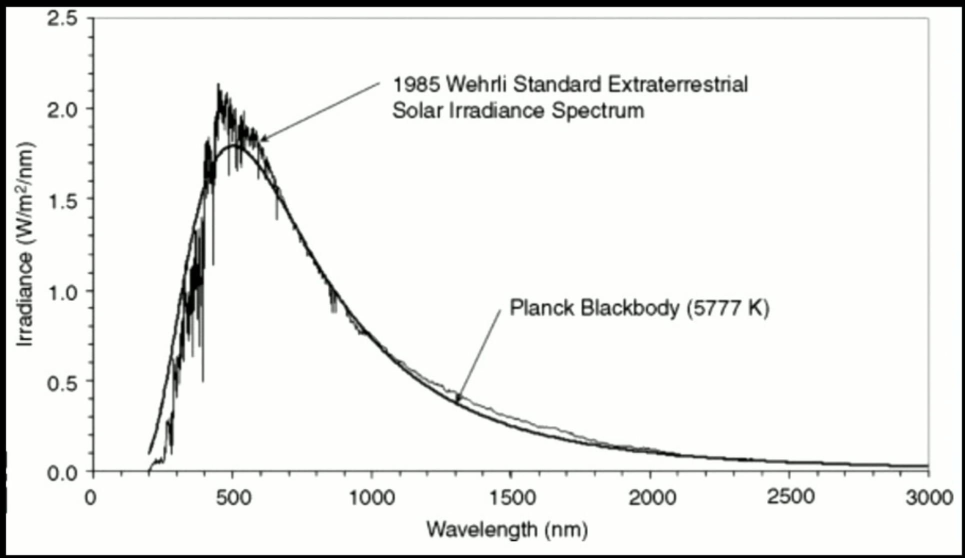
Credit: Pablo Carlos Budassi

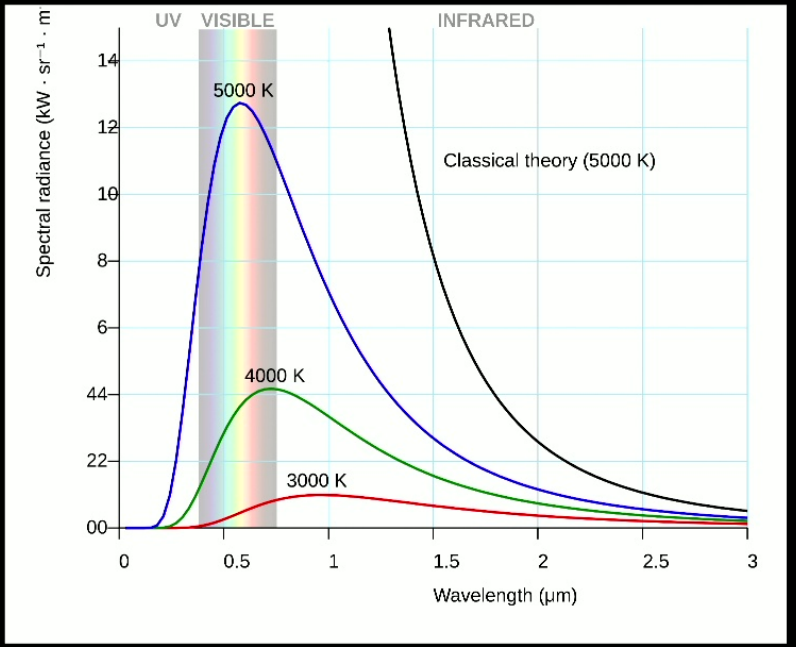
COBE 1992



Cosmic Microwave Background Spectrum from COBE
COBE Data
Black Body Spectrum
Intensity [MJy/sr]
Frequency [1/cm] ν
Boltzmann
$\sim e^{-E/k_B T}$
$E = h\nu$
Planck

the solar spectrum

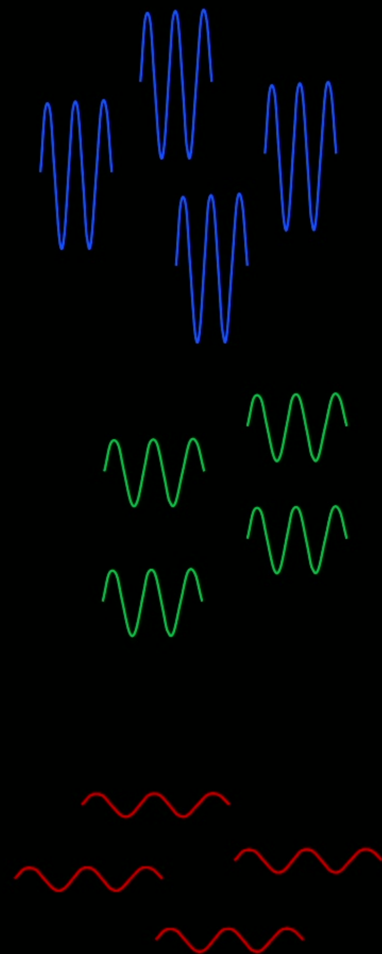


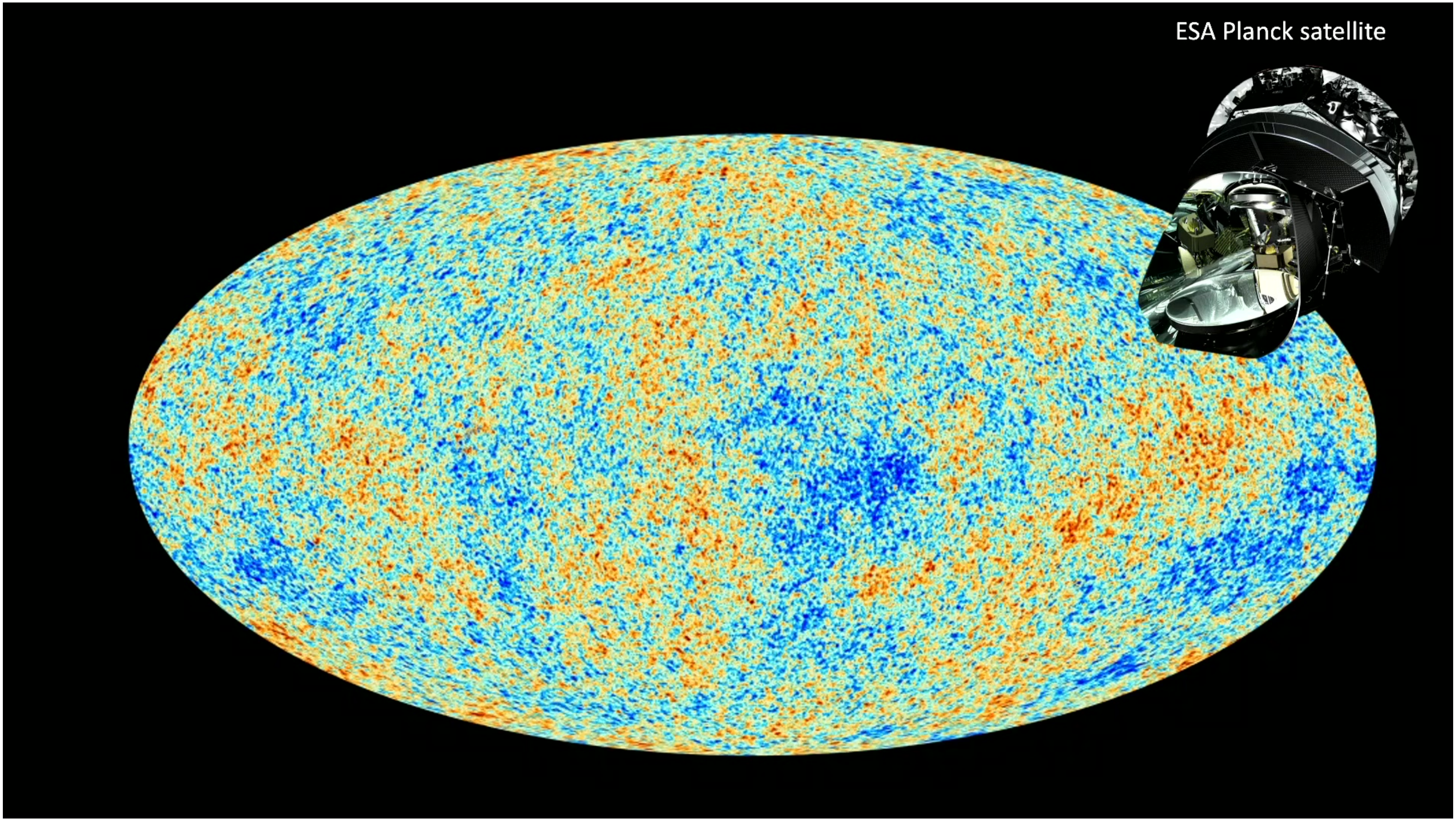


Planck's postulate

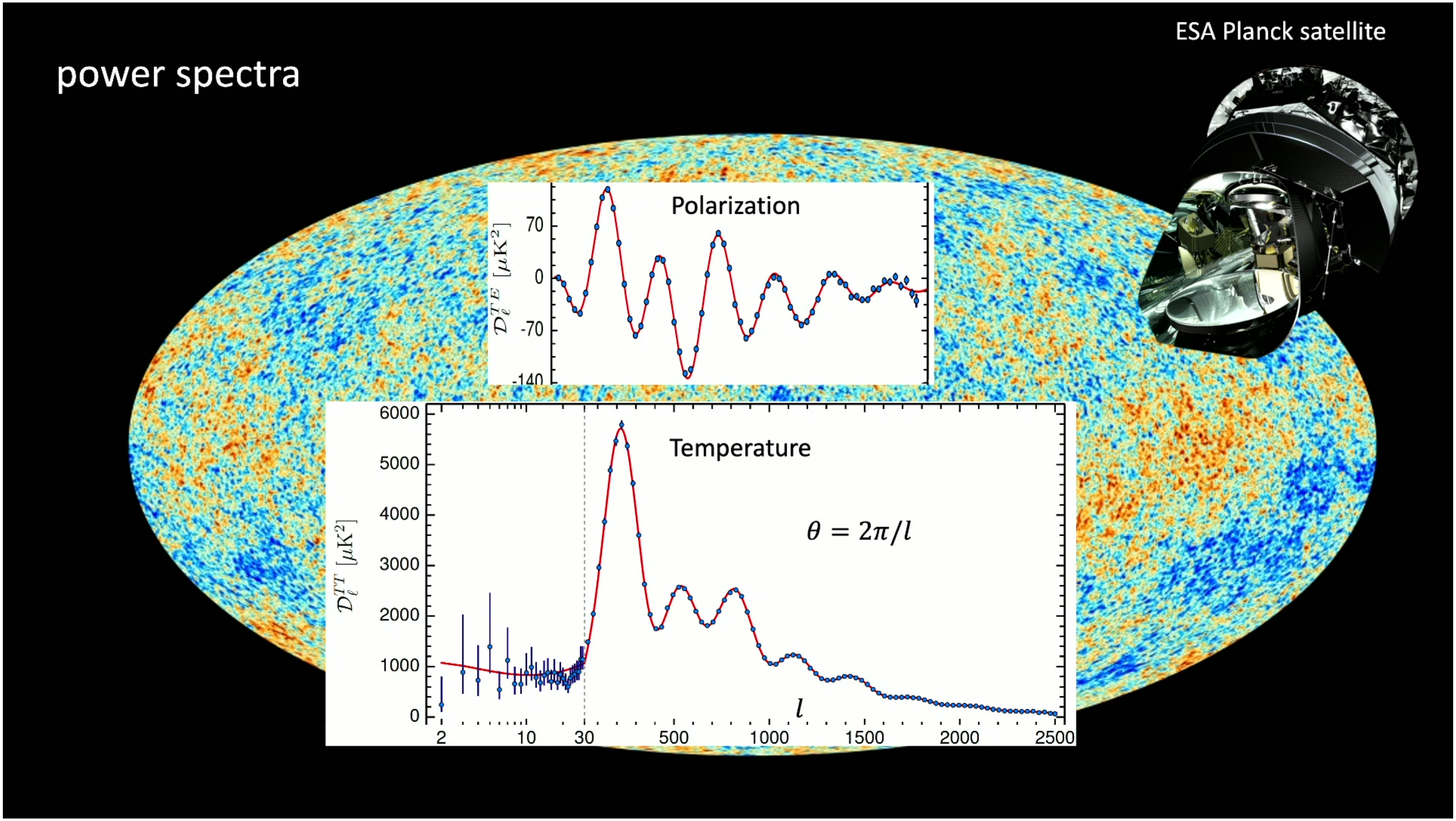
light
comes in
packets of energy
(photons)

$$E = h\nu = \frac{hc}{\lambda}$$




ESA Planck satellite

a random pattern of waves


power spectra
ESA Planck satellite
Polarization
Temperature
$\theta = 2\pi/l$
l
$\mathcal{D}_\ell^{TE}\ [\mu K^2]$
70
0
-70
-140
$\mathcal{D}_\ell^{TT}\ [\mu K^2]$
6000
5000
4000
3000
2000
1000
0
2
10
30
500
1000
1500
2000
2500

Lambda CDM:

just 5 fundamental parameters

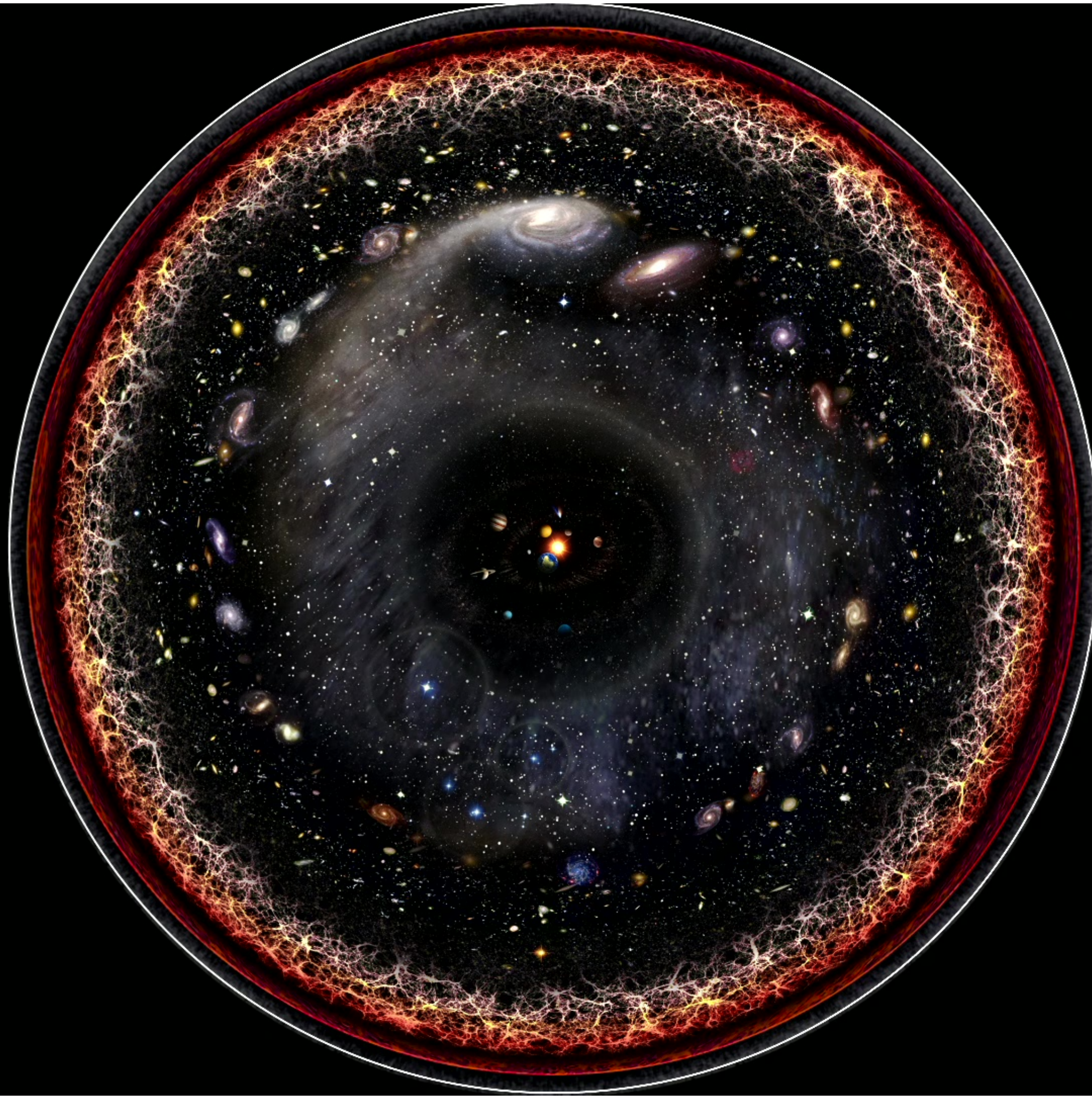
matter/energy

1. cosmological constant Λ
2. dark matter
3. nucleons

primordial density waves

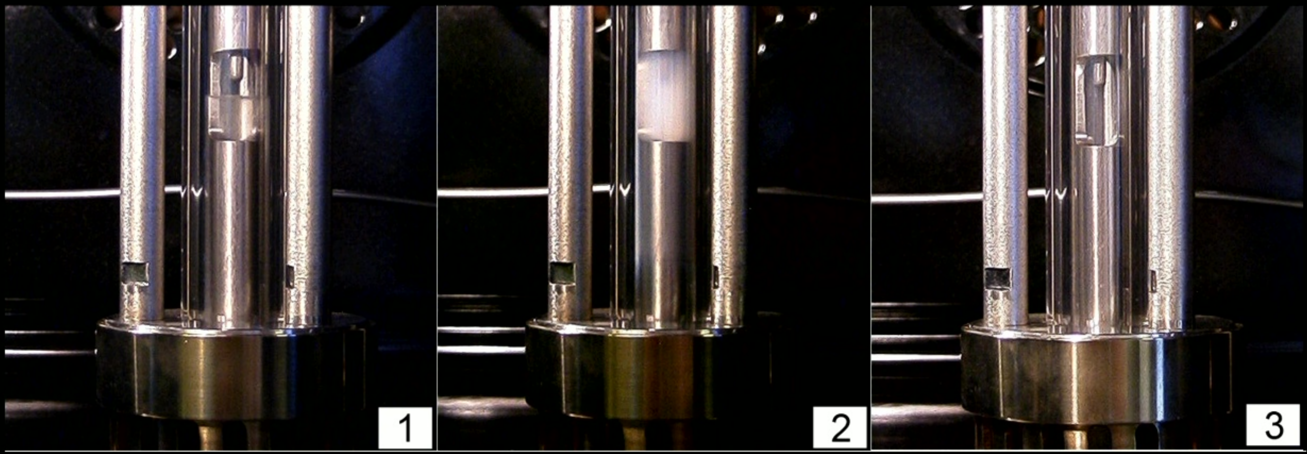
4. amplitude 10^{-5}
5. “red tilt” 0.04

astonishingly simple!



“red tilt”: longer waves are slightly stronger
(7 times* the wavelength ⇒ 4% greater amplitude)

suggestive of “critical behaviour”



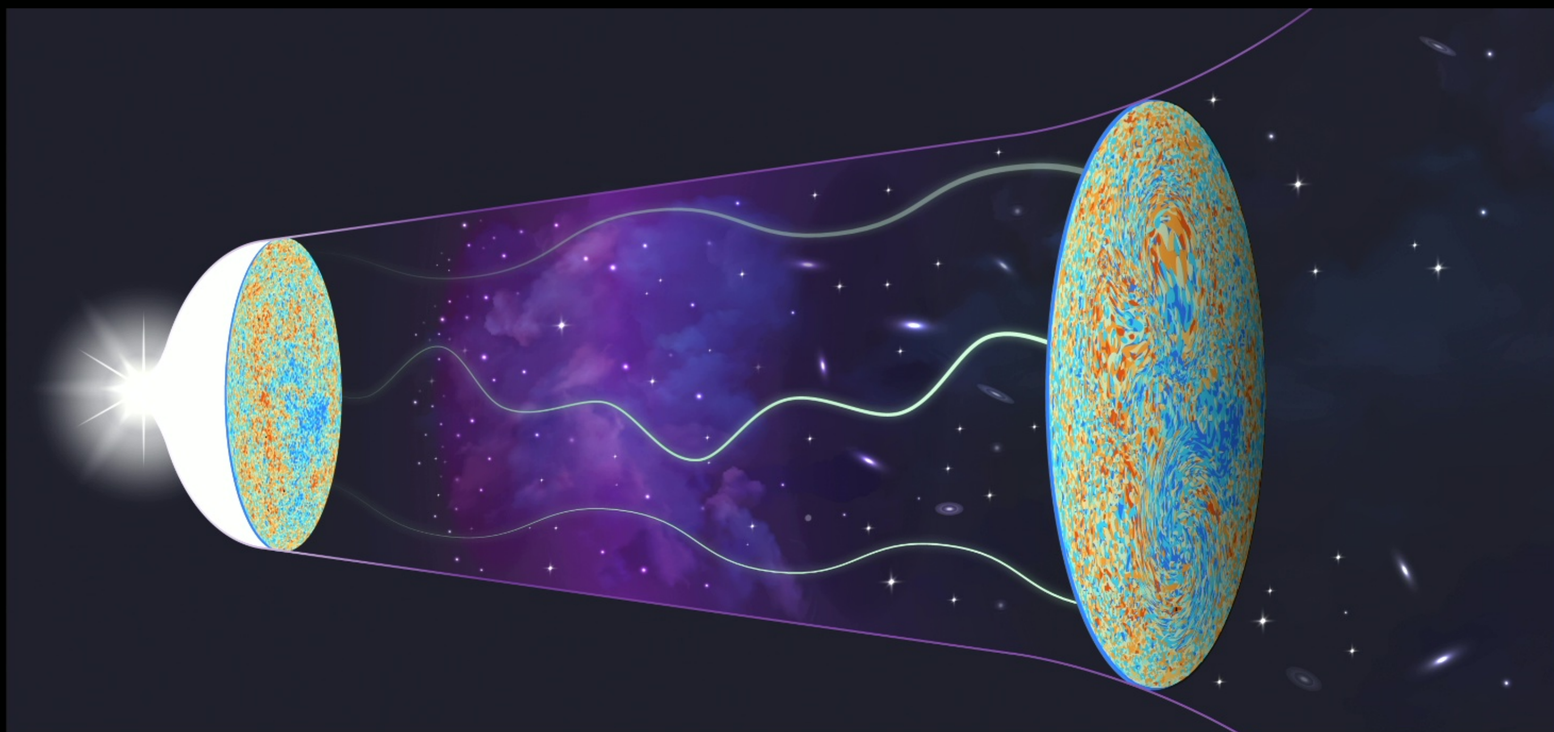
critical opalescence

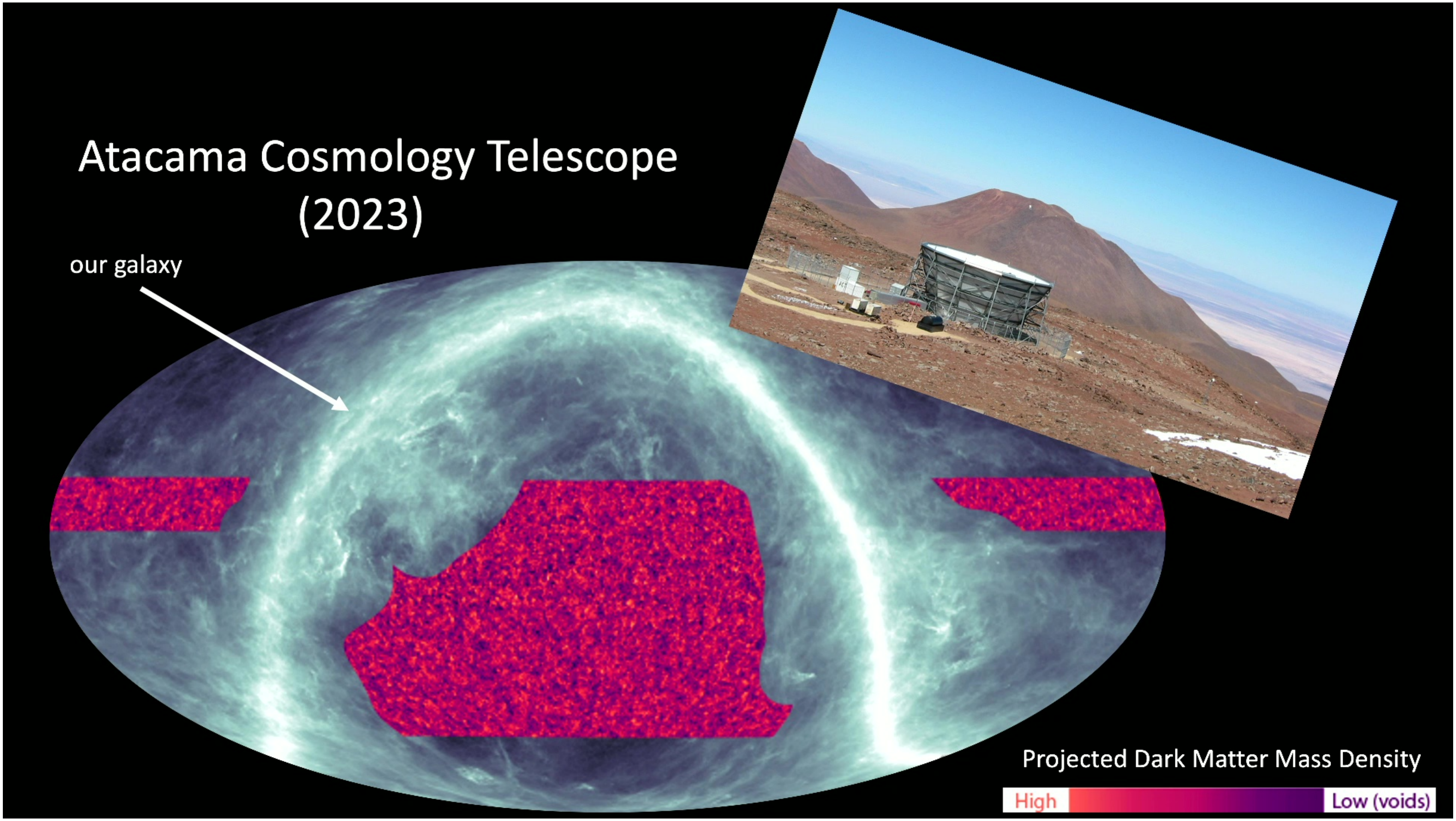
$^*e^2 \approx 7$

cosmological constant (aka “dark energy”)

- gravitationally repulsive: causes the universe to blow up

“seeing” the dark matter with gravitational lensing




Atacama Cosmology Telescope
(2023)
our galaxy
Projected Dark Matter Mass Density
High
Low (voids)

Heisenberg's microscope

a) Determination of the position of a free particle.—As a first example of the destruction of the knowledge of a particle's momentum by an apparatus determining its position, we consider the use of a microscope.[1] Let the particle be moving at such a distance from the microscope that the cone of rays scattered from it through the objective has an angular opening ϵ. If λ is the wave-length of the light illuminating it, then the uncertainty in the measurement of the x-co-ordinate (see Fig. 5) according to the laws of optics governing the resolving power of any instrument is:

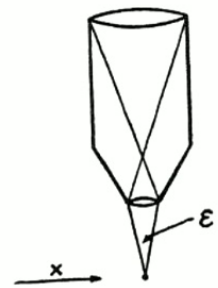


FIG. 5

$$\Delta x = \frac{\lambda}{\sin \epsilon} . \qquad (16)$$

But, for any measurement to be possible at least one photon must be scattered from the electron and pass through the microscope to the eye of the observer. From this photon the electron receives a Compton recoil of order of magnitude h/λ. The recoil cannot be exactly known, since the direction of the scattered photon is undetermined within the bundle of rays entering the microscope. Thus there is an uncertainty of the recoil in the x-direction of amount

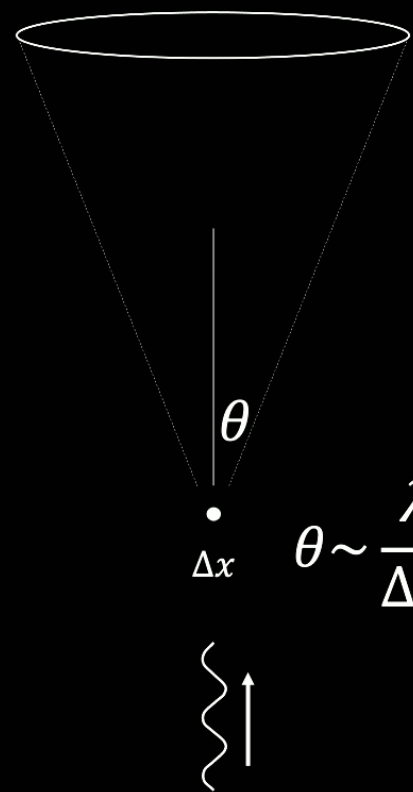
$$\Delta p_x \sim \frac{h}{\lambda} \sin \epsilon , \qquad (17)$$

and it follows that for the motion after the experiment

$$\Delta p_x \Delta x \sim h . \qquad (18)$$

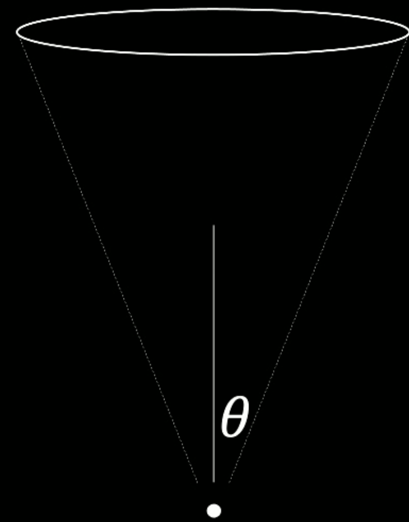
[1] N. Bohr, *loc. cit.*

waves spread



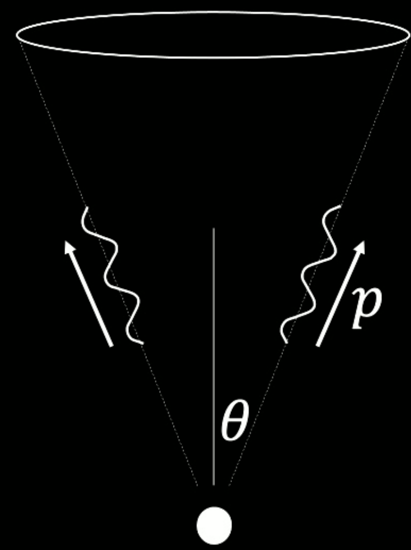
$$\theta \sim \frac{\lambda}{\Delta x}$$

particles kick



$$p = \frac{E}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}$$

particles kick

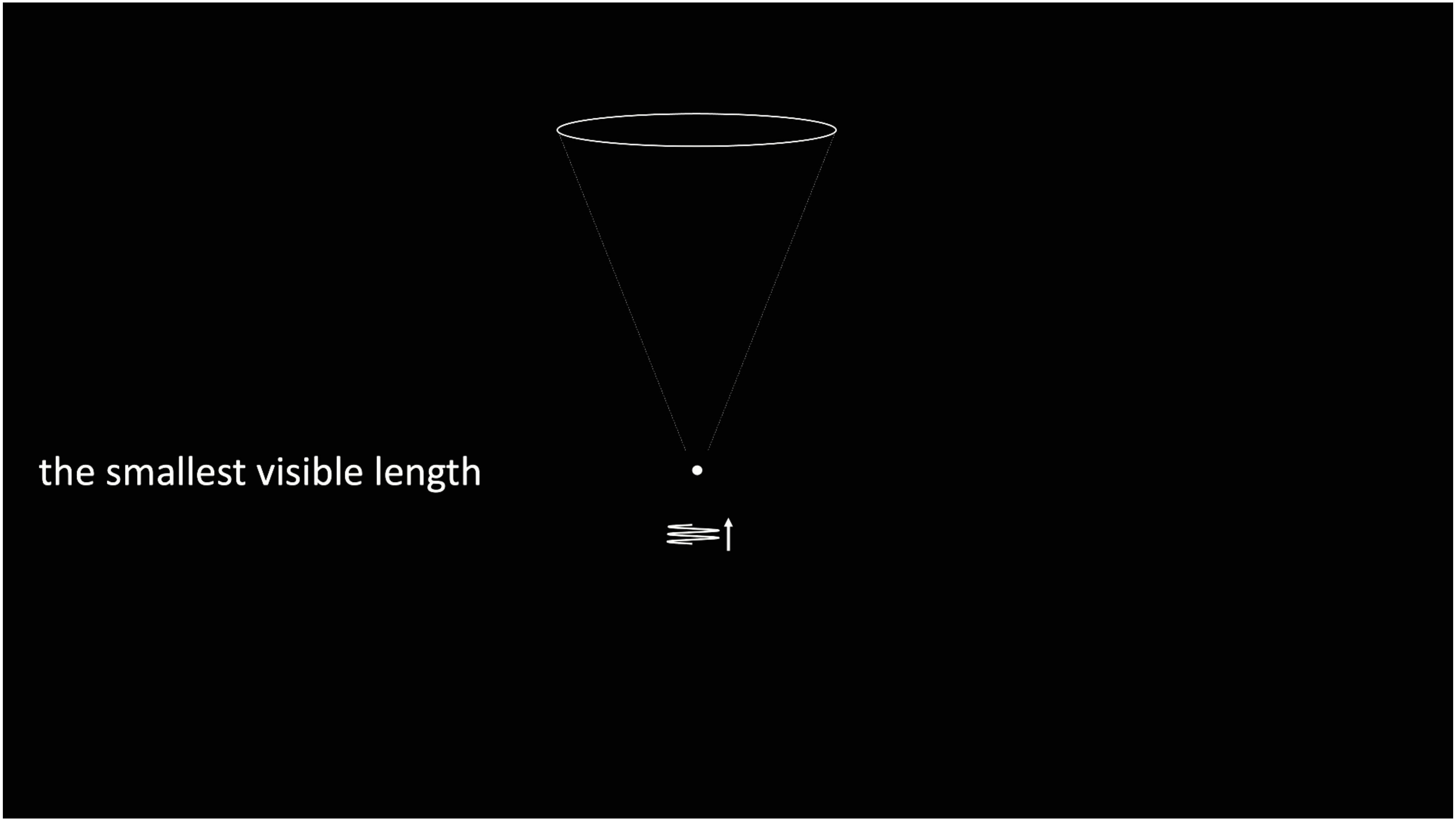


$$\Delta p_x \sim p\,\theta \sim \frac{h}{\lambda}\theta$$

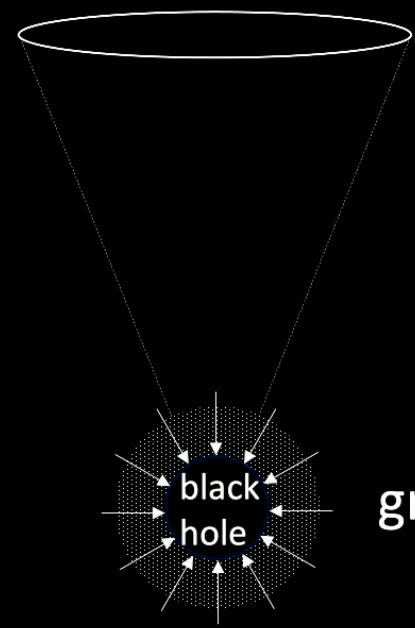
$$\theta \sim \frac{\lambda}{\Delta x}$$

$$\Longrightarrow \Delta x\, \Delta p_x \sim h$$

Heisenberg's
uncertainty relation


the smallest visible length

the Planck length
$10^{-33} cm$

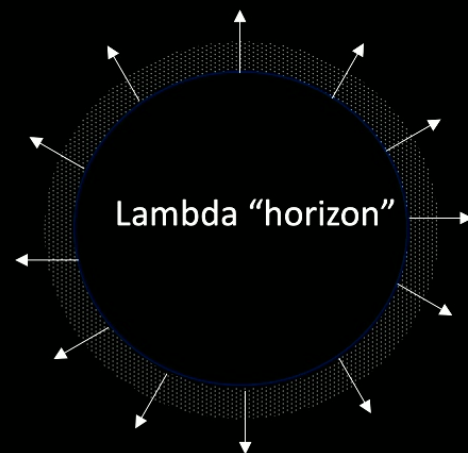


gravity

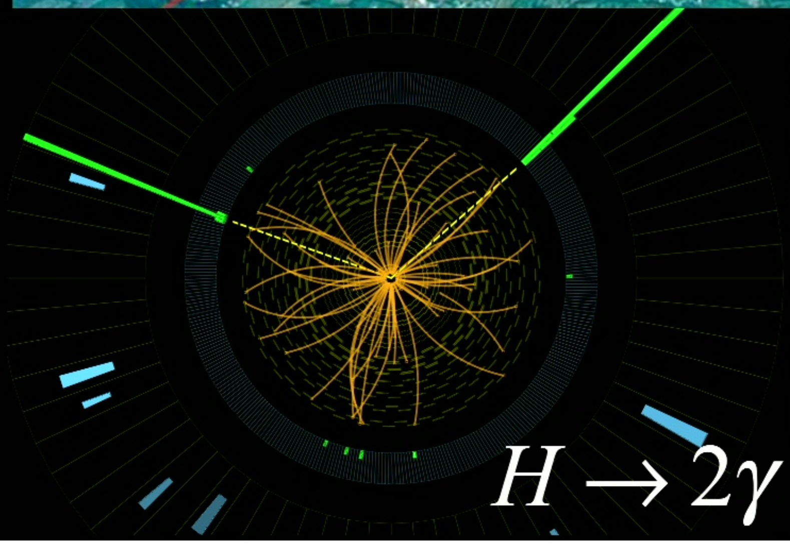
the largest visible length:

$10^{+32} cm$

(due to Λ's repulsive gravity)

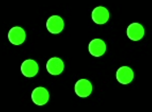


Large Hadron Collider



$H \to 2\gamma$

all known physics

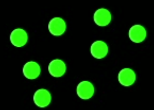


$$\Psi = \int e^{\frac{i}{\hbar}\int\left(\frac{R}{16\pi G} - \frac{1}{4}F^2 + \overline{\psi} i \not{D}\psi - \lambda H\overline{\psi}\psi + |DH|^2 - V(H) \right)}$$

maybe that's all there is...

all known physics



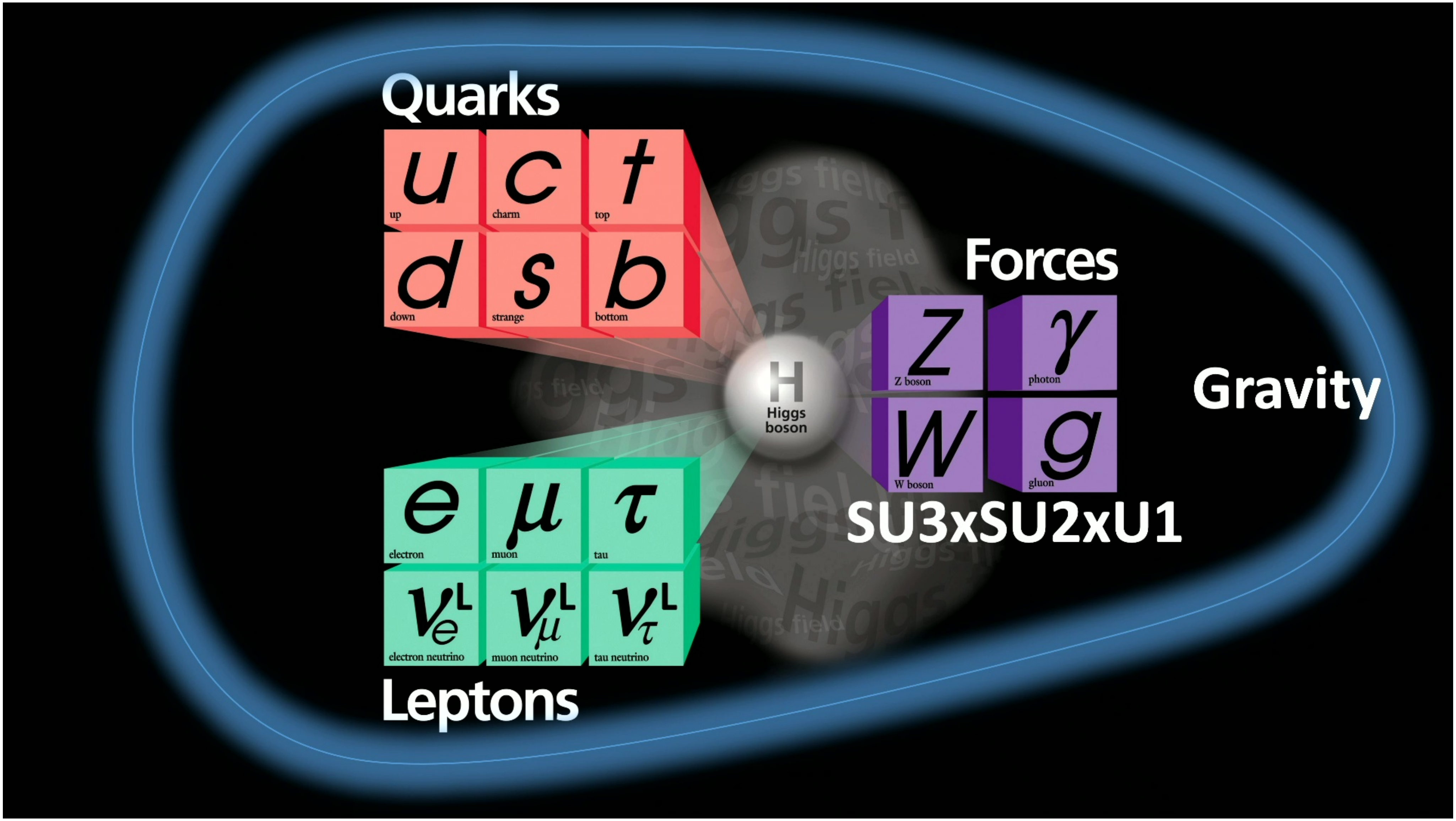


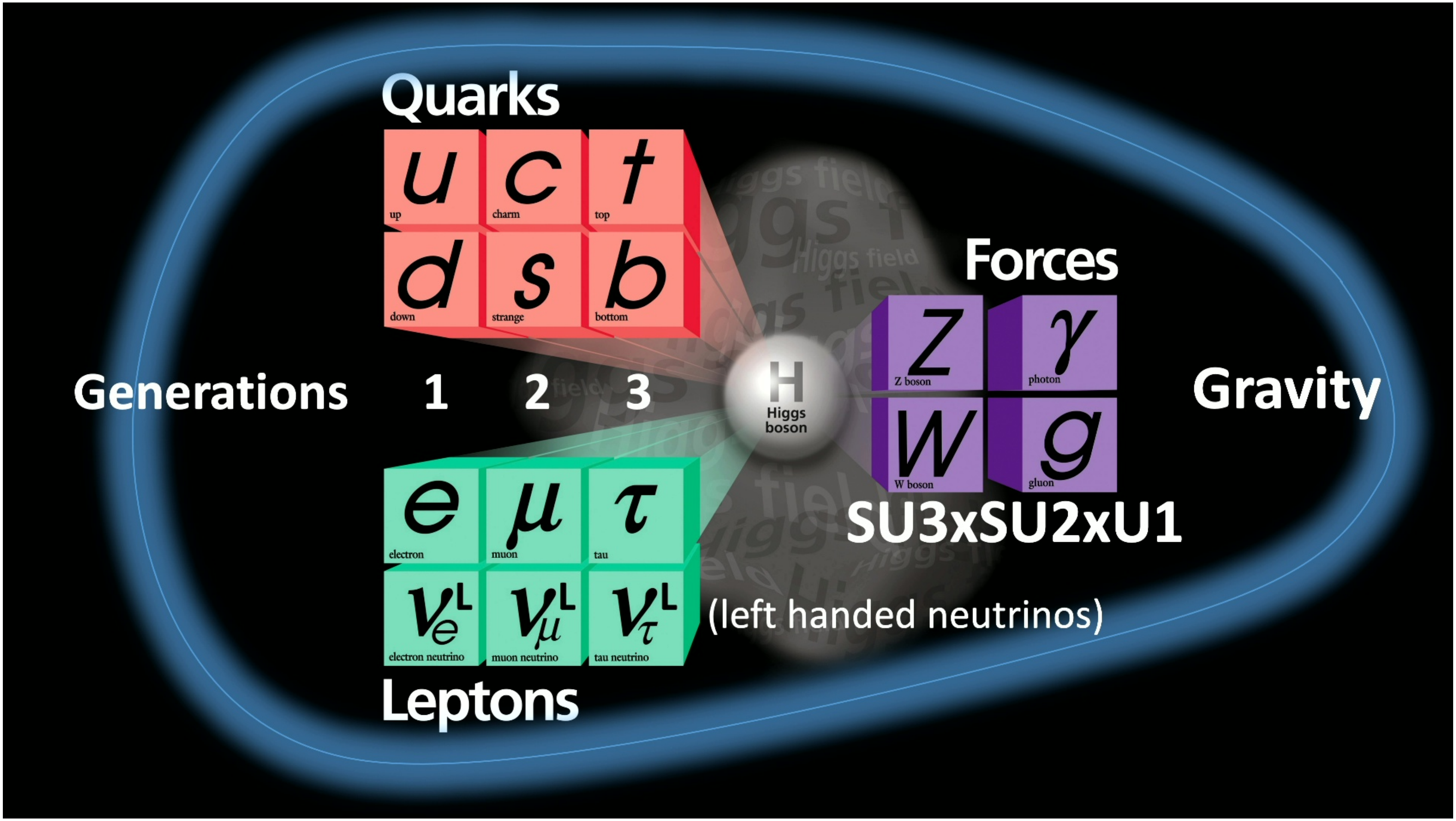

gravity — forces — particles — Higgs

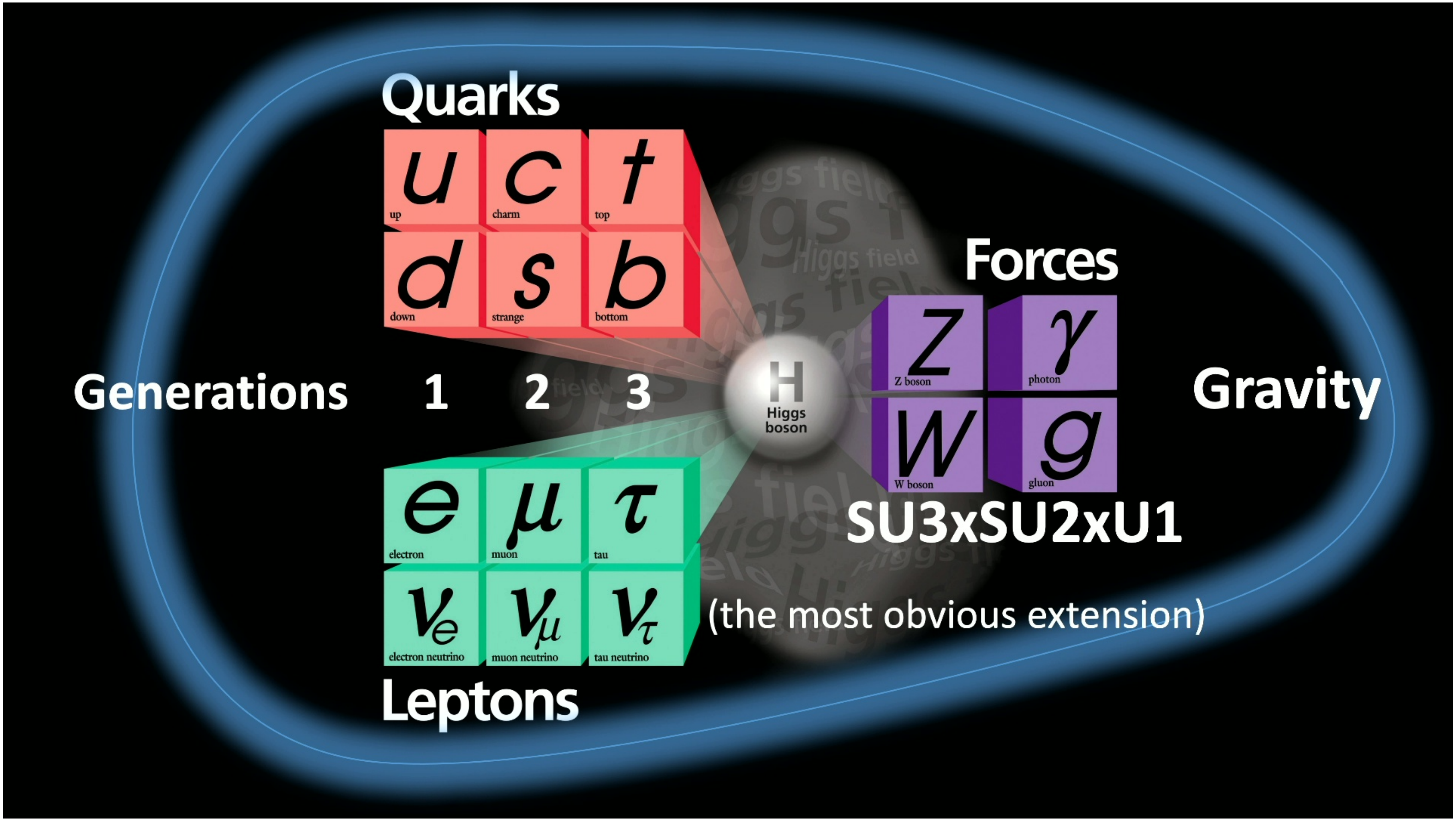
$$\Psi = \int e^{\frac{i}{\hbar}\int \left(\frac{R}{16\pi G} - \frac{1}{4}F^2 + \overline{\psi} i \not{D}\psi - \lambda H \overline{\psi}\psi + |DH|^2 - V(H) \right)}$$

connections

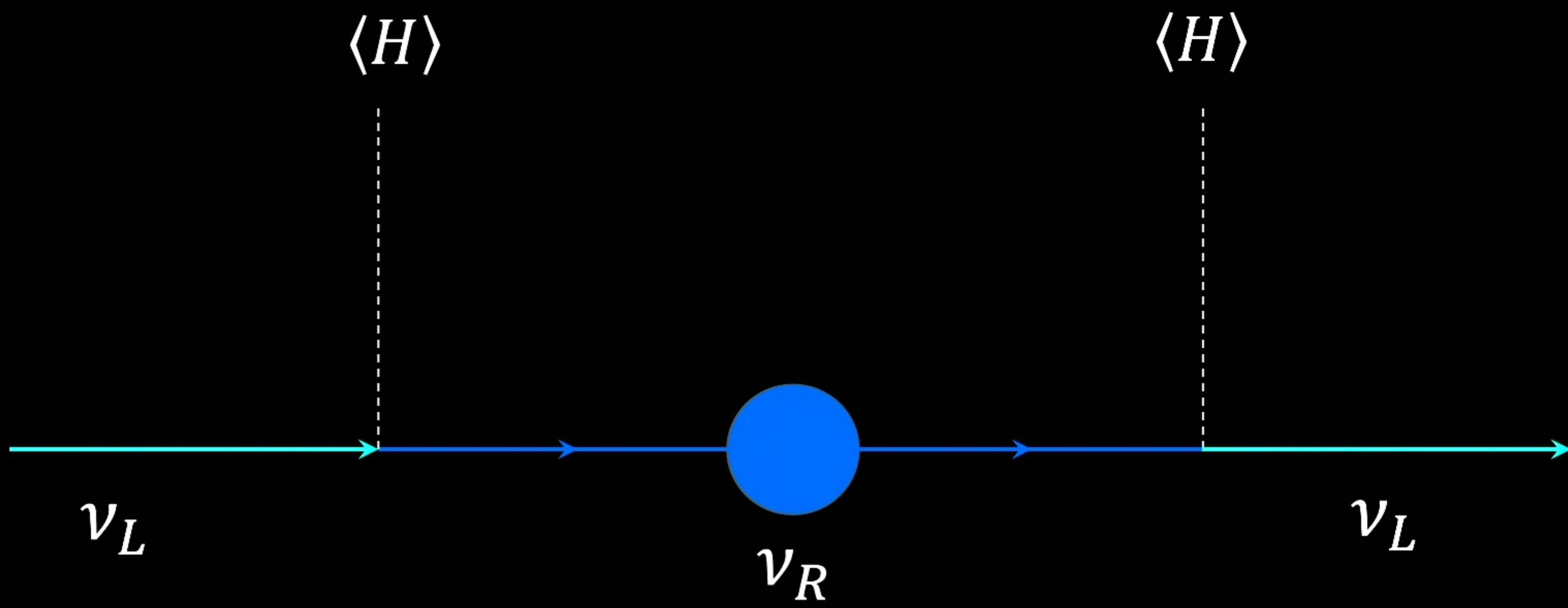
maybe that's all there is...


Quarks
u
up
c
charm
t
top
d
down
s
strange
b
bottom
Higgs field
H
Higgs boson
Forces
Z
Z boson
γ
photon
W
W boson
g
gluon
Gravity
SU3xSU2xU1
e
electron
μ
muon
τ
tau
electron neutrino
muon neutrino
tau neutrino
Leptons


Quarks
u
up
c
charm
t
top
d
down
s
strange
b
bottom
Forces
Z
Z boson
γ
photon
W
W boson
g
gluon
Generations
1
2
3
H
Higgs
boson
Higgs field
Gravity
SU3xSU2xU1
e
electron
μ
muon
τ
tau
ν_e^L
electron neutrino
ν_μ^L
muon neutrino
ν_τ^L
tau neutrino
(left handed neutrinos)
Leptons

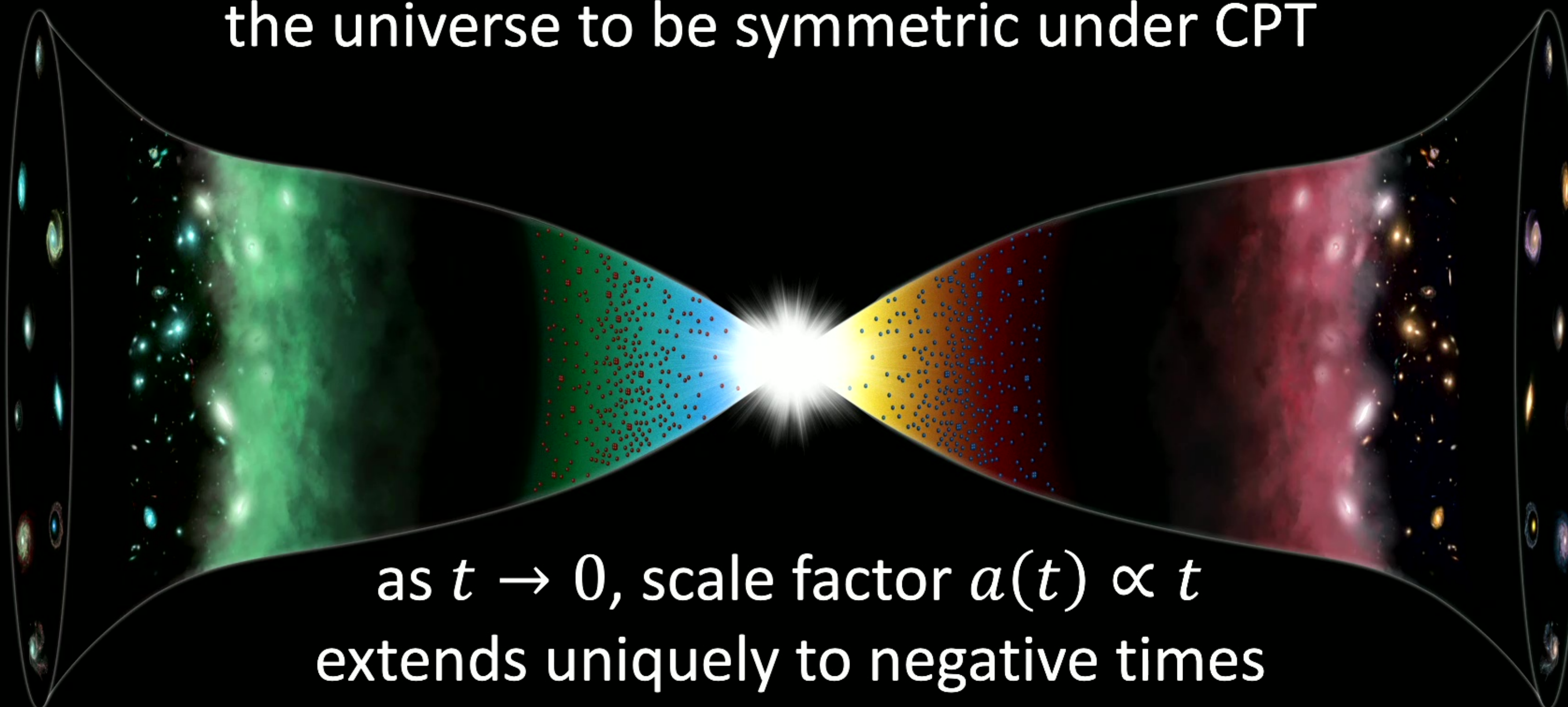

Quarks
u
up
c
charm
t
top
d
down
s
strange
b
bottom
Generations
1
2
3
H
Higgs
boson
Forces
Z
Z boson
γ
photon
W
W boson
g
gluon
Gravity
e
electron
μ
muon
τ
tau
SU3xSU2xU1
νe
electron neutrino
νμ
muon neutrino
ντ
tau neutrino
(the most obvious extension)
Leptons

heavy right-handed neutrinos:

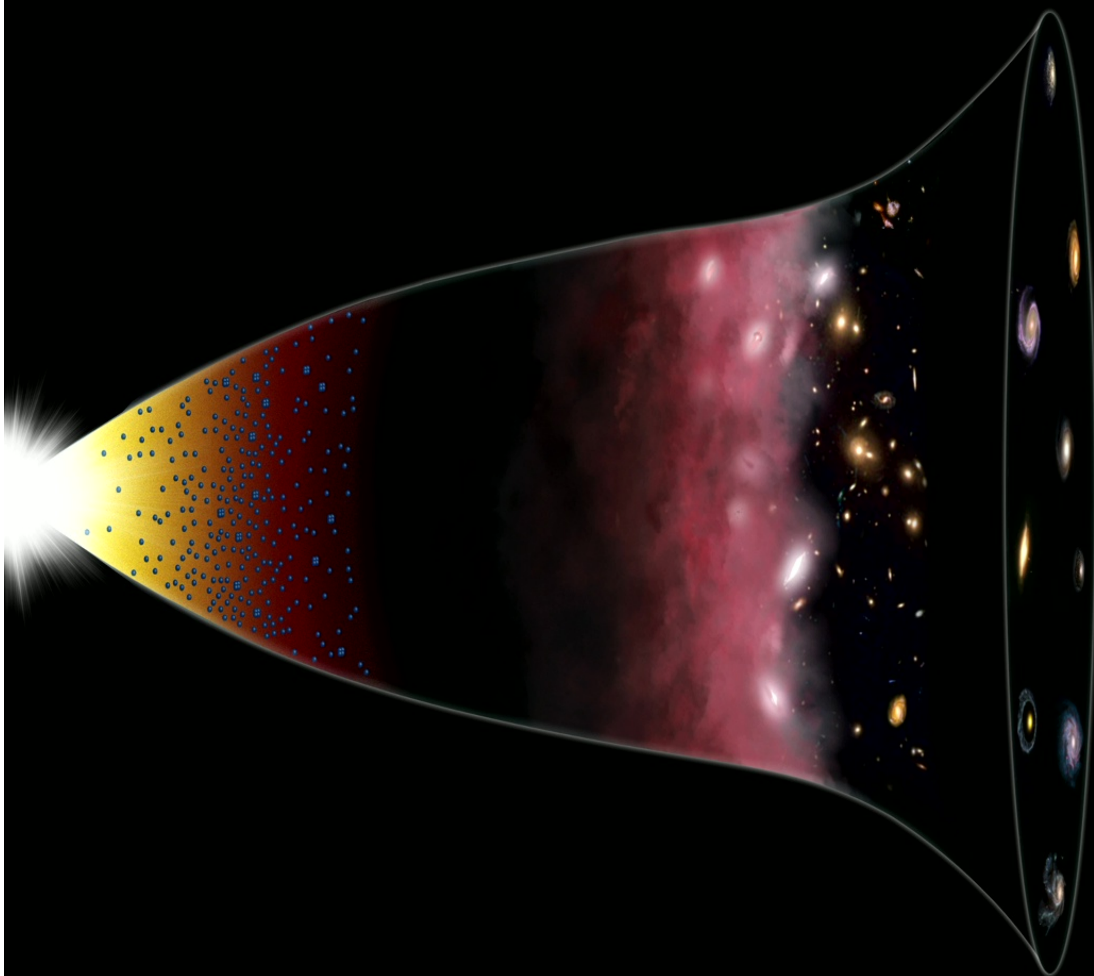


explain the observed light neutrino masses (70's)
via "seesaw" mechanism
they might also comprise the dark matter

We found we could explain their abundance if we assumed the universe to be symmetric under CPT



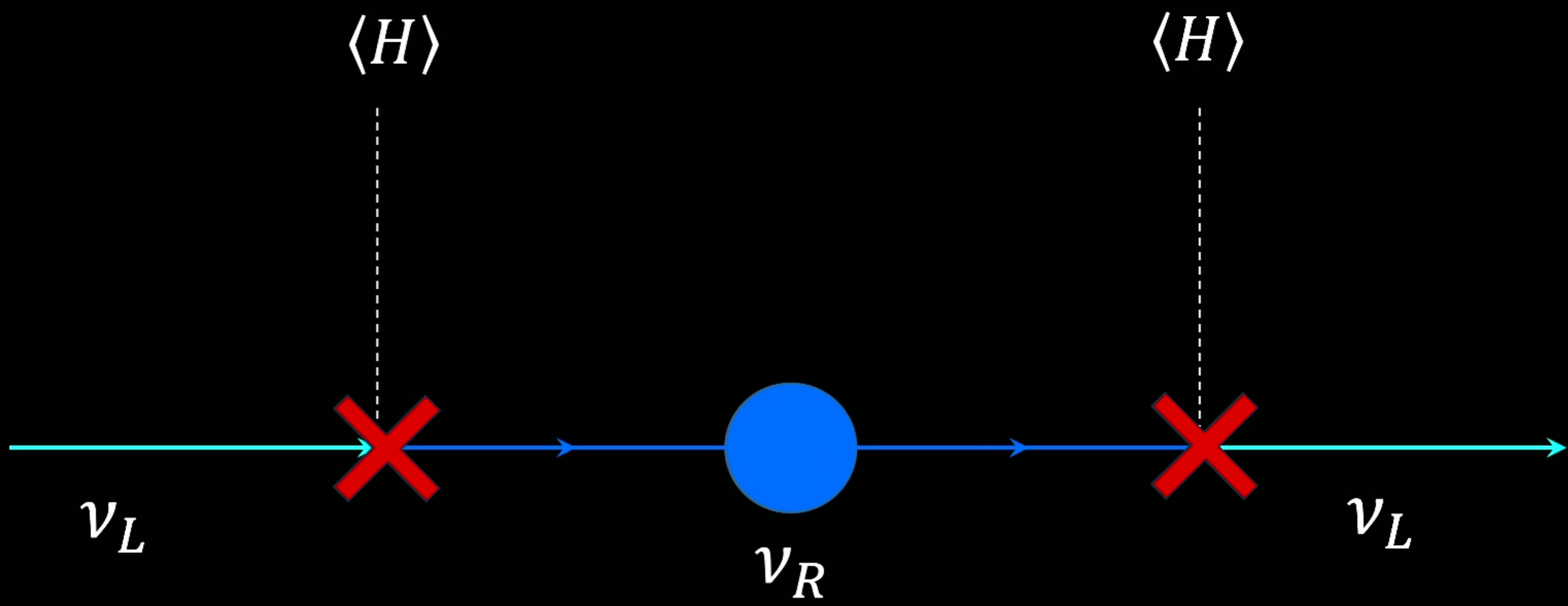
as $t \to 0$, scale factor $a(t) \propto t$ extends uniquely to negative times



the big bang is a CPT mirror

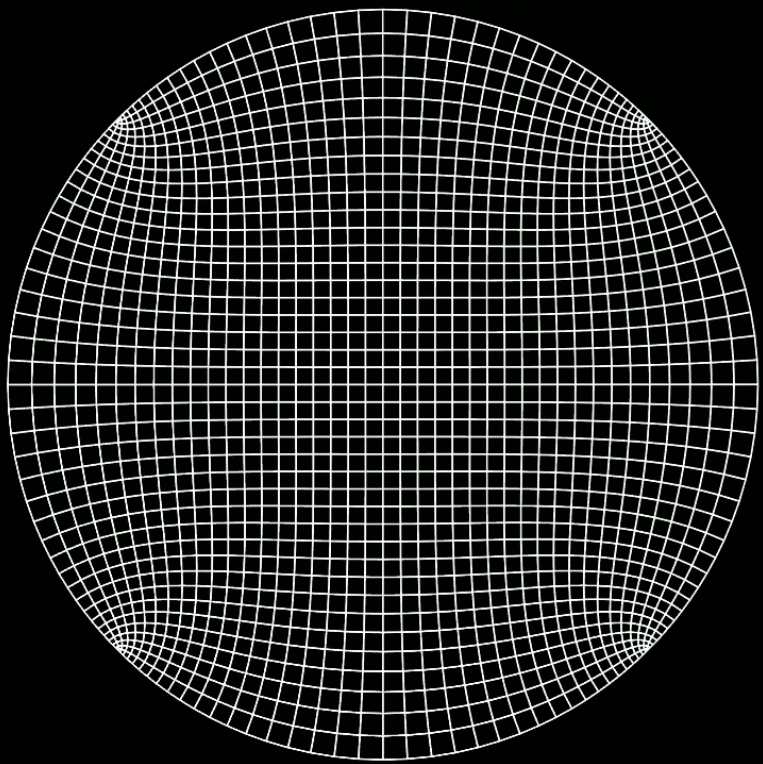
Latham Boyle+NT

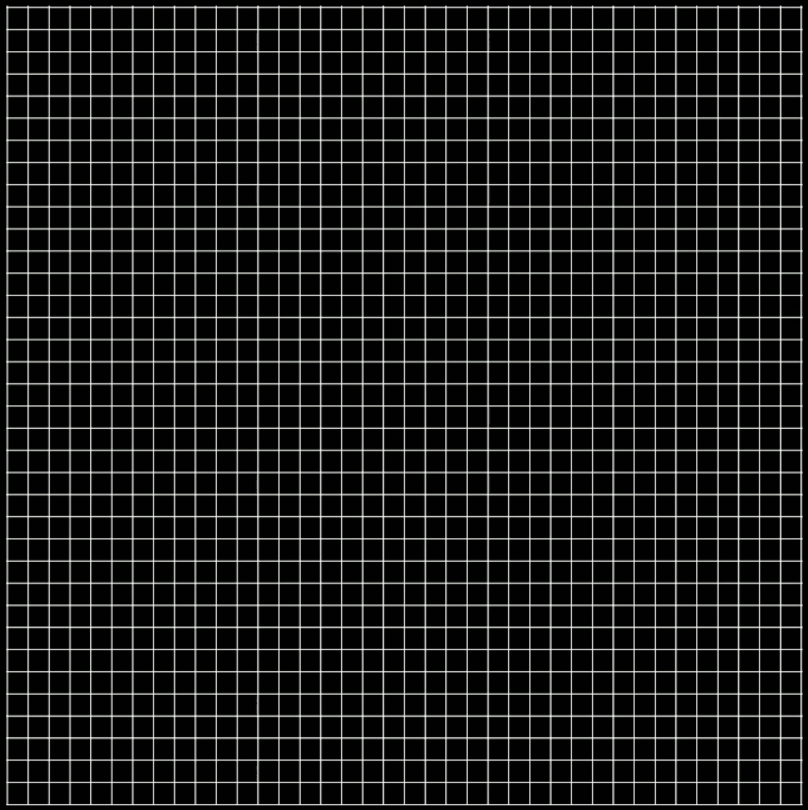
Stability of one RH neutrino $\Rightarrow$ lightest neutrino is massless



this is now being tested using EUCLID and LSST surveys

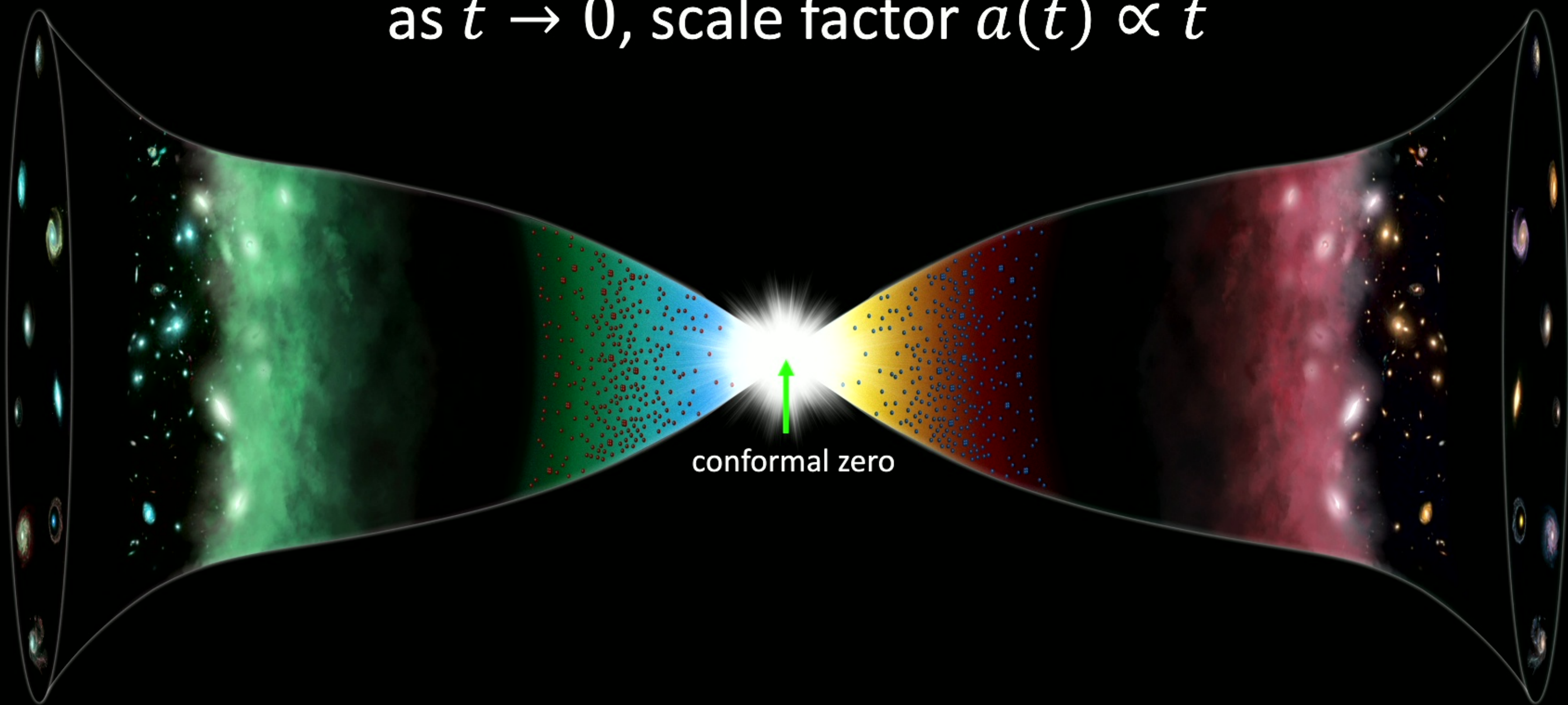
Consistent with Penrose's hypothesis: the initial singularity was "conformal"



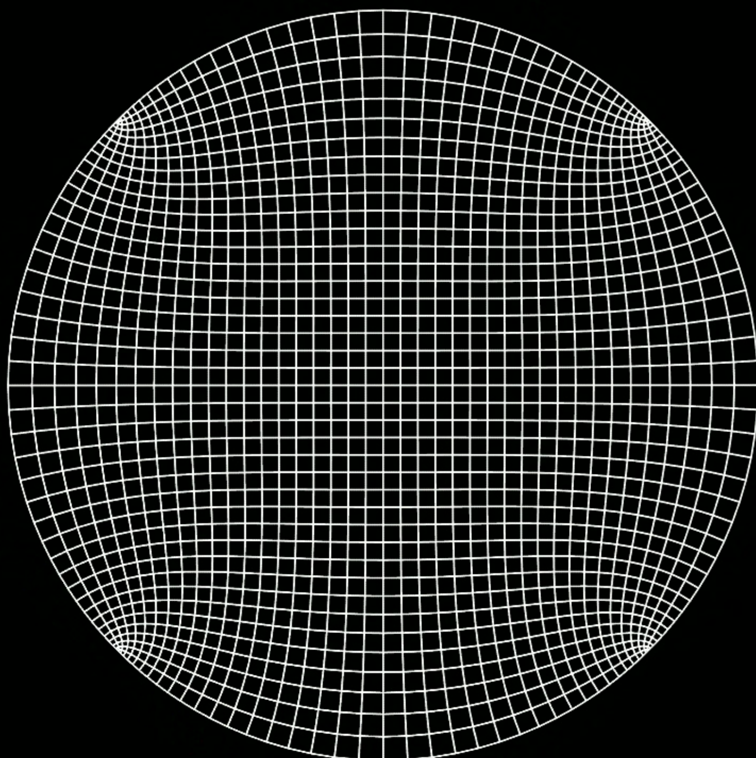


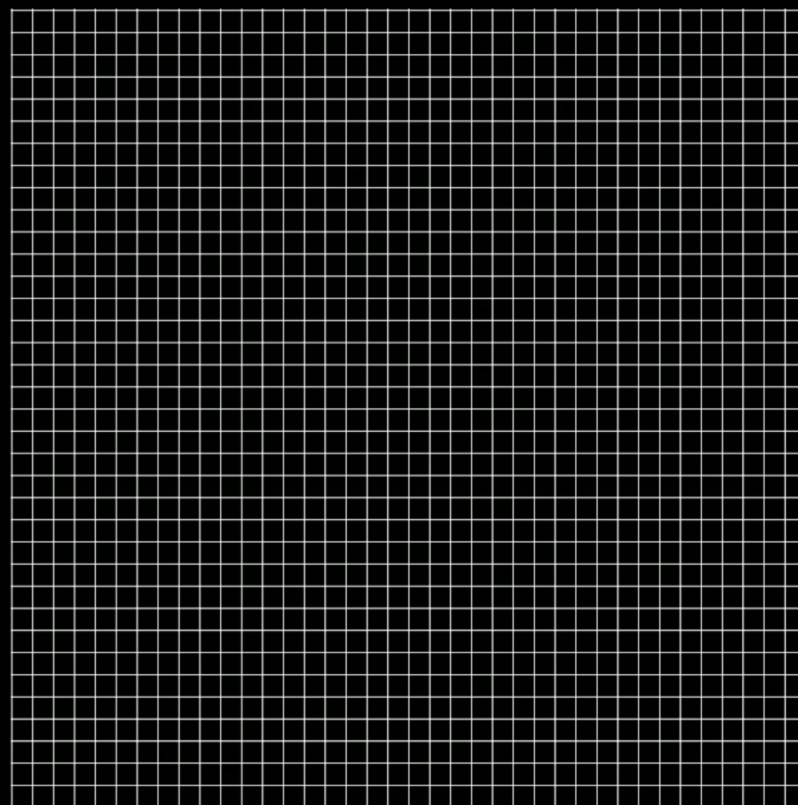
the big bang was a special type of singularity:

as $t \to 0$, scale factor $a(t) \propto t$



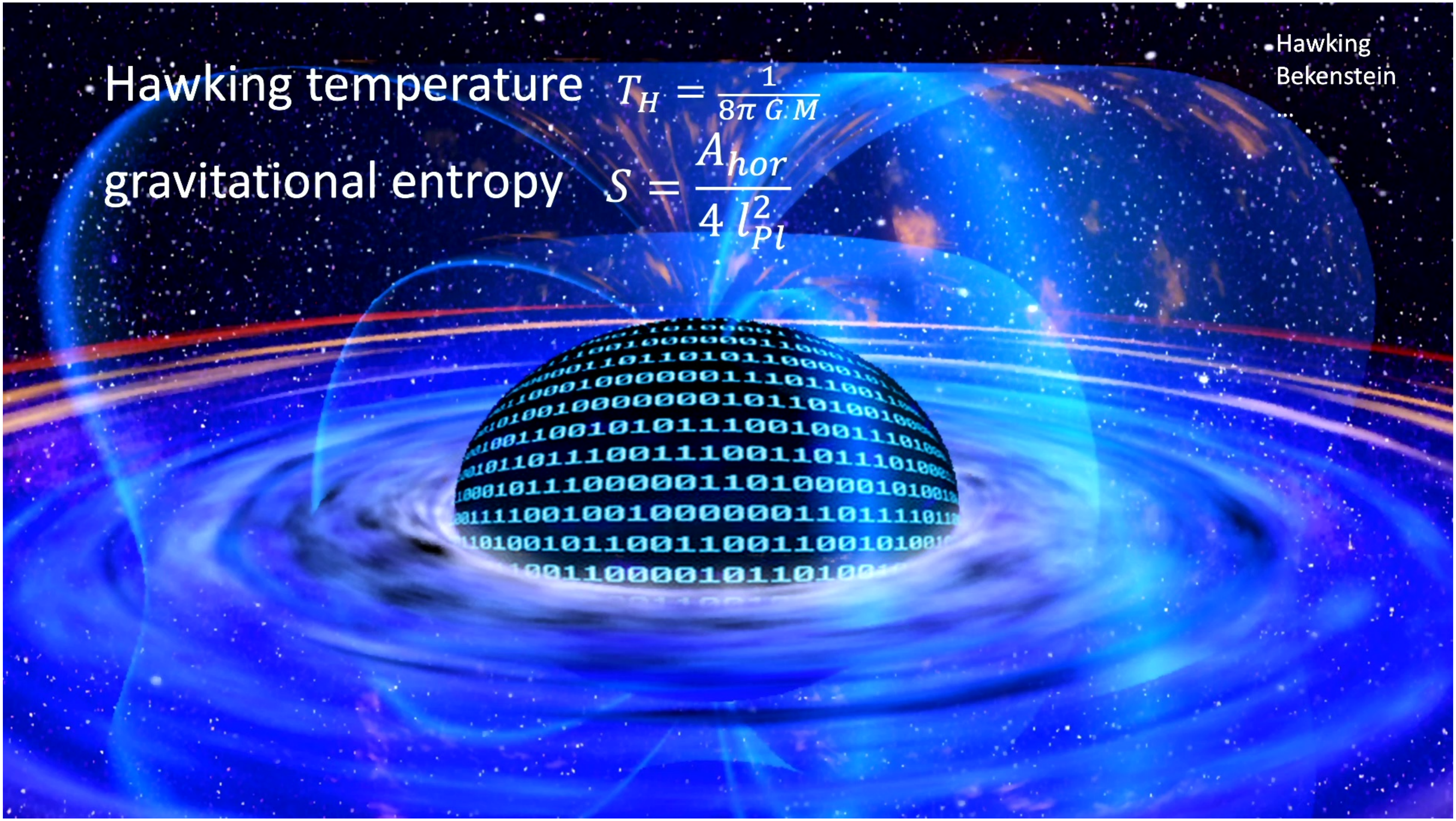
Consistent with Penrose's hypothesis: the initial singularity was "conformal"





the puzzling large-scale geometry of the cosmos

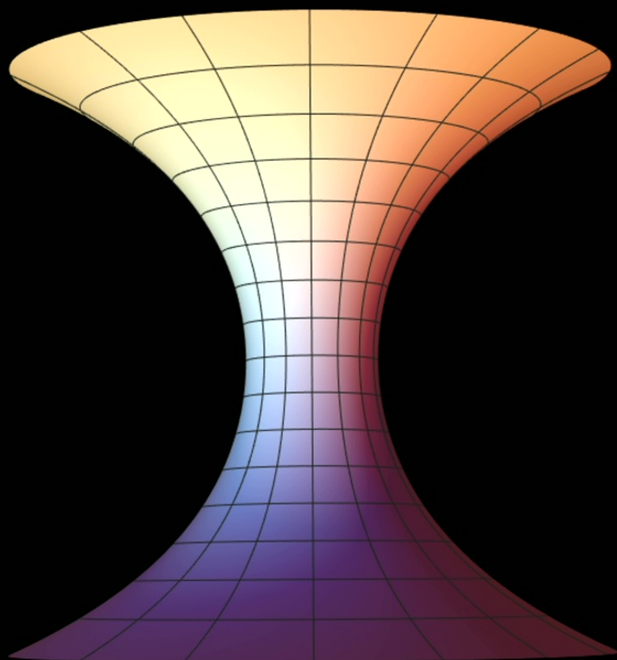
Penrose


Hawking temperature $T_H = \frac{1}{8\pi\, G\, M}$
gravitational entropy $S = \frac{A_{hor}}{4\, l_{Pl}^2}$
Hawking
Bekenstein
...

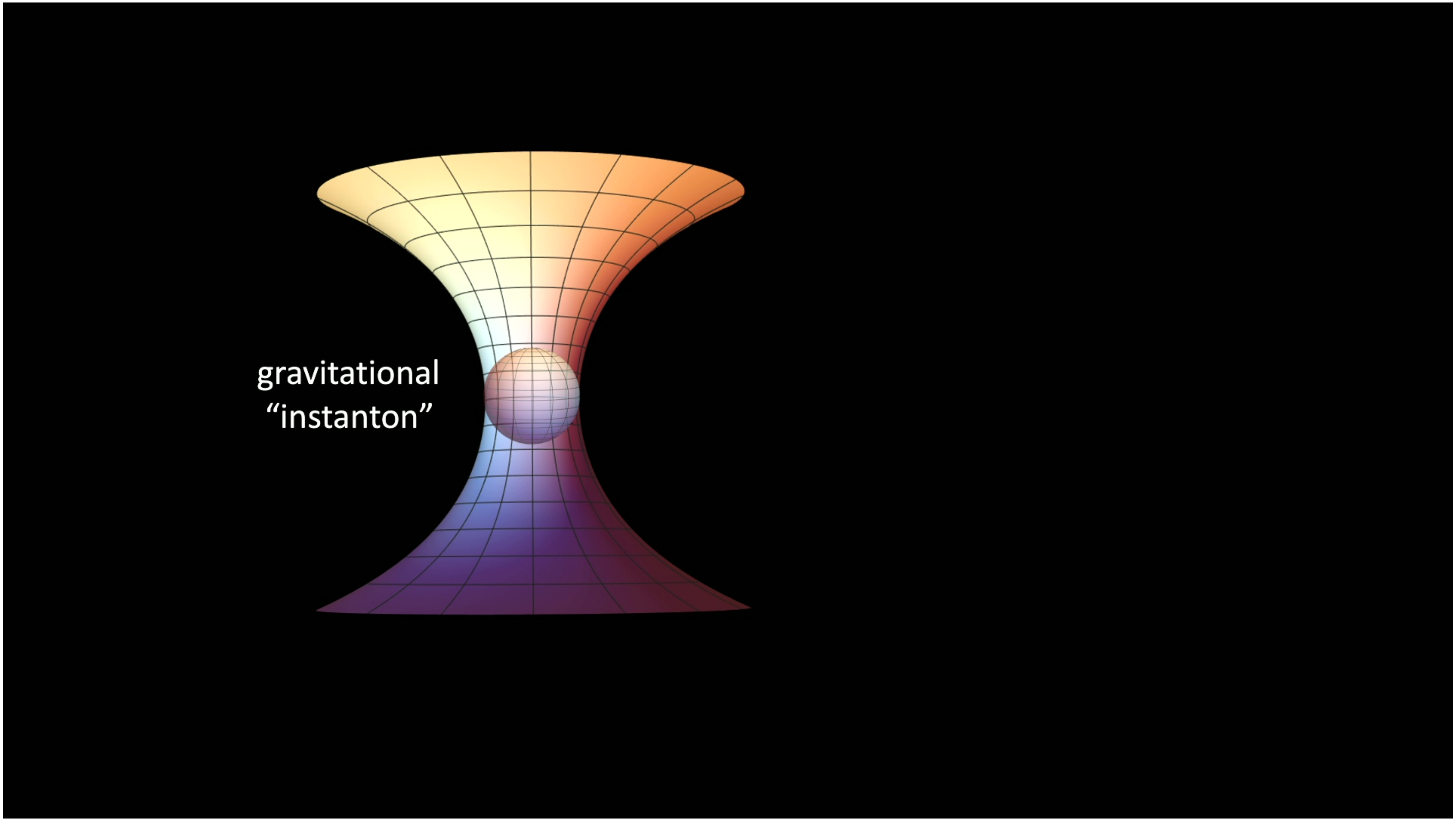

PI

Hawking et al. used a profound mathematical trick (imaginary time) to calculate the Hawking temperature T_H and gravitational entropy S_g of a black hole

We recently used the same method to calculate T_H and S_g for cosmology

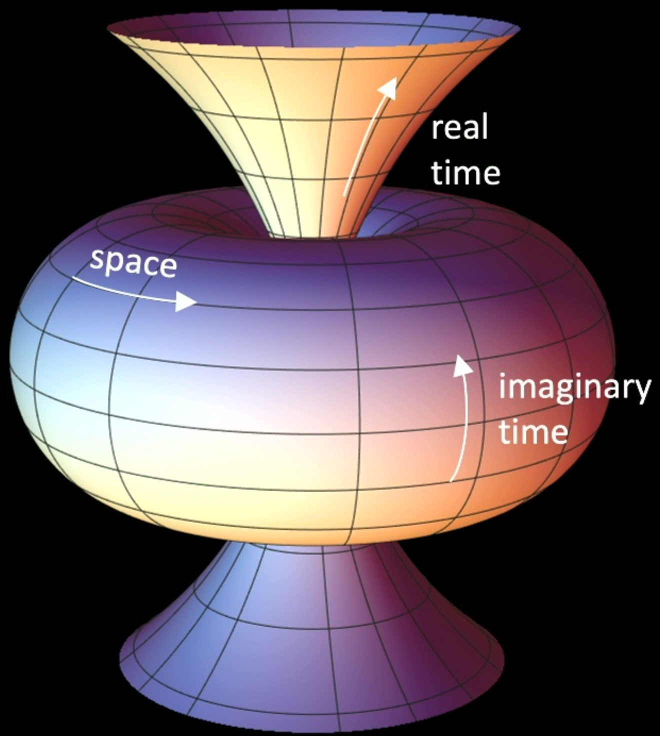


A cosmos with only Lambda
("de Sitter" spacetime)


gravitational
“instanton”

We recently solved Einstein's equations for a general cosmology - with radiation, matter, space curvature and Λ - analytically

gravitational "instanton"



Boyle +NT

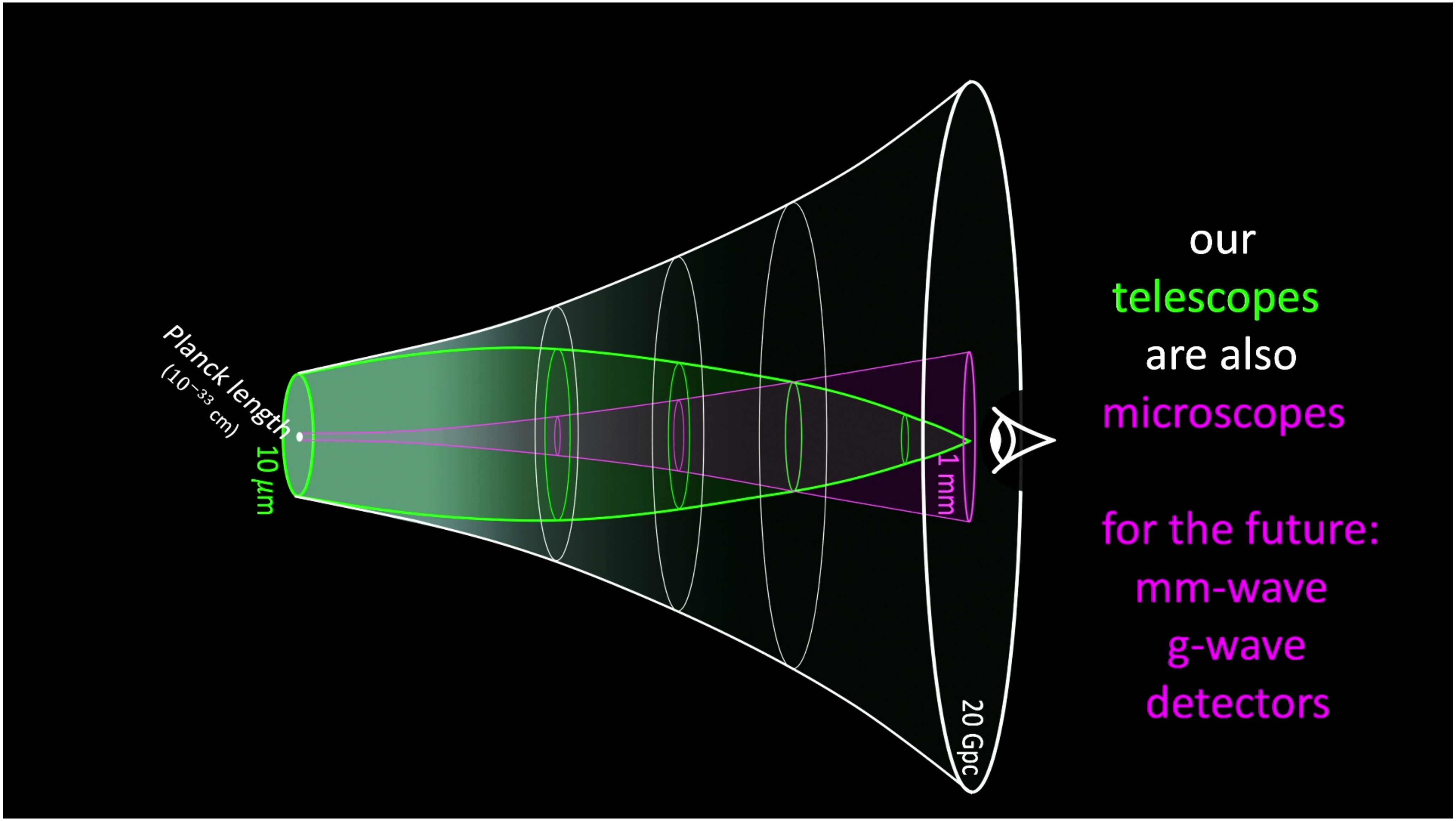
It turns out that the gravitational entropy S_g favours:

1. a spatially flat, homogeneous, isotropic universe
2. a small, positive cosmological constant

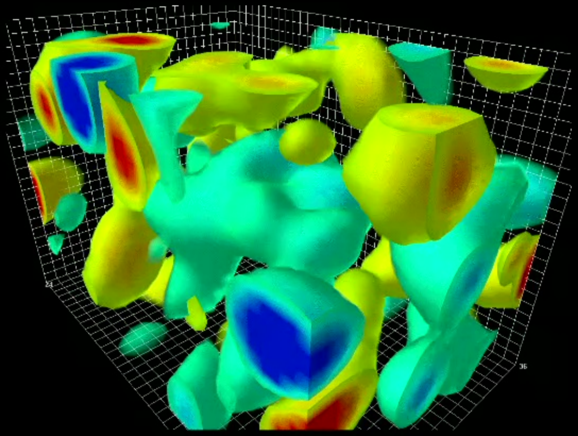
just as observed

This is a thermodynamic explanation of the large-scale geometry of the universe.

No additional smoothing or flattening mechanism is required.


Planck length
(10^{-33} cm)
10 μm
1 mm
20 Gpc
our
telescopes
are also
microscopes
for the future:
mm-wave
g-wave
detectors

Quantum fields and gravity



Vacuum "zero-point" fluctuations have infinite energy

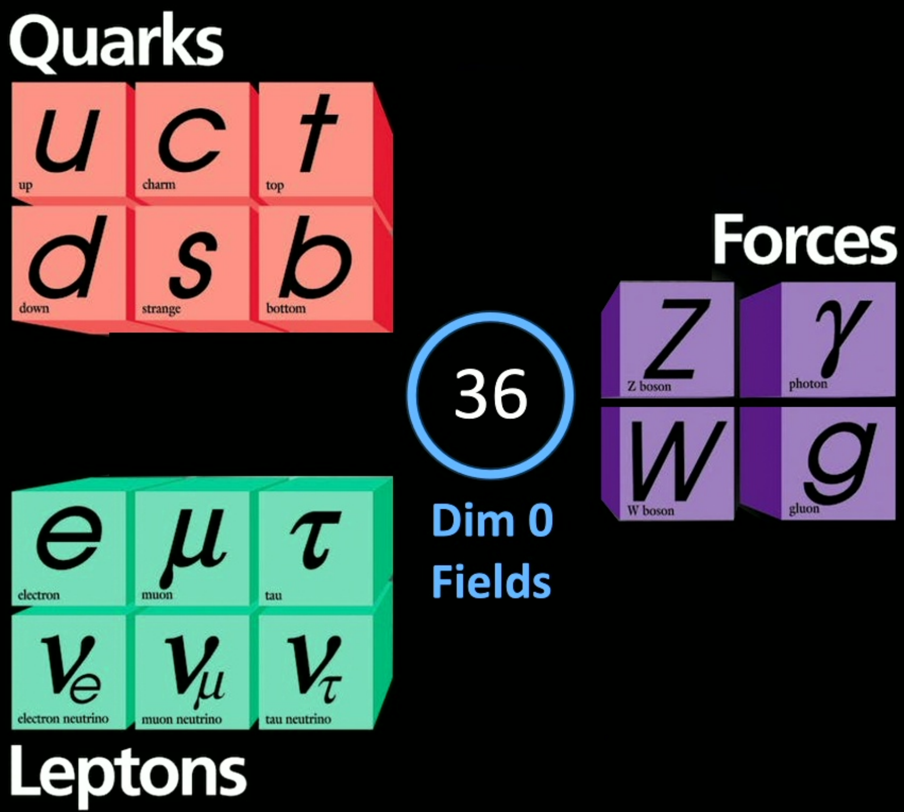
They also spoil the conformal symmetry of Maxwell and Dirac fields

A clue from cosmology: what kind of field has nearly scale-invariant fluctuations?

A "dimension zero" (Dim 0) field: has vacuum energy but no particles

the simplest "gauge theory" (Bogoliubov, 1987)

Including Dim 0 fields drastically improves the SM's coupling to gravity



Cancels the zero point vacuum energy and restores conformal symmetry

Only works for 3 generations of fermions, each with a RH neutrino

Prediction for primordial density waves

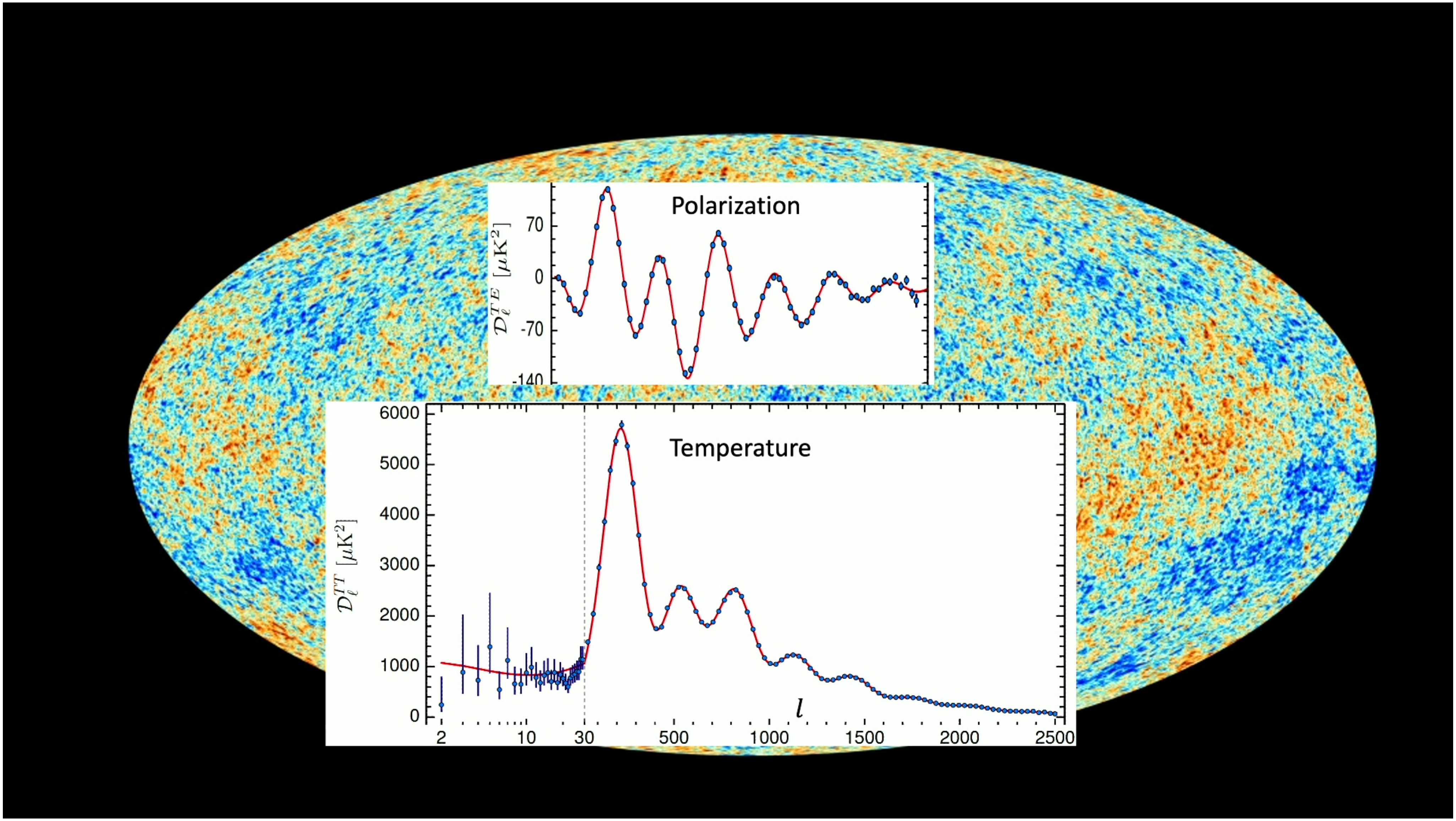
NT+Boyle

$$\mathcal{P}_{\mathcal{R}}(\lambda) = \frac{3^2 5^2}{7(2\,\pi)^4}\left(\frac{c_\beta^{SM}}{\mathcal{N}_{eff}}\right)^2 \left(\frac{\lambda}{l_P}\right)^{\frac{7\alpha_3}{\pi}}$$; l_P= comoving Planck length: 1mm

with $c_\beta^{SM} \equiv \frac{125}{108}\alpha_Y^2 - \frac{95}{72}\alpha_2^2 - \frac{49}{6}\alpha_3^2$ and $\mathcal{N}_{eff} = 106\frac{1}{4}$

Matches the amplitude of primordial waves to within a factor of two!
Explains a "red tilt" of 0.042 (using measurements of α_3 at CERN)
cf. 0.041 ± 0.006 measured by Planck satellite

More detailed theoretical calculations and observations are in progress: if the agreement holds up, the theory will become compelling


Polarization
70
0
-70
-140
$\mathcal{D}_\ell^{TE}$ [μK^2]
Temperature
6000
5000
4000
3000
2000
1000
0
$\mathcal{D}_\ell^{TT}$ [μK^2]
2
10
30
500
1000
1500
2000
2500
l

Thank you for listening!

Boyle, Finn, NT Phys. Rev. Lett. 121 (2018) 251301; Annals of Physics 438 (2022) 168767
arXiv: 2109.06204, 2110.06258, 2201.07279, 2208.10396, 2210.01142, 2302.00344