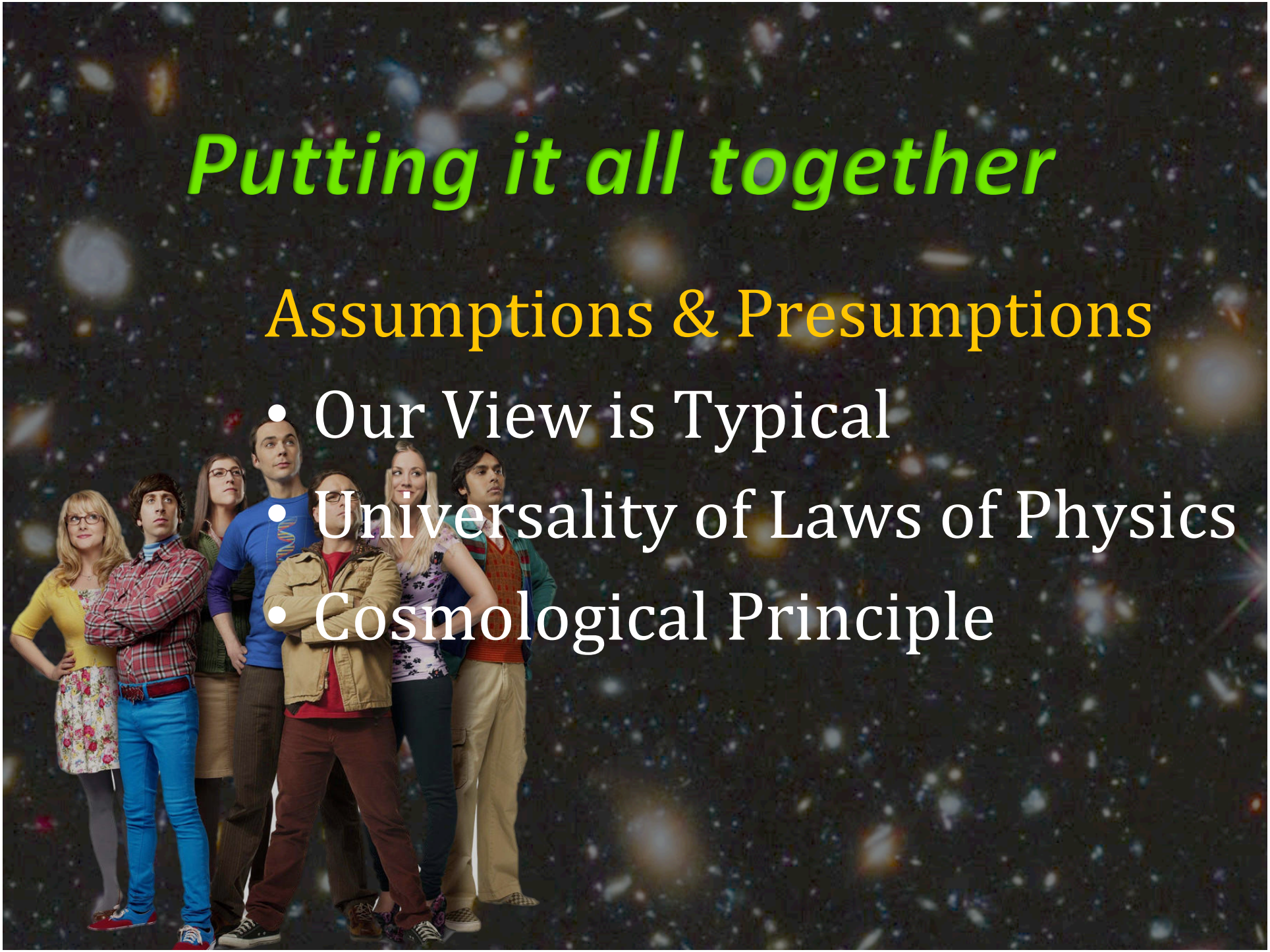
First term paper

- "Vulnerabilities in the BB Model"
- Identify any 3 aspects of the BB Model that you find most vulnerable. Then, for each of them, explain you find them disturbing using scientific standards of good knowledge*.
- 3 – 5 pages. Due Monday
- 15% of course grade

* REQUIRED! Use accepted standards of valid scientific and legal knowledge (presented earlier in the course) in your arguments for vulnerability

Putting it all together



Assumptions & Presumptions

- Our View is Typical
- Universality of Laws of Physics
- Cosmological Principle

Implications of Two Fundamental Observations:

1. The Universe is Not Empty

- Infinite Radius
- Finite Age
- Expanding

Implications of Two Fundamental Observations:

2. The Night Sky is Dark

- Finite Radius
- Finite Age
- Expanding
- (Or any combination)

Essential 20th-century Observations:

1. Expansion
2. Universal He/H ratio ≈ 10%
3. CMB (and its ripples)
4. The uniform large-scale structure of the visible universe
5. Invisible Mass ("dark matter")
6. Acceleration ("dark energy")

Significant 20th-century Findings:

1. Space Expands Uniformly out to about a look-back time of 5 billion years
2. Equivalence of Mass-Energy and the Curvature of Space (Gravity)
3. GR: Open, Closed, or Flat Geometry
4. Hot, dense origin (⇒ the "Big Bang")
5. The early Universe was textured (⇒ galaxy precipitation)
6. $\rho = \rho_c$ (⇒ Flatness)
7. Uniformity of Structure (⇒ Inflation)
8. Acceleration (⇒ Dark Energy rules!)

Fine-Tuning of the Big Bang Model
"Why is the Universe Habitable?"

1. ρ/ρ_c must be 1.0000000…
   "Flatness Problem" (inflation)
2. Uniformity of the visible universe
   "Horizon Problem" (inflation)
3. Ideal density fluctuations in the early universe
   (quantum fluctuations in the Planck Era)
4. The perfect amount of dark energy ($\Lambda \approx 10^{-122}$)
   (same as flatness problem)
5. The ratio of photons to particles
6. The matter-antimatter imbalance
7. Net cosmic charge = 0
8. The absence of magnetic monopoles & exoctica

The Anthropic Principle
Is our existence just dumb luck?

Weak Anthropic Principle (WAP):

if our universe weren't hospitable to life, then we wouldn't be here to wonder about it. (As such, there's no sense in asking why.)

Strong Anthropic Principle (SAP):

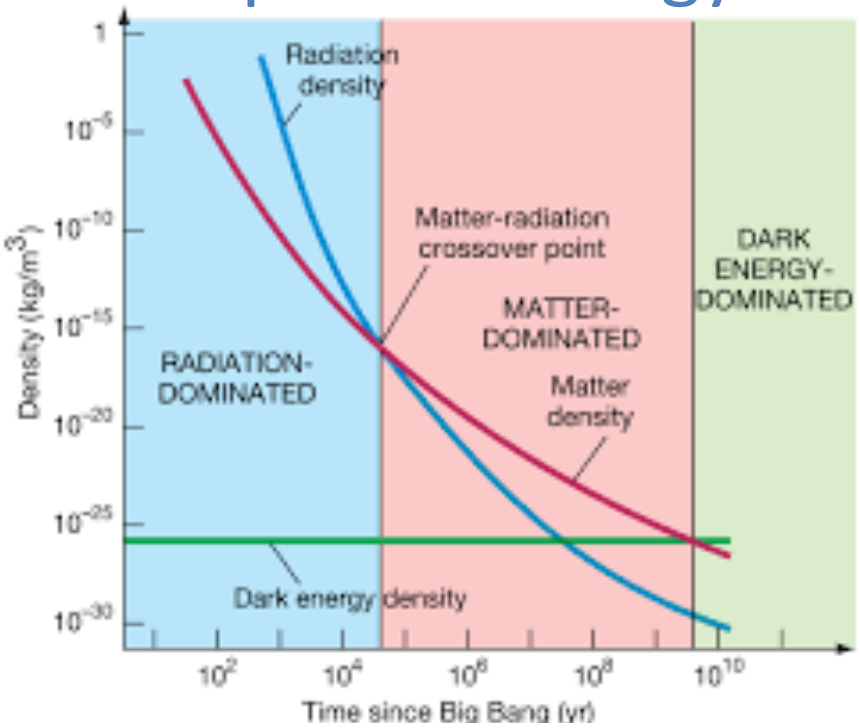
since we live in a universe capable of supporting life, then only life-supporting universes are possible.

Both versions skirt the issue of why (from a physical point of view).

Coincidence? Purpose? Creator? How can we tell?

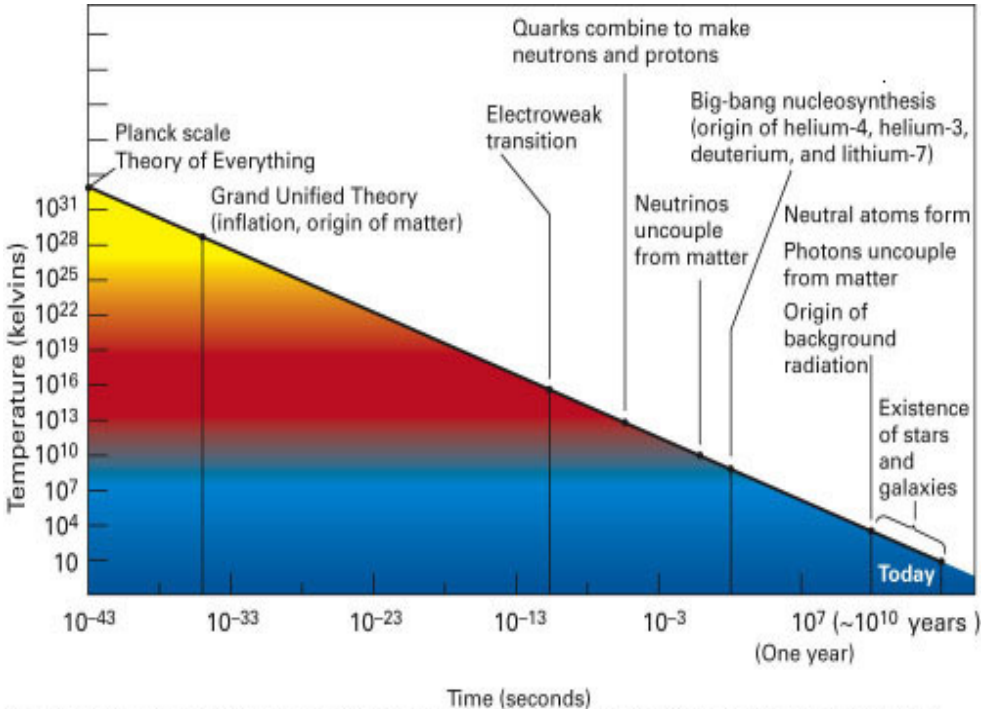
Summary of Cosmic History

Space & Energy



The density of dark matter is fixed. The density of matter and radiation decline as space expands.

Forces & Stuff



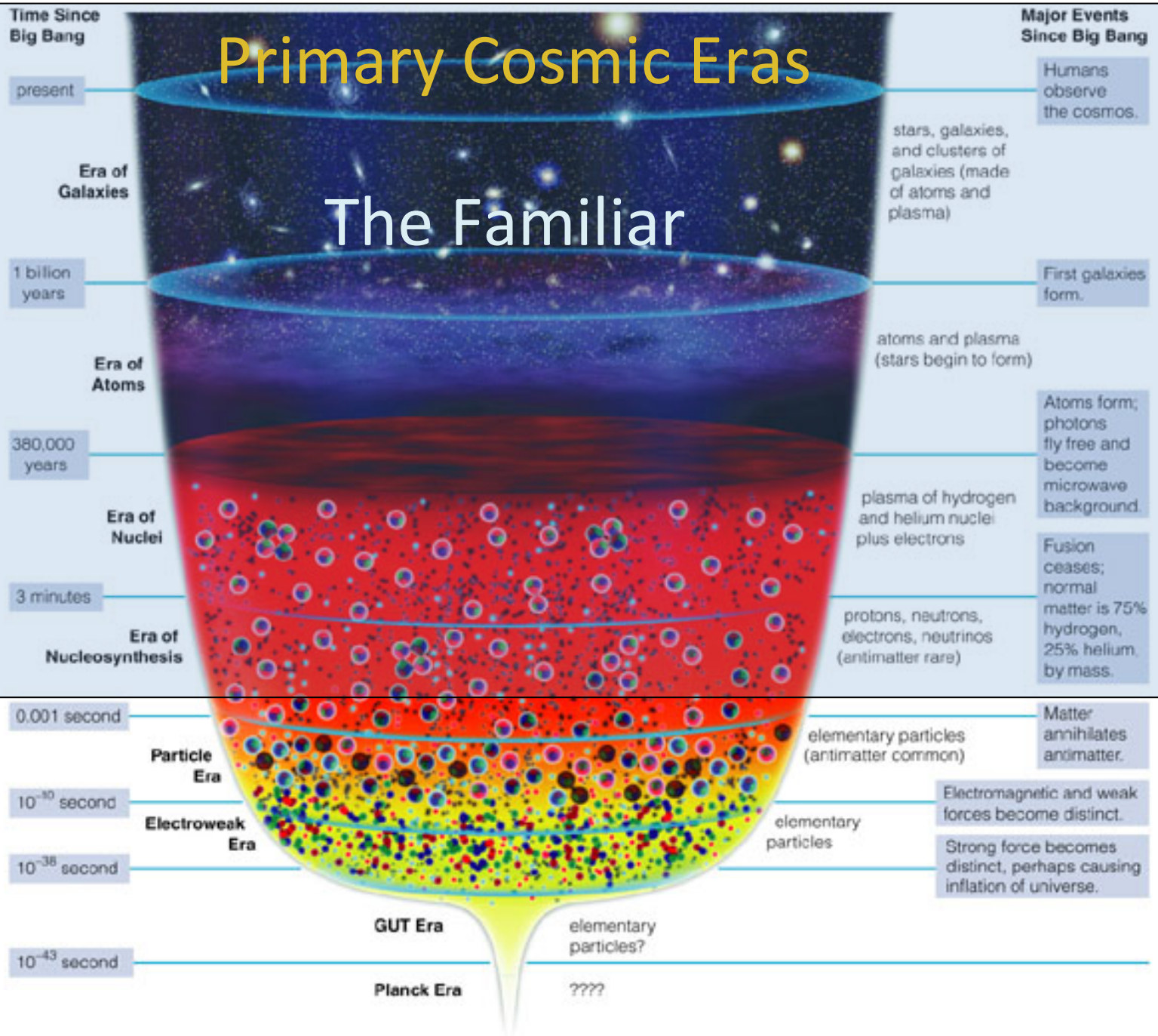
Once forces freeze out, what happens to matter—and when it happens—is governed by temperature. Note: reaction rates usually scale as

density^2 × (function of temp)

Reaching Earliest Cosmic Times

Primary Cosmic Eras

The Familiar



The Unexplored Planck Era:

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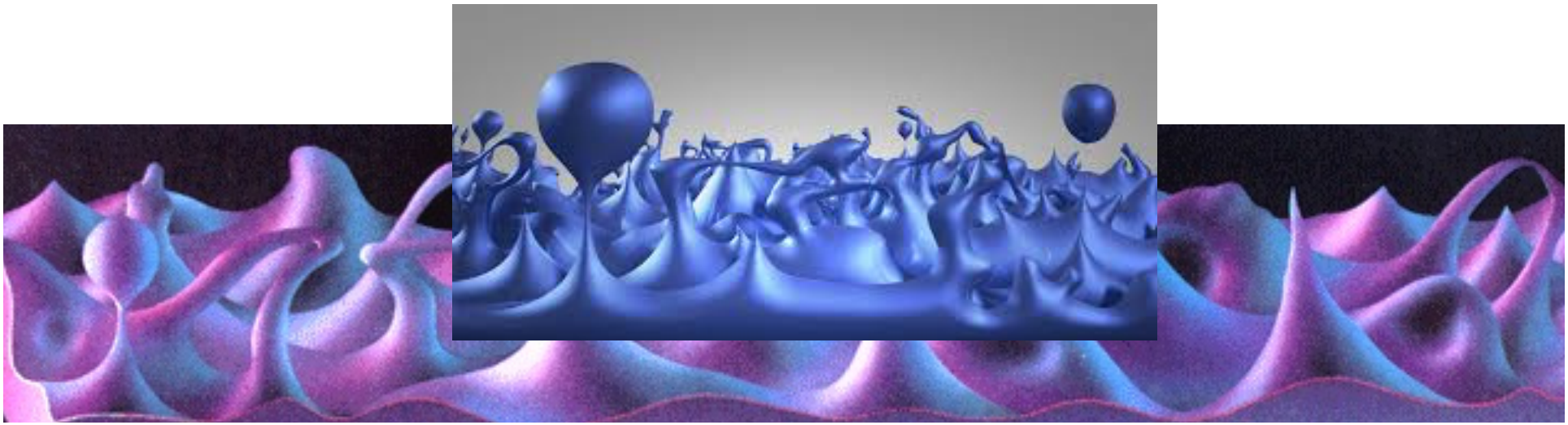
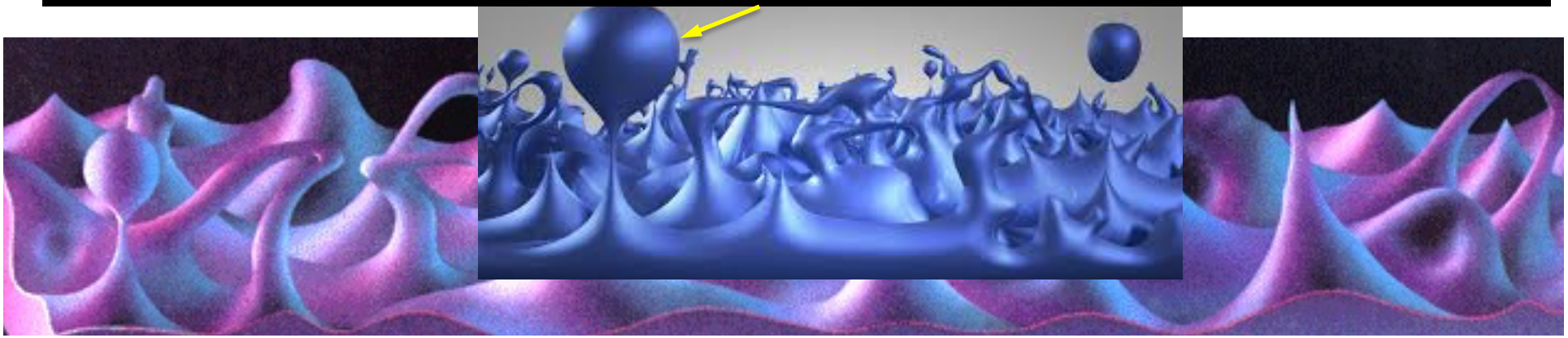
The Quantum "Foam"
Fluctuations Exist/Persist



The Unexplored Planck Era:
$t < 10^{-43}$ s, $T > 10^{+31}$ K

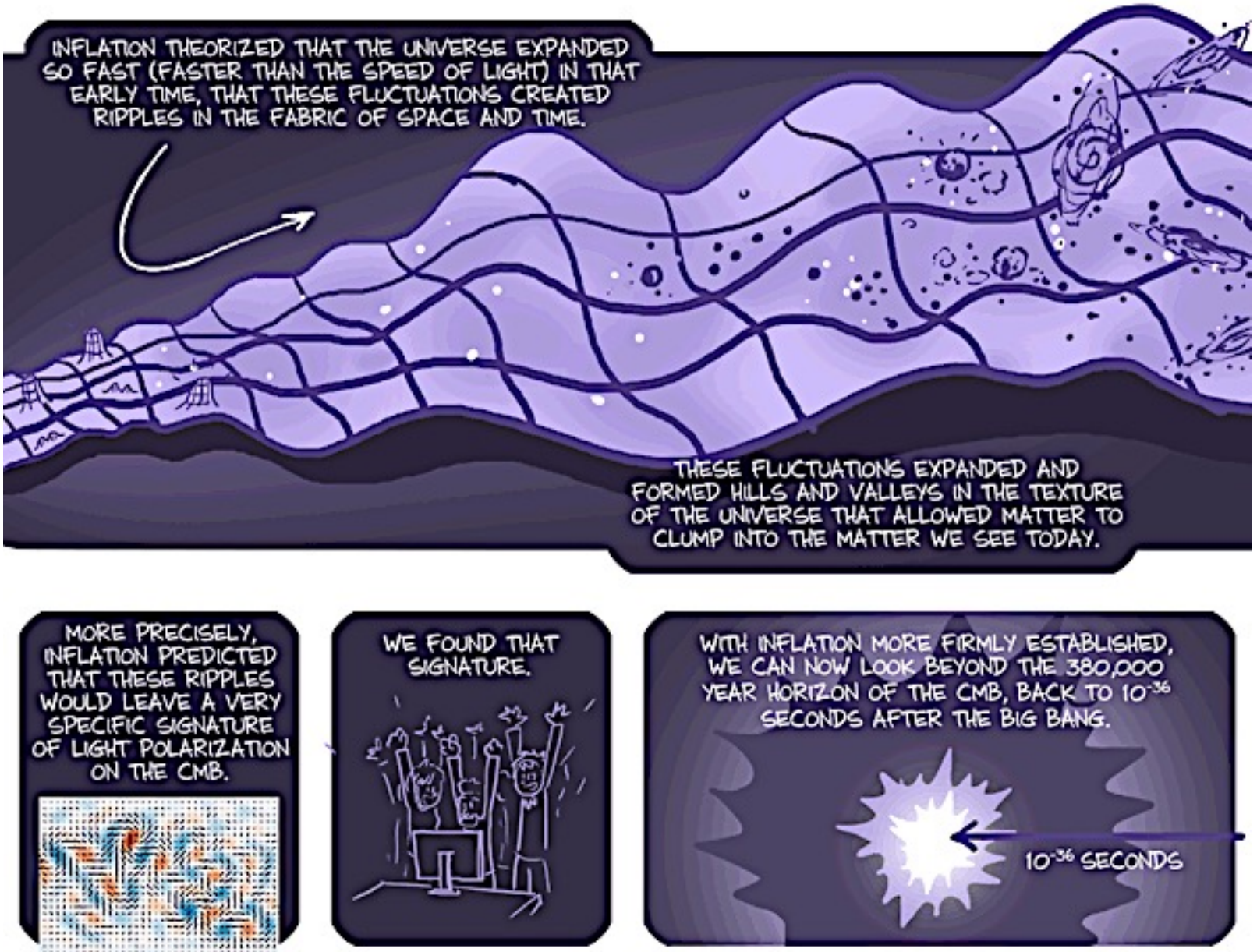
Cosmic Foam. The Principle of Uncertainty suggests that during any 10^{-43} s space time can not be exactly measured or determined since it can exist one moment and not exist the next — all without violation of any laws. Universes come and go continuously. Some randomly "pop loose", expand, and exist for "longer"(whatever "longer" means).

Inside this embryo is the "DNA" with the geometric characteristics and physics of a Universe.

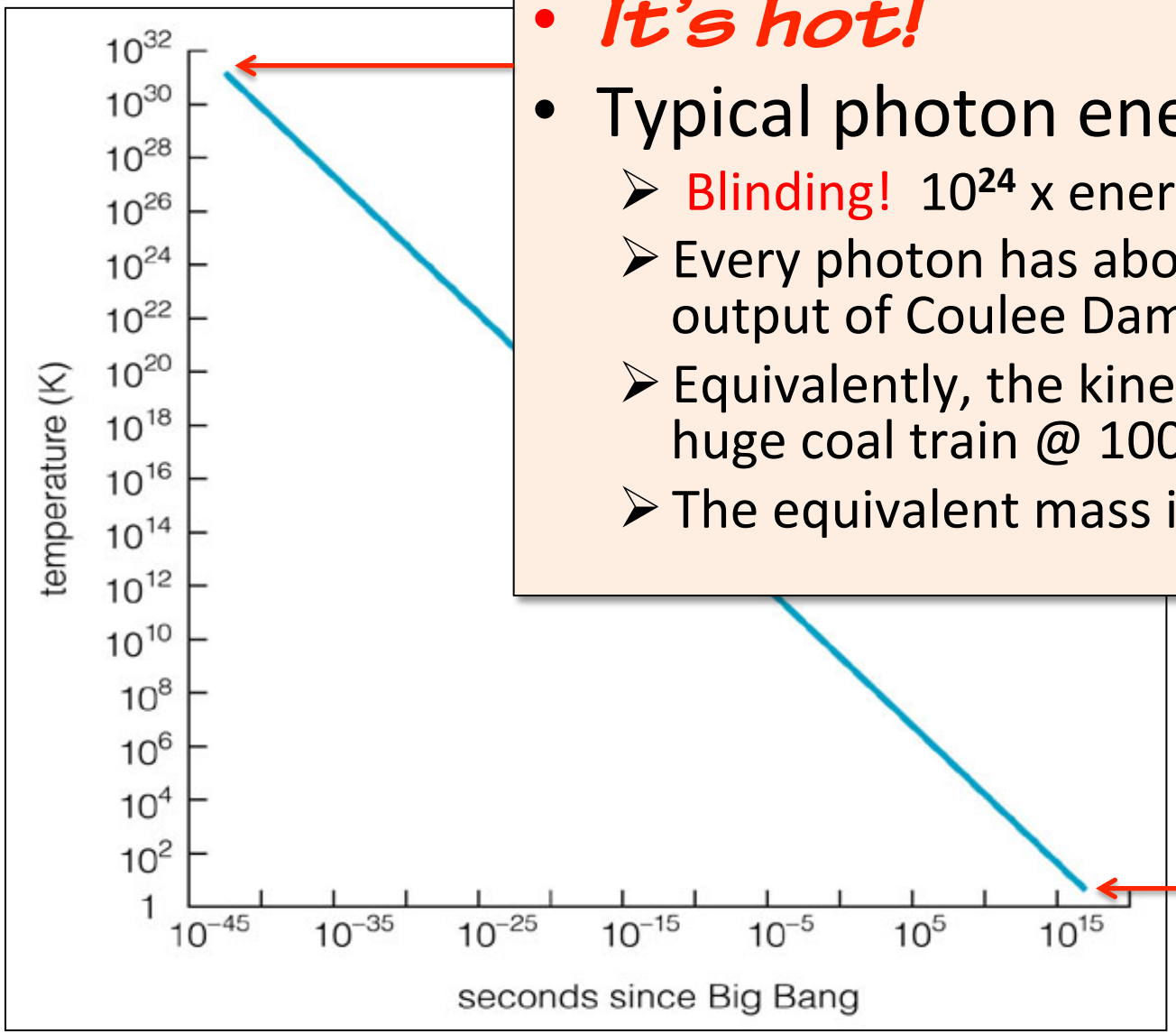


The Unexplored Planck Era:
$t < 10^{-43}$ s, $T > 10^{+31}$ K

- The ripples in the CMB started in this era as quantum fluctuations in space and time produced oscillating "**gravity waves**" that were formed everywhere and that will eternally propagate through space
- Gravity waves start huge, die off as space stretches, especially during inflation.
- Presently, gravity waves from the beginning are very subtle, but we will learn to detect and exploit them.
- *Models of ripple formation glimpse structure in the PE*.


INFLATION THEORIZED THAT THE UNIVERSE EXPANDED SO FAST (FASTER THAN THE SPEED OF LIGHT) IN THAT EARLY TIME, THAT THESE FLUCTUATIONS CREATED RIPPLES IN THE FABRIC OF SPACE AND TIME.
THESE FLUCTUATIONS EXPANDED AND FORMED HILLS AND VALLEYS IN THE TEXTURE OF THE UNIVERSE THAT ALLOWED MATTER TO CLUMP INTO THE MATTER WE SEE TODAY.
MORE PRECISELY, INFLATION PREDICTED THAT THESE RIPPLES WOULD LEAVE A VERY SPECIFIC SIGNATURE OF LIGHT POLARIZATION ON THE CMB.
WE FOUND THAT SIGNATURE.
WITH INFLATION MORE FIRMLY ESTABLISHED, WE CAN NOW LOOK BEYOND THE 380,000 YEAR HORIZON OF THE CMB, BACK TO 10^{-36} SECONDS AFTER THE BIG BANG.
10^{-36} SECONDS

Light at 5 × 10^{-44} seconds



- ***It's hot!***
- Typical photon energies $\gtrsim 10^{9}$ j
  - Blinding! 10^{24} x energy of visible light
  - Every photon has about the energy output of Coulee Dam in 1 second
  - Equivalently, the kinetic energy of a huge coal train @ 100 miles/**second**
  - The equivalent mass is 0.02 milligram

The numbers of cosmic photons have not changed very much, but their energies have now dropped by a factor of 10^{31} as the Universe expanded

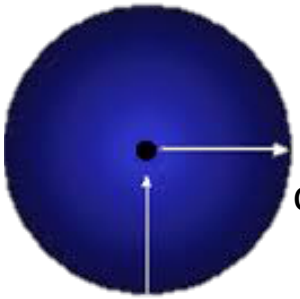
The first light: 5×10^{-44} sec: When Light Was "Black"

- The temperature was ~10^{32} K at $5\ 10^{-44}$ s (Planck Era).
- Energy per photon ~ $2\ 10^{9}$ j (≈ 10^{15} * CERNs), thus E_{ph}/c^2 = photon equiv. "mass" m_{ph} ~ 22 μg.
  - The corresponding density is $1.5\ 10^{92}$ g/cm^3
- The wavelength (i.e. approx size) of each photon is

$$\lambda_{ph} = hc/E_{ph} \sim 10^{-32}\ \text{cm}$$

- The Schw. radius of black hole with a mass of 22 μg is

$$r_s = 2Gm_{ph}/c^2 \approx 3.3\ 10^{-33}\ \text{cm}$$



r_s: radius of no return

Thus the size of a photon of energy $2\ 10^{9}$ j was about the same as a black hole of the same mass-energy!

The first light: 5×10^{-44} sec: When Light Was "Black"

- If our simple physics applies each photon is its own black hole during the Planck era.

  No light would emerge from the Plank era!

- *Space and time as continuous entities cease to have meanings when discussing distances of 10^{-33} meters and times of 10^{-43} seconds. So relativity, a theory of space and time based on a continuum, runs into serious difficulties.*