

Light travels at a finite speed

On to the very big ...



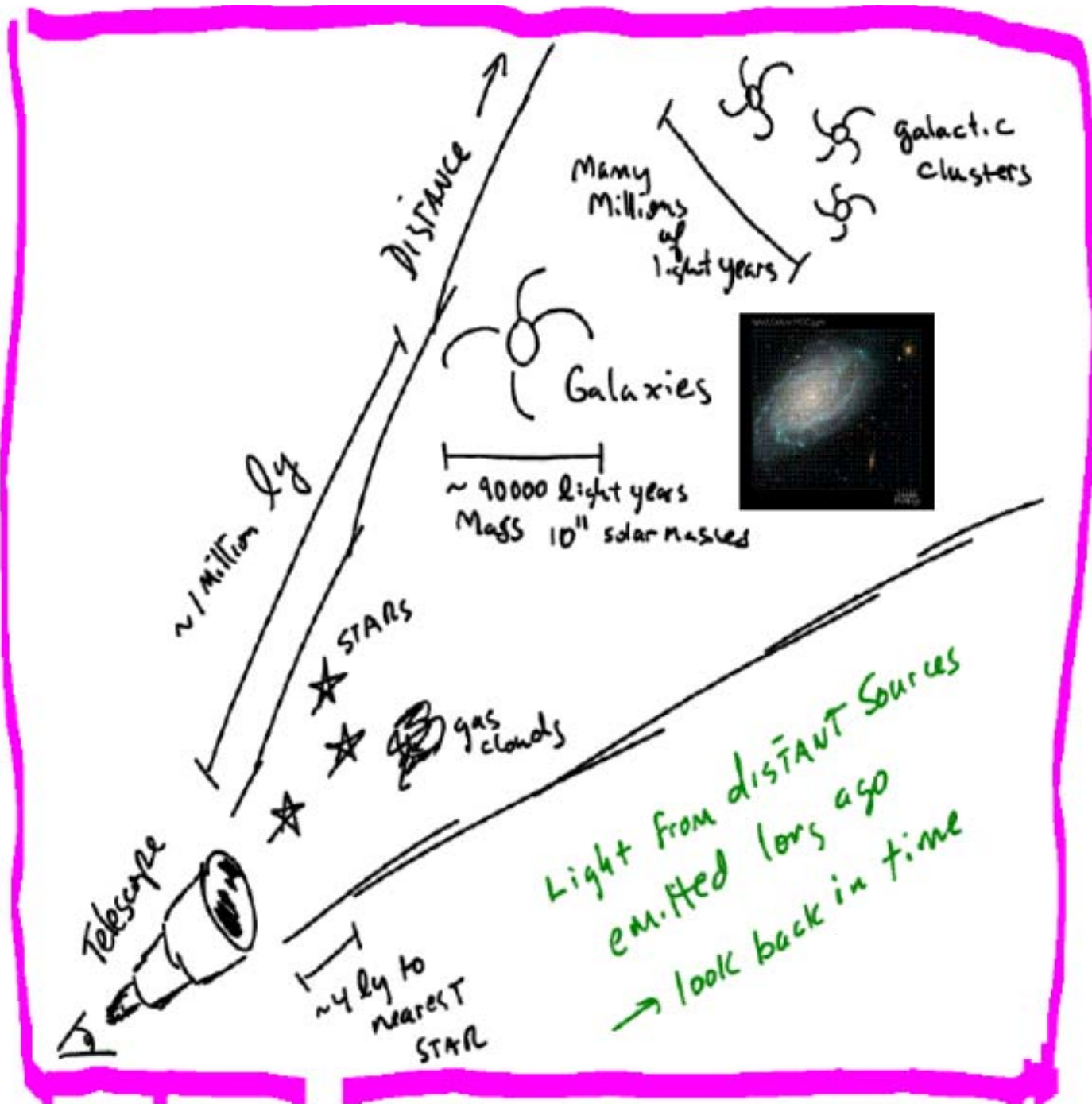
Telescopes are
time machines

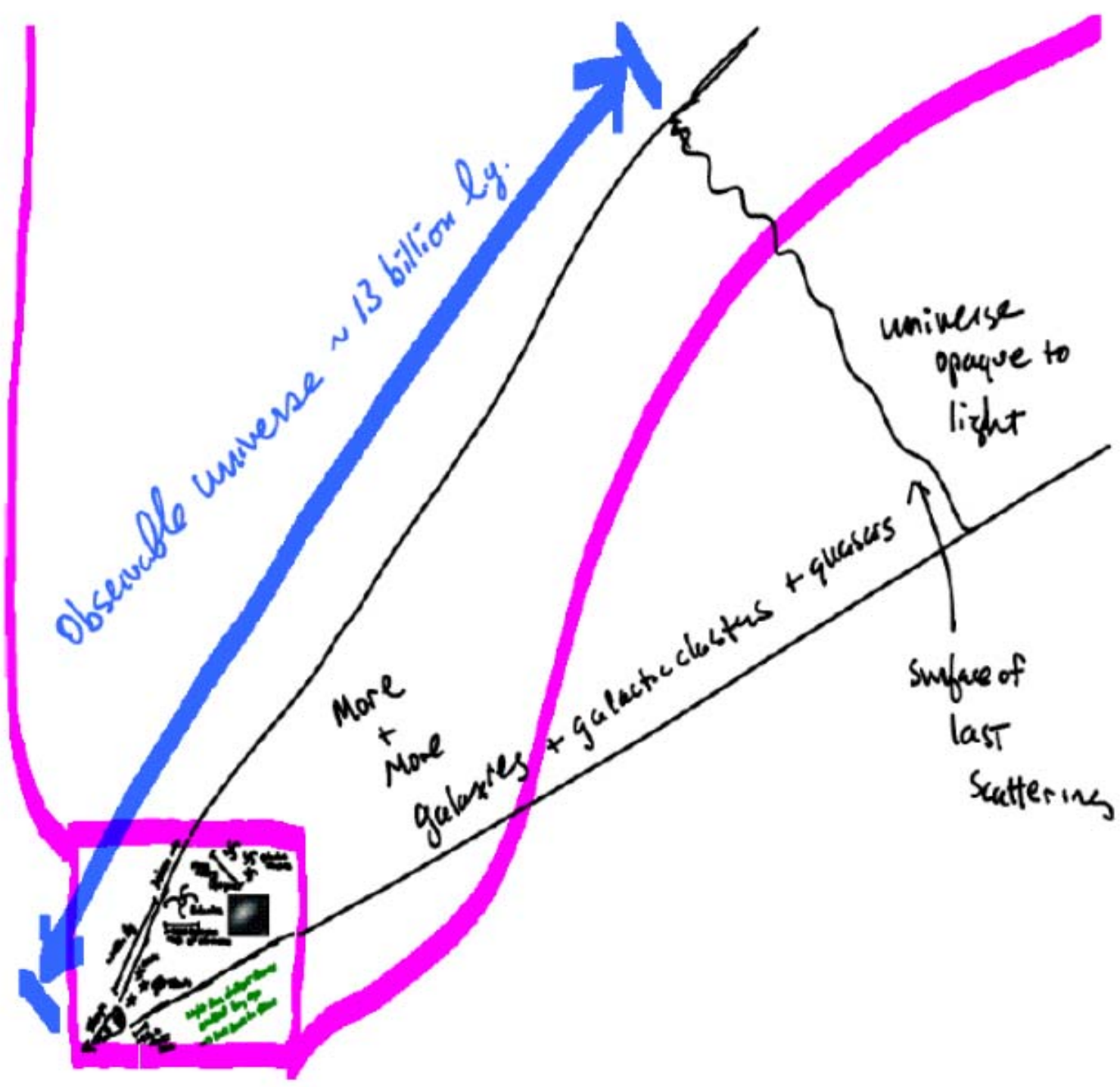
1 Mpc = 1 Megaparsec = 3×10^{22} m

1 light year = 9×10^{15} m

Light travels from NYC to San Francisco in 1/100 second
.... and it travels 1 Mpc in 3 million years

Farther Away, the object ... longer ago light emitted.





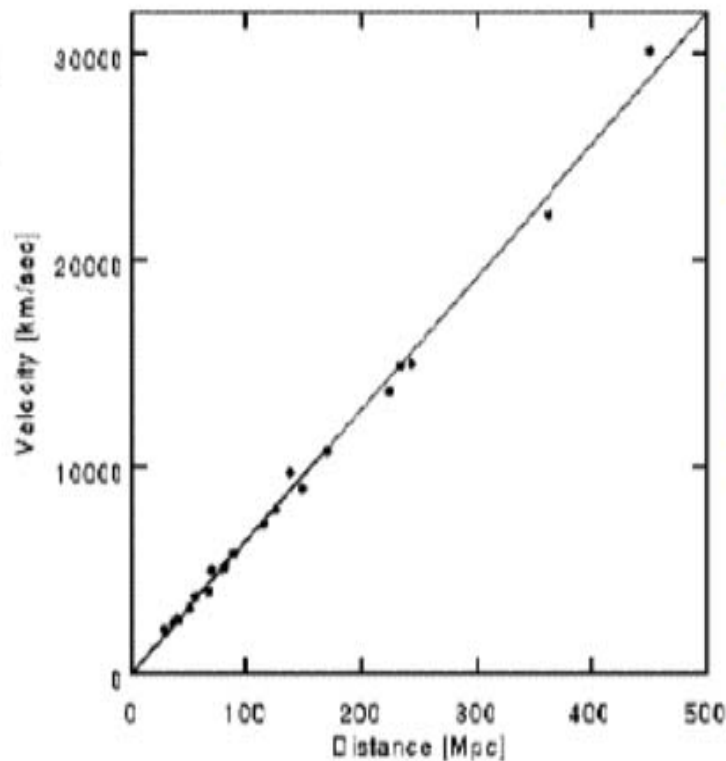
We live in an expanding universe



Edwin Hubble
(1929)

Determined by
redshift of Atomic
Spectral lines

Recession Velocity



Slipher
early 20's

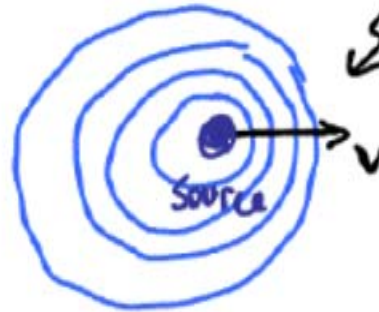
Also
Milton
Humason

Distance to galaxy

Determined by brightness
(Supernova in distant galaxy)

"Redshifted" light

frequency appears lower to objects in direction away from direction of motion

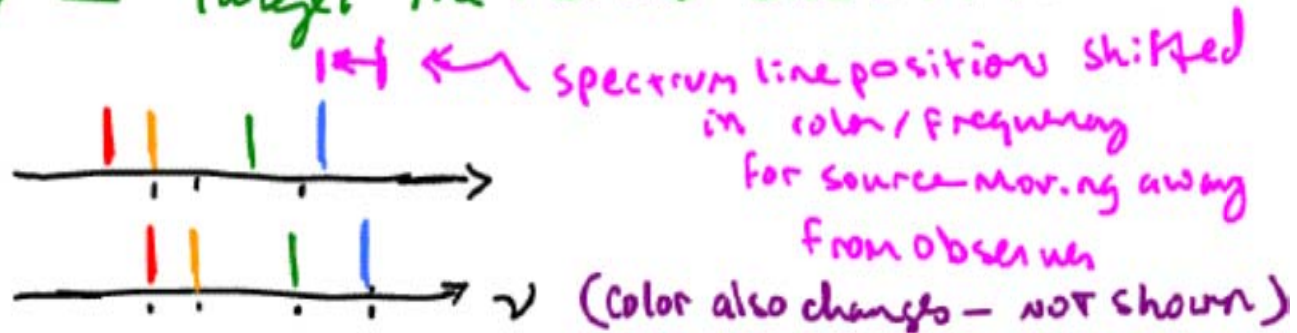


frequency appears higher to observers in direction of motion

"Blueshifted" light

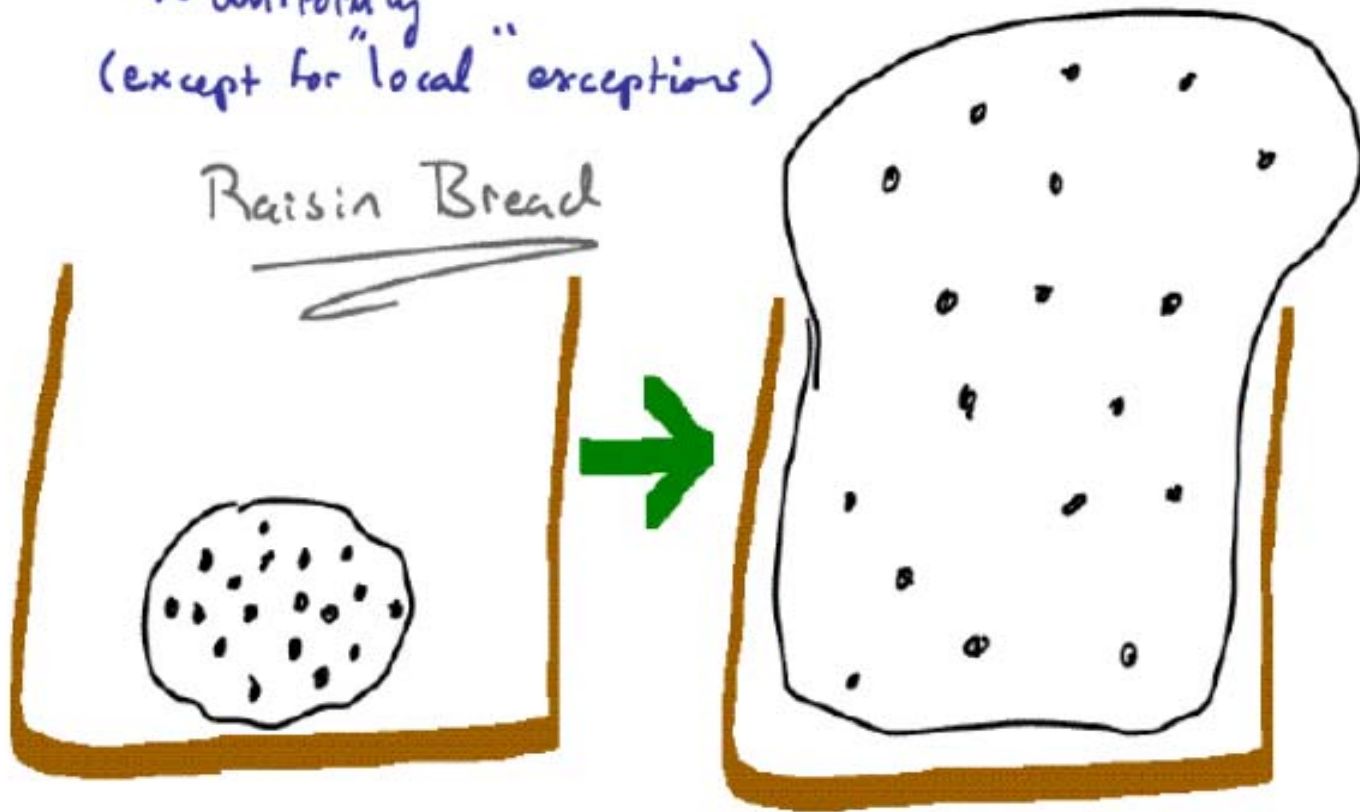
larger v — larger the red and blue shifts.

Atomic Spectrum



Galaxies Receding in all directions
~ Uniformly
(except for "local" exceptions)

Raisin Bread

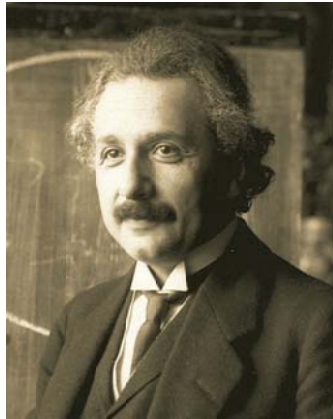


No need to think our galaxy is at center
of universe.

Expansion of space makes effect same to all
observers throughout universe.

Reminder -

Gravitation - The general theory of relativity

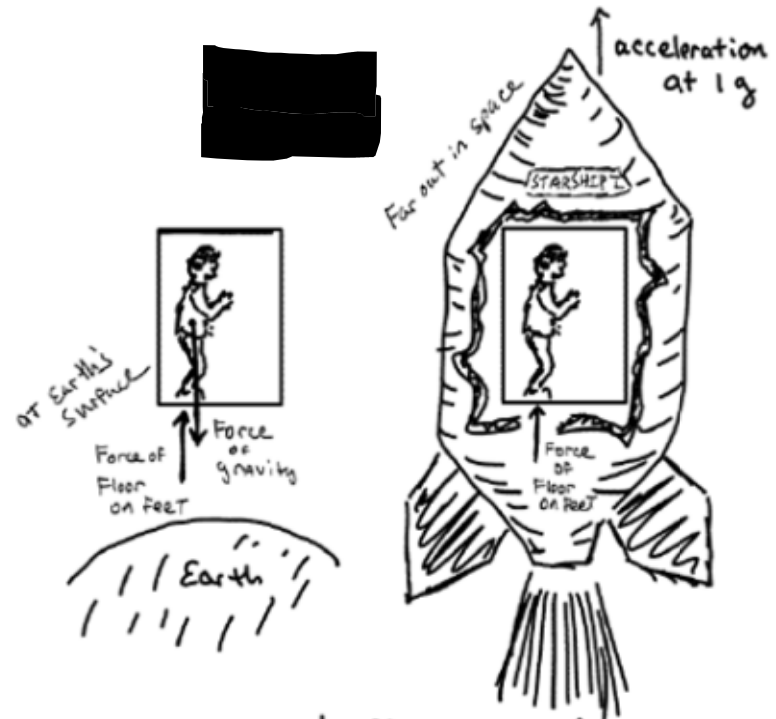


Equivalence principle

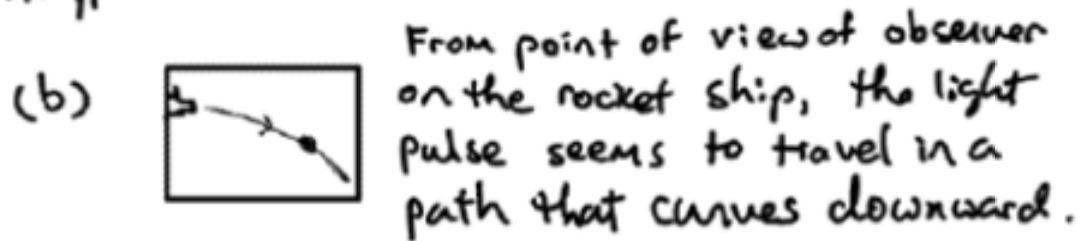
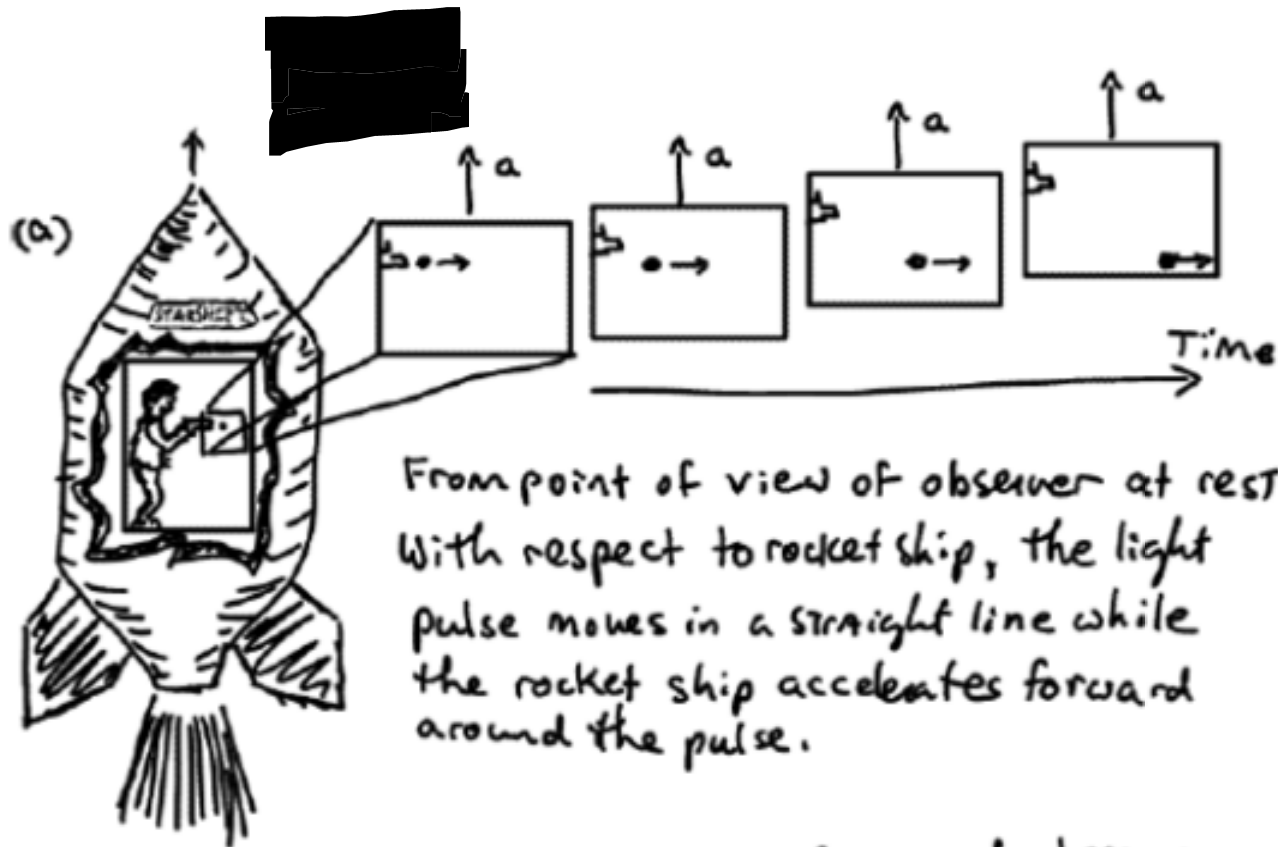
Accelerated reference frame

|||

gravitational field



The force of the floor on your feet is the same in both cases. This is what you perceive as your weight.



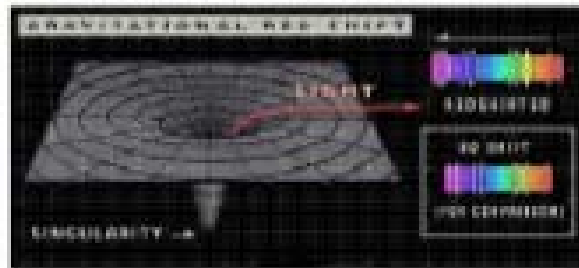


Apparent position

■ Bending of light by gravitational field ✓

Actual position

■ Gravitational redshift of light ✓



■ Perihelion advance of Mercury ✓

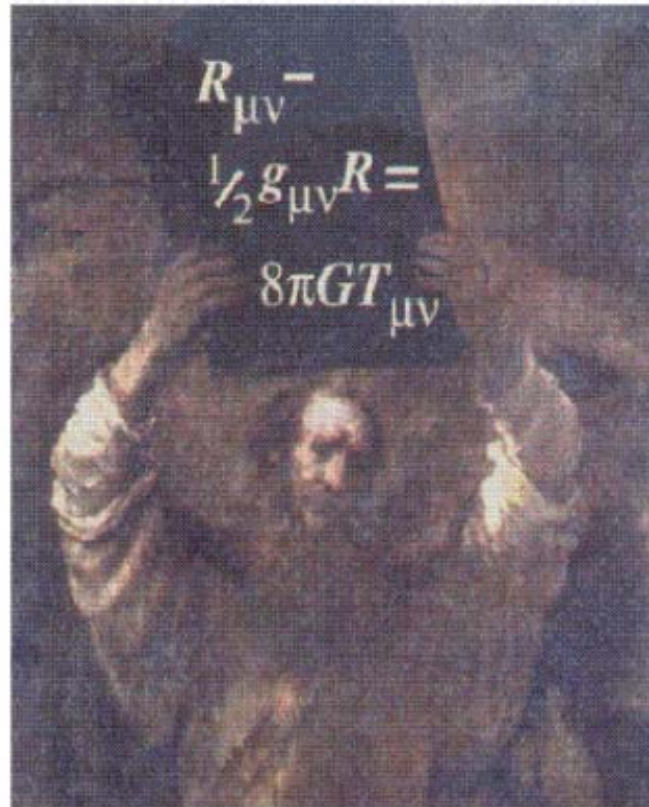


■ Gravitational Waves ?

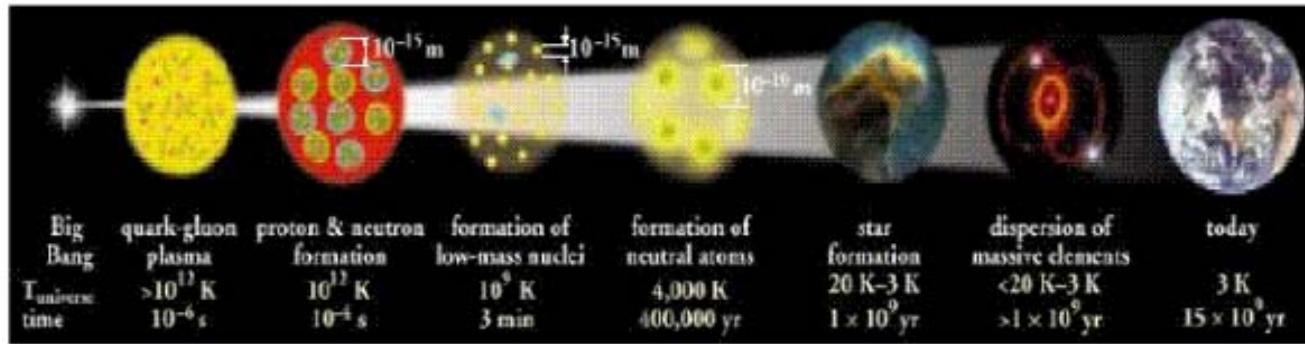
Amplitude $\sim 10^{-16}$ m

LIGO

Why Believe? ...



- R. Kolb



Hot Big Bang predicts this

light should travel to us from time ~ 400 K yr to now ... massively redshifted

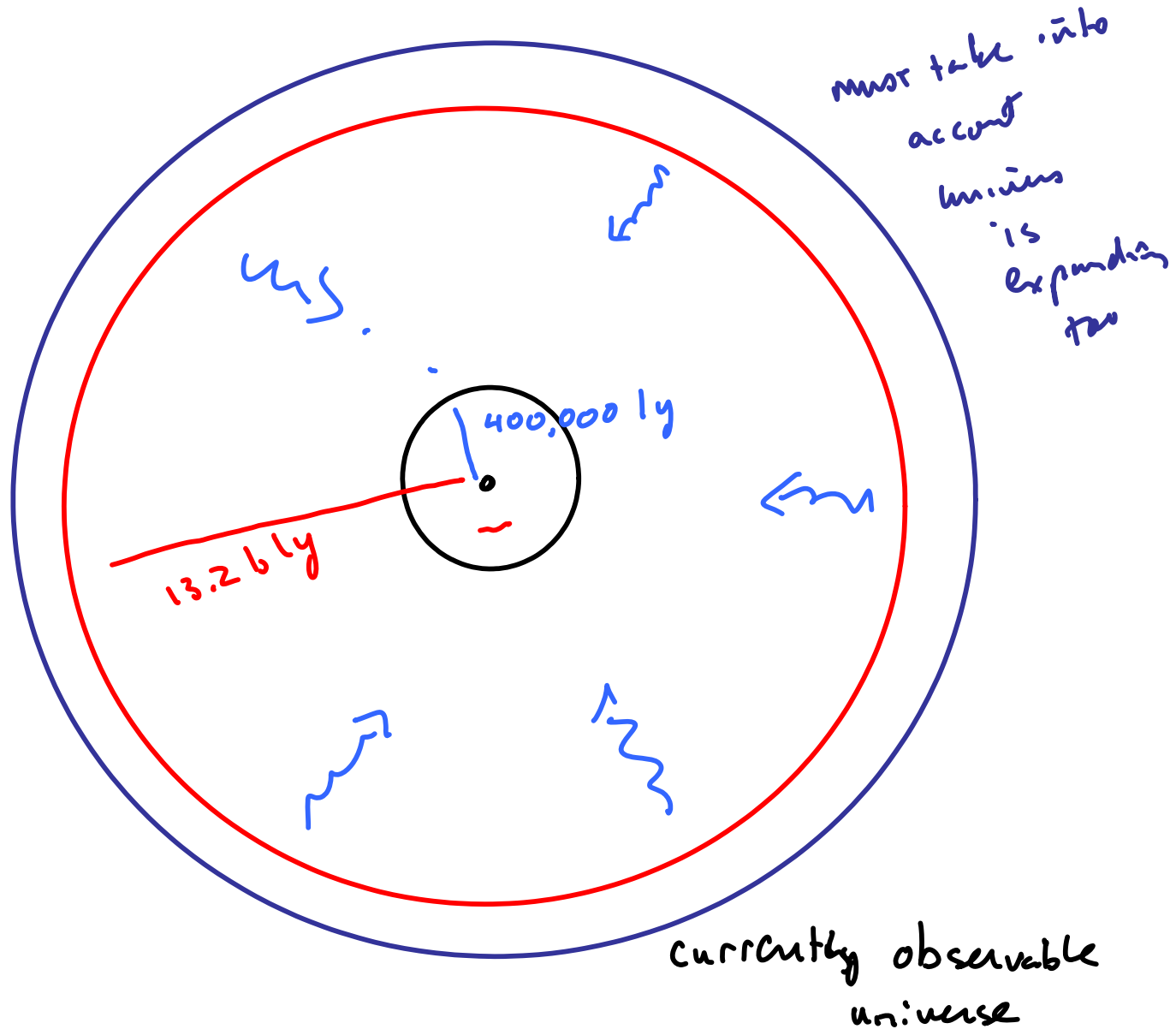
$$t = 4000 \text{ K} \longrightarrow t = 4 \text{ K}$$

"perfect Blackbody"

Should come to us from all directions

"CMB"

Cosmic Microwave Background



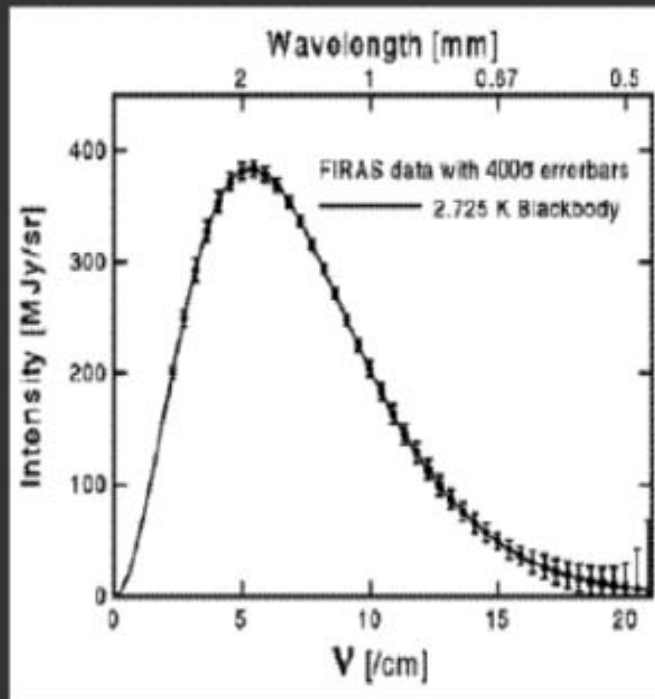
must take into
account
universe
is
expanding
too

currently observable
universe

Evidence for Big Bang

Cosmic Microwave Background

Penzias and Wilson - 1964



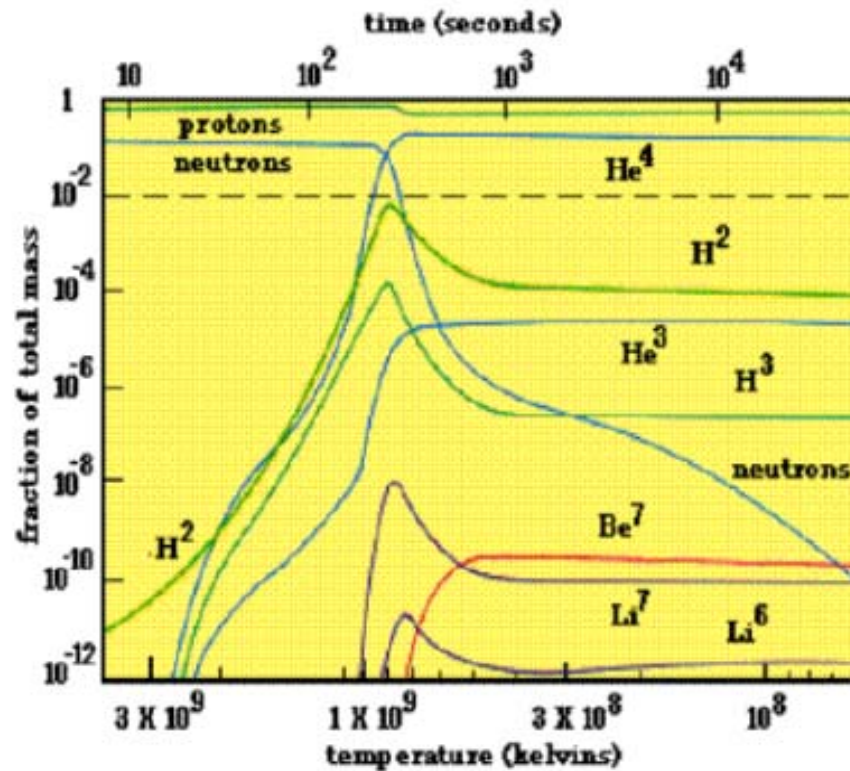
Uniform and isotropic

– in as far as they could measure

1978 Nobel Prize

Big Bang Nucleosynthesis

$t \approx 100$ seconds



<http://www.astro.ucla.edu/~wright/BBNS.html>

We see ~expected distribution of light nuclei in universe.

A tangent: The fecund multiverse

A distraction from big bang cosmology for now. We'll come back to that

The fecund multiverse - cosmological natural selection



Lee Smolin
"The Life of the Cosmos"
Oxford Univ. Press 1997

Fruitful in offspring

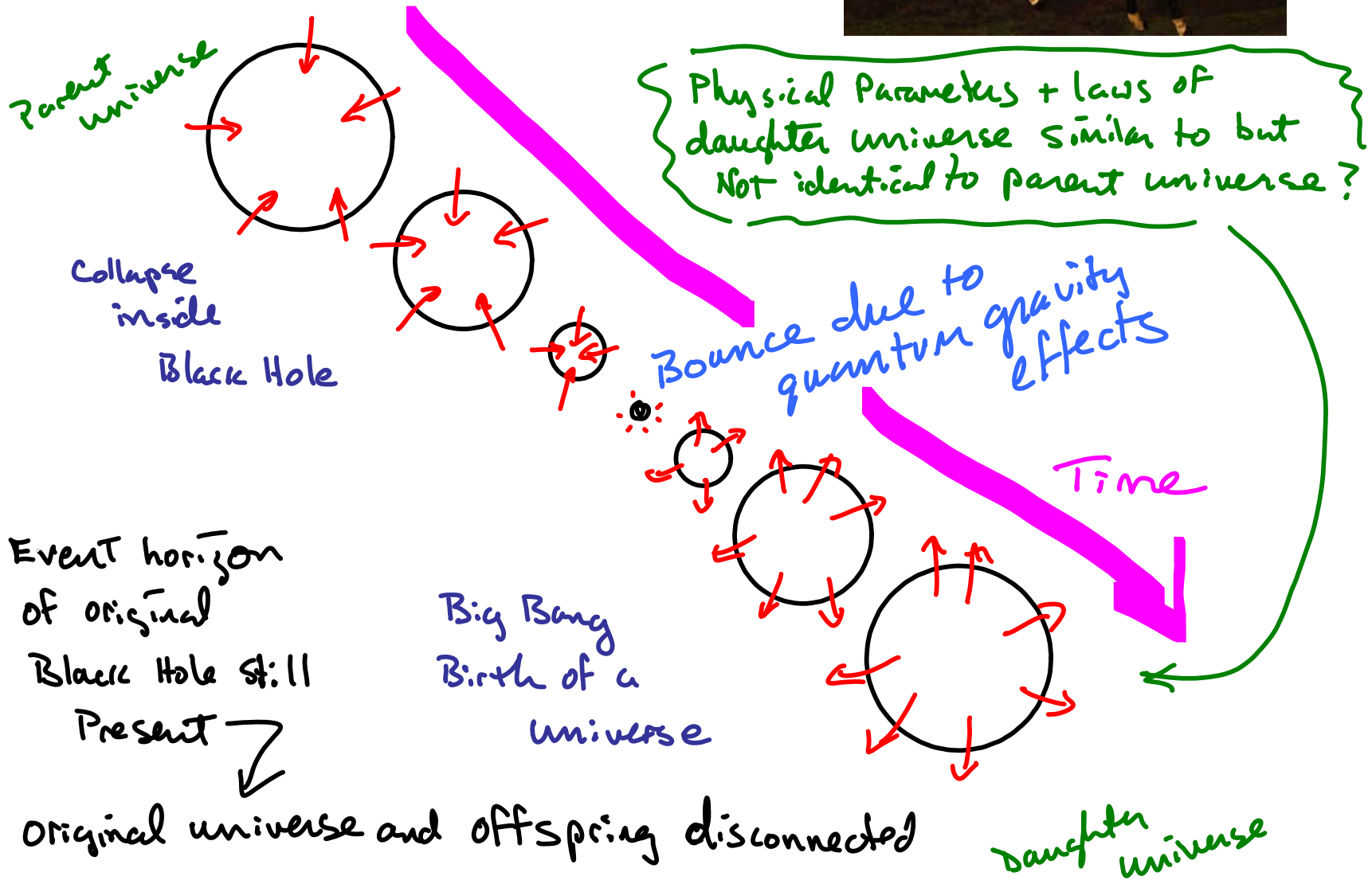
What happens inside a Black hole?



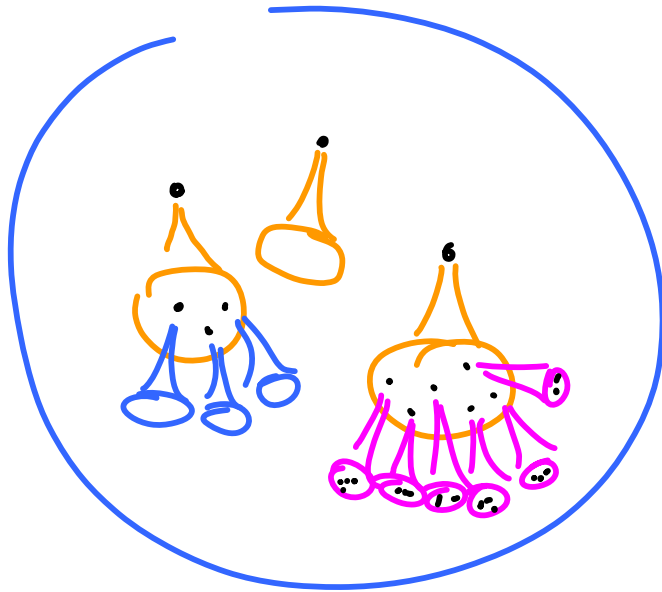
Beasts Dwell here
→ Singularity

classical general relativity:
curvature of spacetime is ∞
Physics as we know it ends

Quantum gravity to the rescue?



Cosmological Natural Selection



Parameters of universes
in the greater cosmos
will evolve toward
optimal production
of Black holes

This type of universe
will be predominant

Black holes → long life stars → also good for
life as we know
it

natural reason for fine-tuning in our universe
Anthropic selection

Falsifiable hypothesis