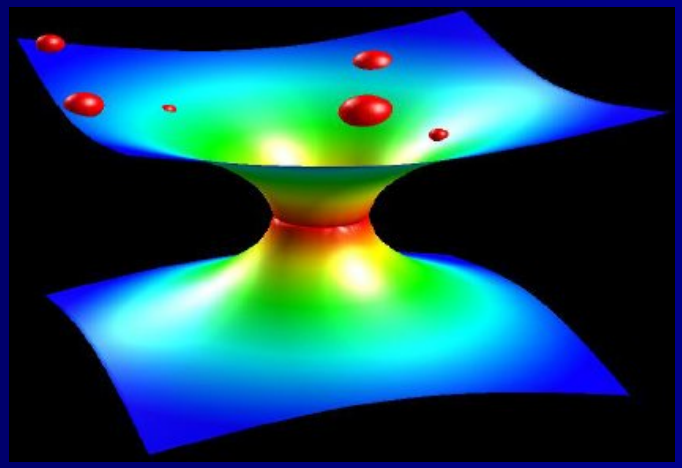
Laser Centre
vrije Universiteit amsterdam

Varying constants and a view on an evolutionary universe

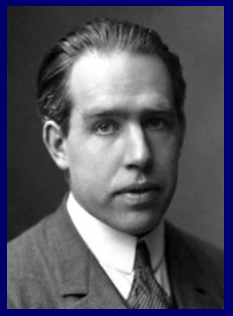


Wim Ubachs

TULIP Summer School IV 2009
Noordwijk, April 15-18

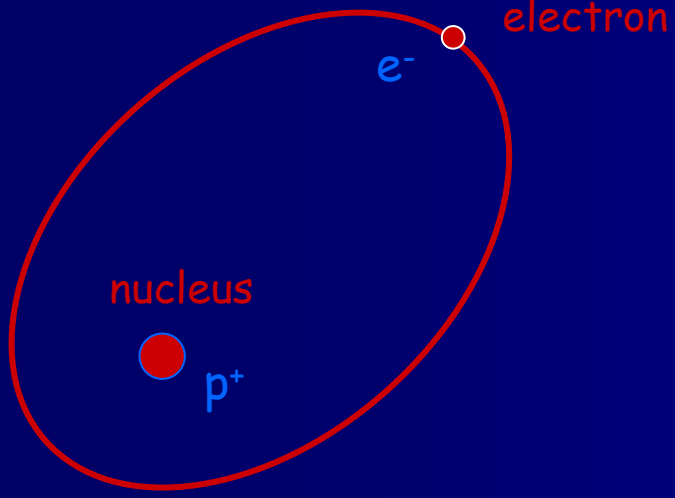
Constants of Nature and the Structure of Matter

Dimensionless numbers



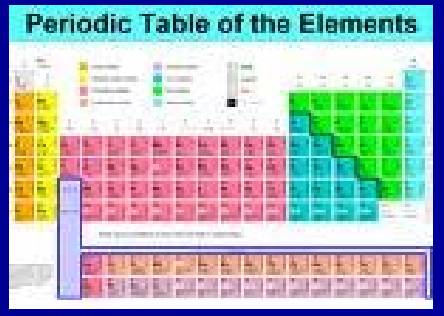
$$E_n = -\frac{1}{2n^2}\alpha^2 m_e c^2$$

Atoms:



$$\alpha = \frac{e^2}{4\pi\varepsilon_0 \hbar c}$$

$$v_n = Z\alpha c$$



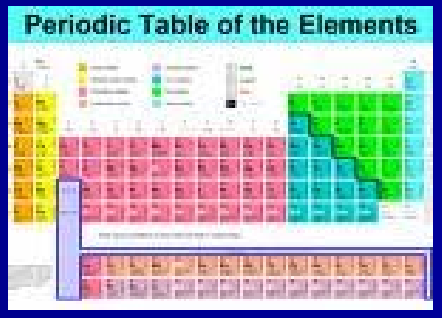
The proton-electron mass ratio

$$\mu = \frac{m_p}{m_e} = 1836.152\,672\,61(85)$$

$\mu \sim \Lambda_{QCD}$

Nuclear stability for:

$Z \leq 100$



α and μ determine structure of common matter

Max Born

$$a_0 \sim \frac{1}{\alpha m_e}$$ α determines size of an atom

$$\lambda_p \sim \frac{1}{M_p}$$ Compton wavelength of proton

$$\frac{R_{nuclear}}{R_{atom}} \sim \frac{\alpha}{\mu} \sim 10^{-6}$$

Subtle play of the constants of nature

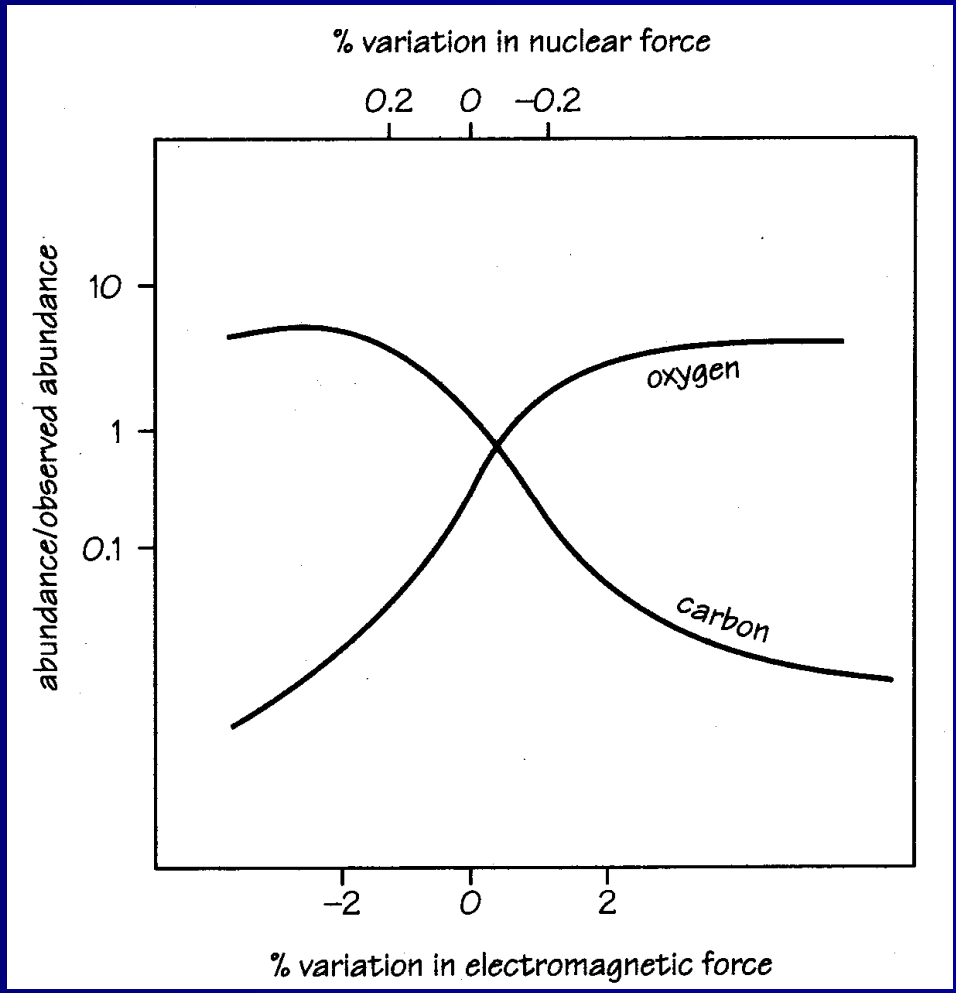
Fusion reacties:

$^{4}He + {}^{4}He \rightarrow {}^{8}Be$

$^{8}Be + {}^{4}He \rightarrow {}^{12}C$

$^{12}C + {}^{4}He \rightarrow {}^{16}O$

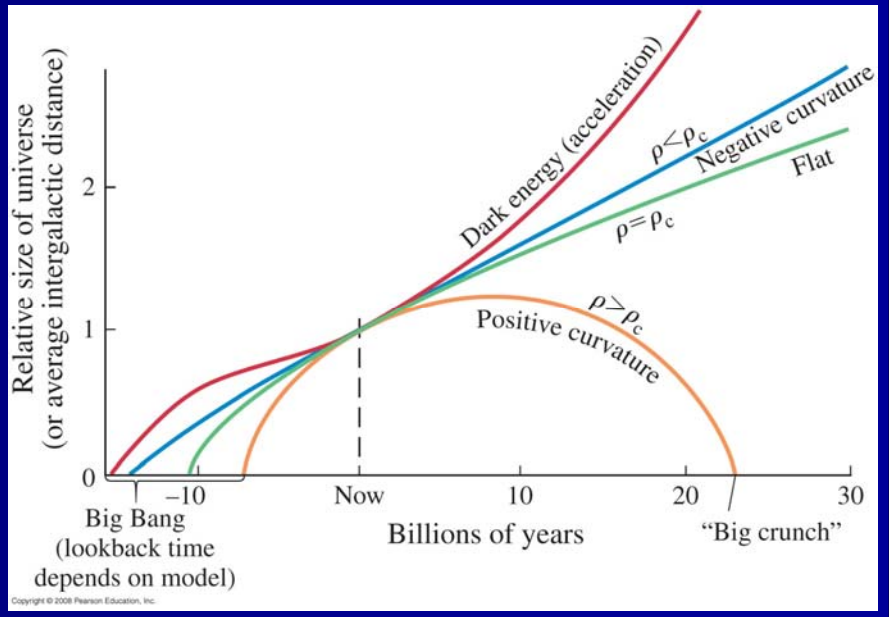
Fred Hoyle



Gravitation – Cosmological constant

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = -\frac{8\pi G}{c^4} T_{\mu\nu}$$

Λ determines the size
and flatness of the universe
i.e the lifetime



→Very tight constraints on Λ to produce a universe like ours (**1 in 10^{60}**)
(star formation, long lived stars, novae, supernovae for heavy elements)
→ Λ and G determine how long a universe lives

A theory for α ??

$$\alpha = \frac{1}{137.035\,999\,710\,(96)}$$

Pauli: the most profound question of atomic physics ….

A theory for μ ??

The Ratio of Proton and Electron Masses

FRIEDRICH LENZ
Düsseldorf, Germany
(Received April 5, 1951)

THE most exact value at present[1] for the ratio of proton to electron mass is 1836.12 ± 0.05. It may be of interest to note that this number coincides with $6\pi^5 = 1836.12$.

[1] Sommer, Thomas, and Hipple, Phys. Rev. **80**, 487 (1950).

Physical Review
82 (1951) 554

α-numerology

$$\alpha = \frac{3^2}{5^3 \pi^2} \qquad \mu = \frac{\pi}{32\alpha^2}$$

Physical Review 20 (1922) 1

$$\alpha = 2\pi(\pi - 1)\mu$$

Naturwissenschaften 16 (1928) 1094

+ more stuff, in particular from A. Eddington

(Bethe: $T_0 = -(2/\alpha - 1)$ Naturwissenschaften 19 (1931) 39)

Variation of constants

Some history

Dirac

$R_{universe}/R_{electron}$

$$N_1 = 10^{40}$$

F_{EM}/F_g

$$N_2 = 10^{40}$$

Large Number Hypothesis

N_p

$$N = 10^{80}$$

Teller

Paleonthology

$$N_1 = N_2 = \sqrt{N} \propto t$$

$$G \propto 1/t$$

Theories for varying constants
while conserving energy

Kaluza-Klein (1924-1927); extra dimensions

Scalar Field models (Bekenstein – Barrow – Pospelov)

Connect some phenomena in a single theory

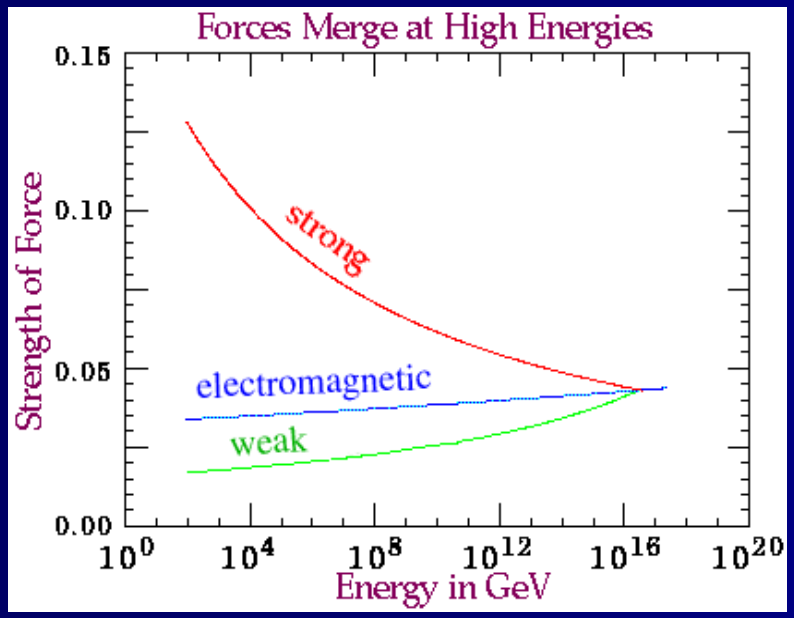
- Long-range forces distinct from GR
- Dark energy
- Variations of masses and coupling constants
- Birefringence of the vacuum
- Photon-axion oscillations
- Non-GR couplings of spins to gravitation

Breakdown of Einsteins equivalence principle

Variation of constants

Interdependence

Coupling constants interdependent in GUT

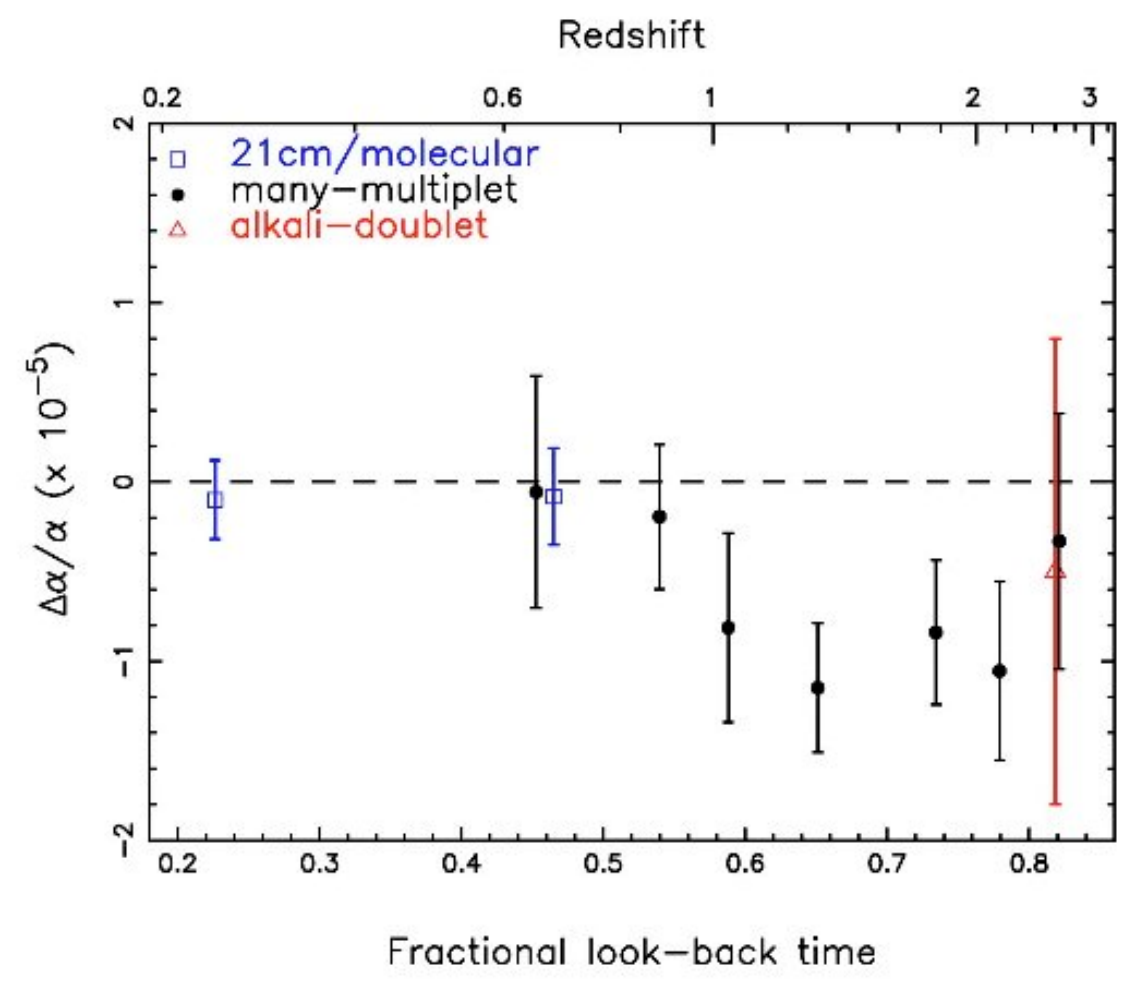


$$\frac{\dot{\mu}}{\mu} = R\frac{\dot{\alpha}}{\alpha}$$

Several theories with $|R|$ large

1. μ more sensitive
2. constraint on α_{EM}
3. Test GU theory via R

Status on α-variation: 5σ effect for z > 0.5



Murphy
Flambaum
Webb

Current status: no theories to explain α, μ, Λ

There exists a
Theory to explain the
Values of these constants,
we just haven't
found it

There exists no
Theory to explain the
Values of these constants.

We live in Universe

$$U(\alpha_0, \mu_0, \Lambda_0)$$

If the constants α, μ, Λ defining a universe vary

More difficult to define a theory explaining the constants

There exists no Theory to explain the Values of these constants.

We live in Universe

$$U(\alpha_0, \mu_0, \Lambda_0)$$

We live in Universe $U(\alpha_0, \mu_0, \Lambda_0)$

We live in the
~~One~~ and ~~Only~~
Special universe
designed ~~for~~ Us with

$$U(\alpha_0, \mu_0, \Lambda_0)$$

The Anthropic Principle
= Religion ≠ Science

There exists no
Theory to explain the
Values of these constants.

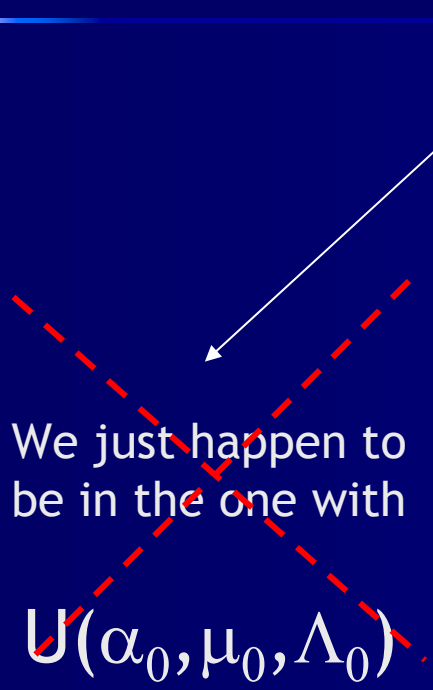
There is a multiple set of universes

$$U_i(\alpha_i, \mu_i, \Lambda_i)$$

And we happen to be in

$$U(\alpha_0, \mu_0, \Lambda_0)$$

There are Multiple Universes $U_i(\alpha_i, \mu_i, \Lambda_i)$



We just happen to
be in the one with

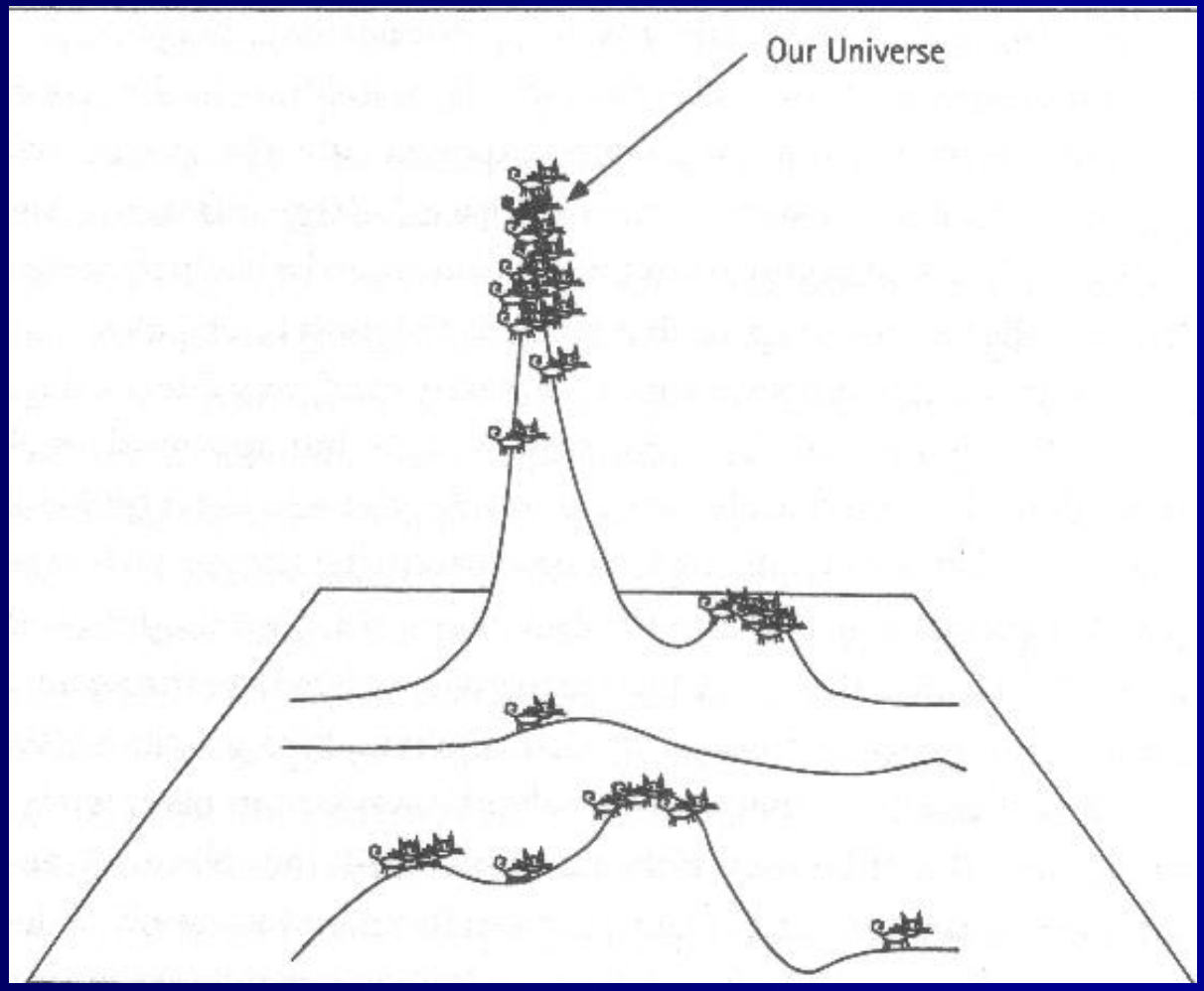
$U(\alpha_0, \mu_0, \Lambda_0)$

The cosmic landscape
is vast
due to the constraints;
It is a matter of improbability,
not of impossibility
Smolin: **1 in 10^{229} estimate**

There exists
a mechanism
based on evolution
and a fitness criterion,
which makes it more probable
to arrive at

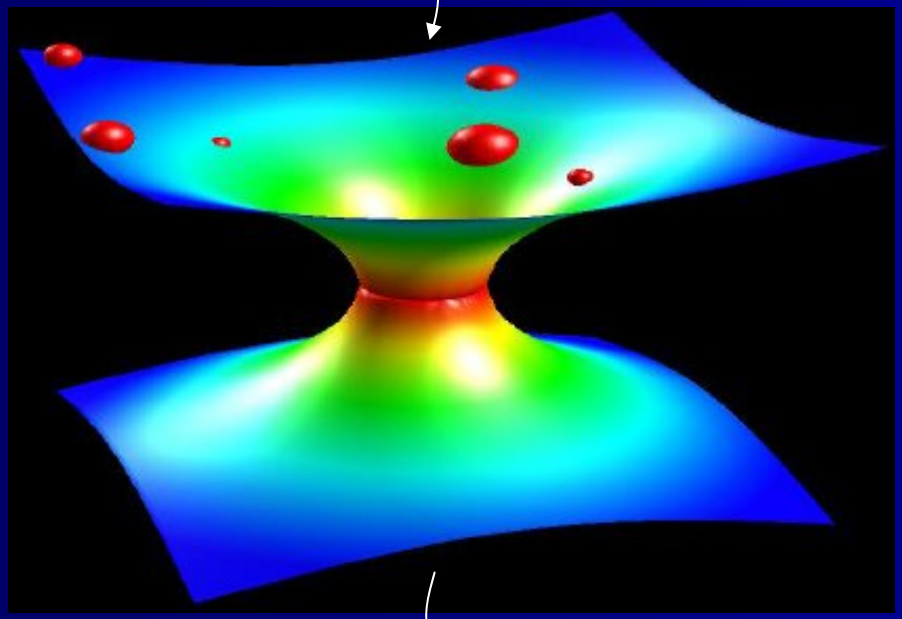
$U(\alpha_0, \mu_0, \Lambda_0)$

Processes of evolution toward finding maxima



Mechanism of reproduction

$U(\alpha_0, \mu_0, \Lambda_0)$



a bouncing
Black Hole
Singularity
(Wheeler & others)

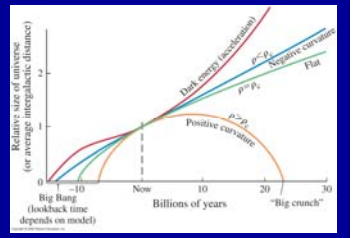
$U'(\alpha_0+\Delta\alpha, \mu_0+\Delta\mu, \Lambda_0+\Delta\Lambda)$

Our Universe $U(\alpha_0, \mu_0, \Lambda_0)$ is very special

10^{17} Black Holes (N_{BH})

(10^{10} spiral galaxies, 1 Super Nova/ 50 years, 10% leave BH, 10^{10} years)

Suggestion: this is an extreme circumstance



fully open universes: no BH

fastly closed universes; 1 single BH – the final crunch

close to flat, longlived universe, required to produce > 1 BH

the time scale and the conditions of massive star formation

Hypothesis: we are near a (local) maximum in population

any mutation will decrease N_{BH}

mutations at a bounce (reproductive process) are small –

to not loose the maximum

methodologies of population biology – such extrema are found and kept

Two issues

Can we deduct some falsifiable scenarios/consequences from this model based on BH-formation

What is the physics behind BH-formation; What are the major constraints

What does that mean for some constants ?

Constraints for black hole formation

1) There must be some stable nuclei (at least up to helium) to allow for a gravitational collaps of matter

2) The CO molecule is a primary engine to form and cool interstellar clouds to the level that massive stars can be formed; so C and O should be formed

3) “A mechanism of self-propagated star formation” depends on a time scale: star formation should be faster than burning stars; long-lived stars burn on hydrogen -
so Big-Bang nuclear synthesis should not proceed too far

4) On the supernova-scenario ...

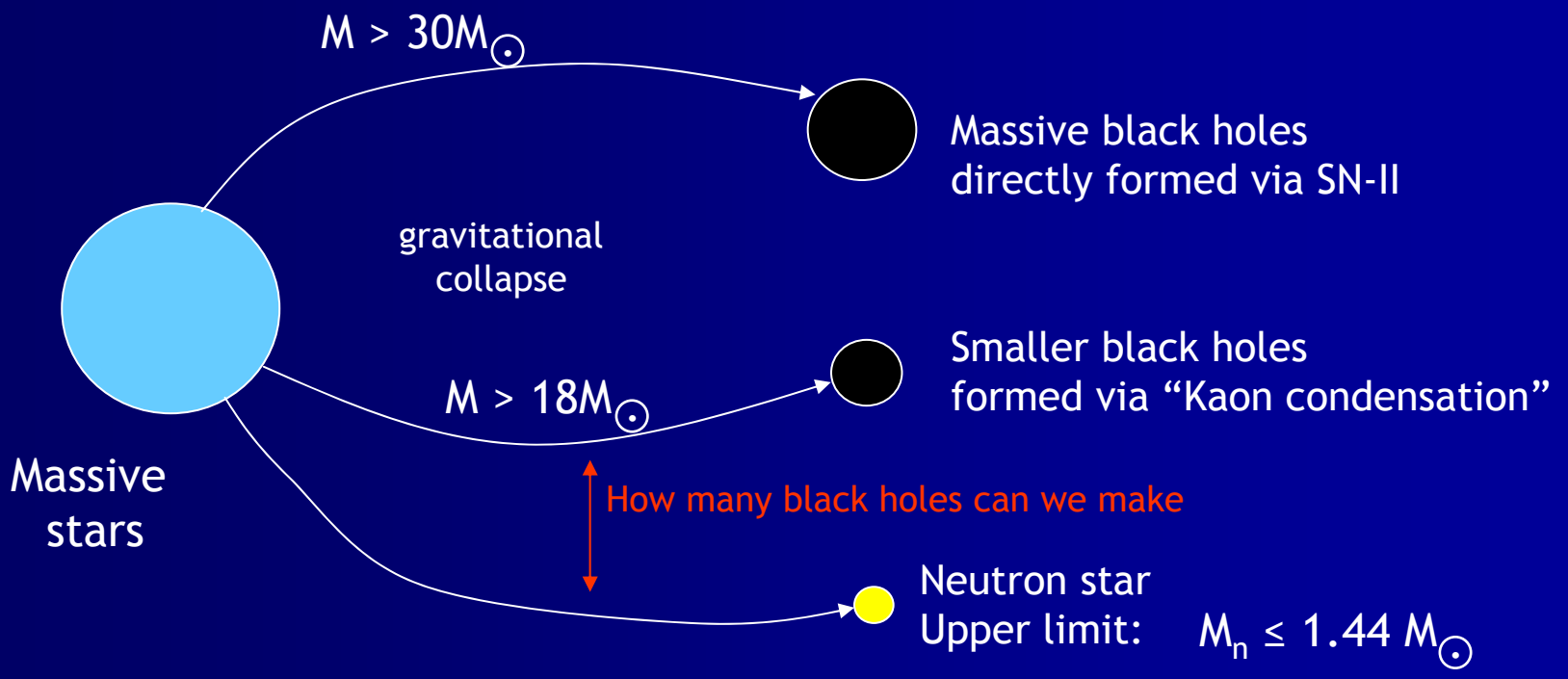
5) The upper mass limit of neutron stars should be as low as possible

A theory of black hole production

A SCENARIO FOR A LARGE NUMBER OF LOW-MASS BLACK HOLES IN THE GALAXY

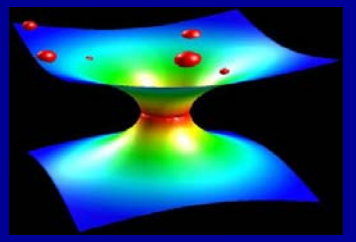
G. E. BROWN[1] AND H. A. BETHE[2]
California Institute of Technology, W. K. Kellogg Radiation Laboratory, 106-38, Pasadena, CA 91125
Received 1993 March 24; accepted 1993 July 27

Astroph. J. 423 (1994) 659



On the falsifiable prediction

Criterion: is in the maximization of black hole offspring in bouncing singularities;
Second scenario (kaon condensation) needed to produce sufficient black holes



Falsifiable model of cosmological natural selection:
Refuted of a neutron star is found with **Mass > 1.45 M_{solar}**

Physica A 340 (2004) 705
Nucl. Phys. B 742 (2006) 142

Lee Smolin

Note: everything breaks down if we produce a theory for **α~1/137**