

52

# THE ANTHROPIC PRINCIPLE: ~~50~~ YEARS ON

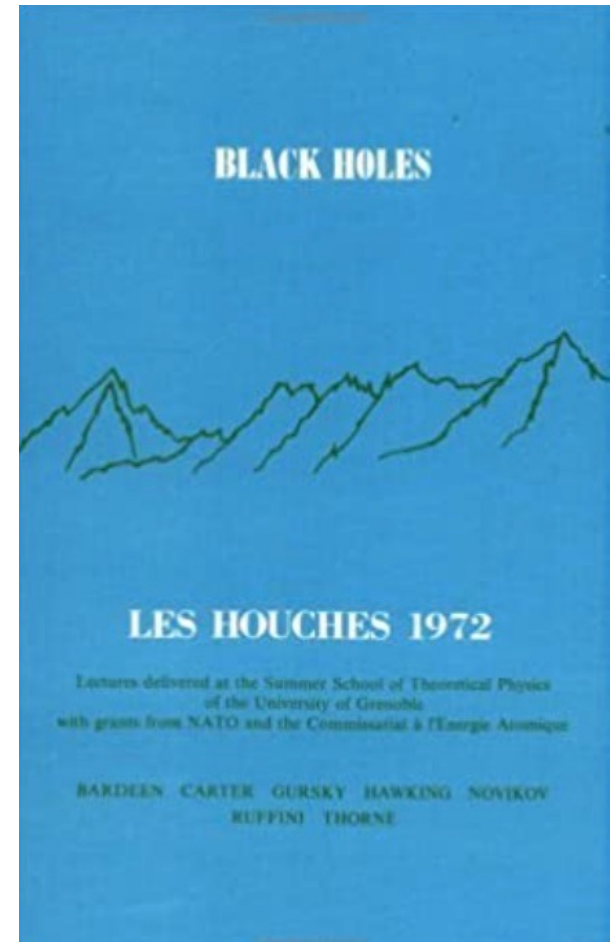
Bernard Carr, Queen Mary University of London



Carter Fest, 5 July 2022

## LES HOUCHES

“After ascent in good conditions, Martin Walker, Chris Cunningham and I were on our way down Mt Blanc when mist set in and we caught up with a crowd of tourists who did not know which way to go to avoid dangerous crevasses because newly fallen snow had hidden the track. Their professional guide was far behind, taking care of weaker straggling tourists. The weak anthropic principle warns that it is not enough to know what is in the world. One also needs to know where one is in it. In those pre-GPS days we had very good topographic maps but in bad visibility we lacked means of knowing our location. But fortunately I had taken the precaution of bringing an old fashioned barometric altimeter, which could situate us on a contour in our map.”



# Brandon introduces Anthropic Principle at IAU meeting in Cracow in 1973

arXiv:0710.3543

*Line by line Transcript (preserving the original page numbering) of the  
stencilled Preprint issued in 1967.*

## LARGE NUMBER COINCIDENCES AND THE ANTHROPIC PRINCIPLE IN COSMOLOGY

BRANDON CARTER

*Dept. of Applied Mathematics and Theoretical Physics, University of Cambridge, U.K.*

### 1. Introduction

Prof. Wheeler has asked me to say something for the record about some ideas that I once suggested (at the Clifford Memorial meeting in Princeton in 1970) and to which Hawking and Collins have referred (*Astrophys. J.* **180**, 317, 1973). This concerns a line of thought which I believe to be potentially fertile, but which I did not write up at the time because I felt (as I still feel) that it needs further development. However, it is not inappropriate that this matter should have cropped up again on the present occasion, since it consists basically of a reaction against exaggerated subservience to the 'Copernican principle'.

“The main ideas of what I later called the ‘anthropic principle’ were developed in a substantial DAMTP preprint entitled "The Significance of Numerical Coincidences in Nature" locally circulated in 1967 in stencilled form and belatedly placed on the arXiv forty years later. Its first public presentation, entitled "Large Numbers in Astrophysics and Cosmology" was at a Princeton meeting organised in 1970 by Wheeler, with participants including Dicke, Wigner, the DeWitts, Hawking and myself, and Dyson who put forth similar ideas a few years later.”

## THE SIGNIFICANCE OF NUMERICAL COINCIDENCES IN NATURE

### Part I

The Role of Fundamental Microphysical Parameters in Cosmogony

Brandon Carter

Department of Applied Mathematics and Theoretical Physics

University of Cambridge

### Abstract

This is the first part of a survey whose ultimate purpose is to clarify the significance of the famous coincidence between the Hubble age of the universe and a certain combination of microphysical parameters. In this part the way is prepared by a discussion of the manner in which familiar local phenomena depend qualitatively, and in order of magnitude, quantitatively on the fundamental parameters of microphysics. In order to keep the account concise while remaining self contained, only the barest essentials of the standard nuclear physical and astrophysical calculations involved are given. Only six of the fundamental parameters play a dominant part, namely the coupling constants of the strong, electromagnetic, and gravitational forces, and the mass ratios of the proton, neutron, electron and  $\pi$ -meson. Attention is drawn to the important consequences of three coincidental relationships between these parameters. It is shown that most of the principle limiting masses of astrophysics arise (in fundamental units) simply as the reciprocal of the gravitational fine structure constant, with relatively small adjustment factors. The dividing point between red dwarf and blue giant stars turns out to be an exception: this division occurs within the range of the main sequence stars only as a consequence of the rather exotic coincidence that the ninth power of the electromagnetic fine structure constant is roughly equal to the square root of the gravitational fine structure constant.

Part 2?

*Nature* **278**, 605 - 612 (12 April 1979); doi:10.1038/278605a0

## **The anthropic principle and the structure of the physical world**

B. J. CARR<sup>\*</sup> & M. J. REES

Institute of Astronomy, Madingley Road, Cambridge, UK

<sup>\*</sup>Present address: California Institute of Technology, Pasadena, California 91109.

**The basic features of galaxies, stars, planets and the everyday world are essentially determined by a few microphysical constants and by the effects of gravitation. Many interrelations between different scales that at first sight seem surprising are straightforward consequences of simple physical arguments. But several aspects of our Universe—some of which seem to be prerequisites for the evolution of any form of life—depend rather delicately on apparent 'coincidences' among the physical constants.**

## TEMPLETON PROJECT

In 2000 'Cosmology & Fine-Tuning' programme awarded grant to BC, Robert Crittenden, Martin Rees & Neil Turok 'Fundamental physics and the problem of our existence'

Cambridge 2001

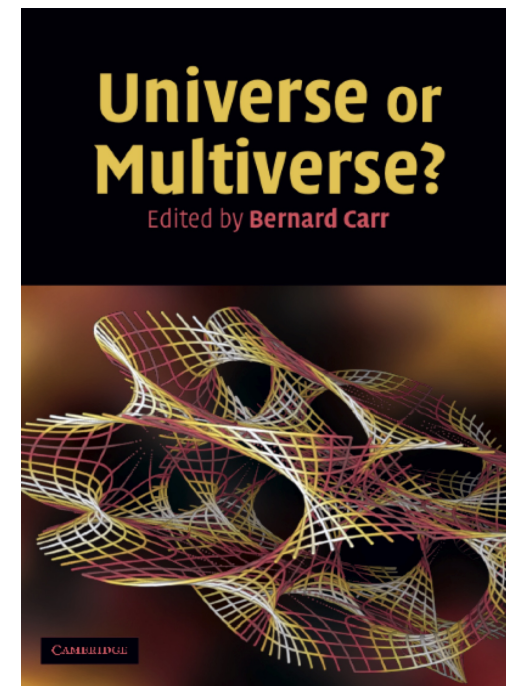
**Anthropic Arguments in Fundamental Physics and Cosmology**

Stanford 2003

**Universe or Multiverse?**

Cambridge 2005

**Expectations of a Final Theory**



**B. Carter, Micro-anthropic principle for quantum theory**

# CAMBRIDGE 2001



# CHANGE IN ATTITUDE TO FINE-TUNING



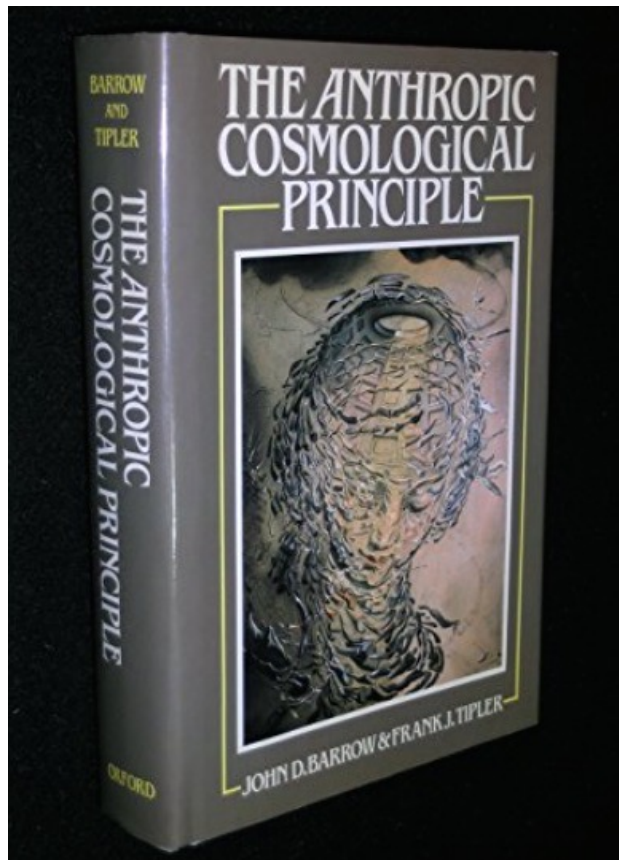
Frank Wilczek

“The previous gathering [2001] had a defensive air. It prominently featured a number of physicists who subsisted on the fringes, voices in the wilderness who had for many years promoted strange arguments about conspiracies among fundamental constants and alternative universes. Their concerns and approaches seemed totally alien to the consensus vanguard of theoretical physics, which was busy successfully constructing a unique and mathematically perfect Universe. Now [2005] the vanguard has marched off to join the prophets in the wilderness.”



Steven Weinberg

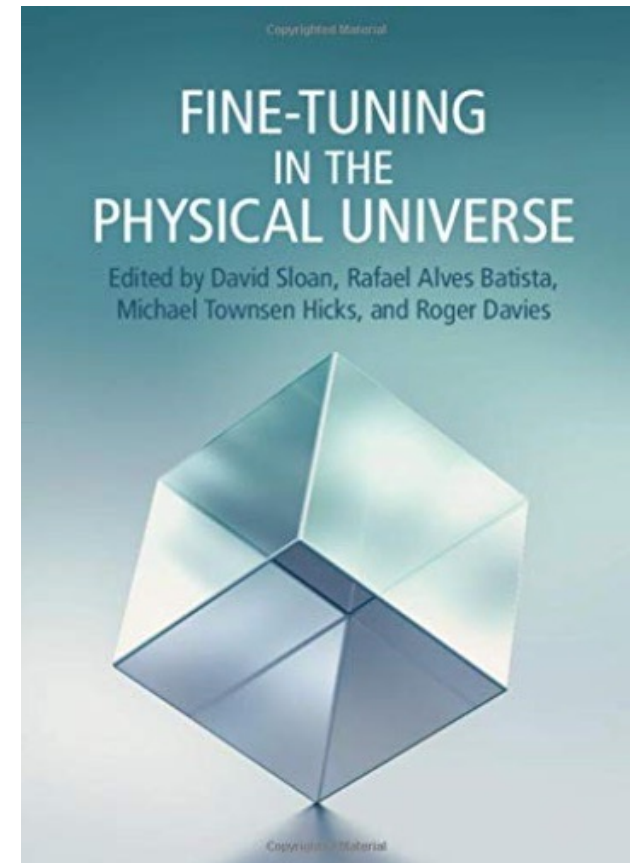
“We usually mark advances in the history of science by what we learn about nature, but at certain critical moments the most important thing is what we discover about science itself. These discoveries lead to changes in how we score our work, in what we consider to be an acceptable theory.”



1986



John Barrow

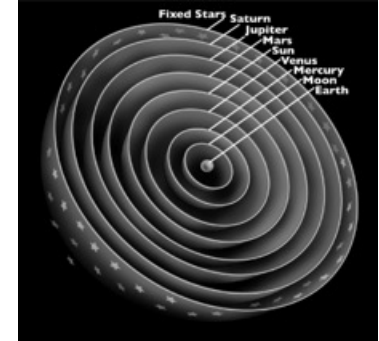


2020



## ANTHROPOCENTRIC VIEW

Humans are “central” to the Universe



## MECHANISTIC VIEW

Universe exists independent of our awareness of it.  
Humans are irrelevant



## ANTHROPIC VIEW

Some features of the Universe are “explained”  
by requirement that observers should arise



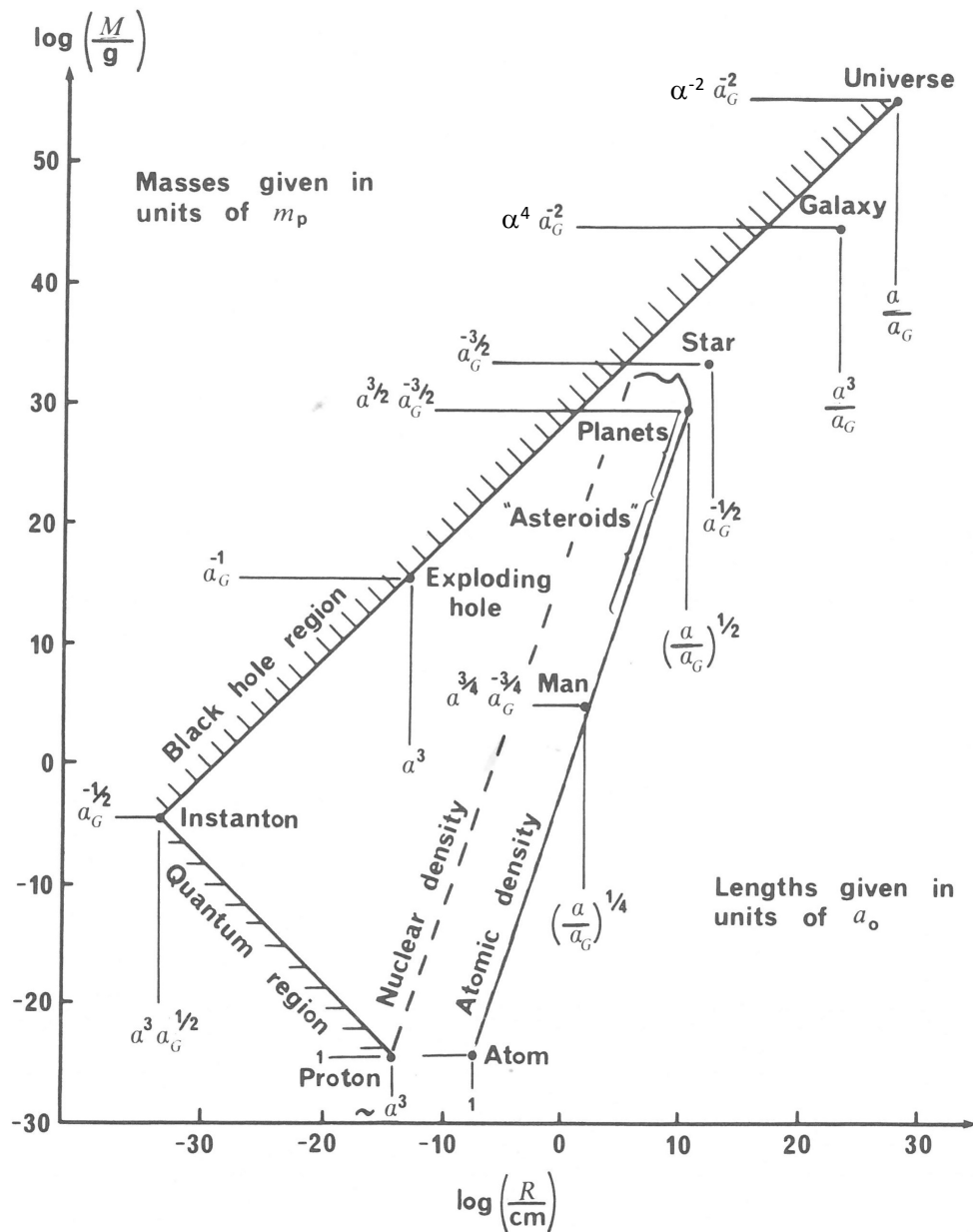
Self-Selection Principle

Cognition Principle

Complexity Principle

## DIFFERENT TYPES OF TUNING

Physics => natural coincidences between scales of structure



Simple physics shows scales of most objects depend on

$$\alpha = e^2/hc = 1/137$$

$$\alpha_G = Gm_p^2/hc = 5 \times 10^{-39}$$

to an order of magnitude

# Mass and length scale of many objects depend on G and e

	Mass/ $m_p$	Size/ $a_o$
Universe	$\alpha^{-2} \alpha_G^{-2}$	$\alpha \alpha_G^{-1}$
Galaxy	$\alpha^4 \alpha_G^{-2}$	$\alpha^3 \alpha_G^{-1}$
Star	$\alpha_G^{-3/2}$	$\alpha_G^{-1/2}$
Jupiter	$\alpha^{3/2} \alpha_G^{-3/2}$	$\alpha^{1/2} \alpha_G^{-1/2}$
Human*	$\alpha^{3/4} \alpha_G^{-3/4}$	$\alpha^{1/4} \alpha_G^{-1/4}$
Proton	1	$\alpha^3$
Planck	$\alpha_G^{-1/2}$	$\alpha^3 \alpha_G^{1/2}$

$m_p$  = proton mass

$a_o$  = atom size

Mass of human ~ geometric mean of atom and planet

Number of galaxies in Universe ~  $\alpha^{-6}$

Number of stars in Galaxy ~  $\alpha^4 \alpha_G^{-1/2}$

\* B.Carter "Objective and subjective time in anthropic reasoning" (arXiv:0708.2367)

## DIFFERENT TYPES OF TUNING

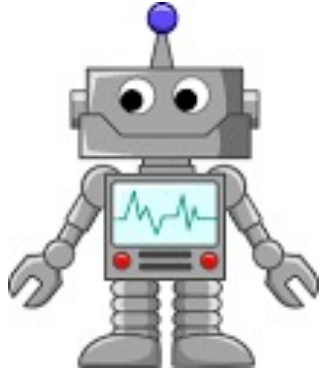
Physics => 'natural' coincidences between scales of structure

Selection effects for when and where observers exist

=> **W**weak **A**Anthropic **P**Principle

# WHY IS UNIVERSE AS BIG AS IT IS?

## *Mechanistic View*



Time since big bang is  $t_0 \sim 10^{10}$  y  
 $\Rightarrow$  size of observable universe is  $ct_0 \sim 10^{10}$  ly

**No particular reason for this!**

## *Anthropic View*



### *Bob Dicke*

Life requires heavy elements made in stars  
 $\Rightarrow$  no life before lifetime of star  $t_s \sim 10^{10}$  y

No stars left for  $t \gg 10^{10}$  y

$\Rightarrow$  life exists when  $t \sim 10^{10}$  y  $\Rightarrow$  size  $\sim 10^{10}$  ly

**This explains coincidence**  $t_0 \sim \alpha_G^{-1} t_p \sim 10^{10}$  y **and**  $N \sim \alpha_G^{-2} \sim 10^{80}$

cf. Dirac model with  $G \sim t^{-1}$

## DIFFERENT TYPES OF TUNING

Physics => 'natural' coincidences between scales of structure

Selection effect for when and where observers exist  
=> **W**weak **A**Anthropic **P**Principle

Fine-tunings between some physical constants needed for observers but not predicted => **S**Strong **A**Anthropic **P**Principle

**SAP becomes WAP in multiverse proposal (Carter)**

# PHYSICAL CONSTANTS

Quantity	Symbol	Value in our universe
Speed of light	$c$	$299792458 \text{ m s}^{-1}$
Gravitational constant	$G$	$6.673 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$
(Reduced) Planck constant	$\hbar$	$1.05457148 \times 10^{-34} \text{ m}^2 \text{ kg s}^{-2}$
Planck mass-energy	$m_{\text{Pl}} = \sqrt{\hbar c/G}$	$1.2209 \times 10^{22} \text{ MeV}$
Mass of electron; proton; neutron	$m_e; m_p; m_n$	0.511; 938.3; 939.6 MeV
Mass of up; down; strange quark	$m_u; m_d; m_s$	(Approx.) 2.4; 4.8; 104 MeV
Ratio of electron to proton mass	$\beta$	$(1836.15)^{-1}$
Gravitational coupling constant	$\alpha_G = m_p^2/m_{\text{Pl}}^2$	$5.9 \times 10^{-39}$
Hypercharge coupling constant	$\alpha_1$	1/98.4
Weak coupling constant	$\alpha_2$	1/29.6
Strong force coupling constant	$\alpha_s = \alpha_3$	0.1187
Fine structure constant	$\alpha = \frac{\alpha_1 \alpha_2}{\alpha_1 + \alpha_2}$	1/127.9 (1/137 at low energy)
Higgs vacuum expectation value	$v$	246.2 GeV
QCD scale	$\Lambda_{\text{QCD}}$	$\approx 200 \text{ MeV}$
Yukawa couplings	$\Gamma_i = \sqrt{2}m_i/v$	Listed in Tegmark et al. (2006)
Hubble constant	$H$	71 km/s/Mpc (today)
Cosmological constant (energy density)	$\Lambda (\rho_\Lambda)$	$\rho_\Lambda = (2.3 \times 10^{-3} \text{ eV})^{-4}$
Amplitude of primordial fluctuations	$Q$	$2 \times 10^{-5}$
Total matter mass per photon	$\xi$	$\approx 4 \text{ eV}$
Baryonic mass per photon	$\xi_{\text{baryon}}$	$\approx 0.61 \text{ eV}$

Which constants are fundamental and how many are independent?



## DIMENSIONLESS COUPLING CONSTANTS

Strong force

$$\alpha_S \sim 10$$

Electric force

$$\alpha_e \sim 10^{-2}$$

Weak force

$$\alpha_W \sim 10^{-10}$$

Gravitational force

$$\alpha_G \sim 10^{-40}$$

Will the Final Theory of Everything explain these values?

# PLANETS AND STARS

Stars have mass  $\sim \alpha_G^{-3/2} m_p$

Division between stars with convective and radiative envelopes at  $\sim \alpha_G^{-2} \alpha^{10} m_p$

$$\Rightarrow \alpha_G \sim \alpha^{20}$$



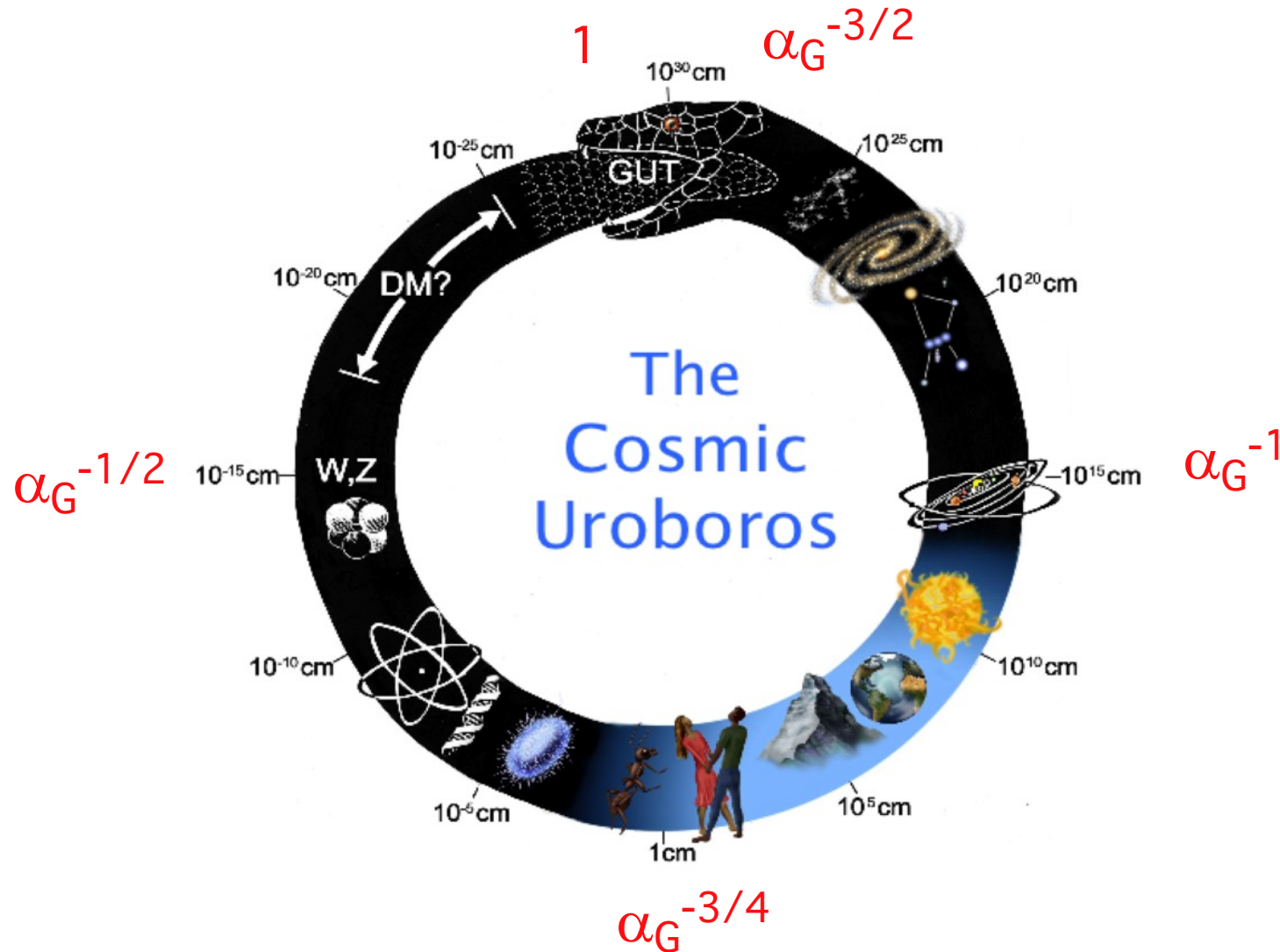
$\Rightarrow$  number stars in galaxy  $\sim$  numbers of galaxies in Universe!

This relationship is required for life but unexplained by physics

Constrains  $e$  to 3% (Page 2007)

Renormalization group argument  $\Rightarrow \alpha^{-1} \sim \ln \alpha_G^{-1} \Rightarrow \alpha \sim 10^{-2}, \alpha_G \sim 10^{-40}$

# Scales in terms of Planck length



Number of stars in Universe  $\sim \alpha_G^{-1/2} \Rightarrow \alpha_G < (\text{prob of life})^2 \lll 1$

# SUPERNOVAE AND BIG BANG NUCLEOSYNTHESIS

Supernovae explosions  $\Rightarrow \alpha_G \sim \alpha_W^4$

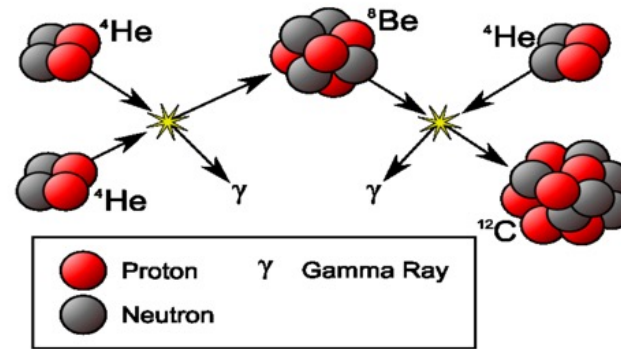


This also generates interesting amount of primordial helium production  
(25% rather than 100% or 0%).

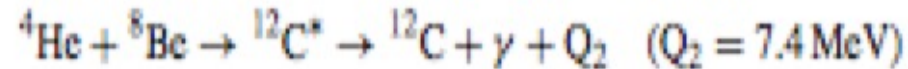
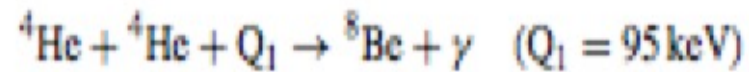
and explains why baryonic and WIMP densities are comparable

(Carr & Turner 1987)

# TRIPLE-ALPHA COINCIDENCE



(Hoyle 1953)



Life requires carbon made in stars through  $3\alpha$  reaction

Beryllium would decay too soon but for finely-tuned resonance

Strong interaction tuned to 0.1%

(Livio et al 1989, Oberhummer et al. 2000, Ekstrom et al. 2009)

# CONSTRAINTS FROM CHEMISTRY

$\alpha_S$  increased by 2%  $\Rightarrow$  all protons go into diprotons at BBNS  
 $\Rightarrow$  no H-burning stars  $\Rightarrow$  no time for life

$\alpha_S$  increased by 10%  $\Rightarrow$  all protons into nuclei of unlimited size  
 $\Rightarrow$  no interesting chemistry

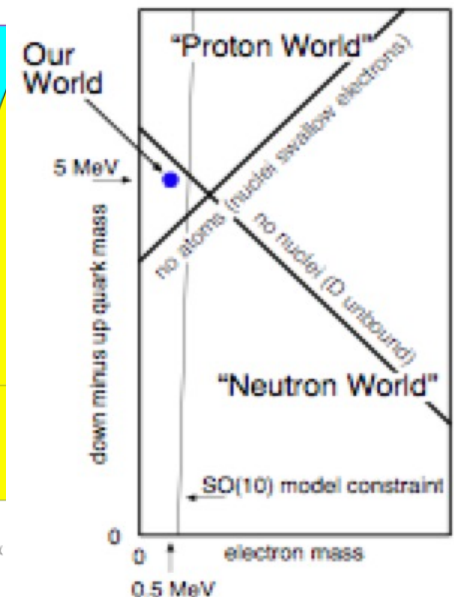
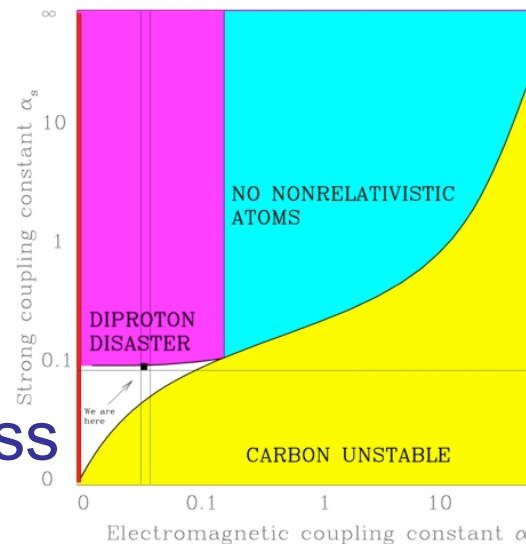
$\alpha_S$  decreased by 5%  $\Rightarrow$  deuterons unbound  $\Rightarrow$  only hydrogen  
 $\Rightarrow$  no interesting chemistry

Other constraints involve masses

$$f^2 \approx 2m_N/m_\pi, \quad \alpha \approx \Delta/m_\pi,$$

$$\Delta/m_e \approx 2, \quad f \approx 1/(3\alpha^{1/2}).$$

But QCD strength and quark mass are more fundamental (Hogan)



## DIFFERENT TYPES OF TUNING

Physics => 'natural' coincidences between scales of structure

Selection effect for when and where observers exist  
=> **W**weak **A**Anthropic **P**Principle

Fine-tunings between physical constants needed for observers  
but not predicted by physics => **S**Strong **A**Anthropic **P**Principle

Fine-tunings of cosmological parameters for observers

## *Just Six Numbers (Martin Rees)*

- 1.  $N$  = electrical force/gravitational force  $\sim 10^{38}$*
- 2.  $E$  = strength of nuclear binding = 0.007*
- 3.  $\Omega$  = matter density in universe in critical units = 0.3*
- 4.  $\Lambda$  = cosmological constant in critical units = 0.7*
- 5.  $Q$  = seeds for cosmic structures = 1/100,000*
- 6.  $D$  = number of spatial dimensions = 3*





## DIFFERENT TYPES OF TUNING

Physics => 'natural' coincidences between scales of structure

Selection effect for when and where observers exist  
=> **W**weak **A**Anthropic **P**Principle.

Fine-tunings between coupling constants needed for observers but not predicted by physics => **S**Strong **A**Anthropic **P**Principle

Fine-tunings of cosmological parameters for observers

Non-anthropropic fine-tunings

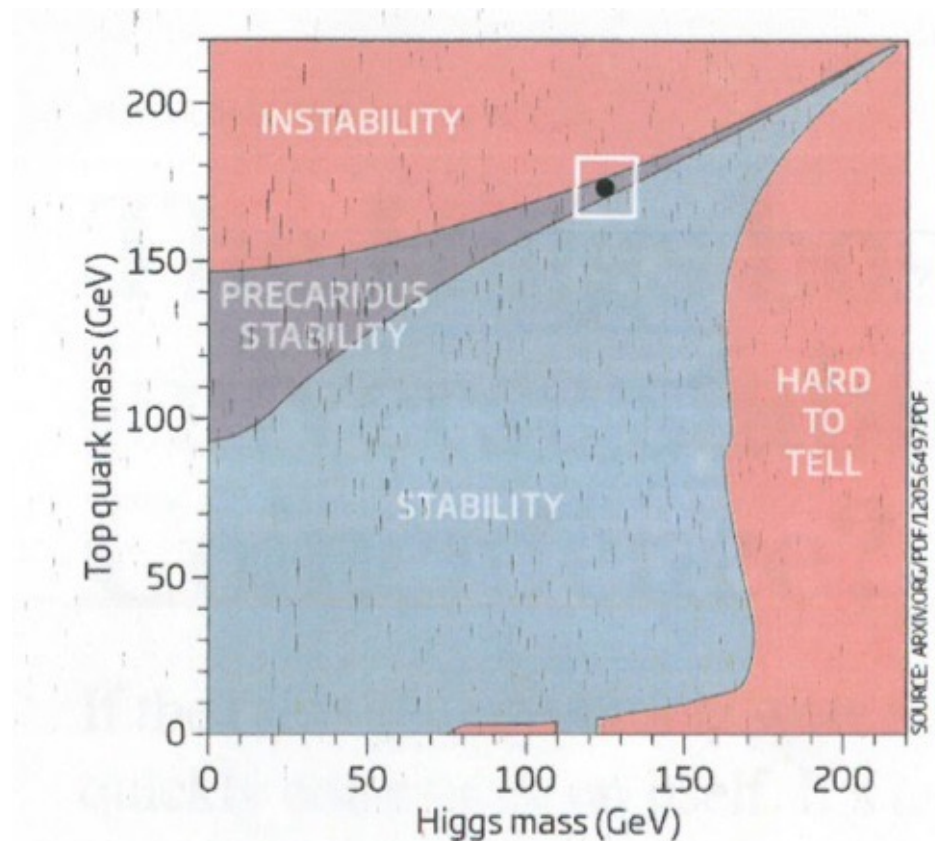
# HIGGS MASS

$M_H = 125 \text{ GeV} \Rightarrow$  Universe just stable

Geometric mean of dark energy mass and Planck mass

$\uparrow$   
 $10^{-4} \text{ eV}$

$\uparrow$   
 $10^{28} \text{ eV}$



# Q: What counts as an observer?

- A human?



- A mouse?



- A robot?

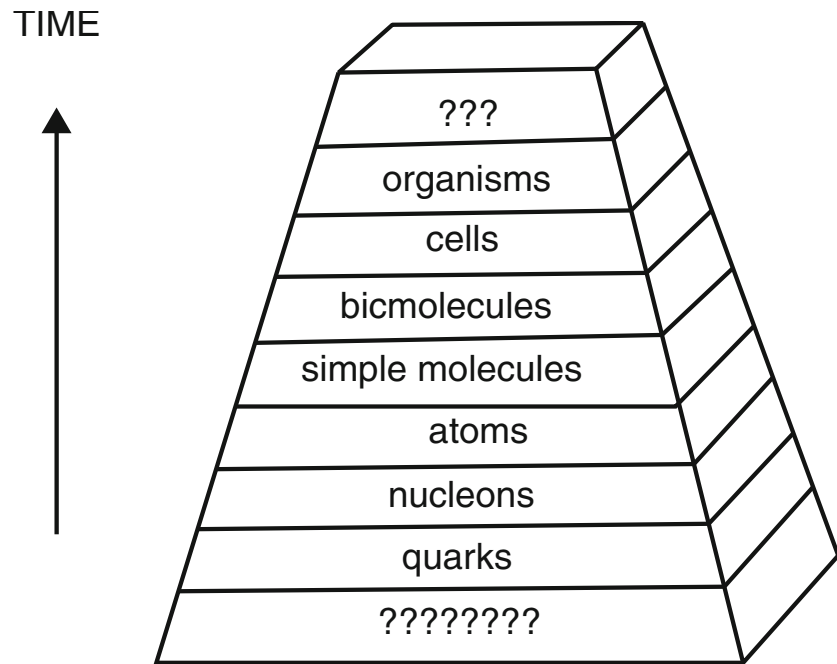


- A photon? ●

Tegmark

“Anthropos” = Man

# PYRAMID OF COMPLEXITY



Development of complexity during big bang requires many fine-tunings

Precise selection criterion may not be crucial because pyramid may inevitably culminate in mind once it starts to arise



I do not feel like an alien in this Universe. The more I examine the Universe and examine the details of its architecture, the more evidence I find that the Universe in some sense must have known we were coming. (Freeman Dyson 1979)

PRO



The influence of the anthropic principle on contemporary cosmological models has been sterile. It has explained nothing and it has even had a negative influence. I would opt for rejecting the anthropic principle as needless clutter in the conceptual repertoire of science. (Heinz Pagels 1972)

ANTI



The anthropic principle is a middle ground between the primitive anthropocentrism of the pre-Copernican age and the equally unjustifiable antithesis that no place or time in the Universe can be privileged in any way. (Brandon Carter 1974)

MIDDLE WAY

# EXPLANATIONS OF FINE-TUNINGS

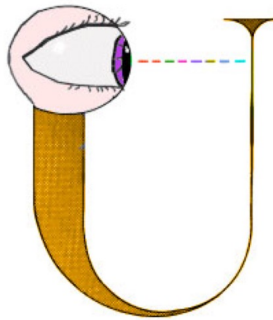
God created universe?



Theology

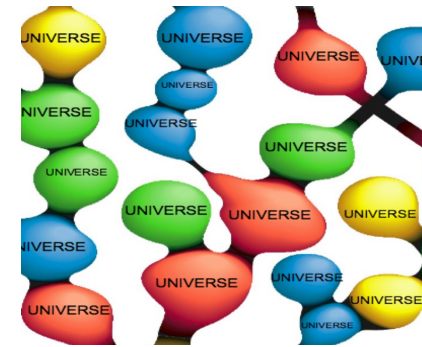


Consciousness creates Universe?



Philosophy

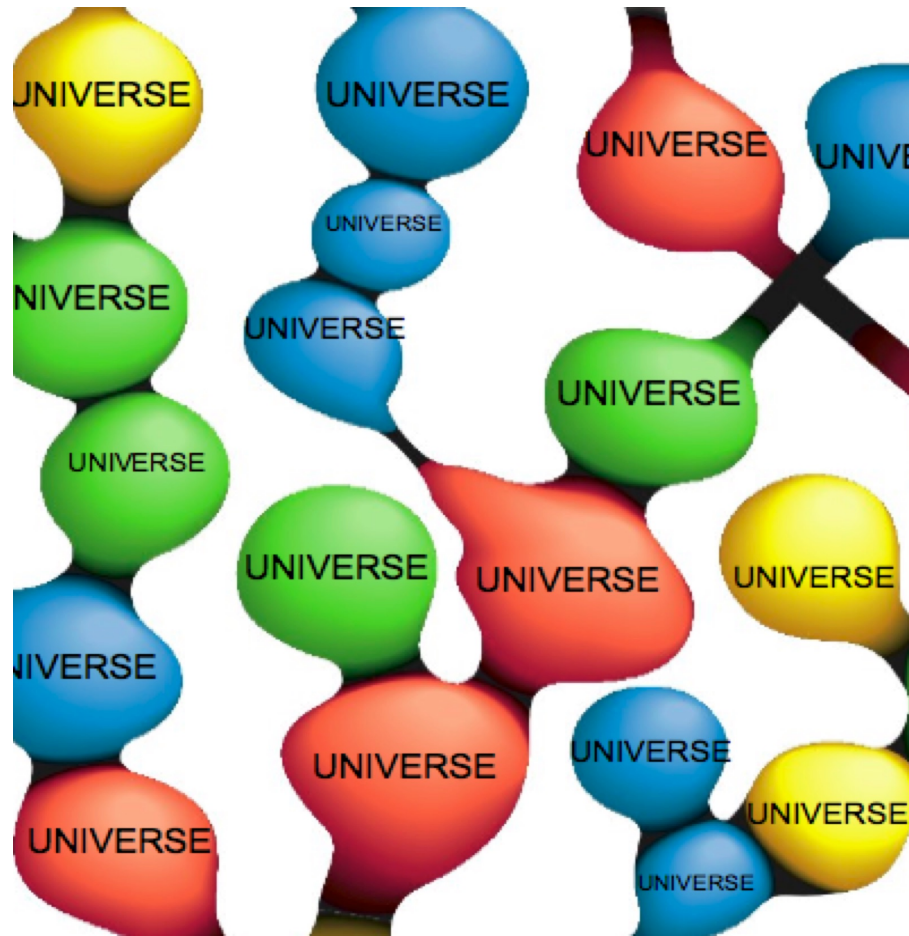
Selection effect in multiverse?



Physics?

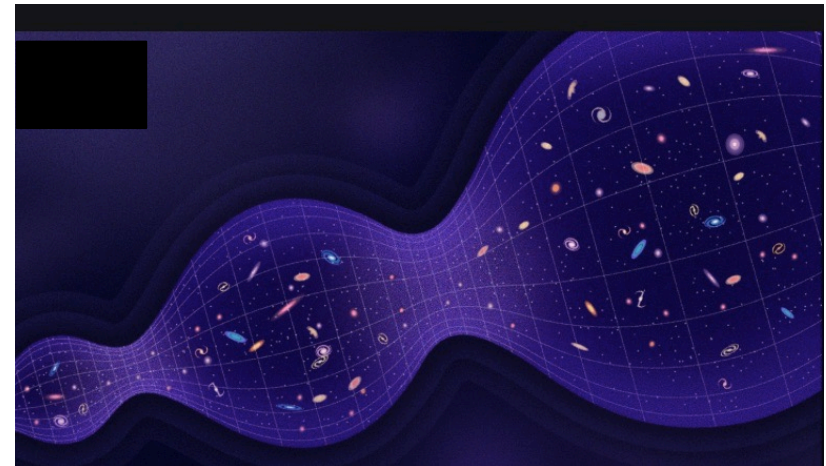
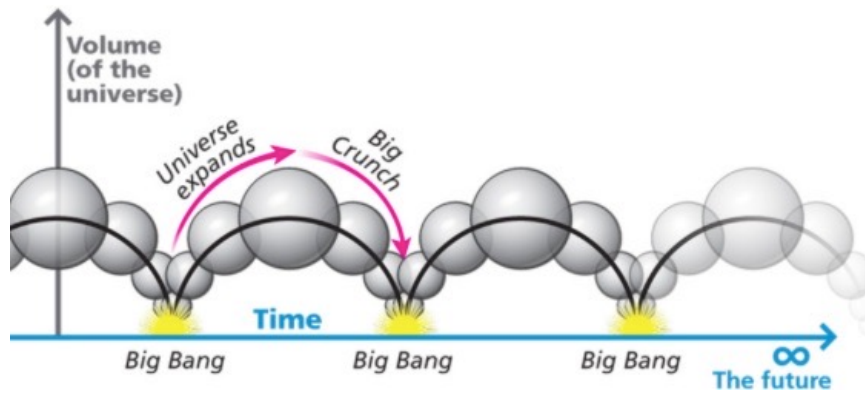
de Chardin Omega Point versus Bainbridge Omicron point!

# Eternal inflation



Many universes in space and time

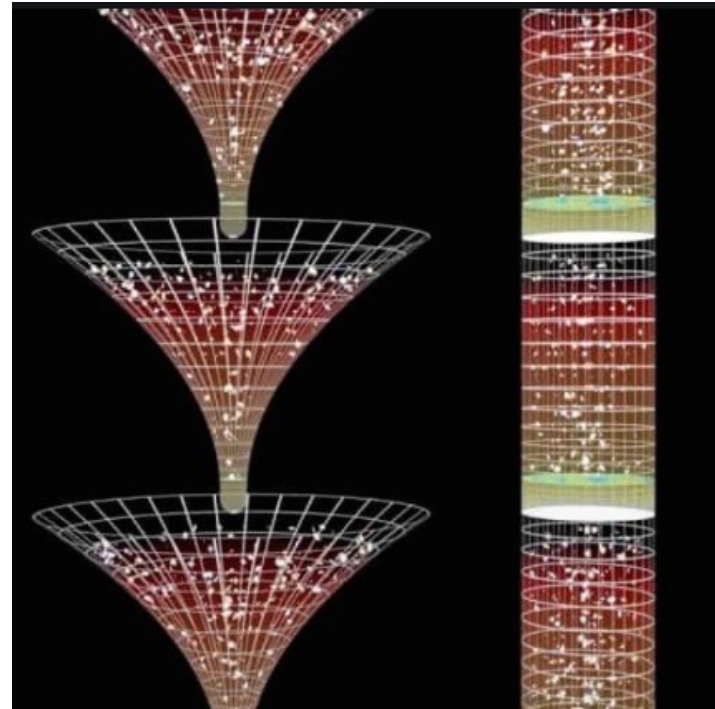
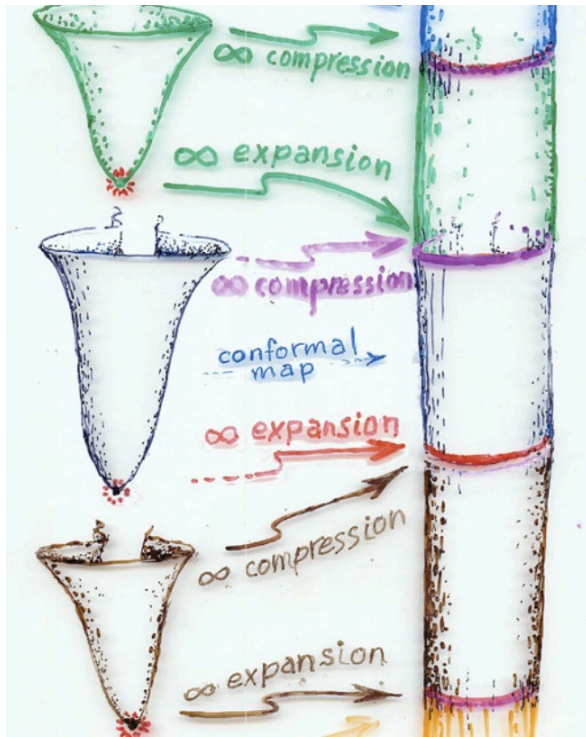
# Cyclic Universe



Many universes in time

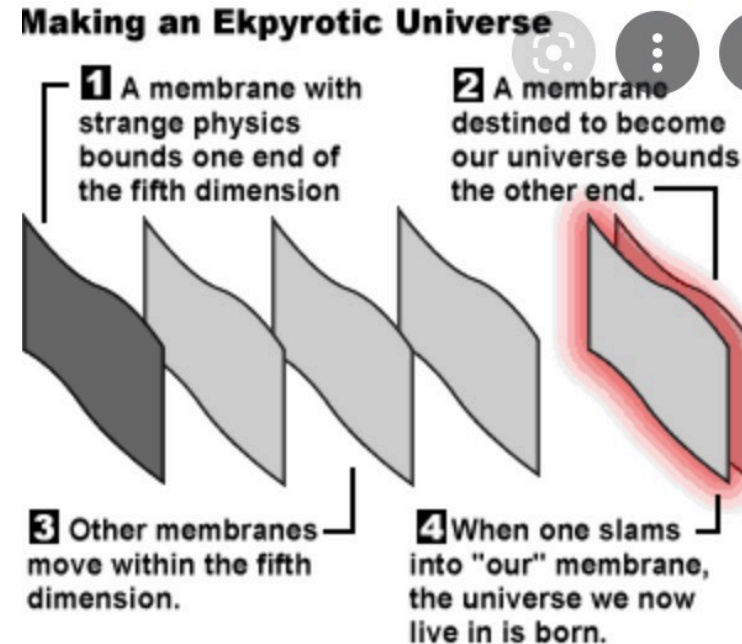
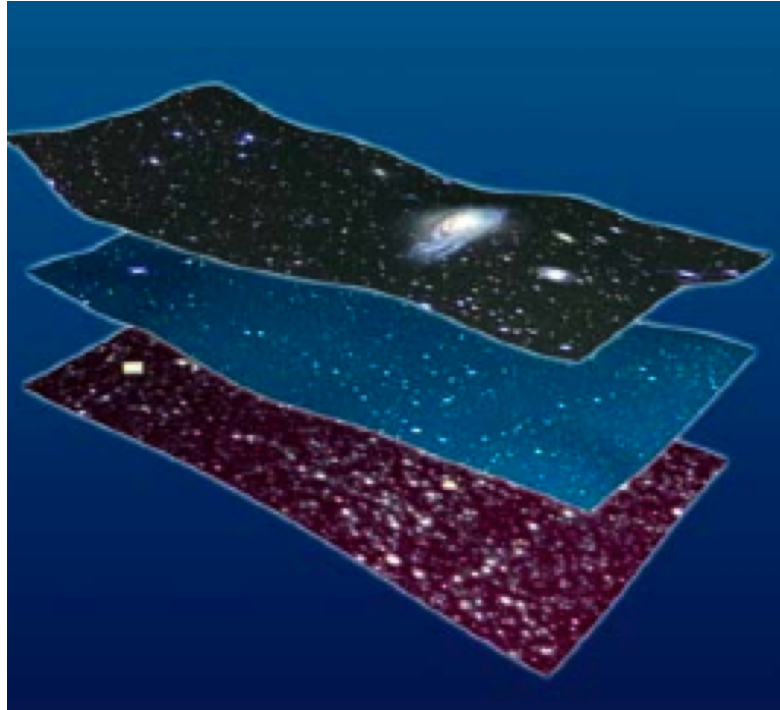


# Conformal Cyclic Model



Successive stupendously long aeons (Penrose)

# Branes

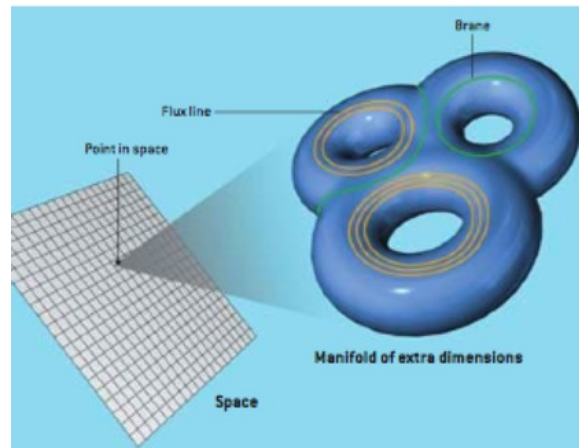


Many universes in 5th dimension

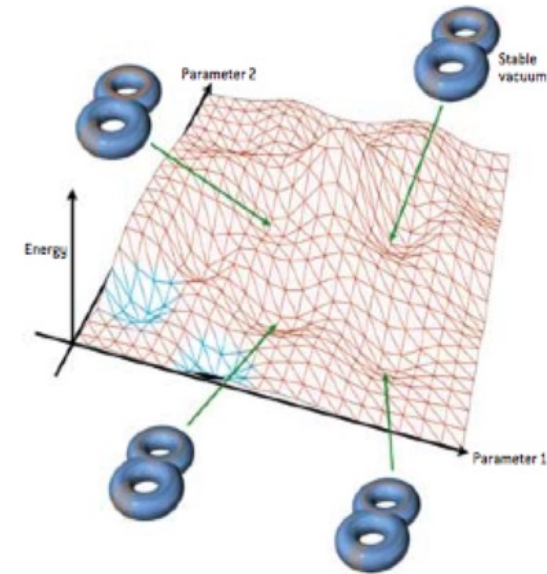
Collision between branes => big bang

# THE STRING THEORY LANDSCAPE

The theory of strings predicts that the universe might occupy one random “valley” out of a virtually infinite selection of valleys in a vast landscape of possibilities



$10^{500}$  vacuum states

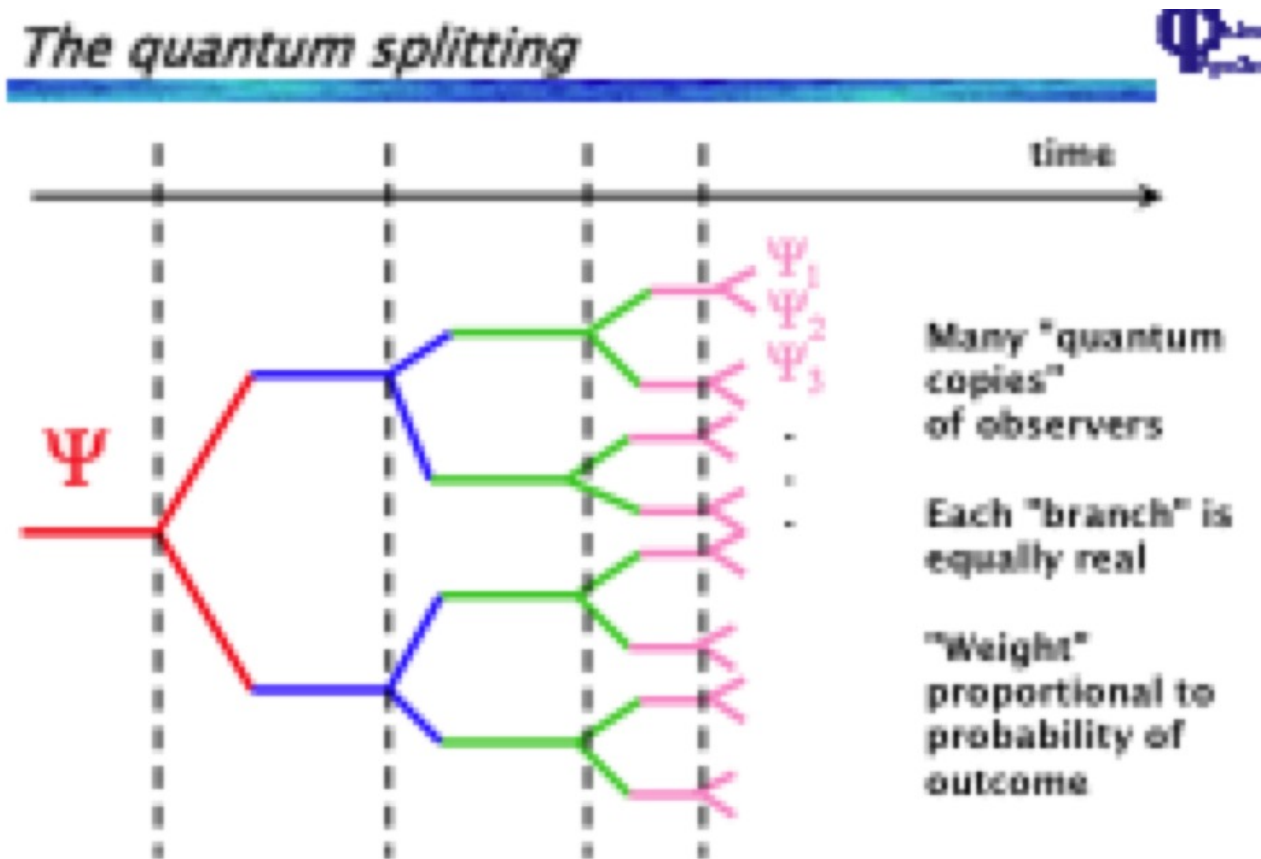


Cosmol' constant 120 orders of magnitude larger than expected

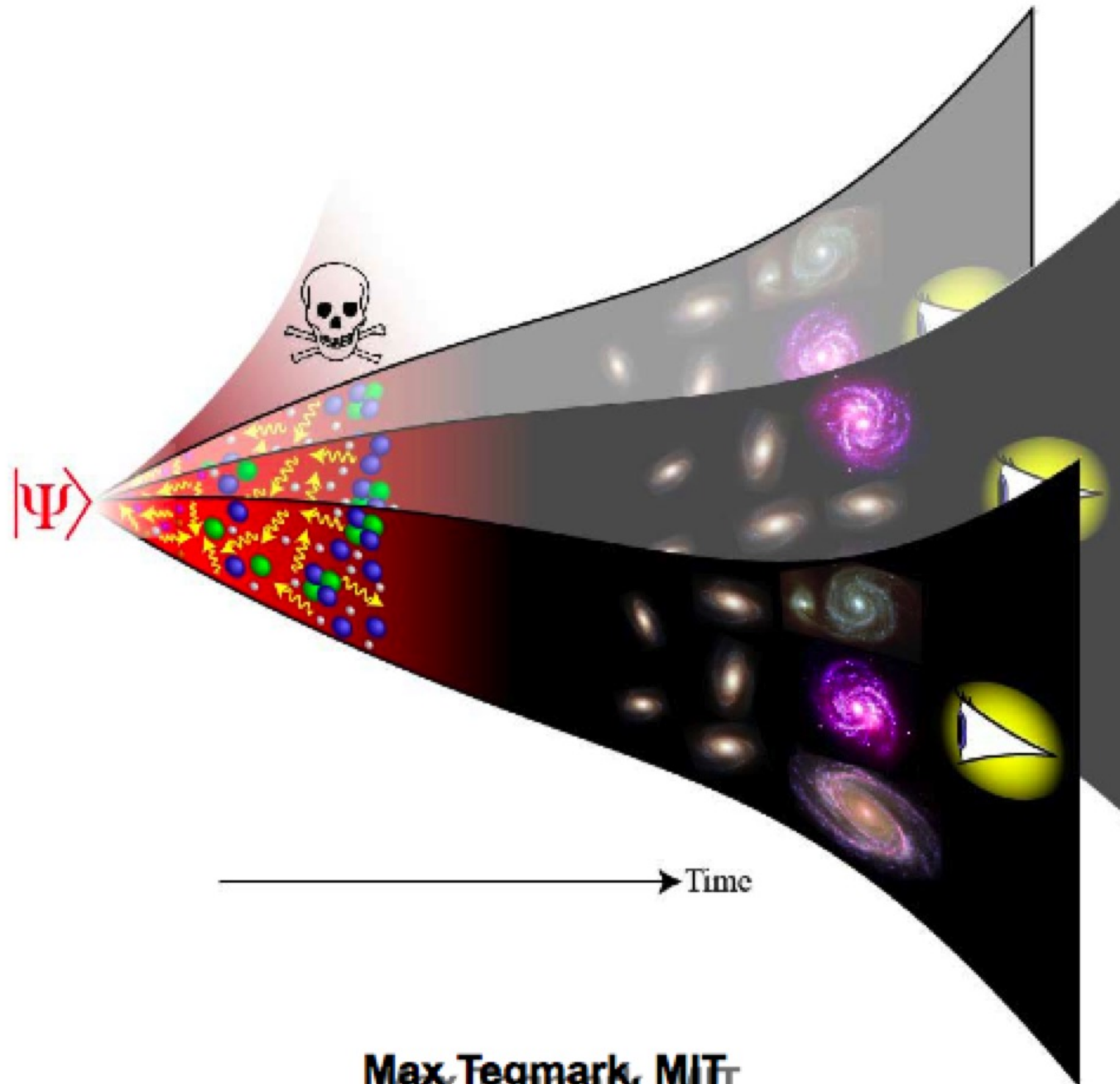
$$10^{-56}\text{cm}^{-2} \vee 10^{66}\text{cm}^{-2}$$

Galaxies cannot form unless  $\Omega_{\Lambda} < 0.6$  (Weinberg 1987)

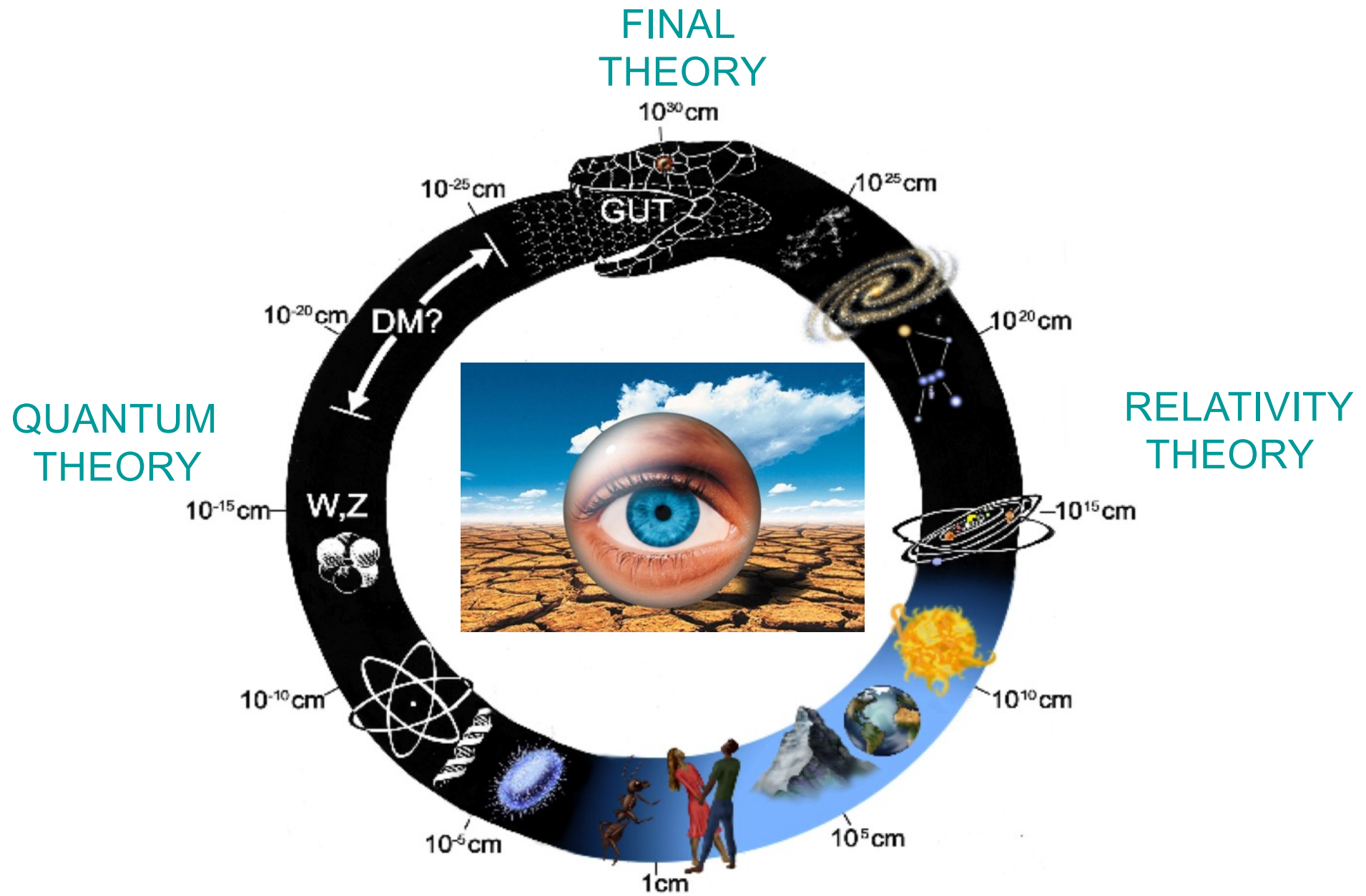
# “Many worlds” interpretation of quantum mechanics



# QUANTUM COSMOLOGY



Max Tegmark, MIT



Will marriage of quantum and relativity theory elucidate tunings?

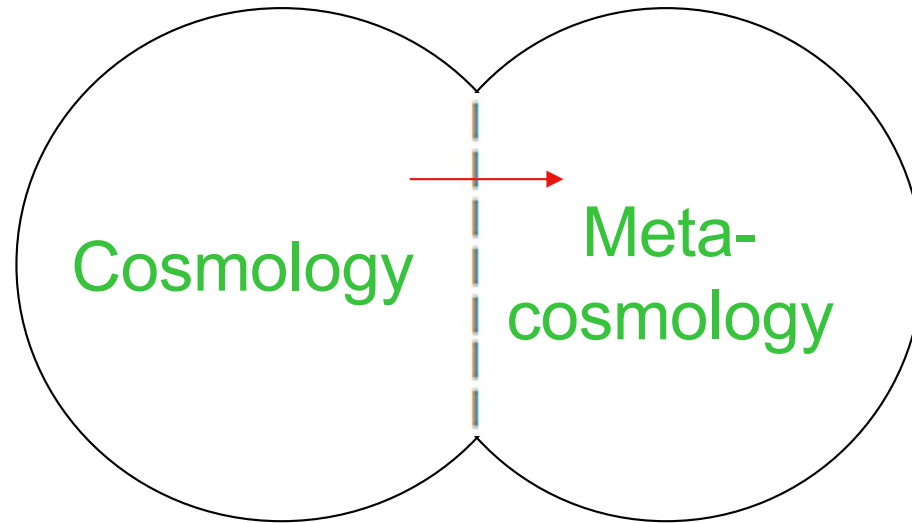
# OBJECTIONS TO ANTHROPIC PRINCIPLE

- Just a coincidence (how many? how fine?)

Victor Stenger "The Fallacy of Fine-Tuning: Why Universe is not Designed for Life". Luke Barnes "The Fine-Tuning of the Universe for Intelligent Life"

- Tunings are mainly *post hoc*  
Triple- $\alpha$  and  $\Lambda$  were predictions
- Too anthropocentric (carbon-based?)  
Fine tunings relate to *complexity* rather than life
- Anthropic arguments don't explain exact values  
Multiverse accommodates this
- Final theory may predict constants uniquely and hence tunings  
But it would remain coincidence that these values allows life
- Too philosophical or theological  
Need some explanation, metacosmology evolves to cosmology

## The cosmology/metacosmology boundary



is fuzzy and evolving

George Efstathiou “Such ideas may sound wacky now, just like the Big Bang theory did three generations ago. But then we got evidence and it changed the whole way we think about the universe”



# Universe need not be optimally biophilic

The anthropic principle and its implications for biological evolution

BY B. CARTER, F.R.S.

*Groupe d'Astrophysique Relativiste, Observatoire de Paris – Meudon,  
5 Place Jules Janssen, 92 Meudon, France*

In the form in which it was originally expounded, the *anthropic principle* was presented as a warning to astrophysical and cosmological theorists of the risk of error in the interpretation of astronomical and cosmological information unless due account is taken of the biological restraints under which the information was acquired. However, the converse message is also valid: biological theorists also run the risk of error in the interpretation of the evolutionary record unless they take due heed of the astrophysical restraints under which evolution took place. After an introductory discussion of the ordinary ('weak') anthropic principle and of its more contestable ('strong') analogue, a new application of the former to the problem of the evolution of terrestrial life is presented. It is shown that the evidence suggests that the evolutionary chain included at least one but probably not more than two links that were highly improbable (*a priori*) in the available time interval.

Phil. Tran. R. Soc.Lond. A 310, 347-363 (1983)

Another striking coincidence: time for life on Earth  $t_L \sim$  age of Earth  $t_0$

$t_L \sim t_0 \Rightarrow$  very unlikely

$t_L \ll t_0 \Rightarrow$  life frequent X

$t_L \gg t_0 \Rightarrow$  life very rare but must arise somewhere in infinite universe

We could be unique in Galaxy or even observable universe!

HAPPY BIRTHDAY BRANDON!



“What really interests me is whether God had any choice in the creation of the world”