Title: What\'s the trouble with the anthropic principle?

Date: Mar 20, 2007 11:00 AM

URL: http://pirsa.org/07030010

Abstract: Anthropic arguments based on selection effects for observers have been claimed to succesfully explain the measured value of the cosmological constant.In this talk I review the fundations of such claims in the context of probability theory and show that different (and equally legitimate) ways of assigning probabilities to candidate universes lead to totally different anthropic predictions. As an explicit example, I discuss a weighting scheme based on the total number of possible observations that observers can carry out over the entire lifetime of the Universe. I show that this leads to an extremely small probability for observing a value of the cosmological constant equal to or greater than what we now measure, in marked contrast with the usual result.
I also discuss principles of consistent probabilistic reasoning, showing that the anthropic principle as applied in most of the literature is logically inconsistent. I conclude that current implementations of the anthropic principle display a worrysome lack of predictivity, and cannot be used to explain the value of the cosmological constant, nor, likely, any other physical parameters.

WHAT'S THE TROUBLE WITH THE ANTHROPIC PRINCIPLE?

Roberto Trotta
(with Glenn Starkman, CWRU)

University of Oxford, Astrophysics
St Anne's College
&
Lockyer Fellow of the Royal Astronomical Society

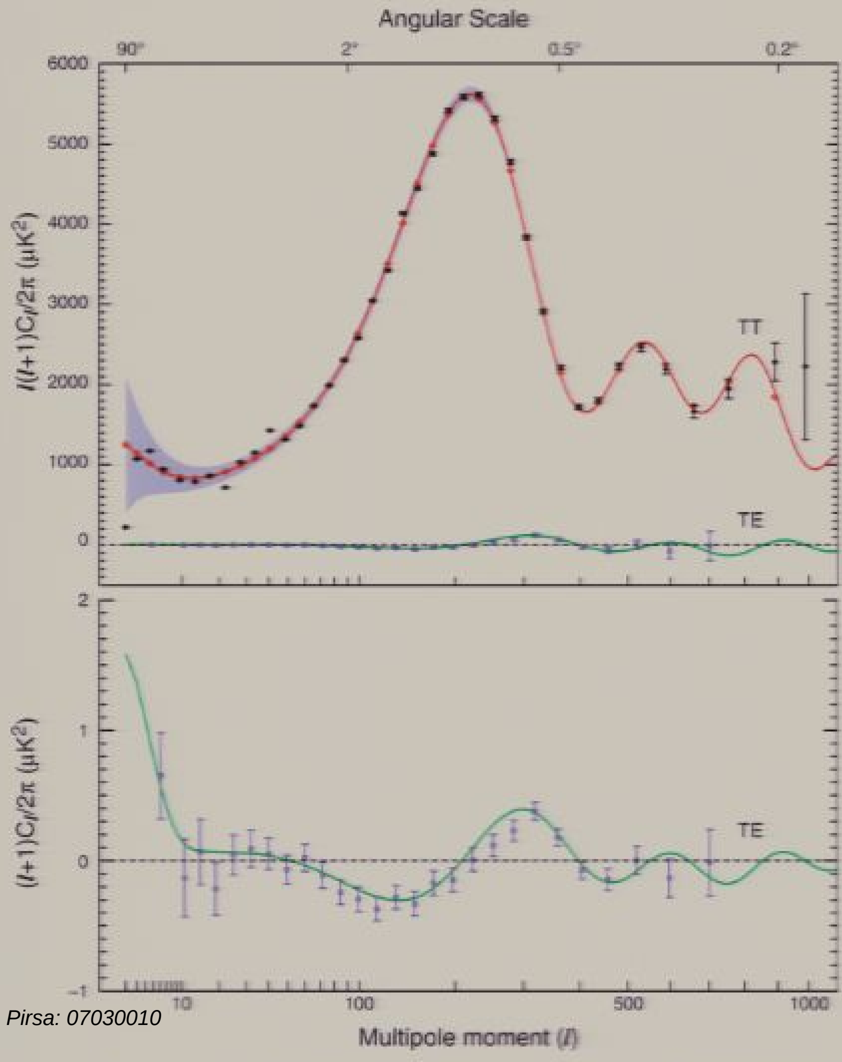
WHAT'S THE TROUBLE WITH THE ANTHROPIC PRINCIPLE?

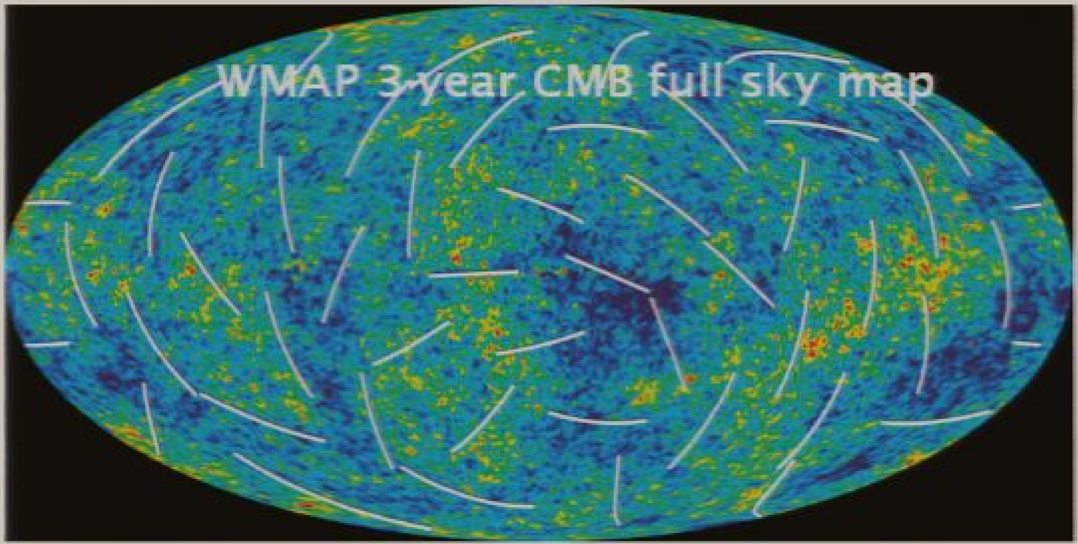
Roberto Trotta
(with Glenn Starkman, CWRU)

University of Oxford, Astrophysics
St Anne's College
&
Lockyer Fellow of the Royal Astronomical Society

Pinning down the cosmic recipe

- *Quality & quantity of data has increased dramatically*

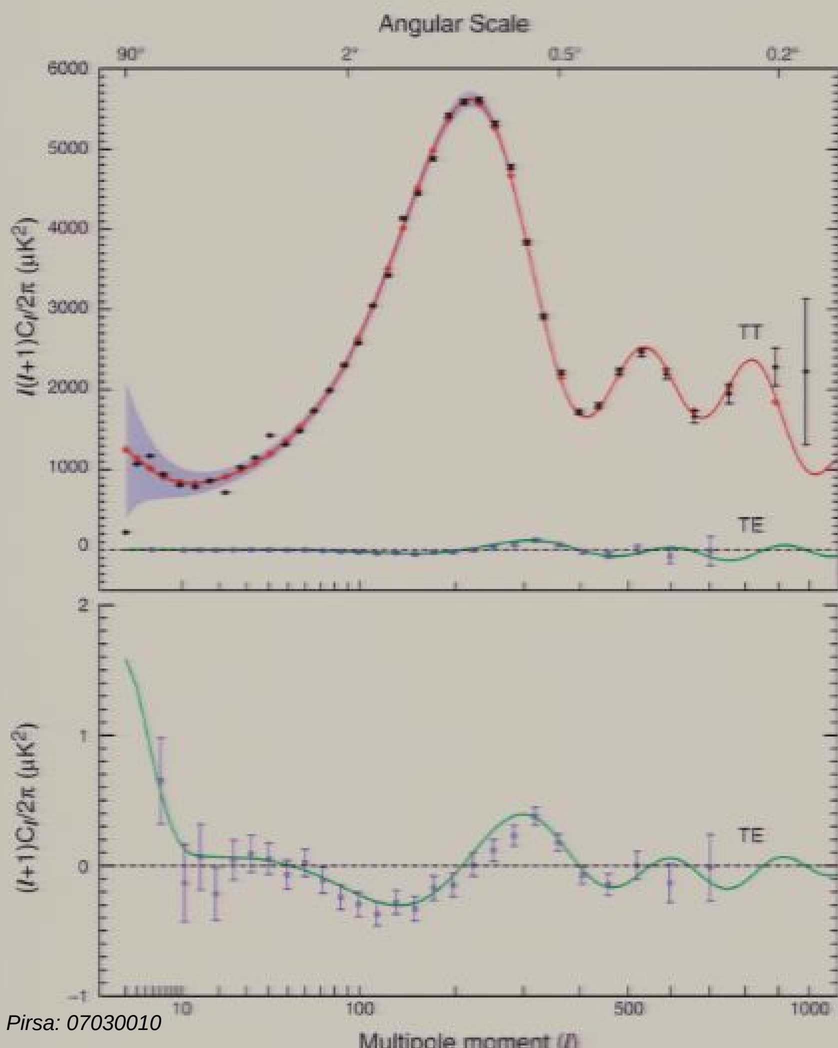


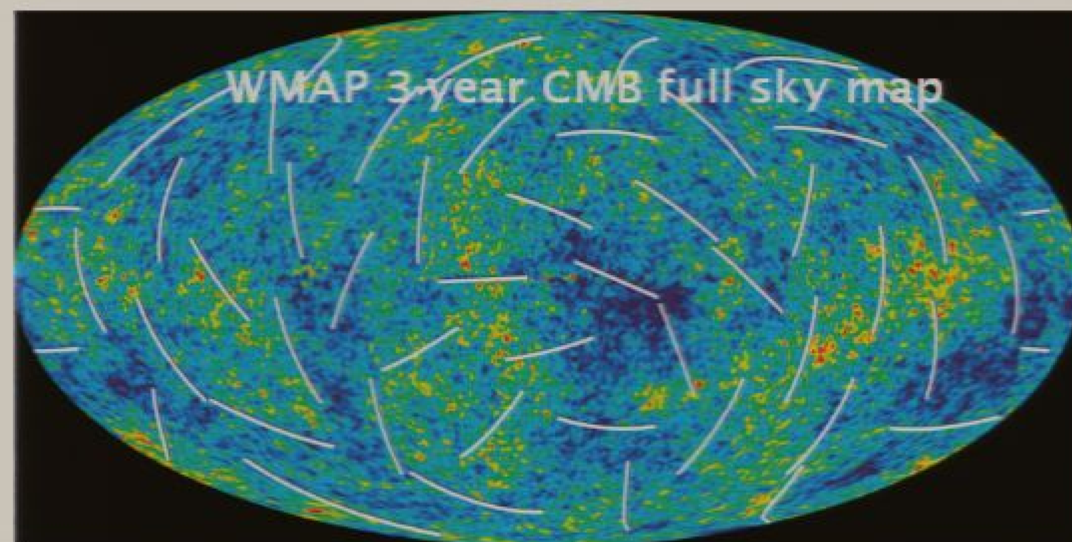


Page et al (2006), Bennett et al (2006), Spergel et al (2006)

Pinning down the cosmic recipe

- *Quality & quantity of data has increased dramatically*





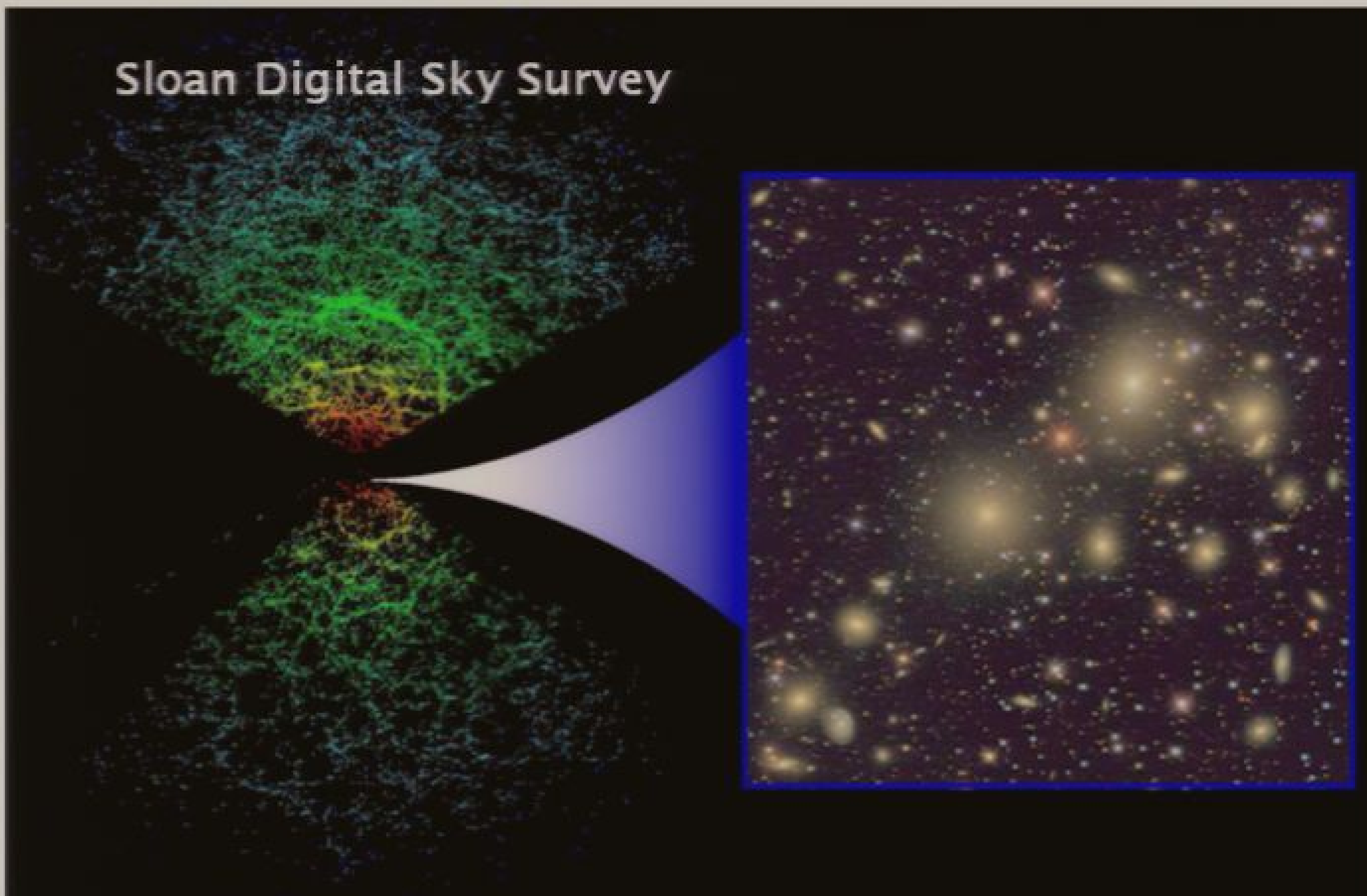
CMB anisotropies probe the high-z Universe:

$$\Omega_b h^2, \Omega_m/\Omega_r, D_A/r_s, n_S, A$$

Page et al (2006), Bennett et al (2006), Spergel et al (2006)

Large scale structure

- *Growth of structures and remnant of the acoustic oscillations in the early Universe*



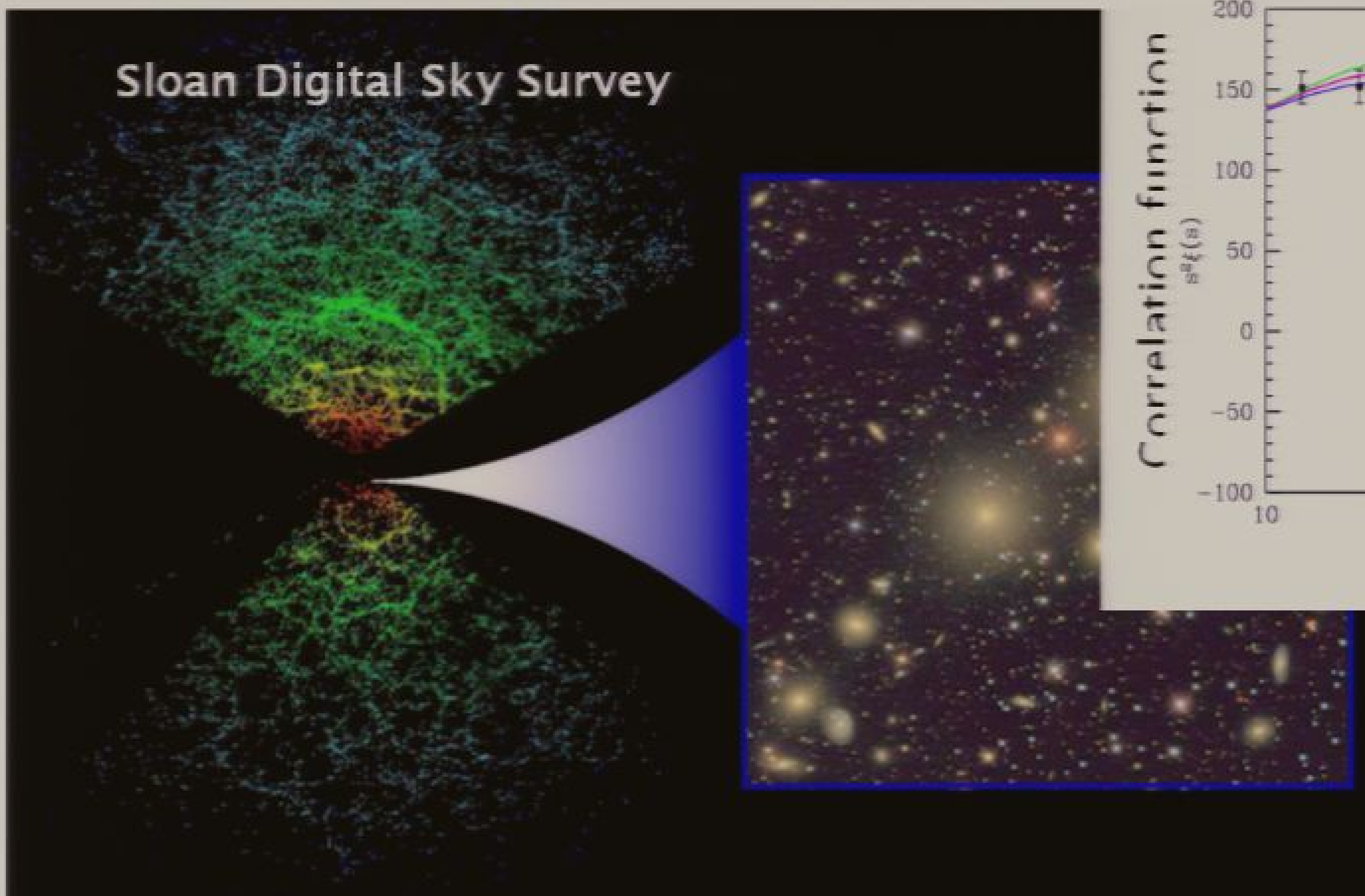
$\Omega_m h, \Omega_b/\Omega_m, n_S, \sigma_8$

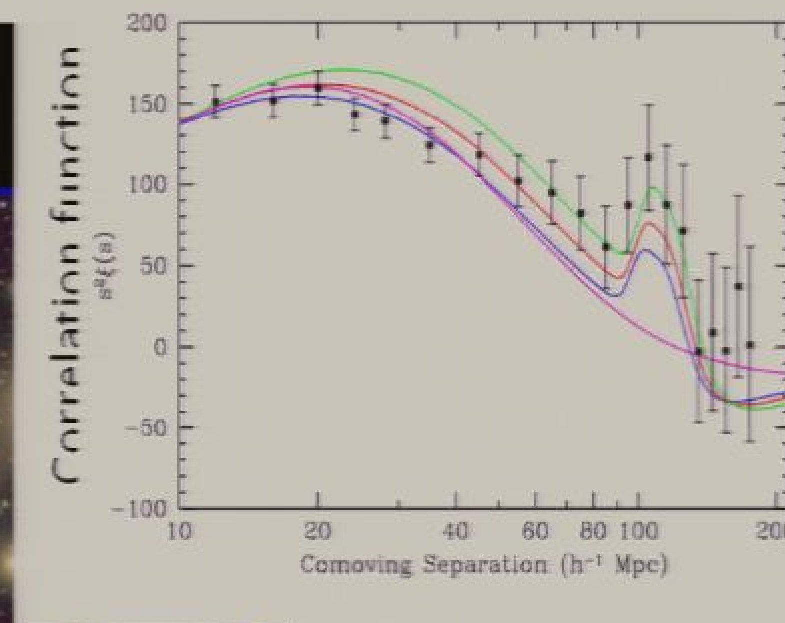
Eisenstein et al (2005)

Large scale structure

- *Growth of structures and remnant of the acoustic oscillations in the early Universe*

BAO signature (SDSS LRG sample)



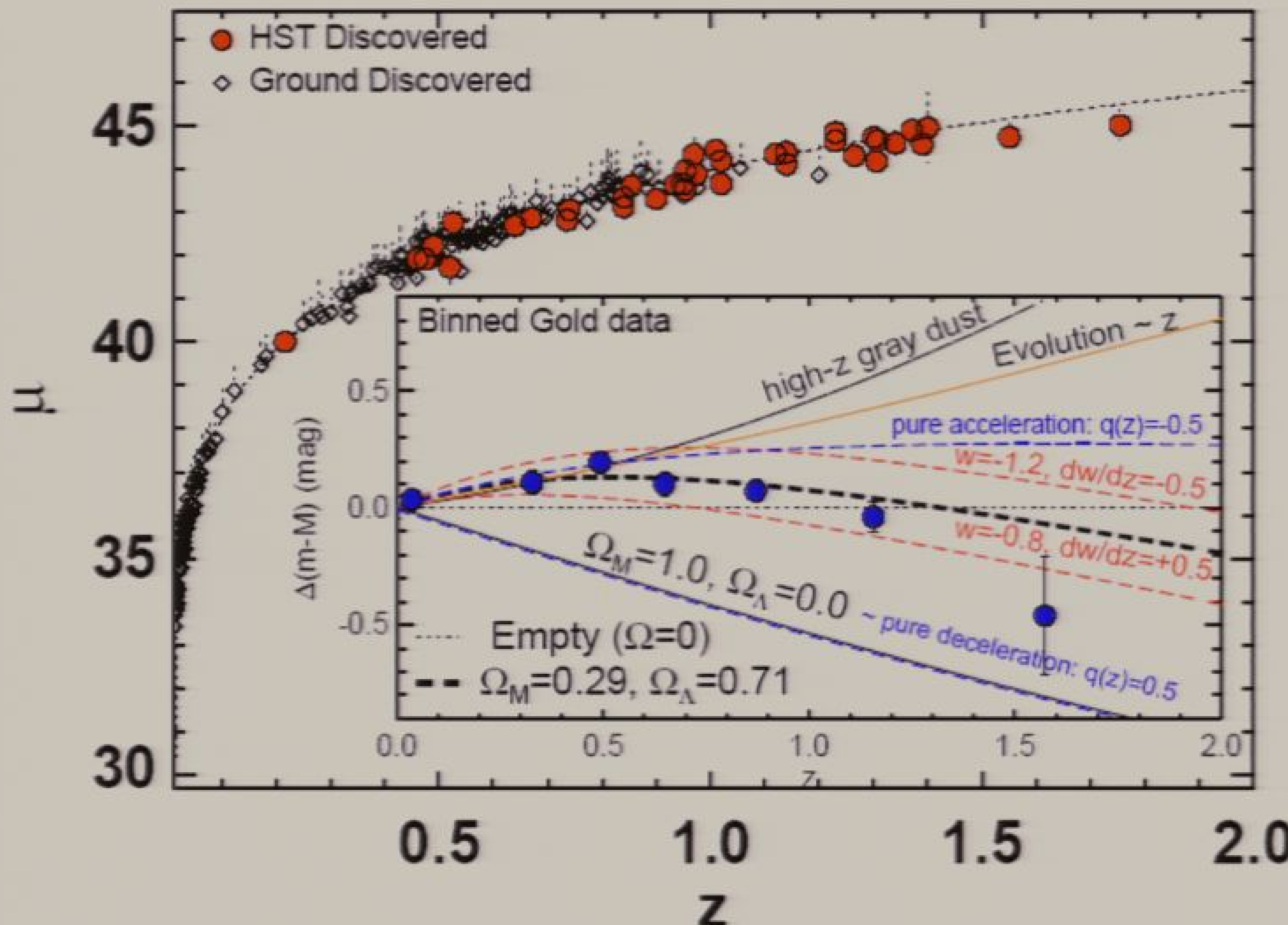


$\Omega_m h$, Ω_b/Ω_m, n_S, σ_8

Eisenstein et al (2005)

Luminosity distance measurements

- Supernovae type Ia as (almost) standard candles

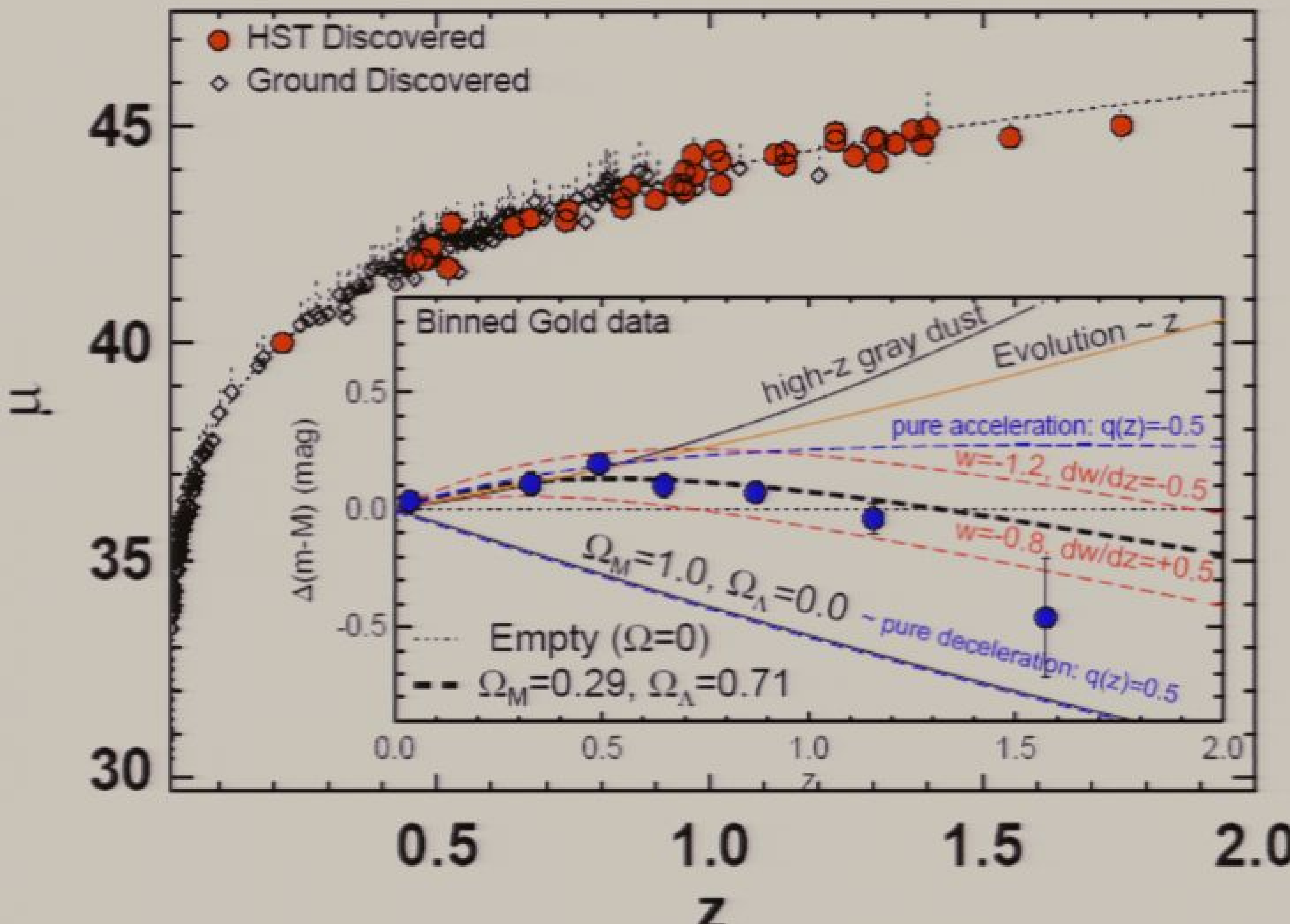


Riess et al (2006)

Luminosity distance measurements

Oxford Physics

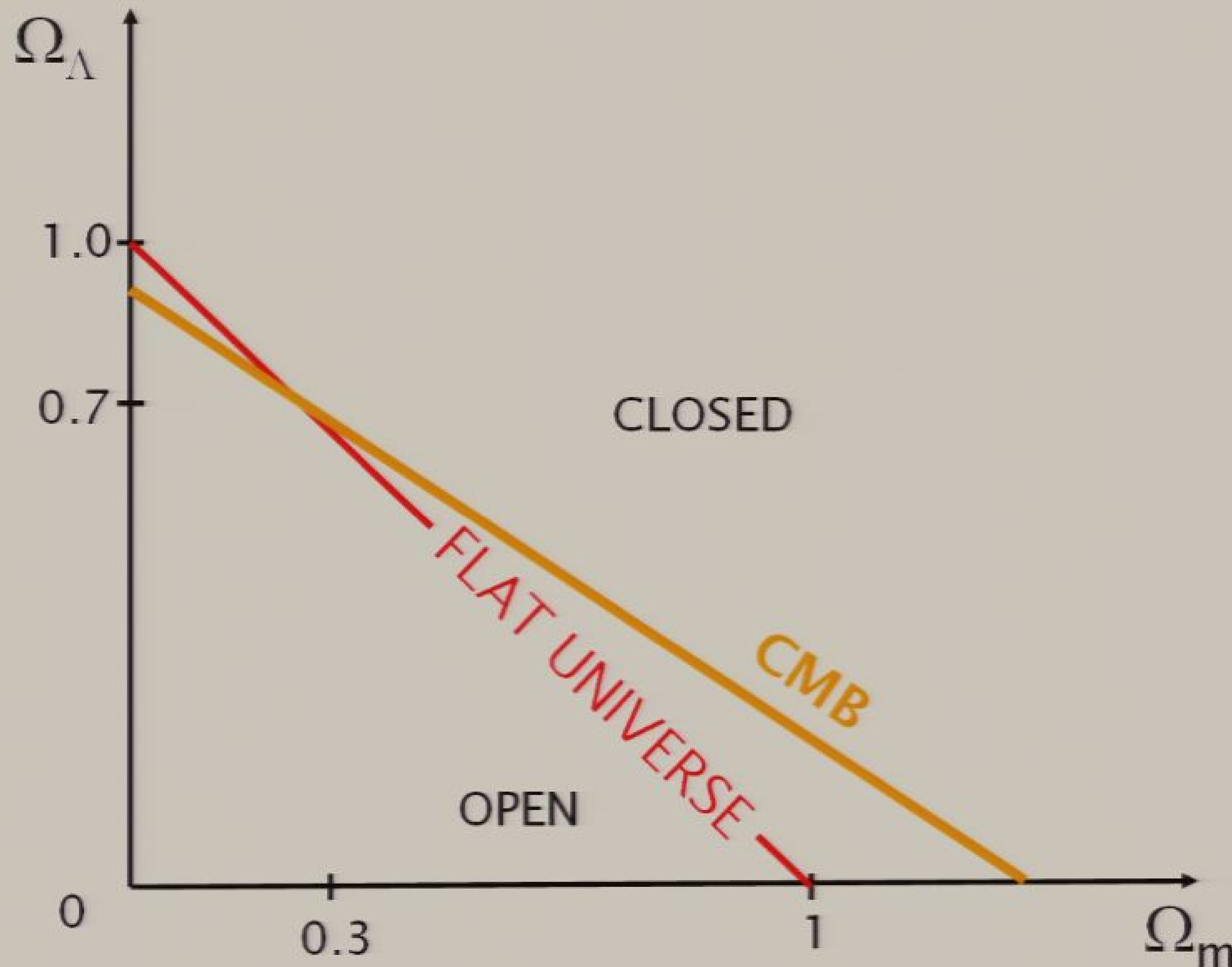
- *Supernovae type Ia as (almost) standard candles*



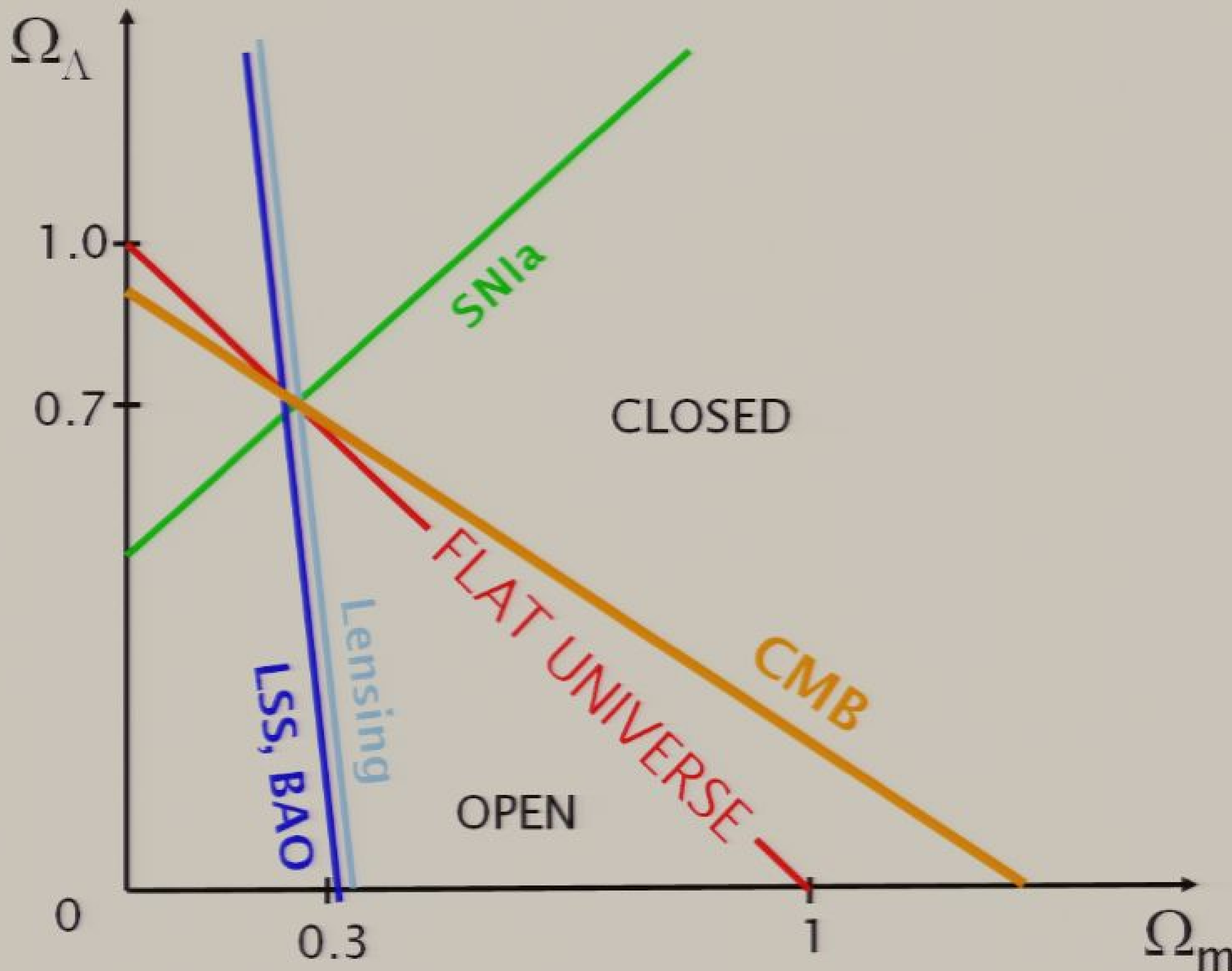
Riess et al (2006)

$D_L(z)$ (a function of Ω_m, Ω_Λ, Ω_κ, H_0)

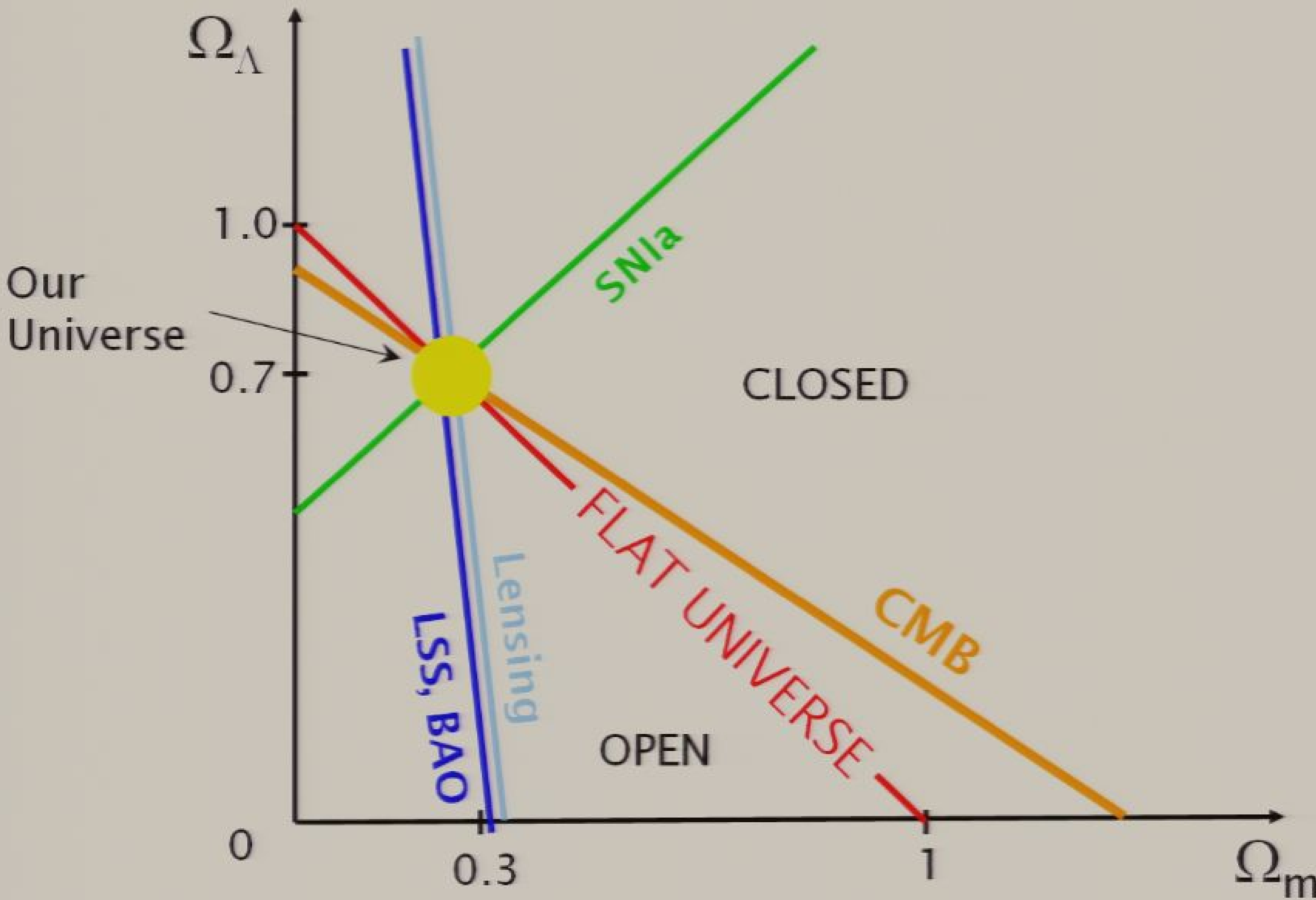
Accumulating evidence



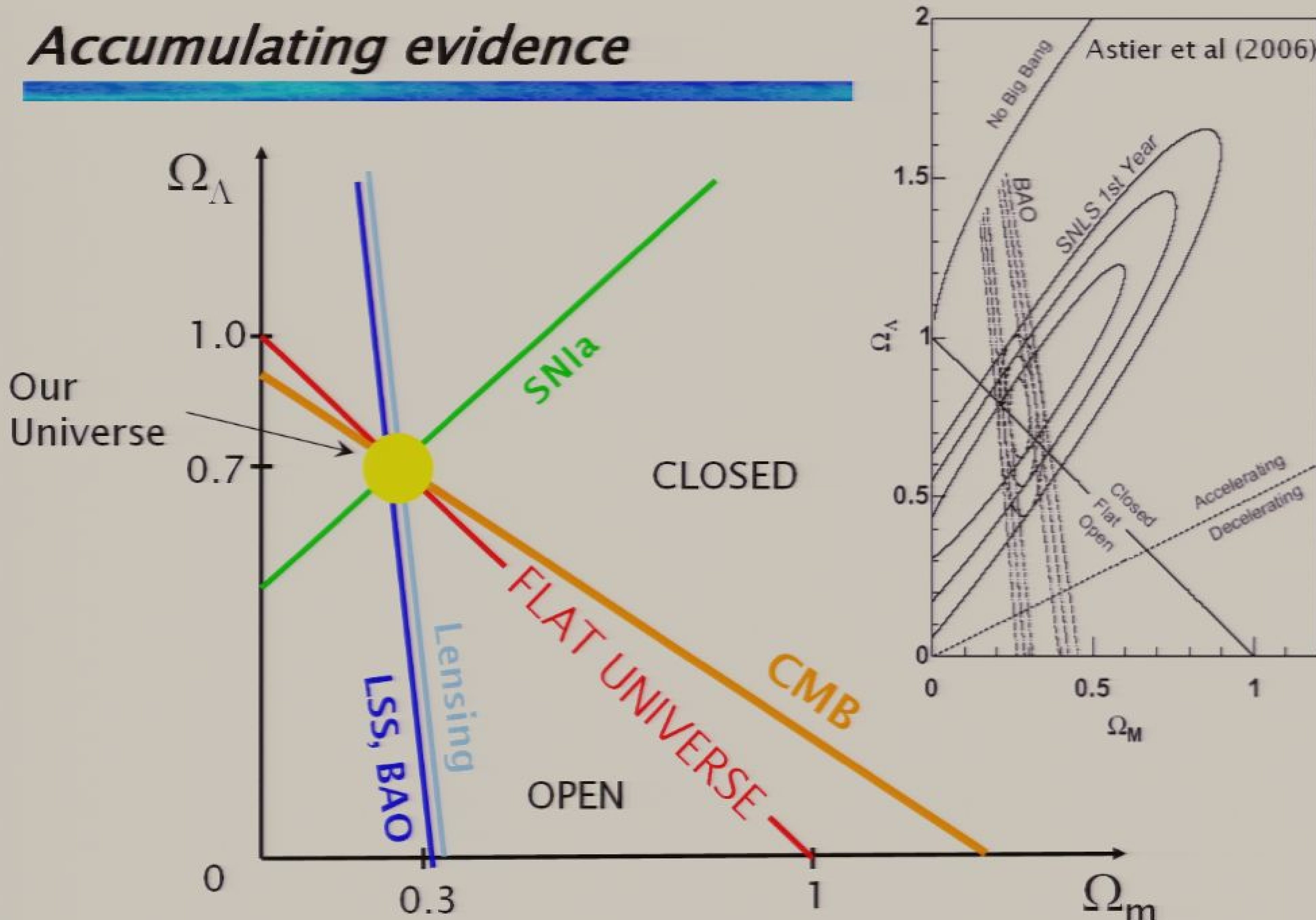
Accumulating evidence



Accumulating evidence



Accumulating evidence



$\Omega_m = 0.271 \pm 0.020, \Omega_\Lambda = 0.751 \pm 0.082$

The accelerating Universe

Oxford Physics

Dark energy: a component with (possibly time dependent) negative pressure

$$\frac{d}{dt}\left(\frac{\dot{a}}{a}\right) = -\frac{4\pi G}{3}\rho(1+3w)$$

$w(z) = p/\rho < -1/3$

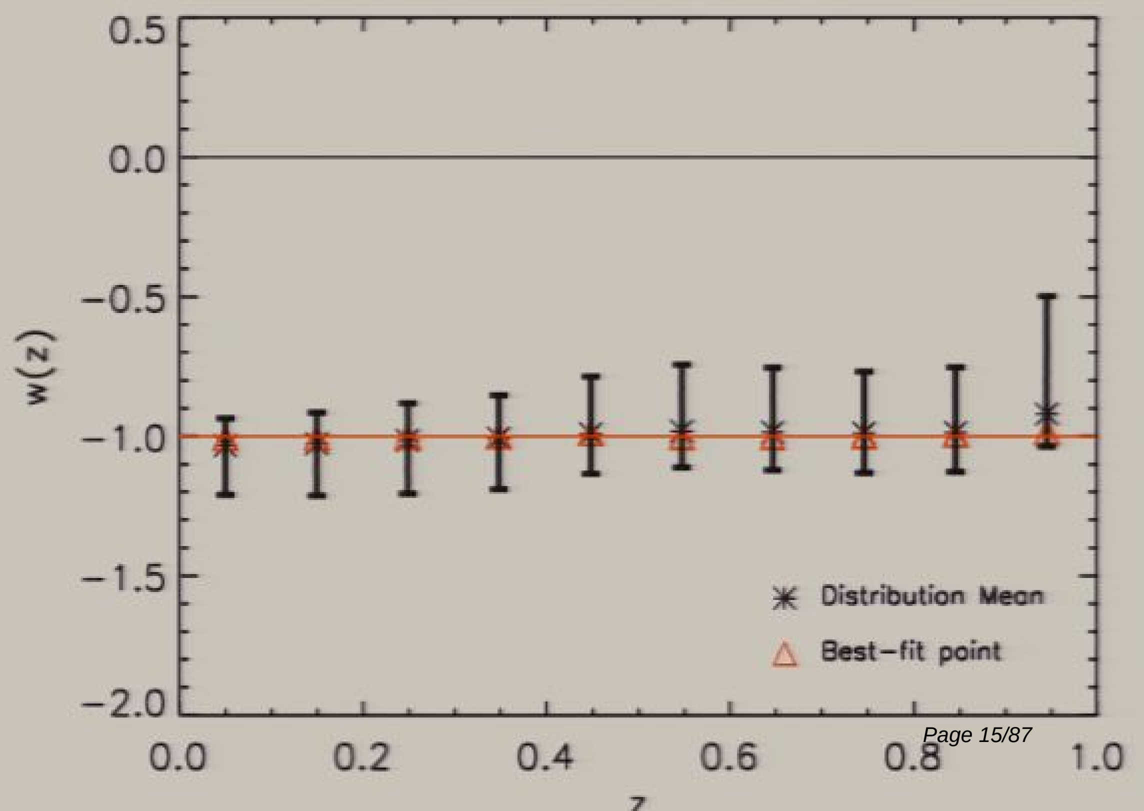
The accelerating Universe

Dark energy: a component with (possibly time dependent) negative pressure

$$\frac{d}{dt}\left(\frac{\dot{a}}{a}\right) = -\frac{4\pi G}{3}\rho(1+3w)$$

$w(z) = p/\rho < -1/3$

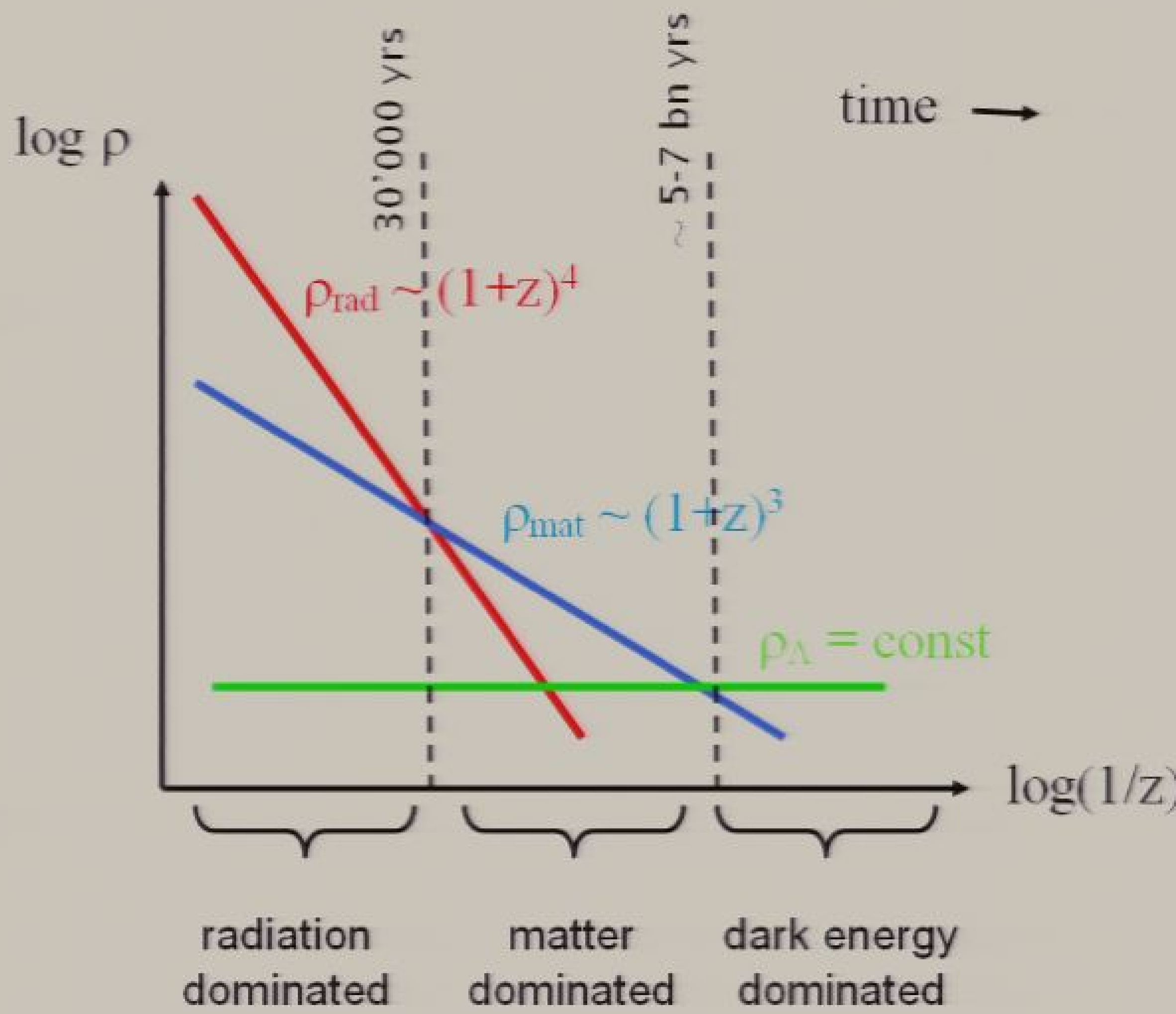
So far, all data compatible with the hypothesis of a cosmological constant ($w = -1$)



Zunckel & Trotta, astro-ph/0702695

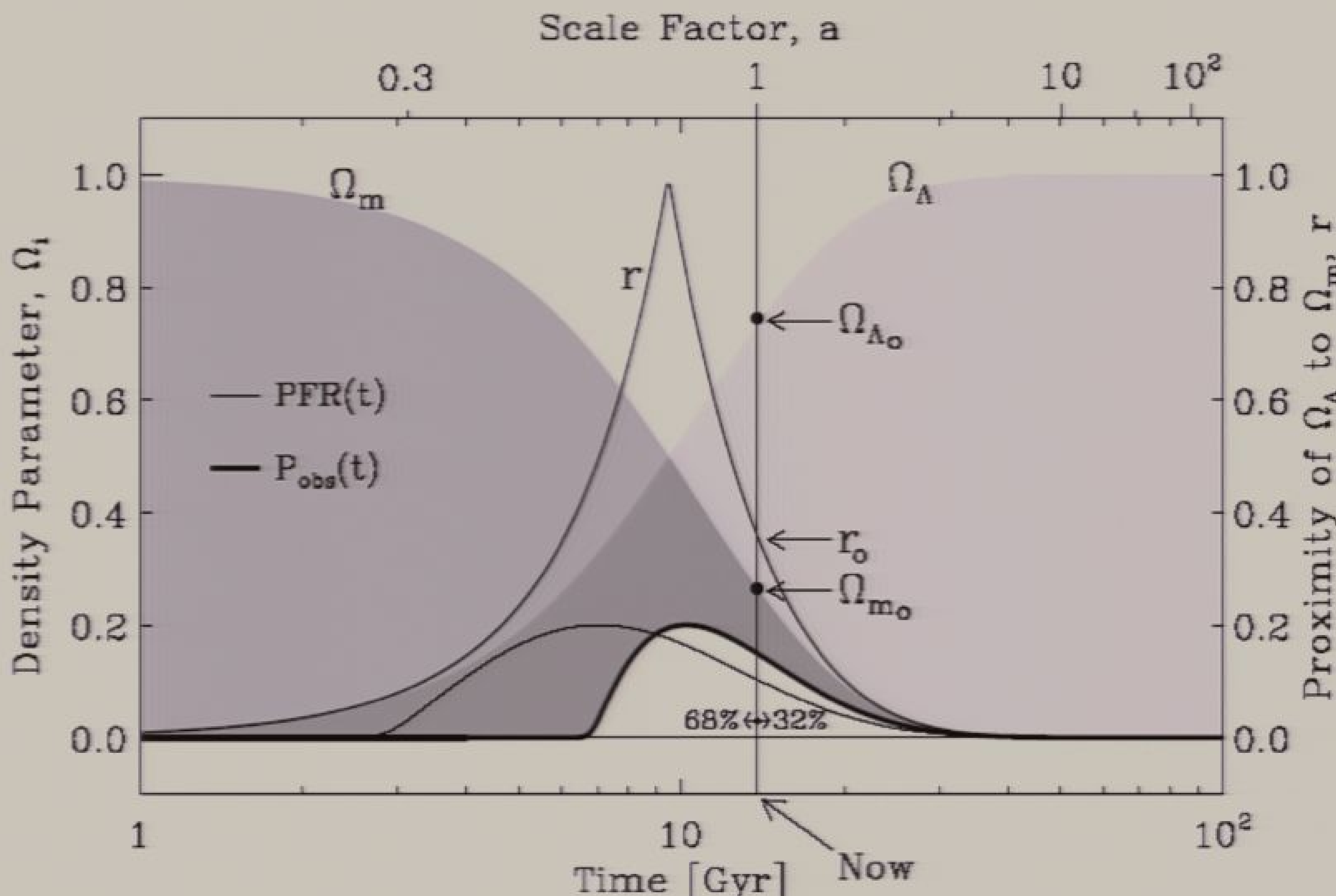
The coincidence problem

- *Since* $\rho_{mat} \propto (1+z)^3$ *but* $\rho_\Lambda = const,$ *matter-cosmological constant equality epoch is at* $z \sim 0.7$
- *Why are the dark matter and cosmological constant energy densities of the same order just today?*



A temporal selection effect?

Lineweaver & Egan, astro-ph/0703429



More anthropic coincidences?

More anthropic coincidences?

Oxford Physics

Coincidence #1: the strength of the strong force

- Apparently fine tuned within 1%
- Weaker: no D fusion; stronger: runaway H burning

More anthropic coincidences?

Coincidence #1: the strength of the strong force

- Apparently fine tuned within 1%
- Weaker: no D fusion; stronger: runaway H burning

Coincidence #2: the strength of the EM force

- The EM force is 10^{40} times stronger than gravity. This numerical coincidence ensures that main sequence stars are stable

More anthropic coincidences?

Oxford Physics

Coincidence #1: the strength of the strong force

- Apparently fine tuned within 1%
- Weaker: no D fusion; stronger: runaway H burning

Coincidence #2: the strength of the EM force

- The EM force is 10^{40} times stronger than gravity. This numerical coincidence ensures that main sequence stars are stable

Coincidence #3: the proton–neutron mass difference

- Key to Big Bang Nucleosynthesis. Fine tuned within 0.1%

More anthropic coincidences?

Coincidence #1: the strength of the strong force

- Apparently fine tuned within 1%
- Weaker: no D fusion; stronger: runaway H burning

Coincidence #2: the strength of the EM force

- The EM force is 10^{40} times stronger than gravity. This numerical coincidence ensures that main sequence stars are stable

Coincidence #3: the proton–neutron mass difference

- Key to Big Bang Nucleosynthesis. Fine tuned within 0.1%

Coincidence #4: the number of spatial dimensions

More anthropic coincidences?

Oxford Physics

Coincidence #1: the strength of the strong force

- *Apparently fine tuned within 1%*
- *Weaker: no D fusion; stronger: runaway H burning*

Coincidence #2: the strength of the EM force

- *The EM force is 10^{40} times stronger than gravity. This numerical coincidence ensures that main sequence stars are stable*

Coincidence #3: the proton–neutron mass difference

- *Key to Big Bang Nucleosynthesis. Fine tuned within 0.1%*

Coincidence #4: the number of spatial dimensions

Coincidence #5: ^{12}C resonance

More anthropic coincidences?

Coincidence #1: the strength of the strong force

- *Apparently fine tuned within 1%*
- *Weaker: no D fusion; stronger: runaway H burning*

Coincidence #2: the strength of the EM force

- *The EM force is 10^{40} times stronger than gravity. This numerical coincidence ensures that main sequence stars are stable*

Coincidence #3: the proton–neutron mass difference

- *Key to Big Bang Nucleosynthesis. Fine tuned within 0.1%*

Coincidence #4: the number of spatial dimensions

Coincidence #5: ^{12}C resonance

- *The production of ^{12}C occurs resonantly via a "triple–alpha process". Energy level fine tuned within 1%*

Fred Hoyle (1915-2001)

Possible viewpoints

Possible viewpoints

- *Deeper symmetries in the laws of Nature*

What determined those symmetries in the first place?

Possible viewpoints

- *Deeper symmetries in the laws of Nature* — *What determined those symmetries in the first place?*
- *Design* — *Outside the scope of scientific enquiry*

Possible viewpoints

Deeper symmetries in the laws of Nature	What determined those symmetries in the first place?
Design	Outside the scope of scientific enquiry
Any parameters will do	No explanatory power, probably wrong

Possible viewpoints

- *Deeper symmetries in the laws of Nature*

  What determined those symmetries in the first place?

- *Design*

  Outside the scope of scientific enquiry

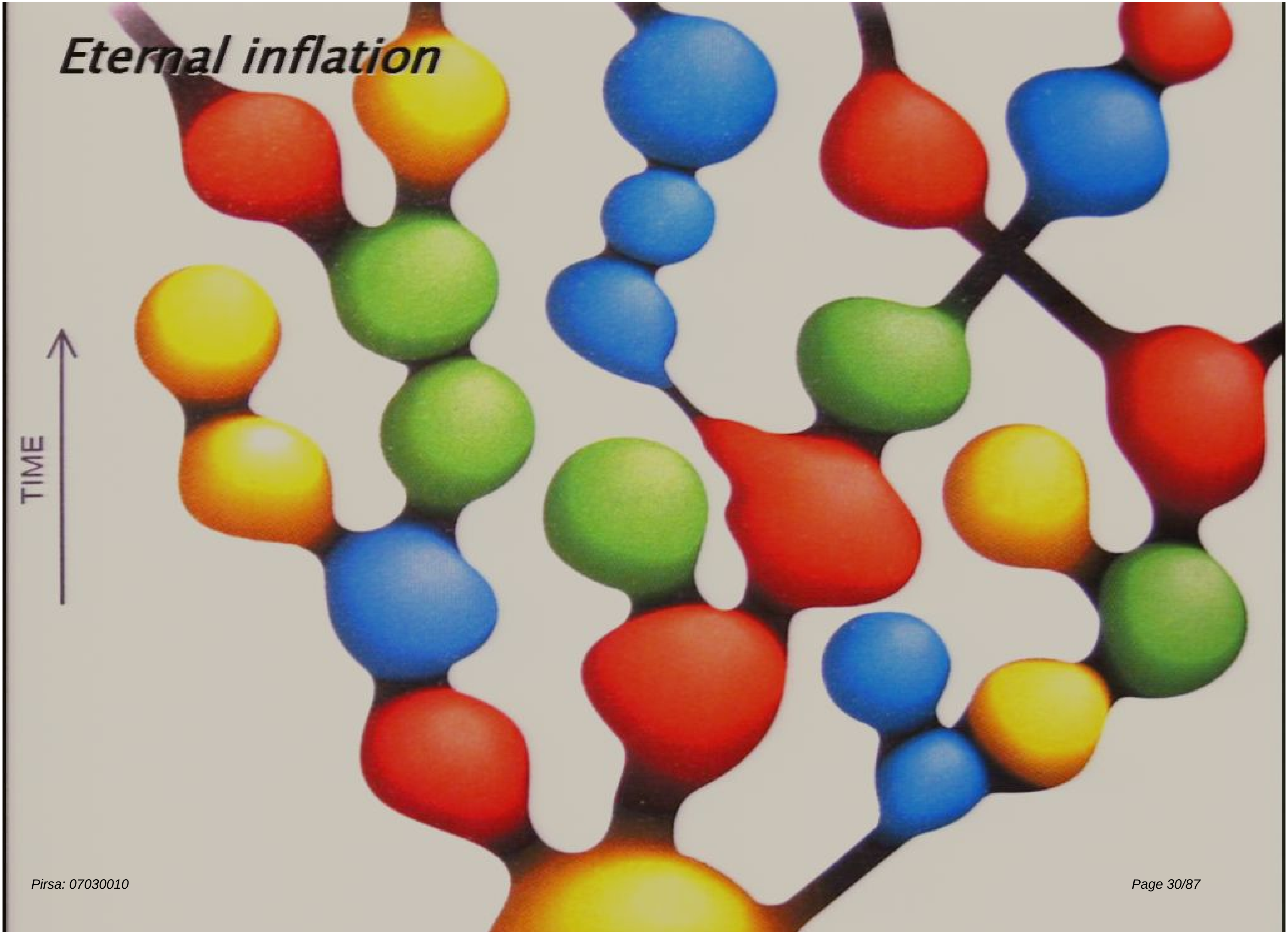
- *Any parameters will do*

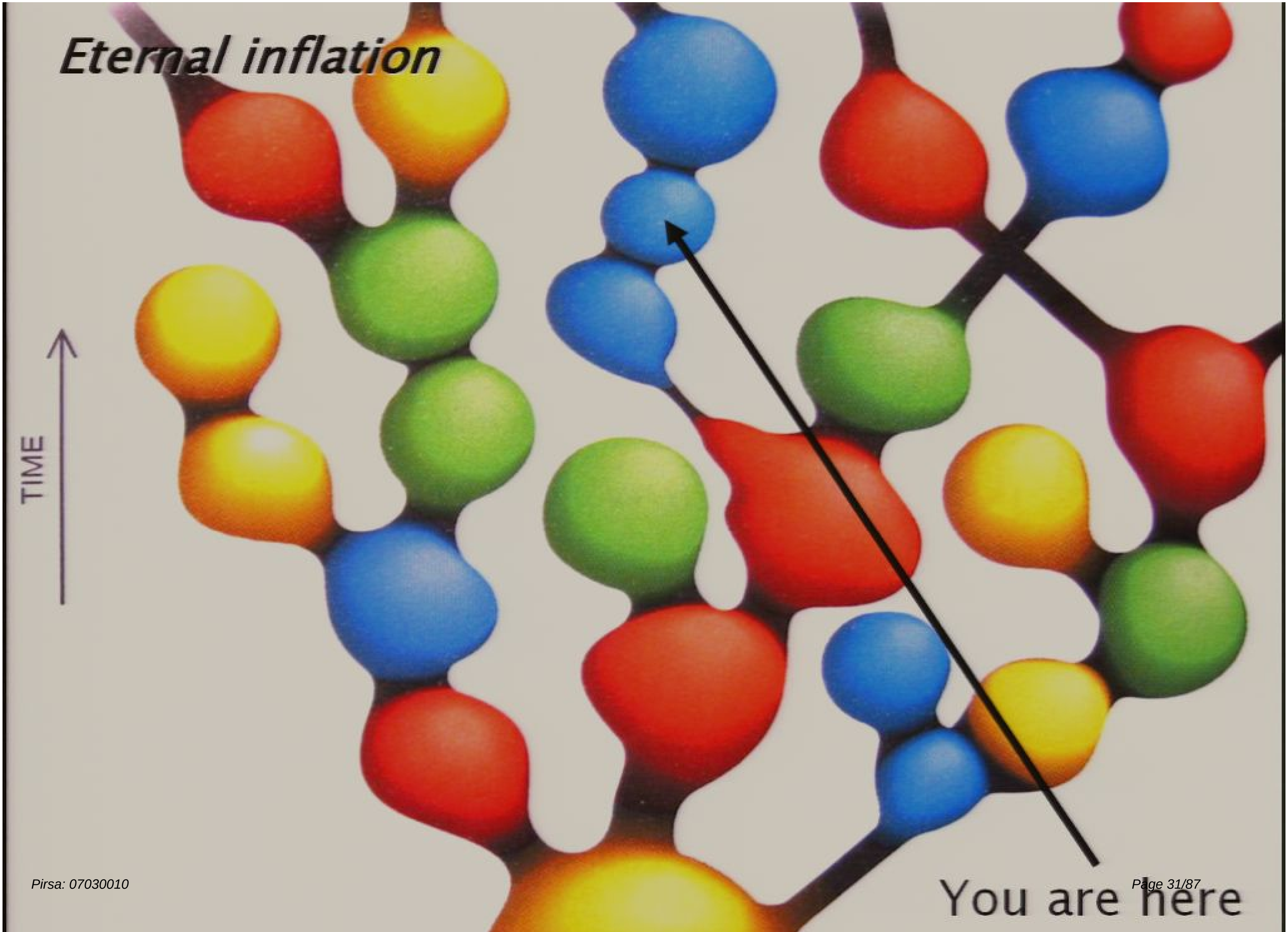
  No explanatory power, probably wrong

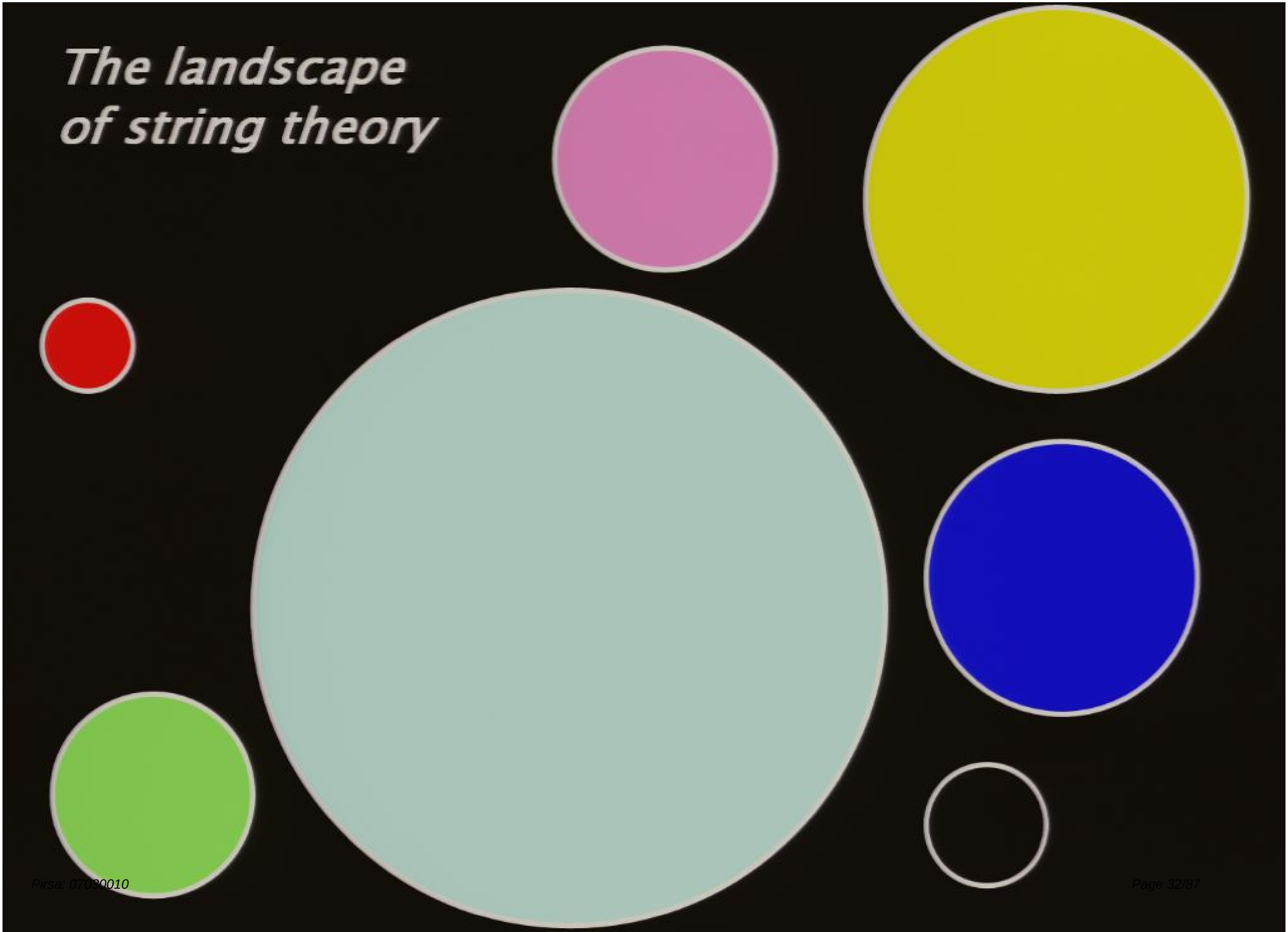
- *Multiverse + Anthropic Principle: we must live in one "realization" favourable for life*

  Introduces a (possibly infinite) number of unobservable Universes. Physical reality?

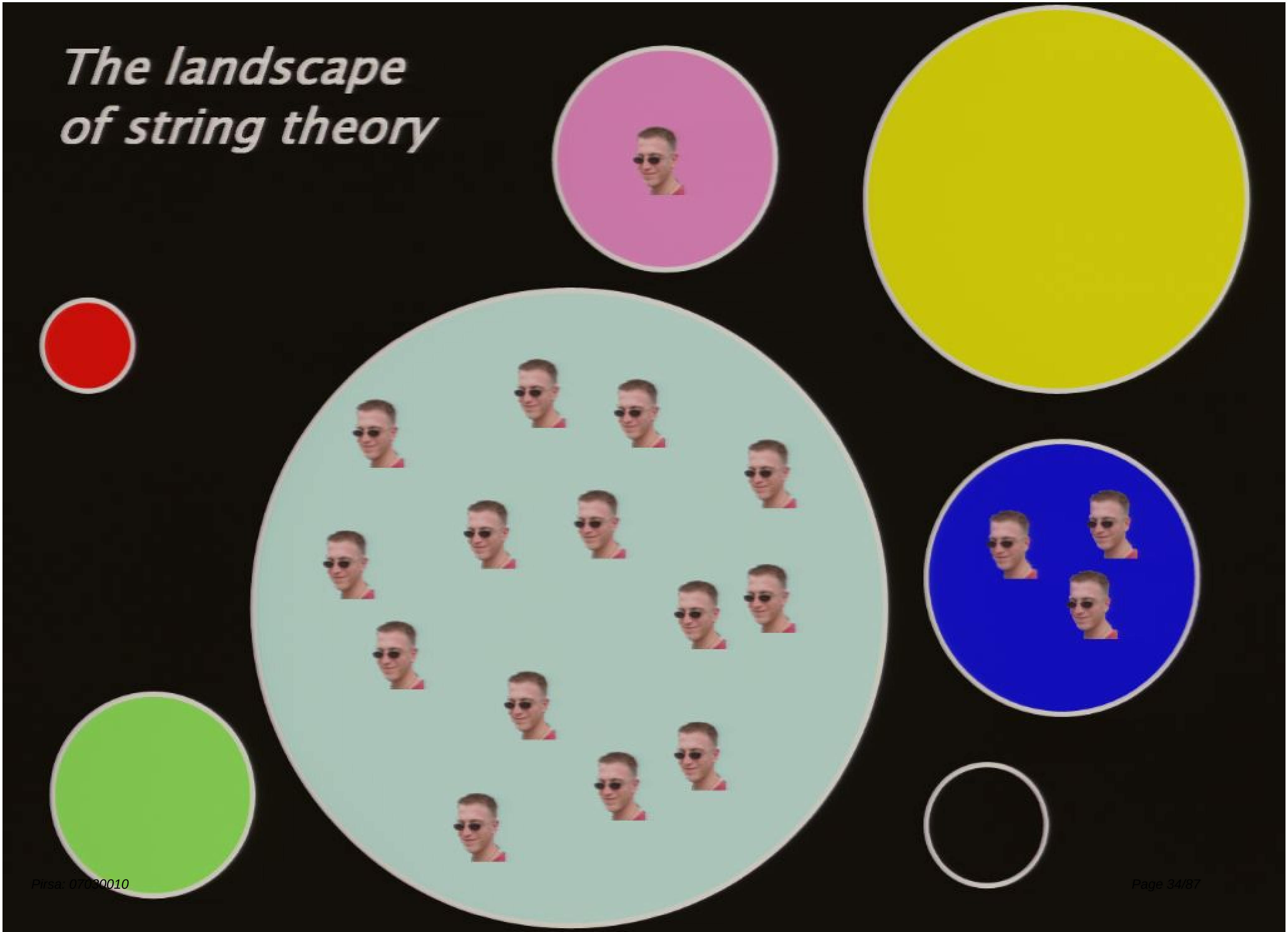
Eternal inflation

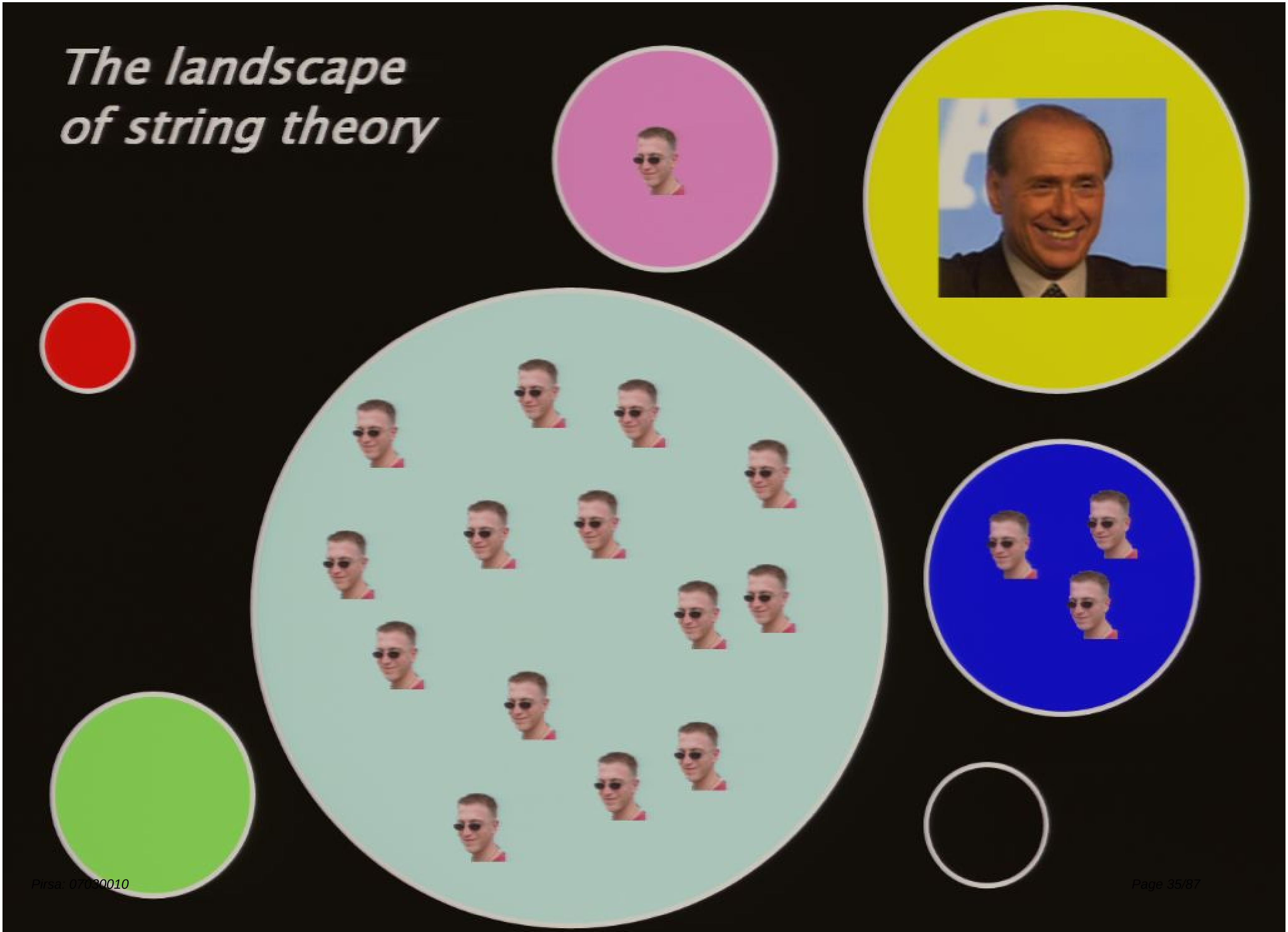



Eternal inflation
TIME
You are here


The landscape
of string theory


The landscape
of string theory


The landscape
of string theory


The landscape
of string theory

The cosmological constant problem

If the cosmological constant is a manifestation of vacuum energy, its magnitude ~ M^4_{Pl}
(possibly the most spectacularly wrong prediction in the history of science)

The cosmological constant problem:

why is $\Lambda_0/M^4_{Pl} \approx 10^{-123}$?

The cosmological constant problem

Oxford Physics

If the cosmological constant is a manifestation of vacuum energy, its magnitude ~ M^4_{Pl}
(possibly the most spectacularly wrong prediction in the history of science)

The cosmological constant problem:

$$\text{why is } \Lambda_0/M^4_{Pl} \approx 10^{-123} \text{ ?}$$

An anthropic selection effect?

if $\rho_\Lambda/\rho_0 \gtrsim 550$, galaxies cannot form
hence no observers

The cosmological constant problem

If the cosmological constant is a manifestation of vacuum energy, its magnitude ~ M^4_{Pl}
(possibly the most spectacularly wrong prediction in the history of science)

The cosmological constant problem:

$$\text{why is } \Lambda_0/M^4_{Pl} \approx 10^{-123} \text{ ?}$$

An anthropic selection effect?

if $\rho_\Lambda/\rho_0 \gtrsim 550$, galaxies cannot form hence no observers

Weinberg, PRL, 59, 22 (1987):

"We may conclude that anthropic considerations **do not** explain the smallness of the cosmological constant"


CONSTANTS
SPEED OF LIGHT: c
GRAVITY: G
ELEMENTARY CHARGE: e
1ST RADIATION CONSTANT: 8πhc
MASS UNIT: u
ELECTRON MASS: me
PROTON MASS: mp
NEUTRON MASS: mn
ELECTRON RADIUS: re
GAS CONSTANT: R
S. Harris

Brands of the anthropic principle

Brands of the anthropic principle

Oxford Physics

- *Weak anthropic principle (Barrow & Tipler, 1986):*
  The measured values of physical constants are restricted by the requirement that the conditions are met so that carbon–based life (us) can evolve

Brands of the anthropic principle

Oxford Physics

- *Weak anthropic principle (Barrow & Tipler, 1986):*
  The measured values of physical constants are restricted by the requirement that the conditions are met so that carbon–based life (us) can evolve
- *Strong anthropic principle (Carter, 1974):*
  The Universe must have the properties that allow life to exist

Brands of the anthropic principle

Oxford Physics

- *Weak anthropic principle (Barrow & Tipler, 1986):*
  The measured values of physical constants are restricted by the requirement that the conditions are met so that carbon–based life (us) can evolve
- *Strong anthropic principle (Carter, 1974):*
  The Universe must have the properties that allow life to exist
- *Participatory anthropic principle (Wheeler, 1975):*
  Observers are necessary to bring the Universe into being

The weak AP as selection effect

By using Bayes theorem:

$$\Pr(\Lambda|\text{life}) \propto \Pr(\Lambda)\ \Pr(\text{life}|\Lambda)$$

*prob of observing = prior distribution * likelihood function*

The weak AP as selection effect

Oxford Physics

By using Bayes theorem:

$$\Pr(\Lambda|\text{life}) \propto \Pr(\Lambda)\,\Pr(\text{life}|\Lambda)$$

*prob of observing = prior distribution * likelihood function*

$\Pr(\Lambda)$: the prior distribution

- *Reflects our prior state of knowledge (Bayesian) or relative frequency of outcomes (Frequentist)*
- *Must be worked out from first principles, usually waved away as being 'flat'. Might need to be adjusted for the presence of observers*

The weak AP as selection effect

By using Bayes theorem:

$$\Pr(\Lambda|\text{life}) \propto \Pr(\Lambda)\,\Pr(\text{life}|\Lambda)$$

*prob of observing = prior distribution * likelihood function*

$\Pr(\Lambda)$: the prior distribution

- *Reflects our prior state of knowledge (Bayesian) or relative frequency of outcomes (Frequentist)*
- *Must be worked out from first principles, usually waved away as being 'flat'. Might need to be adjusted for the presence of observers*

$\Pr(\text{life}|\Lambda)$: the selection function

- *Encompasses observers selection effects for a given value of Λ*
- *What do we mean by 'life'? What count as observers?*

Does the AP explain Λ?

Efstathiou, MNRAS 274, L37-L76 (1995) argues in favour of the AP:

- *Assume that the probability of life $\propto$ space density of (L_*, M_*) galaxies*
- *Assume that the prior probability of Λ is uniform*
- *Assume that the photon entropy per CDM particle is constant*
- *Assume all of the other constant of Nature fixed*
- *Assume that Λ only influences life up to the formation of galaxies*

The weak AP as selection effect

Oxford Physics

By using Bayes theorem:

$$\Pr(\Lambda|\text{life}) \propto \Pr(\Lambda)\, \Pr(\text{life}|\Lambda)$$

*prob of observing = prior distribution * likelihood function*

$\Pr(\Lambda)$: the prior distribution

- *Reflects our prior state of knowledge (Bayesian) or relative frequency of outcomes (Frequentist)*
- *Must be worked out from first principles, usually waved away as being 'flat'. Might need to be adjusted for the presence of observers*

$\Pr(\text{life}|\Lambda)$: the selection function

- *Encompasses observers selection effects for a given value of Λ*
- *What do we mean by 'life'? What count as observers?*

Does the AP explain Λ?

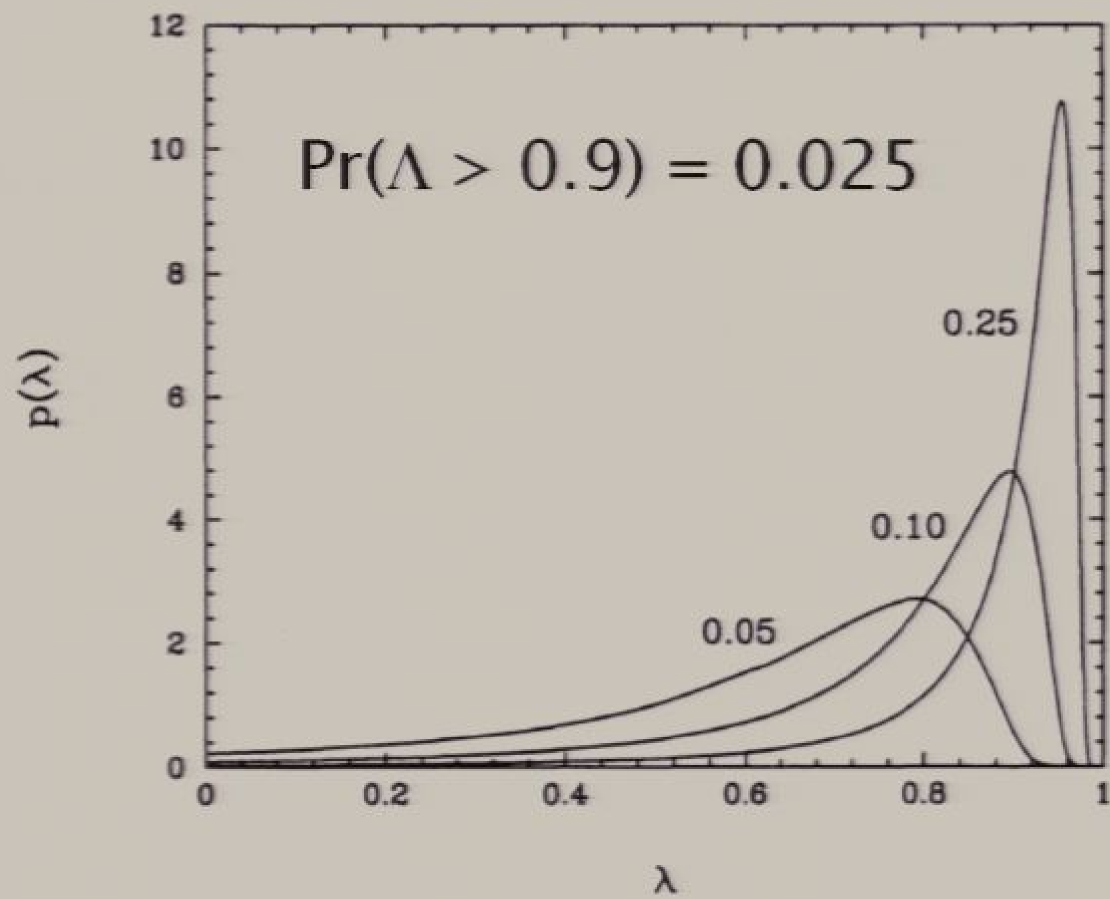
Efstathiou, MNRAS 274, L37-L76 (1995) argues in favour of the AP:

- *Assume that the probability of life $\propto$ space density of (L_*, M_*) galaxies*
- *Assume that the prior probability of Λ is uniform*
- *Assume that the photon entropy per CDM particle is constant*
- *Assume all of the other constant of Nature fixed*
- *Assume that Λ only influences life up to the formation of galaxies*

Does the AP explain Λ?

Efstathiou, MNRAS 274, L37-L76 (1995) argues in favour of the AP:

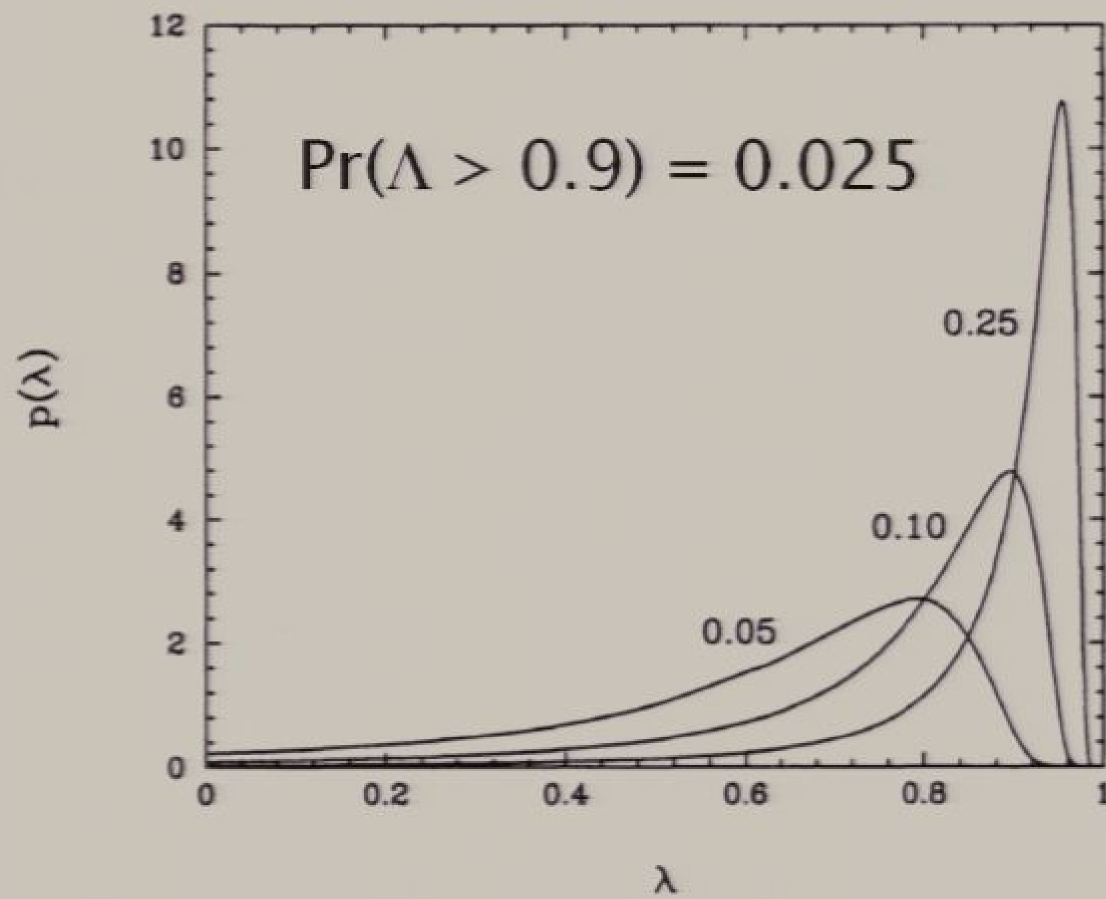
- *Assume that the ɥ galaxies*
- *Assume that the ɥ*
- *Assume that the ɥ*
- *Assume all of the*
- *Assume that Λ on galaxies*



Does the AP explain Λ?

Efstathiou, MNRAS 274, L37-L76 (1995) argues in favour of the AP:

- *Assume that the ¡*
  galaxies
- *Assume that the ¡*
- *Assume that the ¡*
- *Assume all of the*
- *Assume that Λ on*
  galaxies



"These assumptions suggest that the small value of the cosmological constant may be explained by the AP"

Criticisms of the AP

Criticisms of the AP

Oxford Physics

- Instability wrt definition of observers:

how do we compute the density of observers for a given cosmological model? Currently mostly taken proportional to the fraction of gas in structures – MANO offers an explicit counter-example (Starkman & Trotta, 2006)

Criticisms of the AP

Oxford Physics

- Instability wrt definition of observers:
how do we compute the density of observers for a given cosmological model? Currently mostly taken proportional to the fraction of gas in structures – MANO offers an explicit counter-example (Starkman & Trotta, 2006)

- The AP is inconsistent reasoning:
'Reference class of observers' and the Self-Indication Assumption (Neil, 2006)

Criticisms of the AP

- Instability wrt definition of observers:
how do we compute the density of observers for a given cosmological model? Currently mostly taken proportional to the fraction of gas in structures – MANO offers an explicit counter-example (Starkman & Trotta, 2006)

- The AP is inconsistent reasoning:
'Reference class of observers' and the Self-Indication Assumption (Neil, 2006)

- Which parameters are allowed to vary?
If we change other fundamental parameters at the same time, we can compensate for larger values of Λ (Aguirre, 2001)

The selection function

$$\Pr(\Lambda|\text{life}) \propto \Pr(\Lambda)\,\Pr(\text{life}|\Lambda)$$

The selection function

$$\Pr(\Lambda|\text{life}) \propto \Pr(\Lambda)\ \Pr(\text{life}|\Lambda)$$

The selection function $\Pr(\text{life}|\Lambda)$

What counts as "observers"?

How do we predict the emergence of "life" in other Universes?

Proportionality to n_{gal} could be anything

Certainly important to integrate over time

The selection function

$$\Pr(\Lambda|\text{life}) \propto \Pr(\Lambda)\,\Pr(\text{life}|\Lambda)$$

The selection function $\Pr(\text{life}|\Lambda)$

What counts as "observers"?

How do we predict the emergence of "life" in other U[illegible]es?

Proportionality to n_{gal} could be anything

Certainly important to integrate over time

The selection function

$$\Pr(\Lambda|\text{life}) \propto \Pr(\Lambda)\ \Pr(\text{life}|\Lambda)$$

The selection function Λ)

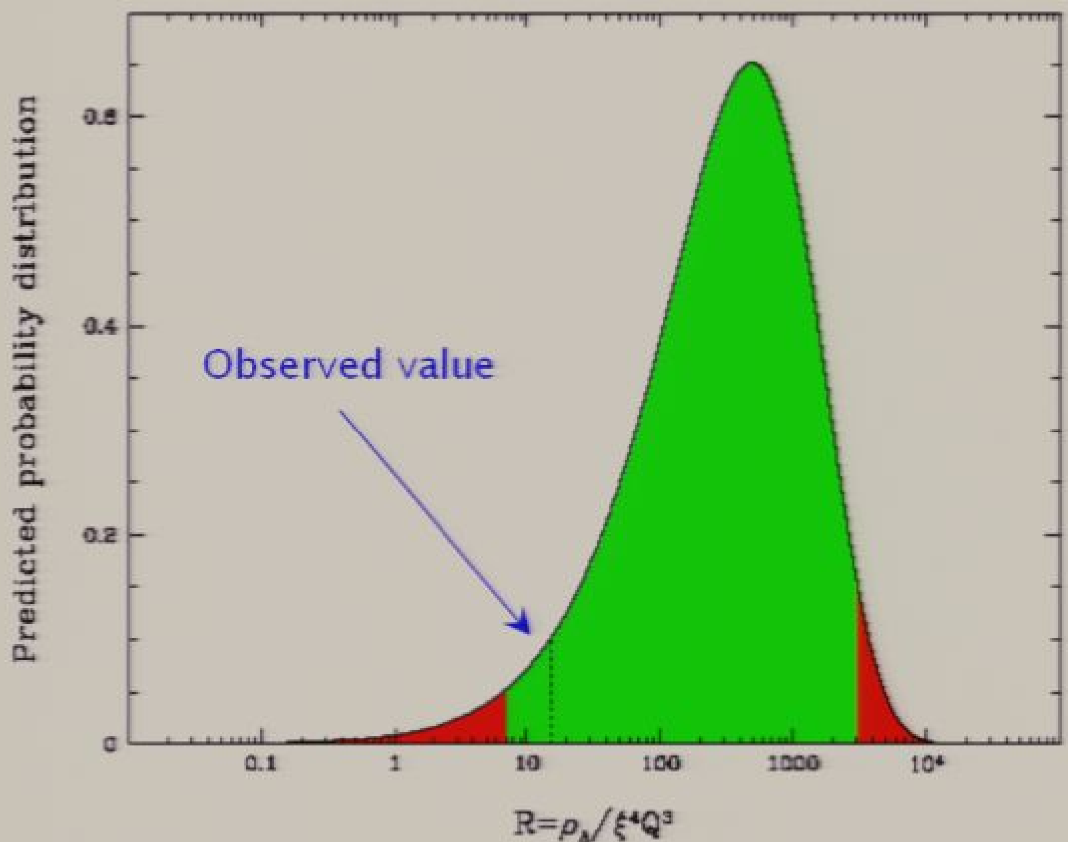
What counts as "observers"?

How do we predict the emergence of "li es?

Proportionality to n_{gal} could be anything

Certainly important to integrate over tir

Λ is not enough



Antrhopic prediction only 'works' if one fixes (ξ, Q) to their observed values

Aguirre (2001) considers varying

η_γ, Q, η_{dm}, η_L, R, Λ

Applying a variety of selection effects, normalizing to the observed values, other widely different cosmologies equally plausible, eg:

10^{-9}, 10^{-4}, 0, 1, 10^5, 10^{17}

Tegmark at al (2006)

Which parameters should vary?

Parameter	Meaning	Measured value
g	Weak coupling constant at m_Z	0.6520 ± 0.0001
θ_W	Weinberg angle	0.48290 ± 0.00005
g_s	Strong coupling constant at m_Z	1.221 ± 0.022
μ^2	Quadratic Higgs coefficient	$\sim -10^{-33}$
λ	Quartic Higgs coefficient	$\sim 1?$
G_e	Electron Yukawa coupling	2.94×10^{-6}
G_μ	Muon Yukawa coupling	0.000607
G_τ	Tauon Yukawa coupling	0.0102156233
G_u	Up quark Yukawa coupling	0.000016 ± 0.000007
G_d	Down quark Yukawa coupling	0.00003 ± 0.00002
G_c	Charm quark Yukawa coupling	0.0072 ± 0.0006
G_s	Strange quark Yukawa coupling	0.0006 ± 0.0002
G_t	Top quark Yukawa coupling	1.002 ± 0.029
G_b	Bottom quark Yukawa coupling	0.026 ± 0.003
$\sin\theta_{12}$	Quark CKM matrix angle	0.2243 ± 0.0016
$\sin\theta_{23}$	Quark CKM matrix angle	0.0413 ± 0.0015
$\sin\theta_{13}$	Quark CKM matrix angle	0.0037 ± 0.0005
δ_{13}	Quark CKM matrix phase	1.05 ± 0.24
θ_{qcd}	CP-violating QCD vacuum phase	$< 10^{-9}$
G_{ν_e}	Electron neutrino Yukawa coupling	$< 1.7 \times 10^{-11}$
G_{ν_μ}	Muon neutrino Yukawa coupling	$< 1.1 \times 10^{-6}$
G_{ν_τ}	Tau neutrino Yukawa coupling	< 0.10
$\sin\theta'_{12}$	Neutrino MNS matrix angle	0.55 ± 0.06
$\sin 2\theta'_{23}$	Neutrino MNS matrix angle	≥ 0.94
$\sin\theta'_{13}$	Neutrino MNS matrix angle	≤ 0.22
δ'_{13}	Neutrino MNS matrix phase	?
ρ_Λ	Dark energy density	$(1.25 \pm 0.25) \times 10^{-123}$
ξ_b	Baryon mass per photon ρ_b/n_γ	$(0.50 \pm 0.03) \times 10^{-28}$
ξ_c	Cold dark matter mass per photon ρ_c/n_γ	$(2.5 \pm 0.2) \times 10^{-28}$
ξ_ν	Neutrino mass per photon $\rho_\nu/n_\gamma = \frac{3}{11}\sum m_{\nu_i}$	$< 0.9 \times 10^{-28}$
Q	Scalar fluctuation amplitude δ_H on horizon	$(2.0 \pm 0.2) \times 10^{-5}$
n_s	Scalar spectral index	0.98 ± 0.02
α_n	Running of spectral index $dn_s/d\ln k$	$\lvert\alpha\rvert \lesssim 0.01$
r	Tensor-to-scalar ratio $(Q_t/Q)^2$	$\lesssim 0.36$
n_t	Tensor spectral index	Unconstrained
w	Dark energy equation of state	-1 ± 0.1
κ	Dimensionless spatial curvature k/a^2T^2 [85]	$\lvert\kappa\rvert \lesssim 10^{-60}$

Which parameters should vary?

Parameter	Meaning	Measured value
g	Weak coupling constant at m_Z	0.6520 ± 0.0001
θ_W	Weinberg angle	0.48290 ± 0.00005
g_s	Strong coupling constant at m_Z	1.221 ± 0.022
μ^2	Quadratic Higgs coefficient	$\sim -10^{-33}$
λ	Quartic Higgs coefficient	$\sim 1?$
G_e	Electron Yukawa coupling	2.94×10^{-6}
G_μ	Muon Yukawa coupling	0.000607
G_τ	Tauon Yukawa coupling	0.0102156233
G_u	Up quark Yukawa coupling	0.000016 ± 0.000007
G_d	Down quark Yukawa coupling	0.00003 ± 0.00002
G_c	Charm quark Yukawa coupling	0.0072 ± 0.0006
G_s	Strange quark Yukawa coupling	0.0006 ± 0.0002
G_t	Top quark Yukawa coupling	1.002 ± 0.029
G_b	Bottom quark Yukawa coupling	0.026 ± 0.003
$\sin\theta_{12}$	Quark CKM matrix angle	0.2243 ± 0.0016
$\sin\theta_{23}$	Quark CKM matrix angle	0.0413 ± 0.0015
$\sin\theta_{13}$	Quark CKM matrix angle	0.0037 ± 0.0005
δ_{13}	Quark CKM matrix phase	1.05 ± 0.24
θ_{qcd}	CP-violating QCD vacuum phase	$< 10^{-9}$
G_{ν_e}	Electron neutrino Yukawa coupling	$< 1.7 \times 10^{-11}$
G_{ν_μ}	Muon neutrino Yukawa coupling	$< 1.1 \times 10^{-6}$
G_{ν_τ}	Tau neutrino Yukawa coupling	< 0.10
$\sin\theta'_{12}$	Neutrino MNS matrix angle	0.55 ± 0.06
$\sin 2\theta'_{23}$	Neutrino MNS matrix angle	≥ 0.94
$\sin\theta'_{13}$	Neutrino MNS matrix angle	≤ 0.22
δ'_{13}	Neutrino MNS matrix phase	?
ρ_Λ	Dark energy density	$(1.25 \pm 0.25) \times 10^{-123}$
ξ_b	Baryon mass per photon ρ_b/n_γ	$(0.50 \pm 0.03) \times 10^{-28}$
ξ_c	Cold dark matter mass per photon ρ_c/n_γ	$(2.5 \pm 0.2) \times 10^{-28}$
ξ_ν	Neutrino mass per photon $\rho_\nu/n_\gamma = \frac{3}{11}\sum m_{\nu_i}$	$< 0.9 \times 10^{-28}$
Q	Scalar fluctuation amplitude δ_H on horizon	$(2.0 \pm 0.2) \times 10^{-5}$
n_s	Scalar spectral index	0.98 ± 0.02
α_n	Running of spectral index $dn_s/d\ln k$	$\lvert\alpha\rvert \lesssim 0.01$
r	Tensor-to-scalar ratio $(Q_t/Q)^2$	$\lesssim 0.36$
n_t	Tensor spectral index	Unconstrained
w	Dark energy equation of state	-1 ± 0.1
κ	Dimensionless spatial curvature k/a^2T^2 [85]	$\lvert\kappa\rvert < 10^{-60}$

Which parameters should vary?

Parameter	Meaning	Measured value
g	Weak coupling constant at m_Z	0.6520 ± 0.0001
θ_W	Weinberg angle	0.48290 ± 0.00005
g_s	Strong coupling constant at m_Z	1.221 ± 0.022
μ^2	Quadratic Higgs coefficient	$\sim -10^{-33}$
λ	Quartic Higgs coefficient	$\sim 1?$
G_e	Electron Yukawa coupling	2.94×10^{-6}
G_μ	Muon Yukawa coupling	0.000607
G_τ	Tauon Yukawa coupling	0.0102156233
G_u	Up quark Yukawa coupling	0.000016 ± 0.000007
G_d	Down quark Yukawa coupling	0.00003 ± 0.00002
G_c	Charm quark Yukawa coupling	0.0072 ± 0.0006
G_s	Strange quark Yukawa coupling	0.0006 ± 0.0002
G_t	Top quark Yukawa coupling	1.002 ± 0.029
G_b	Bottom quark Yukawa coupling	0.026 ± 0.003
$\sin\theta_{12}$	Quark CKM matrix angle	0.2243 ± 0.0016
$\sin\theta_{23}$	Quark CKM matrix angle	0.0413 ± 0.0015
$\sin\theta_{13}$	Quark CKM matrix angle	0.0037 ± 0.0005
δ_{13}	Quark CKM matrix phase	1.05 ± 0.24
θ_{qcd}	CP-violating QCD vacuum phase	$< 10^{-9}$
G_{ν_e}	Electron neutrino Yukawa coupling	$< 1.7 \times 10^{-11}$
G_{ν_μ}	Muon neutrino Yukawa coupling	$< 1.1 \times 10^{-6}$
G_{ν_τ}	Tau neutrino Yukawa coupling	< 0.10
$\sin\theta'_{12}$	Neutrino MNS matrix angle	0.55 ± 0.06
$\sin 2\theta'_{23}$	Neutrino MNS matrix angle	≥ 0.94
$\sin\theta'_{13}$	Neutrino MNS matrix angle	≤ 0.22
δ'_{13}	Neutrino MNS matrix phase	?
ρ_Λ	Dark energy density	$(1.25 \pm 0.25) \times 10^{-123}$
ξ_b	Baryon mass per photon ρ_b/n_γ	$(0.50 \pm 0.03) \times 10^{-28}$
ξ_c	Cold dark matter mass per photon ρ_c/n_γ	$(2.5 \pm 0.2) \times 10^{-28}$
ξ_ν	Neutrino mass per photon $\rho_\nu/n_\gamma = \frac{3}{11}\sum m_{\nu_i}$	$< 0.9 \times 10^{-28}$
Q	Scalar fluctuation amplitude δ_H on horizon	$(2.0 \pm 0.2) \times 10^{-5}$
n_s	Scalar spectral index	0.98 ± 0.02
α_n	Running of spectral index $dn_s/d\ln k$	$\lvert\alpha\rvert \lesssim 0.01$
r	Tensor-to-scalar ratio $(Q_t/Q)^2$	$\lesssim 0.36$
n_t	Tensor spectral index	Unconstrained
w	Dark energy equation of state	-1 ± 0.1
κ	Dimensionless spatial curvature k/a^2T^2 [85]	$\lvert\kappa\rvert \lesssim 10^{-60}$

Tegmark at al (2006) consider variations in 3 parameters:

- ξ_c (CDM density per photon)
- ρ_Λ (CC energy density)
- Q (amplitude of initial fluct'ons)

Which parameters should vary?

Parameter	Meaning	Measured value
g	Weak coupling constant at m_Z	0.6520 ± 0.0001
θ_W	Weinberg angle	0.48290 ± 0.00005
g_s	Strong coupling constant at m_Z	1.221 ± 0.022
μ^2	Quadratic Higgs coefficient	$\sim -10^{-33}$
λ	Quartic Higgs coefficient	$\sim 1?$
G_e	Electron Yukawa coupling	2.94×10^{-6}
G_μ	Muon Yukawa coupling	0.000607
G_τ	Tauon Yukawa coupling	0.0102156233
G_u	Up quark Yukawa coupling	0.000016 ± 0.000007
G_d	Down quark Yukawa coupling	0.00003 ± 0.00002
G_c	Charm quark Yukawa coupling	0.0072 ± 0.0006
G_s	Strange quark Yukawa coupling	0.0006 ± 0.0002
G_t	Top quark Yukawa coupling	1.002 ± 0.029
G_b	Bottom quark Yukawa coupling	0.026 ± 0.003
$\sin\theta_{12}$	Quark CKM matrix angle	0.2243 ± 0.0016
$\sin\theta_{23}$	Quark CKM matrix angle	0.0413 ± 0.0015
$\sin\theta_{13}$	Quark CKM matrix angle	0.0037 ± 0.0005
δ_{13}	Quark CKM matrix phase	1.05 ± 0.24
θ_{qcd}	CP-violating QCD vacuum phase	$< 10^{-9}$
G_{ν_e}	Electron neutrino Yukawa coupling	$< 1.7 \times 10^{-11}$
G_{ν_μ}	Muon neutrino Yukawa coupling	$< 1.1 \times 10^{-6}$
G_{ν_τ}	Tau neutrino Yukawa coupling	< 0.10
$\sin\theta'_{12}$	Neutrino MNS matrix angle	0.55 ± 0.06
$\sin 2\theta'_{23}$	Neutrino MNS matrix angle	≥ 0.94
$\sin\theta'_{13}$	Neutrino MNS matrix angle	≤ 0.22
δ'_{13}	Neutrino MNS matrix phase	?
ρ_Λ	Dark energy density	$(1.25 \pm 0.25) \times 10^{-123}$
ξ_b	Baryon mass per photon ρ_b/n_γ	$(0.50 \pm 0.03) \times 10^{-28}$
ξ_c	Cold dark matter mass per photon ρ_c/n_γ	$(2.5 \pm 0.2) \times 10^{-28}$
ξ_ν	Neutrino mass per photon $\rho_\nu/n_\gamma = \frac{3}{11}\sum m_{\nu_i}$	$< 0.9 \times 10^{-28}$
Q	Scalar fluctuation amplitude δ_H on horizon	$(2.0 \pm 0.2) \times 10^{-5}$
n_s	Scalar spectral index	0.98 ± 0.02
α_n	Running of spectral index $dn_s/d\ln k$	$\lvert\alpha\rvert \lesssim 0.01$
r	Tensor-to-scalar ratio $(Q_t/Q)^2$	$\lesssim 0.36$
n_t	Tensor spectral index	Unconstrained
w	Dark energy equation of state	-1 ± 0.1
κ	Dimensionless spatial curvature k/a^2T^2 [85]	$\lvert\kappa\rvert \lesssim 10^{-60}$

Tegmark at al (2006) consider variations in 3 parameters:

ξ_c	(CDM density per photon)
ρ_Λ	(CC energy density)
Q	(amplitude of initial fluct'ons)

Which parameters should vary?

Parameter	Meaning	Measured value
g	Weak coupling constant at m_Z	0.6520 ± 0.0001
θ_W	Weinberg angle	0.48290 ± 0.00005
g_s	Strong coupling constant at m_Z	1.221 ± 0.022
μ^2	Quadratic Higgs coefficient	$\sim -10^{-33}$
λ	Quartic Higgs coefficient	$\sim 1?$
G_e	Electron Yukawa coupling	2.94×10^{-6}
G_μ	Muon Yukawa coupling	0.000607
G_τ	Tauon Yukawa coupling	0.0102156233
G_u	Up quark Yukawa coupling	0.000016 ± 0.000007
G_d	Down quark Yukawa coupling	0.00003 ± 0.00002
G_c	Charm quark Yukawa coupling	0.0072 ± 0.0006
G_s	Strange quark Yukawa coupling	0.0006 ± 0.0002
G_t	Top quark Yukawa coupling	1.002 ± 0.029
G_b	Bottom quark Yukawa coupling	0.026 ± 0.003
$\sin\theta_{12}$	Quark CKM matrix angle	0.2243 ± 0.0016
$\sin\theta_{23}$	Quark CKM matrix angle	0.0413 ± 0.0015
$\sin\theta_{13}$	Quark CKM matrix angle	0.0037 ± 0.0005
δ_{13}	Quark CKM matrix phase	1.05 ± 0.24
θ_{qcd}	CP-violating QCD vacuum phase	$< 10^{-9}$
G_{ν_e}	Electron neutrino Yukawa coupling	$< 1.7 \times 10^{-11}$
G_{ν_μ}	Muon neutrino Yukawa coupling	$< 1.1 \times 10^{-6}$
G_{ν_τ}	Tau neutrino Yukawa coupling	< 0.10
$\sin\theta'_{12}$	Neutrino MNS matrix angle	0.55 ± 0.06
$\sin 2\theta'_{23}$	Neutrino MNS matrix angle	≥ 0.94
$\sin\theta'_{13}$	Neutrino MNS matrix angle	≤ 0.22
δ'_{13}	Neutrino MNS matrix phase	?
ρ_Λ	Dark energy density	$(1.25 \pm 0.25) \times 10^{-123}$
ξ_b	Baryon mass per photon ρ_b/n_γ	$(0.50 \pm 0.03) \times 10^{-28}$
ξ_c	Cold dark matter mass per photon ρ_c/n_γ	$(2.5 \pm 0.2) \times 10^{-28}$
ξ_ν	Neutrino mass per photon $\rho_\nu/n_\gamma = \frac{3}{11}\sum m_{\nu_i}$	$< 0.9 \times 10^{-28}$
Q	Scalar fluctuation amplitude δ_H on horizon	$(2.0 \pm 0.2) \times 10^{-5}$
n_s	Scalar spectral index	0.98 ± 0.02
α_n	Running of spectral index $dn_s/d\ln k$	$\lvert\alpha\rvert \lesssim 0.01$
r	Tensor-to-scalar ratio $(Q_t/Q)^2$	$\lesssim 0.36$
n_t	Tensor spectral index	Unconstrained
w	Dark energy equation of state	-1 ± 0.1
κ	Dimensionless spatial curvature k/a^2T^2 [85]	$\lvert\kappa\rvert \lesssim 10^{-60}$

Tegmark at al (2006) consider variations in 3 parameters:

ξ_c (CDM dens [illegible])

ρ_Λ (CC energy [illegible]

Q (amplitude [illegible] ons)

Next
Previous
Last Viewed
Go to Slide
Custom Show
Screen
Pointer Options
Help
Pause
End Show

The selection function

$$\Pr(\Lambda|\text{life}) \propto \Pr(\Lambda)\,\Pr(\text{life}|\Lambda)$$

The selection function $\Pr(\text{life}|\Lambda)$

What counts as "observers"?

How do we predict the emergence of "life" in other Universes?

Proportionality to n_{gal} could be anything

Certainly important to integrate over time

The selection function

$$\Pr(\Lambda|\text{life}) \propto \Pr(\Lambda)\,\Pr(\text{life}|\Lambda)$$

The selection function $\Pr(\text{life}|\Lambda)$

What counts as "observers"?

How do we predict the emergence of "life" in other Universes?

Proportionality to n_{gal} could be anything

Certainly important to integrate over time

An explicit counter-example: MANO weighting

Maximum Number of Allowed Observations

The maximum number of observations

- We suggest to use the maximum number of observations that can be carried out instead.
- Consider the maximum amount of energy accessible to observers:

The maximum number of observations

- We suggest to use the maximum number of observations that can be carried out instead.
- Consider the maximum amount of energy accessible to observers:

$$E_{\max} \propto \min\left(\frac{4\pi}{3}\left[(\eta_\infty - \eta_\star)a_\star\right]^3, n_{\rm obs}^{-1}\right)\rho_m(a_\star)$$

η_* = conformal time when observers start collecting

$a(\eta_\infty) = \infty$

n_{obs} = comoving observers density

The maximum number of observations

- *We suggest to use the maximum number of observations that can be carried out instead.*
- *Consider the maximum amount of energy accessible to observers:*

$$E_{\max} \propto \min\left(\frac{4\pi}{3}\left[(\eta_\infty - \eta_\star)a_\star\right]^3, n_{\text{obs}}^{-1}\right)\rho_m(a_\star)$$

η_* = conformal time when observers start collecting
$a(\eta_\infty) = \infty$
n_{obs} = comoving observers density

- *Maximum number of thermodynamic processes in a $\Lambda > 0$ Universe (rare observers limit):*

$$N_{max} < E_{max} / k_B T_{ds}$$

MANO weighting of Universes

MANO = Maximum Allowed Number of Observations

The maximum number of observations

- *We suggest to use the maximum number of observations that can be carried out instead.*
- *Consider the maximum amount of energy accessible to observers:*

$$E_{\max} \propto \min\left(\frac{4\pi}{3}\left[(\eta_\infty - \eta_\star)a_\star\right]^3, n_{\rm obs}^{-1}\right)\rho_m(a_\star)$$

η_* = conformal time when observers start collecting
$a(\eta_\infty) = \infty$
n_{obs} = comoving observers density

- *Maximum number of thermodynamic processes in a $\Lambda > 0$ Universe (rare observers limit):*

$$N_{max} < E_{max} / k_B T_{ds}$$

The maximum number of observations

- *We suggest to use the maximum number of observations that can be carried out instead.*
- *Consider the maximum amount of energy accessible to observers:*

$$E_{\max} \propto \min\left(\frac{4\pi}{3}\left[(\eta_\infty - \eta_\star)a_\star\right]^3, n_{\rm obs}^{-1}\right)\rho_m(a_\star)$$

η_* = conformal time when observers start collecting
$a(\eta_\infty) = \infty$
n_{obs} = comoving observers density

The maximum number of observations

- *We suggest to use the maximum number of observations that can be carried out instead.*
- *Consider the maximum amount of energy accessible to observers:*

$$E_{\max} \propto \min\left(\frac{4\pi}{3}\left[(\eta_{\infty}-\eta_{\star})a_{\star}\right]^{3}, n_{\rm obs}^{-1}\right)\rho_{m}(a_{\star})$$

η_* = conformal time when observers start collecting
$a(\eta_\infty) = \infty$
n_{obs} = comoving observers density

- *Maximum number of thermodynamic processes in a $\Lambda > 0$ Universe (rare observers limit):*

$$N_{max} < E_{max} / k_B T_{ds}$$

MANO weighting of Universes

MANO = Maximum Allowed Number of Observations

MANO weighting of Universes

MANO = Maximum Allowed Number of Observations

- *Rare observers limit – max number of observations that each observer can perform*

MANO weighting of Universes

Oxford Physics

MANO = Maximum Allowed Number of Observations

- *Rare observers limit – max number of observations that each observer can perform*
- *If accessible volumes for observers overlap, the answer depends on the interaction between observers – effectively unknowable!*

MANO weighting of Universes

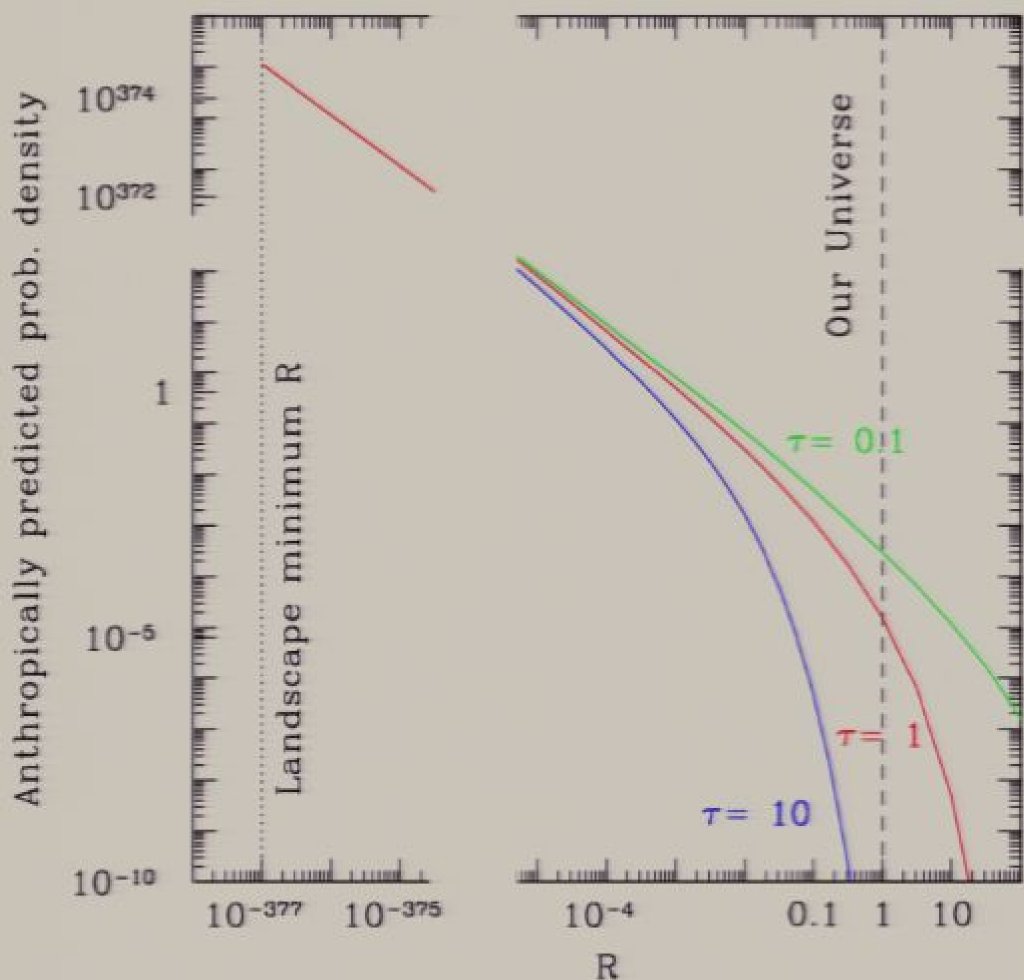
Oxford Physics

MANO = Maximum Allowed Number of Observations

- *Rare observers limit – max number of observations that each observer can perform*
- *If accessible volumes for observers overlap, the answer depends on the interaction between observers – effectively unknowable!*
- *The correspondence between observers and observations is difficult to compute. If we assume it is a constant, than our scheme is equivalent to traditional AP applications, but integrated over lifetime of the Universe*

MANO weighting of Universes

Starkman & Trotta, Phys Rev Lett **97**, 201301 (2006)



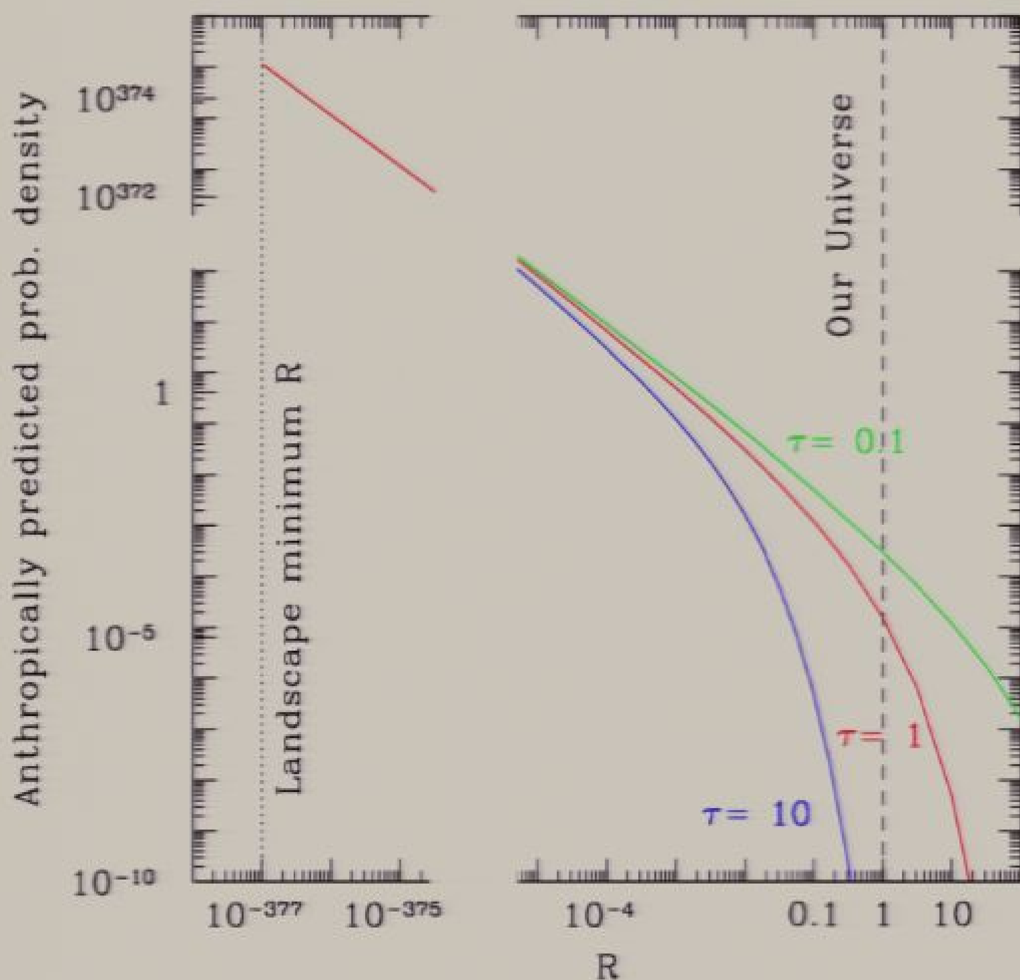
$$R = \Lambda/\Lambda_0$$

$$\tau = t_{obs}/t_0$$

controls the time when intelligent observers arise and begin collecting energy

MANO weighting of Universes

Starkman & Trotta, Phys Rev Lett **97**, 201301 (2006)



$$R = \Lambda/\Lambda_0$$

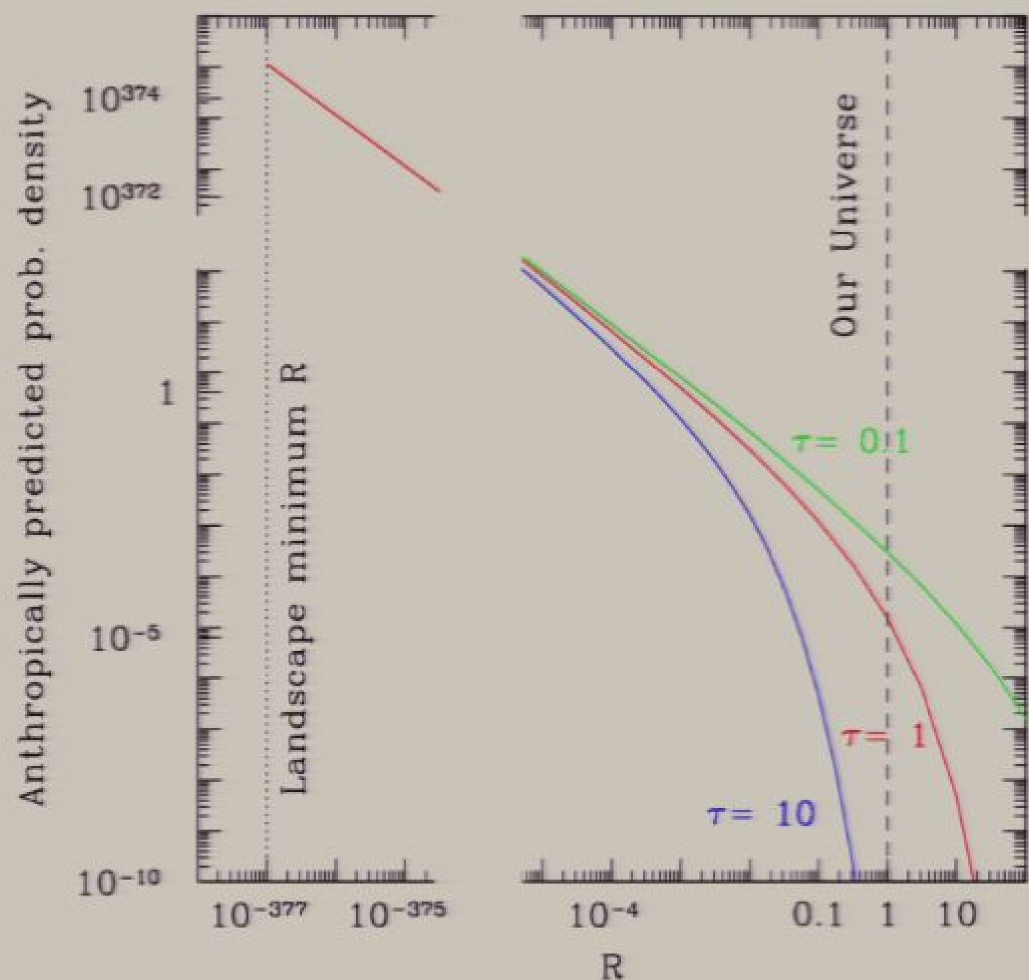
$$\tau = t_{obs}/t_0$$

controls the time when intelligent observers arise and begin collecting energy

τ	Pr (R>1)
.1	5×10^{-4}
1	9×10^{-6}
10	4×10^{-12}

MANO weighting of Universes

Starkman & Trotta, Phys Rev Lett **97**, 201301 (2006)



$$R = \Lambda/\Lambda_0$$

$$\tau = t_{obs}/t_0$$

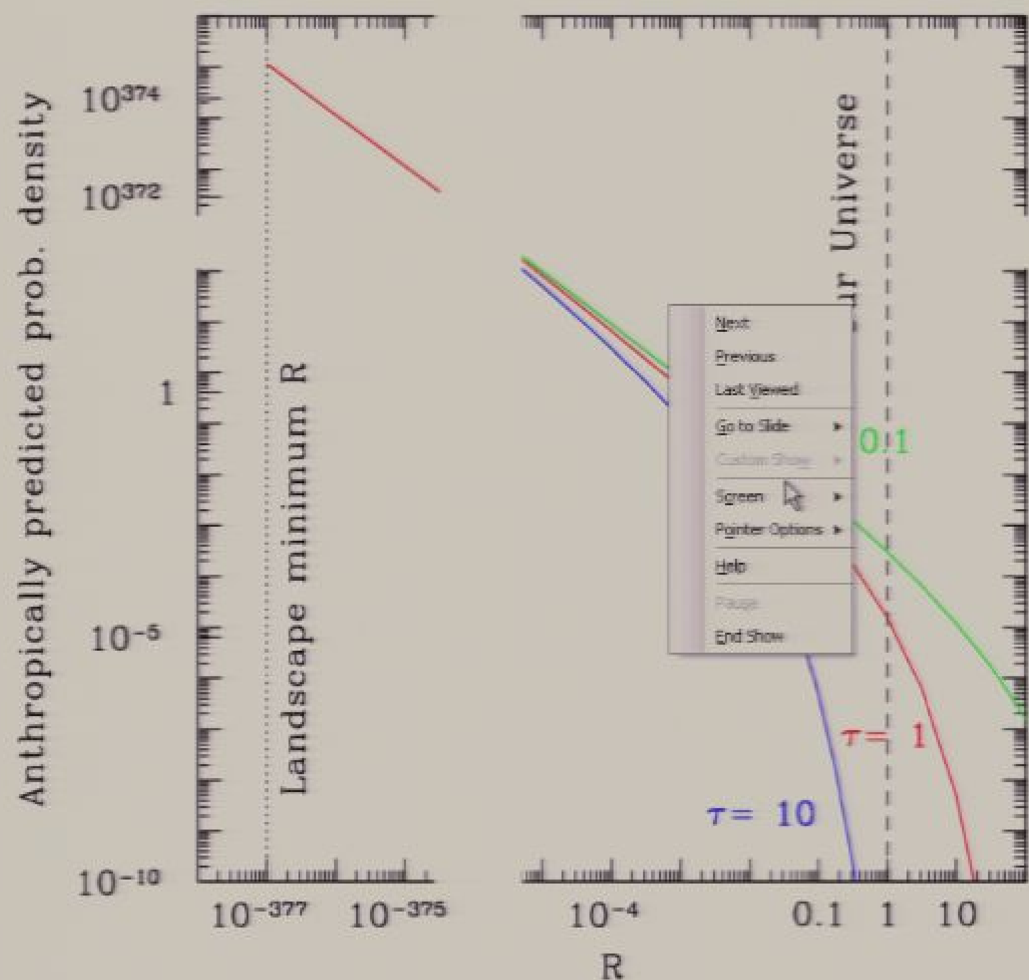
controls the time when intelligent observers arise and begin collecting energy

τ	Pr (R>1)
.1	5×10^{-4}
1	9×10^{-6}
10	4×10^{-12}

The probability of Λ being as large or larger than in our Universe is ~ 10^{-5}

MANO weighting of Universes

Starkman & Trotta, Phys Rev Lett **97**, 201301 (2006)



$$R = \Lambda/\Lambda_0$$

$$\tau = t_{obs}/t_0$$

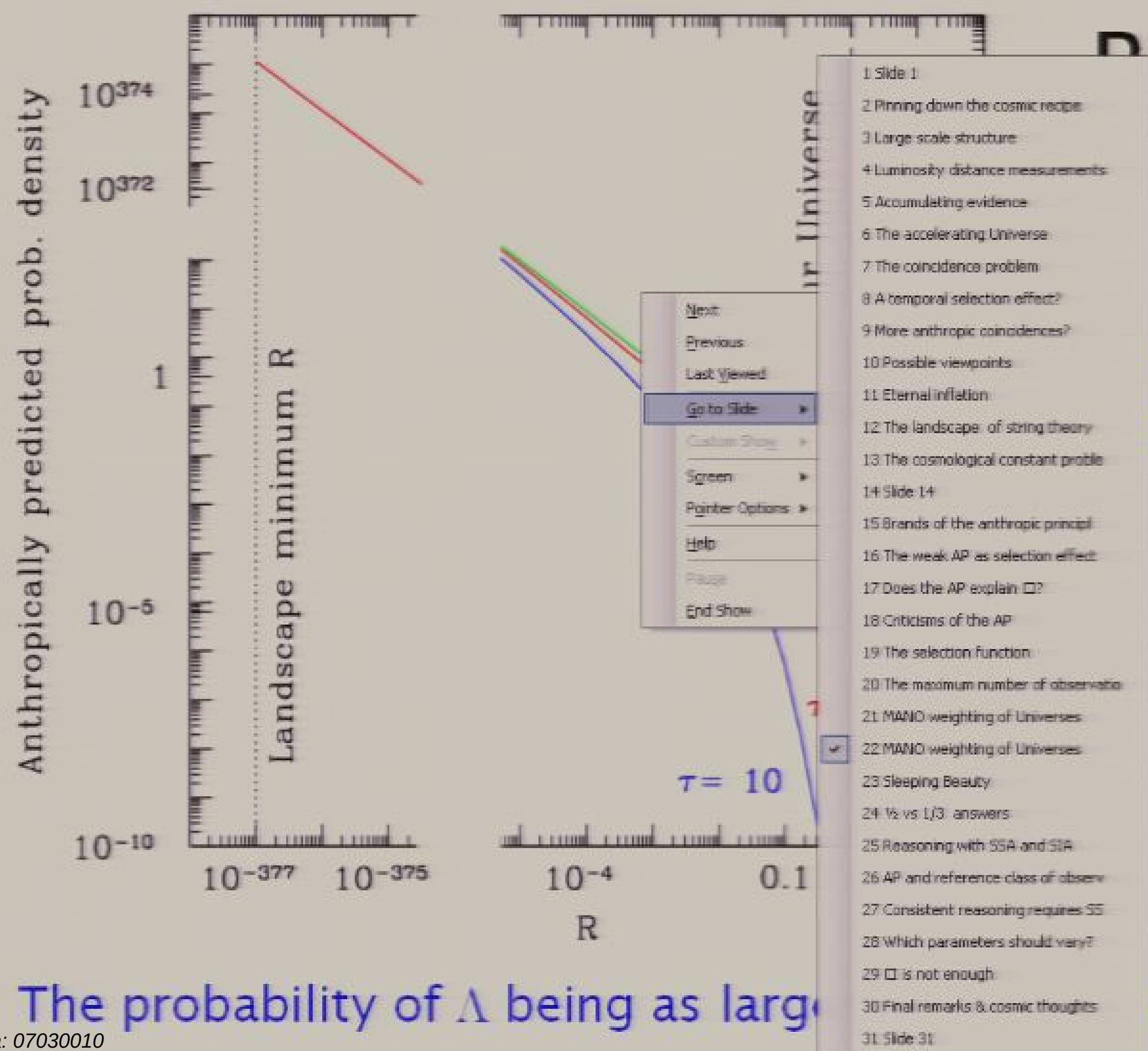
controls the time when intelligent observers arise and begin collecting energy

τ	Pr (R>1)
.1	5×10^{-4}
1	9×10^{-6}
10	4×10^{-12}

The probability of Λ being as large or larger than in our Universe is ~ 10^{-5}

MANO weighting of Universes

Starkman & Trotta, Phys Rev Lett **97**, 201301 (2006)



$$= \Lambda/\Lambda_0$$

$$= t_{obs}/t_0$$

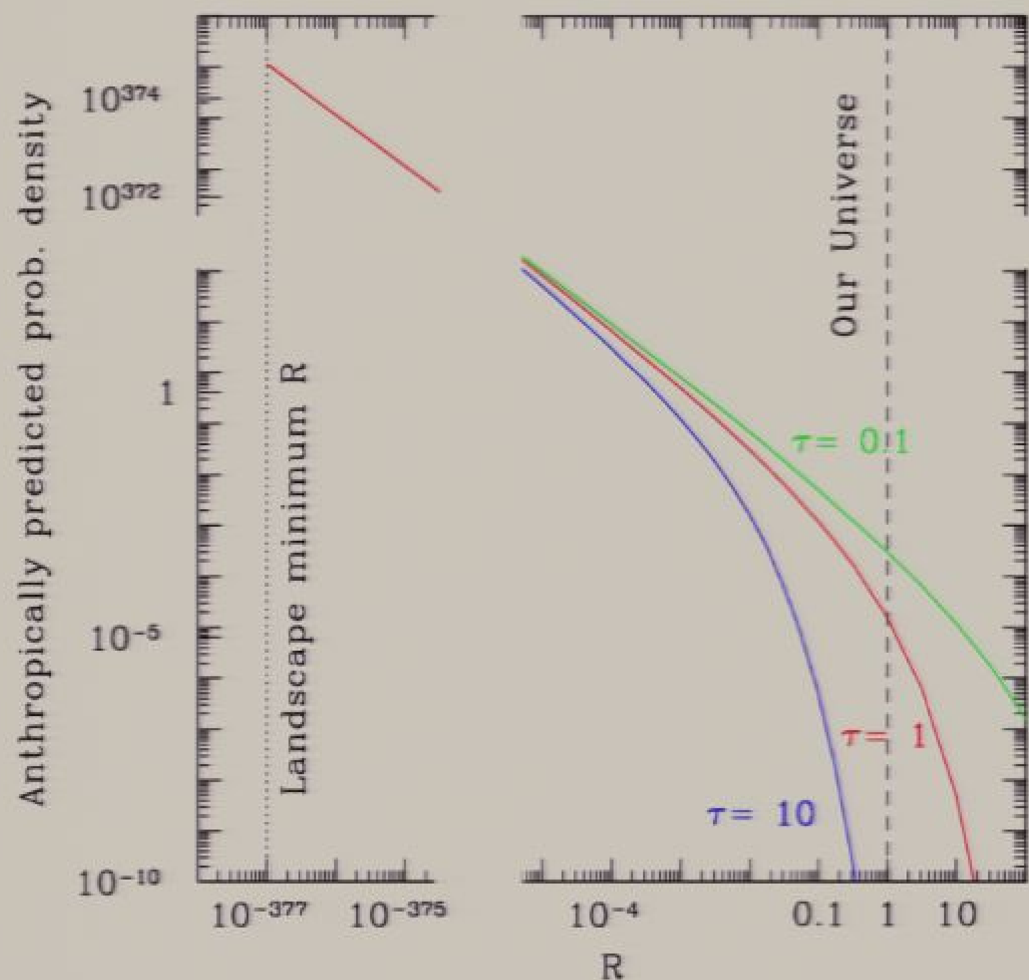
...trols the time when intelligent ...ervers arise and begin collecting ...rgy

τ	Pr (R>1)
.1	5×10^{-4}
1	9×10^{-6}
10	4×10^{-12}

The probability of Λ being as larg... ...n in our Universe is ~ 10^{-5}

MANO weighting of Universes

Starkman & Trotta, Phys Rev Lett **97**, 201301 (2006)



$$R = \Lambda/\Lambda_0$$

$$\tau = t_{obs}/t_0$$

controls the time when intelligent observers arise and begin collecting energy

τ	Pr (R>1)
.1	5×10^{-4}
1	9×10^{-6}
10	4×10^{-12}

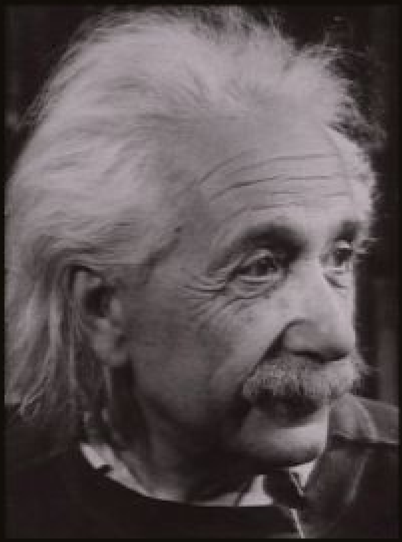
The probability of Λ being as large or larger than in our Universe is ~ 10^{-5}

Final remarks & cosmic thoughts

- *Selection effects are unavoidable: our observations are conditional on the fact that we exist*
- *There have been attempts to "solve" the cosmological constant problem by invoking selection effects in some kind of multiverse (WAP)*
- *Criticisms to the anthropic principle:*
  - instability wrt definition of observers: different ways of counting observers lead to totally different "predictions"
  - which parameters should vary?
  - consistent reasoning requires either SSA+SIA or common reference class of observers. Answer depends on number of companions in the class

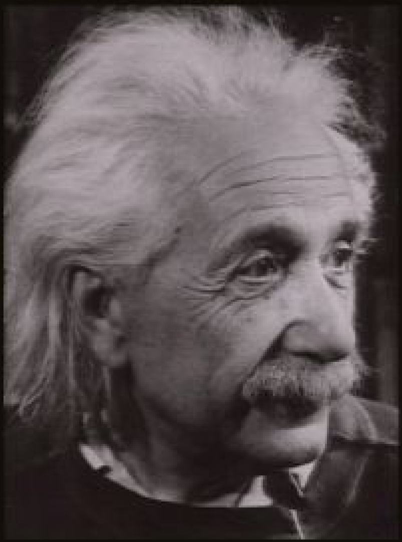
"What I'm interested in understanding is whether God did have a choice in creating the Universe"

(Albert Einstein)



"What I'm interested in understanding is whether God did have a choice in creating the Universe"

(Albert Einstein)



"If only God would give me some clear sign! Like making a large deposit in my name in a Swiss bank"

(Woody Allen)