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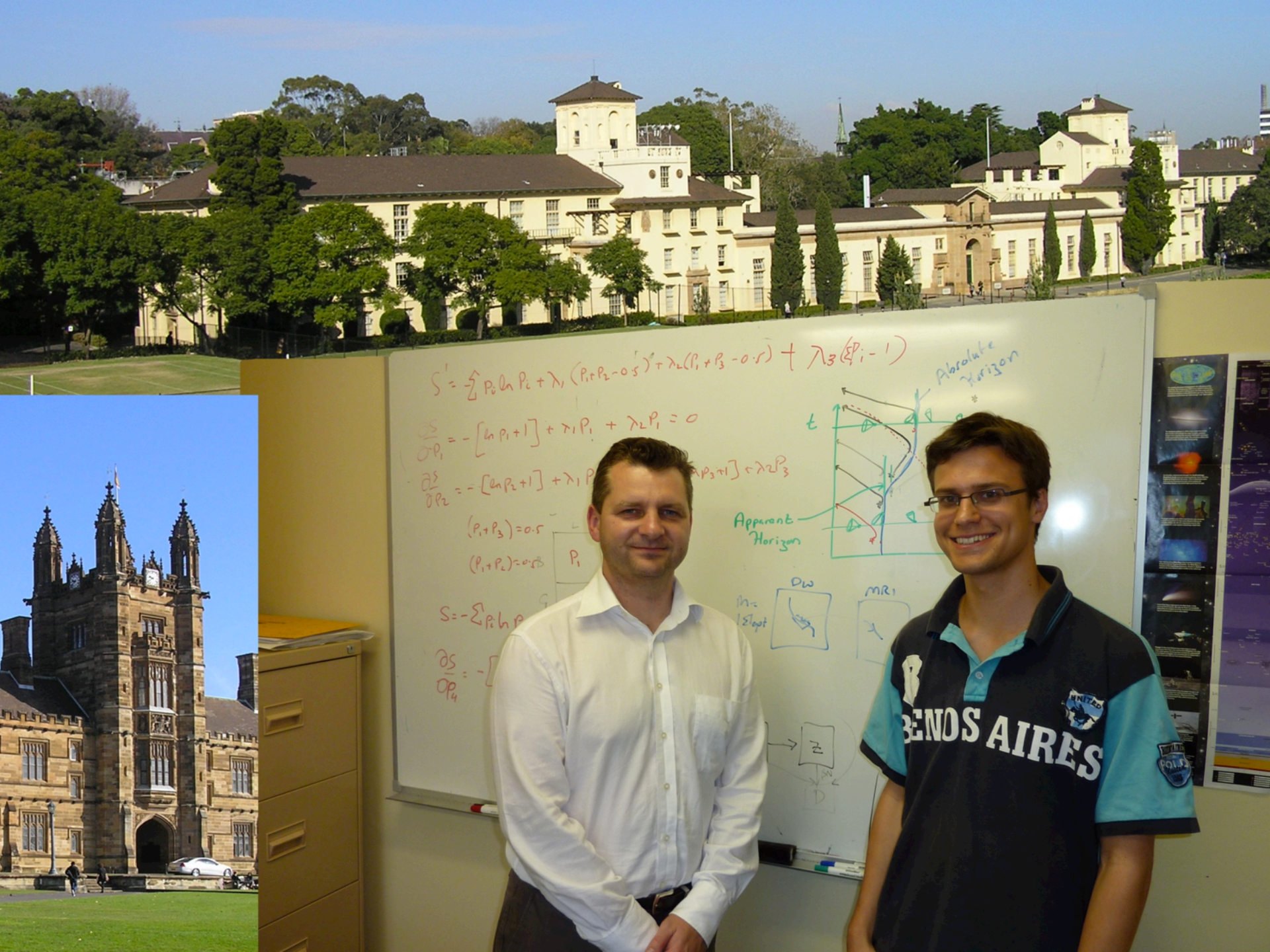
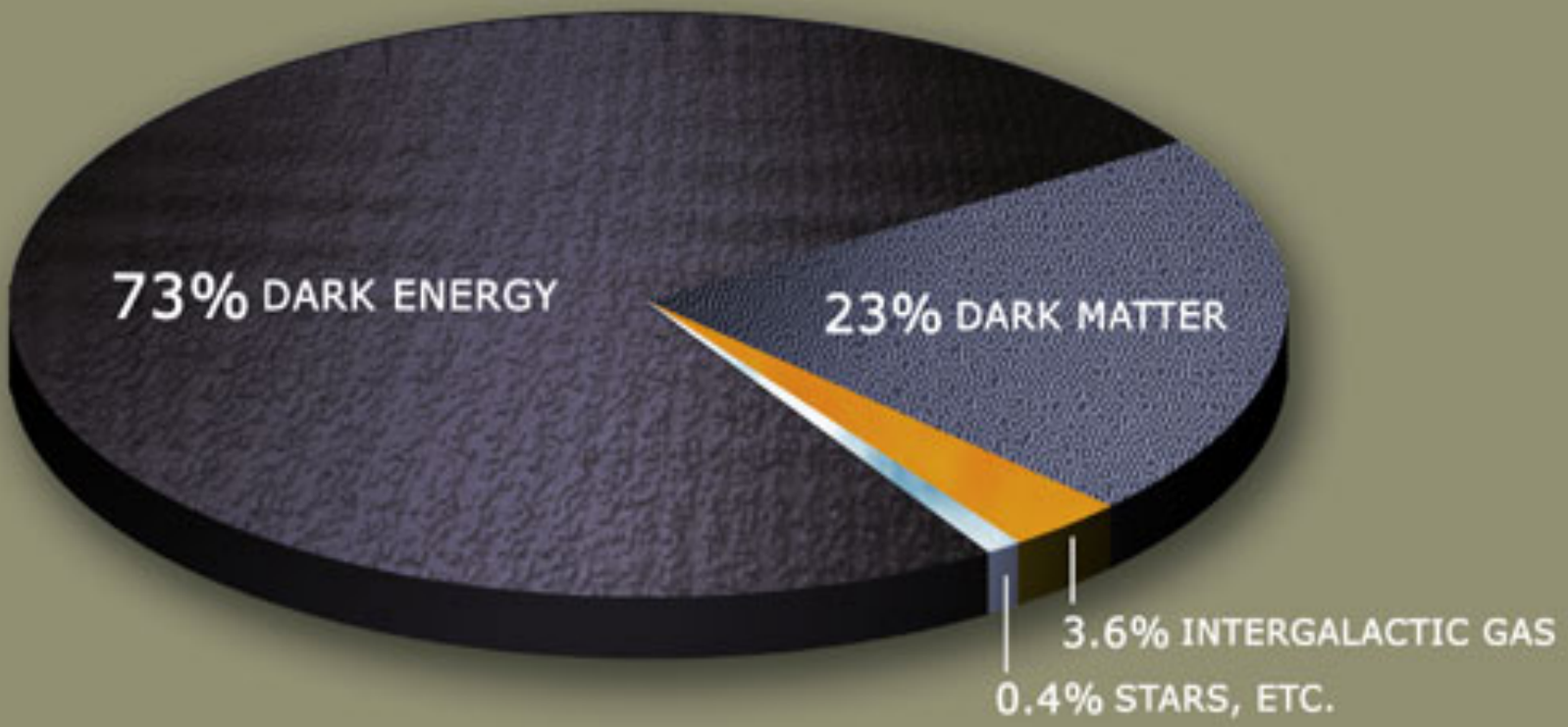
Cosmic Horizons and Coincidences

In honour of Jan Kuijpers' 65th Solar revolution

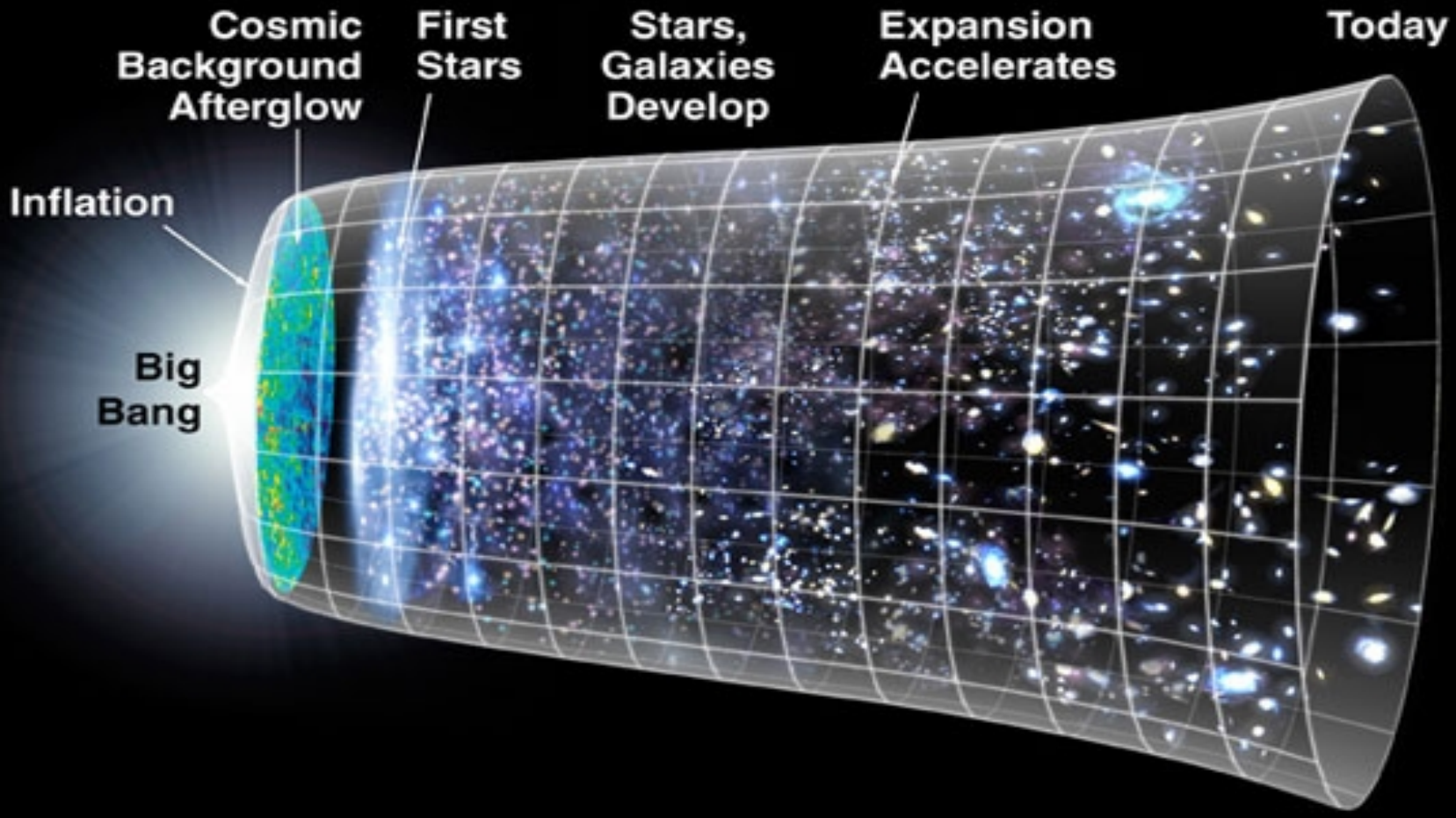
Pim van Oirschot 25-08-2011


Absolute Horizon
t
Apparent Horizon
DW
MRI
BENOS AIRES

Dark Energy


73% DARK ENERGY
23% DARK MATTER
3.6% INTERGALACTIC GAS
0.4% STARS, ETC.

The Expanding Universe: A Capsule History



Equations of state

	w_i
matter	0
radiation	$1/3$
cosmological constant	-1
dark energy	-1.12 ± 0.12

(Riess et al. 2009)

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Through the looking glass: why the 'cosmic horizon' is not a horizon*

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ABSTRACT

The present standard model of cosmology, Λ cold dark matter (ΛCDM), contains some intriguing coincidences. Not only are the dominant contributions to the energy density approximately of the same order at the present epoch, but we also note that contrary to the emergence of cosmic acceleration as a recent phenomenon, the time-averaged value of the deceleration parameter over the age of the Universe is nearly zero. Curious features like these in ΛCDM give rise to a number of alternate cosmologies being proposed to remove them, including models with an equation of state $w = -1/3$. In this paper, we examine the validity of some of these alternate models and we also address some persistent misconceptions about the Hubble sphere and the event horizon that lead to erroneous conclusions about cosmology.

Key words: cosmology: theory.

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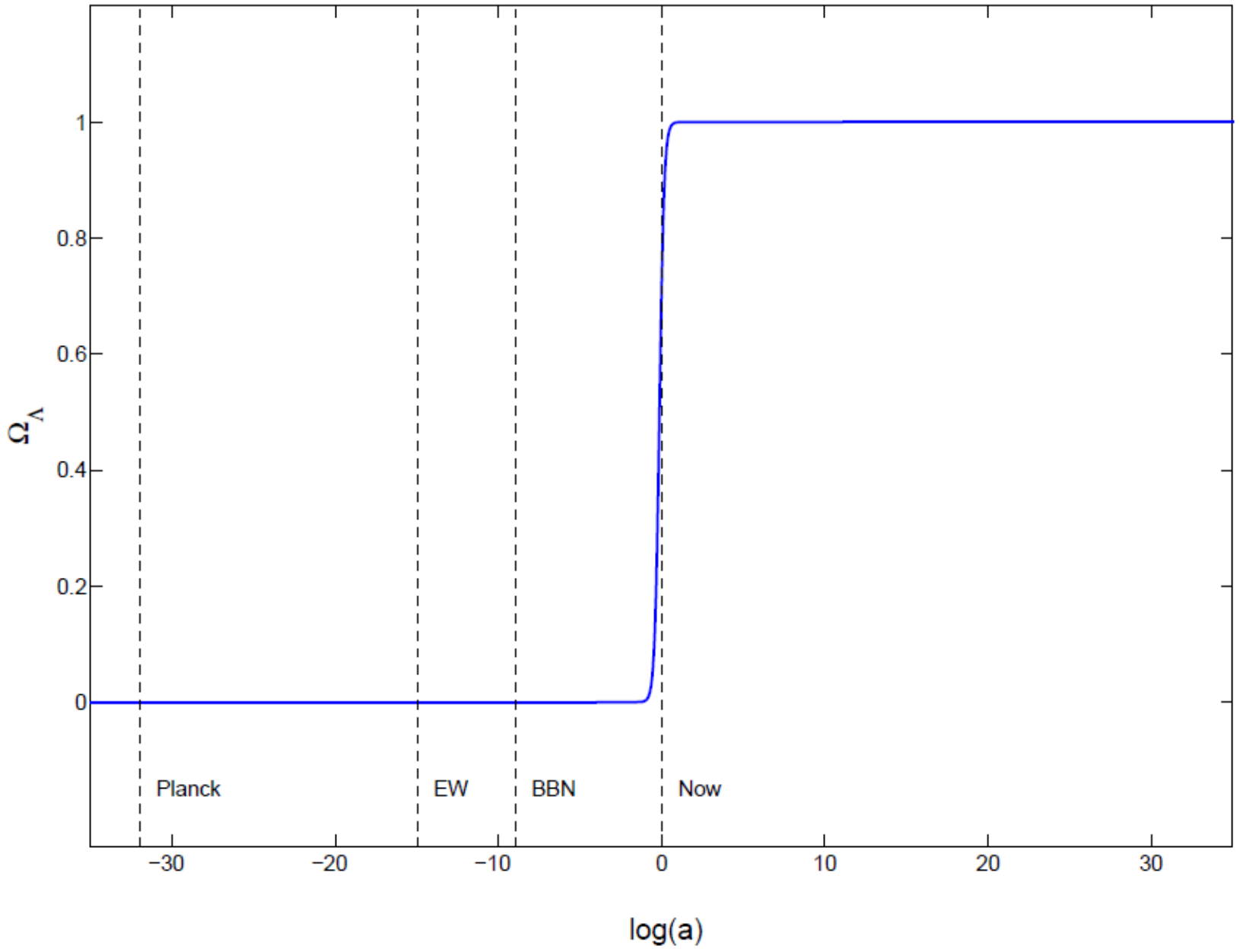
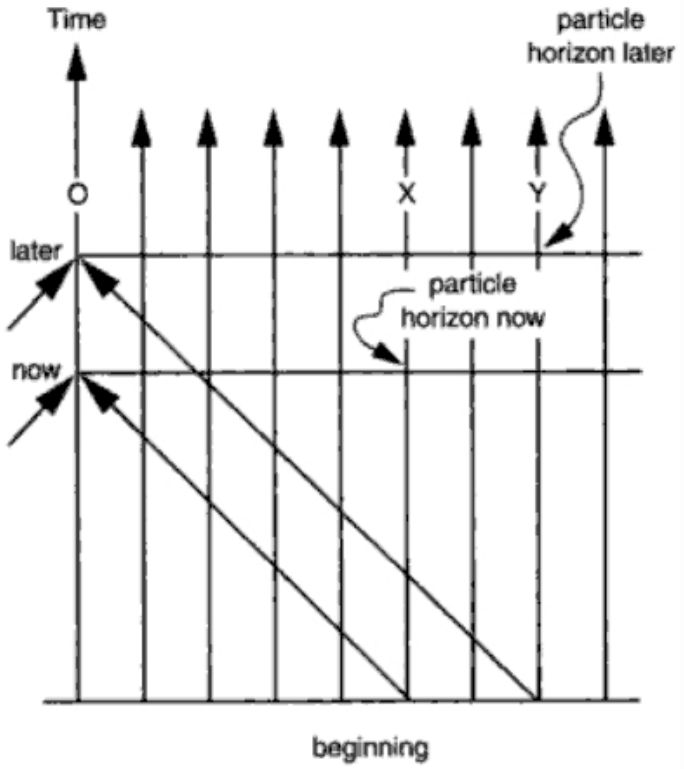

1
0.8
0.6
0.4
0.2
0
Ω_Λ
Planck
EW
BBN
Now
−30
−20
−10
0
10
20
30
log(a)

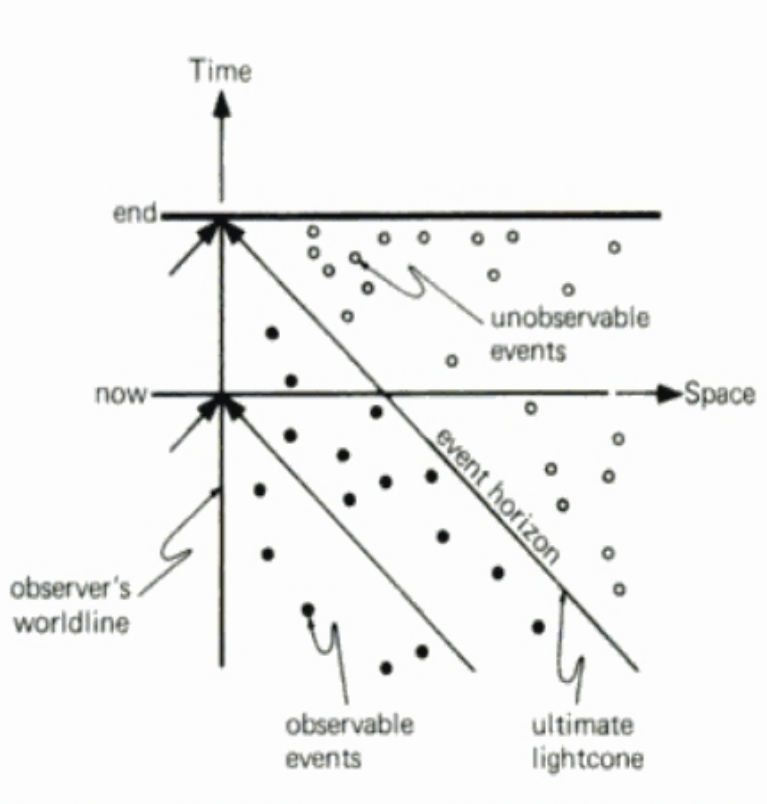
What are cosmic horizons?

- First definitions were given by W. Rindler in 1956
- Particle horizon (observer A, t) divides particles into two classes:
  1. Those that have already been observable by A at time t
  2. Those that have not yet been observable by A at that time
- Event horizon (observer A) divides events into two classes:
  1. Those that have been, are or will be observable by A
  2. Those that are forever outside A's possible powers of observation

Particle Horizon



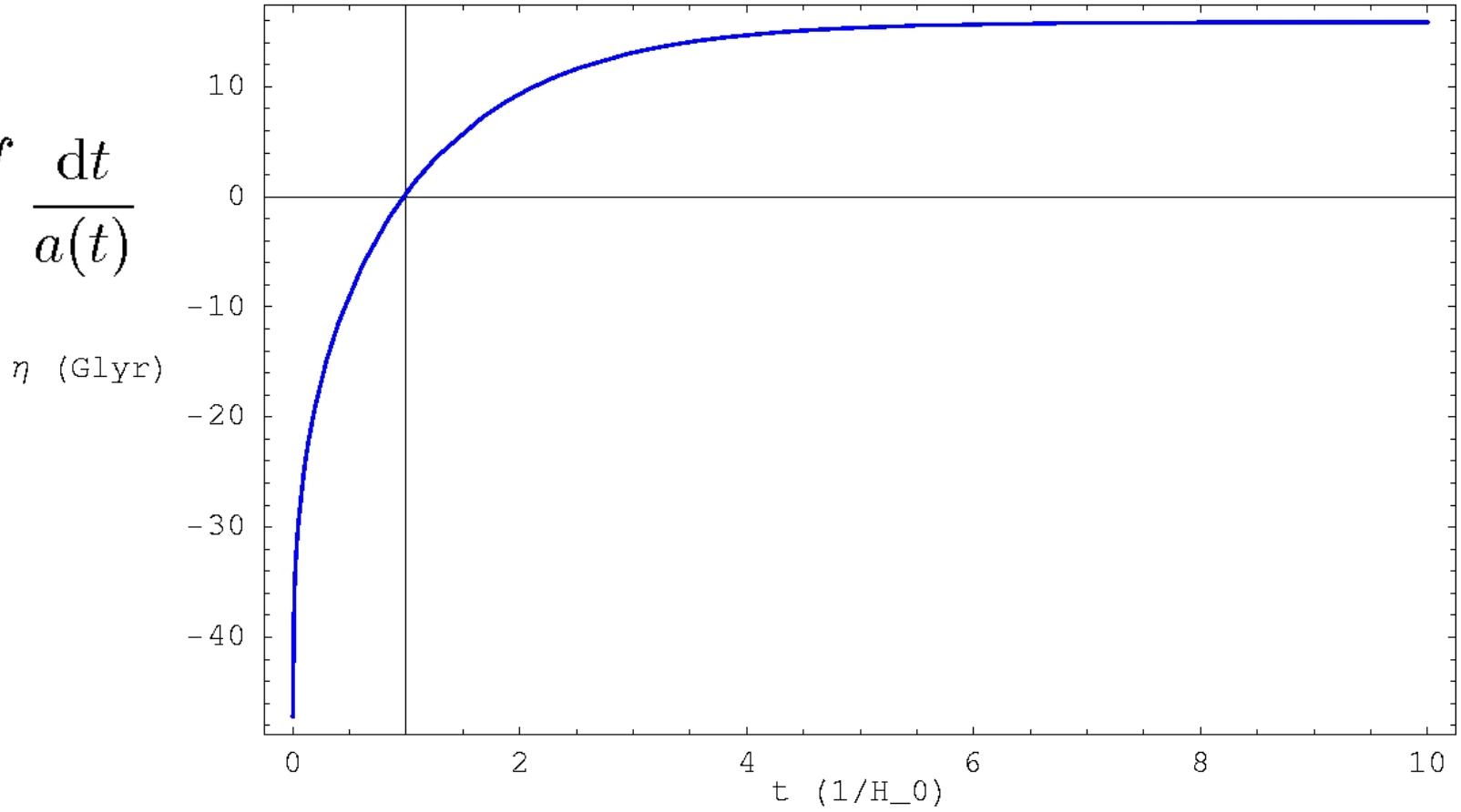
Event Horizon



Harrison, Cosmology - 1981

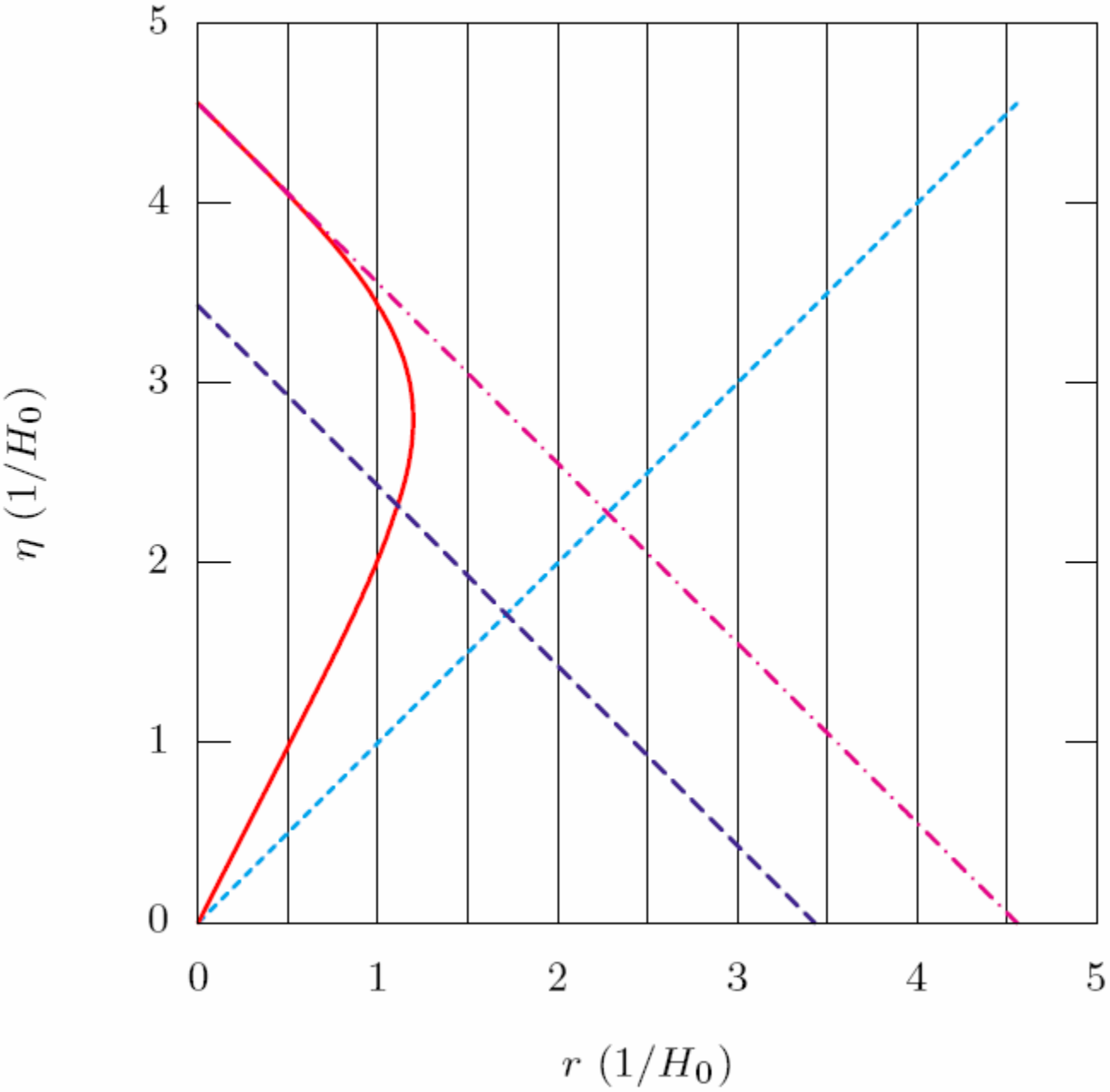
Conformal Convergence

$$\eta = \int \frac{\mathrm{d}t}{a(t)}$$

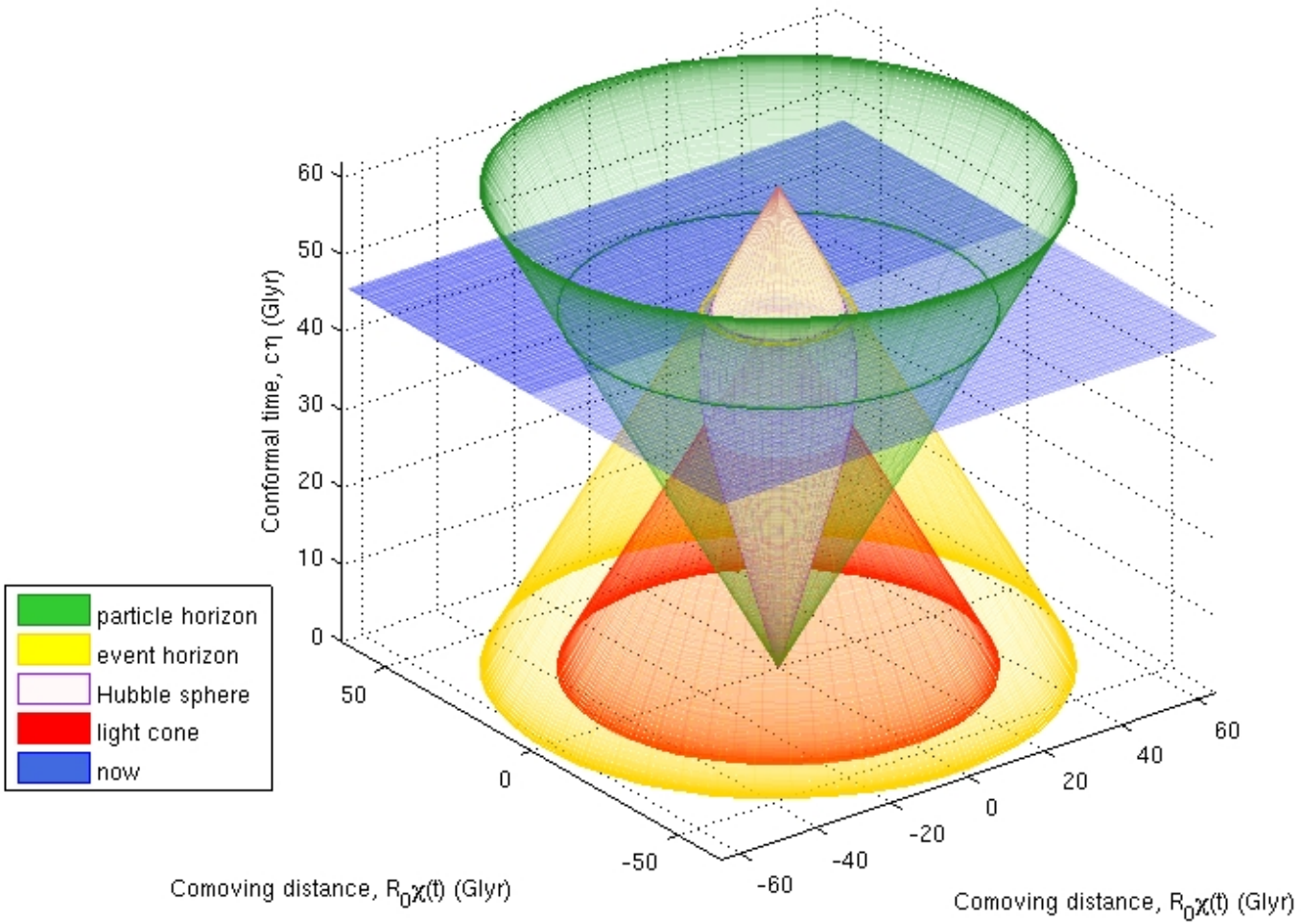


Not a cosmic horizon

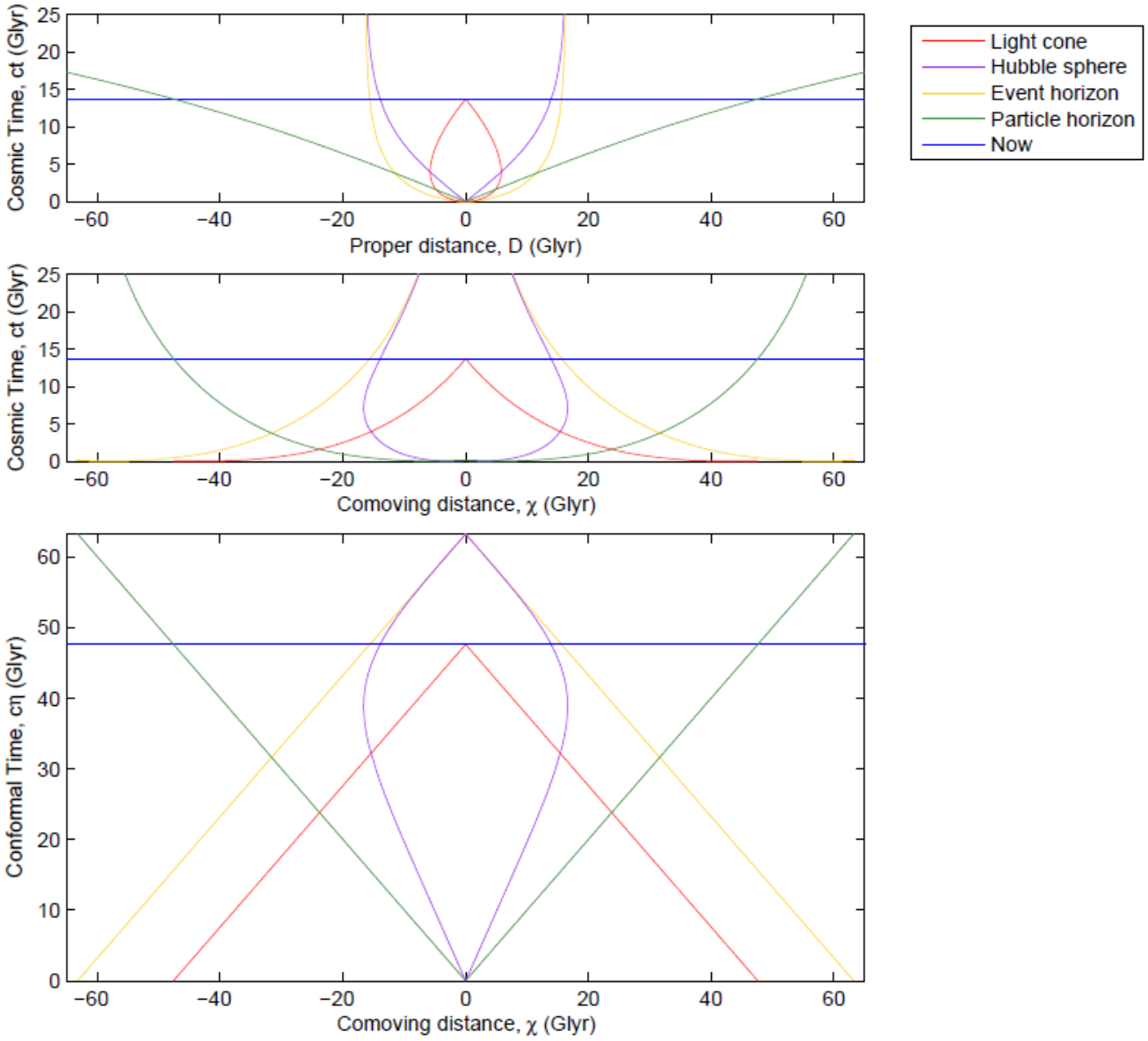
- Hubble's law $V = H\,D.$ gives rise to a distance $D_{\mathrm{H}} = \frac{c}{H}$
- This is the distance beyond which V exceeds the speed of light, c, called the Hubble distance
- We can see beyond the Hubble sphere, because it currently lies near redshift 1.5


5
4
3
2
1
0
0
1
2
3
4
5
$\eta\ (1/H_0)$
$r\ (1/H_0)$

A Conformal Diagram

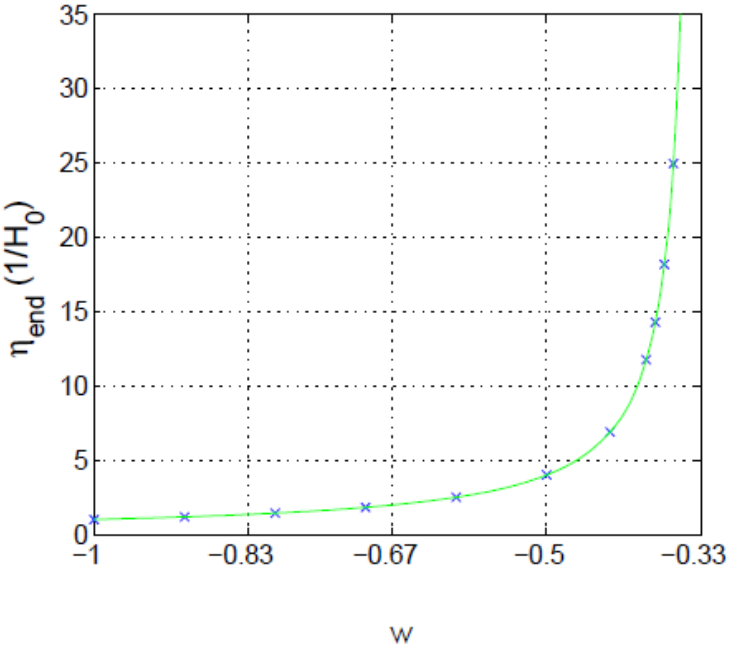


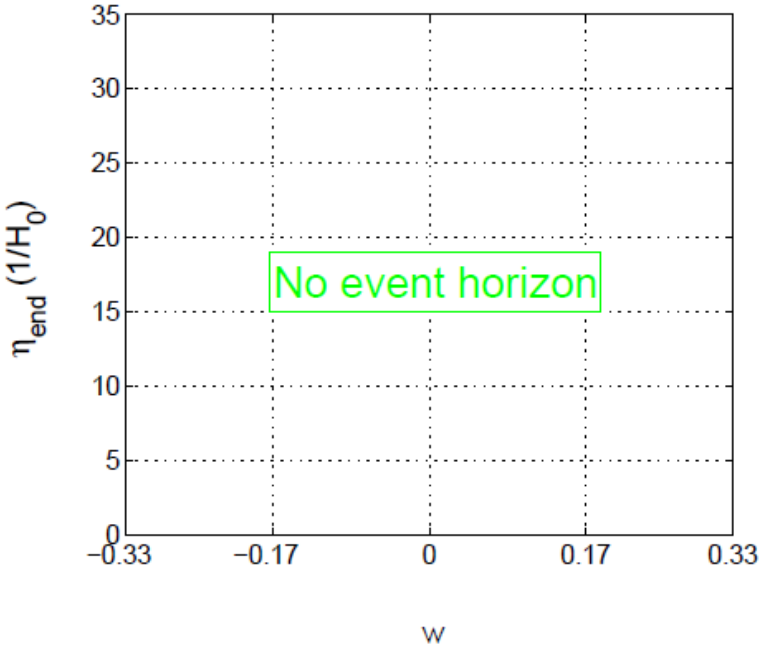
Cosmic Horizons

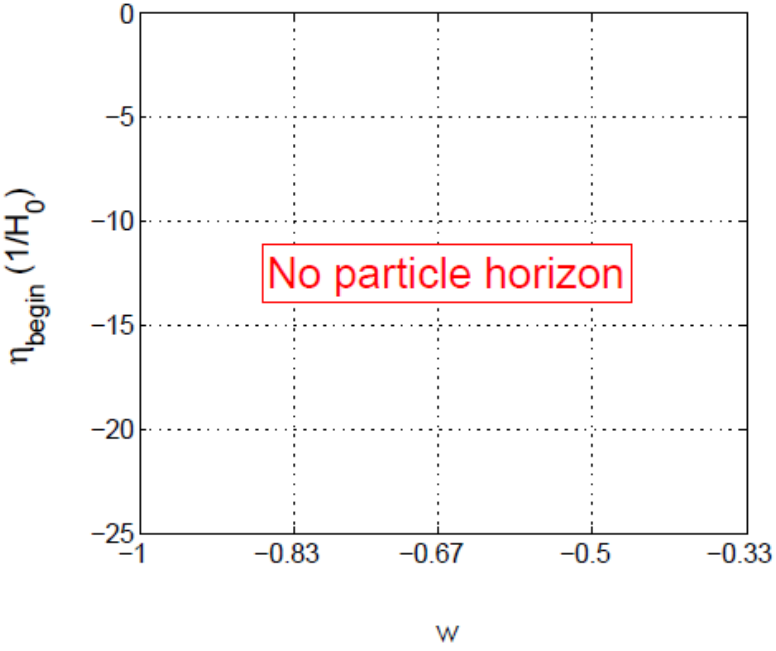


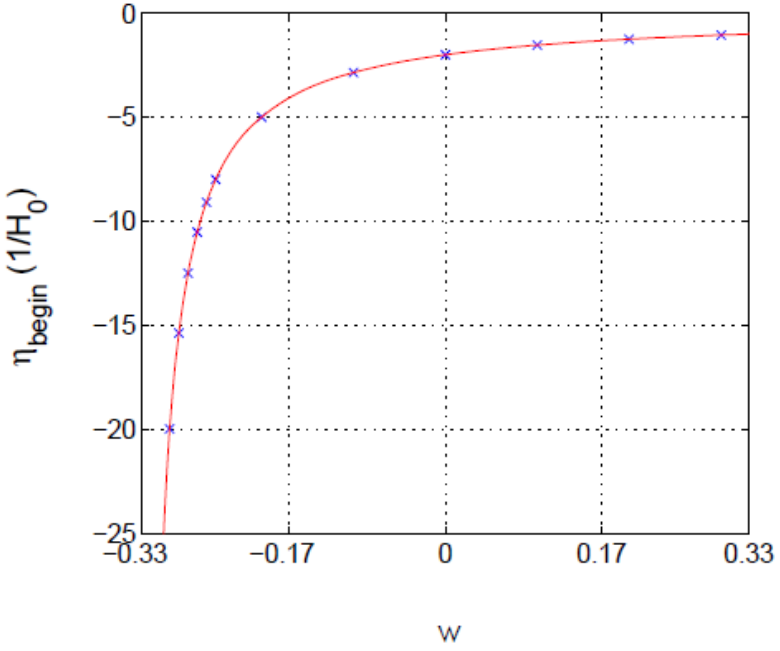
So far cosmic horizons...

What do they have to do with dark energy?


35
30
25
20
15
10
5
0
−1
−0.83
−0.67
−0.5
−0.33
η_{end} $(1/H_0)$
w


35
30
25
20
15
10
5
0
−0.33
−0.17
0
0.17
0.33
η_{end} $(1/H_0)$
No event horizon
w


0
−5
−10
−15
−20
−25
−1
−0.83
−0.67
−0.5
−0.33
η_{begin} $(1/H_0)$
No particle horizon
w


0
−5
−10
−15
−20
−25
−0.33
−0.17
0
0.17
0.33
η_{begin} $(1/H_0)$
w

The apparent horizon

- Rindler and Hawking wrote about the apparent horizon of the universe.
- This is a Schwarzschild type of horizon

$$\frac{2GM(R_{\rm h})}{c^2} = R_{\rm h} = \frac{c}{H}$$

$$\dot{R}_{\rm h} = \frac{3}{2}(1+\omega)\,c$$

Notes on the apparent horizon

1. The apparent horizon also exists for open (hyperbolic) and closed (spherical) universes, in which case it is not c / H

2. We can see beyond the apparent horizon, like we can see beyond the Hubble sphere

Another coincidence problem

- $R_{\rm h} = \dfrac{c}{H}$
- $\dot{R}_{\rm h} = \dfrac{3}{2}(1+\omega)\,c$

$$ct_0 \approx R_{\rm h}(t_0)$$

- Claim: Because the age of the universe is one Hubbletime today, the apparent horizon should be equal to *ct* at all times
- The equation of state of dark energy, $w = -1/3$

Relating the apparent horizon to q

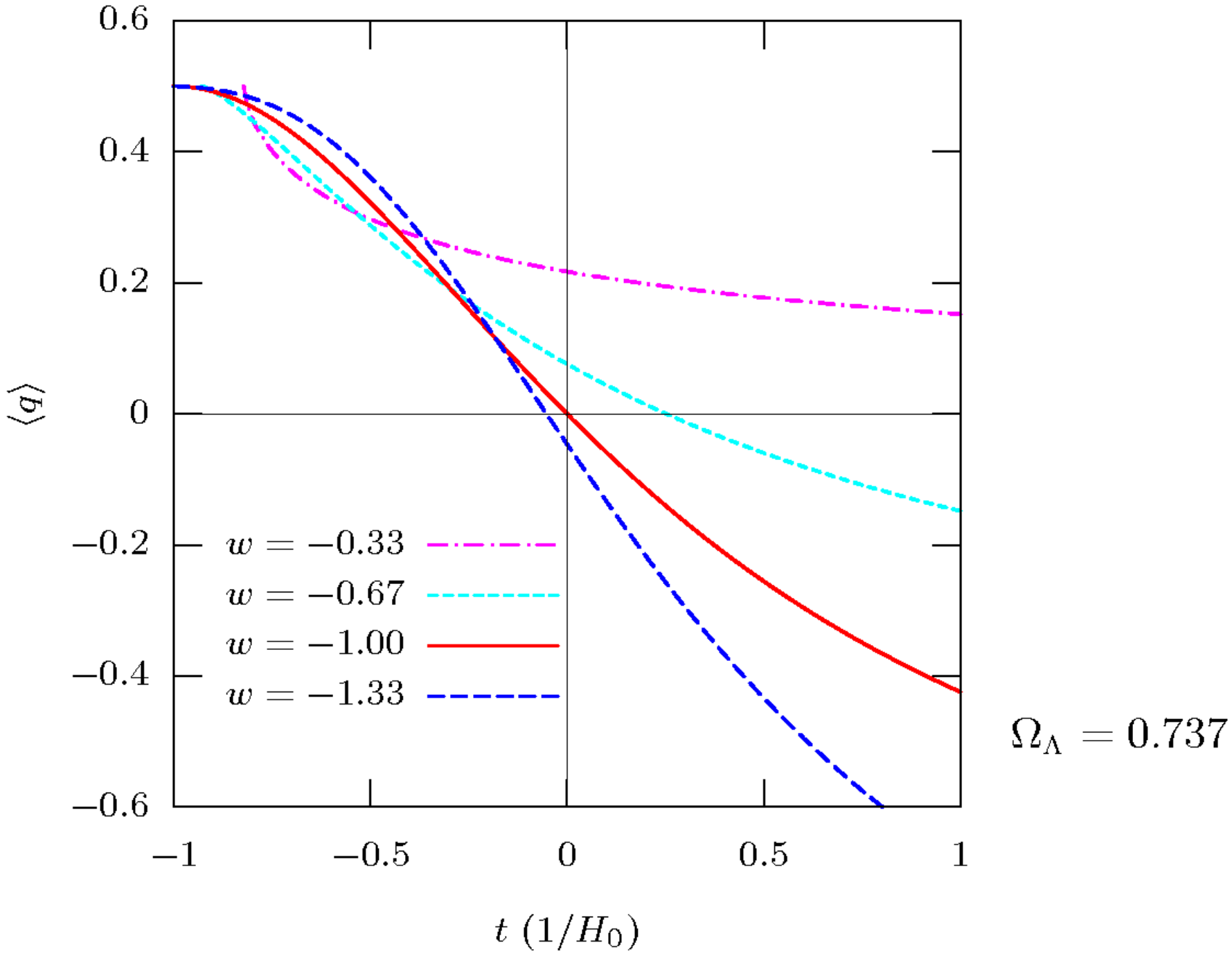
$$\dot{R}_\mathrm{h} = \frac{3}{2}(1+\omega)\,c$$

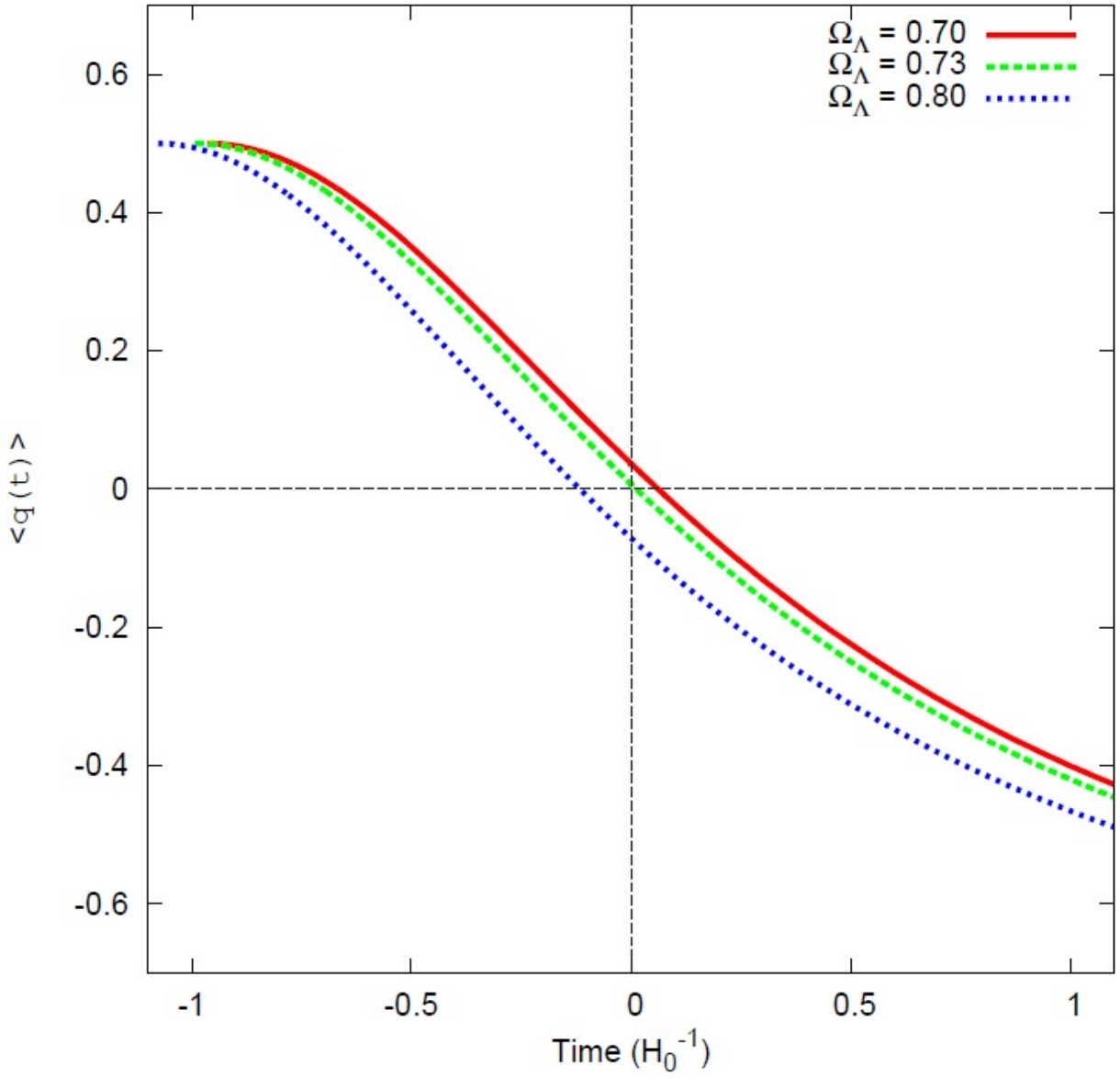
$$q \equiv -\frac{\ddot{a}a}{\dot{a}^2} = \frac{1+3w}{2}$$

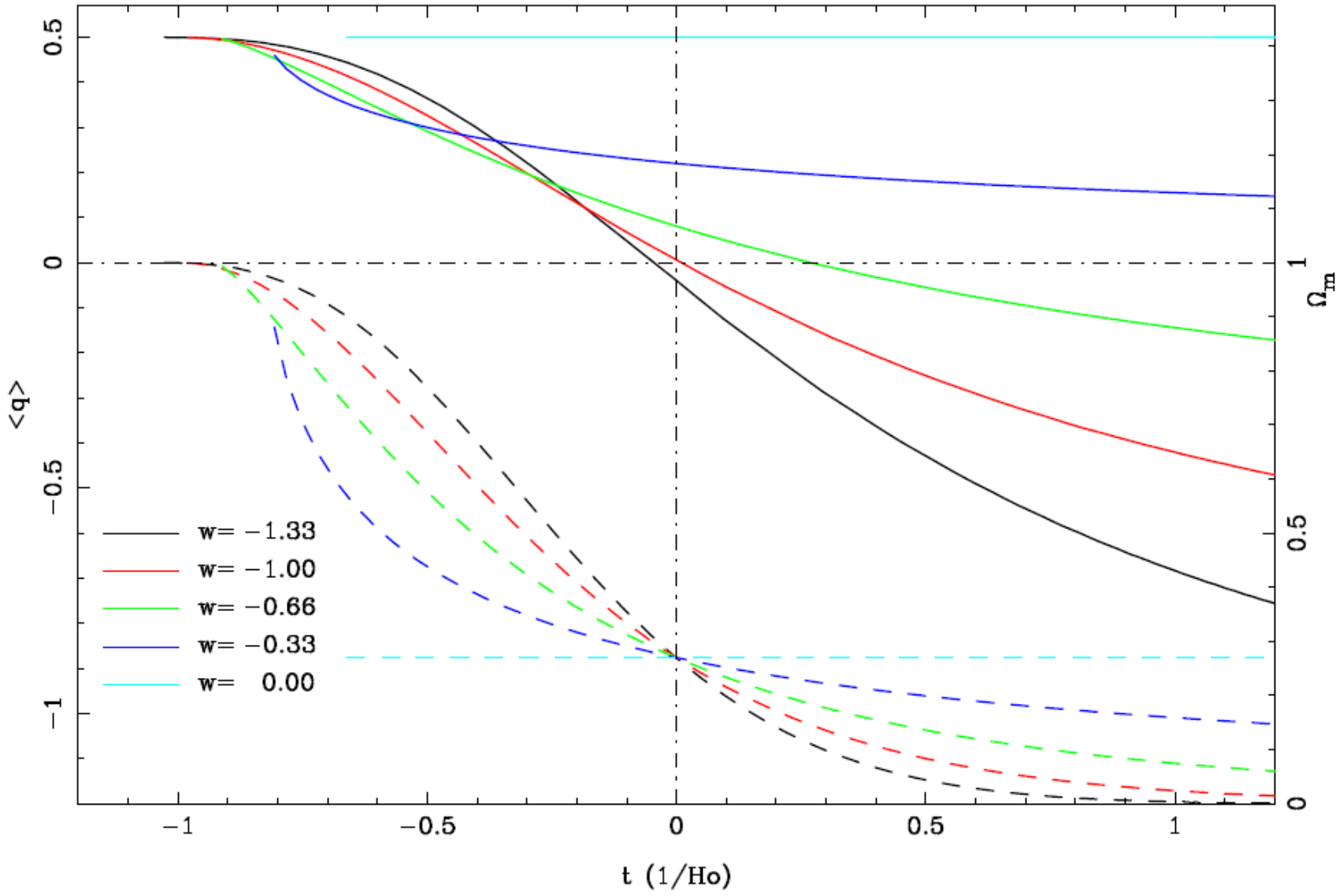
$$q \equiv \frac{\ddot{a}a}{\dot{a}^2} = \dot{R}_\mathrm{h} - 1$$

$$\langle q \rangle = \frac{1}{t}\int_0^t q(t')\,\mathrm{d}t'$$

$$\langle q(t) \rangle = \frac{1}{t}\int_0^t \left(\dot{R}_\mathrm{h}(t') - 1\right)\mathrm{d}t' = \frac{1}{tH} - 1$$


0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−1
−0.5
0
0.5
1
⟨q⟩
t (1/H0)
w = −0.33
w = −0.67
w = −1.00
w = −1.33
ΩΛ = 0.737


Ω_Λ = 0.70
Ω_Λ = 0.73
Ω_Λ = 0.80
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
<q(t)>
-1
-0.5
0
0.5
1
Time (H_0^{-1})


0.5
0
−0.5
−1
<q>
−1
−0.5
0
0.5
1
t (1/Ho)
1
0.5
0
Ω_m
w= −1.33
w= −1.00
w= −0.66
w= −0.33
w= 0.00

Conclusions

- A number of outstanding, fundamental questions concerning the standard model of cosmology remain unsolved.
- Exploring the nature of Dark Energy might help us finding an answer to these questions
- The theory of Cosmic Horizons is not in disagreement with the existence of a non-zero cosmological constant