Phantom Energy: Dark Energy with w <-1 Causes a Cosmic Doomsday

Supernova searches and the stunning cosmic microwave background (CMB) results from balloon and ground experiments and now from Wilkinson Microwave Anisotropy Probe (WMAP) indicate an accelerating cosmological expansion ,

so the Universe additionally consists of some sort of negative-pressure dark energy.

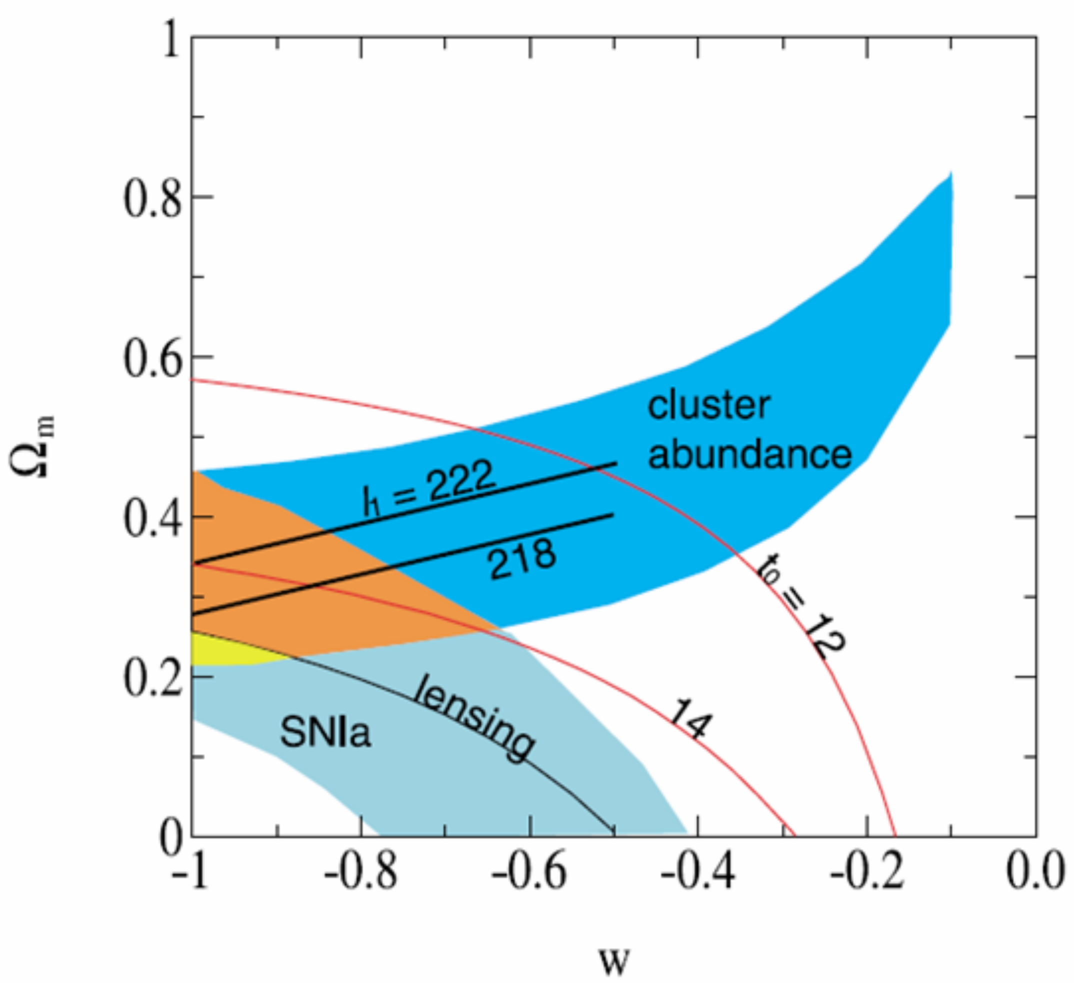
- "equation of state" parameter $w \equiv p/\rho$

  w<-1/3 is required for cosmic acceleration.

- One candidate is quintessence, a cosmic scalar field that is displaced from, but slowly rolling to, the minimum of its potential.

  In such model, -1 < w < -1/3

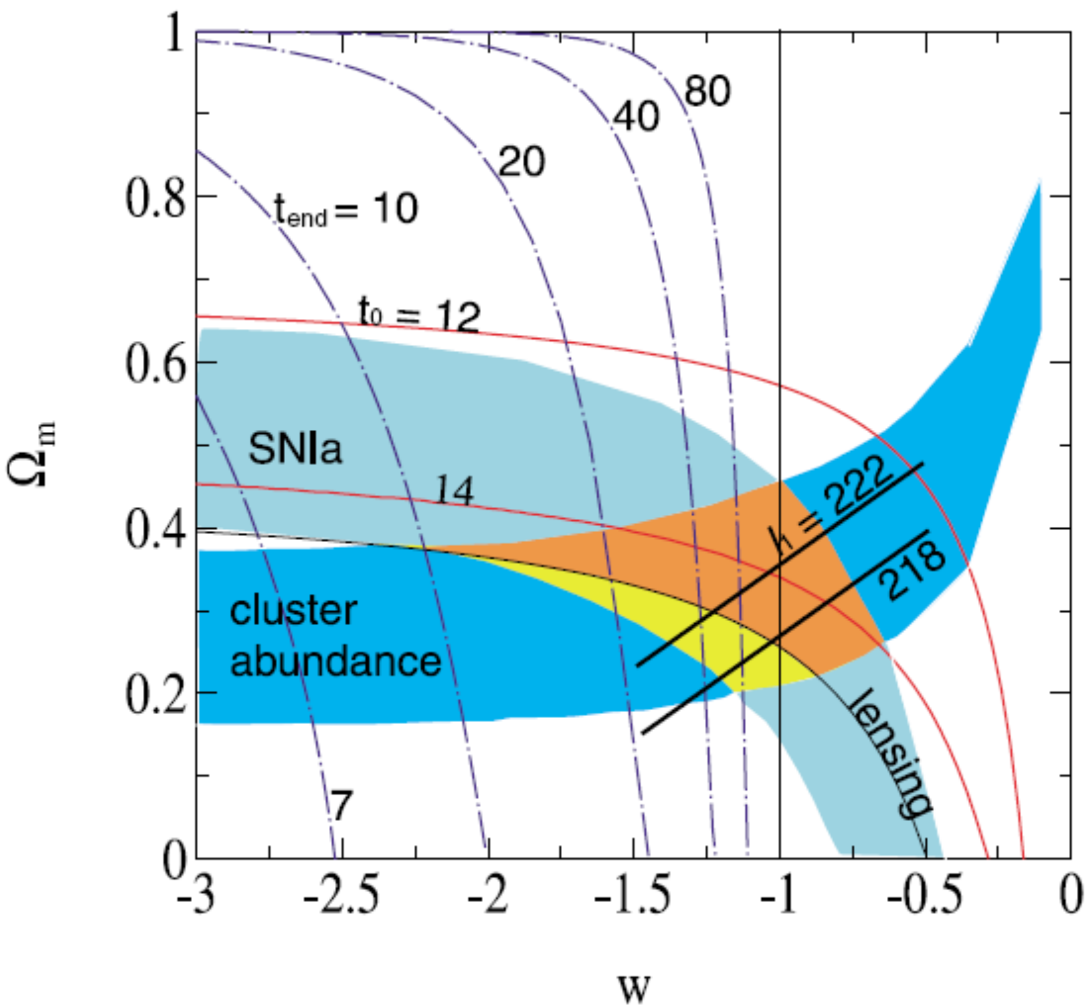
  dark energy density $\rho_Q \propto a^{-3(1+w)}$



As the figure shows, *w* seems to be converging to *w* = -1

Phantom energy :$w<-1$

- The energy density of phantom energy increases with time.
- It also violates the dominant-energy condition , a notion that helps prohibit time machines and wormholes.



80
40
20
t_{end} = 10
t_0 = 12
14
7
SNIa
cluster
abundance
lensing
h = 222
218
Ω_m
w
1
0.8
0.6
0.4
0.2
0
-3
-2.5
-2
-1.5
-1
-0.5
0

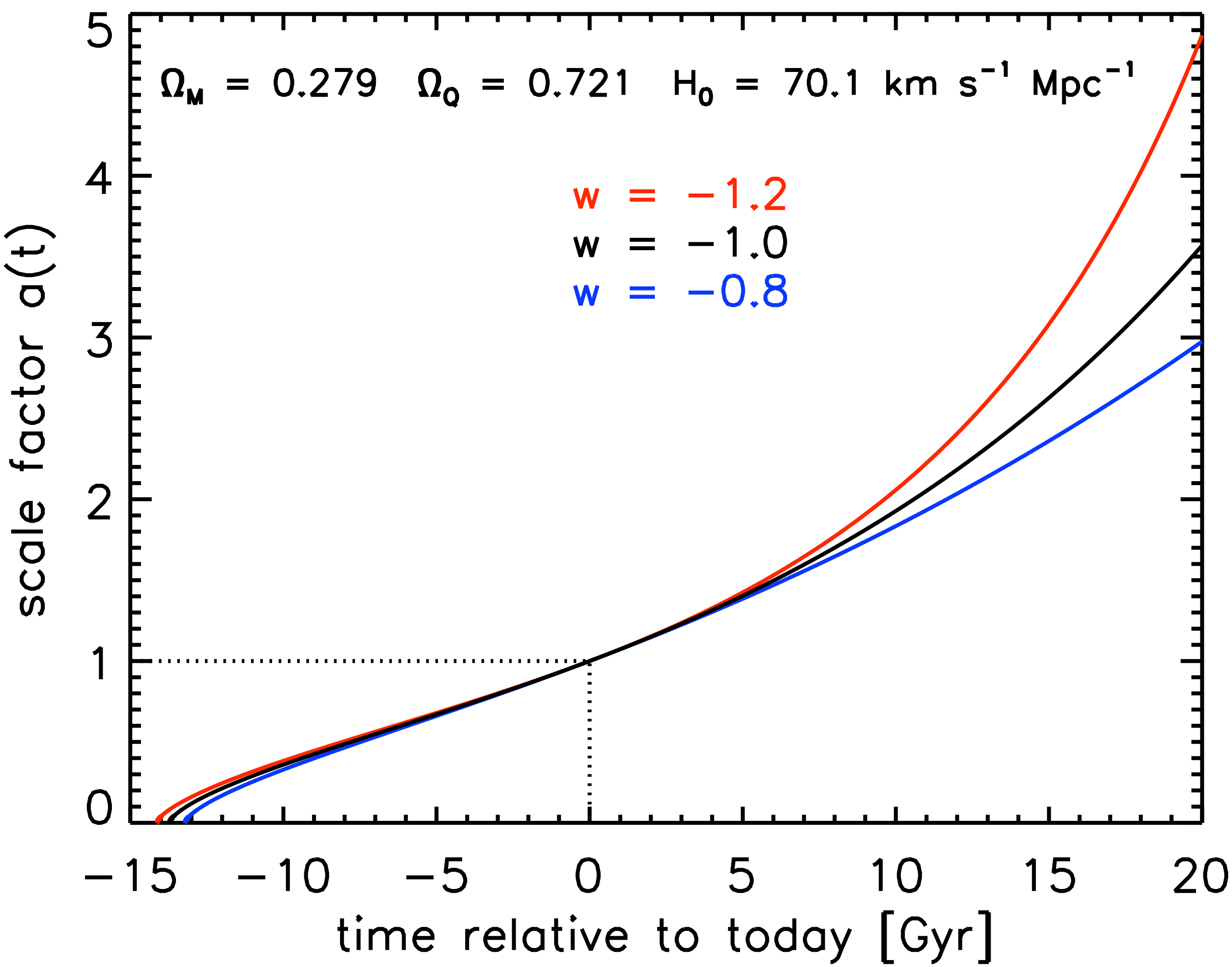
- A flat or open Universe without dark energy, the horizon grows more rapidly than the scale factor. The number of visible galaxies grows.

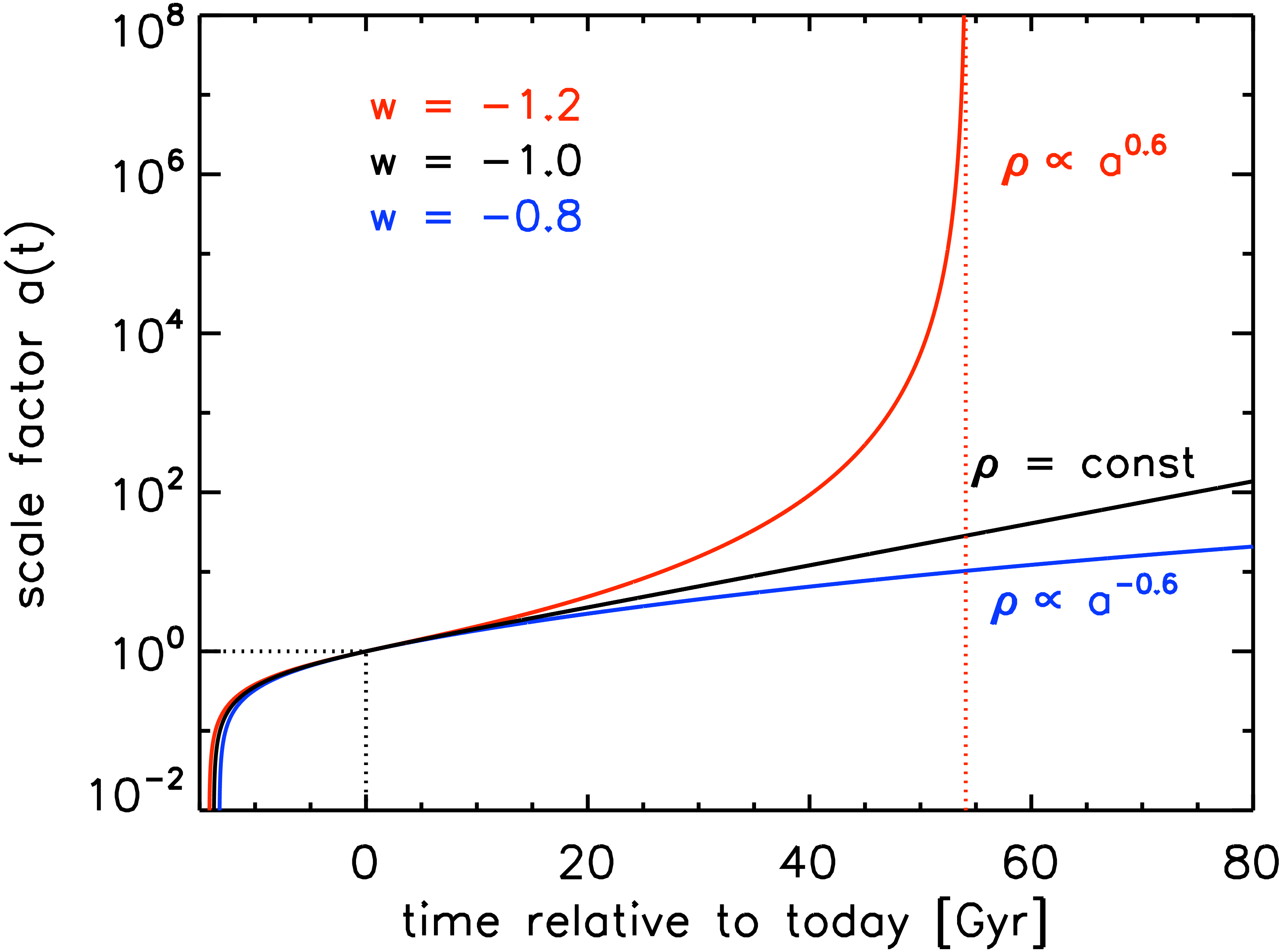
- If the expansion is accelerating, $-1<w<-1/3$, then the scale factor grows more rapidly than the horizon. Galaxies disappear beyond the horizon.

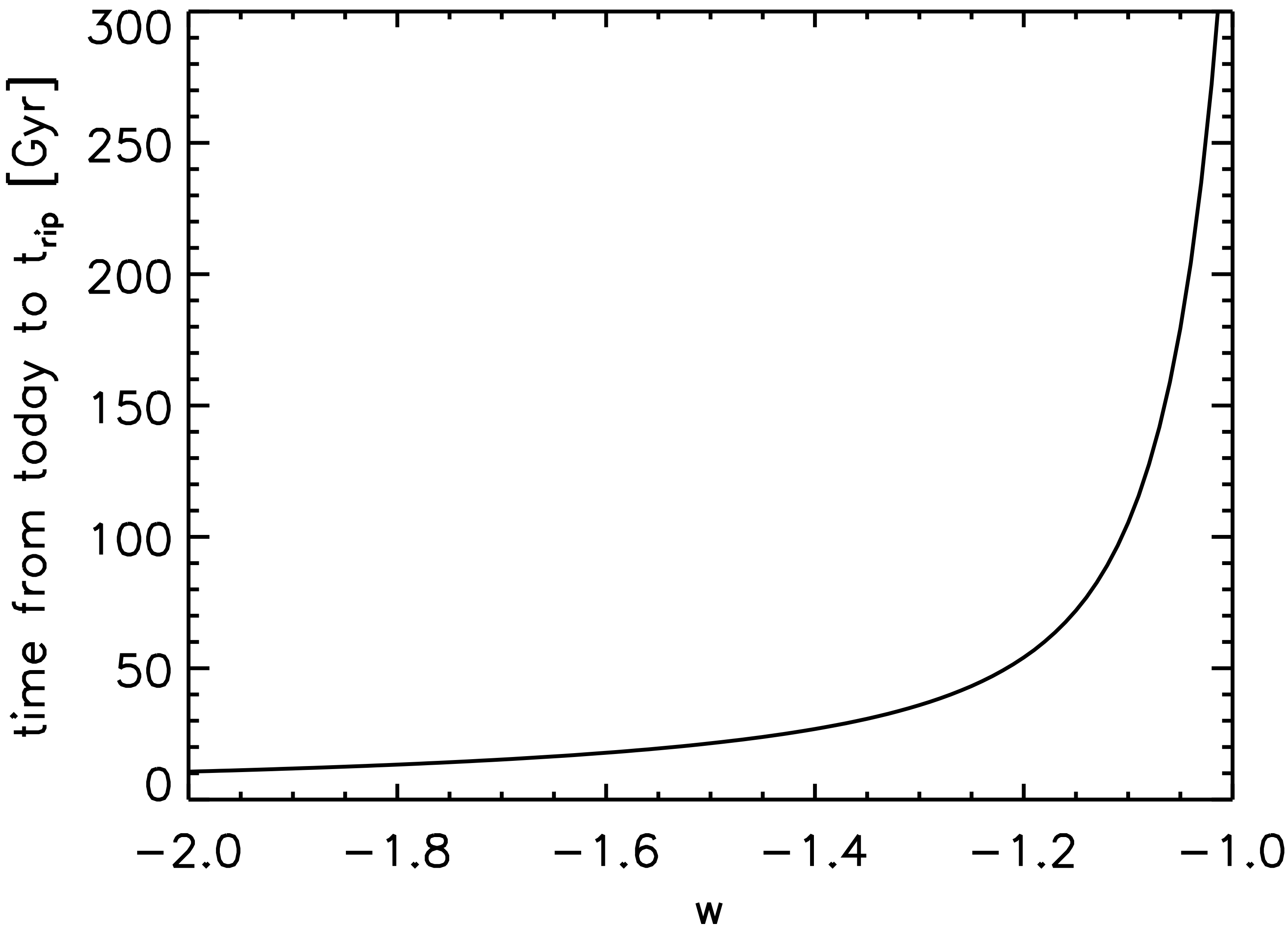
- The phantom energy density becomes infinite in finite time, which will rip apart the Universe.

- A cosmological constant Universe, the scale factor grows more rapidly than the Hubble distance 1/H and galaxies will begin to disappear beyond the horizon.
- With phantom energy, the expansion rate H grows with time, the Hubble distance decreases, and the disappearance of galaxies is accelerated.

$$\left(\frac{da}{d\tau}\right)^2 = \sum_i \frac{\Omega_i}{a^{(1+3w_i)}} \qquad a(t_{\rm now}) \equiv 1 \qquad \tau \equiv H_0 t$$




w = −1.2
w = −1.0
w = −0.8
ρ ∝ a^0.6
ρ = const
ρ ∝ a^−0.6
scale factor a(t)
10^8
10^6
10^4
10^2
10^0
10^−2
0
20
40
60
80
time relative to today [Gyr]



time from today to t_{rip} [Gyr]
300
250
200
150
100
50
0
−2.0
−1.8
−1.6
−1.4
−1.2
−1.0
w

TABLE I. The history and future of the Universe with $w = -3/2$ phantom energy.

Time	Event
$\sim 10^{-43}$ s	Planck era
$\sim 10^{-36}$ s	Inflation
First three minutes	Light elements formed
$\sim 10^{5}$ yr	Atoms formed
~ 1 Gyr	First galaxies formed
~ 15 Gyr	*Today*
$t_{\rm rip} - 1$ Gyr	Erase galaxy clusters
$t_{\rm rip} - 60$ Myr	Destroy Milky Way
$t_{\rm rip} - 3$ months	Unbind solar system
$t_{\rm rip} - 30$ min	Earth explodes
$t_{\rm rip} - 10^{-19}$ s	Dissociate atoms
$t_{\rm rip} = 35$ Gyr	Big rip

- The “why now?” question in a cosmological-constant universe asks why our epoch happens to be so close to the time at which Λ comes to dominate. On the infinite timeline of cosmic history it seems unlikely that these two events would be so close together unless linked by some common phenomenon.

- If the timeline were finite, as in the case of the big rip, the proximity of these two events would be much less enigmatic. A big rip renders the “why now?”, or question of cosmic coincidence, irrelevant.

- The current data indicate that our Universe is poised somewhere near the razor-thin separation between phantom energy, cosmological constant, and quintessence.
- Future work, and the longer observations by WMAP, will help to determine the nature of the dark energy.