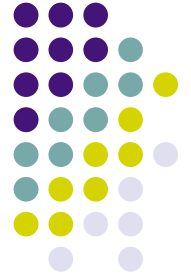




Phantom Energy: Dark Energy with $w < -1$ Causes a Cosmic Doomsday



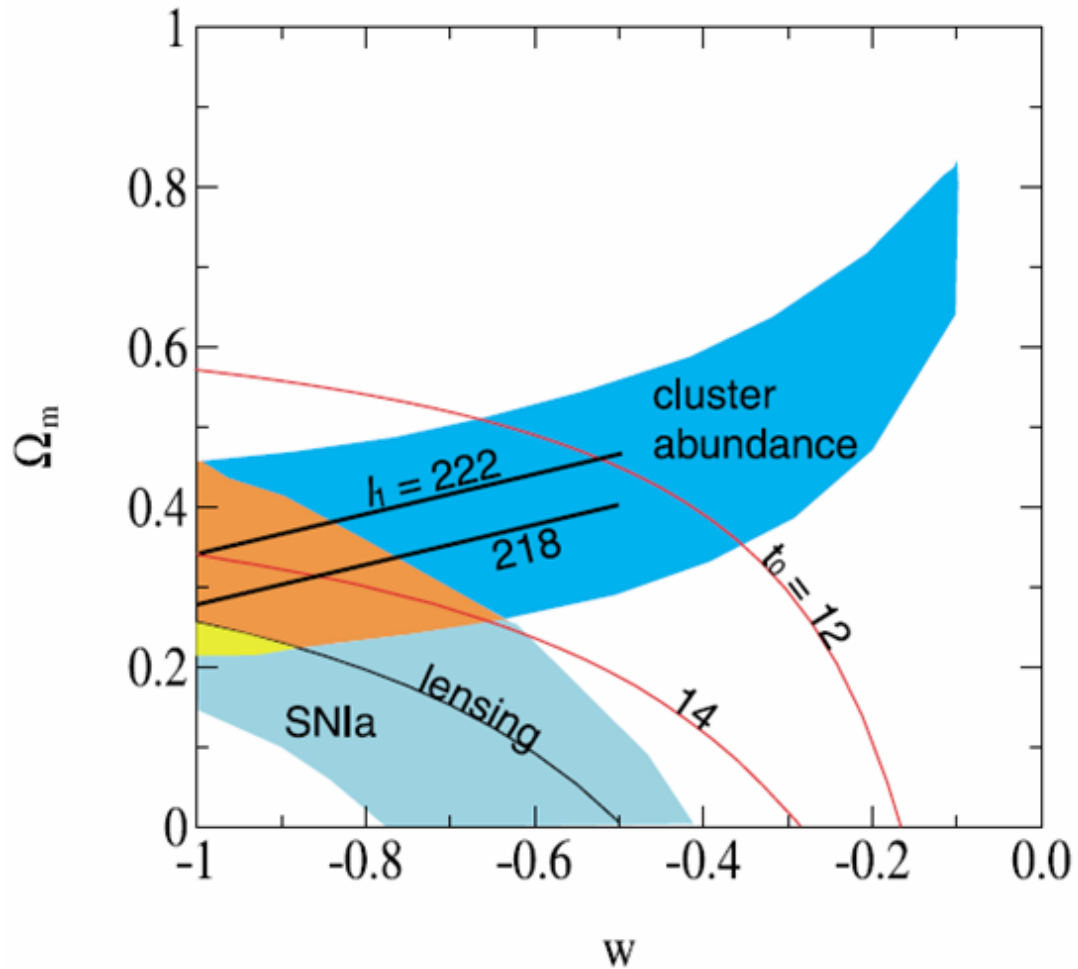
Supernova searches and the stunning cosmic microwave background (CMB) results from balloon and ground experiments and now from Wilkinson Microwave Anisotropy Probe (WMAP) indicate an accelerating cosmological expansion ,
so the Universe additionally consists of some sort of negative-pressure dark energy.



- “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 $\rho_Q \propto a^{-3(1+w)}$

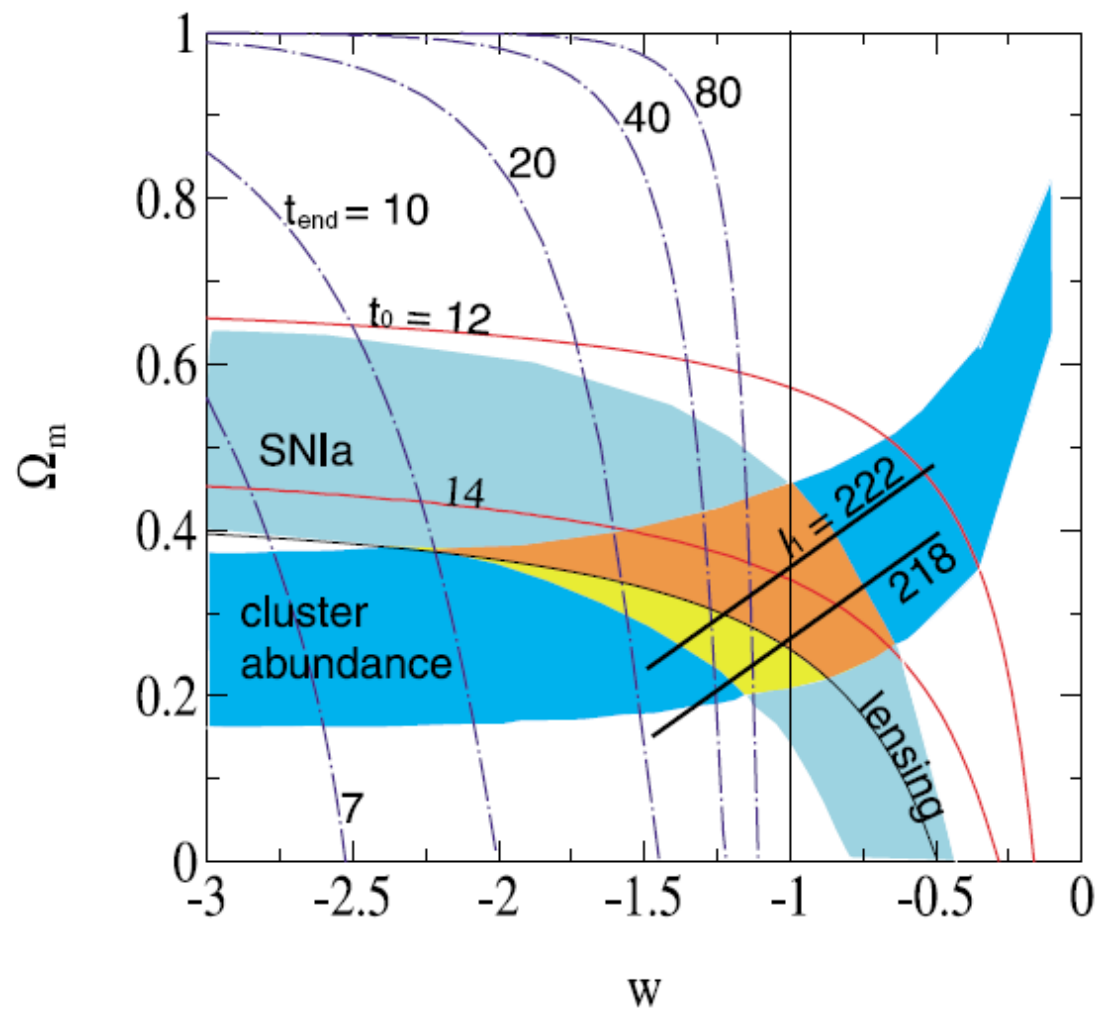


As the figure shows, w seems to be converging to $w = -1$



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.



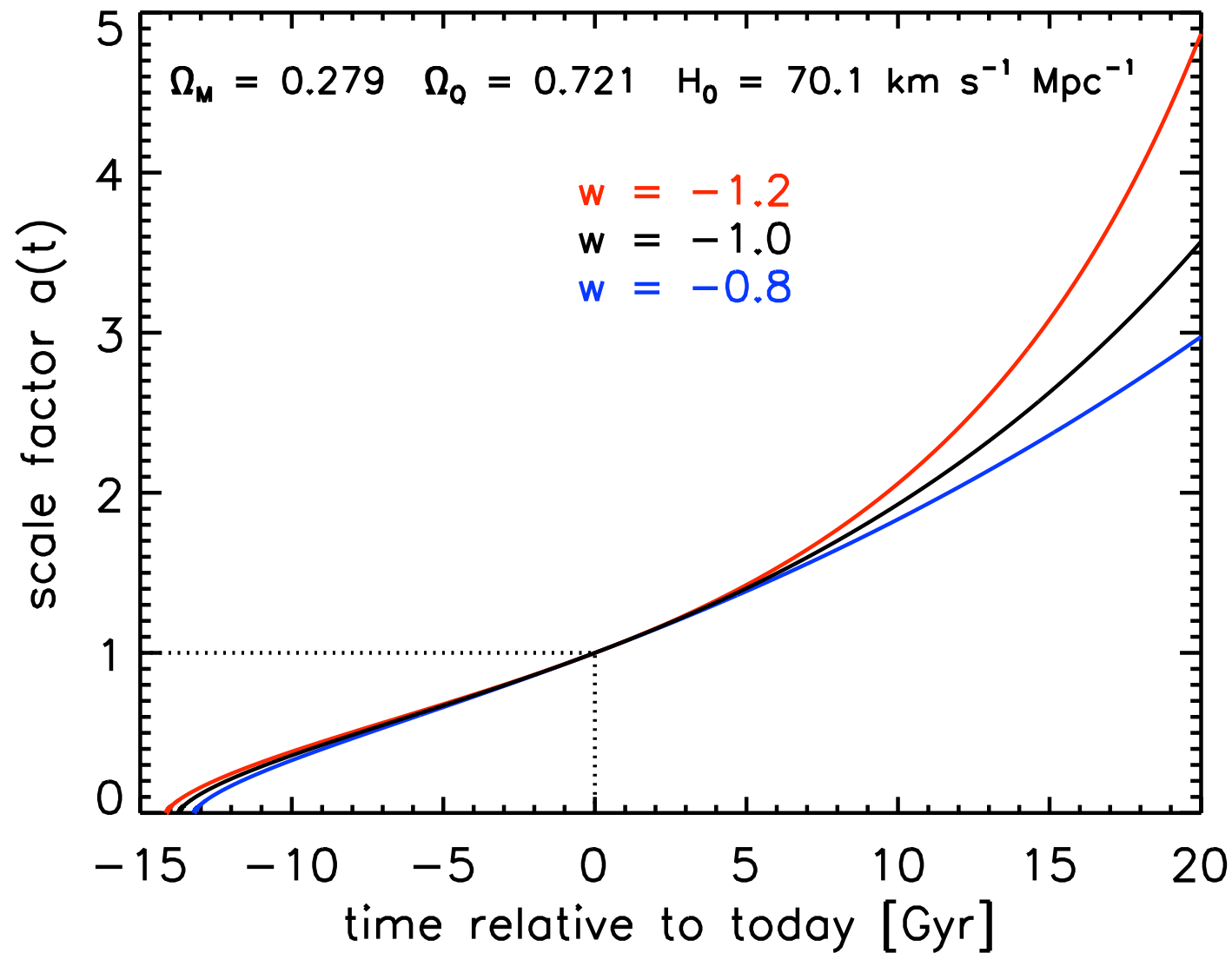


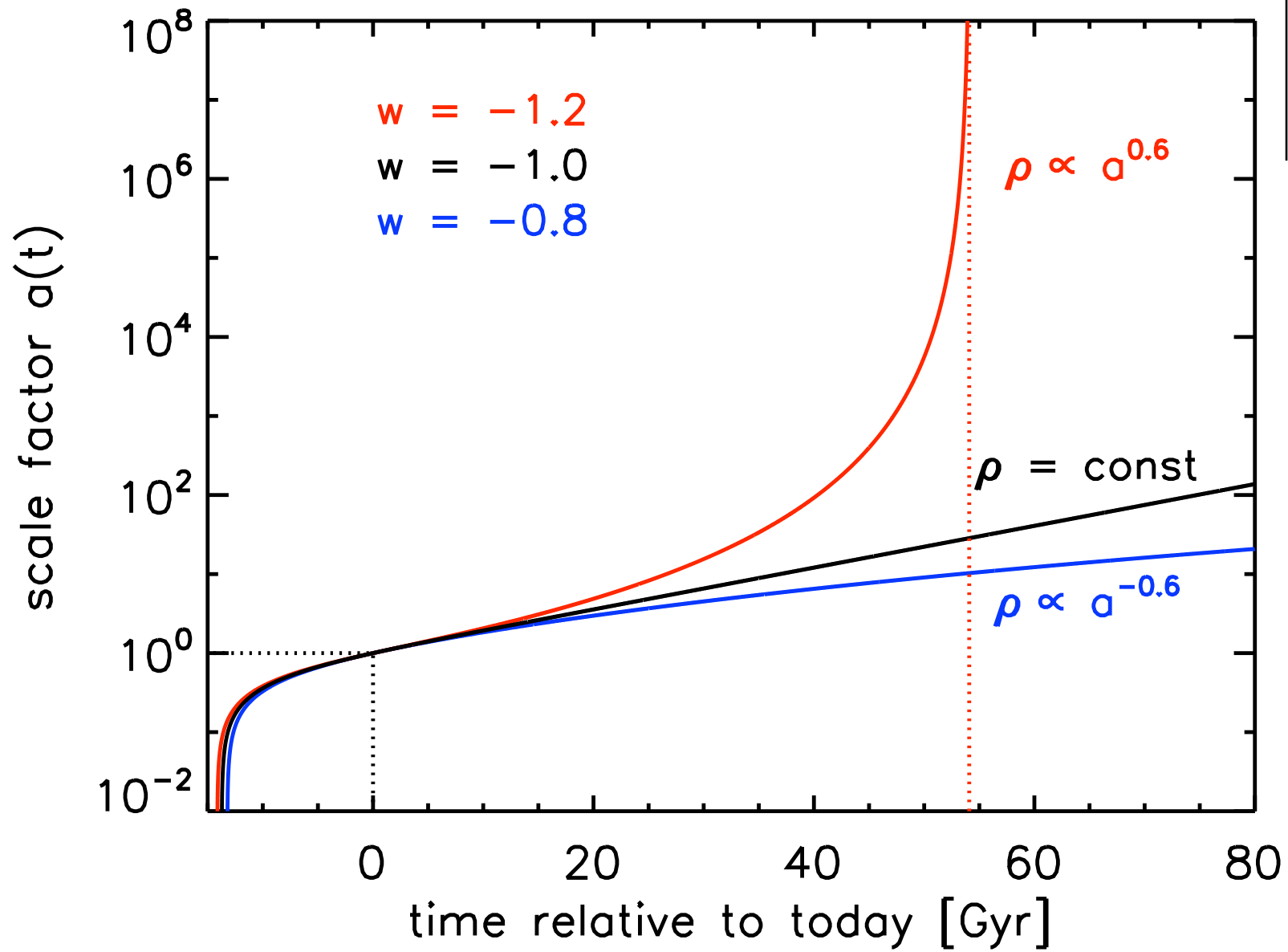
- A flat or open Universe without dark energy, the horizon grows more rapidly than the scale factor. The number of visible galaxies grows.
- If the expansion is accelerating, $-1 < w < -1/3$, then the scale factor grows more rapidly than the horizon. Galaxies disappear beyond the horizon.
- The phantom 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.

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





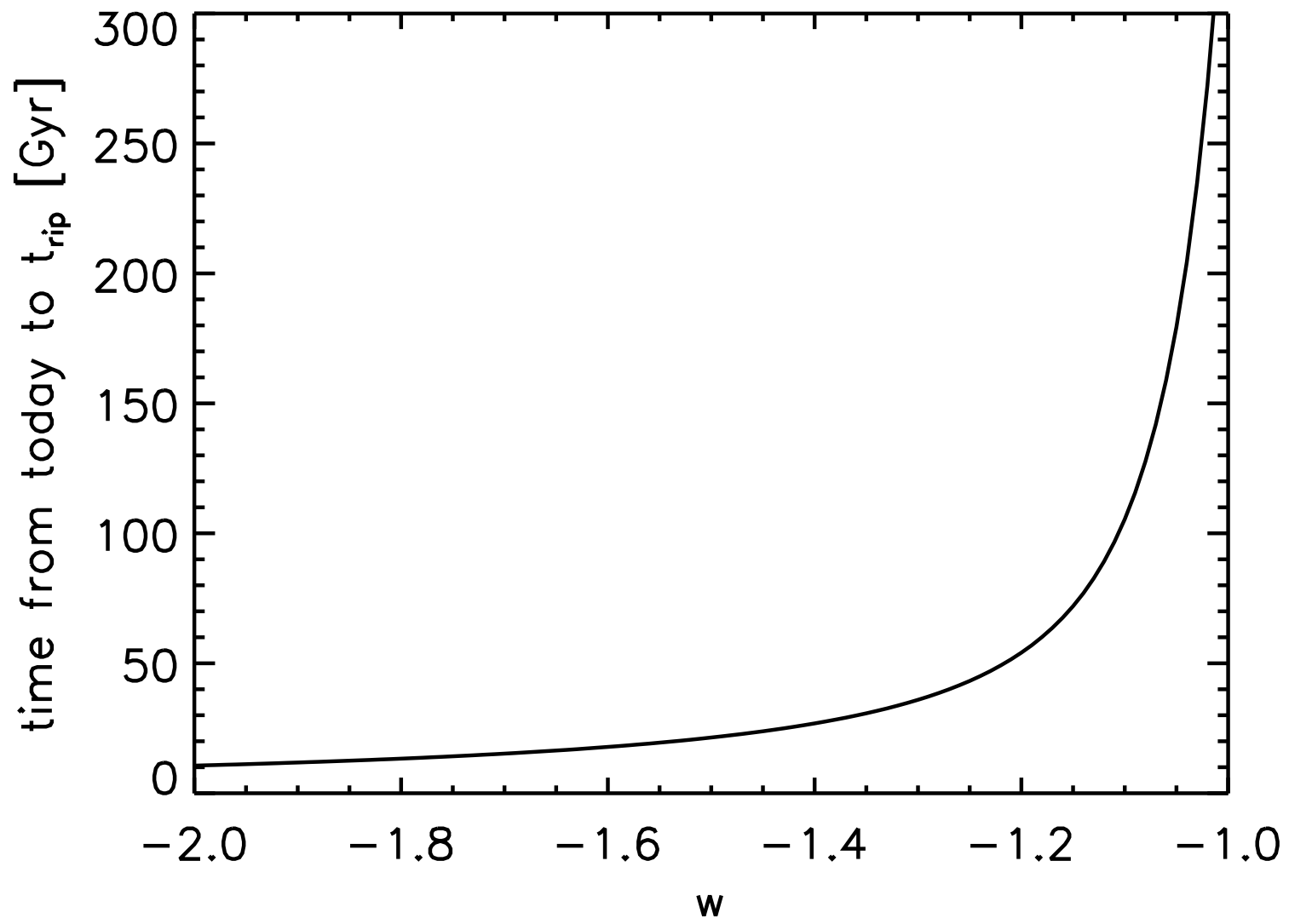


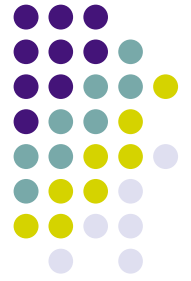


TABLE I. The history and future of the Universe with $w = -3/2$ phantom energy.

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	<i>Today</i>
$t_{\text{rip}} - 1$ Gyr	Erase galaxy clusters
$t_{\text{rip}} - 60$ Myr	Destroy Milky Way
$t_{\text{rip}} - 3$ months	Unbind solar system
$t_{\text{rip}} - 30$ min	Earth explodes
$t_{\text{rip}} - 10^{-19}$ s	Dissociate atoms
$t_{\text{rip}} = 35$ 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.