Model Universes

Einstein Equation

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} - \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

Sterrewacht
Leiden

Friedmann Equations

$$\left(\frac{da}{dt}\right)^2 = \frac{8\pi}{3}G\rho a^2 - kc^2 + \frac{\Lambda}{3}a^2$$

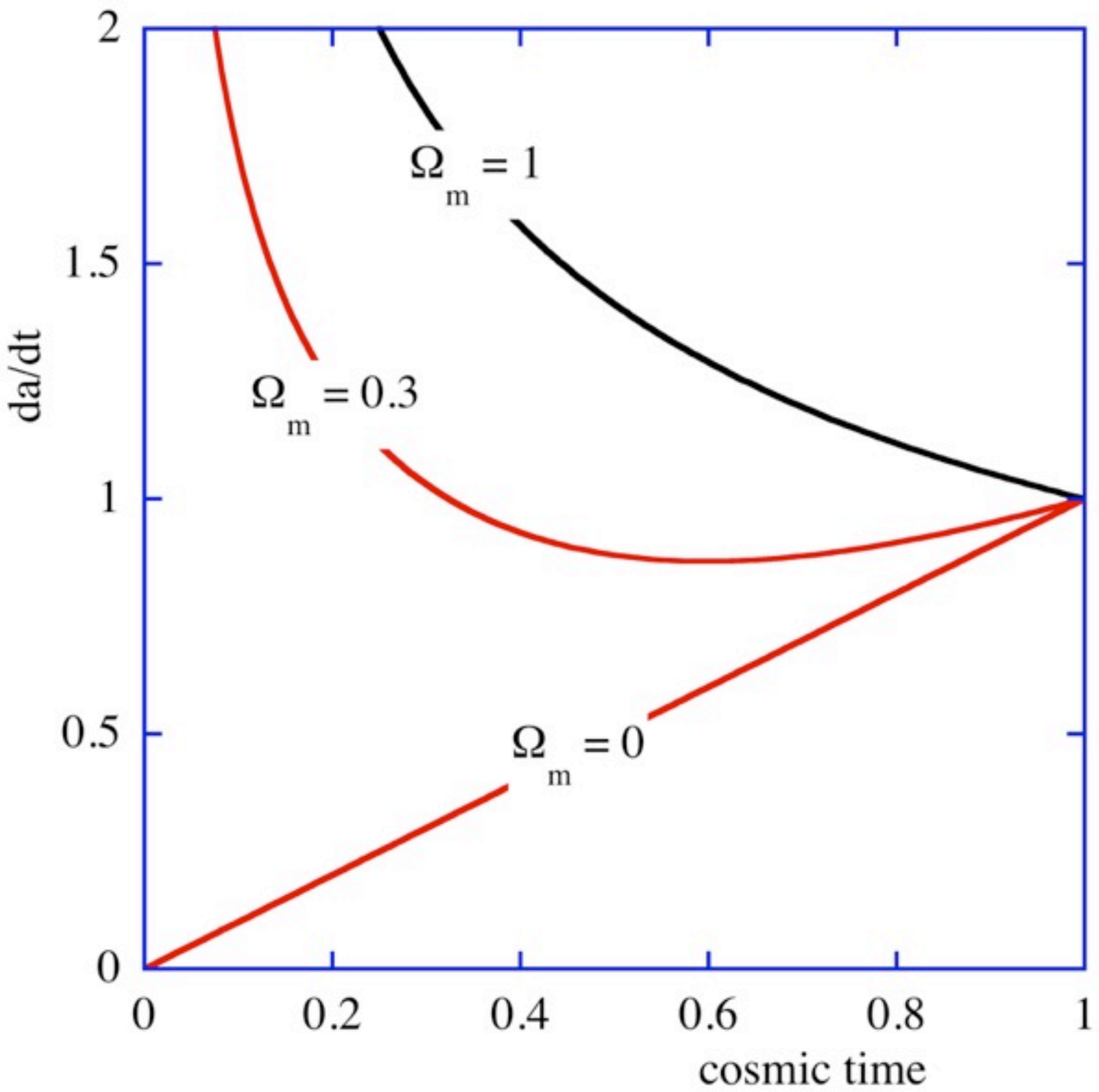
$$\frac{d}{dt}\left(\rho a^3\right) + \frac{P}{c^2}\frac{da^3}{dt} = 0$$

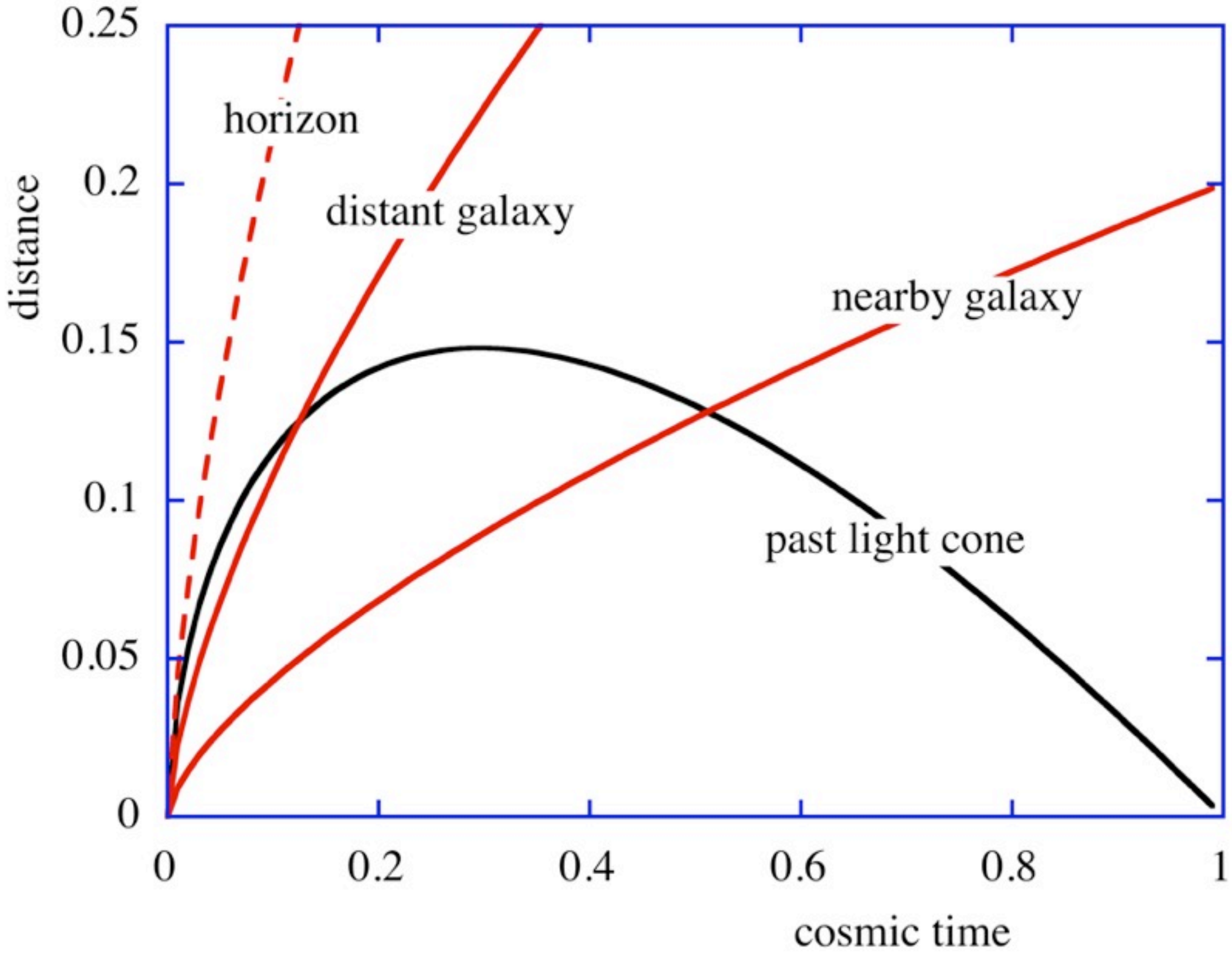
Sterrewacht Leiden

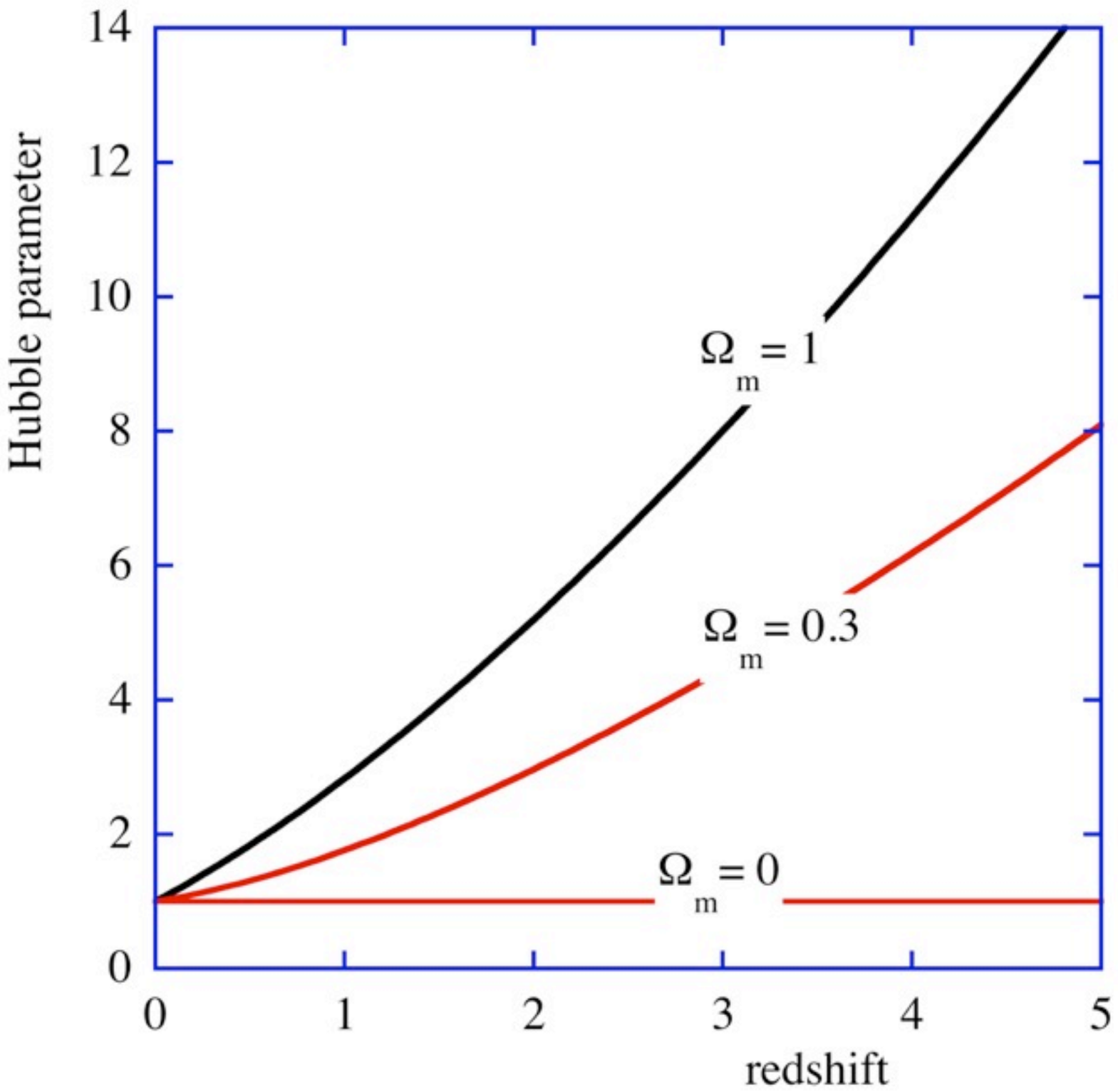
Generic solutions

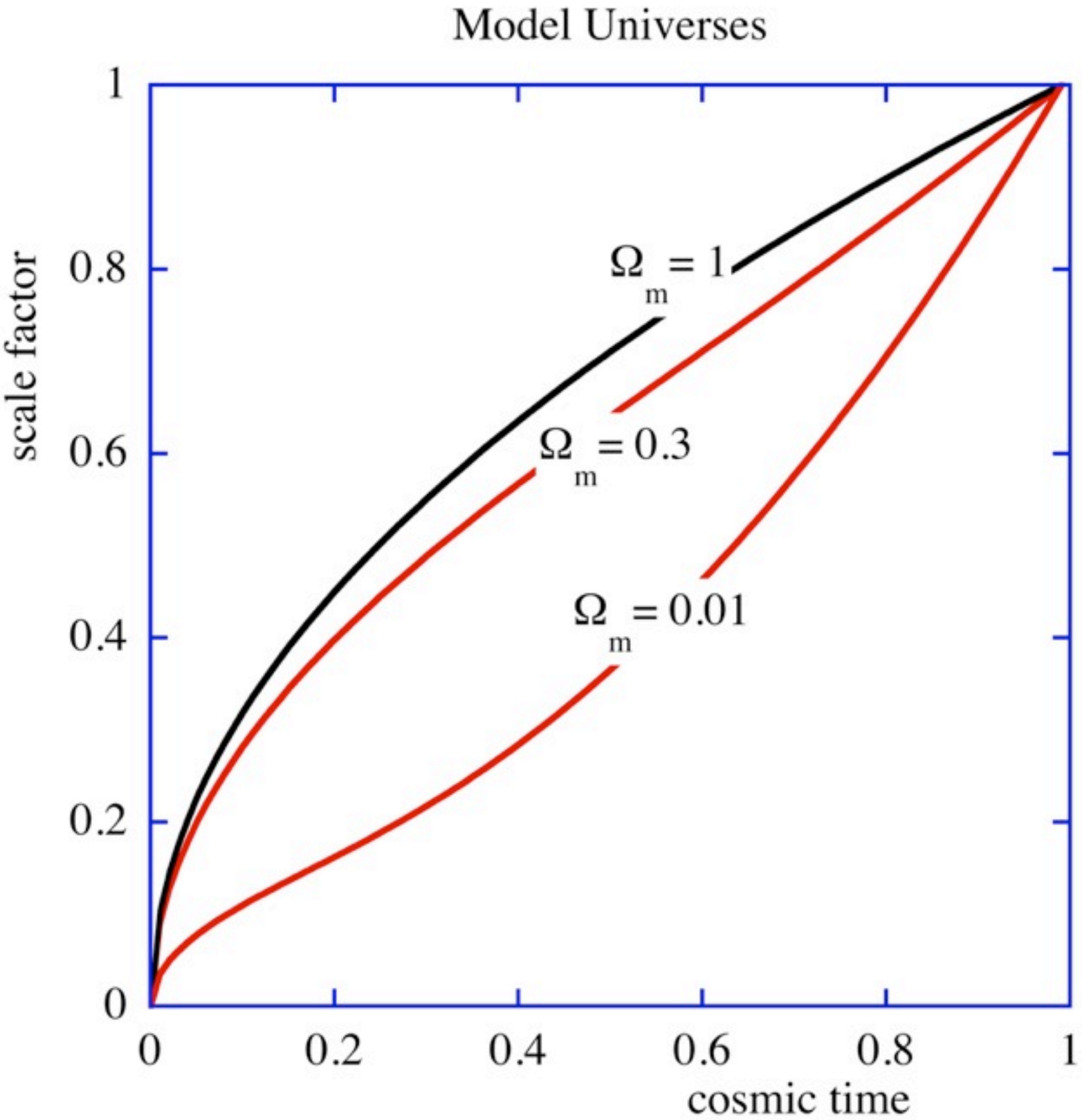
- Present epoch
- Ionized plasma
- Relativistic plasma
- Quantum plasma?
- Evolution of mass scales, looking ahead to interpretation of CMBR observations

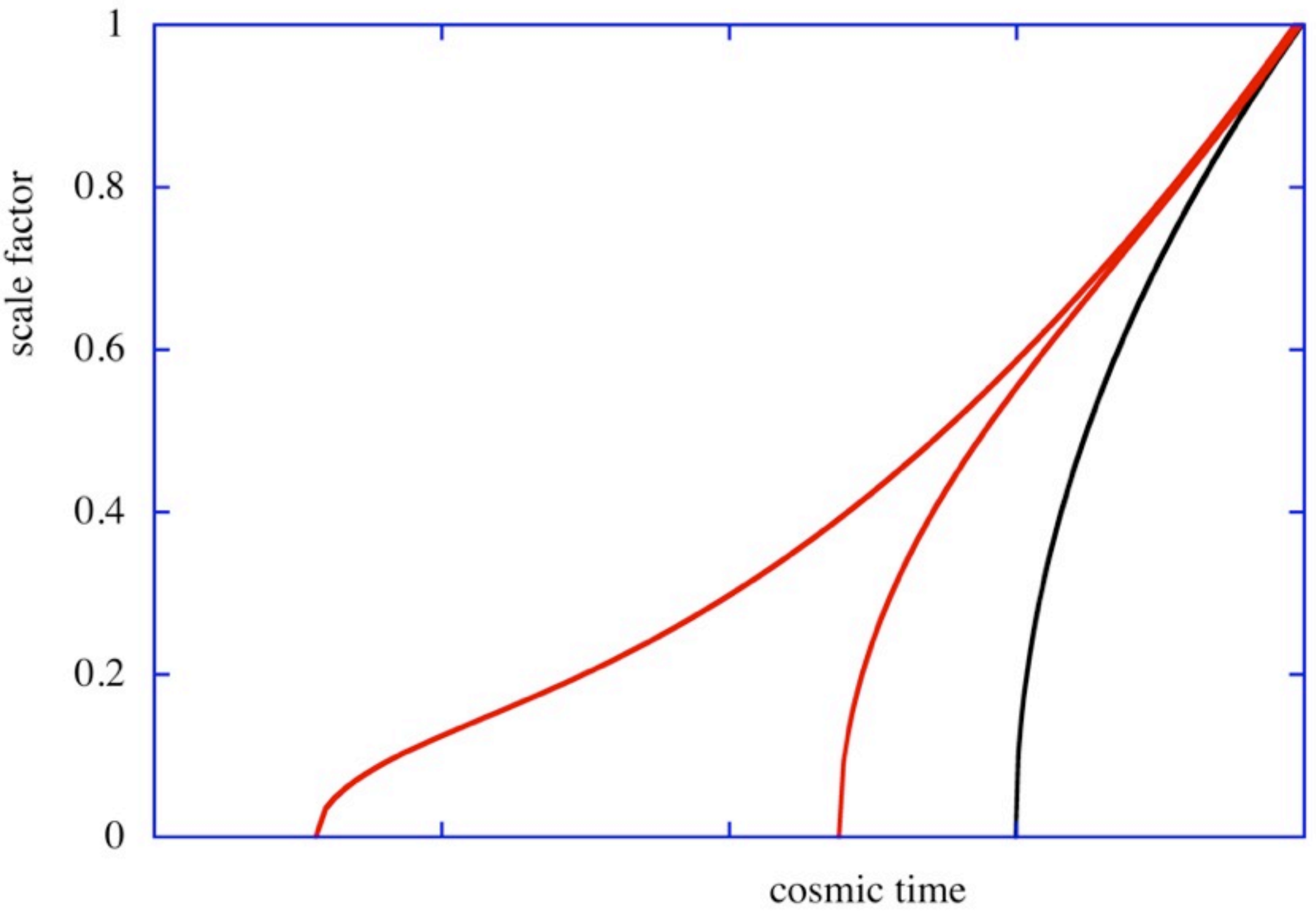
Sterrewacht Leiden

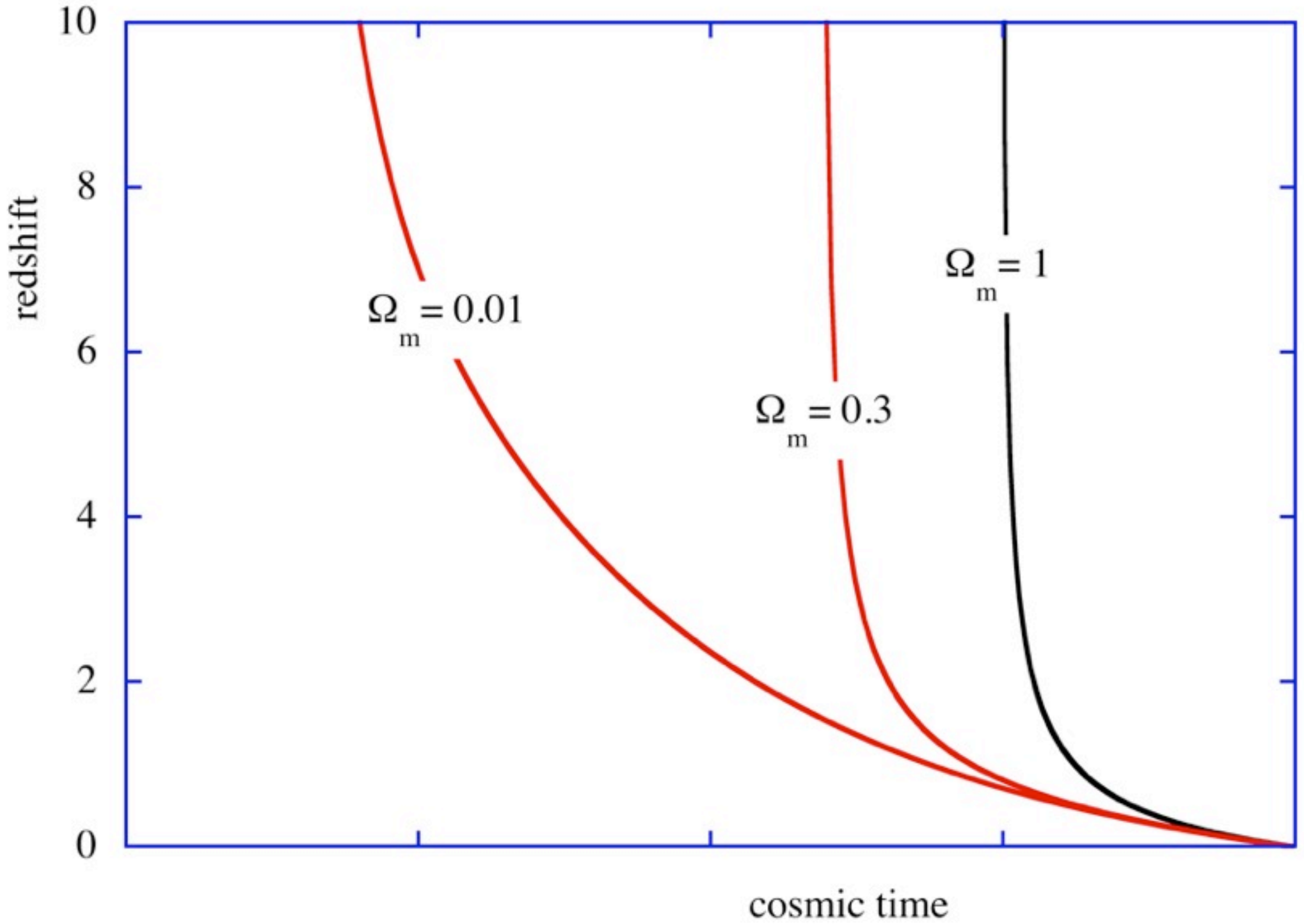

2
1.5
1
0.5
0
da/dt
$\Omega_m = 1$
$\Omega_m = 0.3$
$\Omega_m = 0$
0
0.2
0.4
0.6
0.8
1
cosmic time

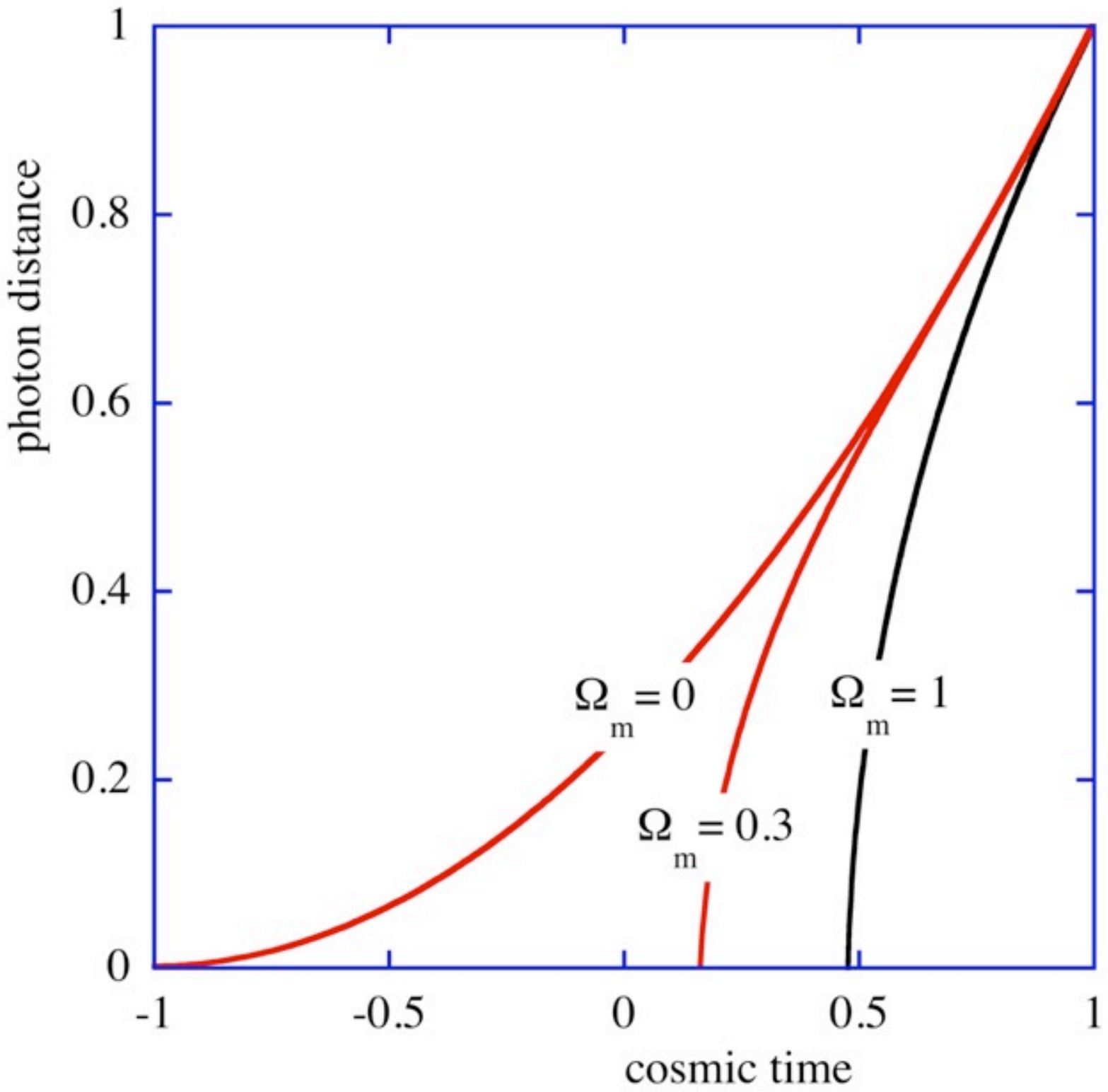

0.25
0.2
0.15
0.1
0.05
0
distance
horizon
distant galaxy
nearby galaxy
past light cone
0
0.2
0.4
0.6
0.8
1
cosmic time

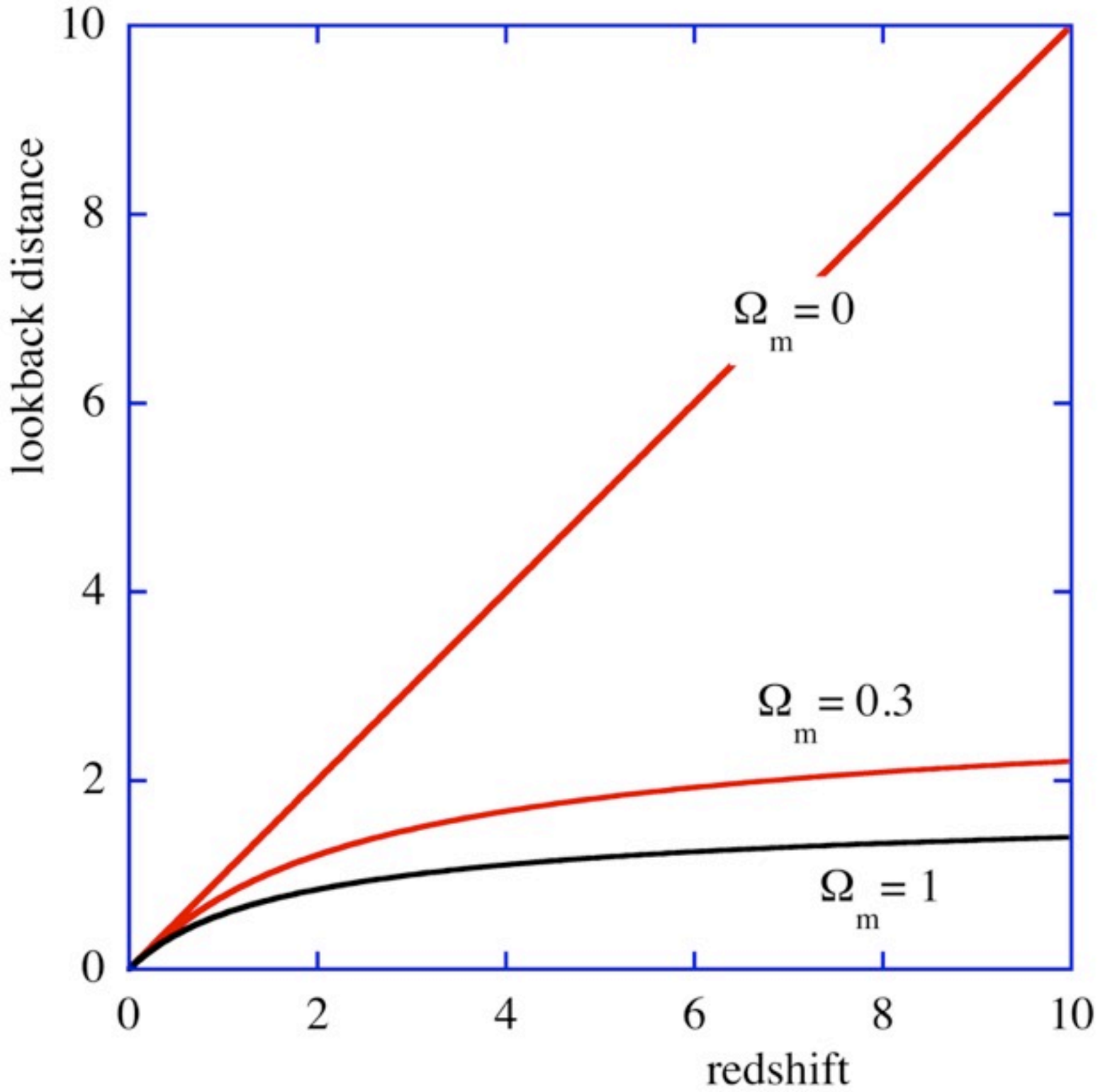

Hubble parameter
14
12
10
8
6
4
2
0
0
1
2
3
4
5
redshift
Ω m = 1
Ω m = 0.3
Ω m = 0

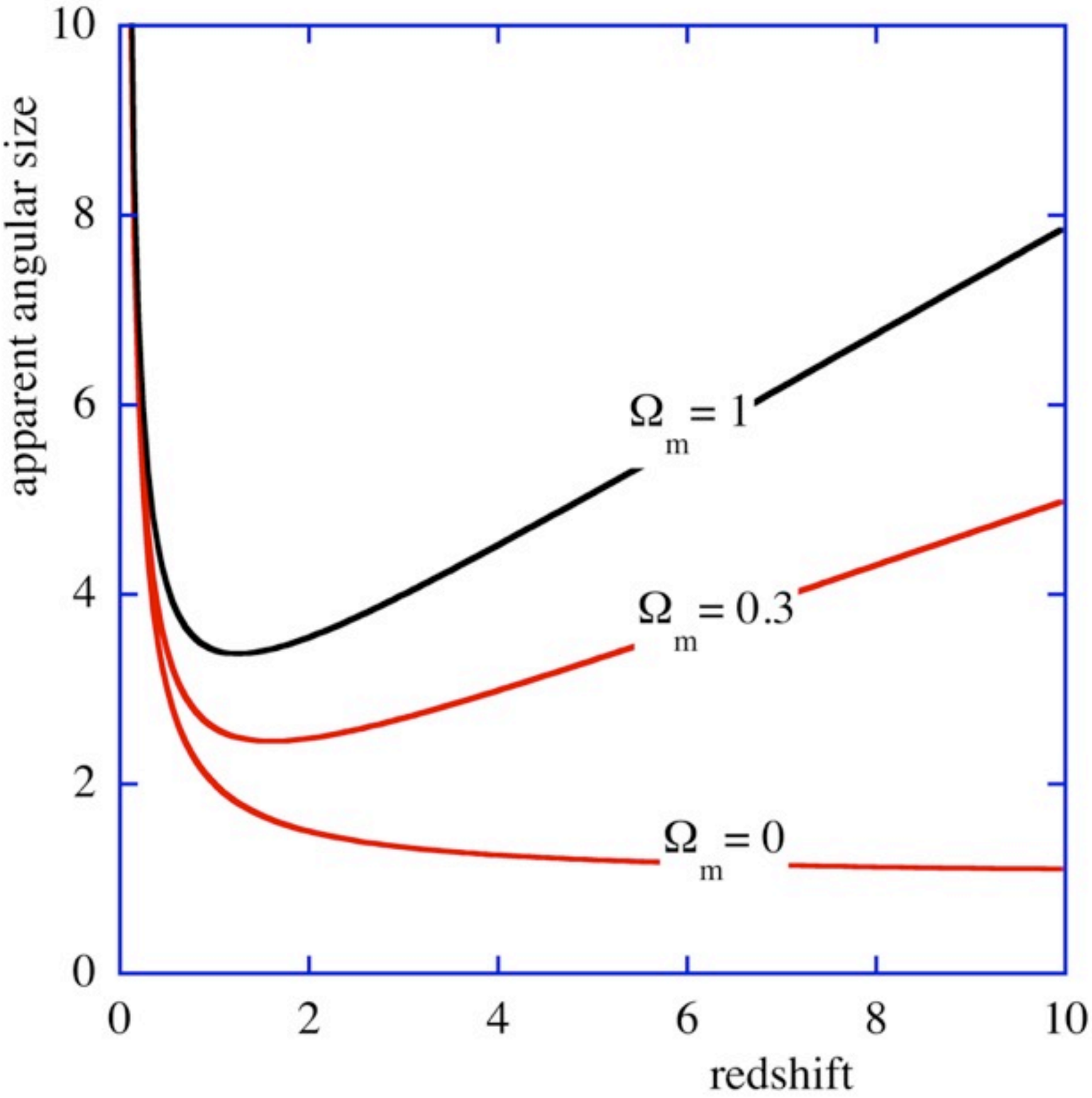

Model Universes
scale factor
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
cosmic time
Ω m = 1
Ω m = 0.3
Ω m = 0.01

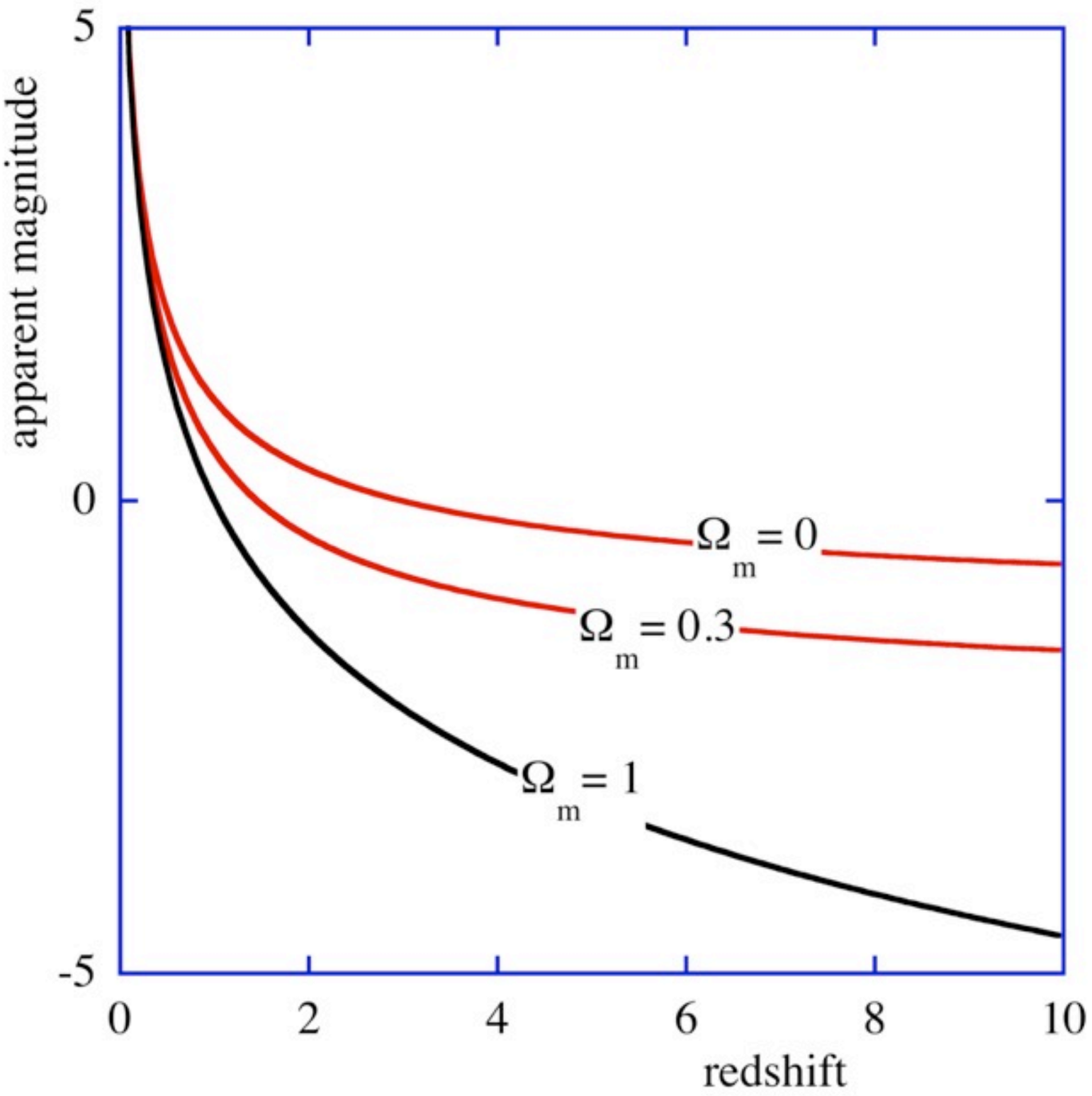

1
0.8
0.6
0.4
0.2
0
scale factor
cosmic time


10
8
6
4
2
0
redshift
$\Omega_m = 0.01$
$\Omega_m = 0.3$
$\Omega_m = 1$
cosmic time


photon distance
1
0.8
0.6
0.4
0.2
0
-1
-0.5
0
0.5
1
cosmic time
Ω m = 0
Ω m = 0.3
Ω m = 1


lookback distance
redshift
0
2
4
6
8
10
$\Omega_m = 0$
$\Omega_m = 0.3$
$\Omega_m = 1$


apparent angular size
redshift
0
2
4
6
8
10
$\Omega_m = 1$
$\Omega_m = 0.3$
$\Omega_m = 0$

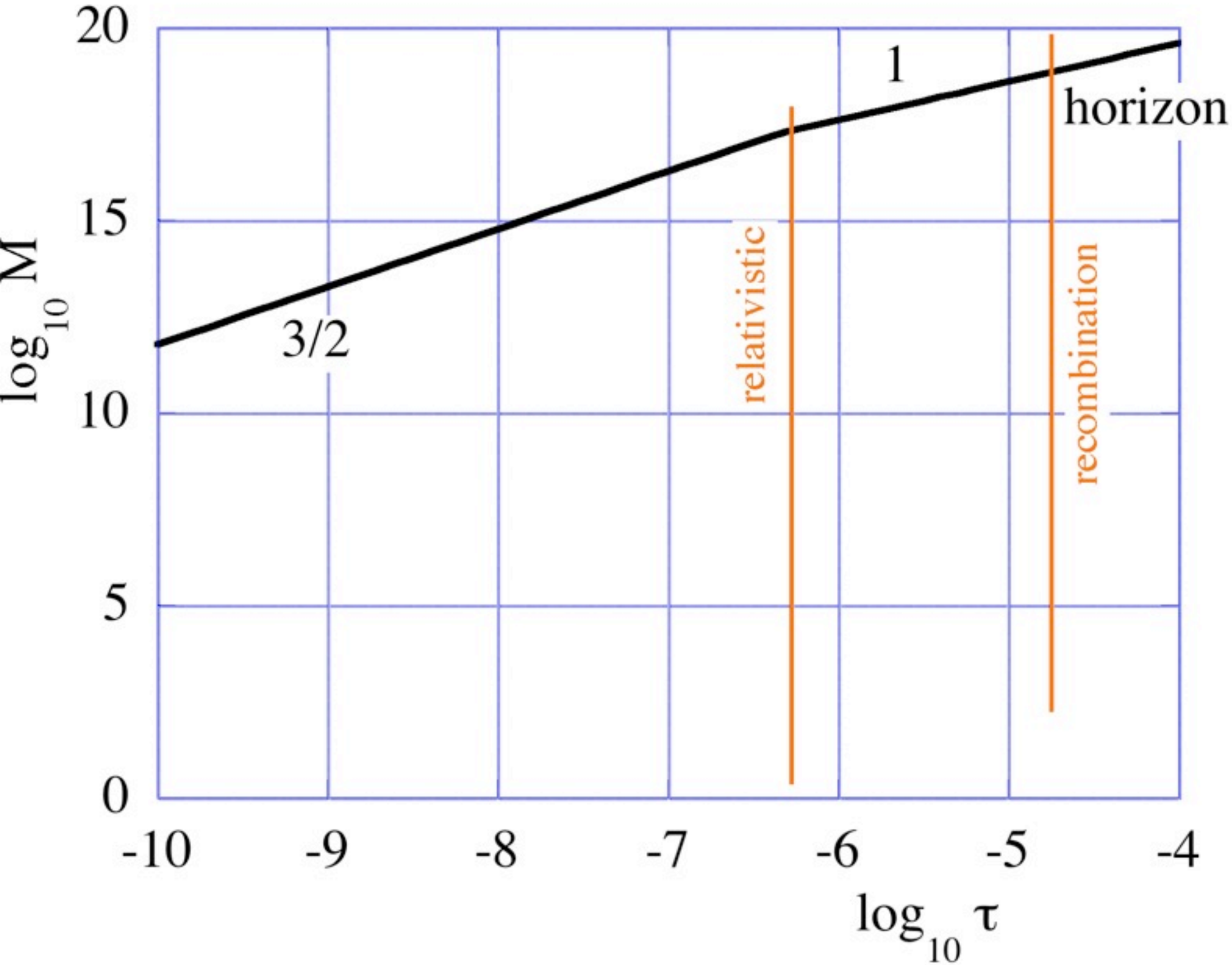

5
0
-5
apparent magnitude
$\Omega_m = 0$
$\Omega_m = 0.3$
$\Omega_m = 1$
0
2
4
6
8
10
redshift

Characteristic Scales

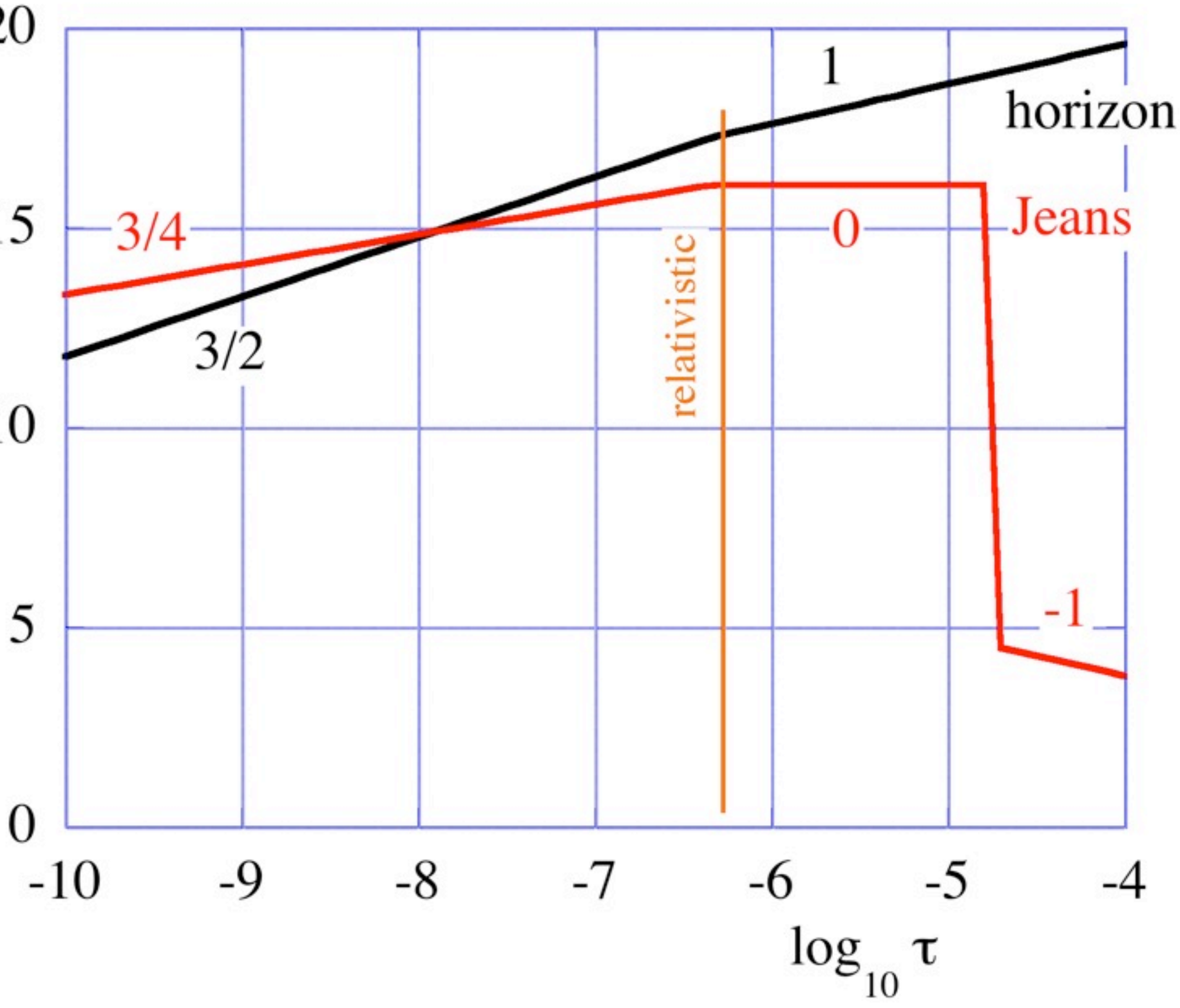
- A specific model universe
- Predicts scales of mass, temperature, time, etc. etc.
- Is used for quantitative analysis of global observables…
- …and local deviations thereof

Sterrewacht Leiden

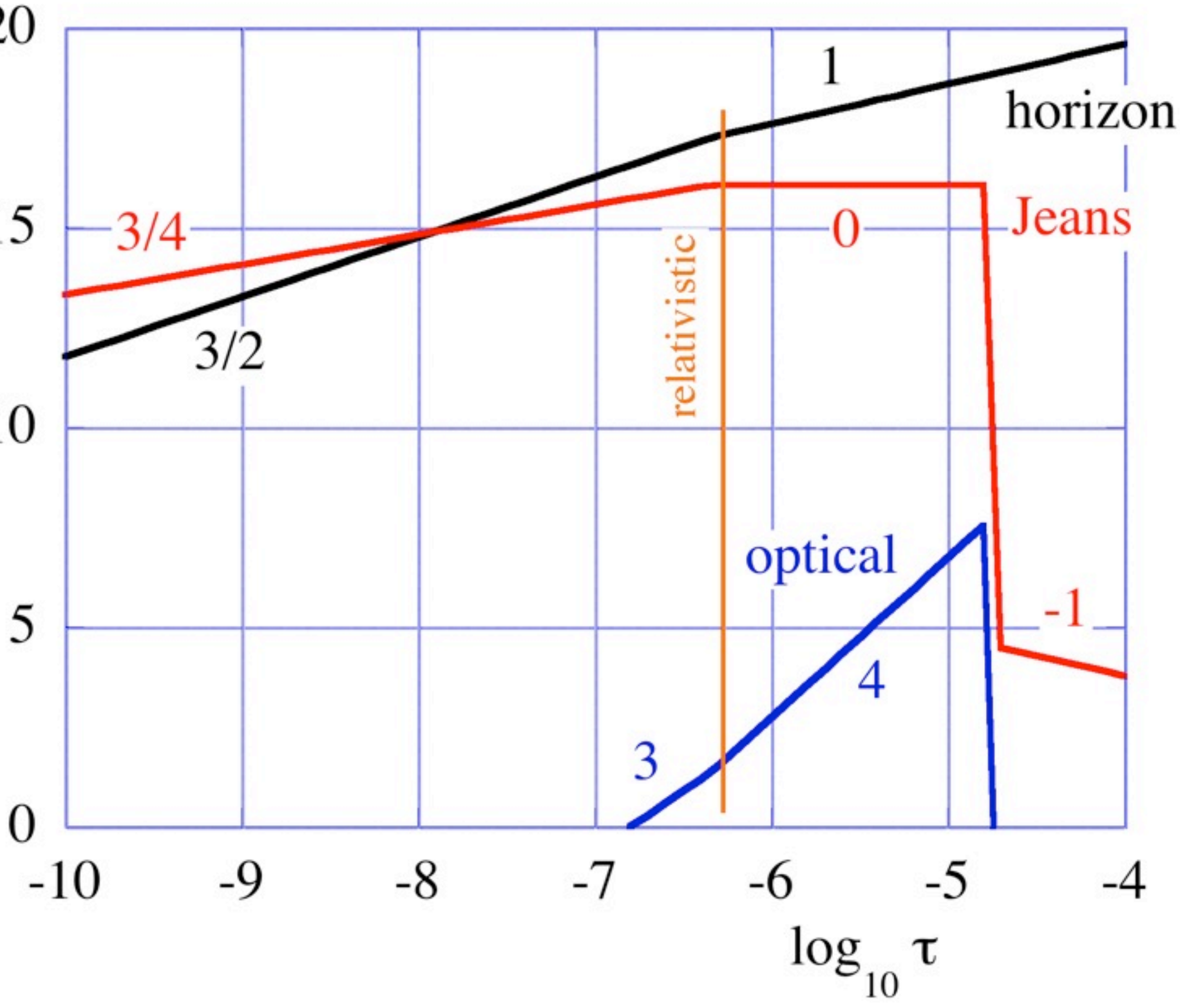
Cosmic Mass Scales



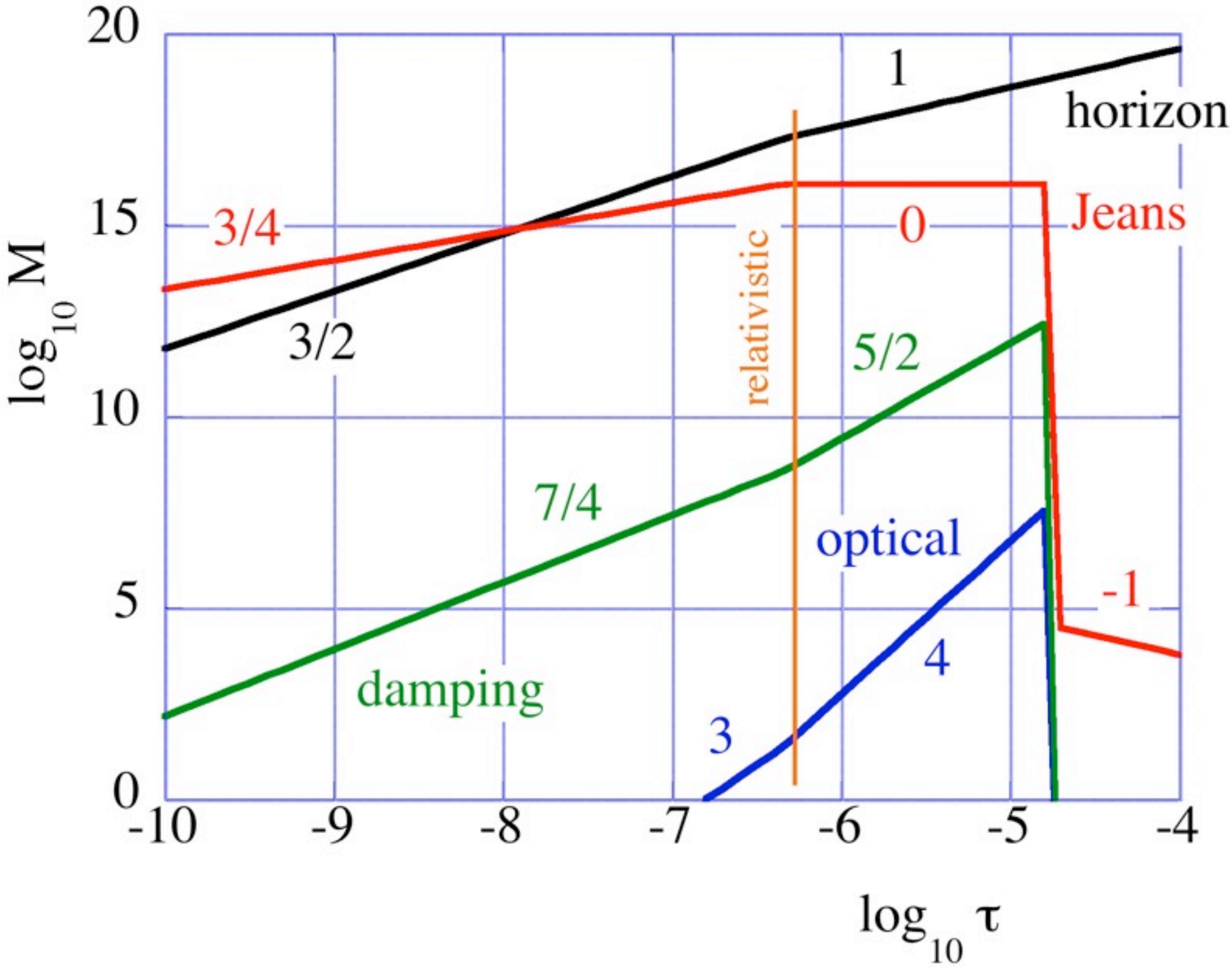
Cosmic Mass Scales



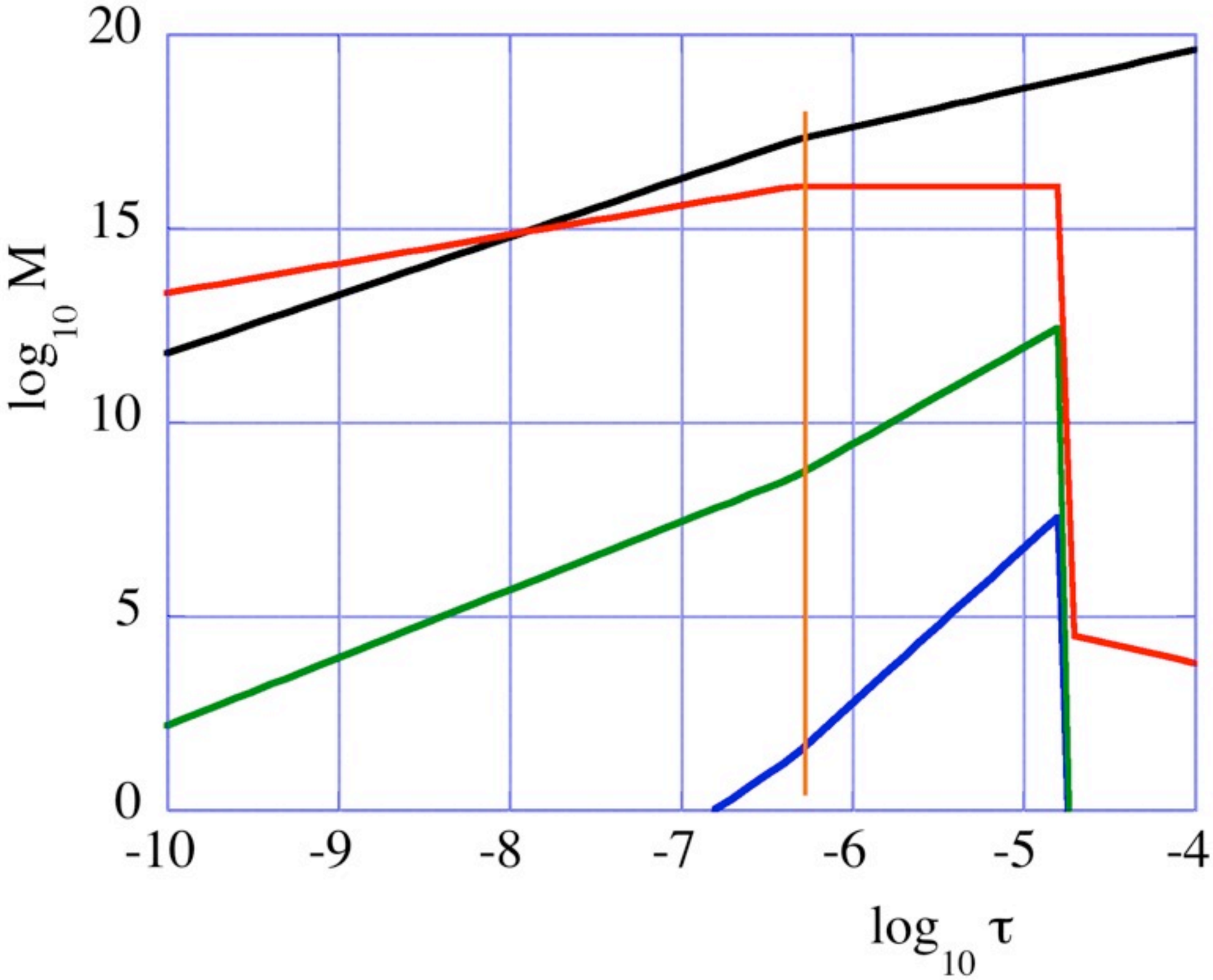
Cosmic Mass Scales



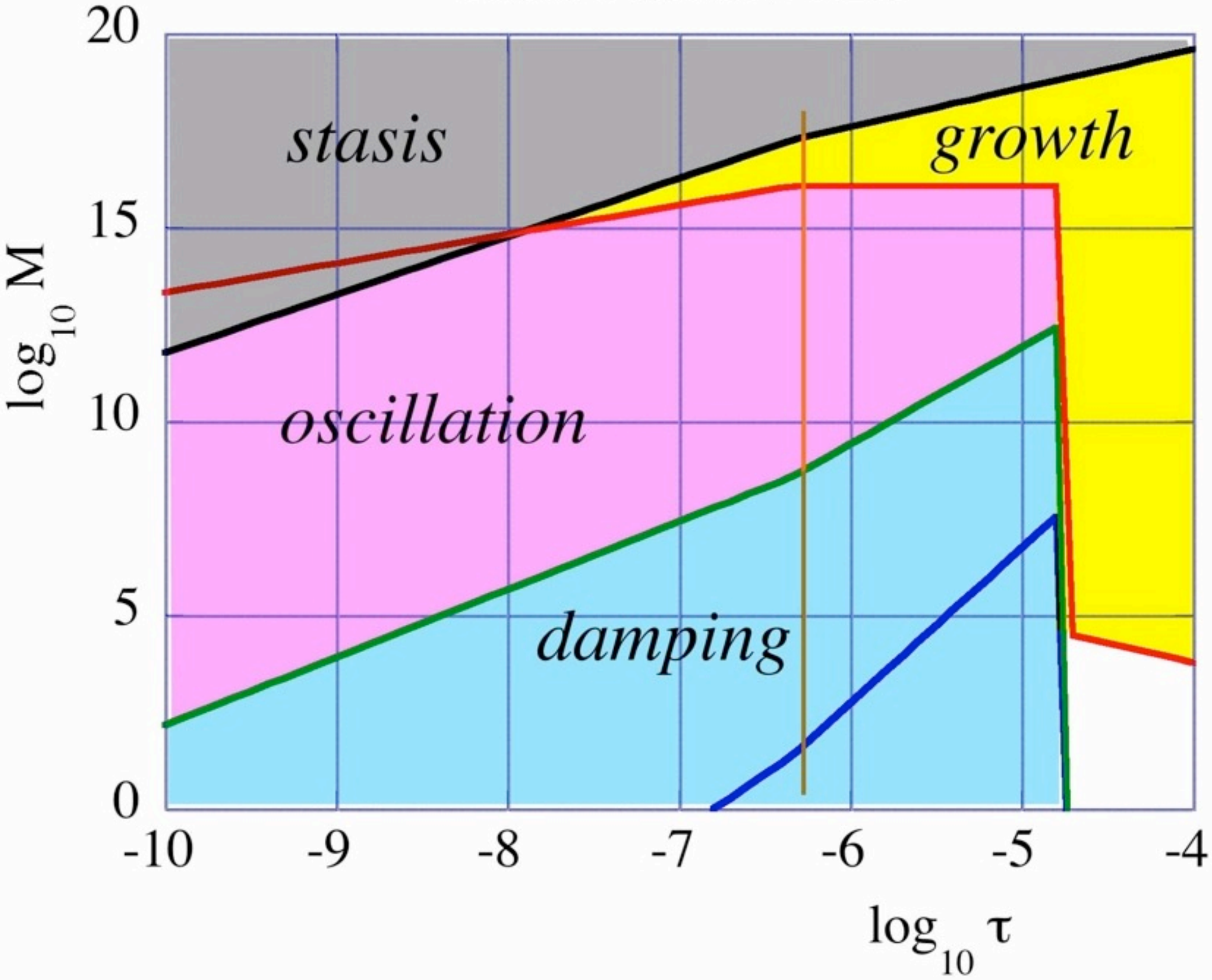
Cosmic Mass Scales



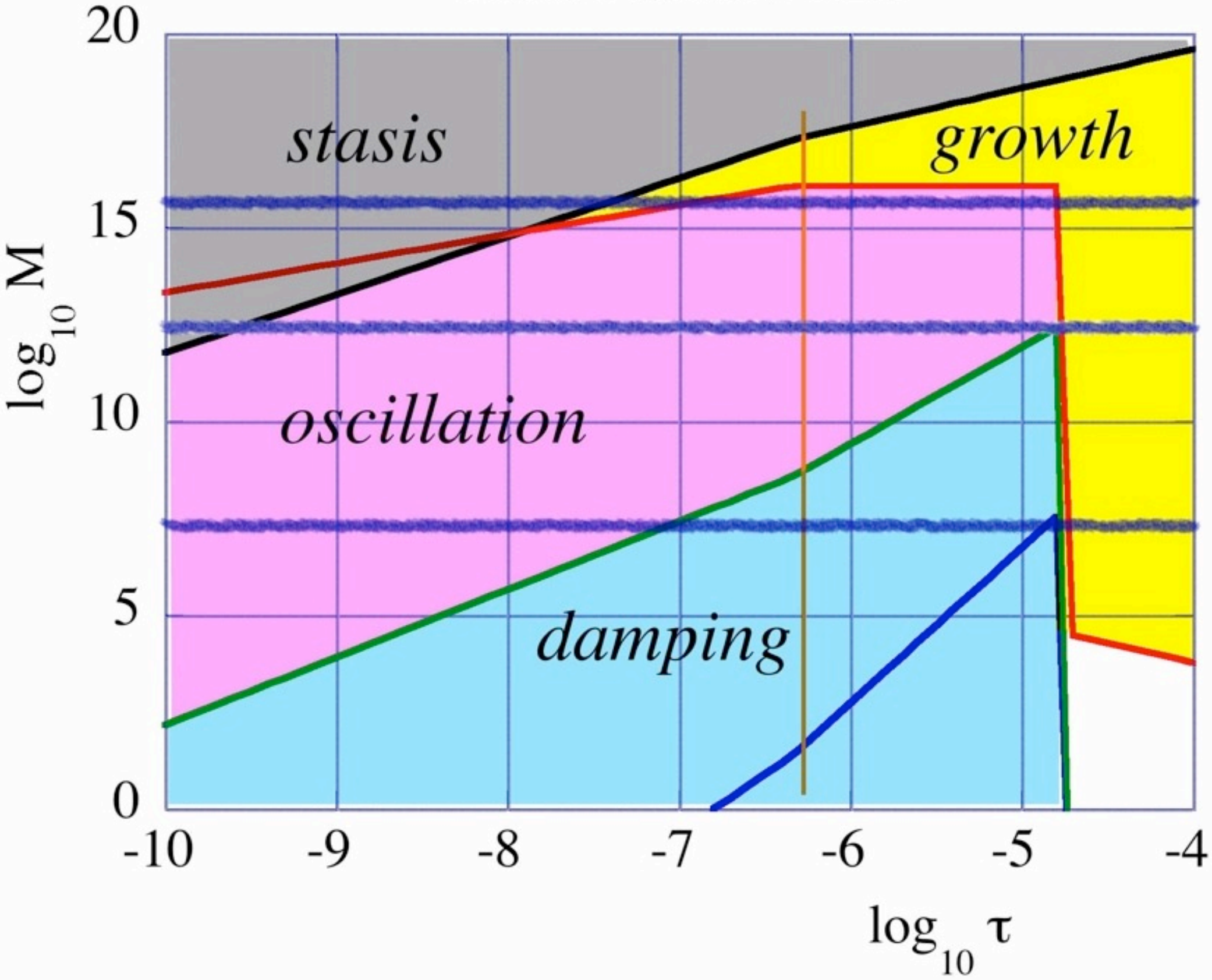
Cosmic Mass Scales



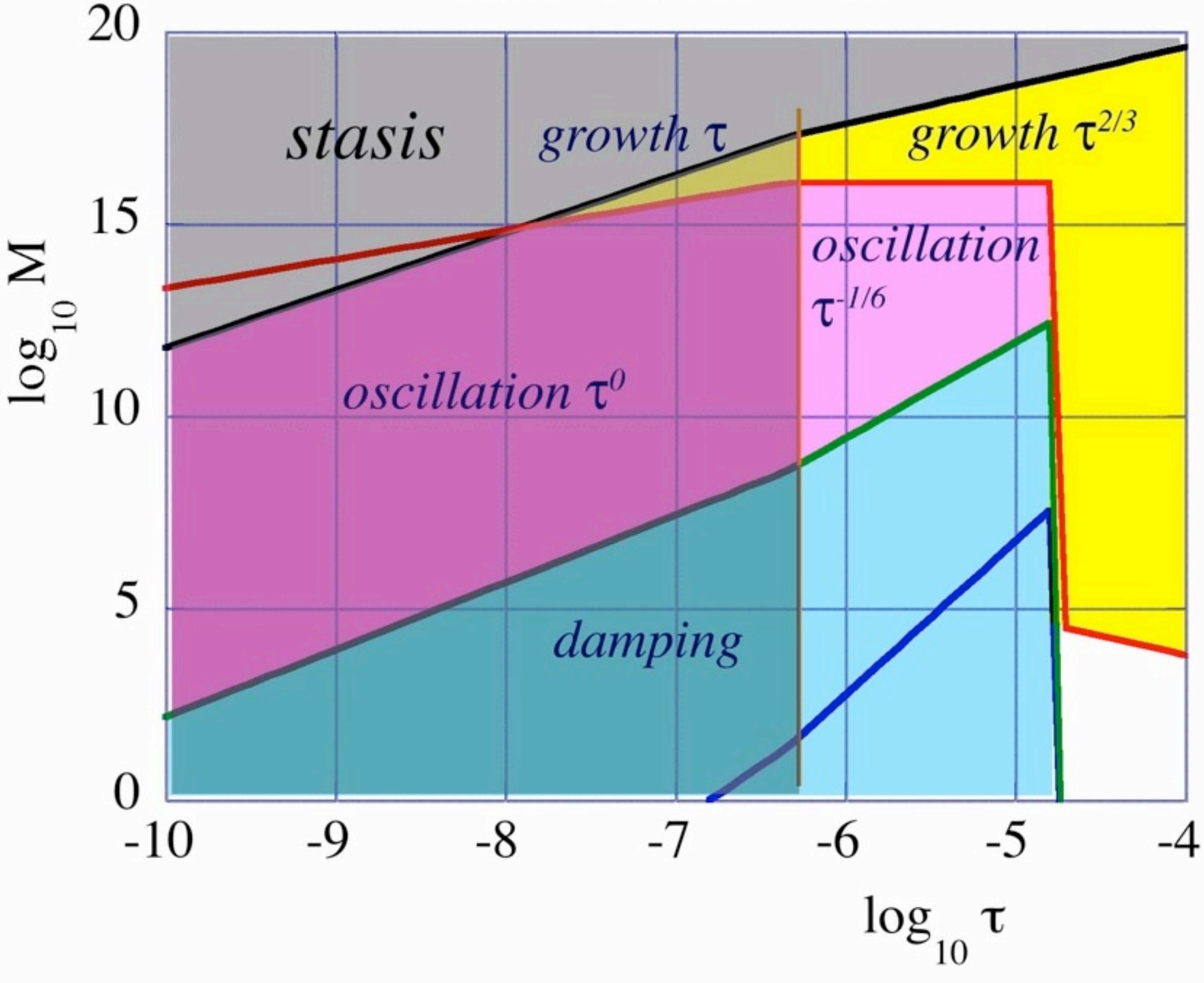
Cosmic Mass Scales



Cosmic Mass Scales



Cosmic Mass Scales



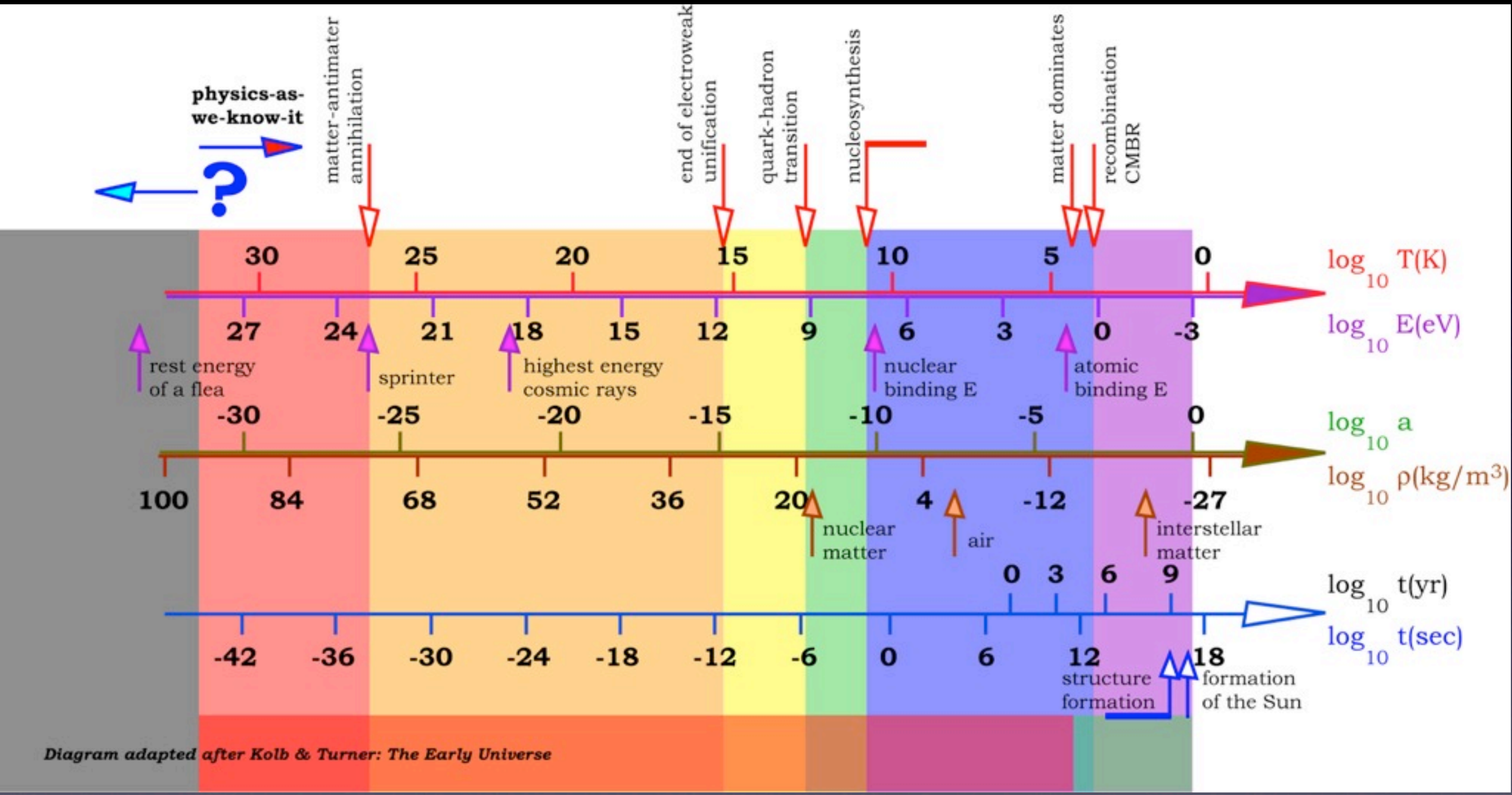


Diagram adapted after Kolb & Turner: The Early Universe