1) Radiation dominated < 47 kyr
Matter " 47 kyr $- 9.8$ Gyr
Dark energy " > 9.8 Gyr
maybe also in inflationary period

2) L15 slide 17

3) $z = \frac{\lambda_{obs} - \lambda_0}{\lambda_0} = \frac{\lambda_0/a - \lambda_0}{\lambda_0} = \frac{1}{a} - 1$

$\lambda_{obs} = \lambda_0 / a$

4) $u_r \propto a^{-4}$

$u_r(z=1100) = a(z=1100)^{-4} \cdot u_{r,0}$

$a(z=1100)$ $\quad z = \frac{1}{a} - 1 \quad z-1 = \frac{1}{a} \quad a = \frac{1}{z-1}$

$u_r(z) = (z-1)^4 \, u_{r,0} = 1100^4 \cdot 0.26 \text{ MeV m}^{-3}$

$= 3.8 \times 10^{11} \text{ MeV} \cdot \text{m}^{-3}$

5) $\ddot{a} = H_0^2 \left[-\frac{\Omega_{r,0}}{a^3} - \frac{\Omega_{m,0}}{2a^2} + \Omega_\Lambda a \right]$

$\Omega_\Lambda \gg \Omega_r, \Omega_m$

$\ddot{a} = H_0^2 \Omega_\Lambda \, a$

try $\quad a = e^{kt}$

$\dot{a} = k e^{kt} \qquad \ddot{a} = k^2 e^{kt}$

$k^2 e^{kt} = H_0^2 \Omega_\Lambda e^{kt}$

solution with $\quad k = H_0 \sqrt{\Omega_\Lambda}$

exponential growth with time constant

$1/k = H_0^{-1} \Omega_\Lambda^{-1/2} \approx 17 \text{ Gyr}$