$E_\gamma = h\nu = \frac{hc}{\lambda}$

Radiation: anything that has $p \gtrsim mc$

$E_{rel} = \sqrt{m^2c^2 + \vec{p}^2} \cdot c$

red shift $z = \frac{a_0}{a(t)} - 1$

$n \to p + e^- + \bar{\nu}_e$

t		Size
0	Big Bang (quantum fluctuation)	
10^{-37} s t_1	inflation	10^{-30} m
10^{-35} s t_2	inflatons decay	10^{-2} m
	$a(t) \sim \sqrt{H_{t_2} t}$ radiation-dominated universe	
10^{-4} s	p, n, e^- (matter), γ, ν (radiation) + dark matter (matter) + energy (Λ)	
10^{-2} s	$p + n \to d$, ^4He, ^3He, $^{6,7}Li$ ...	
10000 yr (radiation)	+ Clumping of dark matter	
380,000 yr (matter dominated, $a \sim t^{2/3}$)	mix of radiation + matter; (re)combination: $p + e^- \to {}^1H$, $p + \alpha \to {}^4He$	3000 K, $a(t) = \frac{1}{1100} \cdot a_{today} \approx 40$ Mlyr ⟹ CMB
few 100 Mio yr → 1 Byr	formation of large-scale structure for galaxies, stars, quasars, reionization	

net energy = 0 ⟺ K = 0

Inflatons (ρ = const) → $a(t) = a(t_1) \cdot e^{H(t_1) \cdot t}$

Inflatons → quarks (6), leptons ($e^-, \mu^-, \tau^-, \nu_e, \nu_\mu, \nu_\tau$), $\gamma, W^\pm, Z, g, H$ + antiparticles
+ dark matter (supersymmetric partners to all)
+ ? ? ? , dark energy

10 Byr: $\Omega_\Lambda > \Omega_M$ — 70% 30% today; $a(t) \sim e^{H_0 t}$

14 Byr: today $T \sim 2.7$ K

100's Byr: Big RIP + darkness

t since Big Bang

4 Byr Milky Way!

Star formation (in arms)

Hot, big stars (blue) →

9.5 Byr → solar system

H + H → ^4He , CNO

(p + p → p + n + e^+ + ν_e)
(p + n = d)

^4He + ^4He + ^4He → ^{12}C (+ ^4He → ^{16}O)

oxygen, neon, .. Si ... Fe

→ Supernova

↳ heavier elements

↳ dispersion

r_c → distance?

a (t)

"radius of the universe"

distance = $r_c \cdot a(t)$