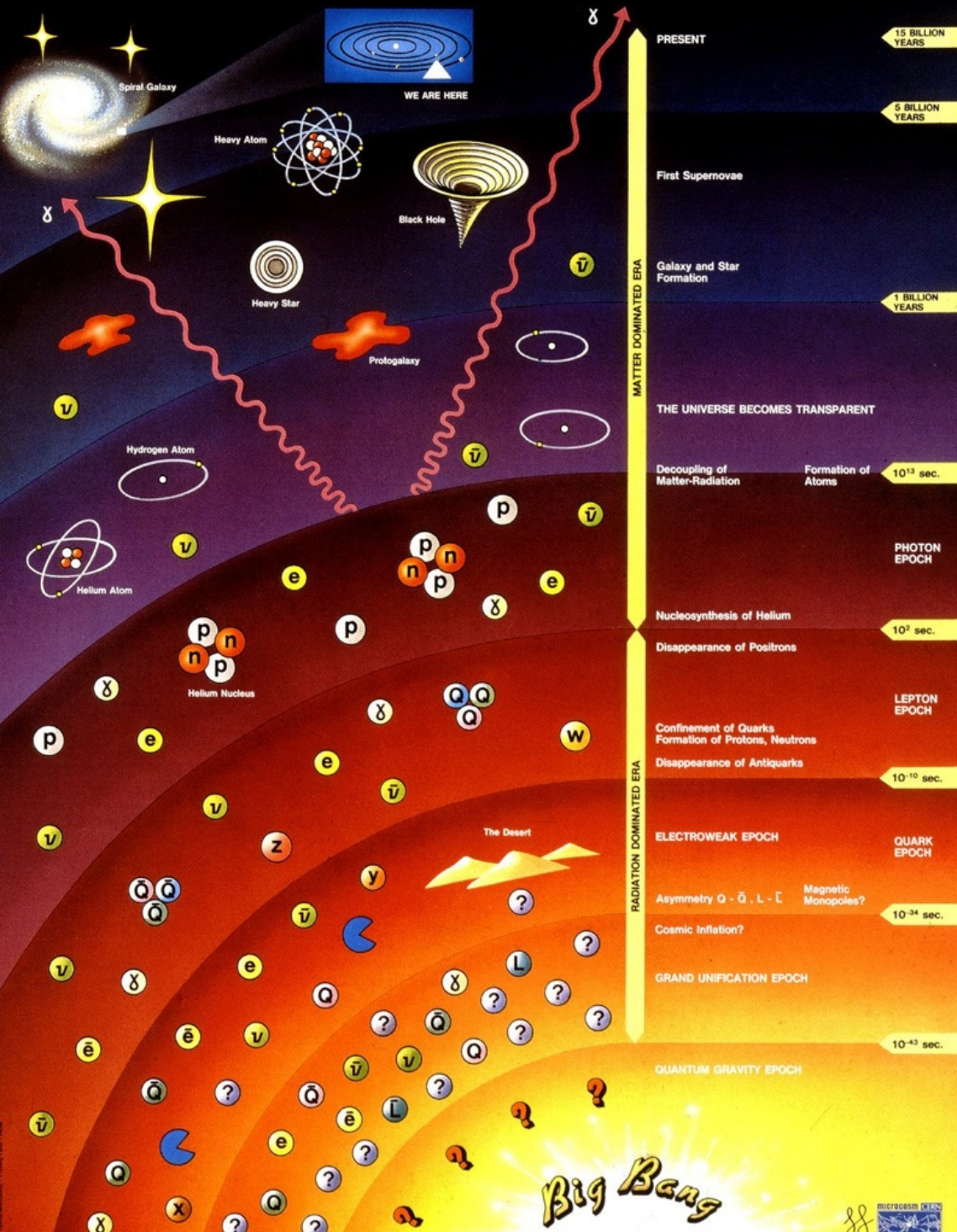
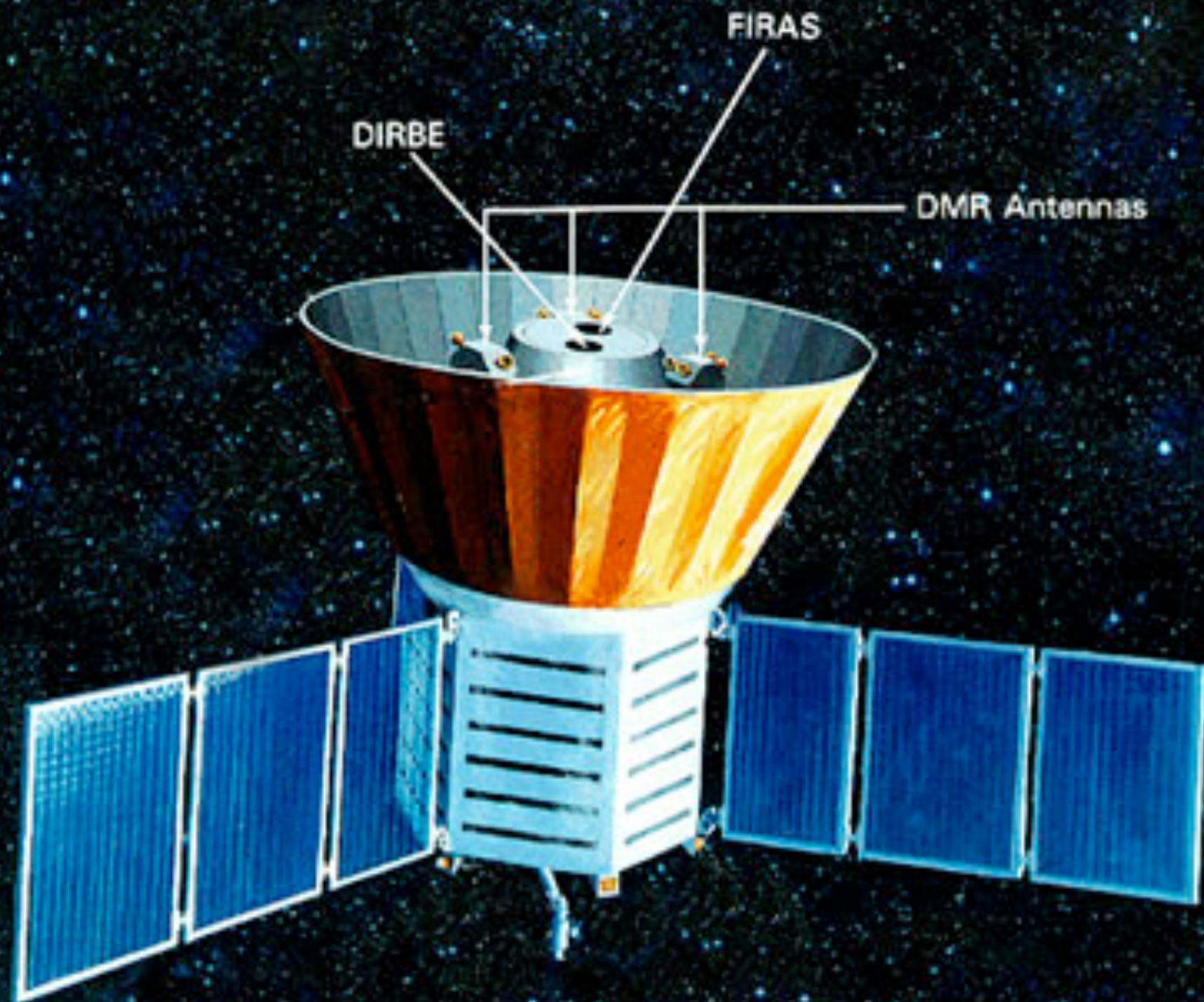


# History of the Universe



# Introduction to Cosmology

## Lecture 7



Cosmic Microwave Background Spectrum from COBE

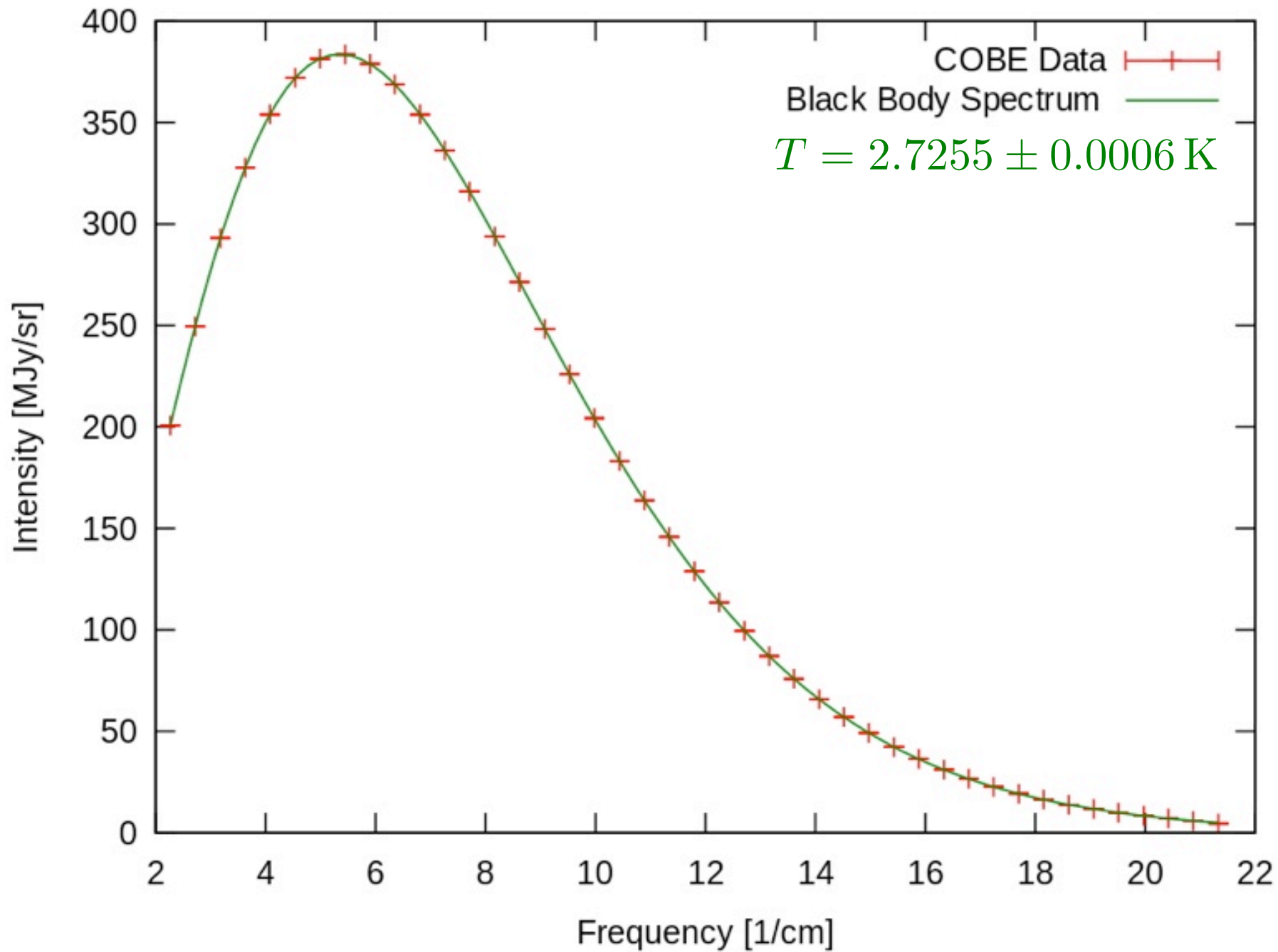
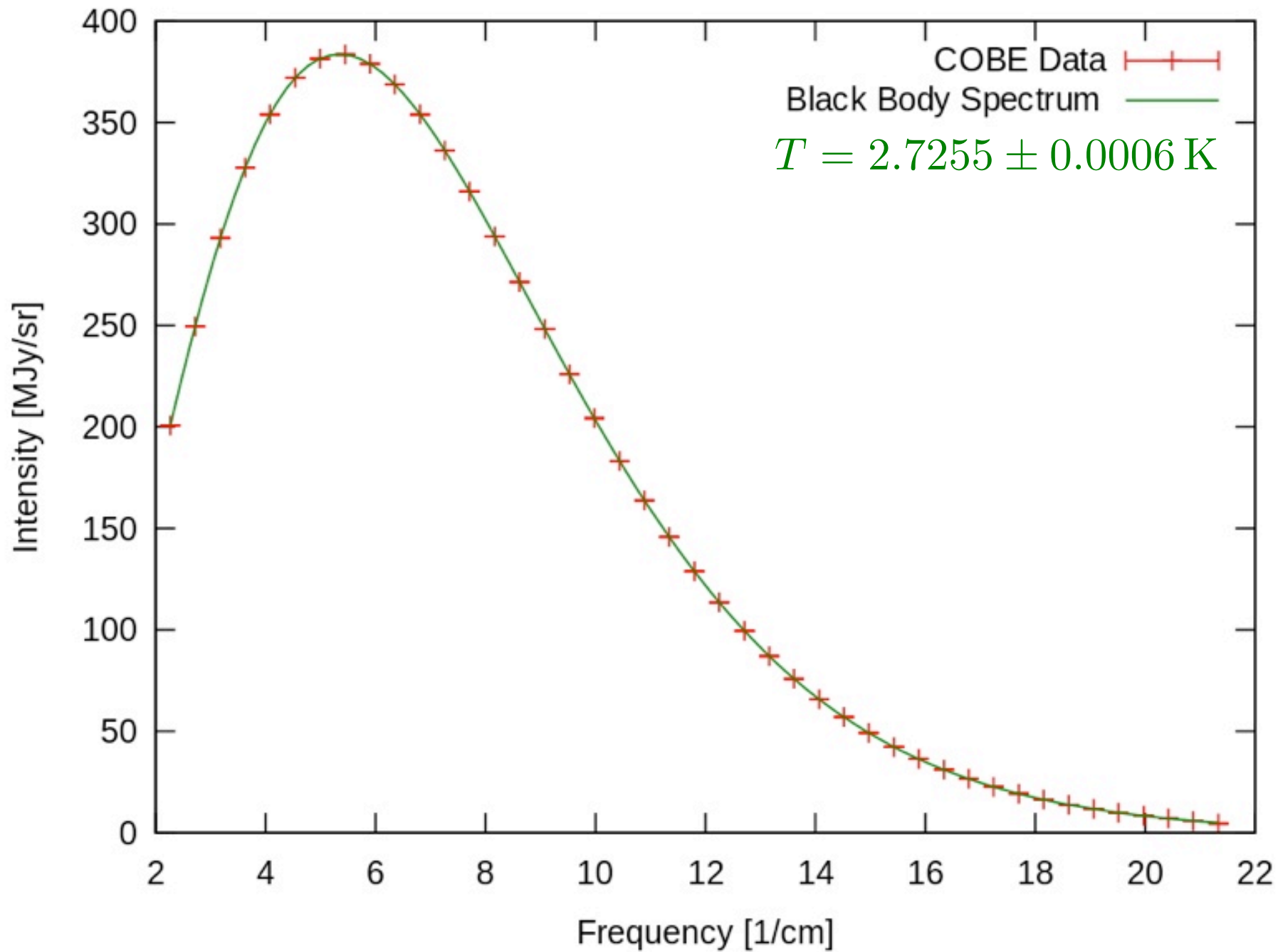
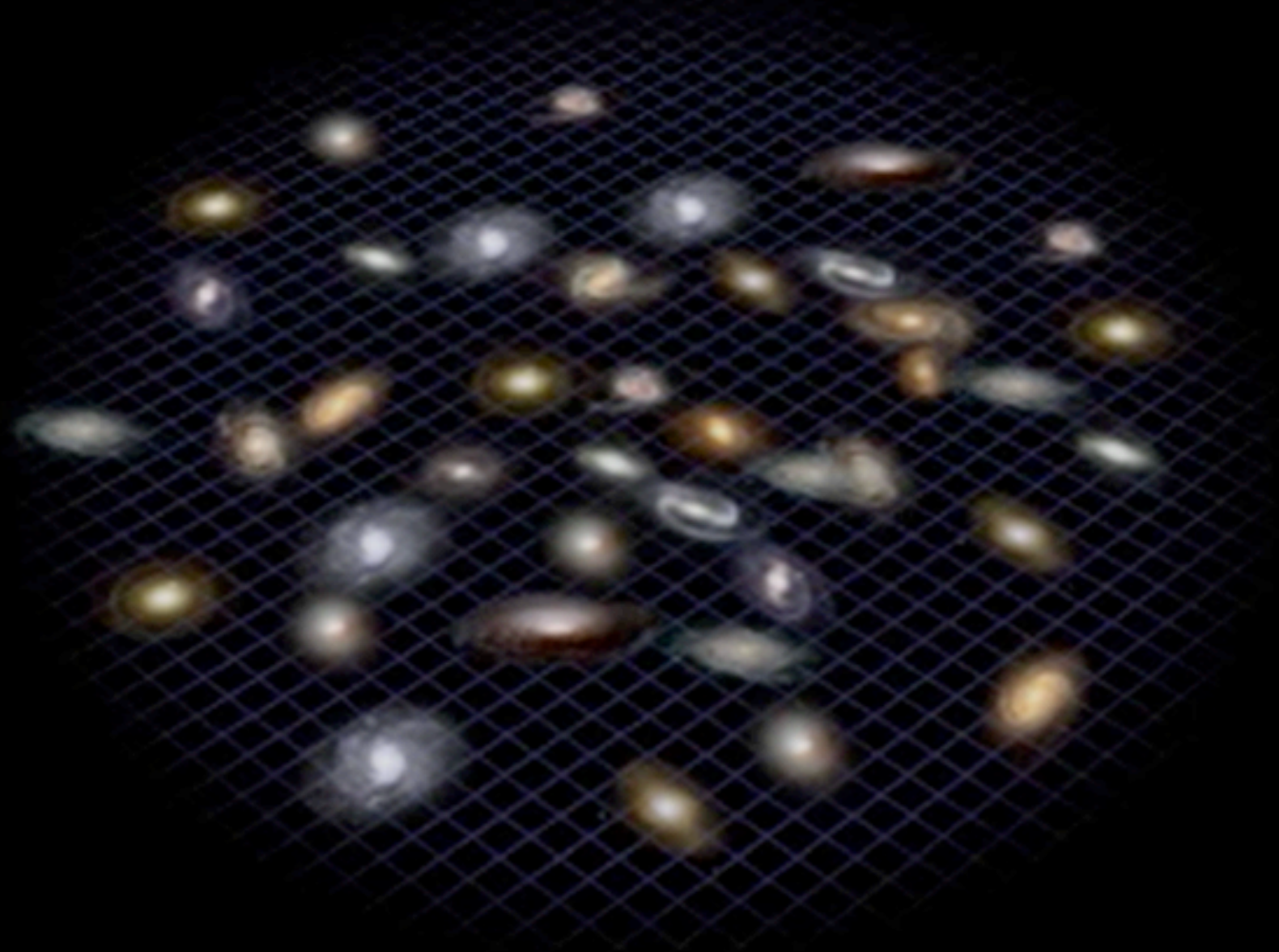


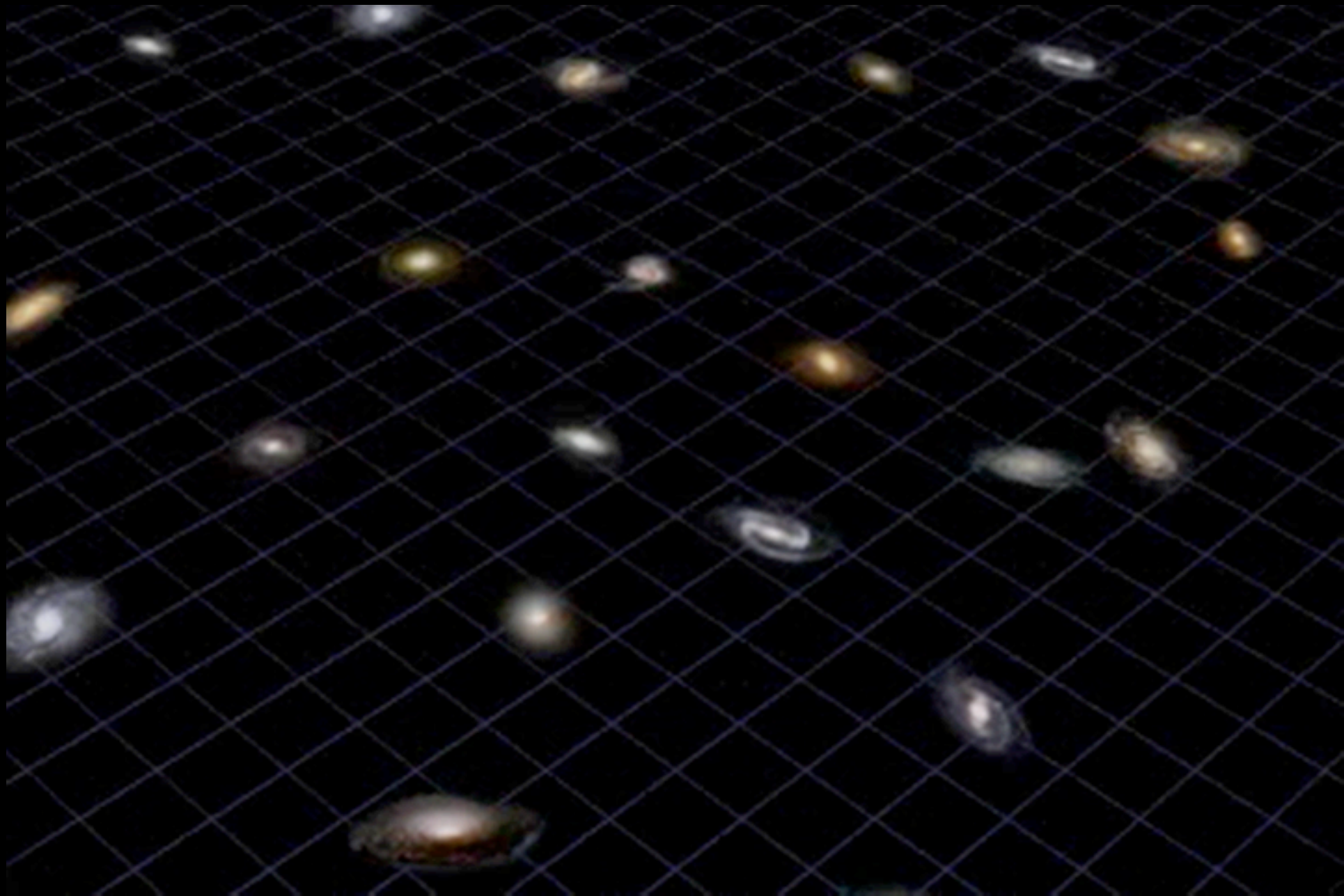
Table 1.1: COSMIC INVENTORY

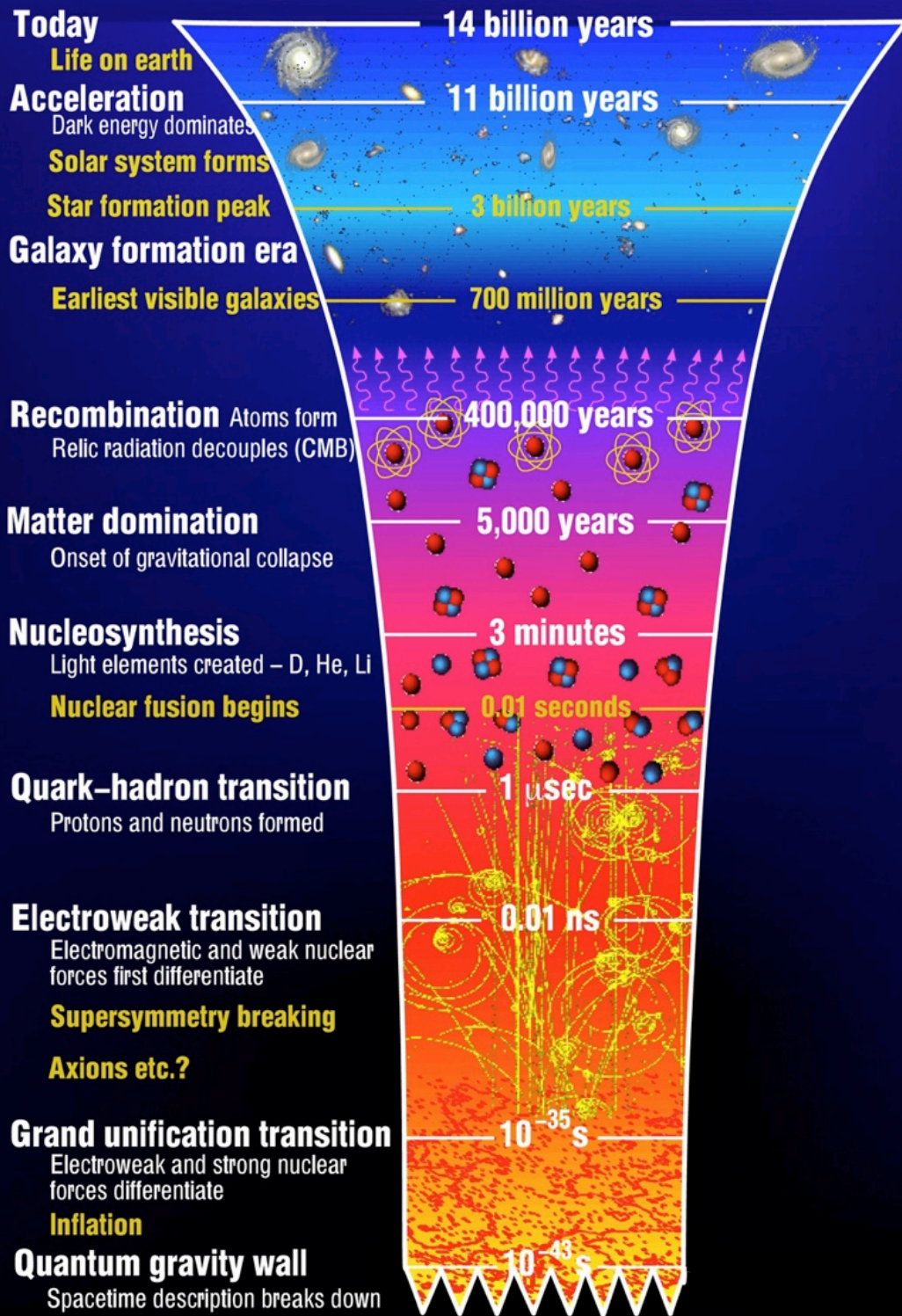
Component	$\Omega (\rho/\rho_c)$
Dark Energy	$0.691 \pm 0.006$
Matter (baryonic and non-baryonic)	$0.312 \pm 0.009$
Baryons (Total)	$0.0488 \pm 0.0004$
Baryons in stars and stellar remnants	$\sim 0.003$
Neutrinos	$\sim 0.001$
Photons (CMB)	$5 \times 10^{-5}$

# Cosmic Microwave Background Spectrum from COBE











Temperature  
of universe

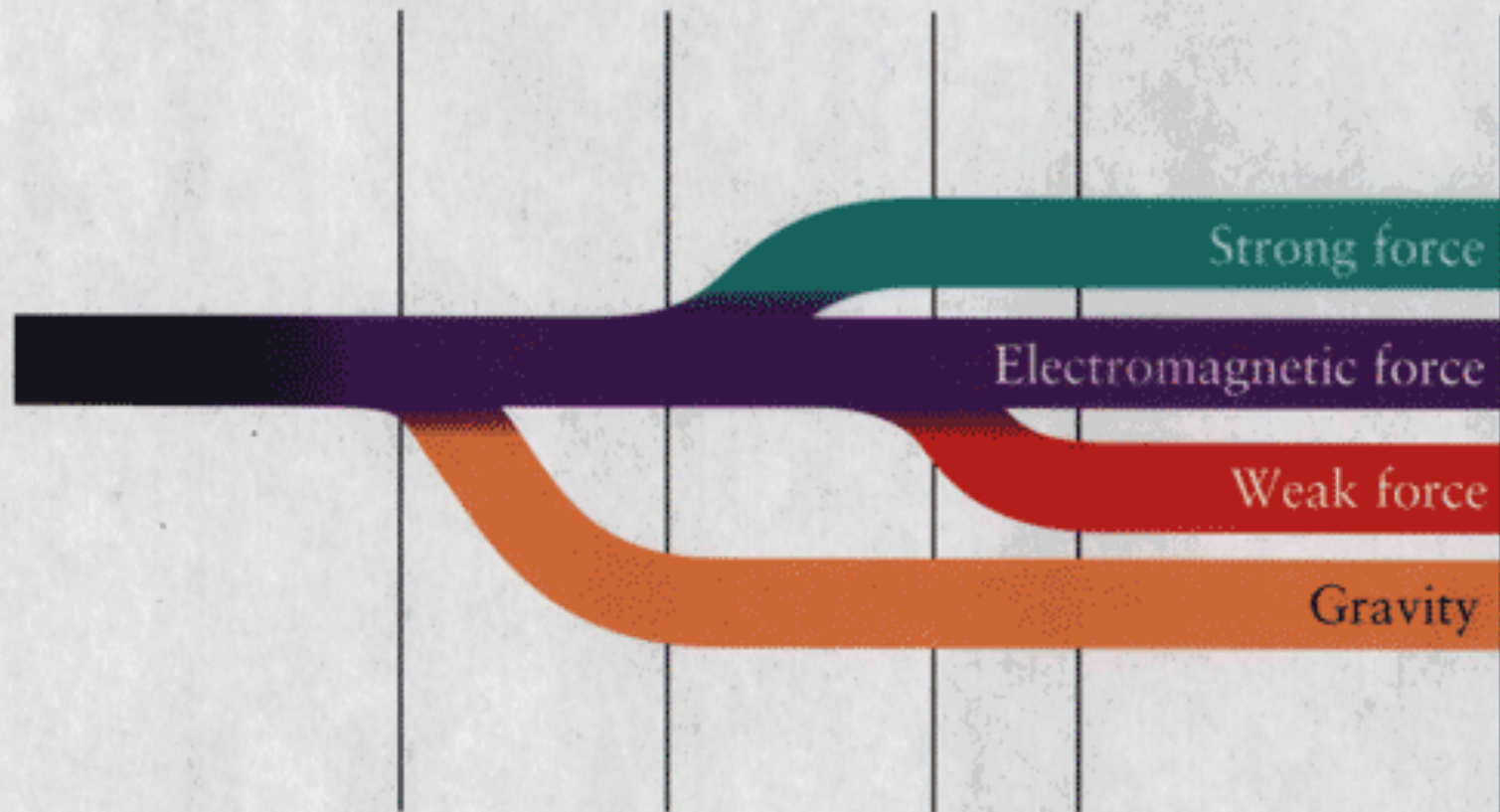
$10^{32}$  K

$10^{27}$  K

$10^{15}$  K

$10^{13}$  K

3 K



Strong force

Electromagnetic force

Weak force

Gravity

Time after  
Big Bang

$10^{-43}$  s

$10^{-35}$  s

$10^{-12}$  s

$10^{-6}$  s

$5 \times 10^{17}$  s  
(= now)

# Three Generations of Matter (Fermions)

	I	II	III	
mass →	2.4 MeV/c <sup>2</sup>	1.27 GeV/c <sup>2</sup>	171.2 GeV/c <sup>2</sup>	0
charge →	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
spin →	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
name →	<b>u</b> up	<b>c</b> charm	<b>t</b> top	<b>γ</b> photon
Quarks	4.8 MeV/c <sup>2</sup>	104 MeV/c <sup>2</sup>	4.2 GeV/c <sup>2</sup>	0
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	<b>d</b> down	<b>s</b> strange	<b>b</b> bottom	<b>g</b> gluon
Leptons	<2.2 eV/c <sup>2</sup>	<0.17 MeV/c <sup>2</sup>	<15.5 MeV/c <sup>2</sup>	91.2 GeV/c <sup>2</sup>
	0	0	0	0
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	<b>ν<sub>e</sub></b> electron neutrino	<b>ν<sub>μ</sub></b> muon neutrino	<b>ν<sub>τ</sub></b> tau neutrino	<b>Z<sup>0</sup></b> Z boson
	0.511 MeV/c <sup>2</sup>	105.7 MeV/c <sup>2</sup>	1.777 GeV/c <sup>2</sup>	80.4 GeV/c <sup>2</sup>
	-1	-1	-1	$\pm 1$
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	<b>e</b> electron	<b>μ</b> muon	<b>τ</b> tau	<b>W<sup>±</sup></b> W boson
				Gauge Bosons