The Beginning and The End

IB PHYSICS | ASTROPHYSICS

IB Physics Data Booklet

Sub-topic D.1 – Stellar quantities	Sub-topic D.2 – Stellar characteristics and stellar evolution
$d\ (\text{parsec}) = \frac{1}{p\ (\text{arc–second})}$ $L = \sigma A T^4$ $b = \frac{L}{4\pi d^2}$	$\lambda_{\max} T = 2.9 \times 10^{-3}\ \text{m K}$ $L \propto M^{3.5}$
Sub-topic D.3 – Cosmology	**Sub-topic D.5 – Further cosmology (HL only)**
$z = \frac{\Delta\lambda}{\lambda_0} \approx \frac{v}{c}$ $z = \frac{R}{R_0} - 1$ $v = H_0 d$ $T \approx \frac{1}{H_0}$	$v = \sqrt{\frac{4\pi G\rho}{3}} r$ $\rho_c = \frac{3H^2}{8\pi G}$

IB Physics Data Booklet

Unit conversions

1 radian (rad) $\equiv \frac{180°}{\pi}$

Temperature (K) = temperature (°C) + 273

1 light year (ly) = 9.46×10^{15} m

1 parsec (pc) = 3.26 ly

1 astronomical unit (AU) = 1.50×10^{11} m

1 kilowatt-hour (kWh) = 3.60×10^{6} J

$hc = 1.99 \times 10^{-25}$ J m = 1.24×10^{-6} eV m

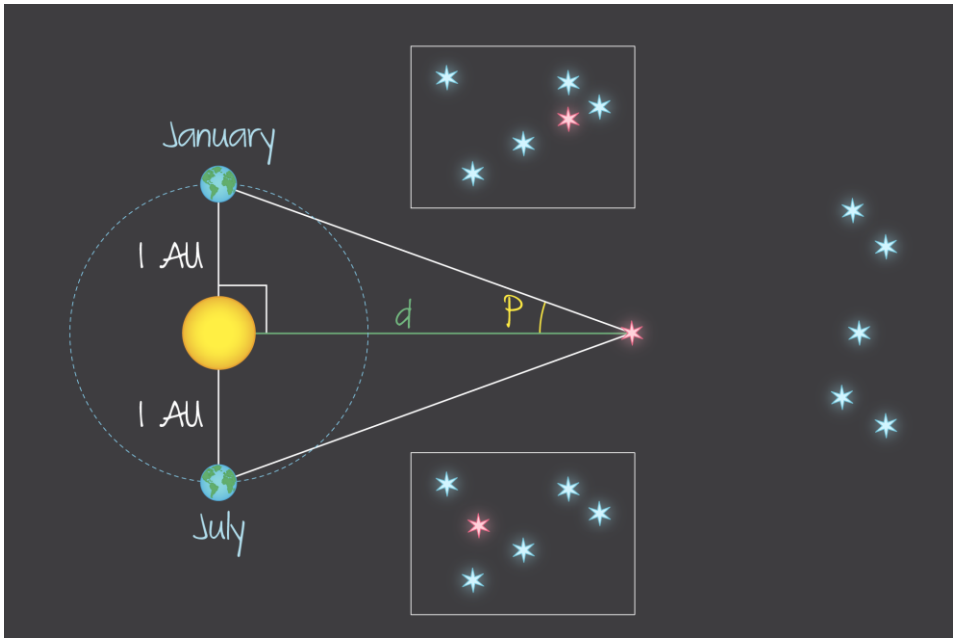
Stefan–Boltzmann constant	σ	5.67×10^{-8} W m^{-2} K^{-4}
Coulomb constant	k	8.99×10^{9} N m^{2} C^{-2}
Permittivity of free space	ε_0	8.85×10^{-12} C^{2} N^{-1} m^{-2}
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ T m A^{-1}
Speed of light in vacuum	c	3.00×10^{8} m s^{-1}
Planck's constant	h	6.63×10^{-34} J s
Elementary charge	e	1.60×10^{-19} C

Measuring the Universe

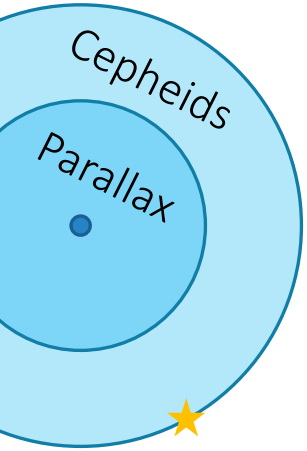
Distance | Parallax

$$d\ (parsec) = \frac{1}{p\ (arc\ second)}$$

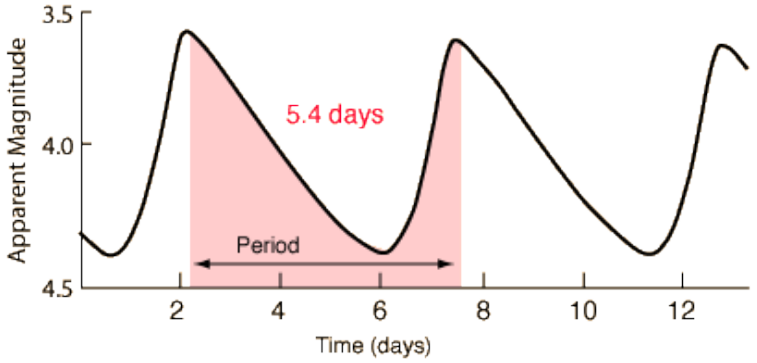
1 parsec (pc) = 3.26 ly

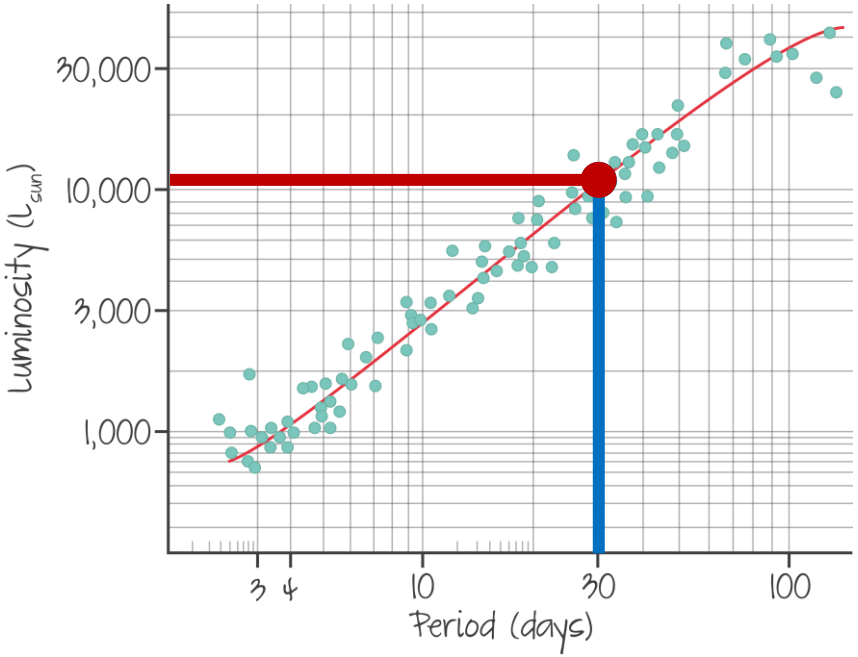


Distance | Cepheid Variables

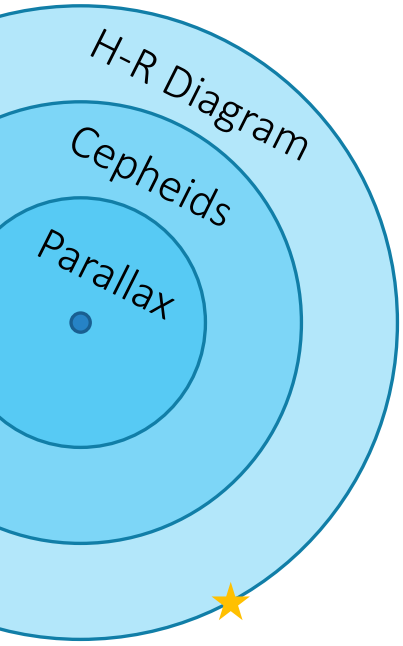


$$b = \frac{L}{4\pi d^2}$$

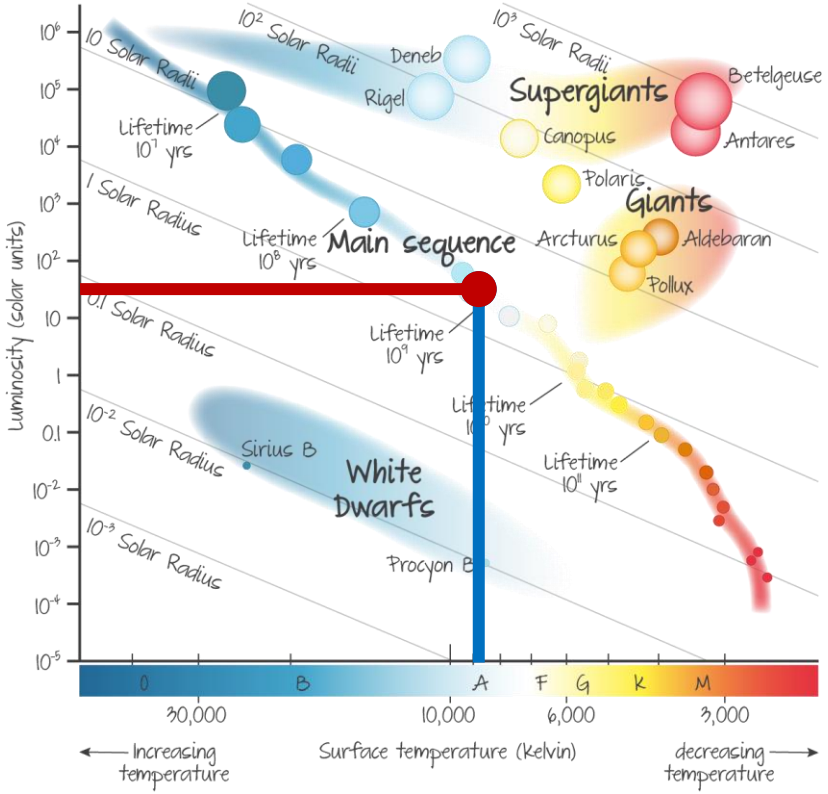




Distance | H-R Diagram

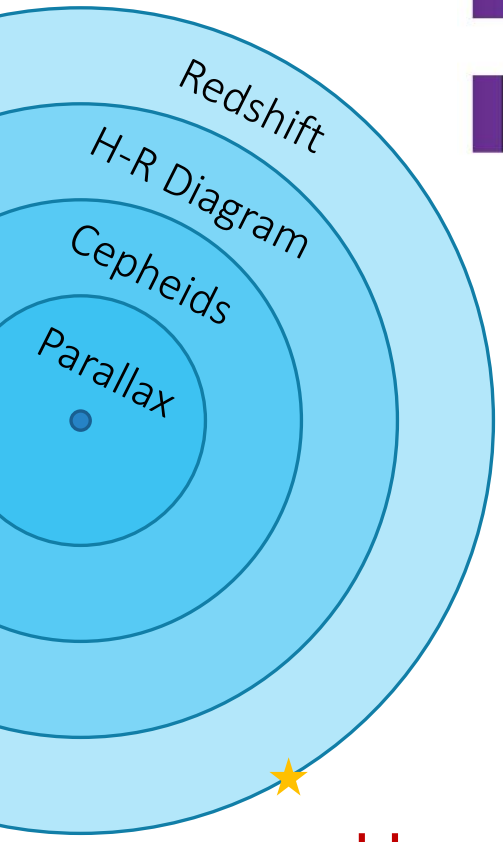


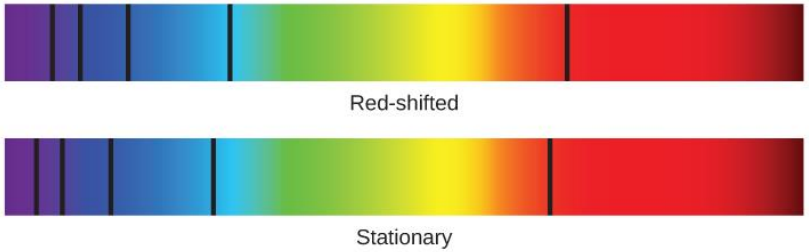
$$\lambda_{\max} T = 2.90 \times 10^{-3}\ \text{mK}$$



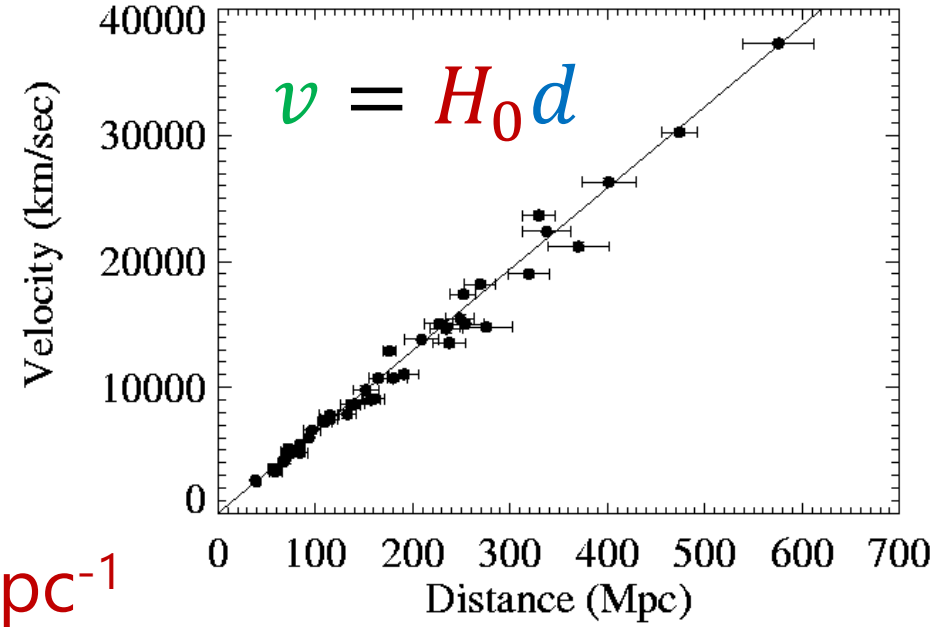
$$b = \frac{L}{4\pi d^2}$$

Distance | Redshift & Hubble's Law



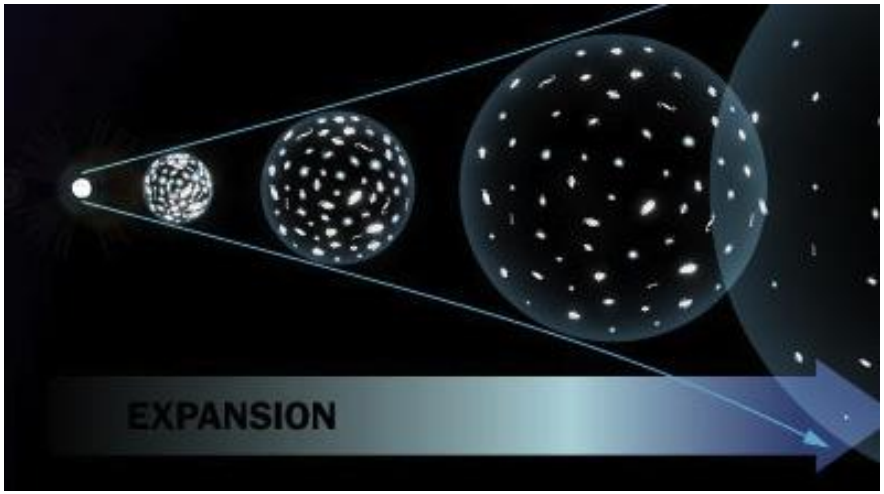


$$z = \frac{\Delta\lambda}{\lambda_o} \approx \frac{v}{c}$$



$H_0 \approx 70$ km s^{-1} Mpc^{-1}

How Old is the Universe?



$$v = H_0 d$$

$$H_0 \approx 70\ \text{km s}^{-1}\ \text{Mpc}^{-1}$$

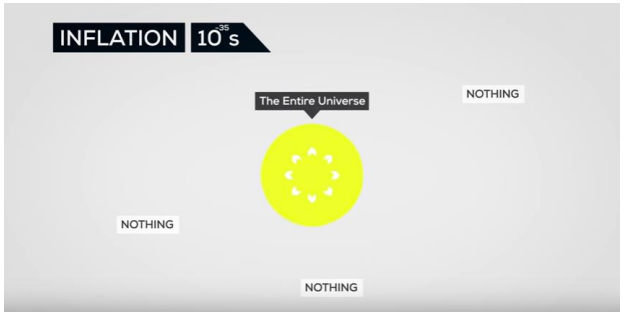
$$v = \frac{d}{t} \rightarrow H_0 d = \frac{d}{t} \rightarrow t = \frac{1}{H_0}$$

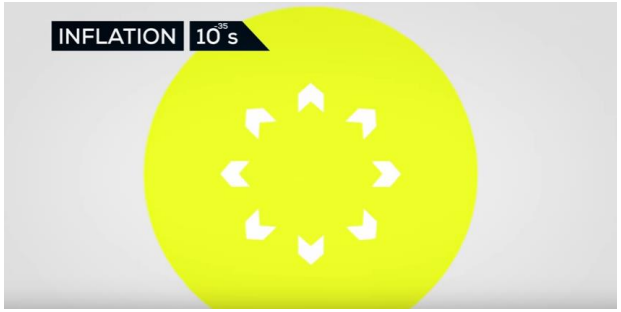
$$t = \frac{1}{70\ \text{km s}^{-1}\ \text{Mpc}^{-1}} = 0.0142\ \text{s Mpc km}^{-1}$$

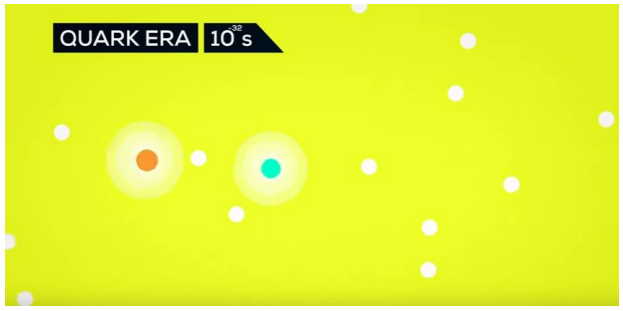
$$\frac{0.0142\ \text{s}\ \cancel{\text{Mpc}}}{\cancel{\text{km}}} \times \frac{10^6\ \cancel{\text{pc}}}{1\ \cancel{\text{Mpc}}} \times \frac{3.26\ \cancel{\text{ly}}}{1\ \cancel{\text{pc}}} \times \frac{9.46 \times 10^{15}\ \cancel{\text{m}}}{1\ \cancel{\text{ly}}} \times \frac{1\ \cancel{\text{km}}}{1000\ \cancel{\text{m}}} = \mathbf{4.4 \times 10^{17}\ s}$$

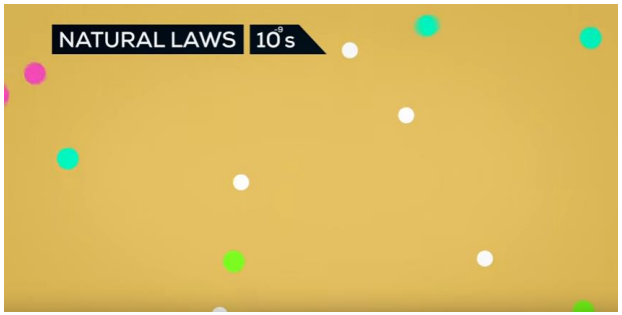
$\approx 13.8\ billion\ years$

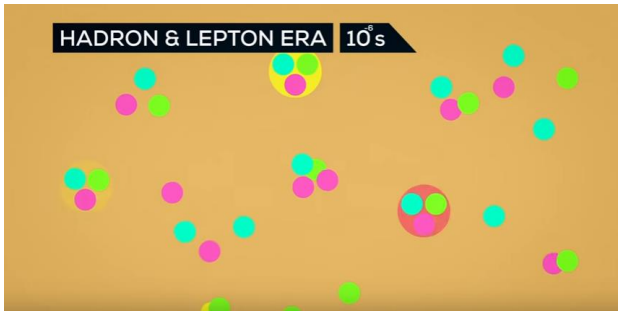
The “Big Bang”

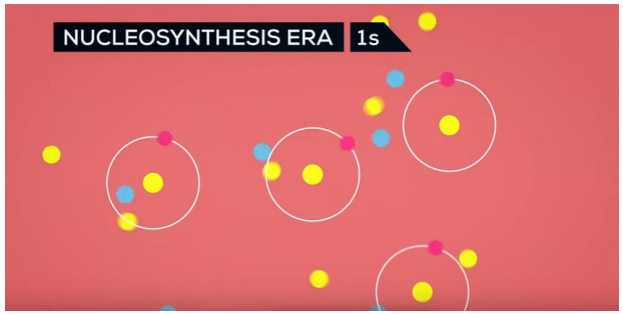

INFLATION 10⁻³⁵ s
The Entire Universe
NOTHING
NOTHING
NOTHING

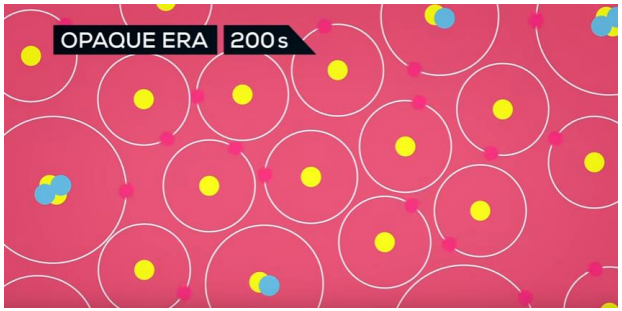

INFLATION 10⁻³⁵ s

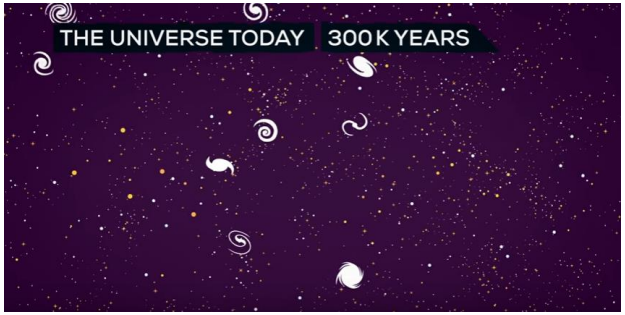

QUARK ERA 10⁻³⁵ s


NATURAL LAWS 10⁻⁹ s

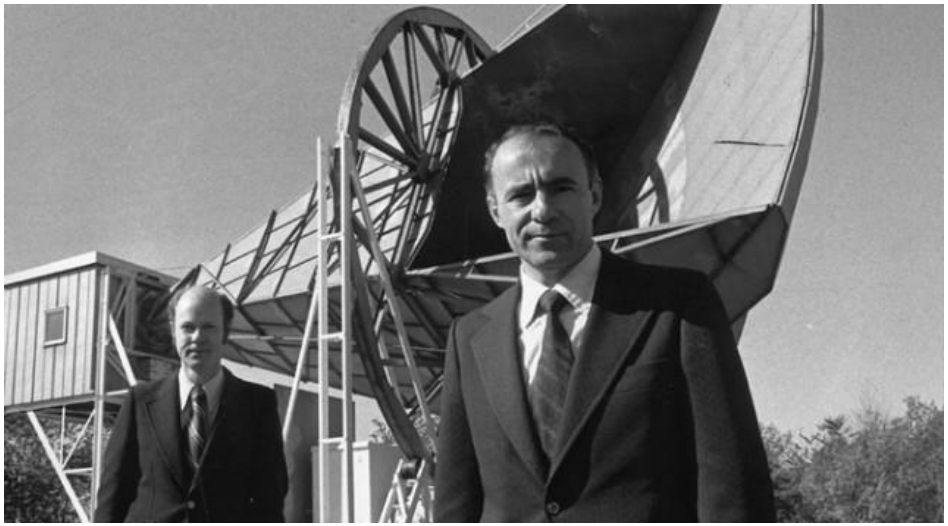

HADRON & LEPTON ERA 10⁻⁶ s


NUCLEOSYNTHESIS ERA 1s


OPAQUE ERA 200s

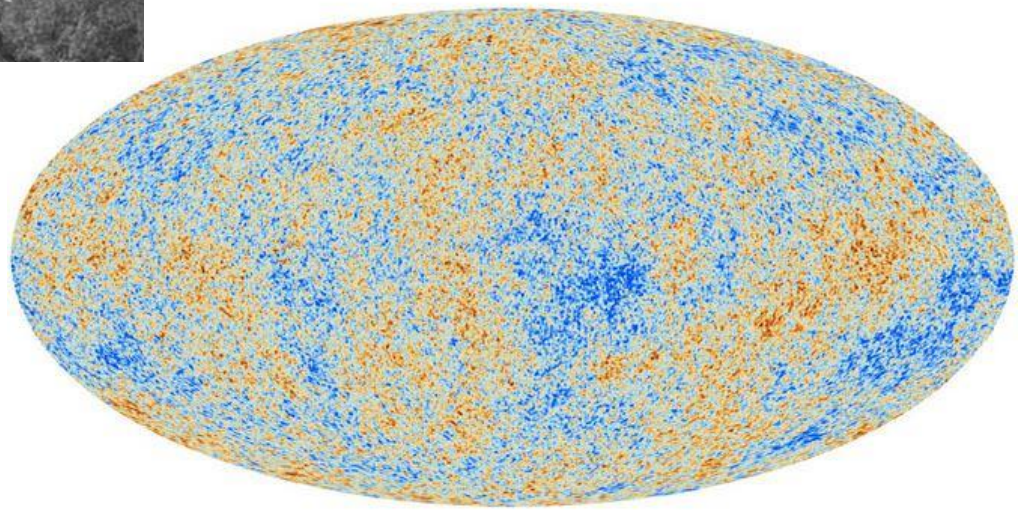

THE UNIVERSE TODAY 300 K YEARS

Where's the Evidence??



CMB

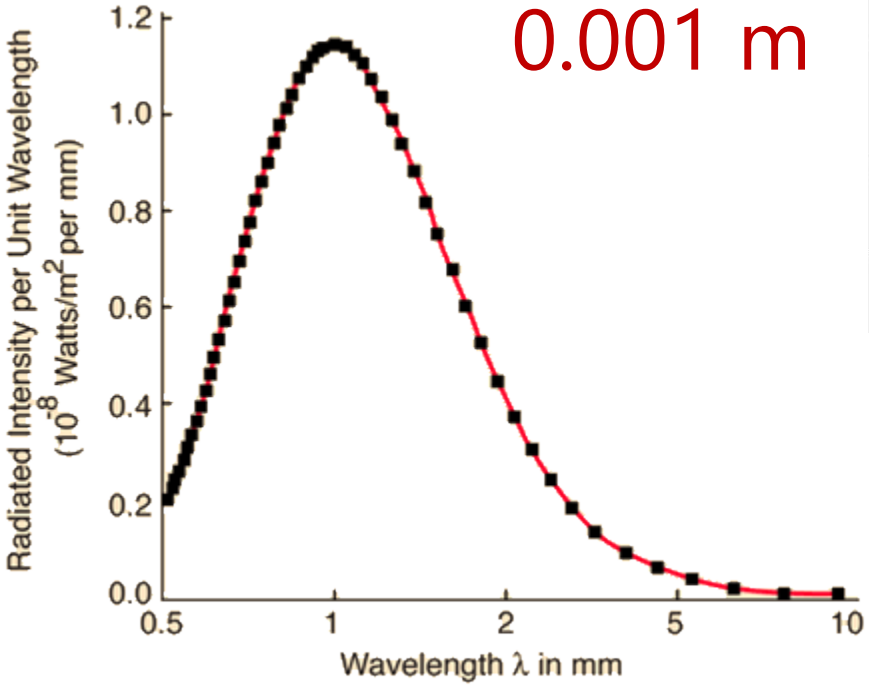
Cosmic Microwave Background



Cosmic Microwave Background

$\lambda_{max} = 1$ mm

0.001 m



Cosmic Microwave Background Explained | Space Time | PBS Digital Studios

$$T = \frac{2.9 \times 10^{-3}}{0.001} = \mathbf{2.9\ K}$$

Temperature of the Universe

What's Next?

1. Static and Infinite
2. Expanding and slowing to a stop
3. Expanding, slowing, and contracting in a "big crunch"
4. Expanding and accelerating