



## How old is the Universe? How do we know?

### I. Solar system age : 4.6 billion years

- ▶ Radiometric dating
  - Half-life
  - K-40/Ar-40 ratios
  - Starting ratios : Ar-40 doesn't chemically combine, only there if trapped
- ▶ Geological, evolutionary timescales
- ▶ Powering the Sun
  - Contraction : only lasts millions of years
  - **Fusion** : can last long enough
  - $E=mc^2$
  - Efficiency *eff* for various processes (chemical :  $10^{-9}$  ; fusion,  $10^{-2}$ ); not the same as rate fuel is "used," but rate mass goes to energy.

### II. All about light

- ▶ Electromagnetic spectrum
  - Wavelength and frequency,  $\lambda f = c$
  - E-M spectrum : radio-IR-visible-UV-X-rays-Gamma rays
  - Bluer = shorter wavelength
- ▶ Photons
  - $E = hf$
- ▶ Continuum, absorption, & emission spectra
  - transitions in atoms: one photon at a time
  - abs. & emis. spectra require *low-density* gas
- ▶ Blackbody radiation
  - Bluer = hotter (higher temperature)
  - Bluer = brighter *for sources of the same size*
  - $L = A \sigma T^4 = (4\pi R^2) \sigma T^4$

## II. All about light (continued)

### ▶ Brightness & distance

- $B = \frac{L}{4\pi d^2}$
- $B \propto \frac{1}{d^2}$

### ▶ Doppler Effect

- Redshift  $z$  :  $z = \frac{\lambda_{\text{obs}} - \lambda_{\text{emit}}}{\lambda_{\text{emit}}}$
- Doppler effect for  $v \ll c$  :  $z = \frac{v}{c}$
- $v > 0$  = receding = redshift
- $v < 0$  = approaching = blueshift

## III. Ages of the oldest stars : 12-13 billion years

### ▶ Spectral classification : OBAFGKM

- *All stars*: Sequence of temperature & color
- *Main sequence stars only* : sequence of decreasing temperature, luminosity, mass

### ▶ The H-R Diagram

- Luminosity vs. Color (or temperature)
- Regions : main sequence, giants, supergiants, white dwarfs
- Motion on diagram during evolution

### ▶ Stellar Evolution

- Stages : protostar, main sequence, giant, stellar remnant
- Endpoints for low-mass and high-mass stars (white dwarf, neutron star, black hole)
- Lifetime: longer for lower-mass stars

## III. Ages of the oldest stars (continued)

### ▶ Star clusters

- Stars all formed at once
- Stars all about the same distance from Earth
- Open & Globular clusters

### ▶ The H-R Diagram of Clusters

- Main sequence turn-off
- Match to stellar evolution models
- Ability to date the cluster

### ▶ Oldest globular clusters:

- 12—13 billion years old