# Supernovae type Ia as standard candles

A concept for a school lesson

HERAEUS Summer school, Group 3

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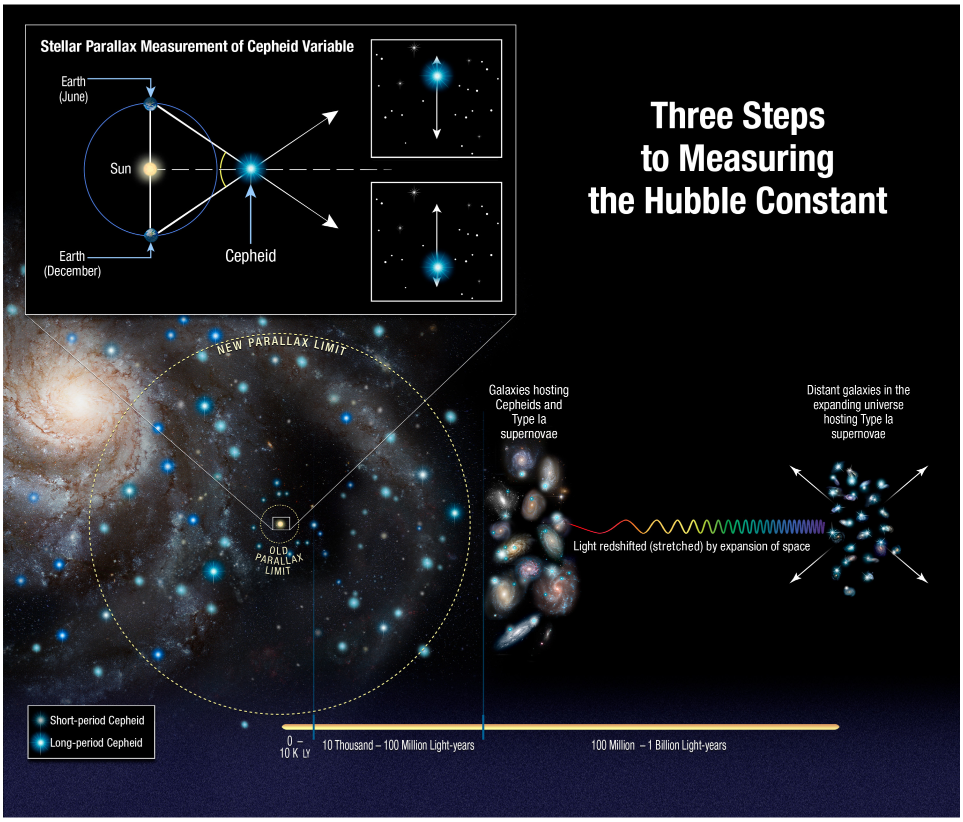


Figure 1: distance ladder showing different measurement methods and their limits. Image: NASA, ESA, A. Feild (STScI), and A. Riess (STScI/JHU)

# 1 distance measurements

- restricted via range of applicability (see Figure 1)

## 1.1 parallaxes

- e.g. orbital motion of the earth
- mathematical relation $r \sim \frac{1}{p}$
- $D \simeq \frac{1\,\mathrm{AU}}{p}$
- definition of the parsec ("$1\,\mathrm{pc} = 1''^{-1}$")
- range of validity up to $200\,\mathrm{pc}$

## 1.2 photometry

- star's luminosity decreases with the distance:

  - $I = \frac{L}{4\pi r^2}$

- comparison of apparent and absolute magnitude yields the distance

### 1.2.1 Weber-Fechner law

- logarithmic dependencies in brightness measures ($p = k \ln \frac{S}{S_0}$)
- comparison e.g. dB from acustics
- for brightness $\Delta R = \left(\frac{I}{I_0}\right)^{2.5}$

### 1.2.2 apparent and absolute magnitudes

- definitions $M$, $m$:
  - using the brightness-distance relation
  - $m = -2.5 \log I + \text{const.} = -2.5 \log L + 5 \log r + \text{const.}$
  - $M = m\,(r = 10\,\text{pc}) = 5 - 2.5 \log L + \text{const.}$

### 1.2.3 distance modulus

- $\Delta m = m - M = 5\,(\log r[\text{pc}] - 1) \quad \Rightarrow \quad r = 10^{1+\Delta m/5}\,\text{pc}$

## 1.3 errors and difficulties

- are effects altering the measurements, e.g. absorption, refraction, aberration, redshift
  - $\Delta m \to \Delta m + A$
- spectra and DOPPLER's effect as physical approach to redshifts
  - $z = \frac{\lambda' - \lambda}{\lambda}$
- method of analyzing a stars composition and temperatures and to determine redshifts
  - conclusion by seen lines in the spectrum and its intensity distribution

## 1.4 standard candles

- astronomical object whose absolute magnitude is obtainable by measuring physical properties
  - e.g. cepheids, variable stars, supernovae

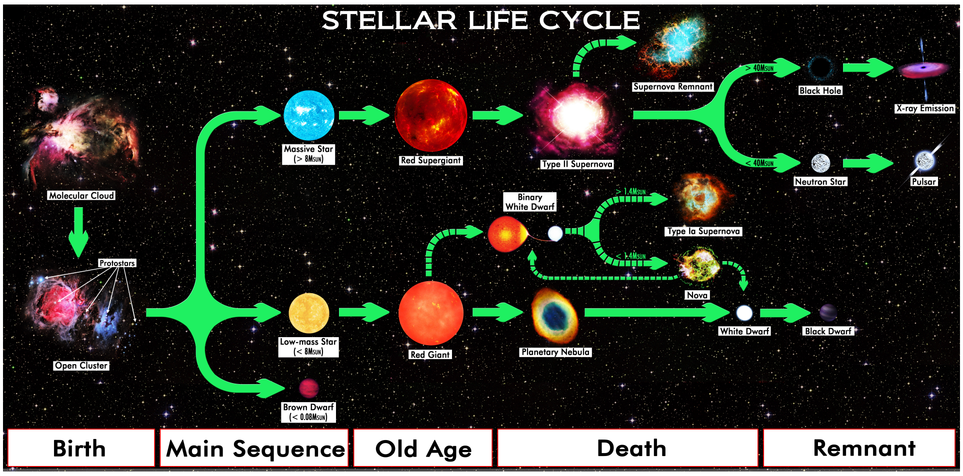


Figure 2: flowchart despicting the evolution of a star.Image: R.N. Bailey

# 2 stellar evolution (or on the way to a supernova)

## 2.1 basics: gravity

- Newton:
  - $g = \frac{GM}{r^2}$
- mechanical equilibrium

## 2.2 lifecycle of a star

- general pattern, differences only by mass (see Figure 2.2):
- gravitational contraction of nebulous interstellar clouds
- high pressure results in nuclear fusion (hydrogen to helium)
- contraction via loss of hydrogen (missing radiational pressure)
- after hydrogen is used up mass comes into play
- to small masses result in ejection of the outer layers via radiation and remaining white dwarf
- for helium fusion pressure and temperature has to increase massively (required minimum mass needed)

## 2.3 supernova

- two main kinds of supernova:

- collapse-supernova:
  * initial mass is above $8M_\odot$
  * fusion continues til the stage of iron
  * fusion to higher elements requires energy instead of producing it
  * collapse to neutron star or even black hole (if leftover mass is above $2.5M_\odot$)
  * remaining outer layers are deflected by the really dense core
- binary system supernova:
  * white dwarf is gaining mass via a binary partner
  * if dwarf's mass reaches Chandrasekhar limit of $1.44M_\odot$ it collapses
  * carbon fusion ignites and rips apart the star in a supernova

### 2.3.1 supernova classification

- based on presence of certain features in their optical spectra
- different types
  - Ia: thermonuclear explosion of white dwarf
  - Ib, Ic, II: core-collapse of massive stars

### 2.3.2 Supernova type Ia

- progenitors are low mass stars
- short duration of peak phase in light curve (indicates low ejected mass)
- take place in every galaxy without preference for arms of spiral galaxies
- luminosity-decline rate relation is known via theory (see Figure 2.3.2)
- very precise distance indicators over large distances

# 3 conclusion and outlook

- observation of SNIa's allows precise measurements of cosmological scales
- comparison of data and model allows to make more precise predictions about the universe (see Figure 3)[1]

[1]source: `supernova_fit.py`

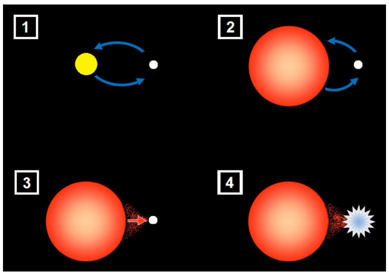


Figure 3: Typical luminosity-time curve for a SNIa.
Image: Wikipedia-author FT2

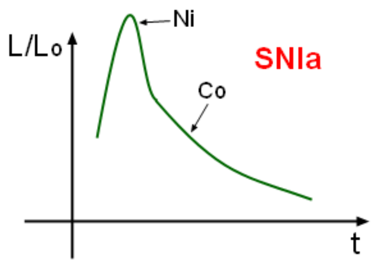


Figure 4: Typical luminosity-time curve for a SNIa.
Image: Wikipedia, claimed as open source (https://commons.wikimedia.org/wiki/File:SNIacurva.png)

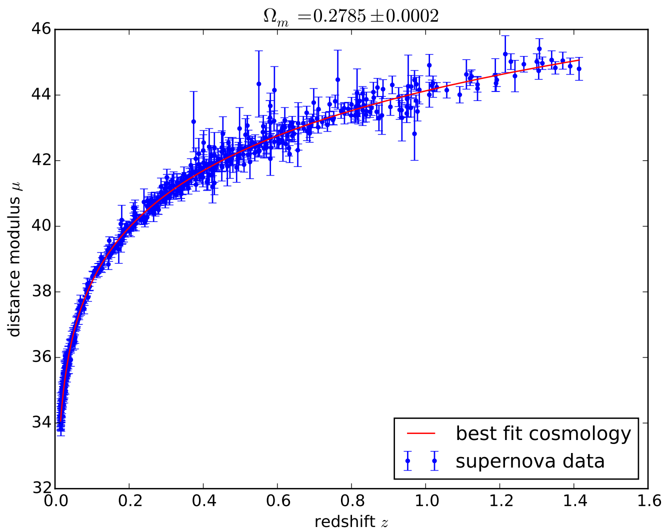


Figure 5: fit of a cosmological model to the measured SNIa data