XIII A. Standard Candle 2: *Type 1a Supernovae (SN)*

$q_0 := -0.53$

Introduction to Cosmology, Ryden, pg. 116 (Ryden's Distance Equation for Distance Modulus, Dmod)

"To determine the acceleration of the universe, we need to view standard candles for which the relation between d_L and z deviates significantly from the linear relation that holds true at lower redshifts. In terms of H_0 and q_0, the equations for **luminosity distance d_L** and **distance modulus $D_{mod}(z)$** at small redshift ($z < 1$) is, (Ryden 2nd Ed. Eq. 6.51),

$$d_L(z) := \frac{c}{H_0} z \cdot \left[1 + \left(\frac{1 - q_0}{2}\right) z\right] \qquad D_{mod}(z) := 43.23 - 5\,log\left(\frac{H_0}{68 km \cdot s^{-1}\, Mpc^{-1}}\right) + 5\,log(z) + 1.086\left(1 - q_0\right)z$$

At a redshift $z = 0.2$, for instance, the luminosity distance d_L in the Benchmark Model (with $q_0 = -0.53$) is 5 percent larger than dL in an empty universe (with $q_0 = 0$).

For a standard candle to be seen at $d_L > 1000$Mpc, it must be very luminous. In recent years, the standard candle of choice among cosmologists has been type *Ia supernovae*. A supernova may be loosely defined as an exploding star. Early in the history of supernova studies, when little was known about their underlying physics, supernovae were divided into two classes, on the basis of their spectra. Type I supernovae **contain no hydrogen absorption lines in their spectra**; type II supernovae contain strong hydrogen absorption lines. Gradually, it was realized that all type II supernovae are the same species of beast; they are massive stars ($M > 8\,M_\odot$) whose cores collapse to form a black hole or neutron star when their nuclear fuel is exhausted. During the rapid collapse of the core, the outer layers of the star are thrown off into space. Type I supernovae are actually two separate species, called type Ia and type Ib. Type Ib supernovae, it is thought, are massive stars whose cores collapse after the hydrogen-rich outer layers of the star have been blown away in strong stellar winds. Thus, type Ib and type II supernovae are driven by very similar mechanisms – their differences are superficial, in the most literal sense. **Type Ia supernovae**, however, are something completely different. They **begin as white dwarfs**; that is, stellar remnants that are supported against gravity by the quantum mechanical effect known as electron degeneracy pressure. The maximum mass at which a white dwarf can be supported against its self-gravity is called the Chandrasekhar mass; the value of the Chandrasekhar mass is $M \approx 1.4\,M_\odot$. A white dwarf can go over this limit by merging with another white dwarf, or by accreting gas from a stellar companion. If the Chandrasekhar limit is approached or exceeded, the white dwarf starts to collapse until its increased density triggers a runaway nuclear fusion reaction. The entire white dwarf becomes **a fusion bom**b, blowing itself to smithereens; unlike type II supernovae, type Ia supernovae do not leave a condensed stellar remnant behind.

Within our galaxy, type Ia supernovae occur roughly **once per century**, on average. Although type Ia supernovae are not frequent occurrences locally, they are **extraordinarily luminous**, and hence can be seen to large distances. The luminosity of an average type Ia supernova, at peak brightness, is $L = 4 \times 10^9\ L\ M_\odot$; that's **100,000 times more luminous than even the brightest Cepheid**. For a few days, a type Ia supernova in a moderately bright galaxy can **outshine all the other stars in the galaxy combined**. Since moderately bright galaxies can be seen at $z \approx 1$, this means that type Ia supernovae can also be seen at $z \approx 1$.

So far, type Ia supernovae sound like ideal standard candles; very luminous and all produced by the same mechanism. There's one complication, however. Observation of supernovae in galaxies whose distances have been well determined by Cepheids reveals that **type Ia supernovae do not have identical luminosities**. Instead of all having $L = 4 \times 10^9\ L_\odot$, their peak luminosities lie in the fairly broad range $L \approx (3 - 5) \times 10^9\ L_\odot$. However, it has also been noted that the peak luminosity of a type Ia supernova is tightly correlated with the shape of its light curve. Type Ia supernovae with luminosities that shoot up rapidly and decline rapidly are less luminous than average at their peak; supernovae with luminosities that rise and fall in a more leisurely manner are more luminous than average. Thus, just as the period of a Cepheid tells you its luminosity, **the rise and fall time of a type Ia supernova tells you its peak luminosity."** **Refer to the Two Classes of Light Curve Graphs Below**

Compare Supernovae Types: Characteristics and Light Curve Differences

Two Basic Scenarios of Stellar Death:

Ia. Thermonuclear runaway at degenerate conditions (drives the destruction of white dwarf stars in Type Ia Sne)
II. Implosion of stellar cores (associated with what is called core-collapse supernovae (CCSNe) of Types II, Ib/c

Type Ia supernova, needs several very specific events to push the white dwarf over the Chandrasekhar limit. Type II events occur during the regular course of a massive stars evolution.

Type Ia Supernovae

Pretty Good Standard Candles, Mv ~ -19.3. Believed to be caused by accretion of material from binary companion star to a white dwarf (WD), pushing it over its Chandrasekhar limit, causing its collapse.

Type Ia

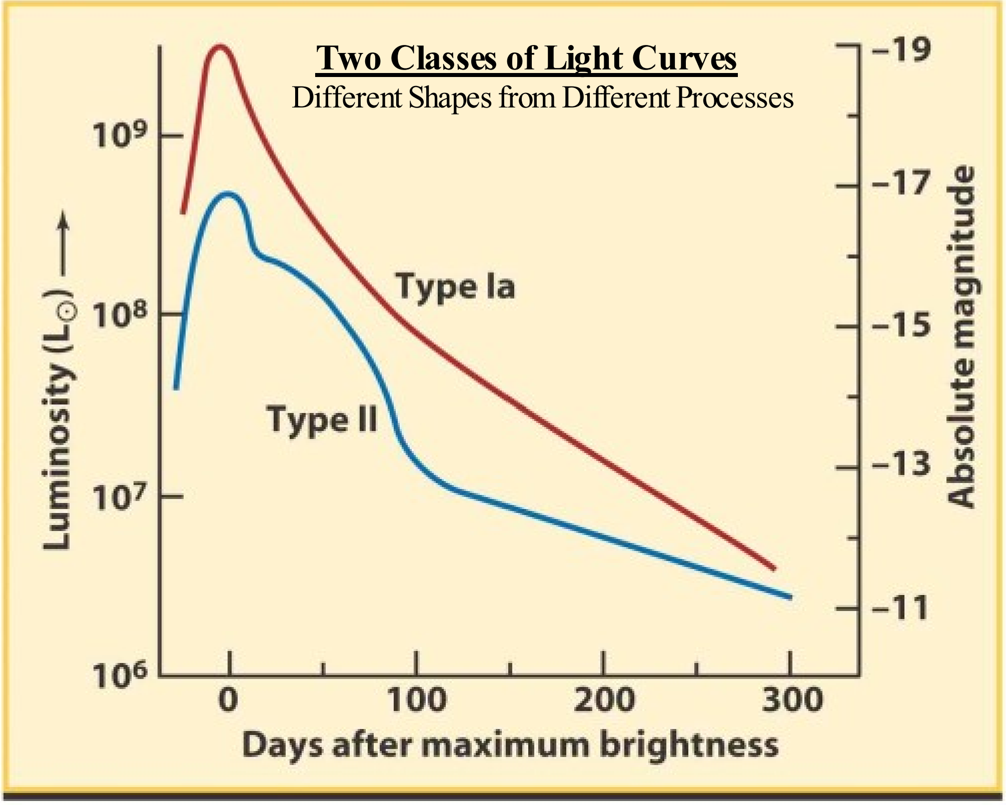
- **No H, He in spectrum**
- No visible progenitor (WD)
- Kinetic Energy: 10^{51} erg
- Total EM Radiation: 10^{49} erg
- Likely no neutrino burst
- Rate: 1/300 yr in Milky Way
- Occur in spirals and ellipticals
- No remnant
- most of the explosion energy is in **heavy element synthesis** and kinetic energy of the ejecta

Type II Supernovae

Formed by collapse of massive stars (also Type Ib). Not good standard candles, but we can measure their distance using the Baade-Wesselink method of measuring the expansion of the outer envelope.
Not as bright as Type Ia's.

Type II

- **Both H, He in spectrum**
- Supergiant progenitor
- Kinetic Energy: 10^{51} erg
- Total EM Radiation: $10^{48\text{-}49}$ erg
- Neutrinos: 10^{53} erg
- Rate: 1/50 yr in Milky Way
- Occur mainly in spiral galaxies
- Remnant: NS or BHs
- vast majority of the energy is in neutrino emission



Source: https://www.astro.umd.edu/~richard/ASTR480/A480_supernova_remnants_2016_lec1.pdf