**Lecture 9: Supernova Rates**

**Star-Formation Efficiency, Yield**

How many supernovae per year for each galaxy type? Use power-law IMF, Salpeter slope $-7/3 = -2.33$

\[ N(M) \propto M^{-7/3} \]

Log-log plot of supernova distribution.

- **Supernova Rate**
  - Median mass: $M_{\text{SN}} = 0.072 \times 0.6 = 0.043 M_\odot$
  - Most stars at low-mass end!

- **SN Mass Fraction**
  - Supernovae are rare, but each is very massive.
  - What fraction of the mass goes into SNe?
    - $f_M = \frac{\int \frac{N(M) \times M^2}{\int N(M) dM}}{\int \frac{N(M) \times M^2}{\int N(M) dM} dM} = \frac{0.018 + 0.063}{0.018 + 21.544} = 0.008$ (0.2%)
    - Most stars at low-mass end!
    - $f_M = 7.2\%$

**“Universal” IMF** (Kroupa 2002)

\[ N(M) = M^{-\alpha} \]

- $\alpha = -7/3$ for $M > 1 M_\odot$
- $-4/3$ for $0.1 - 1 M_\odot$
- $-1/3$ for $0.1 M_\odot$

\[ f_{\text{SN}} \approx 0.072 \times 0.6 M_\odot \]

- Log-log plot of supernova distribution.

**SN Rates vs Galaxy Type**

- **Spiral Galaxy**
  - SFR: $\sim 8 M_\odot$ yr$^{-1}$.
  - 7.2% have $M > 8 M_\odot$.
  - $\Rightarrow (8 M_\odot$ yr$^{-1}) \times 0.072 \approx 0.6 M_\odot$ yr$^{-1}$ go into SNe
- **SN rate**
  - $0.6 M_\odot$ yr$^{-1}$
  - $\frac{1}{12.2 M_\odot}$ yr$^{-1}$ (fewer seen due to dust)

- **Irregular Galaxy**
  - $-10$x this rate during bursts (1 SN per 2 yr).
  - No SNe between bursts.
Estimates for efficiency $\alpha$, yield in X, Y, Z
Assume:
1. Type-II SNe enrich the ISM.
   (Neglect: Type-I SNe, stellar winds, PNe, ...)
2. Closed Box Model:
   (Neglect: Infall from the IGM, outflow to the IGM)
3. SN 1987A is typical Type-II SN.
Better models include these effects.
What do we know about SN 1987A?

SN 1987A
23 Feb 1987 in LMC
Brightest SN since 1604!
First SN detected in neutrinos.
Visible (14 -> 4.2 mag) to naked eye, in southern sky.
Progenitor star visible:
~20 Msun blue supergiant.
3- ring structure (pre-SN wind)
Shockwave reaches inner ring 2003.

Star Formation Efficiency
Use SN 1987A to calculate $\alpha$ and yield.
SN 1987A: progenitor star mass = 20 $M_\odot$
  remnant neutron star mass = 1.6 $M_\odot$
mass returned to the ISM = 18.4 $M_\odot$
From IMF, 7.2% of $M_\odot$ is in stars with $M > 8 M_\odot$
$\beta = \text{Fraction of } M_\odot \text{ returned to ISM}:
\beta = \frac{\text{mass returned to gas}}{\text{mass turned into stars}} = \frac{0.072 \times 18.4}{20} = 6.6\%$

Star Formation Efficiency
$\alpha = \text{fraction of } M_\odot \text{ retained in stars}:
\alpha = 1 - \beta = 93\%$
SN 1987A Lightcurve
Powered by radioactive decay of r-process nuclei.
Use to measure metal abundances in ejected gas.

$^{56}\text{Ni} \rightarrow ^{56}\text{Co}$  6d half-life
$^{56}\text{Co} \rightarrow ^{56}\text{Fe}$  78d half-life

$X, Y, Z$ of ejecta from SN1987A

- Initial mass $\sim 20\, M_\odot$
- NS mass $\sim 1.6\, M_\odot$
- Mass ejected $\sim 18.4\, M_\odot$
  - in H $9.0\, M_\odot$
  - He $7.0\, M_\odot$
  - Z $2.4\, M_\odot$

$\Rightarrow X = \frac{9}{18.4} = 0.49$
$Y = \frac{7}{18.4} = 0.38$
$Z = \frac{2.4}{18.4} = 0.13$