Astrophysics I: Stars and Stellar Evolution AST 4001

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Stars and Stellar Evolution, Fall 2008

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Supernovae

Overview



2 Stellar Fates Summary

- Remnants as a Function of Mass
- Supernovae as a Function of Mass and Metallicity
- Remnants as a Function of Mass and Metallicity

3 Binary Stars

- Binary Types
- The Roche Model
- Interacting Binaries

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Supernovae

SN 1987A



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Supernova Energetics

- \bullet Core collapse Supernovae (neutron star Type Ib/c, II)
 - $\bullet~\sim 3{\times}10^{53}\,\text{erg}$ in neutrinos
 - $\sim 10^{51}\,\mathrm{erg}$ in mechanical (kinetic) energy
 - $\sim 10^{49}\, \text{erg}$ in (visible) photons
 - $\bullet~\sim 0.1\,M_\odot{}^{56}\text{Ni}$
- Type la supernovae (thermonuclear)
 - $\bullet~\sim 10^{51}\, erg$ in mechanical (kinetic) energy
 - $\sim (2-3){\times}10^{49}\,\text{erg}$ in (visible) photons
 - $\bullet~\sim 0.5\,M_\odot{}^{56}\text{Ni}$

origin of 56 Fe in the sun:

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$$\sim \frac{1}{3}$$
 from core collapse supernovae

• $\sim \frac{2}{3}$ from Type Ia supernovae

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Recap Stellar Fates Summary Binary Stars Remnants as a Fu Remnants as a Fu

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Remnants as a Function of Mass

Supernovae as a Function of Mass and Metallicity Remnants as a Function of Mass and Metallicity

Stellar Mass Ranges - Solar Metallicity



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Remnants as a Function of Mass

Supernovae as a Function of Mass and Metallicity Remnants as a Function of Mass and Metallicity

Lifetimes of Low-Mass Stars



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Remnants as a Function of Mass Supernovae as a Function of Mass and Metallicit Remnants as a Function of Mass and Metallicity

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White Dwarf Initial-Final Mass Function



Remnants as a Function of Mass

Supernovae as a Function of Mass and Metallicity Remnants as a Function of Mass and Metallicity

Stellar Mass Ranges - Population III Stars



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Remnants as a Function of Mass Supernovae as a Function of Mass and Metallicity Remnants as a Function of Mass and Metallicity

Supernovae - Mass and Metallicity



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Remnants - Mass and Metallicity



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Binary Types The Roche Model Interacting Binaries

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Binary Types The Roche Model Interacting Binaries

Binary Stars ('Binaries')



Binary Types The Roche Model Interacting Binaries

Binary Stars

about half of all massive stars are in binaries

close binary: interaction in lifetime of star wide binary: no interaction

Observationally: •spectroscopic binaries •eclipsing binaries •resolved binaries

Binary Types

Binary Types The Roche Model Interacting Binaries

Roche Model

$$\phi(x,y,z) = -\frac{GM_{1}}{|\vec{r}_{1}|} - \frac{GM_{2}}{|\vec{r}_{2}|} - \frac{1}{2} |\vec{S}|^{2} \omega^{2}$$

$$centrifugal potential$$

$$|\vec{r}_{1}| = (x^{2} + y^{2} + z^{2})^{1/2} , \quad |\vec{r}_{2}| = ((A - x)^{2} + y^{2} + z^{2})^{1/2}$$

$$|\vec{S}| = ((x - x_{5})^{2} + y^{2})^{1/2} = \left[\left(x - \frac{M_{2}}{M_{1} + M_{2}} A \right)^{2} + y^{2} \right]^{1/2}$$

$$\omega^{2} = \frac{G(M_{1} + M_{2})}{A^{3}} : \quad 3^{rd} \text{ Kepler's Law}$$

$$Introduce dimensionless variables: \quad \xi = \frac{x}{A} ; \quad \gamma = \frac{y}{A} ; \quad \xi = \frac{z}{A} ; \quad q = \frac{M_{1}}{M_{2}}$$

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Roche Potential



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Lagrange Points



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Five Lagrange points:

L1, L2, L3: unstable

L4,L5: stable

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Binary Types The Roche Model Interacting Binaries

Contact Binaries



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Binary Mass Transfer

Stability of mass transfer depends on reaction of donor and receiving star



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Binary Types The Roche Model Interacting Binaries

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Compact Binary Types

Star + compact remnant + Roche-Lobe overflow: X-ray binaries

WD + companion: Novae, Dwarf Novae, Type la supernovae

NS + companion: X-ray bursts, millisecond pulsars, ...

NS+NS: Binary pulsars

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Binary Pulsar Production



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Binary Types The Roche Model Interacting Binaries

Supernovae from Binaries

Binaries

	initial mass	tial mass binary mass transfer			cingle stor
	M₀	Case A	Case B	Case C	single star
	~813	WD	WD	SN lb, NS	SN IIp, <mark>NS</mark>
	~1316	WD	SN lb/c, <mark>NS</mark>	SN Ib, NS	SN IIp, <mark>NS</mark>
	~1625	SN Ic, NS	SN Ib, NS	SN Ib, NS	SN llp, <mark>NS</mark>
	~2535	SN Ic, NS	SN Ic, NS	SN Ib, BH	SN IIL, BH
	>35	SN Ic, NS/BH	SN Ic, NS/BH	SN Ib, NS/BH	SN Ic, NS/BH
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