The Effects of Binary Stars on AGB Nucleosynthesis

in particular the consequence for the Progenitors of Type Ia Supernovae

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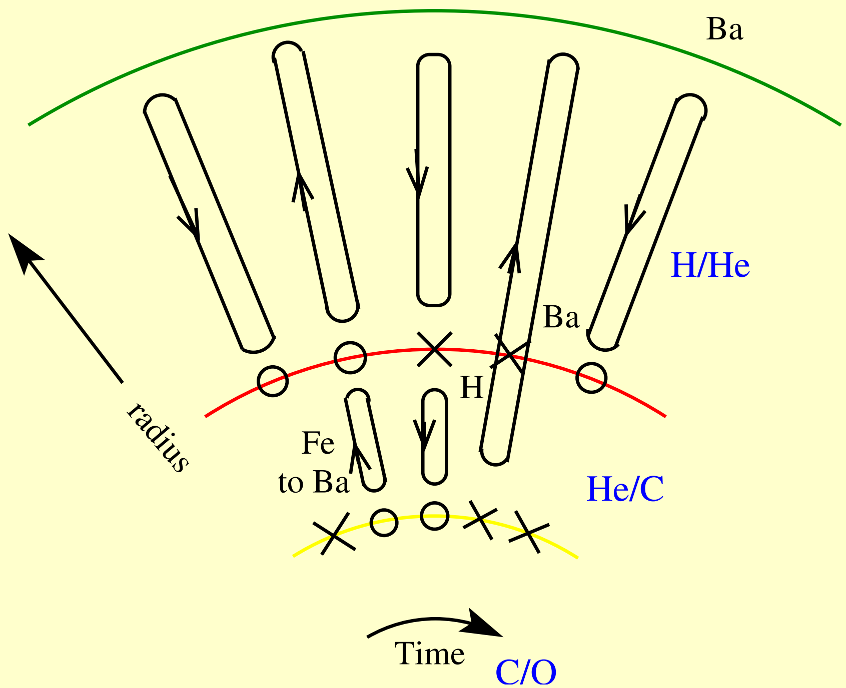
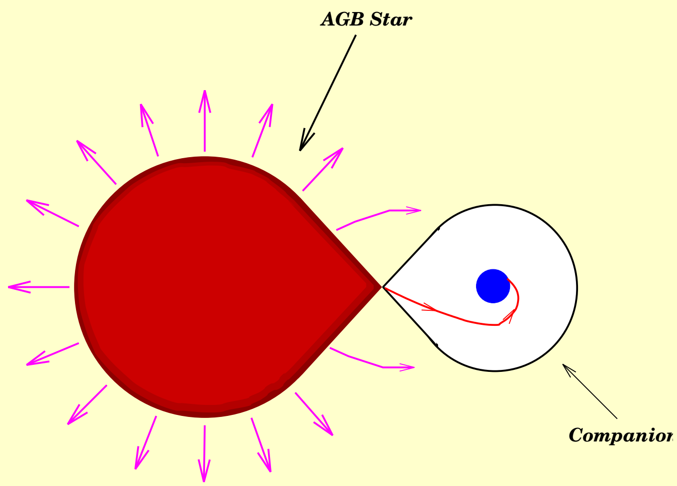


Roche Lobe Overflow



Stars expand more on the AGB than earlier

They also have dense but slow winds that can be captured

The effect is to truncate the TPAGB

– yields of C down 10% and N down 20% – Izzard et al.

Makes Interesting White Dwarfs

Other Effects

Stars are tidally spun up

– enhanced magnetic dynamos

– enhanced mass loss

– companion reinforced attrition process Tout & Eggleton

– S-type symbiotic stars

Rotation surely affects extra mixing – how?

For supernovae we are interested in what gets into the core

SN 1994D in NGC 4562

Supernovae Type Ia

Brightest Objects in Normal Galaxies

$M_{\mathrm{B}} \approx -19.5\,\mathrm{mag}$ about $5 \times 10^{9}\, L_{\odot}$

Remarkable Standard Candles Baade 1938

$\Delta M_{\mathrm{B}} \approx \pm 0.5\,\mathrm{mag}$ or $\pm\, 60\%$ in L

Cosmology Projects

A correlation between peak L and light curve shape
reduces M_{B} to $\pm 0.15\,\mathrm{mag}$ or 15% in L Phillips

Perlmutter *et al.* and Riess *et al.*

The Universe is accelerating – Ω_Λ

at $z = 1$ SNe Ia are 30% fainter than if $\Omega_\Lambda = 0$

(a factor of 2 fainter if $\Omega_M = 1$, $\Omega_\Lambda = 0$)

Nucleosynthesis

SNe Ia are a major source of Fe – Fe is lost in neutron stars

Binary Star Evolution

Progenitor evolution is convoluted

Type Ia – thermonuclear explosions of CO white dwarfs

Available nuclear energy can exceed the WD binding energy

most reaches nuclear statistical equilibrium

and about $0.8\,M_\odot$ of ^{56}Ni is expelled

$^{56}\mathrm{Ni} \rightarrow {}^{56}\mathrm{Co} \rightarrow {}^{56}\mathrm{Fe}$ observed

Energy – $1\,M_\odot$ of 20% ^{12}C + 80% $^{16}\mathrm{O} \rightarrow {}^{56}$Fe releases 1.8×10^{44} J

Decay of $1\,M_\odot$ of $^{56}\mathrm{Ni} \rightarrow {}^{56}$ Fe releases 2×10^{43} J of this

enough for 80 days at $5 \times 10^{9}\,L_\odot$

CO white dwarfs are the cores of AGB stars

In standard models these accrete by
Roche lobe overflow from a companion

– current standard is an evolved MS/HG star with a limited accretion rate

– problems with hydrogen

– another CO white dwarf

– but must be very low mass

– or have a limited accretion rate

Why does the Peak Luminosity vary?

It depends directly on the mass of ^{56}Ni ejected

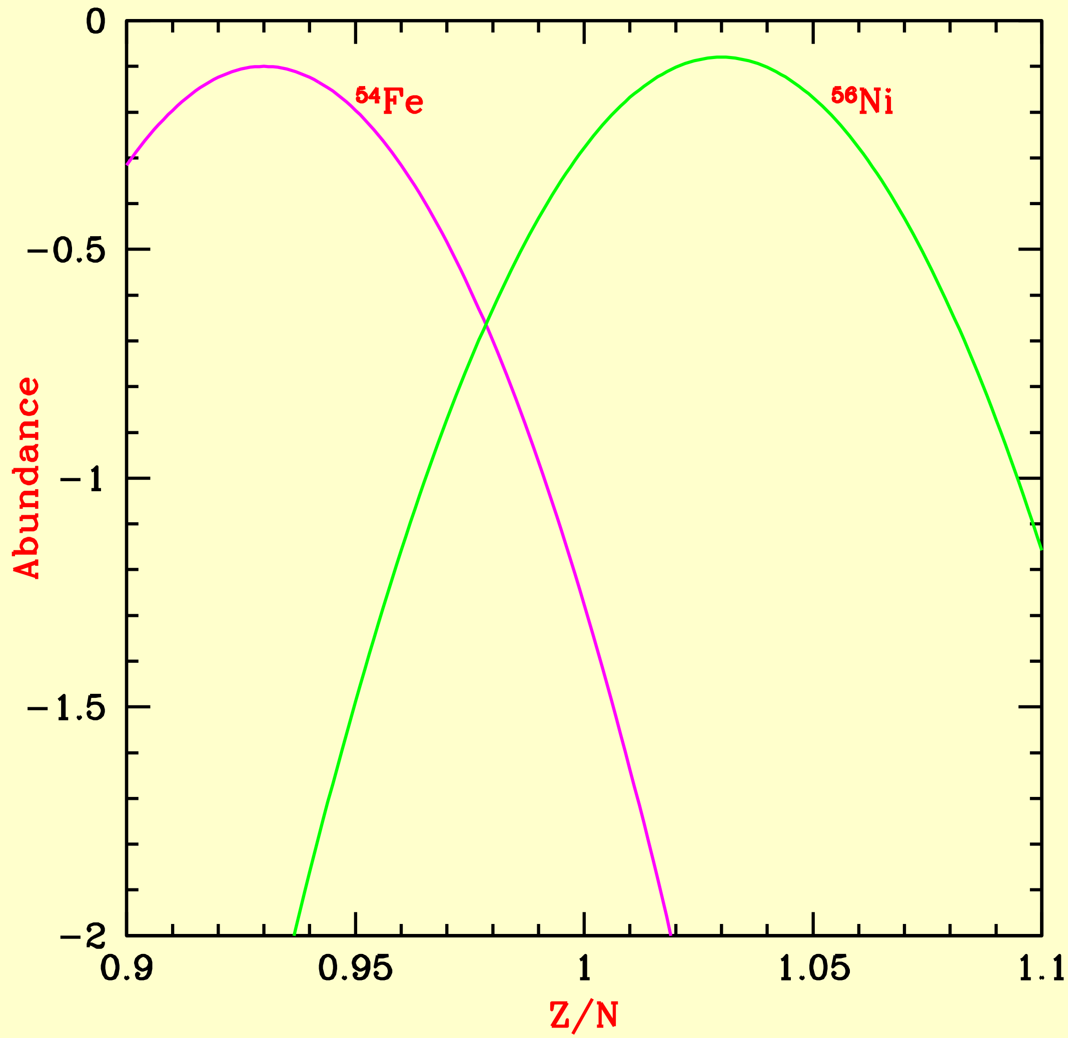
Current explosion models at $1.38\,M_\odot$ show that typically the inner $0.2\,M_\odot$ to $0.8\,M_\odot$ of CO material burns to nuclear statistical equilibrium in a deflagration that ends at ρ_{DD} which is independent of composition.

In the inner $0.2\,M_\odot$ weak interactions are important

Outside $0.8\,M_\odot$ there is incomplete burning $\longrightarrow$ Si

So the mass of ^{56}Ni depends mainly on the ratio of protons to neutrons $\frac{Z}{N}$ (or $Y_{\mathrm{e}} = \frac{Z}{A}$)

Nuclear Statistical Equilibrium



Neutron-Rich Material

Dominated by ^{23}Na from C burning

and ^{22}Ne from α-processed CNO

Variation in CNO for $\frac{1}{3} < \frac{Z}{Z_\odot} < 3$ can account for the variations in peak luminosity – Timmes, Brown & Truran 2003

Note high $z \Longrightarrow$ low $Z \Longrightarrow$ brighter SNe

TPAGB stars produce primary ^{22}Ne

Stancliffe & Tout 2006

The Phillips Relation

Brighter SNe Ia have broader slower light curves

So the light curve shape depends on ^{56}Ni too?

$$\tau_{\rm LC} \propto \kappa_{\rm opt}^{1/2} M_{\rm ej}^{3/4} E_{\rm k}^{-1/4} \qquad \text{Arnett}$$

$\kappa_{\rm opt}$ is the optical opacity of the ejecta – iron group isotopes – probably constant

$M_{\rm ej}$ is the ejected mass – constant in standard models

$E_{\rm k}$ is the ejection energy – increases with C/O ratio

But C/O ratios are larger in low-Z progenitors!

And the Correlation is in the wrong direction!

We must Understand the Progenitors first

AGB Evolution and WD Composition

Depending on dredge-up efficiency the core may grow $0.1 - 0.3\,M_{\odot}$ on the AGB

Hydrogen burning followed by helium burning creates neutron rich ^{22}Ne from primary ^{12}C

How many extra neutrons end up in the core?

How does this depend on the binary progenitors?

Conclusions

- Binary interaction truncates AGB evolution – reduces average yields
- Binary interaction creates the white dwarfs that become SNe Ia
- Binary star parameters may lead to significant variations in Z/N that may account for the range in SNe Ia peak luminosities