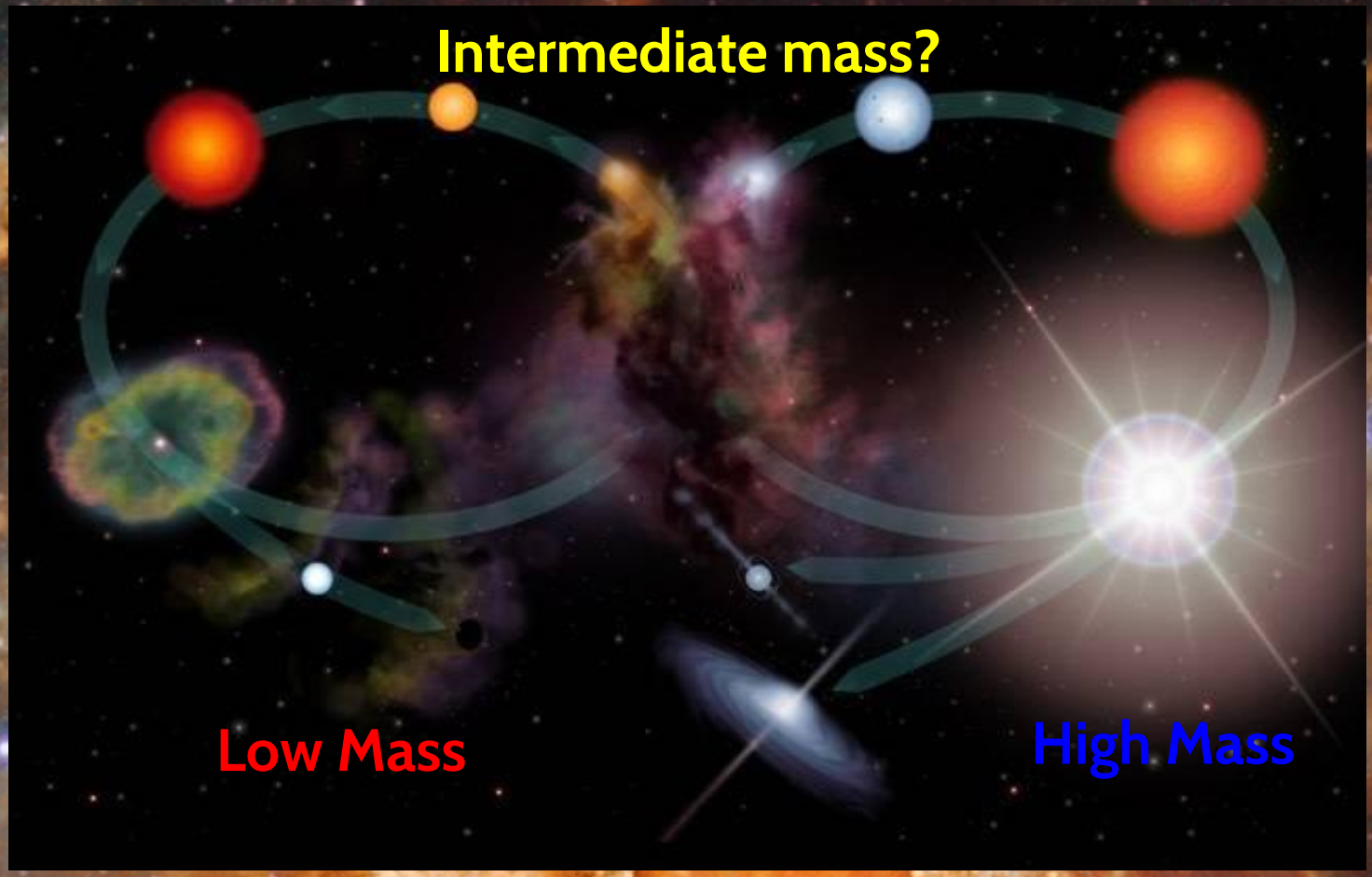


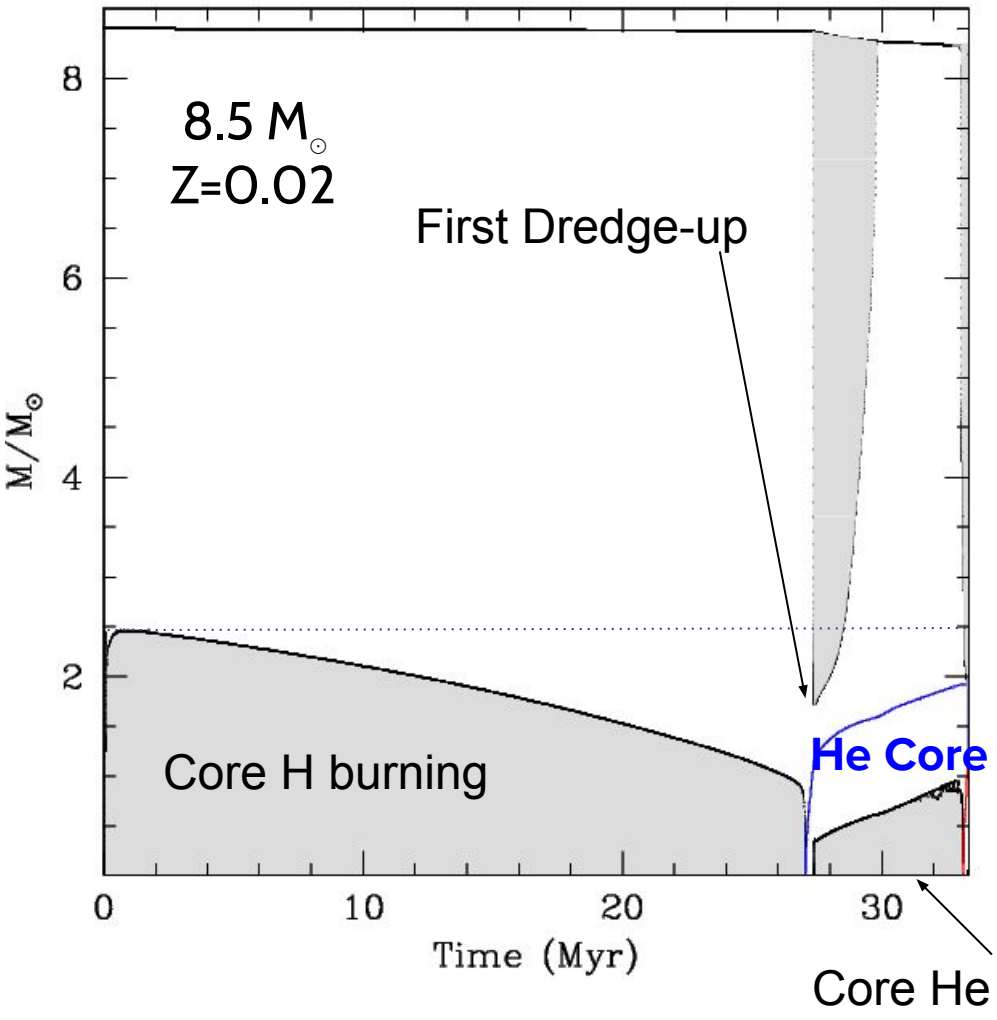
Closing the Divide

Super-AGB stars vs. Red Supergiants

Carolyn Doherty (Budapest)

J.W. den Hartogh (Budapest), P. Gil-Pons (Barcelona),
S.Campbell (Monash), A. Heger (Monash), P. Banerjee (Shanghai)

Evolution of intermediate mass stars 6-12 $M_\odot$



Intermediate & (low mass) massive stars undergo similar early evolution
H burning lifetime ~ 18-40Myrs

First Dredge-up increases surface in ^{4}He and CNO cycled material (^{14}N,^{13}C,^{17}O^{23}Na)

Helium burning
He burning lifetime ~ 2-6Myrs

Second dredge-up (2DU)

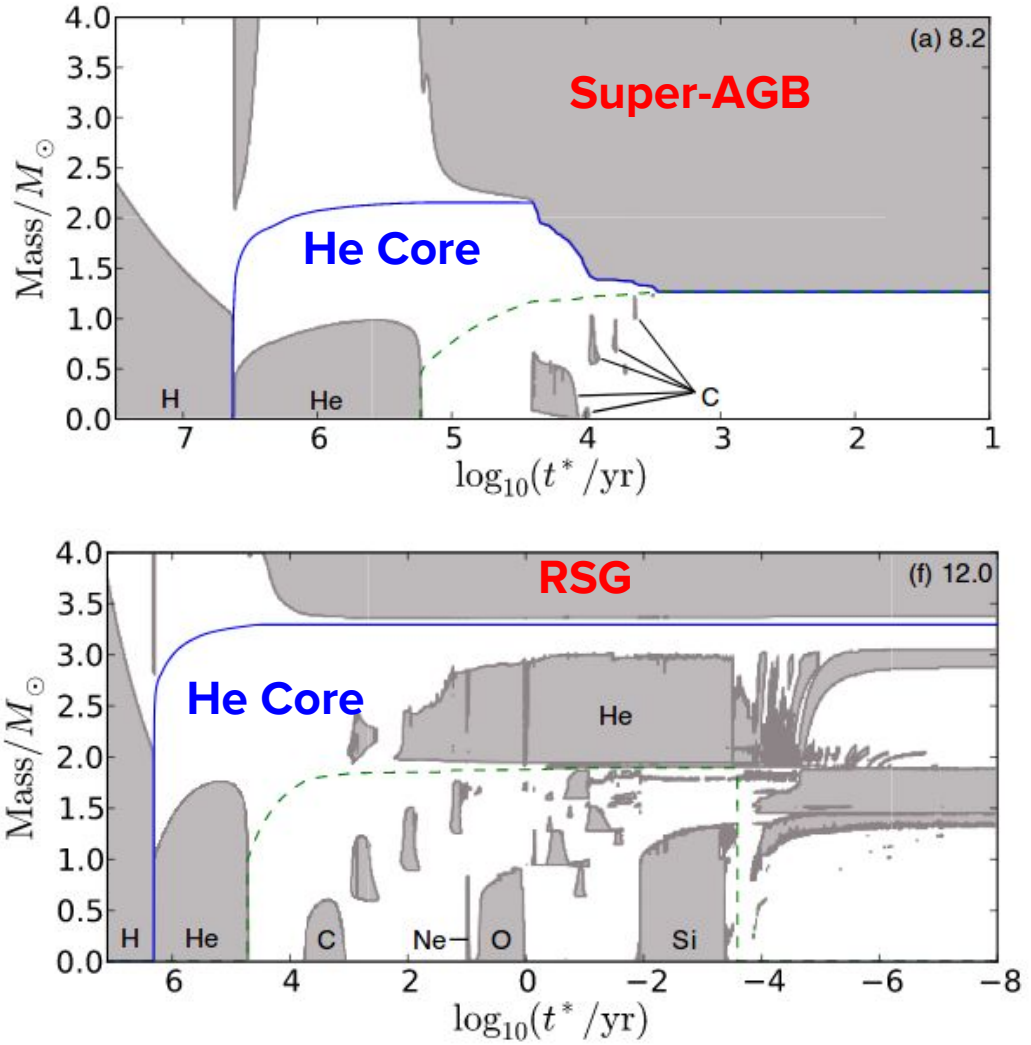
Intermediate/high mass star evolution diverges here

Second dredge-up reduces the core mass below the Chandrasekhar mass

Very large increases in ^{4}He and proton capture nucleosynthesis products

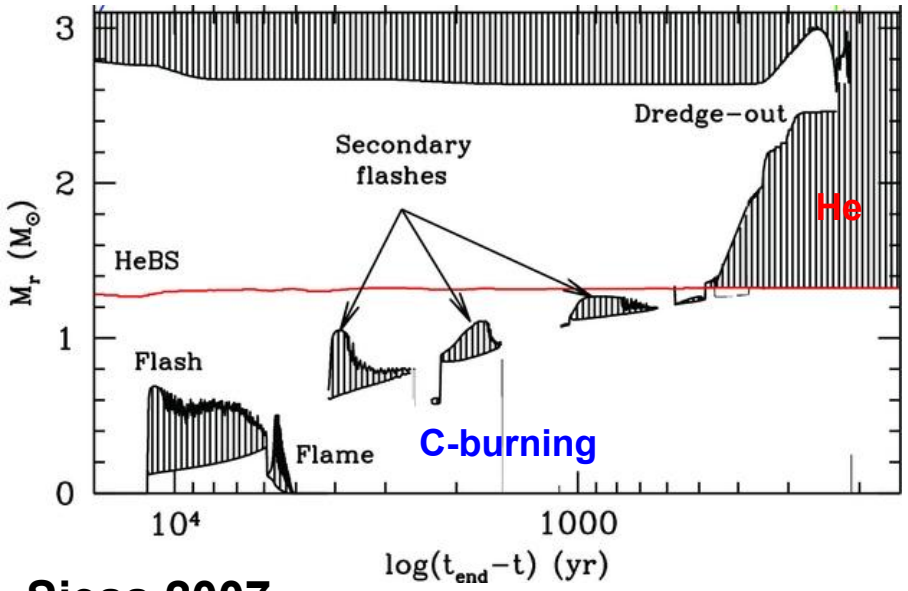
$M_{Core\_super\text{-}AGB} \sim 1.0\text{-}1.4\ M_\odot$

$M_{Core\text{-}RSG} > 2.6 M_\odot$



Jones+2013

Dredge-out event



Siess 2007

Protons are mixed down to high temperature He (and C) regions

H flash from $^{12}C(p,g)^{13}N$

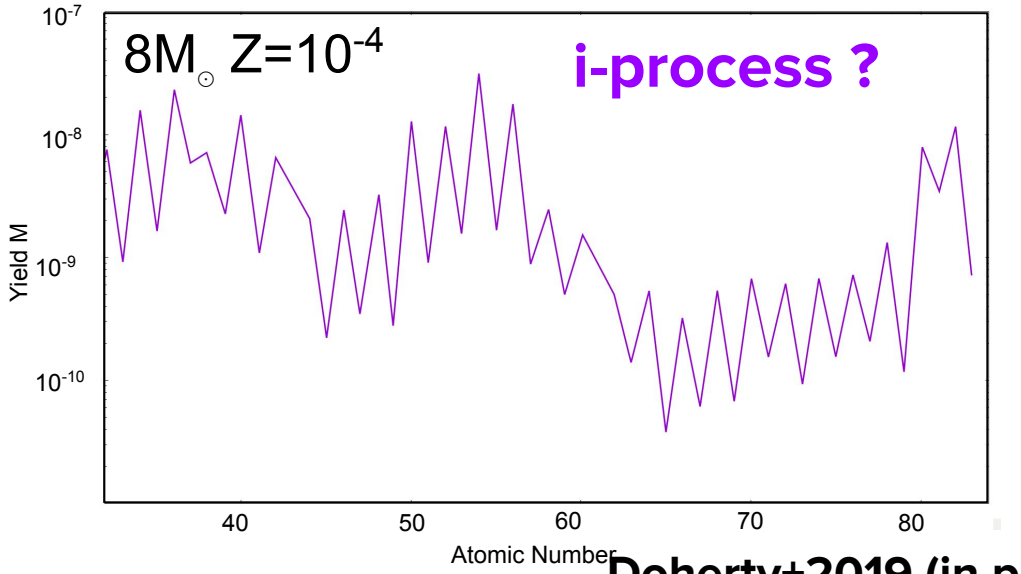
$^{13}N(e^+\nu_e)^{13}C$ decays in 10min

Neutron source

$^{13}C(a,\mathbf{n})^{16}O$

Preliminary calculations with 1000 species network using KEPLER code

Unusual heavy element abundance pattern! Observable?

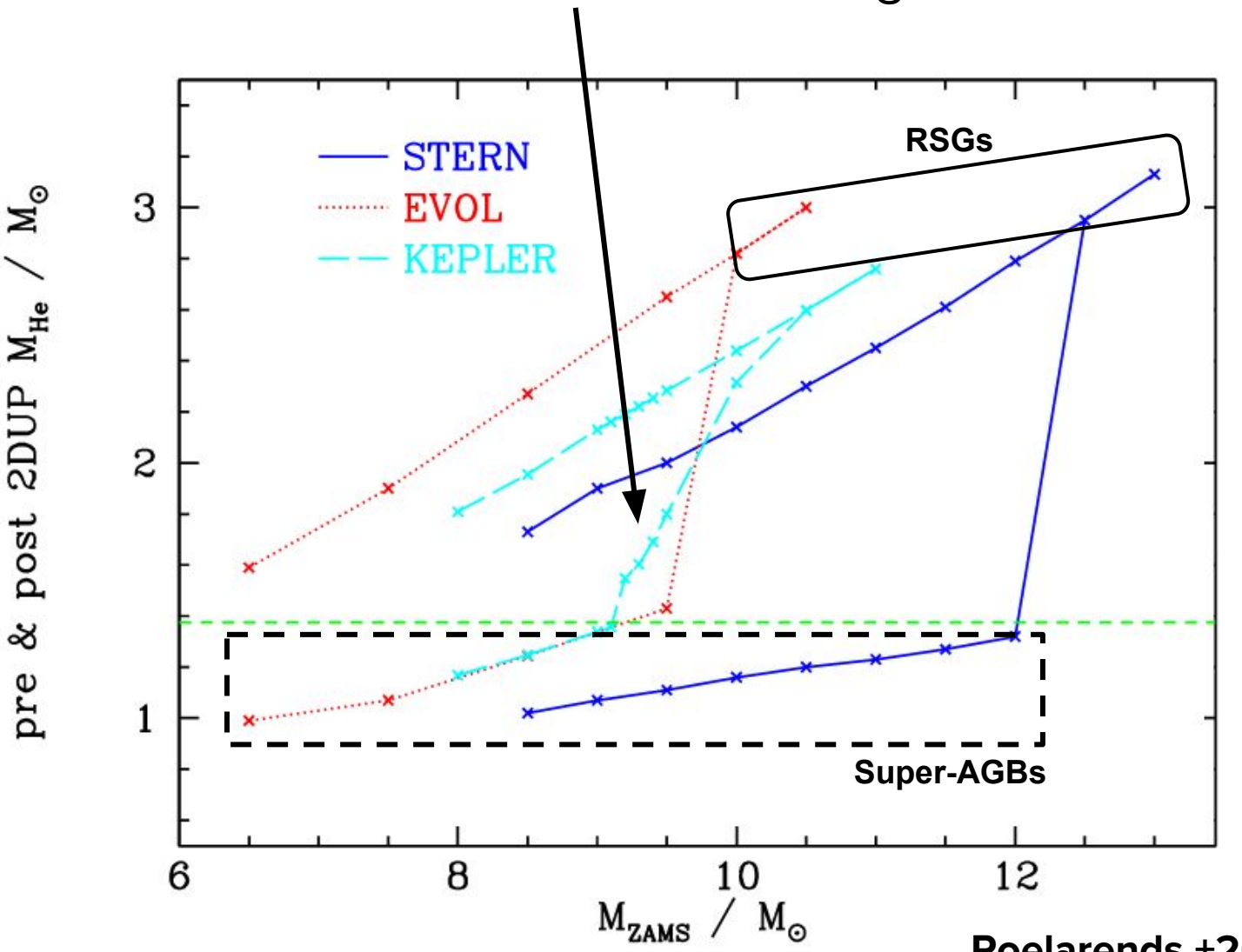


Doherty+2019 (in prep)

Yield at base of He convective zone

Second dredge-up / Dredge-out

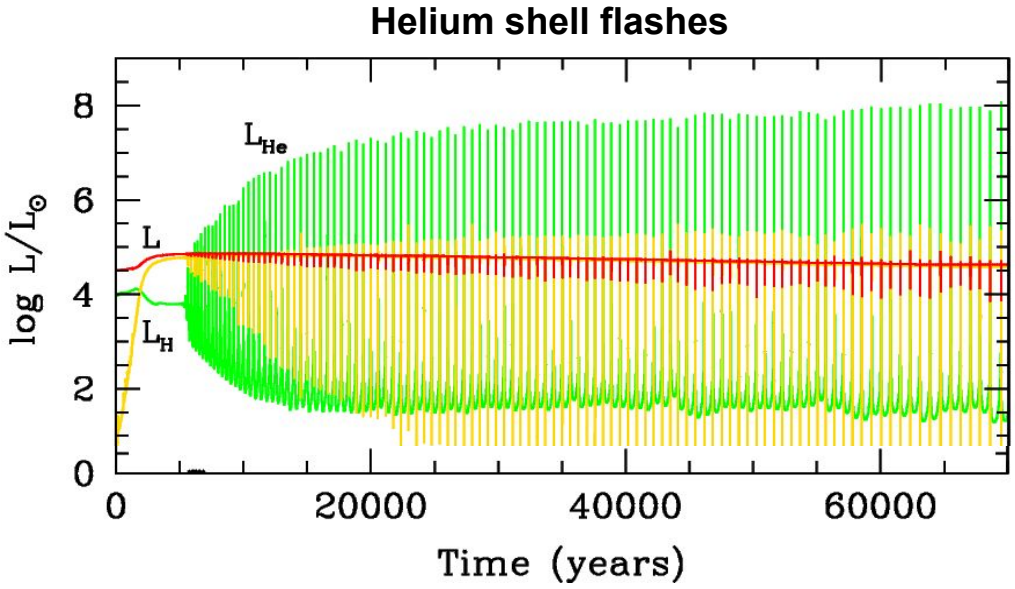
Caveat: Some RSG stars still undergo some 2DU



Poelarends +2008

Super-AGB stars

- ★ M_{ini} ~ 6-12 $M_{\odot}$
- ★ Off-centre carbon ignition
- ★ No further central burning
- ★ ONe core
- ★ 10-1000s of thermal pulses
- ★ Red, cool ~3000-4000K
- ★ Large envelopes ~ 1000 $R_{\odot}$
- ★ Short lived ~ 10^5 yrs
- ★ 10^{-4} - 10^{-5} $M_{\odot}$/yr



Very luminous :

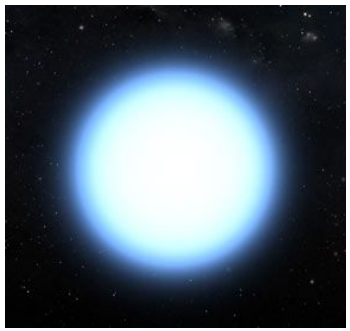
M_{bol} ~ -8.2 (150,000 $L_{\odot}$)

> Paczynski limit of M_{bol} ~ -7.1

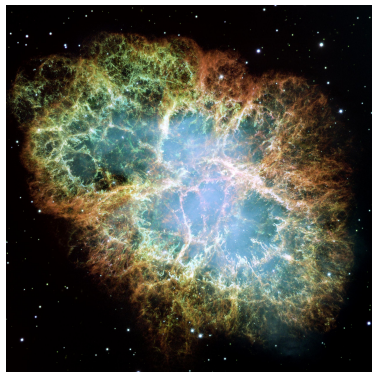
Pioneering works: Garcia-Berro, Iben & Ritossa 1994-1999
Recent review: Doherty, Gil-Pons, Siess & Lattanzio 2017 - PASA

How do super-AGB stars die?

ONe white dwarfs, or as neutron stars* after undergoing an electron capture supernova (EC-SN)?



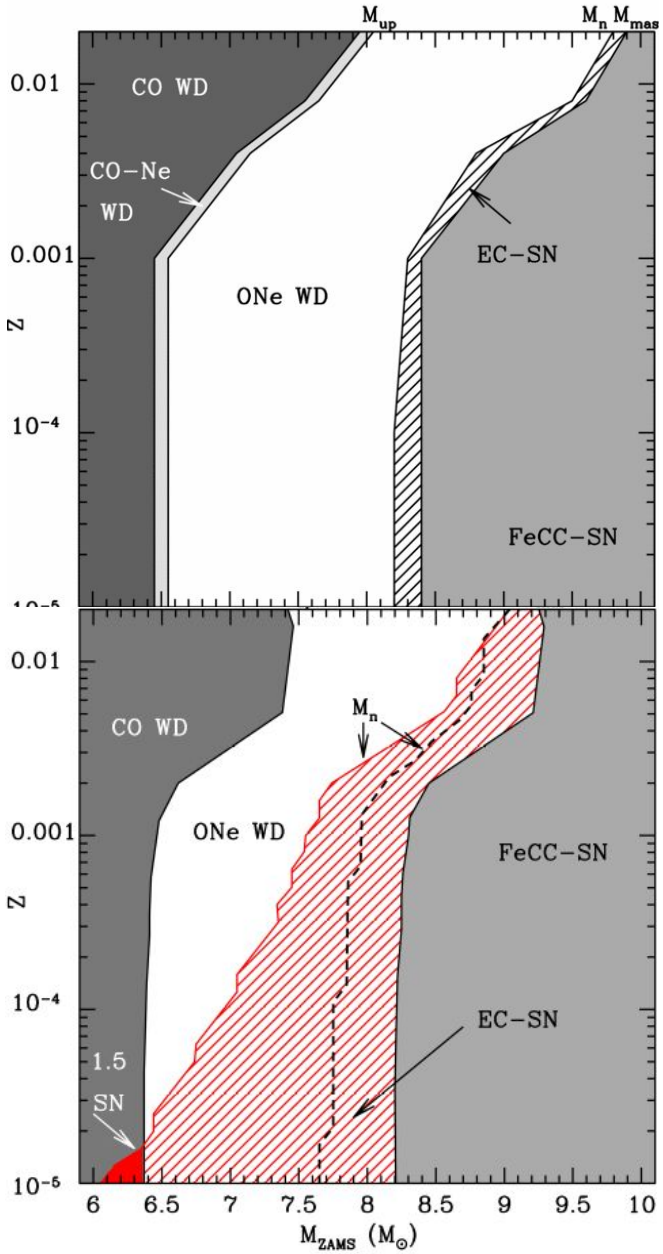
OR



Core growth vs. mass loss determines fate.

If the core reaches $M_{EC} \sim 1.375\ M_{\odot}$ (Nomoto 1987) an EC-SN will occur.

* Debate rages over final fate of an EC-SN either as neutron star or ONeFe remnant (Isern+1991, Canal+1992, Jones+2016)



Doherty+2015 (Top)
Poelarends+2007/8 (Bottom)

No observationally confirmed super-AGB star!

Why haven't we found them?

Liu Bolin
The invisible Man

Are they hiding in plain sight?

Elusive super-AGB stars hiding as?

Massive-AGB stars

$M_{ini} > 5 M_{\odot}$ (CO core)

Red supergiants (RSG)

$M_{ini} > 10\ M_{\odot}$

How to identify a super-AGB star

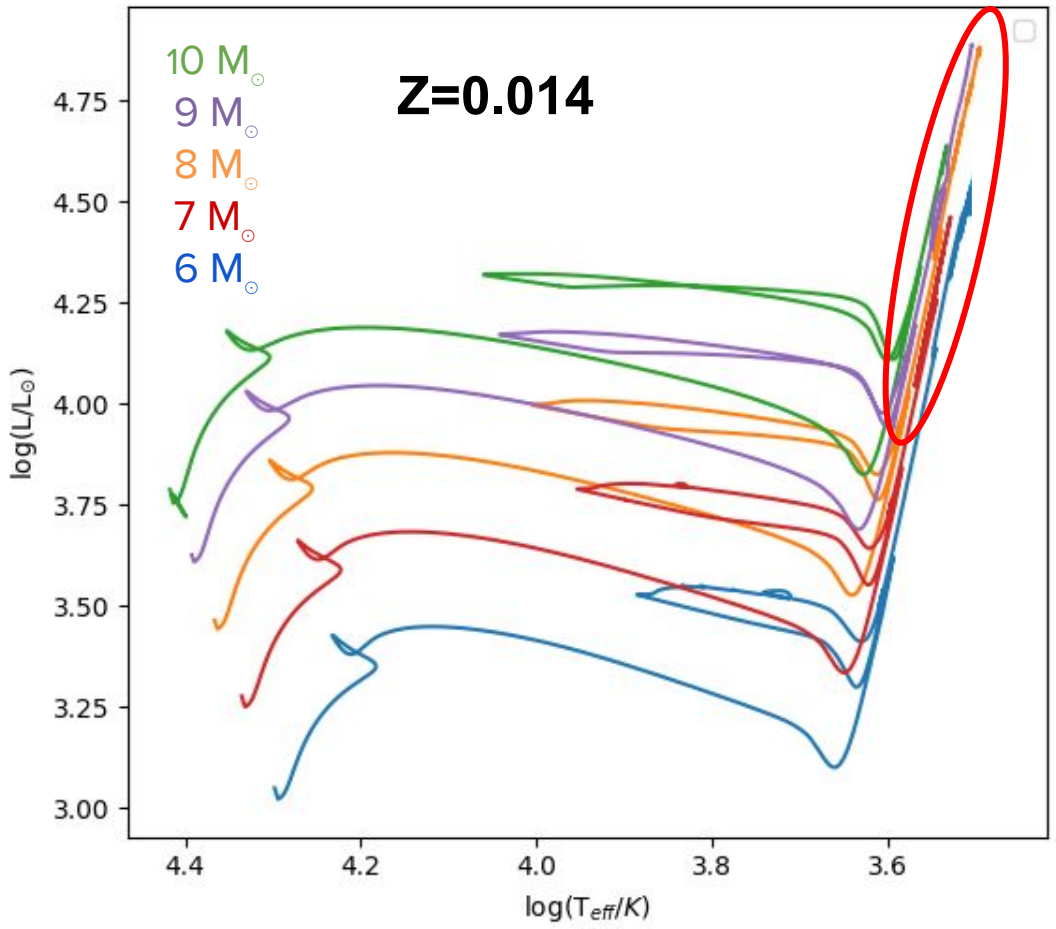
STRUCTURE

NUCLEOSYNTHESIS

STATISTICS

Structure

Massive-AGB star vs. Super-AGB star vs. RSG



All three types of stars have:

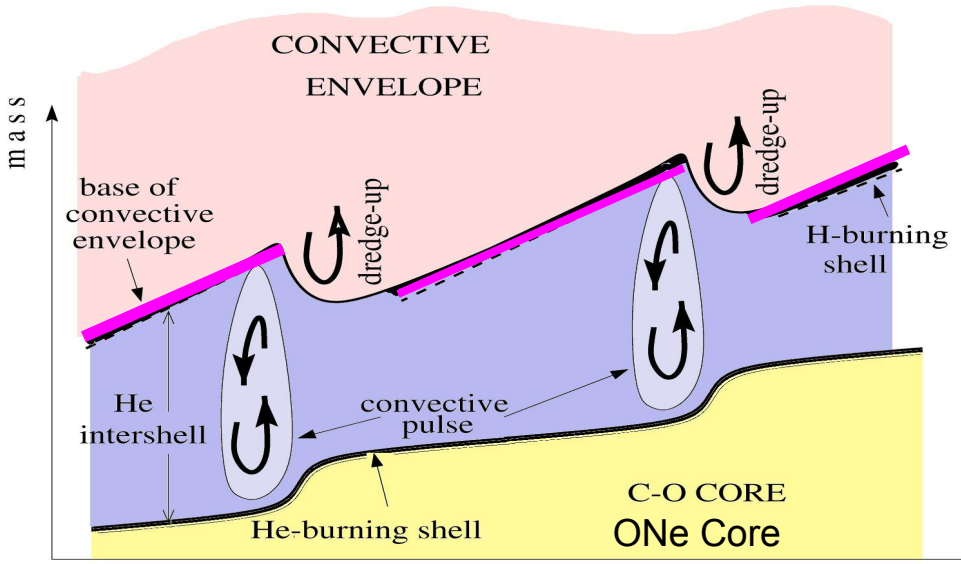
Very similar:

- ★ temperatures
- ★ luminosities
- ★ radii
- ★ log g
- ★ mass loss rate?
- ★ lifetimes

Stellar variability?

Computed using the MESA stellar evolution code (Paxton+2011/13/15/18)

Nucleosynthesis - Thermally Pulsing Phase



Hot bottom burning

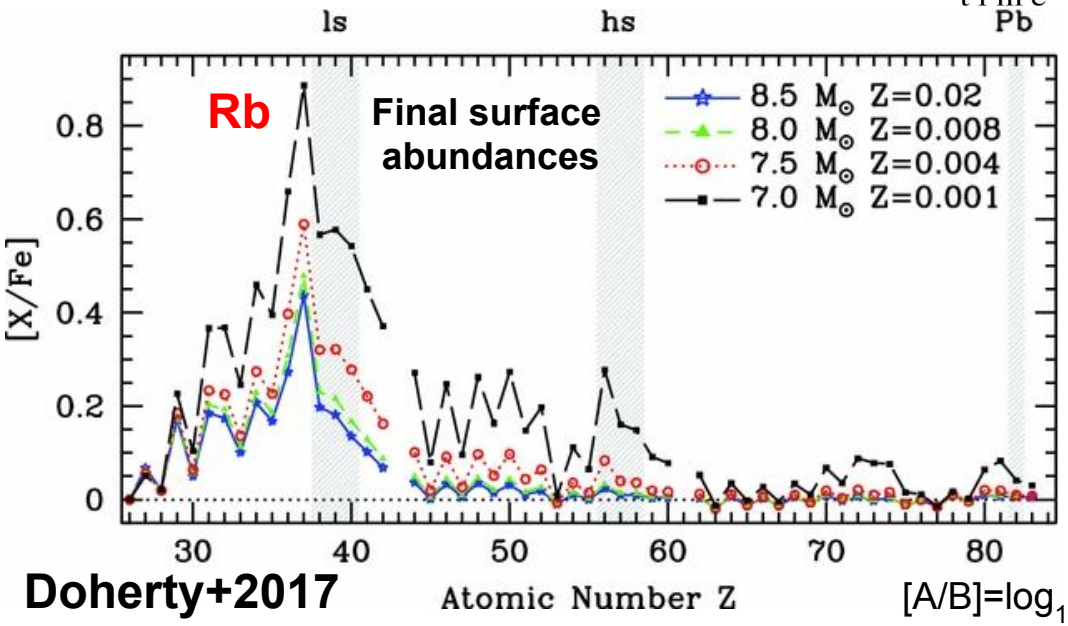
Temperature at base of envelope ~ 80-160MK

CNO, NeNa, Mg-Al cycles +Li+K

^{14}N,^{13}C, ^{23}Na,^{25}Mg,^{26}Al, ^{39}K

Third dredge-up

If third dredge-up occurs surface enriched in C + Rb



Doherty+2017

Rb observations in massive O-rich AGB stars (Garcia-Hernandez+2006/09 Pérez-Mesa+2017)

Same as massive AGB stars...

$[A/B]=\log_{10}(n(A)/n(B))_{*} - \log_{10}(n(A)/n(B))_{\odot}$

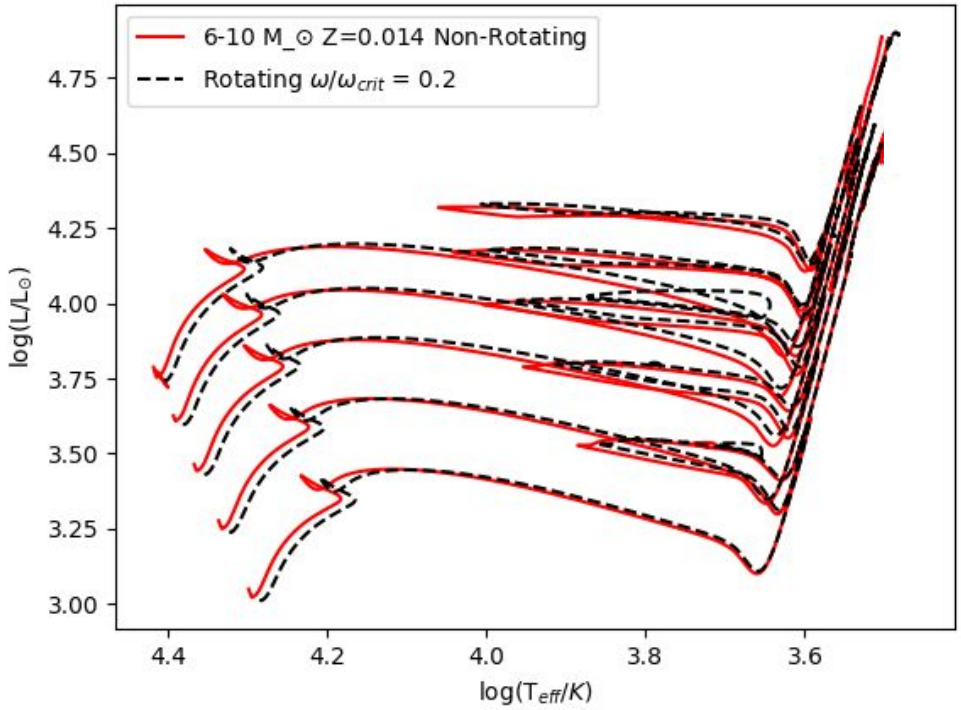
But stars rotate (and very model dependently!)

Will rotation give a structural or nucleosynthetic signature to help finally disentangle super-AGB stars from RSGs?

Many rotating intermediate mass stars up until pre-AGB phase (e.g. Maeder & Meynet 2000; Brott+2011, Lagarde+2012, Ekström+2012, Georgy+2013, Farmer+2015, Choi+2016 +many others)
Unfortunately most grids do not evolve until end of 2DU

None followed the full super-AGB phase including rotation

Computing a grid of super-AGB & RSGs, using MESA and KEPLER stellar evolution programs



A few impacts of rotation on super-AGBs/RSG

May reduce the initial mass of the AGB/SN boundary
ie. rotating stars have larger cores for the same initial mass

Rotation blurs out the impact of second dredge-up
Rotating RSGs will look more similar to super-AGB stars, ie ^{4}He

Rotation increases the metals in the envelope
Leads to lower temperatures at the base of the envelope, less burning and have reduced luminosity on super-AGB phase

At low metallicity, increased metals at surface due to rotation will aid in mass loss. May change the final fates of primordial super-AGB stars - less SN

Summary/Current Work

Super-AGB stars may be (are) hiding in RSG surveys

Rotation blurs out the clear impact of second dredge-up and makes super-AGB stars and RSGs more chemically similar

Super-AGB stars may produce a selection of heavy elements including Rb, or even an “i-process” heavy element pattern

We are computing a range of (non-)rotating super-AGB stars & RSG stars for a range of metallicity. Especially interesting at low Z

Do you have any observed potential super-AGB stars candidates?