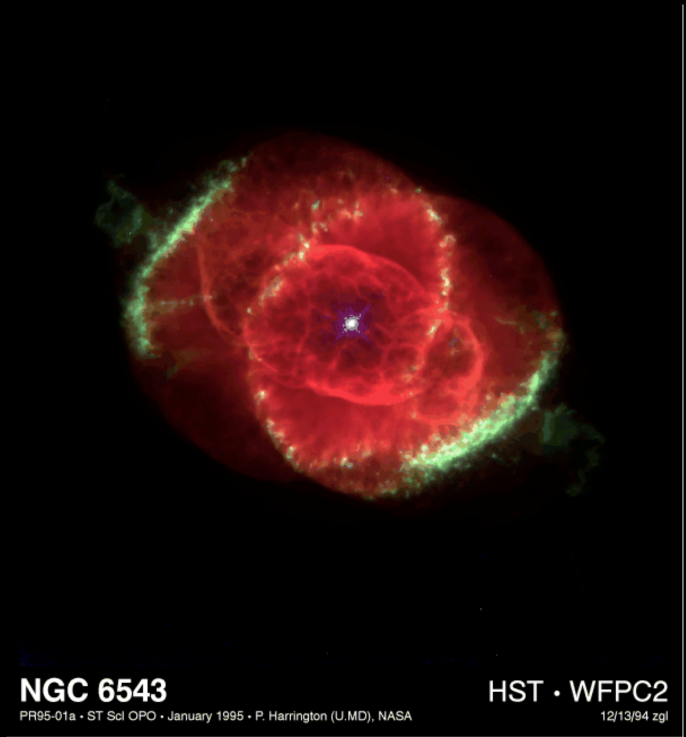
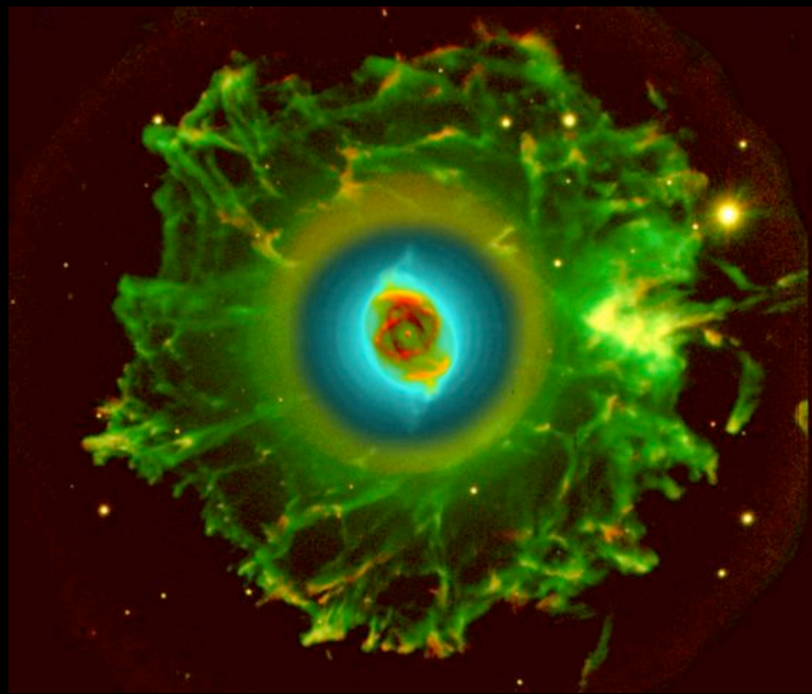
Post-AGB and PN :
Crucial probes of stellar nucleosynthesis





Corinne Charbonnel
Geneva Observatory & CNRS

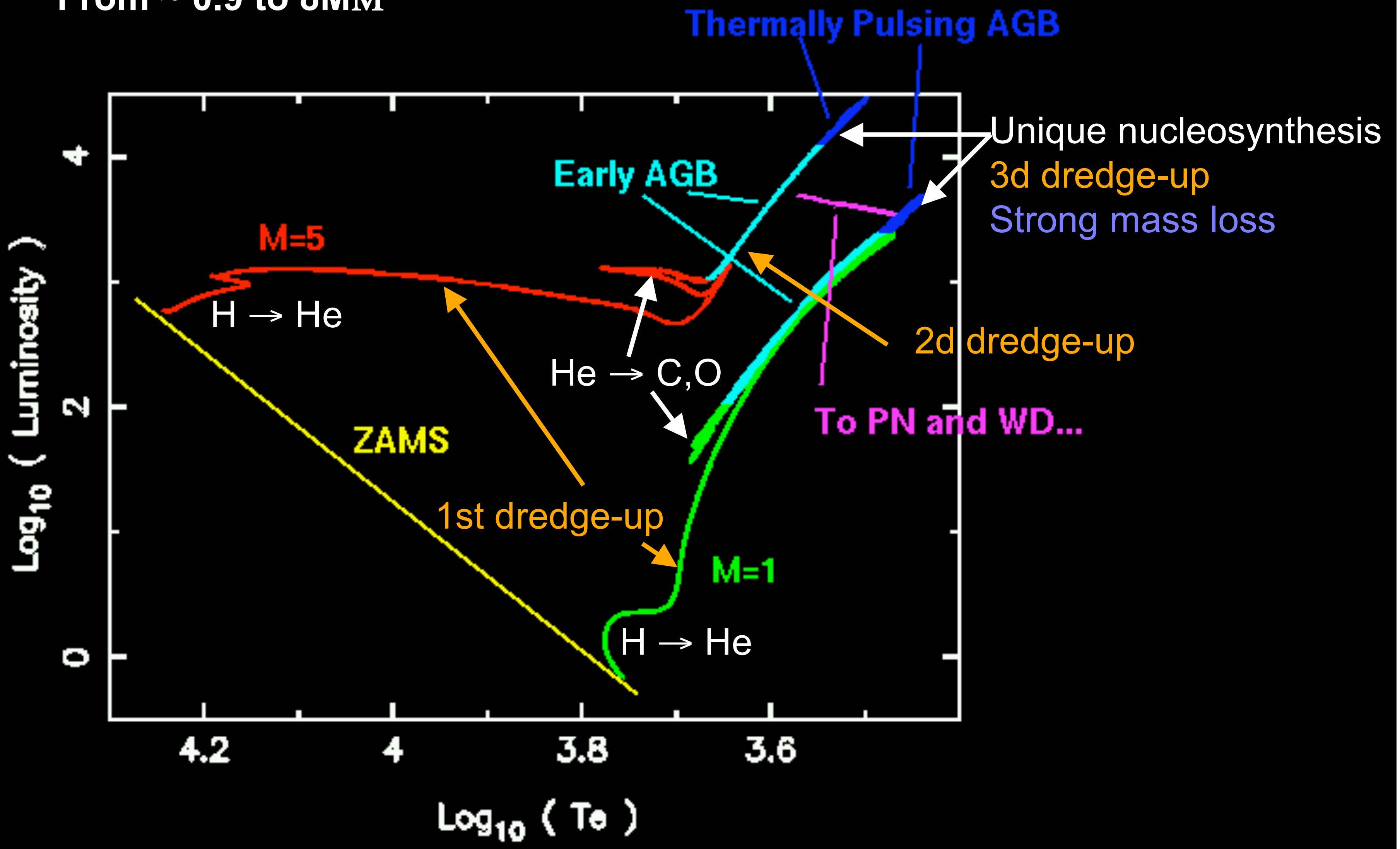
Post-AGB and PN :
Crucial probes of stellar nucleosynthesis

- Nucleosynthesis in low- and intermediate-mass stars :
  A global overview

- The impact of the input physics on the theoretical yields:
  Mass loss, convection, HBB, 3DUP, rotation

- Crucial constraints from PNe and post-AGBs

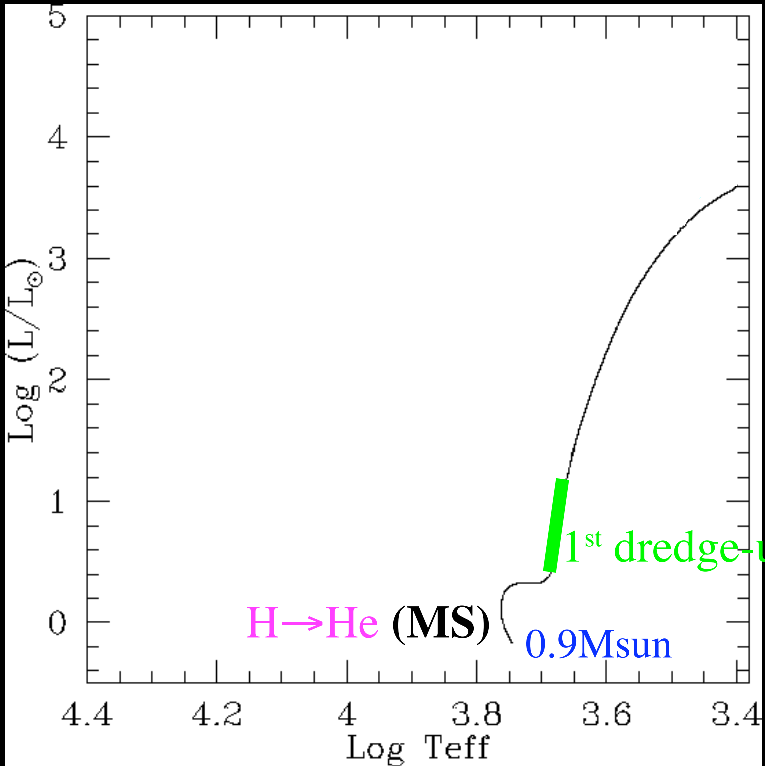
From ~ 0.9 to 8MM

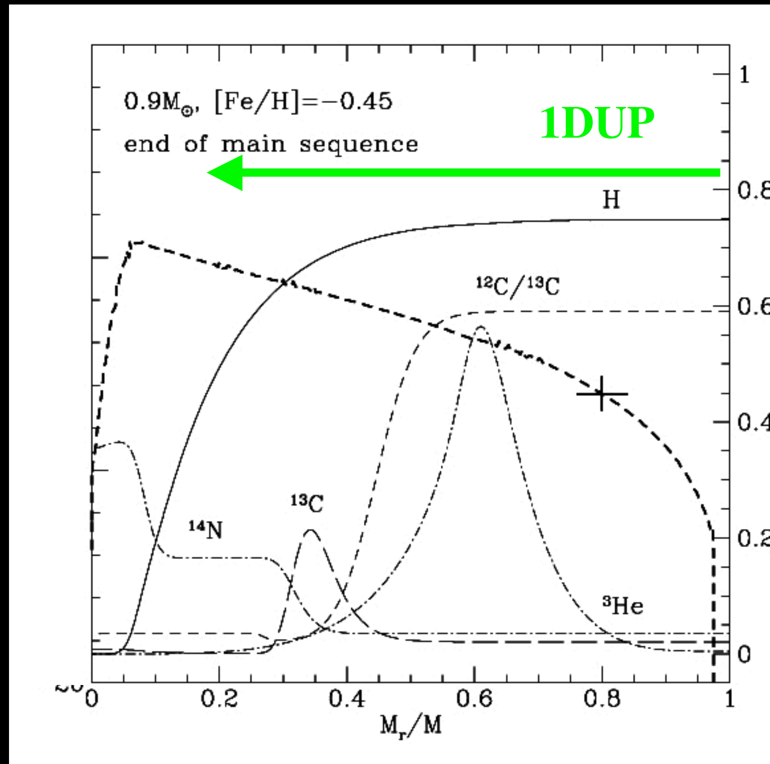


Adapted from Lattanzio

Nucleosynthesis before the TP-AGB

Main sequence and 1st dredge-up : The cases of ^{3}He and ^{12}C/^{13}C



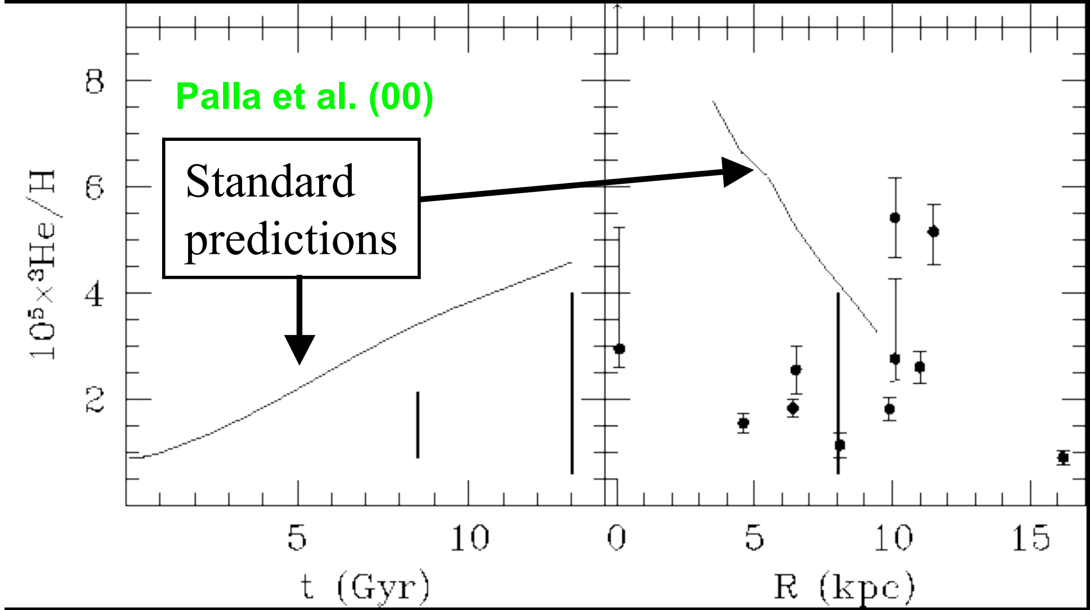


Mass fractions
100 x X(^{3}He, ^{14}N)
1000 x X(^{13}C)
^{12}C/^{13}C / 100

^{3}He ↑, ^{7}Li ↓ (~/25), ^{12}C/^{13}C ↓ (90→ 30, 20), ^{12}C ↓ (~30 %) , ^{14}N ↑ (x 2)

O, heavier elements unchanged

Consequences for the evolution of ^{3}He in the Galaxy ?



Solar neighborhood (PSC & LIC)
Geiss (93)
Gloeckler & Geiss (96)

HII regions
Rood et al. (95)

« The galactic ^{3}He problem »

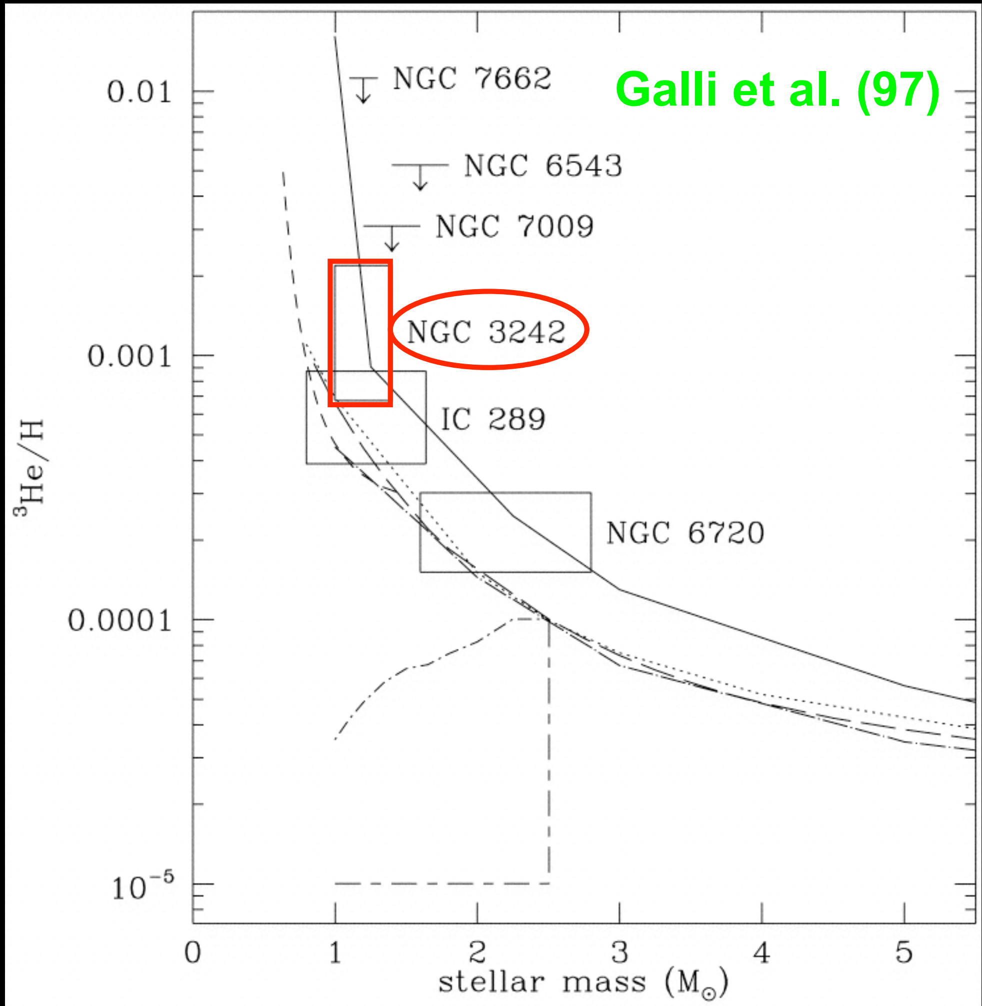
A nuclear solution?

Low energy resonance in the cross section of

$^3He(^3He,2p)^4He$?

Excluded by the LUNA experiment (Gran Sasso)
Junker et al. (98)

Consequences for the evolution of ^{3}He in the Galaxy ?



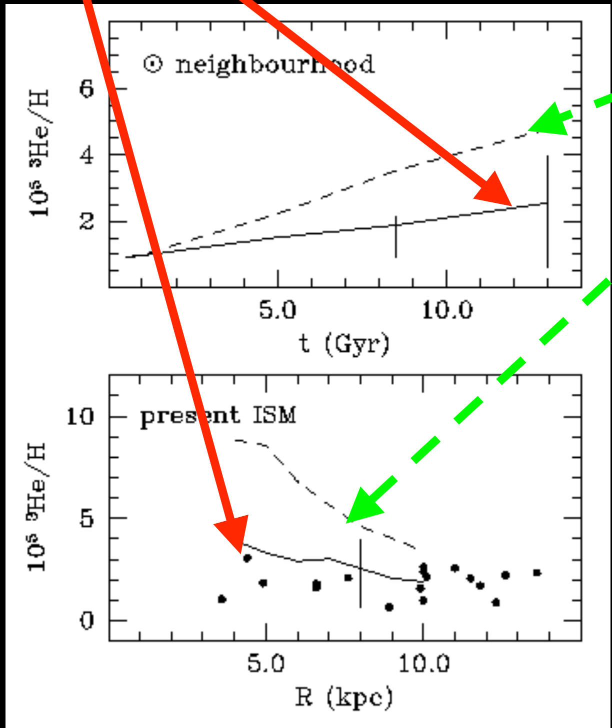
A nuclear solution?

Excluded by the ^{3}He measurement in PNe

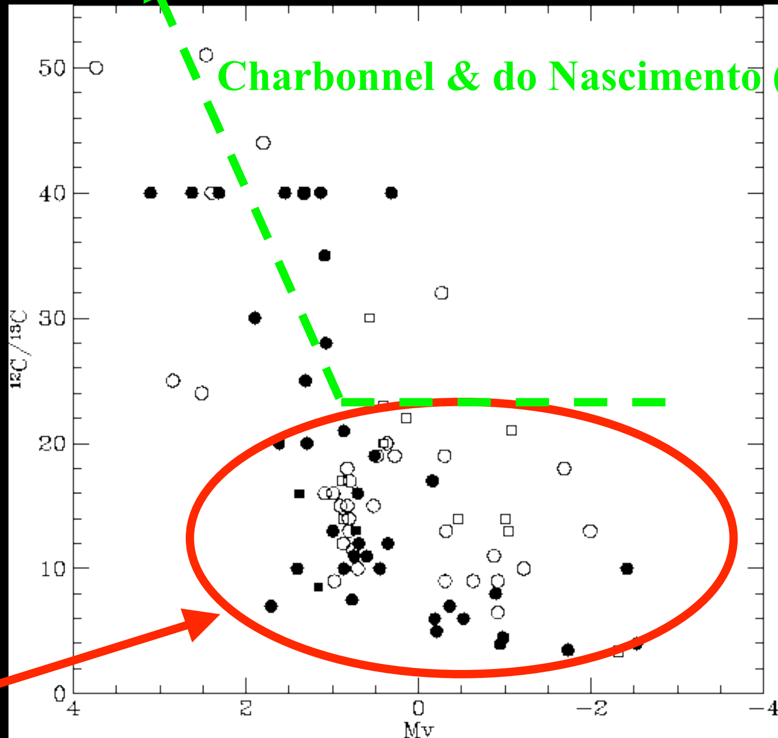
C. Charbonnel. Conference « PN as astrophysical tools », Gdansk, Polland, june 05

> 90% of the low-mass stars must destroy ^{3}He

Standard predictions



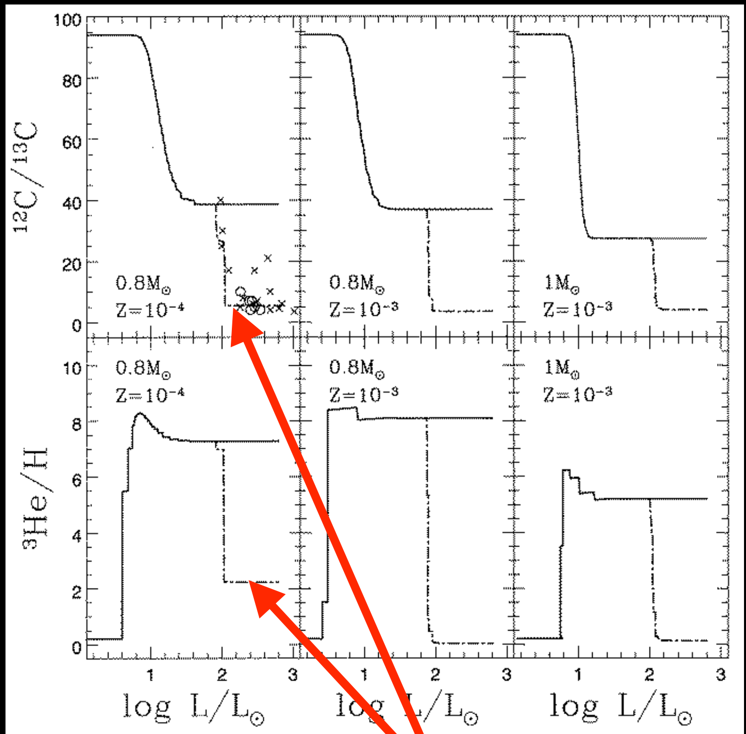
Palla et al. (02)
See also Tosi (98)



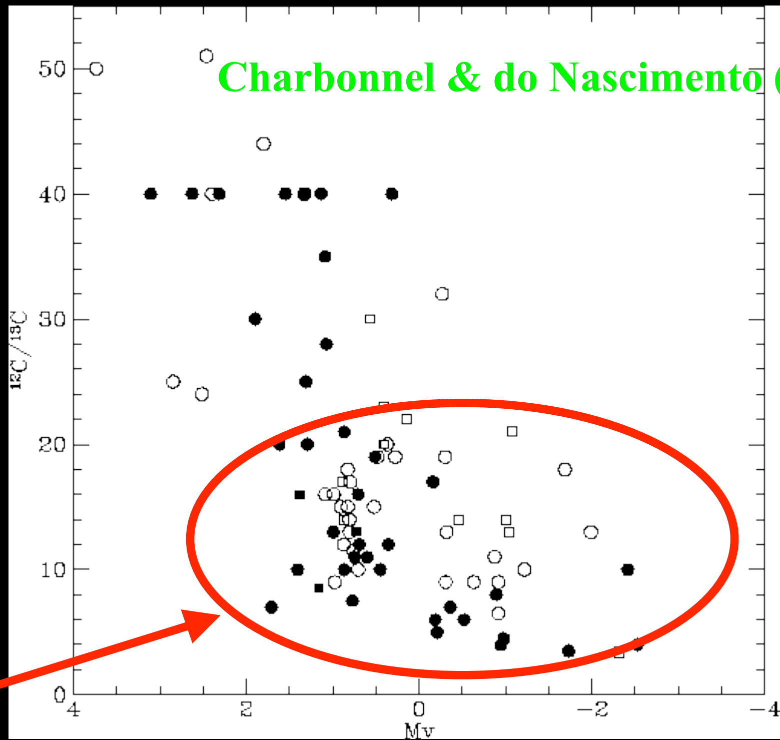
Charbonnel & do Nascimento (98)

> 96% of the low-mass stars further decrease $^{12}C/^{13}C$ (mixing process beyond standard theory)

> 90% of the low-mass stars must destroy ^{3}He



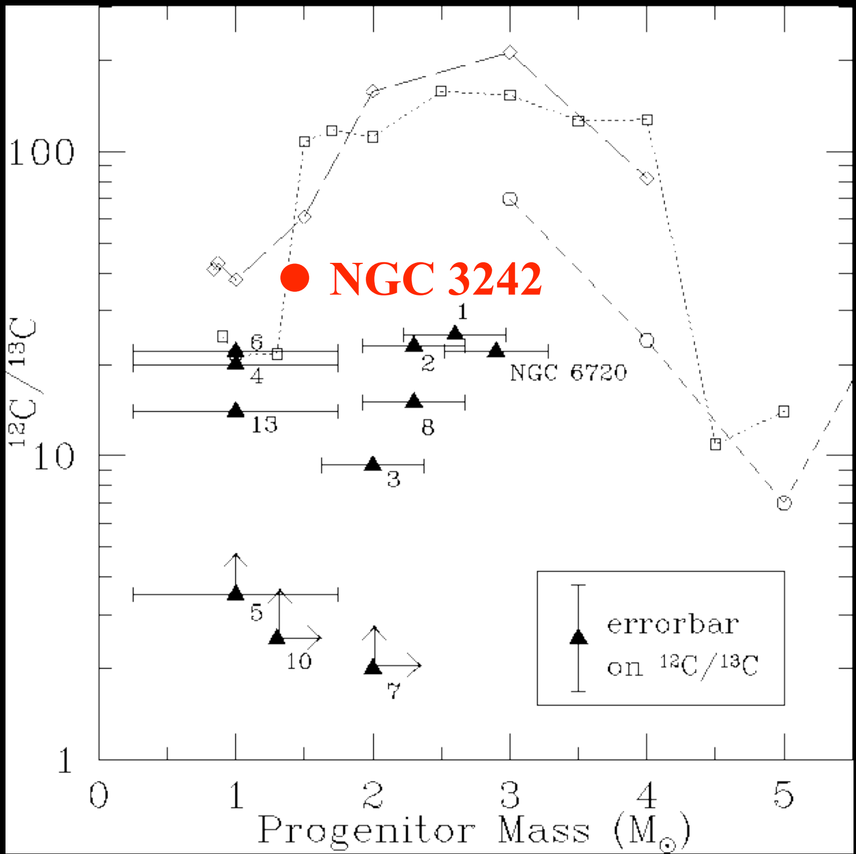
Charbonnel (95)



———	Standard
- - - - - -	Rotation

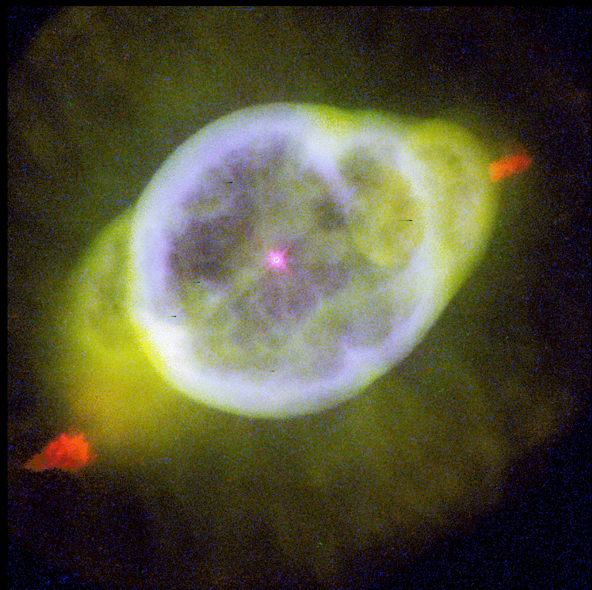
> 96% of the low-mass stars further decrease $^{12}C/^{13}C$ (mixing process beyond standard theory)

$^{12}C/^{13}C$ in PNe



Palla et al. (00)
Palla et al. (02)

Ejecta at the tip of the AGB (ZM) :
Van den Hoek & Groenewegen (97)
Forestini & Charbonnel (97)
Marigo (98)



NGC 3242 belongs to the 4% of LMS which do not destroy ^{3}He nor lower $^{12}C/^{13}C$

Nucleosynthesis on the TP-AGB

C. Charbonnel. Conference « PN as astrophysical tools », Gdansk, Polland, june 05

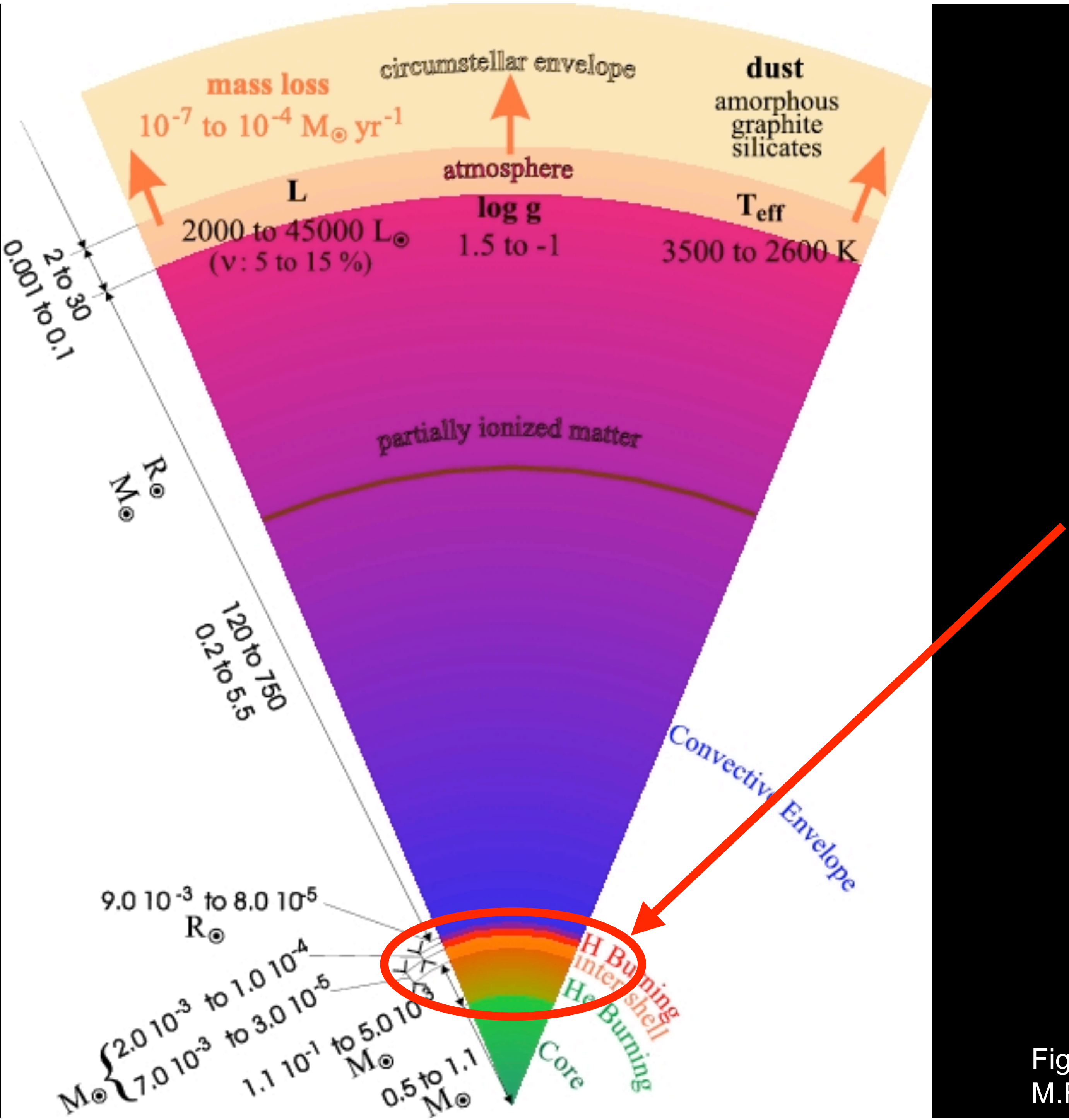
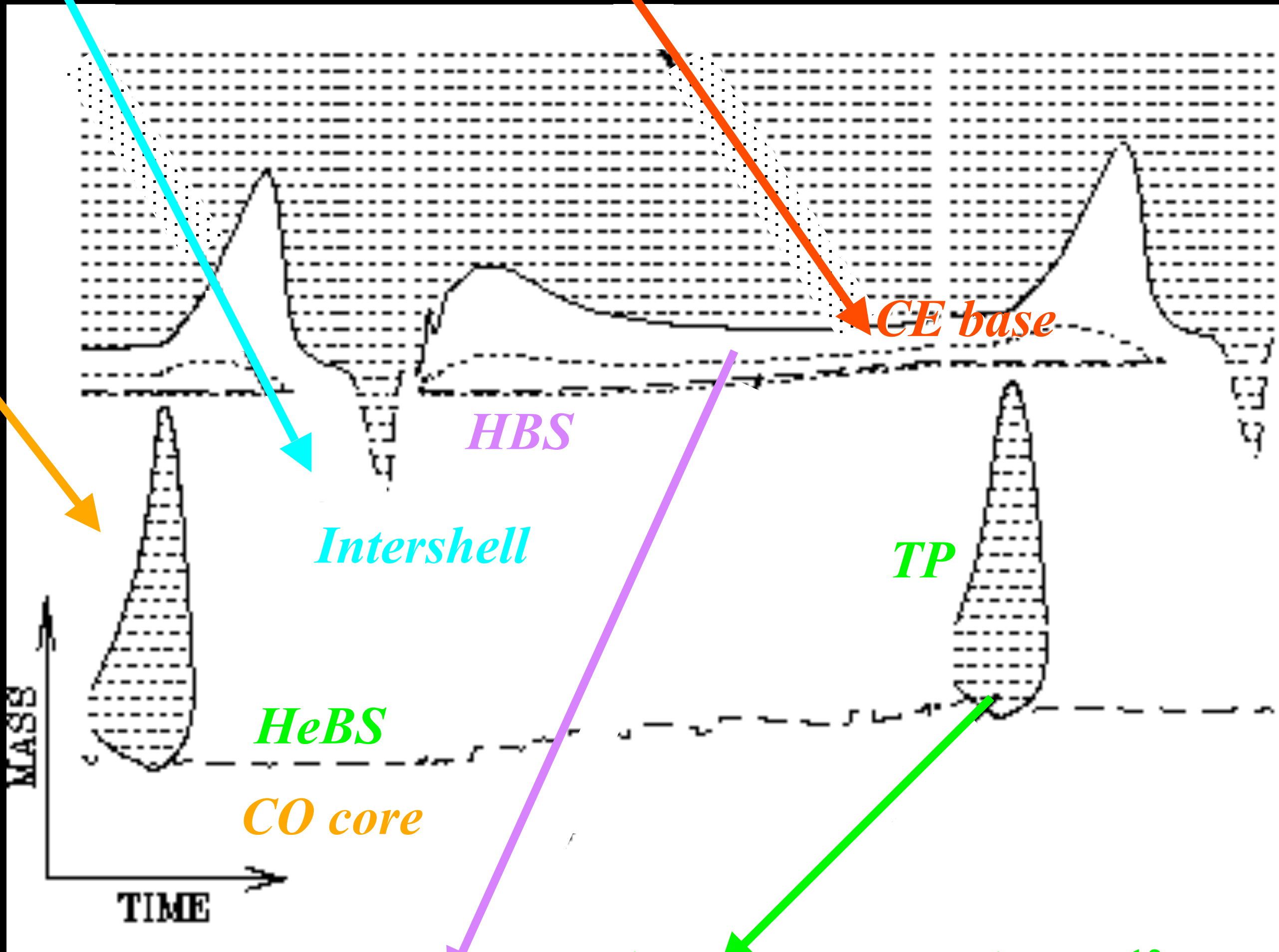


Figure by
M.Forestini

Transport of H into C-rich layers
Radiative s-process via $^{13}C(\alpha,n)^{16}O$
during the interpulse

HBB ($M \geq 4M_{sun}$)
CNO (primary ^{14}N), NeNa, MgAl
^{7}Li via Cameron-Fowler mechanism



3d dredge-up
ashes of the
thermal pulse
brought to the
surface
He, ^{12}C
^{16}O, ^{22}Ne, ^{25}Mg
s-process

H burning
CNO, NeNa, MgAl

He burning $3\alpha \rightarrow$ primary $^{12}C \rightarrow$ ^{14}N (CNO)
$^{14}N(\alpha,\gamma)^{18}F(\beta+)^{18}O(\alpha,\gamma)^{22}Ne$
$^{22}Ne(\alpha,n)^{25}Mg$, $^{22}Ne(\alpha,\gamma)^{26}Mg$
s-elements and ^{15}N from intershell ^{13}C burning

C. Charbonnel

✓ Third dredge-up (M ≥ 1.5MM at ZM)

products of He-burning in the TP

^{4}He, ^{12}C, ^{16}O, ^{22}Ne, ^{25}Mg, s-process elements increase

✓ Hot-bottom burning (M ≥ 4 – 4.5MM)

CN-cycle : $^{12}C \rightarrow {}^{13}C \rightarrow {}^{14}N$

ON-cycle : $^{16}O \rightarrow {}^{14}N$

Predictions depend on

✓ Stellar parameters

M, Z

✓ Input physics prescriptions

Nuclear reaction rates, opacities, …

✓ Various incompletely understood physical parameters

Mass loss, convection, transport processes, rotation, …

which rests on *semiempirical calibrations*

(e.g. C star luminosity function, initial-final M relation)

that have to be *extrapolated*

to a range of M, Z for which *no empirical data* are available

Illustration of the uncertainties on the yields

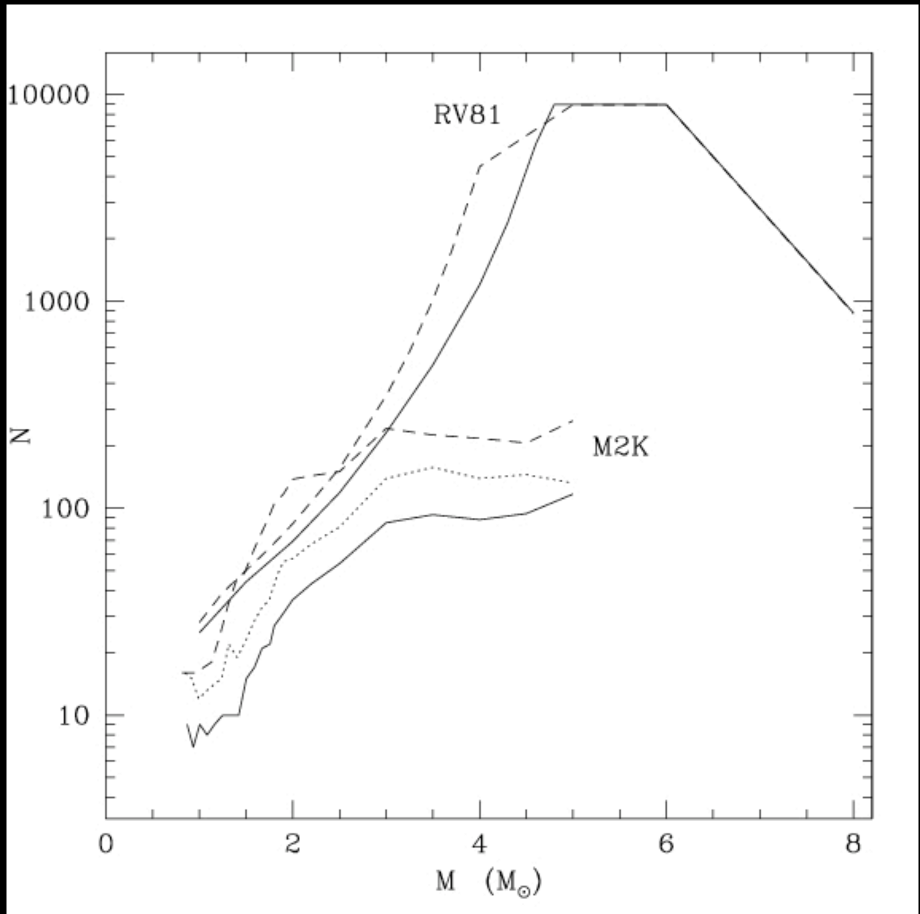
→ Mass loss

Mass loss affects the AGB duration, i.e.

the number and strength of TPs and subsequent 3d DUP events and the growth of Mcore

A minimum $M_{envelop}$ is required for HBB and 3d DUP to occur

HBB may be shut down long before 3d DUP ends



Expected number of TP vs initial M*

Renzini & Voli (81)
Reimers law (75), no superwind

Marigo (00)
Vassiliadis & Wood (93)

Z = ZM ———
0.008 ··········
0.004 — — —

Marigo (00)

Mass loss affects the AGB duration, i.e.

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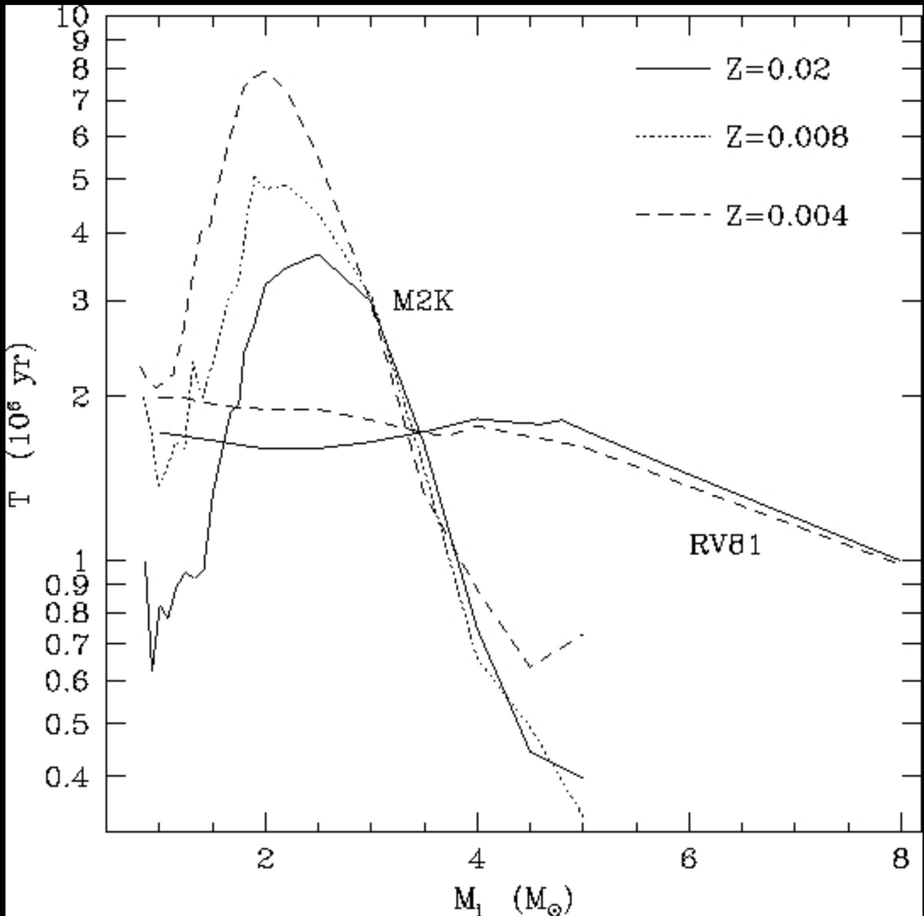

TP-AGB lifetimes vs initial M*

Renzini & Voli (81)
Reimers law (75), no superwind

Marigo (00)
Vassiliadis & Wood (93)

Z = ZM
0.008
0.004

Mass loss affects the AGB duration, i.e.

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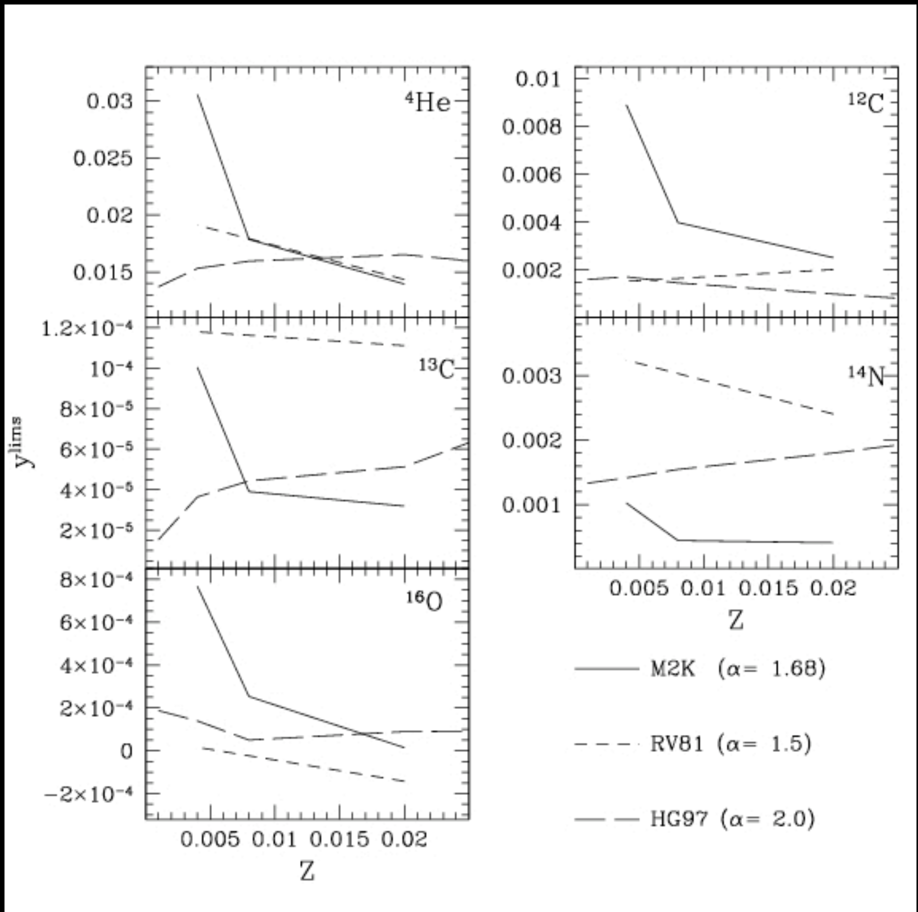


Integrated yields as a function of Z

Renzini & Voli (81) – – –

Reimers law (75), no superwind

Marigo (00) ——

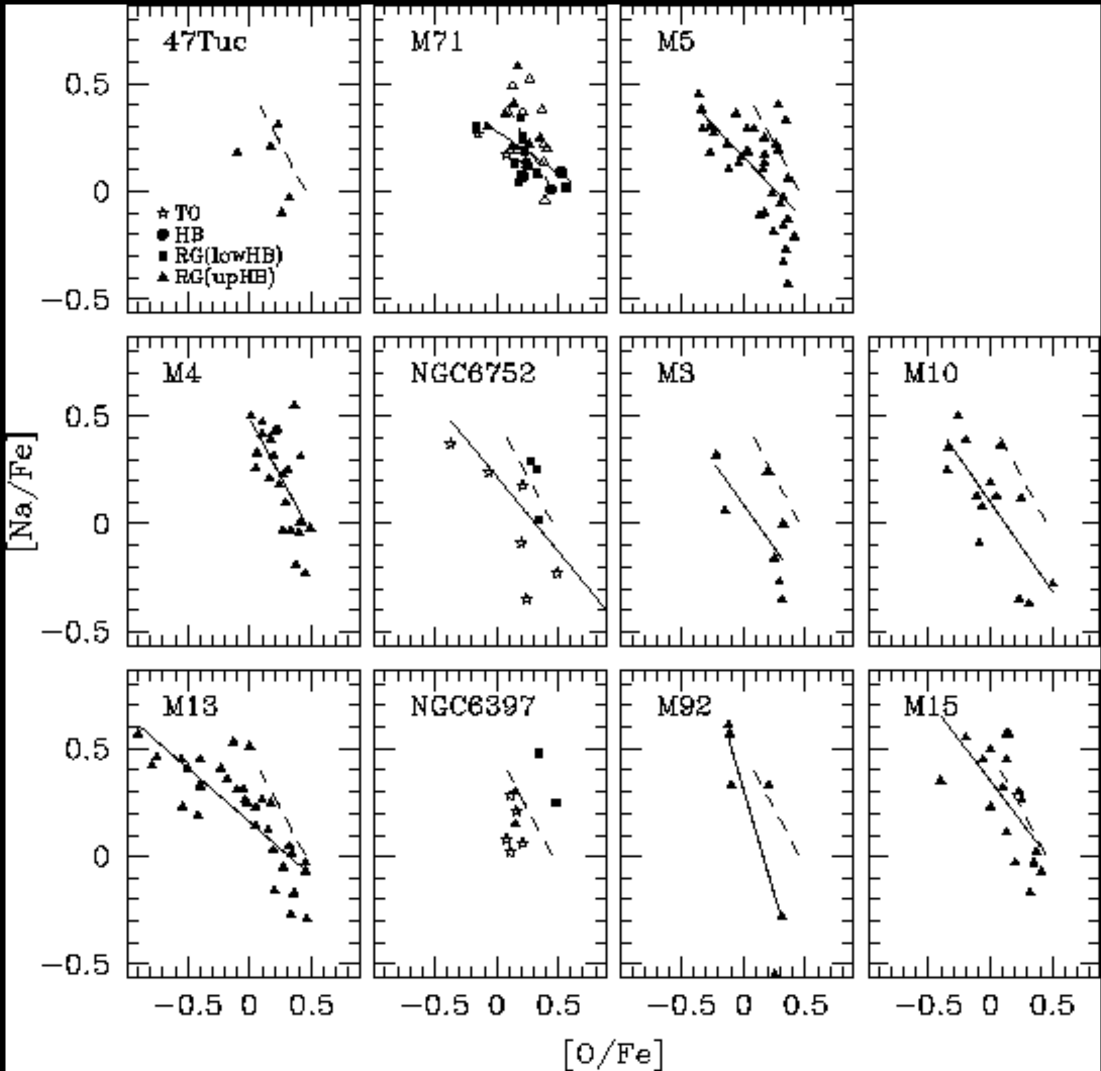
Vassiliadis & Wood (93)

Marigo (00)

Illustration of the uncertainties on the yields

→ HBB and 3d DUP

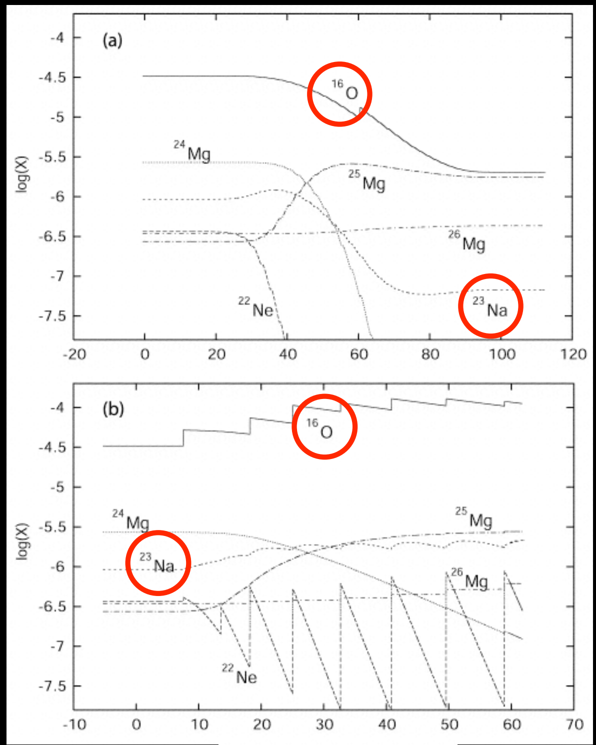
O-Na anticorrelation in galactic globular clusters



Ramirez & Cohen (2002)

O, Na evolution at the surface of a low-Z massive TP-AGB star

Delicate interplay of 3d dredge-up and hot bottom burning



(a) <u>No 3DUP, only HBB</u>
→ Large ^{16}O depletion
→ ^{23}Na depletion
(due to the lack of ^{22}Ne dredged-up)

(b) <u>Strong 3DUP, HBB, no mass loss</u>
→ 3DUP of the ^{16}O-rich layers below the TP
→ ^{23}Na increase (from dredged-up ^{22}Ne)

Full evolution models

Denissenkov & Herwig (03)

Illustration of the uncertainties on the yields

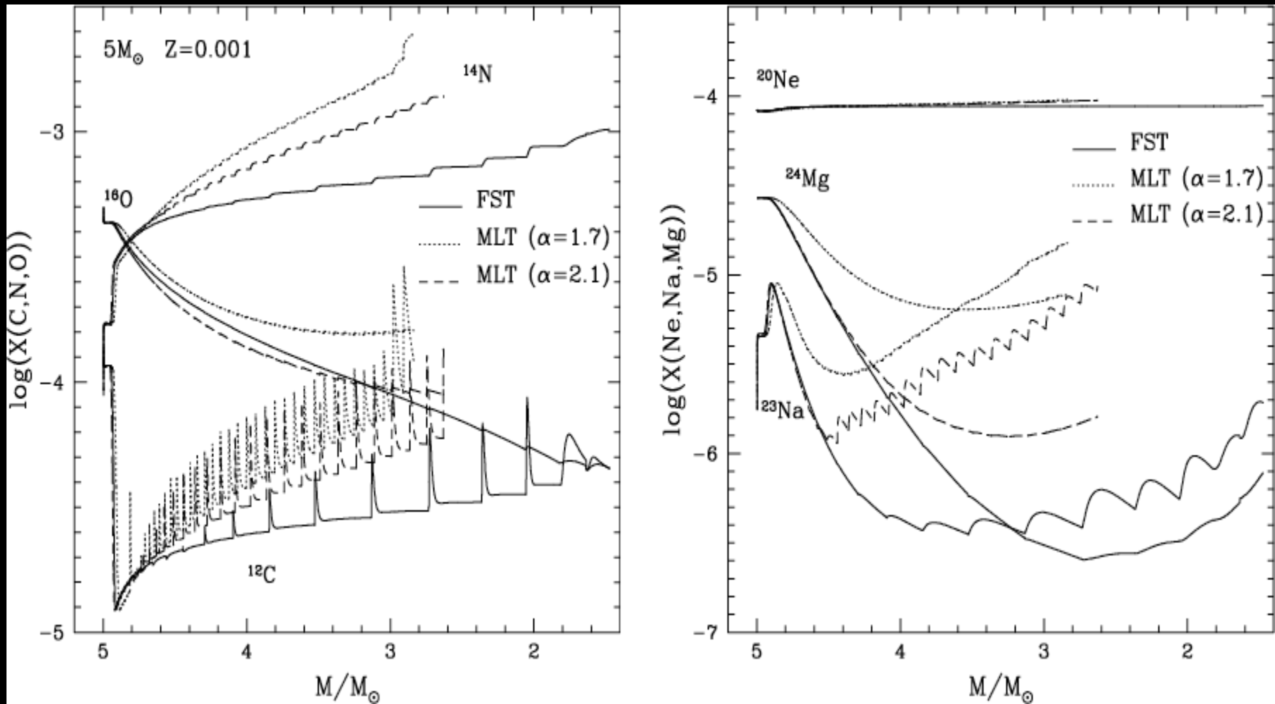
→ Convection

Impact of convection on nucleosynthesis

Ventura & D'Antona (05 I)

See also Renzini & Voli (81), Sackmann & Boothroyd (91), Blöcker & Schönberner (91), D'Antona & Mazzitelli (96)

Full Spectrum of Turbulence (Canuto & Mazzitelli 91)
→ **much more efficient HBB** than with MLT
(on the AGB : higher L, stronger mass loss)



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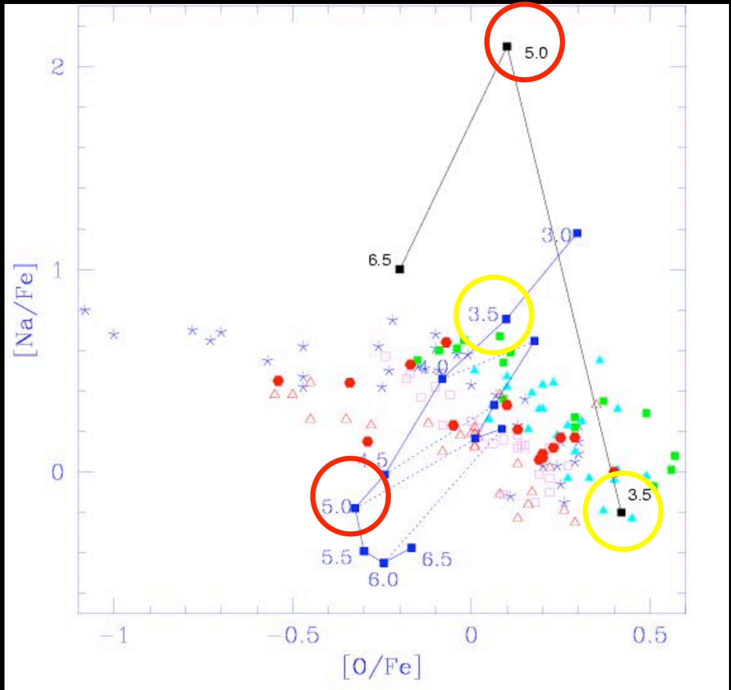
MLT17 : ....
Little O depletion (factor of ~2)
Extremely large increase of Na and N
C+N+O increase by ~ 0.8dex

FST : ————
Largest O depletion
Slight decrease of Na
C+N+0 conserved

Impact of convection on nucleosynthesis

Ventura & D'Antona (05 II)



Fenner et al.(04)

Overproduction of (primary) ^{23}Na

due to the burning of dredged-up ^{20}Ne

Ventura & D'Antona (05II)

Underproduction of ^{23}Na

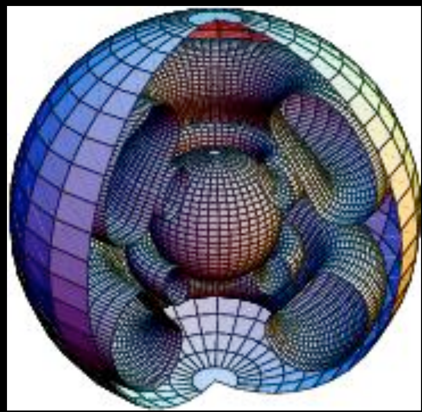
due to smaller number of 3DUP episodes and larger T

Both sets are unable to reproduce the data

« The predictive power of AGB models is still undermined by many uncertainties » (VD'A05)

Illustration of the uncertainties on the yields

→ Rotation

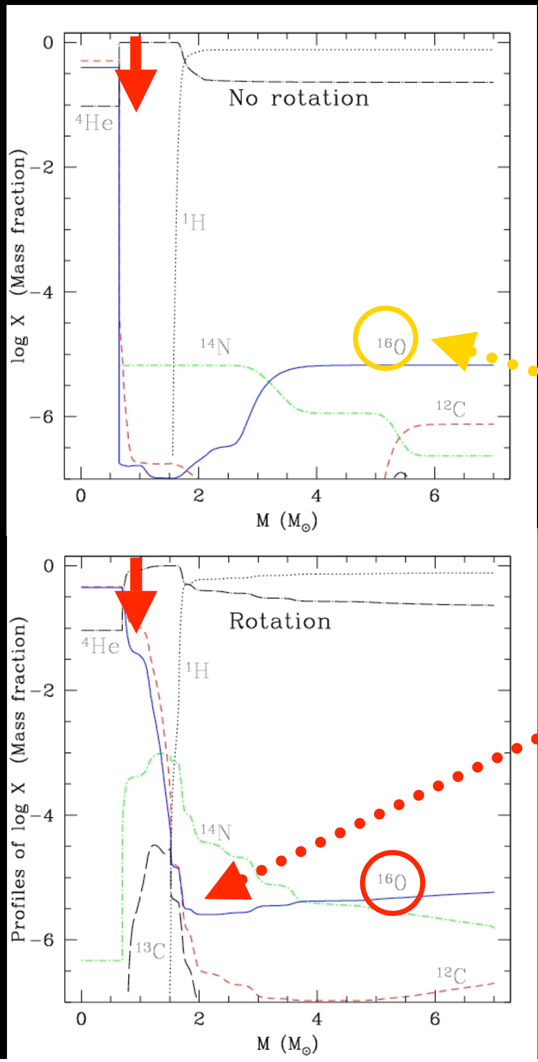


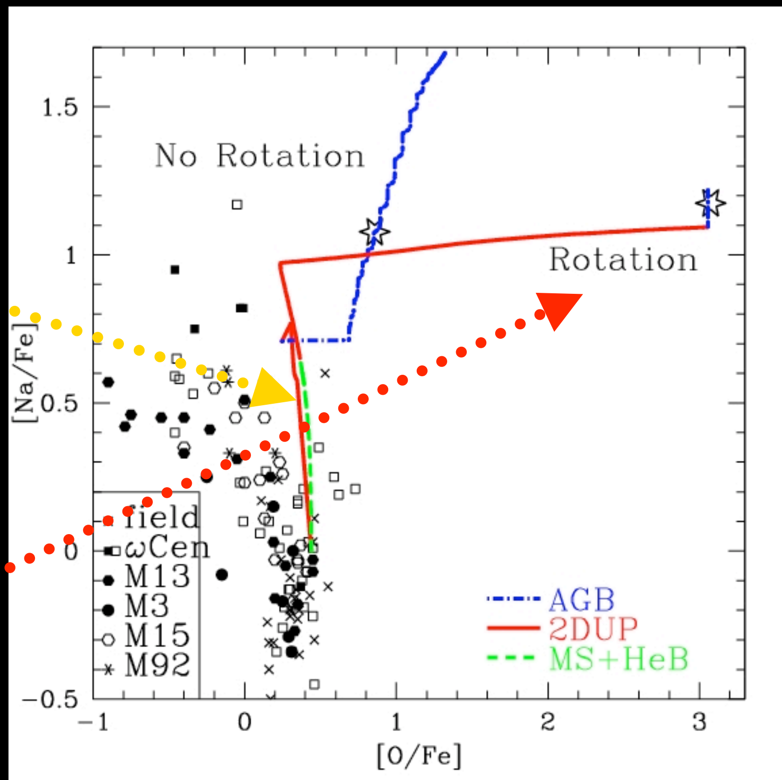
O and Na
in rotating intermediate-mass stars

Decressin, Charbonnel, Siess, Palacios, Meynet (05)

$7M_M$ star,
$Z = 10^{-5}$

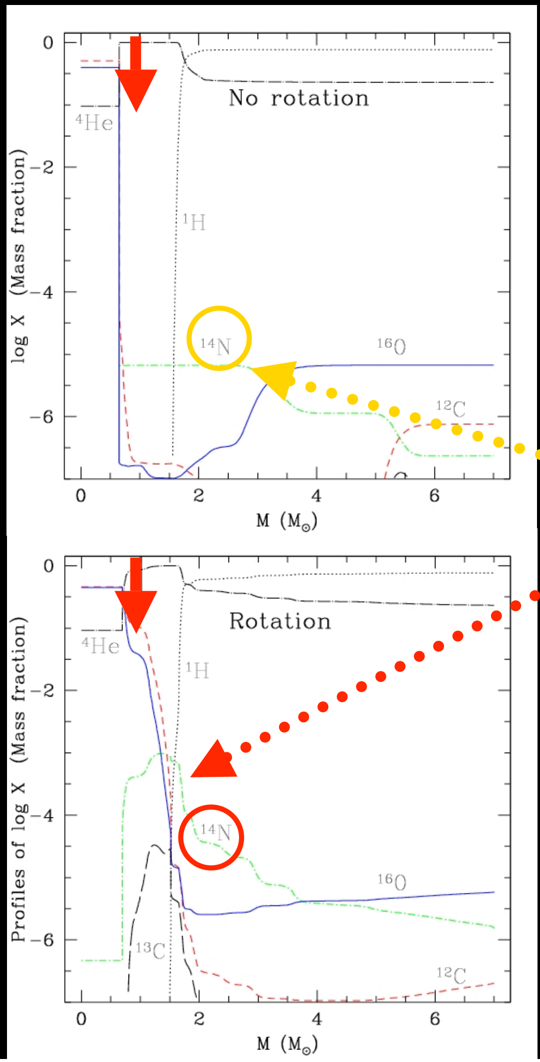
Profiles
at the end of
central He-burning

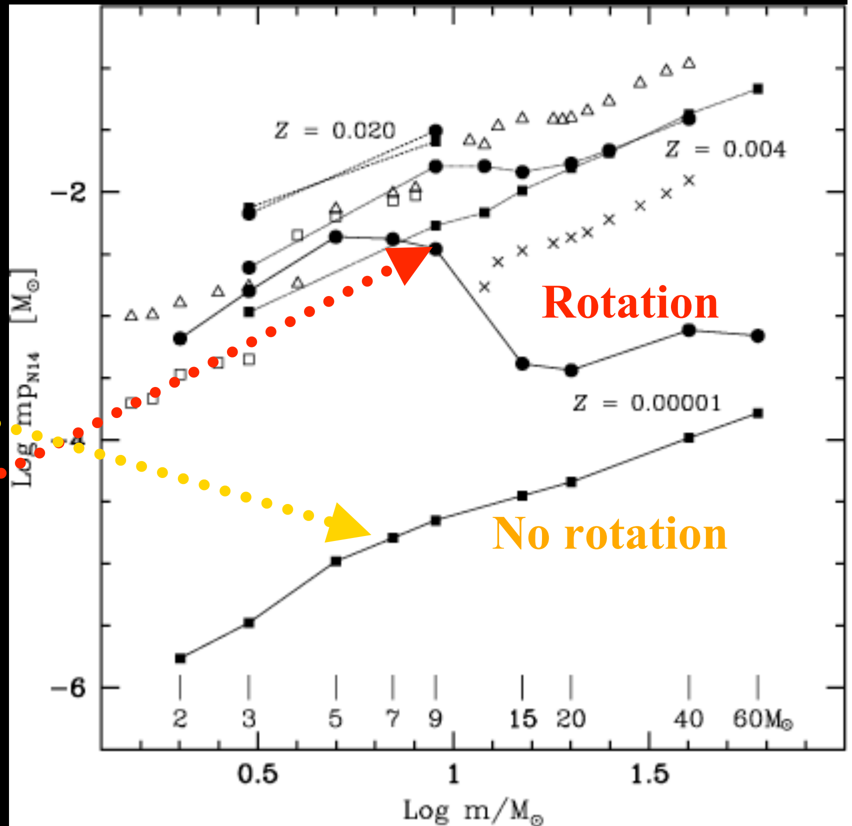




Primary ^{14}N in rotating intermediate-mass stars

Meynet & Maeder (02)





$7M_M$ star,
$Z = 10^{-5}$

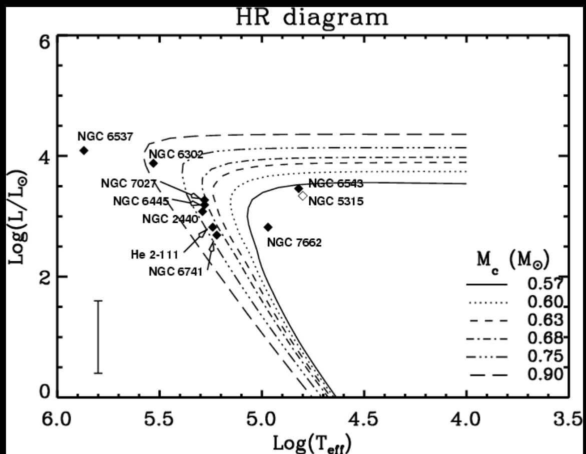
Profiles
at the end of
central He-burning

C. Charbonnel. Conference « PN as astrophysical tools »

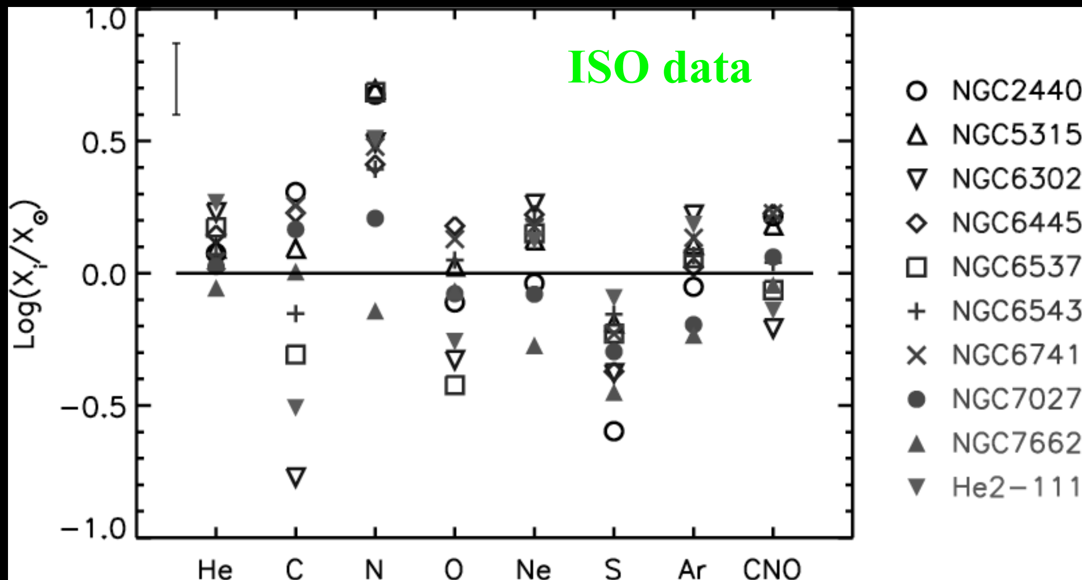
The importance of PNe as constraints on nucleosynthesis

Insight on the nucleosynthetic properties of the PNe progenitors

- ✓ C, N : Efficiency of 3d DUP vs HBB
- ✓ He : Cumulative effect of the 1st, 2d, 3d dredge-up, and HBB
- ✓ O : Composition of the TP, efficiency of HBB
- ✓ Ne : Synthesis during the TP, efficiency of HBB, s-process $^{22}Ne(\alpha,n)^{25}Mg$



Marigo et al. (03)
vs Grevesse & Sauval (98)
+ O from Allende-Prieto et al. (01)



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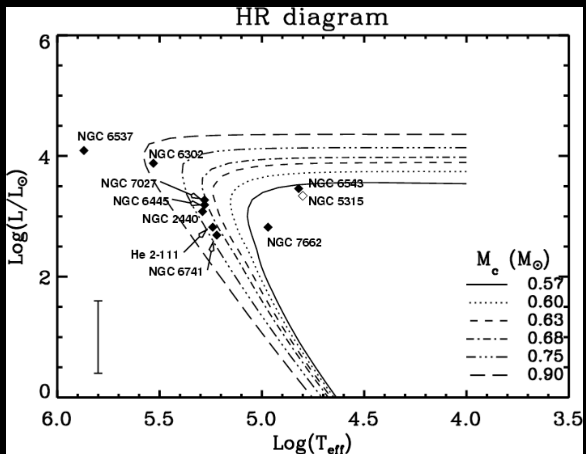
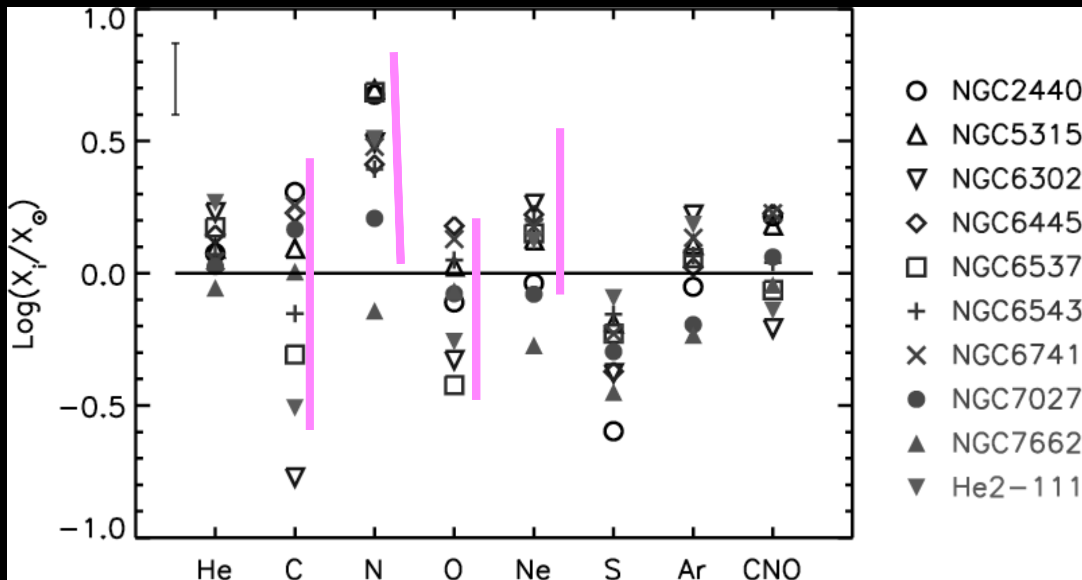
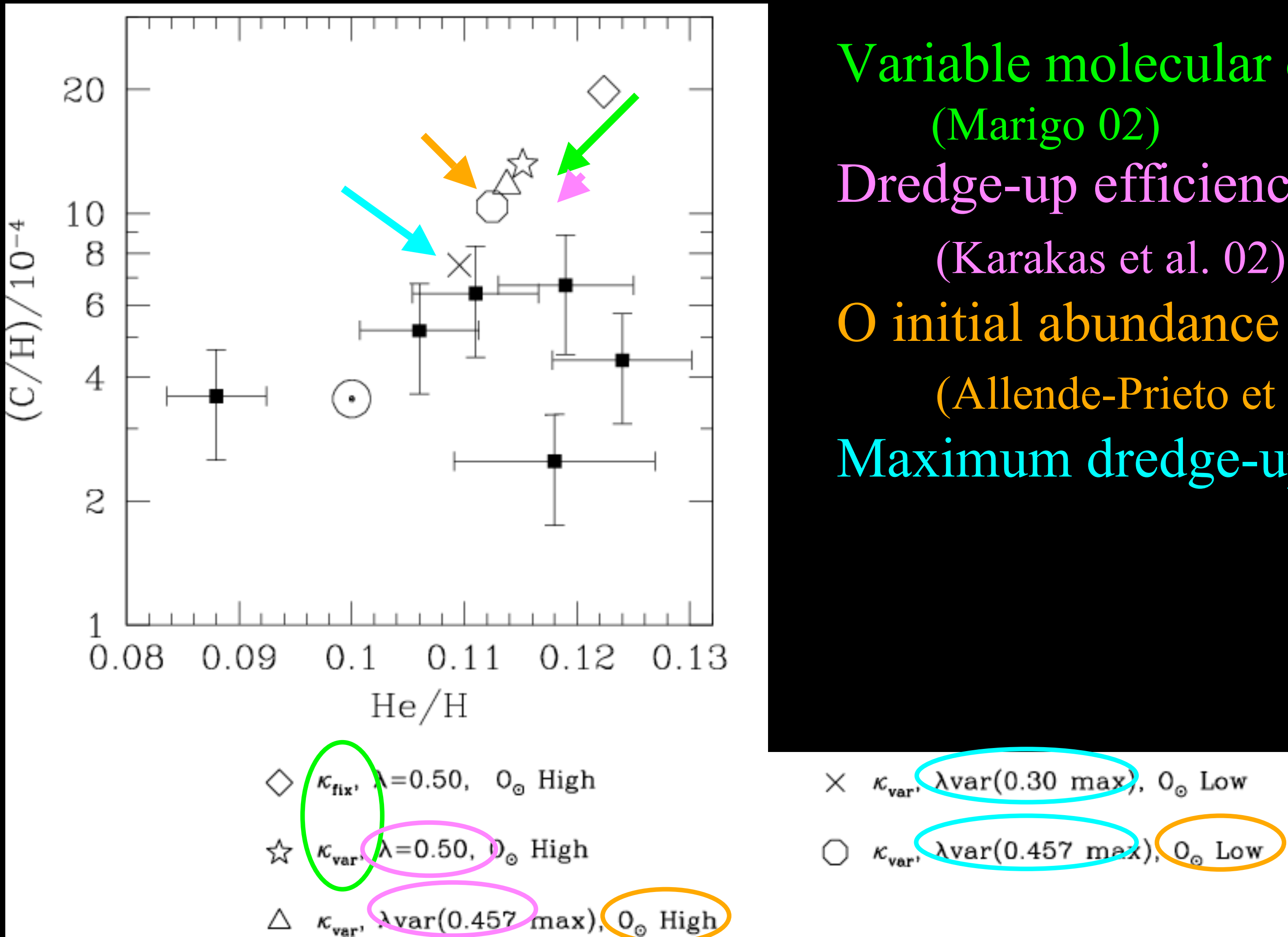


Marigo et al. (03)
vs Asplund et al. (05)



C. Charbonnel. Conference « PN as astrophysical tools », Gdansk 05

Reproducing the C enrichment



Variable molecular opacity
(Marigo 02)

Dredge-up efficiency α t_{AGB},M, Z
(Karakas et al. 02)

O initial abundance
(Allende-Prieto et al. 01)

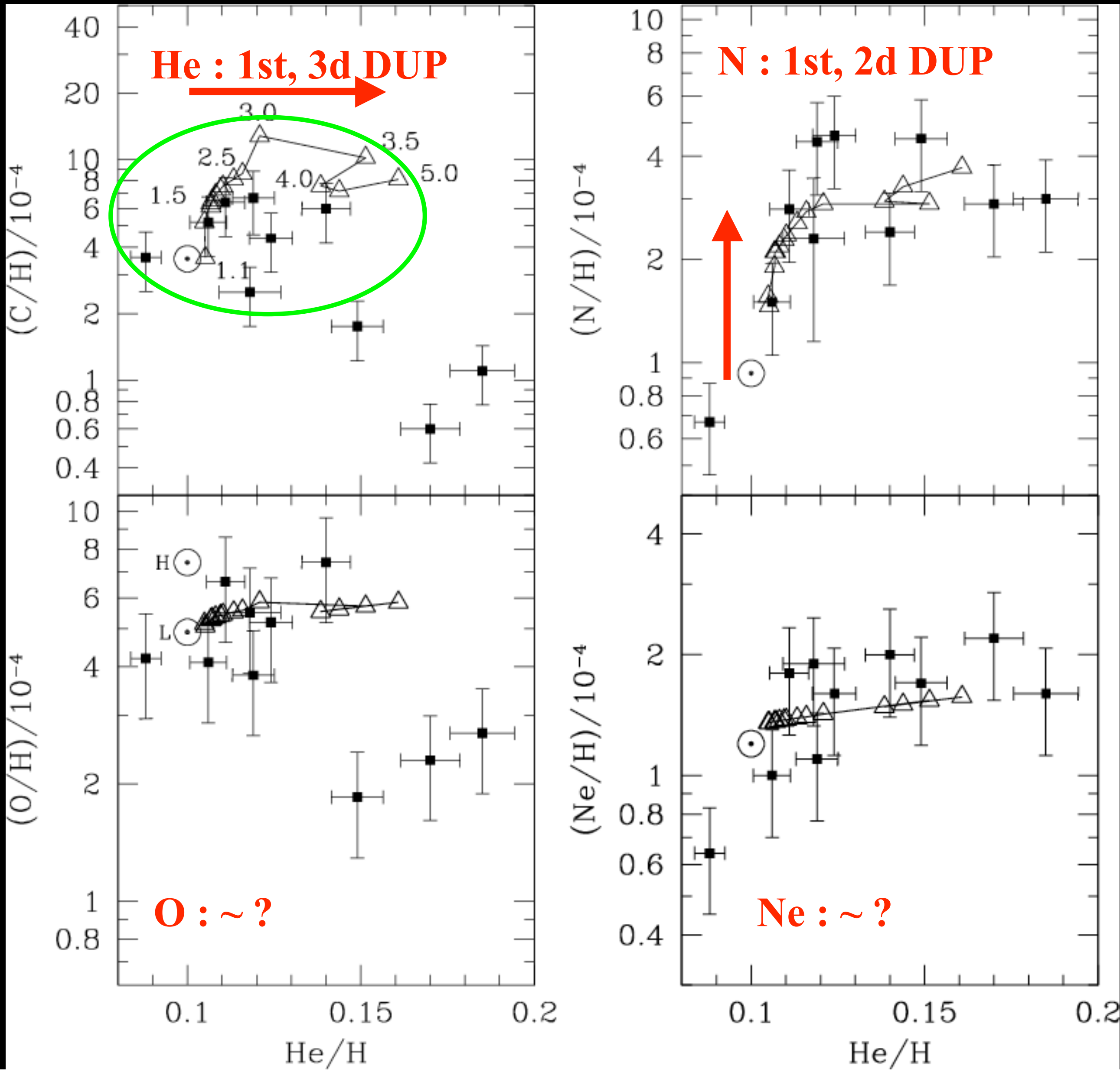
Maximum dredge-up efficiency

Synthetic AGB calculations, Mi = 2M, Z = 0.019

Marigo et al. (03)

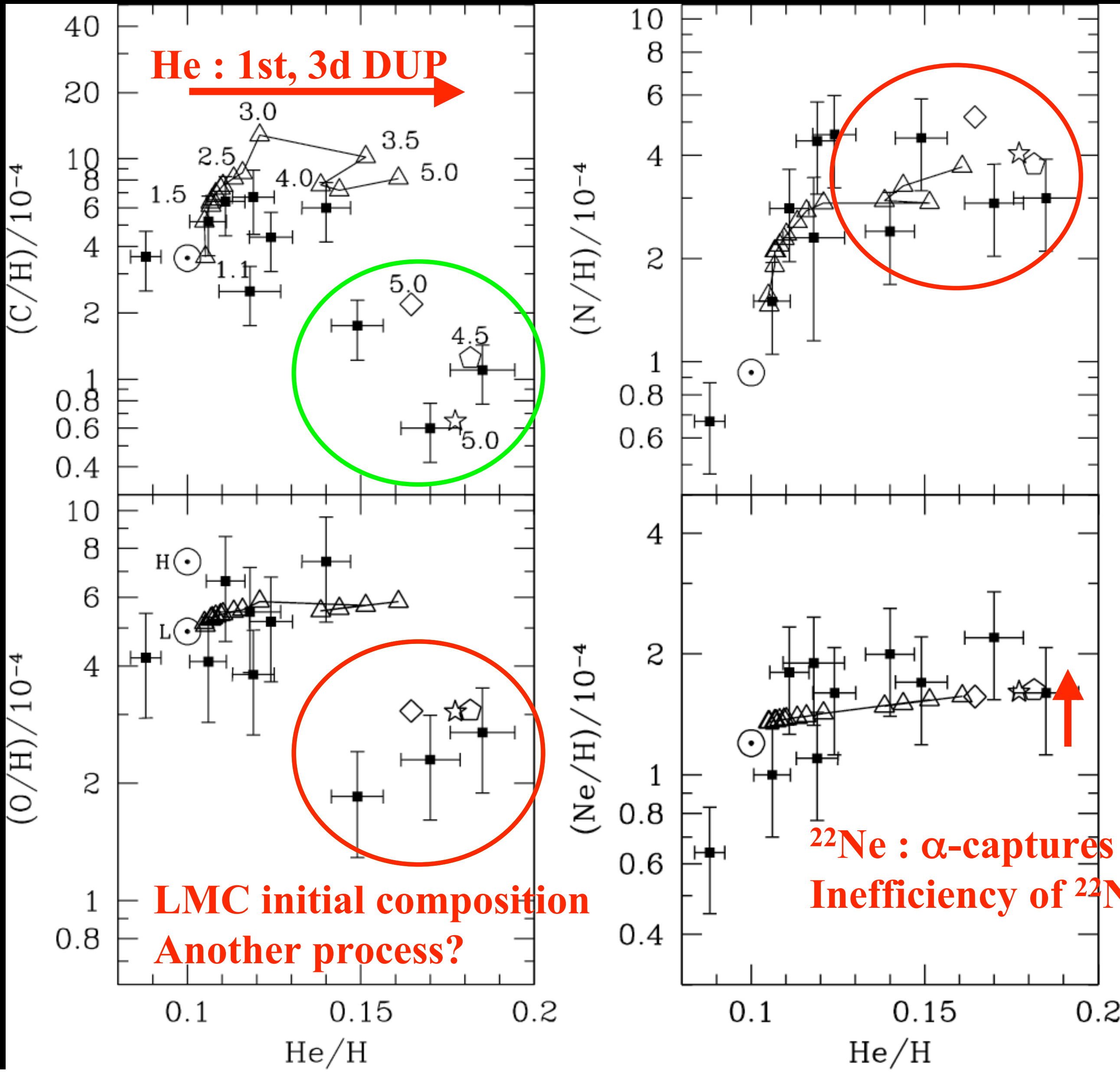
Synthetic AGB calculations, ZM

Marigo et al. (03)



Synthetic AGB calculations

Marigo et al. (03)



The importance of post-AGBs as constraints on nucleosynthesis

The advantages of the post-AGBs

- ✓ Stellar mass can be directly obtained from the observed stellar spectrum

  (model atmosphere → Teff, g)

  (easier than for the hotter and buried PNe)

- ✓ Abundances of quite a variety of elements :

  He, Li, C, N, O, Na, Mg, Al, Si, S, Ca, Sc, Ti, Fe, Ni, Zn, …

- ✓ C : smaller uncertainty than in PNe

- ✓ Extend to smaller masses than nuclei of PNe

Post-AGBs as testbeds of nucleosynthesis

Stasinska, Szczerba, Schmidt, Siódmiak (05)

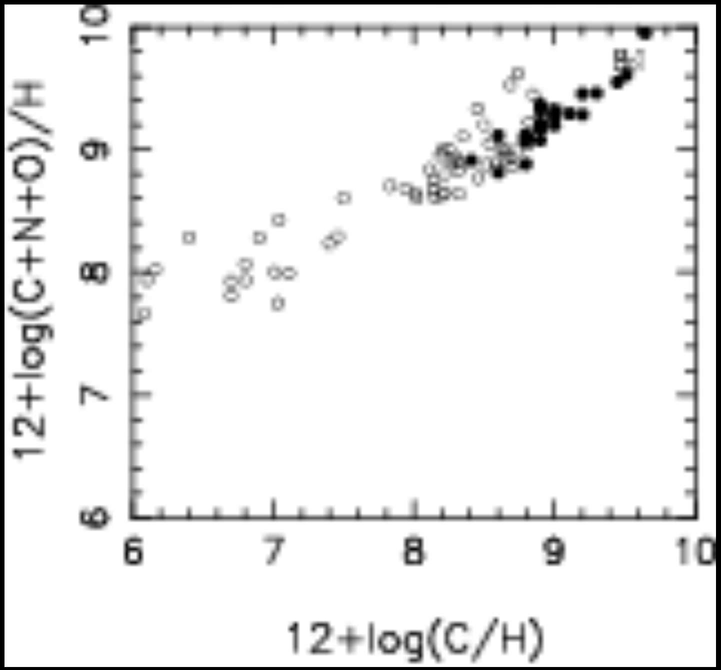
Data base of 177 post-AGB objects
with determined photospheric parameters (Teff, g) and chemical composition

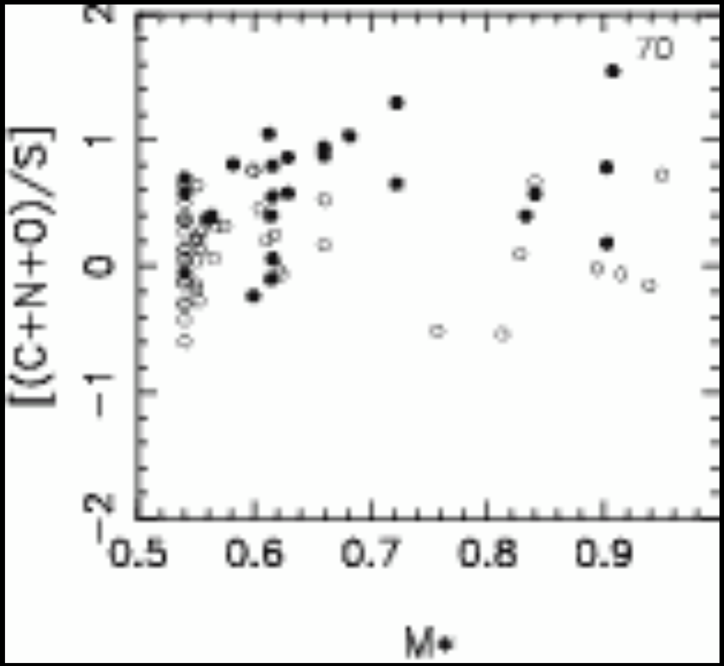
Post-AGBs as testbeds of nucleosynthesis

Stasinska, Szczerba, Schmidt, Siódmiak (05)

3DUP effect

in 73% of the sample stars



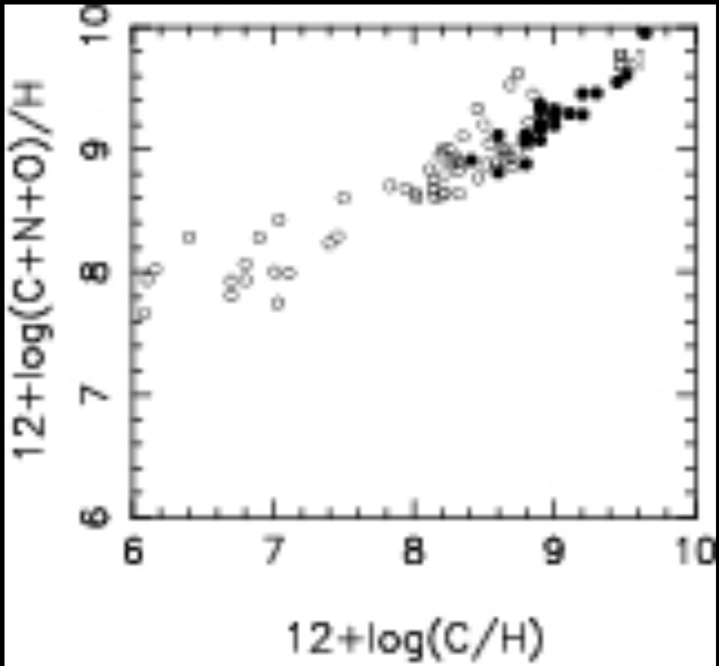


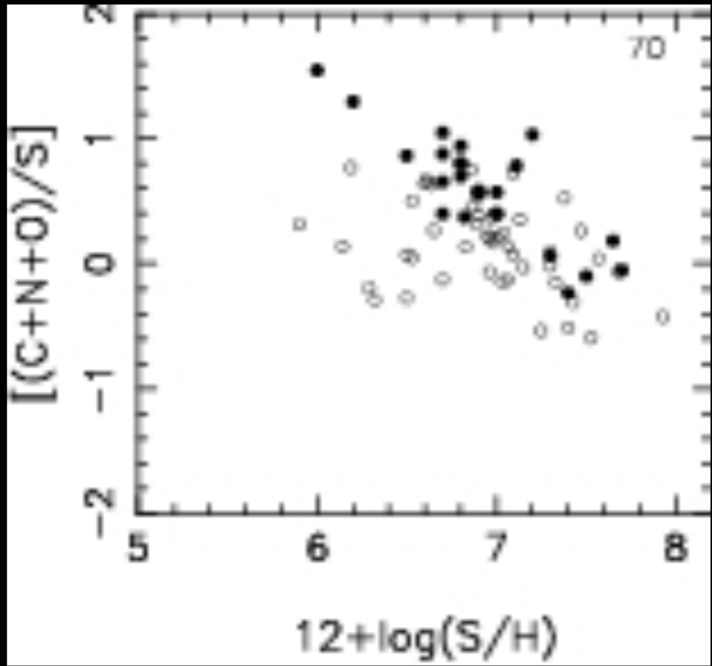
Post-AGBs as testbeds of nucleosynthesis

Stasinska, Szczerba, Schmidt, Siódmiak (05)

3DUP effect

more important at low-Z





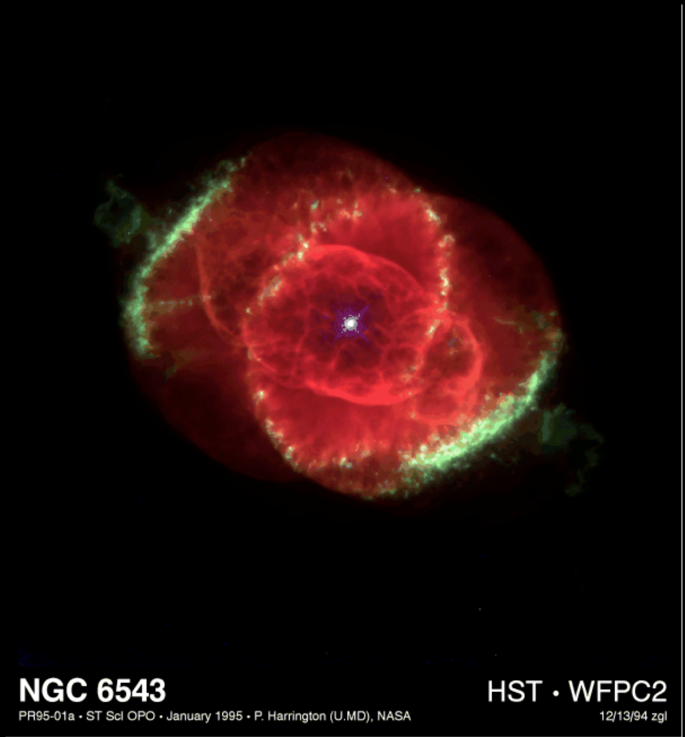
Post-AGB and PN :
Crucial probes of stellar nucleosynthesis

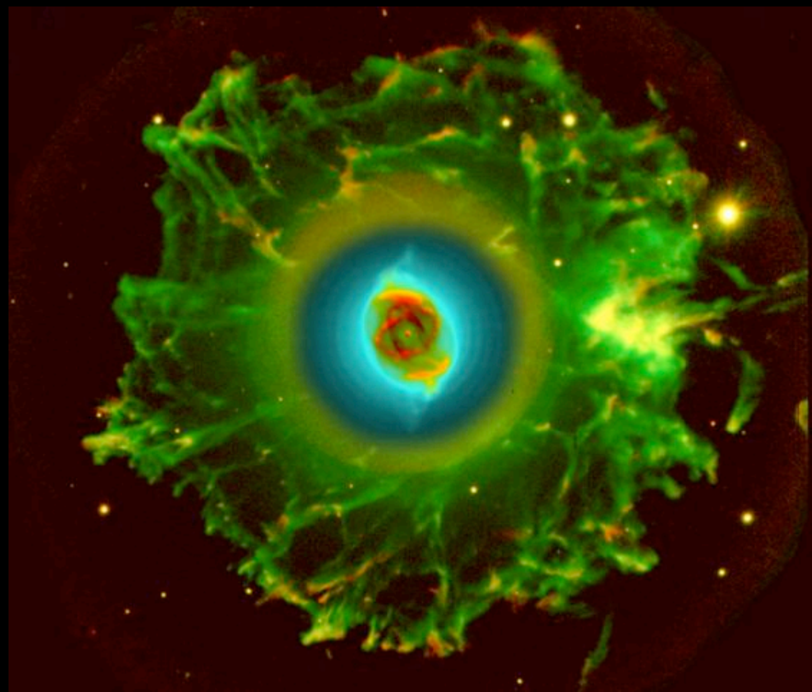
- Nucleosynthesis in low- and intermediate-mass stars :
  Main trends are relatively well understood

- The impact of the input physics :
  Mass loss, convection, HBB, 3DUP, rotation
  The yields are highly uncertain
  Predictive power of the current theoretical models?
  A lots of work remains to be done

- Crucial constraints from PNe and post-AGBs
  High potential, very encouraging

Post-AGB and PN :
Crucial probes of stellar nucleosynthesis





The story goes on …