Planetary Nebulae (LIMS) as tools to understand stellar evolution and the formation of the Milky Way

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The Formation of the Milky Way

The Two Infall Model

(Chiappini, Matteucci & Gratton 1997 ApJ 477, 765)

↓

Halo-thick disk and thin-disk phases disentangled: solar vicinity formed mostly from from extragalactic material on long timescales

+ Threshold in SF process

Thilker et al. 2004 ApJL – Green Bank Telescope 21cm observations have revealed a faint, yet extensive HI cloud population surrounding M31. These newfound objects are likely analogs to HVCs seen around the MW – Possible origin: Local Group Cooling Flow

First detection of extragalactic infall onto the MW – Sembach et al. 2004

D/H = (2.2 +/- 0.7) 10^{-5}

O/H = 1/6 solar

D/O = 0.28 +/- 0.12

"The metallicity (0.17 Zsun), abundance pattern, D/H ratio, and lower distance limit (3.5 kpc) indicate that Complex C is an external system (or remains of an external system) falling into the MW rather than gas ejected from the Galactic disk"

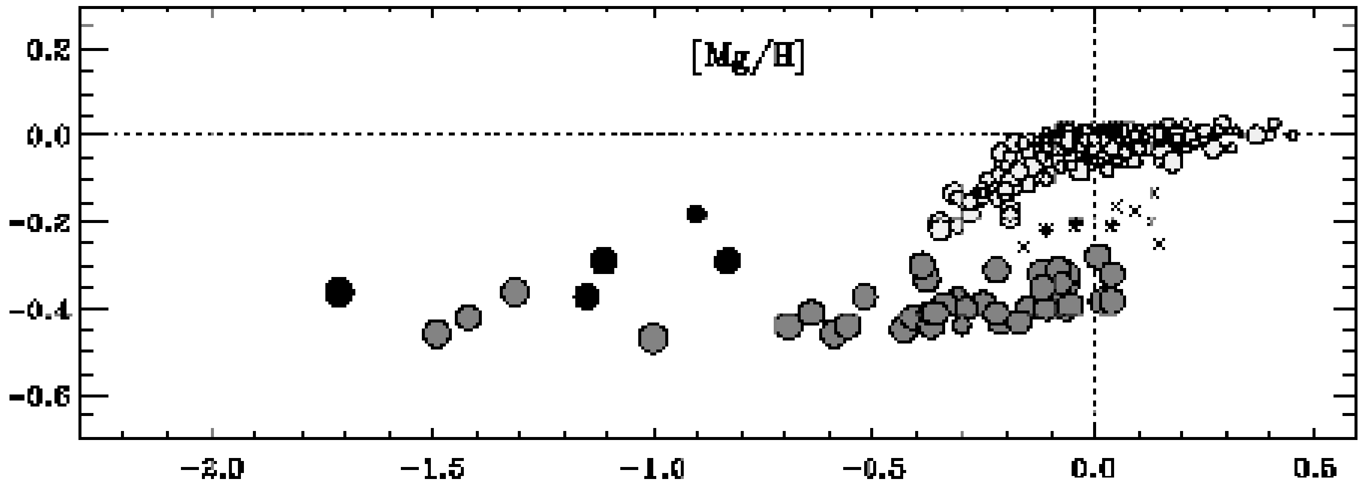
Why a Two Infall Model ?

1. The data indicate a sudden decrease in the SF in the epoch preceding the formation of the thin disk
2. G-dwarf metallicity distribution implies long timescale for thin disk formation
3. Halo and thick disk formed much faster than thin disk

(First shown by Gratton et al. 1996, later confirmed by others)

Halo/Thick disk vs Thin disk discontinuity:

[Fe/Mg]



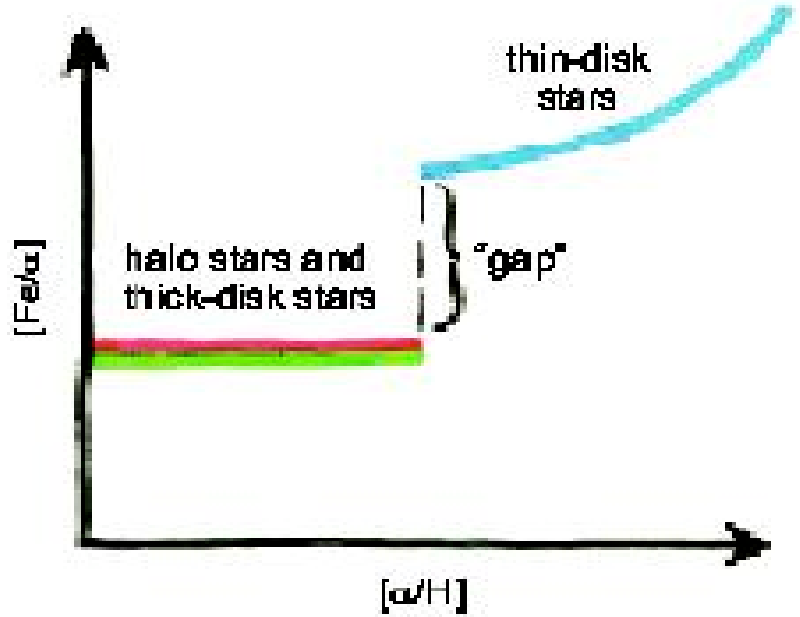
Fuhrmann 2004

[Mg/H]

The data indicate a sudden decrease in the SF in the Epoch preceding the formation of the thin disk

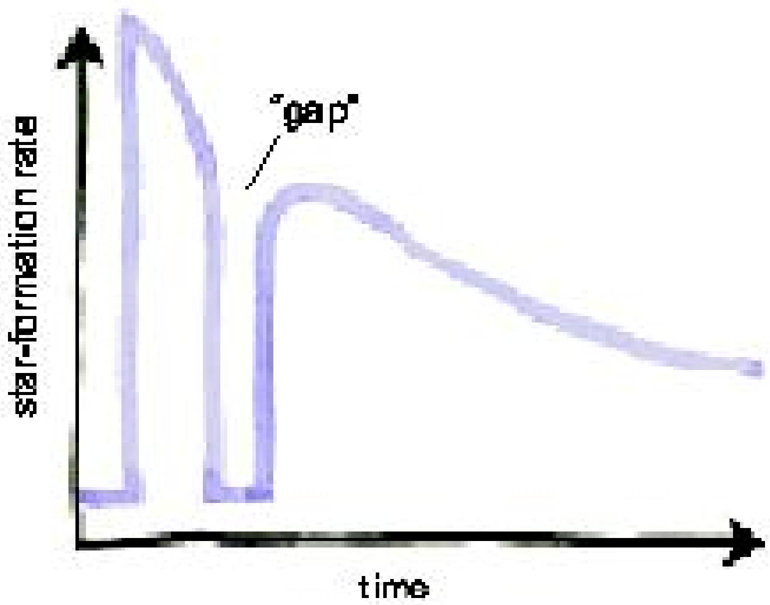
(Chiappini 2001 Am.Sci.)

[Fe/α]



[α/H] (by instance O)

Star Formation History



Time

The star formation gap - support from recent observations !
(Fuhrmann 2004, Gratton et al. 2003, Nissen 2004)

RESULTS

THE SOLAR VICINITY

The importance of LIMS and the strong dependence on the adopted stellar yields

C & N

Stellar Yields in low and intermediate mass stars: van der Hoek & Groenewegen 1997

- $\eta_{AGB} = 4$ for all metallicities
- $\eta_{AGB} = 1,2$ for low metallicities

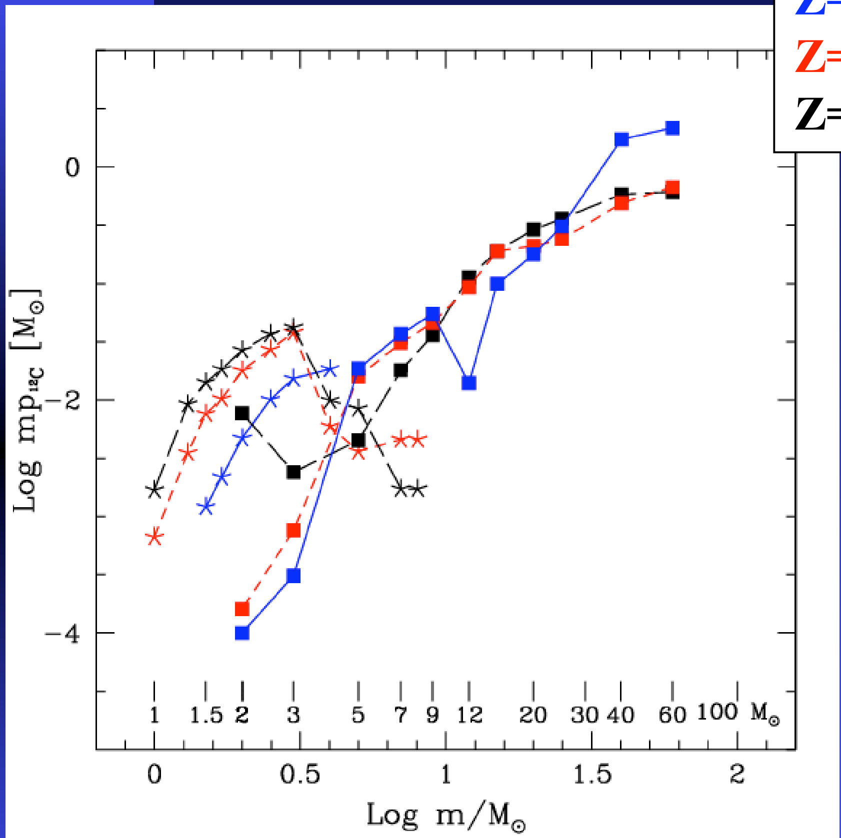
More ^{12}C at low metallicities (factor of 3 at Z=0.001)

Lower mass loss -> longer lifetime -> more thermal pulses -> more ^{12}C dredged up -> larger ISM enrichment … but, on the top of that -> HBB (which will consume C and produce N)

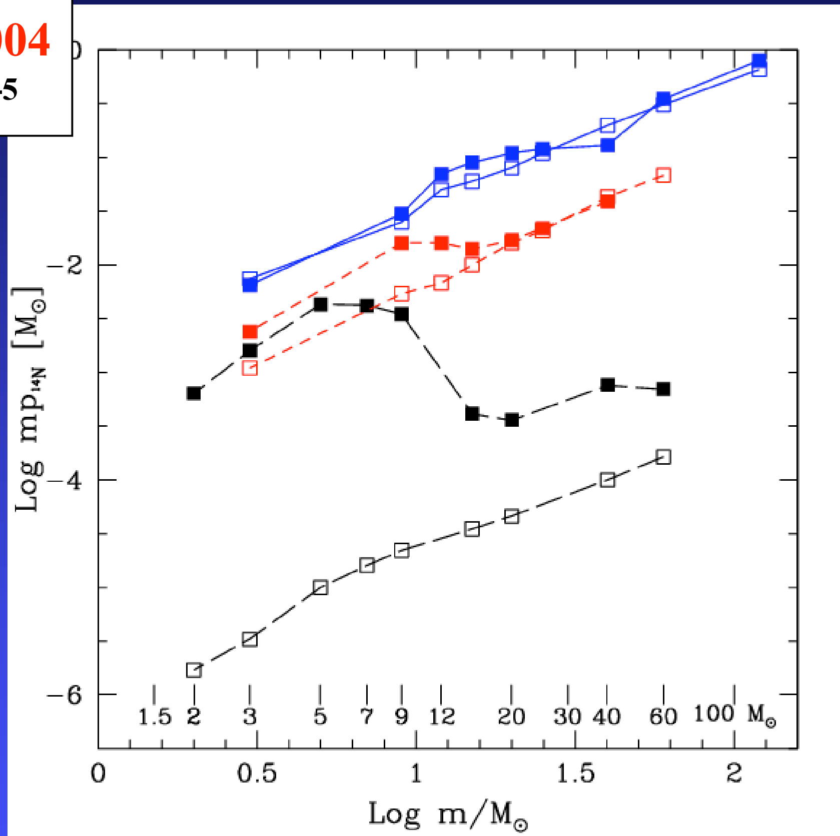
Meynet & Maeder yields DO NOT INCLUDE 3rd dredge up nor HBB

But rotation: strong effect on N

Z=0.020
Z=0.004
$Z=10^{-5}$

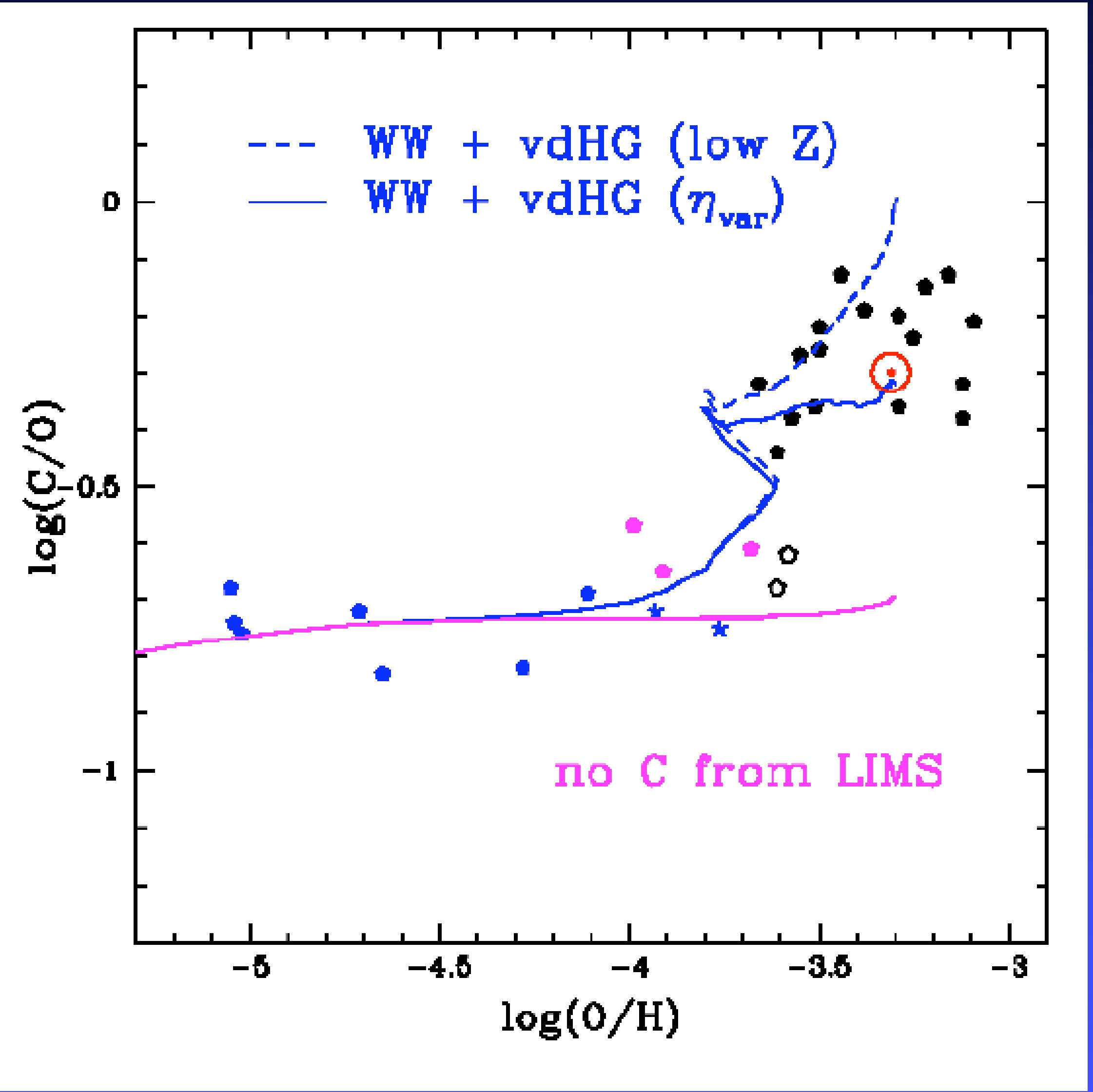


Stellar yields for 12C for the whole stellar mass range, different metallicities as vdHG and MM



Stellar yields for 14N as predicted by MM for the whole stellar mass range with (filled symbols) and without (empty symbols) rotation. Notice the huge effect at low metallicities

^{12}C



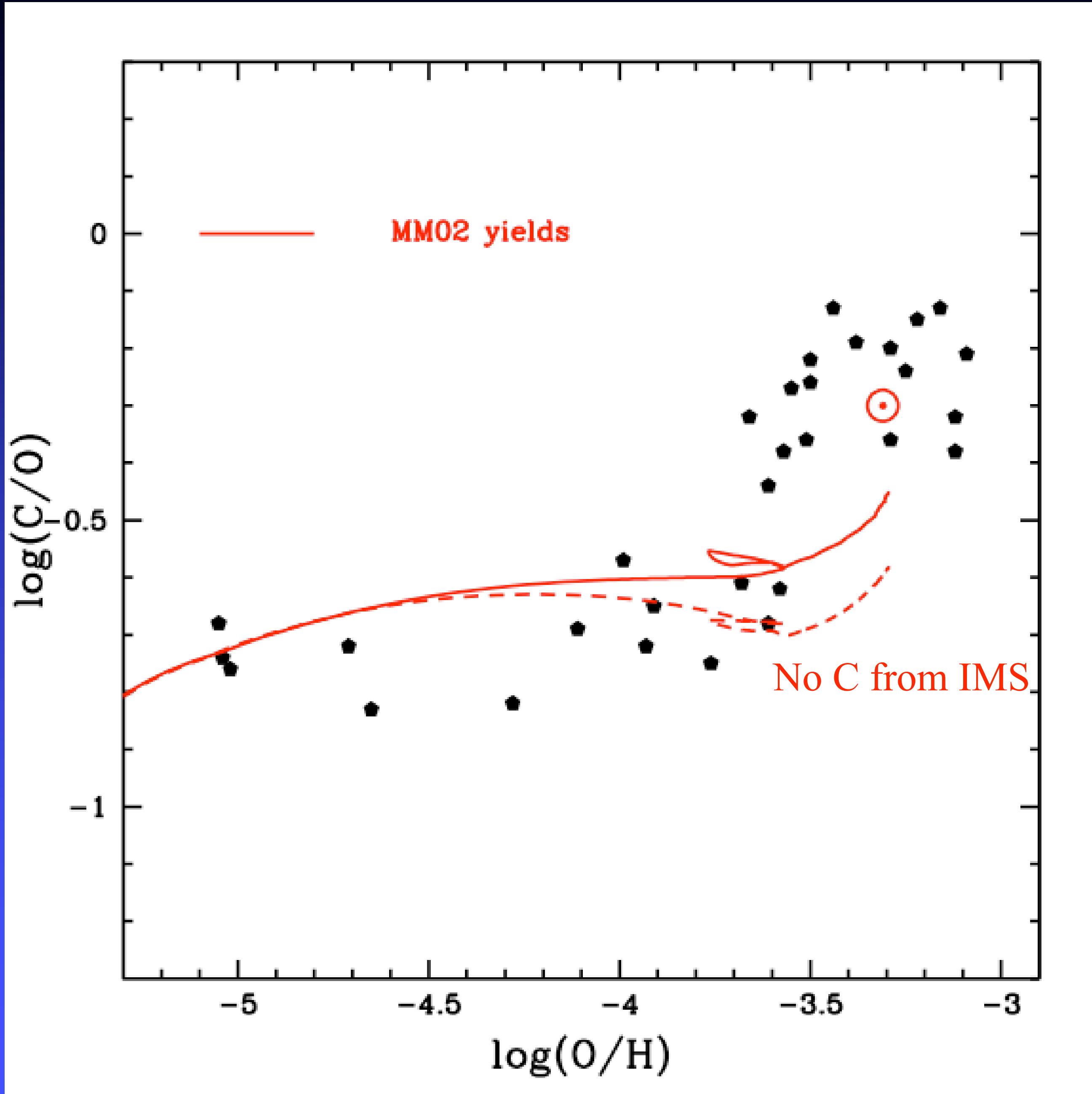
Clearly LIMS are important to explain the solar C/O and the present C/O ratios in the ISM

LIMS=low and intermediate mass stars

Data by Nissen 2003 (homogenous data set)

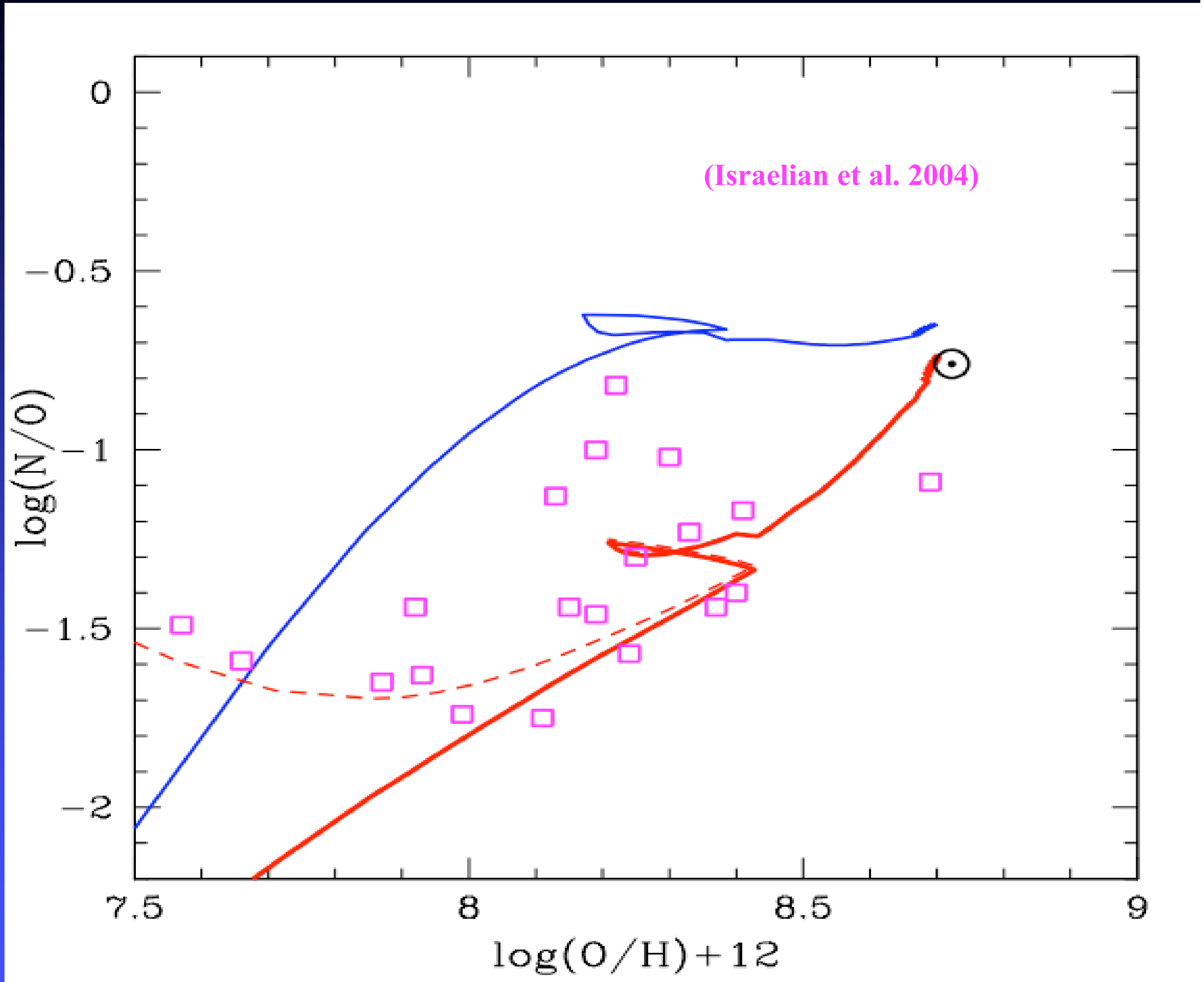
(Chiappini, Matteucci and Romano 2003 MNRAS)

In this case the C from LIMS is not enough. This is expected as in this case the stellar calculations do not include the third dredge-up



(Chiappini, Matteucci and Meynet 2003 A&A)

Models with rotation and no HBB can still account for the N observed in the solar vicinity. HBB will add more N but both processes have to be considered in CEMs



Chiappini et al. 2005

RESULTS

ABUNDANCE GRADIENTS

Constraining stellar yields ?

Gradients Today

HII regions:

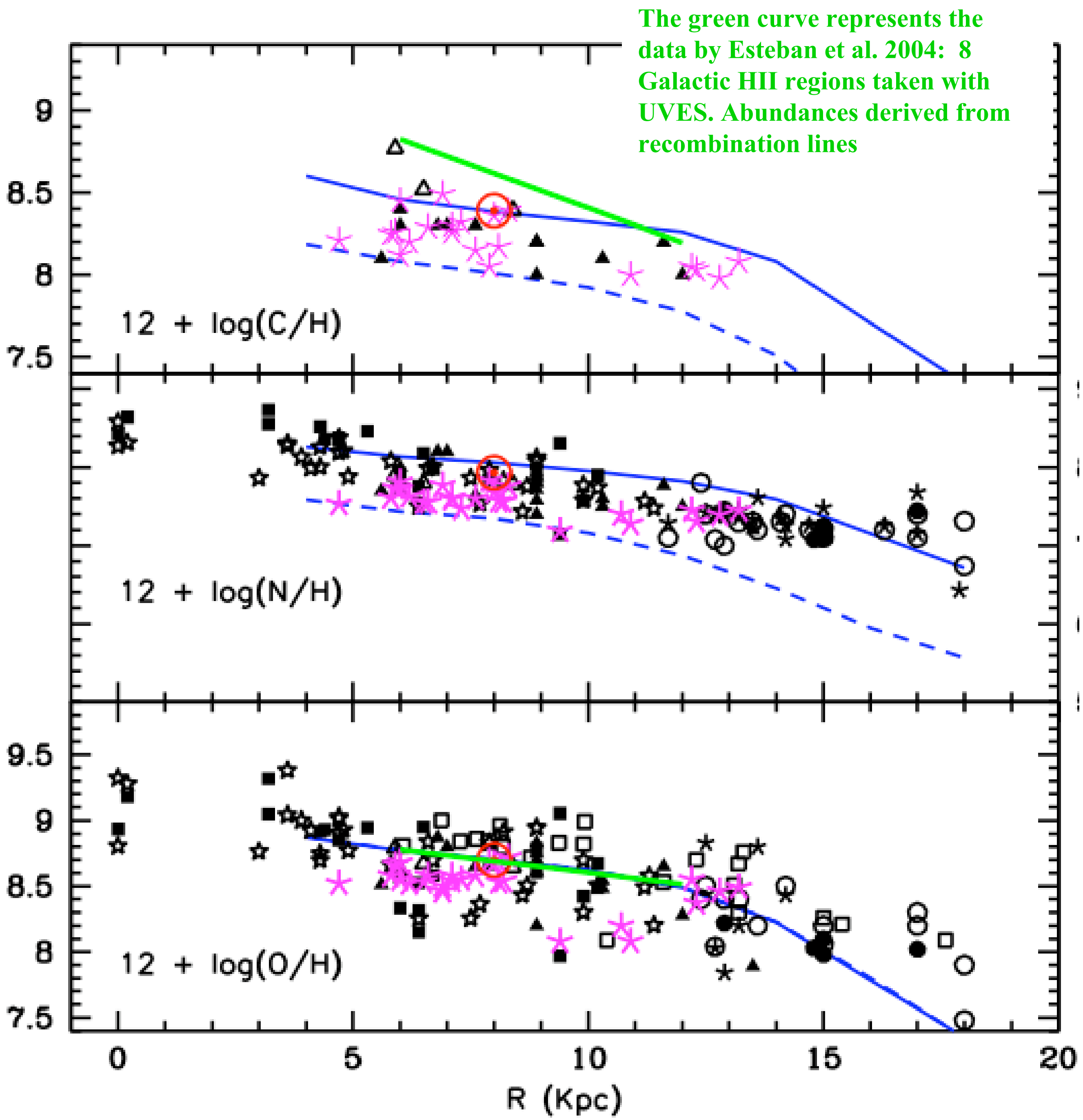
Δ Esteban et al. 1999
O Vilchez & Esteban 1996
● Rudolph et al. 1997
■ Simpson et al. 1995
☆ Afflerbach et al. 1997
✶ Fich & Silkey 1991

B stars:

▲ Gummersbach et al. 1998
★ Daflon & Cunha 2004

Blue curves - Chemical evolution models computed with WW95 + vdHG yields

Dashed curves - without the contribution by low and intermediate mass stars

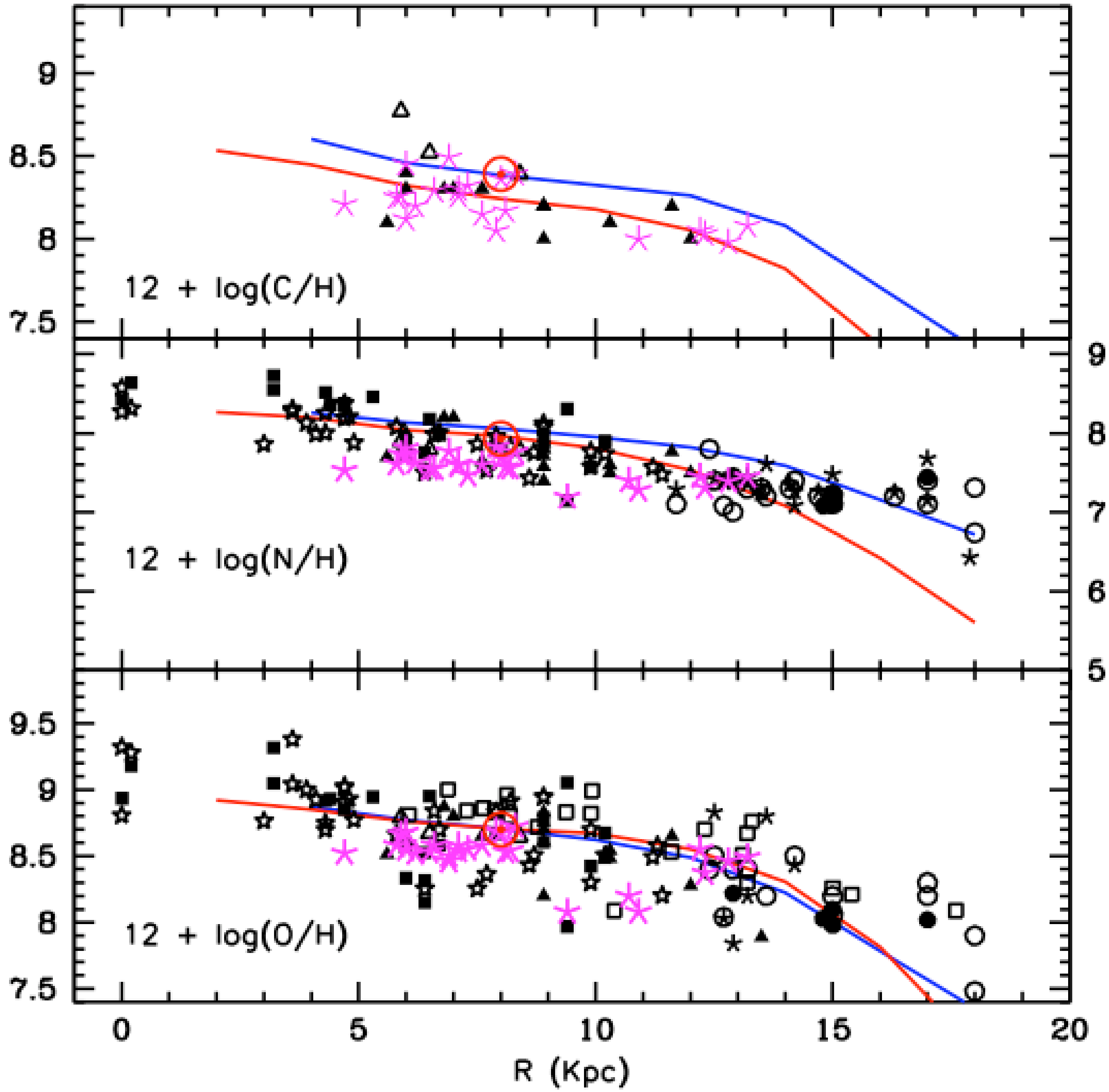


Gradients Today

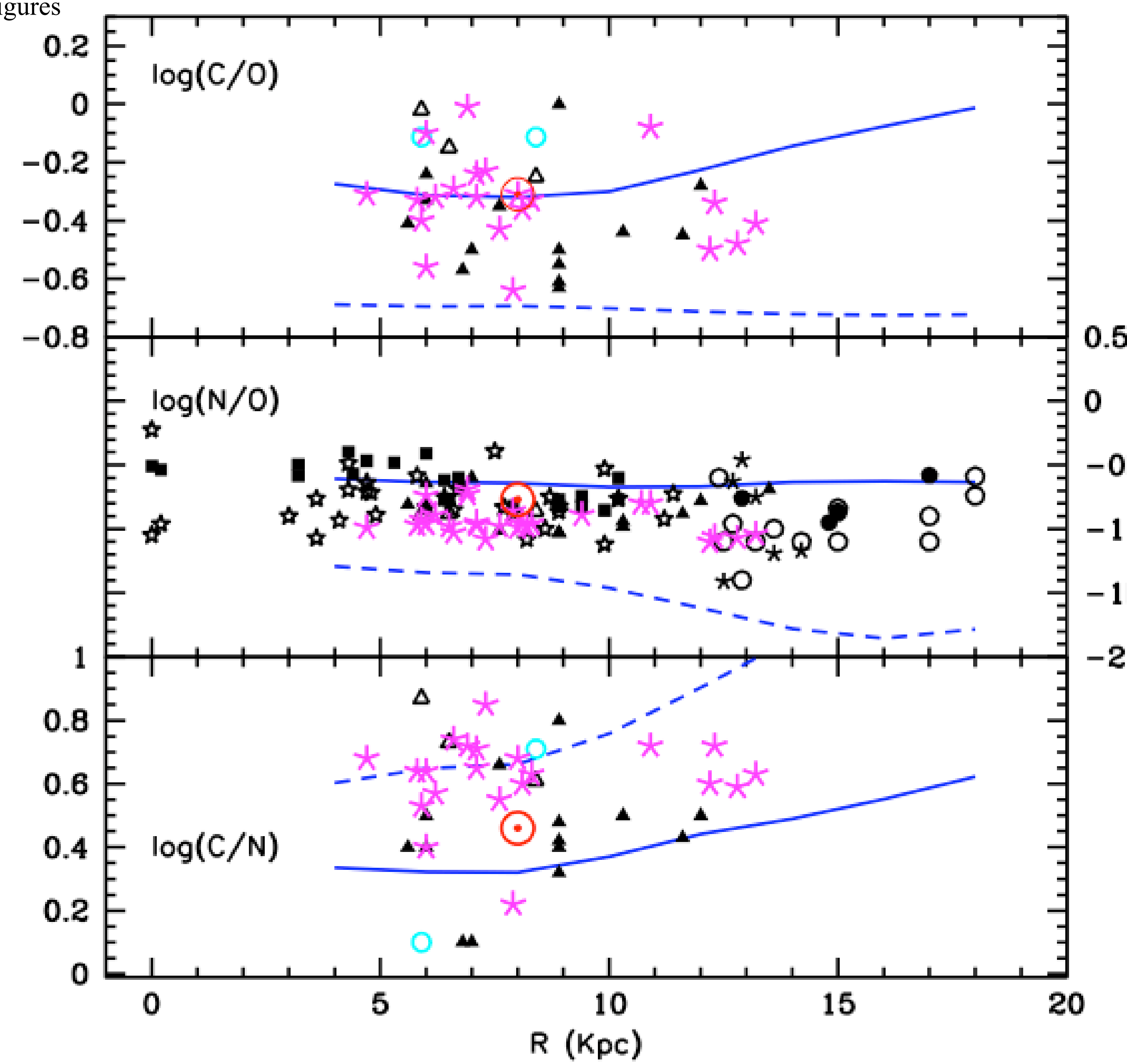
Blue curves - Chemical evolution models computed with WW95 + vdHG yields

Red curves - Chemical evolution models computed with MM yields (which takes into account stellar rotation)

Symbols and green curve as in the previous figure



Symbols and curves as in previous figures

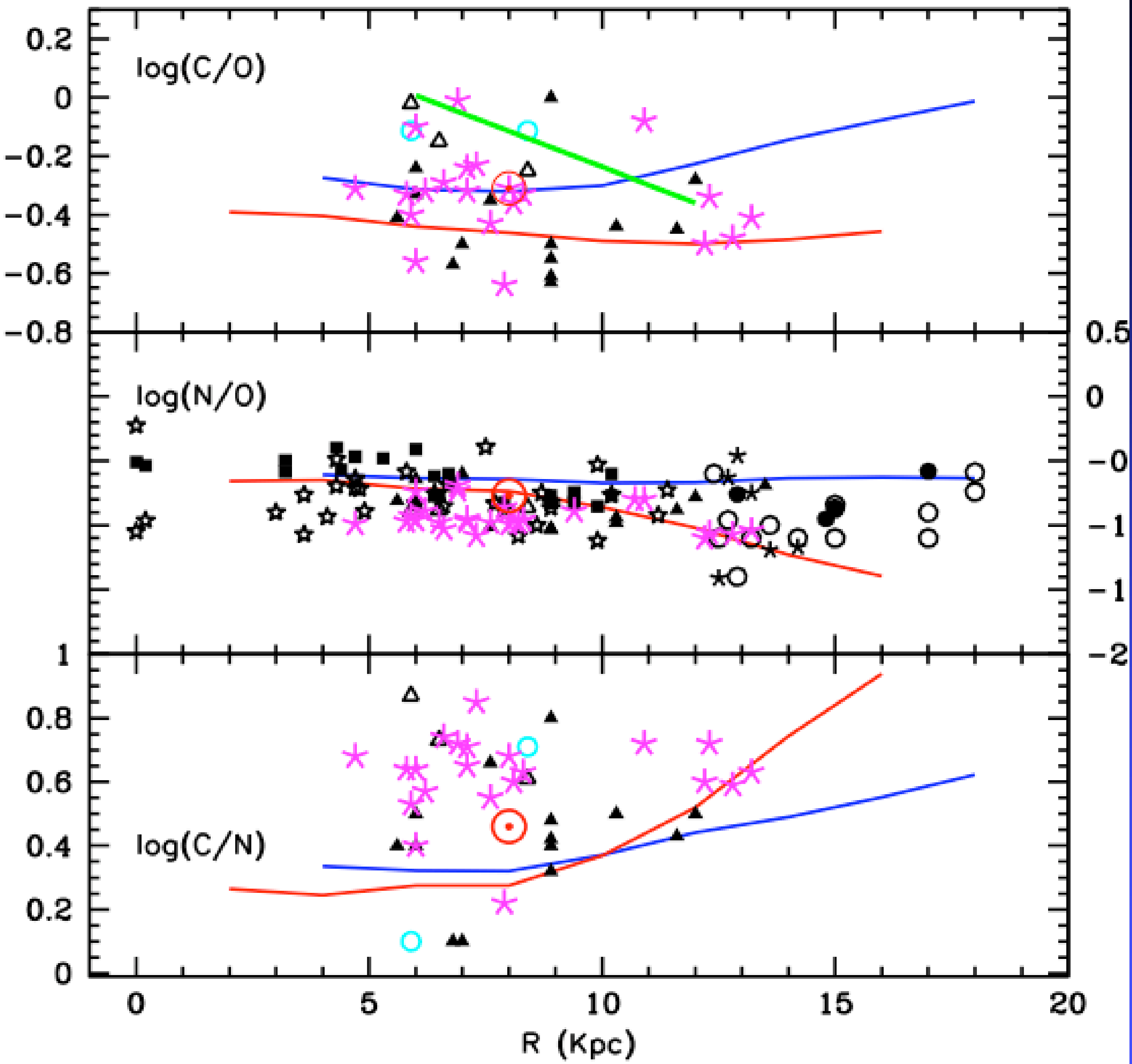


HII regions of Tsamis et al

Present abundance gradients computed with models adopting:

WW95+vdHG yields (blue curves)

Meynet & Maeder yields (red)

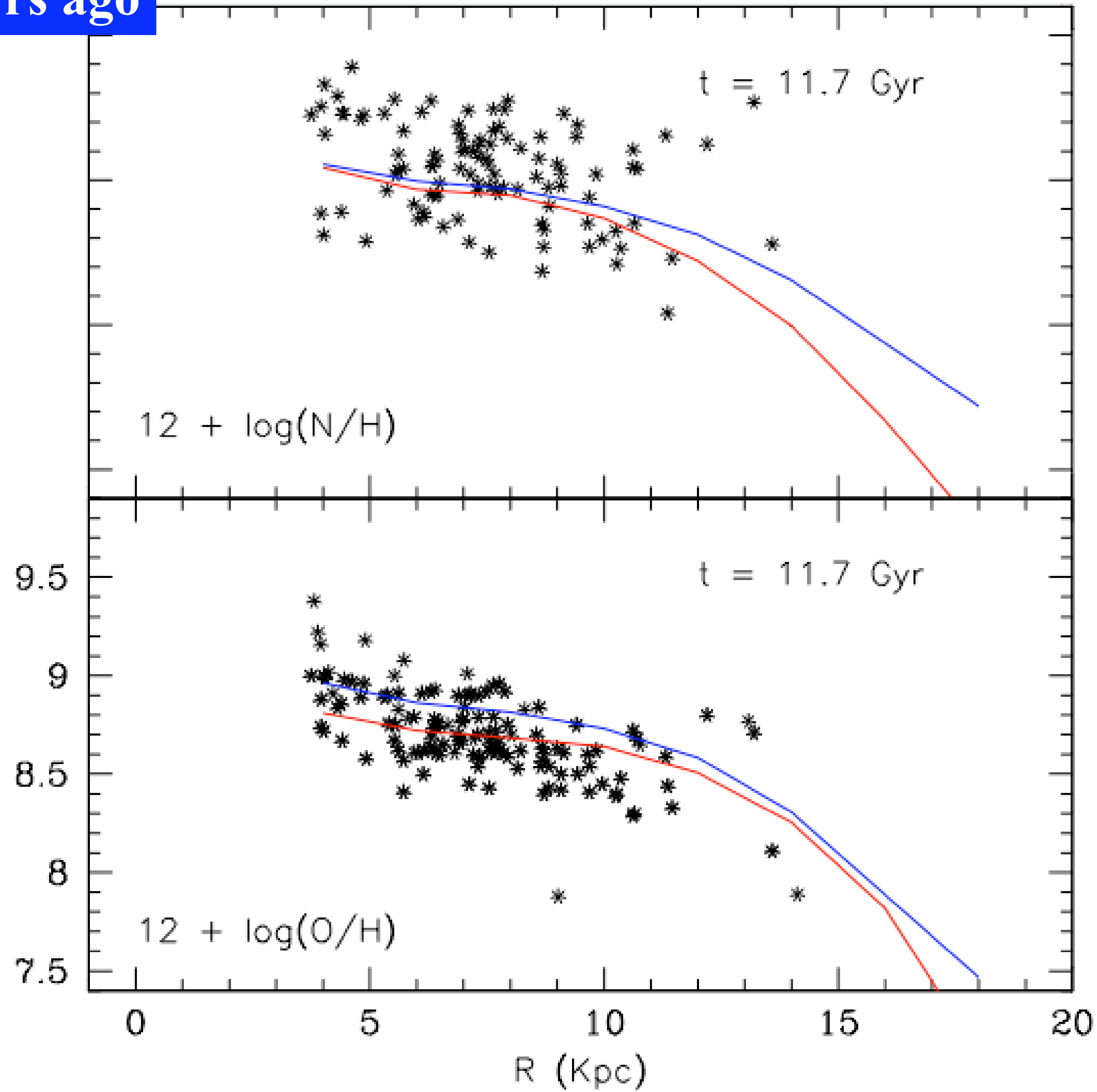


HII regions of Tsamis et al

N/O Gradients are sensitive to primary N production in IMS (Diaz & Tosi 1986)

Gradients 2 Gyrs ago

Planetary Nebulae Type IIb (Maciel & Quireza 1999)



SUMMARY:

- LIMS are required to explain the high C/O observed in the Sun and in solar metallicity stars. With the new stellar yields, massive stars cannot do this job alone! LIMS are also needed to explain the observed gradients of C and N along the galactic disk.

- More data is needed to better understand the C/O gradient which imposes strong constraints both on the CEMs and on stellar models. Here the differences obtained from abundances from RLs and CEL are important and have to be better understood.

- With MM02 yields (which include rotation+mass loss) we obtain a negative abundance gradient of N/O as less N is produced by IMS. Their value could represent a lower limit as no HBB was considered but suggests HBB could be less important than the quantities given by vdHG (in agreement with Marigo 2003). Moreover, rotation leads to more N and this effect has to be taken into account in CEMs. Other spiral galaxies do show N/O gradients which again imply that HBB should be moderate.