V. Chemical Evolution of the Galaxy: C, N, and O Gradients

Manuel Peimbert
Instituto de Astronomía, UNAM

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C,N, and O Galactic Gradients, Role of the Stellar Winds in the C Enrichment

Mónica Rodríguez. INAOE

Ma. Teresa Ruíz. DA, UChile

IAC

César Esteban

Jorge García-Rojas

IA-UNAM

Leticia Carigi

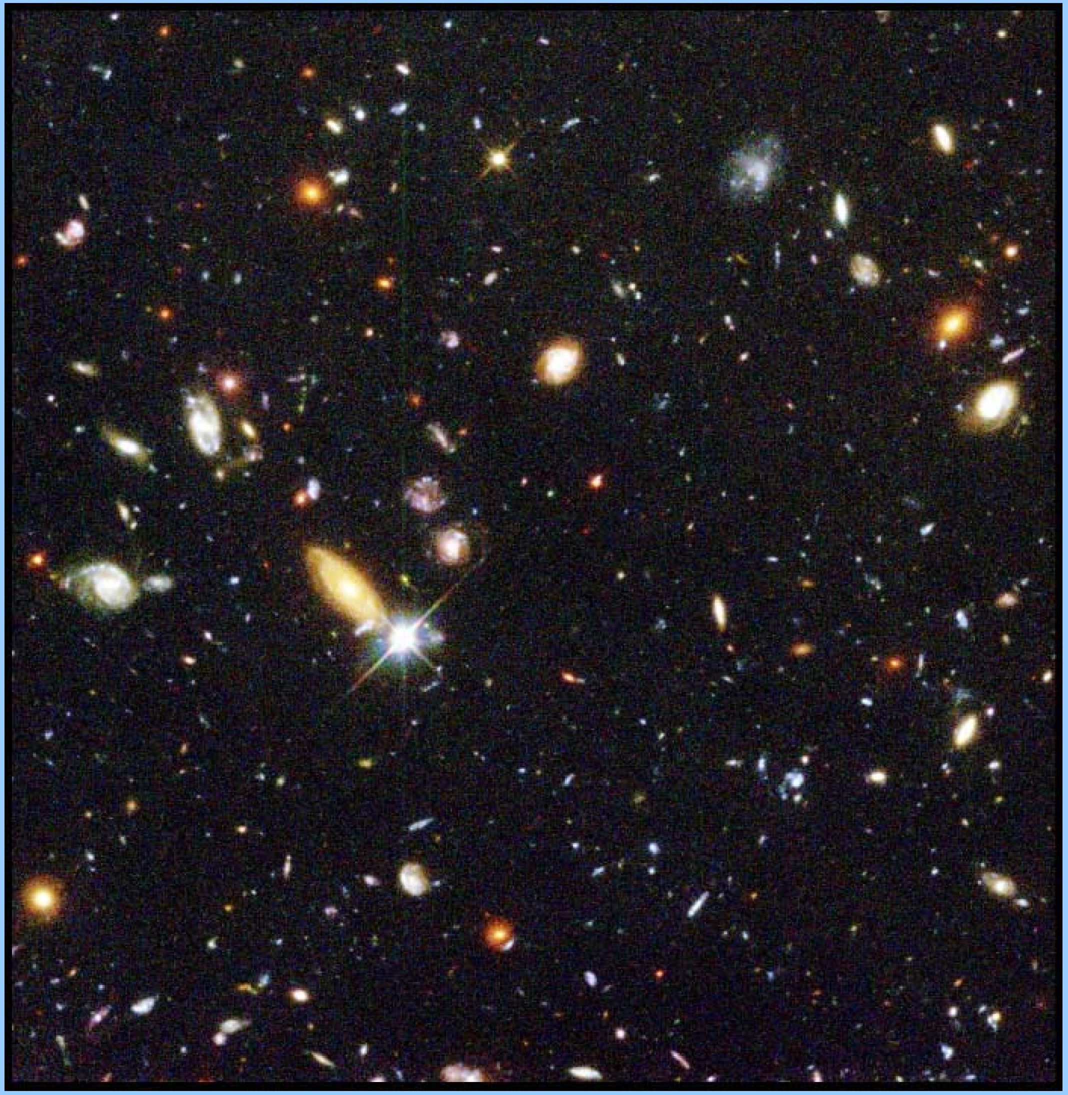
Antonio Peimbert

Manuel Peimbert

Esteban et al. (2005) ApJL, 618, L95

Carigi et al. (2005) ApJ, 623, 213

Introduction



The six more abundant elements in the Universe are:

Hydrogen

Helium

(biogenic) **Oxygen**

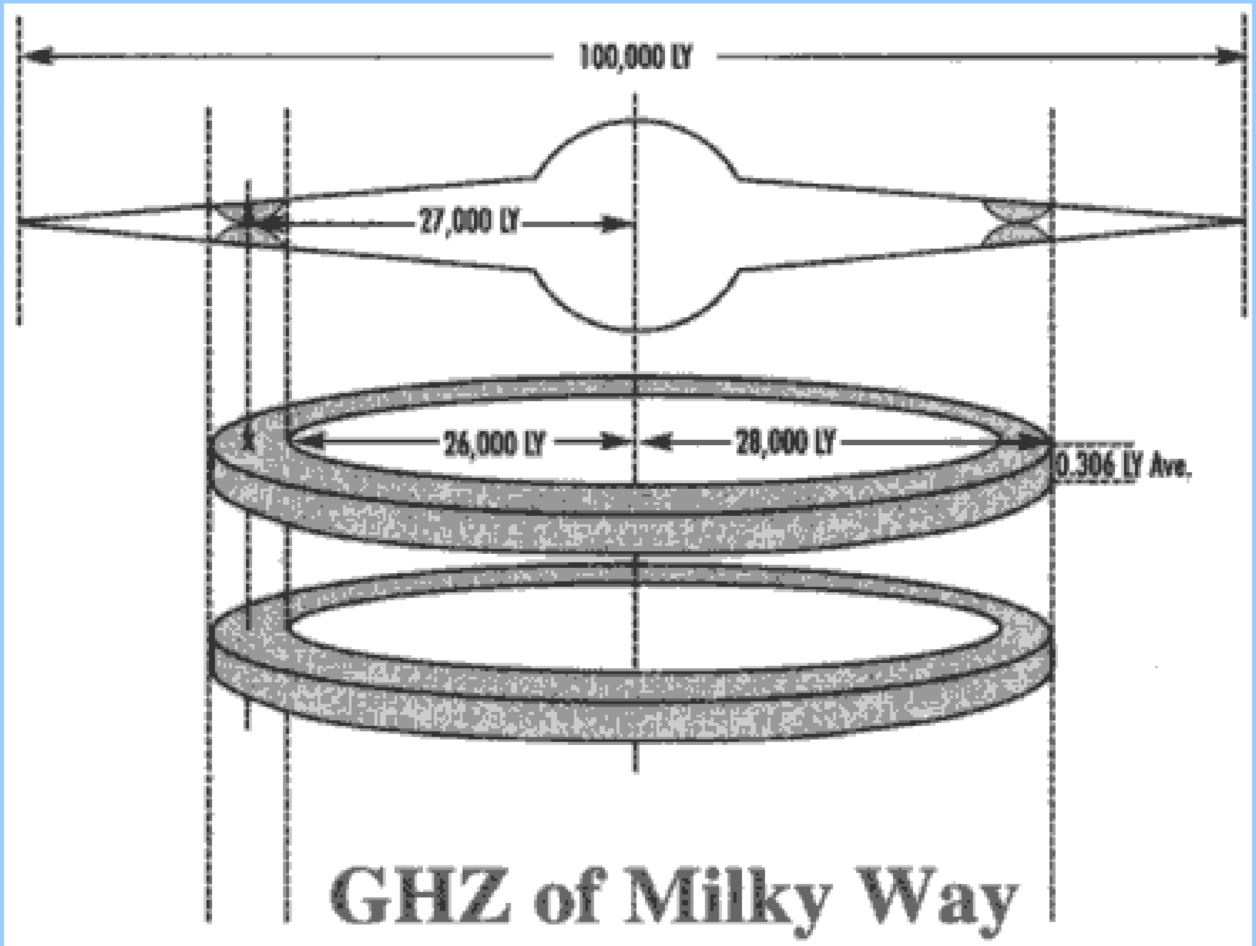
(biogenic) **Carbon**

Neon

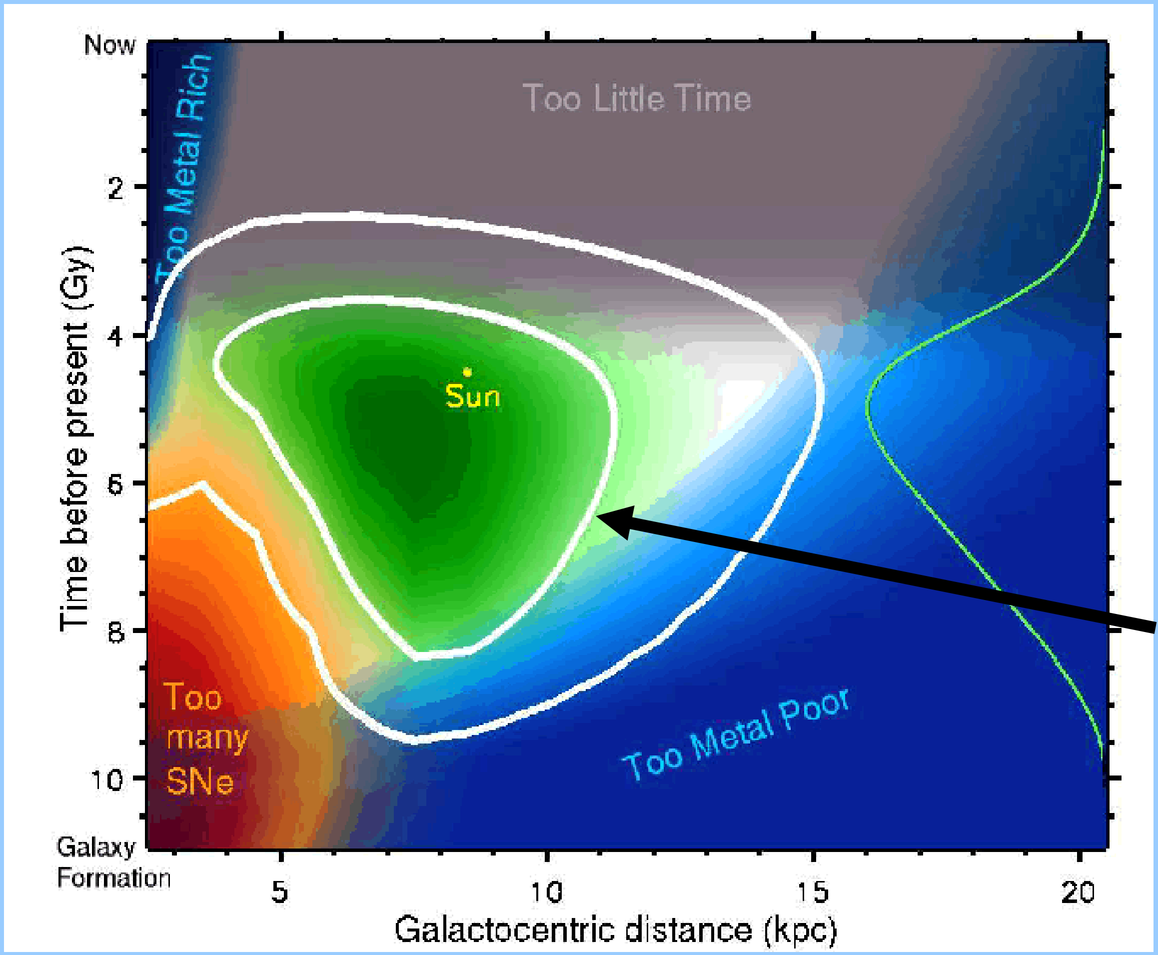
(biogenic) **Nitrogen**

GALACTIC CHEMICAL EVOLUTION

After Lineweaver et al. (2003):



GALACTIC CHEMICAL EVOLUTION



Lineweaver et al. (2003)

This area only Includes 10% of the stars in the Galaxy

Probability of harboring complex life forms as a function Oof the age and position in the Galaxy (assuming that 4Gy are needed for biological evolution)

RELEVANCE OF THE C/O GRADIENT

- C and O are biogenic elements (Galactic Habitable Zones)
- Previous data was not good enough to determine if the C/O gradient was flat, positive, or negative.
- C/O is crucial to study the nucleosynthetic origin of C.
- O is formed by massive stars

OBSERVATIONAL DATA

- C/H, N/H, O/H for 8 H II in the 6.3 to 10.4 kpc range

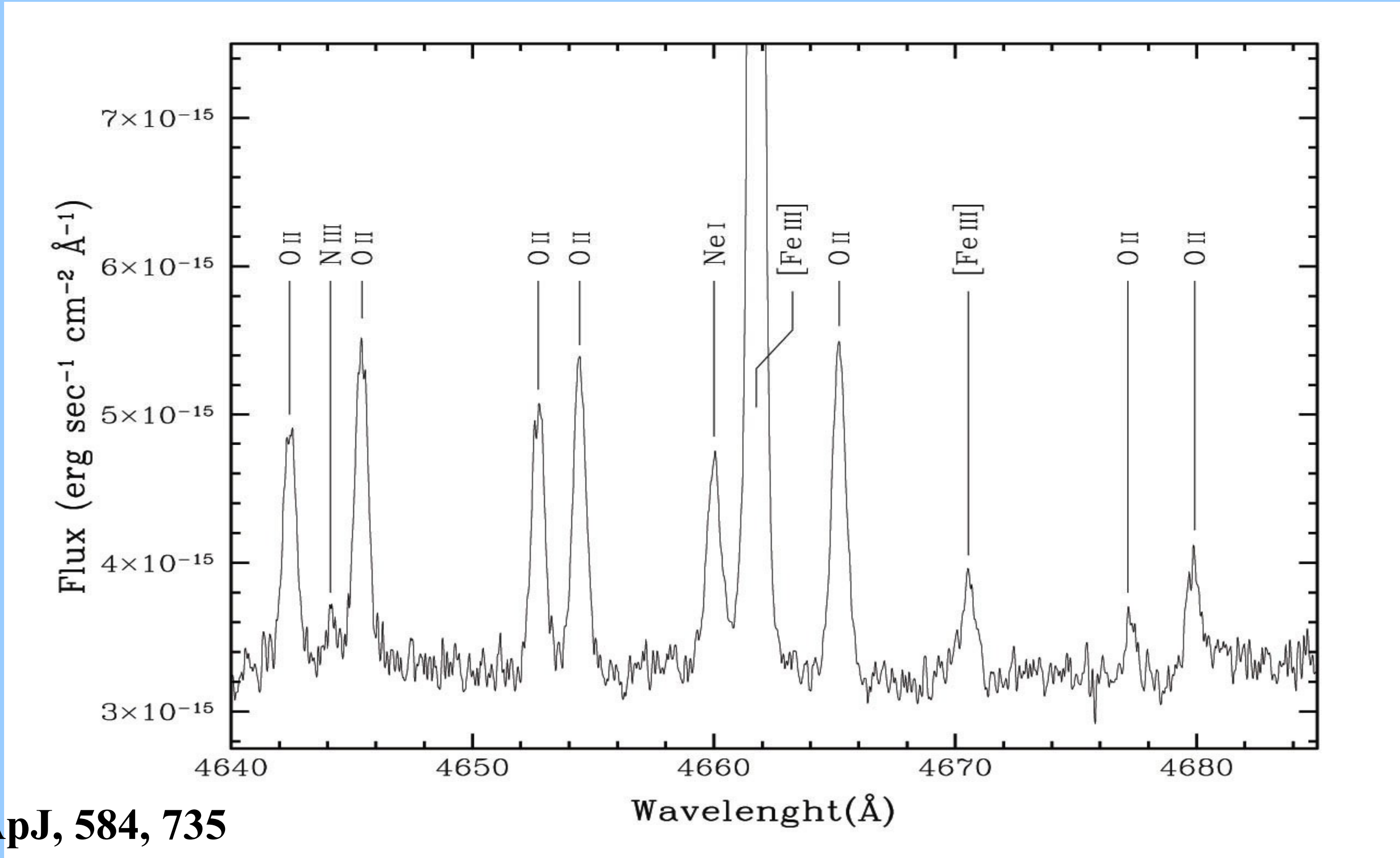
- VLT from Paranal and the UVES spectrograph in the 3100 – 10360 A region.

- Abundances based on recombination lines.

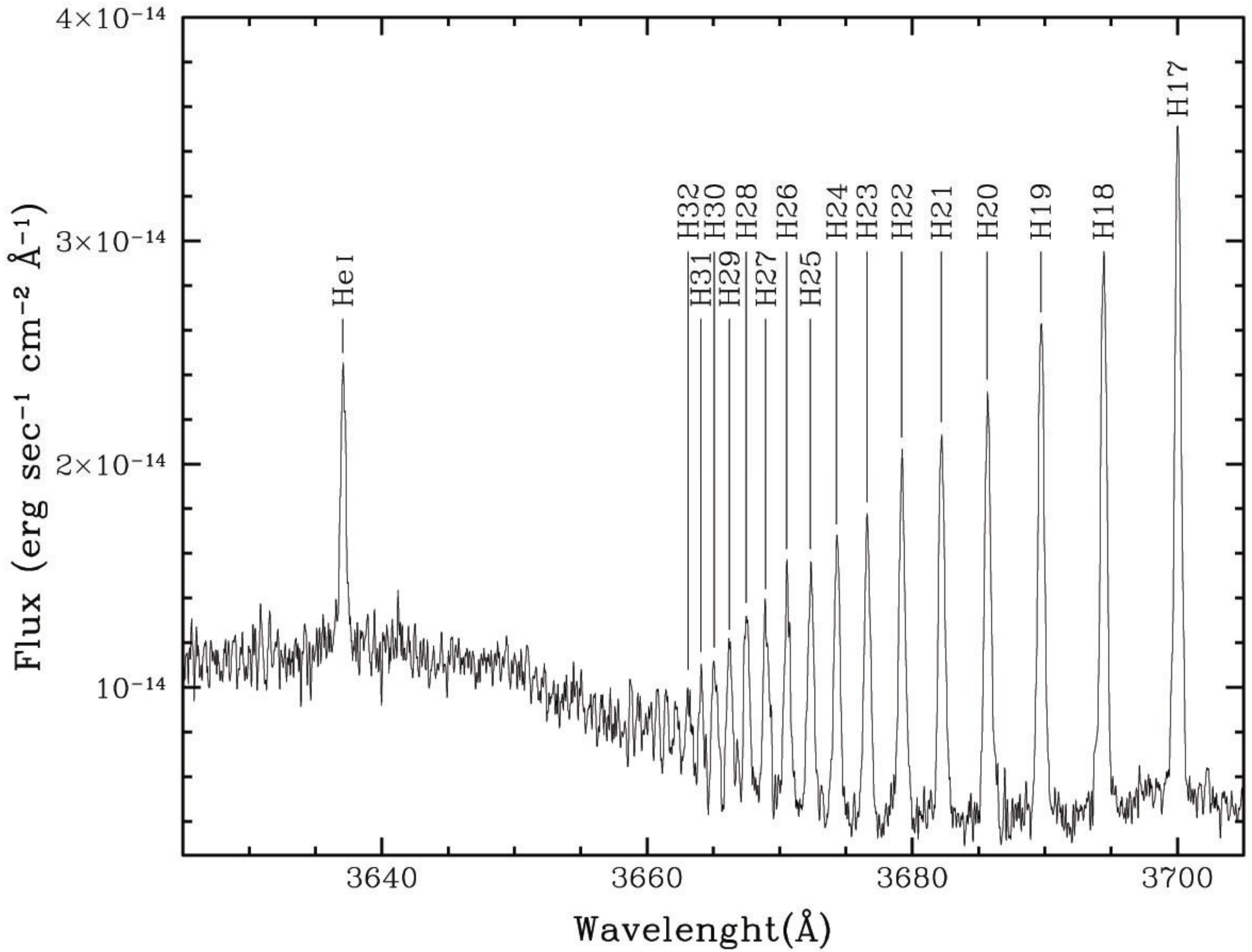
- $t^2 = 0.022 – 0.038$

O II Recombination Lines, Multiplet 1

Due to their faint intensity < 0.0006 I (Hβ) and to blends with other lines, it is usually not possible to measure all 8 lines of this multiplet.

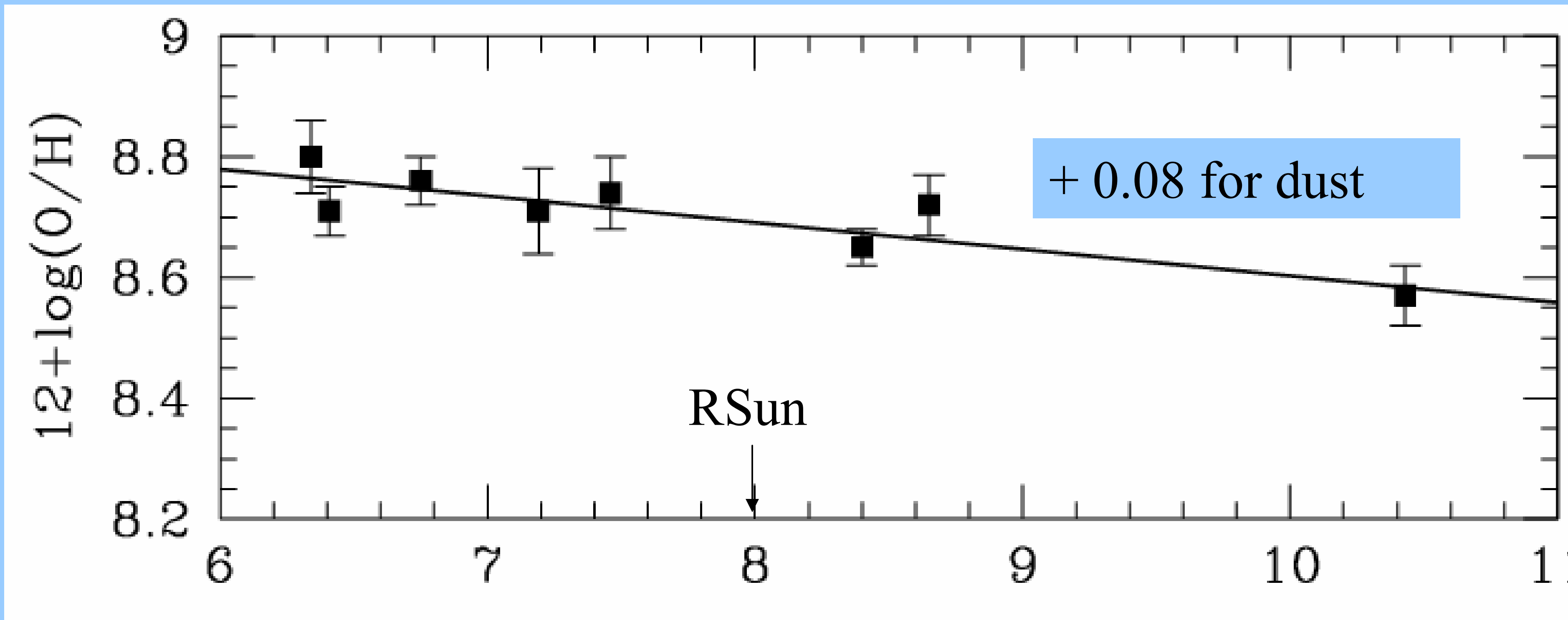


Peimbert, 2003, ApJ, 584, 735



Flux (erg sec⁻¹ cm⁻² Å⁻¹)
4×10⁻¹⁴
3×10⁻¹⁴
2×10⁻¹⁴
10⁻¹⁴
3640
3660
3680
3700
Wavelenght(Å)
He I
H32
H31
H30
H29
H28
H27
H26
H25
H24
H23
H22
H21
H20
H19
H18
H17

Oxygen



Δ(O/H)= - 0.044 dex/kpc

12 + log (O/H) (RSun)= 8.77

Shaver et al. (1983) = -0.080

Afferbach et al. (1997) = -0.070

Deharveng et al. (2000) = - 0.040

Pilyugin (2003) = - 0.051

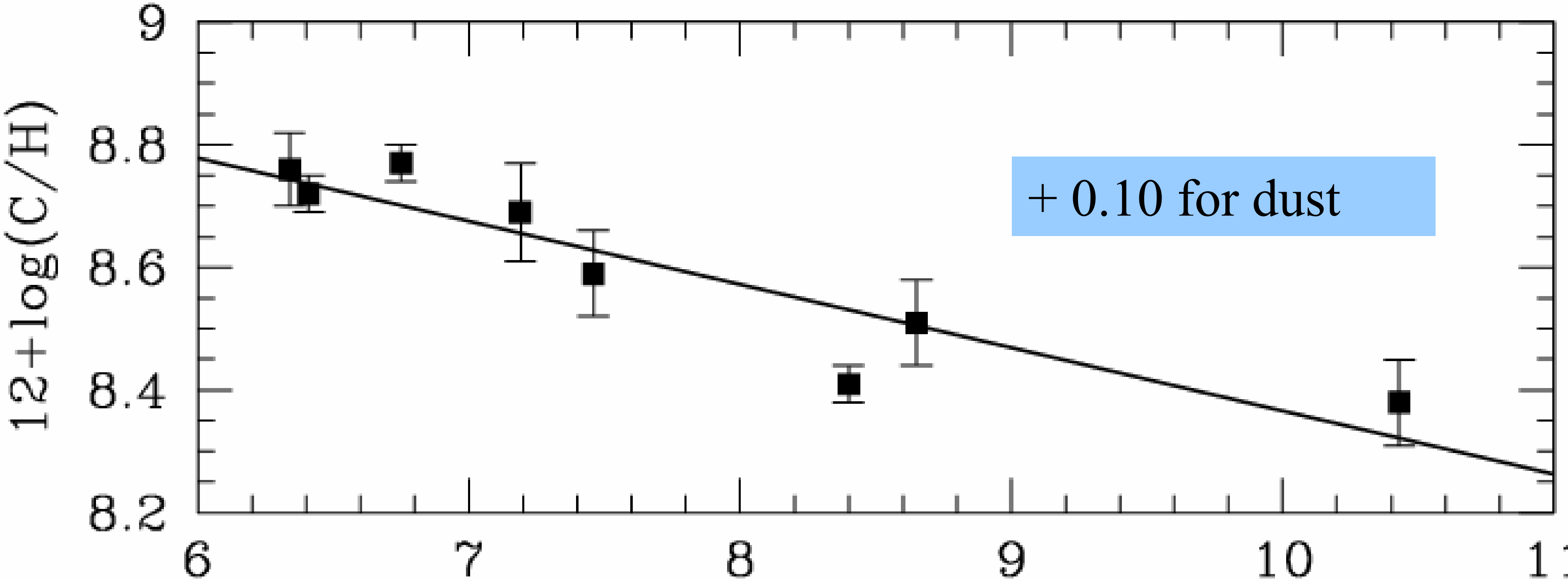
12 + log(O/H)(Sun)= 8.66 (Asplund et al. 2005)

O/H ↑ in the last 4.57 Gy

O/H ~ 2 × O/H

Recombination $t^2 \neq 0.0$ Forbidden $t^2=0.0$

Carbon



12 + log (C/H) (SV)= 8.67

12 + log(C/H)(Sun)= 8.39

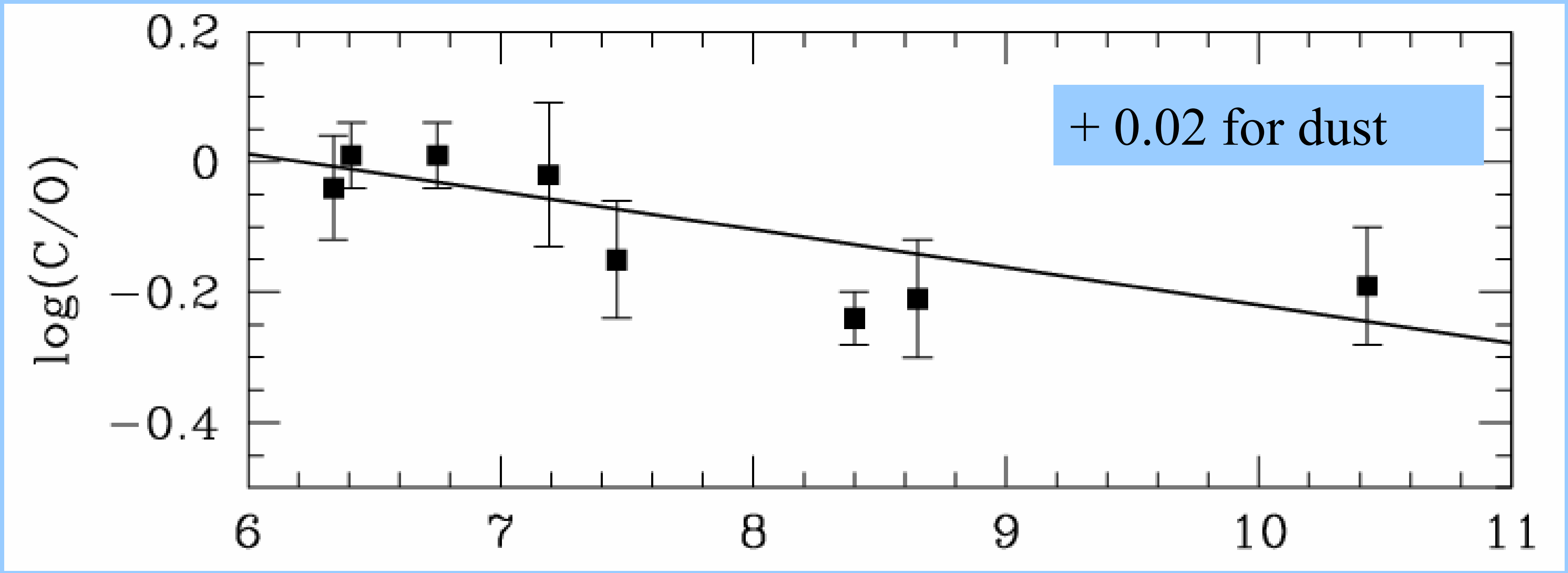
Δ(C/H)= - 0.103 dex/kpc

C/H ↑ in the last 4.57 Gy

Rolleston et al. (2000) = -0.070 (B stars)

12 + log (C/H) (RSun) ~ 7.7 (B stars)

Carbon/Oxygen



Δ(C/O)= — 0.058 dex/kpc

Smartt et al. (2001) = - 0.050 (B stars)

Garnett et al. (1999) = - 0.04 (M 101)

= - 0.05 (NGC 2403)

log (C/O)(solar vicinity)= -0.10

log(C/O) (Sun)= - 0.27

(Asplund et al. 2005)

C/O is paramount to test stellar evolution models and to determine the nucleosynthetic origins of C

Chemical evolution models of:

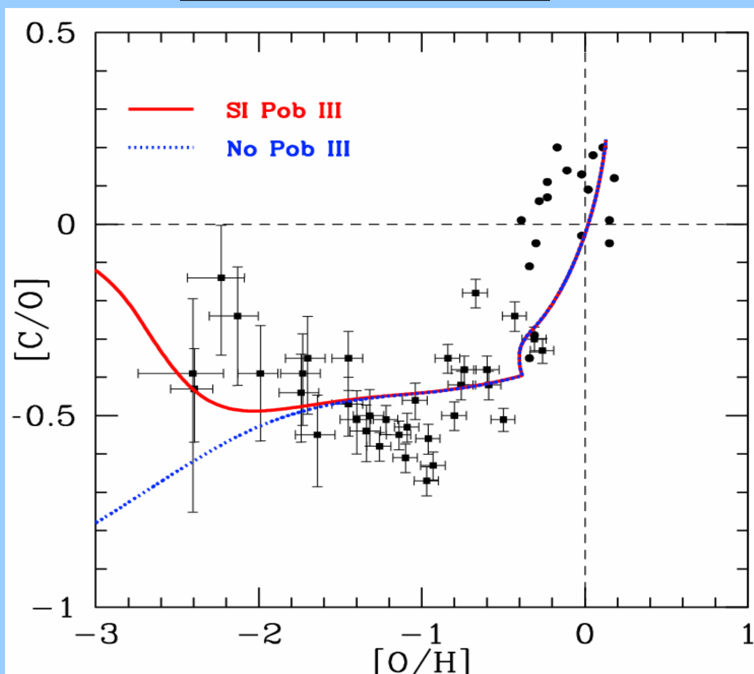
1) The solar vicinity

2) The Galactic disk

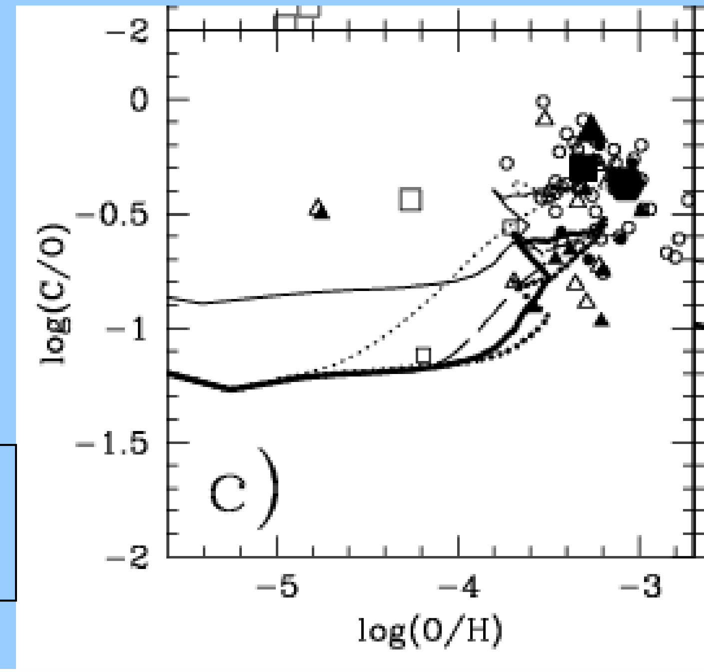
By different authors

The available models reproduce the history of C/O vs O/H of the solar vicinity in a similar fashion

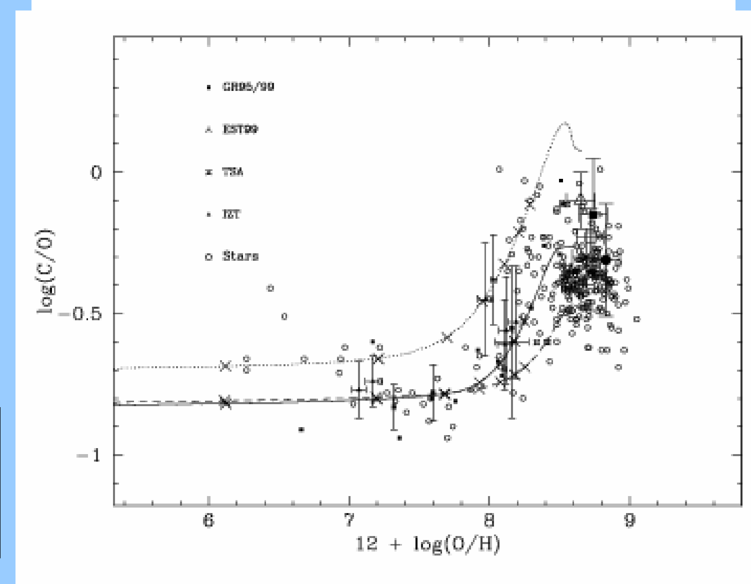
Akerman et al. (2004)



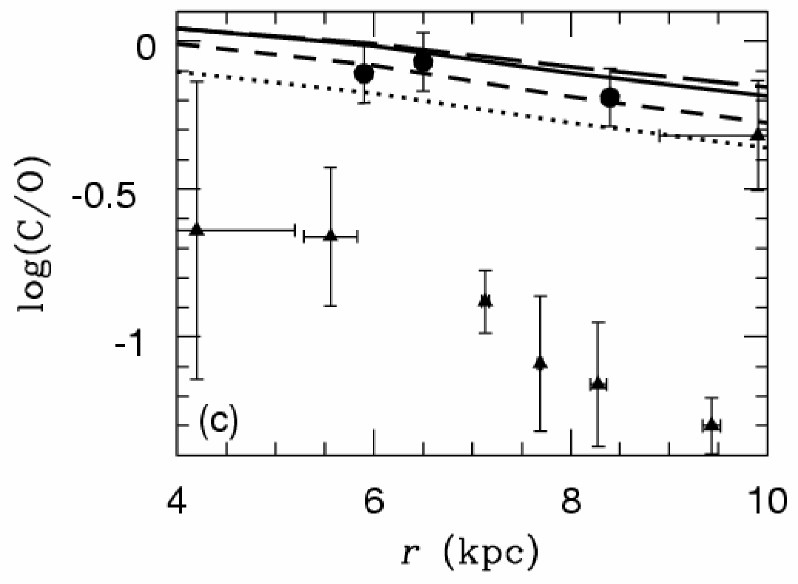
Romano et al. (2003)



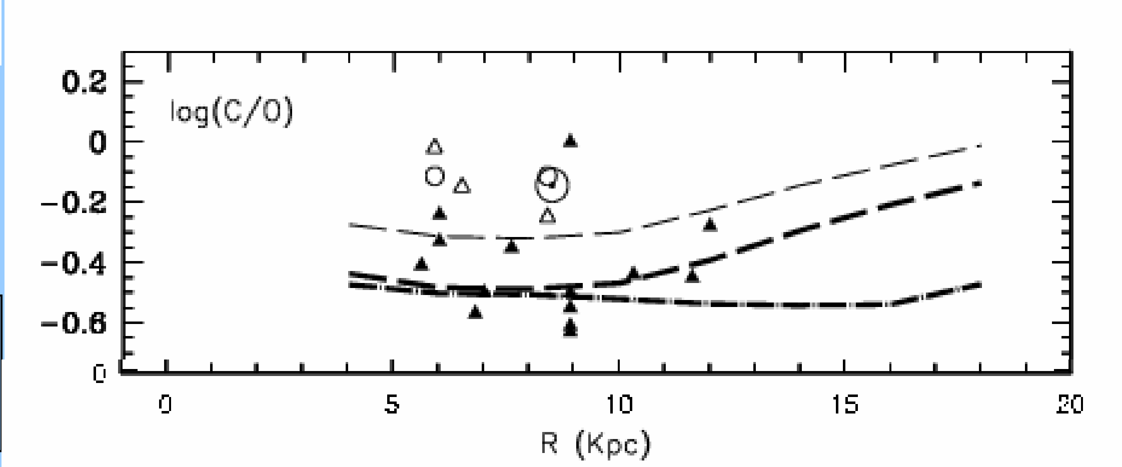
Gavilán et al. (2005)



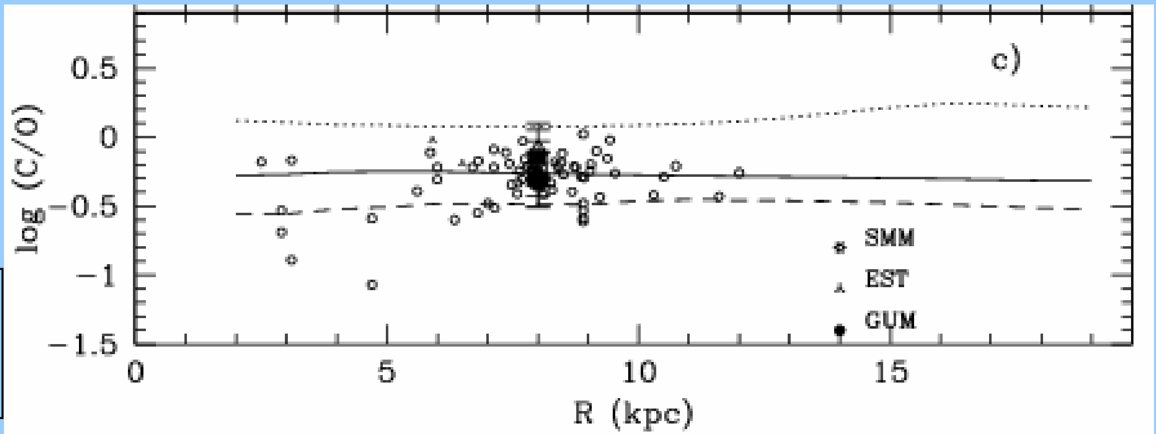
But these models predict different C/O gradients



Carigi (2003)



Romano et al. (2003)



Gavilán et al. (2005)

Why the predicted C/O gradients by the models are different?

The models include similar:

- Galaxy Formation History
- Star Formation History
- Initial Mass Function

But different:

C Yields

(Freshly made C ejected by the stars)

↓

Stellar contribution (from MS and LIMS) to the C in the ISM

Galactic chemical evolution models

- Inside out formation
- Formation of the halo in 0.5 Gy and of the disk in 12.5 Gy
- SFR $\propto$ Mgas $^{1.4}$ Mtot $^{0.4}$
- KTG IMF, with three different slopes, α = -2.7 (for MS)

- Yields (all dependent on Z) with or without:
  - stellar winds
  - rotation
  - SN or PN
  - hot bottom burning

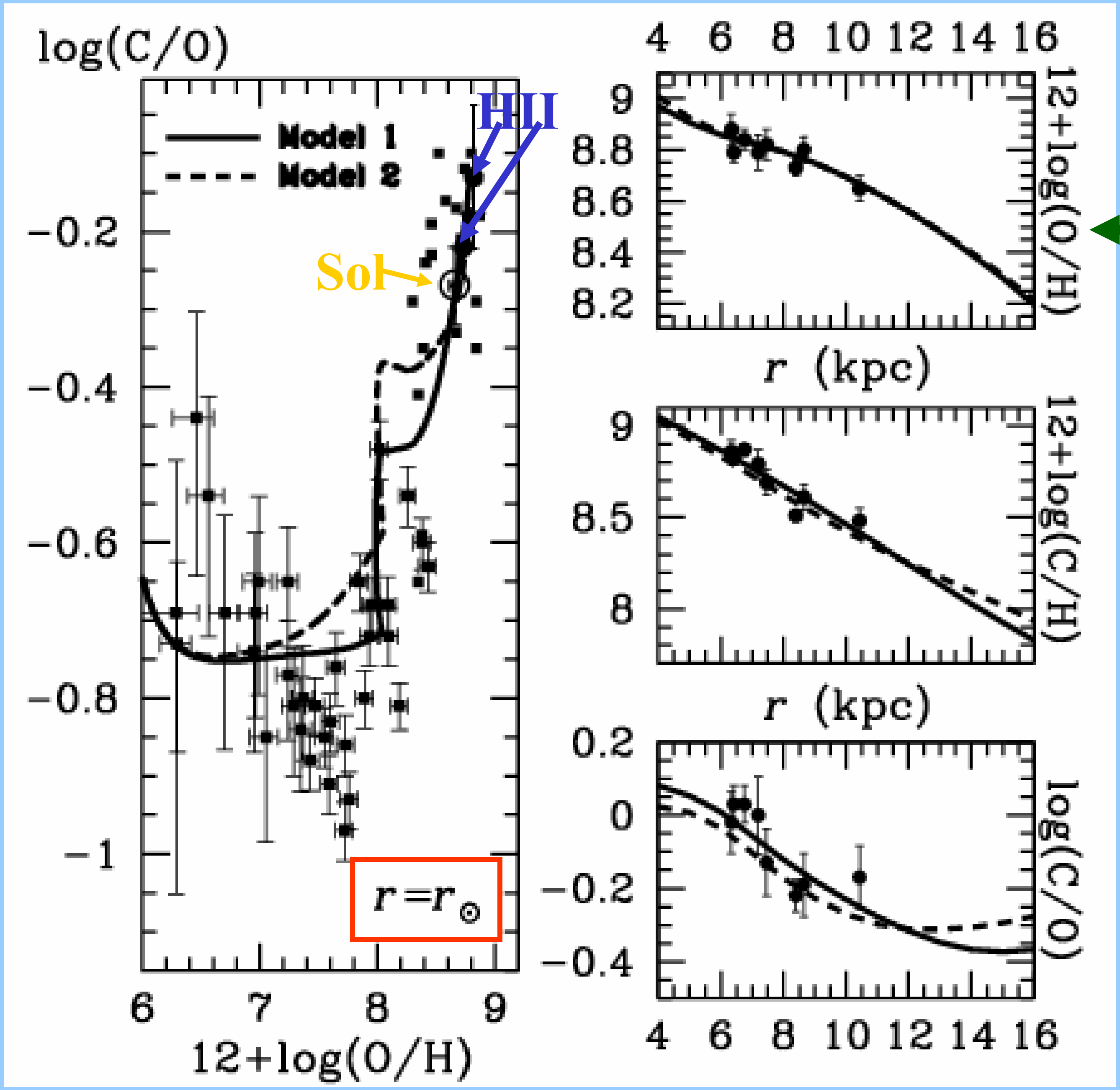
Table 2. Present-day radial gradients

	Assumed Yields			C/O	
	MS	MS	LIMS	value (dex)	slope (dex kpc^{-1})
Model	$0 < Z < 0.02$	$Z \geq 0.02$		$r = r_\odot = 8$ kpc	$6 < r/\text{kpc} < 11$
1	MM02	M92	MBCP	−0.122	−0.057
2	MM02	M92	vdHG.var	−0.172	−0.053
3	MM02	M92	vdHG.const	−0.249	−0.066
4	MM02	M92	MM02	−0.350	−0.068
5	MM02	MM02	MBCP	−0.279	−0.025
6	MM02	MM02	vdHG.var	−0.355	−0.012
7	MM02	MM02	vdHG.const	−0.410	−0.029
8	MM02	MM02	MM02	−0.542	−0.024
9	PCB98	PCB98	MBCP	−0.142	−0.004
10	WW95	WW95	vdHG.var	−0.163	−0.014
11	WW95	WW95	vdHG.const	−0.463	−0.005
Obs [a]				-0.102 ± 0.080	-0.058 ± 0.020

Romano Gavilán → 10

Stellar Winds

StellarWinds



Models made to fit:
O/H (r)
Mgas (r)

MS C ↑ if Z ↑
+
LIMS C ↓ if Z ↑

Stellar wind effects

Table 5. ISM abundance values [a]

	O/H	C/H	N/H	Fe/H	C/O
		At the time the Sun was formed (t = 8.43 Gyr)			
Model 1	8.66	8.38	7.56	7.46	−0.28
Model 2	8.66	8.36	7.89	7.49	−0.30
Solar [b]	8.66 ± 0.05	8.39 ± 0.05	7.78 ± 0.05	7.45 ± 0.05	−0.27± 0.07
		At the present time (t = 13.0 Gyr)			
Model 1	8.79	8.67	7.84	7.72	−0.12
Model 2	8.79	8.62	8.13	7.75	−0.17
H II Regions	8.77 ± 0.05 [c]	8.67 ± 0.07 [c]	7.84 ± 0.10 [d]	−−	−0.10± 0.08 [c]

[a] Given in 12 + log (X/H).

[b] Asplund et al. (2005).

Excelent agreement with the solar value

Increase in C/H and O/H during 4.57 Gy in agreement with $t^2 \neq 0.0$ and with young F and G main sequence stars of the solar vicinity

Galactic Gradient

- **From observations of H II Regions we found a solar vicinity abundance of O/H 8.77 = dex with a gradient of -0.044 dex kpc^{-1}. (Esteban et. al, 2005, ApJ, 618, 95).**

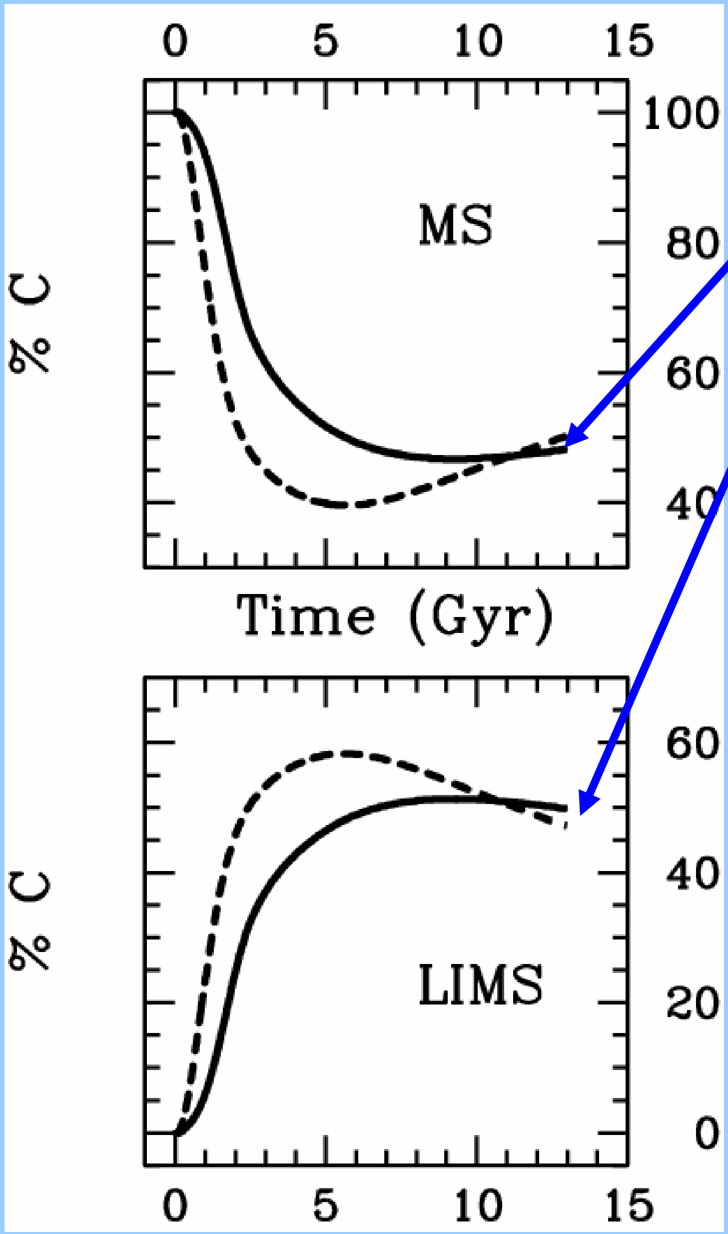
- **This value is in excellent agreement with the O/H = 8.66 dex Solar value derived by Asplund et al. (2005), and with galactic chemical evolution models that estimate that, in the 4.6 Gy since the Sun was formed, there has been an 0.13 dex increase in oxygen abundance of the ISM (Carigi et al. 2005, ApJ, 623, 213).**

Galactic Abundances From Collisionally Excited Lines, Assuming t^2=0.00

- Abundances found from studies based on oxygen forbidden lines, are almost a factor of 2 lower than those we found from solar studies and galactic evolution.
  - Pilyugin et. al (2003, A&A, 401, 557) find O/H = 8.52 dex in the solar vicinity.
  - Deharveng et. al (2000, MNRAS, 311, 329) find O/H = 8.53 dex in the solar vicinity.

- The slopes of these gradients are similar to those derived from recombination lines.

Cumulative % of Carbon

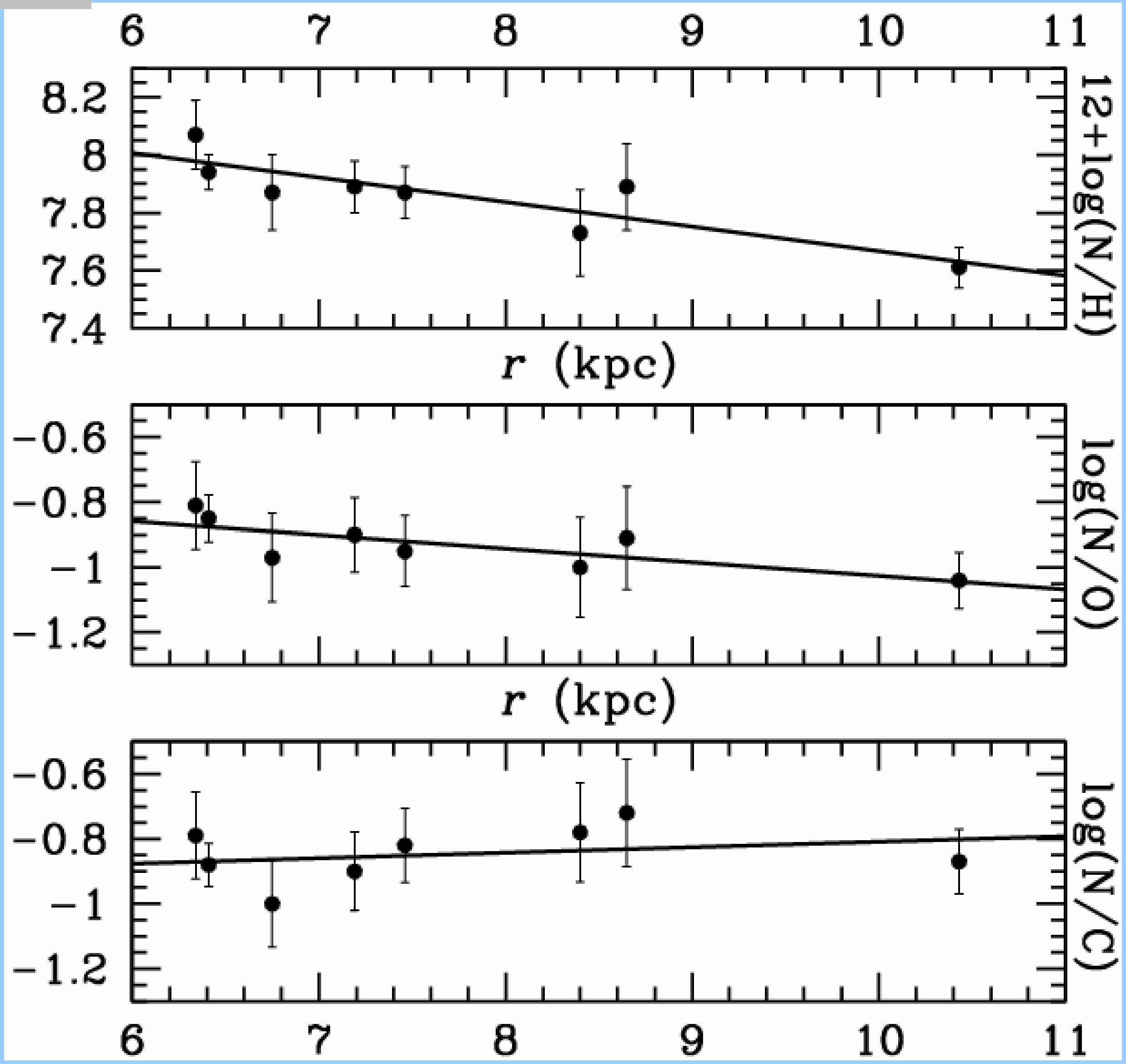


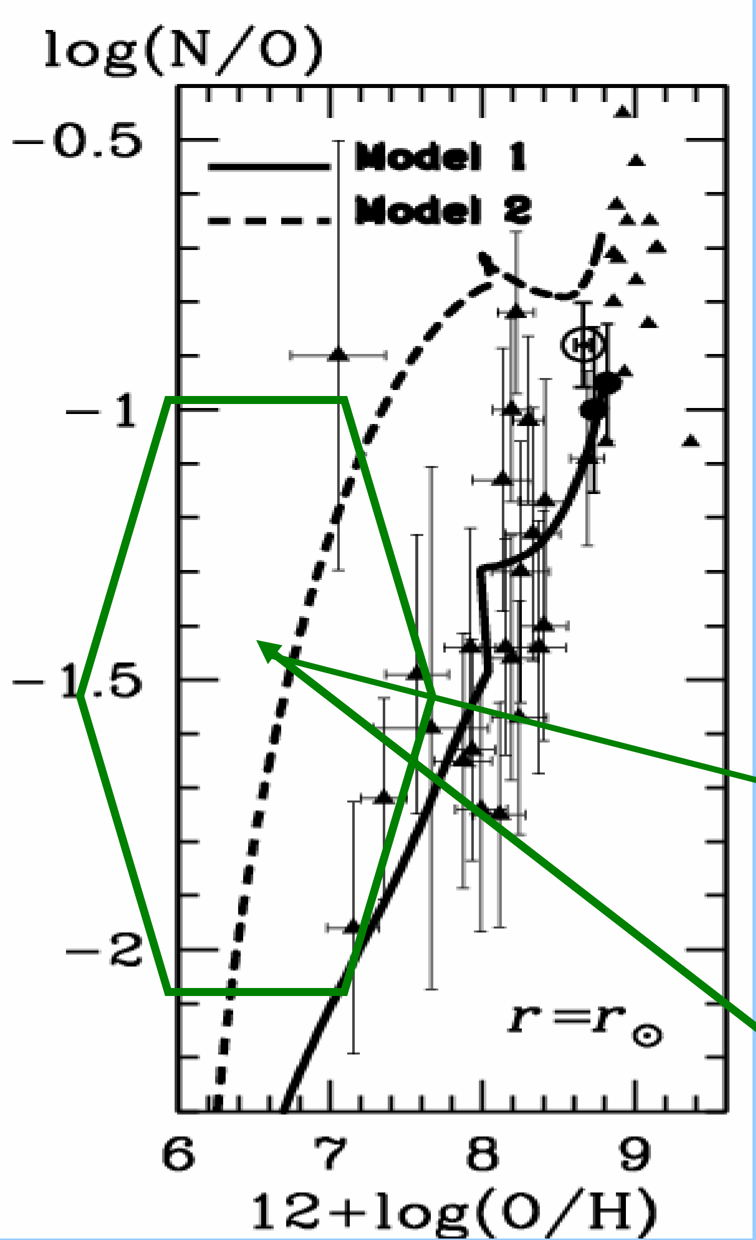
Half of the present C in the ISM at Rsun is due to MS and the other half to LIMS

Depends strongly on *t* and *r*.

r (kpc)	Contribution (per cent) MS	LIMS	SNIa
	Model 1		
4	57.0	40.8	2.2
8	48.2	49.8	2.0
16	40.8	57.2	2.1

Nitrogen


6
7
8
9
10
11
8.2
8
7.8
7.6
7.4
12+log(N/H)
r (kpc)
−0.6
−0.8
−1
−1.2
log(N/O)
r (kpc)
−0.6
−0.8
−1
−1.2
log(N/C)
6
7
8
9
10
11



<u>Data problems</u>:

- Large dispersion in the N/O values among disk stars
- H II < Sun

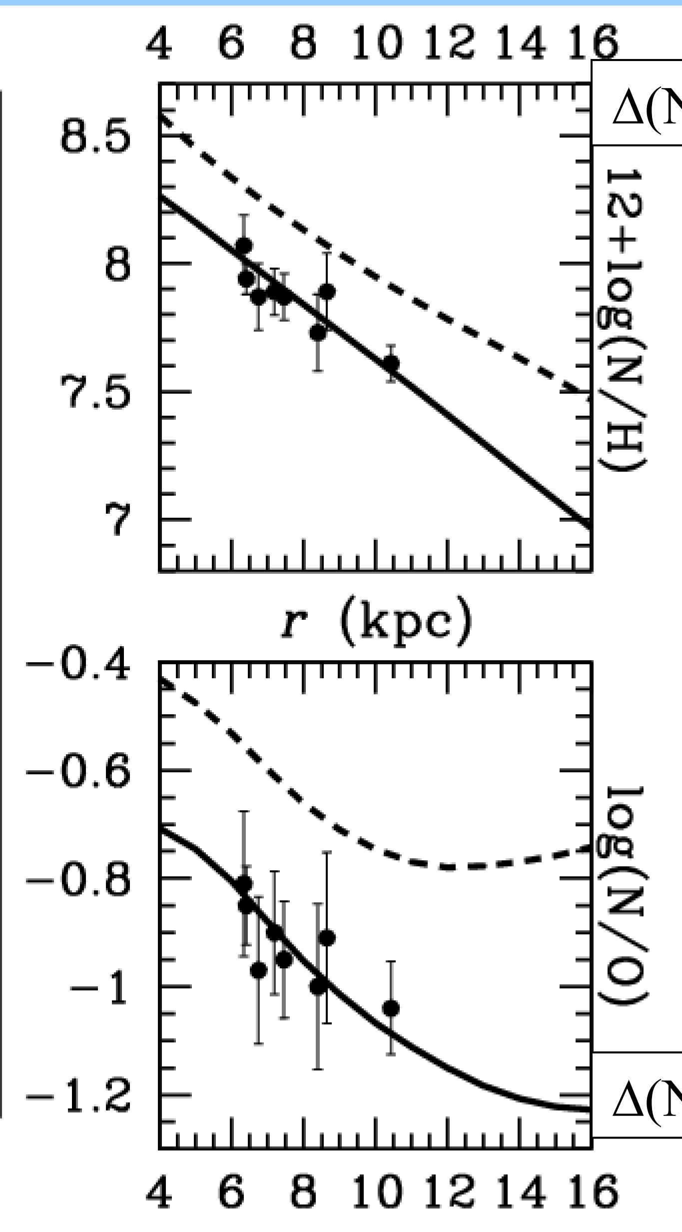
<u>Problems with N yields:</u>

- Pop III
- They do not fit stellar data

Data by Spite et al. (2005)

Confirmed by Israelian

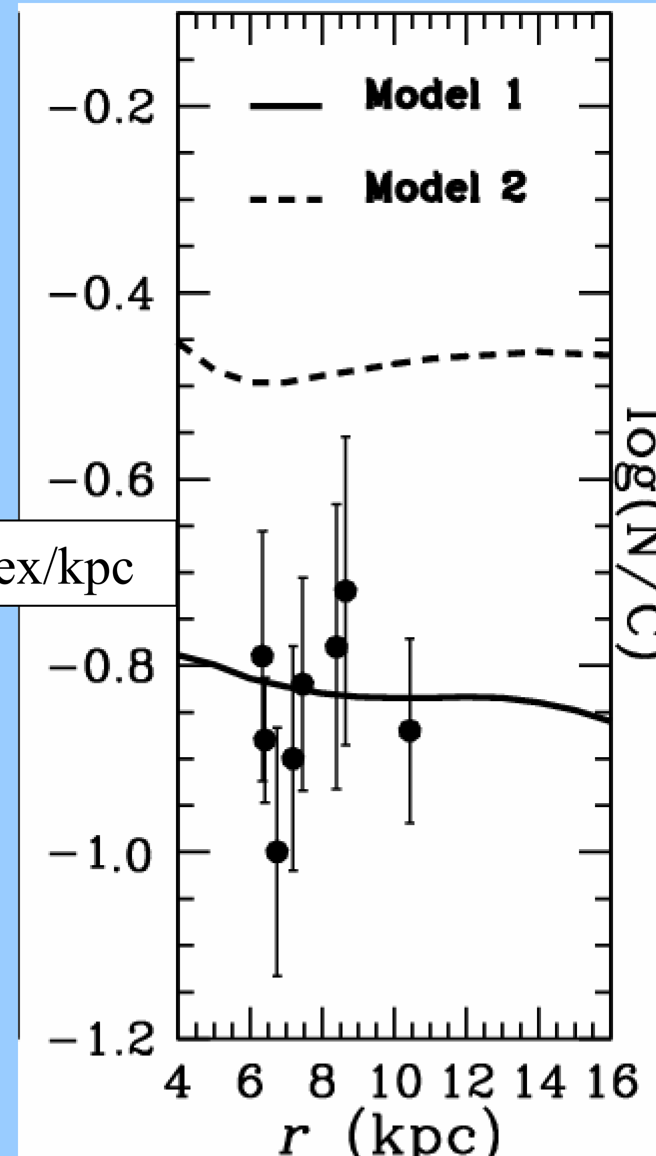
Gradients reproduced by Model 1



Δ(N/H)= - 0.085 dex/kpc

Δ(N/O)= - 0.042 dex/kpc

Δ(N/C)= + 0.017 dex/kpc



Conclusions I

A solution to the C enrichment problem based on the effects of stellar winds:

When *Z* increases the fraction of mass ejected by stellar winds increases

The C yields increase for MS

The C yields decrease for LIMS

½ of the present C in the ISM of th solar vicinity is due to MS and ½ is due to LIMS

The fraction produced by the different types of stars depends on time, location, and the SFH

Conclusions II

The O/H value derived from recombination lines of H II regions of the solar vicinity agrees with the solar value after correcting for galactic chemical evolution.

The C yields derived from collisionally excited lines under the assumption of constant *Te* are from 2-4 times smaller than those predicted by stellar evolution models of IMS.

The C/H values predicted by chemical evolution models of the Galaxy agree with those derived from recombination lines.

Conclusions III

Problems with the N enrichment:

Observational:

• Inconsistencies among the stellar data of the halo, the disk and the Sun.

•Inconsistencies between the stellar data and the H II region data.

•[N/O] ~ 0 for extremely metal poor stars?

Theoretical: Yields of N:

• Primary and secondary origin

•MS and LIMS production

• Effects due to stellar rotation and Hot Bottom Burning

• Models of population III stars

Conclusions IV

Models of chemical evolution of galaxies together with observational chemical abundances of the ISM provide us with strong constraints for:

The models of stellar evolution

The models of the evolution of galaxies in a cosmological context, including the mass assembly history, the possible presence of outflows, and the possible presence of mechanisms that might prevent the accretion of baryonic material from the intergalactic medium

THE END