Reasons to measure Oxygen abundances in the Universe

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Galactic Chemical Evolution ingredients

Stellar properties

(function of mass M and metallicity Z)

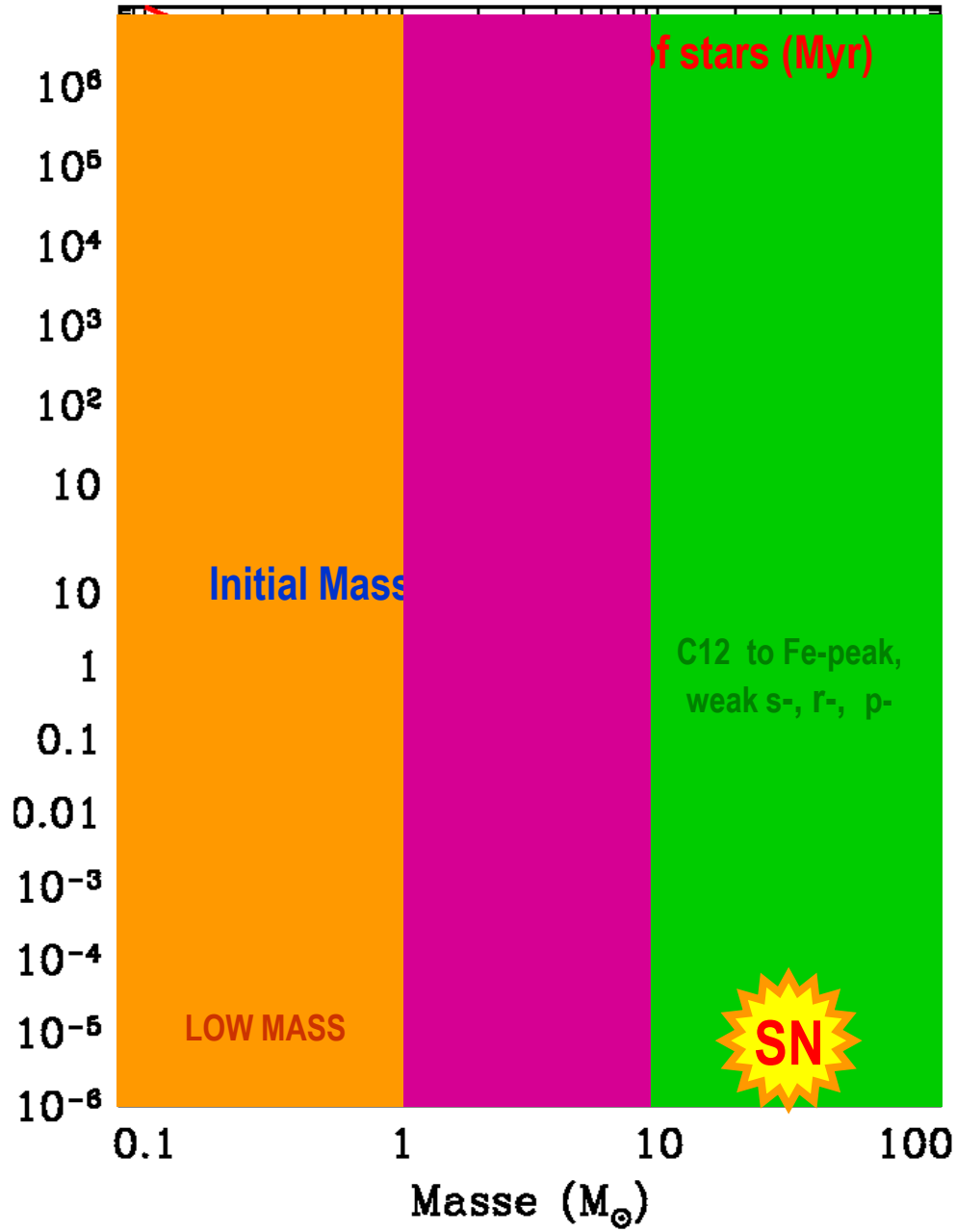
- Lifetimes
- Yields (quantities of elements ejected)
- Masses of residues (WD, NS, BH)

Collective Stellar Properties

- Star Formation Rate (SFR)
- Initial Mass Function (IMF)

Gas Flows

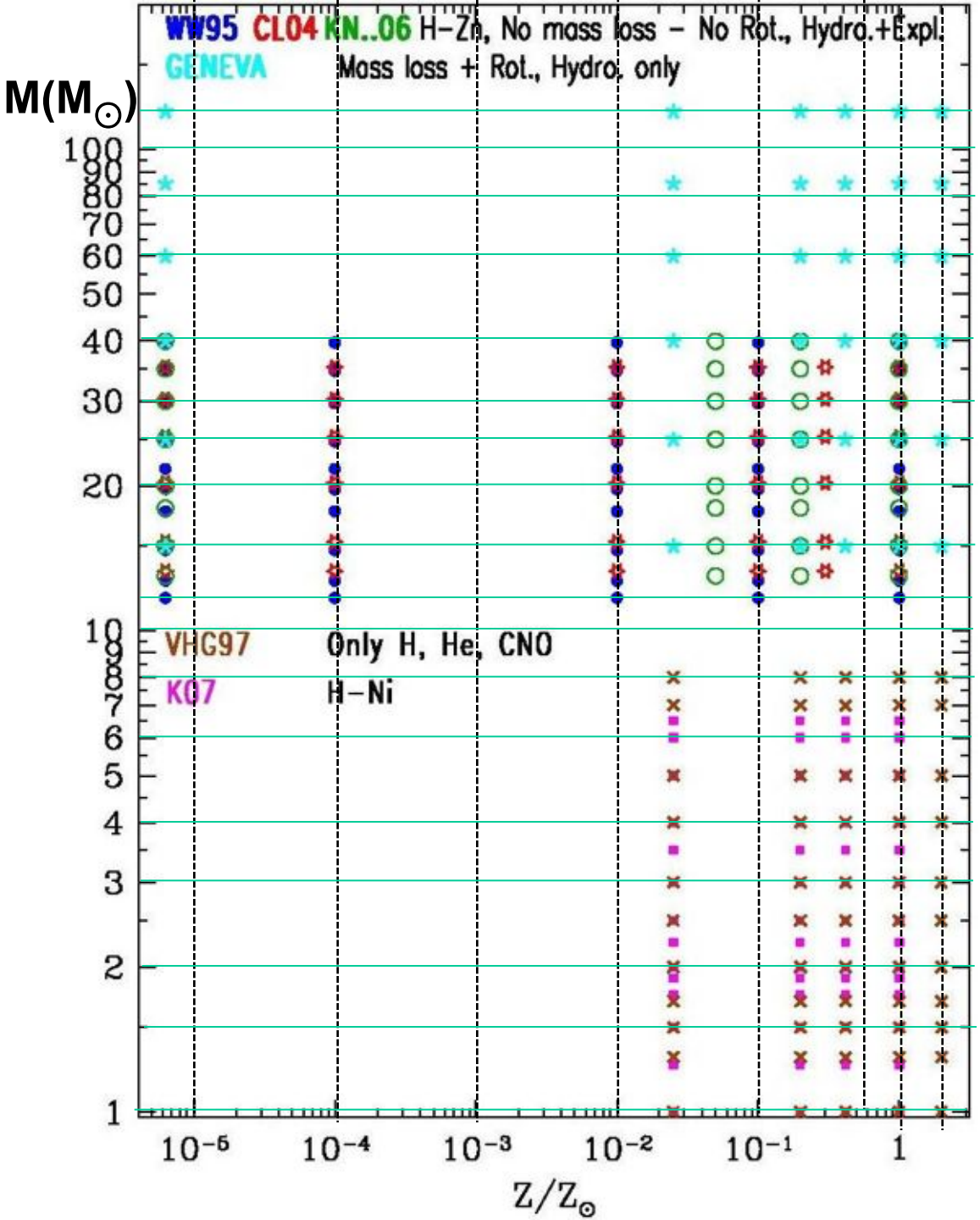
- Infall
- Outflow
- Radial inflows in disks



STELLAR YIELDS

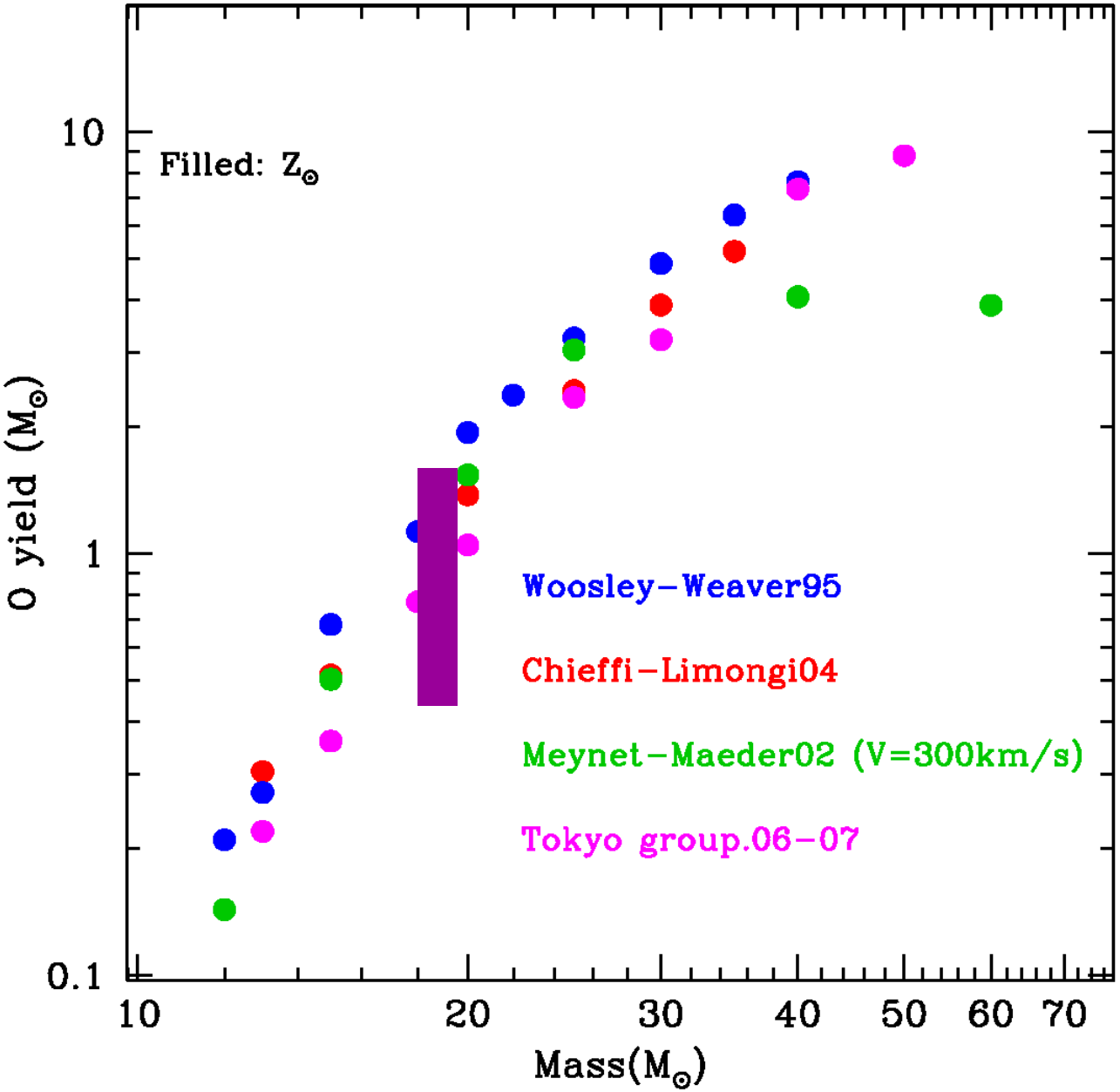
Yields of massive stars
(main oxygen producers)

Yields of intermediate and low mass stars

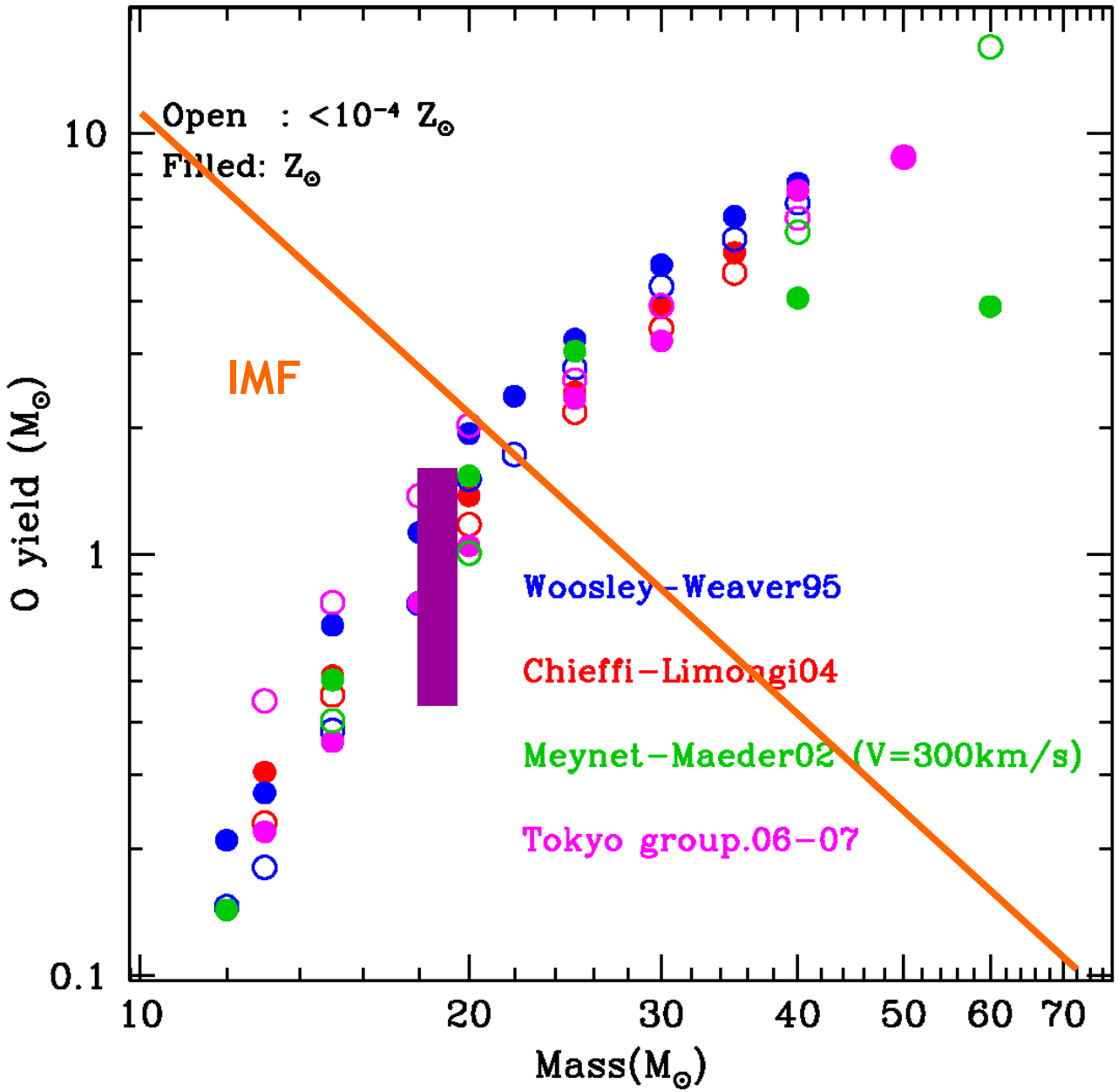


Yields of Oxygen : Physical uncertainties

(*stellar physics*: mass loss, convection ; *nuclear physics*, …)



… and uncertainties from the WAY the yields ARE USED…

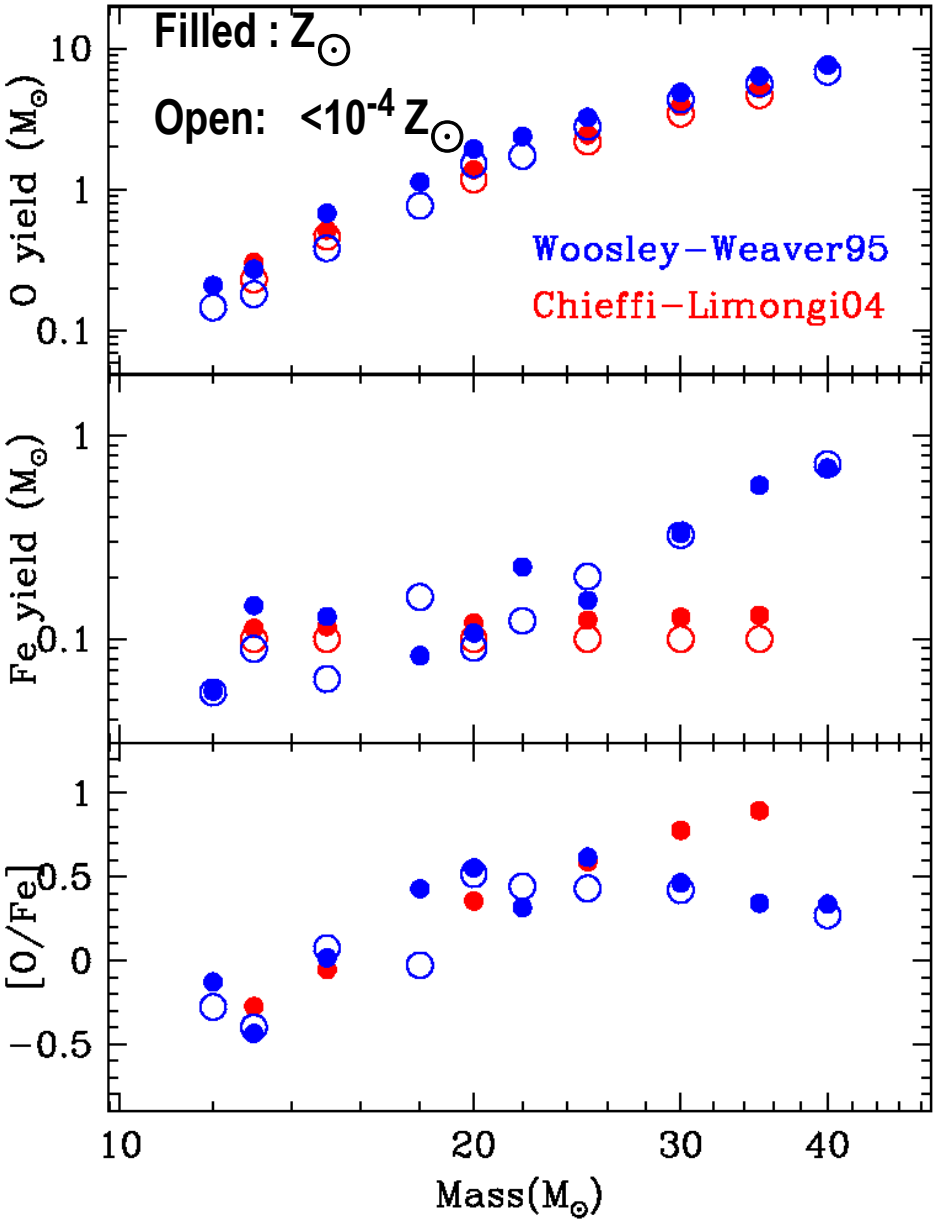


Interpolation in metallicity *(especially in the range -4 < [Fe/H] < -2*

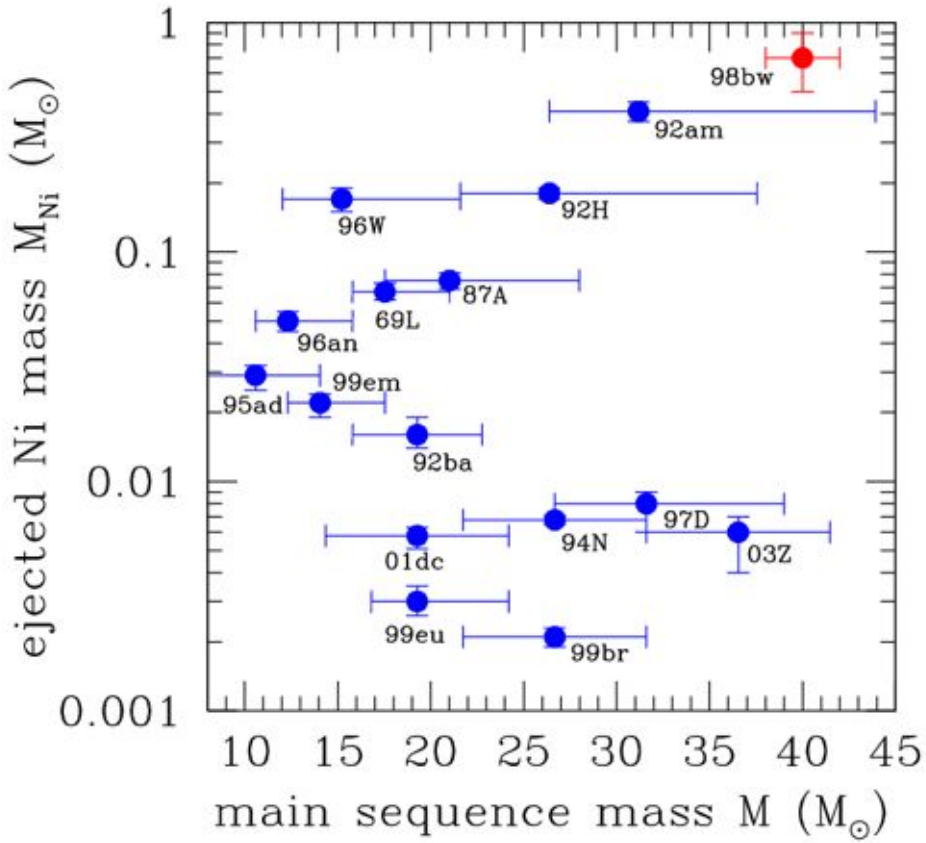
Extrapolation in mass *(M>40 M⊙ for WW95 and CL04)*

What is the fate of stars in that mass range?

...and in some cases, those uncertainties may not even the most important



Uncertainties in BOTH
O yields
(C12(α,γ) rate, convection,..)
AND
Fe yields
(explosion, "mass cut")

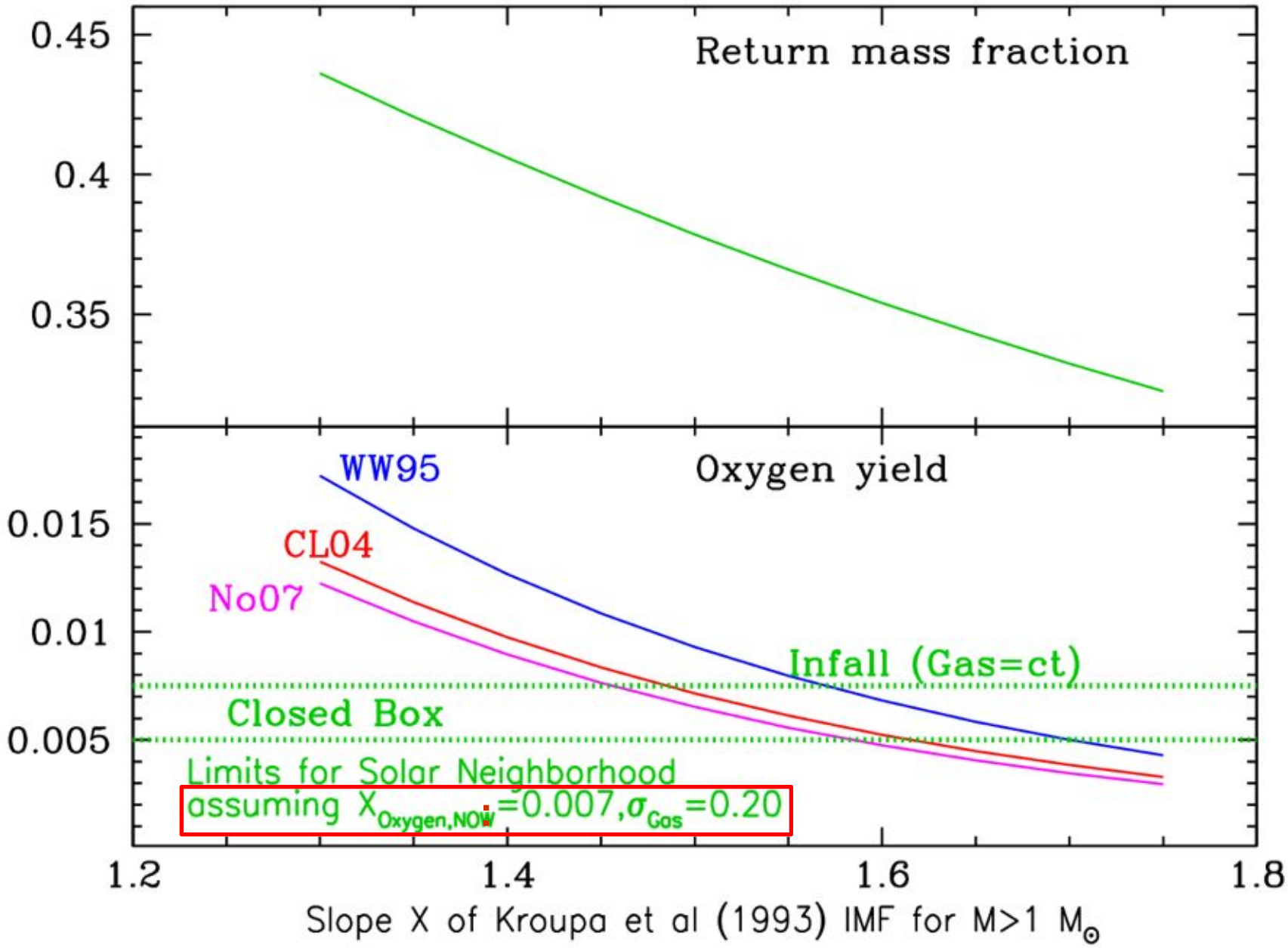


Analytical solutions with Instantaneous Recycling Approximation (IRA), as a function of *Return fraction R* and *yield p*

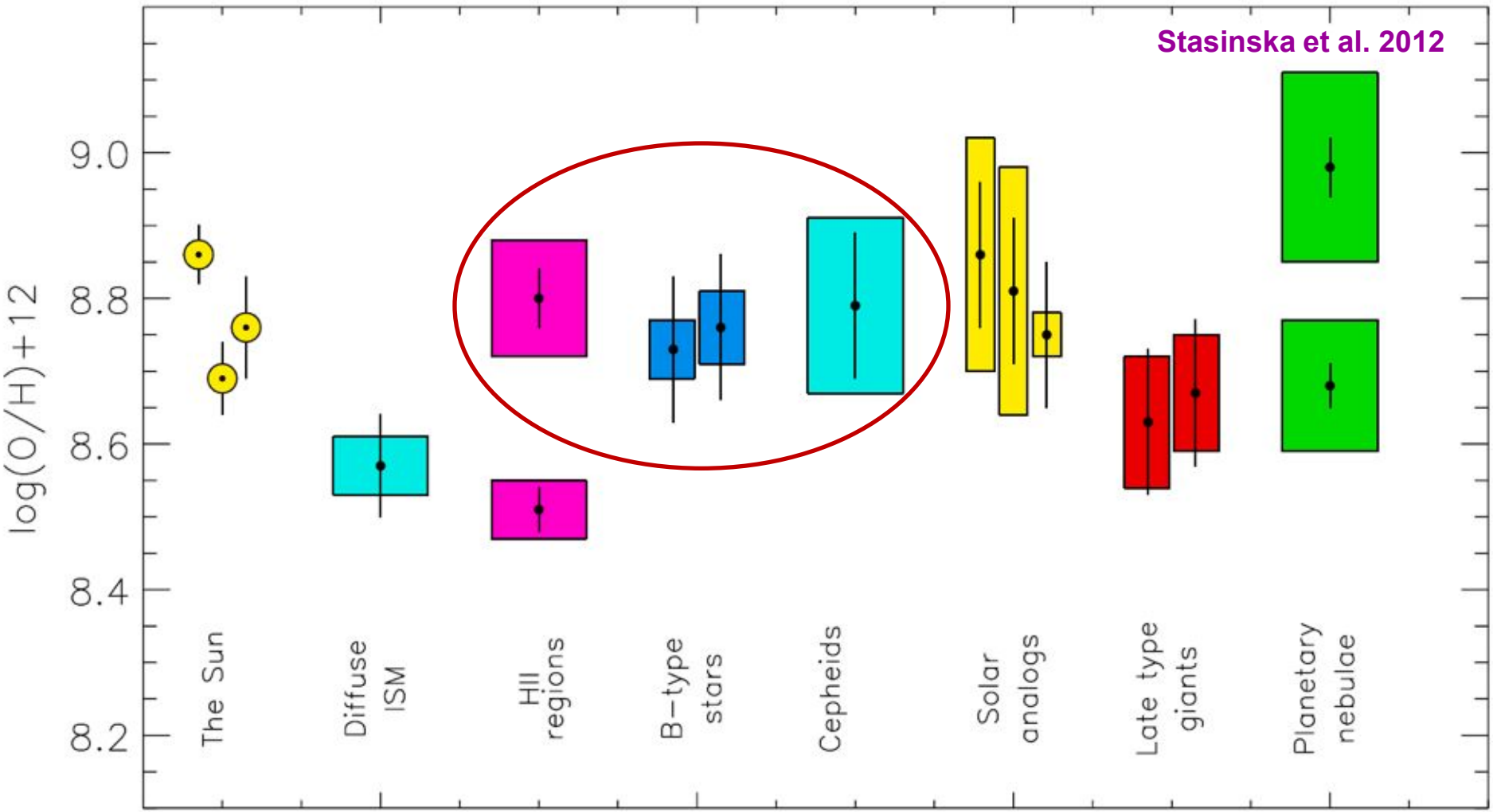
		Closed box or Outflow with $R_{OUT} = k$ SFR and SFR $= \nu\ m_G$	Infall with $m_G = constant$ and SFR $= \nu\ m_G$
Initial conditions		$m_G = m_T = 1$	$m_T = m_G = m_{G,0}$
Gas Mass	m_G	$e^{-\nu(1-R+k)t}$	$m_{G,0}$
Total mass	m_T	$\frac{1+k\ \ e^{-\nu(1+k)t}}{1+k}$	$m_{G,0} + (\nu m_{G,0} - R)t$
H,He,Metals	$X - X_0$		
Deuterium	X / X_0	$m_G^{\frac{R}{1-R+k}}$	$1 - R(1 - e^{\frac{1-1/\sigma}{1-R}})$

In all cases: Gas fraction $\sigma = m_G / m_T$ and stars $m_S = m_T - m_G$

Application: Constraining the oxygen yield in solar neighborhood



Oxygen in the local Galaxy



Important to know that the *young, local* Galaxy has a *homogeneous chemical composition*

Solar Neighborhood

Constraints:

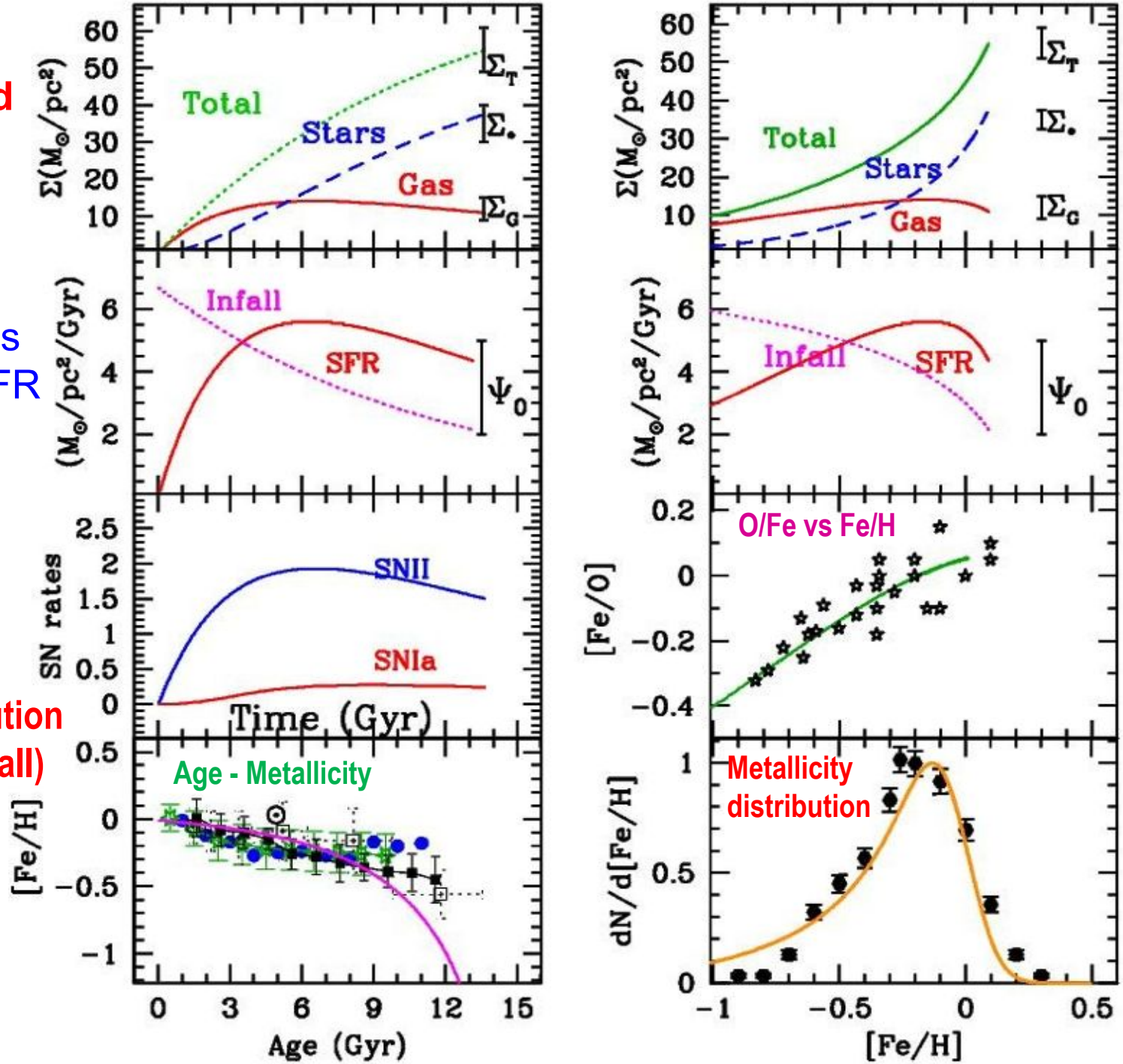
Local column densities Of gas, stars, SFR

as well as

Age – Metallicity (uncertain)

Metallicity distribution (requires slow infall)

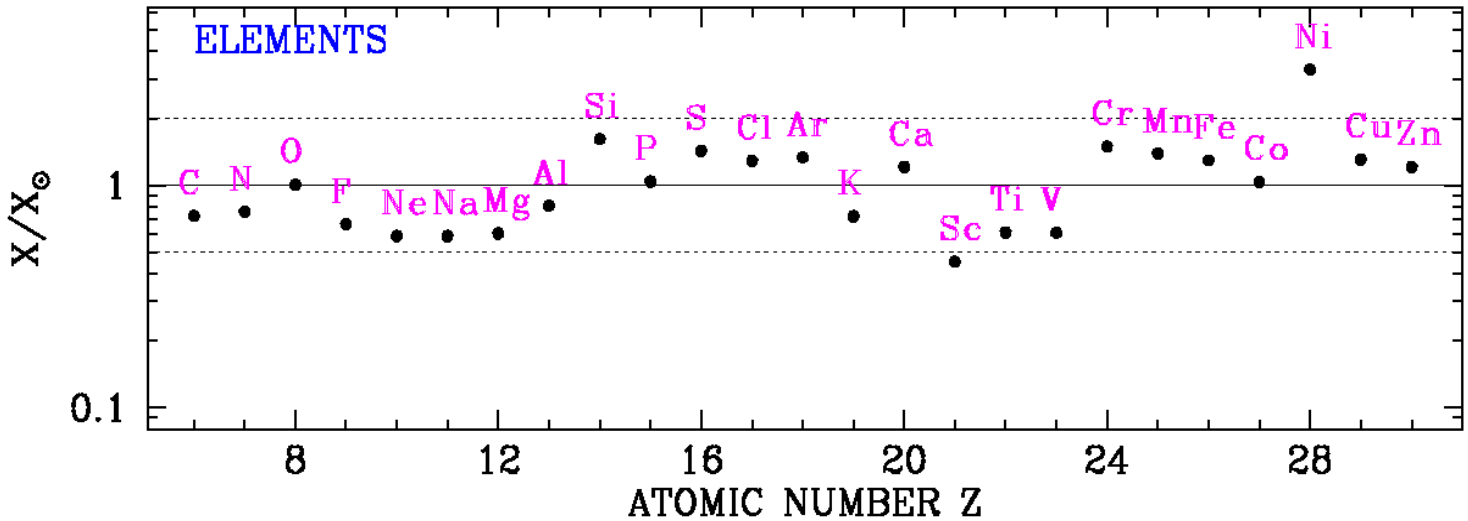
O/Fe vs Fe/H (requires SNIa for late Fe)

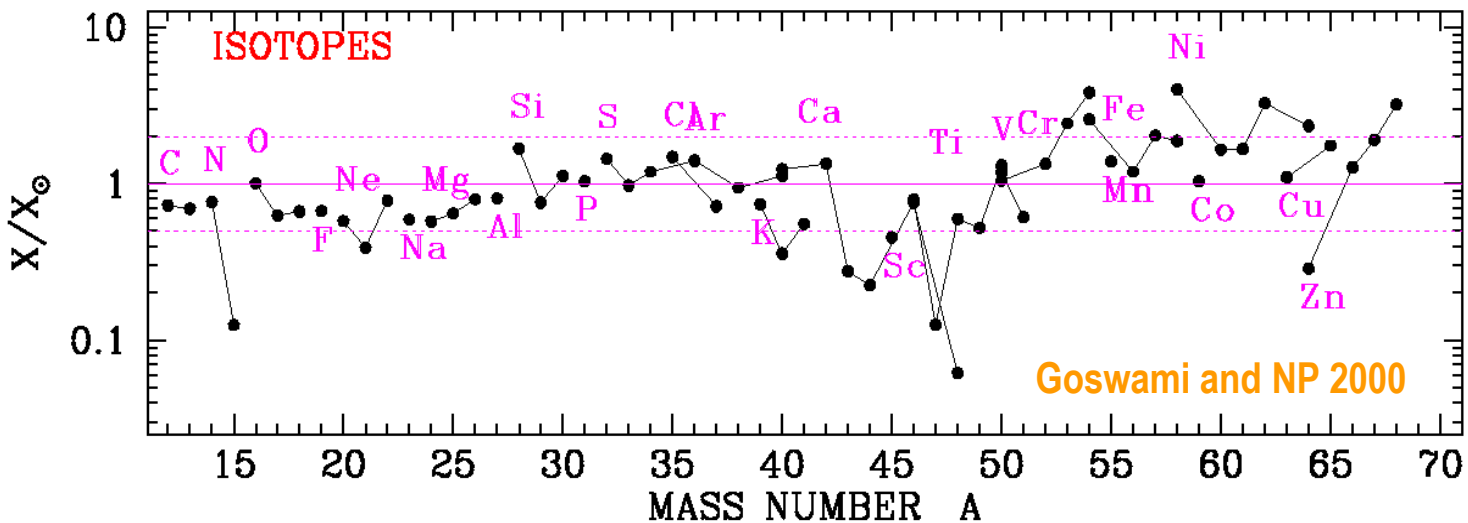


The Solar Neighborhood

Abundances at Solar system formation

(Massive stars: *Woosley+Weaver 1995*; Intermediate mass stars: *van den Hoek+Gronewegen 1997*; SNIa: *Iwamoto et al. 2000*)



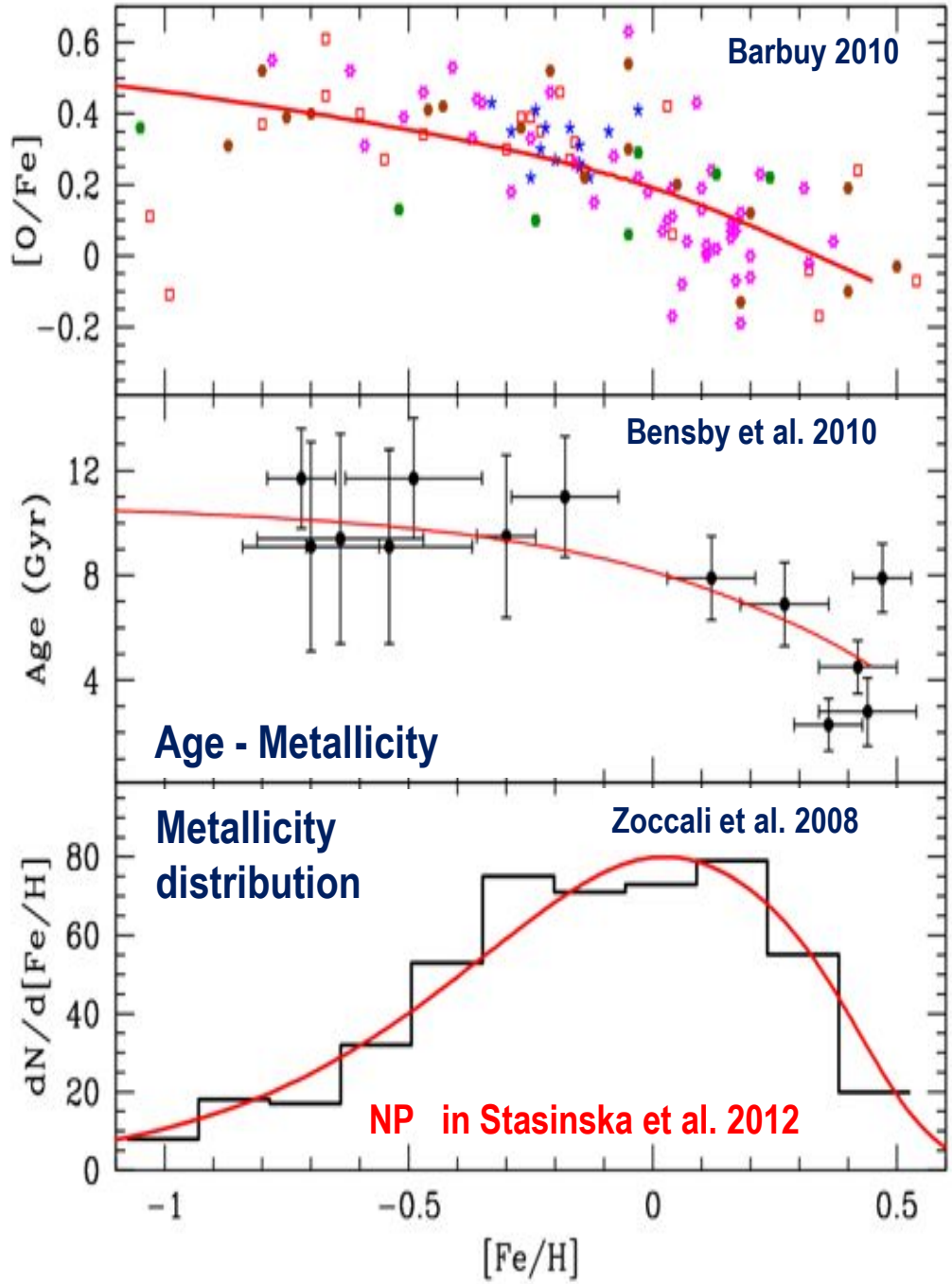


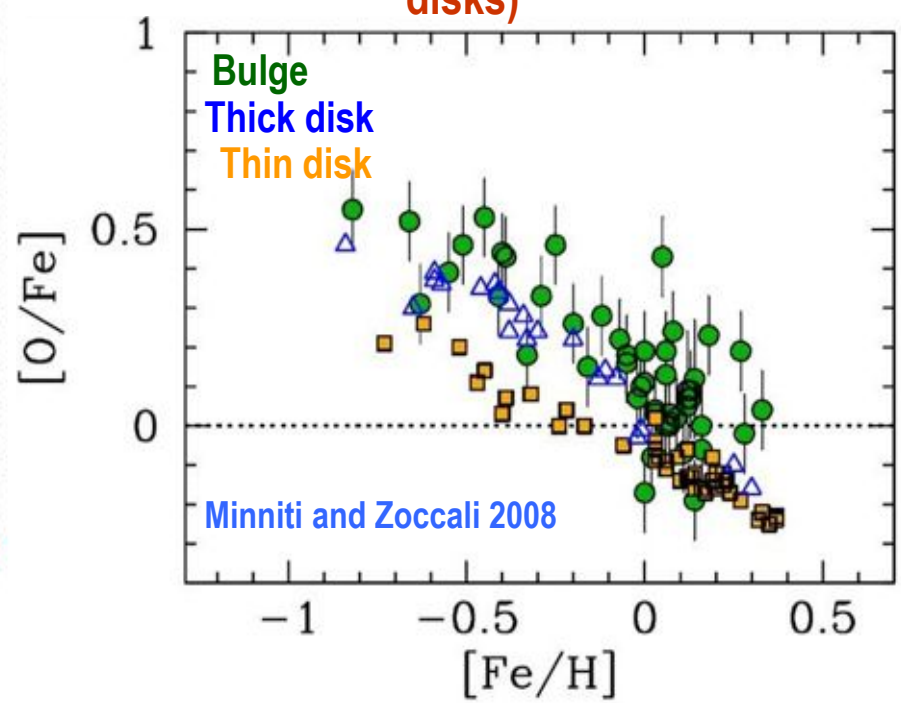
Is the Sun representative of the local ISM 4.5 Gyr ago ?

The Galactic Bulge

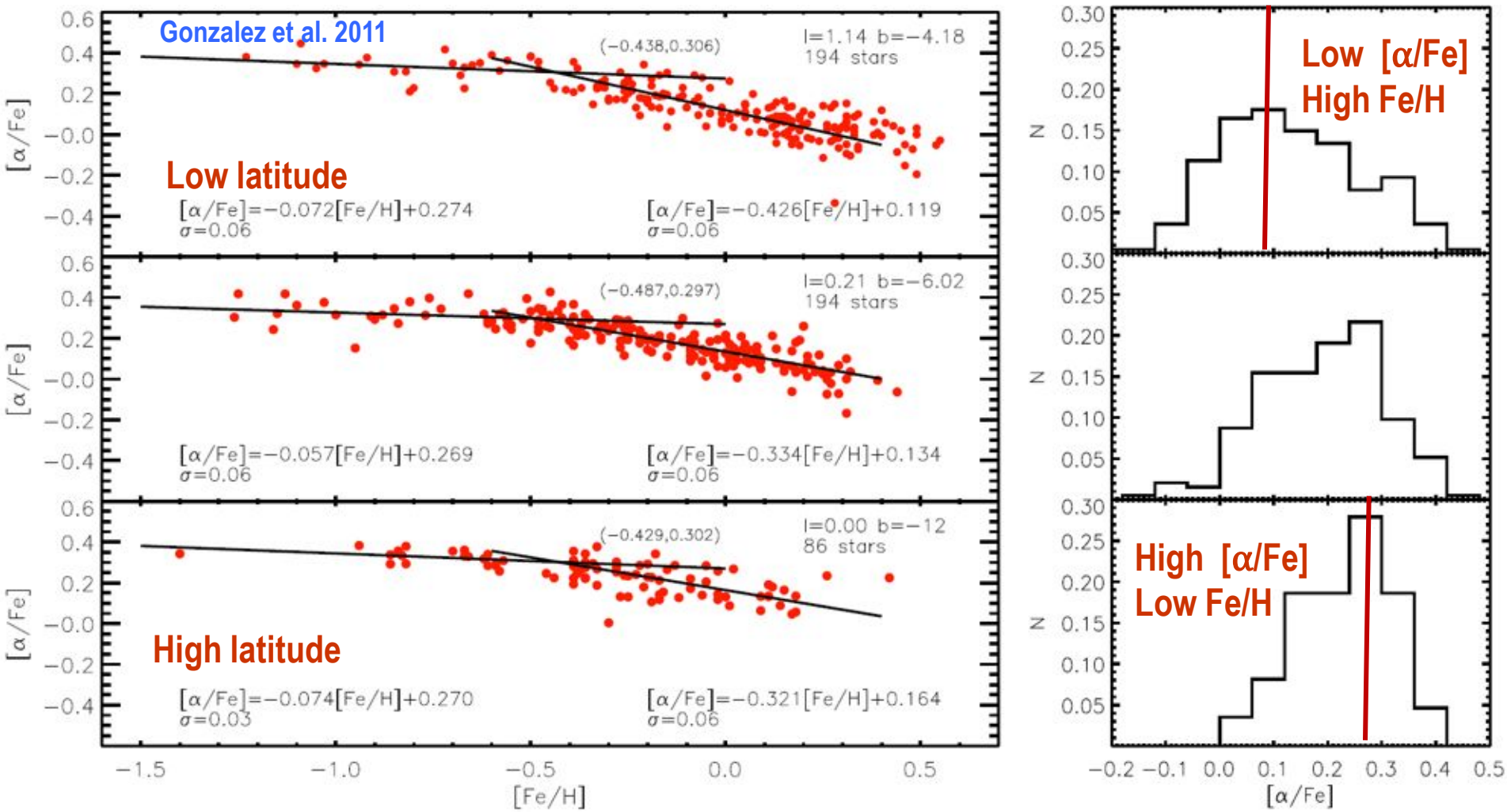
One-zone models of bulge evolution involve a **closed box model**, a **short timescale** of star formation **(~ 1 Gyr)** and an **enhanced SF efficiency**

The late decrease of α/Fe at [Fe/H] > -0.5 suggests a rapid evolution of the bulge (more rapid than in the case of thin or thick disks)





Recent observations of the bulge display a gradient of the mean metallicity and of [α/Fe] with distance from galactic plane



Bulge regions away from the plane are less evolved chemically

Observations OK with *monolithic collapse or early mergers*

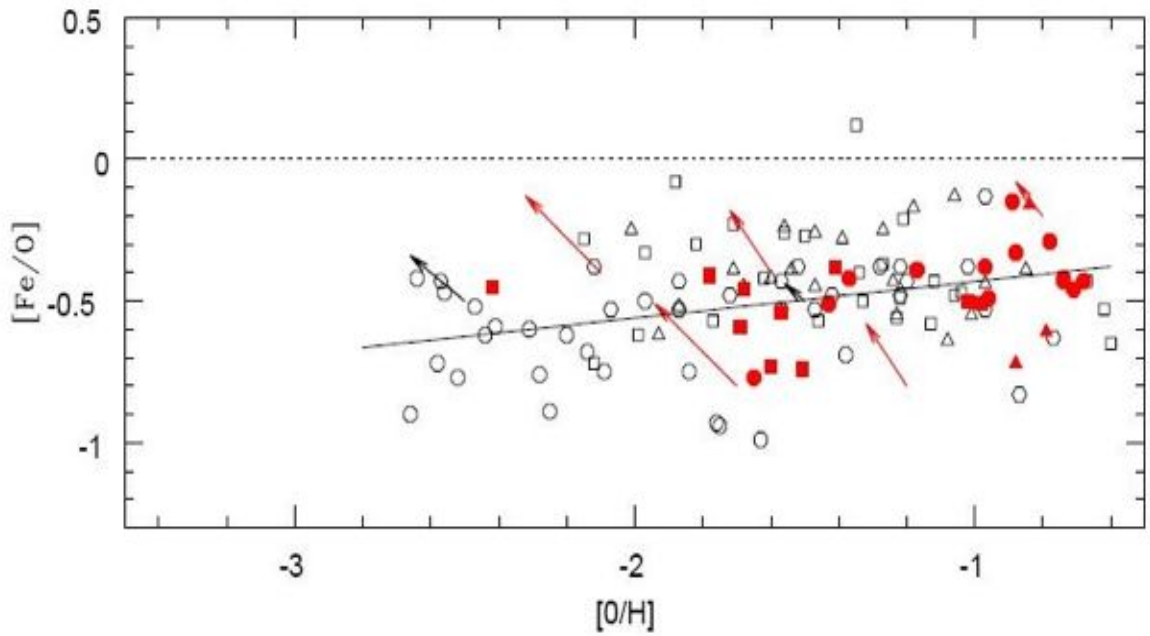
Short timescale *disfavors secular evolution* (e.g. through the action of a bar)

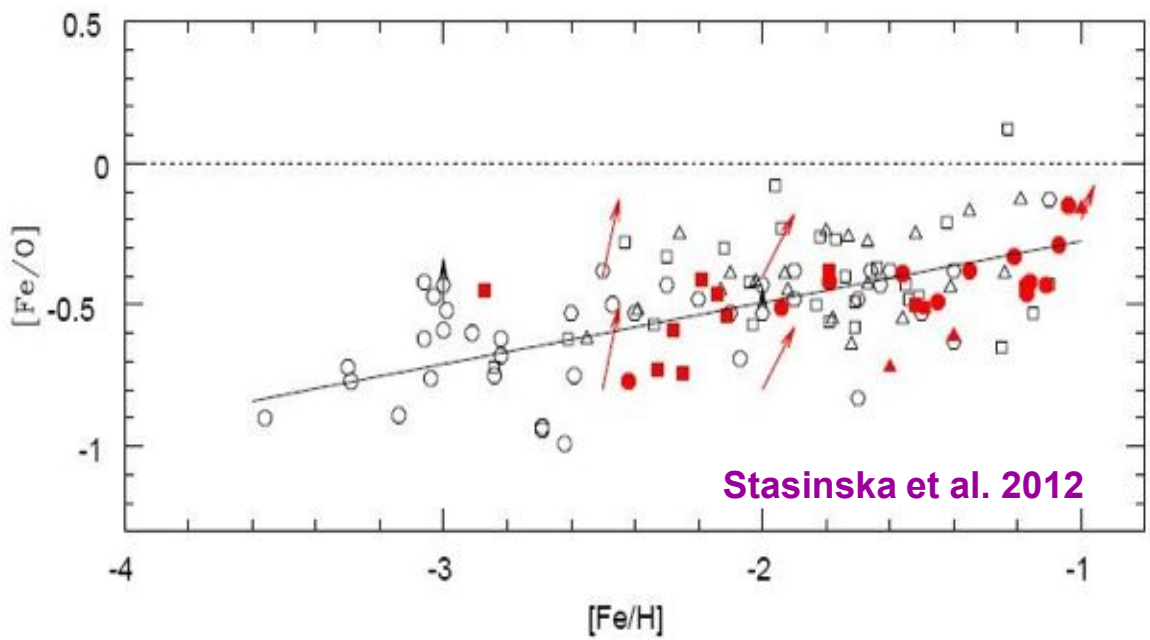
The Galactic Halo

Important to know

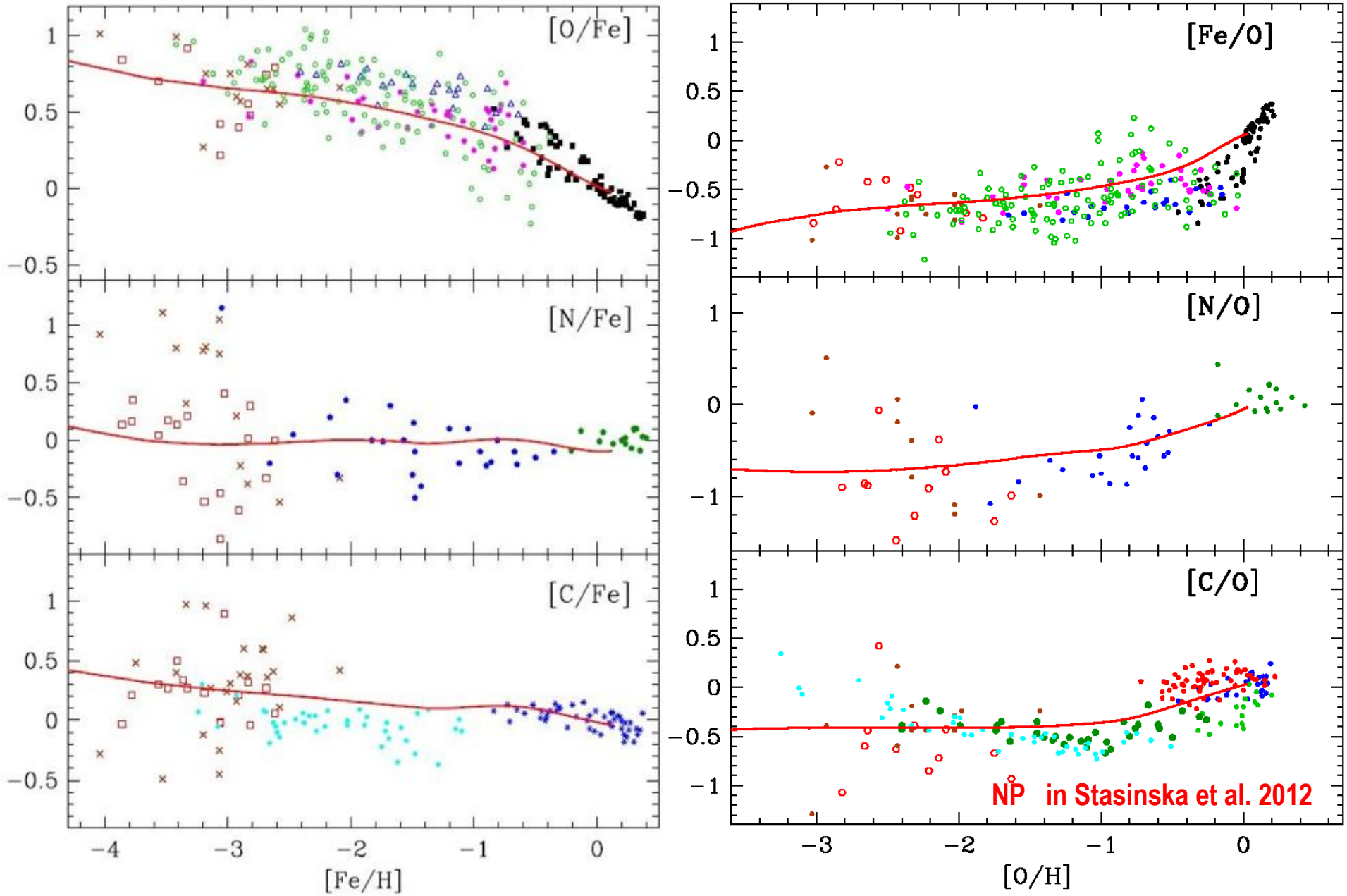
observational trends of O/Fe with Fe/H
(to understand how the O and/or Fe yields vary with metallicity)

and the amount of dispersion
(to probe the degree of homogeneity of chemical evolution)

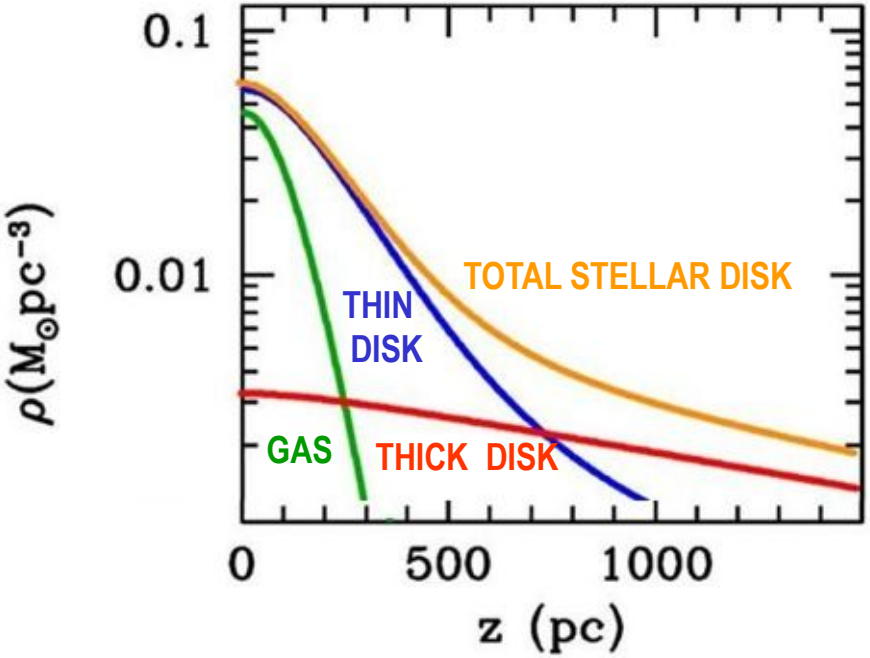




The Galactic Halo



Vertical structure of the Solar neighborhood: the issue of the THICK DISK



			Thin	Thick
Mass density	$\rho_{0,\odot}$	($M_\odot$ pc^{-3})	4.5 10^{-2}	5.3 10^{-3}
Surface density	$\Sigma_\odot$	($M_\odot$ pc^{-2})	28.5	7
Scaleheight	$H_\odot$	(pc)	300	900
Scalelength	L	(pc)	2600	3600
Star mass	M_D	(10^{10} $M_\odot$)	2.3	0.53
$\langle$Age$\rangle_\odot$	$\langle$A$\rangle_\odot$	(Gyr)	5	10
$\langle$Metallicity$\rangle_\odot$	$\langle$[Fe/H]$\rangle_\odot$	(dex)	-0.1	-0.7

a: The indice $\odot$ here denotes quantities measured at Galactocentric distance $R_\odot$=8 kpc. Average quantites are given within $\langle\ \rangle$.

Is it a "puffed-up" part of the disk, which was formed early on ?

(In which case its evolution is the early evolution of the disk) …

Or has it been formed elsewhere (satellite galaxies) and accreted later?

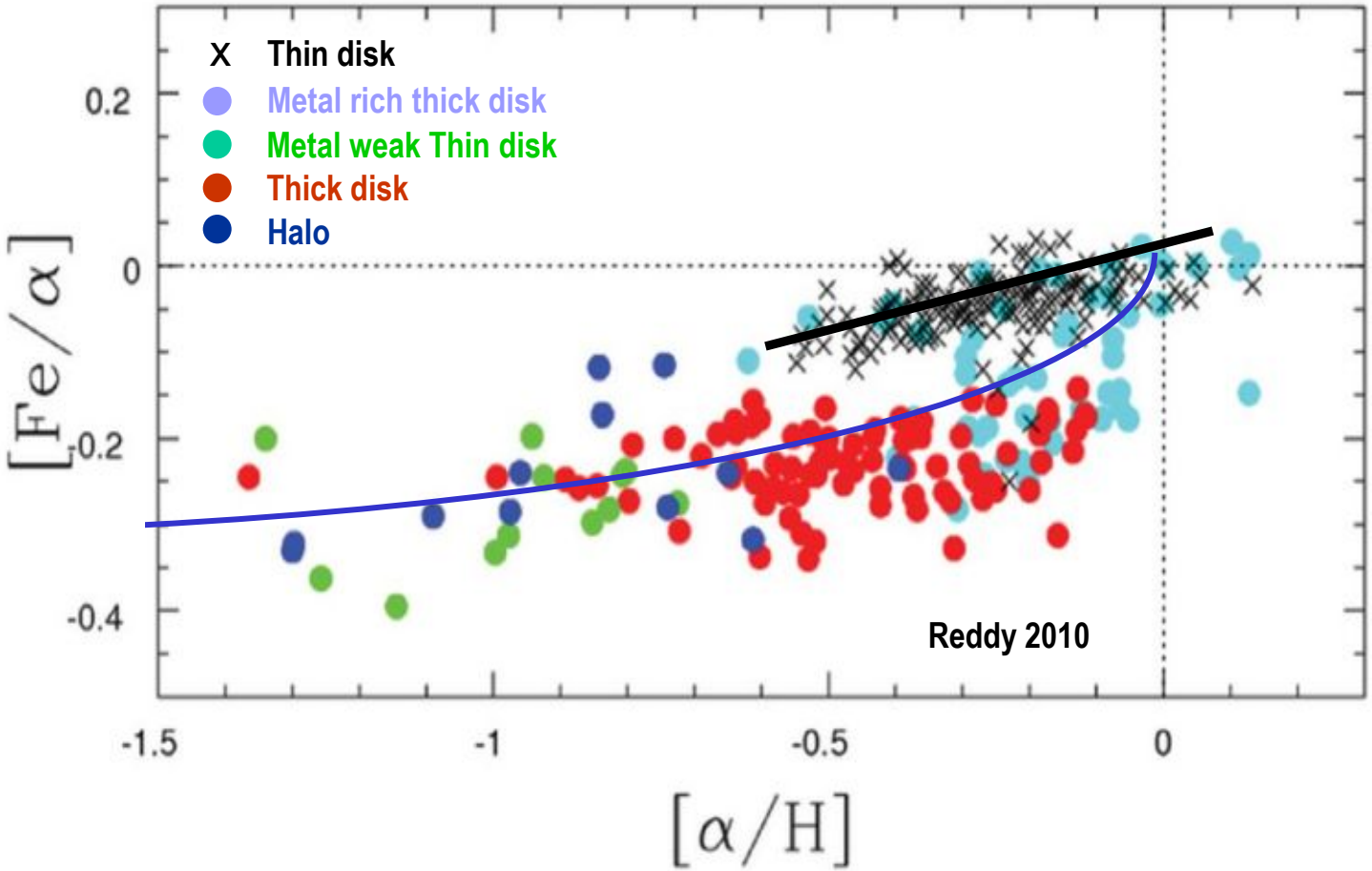
(In which case its evolution is Independent of the evolution of the thin disk) …

Or has it been formed from old stars of the inner disk which migrated here?

(In which case its evolution is coupled to the one of the thin disk) …

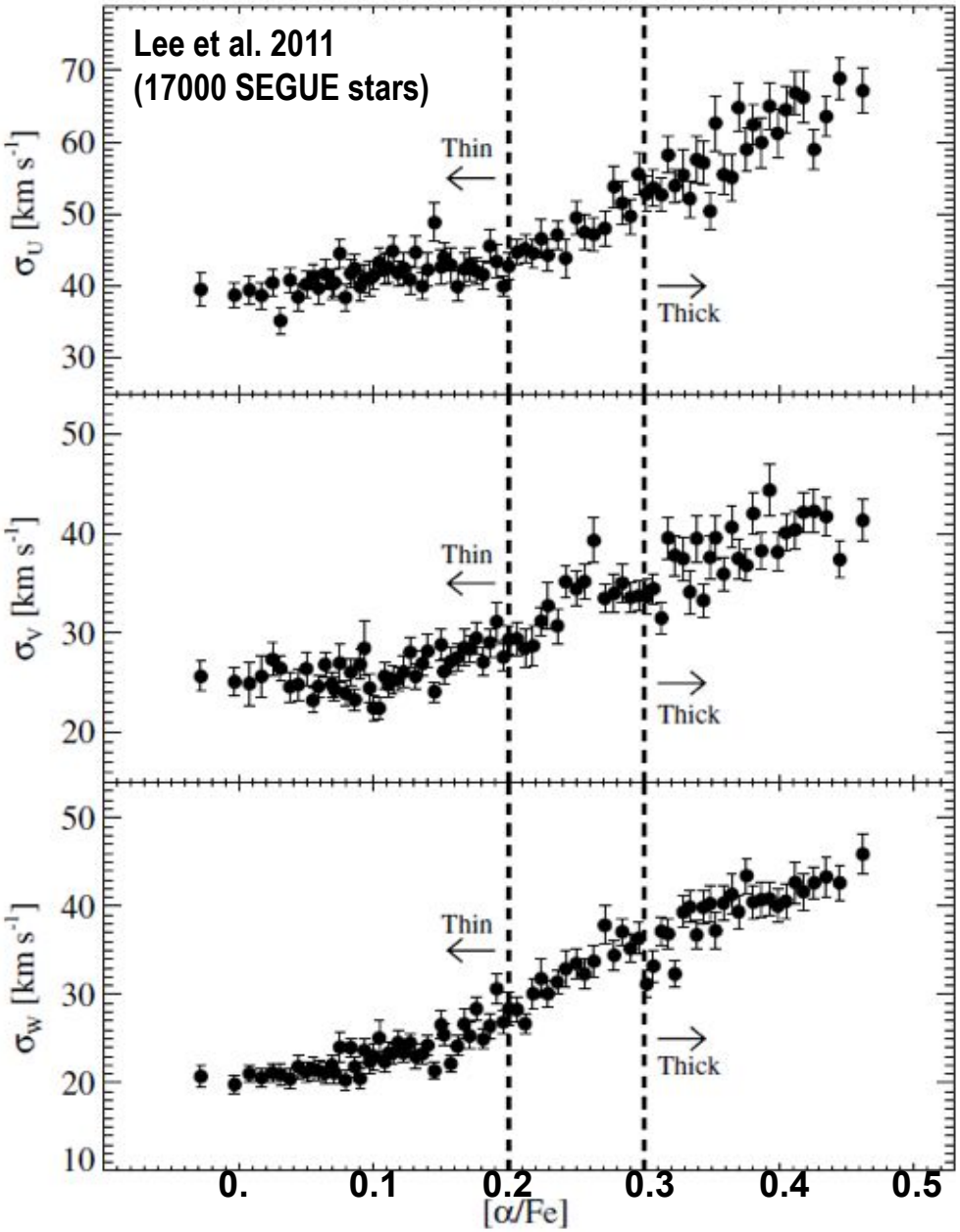
The α/Fe (or O/Fe) ratio evolves differently in the thin and thick disks

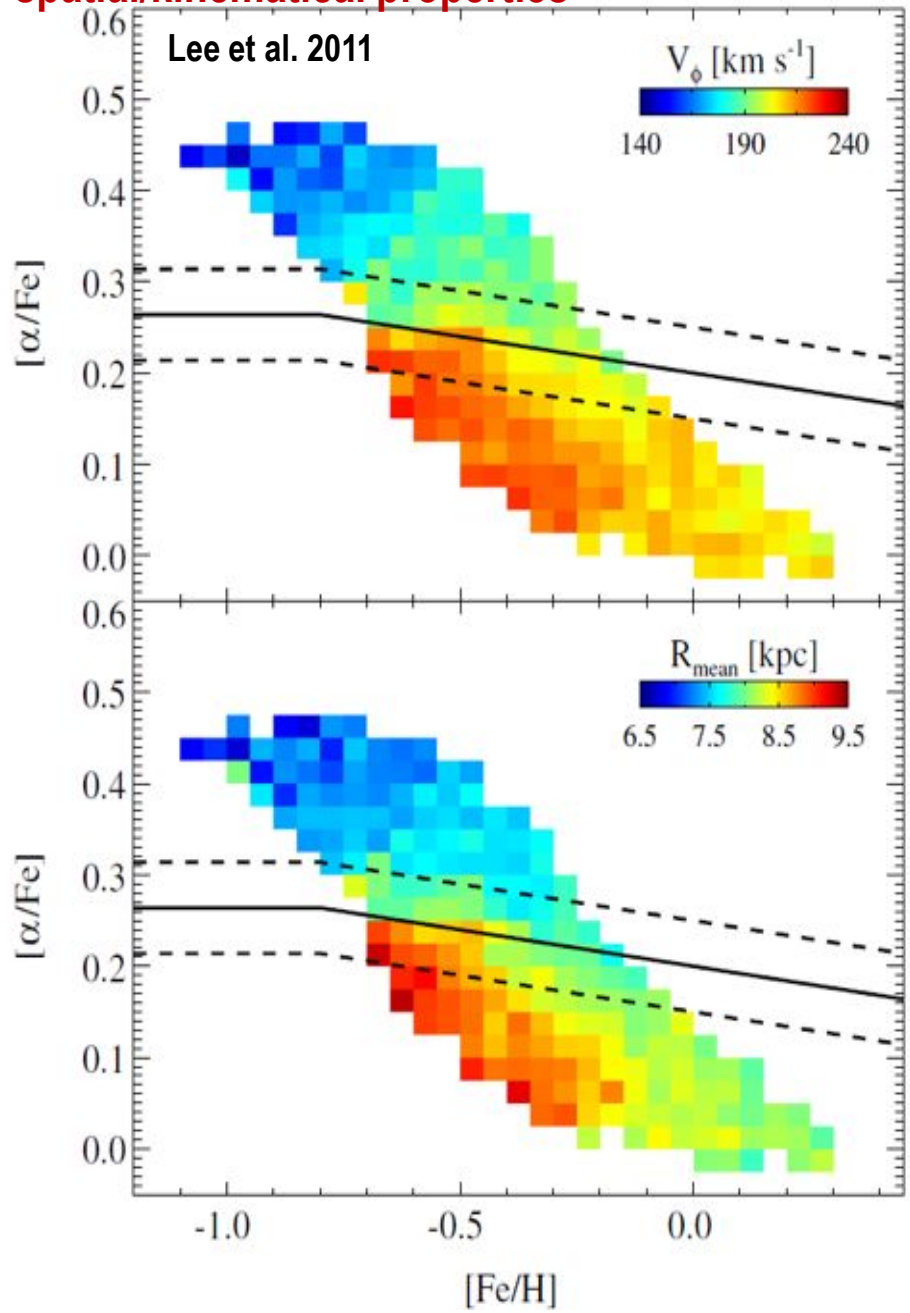
What implications for their evolution ?



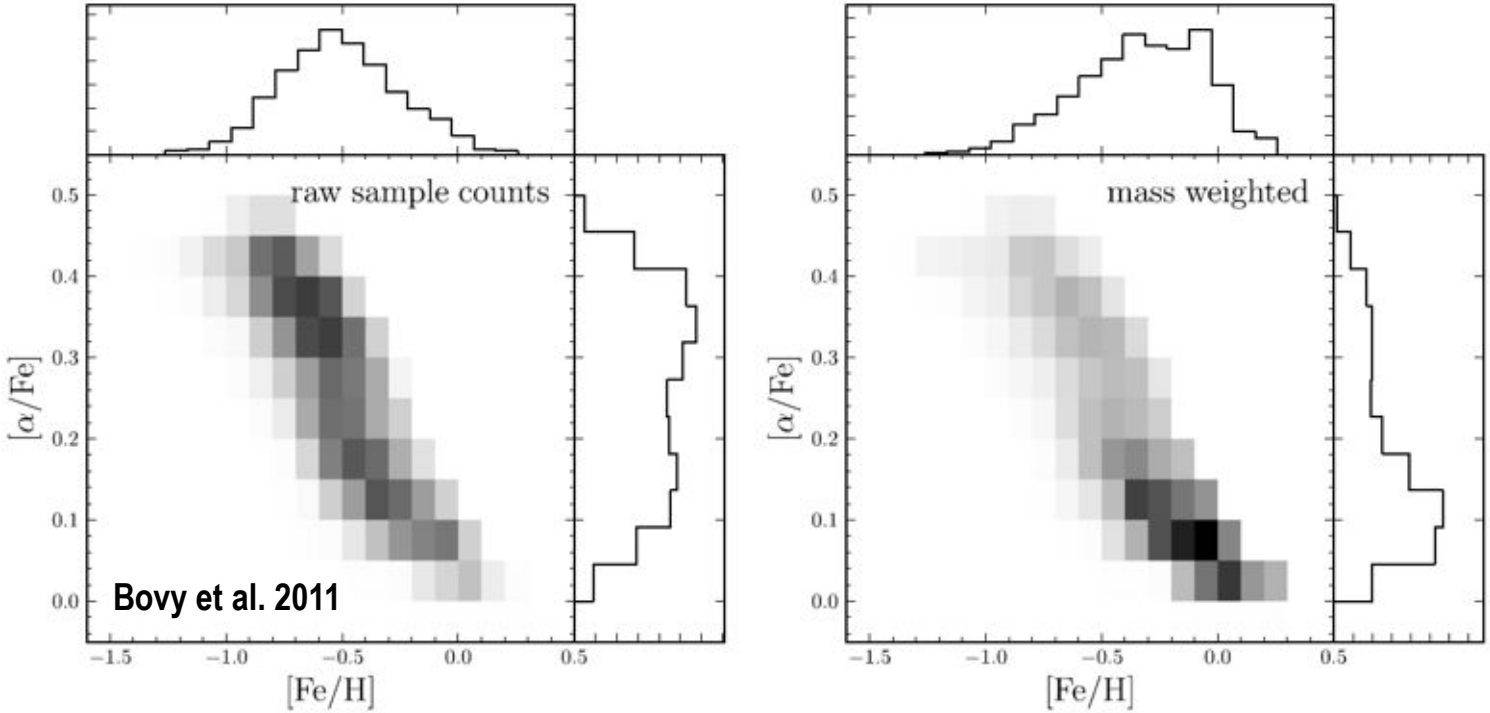
Selection criteria important for attributing stars to thin or thick disks

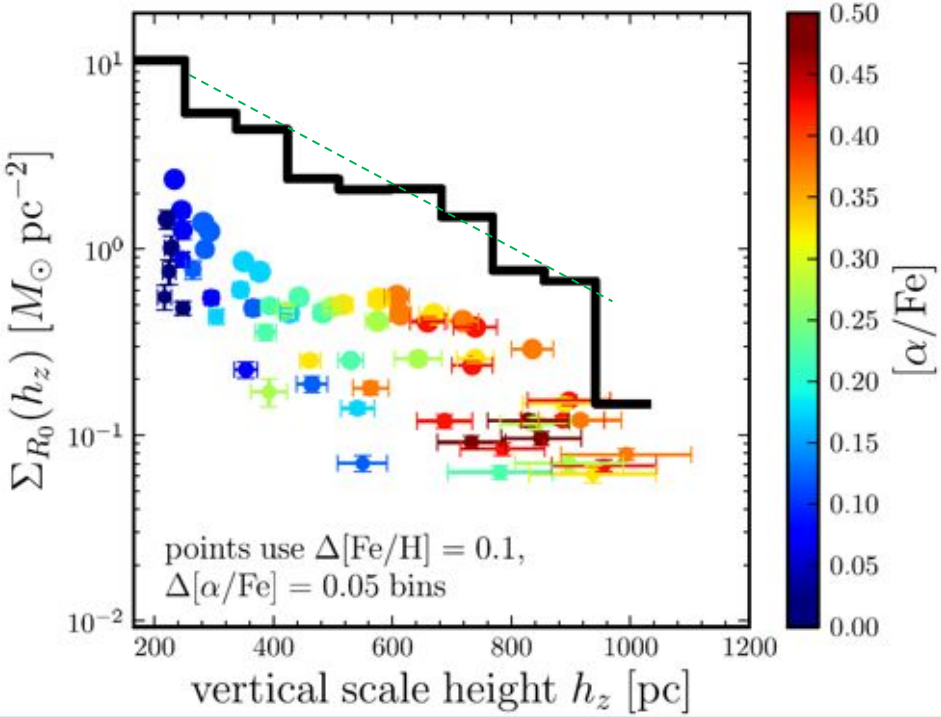
Adopting *chemical* criteria (high vs low α/Fe) instead *of kinematical* ones for thin/thick separation leads to a clear distinction of their spatial/kinematical properties





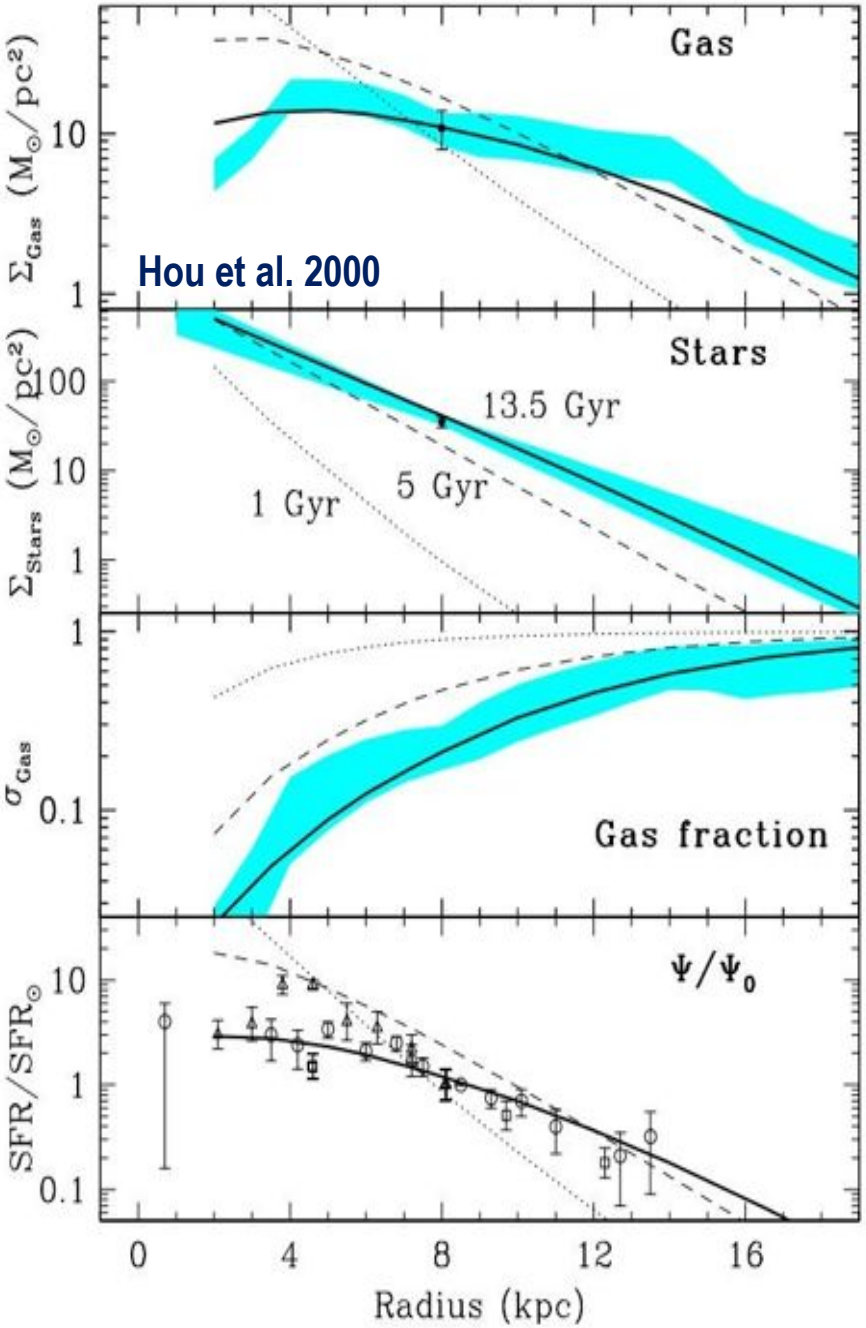
However,
in that case,
after proper
weighting
of the
iso[α/Fe]
populations…





… it is found that the vertical
surface density profile
in the solar neighborhood
is smooth,
i.e. it does not display the
characteristic "double exponential"
profile of thin + thick disks…
(*Bovy et al. 2011*)

The Milky Way disk



Inside-Out formation by infall and radially varying SFR efficiency required to reproduce observed SFR, gas and colour profiles

(Scalelengths: $R_B \cong 4$ kpc, $R_K \cong 2.6$ kpc)

(Boissier and Prantzos 1999)

…and predict abundance gradients

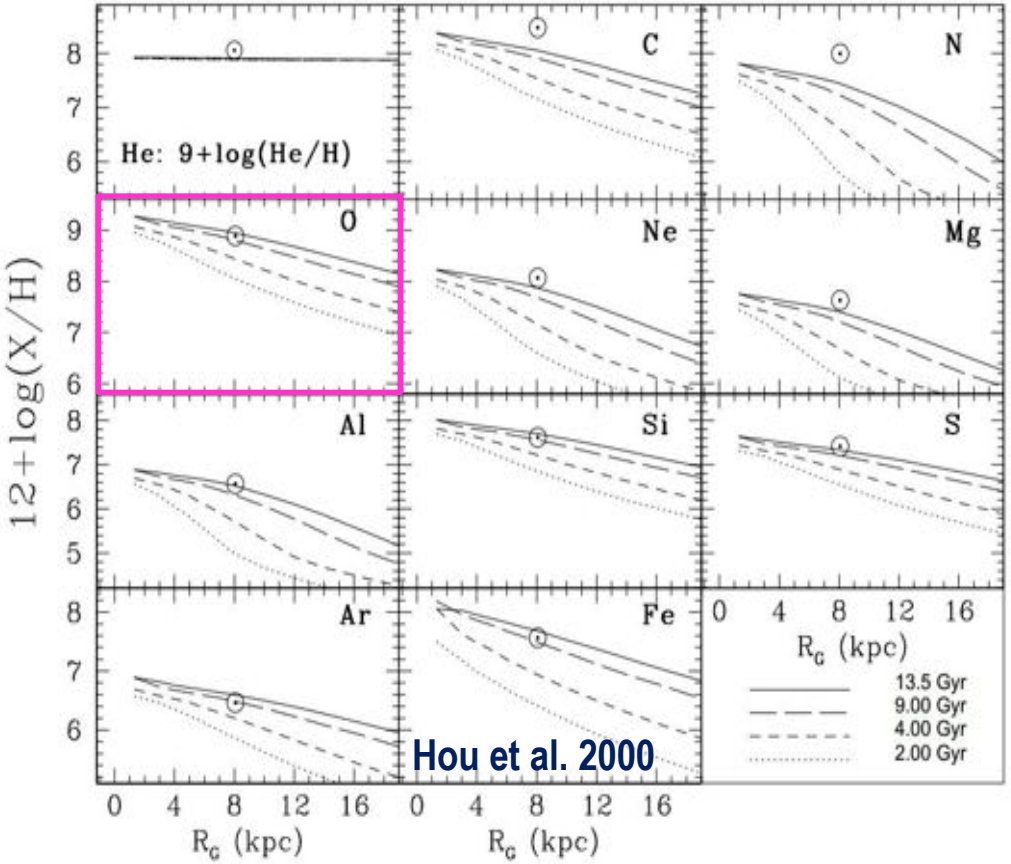
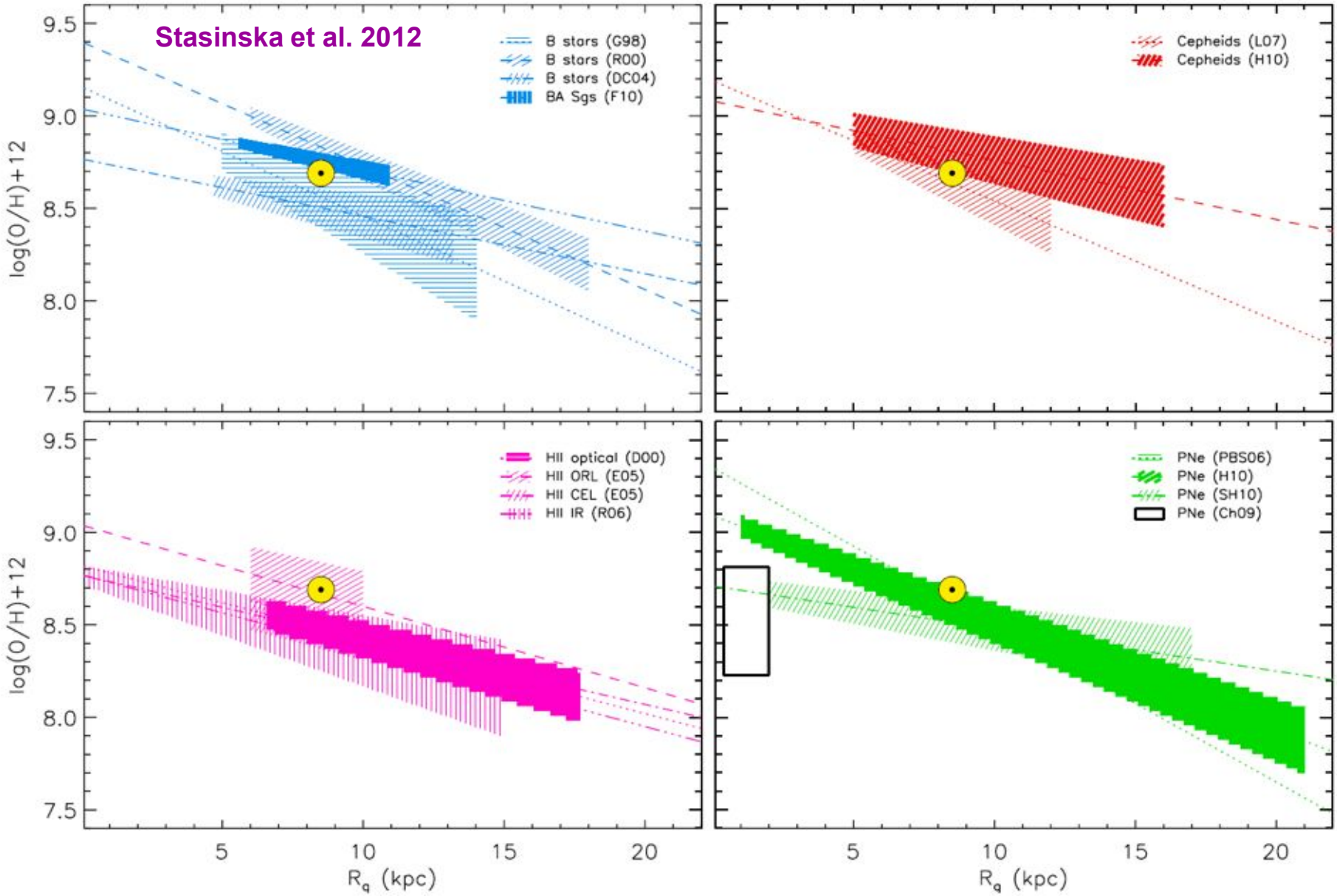


Table 2.15: Summary of oxygen abundance gradients in the Milky Way determined by using different types of objects.

Stasinska et al. 2012

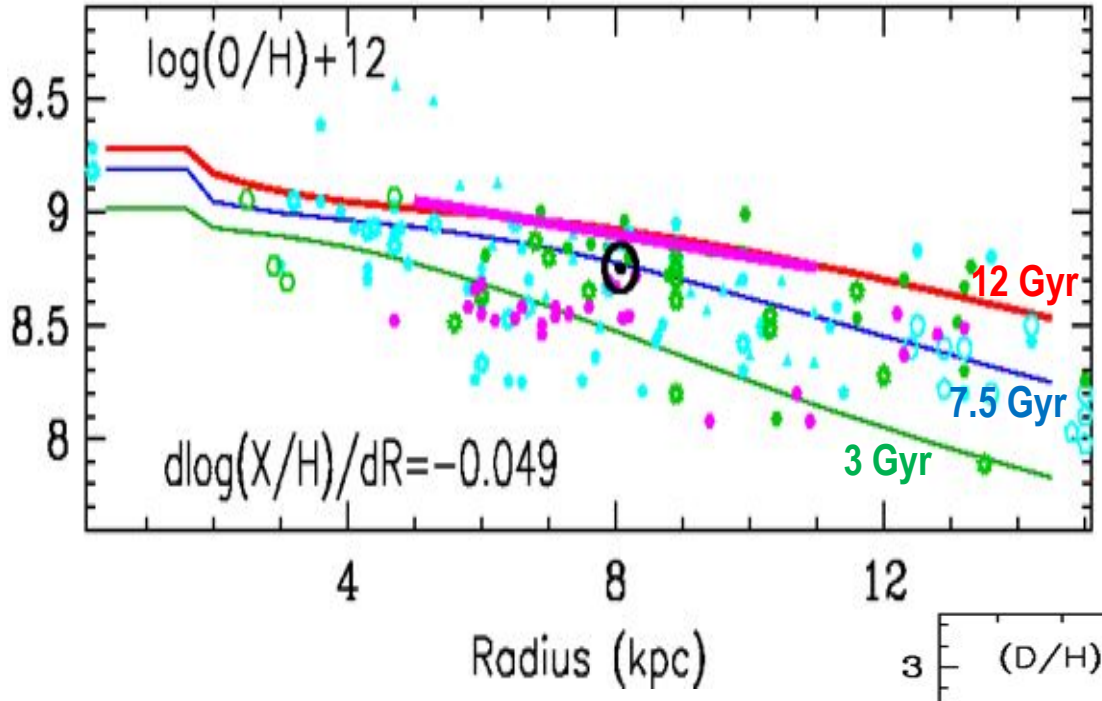
Author	Object type	Range in Rg [kpc]	# objects	$\Delta \log A(O)$ [dex kpc^{-1}]	$A(0)_0$ [dex]
* Deharveng *et al.* (2000)	H II optical	5 – 15	34	-0.040 ± 0.005	8.82 ± 0.05
Esteban *et al.* (2005)	H II optical RL	6 – 10	6	-0.044 ± 0.010	9.04 ± 0.08
Esteban *et al.* (2005)	H II optical CEL	6 – 10	6	-0.035 ± 0.006	8.77 ± 0.05
Rudolf *et al.* (2006)	H II IR	0 – 15	68	-0.041 ± 0.014	8.77 ± 0.05
Pottasch & Bernard-Salas (2006)	PNe	4 – 10	18	-0.085	9.35
Stanghellini & Haywood (2010)	PNe	2 – 17	145	-0.023 ± 0.006	8.71 ± 0.06
* Henry *et al.* (2010)	PNe	1 – 21	124	-0.058 ± 0.006	9.09 ± 0.05
Gummersbach *et al.* (1998)	B-MS stars	5 – 14	16	-0.07 ± 0.02	9.158
Rolleston *et al.* (2000)	B-MS stars	6.0 – 18.0	80	-0.067 ± 0.008	9.401
Daflon & Cunha *et al.* (2004)	B-MS stars	4.7 – 13.2	69	-0.031 ± 0.012	8.767
* Firnstein (2011)	BA-Sgs	5.5 – 11.0	25	-0.033 ± 0.005	9.03
Lemasle *et al.* (2007)	Cepheids	5 – 12		-0.065 ± 0.013	9.19
* This book (Hill)	Cepheids	5 – 16	175	-0.032 ± 0.007	9.08 ± 0.06

The Ogygen profile in the Milky Way disk



What is its true value and shape? Does it flatten (steepen) in the inner or outer disk ?

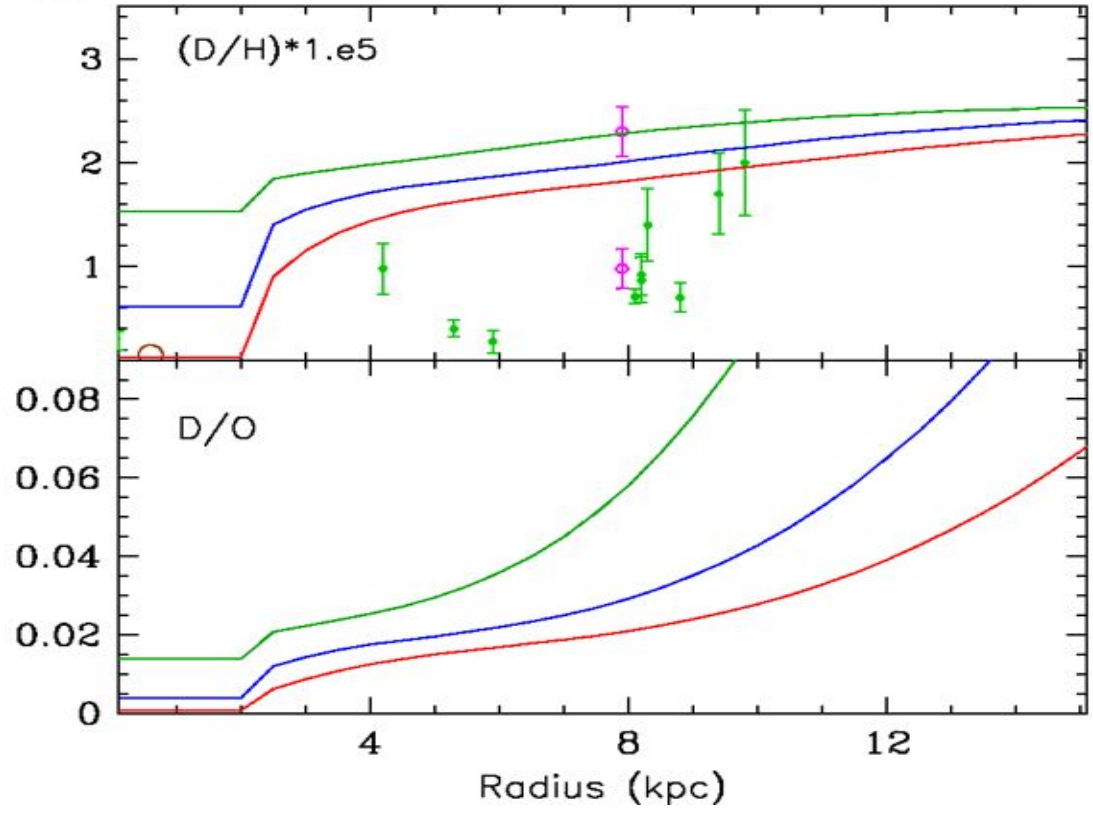
It constrains combination of SFR(R) + infall(R) + radial inflows

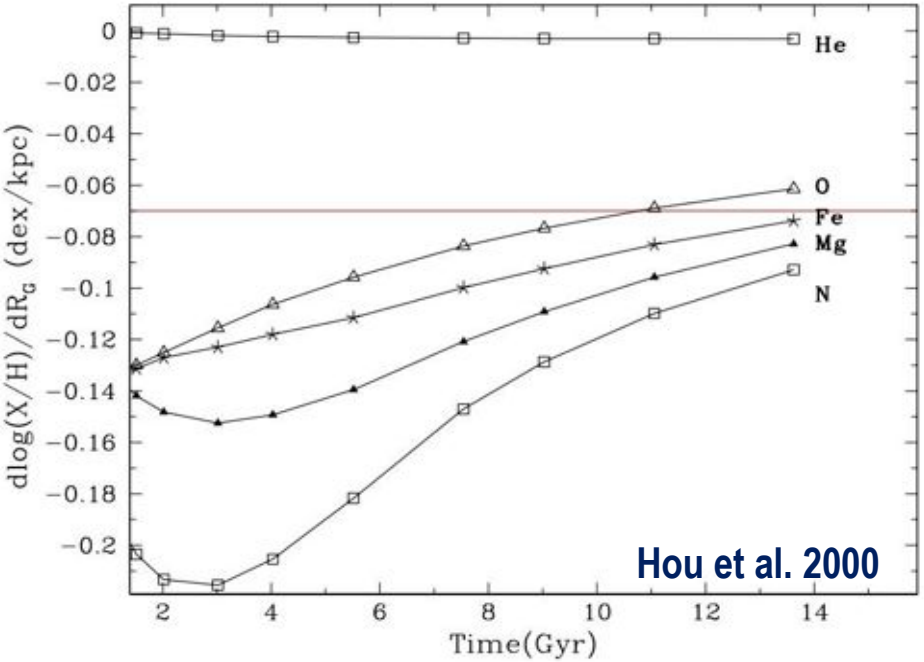


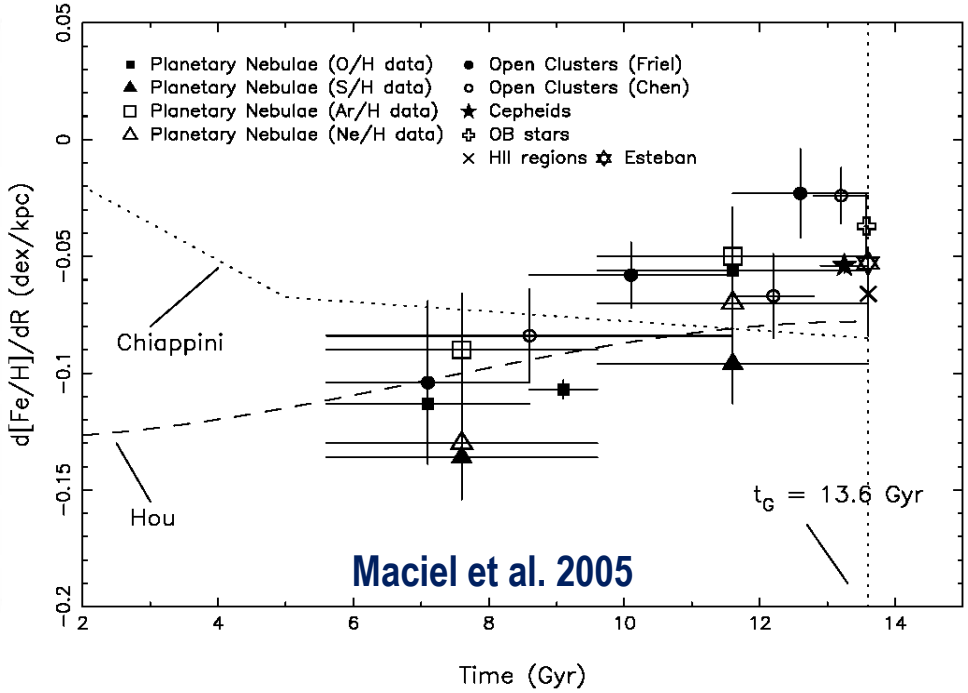
Metallicity profile of Milky Way disk

Present day gradient :
dlog(O/H)/dR ~ - 0.045 dex/kpc

Ideally,
combined observations
of D and O
across the Galactic disk
would offer
a clear picture of
the radial variations
of SFR + infall
(*NP 1996*)



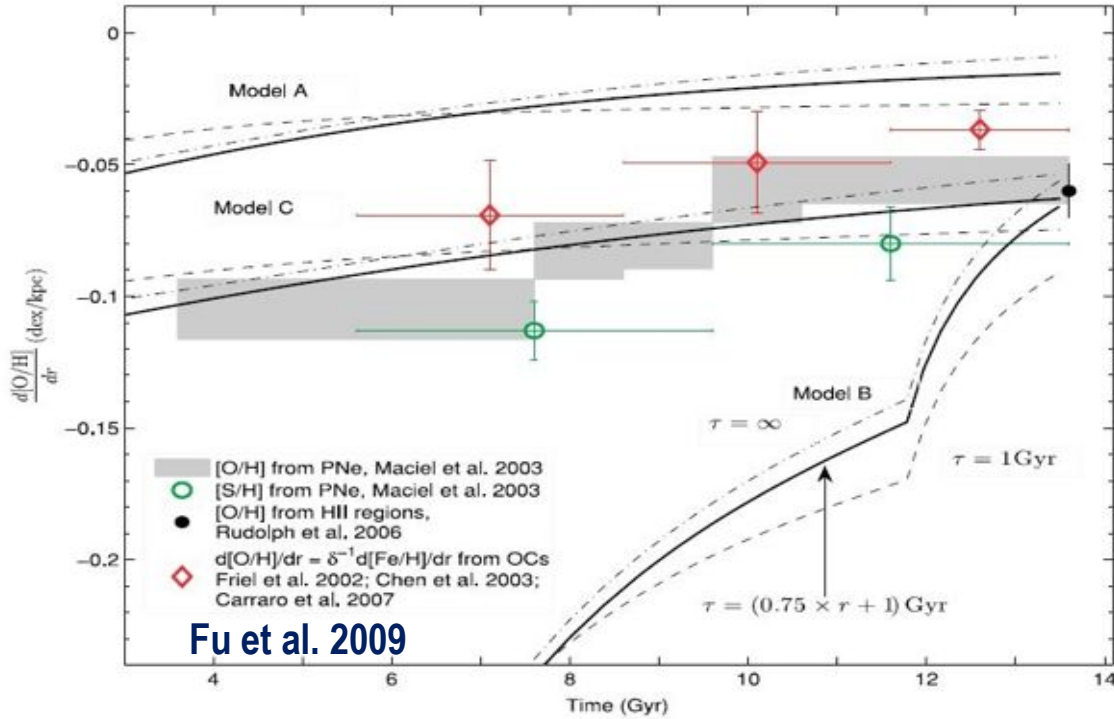




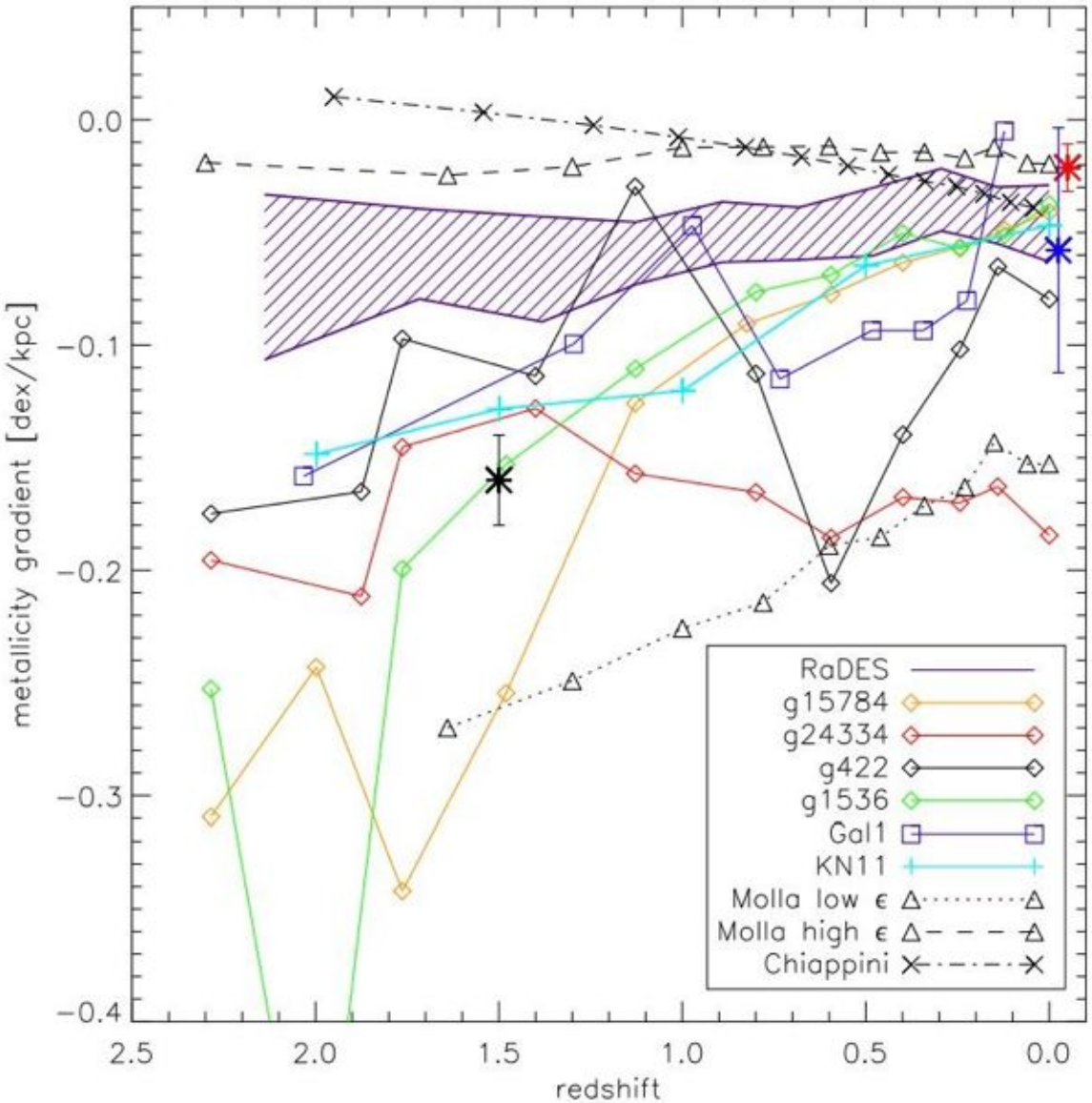
Evolution of the abundance profile

difficult to measure

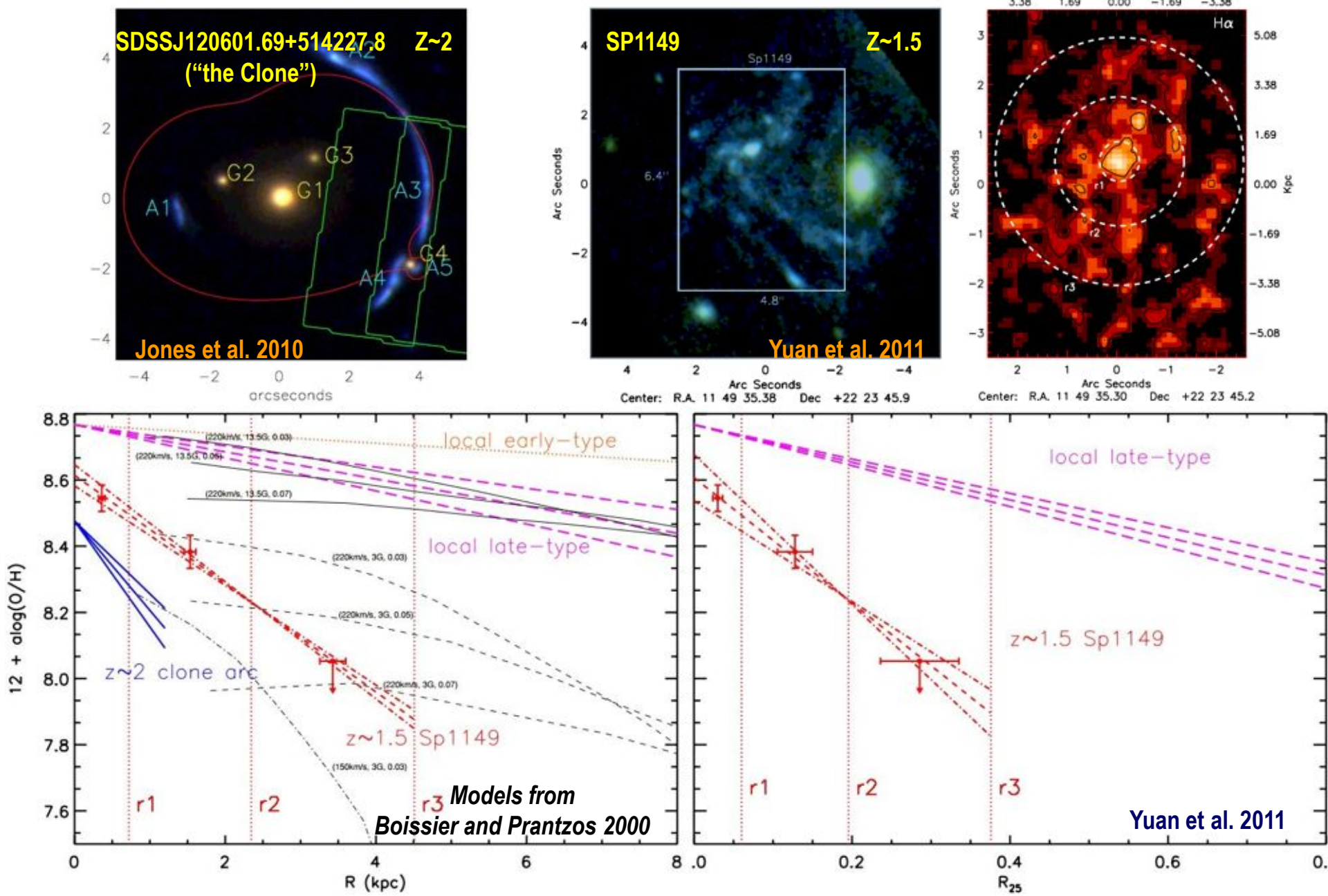
Large uncertainties in both abundance profile (abundances, distances) and age determinations



Theoretical evolution of abundance gradients
(*Pikkington et al. 2012*)



Observation of abundance profiles at high redshift in lensed galaxies

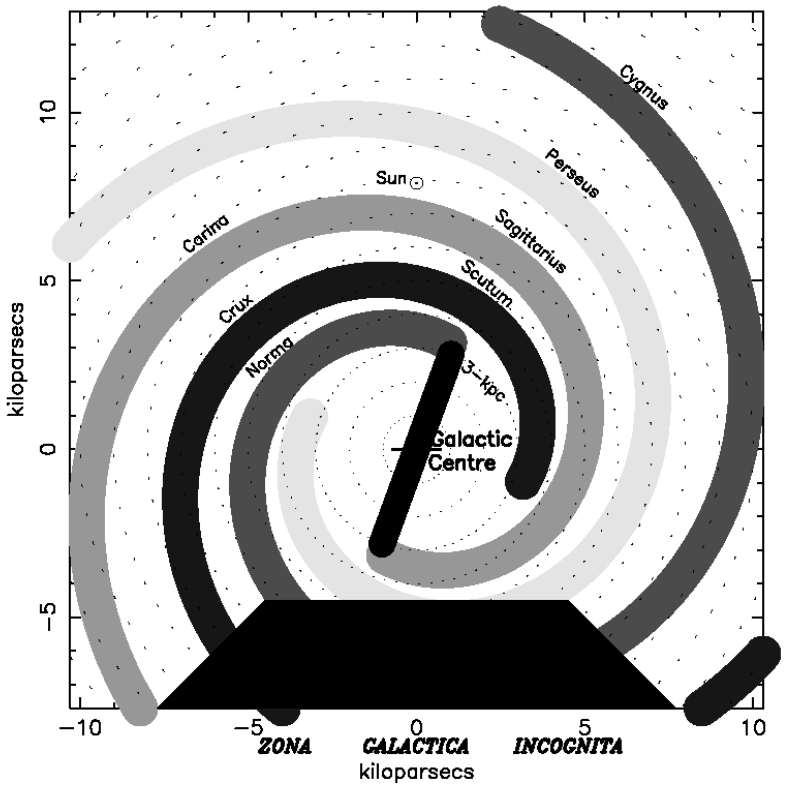


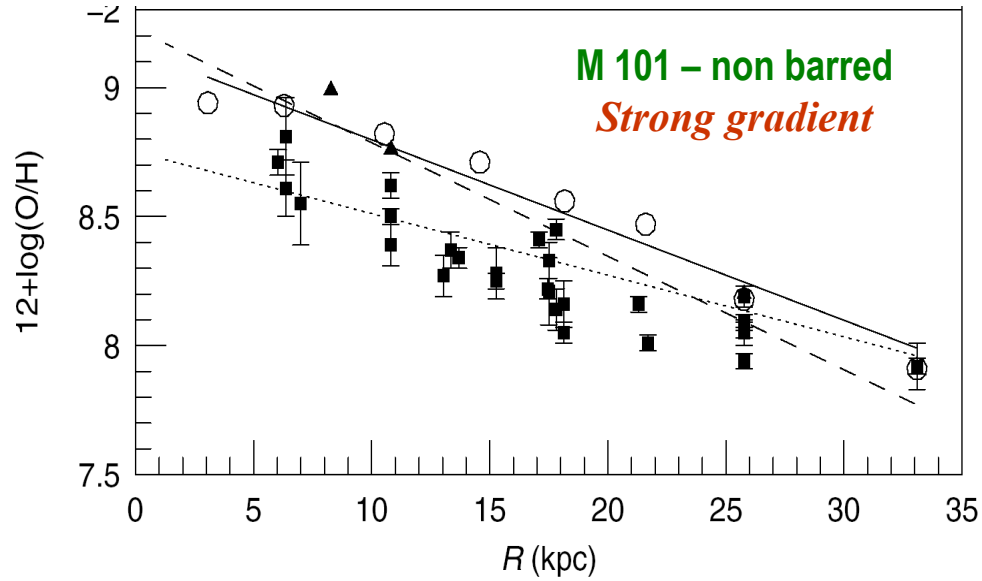
The abundance profiles appear to be much steeper than typical profiles of local disks…

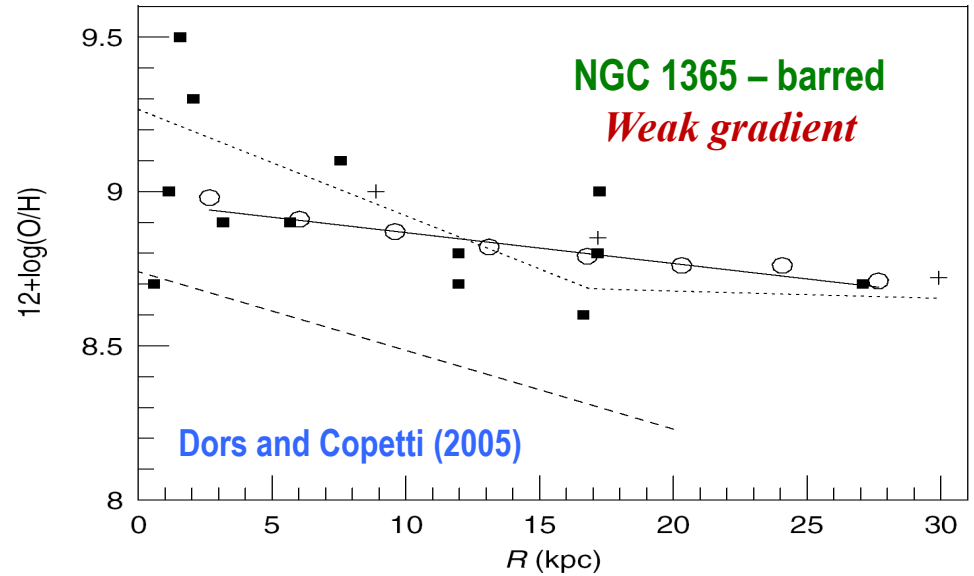
The Milky Way bar ?

The value of the abundance gradient is crucial regarding the action of a **galactic bar**

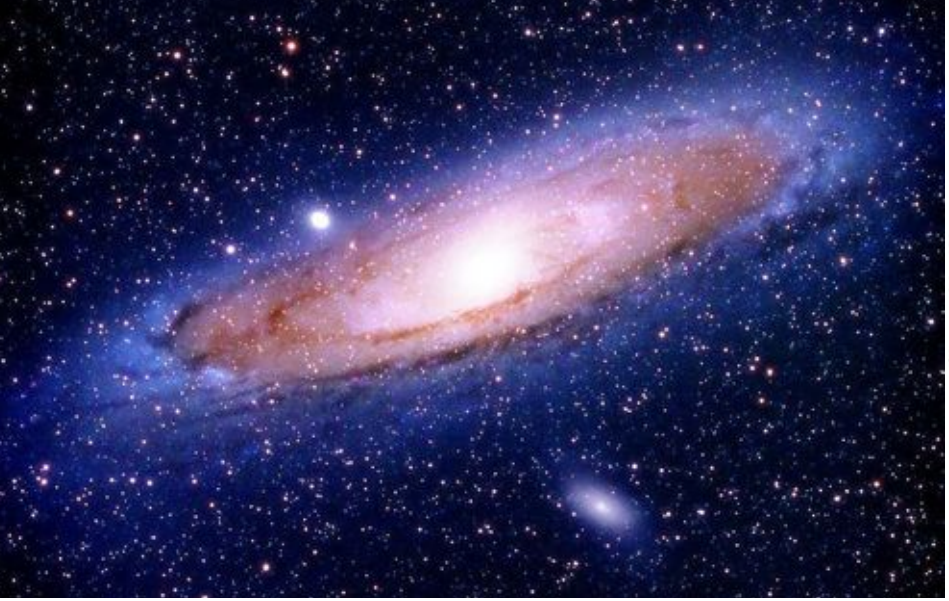
A bar drives (metal-poor) gas from the outer disk inwards, and this **radial inflow** tends to **reduce abundance gradients**

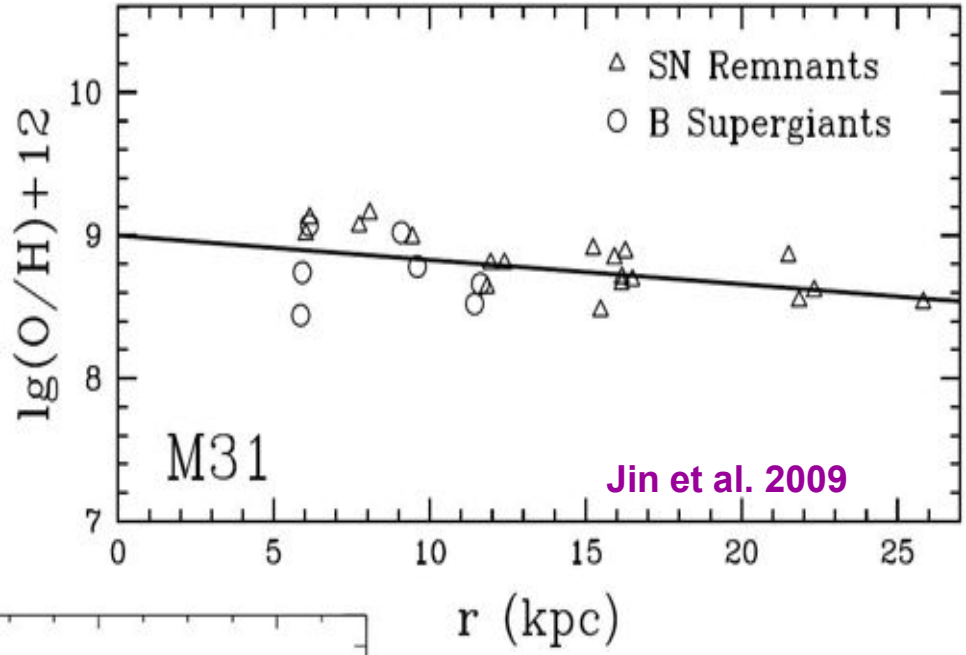


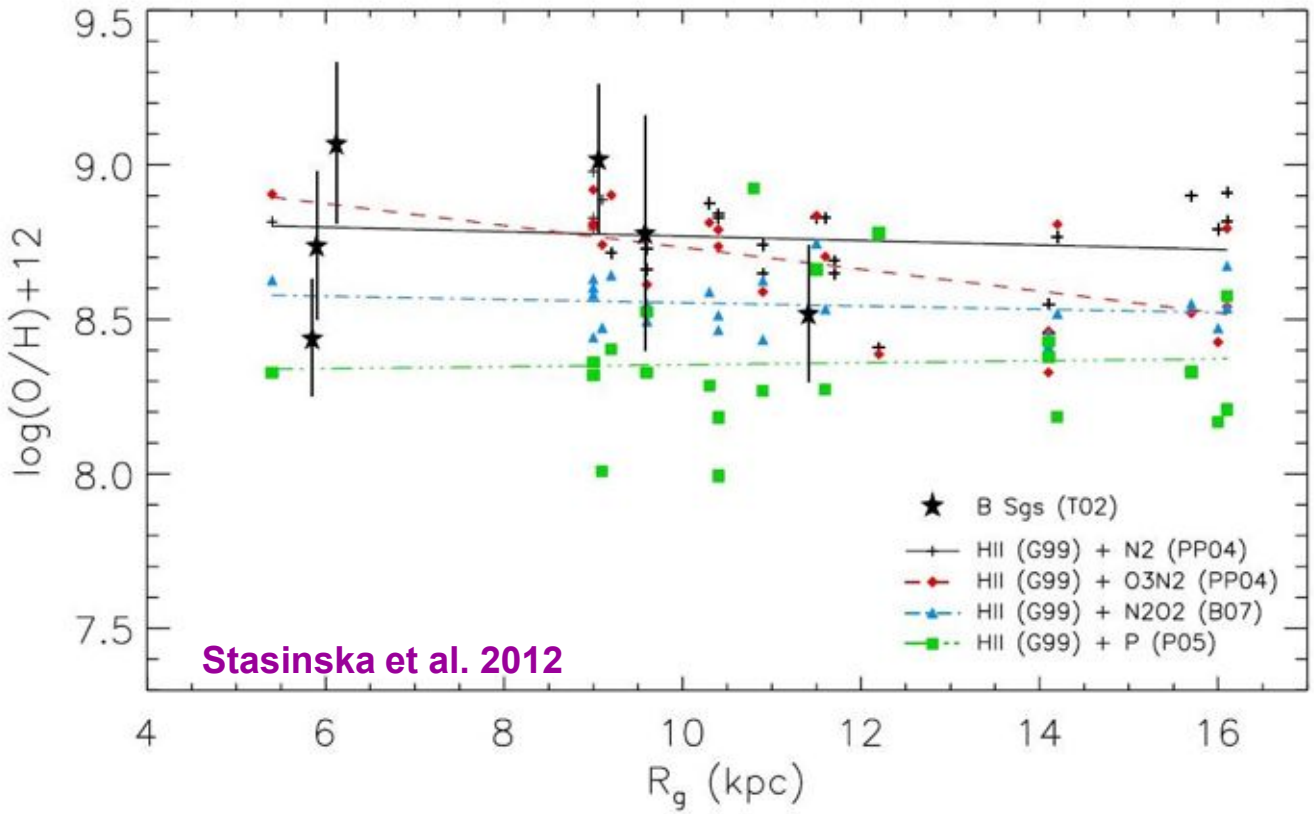




The importance of the Galactic bar for chemical evolution is not well established yet

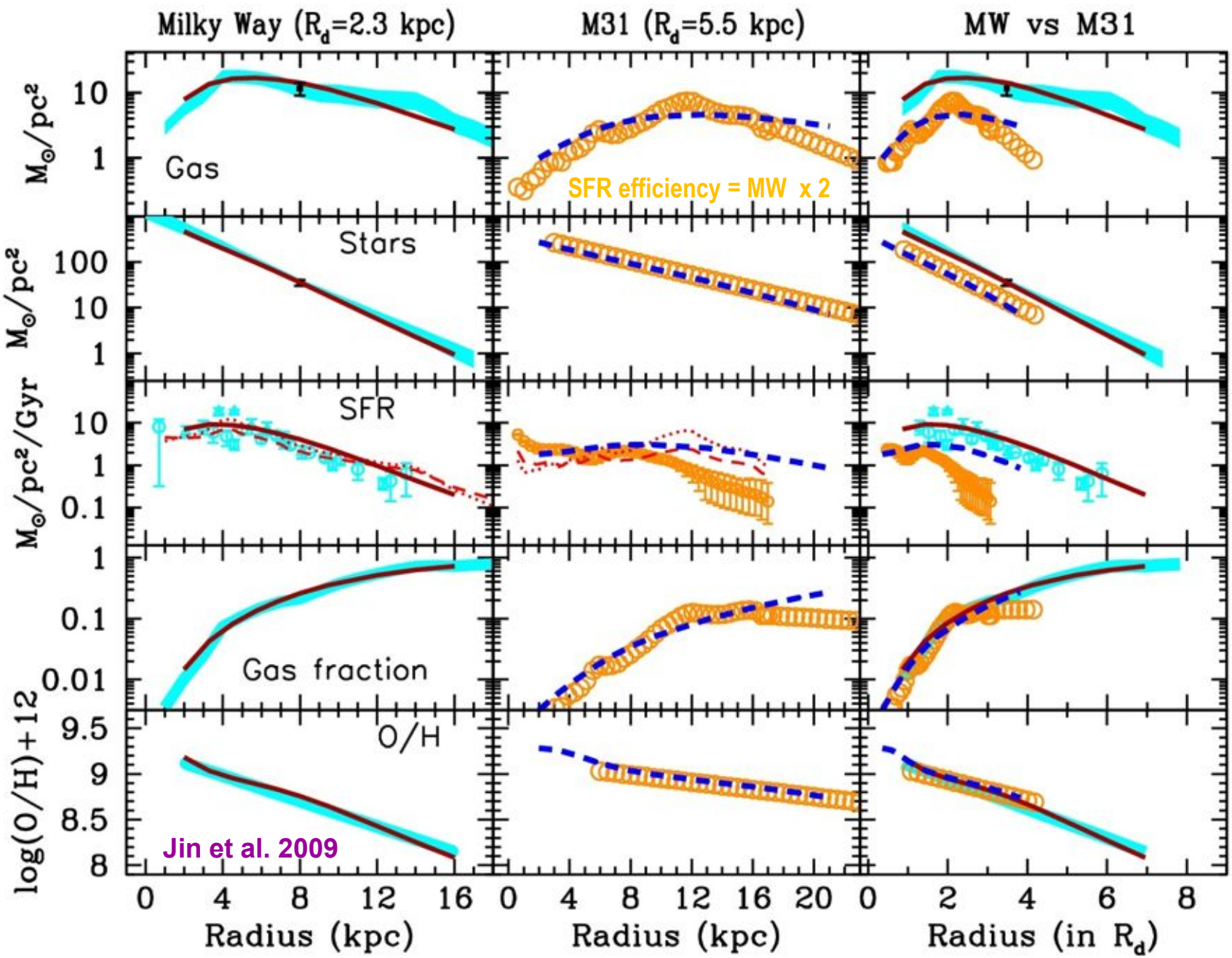


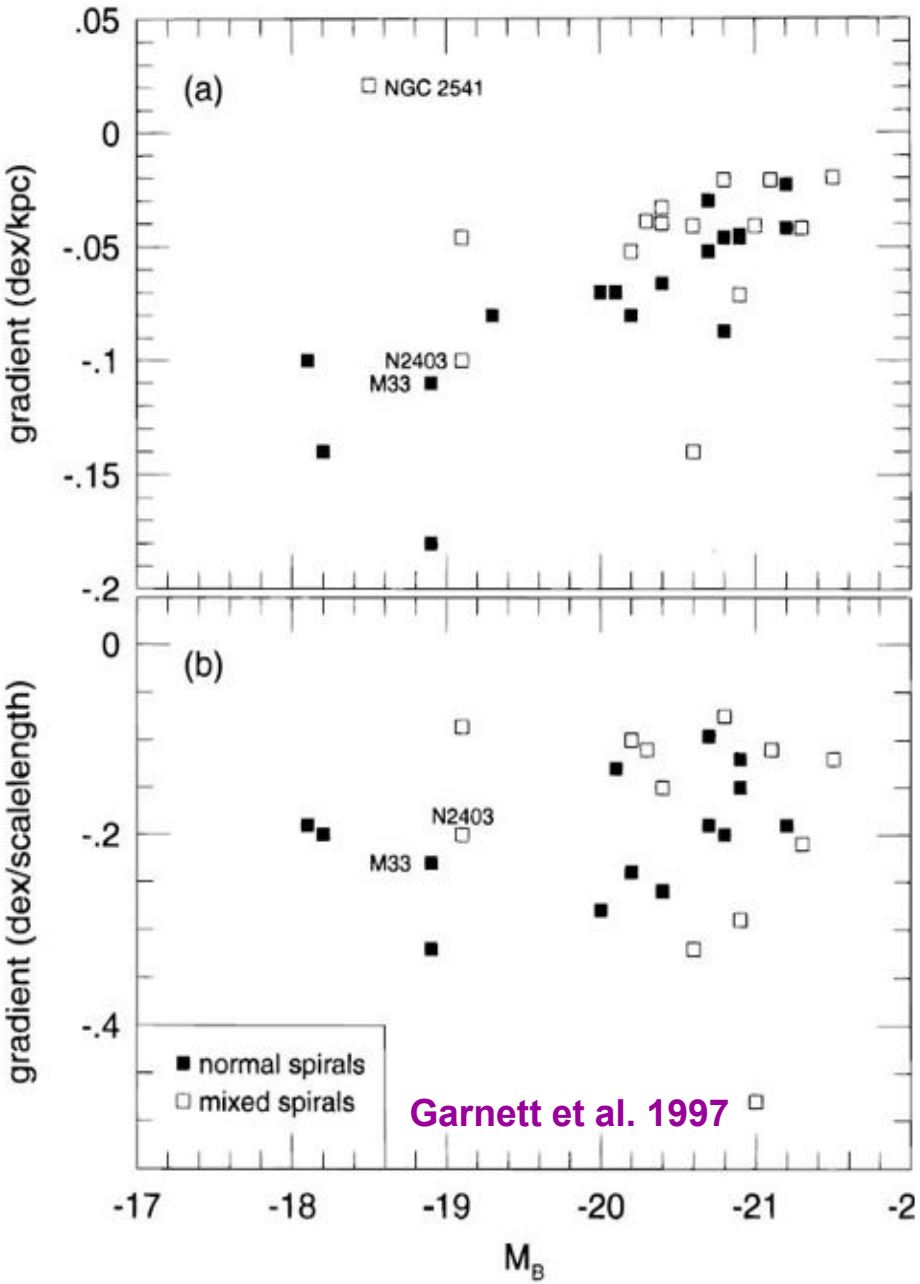




A small abundance gradient in M31

Comparative evolution of the Milky Way and Andromeda

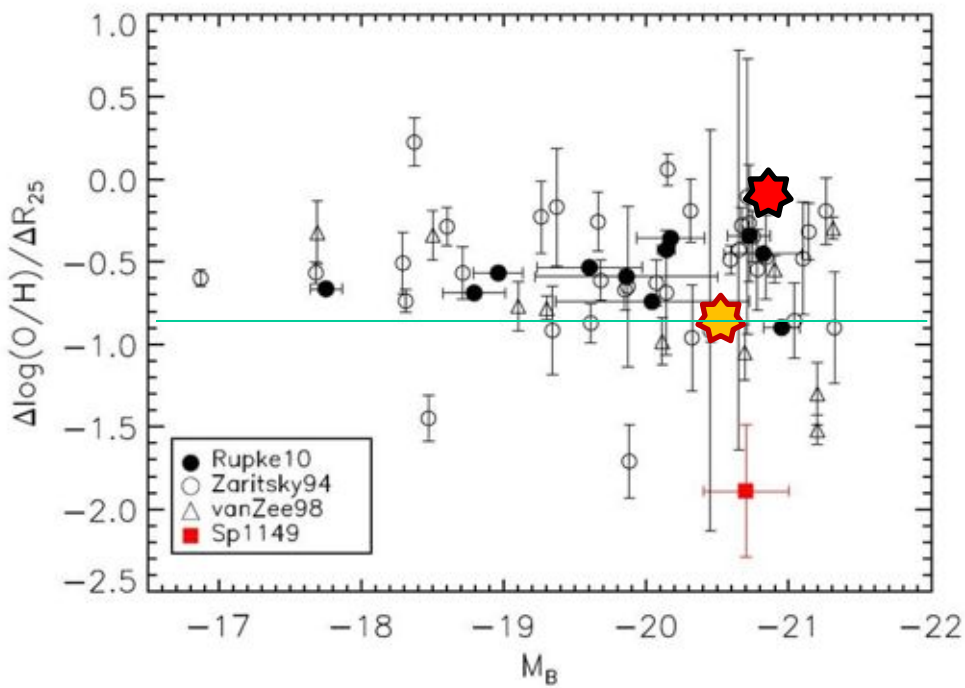




Garnett et al. 1997

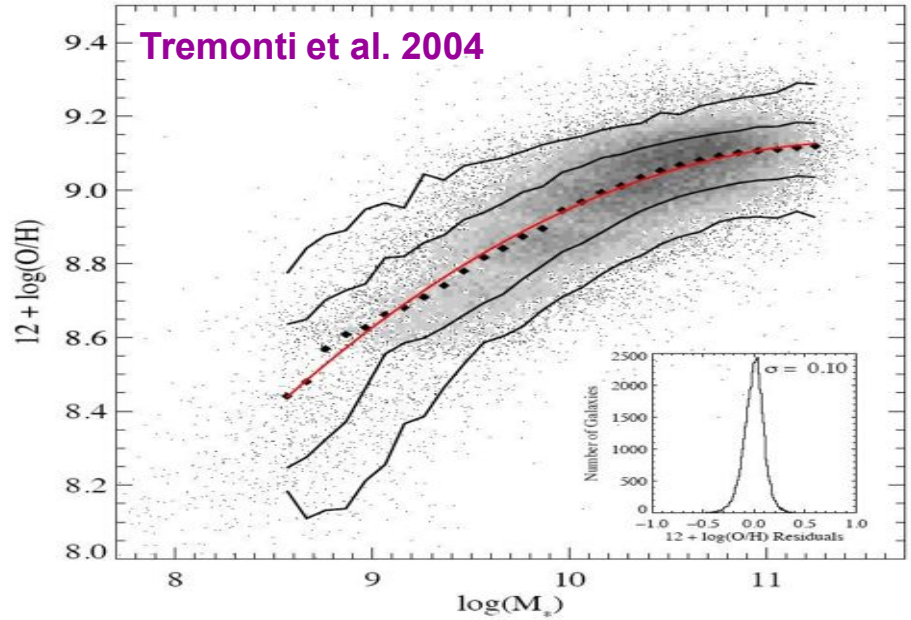
The abundance gradient decreases (in absolute value) with galaxy mass/luminosity when expressed in dex/kpc but is ~constant when expressed in dex/scalength or dex/R25 (*Garnett et al. 1997*: "homologous evolution")

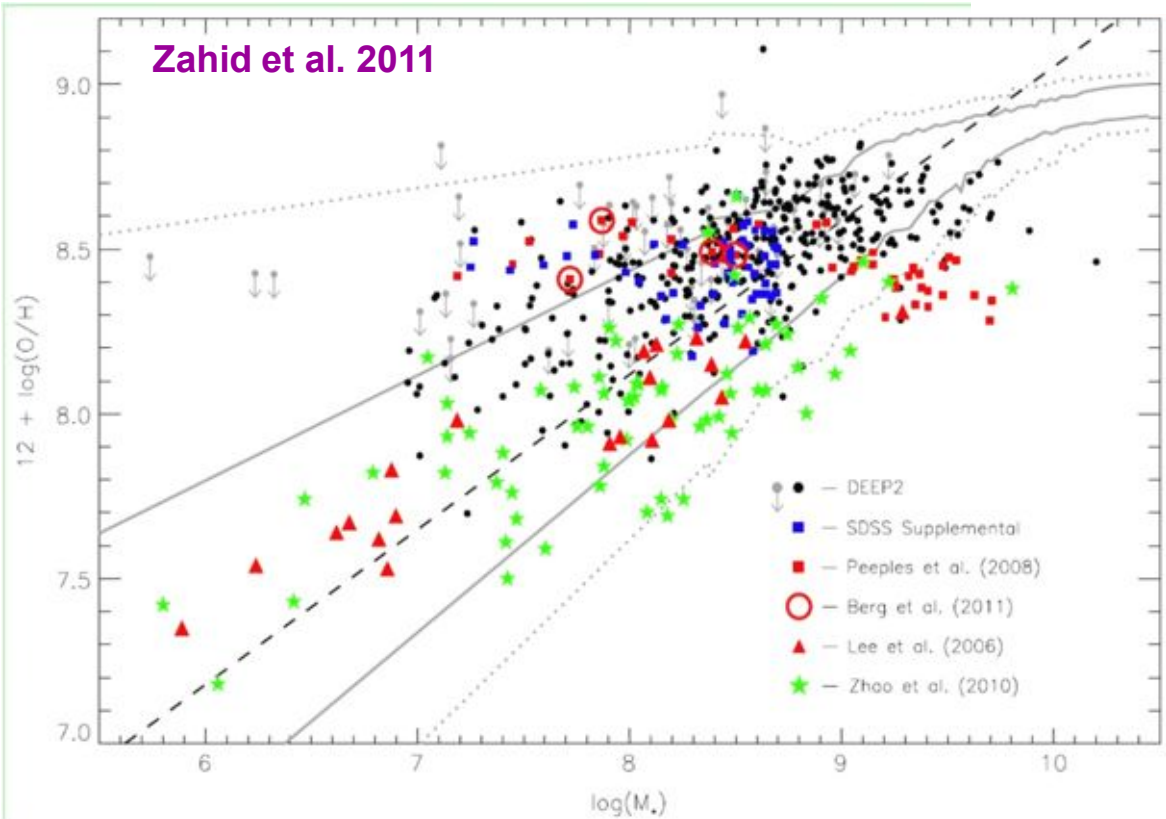
But: what drives such a homologuous evolution?



Mass-metallicity relation

It is shaped by
the complex interplay between
infall, outflow and SFR
in the mass-dependent
galactic potential wells





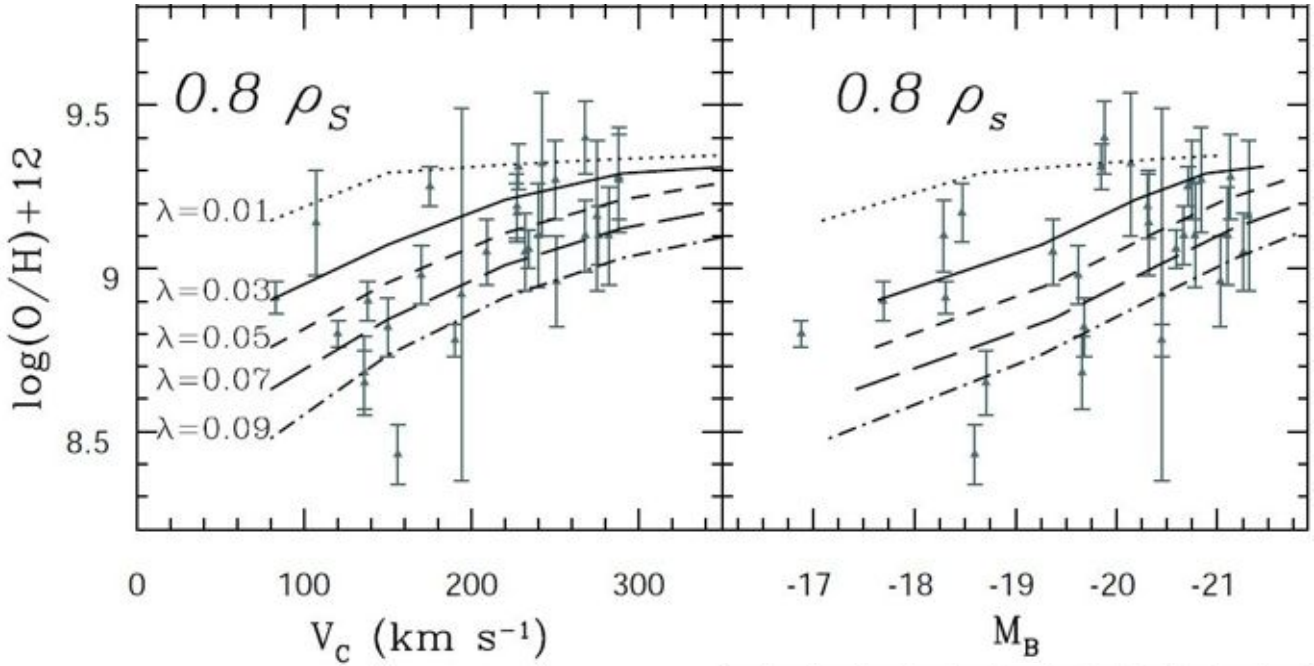
with a mass-dependent scatter:

95% of stars within

~1 dex at logM=8

~0.5 dex at logM=10

Mass-metallicity relation

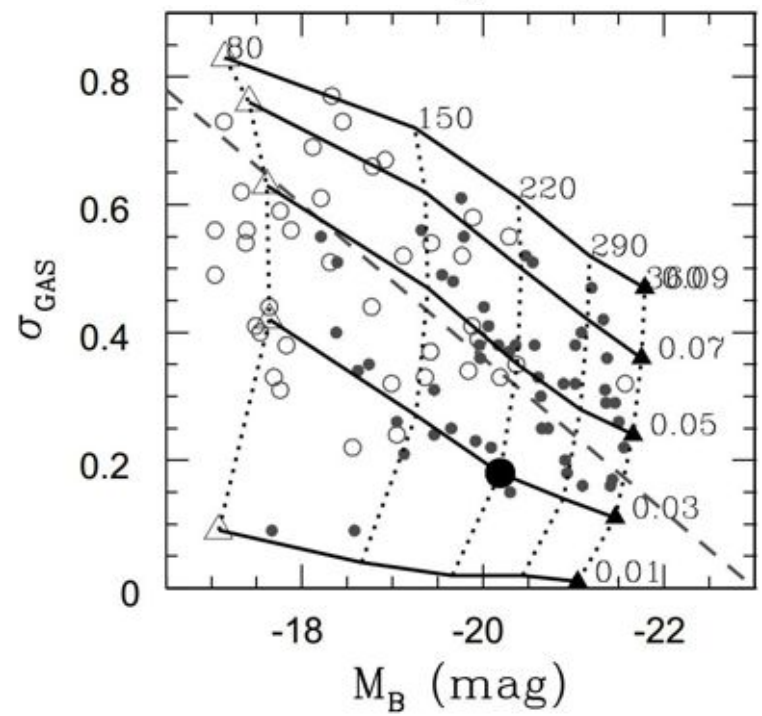


Its upper part (*V_C > 100 km/s*) can be readily explained by more efficient gas processing

$Z = y \ln(1/\sigma)$

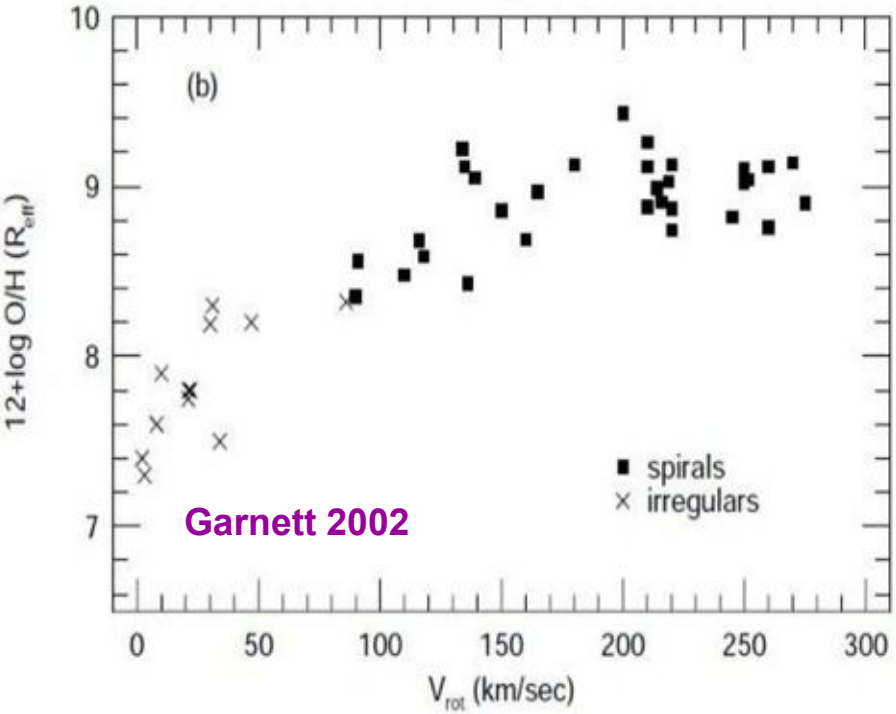
in more massive disks, that are observed to have lower gas fractions σ, *on average*

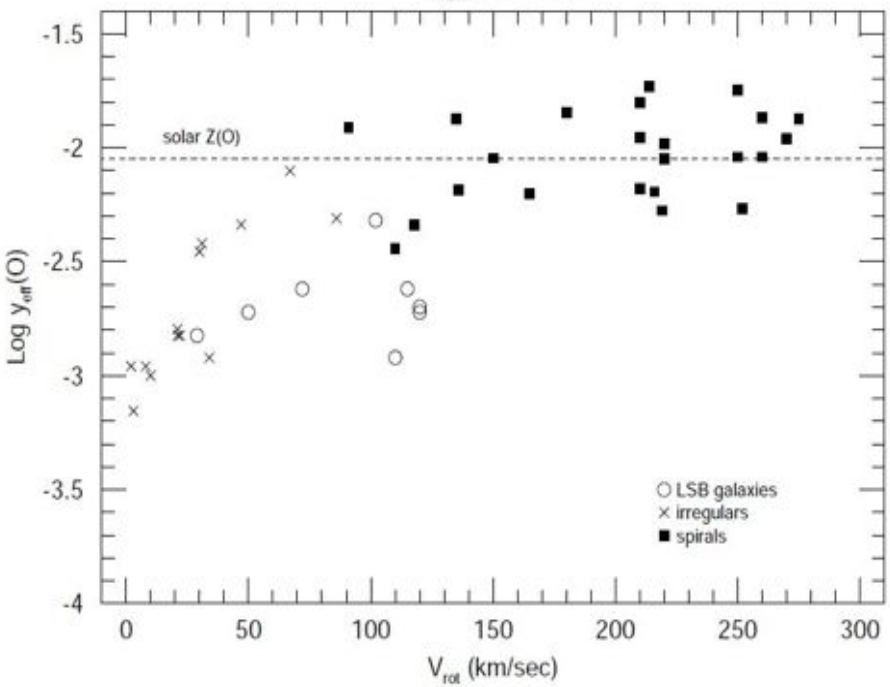
(*Boissier and Prantzos 2000*)

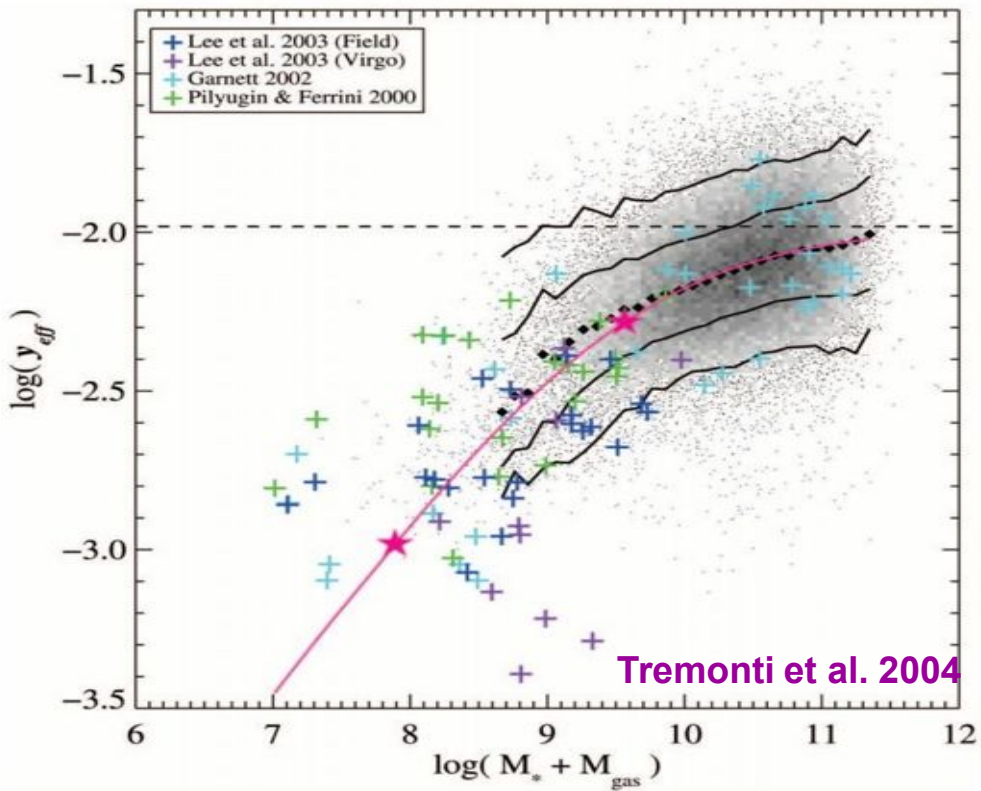


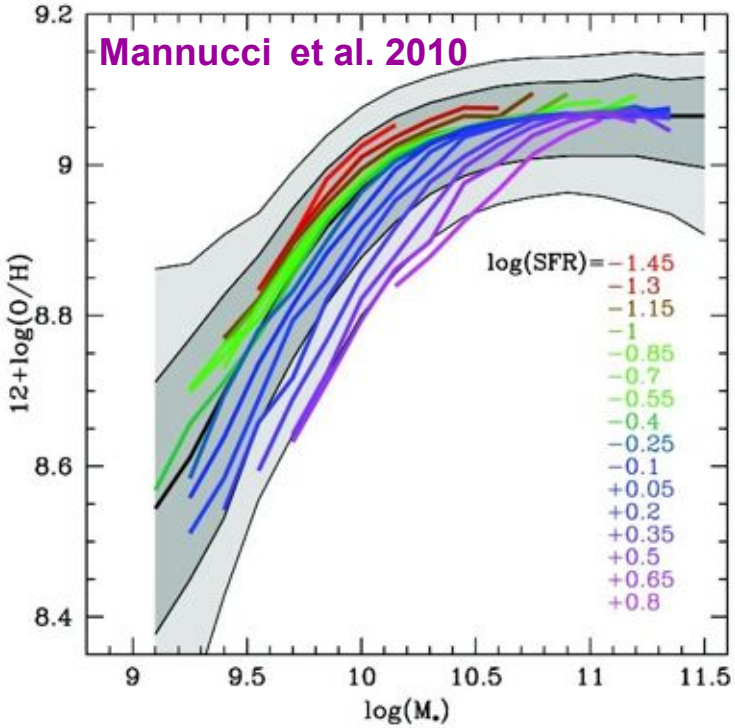
Mass-metallicity relation

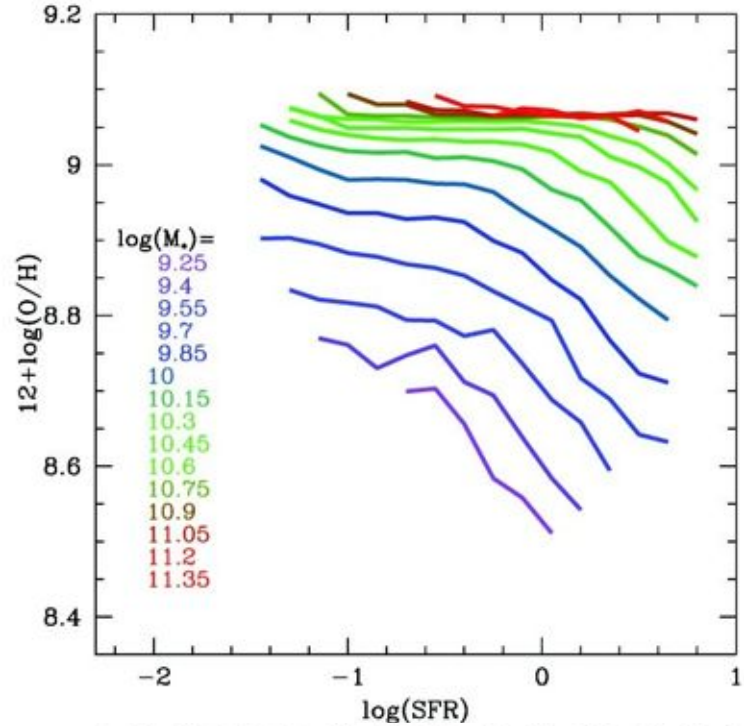
Its lower part ($V_C < 100$ *km/s*) concerns gas rich galaxies ($\sigma \sim 1$) and requires an *effective yield* $y_{eff} = Z / \ln(1/\sigma)$ *decreasing at low masses, i.e.* important outflows (*Garnett 2002, Tremonti et al. 2004*) or a galaxy mass-dependent IMF (*Koppen et al. 2007*)









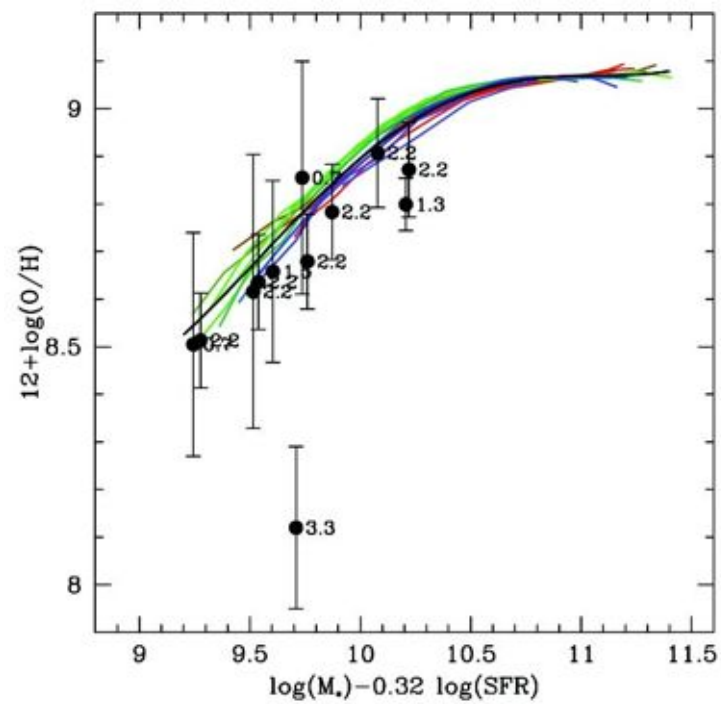


A fundamental relation between

Z, M∗* and *SFR

(Mannucci et al. 2010)

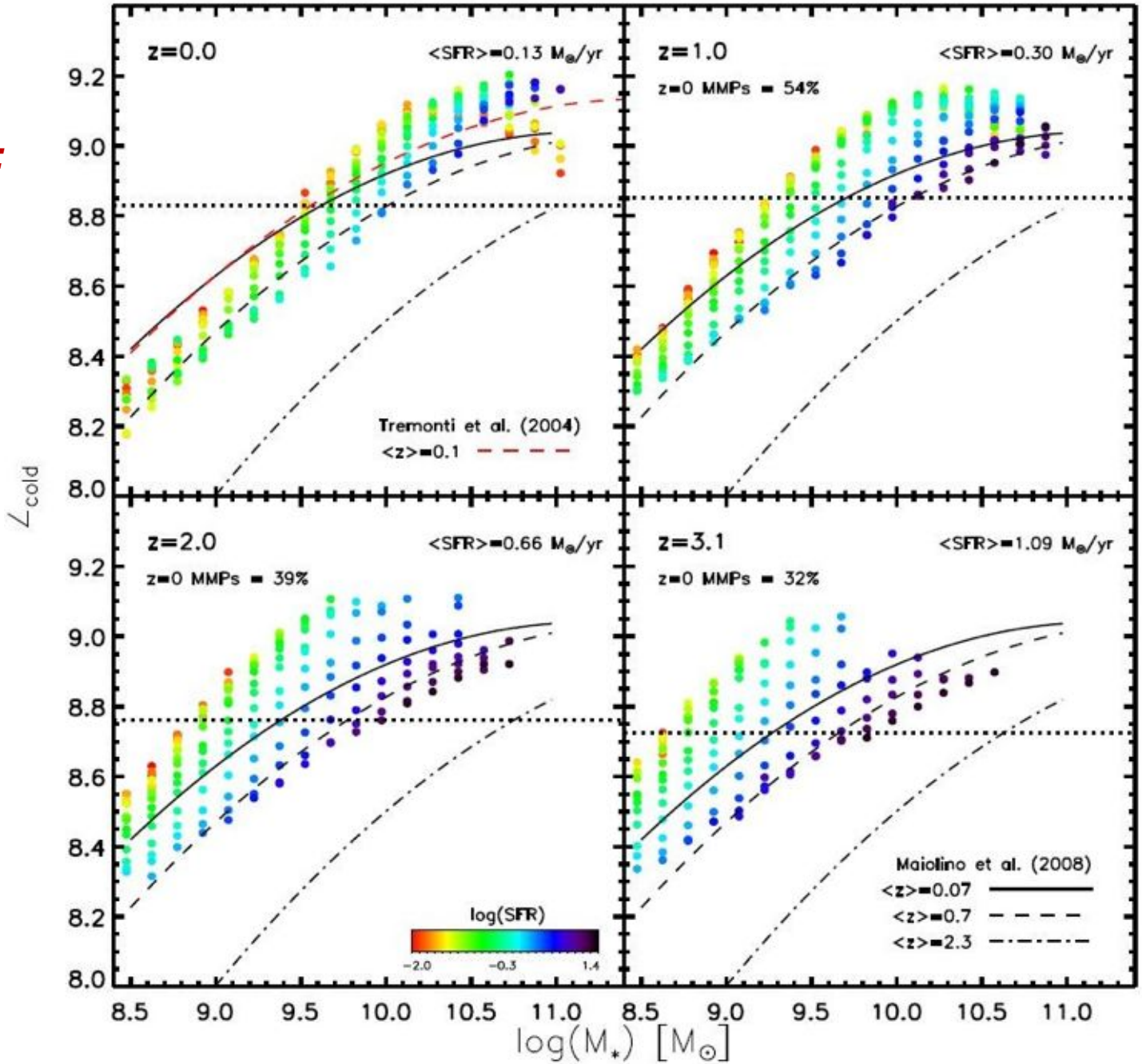
Also valid at higher redshifts *z*



Yates et al. 2012:

Observational and theoretical (*semi-analytical*) investigation of the evolution of the M-Z relation including the effects of the SFR

Unsuccessful at high redshifts

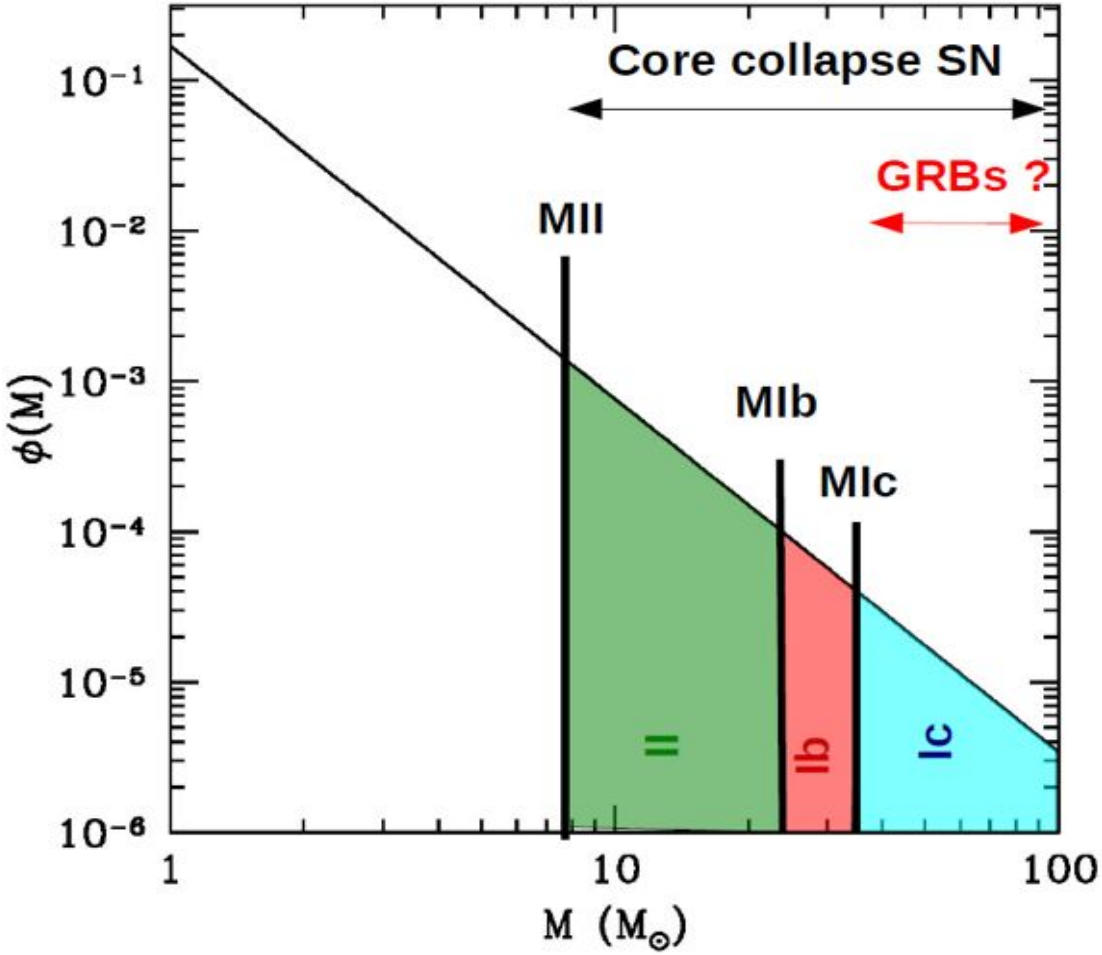


SN rates vs metallicity

The more massive AND metallic a star is
the more mass it loses in stellar wind
and less H (even He) is left
at the SN explosion
SNII → SNIb → SNIc

For a given IMF,
the number ratios
N(II)/N(Ibc) or N(Ic)/N(Ib)
will depend on
the limiting masses MIb, MIc,
which are functions of metallicity

By determining
N(II)/N(Ibc) or N(Ic)/N(Ib)
as a function of metallicity Z in galaxies
one may determine MIb, MIc
and constrain stellar models
(Prantzos and Boissier 2003)



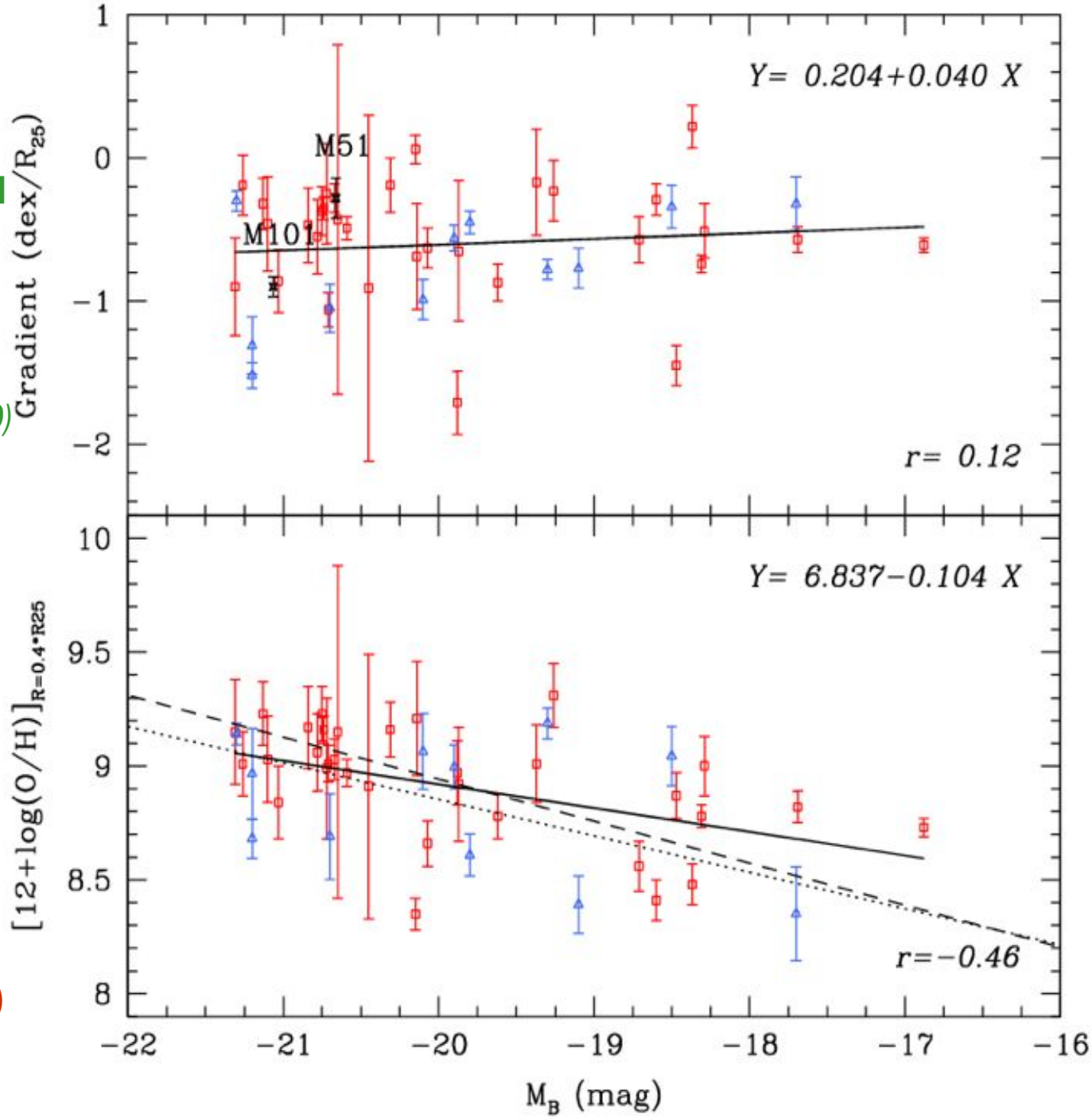
How to determine galaxian metallicity
for a large number of SN?

By using the **metallicity gradient vs luminosity** relation one may correlate **SN ratios** to the **local galaxian metallicity**

(Boissier and Prantzos 2009)

By using the **metallicity vs luminosity** relation one may correlate **SN ratios** to the **global galaxian metallicity**

(Prantzos and Boissier 2003)



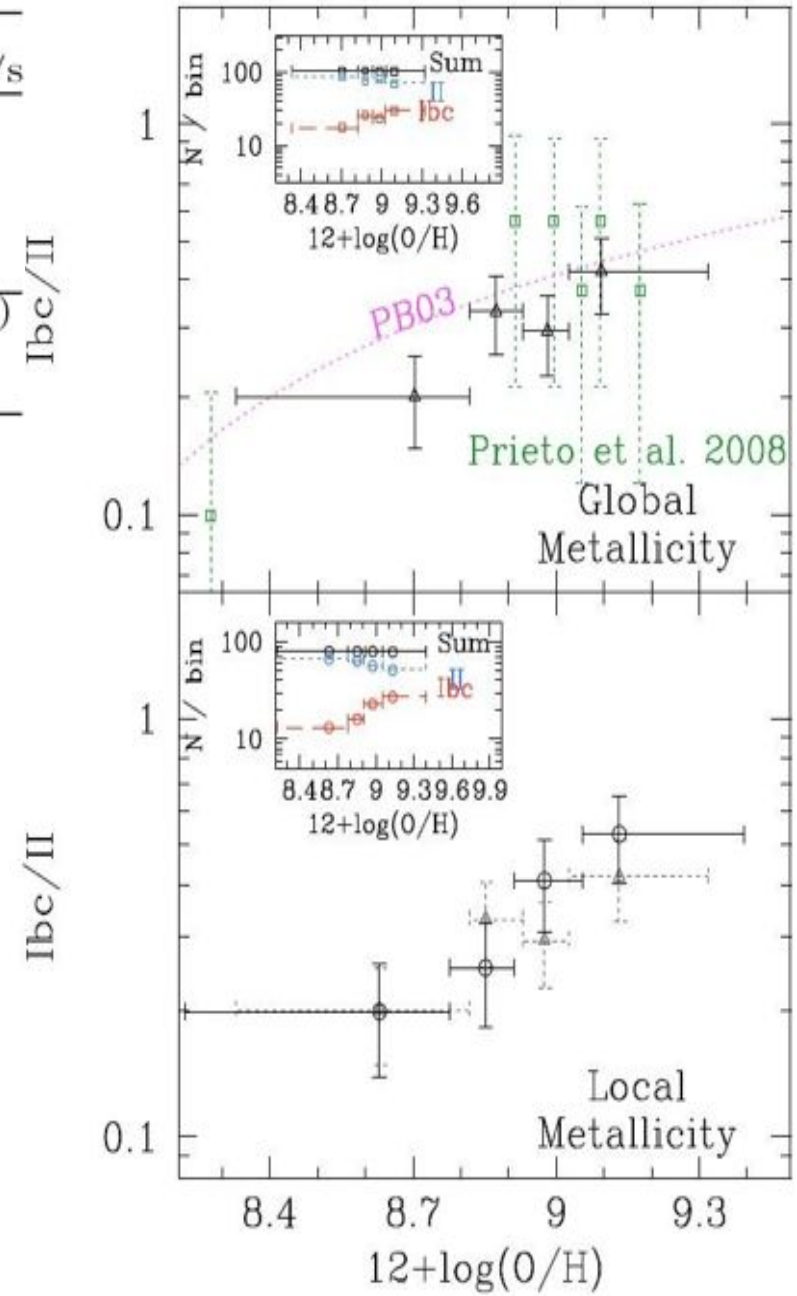
SN Type	Larger statistics $V_{HEL} < 5000$ km/s	Conservative $V_{HEL} < 2000$ km/s
Ic	49 (41)	18 (15)
Ib	32 (25)	15 (12)
Ibc	98 (79)	43 (36)
II	318 (239)	142 (96)
Ia	166 (132)	56 (42)
$N(Ibc)/N(II)$	0.31 ± 0.04 (0.06)	0.30 ± 0.05 (0.06)
$N(Ic)/N(Ib)$	1.53 ± 0.35 (0.30)	1.20 ± 0.42 (0.24)
$N(Ia)/N(CC)$	0.40 ± 0.04 (0.08)	0.30 ± 0.05 (0.06)

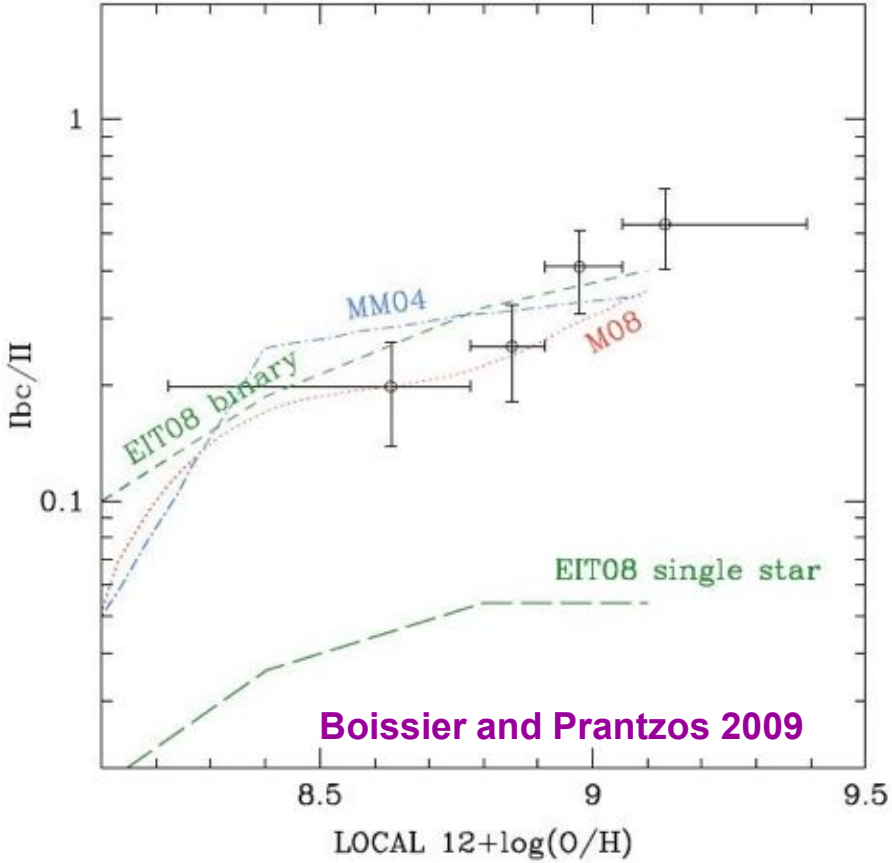
There is indeed a correlation

of N(Ibc)/N(II) with metallicity Z

either on a global level
(Prantzos and Boissier 2003)

or on a local level
(Boissier and Prantzos 2009)

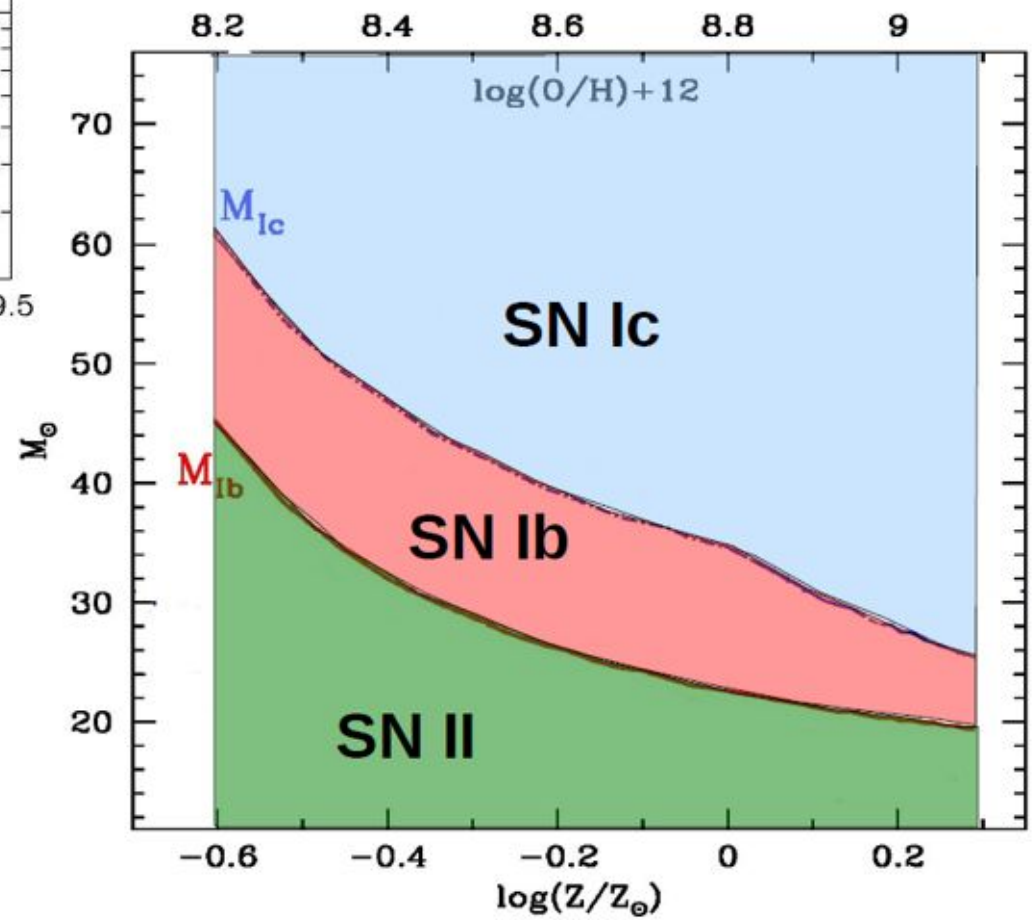


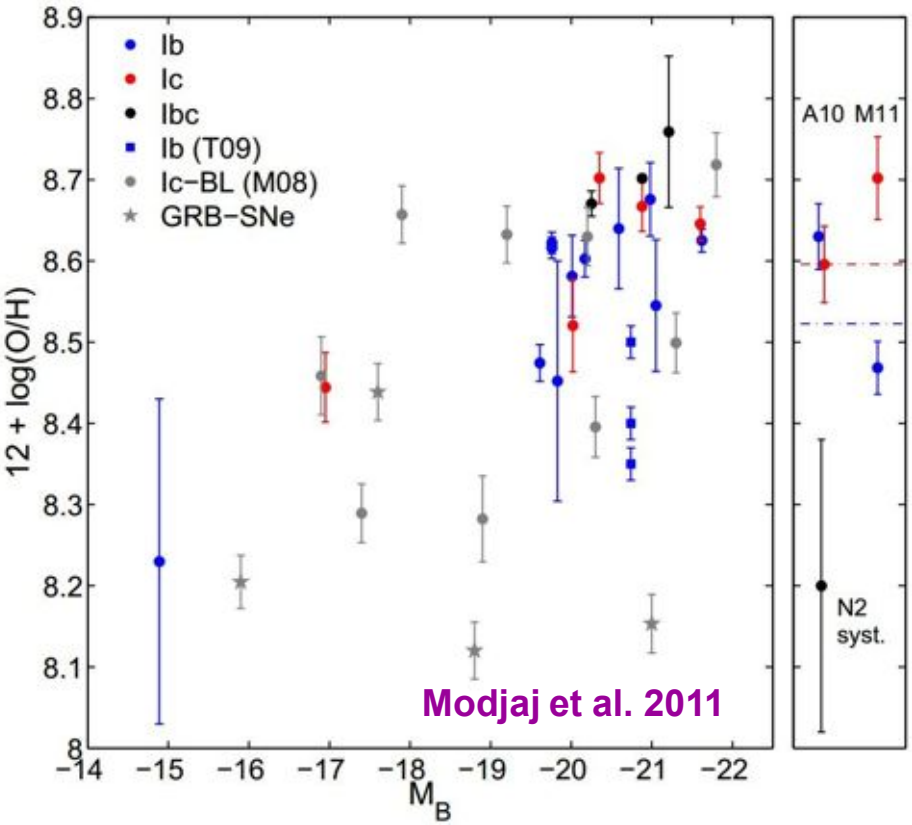


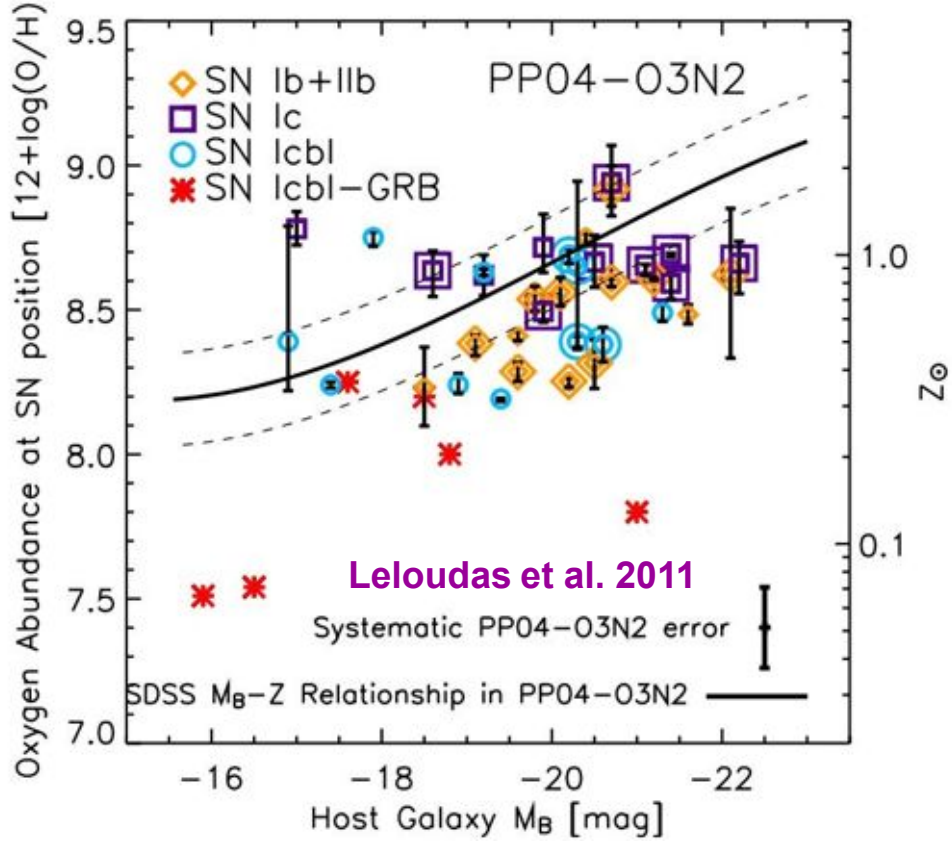
Boissier and Prantzos 2009

This correlation constrains
Single and binary models
of massive star evolution…

… and imposes mass limits
MIb, MIc, as function of metallicity
to single star models







Better: Direct measurements of O abundance at the SN position

But it will take time !

Conclusions

Measurements of oxygen abundances in various sites (stars and ISM) of galaxies are necessary, to constrain models of galactic evolution

but, in most cases, this is done within a theoretical framework involving several other poorly known parameters.

In some cases (SN and GRB host galaxies) measurements constrain directly pre-SN and pre-GRB models