Oxygen abundances in outer galaxy disks

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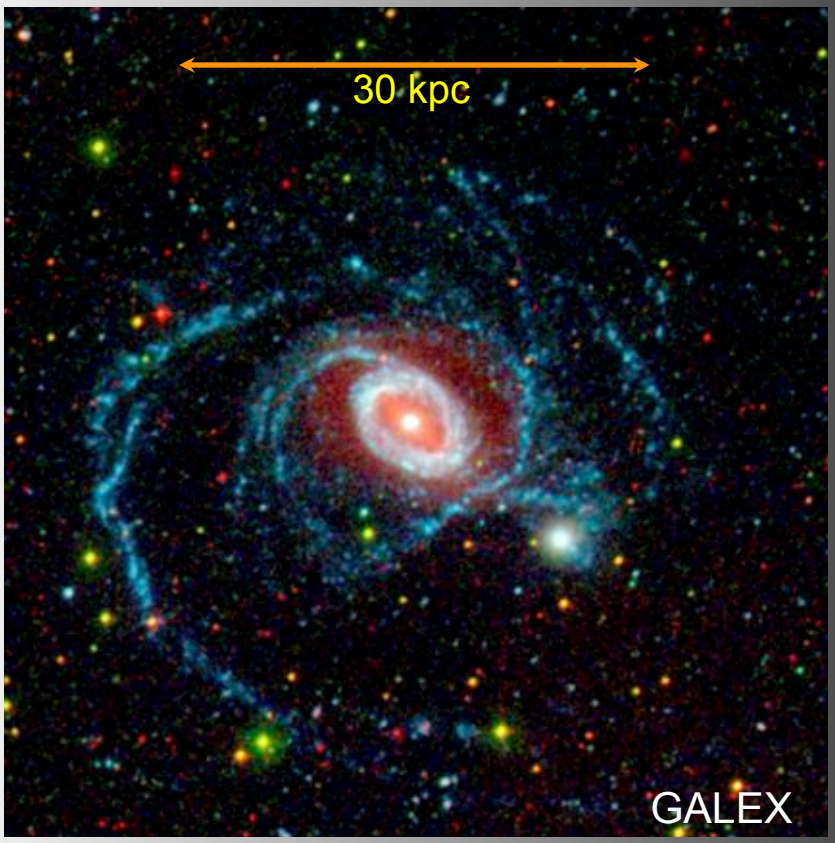
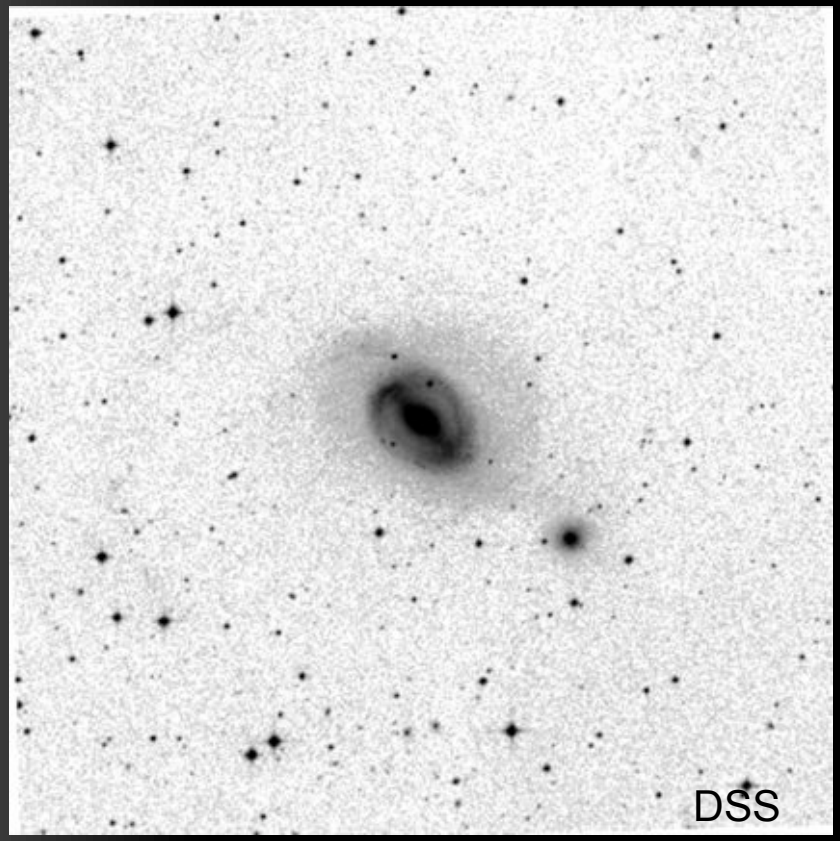
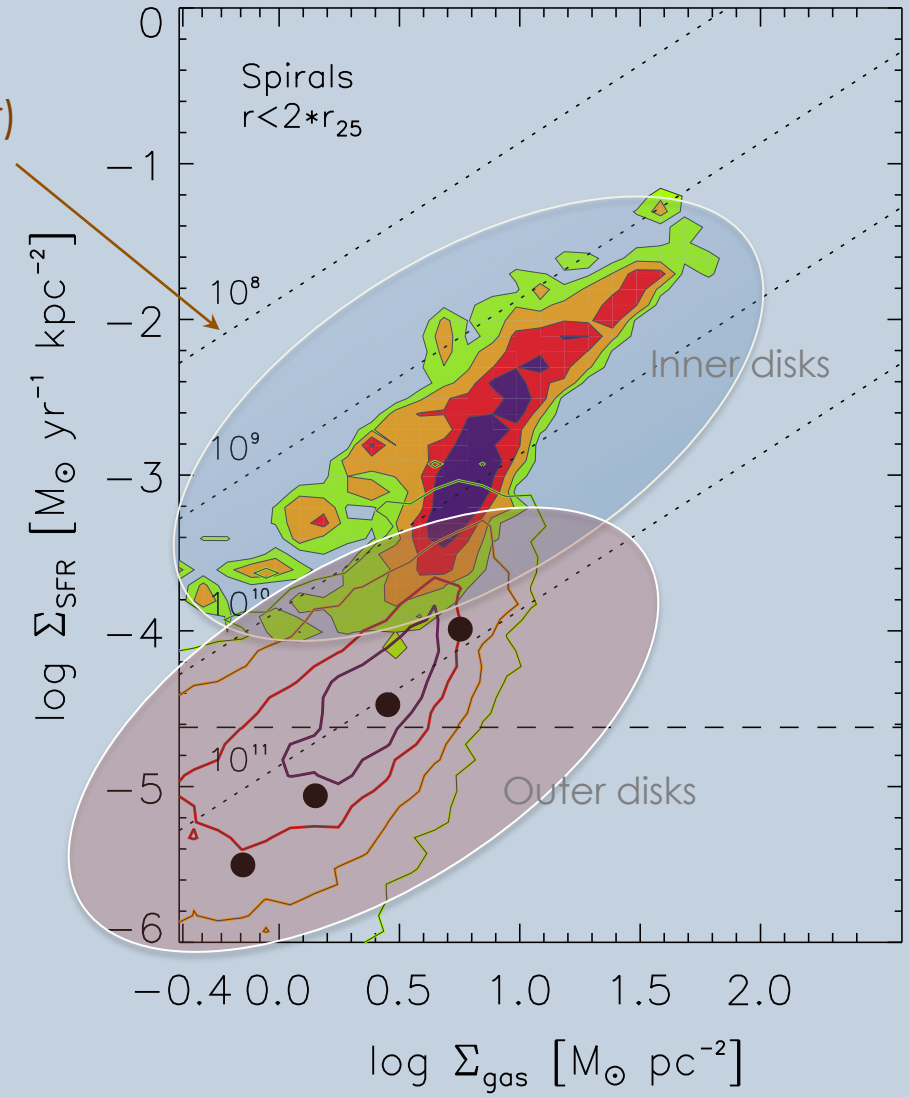

30 kpc
GALEX


DSS

gas depletion times (yr)



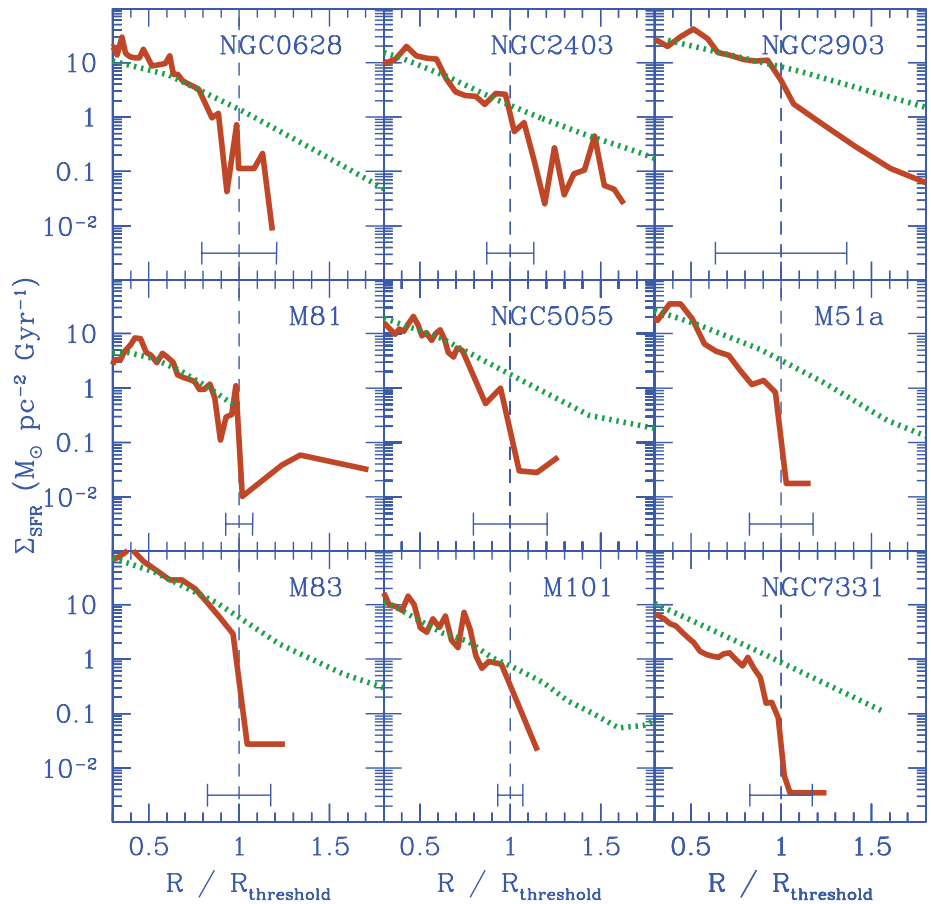
Bigiel et al. 2010

H α vs. UV profiles

at low SFR levels the number of ionizing O stars becomes very small, subject to stochastic sampling of the upper IMF

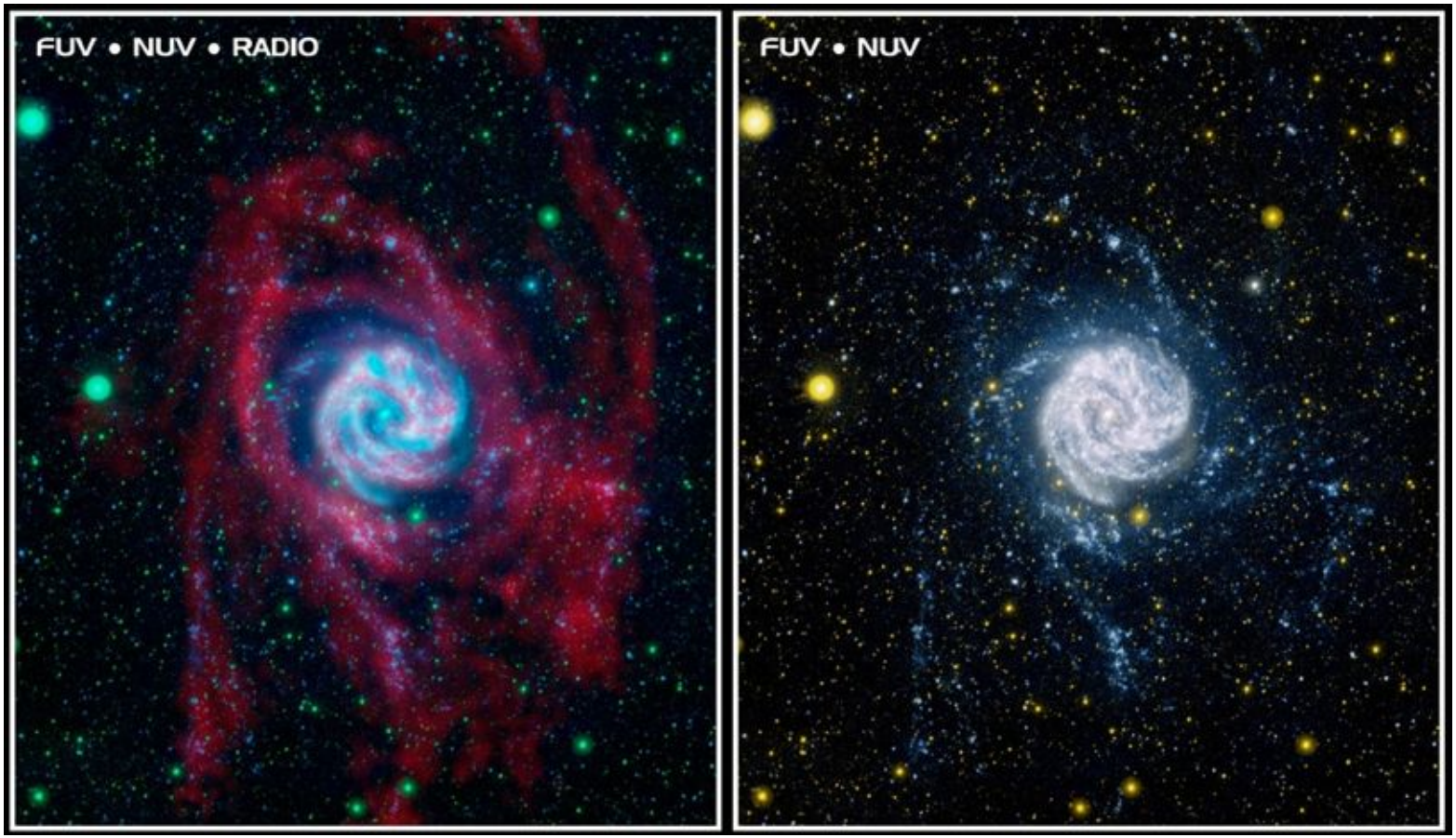
the UV comes from longer-lived (100 Myr), smaller mass B stars

NO NEED for IMF changes



a gas density threshold for star formation? Different IMF?

Boissier et al. 2007



why do stars form in outer disks?

Localized higher gas density

(Dong et al. 2008, Bush et al. 2008)

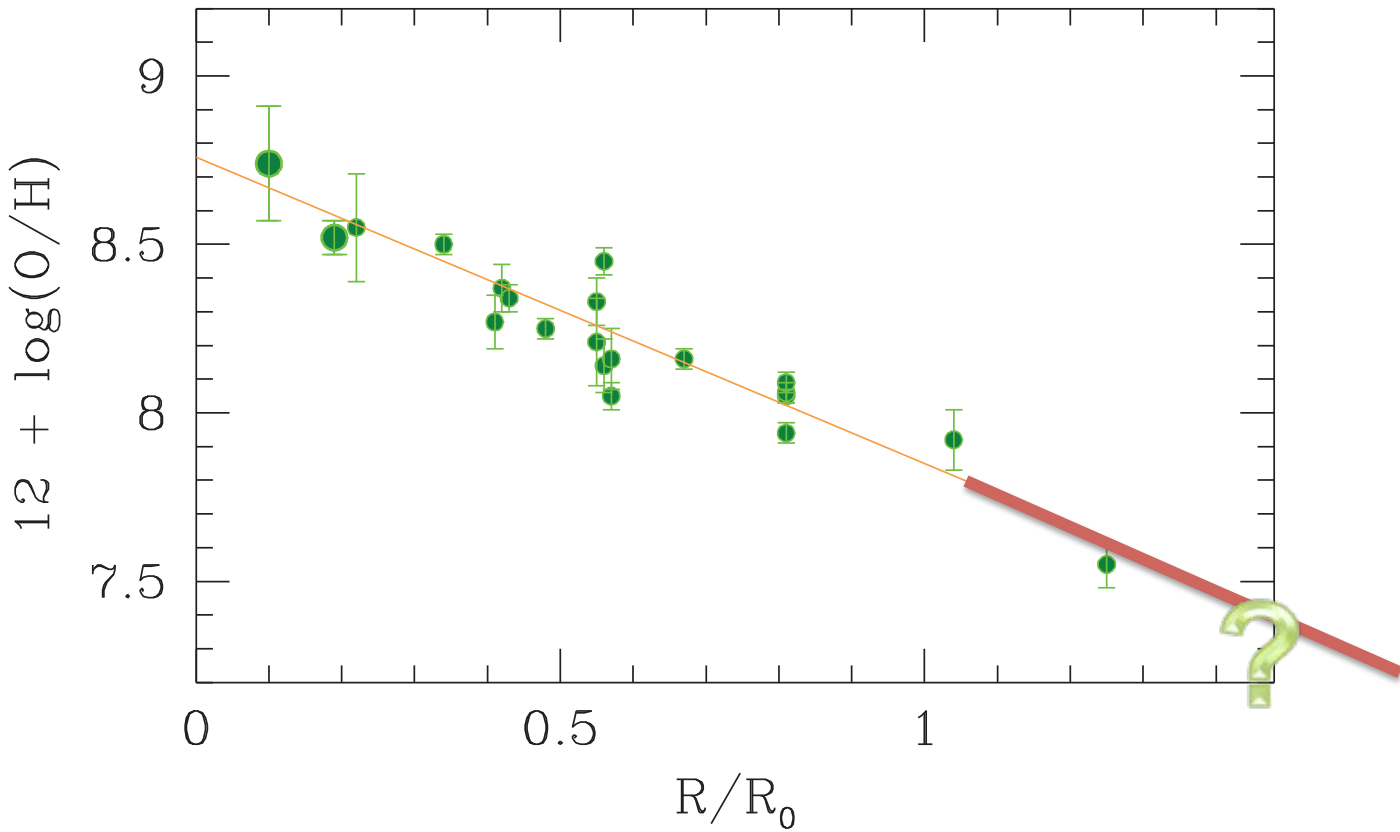
why do stars form in outer disks?

Galaxy interactions

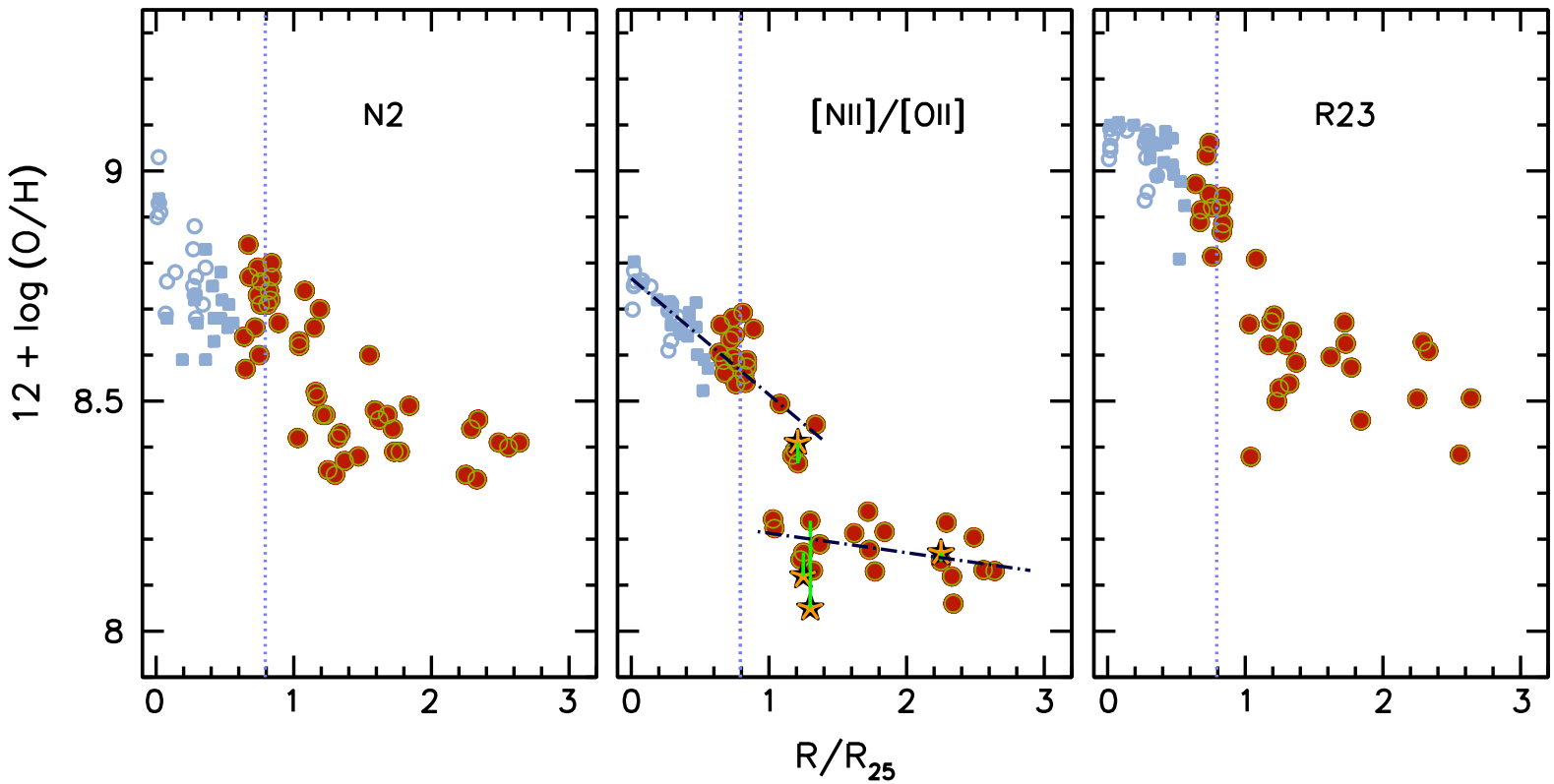
(Gil de Paz et al. 2005)

young?

inside-out



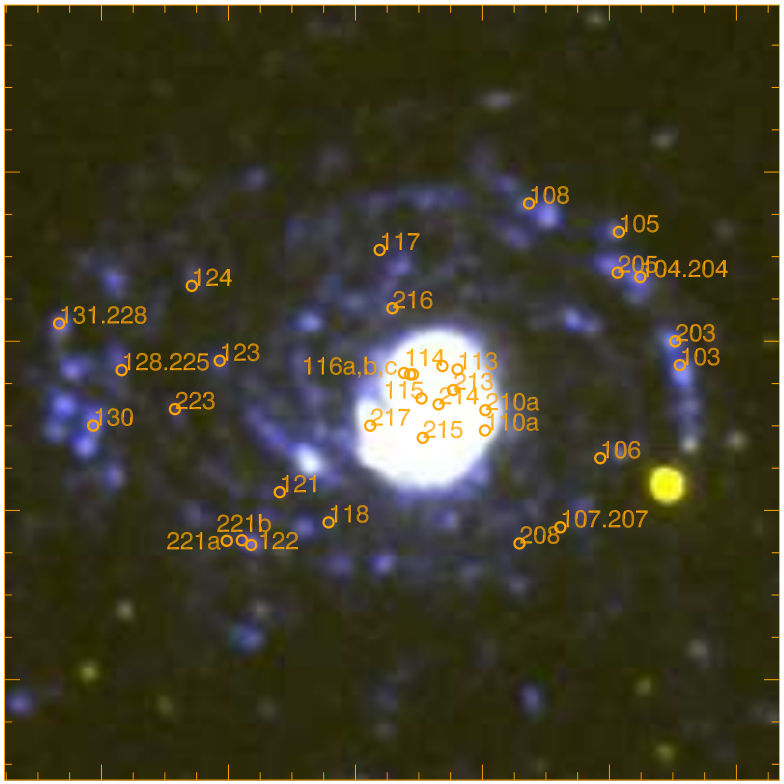
Kennicutt, Bresolin & Garnett 2003; Bresolin 2007

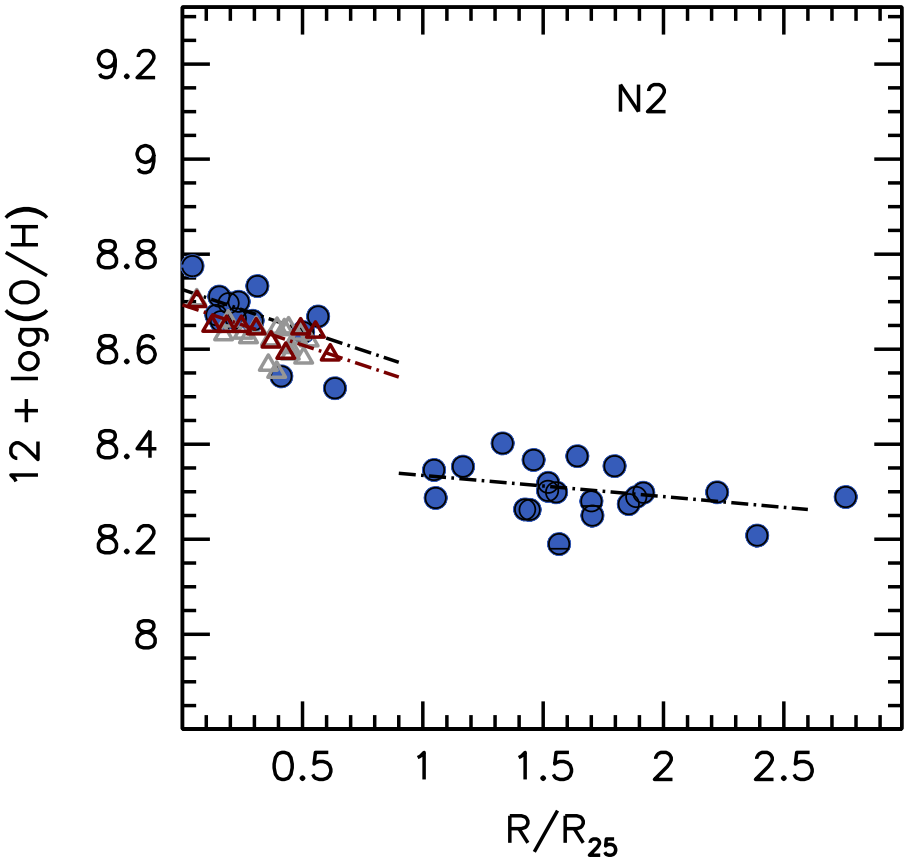


ABUNDANCE GRADIENTS IN OUTER DISKS

M83

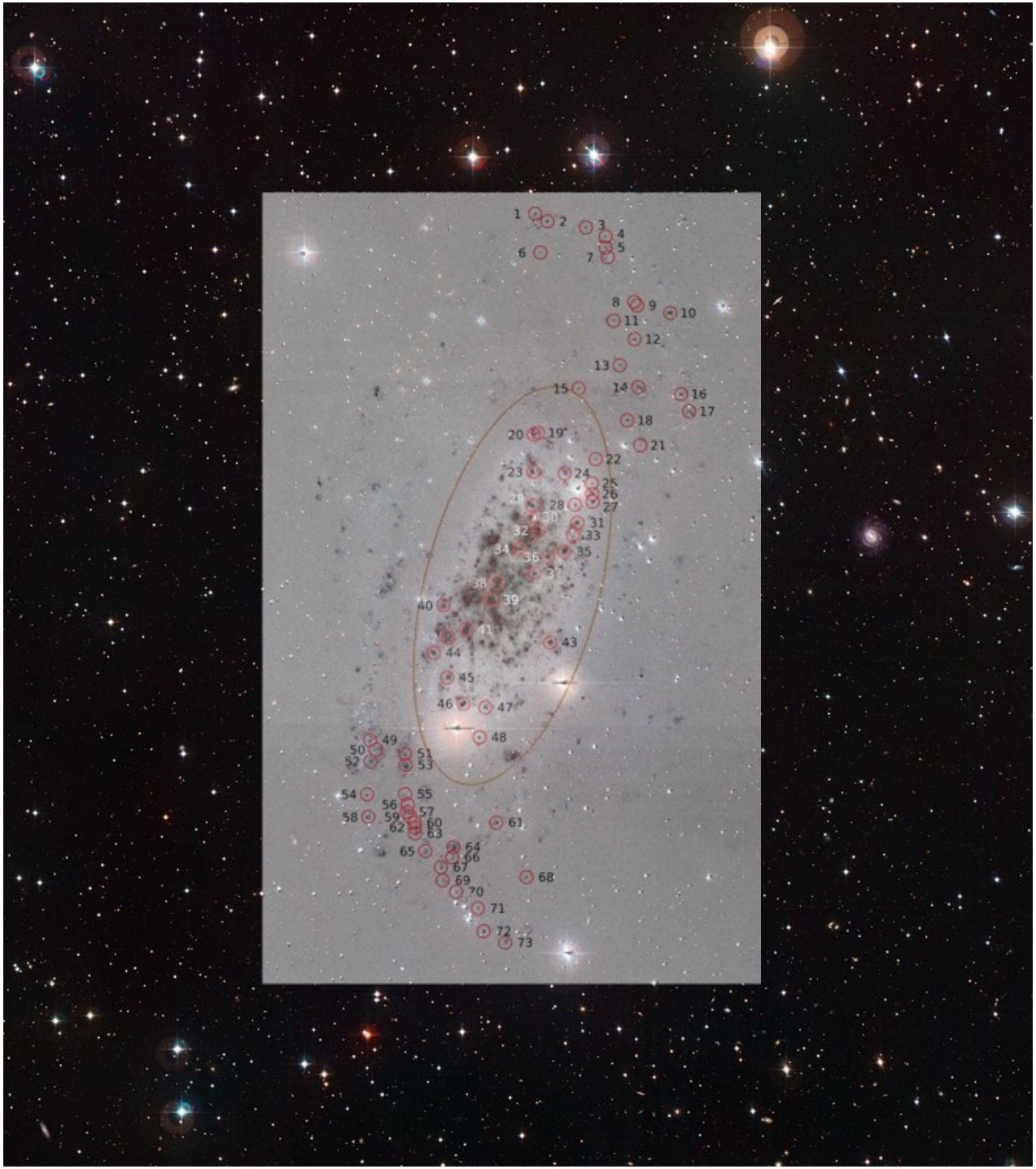
Bresolin, Kennicutt, Ryan-Weber & Goddard 2009





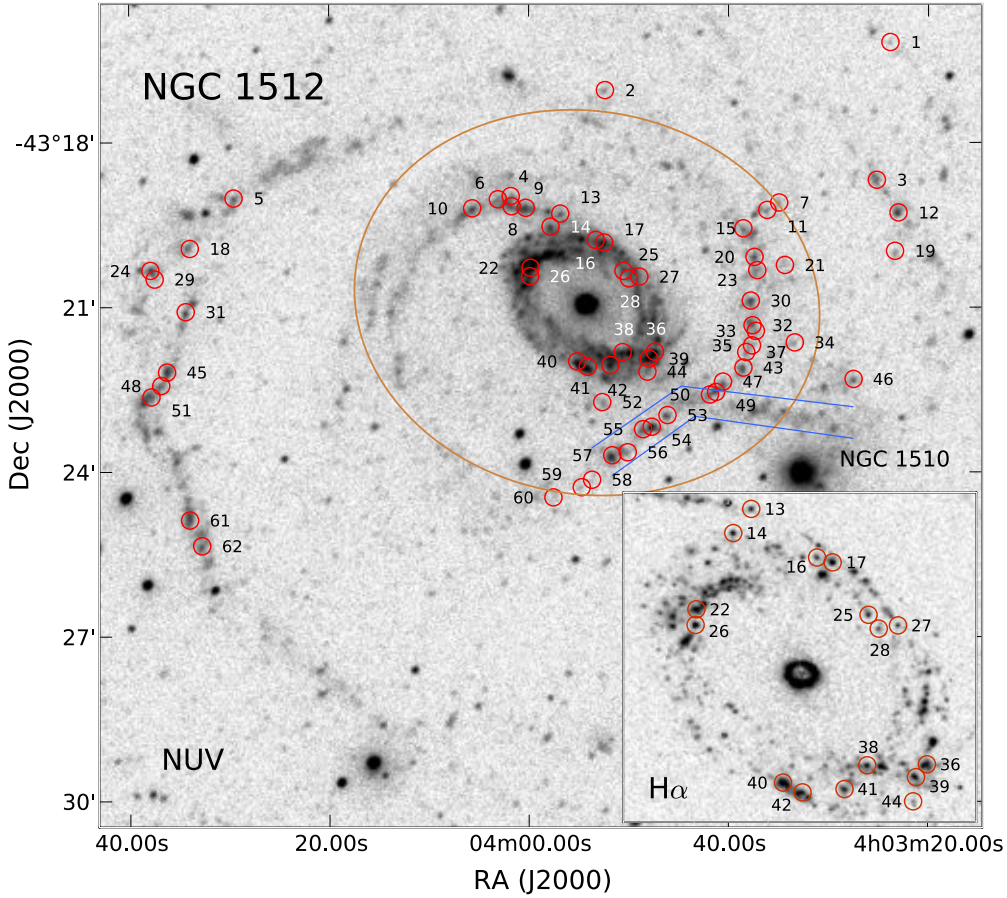
NGC 4625

Goddard et al. 2011



NGC 3621

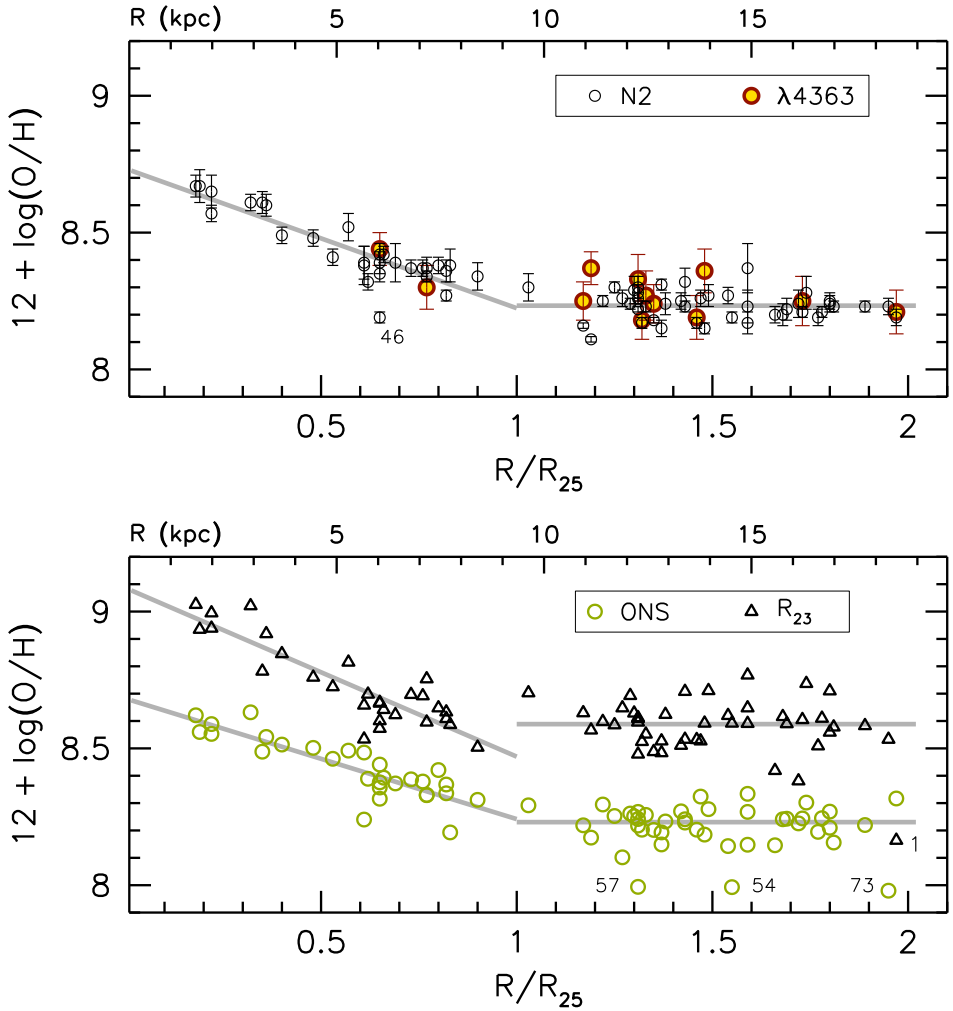
Bresolin et al. 2012



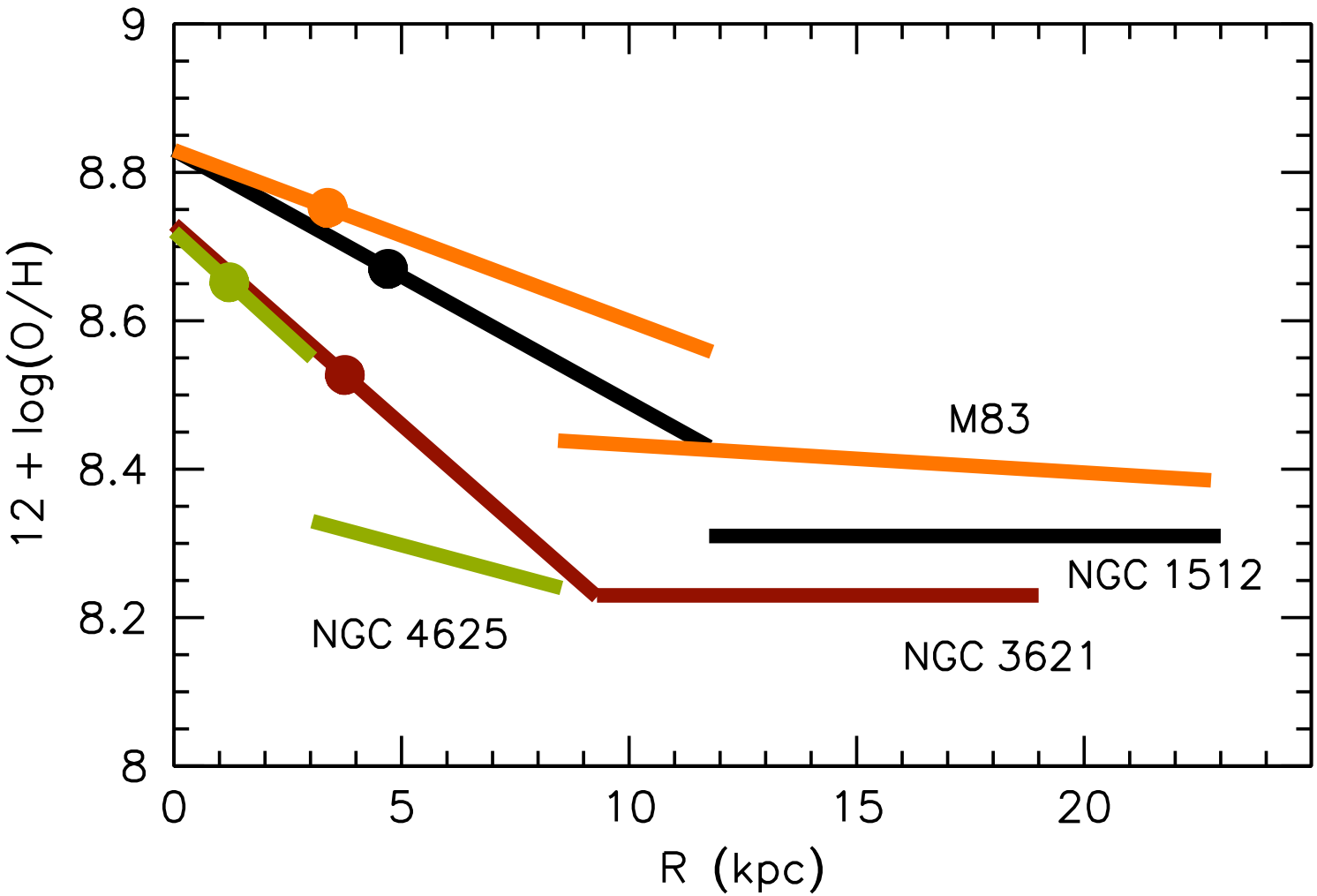
NGC 1512

Bresolin et al. 2012

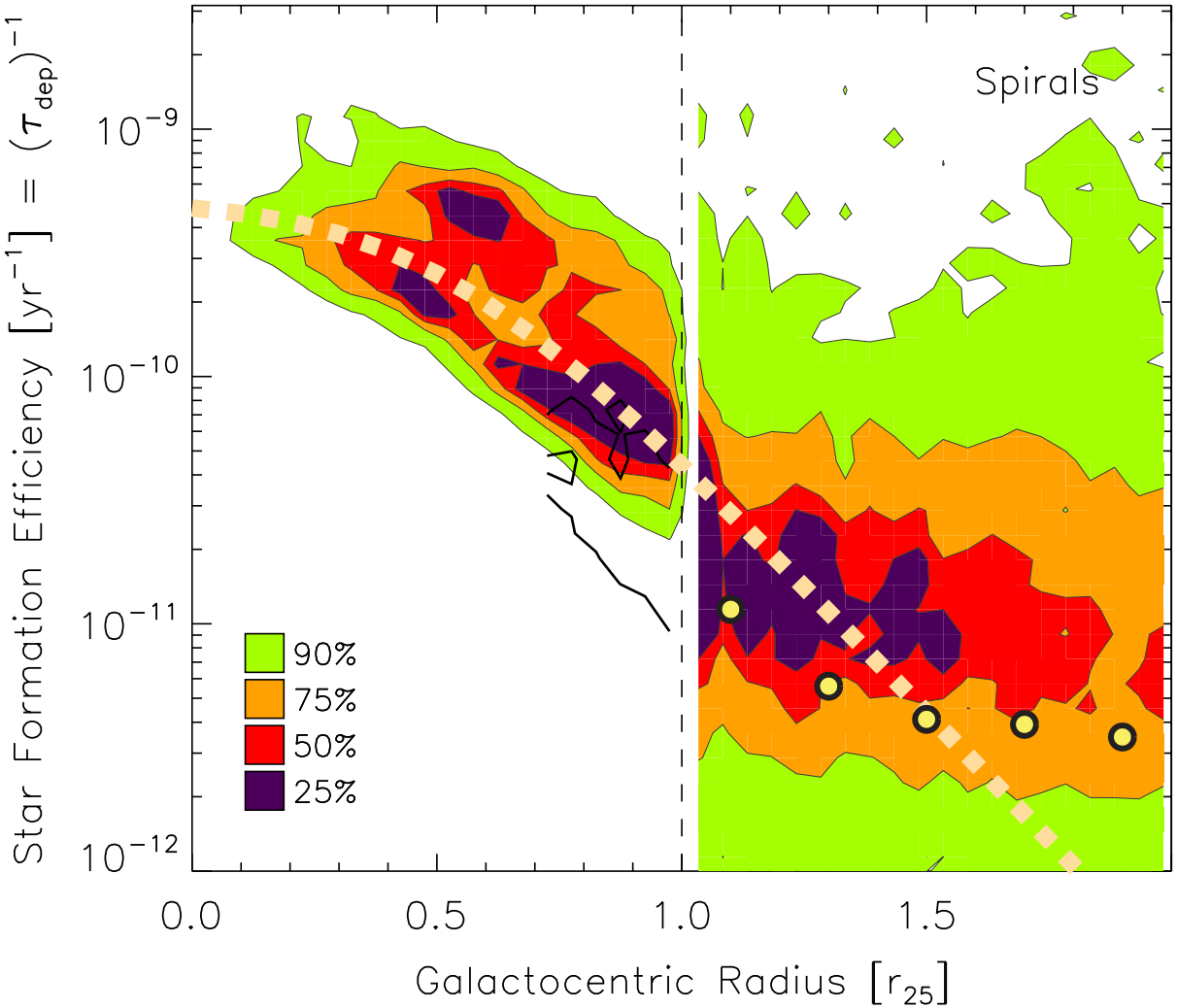
NGC 3621


R (kpc)
5
10
15
N2
λ4363
12 + log(O/H)
9
8.5
8
46
0.5
1
1.5
2
R/R25
R (kpc)
5
10
15
ONS
R23
12 + log(O/H)
9
8.5
8
57
54
73
1
0.5
1
1.5
2
R/R25

OUTER DISKS: SUMMARY



Bigiel et al. 2010



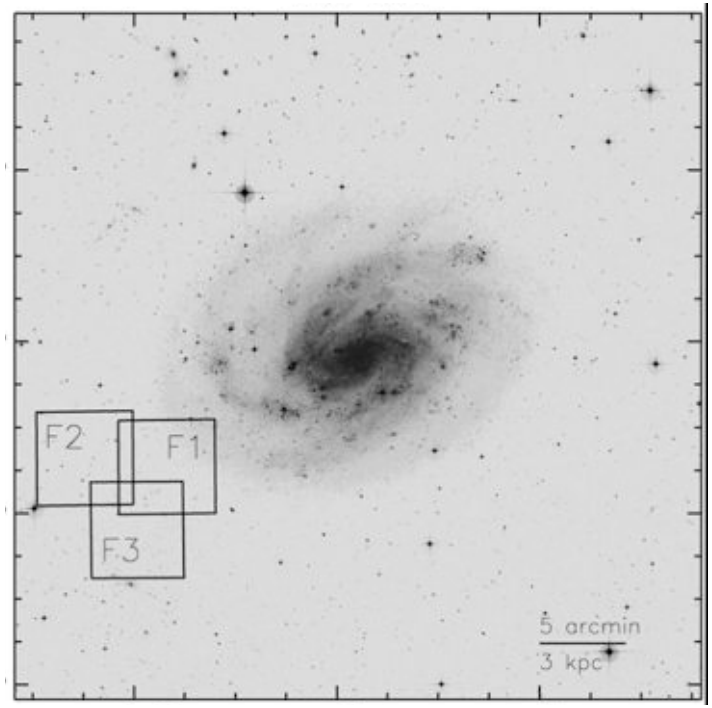
Star formation efficiency: $\Sigma_{SFR}/\Sigma_{gas}$ (FUV/HI)

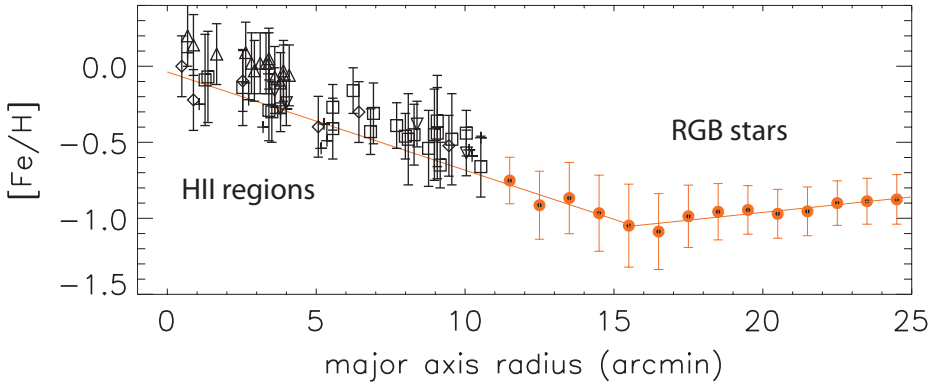
$$\frac{O}{H} = \frac{y_O \, t \, \Sigma_{SFR}}{\mu \, \Sigma_{HI}} \propto SFE$$

FLAT GRADIENTS

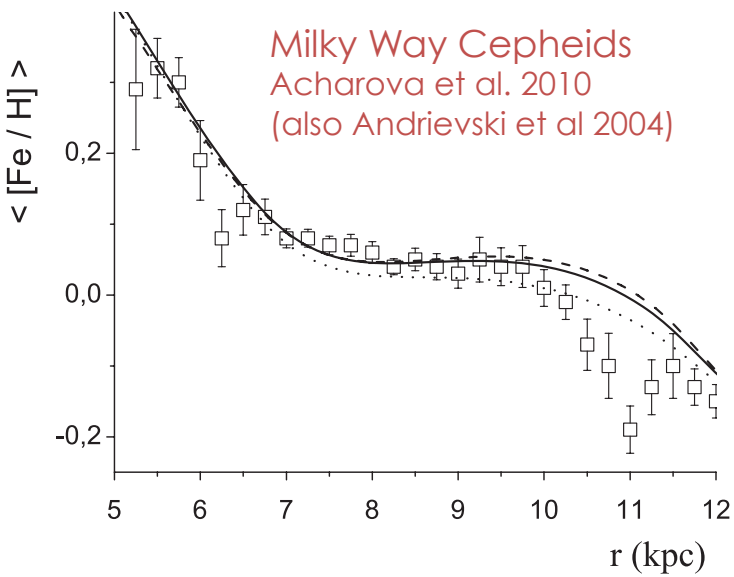
'Intermediate age' (>1 Gyr) stars present

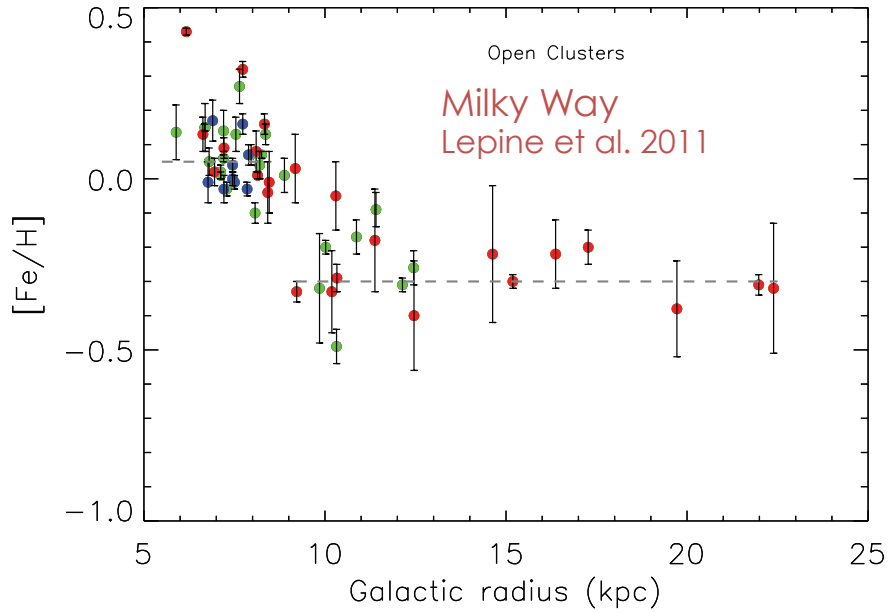
eg M81, M83, M33, NGC 2403 (Davidge 2009, Barker et al.2012)

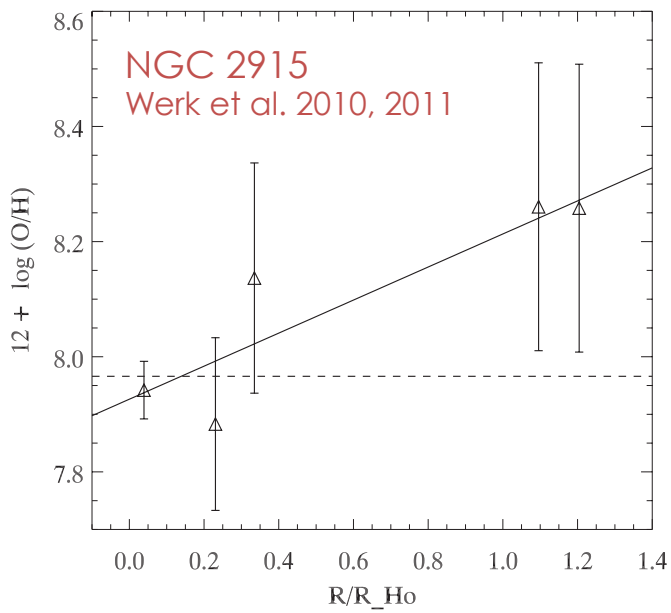




Vlajic et al. 2009







FLAT GRADIENTS

EXPLAINING THE O/H IN OUTER DISKS

The timescales for obtaining the currently observed O/H ratio appear to be longer than a Hubble time

BUT

Analysis of stellar content + SFHs of nearby resolved galaxies + age gradients + inside-out growth + results of cosmological simulations suggest that outer disks cannot have formed stars for more than a few (~4) Gyr

In situ star formation cannot explain observed O/H

Radial Mixing

bars
tidal interactions/mergers
satellite encounters

radial gas flows (Lacey & Fall 1985)

resonance scattering with transient spiral density waves (Sellwood & Binney 2002)

spiral+bar resonances (Minchev et al. 2011)

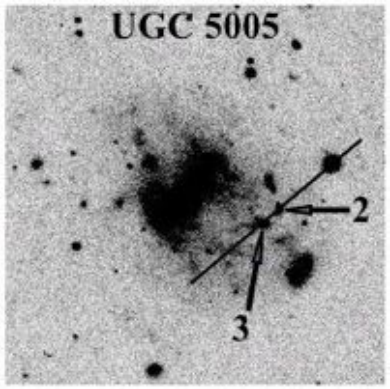
Enriched Infall

Gas accretion modulated by feedback, outflows and SF

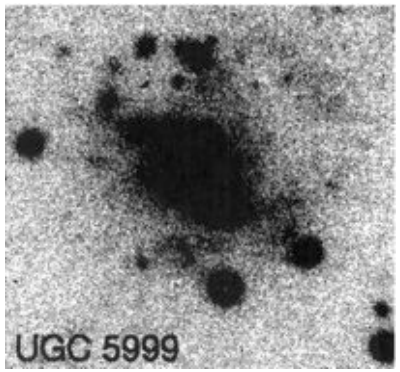
Circumgalactic medium enriched via galactic winds (eg 'wind recycling' models, Oppenheimer & Dave' 2008)

LOW SURFACE BRIGHTNESS GALAXIES

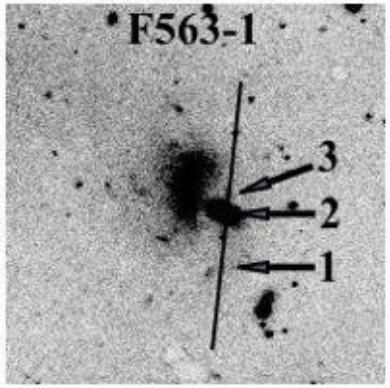
$\mu_{o,B}$ > 23 mag arcsec^{-2}



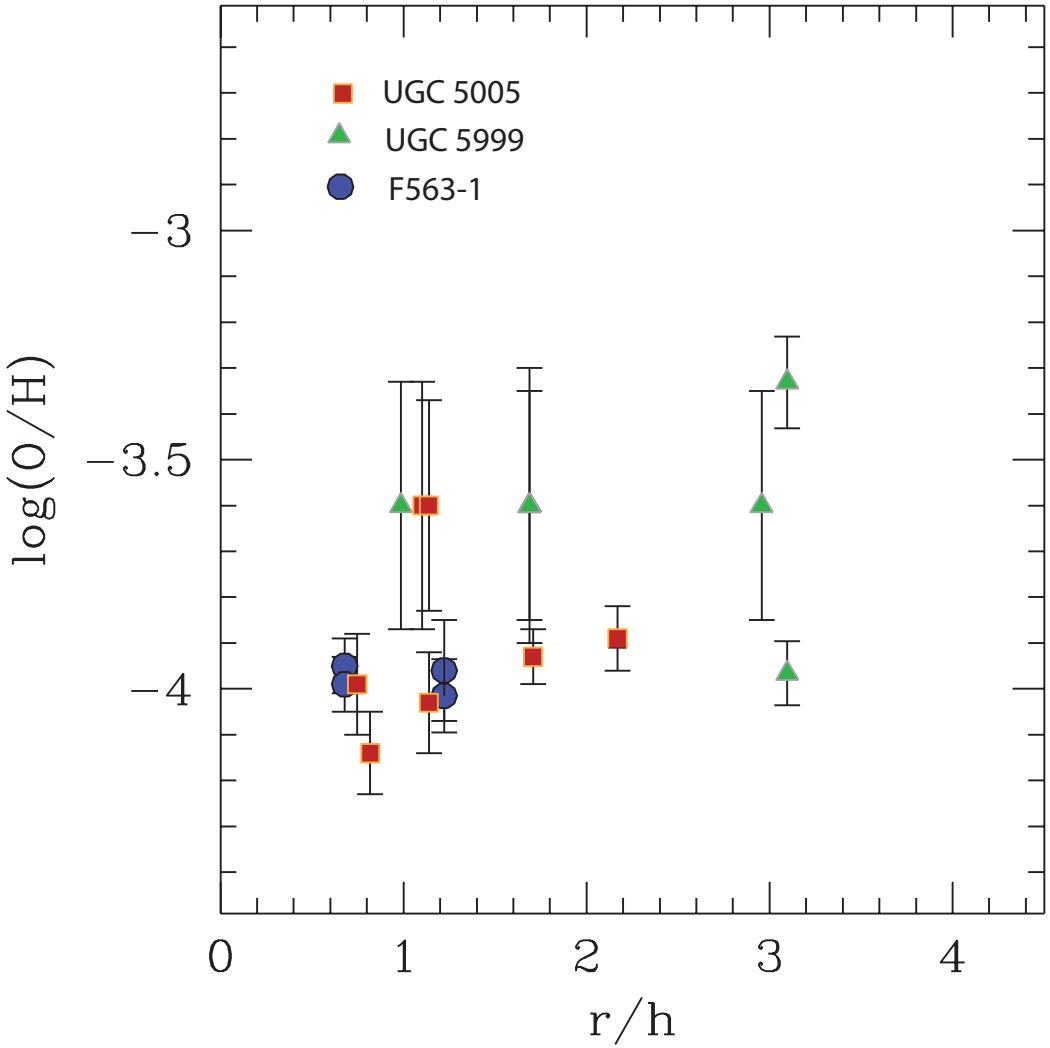
$\mu_{o,B}$ = 23.8 mag arcsec^{-2}



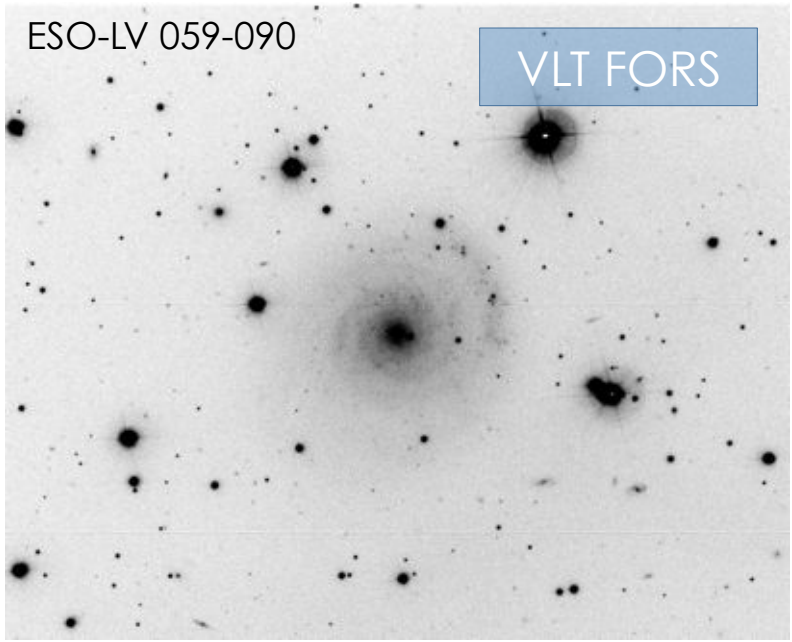
$\mu_{o,B}$ = 23.5 mag arcsec^{-2}



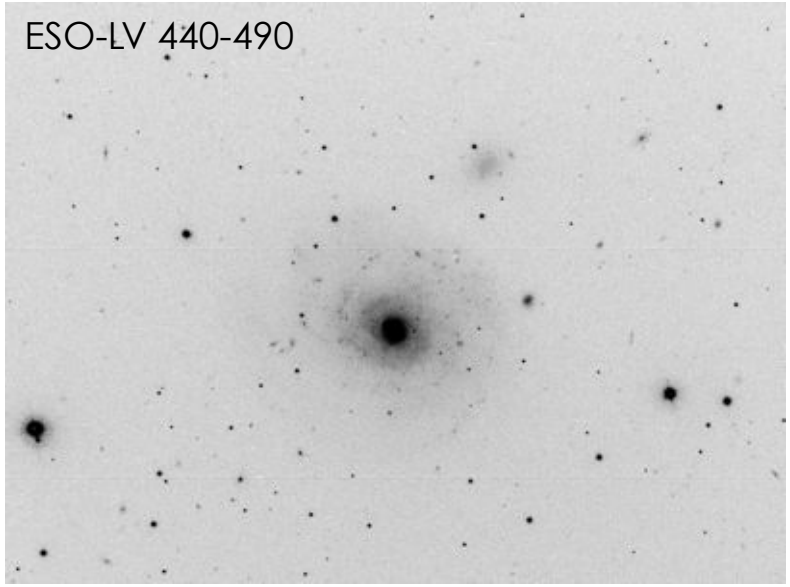
$\mu_{o,B}$ = 23.6 mag arcsec^{-2}



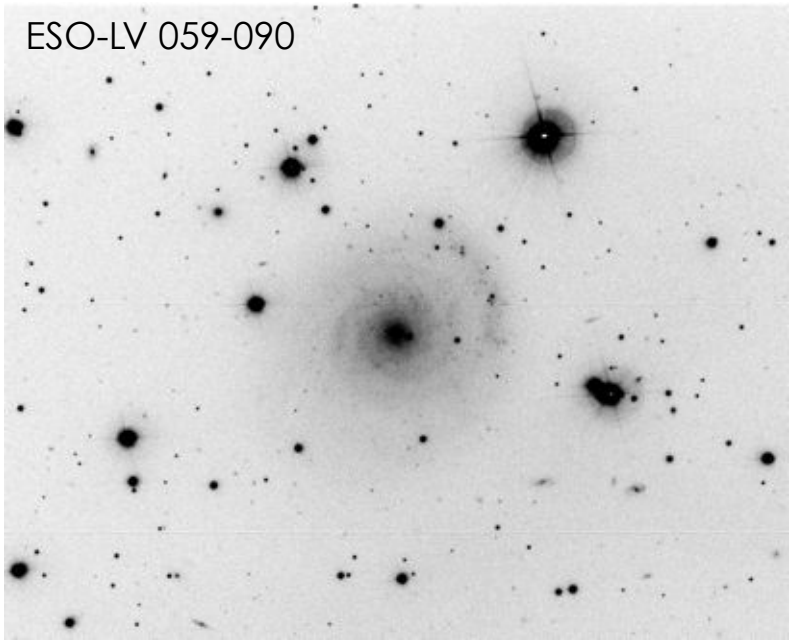
de Blok & van der Hulst 1998

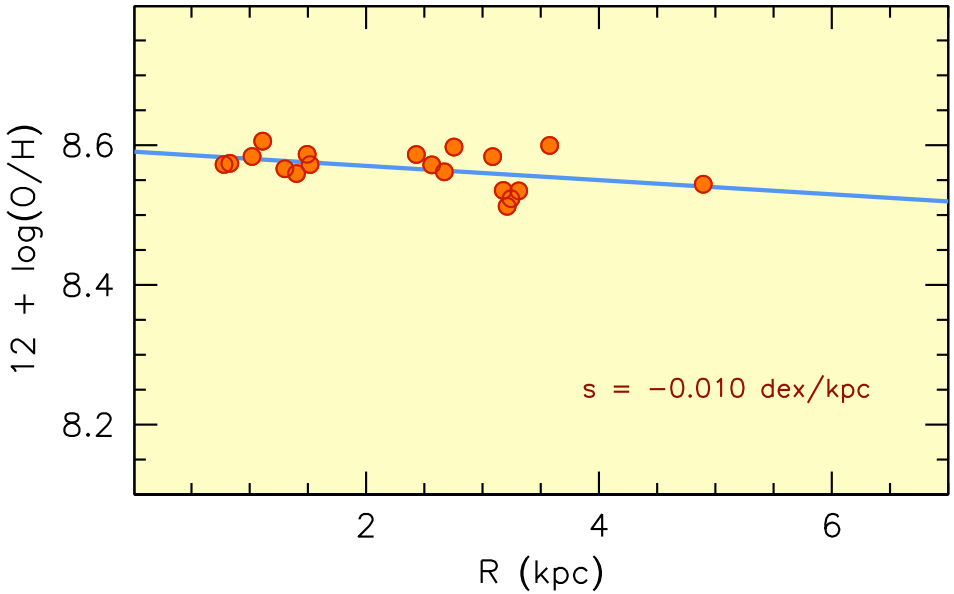


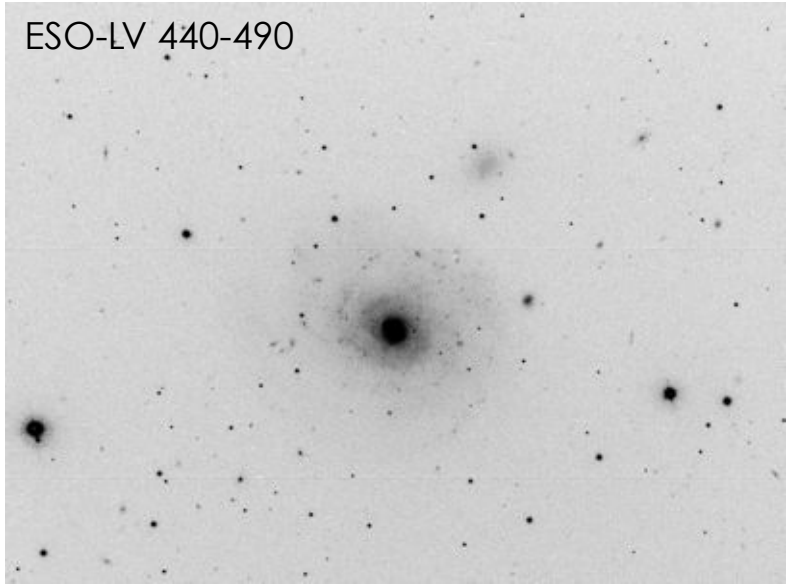
$\mu_{o,B\ (disk)}$ = 23.1 mag arcsec^{-2}

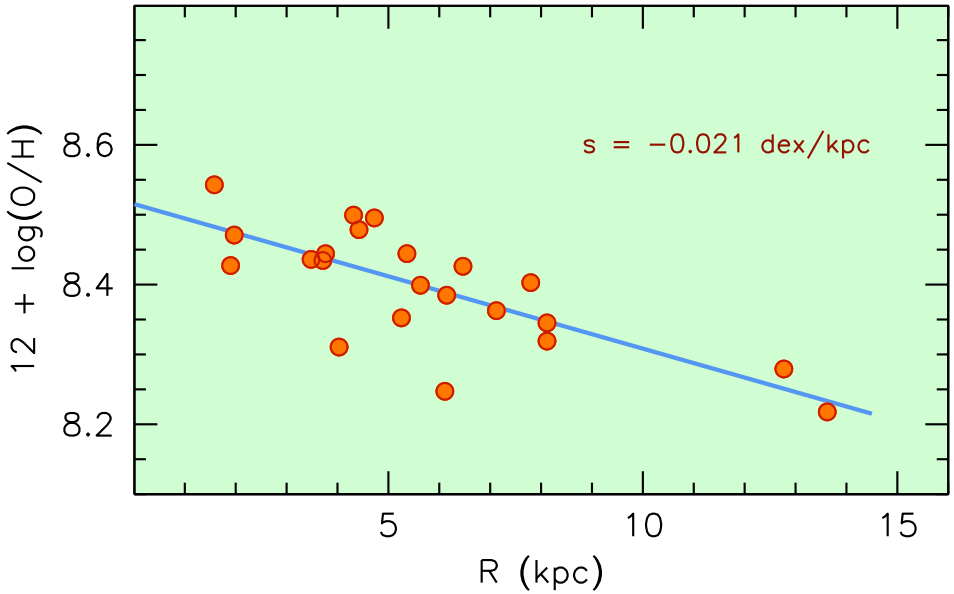


$\mu_{o,B\ (disk)}$ = 24.0 mag arcsec^{-2}

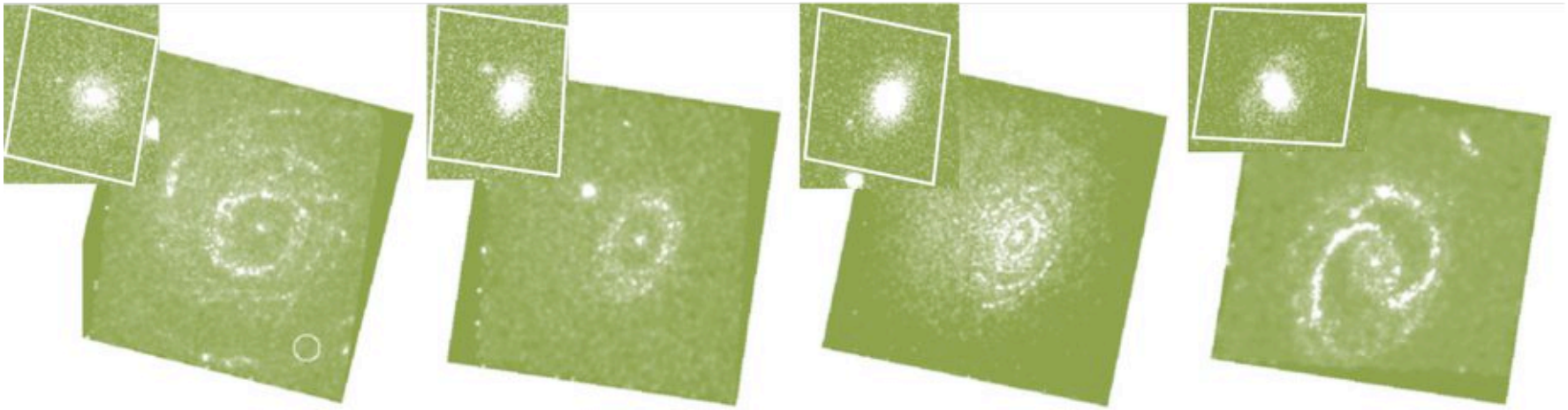

ESO-LV 059-090


12 + log(O/H)
8.6
8.4
8.2
s = −0.010 dex/kpc
2
4
6
R (kpc)


ESO-LV 440-490


12 + log(O/H)
8.6
8.4
8.2
s = −0.021 dex/kpc
5
10
15
R (kpc)

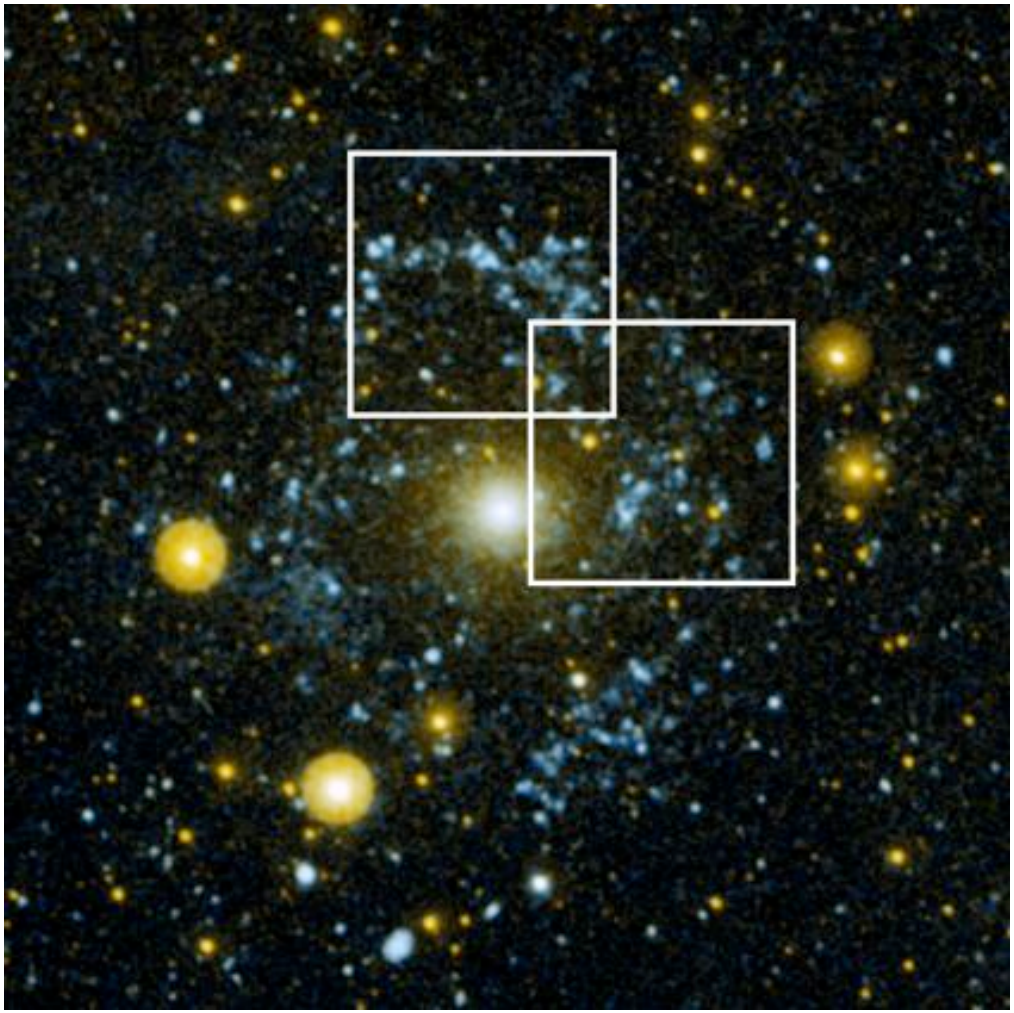
EARLY-TYPE GALAXIES

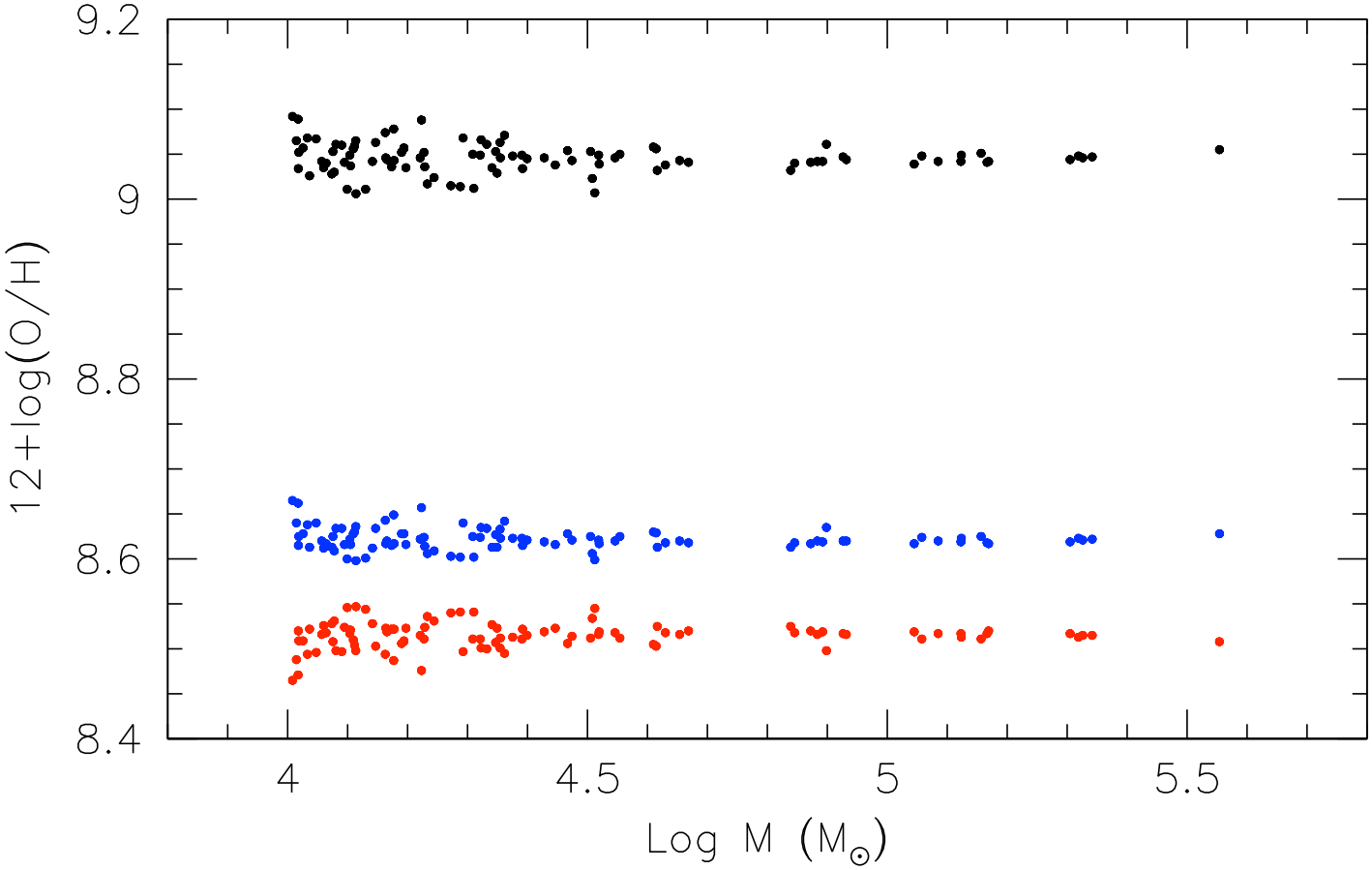


Salim & Rich 2010

EARLY-TYPE GALAXIES

NGC 404
(S0)




9.2
9
8.8
8.6
8.4
12+log(O/H)
4
4.5
5
5.5
Log M (M$_\odot$)