The Origin of the Mass-Metallicity Relation: Insights from 53,000 Star-Forming Galaxies in SDSS

Tremonti et al. 2004

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Stellar Populations

Overview

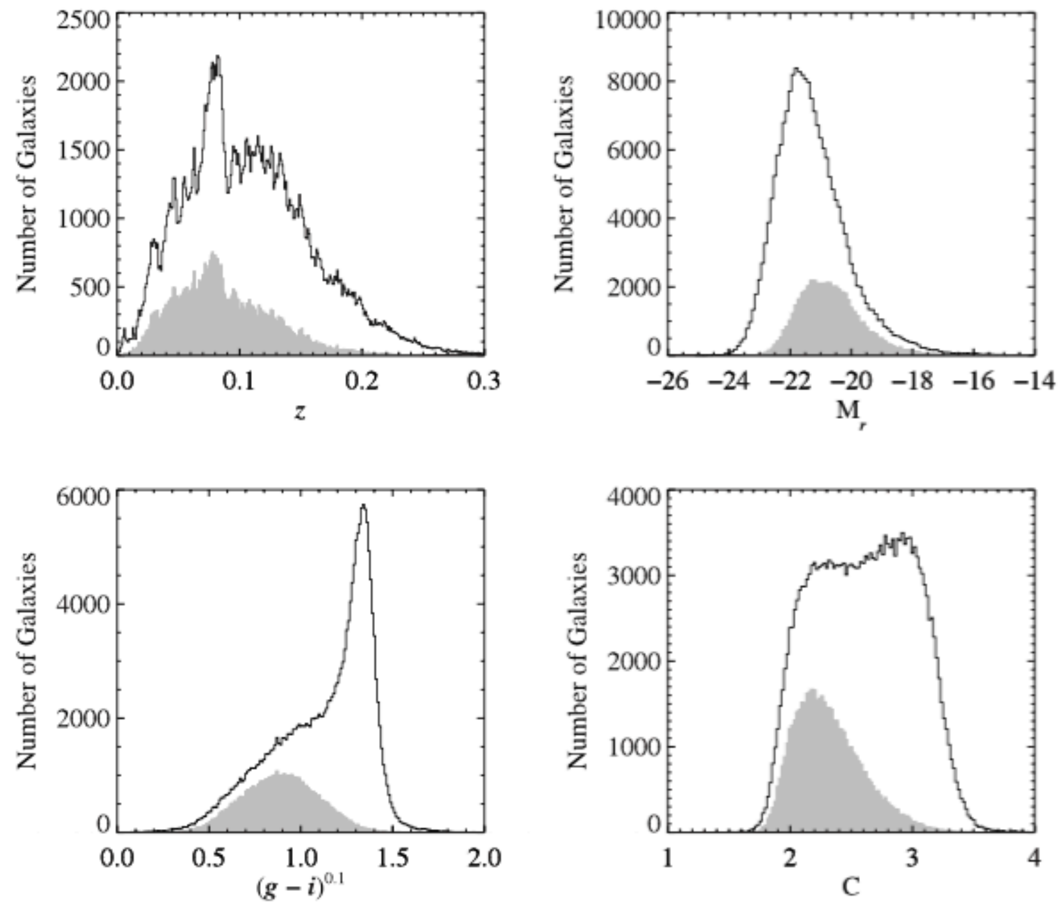
- Uses SDSS imaging and spectroscopy of ~53,000 star-forming galaxies at z~0.1
- Finds tight relation between stellar mass and metallicity
- Metal loss strongly anticorrelated with baryonic mass.
- Galactic winds are ubiquitous and effective at removing metals

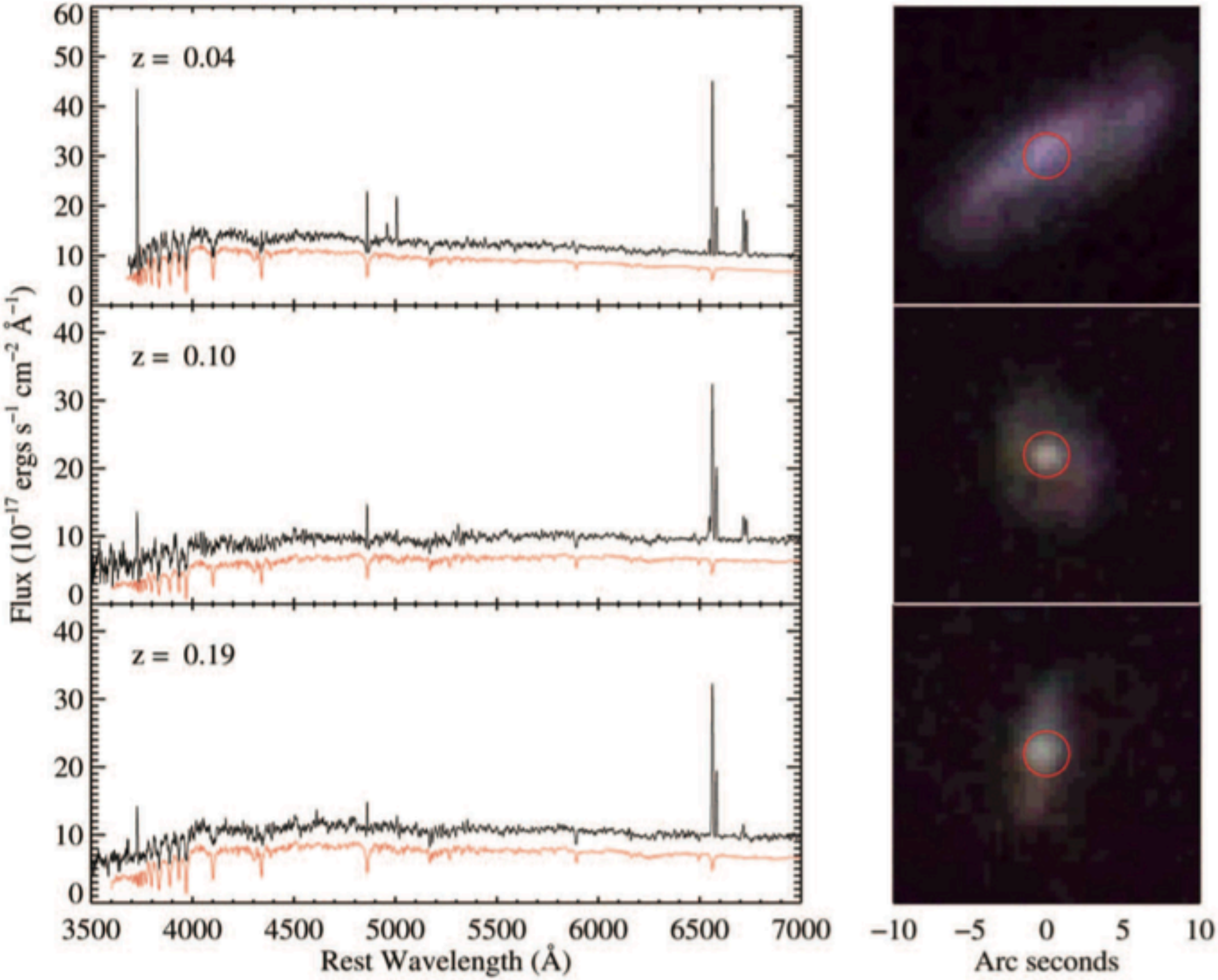
Scientific Motivation

- Stellar mass and metallicity are fundamental metrics for galaxy evolution.
- Feedback from stellar winds and supernovae are an important ingredient in galaxy evolution.
- We can try to track metal depletion to learn about impact of galactic winds

Galaxy Selection

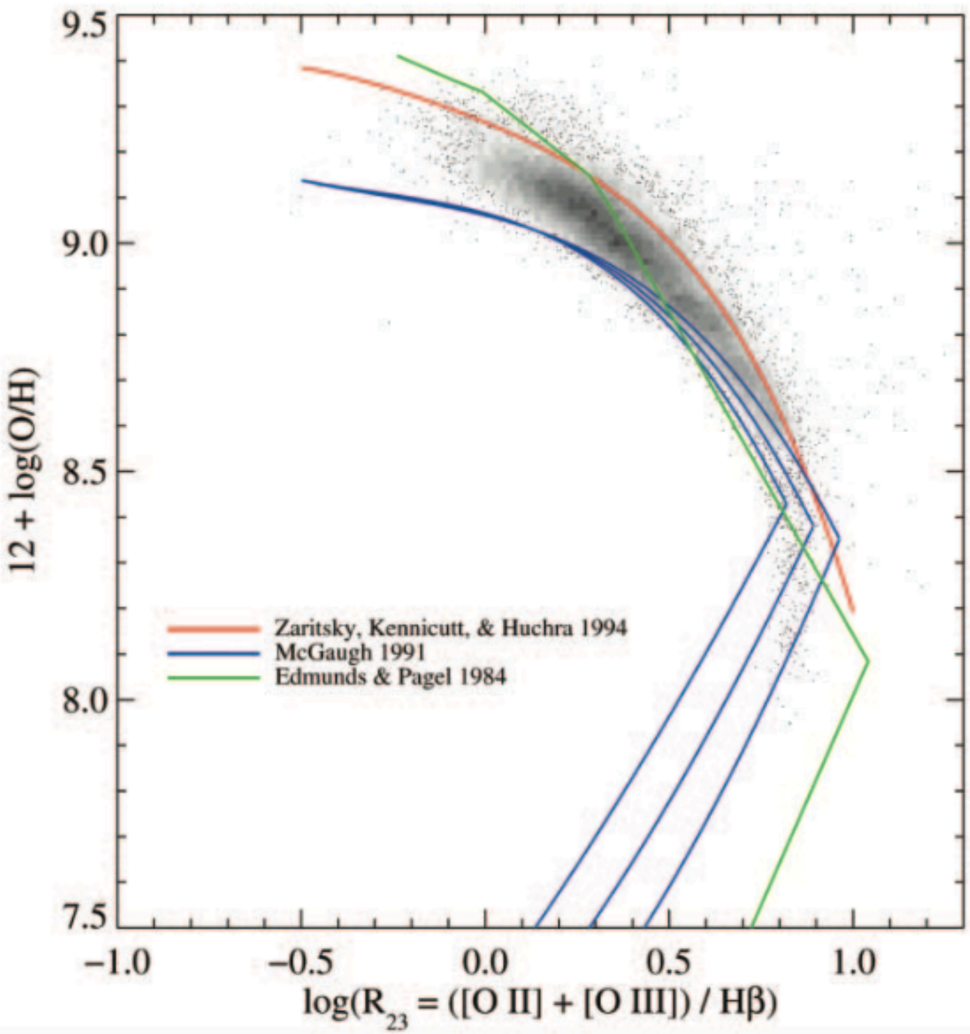
- 53,000 SDSS star forming galaxies
- Emphasis on nebular emission lines spectra of the galaxies





z = 0.04
z = 0.10
z = 0.19
Flux (10^{-17} ergs s^{-1} cm^{-2} Å^{-1})
Rest Wavelength (Å)
Arc seconds

Oxygen

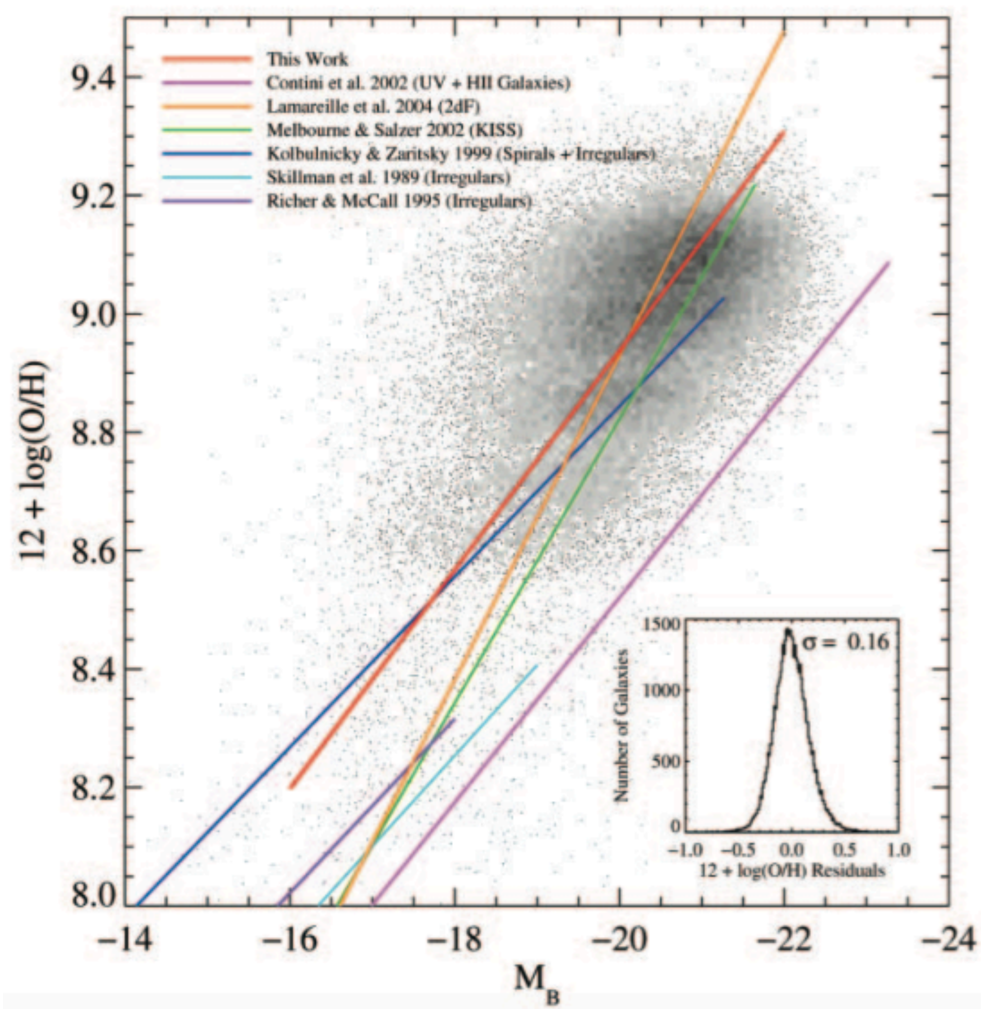


- Oxygen derived from nebular emission lines
- Theoretical and empirical models show agreement with measurements

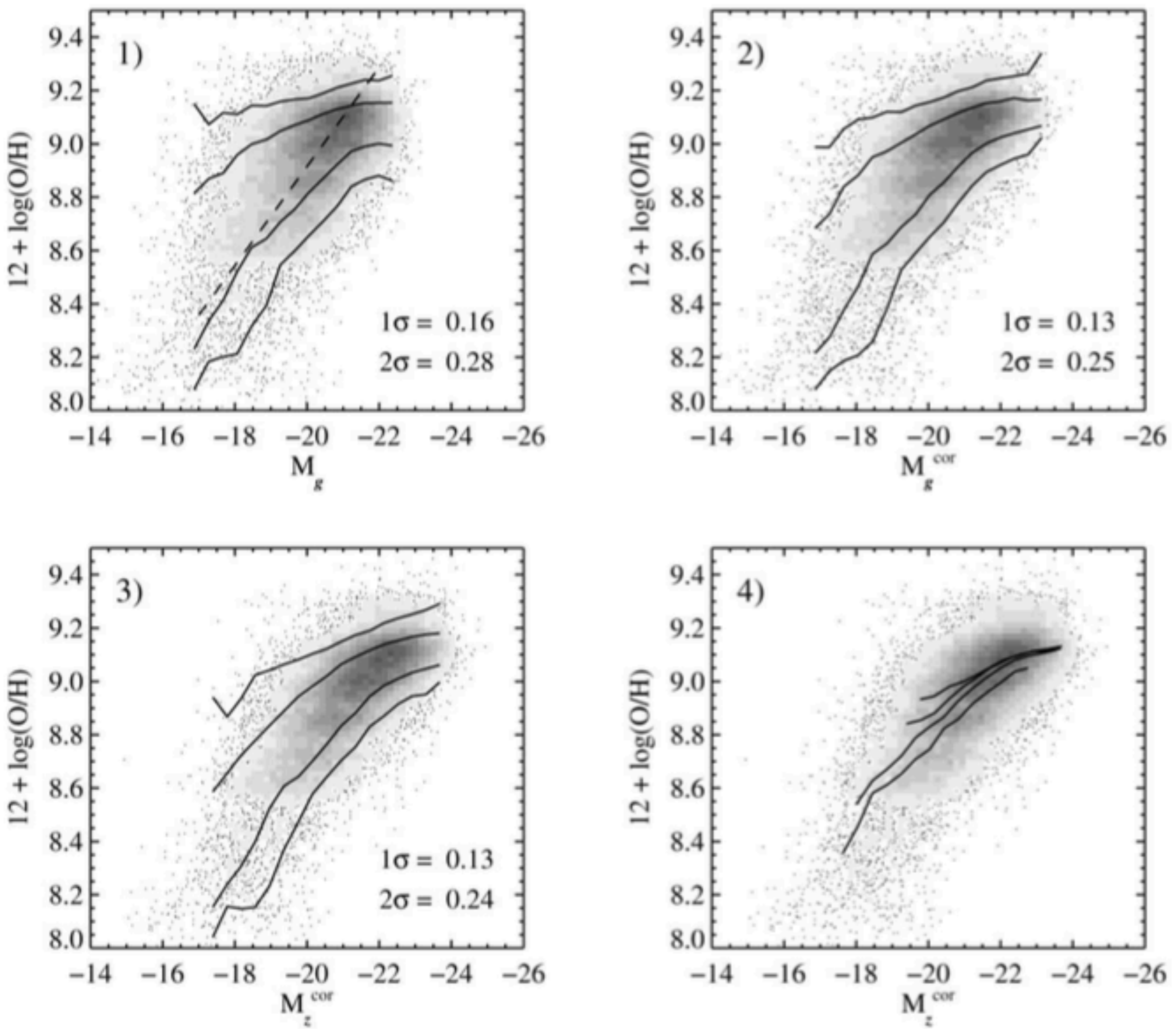
$$12 + \log(\mathrm{O/H}) = 9.185 - 0.313x - 0.264x^2 - 0.321x^3$$

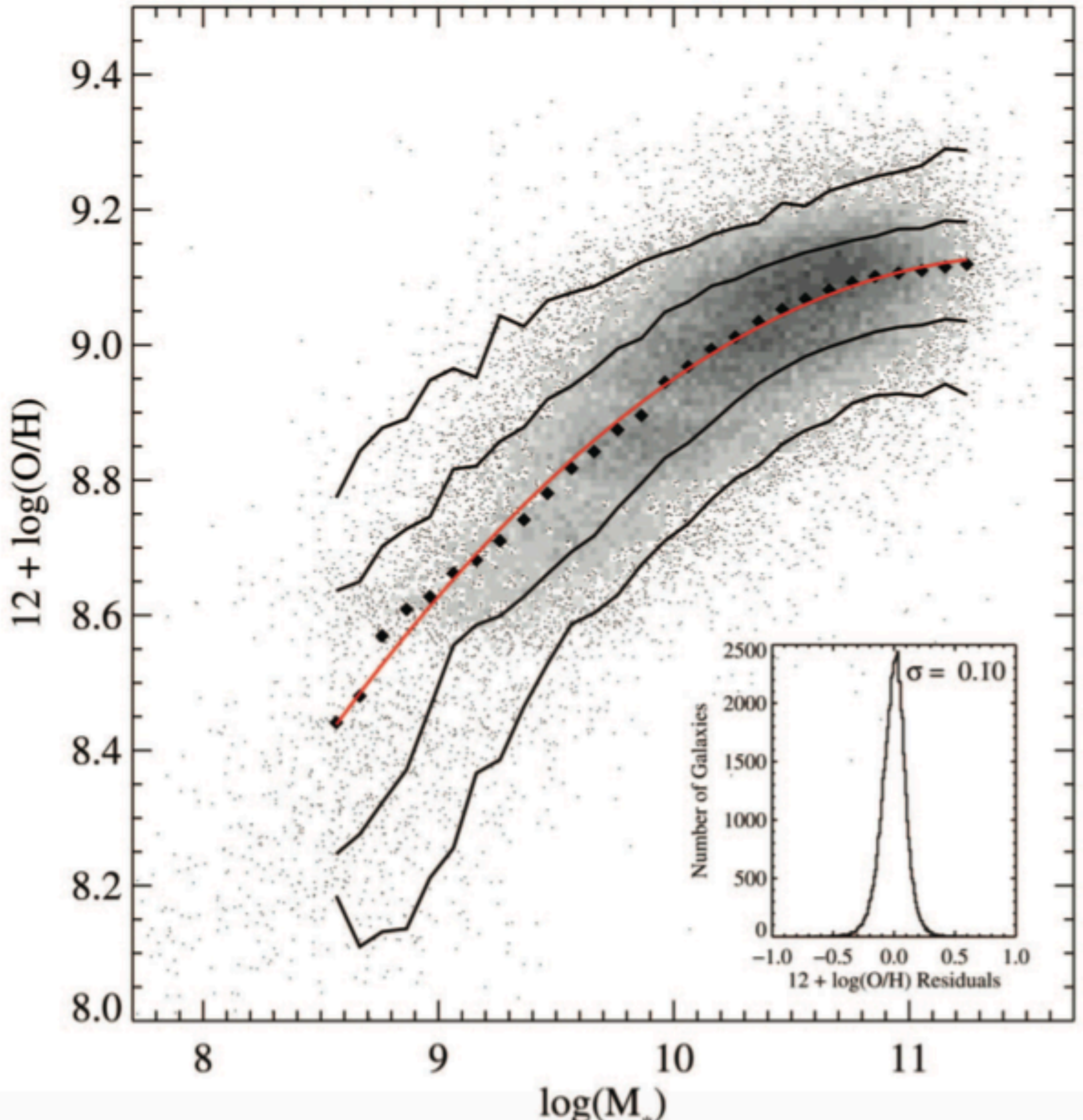
Luminosity Metallicity Relation

- Consistent with other measurements.
- They use linear least squares fit.
- Contini et al. points could imply natural spread due to a lower M/L ratio.



$$12 + \log(\mathrm{O/H}) = -0.185(\pm 0.001) M_B + 5.238(\pm 0.018)$$


1)
1σ = 0.16
2σ = 0.28
12 + log(O/H)
M_g
2)
1σ = 0.13
2σ = 0.25
12 + log(O/H)
M_g^cor
3)
1σ = 0.13
2σ = 0.24
12 + log(O/H)
M_z^cor
4)
12 + log(O/H)
M_z^cor



$$12 + \log(\mathrm{O/H}) = -1.492 + 1.847(\log M_*) - 0.08026(\log M_*)^2,$$

Origin of Mass-Metallicity Relation

- Depletion or enrichment?
  - Maybe more massive galaxies form fractionally more stars and thus more metals
  - Maybe massive and low mass form similar fraction of stars but metals are selectively lost from small potential wells
- These can be disentangled with knowledge about relative mass of gas and stars using closed box evolution models.

Find Stellar Yield (y)

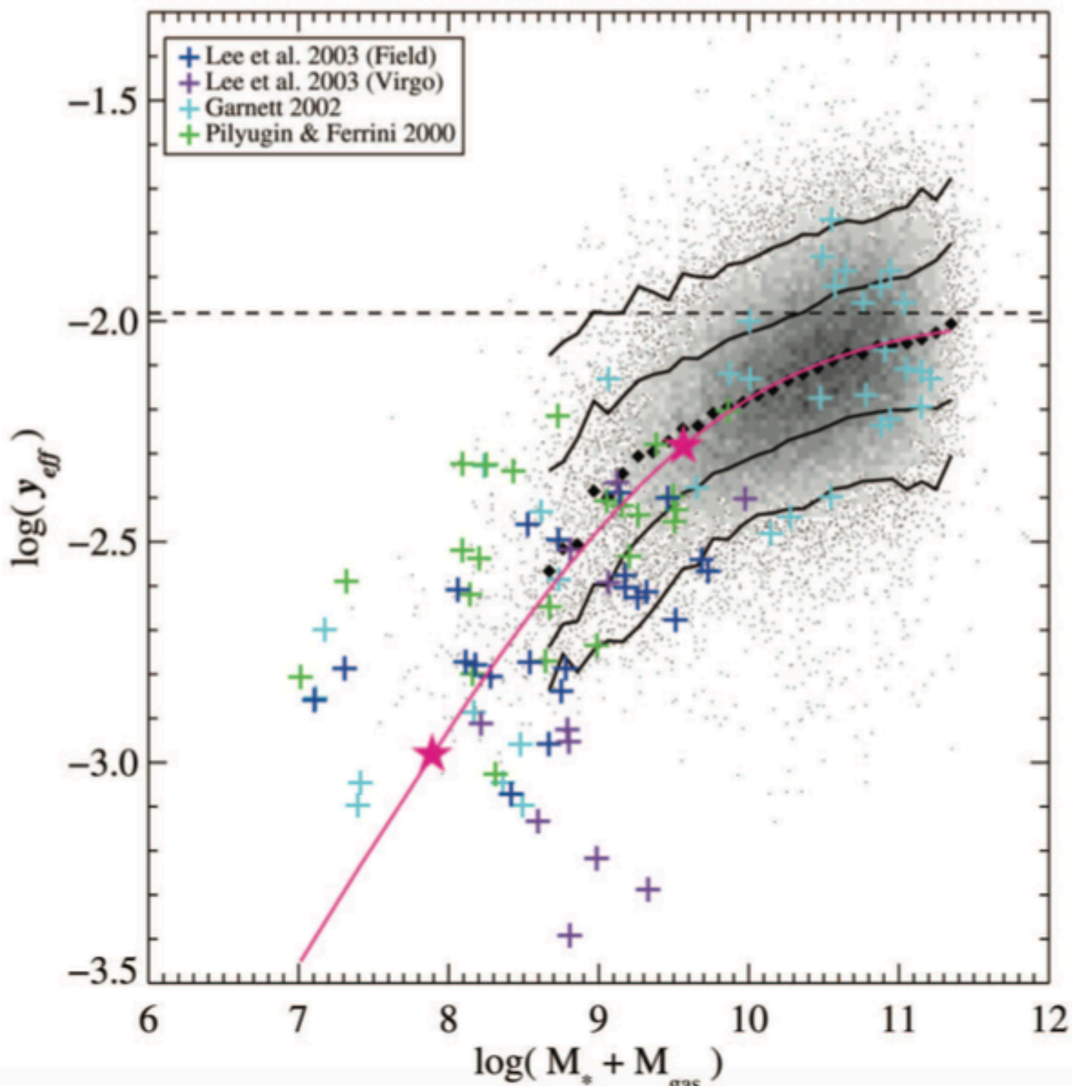
$$Z = y \ln\left(\mu_{\text{gas}}^{-1}\right)$$

- We don't know about HI or HII directly, but we can indirectly find gas surface density through Kennicutt- Schmidt law (relates SF surface density to gas surface density)
- Calculate SFR using Hα luminosity

$$\Sigma_{\text{SFR}} = 1.6 \times 10^{-4} \left(\frac{\Sigma_{\text{gas}}}{1\ M_{\odot}\ \text{pc}^{-2}}\right)^{1.4} M_{\odot}\ \text{yr}^{-1}\ \text{kpc}^{-2}$$

$$\mu_{\text{gas}} = \ \Sigma_{\text{gas}}/(\Sigma_{\text{gas}} + \Sigma_{\text{star}})$$

Galactic winds?



- They argue the relationship between effective yield and baryonic mass is the consequence of metal loss via galactic winds

$$y_{\mathrm{eff}} = \frac{y_0}{1 + \left(M_0/M_{\mathrm{baryon}}\right)^{0.57}}$$

Possible Errors

- Galaxies have radial gradients in physical properties, but observations are through single integrated aperture of only a fraction of galaxies light.
- Deriving gas mass from Hα luminosity using Kennicutt-Schmidt law. While the law is a strong correlation, there is a fair amount of scatter in the regime probed in this study.
- Unclear if central gas mass fraction is the relevant gas mass fraction (unlikely to represent whole galaxy).

Summary

- For 53,000 star-forming galaxies at z ~ 0.1 there is a tight correlation between stellar mass and gas phase oxygen abundance.
- Effective yield decreases from most massive galaxies to dwarfs.
- Straightforward interpretation of correlation between baryonic mass and effective yield is selective loss of metals from galaxies with shallow potentials via galactic winds. ('blowout')