Direct Oxygen Abundances for Low-Luminosity LVL Galaxies

Berg et al. 2012

Presented by Ned Molter, 11/16/16

Outline

- High-res spectroscopy on Local Group dwarf galaxies provides “direct” metallicity measurements
- Compare oxygen abundances with B-band and IR luminosities
- Characterize L-Z, M-Z relationships
- Recommend linear fits to 12+log(O/H) vs M_B, $M_{4.5}$, and stellar mass
- Show this “direct” method is better than “strong line” methods

Background

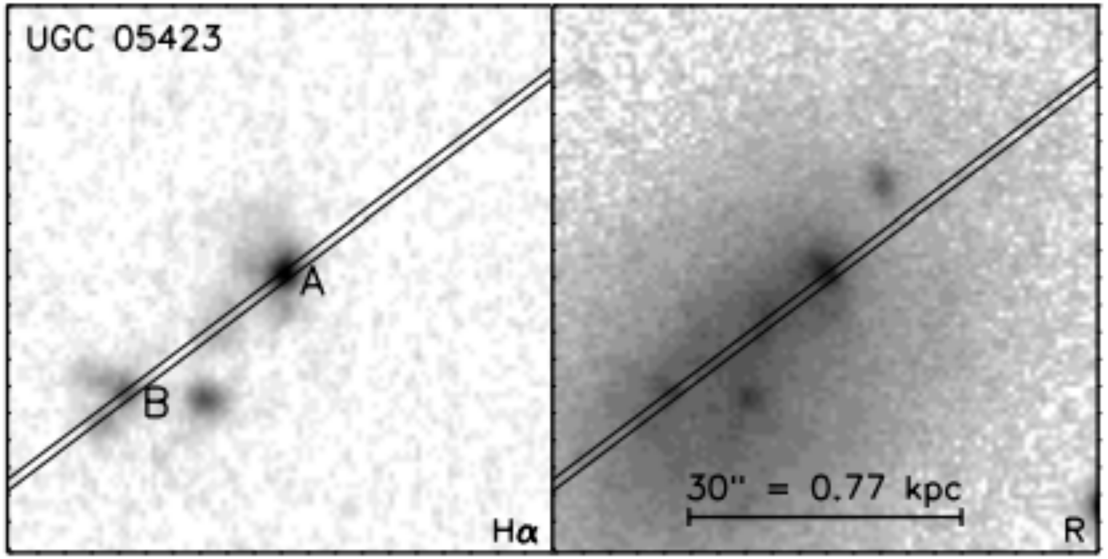
- Stellar mass is fundamentally related to metallicity evolution of a galaxy, the so-called M-Z relation
  - Well-established trend over a range of 10 mags in visible
  - Measured as an L-Z relation, then convert luminosity to stellar mass
- Physical driver of this trend is under debate
  - Lower mass galaxies just started forming stars
  - Lower mass galaxies are less efficient at forming metals
  - SN winds preferentially expel metals from dwarf galaxies
  - SFR-dependent and/or mass-dependent IMF
- Low-luminosity M-Z is still poorly understood

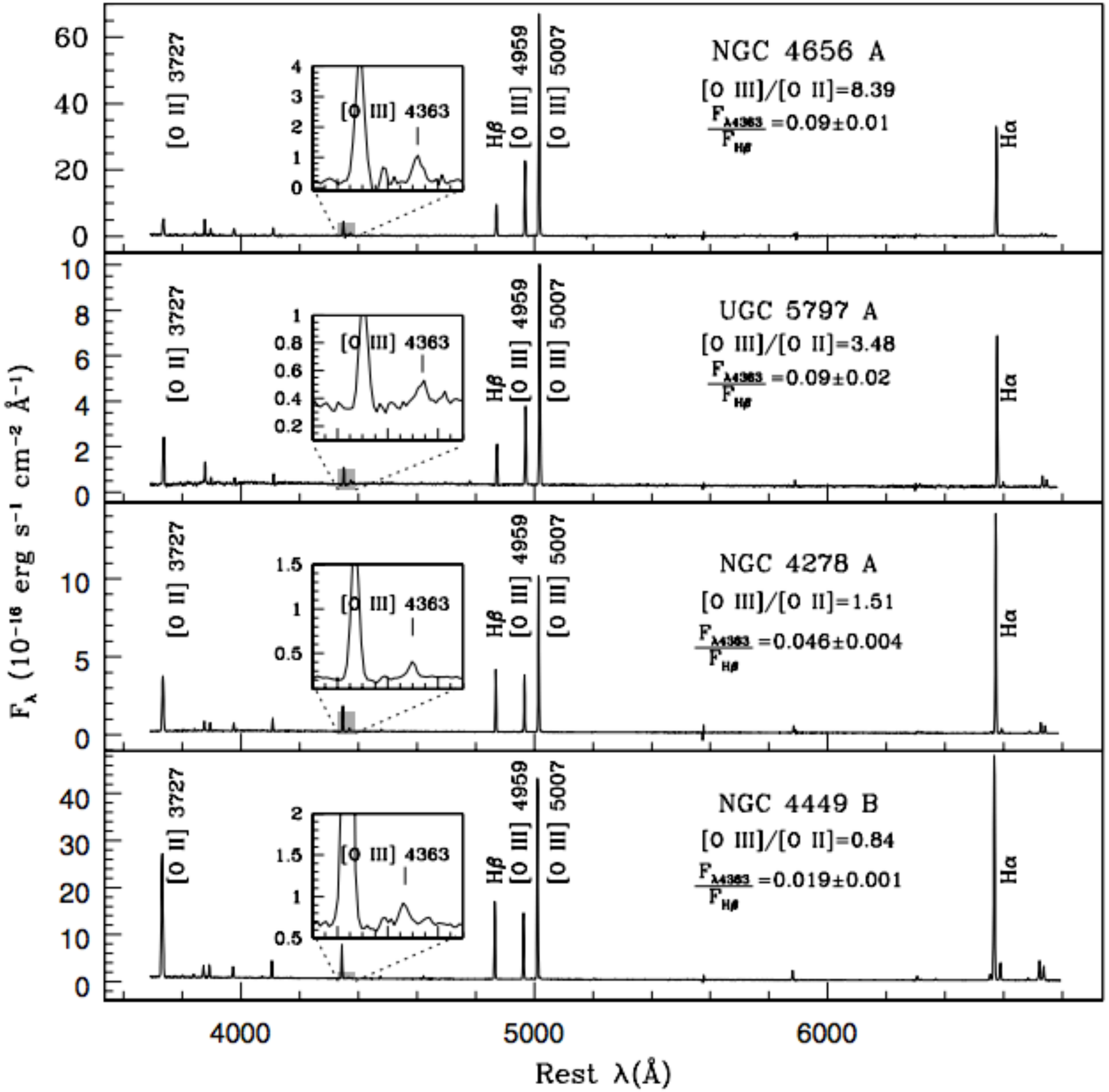
Sample Selection

- *Spitzer* Local Volume Legacy (LVL) galaxies
  - Multi-wavelength observations (UV, optical photometry, IR, radio) already carried out
- Choose 42 low luminosity galaxies for which [OIII] not yet measured
  - $-10.8 > M_B > -18.8$
  - $2.5 < D$ (Mpc) < 14.0
- Add 2 galaxies that motivated the project
  - Outliers in the color-metallicity relationship (come back to this)

Data

- High-res MMT spectra looking for the [OIII] 4363 angstrom line
  - Long-slit spectroscopy oriented to maximally overlap H-alpha regions
- Spitzer IRAC 4.5 micron photometry
- B- and V-band photometry over same aperture as IRAC (van Zee+ ’12)





NGC 4656 A
[O III]/[O II]=8.39
F_λ4363 / F_Hβ =0.09±0.01
UGC 5797 A
[O III]/[O II]=3.48
F_λ4363 / F_Hβ =0.09±0.02
NGC 4278 A
[O III]/[O II]=1.51
F_λ4363 / F_Hβ =0.046±0.004
NGC 4449 B
[O III]/[O II]=0.84
F_λ4363 / F_Hβ =0.019±0.001
[O II] 3727
Hβ
[O III] 4959
[O III] 5007
Hα
[O III] 4363
F_λ (10^-16 erg s^-1 cm^-2 Å^-1)
Rest λ(Å)

Abundance Measurements

- Perform Lorentzian and/or Gaussian fits to spectral lines in order to integrate and find abundances of hydrogen and oxygen
  - H-beta needs a 2-component fit – broad Lorentzian profile for absorption and narrow Gaussian for emission spike
  - H-gamma was fit to a Gaussian
  - [OIII] 4363 is weak but it sits next to H-gamma, so use the same line profile because the widths should be the same
  - Continuum subtraction dominates uncertainty in [OIII] 4363 strength
- 31/42 galaxies can be detected in [OIII] 4363
- [OIII] line ratio (4363/5007) determines electron temperature

Reddening Corrections

- Use Cardelli law, $A_v = 3.1\ E(B\text{-}V)$
- Measure ratio of H-alpha and H-beta fluxes
- The intensities can be determined theoretically assuming an electron temperature from the [OIII] ratio
- Then use the below equation to calculate E, applying chisq minimization

$$\log \frac{I(\mathrm{H}\alpha)}{I(\mathrm{H}\beta)} = \log \frac{F(\mathrm{H}\alpha)}{F(\mathrm{H}\beta)} + 0.4\, E(B-V)\,[A_1(\mathrm{H}\alpha) - A_1(\mathrm{H}\beta)],$$

“Direct” Oxygen Abundance Determinations

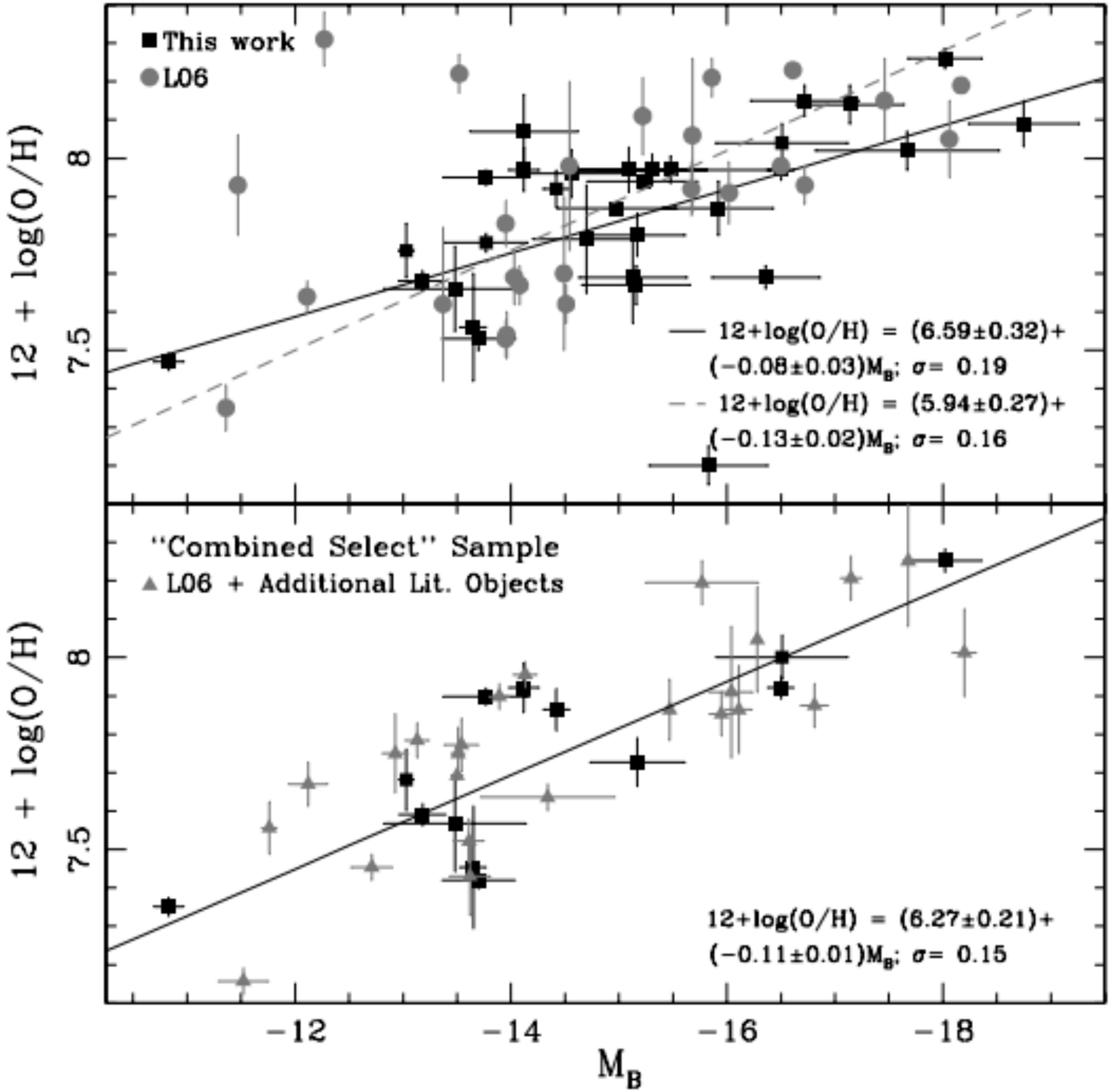
- Assume two-zone model for HII region: low-ionization (O+) and high-ionization (O++) zones
  - [OIII] 4363 line is highly temperature sensitive in high ionization region -> direct temperature there from 4363/5007 ratio
  - Use photoionization modeling to determine temperature of low ionization region (see Campbell et al. 1986, Stasinska 1990, Pagel et al. 1992)
- Determine oxygen abundances based on emission lines from both the O+ and O++ regions, using the two temperatures derived
- 9 galaxies for which 2 H-alpha regions have independently measurable [OIII] 4363 lines
  - Oxygen abundances agree in 7/9 cases -> metals are well mixed
  - Two outliers may be caused by poor mixing or a supernova remnant

The L-Z and M-Z relationships

- Cut sample again to include only galaxies with reliable TRGB/Cepheid distance estimate from other authors
  - 13 objects from this paper pass this test
  - 18 objects require follow-up to get accurate distances
- Add an additional 25 objects from previous work, with similarly derived “direct” oxygen abundances and accurate distances
- Do not include galaxies with evidence for recent mergers
- Total ”select” sample is 38 galaxies
- Estimate masses from near-IR luminosities/colors (less extinction, less affected by recent (<10 Myr) star formation (Lee+ 06)
  - IMF dependent, stellar model dependent
  - Might do better with broadband SED fitting, but data are not available for all galaxies

$$\log M_\star = \log(M_\star/L_K) + [\log L_{[4.5]} - 0.4\,(K - [4.5])].$$

Fitting lines to data!

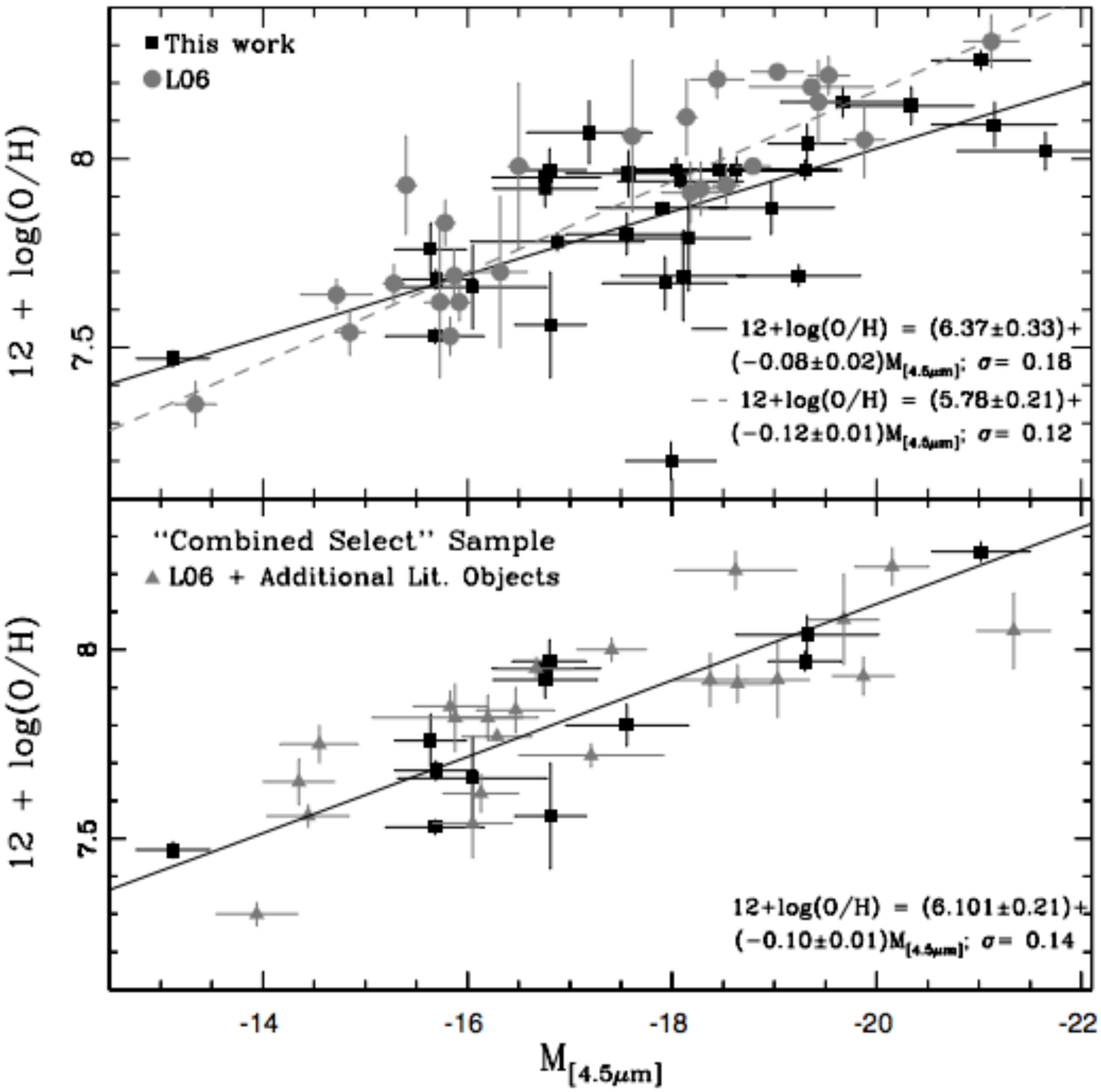


All galaxies

Dashed – L06 fit
Solid – fit L06 + this work

Select sample

Fitting lines to data!



All galaxies

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Select sample

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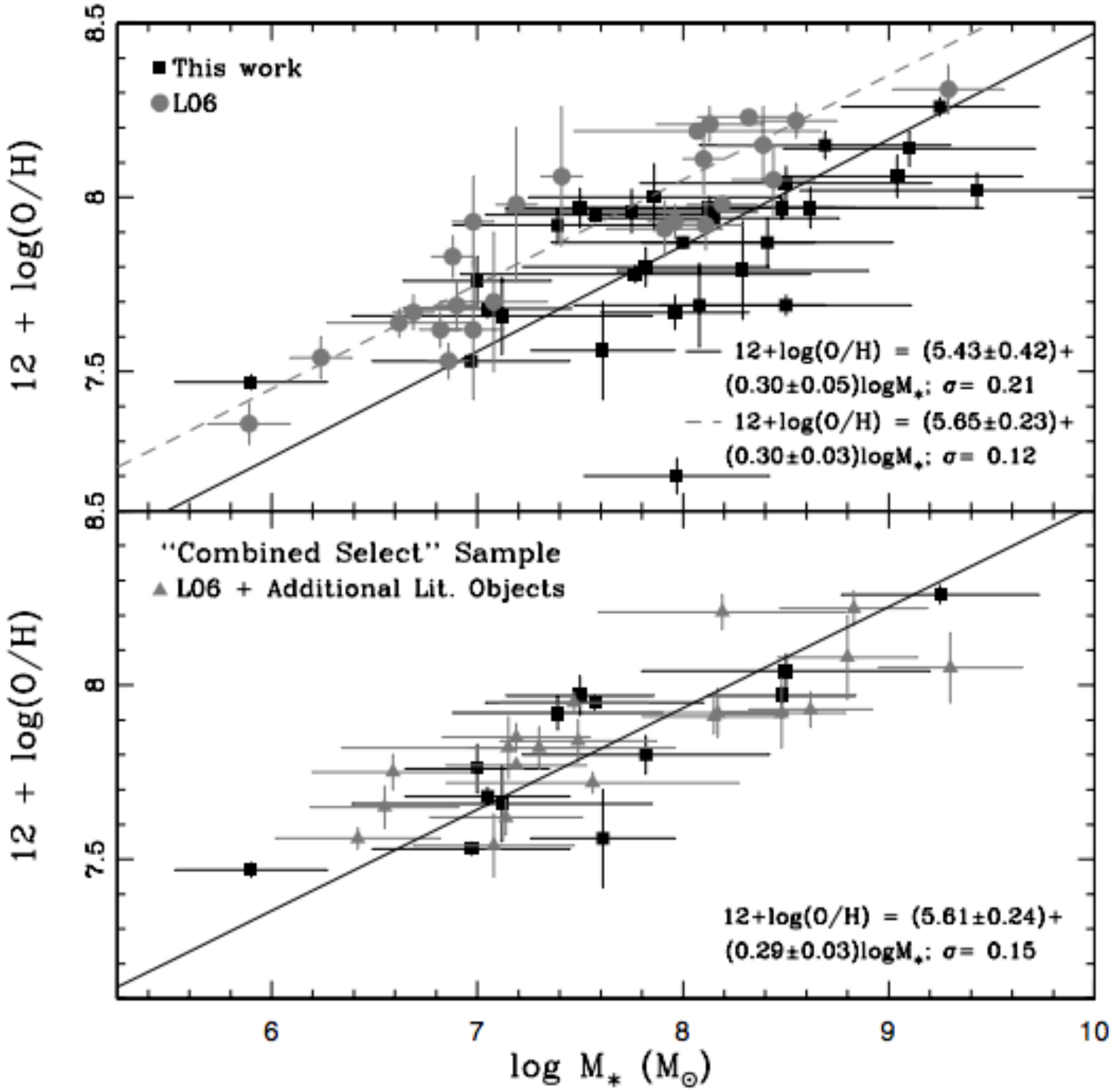


All galaxies

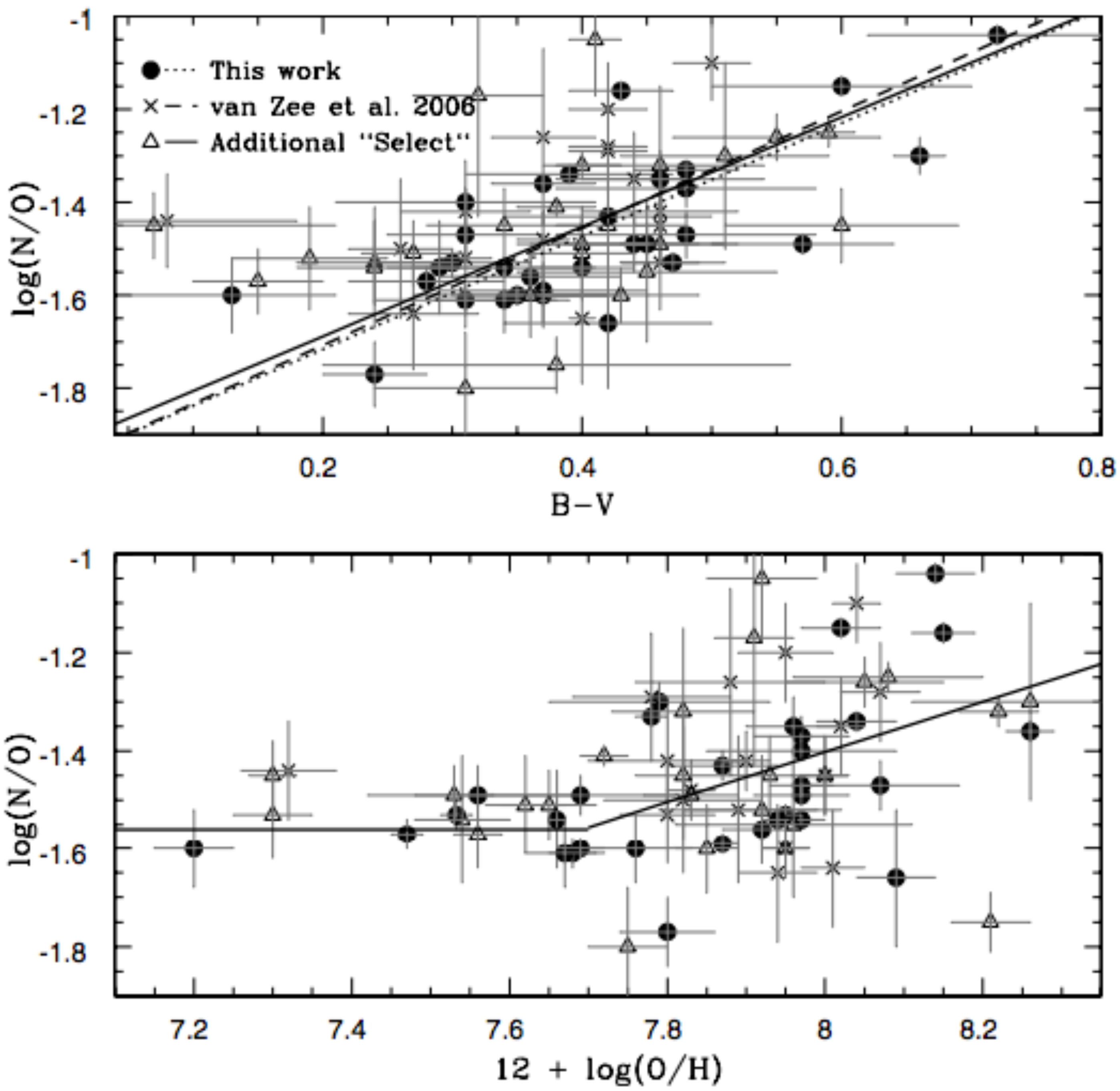
Dashed – L06 fit

Solid – fit L06 + this work

Select sample

N/O Abundances

- Nitrogen release into ISM is delayed relative to oxygen
  - N/O increases with time since last starburst
  - N/O is high in high-Z populations
- Measure [OII] 3727 and [NII] 6584 lines and assume temperature from before
- Find higher N/O correlates somewhat with redder color, similar to previous studies



The 'knee' was determined arbitrarily

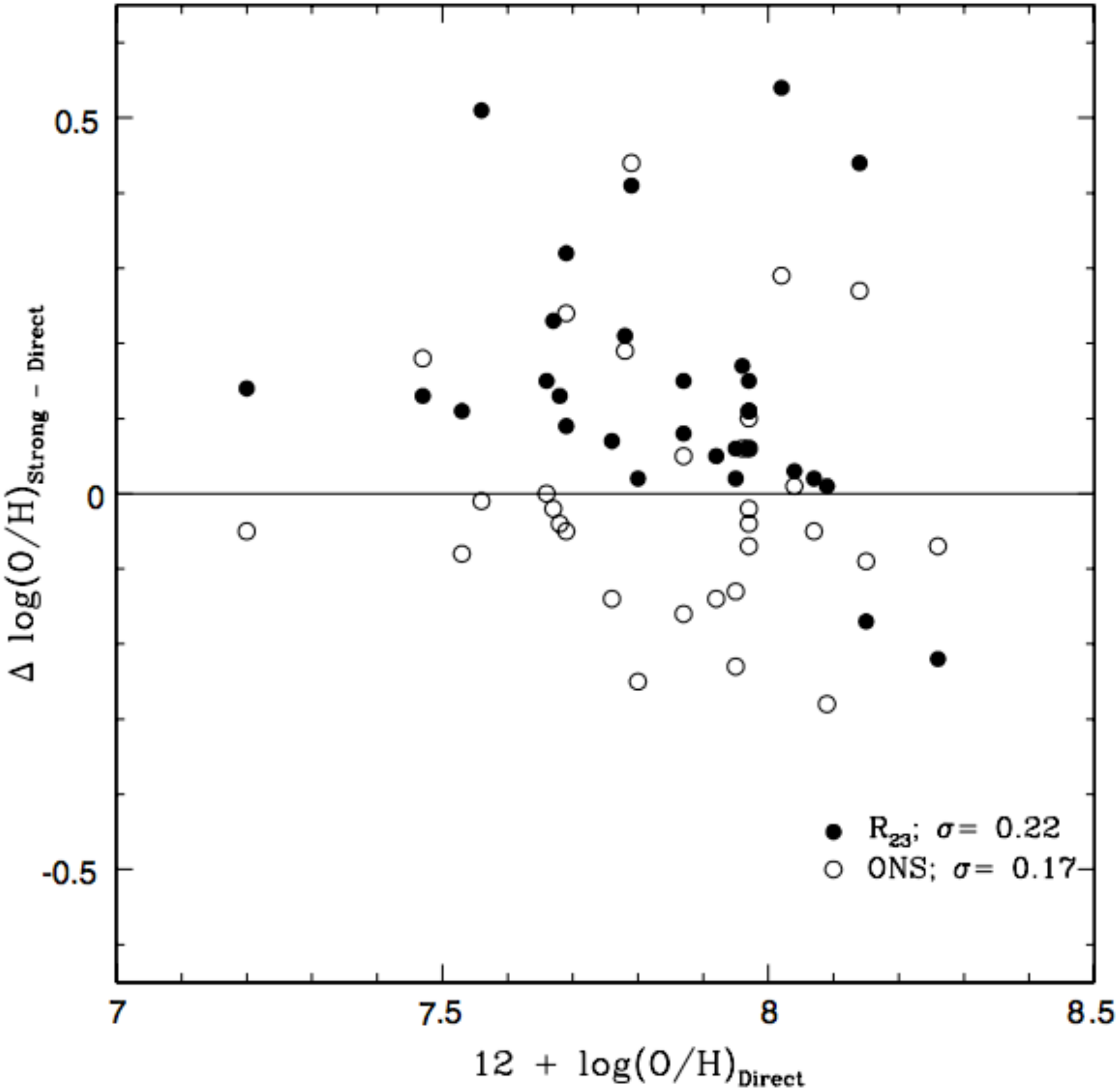
Discussion

- L-Z relation is no easier to measure in NIR than in optical
- NIR-, optical-, and mass-metallicity relationships are all remarkably tight, with mass being the best correlated
- Galaxies look mostly chemically homogeneous
- Measurement errors are small enough to determine intrinsic scatter – how to explain this scatter?
  - Different star formation histories
  - AGB stars (for the NIR)
  - Dust (but similarity between optical and IR suggests otherwise)
  - Pristine gas infall
  - IMF variations, SF efficiency variations

Discussion

- N/O plateau in metallicity
  - Suggested to be due to dwarf galaxies being young in terms of SF – that is, no delayed release of nitrogen has occurred yet – but doesn't fit the data
  - Nitrogen behaving as a primary element at low metallicities?
  - Physical cause is unclear
- How good are the abundance determinations?
  - Inhomogeneous electron temperatures -> temperature underestimates
  - Better than "strong line" (no strongly temperature dependent lines), which have large uncertainties and produce discrepant results

No clear way to calibrate strong line methods



Open circles vs closed circles – two different methods for measuring abundances with strong lines