Observational Evidence of the Large-Scale Environmental Influence on Dwarf Galaxy Evolution

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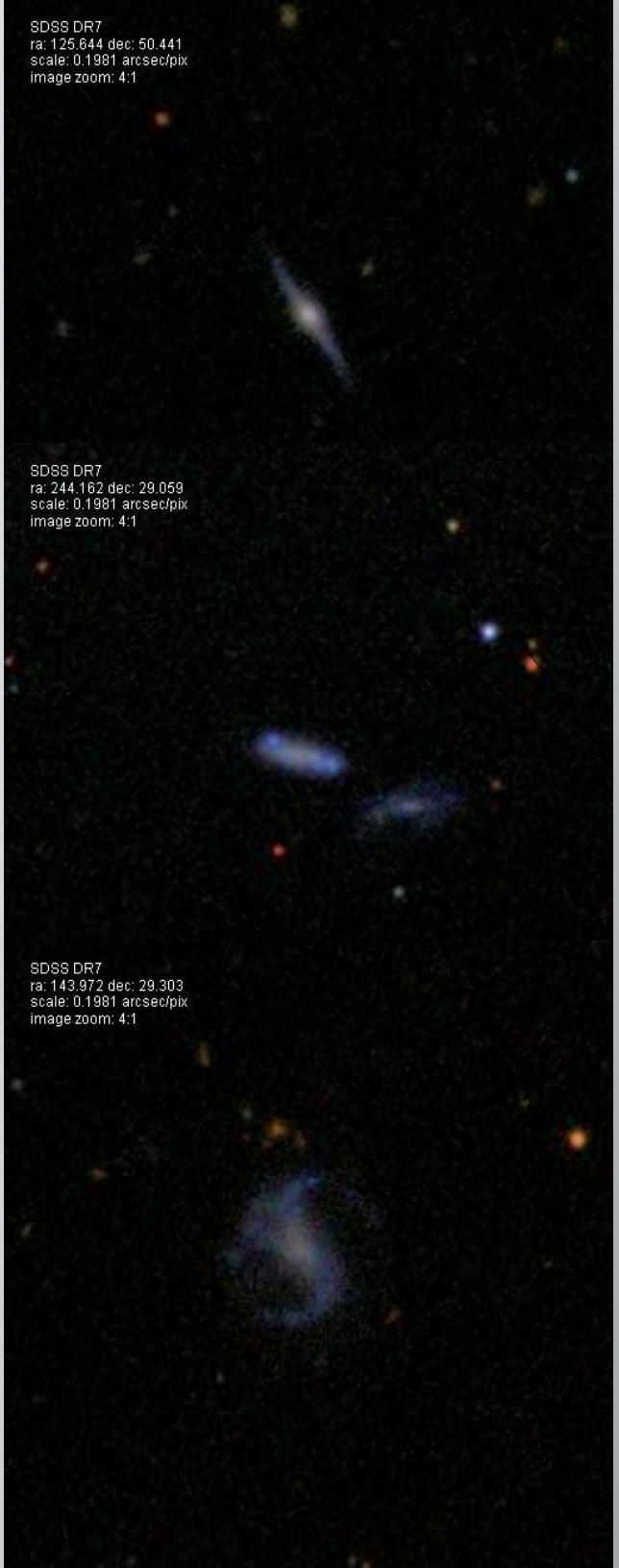
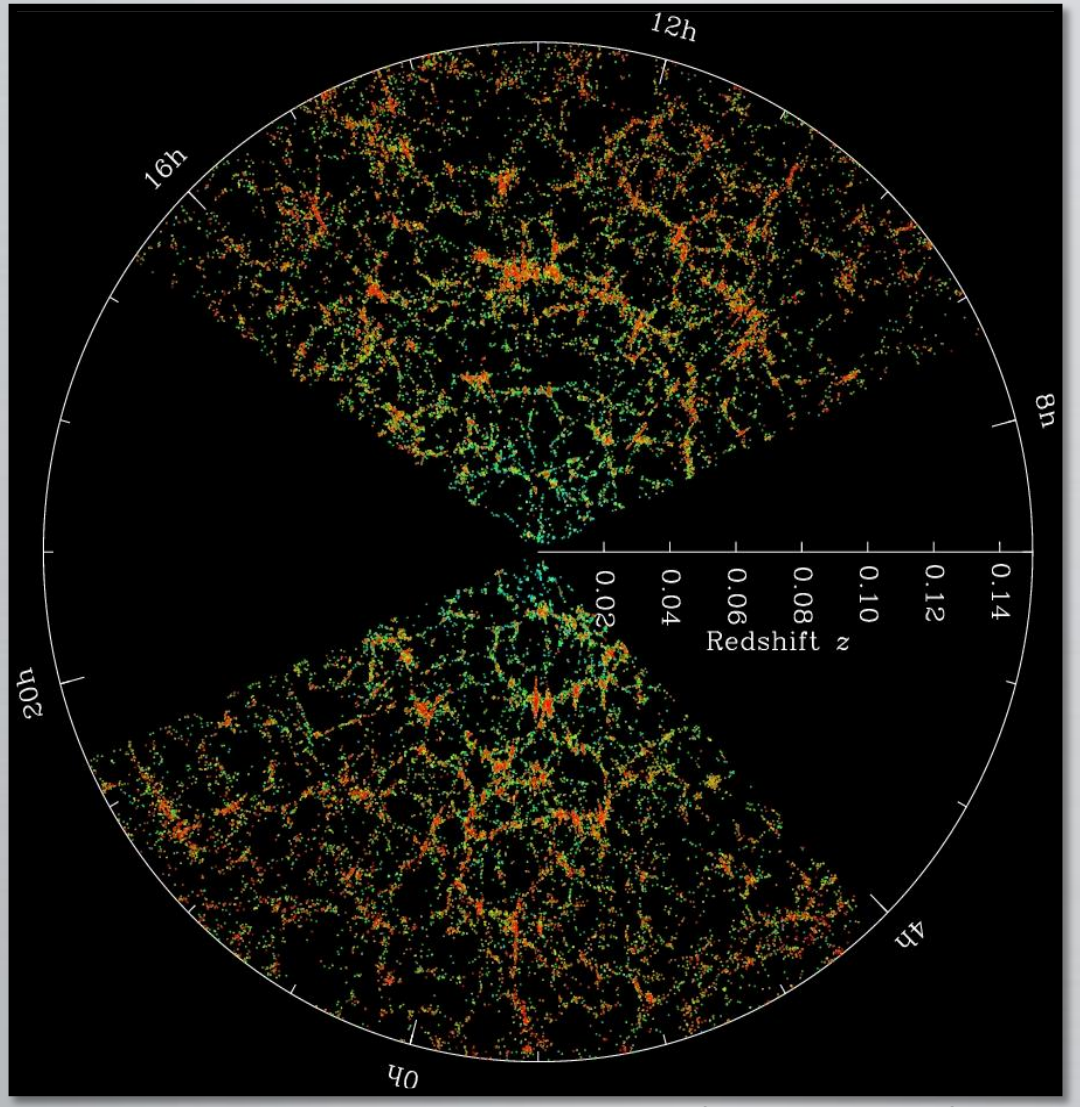
7 July 2017

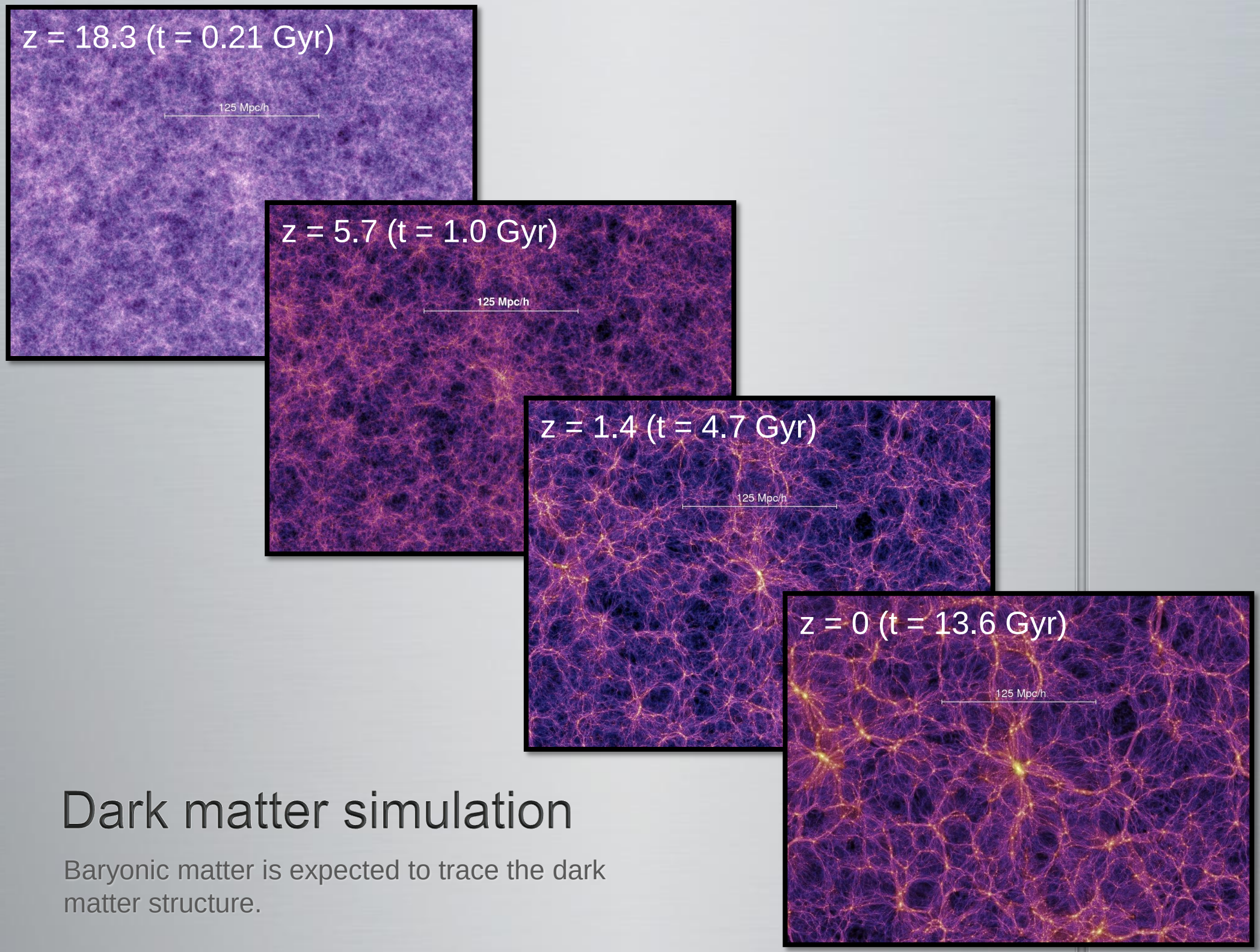


The cosmic web

The large-scale structure of our universe is a non-uniform, sponge-like distribution of galaxies.



SDSS galaxy map – www.sdss.org

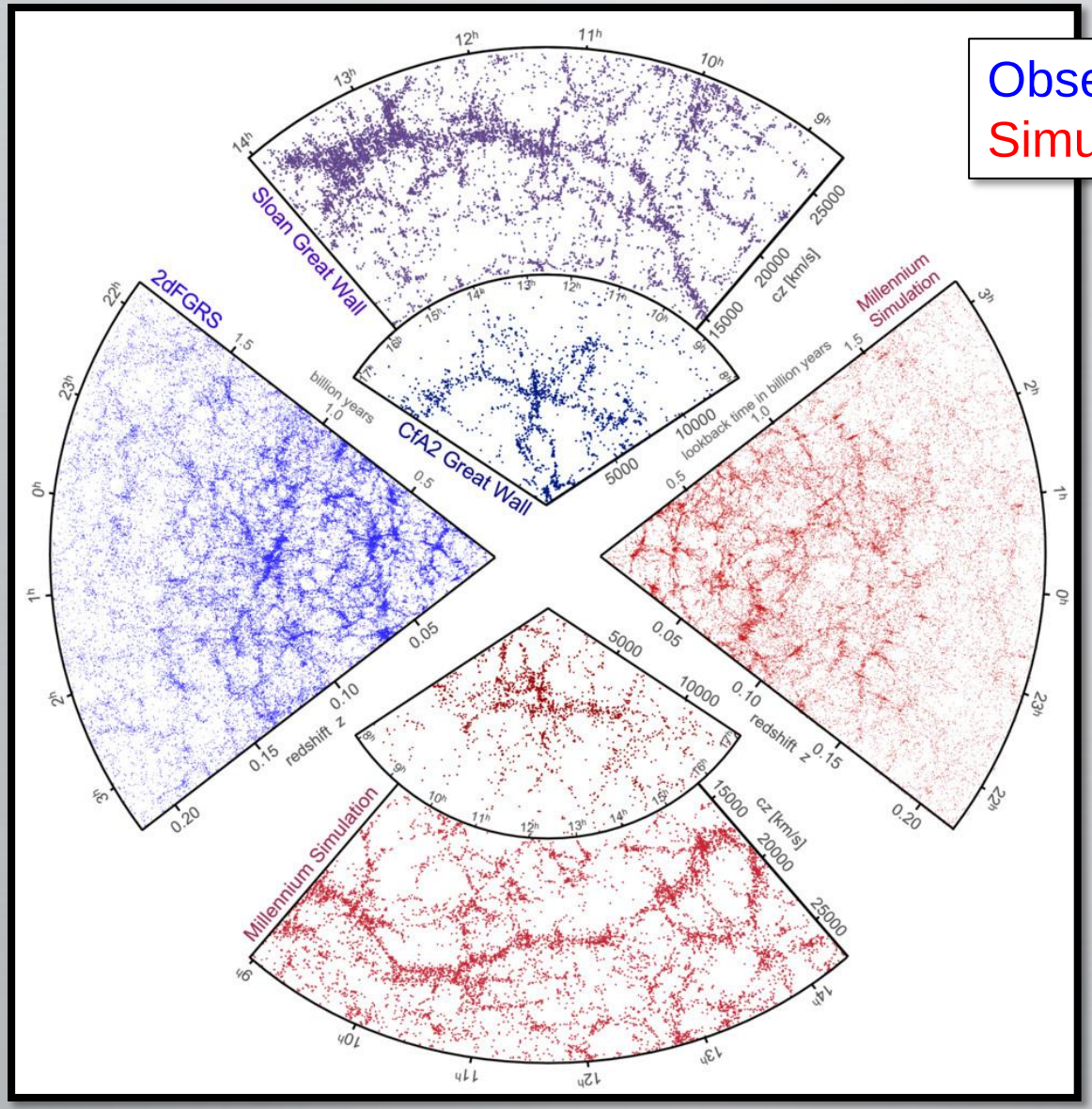


Dark matter simulation

Baryonic matter is expected to trace the dark matter structure.

Millennium Simulation project – wwwmpa.mpa-garching.mpg.de

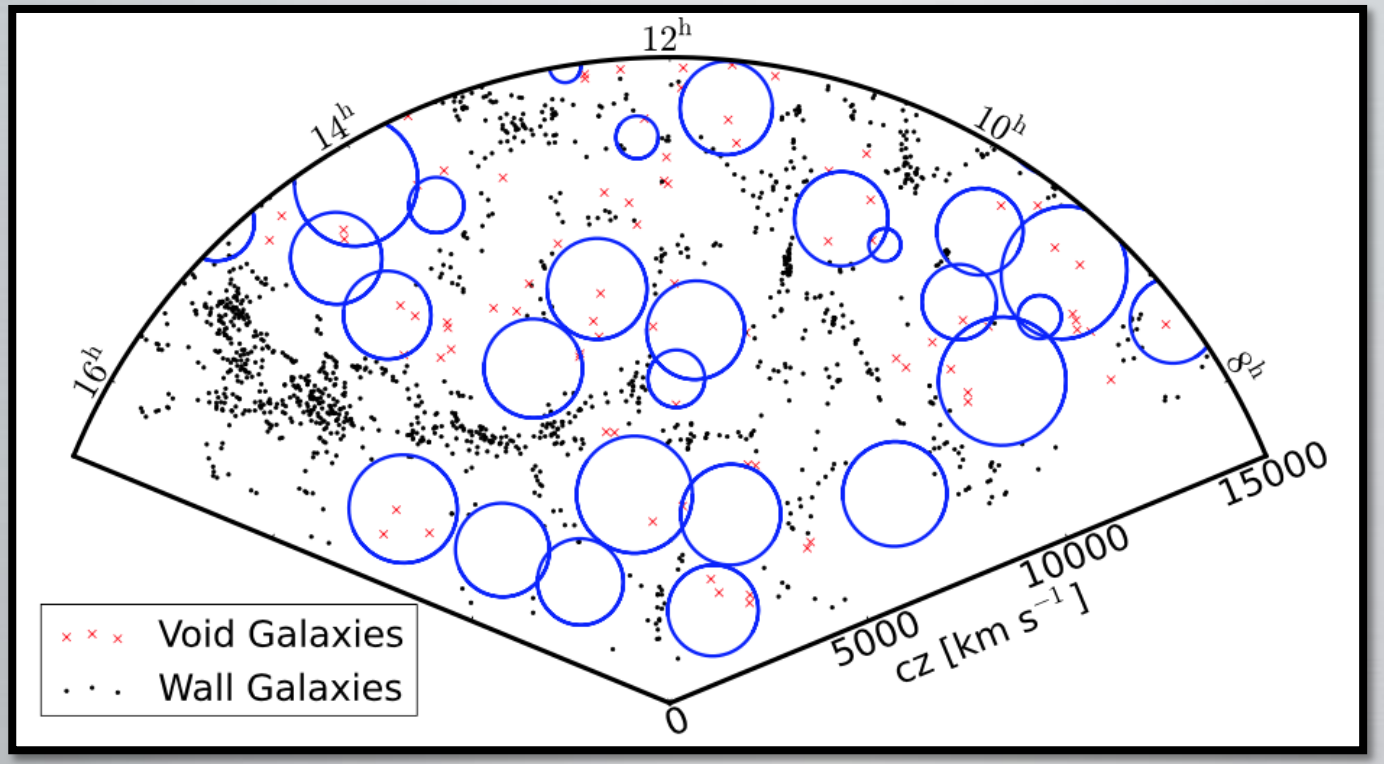
Simulations match observations on the large scale



Millennium Simulation project – wwwmpa.mpa-garching.mpg.de

How does the large-scale environment affect galaxy evolution?

1. Define the galaxy's environment
2. Use the smallest galaxies possible
3. Determine physical properties of the galaxies from spectroscopy
4. How do the properties of the gas and the history of star formation depend on the environment? What does this tell us about the dark matter structure and history of the galaxy?



Moorman et al. (2014)

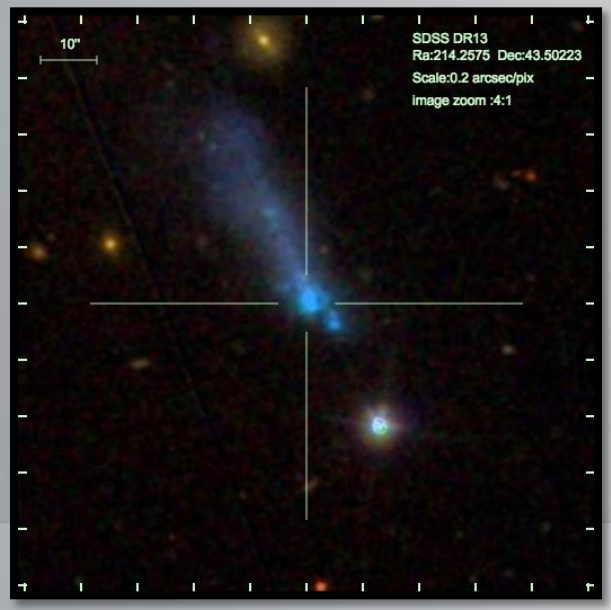
Void galaxies

Existing in the cosmological voids (space between galactic filaments), void galaxies are thought to demonstrate the fundamental characteristics of galactic evolution.

The influence of the large-scale environment: What we know so far

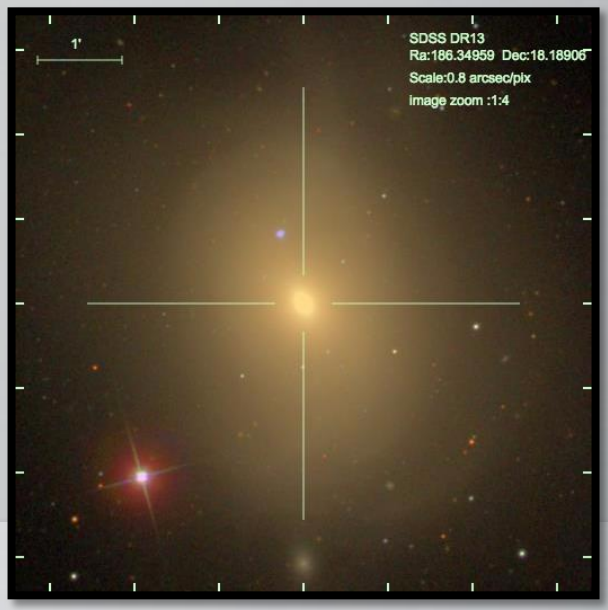
Voids

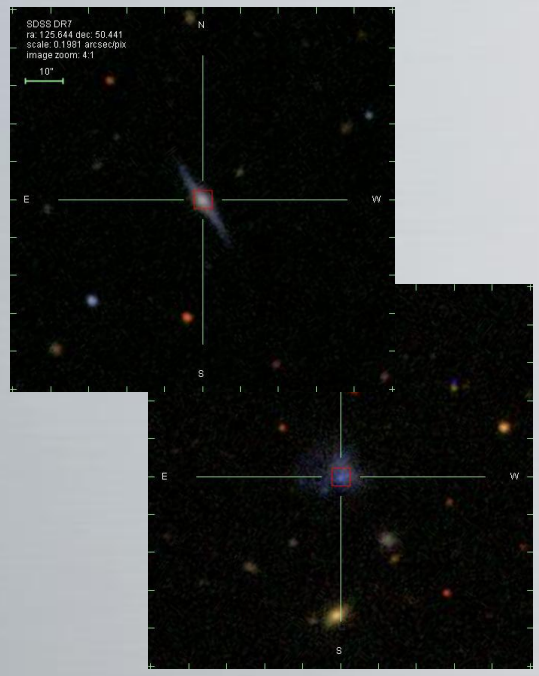
- Blue spiral and irregular galaxies
- Currently forming stars



Walls

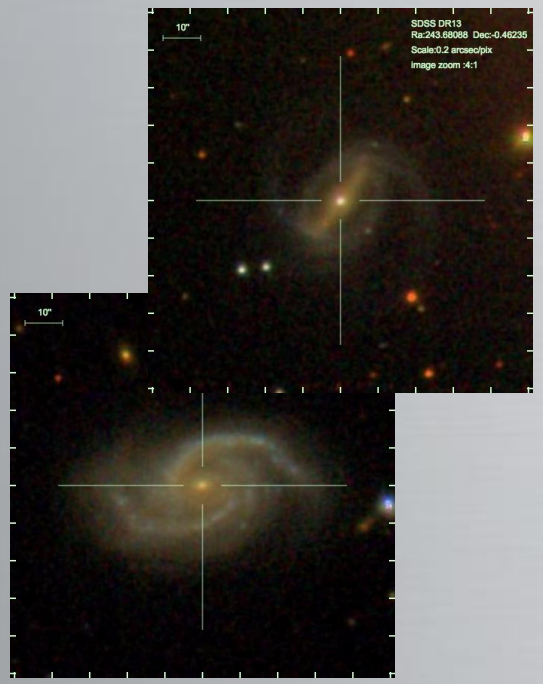
- Red elliptical galaxies
- No longer forming stars

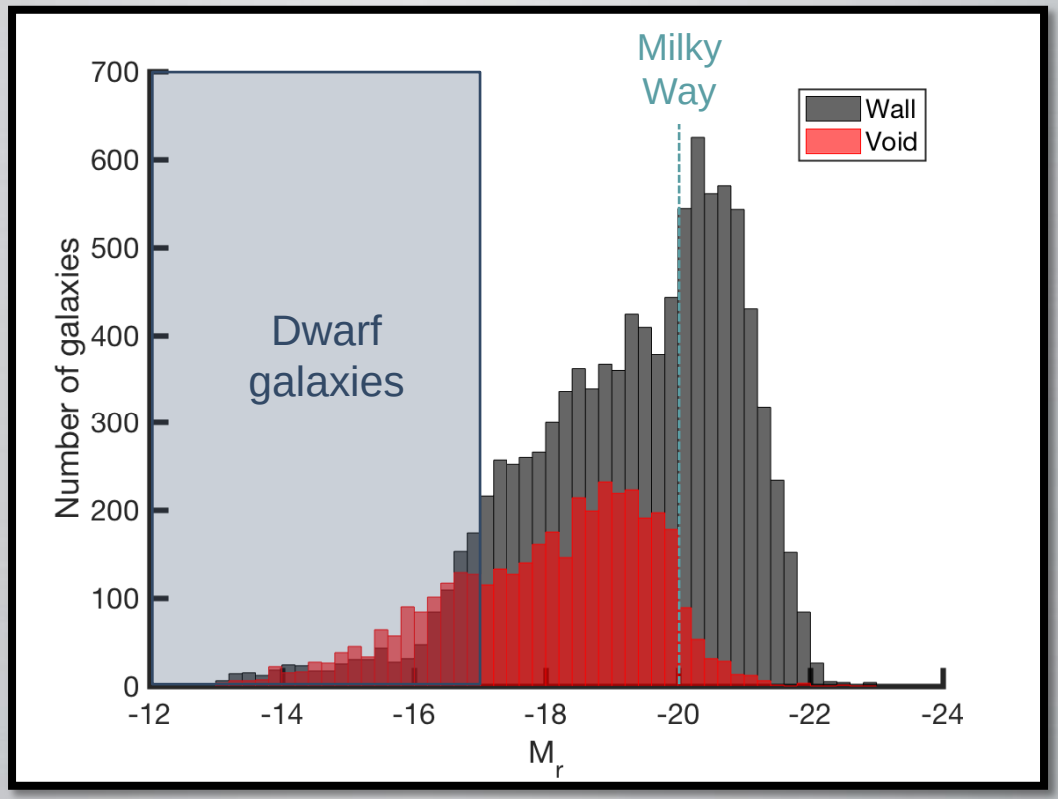




Dwarf galaxies

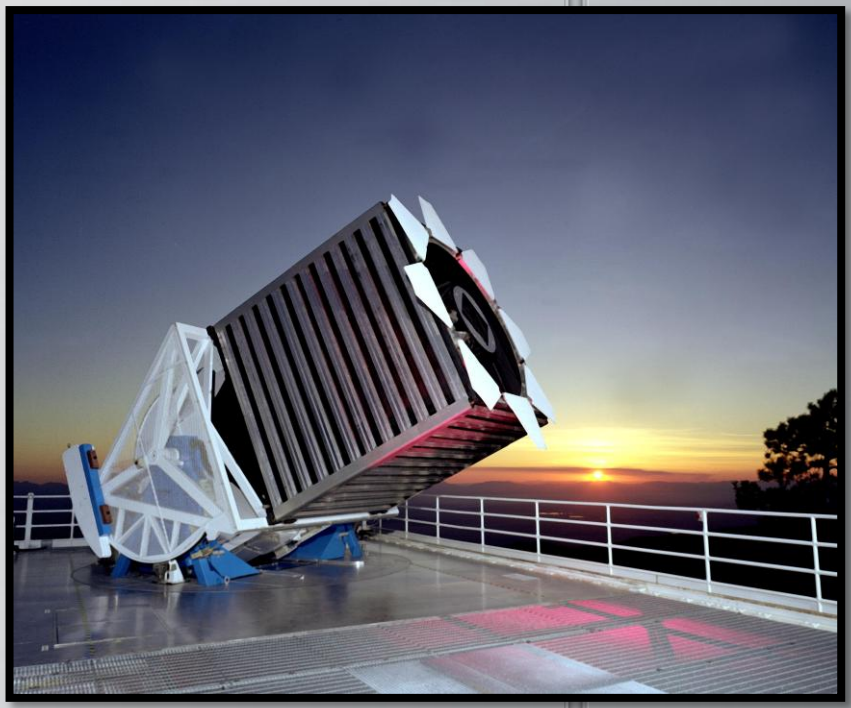
- Galaxies fainter than M_r = -17
- Low stellar masses (10^6 – 10^9 $M_\odot$)
- More sensitive to environmental effects

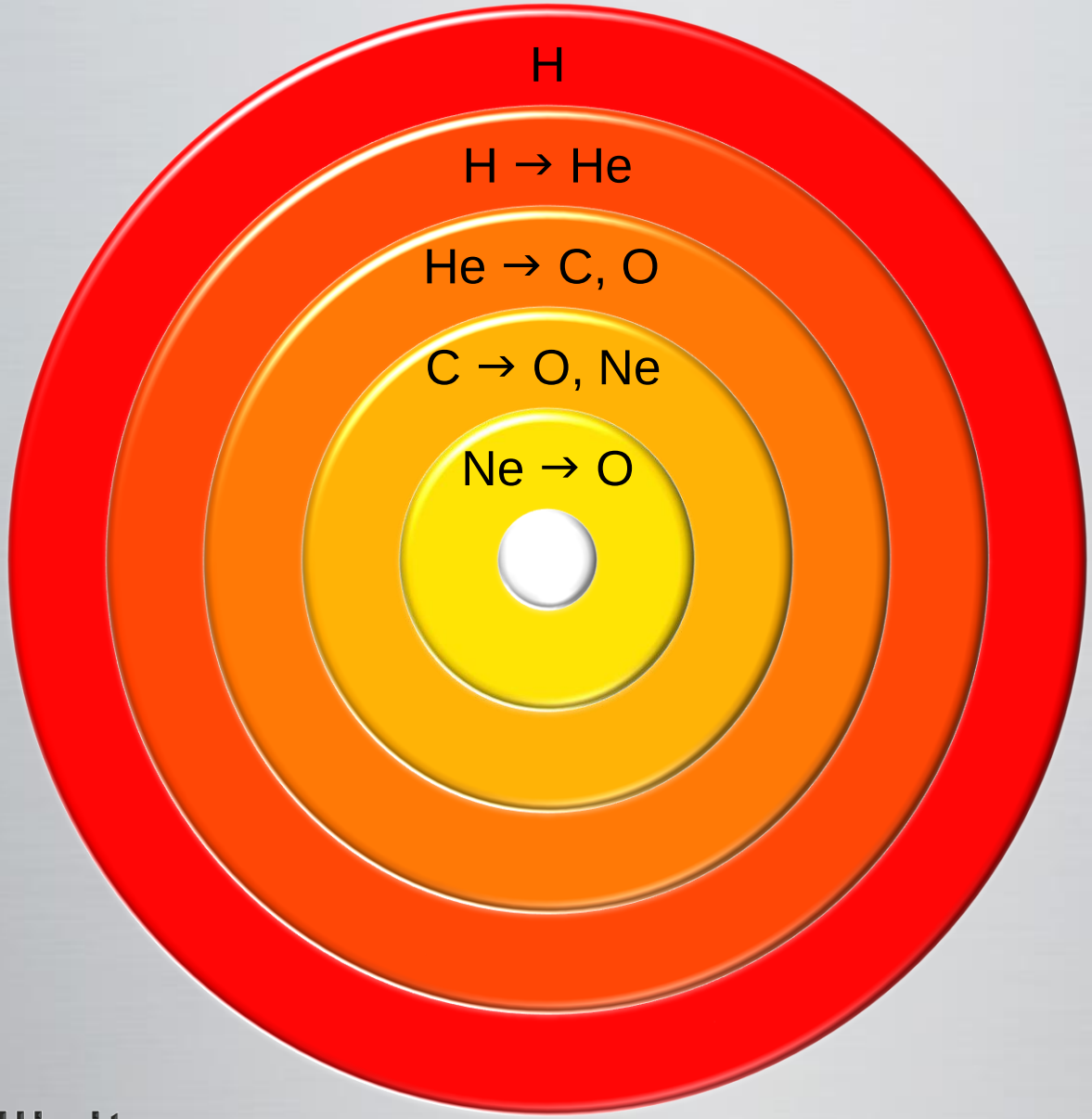




Sloan Digital Sky Survey DR7 (SDSS)

- Large photometric and spectroscopic survey covering approximately ¼ of the sky
- Data taken with 2.5-meter telescope at Apache Point Observatory in New Mexico
- Spectra are within a rest wavelength range of 3800Å to 9200Å with a resolution $\lambda/\Delta\lambda \approx 1800$
- Of about 800,000 galaxies in the main spectroscopy survey, only about 11,050 are dwarf galaxies!



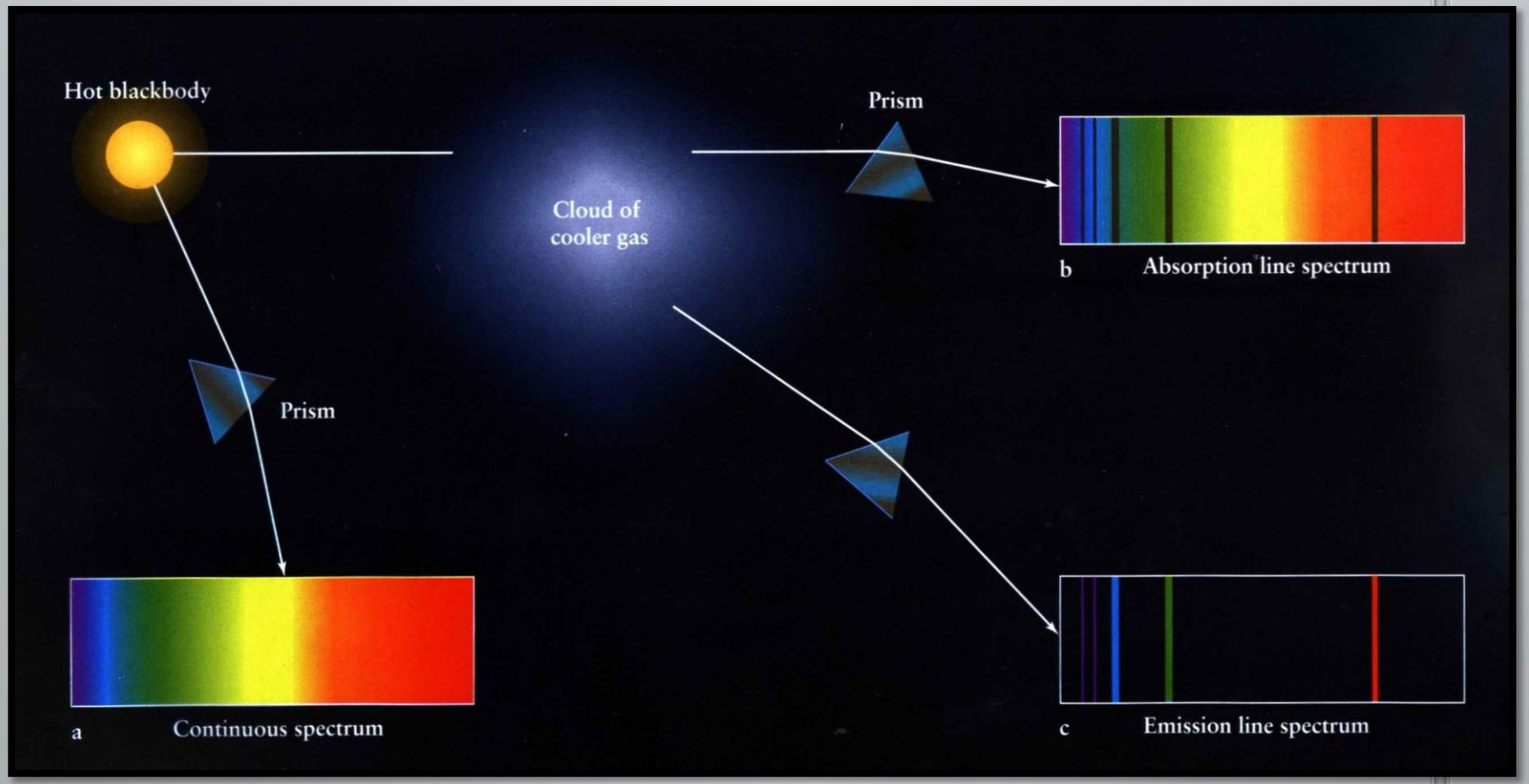


Metallicity –
The ratio of heavy elements to hydrogen

Stellar nucleosynthesis: H → He → C → Ne → O → Si

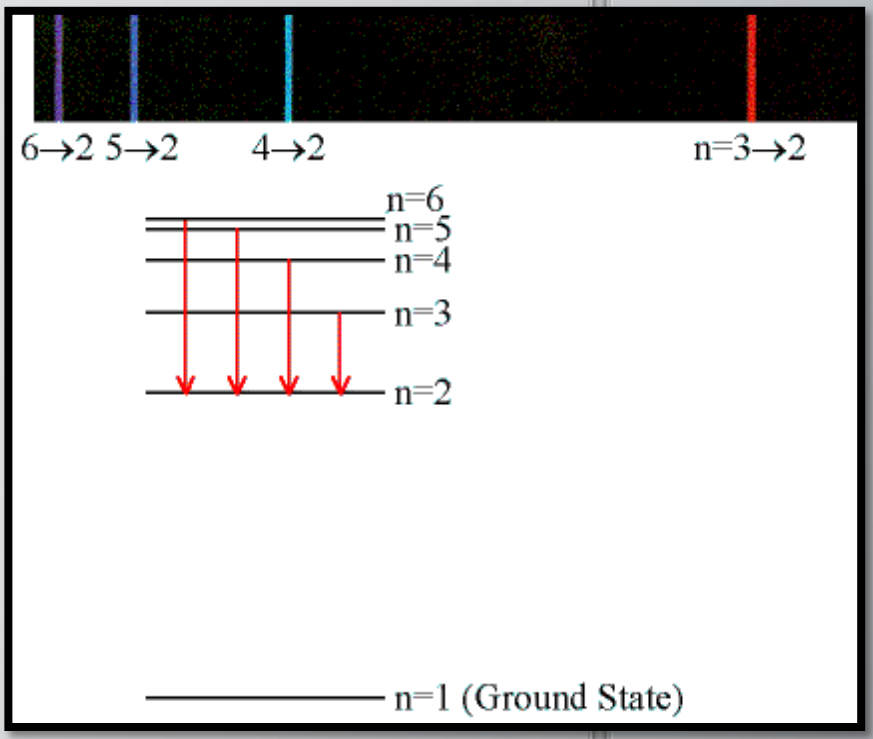
Kirchhoff's Laws of Spectroscopy

A galaxy's spectrum is a superposition of light from the stars and emission lines from the gas.



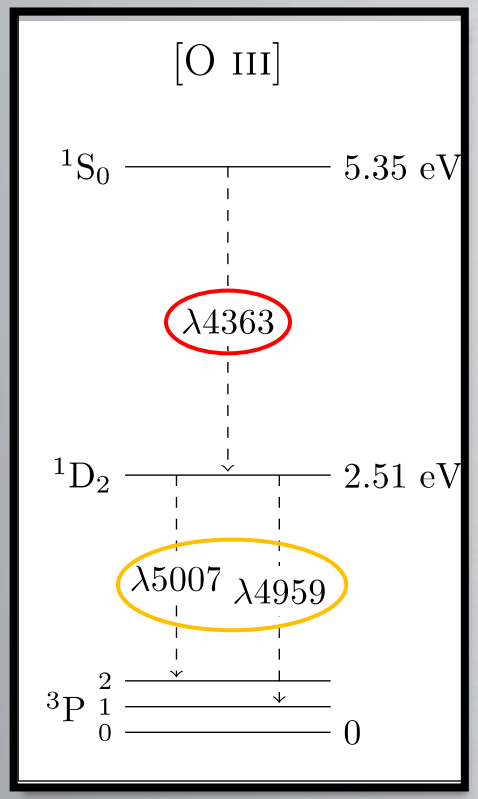
Forbidden Emission Transitions

- "Classical" transitions – electric dipole selection rules
- Forbidden transitions – result of magnetic dipole and/or electric-quadrupole transitions
- Lifetimes
  - "Classical" transitions: 10^{-6} s
  - Forbidden transitions: 10^{-1} – 10^{4}s

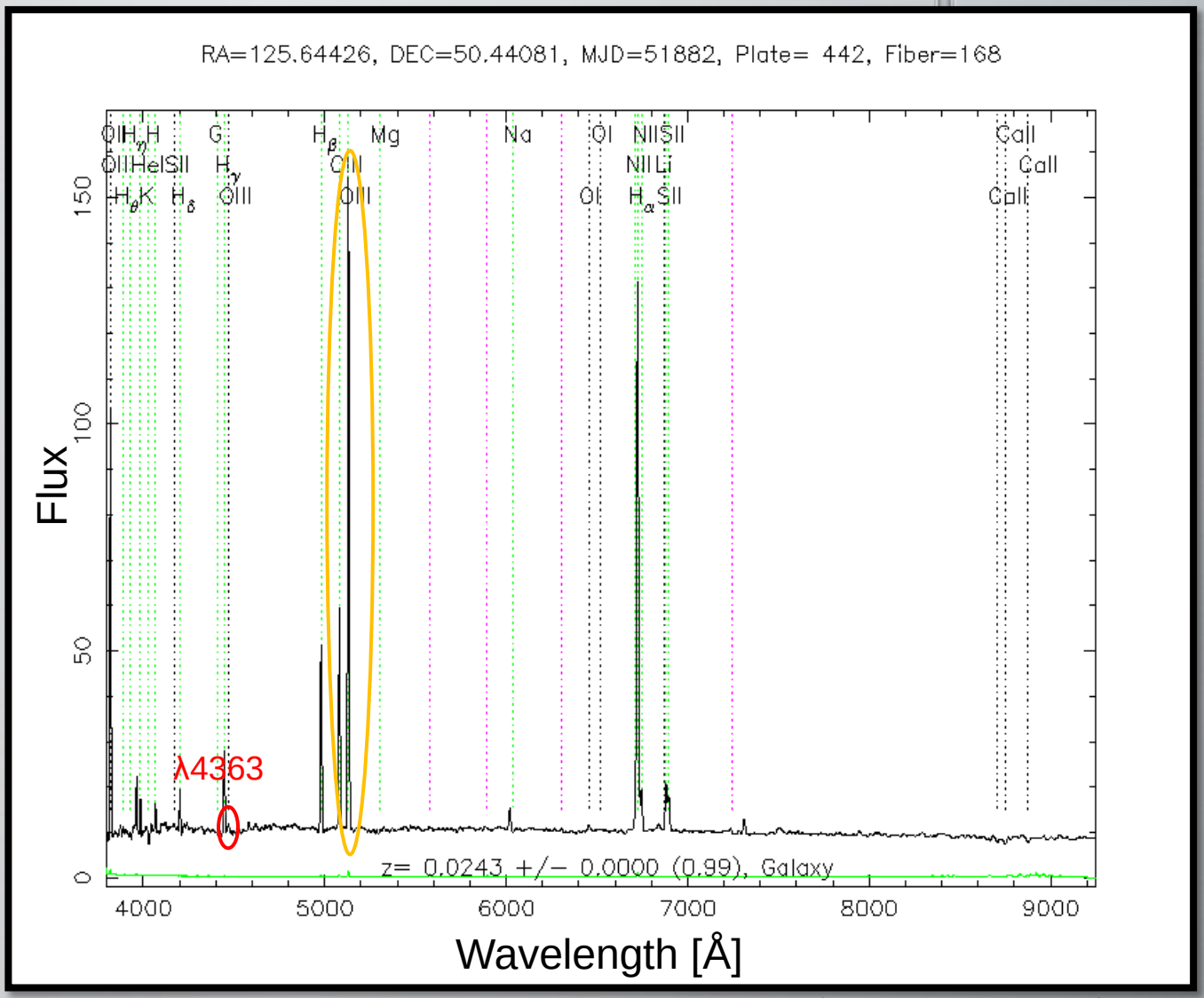


Spectroscopy reveals gas properties

- [OIII] is temperature-sensitive
- [SII] is sensitive to the electron number density



Douglass & Vogeley (2017a)



SDSS DR7 galaxy spectrum – www.sdss.org

Oxygen abundance

- Metallicity often described in terms of the oxygen abundance O/H
- Temperature from [OIII] line ratio
- Density from [SII] line ratio (=100 cm^{-3})

T_e & n_e & flux → abundance

Accounting for ions of O & N

- For oxygen,

$$\frac{O}{H} = \frac{O^{++}}{H} + \frac{O^{+}}{H}$$

- Can only observe N^{+} - must use an Ionization Correction Factor (ICF)

$$\frac{N}{H} = ICF\,\frac{N^{+}}{H}$$

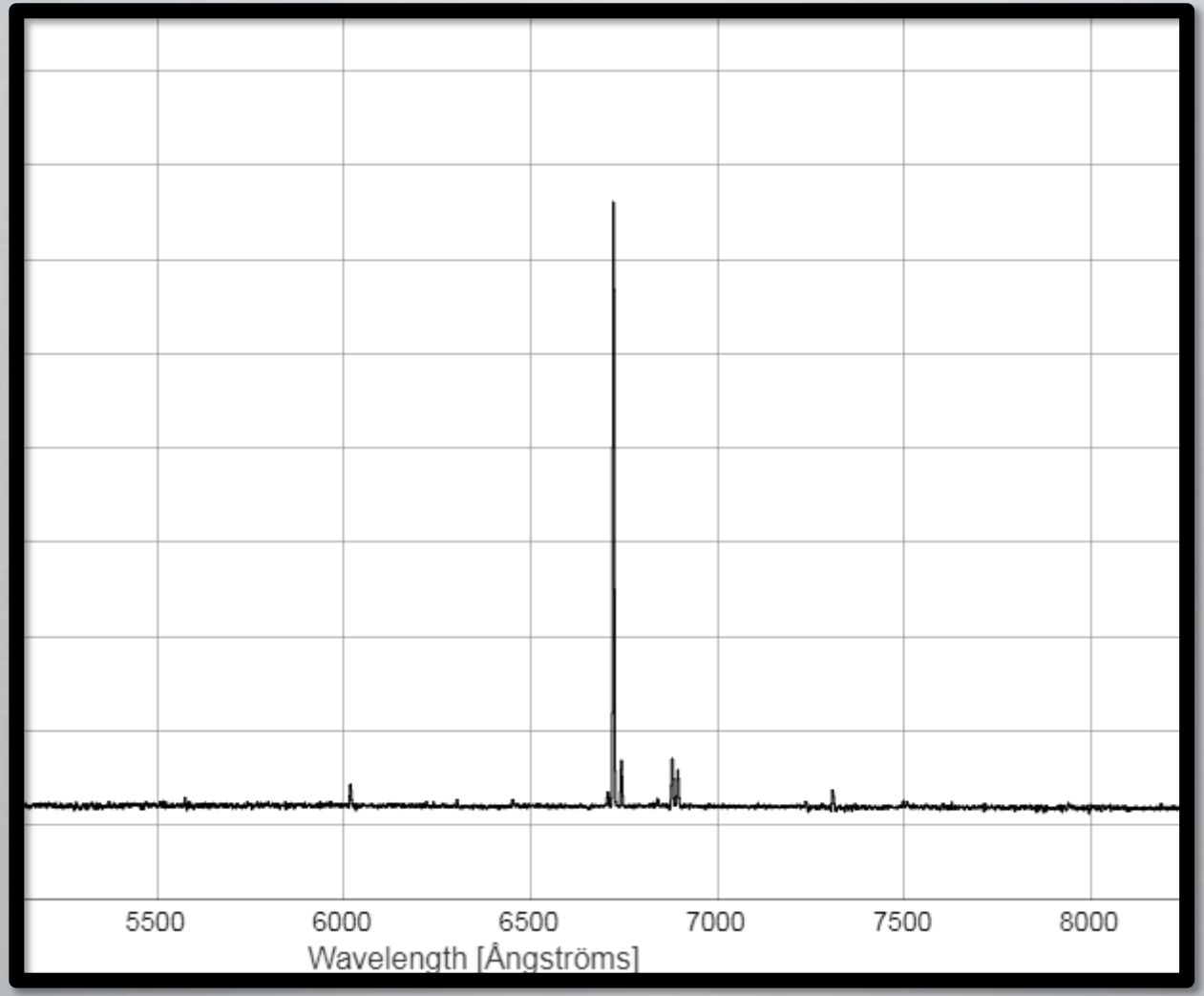
Galaxy selection criteria

- Dwarf galaxies: $M_r > -17$
- $z < 0.03$: SDSS is a magnitude-limited survey
- Star-forming: ultraviolet photons are needed to excite interstellar gas
  - All required lines must be emission lines
  - Minimum 5σ detection of Hβ
  - Minimum 1σ detection of [OIII] λ4363
- $T_e(OIII) < 3x10^4$ K

993 void dwarf galaxies & 759 wall dwarf galaxies

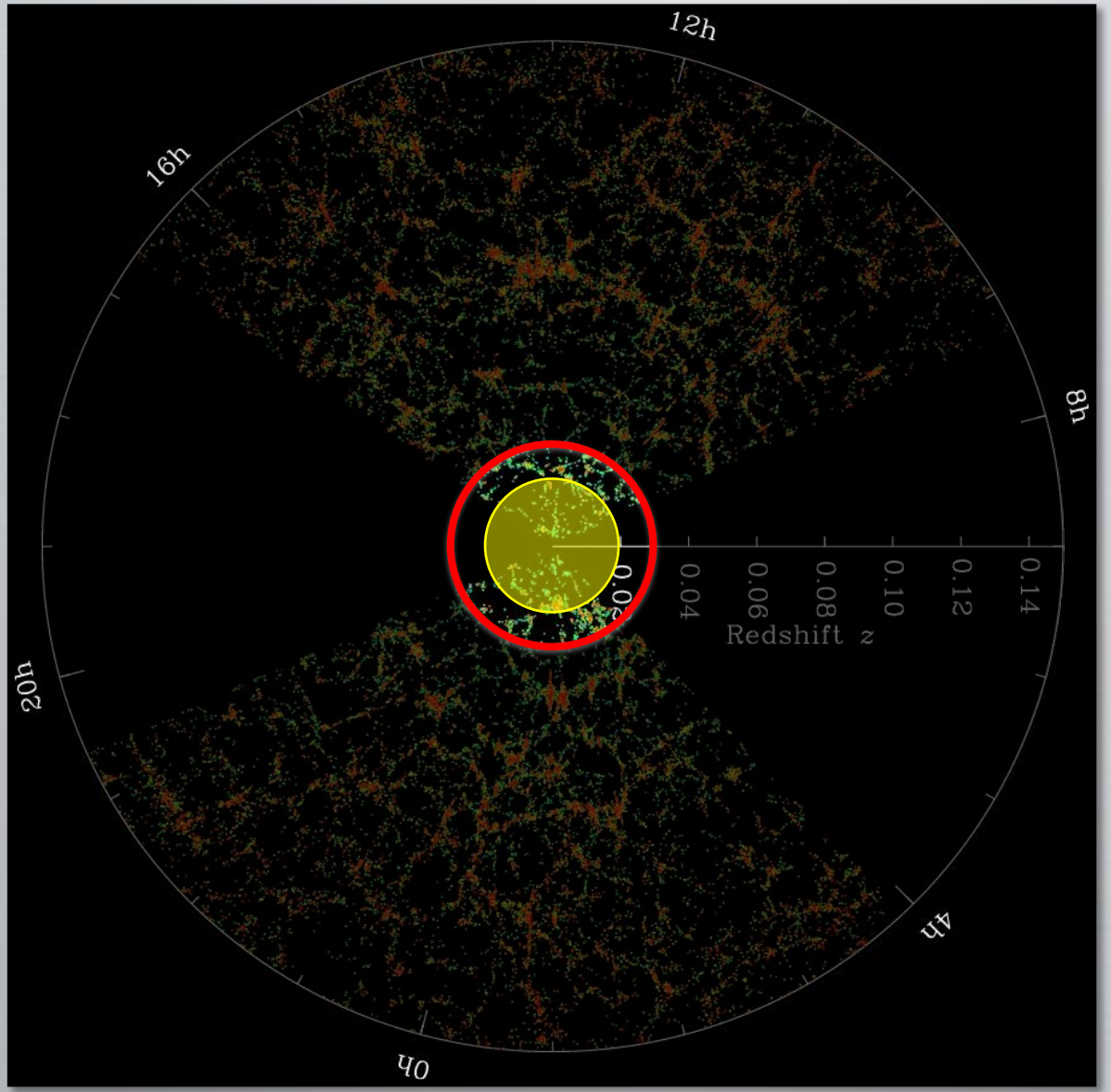
Redshift & a Spectrum

Different parts of a spectrum are visible depending on the galaxy's redshift.



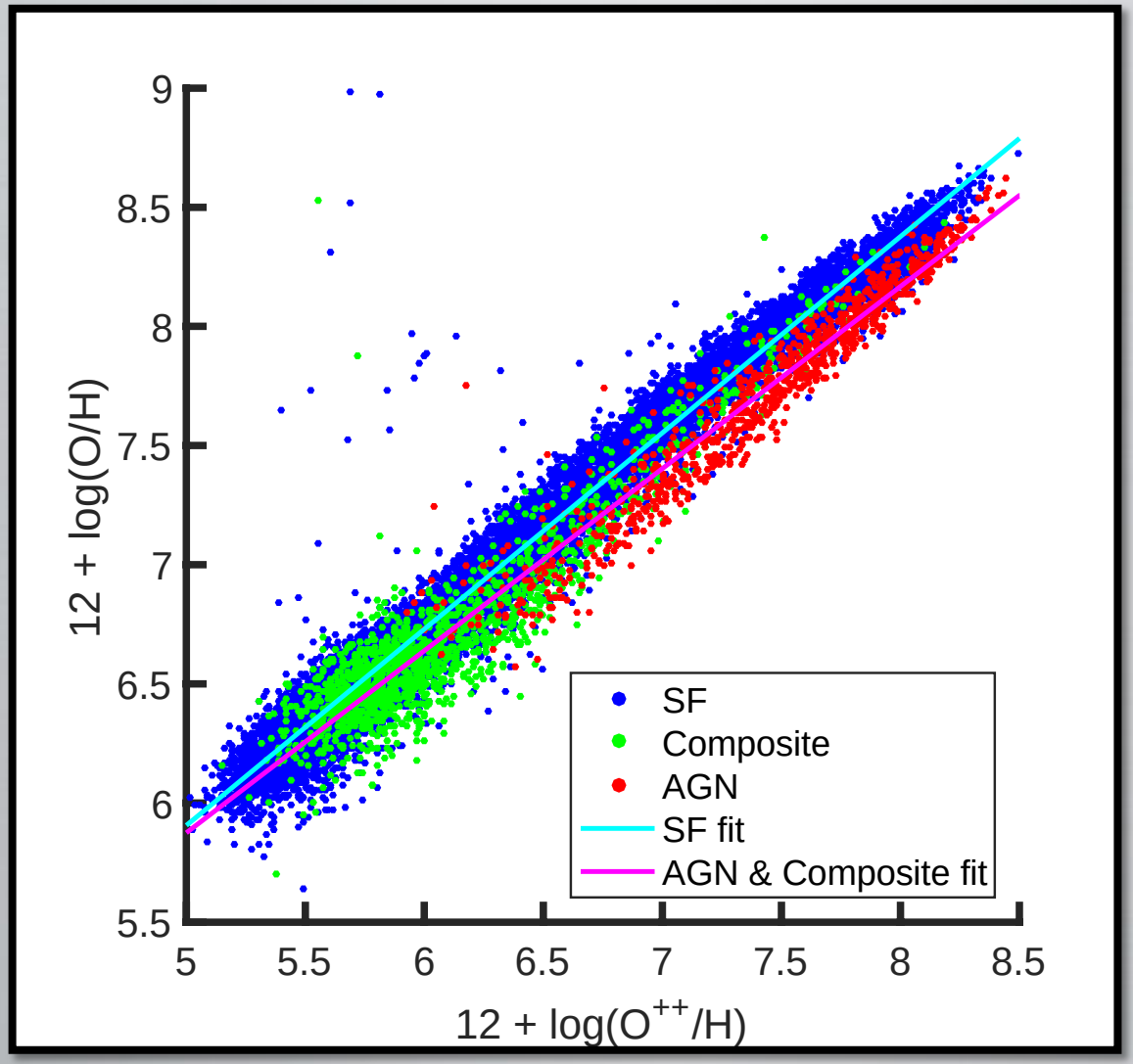
O^+ abundance approximation

Developing a substitute for the [OII] λ3727 doublet, we can now study SDSS dwarf galaxies at redshifts z < 0.02



How is O^{++}/H related to O/H?

Different relationship for SF and AGN/composite galaxies

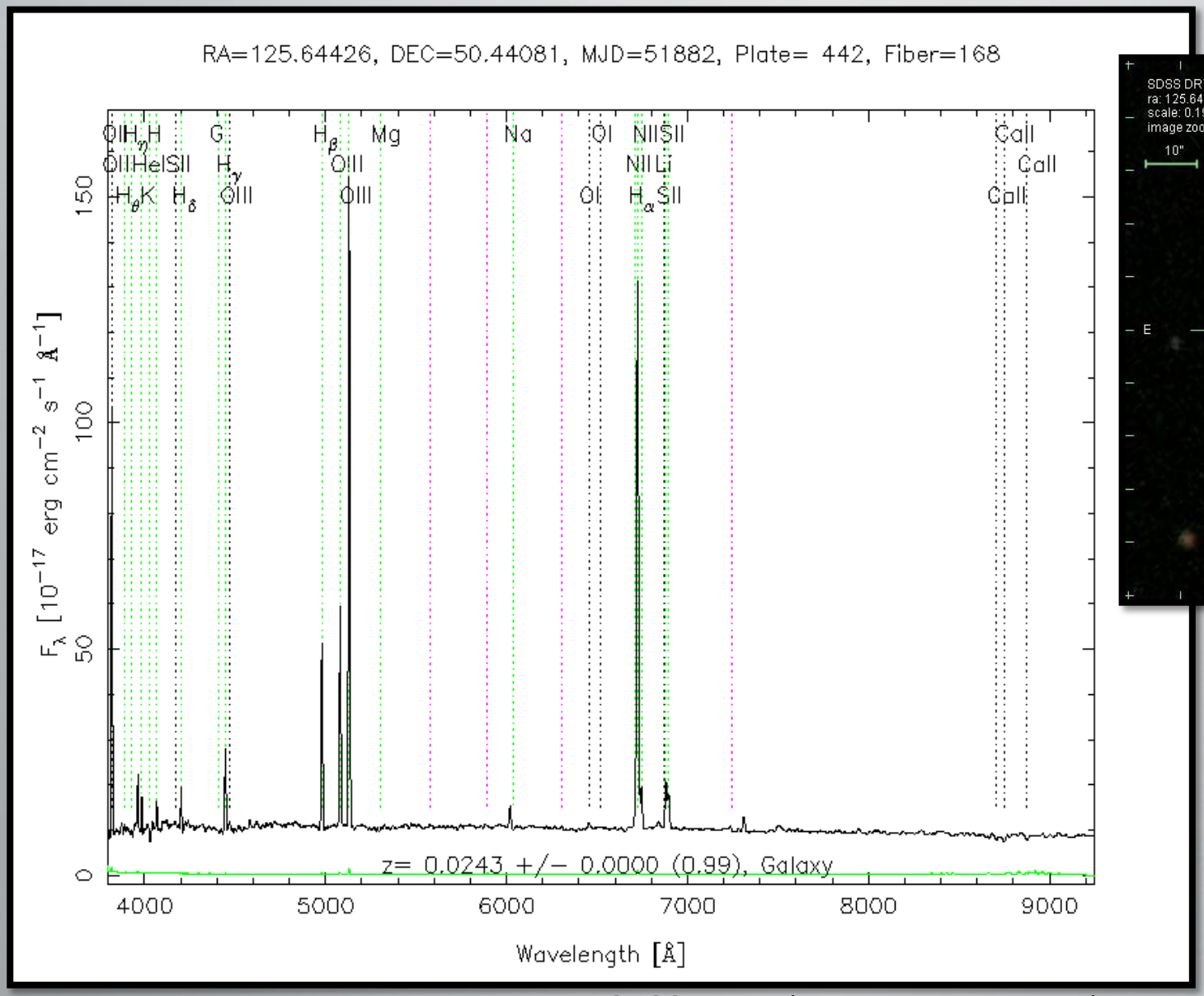


Douglass et al. (2017)

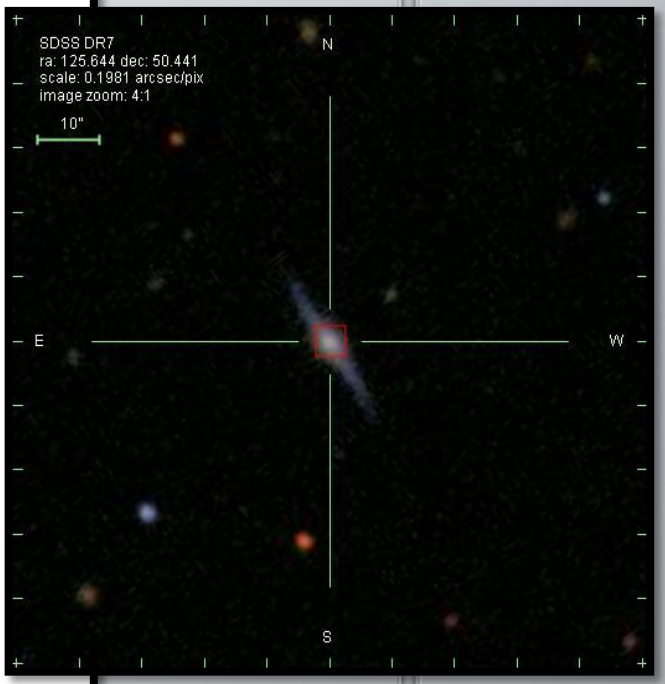
Dwarf sample increase

	Without approximation	With approximation
Void dwarf galaxies	42	993
Wall dwarf galaxies	89	759
Uncertain dwarf galaxies	4	168

Sample dwarf galaxy



SDSS DR7 galaxy spectrum – www.sdss.org



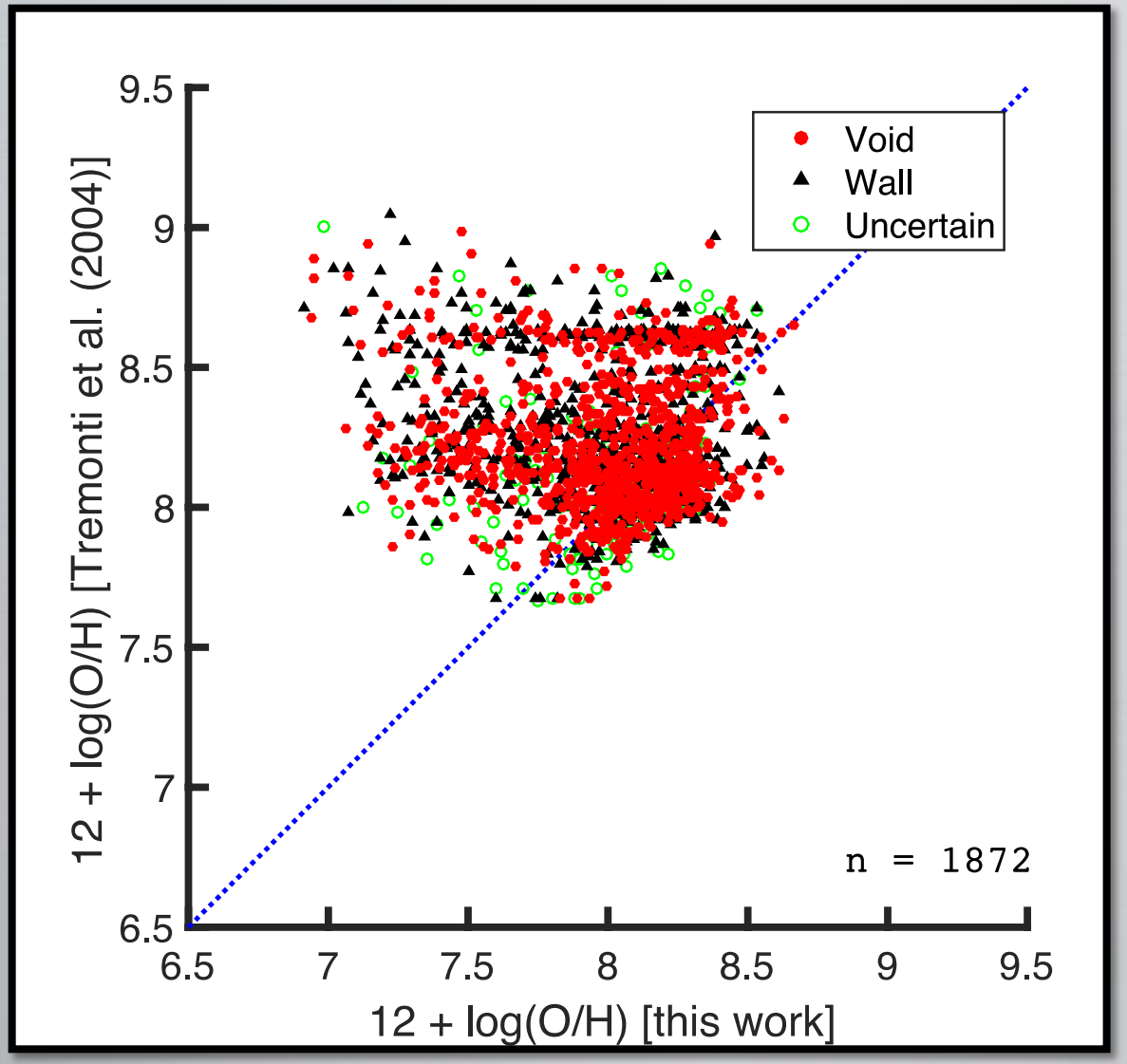
www.sdss.org

12 + log(O/H) = 8.35 ± 0.159

12 + log(N/H) = 7.05 ± 0.118

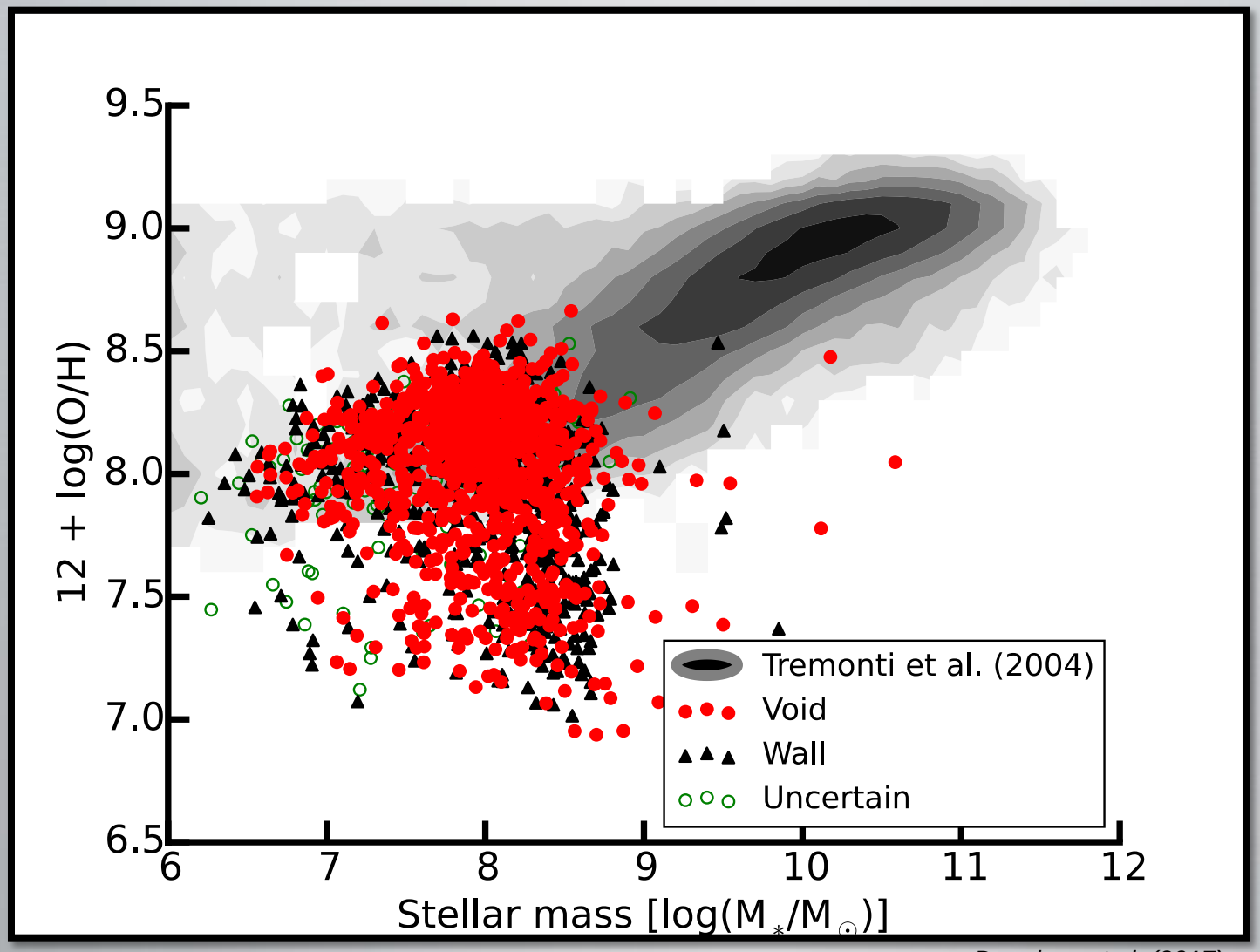
log(N/O) = -1.31 ± 0.198

Comparison to previously published values



Douglass et al. (2017)

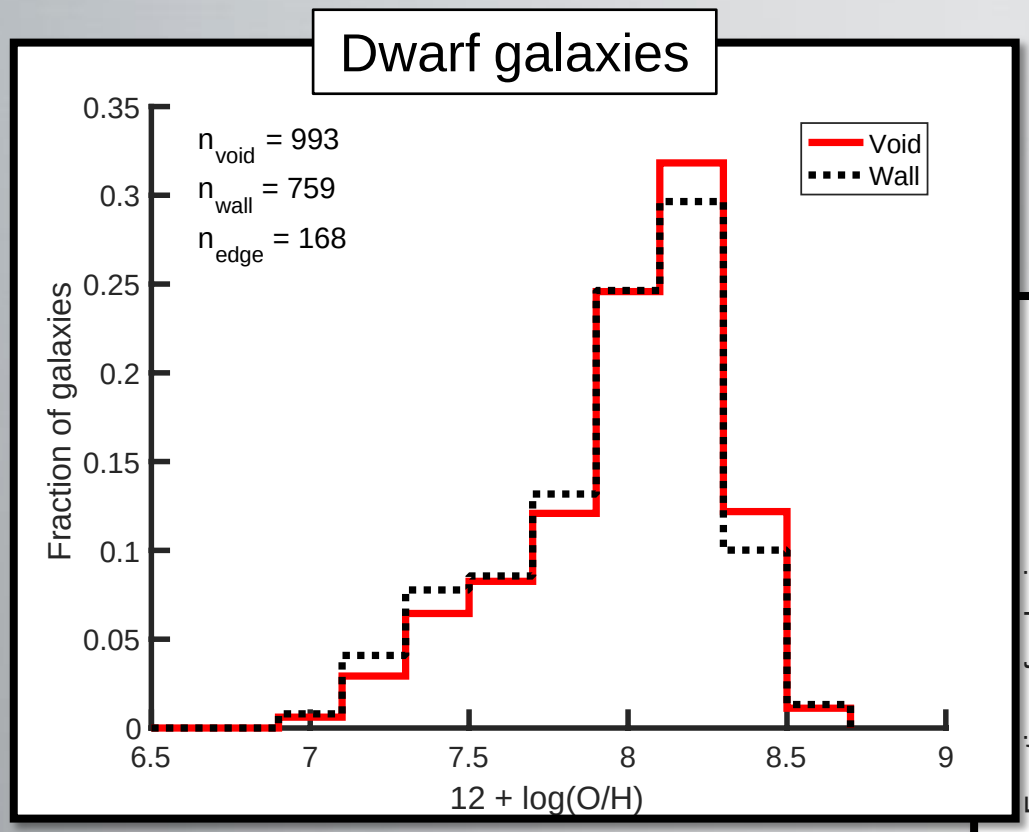
Mass – Metallicity relationship



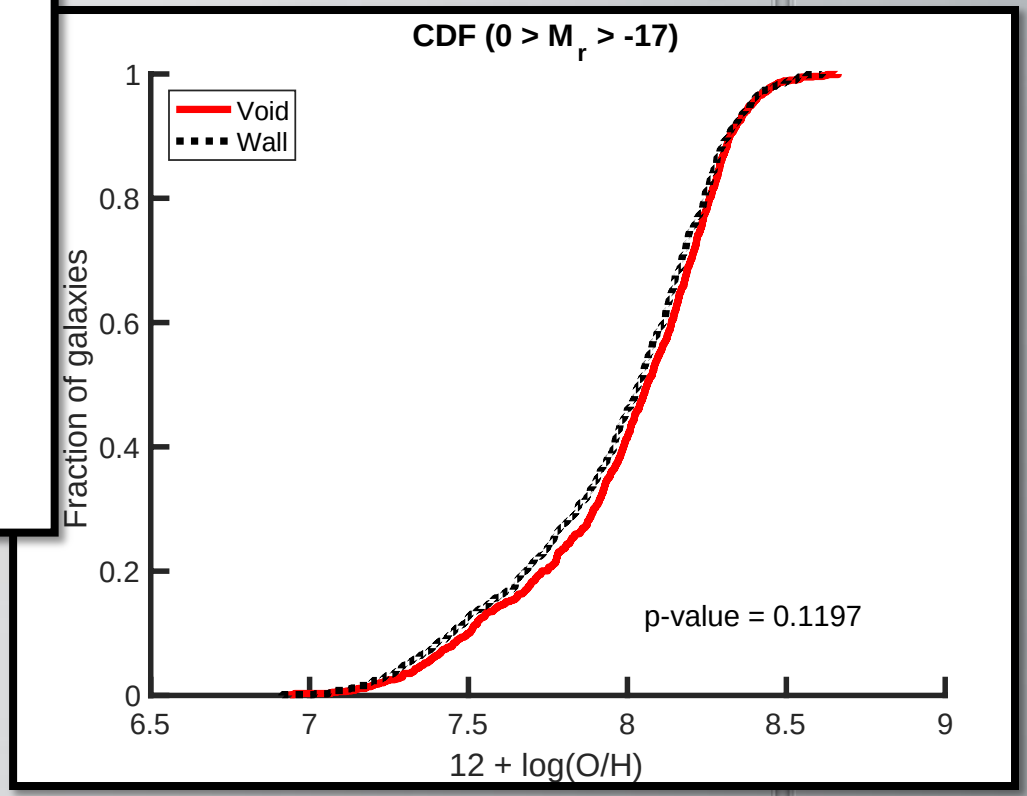
Douglass et al. (2017)

Large-scale environmental dependence of gas-phase oxygen (O/H)

M_r range	Average shift
Dwarf galaxies	**-0.03±0.012 (7%)**
-17 > M_r > -18	-0.02±0.015 (5%)
-18 > M_r > -19	-0.00±0.014 (0%)
-19 > M_r > -20	-0.04±0.016 (10%)

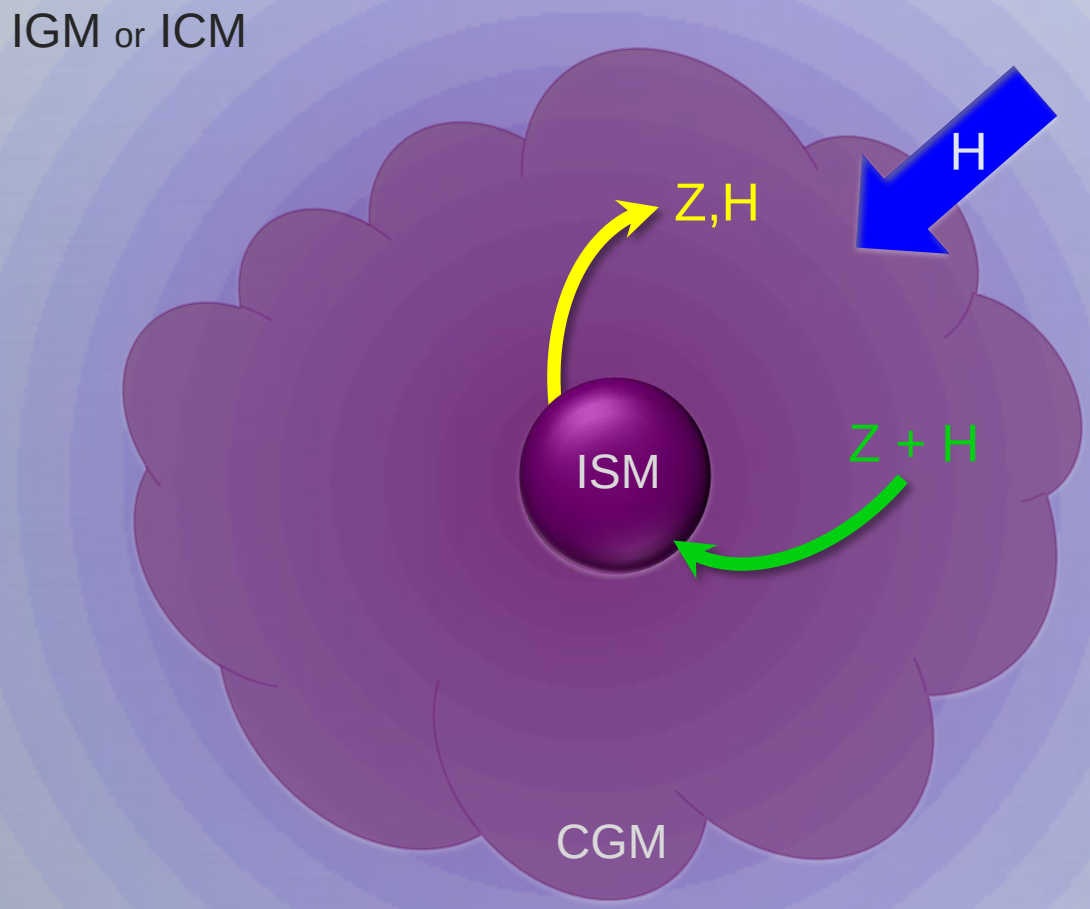


Douglass et al. (2017)



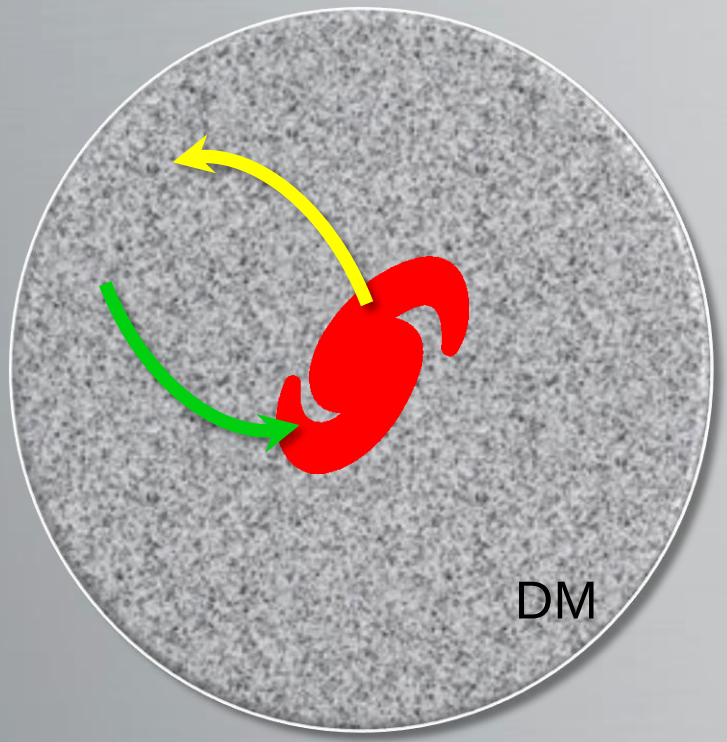
Douglass et al. (2017)

Chemical enrichment of ISM



$M_{DM\ halo}/M_*$ larger in void galaxies?

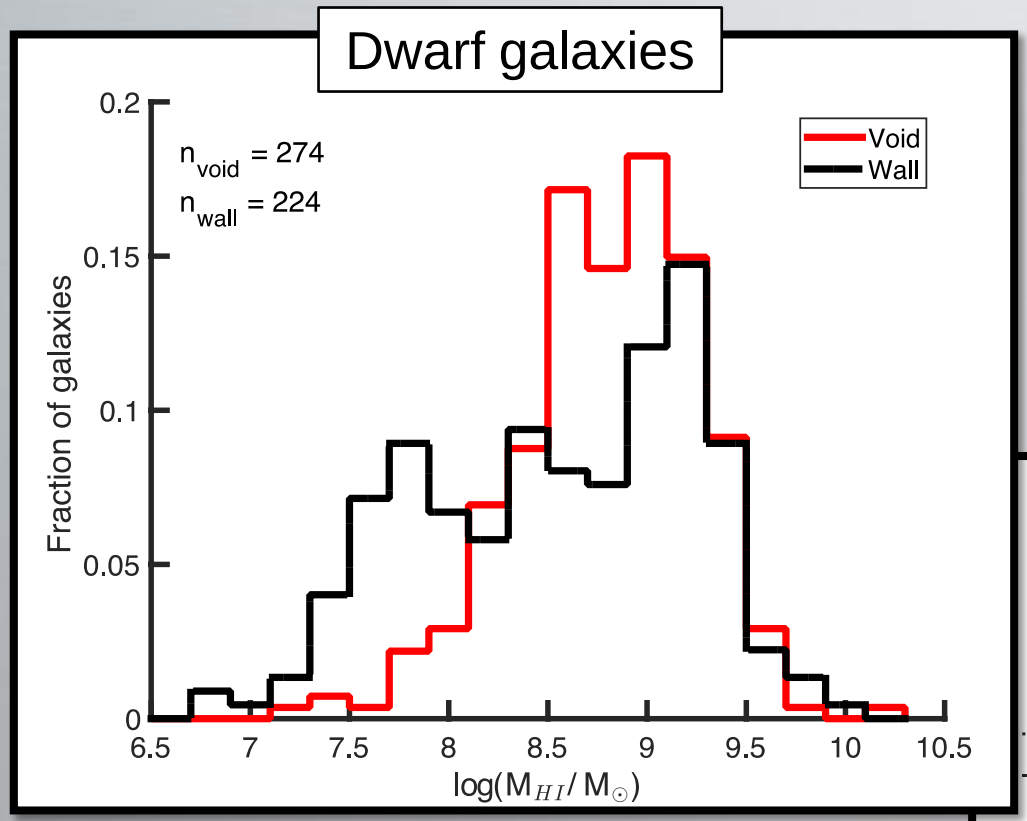
Void central galaxy



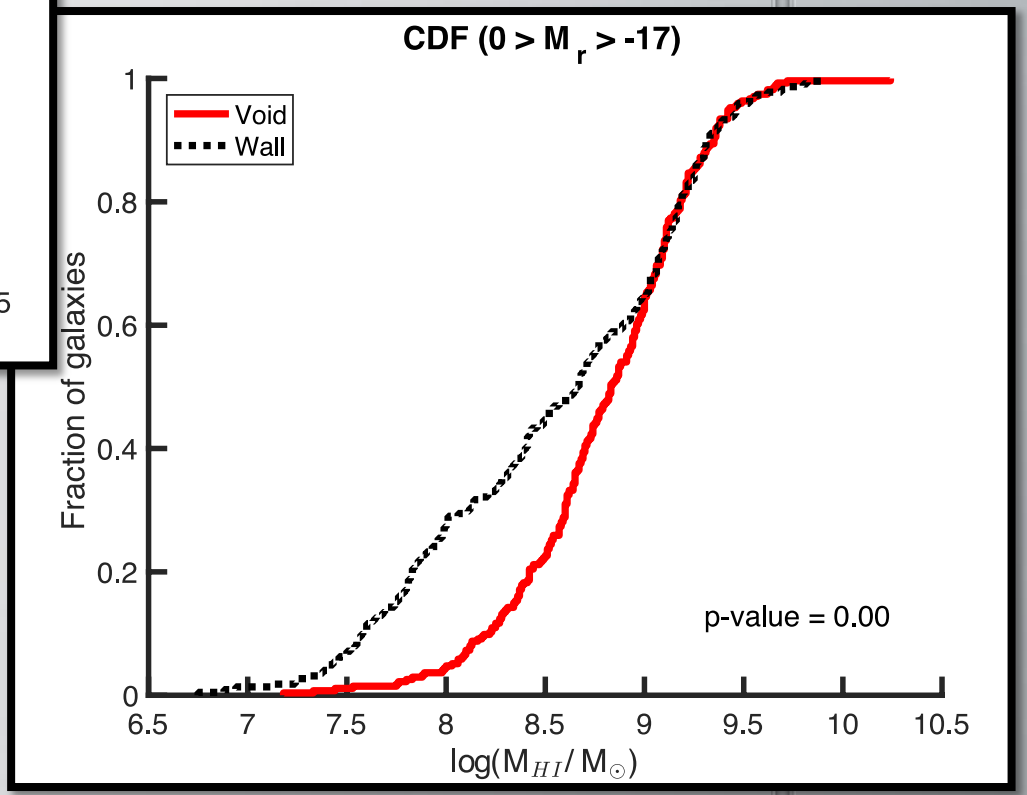
Wall central galaxy

Simulation results of Jung et al. (2014) and Tonnesen & Cen (2015)

HI mass dependence on large-scale environment



Douglass et al. (2017)

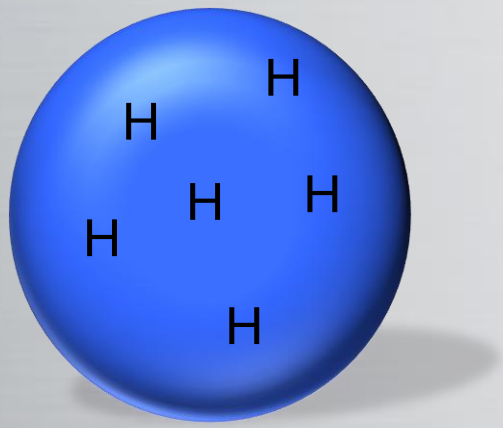


Douglass et al. (2017)

Nitrogen synthesis

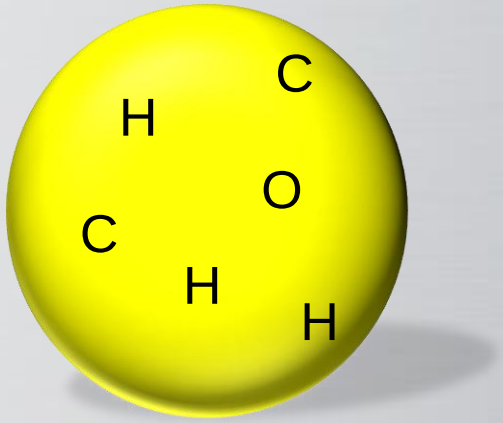
Nitrogen behaves as both a primary and secondary element, depending on the initial metallicity of the star.

Low-metallicity star



C,O,N
all produced in same ratio

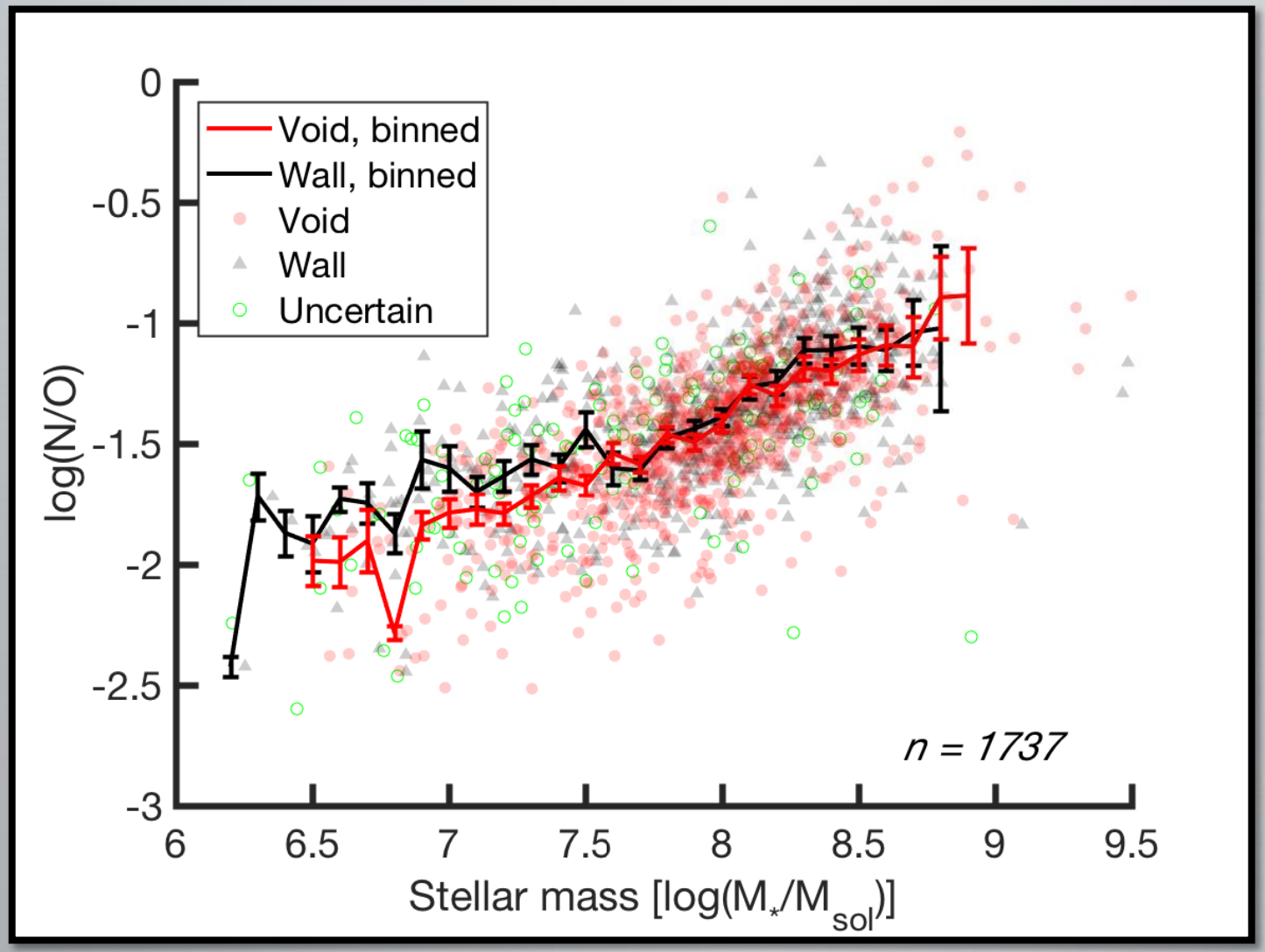
High-metallicity star



N produced in higher ratio than C,O

Mass – log(N/O) relationship

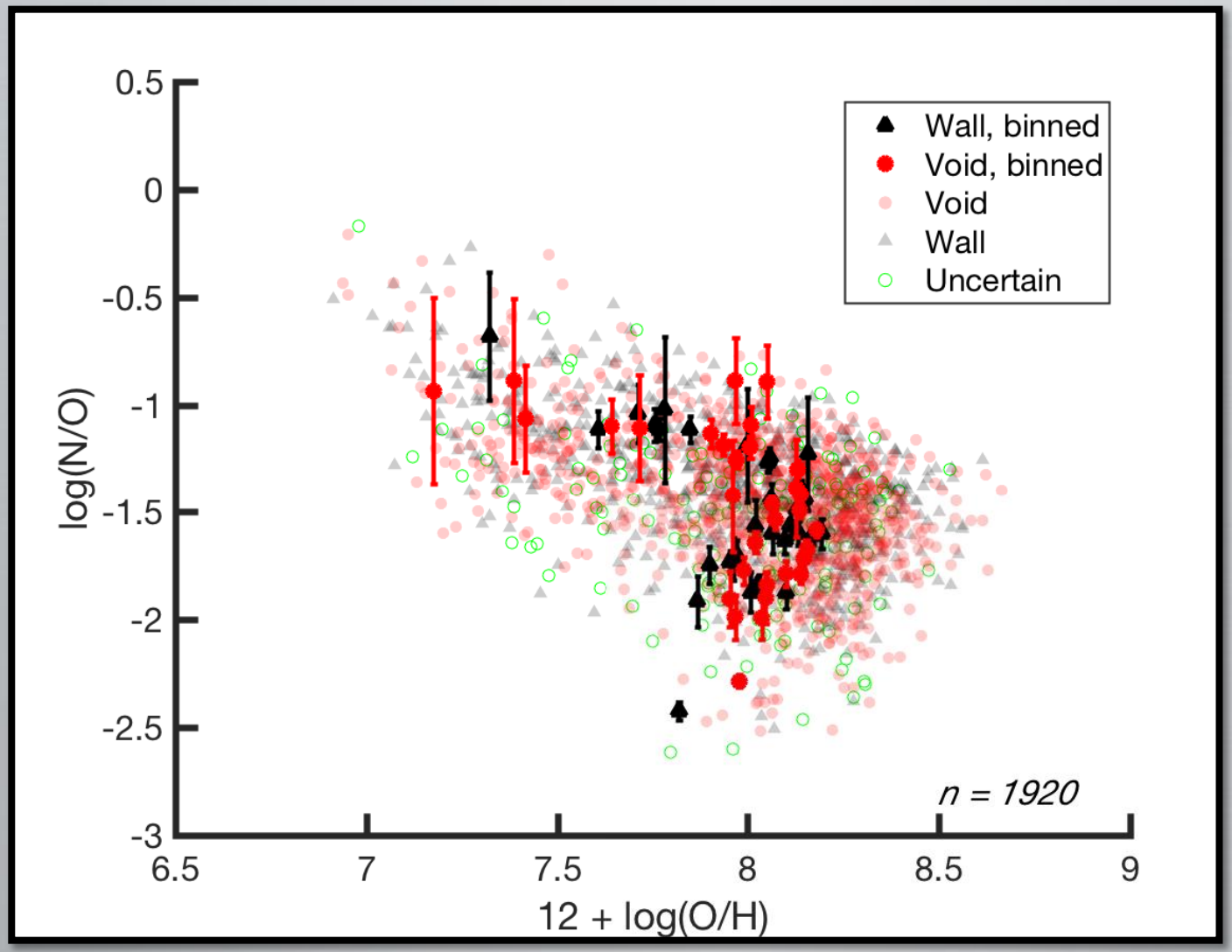
Same slope for both void and wall galaxies, but the critical mass for the N/O plateau is lower for void galaxies (≈7.2) than wall galaxies (≈7.6)



Douglass et al. (2017)

O/H – N/O relationship

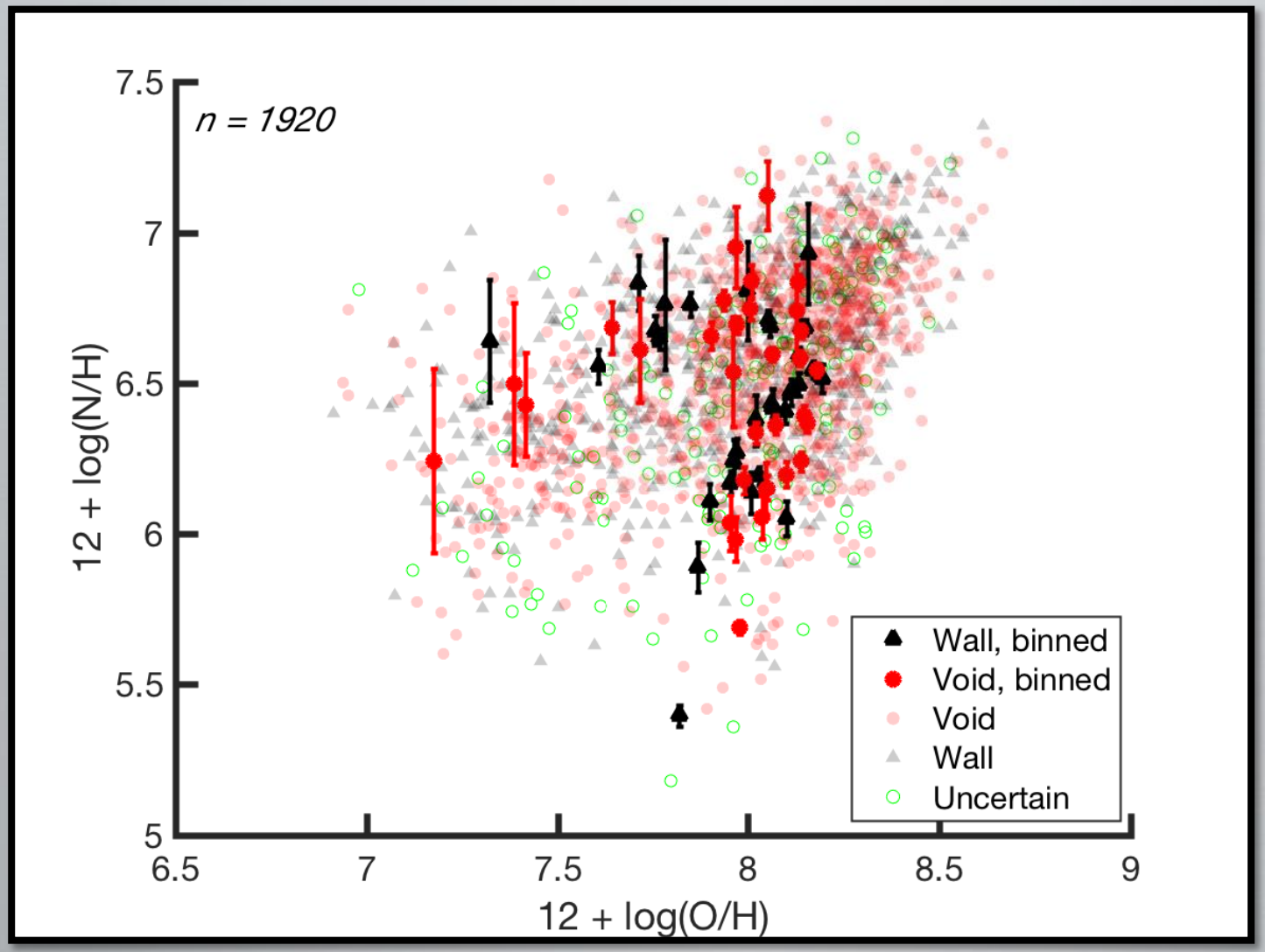
We find an inverse relationship between N/O and O/H instead of a constant N/O “plateau” predicted for primary N production.



Douglass et al. (2017)

O/H – N/H relationship

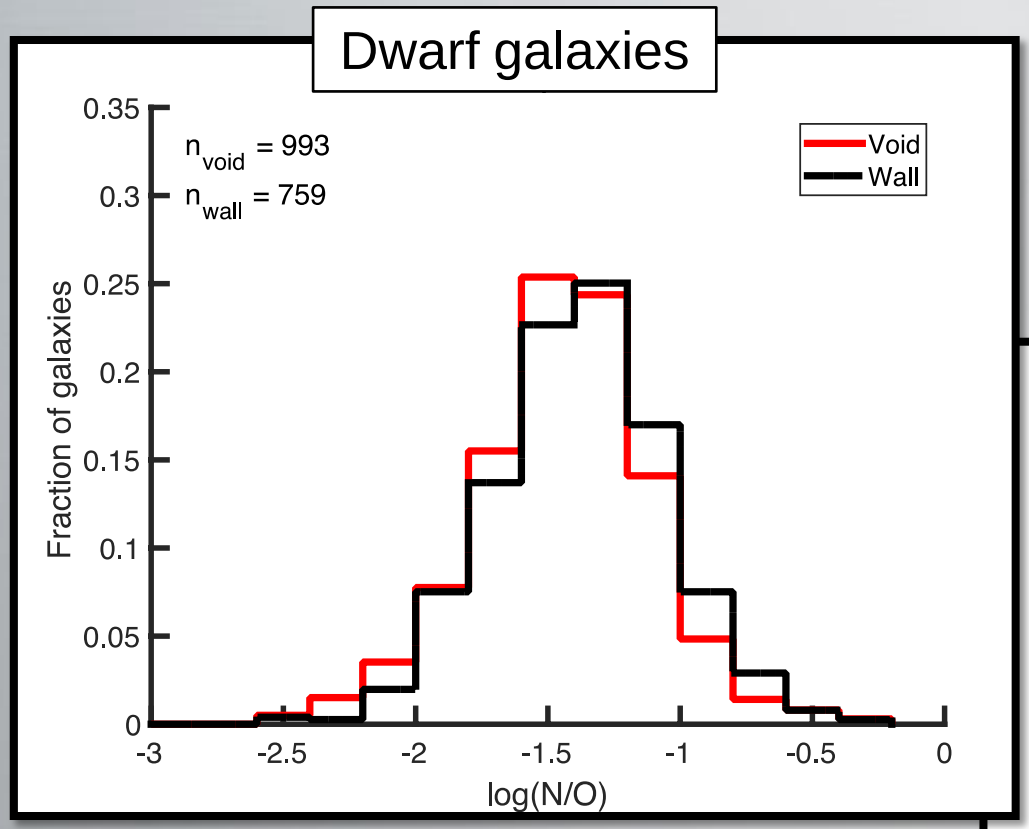
Evidence of two evolutionary tracks, one with a much steeper slope than the other



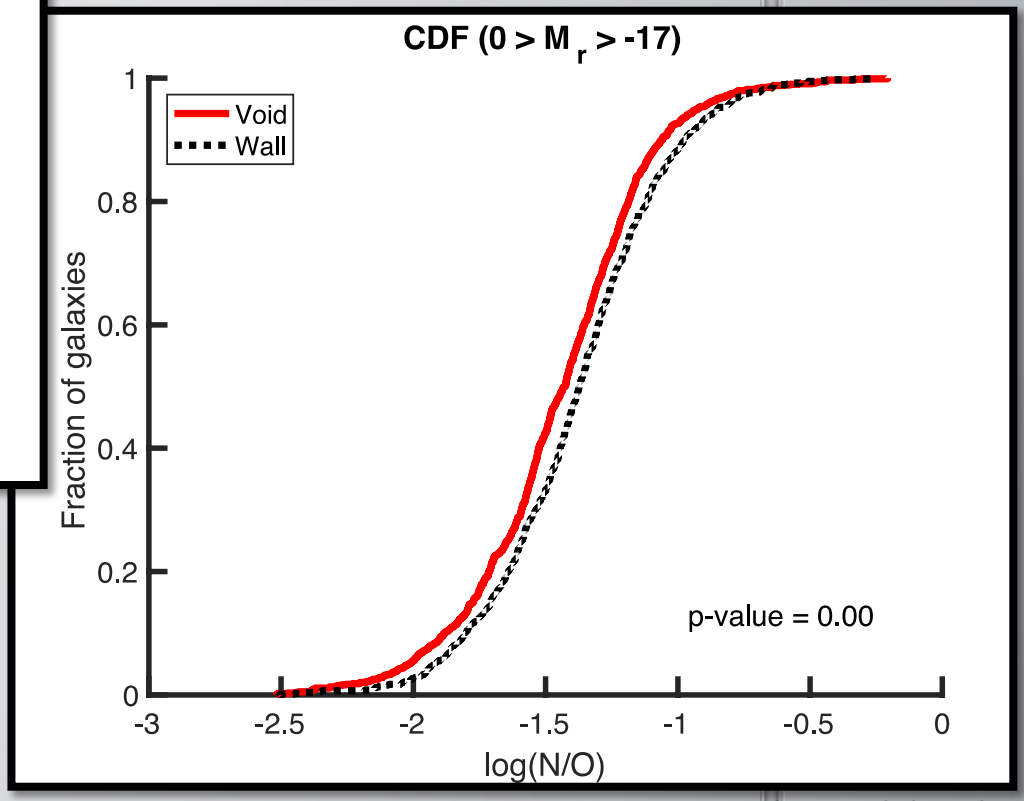
Douglass et al. (2017)

Large-scale environmental dependence of N/O

M_r range	Average shift
Dwarf galaxies	**0.07±0.016 (17%)**
-17 > M_r > -18	-0.00±0.019 (0%)
-18 > M_r > -19	0.00±0.018 (0%)
-19 > M_r > -20	0.02±0.020 (5%)



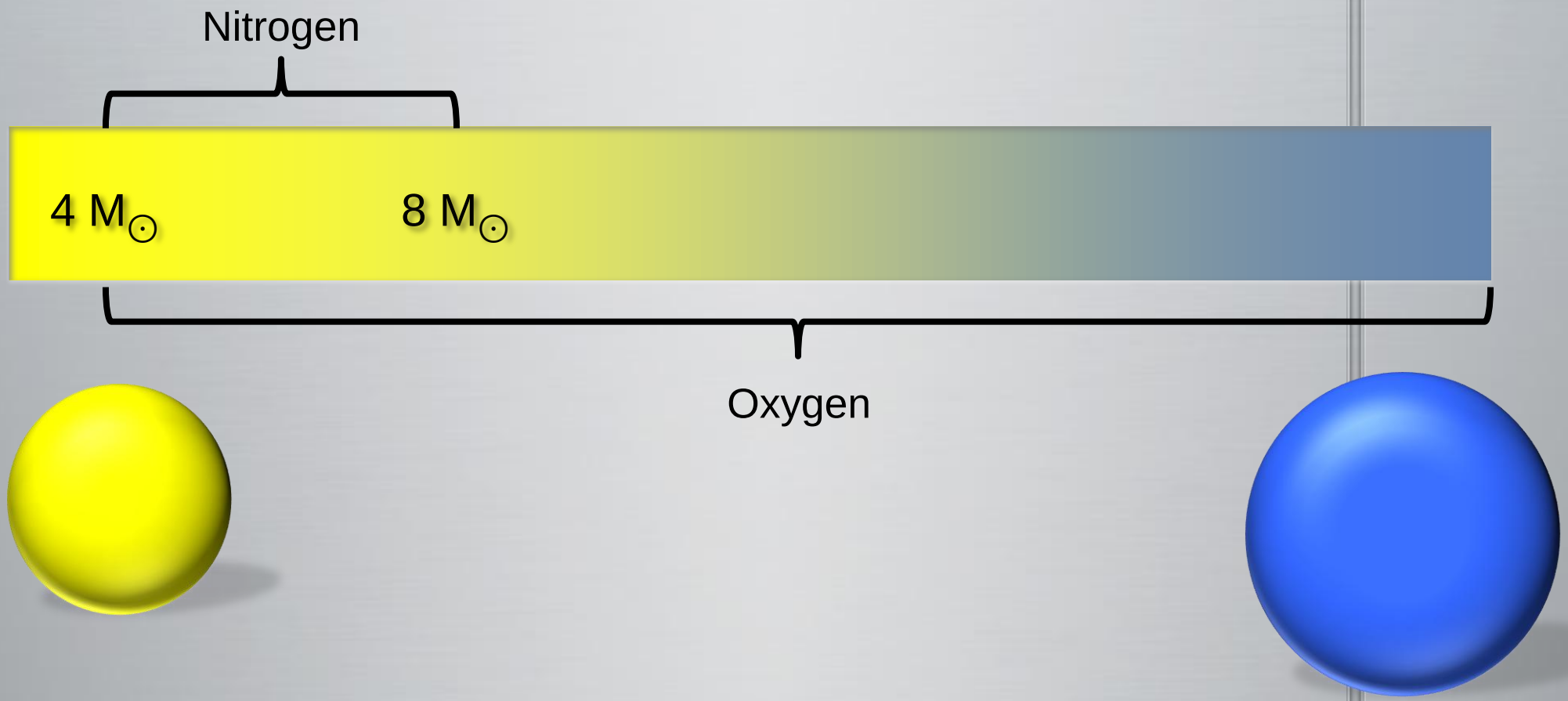
Douglass et al. (2017)



Douglass et al. (2017)

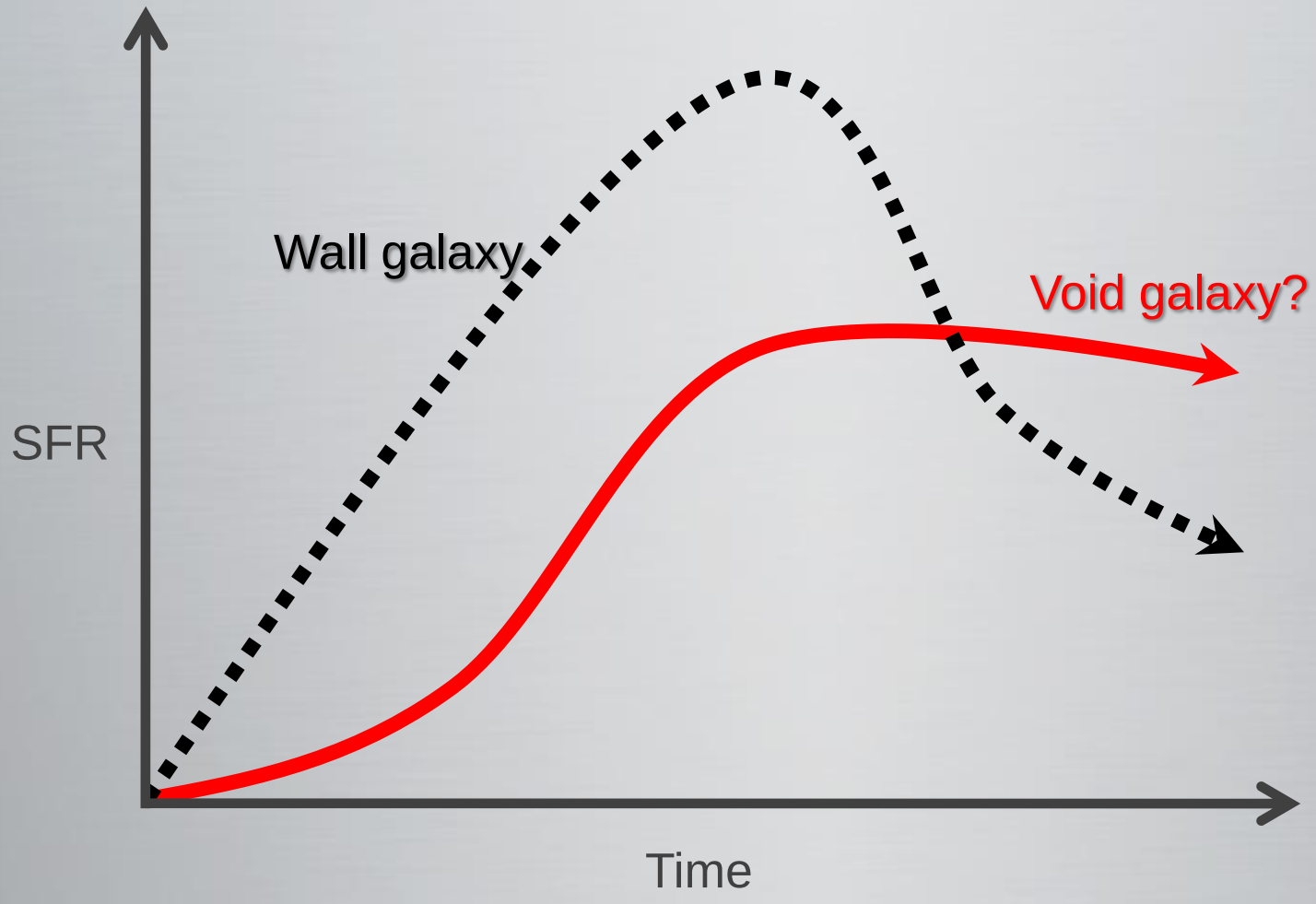
Oxygen, Nitrogen synthesis

Larger stars die first, creating a time delay between the release of oxygen and nitrogen.



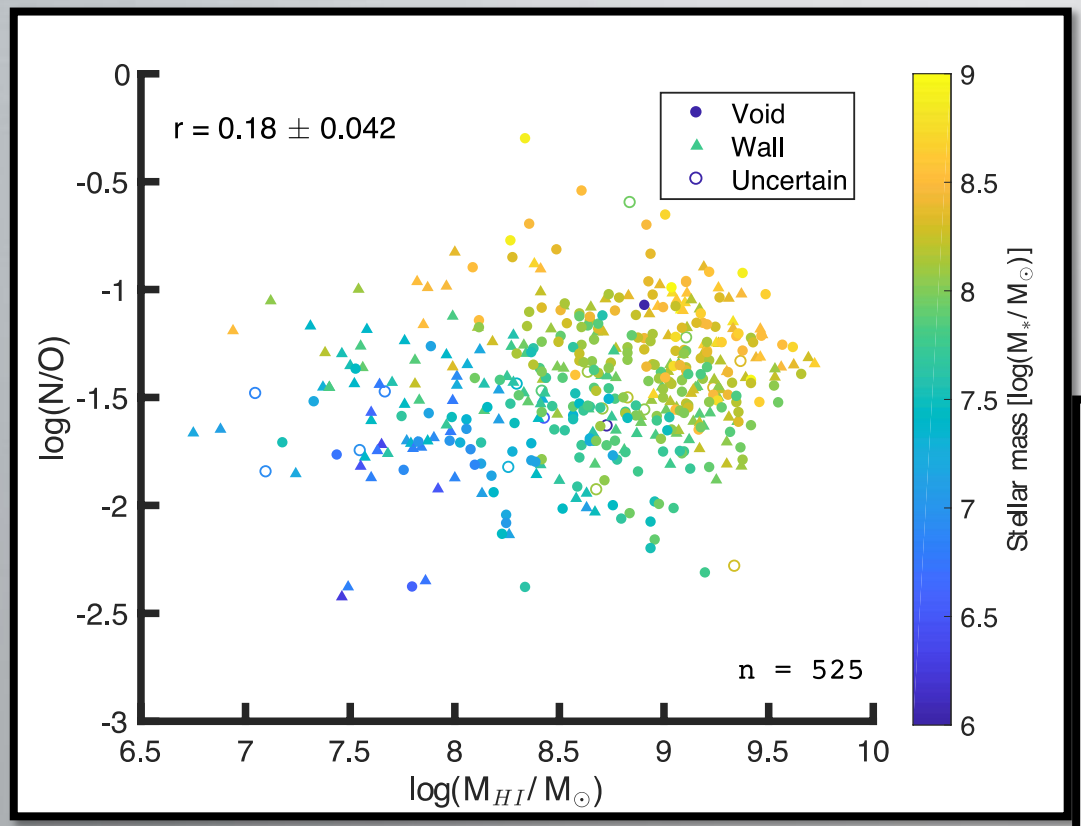
Is cosmic downsizing influenced by the environment?

Lower N/O in void dwarf galaxies might indicate a more constant SFR for void galaxies than for galaxies in more dense environments.

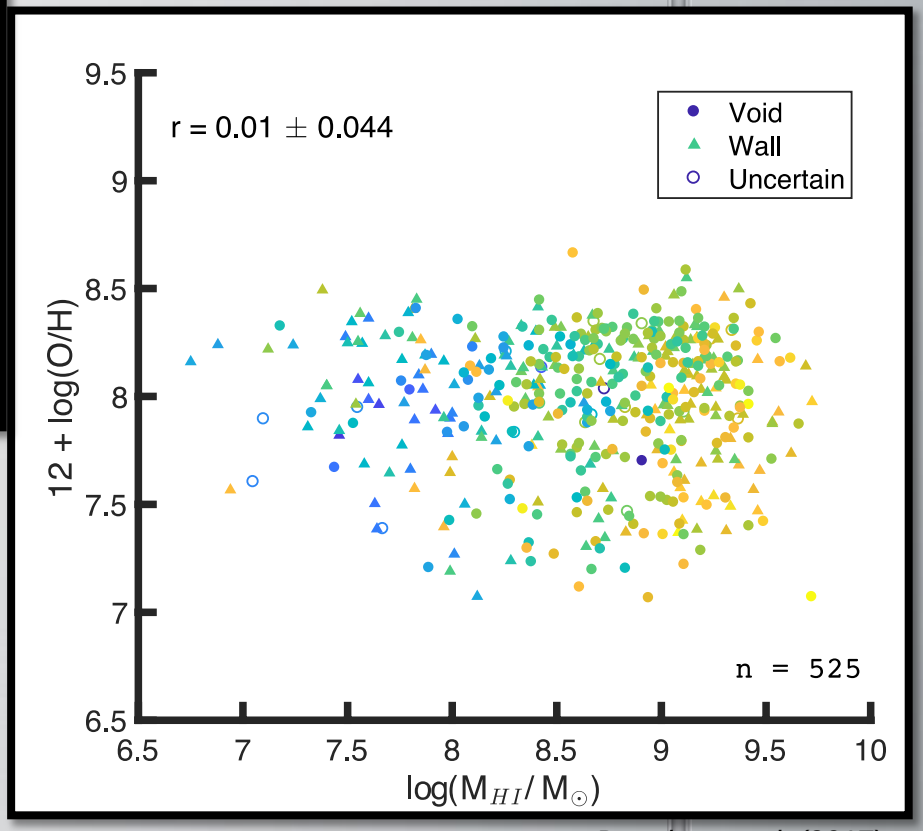


Based off the Lilly-Madau plot (Madau et al. 1996)

HI mass – abundance relationships

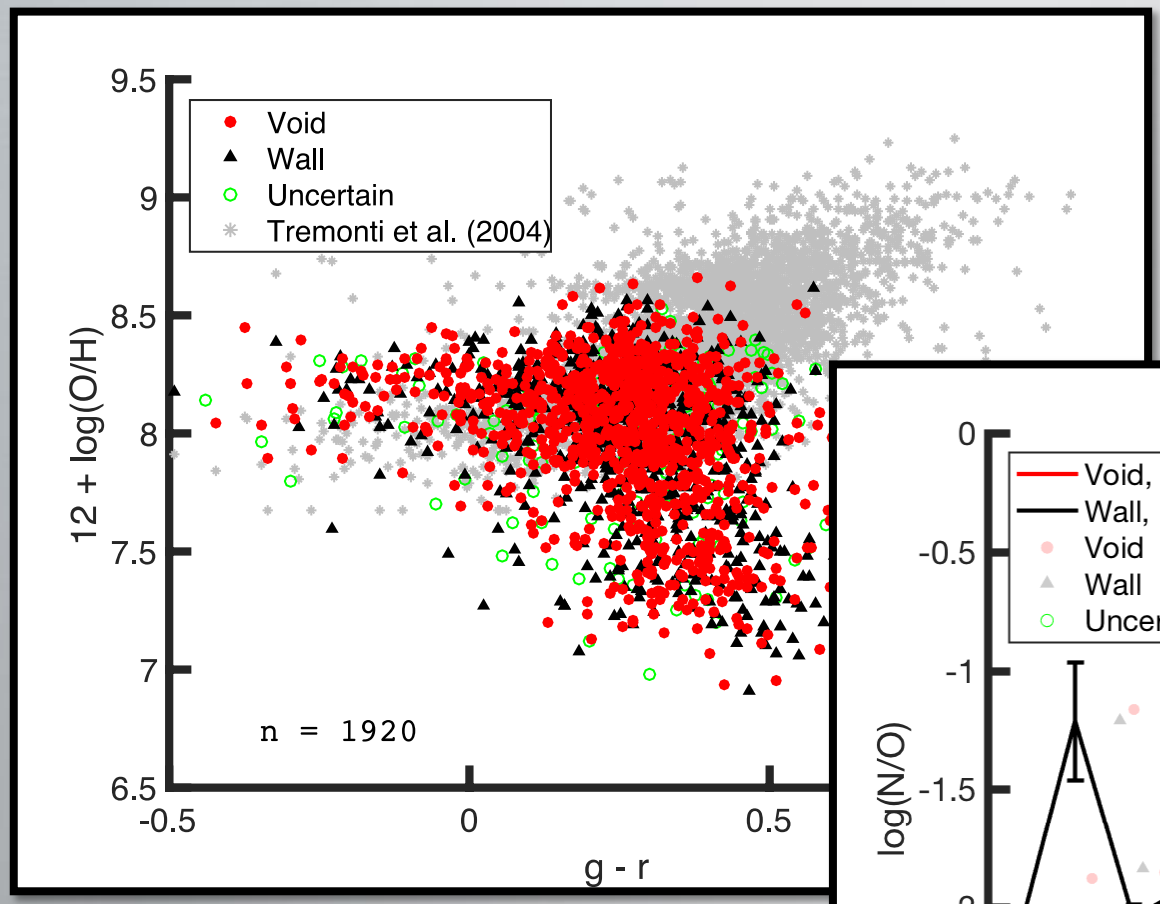


Douglass et al. (2017)

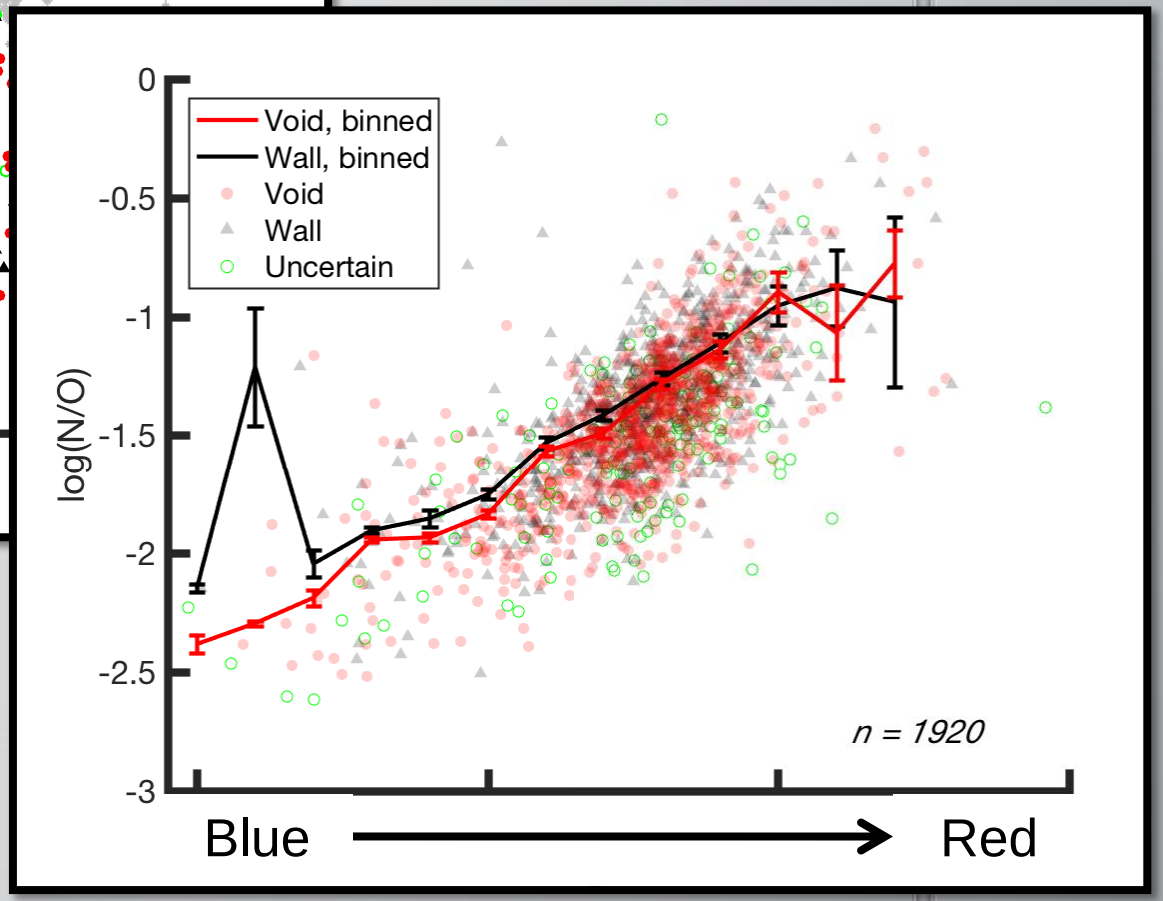


Douglass et al. (2017)

Color - abundance relations

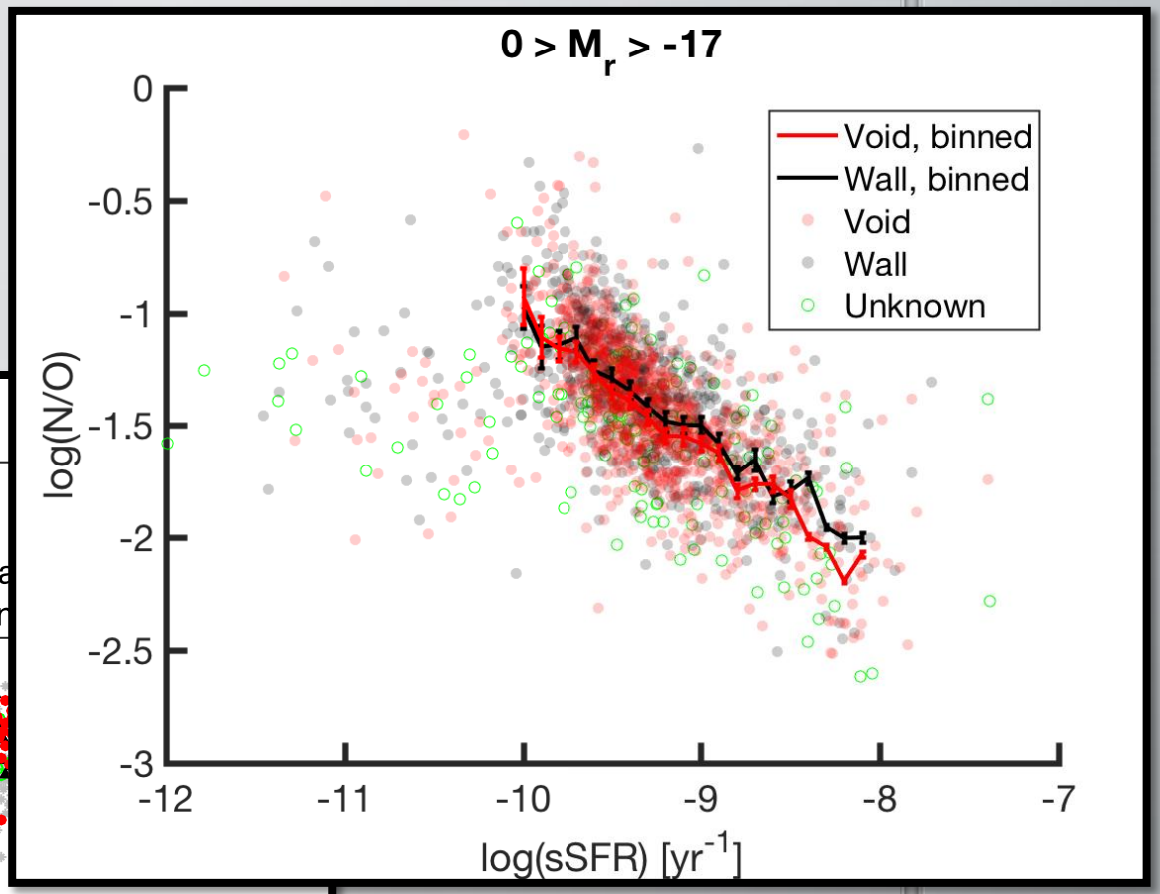


Douglass et al. (2017)

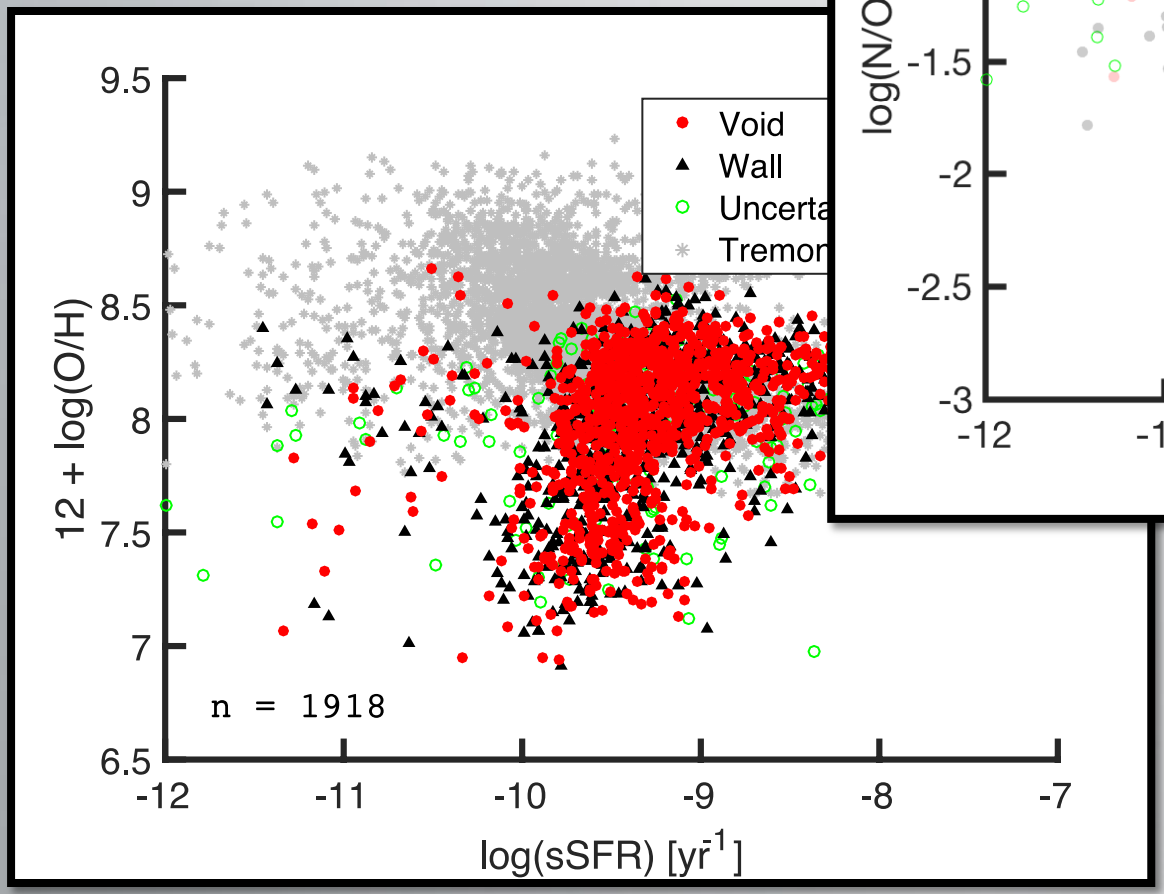


Douglass et al. (2017)

specific Star Formation Rate (sSFR) – abundance relations

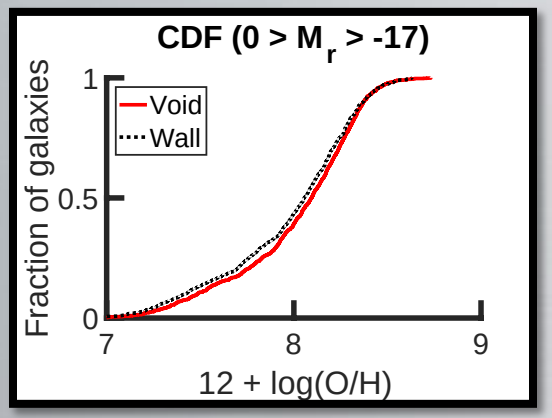


Douglass et al. (2017)

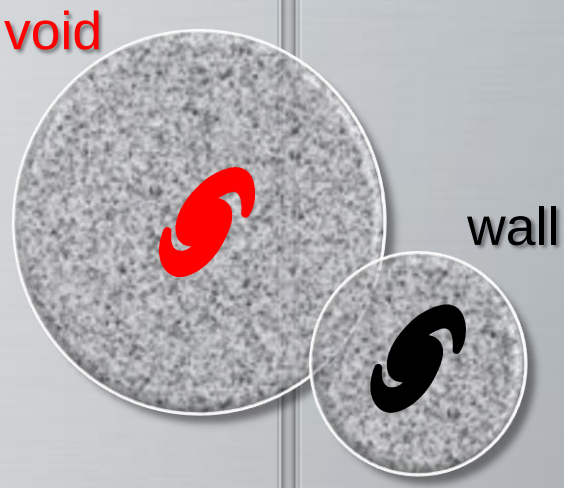


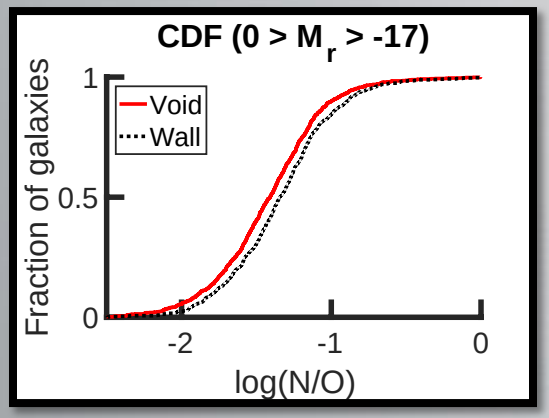
Douglass et al. (2017)

Large-scale environmental influence on dwarf galaxy evolution

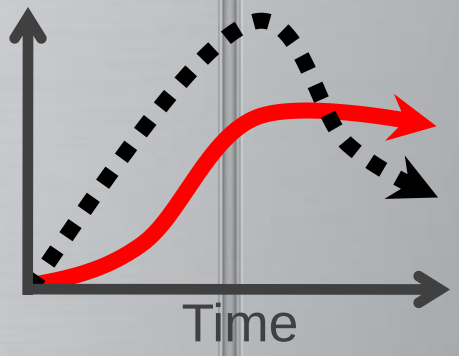


- Void dwarf galaxies have higher O/H values than dwarf galaxies in more dense regions → larger $M_{DM\ halo}/M_*$ ratios in void galaxies?





- Void dwarf galaxies have lower N/O ratios than dwarf galaxies in more dense regions → observational evidence of environmentally dependent cosmic downsizing?



Thank you!

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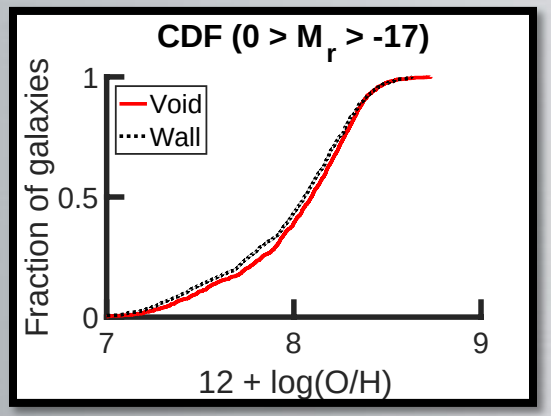
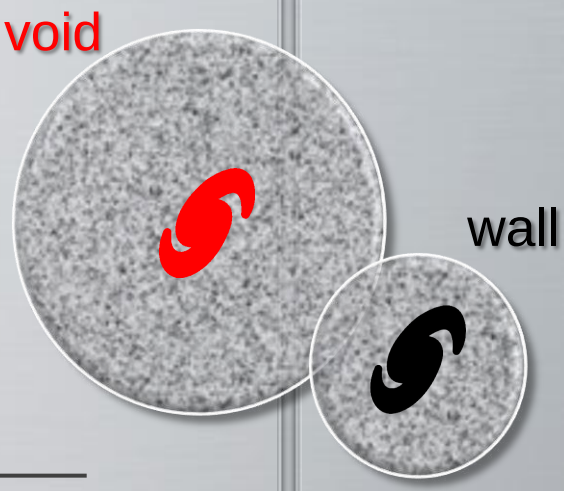
- Undergraduates: Brean Prefontaine, Salvatore Zerbo, Jinfu Dai, Daniele Schneider

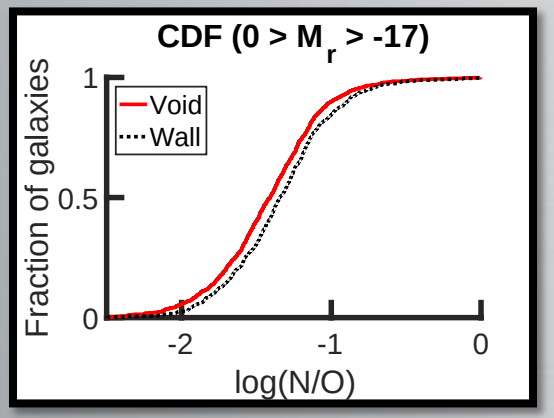
Funding provided by NSF grant AST-1410525

Large-scale environmental influence on dwarf galaxy evolution

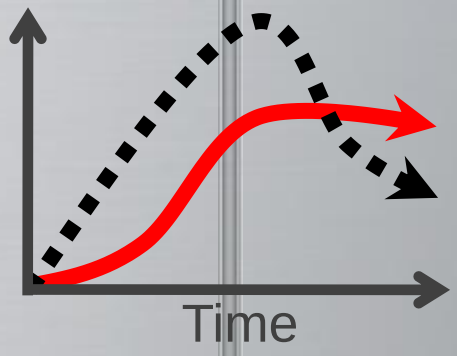


- Void dwarf galaxies have higher O/H values than dwarf galaxies in more dense regions → larger $M_{DM\ halo}/M_*$ ratios in void galaxies?





- Void dwarf galaxies have lower N/O ratios than dwarf galaxies in more dense regions → observational evidence of environmentally dependent cosmic downsizing?



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