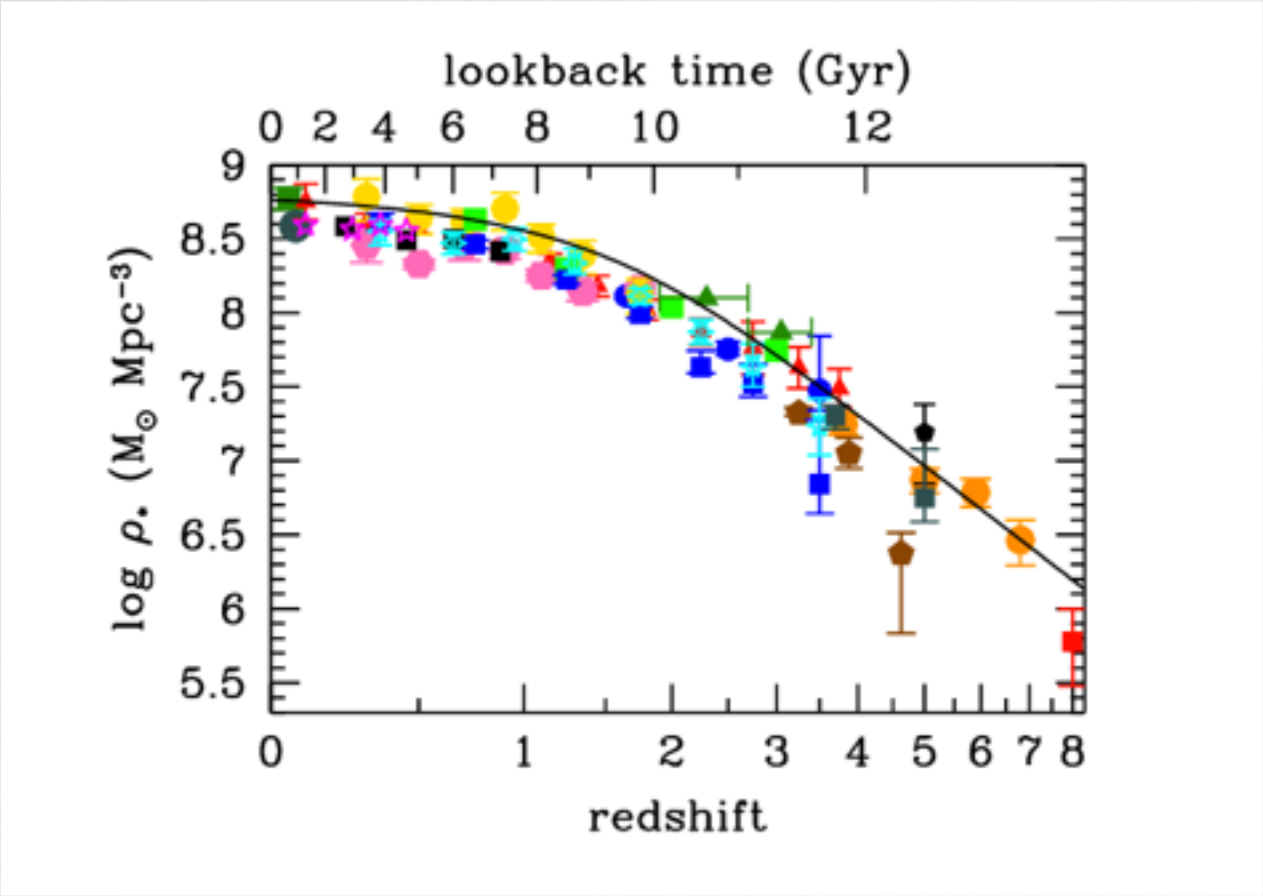
The metallicity evolution of galaxies

New science in the era of large area grism surveys

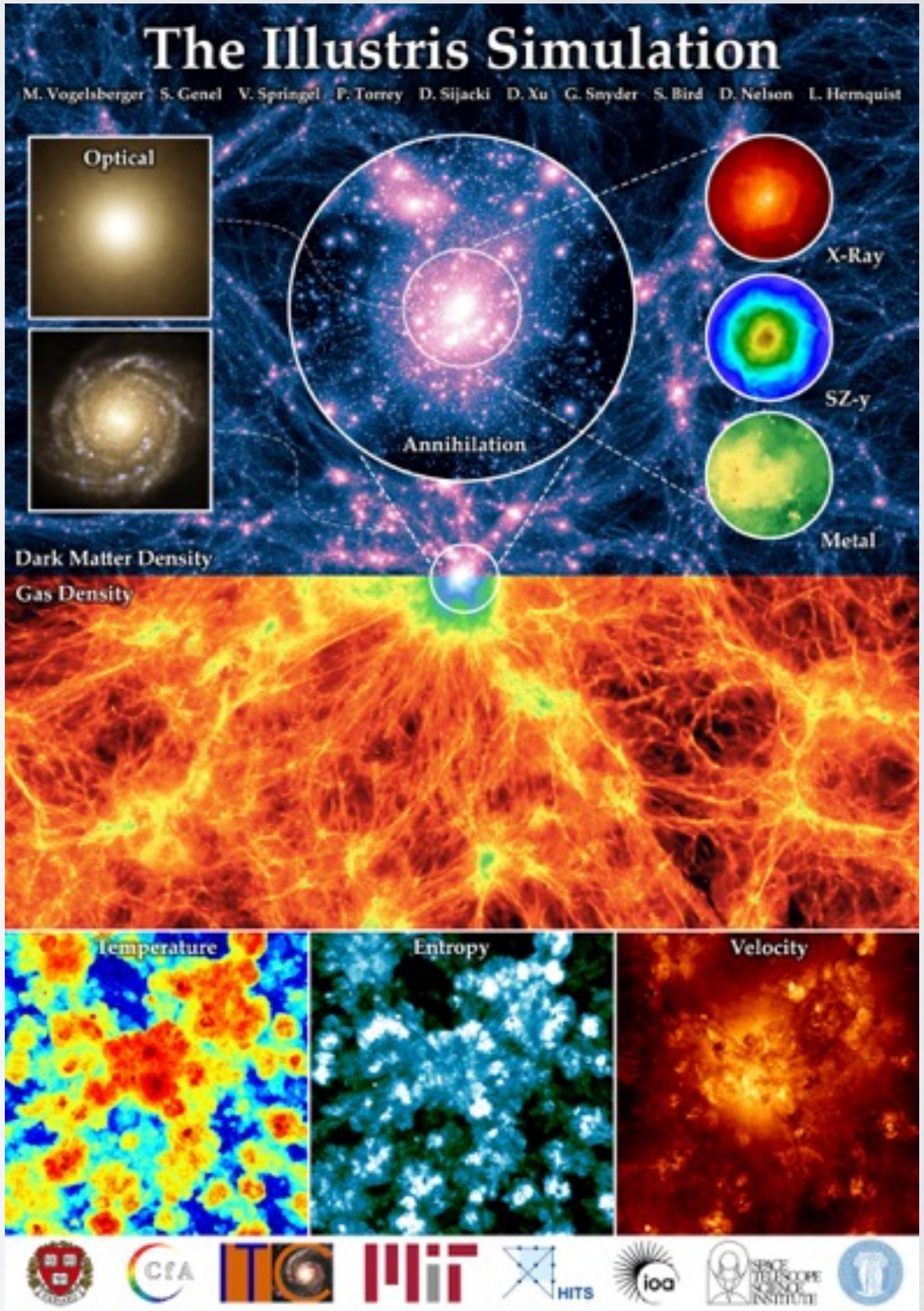
Alaina Henry
NASA Goddard Space Flight Center

While we are building consensus on the growth of stars in galaxies, do we really understand why and how?

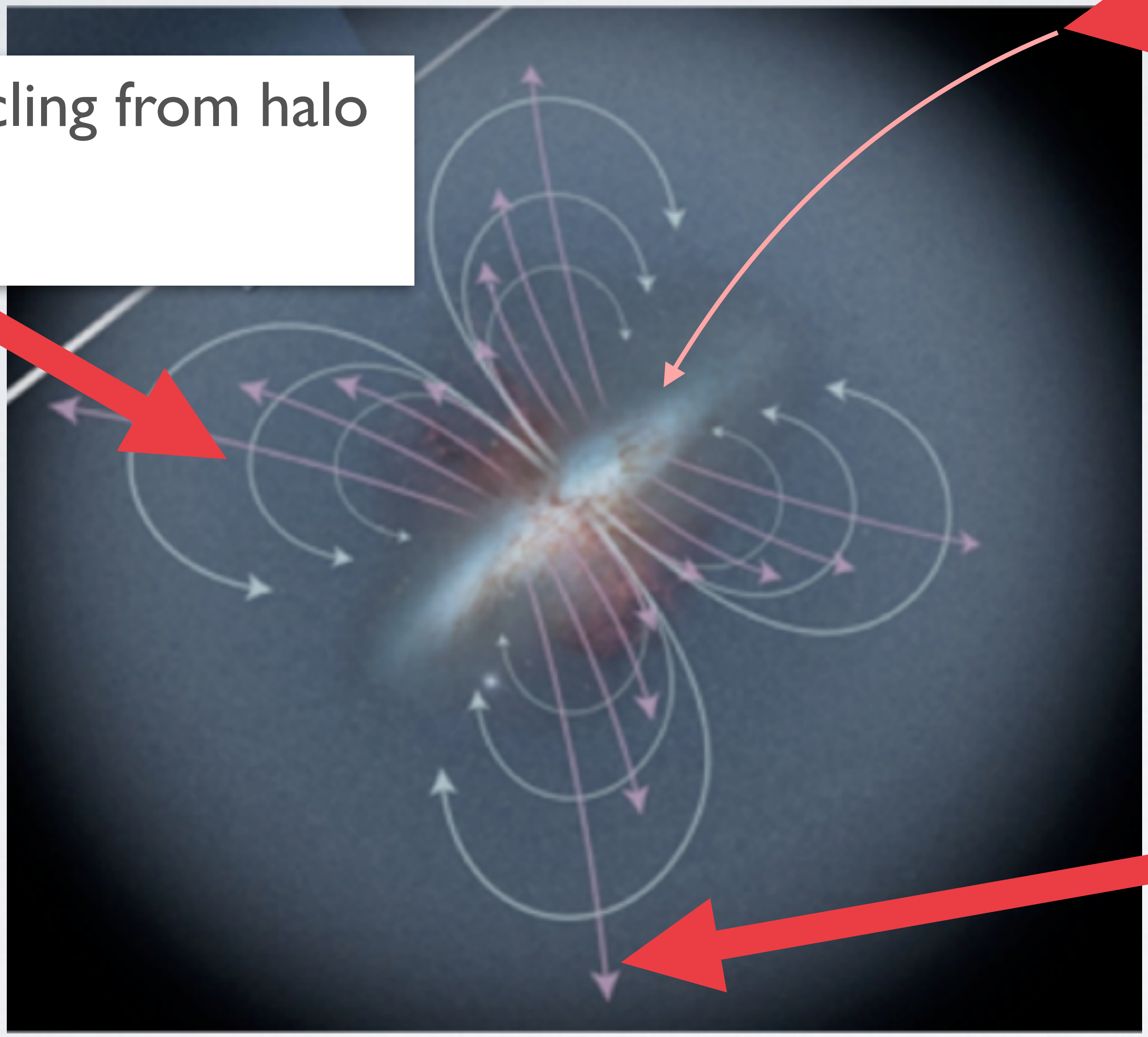


Madau & Dickinson (2014)

Feedback is required but highly uncertain. Constraints from many different feedback-sensitive observations are necessary.



How do metals tell us about feedback and the baryon cycle?



- gas recycling from halo

- pristine gas inflows:
  - fuel star-formation (creates metals)
  - dilute existing metallicity

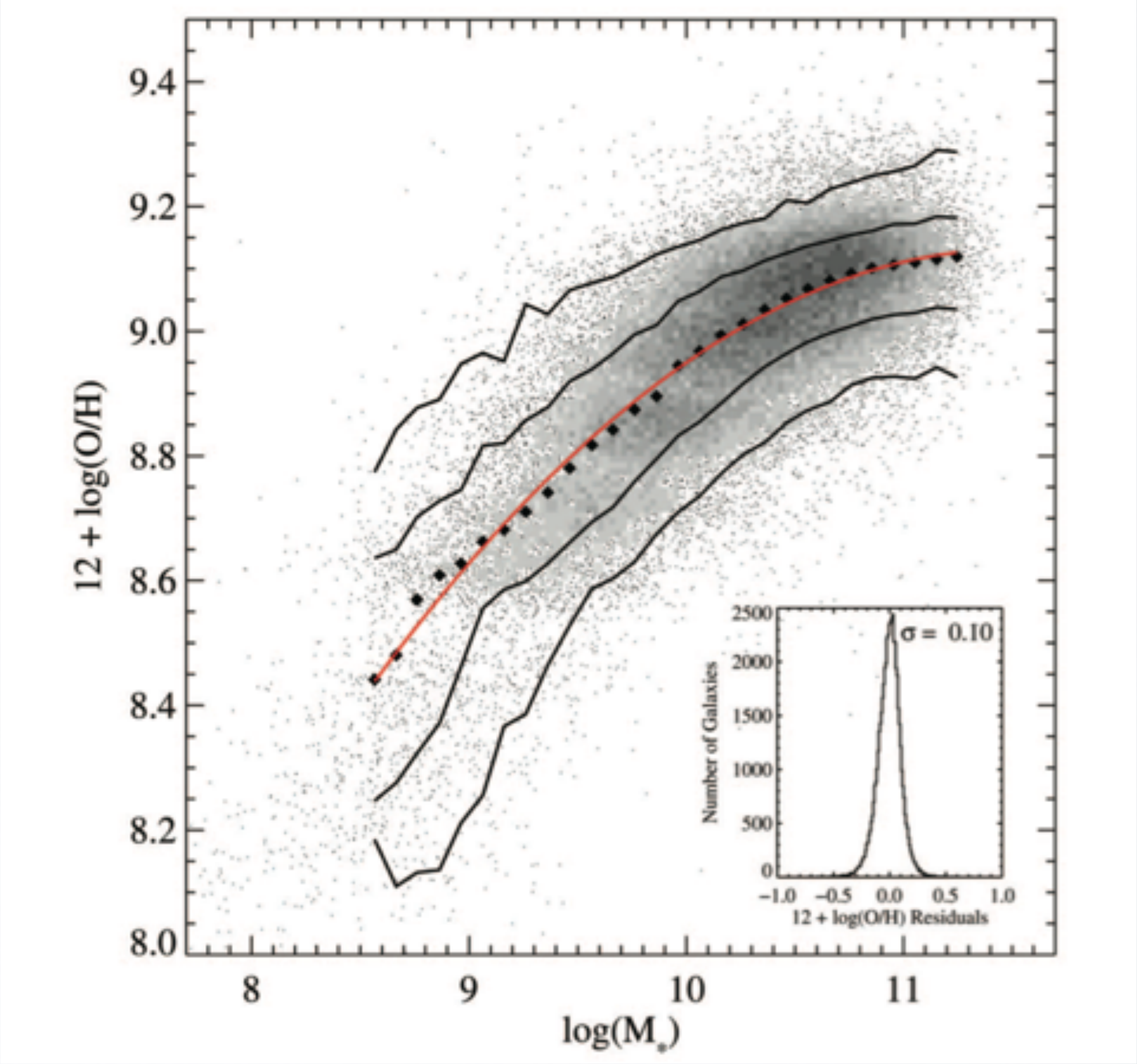
- outflows:
  - slows star-formation (feedback)
  - removes gas that may be preferentially enriched (relative to average ISM)

credit: NASA/STScI/Ann Feild

All of these processes depend on mass (gravity), and evolution with redshift is expected.

The mass-metallicity relation

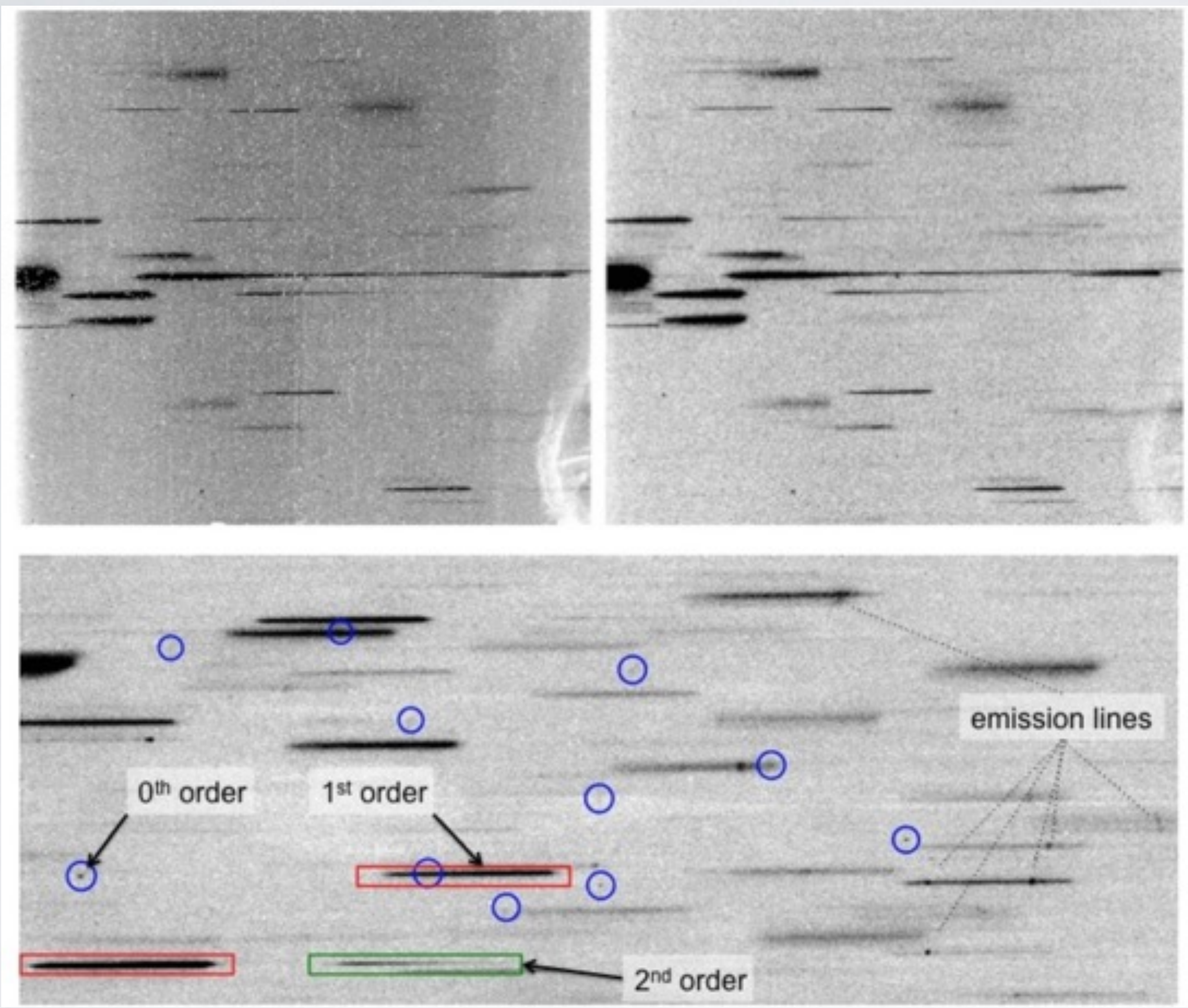
- Locally, mass and metallicity correlate tightly.
  - Settled with oxygen abundance measurements from ~50,000 galaxies in the SDSS
  - Although a correlation could be predicted from the closed box model —$Z(t) = - y \ln (M_{gas} / M_{gas} + M_{stars})$— the slope is incorrect.
  - Outflows are the favored explanation



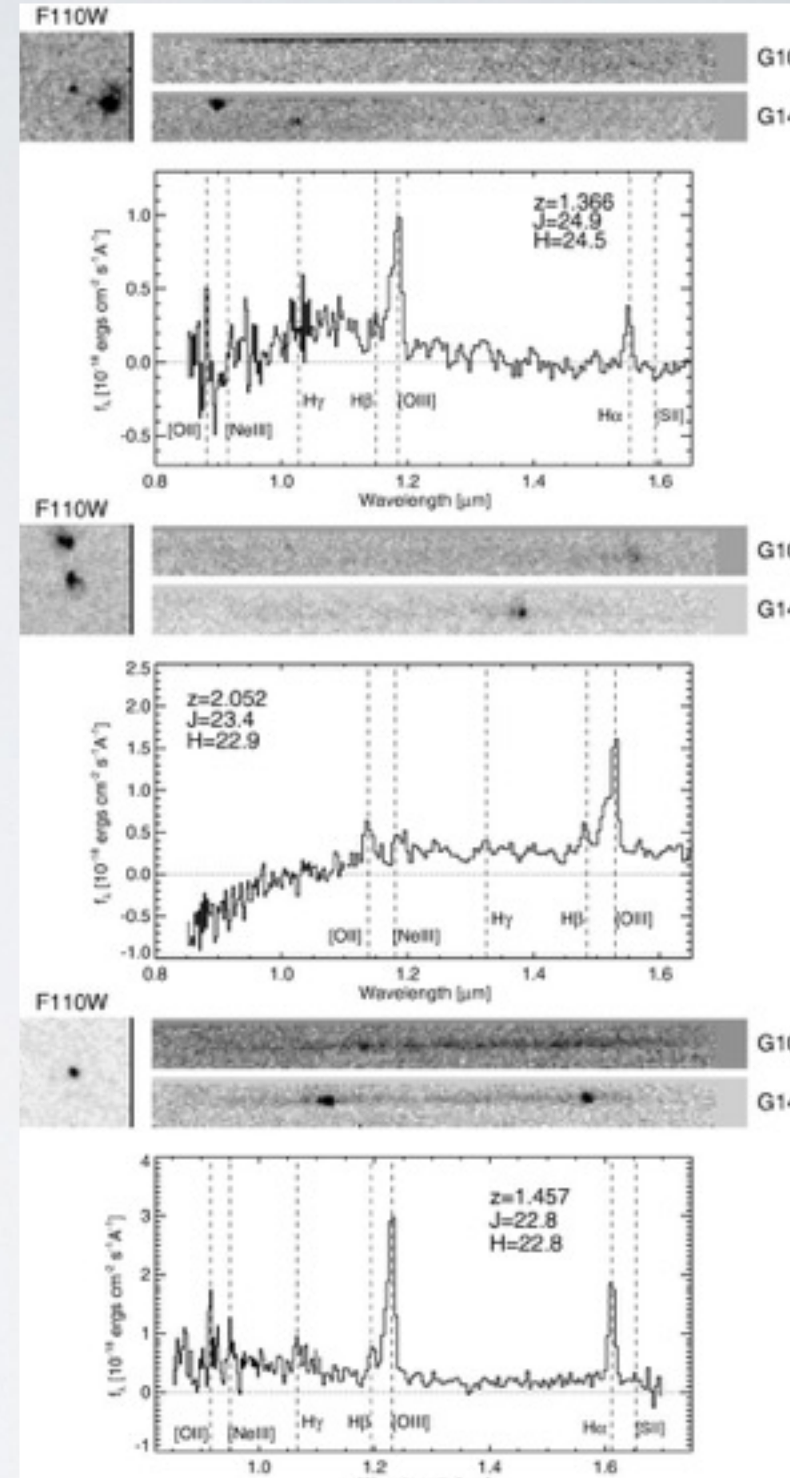
Tremonti et al. (2004)

of course, we want to measure evolution. IR spectroscopy required.

Slitless spectroscopy with the *Hubble Space Telescope*

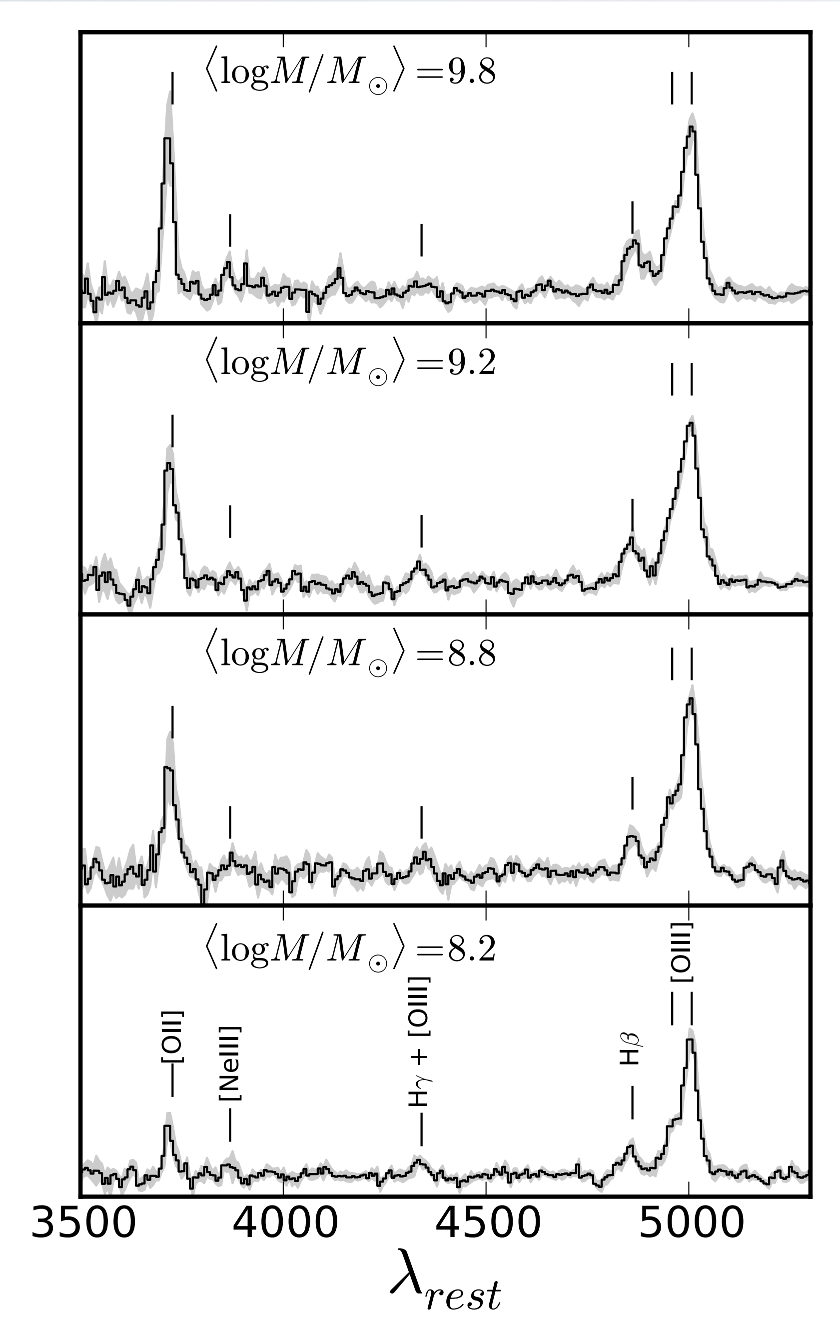


Atek et al. (2010)



Combining two grisms (G102+G141) cover metallicity sensitive lines from $1.3 < z < 2.3$.

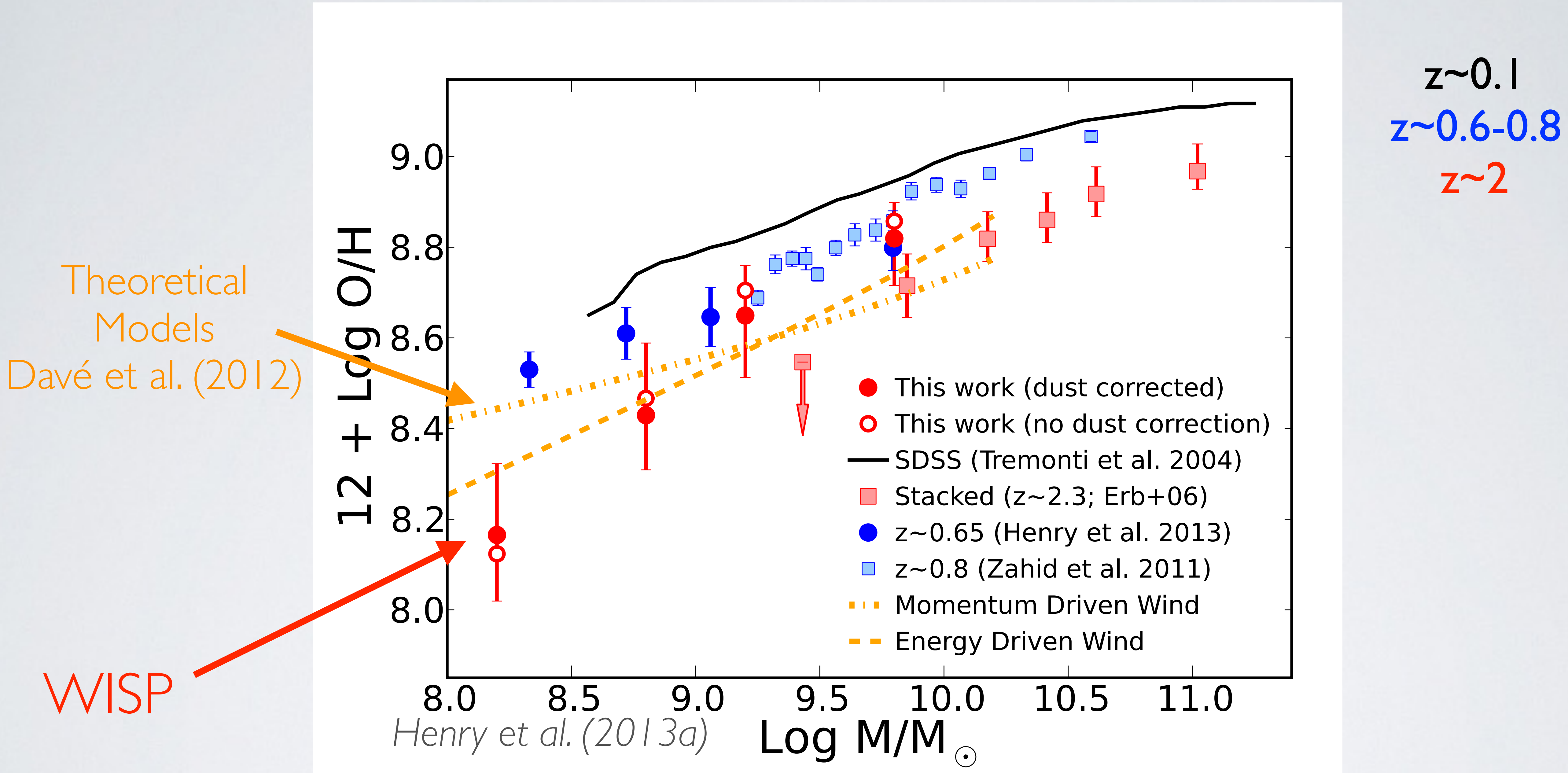
Measuring metallicity with the HST WISP Survey



Henry et al. (2013a)

- First result from 29 fields + Hubble Ultra Deep Field
- No requirement that Hβ be detected in individual spectra
- We found 83 galaxies
  - The best solution was stacking— averaging spectra together to get better signal-to-noise
  - low-mass stack is 1.5 dex lower mass than most ground-based spectroscopic surveys.

The WISP mass-metallicity relation



Lower mass cutoff is 1.5 dex below previous work!

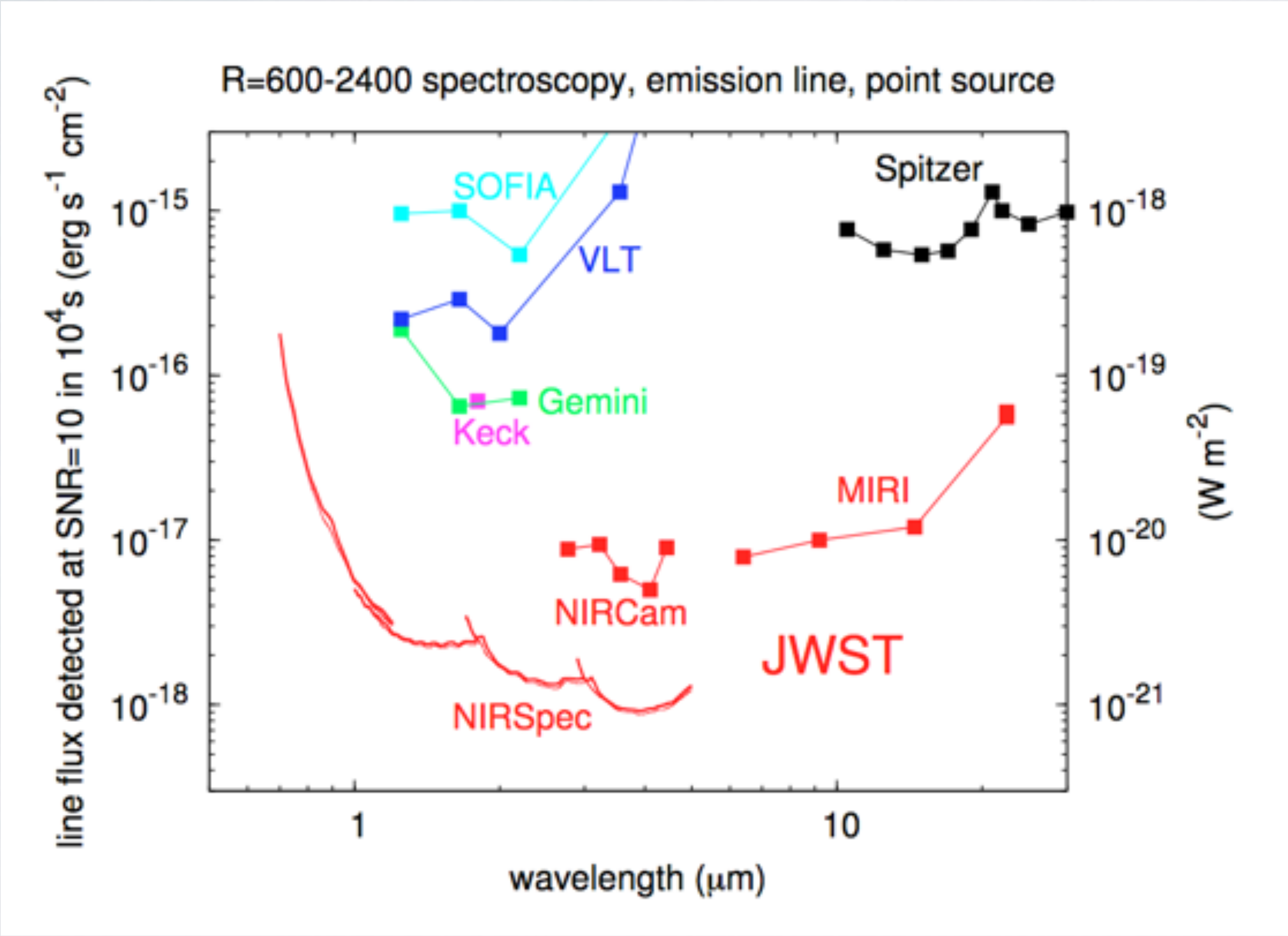
Evolution about 0.3 dex from z~1.8 to z~0.1

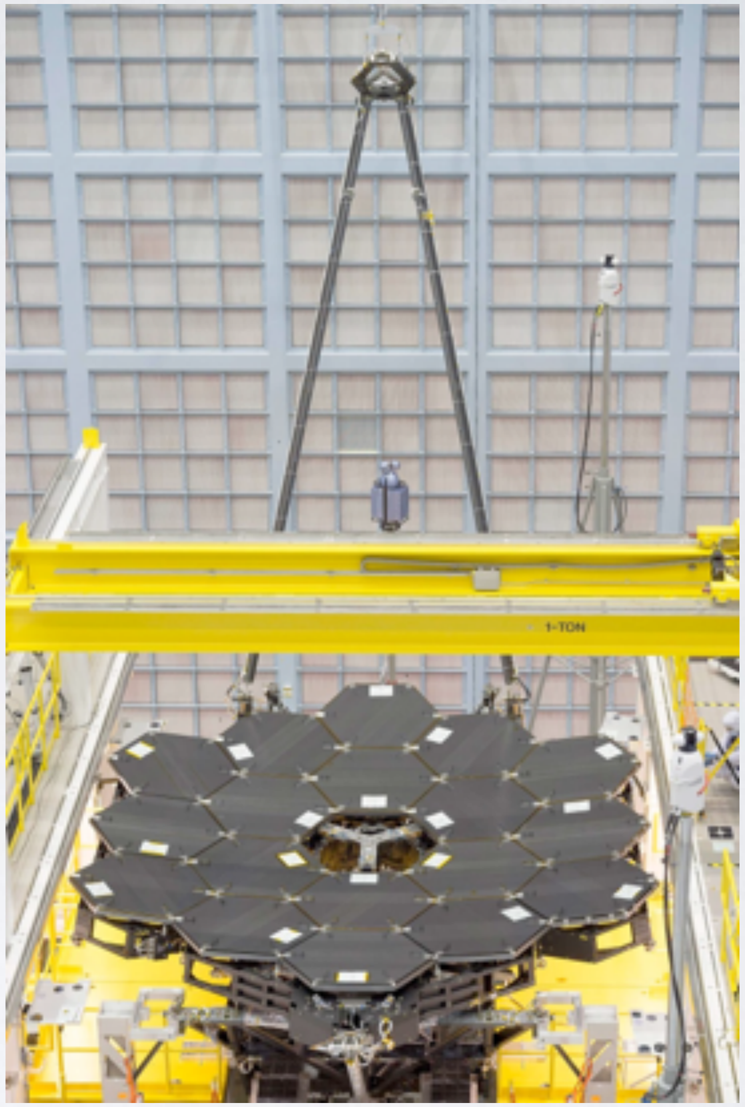
WISP is just the beginning!

- The Grism Lens-Amplified Survey from Space (GLASS; PI Treu) targets 10 strong lensing clusters; luminosities ~10x deeper than WISP.

- Will extend the mass-metallicity relation to ~10^7 M_{sun}.

And JWST….





JWST in the clean room at Goddard; all mirrors attached! 2/2016

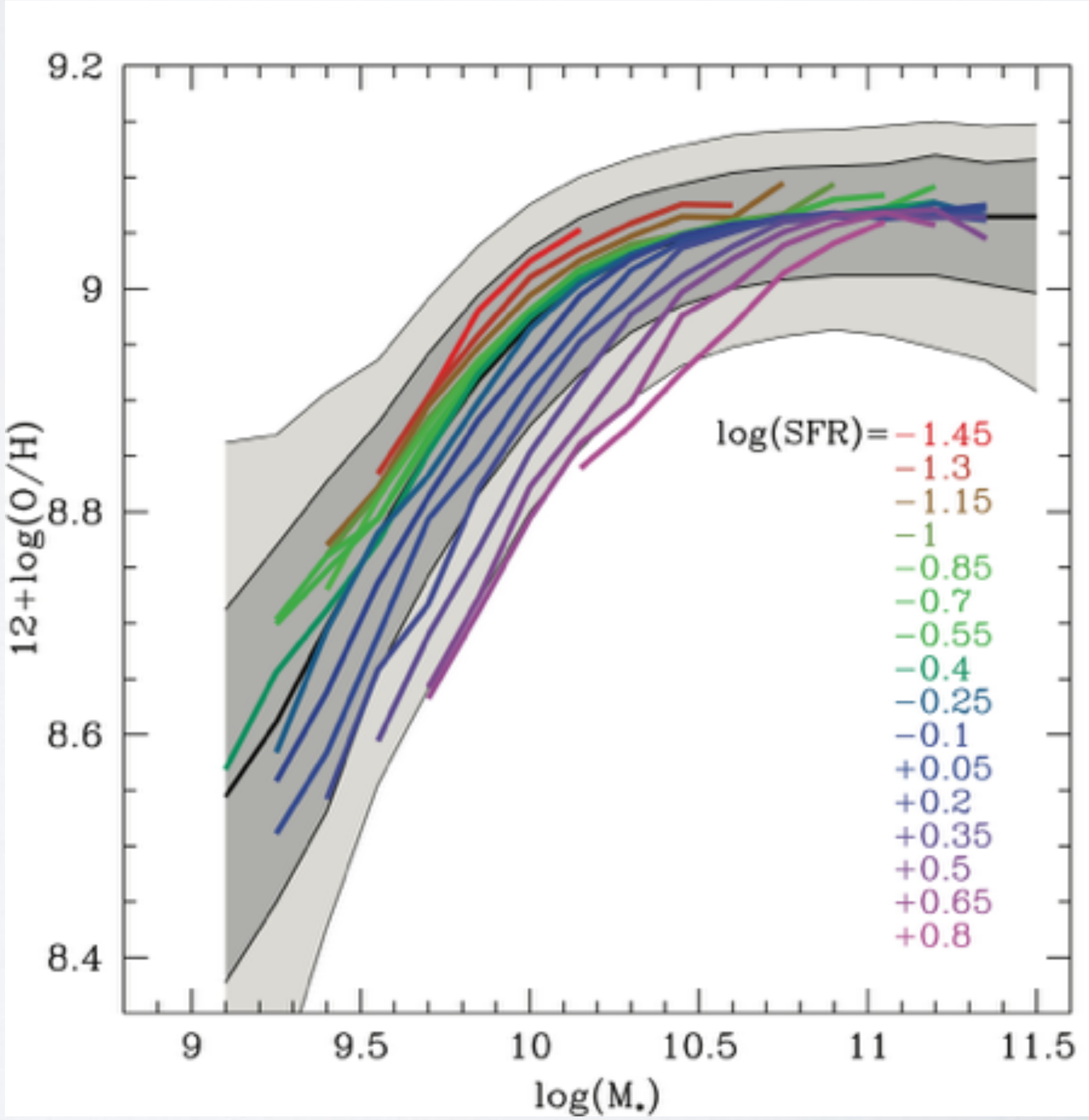
NIRSPEC multi-object spectroscopy
lower backgrounds (from slits), larger telescope
longer wavelength coverage than possible from ground
== metals at earlier cosmic times

So what does WFIRST provide for metallicity science?

What does a wide-area grism survey provide?

statistics = characterization of intrinsic scatter

- SFR scatter found in SDSS
  - evidence for stochastic, accretion driven SF.

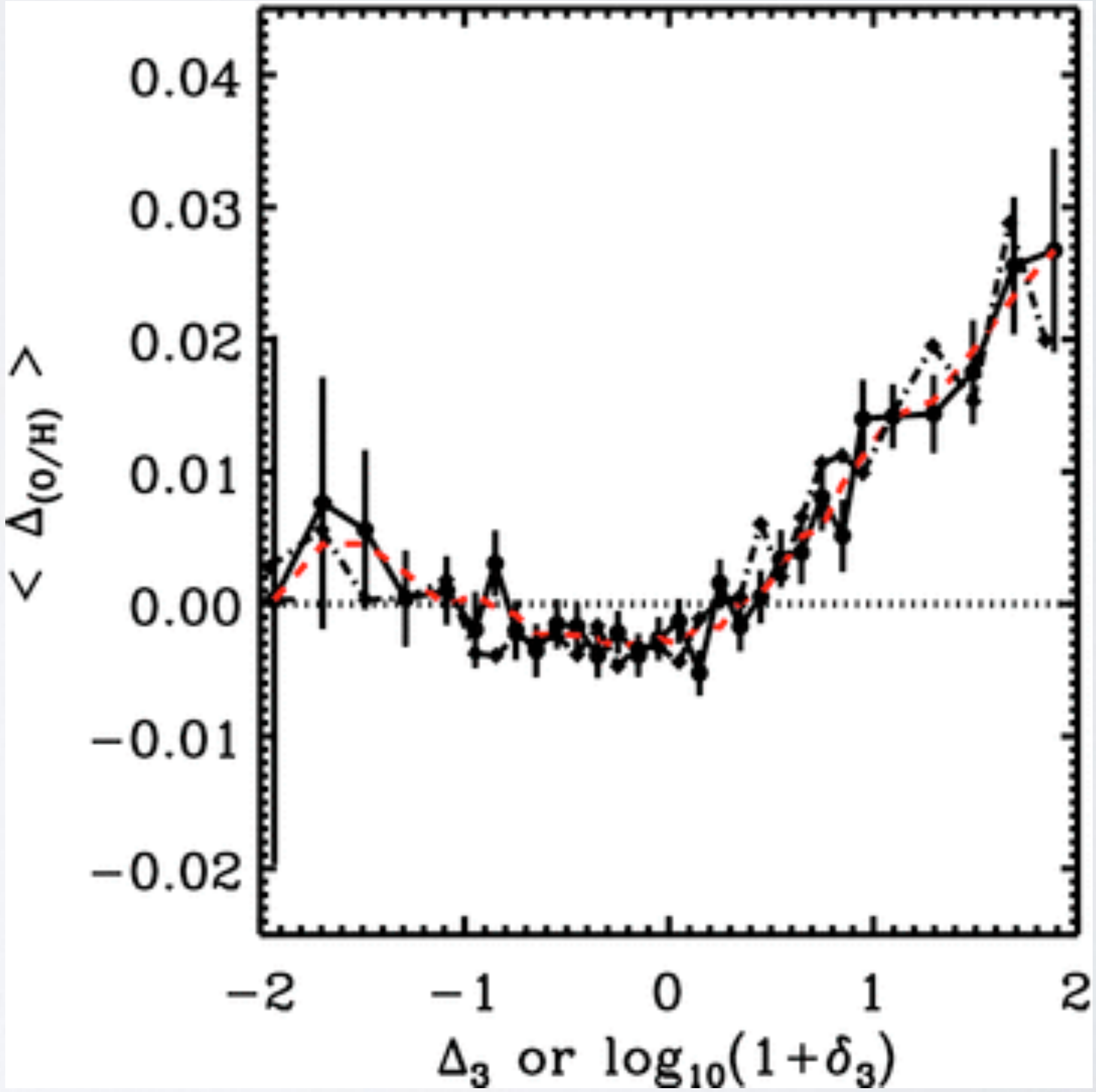


Mannucci et al. (2010)

What does a wide-area grism survey provide?

statistics = characterization of intrinsic scatter

- Environmental scatter also found in SDSS
  - denser regions are more evolved, more metal enriched



Cooper et al. (2008)

What does a wide-area grism survey provide?

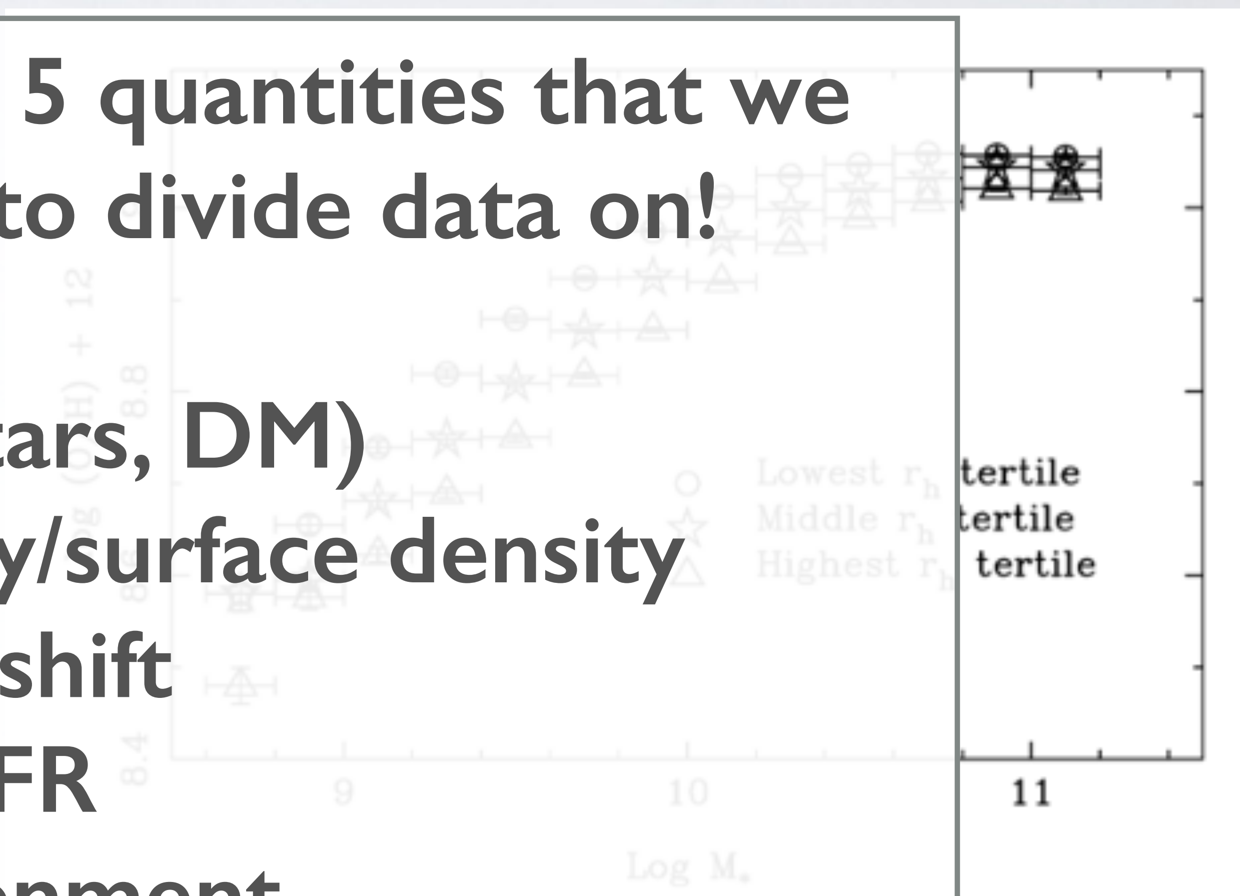
statistics = characterization of intrinsic scatter

- size scatter also found in SDSS
  - large galaxies have lower metallicity in SDSS
  - or is it surface density?

$$\left\langle \frac{\dot{M}_{\rm wind}}{\dot{M}_*} \right\rangle_R \approx 10\eta_1 \left(\frac{V_c(R)}{100\,{\rm km\,s^{-1}}}\right)^{-(1+\eta_2)} \left(\frac{\Sigma_{\rm gas}(R)}{10 M_\odot\,{\rm pc}^{-2}}\right)^{-(0.5+\eta_3)}$$

where η_1, η_2, η_3 incorporate the uncertainty from the fits ($\eta_1 \sim 0.7 - 1.5$, $\eta_2 \sim \pm 0.3$, $\eta_3 \sim \pm 0.15$). A comparison between this fit and the simulation results is shown in Fig. 8.

Hopkins et al. (2012)



Ellison et al. (2008)

There are (at least) 5 quantities that we want to be able to divide data on!

mass (stars, DM)
size/morphology/surface density
redshift
SFR
environment

What do we need to measure metallicity with WFIRST?

the trade space on line diagnostics (the main contenders)

- Option 1: [NII]/Hα

  + close in wavelength, usable over z~1-2

  + needed for the BPT diagram

  — need higher dispersion (current = 11A/pix)

- Option 2: R23 = ([OIII] + [OII])/Hβ

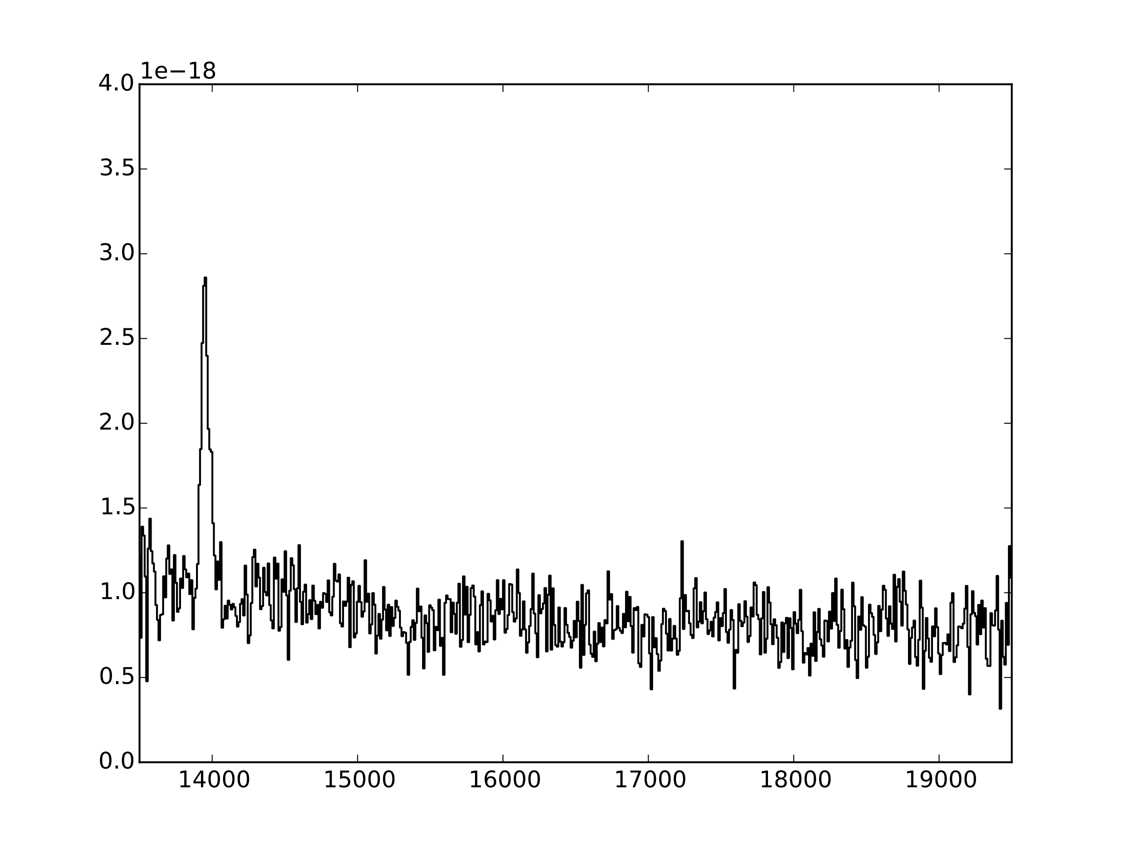
  + getting O/H doesn't depend on N/O ratios

  — double valued? but average on upper branch?

  — needs broader wavelength coverage than 1.35 to 1.95 um:

  - no [OII] to Hα
  - [OII] to [OIII] for only 2.7 < z < 2.9

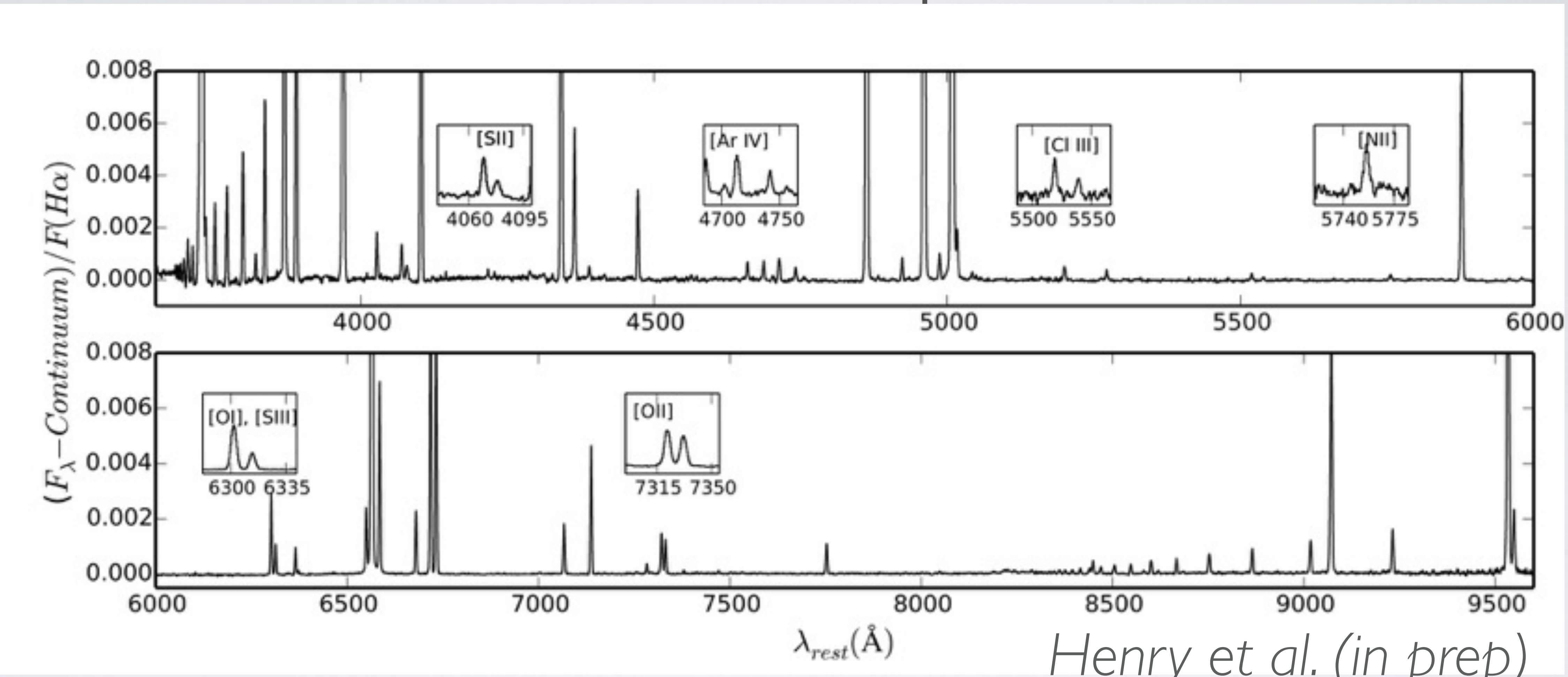
  — or ground-based spectroscopy (e.g DESI? PFS?)



simulated WFIRST spectrum (J. Colbert)
Hα + [NII] ~10^{-16} erg s^{-1} cm^{-2}
[NII]/Hα = 0.29

metallicity diagnostic issues will have to be addressed as well…

Addressing diagnostic issue by stacking ~500 SDSS/BOSS spectra.



Henry et al. (in prep)

Stacking SDSS/BOSS spectra of Green-Pea-like galaxies brings us into an entirely different diagnostic regime (think, HII region spectroscopy!):

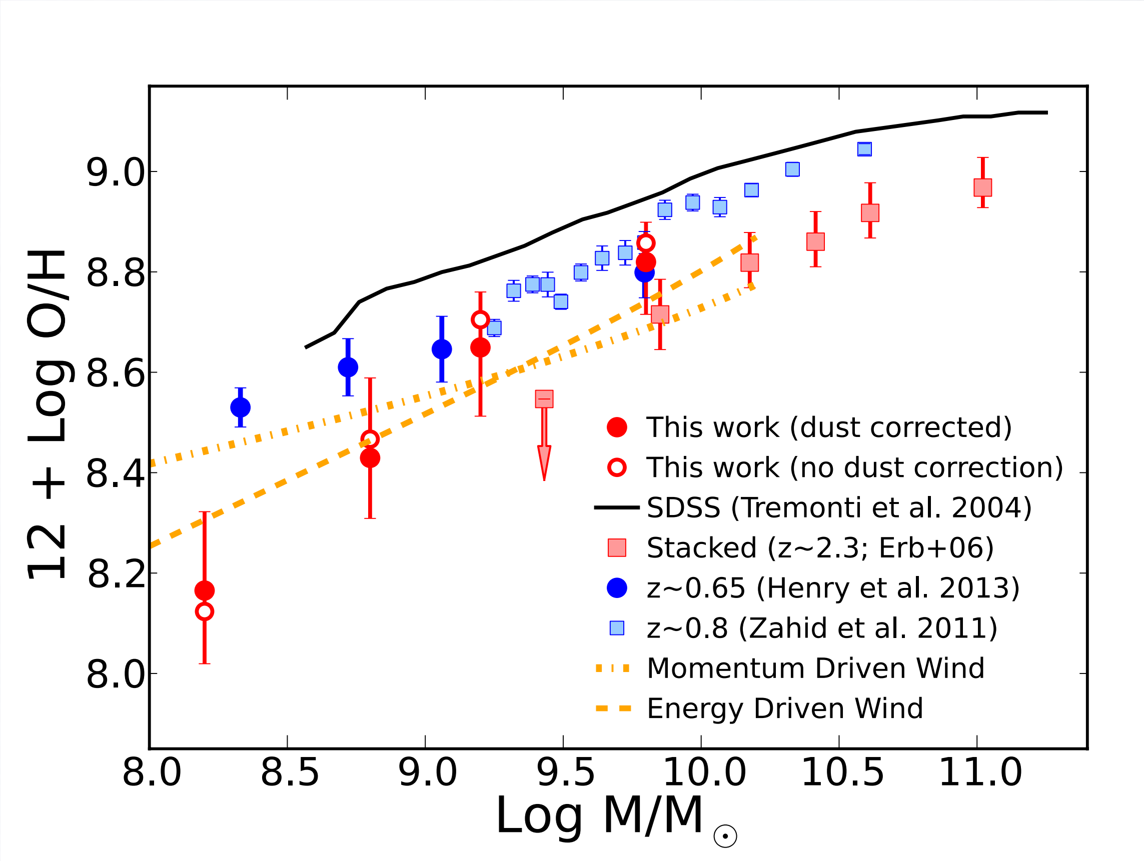
- multiple electron temperature/metallicity diagnostics!
- nebular He II 4686—counting the hard ionizing photons
- density diagnostics from more highly ionized zones ([Cl III], [Ar IV])
- stacked subsets by BPT diagram location will test whether N/O or something else causes offset

Conclusions

- **Gas-phase metallicities are key to understanding the baryon cycle- the inflows that feed galaxies and outflows that slow star-formation**

- Sensitive, multi-object IR spectroscopy is now opening up redshift evolution by accessing diagnostics.

- **WFIRST will unlock the scatter** in the mass-metallicity relation, e.g.
  - size/morphology/surface density
  - SFR
  - environment, halo mass
  - redshift evolution



- Our measurement of **the WISP mass-metallicity relation (Henry et a. 2013) is paving the way** for the future with Hubble, JWST, WFIRST, and more…