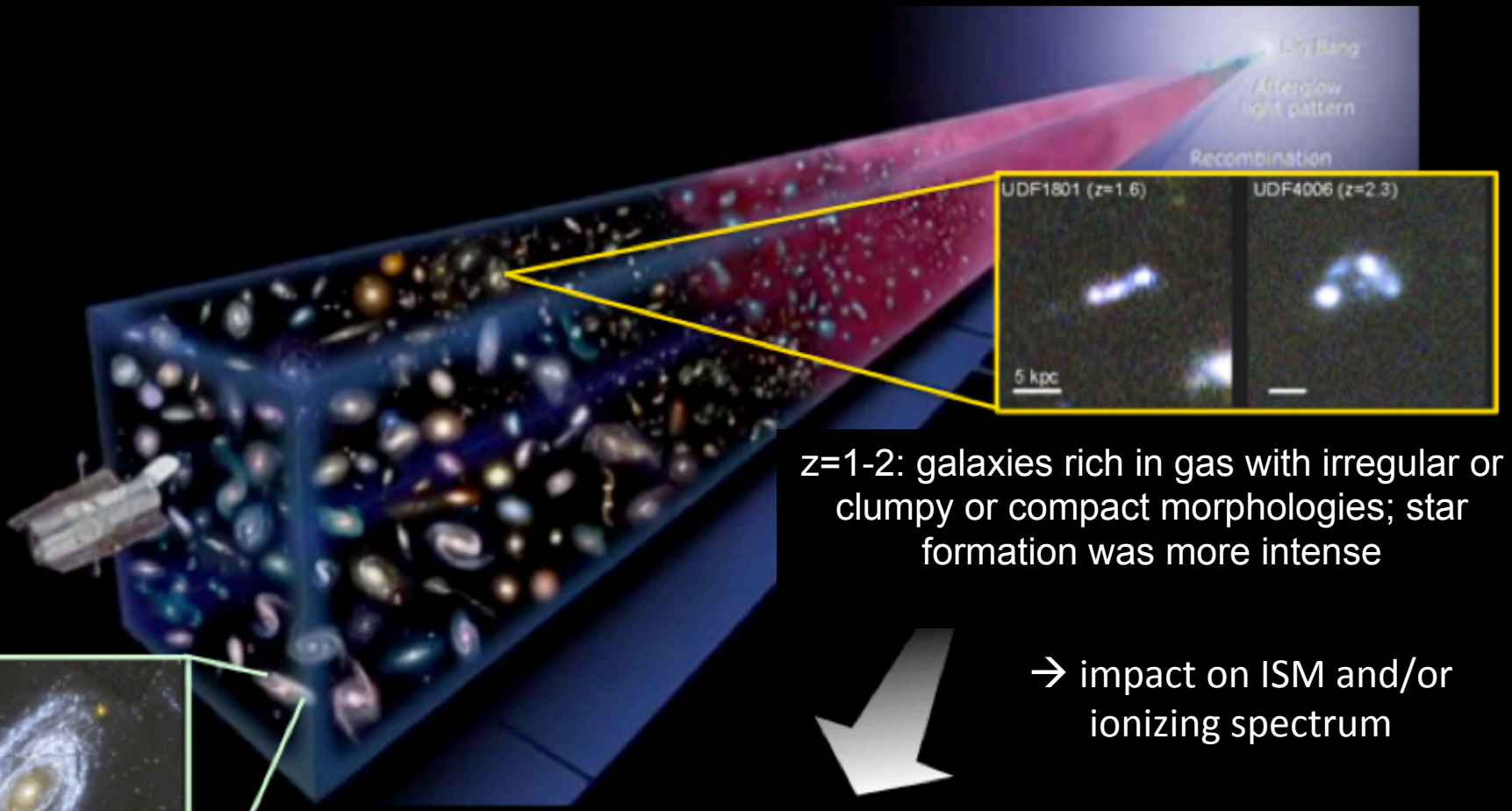
# Evolving Nebular Emission in Galaxies across Cosmic Time

**Stéphanie Juneau**
CEA-Saclay
@StephaJuneau

**FMOS-COSMOS**: J. Silverman, D. Sanders, N. Arimoto, E. Daddi, A. Renzini, J. Kartaltepe, D. Kashiro, H.J. Zahid, L. Kewley, G. Rodighiero, S. Lilly, +

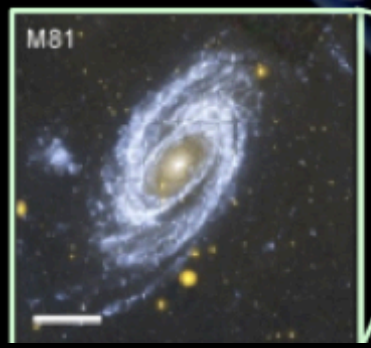
# Evolution of Galaxies




(Image credit: NASA/ESA/A.Feild (STScI)

z=1-2: galaxies rich in gas with irregular or clumpy or compact morphologies; star formation was more intense

→ impact on ISM and/or ionizing spectrum




**z≈0** (current epoch): galaxies are poor in gas and have regular shapes/morphologies (spiral arms, elliptical, etc.)
→ can only grow stars and black holes at *much lower rates*

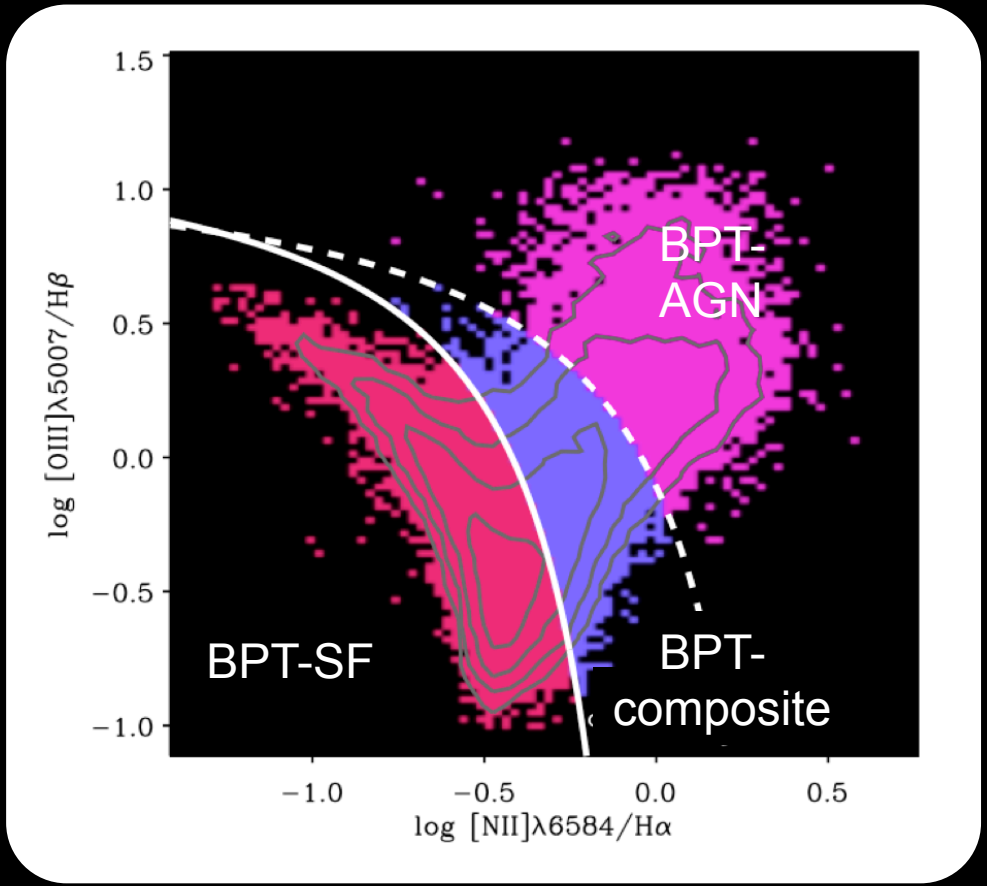
# BPT Diagnostic

(Baldwin, Phillips & Terlevich 81)

Tool to identify the source(s) of ionization in galaxies

Also can be use to infer physical properties of ISM and/or ionizing spectrum

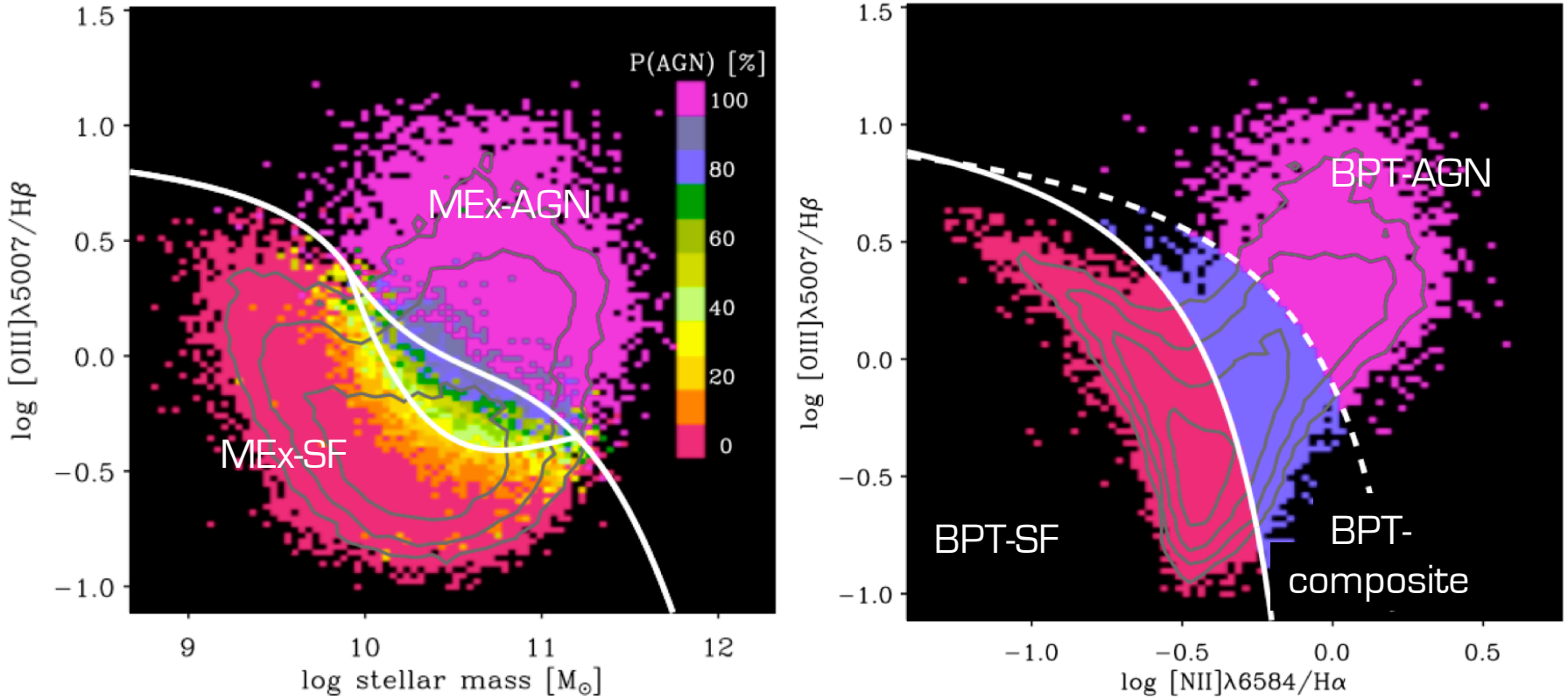
Challenge: line ratios do not uniquely depend on a single parameter → why we are still arguing about it



# Mass-Excitation (MEx) Diagnostic

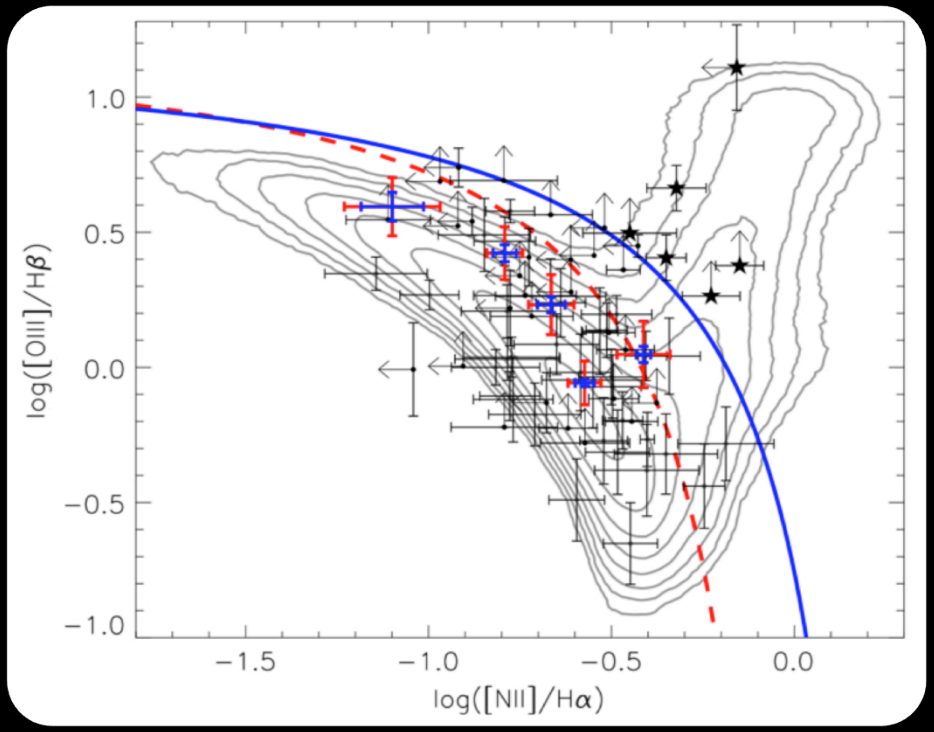
1- Empirical dividing Lines (from >100,000 SDSS galaxies at 0.05<z<0.1)

2- Probabilistic approach → P(AGN) = probability of presence of AGN

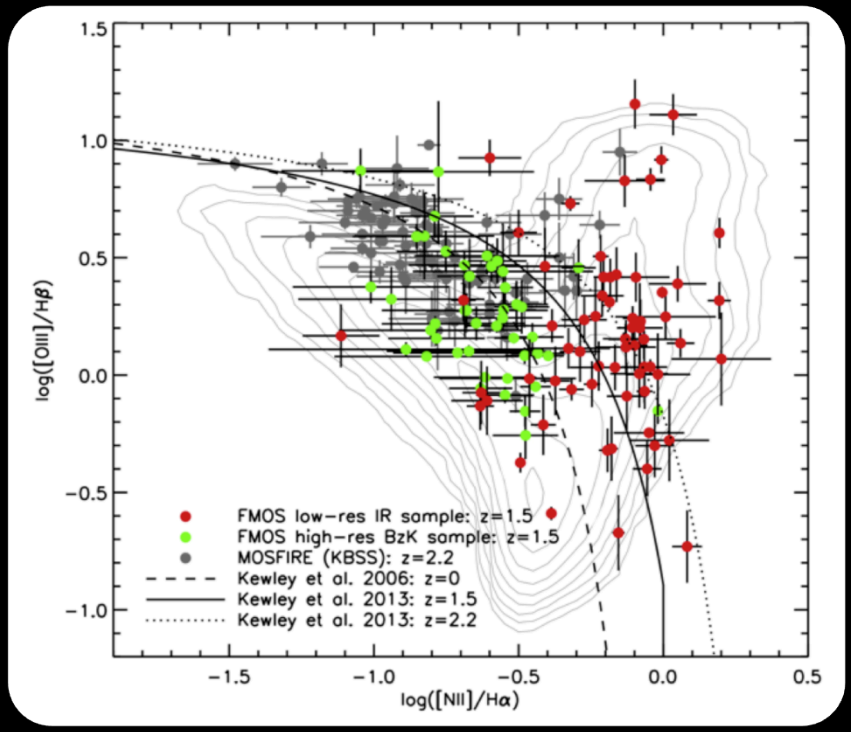



(adapted from Juneau+ 2011; tested at z~1.5 by Trump+13; z~2 by Newman+14; Coil+15)

# BPT Diagram at z>1.5 (Baldwin+81)




Zahid+14a

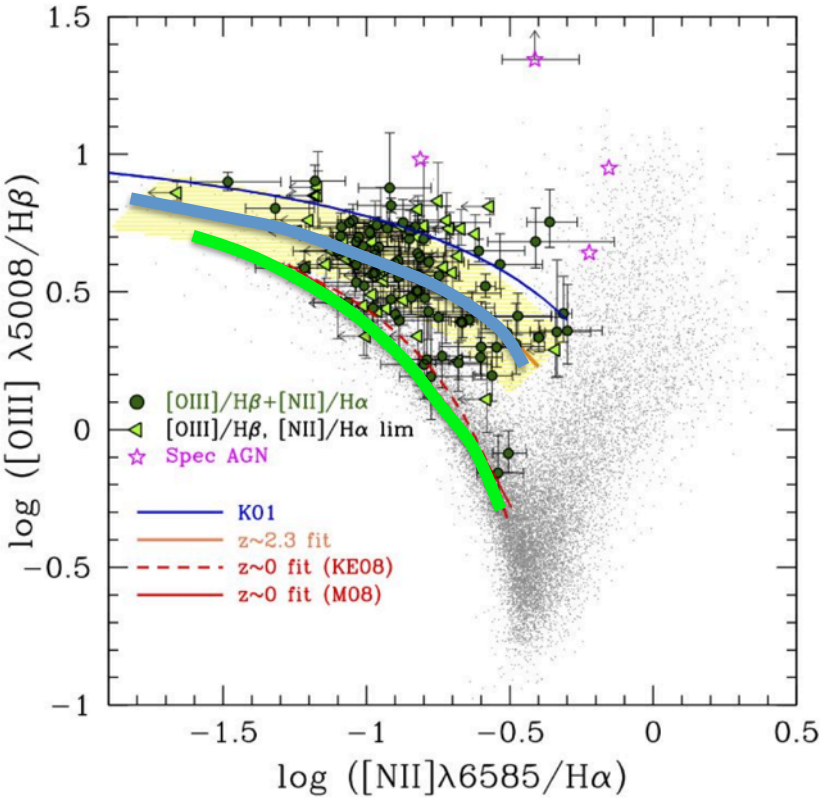


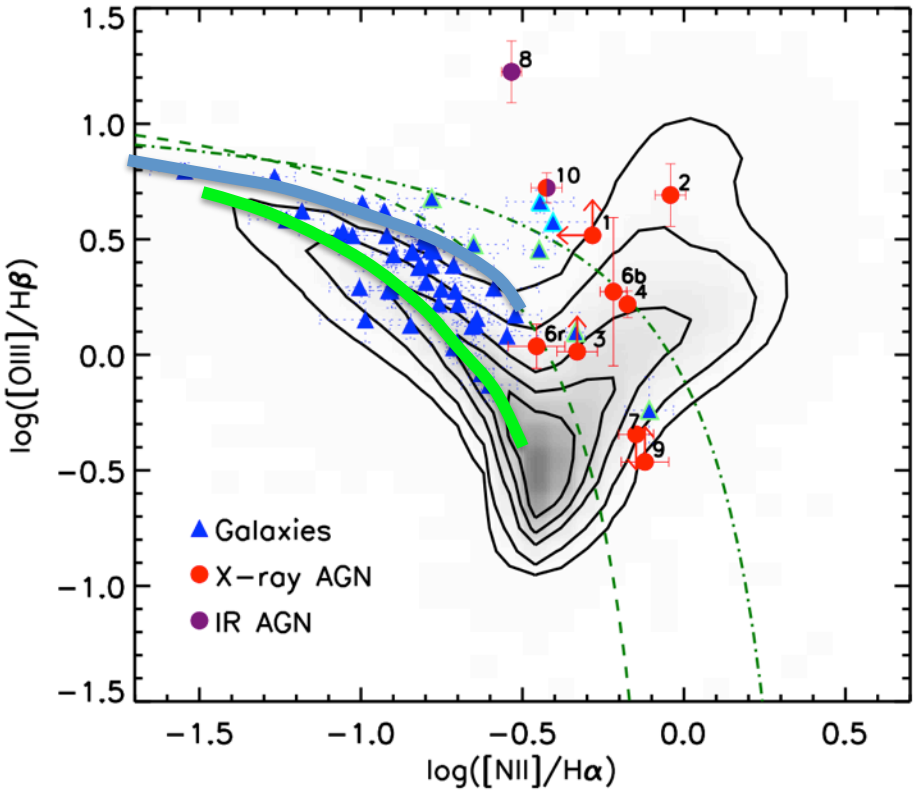

Kartaltepe+15

Many more: Erb+06, Liu+08, Brinchmann+09, Trump+11, Yabe+12, Andrews+13, Masters+14, Steidel+14, Coil+15, Shapley+15, Masters+16, Steidel+16

# BPT Diagram at z > 2

KBSS *vs.* MOSDEF

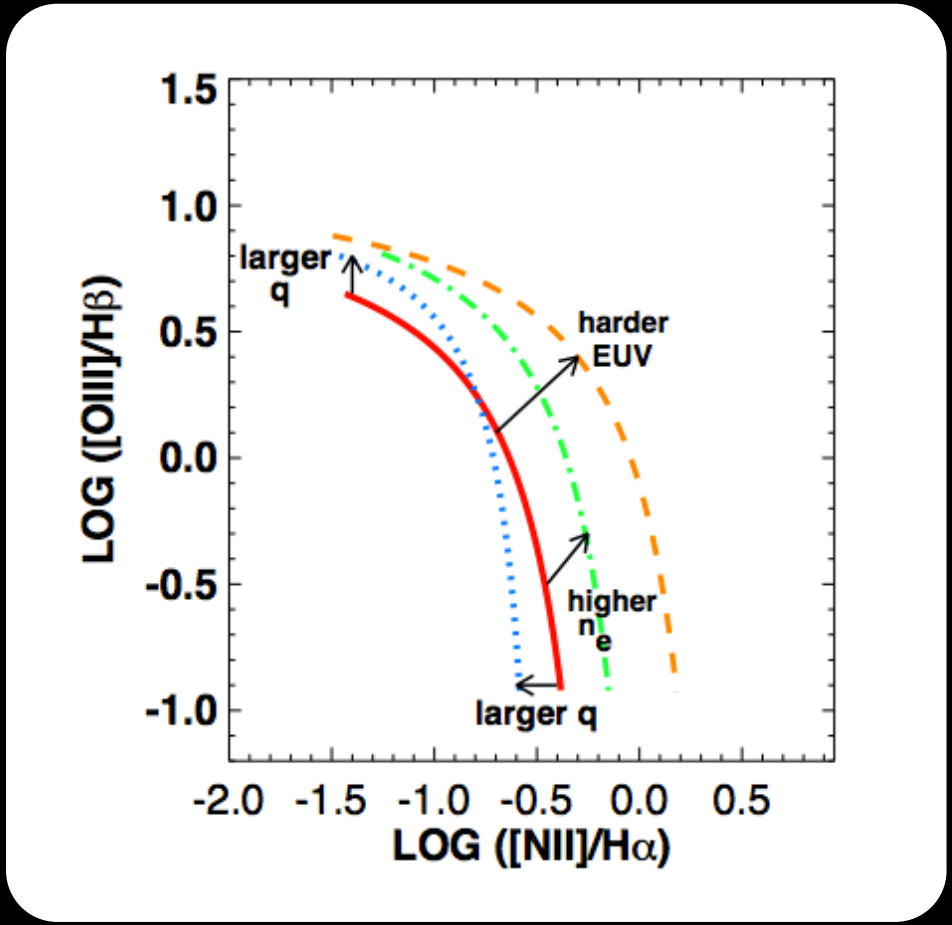



Steidel+ 2014 (Strom+ in prep)

Coil+ 2015 (also Shapley+ 2015)

# BPT diagnostic at higher redshifts




Kewley+ 2013a

- Changing HII region conditions?

→ Theoretical predictions based on stellar population and photoionization models (e.g., Kewley + 2013a)

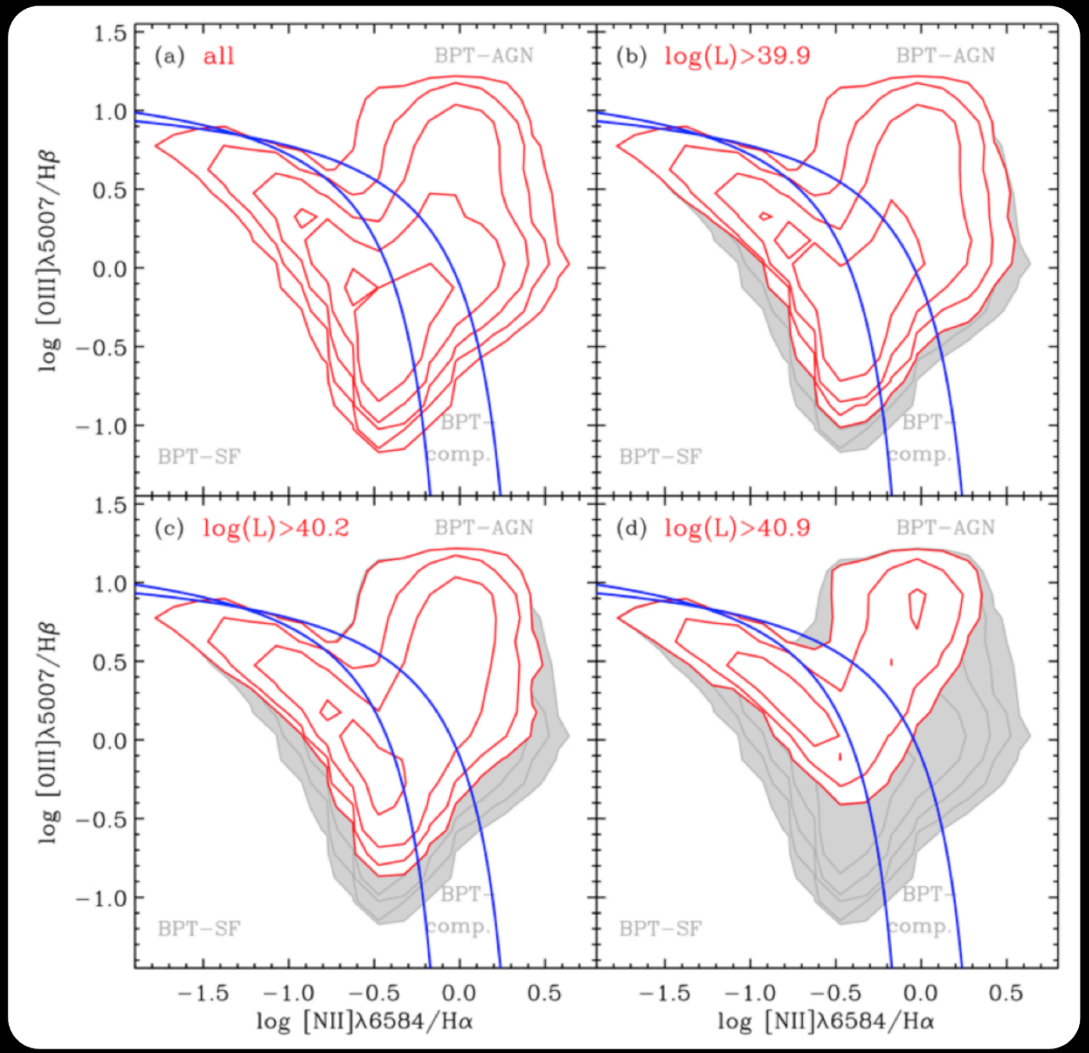
→ Potentially important impact to get self-consistent treatment of stellar emission and gas emission is galaxies (e.g., Pacifici+2012) and to properly identify AGN

→ Can also help to constrain formation of disk galaxies (inside-out?)

# Low-z Analogs

- Lyman Break Analogs (talk by Heckman)
- Green Peas (talks by Heckman, Henry, James)
- Lowest Metallicity Galaxies (talk by Wofford)
- BTP Analogs (poster by F. Bian)
- z=2-3 analogs to primeval galaxies (talks by Erb, Berg, Amorin)

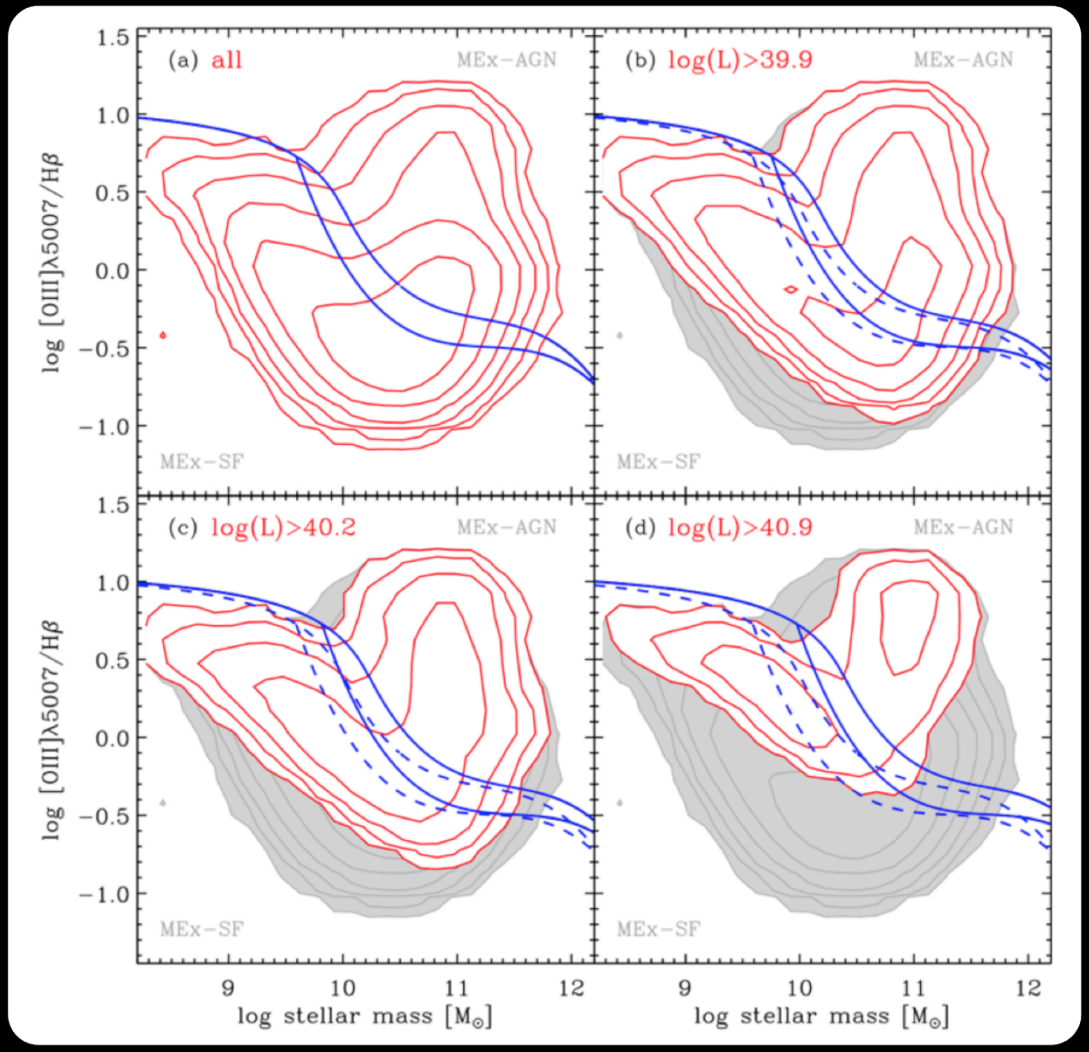
# Luminosity Limit on BPT




- SDSS DR7 at 0.04<z<0.2
- Apply luminosity cutoffs to [OIII]5007 & Hα
- Apparent offset w/ increasing line cutoff luminosity

(Juneau+14)

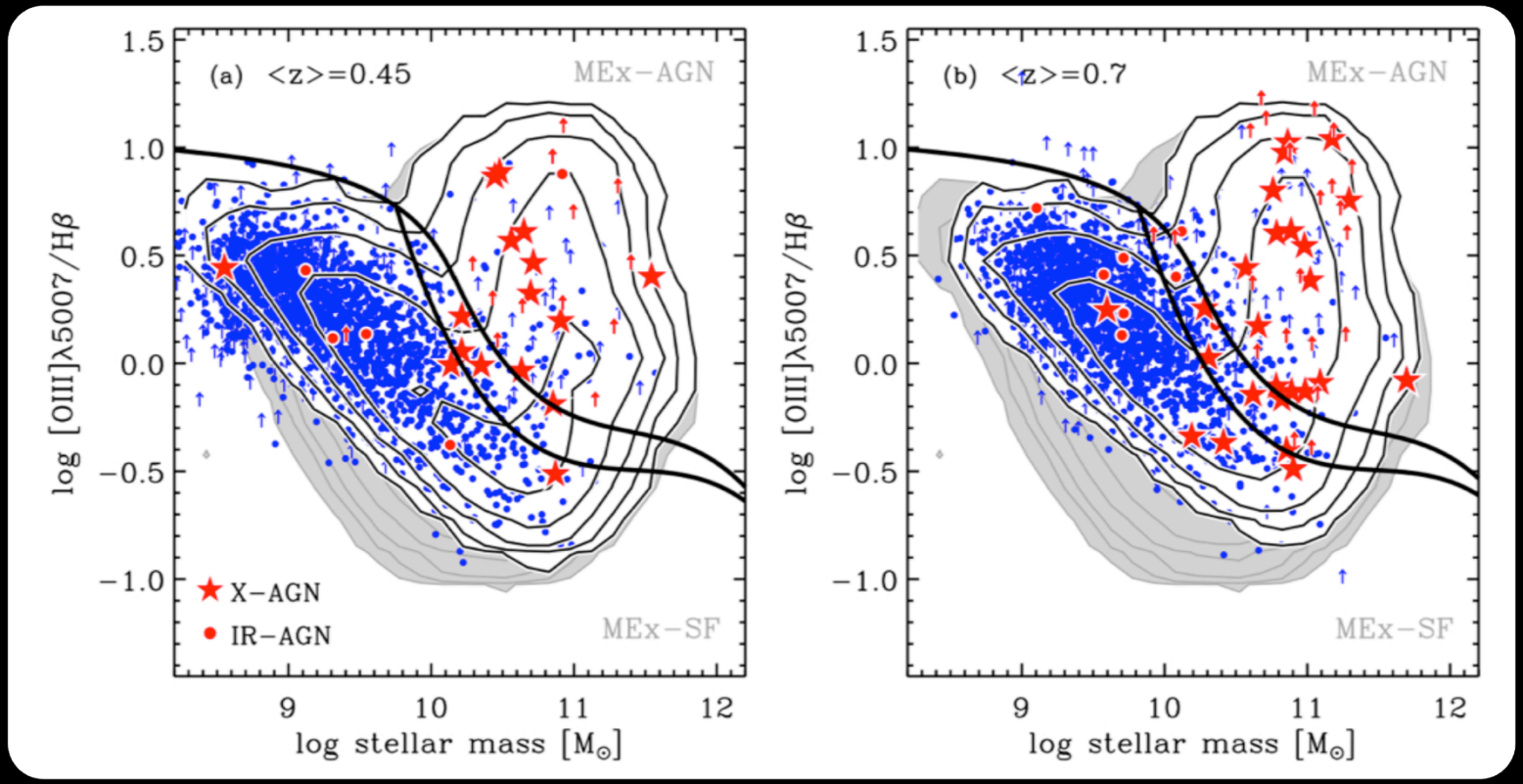
# Luminosity Limit on MEx




- SDSS DR7 at 0.04<z<0.2
- Apply luminosity cutoffs to [OIII]5007 & Hα
- Apparent offset w/ increasing line cutoff luminosity

(Juneau+14)

# [OIII] vs. Hβ



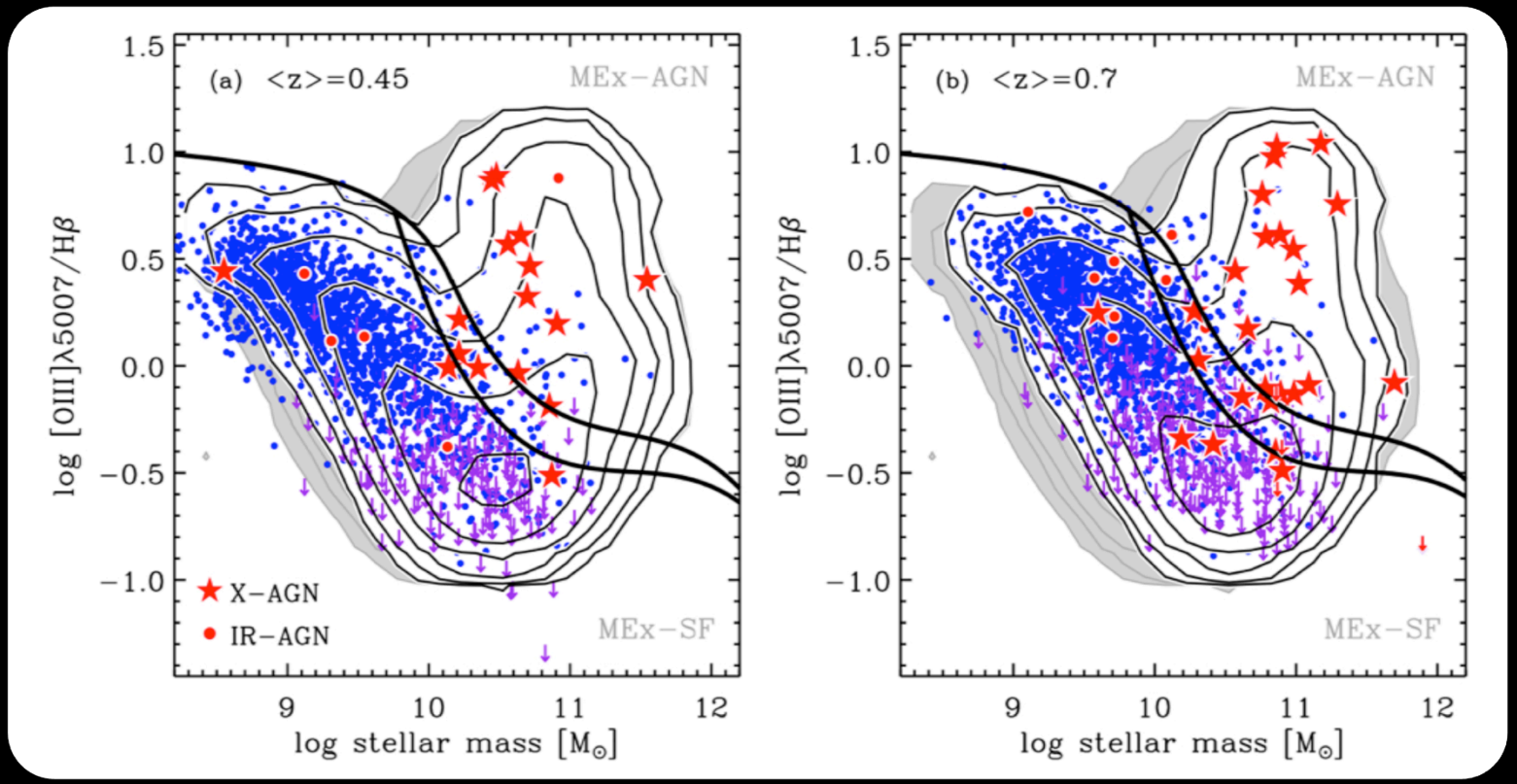

(Juneau+14)

Gray contours = SDSS DR7 at 0.04<z<0.2

White-filled contours = correspondingly "selected" SDSS

Colored points = GOODS-N & EGS at 0.3<z<1 (Juneau+11 sample)

# [OIII] vs. Hβ



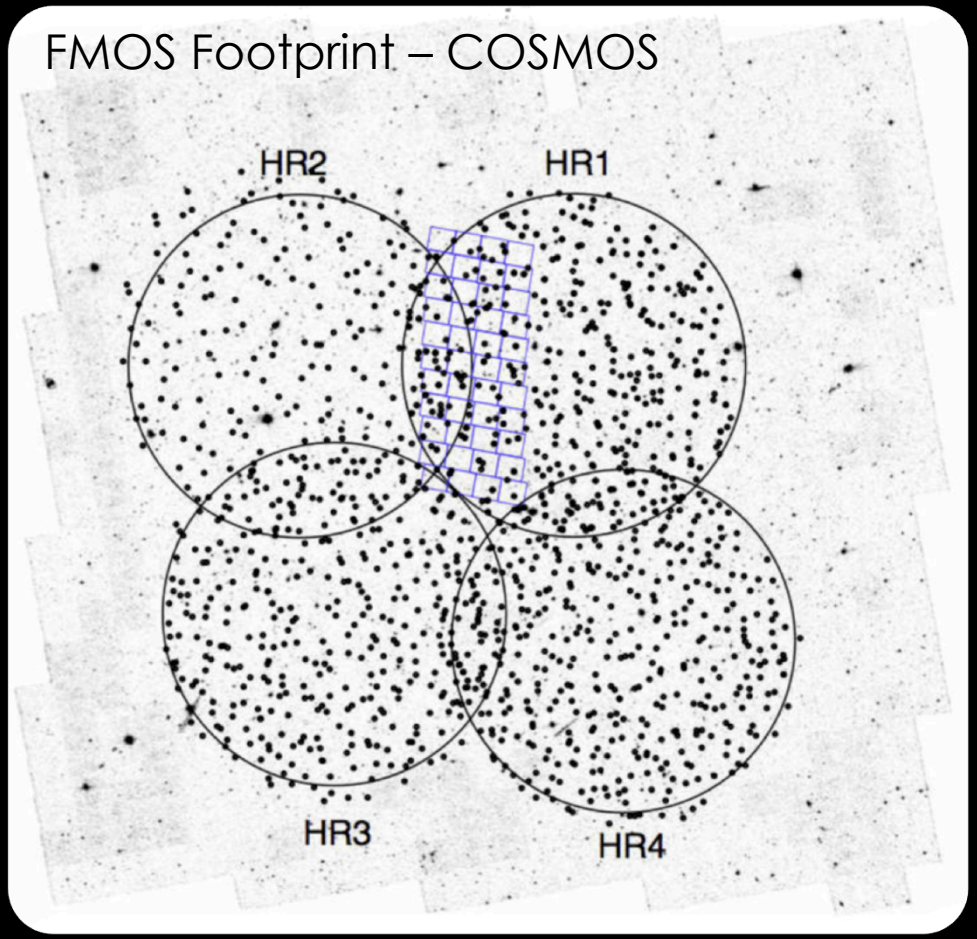

(Juneau+14)

Gray contours = SDSS DR7 at 0.04<z<0.2

White-filled contours = correspondingly "selected" SDSS

Colored points = GOODS-N & EGS at 0.3<z<1 (Juneau+11 sample)

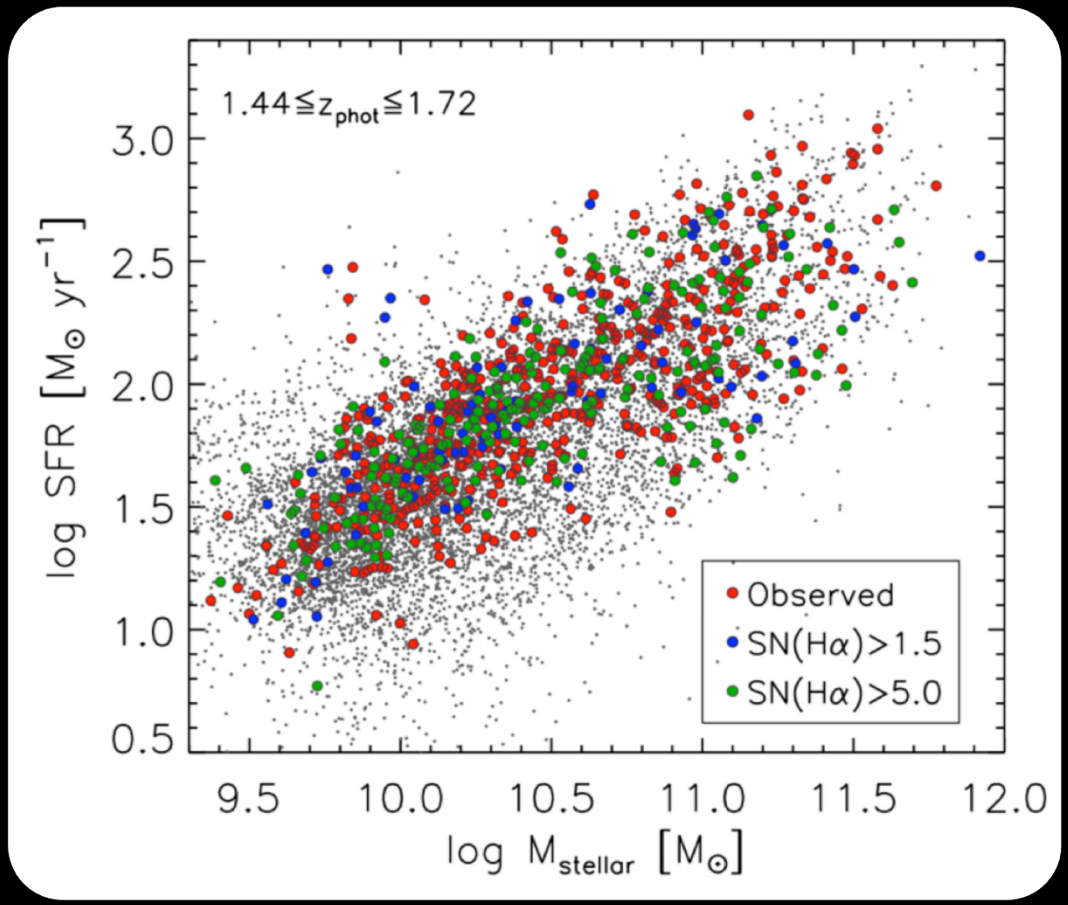
# FMOS-COSMOS @z=1.6




Silverman+2015 (arXiv1409.0447)

- Central square degree of the COSMOS field using Subaru/ FMOS (JH)
- $K_s$ < 23 AB
- 1.43 < $z_{phot}$ < 1.74 → Hα in FMOS H-long
- M* > $10^{10}$ $M_\odot$ (fillers >$10^9$); from Ilbert+13
- B-z and z-K colors of star-forming (s)BzK – Daddi+04
- Expected Hα flux > 4e-17 cgs

# FMOS-COSMOS @z=1.6




Sample properties:

- 9.4 < log(M*)<11.7
- 10 < SFR < 1000

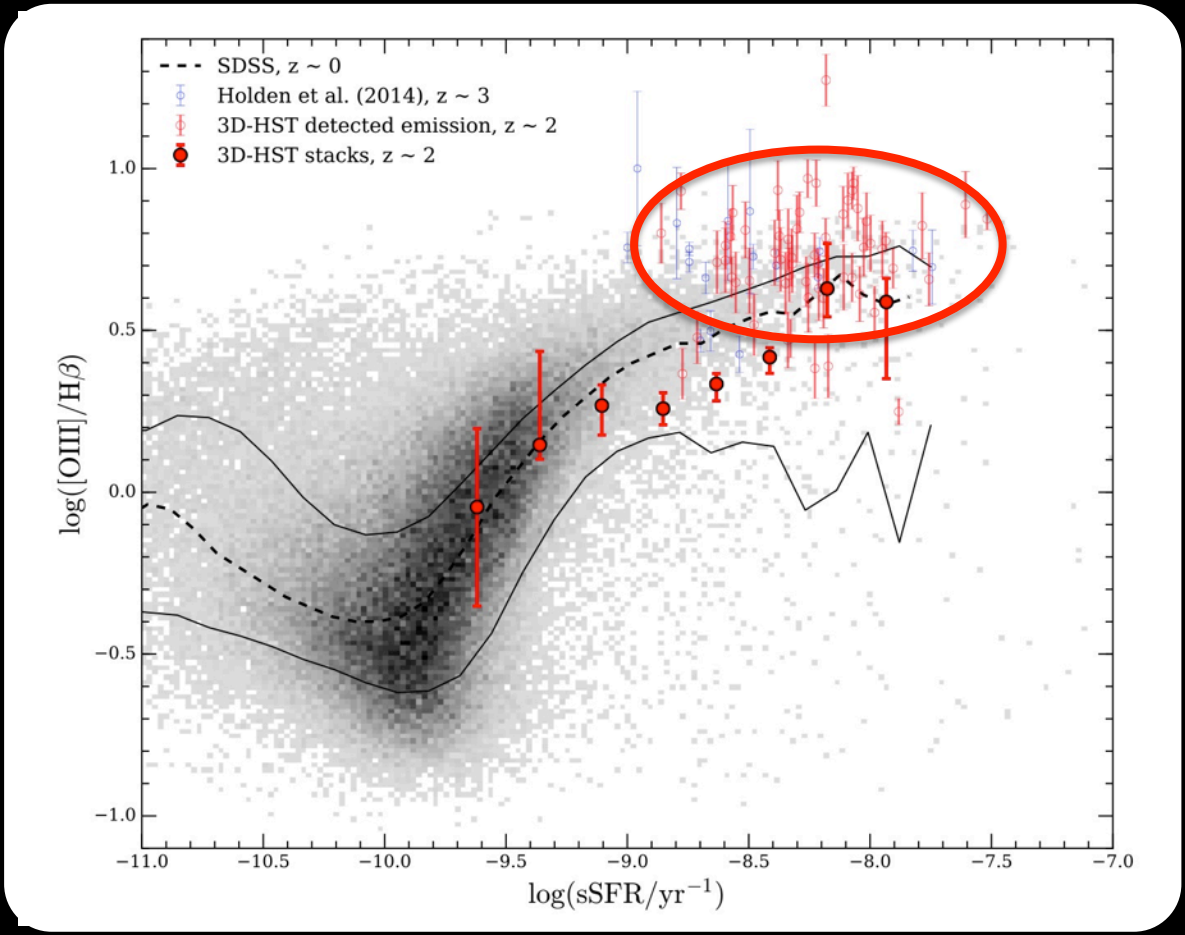
Successful spec z's:

- 613 $M^*>10^{9.8}$
- 183 low-M* fillers
- 47 Herschel/PACS

Silverman+2015 (arXiv1409.0447)

Result Highlights: Kashino+13; Zahid+14a,b; Kartaltepe+15

# [OIII]/Hβ vs. sSFR

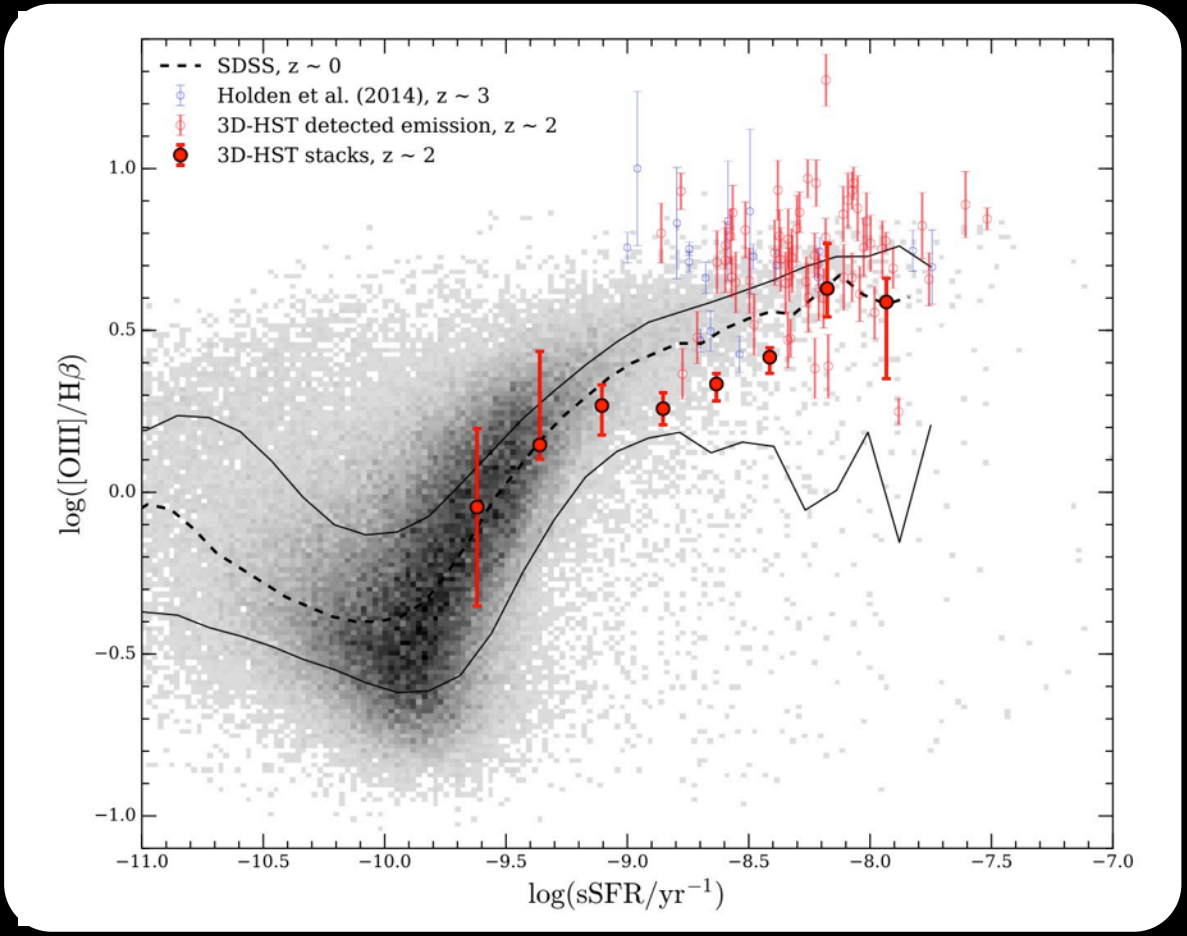



Also:
Brinchmann+2008
Holden+2014
Kewley+2015

Talks by Brinchmann, Hirschmann, Shapley, Steidel, Strom, etc.

3D-HST for stacking to higher M* and sSFR at z~2 (Dickey+2016)

# Stacking → higher Sensitivity

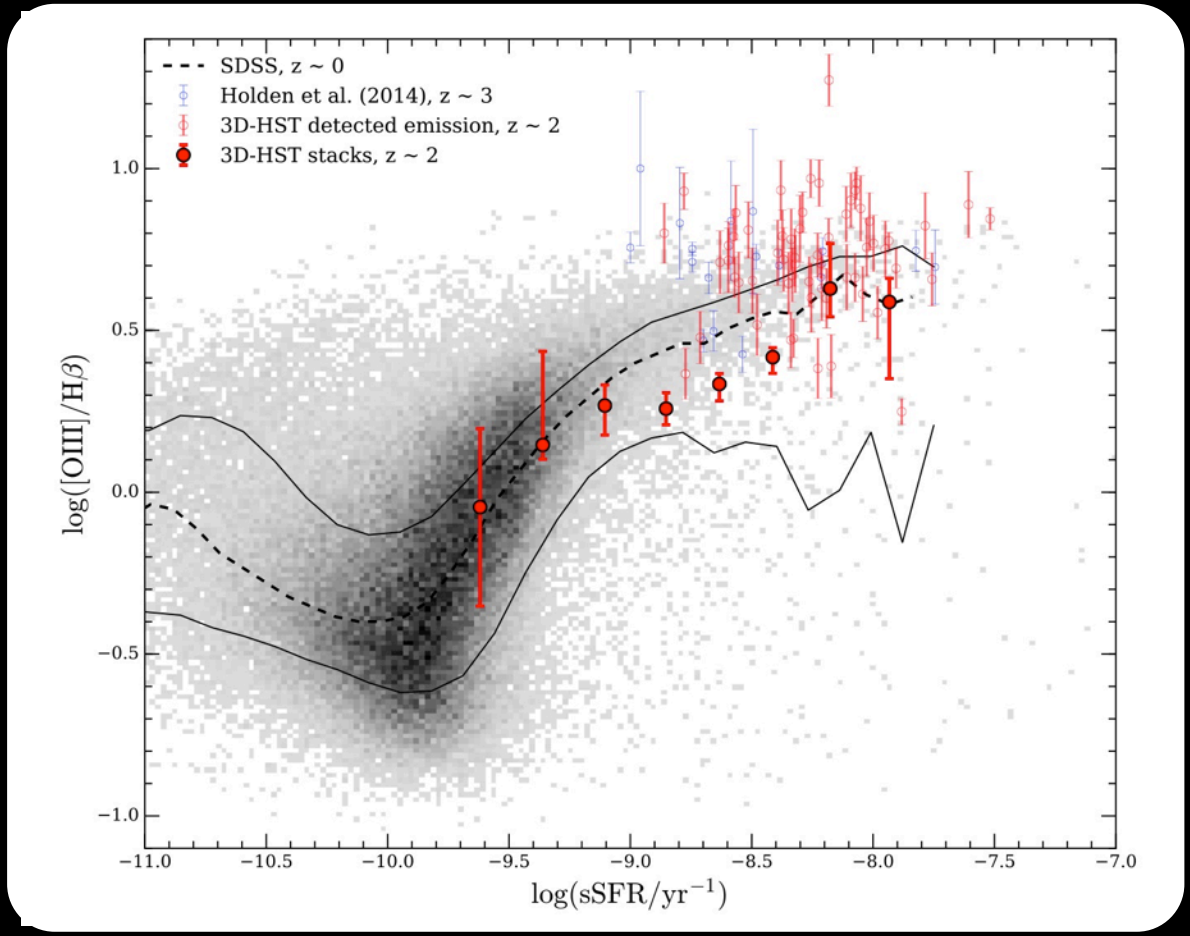



Stacking spectra in sSFR bins:

- Lower [OIII]/Hb in high sSFR bins
- Reaching lower sSFR at fixed z
- Consistent with z~0 trend(?)
- More work needed to confirm

3D-HST for stacking to higher M* and sSFR at z~2 (Dickey+2016)

# Stacking to lower sSFR




JWST will probe to high z but ***also*** detect individual galaxies at z~2-3 down to lower sSFRs (and higher gas-phase O/H)

3D-HST for stacking to higher M* and sSFR at z~2 (Dickey+2016)

# Possible explanations

- AGN contribution (e.g., Wright+10, Trump+11)
- Higher electron density/pressure (Shirazi+14, Shimakawa+14)
- Higher Ionization Parameter (Kewley+15, Kashino+16)
- Hotter stars (Steidel+14) ; low-Z massive binaries (Steidel+16)
- Evolving [N]/[O] abundance (Shapley+15, Sanders+15, Masters+16)
- Selection due to line flux limit (modulating effect, Juneau+14)

The jury is still out but we MUST account for selection effects !!

# Summary

- Emission lines diagnostics subject to strong selection effects of parent sample & spectroscopy limits

- Can select better low-redshift comparison samples by including line luminosities (Juneau+14, Cowie+15) and use as a tool for:
  - finding analogs (compare w/ green peas, LBAs, Bian+15)
  - Pushing toward the extreme (redshift, luminosities) may reveal evolution beyond anything that exists at low-z