# The final act of FMOS-COSMOS: The FMOS Legacy Survey of High-z Massive Galaxies and AGNs in COSMOS

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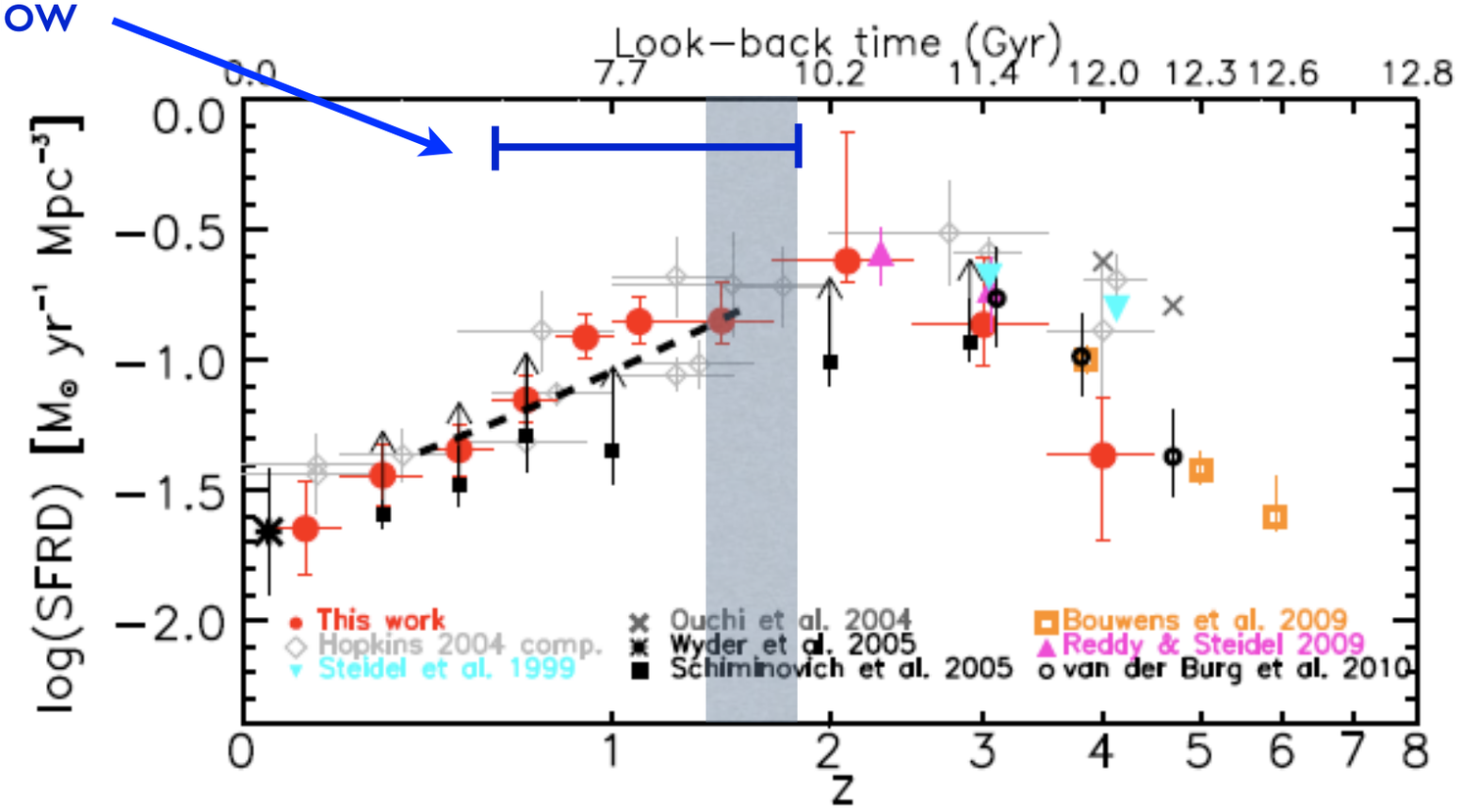
# The Era of NIR multi-object spectrographs

Rest-frame optical spectroscopic surveys of >1000 galaxies with z > 1 are now feasible and efficient in terms of observing time

Detect all four key diagnostic emission lines (Hβ, [OIII]5007, Hα, [NII]) in the IR

| Keck/MOSFIRE | VLT/KMOS | Subaru/FMOS |
|---|---|---|
| Steidel et al. 2014 | Wisnioski et al. 2014 | Yabe et al. 2014; Kashino et al. 2013; JDS et al. 2015; Tonegawa et al. 2015 |

FMOS Hα window




Cucciati et al. 2011

# Fundamental questions in galaxy evolution at z ~ 1.6

✳ How does the sfr - mass relation evolve with redshift?

✳ What are the chemical properties of high-z galaxies?

Test whether a relation between
metallicity-mass-(SFR) exists (Mannucci et al. 2010)

✳ Does the ionization conditions evolve with redshift?
(Kewley et al. 2013a,b)

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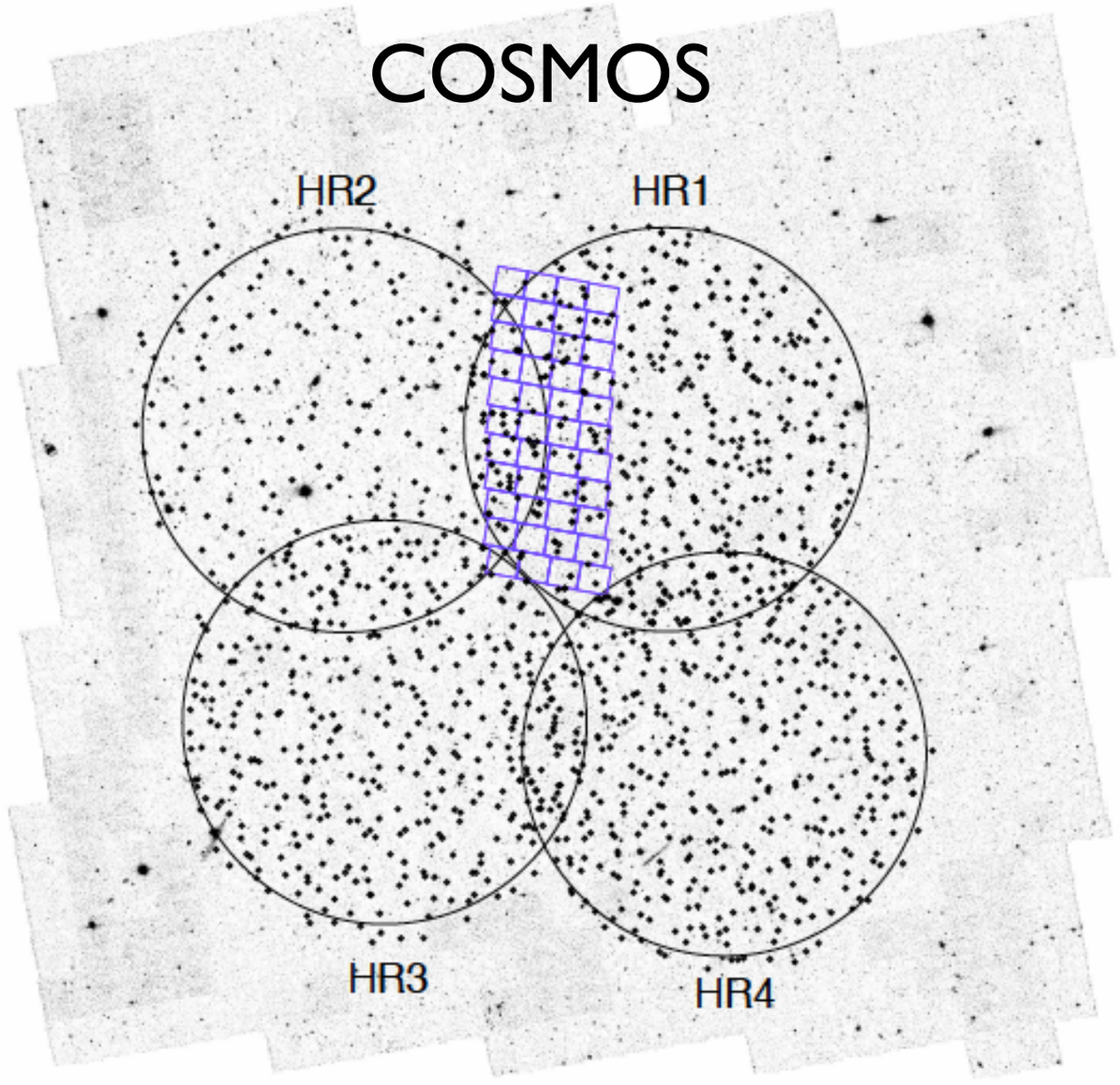
✳ Is the sfr - mass relation sensitive to local overdensity?

✳ What is the role of galaxy mergers and AGN?

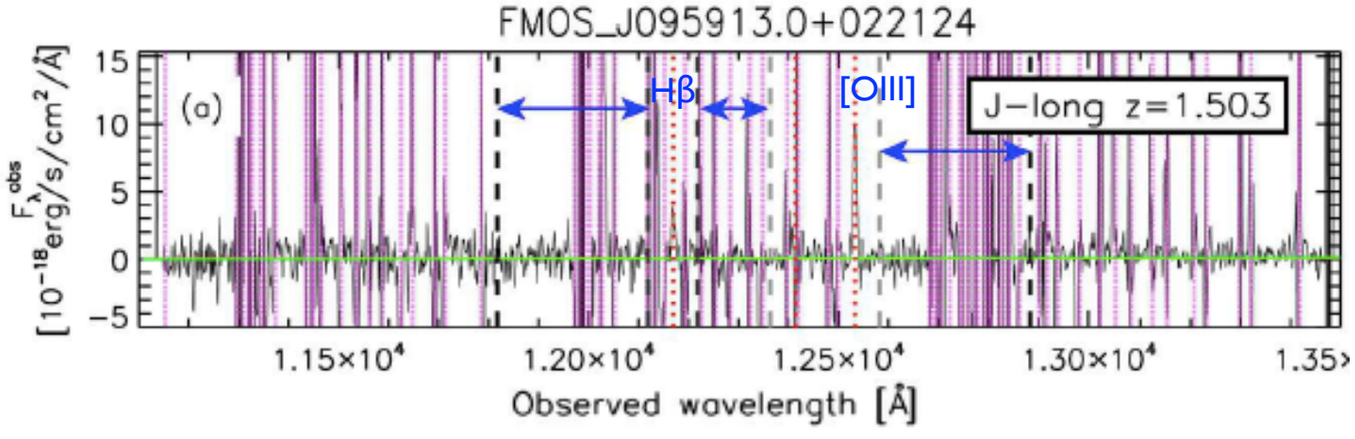
# A Subaru/FMOS NIR survey of SF galaxies at z ~ 1.6

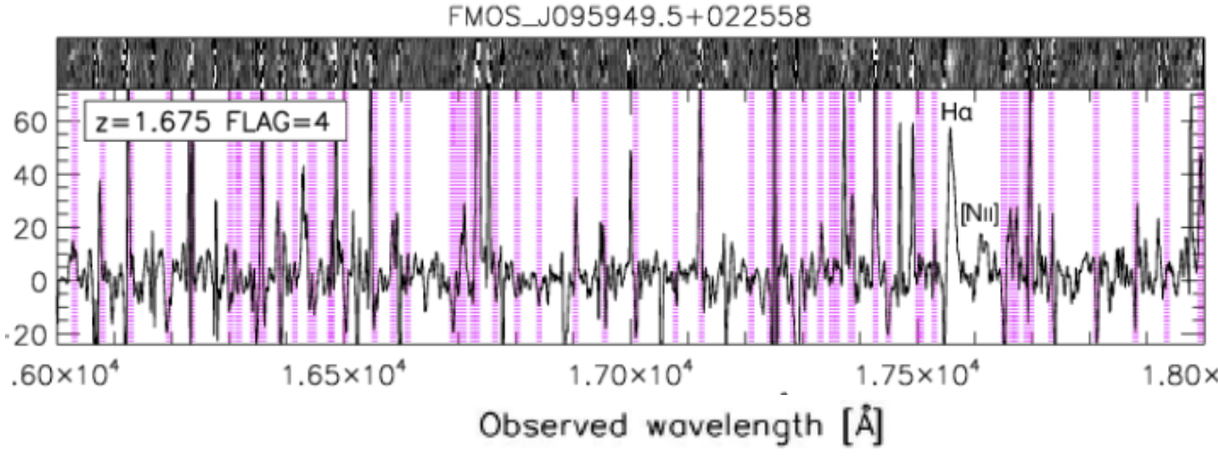
JDS et al. 2015, ApJS, 220, 12

- Emission-line survey of star-forming galaxies
  - 3 Intensive Subaru programs (PI JDS; 23 nights)
  - H-long grating (1.6-1.8 μm)
  - Hα, [NII] and [SII]



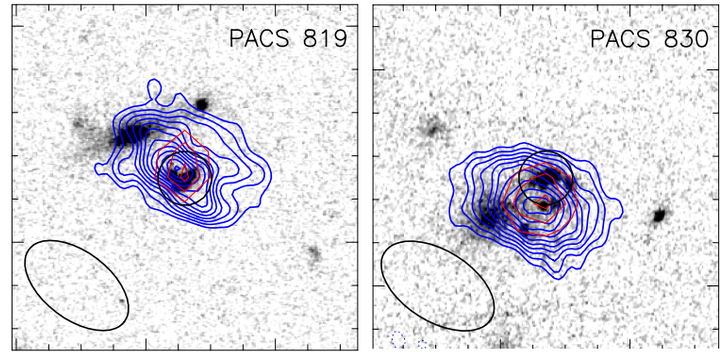

- Followup J-long observations (PI Dave Sanders - UH/IfA)
  - J-long grating (1.11-1.35 μm)
  - Hβ, [OIII]5007



# Target selection

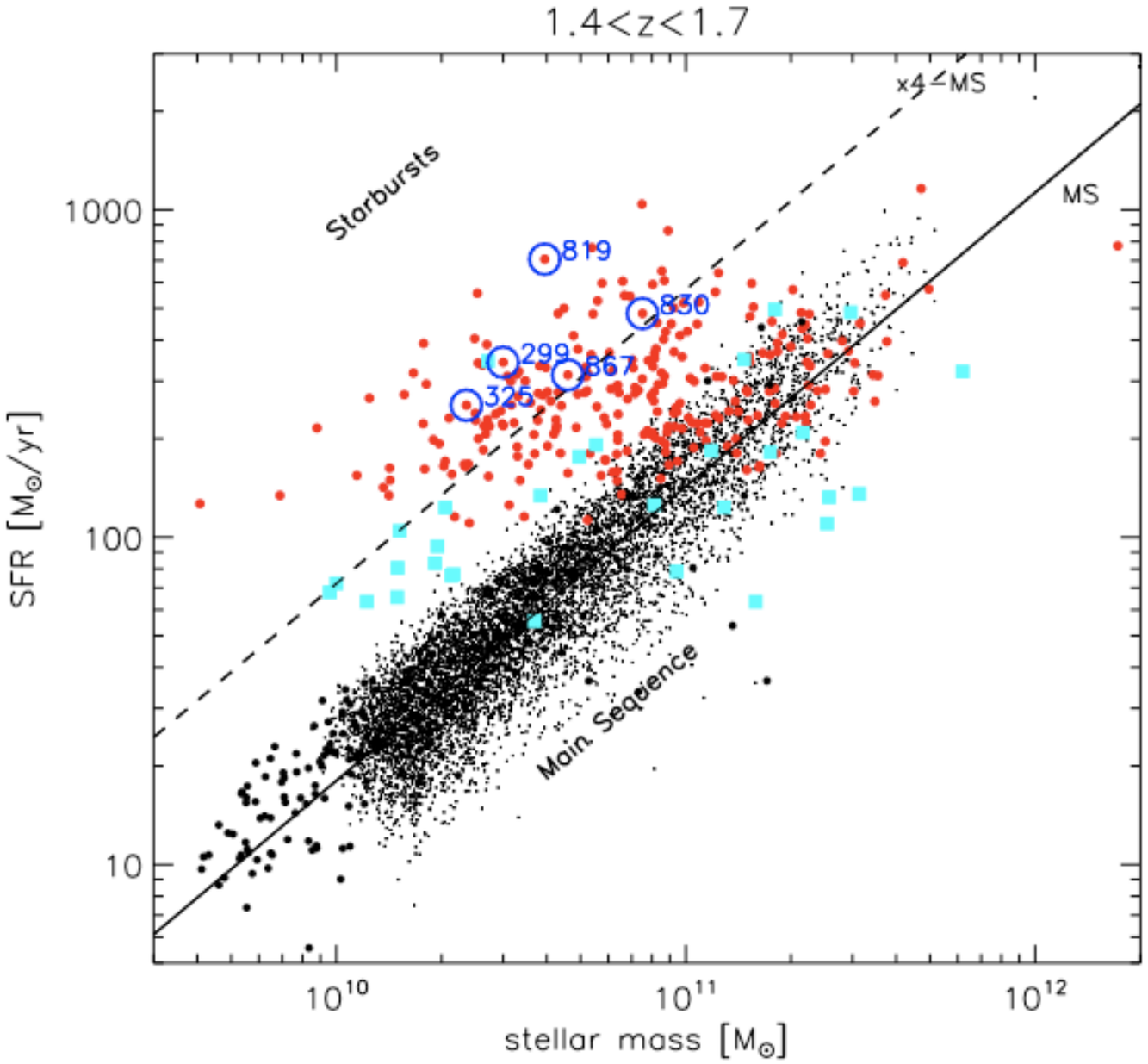
ALMA CO 2-1
JDS et al. 2015




- star-forming galaxies
  - K-selected (K < 23.5)
  - $M_* > 10^{10}\ M_\odot$
  - sBzK
  - along the star-forming main sequence
  - $f_{H\alpha} > 4 \times 10^{-17}$ erg cm$^{-2}$ s$^{-1}$
    - SFR: B-band
    - E(B-V): B-z color
    - $E(B-V)^{neb}=E(B-V)^{stellar}/0.44$ (Calzetti et al. 2000)

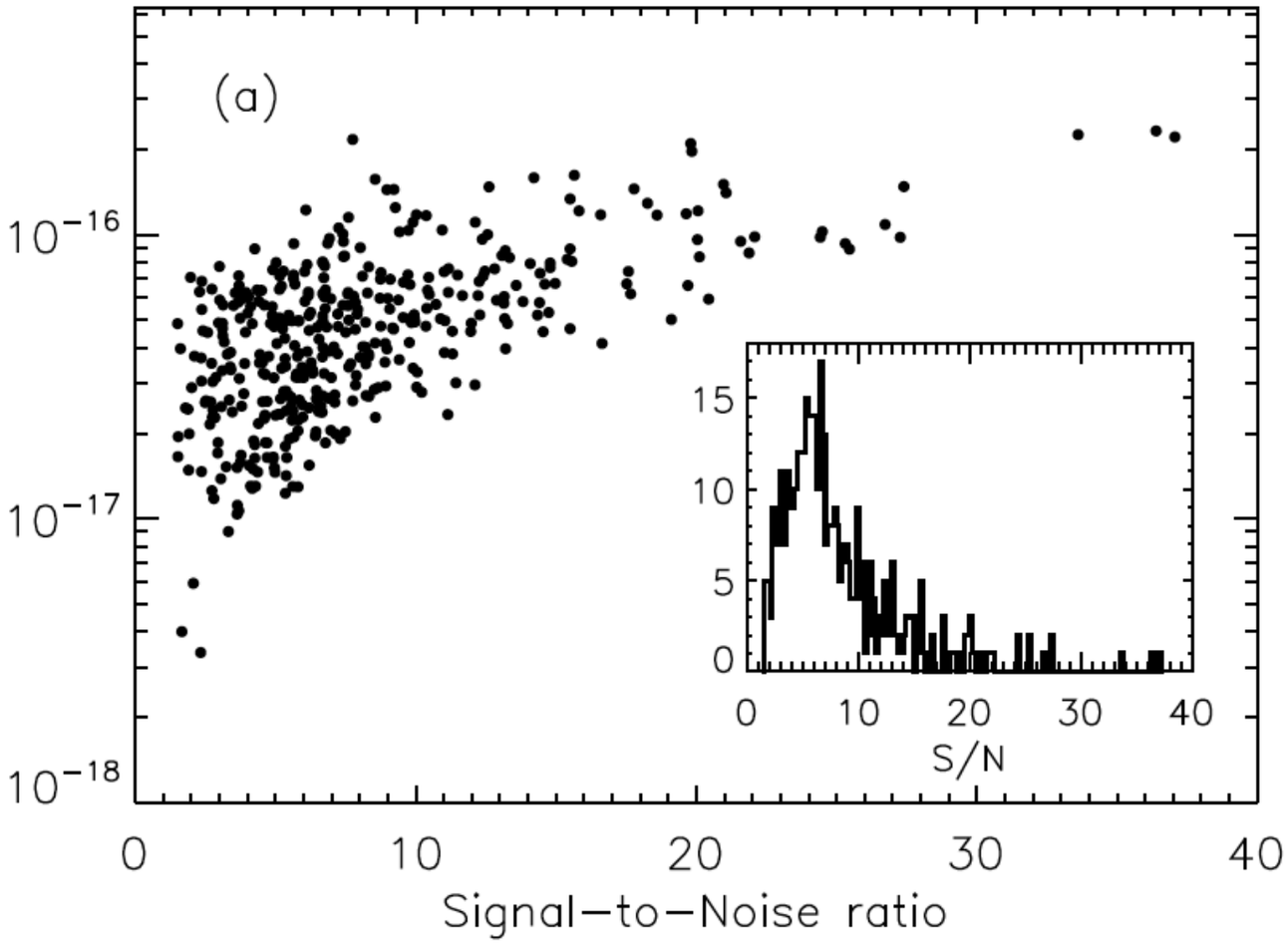
- Herschel/PACs sources
  - highly obscured SF galaxies
  - above or on M-S
  - near bright stars for future IFU/AO observations

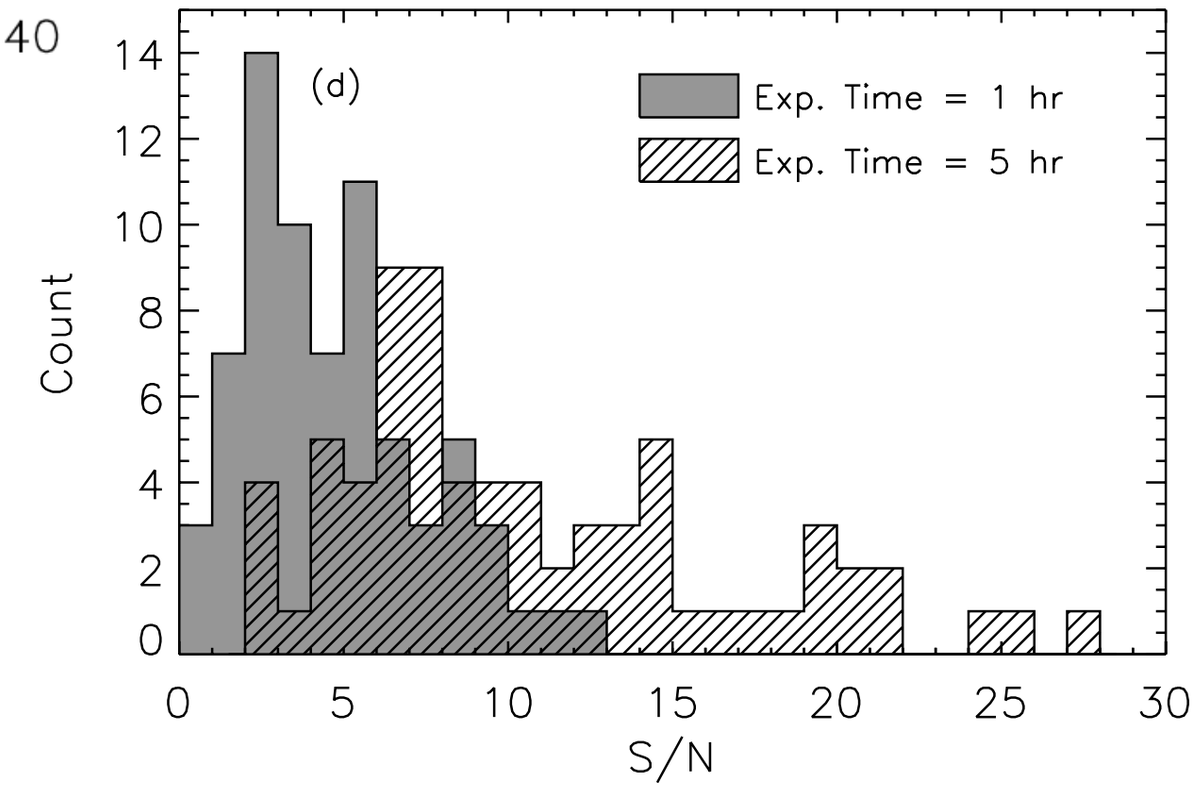
Filler targets: AGNs, low-mass galaxies



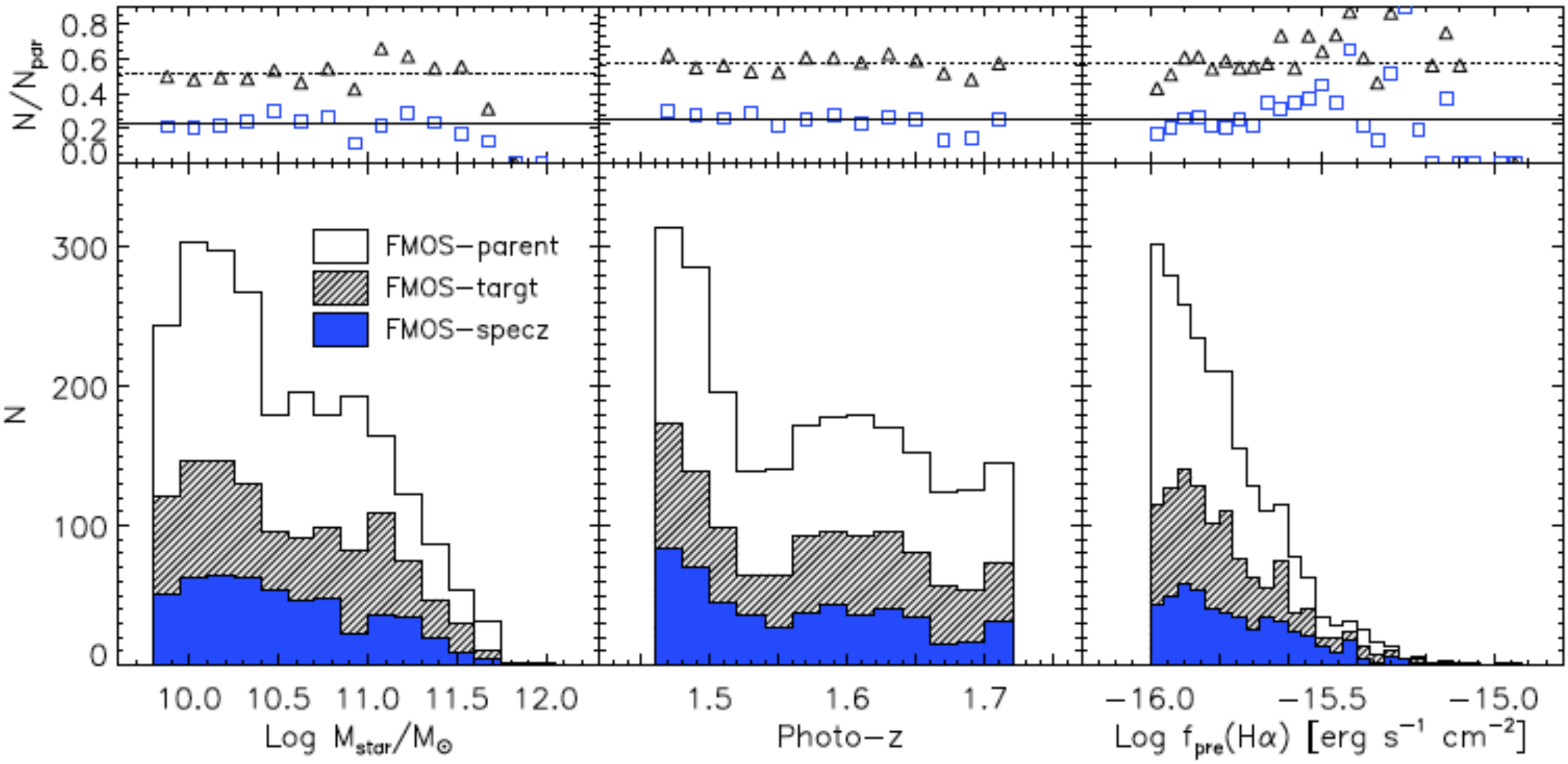

Rodighiero et al. 2010

# FMOS performance

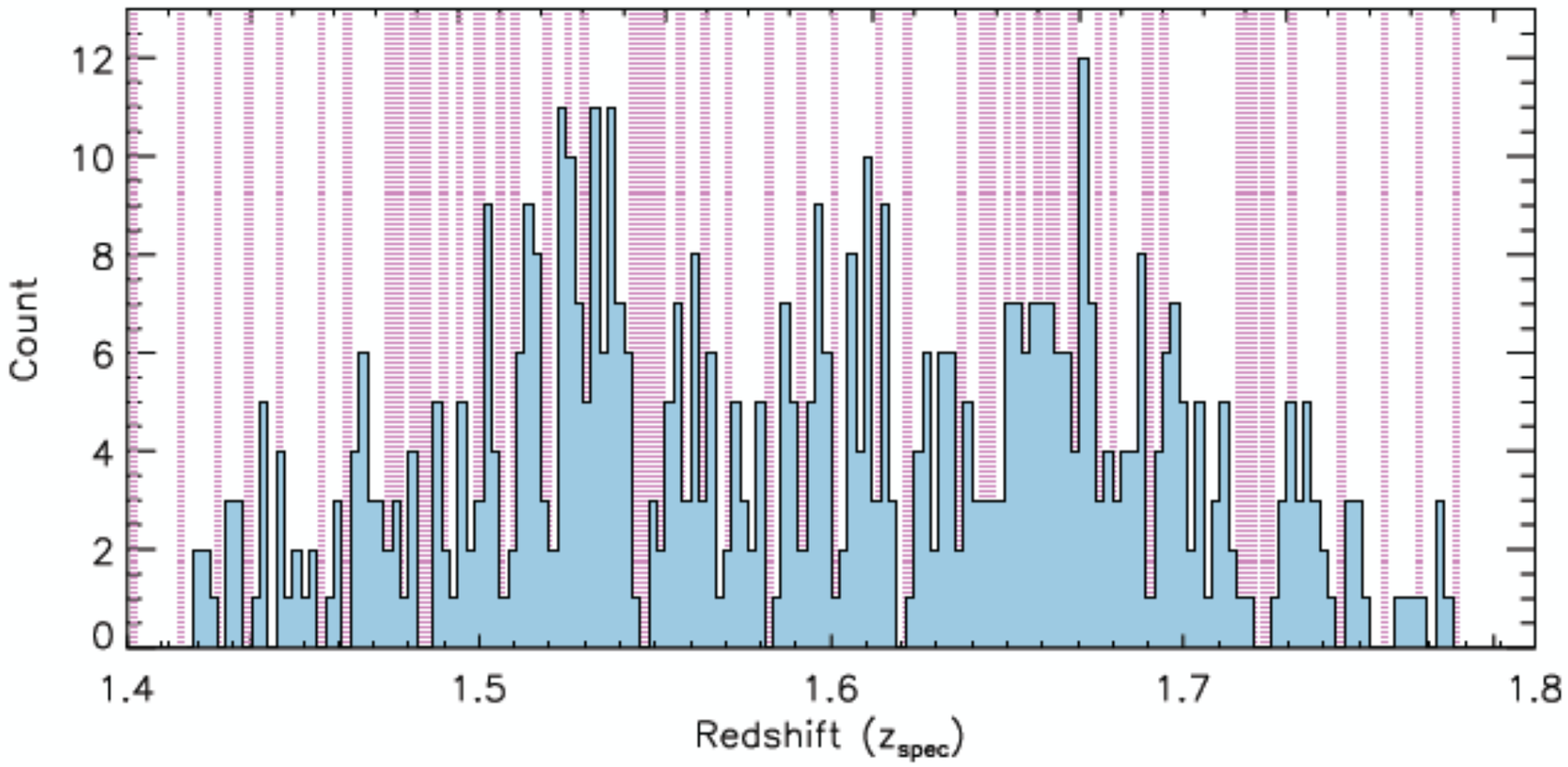


# Target sampling and line detection rate

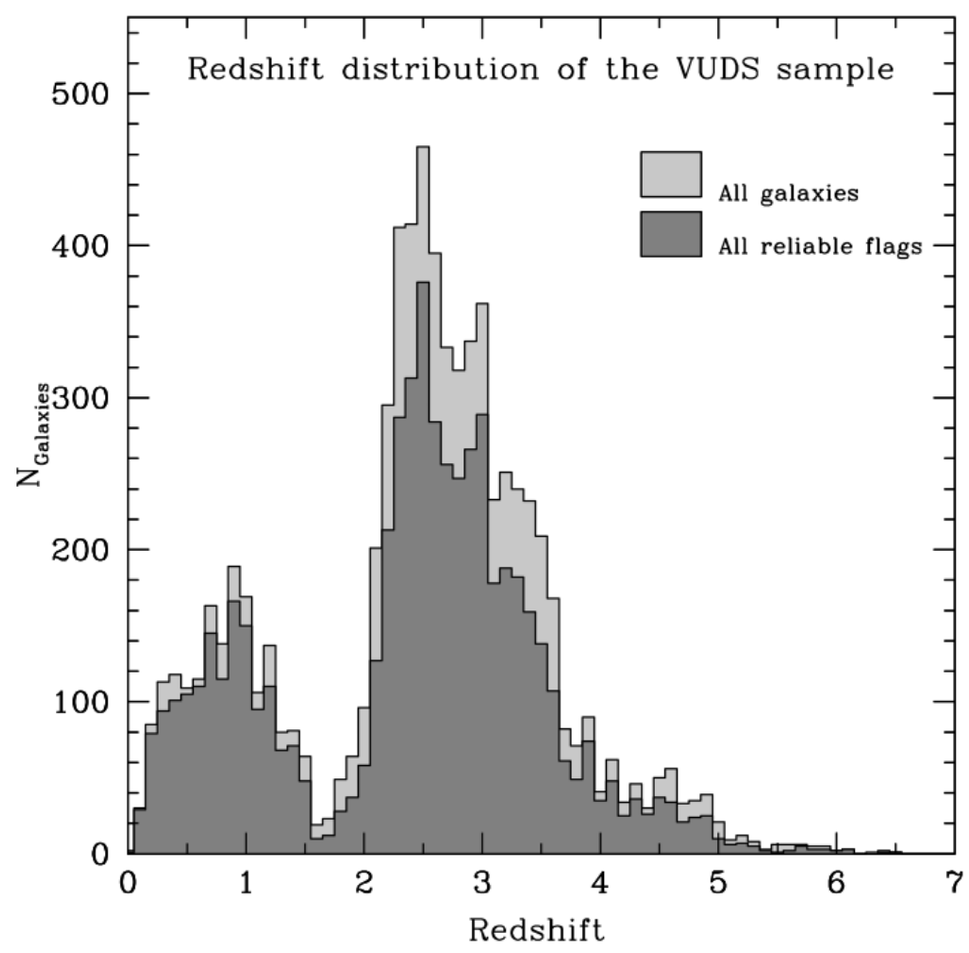



~40% redshift success rate




Le Fevre et al. 2015

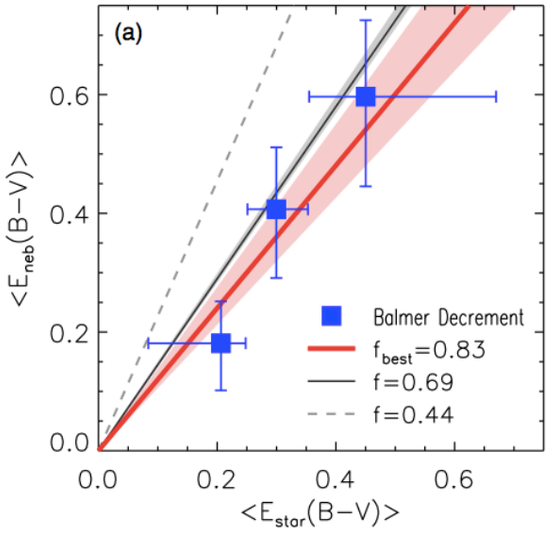
close to 1000 redshifts



# FMOS-COSMOS Intensive Program 1: published results at z ~ 1.6

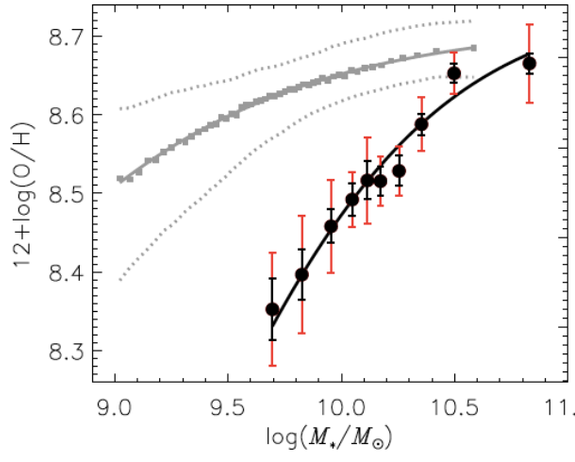
Dust properties:
Kashino et al. 2013

Different than local starbursts




Mass - metallicity relation:
Zahid et al. 2014a,b

Evolves with redshift
Steeper than UV-selected samples
Massive galaxies at local level of enrichment
FMR may not be so fundamental after all



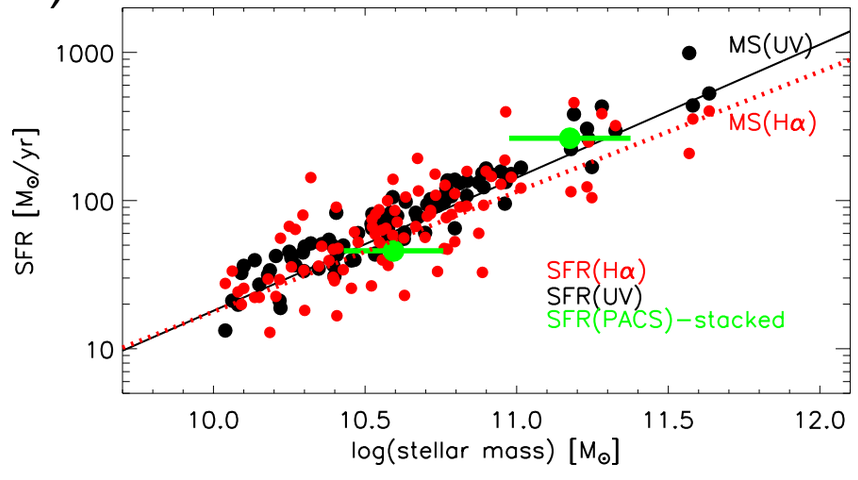

ISM conditions:
Kartaltepe et al. 2015

Elevated ionization state
High-z galaxies offset from local BPT relation

Star formation rates:
(corrected for dust)
Rodighiero et al. 2014

Tight star-forming main sequence (MS)

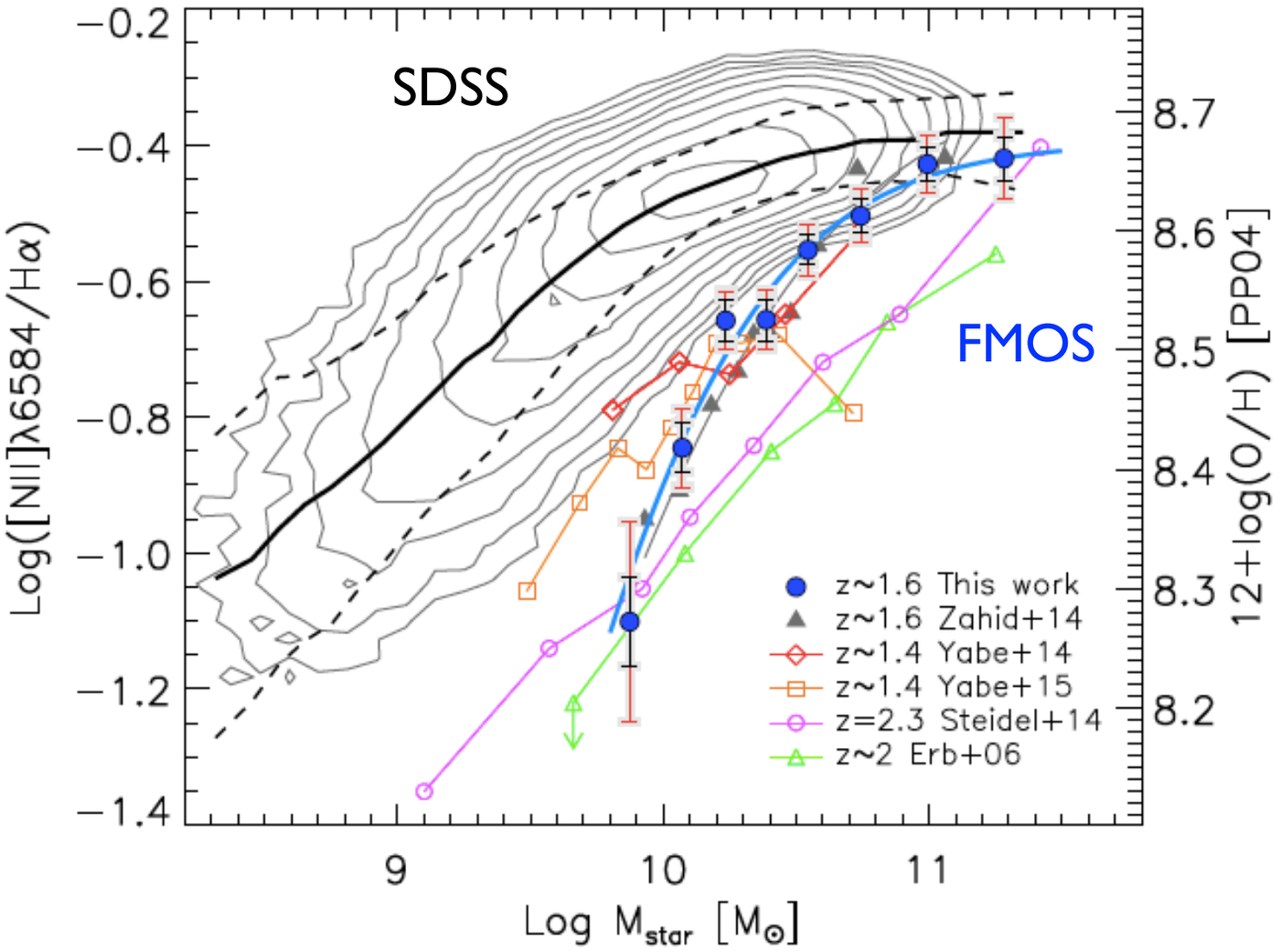
Agreement between IR, UV and FIR SFRs for MS galaxies using local calibrations



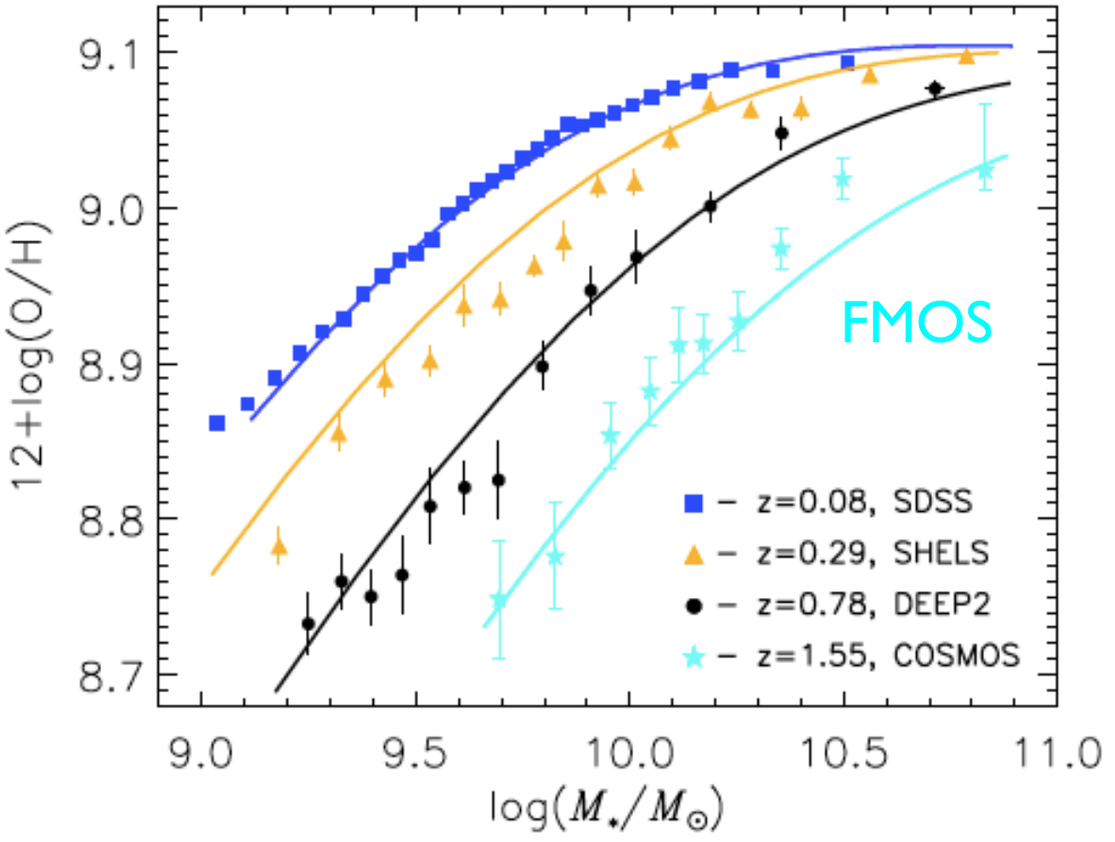

Survey design paper

JDS et al. 2015, ApJS, 220, 12

# Mass - metallicity relation at z ~1.6

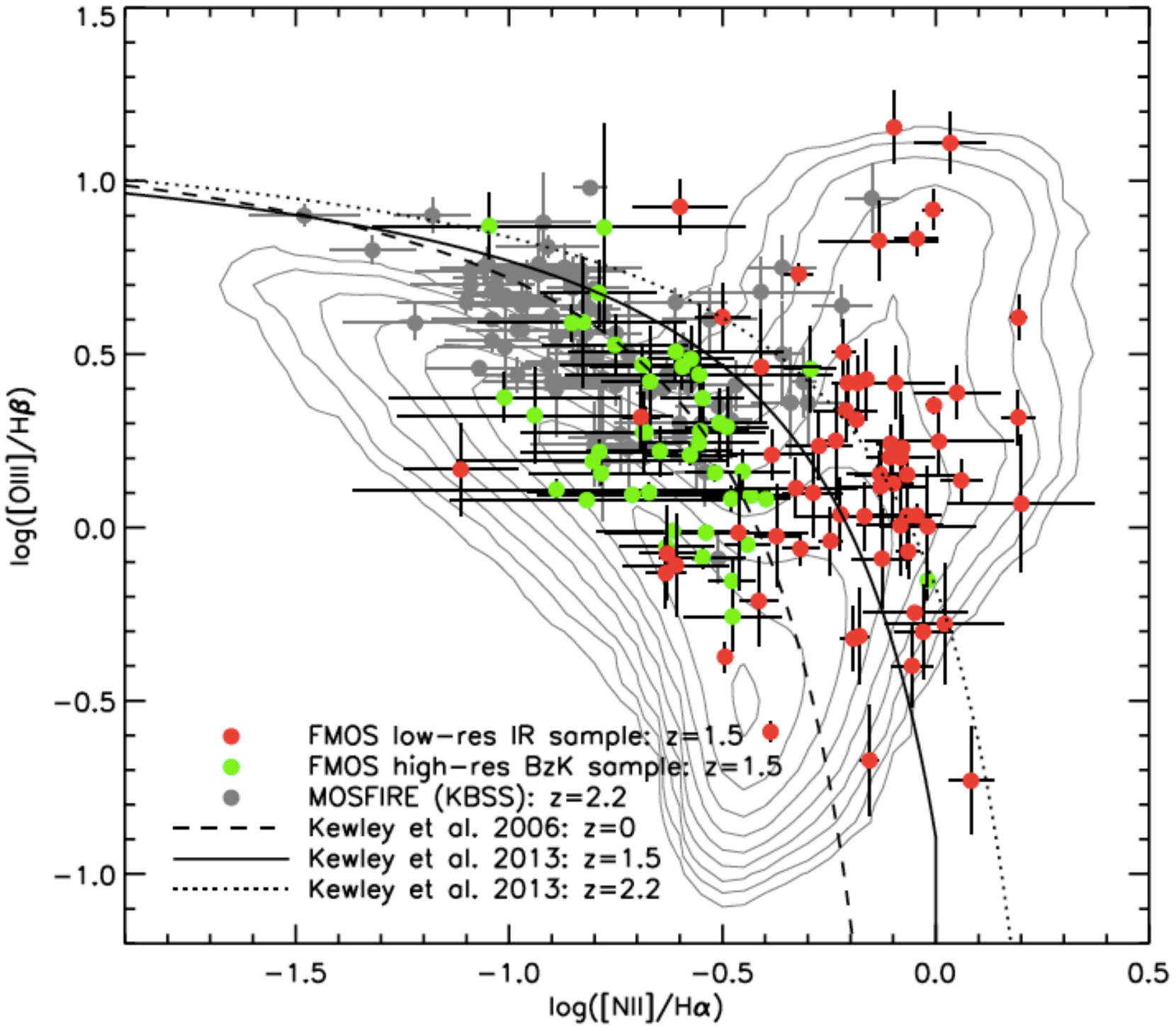



Kashino et al. in prep
Zahid et al. 2014b




Zahid et al. 2014a

# SF - AGN separation at high-z (BPT)




Kartaltepe, Sanders, JDS et al. 2015

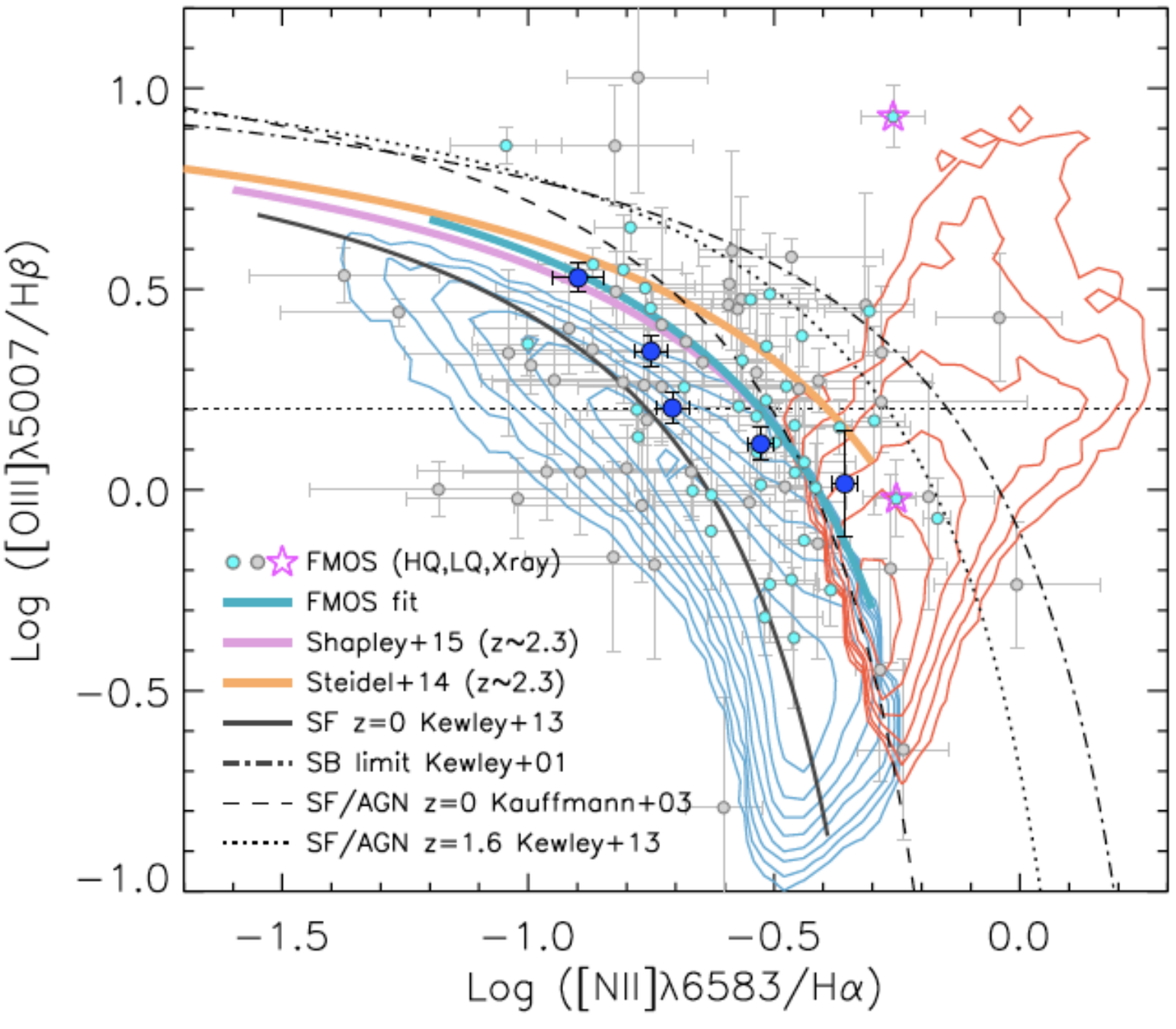
see Steidel et al. 2014; Coil et al. 2014; Shapley et al. 2015

# Ionization conditions in high-z galaxies

FMOS z~1.6

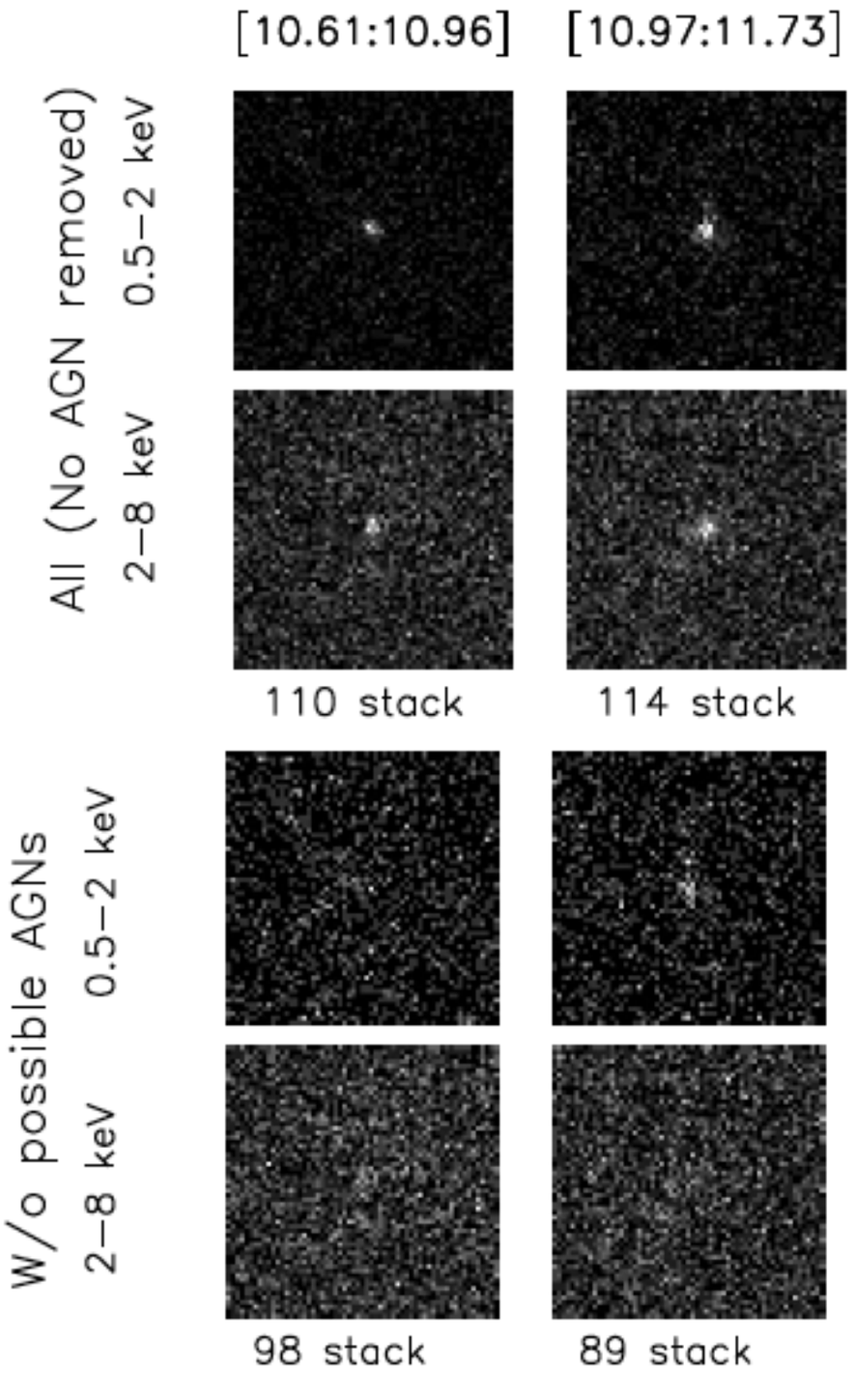
Stack (M★ bin)

Contour: SDSS

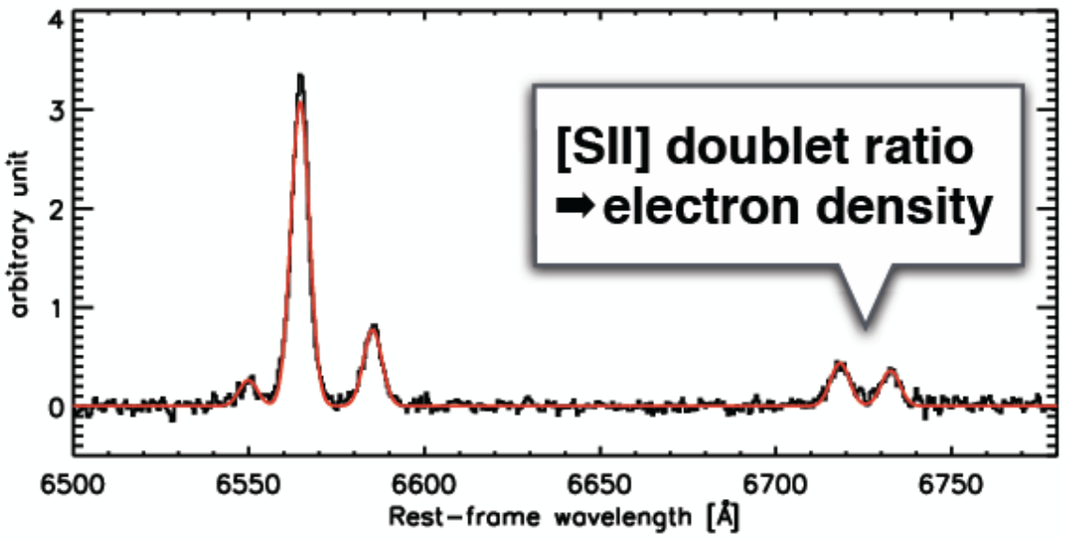


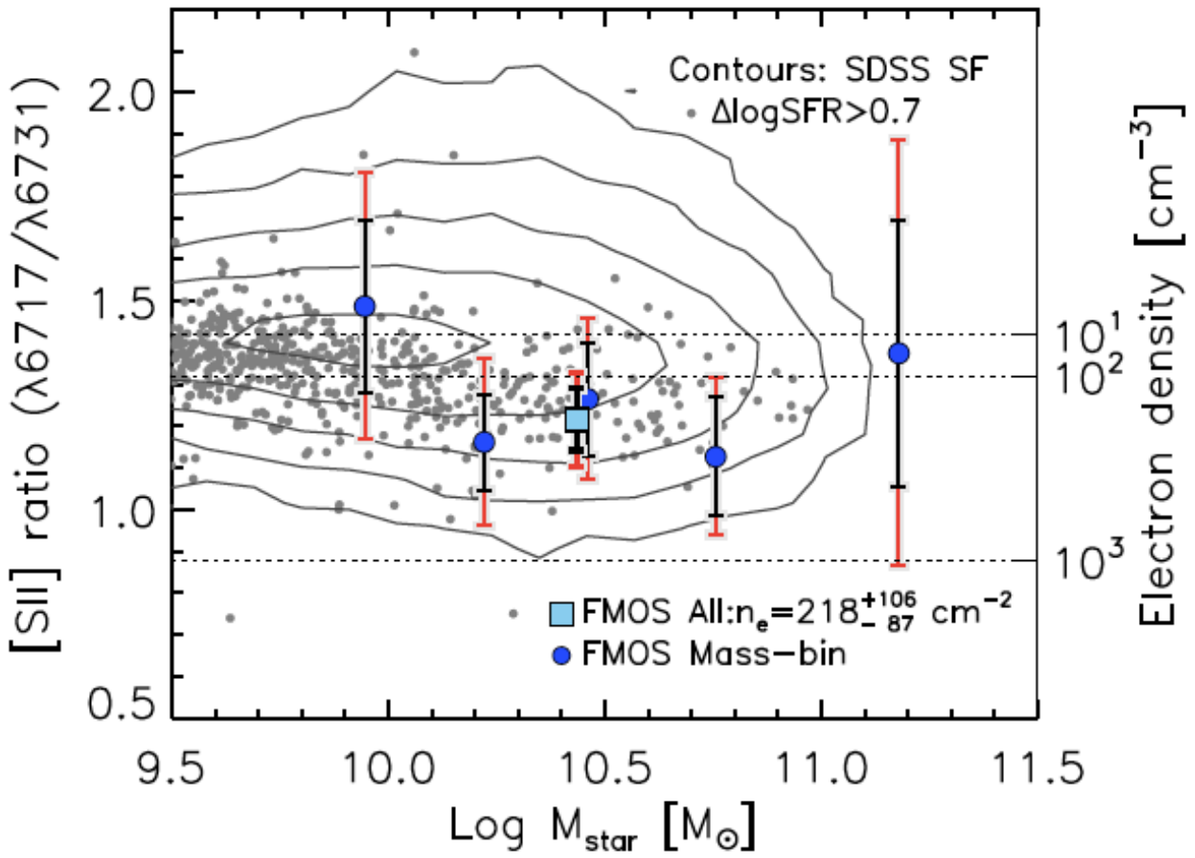

Kashino et al. in preparation

Stacked Chandra image



# Electron density




**Average electron density:** $n_e = 218^{+169}_{-126}$ cm$^{-3}$

Local star-forming galaxies: 10-100 cm$^{-3}$ (e.g., Brinchmann+08)

moderately (x2–10) **enhanced** from the average of local SF galaxies

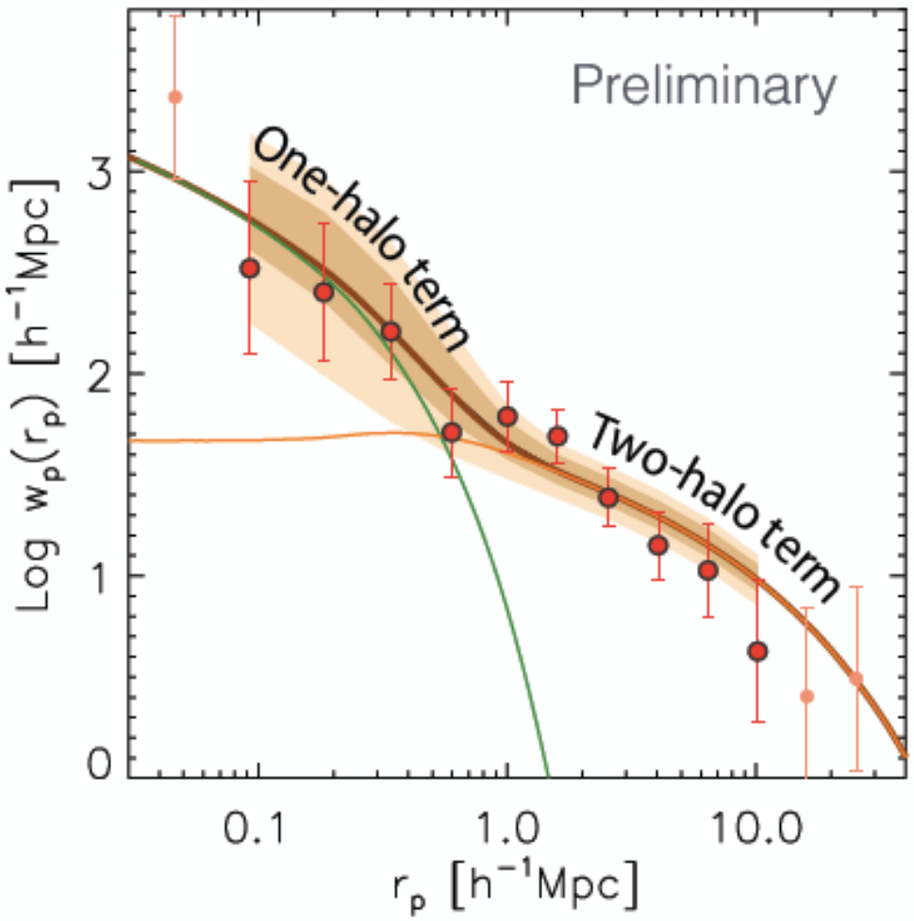
Consistent with recent studies at z>2 (e.g., Shimakawa+15, Sanders+15)

Kashino et al. in preparation

# Galaxy-DM halo connection

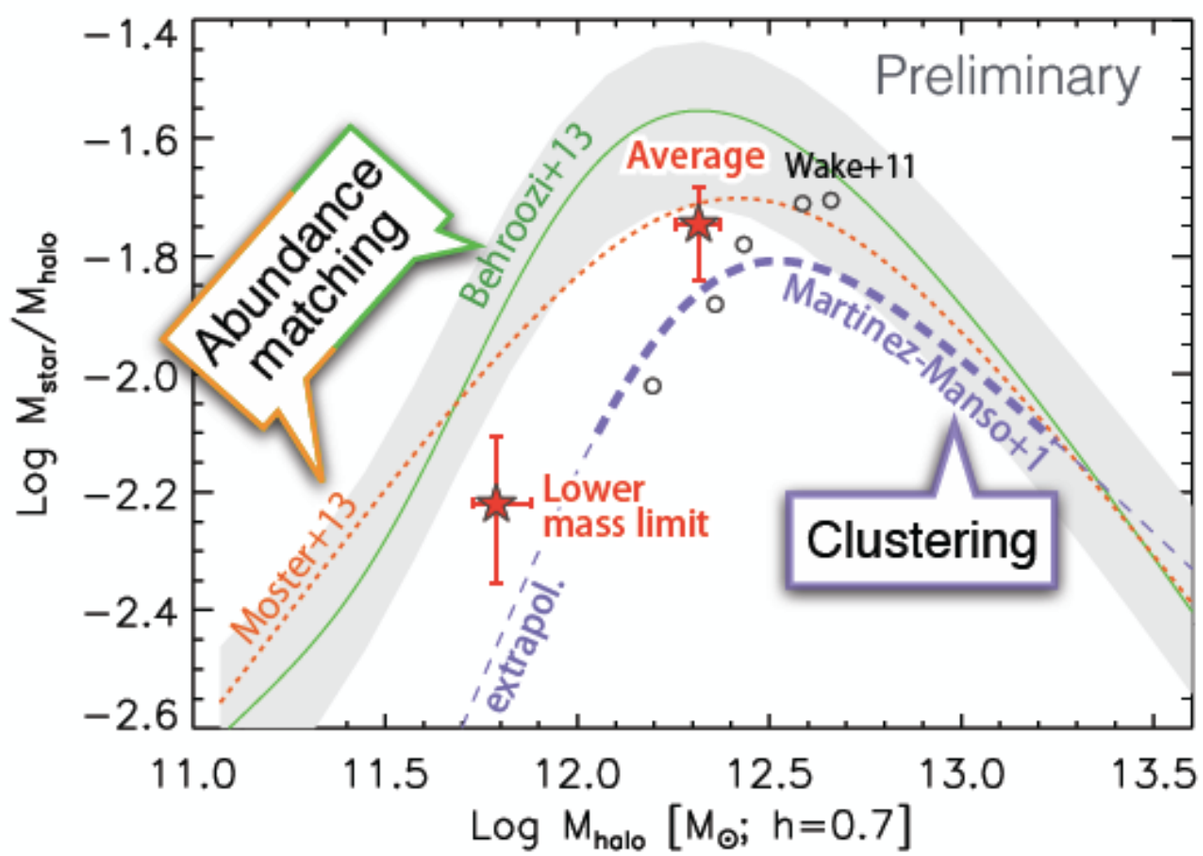
**Kashino** et al. submitted soon

- Correlation function with **500 $z_{spec}$'s**
- HOD modeling
  - Significant **one-halo** term
  - Effective constraints on the HOD parameters



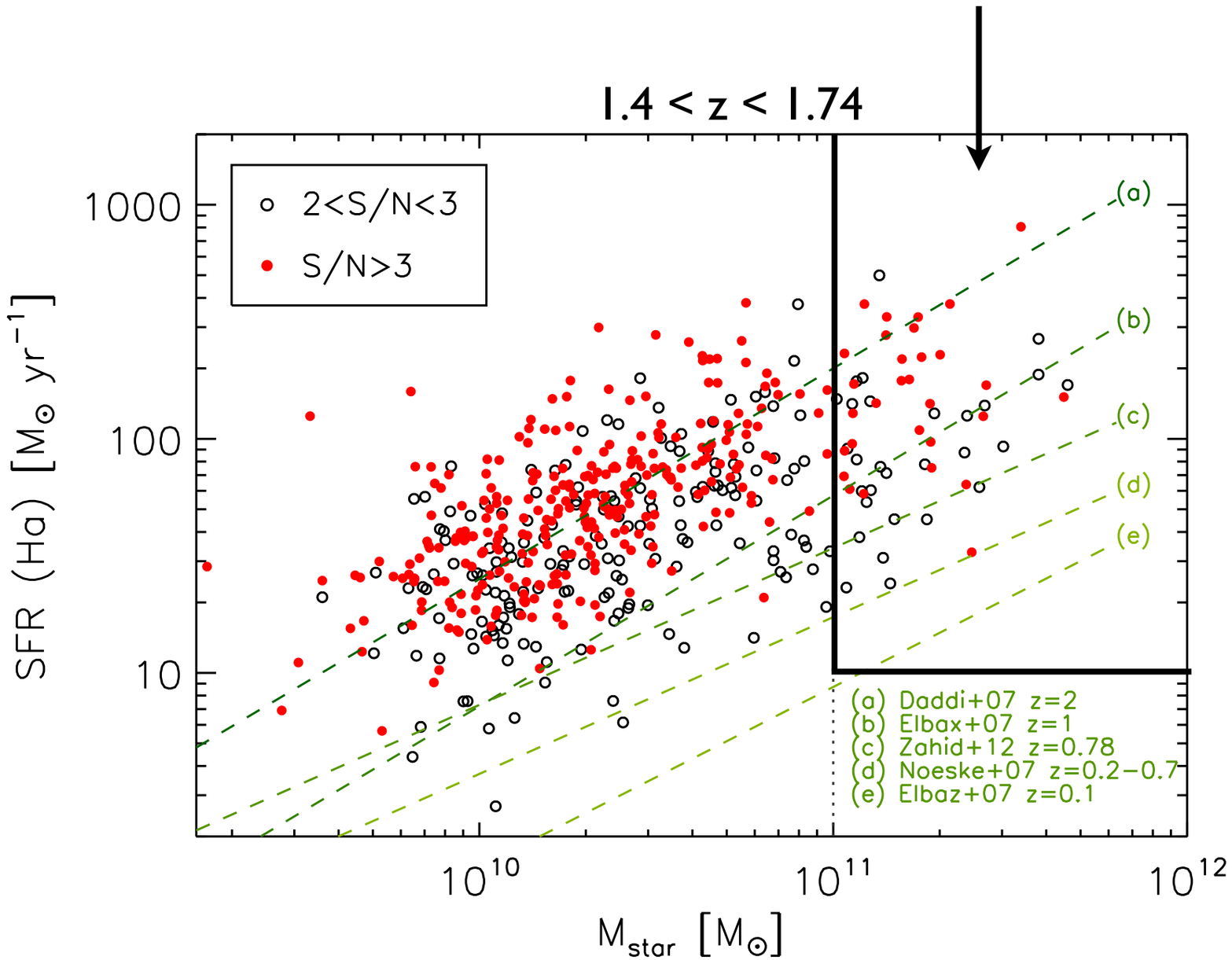

- On average, SF galaxies at z~1.6 ($M_\star > 10^{9.8} M_\odot$) **live in a few × $10^{12}$ $M_\odot$/h haloes.**

**Stellar-to-halo mass ratio**



# FMOS-COSMOS Intensive Program I1+III:
## Rare key populations - Massive galaxies and AGN

### Lack of massive galaxies at z > 1 in all NIR samples

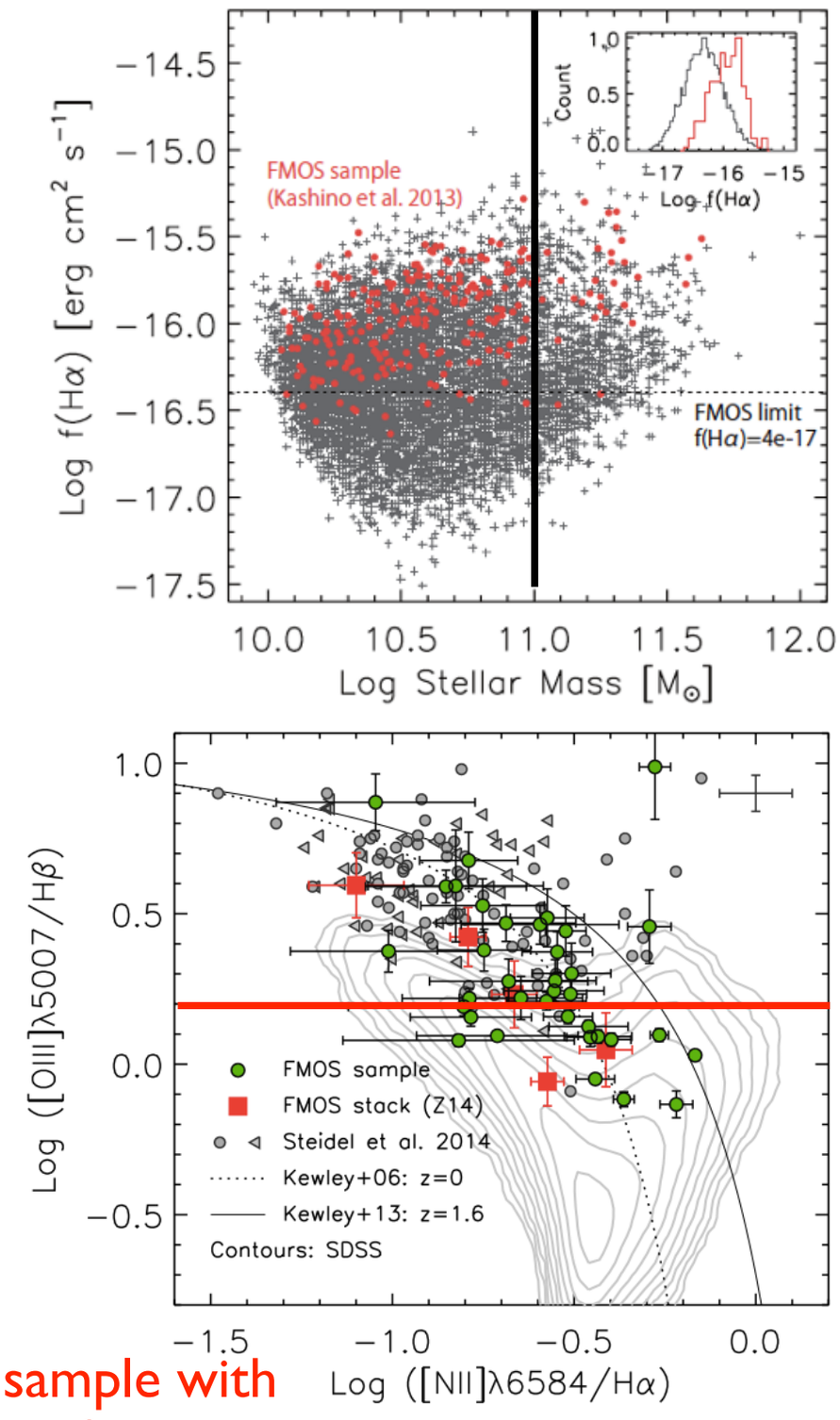



Aim: ~200-300 massive ($M > 10^{11}\ M_\odot$) galaxies at $z \sim 1.6$

# FMOS-COSMOS Intensive Program II+III:
## Rare key populations - Massive galaxies and AGN

Primary science objectives:

- Are there signs of quenching at high-masses (log M > 11)?




- Are the ISM conditions dissimilar to local galaxies?

- Do AGNs reside in the majority of massive galaxies?

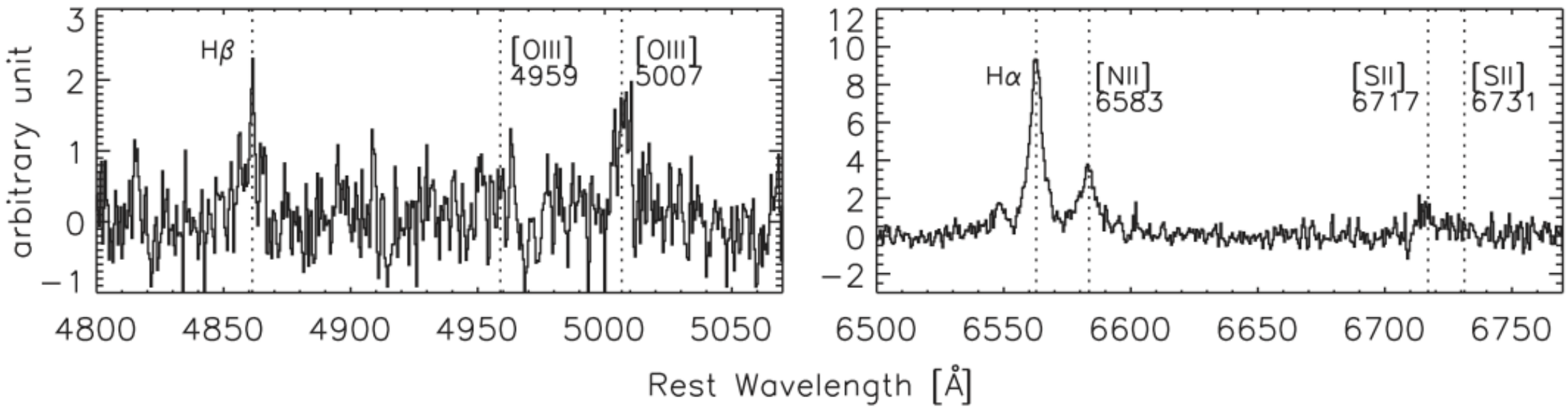
- increase sample with log [OIII]/Hβ < 0.2

# FMOS-COSMOS Intensive Program II+III:
## Rare key populations - Massive galaxies and AGN

J-long followup (1.1.-1.35 μm; Hβ, [OIII]5007)
of galaxies with positive Hα detections

- Improve the number of individual Hβ and [OIII]5007 detections
- Higher S/N detection with average line strengths

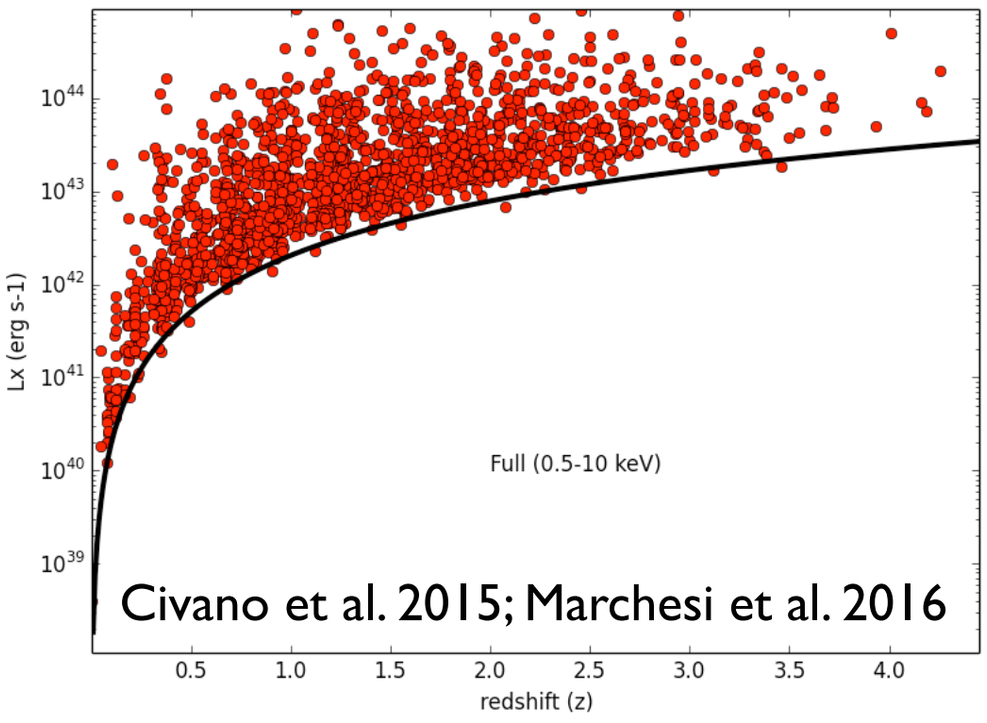
Stack of 25 (J-long) and 68 (H-long) massive (log Mstellar > 11) galaxies



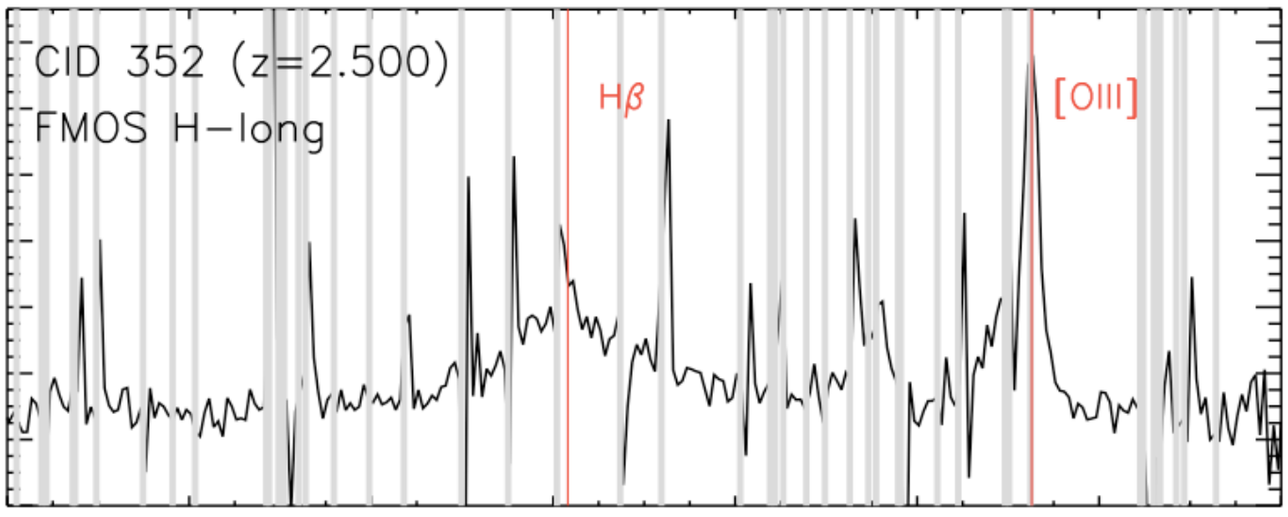
# FMOS-COSMOS Intensive Program II+III:
## Rare key populations - Massive galaxies and AGN

New full Chandra X-ray coverage of COSMOS (4016 X-ray point sources)

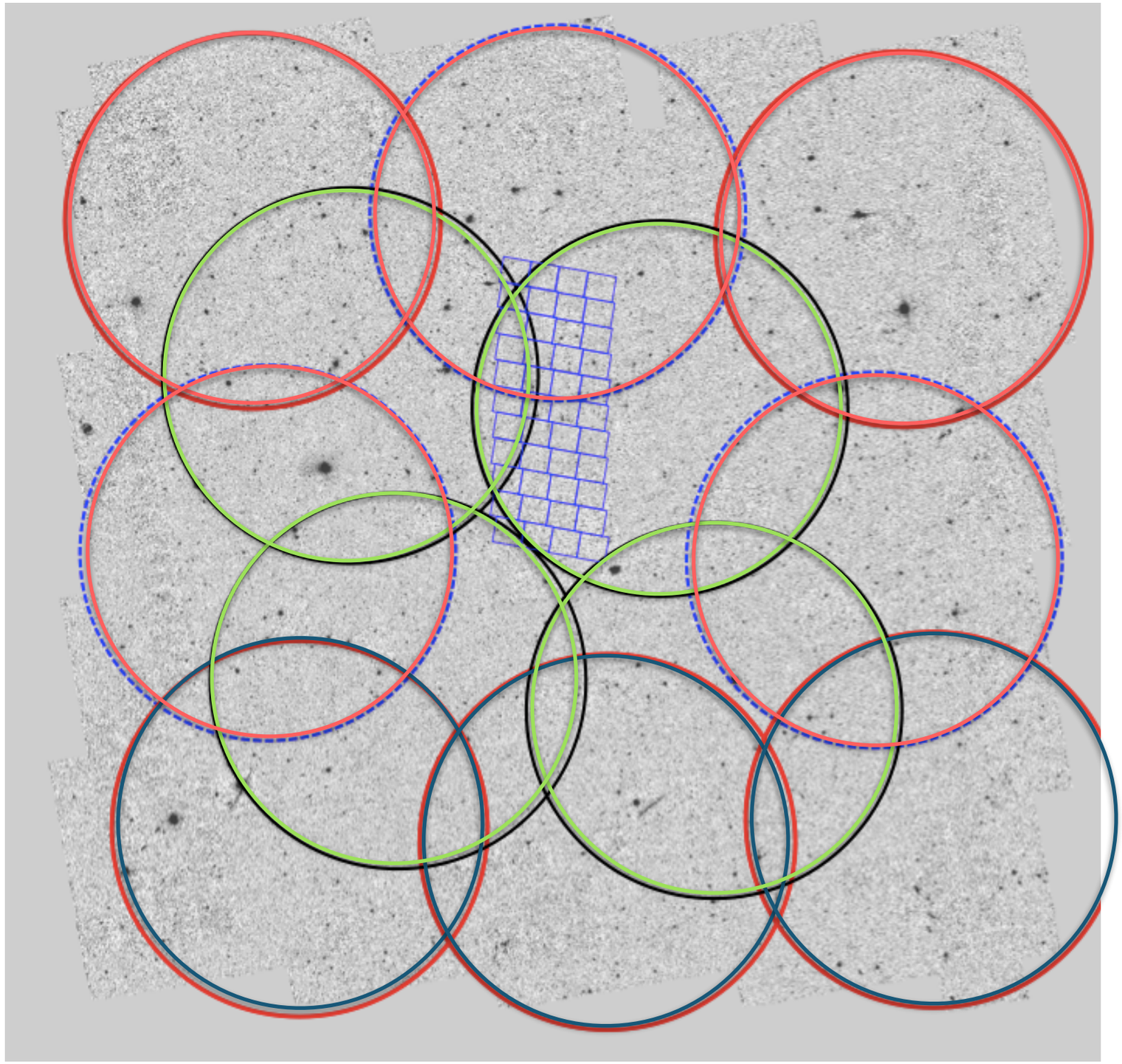
- Black hole mass estimates using the Hα, Hβ and MgII broad emission lines (Matsuoka, JDS et al. 2013)
  - enables an assessment of the accretion efficiency ($L_{BOL}/L_{Edd}$) and relation to coronal X-ray emission (Brightman, JDS et al. 2013)
  - determine the mass function of active (type 1) AGN and active fraction of galaxies at $1 < z < 2$
- Establish the high-z AGN selection using rest-frame optical emission lines
  - Local BPT selection may not be applicable at high-z (Kewley et al. 2013)
- Kinematics of both the broad line and narrow line regions with the latter providing evidence of AGN-driven outflows (see asymmetric wing on [OIII])



Civano et al. 2015; Marchesi et al. 2016

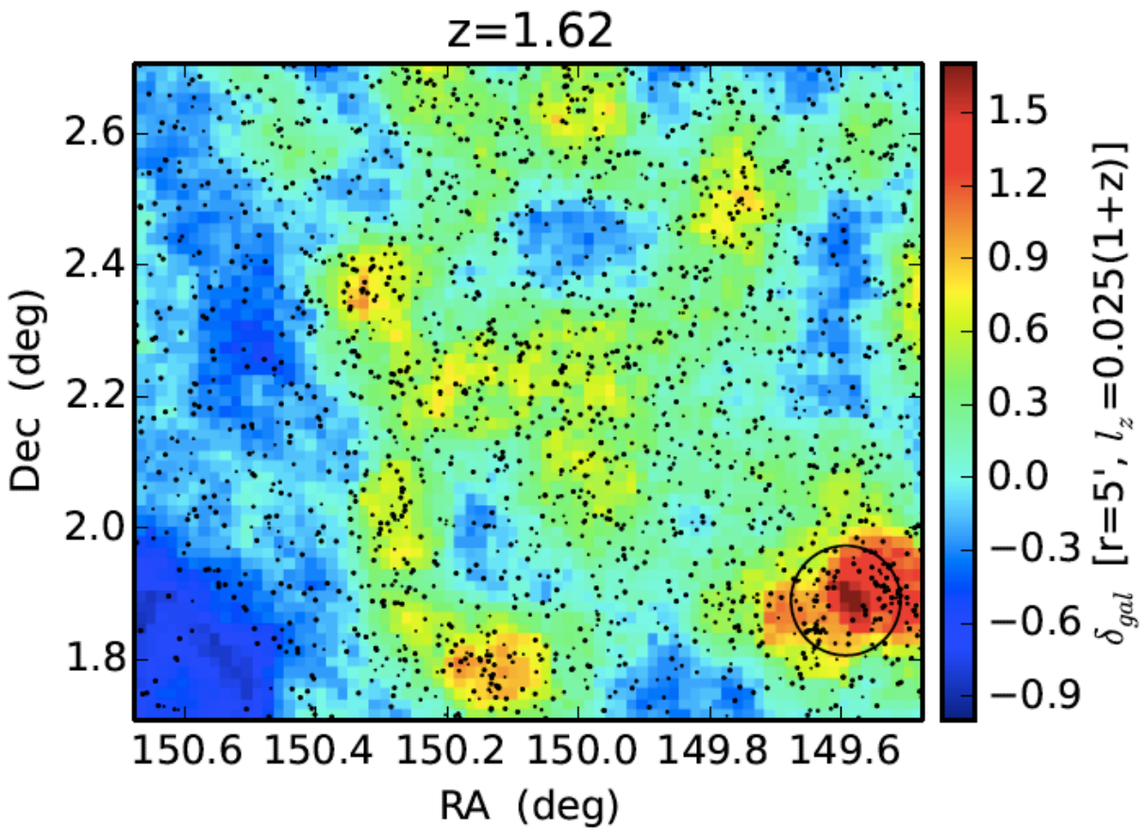


# FMOS-COSMOS Intensive Program II+III:
## Observing plan

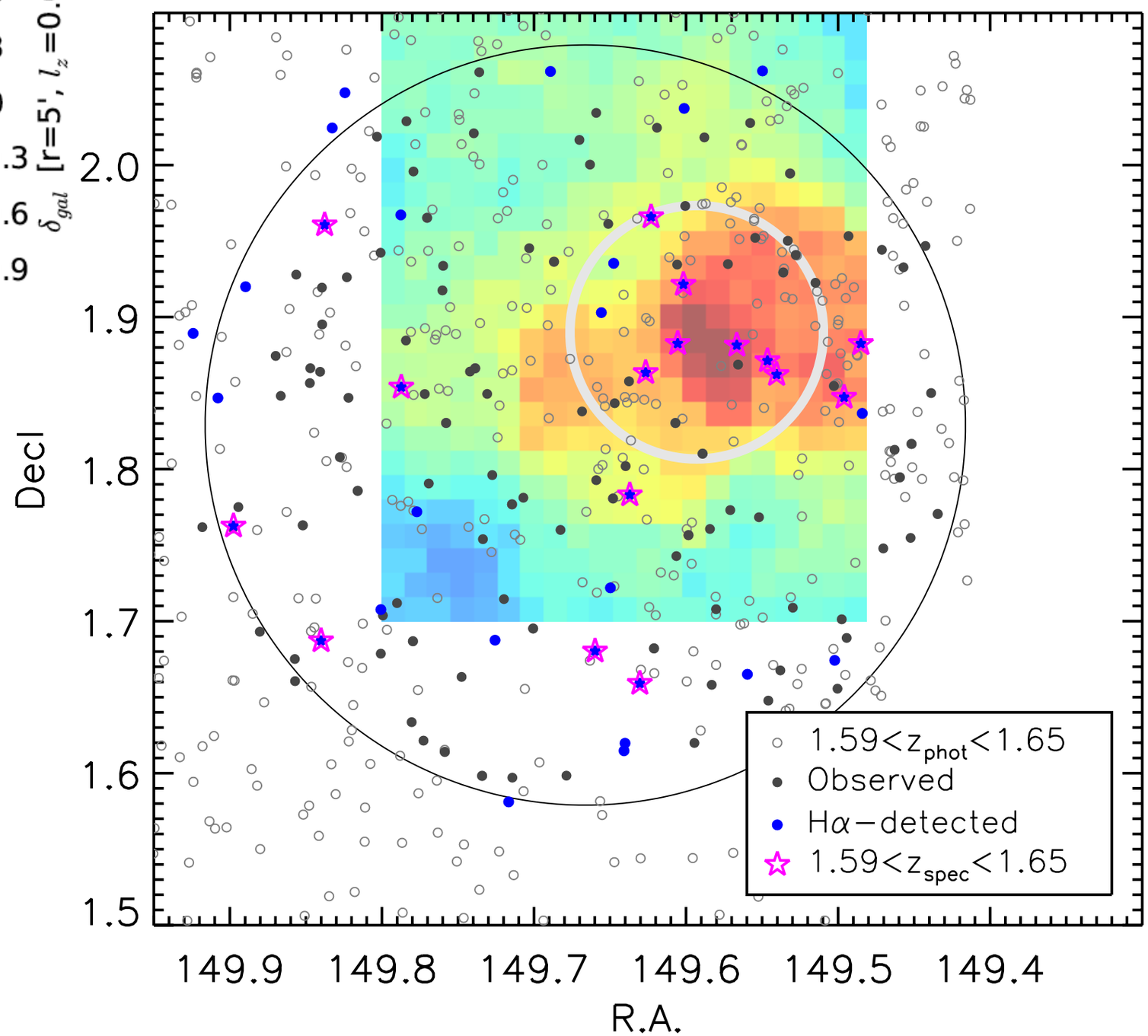


New pointings in red and blue

# Confirming a galaxy overdensity in COSMOS at z ~ 1.6



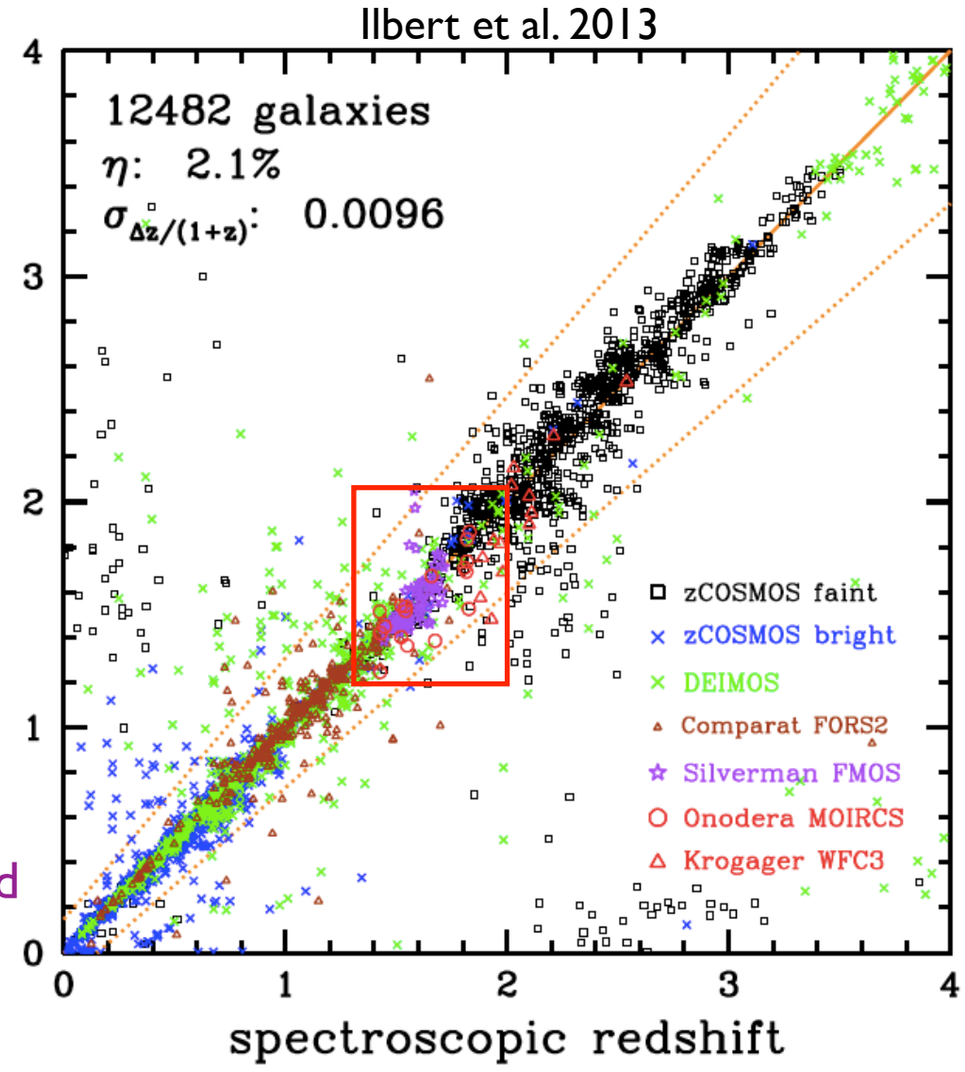

Chiang, Overzier et al. 2015



# FMOS-COSMOS Intensive Program II+III:
## Legacy value

- FMOS spectroscopy fills a void in the wide spectroscopic redshift coverage of COSMOS, a key extragalactic survey field and an HSC Ultradeep field

- FMOS spectroscopy is improving photo-z estimation for HSC surveys and target selection for cosmology experiments with PFS




- All high-level data are released to the public

- Flux calibrated 1D spectra in fits format (object + error spectra)

- Redshift catalogs

- Line flux measurements

Data release from the first intensive program has been accomplished
http://member.ipmu.jp/fmos-cosmos/FMOS-COSMOS.html
(includes catalogs, 1D and 2D science grade spectra)

# Other studies underway:

## Hα luminosity function and implications for Euclid

w/ Olivier Le Fevre, L. Tasca, E. Daddi

## [OII] followup on Keck and VLT: Fine-tuning the PFS BAO experiment at z ~ 1.6

w/ L. Kewley (PI Keck), S. Juneau (PI VLT), K. Yabe

## ALMA CO [2-1] imaging of high-z starbursts in Cycle 3

JDS et al. 2015