ULTIMATE-Subaru Science Workshop 2014

July 28 - 29th, 2014, Mitaka, Japan

Formation and role of accreting SMBHs in forming massive galaxies

KOHNO Kotaro

The Univ. of Tokyo

Outline of this talk

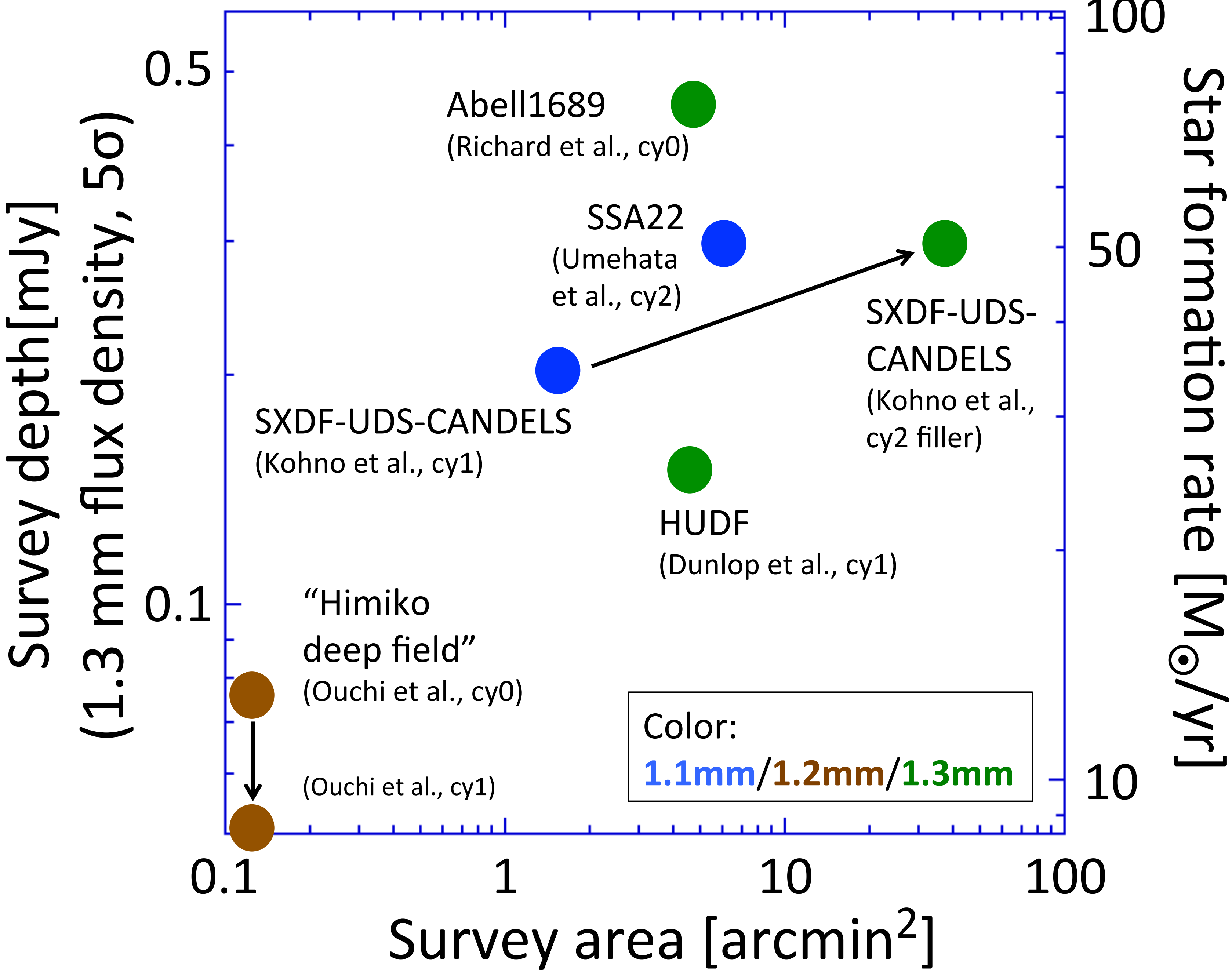
- ULTIMATE-Subaru: synergy with ALMA
  - On-going/upcoming ALMA deep surveys
  - Importance of NB-selected (line emitting) galaxies

- A possible science case: formation and role of accreting SMBHs in the forming high-z (z>2) massive galaxies in the biased environment

ULTIMATE-Subaru: Synergy with ALMA

- 0”.2 resolution, ~13’ FoV (imaging) ➔ well fitted to the specifications of the on-going/upcoming ALMA deep surveys
  - 0”.9~0”.5 resolution deep imaging over a few $arcmin^2$ area (cy0, cy1, cy2) ➔ ~0”.2 resolution imaging (cy3+) to achieve high resolution (without losing sensitivity to extended emission); wider surveys up to a few 10 $arcmin^2$ will also be executed
  - λ ~1mm dust continuum, SFR ~ a few 10 $M_{\odot}$/yr ➔ emission-line galaxies (Hα emitters, [OII] emitters, etc.) uncovered by NB imaging survey using ULTMATE-Subaru can also be detected by these ALMA deep surveys

On-going deep surveys using ALMA

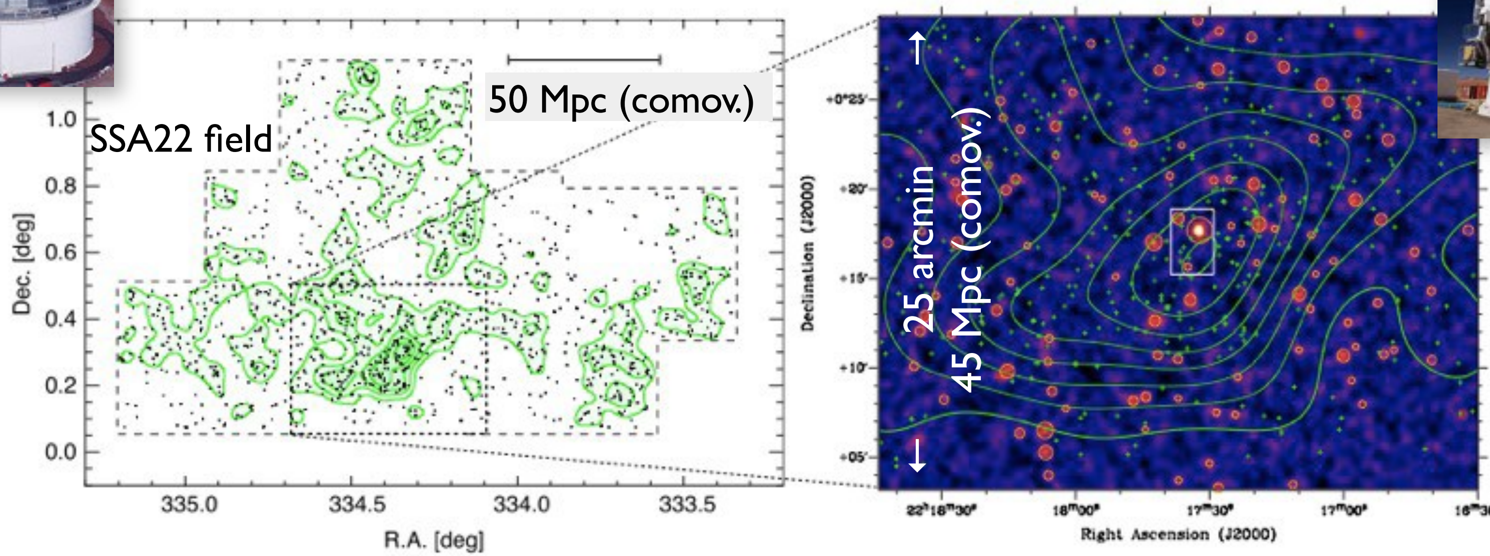


Obscured Star Formation in the Largest Protocluster at z = 3.1

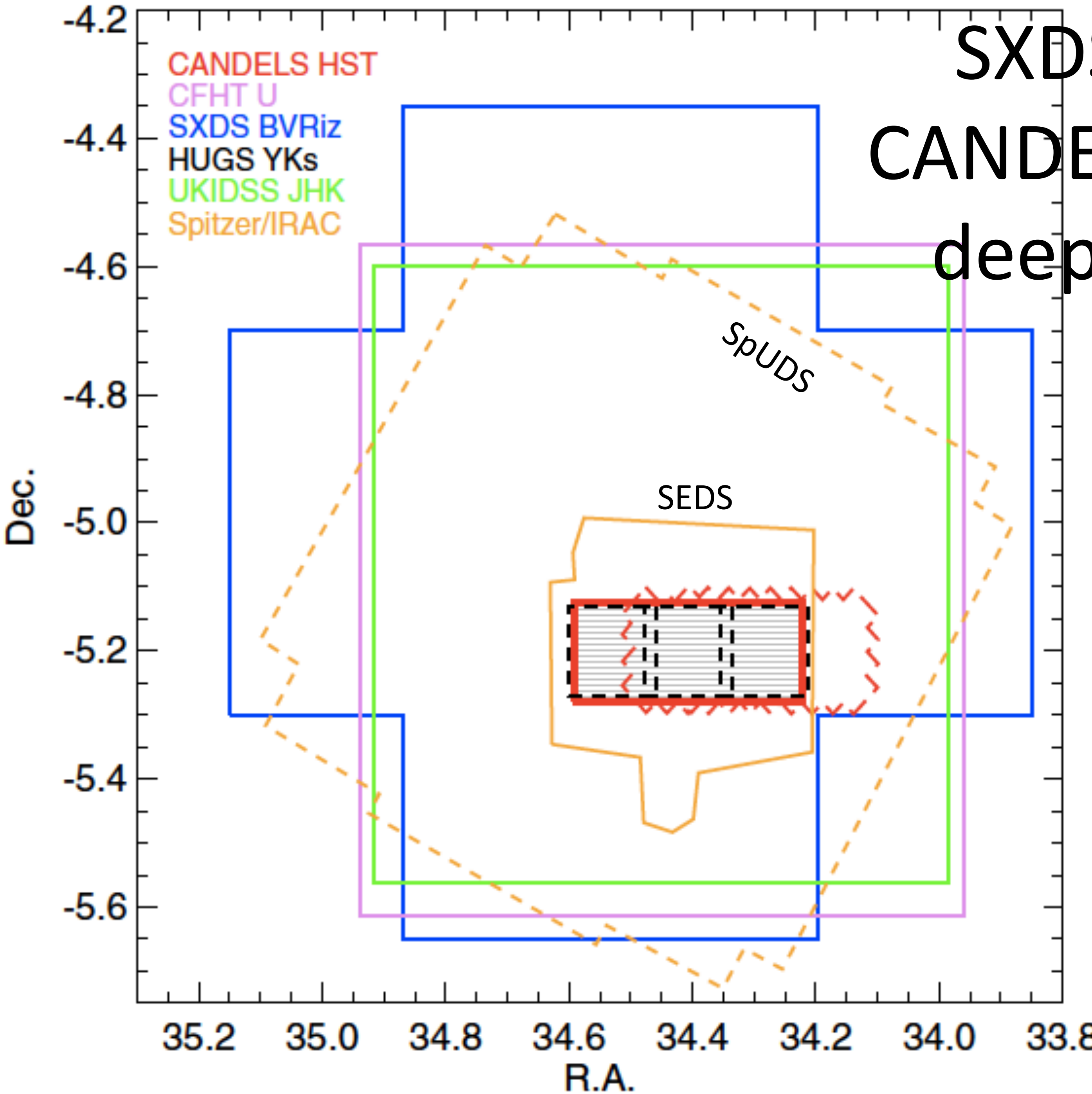
- Many galaxies (LAEs, LABs, LBGs, DRGs, AGNs, SMGs) are identified (Steidel+98, 00; Barger+99; Hayashino+04; Matsuda+04, 05; Uchimoto +08, 12; Yamura+09; Lehmer+09ab; Kubo+13;).
- SMGs can be signposts of underlying large-scale structures (LSSs) (Tamura +09; Umehata+14)
- The brightest SMG w/ a buried quasar seems to be associated with a z = 3.1 LSS (Tamura+10)

Lyα emitters (LAEs, dots) and LAE density (green shade)

1.1-mm map (background) and LAE density (contours)



SXDS-UDS-CANDELS-ALMA deep survey



CANDELS-UDS
(+ VLT/HAWK-I)
22’.3 x 9’

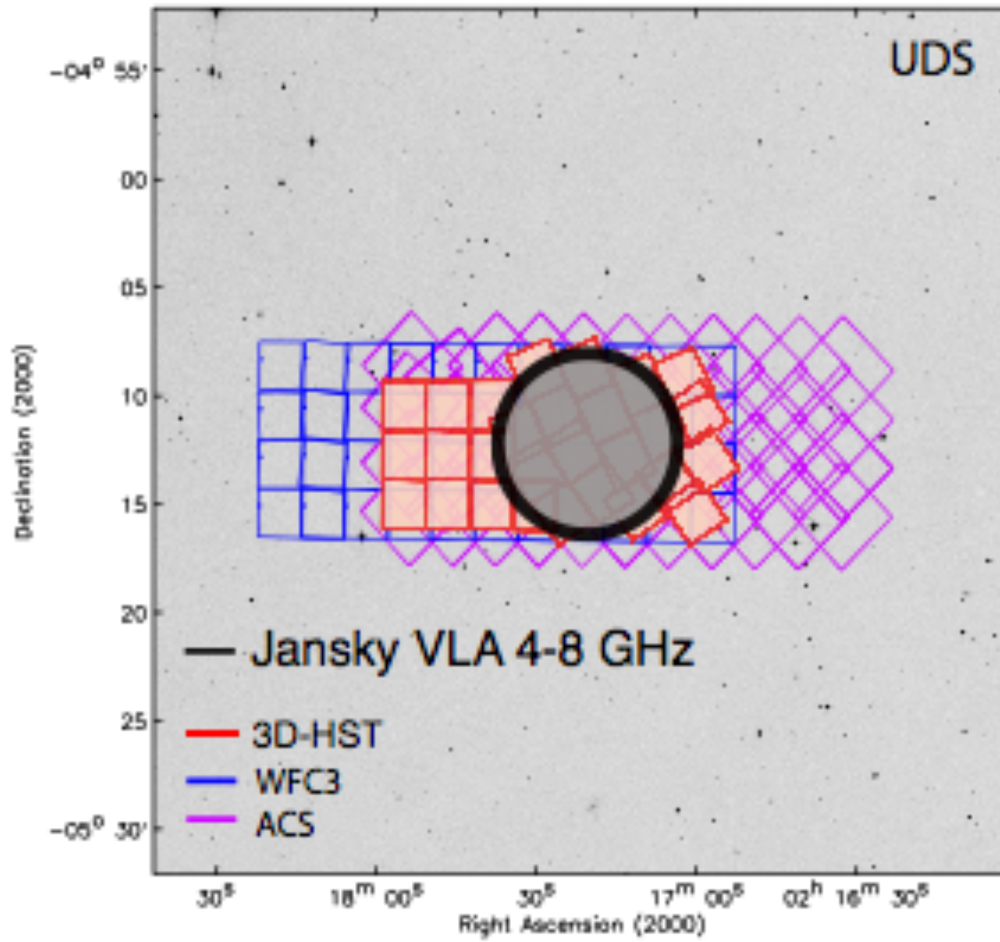
Galametz et al. 2013, ApJS, 206, 10

SXDS-UDS Ancillary data (submm-radio)

- AzTEC/ASTE 270 GHz (1.1 mm) (Ikarashi et al.)
- Herschel PACS/SPIRE
- JVLA 1.4 GHz (20cm)
- JVLA 4-8 GHz

  (5cm, C-band)

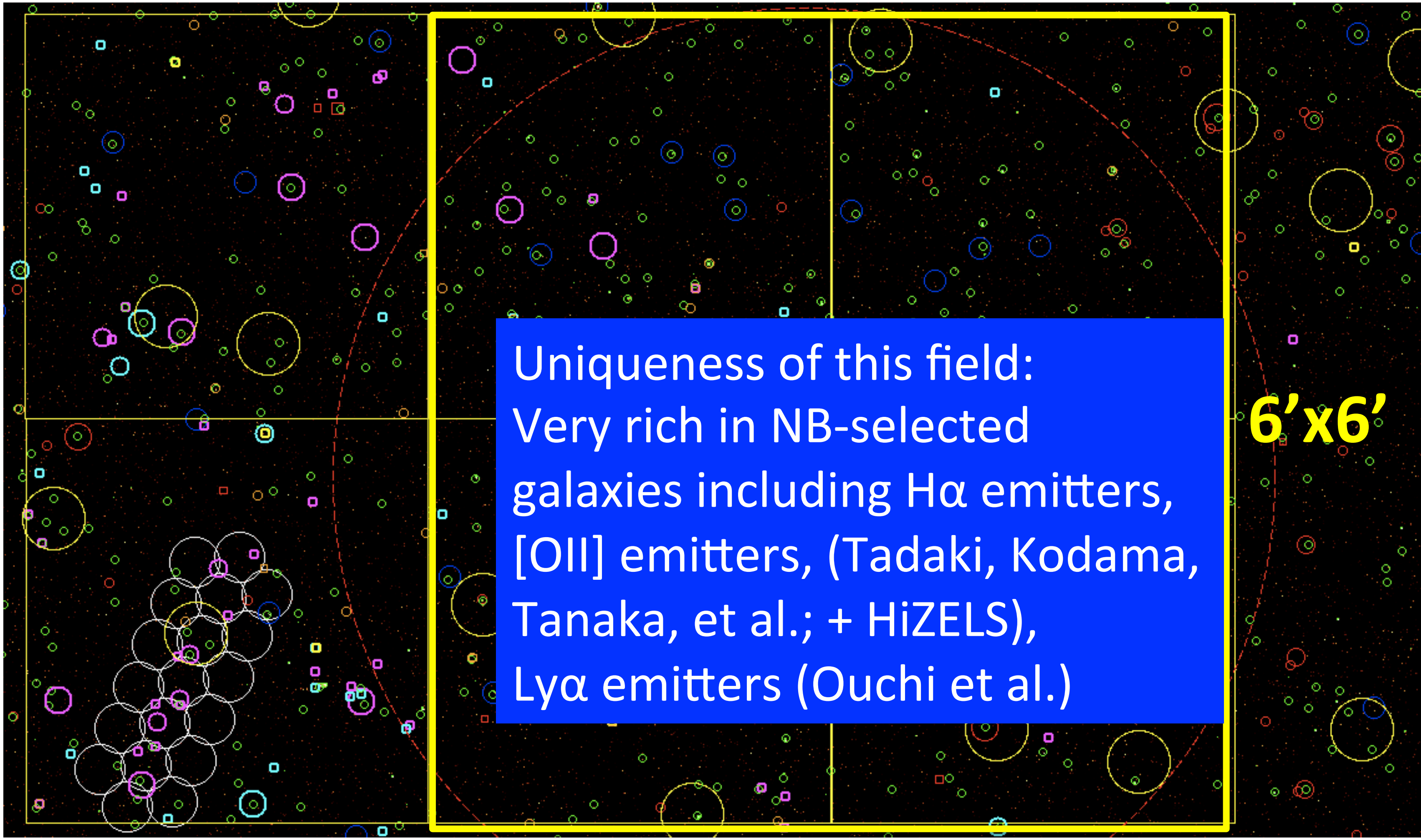
  (Rujopakarn et al.)
  - 0".28 resolution
  - 0.55 μJy/beam (!)



Survey area

Large red dashed cirlce
JVL C-band FoV (7arcmin)

Yellow squares: proposed ALMA FoV
Large yellow circles: AzTEC source

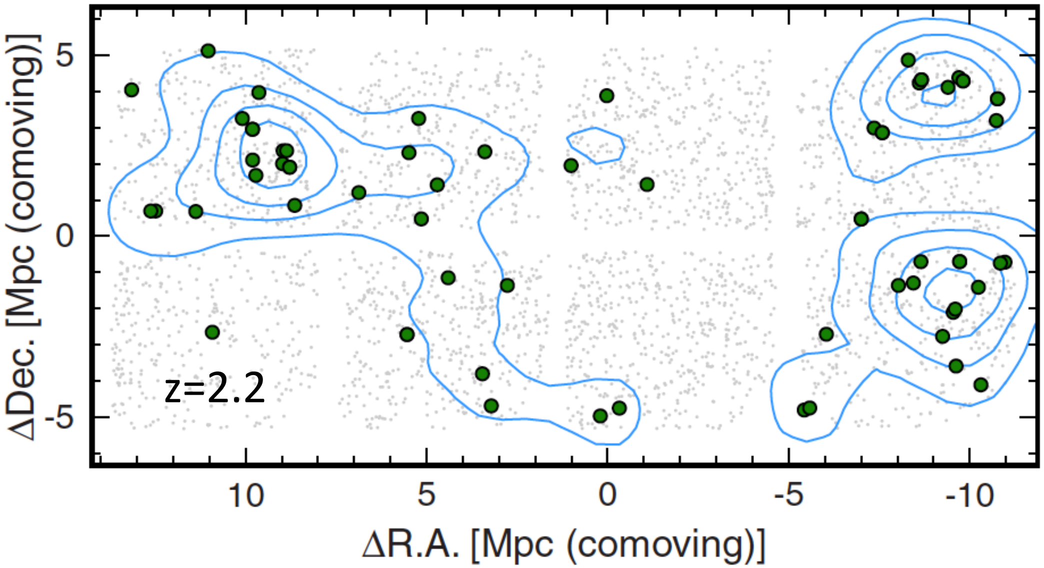


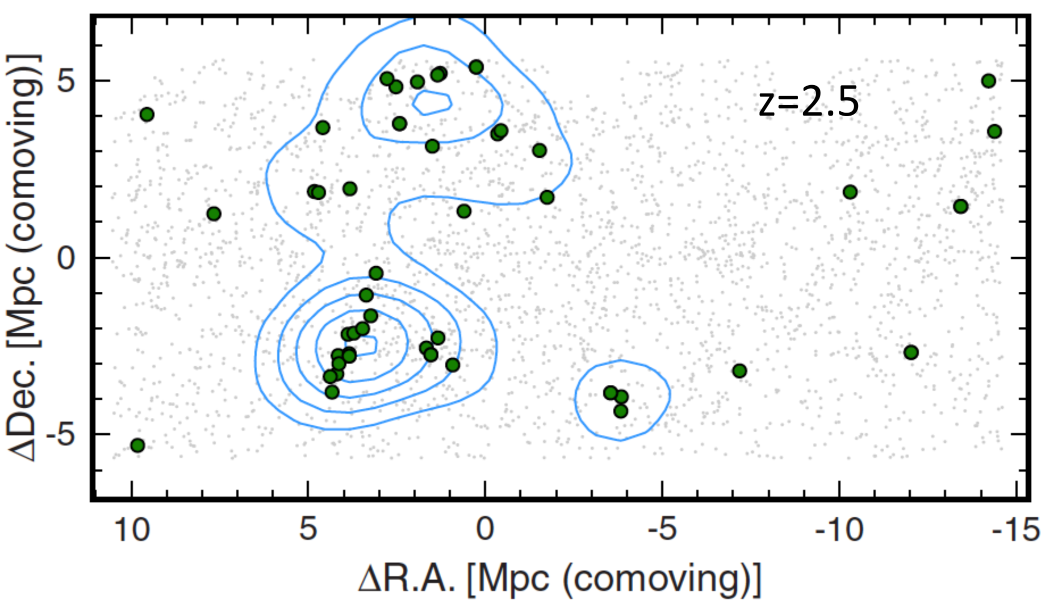
Uniqueness of this field:
Very rich in NB-selected galaxies including Hα emitters, [OII] emitters, (Tadaki, Kodama, Tanaka, et al.; + HiZELS),
Lyα emitters (Ouchi et al.)

Green circle: MIPS 24μm
Magenta circle: Hα emitters at z=2.53 (MAHALO)
Red circle: Hα emitters at z=2.19 (MAHALO)
Red square: Hα emitters at z=2.23 (HiZELS)

Orange circle: Hα emitters with [OIII], [NII] lines at z=1.4-1.7
Orange square: Hα emitters at z=1.47 (HiZELS)
Cyan circle: [OII] emitters at z=1.6-1.7
Blue circle: XMM-Newton sources

Large scale structures traced by Hα-selected galaxies

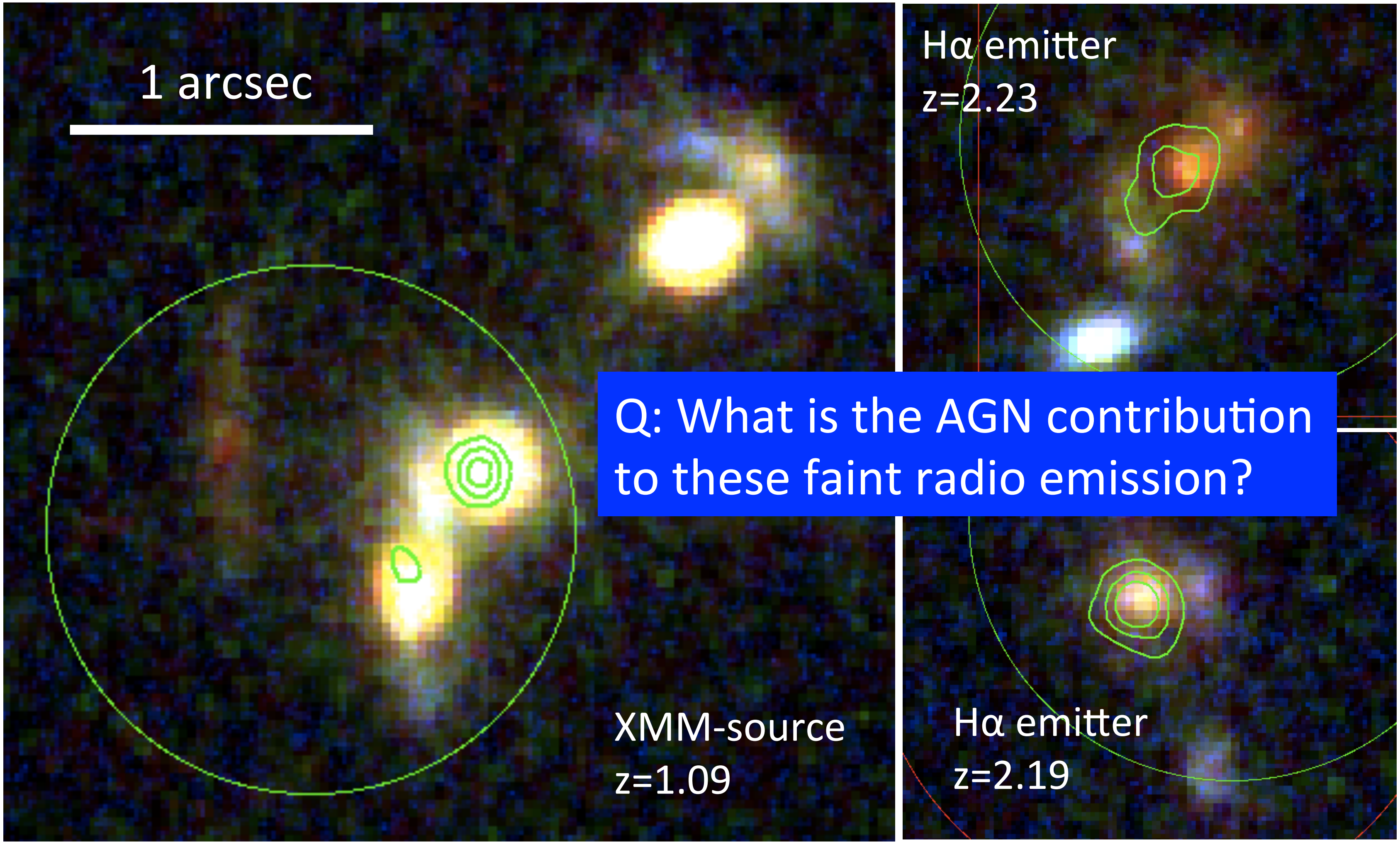




- High-z Hα emitters in the over-dense regions ➔ progenitors of massive and quiescent galaxies like giant elliptical galaxies in the local clusters/groups
- Do they host AGNs?
- (if yes) What is the roles of AGNs in these Hα-selected galaxies?

Tadaki et al. 2014, ApJ, 780, 77

AGN and starburst galaxies with MIPS 24μm and VLA 5cm emission



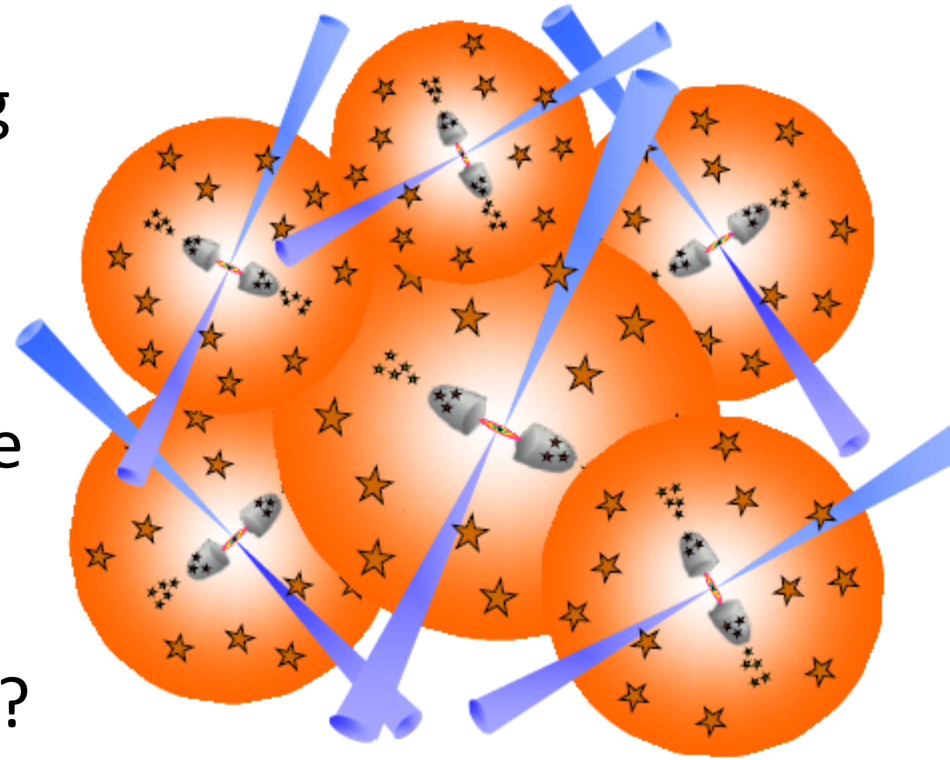
Q: What is the AGN contribution to these faint radio emission?

VLA C-band (5cm) radio contours on WFC3 pseudo-color image (F160W/F120W/F814W)
Green circles mark the position of MIPS 24μm sources.

Science case for ULTIMATE-Subaru: understanding the formation and role of SMBH in forming massive galaxies in the biased environments

Off-center, multiple AGNs as one of the possible paths toward SMBH

- Off-center multiple AGNs can be expected as building blocks of SMBHs if both merging of seed BHs and accretion onto them occur
- Can we observe them in the early universe?
- Can major mergers host multiple (accreting) SMBHs?



http://astrophysics.jp/ALMA-Hokudai2012/presentation/Umemura(Hokudai13).pdf

Single-pointed spectroscopy with MOS is not sufficient.

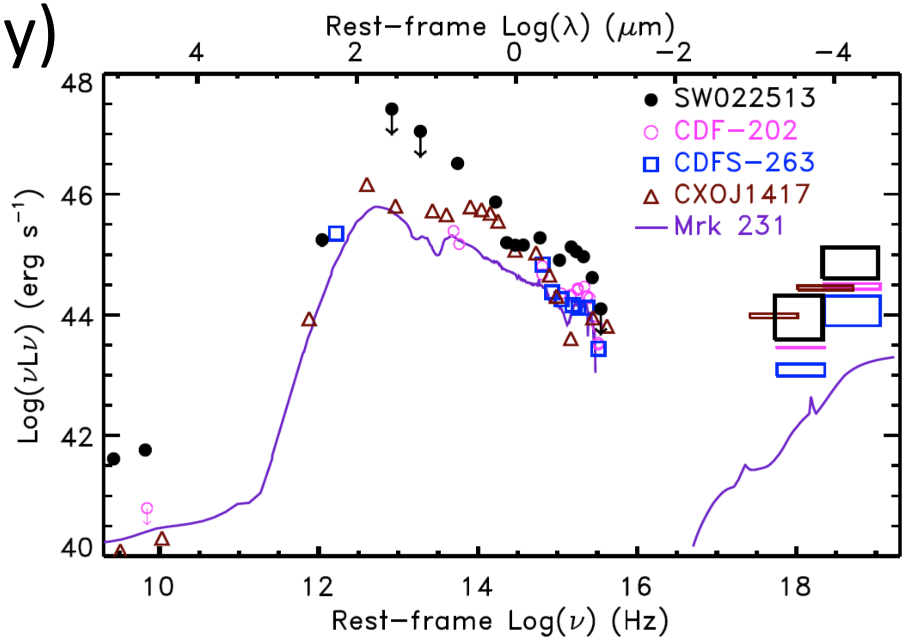
➔ spatially-resolved imaging spectroscopy using IFU !

A possible observing program using ULTIMATE-Subaru

- [OIII]5007 & Hβ imaging spectroscopy toward forming massive galaxies in the biased environment
  - Possible target fields (just example):
    - 4C23.56 @z=2.5 ([OIII] @1.75μm, Hβ @1.70μm)
    - SSA22 @z=3.09 ([OIII] @2.05μm, Hβ @1.99μm)
  - Similar galaxies in the blank field are also needed for comparison
    - Hα emitters in SXDF @z=2.2, 2.5 (Tadaki et al. 2014)
  - Identify AGN(s) and its/their roles (feedback) via [OIII] velocity field and [OIII]/Hβ line ratios

Even in dusty galaxies, rest-frame optical emission line can work (?)

- Example: SWIRE J022513 (z=3.43)
  - Selected as 24μm-bright sources in the SWIRE survey
  - Dust-obscured (but type-1) quasar; detected by MAMBO 1.2mm (~5 mJy)

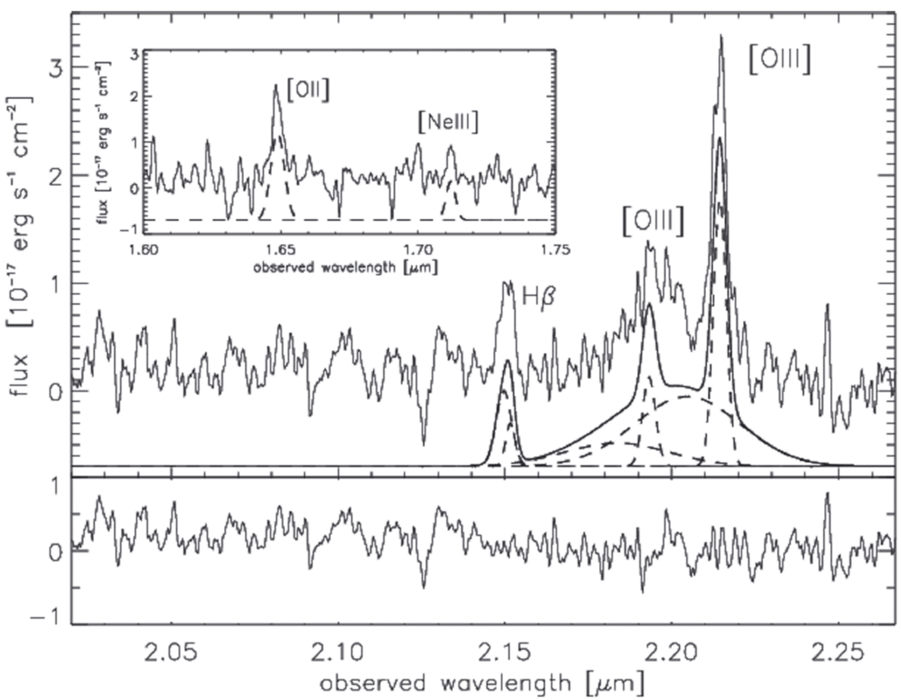


Polletta et al. 2008, A&A, 492, 81

Spatially resolved [OIII] imaging spectroscopy in a dust-obscured quasar

- SINFONI/VLT, 3 hours (on-source)

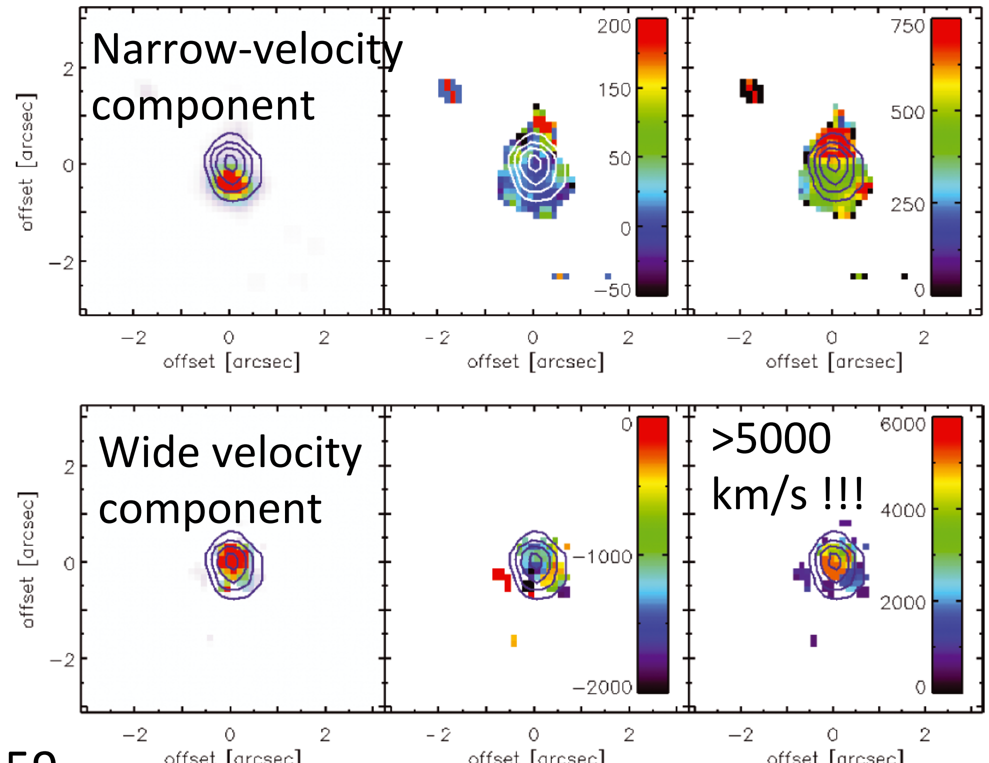
0.4”x0.4” spectrum centered
on the continuum peak (i.e., nucleus?)



Integrated flux

Velocity
(relative)

Line width



Nesvadba et al. 2011, MNRAS, 415, 2359

Massive outflows in ionized and molecular ISM

- Combining [OIII], Hβ, and CO spectroscopy ➔ appropriate estimate of Vsys: essential for the derivation of outflow velocity (and to see if they exceed escape velocity)

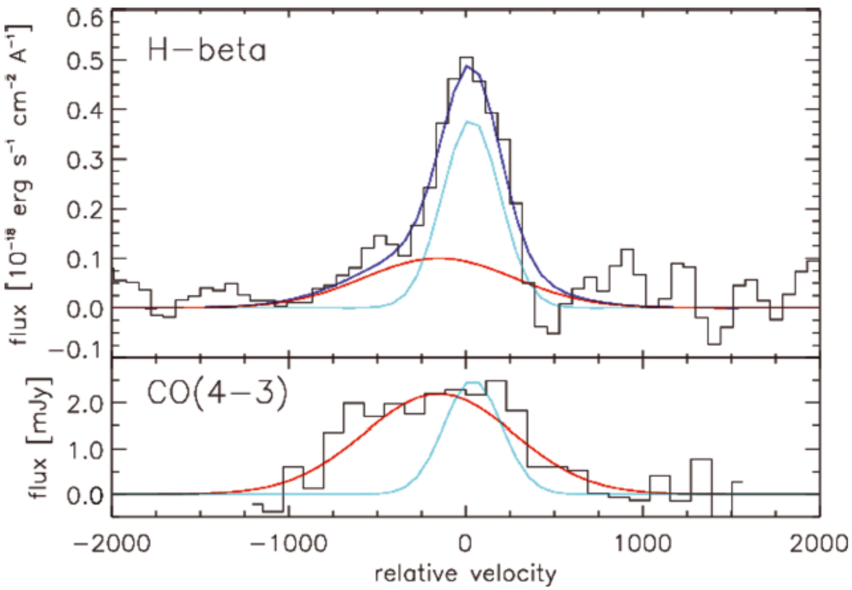


Figure 7. Comparison of the line profile of Hβ near the nucleus (upper panel, see also the middle panel of Fig. 3) and the CO(4–3) emission-line spectrum of SW022513 (lower panel) presented by Polletta et al. (2011). The red, cyan and blue Gaussian distributions show the CO(4–3), narrow Hβ component and sum of both spectra, respectively. The red and cyan distributions have the same wavelength and width in both panels.

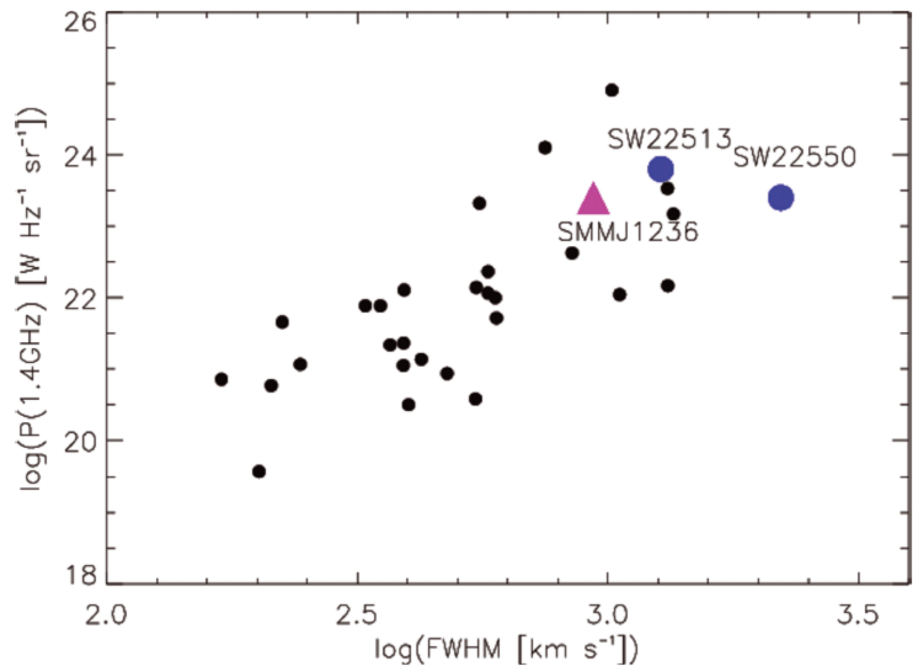
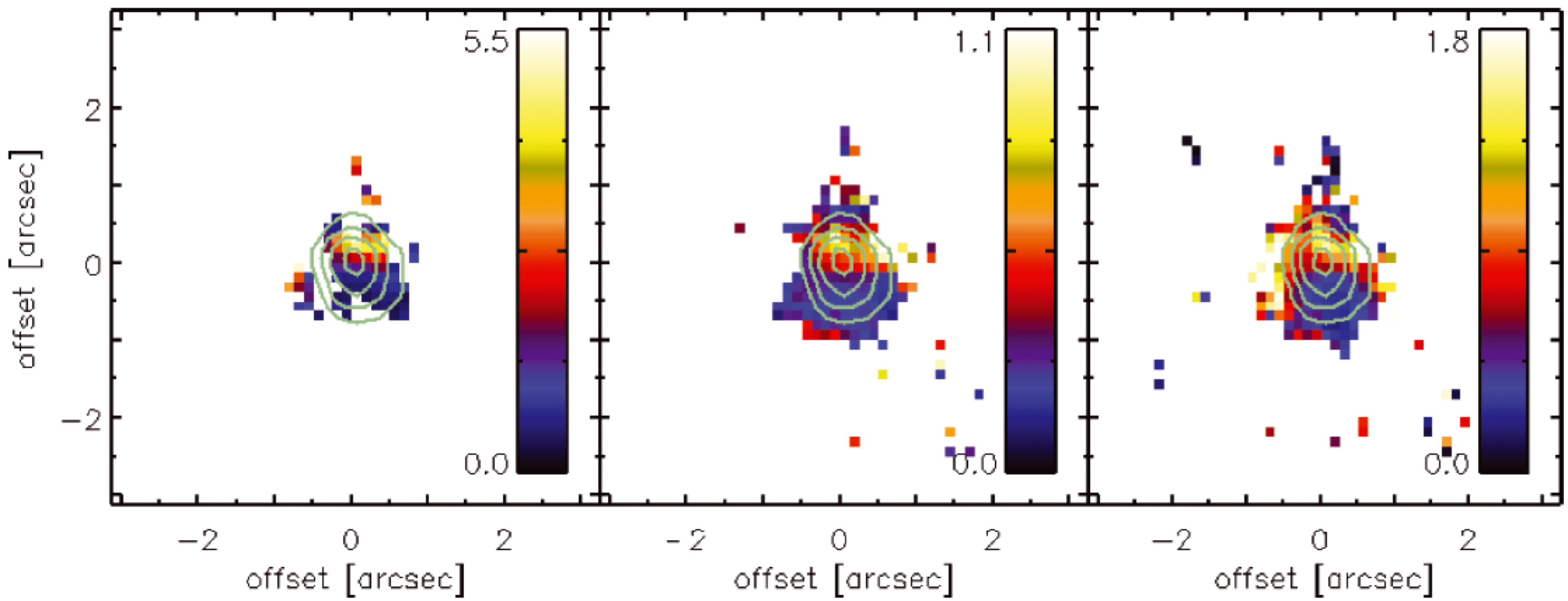


Figure 8. Radio power measured at 1.4 GHz in the rest frame as a function of FWHM of the [O III] λ5007 emission line. Small black dots show nearby AGN spanning a large range in radio power, and are taken from the original version of this plot shown in Heckman et al. (1981). Large blue dots show SW022550 and SW022513, the red triangle shows SMM J1237+6203 (Alexander et al. 2010).

Nesvadba et al. 2011, MNRAS, 415, 2359

Spatially resolved [OIII]/Hβ line ratio map

- Consistent with (single) AGN



Can we find galaxies with signature for multiple, off-center AGNs ???

Nesvadba et al. 2011, MNRAS, 415, 2359

Why ULTIMATE-Subaru?

- Do you really need ***multiple-***IFU spectroscopy? Isn’t it just enough to observe a possible AGN-hosting galaxy one by one? (because the source density must be too small for the FoV of ULITIMATE-Subaru?)
- Two reasons:
  - We are searching for very rare object. Observing large number of targets must be essential. ➔ multiplicity is indeed important.
  - Fraction of forming galaxies with AGN may be increased in the biased environment (?)

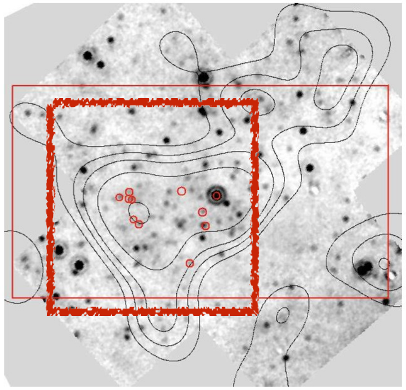
4C23.56

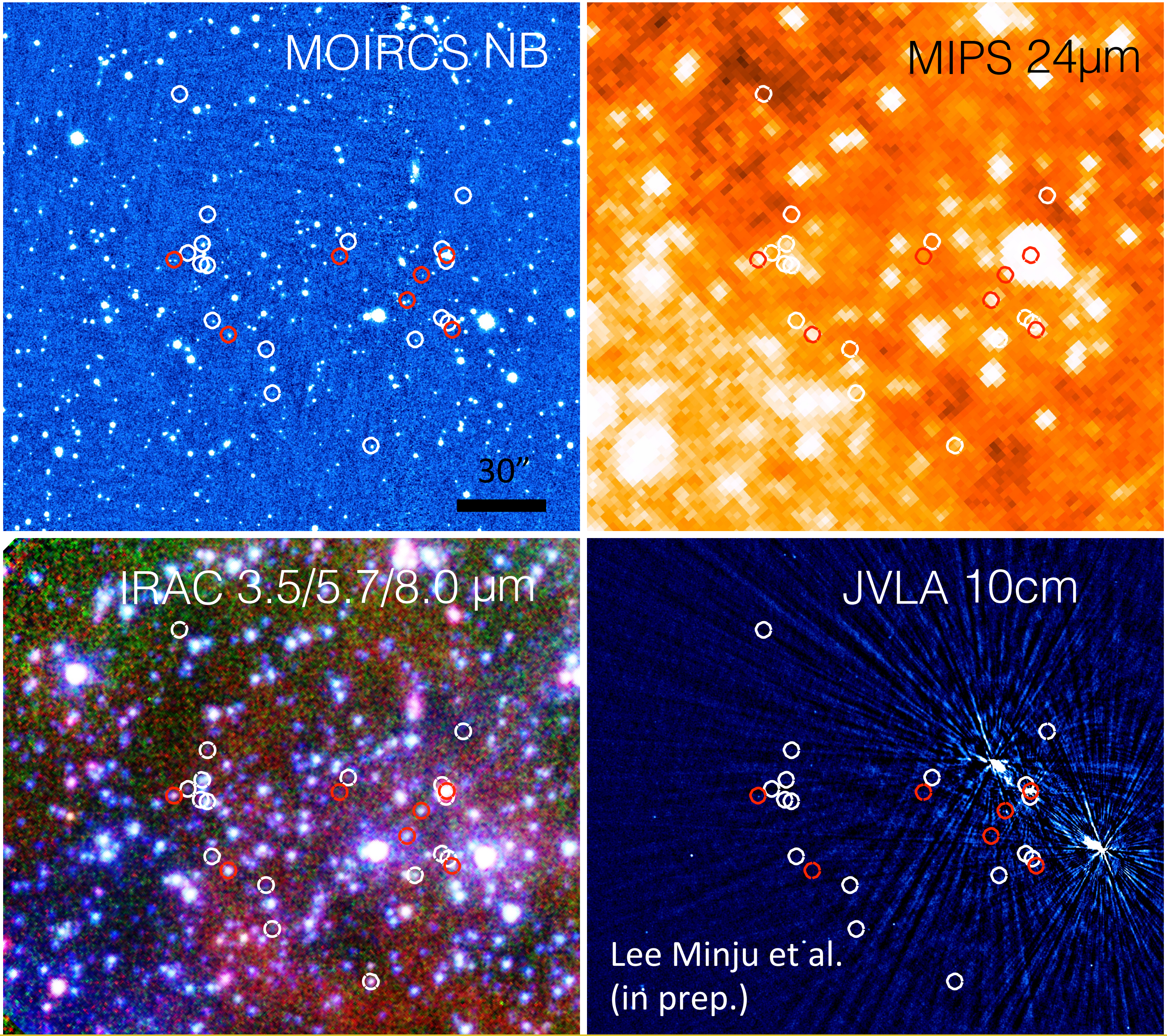
Proto-cluster

z=2.5

Circles:
Hα-selected galaxies

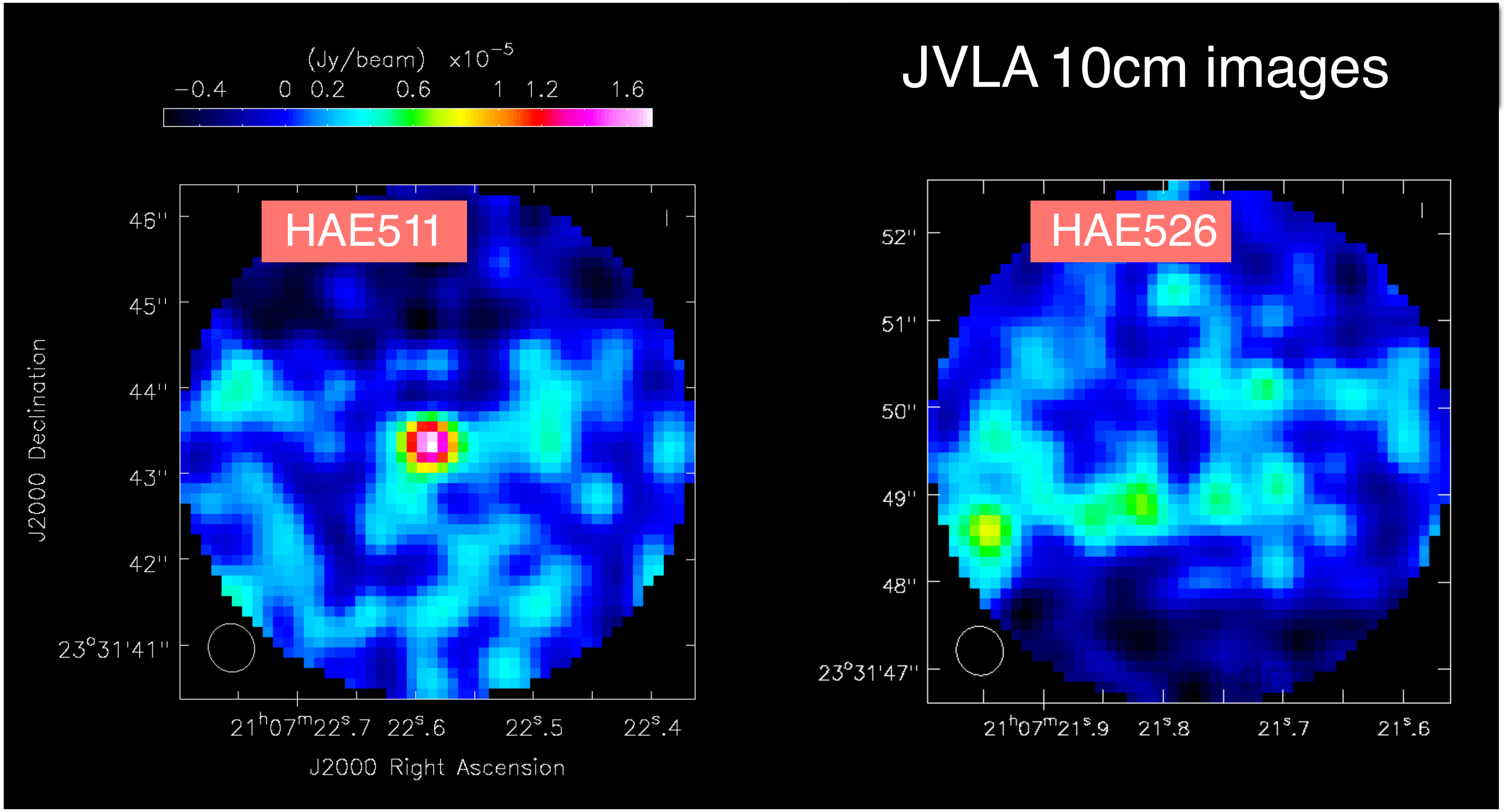
Tanaka et al. 2011, PASJ, 63, 415





Red : radio-detected(7/25), White : non-detected(18/25)

Radio (10cm) view of Hα emitting galaxies in the 4C23.56 proto-cluster (z=2.5)

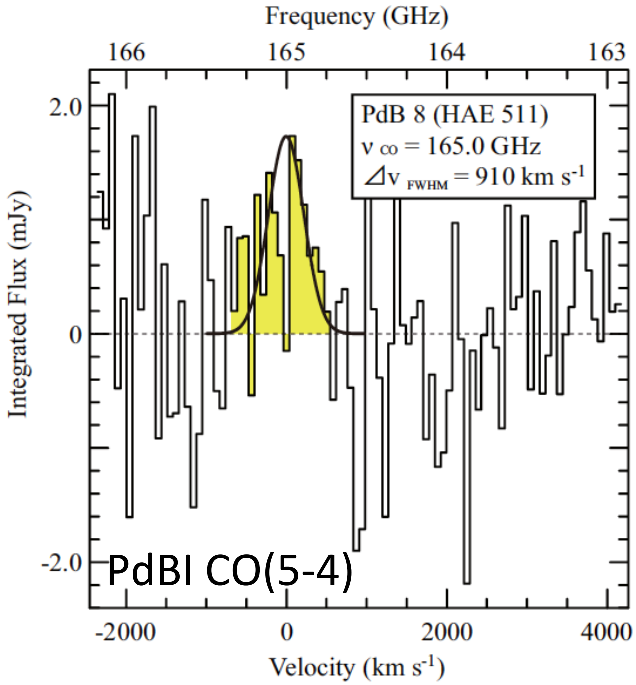


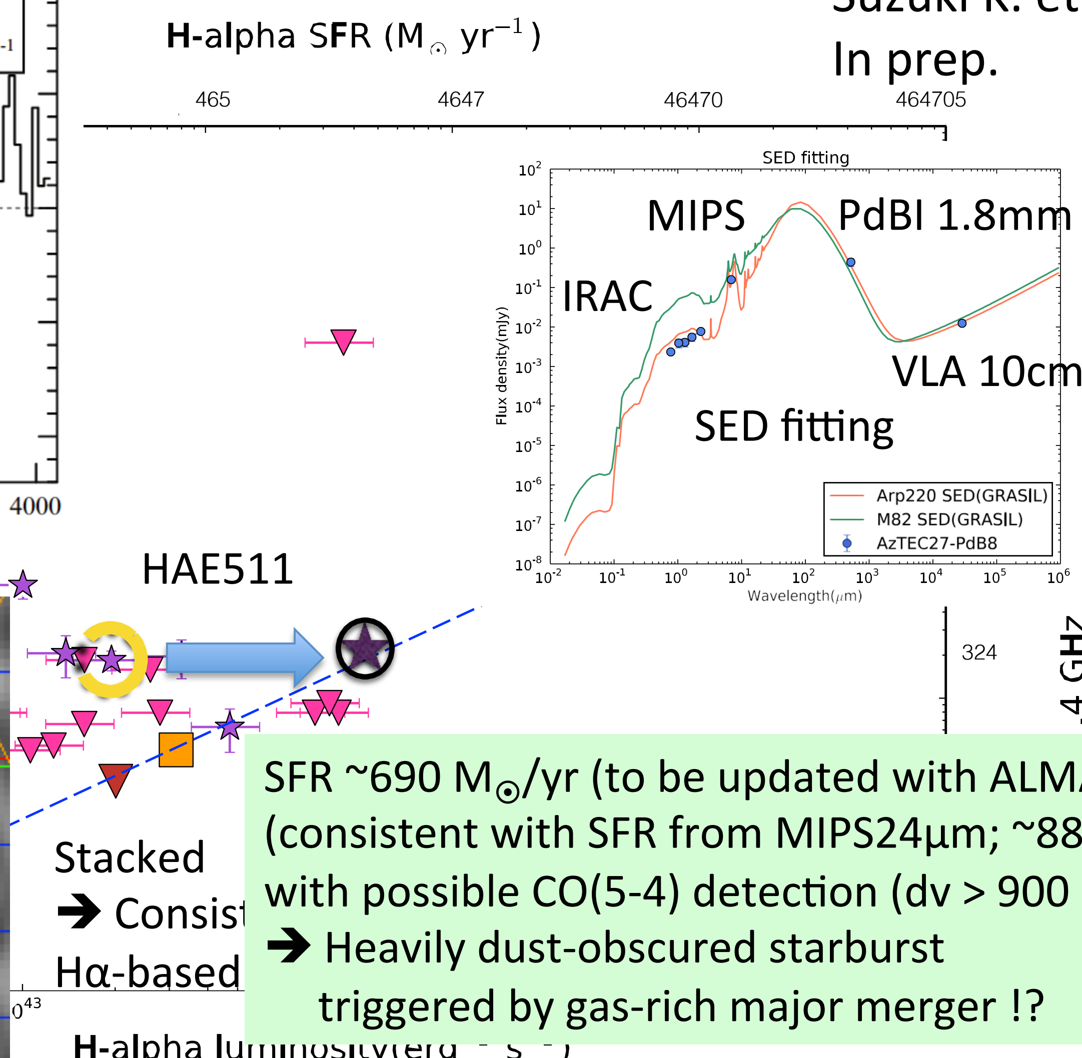
- There are radio-bright ones!

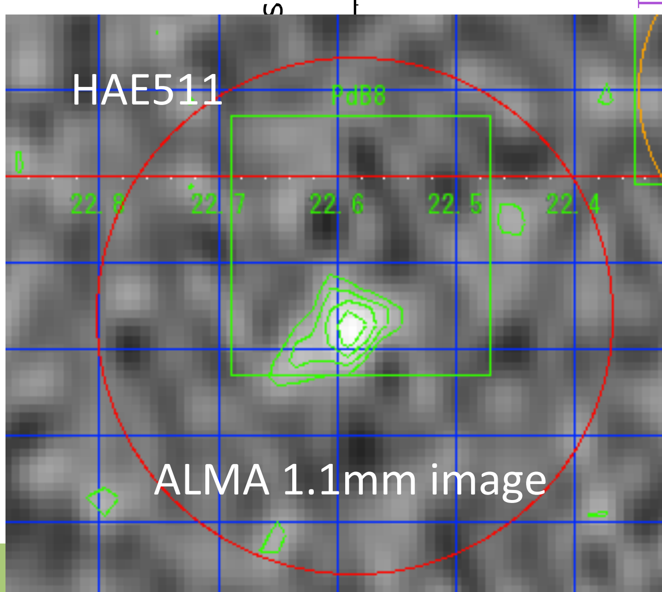
Lee Minju et al., In prep.

Radio view of HAEs in the protocluster : radio correlation

Lee Minju et al.;
Suzuki K. et al.,
In prep.



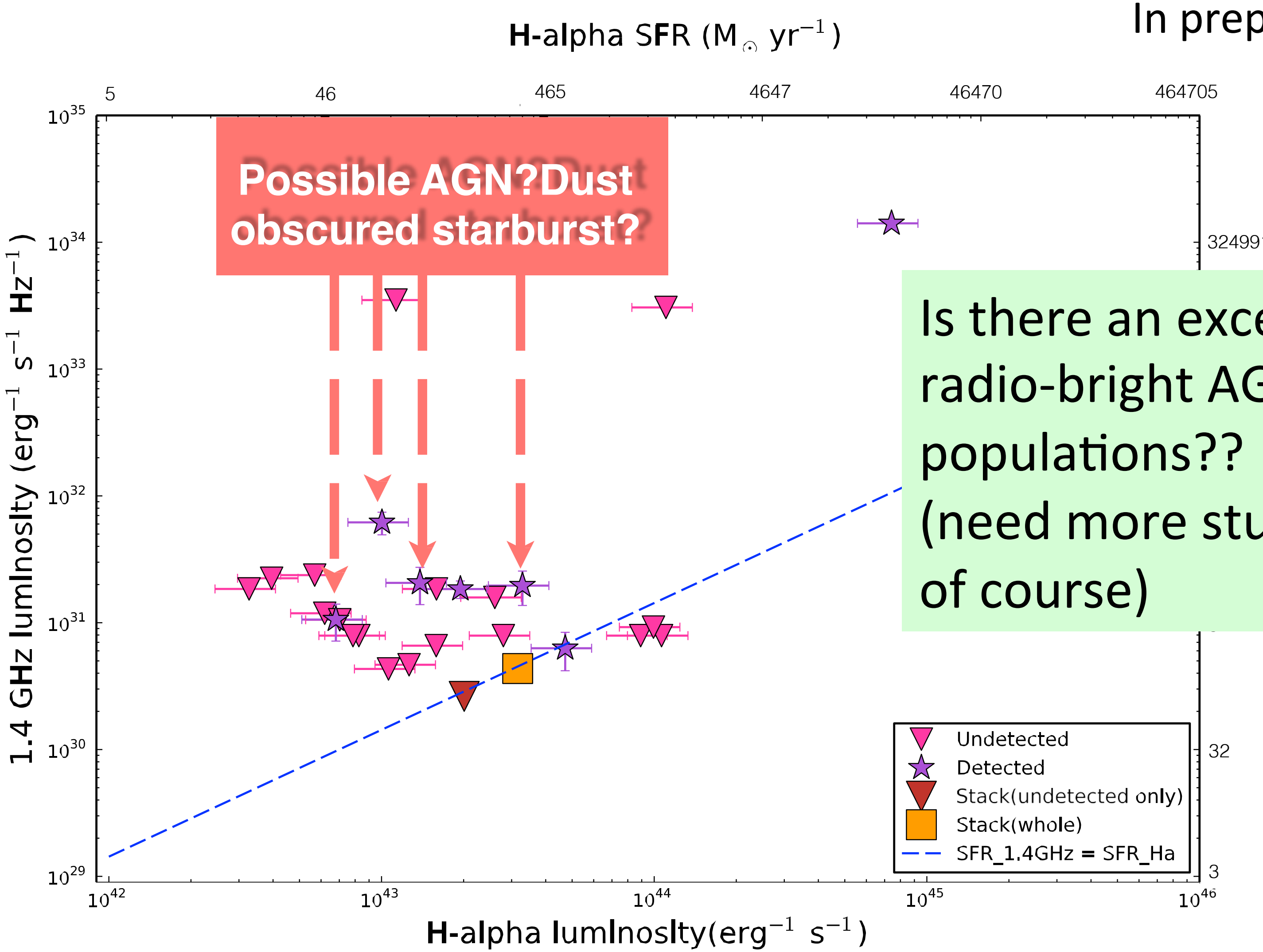




SFR ~690 $M_{\odot}$/yr (to be updated with ALMA data)
(consistent with SFR from MIPS24μm; ~880 $M_{\odot}$/yr)
with possible CO(5-4) detection (dv > 900 km/s)
➔ Heavily dust-obscured starburst
triggered by gas-rich major merger !?

Radio view of HAEs in the protocluster : Hα – radio correlation

Lee Minju et al., In prep.

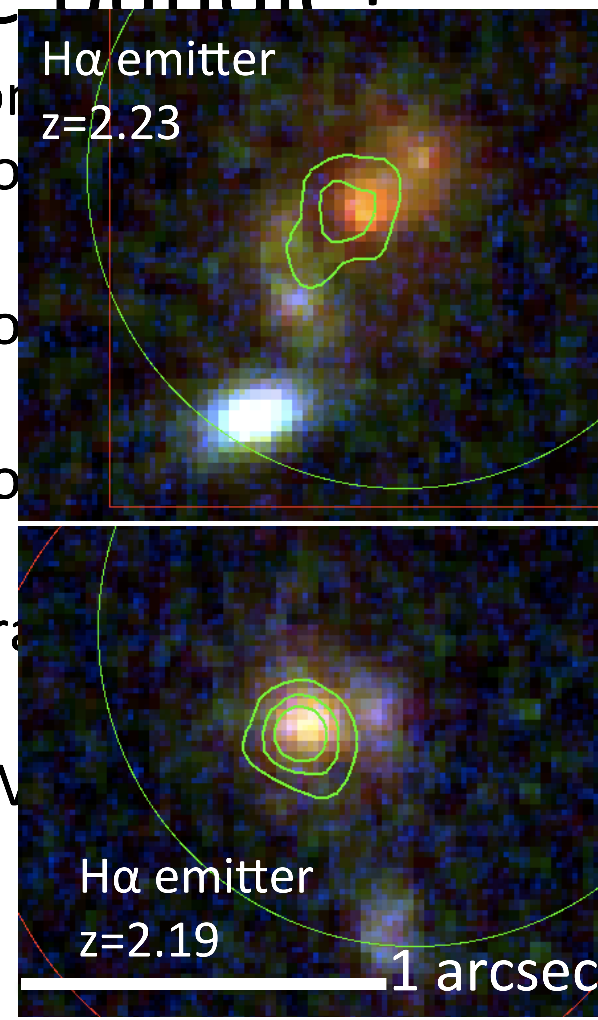


Is there an excess of radio-bright AGN populations?? (need more study, of course)

Summary

- ULTIMATE-Subaru: good synergy with deep surveys using ALMA
  - Sub-arcsec deep ~1mm continuum imaging with a sensitivity down to SFR ~a few 10 $M_{\odot}$/yr
  - NB-selected emission-line galaxies are indeed attractive for ALMA surveys too
- Possible science case: search for off-center, multiple accreting SMBHs
  - [OIII] & Hβ imaging survey of forming massive galaxies in the high-z (up to z=3) biased environment
  - Example: outflow characterization & [OIII]/Hβ line ratio diagnostic in a dusty quasar using SINFONI/VLT
  - an excess of AGN population in the proto-cluster ? (e.g., 4C23.56 @z=2.5) ➔ encouraging for multiple-IFU obs.

(Q1) What is the optimum spatial sampling (or diameter in arcsec of each fiber in the bundle) and FOV of the bundle?



The followings are the baseline configuratio

(Config1): spatial sampling=0 ".2, number o
of the bundle~1 ".4, number of bundles~26

(Config2): spatial sampling=0 ".2, number o
of the bundle~1 ".0, number of bundles~52

(Config3): spatial sampling=0 ".2, number o
of the bundle~1 ".8, number of bundles~16

Please select one of your preferred configura
your required configuration

(e.g., 0 ".15 sampling fibers with smaller FOV
smaller number of bundles).

A: Considering the typical size of targets, config. 1 seems to be fine.

(Q2) What is the optimum and minimum number of the fiber bundles (or multiplicity) in the 13'.6 diameter FOV?

The baseline specifications assume that multiplicity is 26, 52, or 16 for config 1, 2, or 3, respectively.

Please select one of you preferred configuration or propose your required number.

Please consider if your required number of multiplicity is high enough to be unique or competitive compared with any other instruments in 2020s.

A: covering the outskirts of merging galaxies is essential.
FoV of 1” seems to be too narrow (is this true? Is the sensitivity sufficient??? Perhaps not..) Therefore 1.4” (or larger) is preferable, though multiplicity is not very outstanding, compared with other instruments in this case.

(Q3) What is the critical wavelength range in near-infrared covered by the Starbug system (0.9-2.0micron)?

Current baseline specification does not include K-band since the fiber throughput severely decreases at 2.0 micron or longer.

Implementation of the K-band fiber would be very hard and expensive.

A: key redshift range would be around $z = 1 – 2.5$
to be coordinated with MAHALO survey
➔ 1 – 1.7 μm range would be important.

(Q4) What is the optimum spectral resolution?

The spectral resolution of the Starbugs + newMOIRCS with 0 ".2 sampling is expected to be roughly 2-3 times higher than that of current MOIRCS with 0 ".6 slit.

(see baseline specification of the MOIRCS)

A: R=3000 (dv=100 km/s) would be sufficient for the proposed case.

(Q5) What is the sensitivity requirement for the phase-I instrument?

Our baseline specifications assume that the sensitivity would be around 40-50% of Keck/MOSFIRE.

Sorry, I will check the sensitivity later.

(Q6) Please describe a brief observation plan for your science case with the fiber bundle multi-object IFU.

- Number of objects / Survey area
  > 100 over a few 100 arcmin^2
- Fields
  4C23.56, SSA22, SXDF, etc.
- Number of nights to complete your survey
  (to be estimated)
- Uniqueness
  rich in deep mm/submm and radio data

(Q7) How could the proposed science cases be competitive or complementary to the science with 30m class telescopes (e.g. TMT) or space telescopes (e.g. JWST) in 2020s?

A: Once we identify interesting objects from our surveys, TMT and/or JWST will be used to make extensive follow-up.
Making a survey of >100 sources can be the unique role for ground-based telescopes/instruments like ULTIMATE-Subaru system.

(Q8) Please describe the requirements for Phase-II instrument (Starbugs + dedicated spectrograph) to develop your science case.

- Fiber bundle configurations (spatial sampling, FOV of each bundle, number of bundles in 13'.6 FOV)
- Wavelength coverage
- Spectral resolution
- Sensitivity

A: implementation of >2 μm band is very attractive.

(Q9) What is the unique point of the fiber bundle multi-object IFU with Starbugs compared to the imager or multi-object slit spectrograph?