# Search for extremely strong emission line galaxies at z < 1 using Subaru/HSC

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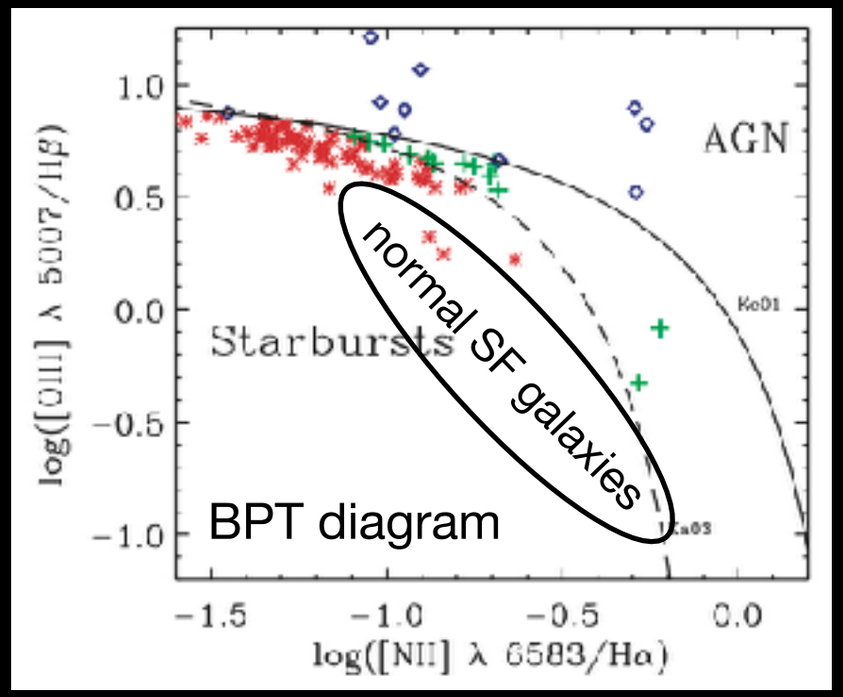
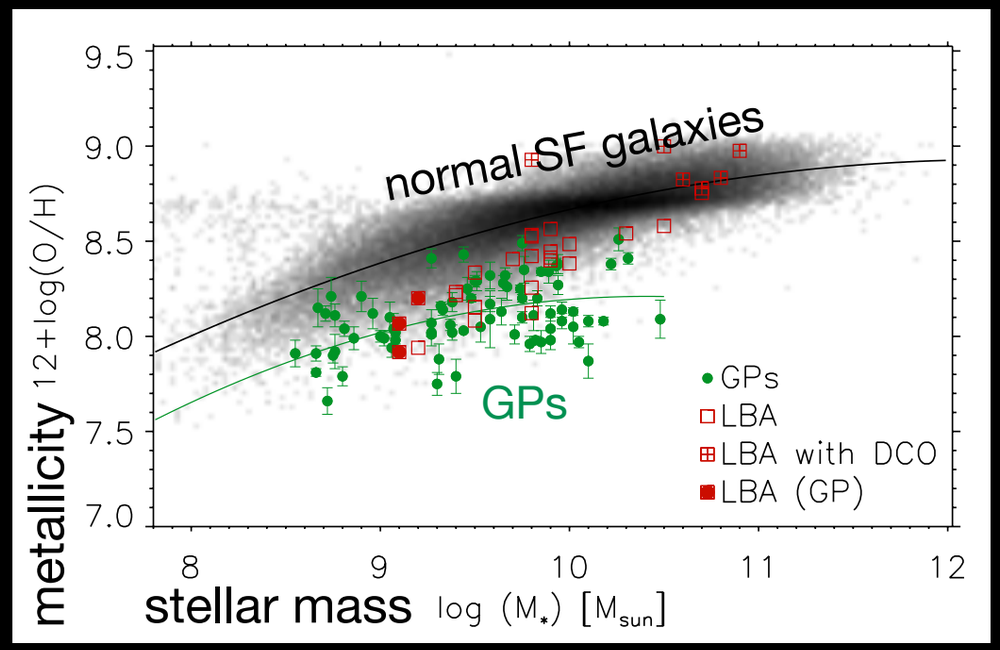
Hyper Suprime-Cam Subaru Strategic Program

# Background:

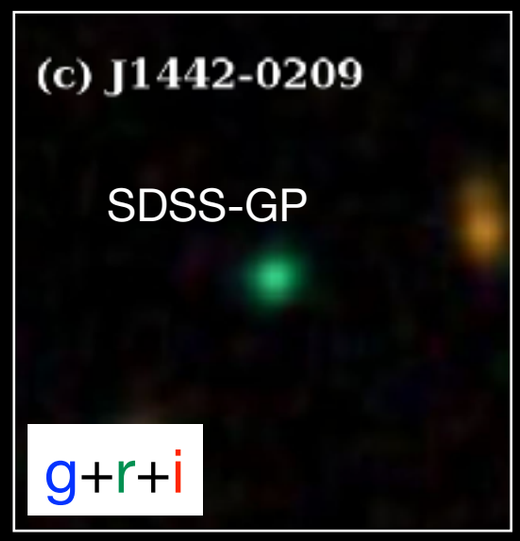
- Properties of galaxies at very high redshift
  - Important to understand the early phase of the galaxy formation and evolution
  - Observationally difficult due to their faintness
  - Examine similar galaxies at lower redshift
- Galaxy populations at z<0.3 such as "Green Peas (GPs)" (Cardamone+09) and recently found "Blueberry Galaxies (BGs)" (Yang+17)
  - Low stellar mass and high star-formation rate (SFR) : High specific SFR
  - Very strong emission lines
  - High [OIII]/Hβ emission line ratio
  - Metal poor
  - Compact
- Low-z analogue to primordial galaxies?




Cardamone+09




Amorin+10



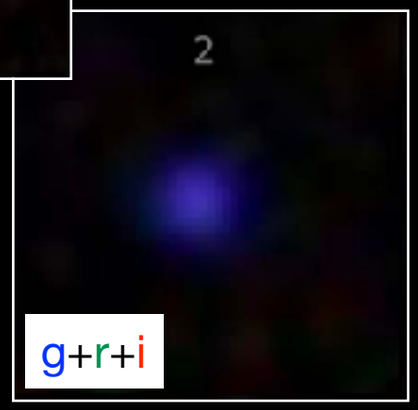

Izotov+16

# Background:

"very low-z"


SDSS-GPs

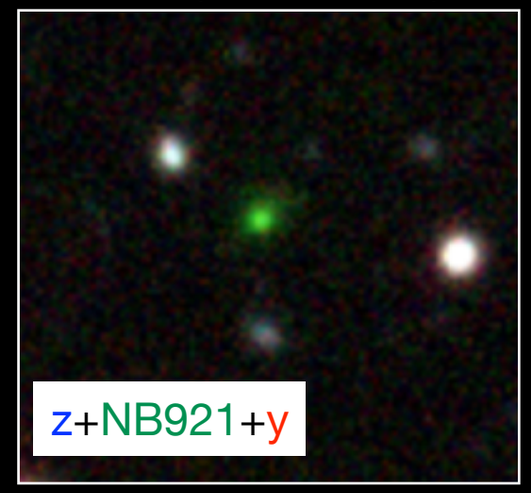
SDSS-BGs




?

"very high-z"

CR7 (LAE@z=6.6)

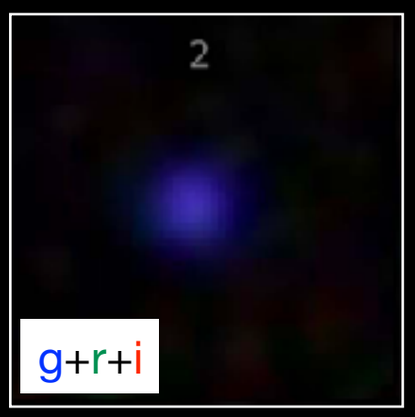



- Missing link between very high-z(such as LAEs) and very low-z (GPs and BGs)
- Narrow/Intermediate band excess galaxies at z<1 (e.g., Kakazu+07, Ly+14, 16)
- The sample size of (especially extreme) objects is limited
- Systematic search of lower stellar mass and stronger emission line galaxies at z>0.3 with deep and wide Subaru/Hyper Suprime Cam (HSC) data

# Sample selection:

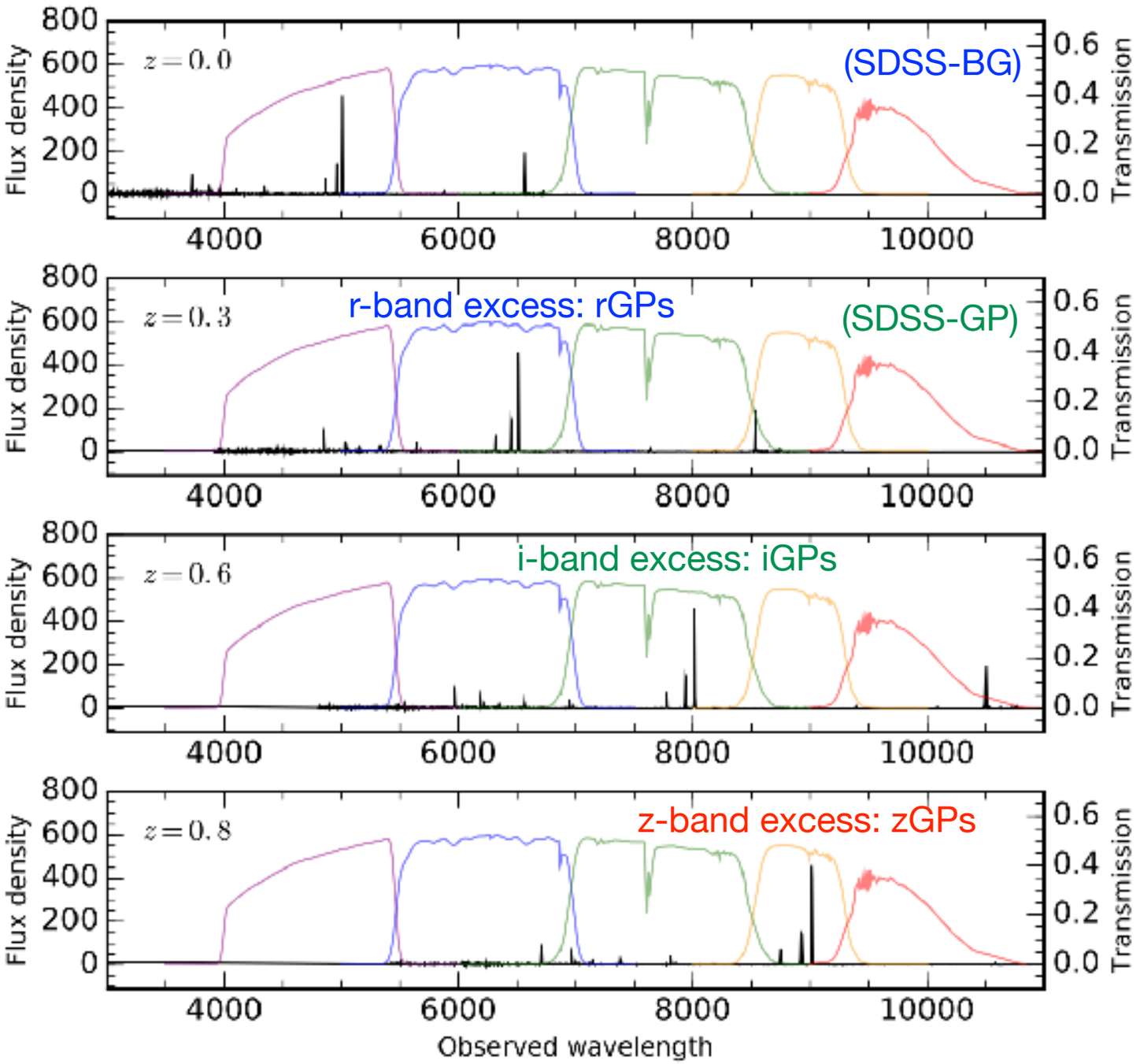
- Detecting broad-band excess due to strong emission lines
  - Similar technique to the SDSS GPs (with strong [OIII] emission line)
  - HSC 5 broad-band filters (g, r, i, z, y)
  - r-band excess (rGPs@z~0.3)
  - i-band excess (iGPs@z~0.6)
  - z-band excess (zGPs@z~0.8)
- More quantitatively, two-color diagrams are used to detect the broad-band excess (see next)


SDSS-GPs



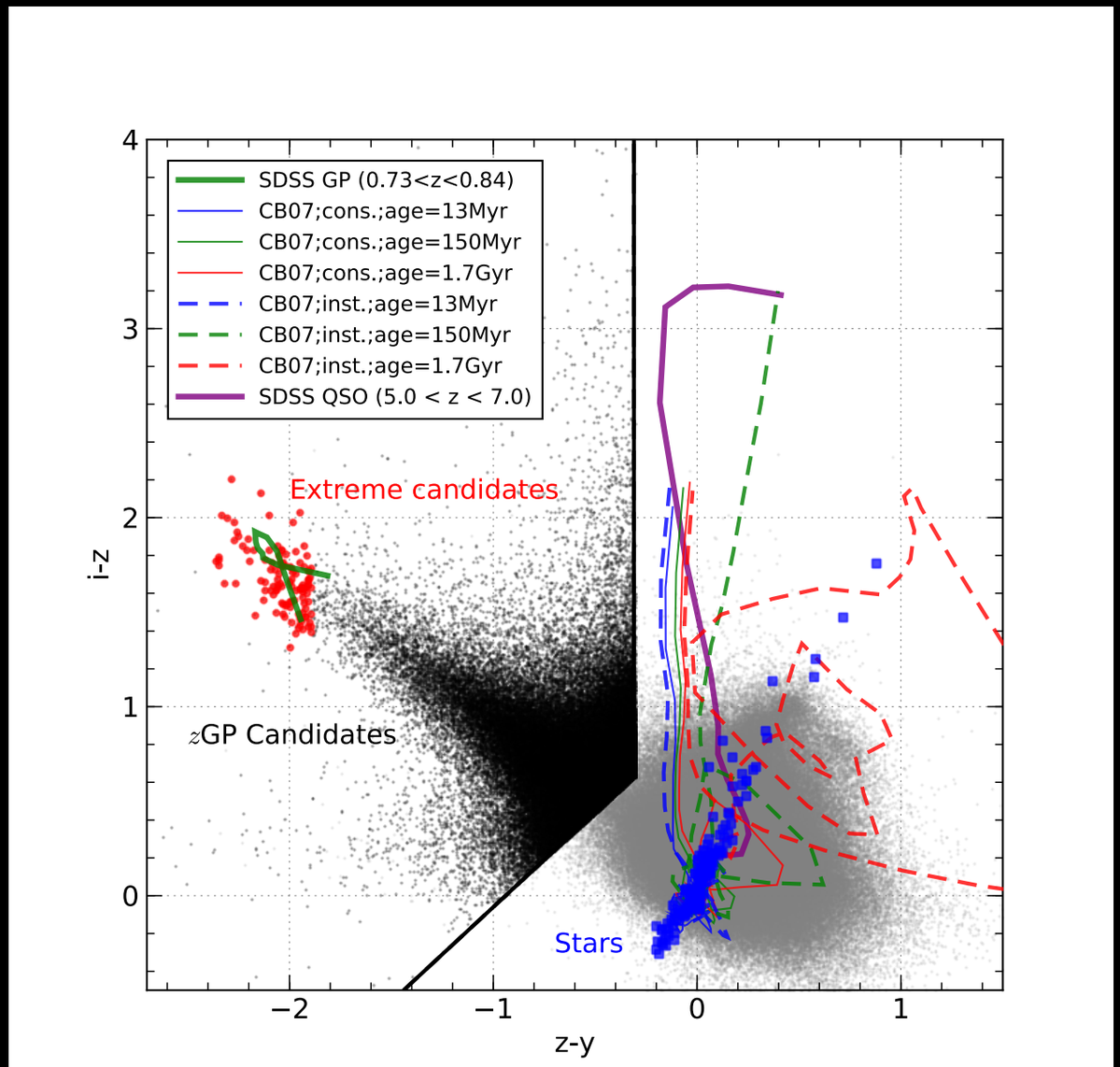

SDSS-BGs

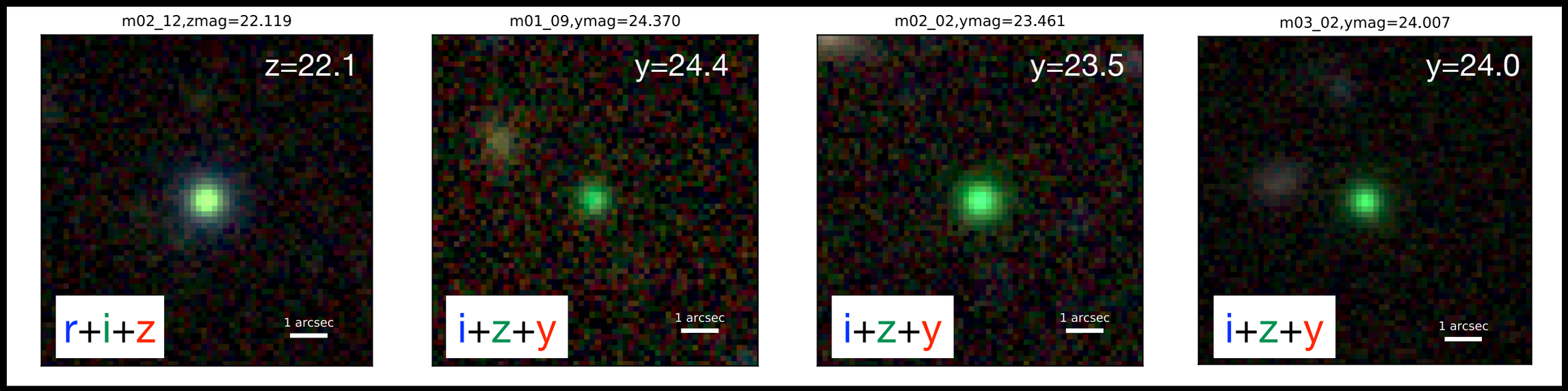
HCS filter set with GP template



# Sample selection:

- HSC SSP internal data release (S17a)
  - HSC-Wide: ~500 deg$^2$, $r_{limit}$~26 AB
  - HSC-Deep: ~27 deg$^2$, $r_{limit}$~27 AB
  - HSC-UltraDeep: ~3 deg$^2$, $r_{limit}$~28 AB
- Broad-band excess by strong emission lines
  - r-excess from g-r vs. r-i (rGPs@z~0.3)
  - i-excess from r-i vs. i-z (iGPs@z~0.6)
  - z-excess from i-z vs. z-y (zGPs@z~0.8)
- The expected $EW^{rest}$ > 100 Å
- The number density = ~20 deg$^{-2}$ (EW>1000Å) to ~400 deg$^{-2}$ (EW>100 Å)
- Very compact appearance

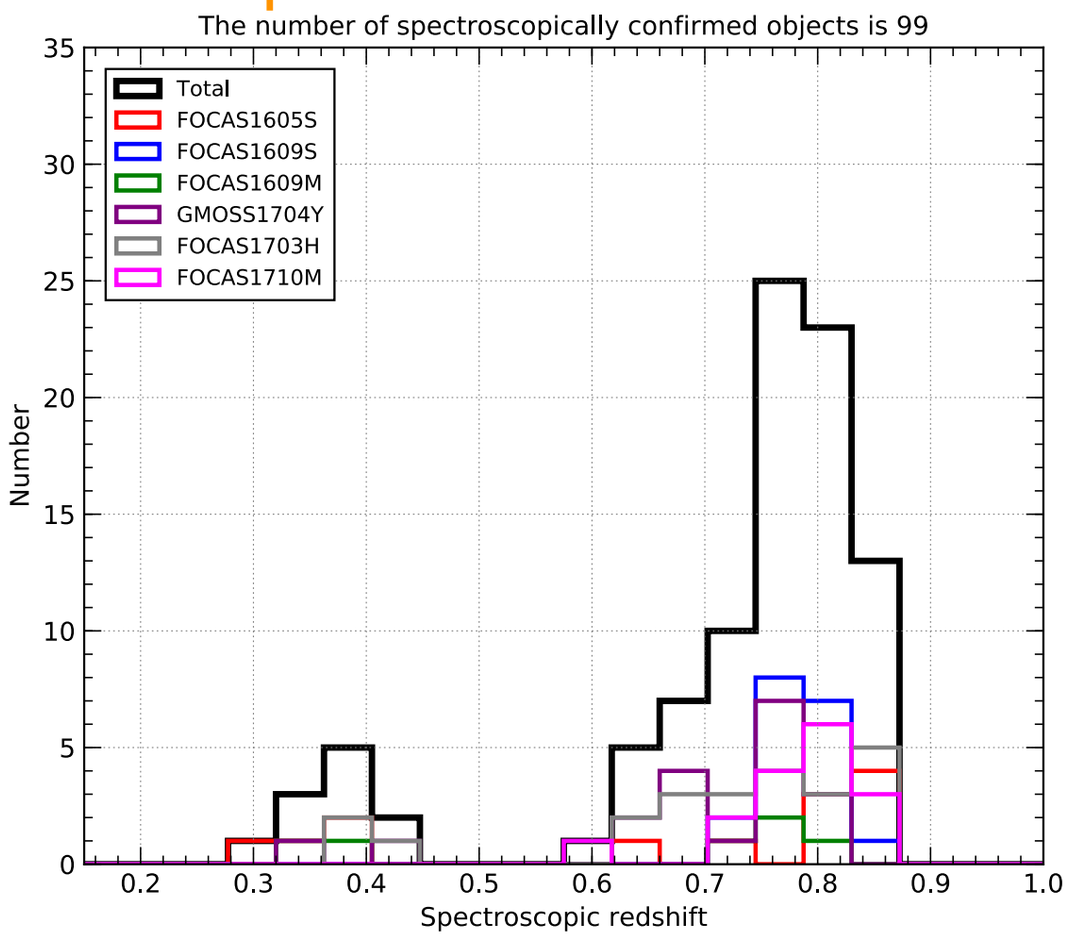


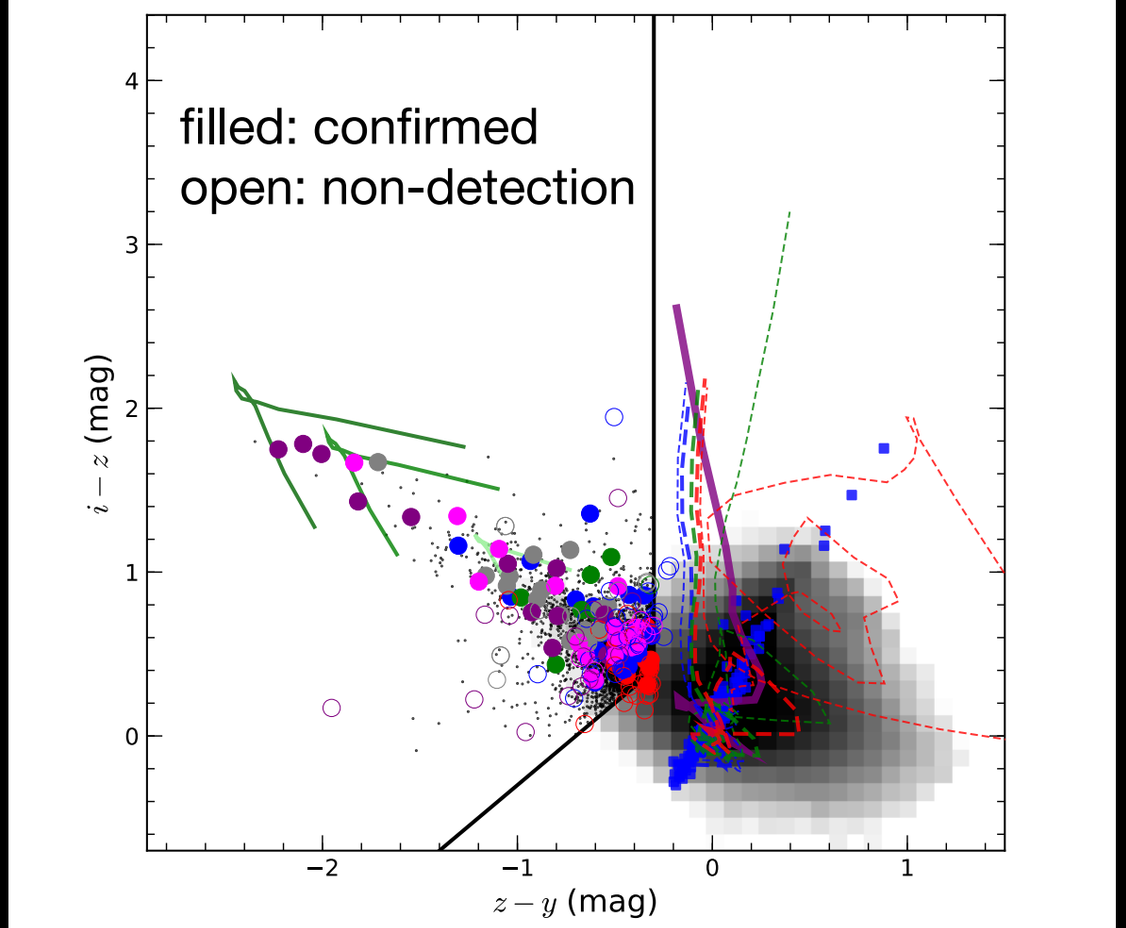
# Follow-up spectroscopic observation:

- Follow-up spectroscopic observations are on going
  - Filler targets in several Subaru/FOCAS observations
  - Main sample in Gemini/GMOS-S observation
  - Main sample in the coming Subaru/FOCAS observation in July
- Spectroscopic redshift confirmation for ~100 objects at z=0.3-0.85
- Detection rate is higher for objects far from the selection criteria

## spec- z distribution

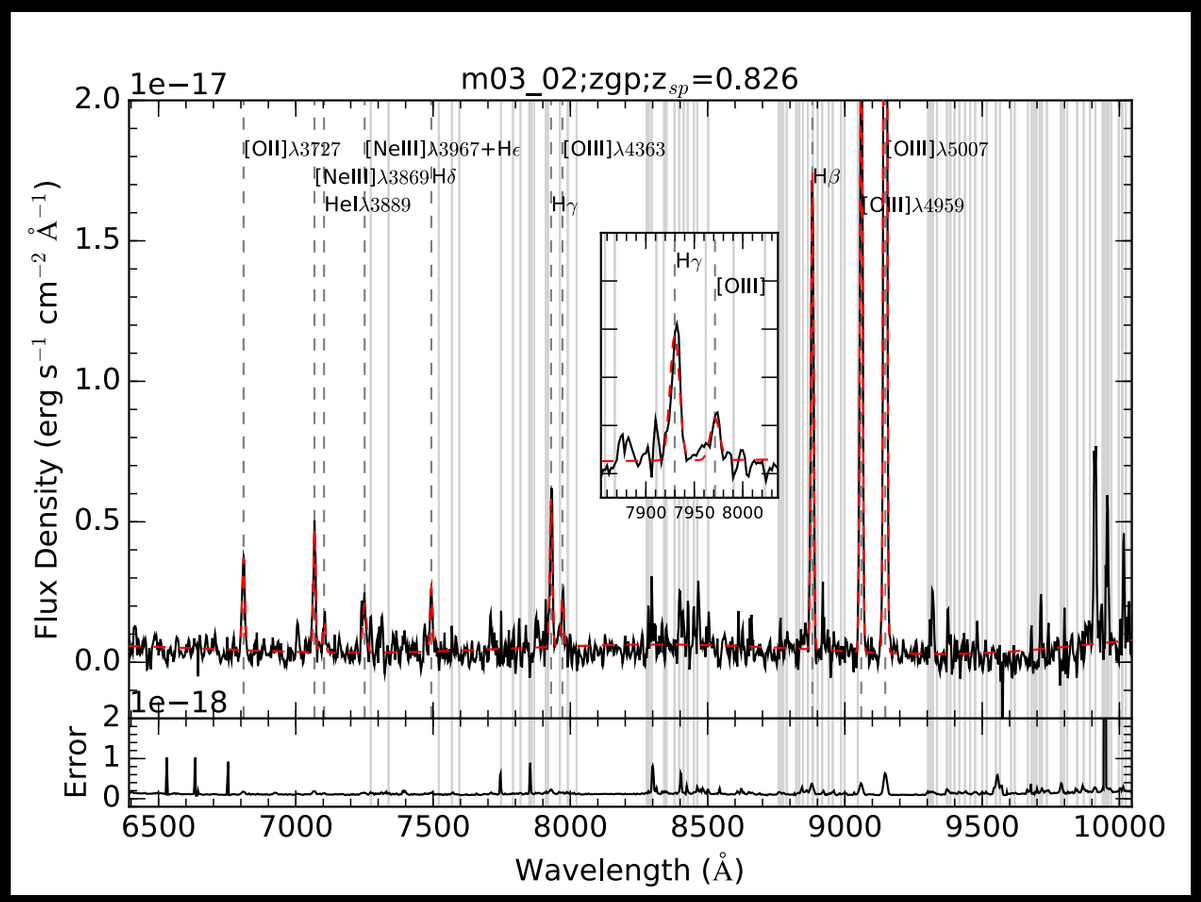



## two-color diagram for zGPs

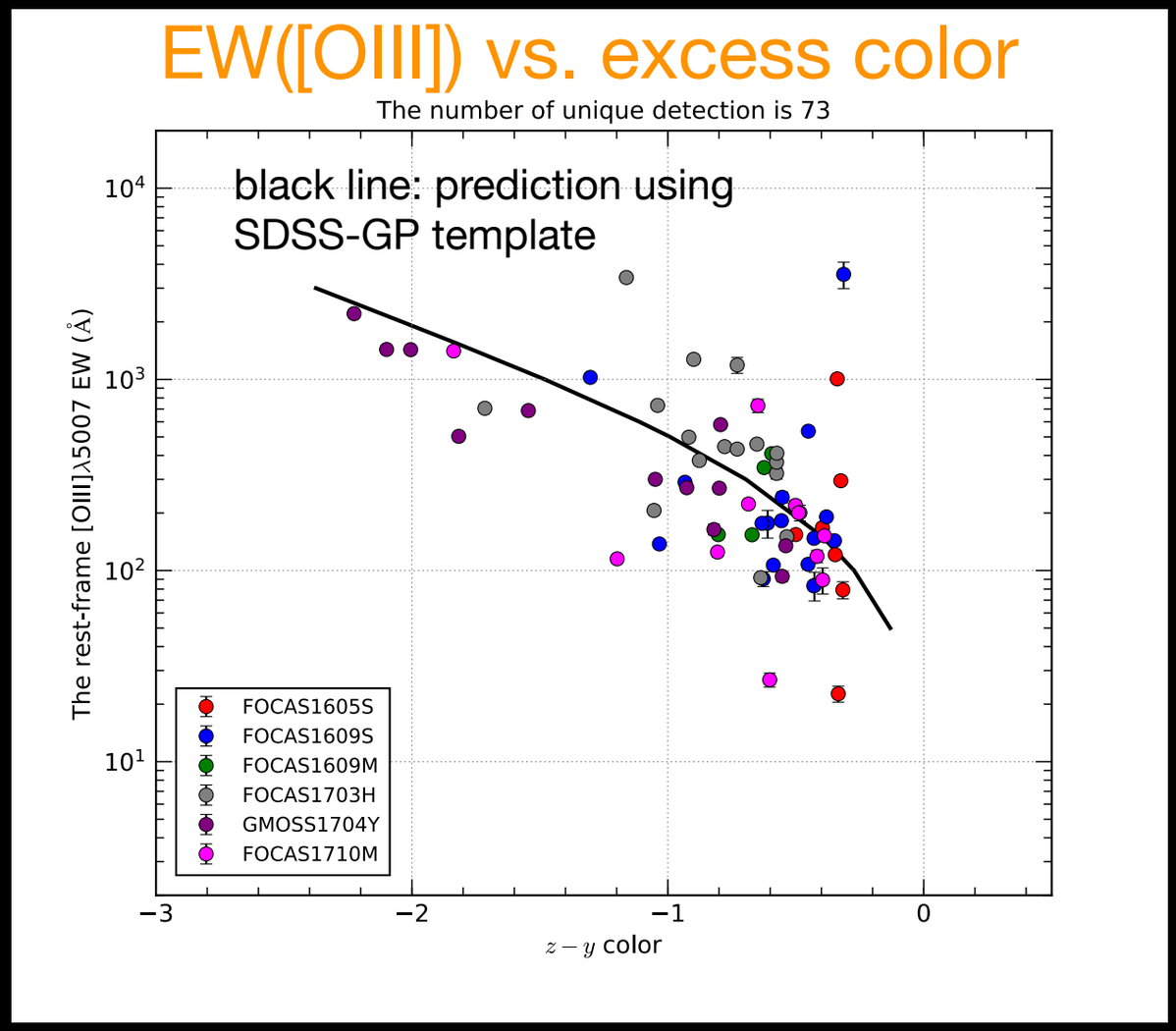


# Follow-up spectroscopic observation:

- Very high [OIII]λ5007 equivalent width (EW)
  - $EW^{rest}$ range from 100 Å to 3000 Å
  - In agreement with model predictions
- A weak [OIII]λ4363 emission line is detected significantly from 5 objects




An example of the GMOS-S spectra in 1 hour integration



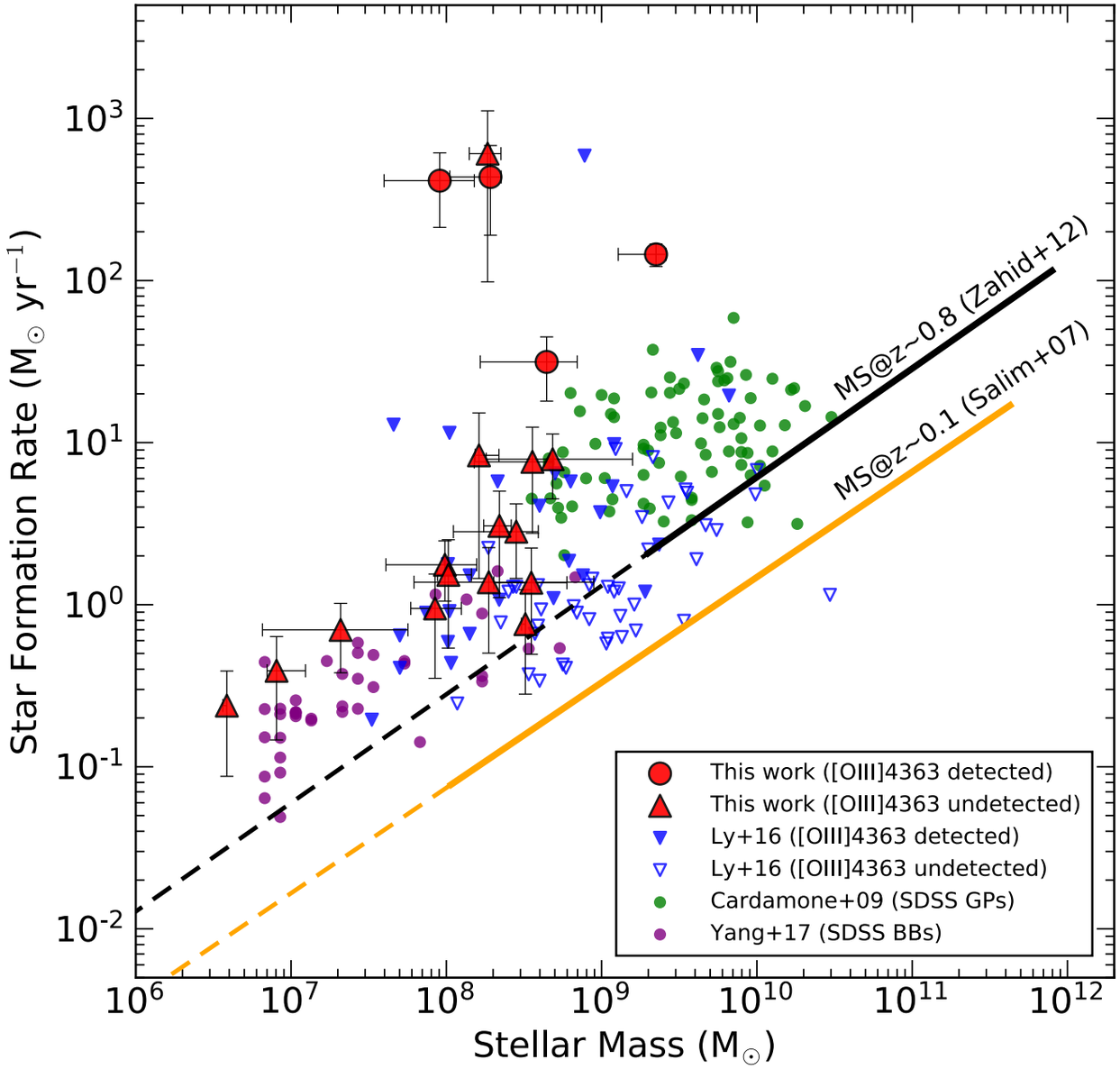

We will show some results obtained with Gemini/GMOS-S

# Stellar mass and star formation rate:

- Stellar mass: from SED fittings after subtracting the contribution from the emission lines
- Dust extinction: from Balmer decrements using Hβ, Hγ, Hδ (if possible)
- Star formation rate (SFR): from the extinction corrected Hβ luminosity

- Very low stellar mass
- Very high SFR (up to 1000x higher than normal galaxies)

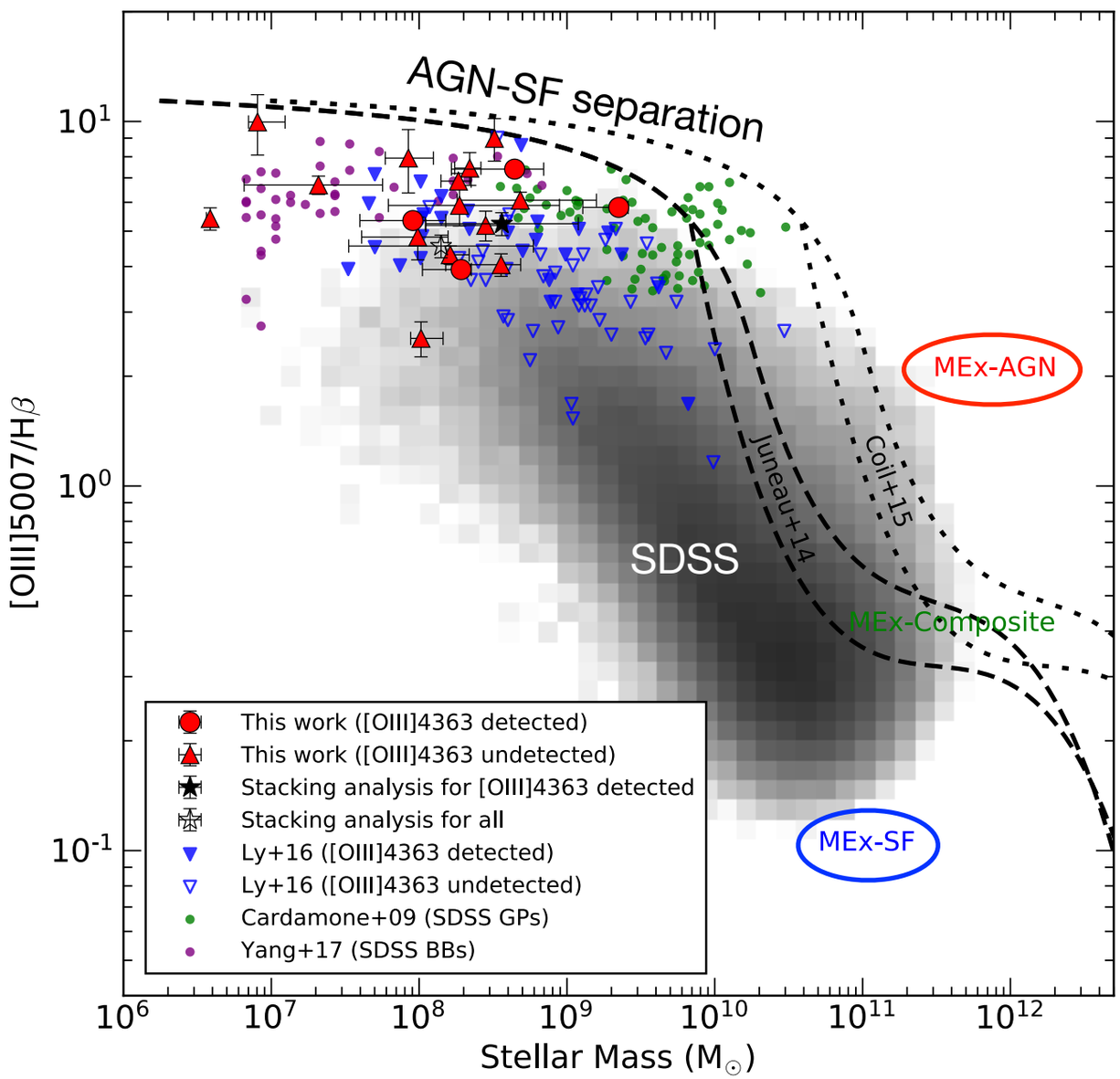
## Stellar mass - SFR diagram



# AGN emission line ratio diagnostics:

- BPT diagnostics cannot be used because no [NII]/Hα ratio is available
- Stellar mass vs. [OIII]/Hβ (MEx) diagram (e.g., Juneau+14)

## Mass Excitation (MEx) diagram

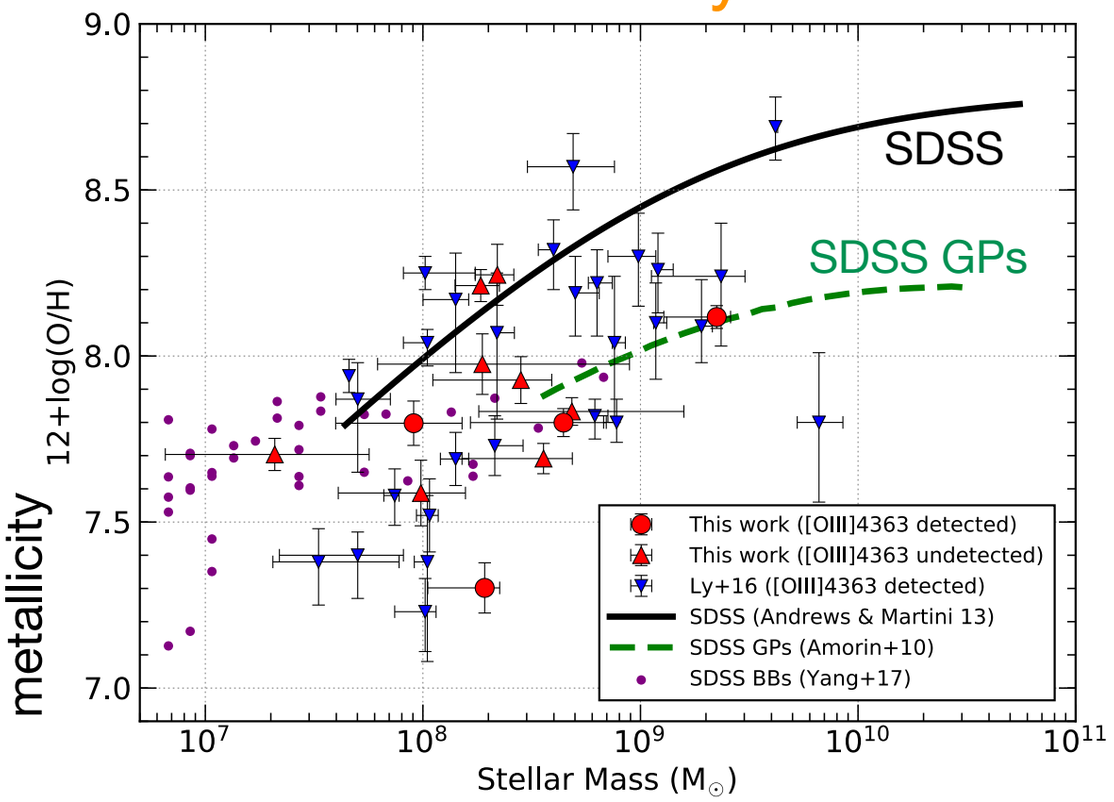



- Our sample is basically within SFG region on the MEx diagram
- Our sample shows smaller stellar mass and higher [OIII]/Hβ ratio than normal SDSS galaxies at z~0.1 and comparable [OIII]/Hβ ratio to the SDSS GPs and BGs

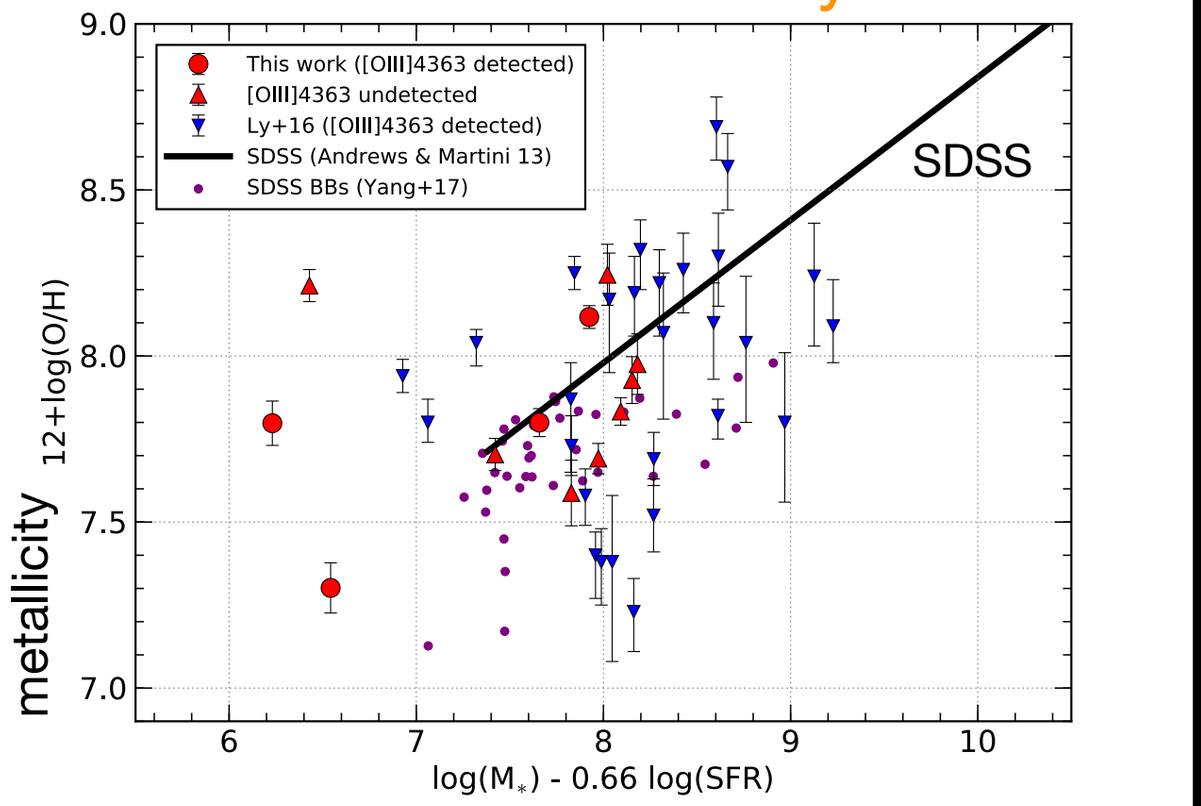
# Metallicity (oxygen abundance):

- The "direct" method if [OIII]λ4363 is detected
  - "$T_e$" measured from [OIII]λ4363/[OIII]λ5007
  - Following Izotov+06 method
- The "strong line" method if [OIII]λ4363 is not detected
  - KK04 (Kobulnicky&Kewley04) is used (R23 indicator)
  - ~0.3-0.7 dex overestimated compared to the "direct" method --> "correction"
- 7.3 (extremely metal poor) < 12+log(O/H) < 8.3
- The mass-metallicity relation (MZR) is the extension of the MZR of the SDSS GPs
- The fundamental metallicity relation (FMR; SFR dependence of the MZR) is in rough agreement with the local (SDSS) FMR

## mass-metallicity relation




## fundamental metallicity relation

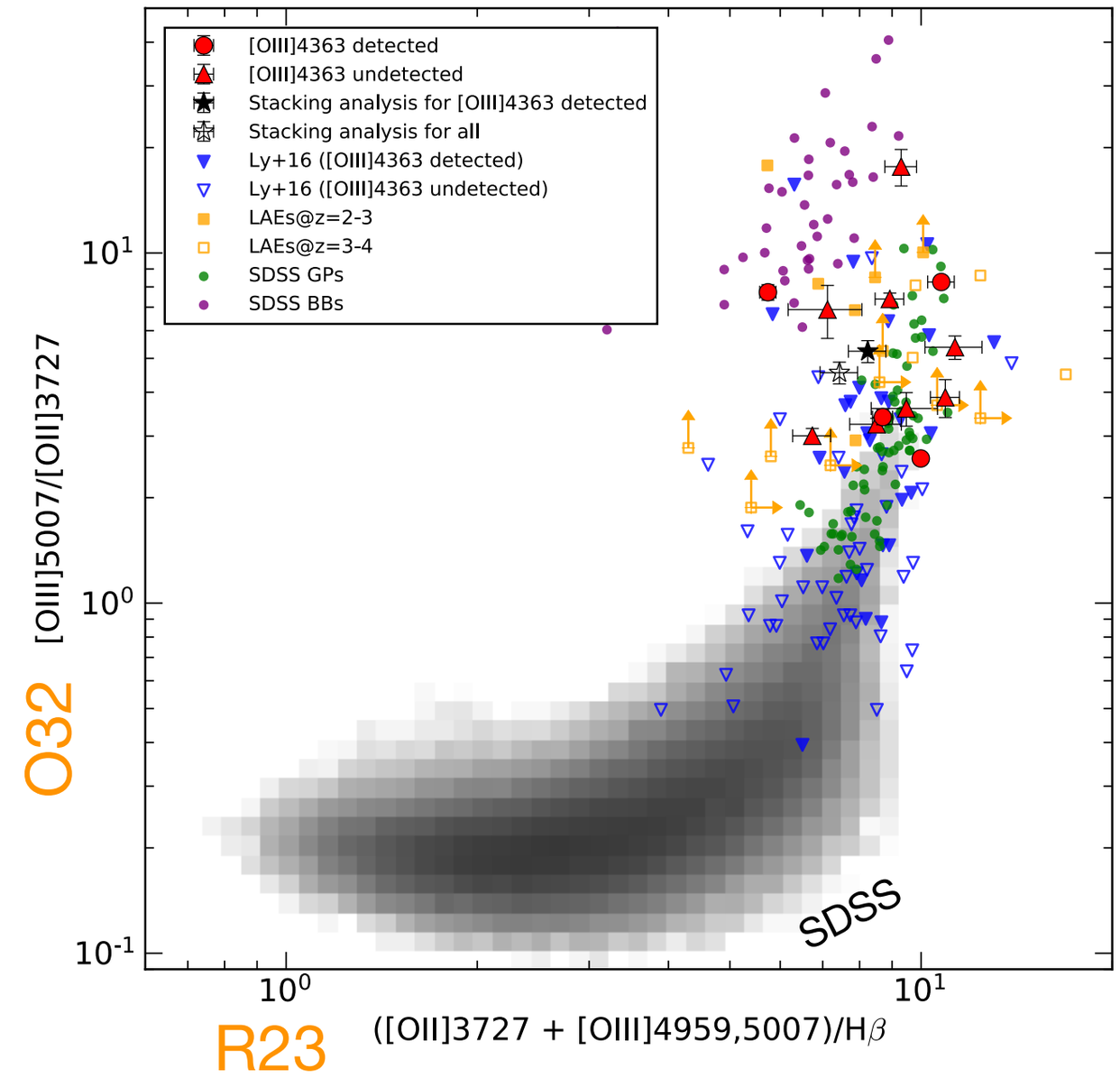


# Ionization state:

- Ionization diagnostics
  - R23 index (metallicity sensitive) vs. O32 index (ionization parameter sensitive)

- Very high [OIII]λ5007/[OII]λ3727
  - Comparable or higher than that of the SDSS GPs and other emission line galaxies at the similar redshift
  - Comparable to the LAEs at z=2-4

R23 ([OIII]+[OII]/Hβ) vs. O32 ([OIII]/[OII])



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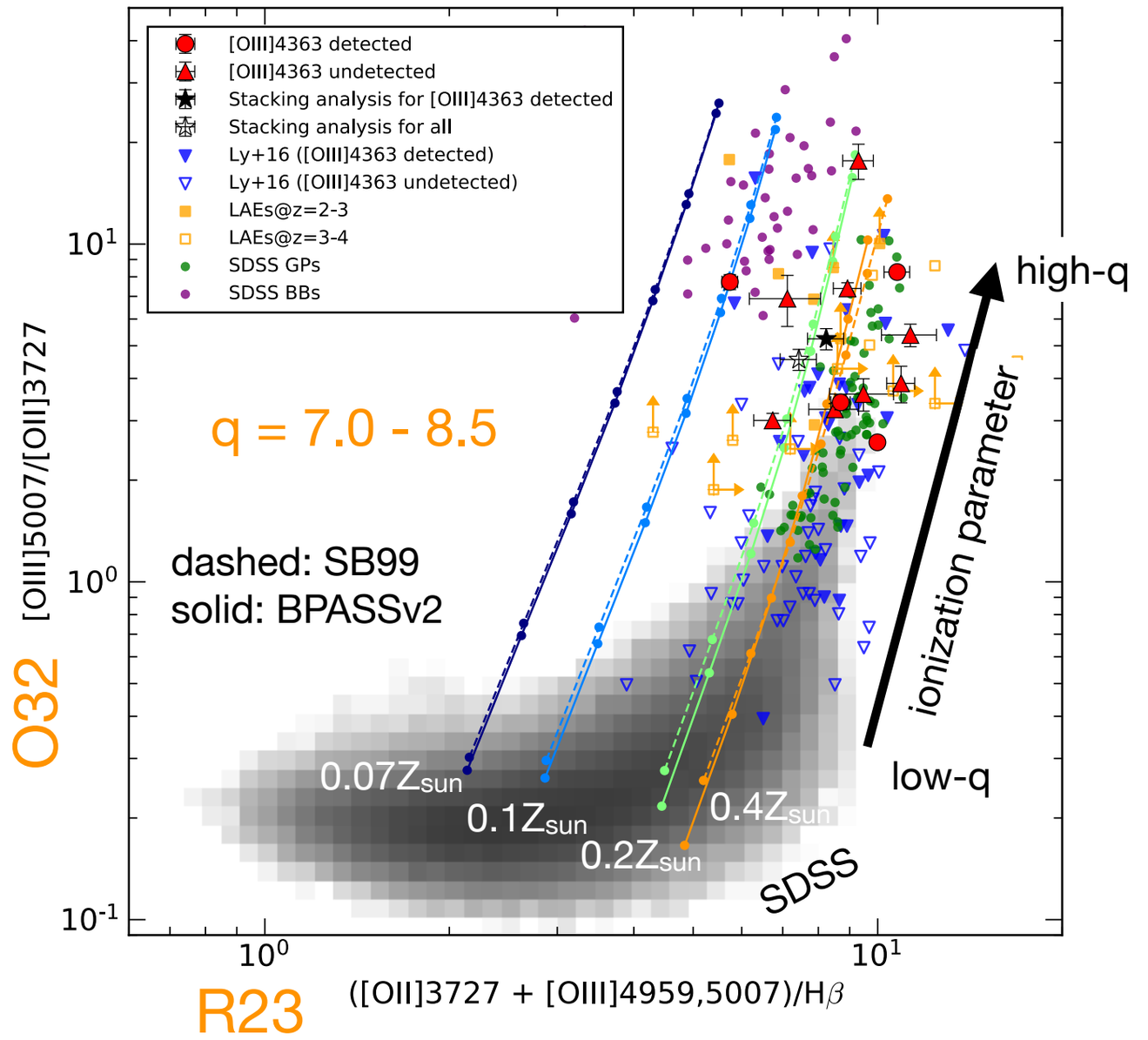
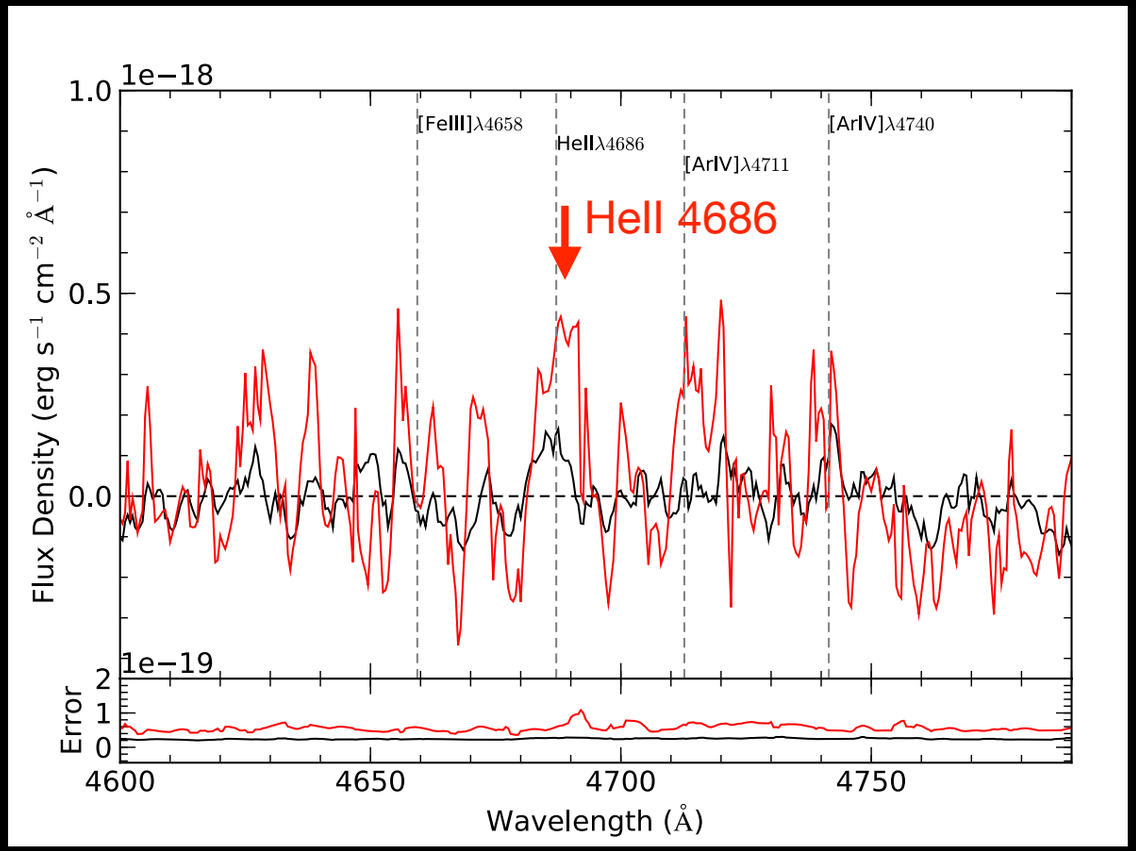
- Comparison to photoionization models using CLOUDY (c17.00)
  - Explained by models with very high ionization parameters
  - Some cannot be explained by the normal models
  - Harder ionizing spectra may be required?

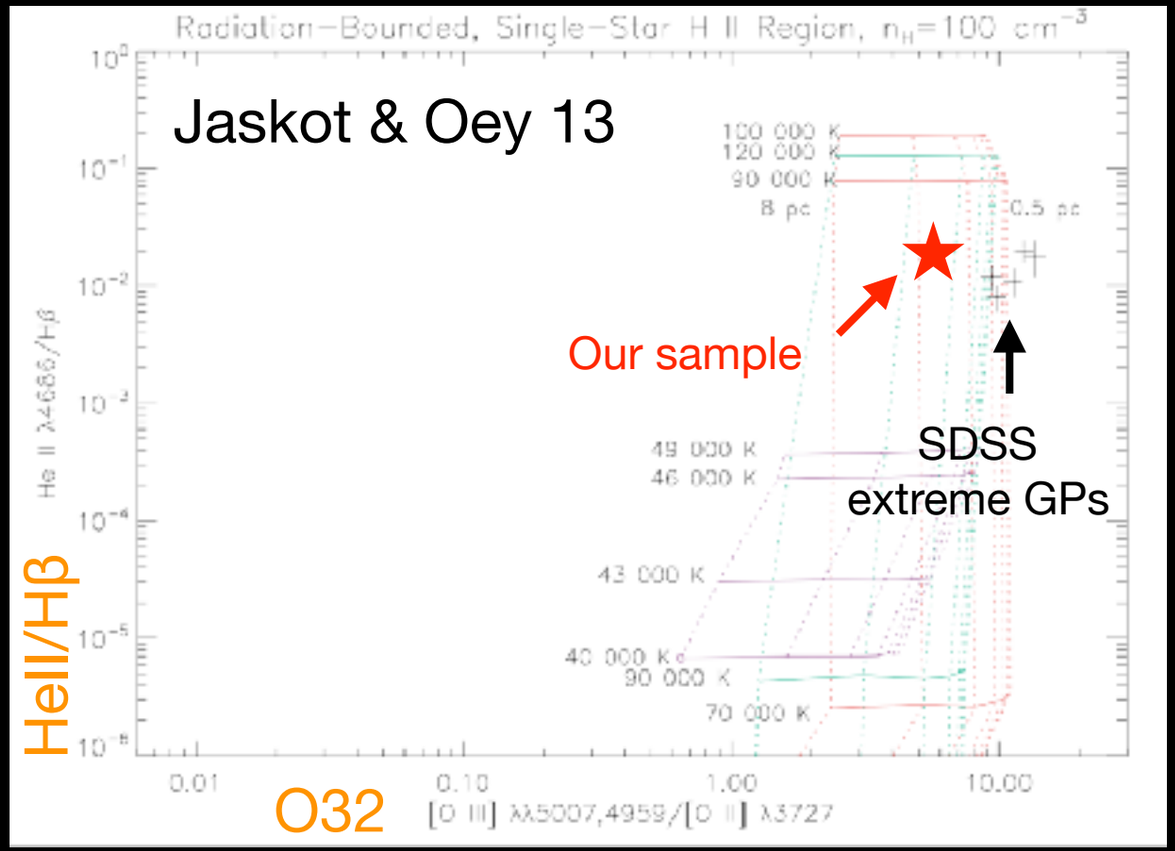
R23 ([OIII]+[OII]/Hβ) vs. O32 ([OIII]/[OII])



# What is the ionization source?:

- Weak HeII λ4686 emission line is detected in the stacked spectra
- What is the origin of HeII λ4686 ?
  - Wolf-Rayet (WR) or very hot O-star?
  - Contamination of weak AGN?
  - High-Mass X-ray Binary?
  - Shock by SNe / galactic wind?
- Models with very hot WR (Jaskot & Oey 13) can explain the observed [OIII]/[OII] and HeII4686/Hβ emission line ratio
- Contribution of WR stars is large



# Summary:

- Systematic Search for extremely strong emission line galaxies with Subaru/HSC
- Follow-up spectroscopy using Subaru/FOCAS Gemini/GMOS-S is ongoing
  - multiple emission lines from ~100 objects at z=0.3-0.85
  - $EW^{rest}$([OIII]λ5007) = 100 - 3000 Å
  - [OIII]λ4363 detections from 5 objects
- From our GMOS-S run, we found the following:
  - Very low-mass and high SFR (i.e., very high sSFR)
  - Possibility of AGN is low
  - Metal poor comparable to local extremely metal poor galaxies
  - High [OIII]λ5007/Hβ and [OIII]λ5007/[OII]λ3727: high ionization parameter
  - Possibility of a large contribution from WR stars to the obtained line ratio