すばるHSCによる超強輝線銀河探査

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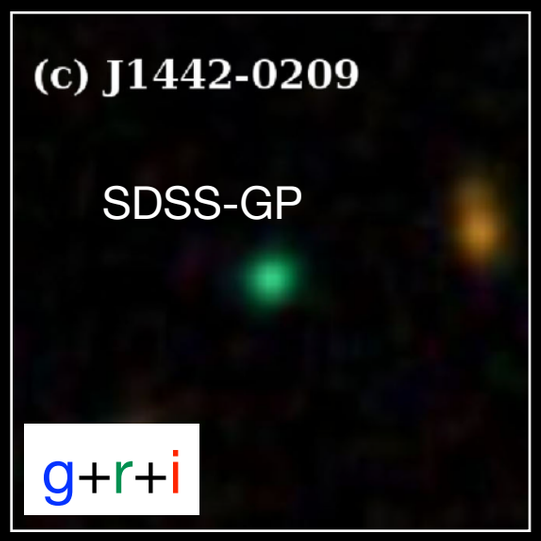
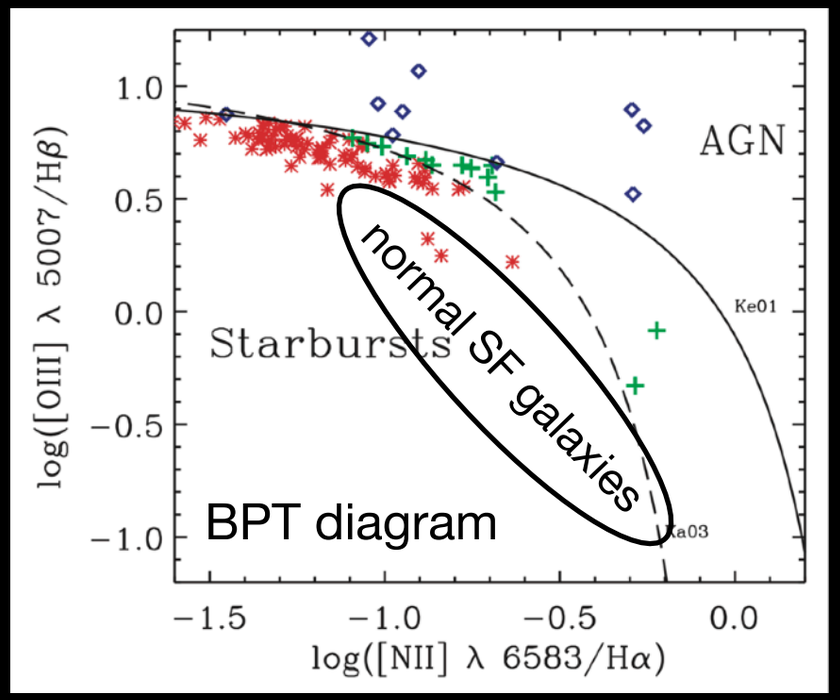
Hyper Suprime-Cam Subaru Strategic Program

Background:

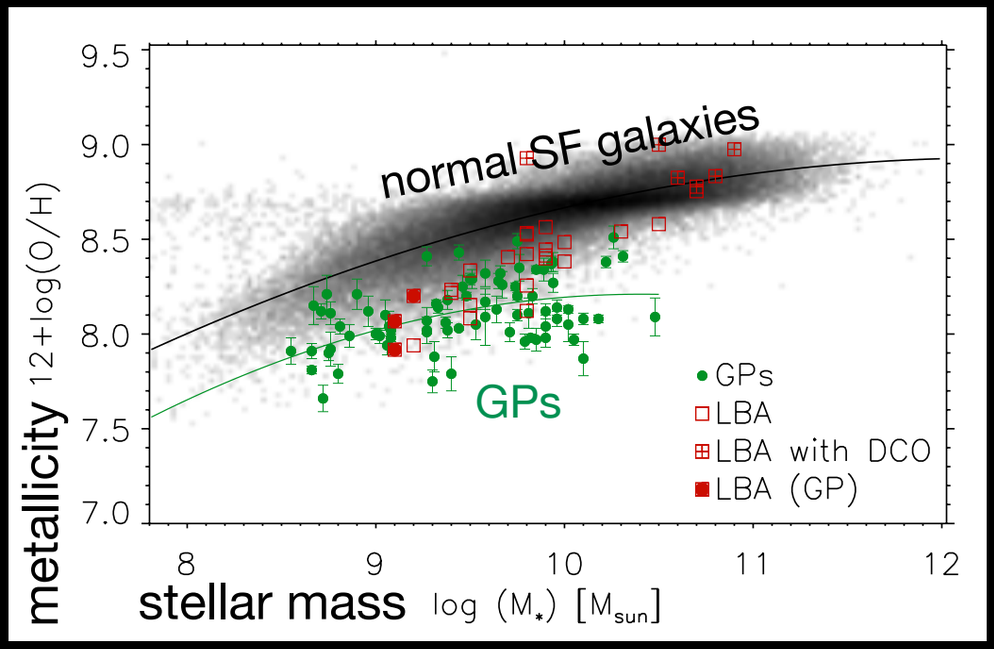
- Properties of galaxies at very high redshift
  - Important to understand the early phase of the galaxy formation and evolution
  - Observationally difficult due to their faintness
  - Examine similar galaxies at lower redshift
- Galaxy populations at z<0.3 such as "Green Peas (GPs)" (Cardamone+09) 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?



Izotov+16



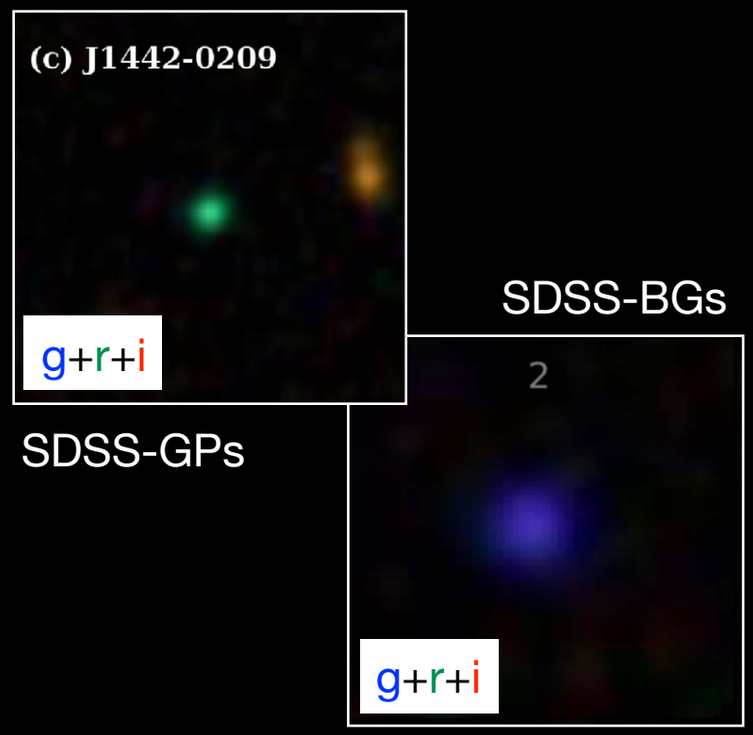
Cardamone+09



Amorin+10

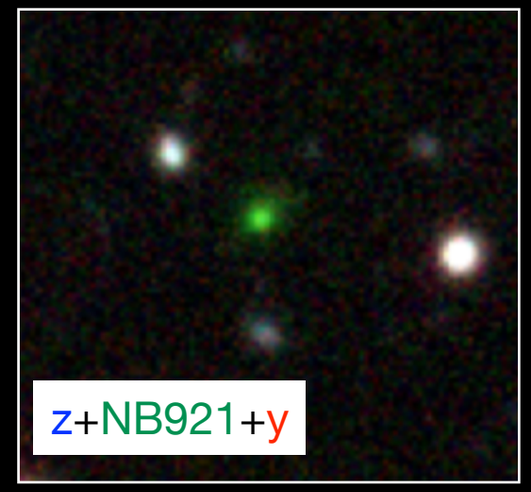
Background:

"local Universe"



"high redshift"

CR7 (LAE@z=6.6)

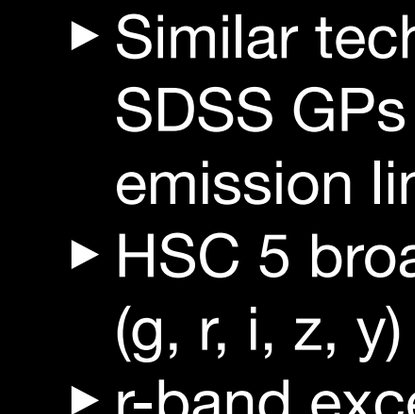


?

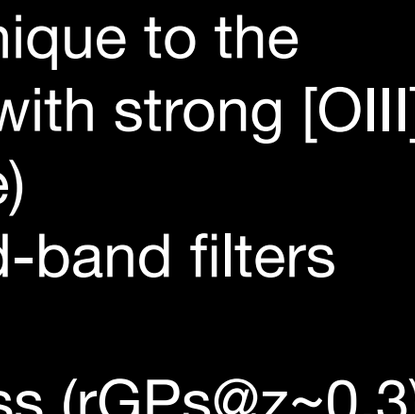
- Missing link between strong emission line galaxies at very high redshift (such as LAEs) and those in the local Universe (such as GPs and BGs)
- Narrow/Intermediate band excess galaxies at z<1 (e.g., Kakazu+07, Ly+14, 16)
- The sample size of (especially extreme) objects is limited
- Deep and wide Subaru/Hyper Suprime Cam(HSC) data can provide us galaxy sample at higher redshift with lower stellar mass and stronger emission line compared to the SDSS GPs

Sample selection:

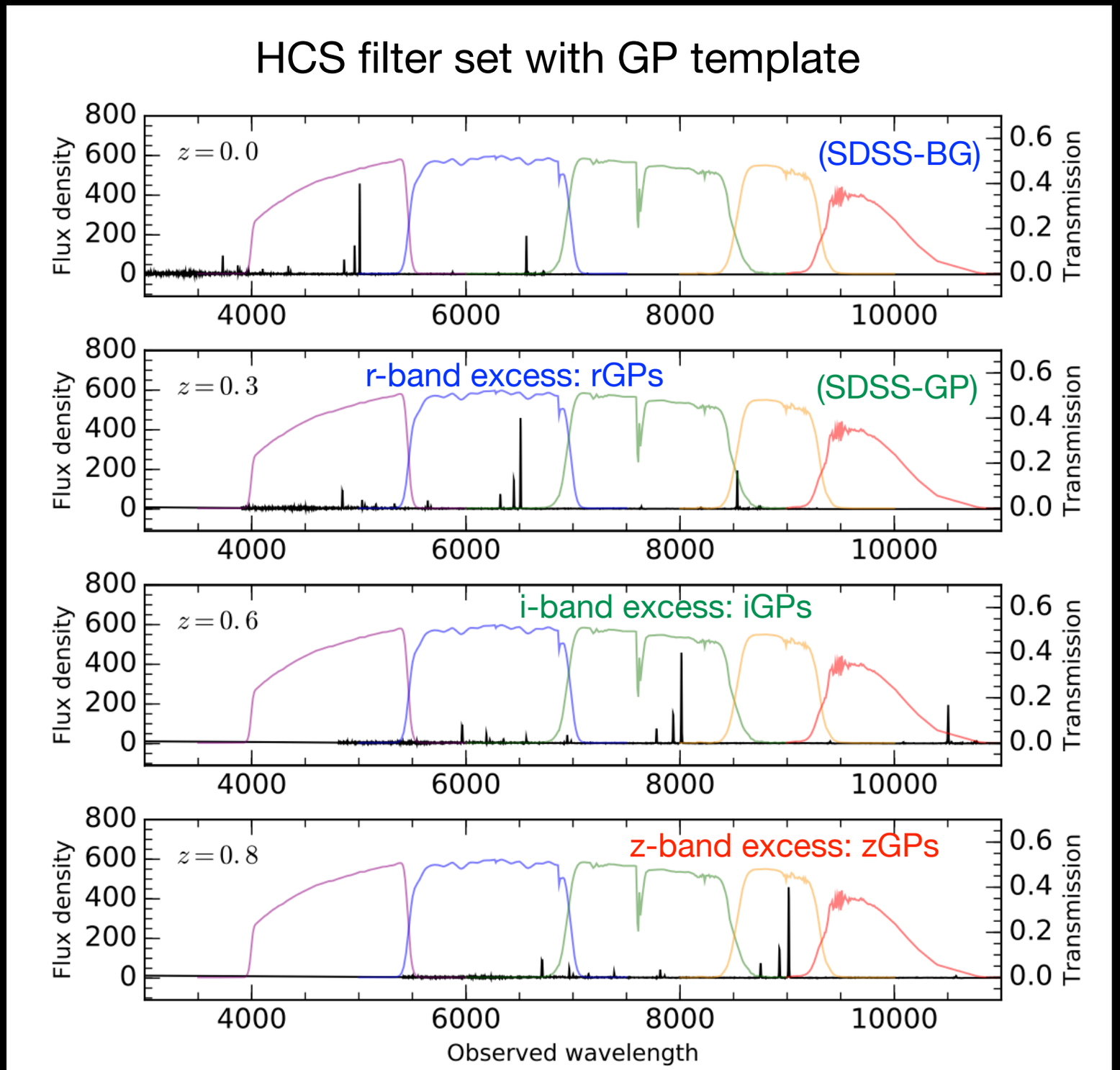
- Detecting broad-band excess due to strong emission lines
  - Similar technique to the SDSS GPs (with strong [OIII] emission line)
  - HSC 5 broad-band filters (g, r, i, z, y)
  - r-band excess (rGPs@z~0.3)
  - i-band excess (iGPs@z~0.6)
  - z-band excess (zGPs@z~0.8)
- More quantitatively, two-color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



SDSS-GPs

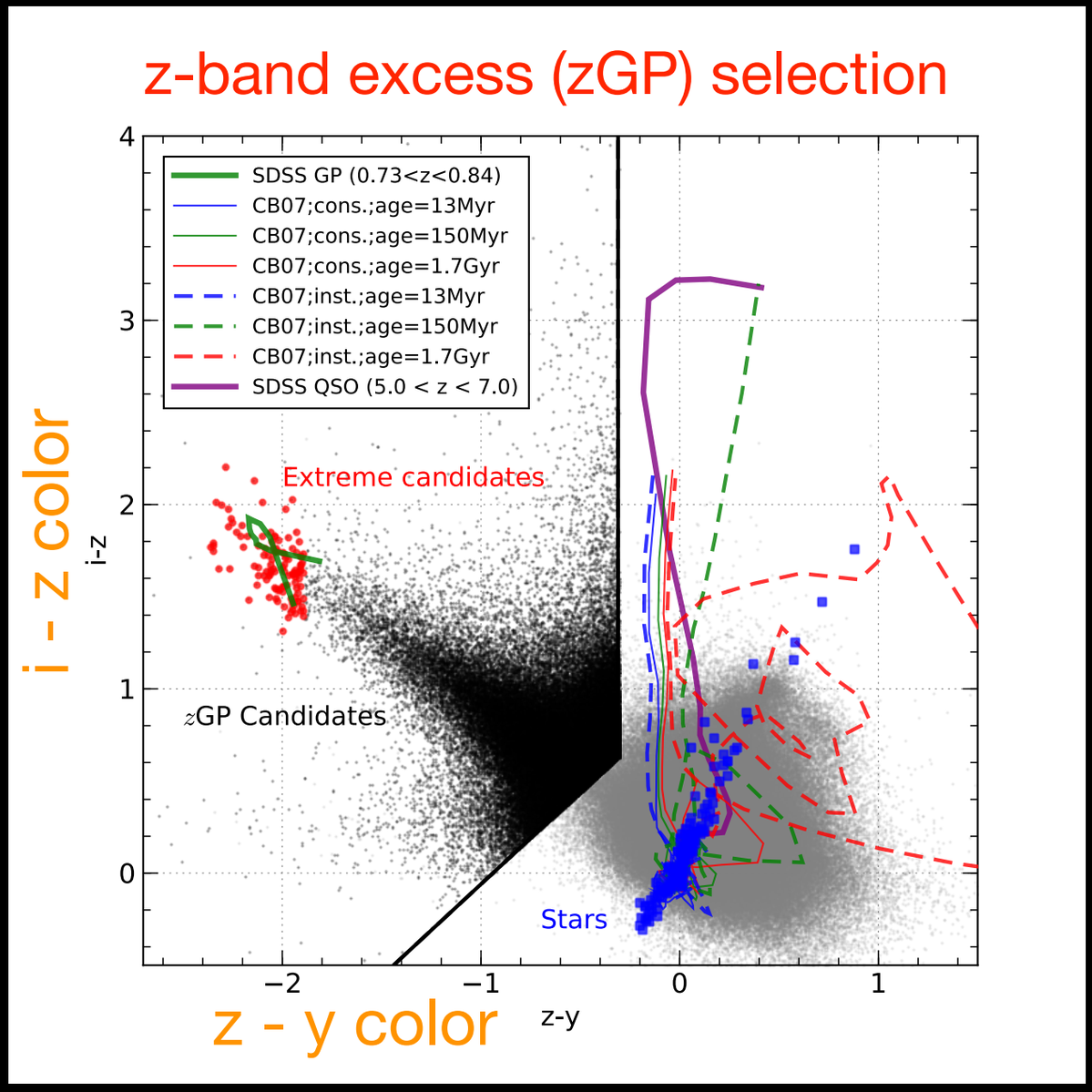


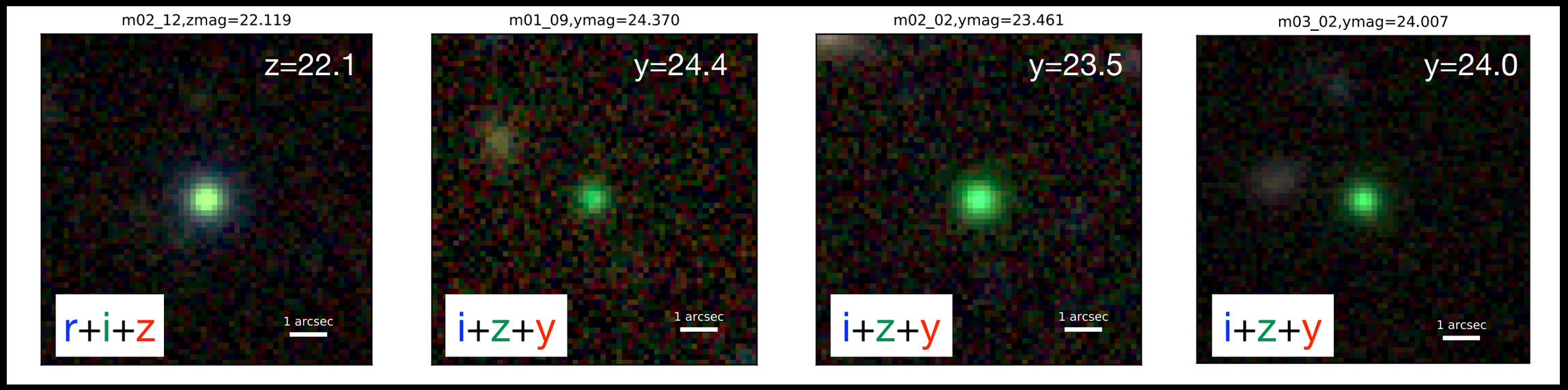
SDSS-BGs



Sample selection:

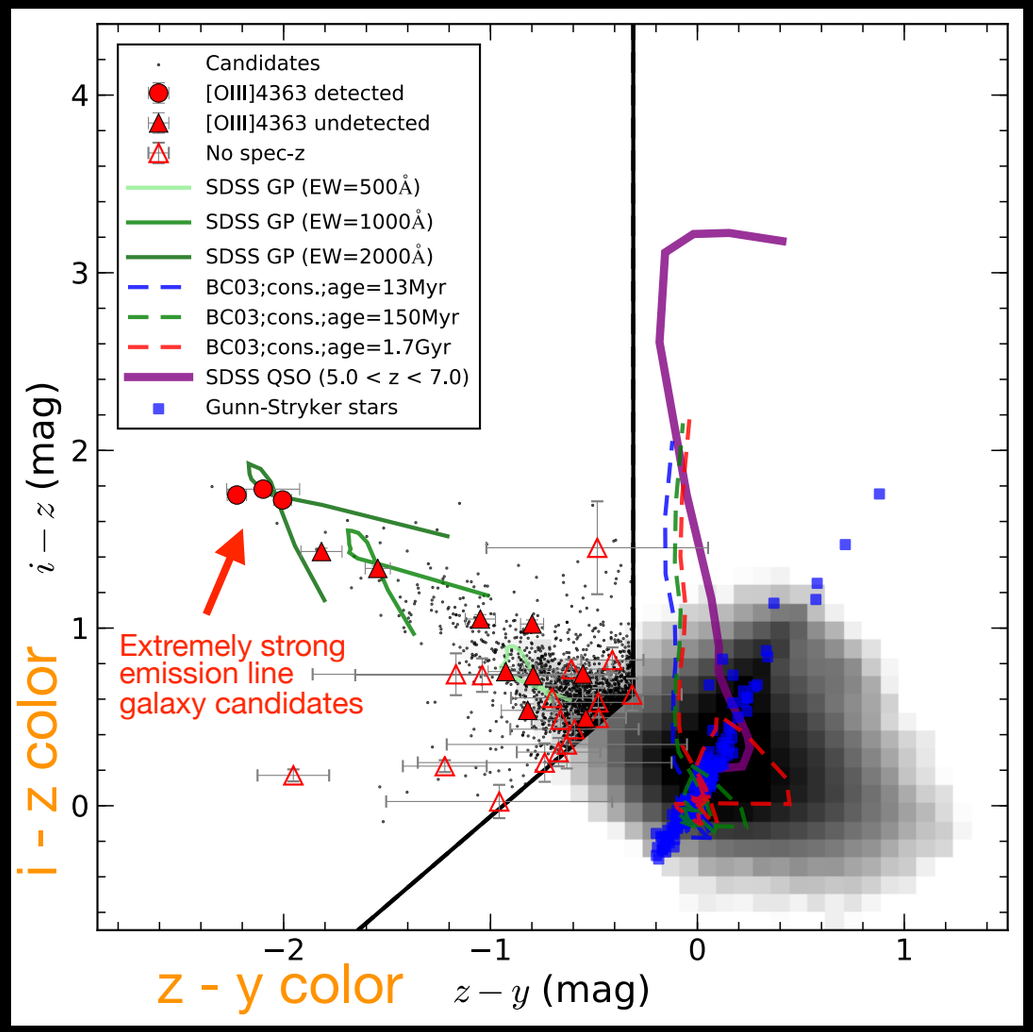
- HSC SSP internal data release (S16a)
  - HSC-Wide: ~300 deg^2, r_{limit}~26 AB
  - HSC-Deep: ~27 deg^2, r_{limit}~27 AB
  - HSC-UltraDeep: ~3 deg^2, r_{limit}~28 AB
  - All 5 broad-band data is available
- Broad-band excess by strong emission lines
  - i-band excess from r-i vs. i-z (iGPs)
  - z-band excess from i-z vs. z-y (zGPs)
  - z<26 AB (iGPs) and y<26 AB (zGPs)
- The number density
  - ~300 deg^{-2} (iGPs)
  - ~500 deg^{-2} (zGPs)
- The expected EW^{rest} > a few x 100 Å
- Very compact (almost point sources)

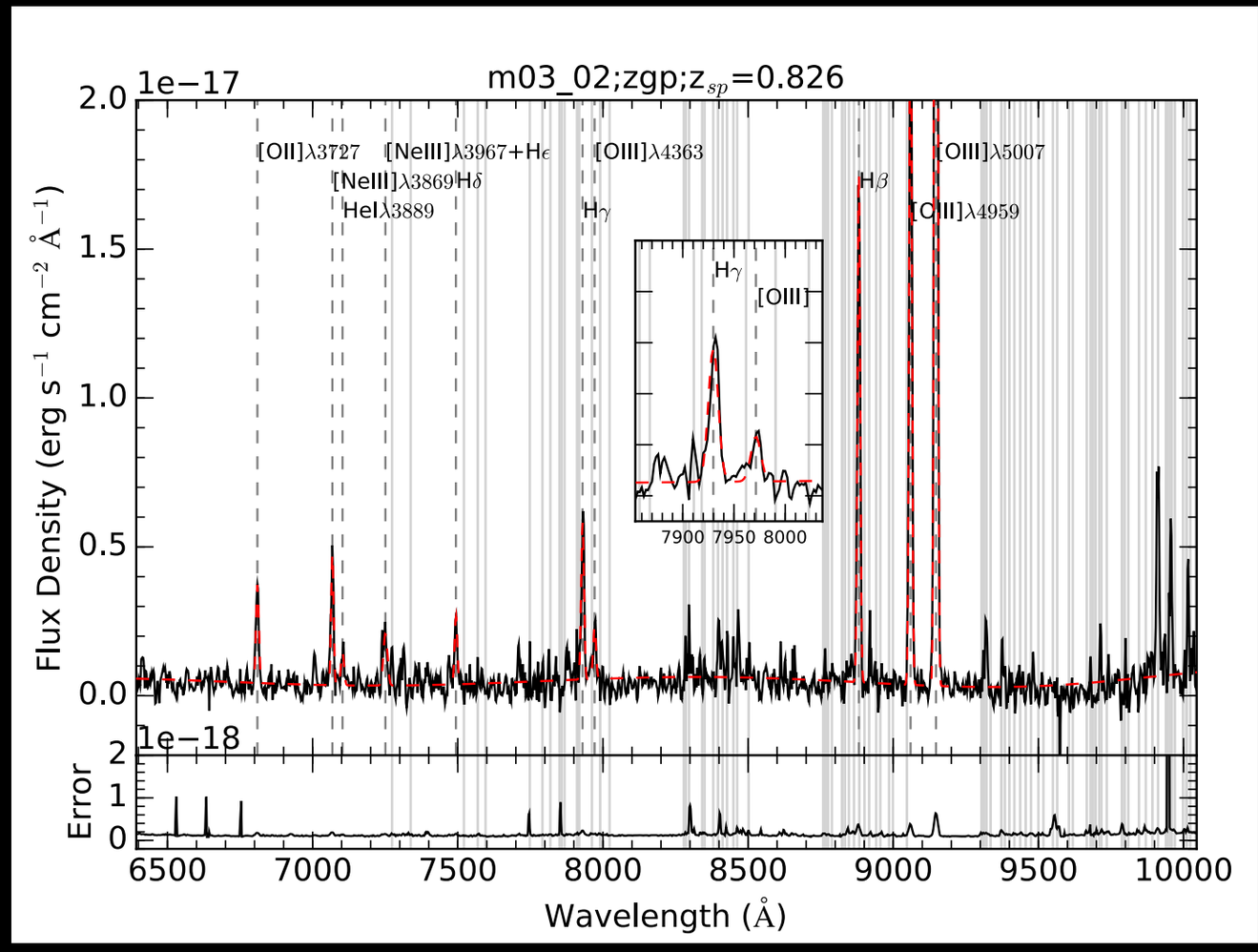




Follow-up spectroscopic observation:

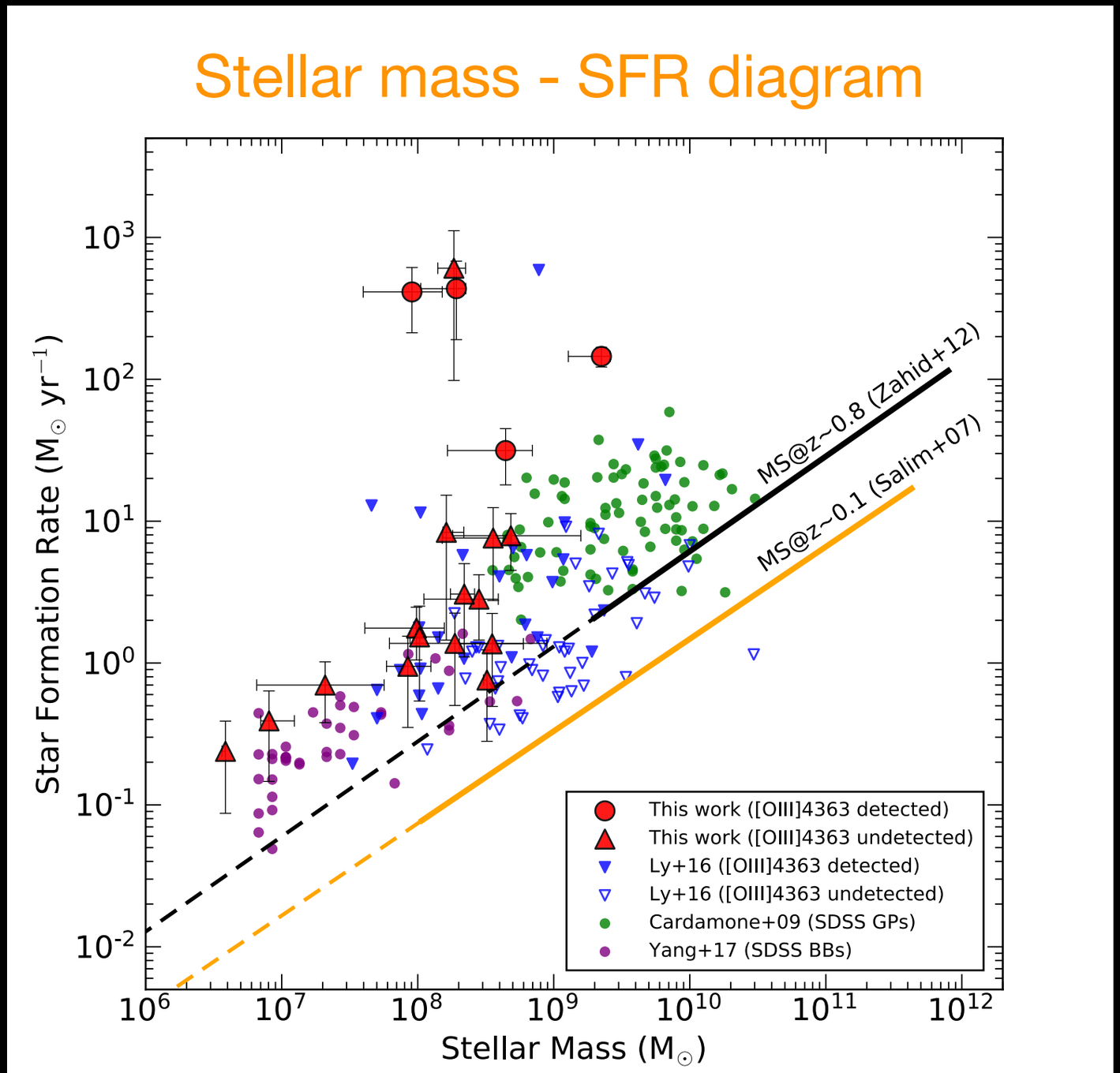
- Spectroscopic follow-ups with Subaru and Gemini are ongoing
- Gemini/GMOS-S observation (Yabe et al. 2018 to be submitted soon)
  - R150_G5326 (R~700), λ=5000-10000Å, MOS mode
  - Total on-source exposure time of each object is 3600 sec.
  - 40 objects were observed in total
- Detected multiple emission lines from 19 objects at z=0.3-0.85
- A weak [OIII]λ4363 emission line is detected significantly from 4 objects
- [OIII]λ5007 EW^{rest} is 100 Å - 2000 Å (extremely strong emission line)





Stellar mass and star formation rate:

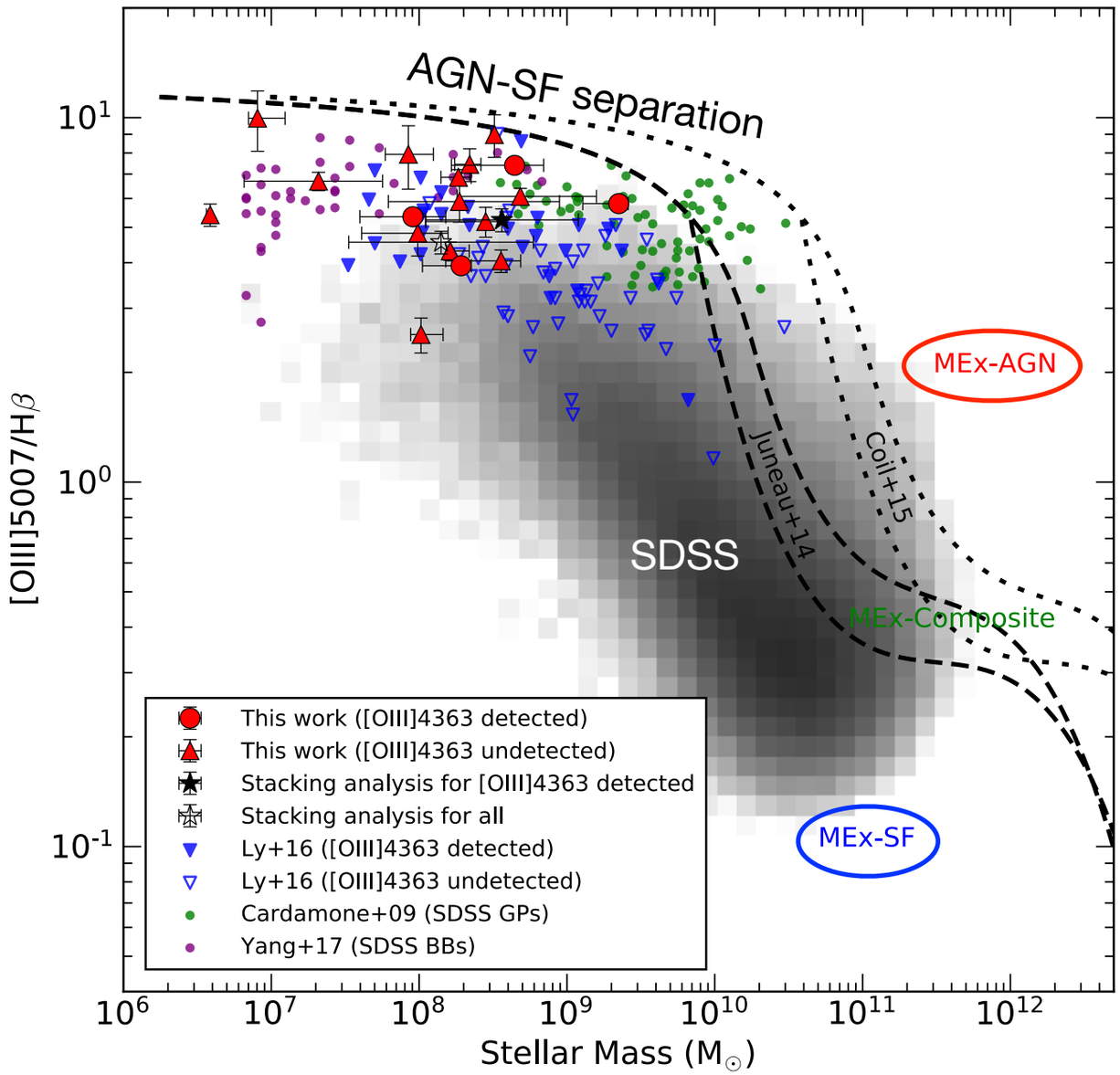
- Stellar mass is derived from SED fittings using broad-band photometry after subtracting the contribution from the emission lines
- Dust extinction is derived from Balmer decrements using Hβ, Hγ, Hδ if possible
- Star formation rate (SFR) is derived from the extinction corrected Hβ luminosity
- Our sample shows higher SFR by up to 1000x compared to normal star-forming galaxies at the similar redshift



AGN emission line ratio diagnostics:

- Line ratio diagnostics to distinguish star-forming galaxies and AGNs (e.g., BPT diagram)
- No [NII]/Hα ratio for our sample, but [OIII]/Hβ ratio is available
- Stellar mass vs. [OIII]/Hβ (MEx) diagram (e.g., Juneau+14)

Mass Excitation (MEx) diagram

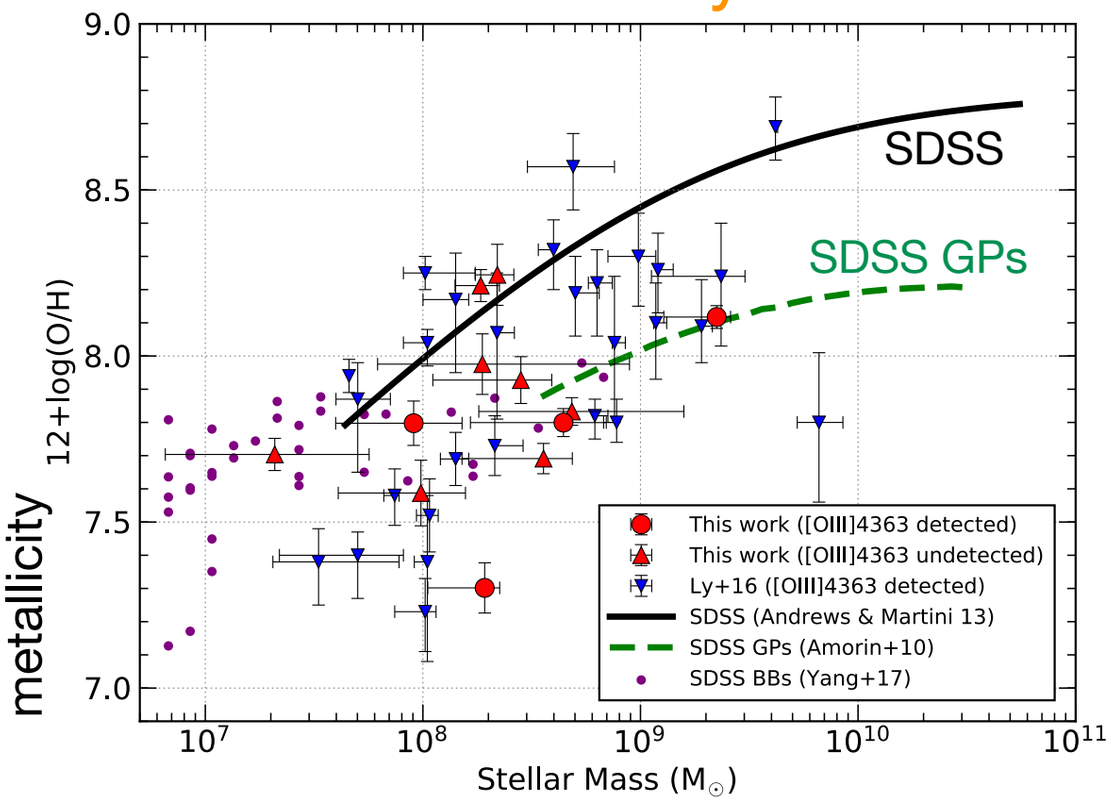


- Our sample is basically within SFG region on the MEx diagram
- Our sample shows smaller stellar mass and higher [OIII]/Hβ ratio than normal SDSS galaxies at z~0.1 and comparable [OIII]/Hβ ratio to the SDSS GPs and BGs

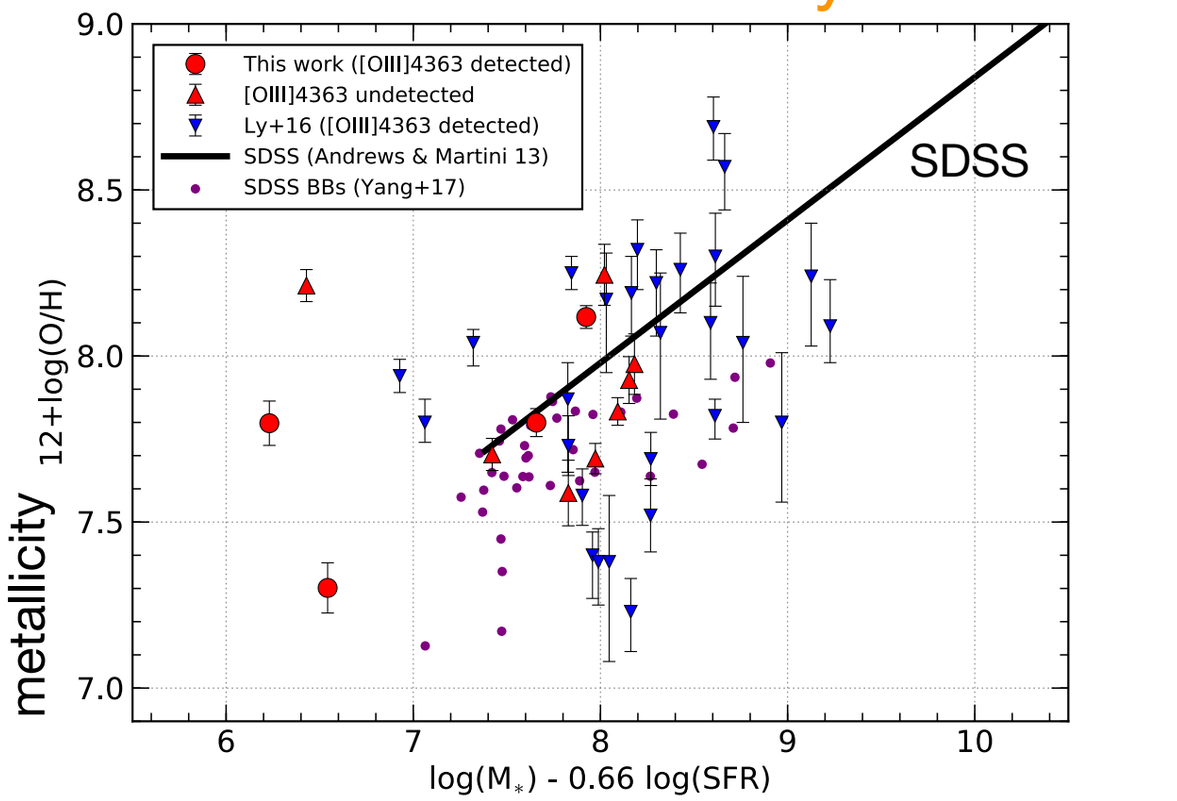
Oxygen abundance:

- The "direct" method for gas phase metallicity measurements if [OIII]λ4363 is detected
  - Electron temperature measured from [OIII]λ4363/[OIII]λ5007
  - We follow Izotov+06 for the "direct" method
- The "strong line" method if [OIII]λ4363 is not detected
  - KK04 (Kobulnicky&Kewley04; theoretical approach) is used (R23 indicator)
  - ~0.3-0.7 dex overestimated compared to the "direct" method --> correction
- The oxygen abundance of our sample: 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

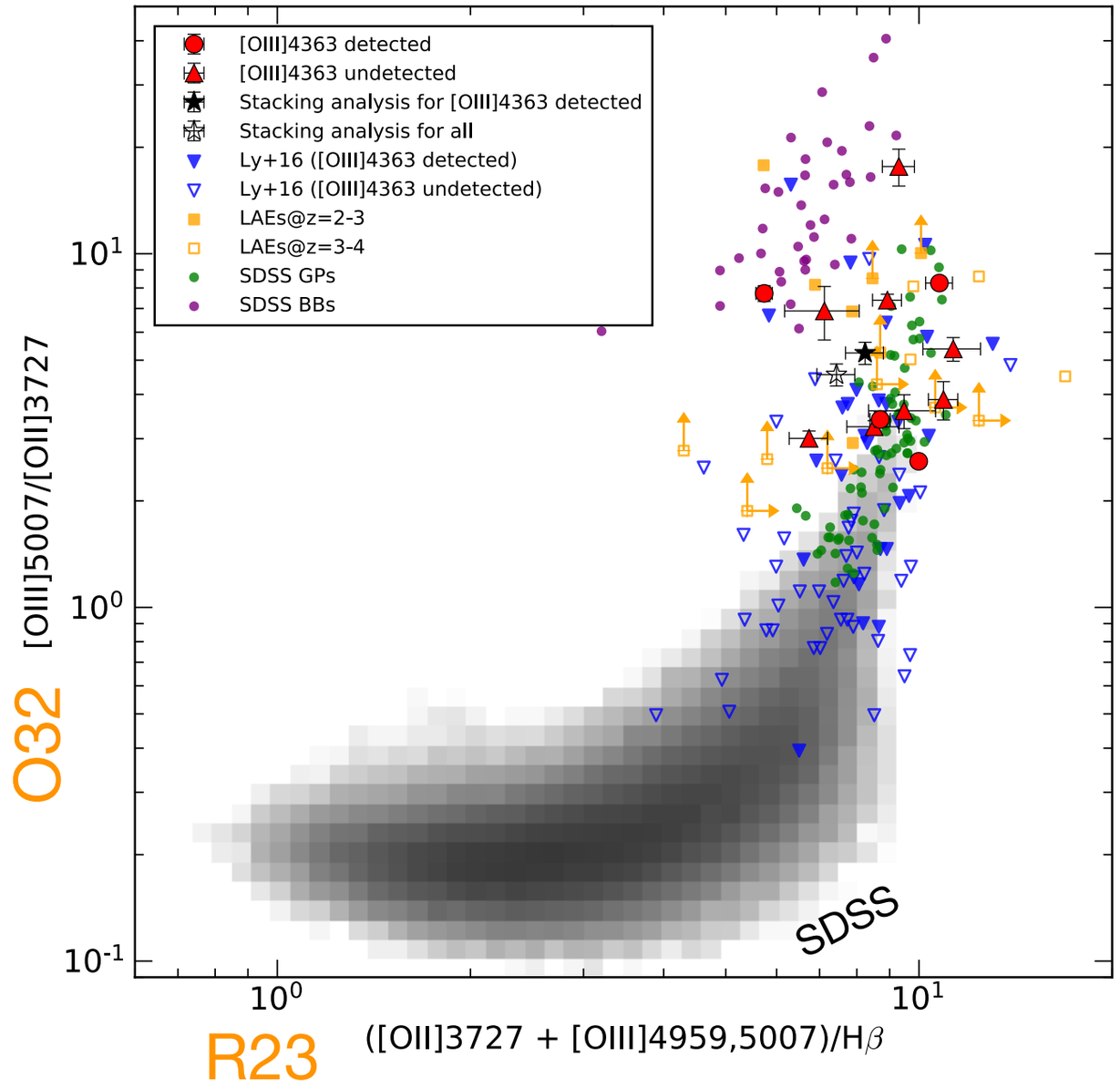


Ionization state:

- Ionization diagnostics by using emission line ratios
  - R23 index (metallicity sensitive) vs. O32 index (ionization parameter sensitive)

- Our sample has very high [OIII]λ5007/[OII]λ3727 ratio
  - 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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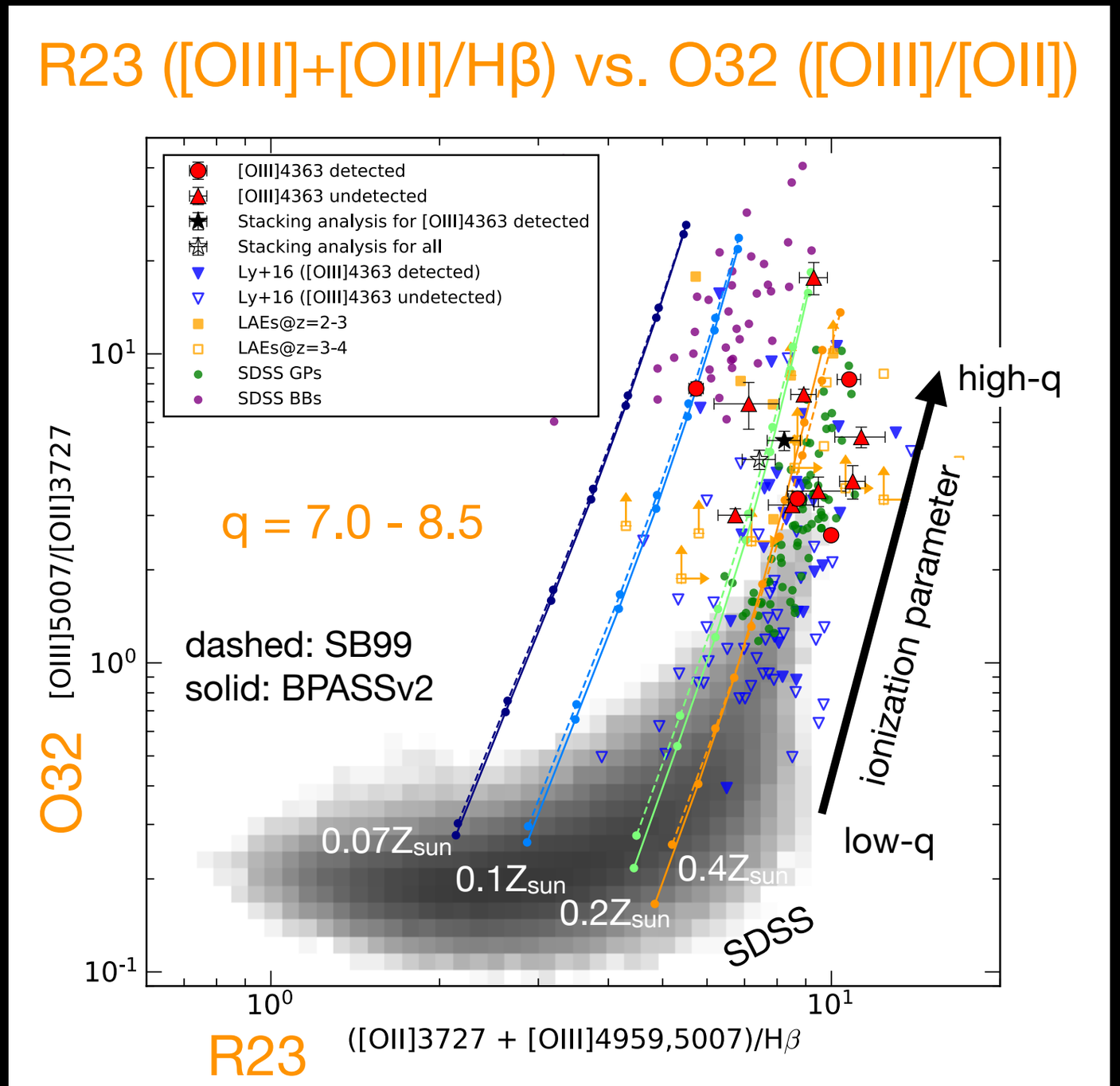
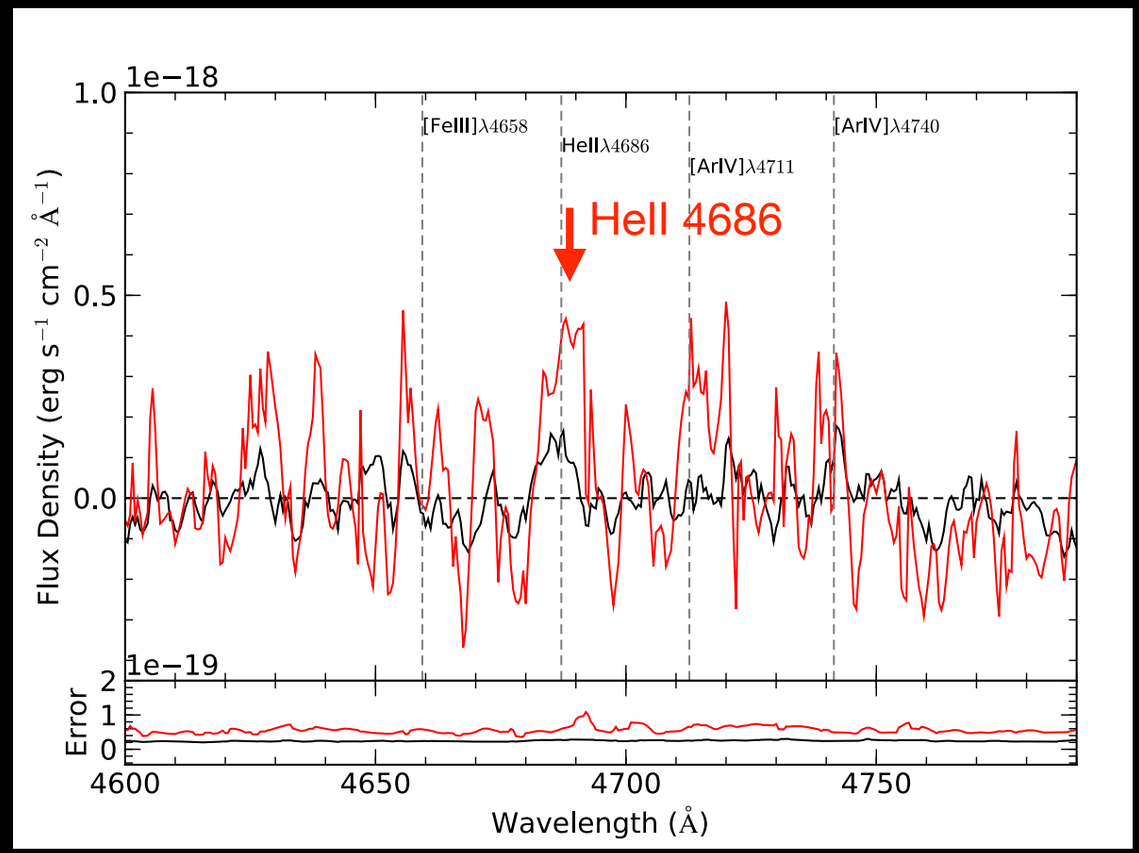
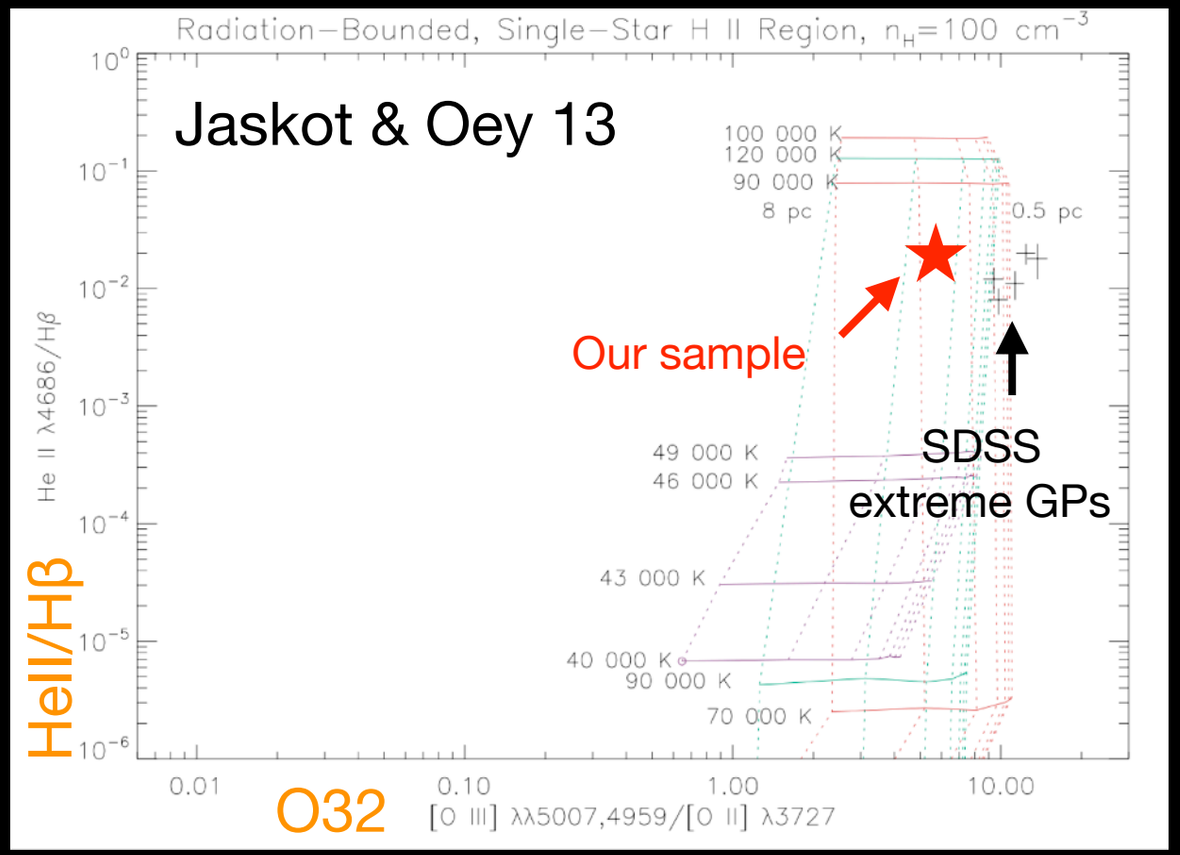
- Our sample has very high [OIII]λ5007/[OII]λ3727 ratio
  - Comparable or higher than that of the SDSS GPs and other emission line galaxies at the similar redshift
  - Comparable to the LAEs at z=2-4
- Comparison to photoionization models using CLOUDY (c17.00)
  - The observed line ratio can be explained by models with very high ionization parameters
  - Some objects cannot be explained the normal models
  - Harder ionization sources are required?



What is the ionization source?:

- Weak HeII λ4686 emission line is detected in the stacked spectra
- What is the origin of HeII λ4686 ?
  - Contamination of weak AGN?
  - High-mass X-ray binary?
  - Shock by supernova wind?
  - Wolf-Rayet (WR) or very hot O-star?
- The obtained HeII4686/Hβ is:
  - 0.023±0.003 (only [OIII]4363 detected)
  - 0.035±0.005 (all sample)
- Very hard spectral model with very hot WR (Jaskot & Oey 13) can explain the observed [OIII]/[OII] and HeII4686/Hβ emission line ratio





Summary:

- Searching for extremely strong emission line galaxies is ongoing using Subaru/HSC
- Follow-up observation by using Gemini/GMOS-S to examine detailed properties
  - multiple emission lines from 19 objects at z=0.3-0.85
  - EW^{rest}([OIII]λ5007) = 100 - 2000 Å
  - [OIII]λ4363 detections from 4 objects
- We found the following:
  - Very low-mass and high SFR (i.e., very high sSFR)
  - Possibility of AGN is low according to mass vs. [OIII]λ5007/Hβ diagram
  - Metal poor comparable to local extremely metal poor galaxies
  - High [OIII]λ5007/Hβ and [OIII]λ5007/[OII]λ3727 indicating high ionization parameter
  - Possibility of large contribution from WR stars to the obtained line ratio