Local Extreme Emission Line Galaxies in wide narrow band surveys: gateways to the early Universe

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IAA (J.M. Vílchez, E. Pérez-Montero, C. Kehrig, J. Iglesias-Páramo, A. Arroyo Polonio)

FONDO DE INVERSIONES DE TERUEL
GOBIERNO DE ARAGON
MINISTERIO DE CIENCIA E INNOVACIÓN
Plan de Recuperación, Transformación y Resiliencia
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Outline

- 1. Introduction and motivation
- 2. Detection of extreme emission line galaxies at z<0.35 in the multifilter J-PLUS survey
  - Sample selection
  - Photometric results
- 3. Follow-up analysis
  - Spectroscopy
    - Estimation of physical parameters
    - Comparison with other analogs, LyC leakers, and high-z objects
  - Other follow-up studies
- 4. Conclusions

Introduction

- From the 1960s, many surveys have uncovered strongly star-forming galaxies in the nearby Universe (HII galaxies, BCDs...)

In the past 15 years, more and more extreme samples of galaxies have been identified

- z~0.3 Green Peas (Cardamone et al. 2009)
- z~0 Blueberry Galaxies (Yang et al. 2017)
- Higher-z EELGs (Amorin et al. 2015, Sanders et al. 2020)

These samples share some properties with typical galaxies at high redshift

- Compact morphology
- Strong emission lines
- Low metallicity
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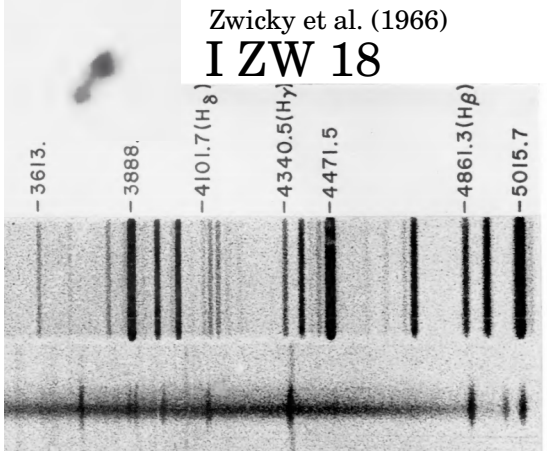
Are they truly analogs of galaxies in the epoch of reionization?

- A few studies in the past years pointed in that direction (i.e. Izotov et al. 2021)
- JWST spectra has shown striking similarities between the z>4 galaxies and low-z analogs (e.g. Schaerer et al. 2022)

Analyzing in detail the properties of enough local EELGs can help uncover the nature of the first galaxies in the history of the Universe



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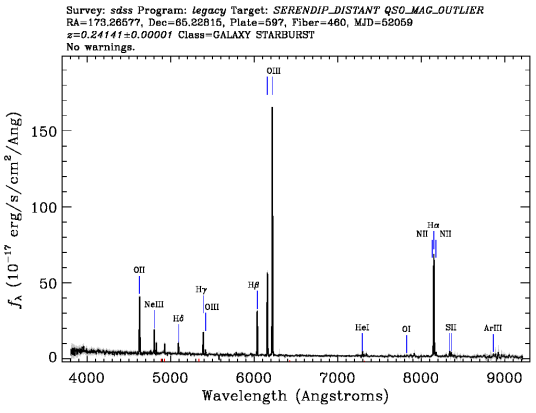

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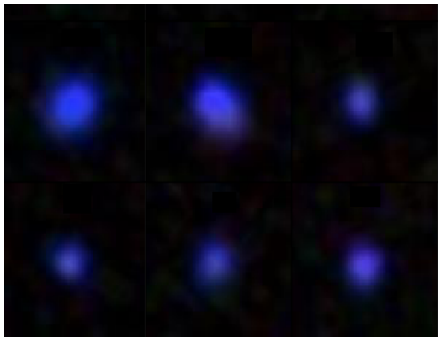
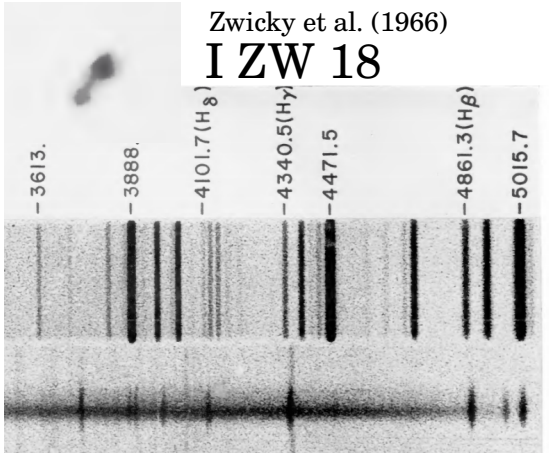


Blueberries (Yang et al. 2017)

Zwicky et al. (1966)



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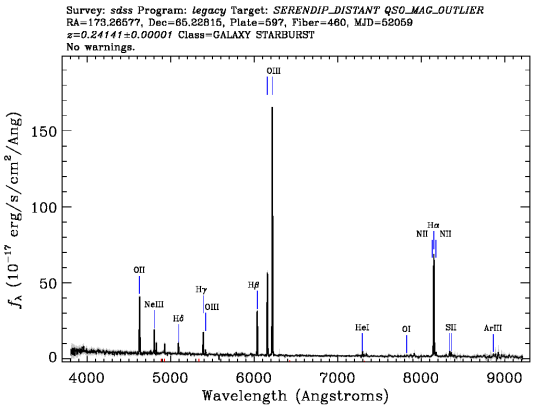

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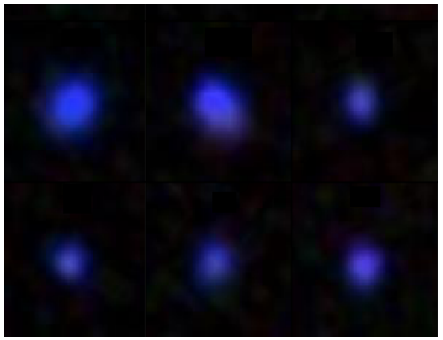

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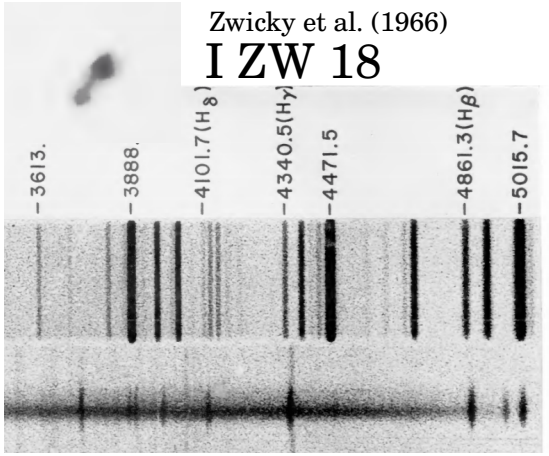

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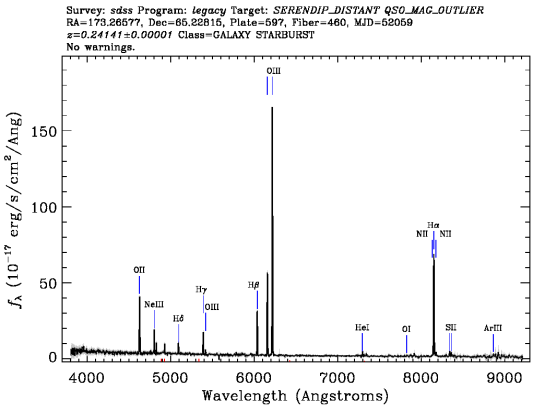

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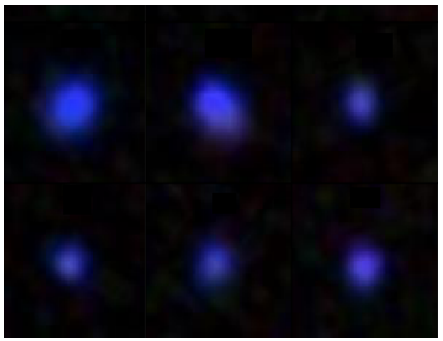

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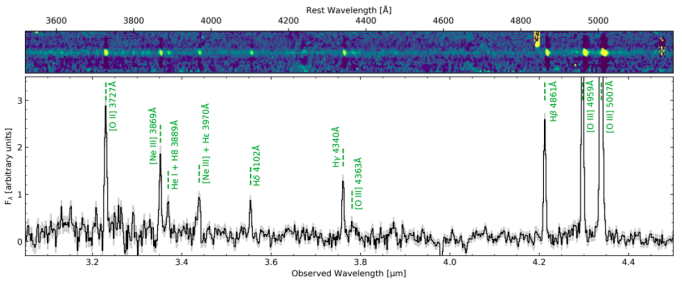
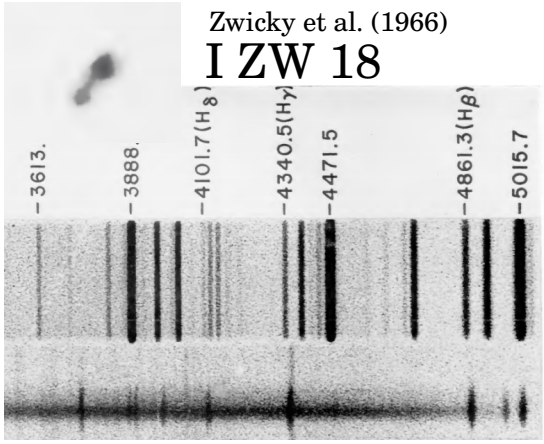
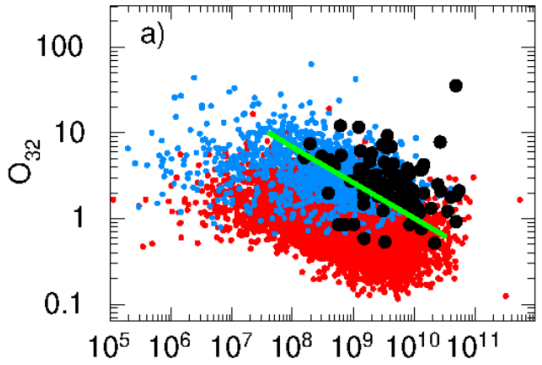
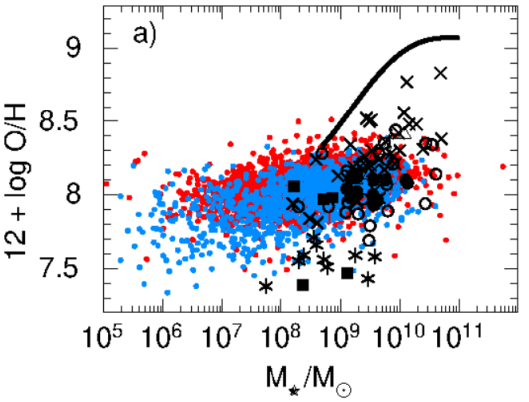


Schaerer et al. 2022







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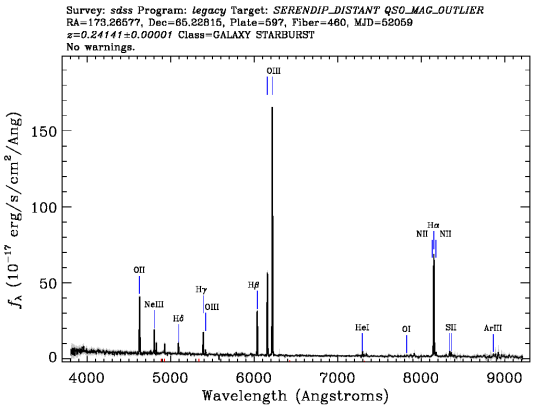

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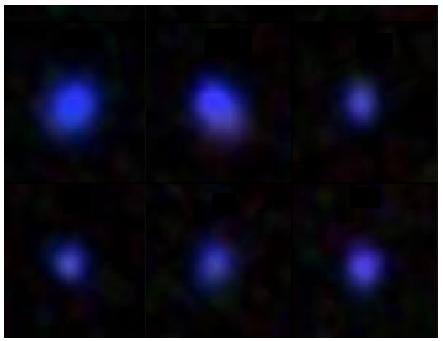

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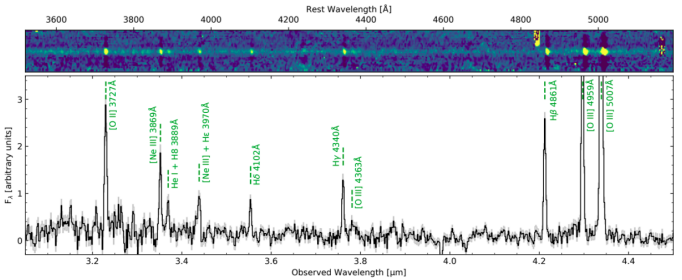

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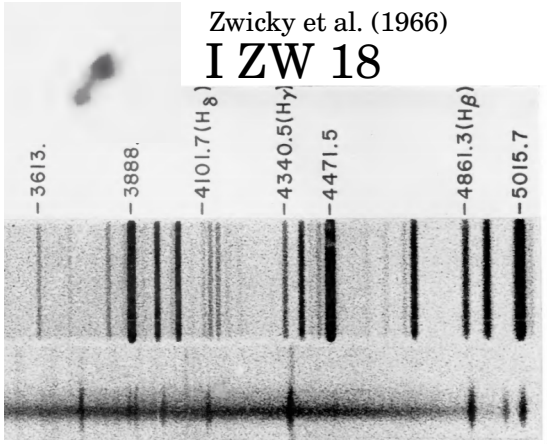

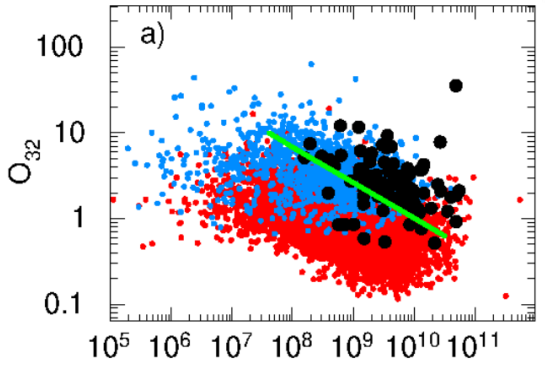

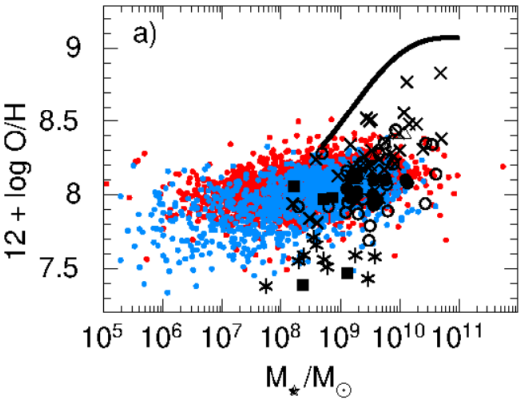

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- Create a complete census of EELGs in the local Universe and follow them up

To fully understand their statistical properties

To identify those that are the best analogs of the first galaxies in the Universe

Local EELGs can be studied in more detail than distant galaxies

obtain that, we need:

A very wide survey

EELGs are very rare & at low-z you have small volume per area

A (relatively) deep survey (EELGs are low-mass)

i<17.8 mag SDSS spectra, i<19 mag DESI spectra

Better spectral resolution than broadband surveys

And that is... J-PLUS

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Wide, photometric multiband survey

DR3 – 3000 deg²

Planned (2025): DR4 – 5000 deg²

12 filters (5 broad, 7 narrow-medium 120-400 Å wide)

Depth: 5σ 20.3 – 21.75 mag

Precursor of J-PAS

56 filters!!

See upcoming talks

Open access:

Images, catalogs, cross-matchs

Cenarro et al. 2019

S-PLUS: "Twin" in the South

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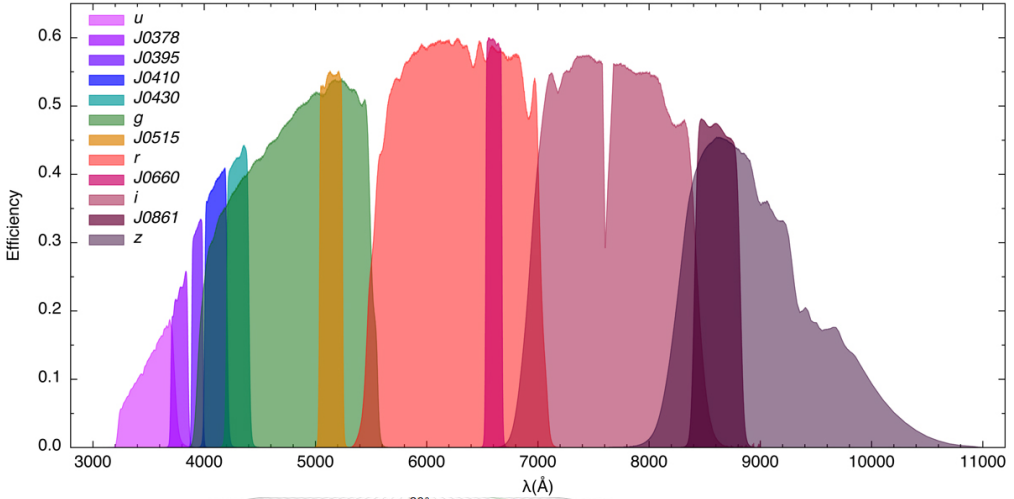

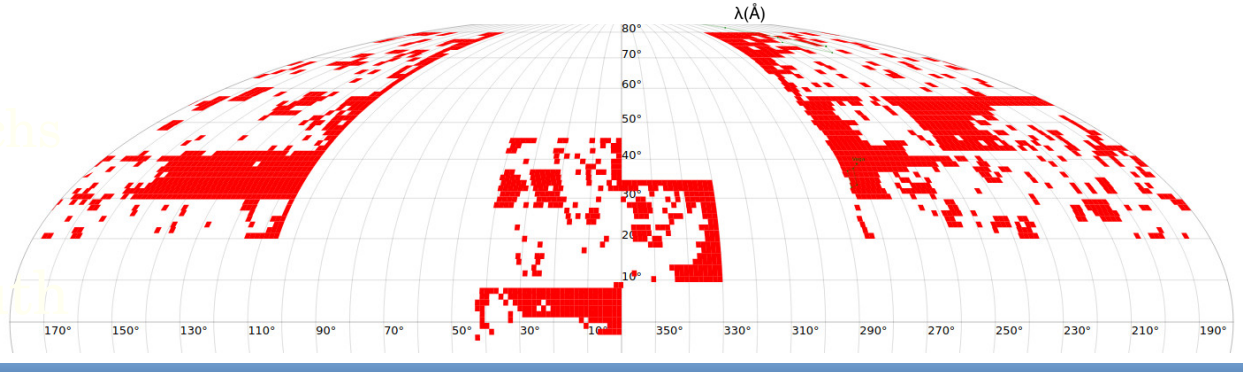

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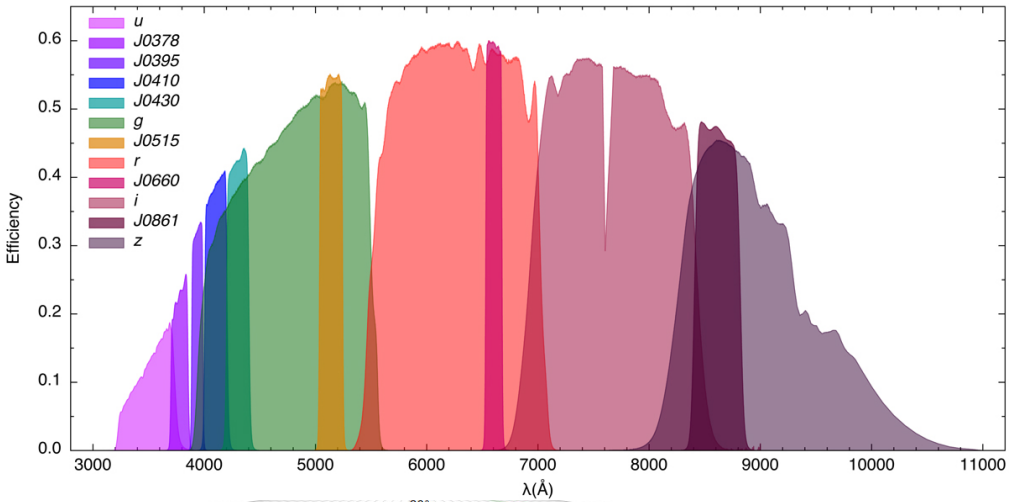

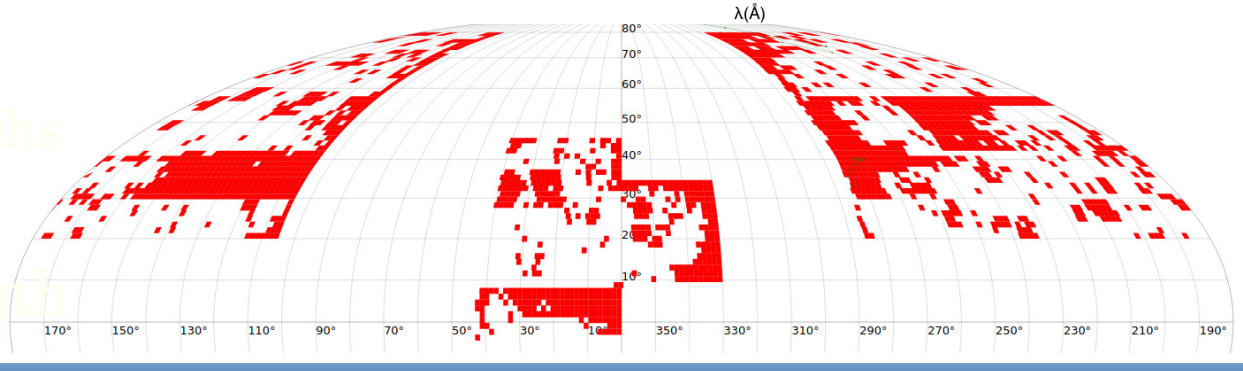

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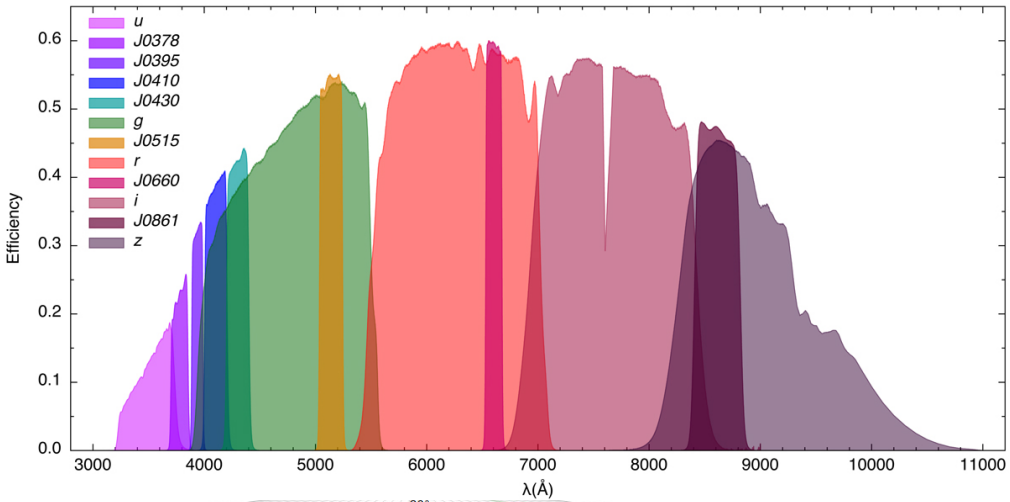

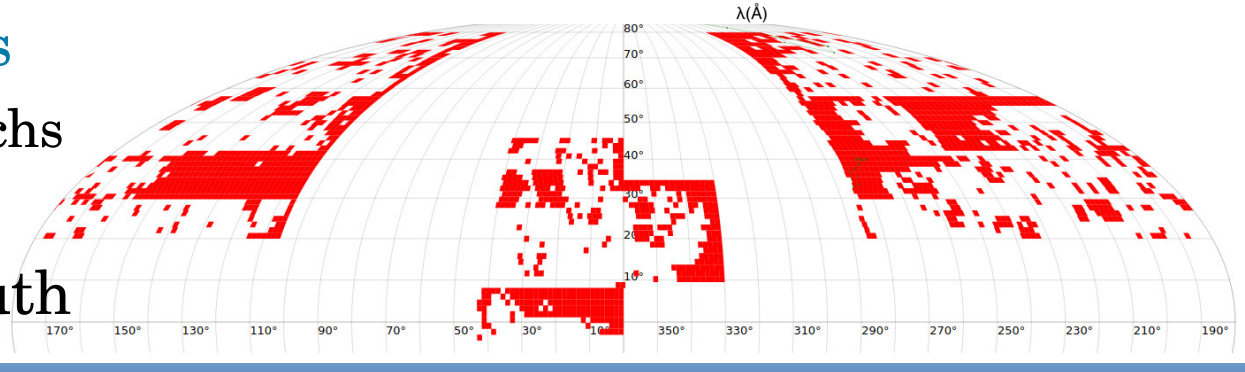

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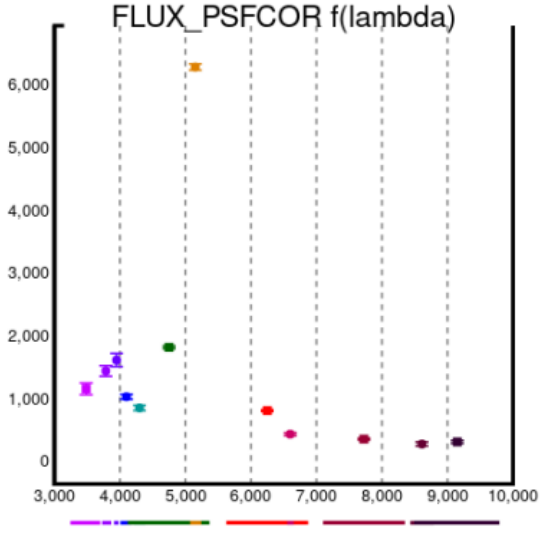

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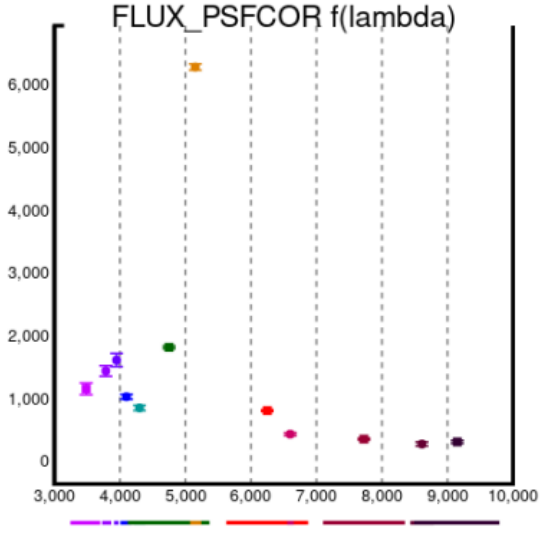

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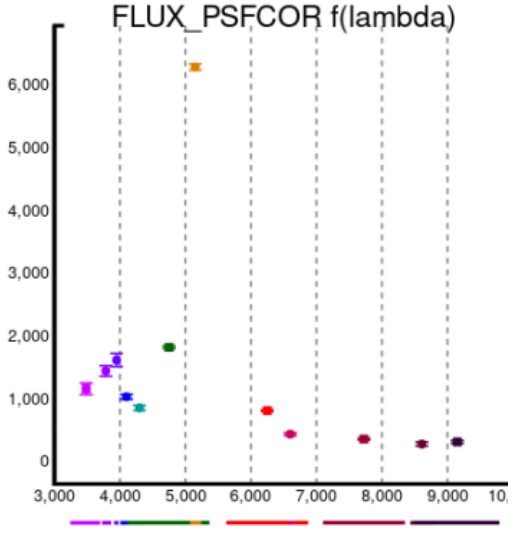

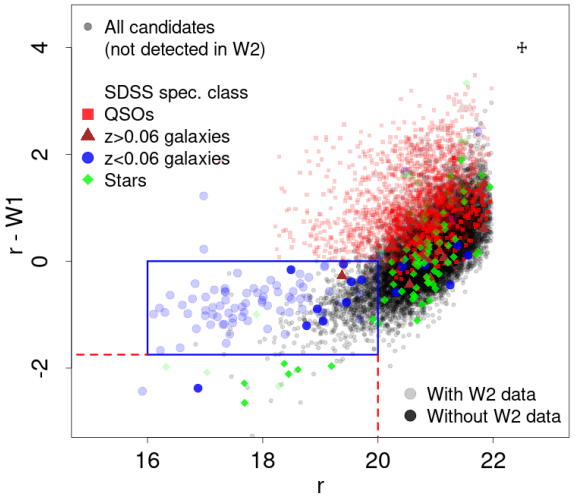

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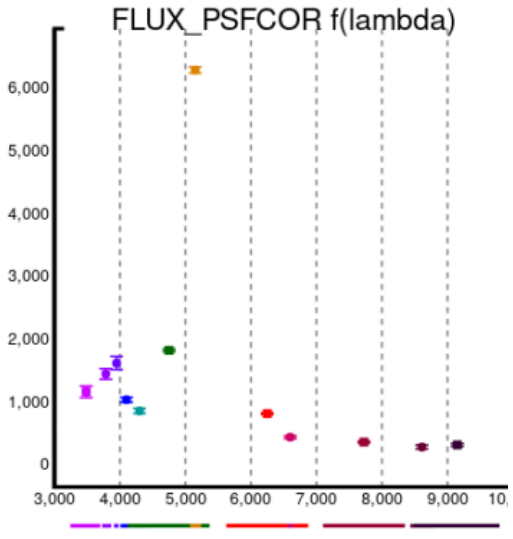

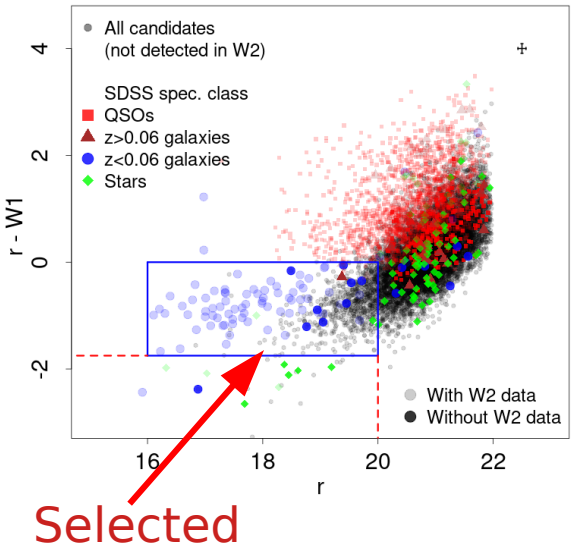

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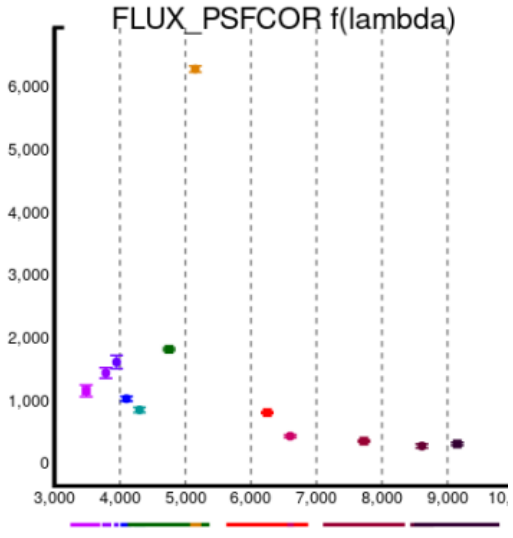

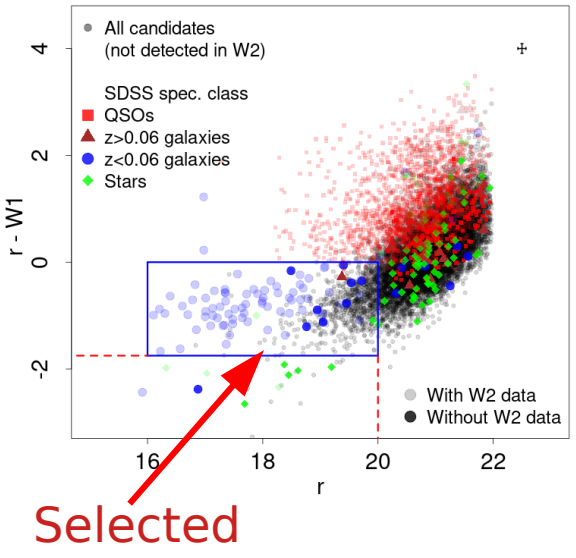

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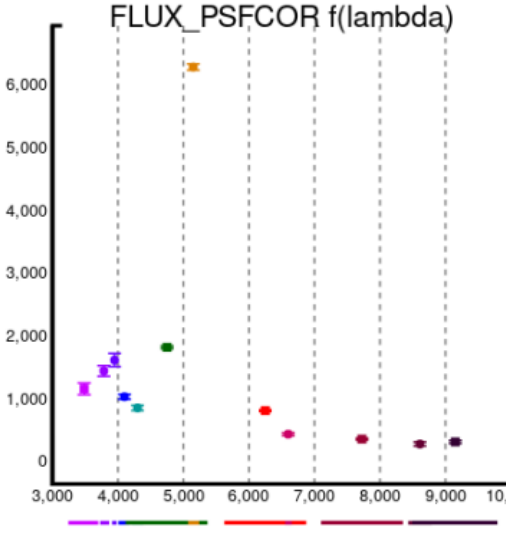

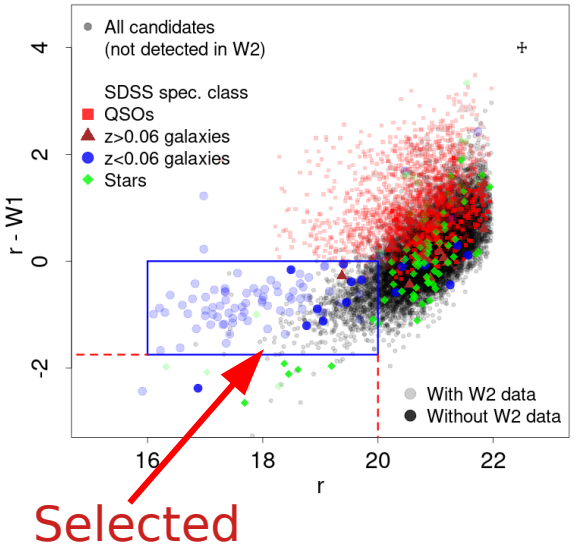

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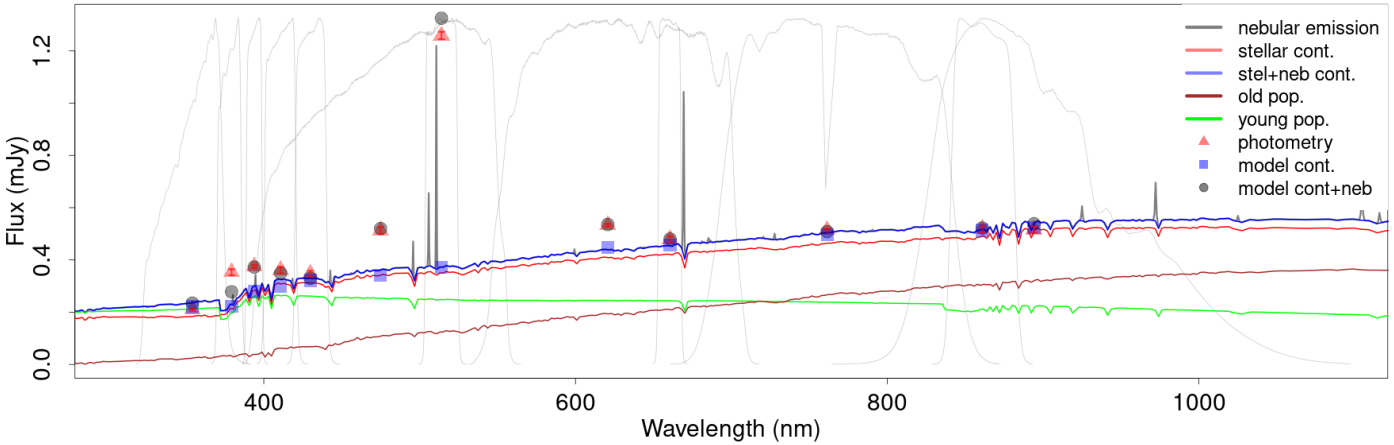

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- Very young burst (<=6 Myr)
- Low-mass galaxies
  - Median value $\log(M_*/M_\odot) \sim 8\ M_\odot$ (7.5-9)
- Low dust extinction E(B-V) ~ 0.15
- EW up to ~ 3000 Å
- sSFR typical for high-z galaxies
  - $10^7\ M_\odot$: sSFR ~ 1 $\log(Gyr^{-1})$
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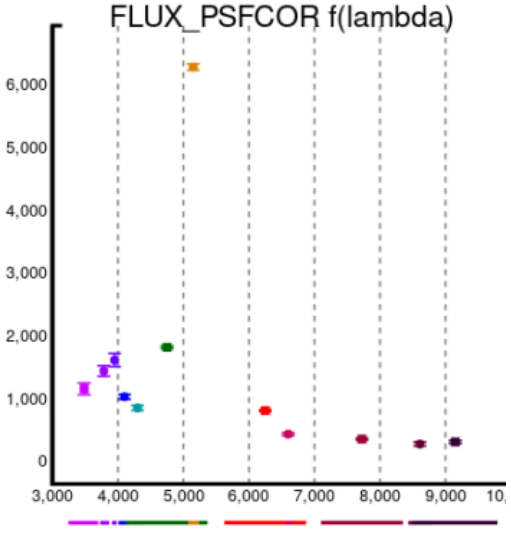

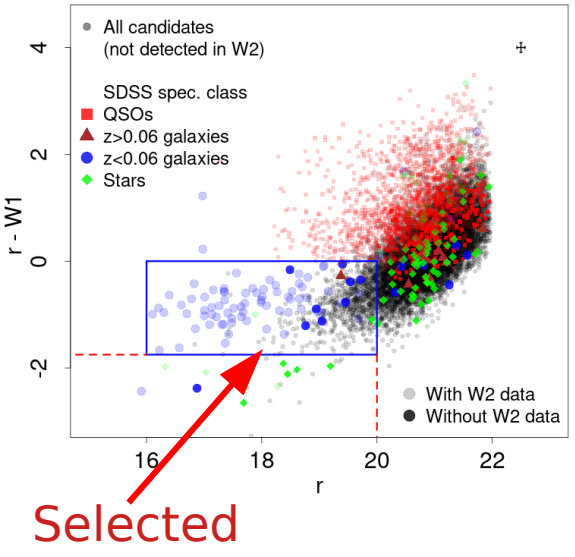

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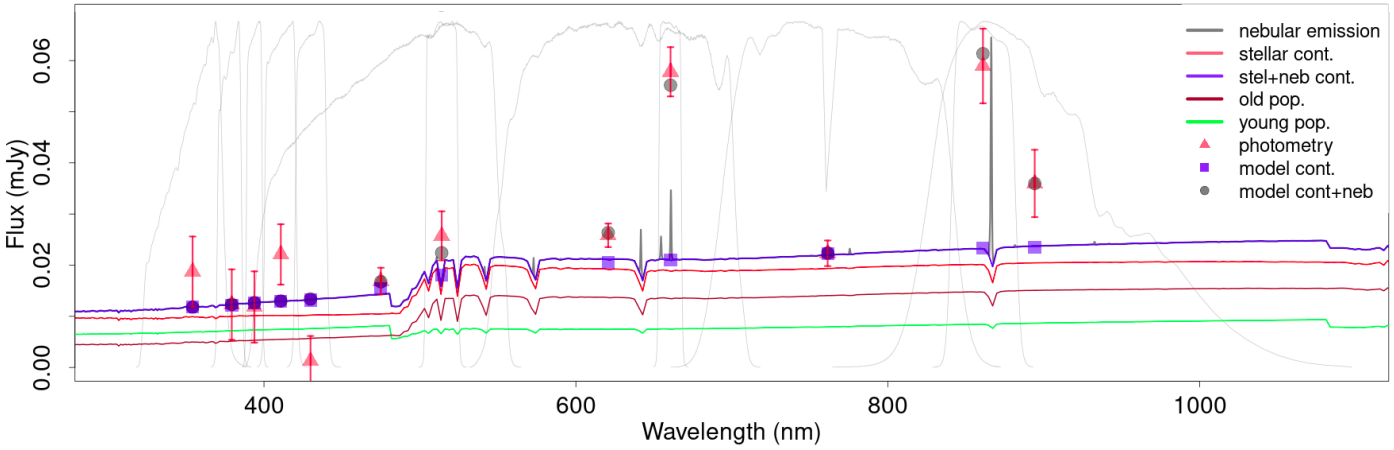

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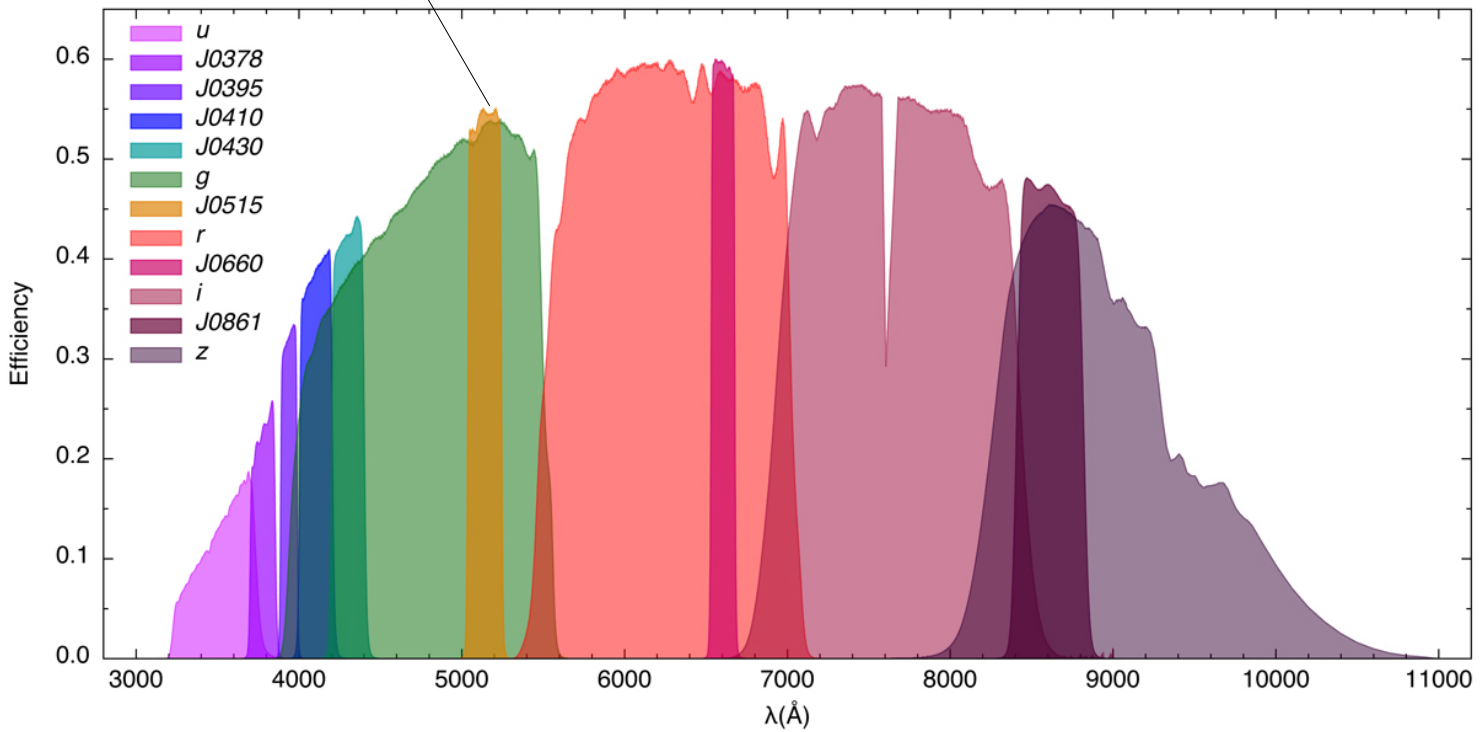

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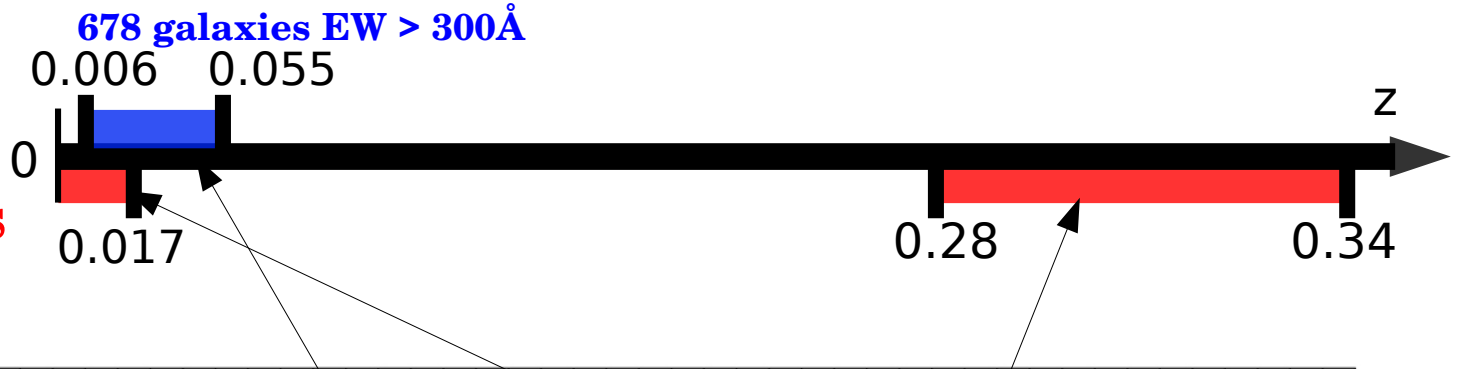

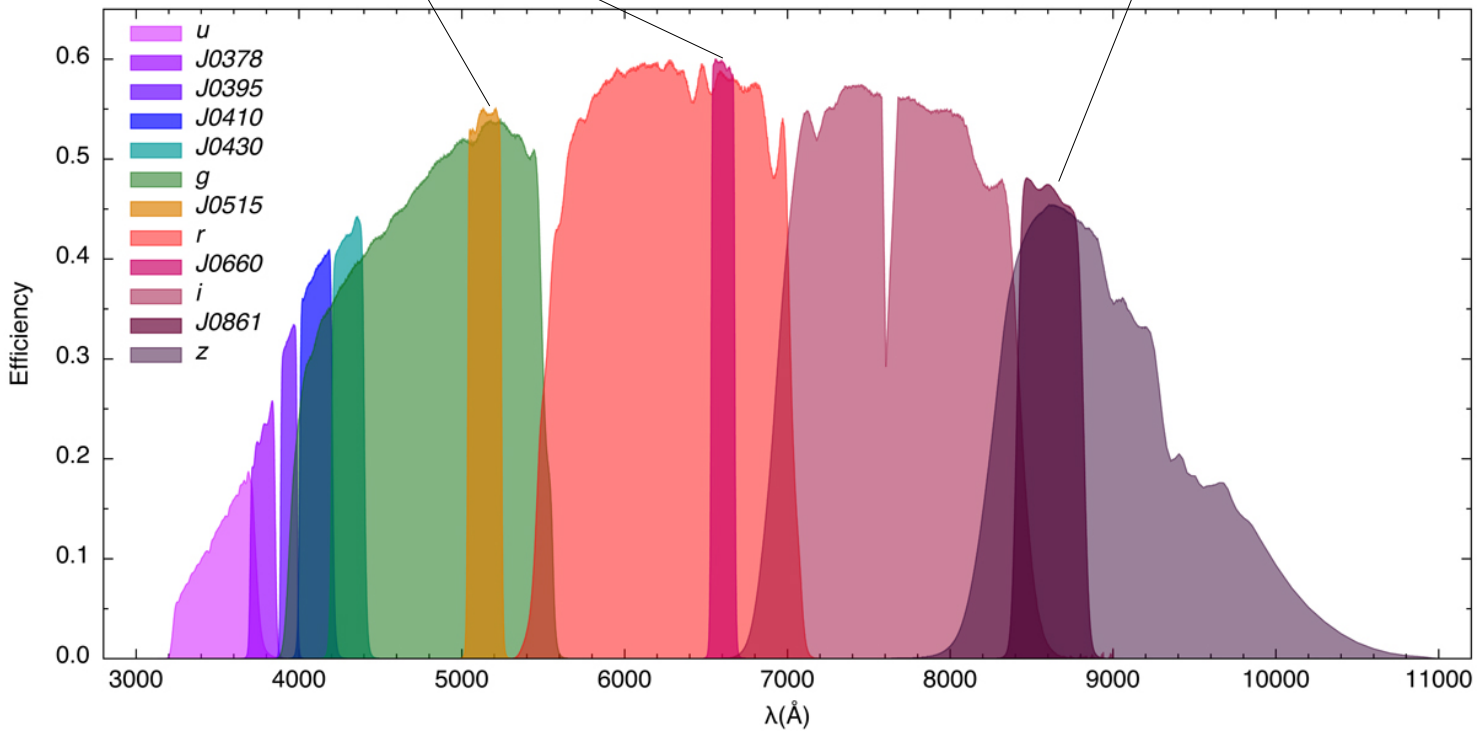

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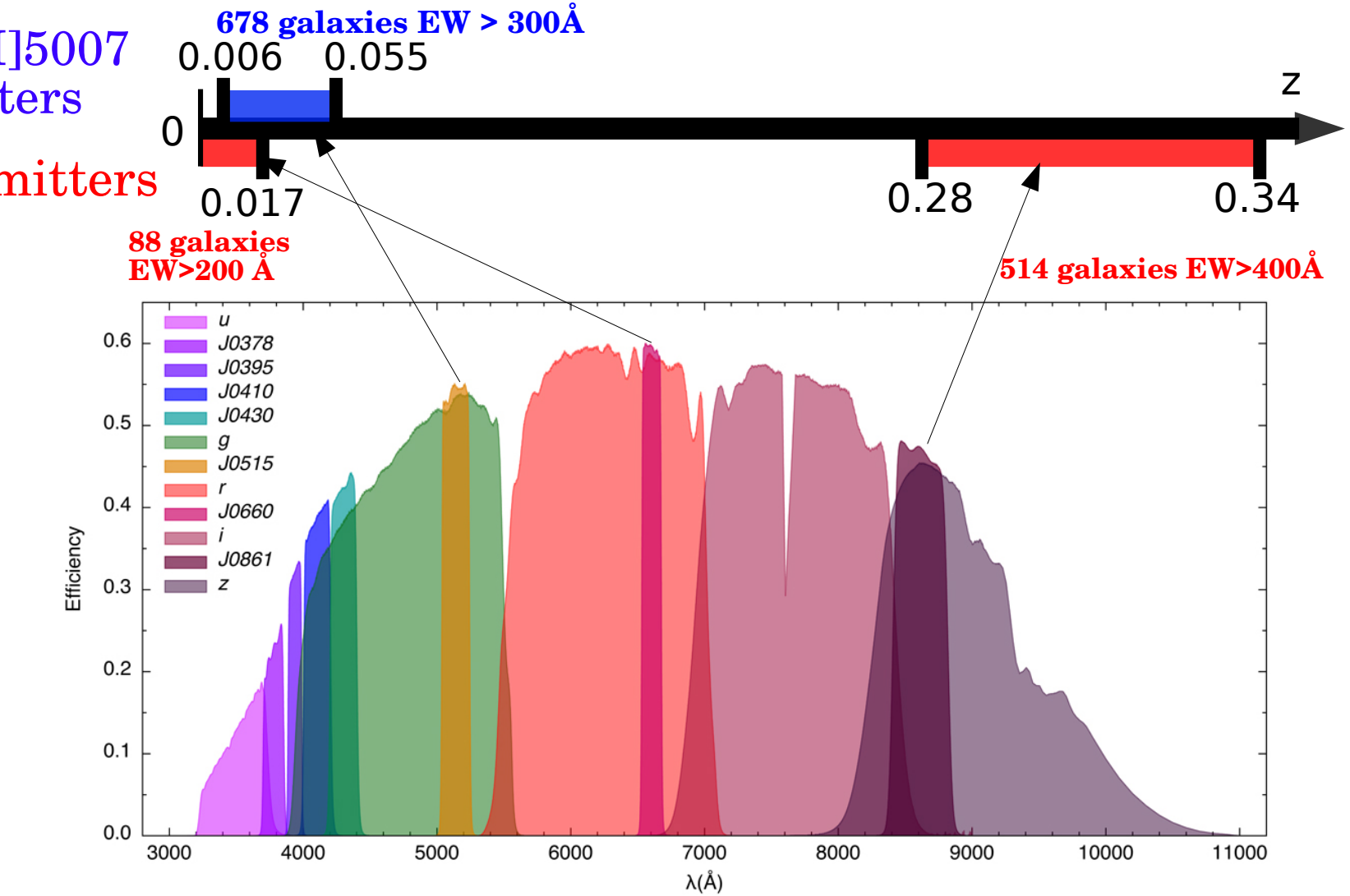

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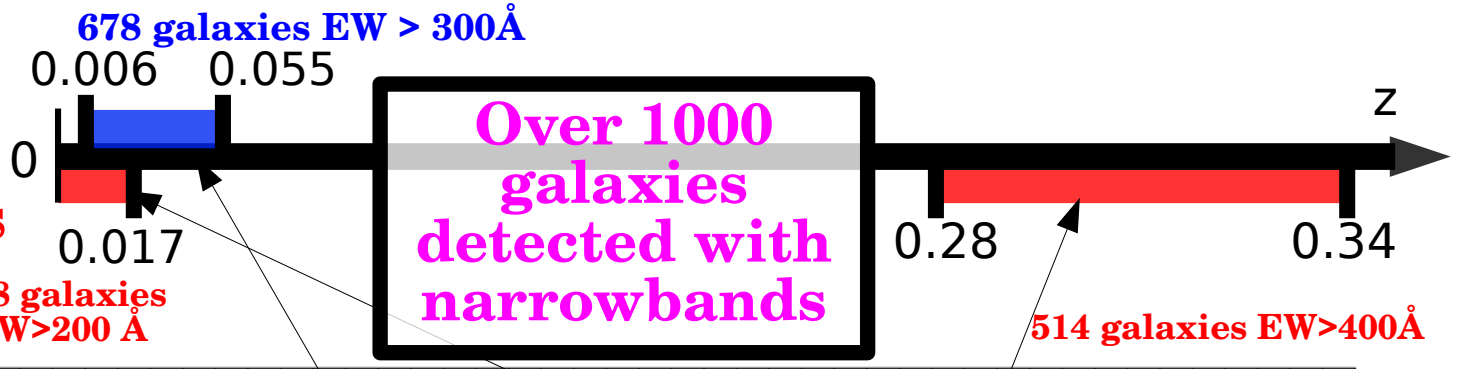

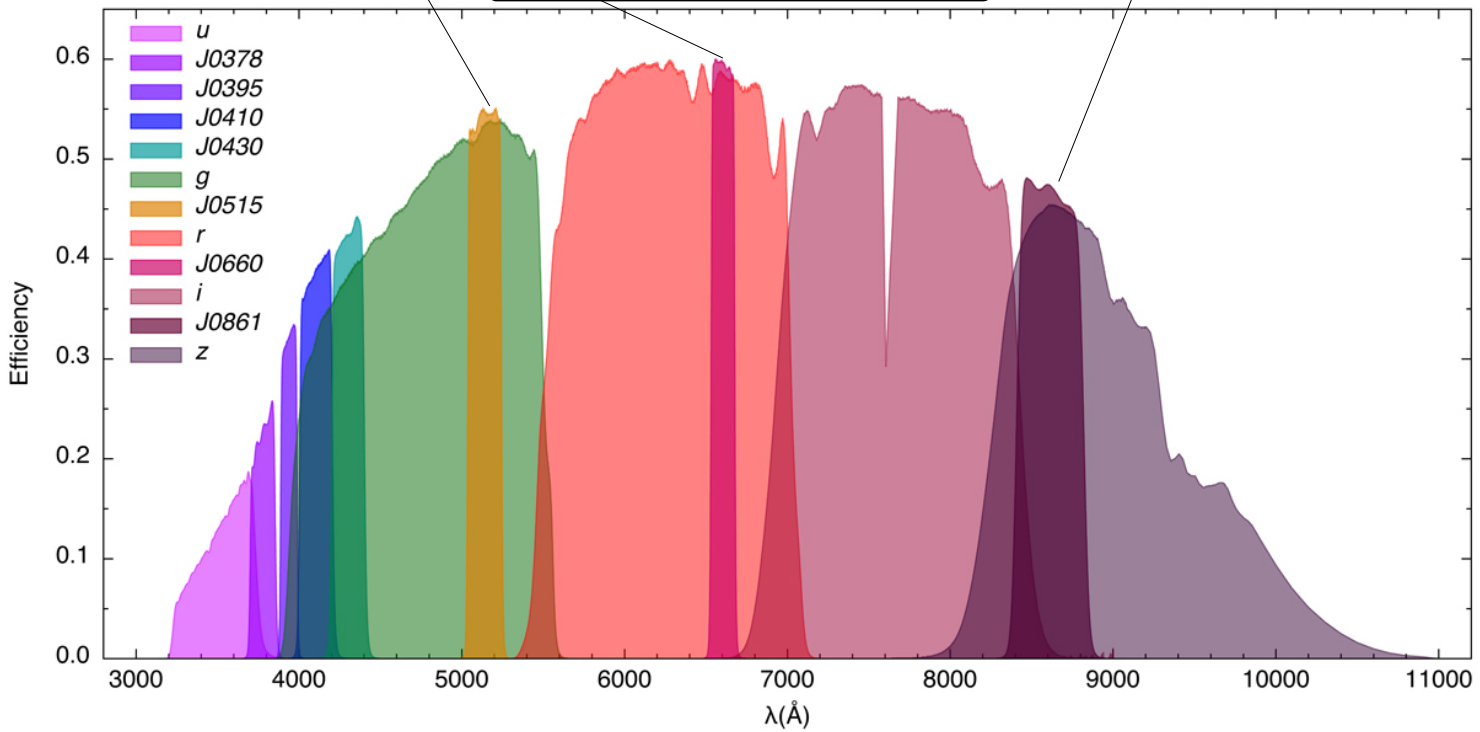

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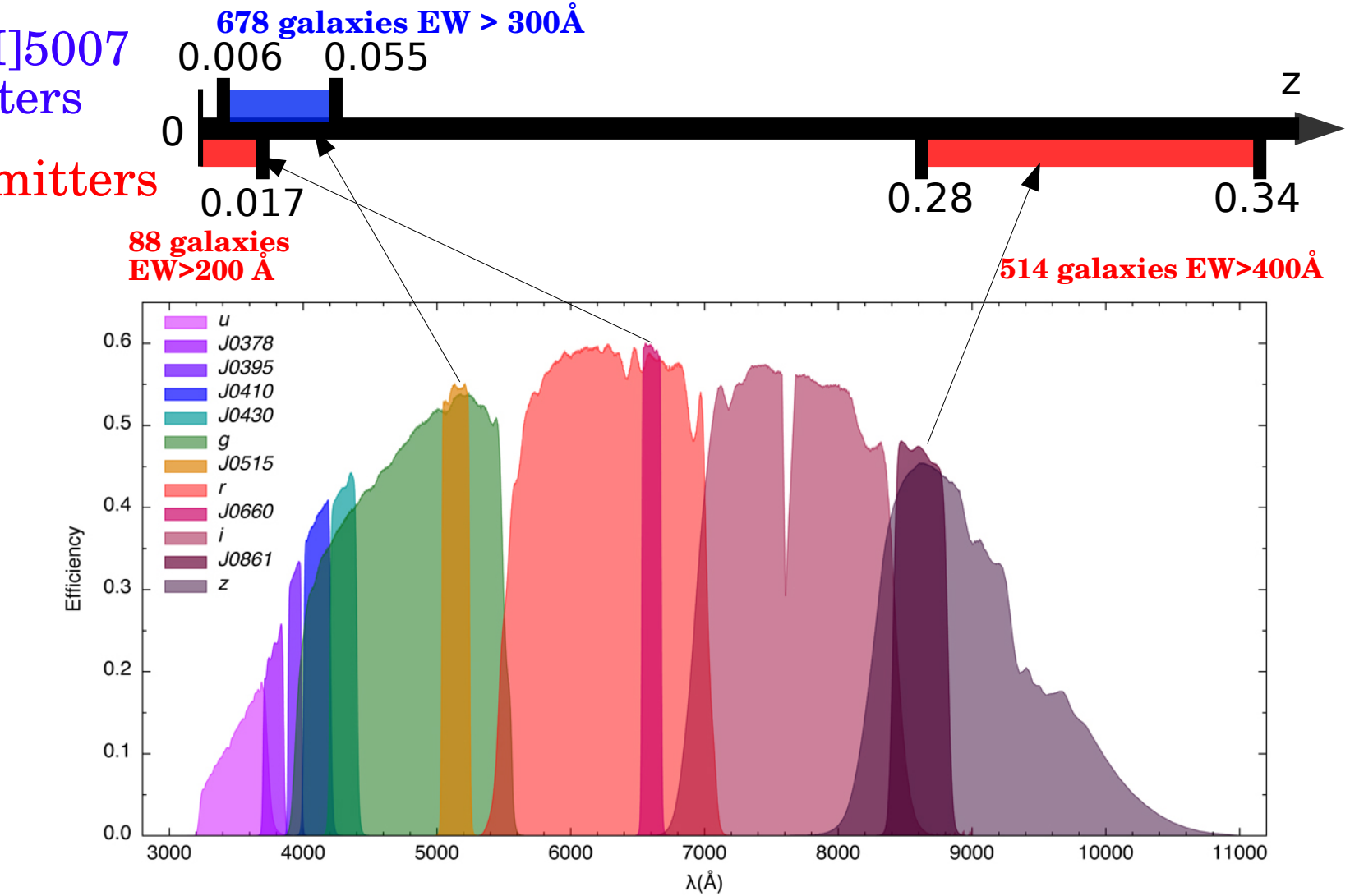

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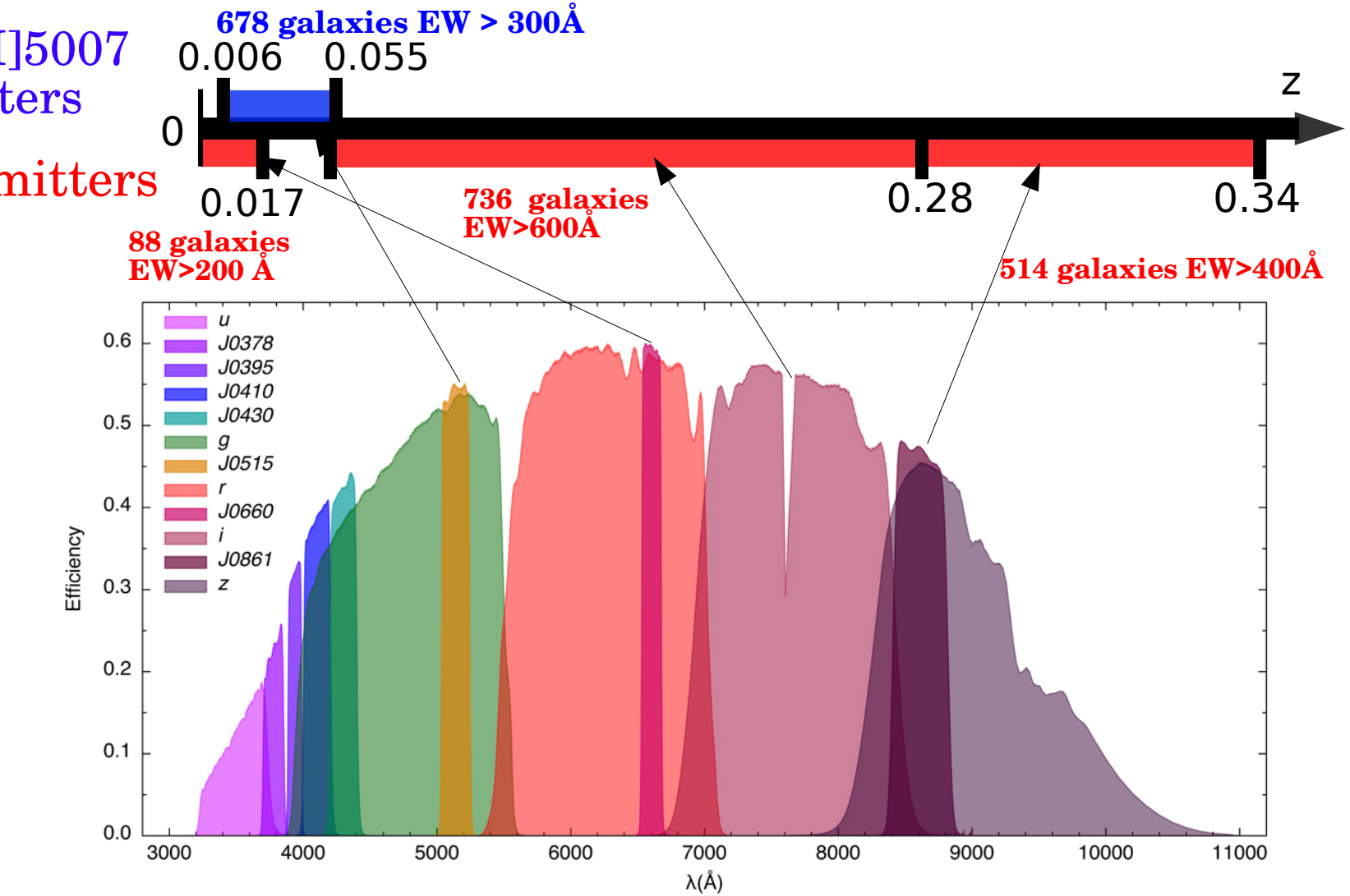

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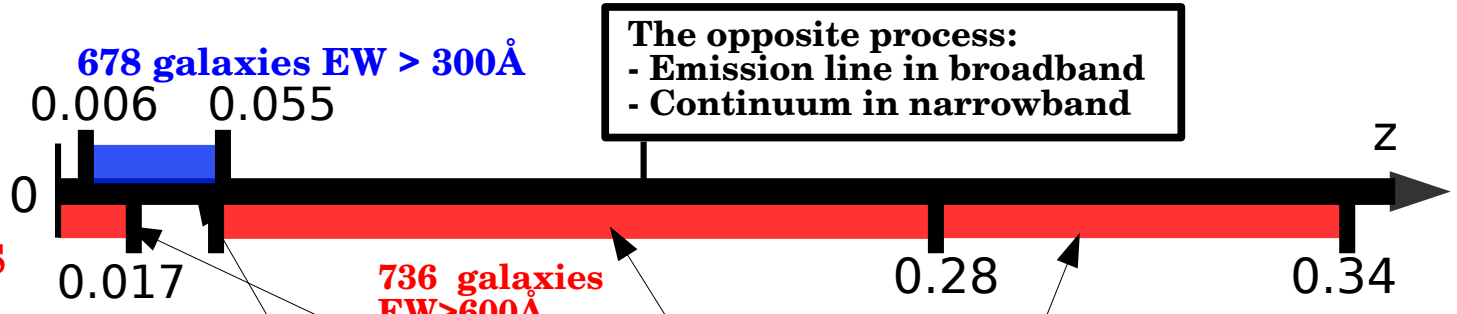

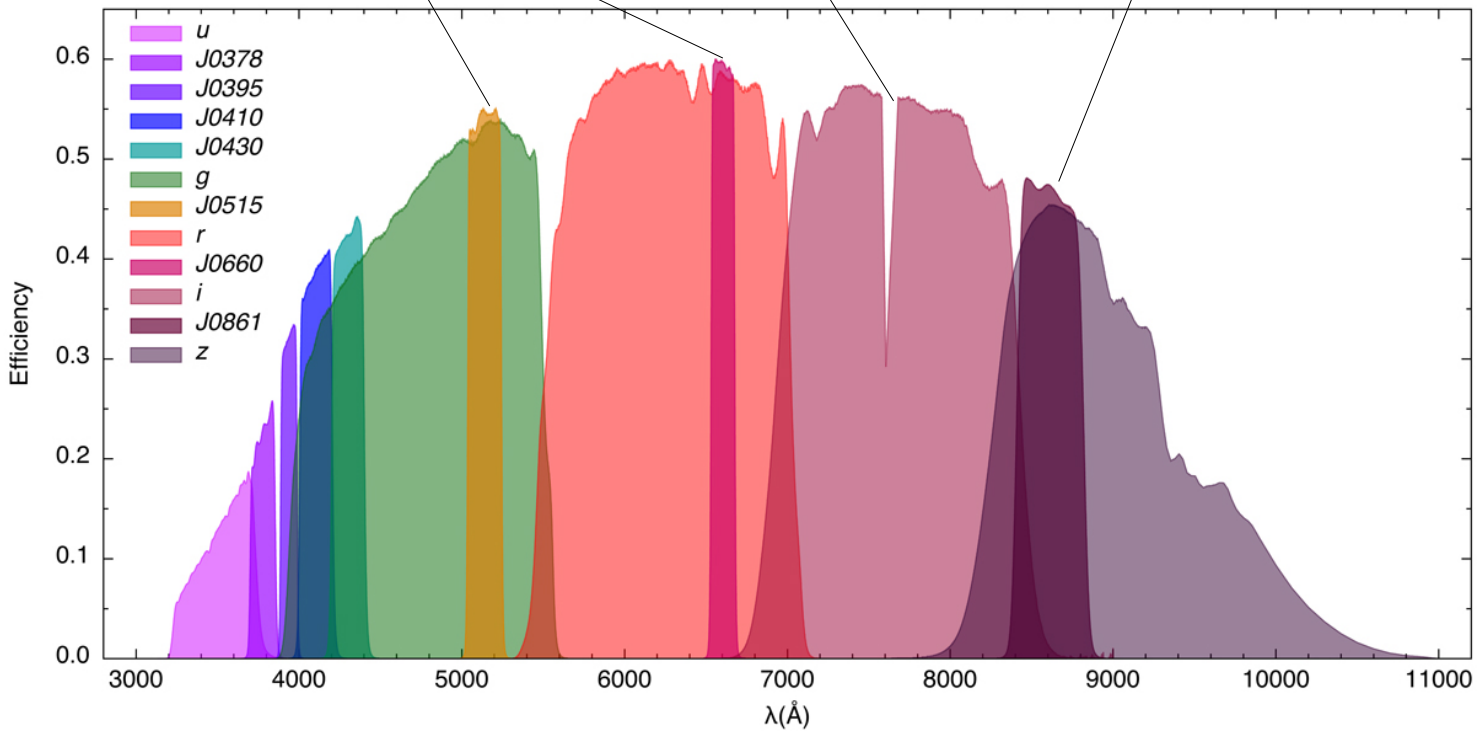

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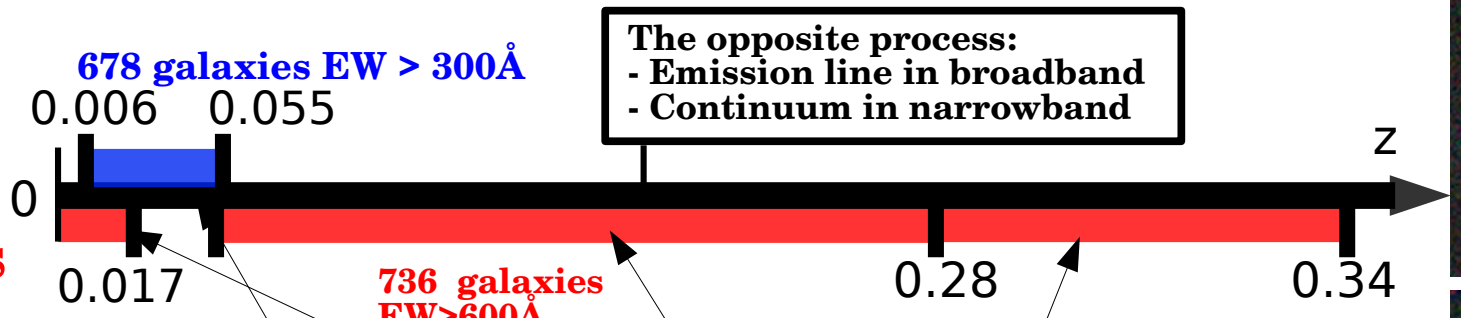

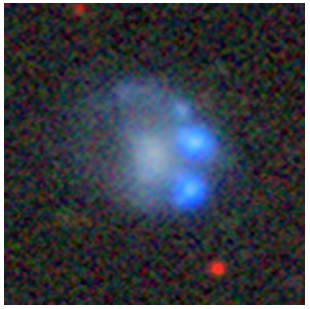

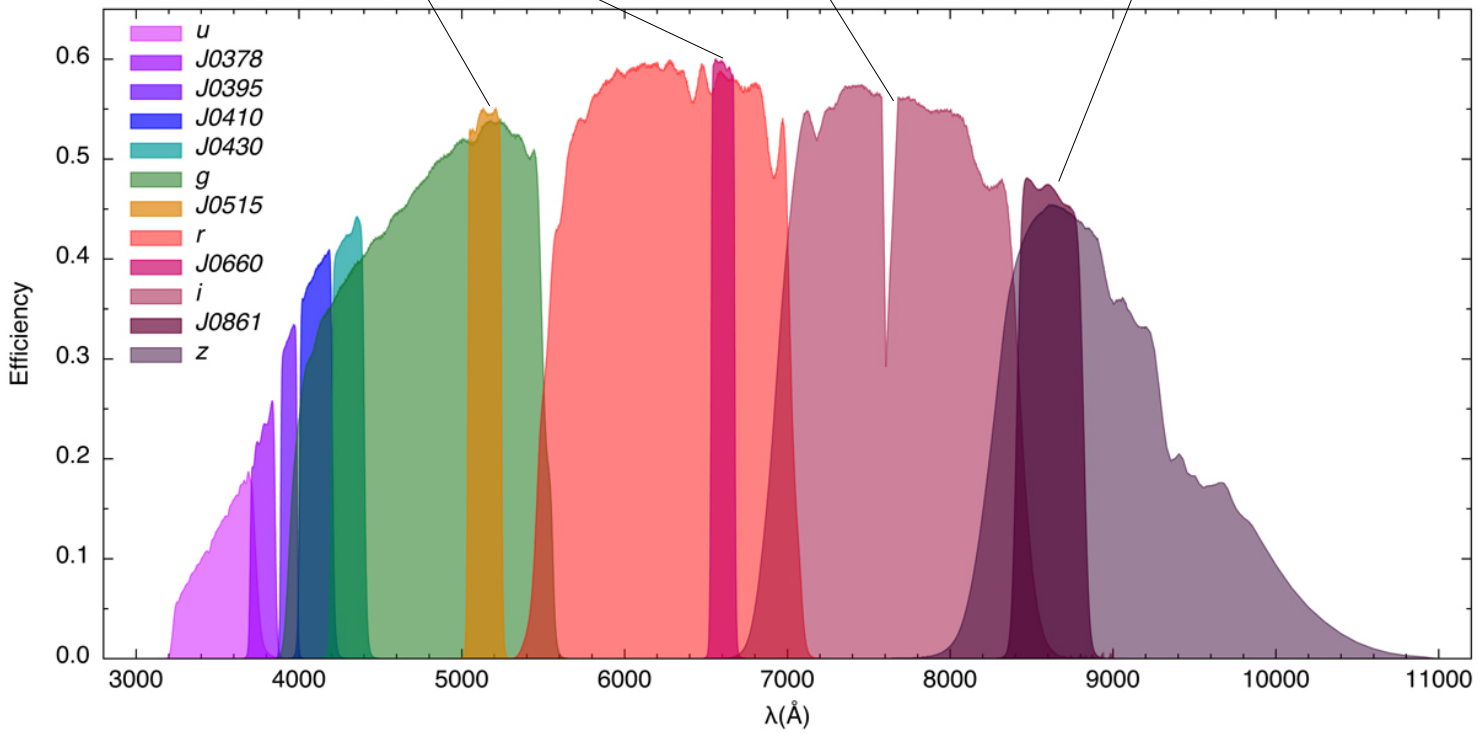

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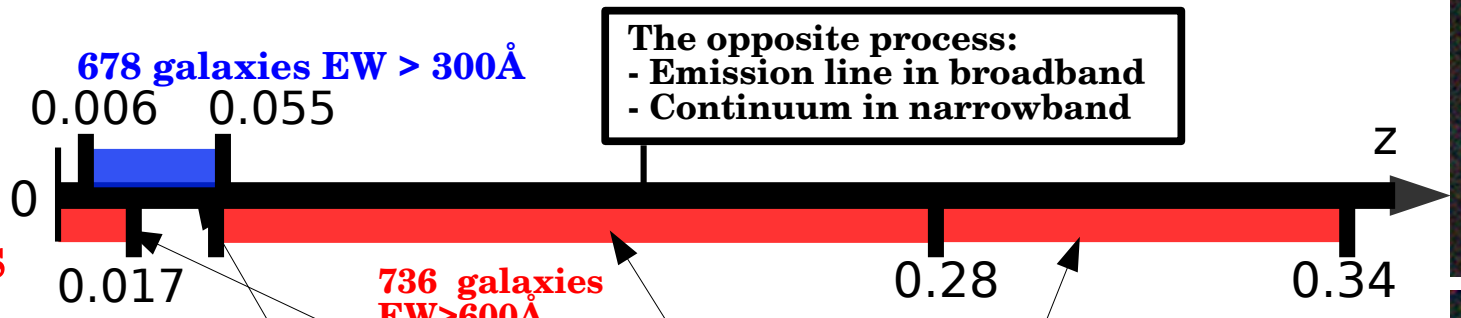

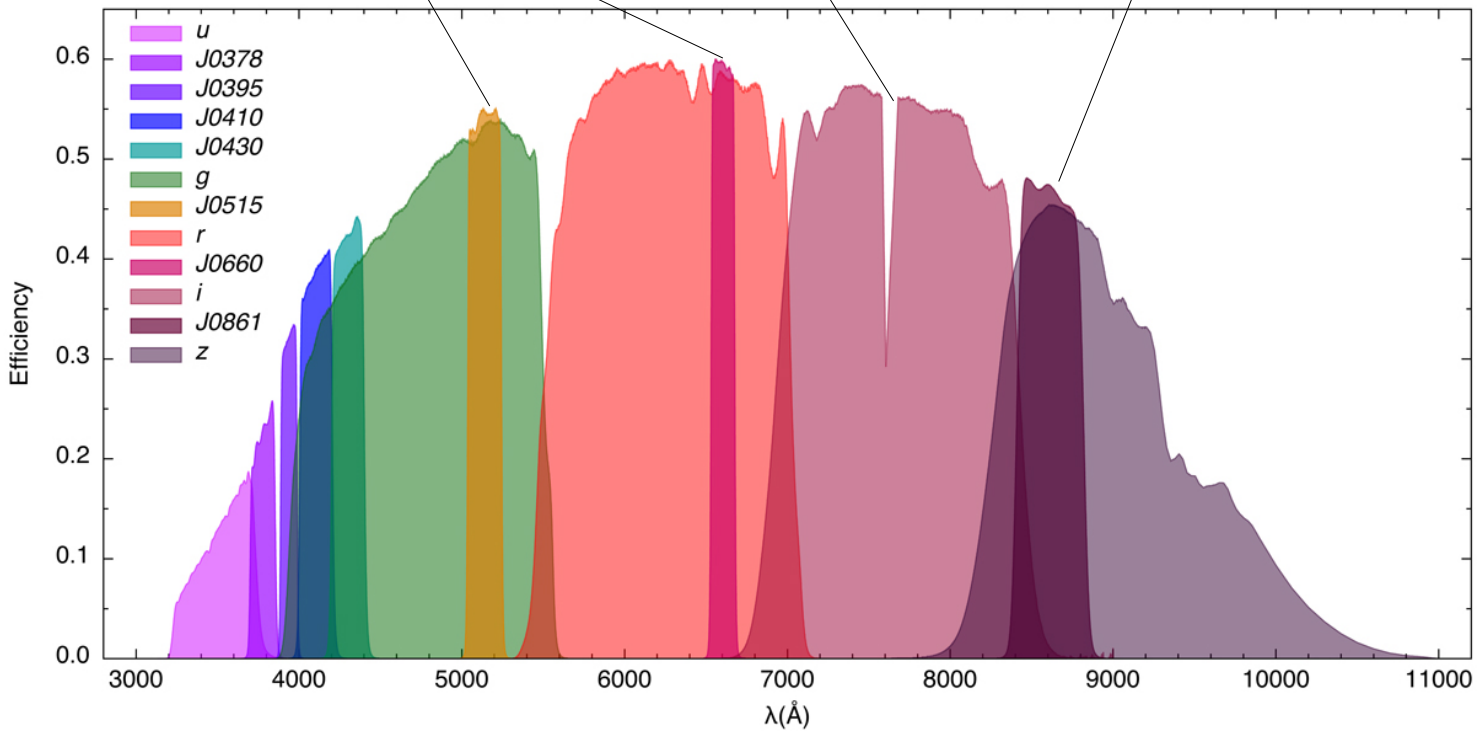

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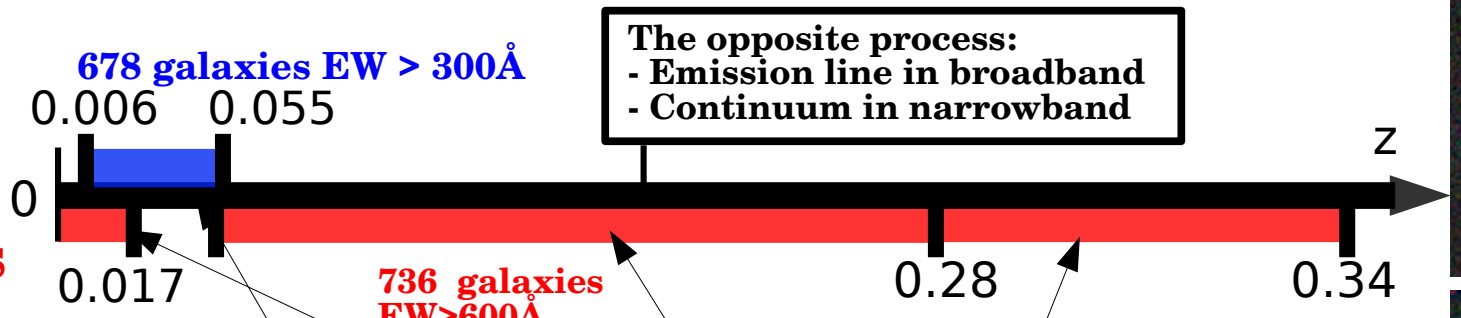

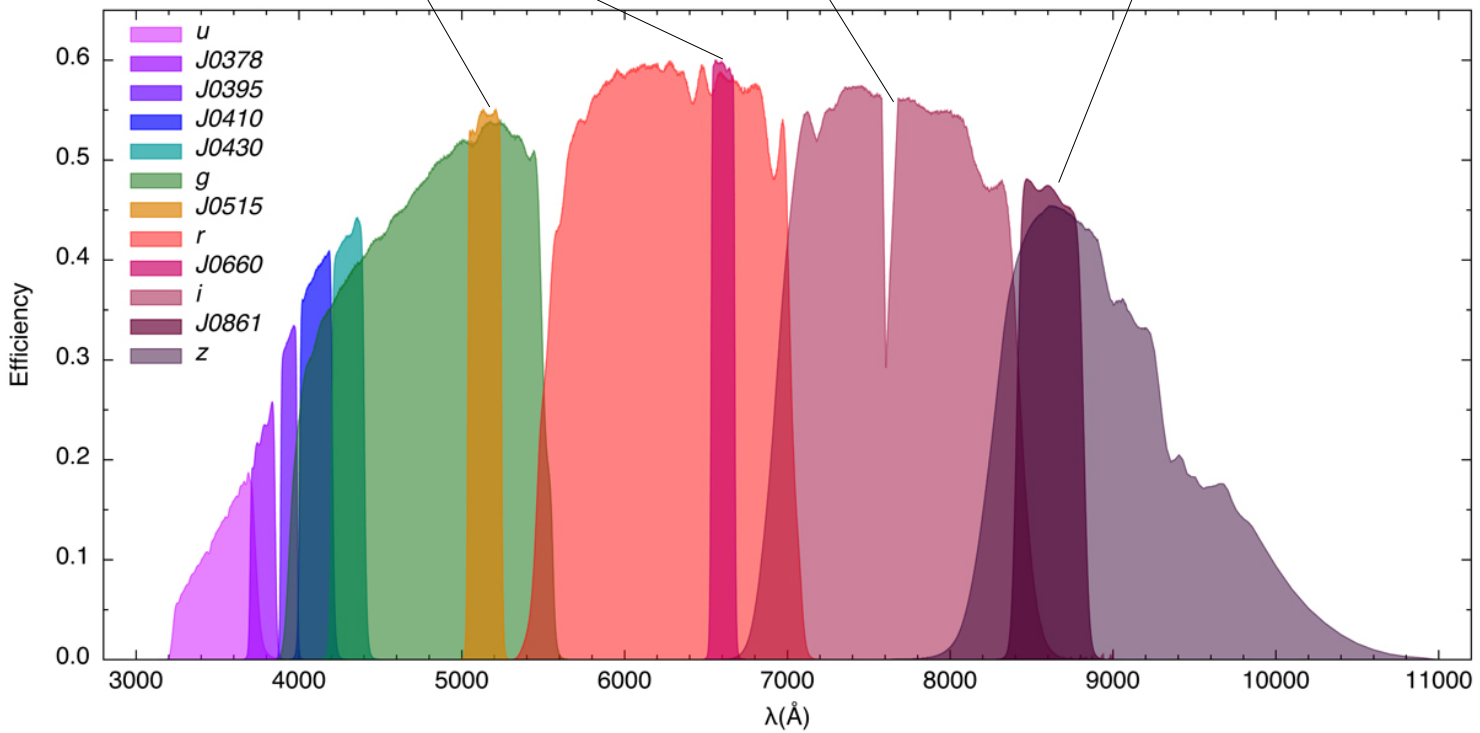

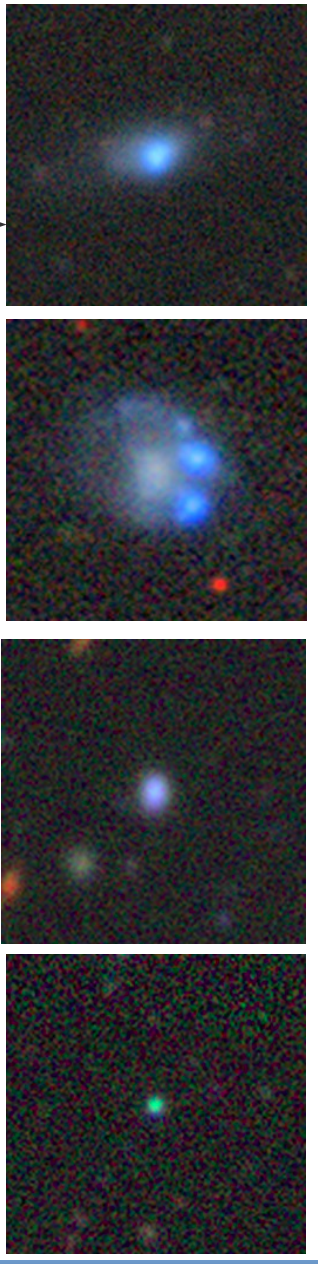

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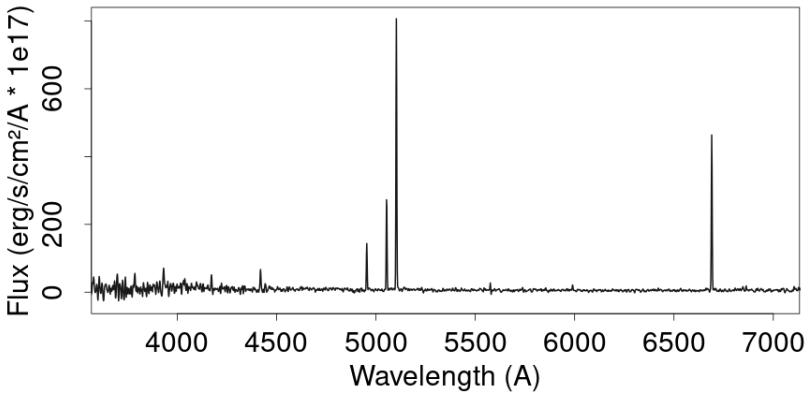

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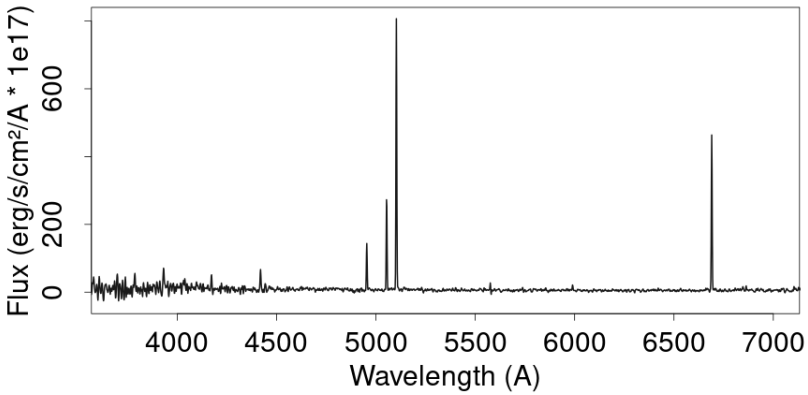

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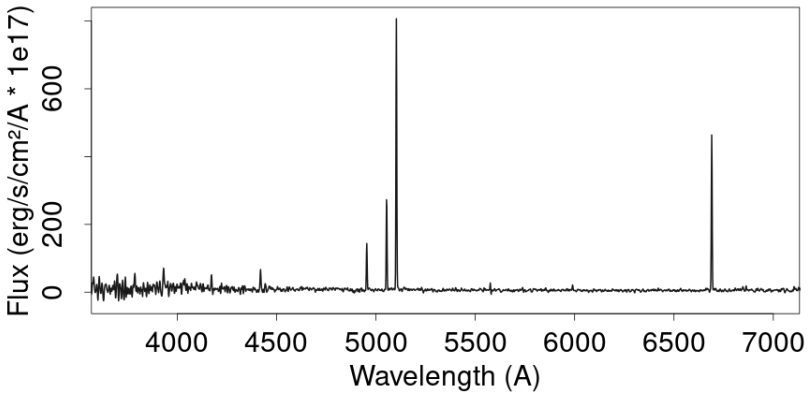

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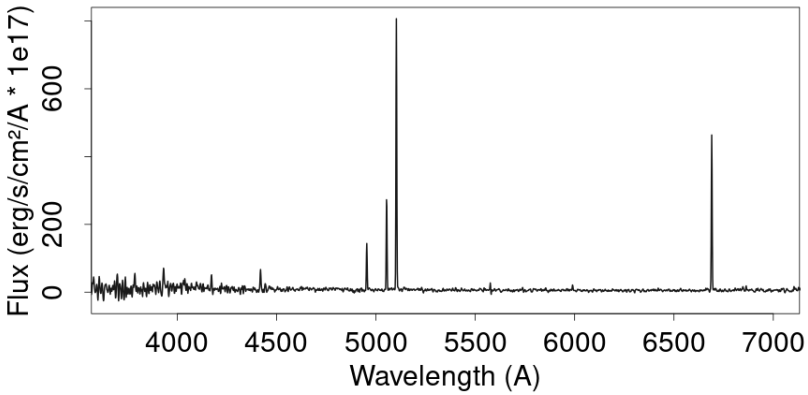

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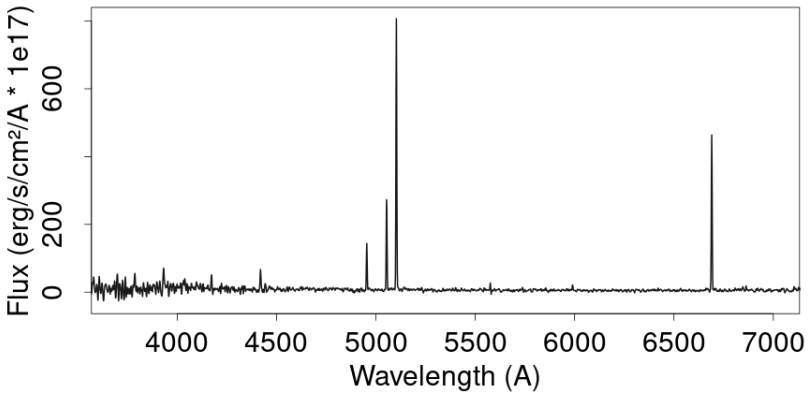

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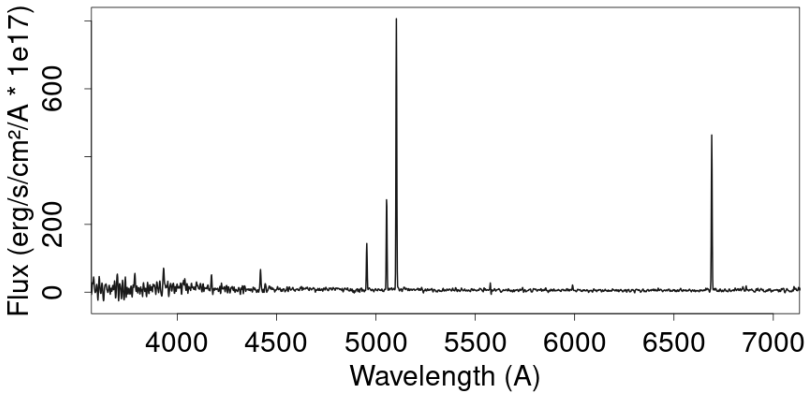

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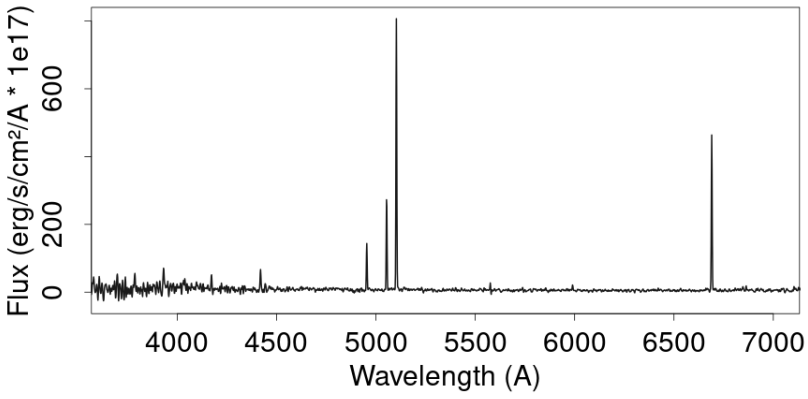
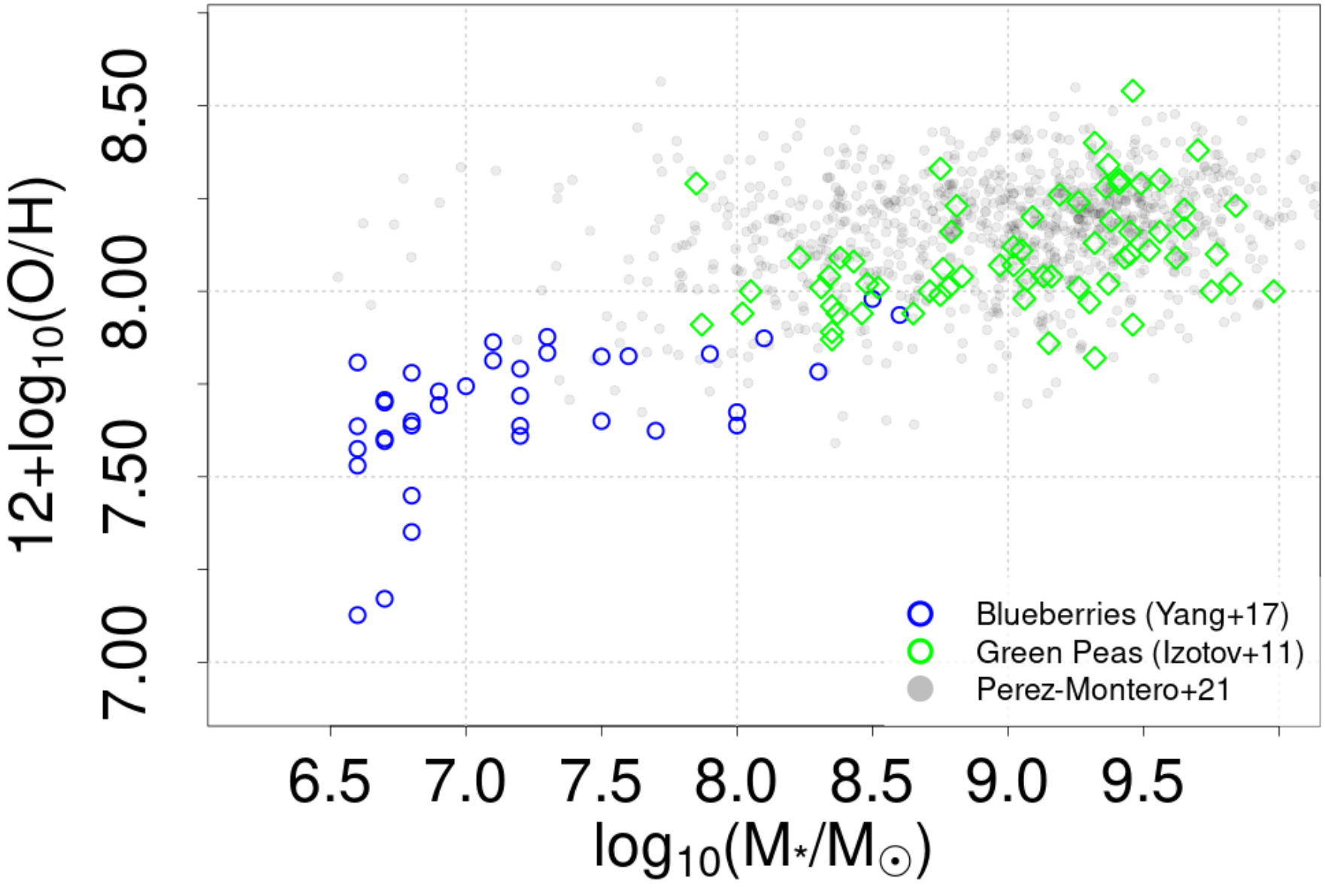


Mass – metallicity relation



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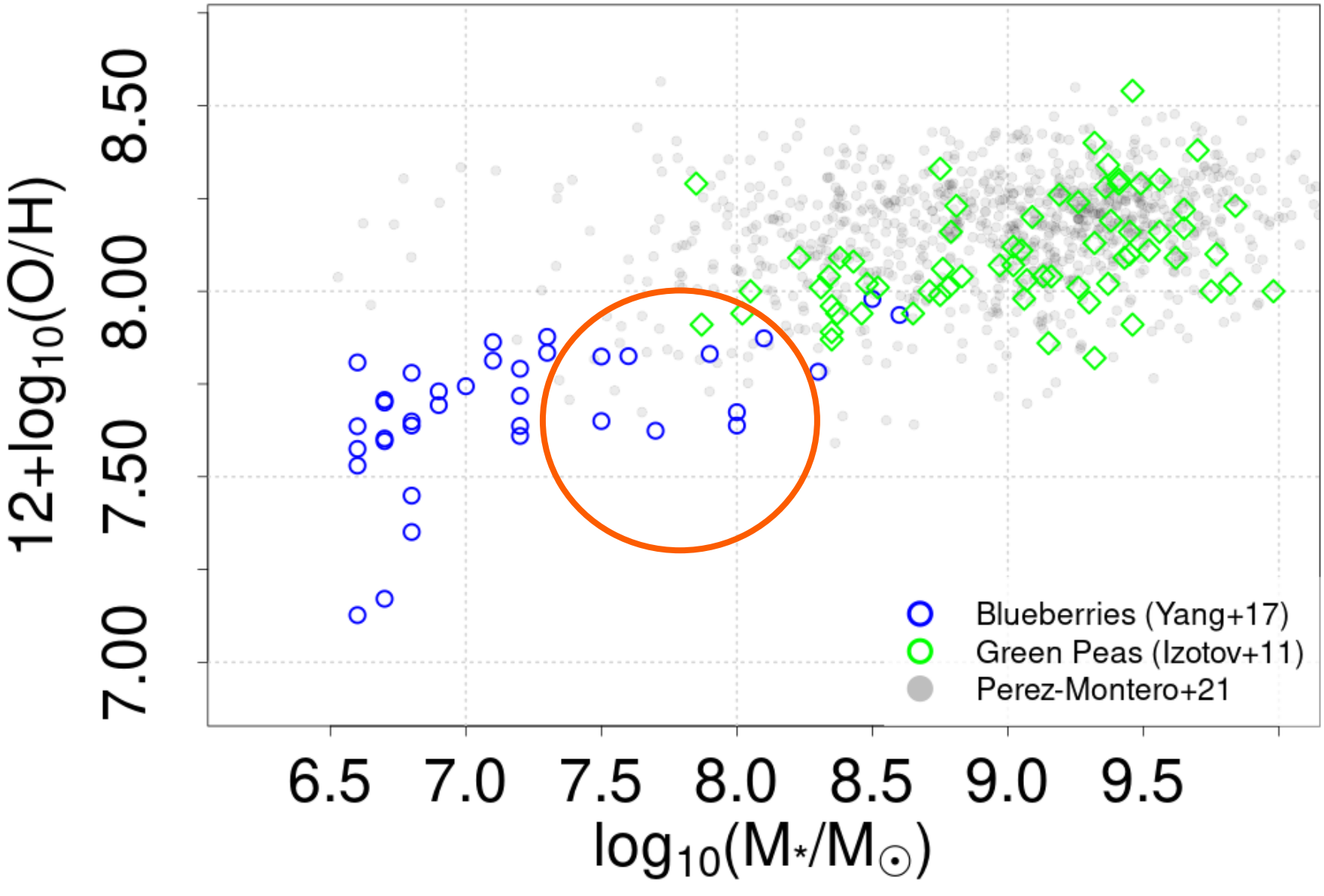

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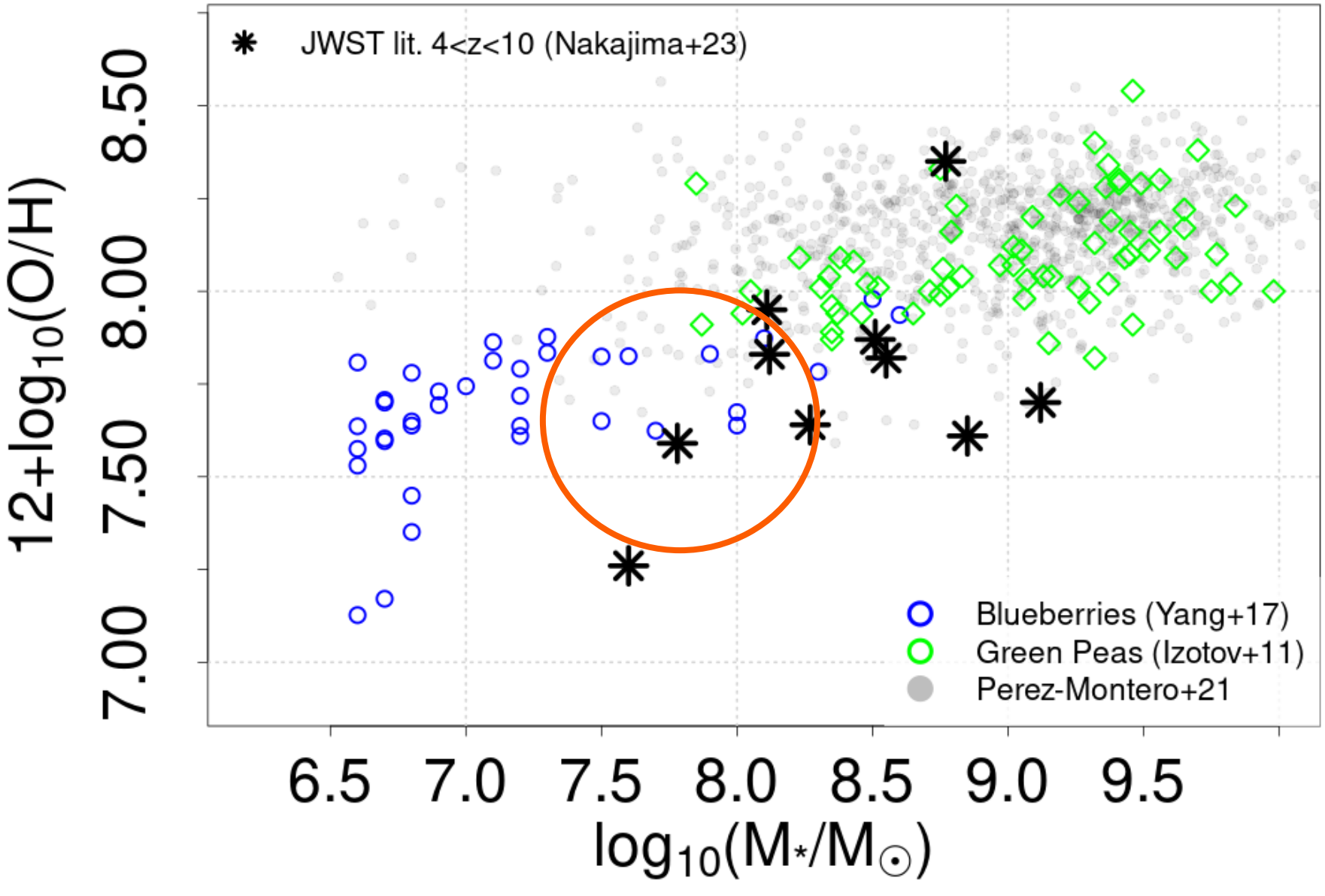

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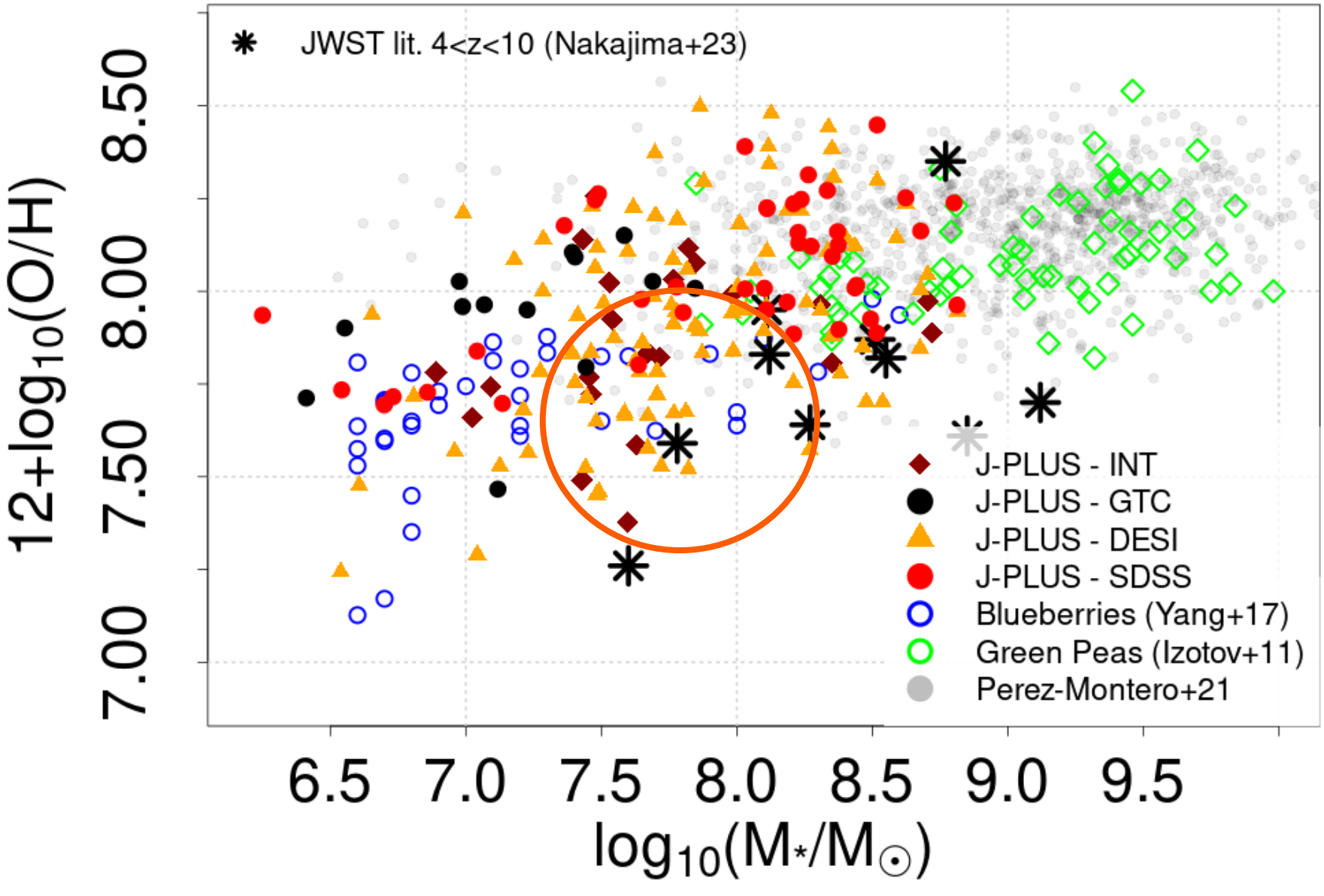

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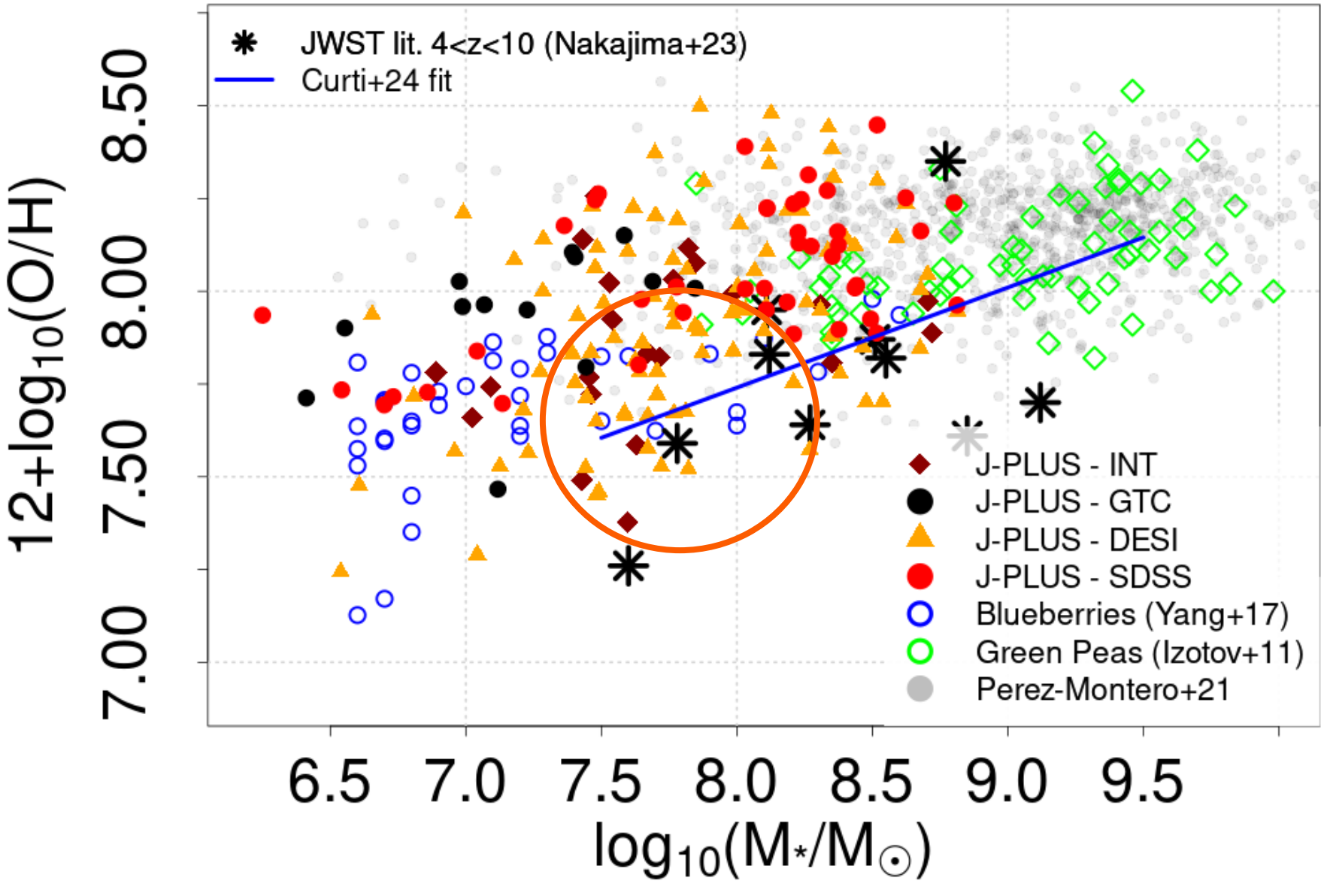

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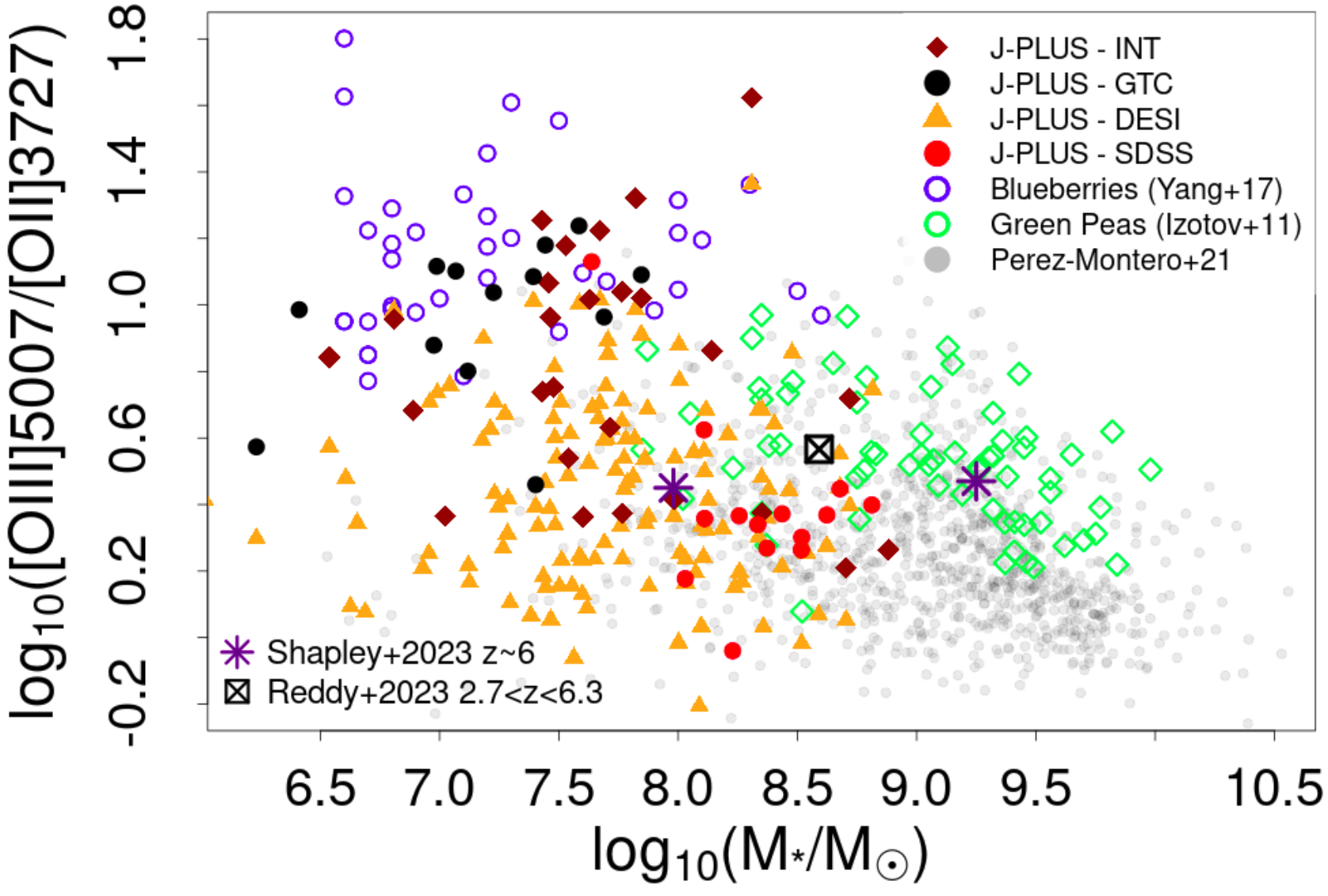
  - For now, we can study some proxies for Lyman continuum leakage

[OIII]/[OII]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Blueberries (Yang+17)
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Perez-Montero+21
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Reddy+2023 2.7<z<6.3
log10([OIII]5007/[OII]3727)
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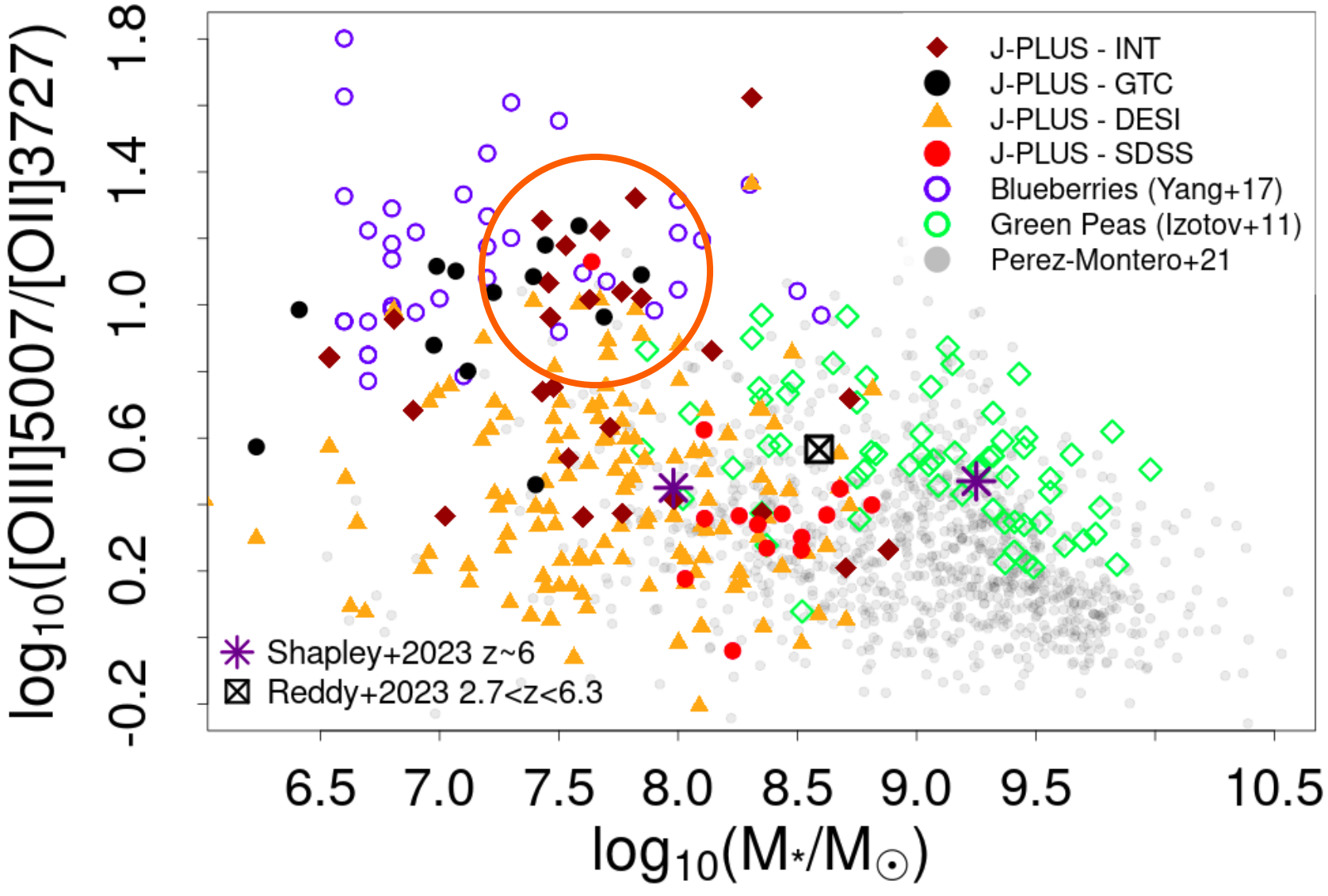
0.2
0.6
1.0
1.4
1.8
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.5
log10(M*/M⊙)

[OIII]/[OII]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log10([OIII]5007/[OII]3727)
-0.2
0.2
0.6
1.0
1.4
1.8
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.5
log10(M*/M⊙)

[OIII]/[OII]

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  - Above 0.9/1 the likelihood of significant escape is high
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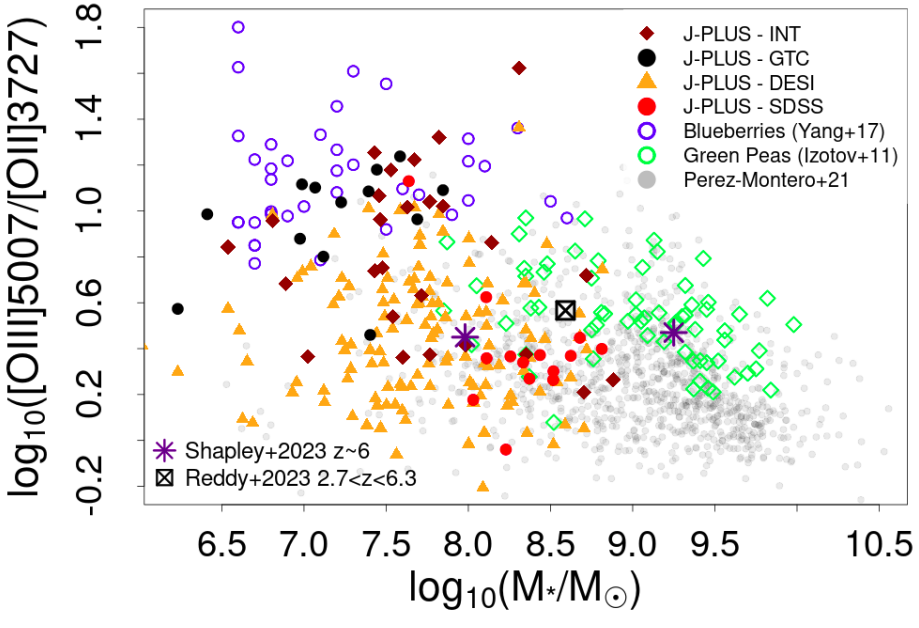

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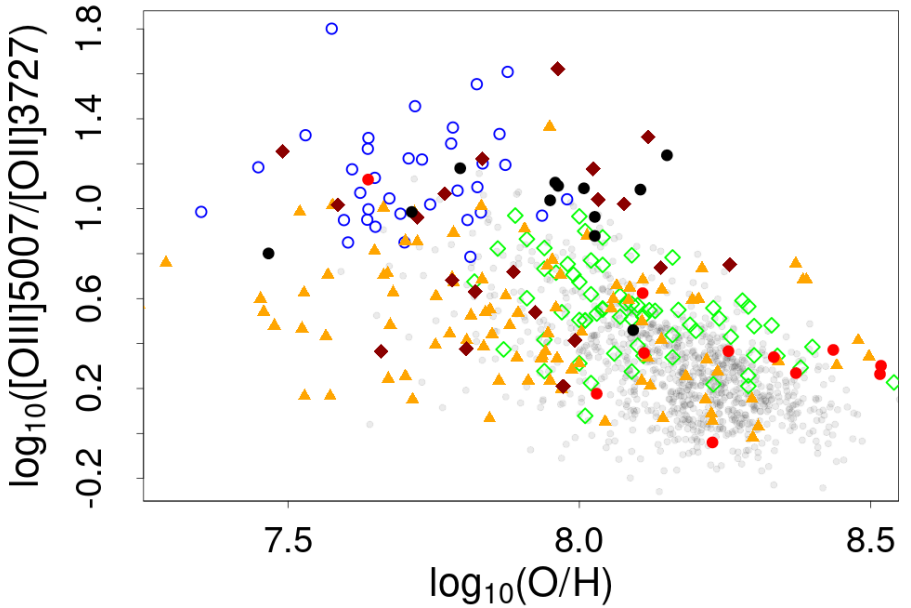

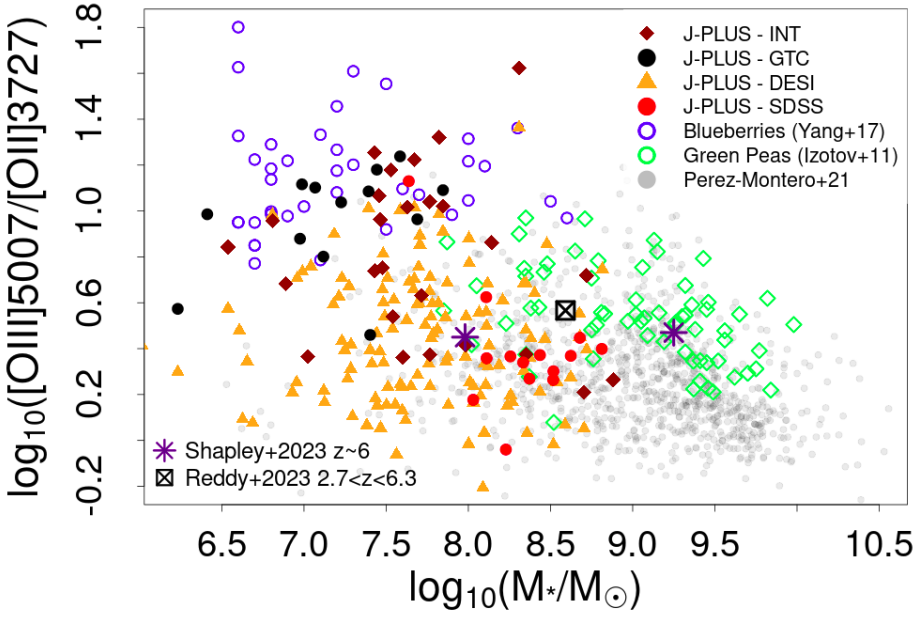

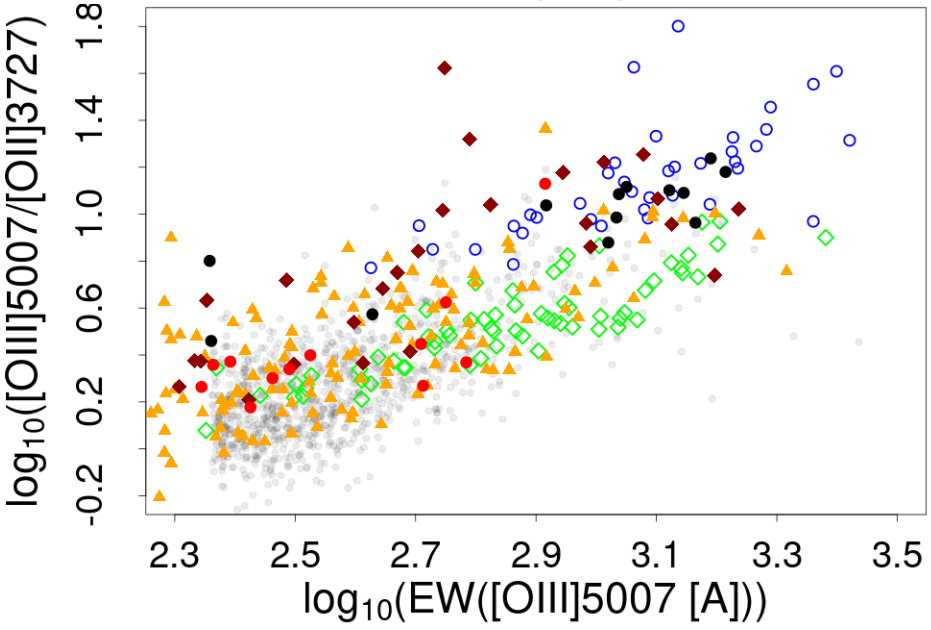

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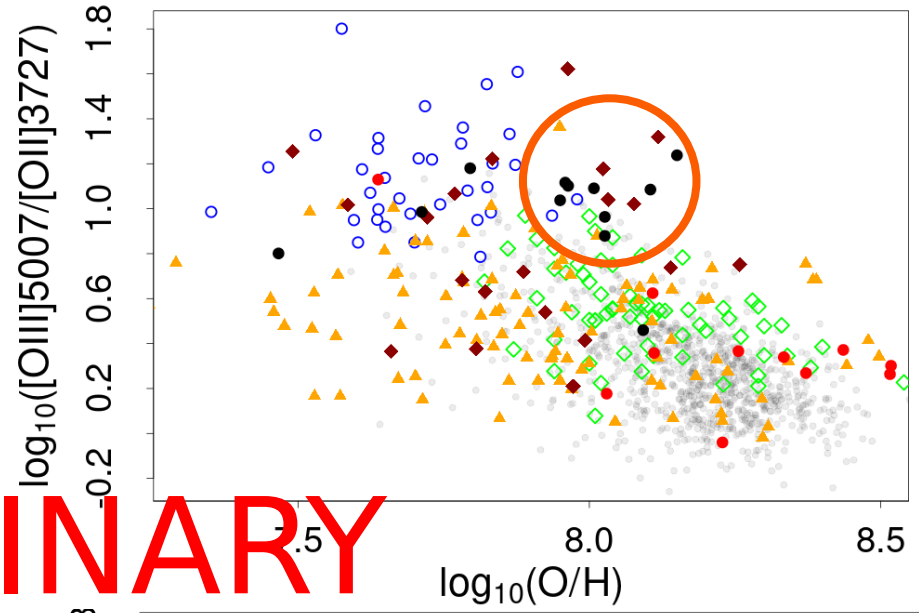
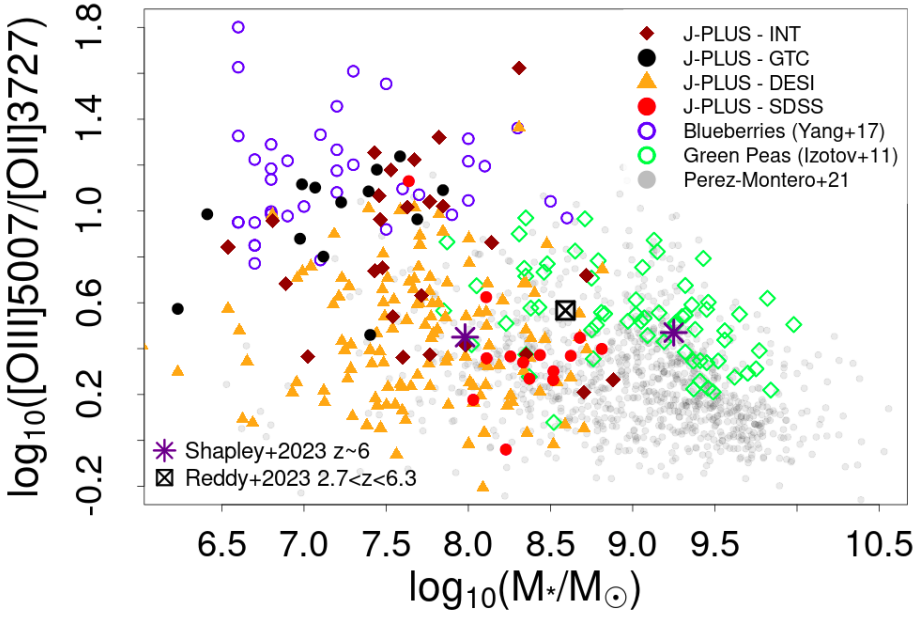
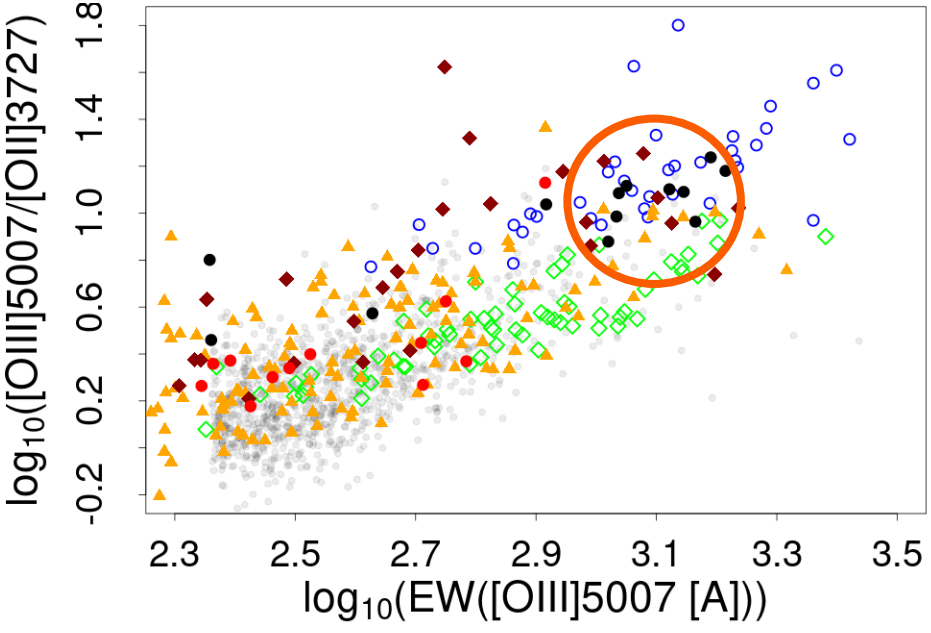


PRELIMINARY





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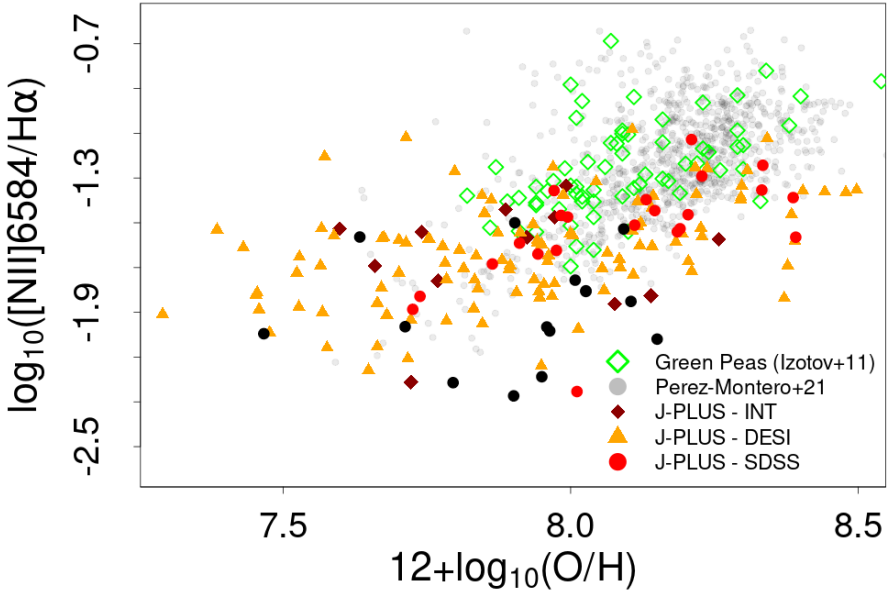

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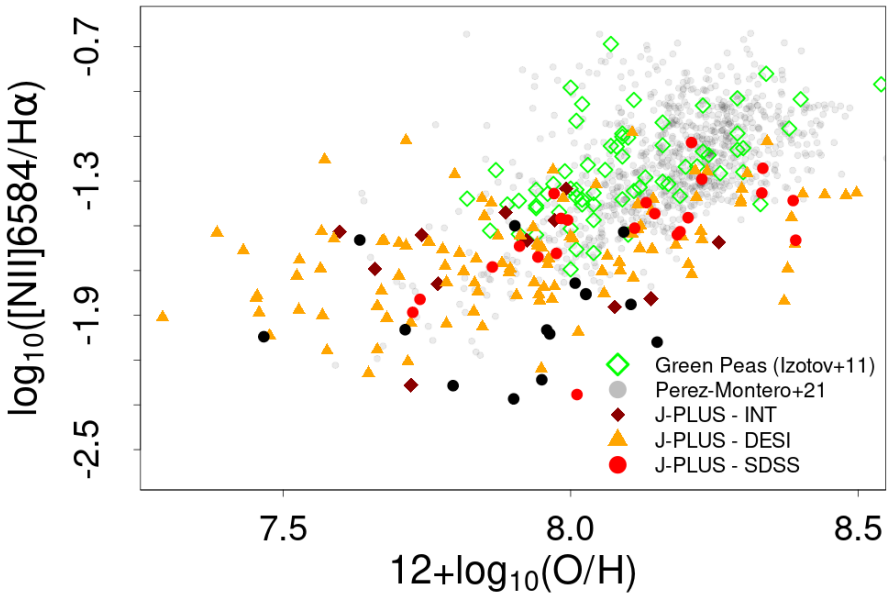

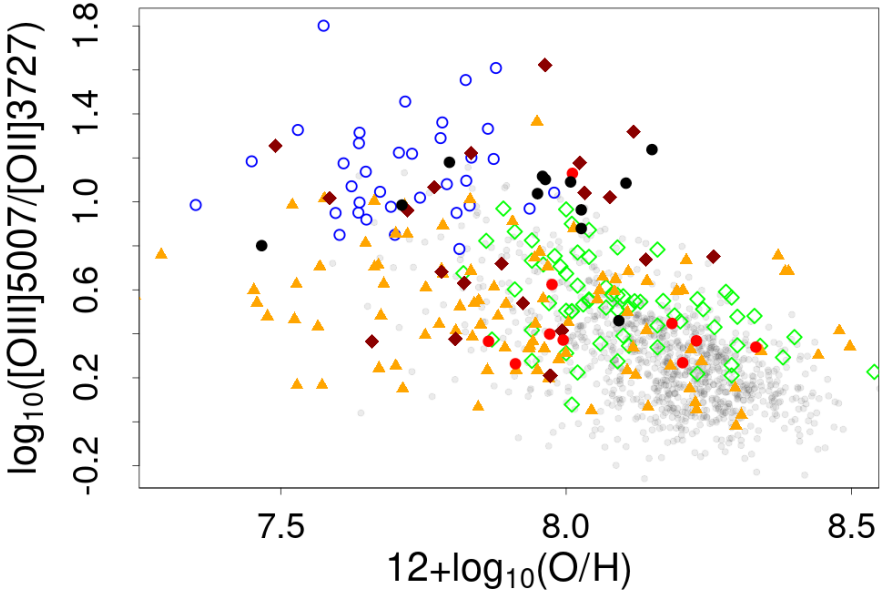

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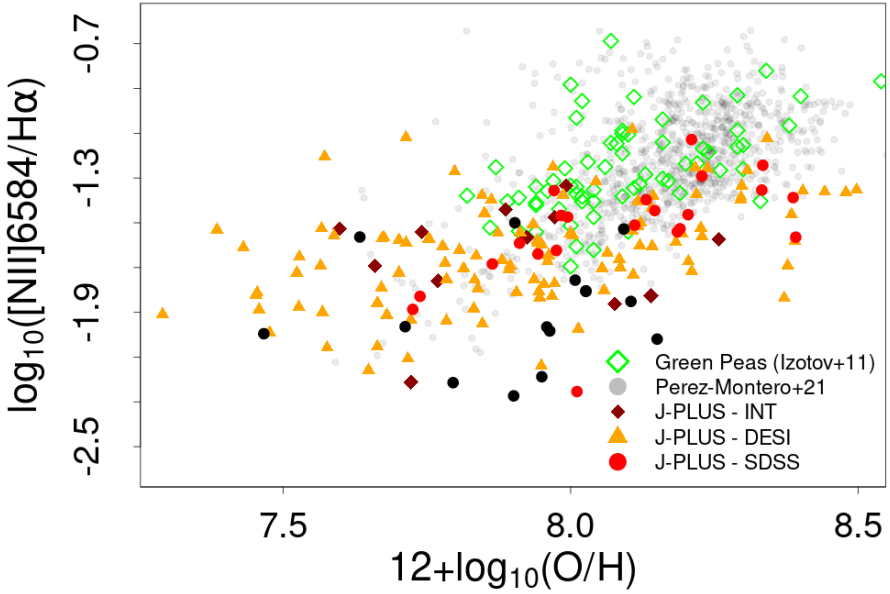

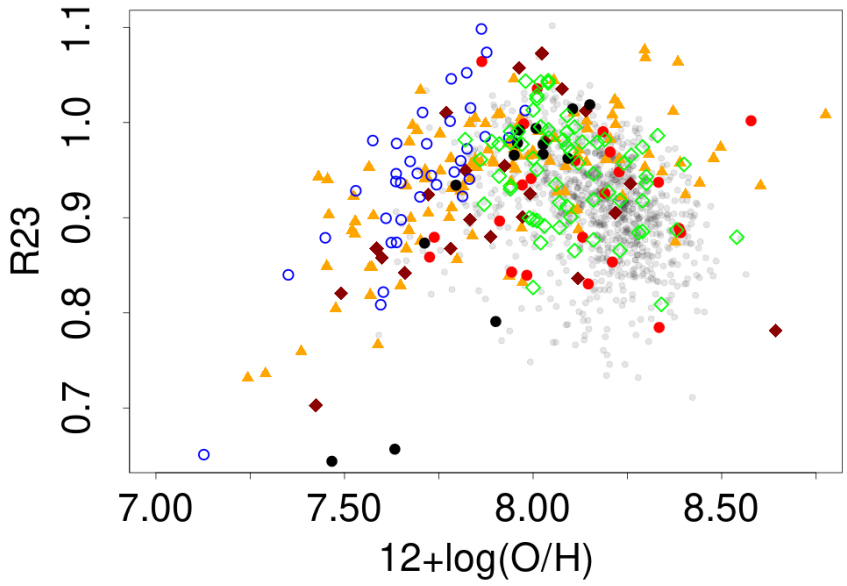

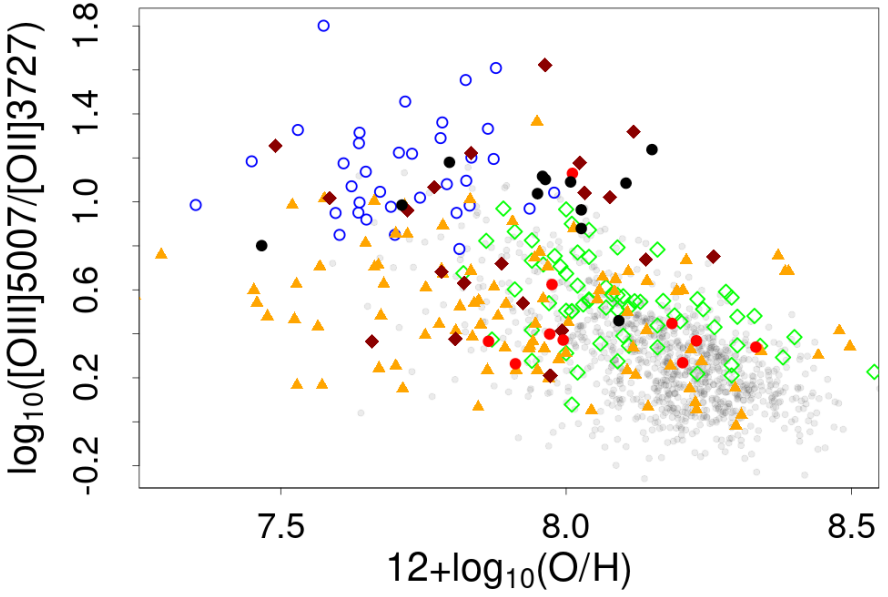

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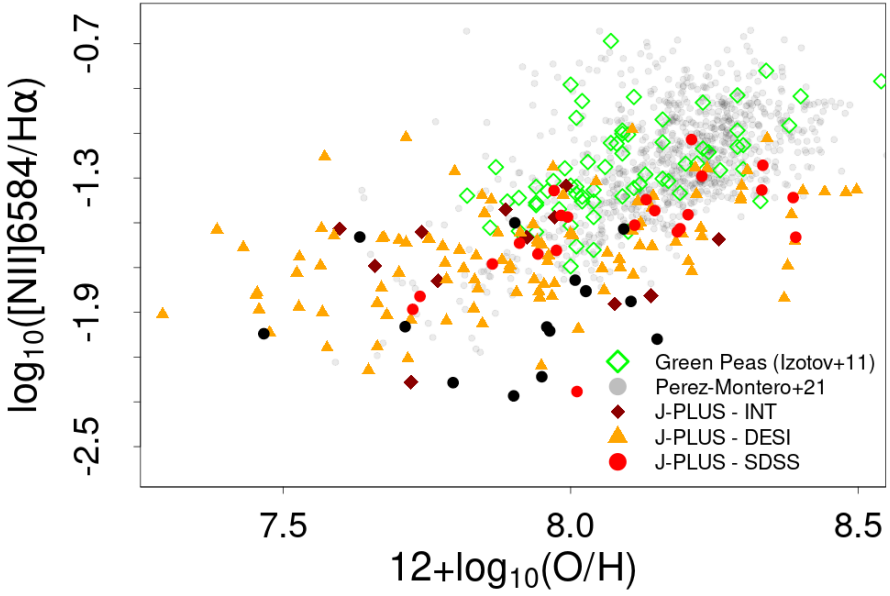

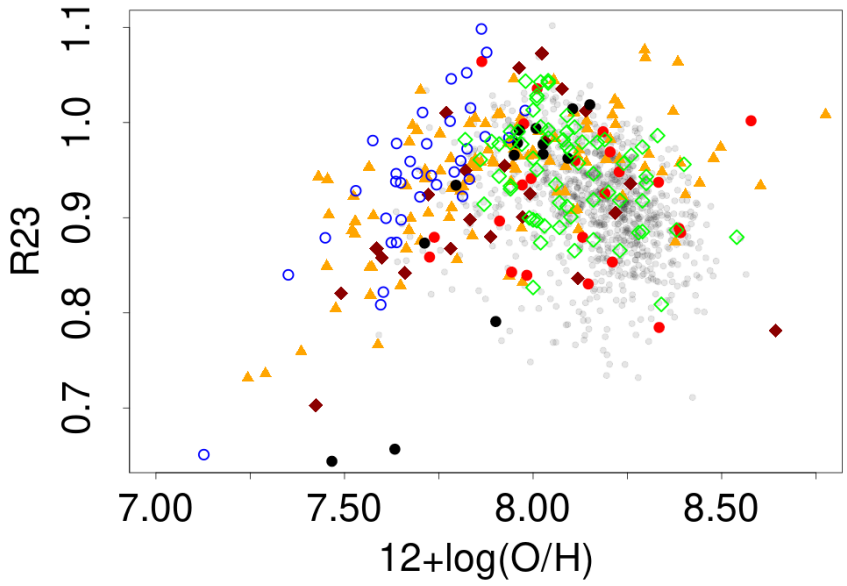

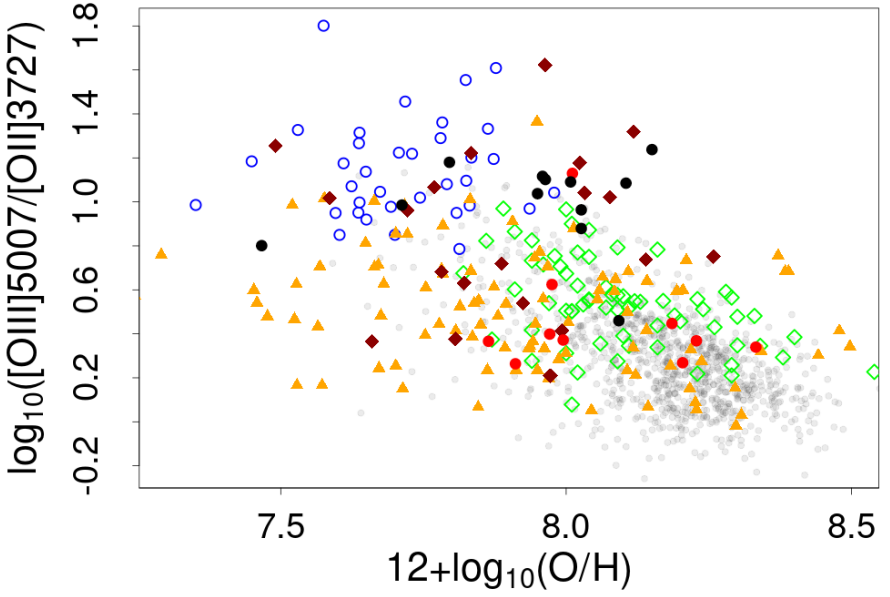

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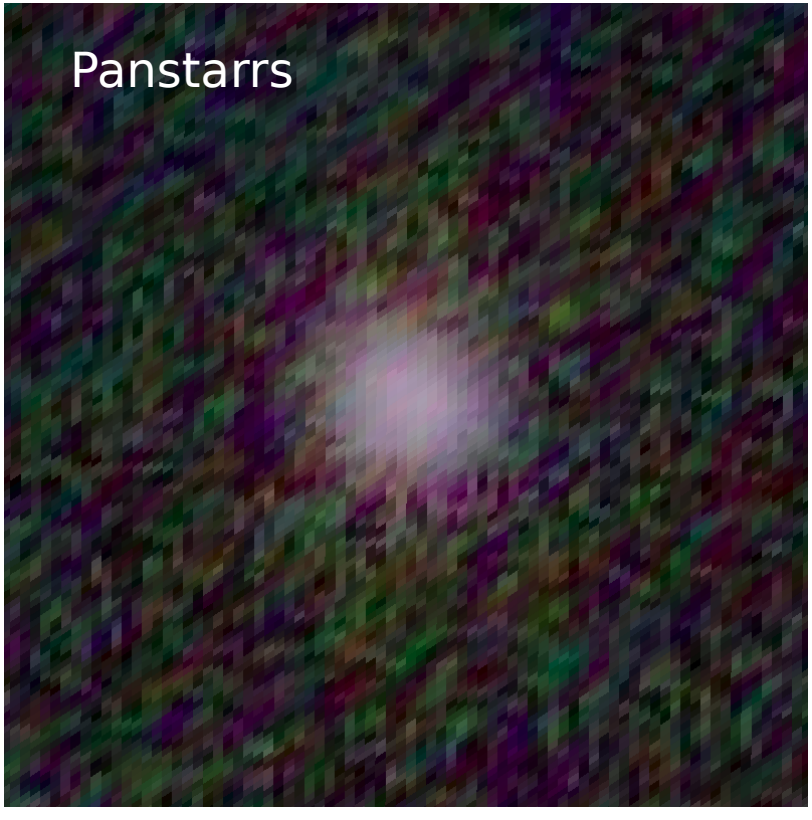

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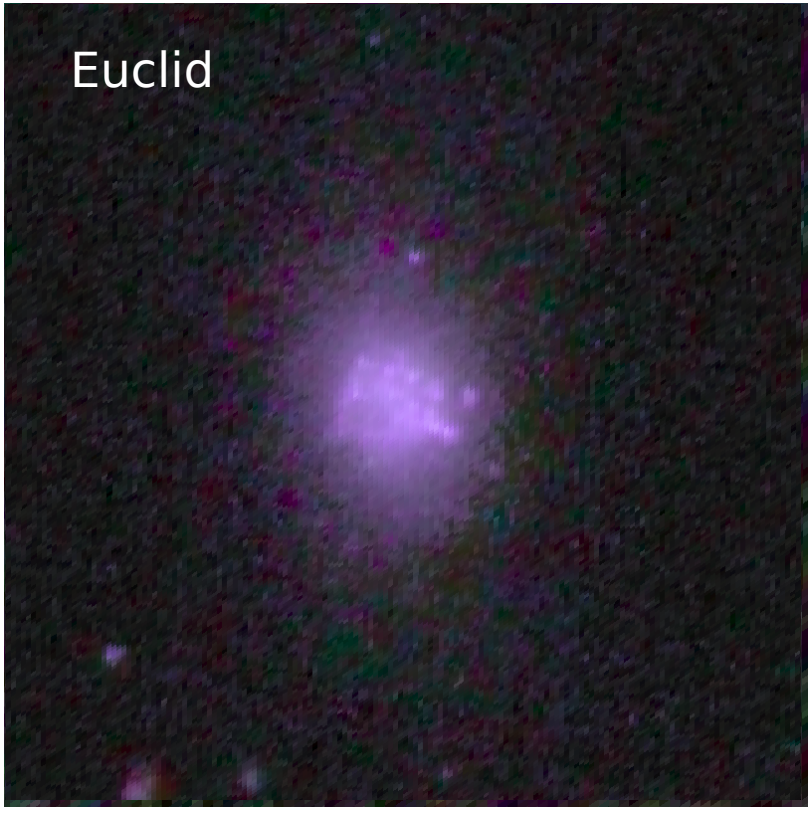

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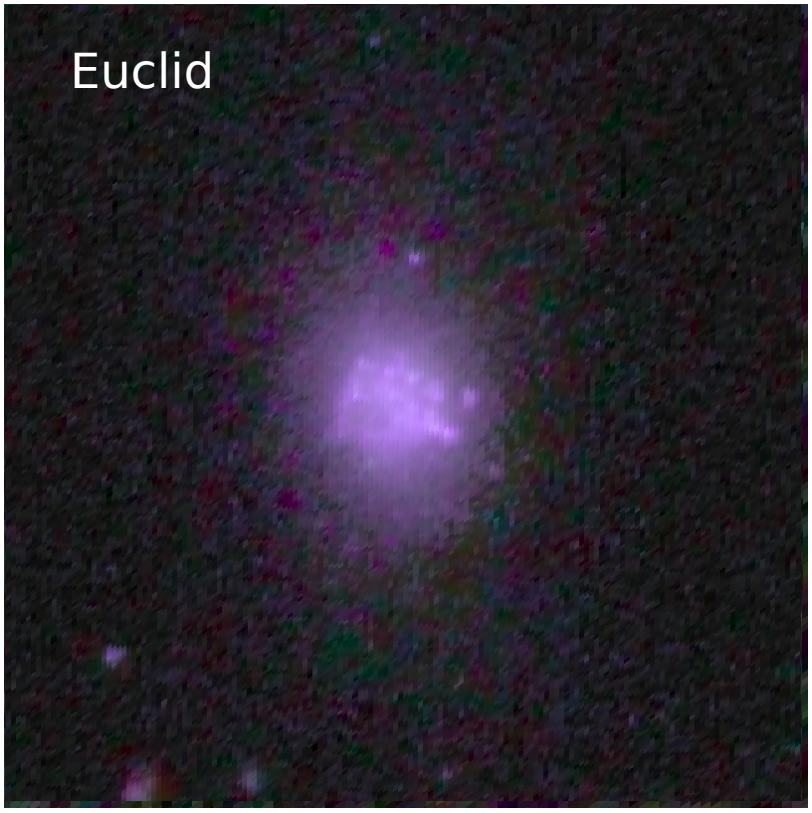

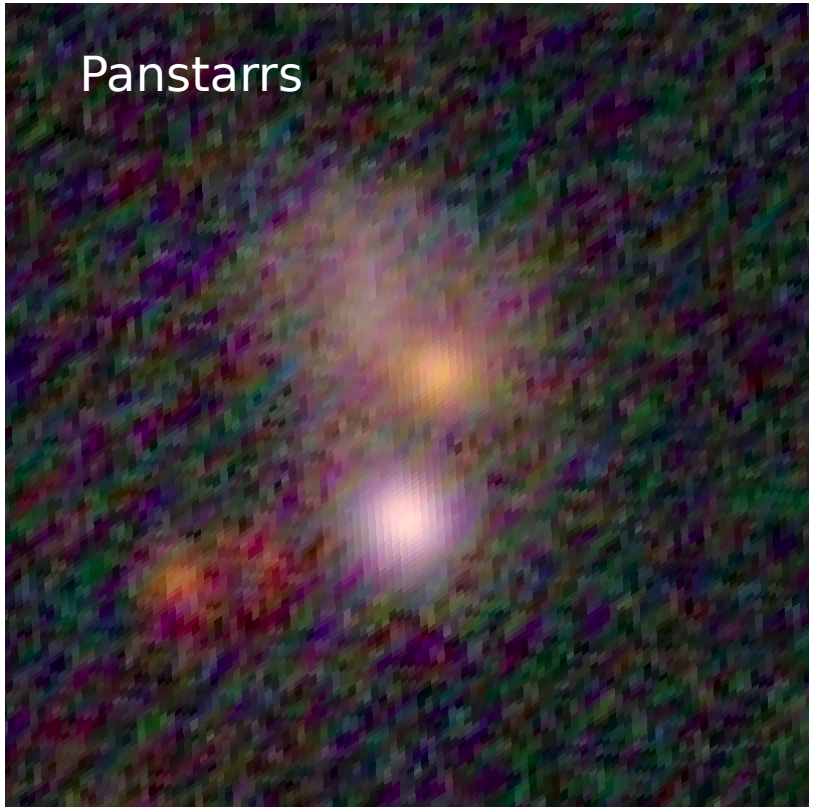

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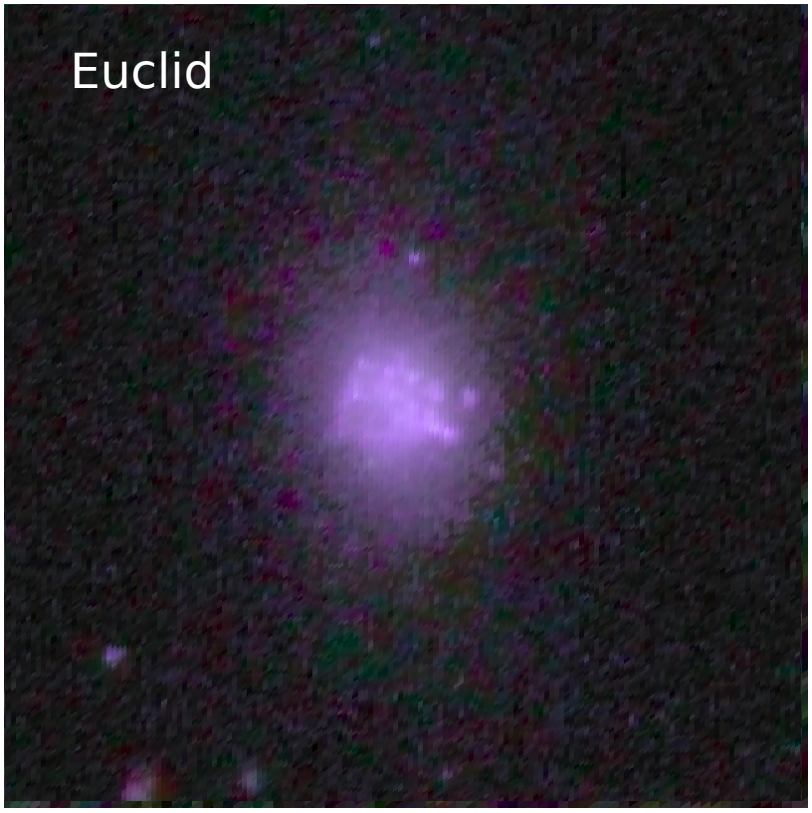

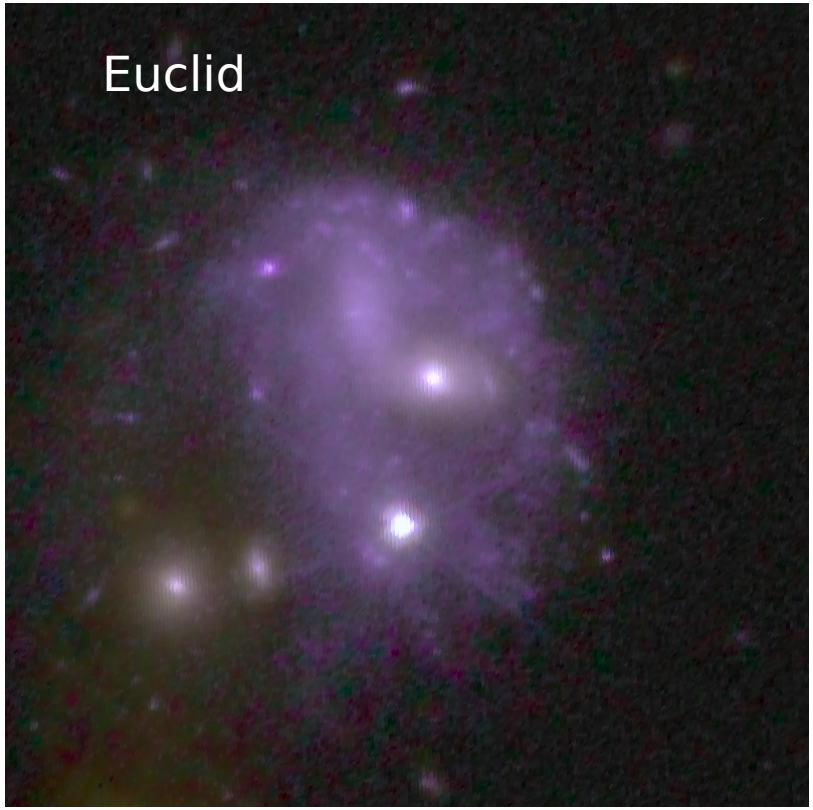

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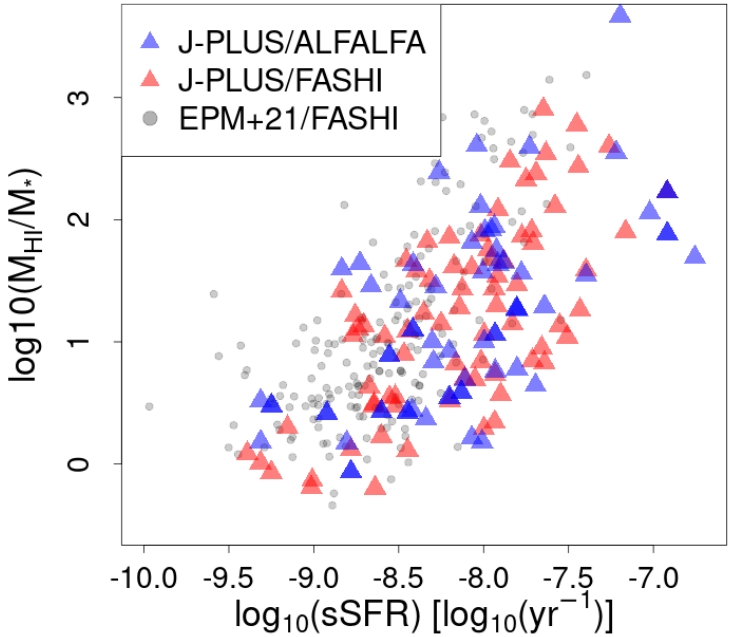
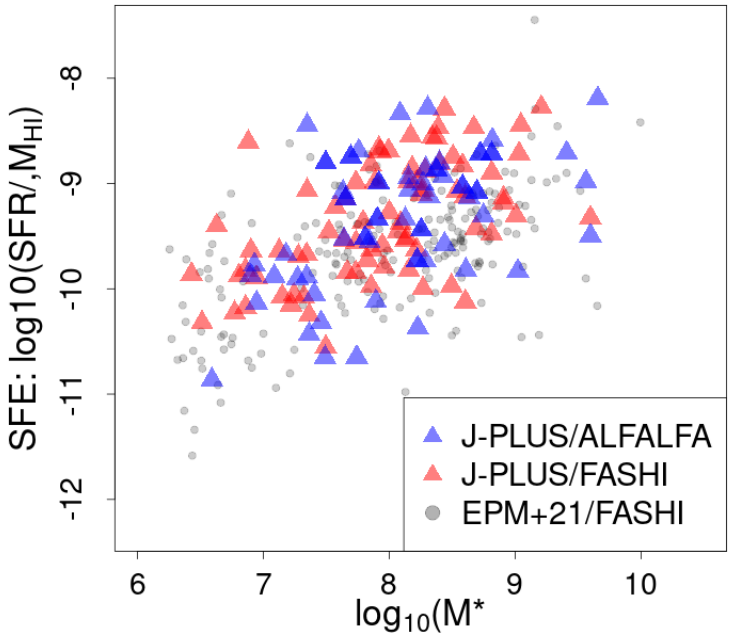
    - Star formation efficiency diminishes at very low mass

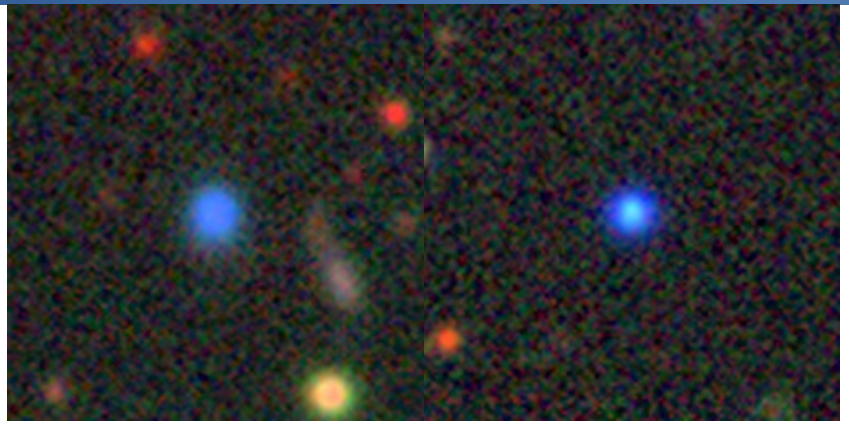




Conclusions

- **With the J-PLUS mediumband survey, we compile the largest photometric samples of extreme emission line galaxies at low-z**
  - Almost 2000 extreme galaxies at z<0.35
    - EW([OIII])>300Å or EW(Ha)>400Å
    - ~ 80% new discoveries
  - Very efficient, unbiased selection of EELGs
  - High purity (>90%), high completeness (>90%)
- SED fitting reveals very young, low mass galaxies with little dust extinction
- SFR and EW comparable to high-redshift (z ~ 3-5) systems
- Spectroscopic analysis
  - Stellar masses and metallicities cover a “gap” between Blueberrys and Green Peas
  - Covering a wide variety of excitation states ([OIII]/[OII] and [OIII]/Hα ratios)
  - Reaching very high [OIII]/[OII] values at ~7.5 log(M*), potentially leaking LycC?
- Ongoing work
  - 2-D analysis of resolved targets
  - Synergies with other surveys (SKA precursors, space-based observatories)

Results: Morphologies



Compact

(majority of the sample)

- Compact - 43 %
- Semi-compact - 38 %
- Extended -19 %

Semi-compact

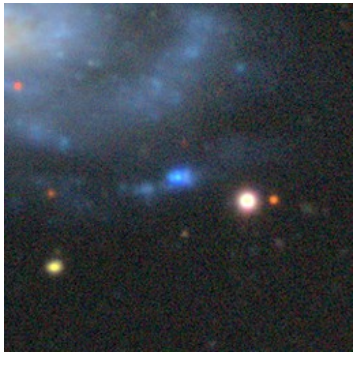
(tadpole, SF region + diffuse area, etc.)

- Extended objects are slightly more massive ($10^{8.32}$ $M_\odot$ vs. $10^{8.04}$ $M_\odot$ in compact or $10^{8.15}$ $M_\odot$ in semi-compact galaxies)
- Extended show slightly lower EW (397 Å vs. 466 Å and 445 Å respectively)

Complex morphology

(multiple SF regions, mergers, etc.)

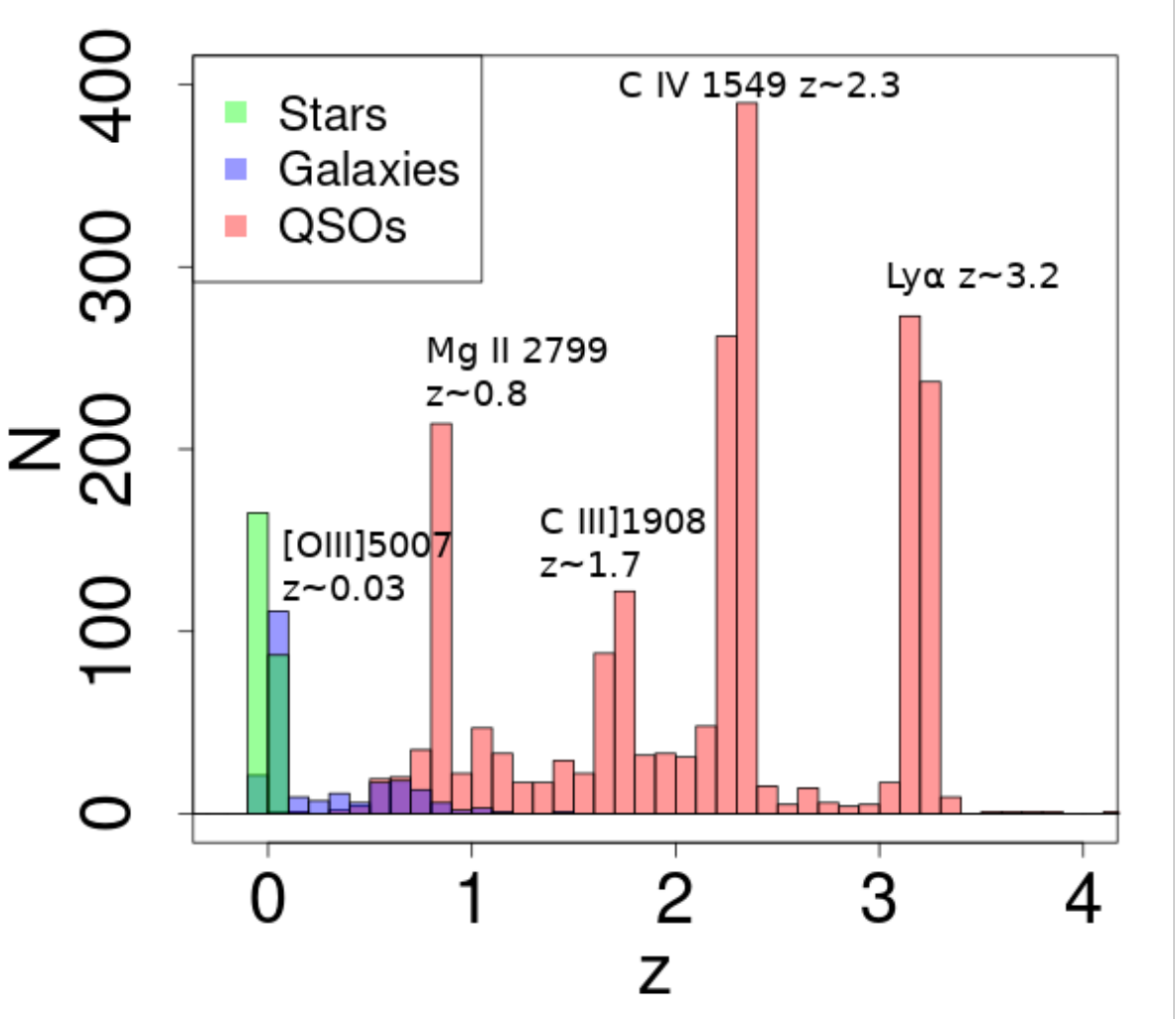
Rejected: SF regions in large-scale spirals



Images from the Legacy Survey viewer www.legacysurvey.com/viewer

Sample selection - Interlopers

- SDSS spectra of the selected objects (2560 spectra / 30336 objects)
- Main issue: Stars and interlopers at higher redshifts
  - The J0515 filter corresponds to different emission lines at different redshift
  - How to remove them?



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- Very young burst (<=6 Myr)
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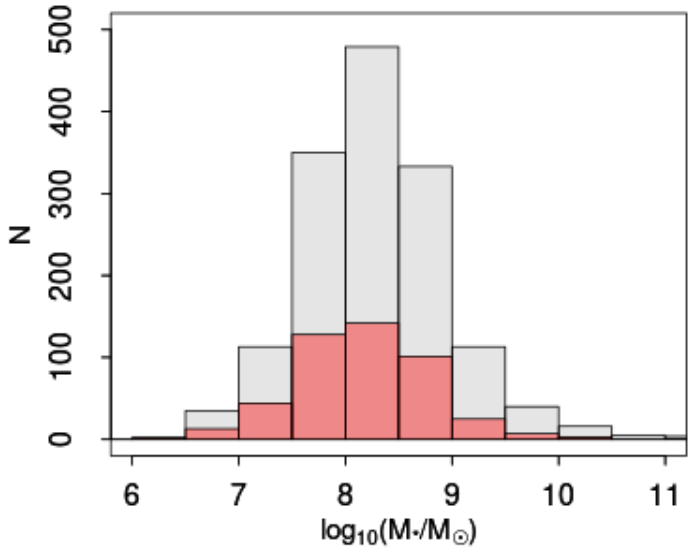
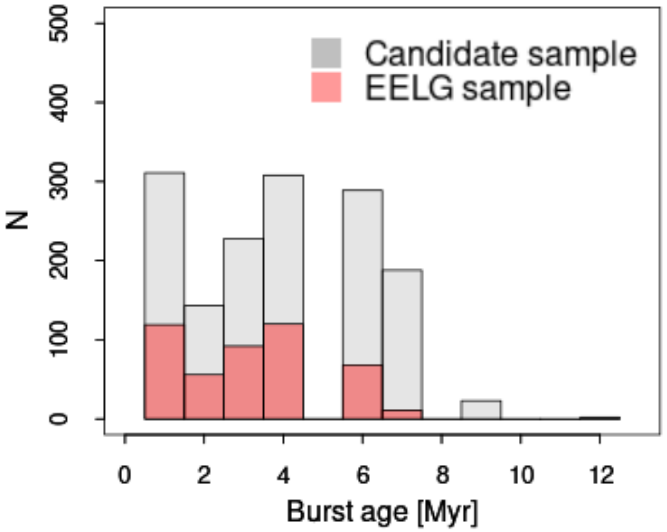
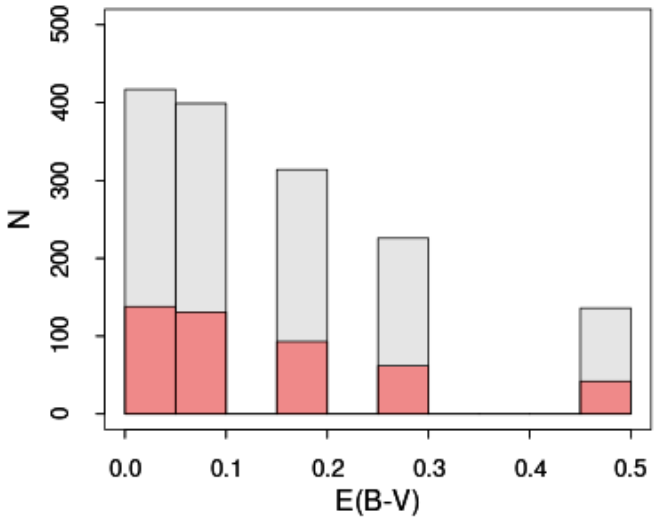
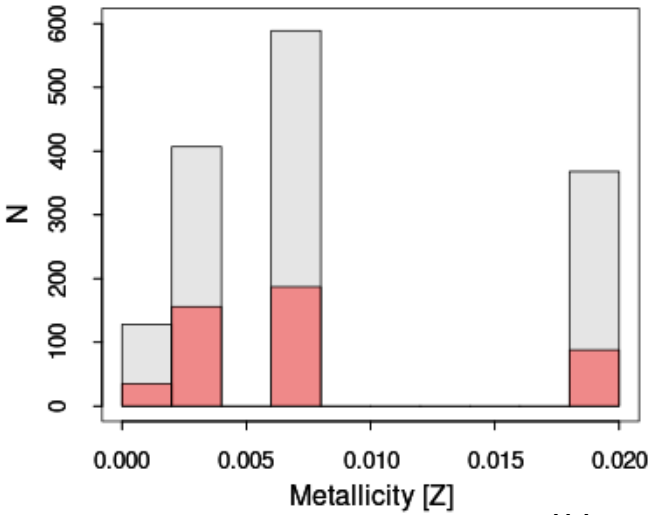


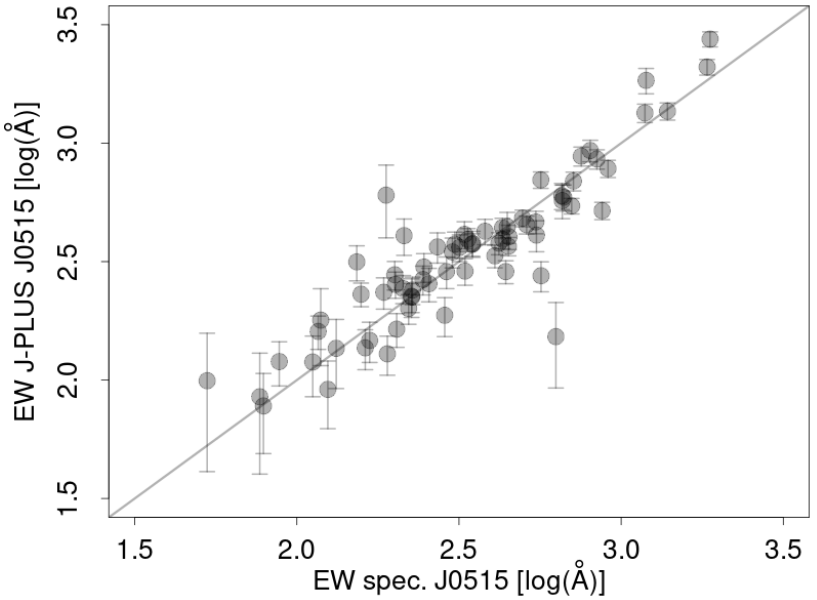


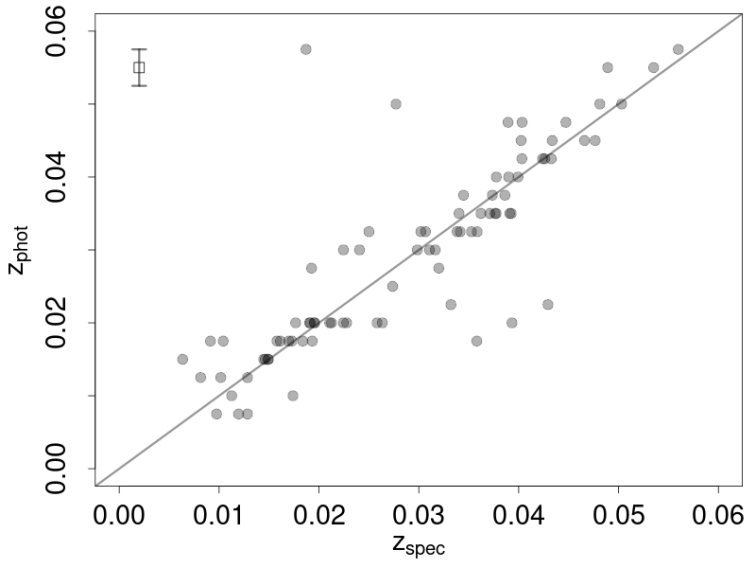


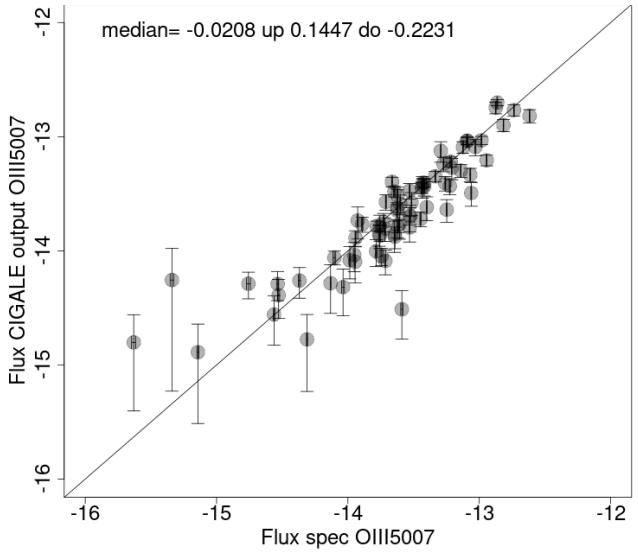


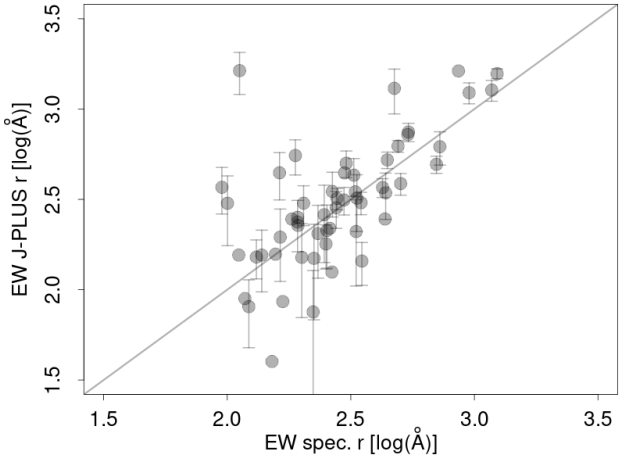
Comparison with SDSS spectra

- Good consistency of [OIII] and Hα EW and fluxes estimated with our data comparing with those with SDSS spectra available
  - Comparison performed using 3 arcsecond apertures
  - Hα flux/EW estimated using r band!
- Very good agreement in redshift
- J-PLUS photometry captures very well the physical properties of the galaxies



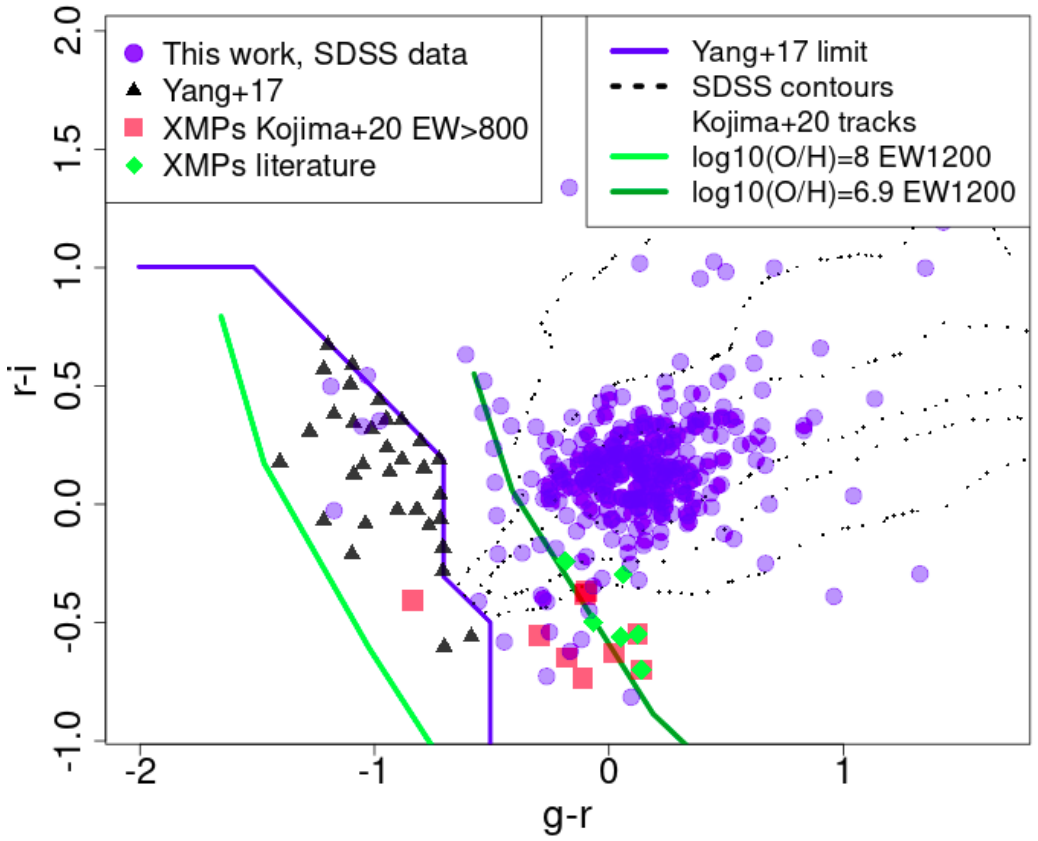






Comparison with previous work

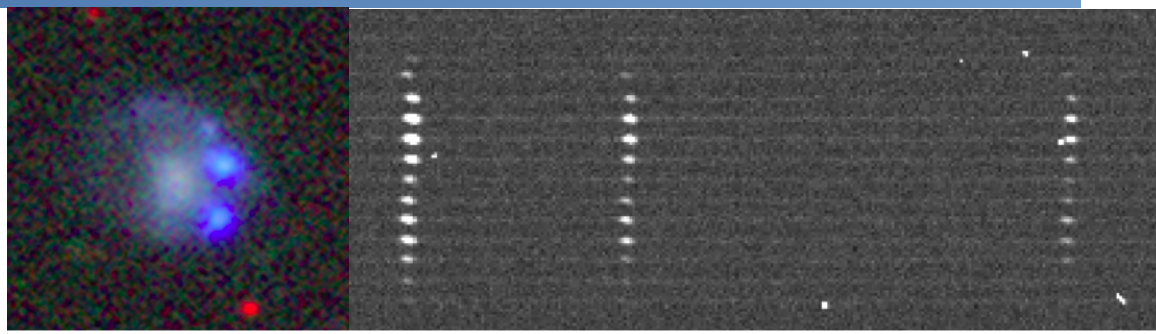
- Broadband selection
  - Advantages:
    - Wider area (SDSS ~14 000 sq. deg.)
    - Deeper observations (SDSS, Legacy surveys, Subaru HSC-SSP)
    - Broader redshift range (sometimes)
  - Disadvantages:
    - Less efficient: need for more extreme systems
    - Scarce information: EW? SED fit?
    - Interlopers at different redshift
    - Biased towards high [OIII]/Hα



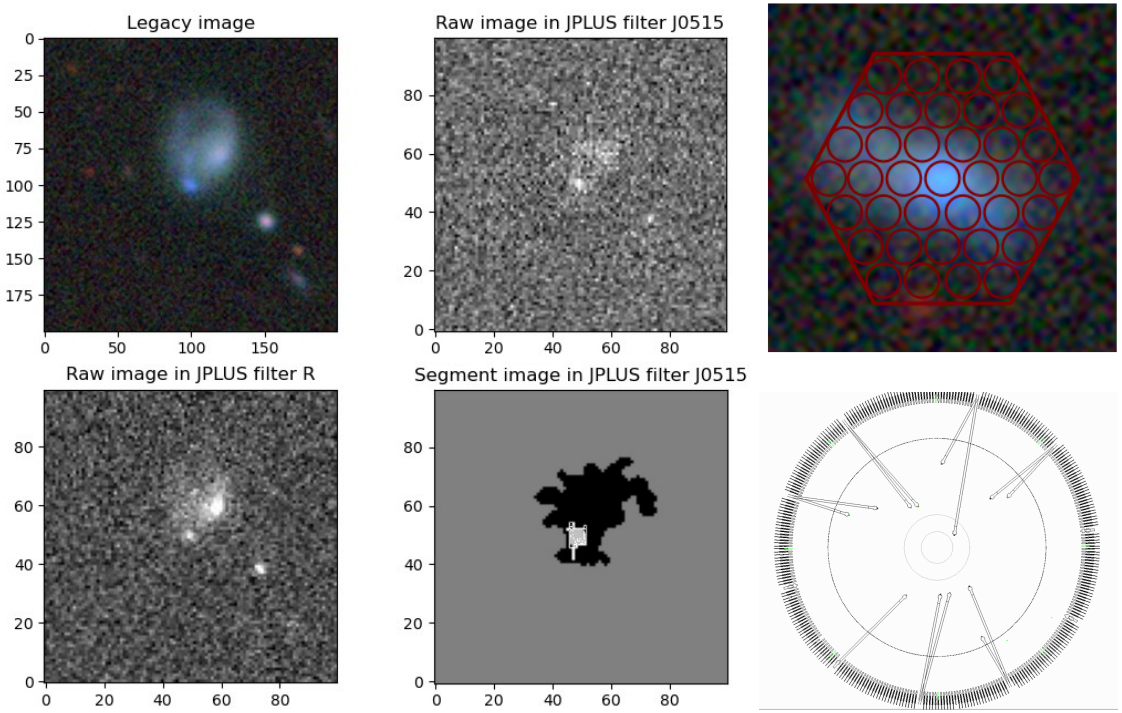
- Spectroscopic surveys
  - Advantages
    - Delivers much more physical information
    - Very precise line and redshift measurements
  - Disadvantages
    - Much more time consuming
    - Only available for bright sources
    - Selection bias

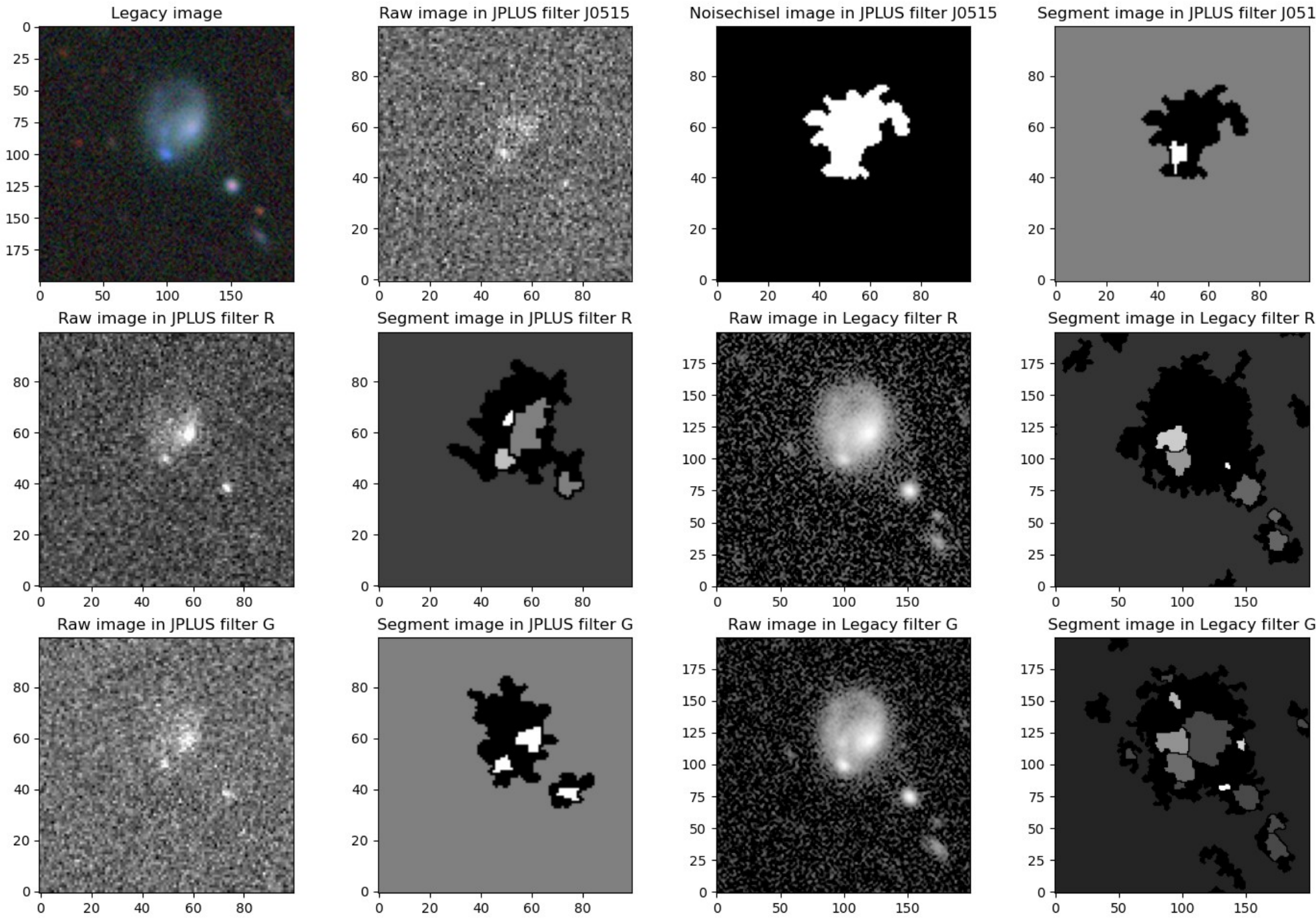
Other follow-up studies

- Spatially resolved spectrocopy (IFU)
  - Pilot program at 3.5m in CAHA (Almería)
  - WEAVE at the 4.2m WHT (La Palma)
    - Science verification
    - 20 mini IFUs per 2deg² field
    - High resolution (R~20 000)



- Resolved photometric analysis of clump properties (Jorge Porrón master thesis)
  - 90 extended EELGs studied, 140 clumps found in [OIII] images
  - Clump masses ~ 10^8 (1/10 of the galaxy)
  - Larger and more star forming clumps towards de center, as found with HST at higher redshift
- X-ray follow-up (XMM-Newton)
  - Test the dependence of X-ray flux with SFR-Metallicity for extreme objects




Legacy image
Raw image in JPLUS filter J0515
Noisechisel image in JPLUS filter J0515
Segment image in JPLUS filter J051
Raw image in JPLUS filter R
Segment image in JPLUS filter R
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Raw image in JPLUS filter G
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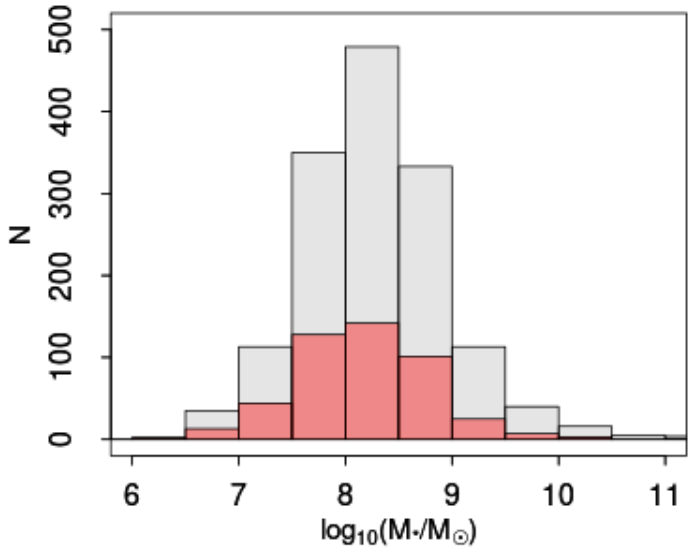
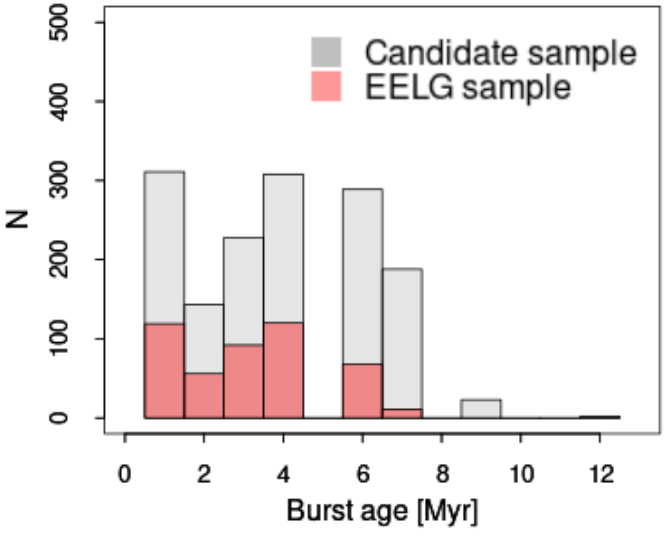
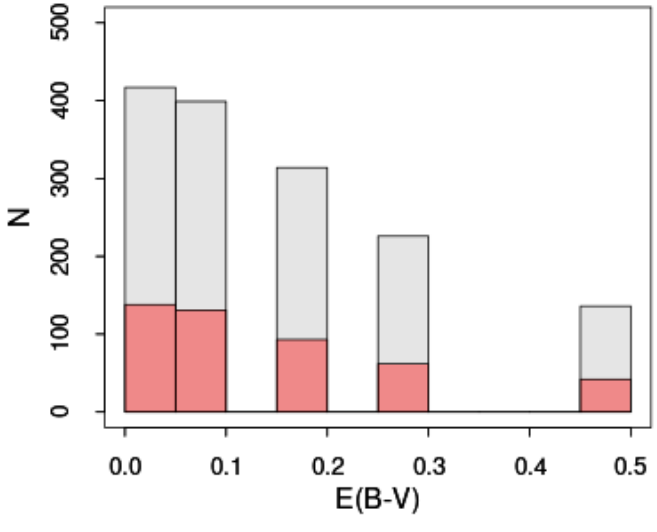
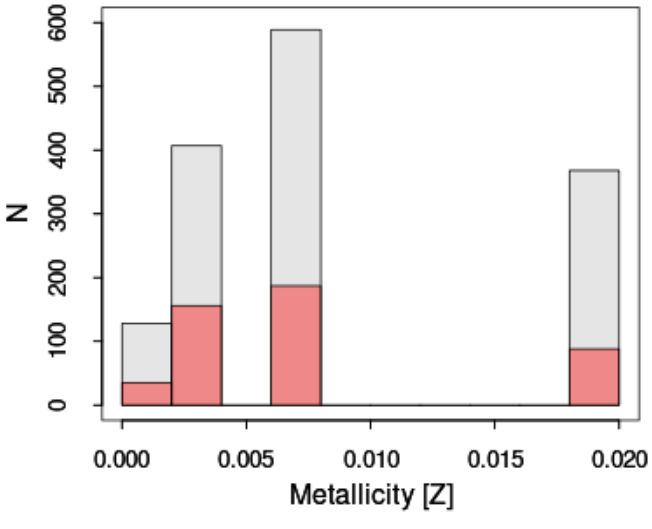
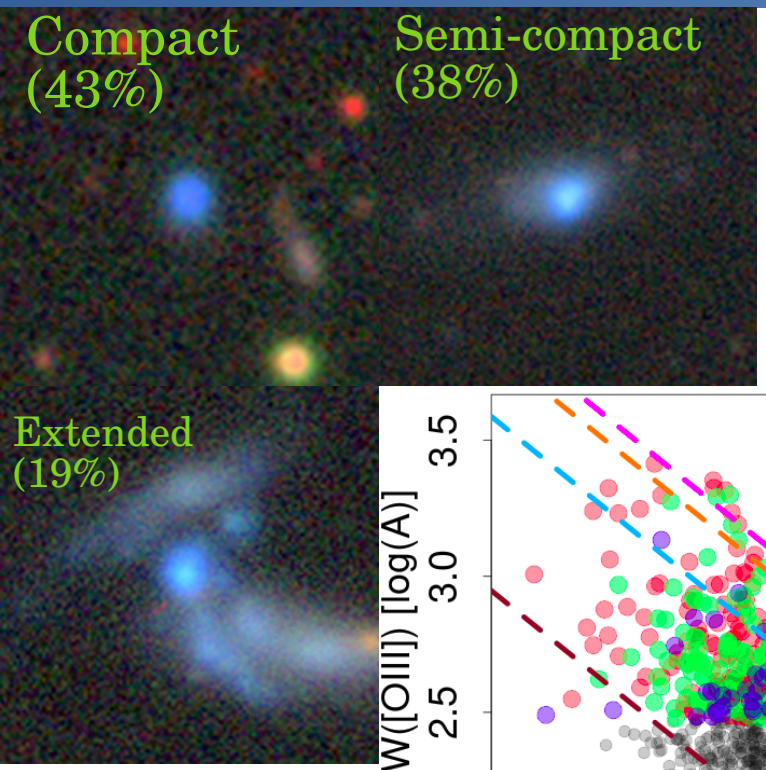




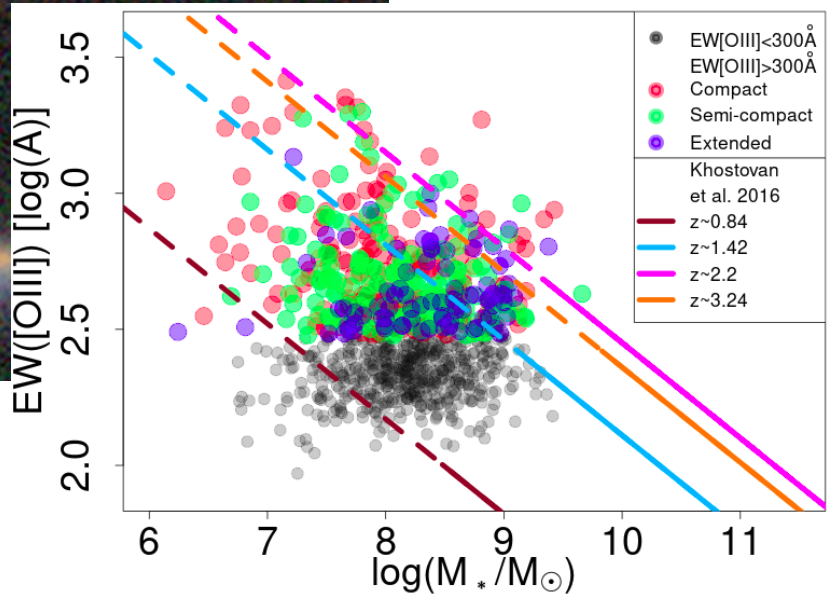




[OIII] sample: morphologies, SFR, EW

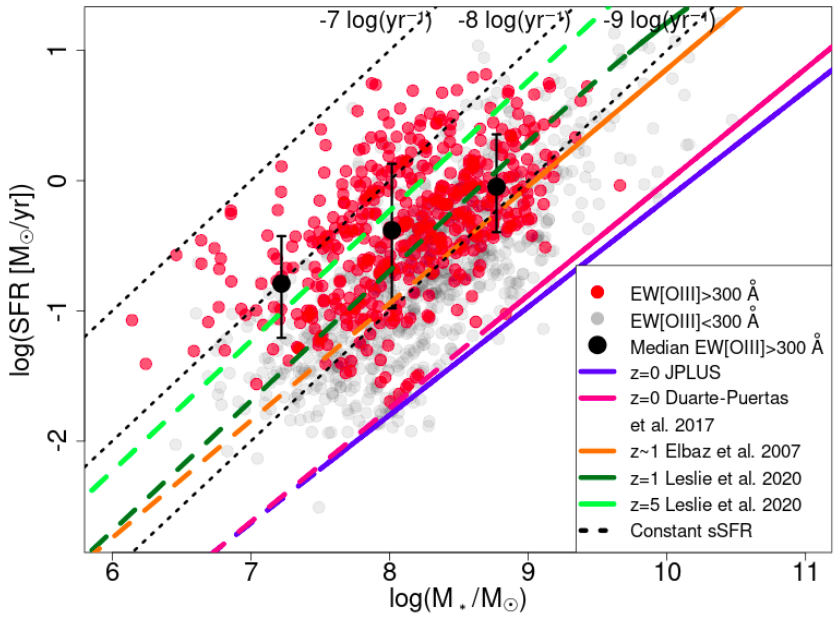


Images from the Legacy Survey viewer www.legacysurvey.com



- $M_{\star}$extend. > $M_{\star}$comp. 8.32 vs 8.04 $\log_{10}(M_{\odot})$
- EWextend. < EW comp. 397 Å vs. 466 Å

- EW [OIII] Comparable to the expectations for typical low mass high-redshift galaxies



- SFR estimation using Hα (Kennicutt+98)
- Typical galaxy in our EW([OIII]) sample: SFR 1.2 dex above local Main Sequence
  - Similar sSFR as typical galaxies at z~3-5
- Depletion time as low as ~ 10 Myr