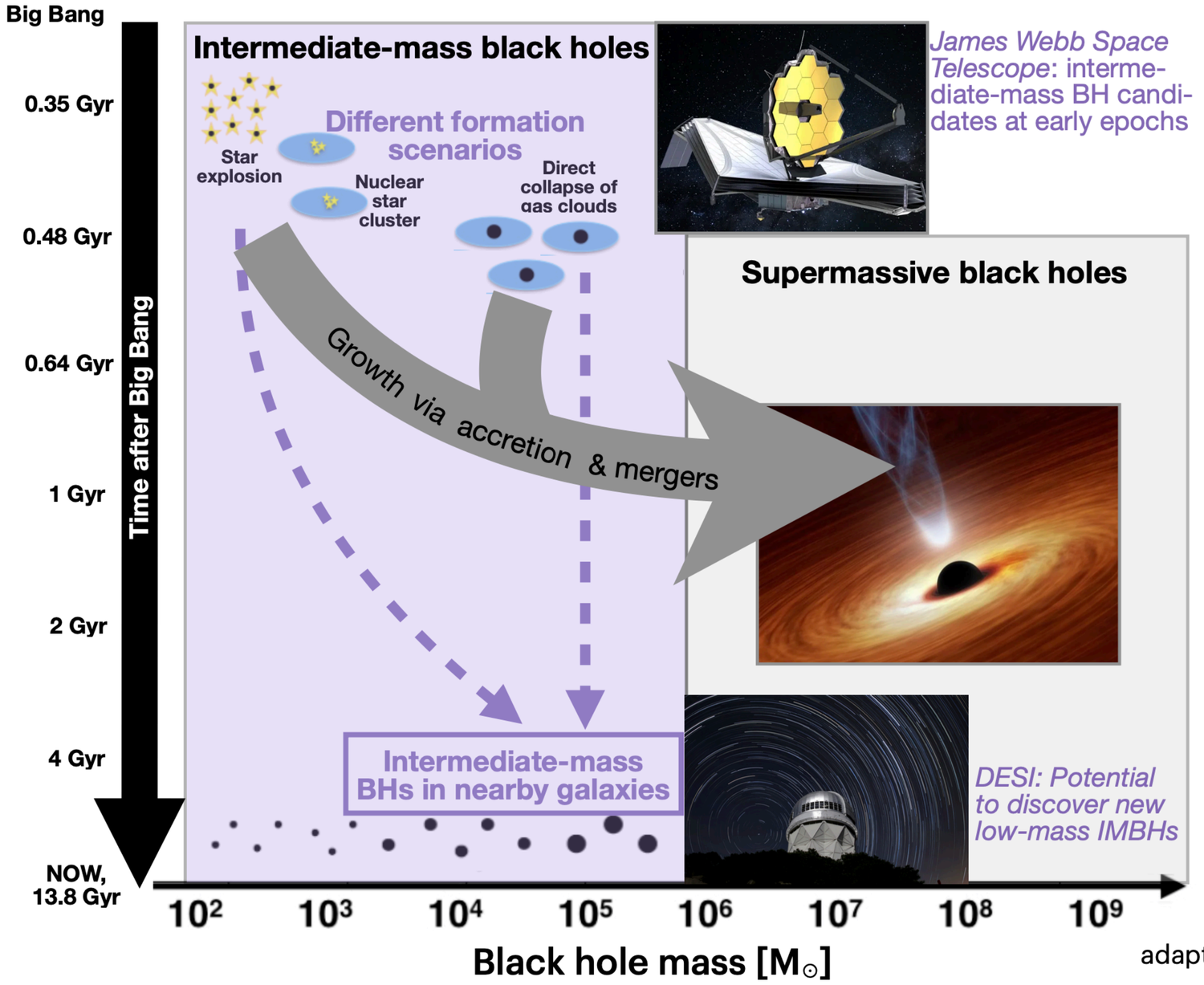
Diagnostics of Intermediate-Mass Black Holes and Ionising Sources

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October 20, 2026

What is the origin of supermassive black-holes ?



James Webb Space Telescope: intermediate-mass BH candidates at early epochs

DESI: Potential to discover new low-mass IMBHs

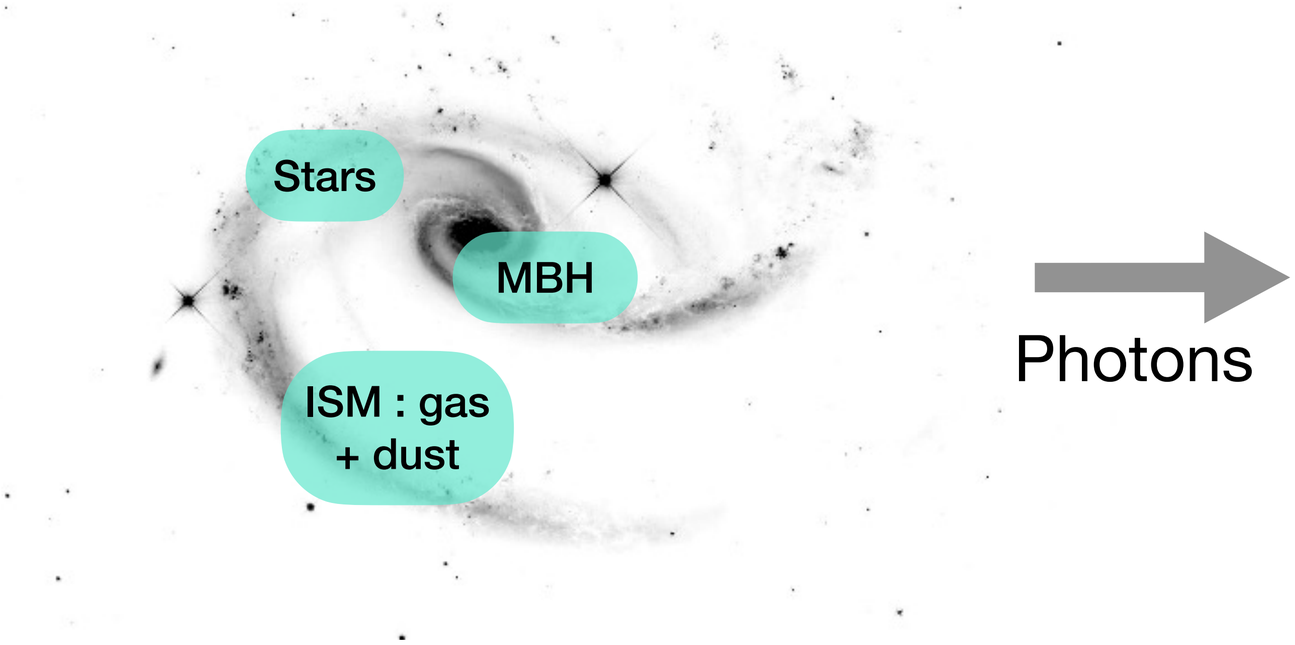
adapted from Mezcua+19

To understand how supermassive black hole form we need to know :

- what was their initial mass when they formed ?
- how fast they accreted mass ?

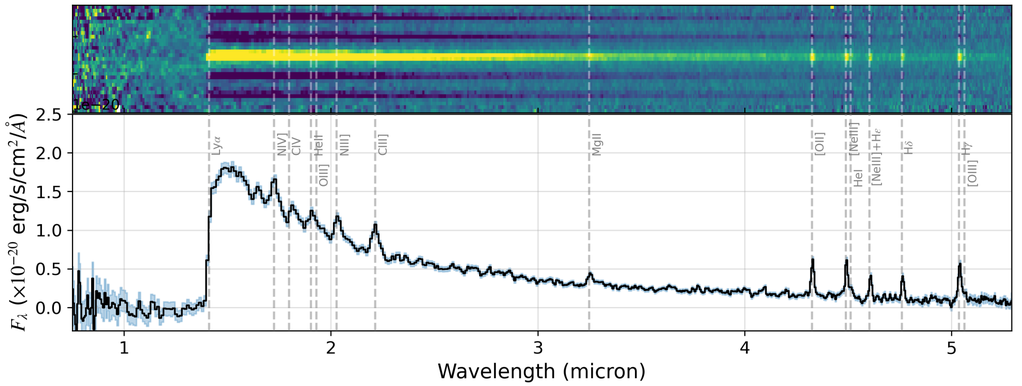
Studying the properties of **intermediate-mass black holes** in **high redshift galaxies** and in **low redshift dwarf galaxies** can help us understand the formation and growth mechanisms of supermassive black-holes.

Large samples of observed galaxy spectra over time



Photons

Observed galaxy spectra



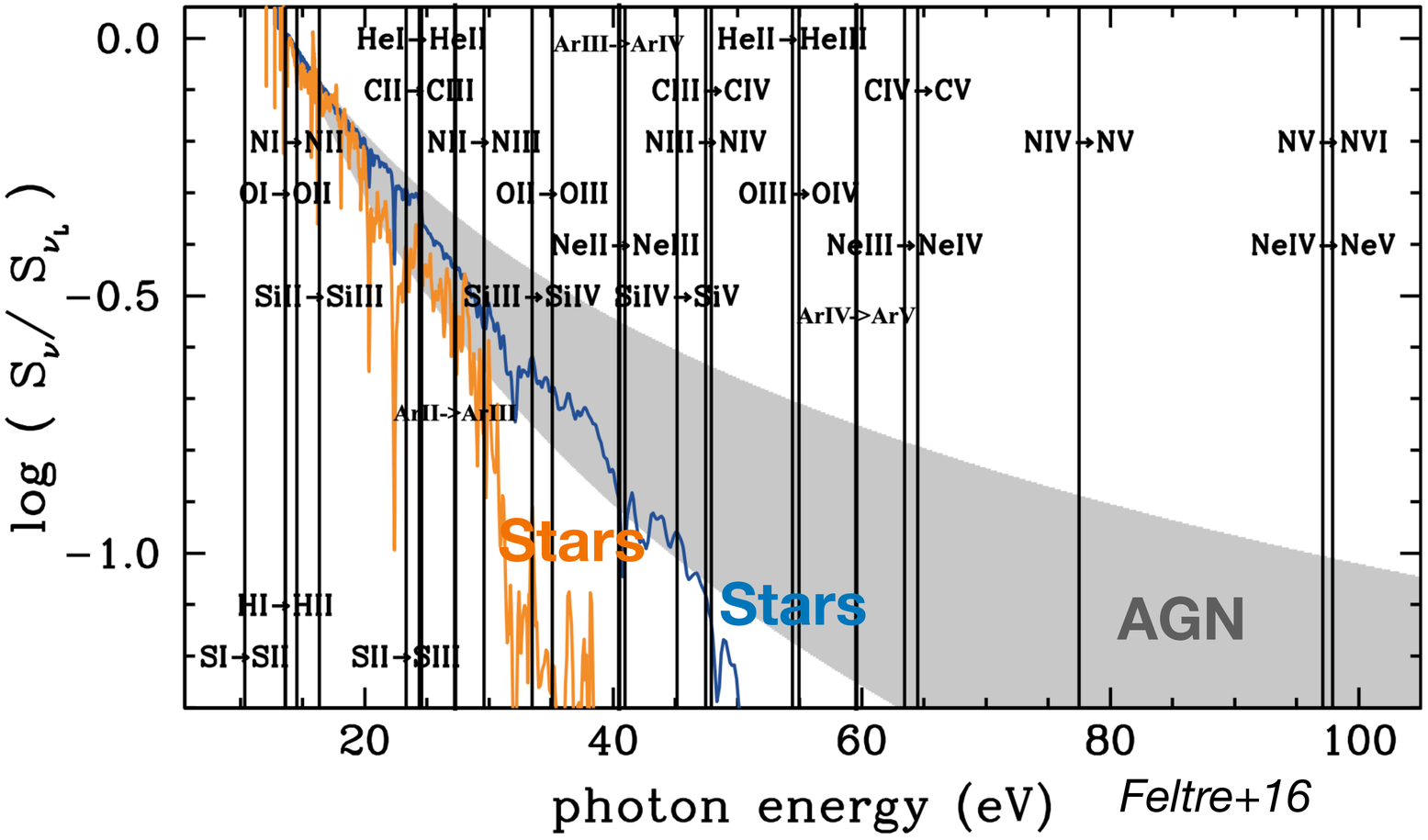
Example of a JWST Spectrum of a high-z galaxy *(Gn-z11, Bunker+23)*

How can we make sense of what we see, i.e. how can we infer redshift and physical galaxy properties from spectra?

- How to distinguish between different sources of ionization in high z galaxies, including pop II, pop III and accreting black-hole and **identify AGN emission** ?
- Can we **infer accurate BH mass and accretion rate** in AGN ?

Distinguish AGN from SF spectral features

Accreting massive BH produce a **harder ionising radiation** with **X-ray** compared to stellar population



➙ Impact the physical state of the surrounding gas :

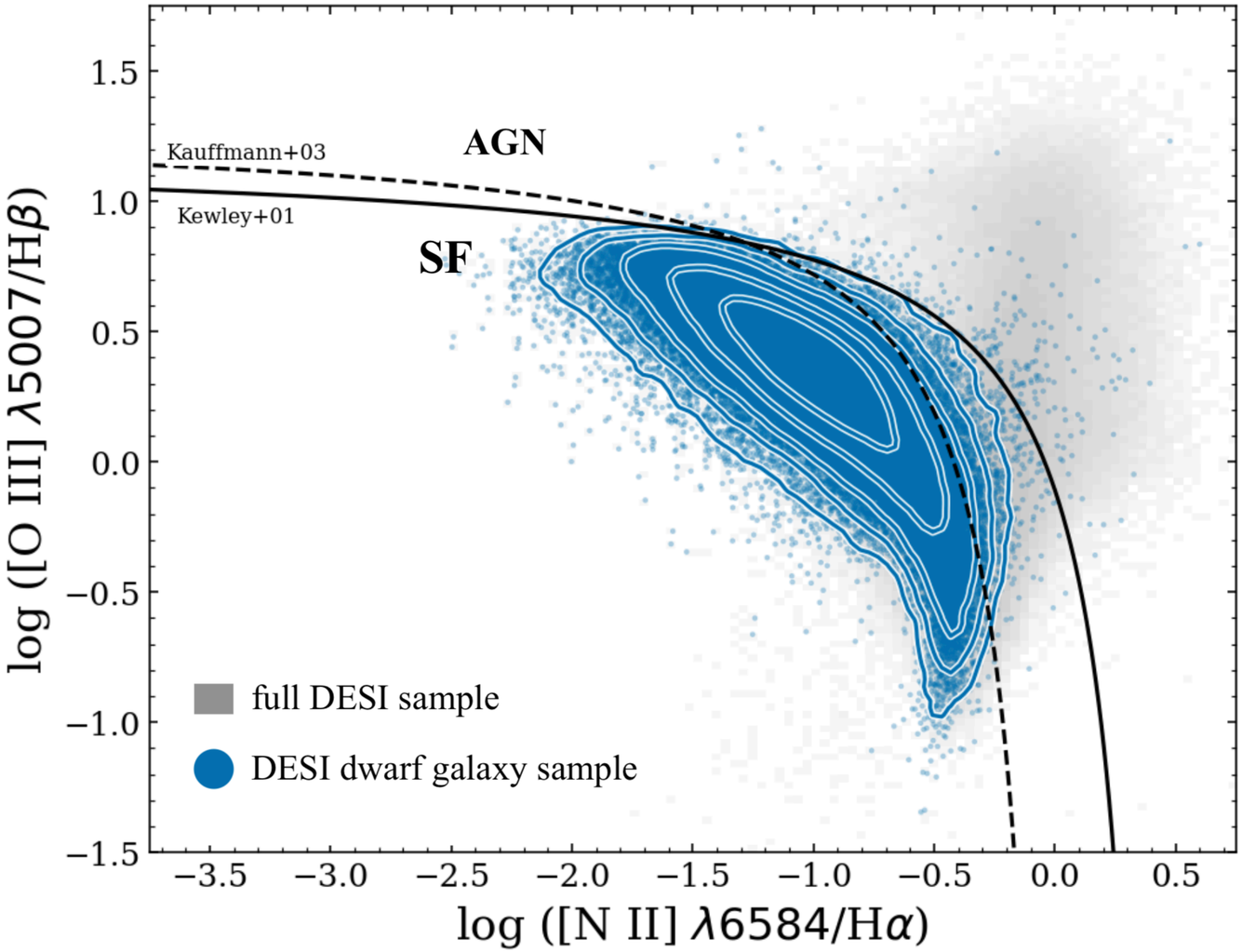
- Increased fraction of high ionisation species
- Elevated electron temperature
- Extended partially ionised zone

➙ This in turn changes the produced **emission lines** :

- Higher [NII]/Ha, [OI]/Ha…
- Stronger HeII, [NeV], ….

How to identify AGN in dwarfs from DESI spectra ?

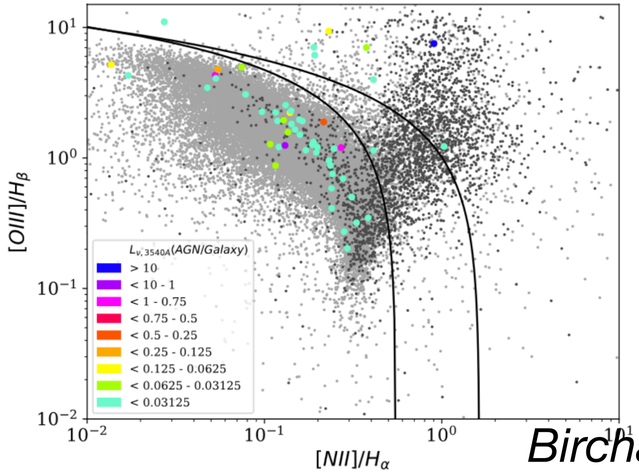
A classical diagram to identify AGNs : the BPT diagram (Baldwin+81)



Dwarf galaxy : $M_\star \leq 10^9 M_\odot$

AGN candidates using Kewley+01 diagnostic : **0.2 %** - against **7 %** for massive galaxies (see also Pucha+26)

But X-ray selected **AGN in dwarfs tend to lie in the SF region of this diagram**

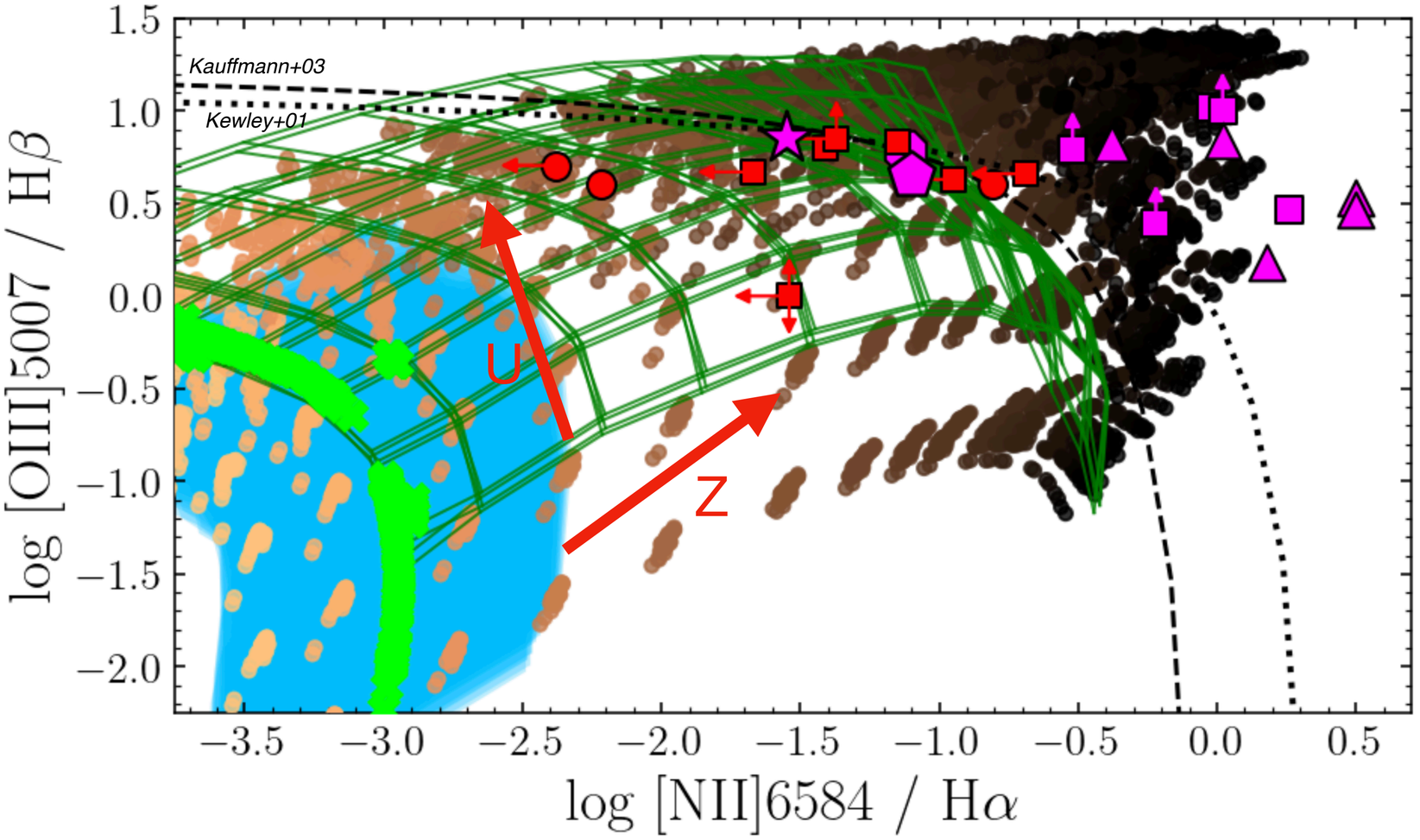


Birchall+20

➙ How to improve selection method to have a **more complete AGN sample** ?

How to identify AGN in dwarfs from DESI spectra ?

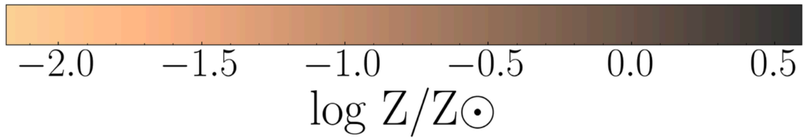
The BPT diagram can miss low metallicity AGN



• SF component :
C&B stellar population (Gutkin+16)
constant SF at 3Myr and 10Myr
Z : 0.0001 to 0.060

• Pop III :
GALSEVN (Lecroq+25)
SSP from 0 yr to 40 Myr
Z_ISM = 1e-11, 1e-4

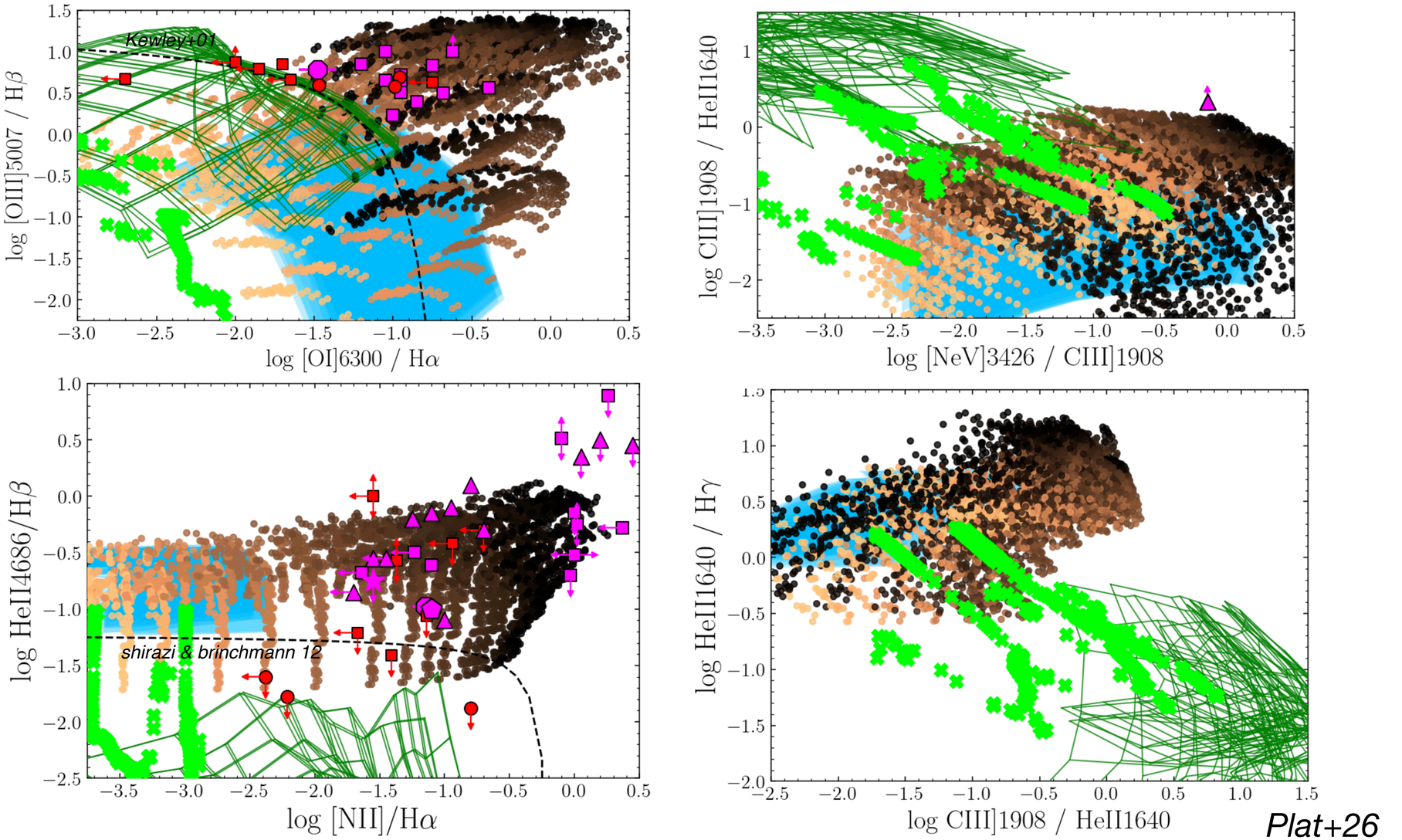
• AGN NLR :
Kubota & Done SED
Z : 0.0001 to 0.060



Plat+26 (see also e.g., Feltre+16, Hirschmann+19)

How to identify AGN in dwarfs from DESI spectra ?

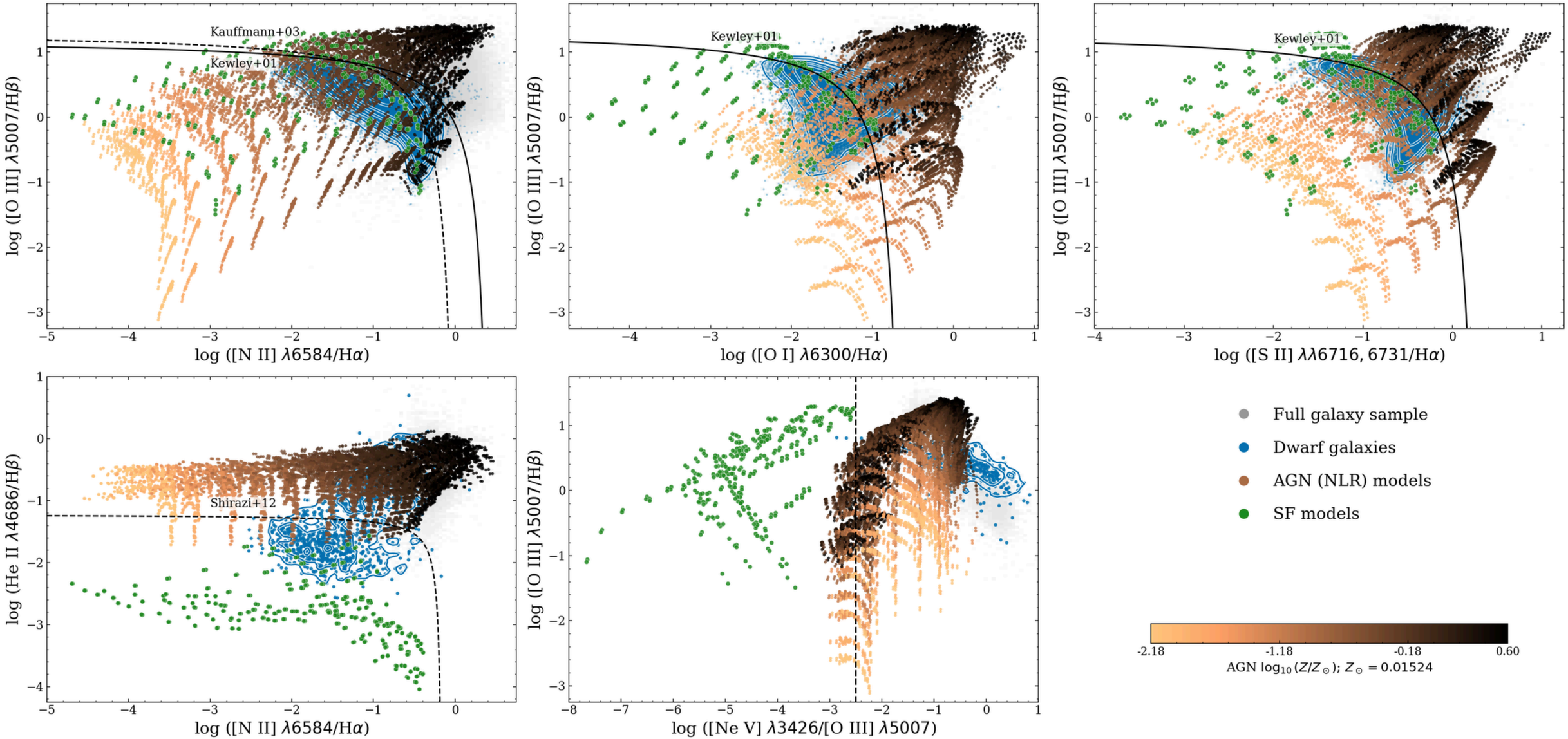
Some diagnostics are less dependent on metallicity and therefore useful to identify AGN in **high redshift galaxies or low redshift dwarfs**



Plat+26

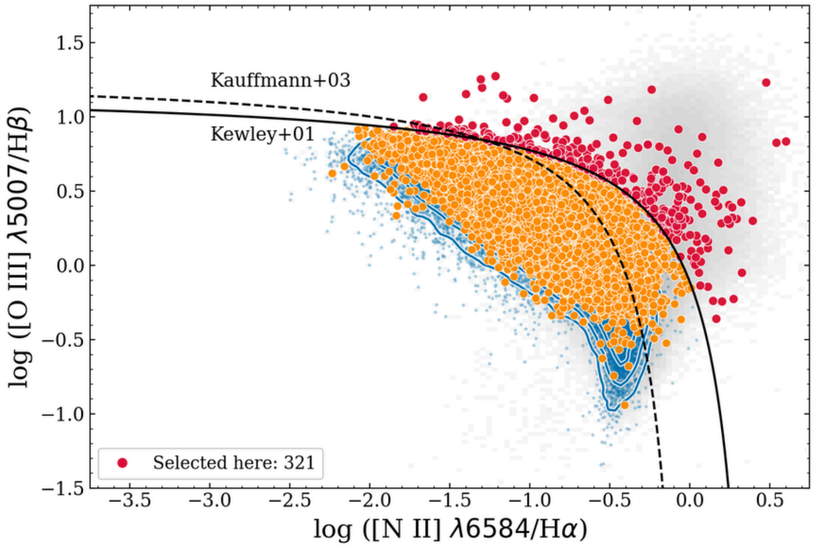
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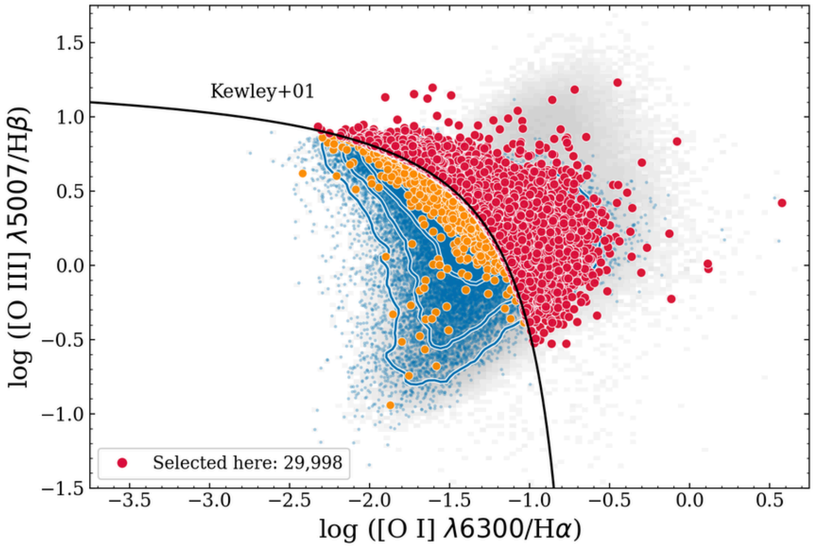
AGN candidates using **multiple** diagnostics

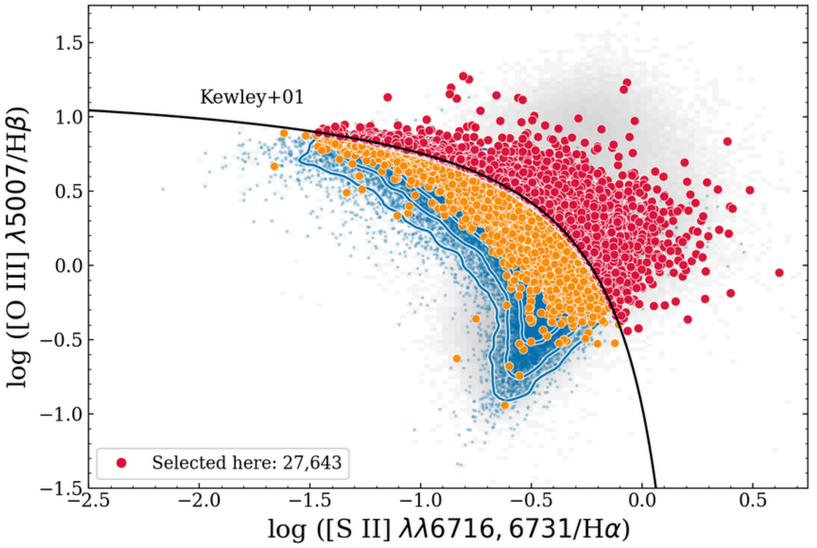


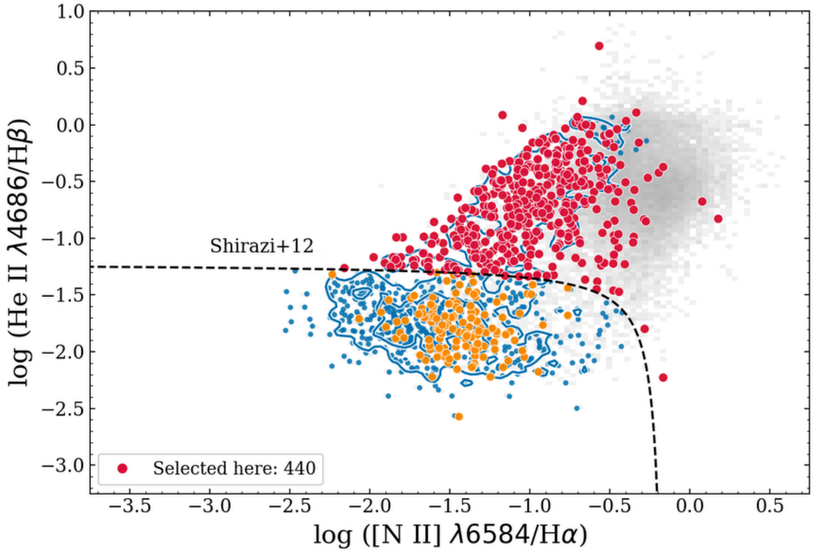
How to identify AGN in dwarfs from DESI spectra ?

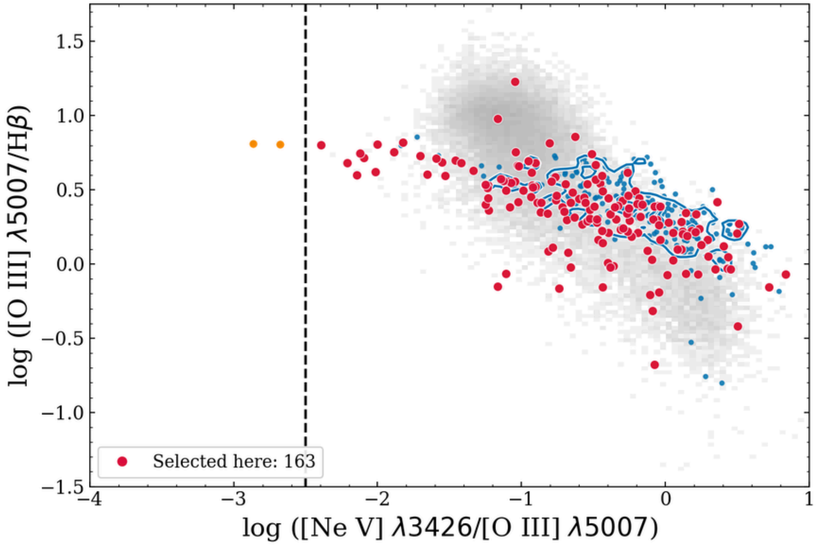
AGN candidates using **multiple** diagnostics : **29 %** of the dwarf sample











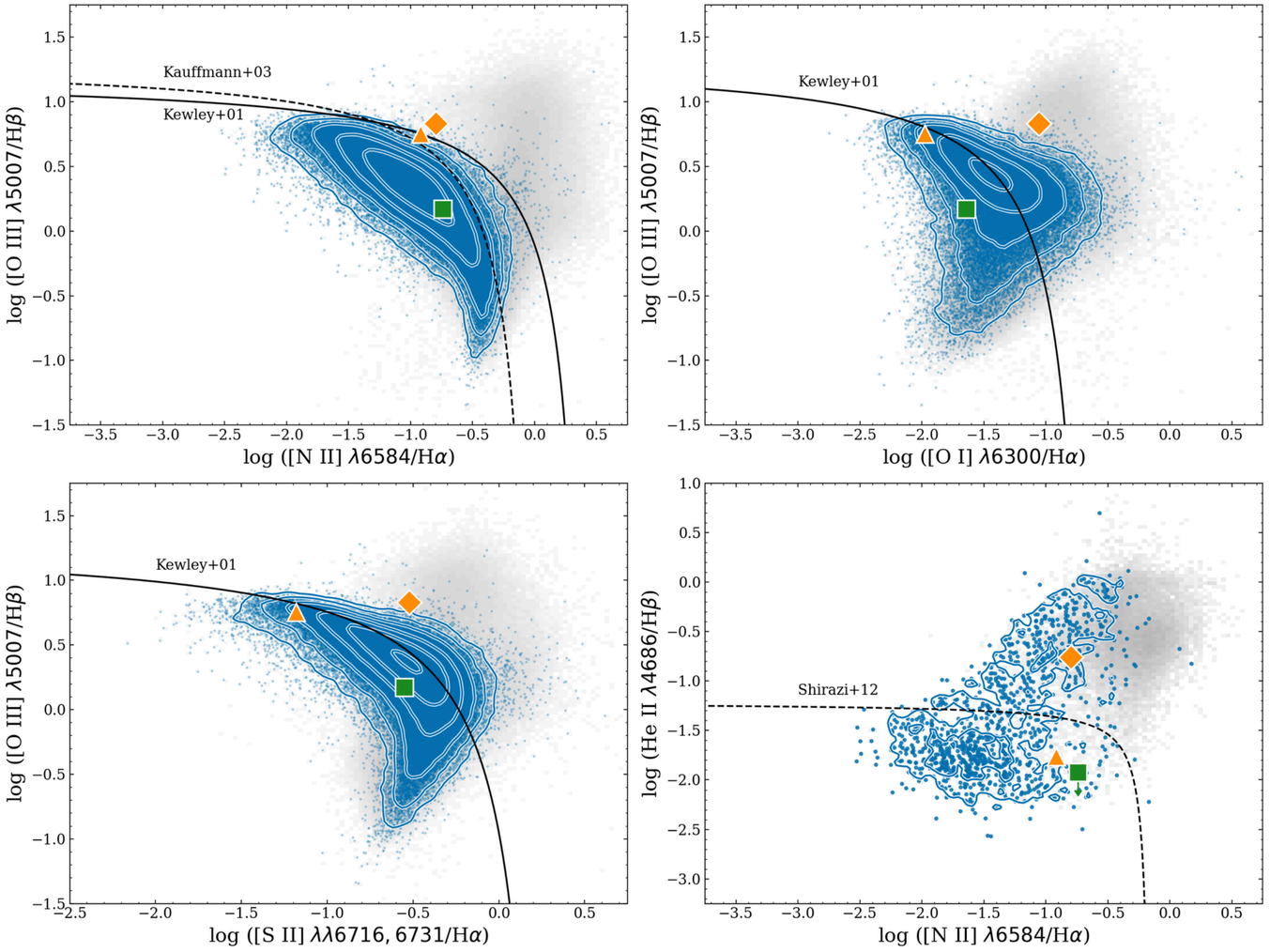
Full galaxy sample

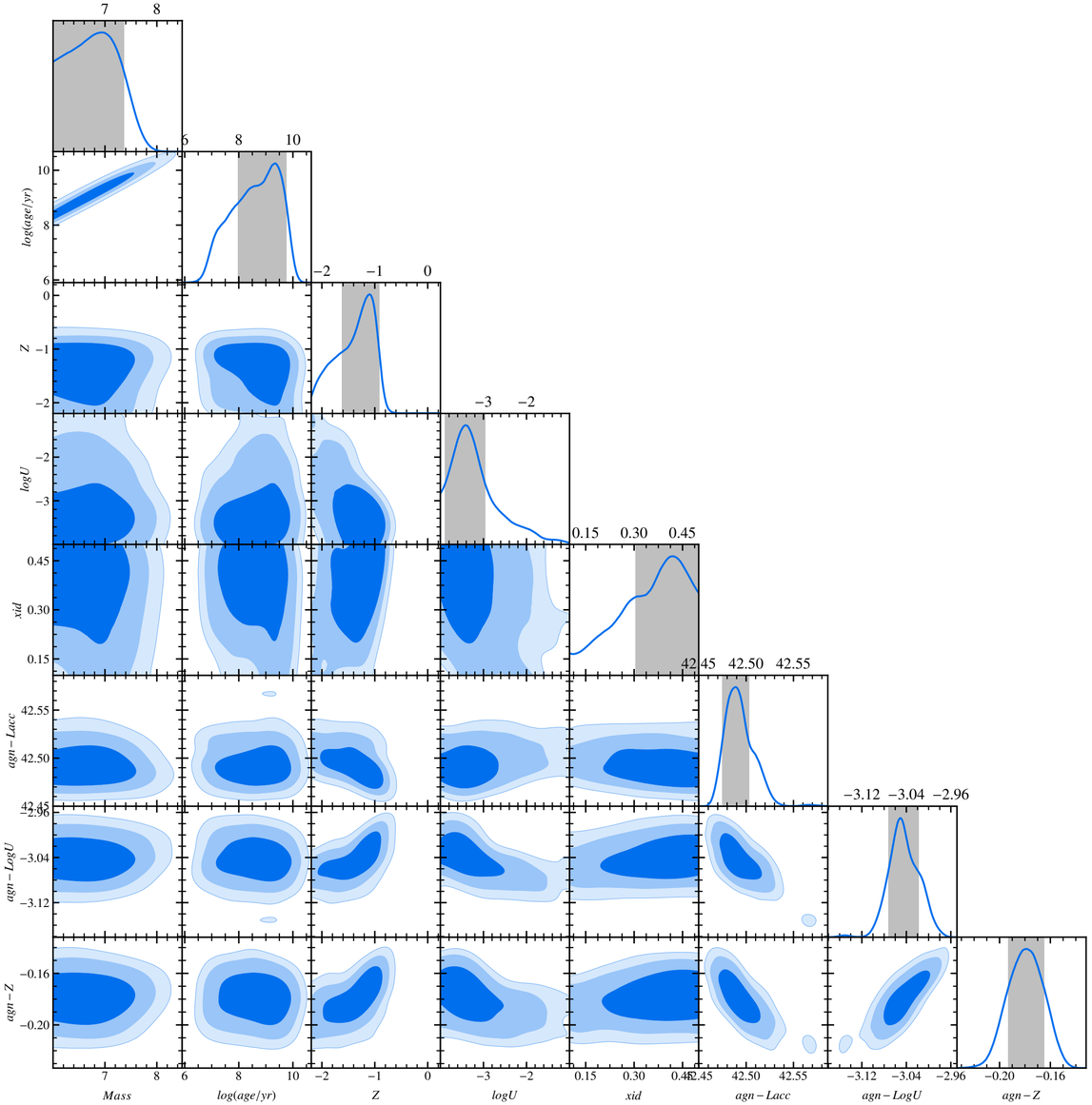
Dwarf galaxies

AGN candidates (combined)

How to identify AGN in dwarfs from DESI spectra ?

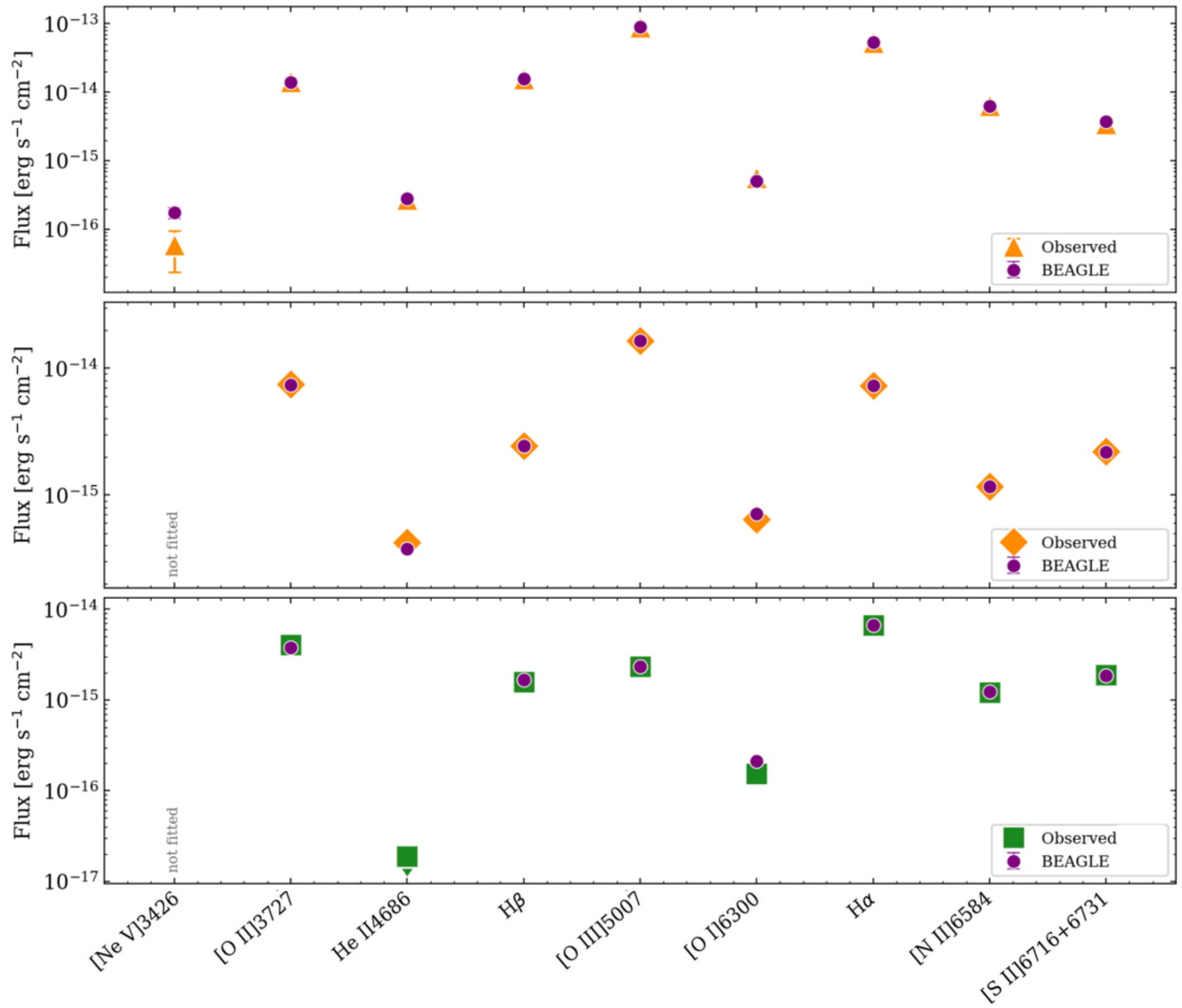
Using **bayesian statistics** to better constrain AGN activity : fitting emission lines with **BEAGLE** for a few dwarf galaxies





How to identify AGN in dwarfs from DESI spectra ?

Using **bayesian statistics** to better constrain AGN activity : fitting emission lines with **BEAGLE** for a few dwarf galaxies



$\log_{10}(M_*/M_\odot) = 9.307^{+0.028}_{-0.022}$

$\mathrm{SFR} = 101.06^{+0.70}_{-0.69}\, M_\odot\ \mathrm{yr}^{-1}$

$\log_{10}(L_{\mathrm{acc}}/[\mathrm{erg\,s^{-1}}]) = 43.716^{+0.016}_{-0.026}$

$Z_{\mathrm{AGN}}/Z_\odot = 1.964^{+0.018}_{-0.022}$

$\log_{10}(M_*/M_\odot) = 6.19^{+0.77}_{-1.00}$

$\mathrm{SFR} = 0.0043^{+0.0016}_{-0.0011}\, M_\odot\ \mathrm{yr}^{-1}$

$\log_{10}(L_{\mathrm{acc}}/[\mathrm{erg\,s^{-1}}]) = 42.491^{+0.018}_{-0.013}$

$Z_{\mathrm{AGN}}/Z_\odot = 0.662^{+0.022}_{-0.021}$

$\log_{10}(M_*/M_\odot) = 8.4499^{+0.0031}_{-0.0057}$

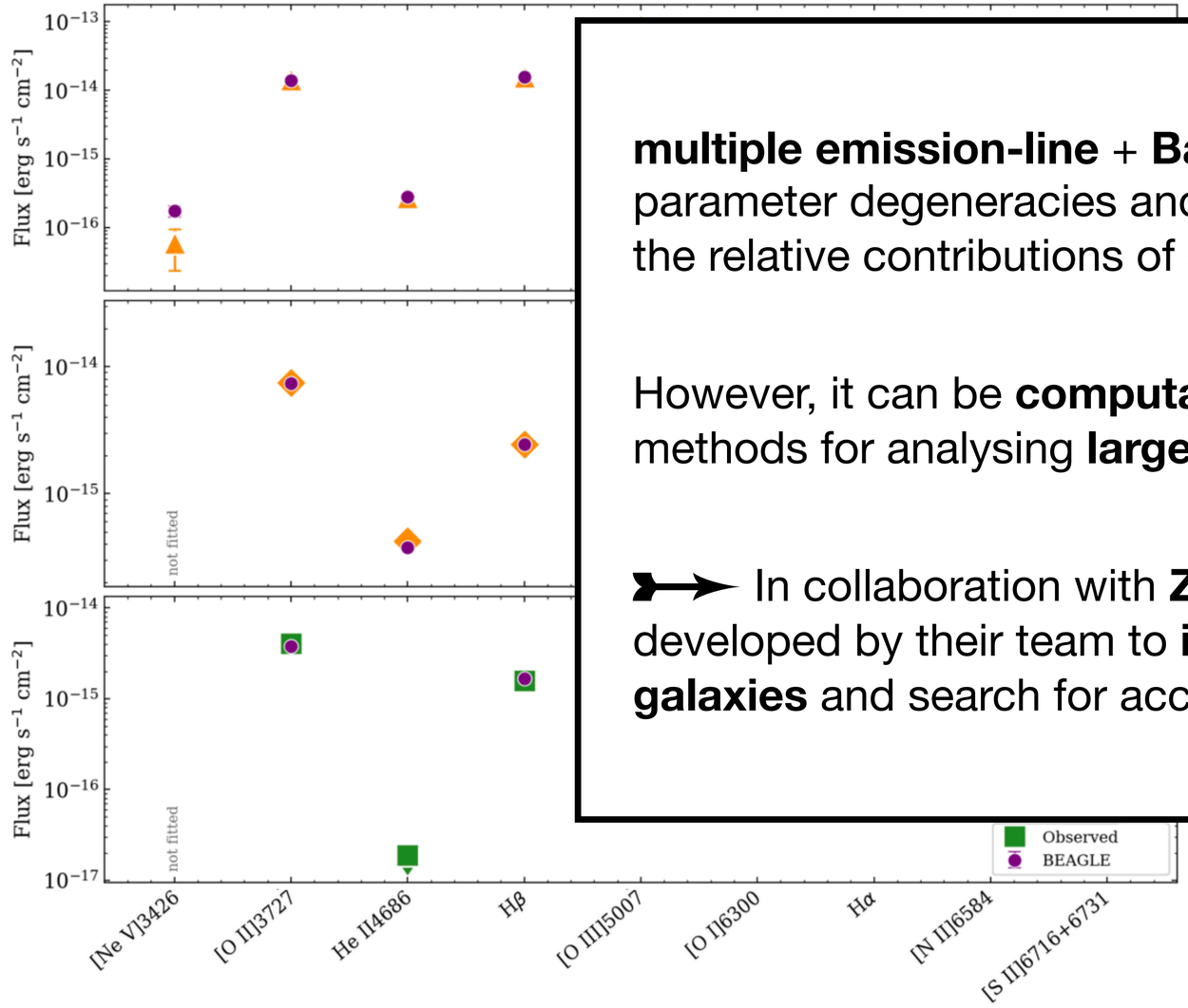
$\mathrm{SFR} = 0.04713^{+0.00021}_{-0.00022}\, M_\odot\ \mathrm{yr}^{-1}$

$\log_{10}(L_{\mathrm{acc}}/[\mathrm{erg\,s^{-1}}]) = 37.0^{+1.4}_{-1.3}$

$Z_{\mathrm{AGN}}/Z_\odot = 0.096^{+0.652}_{-0.081}$

How to identify AGN in dwarfs from DESI spectra ?

Using **bayesian statistics** to better constrain AGN activity : fitting emission lines with **BEAGLE** for a few dwarf galaxies



multiple emission-line + **Bayesian framework** => helps constrain parameter degeneracies and infer galaxy physical properties, including the relative contributions of SF and **AGN emission**.

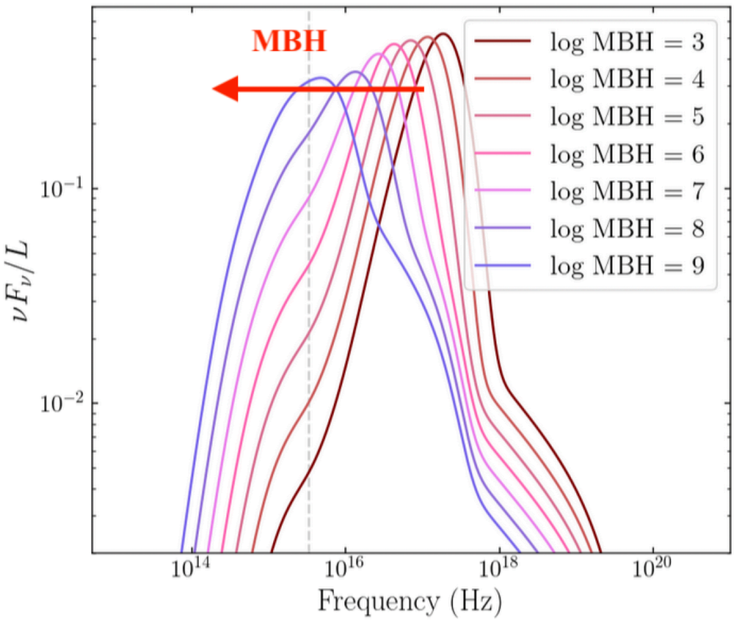
However, it can be **computationally expensive** => we need faster methods for analysing **large spectroscopic surveys**.

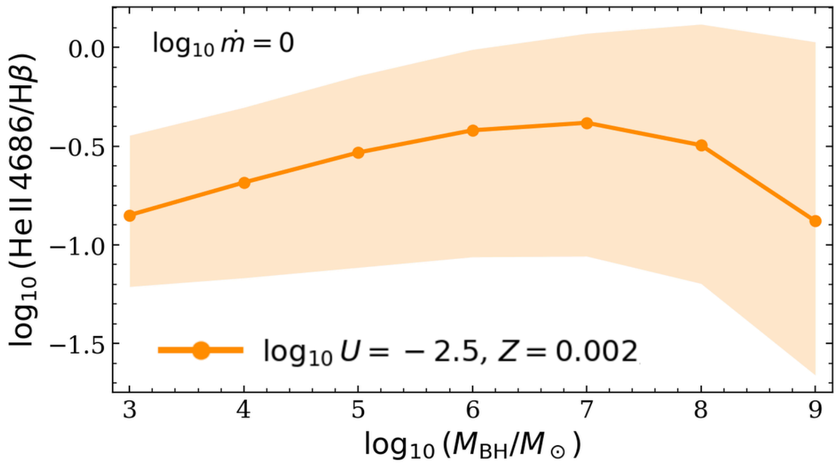
➳ In collaboration with **Zhejiang Lab**, we will use **AI tools** developed by their team to **identify AGN candidates in DESI dwarf galaxies** and search for accreting IMBH.

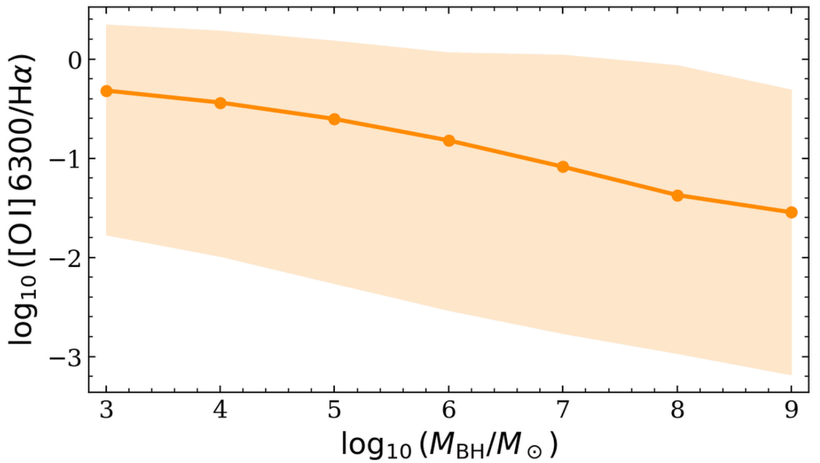
How to identify AGN in dwarfs from DESI spectra ?

Beyond identifying AGN emission : could we constrain **BH mass** and **Eddington ratio** in Type II AGN ?

AGN continuum which depends on Mbh and Fedd from theoretical models, such as Kubota & Done 2018



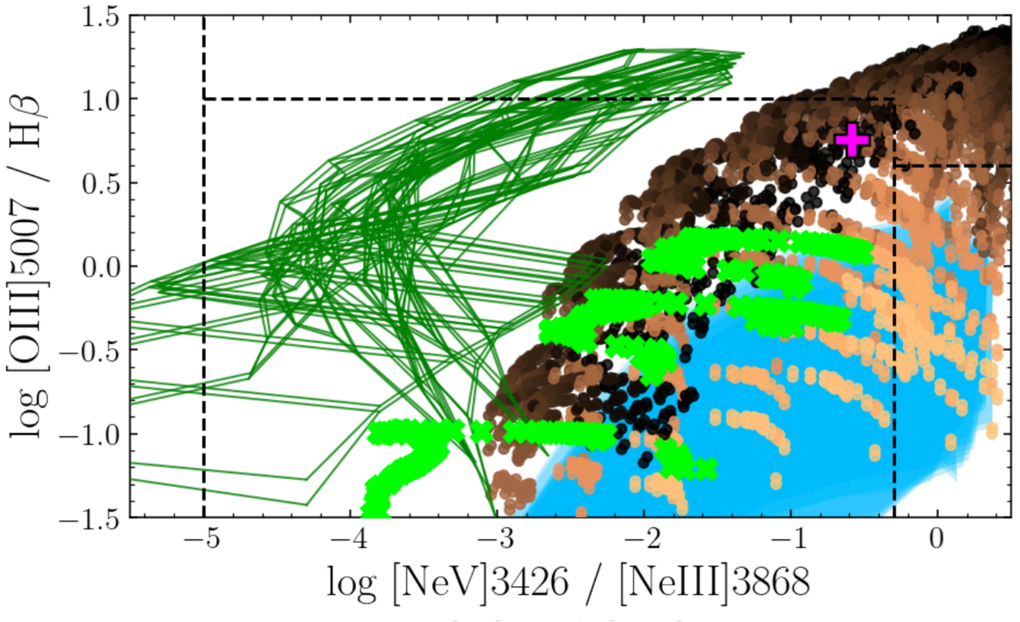


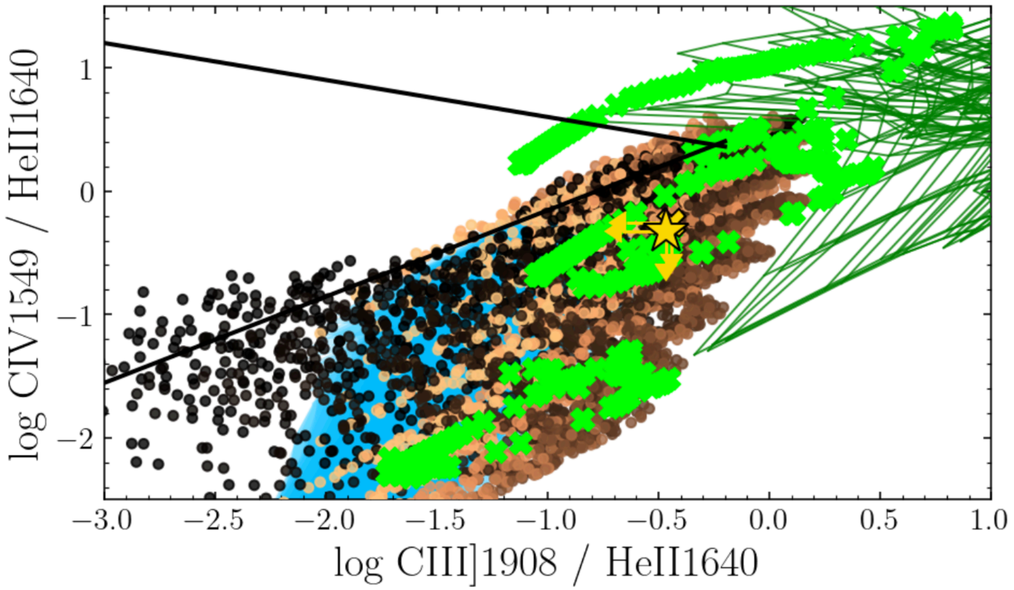


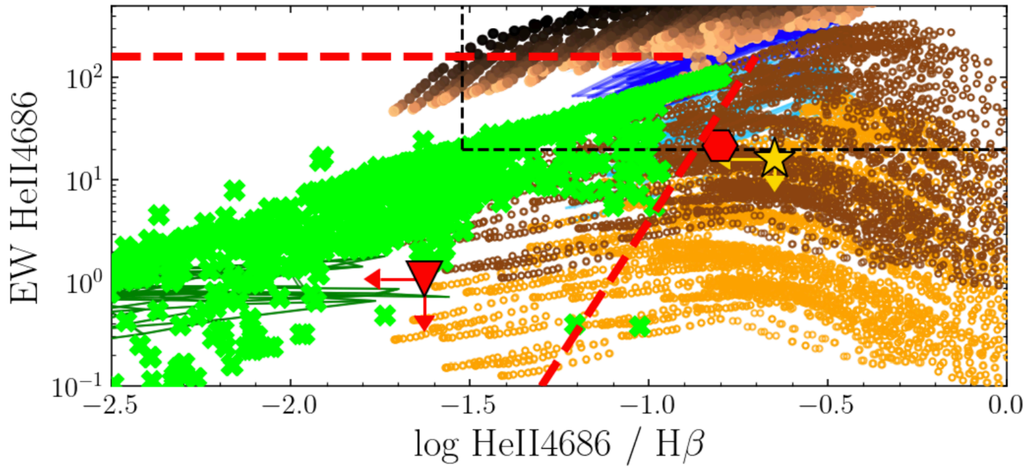
Lots of degeneracies with other model parameters (U, Z…) but using multiple emission lines could potentially help

How to identify AGN in high redshift galaxies ?

Additional challenge at high redshift : emission from **Pop.III stars**







- SF component
- Pop III
- AGN NLR :

Could IA help distinguishing Pop.III sources from AGN emission in high redshift JWST spectra ?

Summary and outlook

How can we identify IMBH in low redshift dwarf galaxy and in high redshift sources ?

- Extensive library of about 2 million spectra with emission lines (optical and UV)
    - for star-forming galaxies
    - for broad-line and narrow-line AGN
- Can be used to interpret galaxy spectra and infer physical properties
    - Using line-ratio diagnostic diagrams ➳ but single line-ratio diagrams suffer from degeneracies between different physical parameters
    - Bayesian statistical fitting codes ➳ but can be computationally expensive to analyse large data set
- New ways to interpret galaxy spectra with ML/AI techniques

  ➳ Use AI to identify AGN and infer galaxy physical properties such as stellar age, metallicity, AGN fraction, …