Data analysis Exercises — 4

Read: P. Schneider—Extragalactic Astronomy Section 3.6, 3.7, 3.8, 3.10 & chapter 5

Identifying star-forming and AGN galaxies in SDSS galaxy catalogues using observed emission line fluxes.

Note that logarithmic scaling is the usual way of visualisation.

1. Find the Halpha luminosities based on the given fluxes and redshifts. Then estimate the SFR's using the Kennicutt+1998 relation and plot the location of galaxies in the SFR-galaxy stellar mass plane (e.g., a scatter plot with contours and/or a 2D histogram). Add the Elbaz+07 (z~0 SDSS) relation for comparison. Which well-known scaling relation is shown?

2. To what extent would this relation be biased if only galaxies with an Ha flux above 10^{-13} erg/s/cm^2 were detected?

3. Plot location of observed galaxies more massive than 1e9 M_{sun} in the classical BPT diagnostic diagram, [OIII]/Hb vs [NII]/Ha (scatter plot). Explain the dependence of the location of a galaxy in this diagram on different gas and radiation properties. In general, what is the significance of the BPT diagram for observational spectroscopic data?

Data analysis Exercises — 4

Identifying star-forming and AGN galaxies in SDSS galaxy catalogues using observed emission line fluxes.

4. Use the classical BPT diagnostic diagram ([OIII]/Hb vs [NII]/Ha) to identify the dominant ionising sources using the selection criteria of Kewley et al. 2001 and Kauffmann et al. 2003 (SF, composite and AGN-dominated galaxies). Which complications/caveats can arise using these selection criteria?

5. Investigate how the SFR-galaxy stellar mass plane changes for different galaxy types, and interpret your findings.

6. Use the scaling of Lamastra+09 to estimate the bolometric AGN luminosity and thus, the BH accretion rate, from the [OIII] line luminosity. You can assume an efficiency η of 0.1. Plot the location of galaxies in the BHAC — SFR plane; interpret your result in the light of the observed BH scaling relations (black hole-stellar mass relation).

Information for Exercises — 4

The SDSS catalogues contains emission line measurements from the Sloan Digital Sky Survey. Fluxes are given in units of 10^{-16} erg/s/cm^2. Astro-III_Ex4_EmissionLines-Snippets.ipynb contains a python routine for reading the relevant line fluxes, as well as the redshift and the stellar masses (given in log10).

The file further contains useful snippets to calculate the luminosity distance and luminosity, as well as the empirical relations which you can plot alongside your data.

Empirical relations — 4

Kennicutt+98

$$\text{SFR}\ (M_\odot\ yr^{-1}) = 7.9 \times 10^{-42}\ L(H\alpha)\ (\text{ergs s}^{-1})$$

Elbaz+07

$$SFR^{z\sim0}_{\text{SDSS}}\ \left[M_\odot\ \text{yr}^{-1}\right] = 8.7\ [-3.7, +7.4] \times \left[M_\star/10^{11}\ M_\odot\right]^{0.77}$$

Kewley+01

$$\log\left(\frac{[\text{O III}]\ \lambda5007}{\text{H}\beta}\right) = \frac{0.61}{\log([\text{N II}]/\text{H}\alpha) - 0.47} + 1.19$$

Kauffmann+03

$$\log([\text{O III}]/\text{H}\beta) > 0.61/\{\log([\text{N II}]/\text{H}\alpha) - 0.05\} + 1.3$$

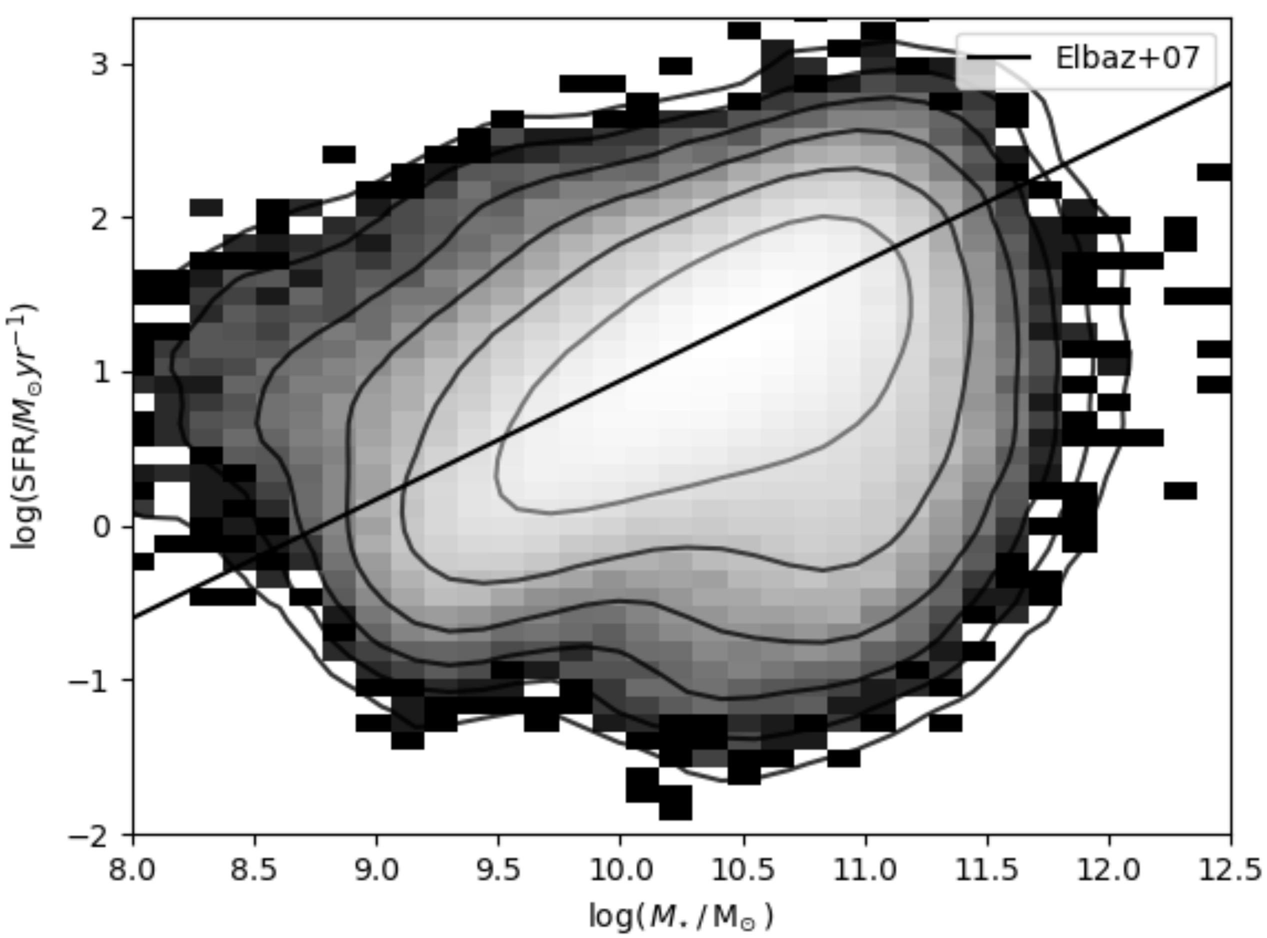
Lamastra+09

[OIII] bolometric correction factor, C_{OIII} in different L_{OIII} ranges to estimate the bolometric luminosity

C_{OIII} = 87, 142, and 454
log L_{OIII} = 38–40, 40–42, and 42–44

1. Find the Halpha luminosities based on the given fluxes and redshifts. Then estimate the SFR's using the Kennicutt+1998 relation and plot the location of galaxies in the SFR-galaxy stellar mass plane (e.g., a scatter plot with contours and/or a 2D histogram). Add the Elbaz+07 (z~0 SDSS) relation for comparison. Which well-known scaling relation is shown?

The star-forming main sequence. Note that there is a large scatter, but most galaxies cluster around the Elbaz+07 relation.

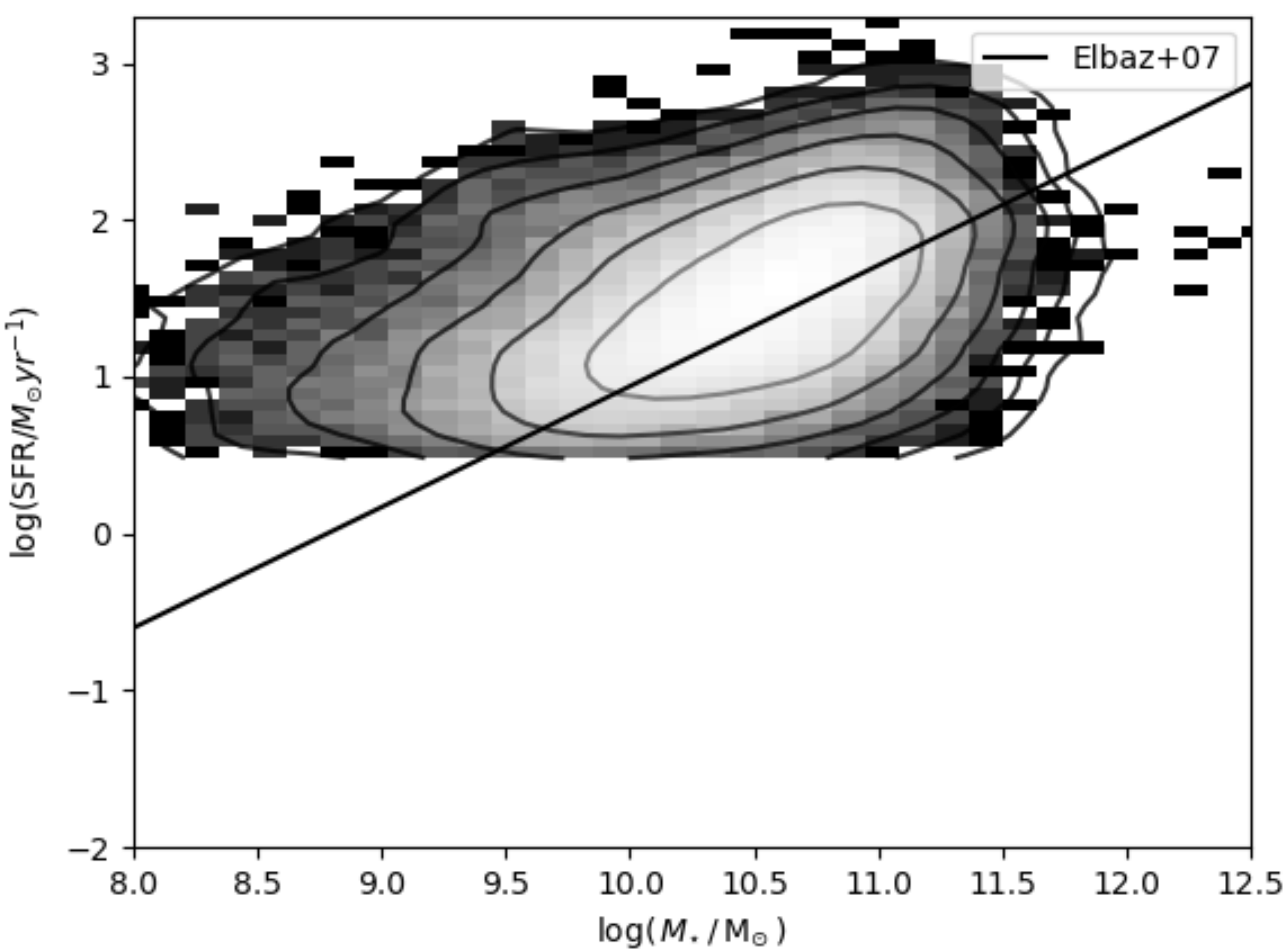


Finding luminosity from Flux

$$F = \frac{L}{4\pi D(z)^2}$$

2. To what extent would this relation be biased if only galaxies with an Ha flux above 10^{-13} erg/s/cm^2 were detected?

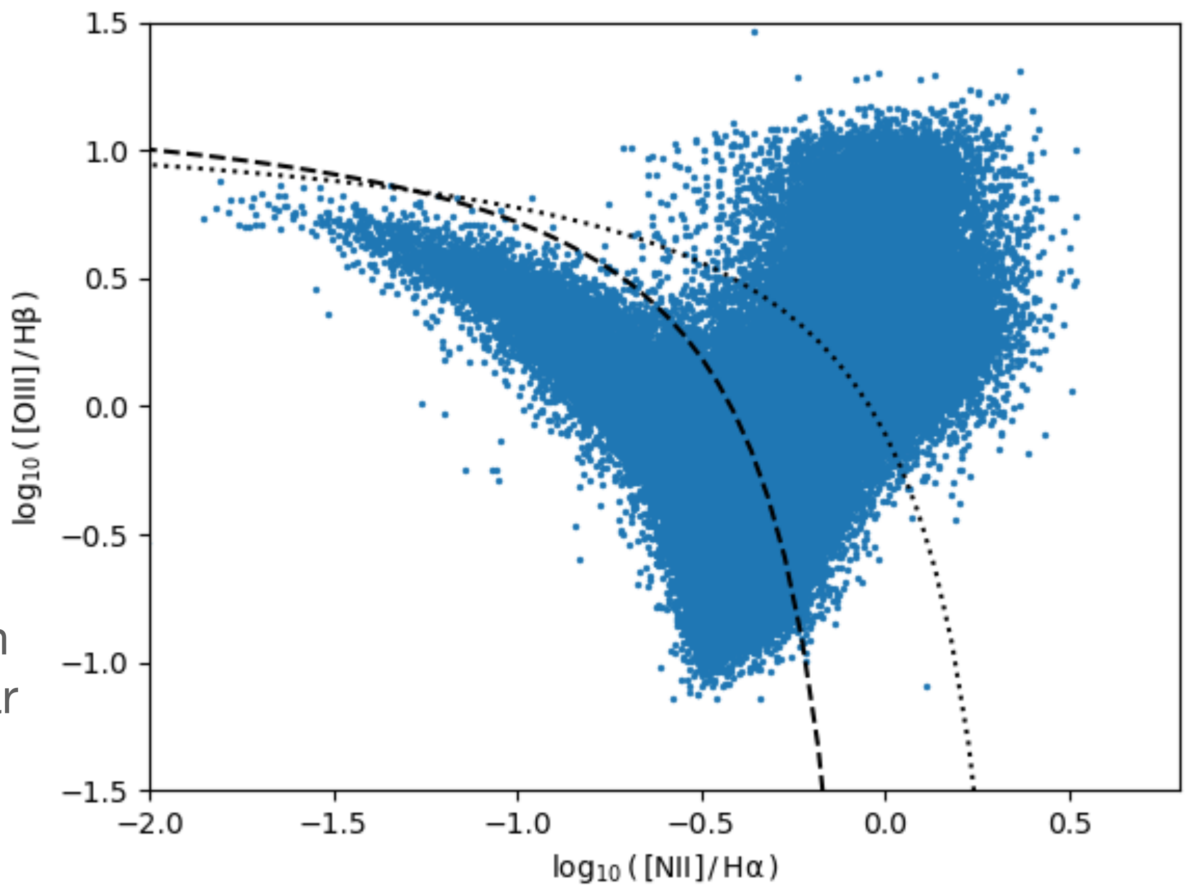
Only the more highly star-forming galaxies are detected.



3. Plot location of observed galaxies more massive than 1e9 M_{sun} in the classical BPT diagnostic diagram, [OIII]/Hb vs [NII]/Ha (scatter plot). Explain the dependence of the location of a galaxy in this diagram on different gas and radiation properties. In general, what is the significance of the BPT diagram for observational spectroscopic data?

The [O III] λ5007 / Hβ ratio reflects the hardness of the ionising radiation as the O(2+) state has a high ionisation energy. AGN produce a harder ionising spectrum, meaning more energetic photons, which is why they lie above the dotted line. The [N II] λ6584 / Hα ratio is similarly sensitive to more energetic photons, as this particular N(+) state has a high excitation potential.

Relative abundances of elements in the gas also affects the emission line ratios. Lower metallicity systems, no matter which type, produce lower line ratios, as less of the heavier element is present. This particularly affects [N II] λ6584 / Hα ratios, as metal-poor systems they are missing the secondary nitrogen production, which requires an enriched ISM and stellar population.



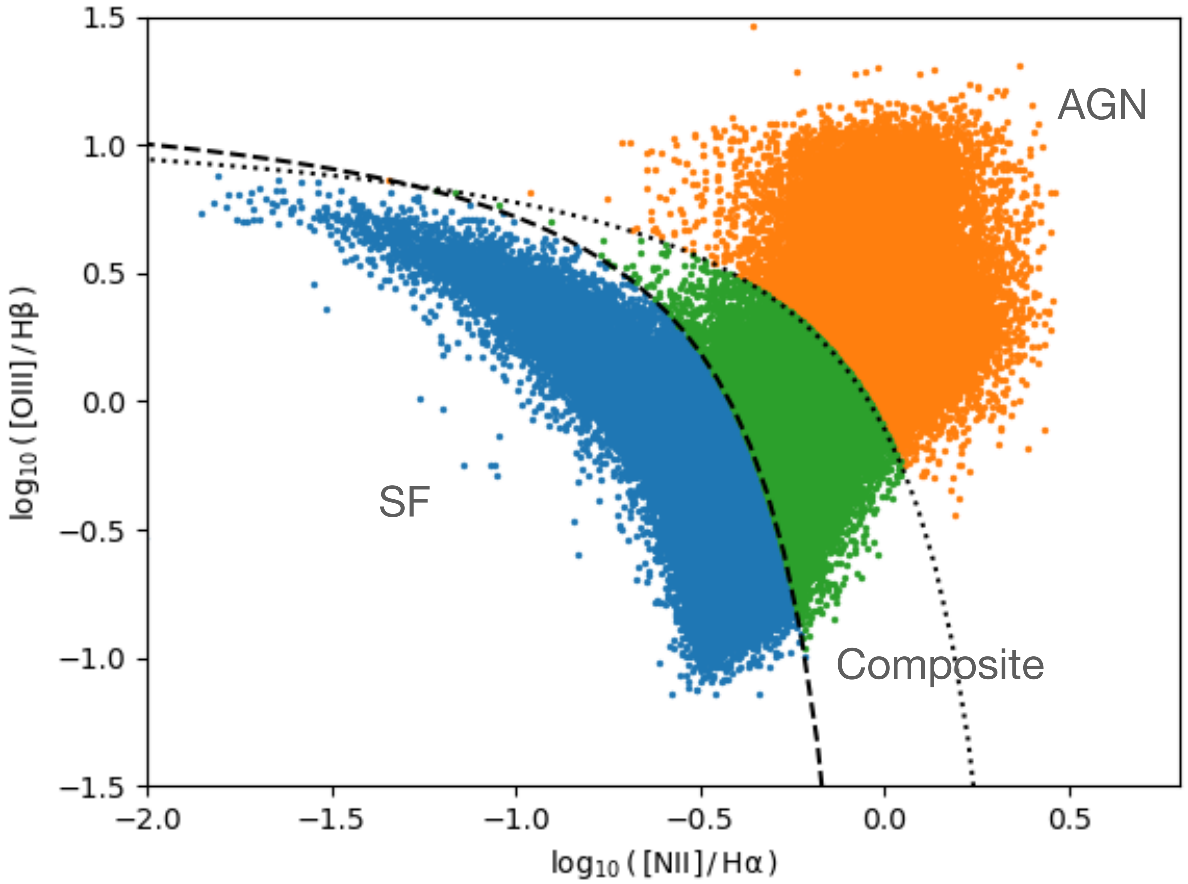
The general significant of this diagram is that it allows observers to distinguish between SF and AGN galaxies.

4. Use the classical BPT diagnostic diagram ([OIII]/Hb vs [NII]/Ha) to identify the dominant ionising sources using the selection criteria of Kewley et al. 2001 and Kauffmann et al. 2003 (SF, composite and AGN-dominated galaxies). Which complications/caveats can arise using these selection criteria?

Besides young stars and AGN, there are other sources of ionisation, such as shocks, post-AGB stars, and evolved stellar populations, which can complicate the interpretation of the diagram.

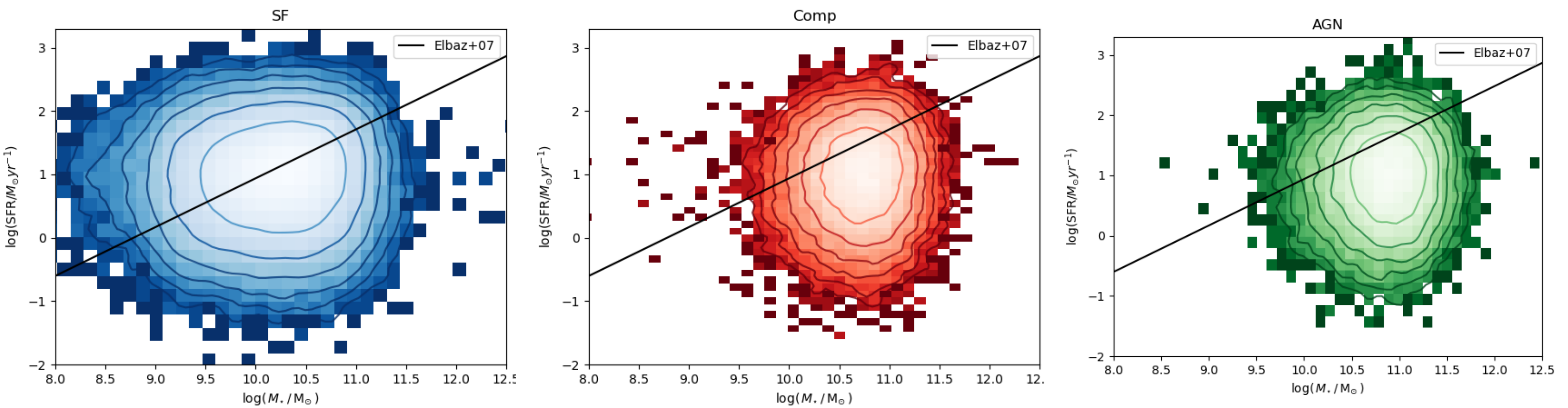
The metallicity of a galaxy's gas can also influence the position of its data points on the BPT diagram. AGN in low metallicity environments may exhibit emission line ratios that resemble those of SF-dominated galaxies, potentially leading to misclassification. This particularly important at high redshifts (as seen in new JWST data), where the ISM is generally more metal-poor.

Other processes that are relevant at high-z, such as the leakage of ionising photons from HII regions, might also affect the way these criteria can be applied.



5. Investigate how the SFR-galaxy stellar mass plane changes for different galaxy types, and interpret your findings.

While the scatter as large, we can see that SF-dominated galaxies align with the Elbaz+07 relation, as the SFR drives the Halpha luminosity in these systems. Composite and AGN-dominated galaxies are mostly located under the relation, as feedback mechanisms from the AGN dispel and heat the cold gas and suppress star formation, primarily in more massive. Radiation from the AGN dominates ionisation and the Halpha emission does not directly correlate with the SFR anymore.



6. Use the scaling of Lamastra+09 to estimate the bolometric AGN luminosity and thus, the BH accretion rate, from the [OIII] line luminosity. You can assume an efficiency η of 0.1. Plot the location of galaxies in the BHAC — SFR plane; interpret your result in the light of the observed BH scaling relations (black hole-stellar mass relation).

Using the AGN luminosity estimated from [OIII], we can use the $L = \eta \dot{M} c^2$ relation to estimate the accretion rate.

The BHAC scales with the SFR, representing the co-evolution of galaxies and BHs and the common cold gas reservoir powering the for SF and BH accretion.
The BHAR/SFR ratio is on average 1e-3 ist, which is what we would expect from the stellar-BH-mass relation (BH mass ~1/1000 Mstar).