Exercises 13

Statistical BH/AGN properties and AGN-host connection at z=0 in the $(500\text{Mpc})^3$-run of the Magneticum simulation set

1. *BH properties*: Plot the distribution of BH accretion rates, AGN luminosities (down to 1e41 erg/s) and Eddington-ratios. Plot a 2D histogram of BH accretion rate versus BH mass (indicate different Eddington ratios as lines).
2. *Host-BH connection*:
   Plot the BH-stellar mass relation (2D histogram and mean relation) and compare to the observed relation of McConell & Ma (2013).
3. *In which hosts are AGN preferentially residing*? Plot the fraction of luminous AGN (L>1e45 erg/s) and of moderately luminous AGN (1e42erg/s<L<1e45 erg/s) as a function of galaxy stellar mass, SFR and sSFR.
4. *Are AGN hosts mostly star-forming, star-bursting or quiescent*? Plot the SFR-stellar mass plane (2D histogram), indicate the main sequence of SF galaxies, first color-code with the number of galaxies, and second/third color-code with the fraction of luminous/moderately luminous AGN.

Interpret your results, also with respect to recent observations. To what extent are BHs and their host galaxies co-evolving?

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Helpful instructions:

- You'll get a catalogue containing galaxies with masses above 1e10 $M_\odot$, and corresponding BHs. The format is the following:

  1. Mhalo 2. Mstellar 3. M_{BH} 4. BHAccRate 5."dummy" 6. cent/sat-status 7. Number_BHs 8. SFR 9."dummy"

  Masses are in $M_\odot$, rates in $M_\odot$/yr, central BH=0 or satellite BH=1

  If BH quantities have values of -99, it means that this galaxy does not contain a BH (normally not yet seeded).
- Bolometric AGN luminosities can be calculate from BH accretion rates, and Eddington accretion rates from M_{BH} (watch out with units!!)
- BH properties (first task) should be calculate for both only central BHs and all BHs, for all the remaining tasks only central BHs more massive than 1e6 $M_\odot$ should be considered (so that they are not too affected by seeding)
- The main sequence of SF can be indicated by fitting the SF galaxies in the simulations (compare to observed relation as well!)
- Note that simulation details you can find in *Hirschmann+14*

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- Reading suggestions
- Some famous large-scale simulations:
  - Schaye et al. 2015: "The EAGLE project: simulating the evolution and assembly of galaxies and their environments"
  - Nelson et al. 2019: IllustrisTNG50
  - Dave et al 20??: Simba simulation
- Early Universe Simulations:
  - Di Matteo et al. 2017: "The origin of the most massive black holes at high-z: BlueTides and the next quasar frontier" (*Gerald*)
  - Rosdahl et al. 2018: "The SPHINX cosmological simulations of the first billion years: the impact of binary stars on reionization
  - Kannan et al. 2022: The Thesan simulation

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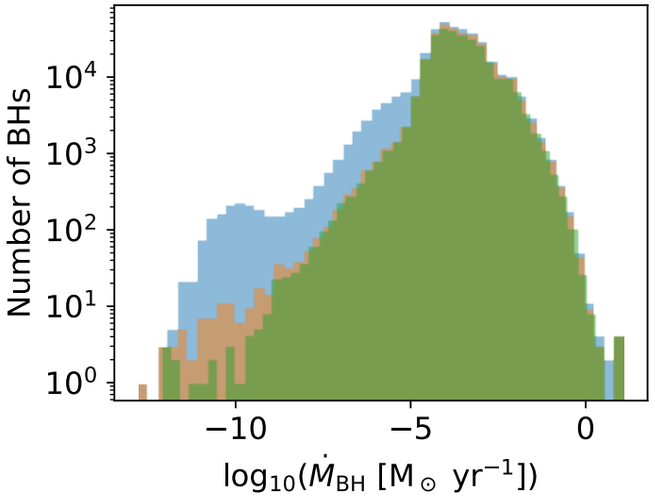
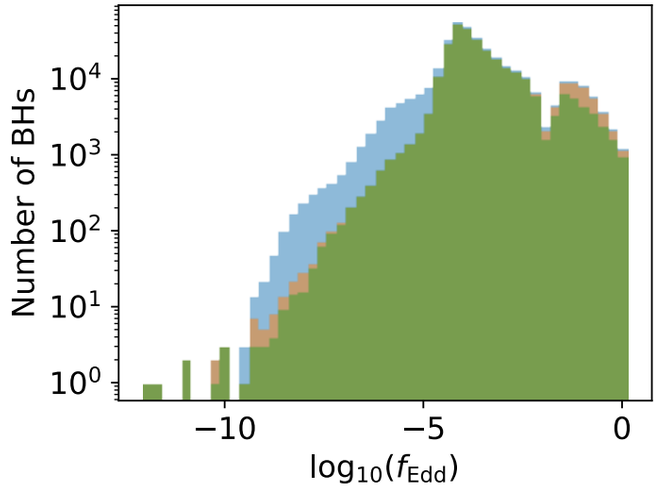
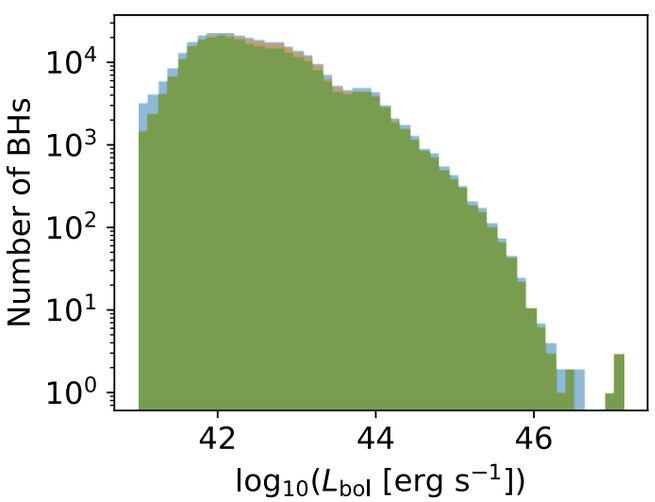
1. *BH properties*: Plot the distribution of BH accretion rates, AGN luminosities (down to 1e41 erg/s) and Eddington-ratios. Plot a 2D histogram of BH accretion rate versus BH mass (indicate different Eddington ratios as lines).

An AGN is considered radiately efficient and inefficient when $f_{\rm Edd} > 0.1$ and $f_{\rm Edd} < 0.1$ respectively.

Useful equations: $$f_{\rm Edd} = \frac{\dot{M}_\bullet}{\dot{M}_{\bullet,\rm Edd}} \qquad L_{\rm bol} = \epsilon_r \frac{dM_\bullet}{dt} c^2$$







These histograms show that most AGN have low luminosities and low Eddington ratios (radiatively inefficient).

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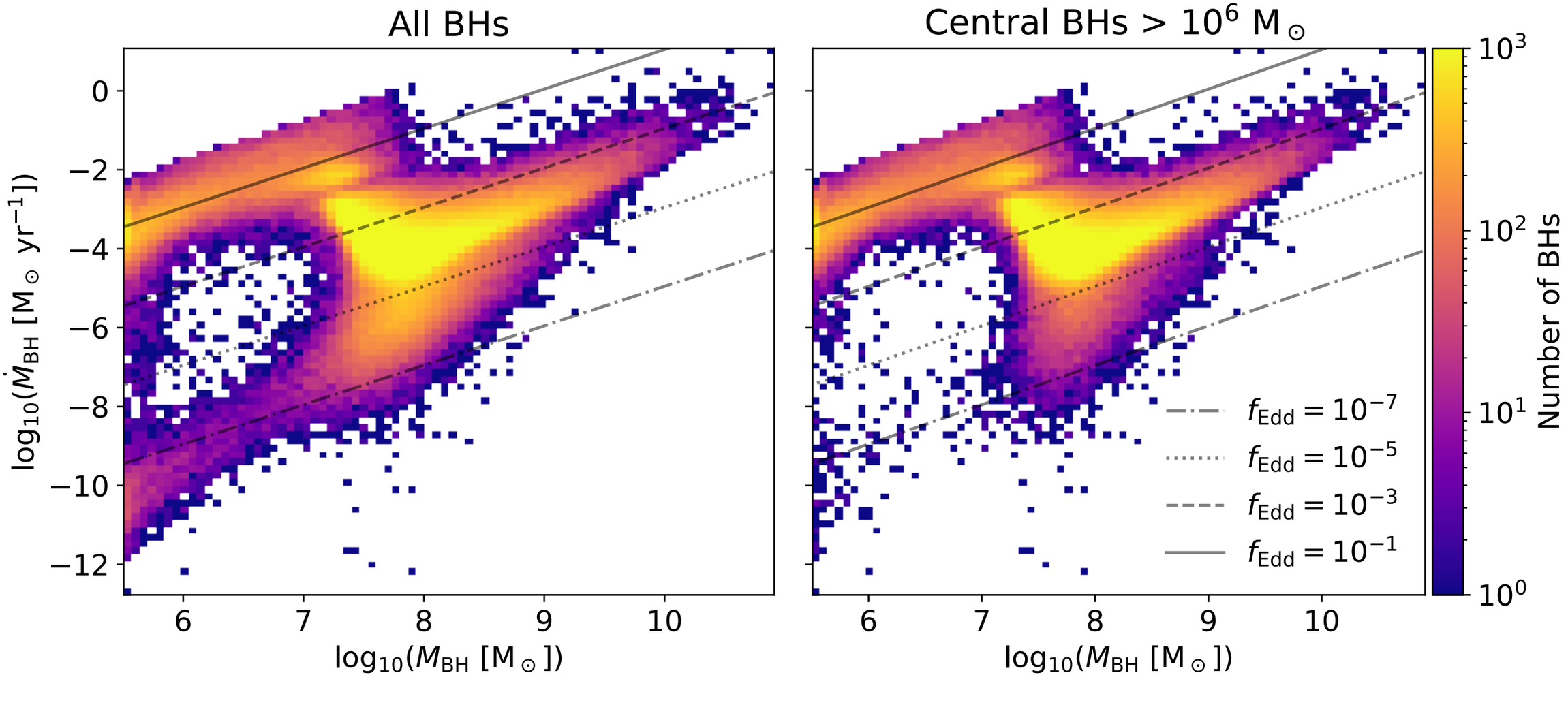
This figure shows that the majority of radiatively efficient (f_{edd} > 0.1) AGN are BHs with masses < 1e8 M_{sun}. At higher BH masses are the majority of AGN instead radiatively inefficient. This is a consequence of massive galaxies have less (cold, dense) gas for accretion available due to AGN fb (i.e. this mechanism is also regulating BH growth).



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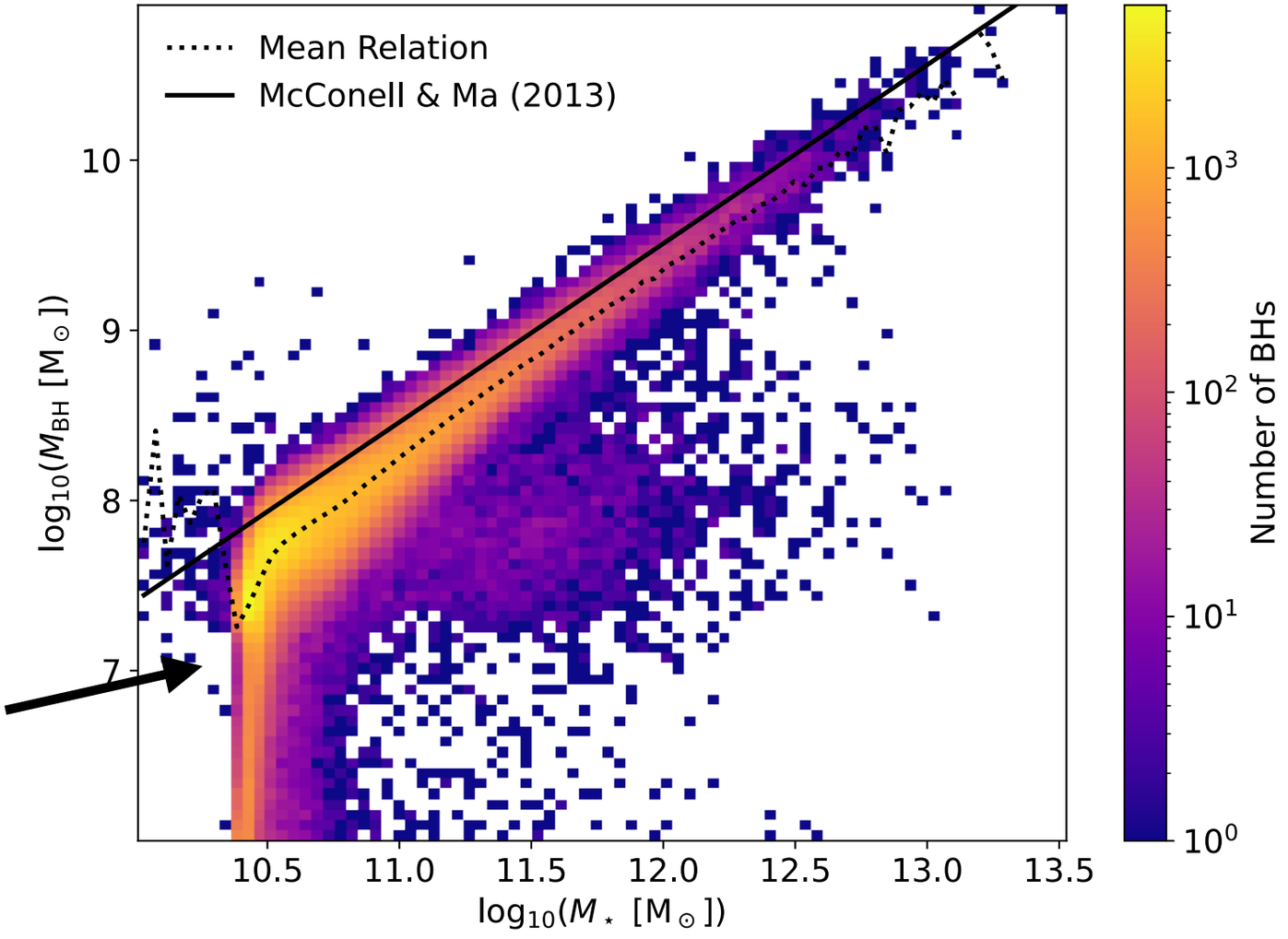
2. *Host-BH connection*:
a) Plot the BH-stellar mass relation (2D histogram and mean relation) and compare to the observed relation of McConell & Ma (2013).

Tight relation between BH mass and stellar mass, mainly due to AGN feedback, i.e. in simulations galaxies and BHs seem to be co-evolving.
Note that normalisation of this relation is typically set by the choice of the AGN feedback efficiency. The mean, simulated relation matches relatively well with the observed scaling relation of McConell & Ma (2013).

Artefact from BH seeding



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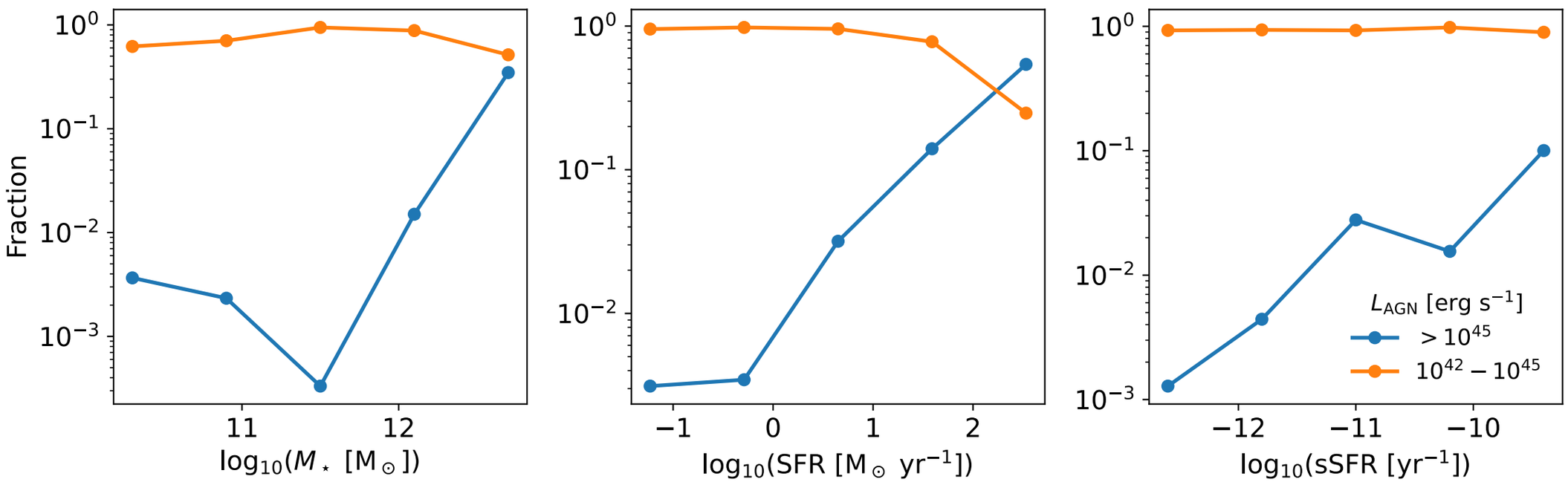
3. *In which hosts are AGN preferentially residing*? Plot the fraction of luminous AGN (L>1e45 erg/s) and of moderately luminous AGN (1e43erg/s<L<1e45 erg/s) as a function of galaxy stellar mass, SFR and sSFR.

Luminous AGN preferentially reside in low-mass star-forming galaxies, and also in massive galaxies. The latter (luminous AGN in massive galaxies at low z) is unrealistic and in Magneticum, this is a consequence of AGN feedback being fairly weak (only thermal energy input), and thus, not suppressing gas cooling sufficiently in most massive galaxies.

Irrespective of stellar mass and sSFR, the fraction of moderately luminous AGN is by up to two orders of magnitude higher, because low-mass BHs and BHs accreting at low f_{edd} are much more abundant. Only for galaxies with highest SFR (which are the most massive ones), the luminous AGN population can be dominant — again an artefact of Magneticum allowing for too much SFR in massive galaxies.



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4. *Are AGN hosts mostly star-forming, star-bursting or quiescent*? Plot the SFR-stellar mass plane (2D histogram), indicate the main sequence of SF galaxies, first color-code with the number of galaxies, and second/third color-code with the fraction of luminous/moderately luminous AGN.

We perform a main sequence (MS) fit on lower-mass ($M_{stellar}$ < 5e11 M_{sun}) star-forming galaxies (since the very massive galaxies in Magneticum are overly star-forming due to too inefficient AGN feedback, and thus, not fully realistic) and compare it to observations in the CALIFA SURVEY (Cano-Diaz et al., 2016). Luminous AGN are predominantly hosted by starburst galaxies with masses below 1e11 M_{sun} (that are mainly low-mass BH accreting at high rates), while instead fainter AGN can be also hosted by normal star-forming and quiescent massive galaxies (where the BH is massive but accreting at low rates).