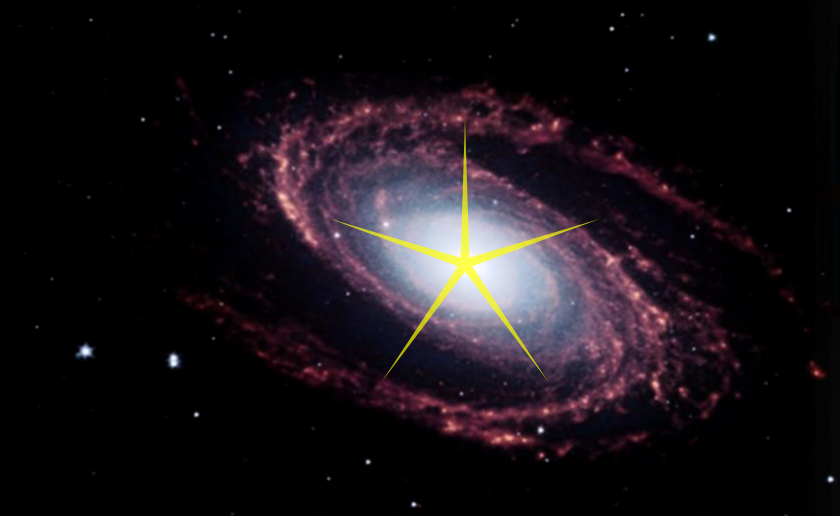
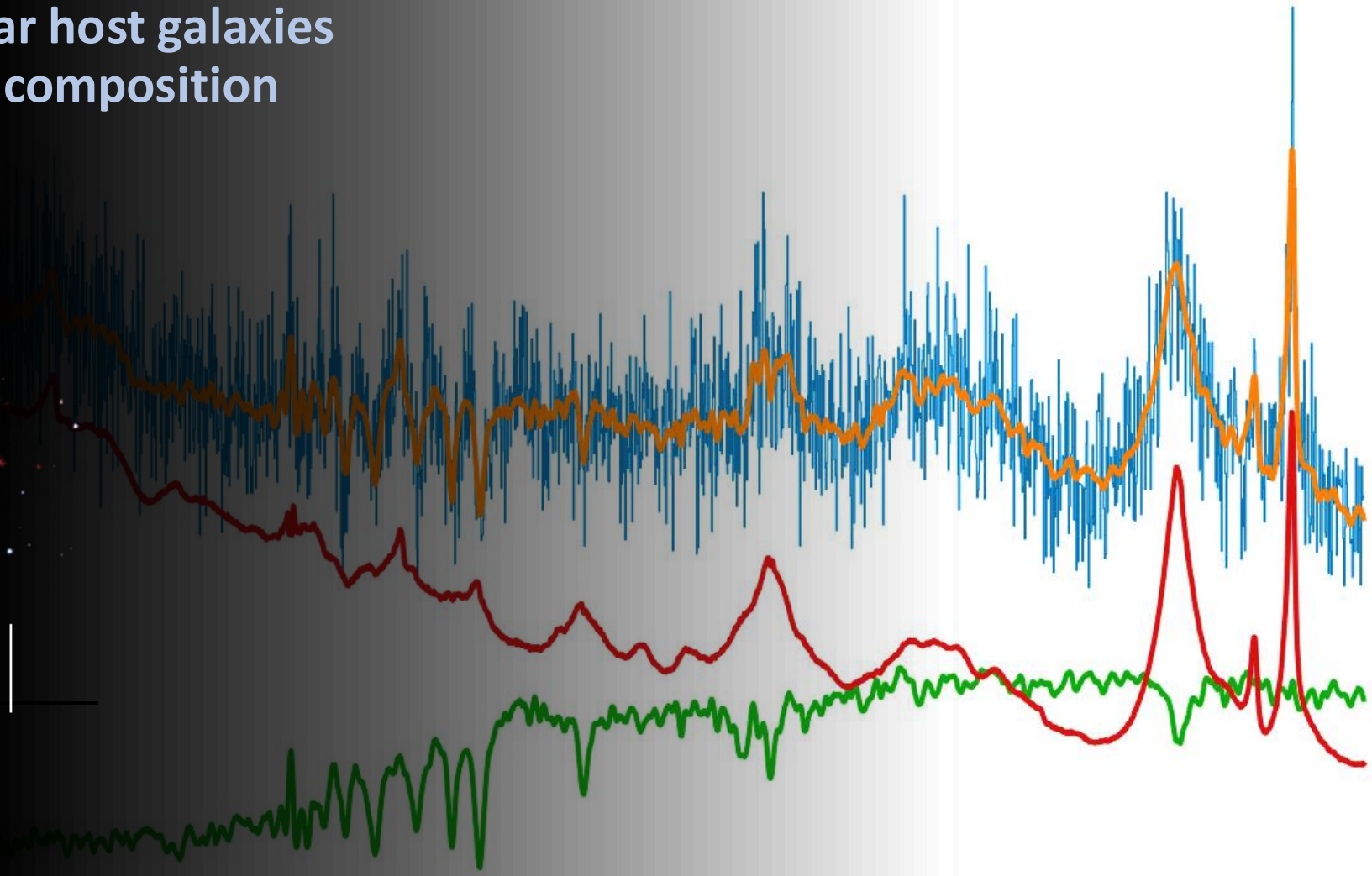
Stellar populations of quasar host galaxies with MFICA spectrum decomposition





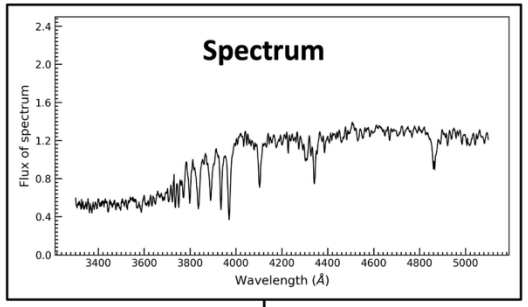
University of St Andrews | FOUNDED 1413

Sahyadri D. Krishna
sk322@st-andrews.ac.uk

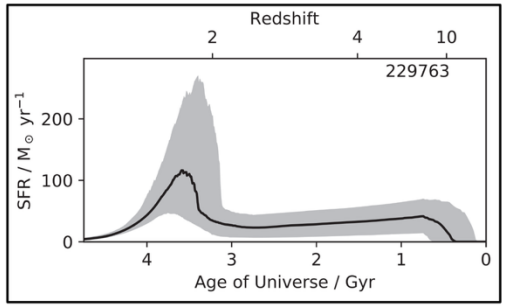
Vivienne Wild (St Andrews), Paul Hewett (Cambridge), Carolin Villforth (Bath)

Optical spectra and the AGN-galaxy connection

Optical spectra provide information on evolution of galaxies and their baryon cycles

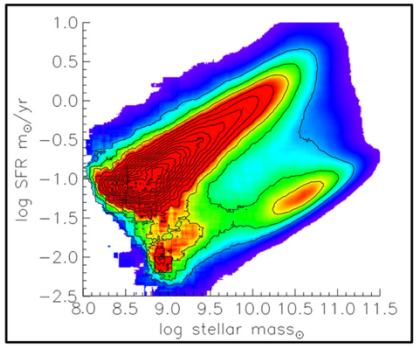


Star-formation history



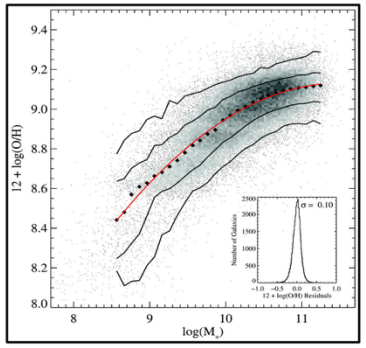
(Wild et al. 2020)

Stellar mass + SFR



(Renzini & Peng, 2015)

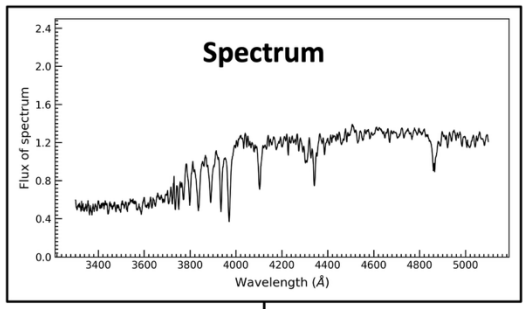
Metallicity + emission lines



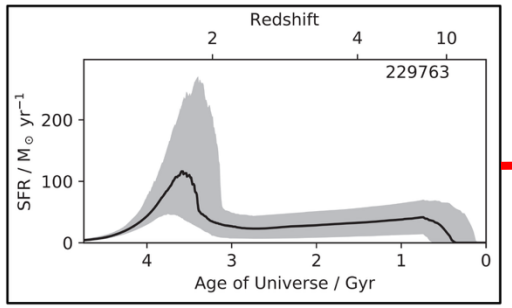
(Tremonti et al. 2004)

Optical spectra and the AGN-galaxy connection

Optical spectra provide information on evolution of galaxies and their baryon cycles



Star-formation history



(Wild et al. 2020)

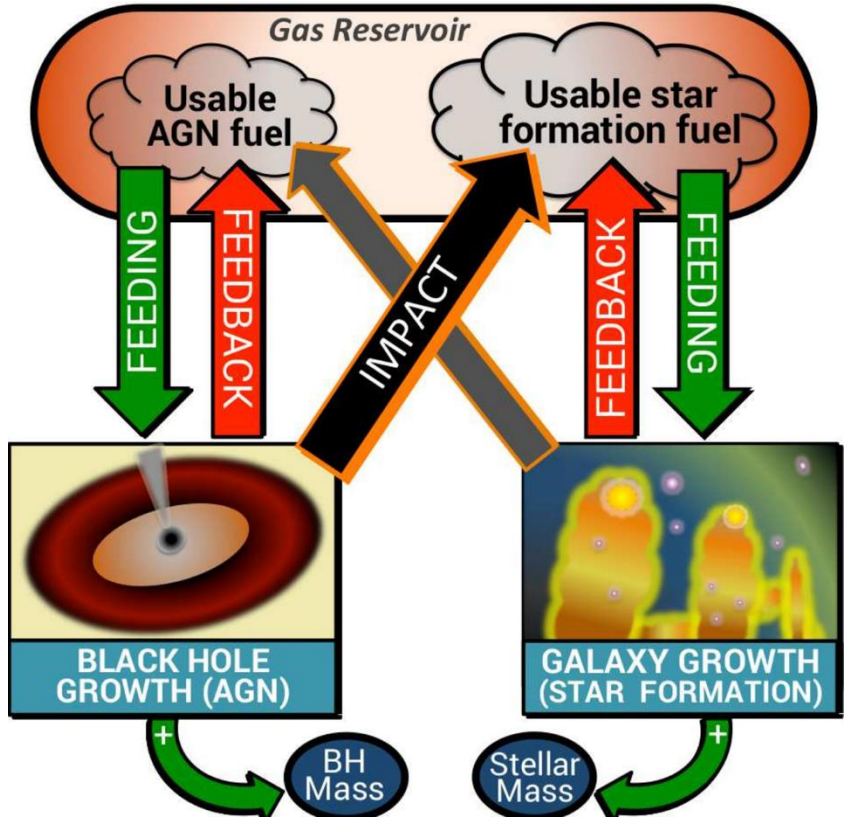
Stellar mass + SFR

Metallicity + emission lines

Stellar populations and SFHs can provide constraints on processes modulating AGN-galaxy connection.

1) How do galaxies quench star-formation?

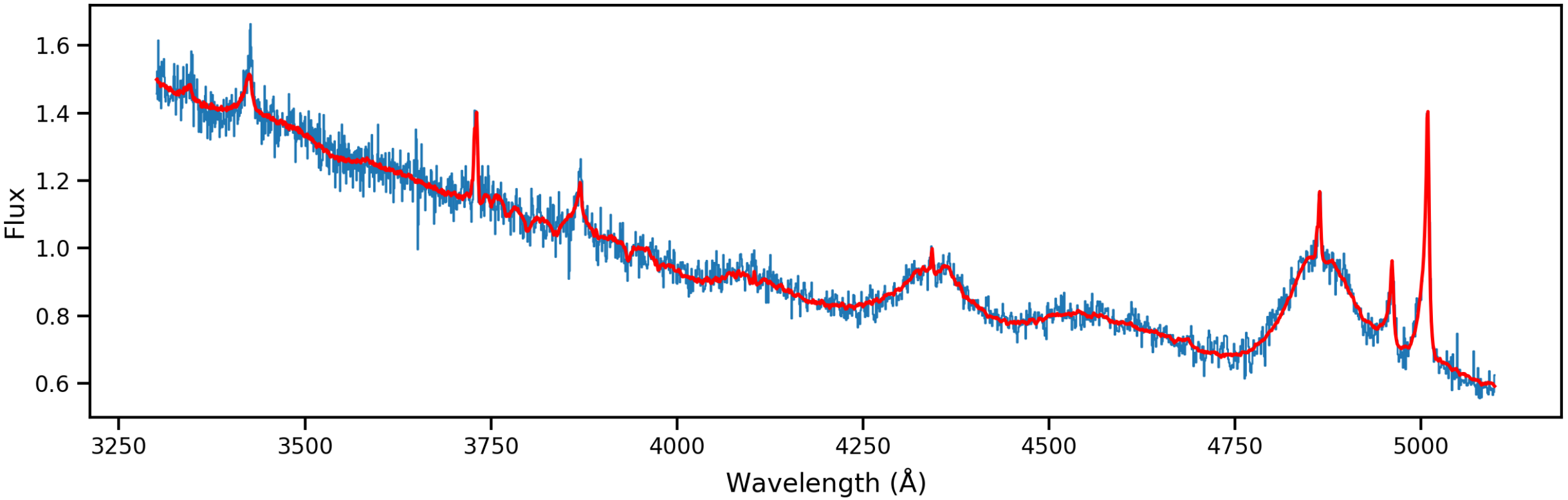
2) What process trigger AGN activity?



Harrison et al. (2017)

Stellar populations from spectra of luminous AGNs?

- Low luminosity AGNs → can obtain stellar populations and SFHs.
- Type-1/high-luminosity AGNs/quasars → host galaxy continuum diluted by AGN.
- **Difficult to obtain stellar populations/SFHs of the hosts of the most luminous quasars.**
- **We obtain stellar populations of quasars using a technique called Mean-Field ICA (MFICA).**

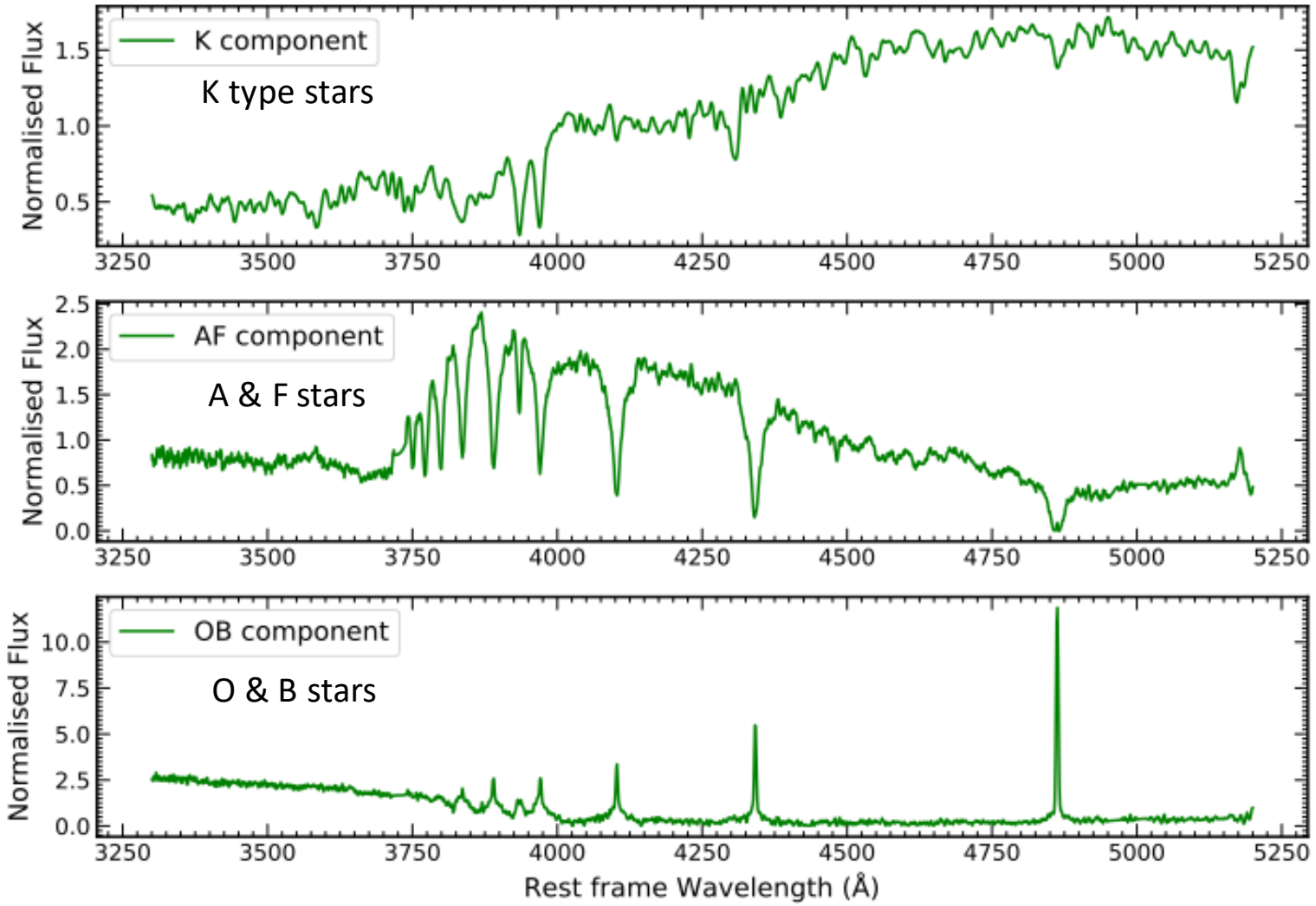


Mean-Field ICA (MFICA) Galaxy Components

Old Stellar population

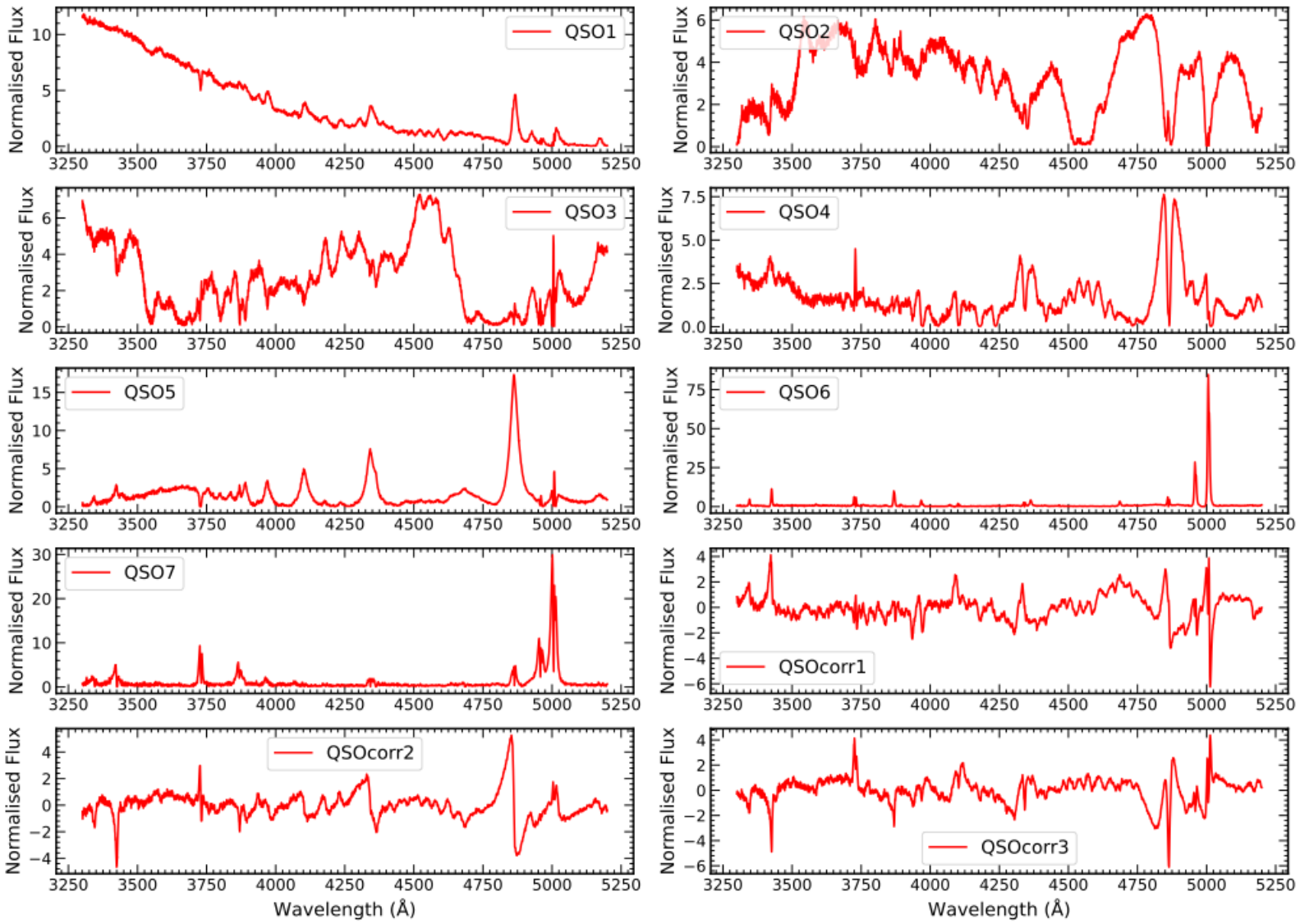
Intermediate Stellar population

Young Stellar population



- Use Mean-Field ICA to obtain **statistically independent** "template"-like components.
- Apply MFICA to a sample of SDSS DR7 galaxy spectra.
- **Galaxy components that resemble stellar populations of different ages, directly from data!**

MFICA (host galaxy-free) quasar Components

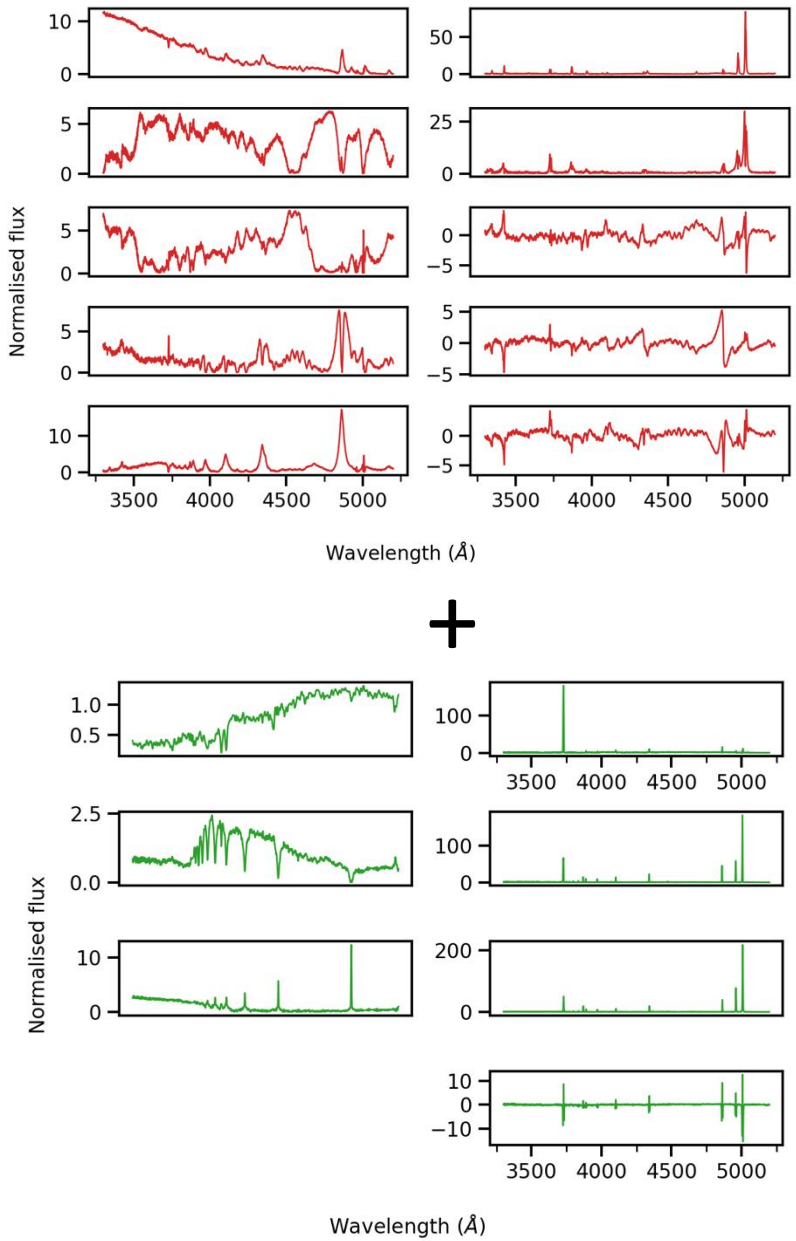


- Apply MFICA to high-luminosity (M_i < -23) SDSS DR7 quasar spectra.

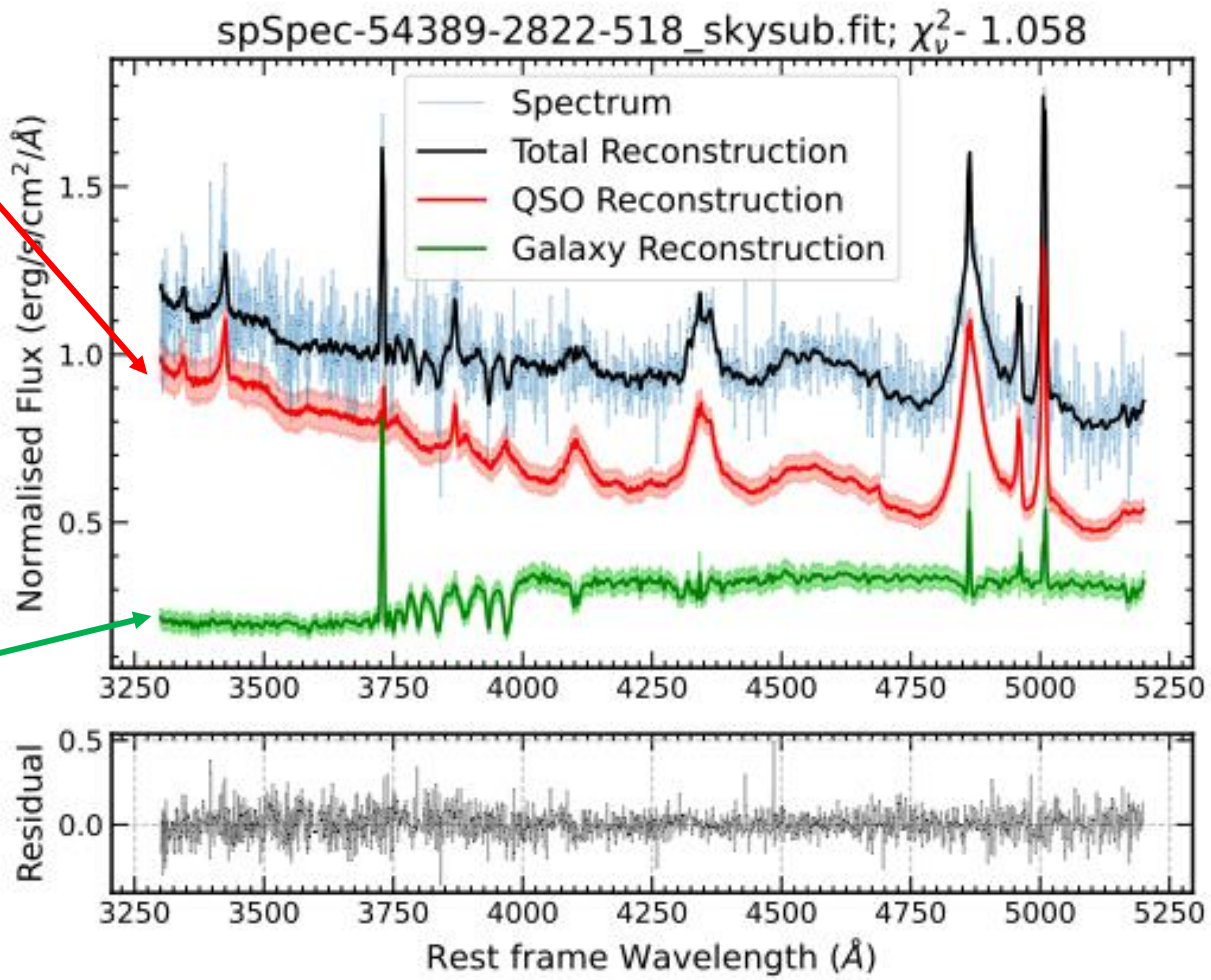
- Generate (sequentially) quasar components that are statistically independent to galaxy (K, AF, emission line) components.

- **Obtain quasar components with host galaxy signatures (like Ca H&K, Mg Ib and Balmer absorption lines) subtracted.**

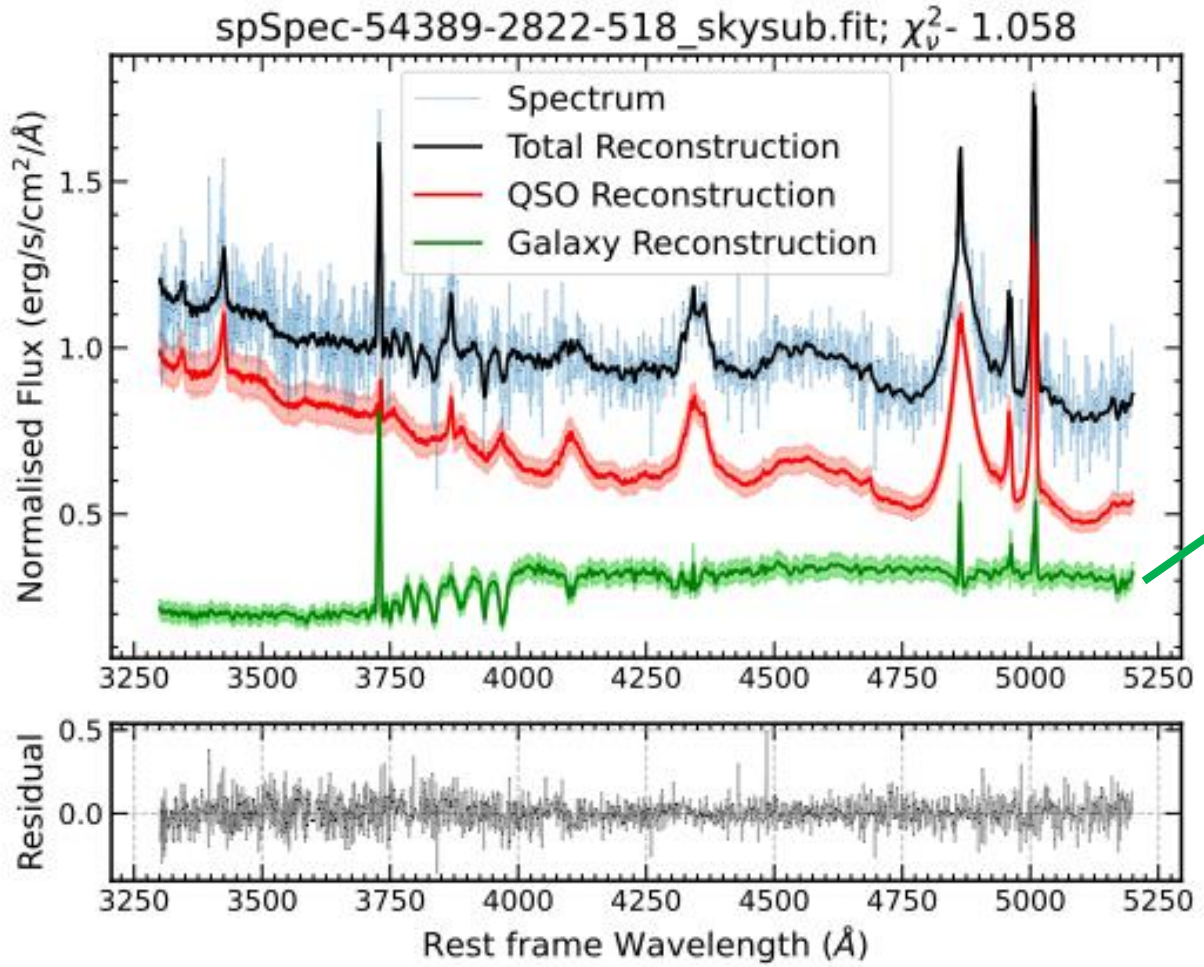
Decomposing quasar spectra

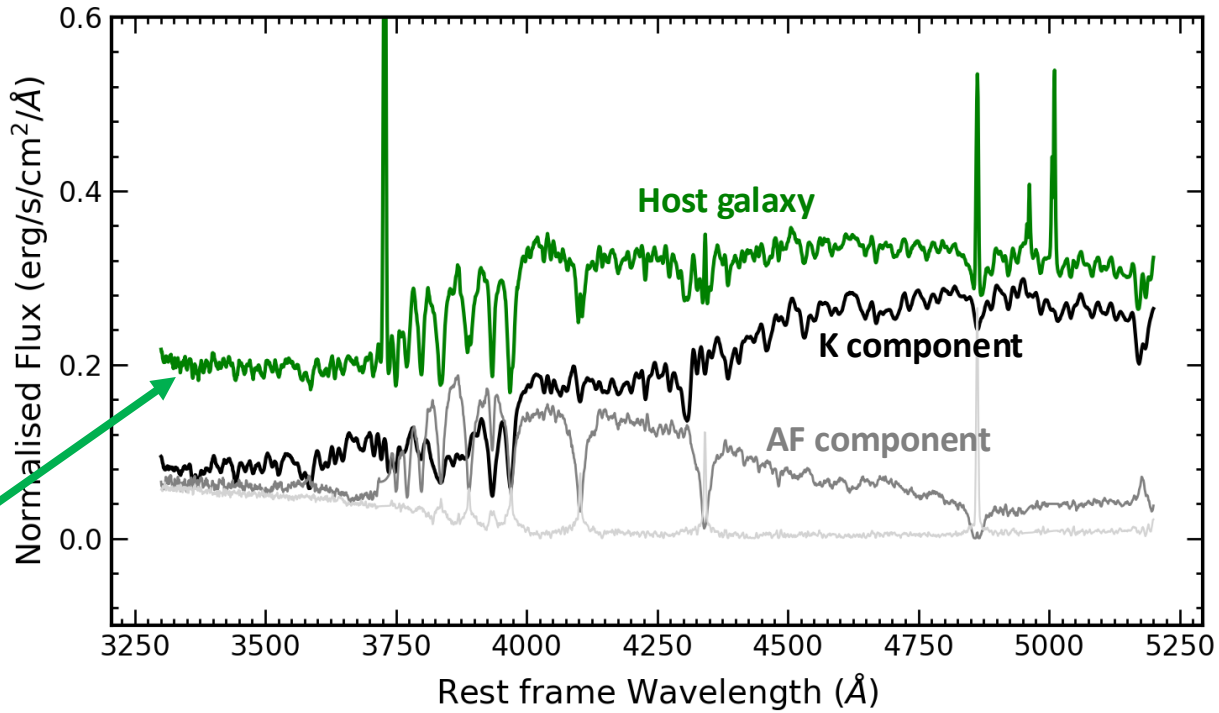


Decompose a quasar spectrum by fitting it with a combination of quasar and galaxy components.



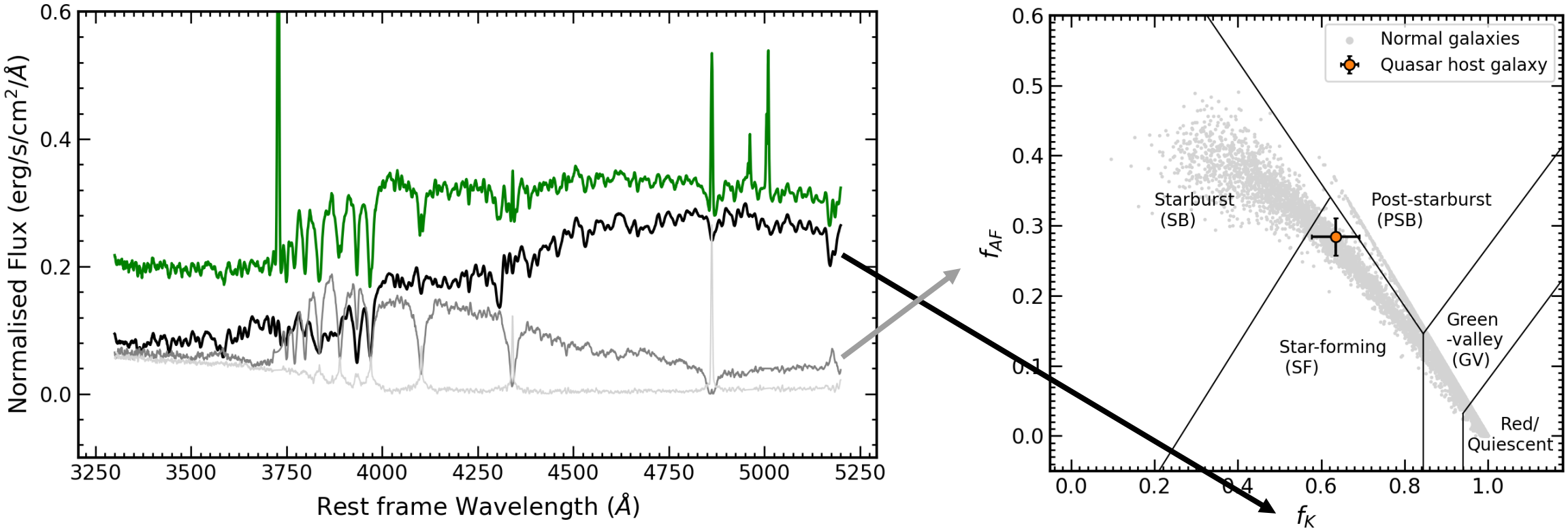
Decomposing quasar spectra





- Decomposed host galaxy composed of different amounts of each galaxy component.
- Galaxy components resemble stellar populations of different ages
- Calculate the fraction of light from each galaxy component.

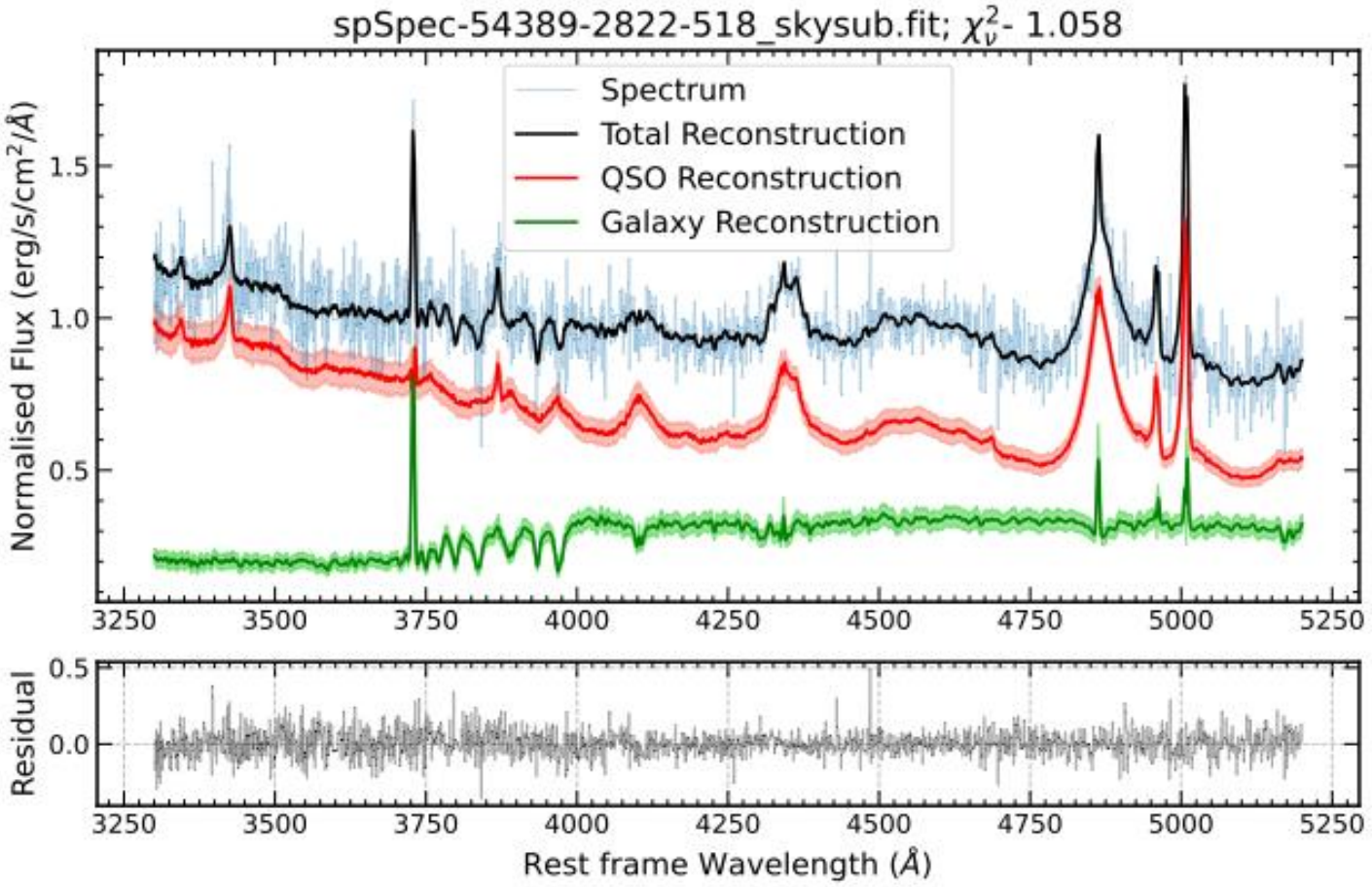
Decomposing quasar spectra

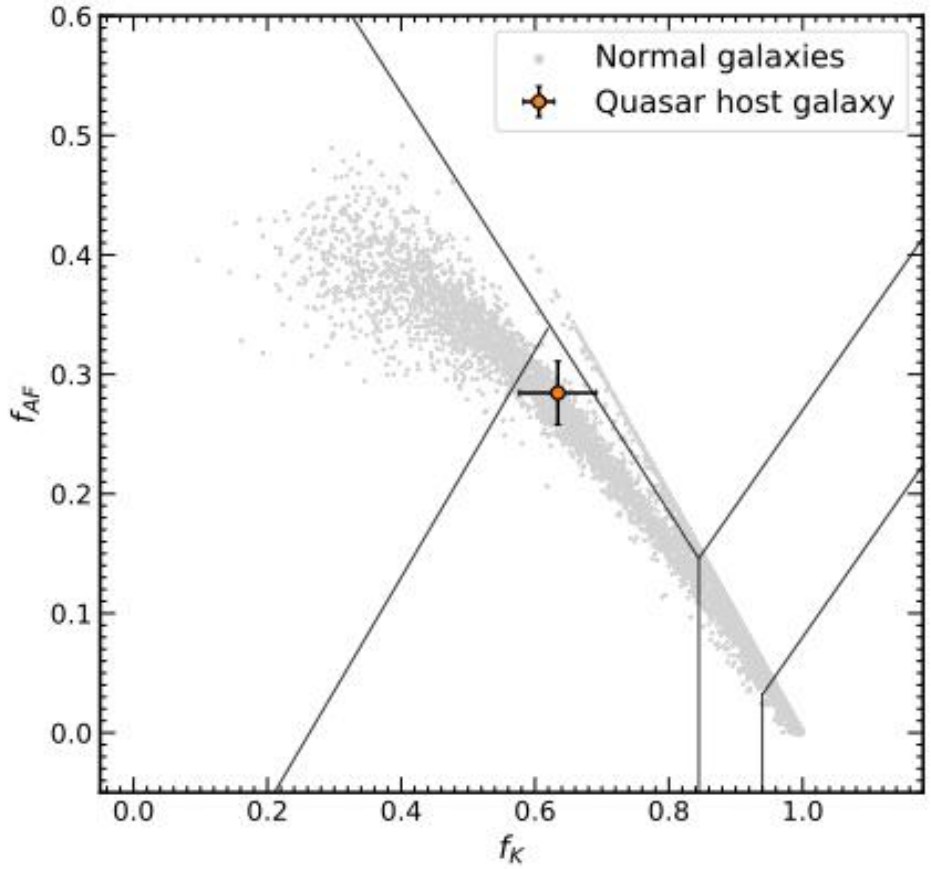


- Calculate the fraction of light from each galaxy component ("component fractions").
  - $f_K = 0.6 \rightarrow$ 60% of the light comes from the K stellar population.

- **Component fractions of quasar host galaxy tells you its current stellar populations, and thus its recent star-formation.**

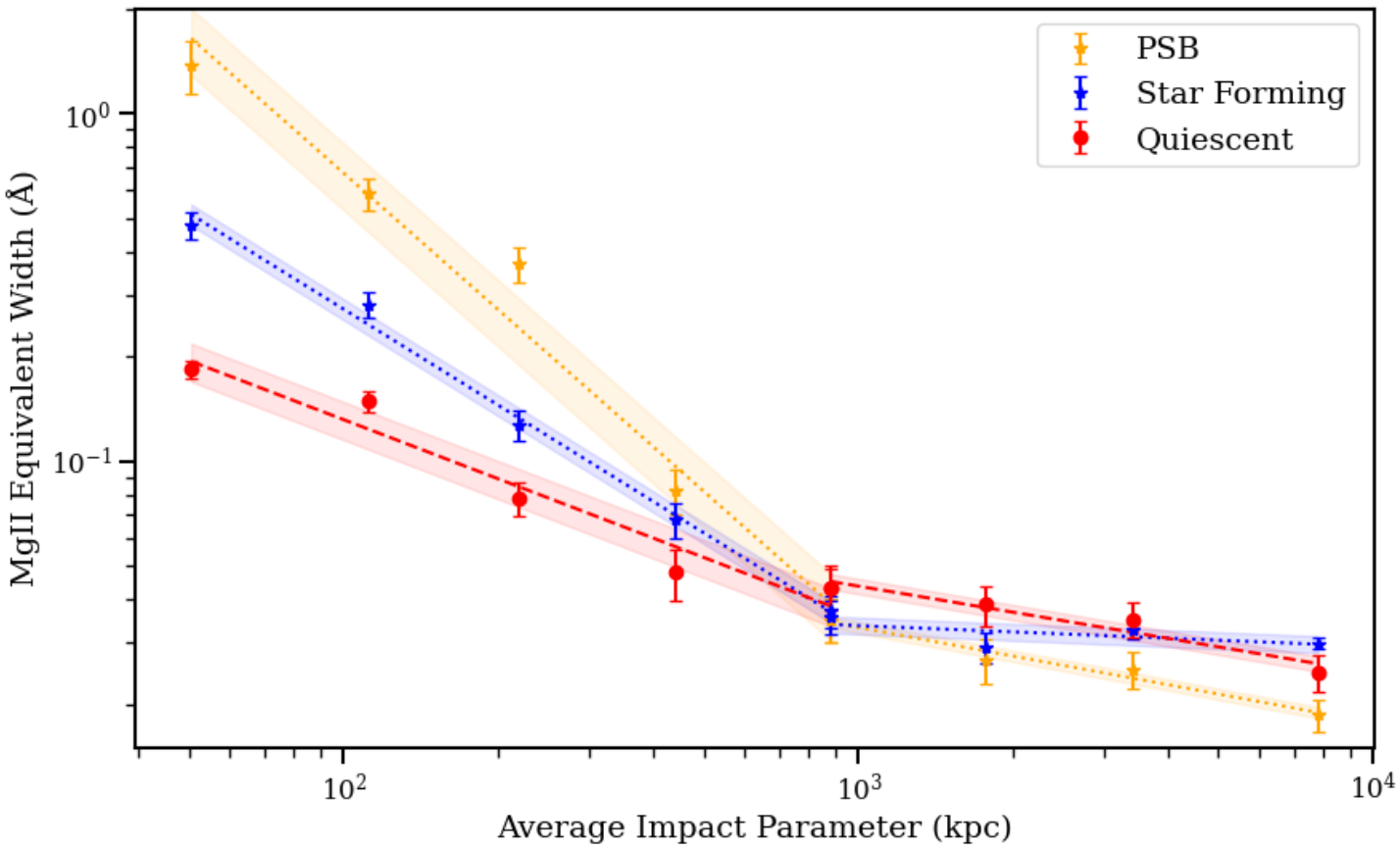
Decomposing quasar spectra





- **Decompose a quasar spectrum by combining galaxy and quasar components.**
- **Component fractions of the quasar host galaxy = current stellar populations/recent star formation history.**

Stellar populations with MFICA – an example!



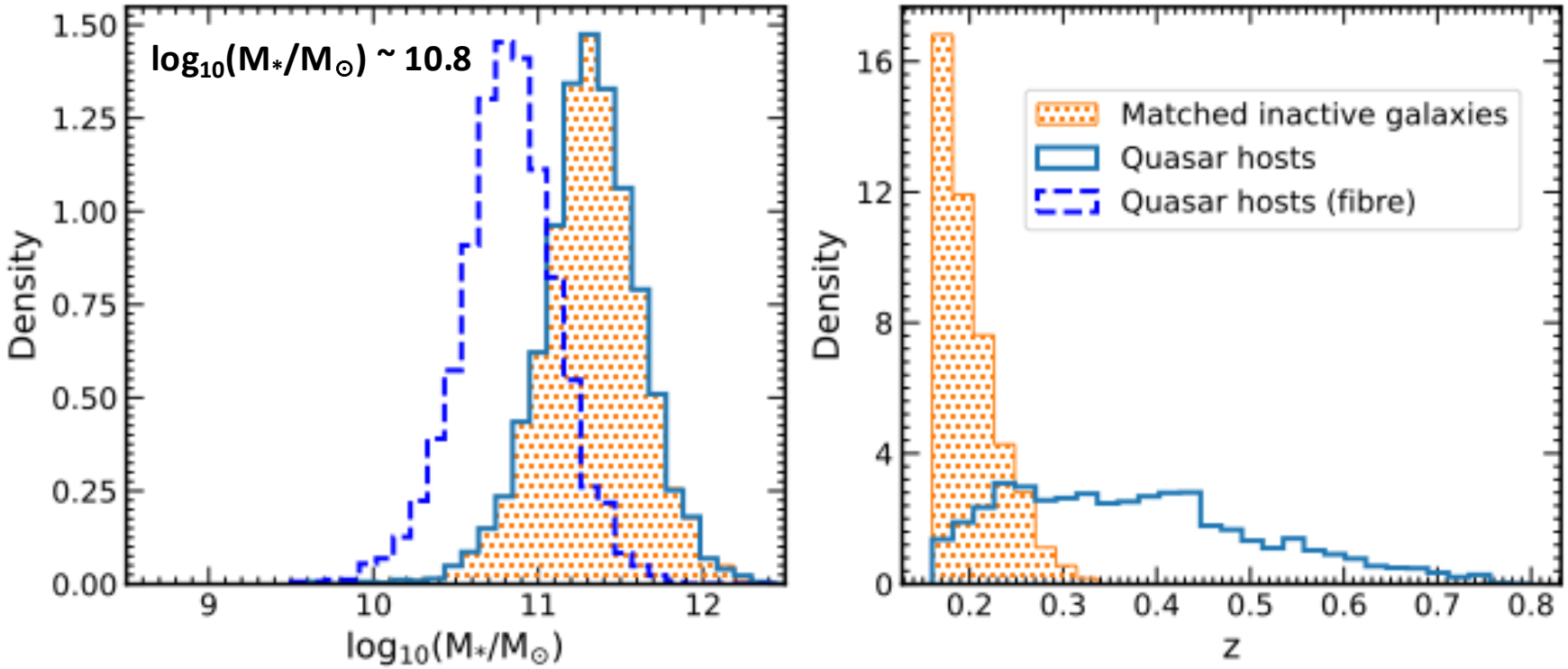
- Harvey, Krishna et al. (2025) - classify BOSS CMASS galaxies using MFICA.

- **Post-starburst galaxies have more cold gas in their CGM than star-forming and quiescent galaxies.**

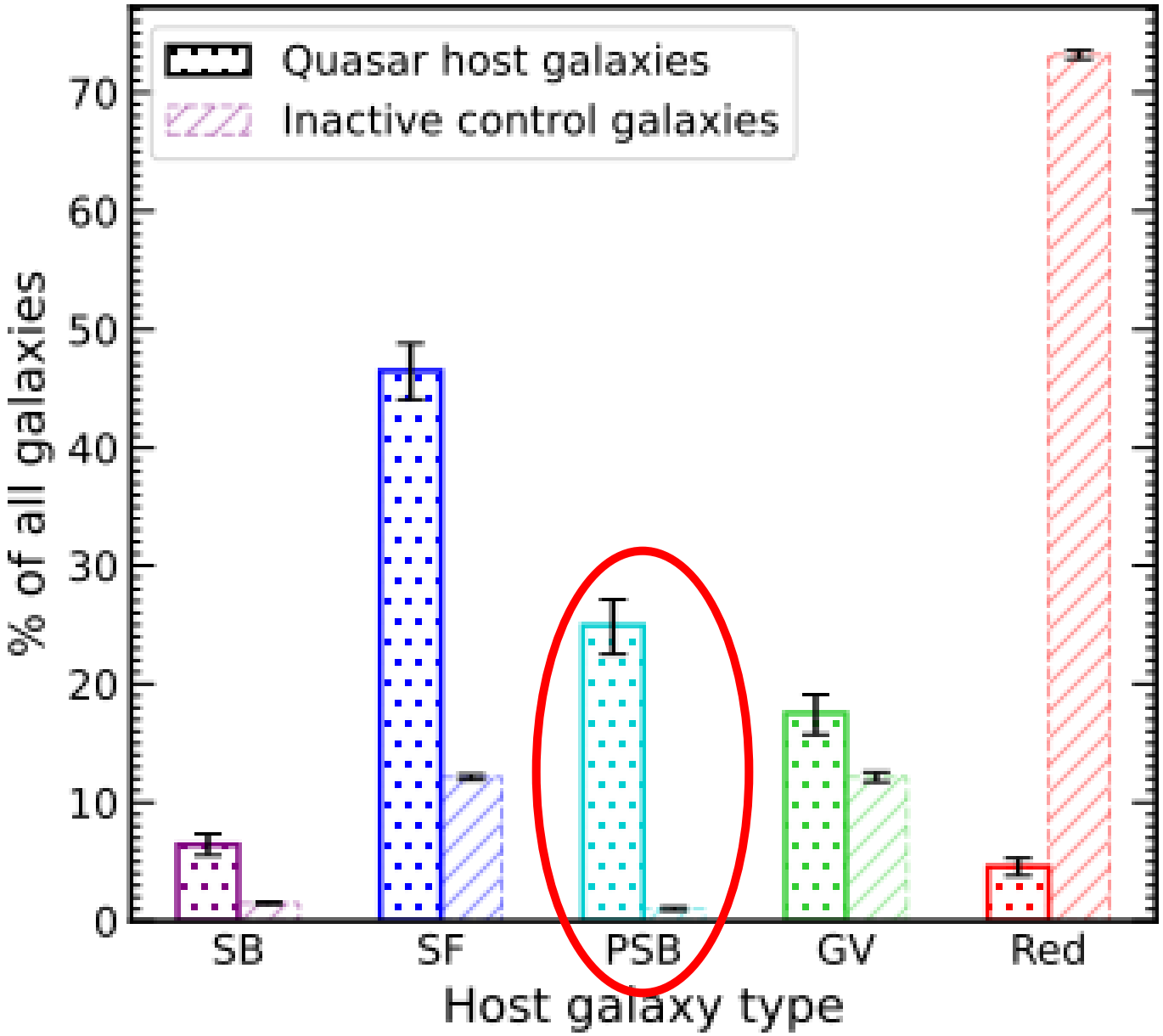
arXiv:2506.22287

Sample of Quasars

- Type-1 Quasars from **SDSS DR7 Quasar Catalogue** ($0.16 \leq z \leq 0.76$)**.**
- Quality cuts - **median S/N ≥ 10 + galaxy light fraction (f_{gal}) ≥ 20%**
- **Compare properties of quasar hosts to ordinary galaxies with the same stellar mass.**
- For each quasar, select two inactive galaxies with the same stellar mass.
- **3376 quasar + 6752 control galaxies.**

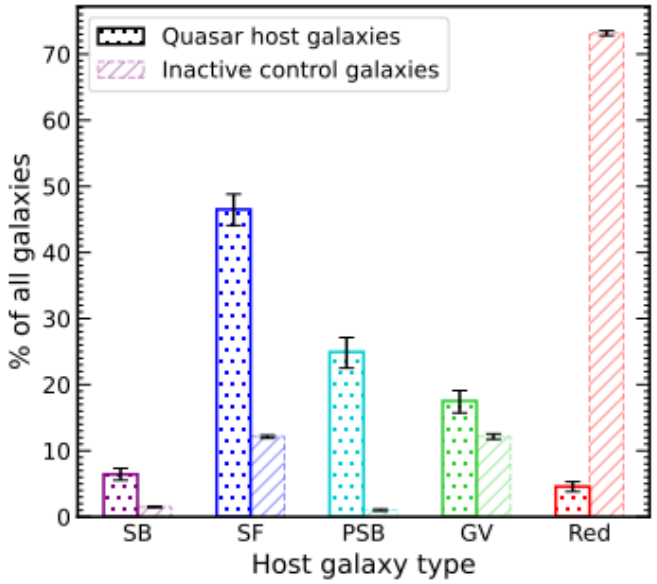


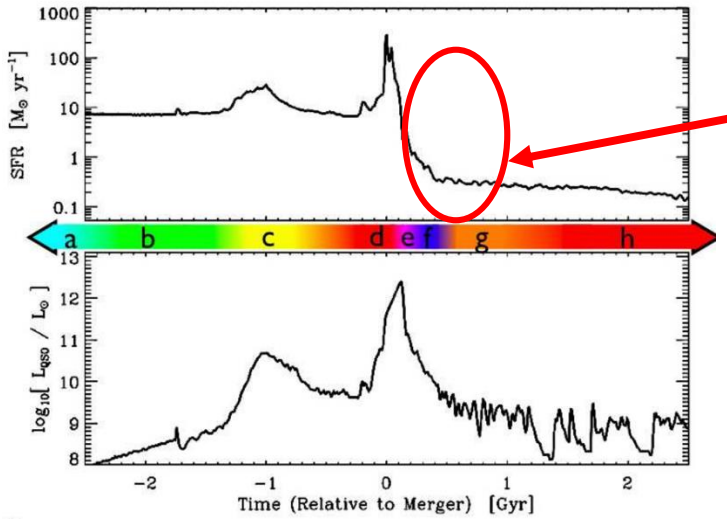
Demographics of quasar host galaxies



- **Most quasar hosts are star-forming galaxies, while mass-matched inactive galaxies are quiescent.**
- **Quasar hosts have younger stellar populations than inactive galaxies.** Quasars hosts are not a random subsample of normal galaxies.
- **24.9 ± 0.6 % of all quasars are post-starburst quasars.**
- Only ~1% of inactive galaxies are post-starburst galaxies (eg: Wild et al. 2016, Rowlands et al. 2018)
- **Post-starburst galaxies are 24 ± 1 times more common among quasar hosts than the control sample.**

Result takeaway: quenching by quasars?

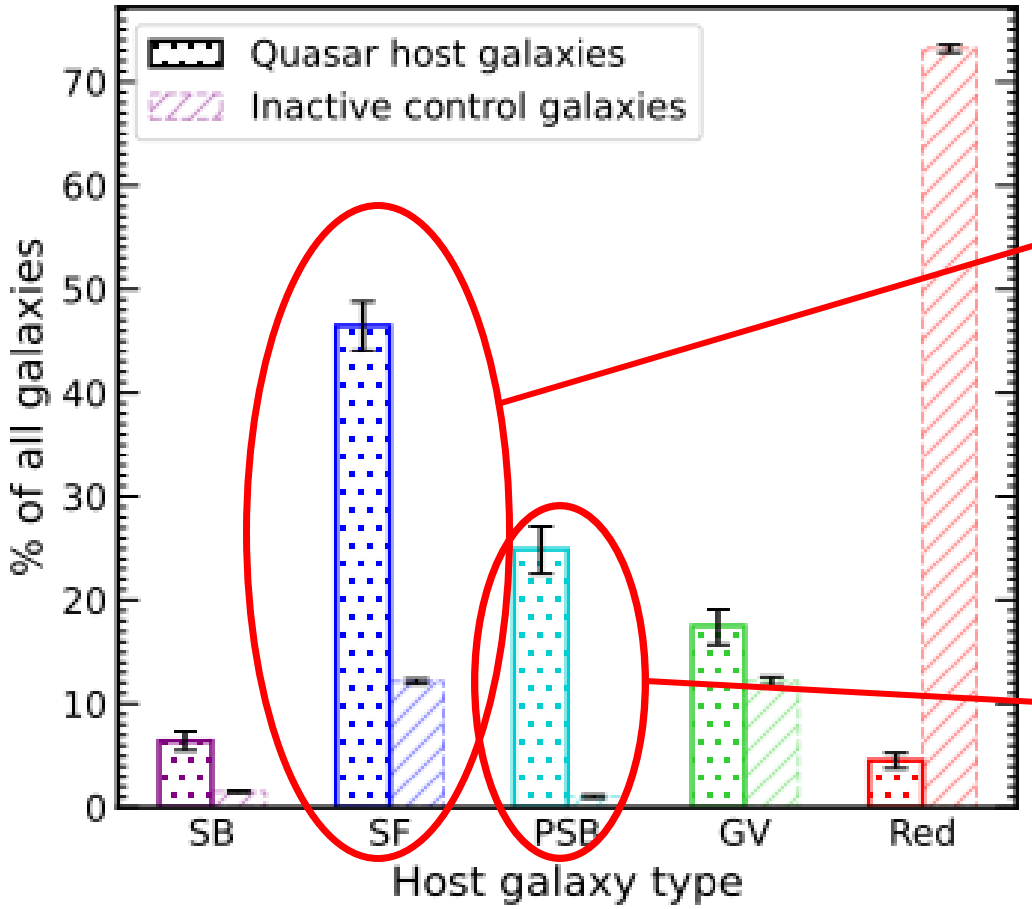




Hopkins et al. (2008) – star-formation rate evolving in a galaxy merger.

- **25% of quasar host galaxies are post-starburst galaxies.**
- In simulations, galaxy mergers lead to a burst in star formation, which may be initially (rapidly) quenched by, say, stellar feedback (Wild et al. 2009, Cen et al. 2012)
- Quasar activated, blows out dust (Hopkins et al. 2008), revealing a post-starburst galaxy (Hopkins and Hernquist 2009) + quenches remaining SFR (Yesuf et al. 2014).
- **Post-starburst quasars = evidence of AGN quenching phase in mergers?**
- **BUT, largest fraction of quasars are star-forming – quasar activity doesn't always correspond to quenching.**
- **Are mergers the key? Eg: Davies et al. (2022, 2023)**

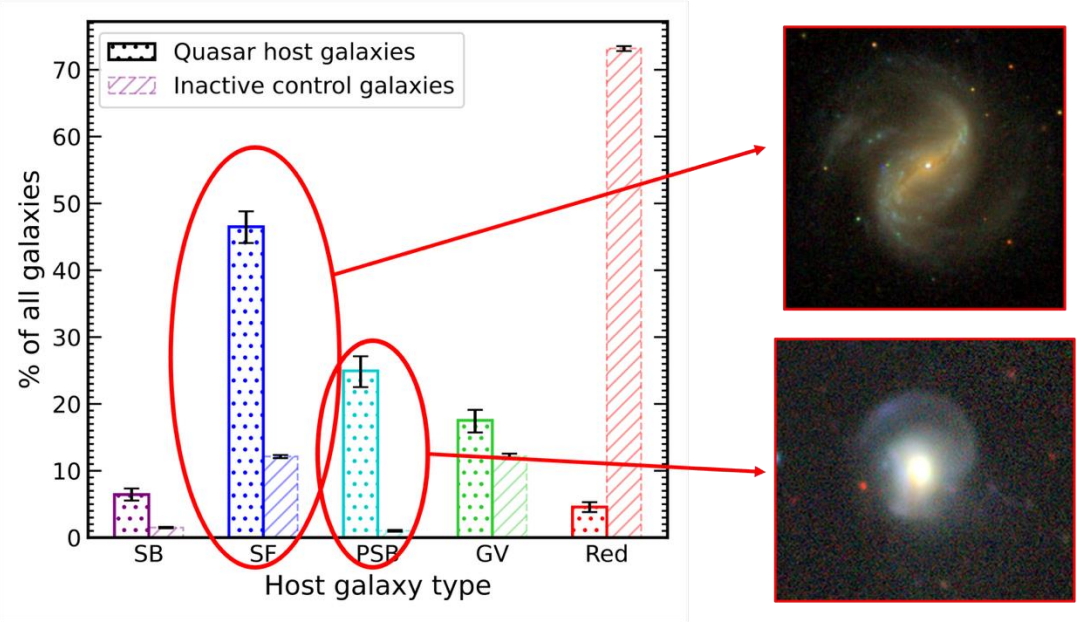
Result takeaway: two modes of quasar feeding?



- Galaxies with disk-like morphologies and continuous star-formation histories free of bursts are unlikely to have experienced a major merger (Martig et al. 2012).
- Thus, **star-forming quasars likely triggered by secular processes** (bars, disk instabilities) or **minor mergers**.
- Most (~90%) high stellar mass PSBs have experienced a recent major merger (Ellison et al. 2024).
- **Post-starburst quasars are likely triggered by major mergers** (eg, Canalizo et al. 2000).

- **Most quasars are triggered/fed by secular processes or minor mergers.**
- Excess of post-starburst quasars - **major mergers are good at triggering quasar activity**, while **quasar activity in star-forming galaxies is likely to be more stochastic.**

Quantifying quasar feeding.



- Make some simplifying assumptions – assume all PSB and SB hosts have experienced a recent major merger + all SF and Red have no recent major mergers + three extreme cases for GVs.

- **30-50% of quasars are fed by major mergers.**

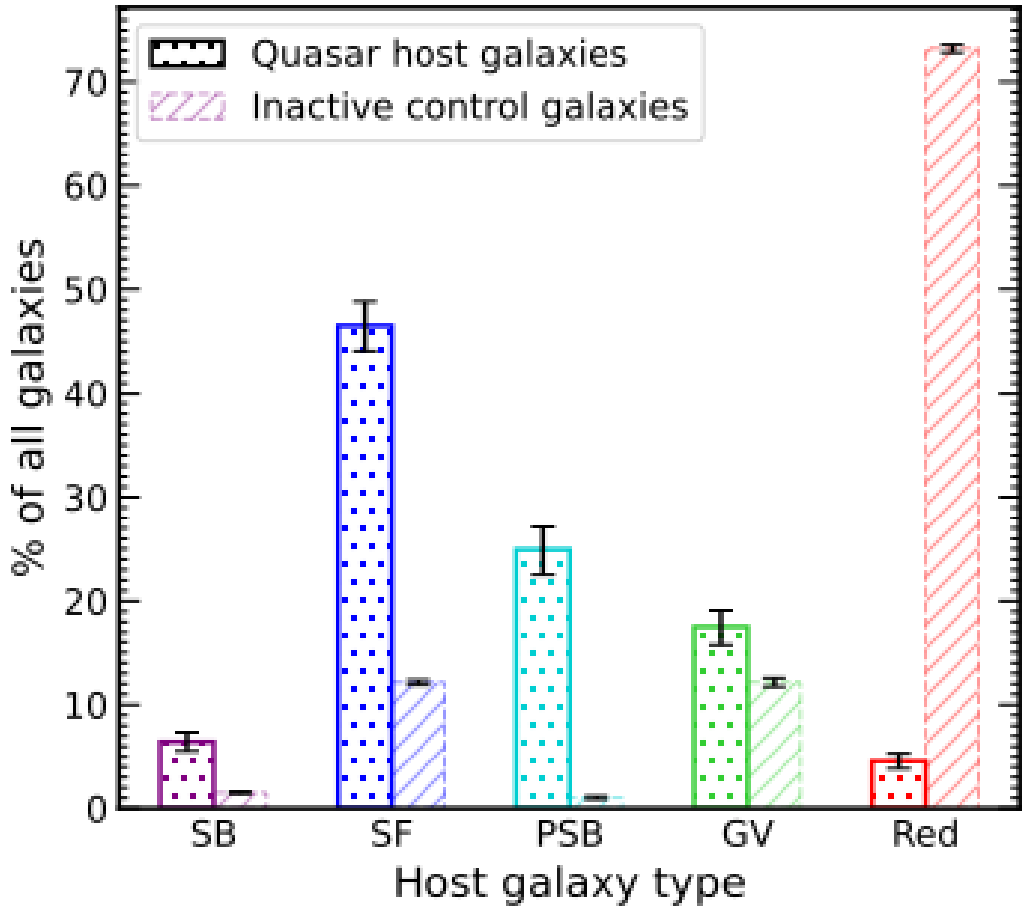
Simplifying assumptions used to arrive at this. Eg: Some PSBs haven't experienced major mergers (Pawlik et al. 2016)

- Results agree with major merger fractions of optical high-luminosity AGN studies:
  - i) Ellison et al. 2019 – 37% mergers.
  - ii) Marian et al. 2020 – 41 ± 12 % mergers.

- **Most quasars are triggered by secular processes (i.e not mergers).**

Conclusions

- MFICA can decompose quasar spectra and reveal the stellar populations/SFHs of their hosts.
- Quasars are predominantly (47%) star-forming, while the inactive galaxies with the same stellar mass are predominantly (73%) quiescent.
- 25% of quasar hosts are post-starburst galaxies – an excess of 24 times compared to the control sample.
- Though most quasars are not quenching, could post-starburst quasars connect quasars and quenching??
- Although post-starburst galaxies, through major mergers, are conducive to quasar activity, most quasars are secularly fed.



If you'd like to use MFICA, or learn about some new work including Type-2 AGNs, come talk to me at any time :D

Email: sk322@st-andrews.ac.uk