Blessing MUSIIMENTA
University of Bologna

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

PhD topic: Incidence and energetics of Active Galactic Nuclei (AGN) winds in the distant Universe

BiD4BEST
Big Data applications for Black hole Evolution Studies

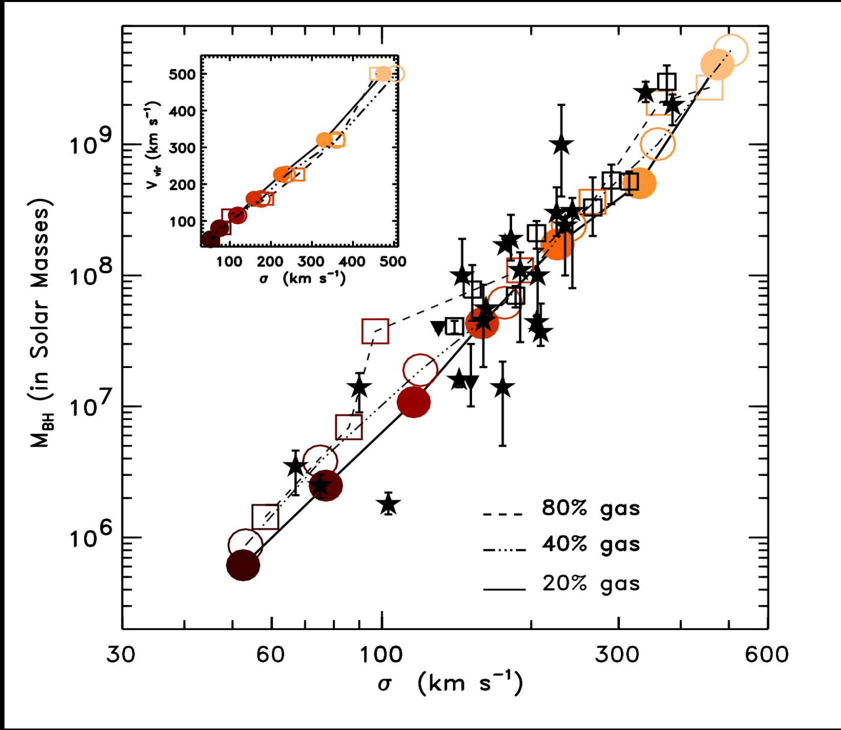
- A new discovery space opened by eROSITA: Ionised AGN outflows from x-ray selected samples (Musiimenta et al. (2023), 679, A84)
- Ionised AGN outflows in the Goldfish galaxy - The illuminating and interacting red quasar eFEDSJ091157.4+014327 at z ~0.6 (Musiimenta+submitted to A&A)
- Selection of AGN in the feedback phase using machine learning (Musiimenta+in preparation)

eROSITA

BiD4BEST meeting
06/02/2024

Active galactic nuclei (AGN) feedback: why do we care?

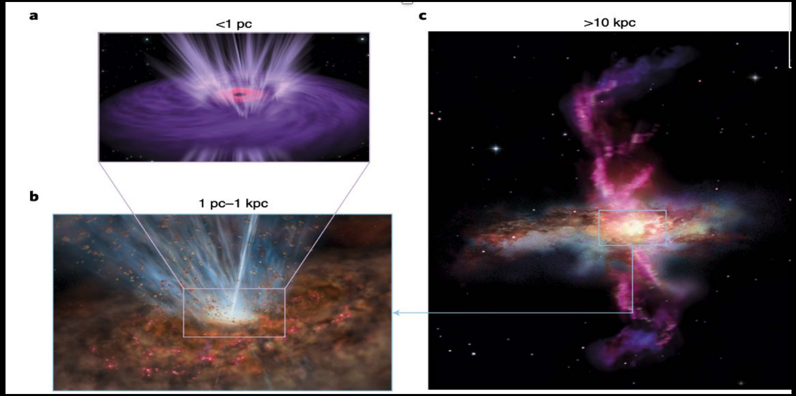
- ➢ Active galactic nuclei
- ➢ Play a crucial role in galaxy formation and evolution



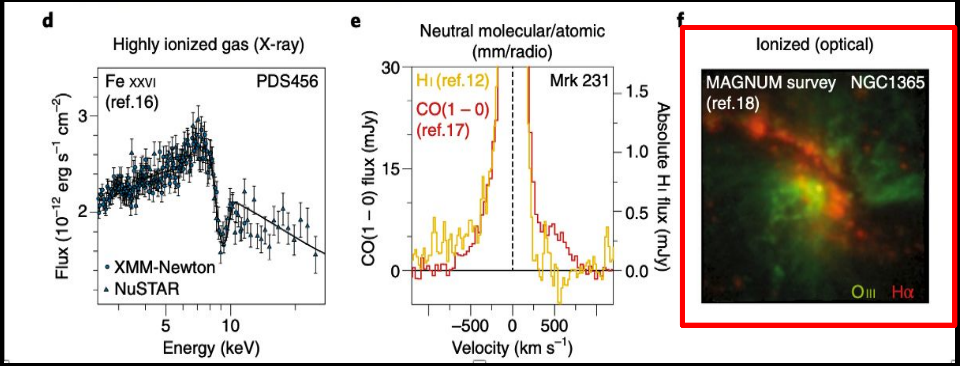
- ❑ Explains AGN and host galaxy co-evolution (e.g DiMatteo+2005, Hopkins+2006).
- ❑ Effect of AGNs on galaxy evolution still not fully understood.

Active galactic nuclei (AGN) feedback: AGN outflows

- ➢ Outflows in form of winds or jets.



Cicone+2018



Tracing outflows

- ➢ Broad and/or blueshifted or asymmetric wings in emission and absorption lines
  - o Integrated spectroscopic data e.g SDSS, X-shooter, etc.
  - o Integral field spectroscopy (IFU) to constrain their spatial extent and gas kinematics e.g MUSE, JWST, KMOS, e.t.c

- ➢ Studying AGN outflow properties provides better constraints for galaxy evolution.

Active galactic nuclei (AGN) feedback: Properties of AGN with outflows

Characterised by their luminous, obscured, and dust-enshrouded environments, as predicted by theoretical models

Properties of QSO in feedback/outflows

- ❖ Physical:
  - Moderate N_H, obscured and 'dusty'
  - Accretion close to Eddington limit
- ❖ Observed:
  - X-ray+IR luminous
  - Faint optical

→ Red colours

- ➢ Blow-out phase is short and sources are rare: need large area surveys to efficiently select them.
- ➢ Innovative selection methods and dedicated observations are usually necessary.

Goal:

Develop an approach to isolate red, obscured and highly accreting QSO at z~0.5-3, search for the presence of ionised outflows and assess the effect of AGN outflows to their host galaxies by comparison with simulations.

A new discovery space opened by eROSITA: Ionised AGN outflows from x-ray selected samples

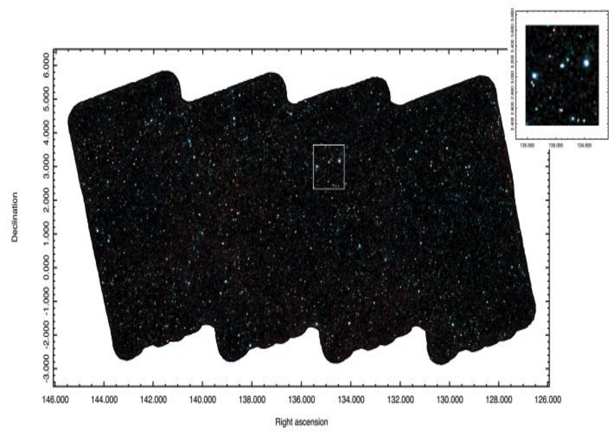
Musiimenta et al. (2023), 679, A84

The eROSITA Final Equatorial-Depth Survey (eFEDS)

eFEDS catalog (Brunner+2022, Salvato+2022, Liu+2022):

- Four days of deep observations (2ks)
- 140 deg^2
- ~28000 X-ray sources
- 0.2-2.3 keV band
- Within the richest multiwavelength coverage (UV - WISE)

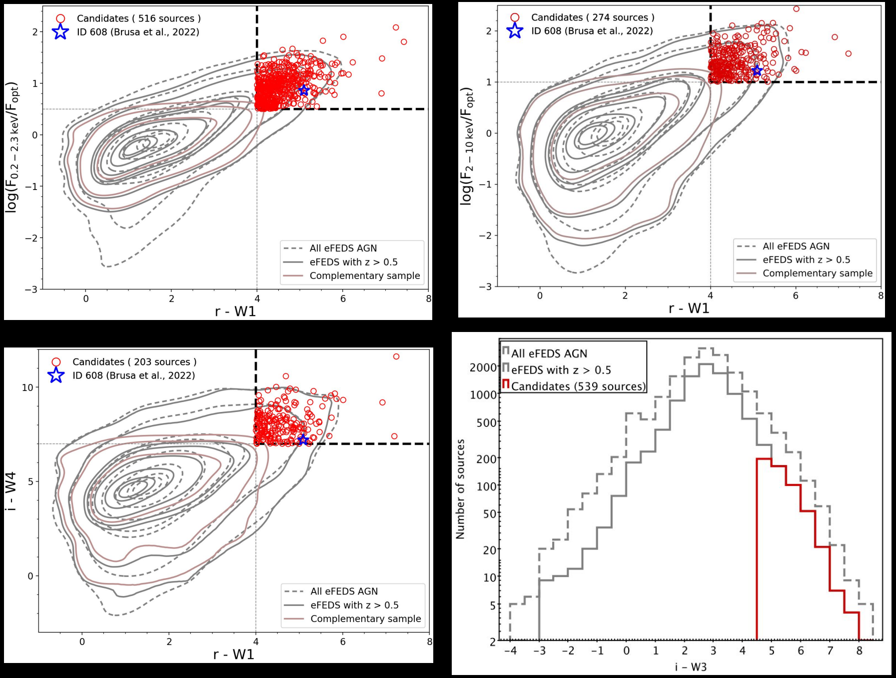
Powerful instrument to select rare, luminous sources (such the "agents of feedback")



Selection of AGN in the feedback phase (z>0.5)

Musiimenta et al. (2023), 679, A84

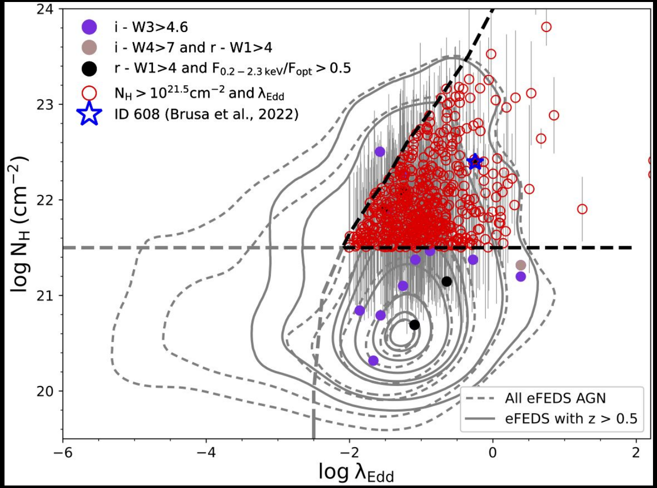
Color selection methods



853 sources

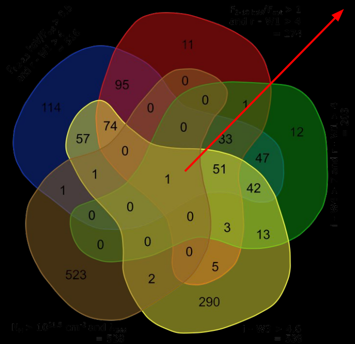
Perna+2015, Brusa+2022, Zakamska+2016, Vayner+2021, perrotta+2019

X-ray and optical spectral propertiies



528 sources

Kakkad+2016, Lansbury+2020



ID608

~1400 candidates isolated

Tracing ionized outflows

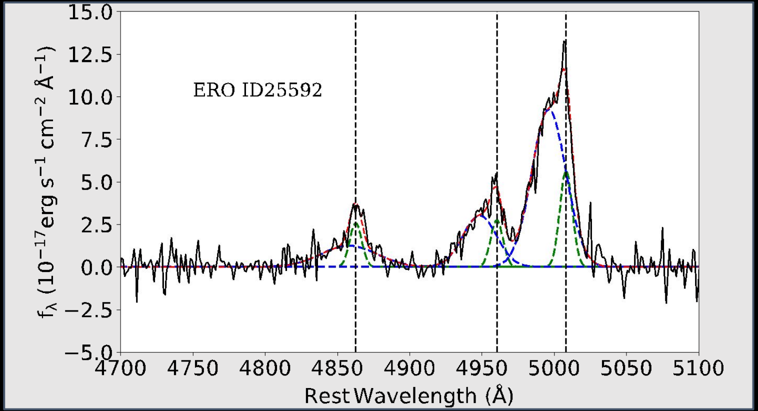
Musiimenta et al. (2023), 679, A84

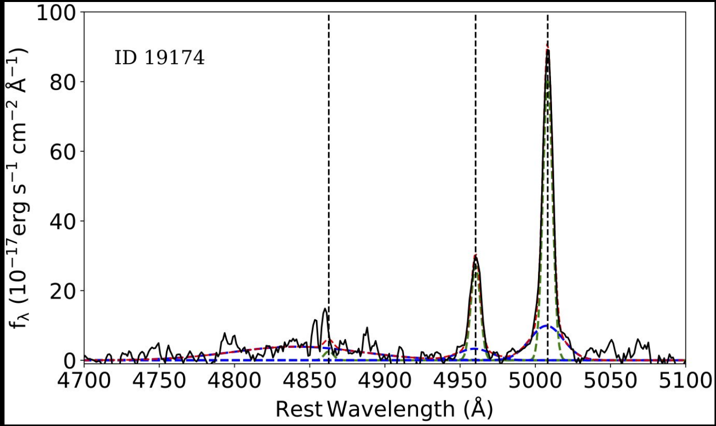
We narrowed down to

- Available SDSS spectra at 0.5<z<1: 82 sources

➢ Spectra fitting using PyQSOFit (Guo+2018,Shen+2019).

- ~50 sources with good quality spectra





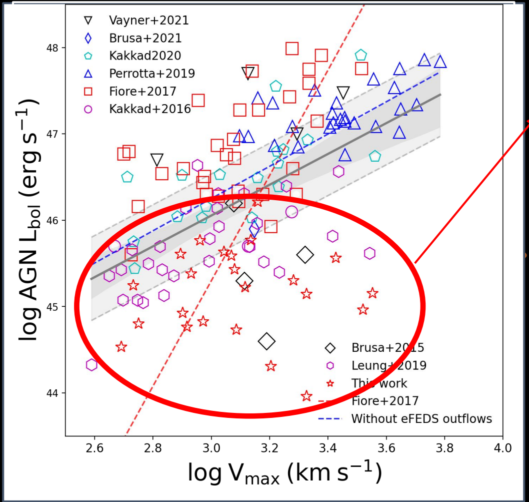
➢ Identified **23/50** outflows

➢ FWHM ~ 600 - 2800 km/s

➢ 12/50 sources are best fit with 1 narrow component (excluded in the final outflows detected sample). **Outflow fraction may be as high as 70%.**

AGN outflow scaling relations

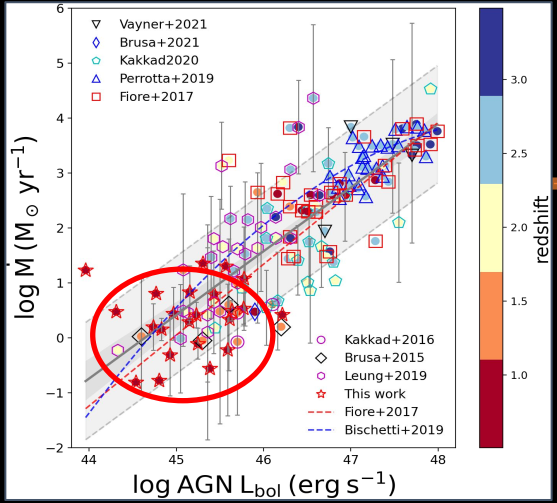
Musiimenta et al. (2023), 679, A84



Weak/no correlation

- X-ray active is best tracer of fastest phase of winds
- Their velocity doesn't depend only on L_{bol}

Importance of "sample selections"



Strong correlation

Large scatter: mass outflow rate also depends on other factors (Ramos Almeida+2022)

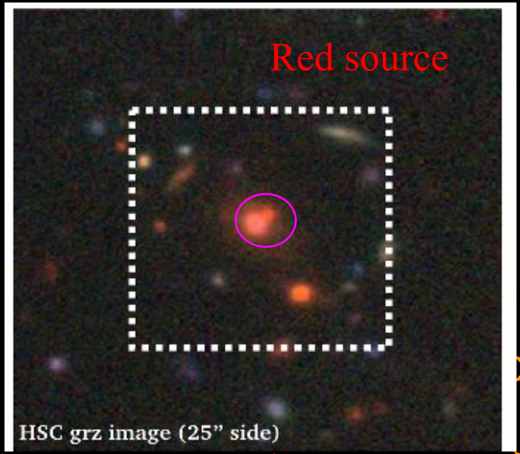
- ➢ Mass outflow rate of 0.2 –23 $M_\odot yr^{-1}$
  Kinetic power of 40 - 44 erg s^{-1}
- ➢ Kinetic coupling efficincies 1-10% (in 30% of the sample)
  - ➢ Indicating that the outflow is **very significant** from the **energetic point of view.**

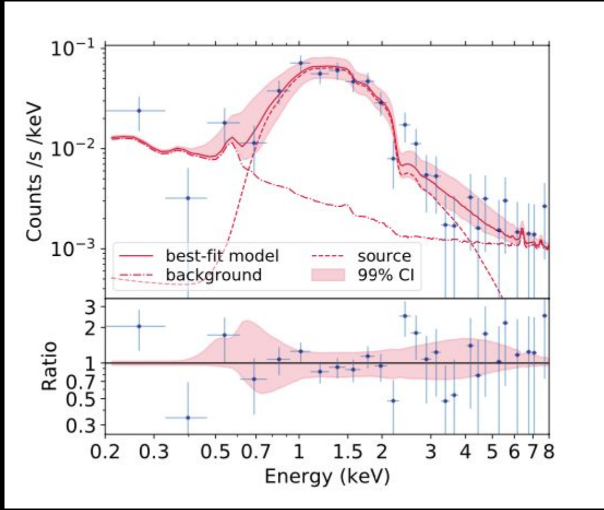
Ionised AGN outflows in the Goldfish galaxy - The illuminating and interacting red quasar eFEDSJ091157.4+014327 (ID608) at z ~0.6 (Musiimenta+submitted to A&A)

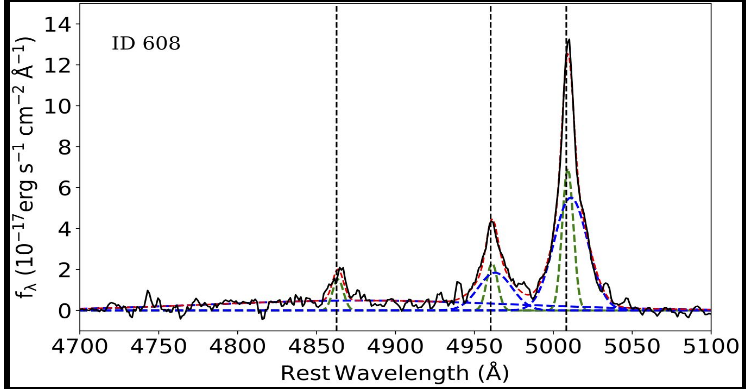
What makes ID608 special?

- $Z = 0.6031$
- $L_{bol,AGN}$=7.8x10^{45} $ergs^{-1}$
- L_{bol}/L_{edd}=0.25

- X-ray type 2 nature
- Lx ~10^{44} $ergs^{-1}$
- N_H~2.7x10^{22} cm^{-2}







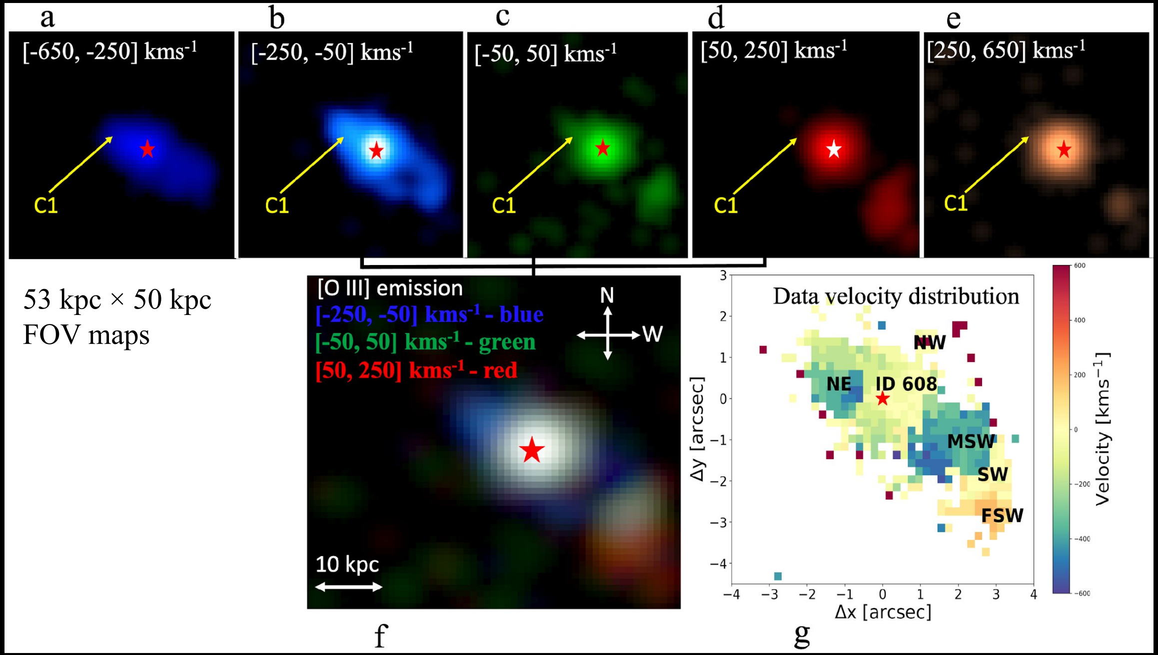
Is it a merger?

- ➢ **Accurate measurement of mass outflow rate and energetics**
- ➢ **Source located in a merging system?**

Brusa+2022
Musiimenta+2023

Gas distribution and searching for companion galaxies (C)

Musiimenta+submitted to A&A

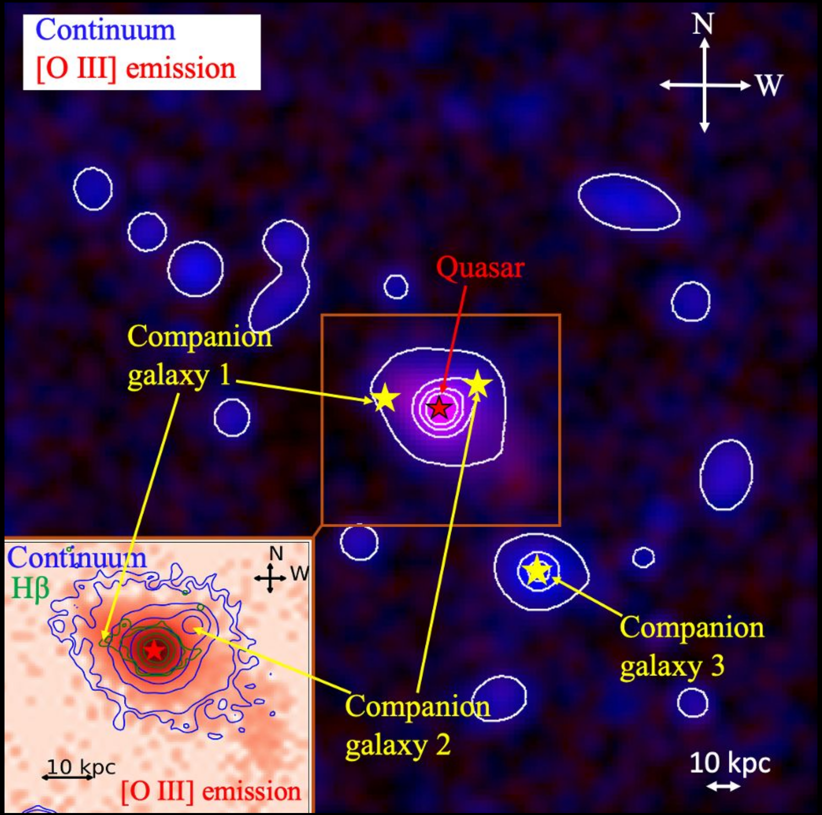


- [-650,-250] km/s: extended emission towards SW and NE.
- [-250,-50] km/s: second peak in NE, bubble-like extended emission towards SW.
- [-50,50] km/s: centered emission
- [50,250] km/s: emission in SW
- [250,650] km/s: centered emission

[O III] intensity maps and velocity maps, indicating **gas distribution and structures** within the system.

Searching for companion galaxies (C)

Musiimenta+submitted to A&A

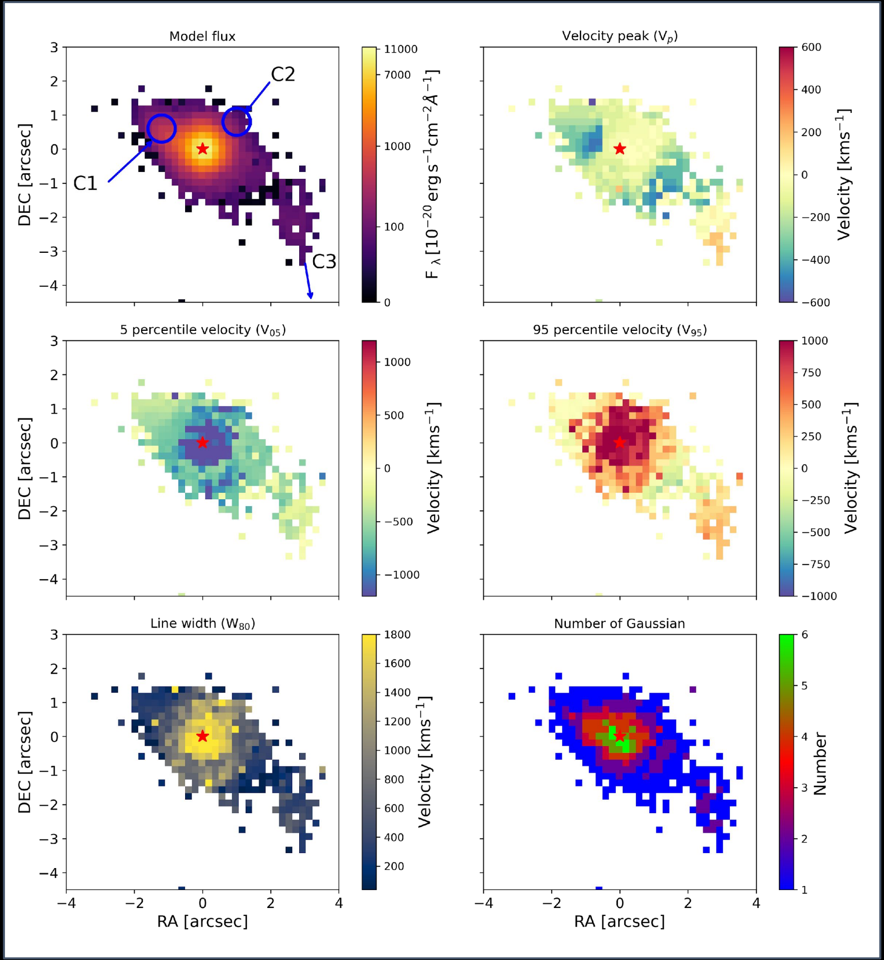


201 × 201 kpc FOV map

- ➢ The quasar is in a **complex interacting system possibly merging** with three other galaxies that are within 50 kpc.

[O III] emission line fitting: Kinematic

Musiimenta+submitted to A&A



Fitting tools: In-house code by G. Speranza

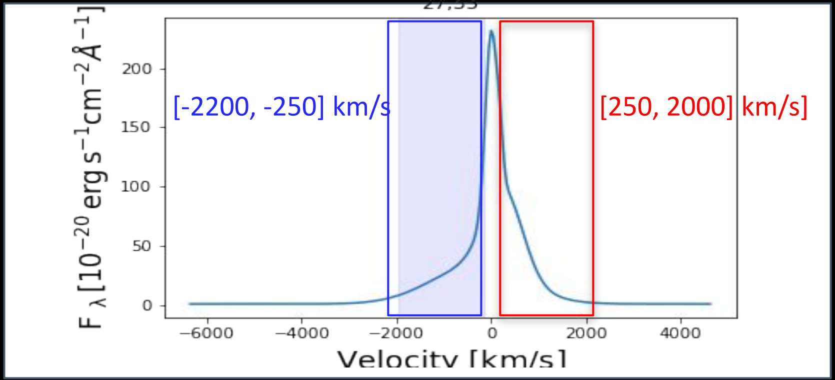
- 5 percentile velocity (V_{05}) = negative outflow velocities. Up to -1200 km/s.
- 95 percentile velocity (V_{95}) = positive outflow velocities. Up to 1000 km/s.
- W80 (V_{90}-V_{10}) = velocity dispersion. In the range 600 - 1800 km/s.

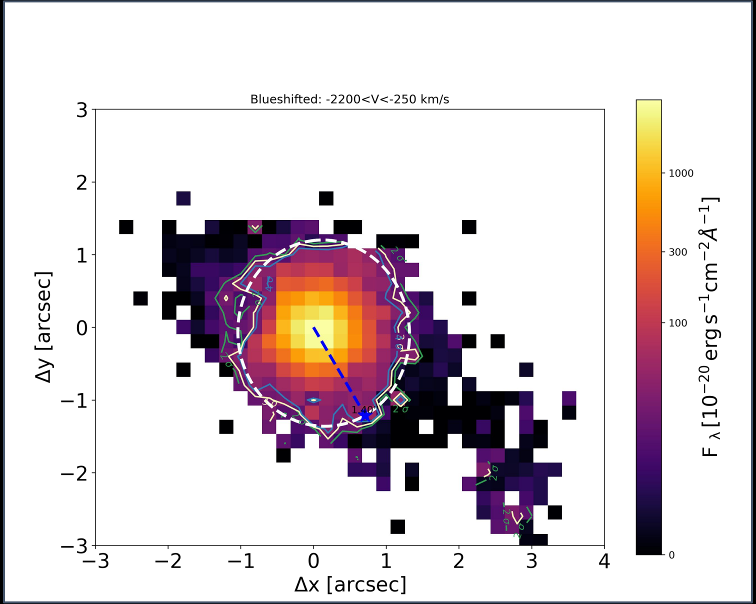
Outflow properties

Measuring the flux and extension

Musiimenta+submitted to A&A

- Outflow mass, $M_{out} \propto \frac{L_{[O\ III]}}{n_e}$ assumed 500 cm^{-3}
- Mass outflow rate, $\dot{M} = k\ M_{out} \frac{V_{out}}{R_{out}}$



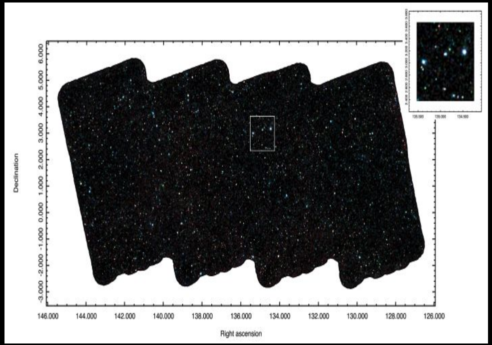


- Total mass outflow rate = 9.6 $M_{\odot} yr^{-1}$
- Total kinetic power = 1.9×10^{42} erg/s

- Kinetic coupling efficiency **too low (0.01-0.2%)**;
  - outflow **not very significant from the energetic** point of view.
  - slightly consistent with theoretical predictions of **radiation-pressure-driven outflows**.
- Outflows are more likely **AGN-driven** than star formation-driven (mass loading is 4.8).

Selection of AGN in the feedback phase using machine learning

(Musiimenta+in preparation)



eFEDS

Data

AGN in feedback sample (fp)
- Ionised outflows (z>0.5)
- 86 sources (including outflows from eFEDS)

Non– feedback phase sample (nfp)
- eFEDS (z>0.5)
- Extragalactic
- [O III]5007 FWHM < 800 kms^{-1}
- 613 sources

Selection features

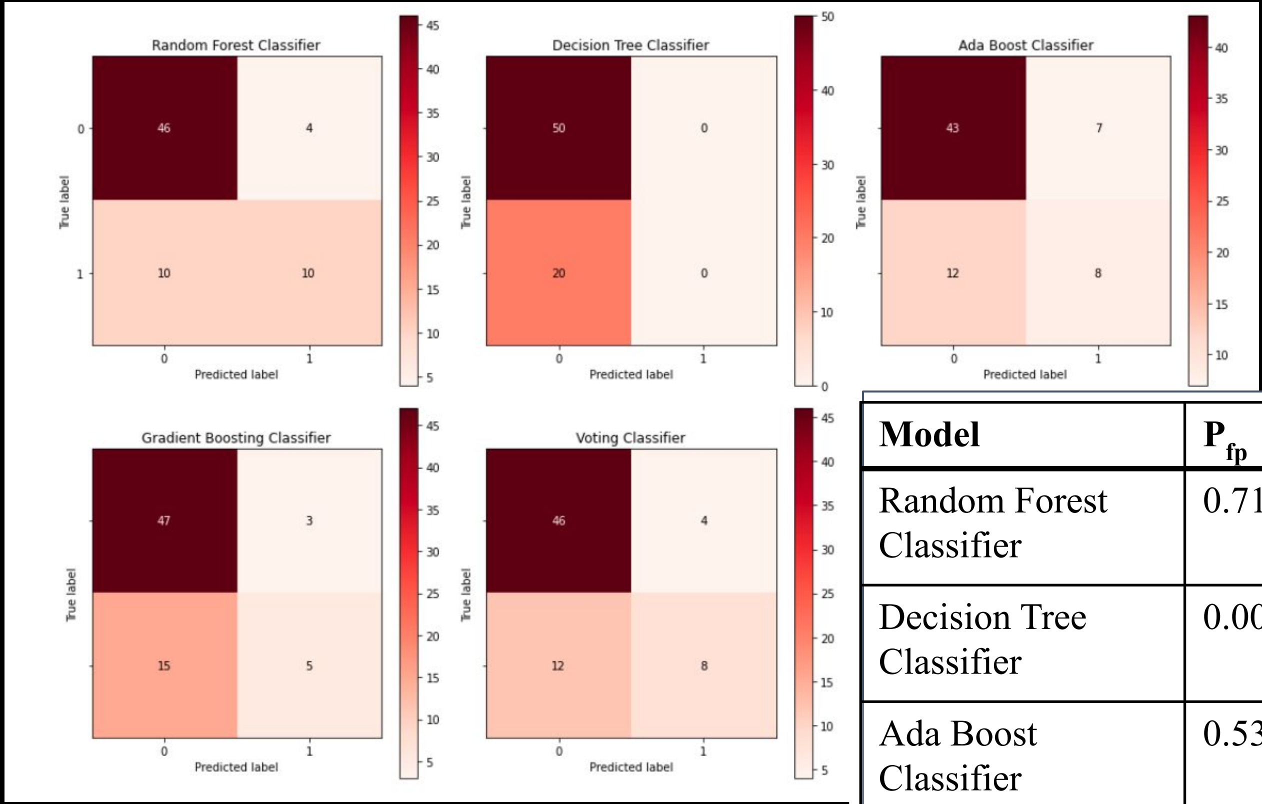
Photometry from Legacy DR10
- W1, W2, W3,W4
- r , i, g, z
- i – W3
- r - W1
- i– W4

X-ray spectral properties from eFEDS
- X-ray flux
- Column density
- Bolometric luminosity

Others
- X-ray to optical flux ratios
- Eddington ratio

→ ML model

Model training and testing



Model	P_{fp}	P_{nfp}	R_{fp}	R_{nfp}	Acc
Random Forest Classifier	0.71	0.82	0.50	0.92	0.80
Decision Tree Classifier	0.00	0.71	0.00	1.00	0.71
Ada Boost Classifier	0.53	0.78	0.40	0.86	0.73
Gradient Boosting	0.62	0.76	0.25	0.94	0.74
Voting Classifier	0.67	0.79	0.40	0.92	0.77

Conclusion

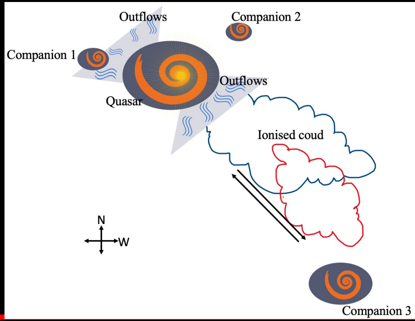
- **X-ray selection** (and eROSITA) is as a powerful discovery machine.
- **Ionised winds** (kiloparsec scale) discovered in red and obscured sources.
- **Weak/no correlation** between maximum velocity and bolometric luminosity.

* **Highlights the importance of sample selections**

- X-ray active,obscured is best tracer of fastest phase of winds

Musiimenta et al. (2023), 679, A84

- A **complex interacting** system, **possibly merging** with **three companion galaxies** within ~50 kpc away.
- **Extended ionised outflows** up to ~ 9.4 kpc.



Musiimenta et al. (2024), submitted to A&A

- Model trained and tested on a small sample of eFEDS.
- Spectral fitting of the full eFEDS and SPIDERS sample to increase the training sample and obtain more reliable outflow properties.
- Application to eRASS:1.

Musiimenta et al. in preparation

Back up slides