PhD STUDENT NAME: Blessing Musiimenta
PhD CYCLE: 36
SUPERVISOR: Prof. Marcella Brusa

TITLE: Incidences and energetics of active galactic nuclei (AGN) winds in the distant Universe

Scientific background and first year research

As shown by simulations, AGN feedback plays a vital role in overall galaxy evolution. During this short phase, the accretion rate of the SMBH is expected to be at a maximum generating high radiation pressure. This, in turn, may lead to radiatively driven outflows that drive away or heat up the gas in the host galaxy thus having a great impact on star formation. Tracing and characterising AGN in the feedback phase, especially at high red-shift (z $>$ 0.5) since AGN feedback is most relevant at this epoch is crucial to understand how AGN outflows affect their host galaxies providing constraints to theoretical models that aid in understanding galaxy evolution. However previous studies focused on few and possibly biased AGN samples, pre-selected in different ways. This limits the complete understanding of relations between AGN, outflow and galaxies properties.

The *main goal* of this PhD is to develop multi-wavelength selection approaches integrated with machine and deep-learning methods to select unbiased samples of supermassive black holes with strong winds among X-ray populations, dissect the interaction of AGN winds with the interstellar medium in high-shift (z$>$0.5) galaxies and constrain AGN outflow physics via comparison with state-of-the-art hydrodynamical simulations.

In this *first year*, my goal was to compile and compare different selection methods previously used to isolate AGN in the feedback phase with the aim of determining the most efficient ones to be applied to large X-ray surveys such as extended ROentgen Survey with an Imaging Telescope Array (eROSITA).

First, I have compiled two catalogues of AGN at z$>$0.5 to encompass different epochs in which the number of luminous AGNs peak: a pure X-ray selected one (parent sample) and quasar with outflow (QWO) catalogues. For the QWO sample, I collected, at my best effort, all X-ray information, AGN and host galaxy properties and physical outflow properties for all AGN published in the literature for which the presence of ionised gas winds has been revealed from [[OIII], H_β, H_α observations. This sample comprises $\sim$ 120 sources and will constitute our training sample for the future. When compared to the parent X-ray sample, *sources in the QWO sample are clustered in the locus of higher AGN bolometric and X-ray luminosities, as exptected from AGN feedback models, although selection effects may be in place and should be investigated further.* .

I then used QWO samples to explore correlations between AGN, host galaxy and outflow properties, similarly to what has been done in Fiore et al. (2017). The correlations between these properties are key to understand the extent to which outflows can contribute to their host galaxies. Given that, outflow properties presented in the literature were obtained with varying assumptions with increased uncertainties. I, re-computed them with the best homogeneous assumptions as much as possible using standardised receipts or assumptions for key quantities such as geometry, the velocity of the outflow and electron density. I compared my QWO sample with the theoretical prediction presented in Harrison et al., 2018. *In addition to having an increased sample ($\sim$ twice larger) of ionised outflows at z$>$0.5 as compared to the most recent one, more than half of our sample have kinetic coupling efficiency that is close to the theoretical predictions*.

I then investigated in more details the different pre-selection techniques of the QWO sample. The methods include various combination of observed properties (such as high X-ray to optical flux ratio vs r- W1 colour) or physical properties (such as column density vs Eddington ratio for the sub-sample for which measurements are available). By populating the selection planes with the parent sample and QWO sample, I figured out the efficiency of each method to better map the properties of the QWO population. *Although the selection methods are not complete in isolating AGN in the feedback phase, they are considered reliable and effective to isolate these types of objects*.

The above selection methods have been applied to the excellent photometric and spectroscpic dataset available in the eROSITA Final Equatorial-Depth Survey (eFEDS). The application of just one selection diagnostic to the relatively small (246 sources) hard X-ray eFEDS sample led to the discovery of a prototypical QSO in the feedback phase (Brusa et al. 2021). I then extended the work to the much larger soft X-ray eFEDS AGN sample ($\sim$22.000 sources, Liu et al., 2021) and I already isolated a few thousand candidates with z$>$0.5. *Many of them are too faint for a detailed spectral analysis and will be the subject of a proposal for a dedicated VLT*

follow-up next semester. Among the redder candidates with public SDSS spectra, sampling the [OIII] line, *I performed spectral fitting with PyQSOFit, isolating 6 sources in which ionised gas outflows are indeed likely present (Musiimenta et al., in preparation)*.

Note: This PhD project is in the framework of BiD4BEST (Big Data Application for Black Hole Evolution Studies), an Innovative Training Network (ITN) funded by the EU under the call H2020-2019-MSCA-ITN (GA: 860744). The Network comprises 10 institutes across Europe and has the main goal of training 13 Early Stage Researchers in the field of Black Hole and Galaxy co-evolution.

WORKSHOPS, CONFERENCES AND MEETINGS

Regular participation in weekly astrophysics talks and Joint Astrophysical Colloquium (JAC), eROSITA AGN meetings, PhD weekly meetings, Durham AGN group weekly meeting (since 27 July 2021), Friday AGN meetings (FAME) at UNIBO.

27 July 2021, Virtual - Durham AGN group weekly meeting.
Talk: "Selection diagnostics of AGN in the feedback phase and application to eROSITA"

28 June -2 July 2021, Virtual - European Astronomical Society annual meeting (EAS).
Poster: "Evolution of massive galaxies: Selection diagnostics of AGN in the feedback phase" in S4: Massive Galaxies: The Build-up of Monsters Through Cosmic History.
Participation in other various sessions. *21 - 24 June 2021*, Virtual - eROSITA Consortium meeting.

23 May 2021, Virtual - PhD weekly meetings.
Talk: "Exploring different methods used to select AGN in the feedback phase and their application to eROSITA".

08-12 March 2021, Virtual - African Astronomical Society (AFAS).

11 February 2021, Virtual - BiD4BEST work package 2 (WP2) , 7 January 2021 BiD4BEST meeting.
Talk: "Exploring different methods used to select AGN in the feedback phase and their application to eROSITA".

11-15 January 2021, Virtual - eROSITA Consortium meeting.

PhD SCHOOLS

As part of the BiD4BEST network, I took part in the following mandatory PhD schools and training activities:

14-16 July 2021, Virtual - Artificial intelligence, machine learning and careers in Data Science school (Bid4BEST-BASF).

07 - 11 June 2021, Virtual - School on Numerical Galaxy Formation (BiD4BEST-LMU)

19 April 2021, virtual - Training with Nature Astronomy - how to read and write scientific papers for publication (BiD4BEST) (link)

March 2021, virtual - Media Relations and Communication training (BiD4BEST-SISSA)

13 -21 January 2021, Virtual - School of Astro-Statistics (BiD4BEST) (link)

INTERNAL COURSES

19 - 23 April 2021, Virtual - Gamma Ray Bursts: from observations to physical properties (link)

5-14 May 2021, Bologna ,Italy and virtual- Writing, talking and presenting Science, (link)

30 November - 01 December 2020, Virtual - The interstellar medium (link)

ISA LECTURES

21 September 2021, Virtual - Monsoon Stories From Desert Trees, University of Arizona, USA.

01 December 2020, Virtual - Data in public communications, history, impact, and key lessons for scientists and policy-makers, National Health Service, UK - Certificate of attendance.

COMPETITIVE TELESCOPE/COMPUTER TIME ALLOCATIONS

Delegated PI of a proposal for 10hrs of MUSE + X-Shooter observations of an obscured QSO at z=0.6 (ESO P108, accepted)

OTHER RELEVANT ACTIVITIES

24 September 2021, Bologna, Italy - Participation to the european researcher's night.
Presented posters about the general BiD4BEST project and my research project (link).
Contribution in blogging to BiD4BEST webpage for eROSITA eFEDS data release (link).
12 March 2021, Virtual - Participation in African Women in Astronomy (AfNWA)
Member of the eROSITA_DE consortium.

PUBLICATIONS

M. Brusa et al., 2021 The eROSITA Final Equatorial-Depth Survey (eFEDS): The first archetypal Quasar in the feedback phase discovered by eROSITA, A&A in press (arXiv:2106.14525).
M. Salvato et al., 2021 The eROSITA Final Equatorial-Depth Survey (eFEDS): Identification and characterisation of the counterparts to the point-like sources, A&A in press (arXiv:2106.14520).