Ph.D. Report – Cycle XXXV

PROJECT TITLE: *"Probing AGN feedback in quasars at the cosmic noon through X-rays"*

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SUPERVISOR: *Prof. C. Vignali*

CO-SUPERVISORS: *Dr. M. Cappi & Dr. M. Dadina*

RESEARCH PROJECT

Scientific background: Common understanding among astrophysicists is that the evolution of massive galaxies is strongly influenced by Active Galactic Nuclei (AGN; e.g., Costa et al., 2020). However, to what extent and in which form are still subjects of debate (e.g. Kormendy & Ho, 2013). Feedback can be triggered by AGN-driven nuclear winds, eventually evolving into galaxy-scale outflows. Some state-of-the-art models (e.g. King & Pounds, 2015) identify such winds in the so-called Ultra-Fast Ouflows (UFOs). Visible in the X-rays, UFOs comprise thick ($N_{\rm H} \simeq 10^{22}-10^{24}$ cm^{-22}), highly-ionized ($\log\left(\xi/{\rm erg\,s^{-1}\,cm}\right) > 3$) gas that is seen to rise from the inner regions (sub-pc scales) of the accretion disk. Coupled with the semi-relativistic speed ($v_{\rm out}$ up to $0.2-0.3\,c$), UFOs' main imprints fall at E$>$7 keV, requiring good quality X-ray spectra to be properly detected and constrained. In fact, they were mostly studied in local AGN. UFOs at $z \leq 0.1$ show a detection fraction (DF) of $\simeq 40\%-50\%$ (e.g. Tombesi et al., 2010) and clear inter- (e.g., Cappi et al., 2009) and intra-observation (e.g. Giustini et al., 2011) variability. The current idea is thus that UFOs might well be common and recurrent, but episodic events, even at high redshift. In particular, to be relevant for AGN–galaxy co-evolution, they are expected to be most effective, thus most visible, around the cosmic noon (z$\simeq$2$-$3). So far, only fourteen AGN at z$>$1 were analyzed to this purpose (Chartas et al., 2021), most of which are gravitationally lensed quasar (GLQs). Their flux is naturally magnified by the lens, providing us with good signal-to-noise spectra of otherwise too faint sources in a sustainable amount of time. To our knowledge, only two of these high-z AGN are not lensed (Lanzuisi et al., 2012; Vignali et al., 2015), affirming the uniqueness of gravitational lenses as means to study UFOs at high-z.

Aim of the project: To test AGN-galaxy co-evolution models and provide reference data for cosmological simulations of AGN feedback, it is mandatory to probe high-z UFOs on a wider statistical basis than what done so far. Of particular interest would be to solidly evaluate the wind duty cycle (WDC) on multiple sources. Its value is still poorly estimated; so far it is commonly, and extremely roughly, assumed as equal to the UFO DF, neglecting the geometric effects. The first and only statistically-robust assessment of the WDC on a single high-z source is based on the study of the Q2237+030 at z=1.695 (Bertola et al., 2020). Aim of my Ph.D. project is to build a sample of tens of sources at $z \gtrsim 1$ with good quality X-ray data to assess the occurrence of high-z UFOs, along with their physical characterization and WDC. Key topic will also be the investigation of any correlation between the UFO properties and those of the AGN (e.g. $L_{\rm bol}$, $\lambda_{\rm Edd}$), coupled with the search for any link between UFOs and kpc-scale outflows.

Second-year work: The high-z GLQs sample that I built last year comprises APM 08279+5255 (hereafter, APM 08279). Placed at $z = 3.91$, this broad-absorption line (BAL) quasar is lensed by a still undetected foreground galaxy. For this reason, different models predict very different magnification values, ranging from $\mu_{\rm L} = 4$ (Riechers et al., 2009) to $\mu_{\rm L} = 100$ (Egami et al., 2000), with UV-to-optical spectroscopy recently favouring $\mu \lesssim 9$ (e.g., Saturni et al., 2018). Regardless of the actual magnification factor, APM 08279 is among the brightest high-z AGN in many bands, thus very well known in many astrophysical research fields, and a peculiar source for high-z UFOs (Hasinger et al. 2002, hereafter, H02, Chartas et al. 2009, hereafter C09, Saez & Chartas, 2011; Saez et al., 2009), providing us some of the fastest ever detected ($v_{\rm out}$ up to 0.76c, C09). Its most remarkable feature is to have shown a double-velocity UFO in all the observations taken up to early 2008 (C09; Saez et al., 2009), except for its first X-ray exposure (H02).
New X-ray observations were taken jointly by XMM-*Newton* and *NuSTAR* in 2019 (two exposures each), that I have reduced, analyzed and presented in Bertola et al. 2021 (paper close to submission). The source is found in a fainter state, about $\sim 1.5\times$ lower than before 2008 (C09; H02). This, combined with its first X-ray broadband spectrum, allowed us to measure the high-energy cutoff and constrain a reflection component for the first time in this source. To assess whether reflection was already in place before 2019, I retrieved, reduced and analyzed all past observations presented in C09; H02. Based on the variation of *i)* the reflection fraction, and of both *ii)* the equivalent width and *iii)* the intensity of the Fe Kα emission line, we infer that reflection was already a feature in APM 08279 spectra but was completely overwhelmed by the intrinsic activity of the central X-ray source. Additionally, we broke the previous redshift record of Lanzuisi et al. (2019) for the farthest high-energy cutoff ever measured, and confirmed their result of high-z AGN showing lower cutoff energies with respect to local sources. However, we cannot discriminate whether this effect is owed to the different luminosity regimes probed at high- and low-z or a byproduct of a potential evolution with cosmic time.
I also carried out a careful spectral analysis to investigate the possibility of UFOs. I searched for absorption lines, and assessed their significance, in three ways: *i)* through the blind search described in Tombesi et al. (2010); *ii)* including the lines in the best fit models and using the F-test; *iii)*, running Monte Carlo simulations to consider the look-elsewhere effect (Protassov et al., 2002). APM 08279 is confirmed to be a unique source for UFOs; we detect a UFO ($\beta = v_{\rm out}/c = 0.46 \pm 0.02$) in both XMM-*Newton* 2019 observations, and hints for a second velocity-component ($\beta_{\rm XMM\ 301} \sim 0.3$, $\beta_{\rm XMM\ 101} \sim 0.55$) are also present in both epochs. Moreover, a key role is played by UFOs features in constraining X-ray reflection due to the interplay between their hard-band spectral imprints. Lastly, I computed key physical properties (mass-outflow rates, energy and momentum loading factors) for UFOs in 2019 and before 2008 C09, and compared them to the recent relations of Chartas et al. (2021). UFOs in APM 08279 are consistent with being radiatively driven, but other mechanisms, such as magnetic driving, are likely needed to explain the outflow velocities.

REFERENCES: •Bertola et al. 2020, A&A, 638, A136. •Cappi et al. 2009, A&A, 504, 401. •Chartas et al. 2021, arXiv:2106.14907. •Chartas et al. 2009, ApJ, 706, 644. •Costa et al. 2020, MNRAS, 497, 5229. •Egami et al. 2000, ApJ, 535, 561. •Giustini et al. 2011, A&A, 536, A49. •Hasinger et al. 2002, ApJ, 573, L77. •King et al. 2015, ARA&A, 53, 115. •Kormendy et al. 2013, ARA&A, 51, 511. •Lanzuisi et al. 2019, ApJ, 875, L20. •Lanzuisi et al. 2012, A&A, 544, A2. •Protassov et al. 2002, ApJ, 571, 545. •Riechers et al. 2009, ApJ, 690, 463. •Saez et al. 2011, ApJ, 737, 91. •Saez et al. 2009, ApJ, 697, 194. •Saturni et al. 2018, A&A, 617, A118. •Tombesi et al. 2010, A&A, 521, A57. •Vignali et al. 2015, A&A, 583, A141.

Marco Polo project

I will spend six months (September 1, 2021 – February 28, 2022) at ESO, Garching to work with Dr. Vincenzo Mainieri and Dr. Gabriela Calistro Rivera. Aim of the project is to investigate the impact of AGN-driven ionized winds on the host-galaxy molecular gas reservoir at cosmic noon. Targets will be drawn from the KASH-z survey, aimed at measuring [OIII] emission and its kinematics in sources at $z \sim 1 - 3$, whose results are available to our group. The data sample will be complemented with archival ALMA observations to trace the molecular gas using the CO emission line. In my first two weeks at ESO, I have started learning how to image ALMA data with the CASA software, I have selected the first six candidate targets for my data analysis and issued the helpdesk tickets to retrieve the calibrated data from the ALMA archive.

Legend

– Activity performed in the second PhD year

• Activity performed in the first PhD year

Workshops, conferences and meetings

– SEPTEMBER 6–9, 2021, Durham (online), UK
Conference: *Black hole accretion disc winds* **Contributed Talk:** *The wind duty cycle of the Einstein Cross*

– JUNE 30 – JULY 2, 2021, Leiden (online), Netherlands
Conference: *EAS 2021* **Contributed Talk:** *Not just a beast for Ultra-fast outflows: measuring the long-lasting X-ray reflection in APM 08279+5255 (z=3.91)*

• JULY 15–16, 2020, Bologna (via Google Meet), Italy
Workshop: *Technological Advances in X-ray Astronomy: Strategizing the Path Forward*

FEBRUARY, 17–19 2020, Bologna, Italy
Lectures: *Active Galactic Nuclei: what's in a name?;*
Lecturer: Dr. Paolo Padovani (ESO), OAS Visiting Scientist

• DECEMBER, 18–19 2019, Bologna, Italy
Meeting: *J1030 Field Collaboration group meeting;*

Other

– 06/2021, Bologna, Italy – online
LOC member of *"Astrofisici cercasi: dall'Università al mondo del lavoro" seminar series*

– A.Y. 2020–2021, Bologna, Italy – online
WPS Coordinator with Ivàn Lopez. Summary of WPS 2021:

• A.Y. 2019–2020, Bologna, Italy
WPS Coordinator with Antonio Pensabene. WPS are a weekly meeting of Ph.D. students; each week we had one seminar and the Journal Club. Speakers were selected among the Bologna Ph.D. students but we also hosted a few invited speakers; two visiting Ph.D. students (from Turin and from Leiden) and Paolo Padovani (ESO). WPS were held from January, 8th until February, 21st and were then suspended due to the COVID-19 outbreak.
Summary of WPS 2020

Ph.D. Schools

– July 2021, *CNRS, CCSD* (France) - online
Title: *International Summer School on the Interstellar Medium of Galaxies, from the Epoch of Reionization to the Milky Way*
Summer school homepage

– June 2021, *Penn State's Center for Astrostatistics*, State College, Pennsylvania (USA) - online,
Title: *Summer School in Statistics for Astronomers XVI*
Summer school homepage

– March 2021, *Smithsonian Astrophysical Observatory offices (SAO)*, Mauna Kea, Hawaii (USA) - online
Title: *2021 Submillimeter Array Interferometry School*
Workshop homepage

– February 2021, *Società Italiana di Relatività Generale e Fisica della Gravitazione (SIGRAV)*, Italy - online
Title: *SIGRAV International School 2021: Gravity of Compact Astrophysical Objects and Gravitational Waves*
Workshop homepage

Internal Courses

- MAY, 5–14 2021, Bologna (online), Italy
  Title: *Writing, talking and presenting Science*;
- APRIL 19-23, 2021, Bologna (online), Italy
  Title: *Gamma Ray Bursts: from observations to physical properties*;
- NOVEMBER, 30 - DECEMBER, 2 2020, Bologna (online), Italy
  Title: *The Interstellar Medium*;
- SEPTEMBER, 17–22 2020, Bologna (online), Italy
  Title: *Gaia: Great Advances In Astrophysics*;
- MAY–JULY 2020, Collaborative Research Center "Neutrinos and Dark Matter in Astro- and Particle Physics" (SFB 1258), Technische Universität München (webinars), Germany
  Title: *Virtual Seminars on Multimessenger Astronomy*.

ISA Lectures

- DECEMBER, 15 2020, Bologna, Italy
  Title: "*Translating texts which do not exist. Pseudo-originality, multistable figures, and Fortini's literary reception of Heine and Brecht*"
  Lecturer: *Dr. Irene Fantappiè*, Institut für Romanische Philologie, Freie Universität Berlin, Germany;
- NOVEMBER, 24 2020, Bologna, Italy
  Title: "*What opera tells us about language, speech, music*"
  Lecturer: *Dr. Costantino Maeder*, Université Catholique de Louvain, Belgium;
- MAY, 19 2020, Bologna, Italy
  Title: "*Exploration of small bodies of the Solar System: focus on comets*"
  Lecturer: *Dr. Maria Cristina De Sanctis*, Institute for Space Astrophysics and Planetology - INAF, Italy;
- NOVEMBER, 12 2019, Bologna, Italy
  Title: "*This turbulent turbulent Word*"
  Lecturer: *Prof. Alexandre Lazarian*, University of Wisconsin - Madison, USA.

Teaching experiences

- March 2021, Bologna, Italy
  Tutoring: Tutor at Astrophysics Laboratory – X-ray Module
  Professor of the course: *Prof. Cristian Vignali*.
- November 2020, Bologna, Italy
  Tutoring: Tutor at Astrophysics Laboratory – X-ray Module
  Professor of the course: *Prof. Cristian Vignali*.

Scientific proposals

- **Telescope:** *Chandra*; **Cycle:** *AO 23*.
  Title: *Probing extreme X-ray winds: breaking the redshift-record for non-lensed QSOs*
  PI: Bertola E.; **Co-I:** *M. Cappi; G. Chartas; C. Vignali; M. Dadina; F. Tombesi; G. Lanzuisi; M. Gaspari; M. Giustini; G. Ponti; B. De Marco; R. Gilli; M. Brusa; M. Perna; L. Zappacosta; E. Piconcelli, A. Comastri*
  TAC evaluation: Marked with a 2.88 grade, threshold for acceptance at 3.5. Not accepted.
- **Telescope:** XMM-*Newton*; **Cycle:** *AO 20*.
  Title: *Probing massive X-ray winds: breaking the redshift-record for a non-lensed QSO*
  PI: Bertola E.; **Co-I:** *M. Cappi; G. Chartas; C. Vignali; M. Dadina; F. Tombesi; G. Lanzuisi; M. Gaspari; M. Giustini; G. Ponti; B. De Marco; R. Gilli; M. Brusa; M. Perna; L. Zappacosta; E. Piconcelli, A. Comastri*
  TAC evaluation: Not accepted.
- **Telescope:** *Chandra*; **Cycle:** *AO 22*.
  Title: *Probing massive X-ray winds: breaking the redshift-record for a non-lensed QSO*
  PI: Bertola E.; **Co-I:** *M. Cappi; G. Chartas; C. Vignali; M. Dadina; F. Tombesi; G. Lanzuisi; M. Gaspari; M. Giustini; G. Ponti; B. De Marco; R. Gilli; M. Brusa; M. Perna; L. Zappacosta; E. Piconcelli*
  TAC evaluation: Marked with a 3.36 grade, threshold for acceptance at 3.5. Not accepted.

Publications

- **BERTOLA E.**, ET AL. - "*The twenty-year X-ray history of the $z = 3.91$ lensed quasar APM 08279+5255: persistent X-ray reflection and X-ray winds*", 2021, to be submitted.
- **BERTOLA E.**, M. DADINA, M. CAPPI, C. VIGNALI, G. CHARTAS, B. DE MARCO, G. LANZUISI, M. GIUSTINI, AND E. TORRESI - "*X-raying winds in distant quasars: The first high-redshift wind duty cycle*", 2020, A&A, 638, A136.