

PhD name: Deborah Costanzo

PhD Cycle: XXXIV

Tutors: Cristian Vignali, Mauro Dadina, Massimo Cappi

RESEARCH PROJECT: Probing inflows and outflows in local Seyfert galaxies

The dynamics and geometry of the material inflowing and outflowing close to the supermassive black hole (SMBH) in active galactic nuclei (AGN) are still largely uncertain; notably, ejection and accretion processes may be linked to each other. Furthermore, it is fundamental to understand the physical properties, the extent, and energetics of the outflows, as they may also have a fundamental role in AGN feedback processes on the host galaxies, influencing their evolution.

The X-ray band is the most suitable to study AGN innermost regions because it includes the Fe K α fluorescence emission line at 6.4 keV, a fundamental proxy of the accretion flows onto the SMBH (Fabian et al. 2000), and possibly Fe resonant absorption lines ($\sim 7\text{-}12$ keV) produced by dense ($N_{\text{H}} \approx 10^{22} - 10^{24} \text{ cm}^{-2}$) winds with a wide range of velocities (from a few $10^{2-3} \text{ km s}^{-1}$ up to $\sim 0.3 c$; Tombesi et al. 2010) and ionization states ($0 \leq \log \xi \leq 3 \text{ erg cm s}^{-1}$, where ξ is the ionization parameter). Depending on their physical properties, winds have been typically classified either as Warm Absorbers (slow and mildly ionized, Blustin et al. 2005) or Ultra Fast Outflows (fast and highly ionized, Tombesi et al. 2010). An interesting case that has arisen in recent years is that of the so-called Obscurers (Kaastra et al. 2014), i.e. transient, optically thick winds typically located in the Broad Line Region that produce a strong spectral hardening in the X-rays, lasting from days to months. Both emission and absorption features in the X-ray spectra are observed to vary on time scales spanning from hours to years, probing phenomena at different distances from the SMBH.

In my research project I have been using time-resolved spectral analysis to simultaneously investigate the accretion flow and the outflows to further characterize them individually and search for possible correlations that could help discover the launching mechanisms of disk winds, which are not totally clear yet. In particular, I have analyzed a set of the X-ray brightest Seyfert 1 galaxies that went through an occultation event observed with XMM-Newton EPIC pn, i.e. the instrument with the largest collecting area in the Fe K energy band; among them, NGC 3783 (Mehdipour et al. 2017), NGC 5548 (Kaastra et al. 2014), NGC 3227 (Mehdipour et al. 2021) are the most noteworthy.

I have analyzed spectral variations sampling the shortest possible time-scales to have acceptable photon statistics, meaning few ks for such bright sources. This has allowed us to explore deeply inside the accretion disk, reaching distances of few gravitational radii from the black hole (given $M_{\text{BH}} \sim 10^7 M_{\odot}$).

The analysis consists of two steps. The first one is running a blind search on the short time-scale spectra extracted in sequence from single pointings. This means that, upon finding a satisfactory model for the continuum emission (typically a power law and some form of cold absorption) and the ubiquitous Fe K α emission line, we search for significant deviations from this model in the form of Gaussian lines, with positive or negative normalization. The significance of these individual lines is further assessed via extensive MonteCarlo simulations. Then, we study the distribution in energy of the detections: this allows us to understand their physical origin and determine the frequency at which they appear. In fact, if some detected lines cluster in a specific energy range, we can assume a common origin for them and thus extrapolate a “global” significance, that includes not only the information of the significance of a single line, but also how many times it is detected.

After assessing the statistical robustness of the results, we pass to the second part of the analysis, which consists in studying the evolution in time and energy of the detected features using the Residual Map technique. This is an upgrade of the Excess Maps technique that in the past gave many interesting results on variability patterns of emission lines (e.g. Iwasawa et al. 2004, De Marco et al. 2009). We visualize simultaneously the positive and negative residuals (i.e. the emission and absorption features) in the time-energy plane, looking for patterns and time intervals of particular interest.

We developed our two-phase technique using NGC 3783 as a test case. It is a local Seyfert 1 galaxy, observed for ~ 0.5 Ms with *XMM-Newton*. This source is the brightest one in our energy range of interest among the sources that have shown an obscuration event, which lasted for about a month in 2016. For this source we found that the energy distribution of the detected features are fairly different between the unobscured and obscured epochs, and notably they appear to be more significant in the obscured state, when they are considered individually. We also found that, in single epochs, the significance of the features does not depend on the flux of the source, even if we register variations of $\sim 30\%$ in the count rate within single pointings. Our time-resolved analysis allowed us to give a deep characterization of the obscurer, constraining the size of its clumps to be $\sim 1.7\text{-}4.2 \cdot 10^{13}$ cm for a distance of $\sim 7\text{-}10$ light days from the primary X-ray source.

The methodology we adopted not only can be applied to currently available X-ray datasets of bright AGN, but also holds strong potentiality for the future. In fact, the X-IFU instrument on board Athena (Barret et al. 2018), with its unprecedented collecting area (~ 3 times larger than the EPIC pn at 7 keV) will allow us to sample even shorter time-scales ($\sim 10^2$ s) on luminous targets, and to probe the innermost regions of fainter AGN, that are currently precluded.

WORKSHOPS, CONFERENCES & MEETINGS

25-27 February 2019 Bologna - "ALMA Science and Proposals workshop"

01-05 July 2019 Sexten, Italy - "From the Dolomites to the event horizon: sledging down the black hole potential well", contributed talk: "Probing accretion/ejection flows in AGN via Fe K emission/absorption lines variability"

06-09 August 2019 Edinburgh, UK - "Quasars in crisis" poster

08-13 September 2019 Bologna - "X-Ray Astronomy 2019" LOC member + poster

14-15 September 2019 Bologna - "Chandra/CIAO Workshop"

15-16 July 2020 online - Technological Advances in X-ray Astronomy

1 September 2020 online - NGC 3783 Consortium Meeting

8 September 2020 online - BLACKOUT Meeting

14-18 September 2021 online - Summer school "ONSCI - Officina di Narrazione della Scienza"

INTERNAL COURSES

17-25 June 2019 Bologna - "Statistics for Astrophysics"

27 May - 22 July 2020 online - "Neutrinos and Dark Matter in Astro- and Particle Physics"

17-22 September 2020 online - "Gaia: Great advances in Astrophysics"

30 November - 2 December 2020 online - "Interstellar medium"

19-23 April 2021 online - "Gamma Ray Bursts: from observations to physical properties"

5-14 May 2021 online - "Writing, talking and presenting Science"

PROPOSALS

"Unraveling the nuclear structure of NGC 3783" proposal 86048 for XMM-Newton AO-19, P.I. Gerard Kriss, STScI - Co-Investigator

"XMM Legacy Observation of the Archetypical AGN Outflow of NGC 3783" proposal 88057 for XMM-Newton AO-20, P.I. Ehud Behar, Technion - Co-Investigator

"XMM Legacy Observation of the Archetypical AGN Outflow of NGC 3783" proposal 90210 for XMM-Newton AO-21, P.I. Ehud Behar, Technion - Co-Investigator

ISA LECTURES

13 November 2018 - "A heart attack: can we re-wire the heart?" Lecture by Damia Mawad, University of New South Wales, Sidney, Australia

9 April 2019- "Are Polymer Nanocomposites Practical for Applications?", Lecture by Sanat K. Kumar, Columbia University, New York, USA

19 May 2020 - "Exploration of small bodies of the Solar System: focus on comets" Lecture by Dr. Maria Cristina De Sanctis, Institute for Space Astrophysics and Planetology - INAF, Italy

27 October 2020 - "Scholarship and Art: Visual and Intellectual Encounters across the Mediterranean" Lecture by Anna Contadini, University of London, UK

9 February 2021 - "Nanoscale pharmacology and biochemistry using advanced fluorescence microscopies" Battistini Lecture by Dr. Paolo Annibale, Max Delbrück Center for Molecular Medicine, Germany

19 October 2021 - "Covid-19 and Dante's Hell: Venturing from a Black Hole on the Thread of a Tune" Lecture by Beatrice Sica, University College London, UK

OTHER RELEVANT ACTIVITIES

12 February 2019 Bologna, Weekly PhD Seminars - Talk: "A dynamic black hole corona in an active galaxy through X-ray reverberation mapping"

28 April 2021 online, Weekly PhD Seminars - Talk: "Probing accretion/ejection flows in AGN via Fe K emission/absorption lines variability"

From January 2021 - Co-founder and host of "Dottorato et al." DIFA outreach podcast

PUBLICATIONS

"Incoherent fast variability of X-ray obscurers. The case of NGC 3783" - De Marco, B.; Costanzo D.; ... - A&A, Volume 634, id.A65, 17 pp.

"Short time-scale X-ray spectral variability in the Seyfert 1 galaxy NGC 3783" - Costanzo et al., re-submitted to A&A after referee revision