Hunting active galaxies within the unidentified high energy sources

Francesco Massaro

22 years of INTEGRAL catching results and discoveries

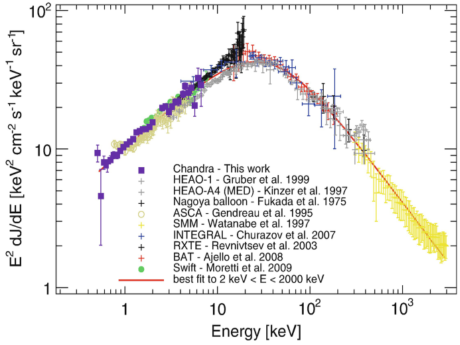
Outline

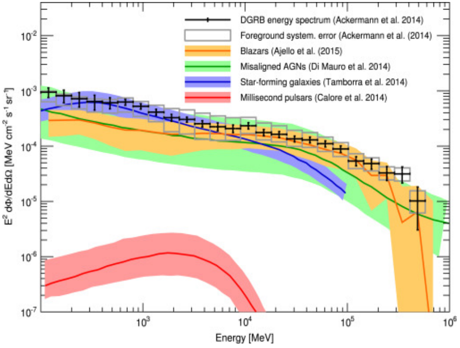
1. The unsolved mystery of the unidentified sources.
2. A brief overview of the sky from the keV to the GeV energy range
3. Hunting extragalactic sources in the hard X-ray sky.
4. Searching for low energy counterparts of unidentified gamma-ray sources.
5. What's next: conclusions and future perspectives.

The material related to references used to create this presentation are reported in the last slide.

What this talk is not about

I will not discuss, with the only exception of this slide, about the importance of unveil the nature of the unidentified sources at high energies and the need of having all follow up campaigns carried out to date, in particular, regarding the focus of this talk on the extragalactic sky.

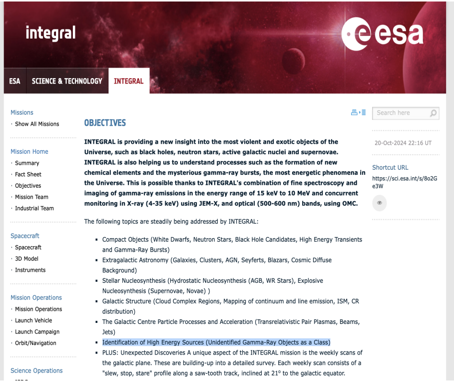




The knowledge of all source classes (and their luminosity functions) is crucial to obtain a complete overview of their contribution to the Cosmic X-ray Background and the Isotropic Gamma-ray Background.

INTEGRAL...Fermi ... and thinking about ROSAT!

One of the main scientific objectives ...



integral

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- Show All Missions

Mission Home
- Summary
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- Industrial Team

Spacecraft
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Mission Operations
- Mission Operations
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Science Operations

OBJECTIVES

INTEGRAL is providing a new insight into the most violent and exotic objects of the Universe, such as black holes, neutron stars, active galactic nuclei and supernovae. INTEGRAL is also helping us to understand processes such as the formation of new chemical elements and the mysterious gamma-ray bursts, the most energetic phenomena in the Universe. This is possible thanks to INTEGRAL's combination of fine spectroscopy and imaging of gamma-ray emissions in the energy range of 15 keV to 10 MeV and concurrent monitoring in X-ray (4-35 keV) using JEM-X, and optical (500-600 nm) bands, using OMC.

The following topics are steadily being addressed by INTEGRAL:

- Compact Objects (White Dwarfs, Neutron Stars, Black Hole Candidates, High Energy Transients and Gamma-Ray Bursts)
- Extragalactic Astronomy (Galaxies, Clusters, AGN, Seyferts, Blazars, Cosmic Diffuse Background)
- Stellar Nucleosynthesis (Hydrostatic Nucleosynthesis (AGB, WR Stars), Explosive Nucleosynthesis (Supernovae, Novae))
- Galactic Structure (Cloud Complex Regions, Mapping of continuum and line emission, ISM, CR distribution)
- The Galactic Centre Particle Processes and Acceleration (Transrelativistic Pair Plasmas, Beams, Jets)
- Identification of High Energy Sources (Unidentified Gamma-Ray Objects as a Class)
- PLUS: Unexpected Discoveries A unique aspect of the INTEGRAL mission is the weekly scans of the galactic plane. These are building-up into a detailed survey. Each weekly scan consists of a "slew, stop, stare" profile along a saw-tooth track, inclined at 21° to the galactic equator.

Search here

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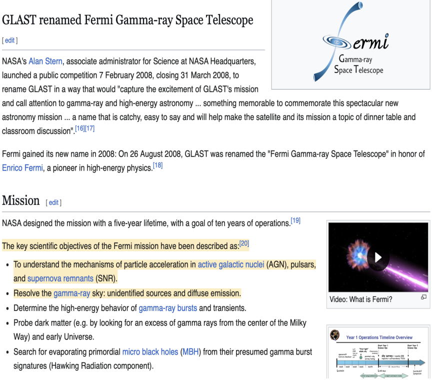


GLAST renamed Fermi Gamma-ray Space Telescope

[edit]

NASA's Alan Stern, associate administrator for Science at NASA Headquarters, launched a public competition 7 February 2008, closing 31 March 2008, to rename GLAST in a way that would "capture the excitement of GLAST's mission and call attention to gamma-ray and high-energy astronomy ... something memorable to commemorate this spectacular new astronomy mission ... a name that is catchy, easy to say and will help make the satellite and its mission a topic of dinner table and classroom discussion".[16][17]

Fermi gained its new name in 2008: On 26 August 2008, GLAST was renamed the "Fermi Gamma-ray Space Telescope" in honor of Enrico Fermi, a pioneer in high-energy physics.[18]

Mission [edit]

NASA designed the mission with a five-year lifetime, with a goal of ten years of operations.[19]

The key scientific objectives of the Fermi mission have been described as:[20]

- To understand the mechanisms of particle acceleration in active galactic nuclei (AGN), pulsars, and supernova remnants (SNR).
- Resolve the gamma-ray sky: unidentified sources and diffuse emission.
- Determine the high-energy behavior of gamma-ray bursts and transients.
- Probe dark matter (e.g. by looking for an excess of gamma rays from the center of the Milky Way) and early Universe.
- Search for evaporating primordial micro black holes (MBH) from their presumed gamma burst signatures (Hawking Radiation component).

Fermi Gamma-ray Space Telescope

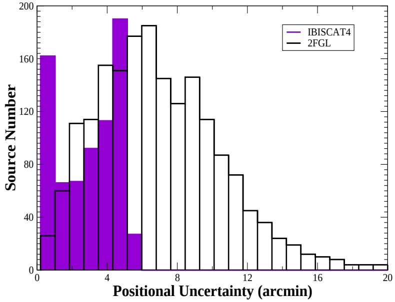
Video: What is Fermi?

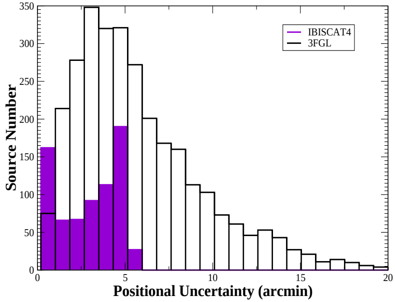
Year 1 Operations Timeline Overview

is "often" ... unveiling the nature of the unidentified sources.

However at high energies ...

To associate and identify an high energy source detected from hard X rays up to the most energetic gamma rays there is always a problem related to ... the positional uncertainty region!

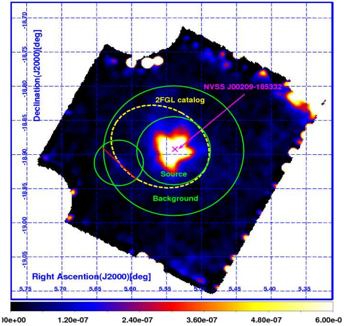


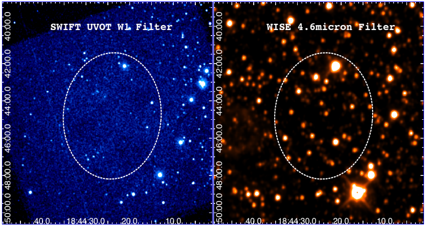


There is one important reason I am not comparing it with the 4FGL and/or the 5FGL.

(Un)Lucky cases

Two examples that can occur when searching for the low energy counterpart of a Fermi sources.

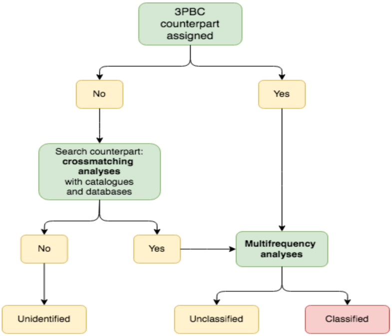


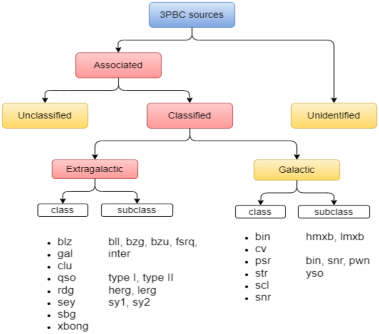


An extended gamma-ray source (on the left) and the infrared and ultraviolet images of the field with the Fermi positional uncertainty region overlaid for a point-like source (on the right).

Association vs identification

This is a scheme collected from an analysis of the Third Palermo BAT catalog (3PBC), in comparison with the latest INTEGRAL IBIS catalog recently done.





Using the same terminology adopted for the Fermi gamma-ray sources:

- ASSOCIATED: implies I know there is a low energy counterpart assigned.
- IDENTIFIED/CLASSIFIED: means I know what is the low energy counterpart.

Follow up campaigns are “always” crucial from radio up to X-rays but at the end the most powerful tool for the identification is more often optical spectroscopy.

A&A 459, 21–30 (2006)
DOI: 10.1051/0004-6361:20066055

Astronomy & Astrophysics

Unveiling the nature of *INTEGRAL* objects through optical spectroscopy

V. Identification and properties of 21 southern hard X-ray sources⋆,⋆⋆

N. Masetti[1], L. Morelli[2], E. Palazzi[1], G. Galaz[2], L. Bassani[1], A. Bazzano[3], A. J. Bird[4], A. J. Dean[4], G. L. Israel[5], R. Landi[1], A. Malizia[1], D. Minniti[2], F. Schiavone[1], J. B. Stephen[1], P. Ubertini[3], and R. Walter[6]

A&A 482, 113–132 (2008)
DOI: 10.1051/0004-6361:20079332

Astronomy & Astrophysics

Unveiling the nature of *INTEGRAL* objects through optical spectroscopy

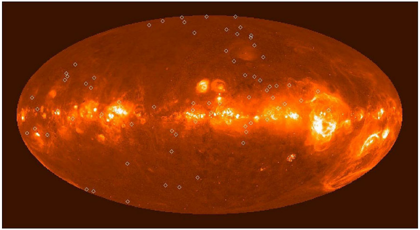
VI. A multi-observatory identification campaign⋆

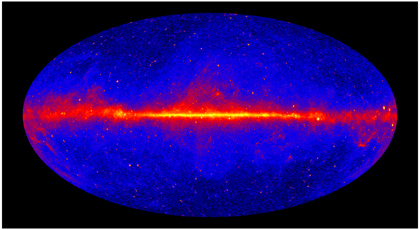
N. Masetti[1], E. Mason[2], L. Morelli[3], S. A. Cellone[4,5], V. A. McBride[6], E. Palazzi[1], L. Bassani[1], A. Bazzano[7], A. J. Bird[6], P. A. Charles[6,8], A. J. Dean[6], G. Galaz[9], N. Gehrels[10], R. Landi[1], A. Malizia[1], D. Minniti[9], F. Panessa[7], G. E. Romero[4,11], J. B. Stephen[1], P. Ubertini[7], and R. Walter[12]

Two examples taken from the works of my colleague N. Masetti and a lot of collaborators. Follow up X-ray observations are also worth mentioning but while these are crucial for INTEGRAL and SWIFT-BAT might not be ideal for the Fermi unidentified sources. However it is worth mentioning the great idea about using the Cool Attitude Targets for Chandra (PI: Koss) as follow up of hard X-ray sources.

The “sky content” from tens keV to hundreds of GeV

There are huge differences (mainly related to the physics of the sources) between the sky seen in the hard X-ray band and that at GeV energies.

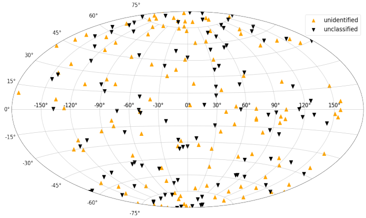


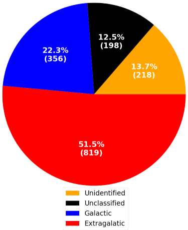


It is extremely hard to accelerate particles emitting in the gamma-rays and in most of the cases you need “beaming”... thus implying that the Fermi sky is dominated by: BLAZARS, also quite common in the hard X-rays.

The “sky content” in the hard X-ray band

Just an overview of the latest analysis some collaborators carried out on the comparison between the 4^{th} INTEGRAL IBIS catalog and the 3PBC.

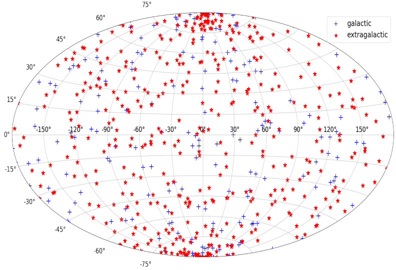


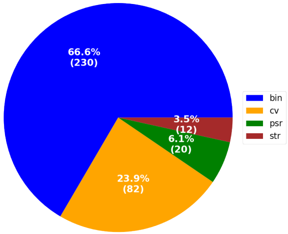


The pie charts and following tables reported here are based on an analysis of the 3PBC catalog in comparison with the 4^{th} INTEGRAL IBIS catalog. The total source number listed in 3PBC to 1593 when considering a signal to noise ratio above 3.8 covering covers 90% of the sky down to a flux limit of $\sim 10^{-11}$ erg cm^{-2} s^{-1}. The INTEGRAL IBIS survey hard X-ray catalogue includes 939 sources detected above a 4.5σ significance threshold in energy band 17-100 keV.

The “sky content” in the hard X-ray band

Just an overview of the latest analysis some collaborators carried out on the comparison between the 4^{th} INTEGRAL IBIS catalog and the 3PBC collected with SWIFT-BAT survey.





The "sky content" in the hard X-ray band

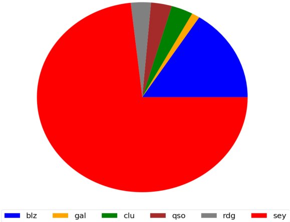
... and in numbers here.

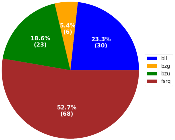
Class symbol	Class number	Subclass symbol	Subclass number
bin	231	hmxb	117
		lmxb	108
		?	6
cv	83		
str	12	-	6
		yso	1
		?	1
psr	21	bin	1
		-	5
		snr	12
		pwn	3
scl	2		
snr	4		
mqso	1		
pn	1		
galcent	1		

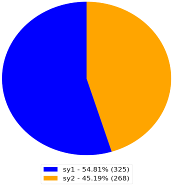
Class symbol	Class number	Subclass symbol	Subclass number
blz	129	bll	30
		bzg	7
		bzu	24
		fsrq	68
gal	10	interacting	3
		-	7
clu	27		
liner	1		
qso	26	type 1	18
		type 2	1
		?	7
rdg	25	herg	21
		lerg	3
		?	1
sey	593	sy1	325
		sy2	268
sbg	5		
xbong	4		

The dominant extragalactic classes in the hard X-ray band

The hard X-ray sky is mainly dominated by Seyfert galaxies, a bit more than 50% belonging to the type 1, generally unobscured in the soft X-rays, while the rest being obscured and optically classified as type 2.



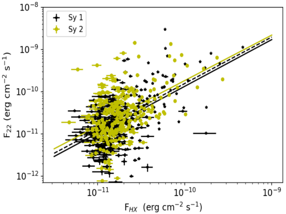


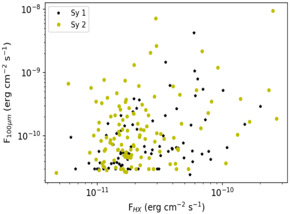


These Seyfert galaxies allowed us to start building the Turin-SyCAT catalog. Its 2nd release includes a total of 633 Seyfert galaxies, with 282 new sources corresponding to an increase of ∼80% with respect to the previous release.

Something "expected" for the Seyfert galaxies

Comparing the hard X-ray and the infrared emissions of Seyfert galaxies we confirm, that there is no clear difference between the flux distribution of the infrared-to-hard X-ray flux ratio of Seyfert galaxies Type 1 and Type 2.

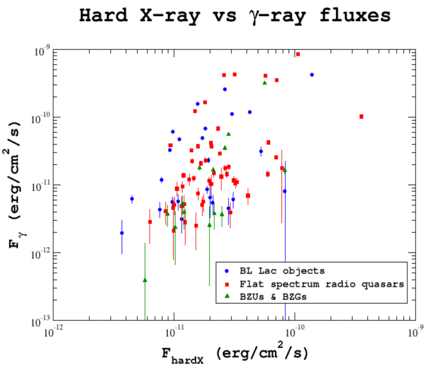


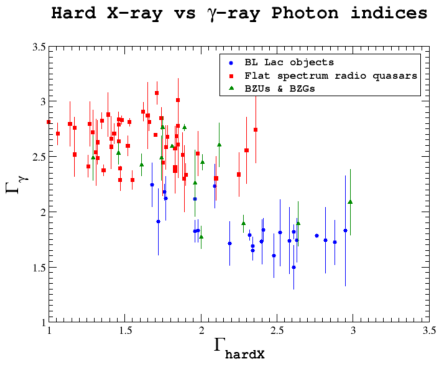


However, there is a significant trend between the mid-IR flux and hard X-ray flux, confirming previous statistical results in the literature. No so clear if tested using longer wavelengths.

A quick focus on the non-thermal hard X-ray sky

Something expected also for blazars, the second dominant extragalactic class in the hard X-ray sky.

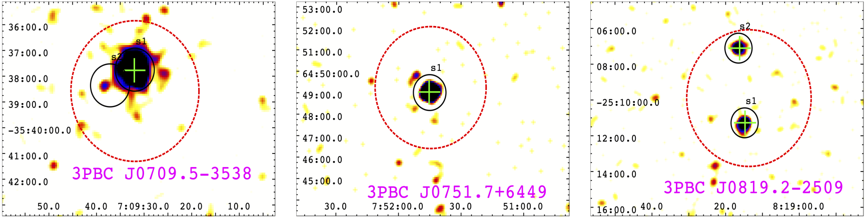




These trends could be clearly related to the nature of the blazars emission, even if poorly investigated in the literature. The second one on the left appear to be more related to a "class bias" opening new questions about the nature of what we identify as blazar.

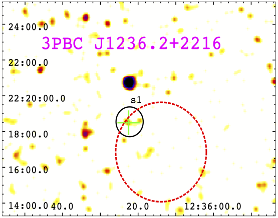
Hunting low energy counterpart with soft X-ray observations

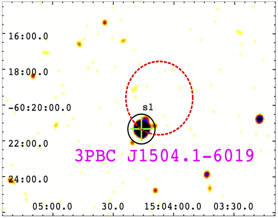
Two examples of clear cases where SWIFT-XRT observations revealed the most probable counterpart and one case where X-ray imaging could be ambiguous but using the spectroscopic information (in the X-ray as well as in the optical band) could reveal the nature of the low energy counterpart.



Hunting low energy counterpart with soft X-ray observations

Additional two cases where the soft X-ray observations were not useful at all.

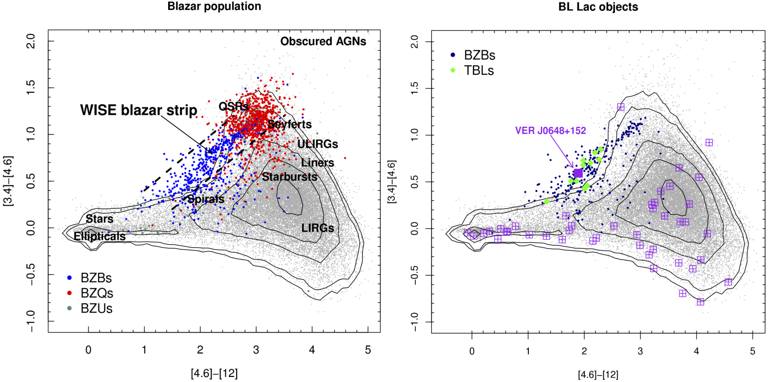




However here optical spectroscopic observations could help, assuming that the nature of the hard X-ray object is extragalactic.

At higher energies ... using mid-infrared colors

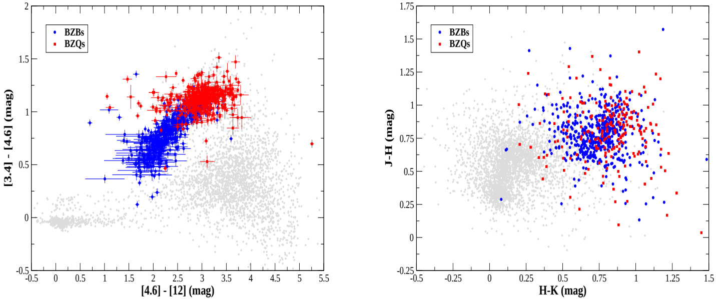
The discovery of the WISE Blazar strip and an example of its potential to looking for the low energy counterpart of a VERITAS unidentified source.



It is worth noting the case of mrk 501 observed in the 2FGL ... hundreds of counterparts detected with WISE but only one having mid-infrared colors of gamma-ray blazars.

At higher energies ... using mid-infrared colors

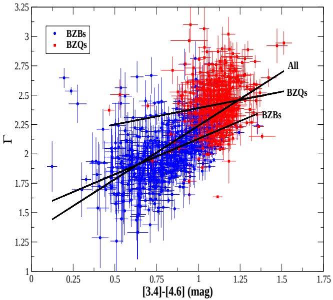
How things evolved over time thanks to the new releases of the Fermi-LAT catalogs. Restricting only to gamma-ray emitting blazars ...

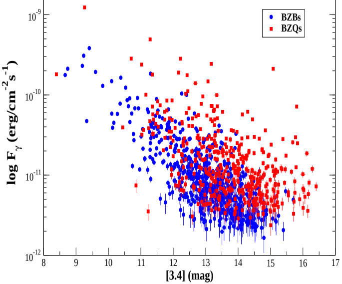


The same seen at mid-infrared colors could also appear at near-infrared energies. Using the WISE Gamma-ray strip more than ∼500 blazars were associated and then identified.

A correlation over ∼13 orders of magnitudes

A correlation between gamma-ray spectral index and mid-infrared color (a surrogate of the spectral shape). Then the presence of a link between gamma-ray and mid-infrared fluxes.





The origin underlying these trends is mainly related to the non-thermal emission seen in blazars. Unfortunately we do not have these trends for extragalactic sources in the hard X-ray sky.

Conclusions and future perspectives

1. The extragalactic hard X-ray sky is dominated by Seyfert galaxies and blazars. For the former ones there is a trend between the hard X-ray flux and the one at mid-infrared frequencies, while the latter ones show a correlation between the hard X-ray and the gamma-ray spectral shapes.
2. To search for low energy counterparts of unidentified gamma-ray sources combining mid-infrared colors and optical spectroscopic observations has been a successful tool. This allowed us to discover up to $\sim$500 blazars, mostly belonging to the BL Lac class.
3. Unveiling the nature of the remaining unidentified sources could potentially reveal new classes of sources emitting in the hard X-ray sky as well as at GeV energies.
4. At the very end ... all follow up observations should be combined with optical spectroscopic observations to obtain a firm conclusive answer.

In general works on the unidentified sources continue even after the end of a mission ... always remember about Mrk 501 with CGRO.

Credits

[1] Cusumano, G., La Parola, V., Segreto, A., et al. 2010, A&A, 524, A64; [2] Bird, A. J., Bazzano, A., Malizia, A., et al. 2016, ApJS, 223, 15; [3] Krivonos, R., Revnivtsev, M., Lutovinov, A., et al. 2007, A&A, 475, 775; [4] Masetti, N., Mason, E., Morelli, L., et al. 2008, A&A, 482, 113; [5] Masetti, N., Parisi, P., Jiménez-Bailón, E., et al. 2012, A&A, 538, A123; [6] Masetti, N., Parisi, P., Palazzi, E., et al. 2009, A&A, 495, 121; [7] Massaro, F. & D'Abrusco, R. 2016, ApJ, 827, 67; [8] Massaro, F., D'Abrusco, R., Ajello, M., Grindlay, J. E., & Smith, H. A. 2011, ApJ, 740, L48; [9] Oh, K., Koss, M., Markwardt, C. B., et al. 2018, ApJS, 235, 4; [10] Ricci, F., Massaro, F., Landoni, M., et al. 2015, AJ, 149, 160; [11] Koss, M., Trakhtenbrot, B., Ricci, C., et al. 2017, ApJ, 850, 74; [12] Beckmann, V., Soldi, S., Shrader, C. R., Gehrels, N., & Produit, N. 2006, ApJ, 652, 126; [13] Bottacini, E., Ajello, M., & Greiner, J. 2012, ApJS, 201, 34; [14] Gilli, R., Comastri, A., & Hasinger, G. 2007, A&A, 463, 79; [15] Abdollahi, S., Acero, F., Ackermann, M., et al. 2020, ApJS, 247, 33.

.. and many more.

Fin

Thank you!