

MULTI-wavelength studies of BLACK hole and nonpulsating NEUTRON star X-ray binaries

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AUDITION INAF RSN4

X-RAY BINARIES ACCRETION AND OUTFLOWS



Fender & Belloni 2012

WHY STUDYING X-RAY BINARIES

- Nearby laboratories of extreme physics - dense matter, strong gravity, superenergetic particle acceleration
- Accretion and ejection follow the same principles at all masses - binaries are smallscale AGN
- Binaries evolve very fast real time astrophysics



THE PROJECT - MULTIBLACKNEUTRONS

A multi-wavelength and multi-tecnique approach to the study of black hole and non-pulsating neutron star X-ray binaries



Long-standing collaboration, systematic from ~2015, involving 20 researchers and 7 institutes (5 INAF, 2 Universities).

MULTIBLACKNEUTRONS is "scheda madre" to P-REX (PI: Capitanio)

THE TEAM - members



14 INAF members

12 staff, 2 post-docs (1.3 FTE/year)

6 associates

5 staff, 1 post-doc (0.3 FTE/year)

International collaborators

UK, Spain, France, The Netherlands, Australia, US

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Fiamma Capitanio, Giovanni Piano

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Luciano Burderi, Alessandro Riggio, Andrea Sanna

Uni. Palermo

Tiziana Di Salvo, Rosario Iaria

THE TEAM



Timing analysis

Spectral-timing

Broad band Spectral analysis

Modelling

Fine spectroscopy

Time-resolved spectroscopy

Polarization

EYES ON THE X-RAY SKY

- Accretion spectroscopy and fast time-variability
- Outflows fine spectroscopy and timeresolved spectroscopy

IXPE

Swift

THE IMAGING X-RAY POLARIMETRY EXPLORER

OBJECTIVES

SCHEDA FIGLIA P-REX, P.I. Fiamma Capitanio

- ASI/NASA mission (launched in December 2021)
- X-ray polarimetry at 2-8 keV
- Provides a combination of imaging, spectral and temporal capabilities
- 3 X-ray telescopes with identical mirrors and polarization-sensitive imaging detectors at their focus.

- Constrain the geometry of Comptonization regions and jets in accreting LMXBs
- Constrain the spin of BHs and NSs
- 1.5 Ms of observations supported by large multi-band observing programs

EVN

Noto (IT)

EYES ON THE RADIO SKY

The physics of relativistic jets

MeerKAT

e-MERLIN

AMI-LA

LBA

VLA

Radio

X-ray

X-ray

Radio

Radio

Radio

Optical

Optical Optical

Optical

NIR

X-ray/x-rays

https://www.media.inaf.it/2019/02/21/i-tre-giorni-dello-scorpione/

MEDIA INAF

Observing time - Three days of multi-band observations of Sco X-1

	Observatory	Approved Time	Proposal code	P.I.	Aim	Notes
1-3	VLBA, EVN and LBA	72-hr over three days	GM074	S.E. Motta	High angular resolution and sen- sitivity continuous monitoring at 8.4 GHz.	Core Observation
4	Chandra	120ks over three day	20400701	S.E. Motta	X-ray timing and fine spec- troscopy.	Core Observation
5	Nicer	As much as possible over 3 days	Legacy program	S.E. Motta and J. Homan	Very high resolution X-ray tim- ing.	Core Observation
6	INTEGRAL	80 ks	1620027	S.E. Motta	Hard X-rays uninterrupted mon- itoring.	Support Observation.
7	VLA	8-hr	VLA/19A-302	S.E. Motta	High time-resolution radio observation at 5 and 8.4 GHz.	Support Observation.
8	OVRO	Best effort basis	NA	S.E. Motta	High-frequency radio monitor-	Support Observation.
9	MeerKAT	1 hr	NA	R. Fender	High-sensitivity radio bserva- tions at 1.3 GHz	Support Observation.
10	ESO VLT	6-hr over 3 nights	0102.D-0418	F. Vincentelli	High time-resolution OIR pho- tometry with Hawk-I.	Support Observation.
11	NOT	3 half-nights		J.J.E. Kajava	High-precision photomety in V- band with ALFOSC.	Support Observation.
12	SALT	Best effort basis		D. Buckely	Spectroscopy	Support Observation.
13	Liverpool Telescope	7.5-hr over 3 nights	PL19A15	S.E. Motta	Fast optical photometry in I+z band.	Support Observation.
14	XMM-Newton	90ks	DDT request	S.E. Motta	Fast X-ray and fast optical pho- tometry with UVM2 filter	Support Observation.
15	TNG	3 hr	A38DDT4	S.E. Motta	High-resolution spectroscopy with HARPS-N	Support Observation.

EUROPEAN r∳idt**N ∀ t**spectros **F**\$ ISTITUTO NAZIONALE DI ASTROFISICA NRF NATIONAL INSTITUTE CSIRO SARAO NETWORK CHANDRA onal Research Foundation South African Radio AV. ESCOPIC esa integral .IMI NAZIONALE xmm-newton European Space Agency GALILEO NRAO

Observing time - The Accretion-Ejection physics in X-ray binaries

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richie	-Eject
From	cretion-
	Aco
	ANA:
	BAN
	ACE-

cility	Source	Time	Year	Ы	Observation details
MM-Newton	GRS 1915+105 (BH)	45ks* 11.5ks	2021 2021	Motta	DDT request, ObsID 0871191401 Proposal 086496, Obs ID 0864960101
	V4641 Sgr (BH)	180ks*	2021	Motta	DDT request, ObsID 0891802001
vift	Bright BH Transient	75 ks*	2022	Del Santo	Approved via Swift guaranteed time
	GRS 1915+105 GRS 1915+105	30 ks* 30 ks	2021 2022	Motta	Approved via Swift guaranteed time
	MAXI J1810-222	23 ks*	2021	Russell	ToO request (source ID 00011105)
	Swift J1729.5-3223	5 ks*	2021	Russell	ToO request (source ID 00014435)
	4U 1820-30	30 ks	2022	Russell	Approved via Swift guaranteed time
TEGRAL	Bright BH Transient	600 ks (pre-approved)	2022	Del Santo	Proposal 1940027 (awarded via INTEGRAL-TAC)
	GRS 1915+105	45ks	2021	Motta	Proposal 086496 (awarded via XMM-TAC)
	V4641 Sgr	380ks*	2021	Motta	DDT, Obs ID 18700080001
CER	4U 1820-30	90 ks	2022	Marino	Proposal 5104 (awarded via NICER TAC)
ISTAR	4U 1820-30	60 ks	2022	Marino	Proposal 5104 (awarded via NICER-NuSTAR TAC)
eerKAT	GRS 1915+105	4 hr (16 pointings)*	2021	Motta	Guaranteed time via ThunderKAT collaboration
lerlin	GRS 1915+105	12hr x 2*	2021	Motta	DDT request, DD12003, DD10008
/N	GRS 1915+105	8hr x 2*	2021	Motta	Proposal E20A012, EM144b,c
CA	New X-ray transient New X-ray transient New X-ray transient	1hr x 3 1hr x 3 1hr x 3	2021 2021 2022	Russell	C2601 (2021APR cycle) (awarded via ATCA-TAC) C2601 (2021OCT cycle) (awarded via ATCA-TAC) C2601 (2022APR cycle) (awarded via ATCA-TAC)
	GX 339-4 MAXI J1803-298 Swift J1729.5-3223 BH Transient	28hr (7 pointings)* 79hr (18 pointings)* 14hr (3 pointings)* 4hr x 10	2021 2021 2021 2022	Russell	C3057 (awarded via ATCA-TAC)
	MAXI J1810-222	40hr (11 pointings)*	2021	Russell	CX445 (awarded via DDT)
	V4641 Sgr	4hr (1 pointing)*	2021	Russell	C1199 (awarded via DDT)
	Swift J1818.0-1607	8hr (1 pointing)*	2021	Russell	CX496 (awarded via DDT)
	4U 1820-30	90hr	2022	Russell	C3456 (awarded via ATCA-TAC)
BA	GX 339-4 BHT	30hr (3 pointings)* 6hr x 4	2021 2022	Russell	V456 (awarded via ATNF LBA-TAC)

Observations obtained in 2021-2022

 ~1600ks in X-rays (XMM, Swift, NICER, INTEGRAL, NuSTAR)

• 356 hours in radio (MeerKAT, eMERLIN, EVN, ATCA)

Observing time - More multi-band observations (since 2018)

- Swift: follow up of BH and NS observed with MeerKAT via SwiftKAT program, ~700ks (since 2019) PI: Motta
- XMM-Newton, approved ToO observations of NGC 3621, 120ks (2020) PI: Motta
- NuSTAR, GRS 1915+105, 45ks (2019) PI: Motta
- MeerKAT, GRS 1915+105, 12 hr (45 pointings, via ThunderKAT 2020) PI: Motta
- VLBA, GRS 1915+105, 8hr (2019) PI: Motta
- EVN, GRS 1915+105, 8hr (2020) PI: Motta
- ATCA, black hole transient, 3 hrs; IGR J17091-3624, 11 hrs; 4u 1543-47, 5 hrs; Swift J1818.0–1607, 12 hr, (between 2018 and 2022) - PI. Russell
- VLA, 4U 1820-30, 6hrs (2018) PI: Russell
- Swift/XRT: faint X-ray transients in the Galactic Center, 80 ks + 54ks (2019 and 2020) PI: Marino
- Astrosat: Swift J1658.2-4242 e GRS 1915+105: 47ks (2018, 2019) PI: Belloni
- INTEGRAL: MAXI J1348-630, MAXI J1820+070: 780 ks (2018, 2019) PI: Belloni
- XMM-Newton: black hole transient ToO, 220ks + 220ks (2018, 2021) PI: Casella
- HAWK-I: black hole transient ToO, 20hr (2019) PI: Casella
- REM: Observations of LMXBs, tens of hr since 2008, 76 hr/yr since 2017 PI: Casella
- > 2000ks of X-rays observations (Swift, XMM, NuSTAR, Astrosat, INTEGRAL)
- 70hr of observations in radio (MeerKAT, VLBA, EVN, ATCA, VLA)
- Hundreds or hours in IR (REM and HAWK-I)

International collaborations

- ThunderKAT
- SKA/MeerKAT+
- EVN

Radio

X-rays

%-rays

- ngEHT
- SOXS
 - eXTP
 - IXPE
 - Athena
 - Theseus
 - Strobe-X
 - Swift/XRT team
- AGILE
 - ASTRI
- CTA

- Motta, Russell

- Motta
- Motta
- Motta, Casella
- Belloni, Del Santo, Motta, Stella, Casella,
 Pinto, Marino, D'Aì, Sanna, Di Salvo,
 Burderi, Iaria
 - Capitanio, Cocchi
 - Pinto, D'Aì, Del Santo, Motta, Marino,
 Di Salvo, Burderi, Iaria
 - Casella, Del Santo, Motta, Marino, Pinto, Pintore, D'Aì, Ambrosi, Di Salvo, Burderi, Iaria
 - Motta, Pintore
- m D'Aì, Ambrosi
 - Piano
 - Pintore, D'Aì, Del Santo, Piano, Segreto
 - D'Aì, Del Santo, Piano, Pintore, Segreto

Team network and collaborations

Since 2015 147 refereed papers +1 (35 in 2021-2022) 980 citations h-index 26

A few highlights coming...

V404 CYG: CLUMPY OUTFLOW FROM EDDINGTON ACCRETION

WHEN THE GRS 1915+105 ENTERED THE OBSCURED PHASE

Motta et al. 2021a

After 26yr of extreme activity

- First transitioned to a ~canonical hard state
- Then entered a prolonged obscured phase

The variable radio jets are fed by variable accretion happening behind a complex layer of absorbing material.

RADIO AND X-RAY OBSERVATIONS OF SCO X-1: ULTRA RELATIVISTIC FLOWS

QPOs are the **only** proxy of launch of the invisible URFs

Motivated the richiesta finanziamento EJECTA

RELATIVISTIC PRECESSION

Constraining black hole (and neutron star) masses and spins via X-ray QPOs

A spin distribution consistent with that from GWs is emerging

Bhargava et al. 2021

Motta et al. submitted

MAXI J1820+070

MODELLING THE JET EMISSION OF BLACK HOLE AND NEUTRON STAR XRBS

- ISHEM (Malzac 2013) cannot reproduce the soft γ-ray tail from GRS 1716-249 unless p < 2
- Challenges the shock acceleration theory
- Non-thermal Comptonisation origin most likely

The "standard scenario" of conical geometry and X-rays PDS does not work for 4U 0614.

- Either parabolic jet + X-rays PDS input
- ➡ Or conical jet + flicker-noise PDS input

CRITICALITIES

Lack of funding and man-power

• Currently no dedicated funding:

Past funding via project **Sco X0** (PI Belloni, audition 2021), **now expired** (ASI/INAF 2017 - 101 k€, ASI/ INAF 2019 - 159 k€, INAF-Mainstream - 40 k€)

• Very limited man-power, especially radio astronomers:

Lack of man-power to handle regular stream of data, especially radio

No funding to form next generation of scientists to prepare for SKA, EHT, Athena, eXTP, etc.

• Post-doc:

Russell - formerly ASI INAF, now Finanziamento Regione Sicilia (until November 2022)

- Ambrosi Swift fondi missione (until April 2023)
- Marino associato, currently abroad

Funding requests

A way out

EJECTA: Extreme JEts from CompacT Accretors	Mini grant	PI: Motta
ACE-BANANA: ACcretion-Ejection physics in Black hole And Neutron star X-rAy biNAries	GO/GTO grant	PI: Del Santo
3D-FAST: A 3D approach to fast variability in black-hole binaries scheda <i>GHATS</i> ,	Large grant	PI: Belloni
XB jet variable polarised emission ————————————————————————————————————	Theory grant	PI: Casella
Development of an automated pipeline for REM data reduction	Mini grant	Pl: Testa, Co-l Casella
BLOSSOM: BLack hOleS Swift fOrMation	Large grant	Pl: Pinto
P-rex: Polarized X-rays from LMXB	Large GO grant	Pl: Capitanio

EJECTA ACA-BANANA	Directly and uniquely related to <i>MULTIBLACKNEUTRONS</i> Travel funding and post-doc (radio astronomer)
3D-FAST	Funding for post-doc (multi-wavelength)
INAF Astrophysics Fellowship	 Post-docs candidates could be joining the team

SUMMARY AND CONCLUSIONS

Important role in the national and international panorama

- Large amount of multi-band data and high publication rate
- Broad involvement in international collaborations
- Vast expertise in relevant areas

We lack man-power and funding to support the team

- We often surrender leadership to other institutes
- We require especially radio-astronomers experienced in galactic transients

A RADIO LOOK AT SCO X-1: THE DISCOVERY OF ULTRA RELATIVISTIC FLOWS

Global VLBI and NICER observations

Some preliminary results

Relative Right Ascension (mas)

- 2 URFs detected already, in the predicted X-ray state
- Core jet switching off
- Orientation changing jets

6 hr of data out of 3.5 days