High-energy emission and disk/jet connection in Galactic black-hole binaries

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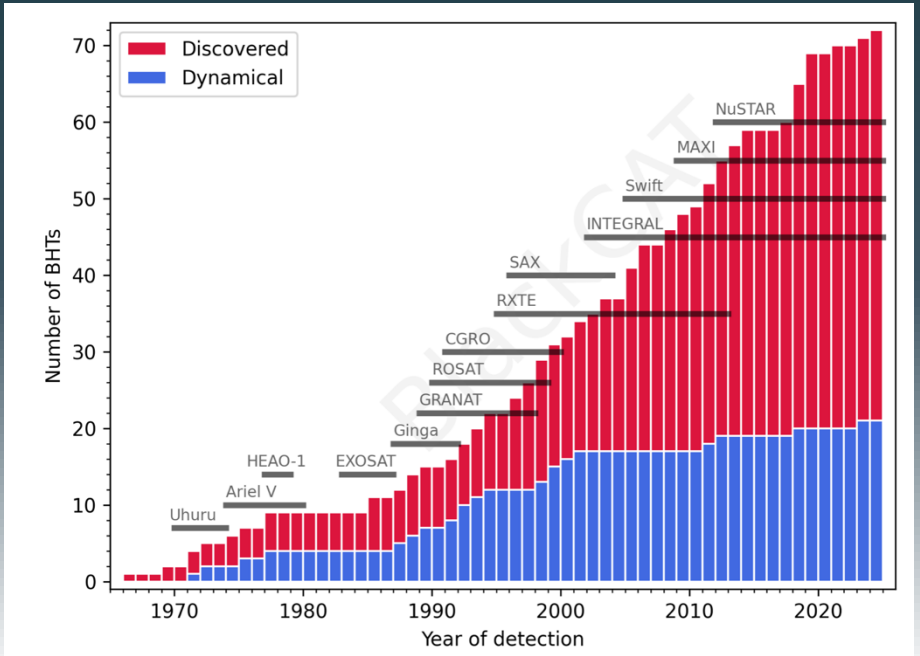
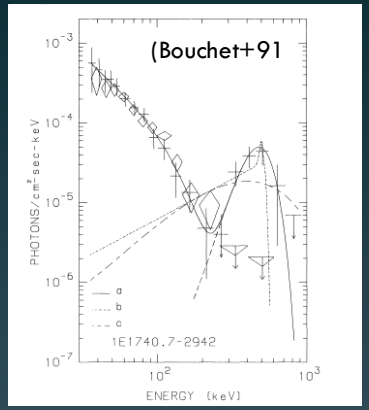
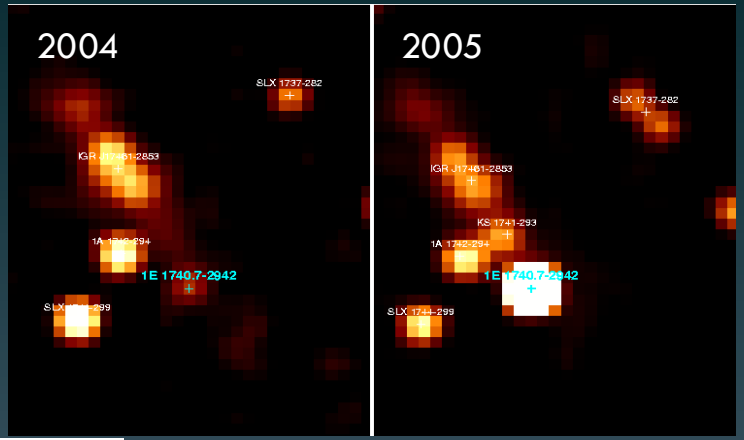
Black Hole X-ray Binaries

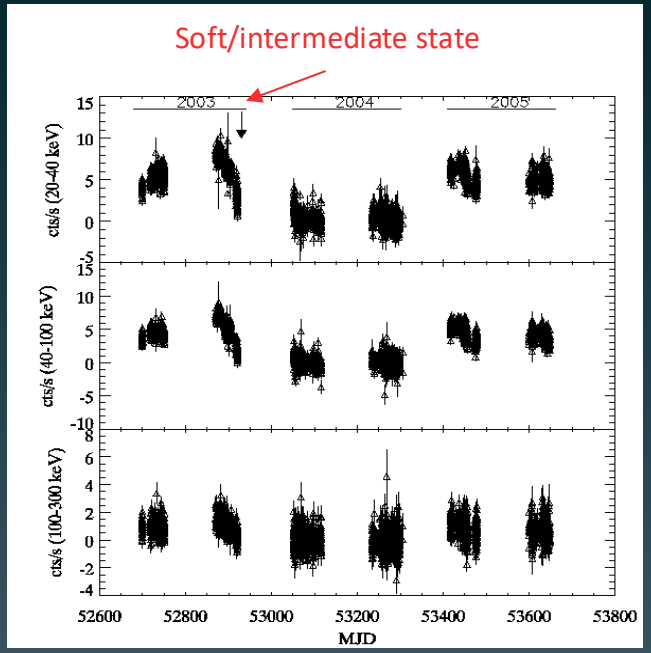
- ✓72 BHTs in the Galaxy
  (Tetarenko+16; Corral-Santana+16 and updates)
- ✓20 dynamically confirmed BHBs
- ✓Masses range up to 15$M_{\odot}$
- ✓11 persistently accreting

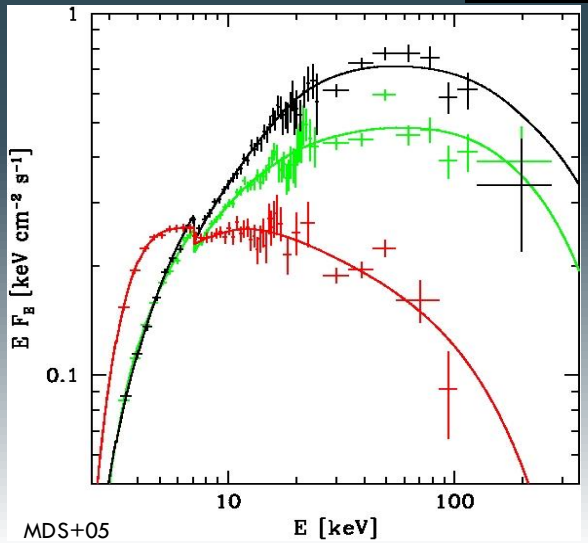


The Great annihilator: 1E 1740.7-2942





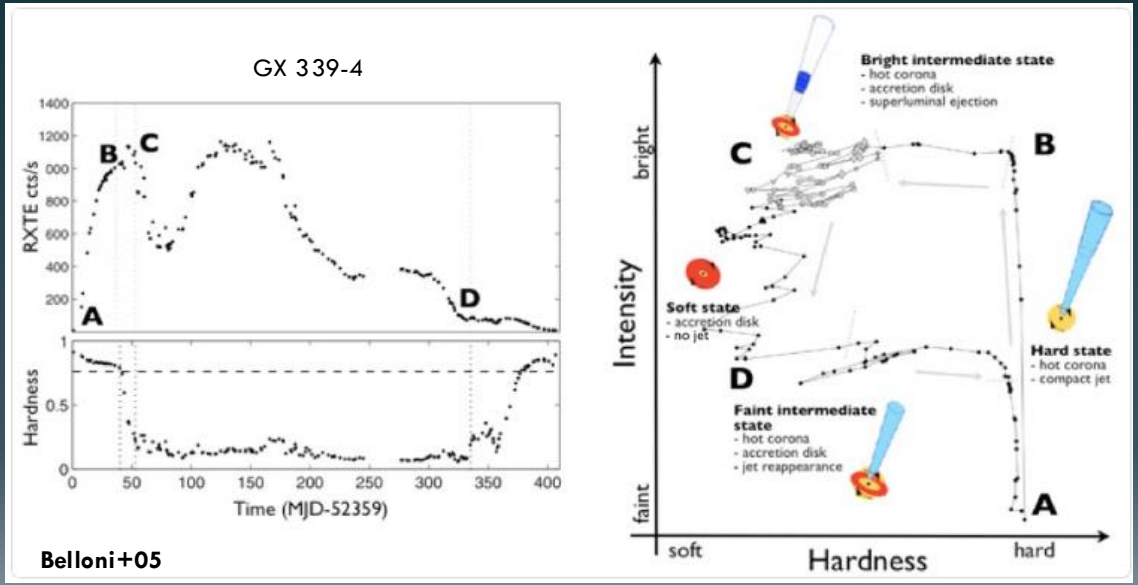




- The source was almost always in hard state. A dim state was observed in 2004. Before the fainting of the source a rare soft state was observed (MDS+05)
- MeV tail and No annihilation line detection (Bouchet, MDS+09)

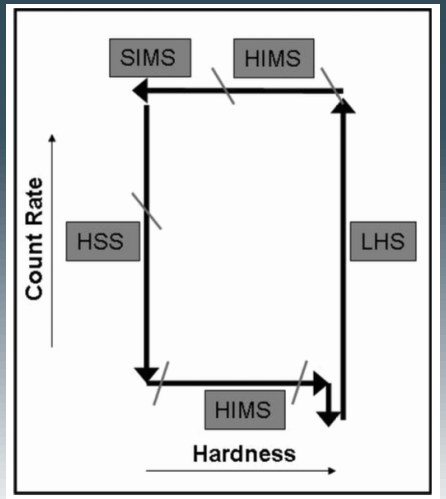
See Rodi's talk

Outbursts evolution in the (not all) transient LMXBs



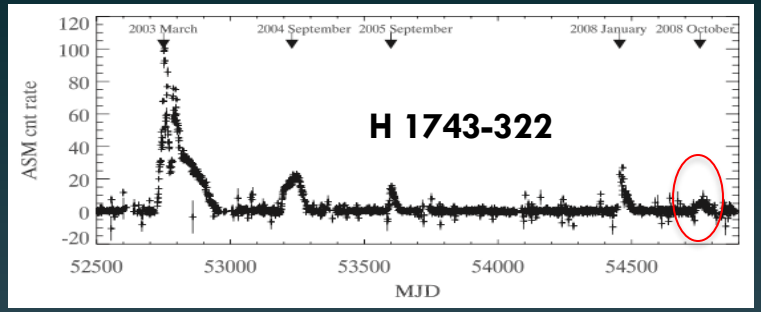
Belloni+05

When in outburst, the BH transients evolve in a Hardness Intensity Diagram following a specific pattern through the spectral states, a diagram called q-diagram.

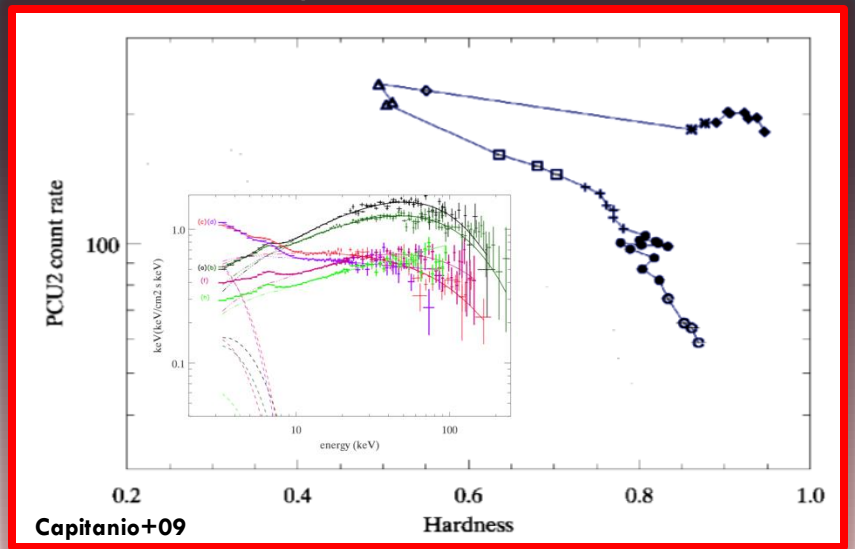


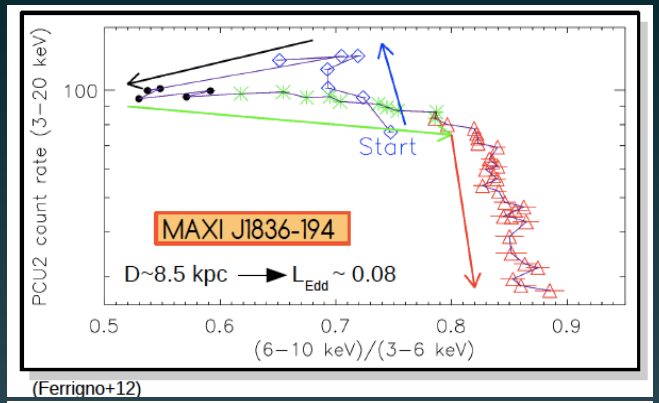
See Motta's talk

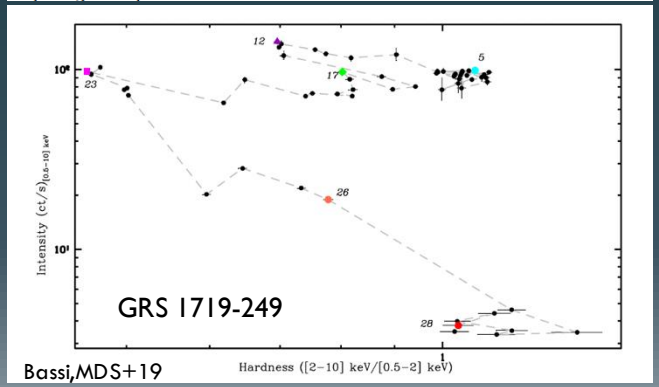
Failed transition outbursts



One of the first peculiar outbursts was observed by INTEGRAL in 2008



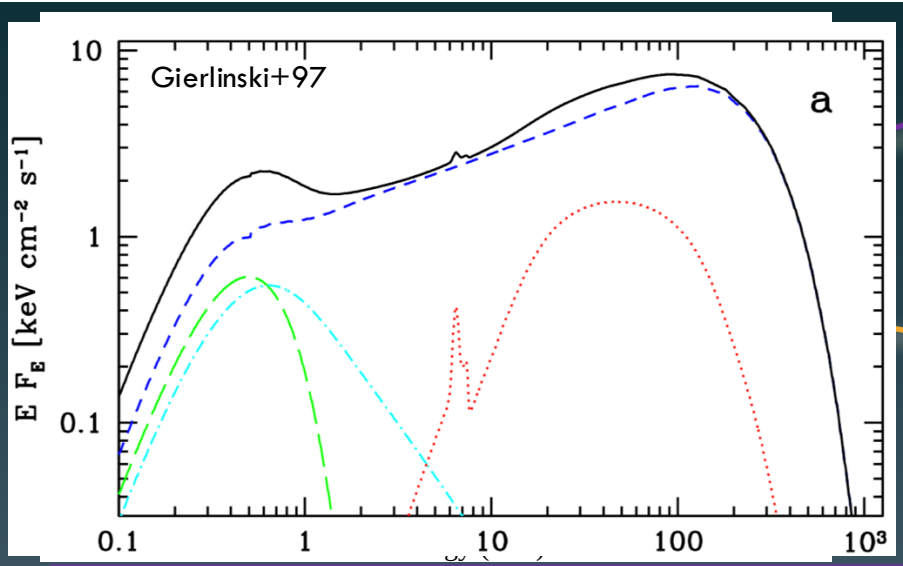


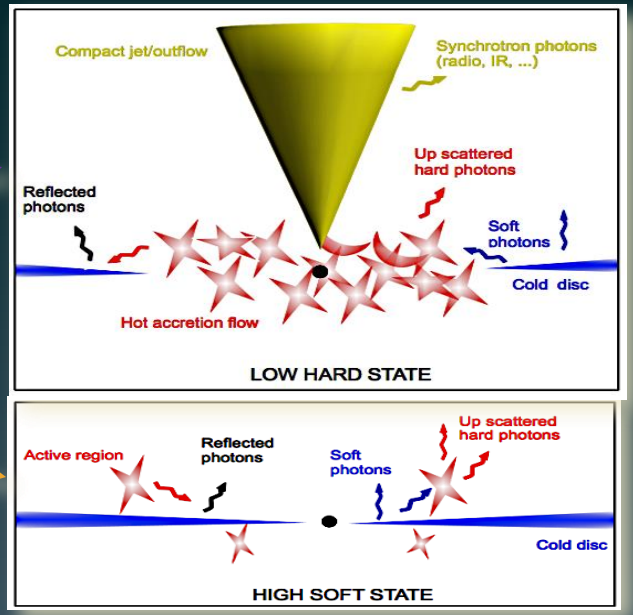


- 40% of BHBs show hard-only behaviour
- peak luminosities lower than 0.11 L_{edd} ?

(Tetarenko+16)

Truncated Disc Model (Done+07)





Hard state

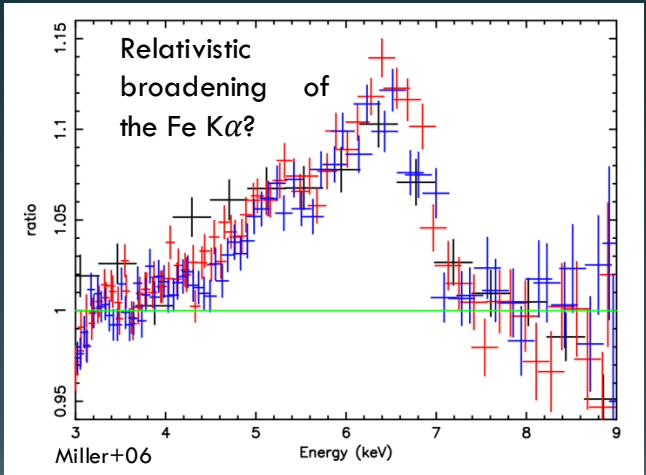
- ✓ Truncated disc at 100 Rg ➡ Faint black-body disc emission
- ✓ Hot accretion flow ➡ thermal Comptonisation in the hot plasma kTe~100keV, τ~1-3
- ✓ Jets ➡ Synchrotron photons (radio, IR)

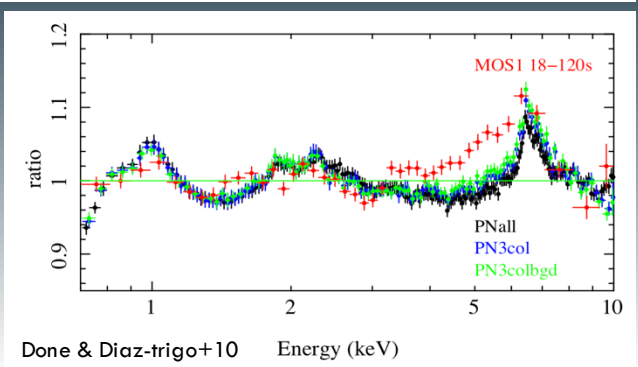
Soft State

- ✓ Disc extended up to the innermost stable circular orbit (ISCO)➡ Dominant disc emission
- ✓ Magnetic corona ➡ Non-thermal Comptonisation in the active regions
- ✓ Faint or quenched radio jets. X-ray winds

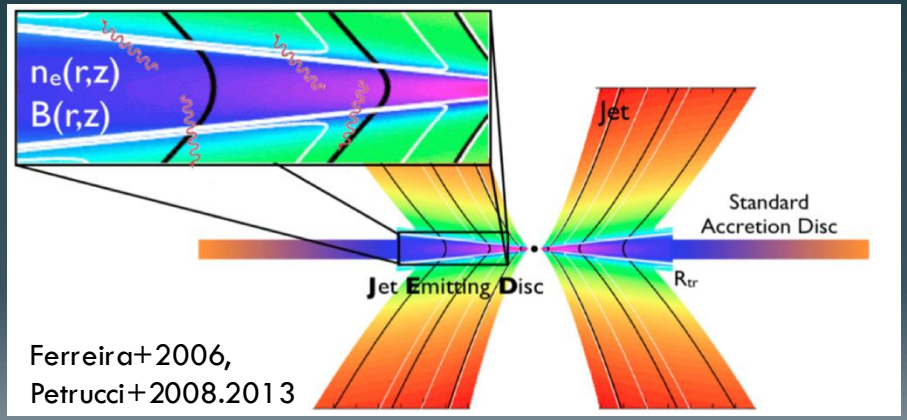
Open questions: geometry of the accretion flow

1. Is the disc truncated in hard state?





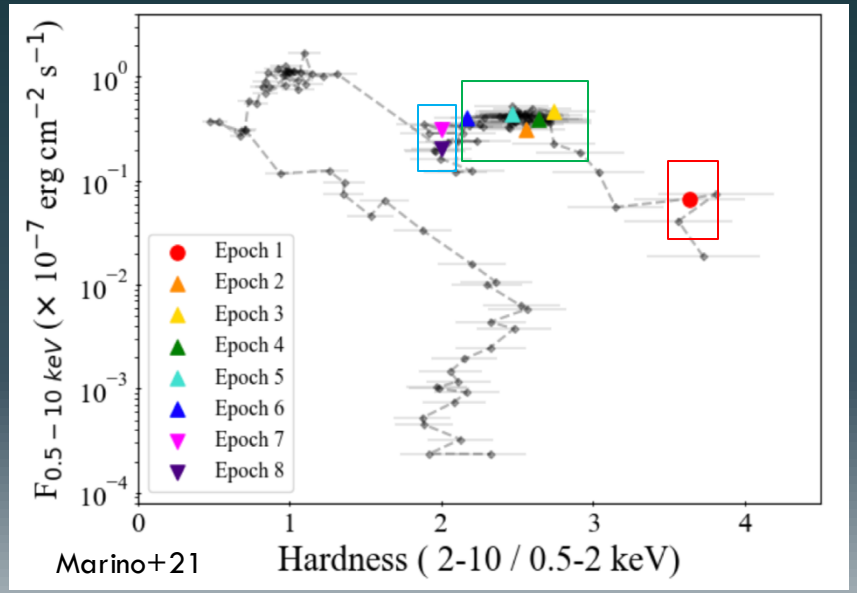
The JED-SAD model:
a unified accretion-ejection paradigm

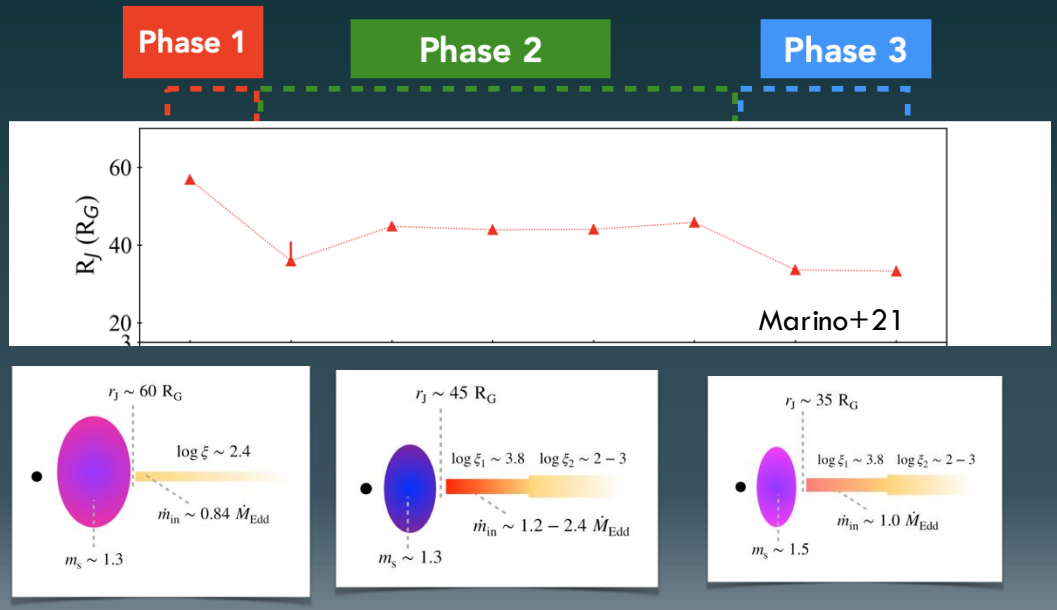


JED-SAD to model the bright BH transient **MAXI J1820+070** in hard state and to give constraints to the inner disc radius (Marino+21).

Disc truncation in the bright BH-XRB MAXI J1820+070

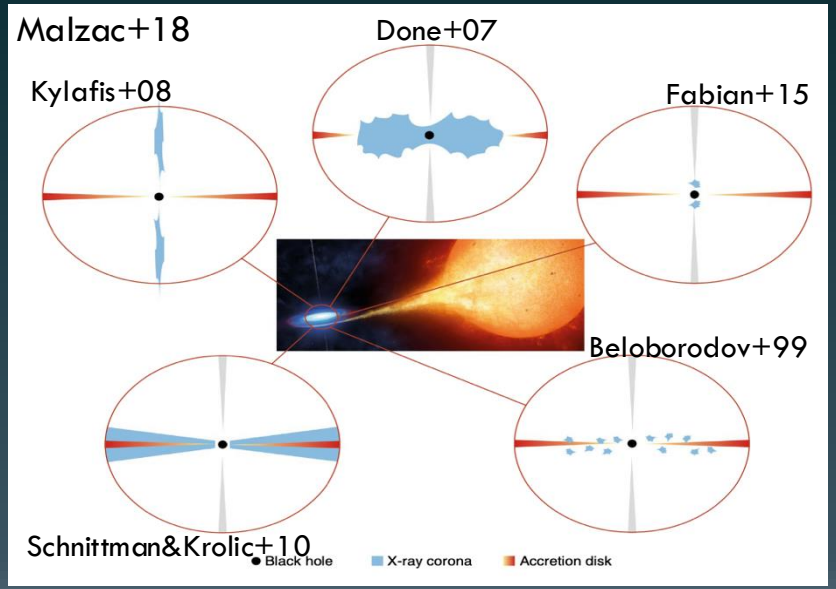
8 broadband spectra
XRT+NuSTAR+NICER+ BAT

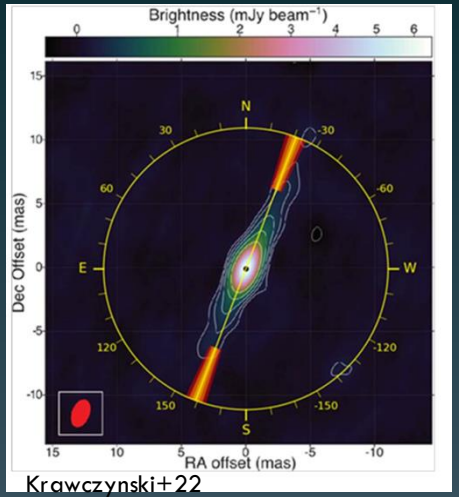




The best-fitting results show that **the disk is truncated** and it approaches the BH during the transition to the intermediate state.

2. Geometry of the innermost accretion structures?





Krawczynski+22

IXPE Polarization results in Cyg X-1 → corona must extend parallel to the disk

MW campaign on GX 339-4 (by ItalianBH team): system configuration with the corona horizontally extended on the plane of the accretion disc GX 339-4

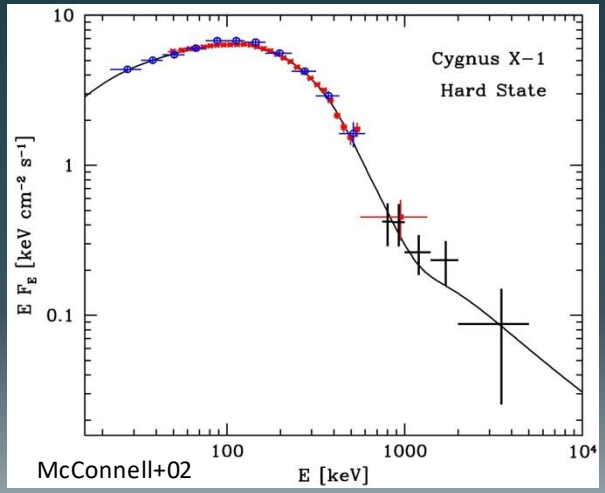
(Mastroserio et al., ApJ, under review)

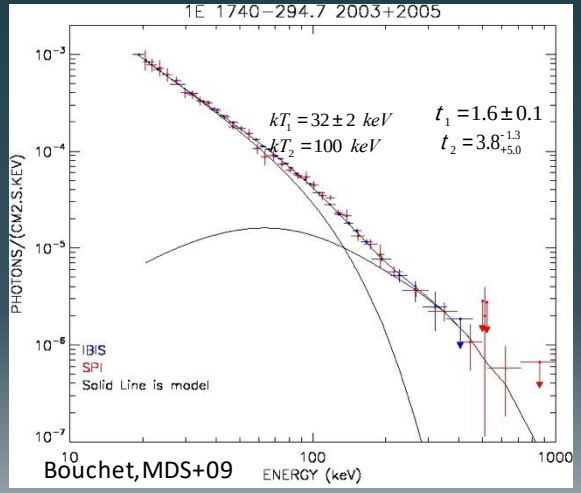
See Capitanio's talk

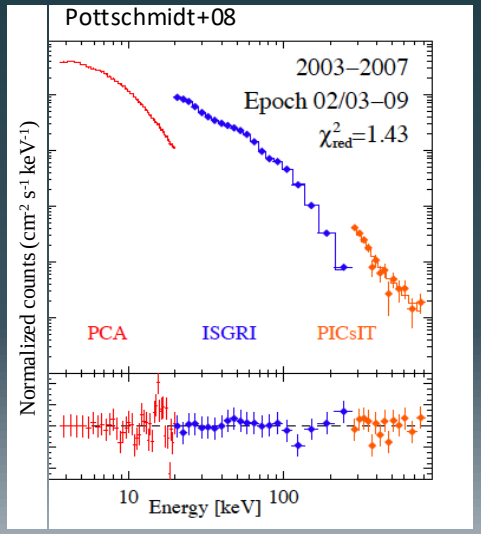
Origin of the high-energy (few hundreds keV) tails in BH binaries in Hard States (?)

From CGRO

To INTEGRAL
(see review by Motta+21)

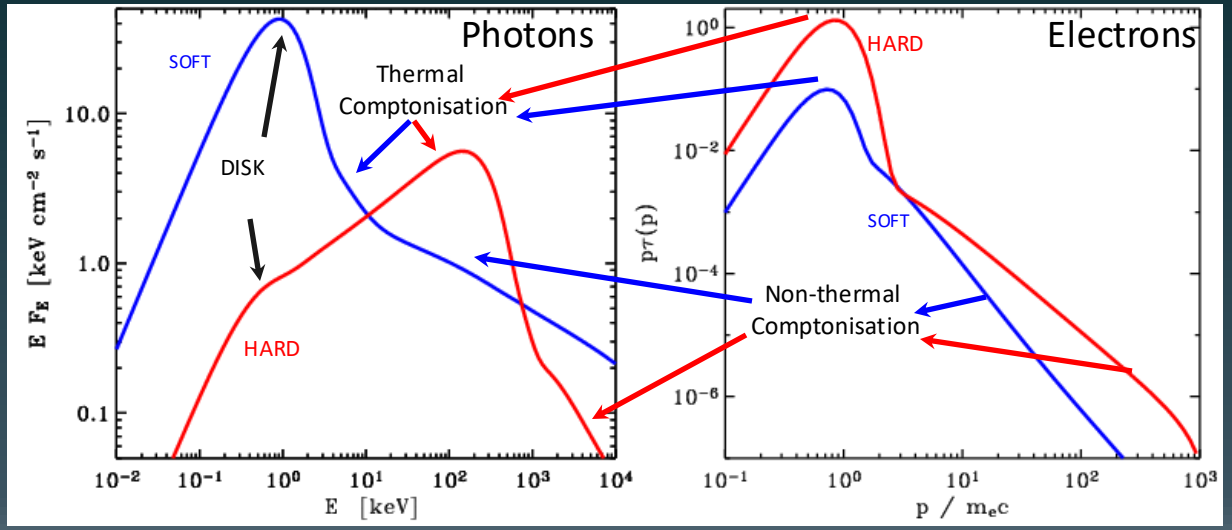






1. Comptonization by a non-thermal electrons population in the corona
2. Synchrotron emission in the JET (polarization measurements, see Cangemi's talk)
3. Two Comptonization by two different thermal electrons population

Hybrid Comptonisation models

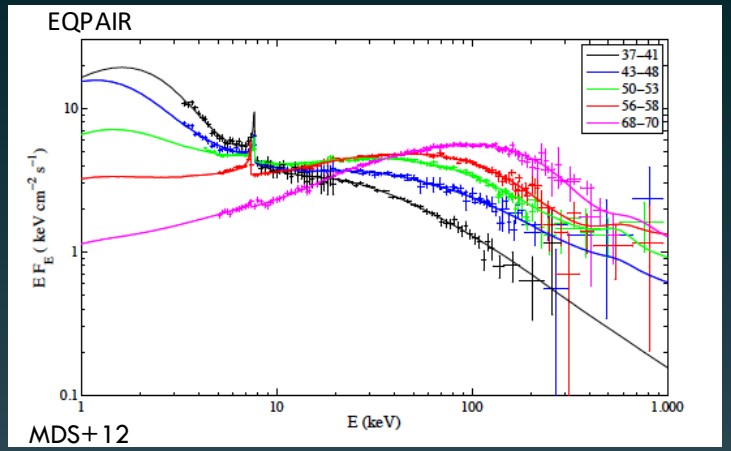


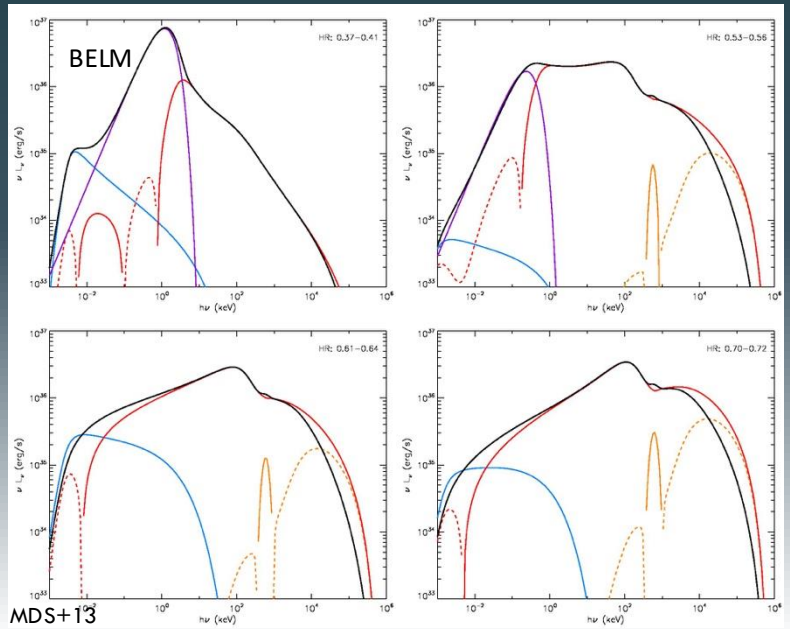
Hard X-rays: hybrid Comptonization

- **EQPAIR (Coppi 1999)**
- **BELM (Belmont+08)** → Magnetic field in the corona

6 years of INTEGRAL observations of Cygnus X-1 (MDS+13)

The additional non-thermal Comptonisation component is required in ALL states





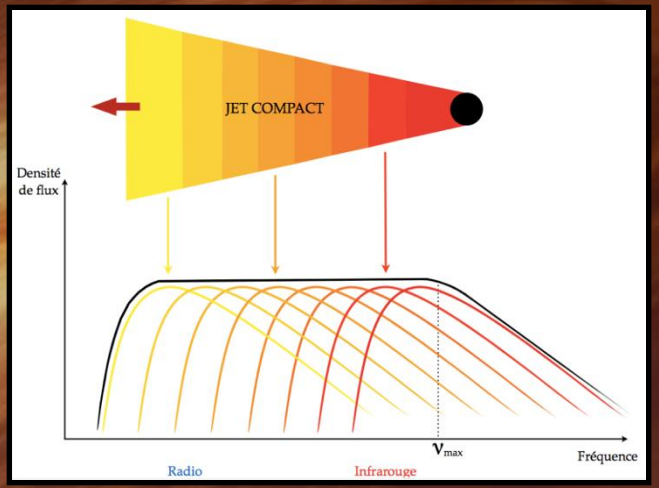
Estimation of the intensity of the magnetic field in the corona

- B ~ 1E+05 G (Hard)
- B ~ 1E+06 G (Soft)

In agreement with qualitative results of Poutanen & Vurm 2009.
Consistent with analytic estimation of Wardzinski & Zdziarski 2002.

Ejection: the other face of the medal

- **Jets:** collimated outflows of ionised particles
- In XRBs, they are typically not resolved (with a few exceptions) -> compact jets
- Radio-to-IR emission is due to self-absorbed synchrotron spectra emitted by the various shells

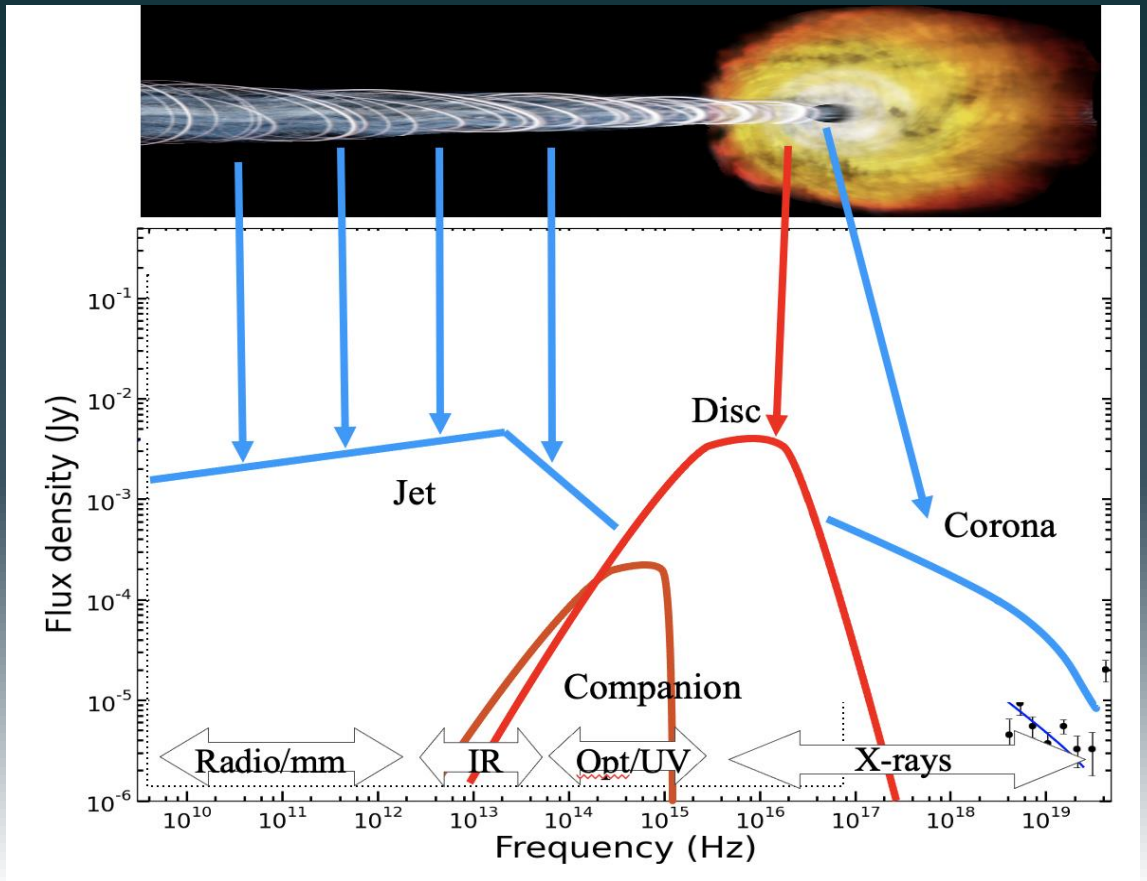


Radio-to-IR jet spectrum, Coriat11

See Motta's, Degenaar's and Bruni's talks

Radiation from a BH low-mass X-ray binary at all wavelengths

Spectral Energy Distribution (SED)



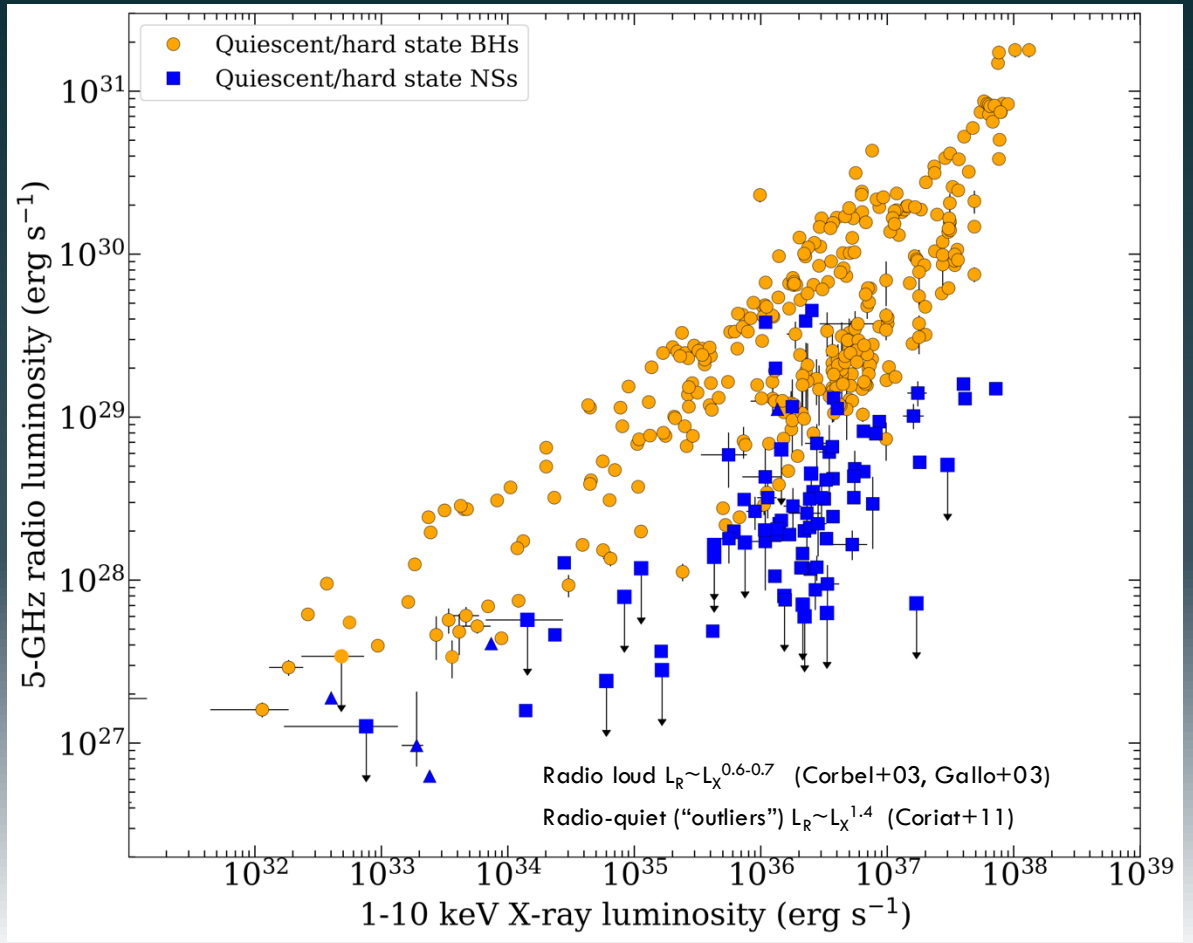
Radio/X-ray correlation: accretion/ejection coupling

Radio (jet) and X-ray (corona) luminosity are correlated, showing a certain level of accretion-ejection interconnection (e.g. Gallo+18)

NS LMXBs are typically radio fainter than BH systems (a factor around 20, Tetarenko+16, Gallo+18);

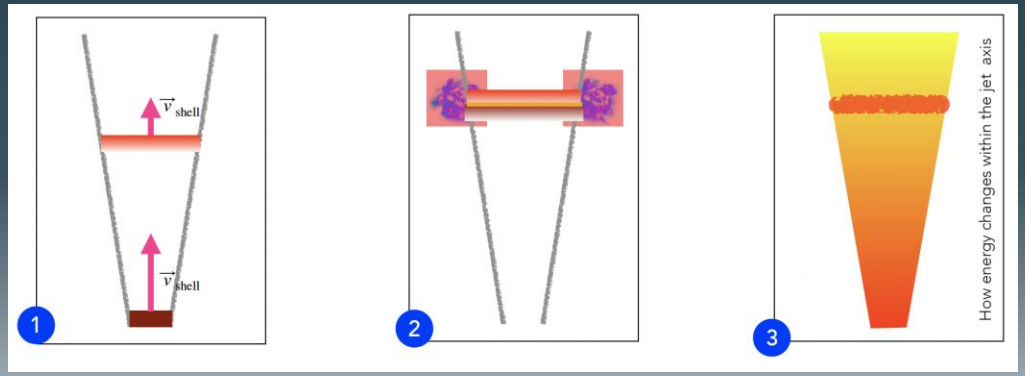
Lr-Lx diagram for NSs and BHs; data from Bahramian+18

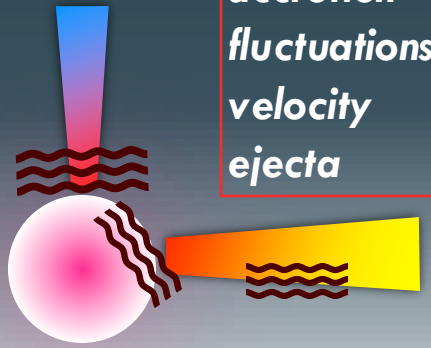
See Motta's talk



THE INTERNAL SHOCKS MODEL (ISHEM; Malzac 2013, 2014)

- The shells are injected at the base of the jet (inner accretion flow) with variable velocities (v_{shell})
- Internal shocks due to collisions between the ejecta along the jet occur and some energy is released locally



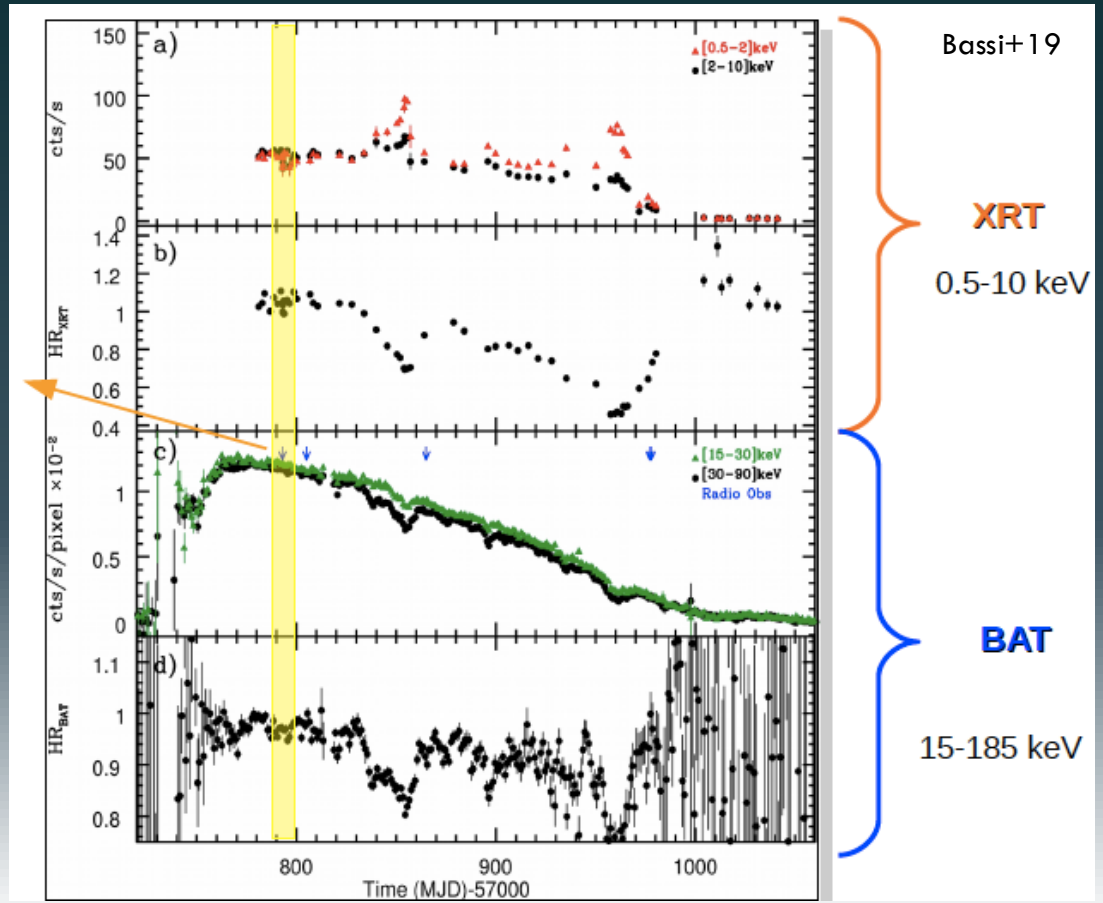


Variability in the accretion drives fluctuations in the velocity of the ejecta

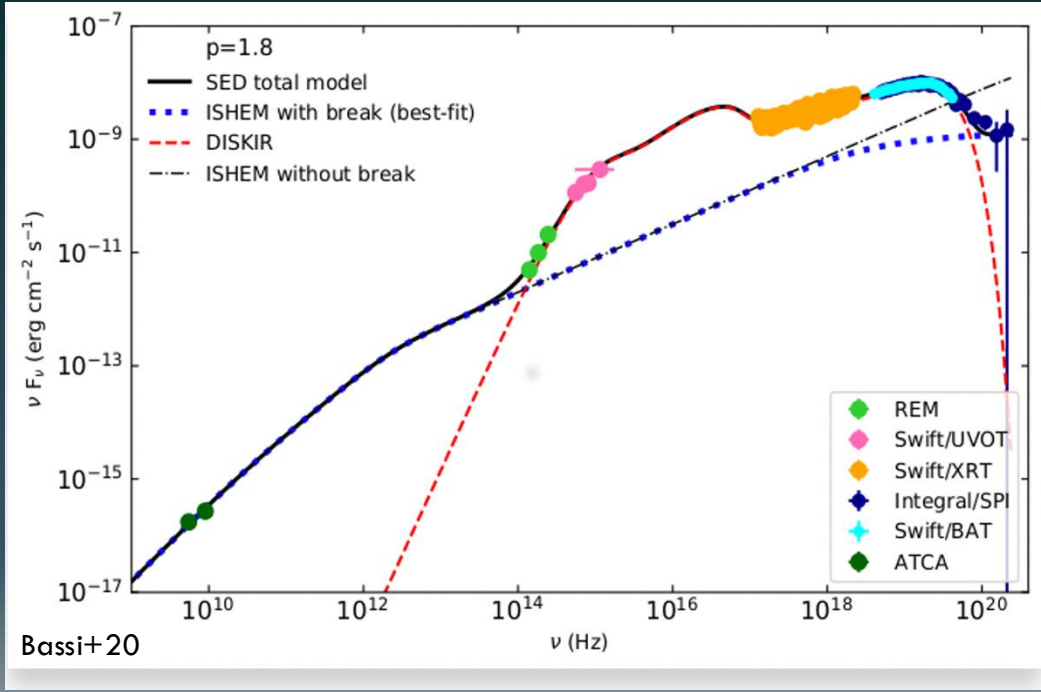
The power density spectra (PDS) derived from the X-rays light curve are used as input (Drappeau+15; Peault+19; Bassi+20; Marino+20)

GRS 1716-249

9 February 2017
MW campaign
(from radio to γ-rays):
- ATCA
- REM
- Neil Gehrels Swift Observatory
- INTEGRAL



ISHEM on the SED of the BH transient GRS 1716-249

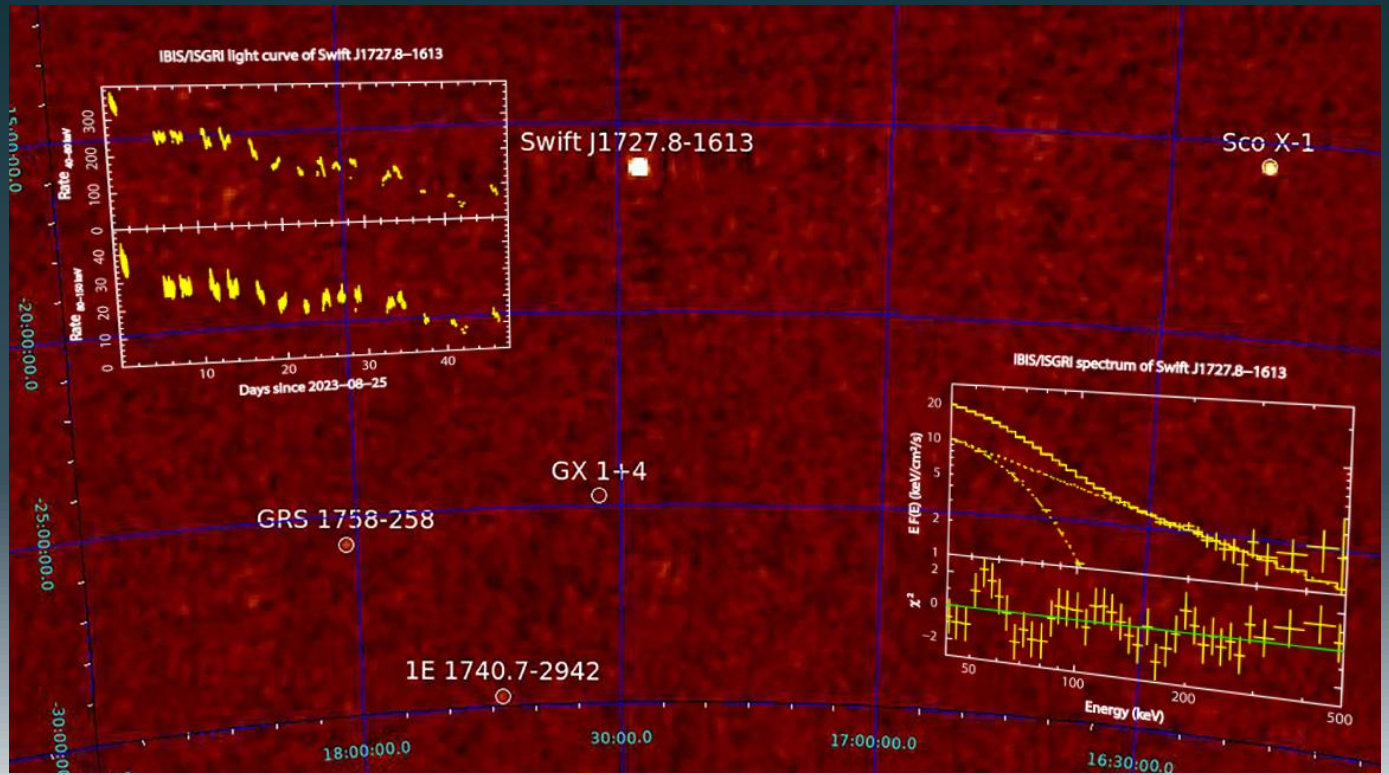


It is not possible to reproduce the soft γ-ray emission with the jet model unless the index of the electron energy distribution (p) <2 → difficult to reconcile with the shock acceleration mechanisms

ISHEM application on a number of bright BH XRBs is on-going.

The bright Swift J1727.8-1613

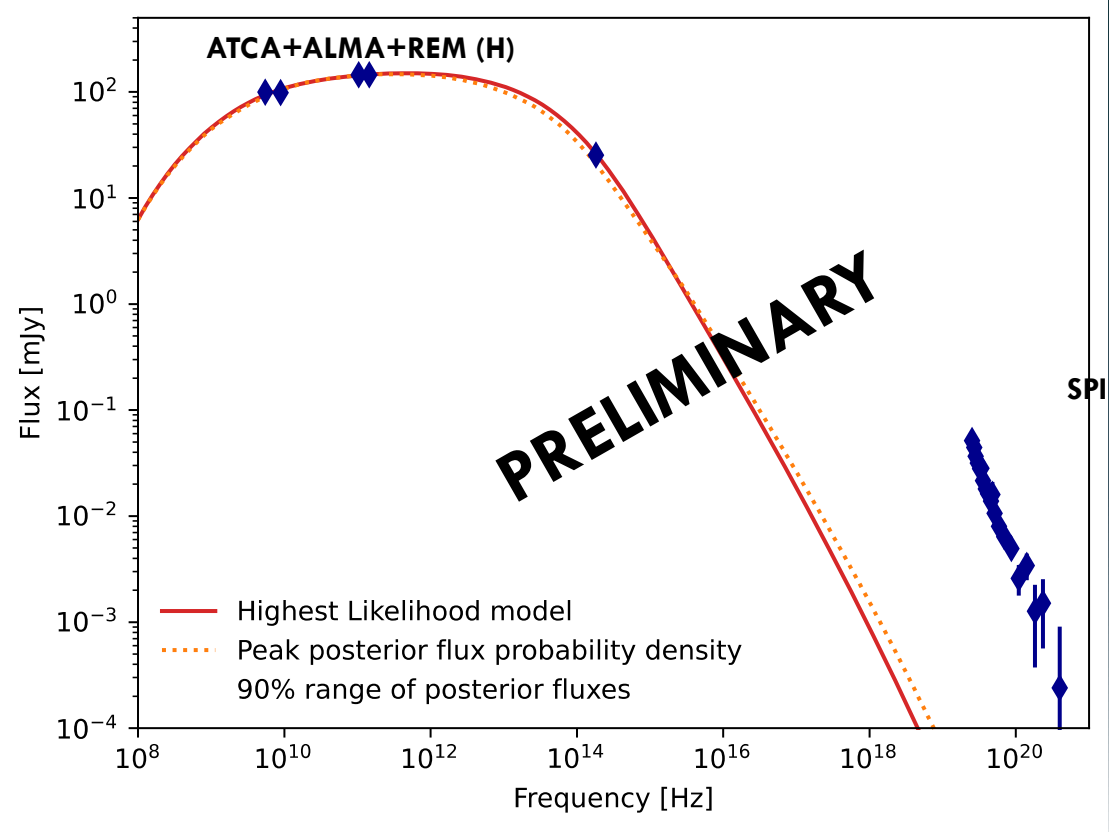
In outburst in 2023



INTEGRAL ToOs were requested by:
T. Belloni,
F. Capitanio,
M. Del Santo,
S. Motta
in the framework of the AO20

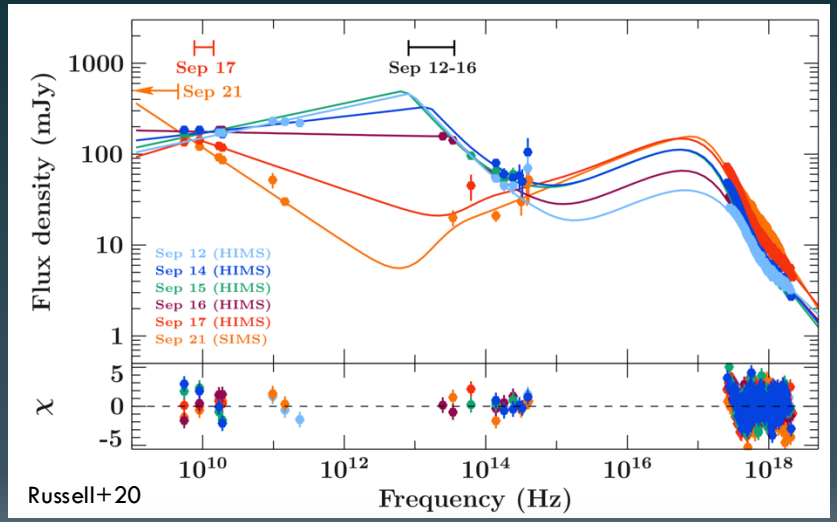
ESA/INTEGRAL POM (dedicated to the Tomaso's loving memory)

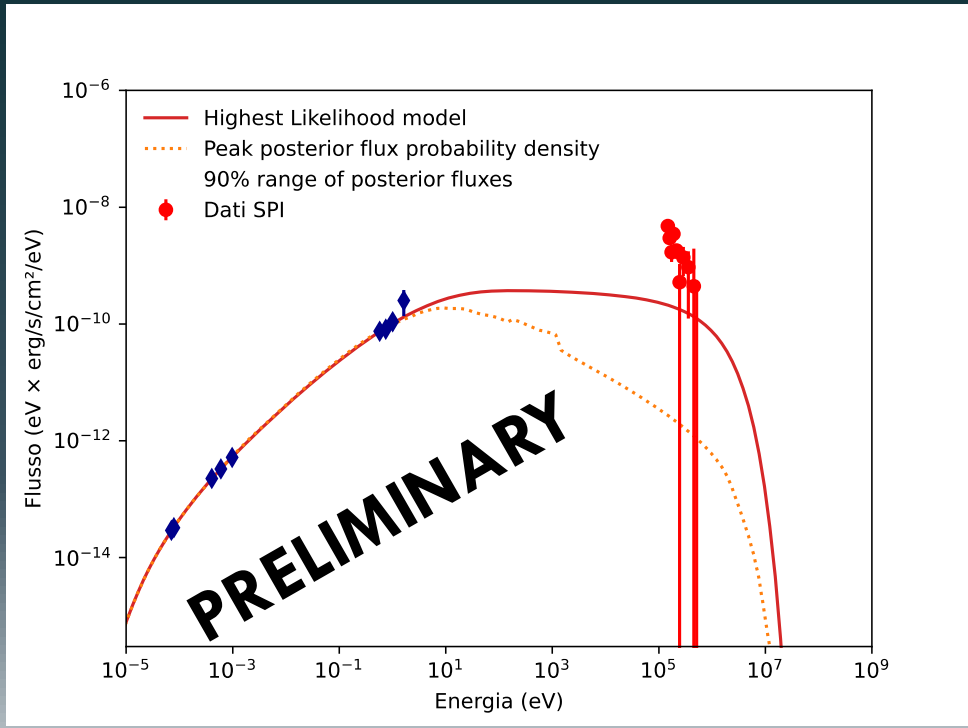
SED of Swift J1727.8-1613 with ISHEM



The preliminary modelling performed on the ATCA, ALMA and REM data does not explain the soft gamma-ray emission (above 100 keV) by SPI

SED of MAXI J1535-571 with ISHEM

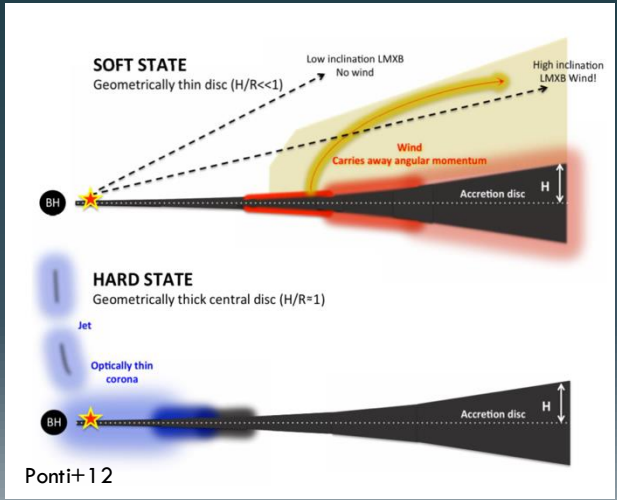




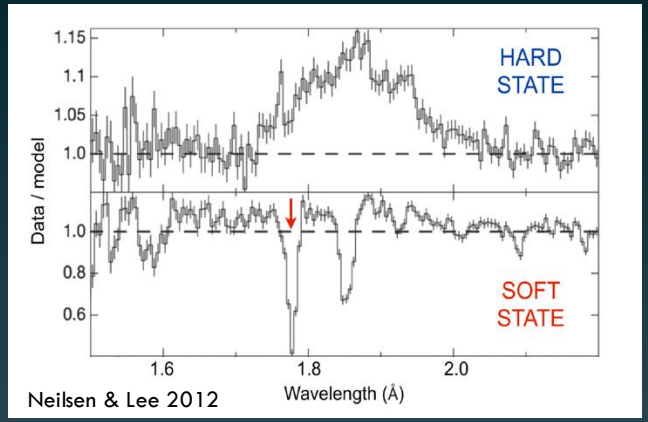
Model fitting of the radio-to-IR data seems to not explain the soft gamma-ray emission (above 100 keV) by SPI.
This result is in agreement with the lack of polarization found by Cangemi+23.

Disc Winds

Identified by absorption features,
mainly Fe XXV and Fe XXVI
blue-shifted (v∽1000 km/s)



Ponti+12

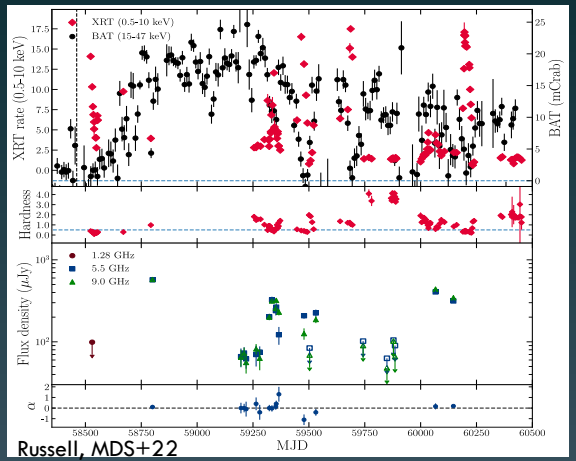


Neilsen & Lee 2012

Open question on the launching mechanism:
Thermal and/or MHD driven winds?

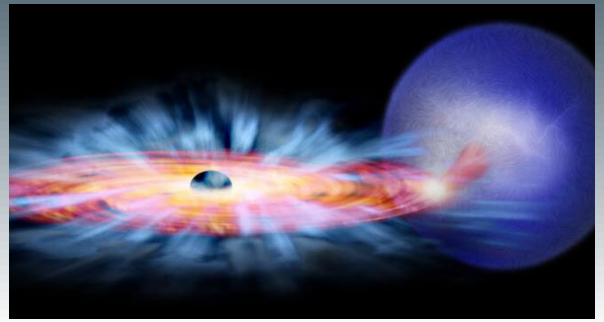
nti & coll. found ubiquitous wind tracer absorption lines
during the soft states
of BH systems viewed at high inclination.

The crazy MAXI J1810-222

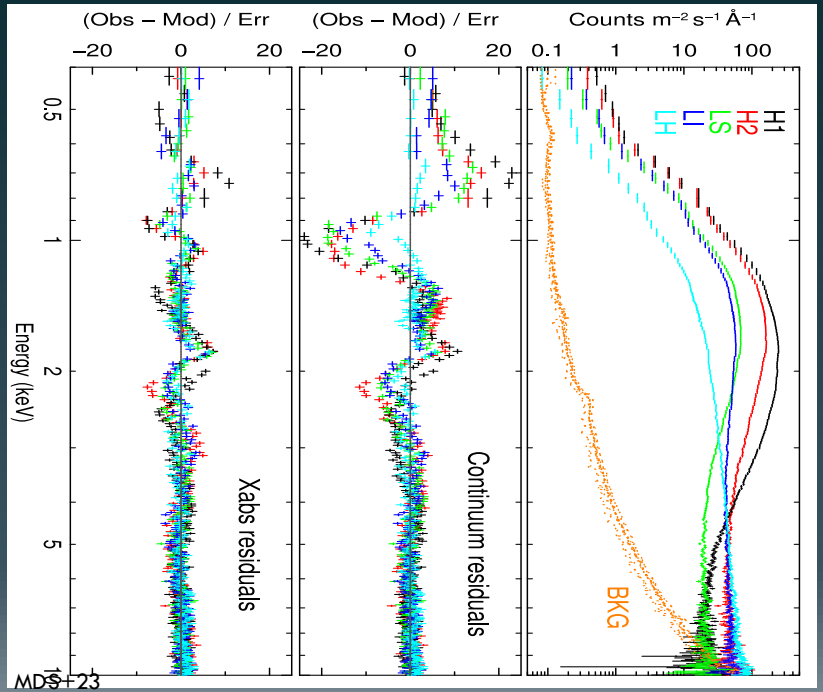


Russell, MDS+22

Discovered in 2018 it is still in outburst after 6 years



Spectral state dependent winds

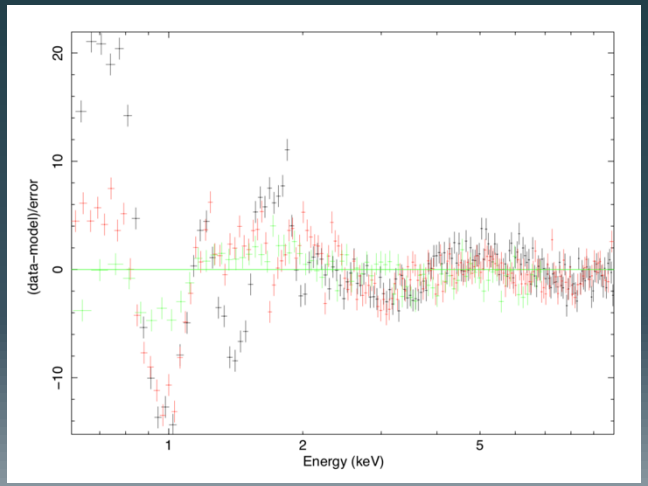


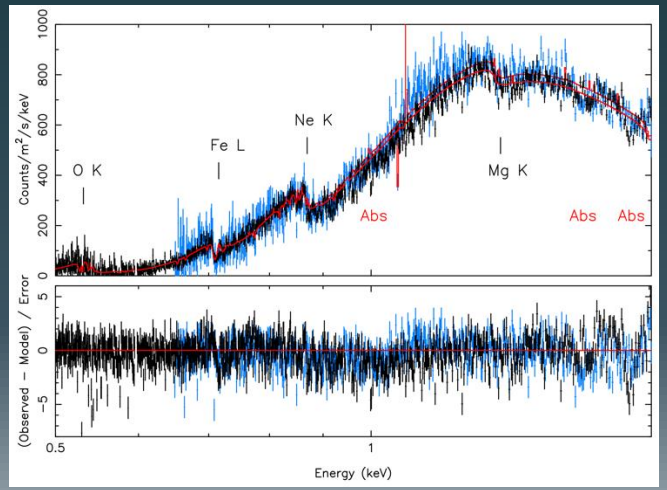
MDS+23

Applying a photoionization model we obtained v~0.15 c (UFOs) when the source was in soft state: this is consistent with MHD winds

High resolution spectroscopy

Observation accepted in AO22 (PI: Del Santo) and performed in September 2023 (∽57 ks).





We found the broad absorption line around ∽ 1keV

Modelling with a photoionization code is on going (Pinto et al. in prep.)

Summary of the things that we do not know (yet) or understand in detail:

- all the mechanisms leading outbursts (Why failed transition outburst?)
- the ingredient(s) driving spectral transitions, in addition to the mass accretion rate
- Accretion flow geometry: disk truncation and coronae (IXPE)
- How are jets and winds formed and what are their launching mechanisms?
- the origin of the soft gamma-ray emission (MeV tail) in BH X-ray binaries

… UFOs in X-ray binaries?

THANKS FOR YOUR ATTENTION