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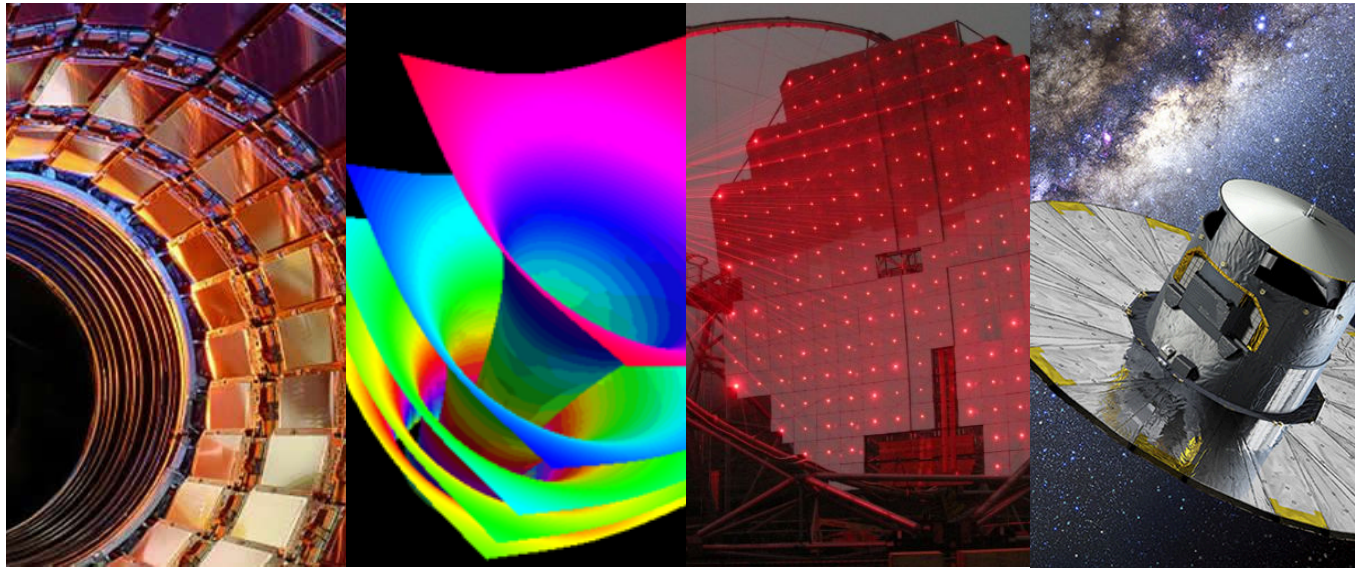

Accretion/ejection coupling in MWC 656 through X-ray and radio observations

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Institute of Cosmos Sciences

Universitat de Barcelona

Variable Galactic Gamma-Ray Sources

Rykkyo University (Tokyo) July 4-7 2017

Japan

UNIVERSITAT DE BARCELONA

Collaborators

Discovery of X-ray emission from the first Be/black hole system
P. Munar-Adrover, J. M. Paredes, M. Ribó, K. Iwasawa, V. Zabalza & J. Casares
ApJ, 786, L11 (2014)

The first simultaneous X-ray/radio detection of the first Be/BH system MWC 656
M. Ribó, P. Munar-Adrover, J. M. Paredes, B. Marcote, K. Iwasawa, J. Moldón, J. Casares, S. Migliari, X. Paredes-Fortuny
ApJ, 835, L33 (2017)

PhD Theses
J. Moldón (2012)
B. Marcote (2015)

Outline

1. Introduction
2. X-ray and radio observations
3. Accretion/ejection coupling
4. Work in progress
5. Conclusions

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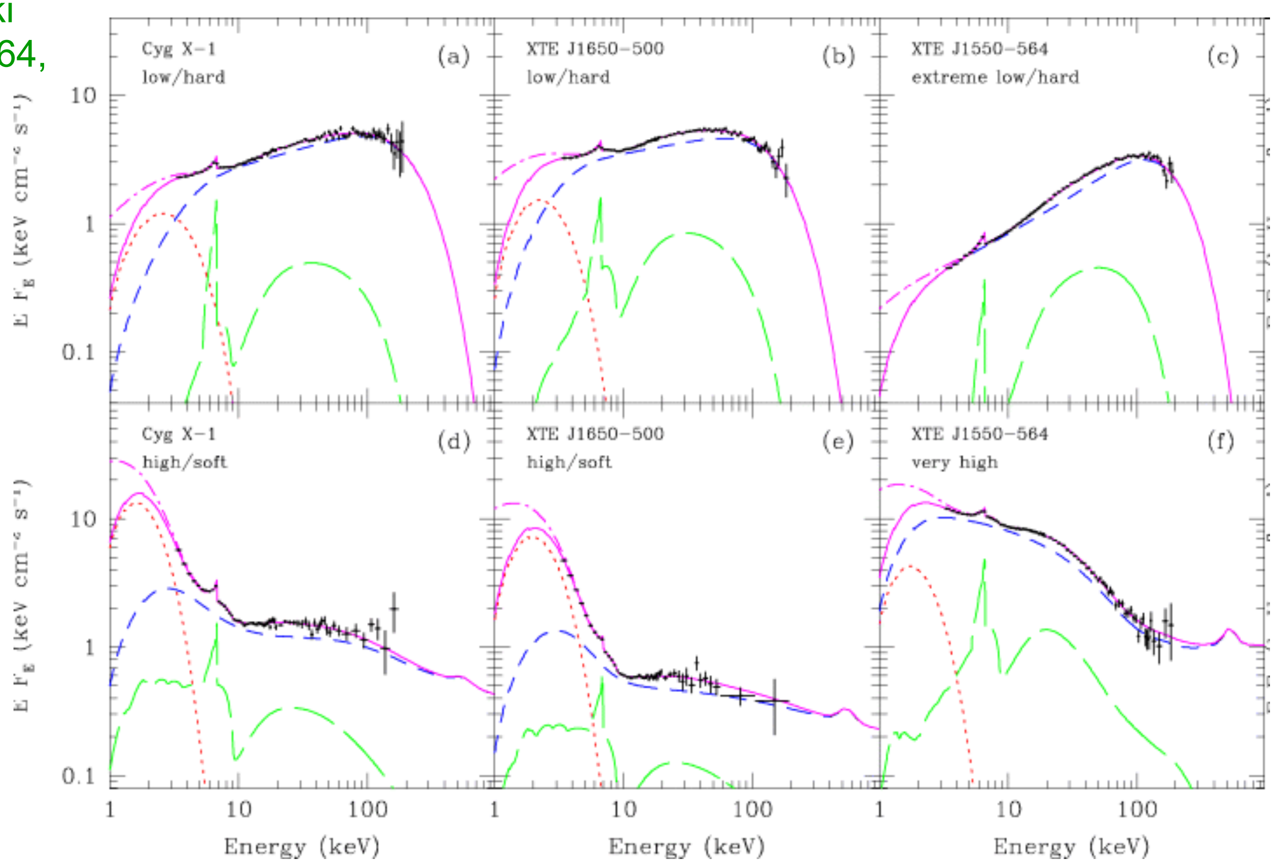
Black holes display different X-ray spectral states

Thermal component: multi-temperature BB disc
Nonthermal component: power law, photon spectrum N(E) α $E^{-\Gamma}$

Done & Gierlinski 2005, MNRAS 364, 208



the multicolour disc (dotted), complex Comptonization (dashed) and its reflection (long-dashed)

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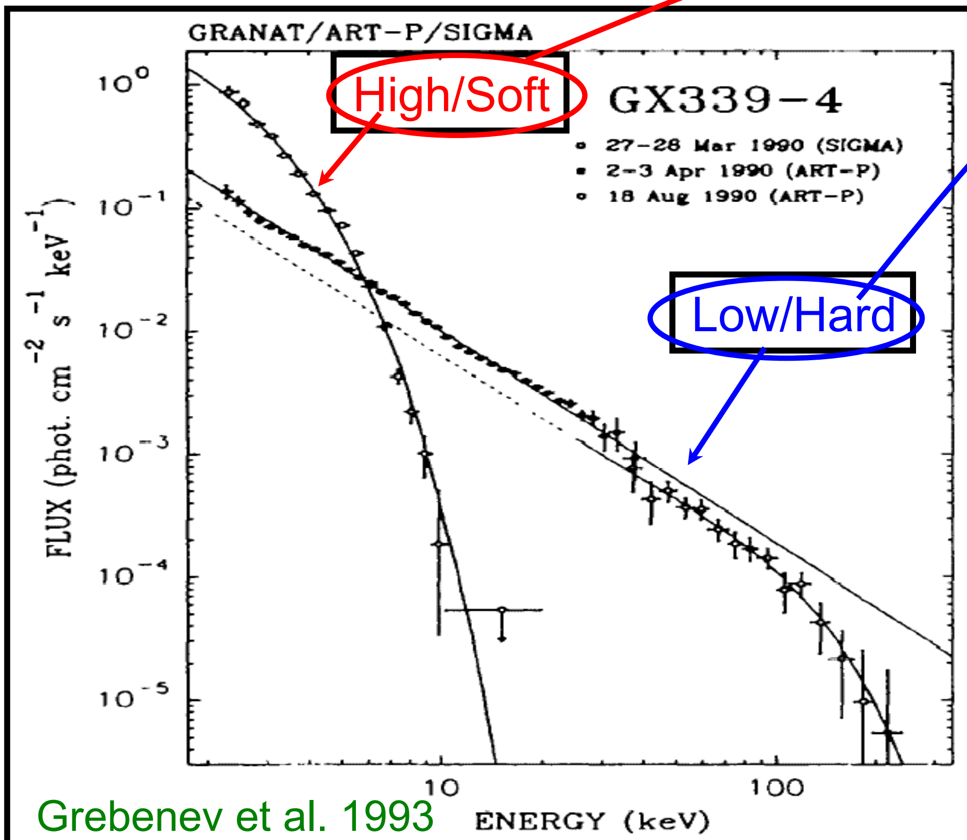
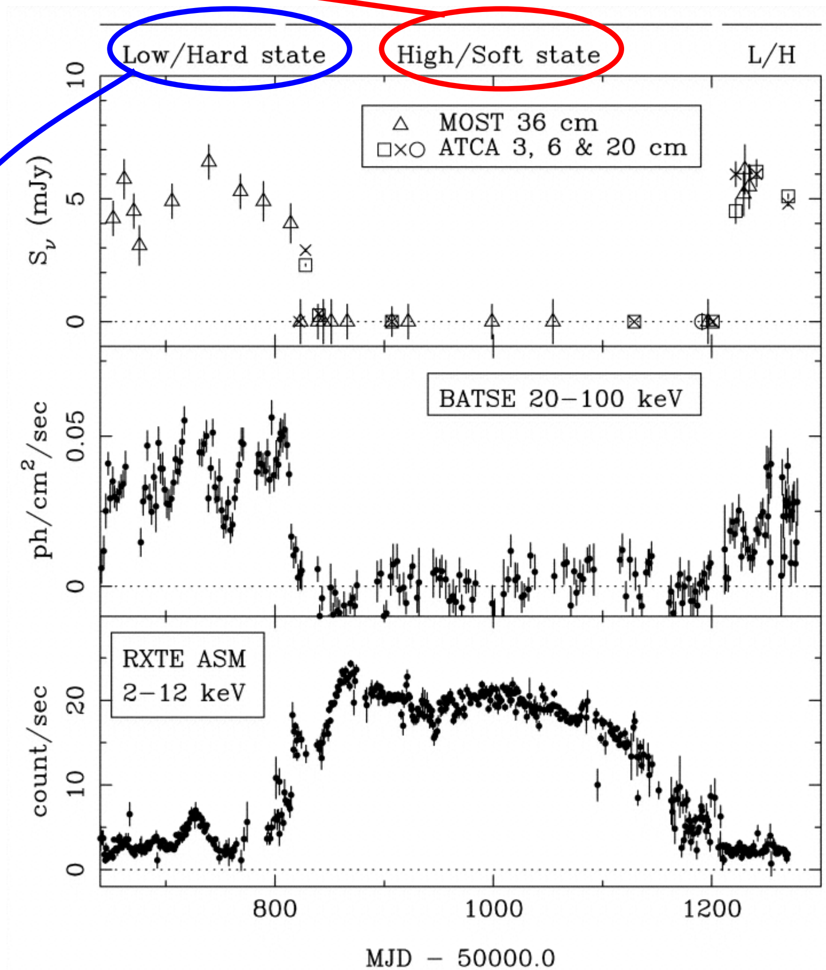
Black holes display different X-ray spectral states

- High/soft state (a.k.a. thermal-dominant state)
- Low/hard state (a.k.a. power-law state)

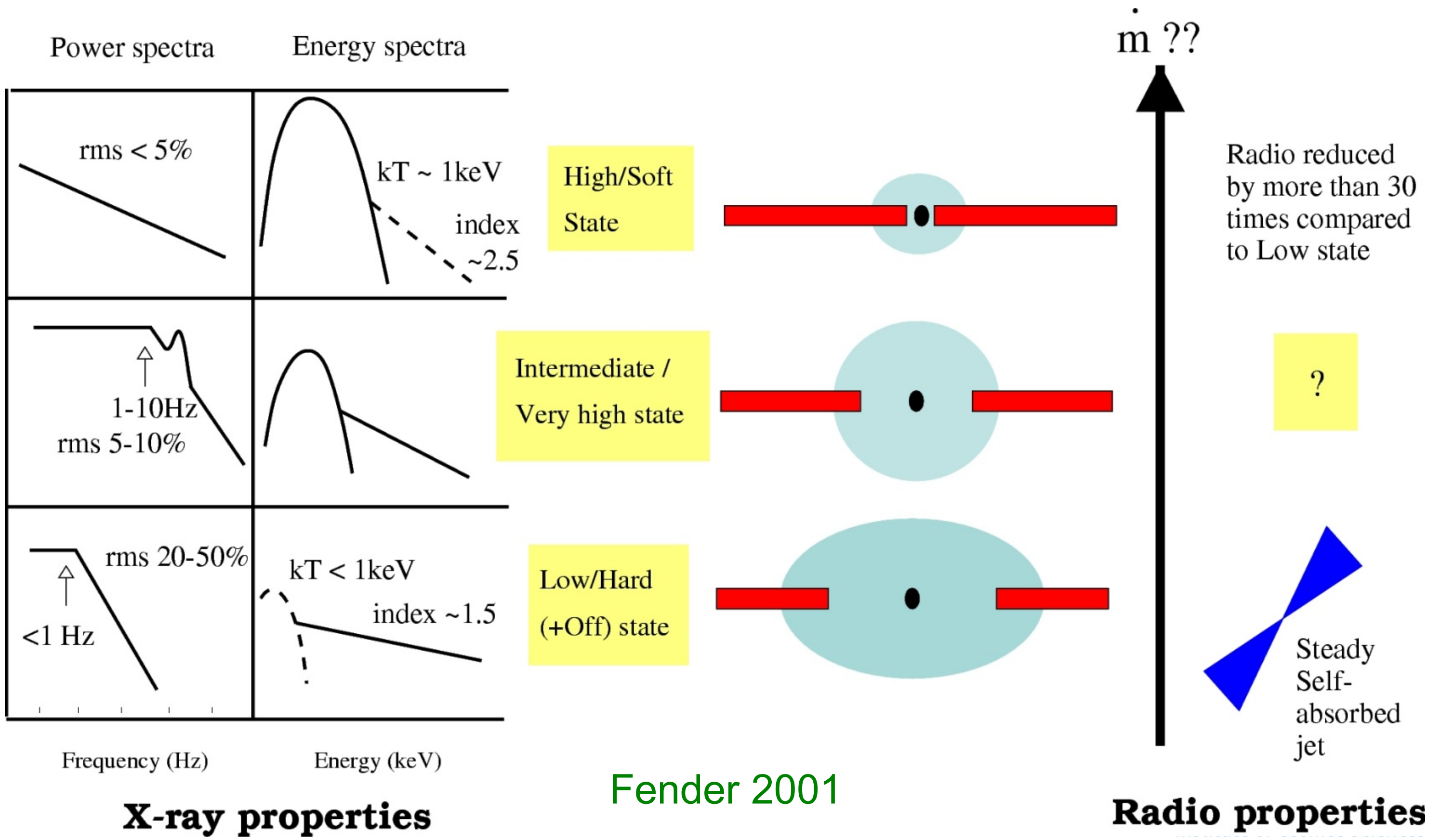
Fender et al. 1999





Black holes display different X-ray spectral states

- High/soft state (a.k.a. thermal-dominant state). No radio emission
- Intermediate and very high states → transitions. Transient radio emission
- Low/hard state (a.k.a. power-law state). Compact radio jet

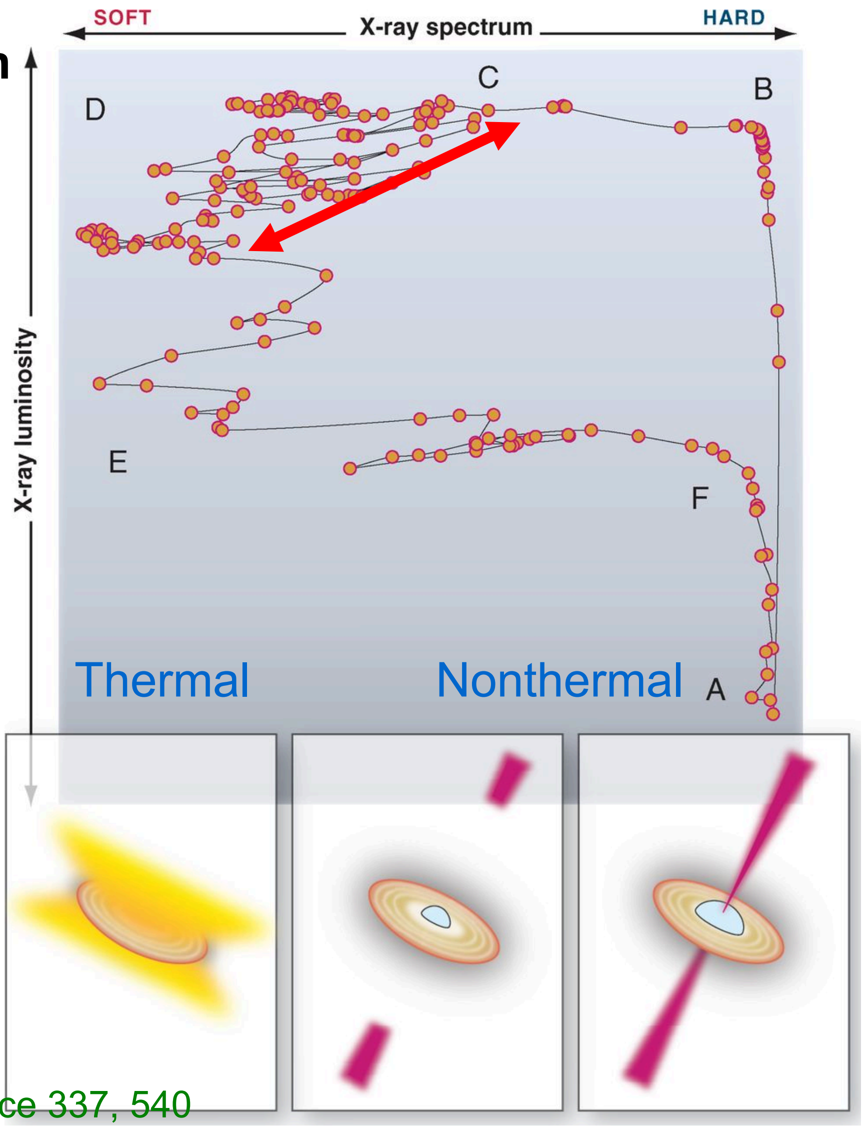


Fender 2001

Black holes display different X-ray spectral states
The Hardness Intensity Diagram

Hard / Soft **transition**
Ballistic jets
$\Gamma > 2$

Soft state
No jets ?
Winds



Spectral slope:
soft = steep
hard = flat

Hard state
Steady jets
$\Gamma < 2$

Fender & Belloni 2012, Science 337, 540

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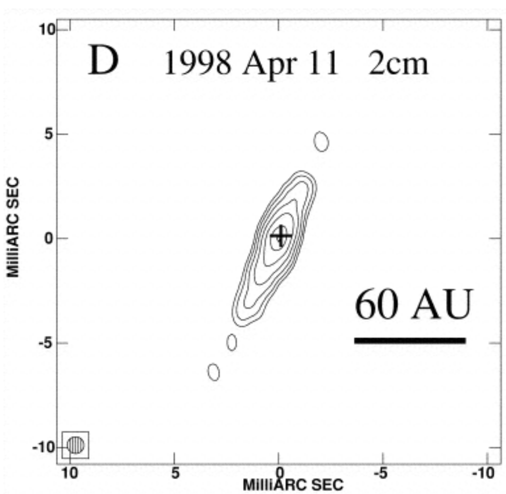
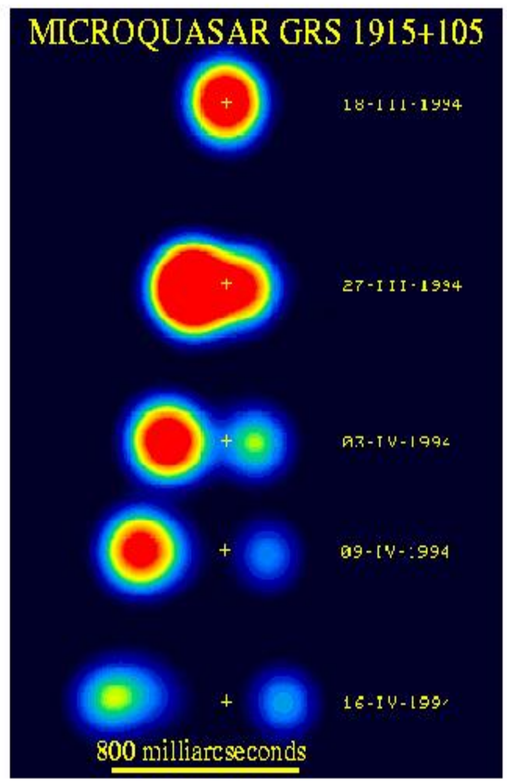
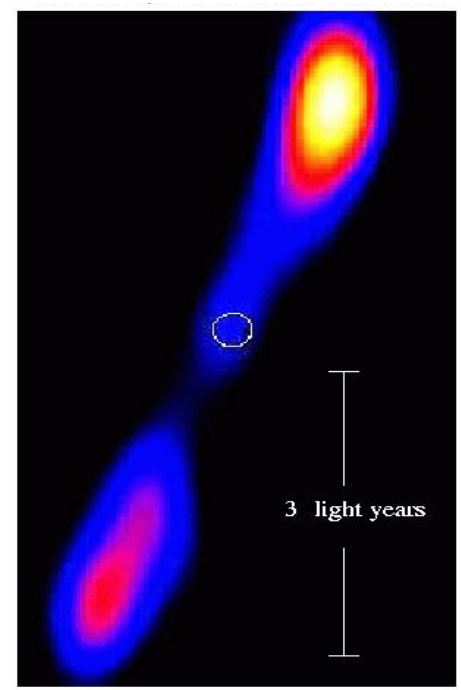
Black holes display different X-ray spectral states
Several types of radio jets

- ➢ Compact jets in low-hard states (mas)
- ➢ Discrete ejections during state transitions (arcsec)
- ➢ Large-scale jets: interactions with the ISM (arcmin)







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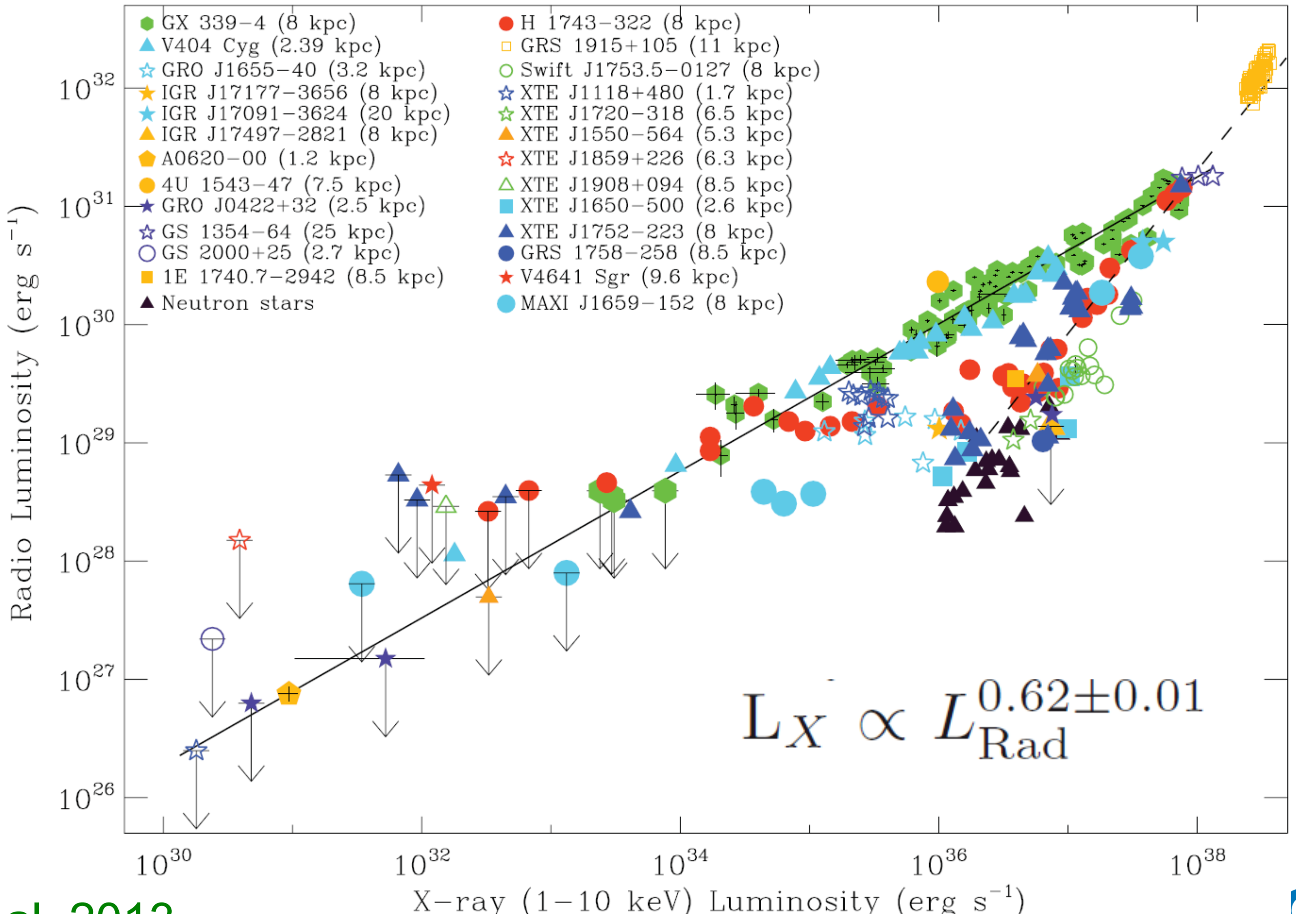
Radio vs X-ray luminosity diagram

There is a well-known **radio/X-ray correlation for LMXBs** in the quiescent and low-hard states, implying a strong **accretion/ejection coupling**



Corbel et al. 2013

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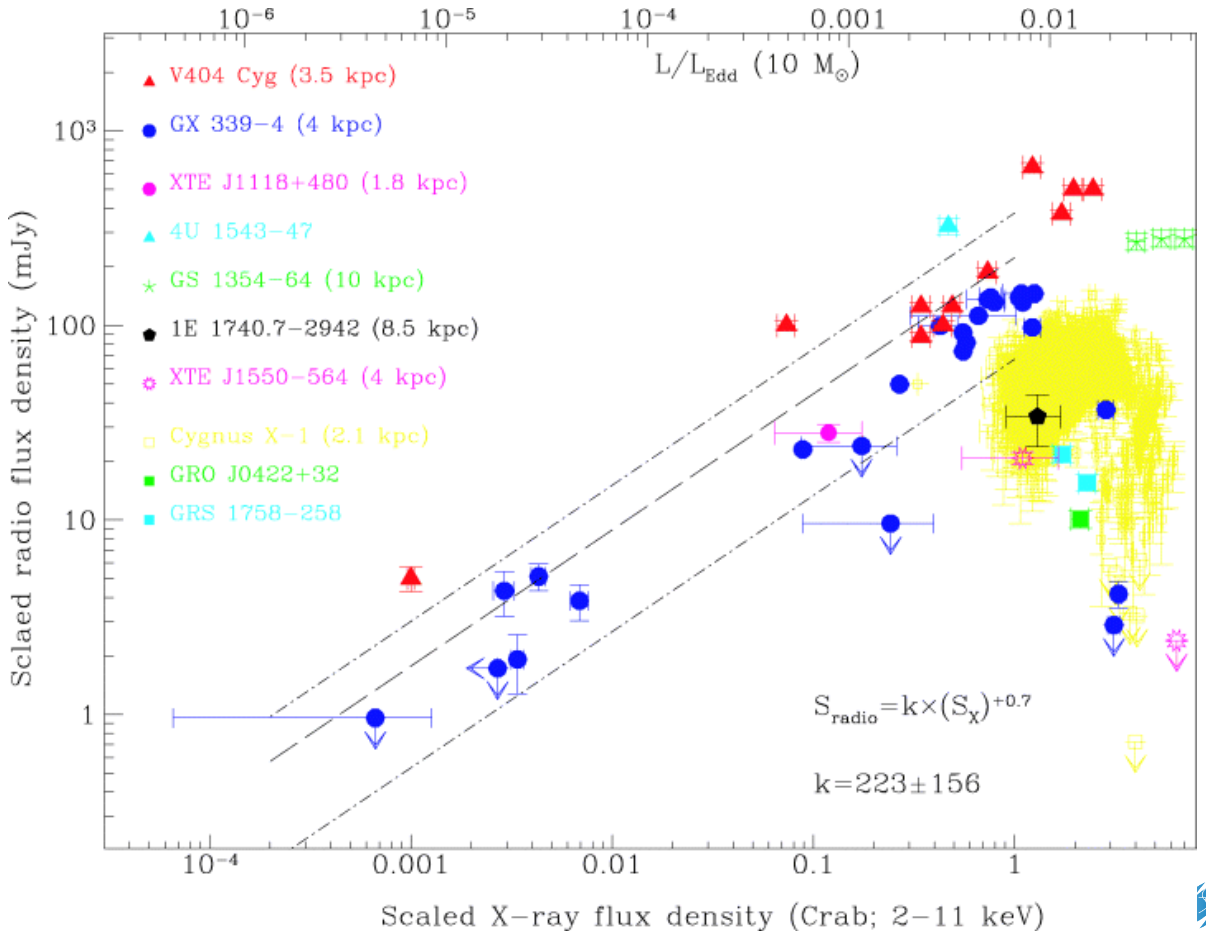
Radio vs X-ray luminosity diagram

Cygnus X-1 is always **very luminous** and the **only one HMXB** galactic source detected at radio and X-rays (Gallo et al. 2003)



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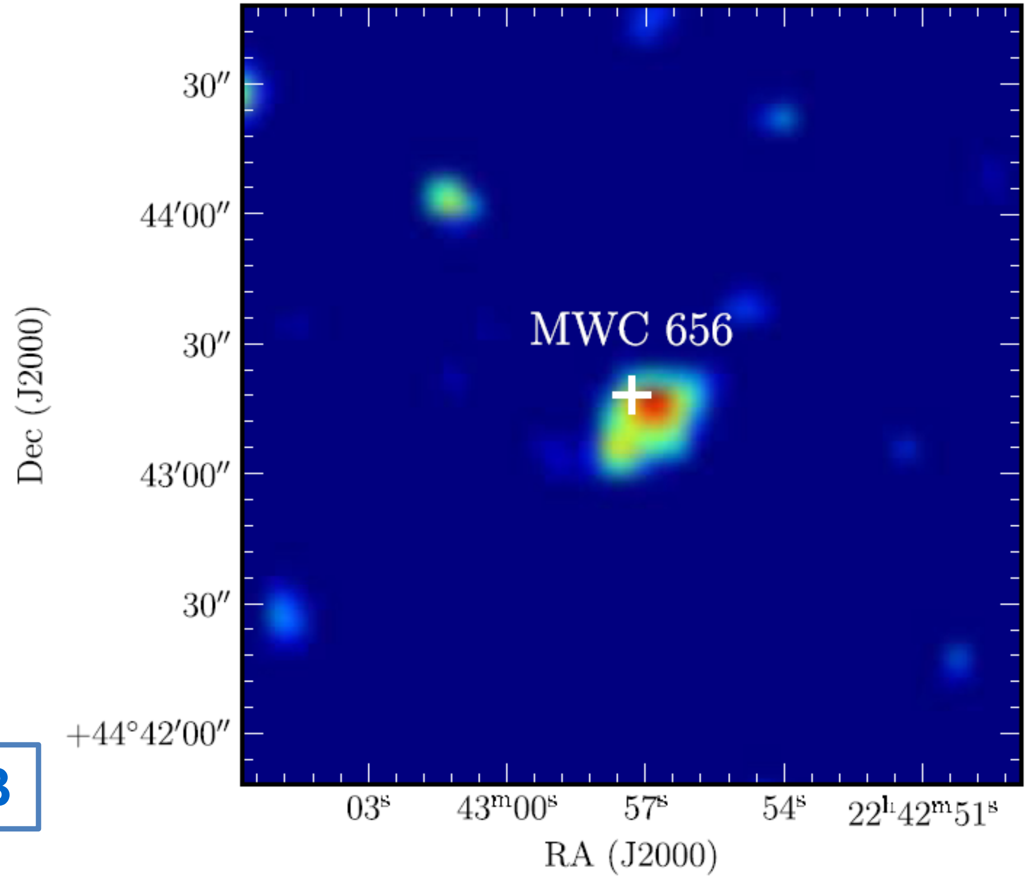
The X-ray counterpart of MWC 656

We conducted a 14-ks *XMM-Newton* observation of MWC 656 on 2013 June 4

- We detect a faint source at 4.4σ coincident with MWC 656
- The X-ray position is compatible with the Hipparcos position of MWC 656 at 2.4σ
- The source is only detected in the low-energy range of the EPIC-pn detector, between 0.3 and 5.5 keV

MWC 656 was a new HMXB



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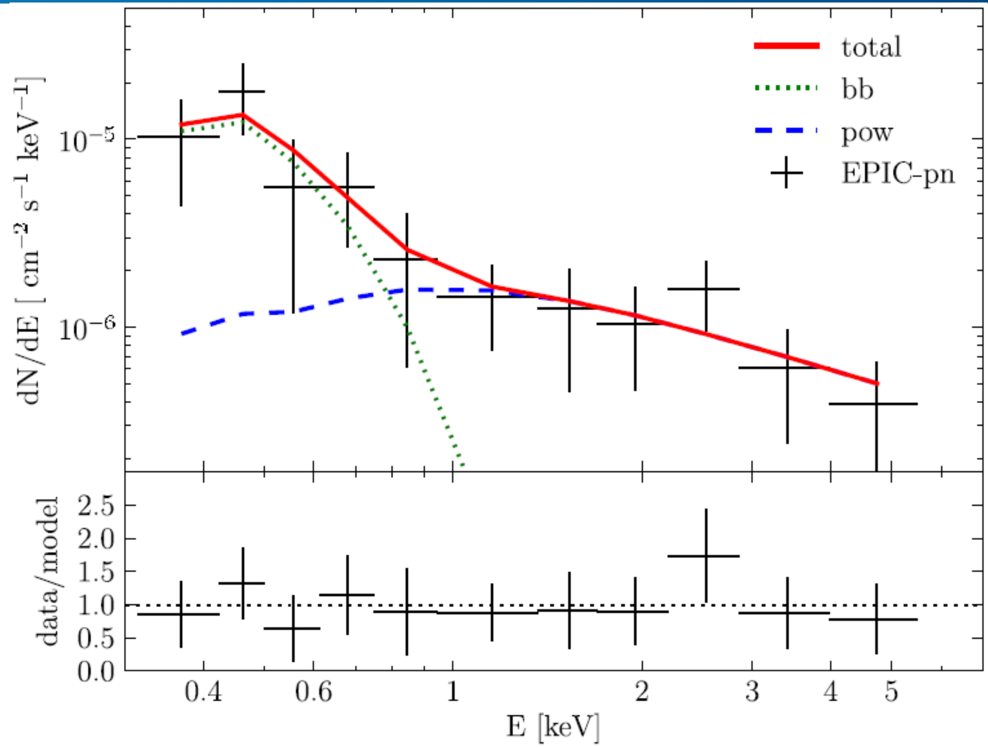
The X-ray counterpart of MWC 656

Absorbed blackbody (green dotted line) plus a power-law (blue dashed line) model

Thermal dominates < 0.8 keV (Munar-Adrover et al. 2014)



The thermal X-ray luminosity is compatible with the correlation $L_X \sim 10^{-7} L_{bol}$ for **isolated B stars** (Berghoefer et al. 1997; Cohen et al. 1997)

The non-thermal X-ray luminosity is $L_X = (3.1 \pm 2.3) \times 10^{-8} L_{Edd}$ for the estimated BH mass, indicating that **MWC 656 was in deep quiescence** (Munar-Adrover et al. 2014)

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Radio observations

Search for the non-thermal radio counterpart of MWC 656

European VLBI Network (EVN)
Three long (4 to 12-h) observations conducted in Jan-Feb 2011 using both the e-EVN and the full EVN at 1.6 GHz. **No detection**, with rms values from 10 to 21 microJy. **3-sigma upper limits** are as low as **30 microJy** (Moldón 2012)

Westerbork Synthesis Radio Telescope (WSRT)
Five long (5 h) observations conducted from Dec 2011 to Feb 2012 at 1.4 GHz. **No detection**, with rms values from 60 to 67 microJy. Therefore, the **3-sigma upper limits** are higher than those of the EVN (Marcote 2015)

Karl G. Jansky Very Large Array (VLA)
Three 1-hour observations conducted in Oct-Dec 2012 using the VLA in its most extended A configuration (higher resolution). **No detection**, with rms values from 13 to 22 microJy. Therefore, the **3-sigma upper limits** are higher than those of the EVN (Marcote 2015)

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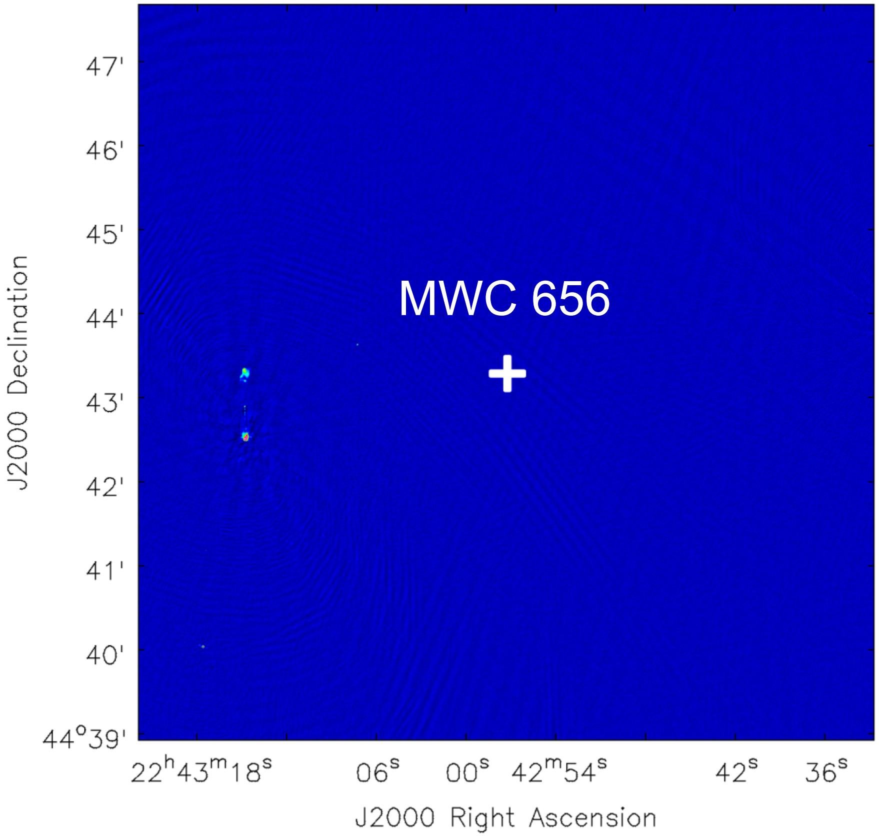
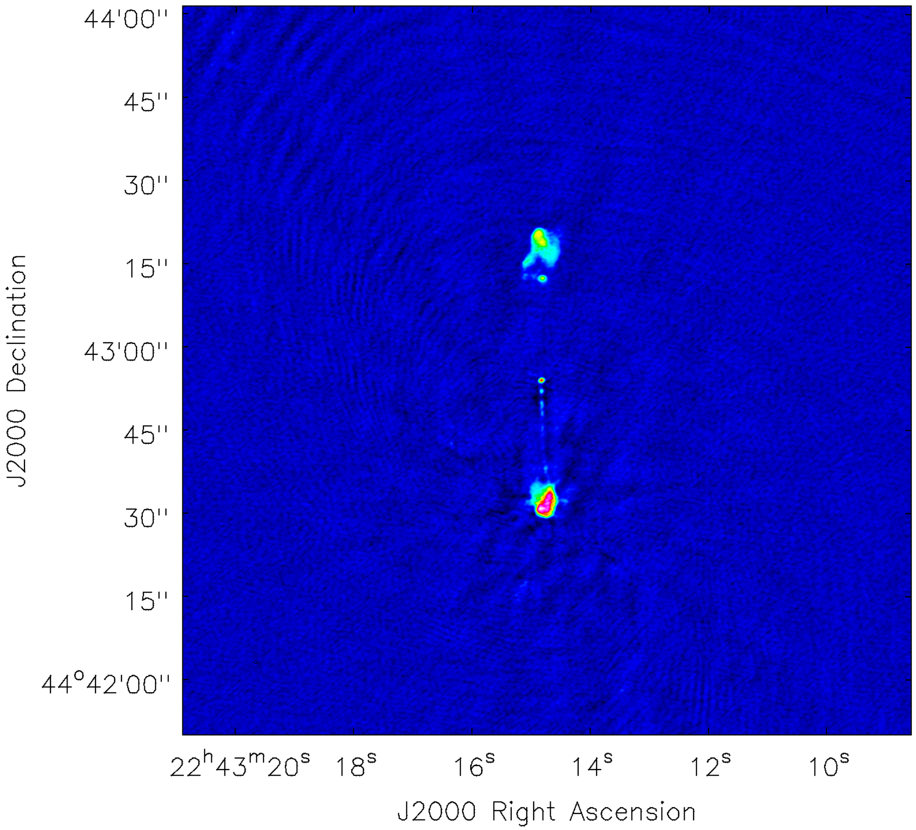
Radio observations

The **VLA** images reveal a **nearby radiogalaxy with a lot of structure** (core, jet and bright extended lobes). This produces an **rms higher than expected**





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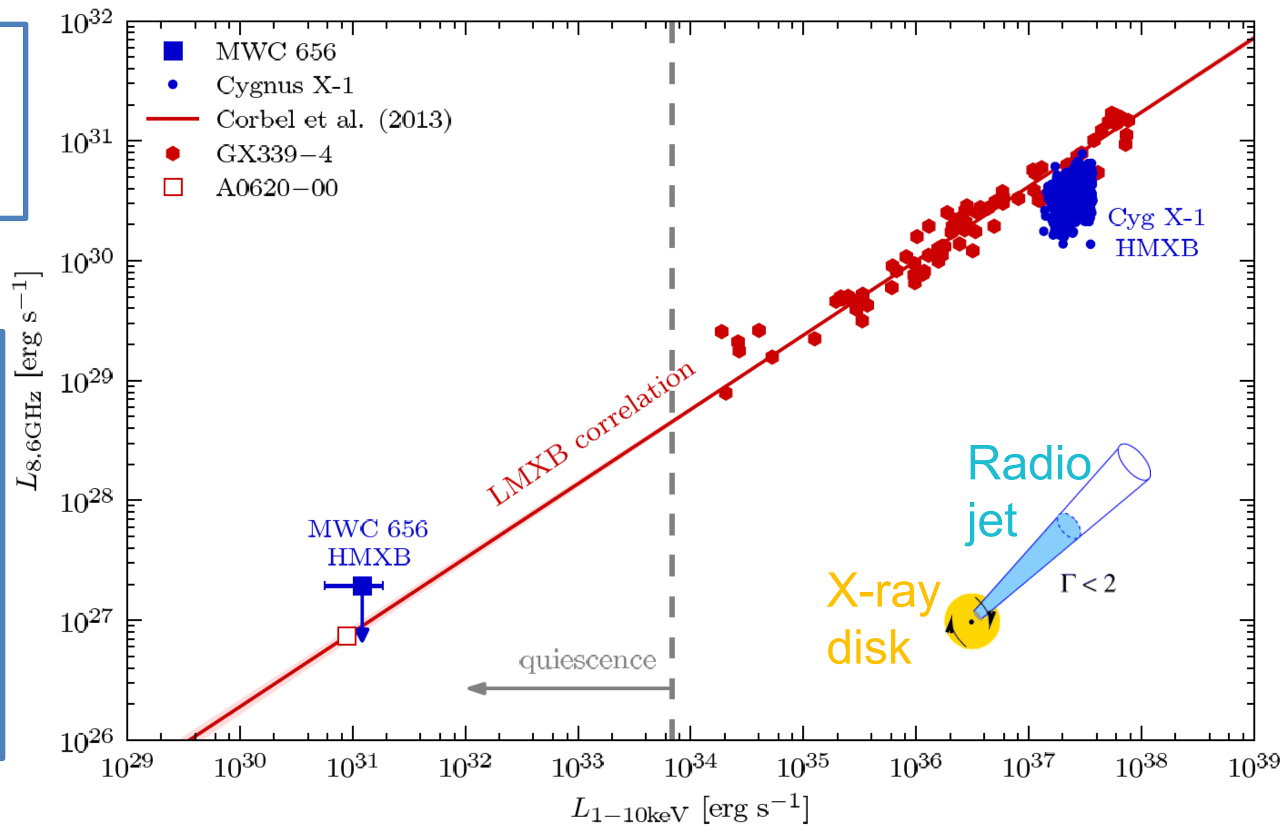
Radio vs X-ray luminosity diagram
Accretion/ejection coupling in quiescent HMXBs

Using non-simultaneous radio flux density upper limits from Moldón (2012) we found that **MWC 656 is located in the lower-left side of the radio/X-ray luminosity diagram,** in a region where it may be consistent with and just above the correlation from Corbel et al. (Munar-Adrover et al. 2014)

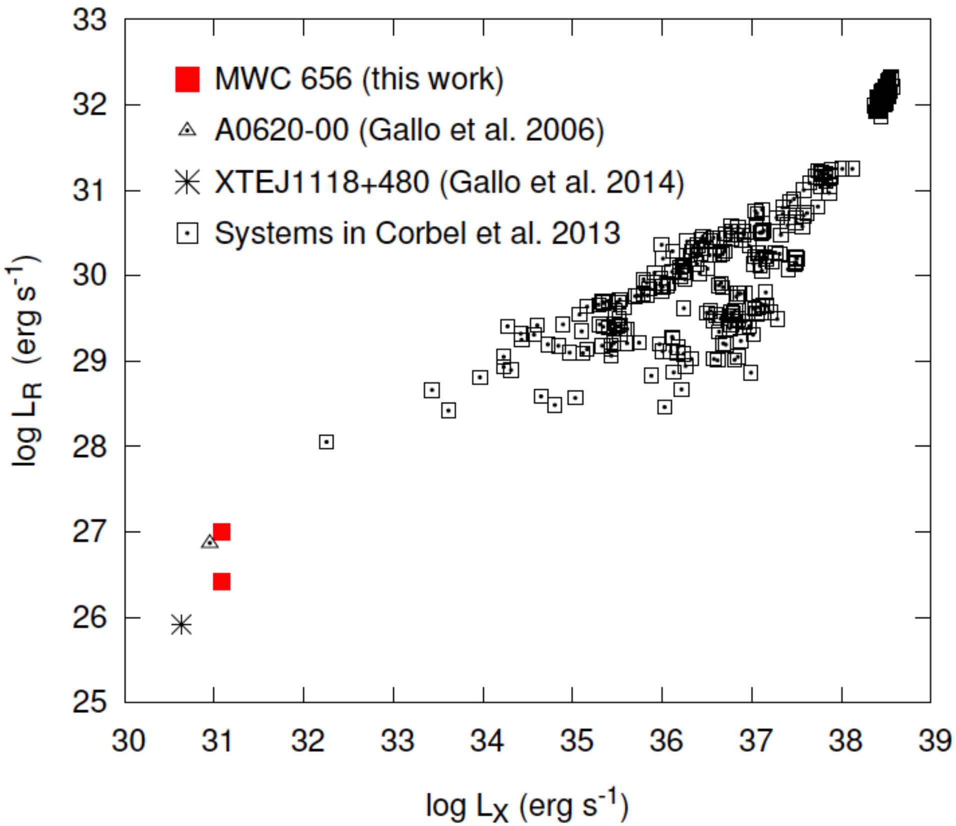
The radio/X-ray correlation could also be valid for **BH HMXBs**

MWC 656 could allow the study of accretion processes and of accretion/ ejection coupling at **very low luminosities** for BH HMXBs



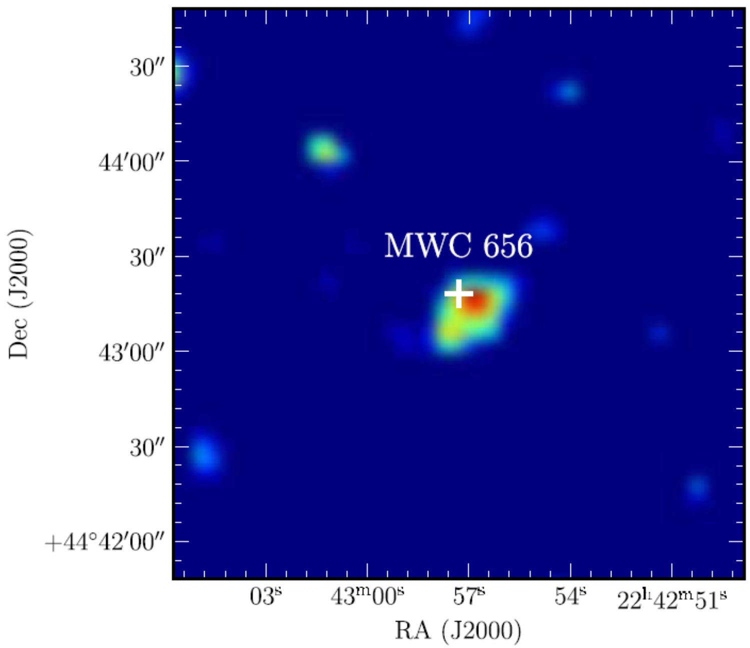
Radio vs X-ray luminosity diagram
Accretion/ejection coupling in quiescent HMXBs

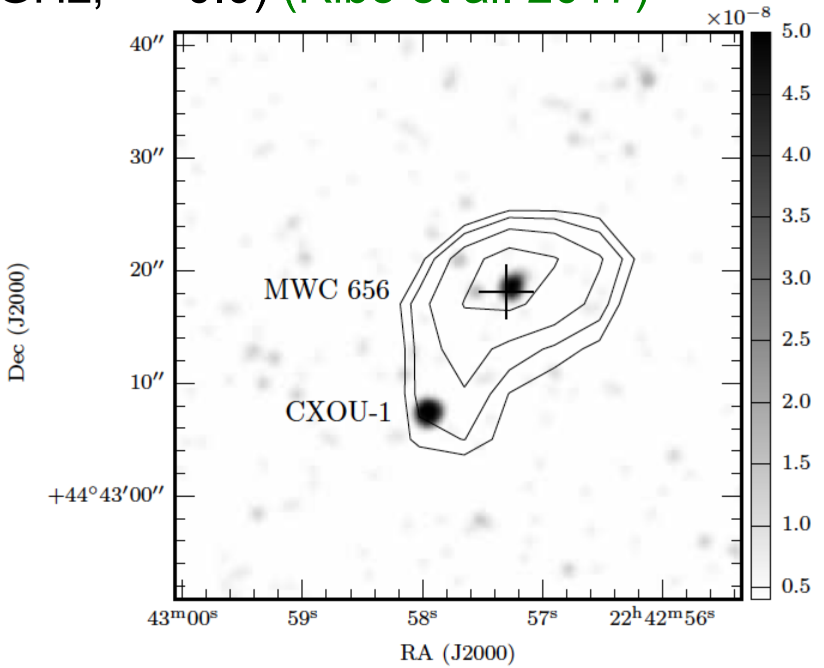
Dzib et al. (2015) conducted new VLA observations in 2015 and reported the **discovery of a faint radio counterpart: 3.7-14.2 μJy**. Using **non-simultaneous** *XMM-Newton* X-ray flux (2013) they plot the source in the X-ray/radio luminosity diagram and found it compatible with the previously known trend.



NEW RESULTS:
Simultaneous **Chandra** & JVLA observations

New deep Joint *Chandra*/VLA observations (2015 July 24: 60 ks of *Chandra*, 6 hours of VLA at 8-12 GHz, ∅ =0.0) (Ribó et al. 2017)





- *XMM-Newton* source is the superposition of two *Chandra* sources!
- MWC 656 is now fainter than the new source (factor of 2 in *Chandra* data)
- The X-ray flux of MWC 656 has decreased a factor of ~7 between 2013 June and 2015 July (Ribó et al. 2017)

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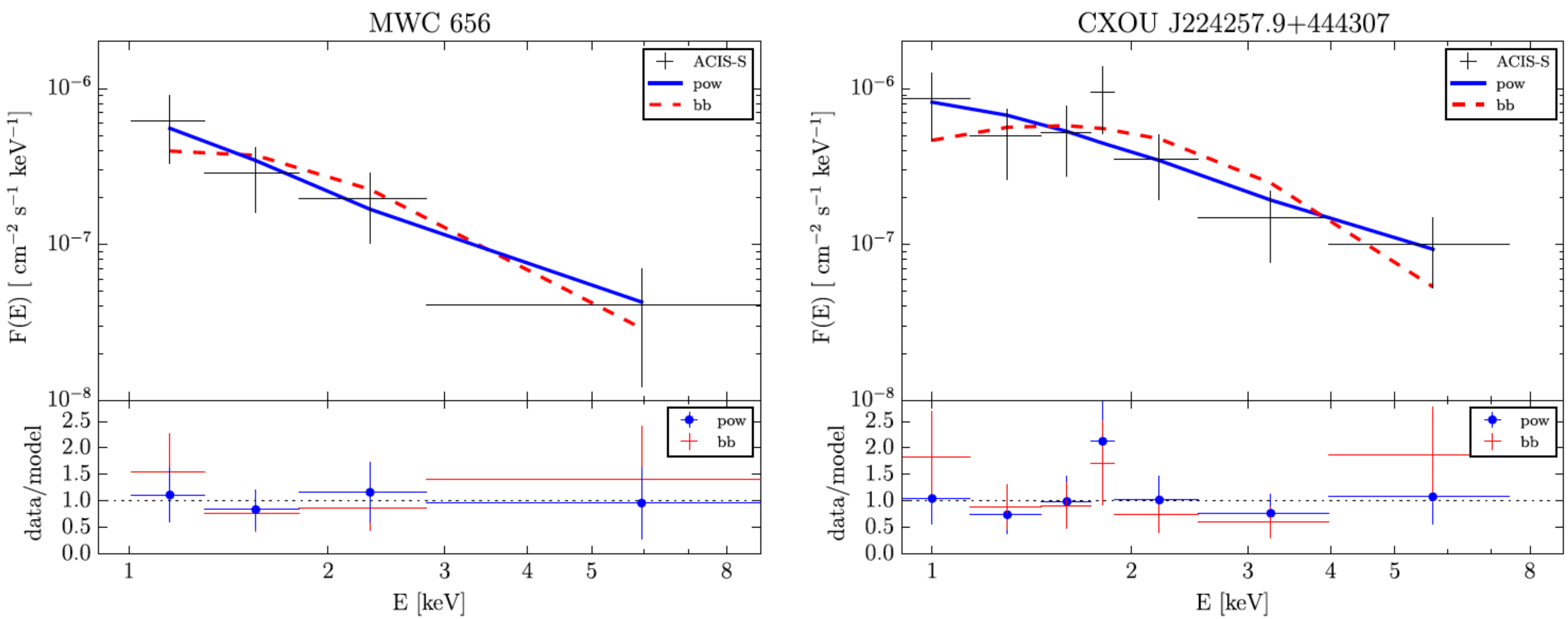
NEW RESULTS:
Simultaneous **Chandra** & JVLA observations



- The spectra of both sources can be fitted with power-law and blackbody models, though power-law models are favored

- The *Chandra* data do not support the two-component model reported in Munar-Adrover et al. (2014) (Ribó et al. 2017)

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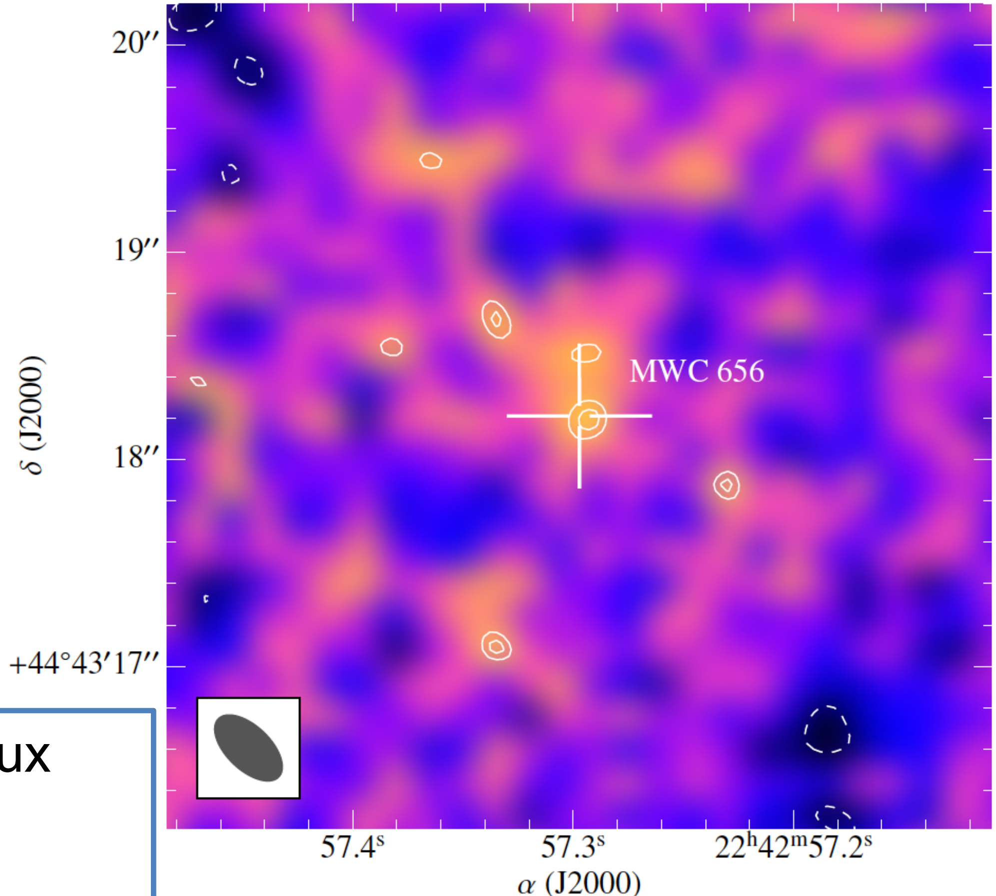
NEW RESULTS: Simultaneous Chandra & **JVLA** observations

- Due to the proximity of a bright quasar we imaged a region of a few arcminutes.
- We conducted a multiscale clean
- We analyzed data using standard clean, different weighting schemes, and different time intervals, which always led to compatible results



A faint radio source with a peak flux density of 3.5±1.1 μJy beam^{-1} is **detected** at the MW 656 position (Ribó et al. 2017)

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NEW RESULTS: Simultaneous Chandra & **JVLA** observations

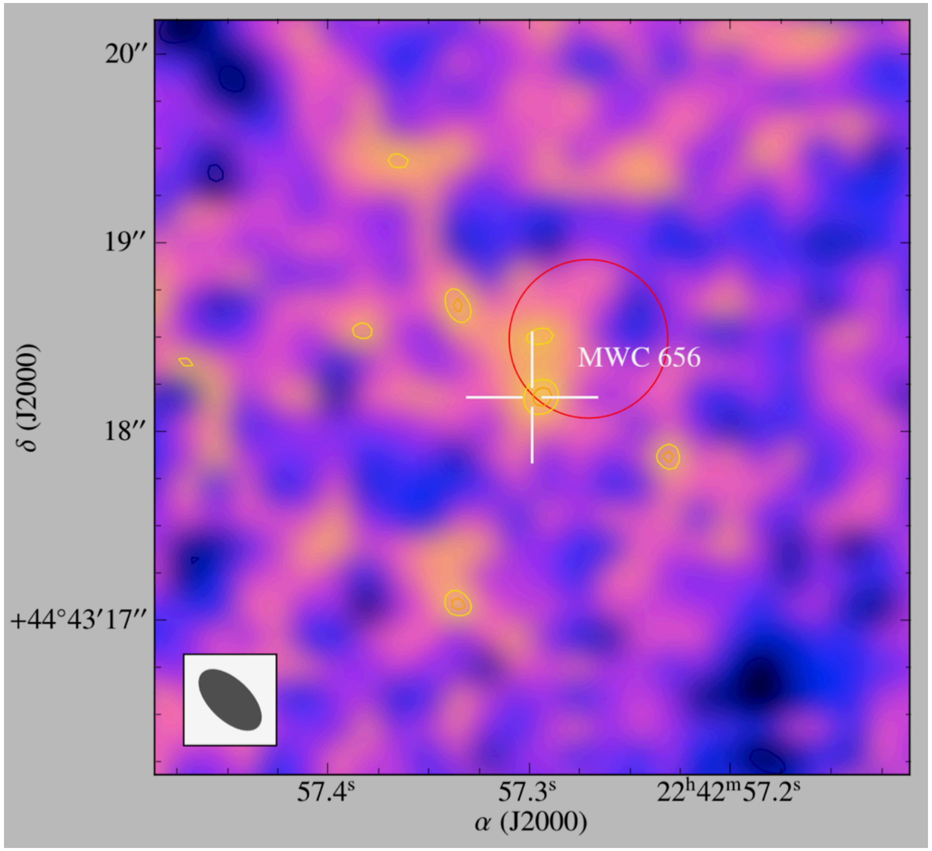
This is a **marginal detection**, but there are several facts that support the reality of the radio source as the counterpart of MWC 656:

1) it is the **brightest radio source** in the image

2) it is the only one located **within the *Chandra* X-ray source** position uncertainty

3) it is fully **compatible with the optical position**

4) there is a **former radio detection** of MWC 656 (Dzib et al. 2015)



Ribó et al. 2017

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NEW RESULTS:
Simultaneous Chandra & **JVLA** observations

Origin of the radio emission?

-Synchrotron emitting electrons in a jet as seen in many X-ray binaries

-Gyro-synchrotron radiation in the magnetic field of the Be star. Requires:

- high magnetic fields
- relatively high electron densities (Dulk 1985; Güdel 2002)

However,

1) the rapid rotation of Be stars prevents the existence of high magnetic fields
2) magnetism is less present in massive binaries than in isolated massive stars

(Schöller et al. 2014; Neiner et al. 2015)

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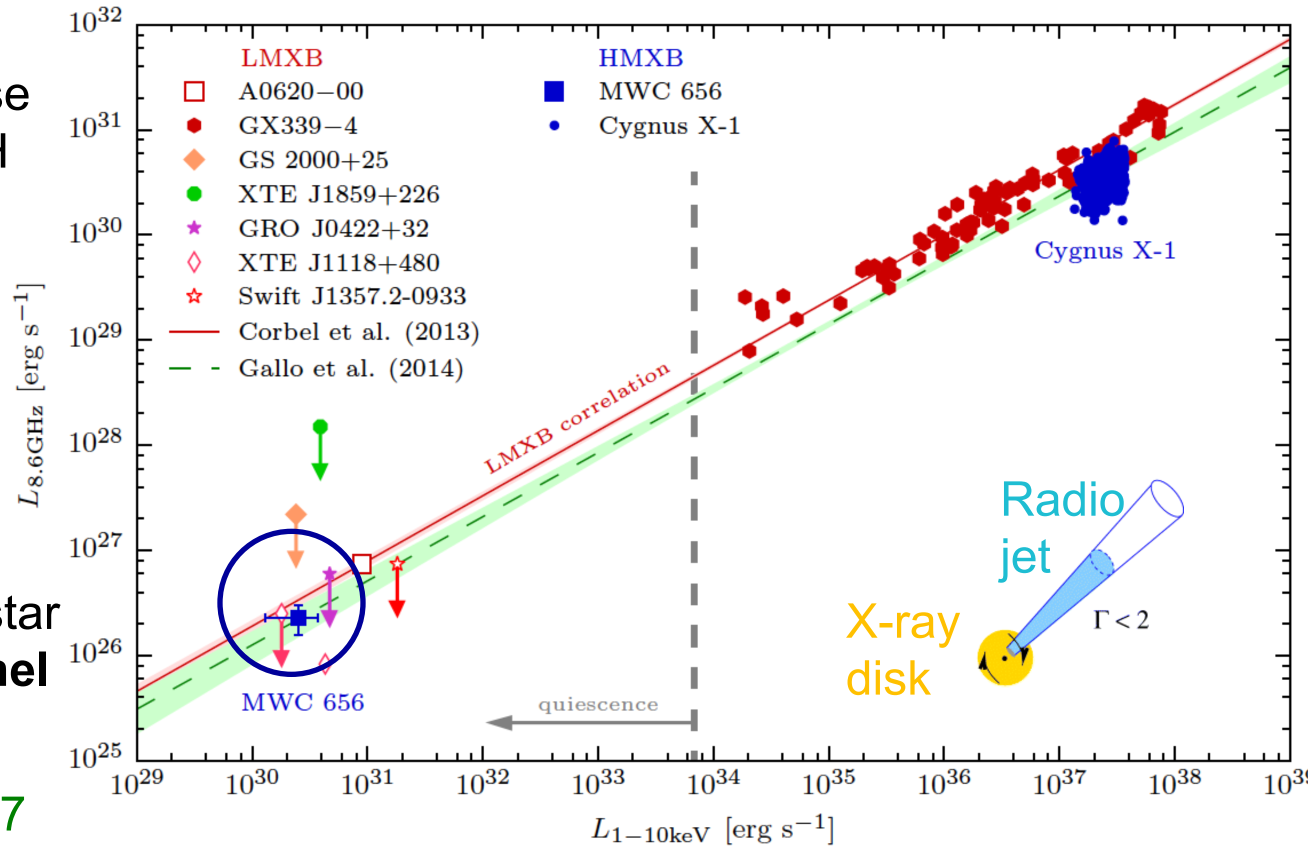
Radio vs X-ray luminosity diagram
Accretion/ejection coupling in quiescent HMXBs

MWC 656 is one of the **faintest stellar-mass BHs** ever detected in X-rays, and the faintest one in X-rays also detected in radio

Luminosities are **compatible** with those of the X-ray/ radio BH LMXB correlations

It is clear that the **accretion/ejection coupling** found in stellar-mass BHs is **independent** of the nature of the **donor** star and **accretion channel**



Ribó et al. 2017

Work in progress

In 2017 March we submitted a **new Joint *Chandra*/VLA proposal** to conduct 3 observation runs of MWC 656 to:

1. **Search for orbital variability** expected as a result of a variable accretion rate in the eccentric orbit and compare with Bondi-Hoyle expectations

2. **Monitor the long-term X-ray variability** and compare it with the optical and GeV results, to understand/model the long-term behavior

3. **Study the accretion/ejection coupling** with different X-ray/radio fluxes using these and previous observations

4. If the source flux is high enough: a) **constrain the photon index**; b) **constrain the hydrogen column density** from X-ray observations

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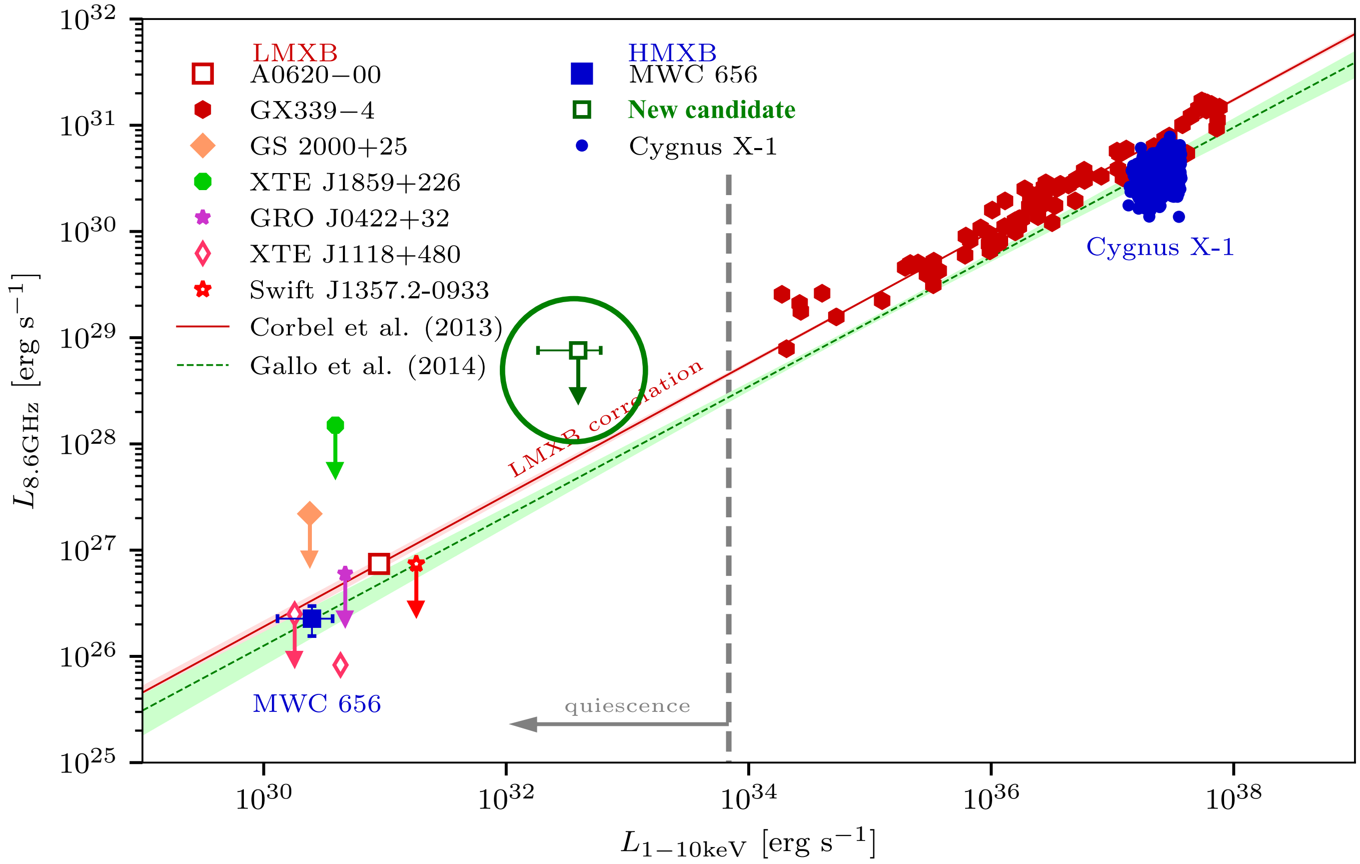
Work in progress

- The very good candidate (previous talk) has a higher luminosity than MWC 656 in X-rays, and should allow to obtain precise values of X-ray/radio fluxes.
- New Joint *Chandra*/VLA observations to be conducted soon



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Conclusions

- The first Be/BH binary is an X-ray binary in **quiescence**
- We are studying the **accretion/ejection coupling in BH HMXBs at low luminosities**
- It is now clear, for the first time, that the **accretion/ejection coupling** in stellar-mass BHs is **independent** of
  the nature of the **donor star** and
  the **mass transfer channel**
- Given the X-ray variability found in MWC 656, future simultaneous X-ray/radio observations should allow us to trace the motion of the source in the radio vs X-ray luminosity diagram, and **directly check the slope** of the correlation at the low-luminosity end for the first time in HMXBs
- Observations of new candidates can allow to trace the correlation at different luminosities

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