From quiescence to outburst: when microquasars go wild!

Porquerolles, 29 September 2017

Accretion/ejection coupling in HMXBs at low luminosities through the study of Be/BH systems

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EXCELENCIA MARÍA DE MAEZTU

IEEC

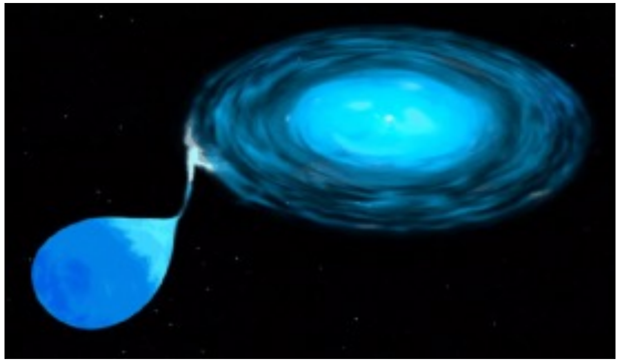
OUTLINE

1. Introduction
2. The Be/BH binary MWC 656
3. X-ray and radio observations (accretion/ejection coupling)
4. Work in progress
5. Conclusions

Introduction

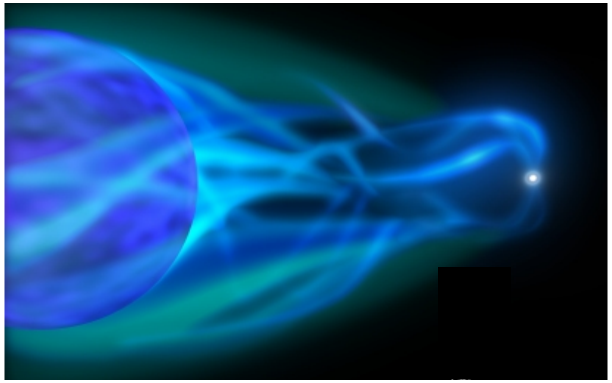
Mass transfer in binary systems:

- **Roche Lobe Overflow**

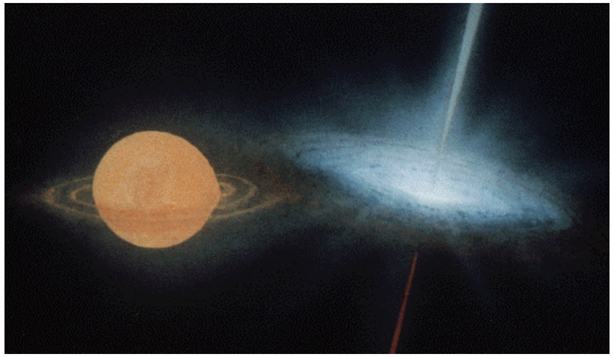


LMXBs

- **Radiatively driven stellar wind**



- **Decretion disk** (Be stars)

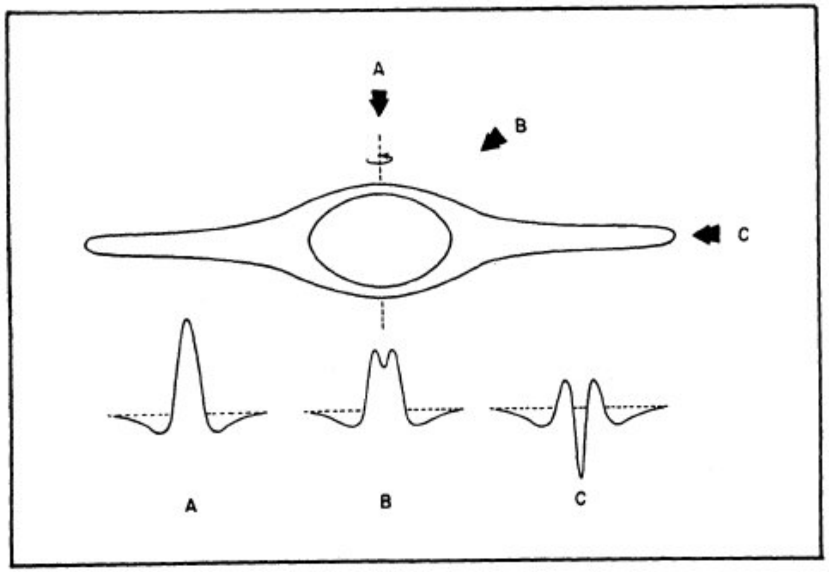


HMXBs

Introduction

Be stars are B stars with spectral **emission lines of hydrogen** (Hα, Hβ, etc.) and other elements and a **high projected rotational velocity** (close to critical when de-projected).

It is well established that Be stars **have a circumstellar envelope** in the form of a **quasi-Keplerian decretion disk** surrounding the star **(see, e.g., Rivinius et al. 2013)**.



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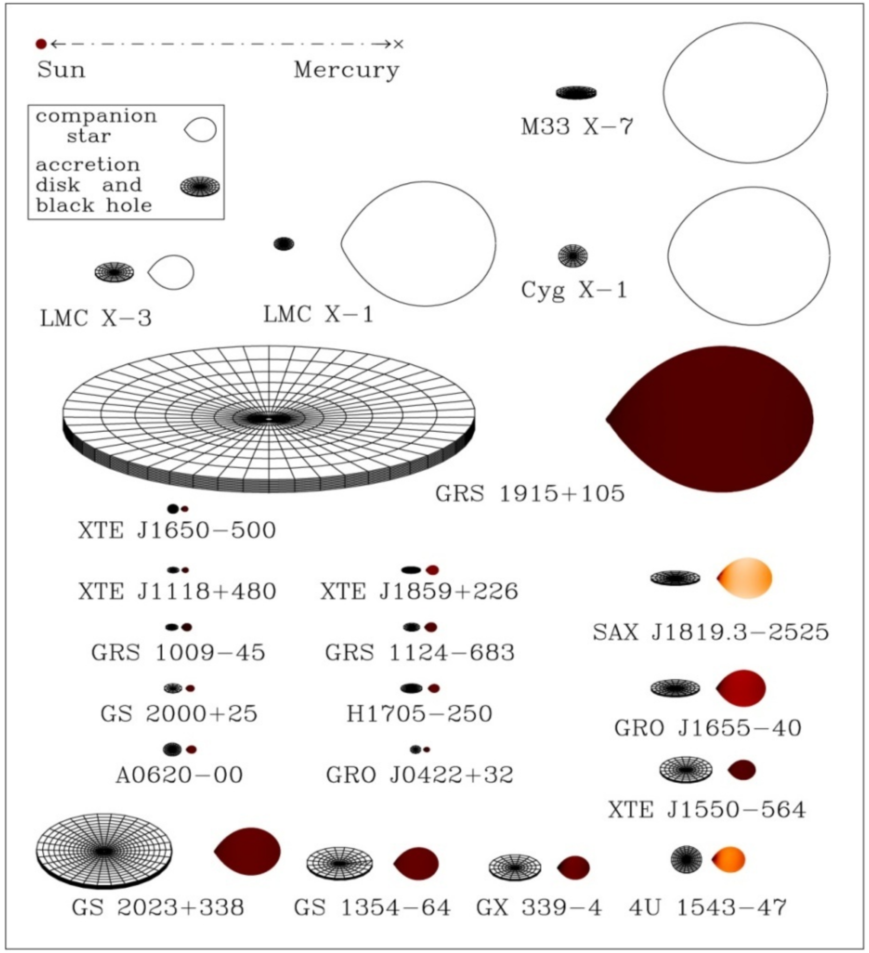


4 HMXBs

- Massive OB donors
- Wind fed
- X-ray persistent

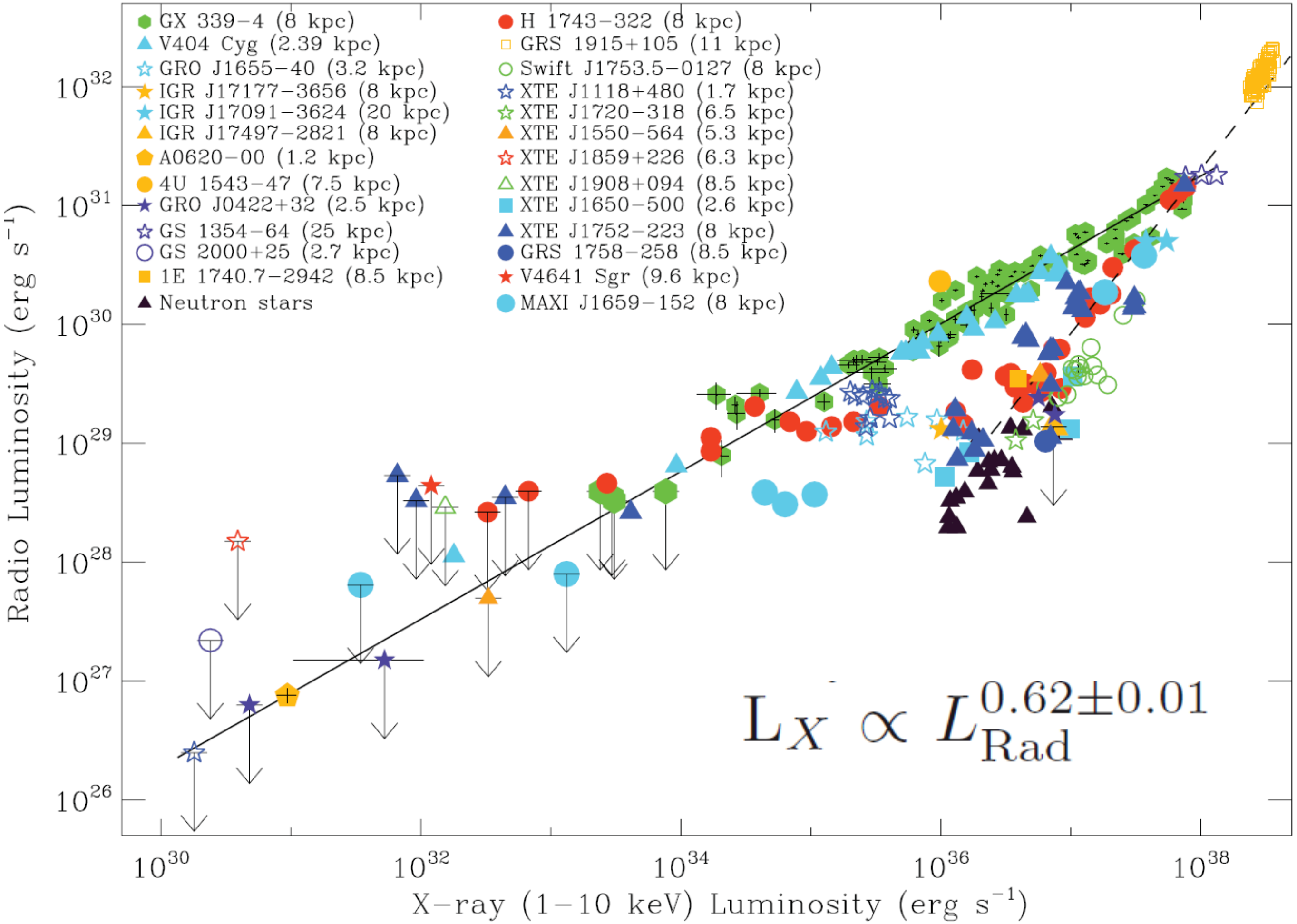
17 LMXBs

They show X-ray outbursts and different BH states

Dynamical black holes in binaries **McClintock et al. (2011)**.
No BH orbiting a Be star known at that time.

Introduction

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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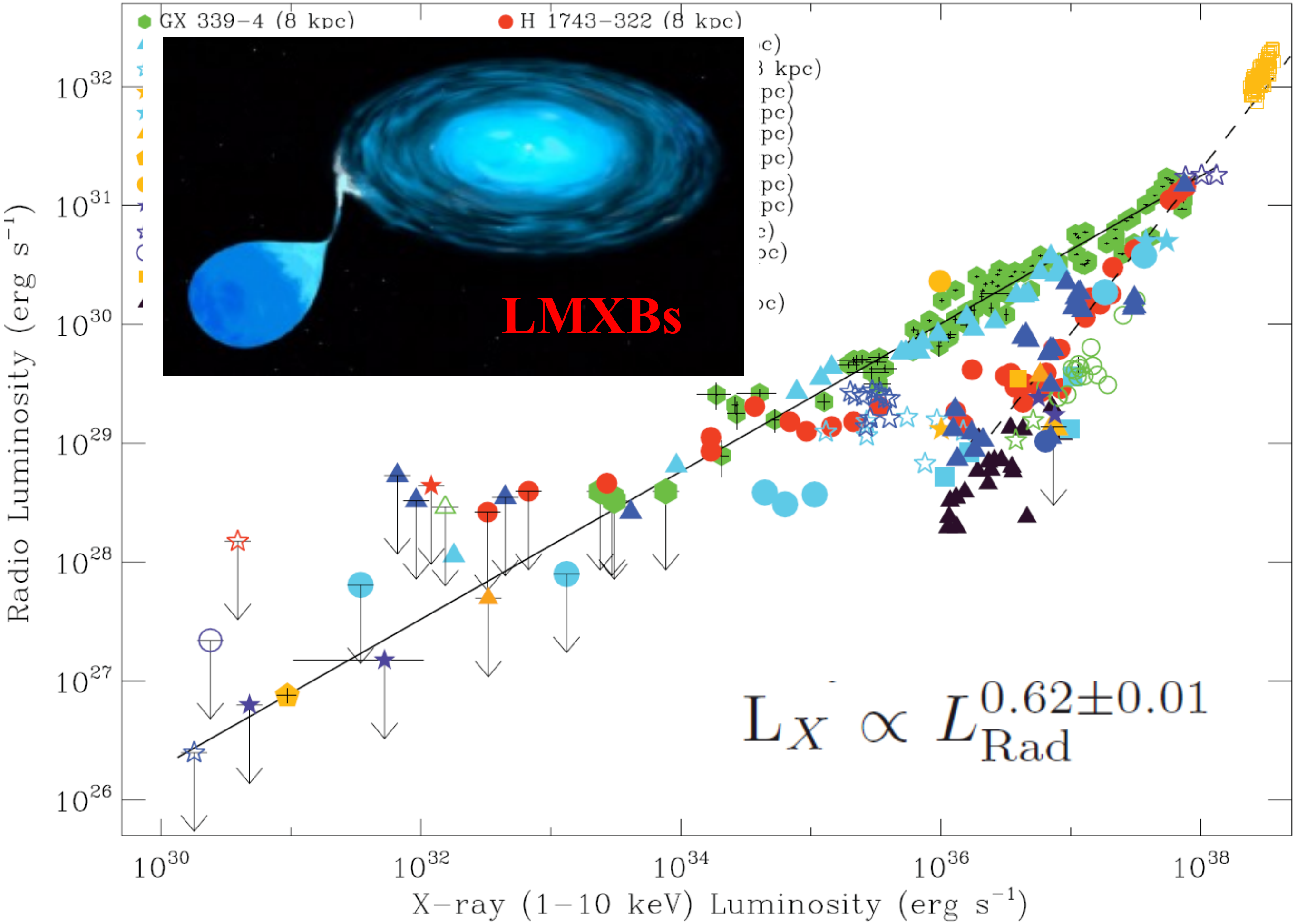

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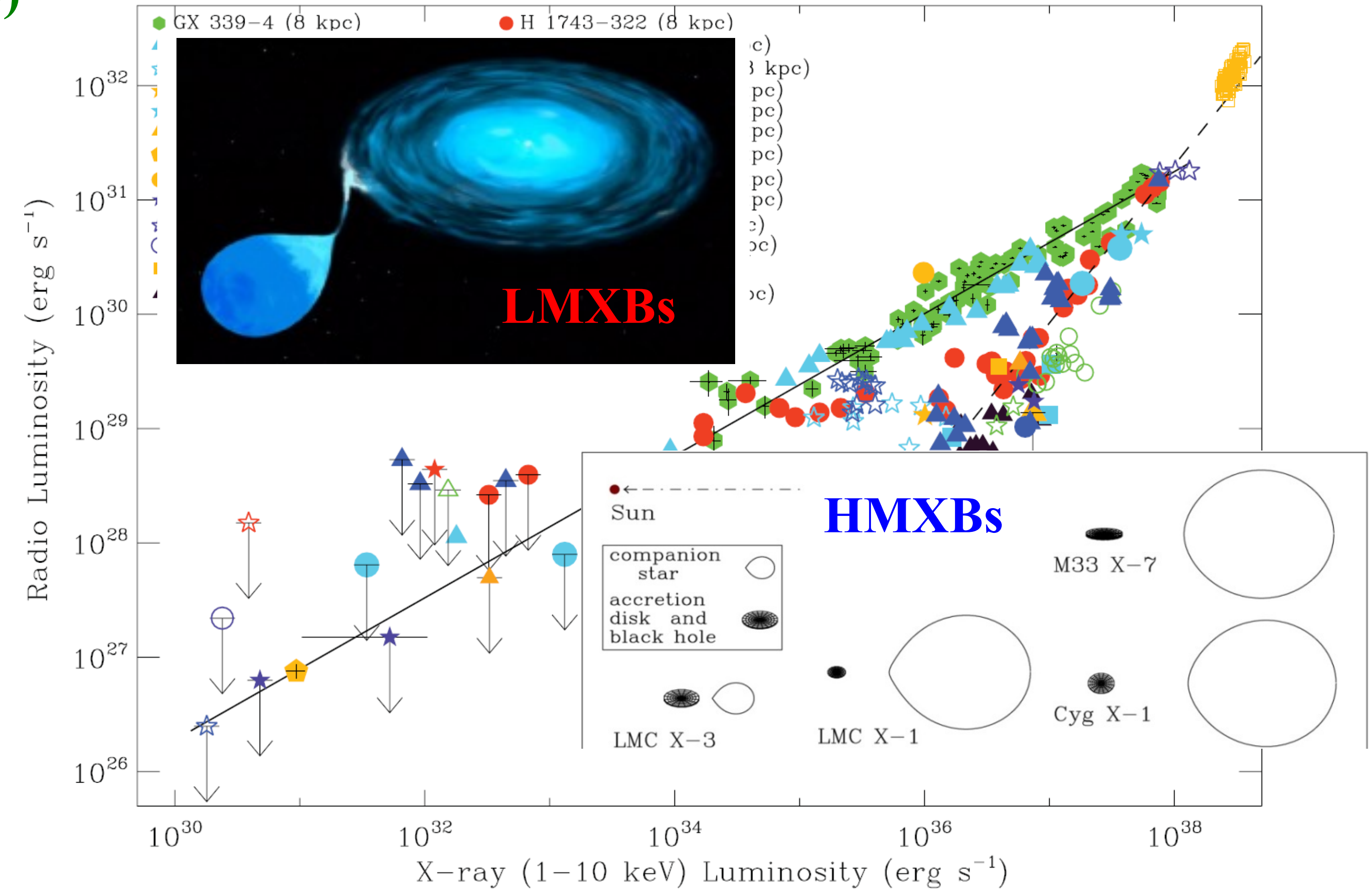
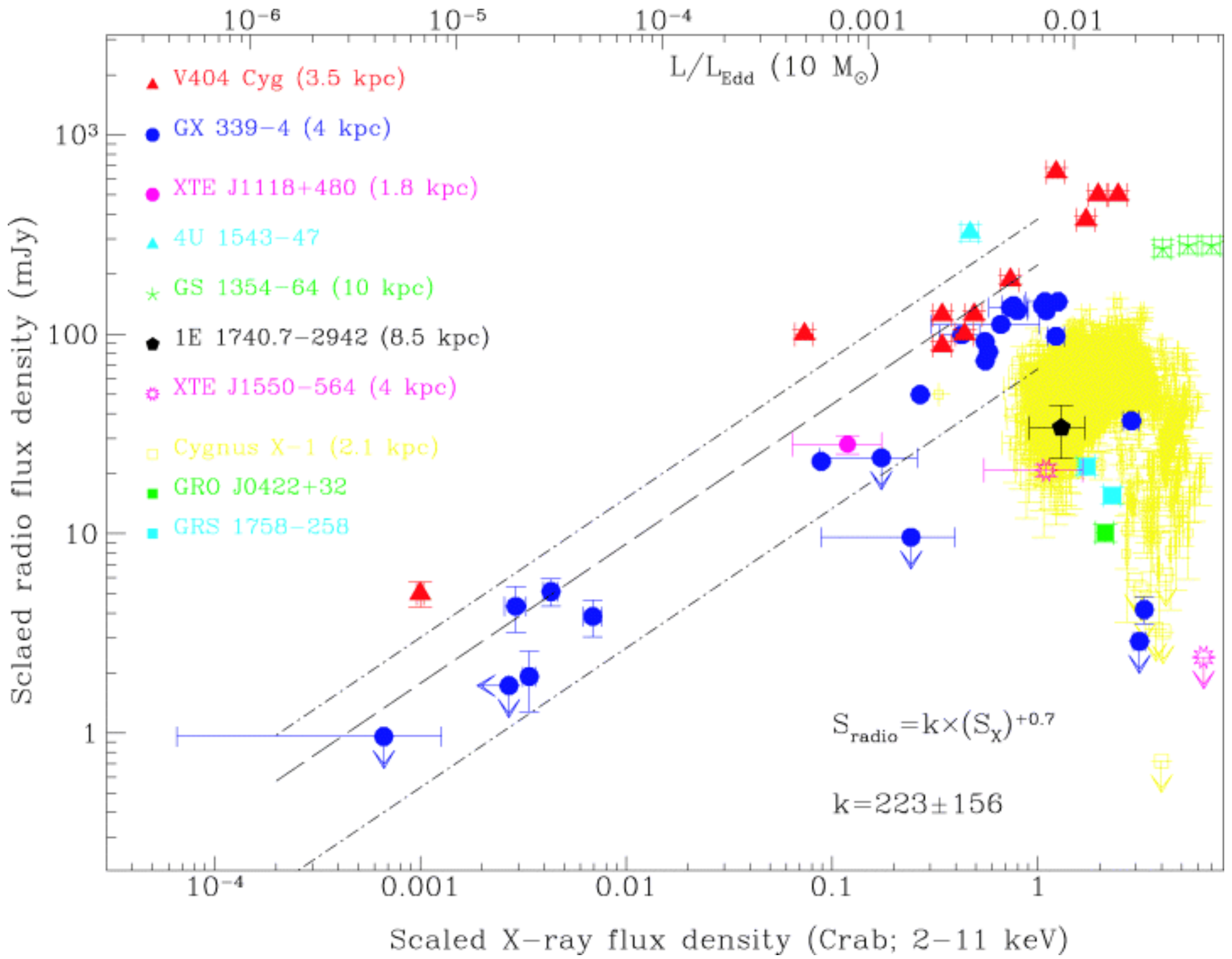


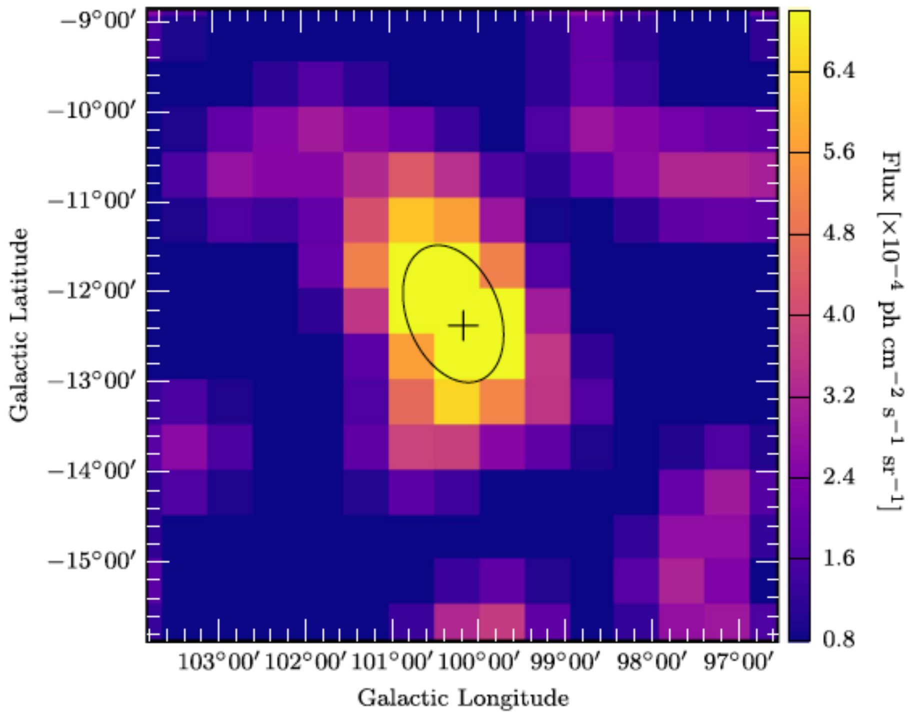
Introduction

The HMXB **Cygnus X-1** is always **very luminous!** **(Gallo et al. 2003)**.



The Be/BH binary MWC 656

- **New *AGILE* source** (GeV): AGL J2241+4454 **(Lucarelli et al. 2010)**.
- Not confirmed by ***Fermi*/LAT**, but ***enhancement of signal*** during the *AGILE* detection **(Alexander & McSwain 2015)**.
- 7 years of *AGILE* provide 9 other transient events with lower significance and a **hint of long-term GeV variability (Munar-Adrover et al. 2016)**.



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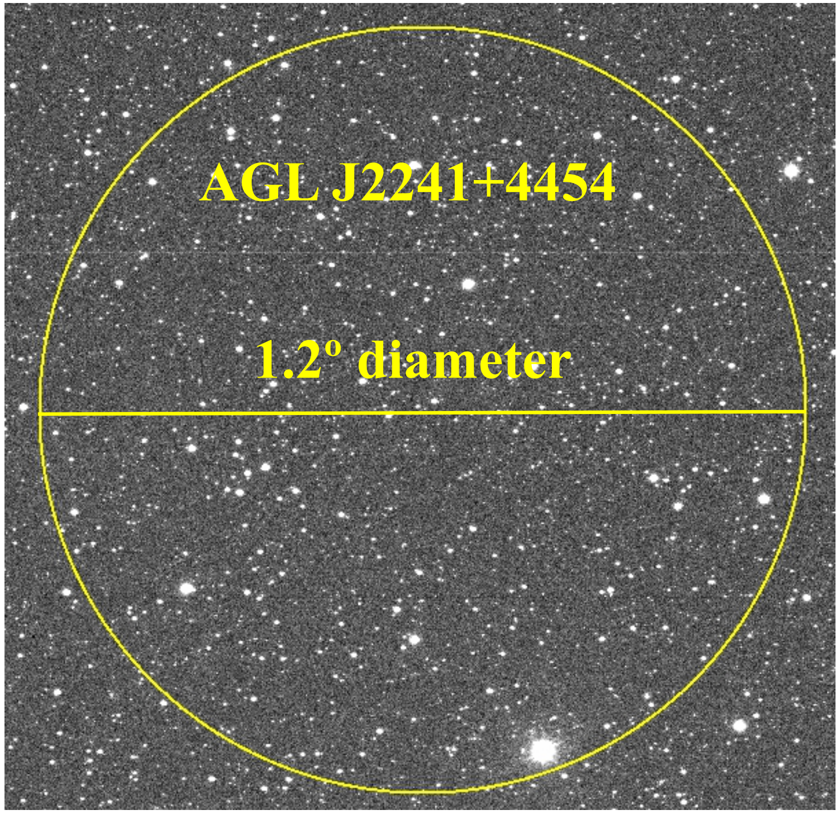
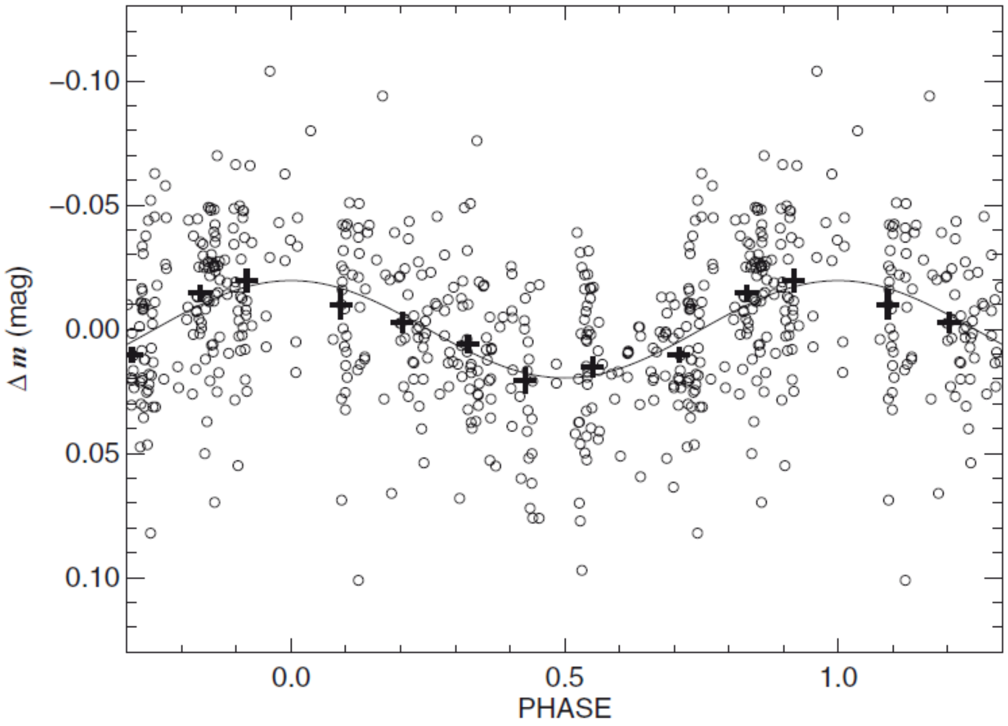
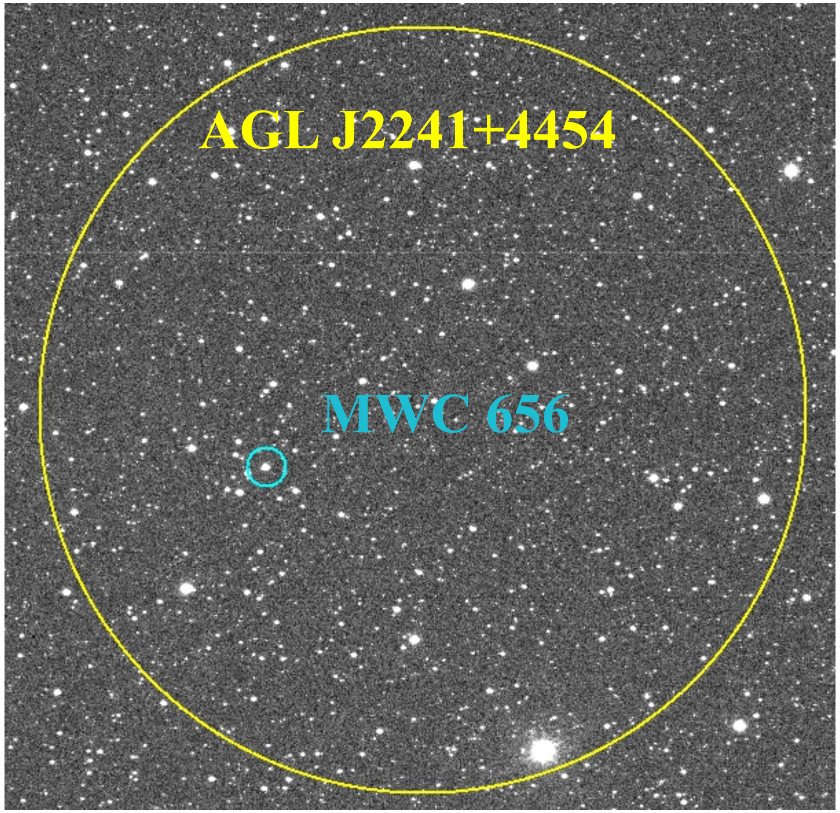
Even if outside the Galactic plane there are **lots of possible counterparts**.



The Be/BH binary MWC 656

- **Williams et al. (2010)** suggested **the Be star HD 215227**, aka **MWC 656**, as possible counterpart.
- Optical photometry (archival data) revealed a **periodicity of 60.37±0.04 d**, suggesting **binarity**.





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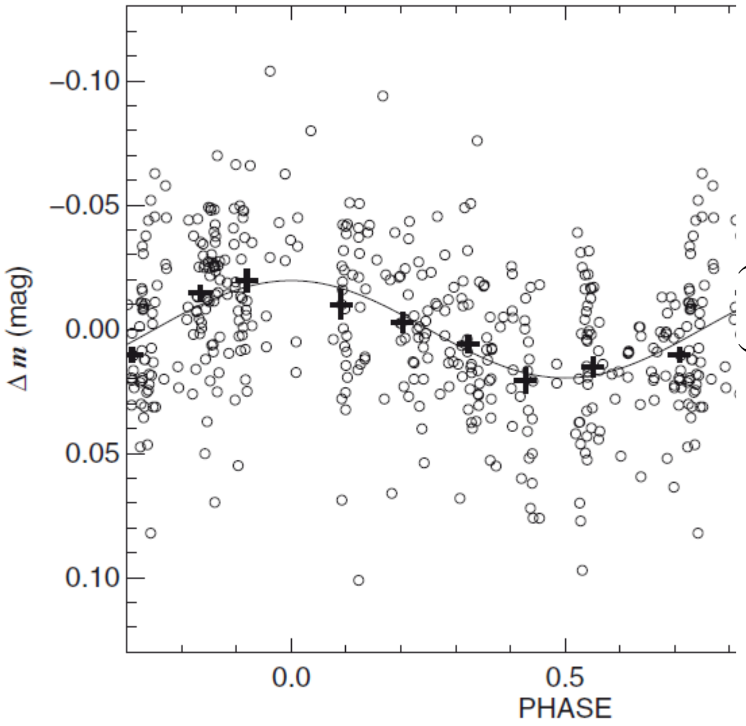
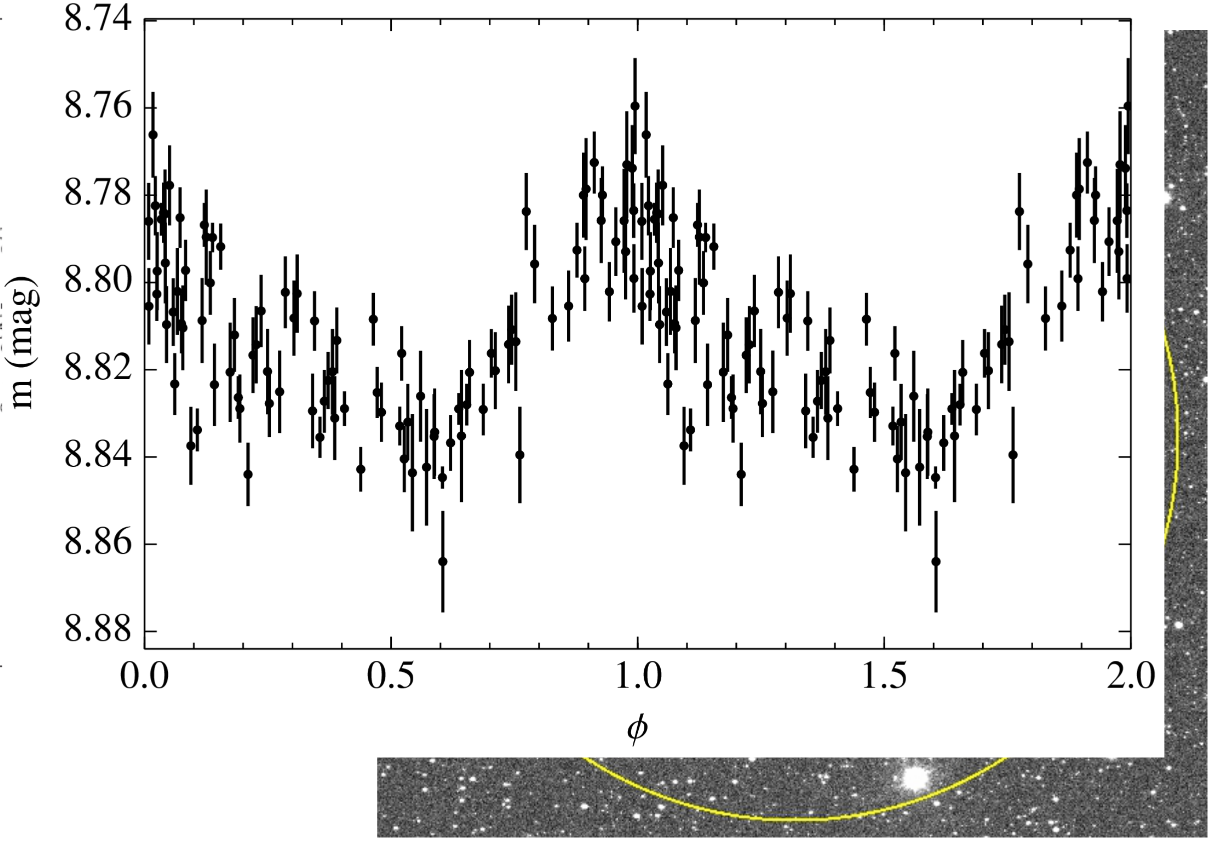
- **Paredes-Fortuny et al. (2012)** confirmed the periodicity with a coherent data set.





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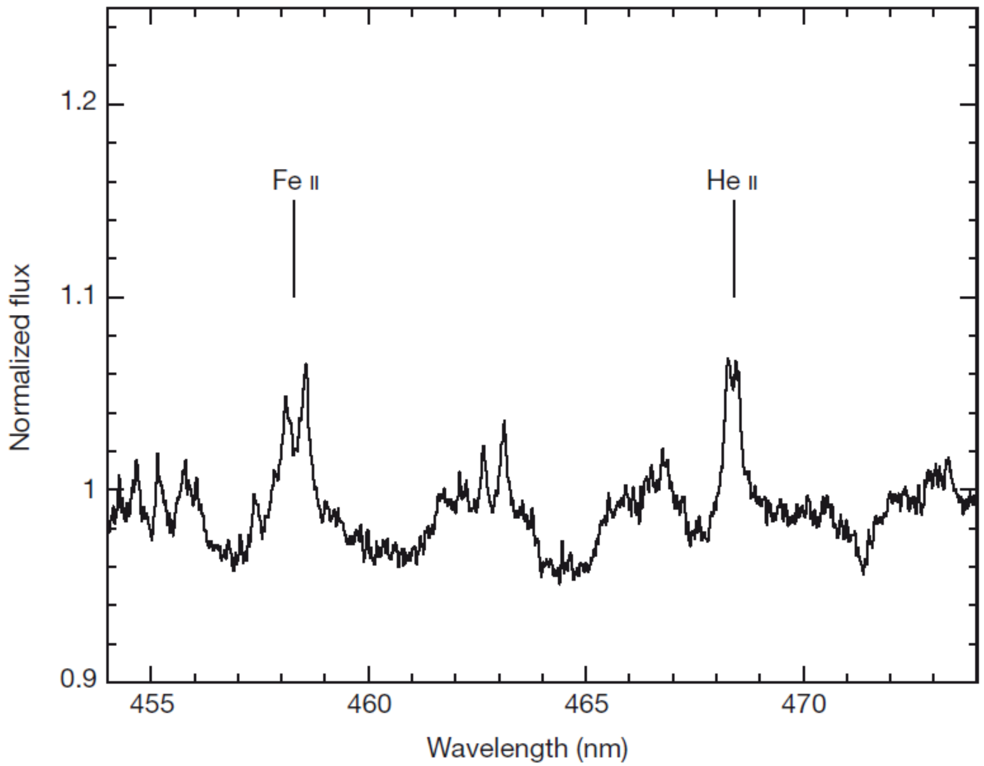

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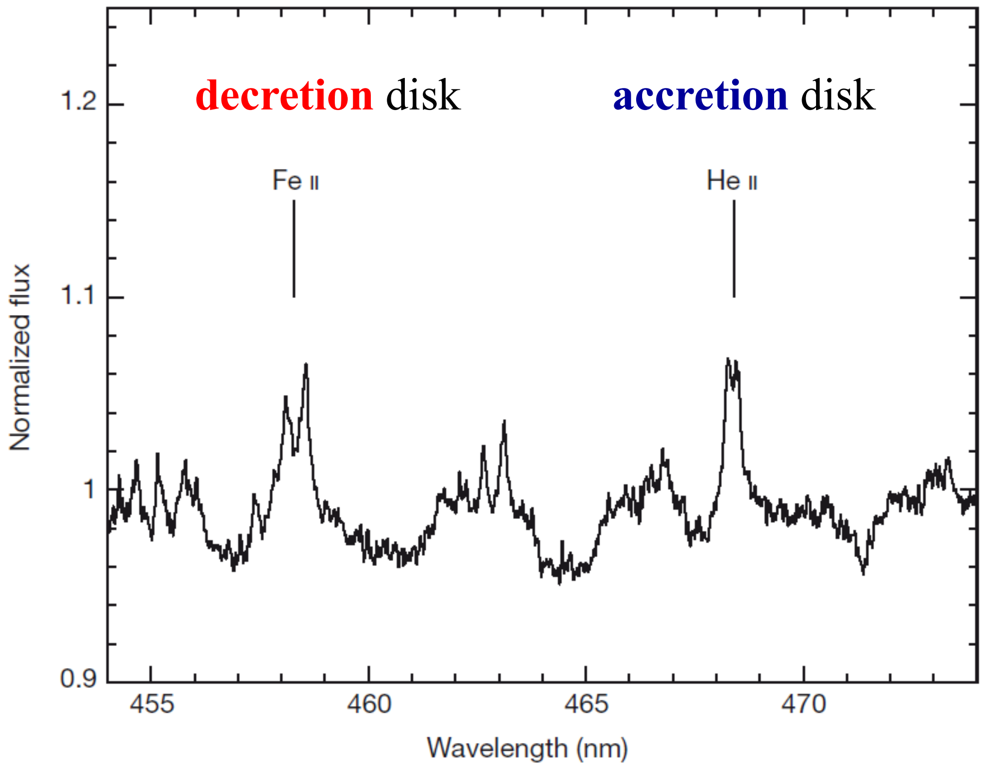
- We see a **decretion** disk and an **accretion** disk! **(Casares et al. 2014)**.



The Be/

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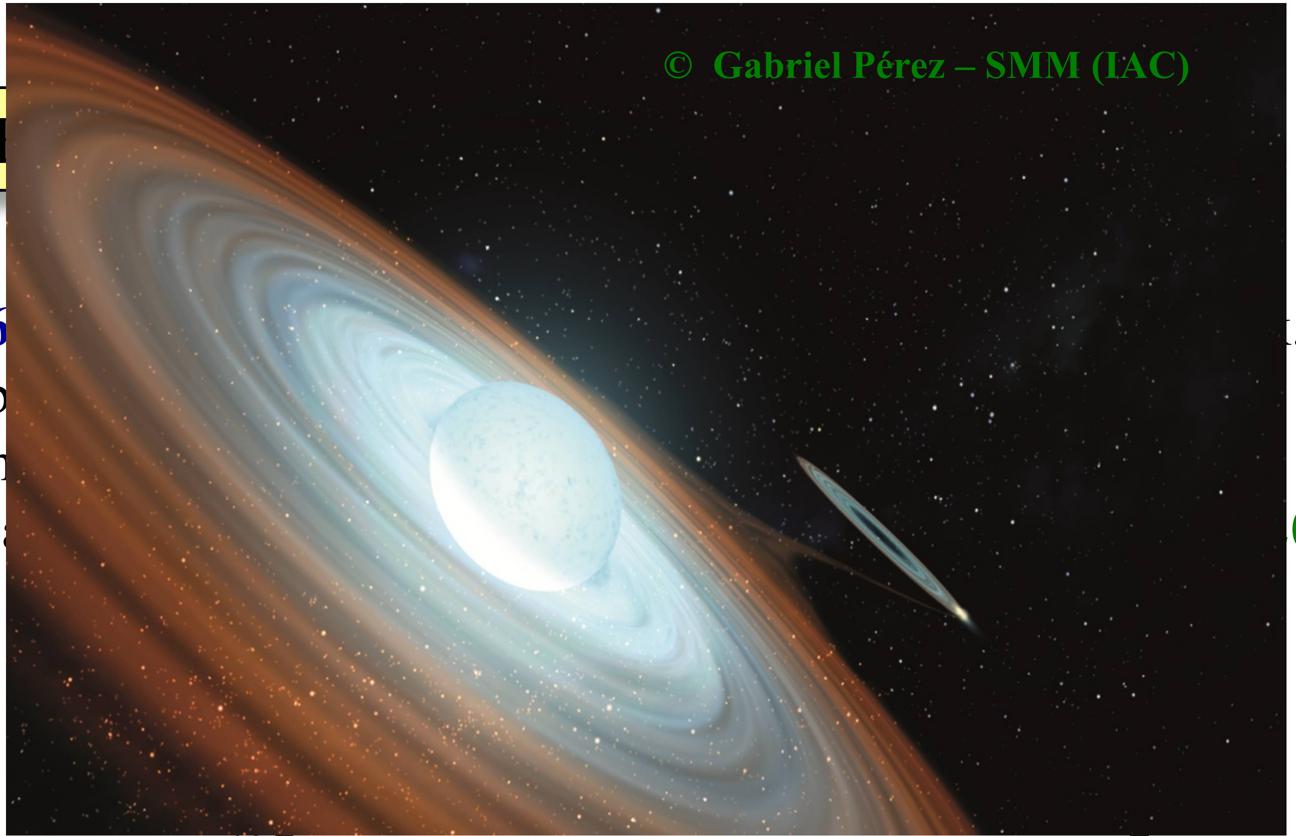
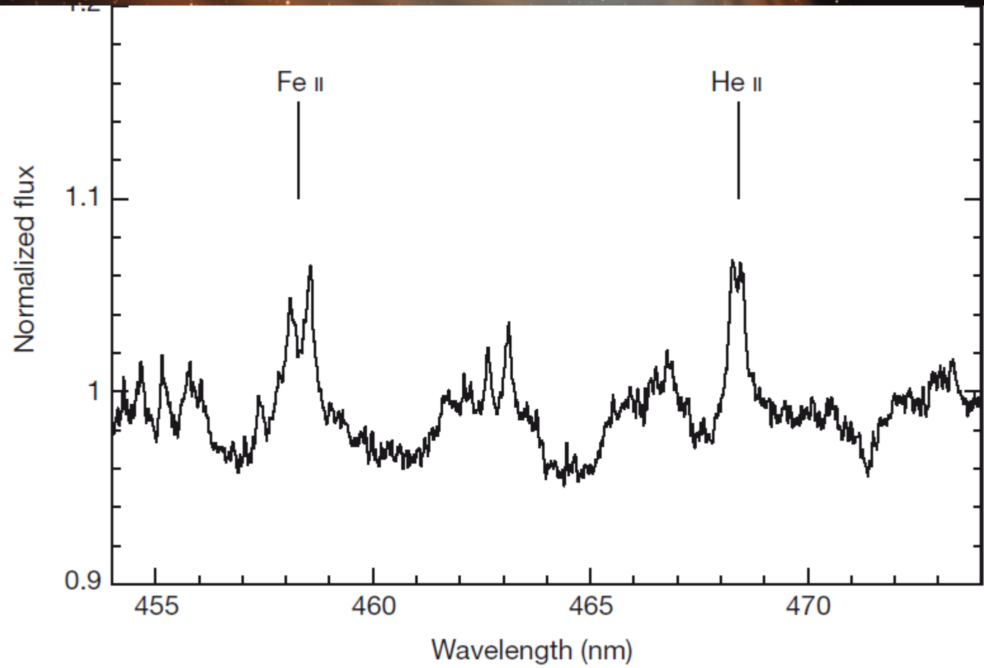
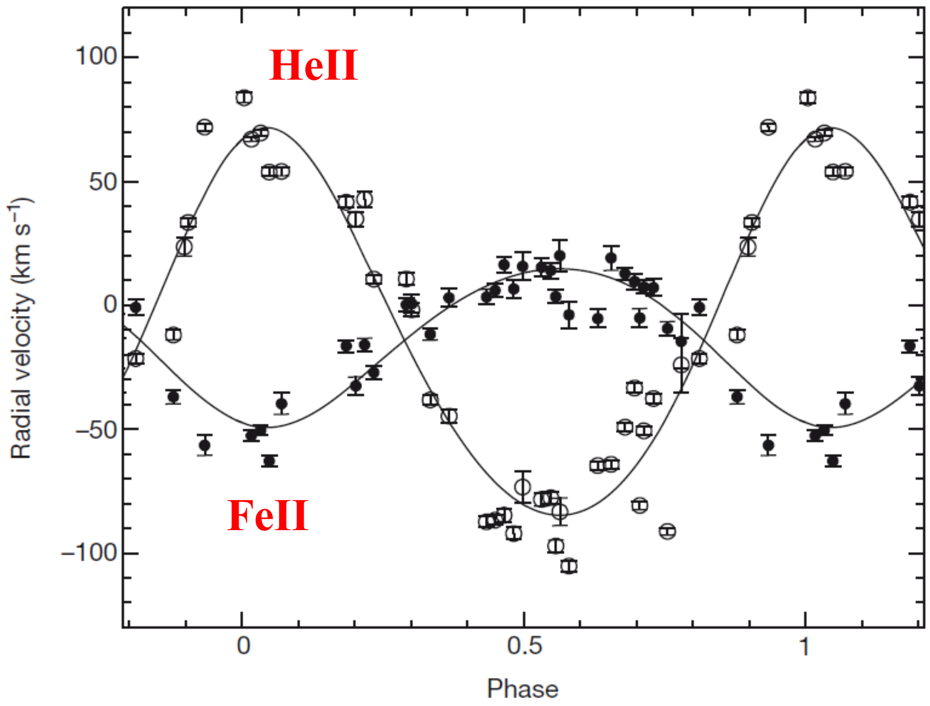
- FeII em
- We see ... 014).





The Be/BH binary MWC 656

- Double-line fit to disk lines provides a **mass ratio** of 0.41±0.07.
- Spectral classification B1.5–B2 III implies **10–16 solar masses** for Be star.
- This yields a **companion star of 3.8–6.9 solar masses**, implying a BH.
- Spectro-photometric distance is **2.6±0.6 kpc** **(Casares et al. 2014)**.



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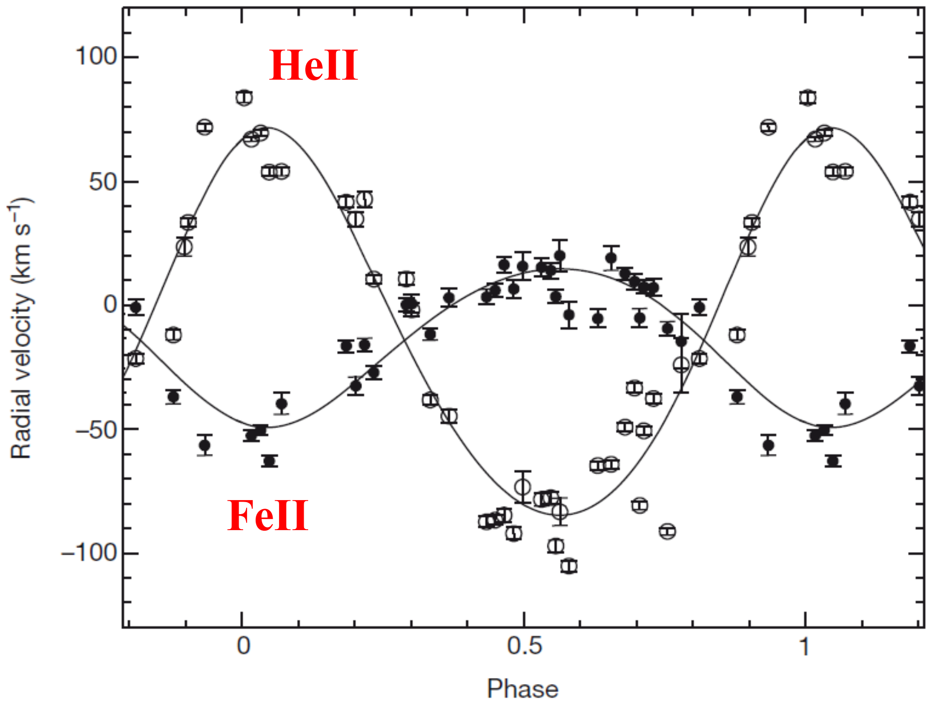
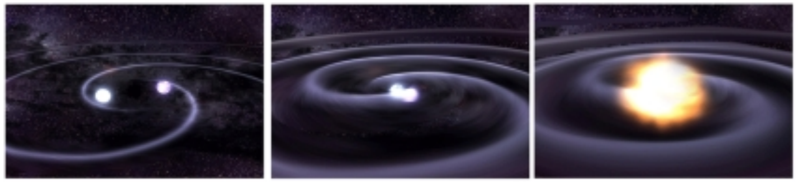


First Be/BH system ever found! Solves the problem of lack of Be/BH systems **(Belczynski & Ziolkowski 2009)**.

The Be/BH binary MWC 656



Binary population synthesis models (StarTrack) to:

- **Understand the formation channel** of MWC 656.
- Constrain the **population of Be/BH systems**.
- Study the **fate of MWC 656 as a possible NS-BH merger**.

Assumption: all donors beyond main sequence are **allowed to survive the Common Envelope phase**.

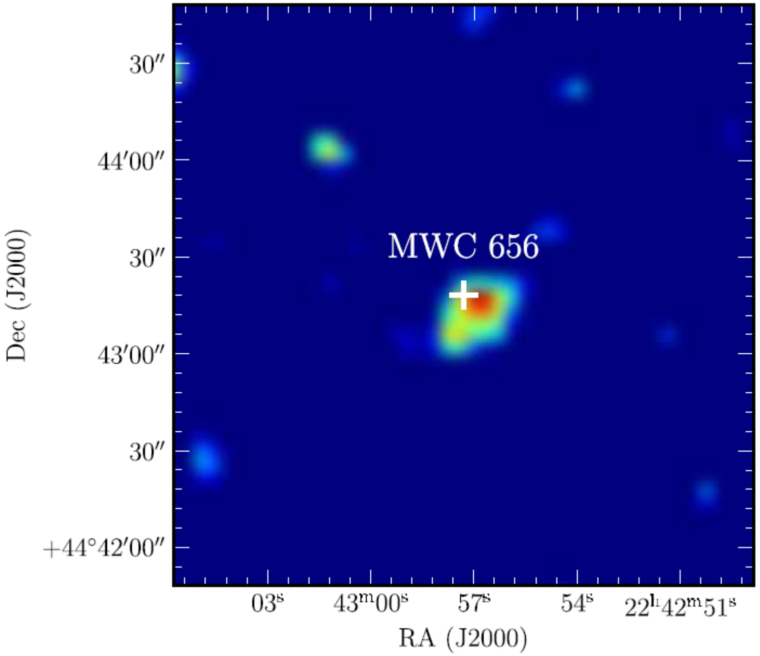
Total number of Be/BH systems formed over entire 10 Gyr of evolution of the Galactic disk is **8700**. Only **13 of them** have periods, eccentricities and masses **similar to MWC 656**.

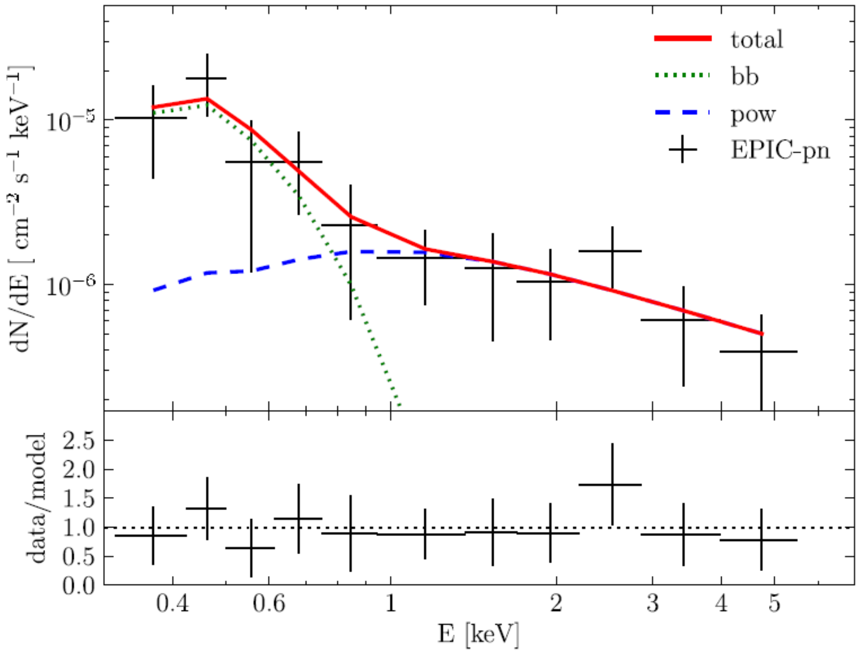
The simulated number of Be/BH systems **at present** is 39, but **only 0.007** with properties **similar to MWC 656** (probability 1%).

The detection of **gravitational waves** from such systems in nearby galaxies is possible for Advanced LIGO and Virgo, with **detection rate** at the level of **0.1±0.1 yr^{-1}** **(Grudzinska et al. 2015)**.

X-ray and radio observations (accretion/ejection coupling)

XMM-Newton observation of MWC 656 on 2013 June 4 (14 ks).
Faint X-ray source (4.4σ) coincident with Hipparcos position at 2.4σ.

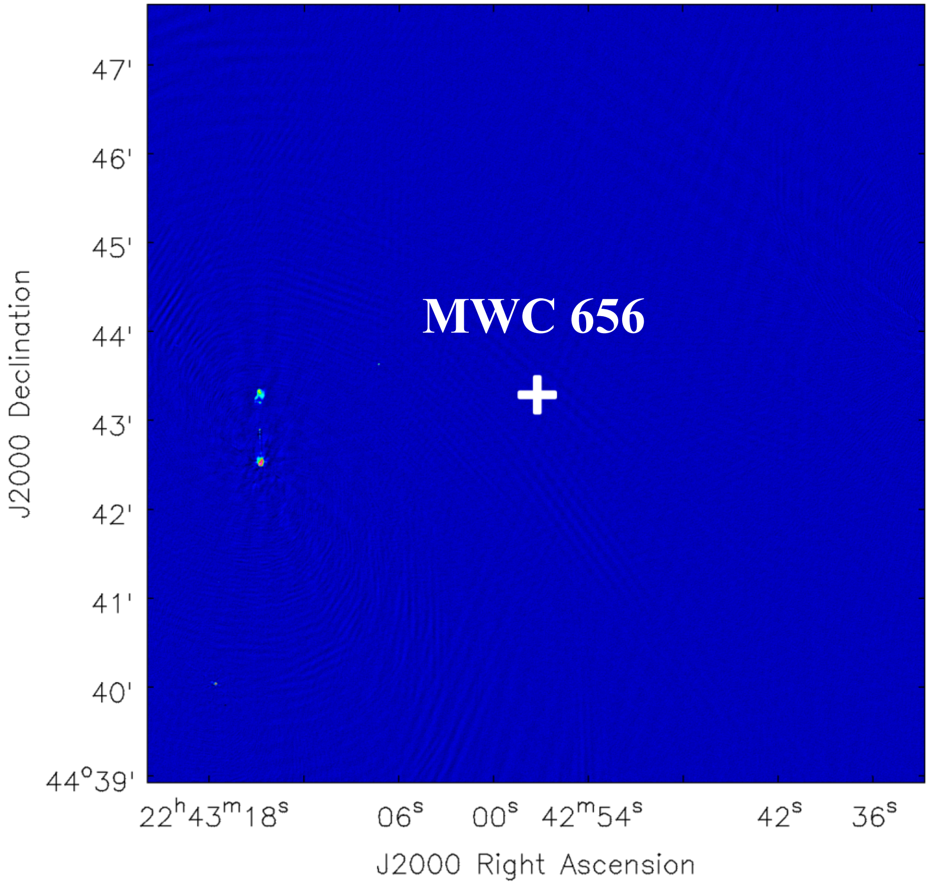


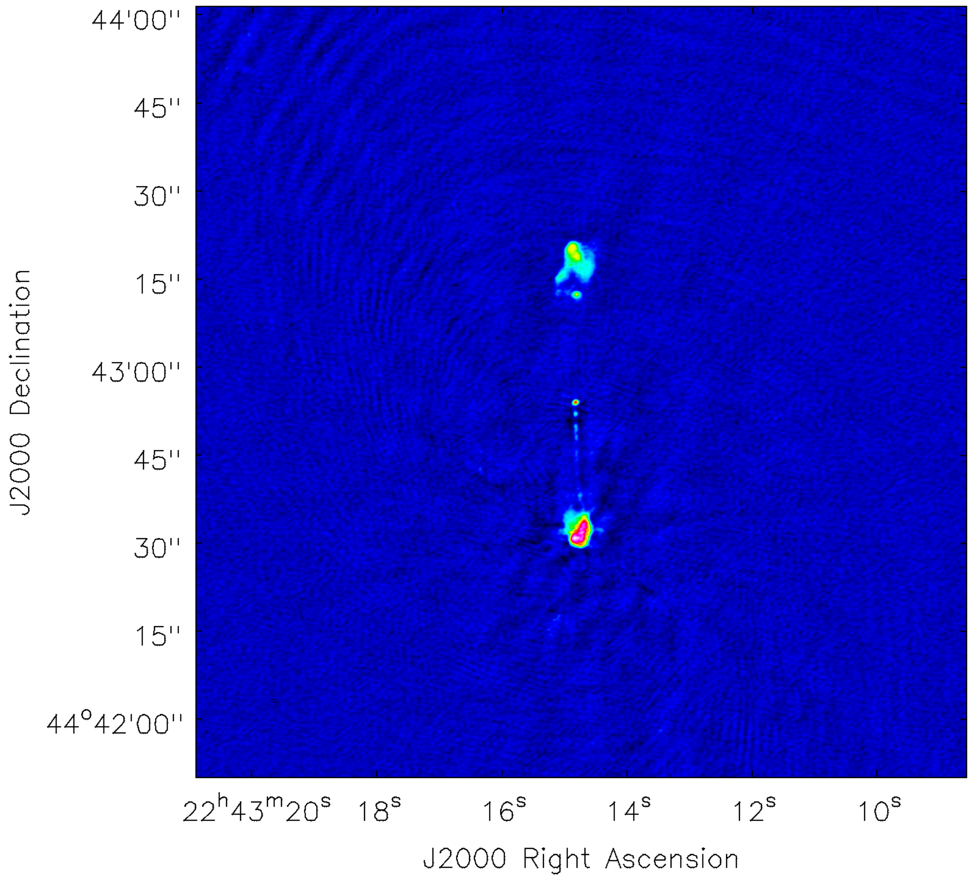


The **thermal X-ray luminosity is compatible** with the correlation $L_X \sim 10^{-7}\, L_{bol}$ for **isolated B stars (Berghoefer et al. 1997; Cohen et al. 1997)**.
The **non-thermal X-ray luminosity** is $L_X = (3.1 \pm 2.3) \times 10^{-8} L_{Edd}$ for the estimated BH mass, indicating that **MWC 656 was in deep quiescence**.
(Munar-Adrover et al. 2014).

X-ray and radio observations (accretion/ejection coupling)

Searches with EVN, WSRT, and VLA failed due to low radio flux density and contamination by a nearby readiogalaxy **(Moldón 2012, Marcote 2015)**.



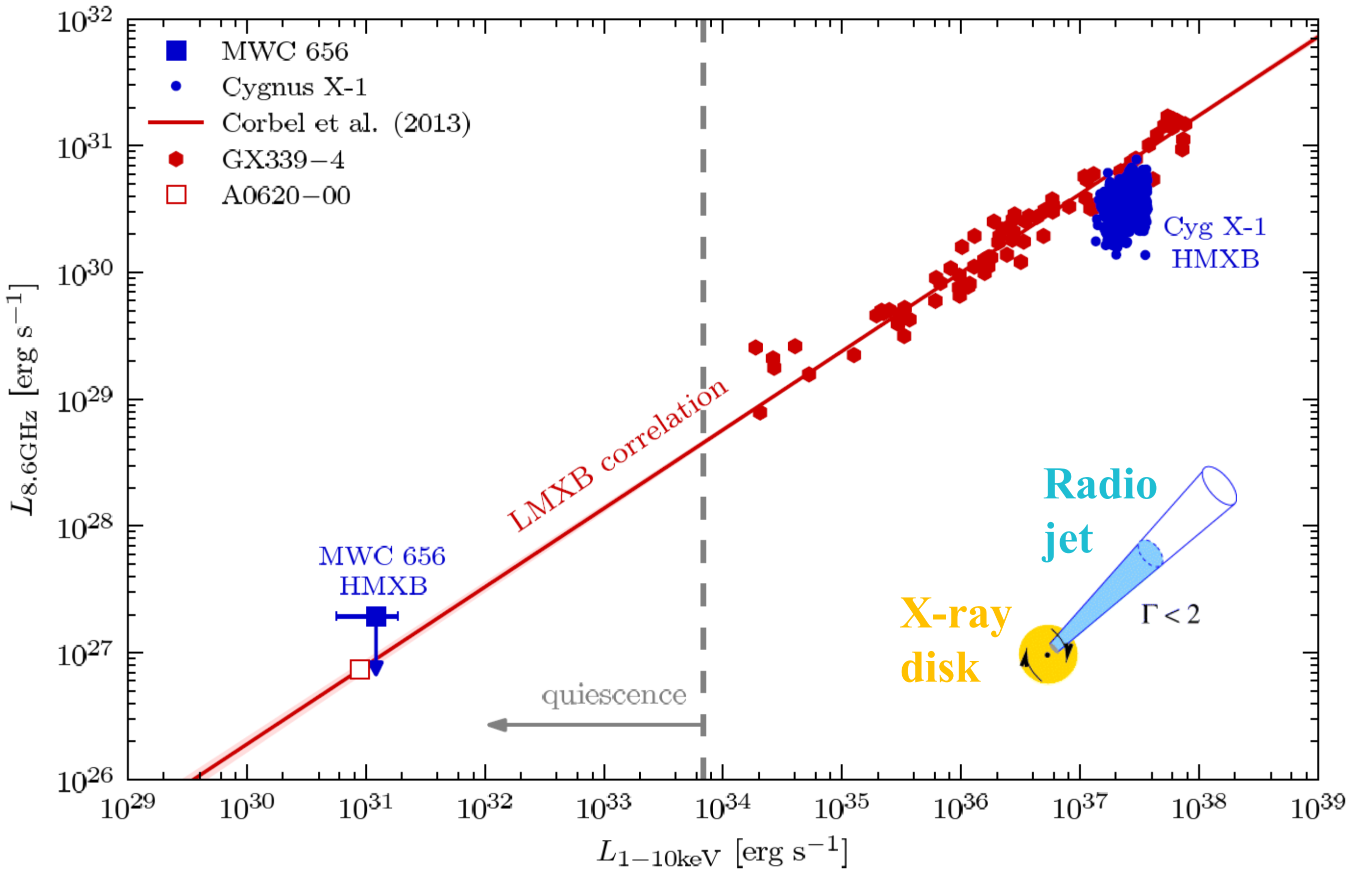


X-ray and radio observations (accretion/ejection coupling)

XMM-Newton detection and non-simultaneous radio flux density EVN upper limits from **Moldón (2012)** show that **MWC 656 is located in the lower-left side of the radio/X-ray luminosity diagram**. It may be consistent with, and just above than, the correlation from Corbel et al. **(Munar-Adrover et al. 2014)**.

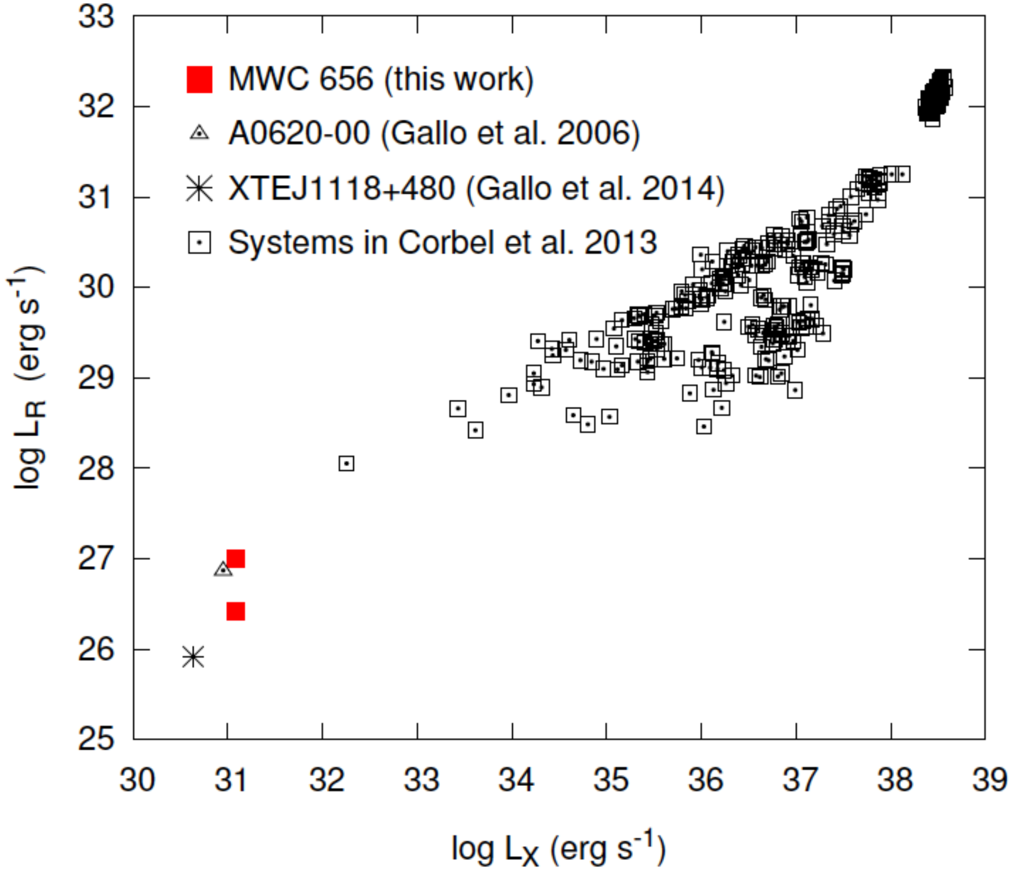
The radio/X-ray correlation could also be valid for BH HMXBs.

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



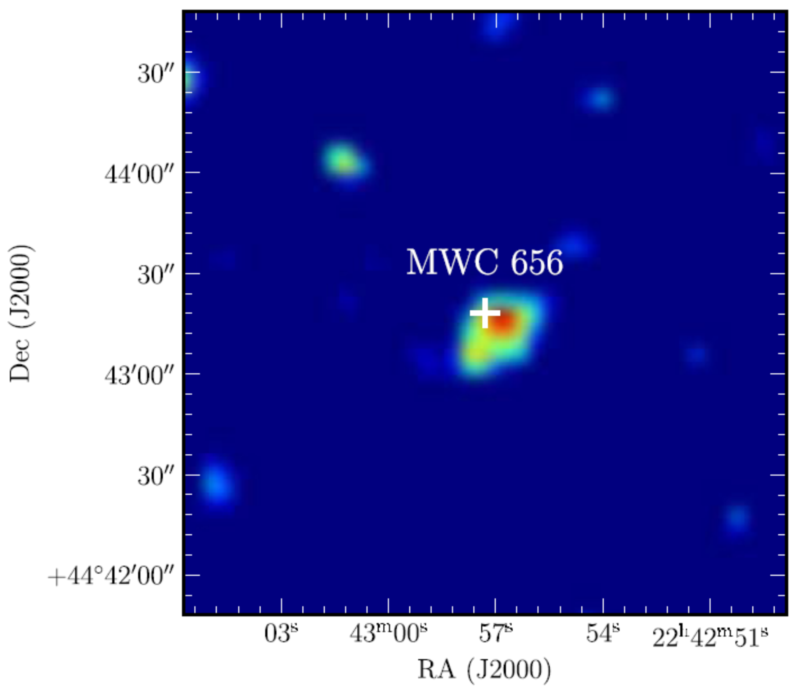
X-ray and radio observations (accretion/ejection coupling)

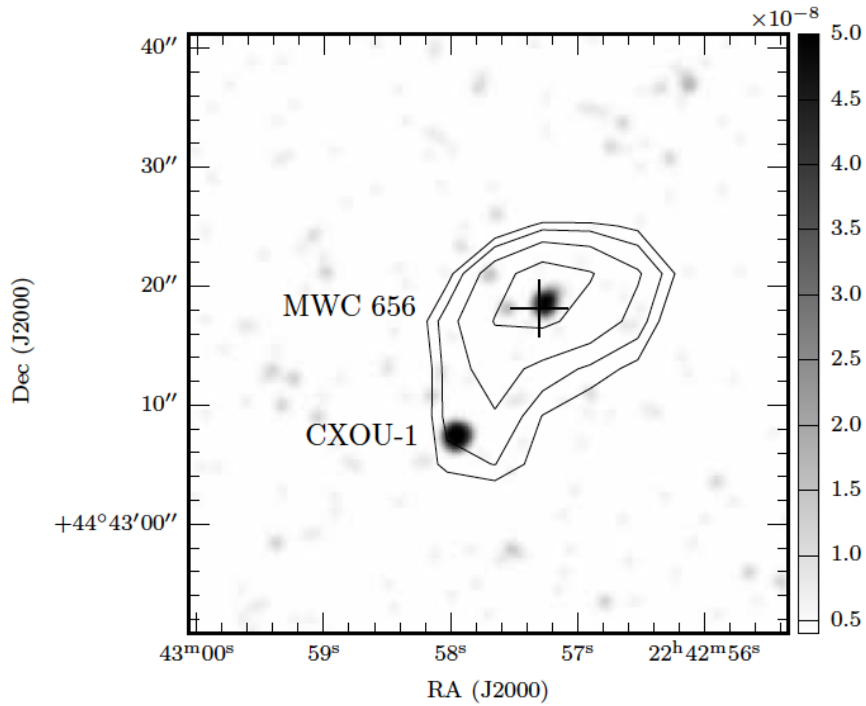
New VLA observations in 2015 provided the **discovery of a faint radio counterpart**: **3.7-14.2 μJy (Dzib et al. 2015)**.
Using **non-simultaneous** *XMM-Newton* X-ray flux (2013) they plotted the source in the X-ray/radio luminosity diagram and found it compatible with the previously known trend.



X-ray and radio observations (accretion/ejection coupling)

New deep Joint *Chandra*/VLA observations (2015 July 24: 60 ks of *Chandra*, 6 hours of VLA at 8-12 GHz, ϕ=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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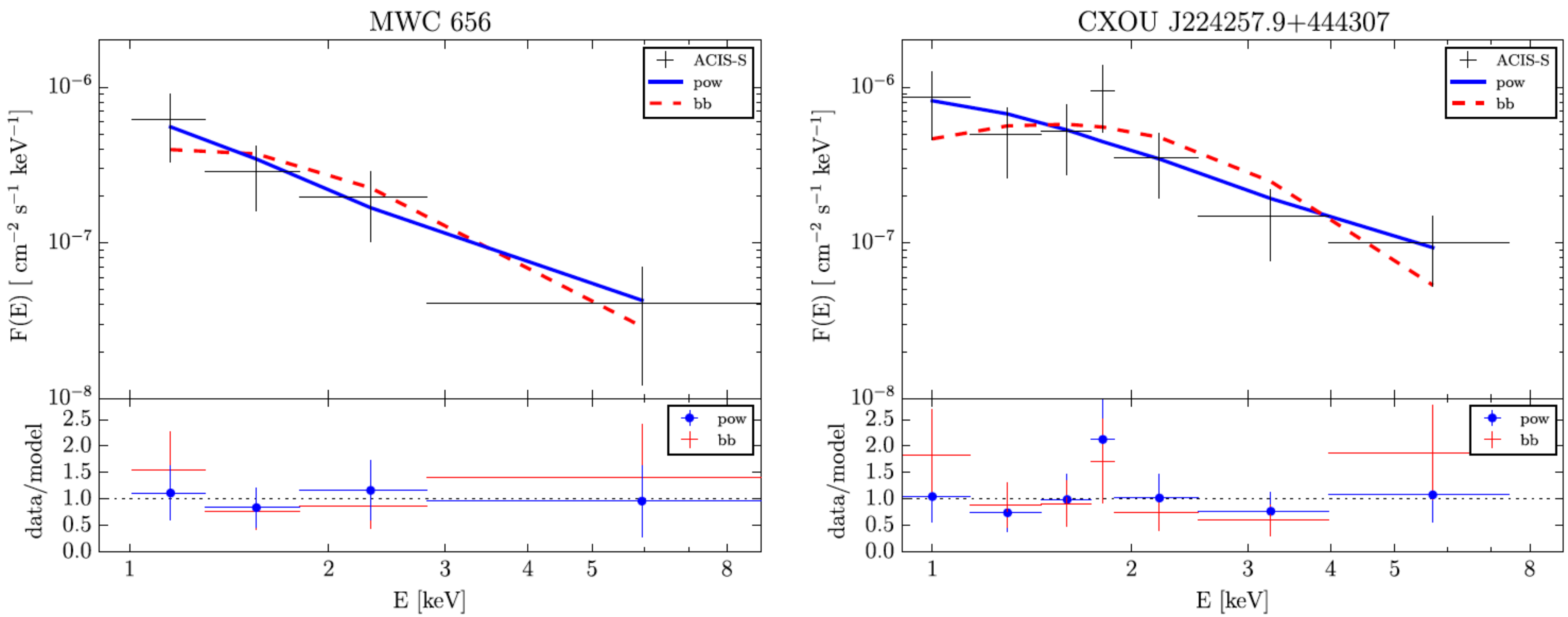

The spectra of both sources can be fitted with power law and blackbody models, though **power law models are favored**.

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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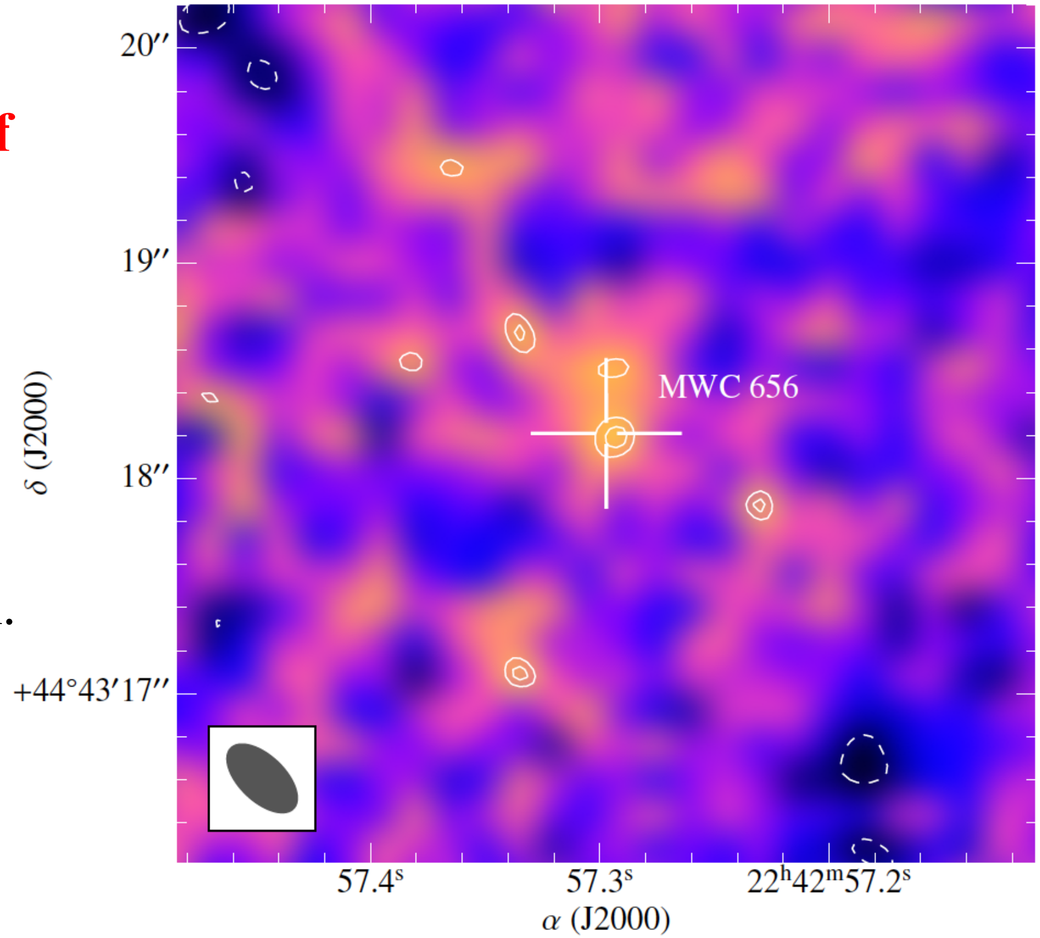
Radio: due to the proximity of the bright quasar we **imaged a region of a few arcminutes**.
We conducted a **multiscale clean**.

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



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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 (see below…)

    \+
  - relatively high electron densities (Dulk 1985; Güdel 2002).

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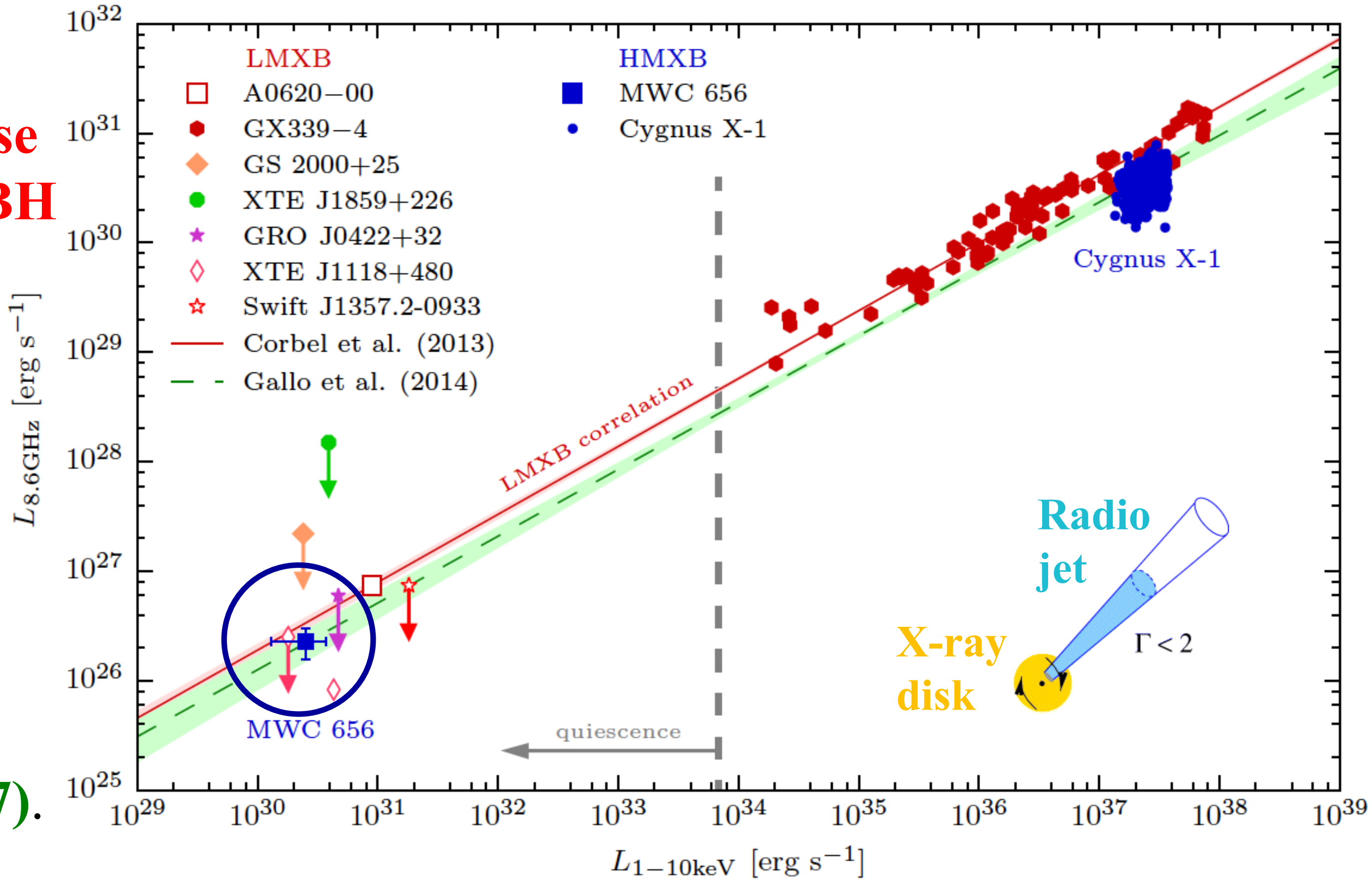
MWC 656 is one of the **faintest stellar-mass BHs** ever detected in X-rays, and the faintest one in X-rays also detected in radio.

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

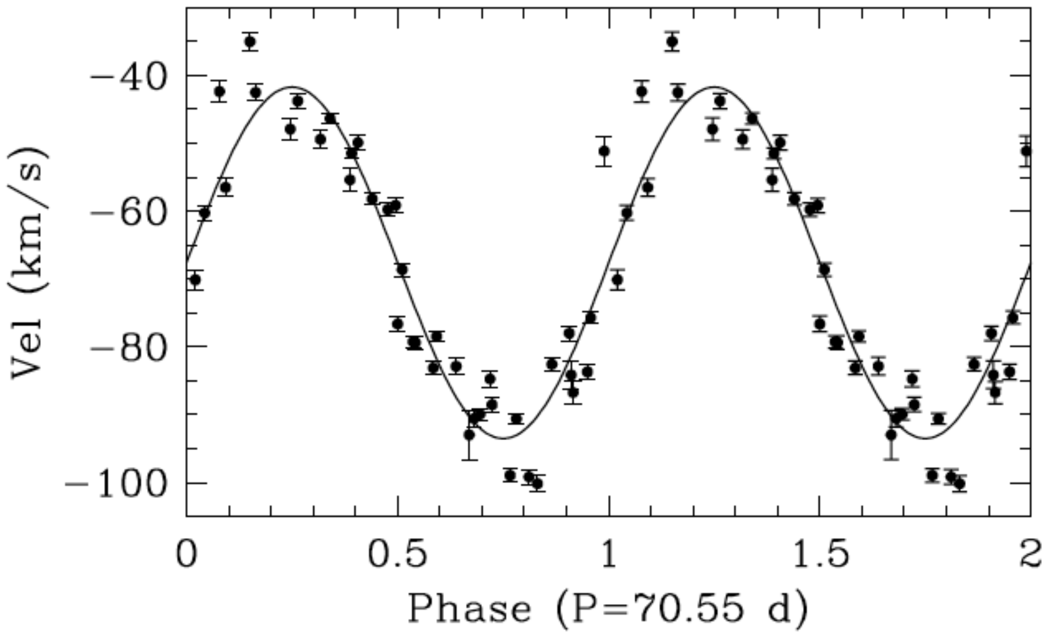
Within the report: "The radio-X-ray correlation seems to be already well-established, both for HMXBs and LMXBs…"

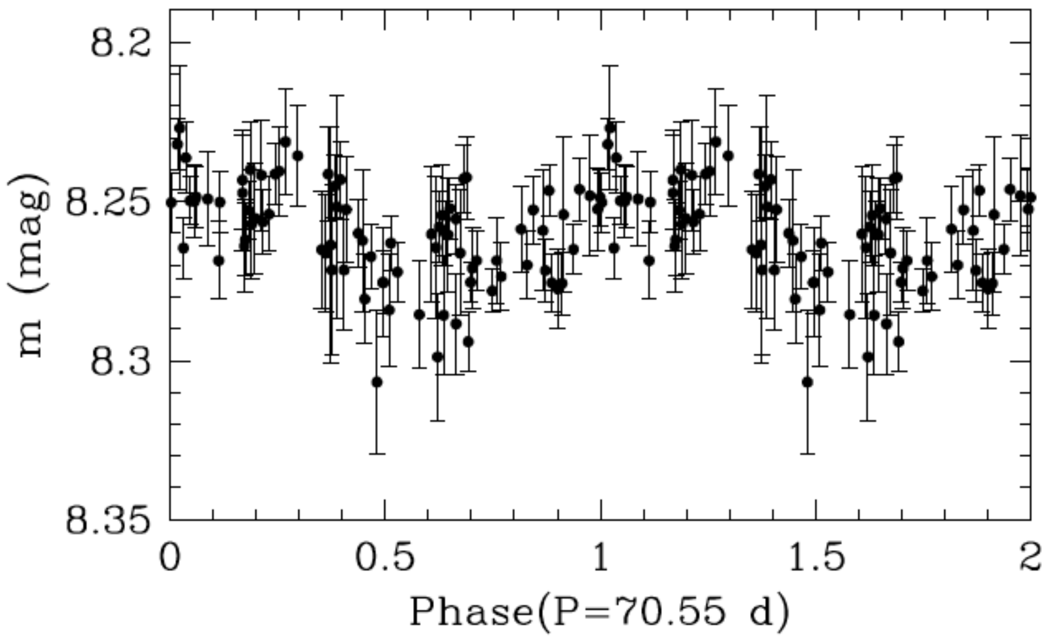
Rejected!

Work in progress

To **search for new Be/BH** binary systems we have searched for the signature of the **HeII 4686 A emission line** in a catalogue of 600 classic Be stars (http://basebe.obspm.fr/basebe).

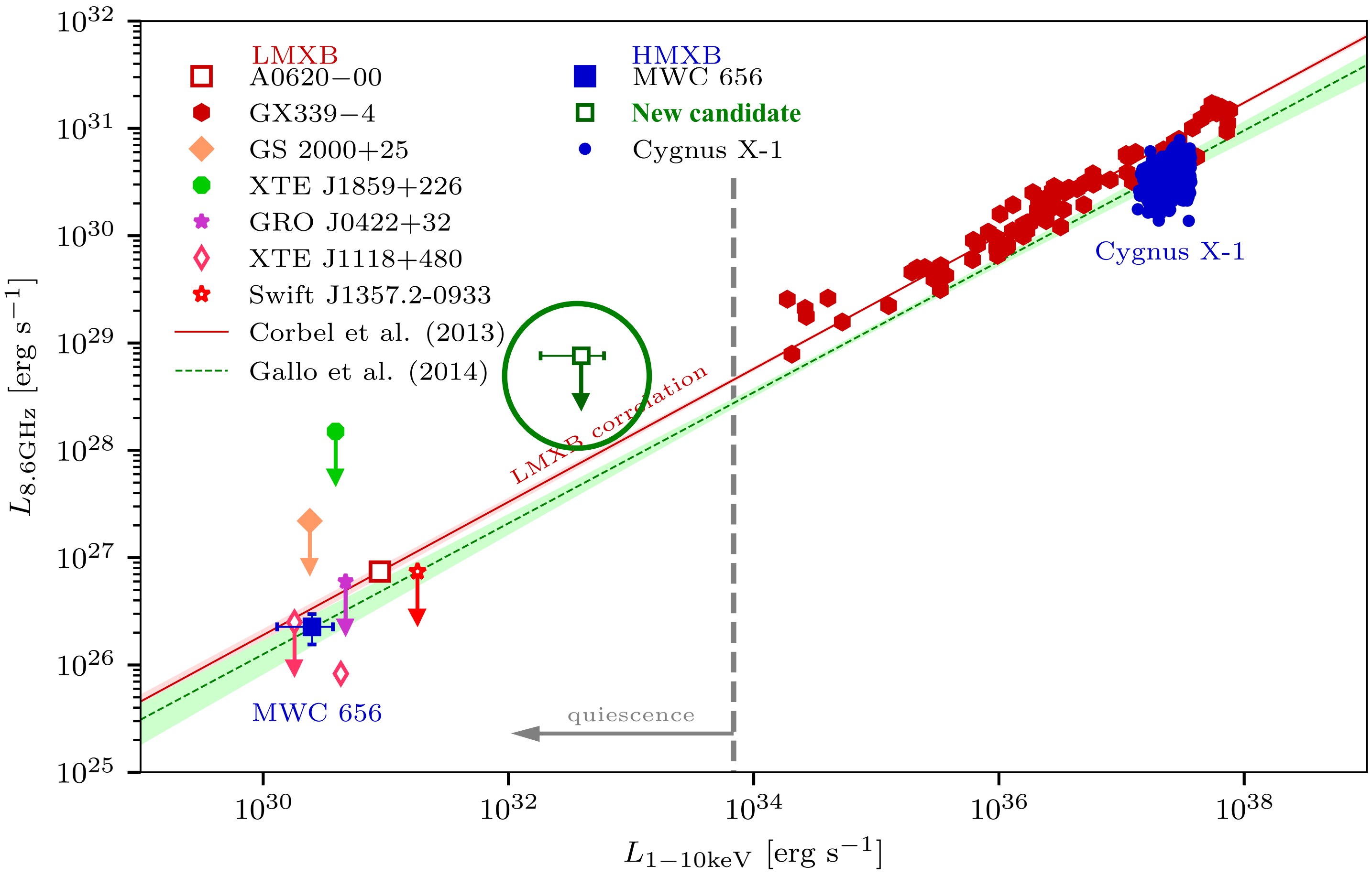
We are now studying the variability of this emission line, and **found at least a very good candidate** with a period of ~70 d in both radial velocities and optical photometry.





Work in progress

The **very good candidate** 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.



Conclusions

- We have **discovered the first Be/BH binary system** after an *AGILE* alert.
- **Be/BH binaries** may evolve into close **BH/NS binaries** that would emit **GWs** during coalescence detectable by LIGO/Virgo in nearby galaxies.
- The first Be/BH binary is an **X-ray binary in deep 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**.
- More systems to be discovered. Is there a large population of **hidden black holes in massive binaries?**