The radio view of MAXI transients

Alex Tetarenko

University of Lethbridge

J. Miller-Jones, P. Casella, T. Maccarone, T. Russell, P. Gandhi, C. Wood, S. Prabu, A. Bahramian, G. Sivakoff, E. Rosolowsky, S. Corbel, N. Degenaar, J. van den Eijnden, C. Sanchez-Fernandez, E. Kuulkers, M. Del Santo, F. Vincentelli, P. Uttley, F. Carotenuto and many more…

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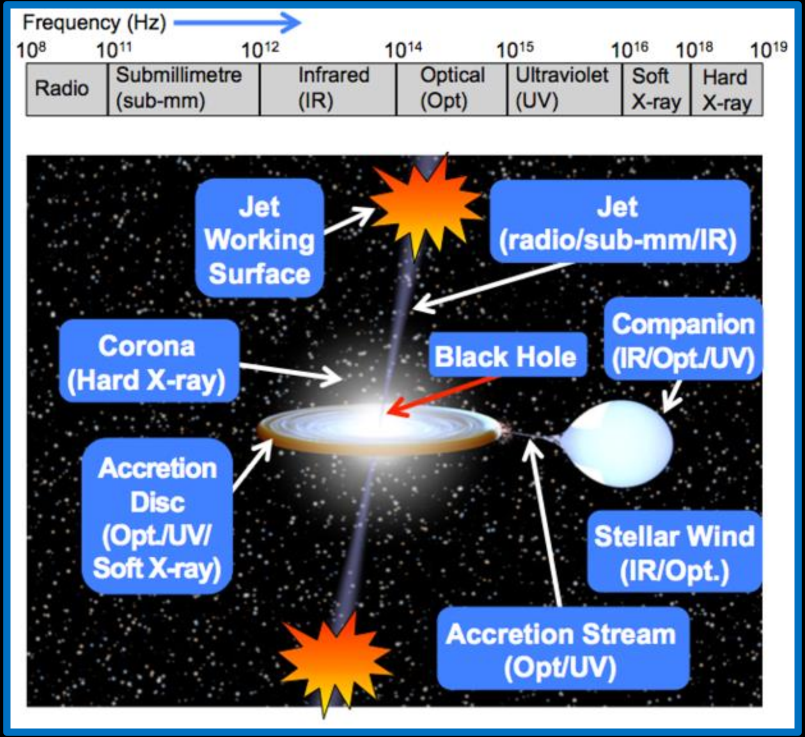
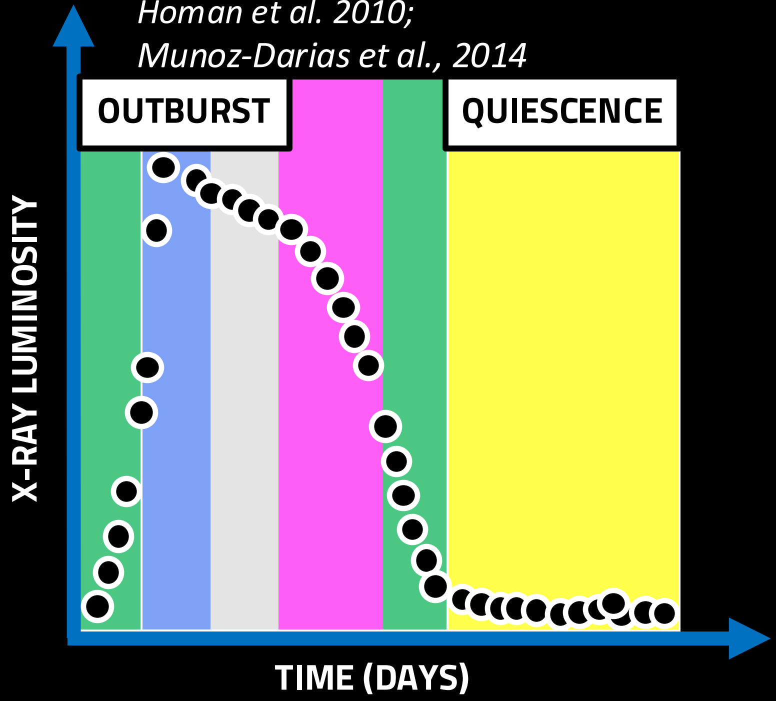
Stellar mass systems – X-ray binaries

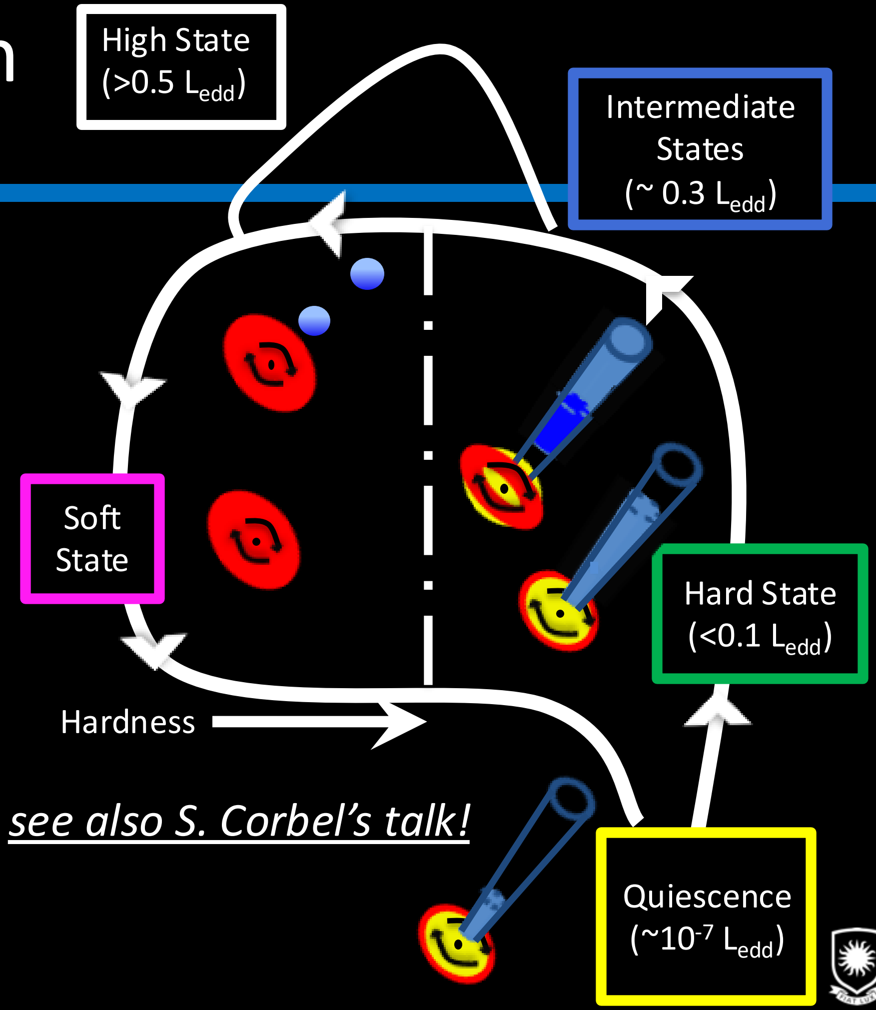


- Compact object (black hole or neutron star) accreting matter from a companion.
- Rapidly evolve through bright outburst periods on timescales of days to months.
- Emit across the electromagnetic spectrum.

Jet Outburst Evolution

Tananbaum et al. 1972;
Fender et al. 2001, 2004, 2009;
Homan et al. 2010;
Munoz-Darias et al., 2014





see also S. Corbel's talk!

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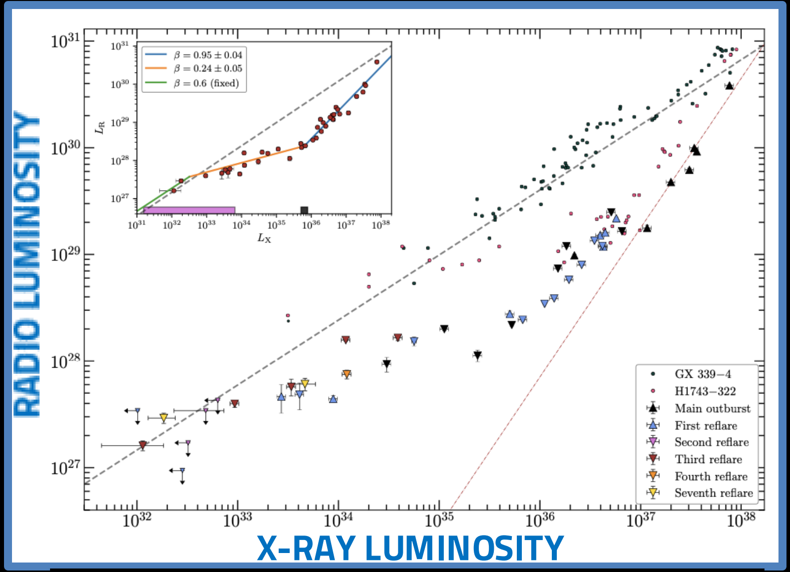
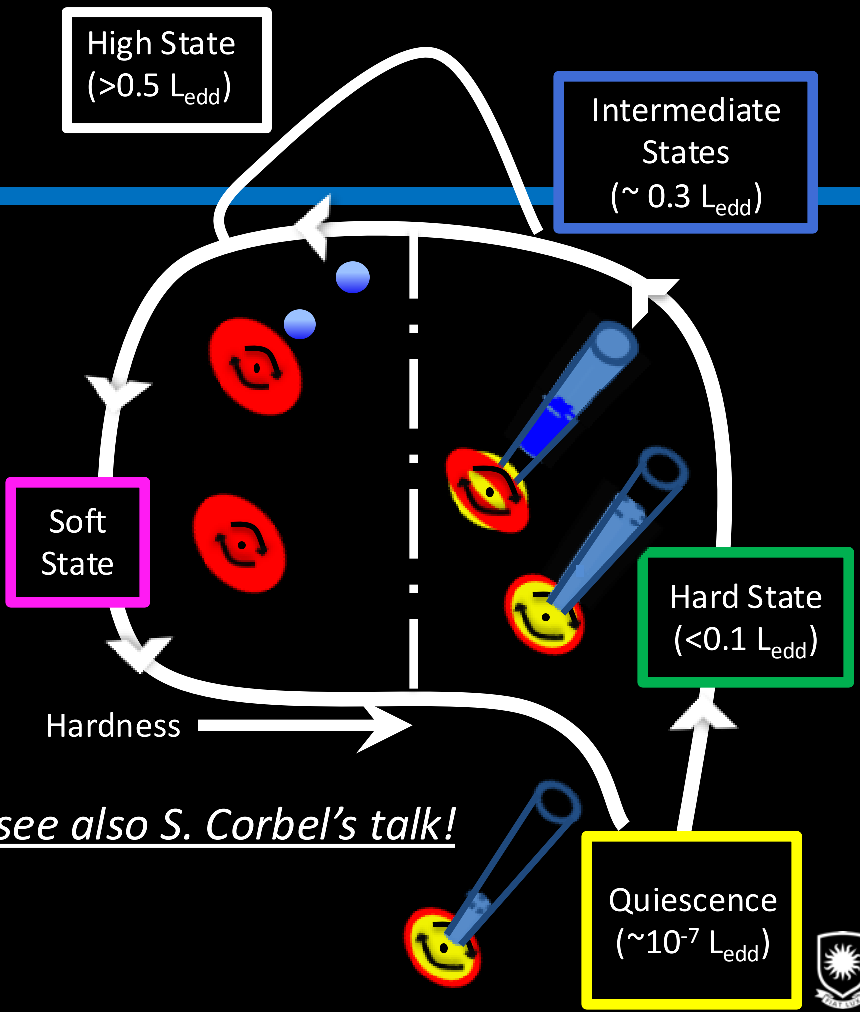
Jet Outburst Evolution



MAXI J1348-530

Carotenuto et al., 2021



see also S. Corbel's talk!

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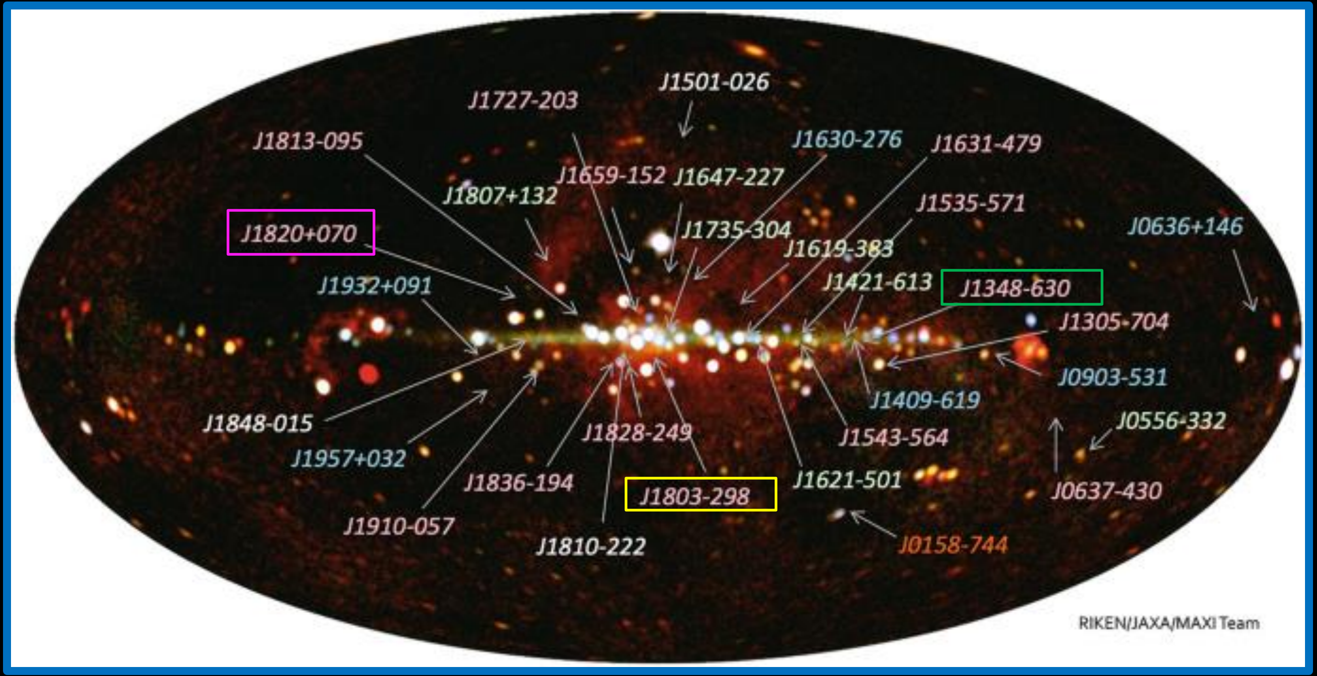
MAXI X-ray Binary Discoveries in the Radio Regime



- Time-domain (MAXI J1820+070)
- High-resolution imaging (MAXI J1803-298)
- Jet Feedback and the local ISM (MAXI J1348-530)

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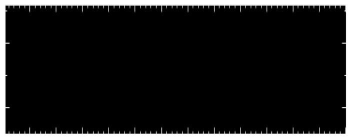
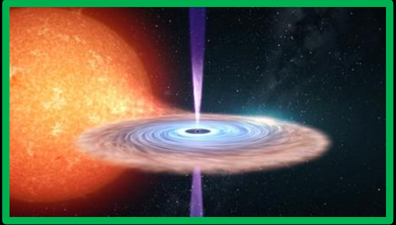
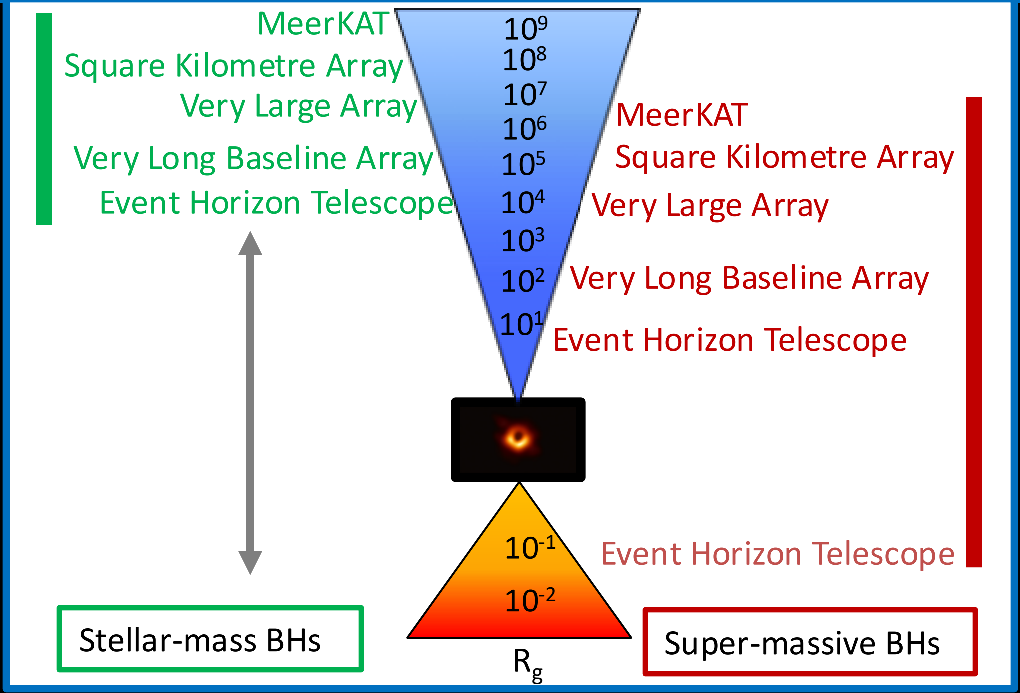
Studying compact objects in the time-domain

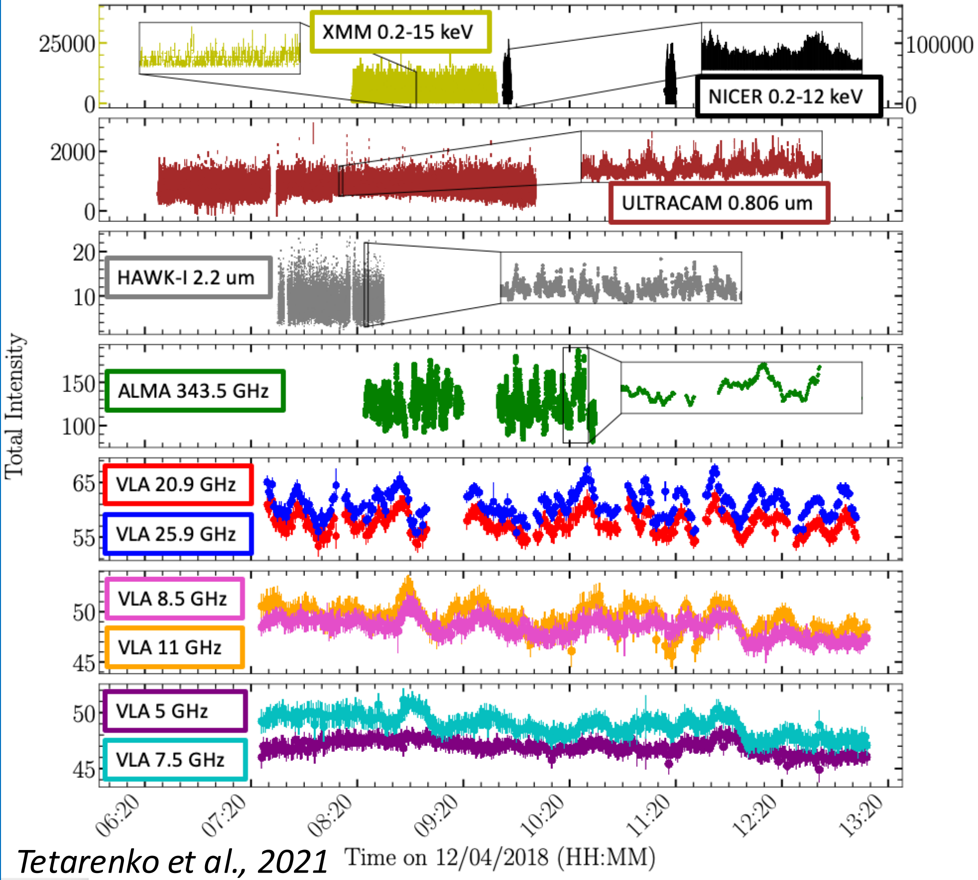




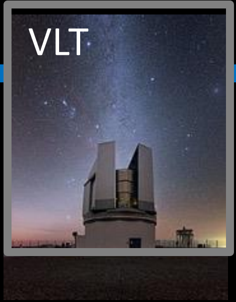


Credit: Rob Fender

Black hole timing - MAXI J1820+070



Tetarenko et al., 2021



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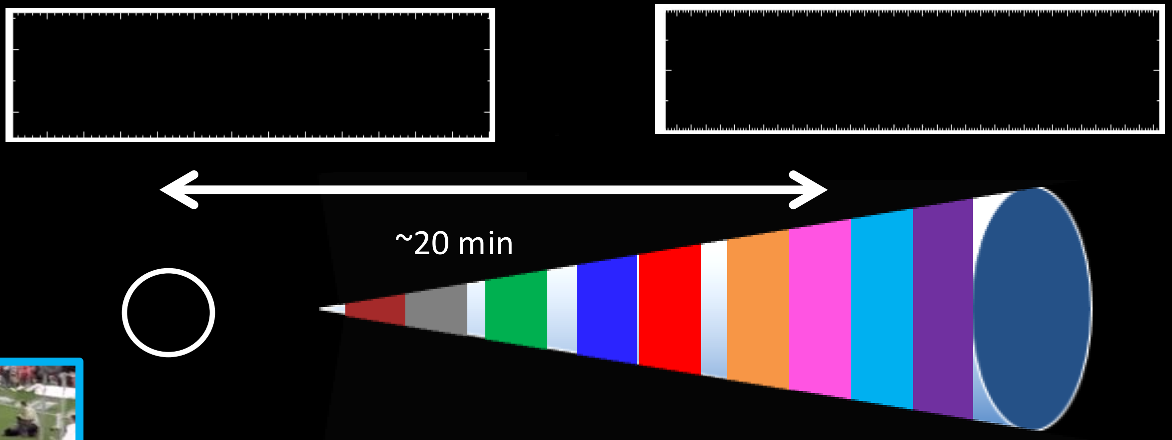
Timing a black hole jet



$$> 75\%\ speed\ of\ light$$

$$\sim 40\ \frac{km}{hr}$$

$$\sim 810000000\ \frac{km}{hr}$$

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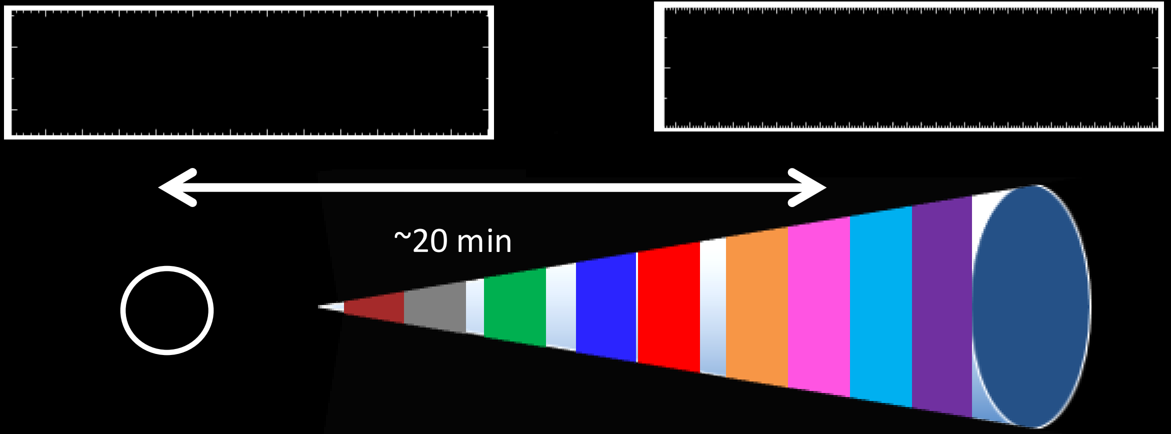
Timing a black hole jet



$> 75\%\ speed\ of\ light$

$\sim 40\ \frac{km}{hr}$

$\sim 810000000\ \frac{km}{hr}$

Going beyond black holes - Do X-ray bursts on neutron stars influence jets?

- *Experimental setup:* long, simultaneous radio and X-ray stares of a bursting neutron star system.

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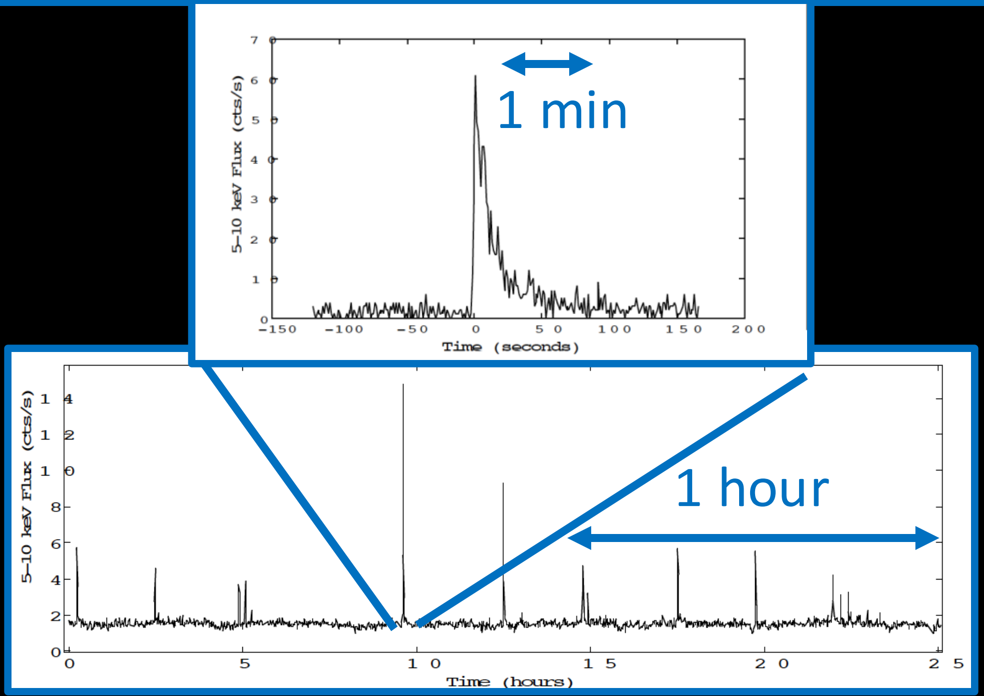
Thermonuclear X-ray bursts on neutron stars

- Thermonuclear fusion on the surface of accreting neutron stars.
- Luminosities reaching Eddington.
- Repeat on hours – days.
- Hundreds of bursters known.
- See *Degenaar et al. 2018* for a recent review.



Boirin et al. 2007

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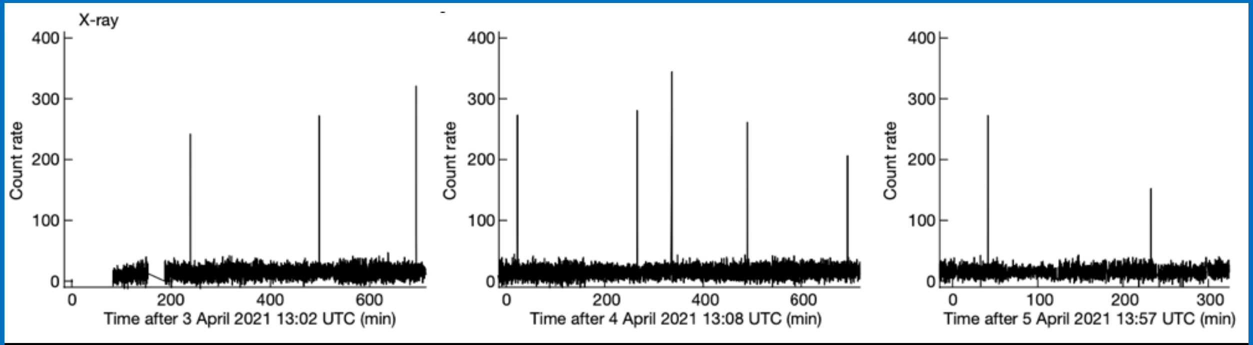
Do X-ray bursts on neutron stars influence jets? – Yes!

- **Expectation:** jet collapses (*reduction in radio emission*).
- **Reality:** ?



?

Russell et al., 2024

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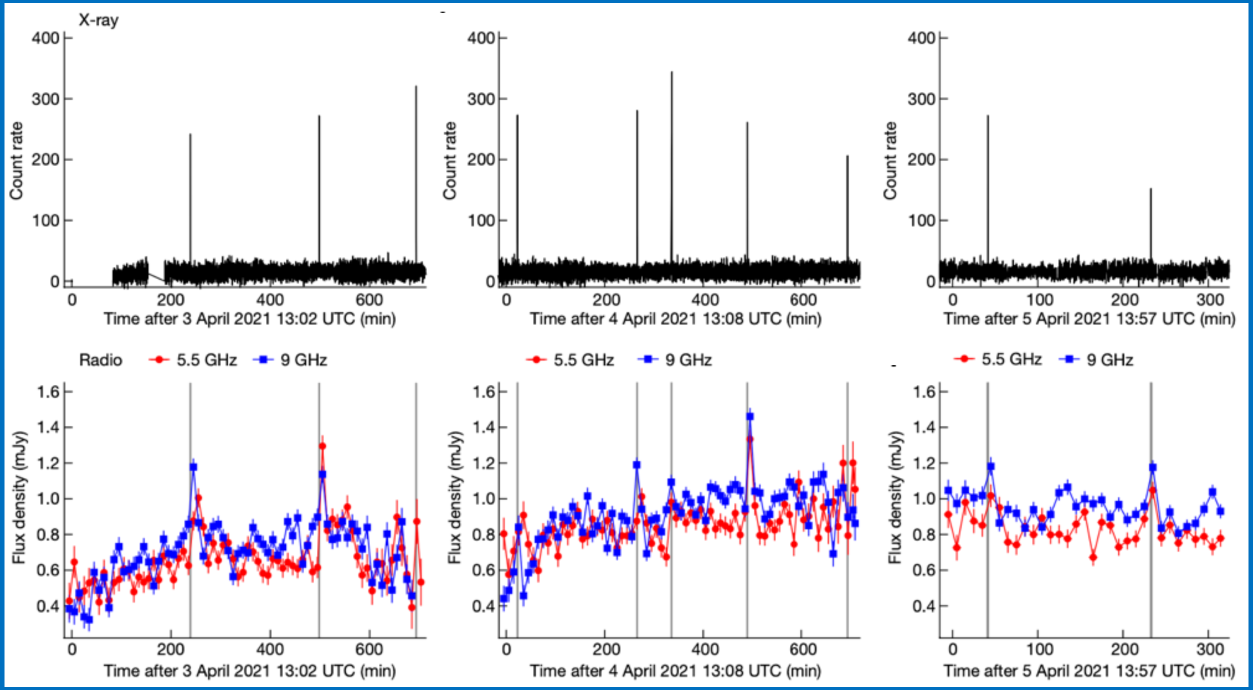
Do X-ray bursts on neutron stars influence jets? – Yes!

- **Expectation:** jet collapses (*reduction in radio emission*).
- **Reality:** the opposite (*enhancement of radio emission*)!



Russell et al., 2024

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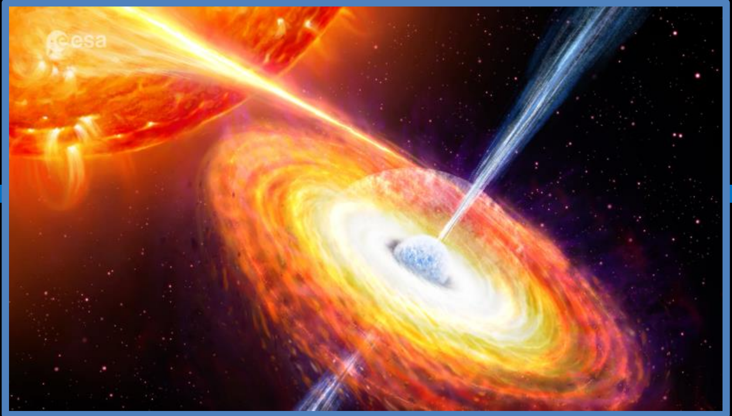
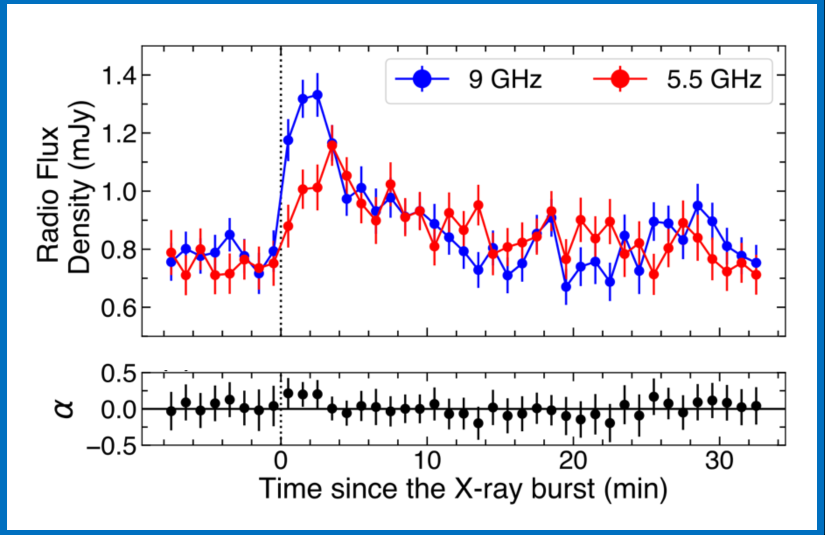
The jet response to X-ray bursts

- Radio flares lag X-ray bursts by minutes.
- Lag is electromagnetic frequency dependent.



Russell et al., 2024



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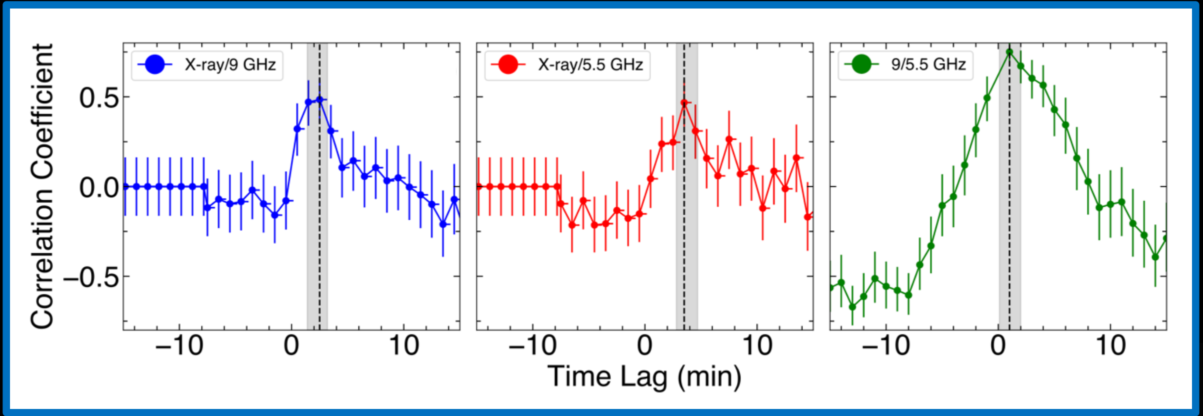
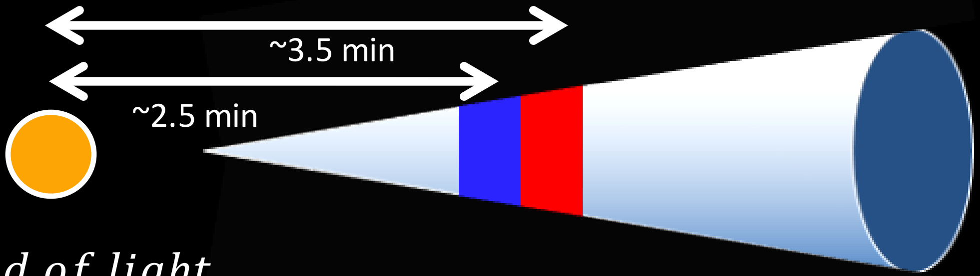
Timing a neutron star jet

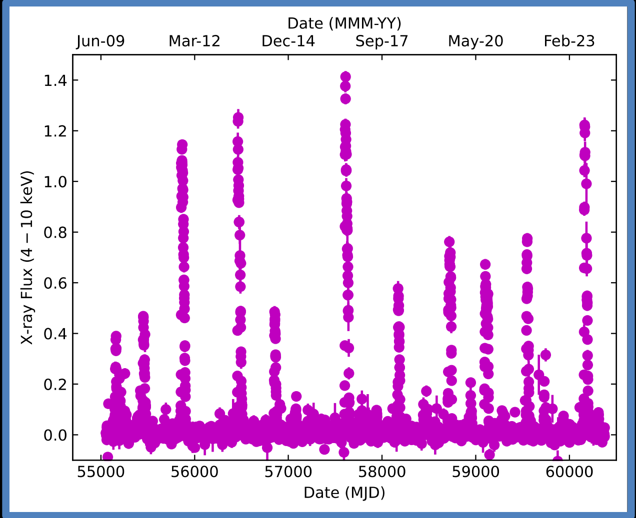


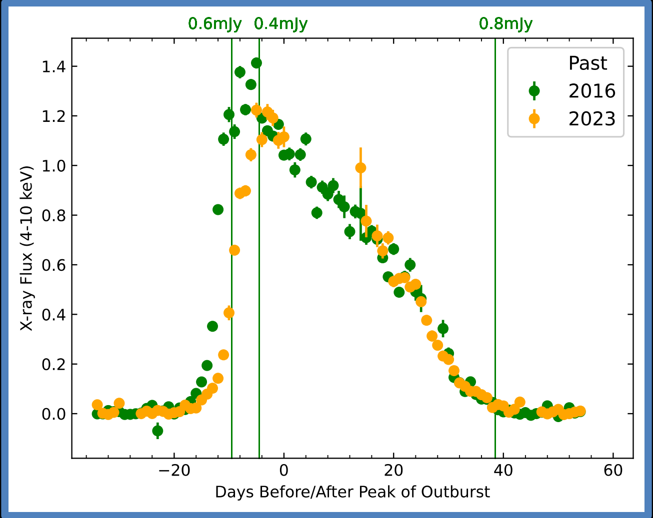
Russell et al., 2024



$\sim 40\ \%\ speed\ of\ light$

Searching for Aql X-1 Millimetre Bursts





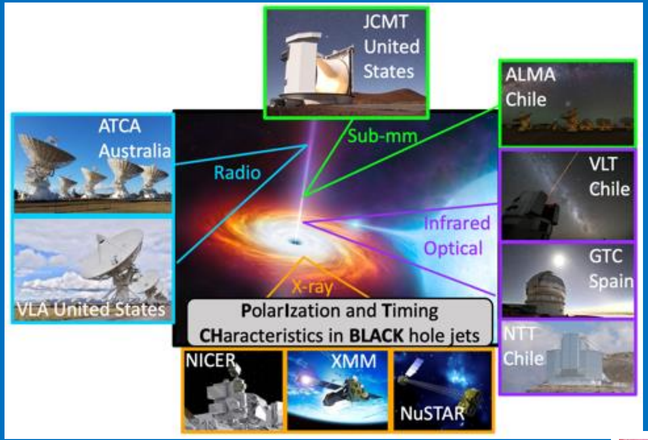
A rare millimetre detected burster with annual outbursts!

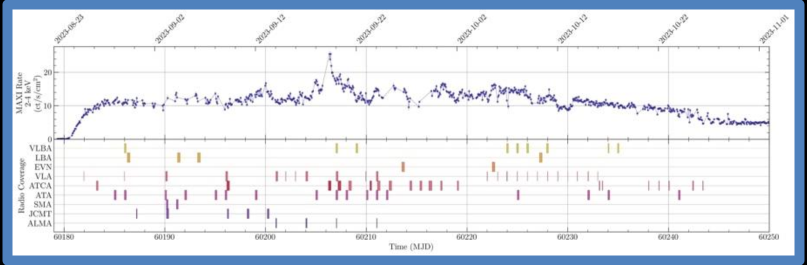
MAXI tracking of outbursts critical for trigger!

The Future of Timing Studies

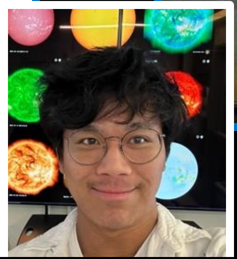
PITCH-BLACK

Elodie Lescure





Credit: Arash Bahramian



Efren Elomina

GOFAST-XRB

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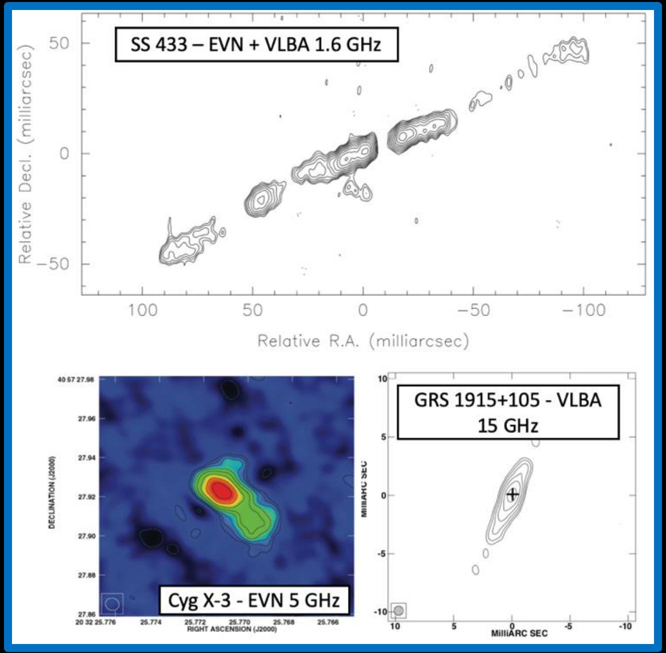
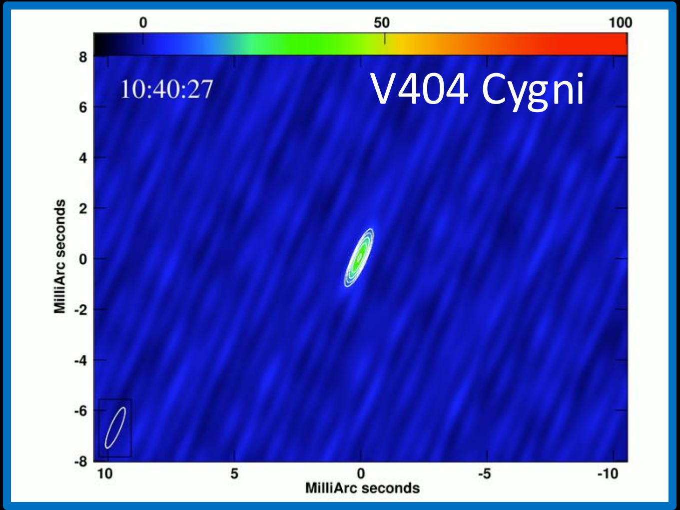
The Challenges of Imaging X-ray Binary Jets



Dhawan et al. 2000, Paragi et al., 2002, Tudose et al., 2010

Miller-Jones et al., 2019



- Rapid, real-time rapid evolution on minute timescales.
- Sensitivity limited.

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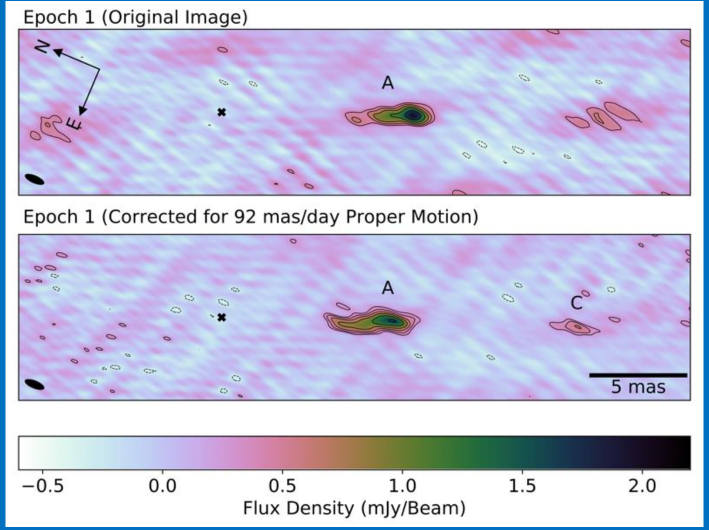
New Imaging Algorithms

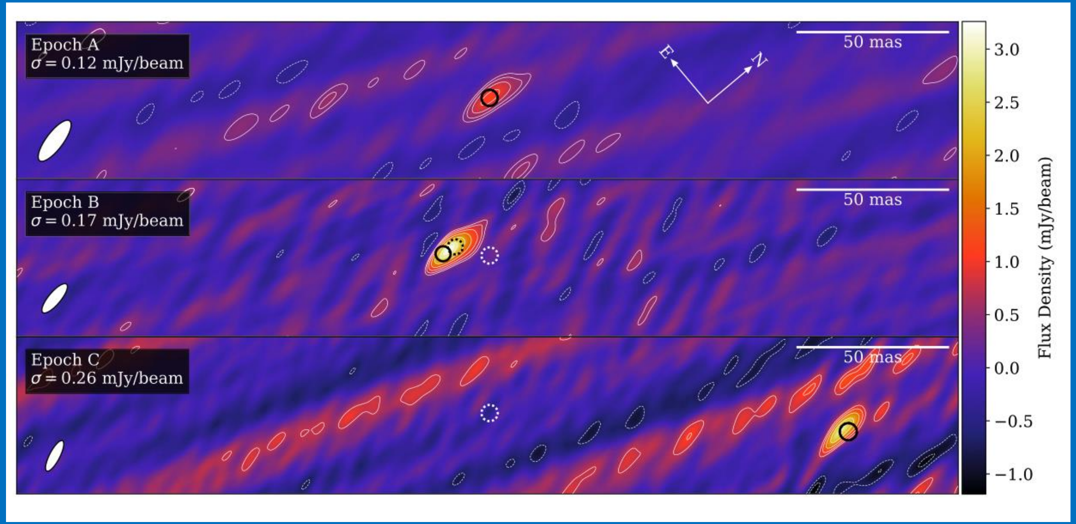
Callan Wood

Phase Center Stacking
MAXI J1820+070



Wood et al., 2021

Time-dependent Visibility Modelling
MAXI J1803-298



Wood et al., 2023

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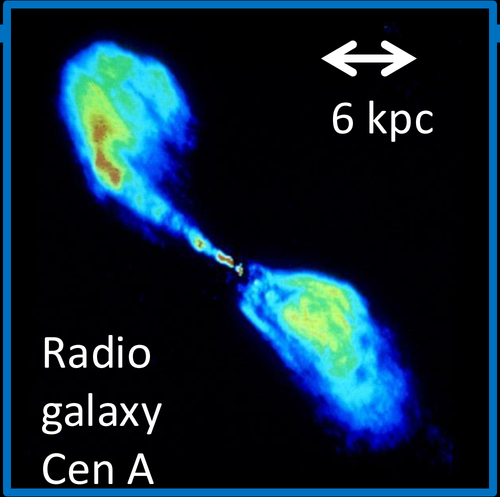
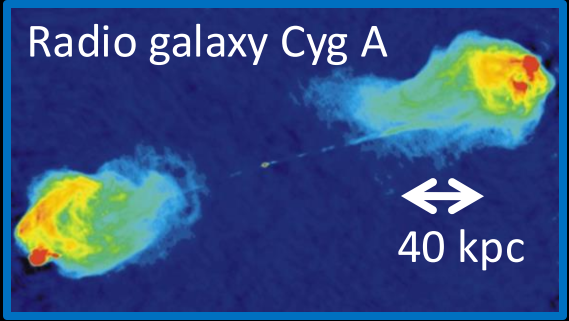
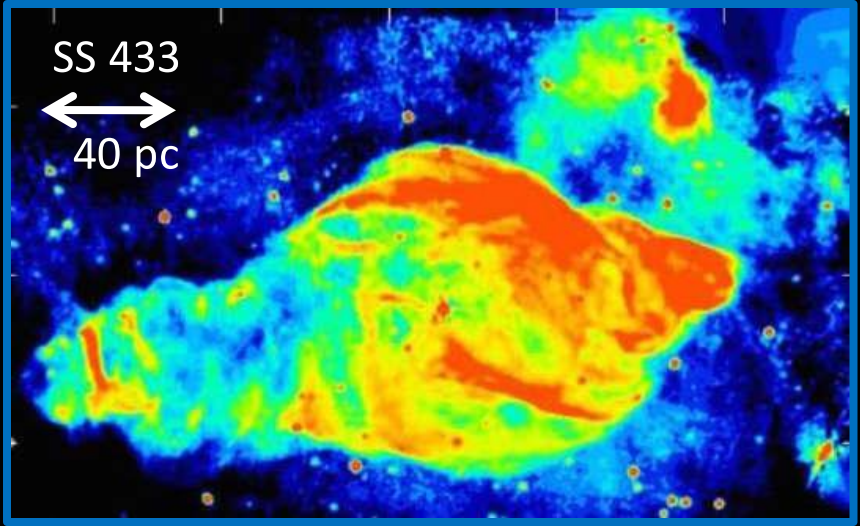
Studies of X-ray Binary Environments and Feedback



Credit: NRAO





Dubner et al, 1998

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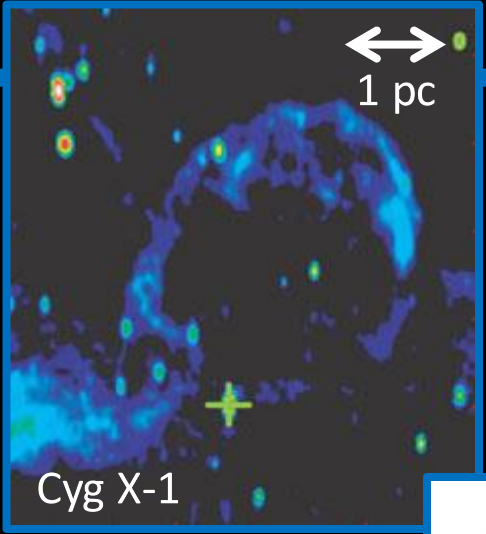
Why are these regions important?

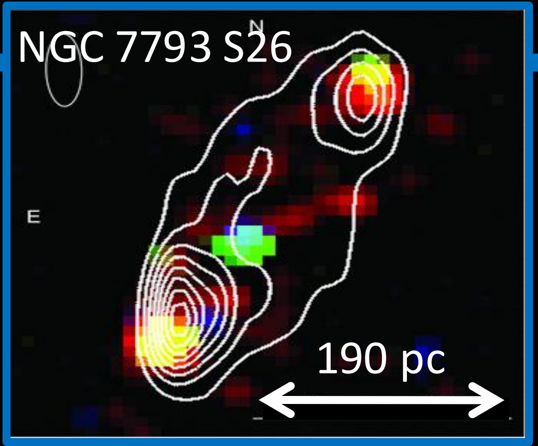
Encoded within interaction zones:

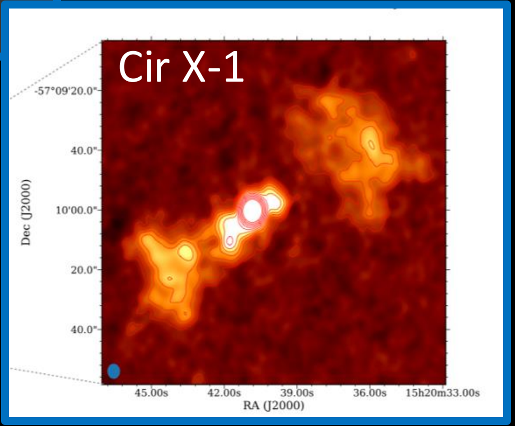
- Total Jet Power
- Radiative Efficiency
- Speed
- Duty Cycles
- Composition



Gallo et al., 2005

Soria et al., 2010





Coriat et al., 2019

**Also see Dubner et al, 1998, Corbel et al. 2005, Tudose et al. 2006, Russell et al. 2007, Sell et al. 2010, Migliori et al. 2017, Tetarenko et al. 2018, Espinasse et al. 2020*

Molecular Lines as Tracers of Jet Feedback

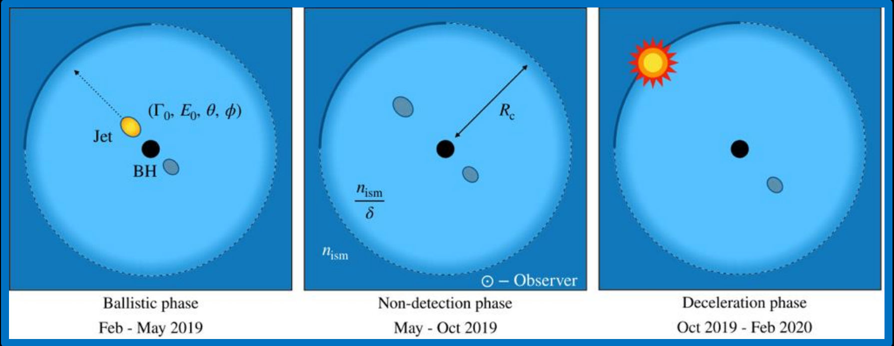
Molecule	**What it traces?**	**Why?**
HCN	Density	High critical density ($10^4 - 10^5 cm^{-3}$) — due to the high electric dipole moment of this molecule, gas needs to be in a high density environment, where many collisions will occur, to become excited.
HCO^+	Density	High critical density ($10^4 - 10^5 cm^{-3}$), and thus is preferentially excited in high density environments.
	Ionization	HCO^+ abundance can be enhanced in regions with a higher fraction of ionization.
SiO	Shocks	Silicon-bearing species — silicon abundance is enhanced during the dust grain destruction process.
HNCO	Density	High critical density ($10^5 - 10^7 cm^{-3}$), and thus can only be excited in high density environments.
	Shocks	HNCO abundance has been found to increase in the presence of slower shocks, in contrast to SiO tracing faster shocks.
CS	Density	High critical density ($10^4 - 10^5 cm^{-3}$), and thus can only be excited in high density environments.
	Shocks	Sulfur-bearing species — similar to silicon, sulfur abundance can be enhanced during the dust grain destruction process.
CO	Density	Probes gas opacity (^{12}CO tends to be optically thick, while ^{13}CO and $C^{18}O$ tend to be optically thin), and is a good tracer of where most of the gas mass is located.
CH_3OH	Shocks	Traces the breakup of the icy mantles during the dust grain destruction process. Indicates the presence of slower shocks, in contrast to SiO, as the grains do not need to be completely destroyed to produce this molecule.

A jet cavity surrounding MAXI J1348-630?

Results redacted as not yet published!

Bosch-Cabot et al., in prep

Pau Bosch-Cabot



Carotenuto et al., 2022

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A Bent Jet in Cyg X-1 – Implications for Jet Feedback

Slide was removed as results are not yet published, sorry!

Summary

- Compact objects and their outflows play an important role throughout the universe.
- X-ray binaries offer a real-time view of the processes of accretion and ejection from compact objects.
- Radio wavelength emission can be very constraining for understanding the physics of X-ray binaries.
- New radio wavelength experiments are enabled and enhanced by MAXI's capabilities.

Thank you!

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