

# **X-ray Binaries**

**Observing Plan(s) and Needed Capabilities**

**Joe Bright 27/10/2025 – TDAMM**

“X-ray Binaries” covers a lot of ground

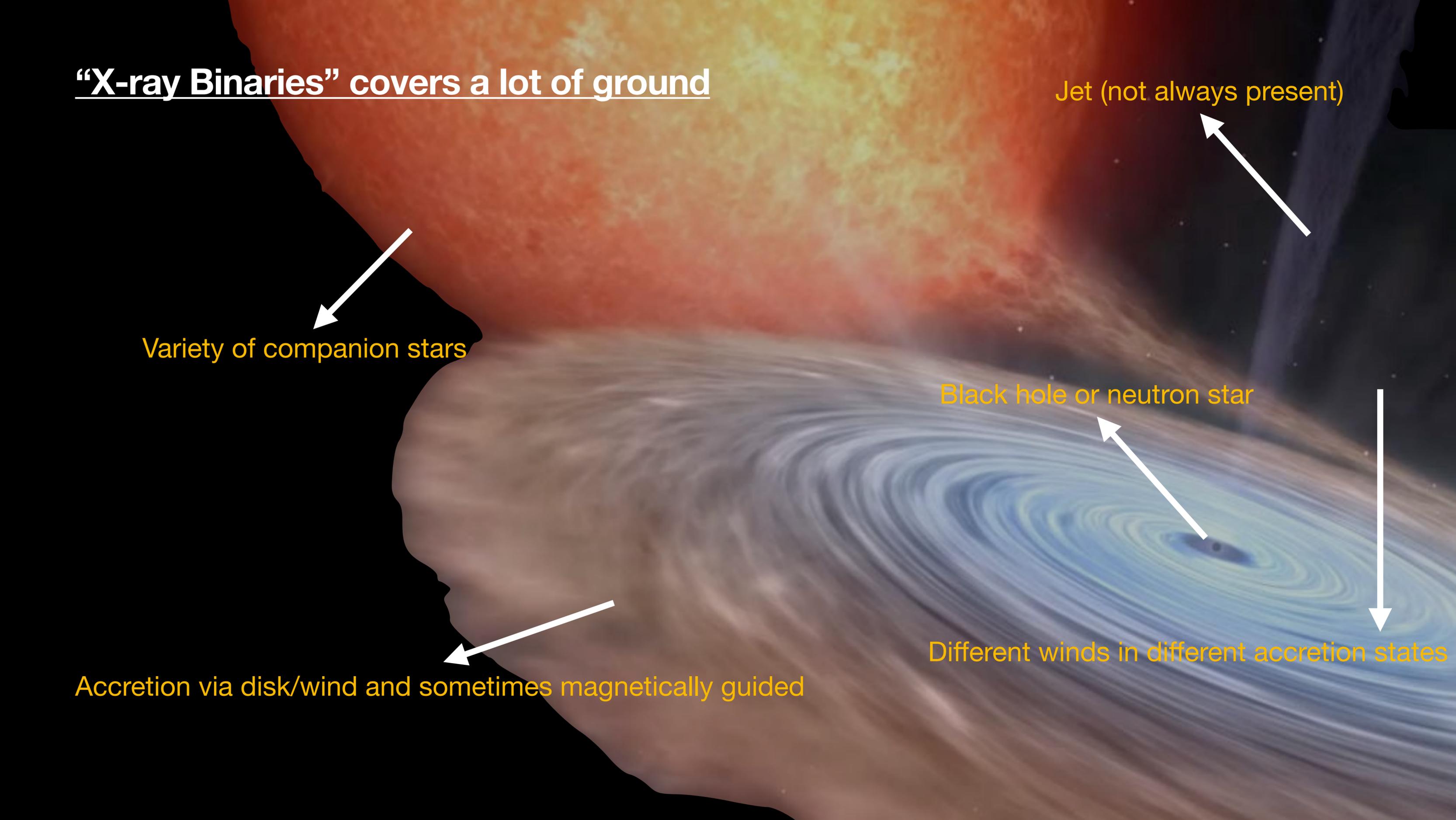
Jet (not always present)

Variety of companion stars

Black hole or neutron star

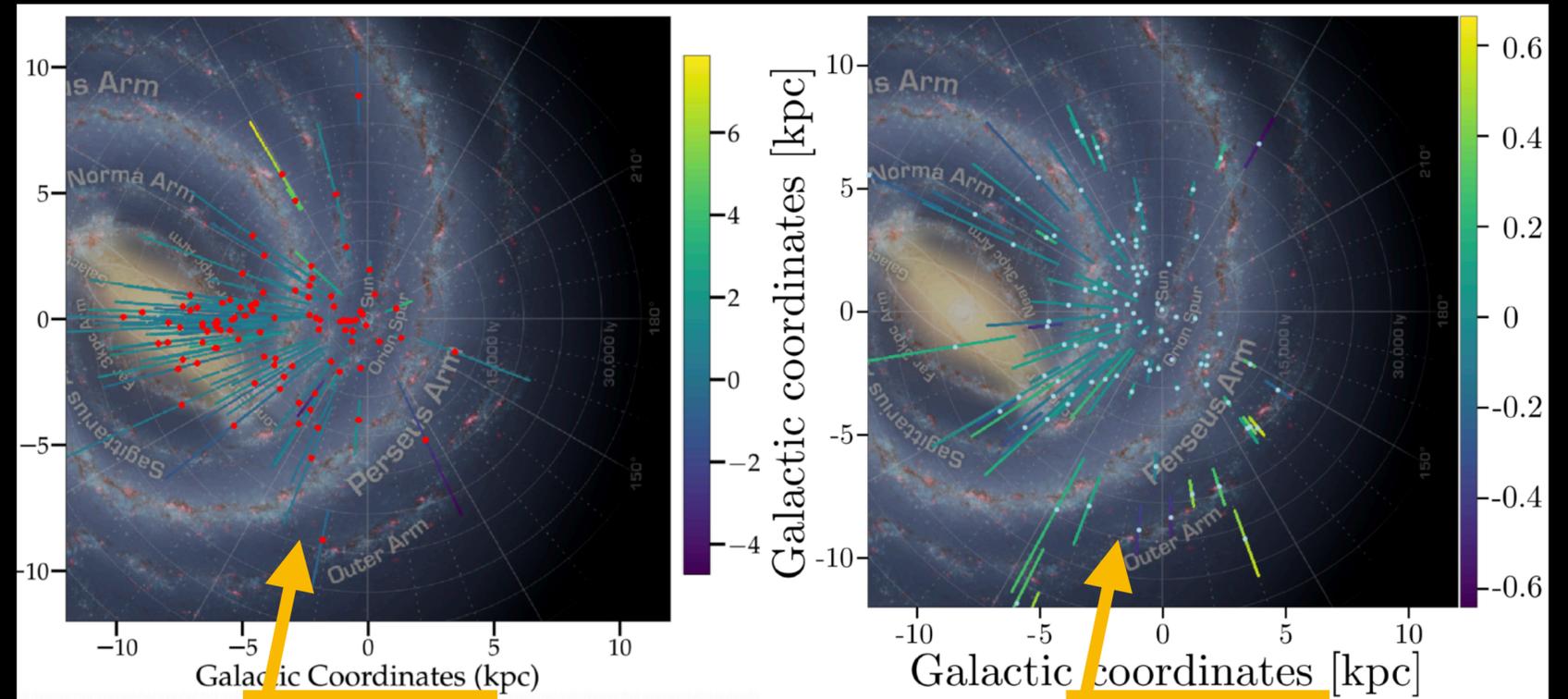
Accretion via disk/wind and sometimes magnetically guided

Different winds in different accretion states



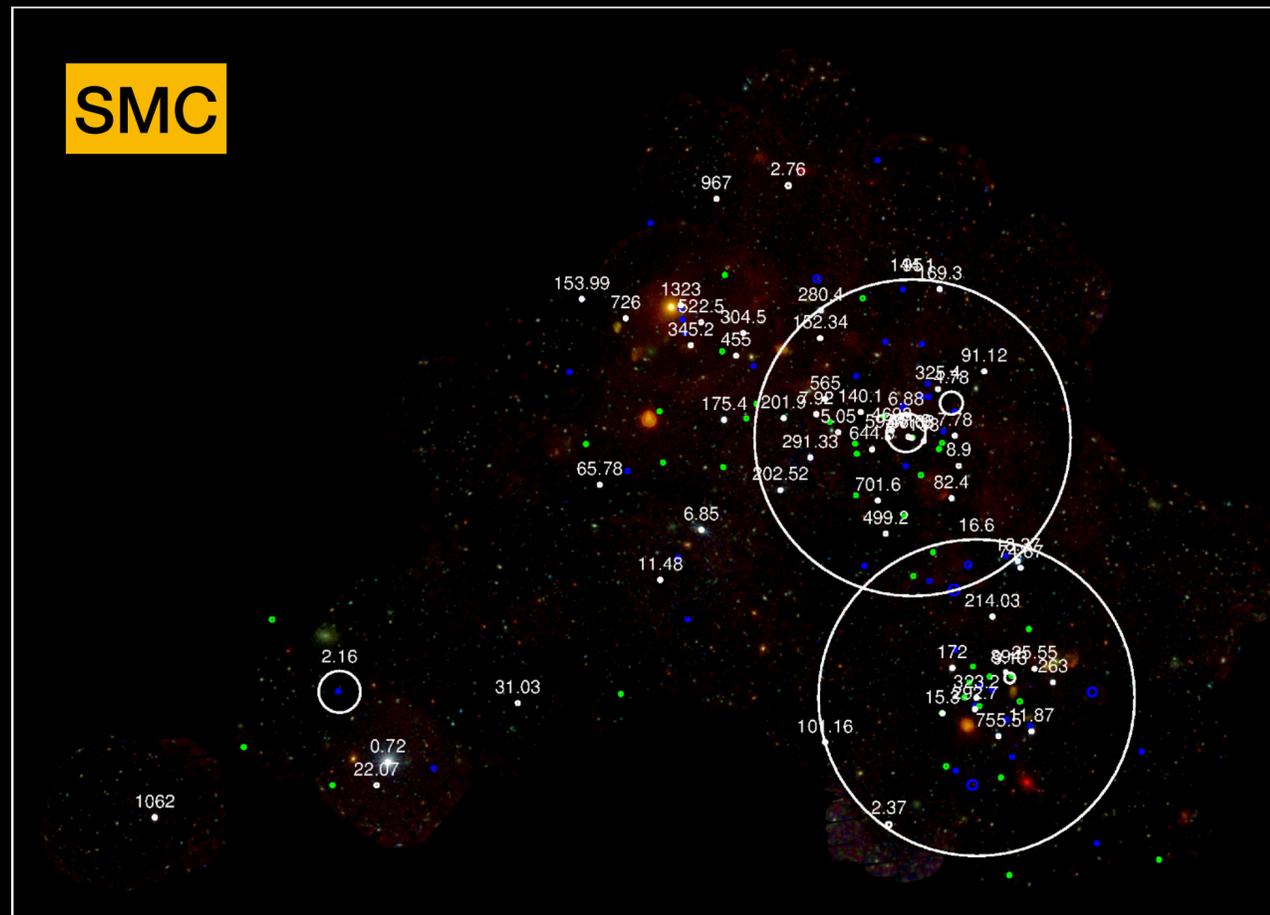
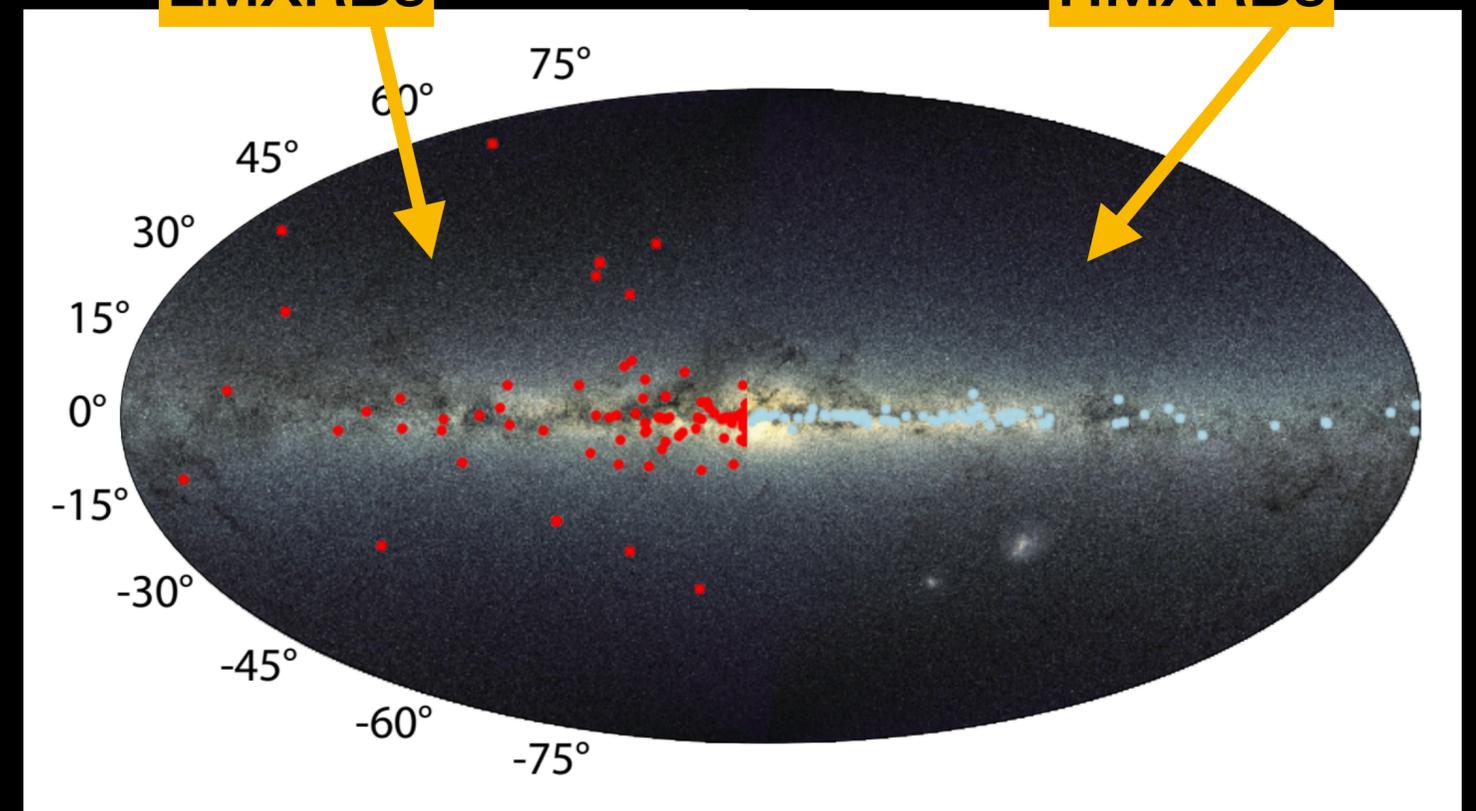
## Source Population(s)

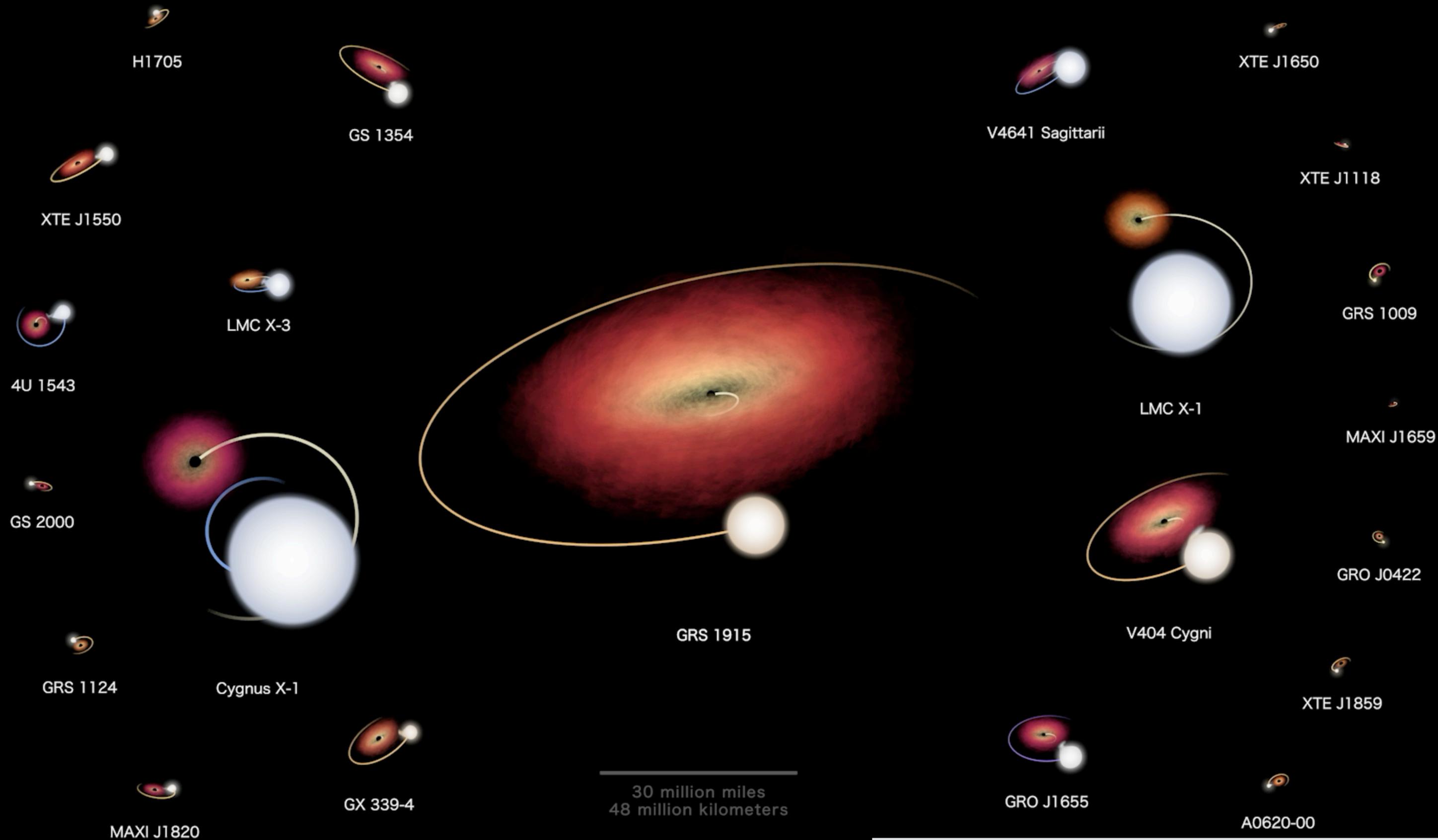
- There are of the order hundreds of known X-ray binaries, with a populations of the order thousands in the galaxy (we see some in the SMC)
- Typically see sources when they enter outburst
- Quiescent systems hard to identify



LMXRBS

HMXRBs

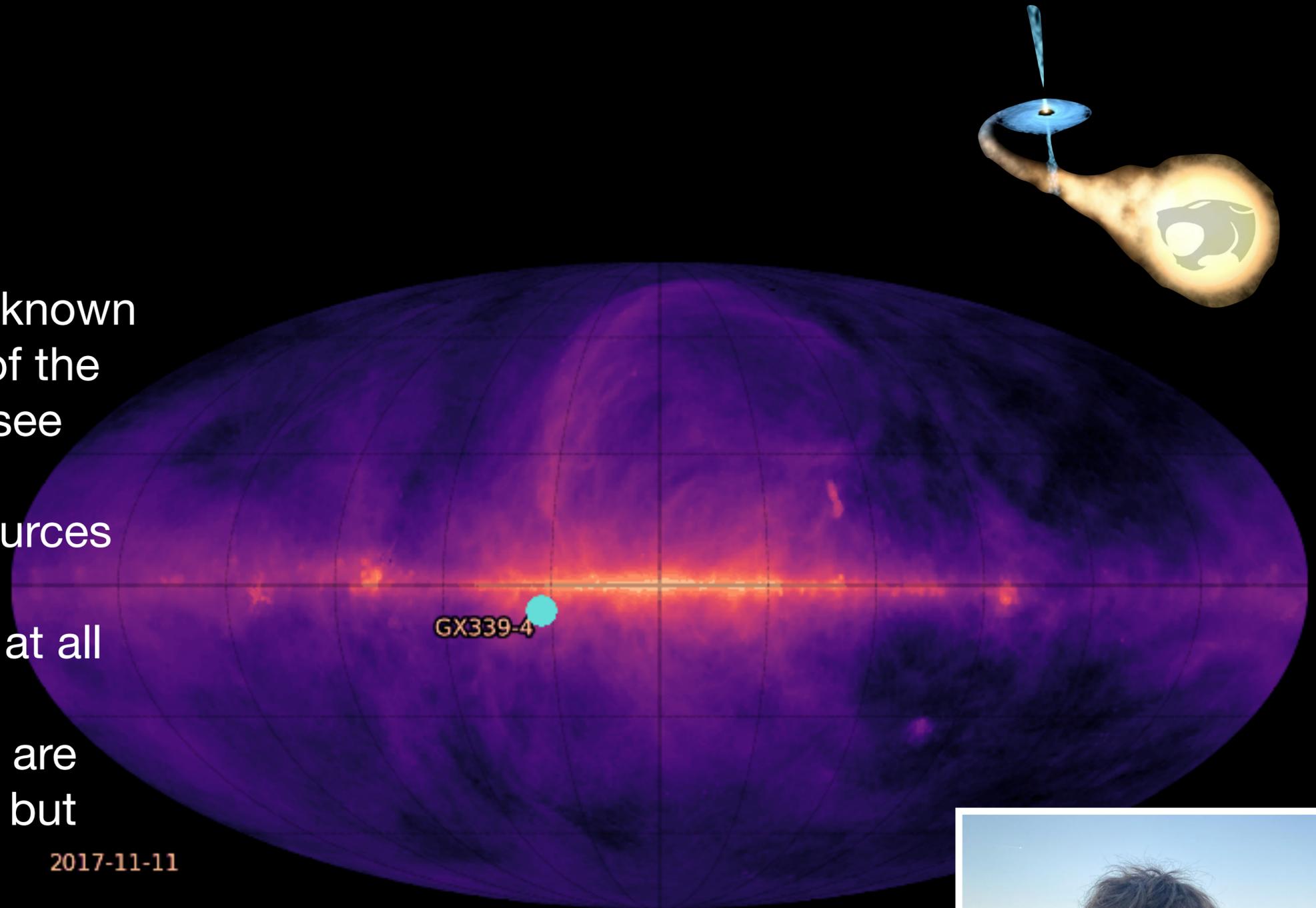




## Source Rates

- There are of the order hundreds of known X-ray binaries, with a populations of the order thousands in the galaxy (we see some in the SMC)
- Usually a handful of outbursting sources at any given time
- Cover a wide range of luminosities at all wavebands
- Also systems in quiescence or that are persistent — coordination required but not necessarily timeliness

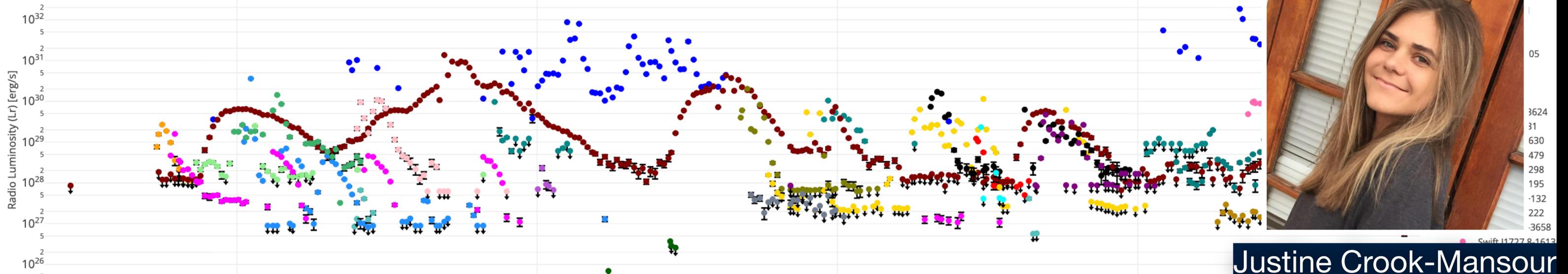
2017-11-11



Fraser Cowie

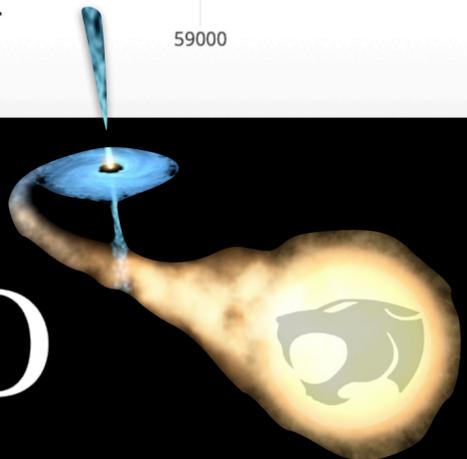
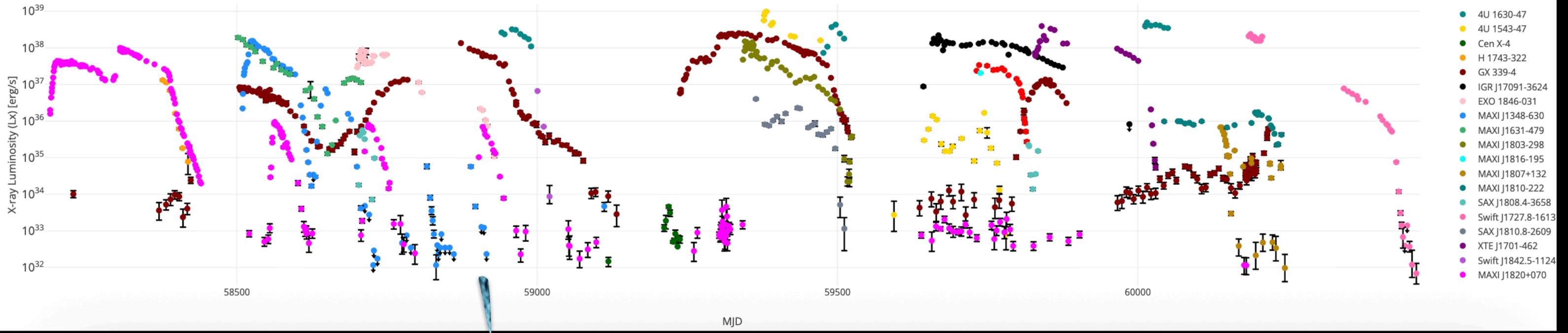


# 1.28 GHz MeerKAT Radio Luminosities



Justine Crook-Mansour

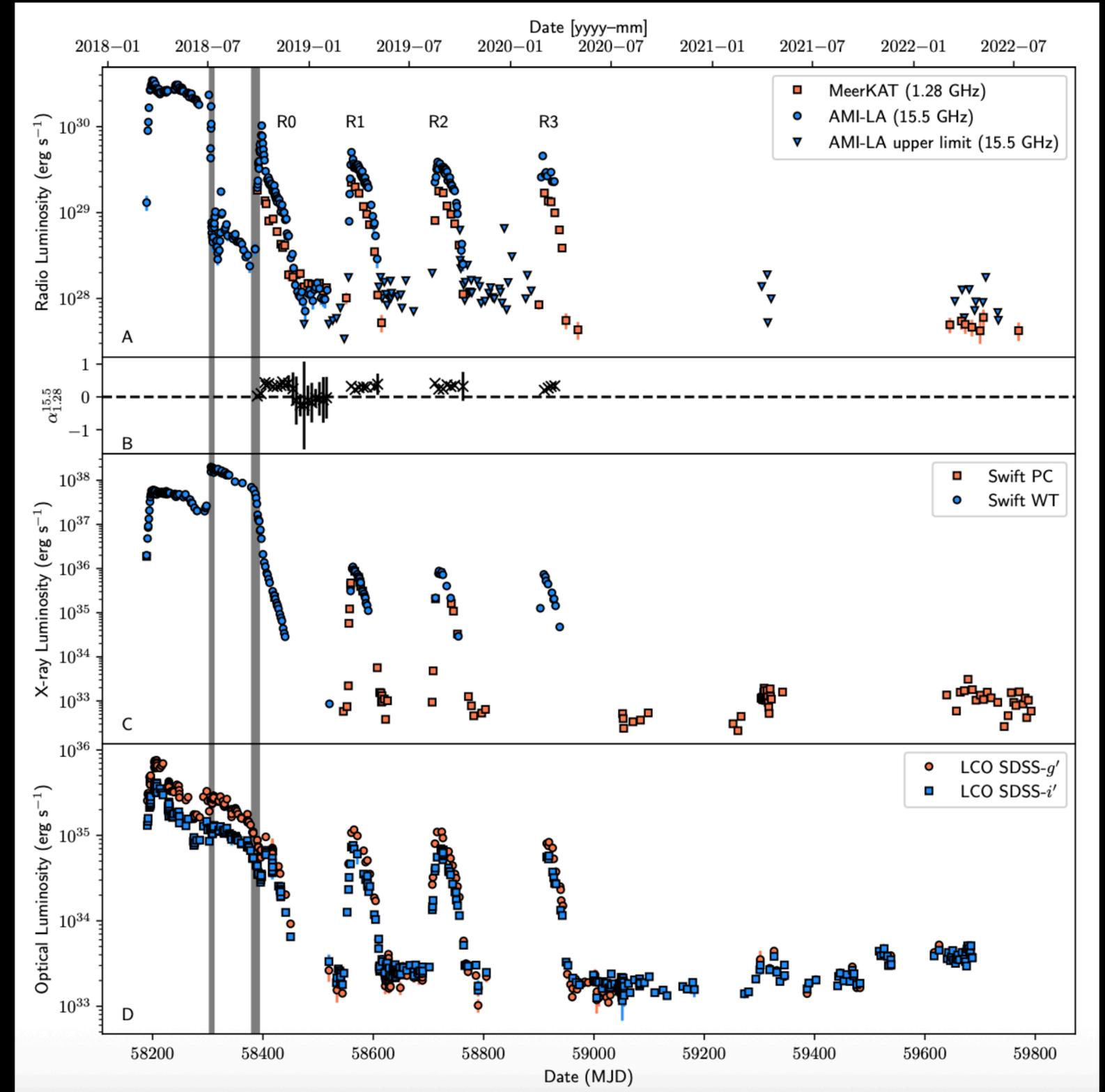
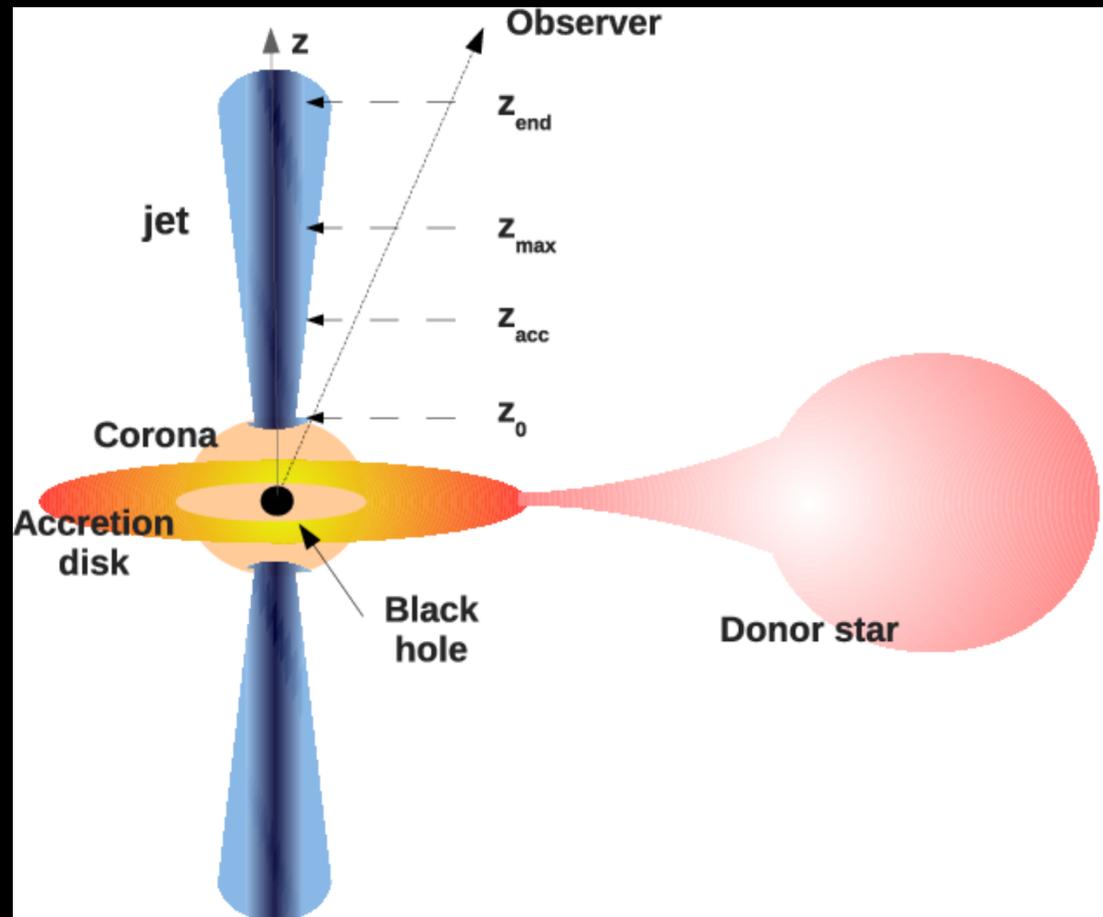
# 1-10 keV Unabsorbed Swift XRT X-ray Luminosities



UNIVERSITY OF CAPE TOWN  
 IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

## Multiwavelength behaviour shows important correlation

- Clear and obvious correlations exist (over a wide range of timescales) at different wavelengths
- This is informative for a range of science goals, particularly (but not limited to) accretion and its connection to jet production
- Plenty of science to be done at individual wavelengths (X-rays particularly useful for a range of things, e.g. disk/corona modelling)

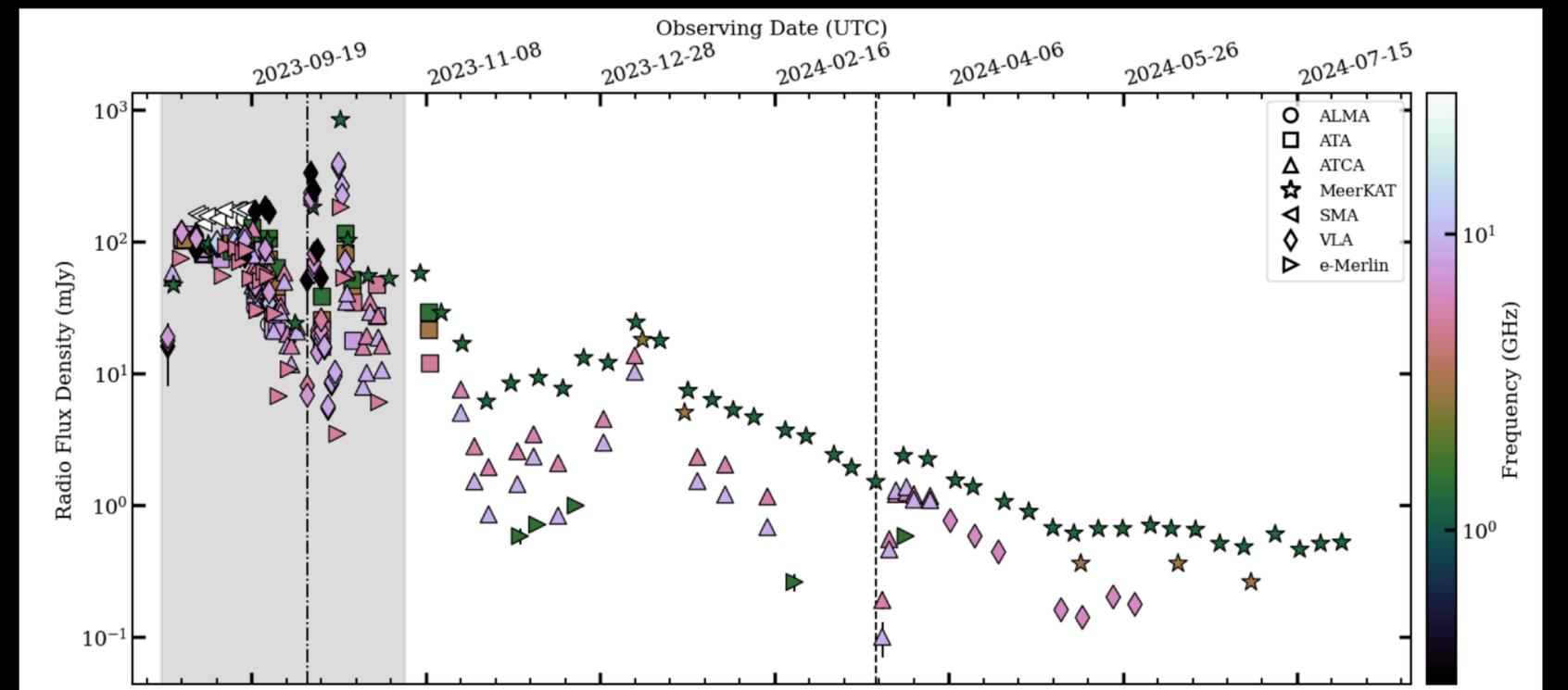
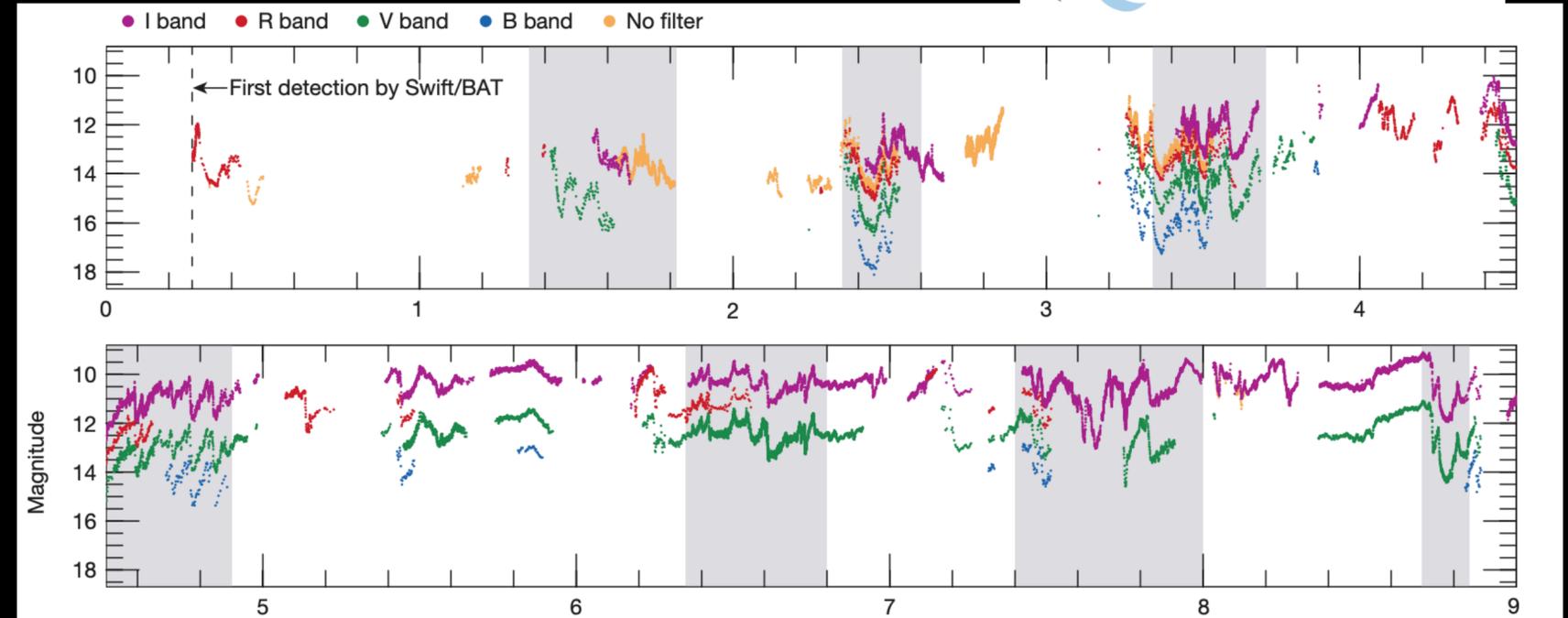


# We (sometimes) have the luxury of high luminosity

Kimura+2016



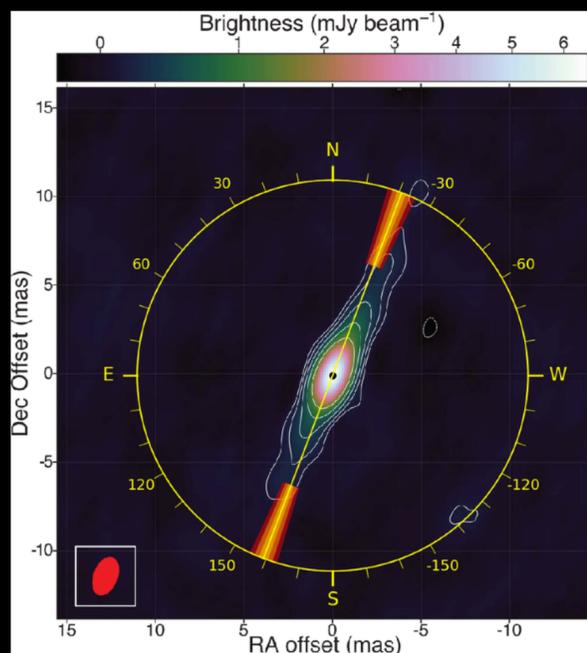
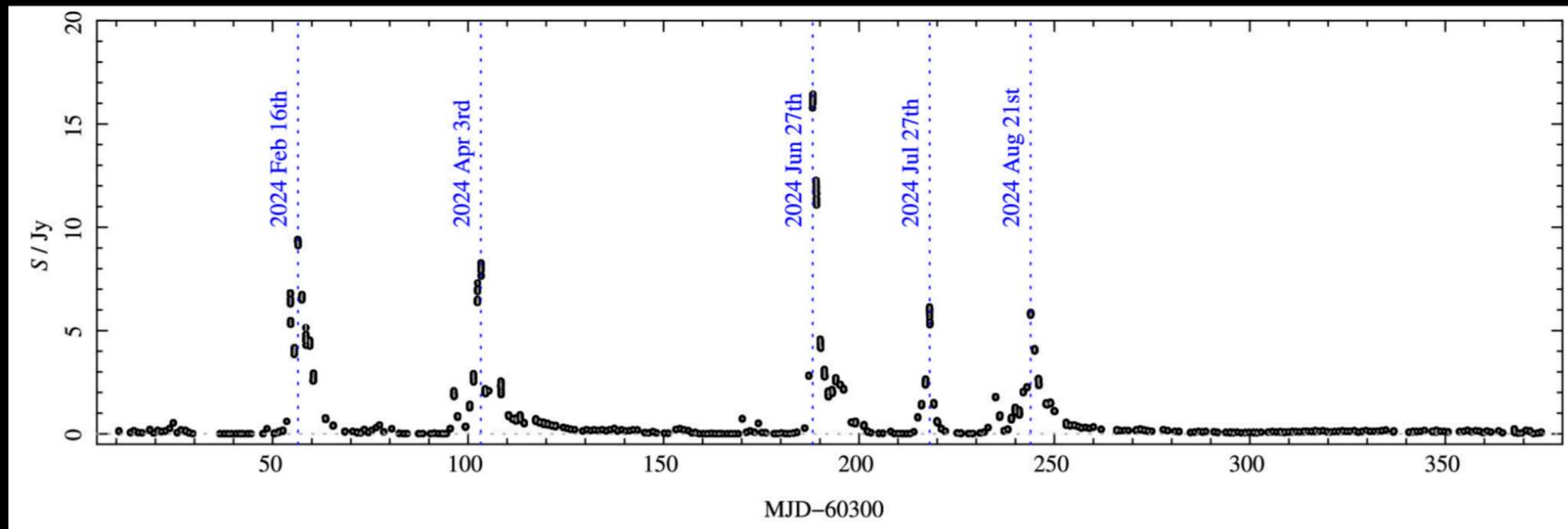
- X-ray binary outbursts can be extremely bright, becoming among the brightest X-ray sources in the sky, optical magnitudes easily observed by small telescopes, and radio flux densities detectable with smaller facilities
- This opens up a range of techniques beyond flux monitoring
- A good problem to have, but makes coordinated and multiwavelength observations essential to understand systems
- However it's not always the case, and shouldn't preclude observations of fainter interesting systems



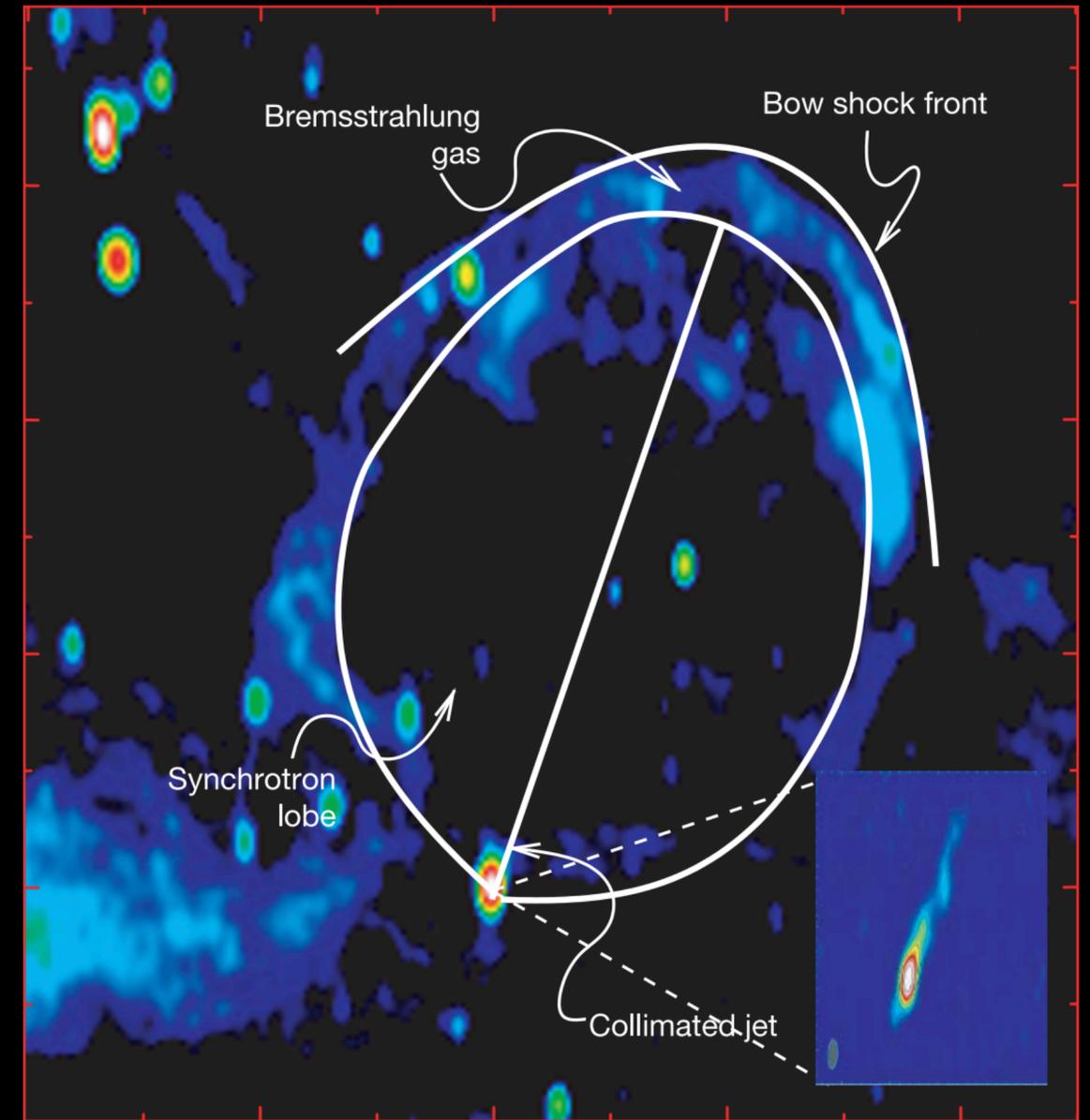
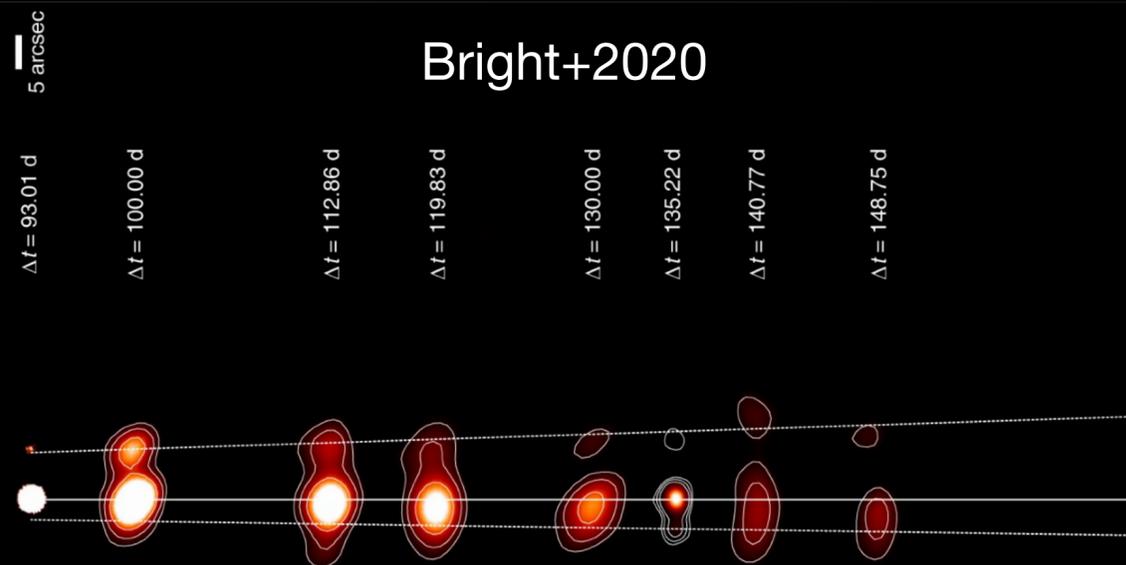
Hughes+2025

# Summary of Key Techniques — Radio Jets, ejections, and feedback, motion

Green+2025

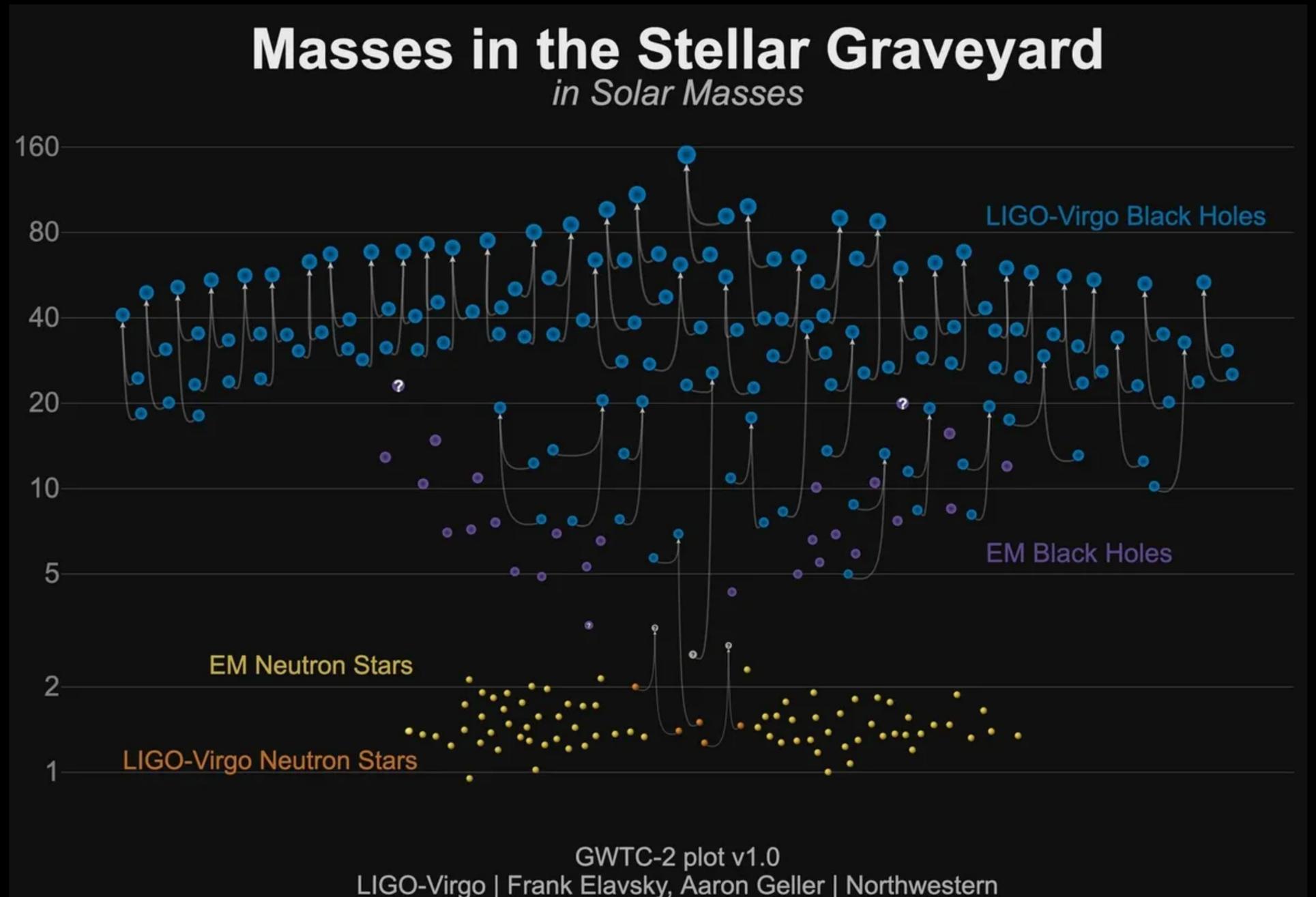
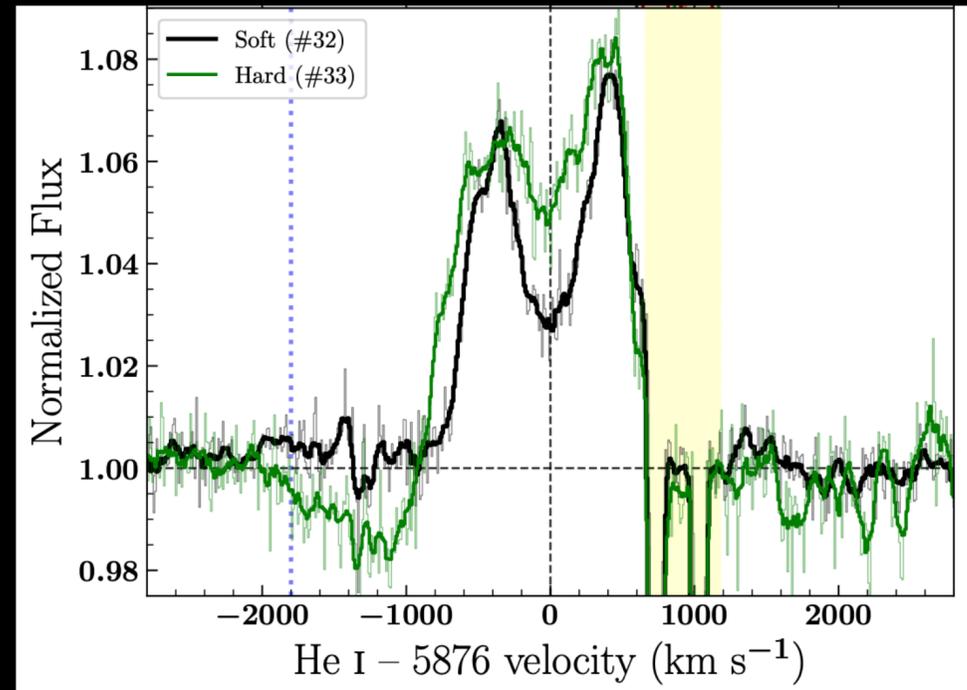
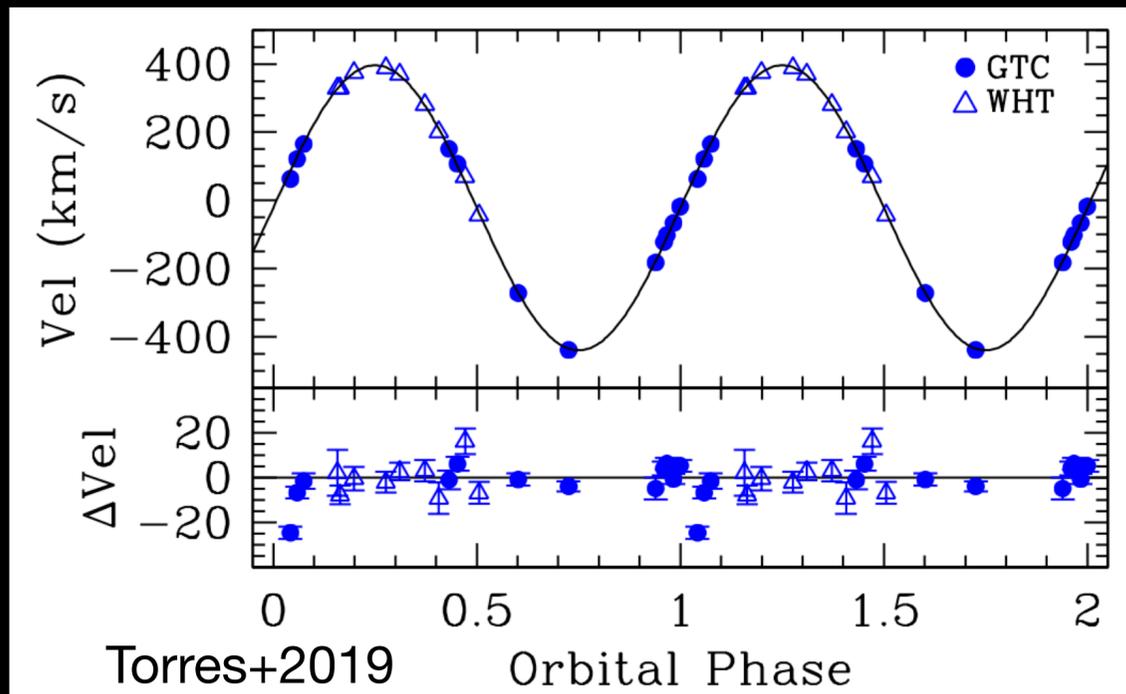


Bright+2020

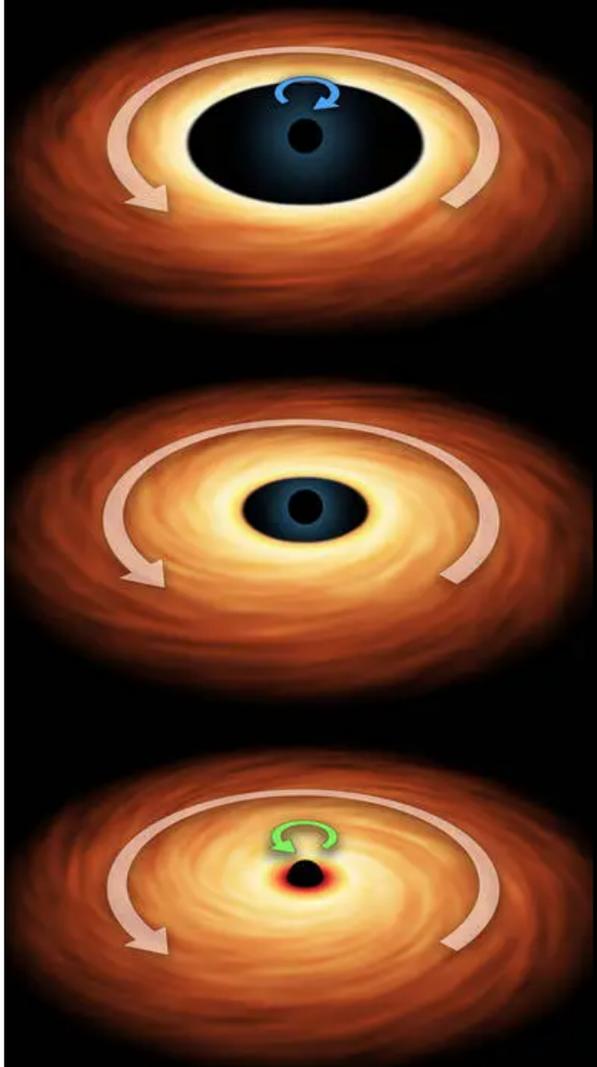
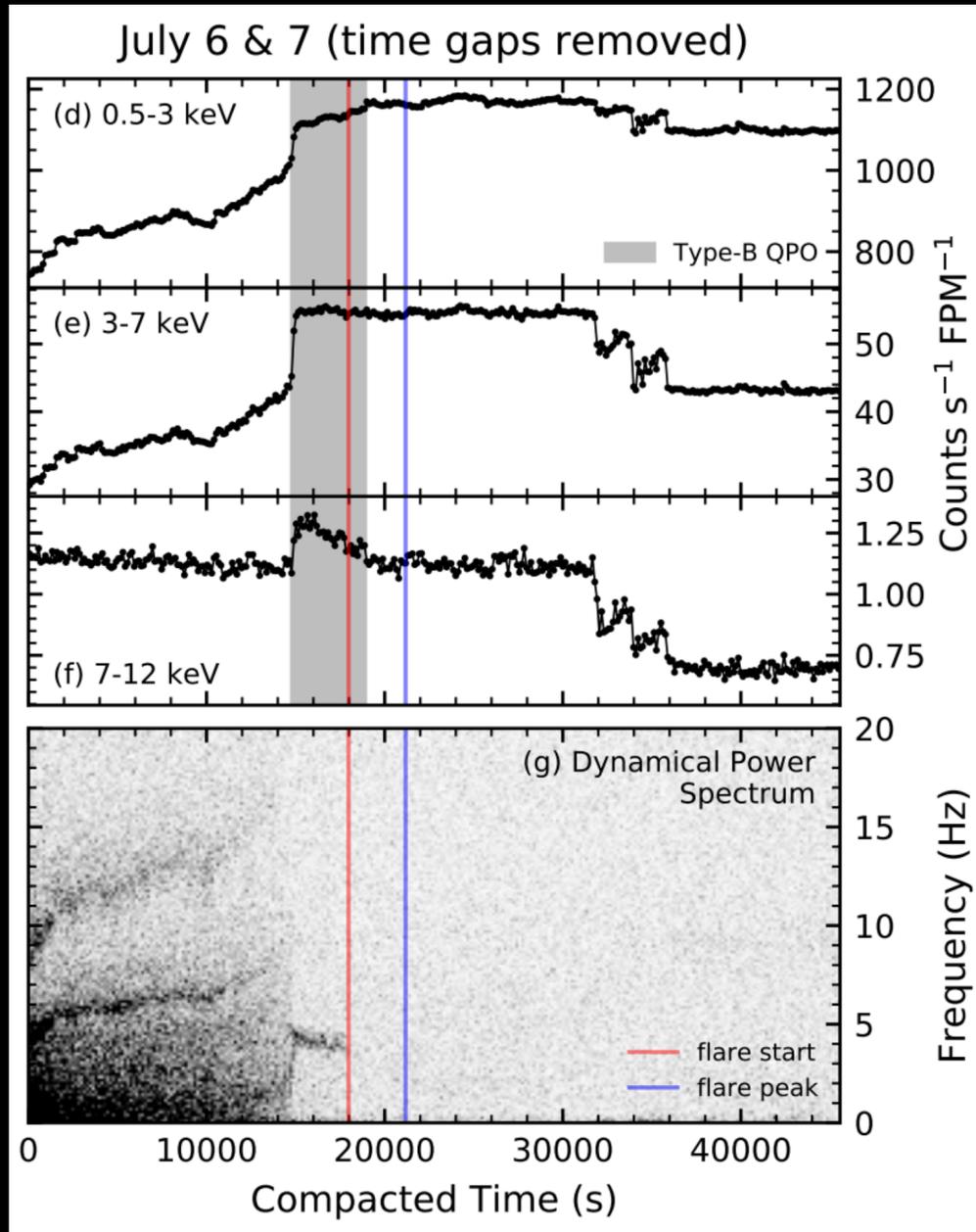


Gallo+2005

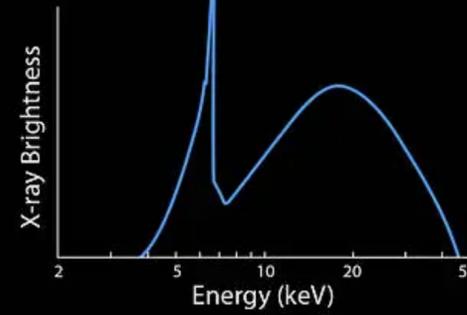
# Summary of Key Techniques — **Optical/UV** Geometries, winds, accretion



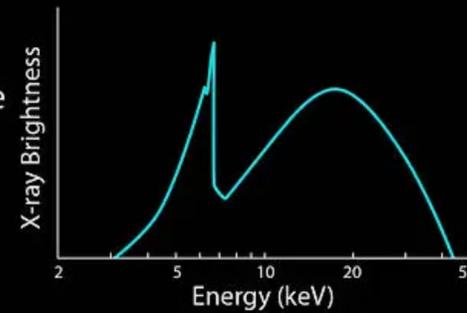
# Summary of Key Techniques — X-ray Disk and corona, black hole properties



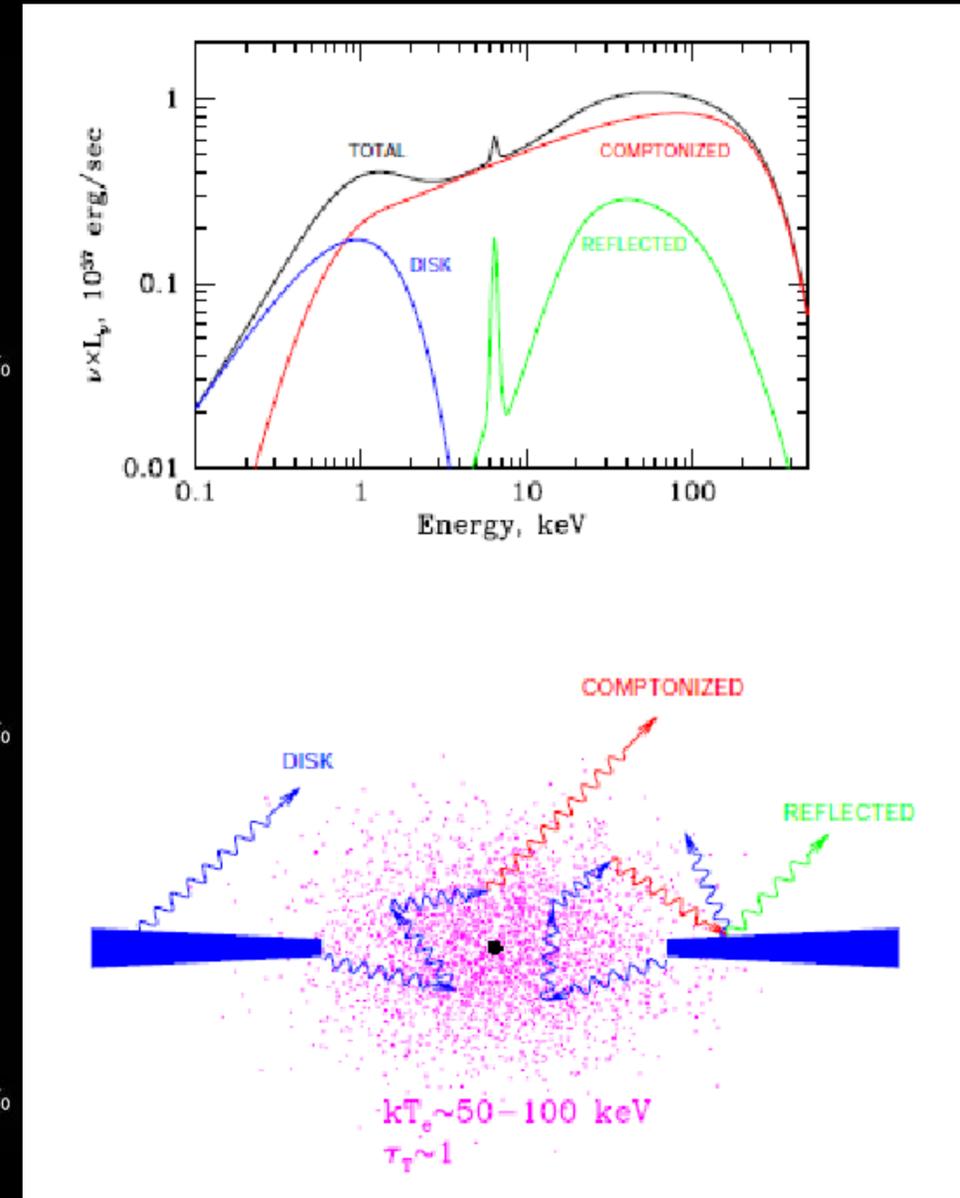
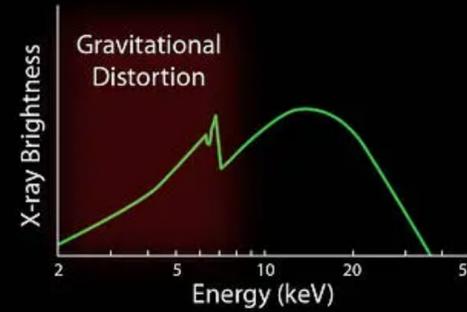
Retrograde Rotation



No Black Hole Rotation

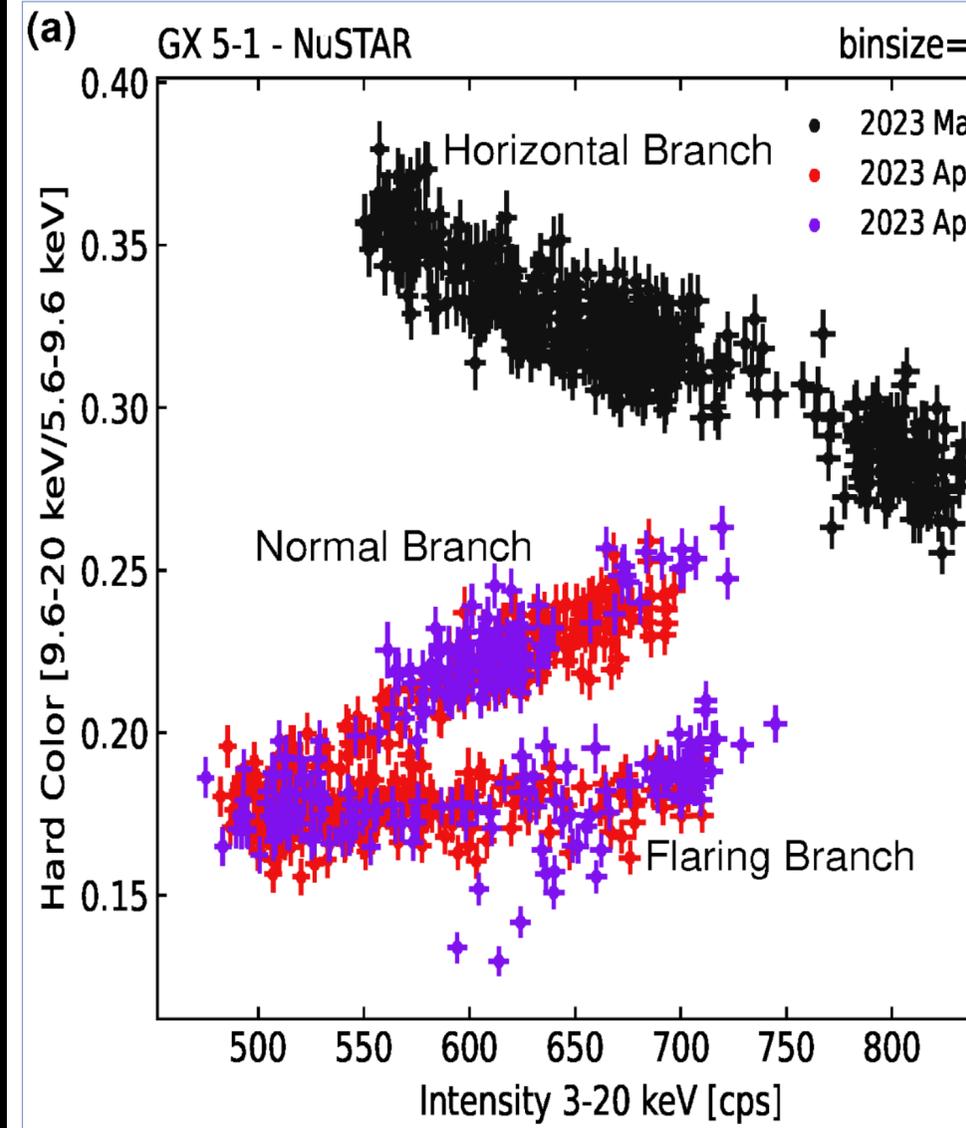
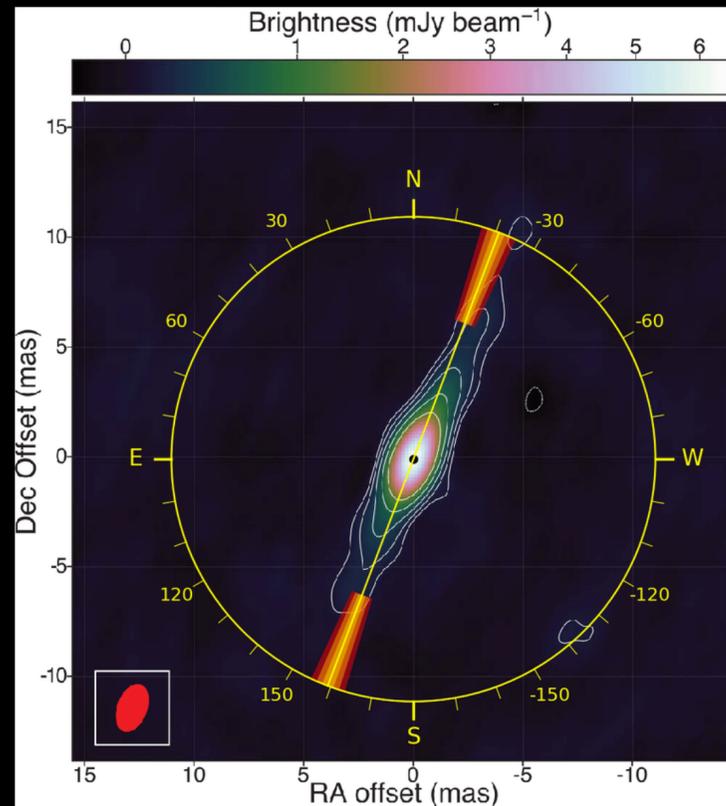


Prograde Rotation

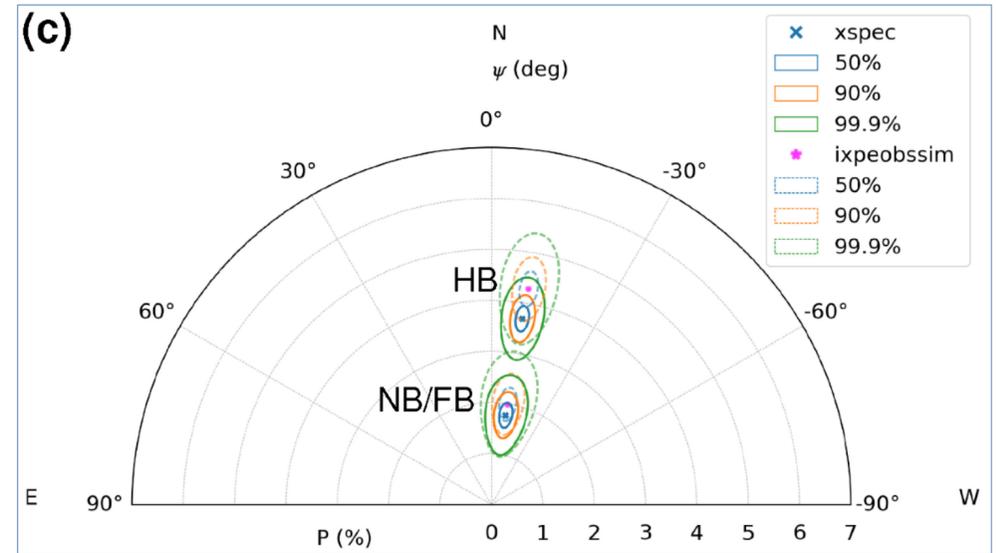
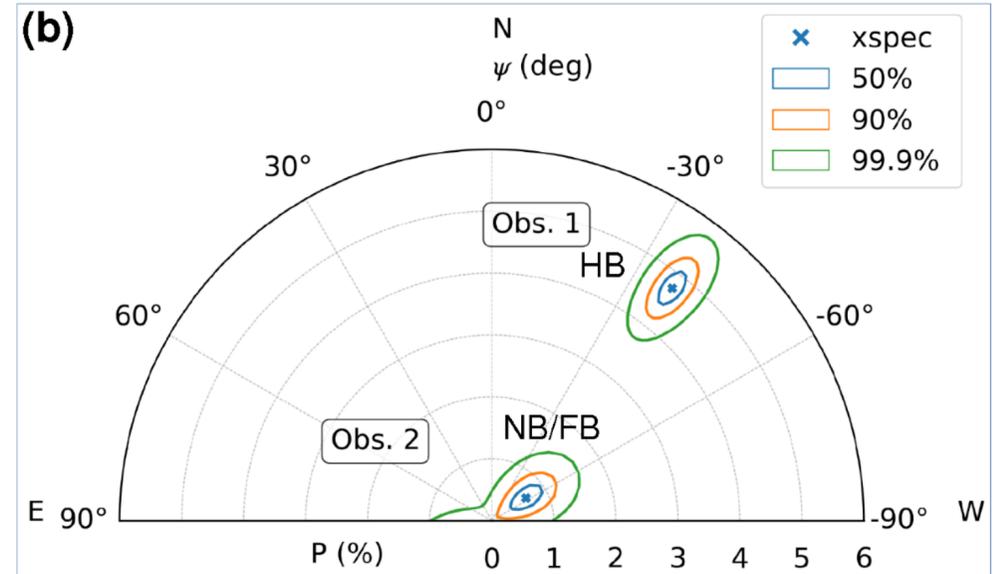


# Summary of Key Techniques — X-ray (Polarisation)

- NASA's IXPE has been particularly important recently in constraining the geometry of the accretion flow
- Able to see changing polarisation throughout source evolution, e.g. for the different branches of the NSXRB GX 5-1



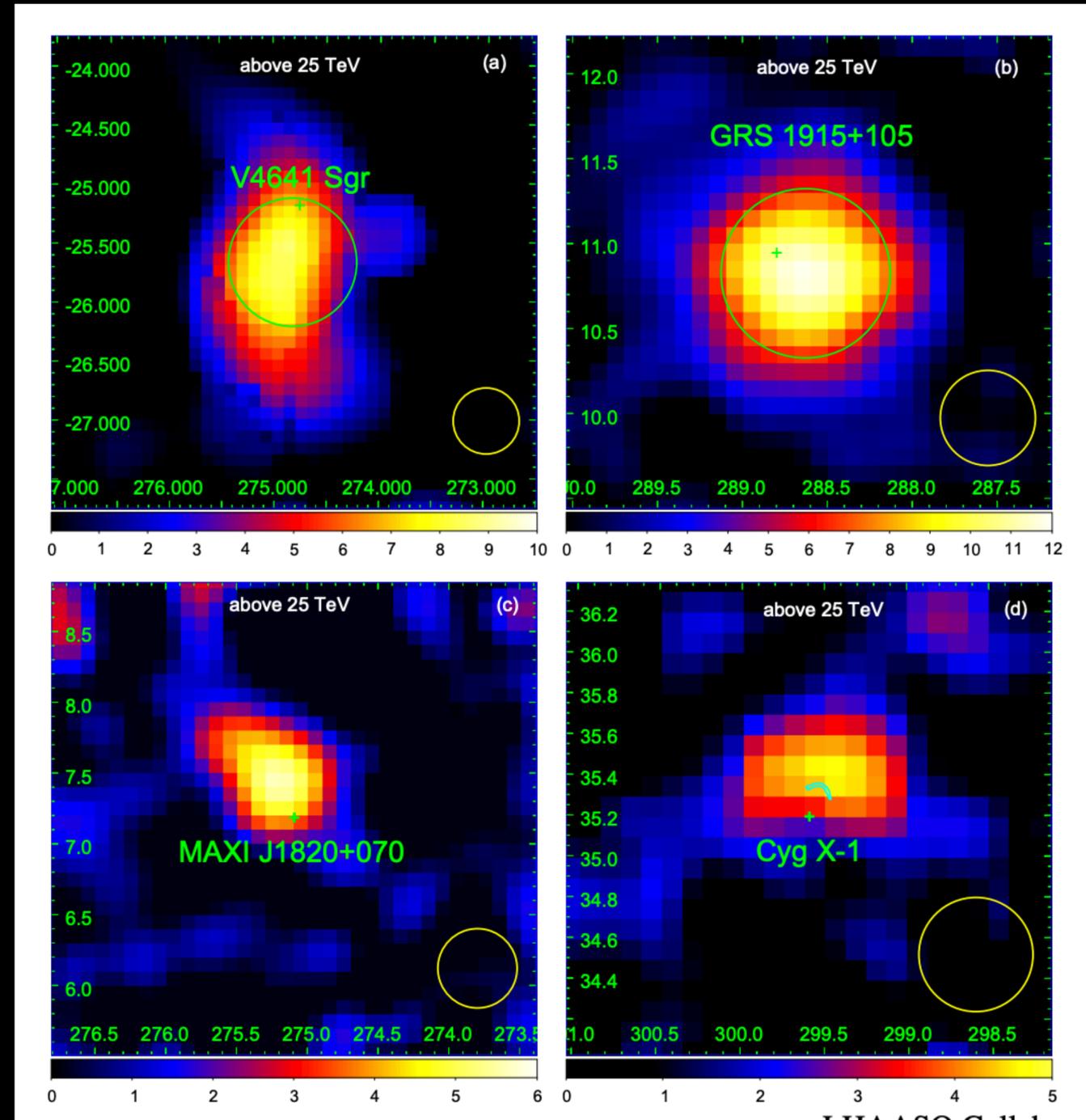
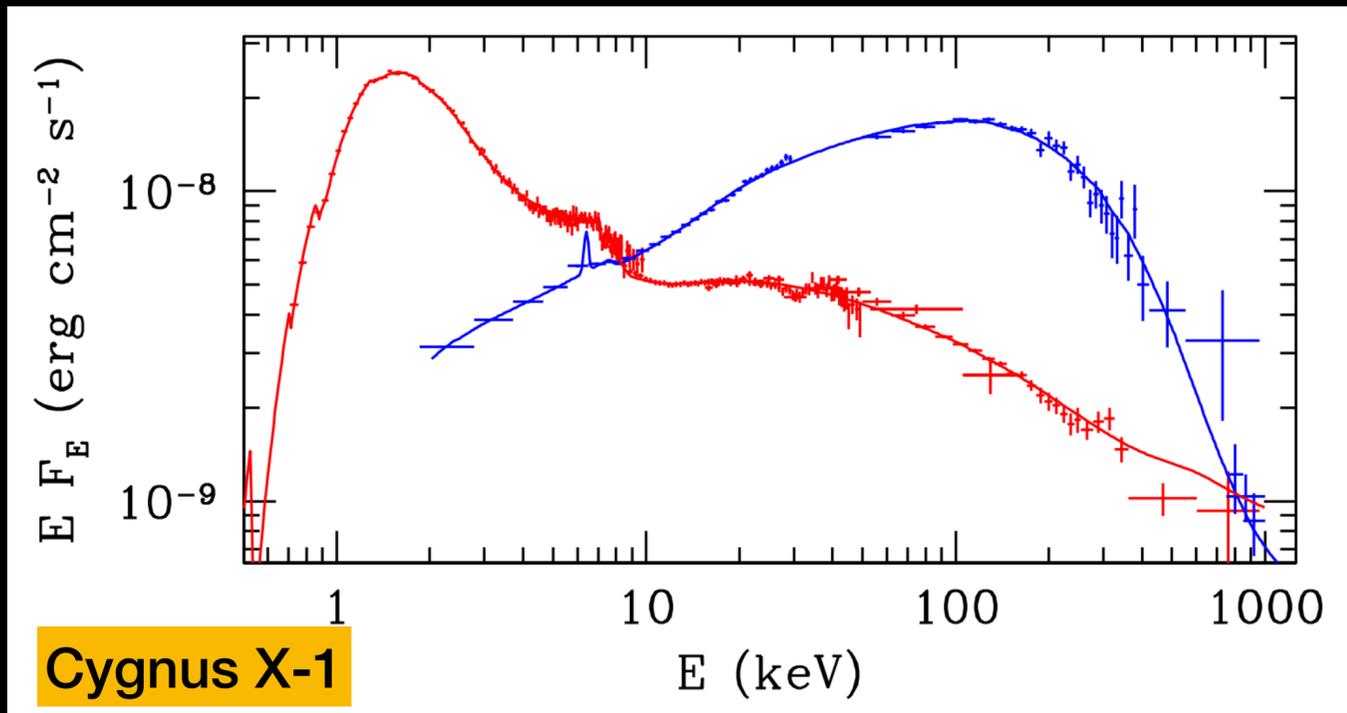
Francesco Ursini



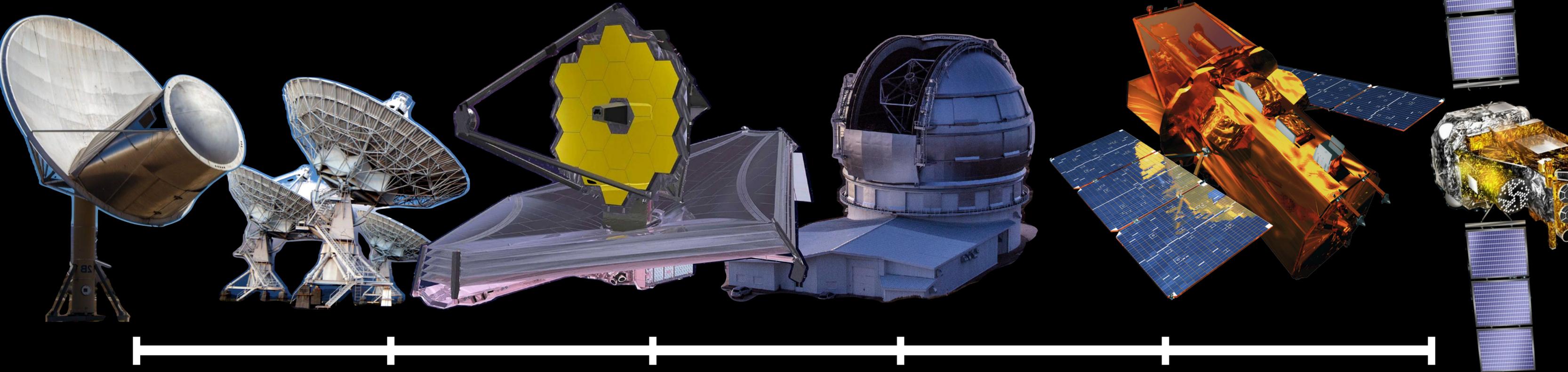
Sergio Fabiani<sup>1</sup>

# Summary of Key Techniques — $\gamma$ -ray+

- Bright sources can be detected by GRB monitors (e.g. *Swift*-BAT)
- Some XRBs seem to sit in regions of extremely high energy gamma-ray activity - cosmic ray contributors
- High energy tails to connect to X-ray spectroscopy



# Facilities\*



Radio

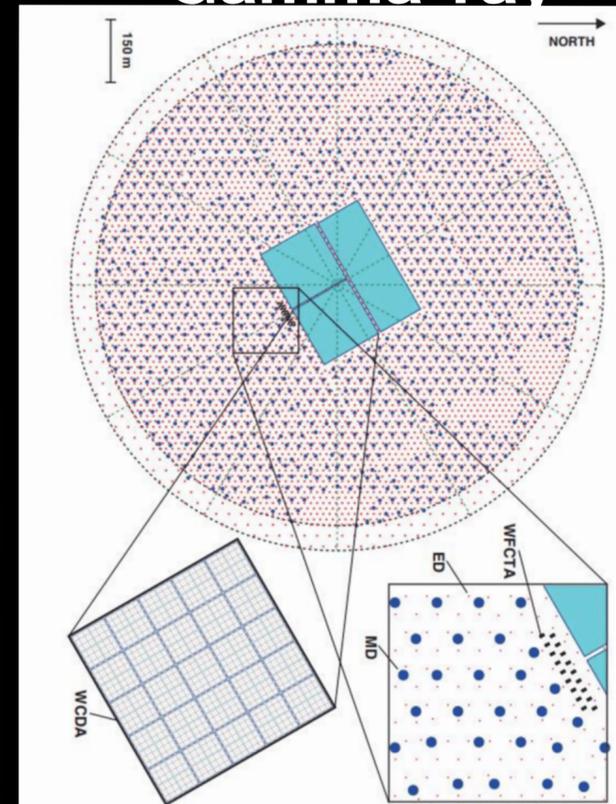
SUB-mm

IR

Optical

X-ray

Gamma-ray



\*subset

# Observing Plan

**There is no observing plan\***

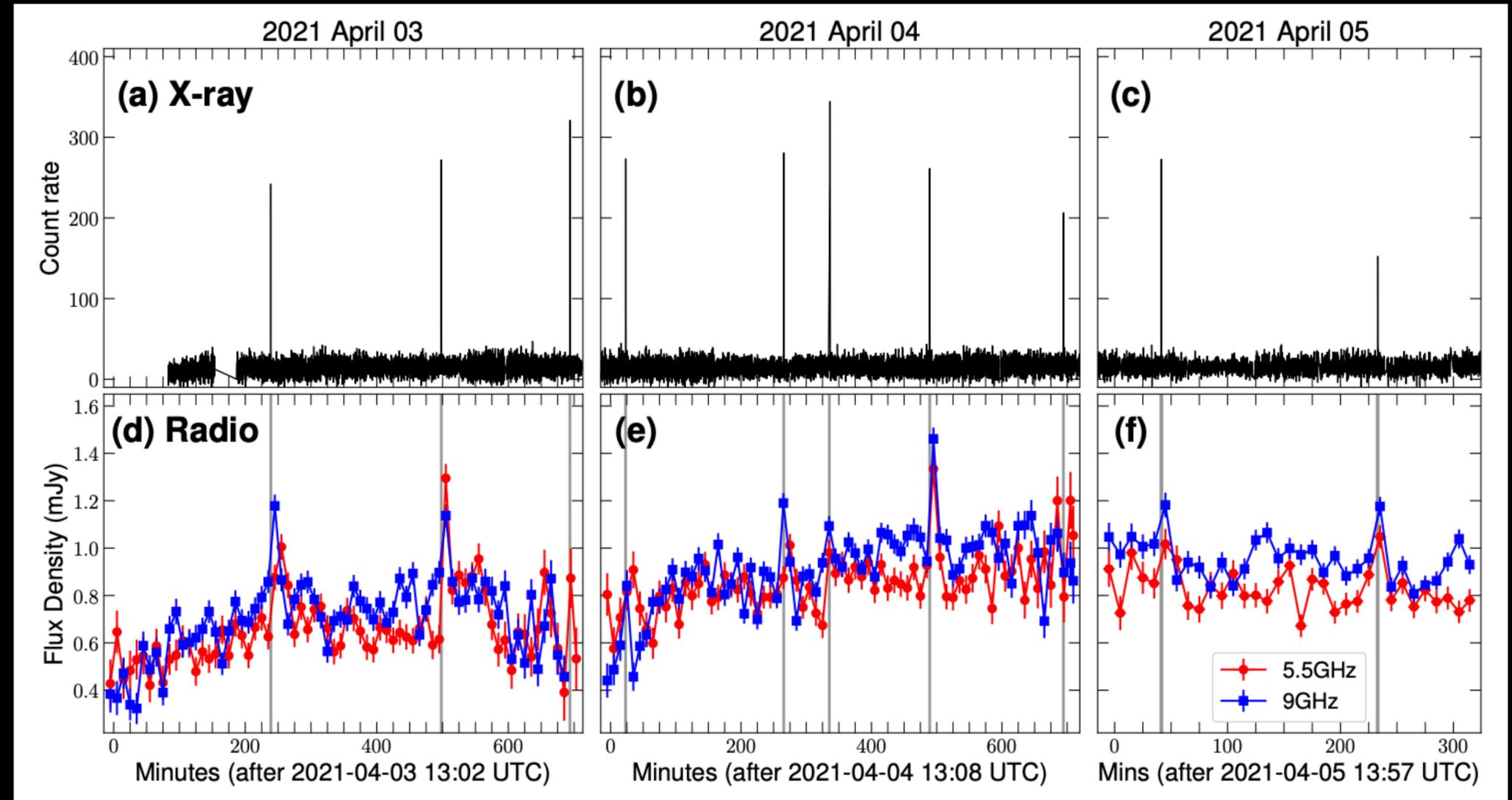
**\*There is no **one** observing plan...**

**Systems are too diverse and the range of science goals too  
broad**

# Past Coordinated Successes

## Neutron Star Jet Speeds from Type I X-ray Bursts

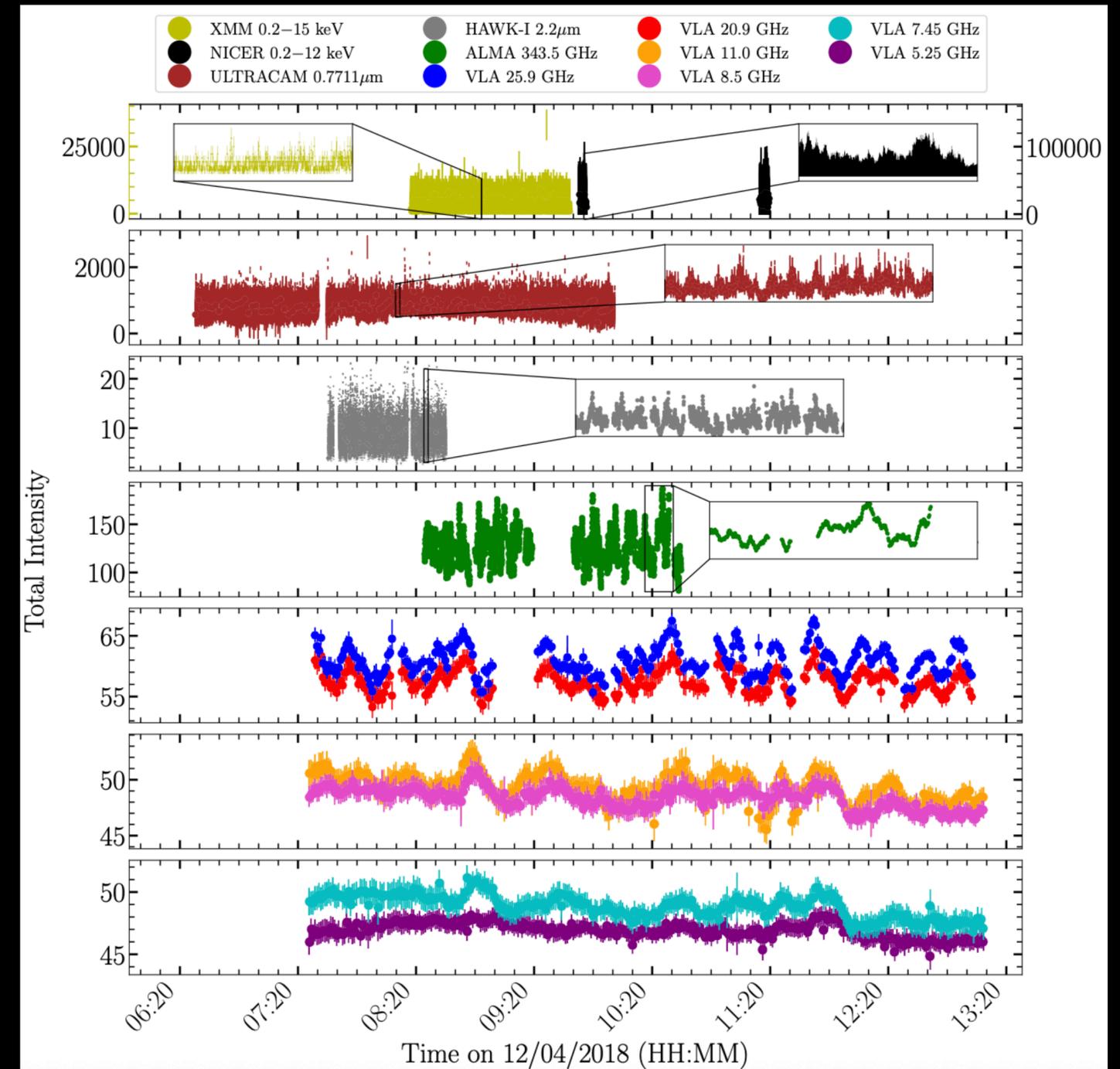
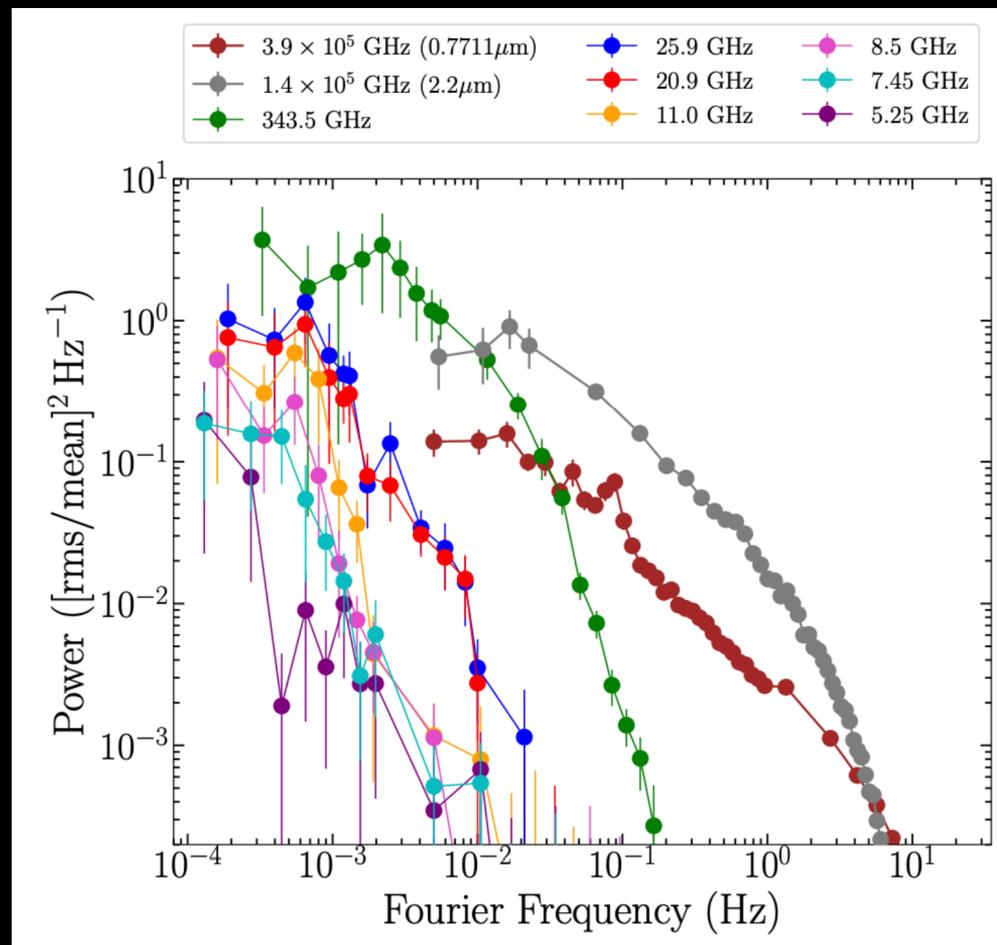
- Excellent example of the advantages of simultaneous observing
- Type I X-ray bursts (from accreted material) on the surface of the neutron star X-ray binary 4U1727 show a response in the radio
- Used to constrain mechanisms for jet launching from NSs
- Able to measure jet speed (lower than for BH systems) in a novel manner



# Past Coordinated Successes

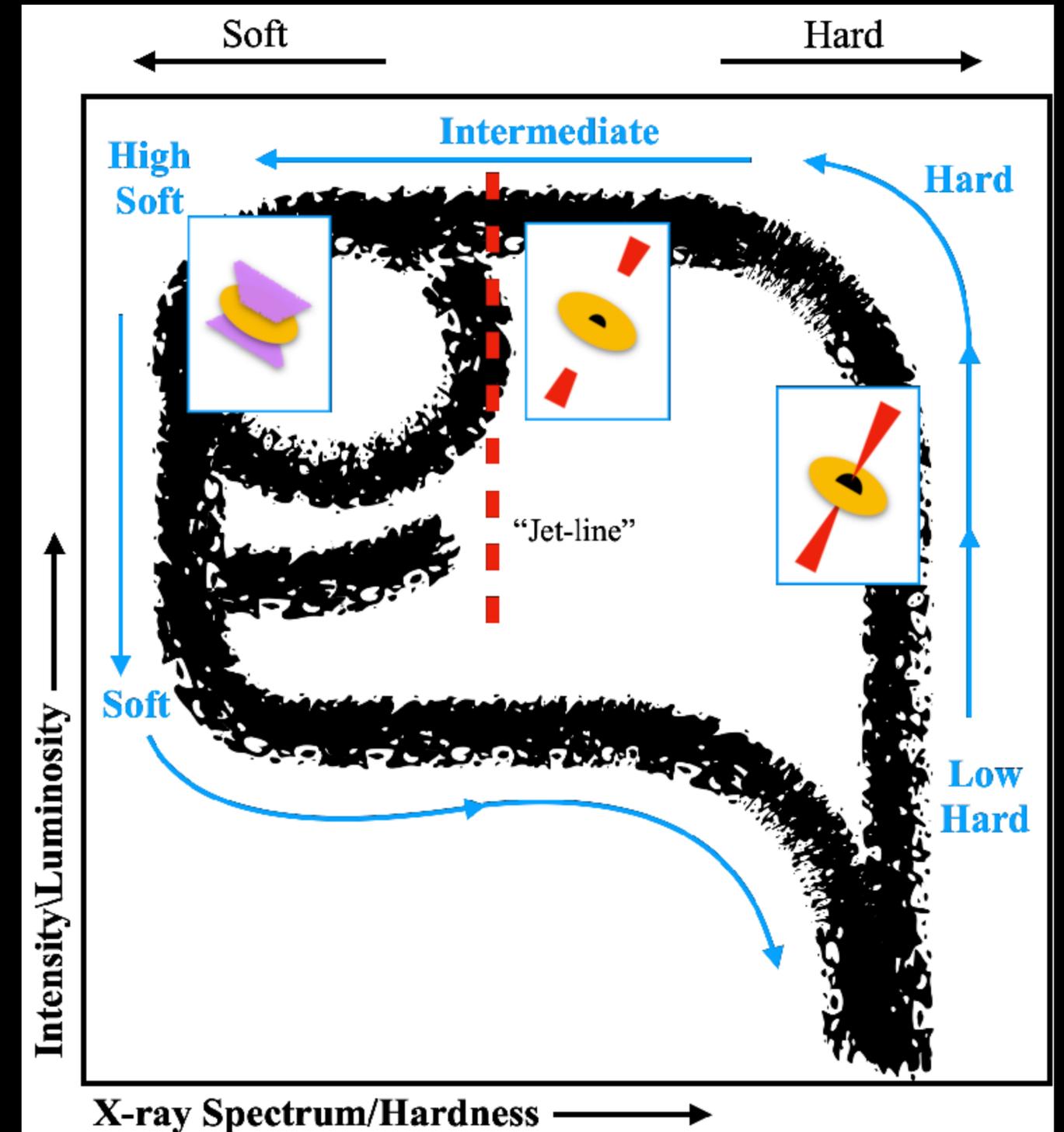
## Fundamental Jet Properties from a Low Mass BH XRB

- Strictly simultaneous radio, sub-mm, IR, optical, soft X-ray observations
- From a programme designed to target bright LMBHXRBs in the hard state, with specific flux density cuts
- Propagation allows for modelling of jets

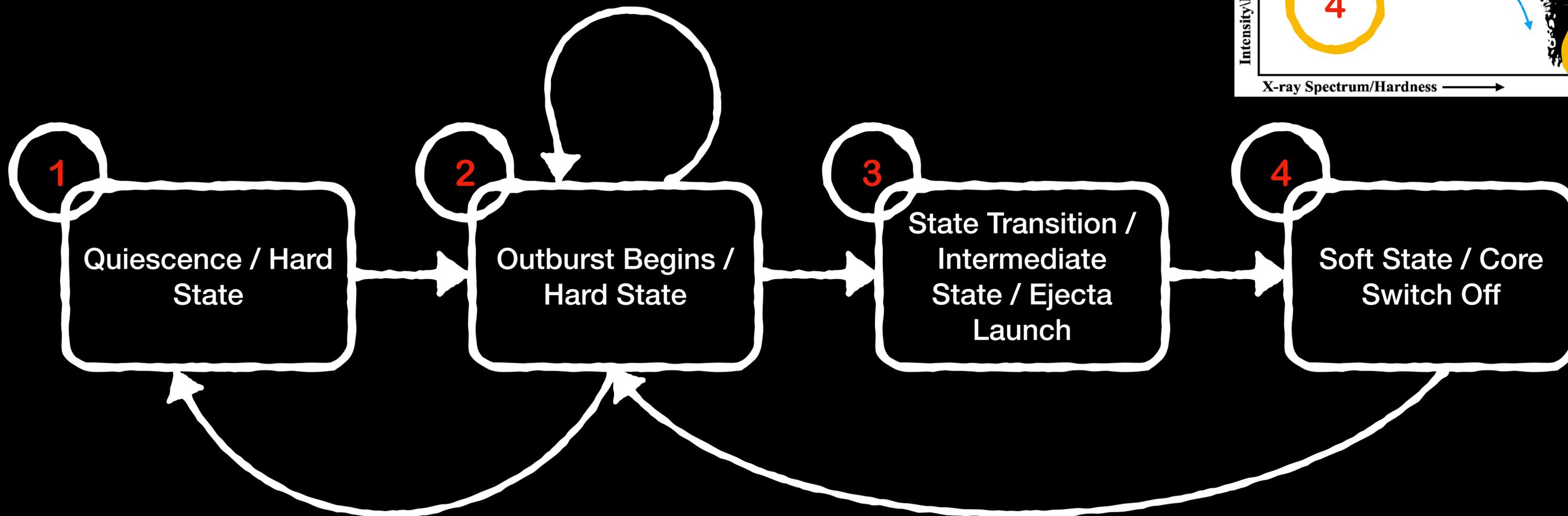
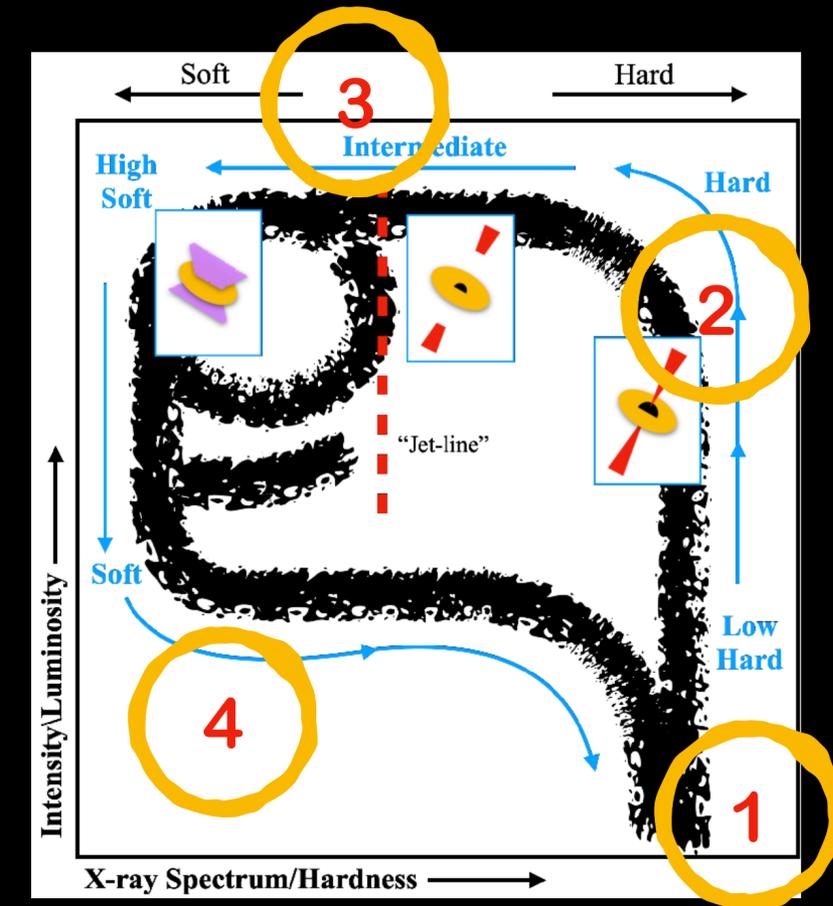


# Example Observing Plan for Outbursting Low Mass X-ray Binaries

- Black hole X-ray binaries go through fairly predictable outbursts, making predetermined observing plans feasible
- These outbursts are defined through accretion states primarily based on X-ray spectral and timing properties
- Sources make tracks in the Q-diagram (hardness intensity)
- Timing is hard to guess, but there are clear signs indicating a source is about to move to another part of the diagram (allows for planning)



# LMBHXRBs in Outburst



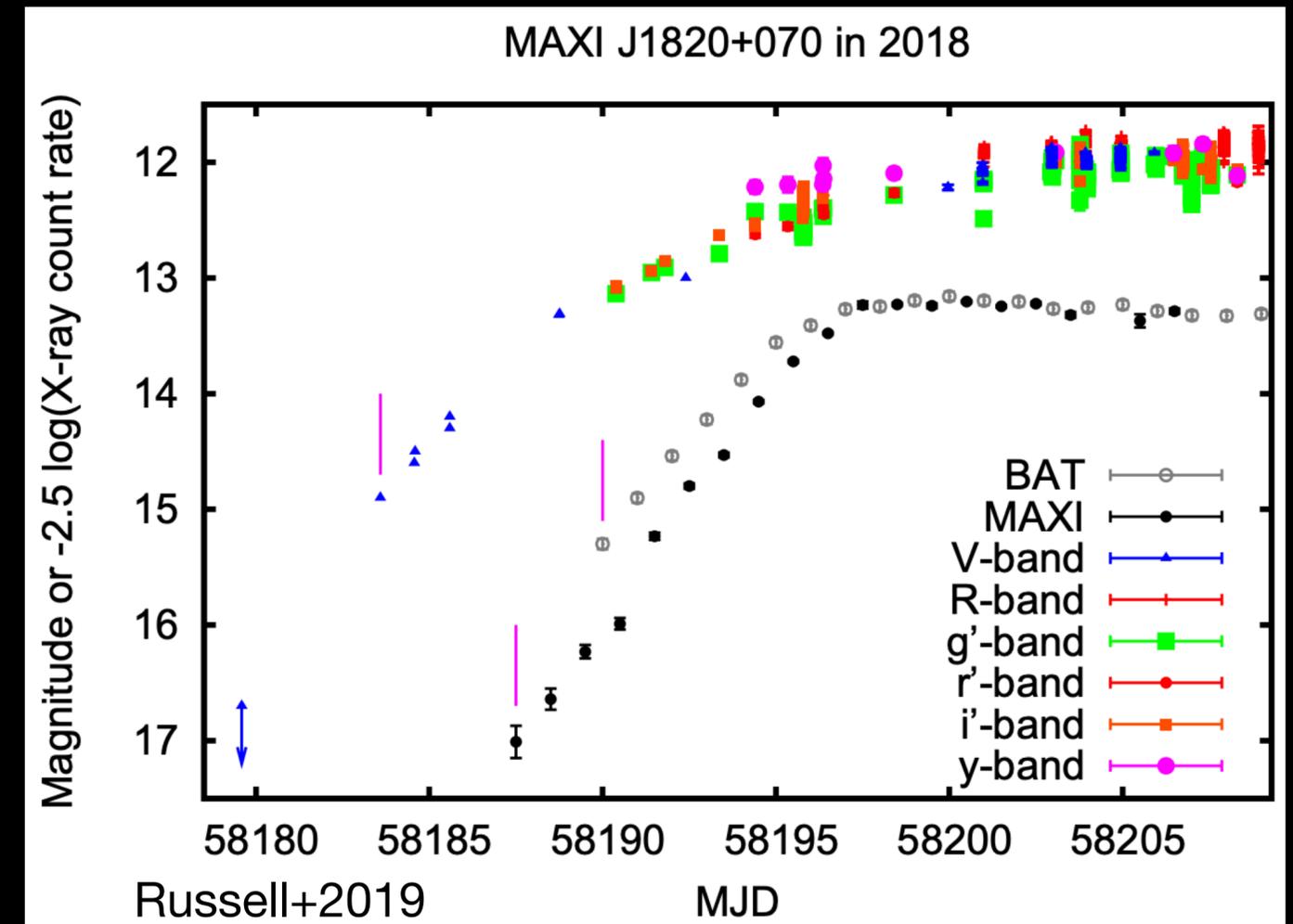
Decades/Centuries recurrence?

- Jet re-ignition
- Can recur on short timescales

# T0 — T0 + 1 week

## XRBs in outburst — **Rising**

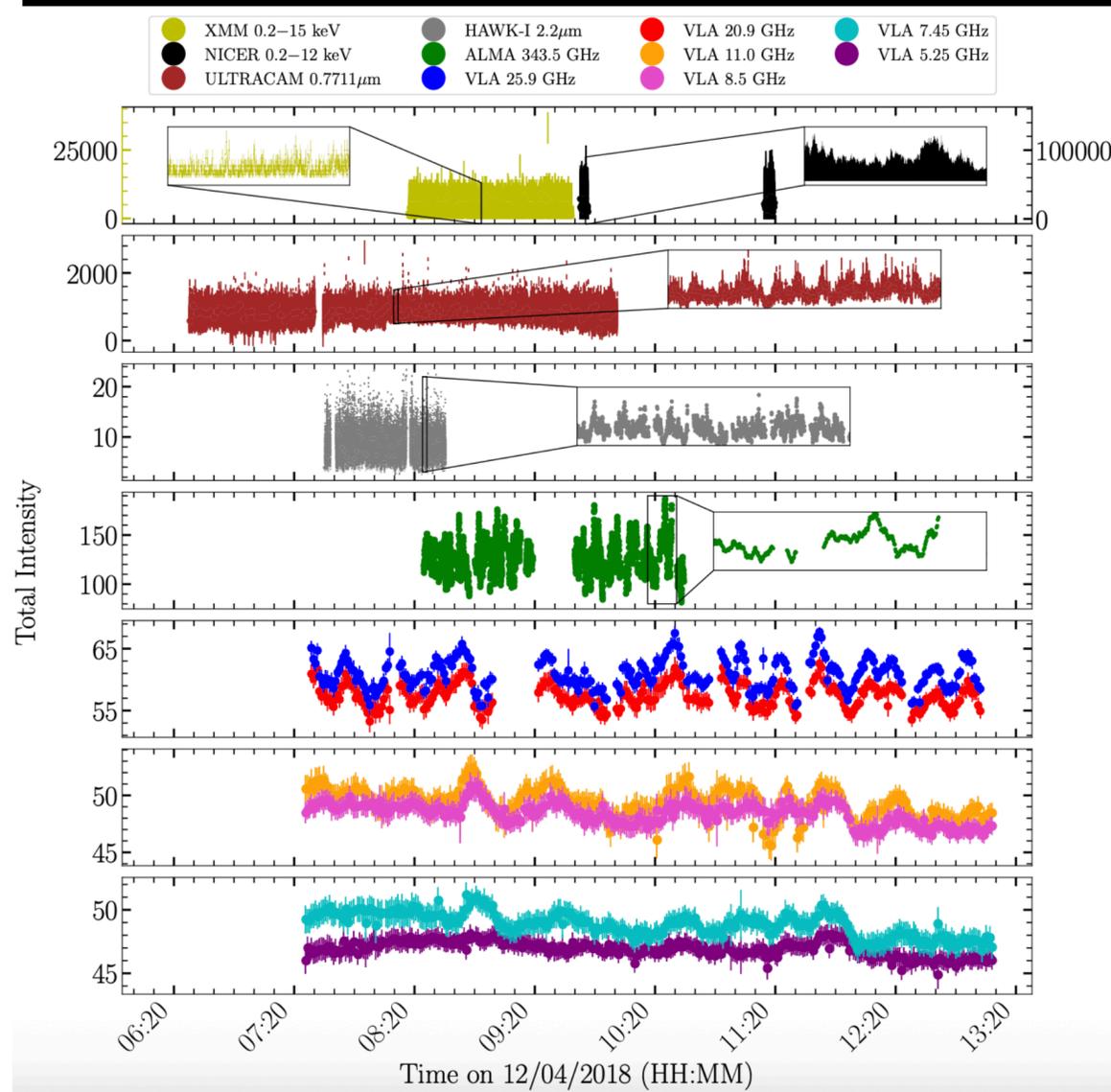
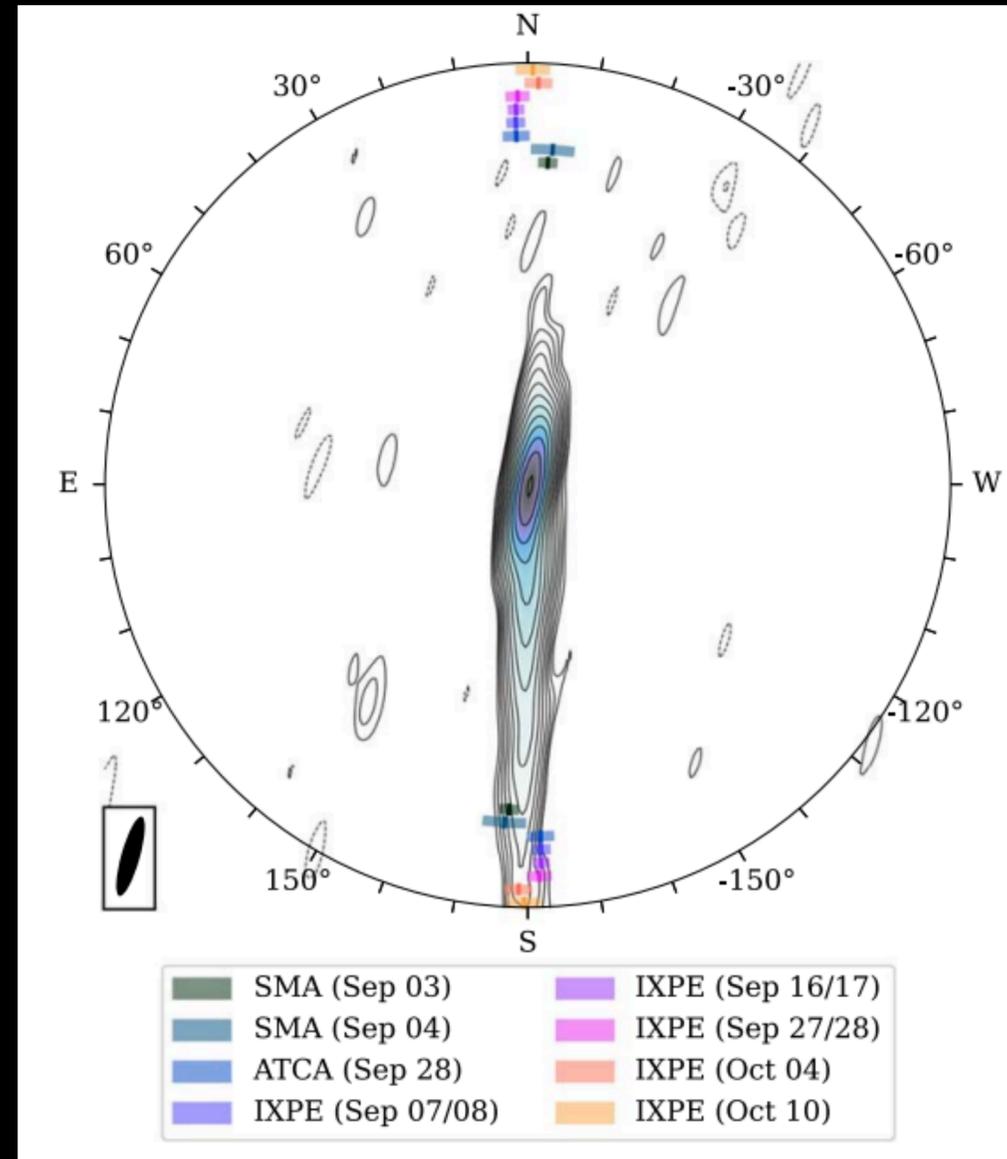
- For a known source entering outburst typically optical monitoring is the best way to know a source is entering outburst
- Rise to maximum on the order of one week
- For new sources this could be from an all sky monitor or a GRB detection mechanism, source could still be rising
- MAXI / BAT / EP / SVOM also good triggers or even optical surveys
- **Science Goals: Understanding DIM, beginning of outbursts, and the accretion — ejection connection**
- **Facilities: Monitoring instruments to track the rise across the EM spectrum (e.g. Swift/MAXI/LCO/AMI-LA/ATA)**



# T0 + 1 week — T0 + ??? (weeks or months)

## XRBs in outburst — **Bright hard state**

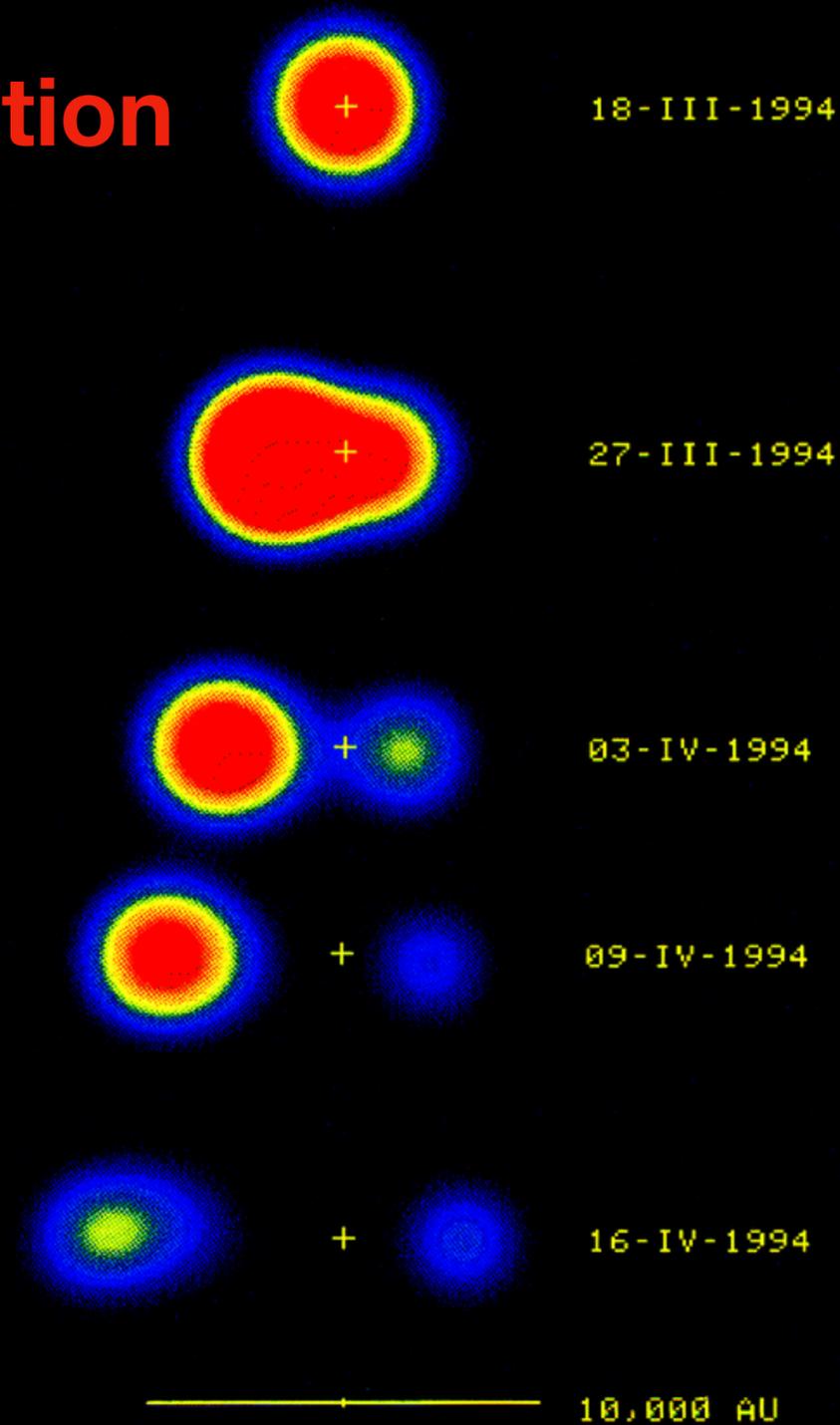
- Once sources have risen to the high hard state they are typically at their brightest, and can remain in this state for a long period of time (weeks/months)
- It is an ideal time to take coordinated observations for high quality spectra, timing, radio imaging, polarisation
- Identified through timing and spectral properties
- **Science Goals: Understanding accretion jet connection, black hole properties, geometries, winds**
- **Facilities: VLBI, IXPE, 10m class optical telescopes, NICER**



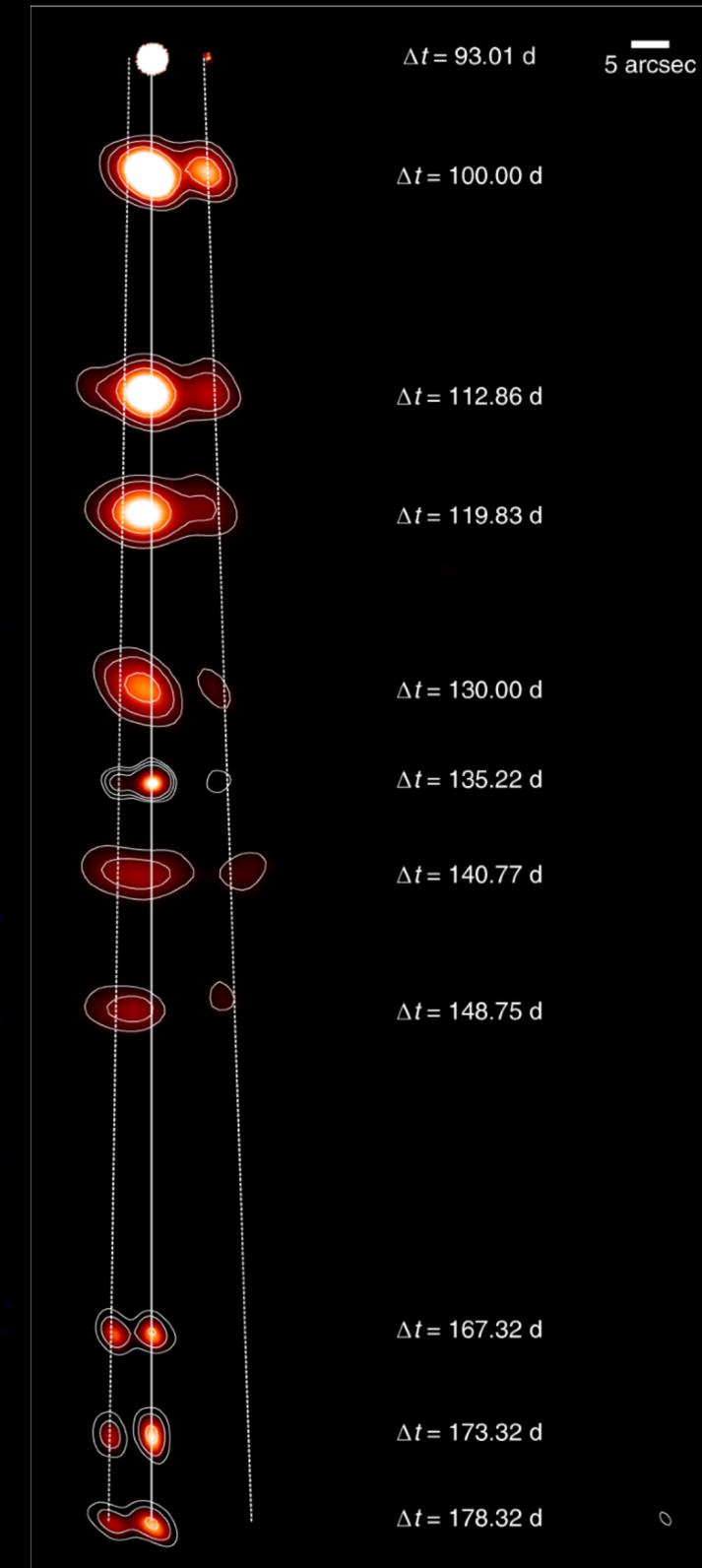
# TO + ???

## XRBs in outburst — State transition

- State transitions can be signalled through evolving accretion disk spectrum, jet properties, and X-ray timing properties
- Consistent monitoring is needed to catch these signs
- Important feedback phase due to the launch of transient ejecta and connection to jet properties
- **Science Goals: Understanding corona evolution and connection to the jet, jet quenching, the launch of transient ejecta**
- **Facilities: VLBI, Radio Monitoring, Timing**



Mirabel and Rodríguez 1994



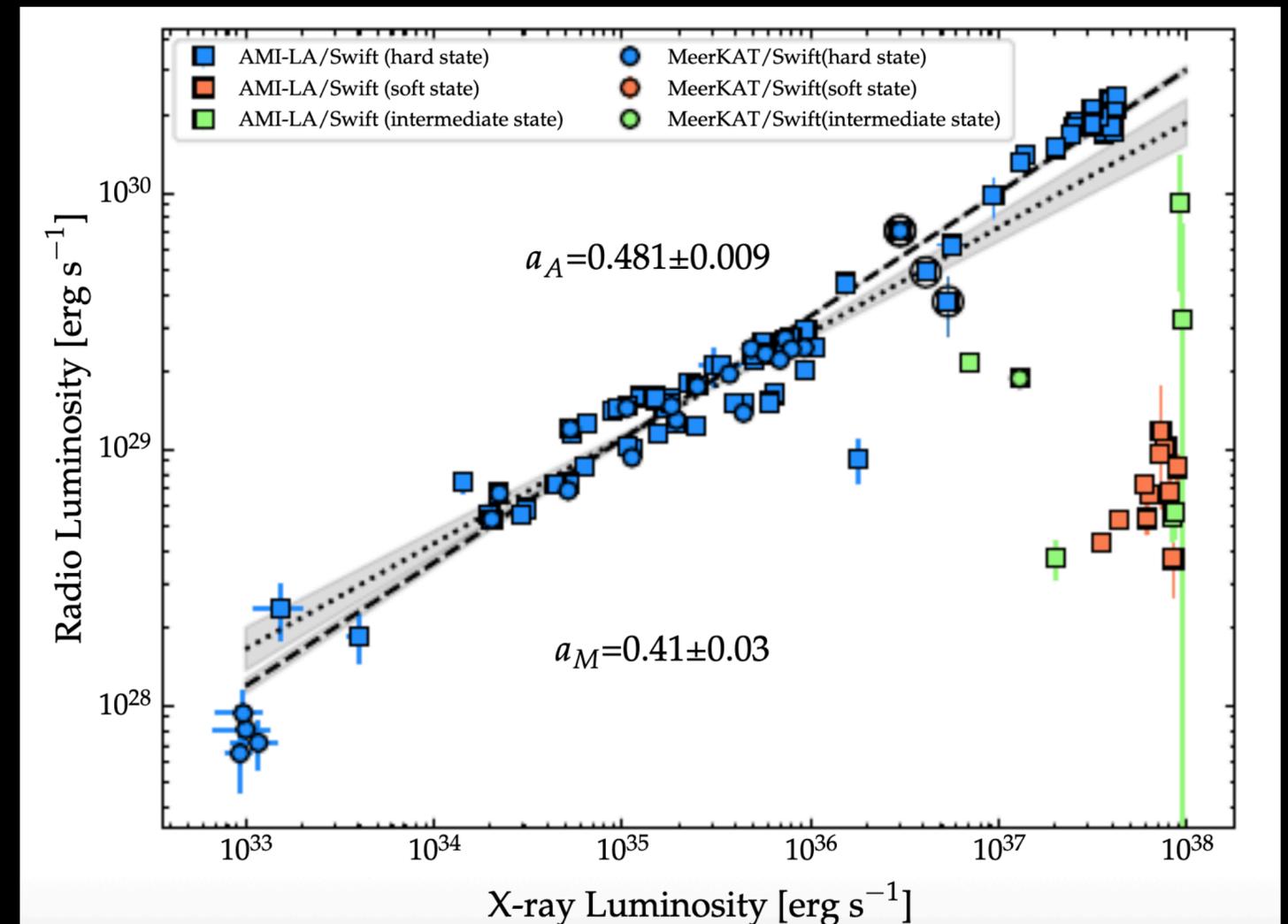
Bright+2020

# T0 + ???

## XRBs in outburst — Return transition

- The reverse transition is typically not associated with ejecta launch
- Core jet does reignite on return to the hard state (how this happens)
- Important to cover these transitions well and in a coordinated way
- **Science Goals: Understanding corona evolution and connection to the jet, jet quenching, the launch of transient ejecta**
- **Facilities: VLBI, IXPE, 10m class optical telescopes, NICER**

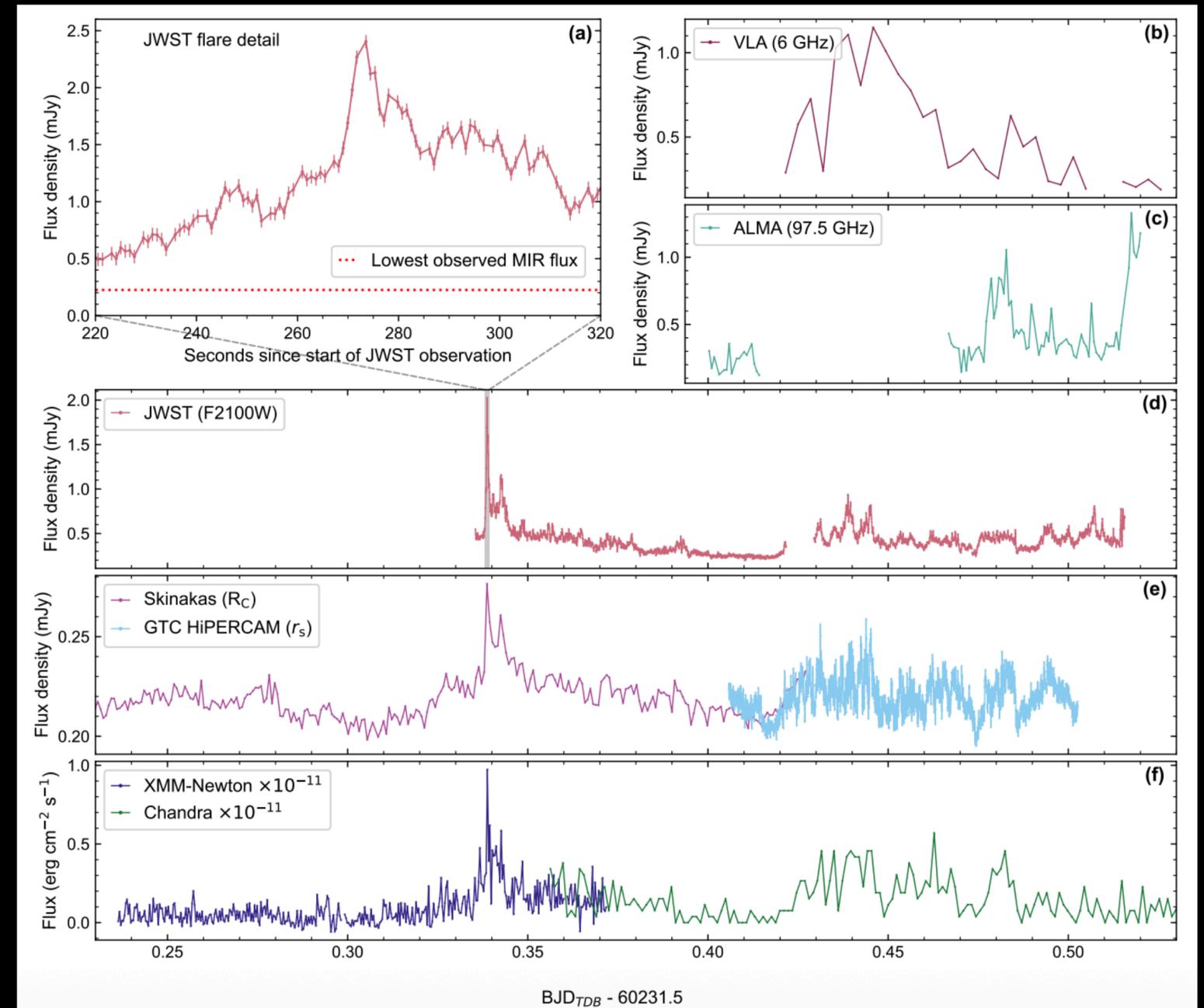
Bright+2025



# TO + ???

## XRBs in outburst — Final hard state, fading and quiescence

- When sources are in quiescence their mass function can be determined, and thus their mass
- If sources are bright for long enough VLBI parallax distances are possible to measure, as are proper motions
- Accretion — Jet connection at the end of the outburst and in quiescence
- **Science Goals: Measuring black hole masses, distances to sources, kicks**
- **Facilities: VLBI, 10m class optical, JWST**

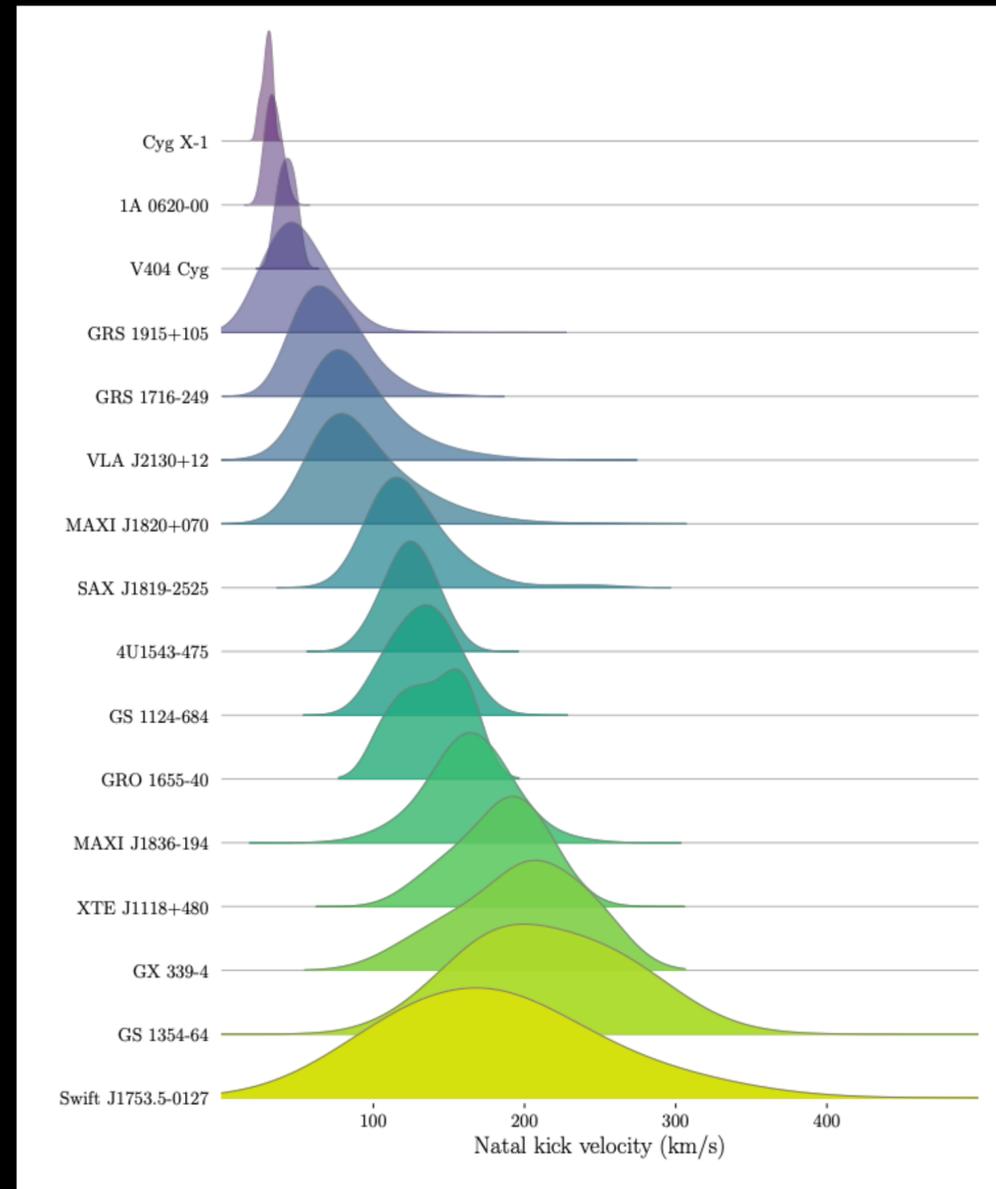


# TO + ???

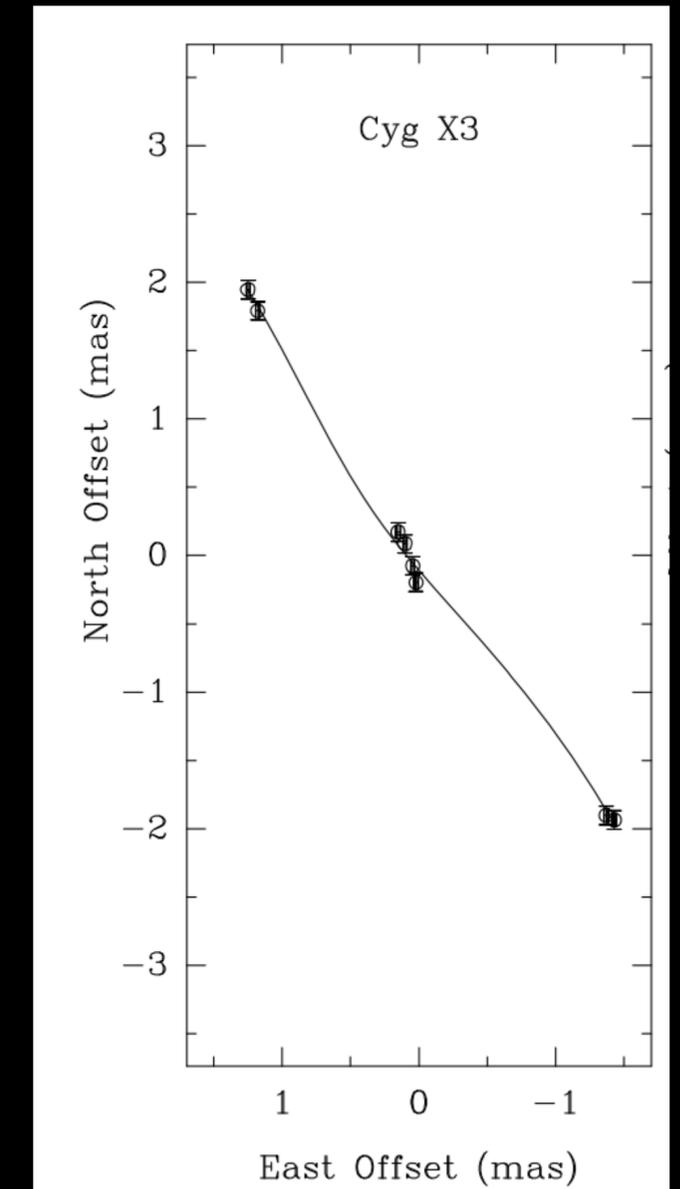
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Atri+2019



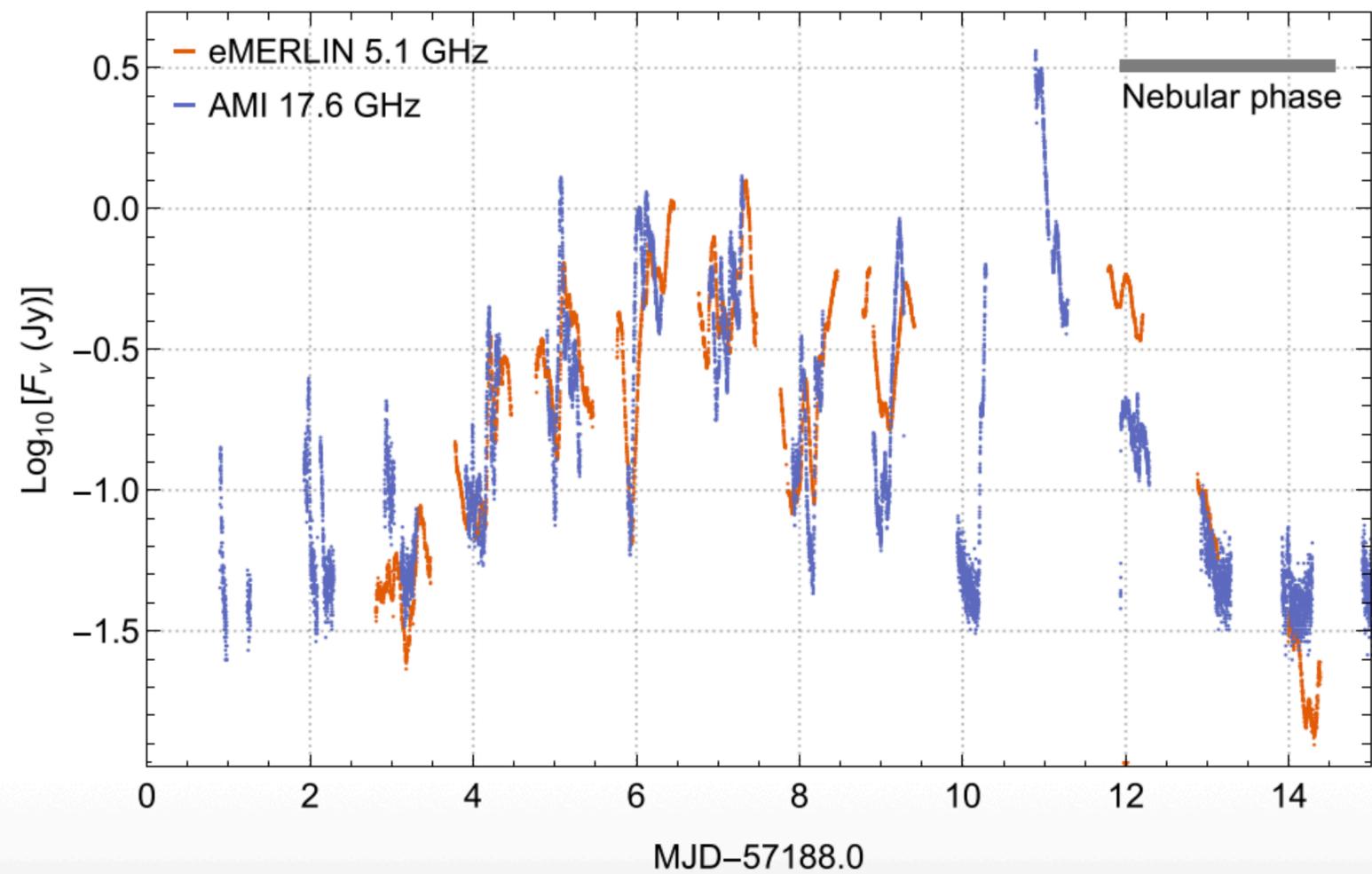
Reid+2023



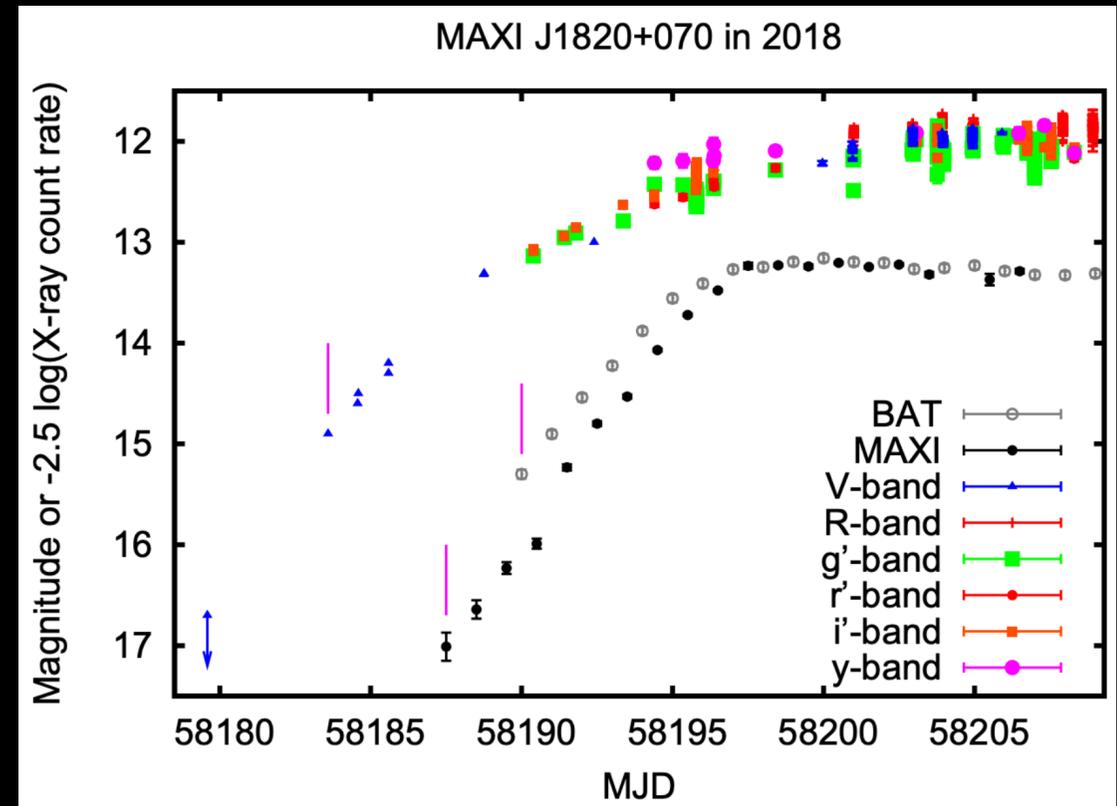
# Future Observatories & Essential Capabilities

## (All Sky) Monitors

Fender+2022



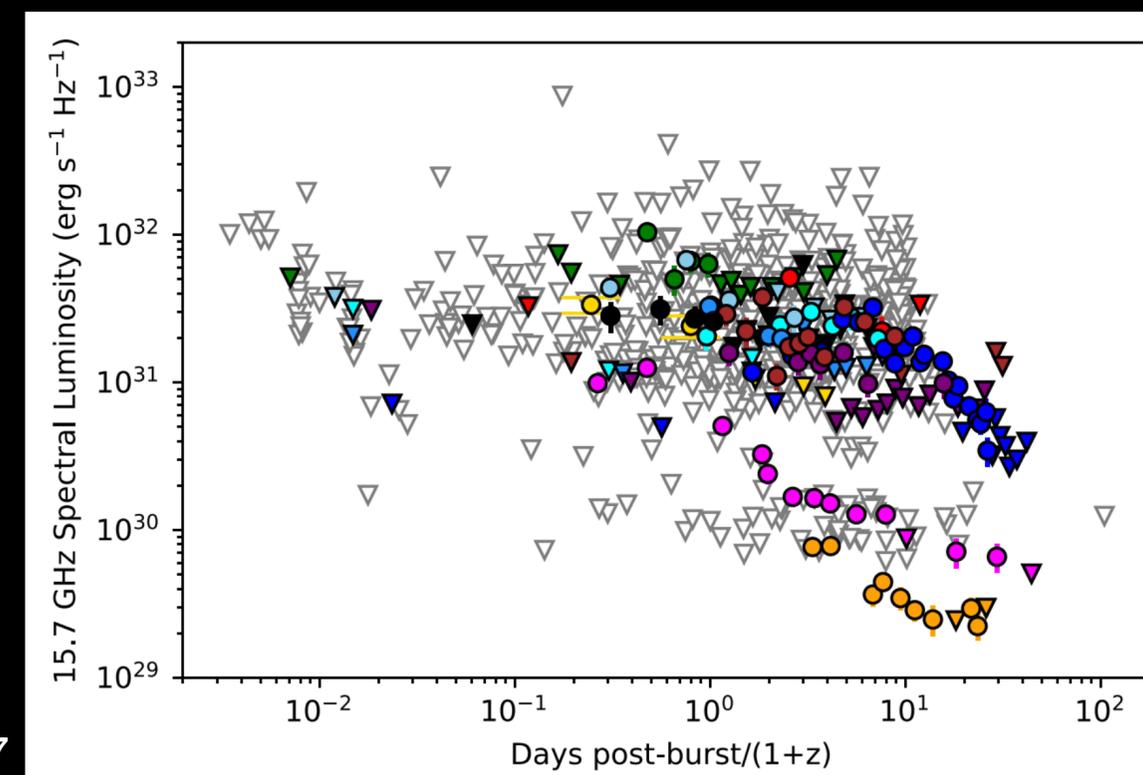
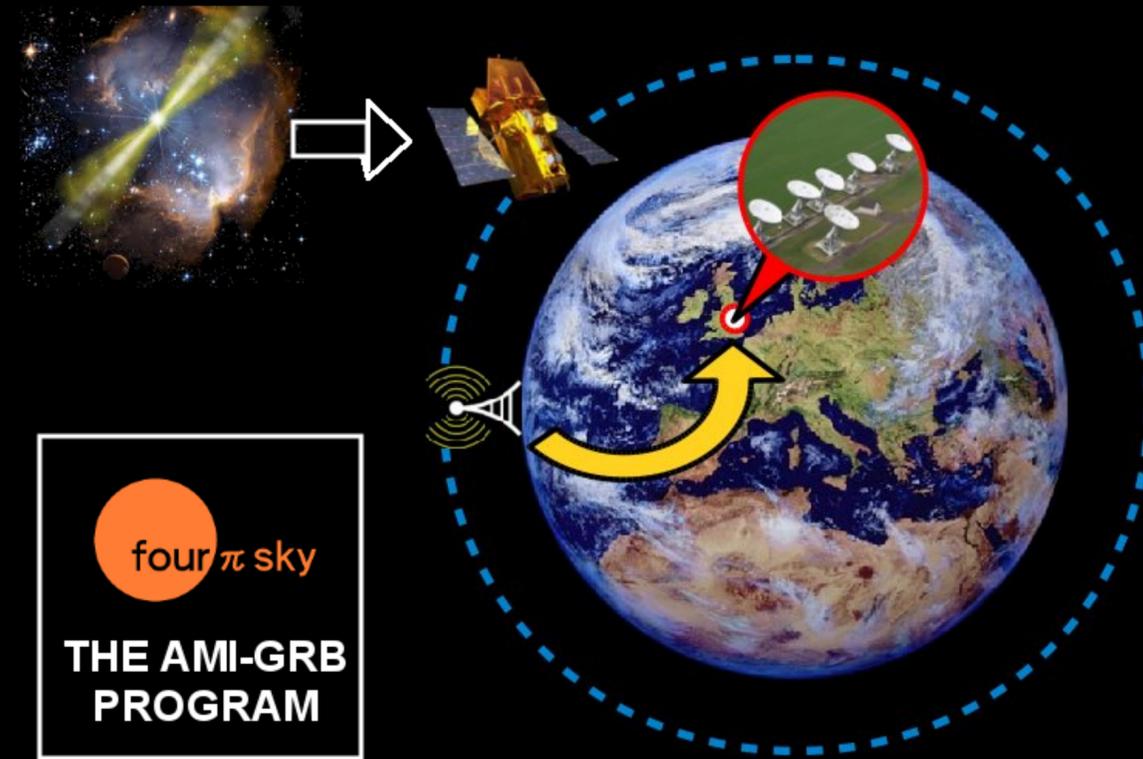
Russell+2019



# Future Observatories & Essential Capabilities

## Coordination

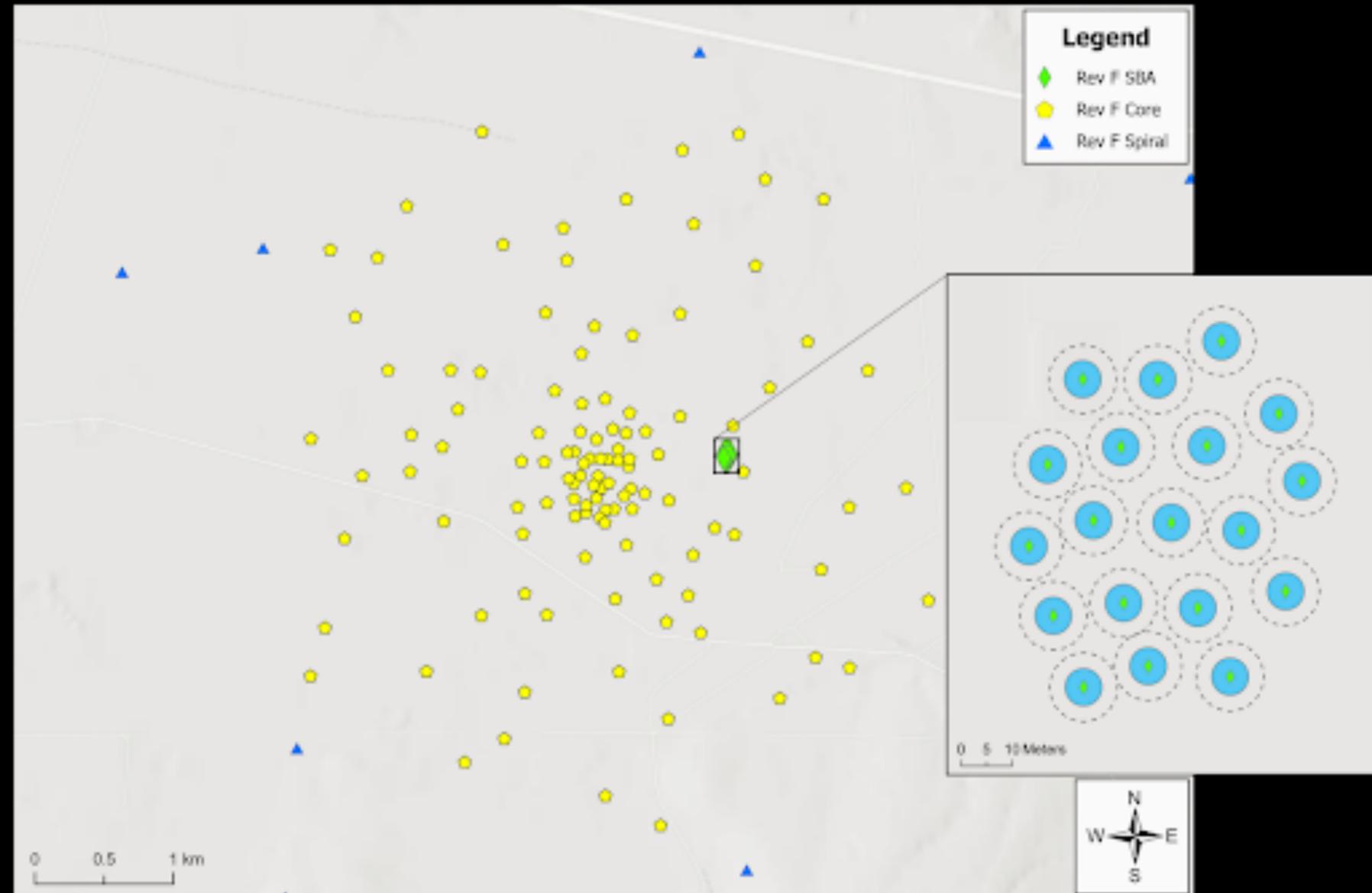
- Some observatories all for formal coordination, but a lot of observing campaigns are put together in an ad-hoc manner
- The ability to pre-arrange observing schedules, or have warning on observing schedules is valuable
- Automated dissemination of alerts in machine readable format also important for robotic follow-up (e.g. AMI-LA for VOEvents)
- e.g. XBNEWS for outburst starts



# Future Observatories & Essential Capabilities

## Bright Source Capability

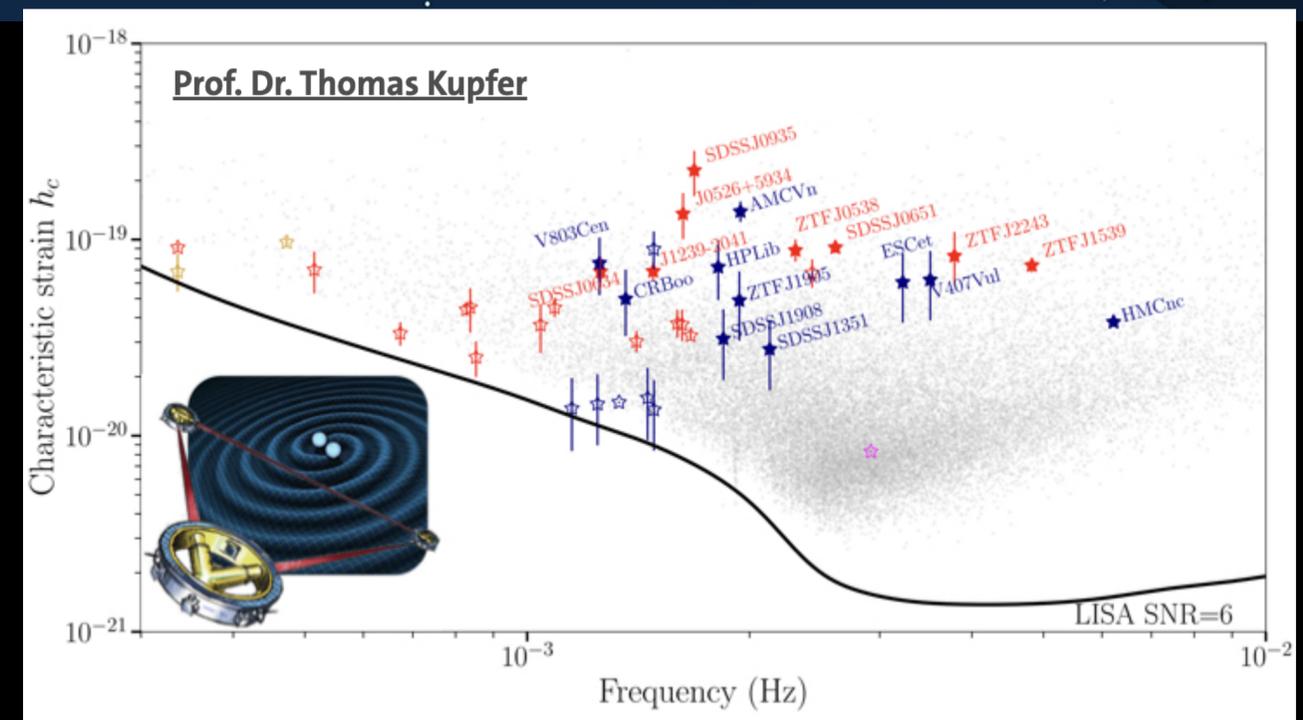
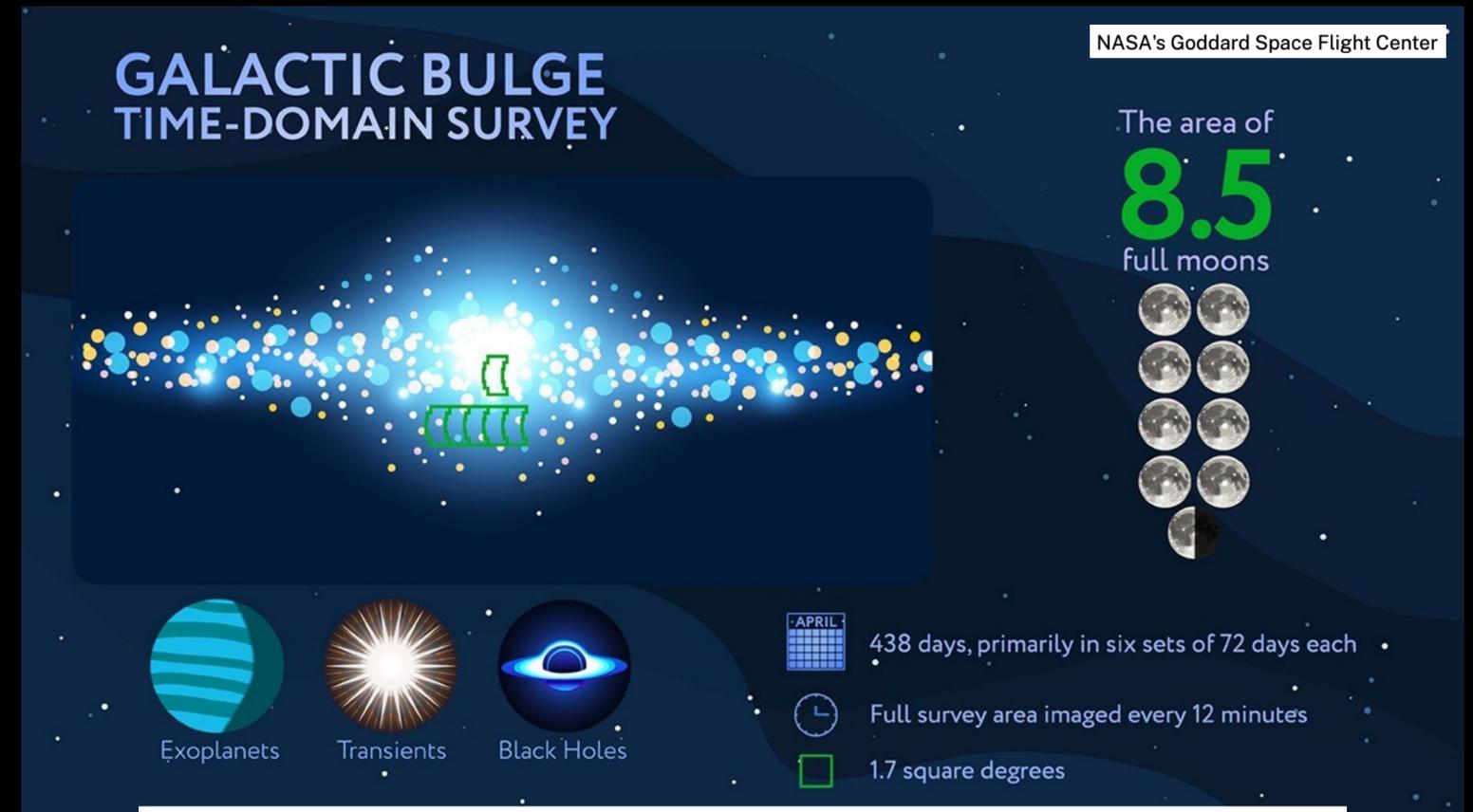
- In the X-rays particularly it can be challenging to observe X-ray binaries as they are too bright
- Often good to e.g. sub-array in radio as sensitivity isn't needed all the time, this will be particularly important for SKA / ngVLA
- Utilisation of smaller facilities when needed e.g. sub-m optical telescopes, smaller radio interferometer, or ISS mounted instruments



# Future Observatories & Essential Capabilities

## Upcoming Missions

- **LSST**: Discovering extragalactic (and galactic) long period XRBs (Blackmon & Maccarone)
- **Roman**: discovering quiescent systems
- **SKA/ngVLA**: proper motion studies for quiescent source detection
- **LISA**: Gravitational waves from ultracompact binaries
- **ARGUS**: All-sky optical monitoring



# Summary & Thanks

- The best X-ray binary science is strictly simultaneous and multi-wavelength
- Rapid variability and multi wavelength connections on short timescales requires coordination
- Making specific response plans with pre-defined timescales it very challenging; sources all behave differently
- Reacting to well-understood system changes is more promising (e.g. LMXRB outbursts)
- ToO and coordinated observations outside of predefined ones still very important



Prof. Tom Maccarone  
Texas Tech



Dr. Payaswini Saikia  
Yale



Prof. David Russell  
NYU Abu Dhabi



Prof. Richard Plotkin  
U. of Nevada, Reno