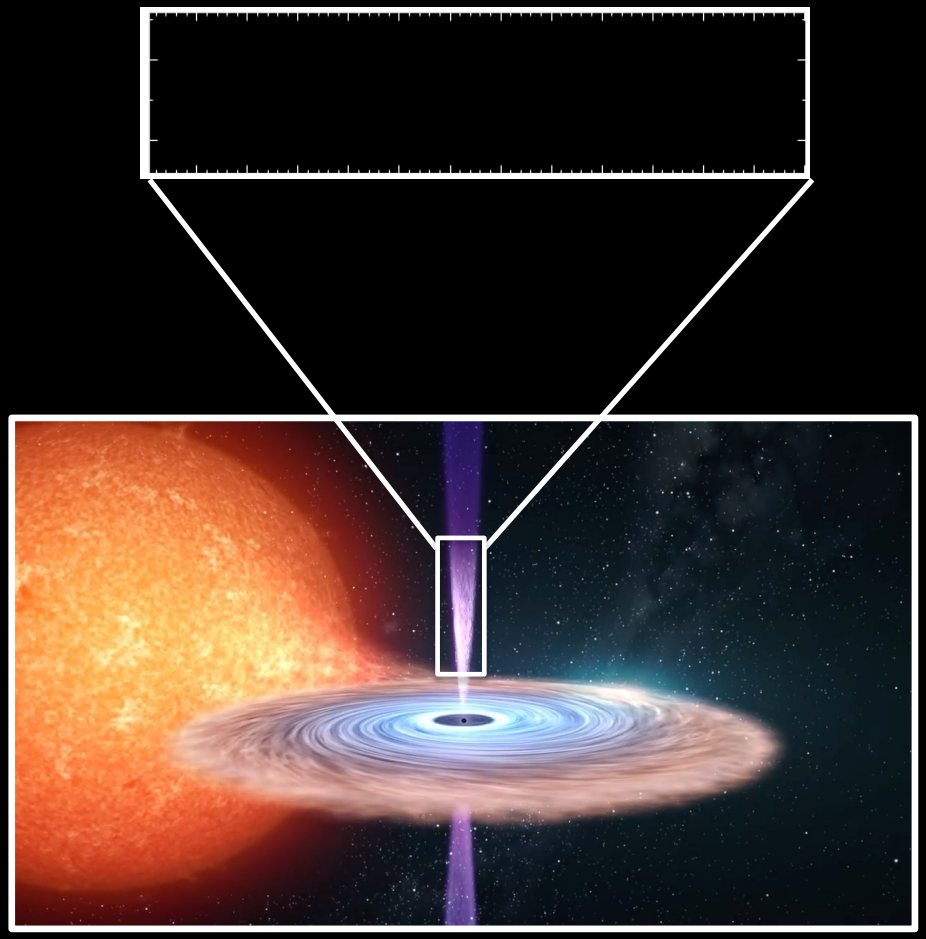

PITCH-BLACK

PolarIzation and Timing CHaracteristics of BLACK Hole Jets

PI: Alex Tetarenko

on behalf of the PITCH-BLACK team

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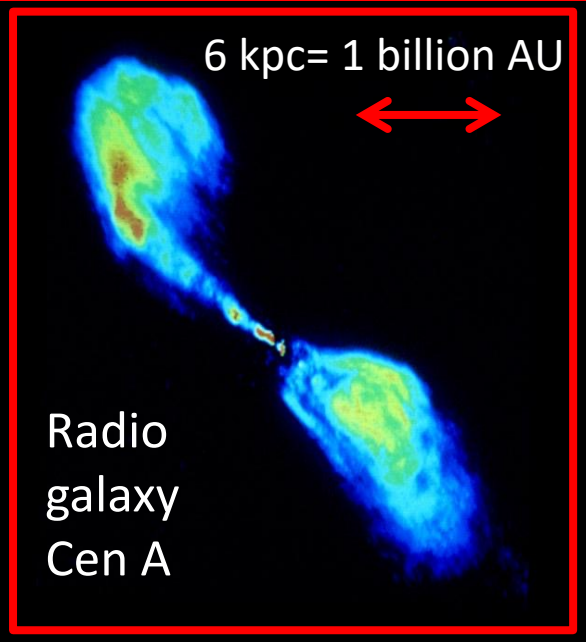
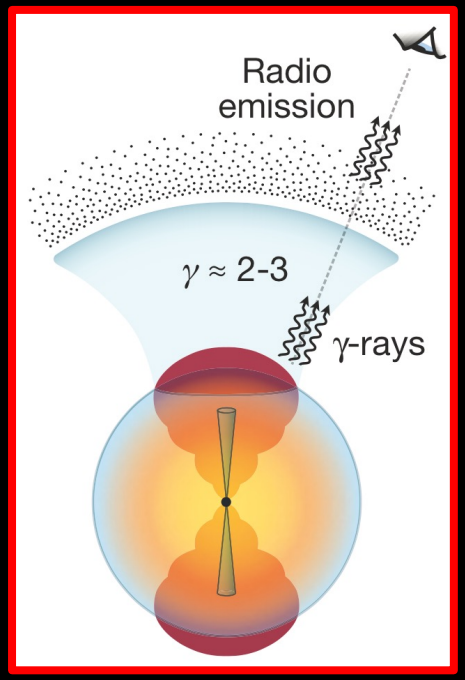
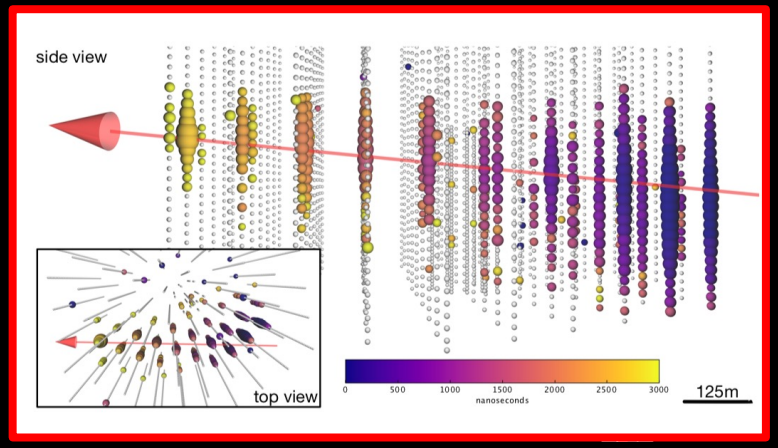
Relativistic Jets Launched From Black Holes



Credit: NRAO



Mooley et al. 2018

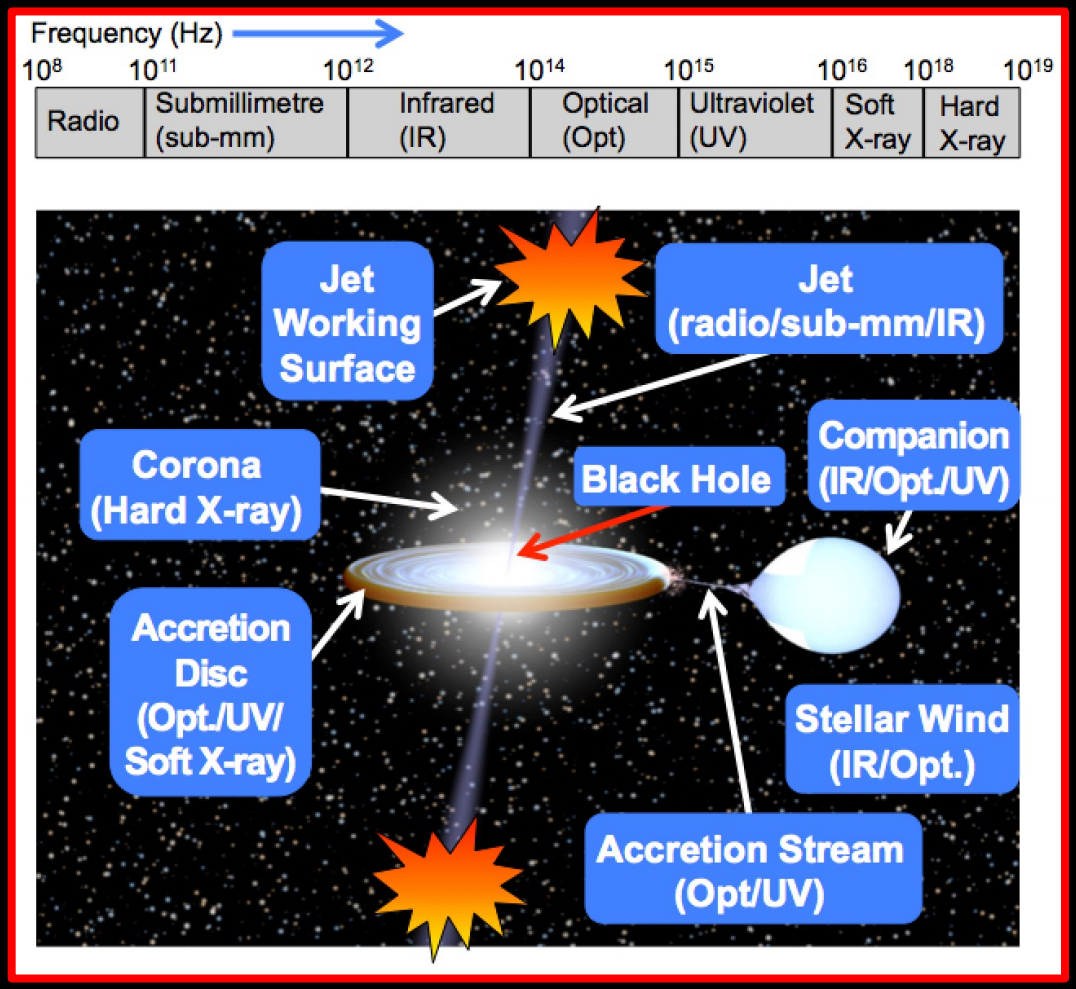


Credit: Ice Cube Collaboration

Jet Unknowns

- How are jets launched and accelerated?
- What are the initial conditions in the launching/ acceleration region?
- What role do black hole mass, spin, and accretion rate play in jet production?
- What factors drive jet evolution during outburst?
- What is the origin and structure of the magnetic fields in jets?
- How does the energy released by jets compare to other feedback processes, such as star formation?

Black Hole X-ray Binaries



- Black hole accreting matter from a companion star
- Rapidly evolve through bright outburst periods on timescales of days to months
- Emit across the electromagnetic spectrum

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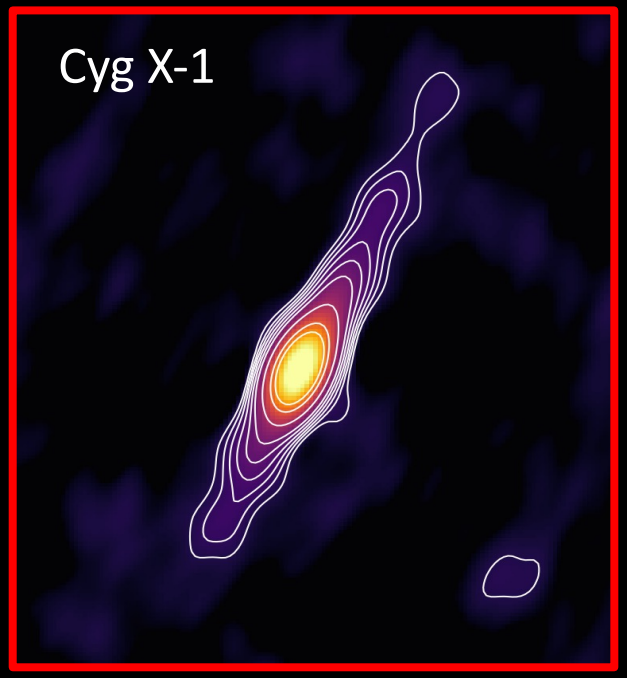
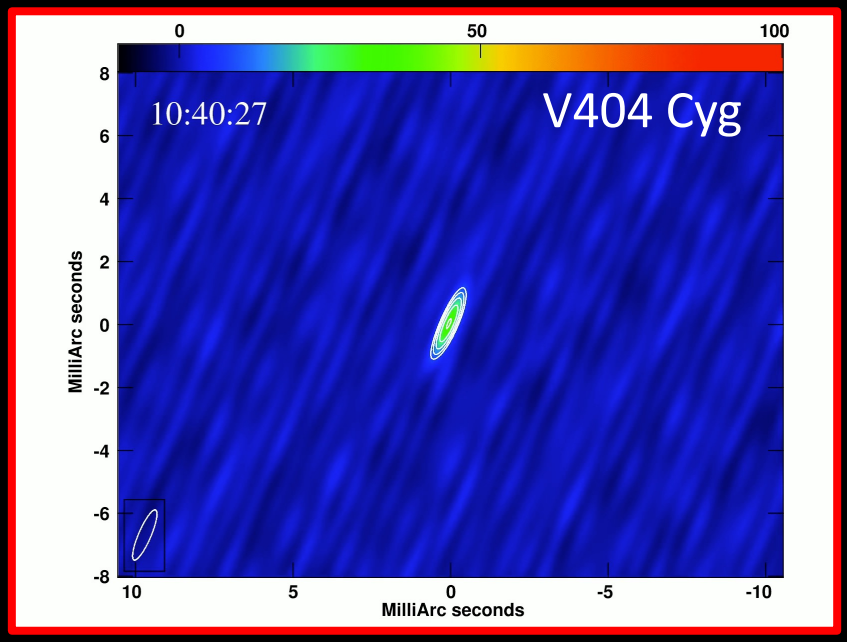
Types of Jets

Compact jets



Jet ejections



Credit: J. Miller-Jones

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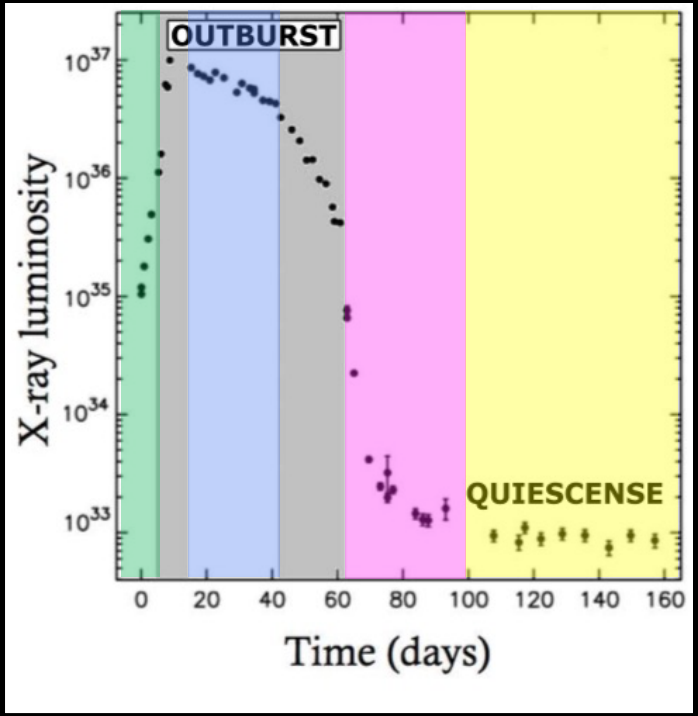
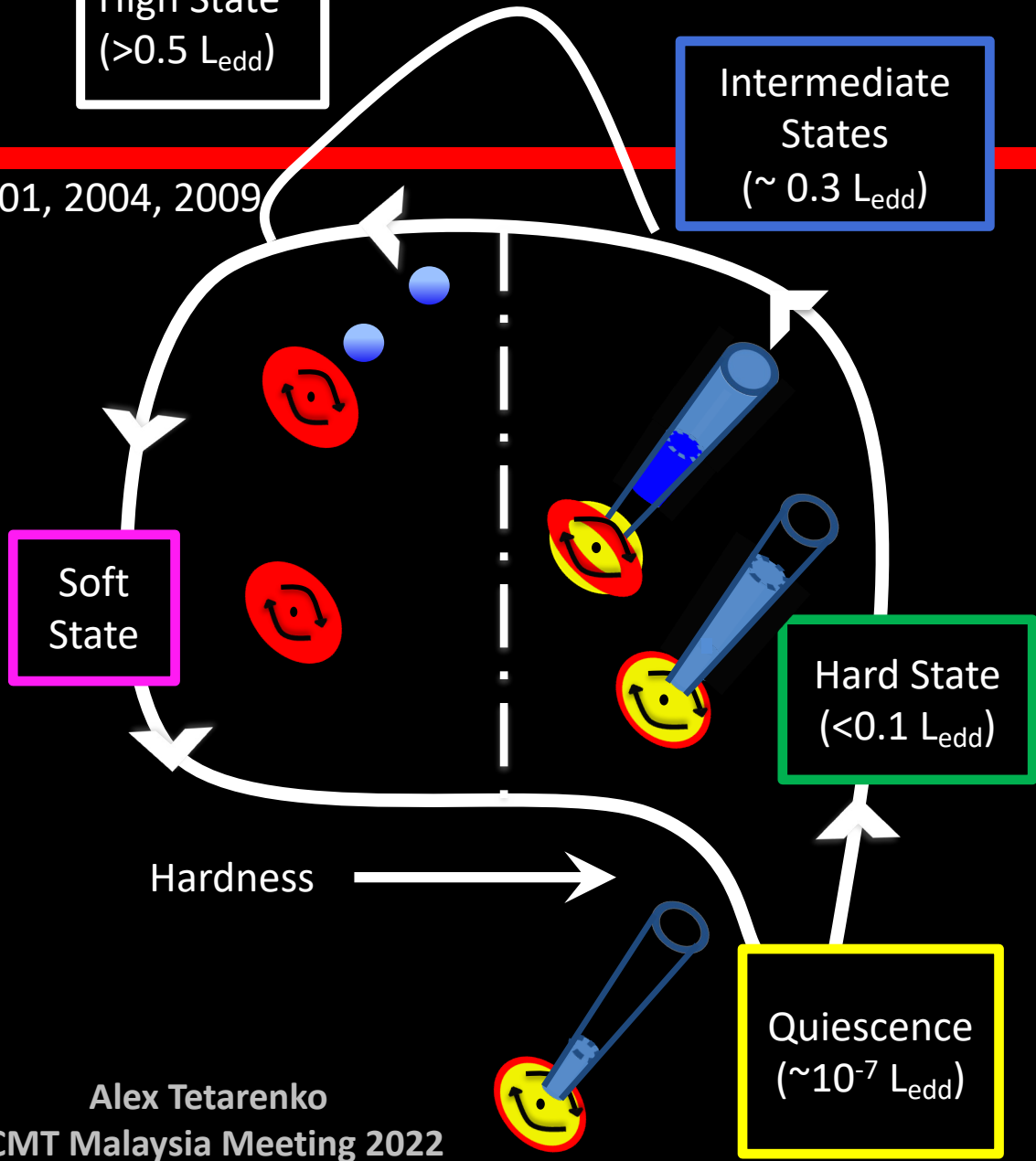
Jet Outburst Evolution

Tananbaum et al. 1972; Fender et al. 2001, 2004, 2009





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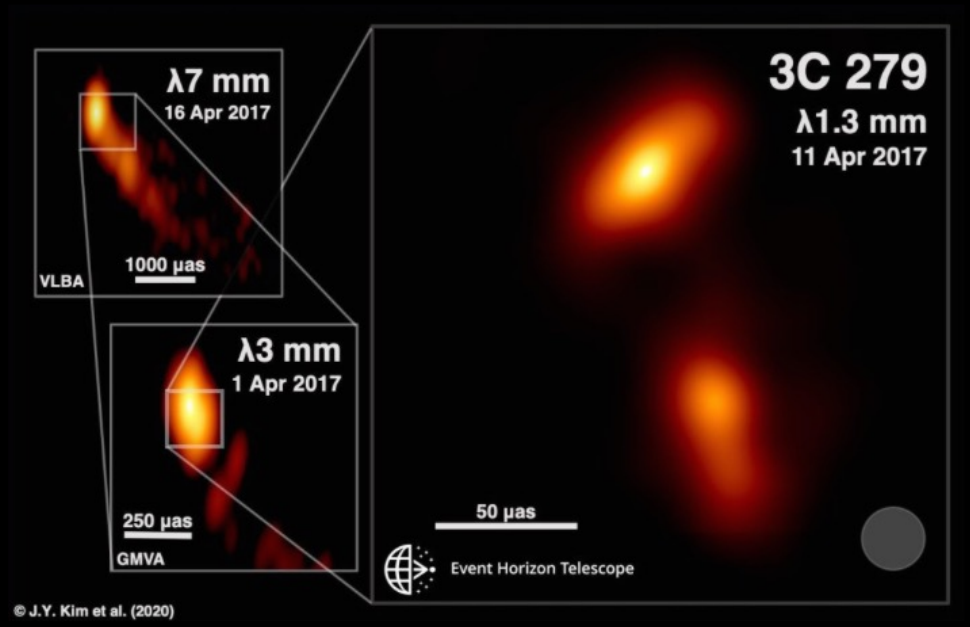
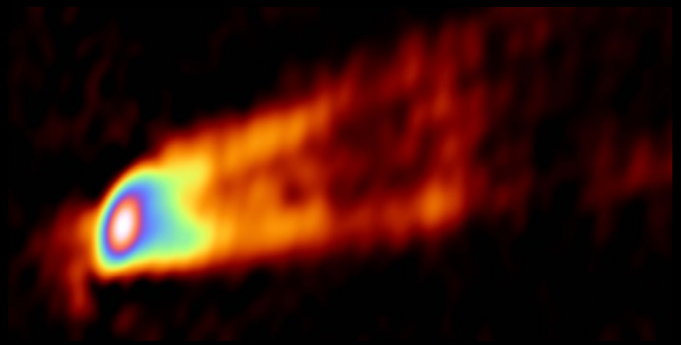
Very Long Baseline Interferometry (VLBI) Studies



J.Y. Kim et al., 2020

Credit: Event Horizon Telescope

M87
Walker et al., 2018



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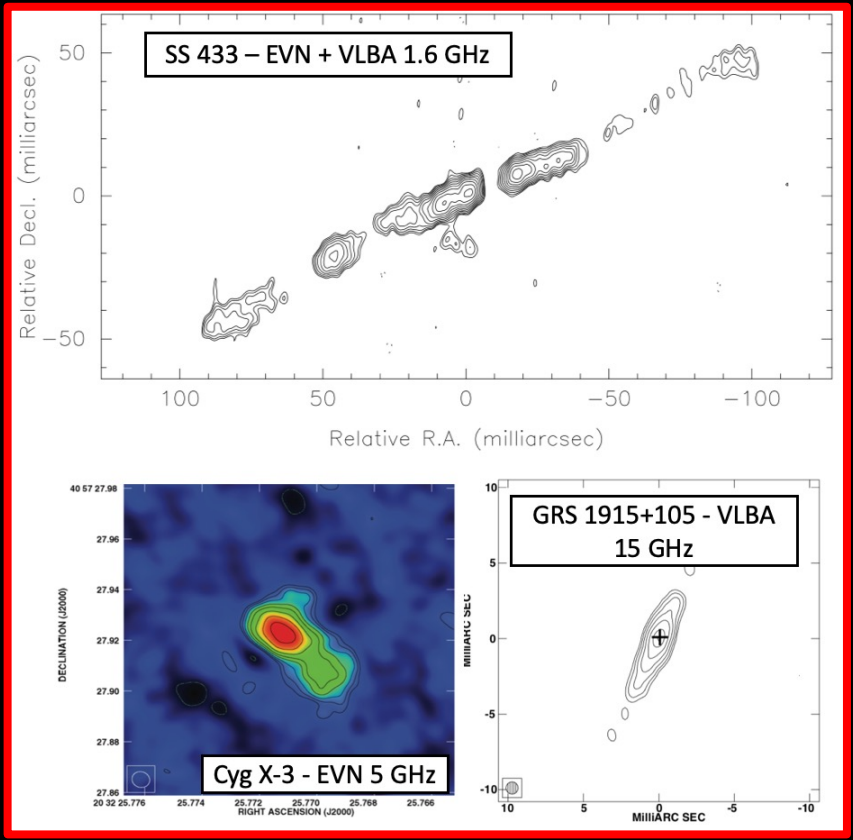
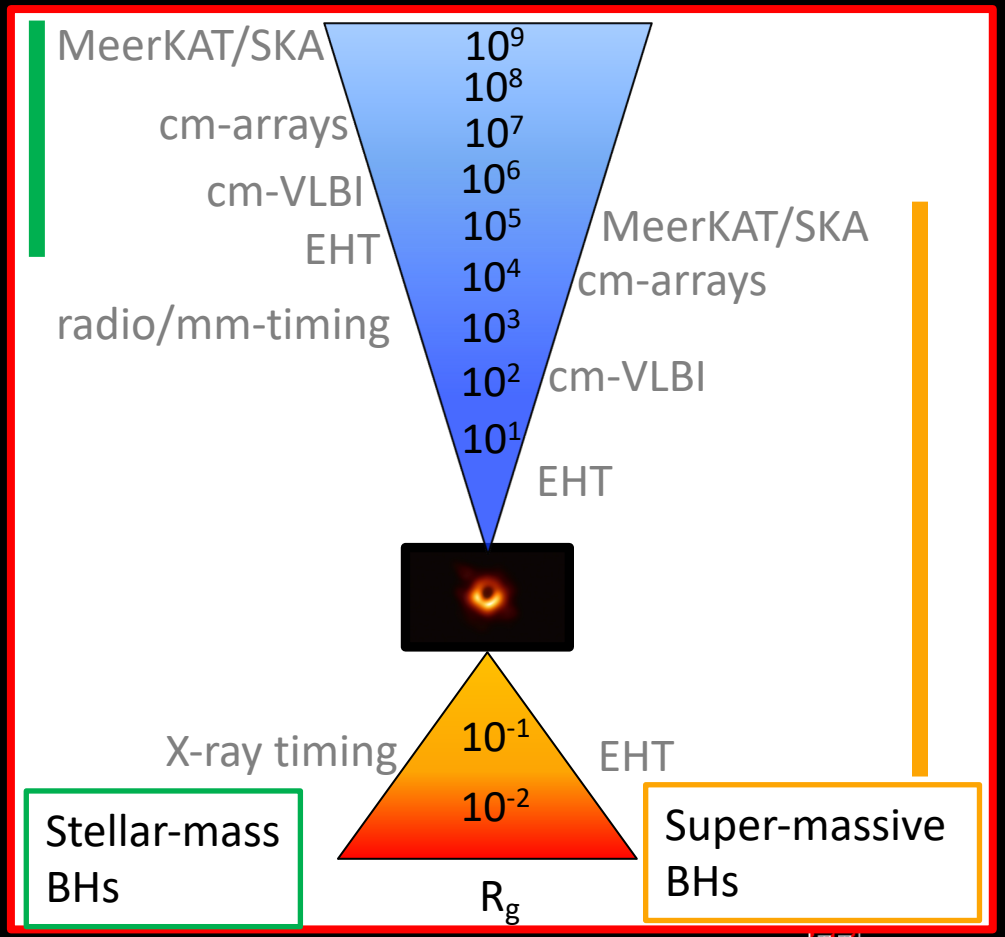
VLBI in X-ray Binaries



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



Credit: R. Fender

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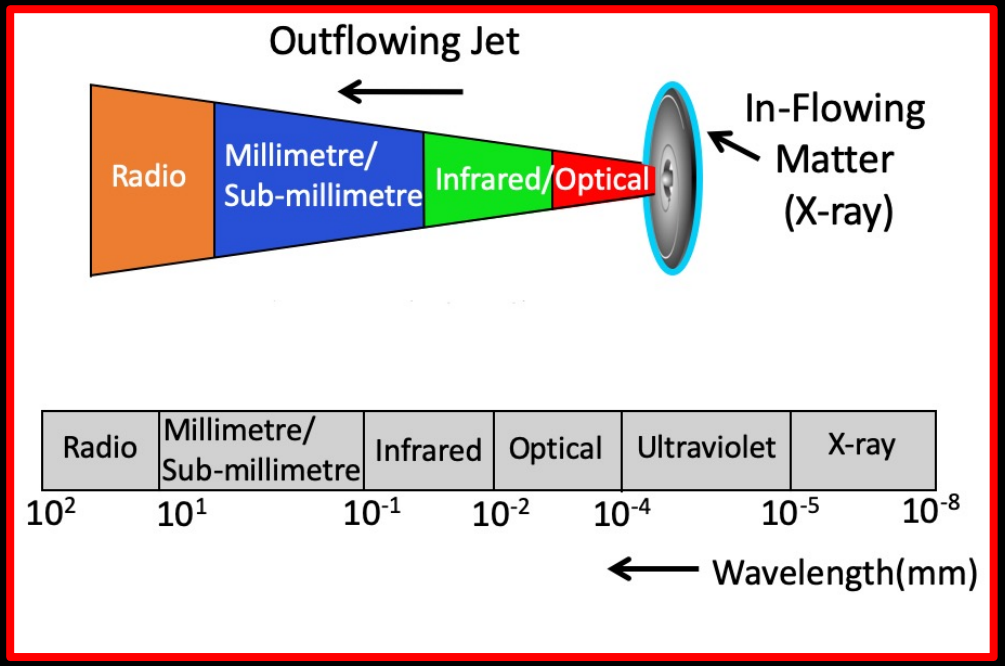
What can we learn from time domain studies of jet emission?

- Map out the jet size scale.
- Probe jet geometry, beyond what we can accomplish with VLBI.
- Measure jet speed, energetics, B-Field.
- Probe the connection between the accretion flow and the jet.



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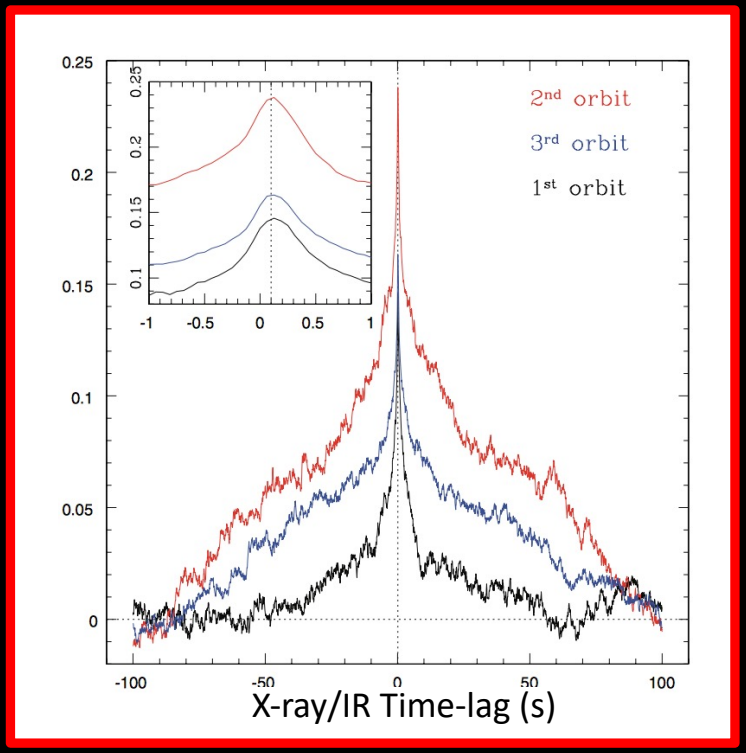
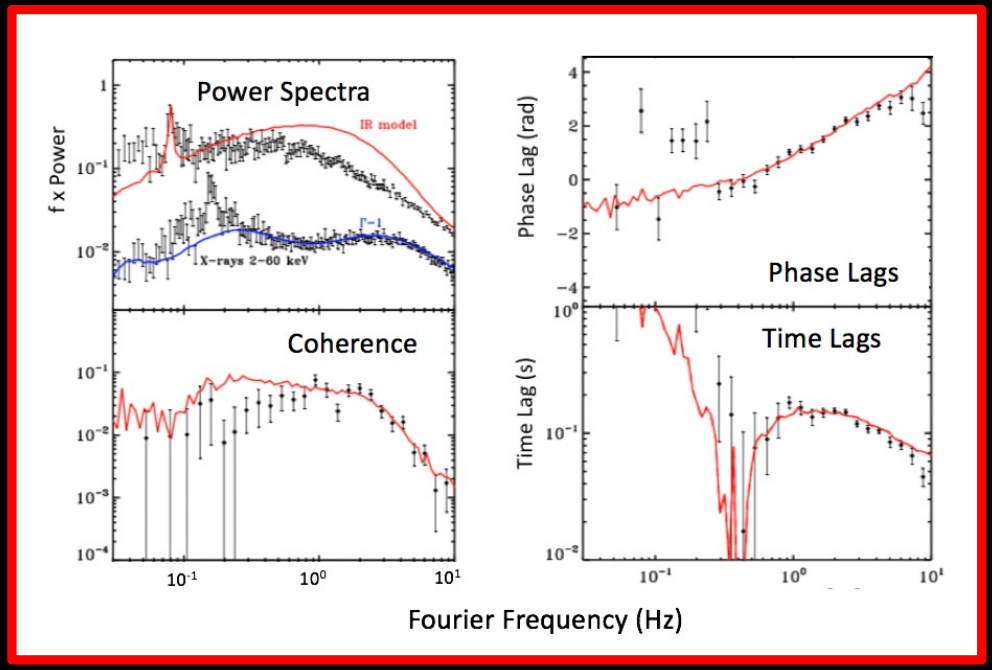
OIR Variability Studies

Cross-correlation Functions



Casella et al. 2010,
Vincentelli et al. 2018

Fourier Domain Metrics



Malzac et al. 2018

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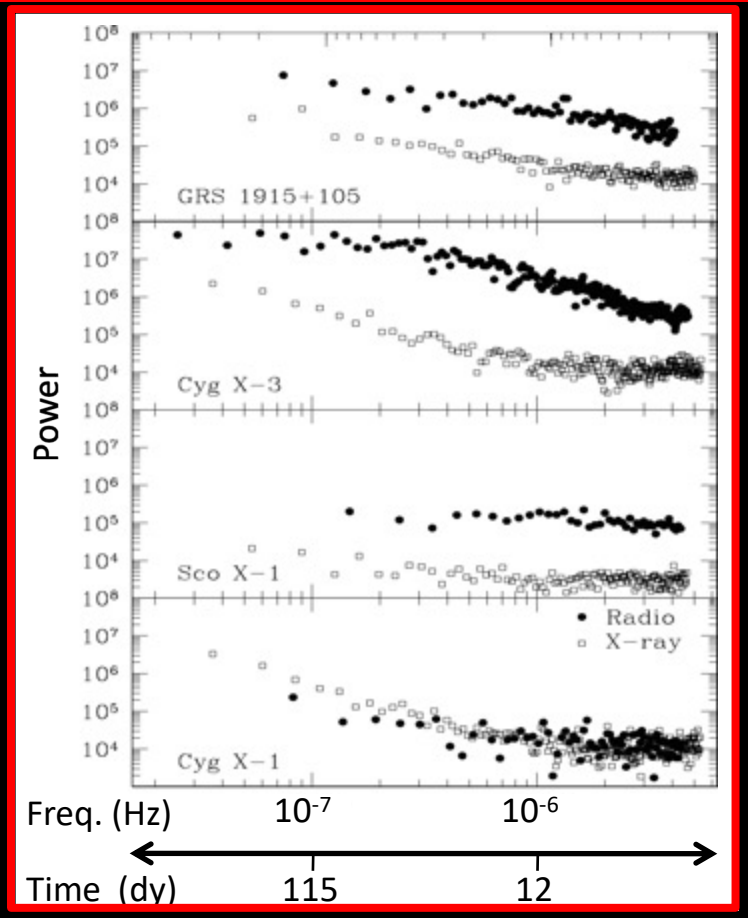
Radio/Sub-mm Variability Studies

- Radio jet emission is highly variable
- Short timescale variability not well studied
- Many challenges with variability studies in the radio/sub-mm



Nipoti et al., 2005

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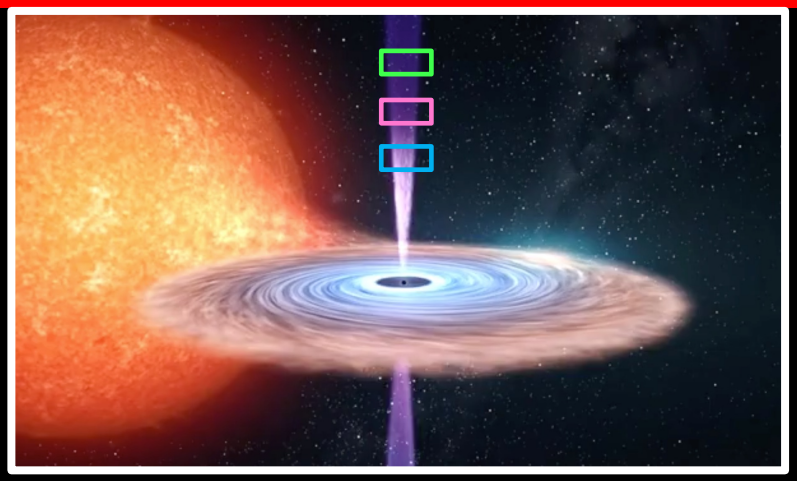
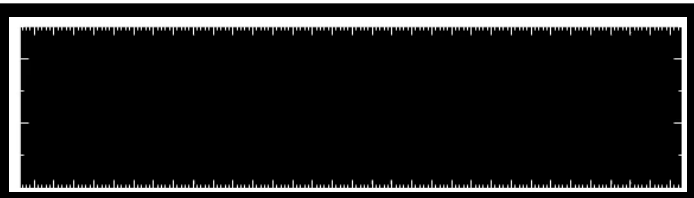
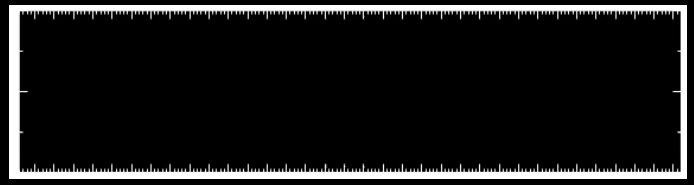
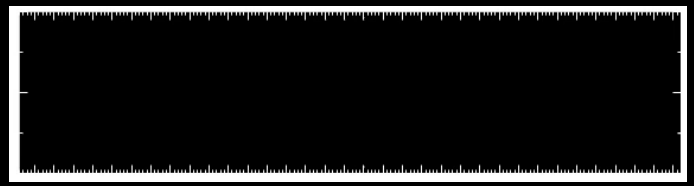
Sub-array with Interferometers

Split full array into up to 3 sub-arrays



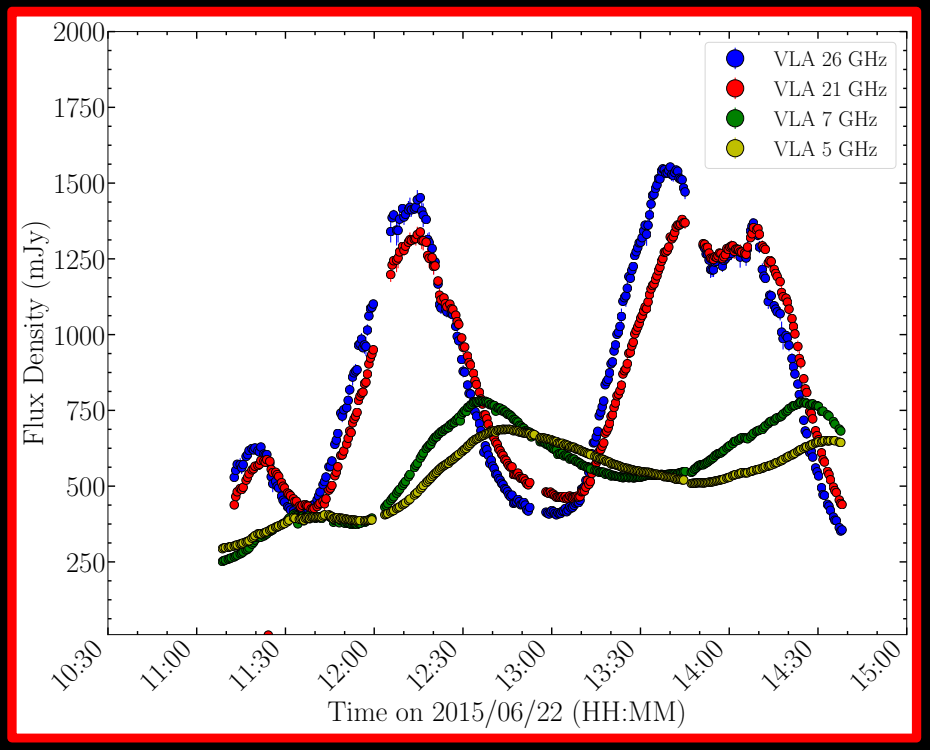




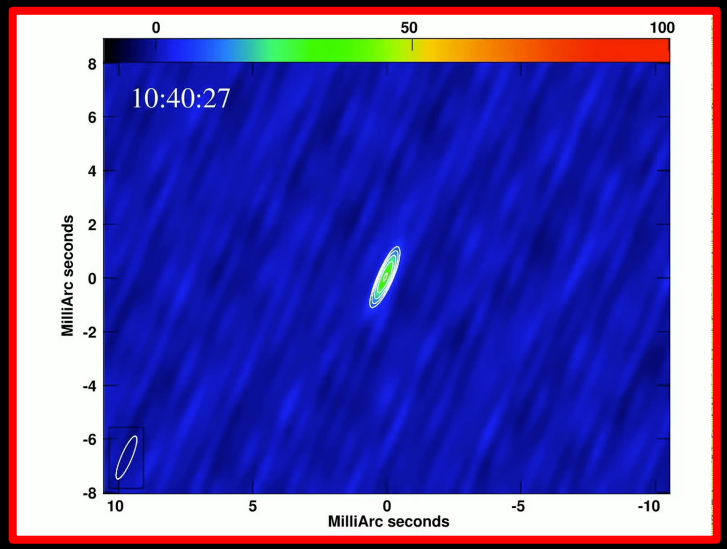


Implementing VLA Sub-arrays

The Pilot Study: V404 Cyg



Tetarenko et al., 2017



Miller-Jones, Tetarenko et al., 2019

- Track rapid flaring from repeated jet ejections!

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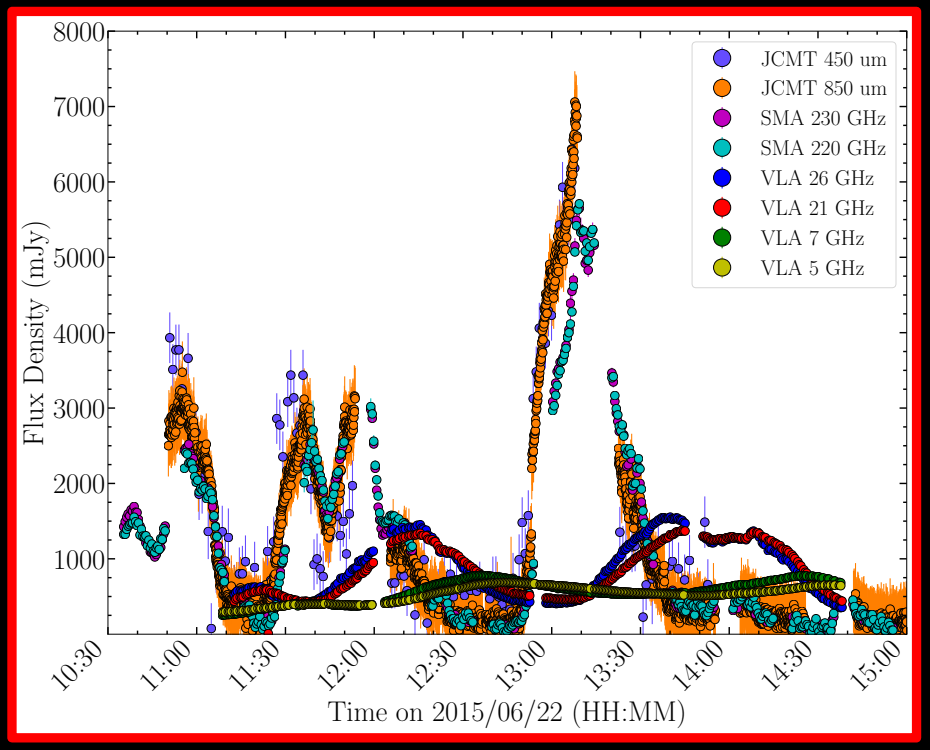
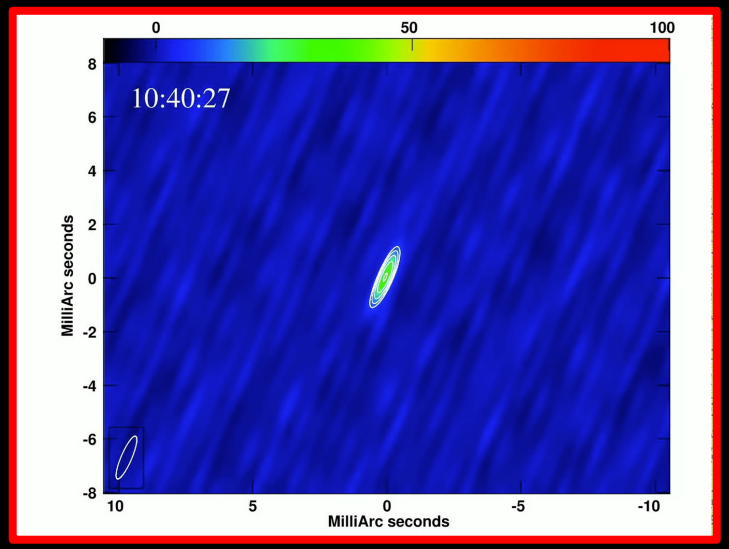
Implementing VLA Sub-arrays

The Pilot Study: V404 Cyg



Tetarenko et al., 2017



Miller-Jones, Tetarenko et al., 2019

- Track rapid flaring from repeated jet ejections!

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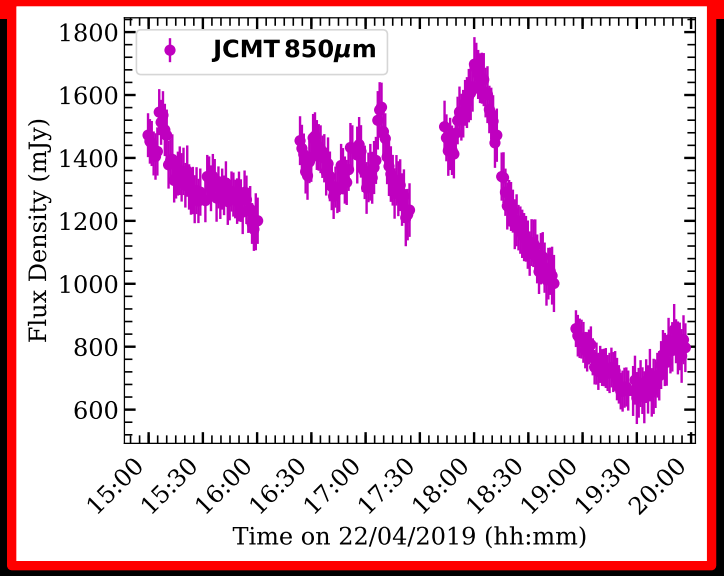
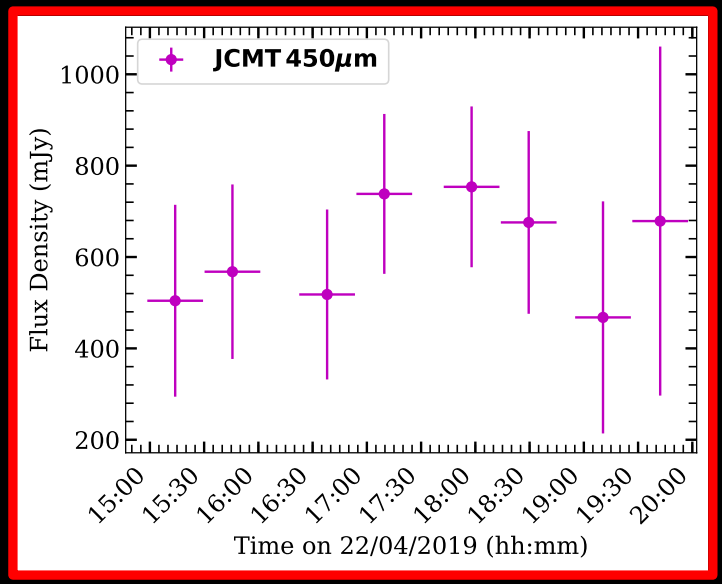
Single Dish mm/sub-mm Timing

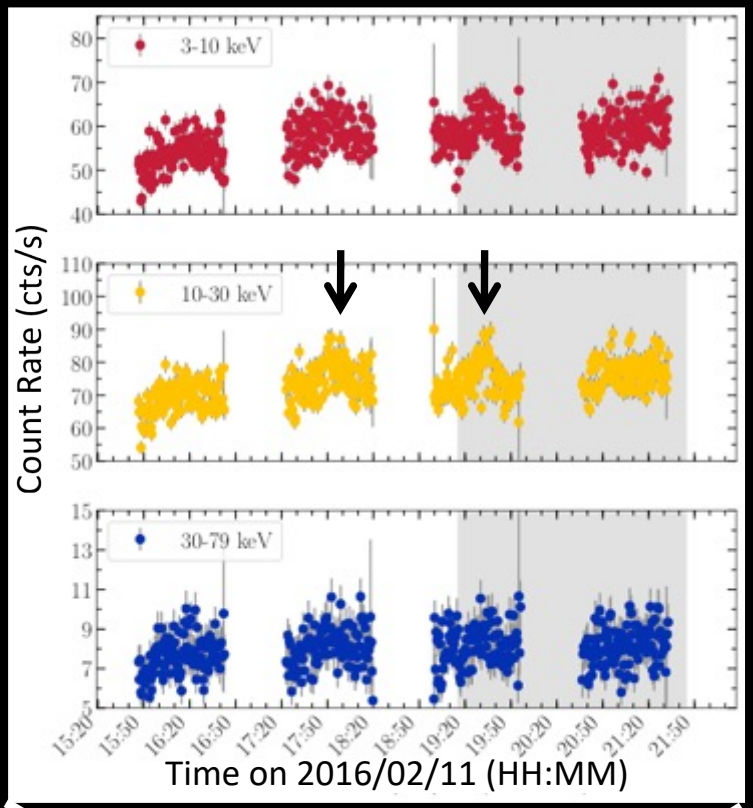
- Pilot study with JCMT completed.
- Challenges more on the software side.
- Our team has a new LMT program recently approved.

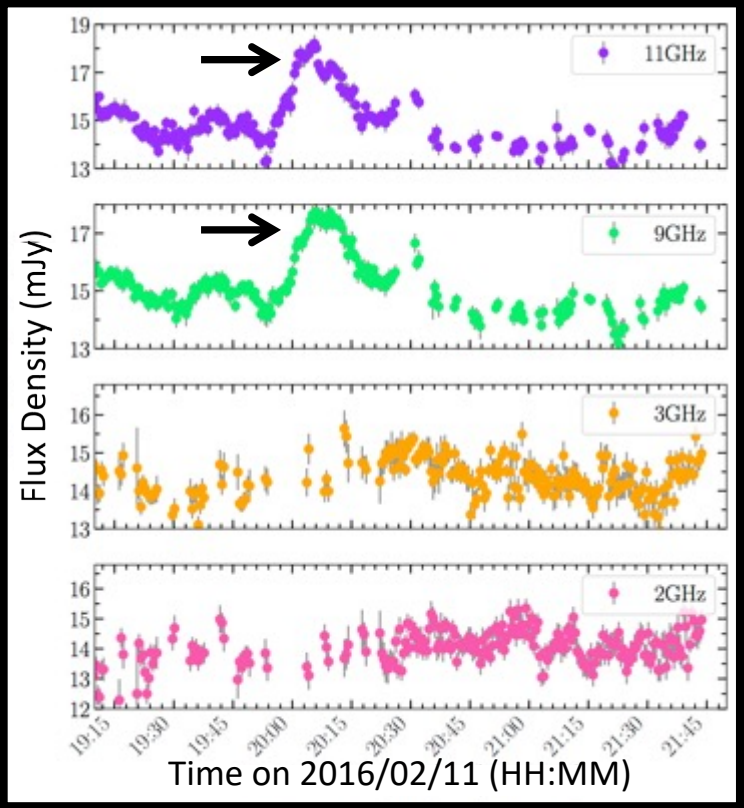




Tetarenko et al. in prep.

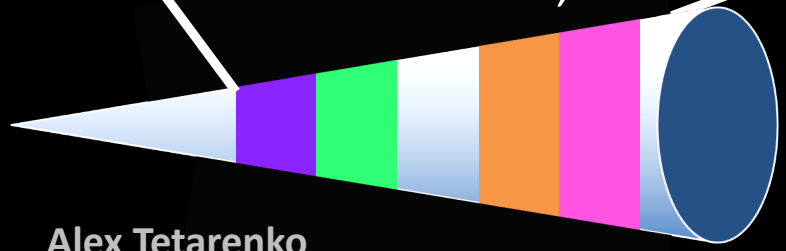
Implementing VLA Sub-arrays





Tetarenko et al., 2019

VLA + X-ray:
Cyg X-1



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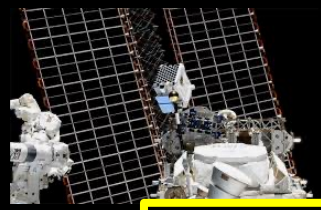
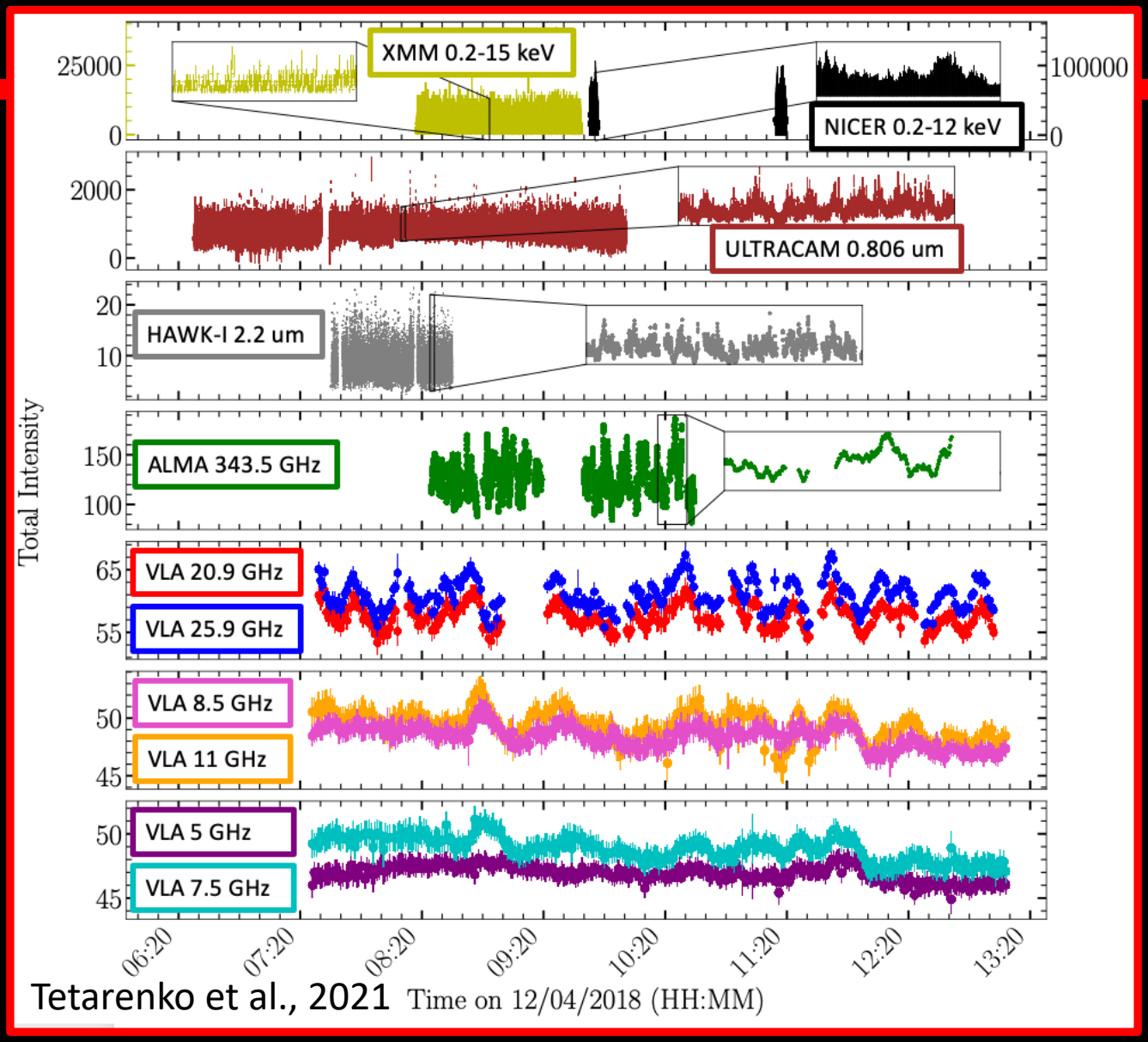
Case Study: MAXI J1820+070



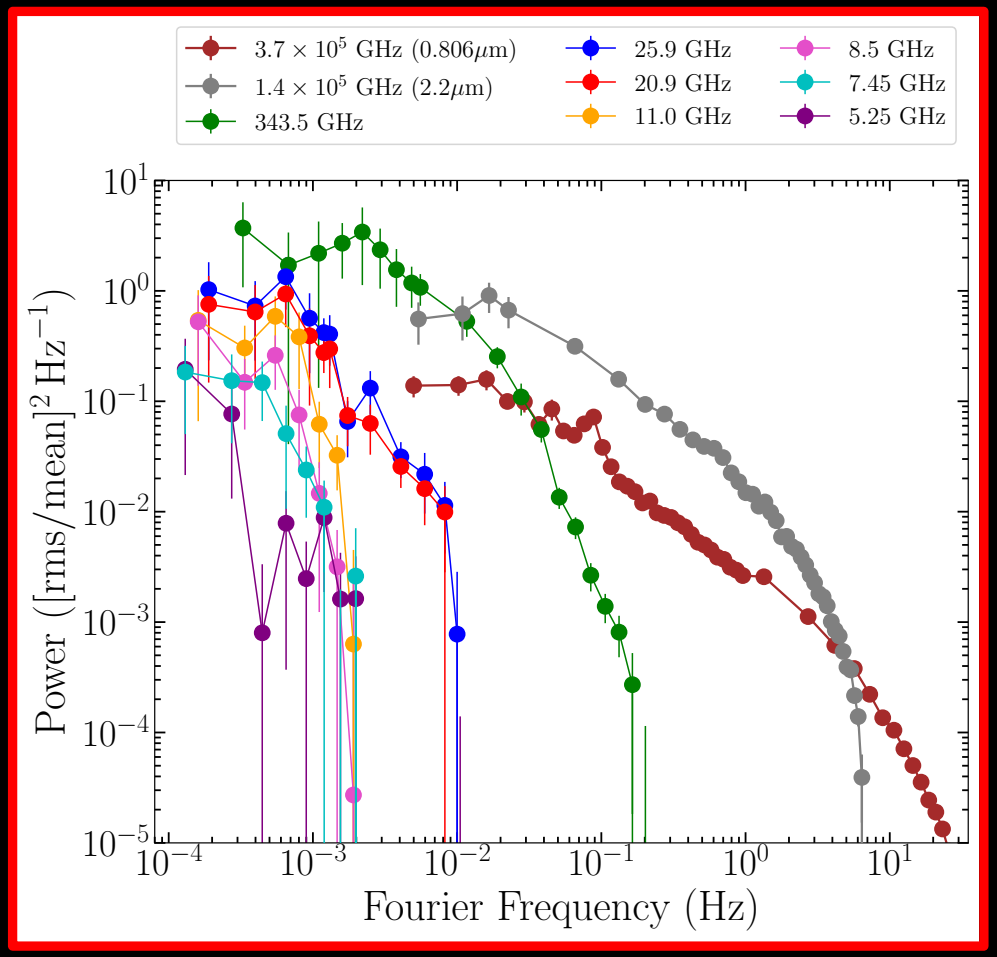


Tetarenko et al., 2021

Measuring Timing Metrics - PSDs

Larger Amplitude Variations

Smaller Amplitude Variations



Tetarenko et al., 2021

Longer Timescales

Shorter Timescales

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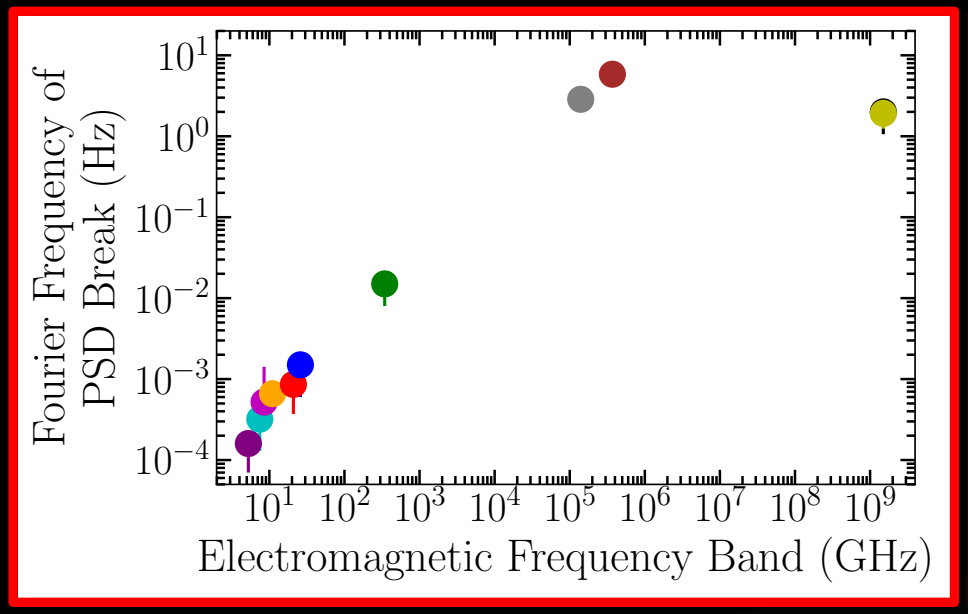
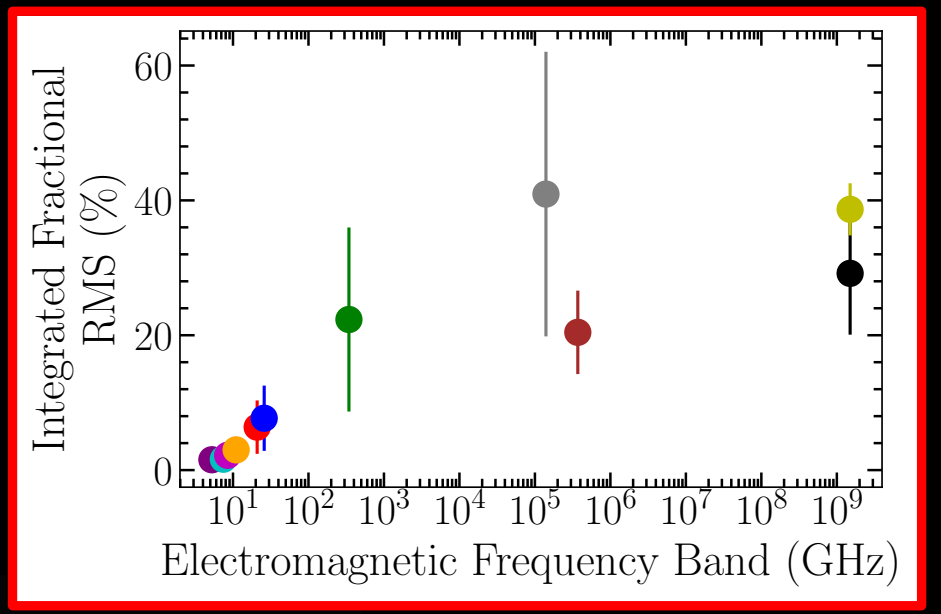
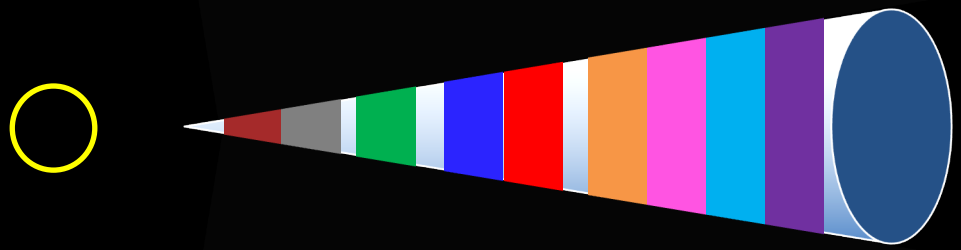
Trends with Electromagnetic Frequency Band!





Tetarenko et al., 2021



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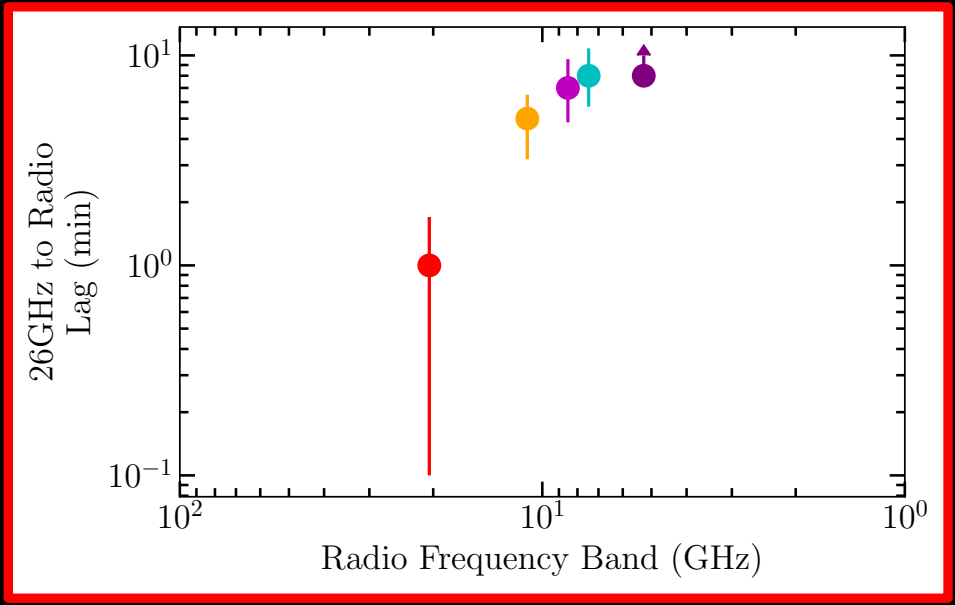
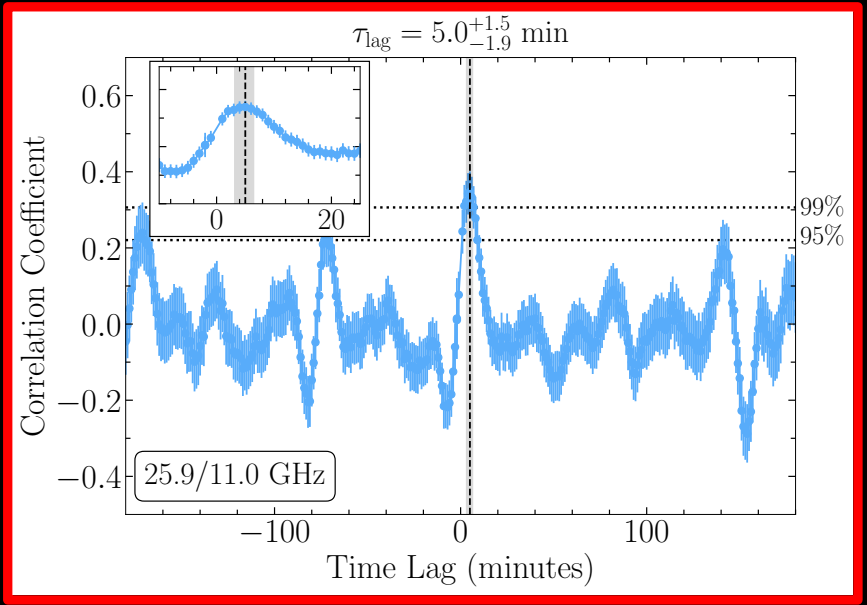
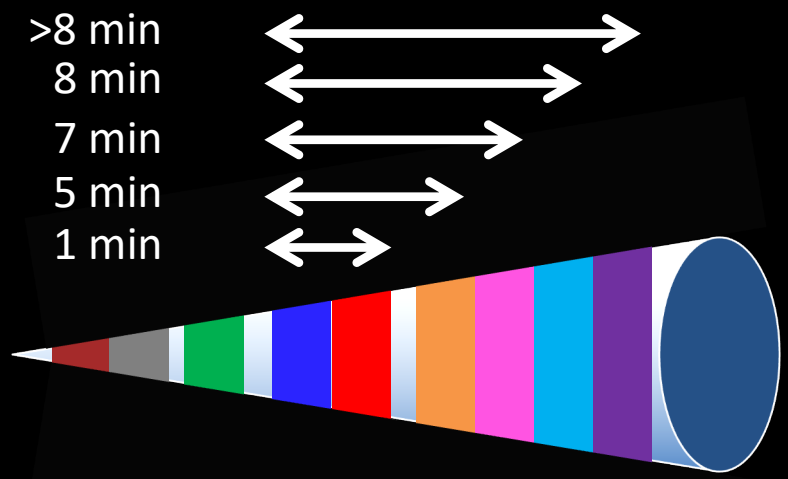
Measuring Timing Metrics - Time-lags





Tetarenko et al., 2021

**Also check out Tetarenko et al., 2019 radio timing work on Cyg X-1!



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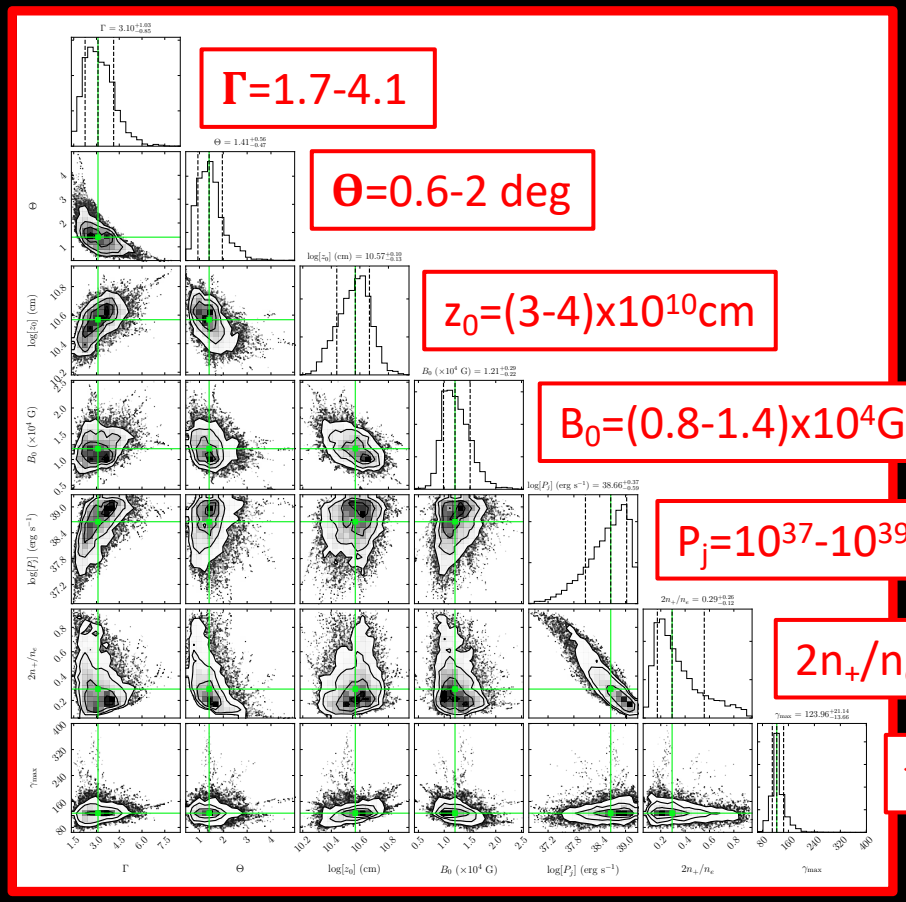
Modelling Timing Metrics



- Implement classic Blandford & Königl jet model.
- To constrain speed:
  - Lower limit: pair production in jet base
  - Upper limit: accretion power

Zdziarski, Tetarenko et al., 2022
Tetarenko et al., 2021

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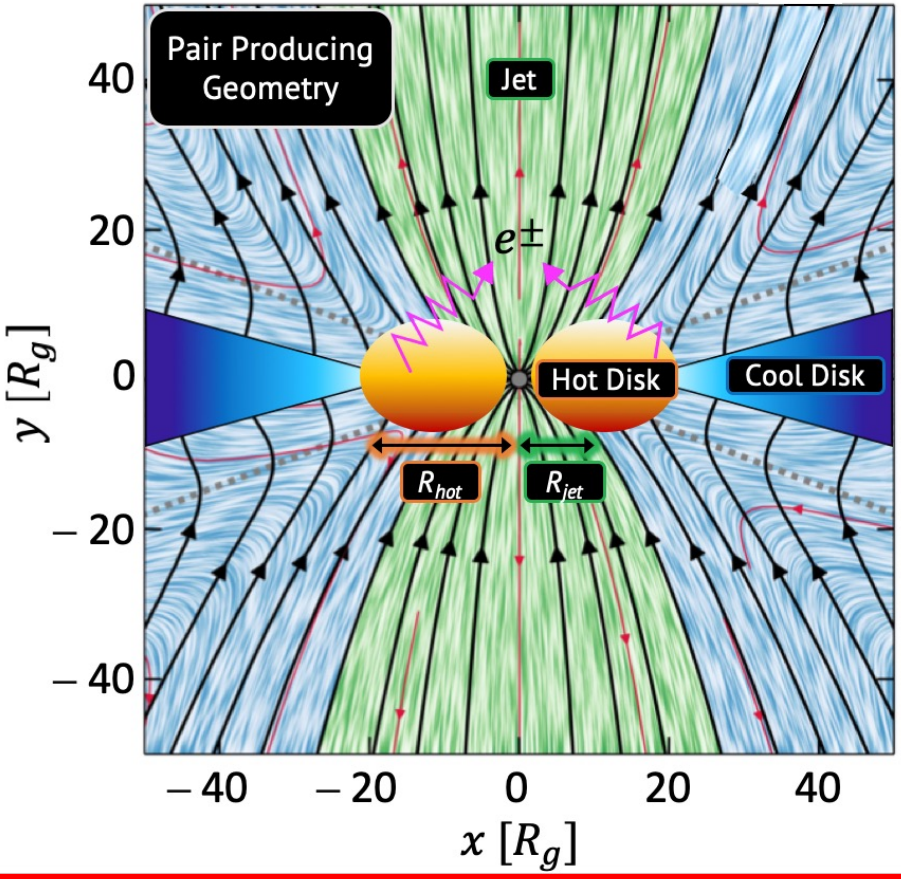
Modelling Timing Metrics



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Zdziarski, Tetarenko et al., 2022
Tetarenko et al., 2021

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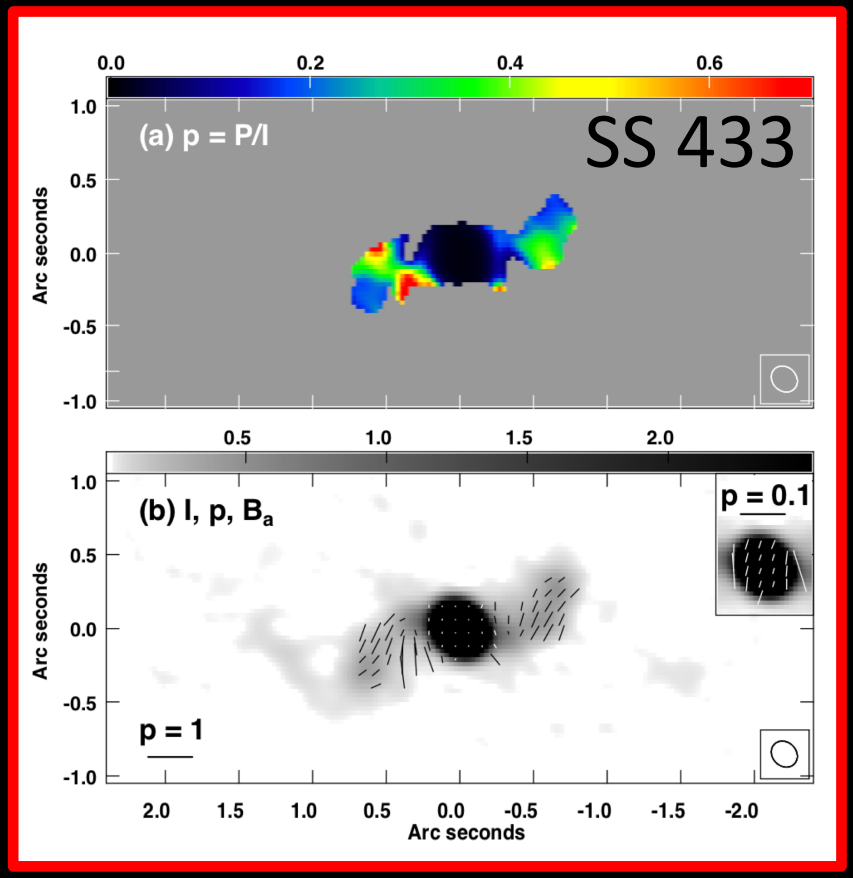
Polarimetry in X-ray Binaries

- 2 key quantities of polarized light: LP and PA
- Study B field strength, orientation, geometry, time-variable phenomena…
- Polarimetry mostly limited to radio/optical studies (e.g. see Hannikainen et al. 2000; Corbel et al. 2000; Fender et al. 2002; Brocksopp et al. 2007; Curran et al. 2014; Russell et al 2015; Russell et al. 2018).



Blundell et al., 2018

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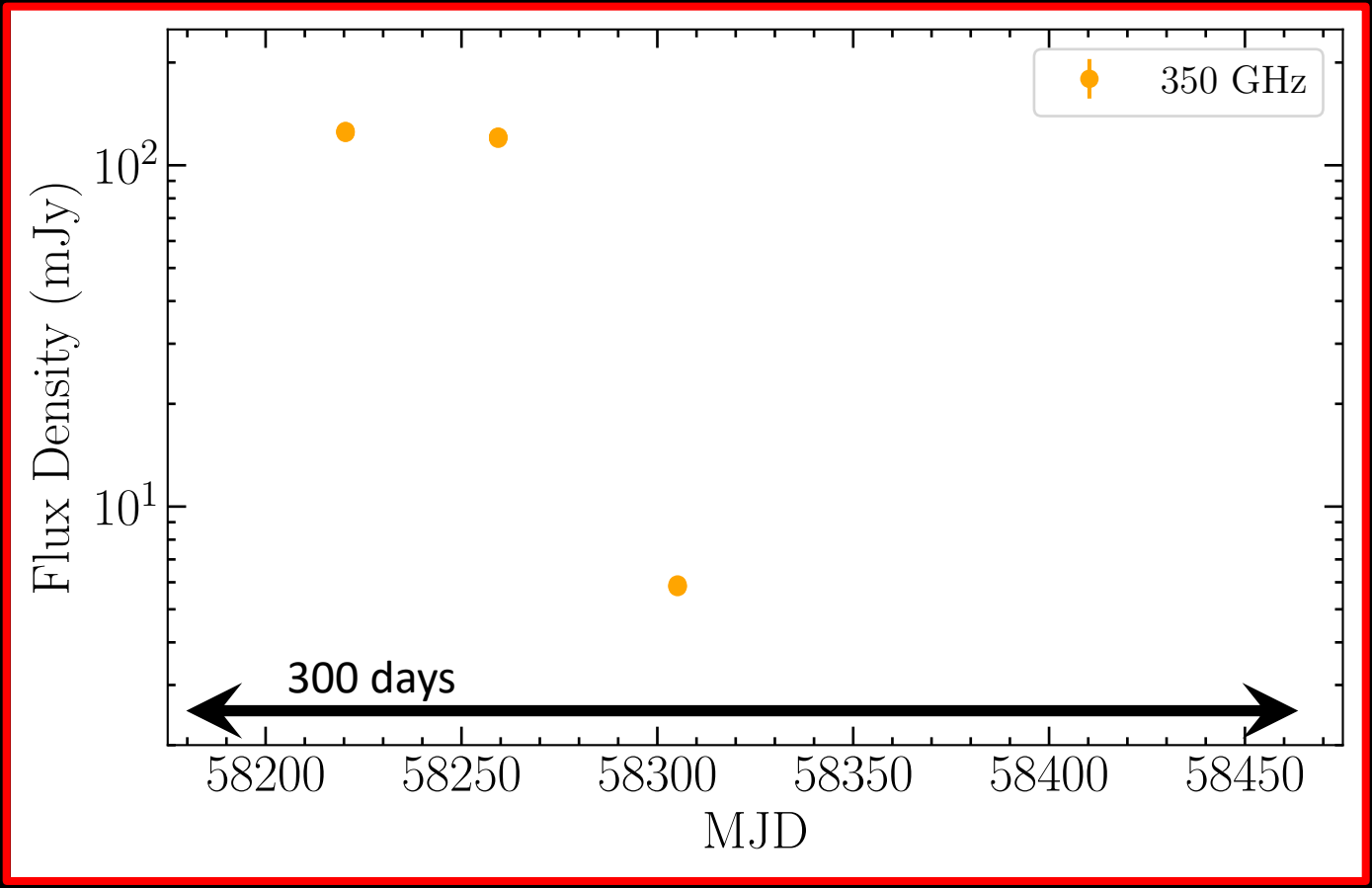
Looking ahead…

Sub-mm Coverage of MAXI J1820+070



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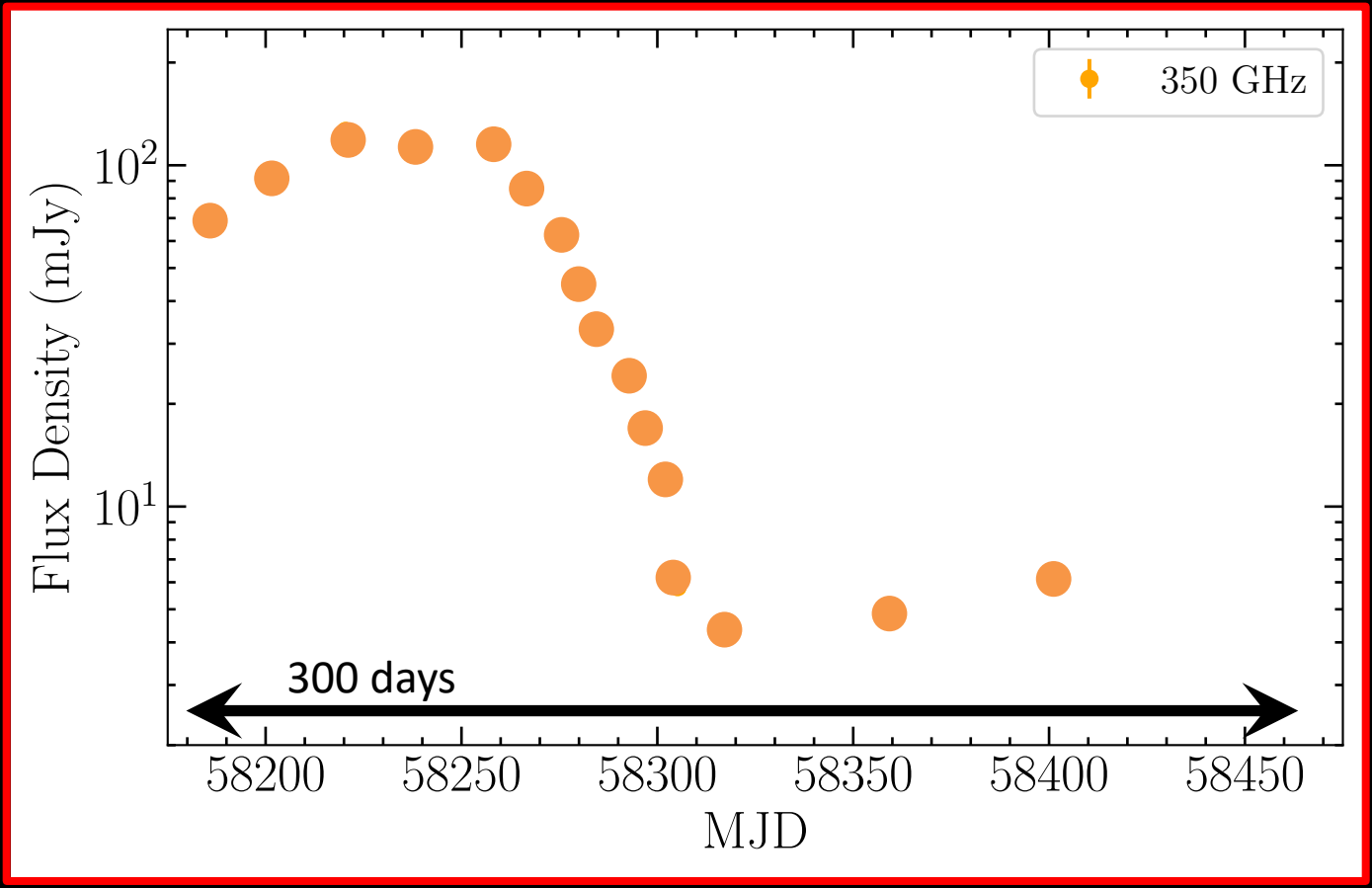
Looking ahead…

Sub-mm Coverage of MAXI J1820+070



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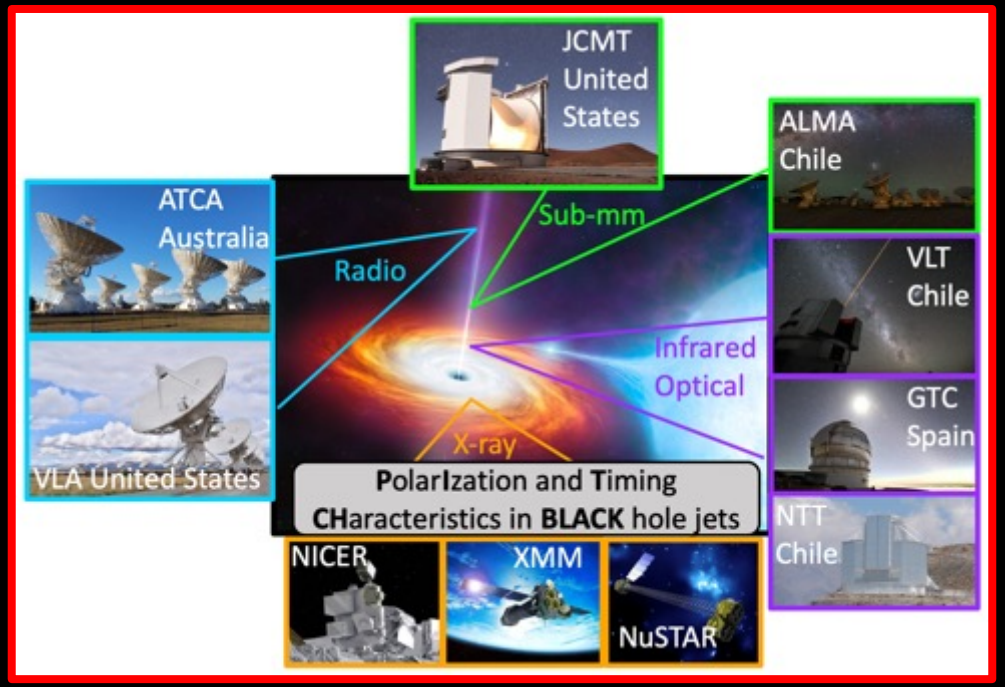
PITCH-BLACK

- Anchored by a JCMT Large Program.
- Aim to combine the diagnostic power of sub-mm timing and polarimetry, with multi-wavelength coverage, to create a detailed probe of BHXB jets.
- Will observe across outburst accretion states, and different BHXB sources.

https://tetarenk.github.io/PITCH-BLACK



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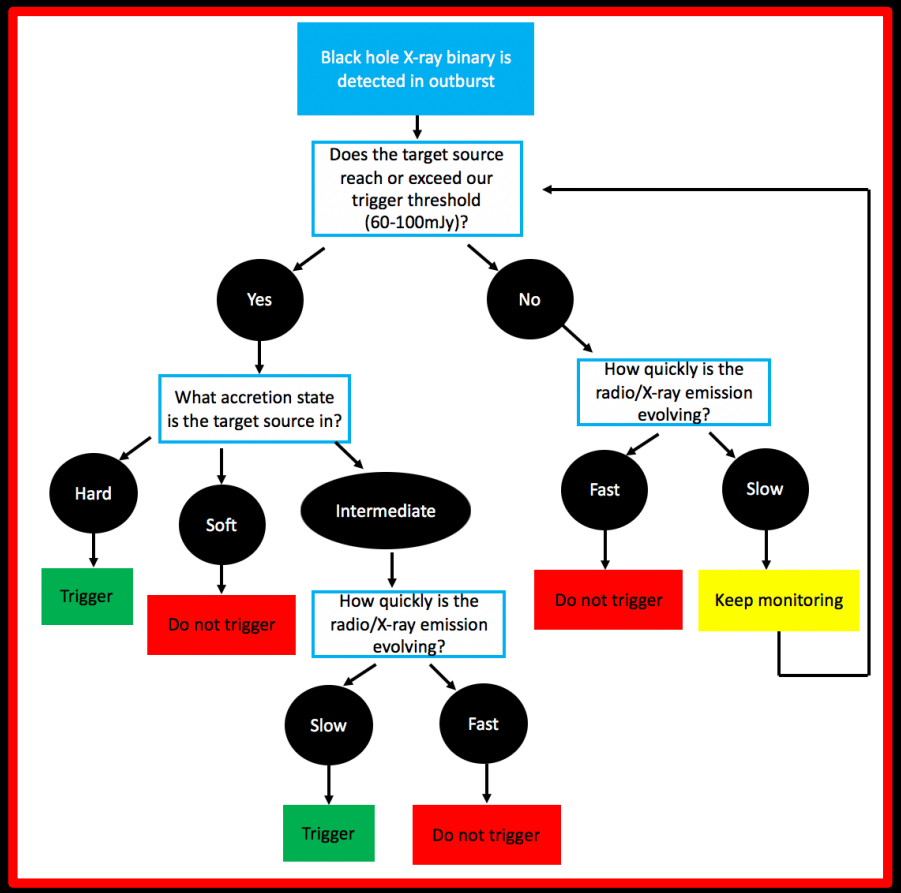
Target Selection and Triggering

- Observe 6 BHXBs throughout outburst
  - 4 short campaigns (8x 4 hrs epochs)
  - 2 long campaigns (16x 4 hrs epochs)
- Identify outburst via X-ray all-sky monitors or optical monitoring.
- Triggering evaluated through the decision tree.
- Cadence largely set by source.



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Membership Overview

- Currently 43 members from seven EAO regions (China, Japan, Taiwan, Indonesia, Canada, UK, and Korea)
- Support from non-member institutes across three continents
- Coordinators chosen for each region. Any volunteers for Malaysia?
- Executive committee for decision making set up.

Management and Staffing

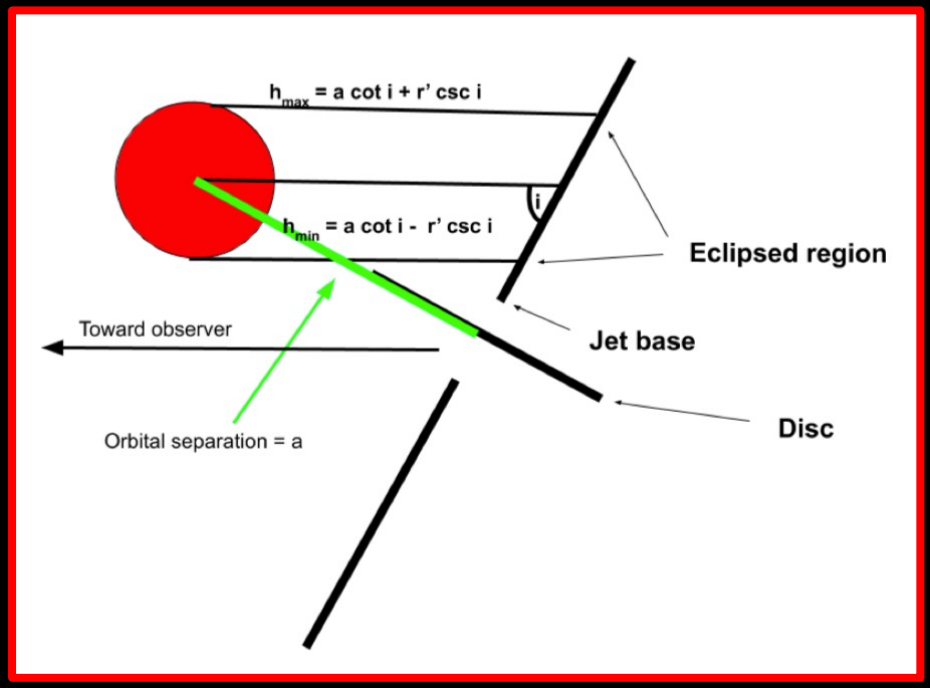
- Infrastructure to facilitate communication:
  - Wiki page
  - Slack group
  - Group email list
  - Project website
  - Project Github
  - Google docs suite: Members list, MW support, working groups, known BHXB candidates…

Work so far…

- No triggers yet but…
  - We have produced a code-base for a data analysis pipeline.
  - In process of setting up a data base to house data and products: CANFARs VOSpace + links on Wiki.
- All EAO region team members have access to raw/reduced data and advanced data products.

New Facilities and Techniques

- Current facilities to add to our suite of fast timing observatories: LMT, Gemini, JWST
- Many next gen facilities to look forward to: ngVLA, ALMA-2030, SKA, ngEHT…
- Jet eclipse mapping
- Higher order Fourier methods (e.g., bispectrum; Arur et al. 2019)



Maccarone et al. 2020

Summary

- Time domain and polarimetry analysis is an incredibly powerful tool for unlocking complicated jet physics.
- We can do timing at long mm/sub-mm wavelengths too!
- We can derive fundamental jet parameters from light curves alone!
- PITCH-BLACK represents a major step forward for studying black hole jet and accretion physics!

Thank you!

Want to get involved?

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