GALACTIC TRANSIENTS: X-RAY BINARIES

ACCRETION & FEEDBACK AROUND STELLAR-MASS COMPACT OBJECTS

INAF
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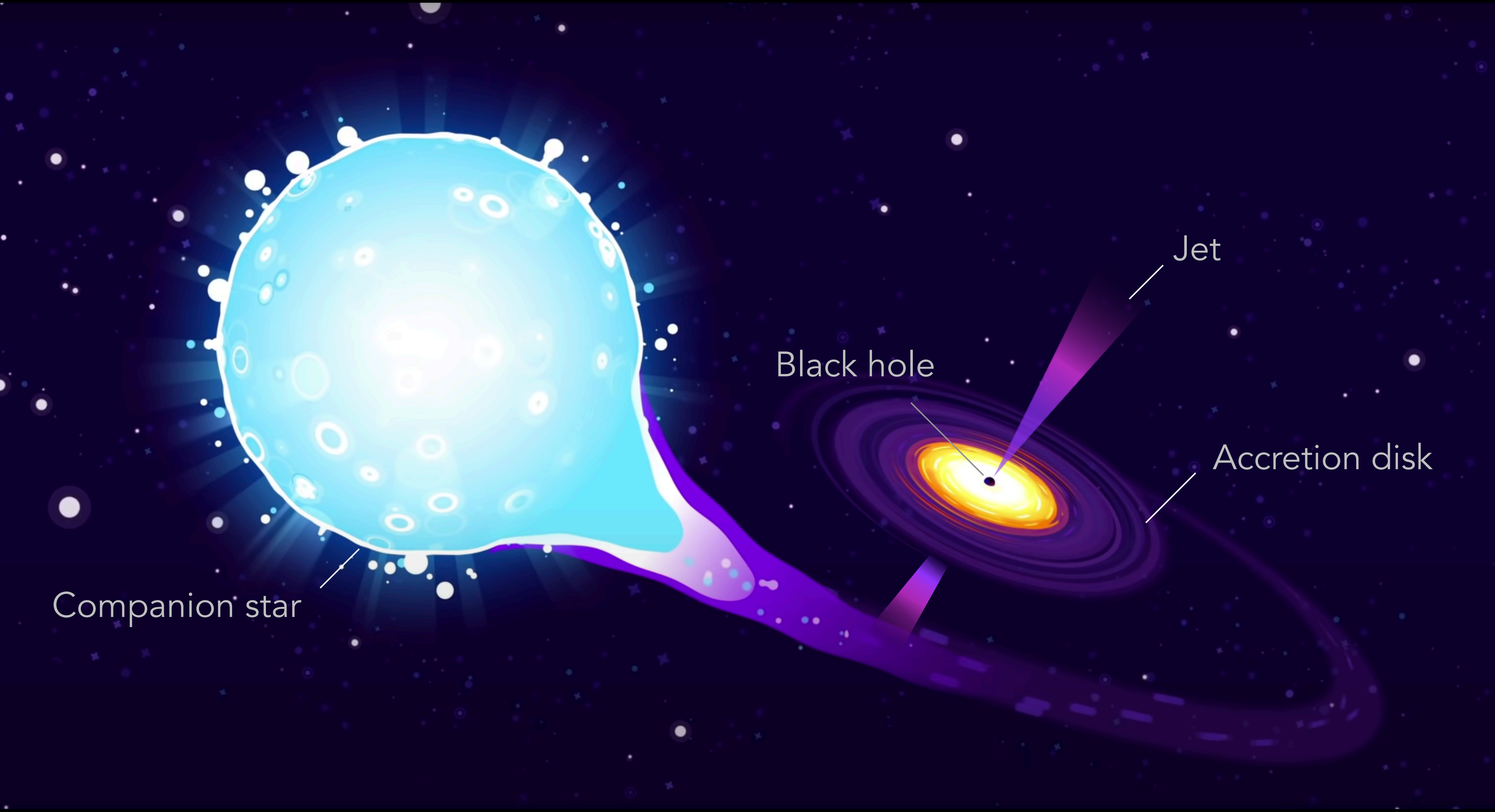
University of Oxford

The Fourth National Workshop on the SKA Project
Sharpening the Italian science case for the SKAO

22 - 26 May 2023

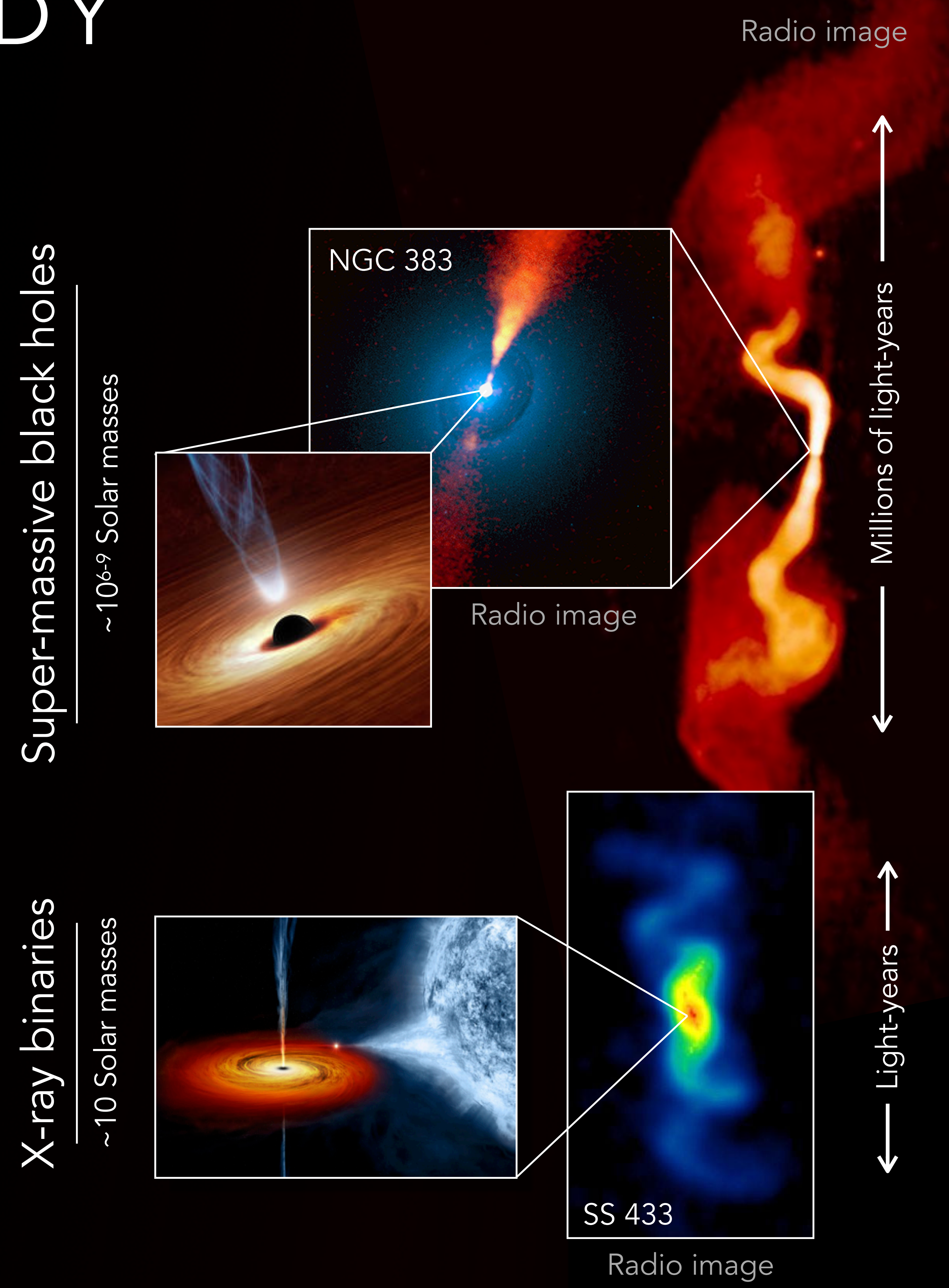
(LOW MASS) X-RAY BINARIES ACCRETION AND FEEDBACK



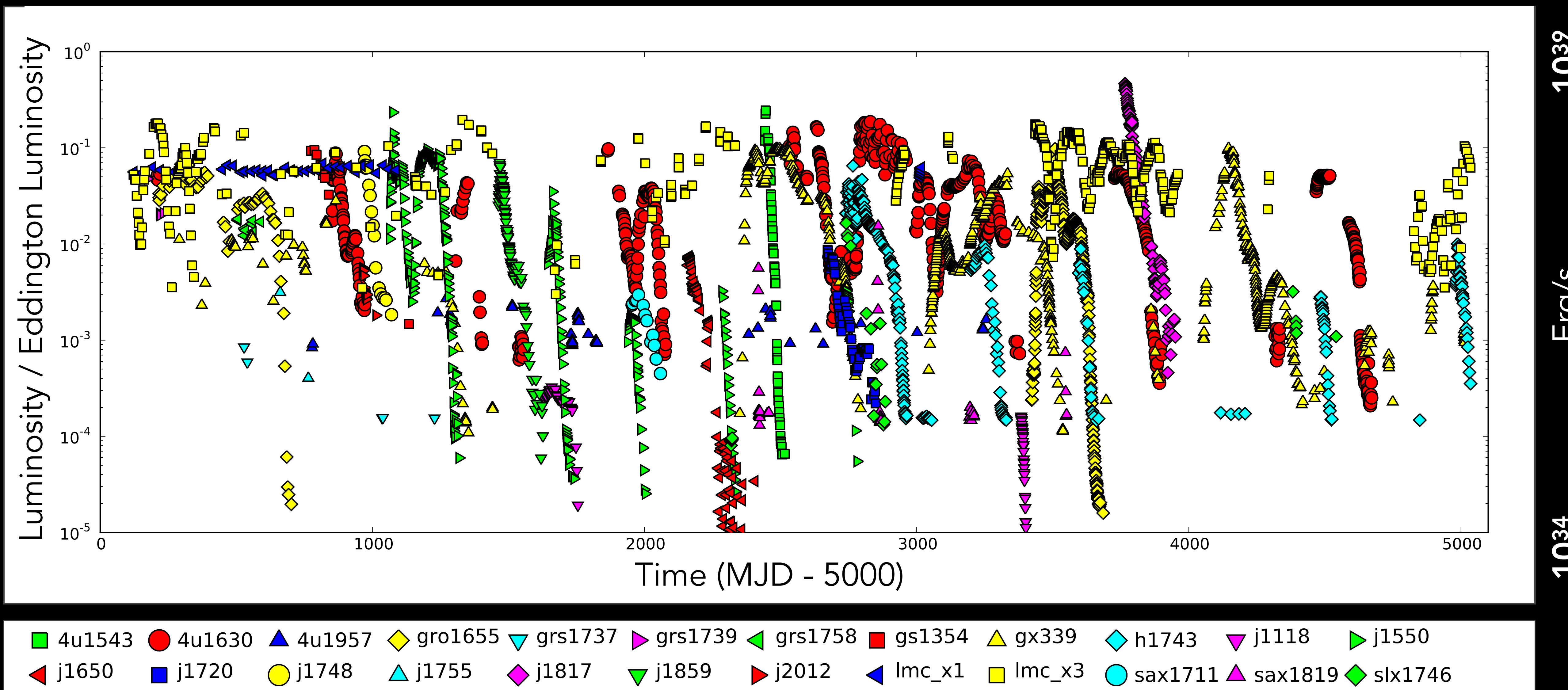
WHY DO WE STUDY X-RAY BINARIES

- Nearby laboratories of extreme physics - ultra-dense matter, strong gravity, super-energetic particle acceleration

- Basic principles of accretion and feedback scale with mass (same principles in X-ray binaries, AGN, kilo-novae, TDEs…)
  Binaries are nearby, always there, and vary fast!



LOW-MASS X-RAY BINARIES: TRANSIENT AND VARIABLE



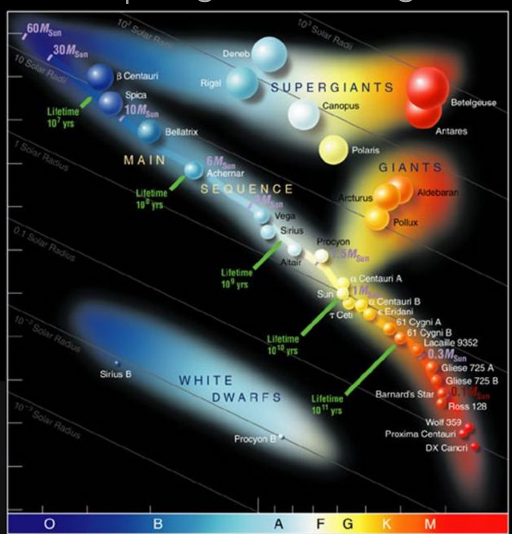
14 years

X-ray light curves from black hole transients

Dunn et al. 2010

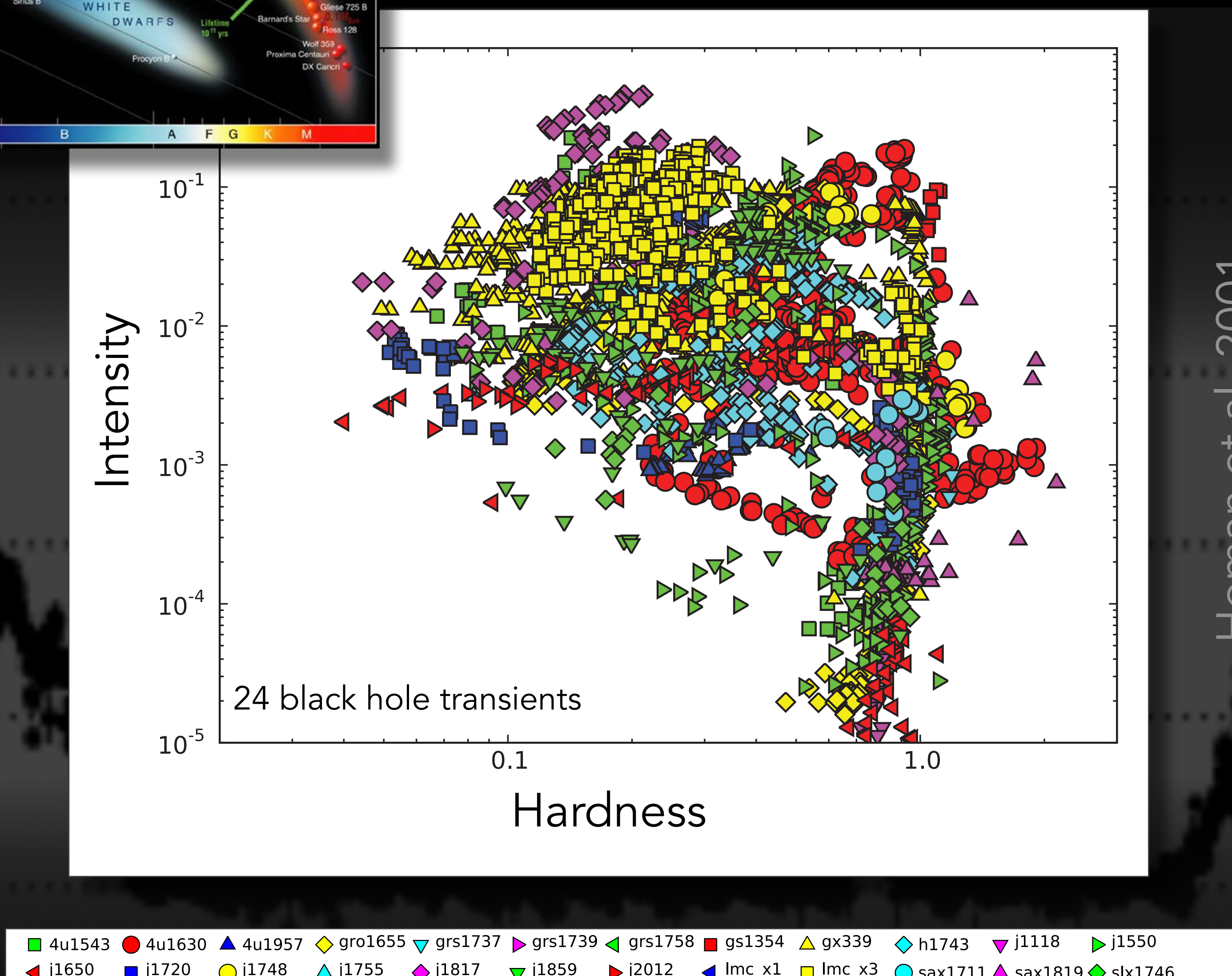
LOW-MASS X-RAY BINARIES: TRANSIENT AND VARIABLE

Hertzsprung–Russell diagram



Hardness Intensity diagram

Dunn et al. 2010

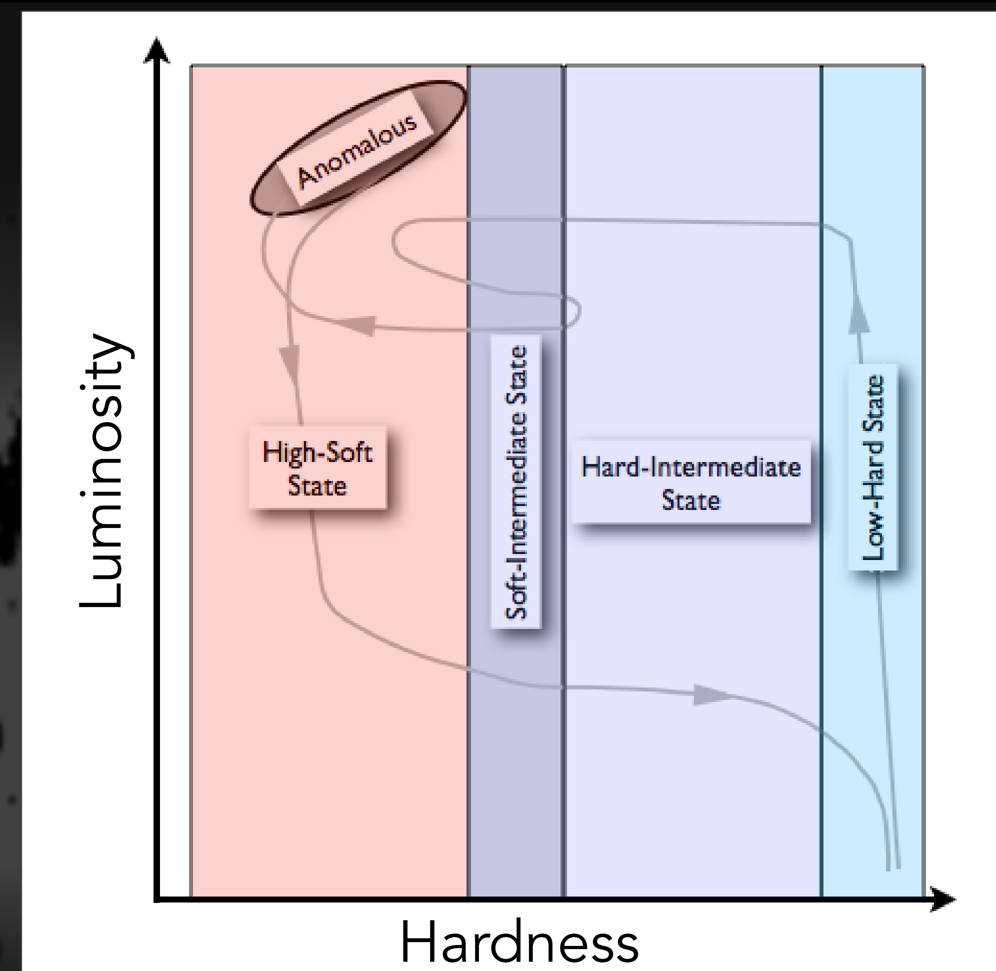


Homan et al. 2001

Soft state

Intermediate States

Hard state

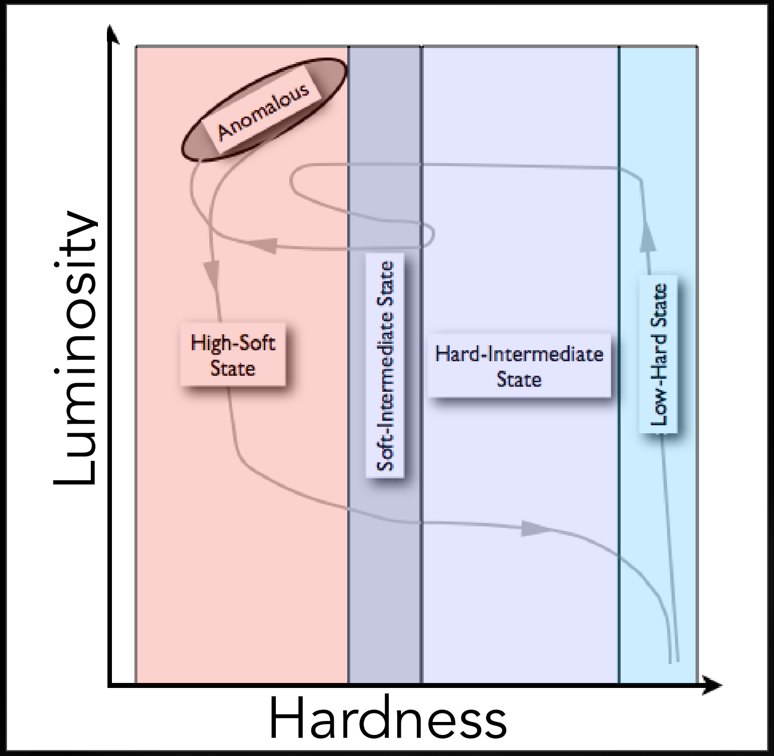


Outburst

Quiescence

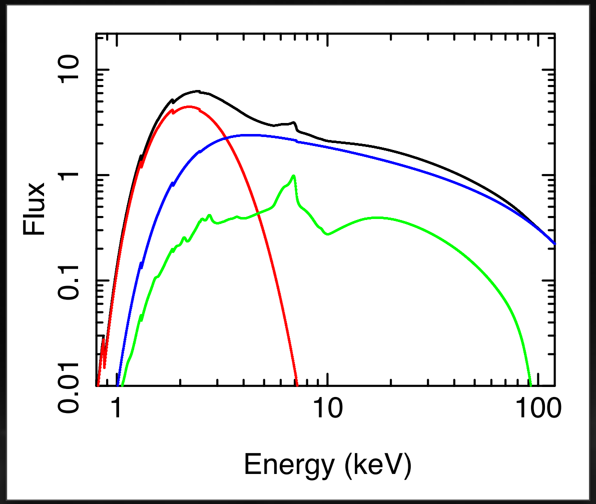
A TRUNCATED DISC

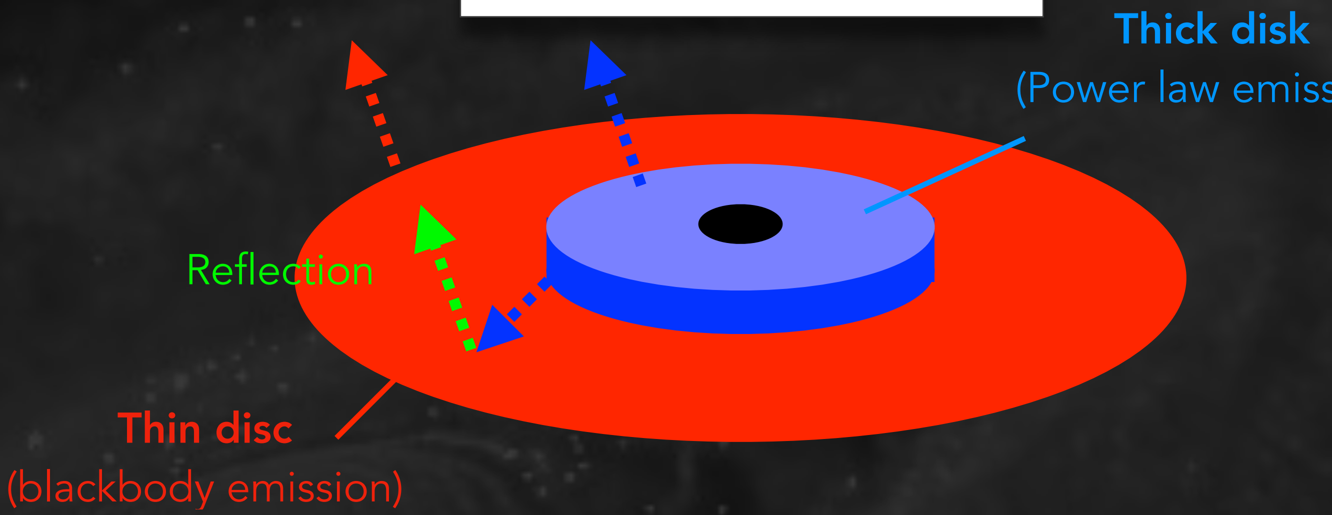
Truncation radius becomes smaller

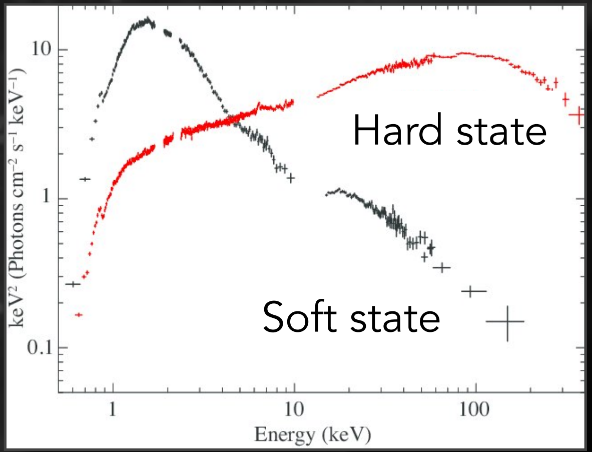


Truncation radius becomes larger

Esin et al. 1997; Poutanen et al.1997







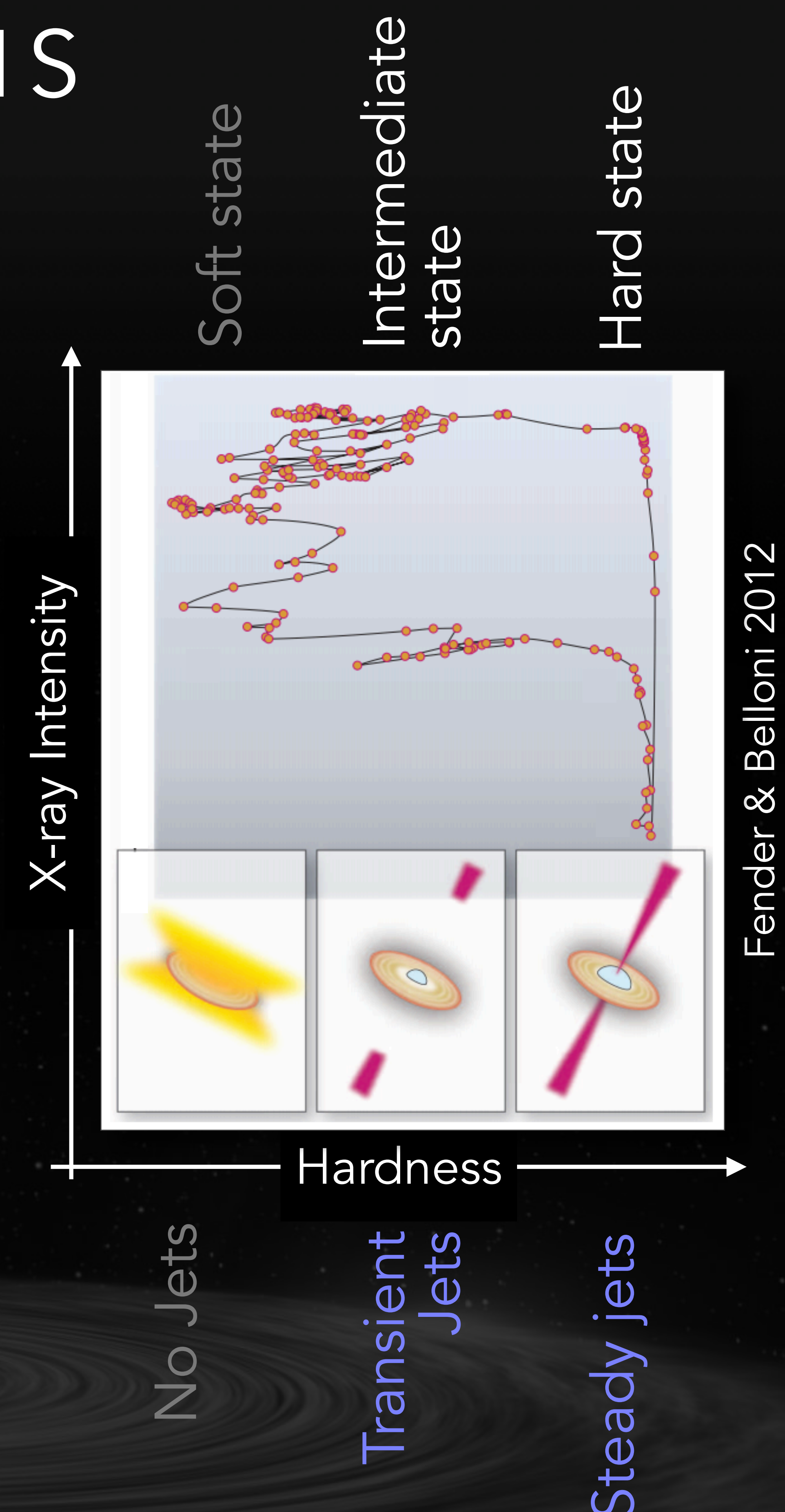
Yamada et al. 2012

STATES, TRANSITIONS AND OUTFLOWS

- States are largely defined based on X-ray properties
  (e.g., Belloni & Motta 2016; Kalemci et al. 2022; De Marco, Motta, Belloni 2022)

- States and transitions are connected to different modes of outflows
  (e.g., Fender et al. 2004, 2009; Ponti et al. 2012…)

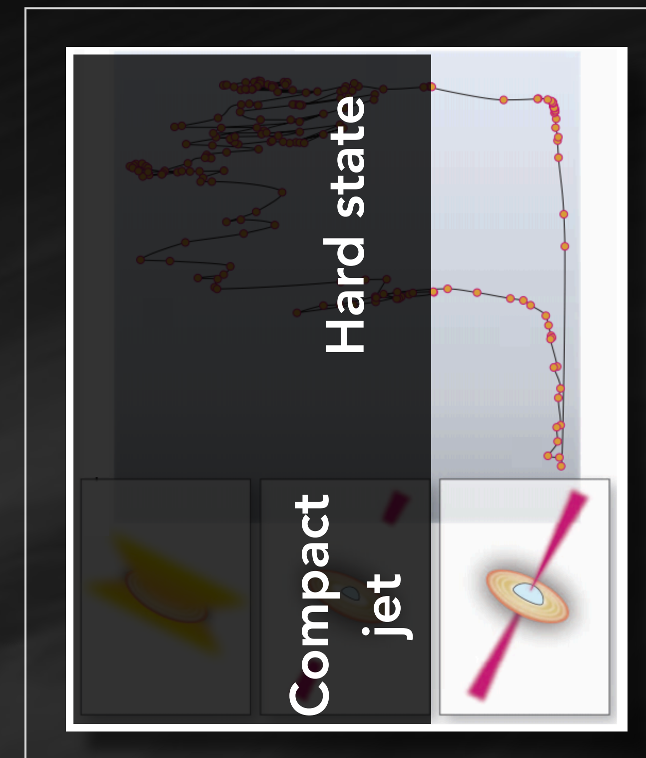
- Two jet modes: steady & compact and transient and extended



COMPACT JETS IN THE HARD STATES

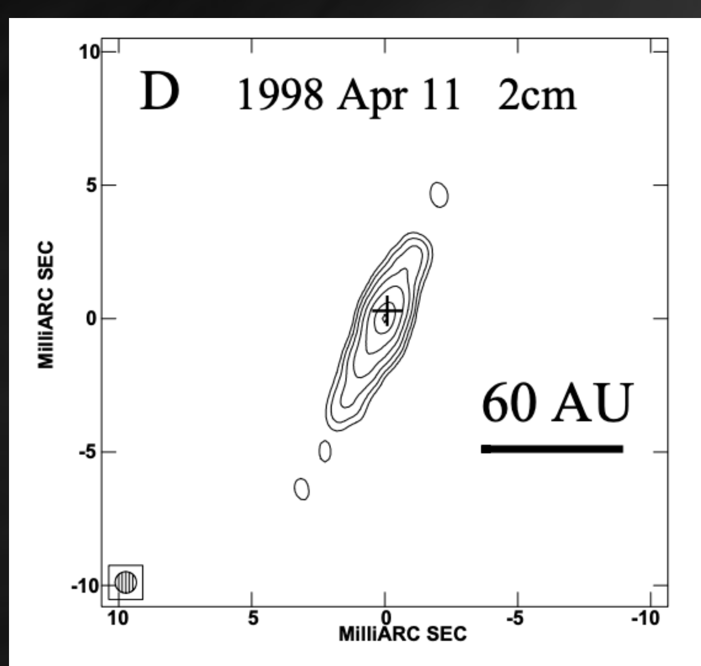
COMPACT AND STEADY CORE JETS

- Long-lived, mildly relativistic, continuous jets
- Typically not resolved with VLBI, but 2 sources show resolved core jets
- Transport a large amount of kinetic energy



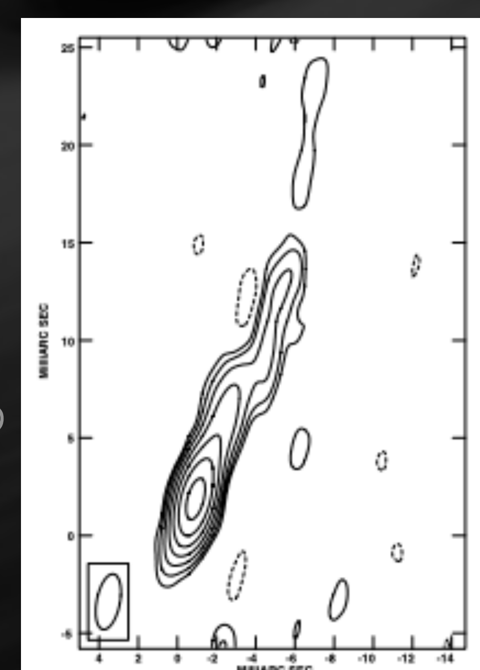
GRS 1915+105

Dhawan et al. 2000

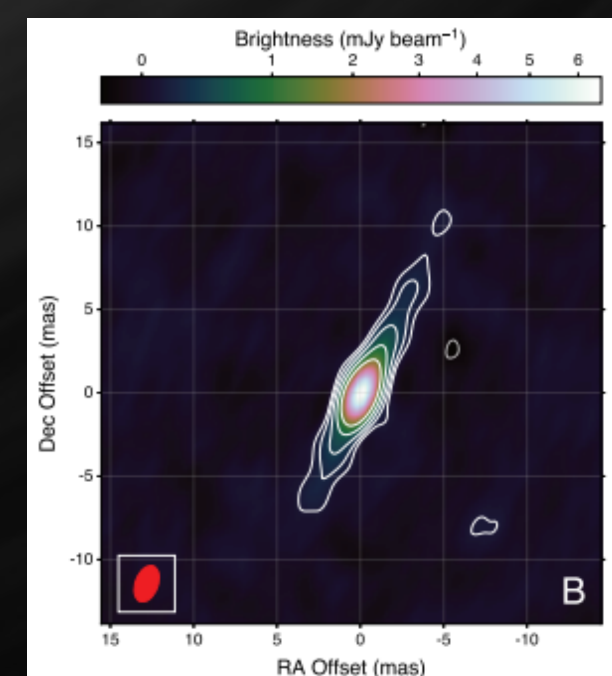


Cyg X-1

Stirling et al. 2001



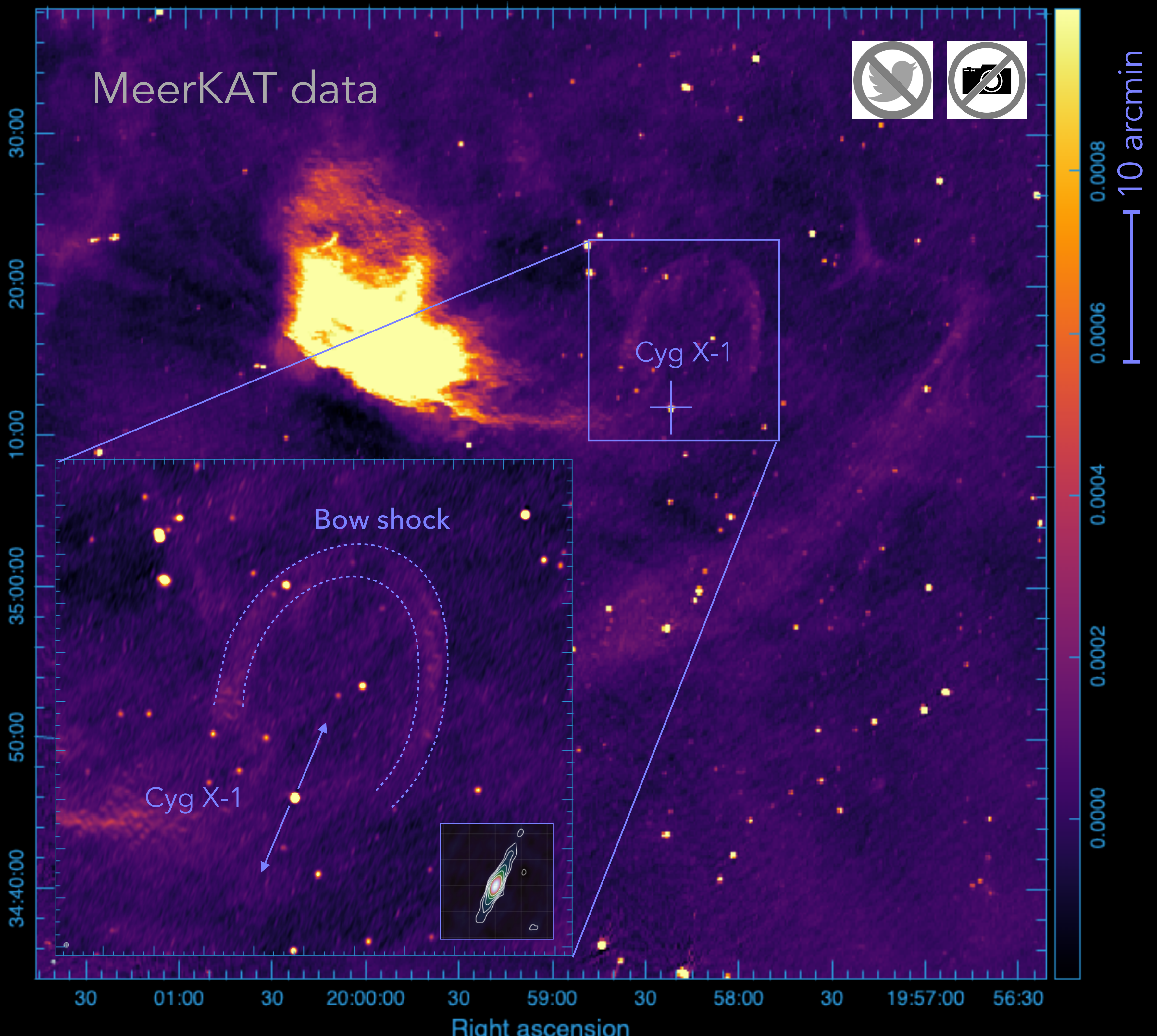
Miller-Jones et al. 2021



COMPACT JETS IN THE HARD STATES

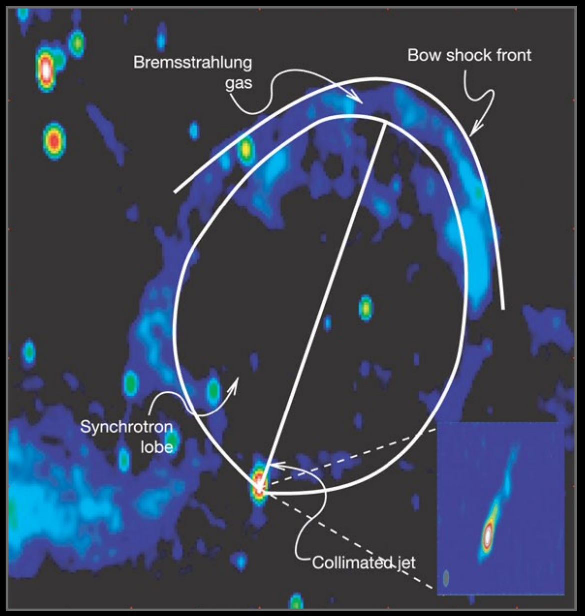
DARK JETS BLOWING BUBBLES

Atri et al. in prep.



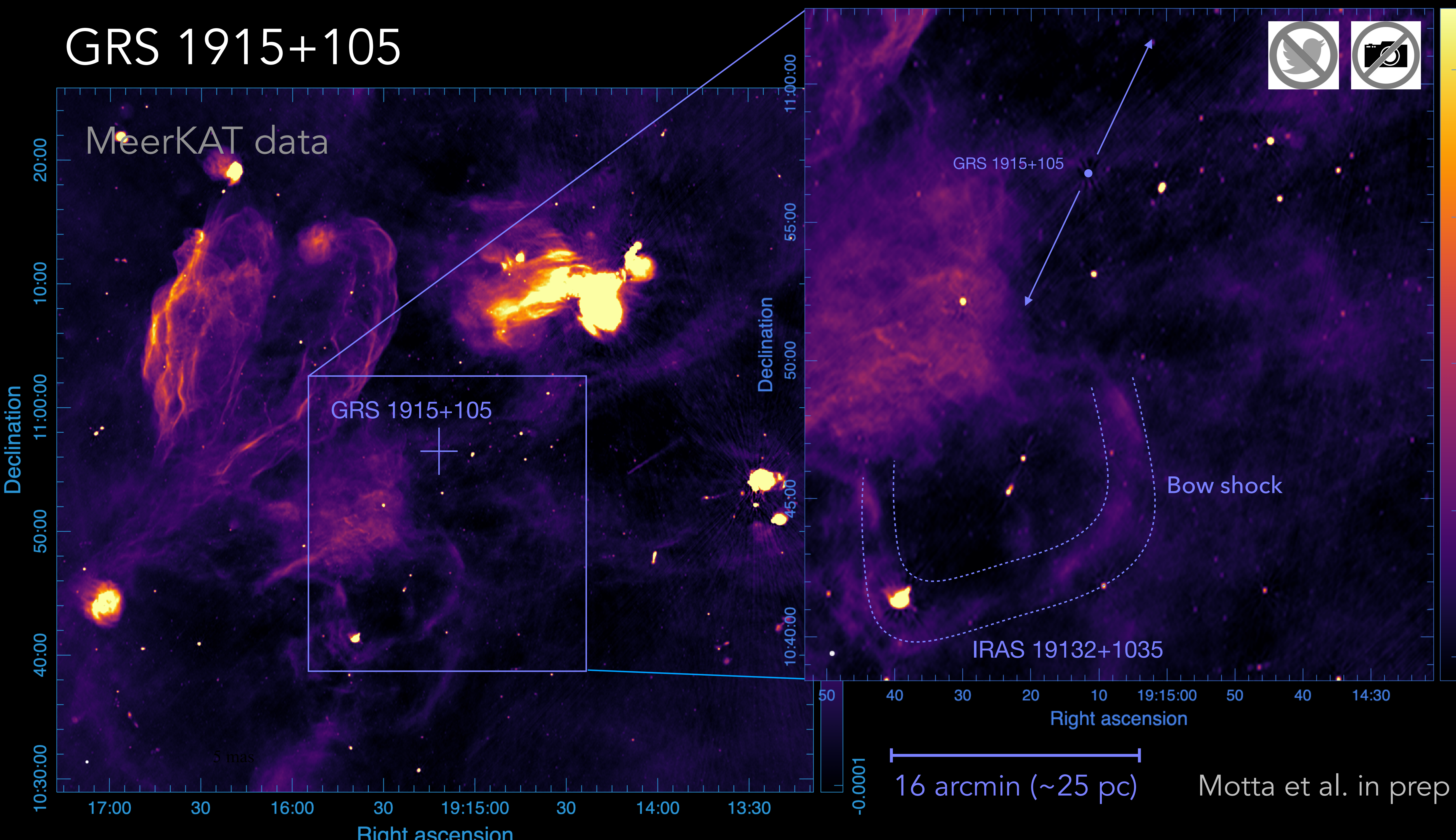
Cyg X-1

Gallo et al. 2005



COMPACT JETS IN THE HARD STATES

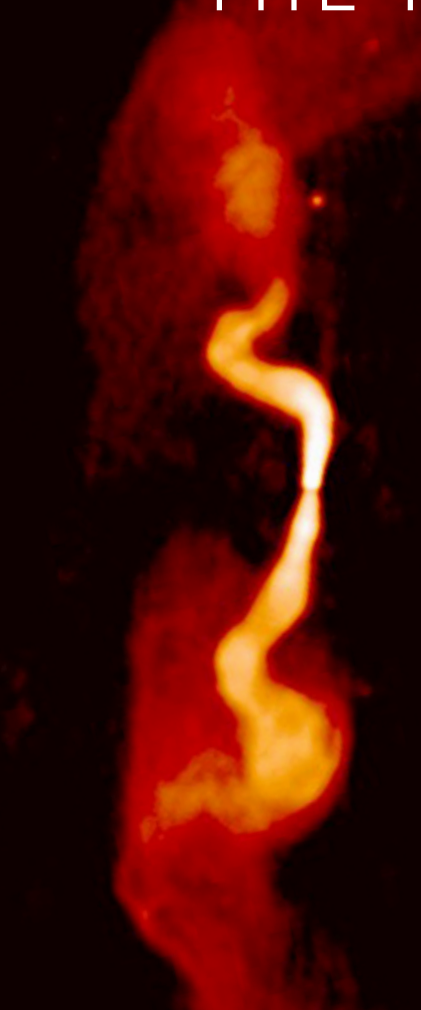
DARK JETS BLOWING BUBBLES



Motta et al. in prep

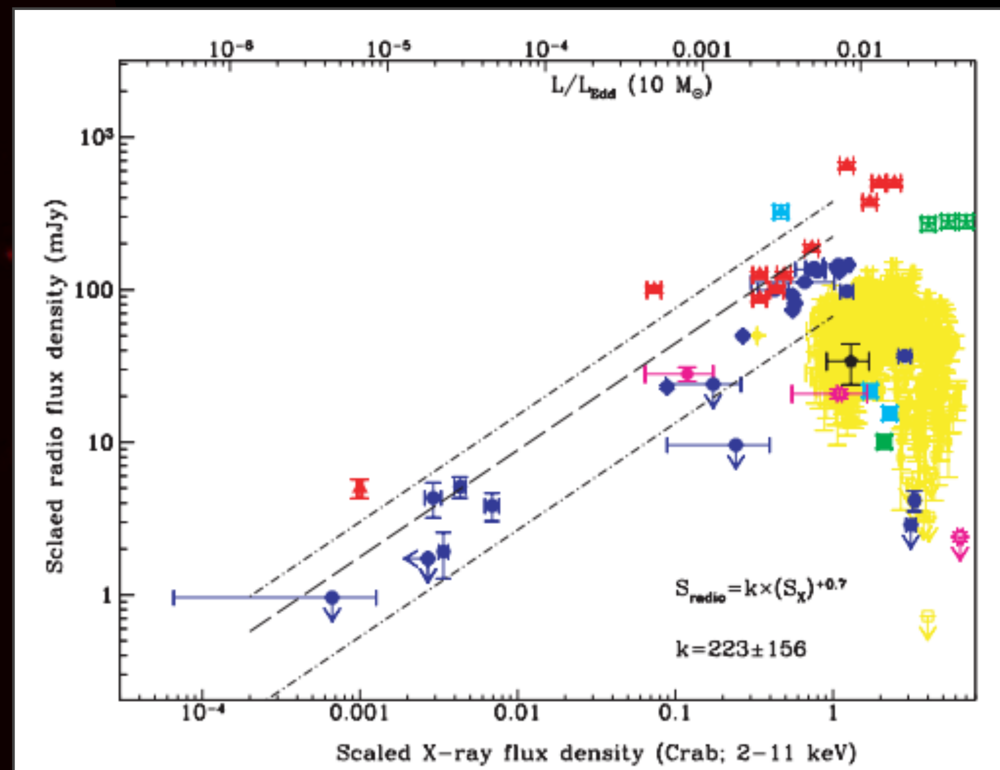
COMPACT JETS IN THE HARD STATES

THE FUNDAMENTAL PLANE OF BLACK HOLE ACTIVITY

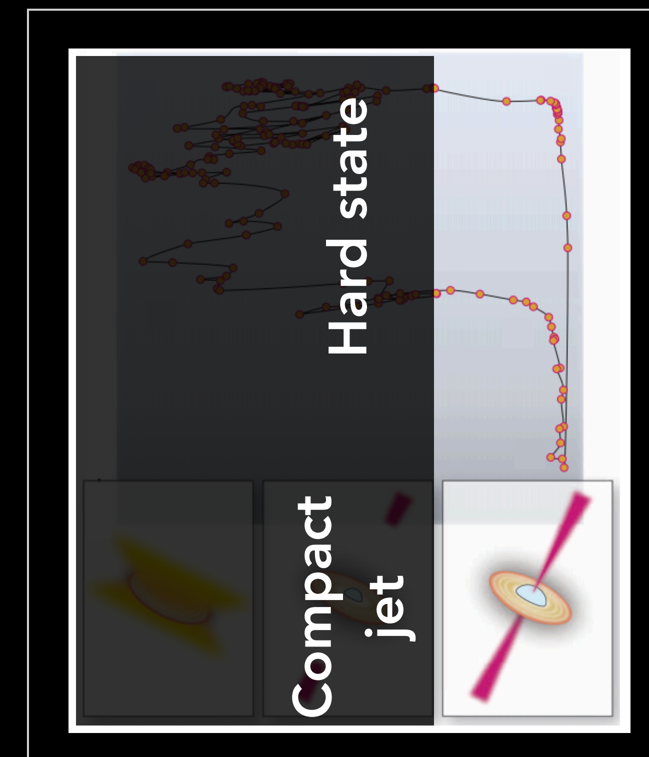


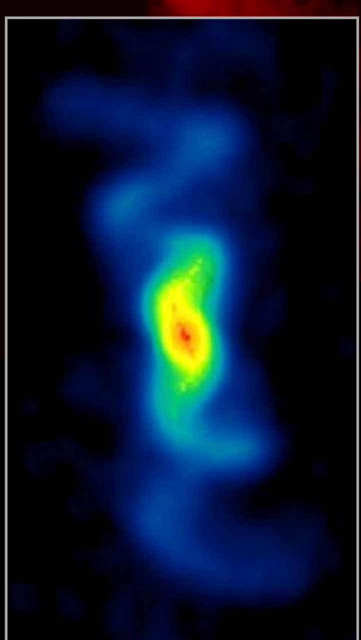
Super-massive black holes

~10^{6-9} Solar masses



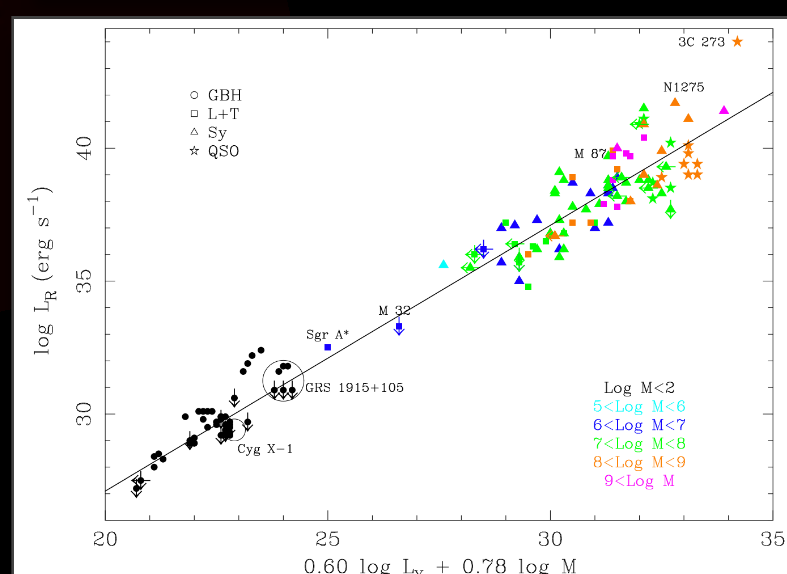
Gallo et al. 2003



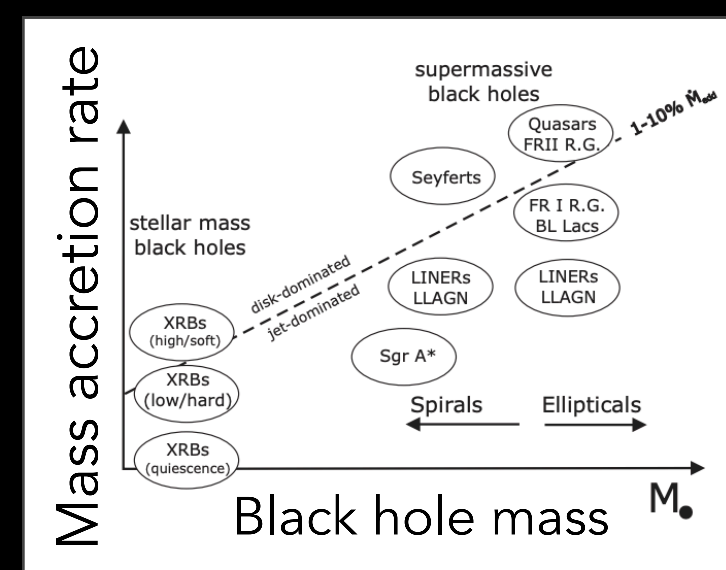


X-ray binaries

~10 Solar masses



Merloni et al. 2003

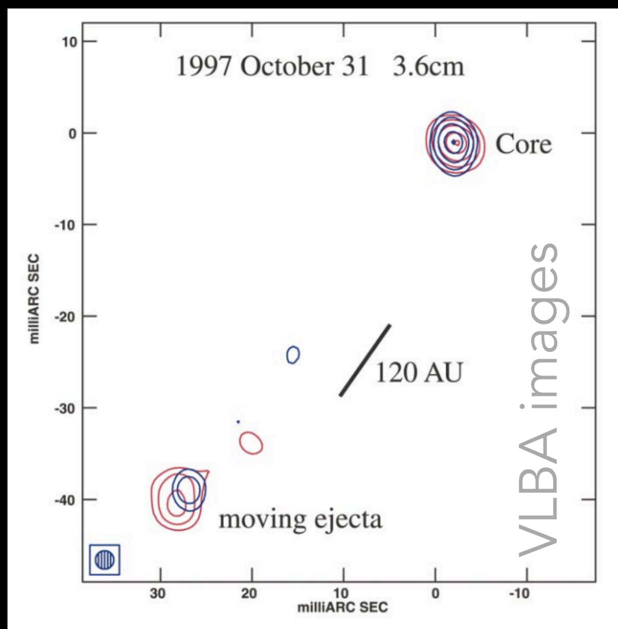


Falcke et al. 2004

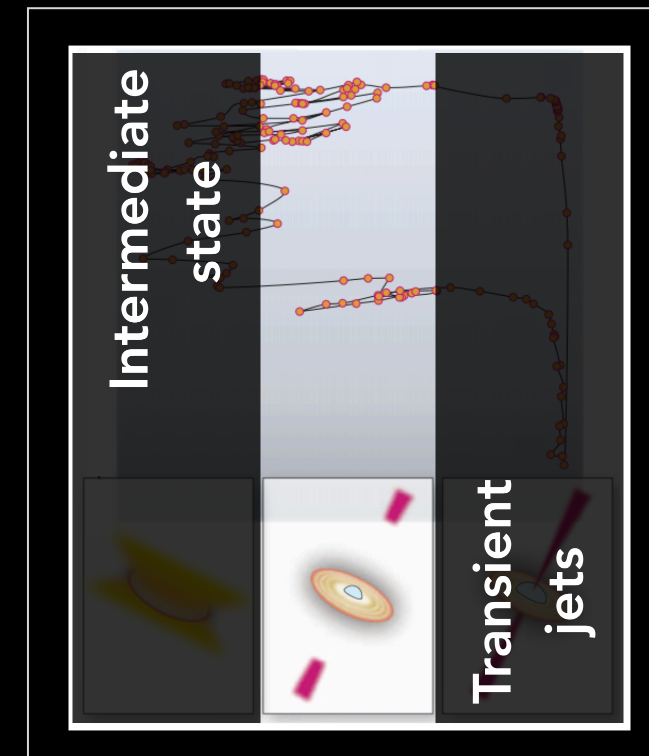
See also Corbel et al. 2013, Gallo et al. 2014, Gallo et al. 2018, Motta et al. 2018, Gültekin et al. 2019, Plotkin et al. 2021, Carotenuto et al. 2021, Bariuan et al. 2022, and many others.

TRANSIENT JETS
IN THE INTERMEDIATE STATES

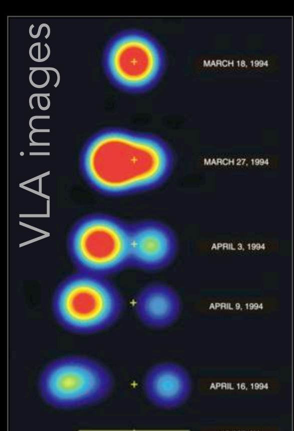
Dhawan et al. 2000



- Highly **relativistic** ejections
- Moving radio-bright spots
- **“Short-lived”**, catching the launch is hard and requires VLBI, but…

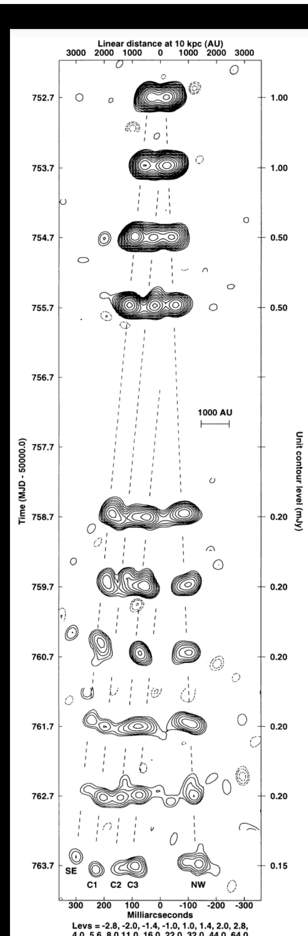


Mirabel & Rodríguez 1994

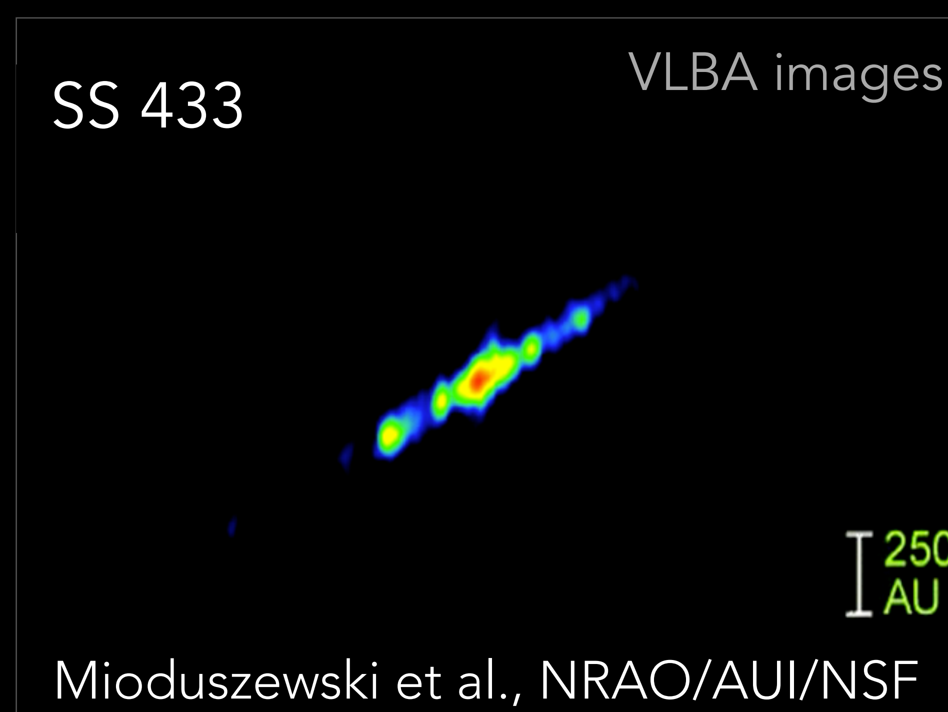


GRS 1915+105

Fender et al. 1999

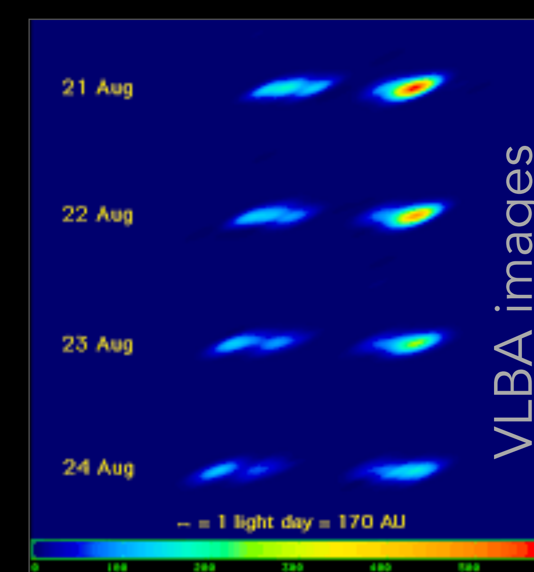


MERLIN images (5 GHz)



Hjellming & Rupen 1995

GRO J1655-40

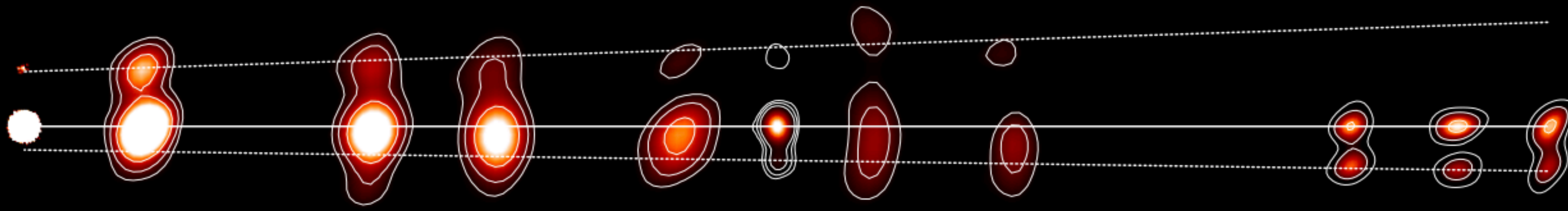


THEN MEERKAT ACCIDENTALLY REVOLUTIONISED THE FIELD

The **ThunderKAT Large Survey Program** started observing weekly active X-ray binaries in 2018

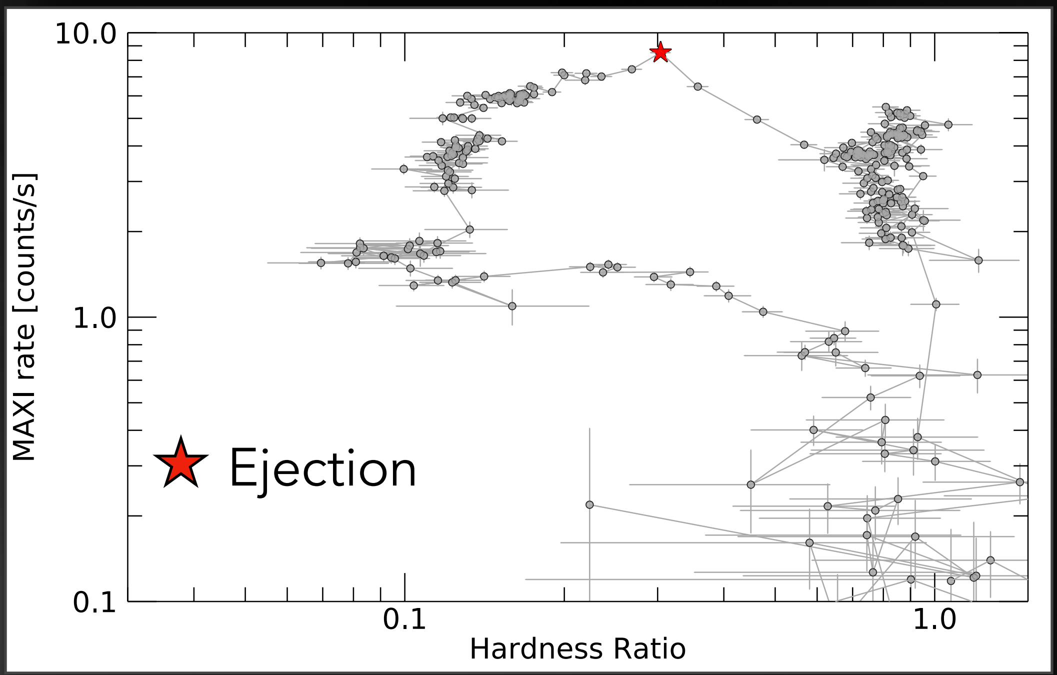
- Extended jets in many X-ray binaries at L-band (1.2 GHz)
- Long-lived jets, detected for months, some clearly decelerating
- Expansion up to > 0.5 pc from the binary

MAXI J1820+070, Bright, et al. 2020

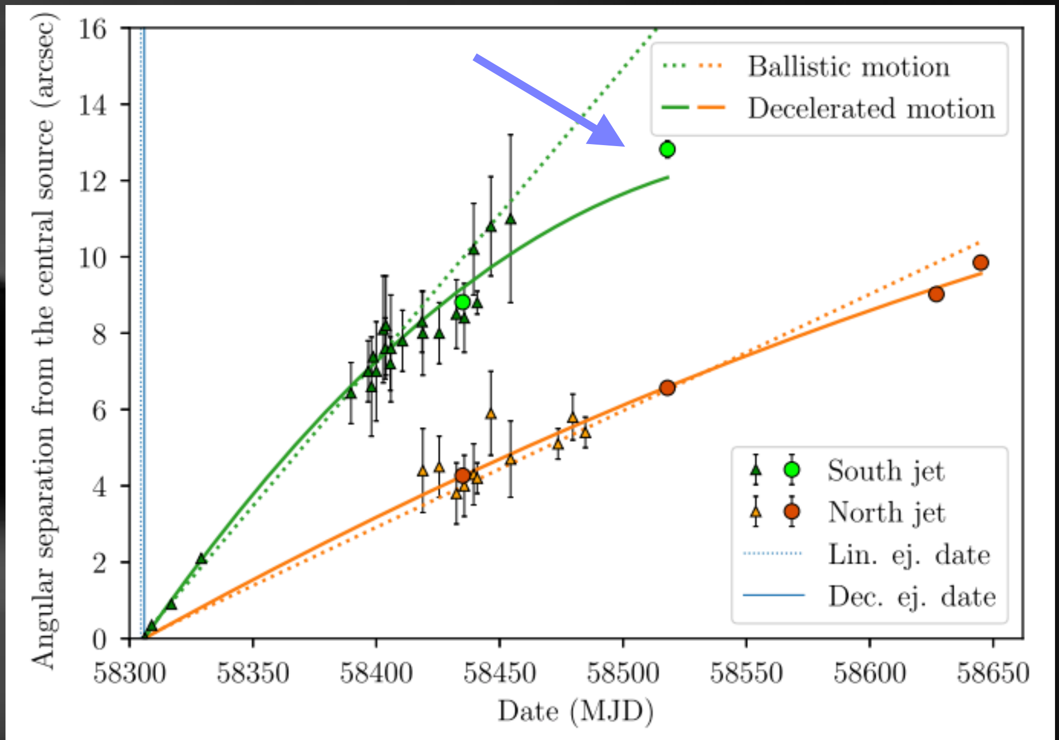


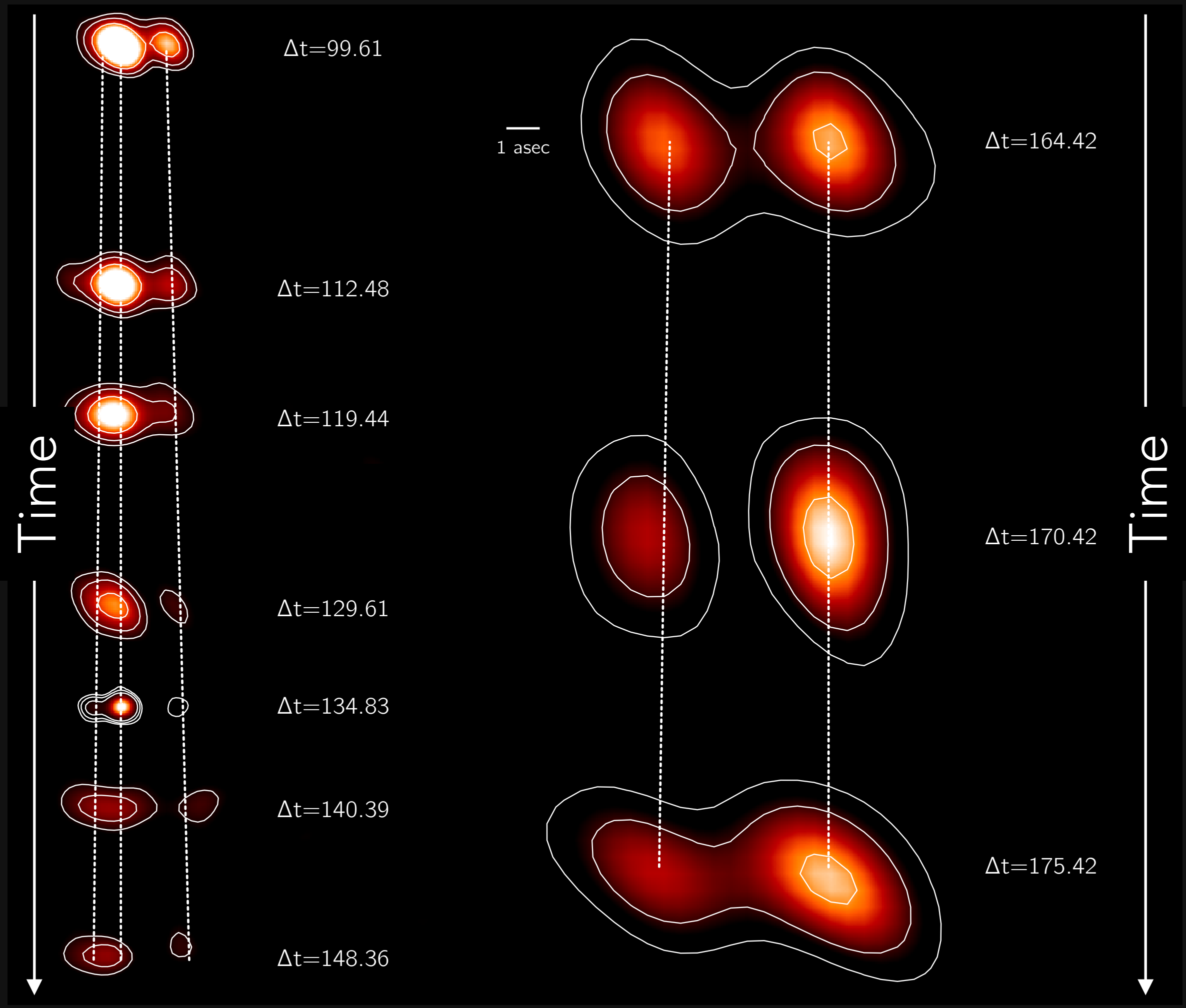
THE FIRST EXTENDED JETS SEEN BY MEERKAT: MAXI J1820+070

Bright et al. 2020



Espinasse et al. 2020



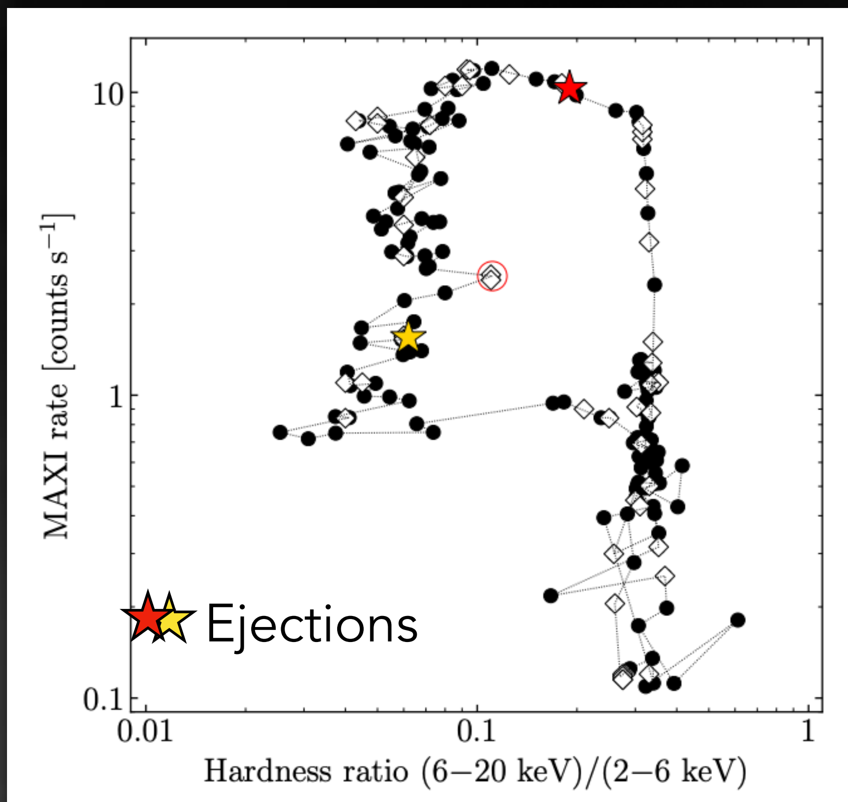


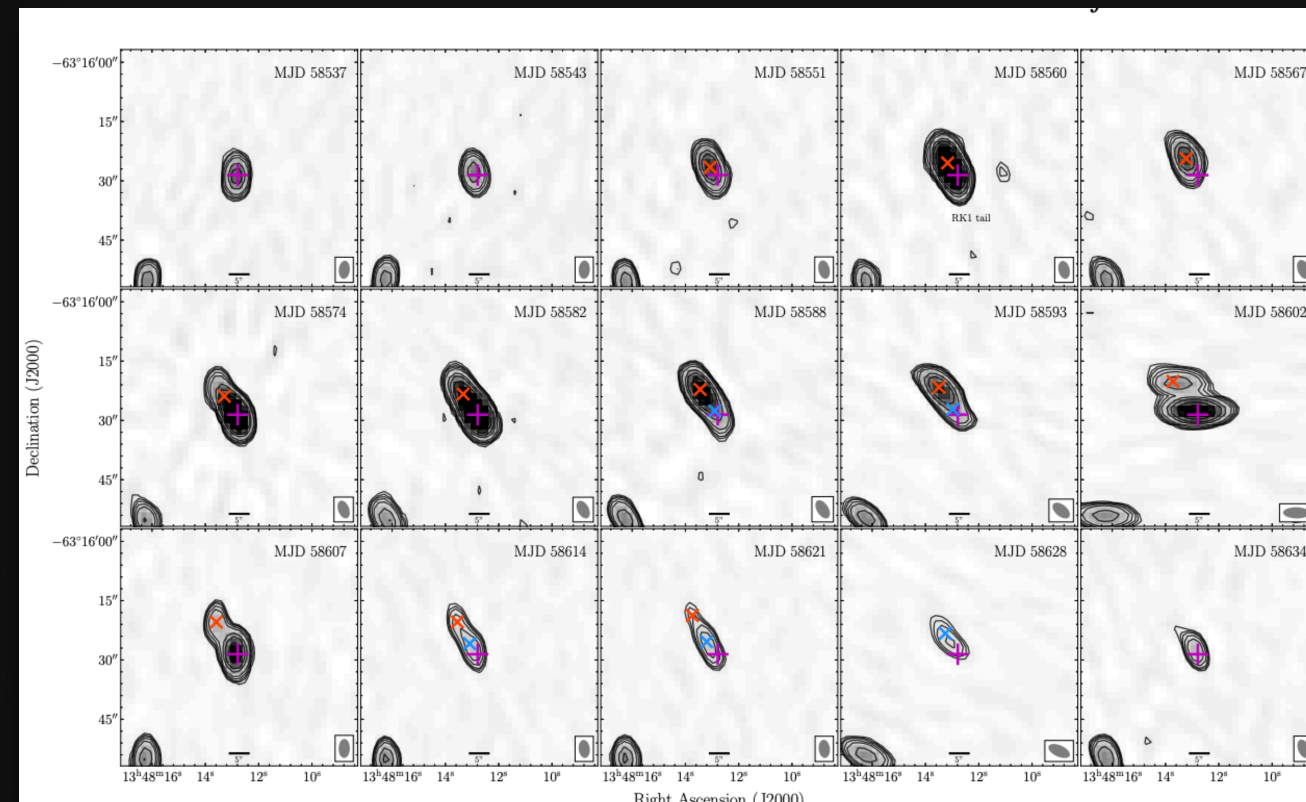
MeerKAT data

- Jets moving ~80 mas/day
- MeerKAT followed the jets to 0.005 pc from the core
- Hints of deceleration

MORE EXTENDED JETS: MAXI J1348–630

Hardness-Intensity diagram

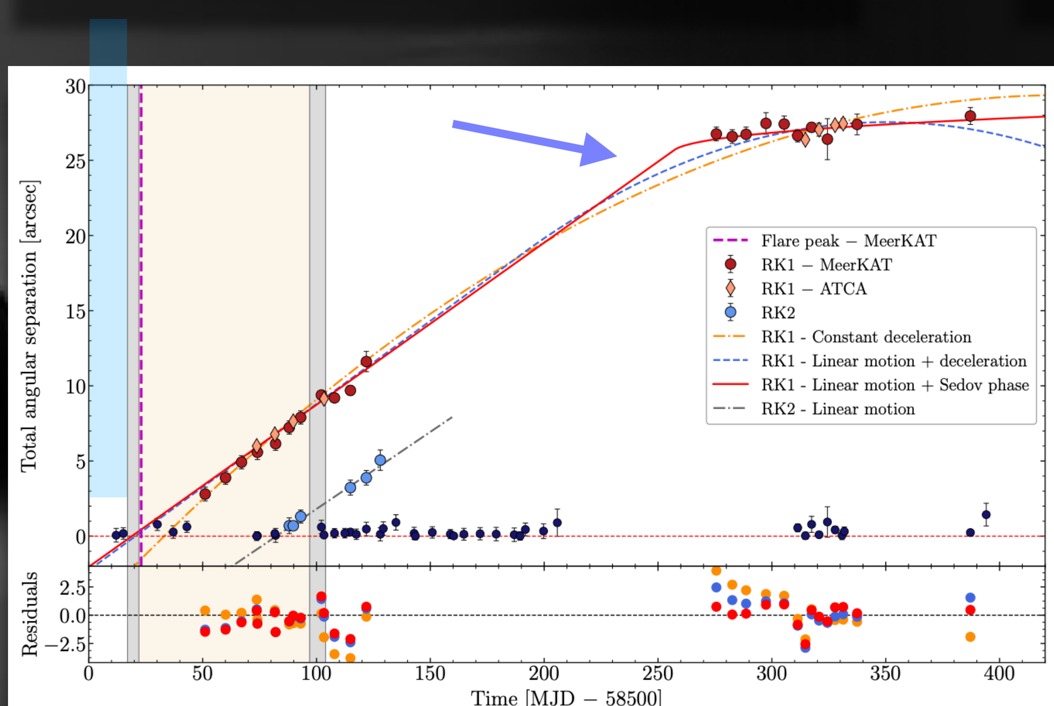




MeerKAT data

Carotenuto et al. 2021a,b

Core-jet separation



- Clear deceleration. Interaction with cavity walls?
- Jets moving **~110 mas/day**
- Extended up to **0.6 pc from the core**

RELATIVISTIC JETS FROM A GLOBULAR CLUSTER X-RAY B INARY: MAXI J1848-015

- Jets moving ~33 mas/day
- Extended up to 0.25 pc from the core
- Clear deceleration

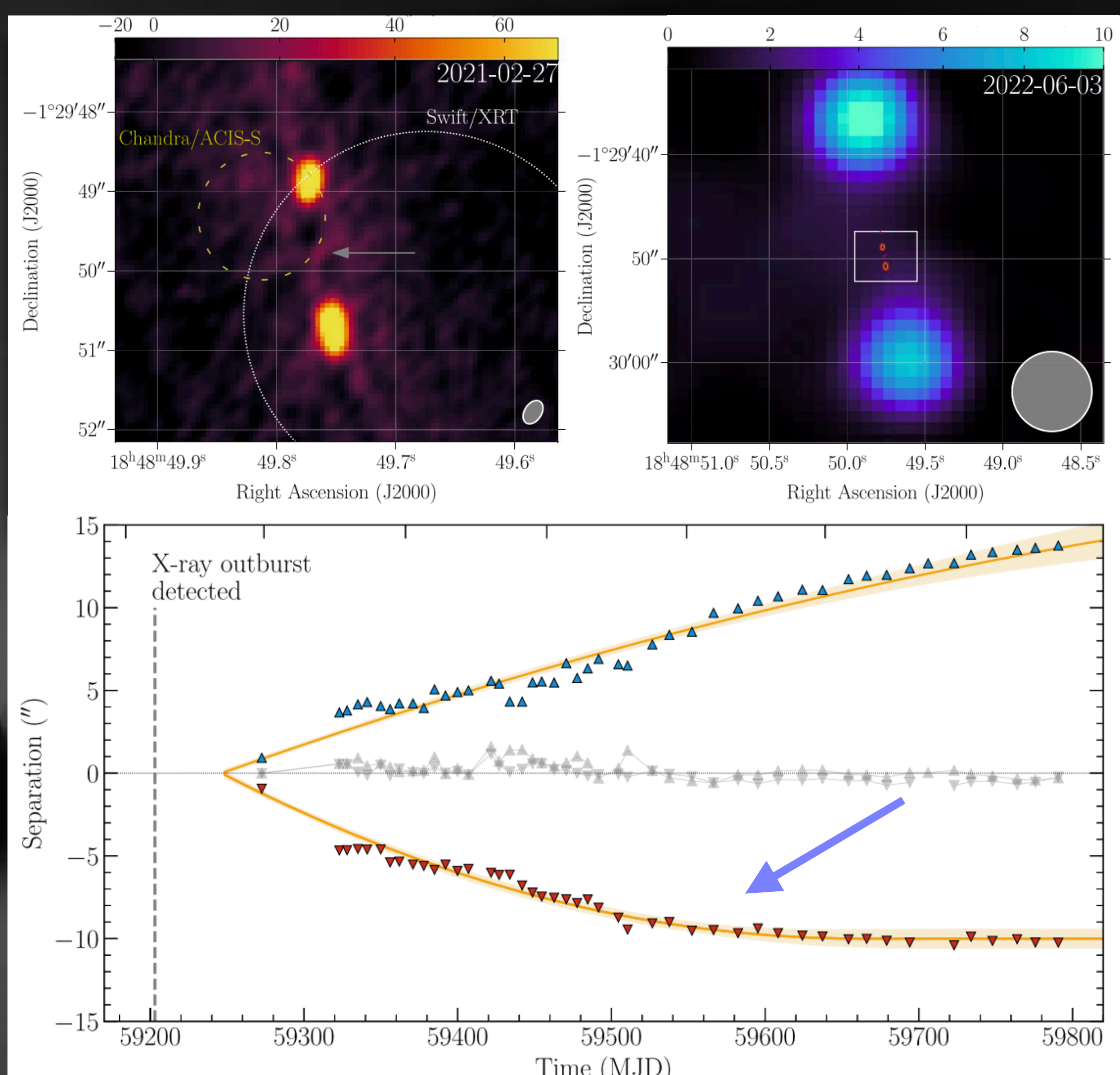
Bahramian et al. 2023

VLA data

MeerKAT data

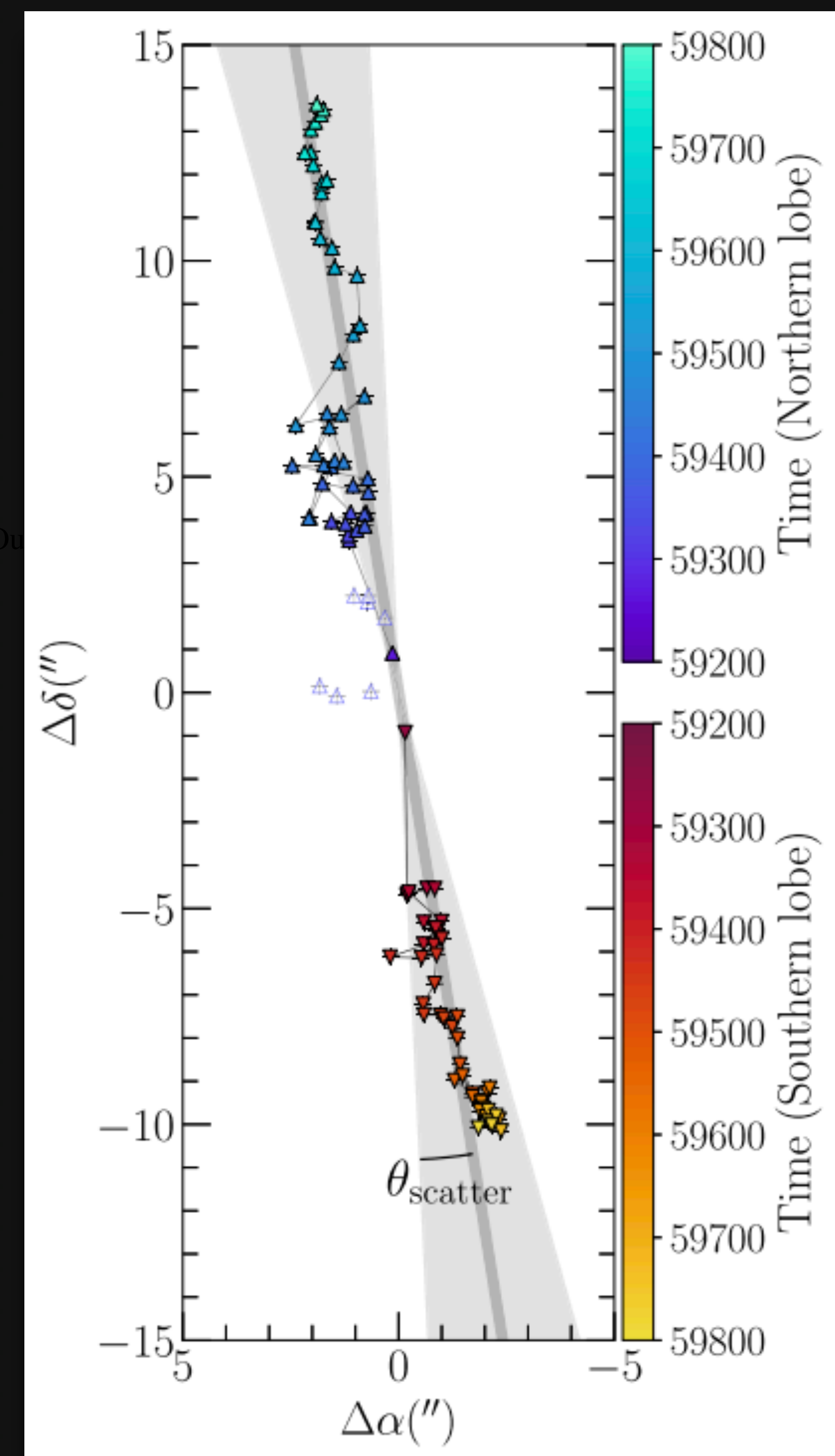
North

South



North (approaching jet)

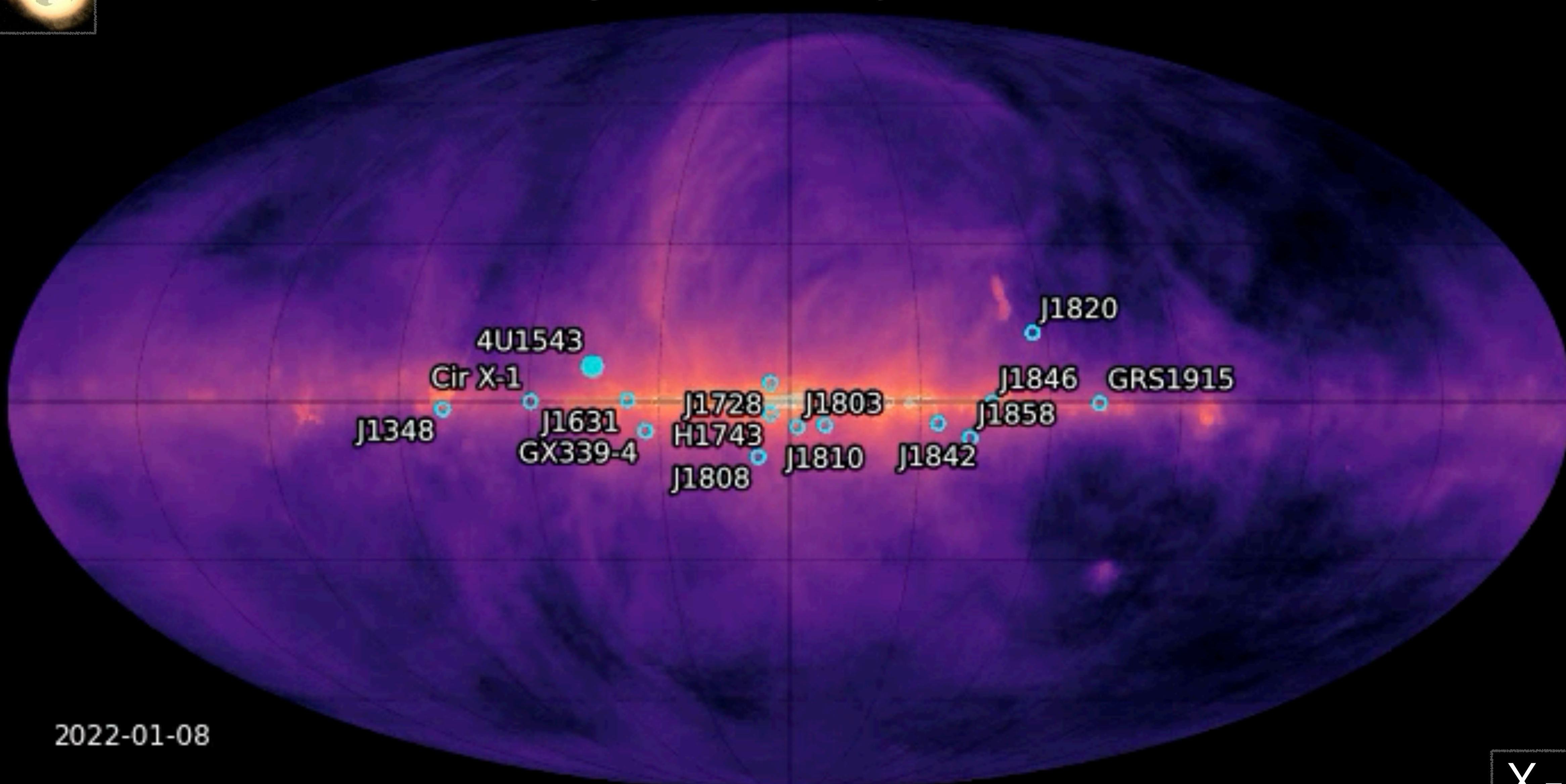
South (receding jet)



THE **MEERKAT** VIEW OF TRANSIENTS GALACTIC XRBs

MeerKAT data acquired as part of the ***ThunderKAT*** Large Survey Program

Produced by Alex Andersson as part of ThunderKAT

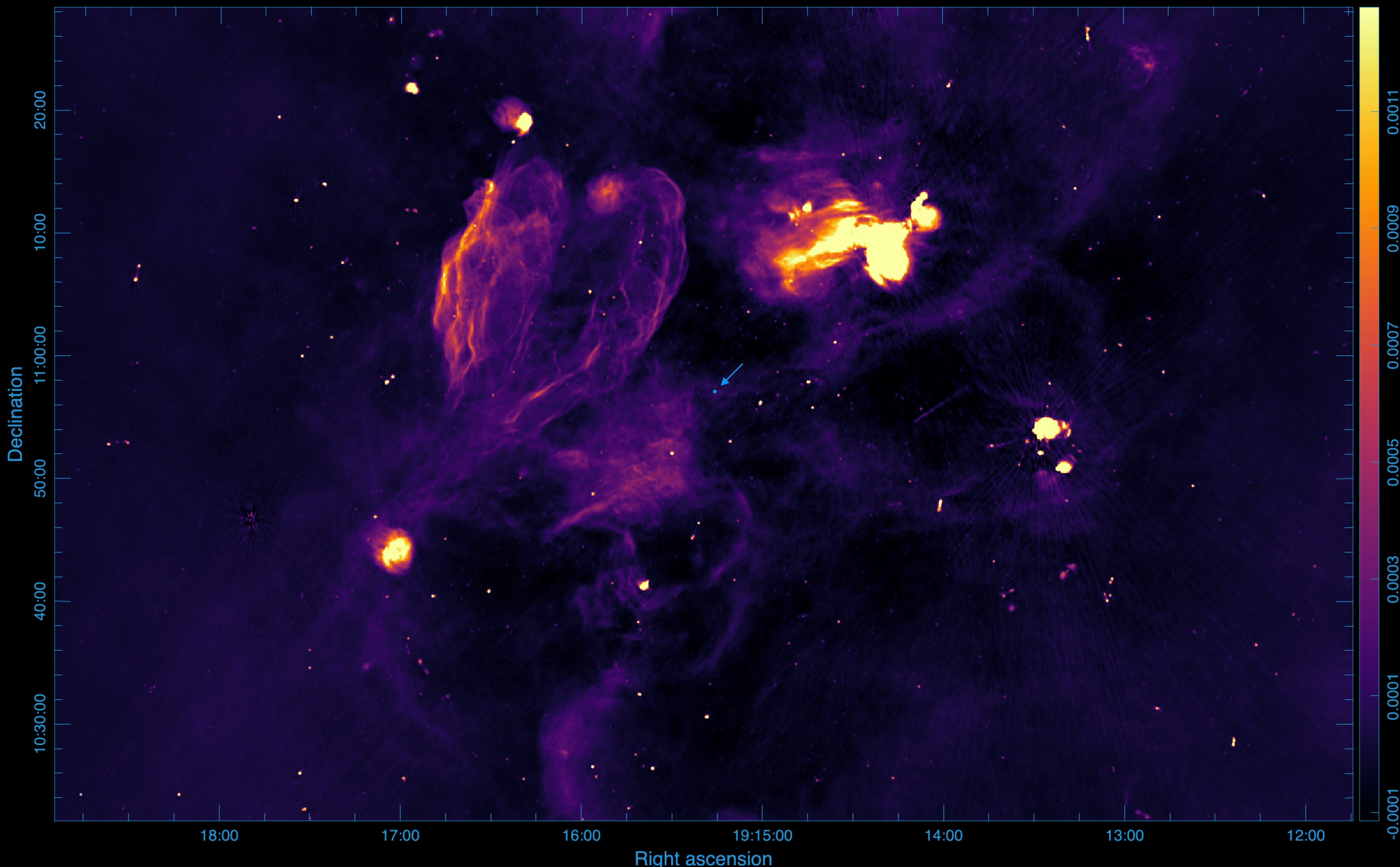


Curtesy of Alex Andersson (ThunderKAT collaboration)

ThunderKAT for X-ray binaries is now called **X-KAT** and will potentially run until MeerKAT becomes SKA-MID

X-KAT

GRS 1915+105



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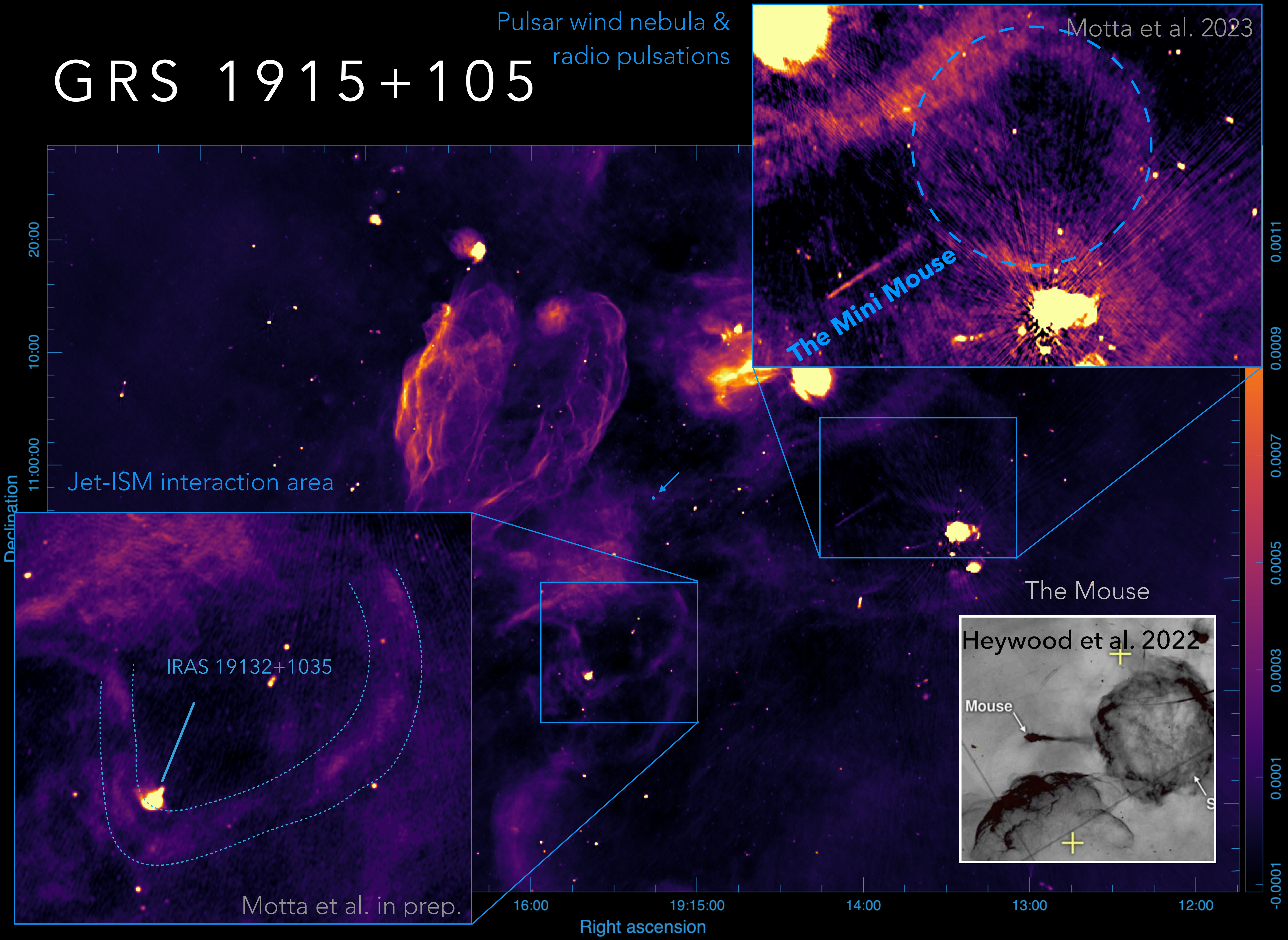
GRS 1915+105


Pulsar wind nebula &
radio pulsations
Motta et al. 2023
The Mini Mouse
Jet-ISM interaction area
IRAS 19132+1035
Motta et al. in prep.
The Mouse
Heywood et al. 2022
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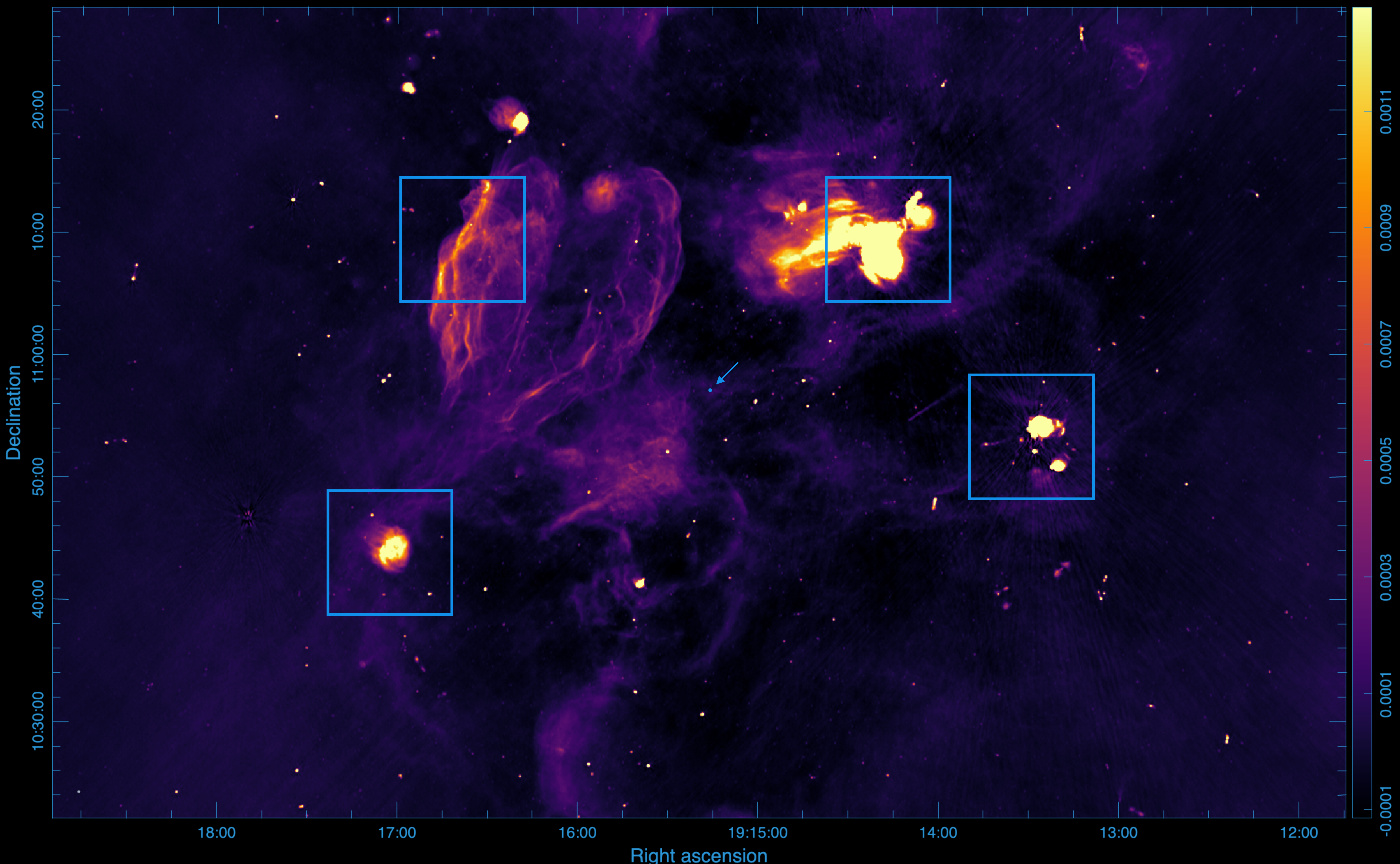
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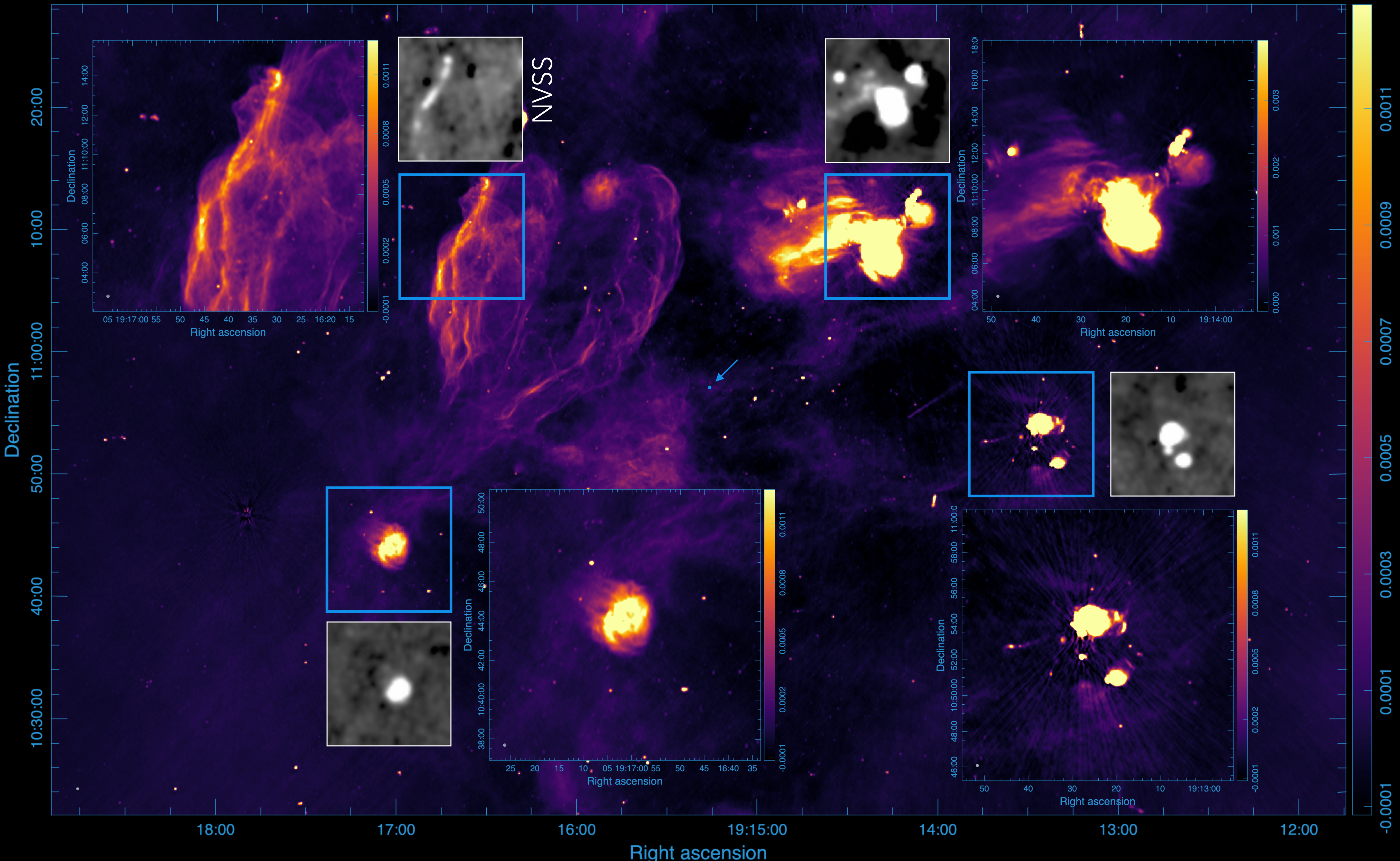

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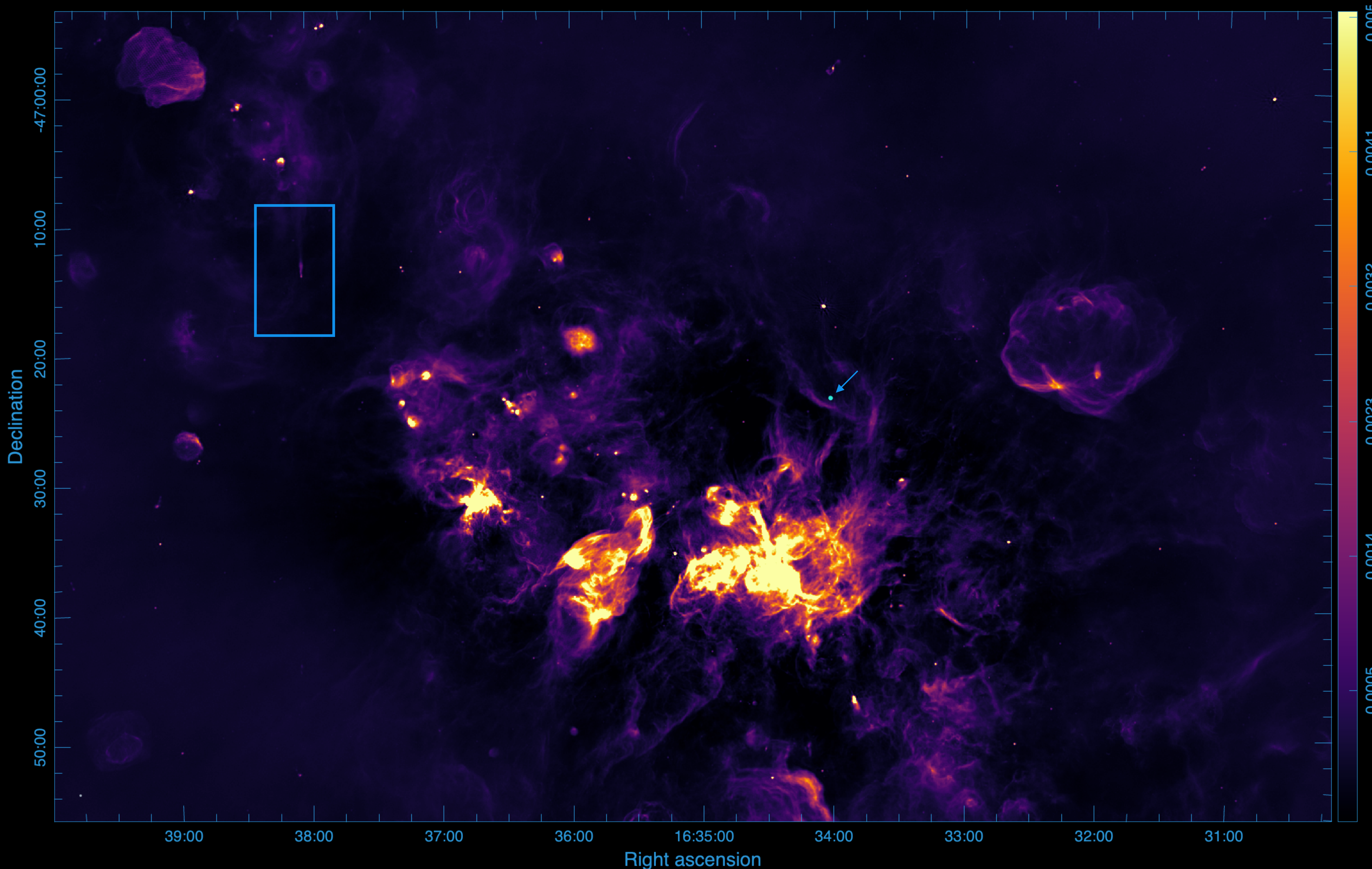

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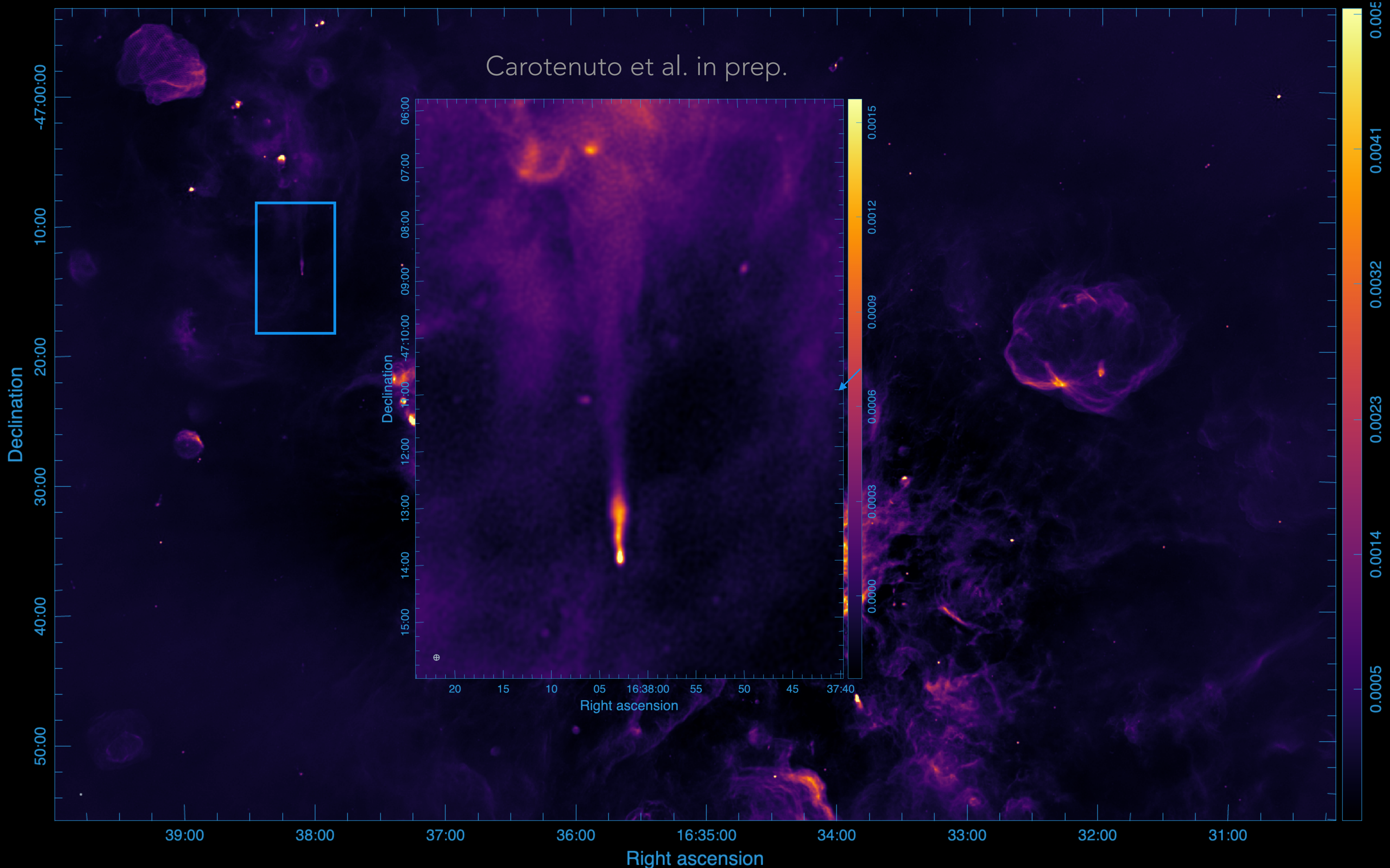
Carotenuto et al. in prep.
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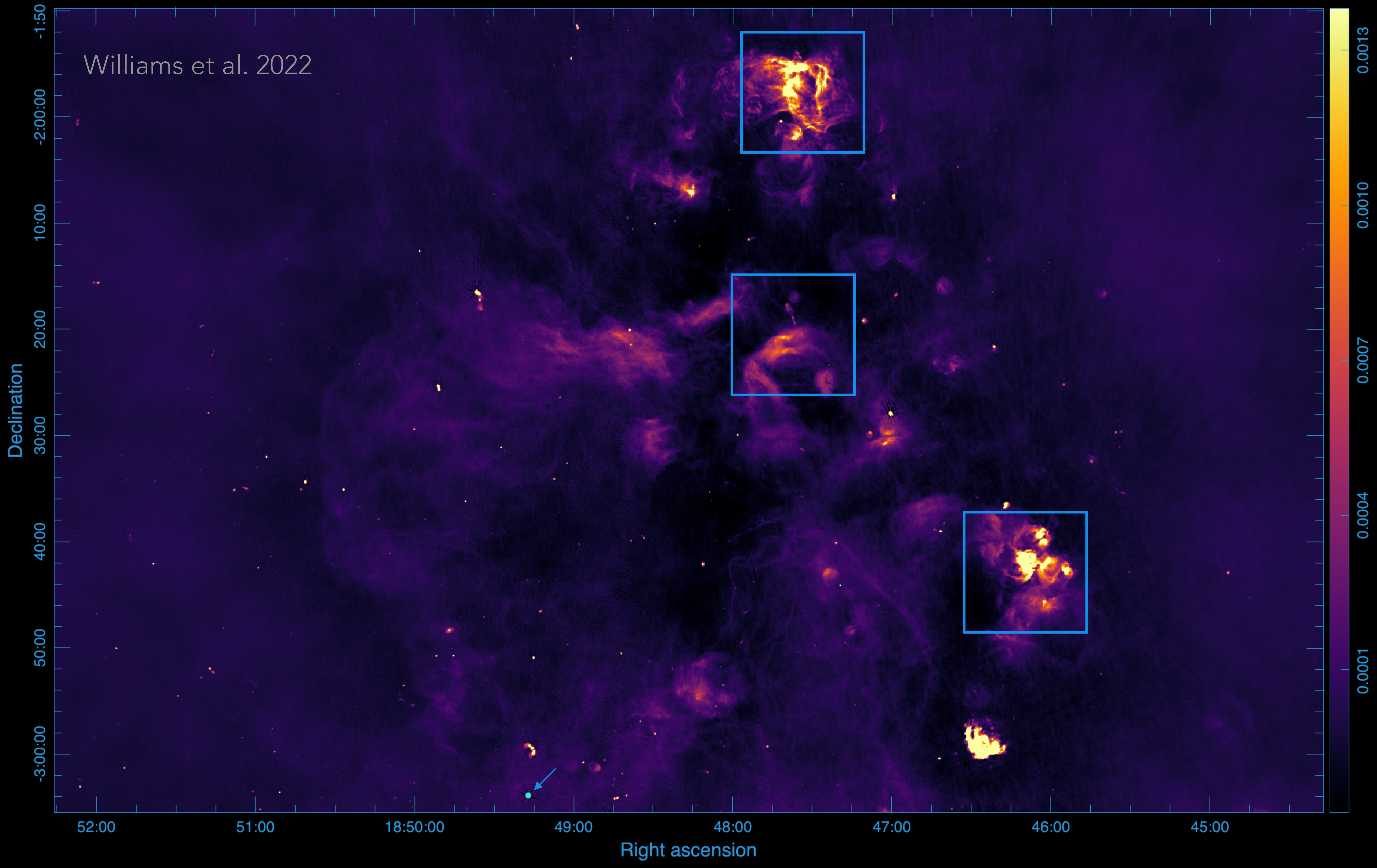

Williams et al. 2022
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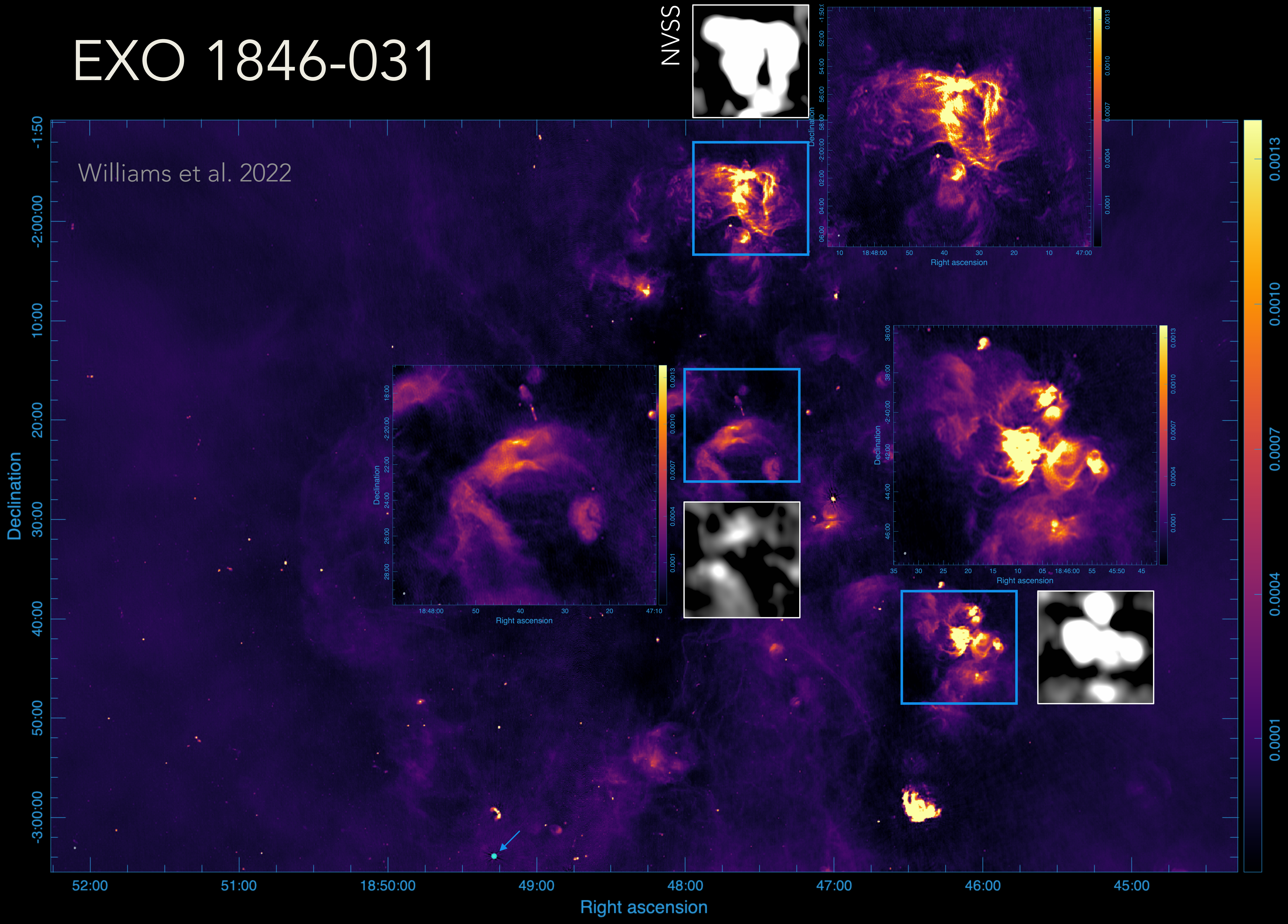
EXO 1846-031


Williams et al. 2022
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CHEETARA

Combined **H**omog**e**n**e**ous *ThunderKAT* **A**nalysis and **R**eduction **A**rchitecture

PIs: S. Motta (INAF), D. Williams-Baldwin (JBO)

With Ian Heywood, Alex Andersson, Jakob Van den Eijden, Victoria Samboco, Francesco Carotenuto, and members of the X-KAT collaboration

Where do we stand

- Every MeerKAT field contains thousands of sources.
- Every observing epoch (15 min) produced 90GB raw data.
- ThunderKAT produced 20 TB/year raw data, X-KAT will produce x2 as much.
- SKA-MID will produce > 300 PB/year raw data!

Aims

- Facilitate commensal science and data exploitation
- Benchmarking for the SKA

What does Cheetara do

- Connects people and their know-how
- Provides book-keeping and work planning
- Provides computational resources, scratch space and data storage (currently at JBO and Oxford Uni.)

OPEN QUESTIONS AND HOW TO ANSWER THEM

- How fast are jets from binaries really?
- How many types of transient jets exist?

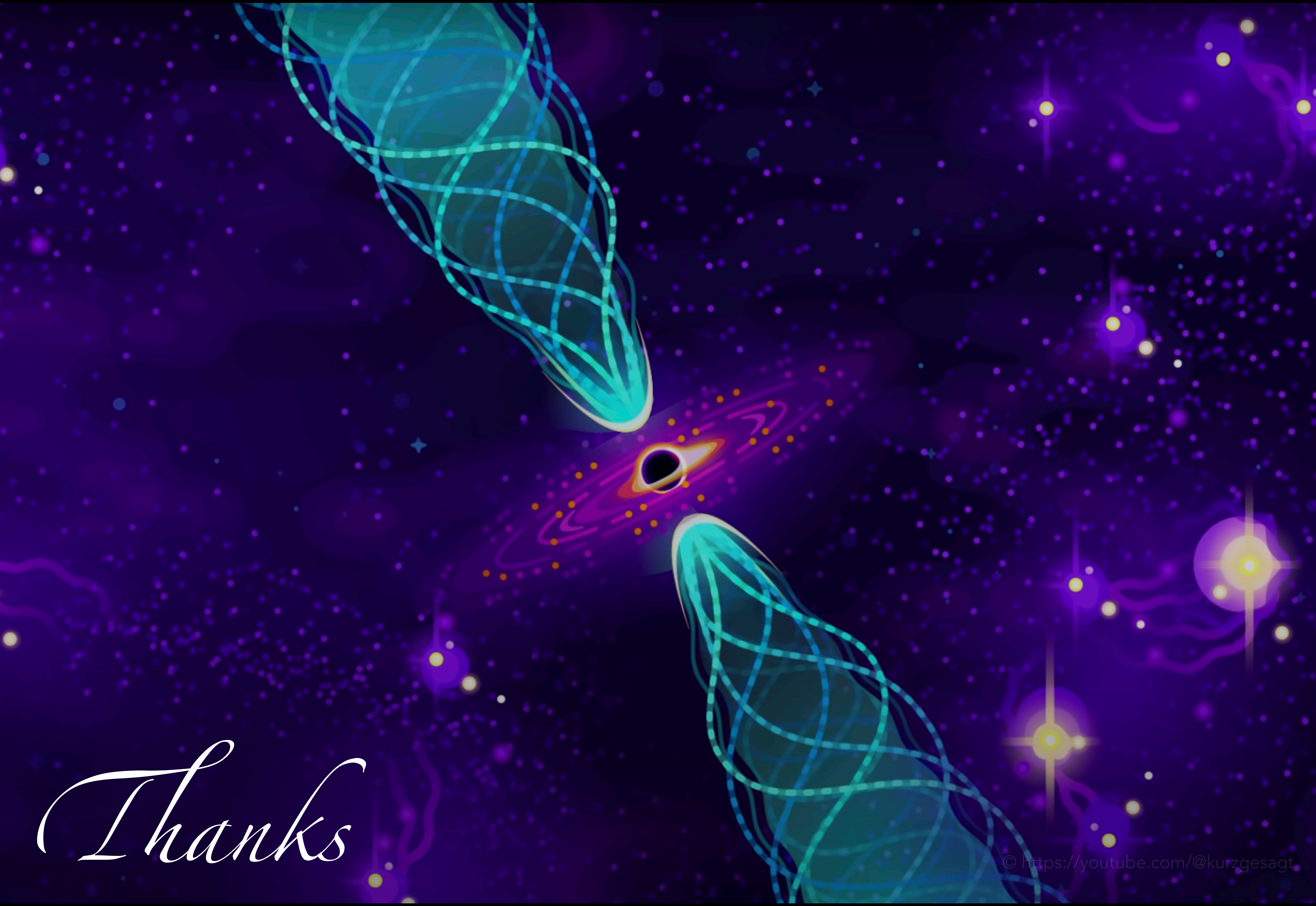
Requires high cadence observations → SKA will monitor binaries jets daily, tracing their position, size, velocity, deceleration, expansion rate

- Do binaries live in ISM cavities?
- How much energy do these jet carry?
- How much is re-injected into the environment?

Requires deep observations → Long exposures of galactic transients will in principle happen for free

- … how do we deal with all the data?!

Requires ~infinite resources → Work in progress. Arriving prepared is key


Thanks
© https://youtube.com/@kurzgesagt