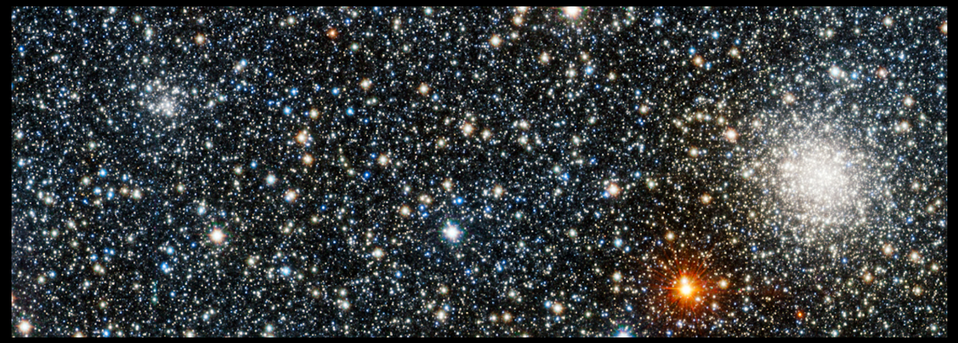
THE FIRST DETECTION OF RELATIVISTICALLY MOVING LARGE SCALE JETS FROM A BLACK HOLE CANDIDATE IN A GLOBULAR CLUSTER

STÉPHANE CORBEL

(UNIV. PARIS CITÉ & CEA SACLAY & OBSERVATOIRE DE PARIS)



With main collaboration from L. Tremou, A. Bahramian, F. Carotenuto, G. Migliori, R. Fender, P. Kaaret, G., J. Orosz, J.A. Tomsick, A.K. Tzioumis, J. Miller-Jones… and the ThunderKAT MeerKAT LSP

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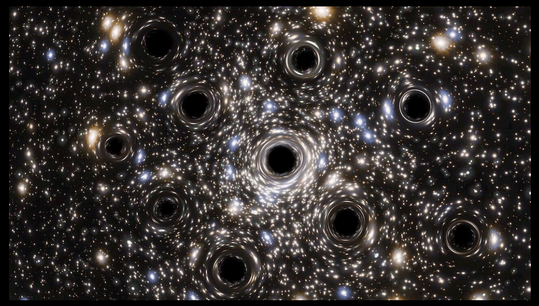
X-RAY BINARIES, BLACK HOLES AND GLOBULAR CLUSTERS

- Compared to Galactic fields, **overabundance of XRBs in globular clusters**, formed mostly via stellar encounters (anim. from A. Geller).
- But **BHs may quickly escape** (Sigurdsson & Hernquist 93) ?

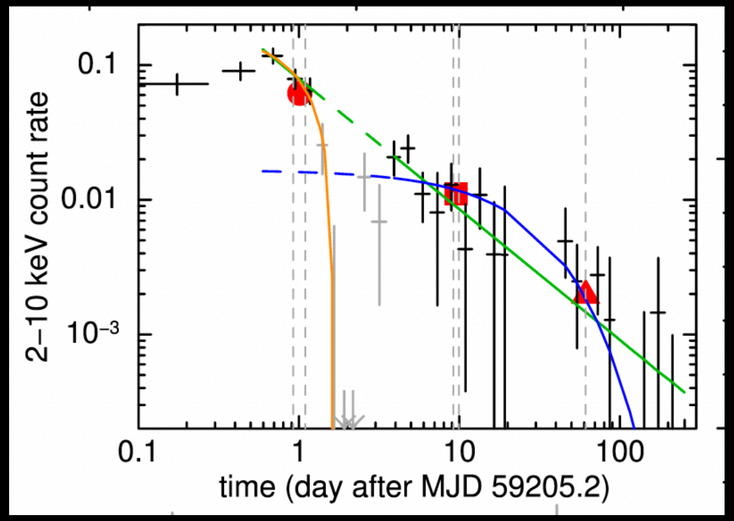
- **No dynamically confirmed BH-XRBs in GCs** yet, but **confirmed detached BHs** (Giesers et al. 18,19) and **strong BH-XRB** candidates in quiescence (e.g. Maccarone et al. 07, Miller-Jones et al. 15).
- Stellar mass BH, supermassive BH, and **Intermediate mass black hole** in GCs ? Link with **GW event** ?



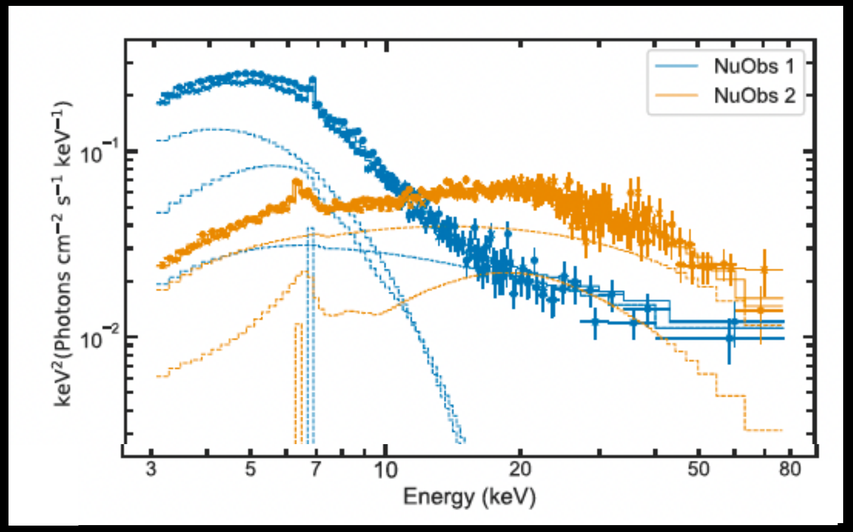
- So do GCs retain their BHs ?

MAXI J1848-015

- **X-ray binary**, discovered in outburst in **December 2020** by **MAXI** (Takagi et al. 20) (while the source was Sun-constrained for almost all other telescopes).



Pike et al. 2022



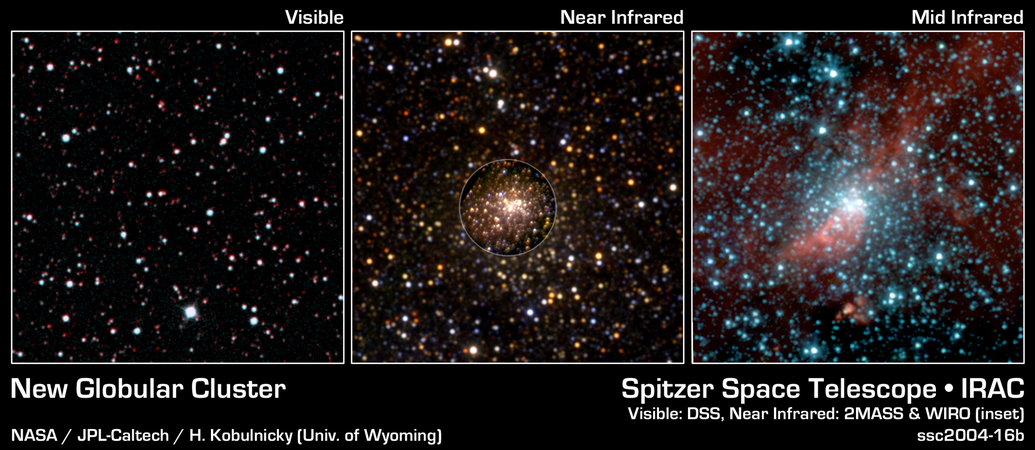
- **NuSTAR** observations (Pike et al. 2022) : State transition (soft, hard), relativistic reflection features, high spin (a = 0.967 +/- 0.013) —> **A black hole candidate ?**

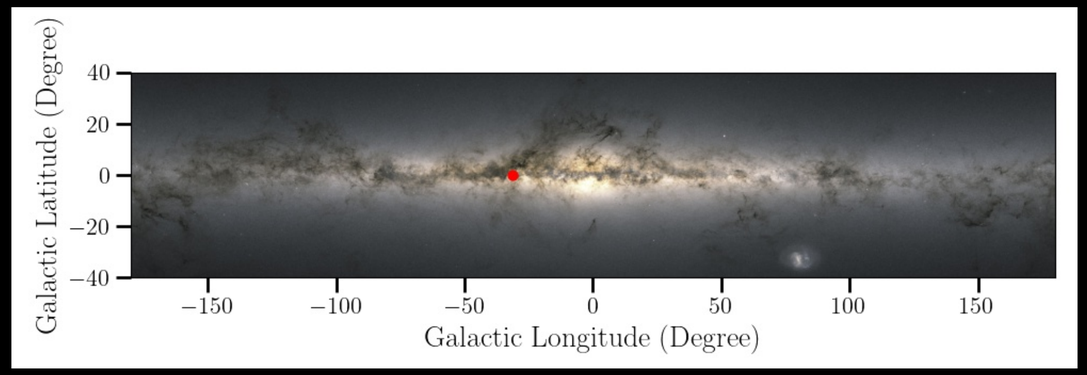
- Early February 2021: **Swift+Chandra** follow-up -> **located in the core of the cluster GLIMPSE-C01** but not coincident with any of the X-ray sources (e.g. Chakrabarty et al. 21).

- Short duration outburst. Radio counterpart (Tremou et al. 21) —> likely radio jets

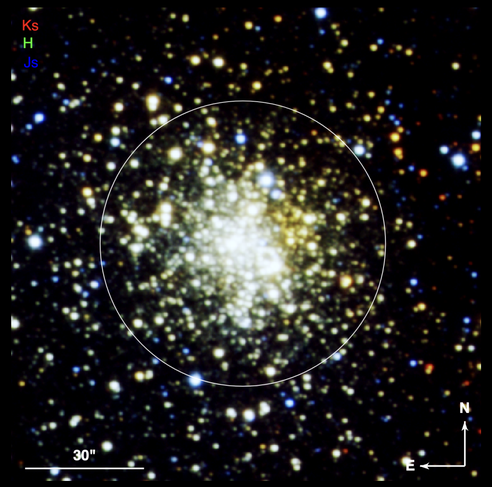
GLIMPSE-C01

- **GLIMPSE-C01**: A poorly understood globular cluster in the Galactic plane with Spitzer (Kobulnicky et al. 05).

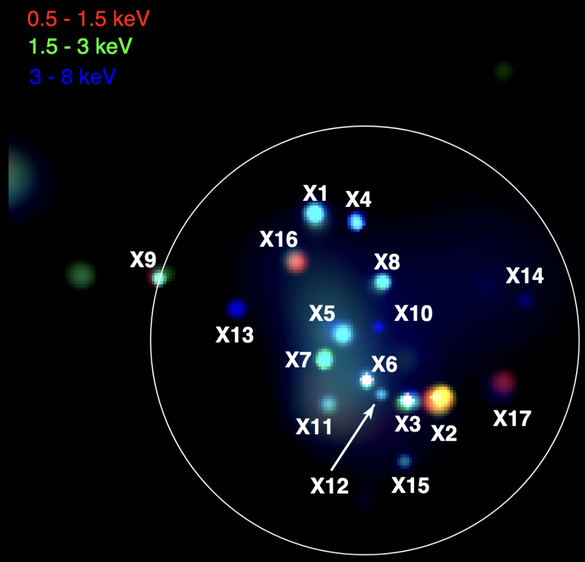




- Distance from us ~3.3 kpc , from the midplane ~ 6pc.
- Heavily extinguished (Av ~15 mag.), ~10^5 $M_\odot$
- Large population of X-ray sources (Chandra)
- A GC passing through the Galactic plane ?
- More compact than typical GC
- A rare intermediate age cluster ?



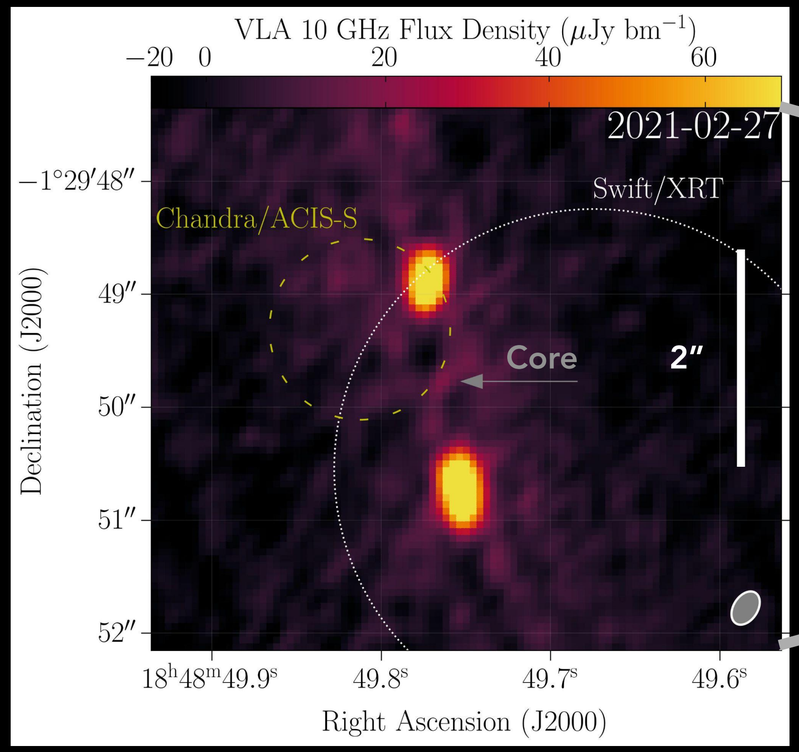
NNT-NIR
Ivanov et al. 2005

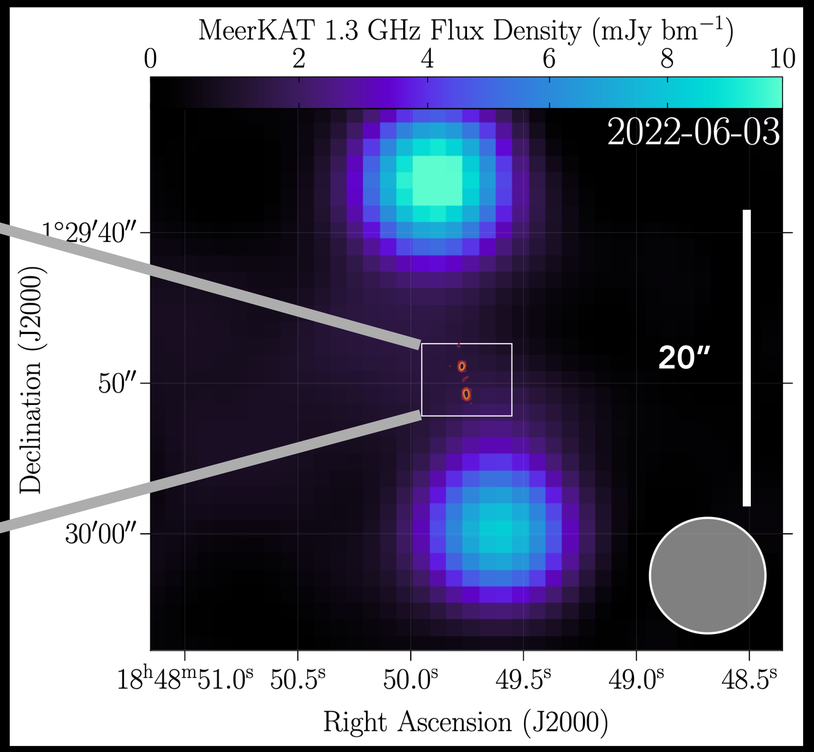


Chandra X-rays
Pooley et al. 2007

MAXI J1848-015

- Late February 2021: VLA observation, beginning of MeerKAT monitoring
- Detection of two moving jets over more than 2 years (still active)

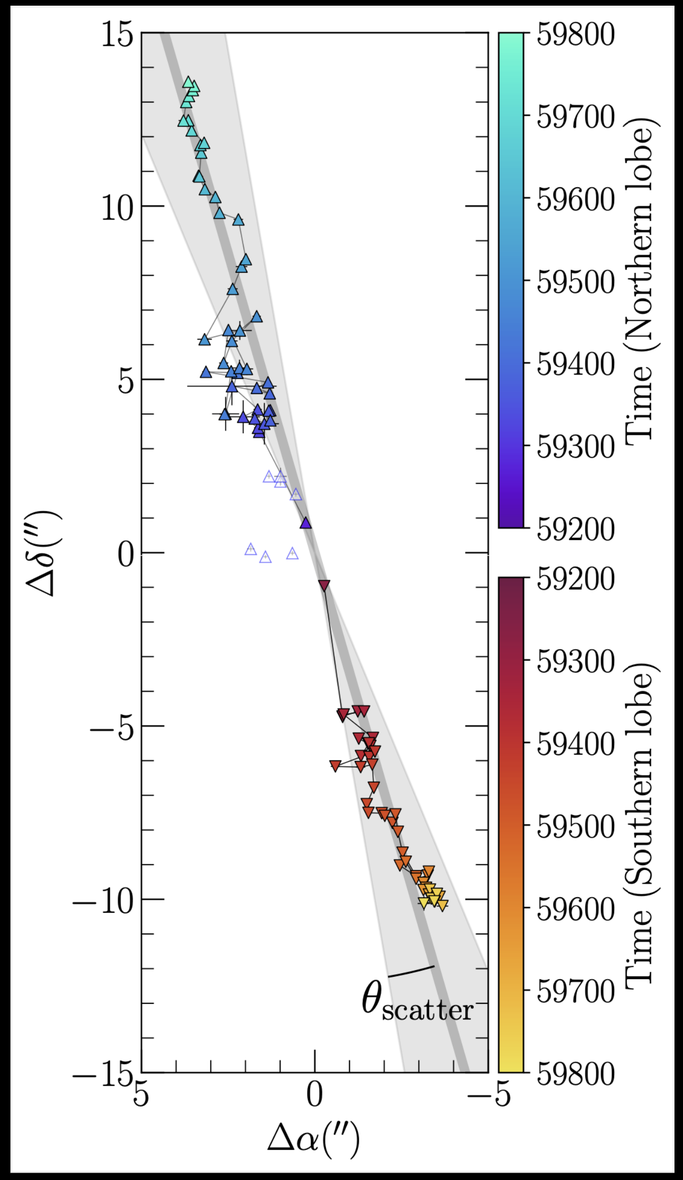


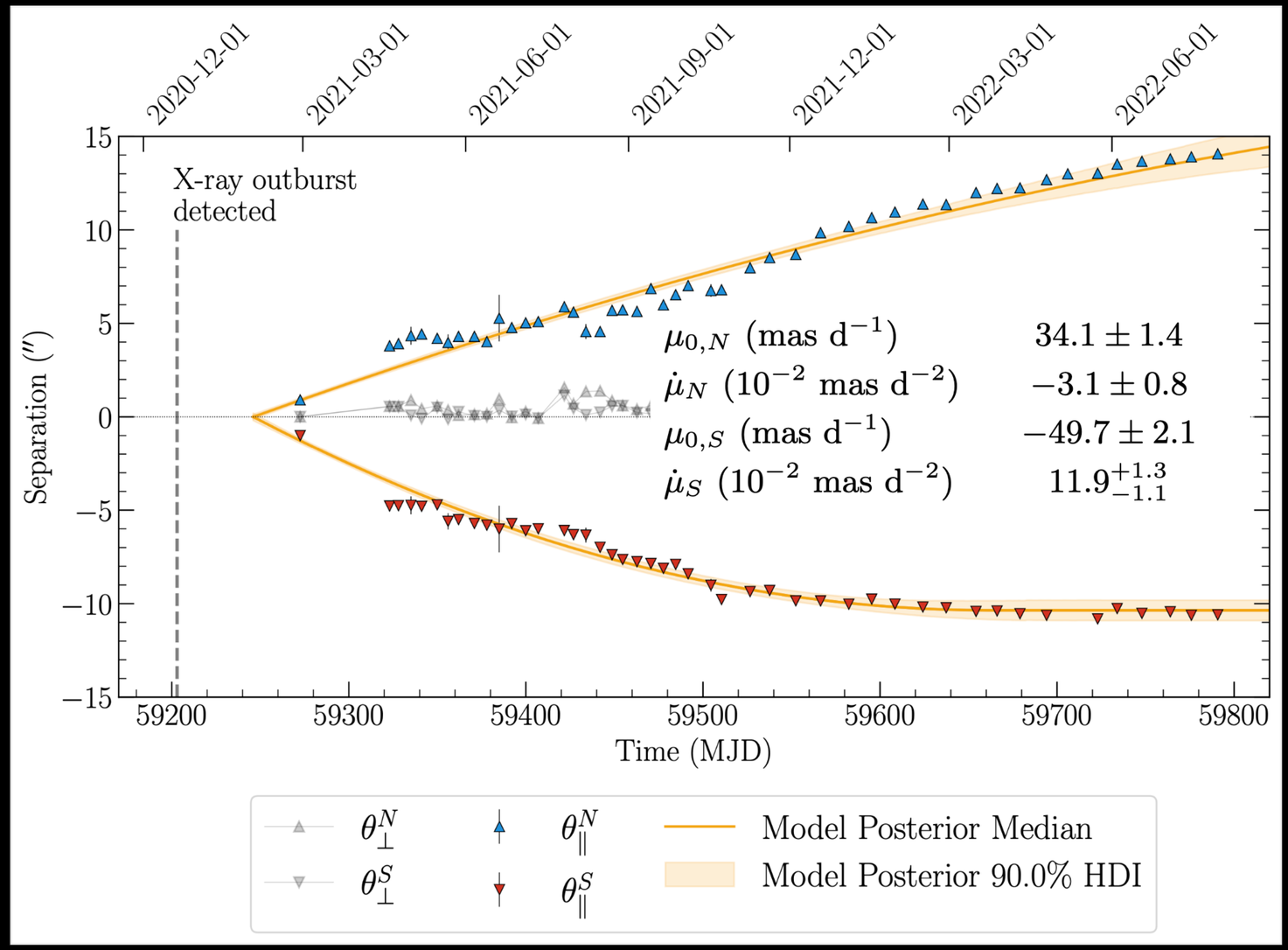


VLA A-config obs in Feb 2021

Bahramian et al., in press

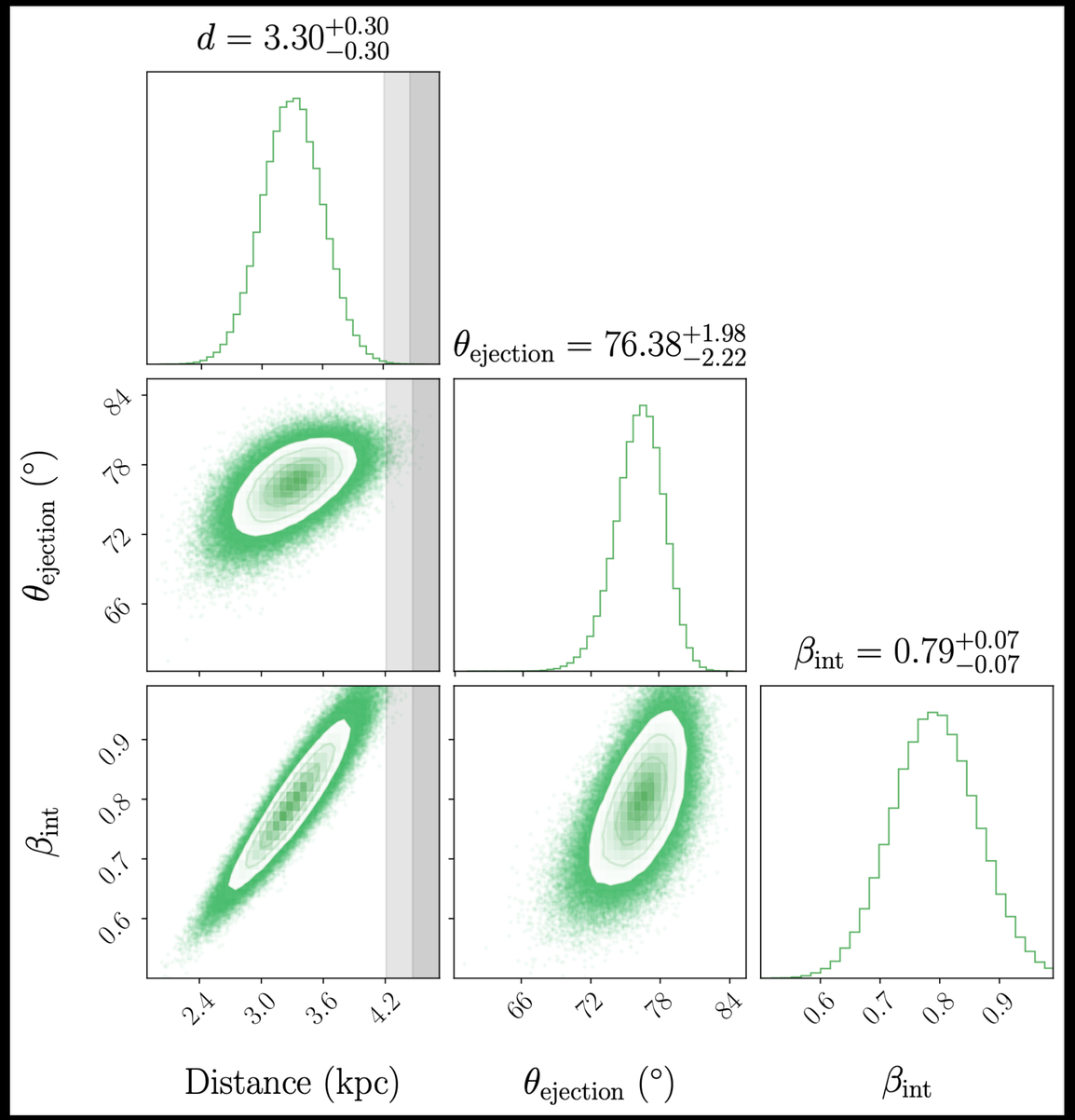
MODELLING THE JETS PROPER MOTION





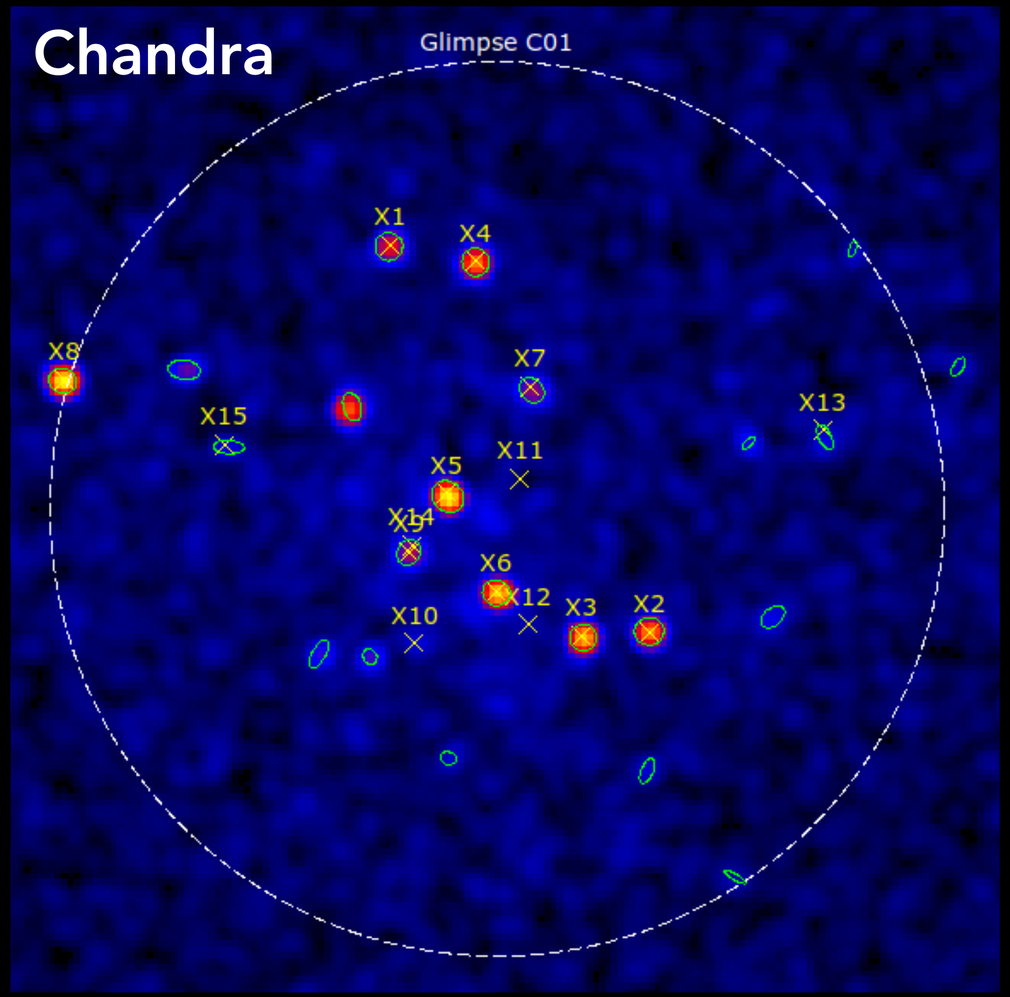
Bahramian et al., in press

- Max **distance** from the jets : 4.2 kpc
- Assuming 3.3 kpc (distance to Glimpse-01):
  - Jet angle: 76 degrees
  - **Intrinsic β = 0.79**
- First conclusions from the MeerKAT monitoring:
  - **First relativistic jets detected from an XRB in a GC (Bahamian et al. in press)**
  - Probing Jet-ISM interaction in an exotic environment
  - **Extended campaign with Chandra and VLA (4 to 18 GHz) (PI: Corbel) + archival Chandra data**

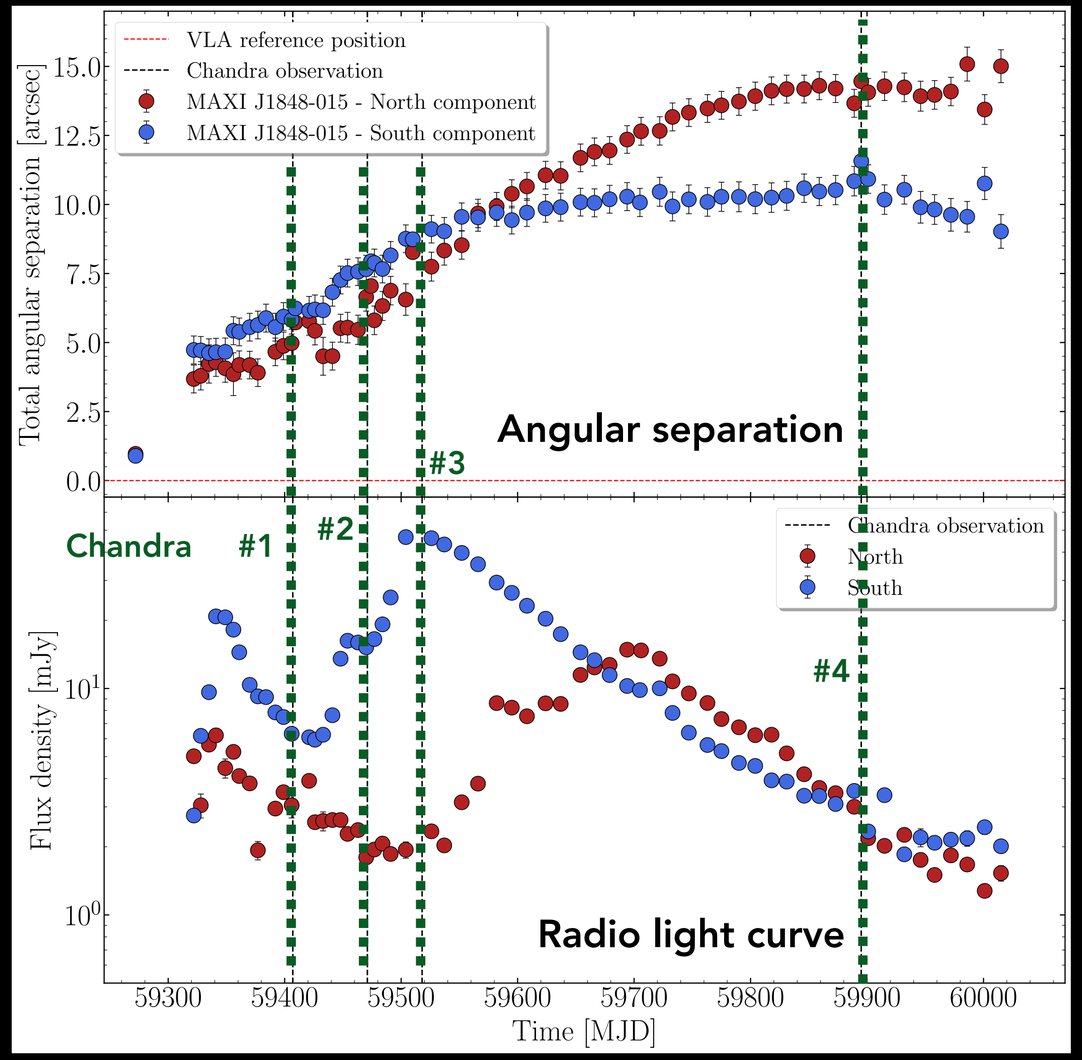


Bahramian et al., in press

GLOBAL CONTEXT OF THE CHANDRA/VLA CAMPAIGN



Archival 180 ks Chandra ACIS-S with X sources from Hare et al. (2018)
Some new X-ray sources, but no X-ray source at core location
New Chandra data registered to X1, X2, X3, X4 and X5 sources
Sub-pixel analysis

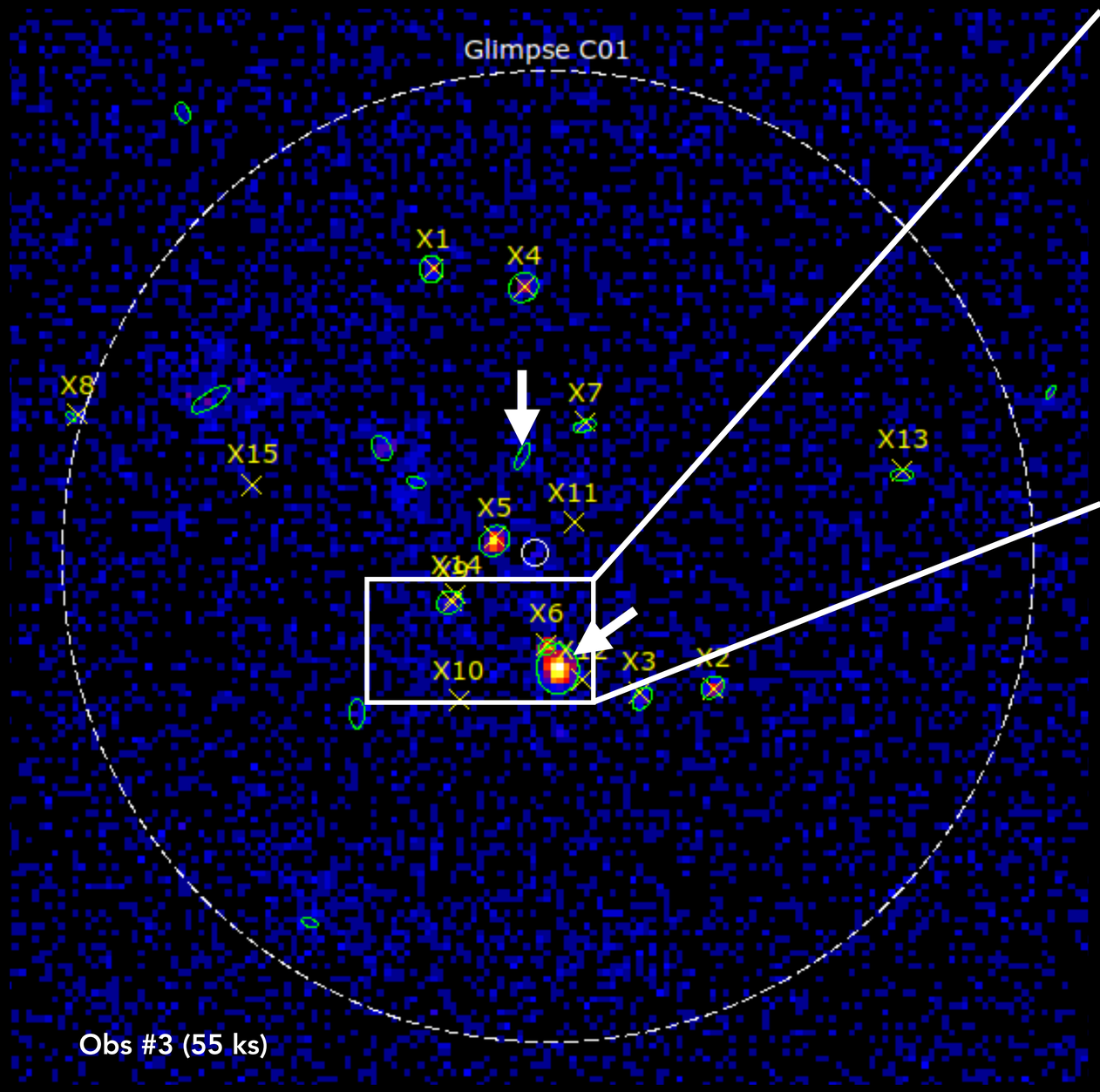


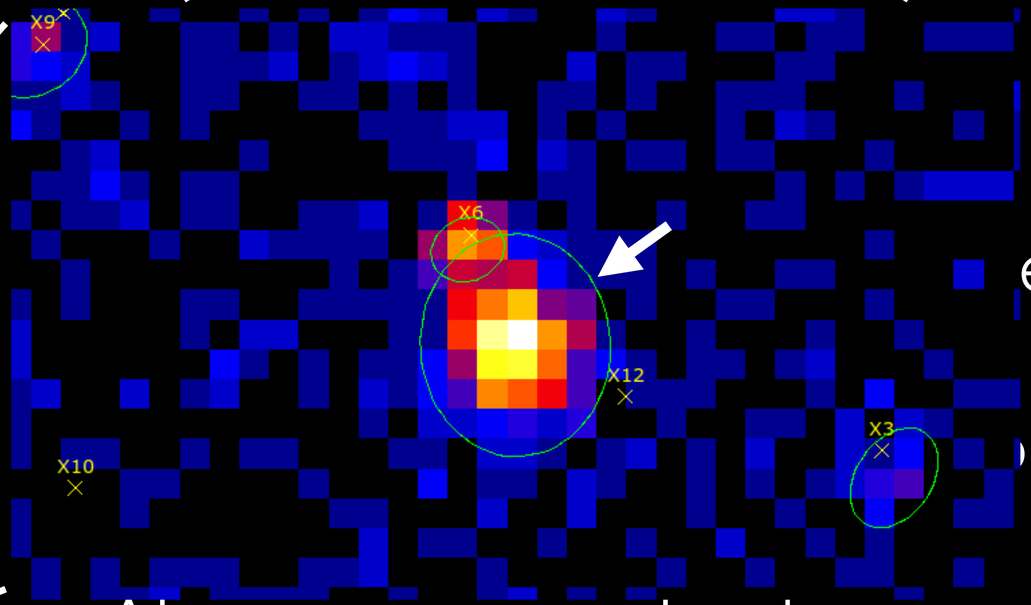
2021 2023

MeerKAT

Tremou et al. (in prep.)

MOVING X-RAY JETS (ONE EXAMPLE)





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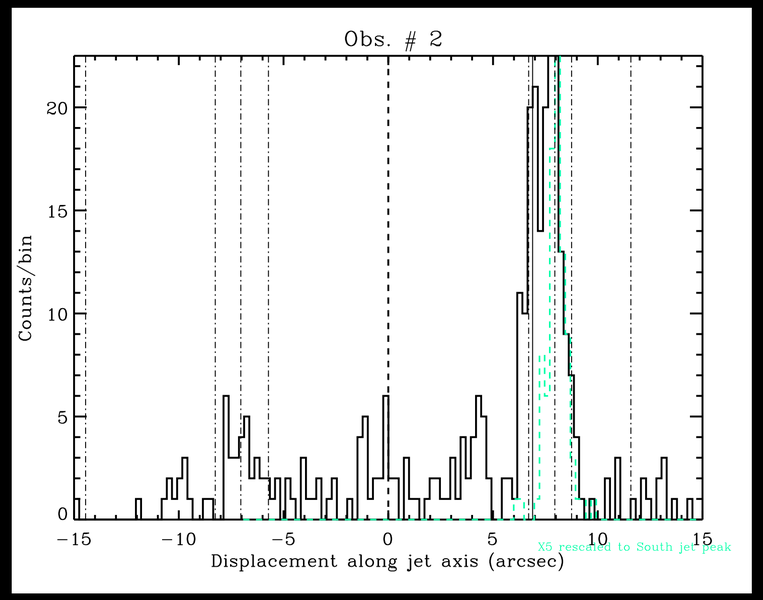
ources

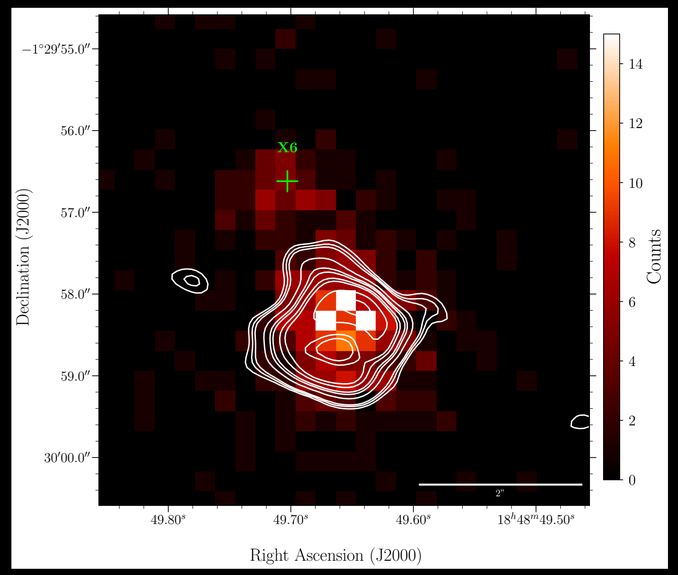
- Also appear resolved
- Discovery of moving X-ray sources associated with both radio jets, extended ?

Corbel et al. (submitted)

THE JETS ARE RESOLVED

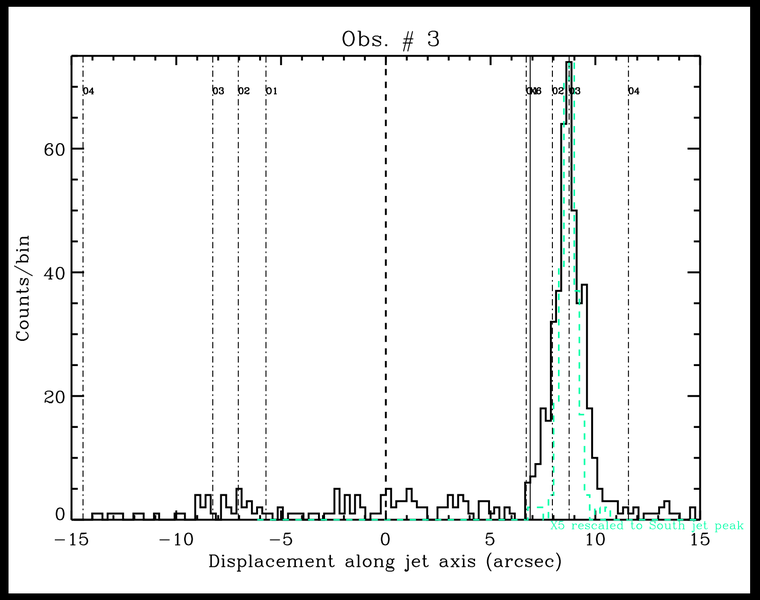
X-ray profile for South jet in Obs #2

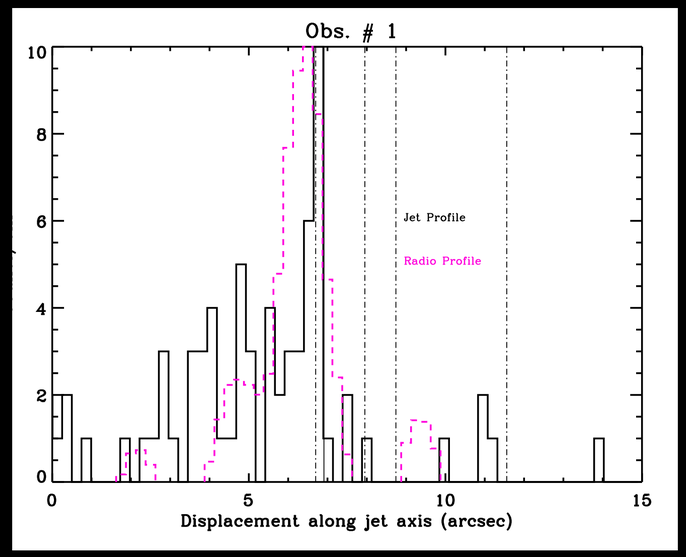




VLA / Chandra South Obs #3

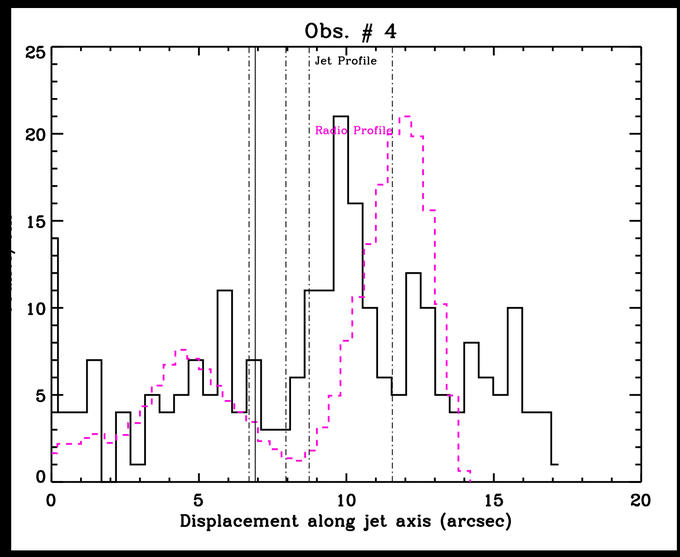
X-ray profile for South jet in Obs #3



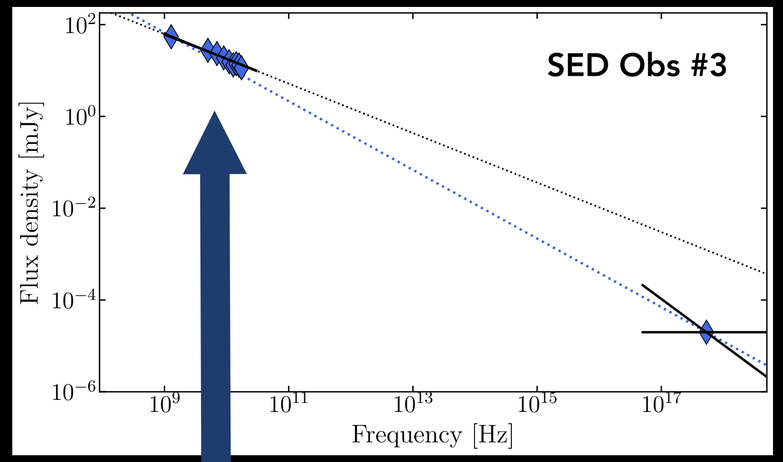


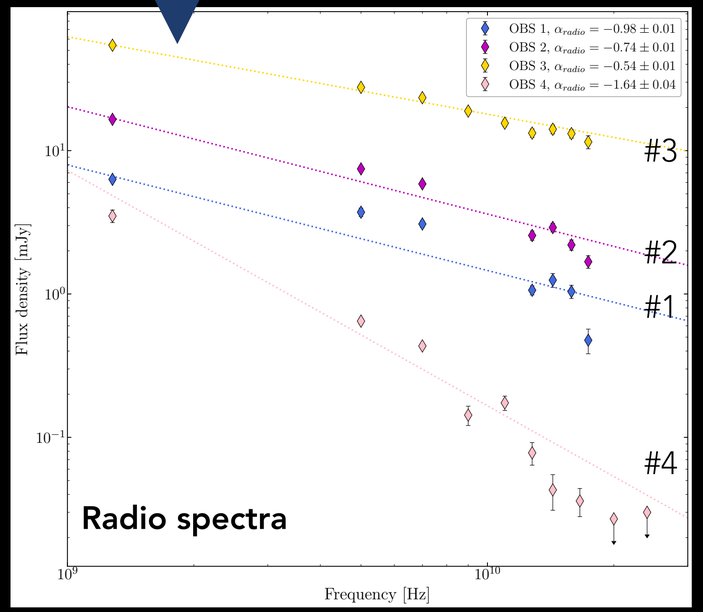
- X-ray jets = a head + a 3″ extended tail
- Complexe evolution of the radio to X-ray profiles

Corbel et al. (submitted)



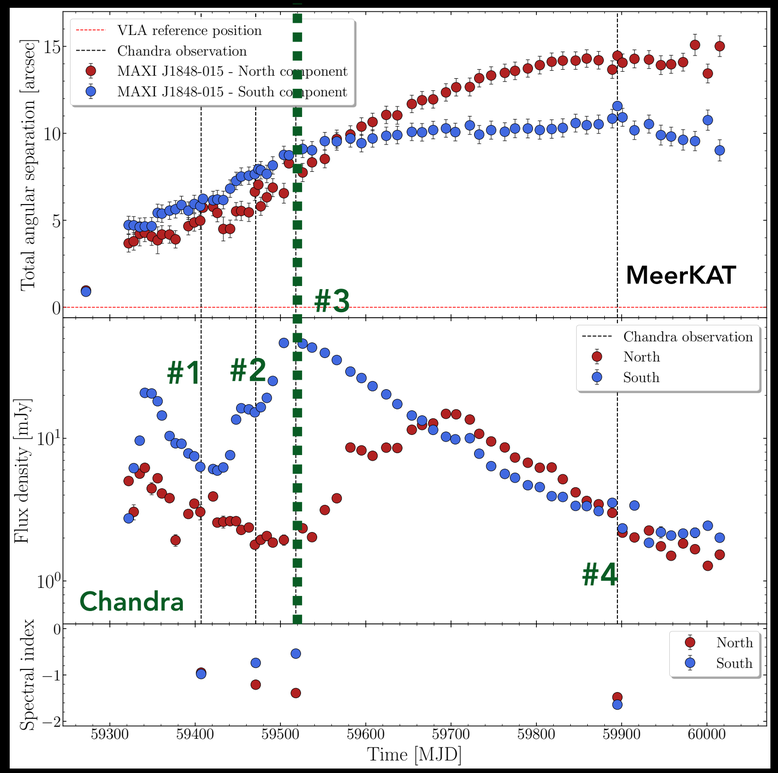
SED ON OBS #3 (SOUTH JET)





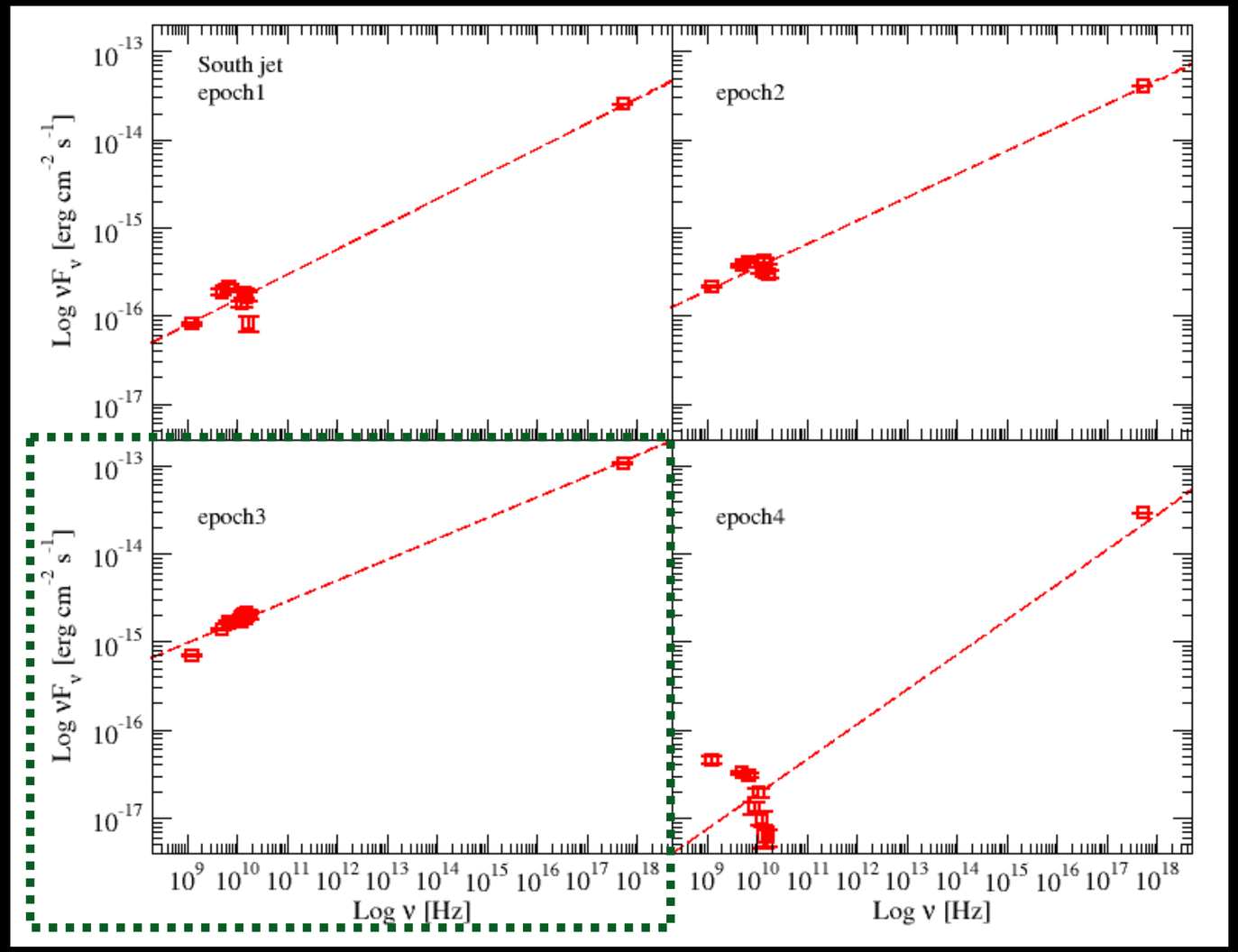
Corbel et al. (submitted)

- SED for Obs #3 is consistent with **synchrotron emission**
- Under **equipartition**:
  - Minimum internal energy ~10^{43} erg
  - Magnetic field ~0.5 mGauss
- X-rays synchrotron —> **electrons with E ~ 10s TeV**
- But some more **complicated and steep radio spectra** for the others observations and North jet



Tremou et al. in prep

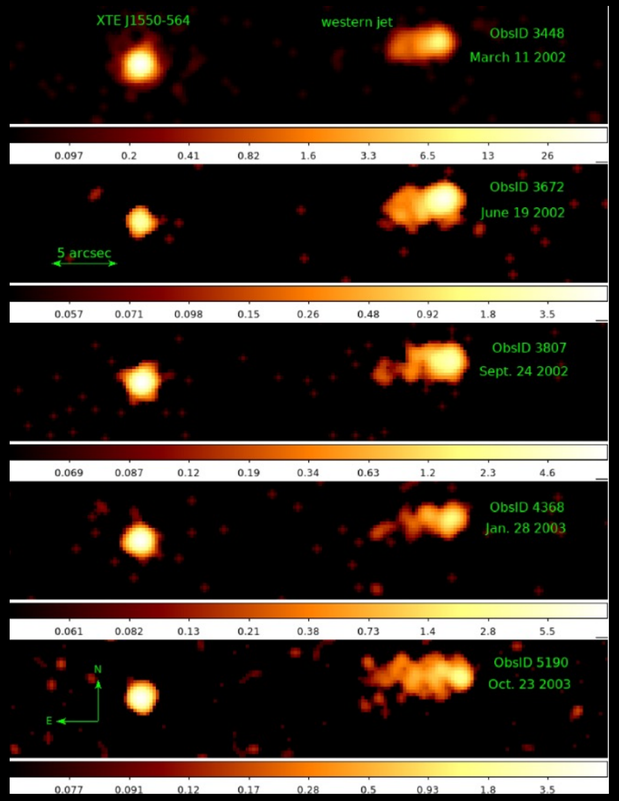
A MORE COMPLICATED SPECTRAL ENERGY DISTRIBUTION



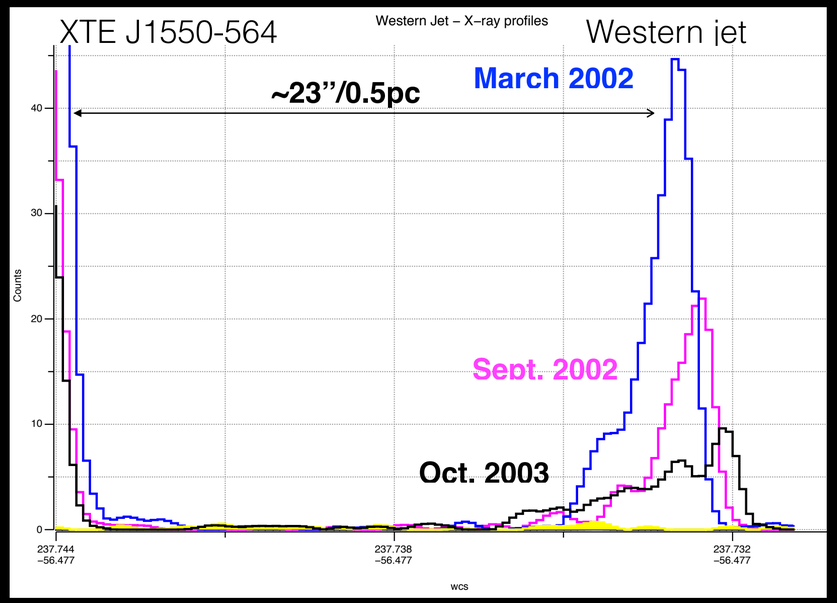
- SED consistent with synchrotron only for Obs #3 (South only): consistent with peak in radio lightcurve (max efficiency for particles acceleration)
- Other epochs:
  - X-rays SSC/IC unrealistic with SEDs (need U_e/U_B extremely high!)
  - Thermal X-rays also unlikely
  - May need 2 diff. populations of electrons, consistent with reverse and forward shocks

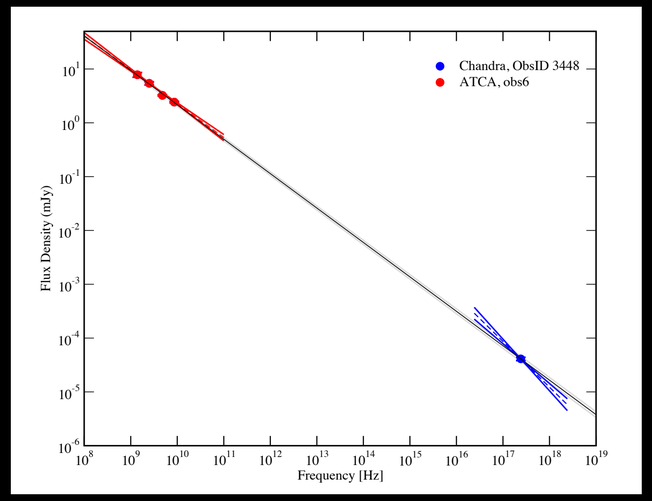
Corbel et al. (submitted)

COMPARISON WITH OTHER SOURCES

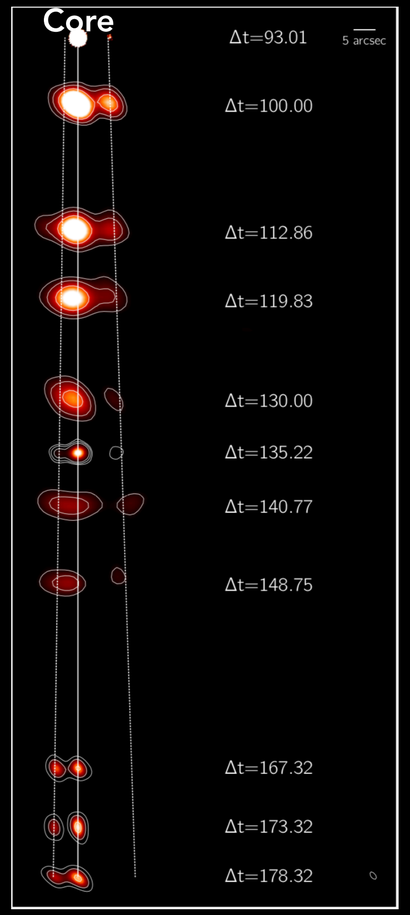


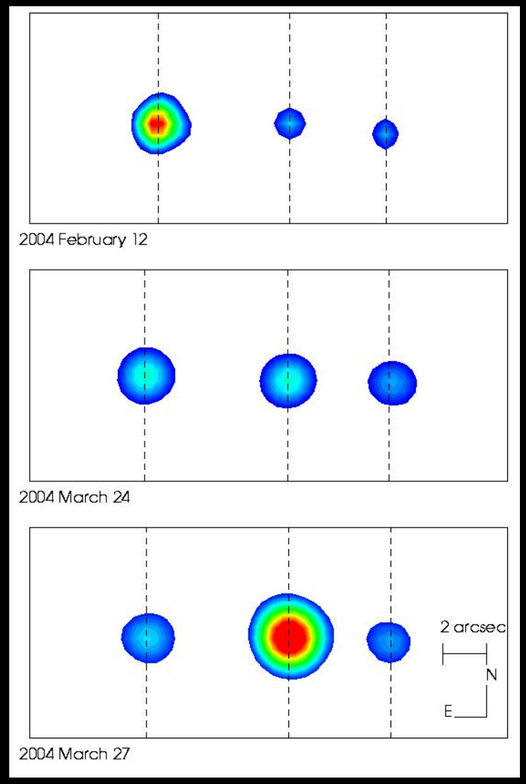
Corbel et al. 2002, Migliori et al. 2017





Bright et al. 2020





Corbel et al. 2005

Derived numbers (Obs #3) consistent with all previous examples, but differing behaviour for other dates

CONCLUSIONS

- **First relativistic jets detected from an XRB in outburst in a globular cluster**
- Further **indications for a black hole primary** for MAXI J1848-015 (no IMBH)
- **Relativistic jets interactions with environment** : particle acceleration up to TeV
- First time that such level of **variability** is observed in radio and X-rays in large scale jets with more **complex SED evolution** (frequent in GRB community).