RADIO OBSERVATIONS OF CIRCINUS X-1

The most relativistic jet source in our Galaxy

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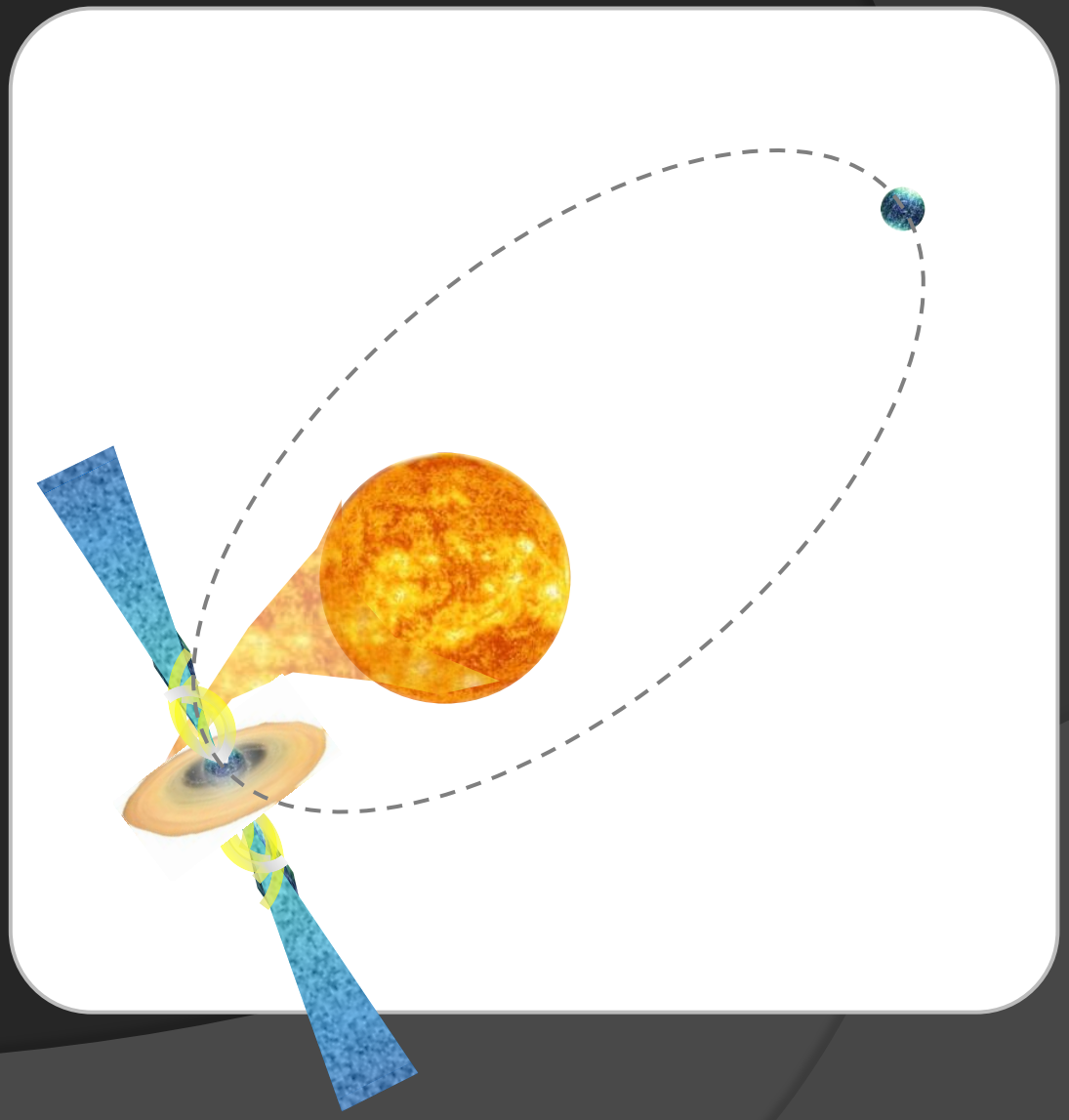
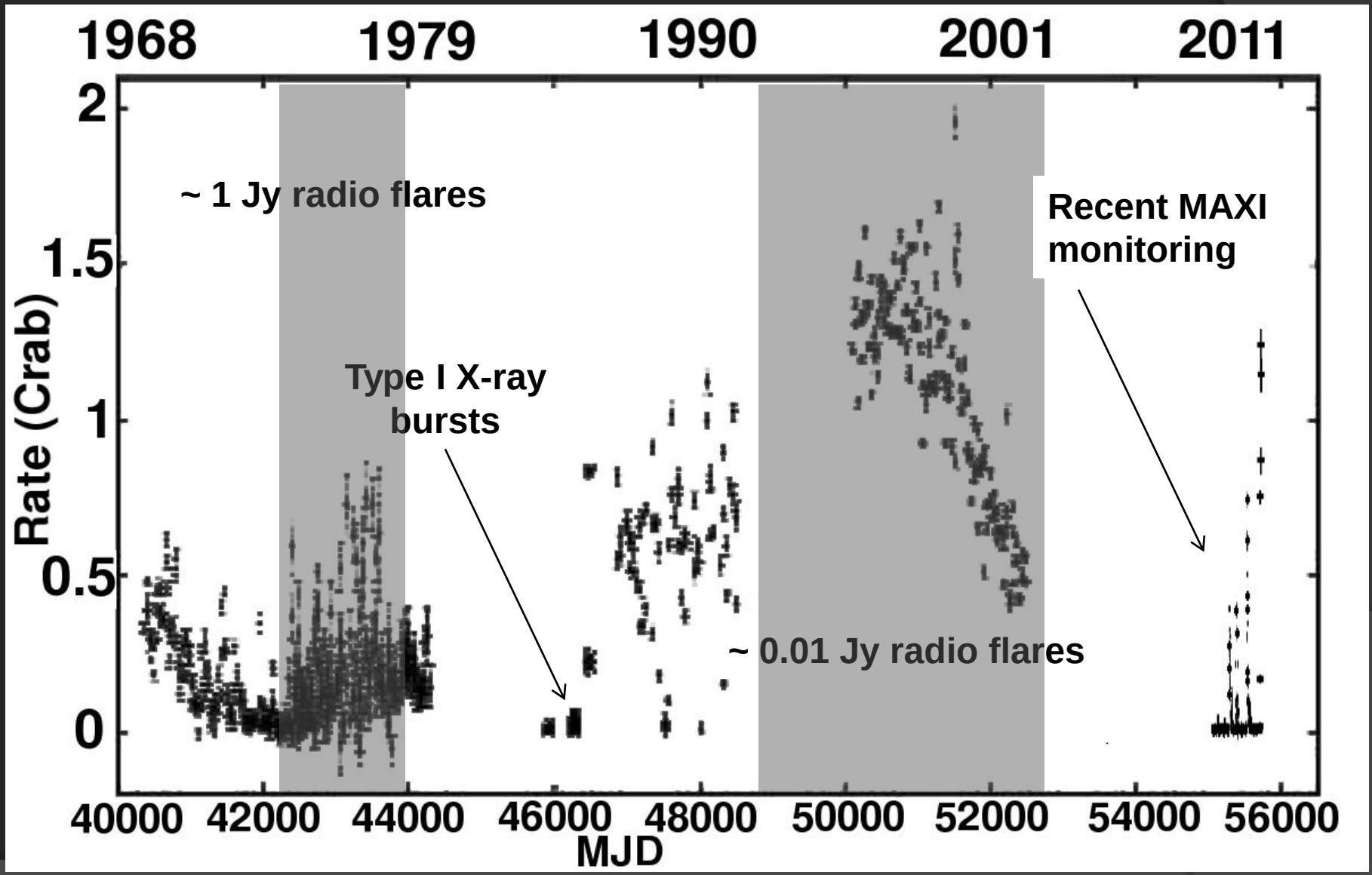
Circinus X-1

- Confirmed neutron star primary (X-ray bursts: Linares et al. 2010)
  - Secondary poorly constrained
- Eccentric orbit results in increased accretion rates at periastron
  - Triggers flare/enhanced jets
- Flare every ~16.5 days
  - Observed in X-ray, IR and radio
  - Steady decline to “quiescence” after most flares
  - Show a variety of intensities and profiles.



A brief history – long term variability



Parkinson et al. 2003; MAXI website; Haynes et al. 1978; Fender et al. 2005; Calvelo et al. 2010; Linares et al. 2010

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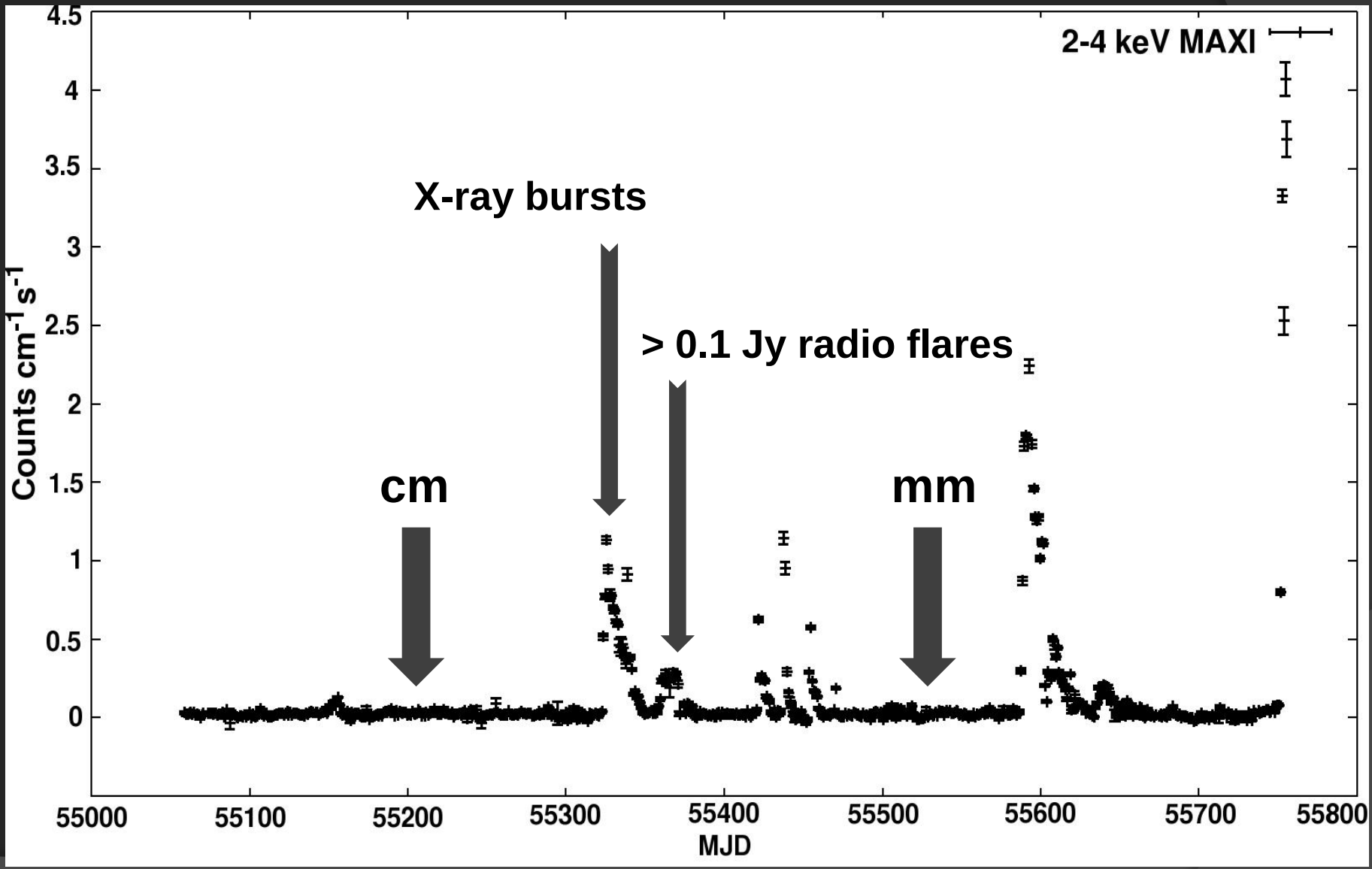
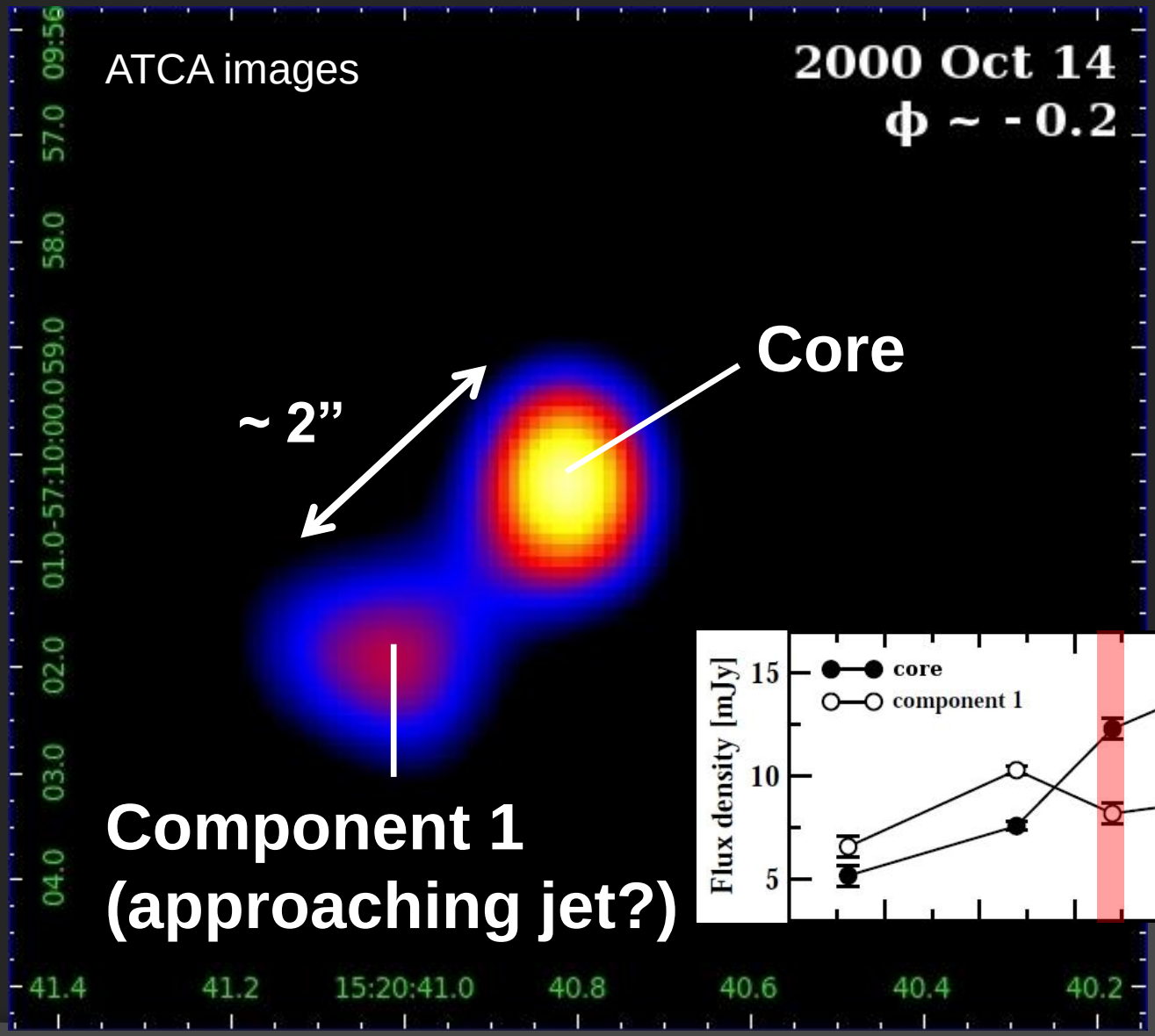


A brief history – radio images



(Fender et al. 2004; Tudose et al. 2008)

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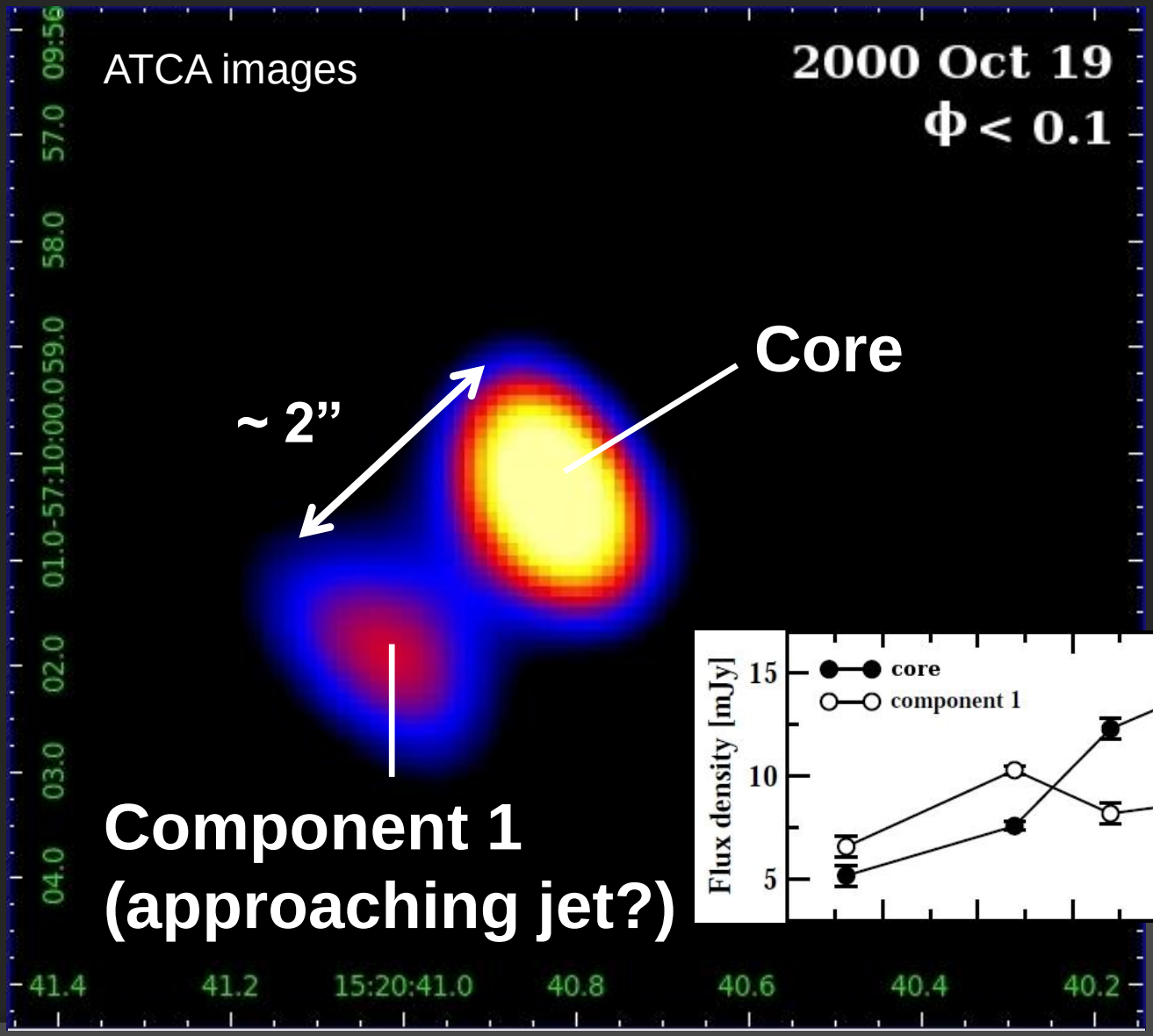

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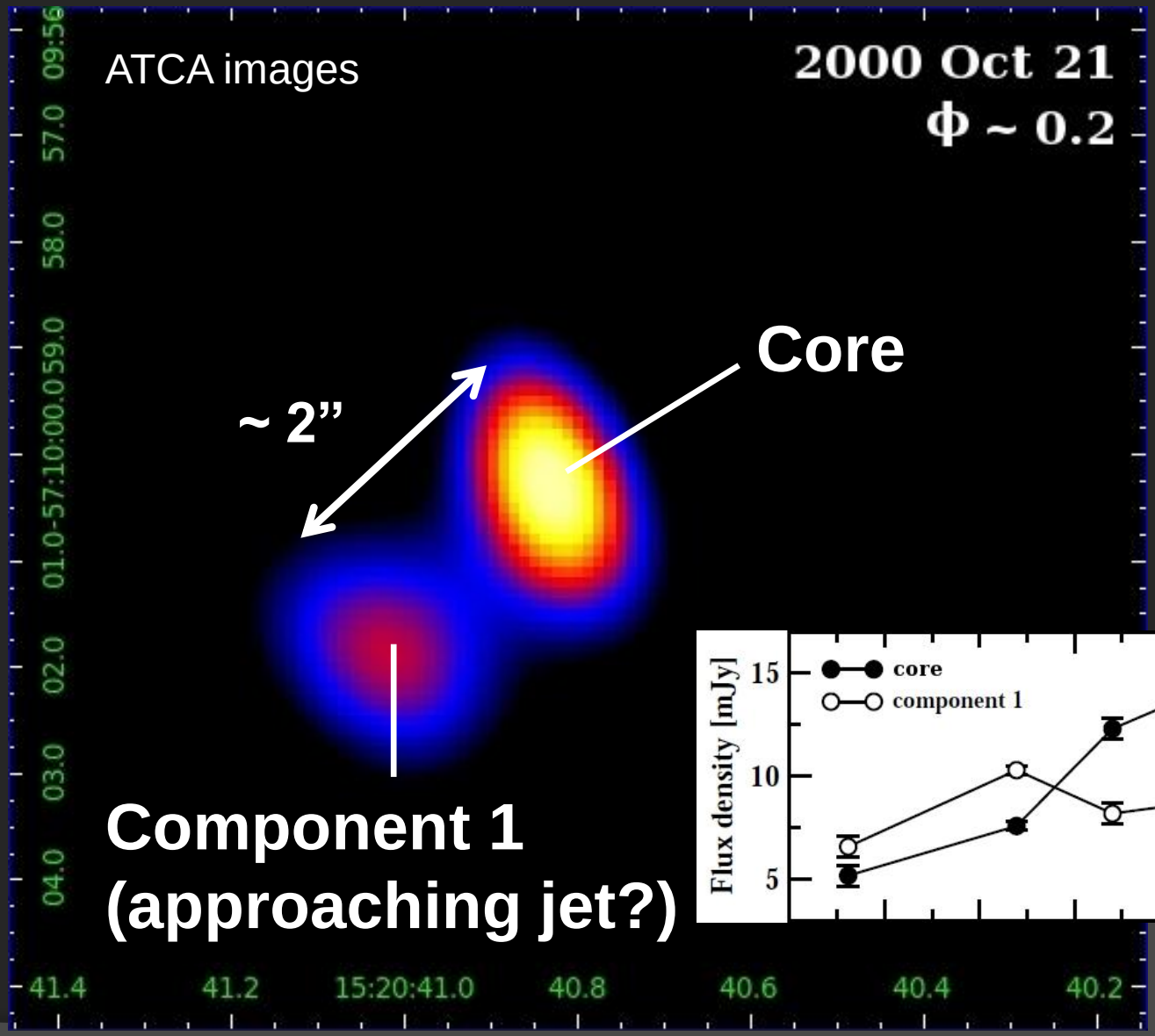
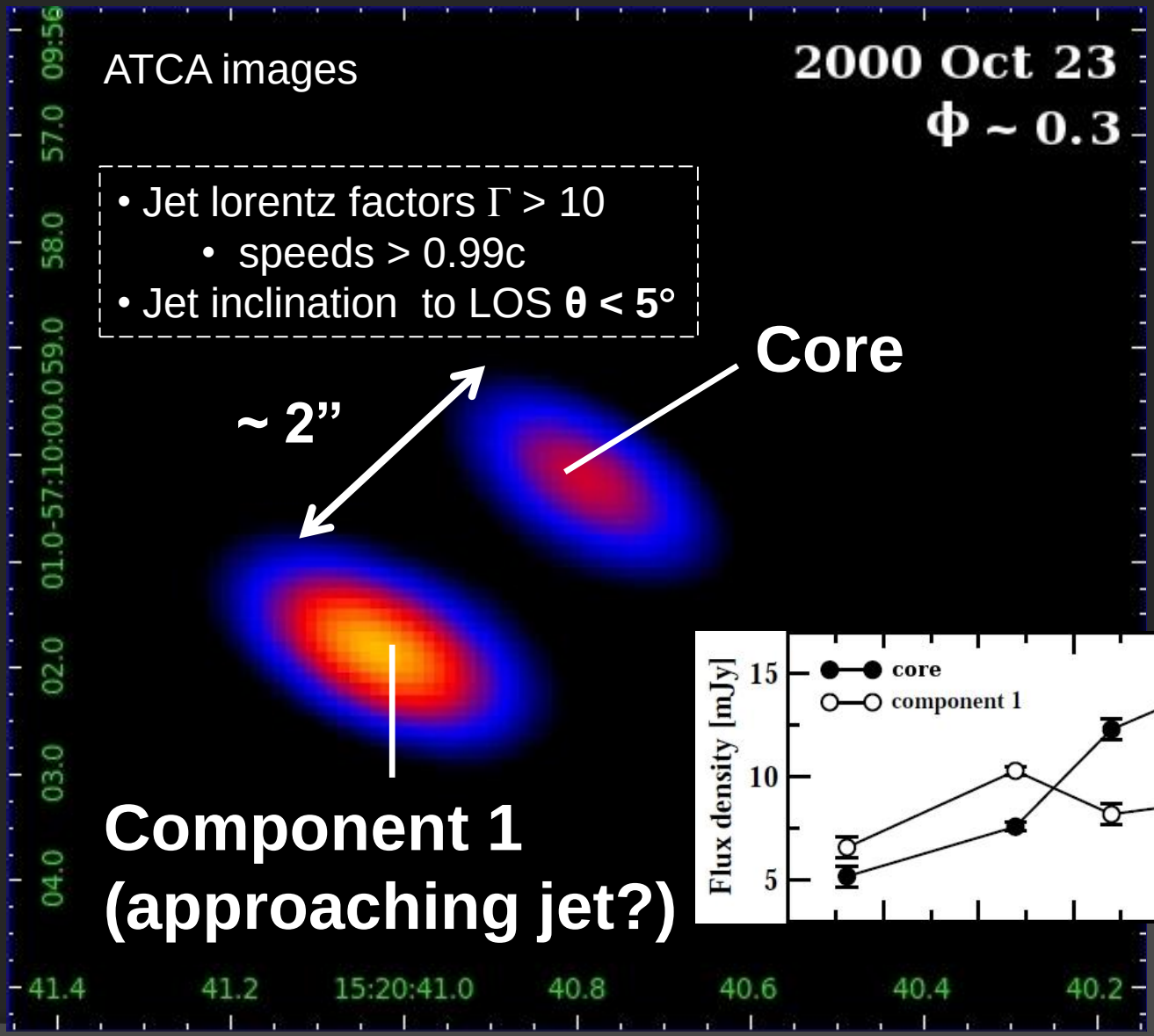


(Fender et al. 2004; Tudose et al. 2008)

A brief history – radio images

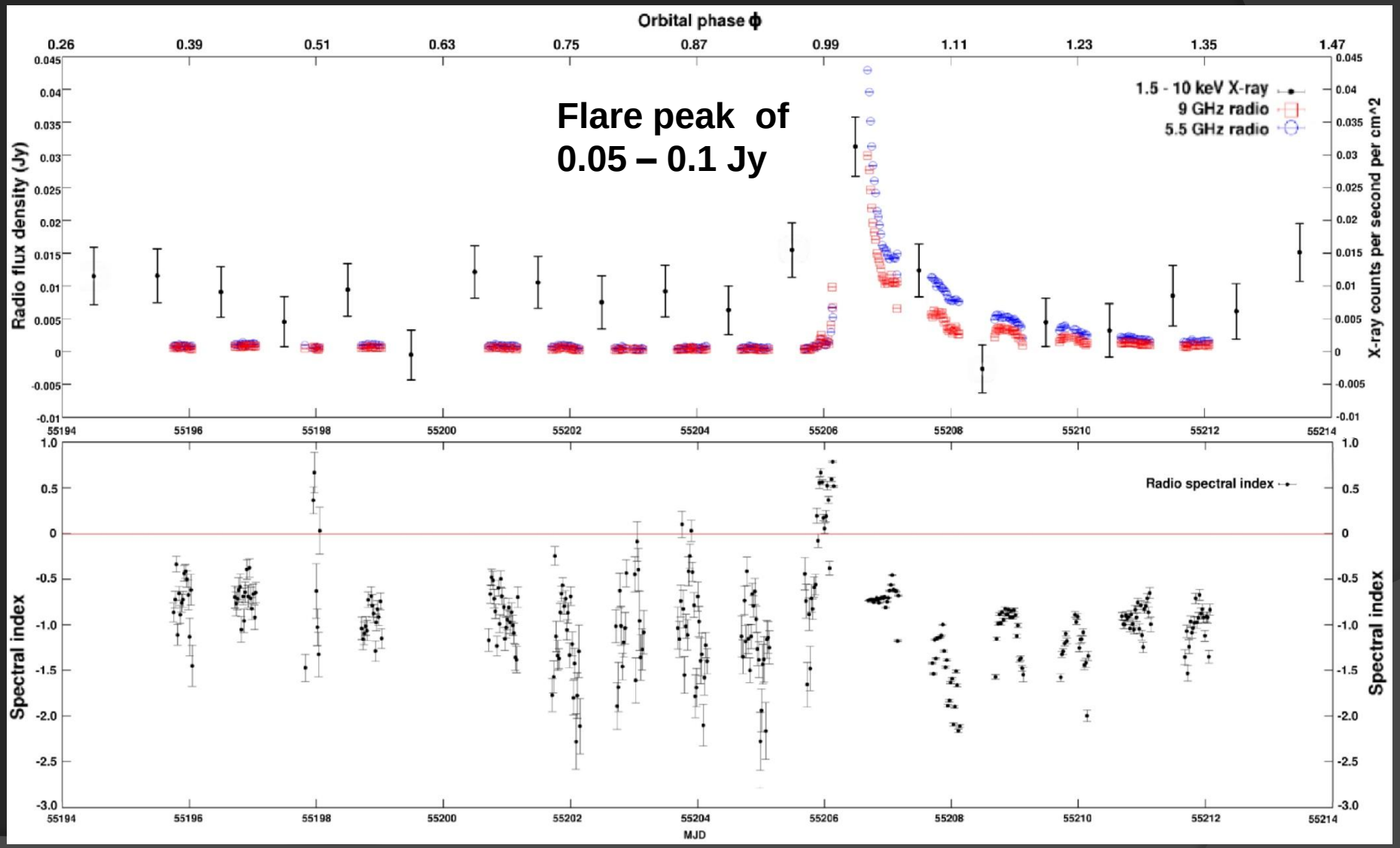


(Fender et al. 2004; Tudose et al. 2008)

A complete orbit during a faint epoch

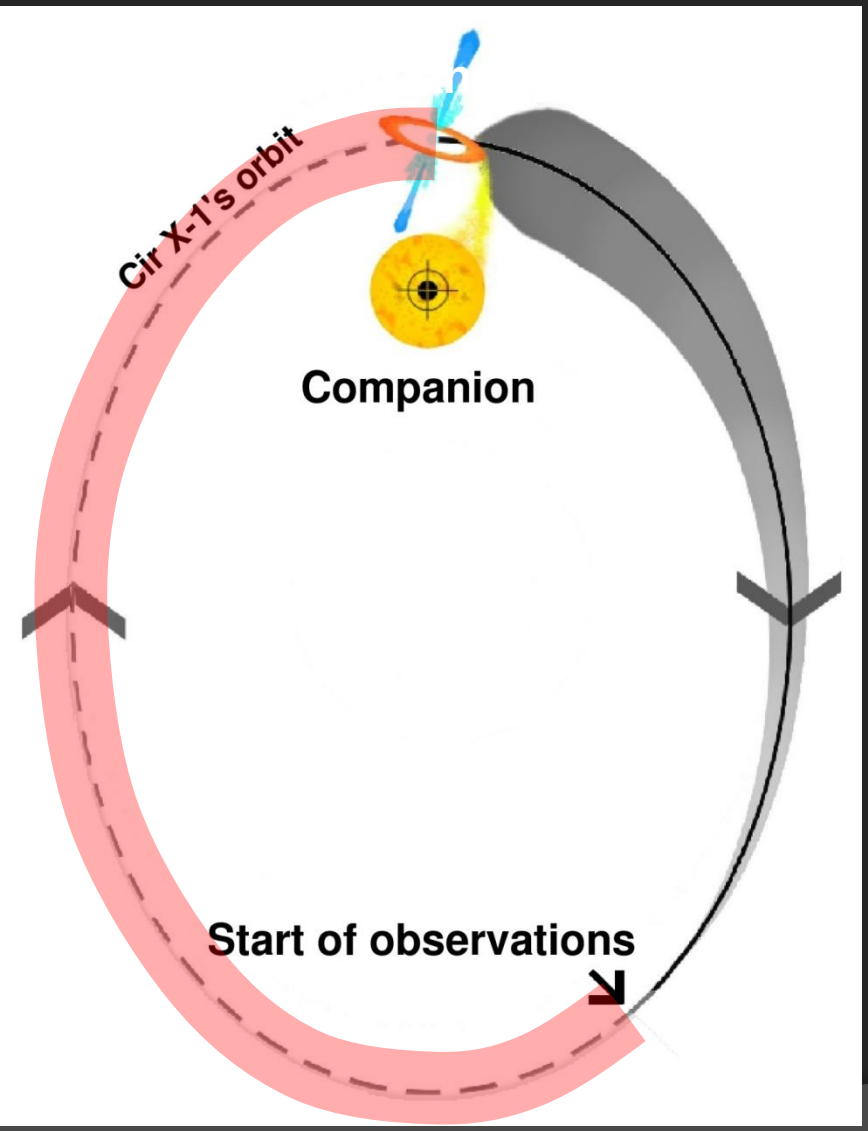
- An attempt to capture radio behaviour over a complete orbit
  - Using the upgraded ATCA – CABB
  - One 9-12 hour observation per day for 16 days (2009 Dec 30 – 2010 Jan 15, Jan 03 omitted)
    - Predicted image rms of < 10 of μJy (5.5 GHz) for a single day.
- Flare predicted to occur on ~ Jan 10
  - Limits our ability to probe the speed of flows from this flare to β apparent ~ 10
  - (Flare actually occurred earlier than expected – β apparent limit ~ 7)
- X-ray coverage via MAXI

Complete orbit light curves



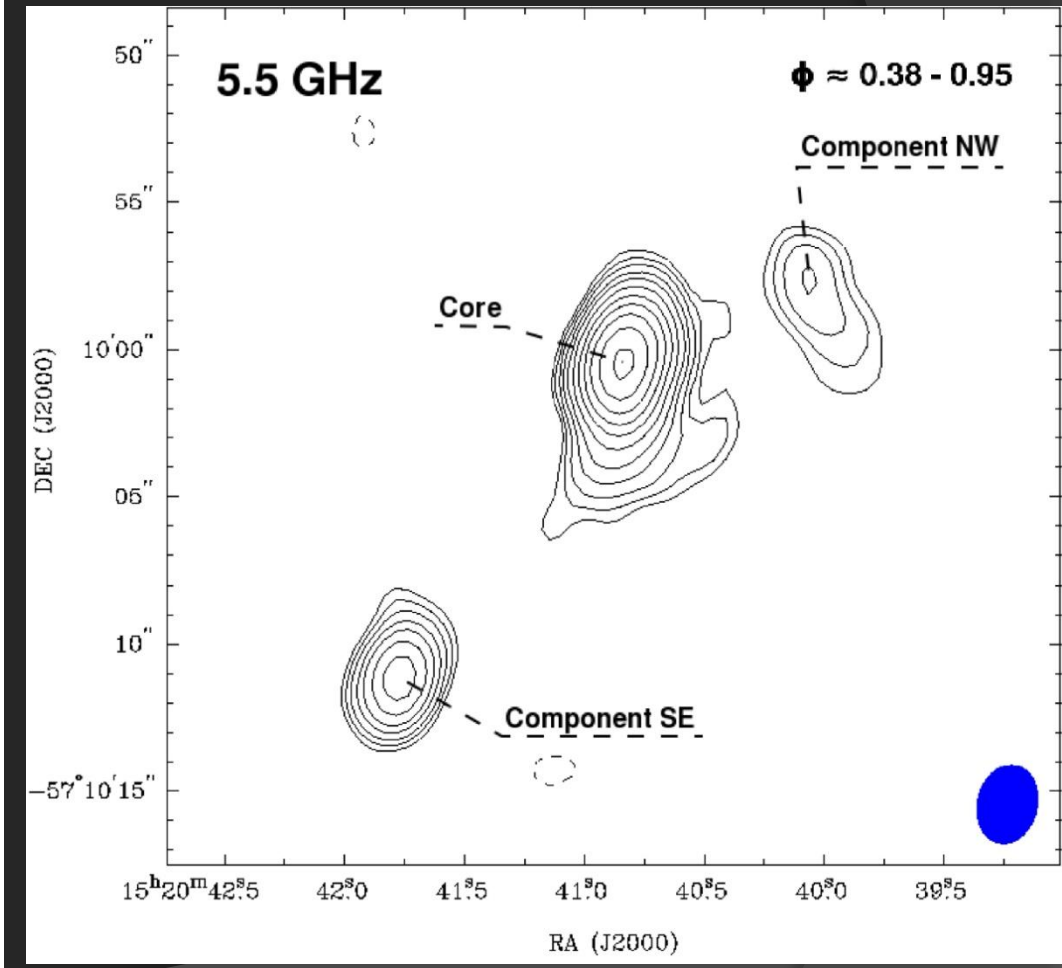
Calvelo et al. submitted

Radio map evolution (5.5 GHz)



Calvelo et al. submitted

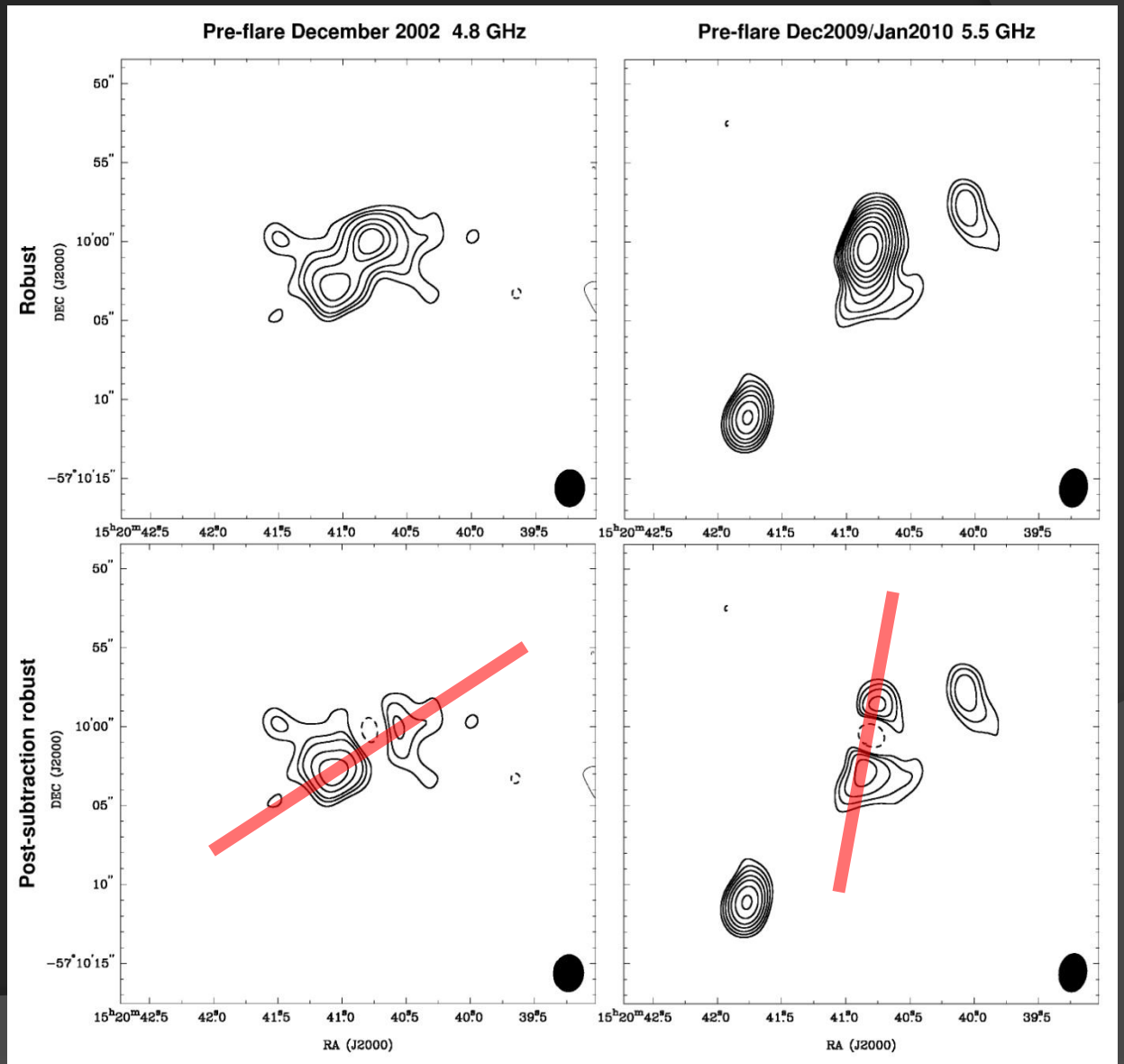
Contours = 3σ and up



8 day stacked deep map

Radio map evolution (5.5 GHz)

Evidence for a change in jet axis



Calvelo et al. submitted

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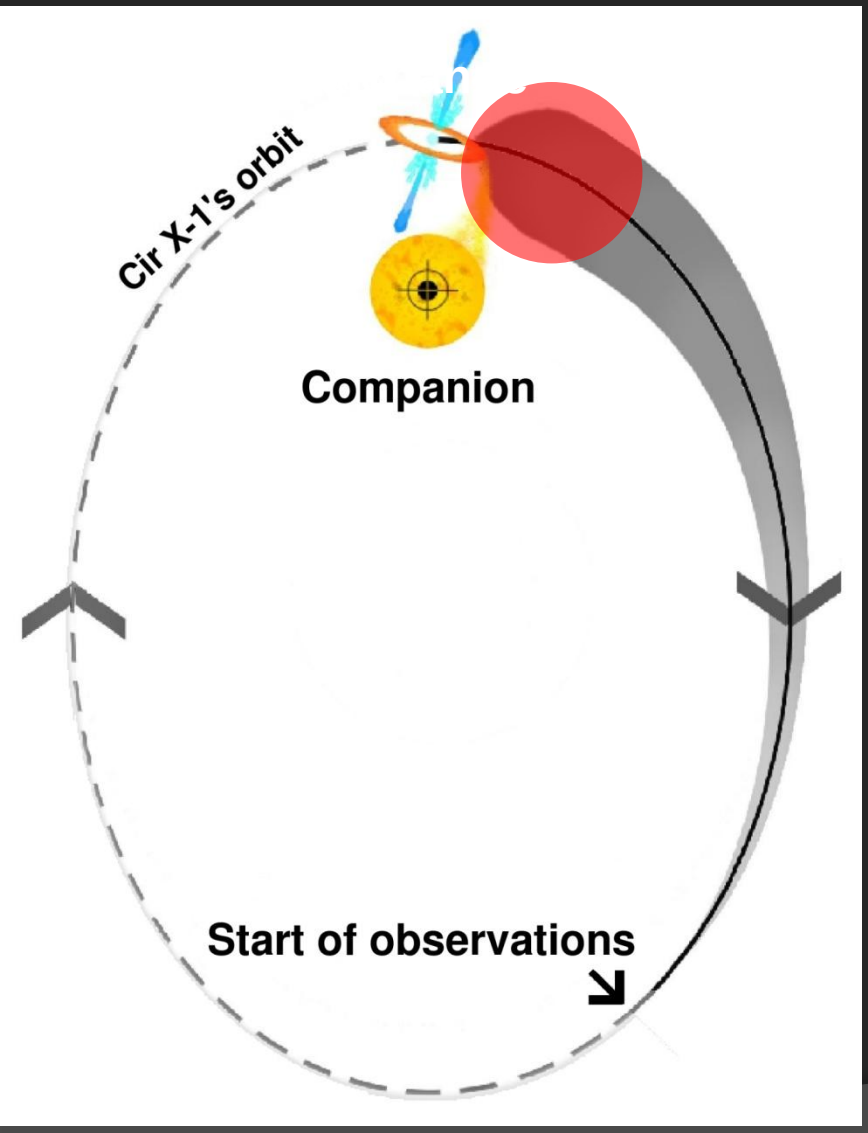

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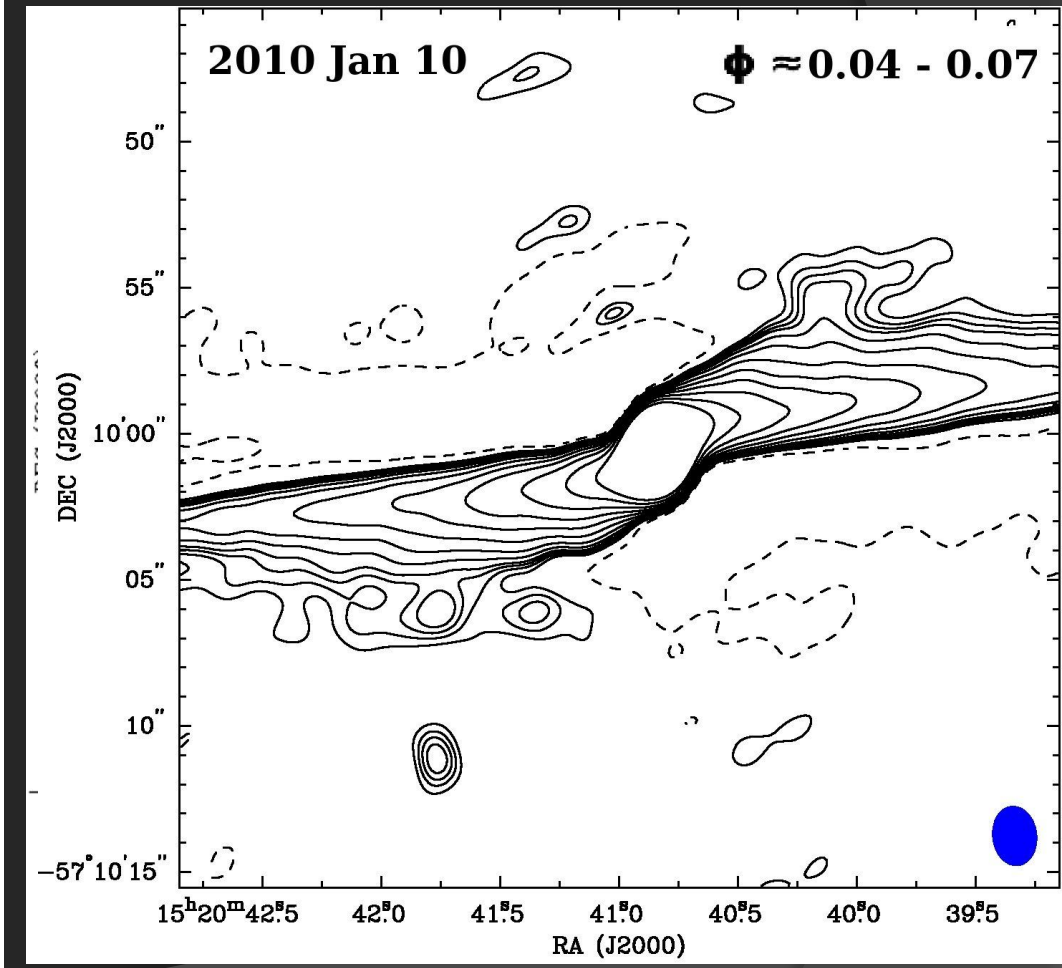
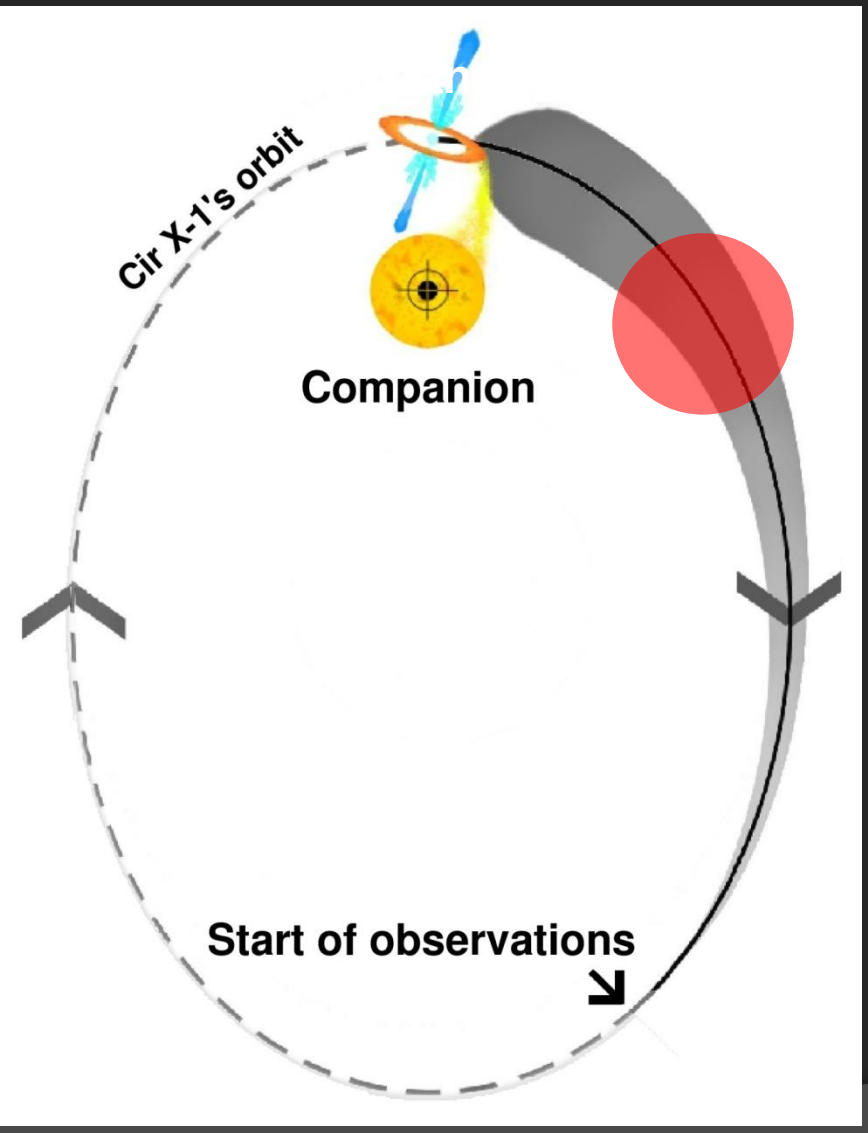


Flare artefacts

Calvelo et al. submitted

Radio map evolution (5.5 GHz)



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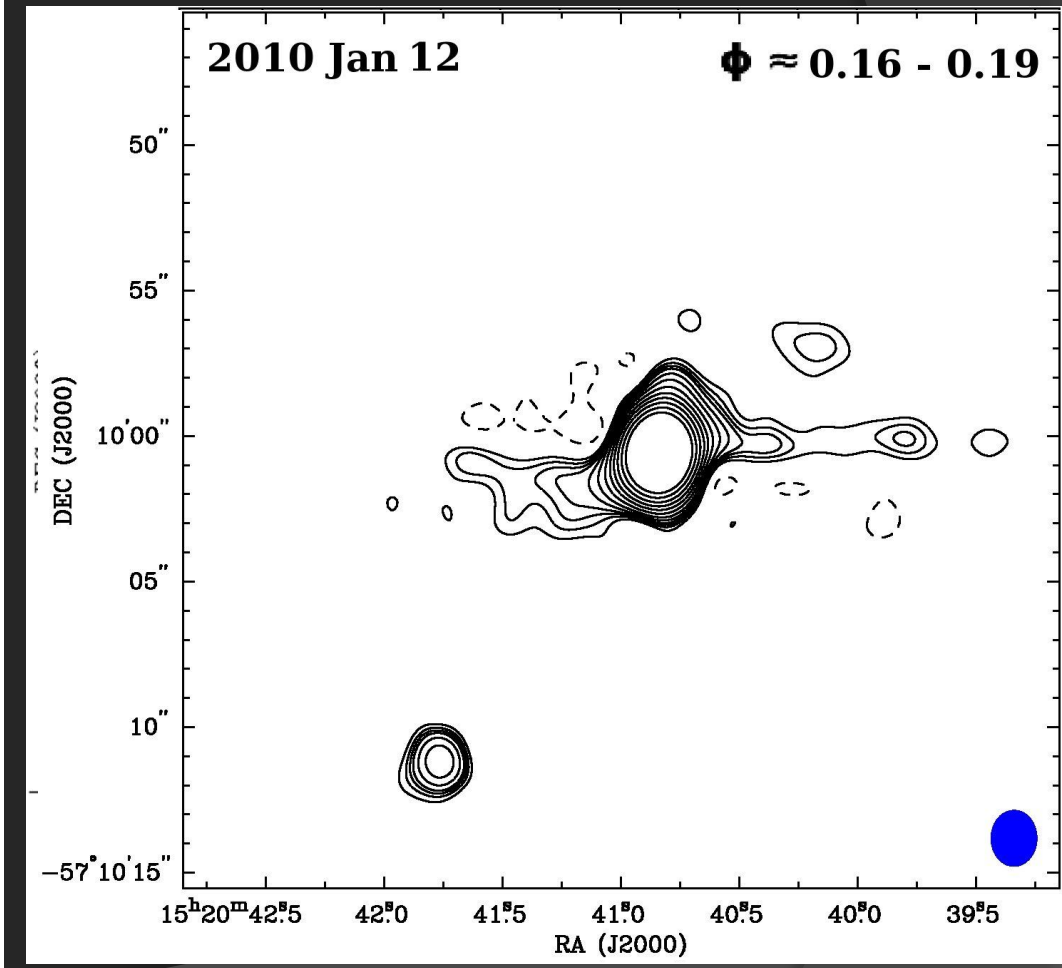

Calvelo et al. submitted

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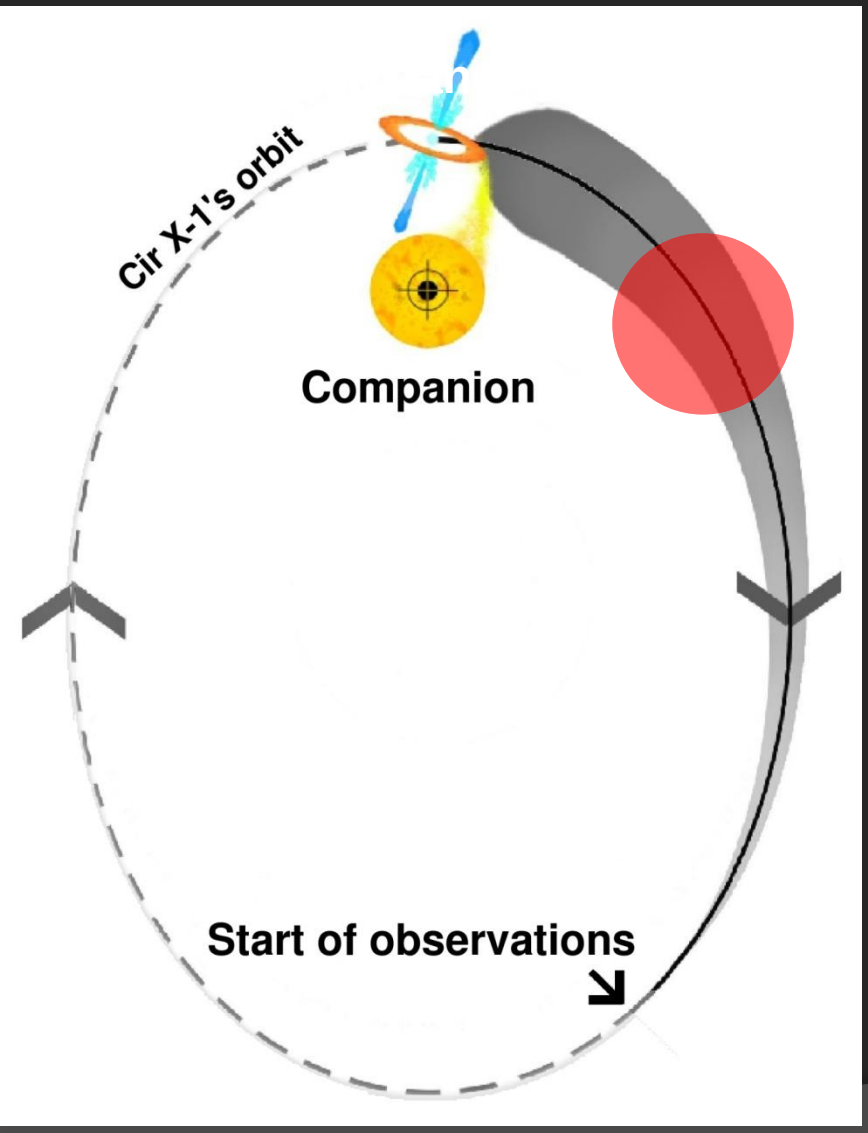

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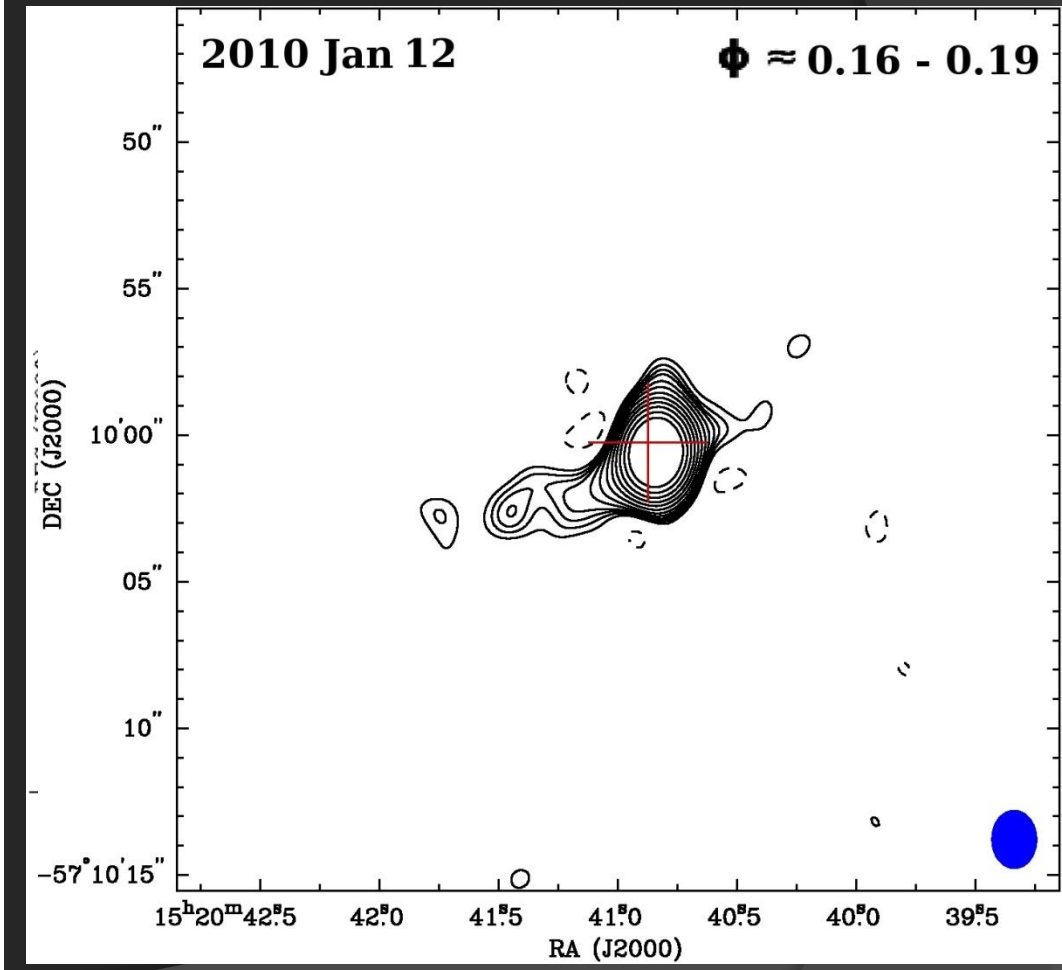
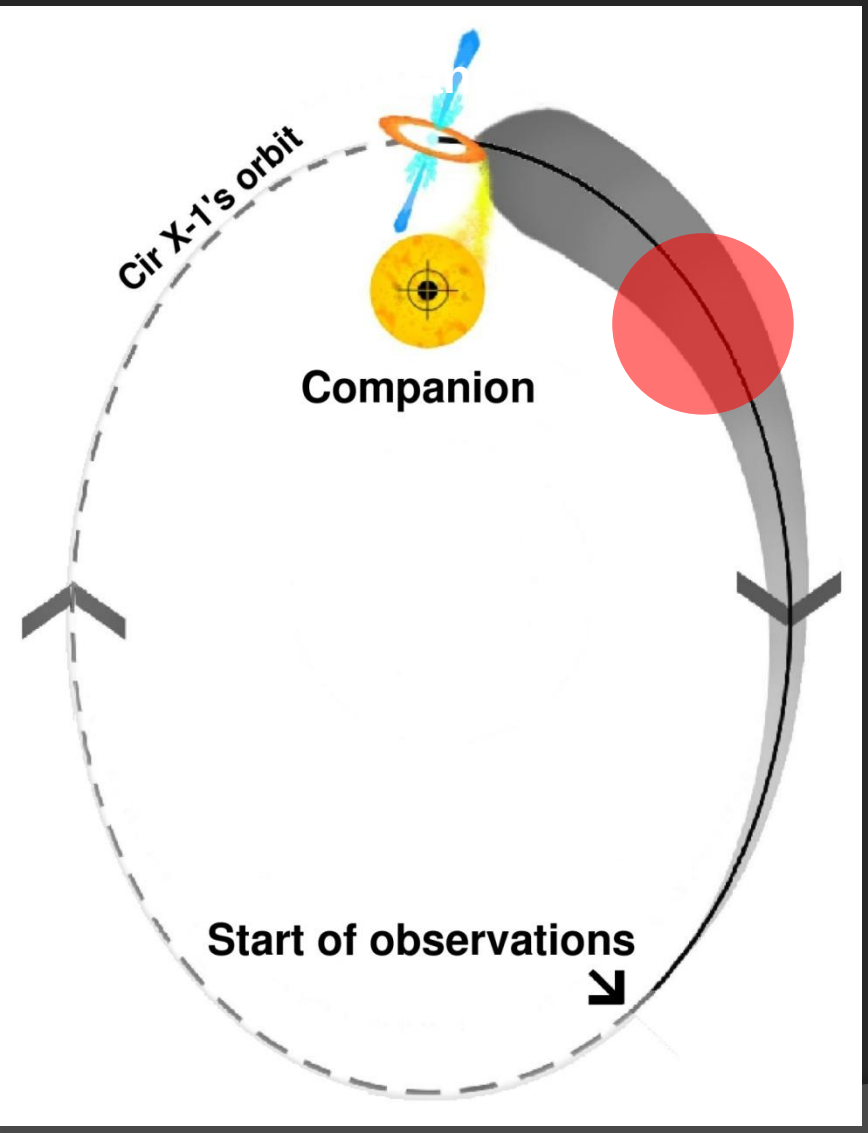


Data from Jan 04 subtracted

Radio map evolution (5.5 GHz)



Calvelo et al. submitted

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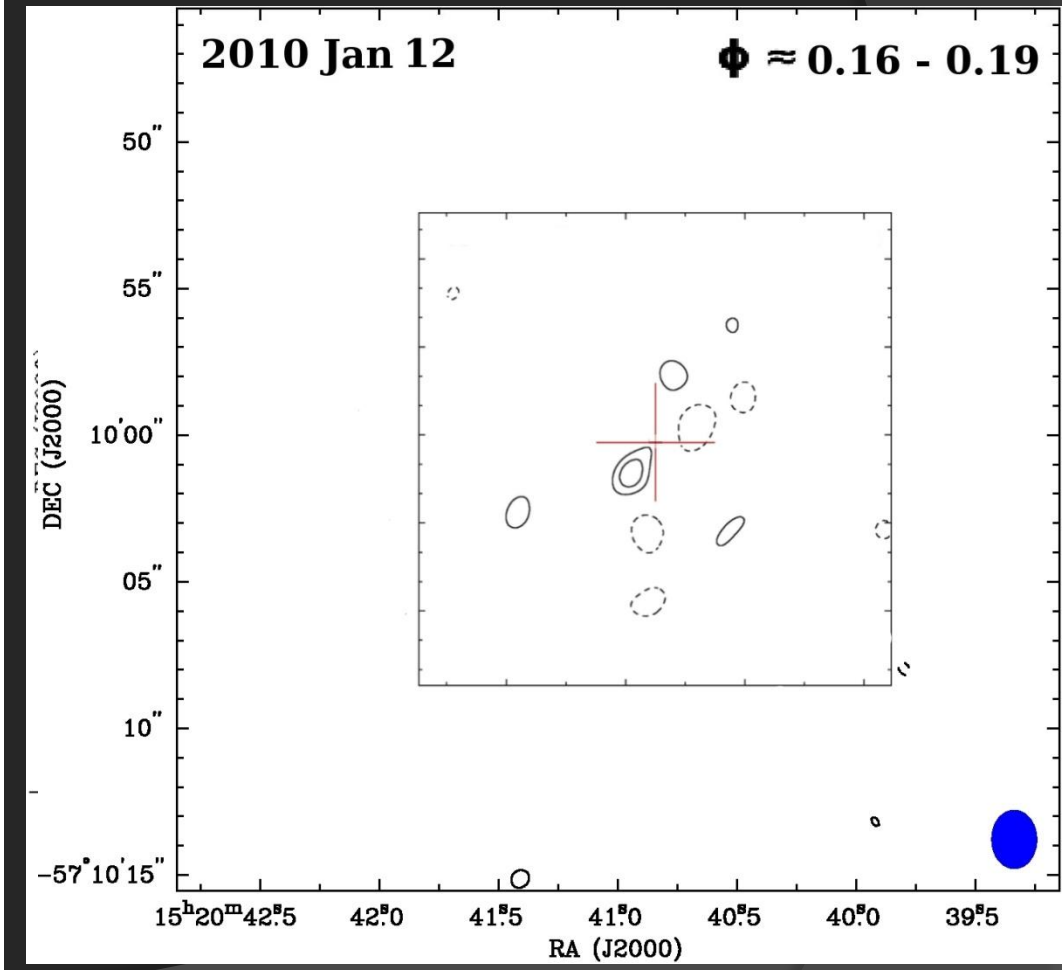
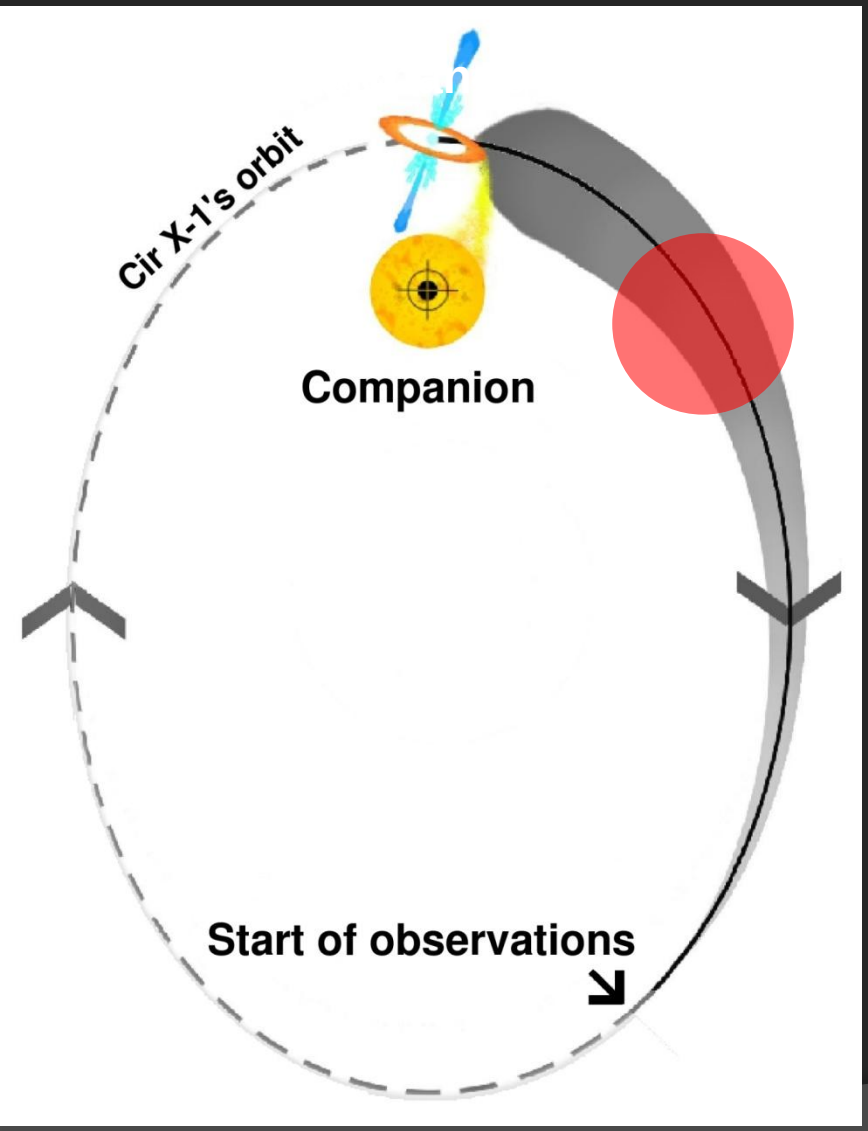
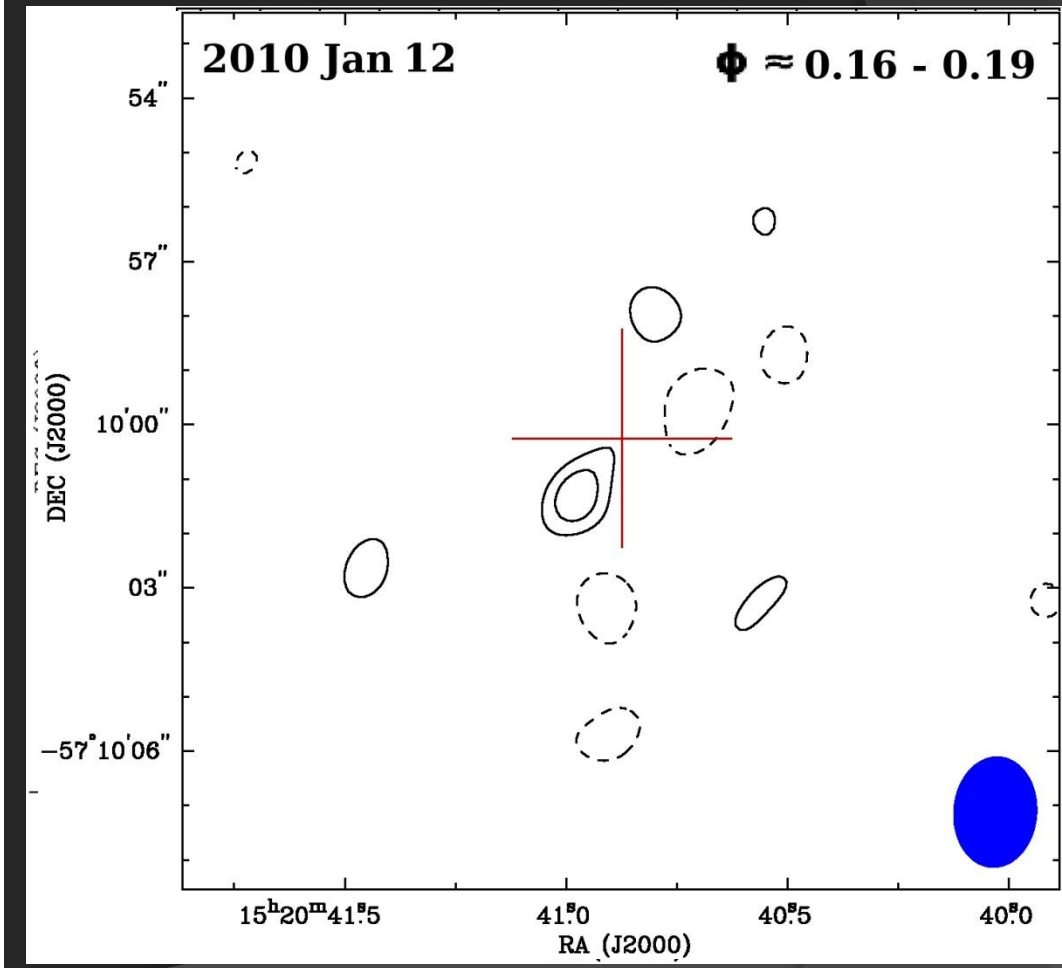


Modelled "core" subtracted

Radio map evolution (5.5 GHz)



Contours = 3σ and up



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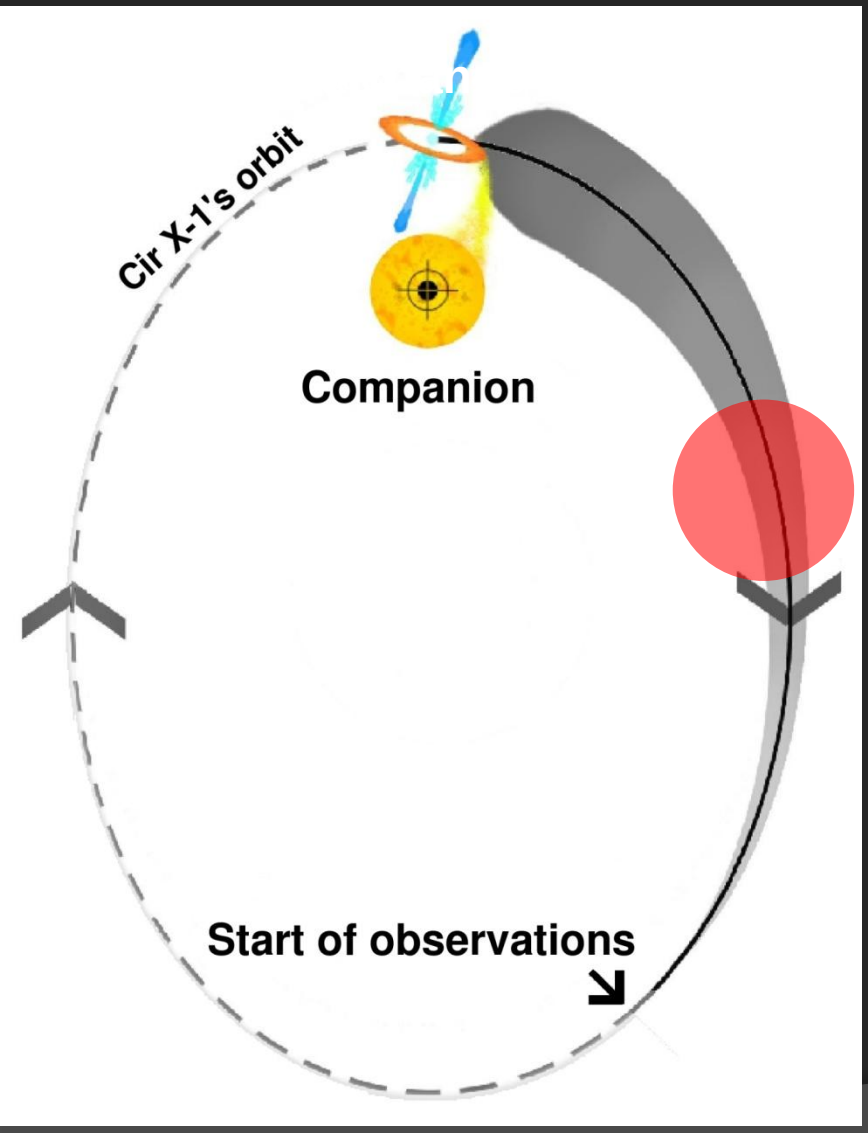

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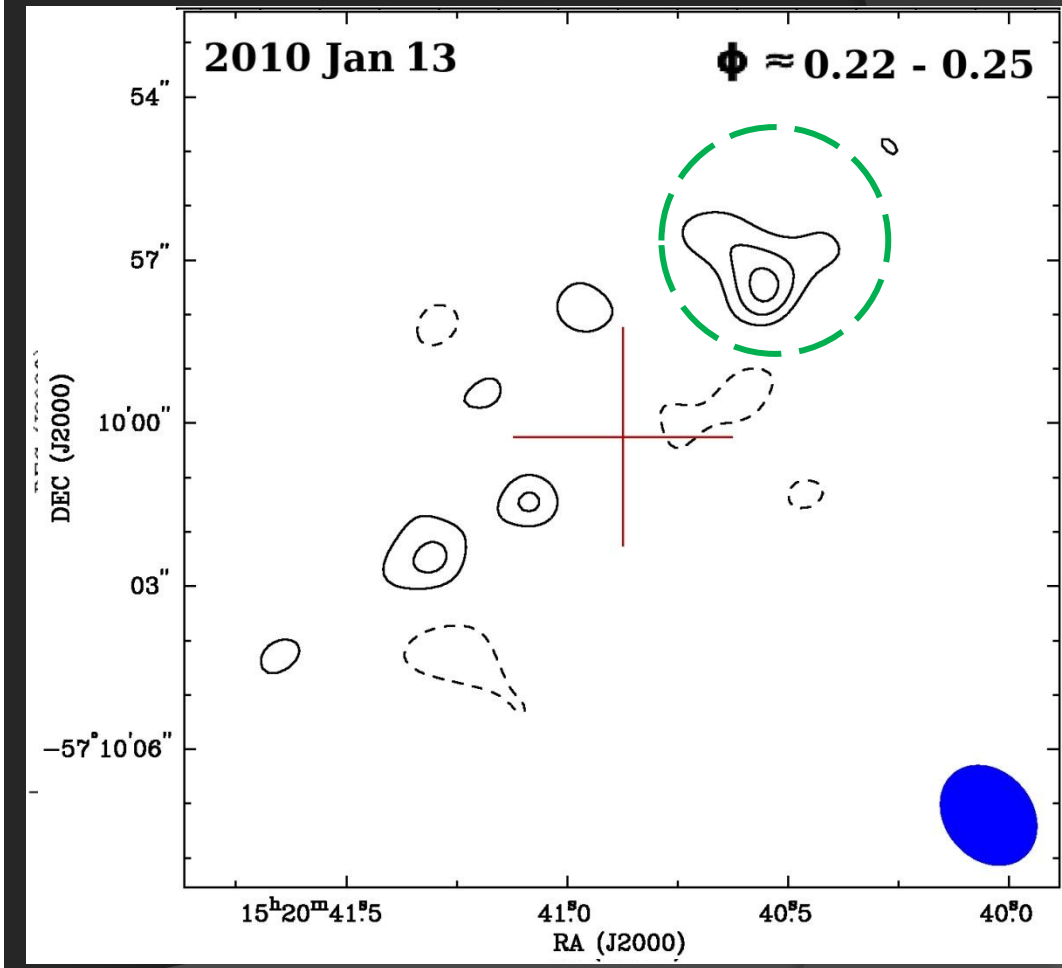

Calvelo et al. submitted

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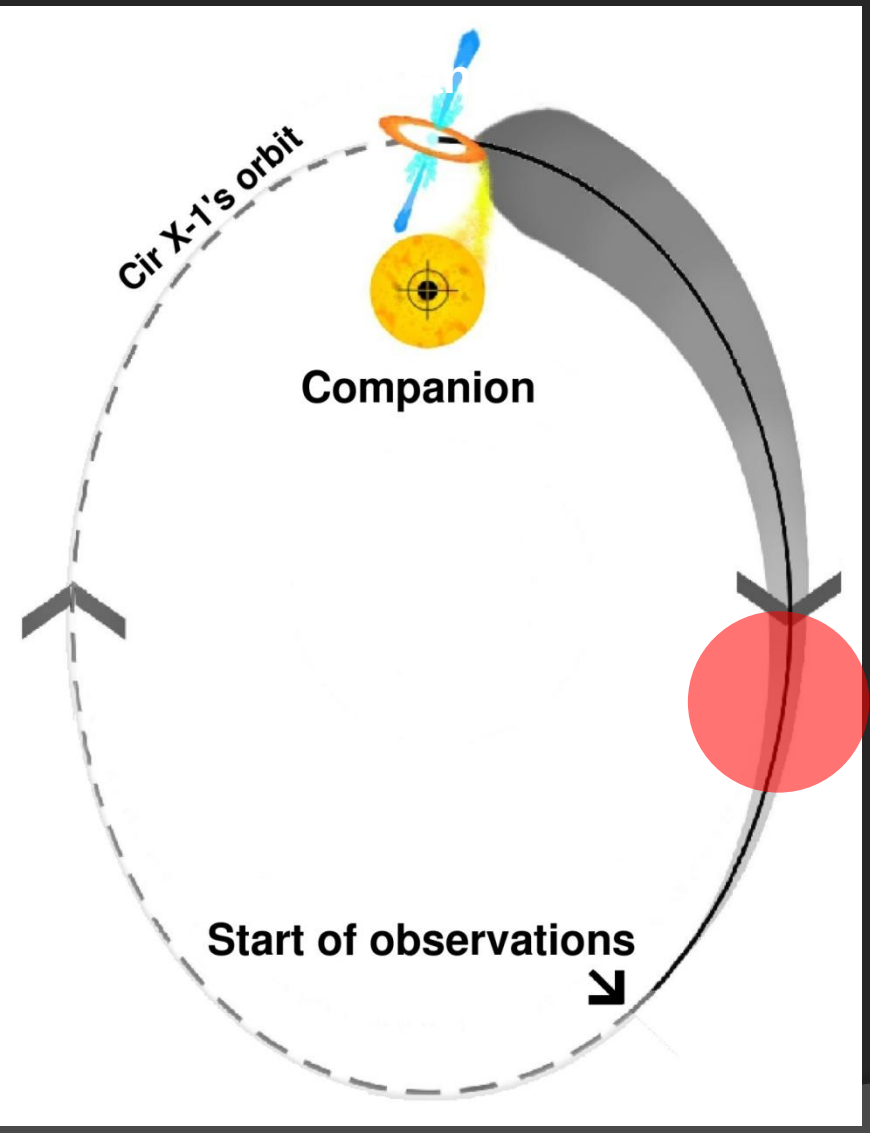

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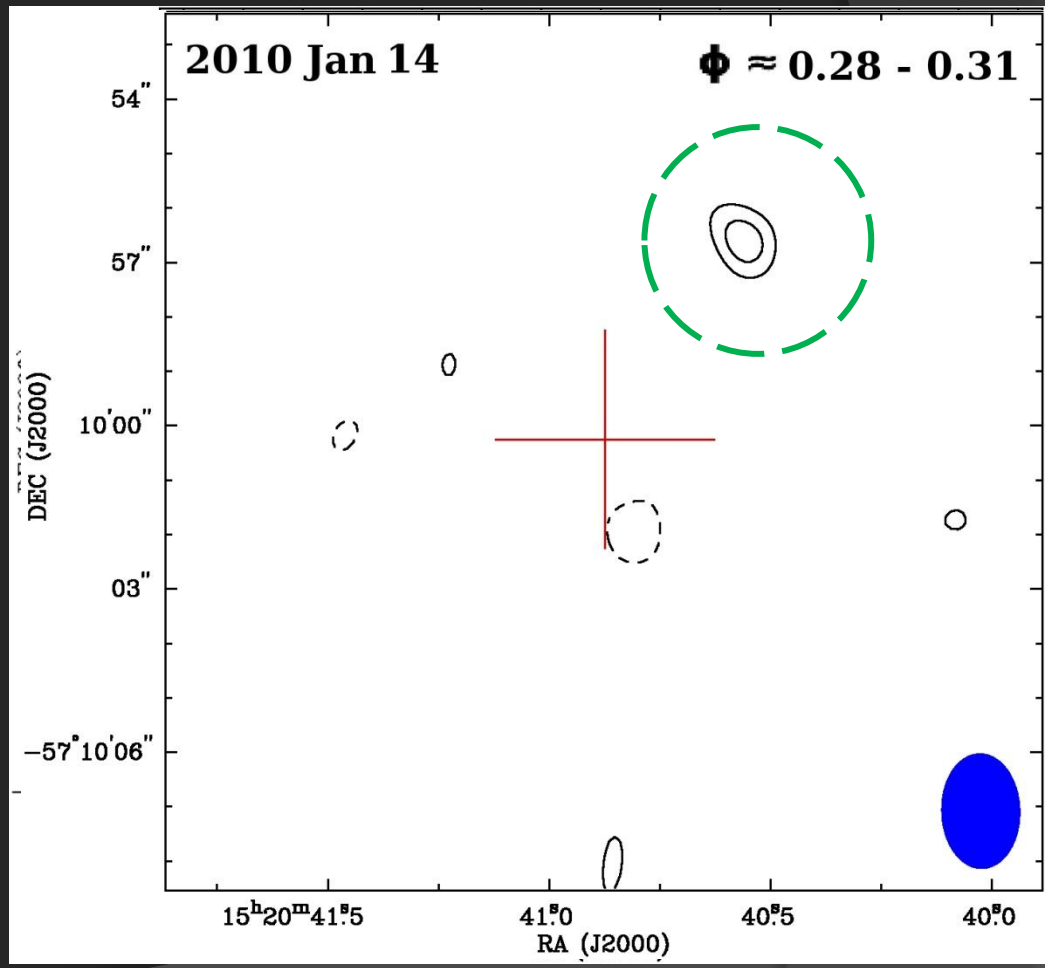

Calvelo et al. submitted

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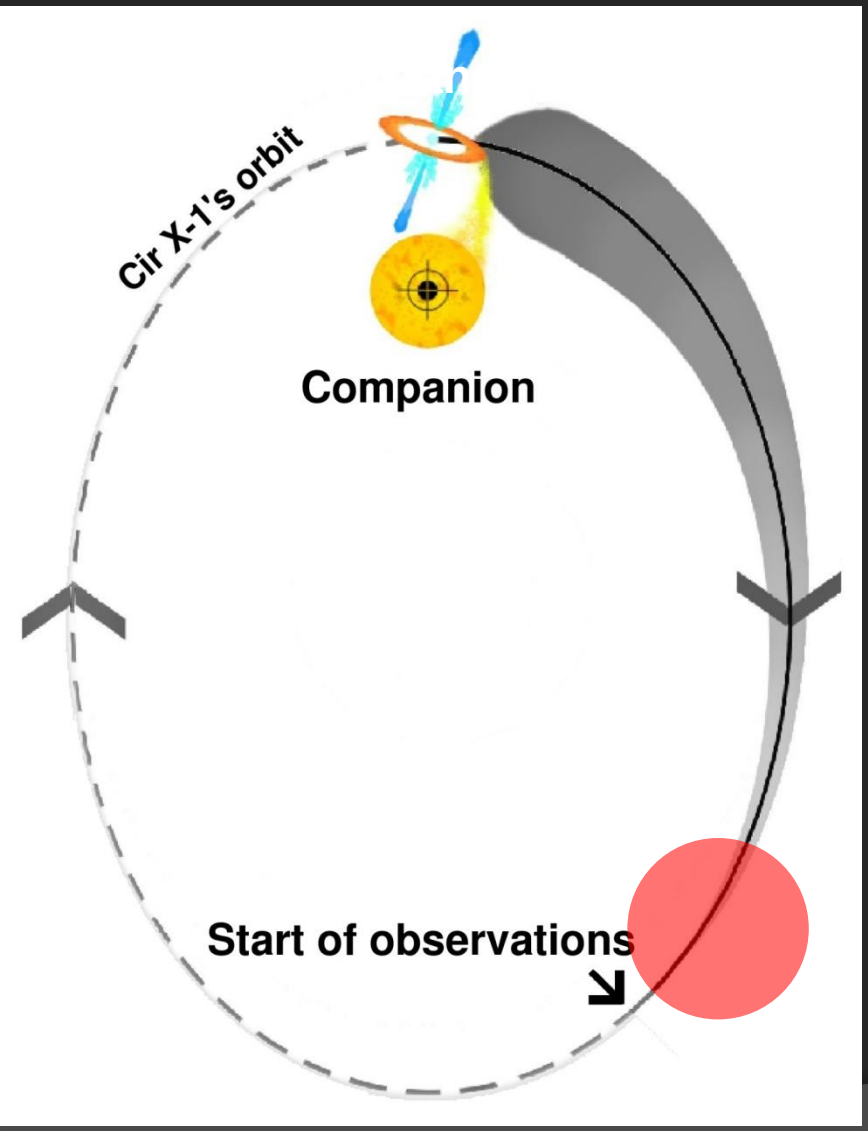

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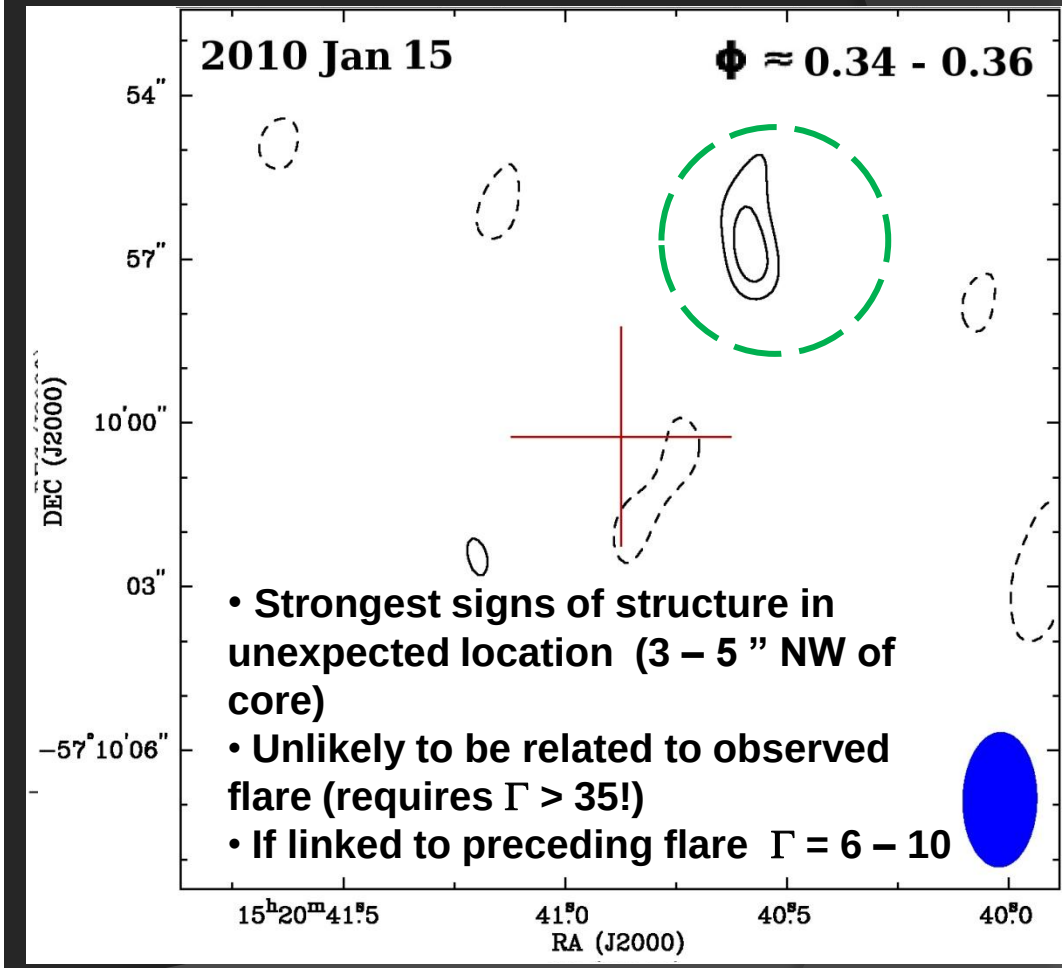
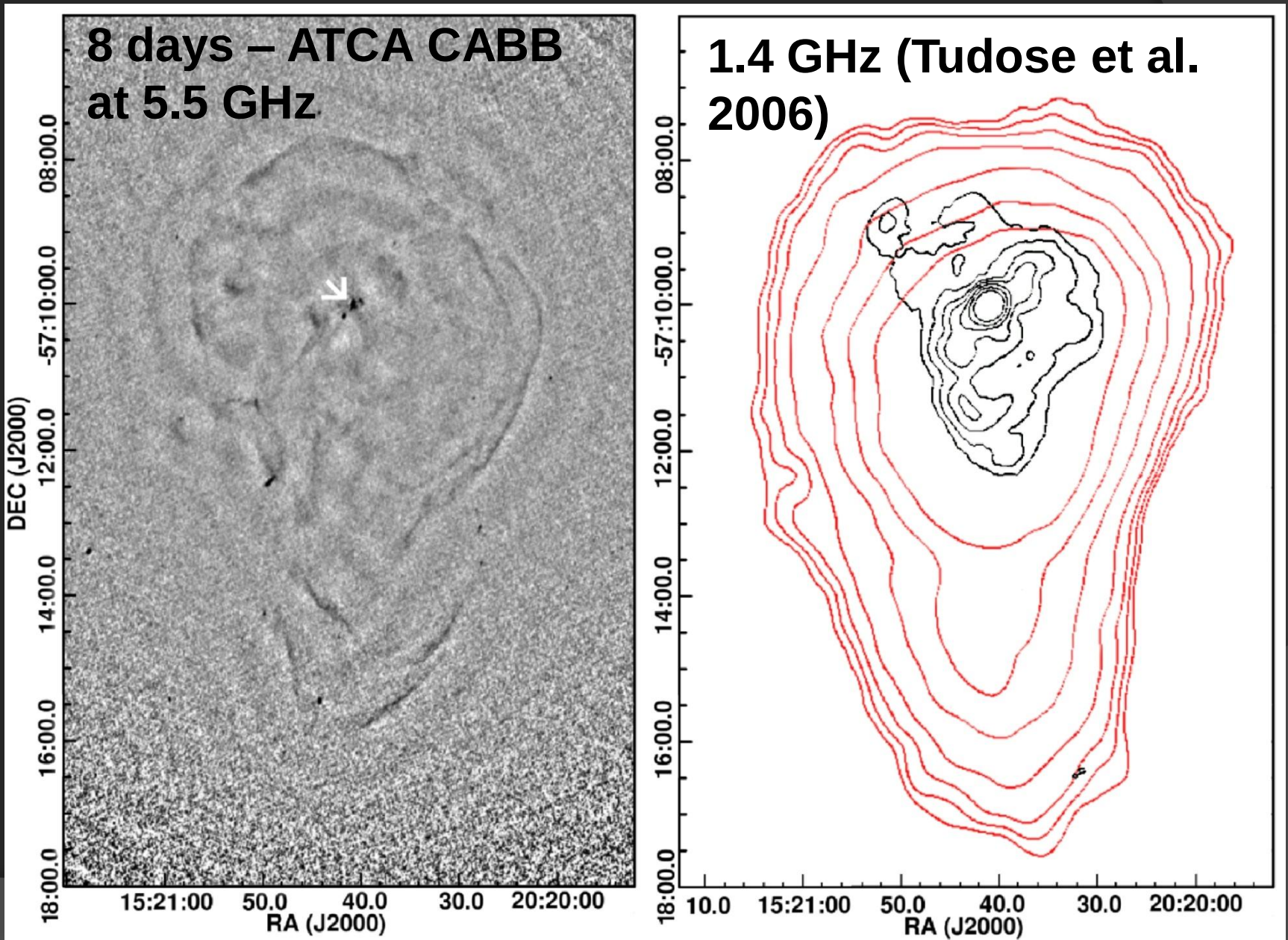


Calvelo et al. submitted

Large scale structure



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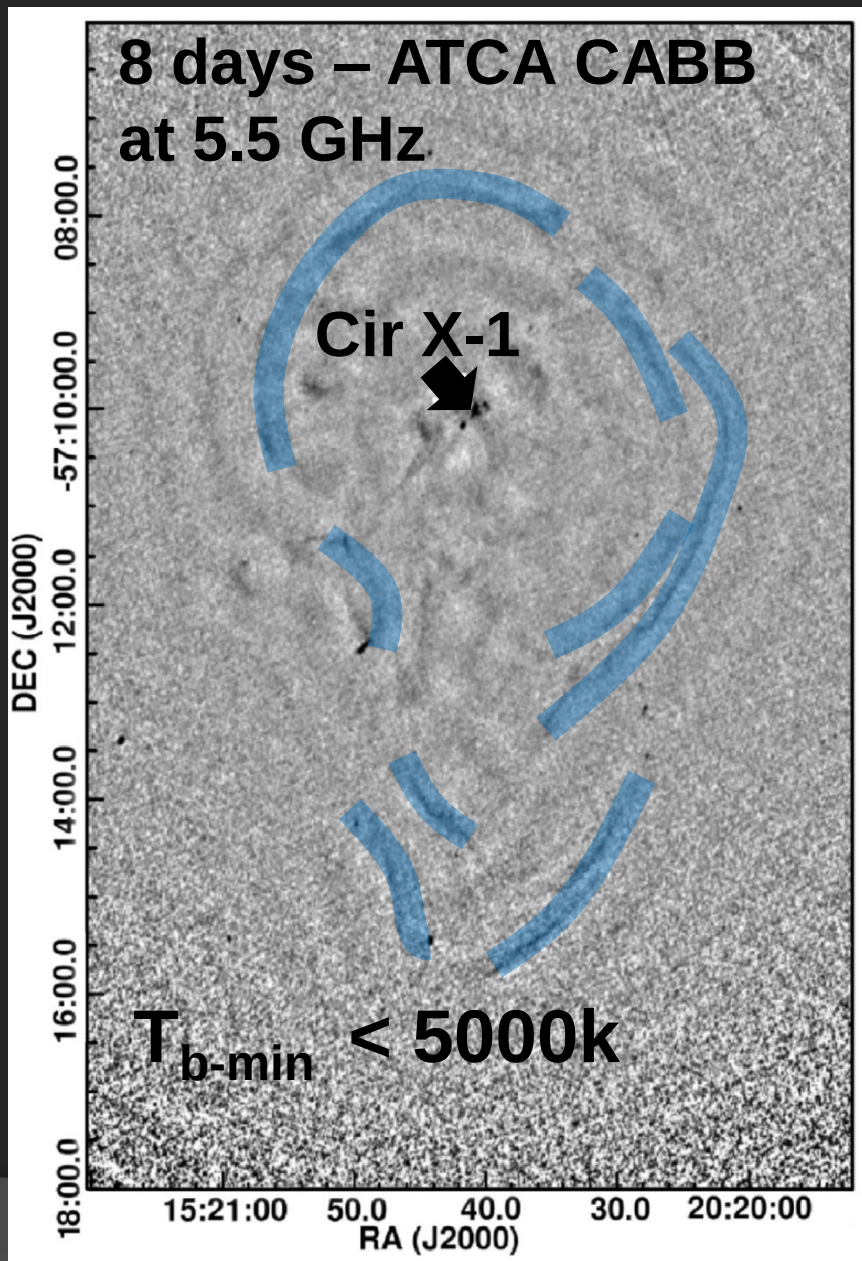
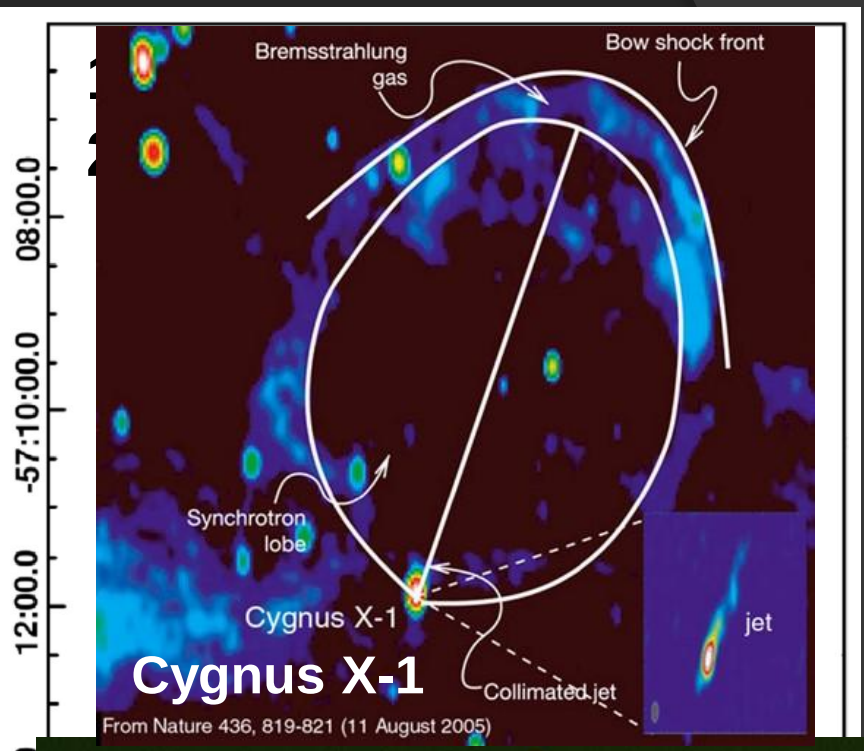
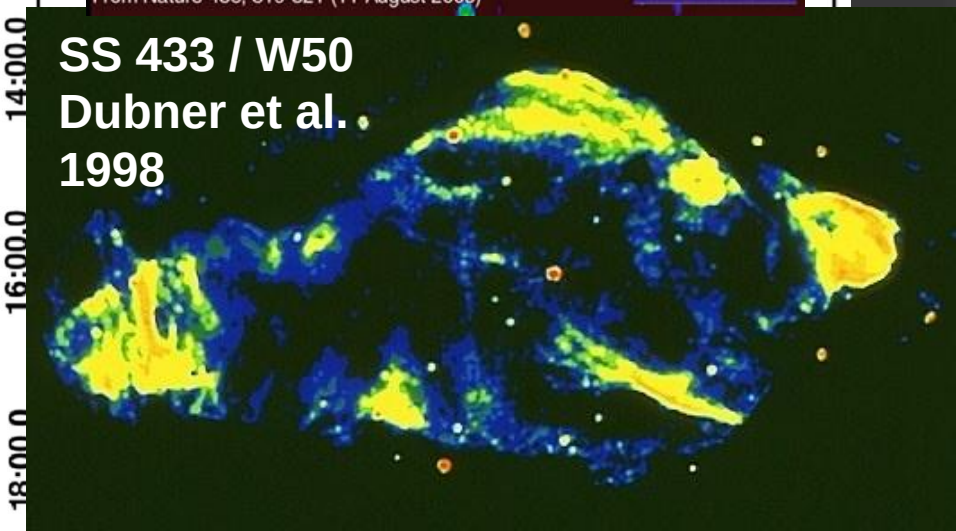


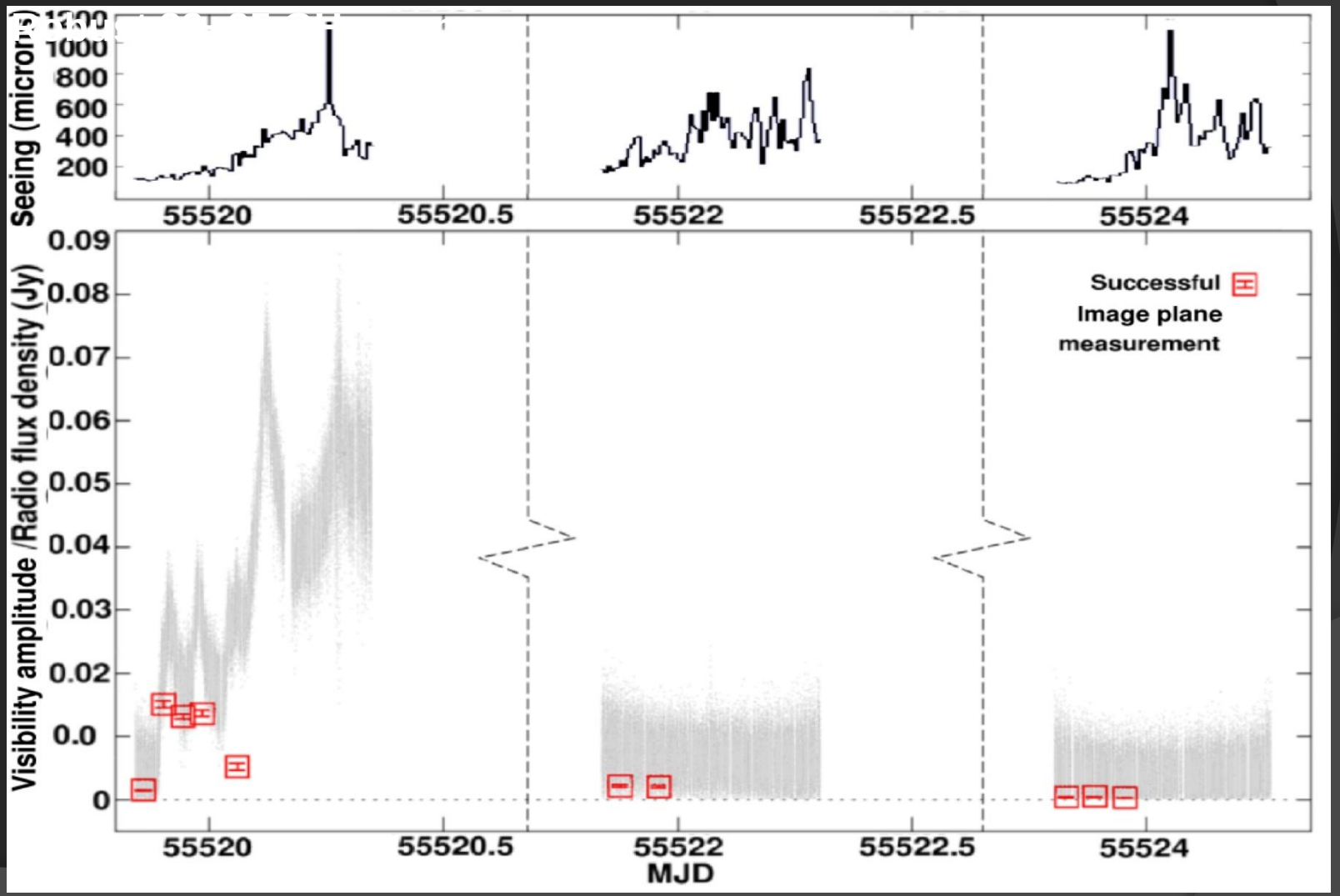




Observations at mm λ

- Attempt to detect a neutron star binary at mm for the first time and probe deeper into near core jet structure
  - High frequencies allow us to examine structure with sub-arcsecond resolutions
  - Three 9 hour observations, spaced two days apart (2010 Nov 19, 21 and 23)
    - Predicted image rms of < 30 of μJy (5.5 GHz) for a single day
    - Not reached due to significant phase errors (50% data flagged)
- Flare predicted to occur during first observation
  - Limits β apparent to > 4
- Both Circinus X-1 and Scorpius X-1 were detected!
  - Will only be discussing Cir X-1 structure today

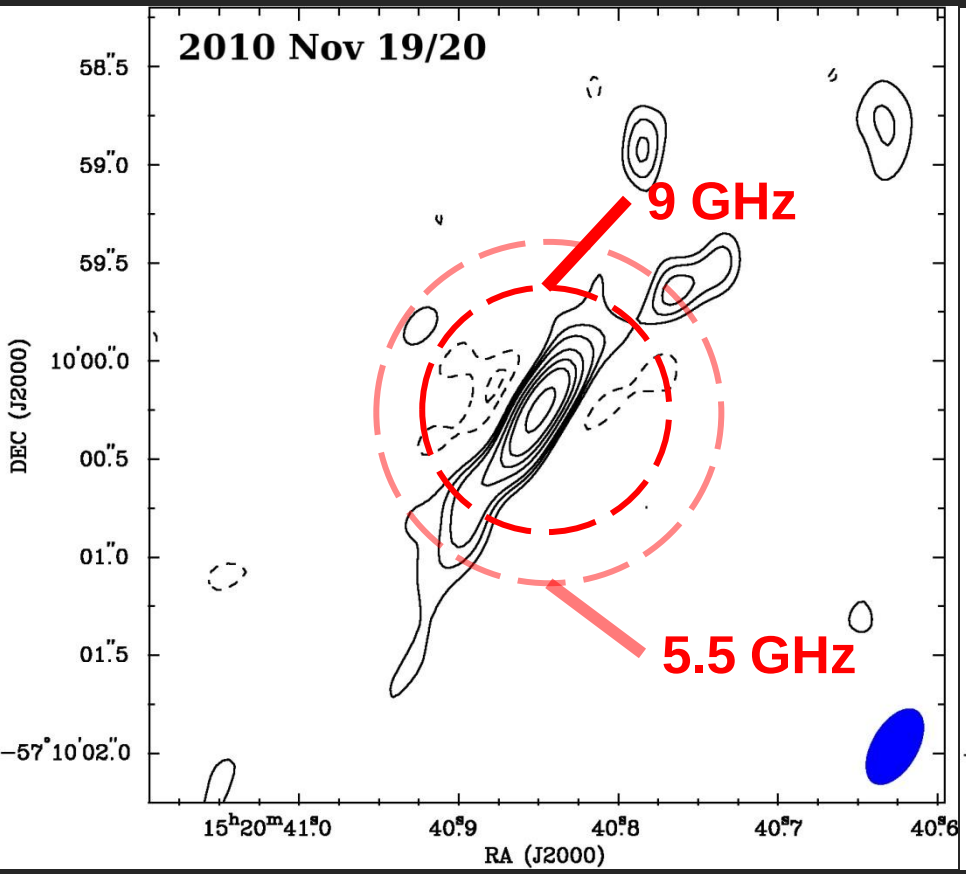
Cir X-1 structure at mm λ



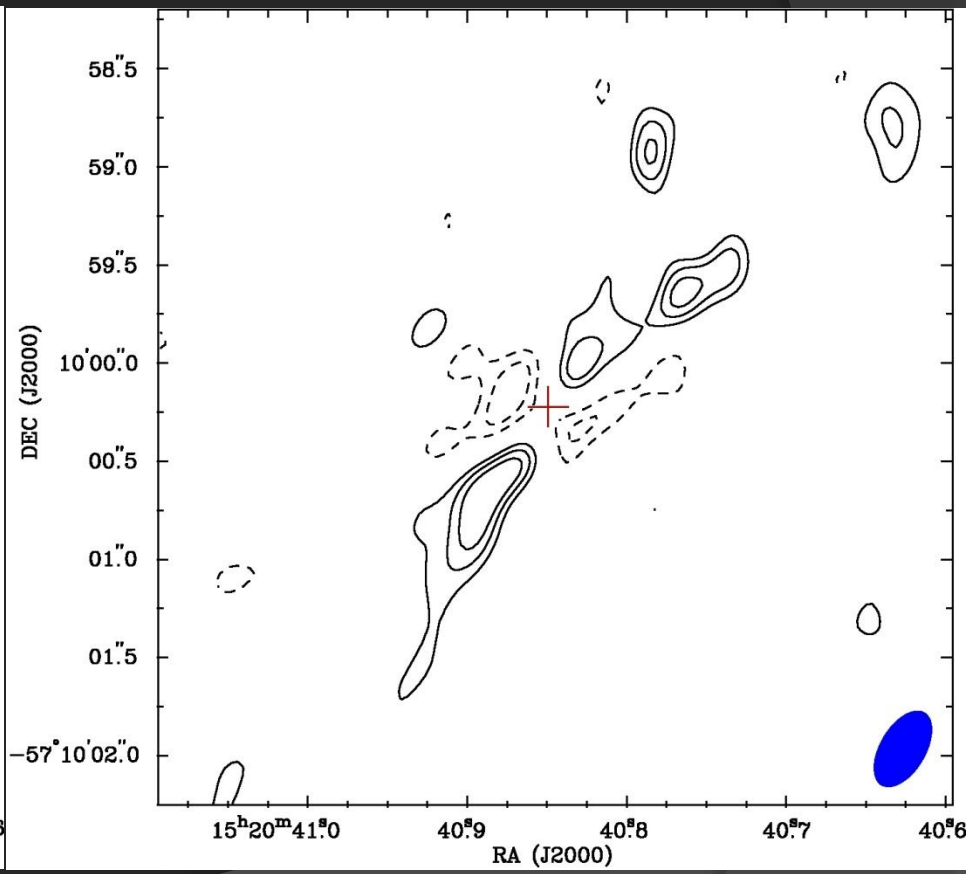
Calvelo et al. submitted

Cir X-1 structure at mm λ

Robust 33+35 GHz map



Fitted point source subtracted



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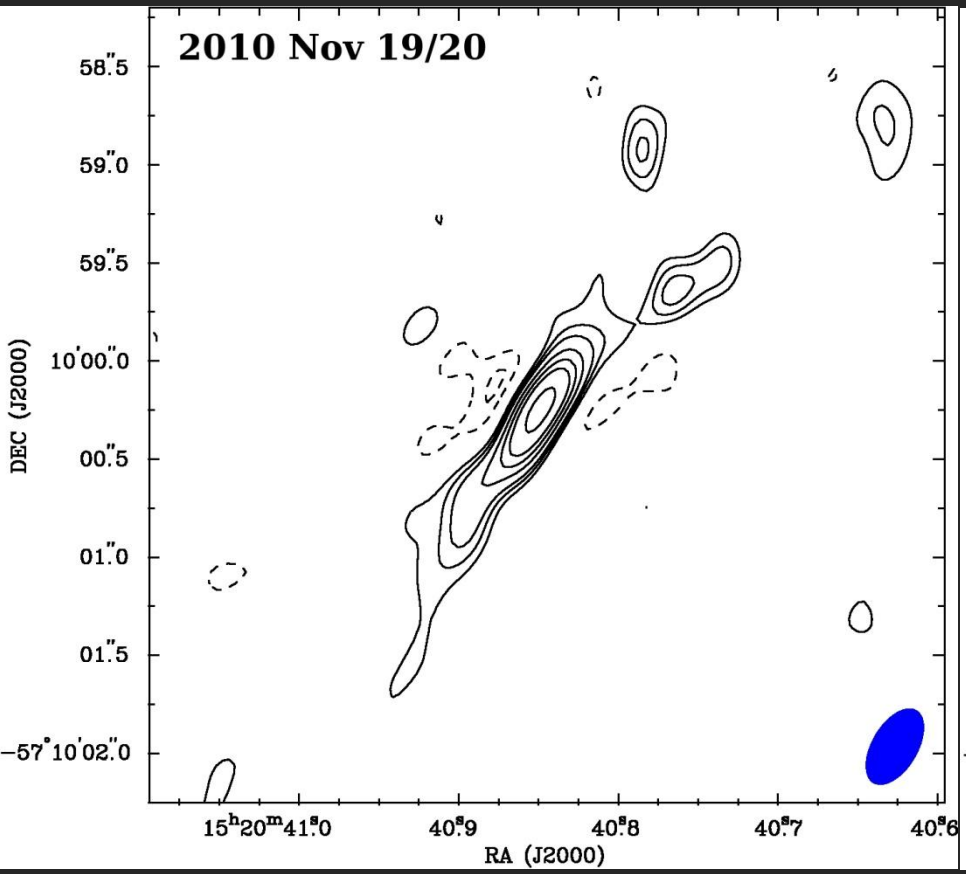

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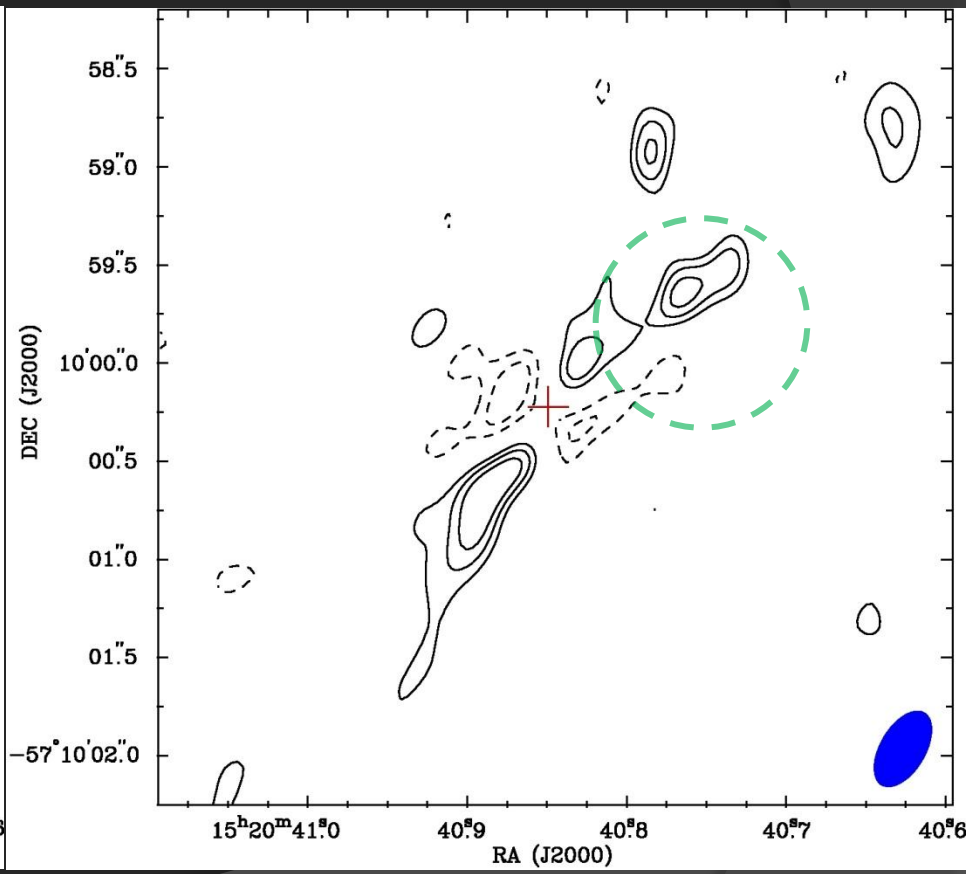

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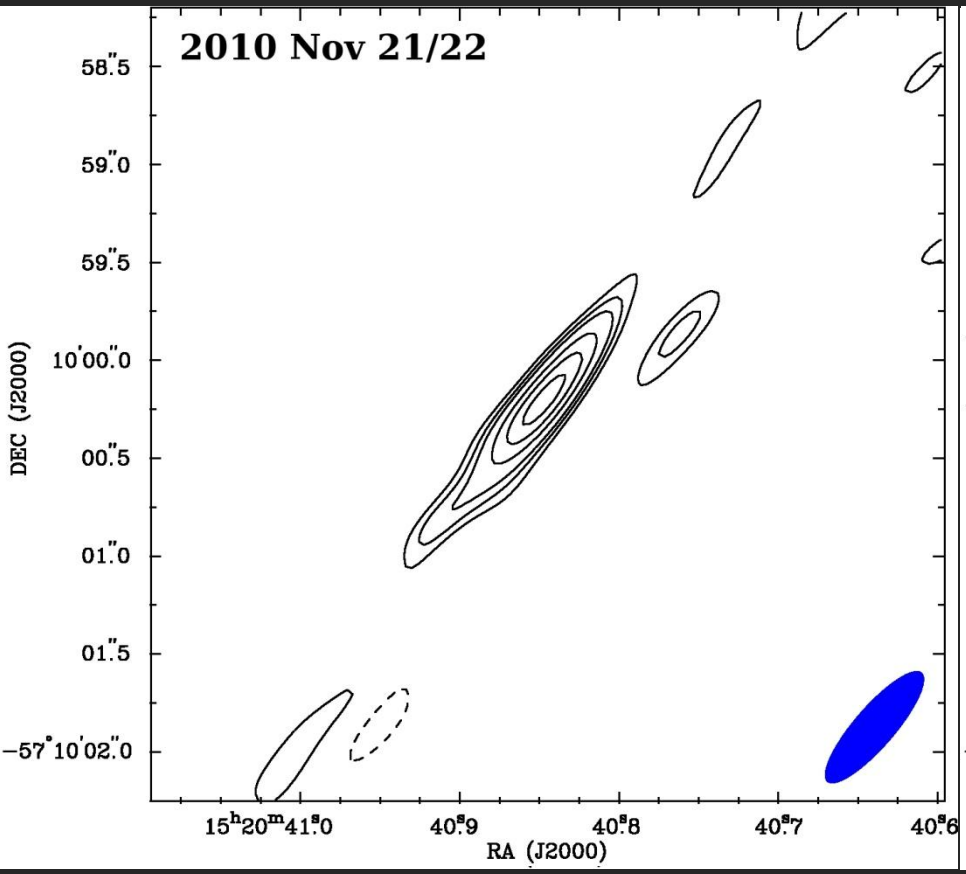

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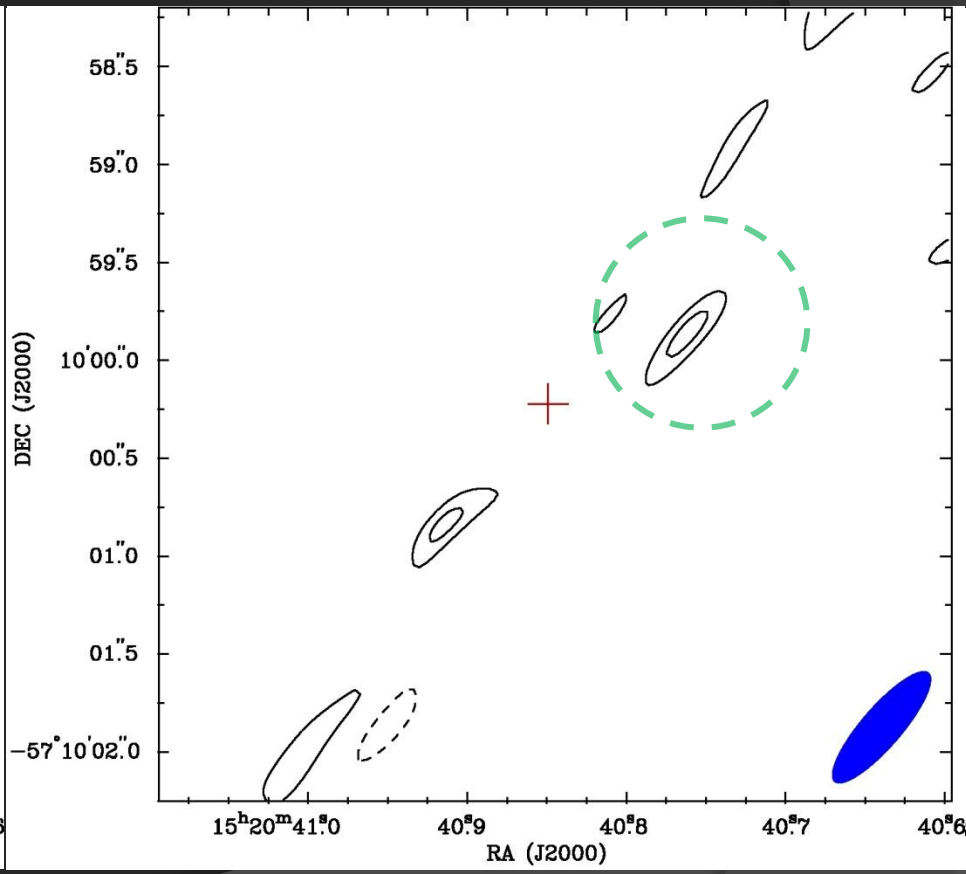

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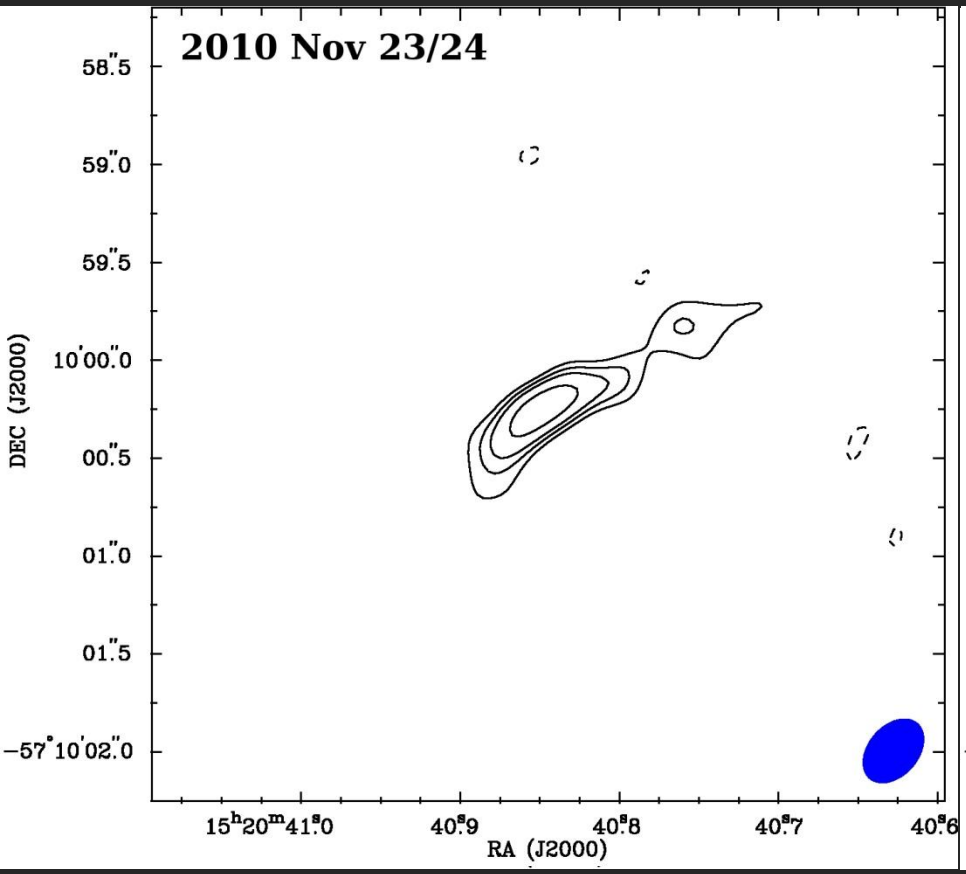

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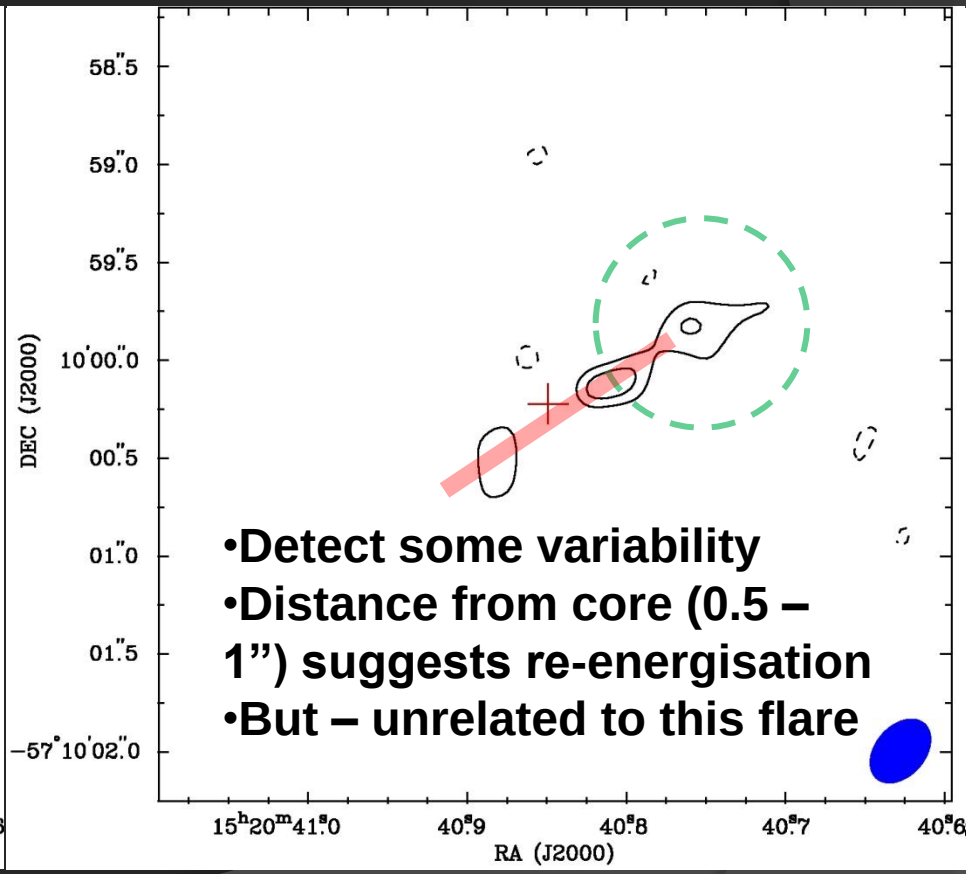

Calvelo et al. submitted

Summary & future projects

- **Observed Circinus X-1 radio emission (cm) over a complete orbit and also detected it (and Sco X-1) at mm wavelengths**
  - **Do not see strong evidence for ultra-relativistic jets**
  - **Do see evidence of variable structure (re-energisation) to the north-west at both cm and mm wavelengths**
- **The variety of observed jet axes suggest precession**
  - **Nebula filaments could also be linked to a precessing jet**
  - **Supported by recent LBA observations (Miller-Jones et al. submitted)**
- **Are we seeing a new epoch of behaviour from Circinus X-1?**
  - **Similarities to theoretical history of SS 433 (Goodall et al. 2010)**
- **Proposals submitted for new multi-frequency observations to investigate precession**
- **Both Cir X-1 and Sco X-1 mm detections will go towards future work on spectral behaviour of NSXRBS**