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Polarised radio emission from X-ray binary jets

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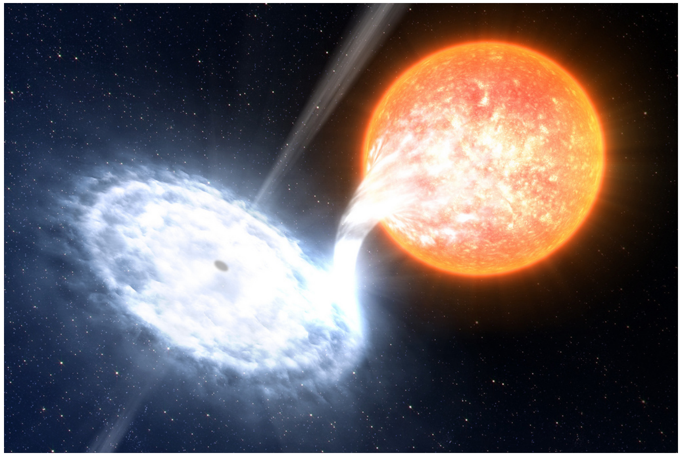

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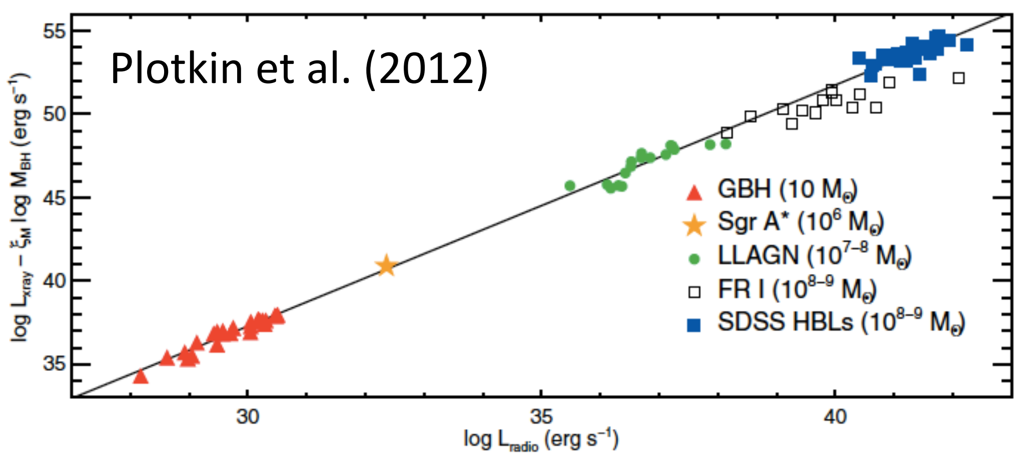
Why study X-ray binary jets?

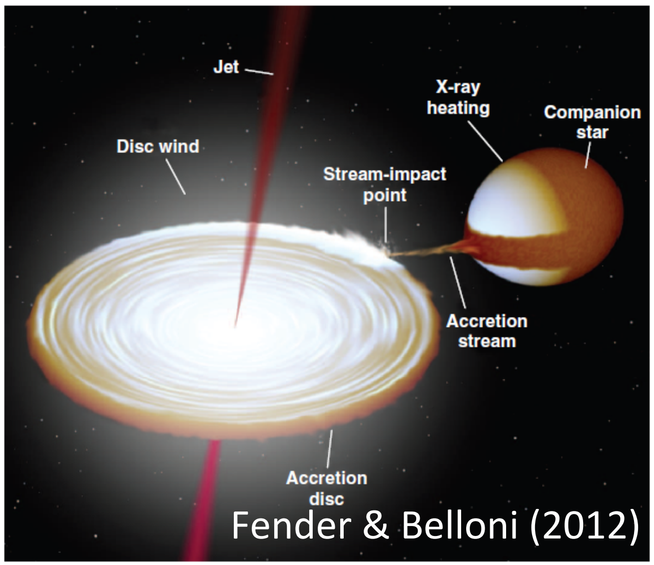
Scale models of AGN

- Probes of jet launching
- How do jets couple to the accretion flow?
- What is their feedback effect?

Timescales proportional to compact object mass

- XRBs ***evolve on human timescales***: unique probe
- Application to AGN (scaling relations)





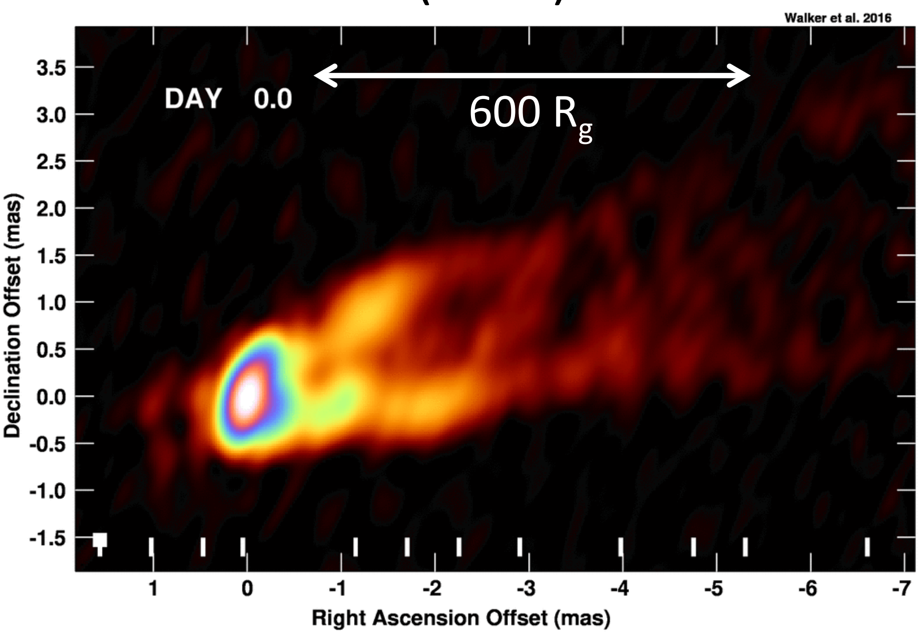
AGN on fast-forward

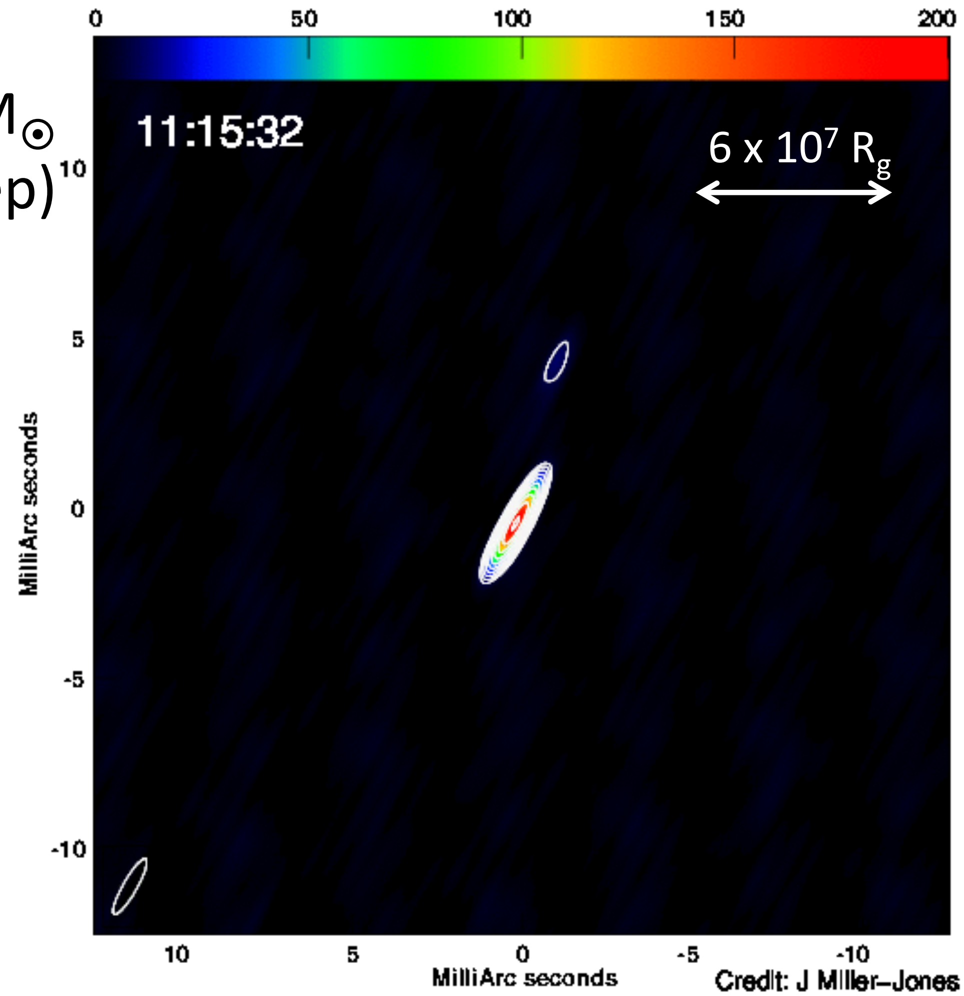
Less spatial resolution in R_g, higher time resolution

- Real-time jet evolution

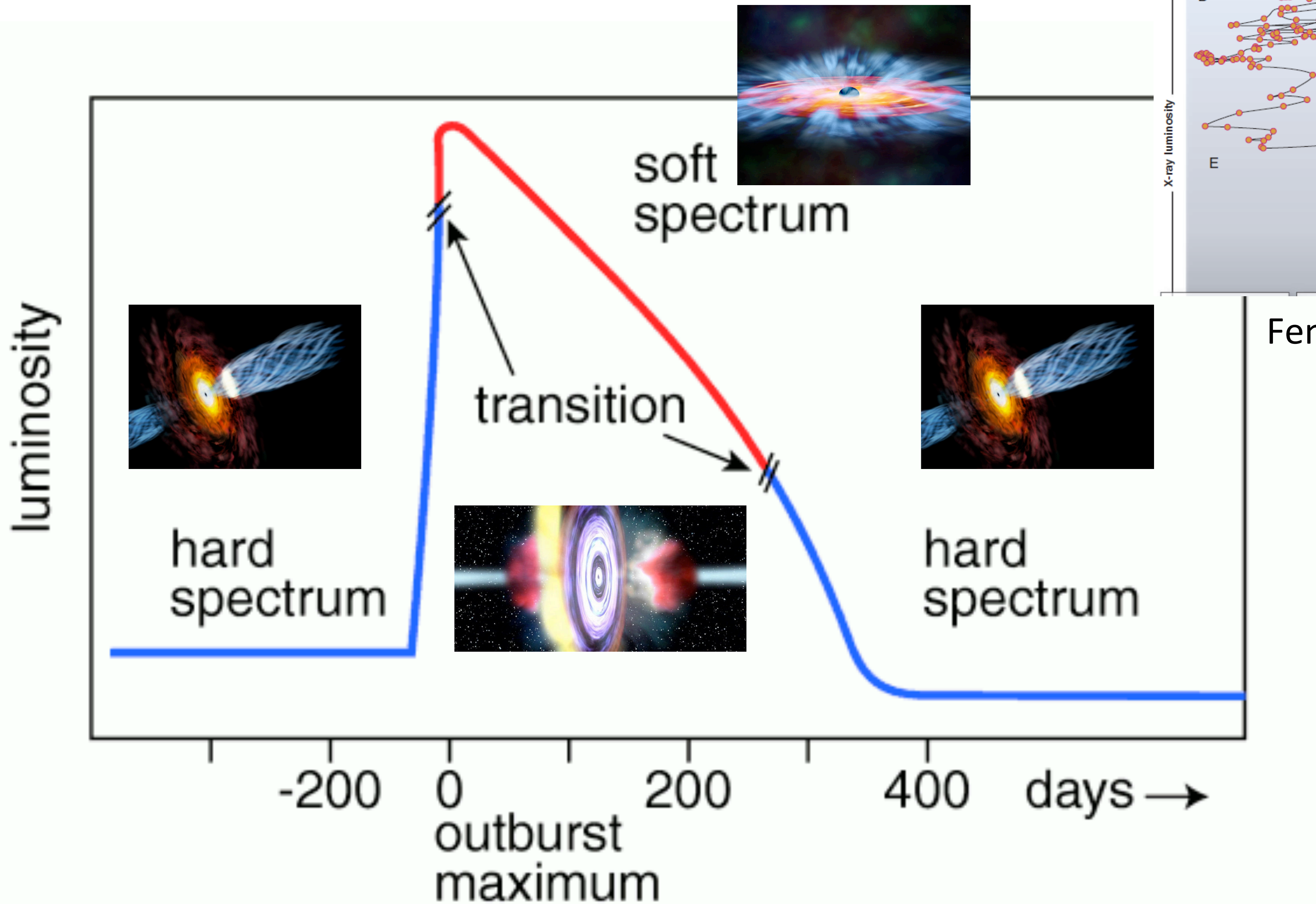
V404 Cyg: 9 $M_\odot$
M-J et al. (in prep)

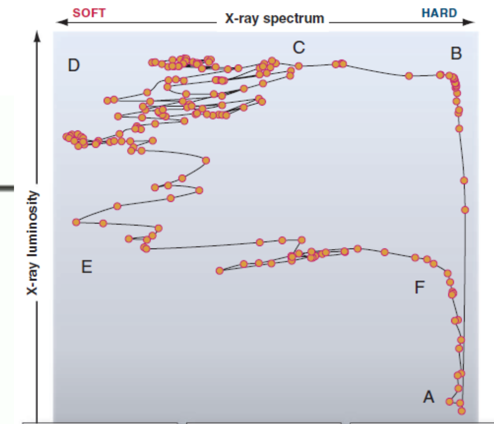
M87: 6.6 x 10^9 $M_\odot$
Walker et al. (2008)





Evolution of an XRB outburst

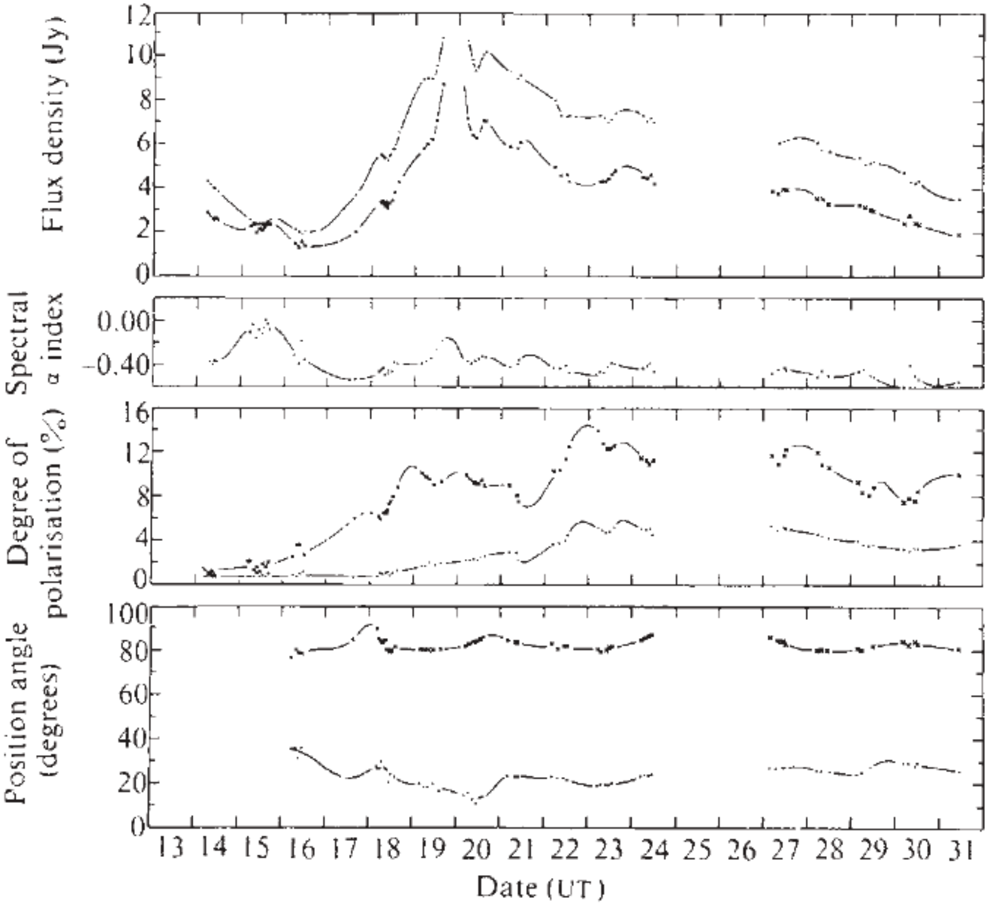




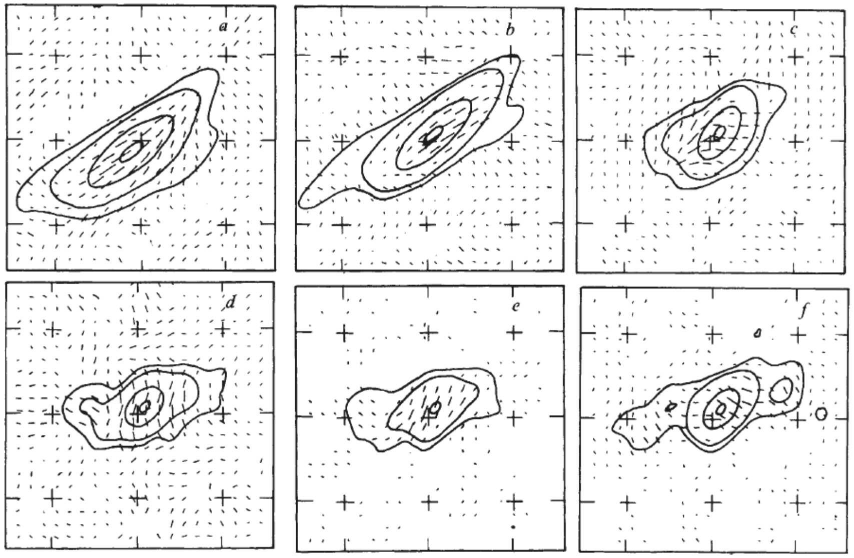
Fender & Belloni (2012)

Transient outbursts: discrete ejecta

Early work: bright sources Cyg X-3, SS 433



Seaquist et al. (1974);
see also Gregory et al. (1972)



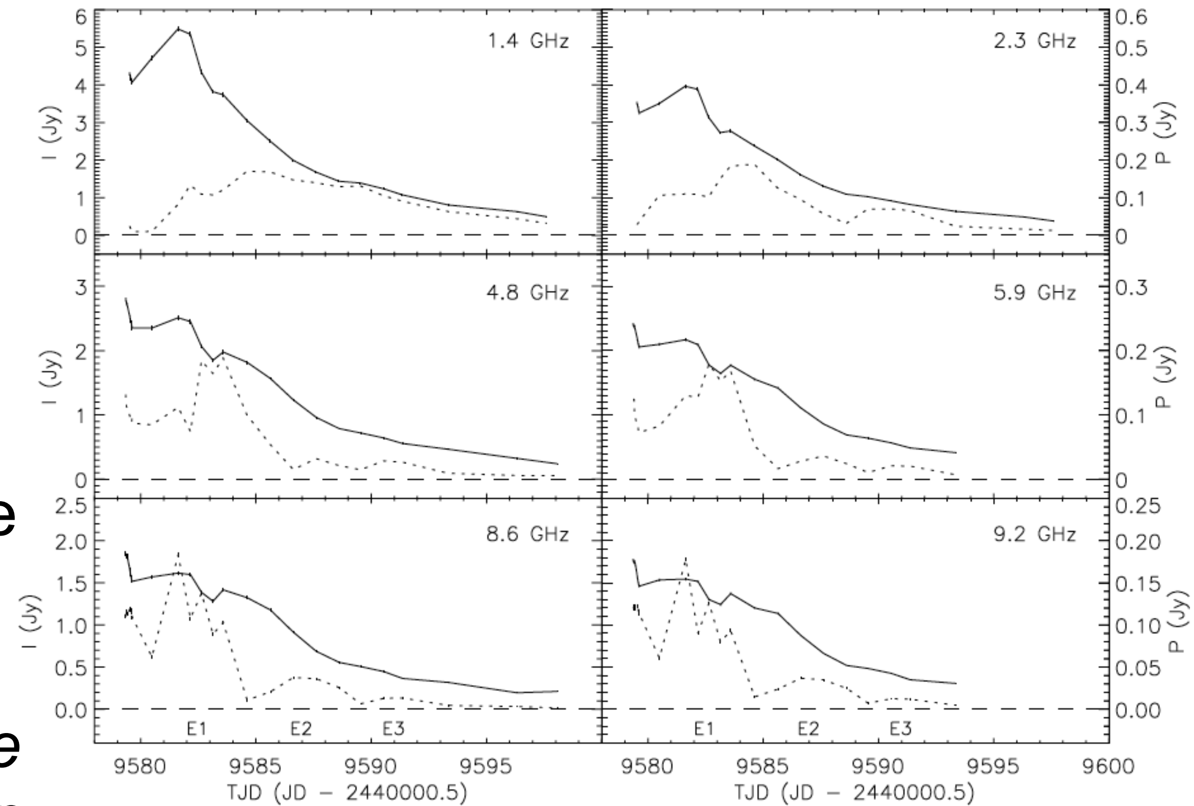
Hjellming & Johnston (1981)

- 1-20% linear polarisation
- Data during flaring events

Frequency dependence

GRO J1655-40

- More variable at high frequency
- Smoothed and delayed at low ν
- Classical synchrotron bubble
- Some events depart from model
- *Not a single bubble*
  - Unsurprising given VLBI images

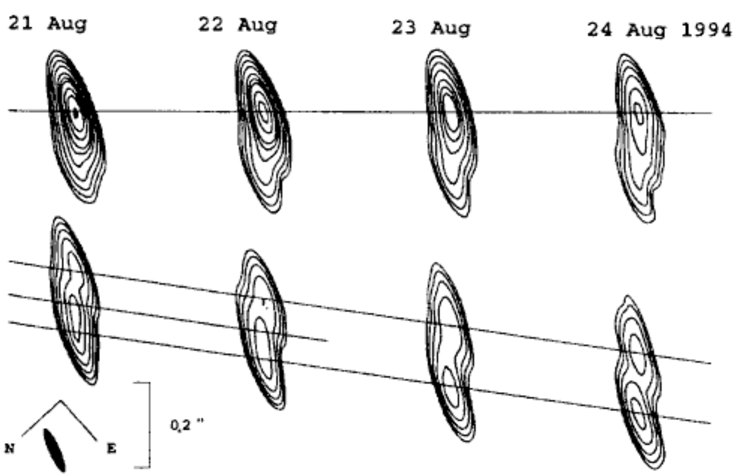


Hannikainen et al. (2000)

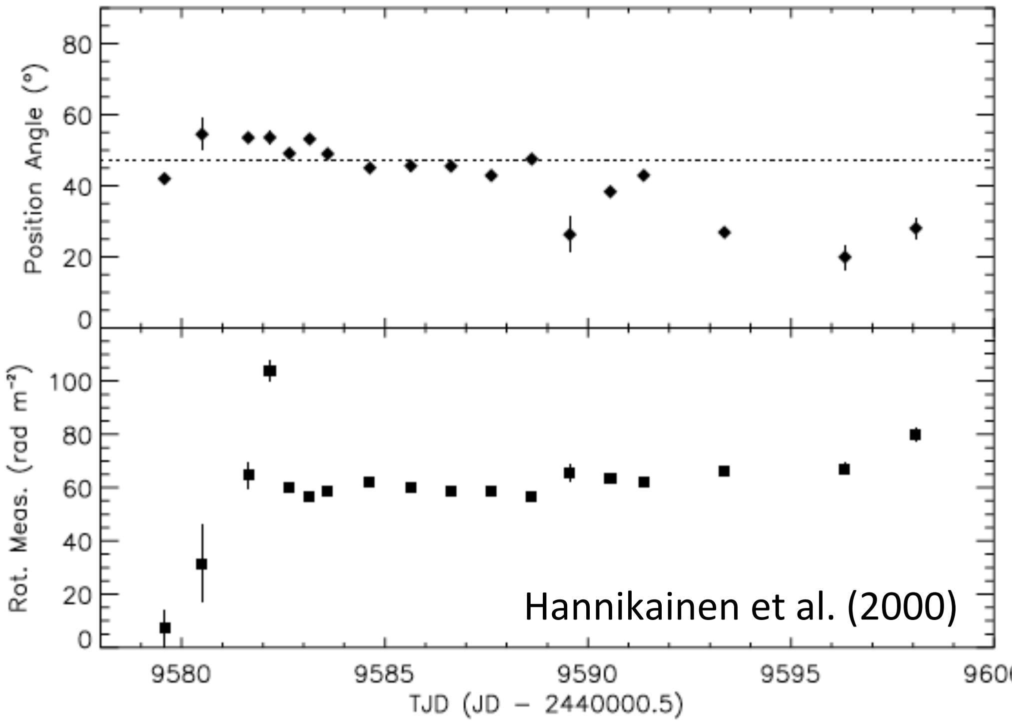
EVPA/RM evolution

GRO J1655-40 (continued)

- Stable initial EVPA
- B-field perpendicular to jet direction
- Late evolution
- Rapid initial RM evolution: local effects
  - B-field realignment?



Tingay et al. (1995)

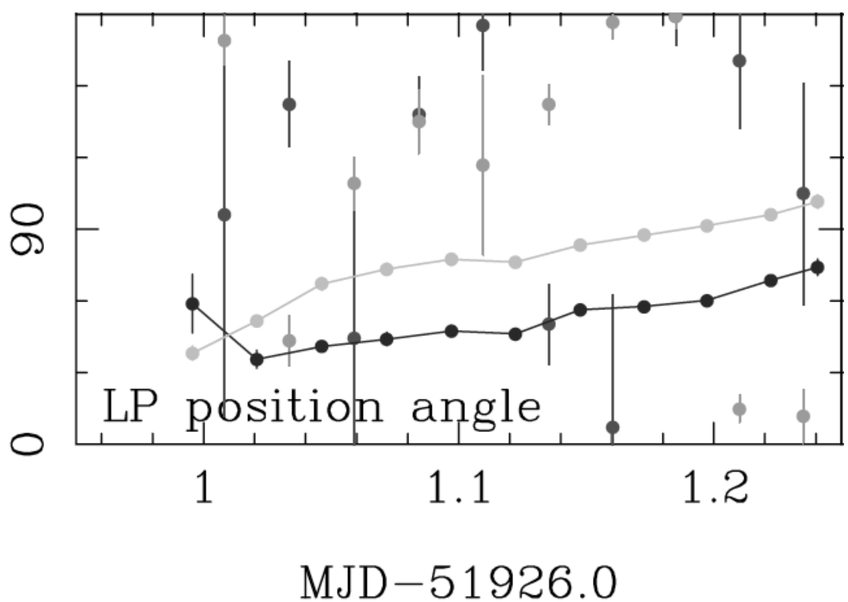


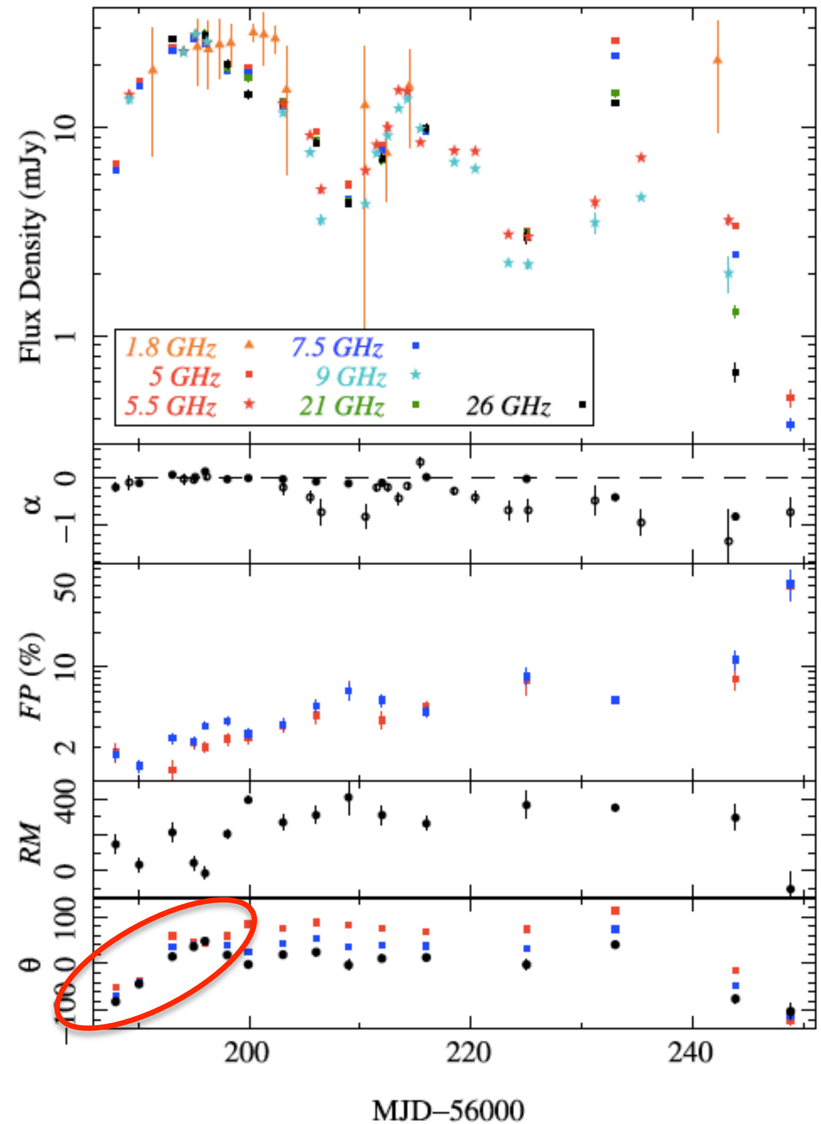
Hannikainen et al. (2000)

“Rotator” events

Smooth rotations

- Several tens of degrees
- Different frequencies move together
- Associated with radio flaring

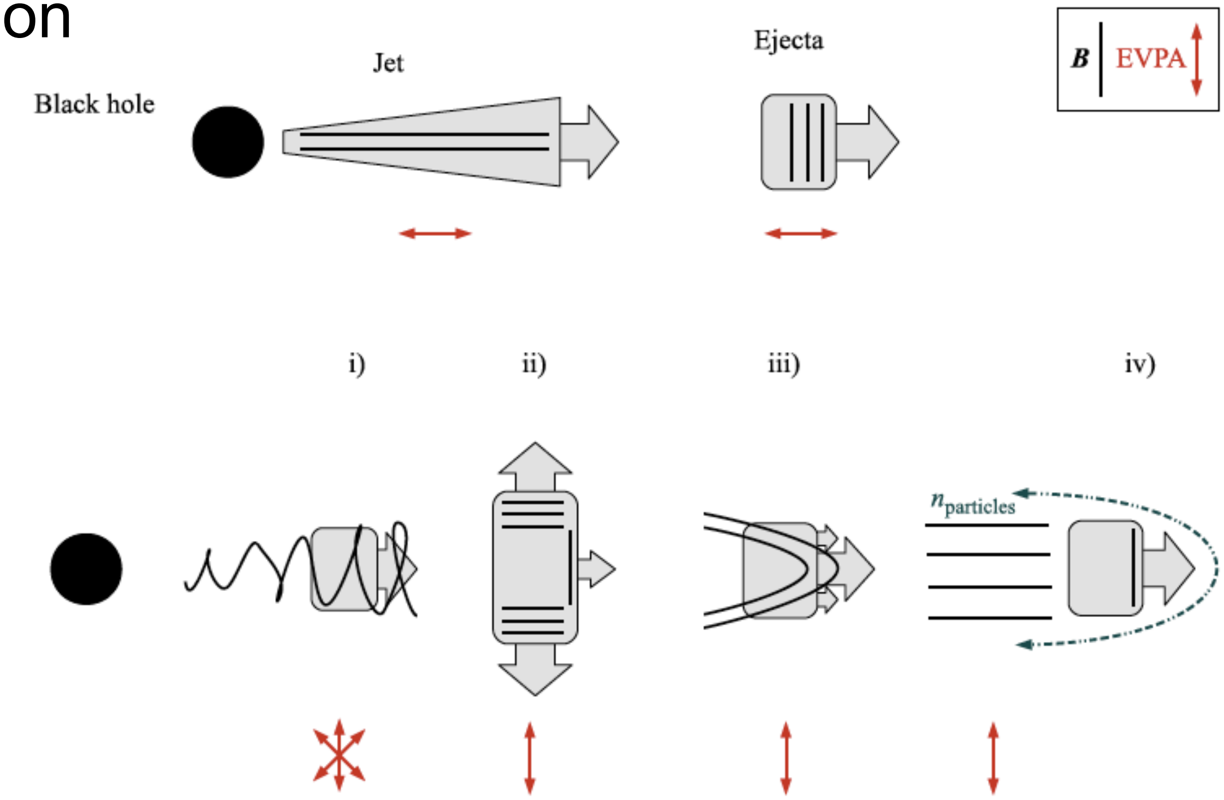




Magnetic field alignment

Mechanisms for giving B parallel to jet axis

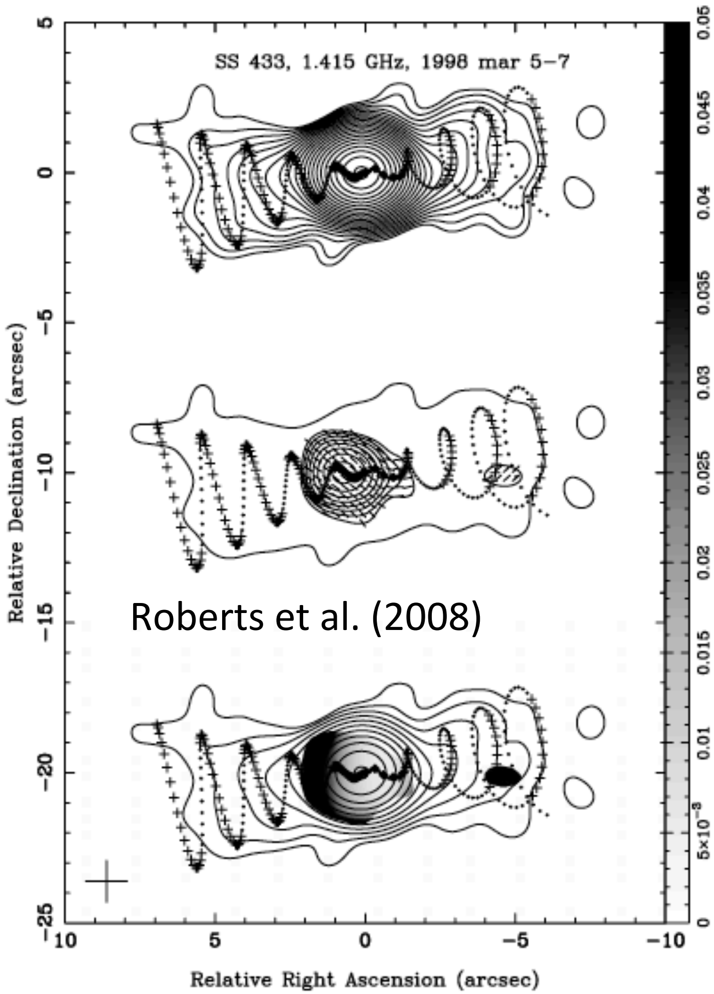
- Helical field
- Lateral expansion
- Velocity shear
- Bow shocks

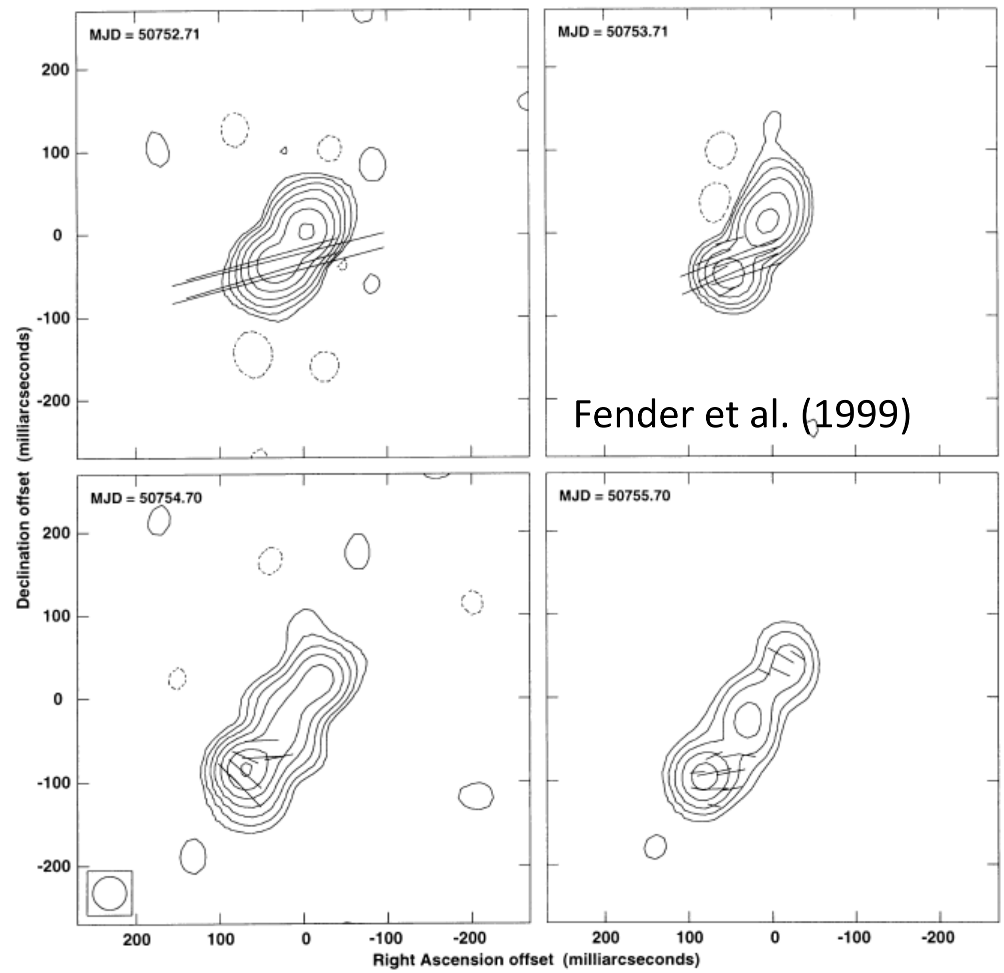


Curran et al. (2014)

Spatial resolution

Polarised ejecta, depolarised core

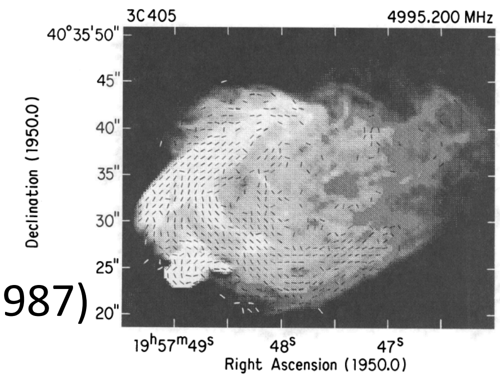




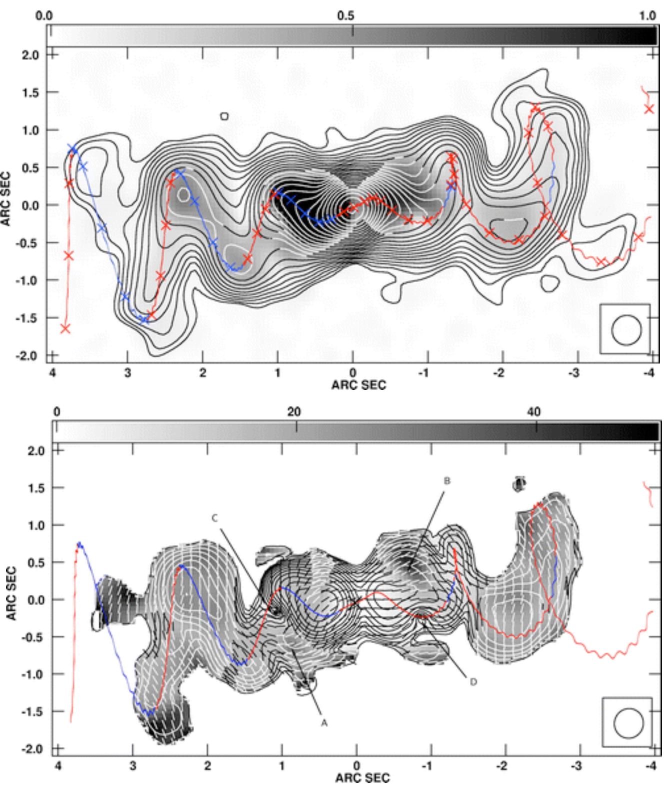
A sequence of discrete ejecta

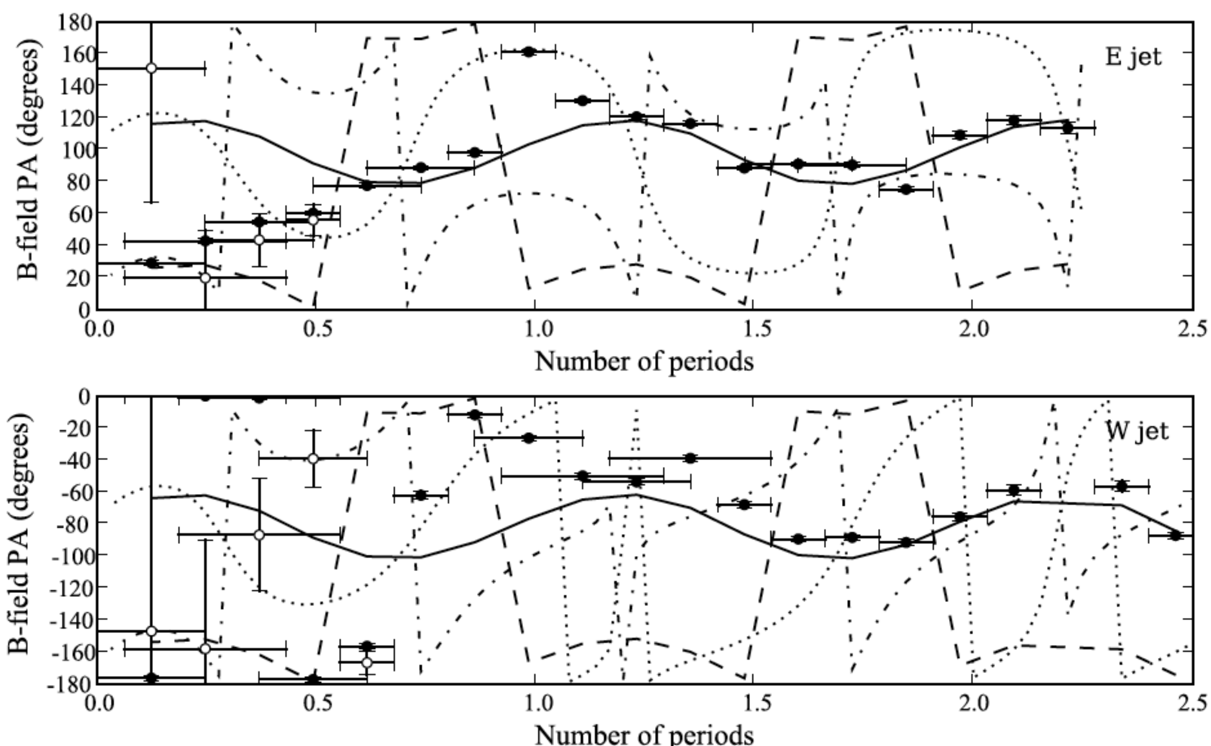
B-field aligned with local velocity

- Unresolved hotspot geometry?
  – Shear/lateral expansion



Dreher et al. (1987)



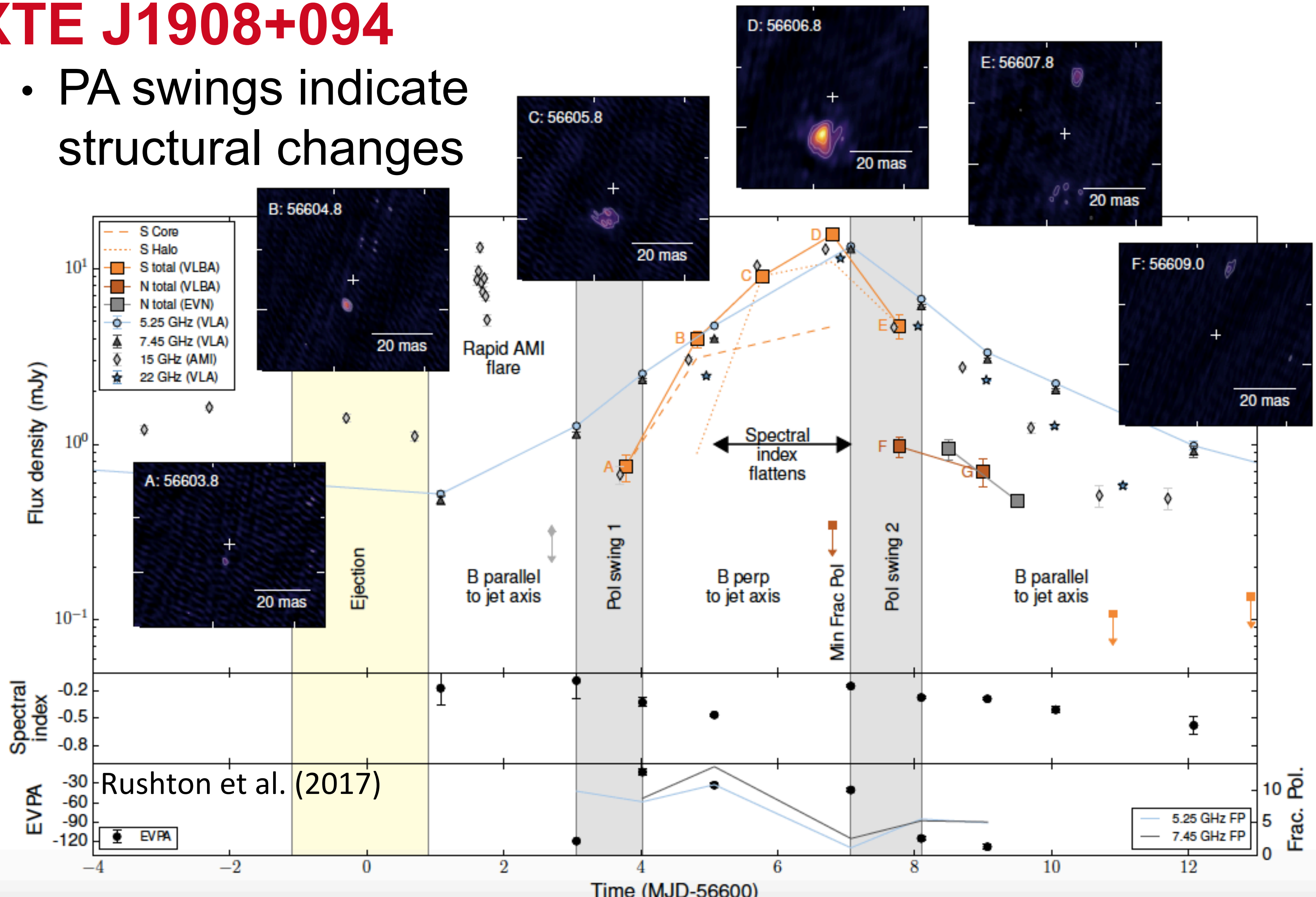


Miller-Jones et al. (2008)

Jets impacting ISM

XTE J1908+094

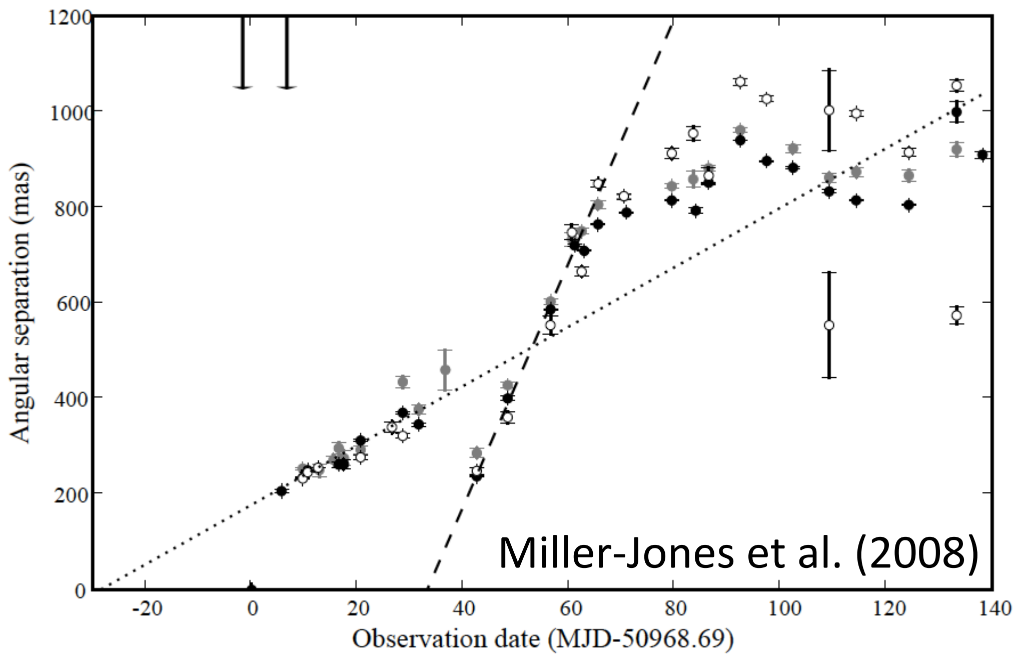
- PA swings indicate structural changes

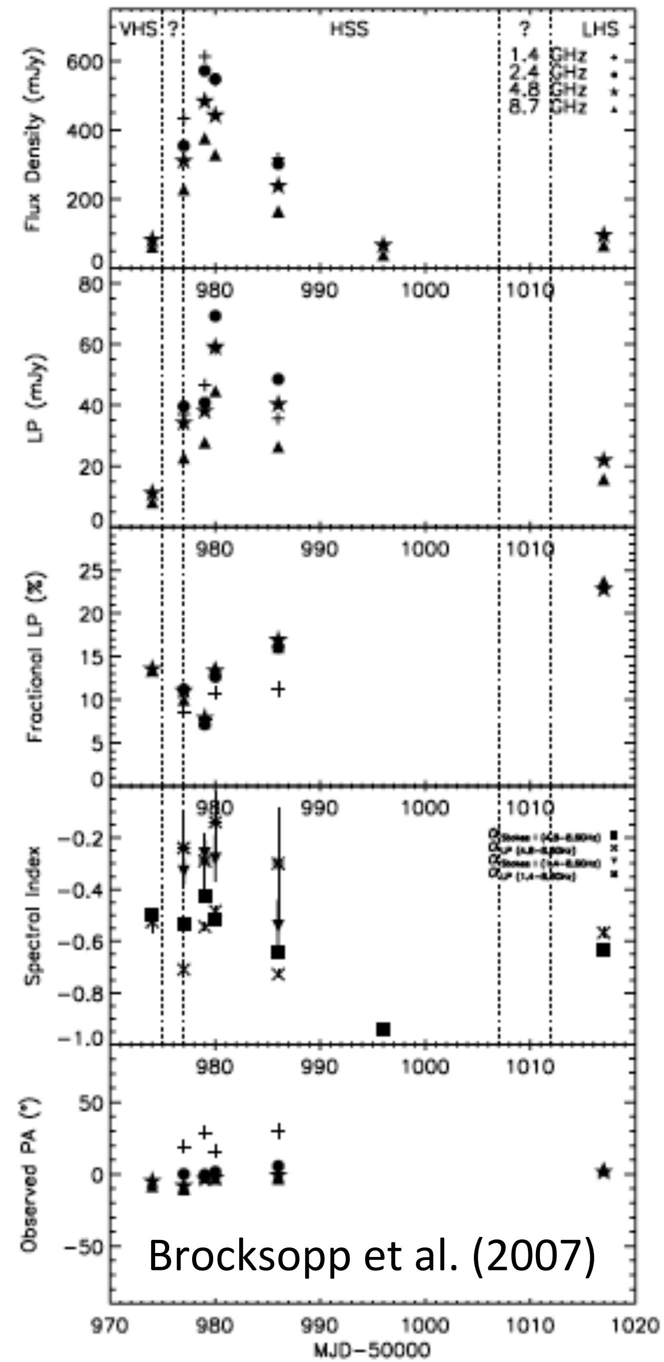


Jets impacting ISM

XTE J1748-288

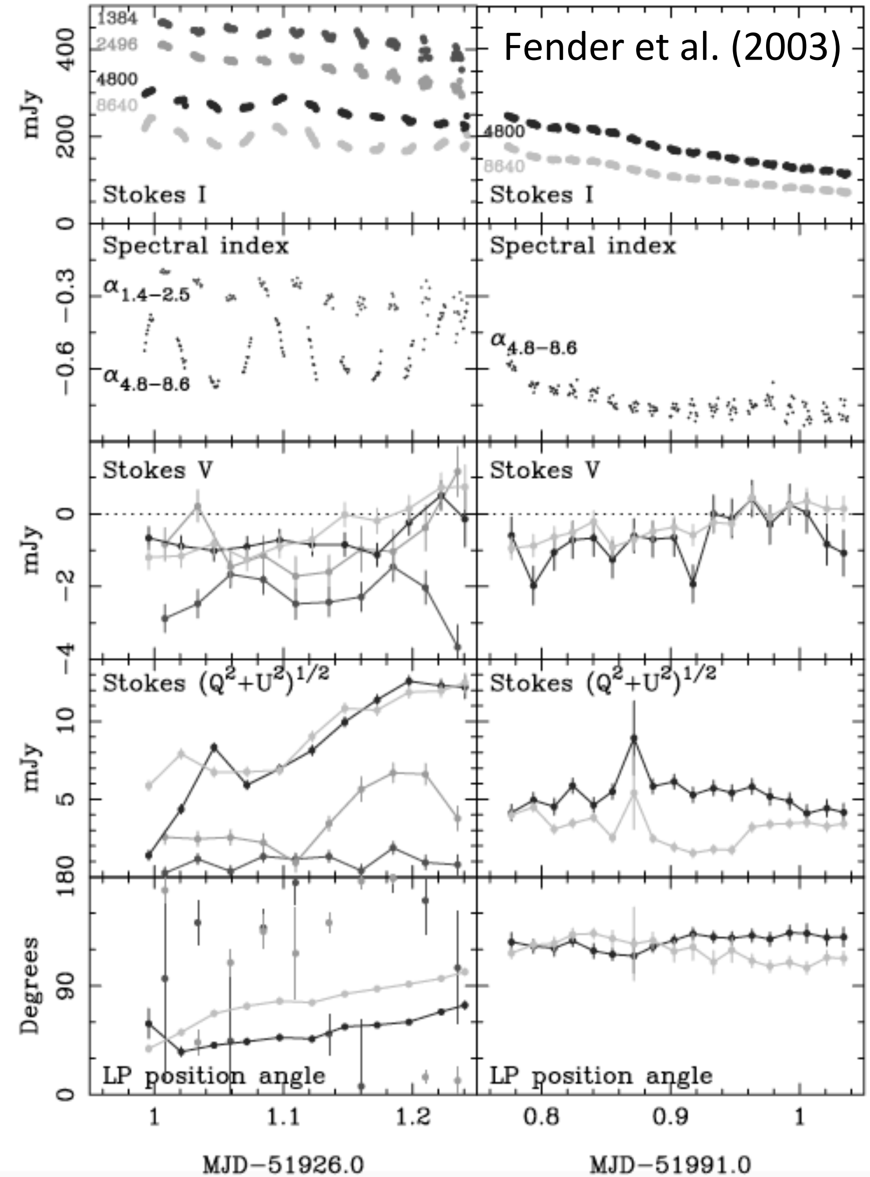
- Typical synchrotron polarization
- Jets hit a `wall’ ~1 arcsec from core
- Orders field, FP starts to rise





Circular polarisation in GRS1915

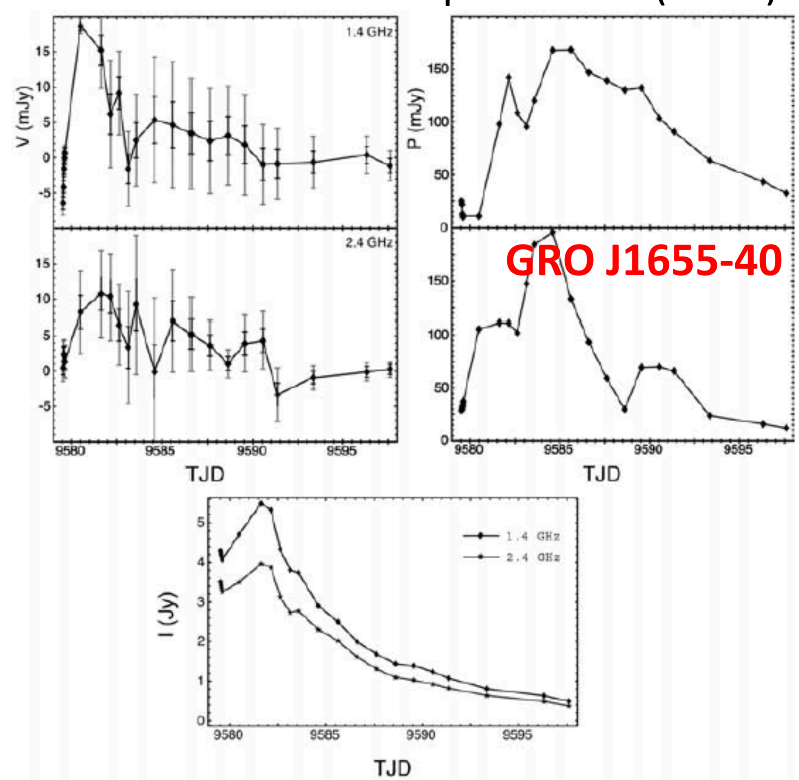
- Seen subsequent to major ejection events
- Source-integrated levels 0.1-0.4%
- Steep spectrum
- Unrelated to LP or I
- Likely a compact source that is a small fraction of total emission
- Amplitude correlated with times of spectral index changes
  - New ejection events

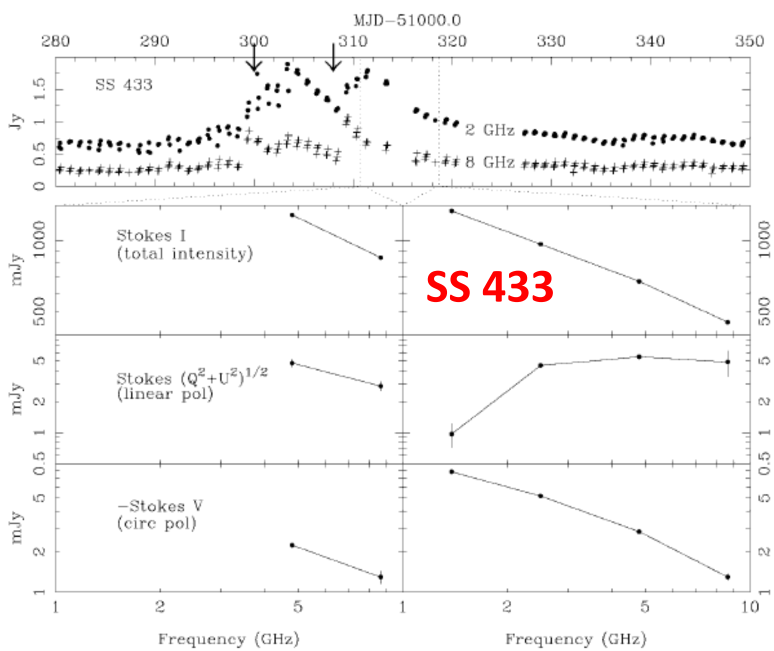


Also GRO J1655-40, SS 433

- V evolves on a shorter timescale than I
- Higher fractional variability
- Sign evolves; realignment of field close to BH
- Possible causes:
  - Faraday conversion of LP to CP
  - Synchrotron/gyrosynchrotron

Macquart et al. (2000)



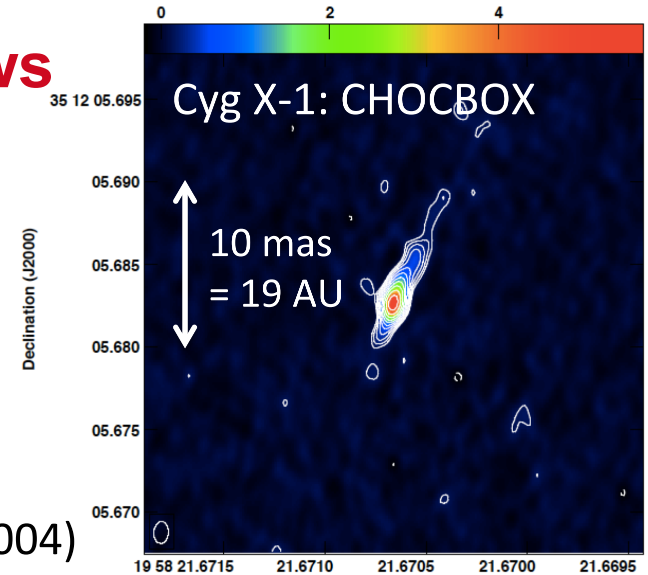


Fender et al. (2000)

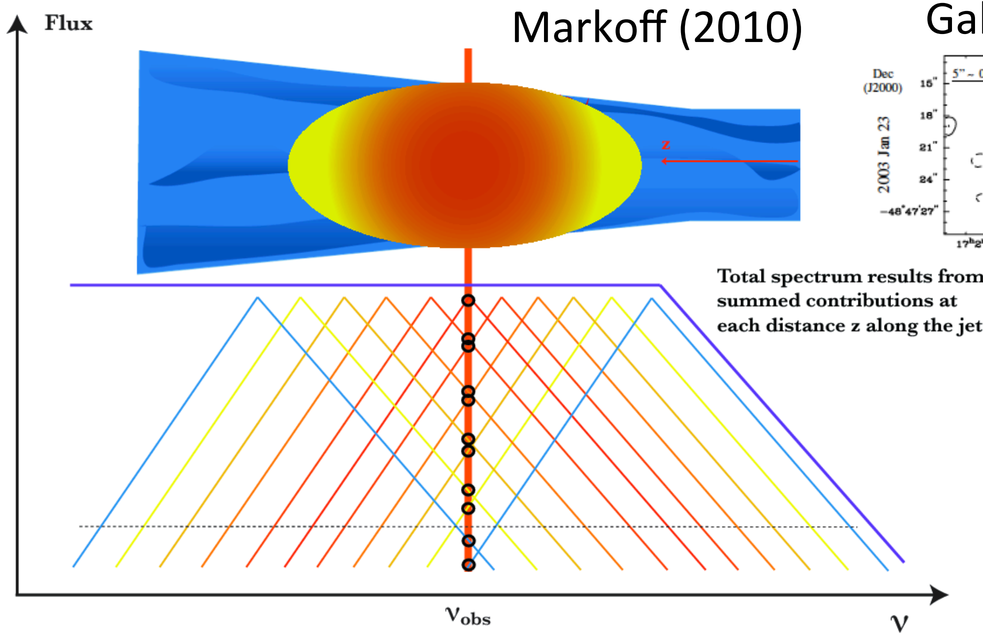
Hard state: steady, compact jets

Partially self-absorbed, conical outflows

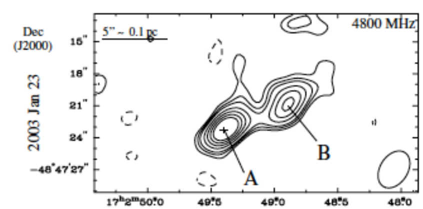
- Directly resolved in several sources
- Flat or slightly inverted radio spectra
- Few percent linear polarization
- EVPA aligned with jet axis
  - Perpendicular B-field

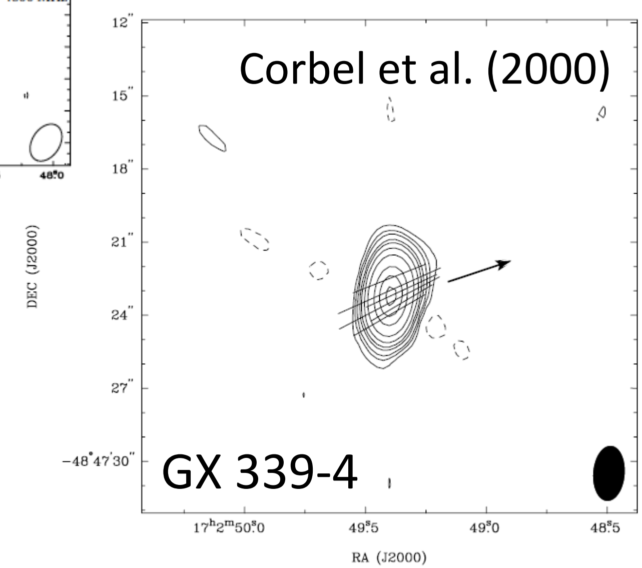


Markoff (2010)



Gallo et al. (2004)

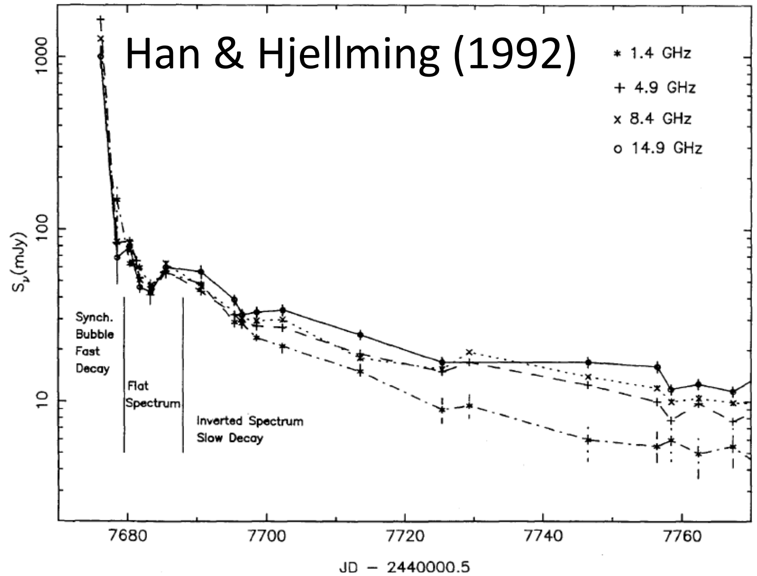


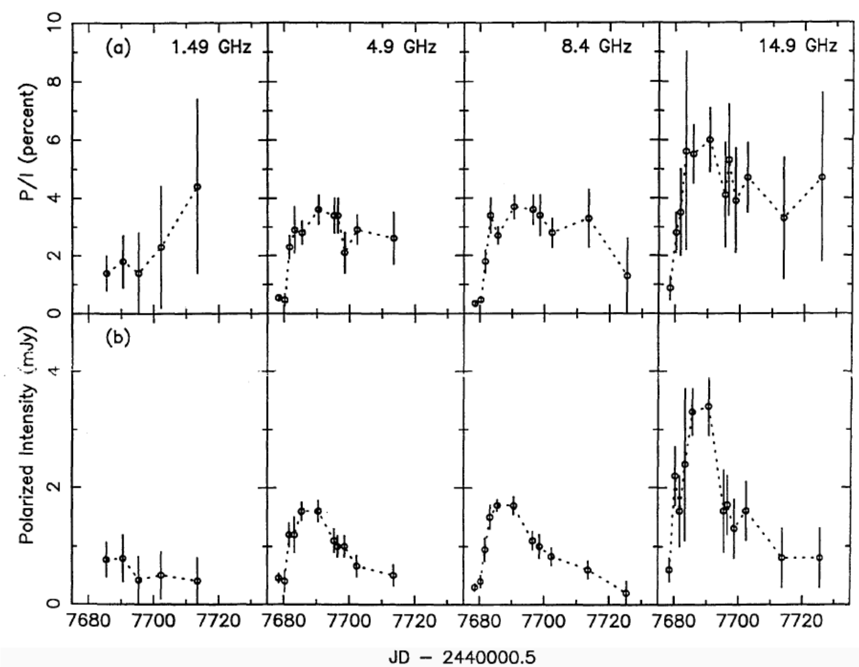


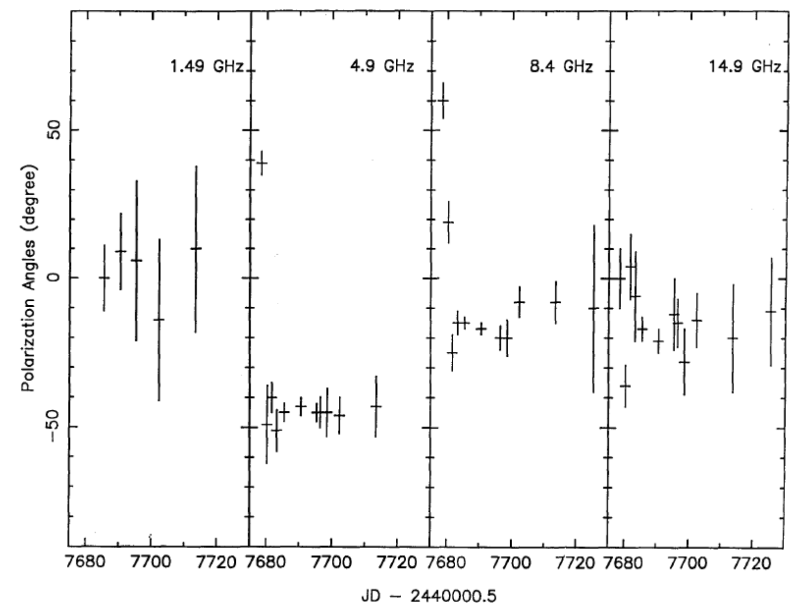
Determining the quiescent jet axis

1989 outburst of V404 Cyg

- Significant LP detected
- PA stabilised during hard state decay phase
- Alignment with jet axis?



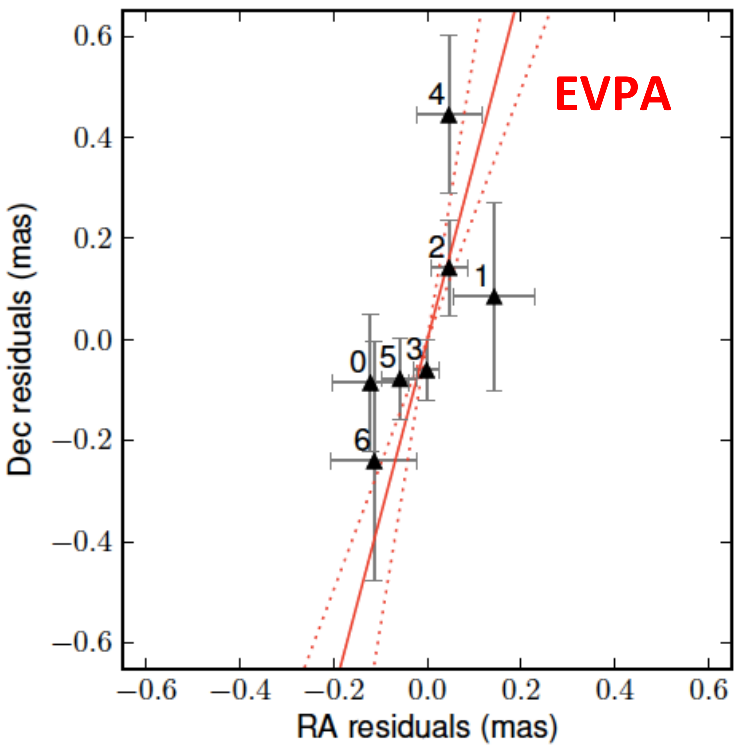


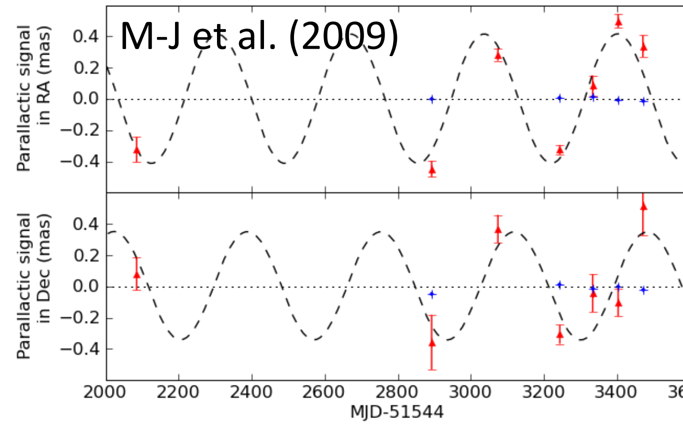


Determining the quiescent jet axis

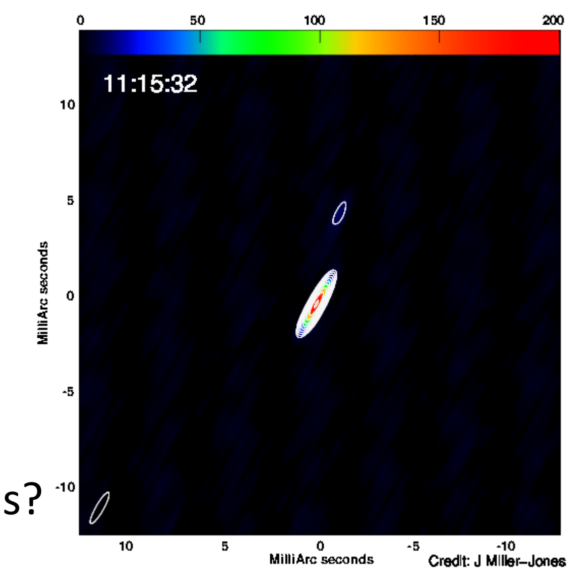
VLBI in quiescence determines parallax distance

- Plot astrometric residuals





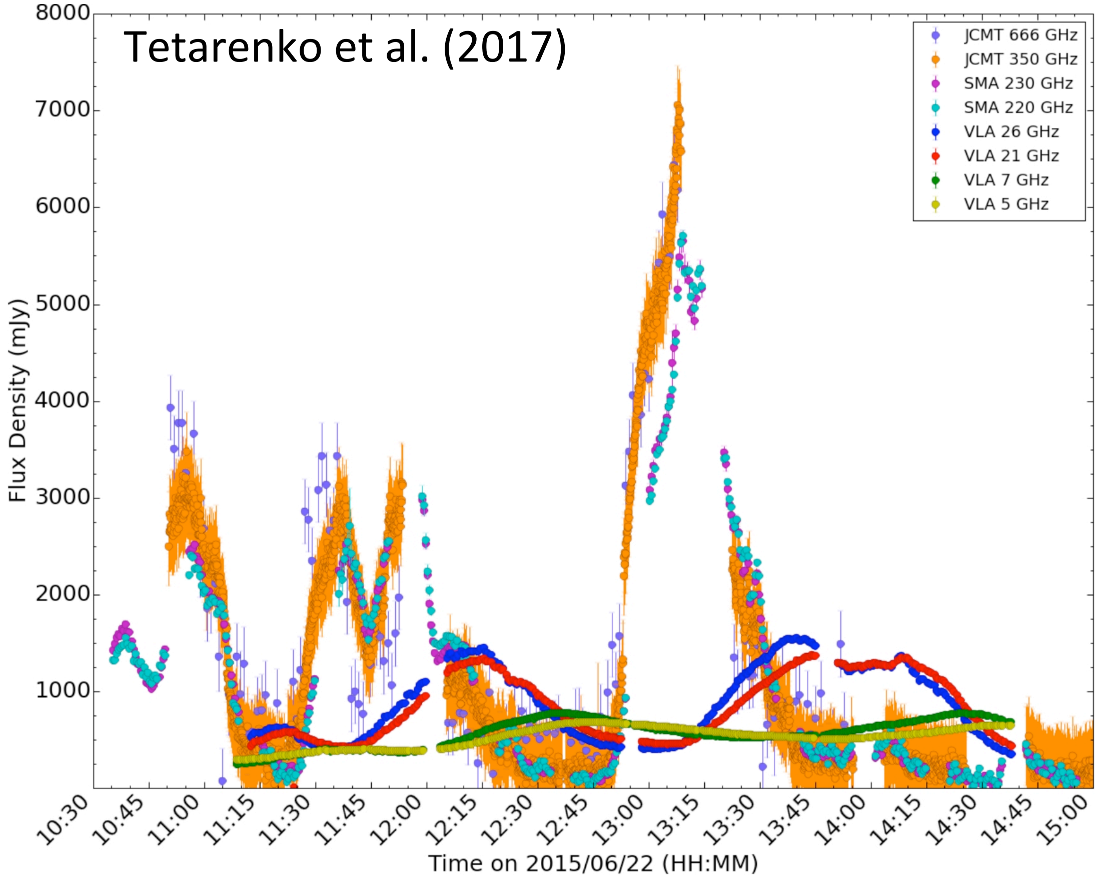
Remember this?



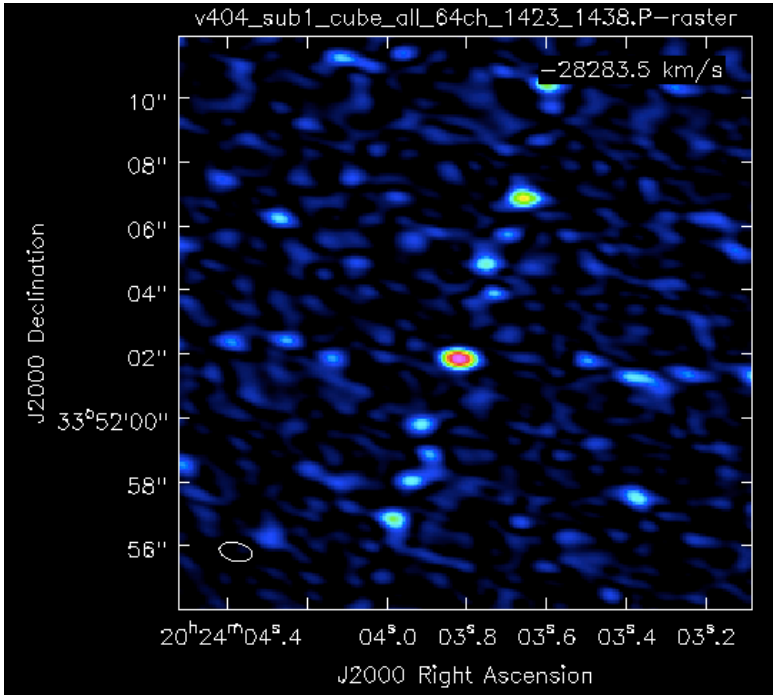
Tracking time-variable polarisation

Simultaneous multi-wavelength coverage

- Preliminary polarisation calibration at the VLA



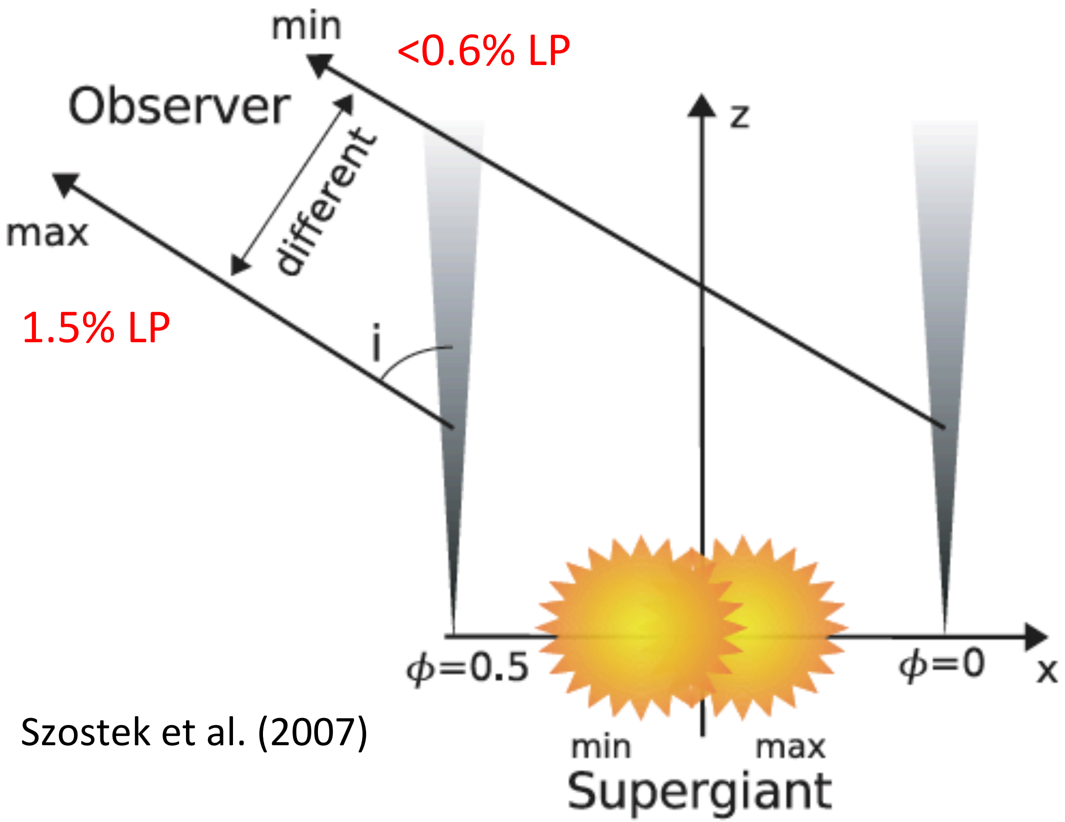
Work by C. MacPherson



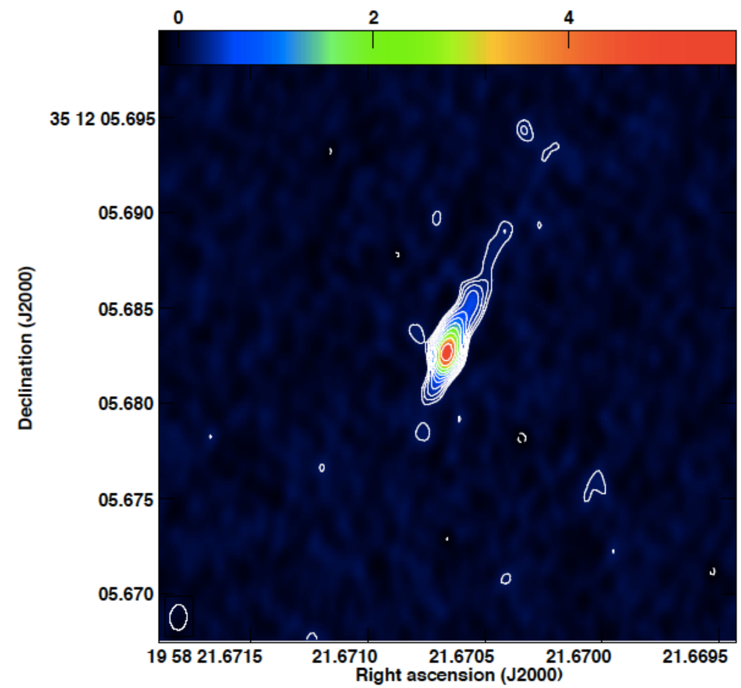
Probe of the environment

Cyg X-1: jet emission propagates through wind

- Polarisation detected at ϕ=0.5, but not at ϕ=0
- Track around full orbit; RM probes wind



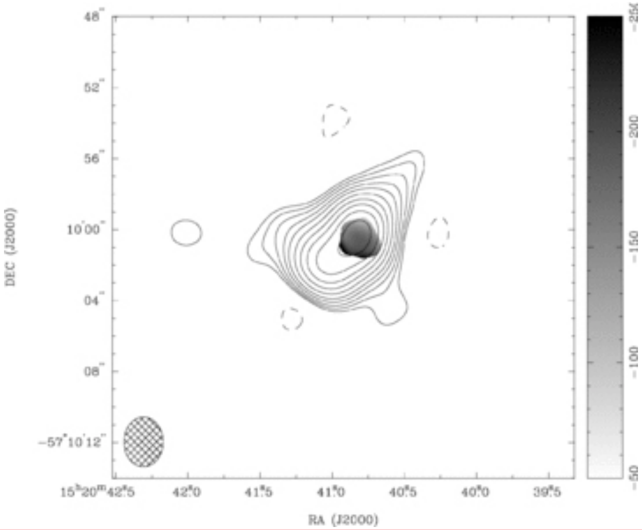
Szostek et al. (2007)

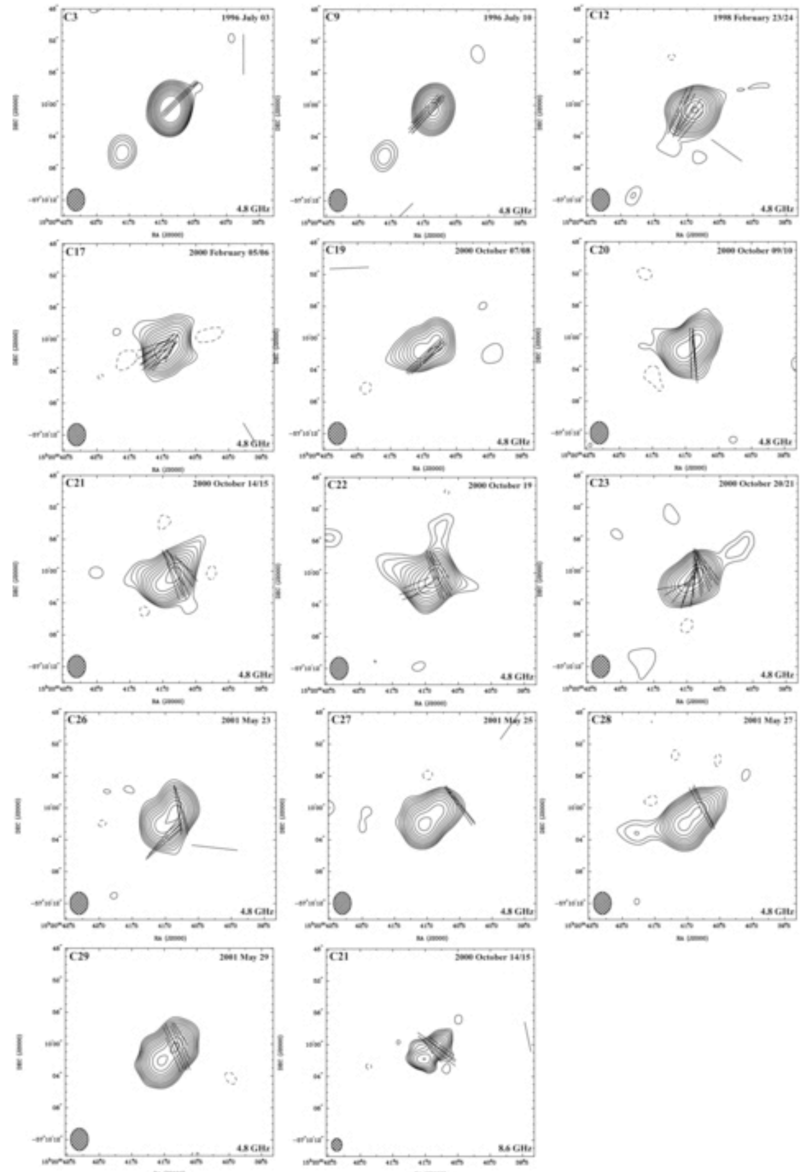


Polarization in NS XRBs

Circinus X-1

- High accretion-rate NS XRB
- Stable PA over 10 years
- A few percent LP
- B aligned perpendicular to jet axis in ejecta – shocks?
- Core has B parallel to jet axis

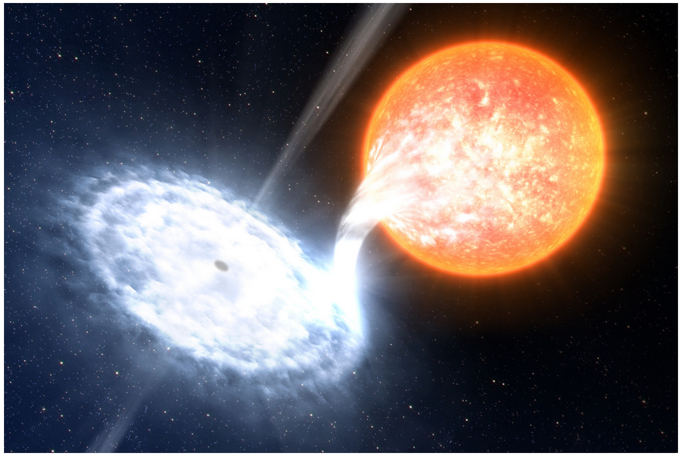




Summary

XRBs allow us to study jets and jet/disc coupling in real time

- Examine sequence of events
  - Ejecta launching
  - Shocks forming (internal/external)
- Typical LP fractions:
  - ~1% in steady, compact jets
  - 1-25% in transient ejecta
- A few cases with measured CP



- Use polarization as probe of jet structure, stellar wind
- Paucity of spatially-resolved polarization
  - Sensitive VLBI arrays
  - Techniques to deal with rapidly-evolving structure