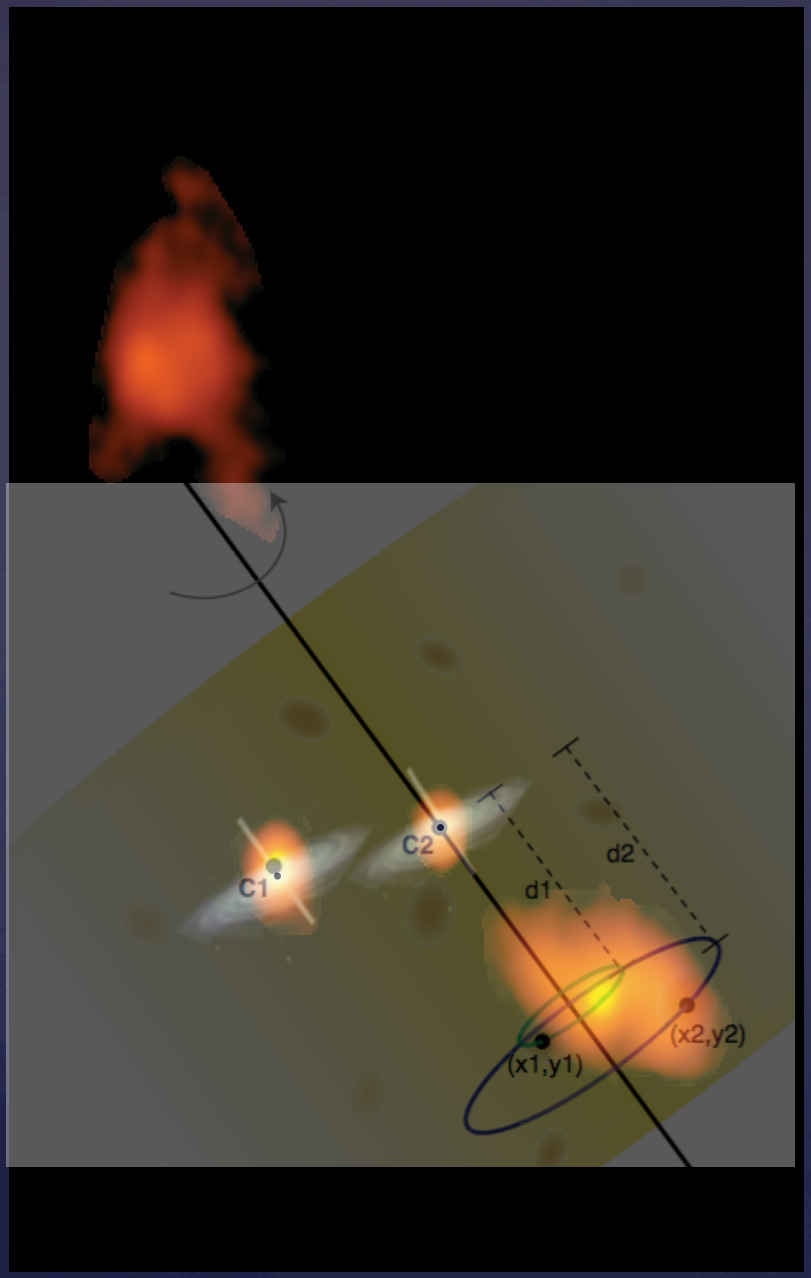


A Compact Symmetric Object with a Candidate Binary Black Hole

Greg Taylor (UNM)

Rimini
May 27, 2015

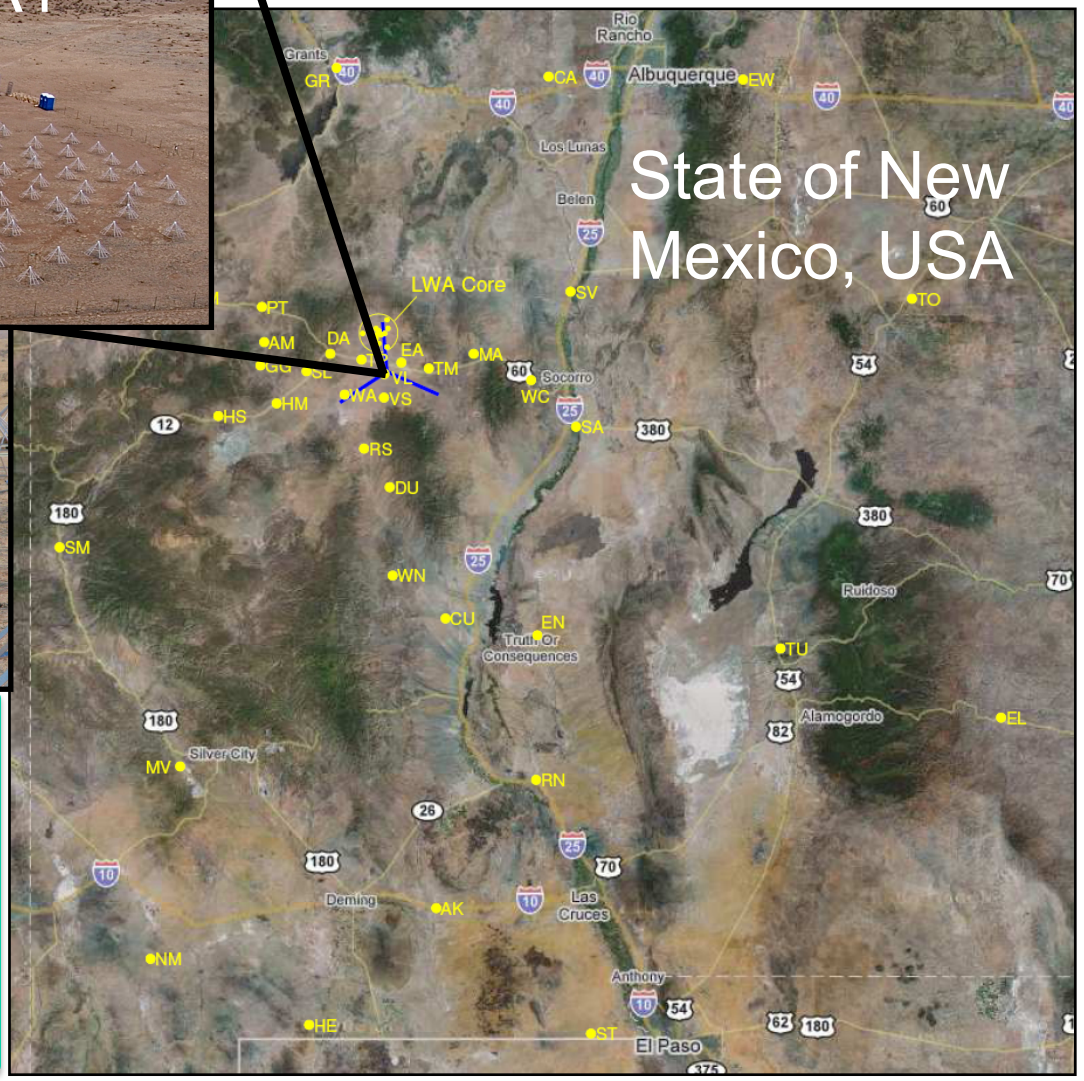
LWA Long Wavelength Array

NRAO

The University of New Mexico

The LWA Instrument

- **10-88 MHz Aperture Synthesis Telescope**
- **4 beams x 2 pol. x 2 tunings x 16 MHz**
- **2 all-sky transient obs. modes**



- LWA1 operational in 2011
- Goal of 53 LWA stations, baselines up to 400 km for resolution 2” at 80 MHz with mJy sensitivity
- LWA-SV under construction

LWA-SV under construction

Note: Science at Low Frequencies II, Dec 2-4, Albuquerque NM

Compact Symmetric Objects (CSOs)

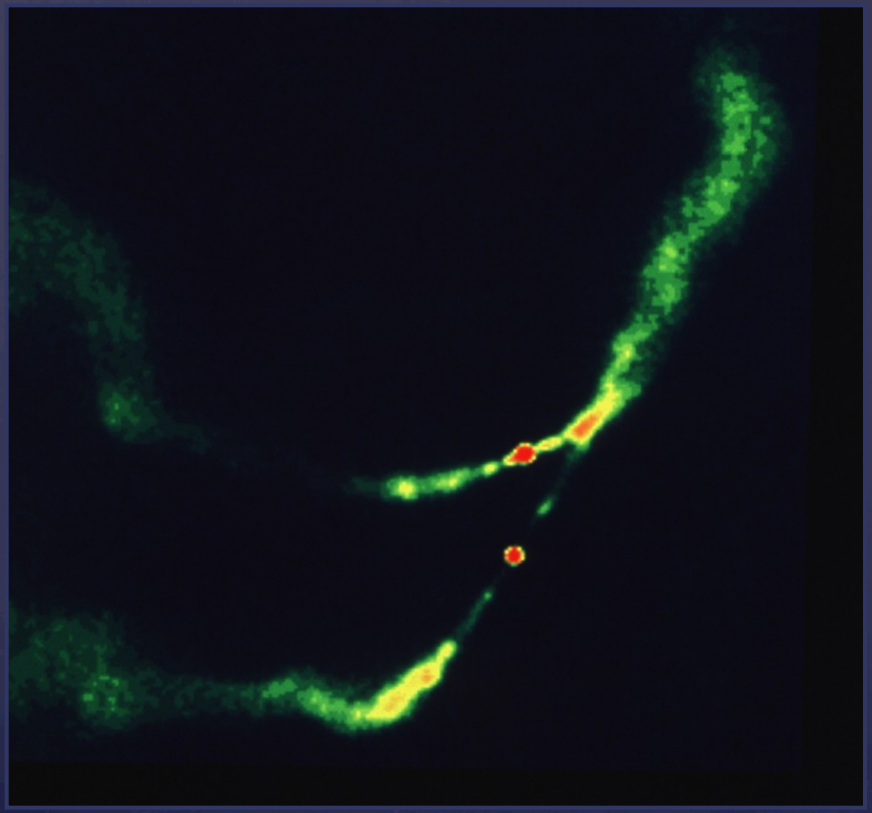
- Central core + bi-directional jets
- Size < 1 kpc
- Low polarization
- CSS or GPS
- Modest hot spot expansion speeds (0.01 - 0.1c)
- Relativistic jet speeds (0.6-0.9c)
- Likely to be young radio galaxies

Taylor et al. 2009

Known Supermassive Binary Black Holes

3C 75

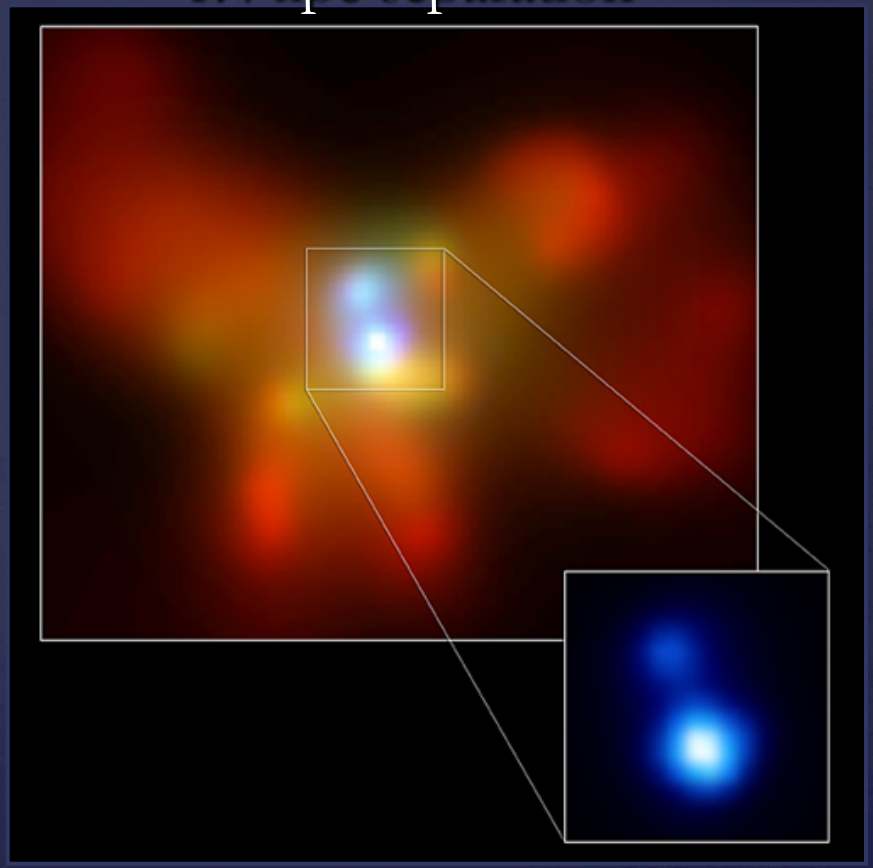
➡ 7 kpc separation



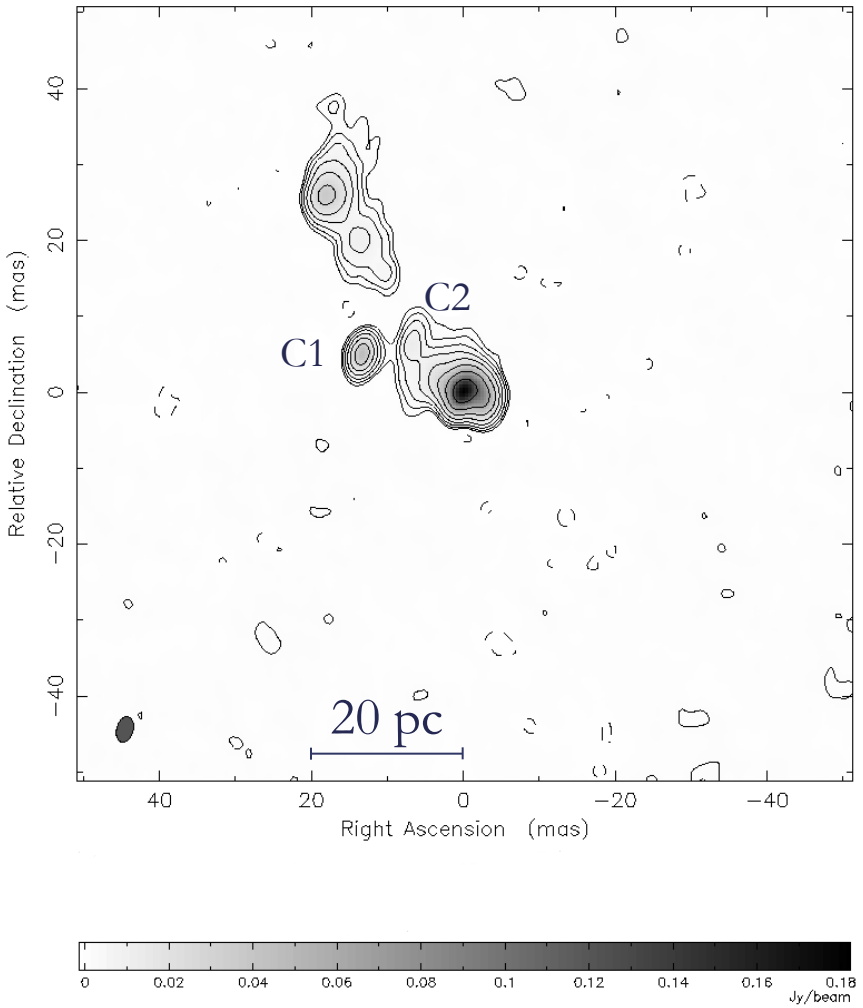
VLA image of 3C 75 at 6 cm (Owen *et al.* 1985)

NGC 6240

➡ 1.4 kpc separation



Chandra image of NGC 6240 (Komossa *et al.* 2003)



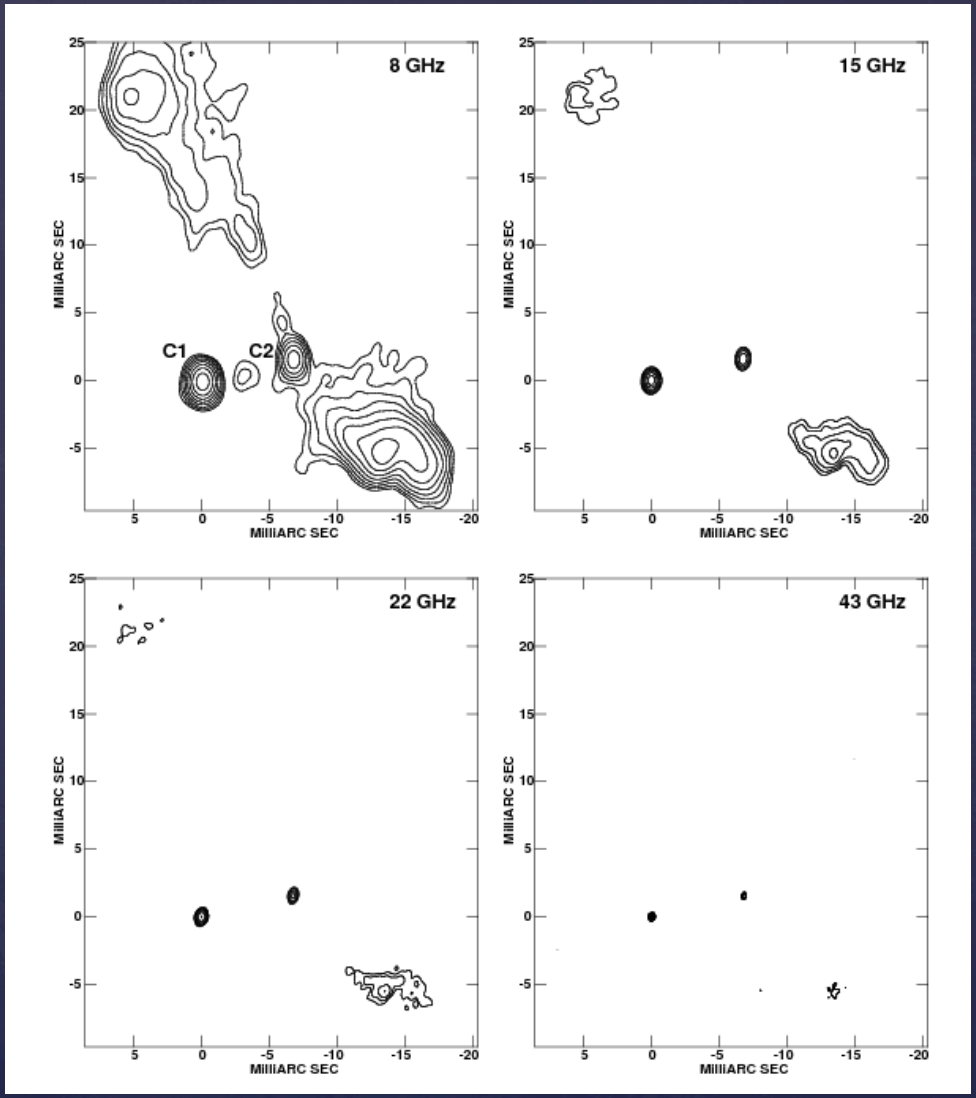
0402+379 at 5 GHz (Pollack *et al.* 2004)

- Re-discovery of 0402+379 by Pollack *et al.* (2004).

- Possible explanations for its properties:

1. Background Source
2. Gravitational Lensing
3. Jet Component
4. Binary Supermassive Black Hole System

Multi-Frequency Results

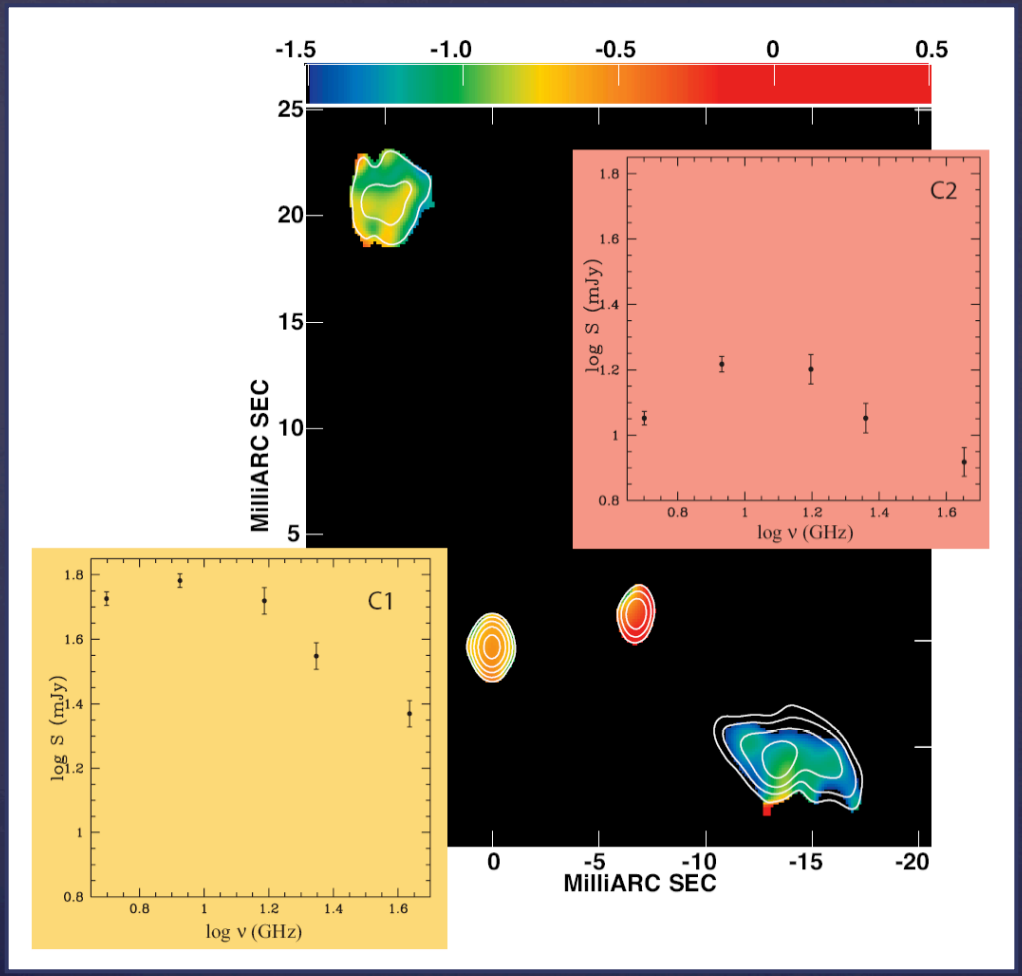


Naturally weighted 2005 VLBA images of 0402+379 at 8, 15, 22, and 43 GHz.

- C1: 0.183 ± 0.048 Jy
- C2: 0.124 ± 0.035 Jy
- Projected separation between C1 and C2 equal to 7.3 pc

Rodriguez et al. 2006

Radio Continuum Spectra



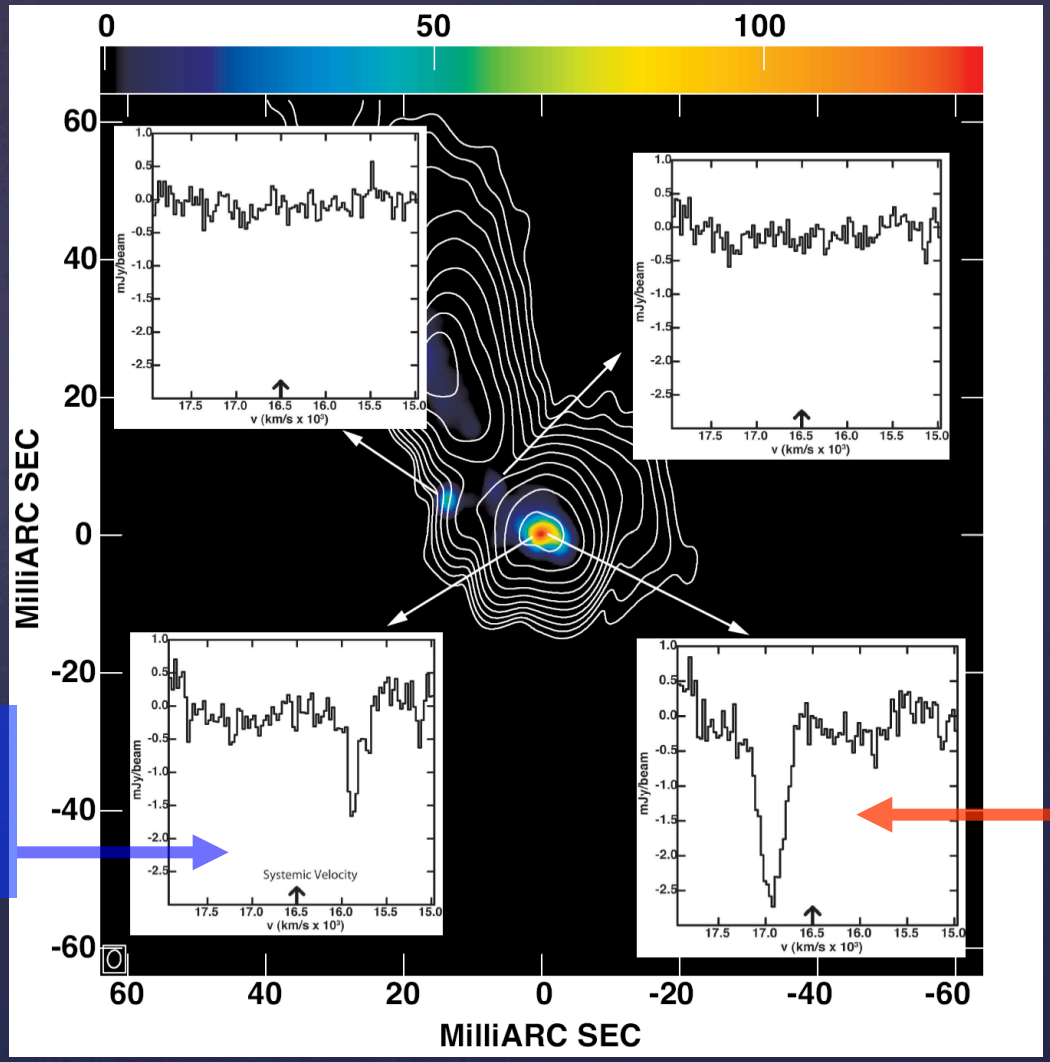
Spectral index distribution between 8 and 22 GHz from the 2005 VLBA observations.

- In both hotspots of the source, N2 and S2, a steep spectrum was found.
- For both central components, C1 and C2, the spectrum peaks at ~10 GHz.

Evidence against lensing

Evidence against jet component

Other Results - 21 cm VLBI



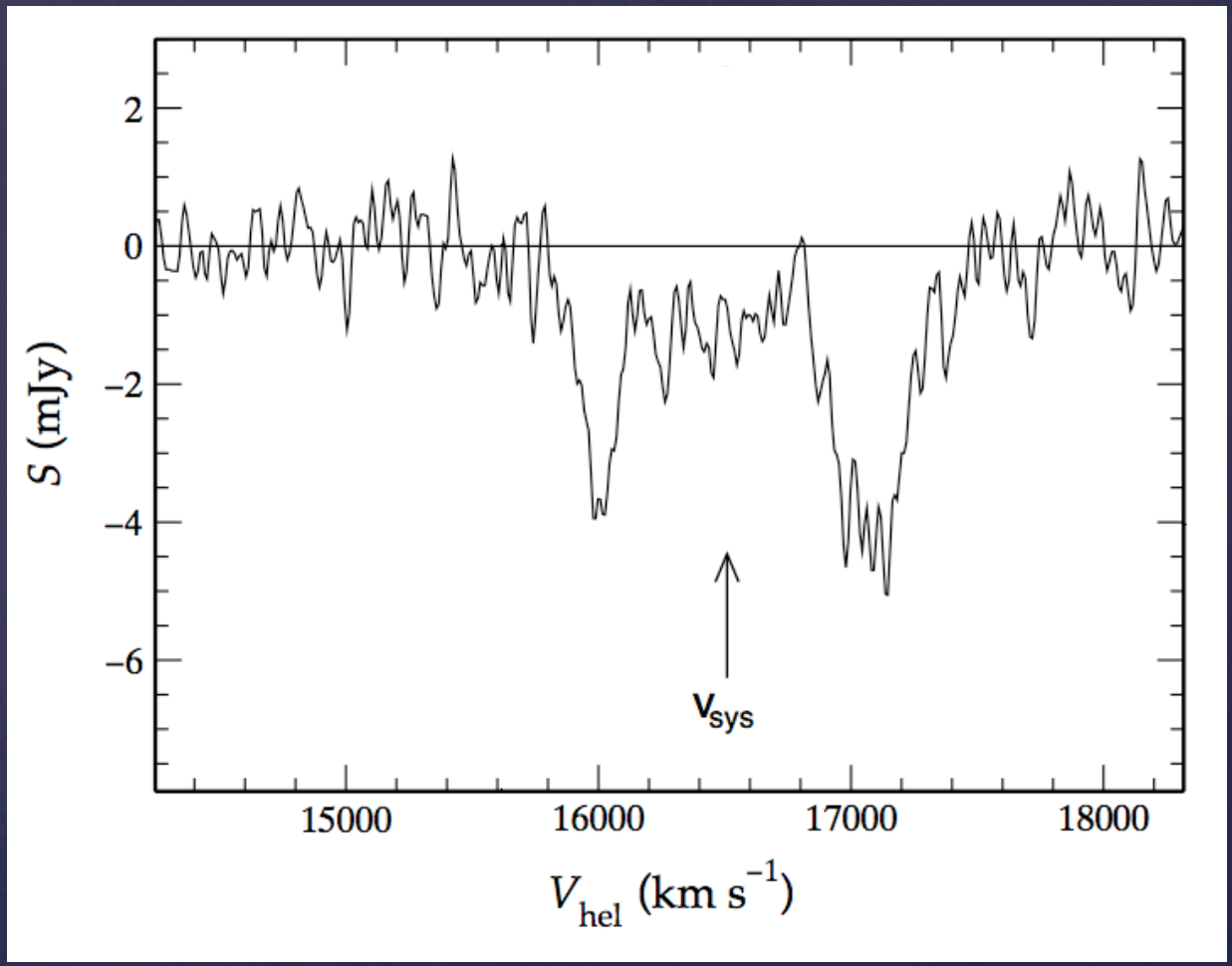
Line blueshifted 700 ± 10 km/s from systemic

Line redshifted 370 ± 10 km/s from systemic

HI absorption profiles

Rodriguez et al. 2009

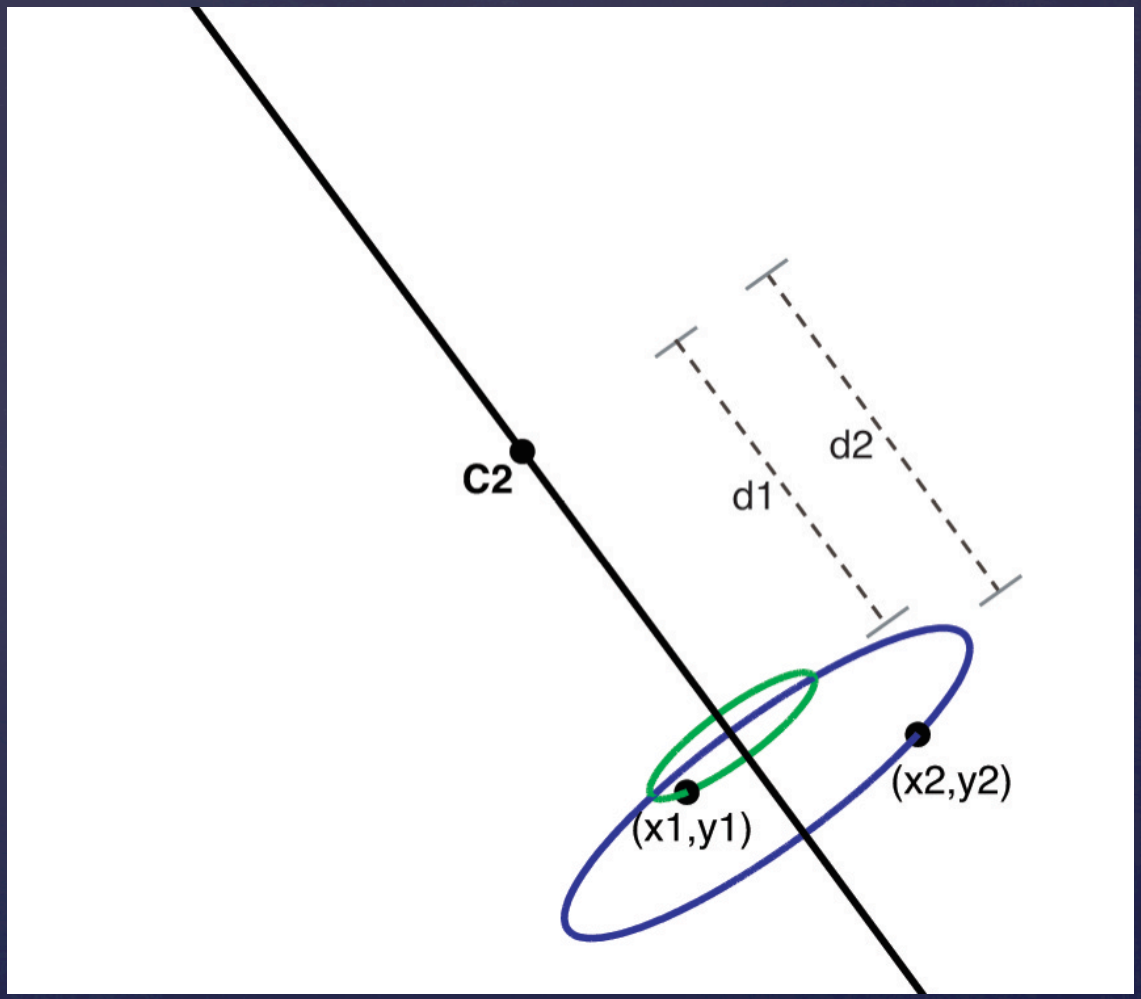
WSRT



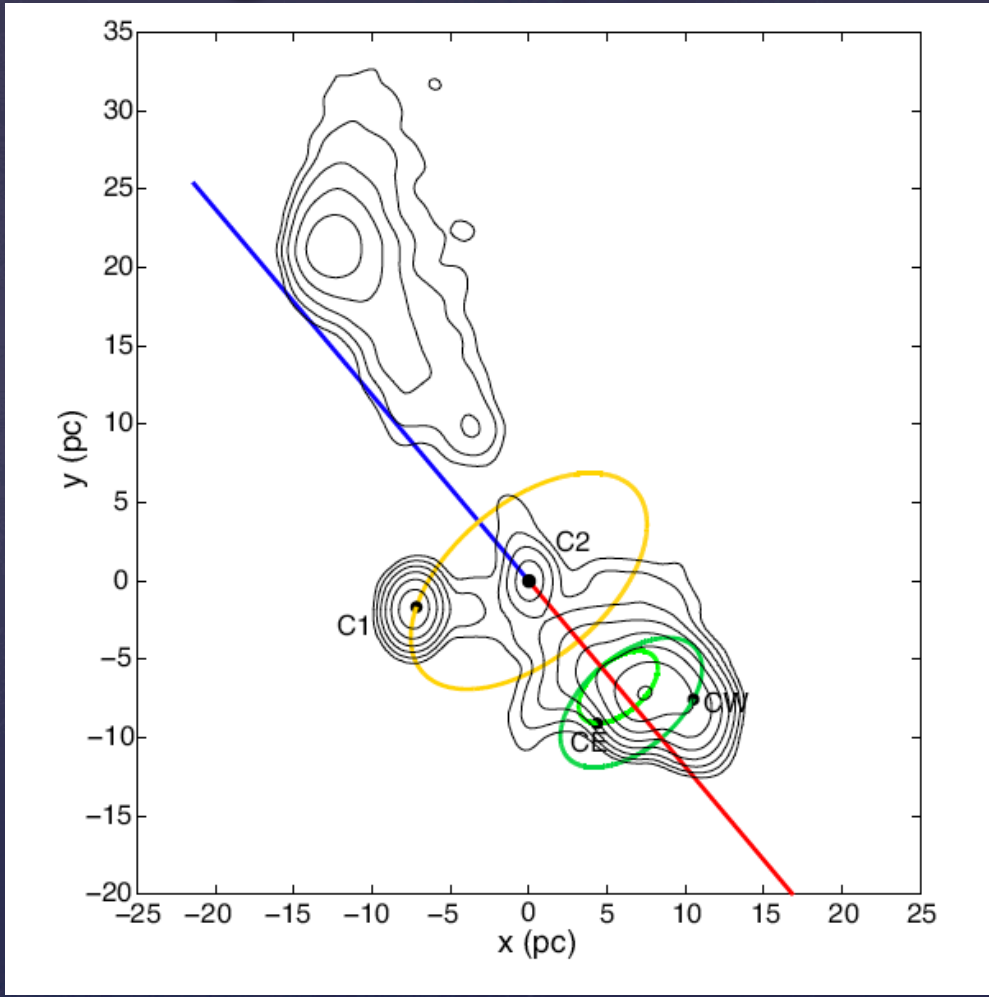
Integrated HI absorption profile from Morganti et al. 2009

Modeling 0402+379

- Model proposed
  - Projected on plane of sky
- C2 chosen as the origin
- Circular orbits drawn

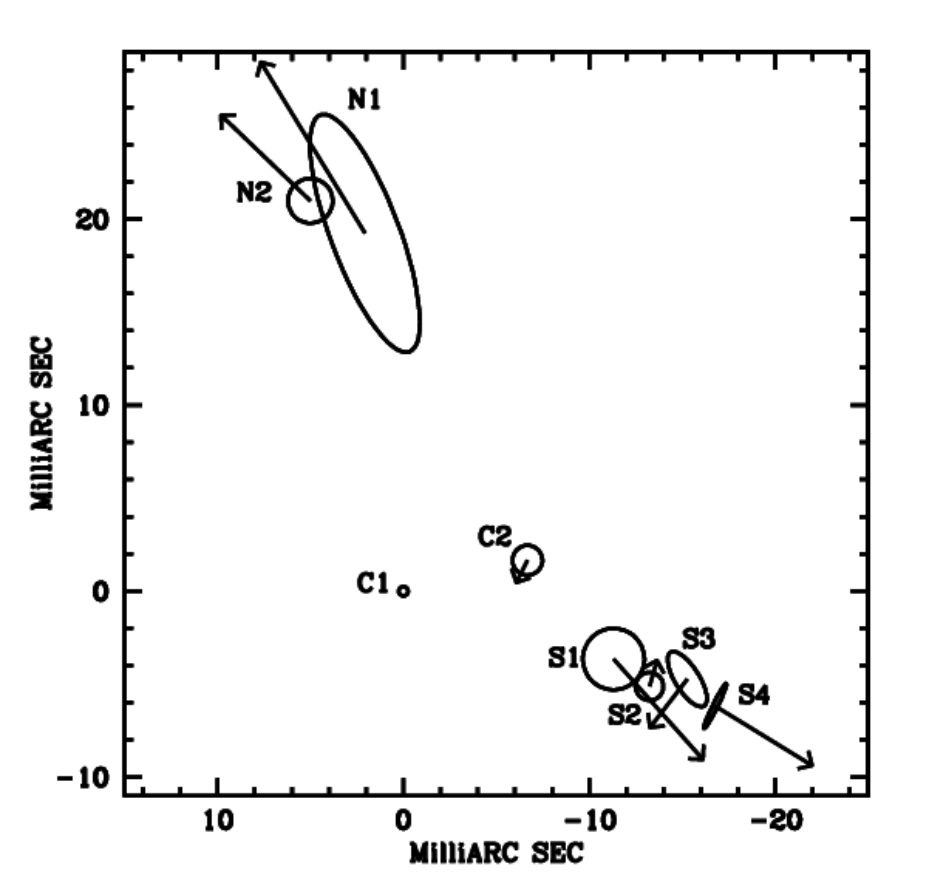


Modeling 0402+379



Thick disk model inclined at 66° from the line-of-sight for a system mass of 7×10^8 M_{sun}

Component Motions at 5 GHz



Components model for the
VLBA observations of 0402+379

- Northern jet is moving away from the two central components to the northeast,
  N1: (0.185 ± 0.008)c
  N2: (0.114 ± 0.019)c
- Southern jet is moving away to the southwest, though more slowly,
  S2: (0.0251 ± 0.0085)c
  S3: (0.056 ± 0.010)c
- The results obtained for C2 show no significant motion < 0.088c
  Expected orbital motion ~600 km/s (~0.002c)

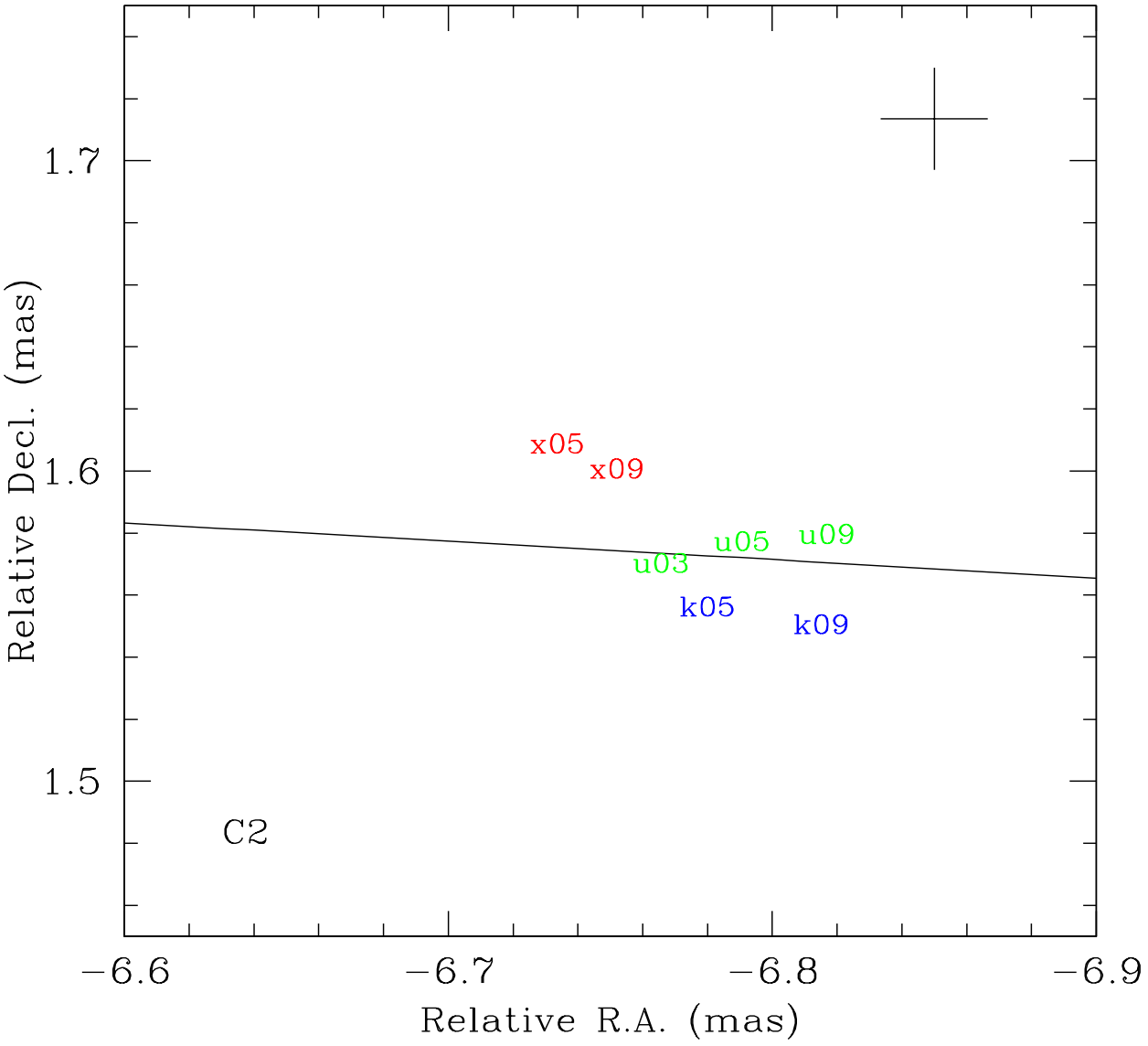
Evidence against jet component

Component Motions
8, 15 and 22 GHz

Disk model inclined at 83° from the line-of-sight

V ~ 0.03c

(0.01 mas/yr)



Component Motions

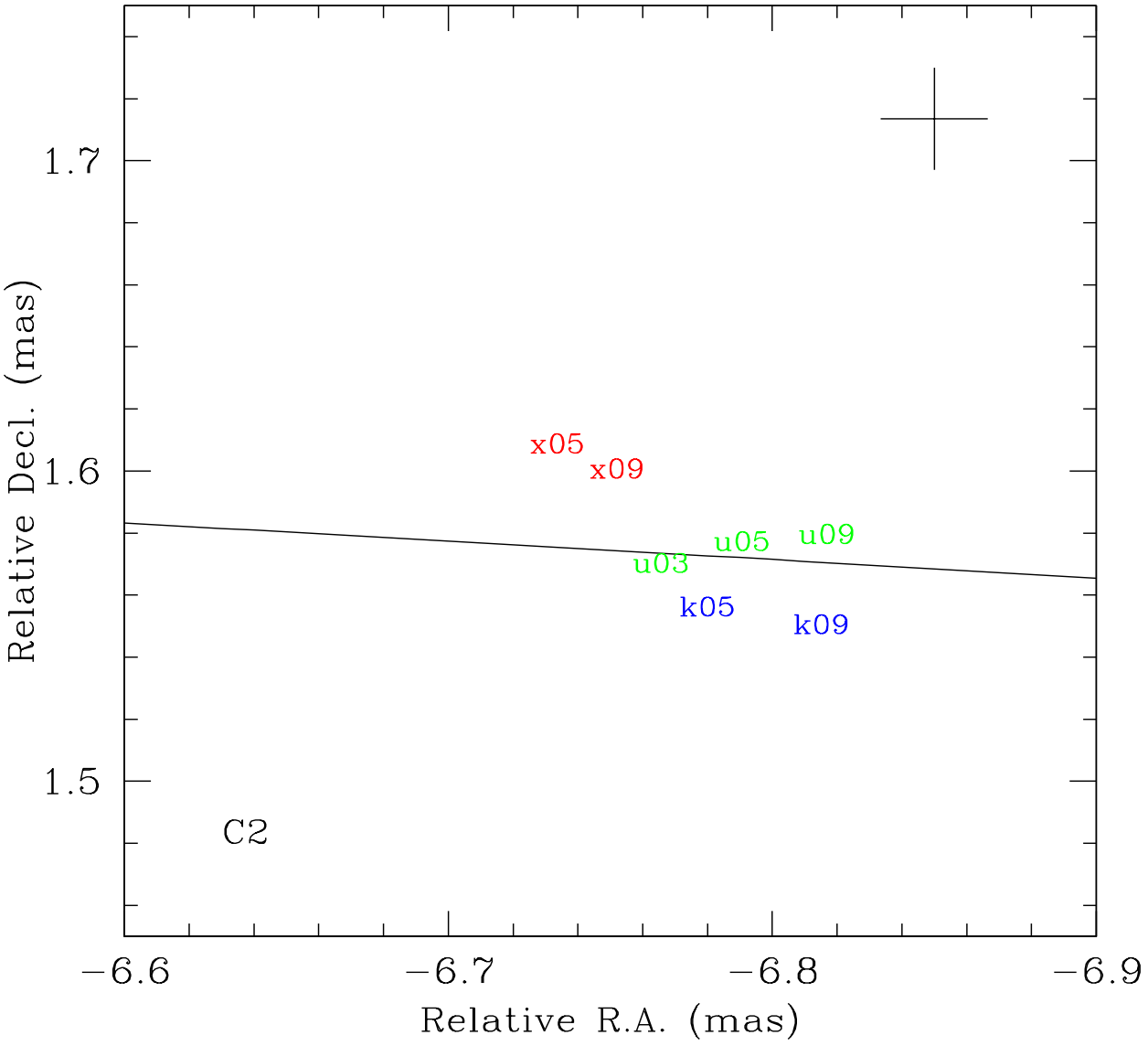
Disk model inclined at 83° from the line-of-sight, and radius 16 pc for a

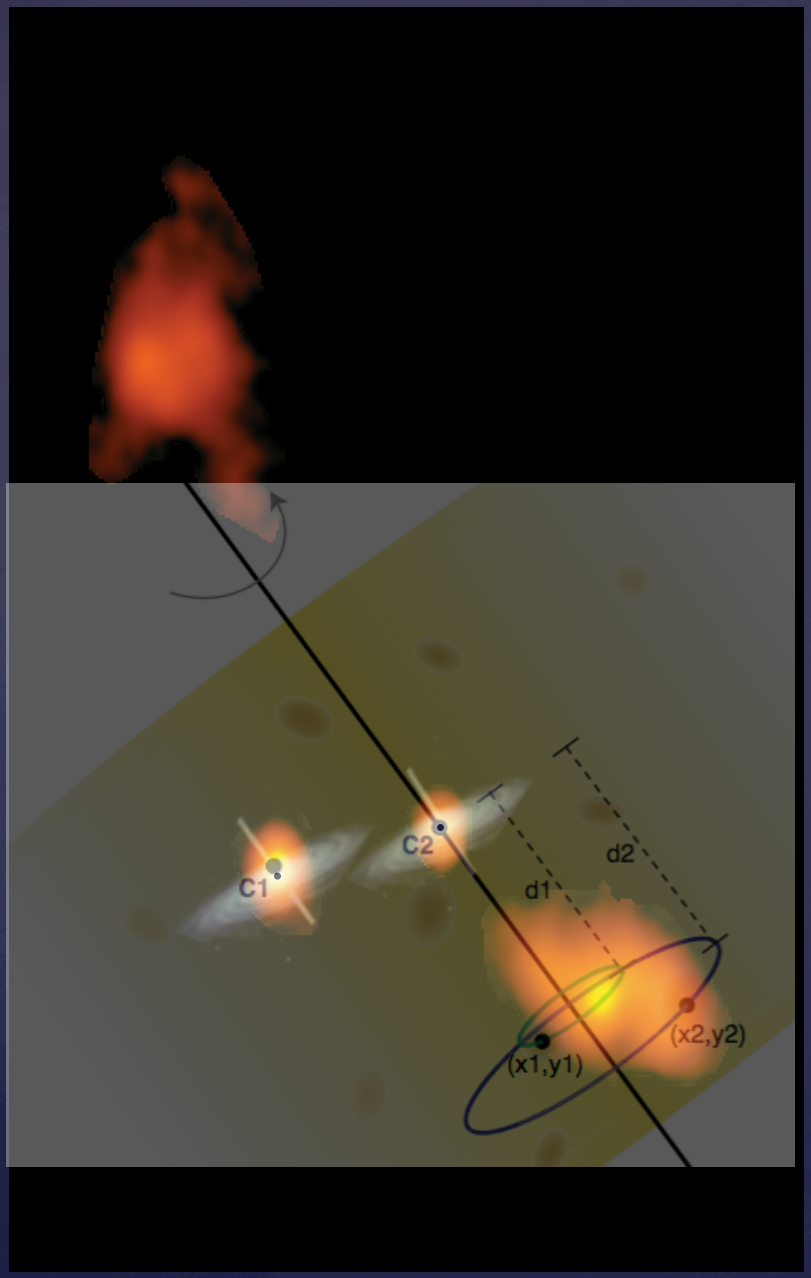
system mass of 4×10^{11} M_{sun}

Based on

V ~ 0.03c

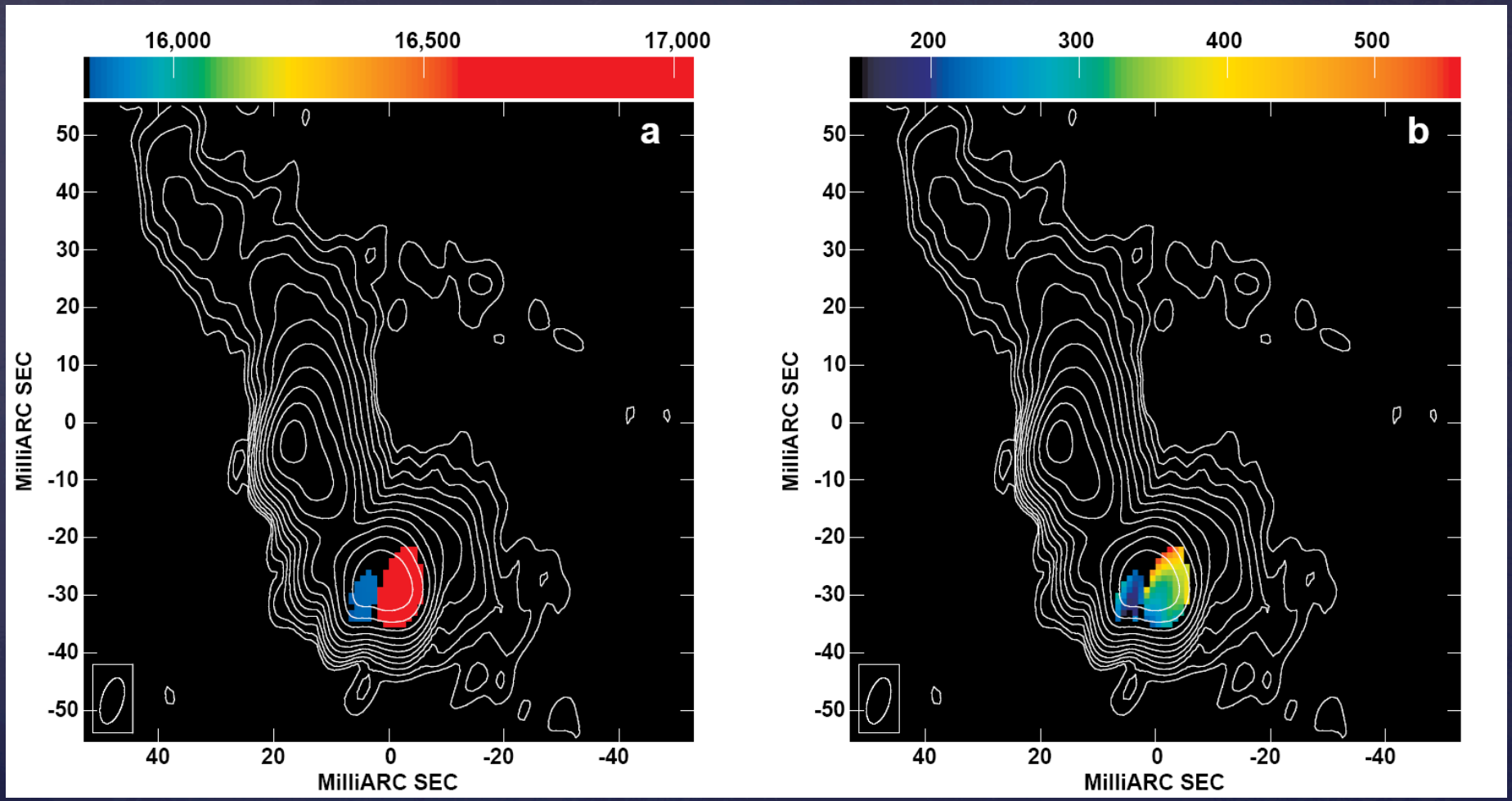
(0.01 mas/yr)





Summary

- 0402+379 : two active nuclei of a single galaxy
- Closest binary black hole system yet discovered. Projected separation of 7.3 pc
- Total mass of the system: 10^9 – 10^{11} M_{Sun} and highly inclined
- New VLBI epoch needed!
- Unique HI signature may be a signpost for SBBH systems



(a) Map of the central velocity and (b) width of the HI absorption profiles

How Lucky Were We?

- 1 compact SBBH out of 293 sources in CJF
- Assume all Es undergo mergers and could have a hidden SBBH
- ~ 10% of Bright Es have an AGN
- ~ 10% of AGN are radio loud
- so 1/100 companion BHs should be radio loud but they have to be within 1 and 1000 mas (1-5000 pc depending on distance)

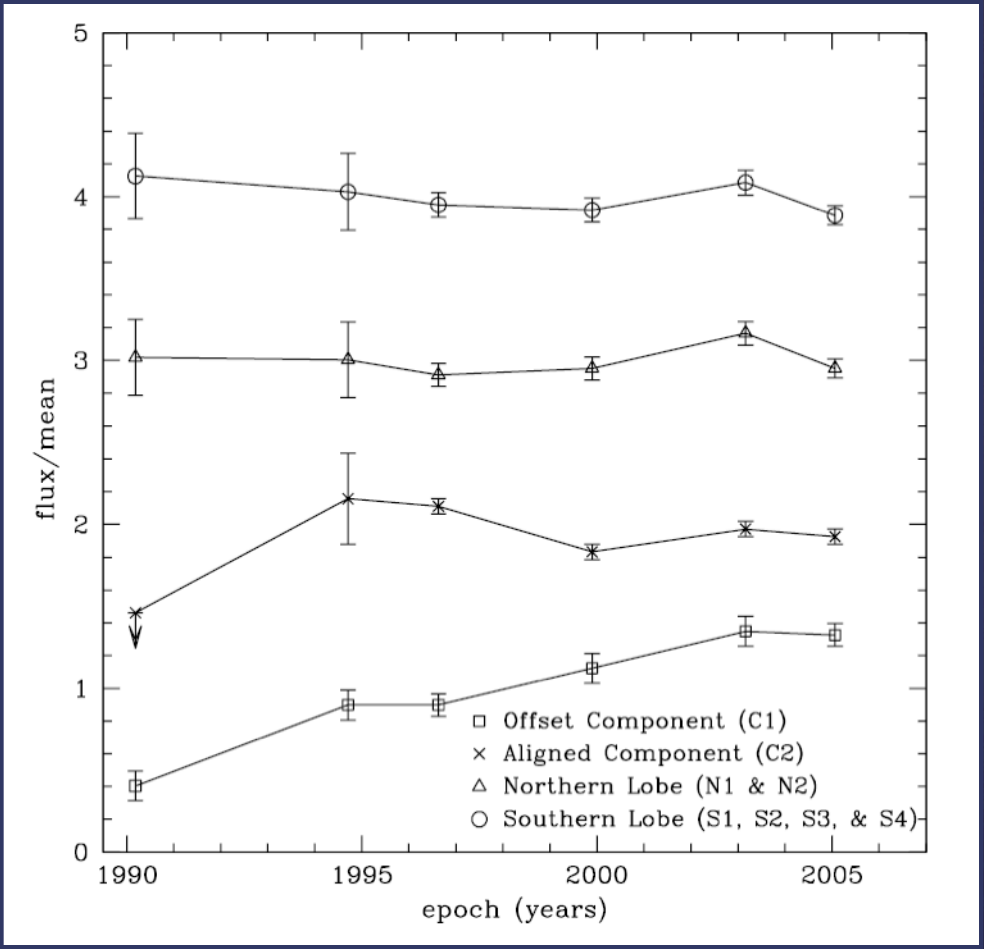
Future plans

- 0402+379
  - constraining the orbital velocity
  - examining the stellar light profile for signs of a SBBH (see Merritt talk)

- Searching for more binary black hole systems. The VLBA Imaging and Polarization Survey (VIPS, Taylor *et al.* 2005, Helmboldt et al. 2007) has imaged 1127 sources. We are analyzing multi-freq follow-up for ~100 sources

- Search for low frequency bursts of coherent emission from inspirals using the Long Wavelength Array

Component Variability



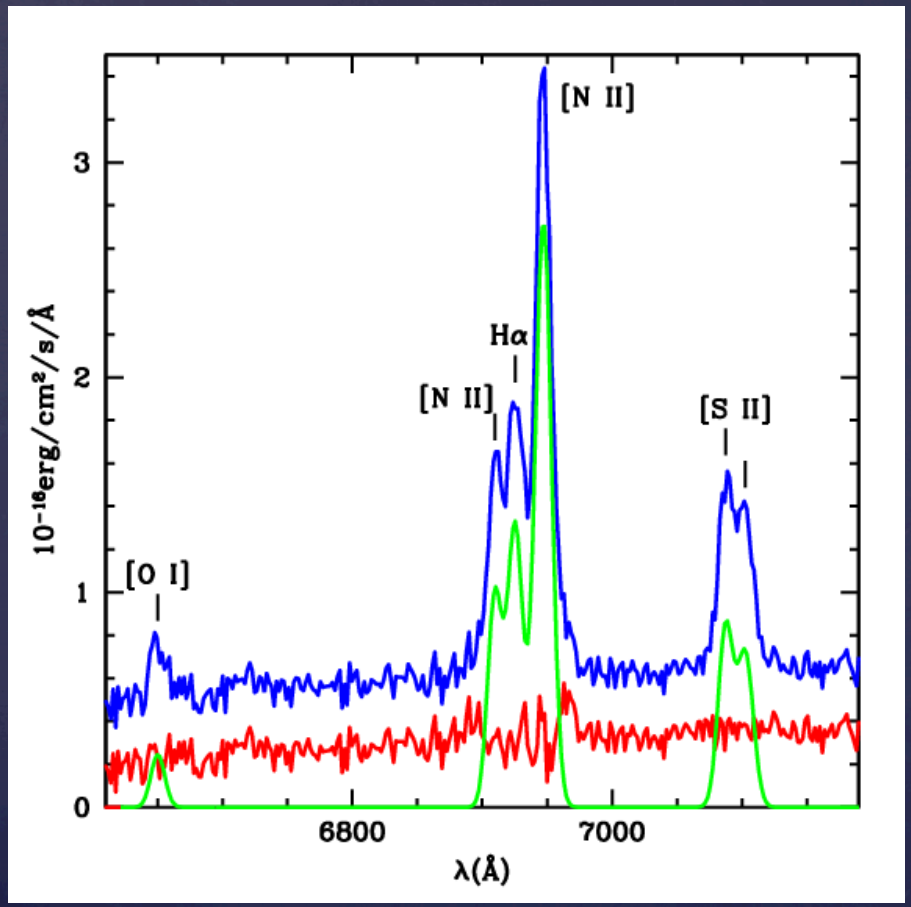
Light curves of the different components of 0402+379 at 5 GHz.

- Component C1 substantially increases in flux density over the 15 y baseline.
- Component C2 is also variable.
- For the southern and northern components, there is no substantial variation in the flux densities over the 15 y baseline.

Evidence against lensing

HET Spectroscopy

- Spectrum of the core of 0402+379 obtained on 2004 December 11 with the 9.2m Hobby-Eberly telescope (HET).



The optical spectrum at 5.6 Å spectral resolution taken by the HET

Hobby-Eberly Telescope

- Red shoulder found suggesting two components with velocity separation of 300 km s^{-1}.