Three Decades of VLBI Monitoring of the Parsec-Scale Jet in 3C 345

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The Source: 3C 345

Classification: BLRG, highly variable/OVV blazar
(one of the first blazars discovered)

Redshift: z=0.593 (Marziani et al., ApjS 1996)

Distance/Sizes: $D_L \approx$ 3.5 Gpc, $D_A \approx$ 1.4 Gpc $\rightarrow$ 6.7 pc/mas
in concordance with H_0 = 70 km s^{-1} Mpc^{-1} and $\Omega_\Lambda = 0.72$

Observed Properties:

- high activity across all wavelengths, from radio to X-rays
- variable on pc-scales in structure and emission around a compact radio 'core'
- one-sided relativistic pc-scale jet with superluminal features

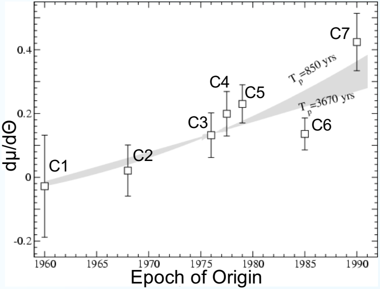
Binary Black Hole? Helical Motion? Accretion Disk Instabilities? ...

Motivation

Detailed long-term study of the pc-scale jet in 3C 345 of:

- **trajectories and speeds**
- **changes in the overall jet pattern**
- flux densities
- turnover frequencies
- spectral changes in individual features
- core shifts and variability

Example: Long-term evolution of component accelerations:



Apparent acceleration of component proper motions, plotted versus component epochs of origin (Lobanov & Roland, 2005).

Results from this kind of analysis are going to give us an important insight in the physics behind relativistic flows and the dynamics of the central regions in AGN.

The Source: Observations

Overview of VLBI observations used in this work:

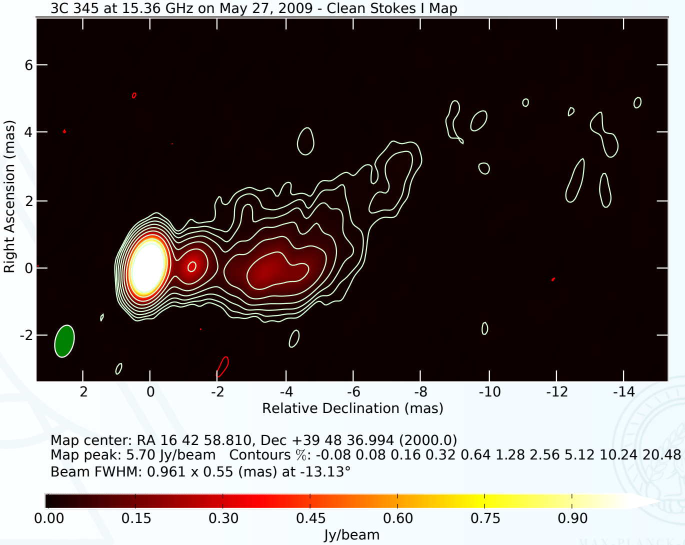
Time	# of epochs	Frequencies	Comment
1995-2009	40	15.4 GHz	archival re-reduced (VLBA)
1995-2009	34	15.4 GHz	MOJAVE Survey (VLBA)
1979-1995	59	2-100 GHz	published data[1]
1979-2009	Total: 133		

Procedure:

1. Archival data reduced using *AIPS* (Astronomical Image Processing System)
2. All epochs 1995-2009 cleaned and modelfitted with *Difmap* using circular Gaussian models
3. Cross-identification of modelfitted components with previous epochs

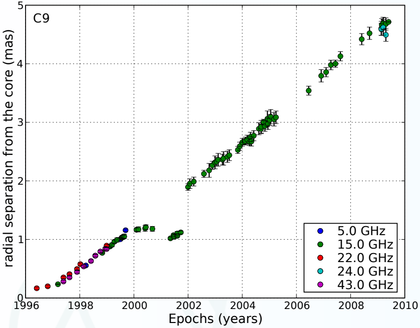
[1] Unwin et al. (1983, 1992), Biretta et al. (1986), Zensus et al. (1995), Bååth (1992), Lobanov (1996), Krichbaum et al. (1993), Ros et al. (2000), Klare (2004)

The Source: Recent VLBA Map

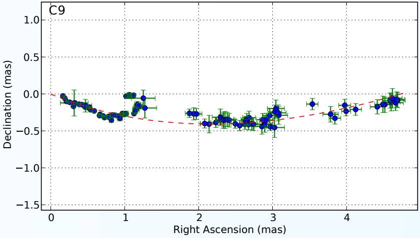


C9: Kinematics

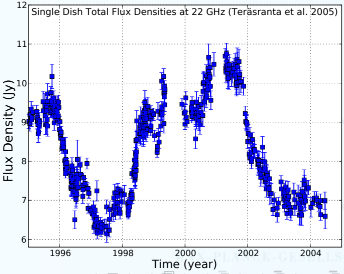
Radial Separation from the core vs Time



Component Trajectory



Single Dish Flux Density vs Time



Time of zero separation:

(*extrapolated from the first few datapoints*)

1995.85 ± 0.29

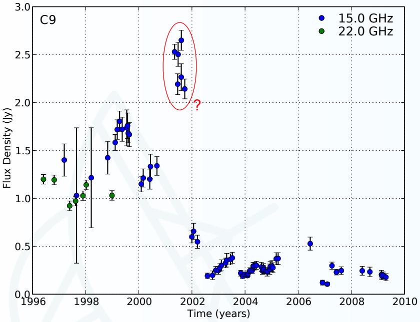
Proper radial motion:

$<$ 0.3 mas: 0.099 mas year^{-1}

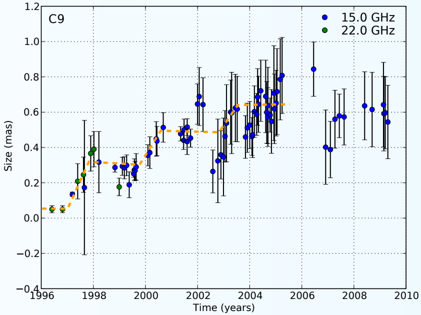
$>$ 0.3 mas: 0.378 mas year^{-1}

C9: Flux Densities/Component Sizes

Evolution of component flux density



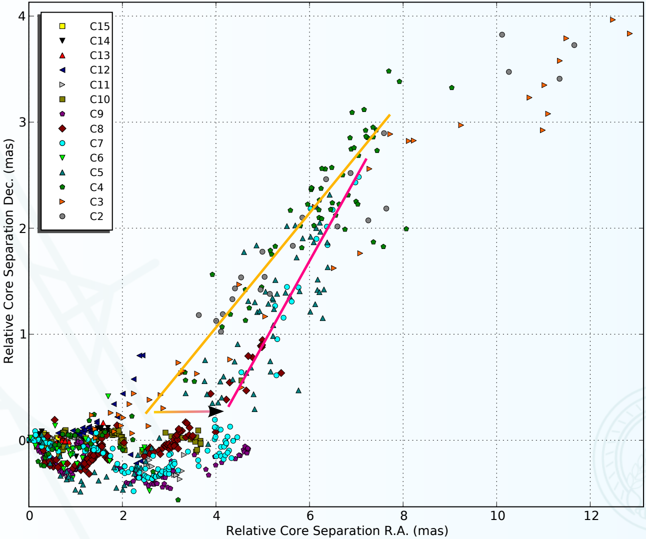
Evolution of modelfit component size



Peak: (1.81 $\pm$ 0.11) Jy
Time of Peak:
(1999.28 $\pm$ 0.10) - (1995.85 $\pm$ 0.29) = 3.43 $\pm$ 0.31
On average (C4-C14, excluding C6):
$\approx$3.2 years from time of zero separation

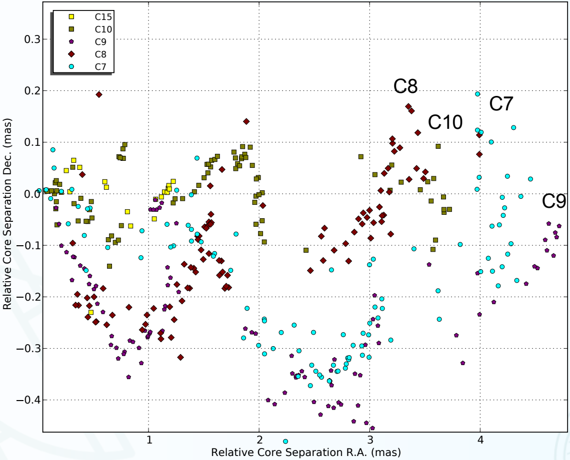
Step-like shape seen in almost all the other components as well.

Trajectories



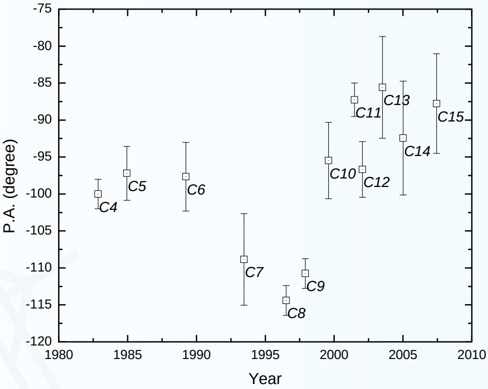
- The late upward turning point seems to evolve with time

Trajectories



- The late upward turning point seems to evolve with time
- C7-C10 alternating trajectories, possibly due to small scale periodicity seen in the ejection angles
- Evolution of trajectory patterns with time

P.A. evolution



Position angles measured at 0.5 mas radial distance from the VLBI core at 15.3 GHz for the components C4-C15 (1983 - 2007).

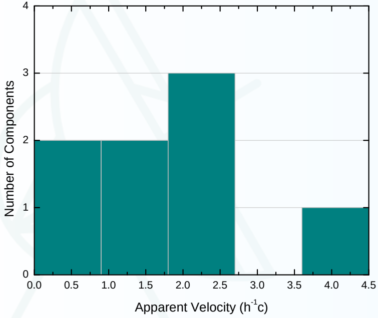
Previous results show a short-term periodicity of 8-10 years with an underlying long-term trend 0.4-2.6° year^{-1} (Lobanov & Roland, 2005; Klare et al., 2003). Further analysis for the difference in results is needed.

Apparent Velocities/Superluminal Motion

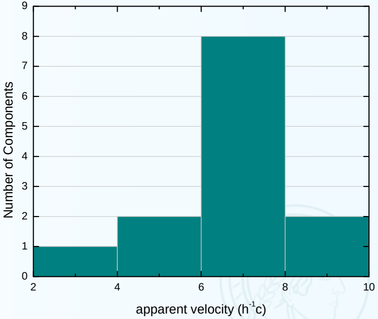
$\beta_{app}(t) = \sqrt{(\frac{dx}{dt})^2 + (\frac{dy}{dt})^2} \cdot D_L\,(1+z)^{-1}$. This translates a proper motion of 1 mas/year to an apparent velocity of 19.7 h^{-1} c.

(h≈0.569 in concordance with given ΛCDM)

β_{app} for r $\lesssim$ 0.7 mas



β_{app} for r $\gtrsim$ 0.7 mas



C4 shows 4 different apparent velocities at different times (1.5, 4.8, 12.7 and 7.1 h^{-1} c)

Summary

- 3C 345 shows a complex jet morphology with many bright features observed with VLBI
- Consistent superluminal motion of VLBI features with at least one acceleration phase observed
- Need to be careful in interpreting modelfit components from flaring epochs (blending, coreshift) - need for spectral data
- Large- and small-scale variations in trajectories of subsequent VLBI features

Outlook

Expand observational analysis to study spectral evolution as well as core shifts.

$\Rightarrow$ Altogether this is going to lead us to a quantitative explanation of the observed phenomena and to develop likely physical scenarios.