Connection between the radio and gamma-ray emission of 3C 345

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The source: 3C 345

Classification: BLRG, highly variable/OVV blazar
(one of the best studied blazars)

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

Distance/Sizes: $D_L \approx 3.5$ Gpc, 6.6 pc/mas, 1 $\frac{\text{mas}}{\text{year}} \rightarrow 34.5$c
in concordance with $H_0 = 71$ km s^{-1} Mpc^{-1} and $\Omega_\Lambda = 0.72$

Properties (*from literature*):

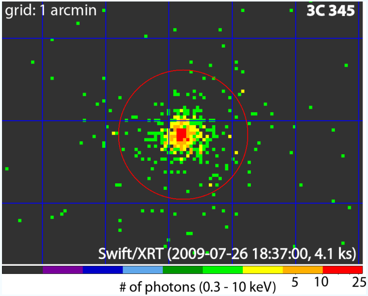
- one sided superluminal jet with apparent speeds $\beta_{\text{app}} \leq 20$c
- viewing angle to the line of sight: $\Theta = (2.6 - 6)^\circ$
- Bulk Lorentz and Doppler factors: $\Gamma \approx 20$; $D \approx 8$
- Jet opening angle: $\alpha_{\text{app}} \approx 12.9^\circ$, $\alpha_{\text{int}} \approx 1.2^\circ$
- high variability across all wavelengths, from radio to X-rays with a long-term periodicity of 3.4-4 years

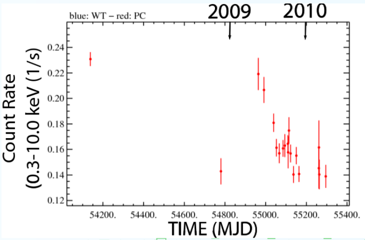
High energy emission

Known as prominent source up to X-ray energies, not in γ-rays (pre Fermi era).

X-ray emission dominated by the jet through inverse Compton has been concluded by Unwin et al. 1994, 1997.

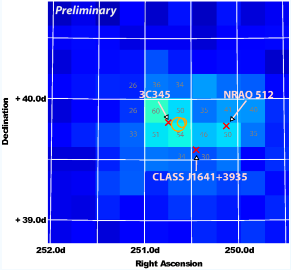
Typical X-ray flux (0.3-10 keV): $(5-9) \cdot 10^{-12}$ erg cm^{-2} s^{-1}

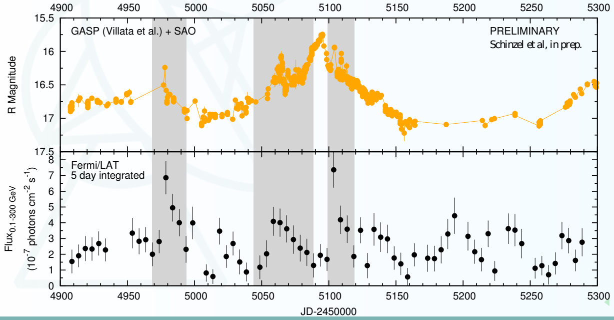




γ-ray detection

Fermi/LAT counts map integrated over 20 months with radio positions of candidate sources and LAT error circles (large circle 11 months, smaller circle 20 months). $\Rightarrow$





$\Leftarrow$ Optical vs γ-ray observations around Oct' 2009 (ATel #2222 Larionov et al.; ATel #2226 Reyes & Cheung).

VLBA radio monitoring

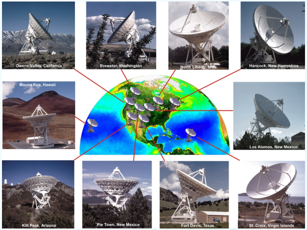
A new cycle of enhanced nuclear activity of 3C 345 began early 2008 observable at all wavelengths.

Followed-up by dedicated VLBA observations (2009 - 2010) and observations as part of the BU blazar sample (Marscher et al.) in approx. monthly intervals:

- Schinzel et al.: 12 epochs; 10 hours each; 15, 24, and **43 GHz**
- Marscher et al.: 14 epochs at **43 GHz**

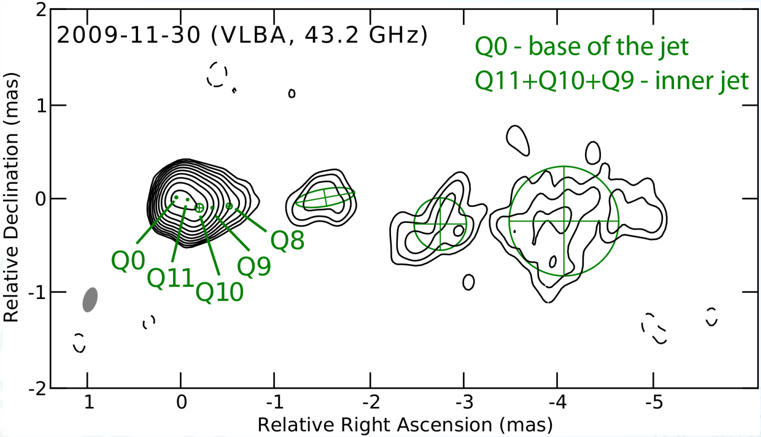
Data Reduction & Analysis:

- AIPS (Astronomical Image Processing System) – calibration
- Difmap – mapping and modelfitting



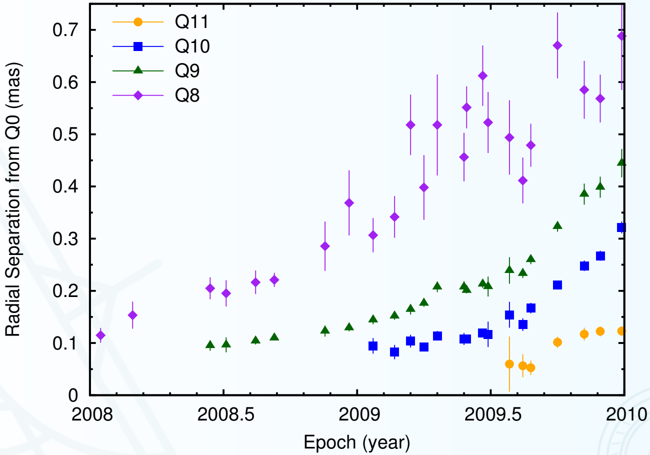
NRAO's Very Long Baseline Array (VLBA)

Source structure at 43 GHz



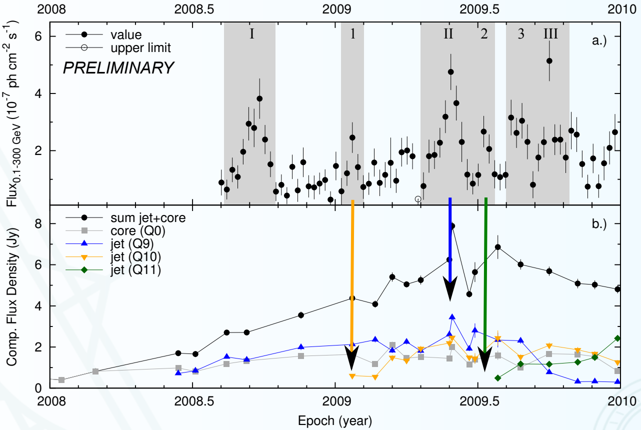
Best representation of the brightness distribution of the core region was determined through optimization of the minimum χ^2 statistics and degrees of freedom.

Radial separation of new features in the jet



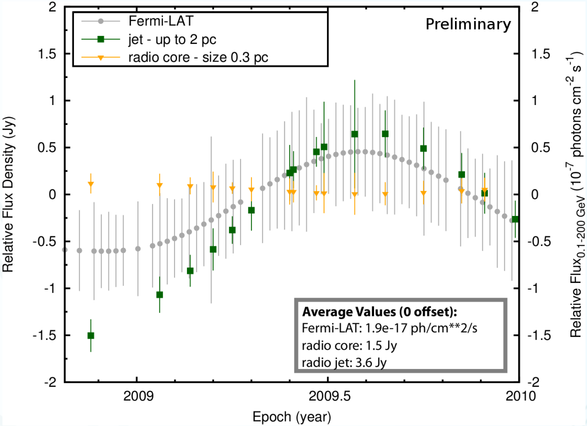
Features apparently accelerate from 2-10c over a time period of 1.5 years and a distance of 0.3 mas (2 pc).

γ-ray flux vs VLBA flux densities



1. γ-ray events aligned with appearance of jet components (1,2).
2. Radio flare in the jet has γ-ray counterpart (flare II).

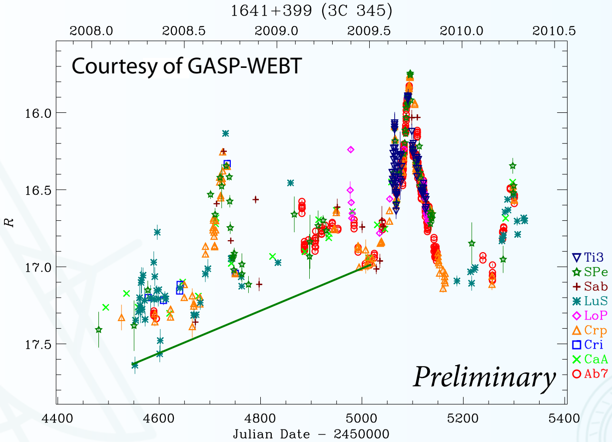
Trends



Long-term trends obtained by fitting cubic splines to the light curves of γ-rays, jet and core, rescaled to their respective mean flux values.

Core shows constant flux density, radio jet and γ-ray trends match.

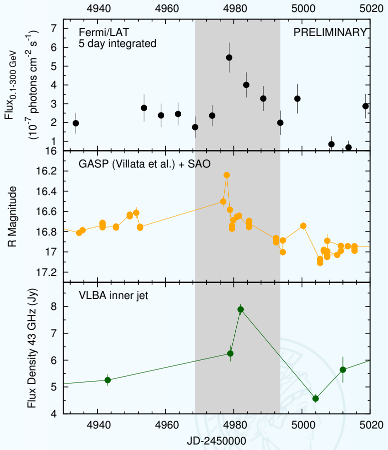
Trend in optical



Similar trend seen in the optical, which implies that baseline optical emission is dominated by the jet.

γ-ray flare II - a jet flare

- One of the radio observations was the same day as the peak of the γ-ray flare (JD 2454979; May 27, 2009). Radio peak observed 4 days later than γ-ray peak.
- A peak in the optical R-band light curve (GASP) was observed one day before the peak of the γ-ray event.
- The region around the jet feature Q9 is most likely the origin of this flare. With a distance of 0.20 ± 0.01 mas (1.3 pc) from the base of the jet.



Summary

- Observation of two new superluminal features producing γ-ray outbursts while passing through the 43 GHz VLBI core of 3C 345.
- Brightening of the inner radio jet at 43 GHz is associated with strong simultaneous γ-ray & optical flares observed at a distance of up to 40 pc from the VLBI core!
- Evidence for a **direct correlation between radio and γ-ray emission – similar trends are observed in radio, optical and γ-rays.** Not a single emission region can be responsible for the observed γ-ray emission.

Interpretation

- Contribution from EC accretion disk photons are ruled out.
- Observations support SSC as the most likely mechanism for production of γ-rays in the source.