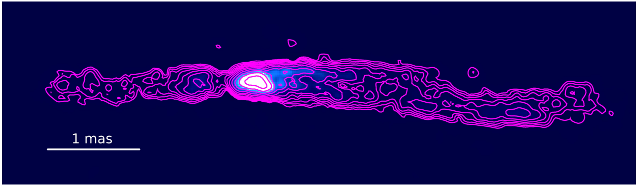
Stacked Global VLBI image of CygA at 7 mm - 1 mas∼1 pc



Bia Boccardi

MPIfR - Bonn

THE STRATIFIED TWO-SIDED JET OF CYGNUS A: ACCELERATION AND COLLIMATION

(Collaborators: T.P. Krichbaum, U. Bach, F. Mertens, E. Ros, V. Karamanavis, W. Alef, J.A. Zensus)

Relativistic Jets: Creation, Dynamics, and Internal Physics - Krakow, 20-24 April 2015

RELATIVISTIC JETS - OPEN PROBLEMS

How are jets launched?
Where and how are they accelerated?
What is the collimation mechanism?

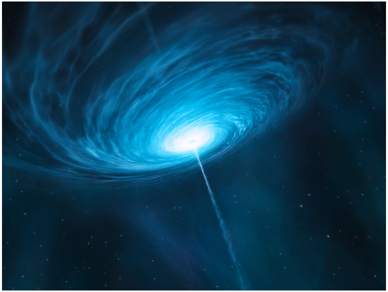


Image credit: ESO/M. Kornmesser

What can VLBI observations of jets (still) provide?

- Speeds
- Structure
- Shape

} on sufficiently small scales

Studying Radio galaxies with VLBI...

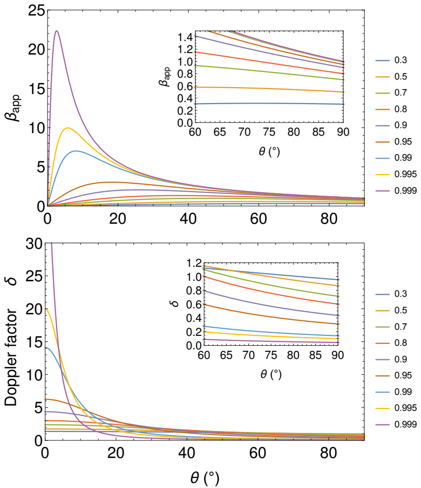
Advantages

- Geometrical effects less prominent than in blazars
- Reduced relativistic boosting **BUT WATCH OUT FOR DE-BOOSTING!**

Disadvantages

- Few compact enough objects, faint at high radio-frequencies!

Apparent β (top) and Doppler factor (bottom) vs Viewing angle θ, for various intrinsic β



CYGNUS A: AN IDEAL TARGET!

Blue: X-ray from Chandra - **Red**: radio from VLA - **Yellow**: optical from HST and DSS.

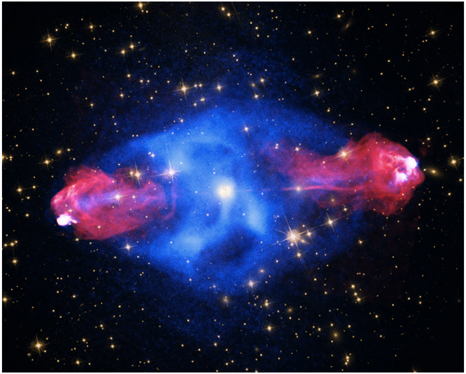


Image Credit: X-ray: NASA/CXC/SAO; Optical: NASA/STScI; Radio: NSF/NRAO/AUI/VLA

- **Sub-parsec scale structure still bright at mm-wavelengths, including counter-jet.**

  $\Rightarrow$ Linear resolution down to $\sim$ 48 milli-pc $\sim$ **200 R_S**! (for $M_{BH} \sim 2.5 \times 10^9 M_\odot$)

- **Transverse resolution of both jet and counter-jet.**

  $\Rightarrow$ study of collimation and stratification.

  $\Rightarrow$ test unification model.

- **Only bright enough FR II with such properties.**

Observations (...and what they tell us)

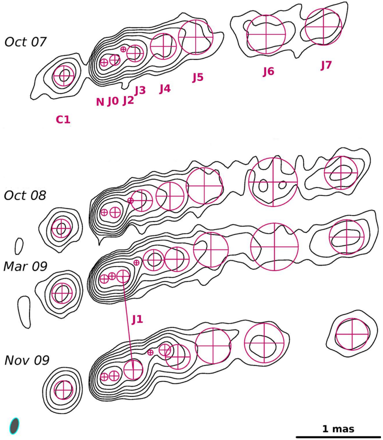
Methods

Kinematical and transverse structure study from Global VLBI data at 7 mm (43 GHz) (13-15 dishes, 0.1 pc or $400R_S$ linear resolution)

Results

- **Speeds** $\Rightarrow$ Parsec scale acceleration
- **Structure** $\Rightarrow$Transverse stratification of speed and flux density (spine-sheath and limb brightening)
- **Shape** $\Rightarrow$ Parabolic jet, cylindrical further downstream.

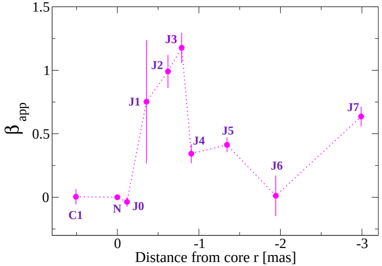
Kinematic analysis



Method (1 mas$\sim$1 pc)

- Modelfitting
- Maps alignment & Cross-identification
- Calculation of proper motions and apparent speeds β_{app}

Apparent speed vs Distance from core

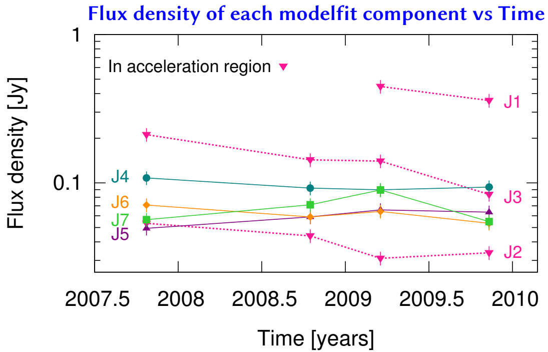


- Acceleration in inner $\sim$0.8 mas of the jet, up to $\beta_{\mathrm{app}} = 1.2 \pm 0.1$.
- Lower speeds in outer jet.
- 3 stationary features (C1, J0, J6), including counter-jet.

Lightcurves

Is the outer jet decelerating?

Check out light-curves! ⇒



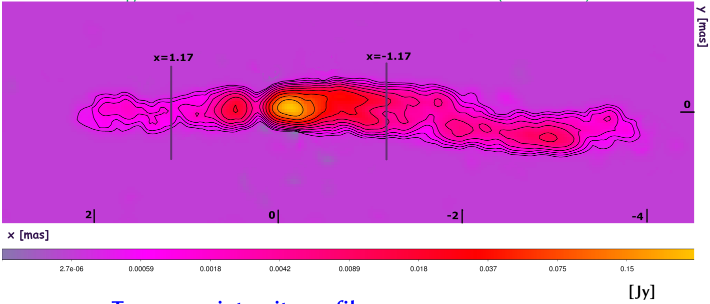
The fast flow is getting dimmer as it accelerates (δ is decreasing!)

⇒ **NO INTRINSIC DECELERATION!**

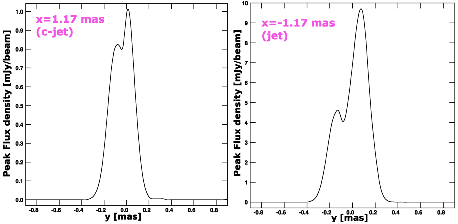
In the outer jet, the emission is dominated by the slower layers.

Study of the transverse structure

Stacked image from Global VLBI observations at 7 mm (2007-2009)

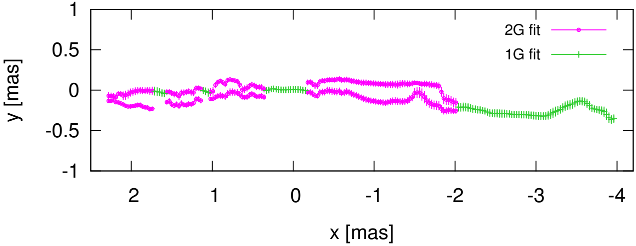


Transverse intensity profiles



- Maps restored with circular beam of 0.15 mas FWHM.
- Sliced transversally pixel by pixel (every 0.03 mas).
- Gaussian fit of the double peaked intensity profiles.

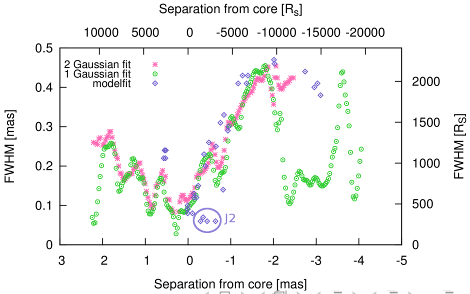
Ridge line



Limb-brightening in jet and counter-jet
$\Rightarrow$ Further evidence for de-boosting and spine-sheath structure!

- Narrowing at $\sim$2 mas
  $\Rightarrow$ stationary feature J6
- Large and asymmetric opening angles.
  $\phi_{\mathrm{j}} = \mathbf{9.8^\circ \pm 0.3^\circ}$
  $\phi_{\mathrm{cj}} = \mathbf{4.7^\circ \pm 0.4^\circ}$
- Jets expands from gap of emission (at r $\sim$ 0.15 mas)

Jet width vs Distance from core



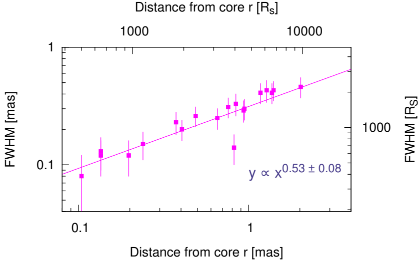
Discussion

...Back to the speeds

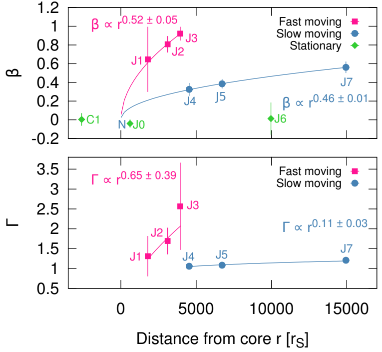
Let us then consider the fast and the slow sections of the flow separately!

$\Rightarrow$ **Slow section is also accelerating, but more mildly. Steeper gradient close to the jet axis.**

Jet width (from modelfit)



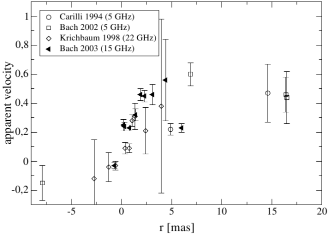
Speed β (top) and Lorentz factor Γ (bottom) vs Distance from core



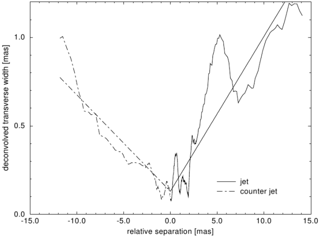
Shape of the jet in acceleration region? **Parabolic!**

Looking at other frequencies...

Bach+ 2003



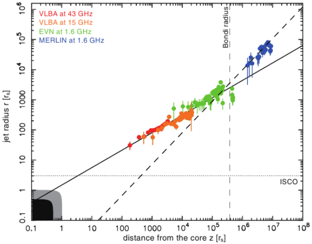
Krichbaum+ 2008, 22 GHz



Acceleration ceases at $\sim 2.5 \times 10^4 R_S$. At the same location, recollimation feature + cylindrical shape (Carilli+ 1991, VLBI@5GHz)

(For more on M87 structure and kinematics, see poster by F. Mertens!)

Asada&Nakamura 2012



M87 switches from parabolic to conical...EQUILIBRIUM vs NON-EQUILIBRIUM regime (Lyubarsky's talk)

Food for though for FRI - FRII dichotomy?

Thank you!