Jet/cloud interactions at pc-scales: 3C120

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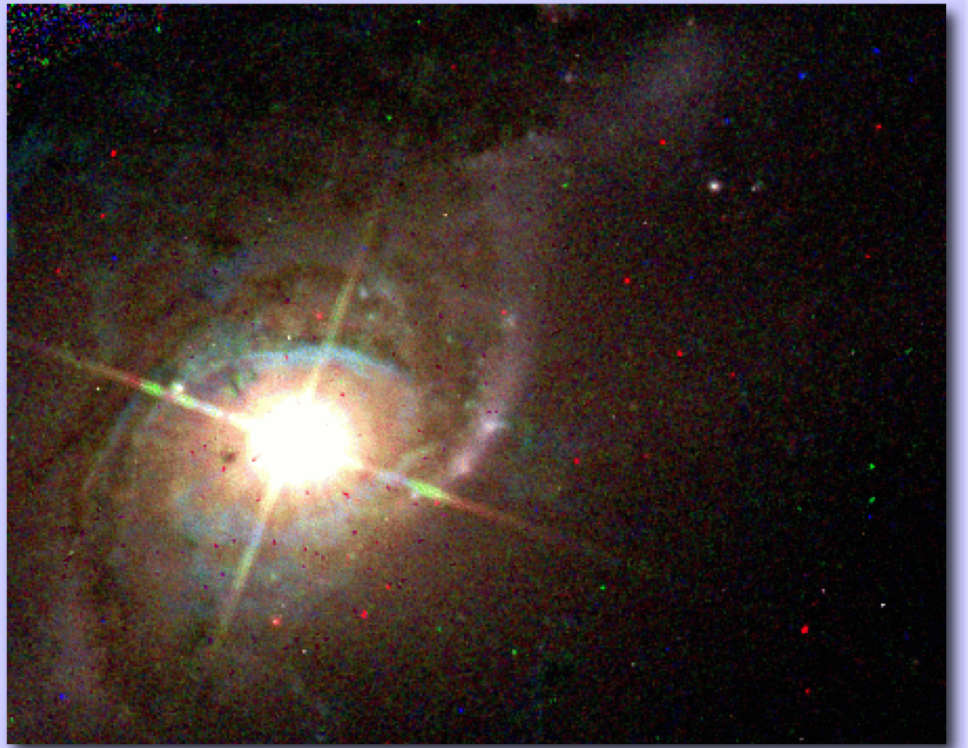
Kraków, June 2006

3C120 Broadband spectrum and radio jet

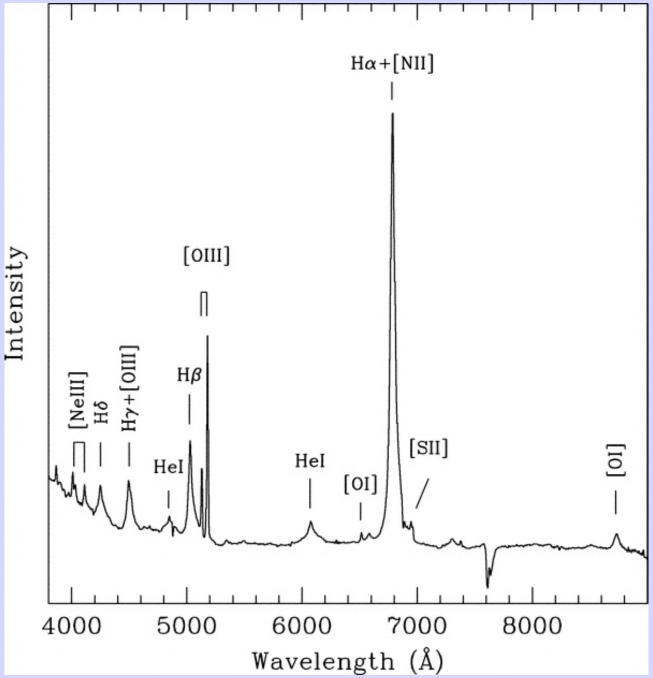
3C120

It is an unusual active galaxy, classified as both, ***Seyfert 1*** and ***broad line radio galaxy***.

- Complex optical morphology, possibly the result of a merger (Moles et al. 1988, García-Lorenzo et al. 2005)



HST image obtained from archive by D. Harris and T. Cheung



Optical spectrum (García-Lorenzo et al. 2005)

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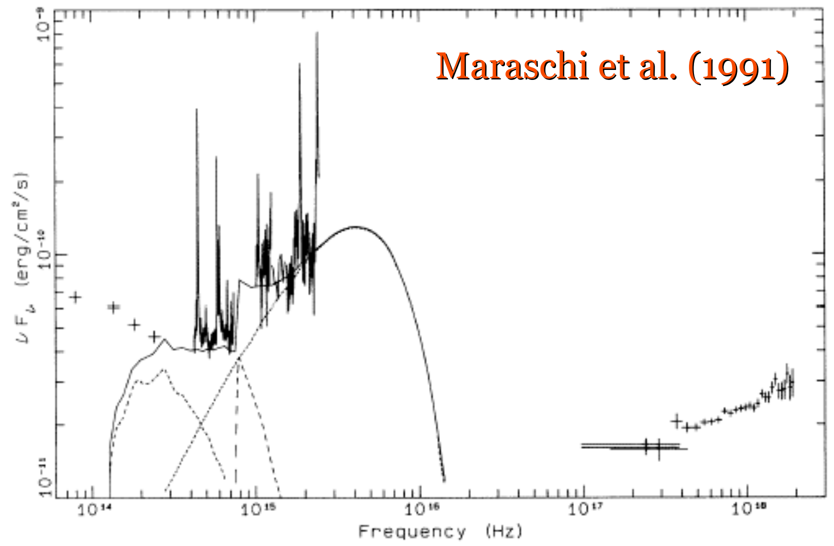
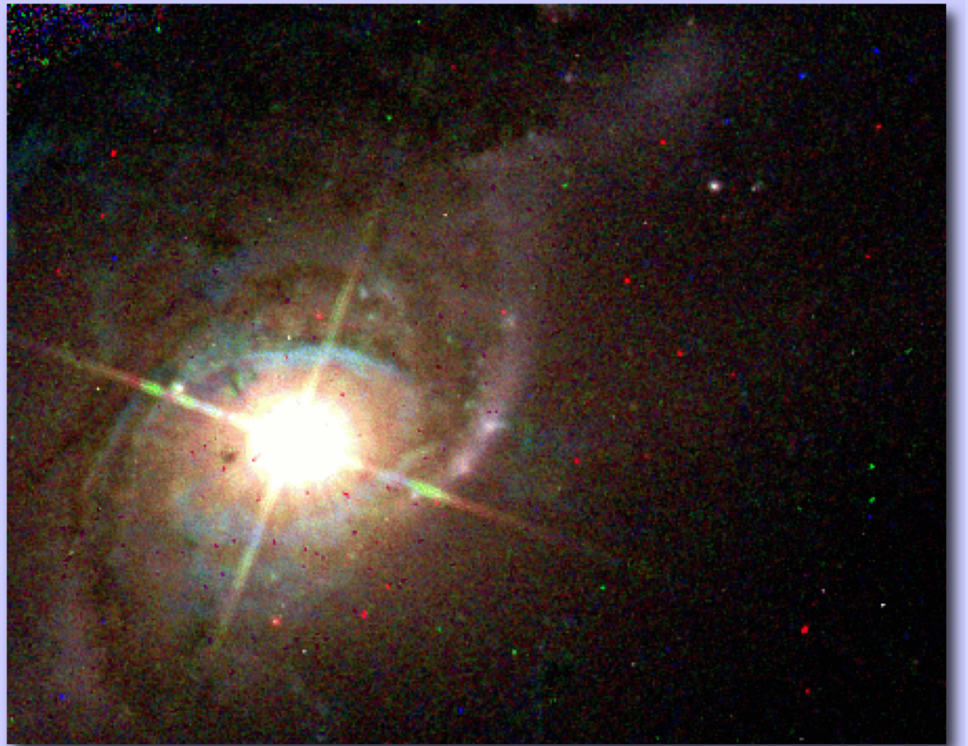


FIG. 8a



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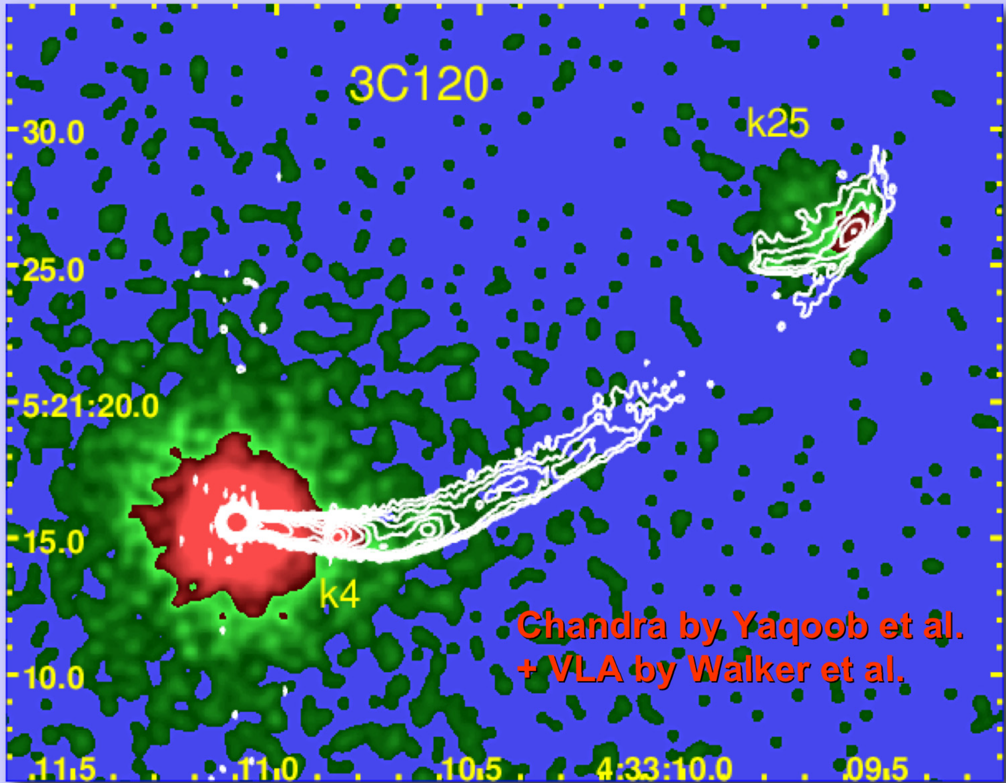
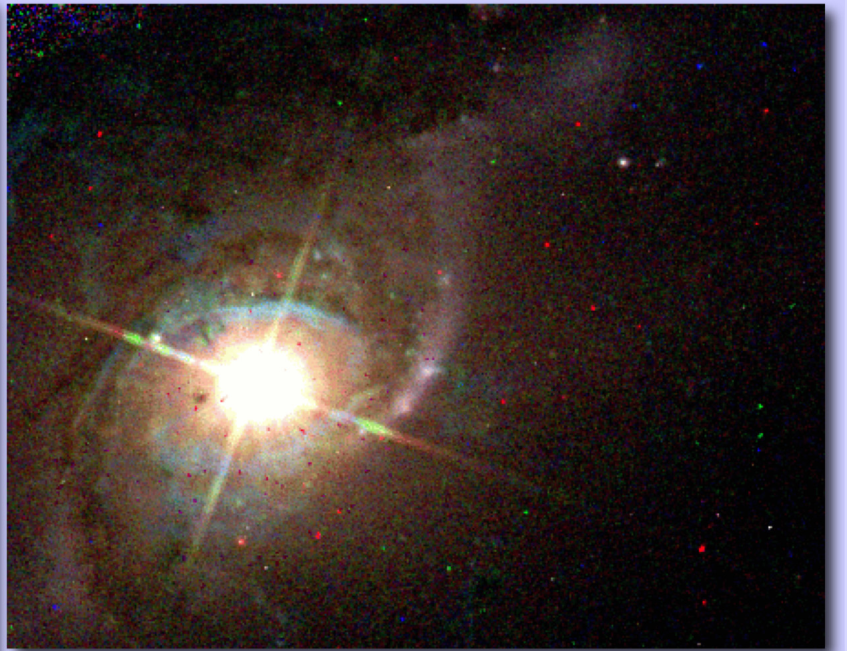
- Powerful and variable emitter along the whole spectrum, powered by a black hole of about 3×10^7 M_o (Wandel et al. 1999)

3C120 Broadband spectrum and radio jet

Harris et al. (2004)



HST image + VLA image by Walker et al.



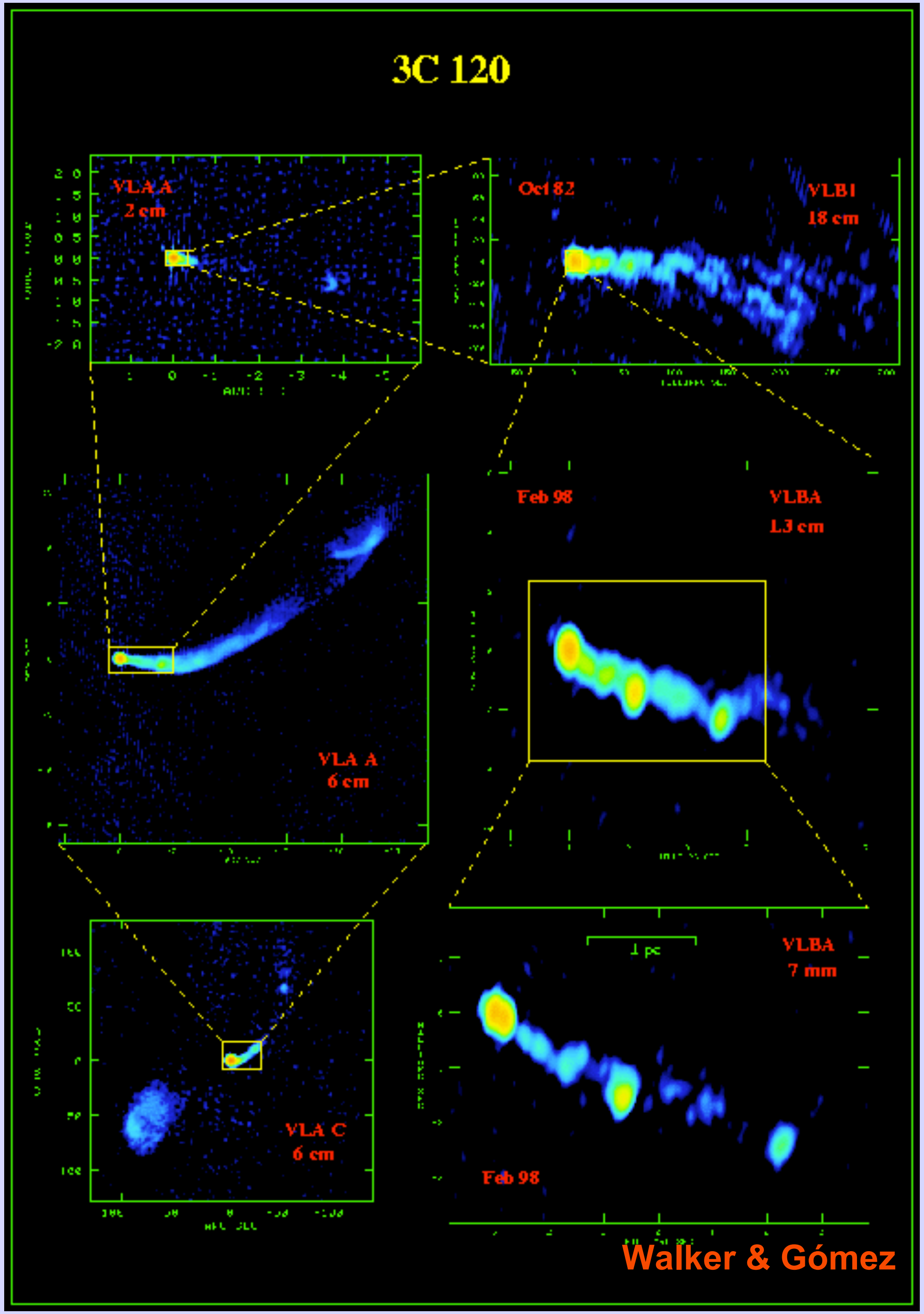
- The jet and knots are also visible in X-rays (Harris et al. 2004, Yaqoob et al.)
- X-ray jet consistent with synchroton, with a second population of electrons for k25

- Prominent one sided jet observed in radio (Walker et al., Gómez et al., Marscher, et al.)

3C120 The radio jet

3C120

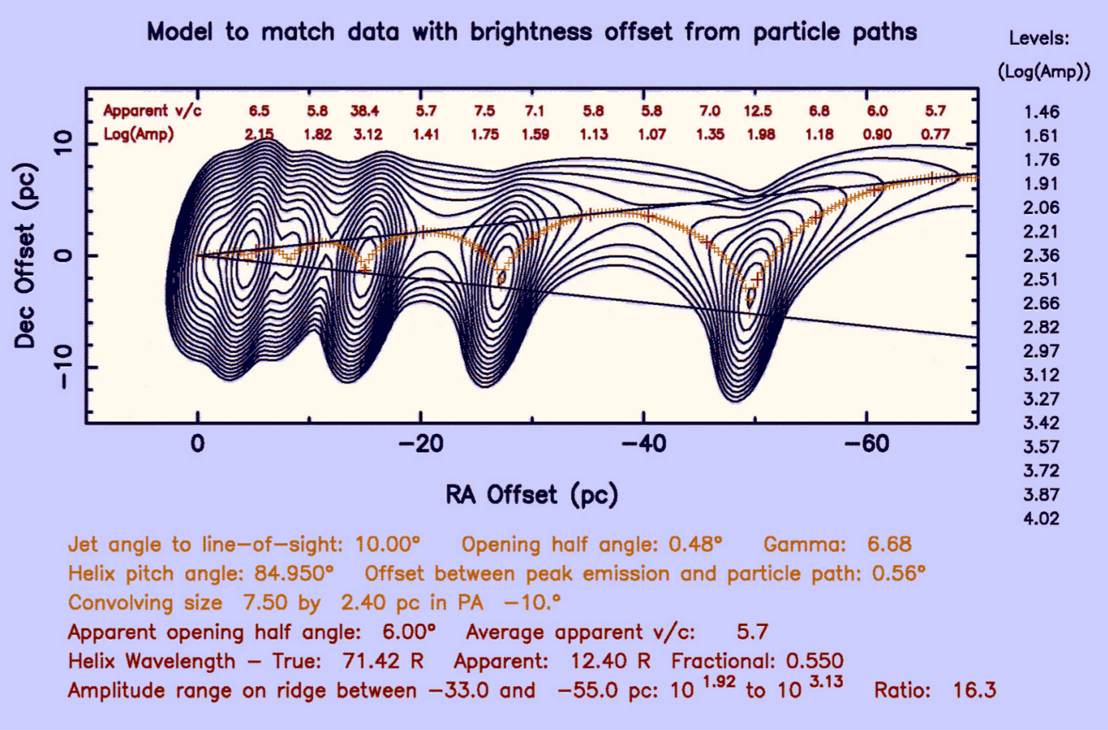
- Prominent radio jet from pc to kpc
- One of the first sources in which superluminal motions (5-6 c) were found
- Very active jet, with multiple components and very rich structure even a the shortest wavelengths
- One of the closest superluminals. At z=0.033 (~125 Mpc), the VLBA at 7 mm provides a linear resolution of 0.07pc (~10^4 R_s)
- **One of the best sources for studying the inner jet properties in superluminals**

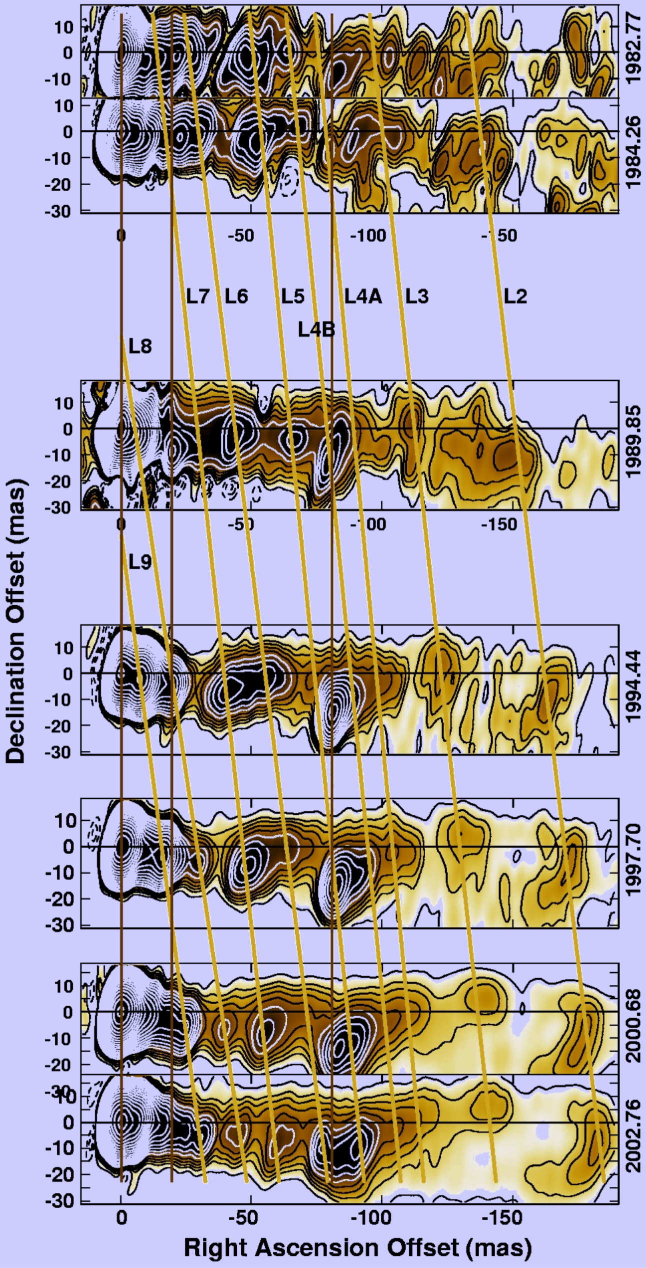


3C120 — The radio jet

- Large scale structure monitored at 1.7 GHz by *Walker et al.*

  Motions and structure are suggestive of a helical pattern seen in projection (helical model by Hardee et al. 2005)





Walker et al. (2001)

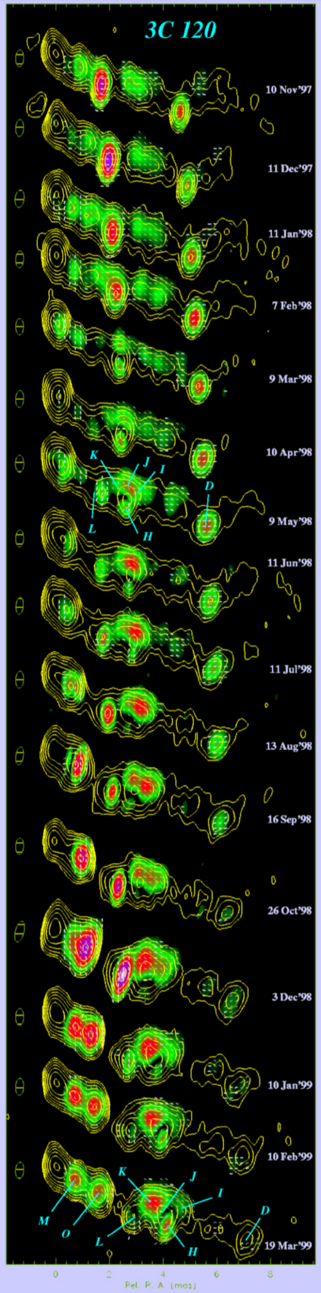
3C120 VLBI monitoring

Continuous monitoring with the VLBA since 1997

- *16 epochs at 22 and 43 GHz from 1997 to 2000:*

Jet dynamics and emission

✓Formation of components
✓Kinematics
✓Jet structure and possible precession
✓Opacity along the jet



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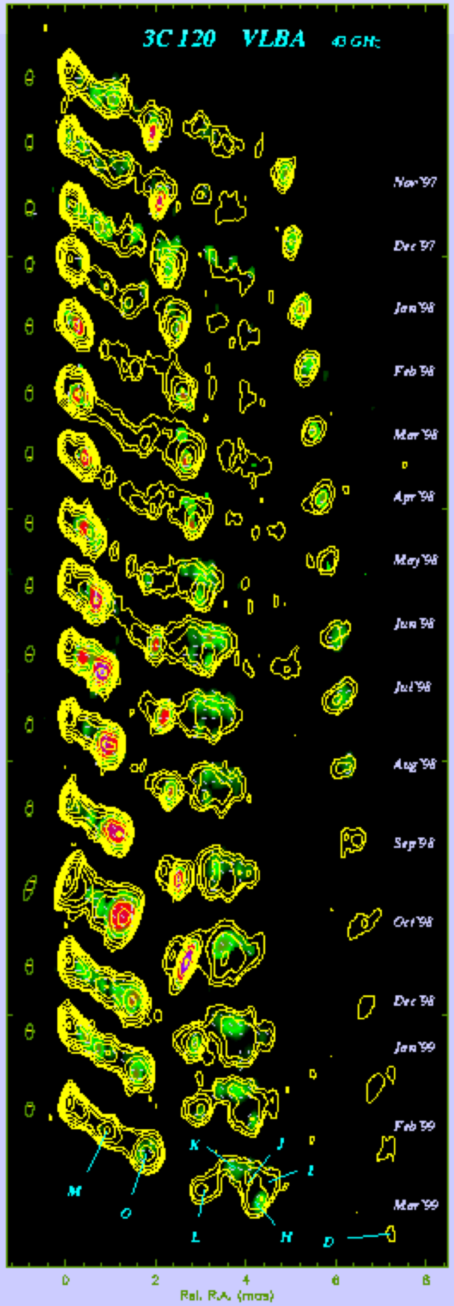
✓Intensity and orientation in the jet and components
✓Testing of shock-in-jet models



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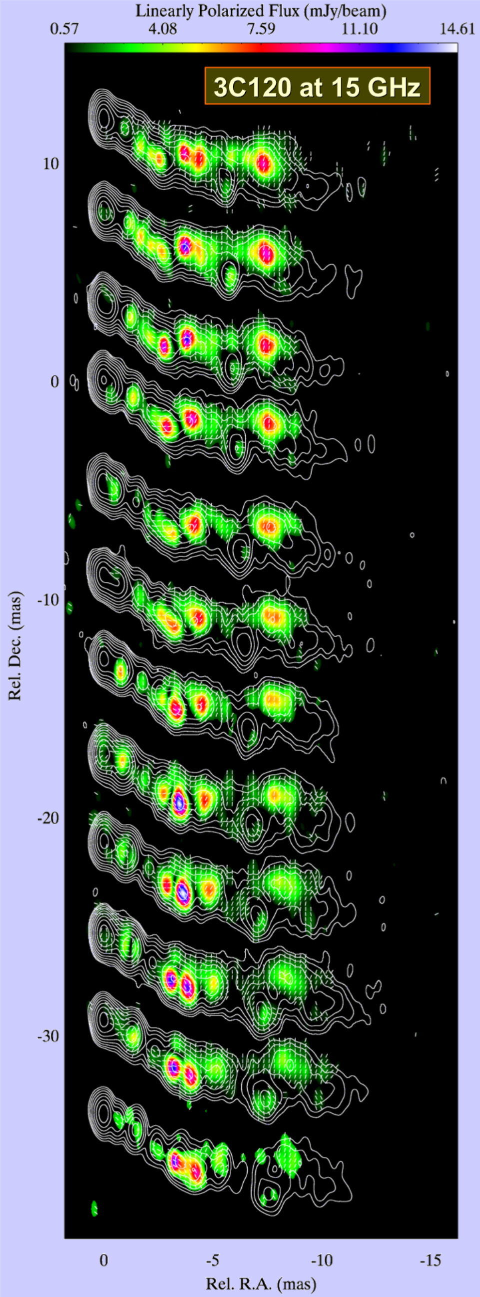
- *12 epochs at 15, 22, and 43 GHz in 2001*

External medium

✓Jet/cloud interactions
✓Faraday rotation along the jet



Gómez et al., in prep.

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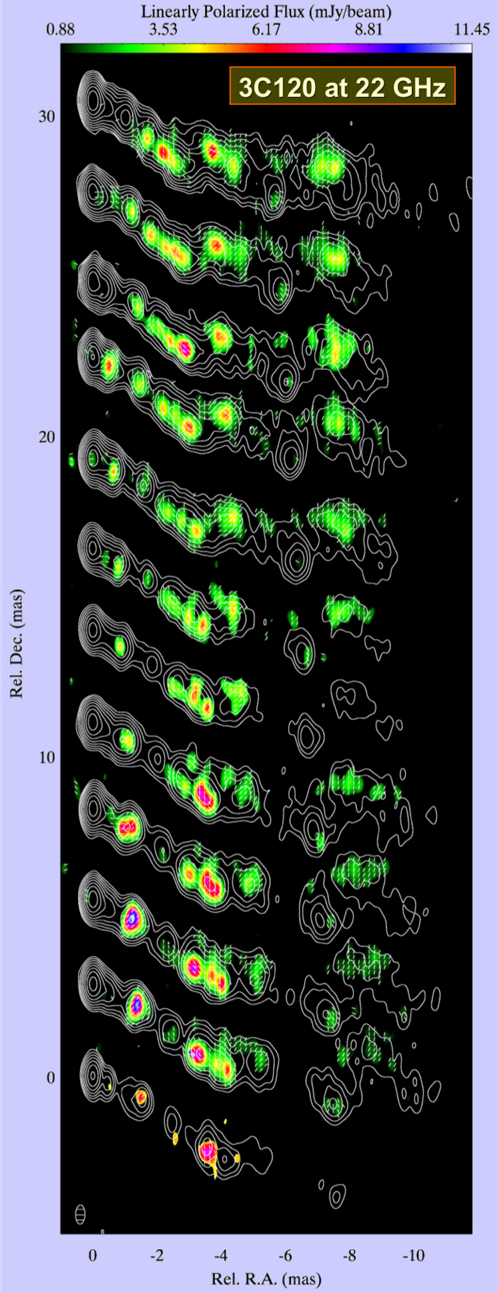

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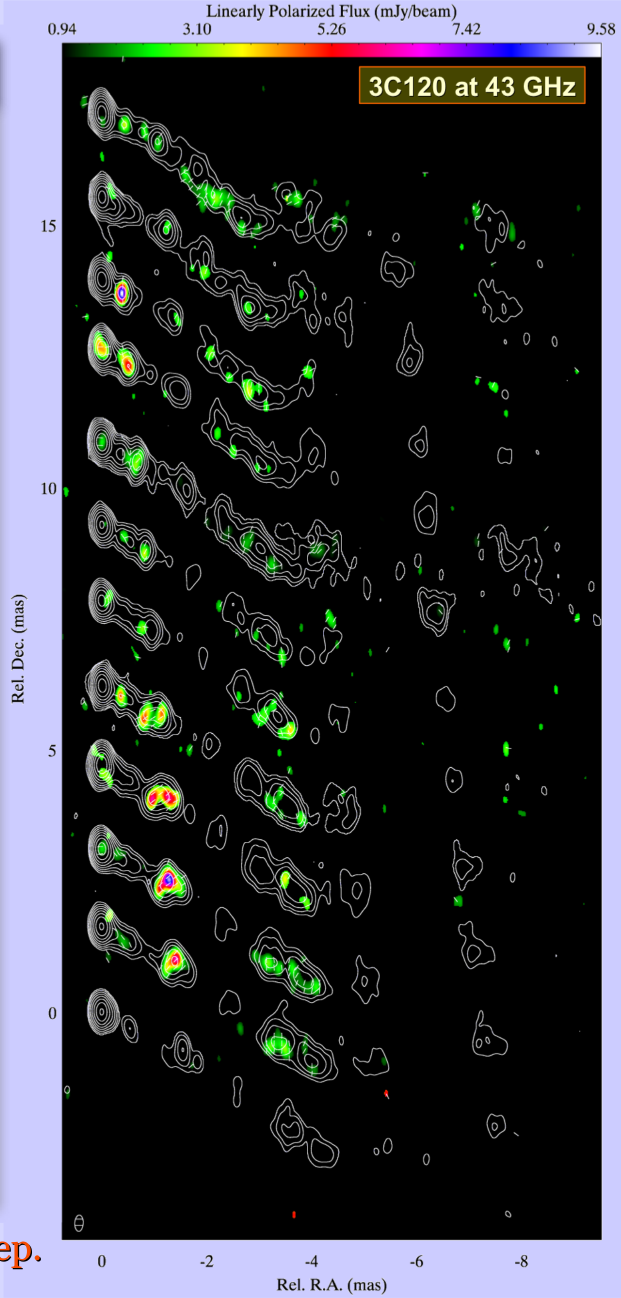

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- *12 epochs at 15, 22, and 43 GHz in 2001*

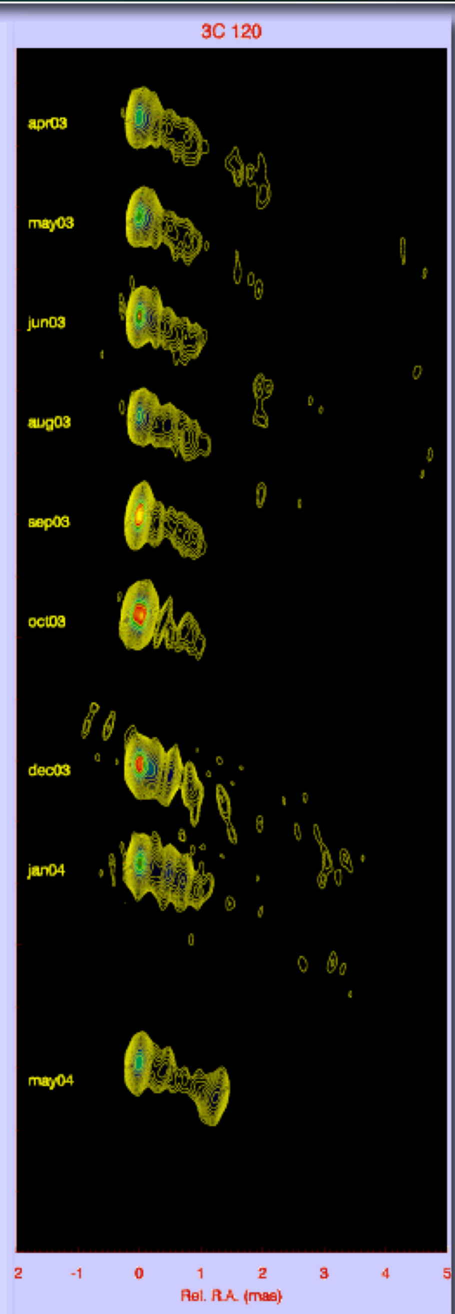
  External medium

  ✓ Jet/cloud interactions
  ✓ Faraday rotation along the jet

- *Bimonthly at 43 GHz since 1999*

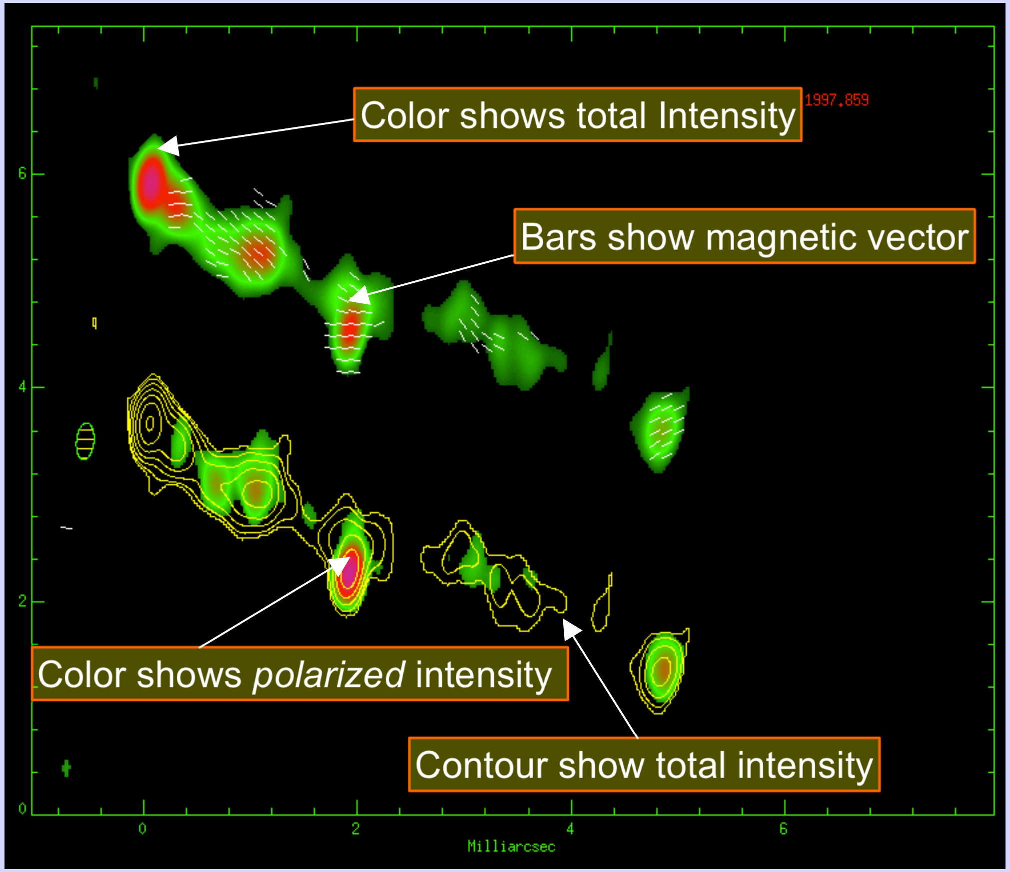
  Jet-disk system

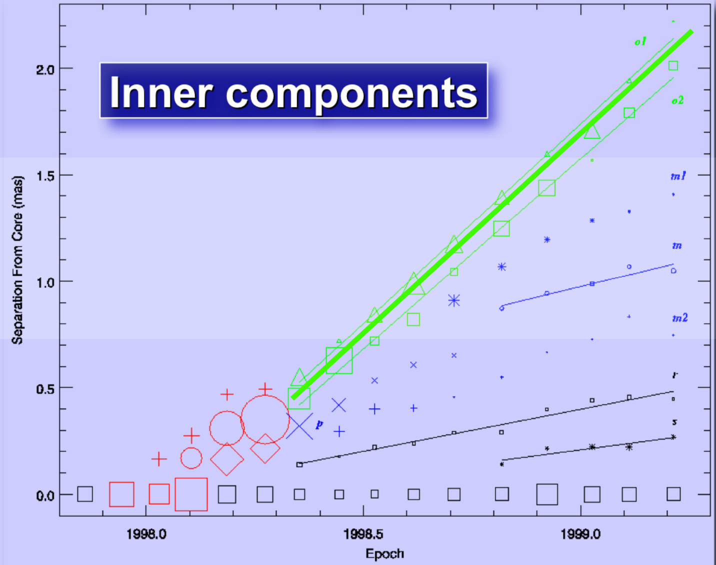
  ✓ Correlation between x-rays from the disk and radio from the jet

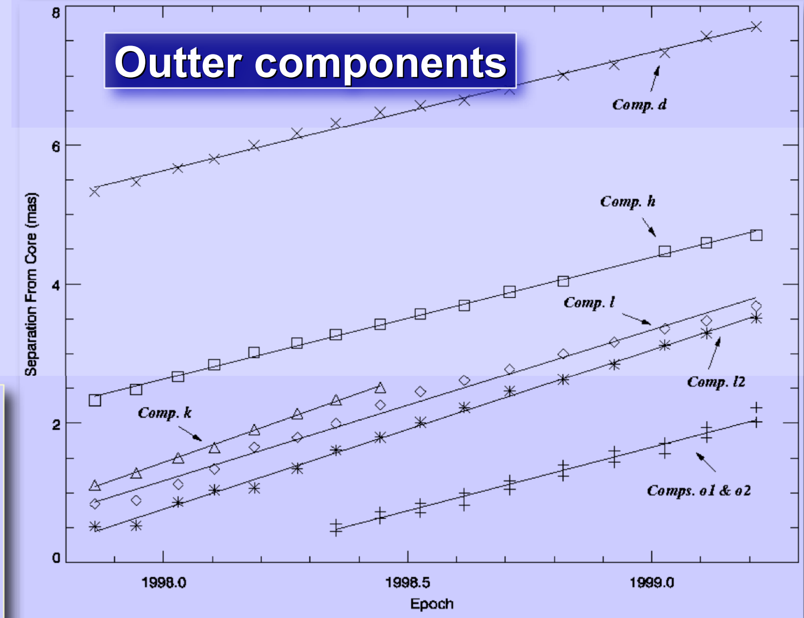


Marscher et al.

3C120 Jet dynamics





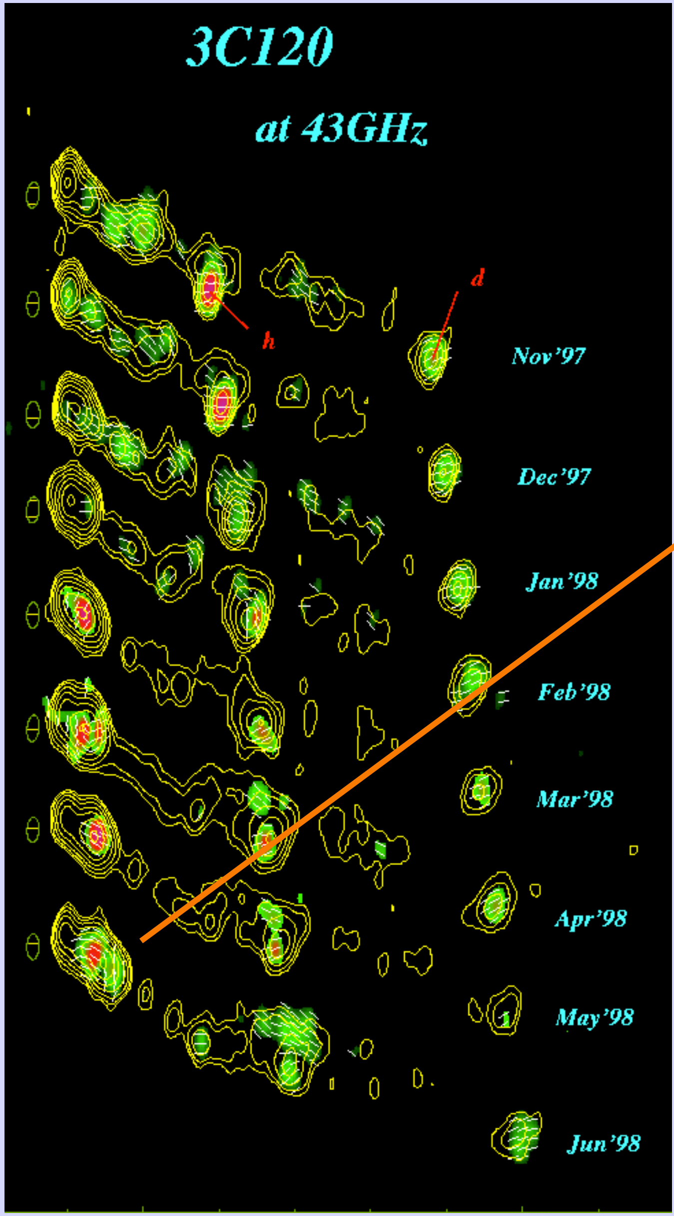


Multiple superluminal components (β_{ap}~4-5c) are observed, with no evidence for acceleration.

The jet is already collimated and “fully” accelerated at pc-scales

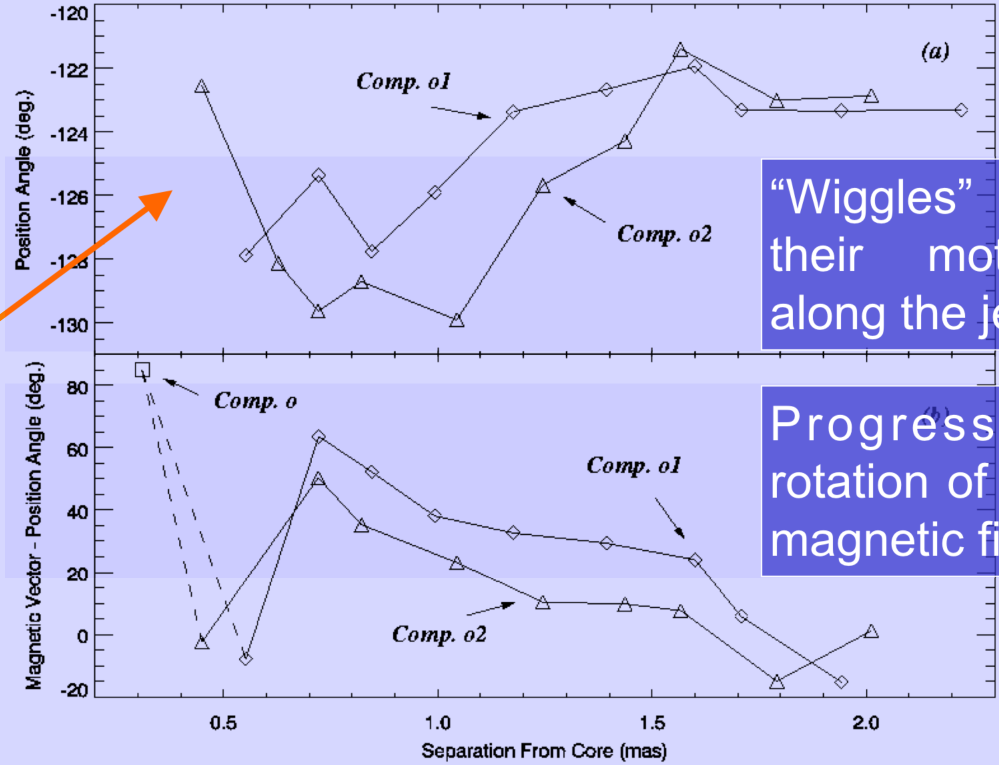
Gómez et al. (2001)

3C120 Jet dynamics



Inner components

Gómez et al. (2001)



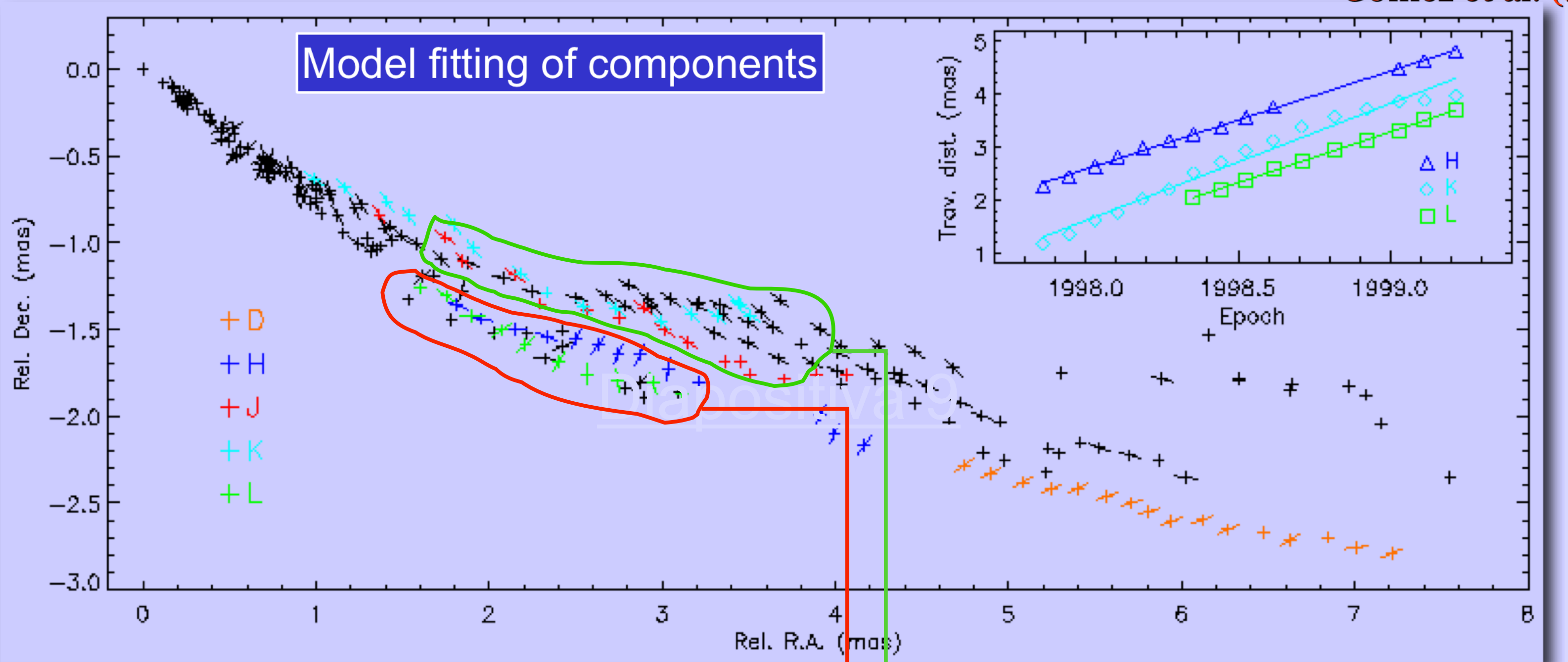
"Wiggles" in their motion along the jet

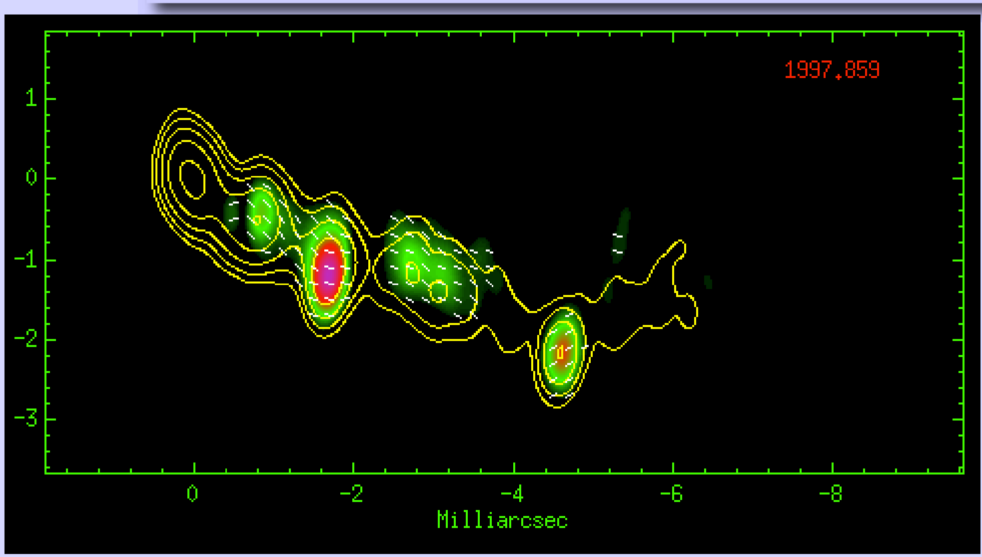
Progressive rotation of the magnetic field

Evidence for a helical structure,
perhaps produced by jet precession

3C120 Jet-cloud interactions at pc-scales

Gómez et al. (2000)



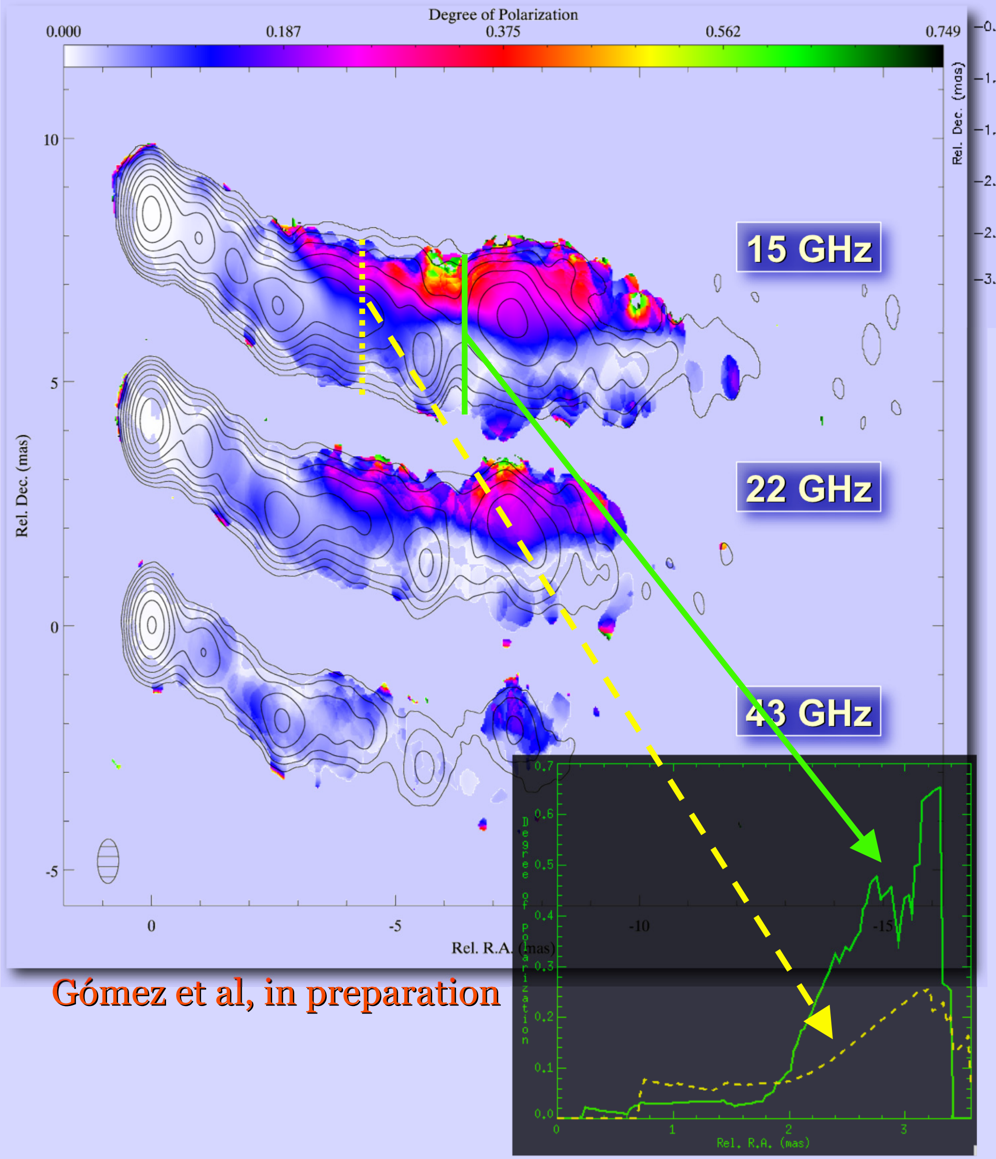


Components do *not* fill the entire jet.

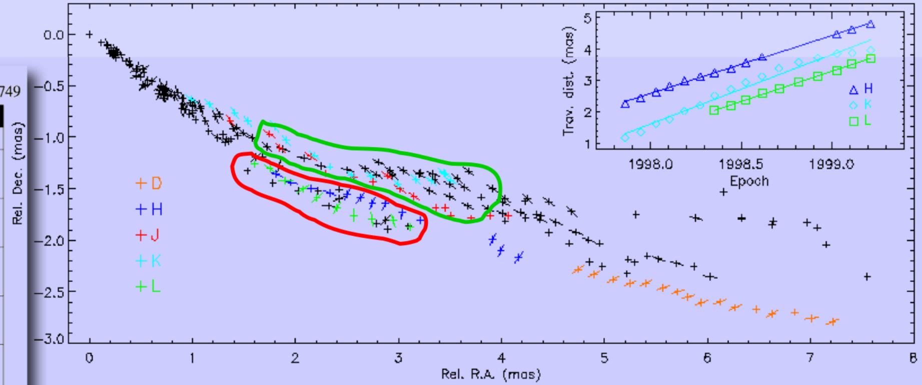
Jet stratification in Polarization:

- Northern components show oblique fields
- Southern show field rotation

3C120 Jet-cloud interactions at pc-scales



Gómez et al, in preparation

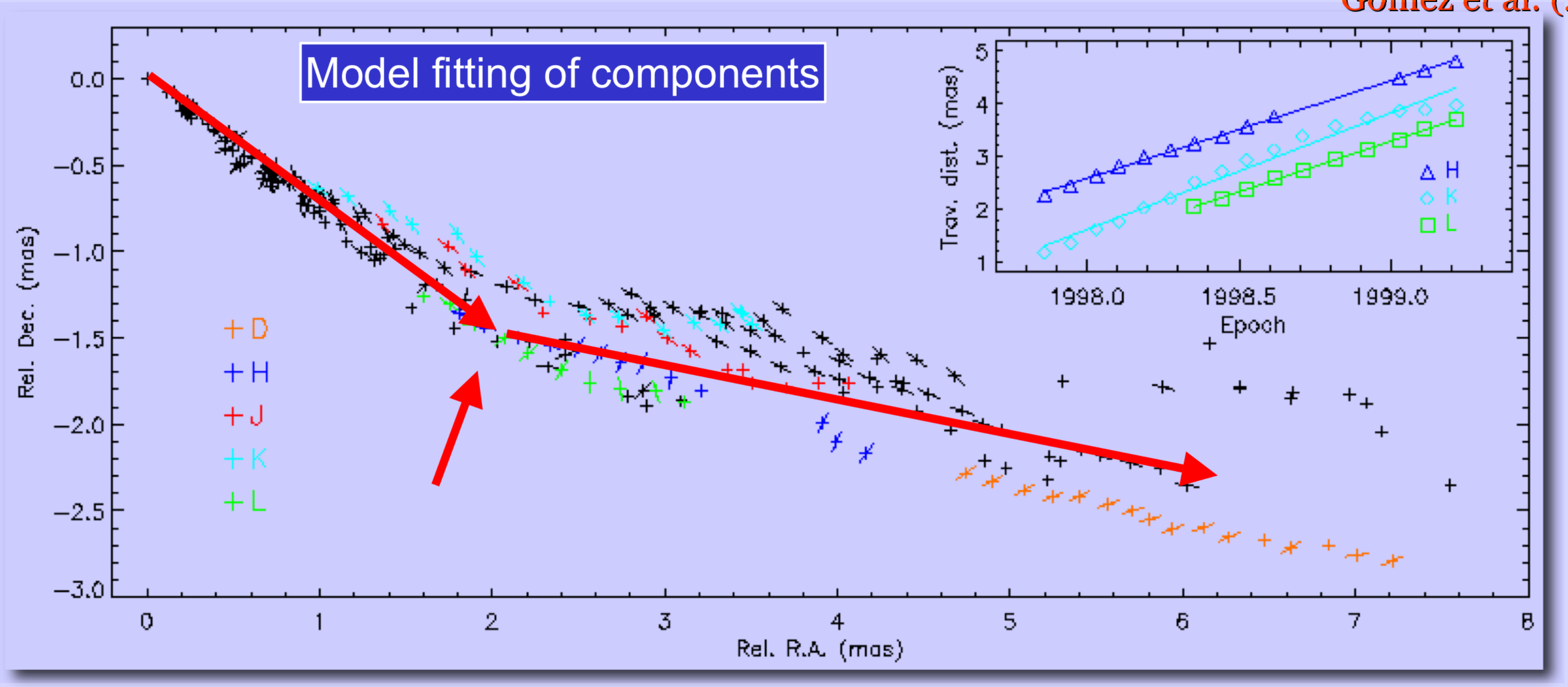


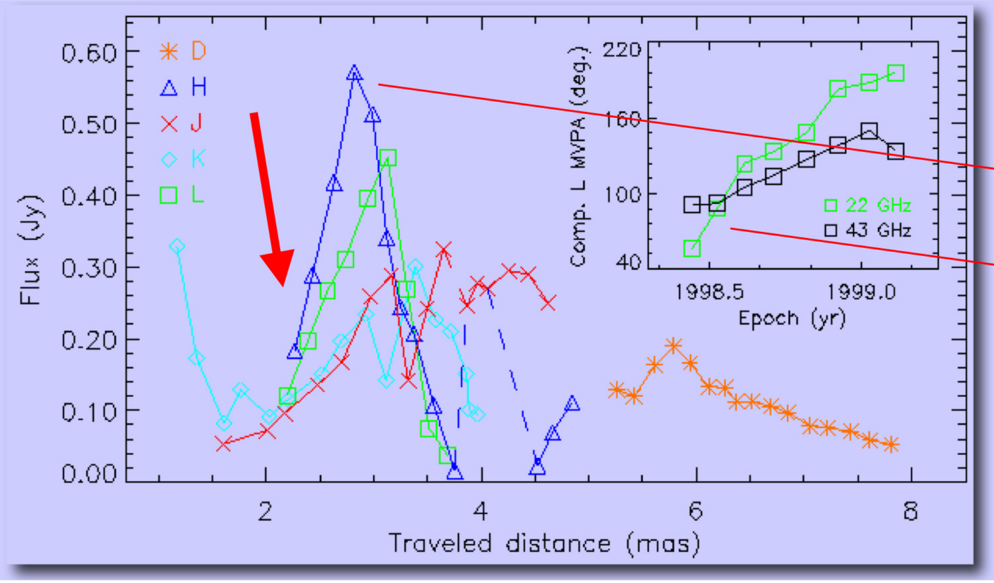
Combined degree of polarization

- Obtained by adding the emission for 12 monthly epochs in 2001
- Remarkable difference, with a sharp transition, between the north and south sides of the the jet:
  - ✓ Northern side shows relatively high degree of polarization (~30-40%)
  - ✓ Weaker degree of polarization at the Southern side (<10%)

3C120 Jet-cloud interactions at pc-scales

Gómez et al. (2000)

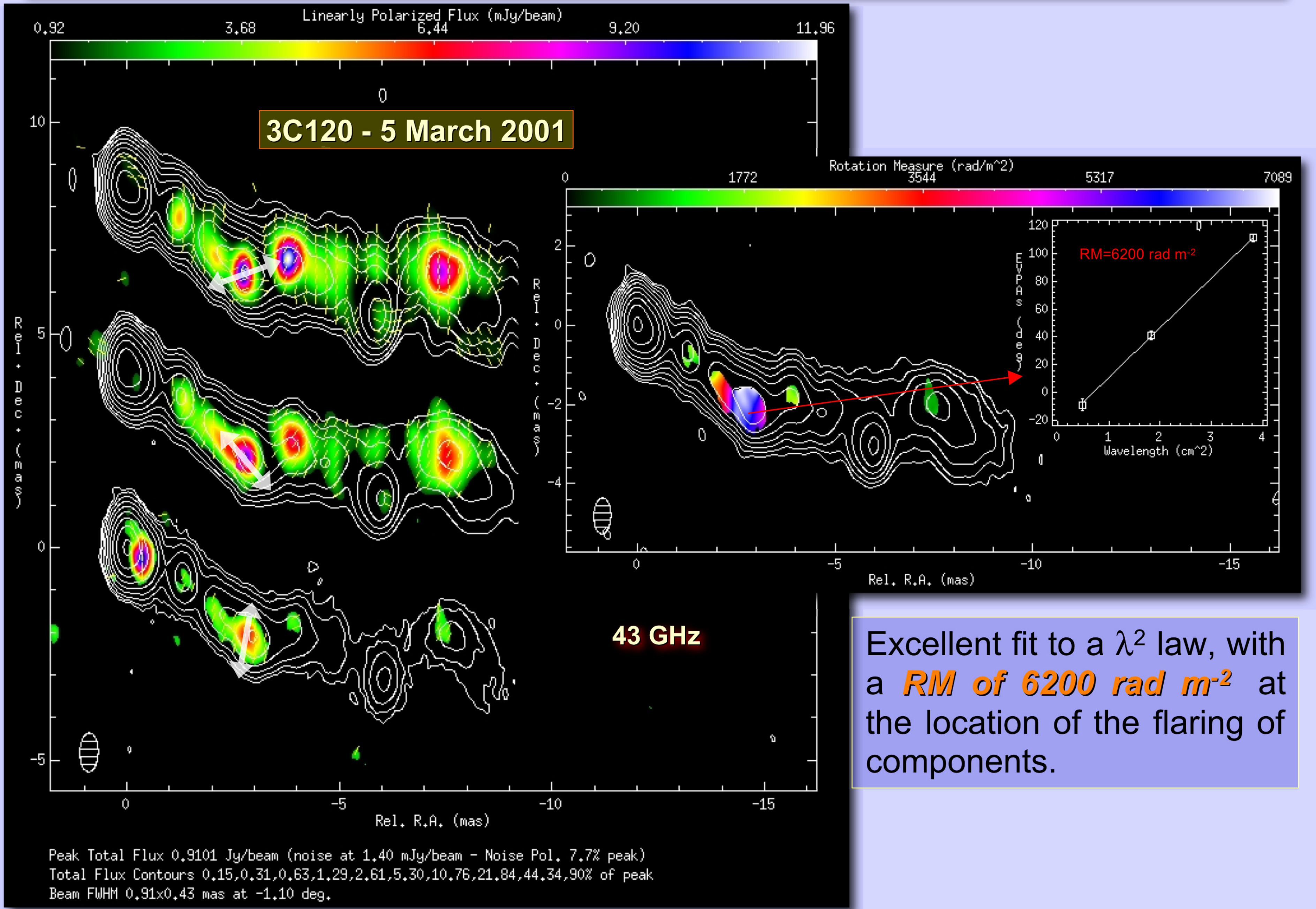




Arrows mark the position at which southern components start:

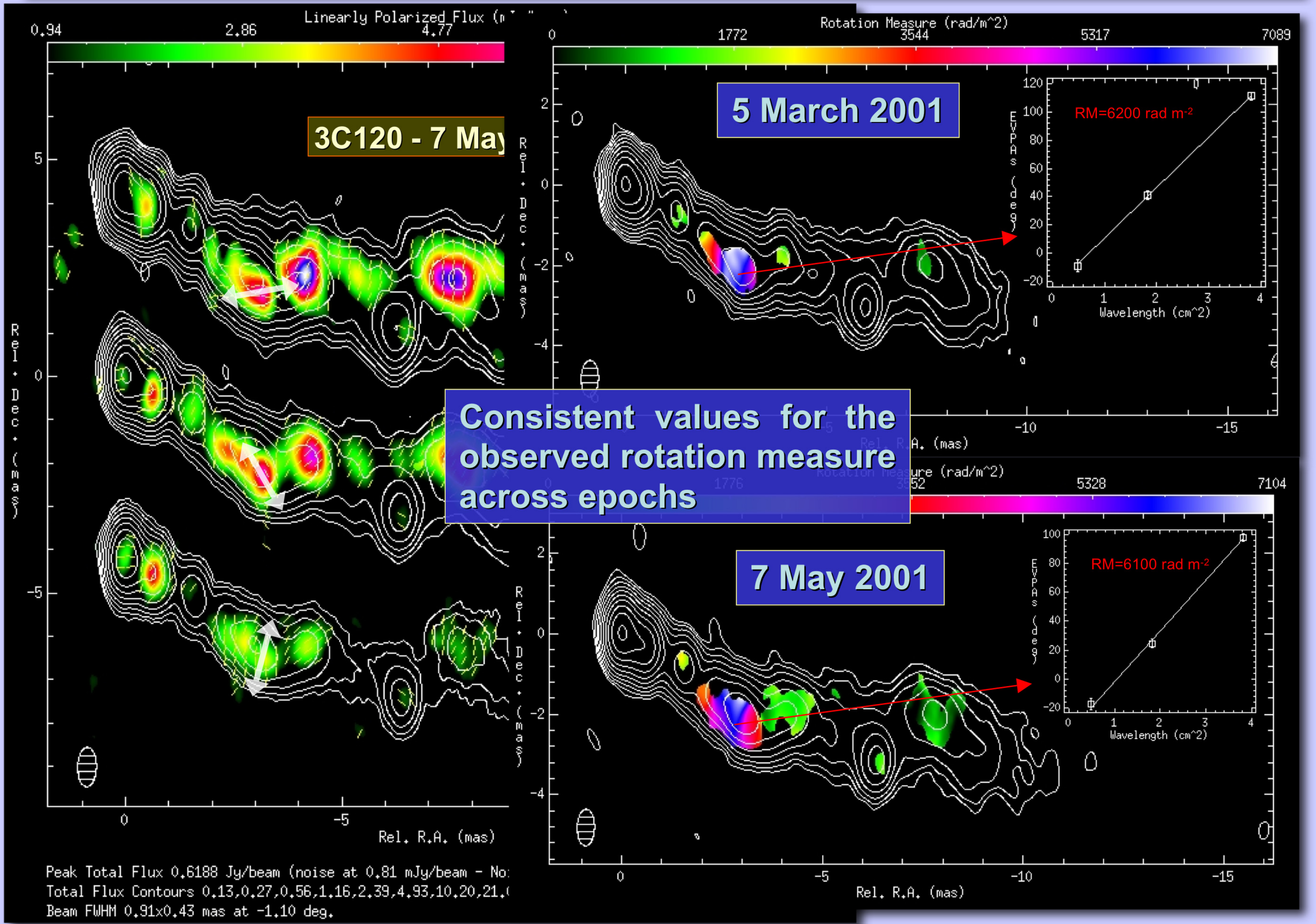
- ✓ Flaring in total and pol. flux
- ✓ Rotating their EVPA

3C120 Jet-cloud interactions at pc-scales



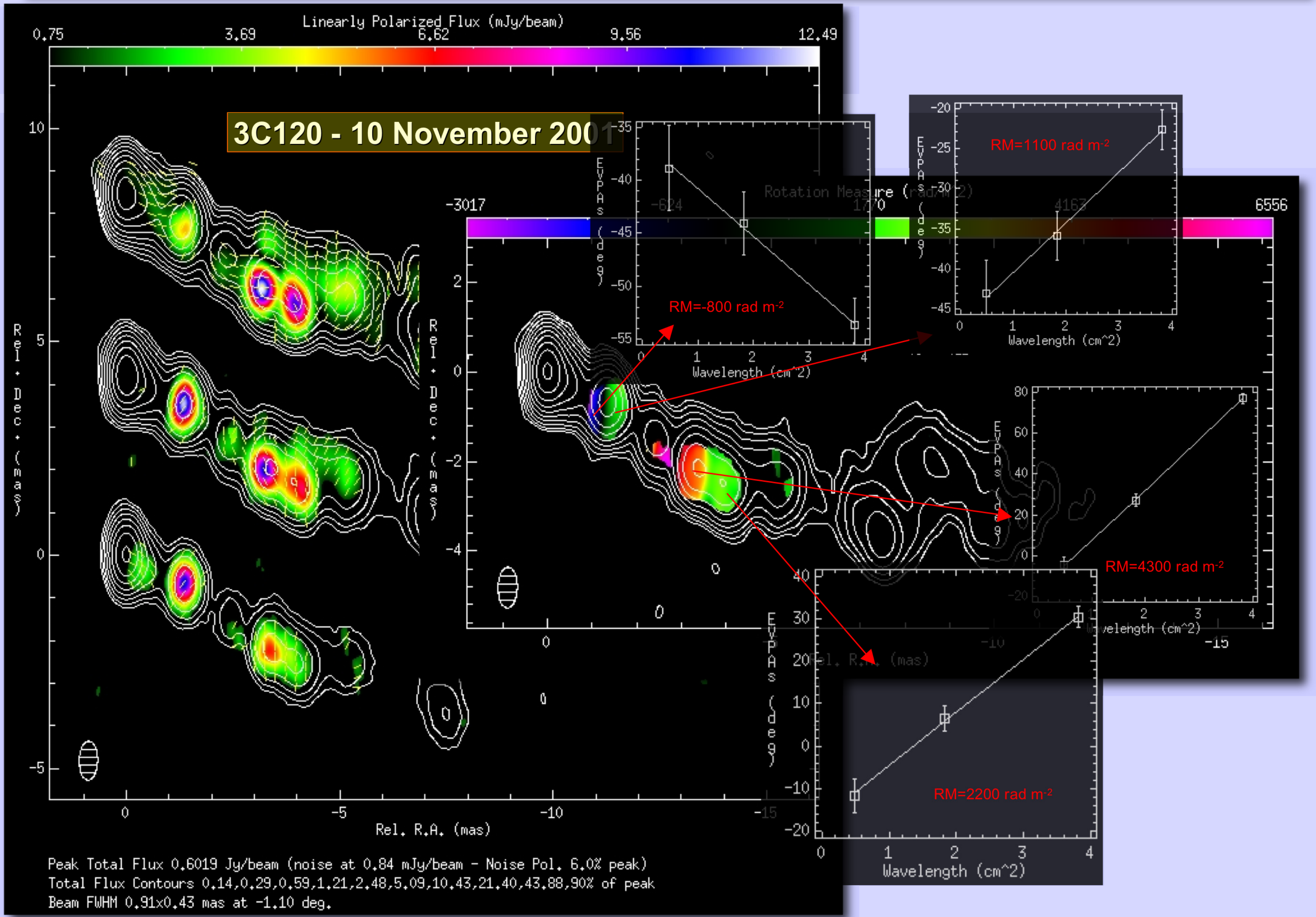
Excellent fit to a λ^2 law, with a ***RM of 6200 rad m^{-2}*** at the location of the flaring of components.

3C120 Jet-cloud interactions at pc-scales



Consistent values for the observed rotation measure across epochs

3C120 Jet-cloud interactions at pc-scales



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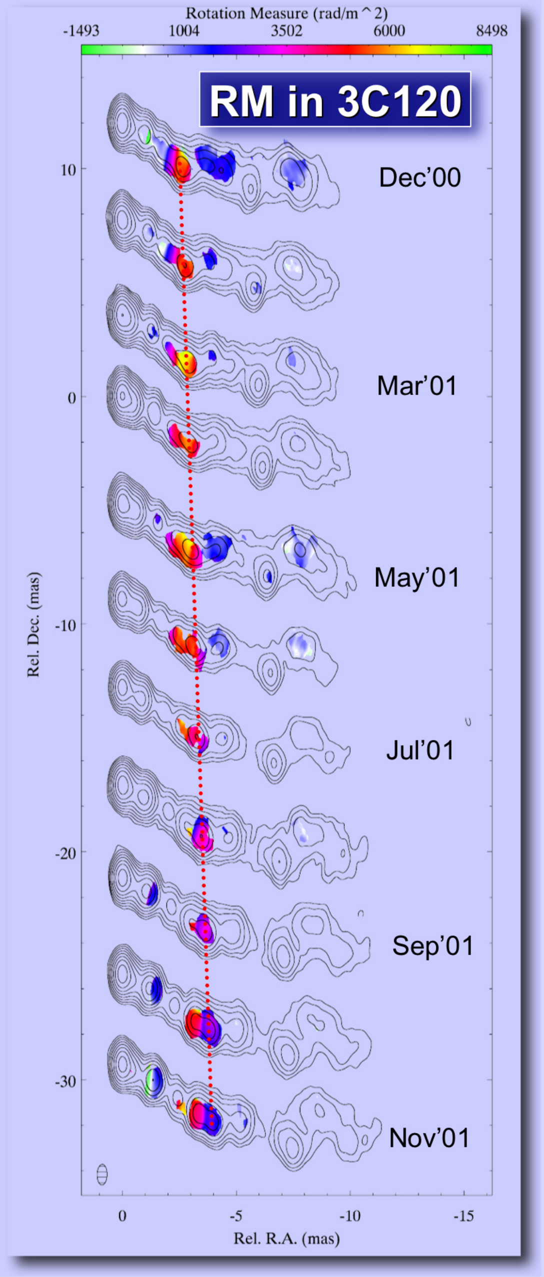
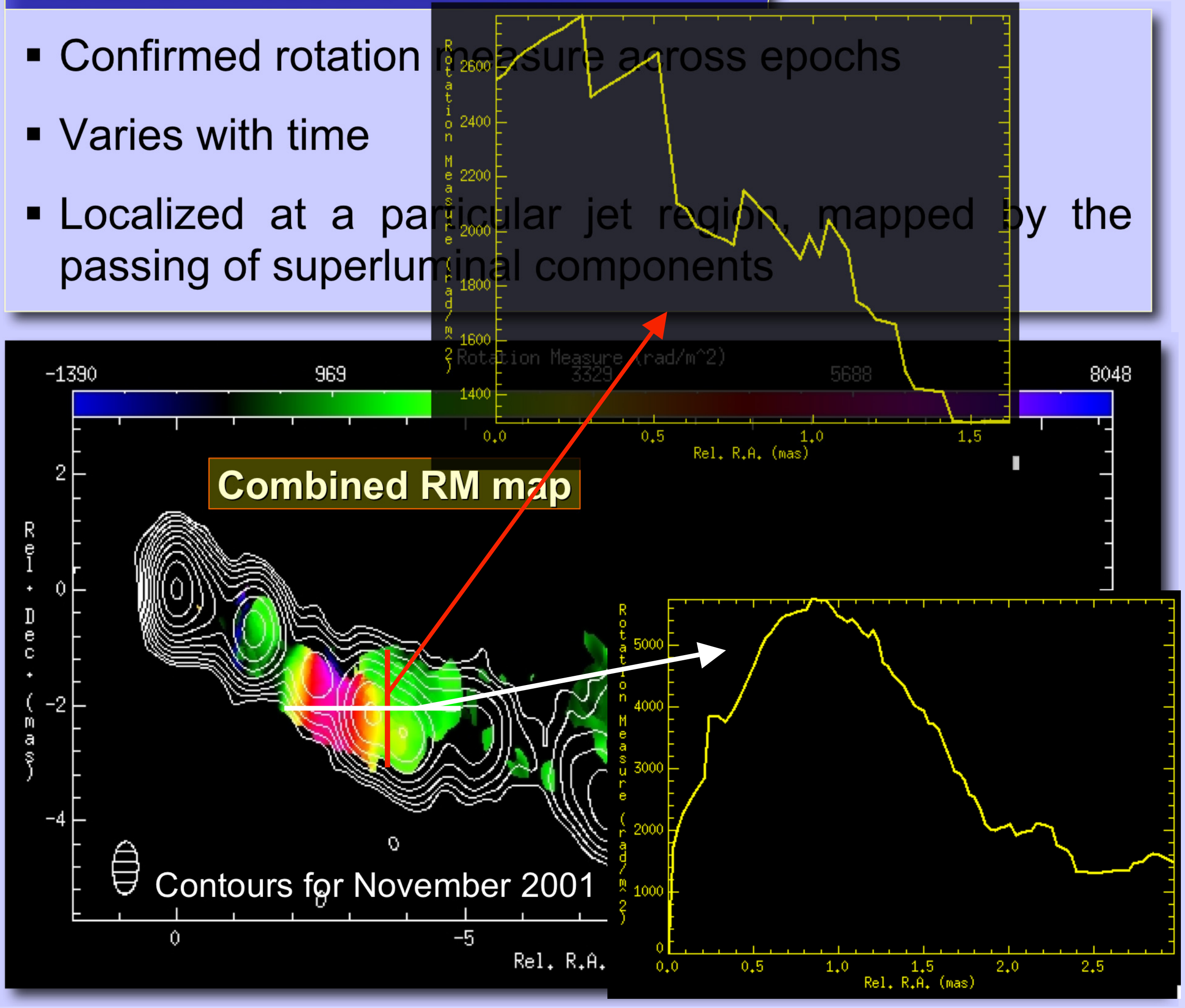
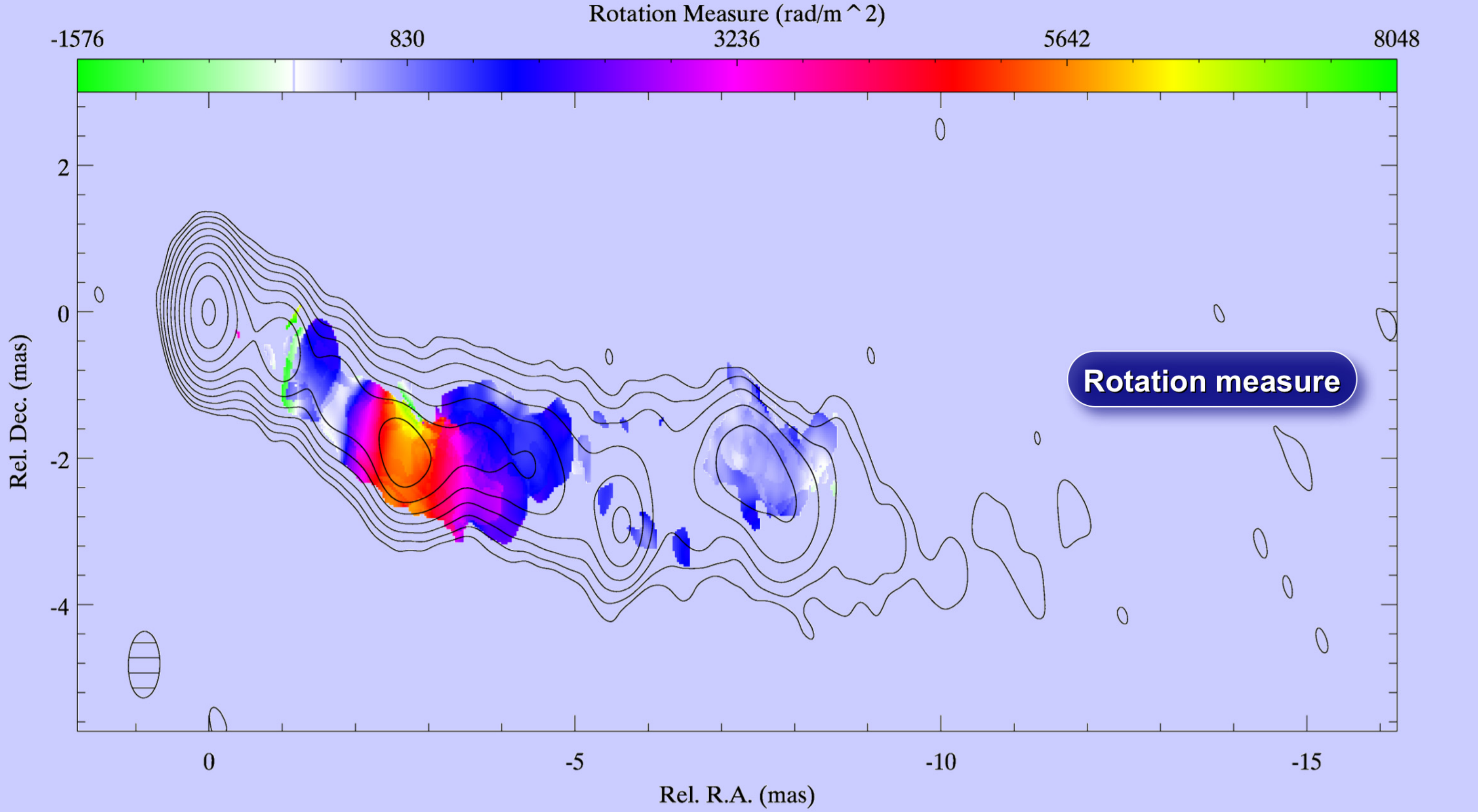


Rotation Measure in 3C120

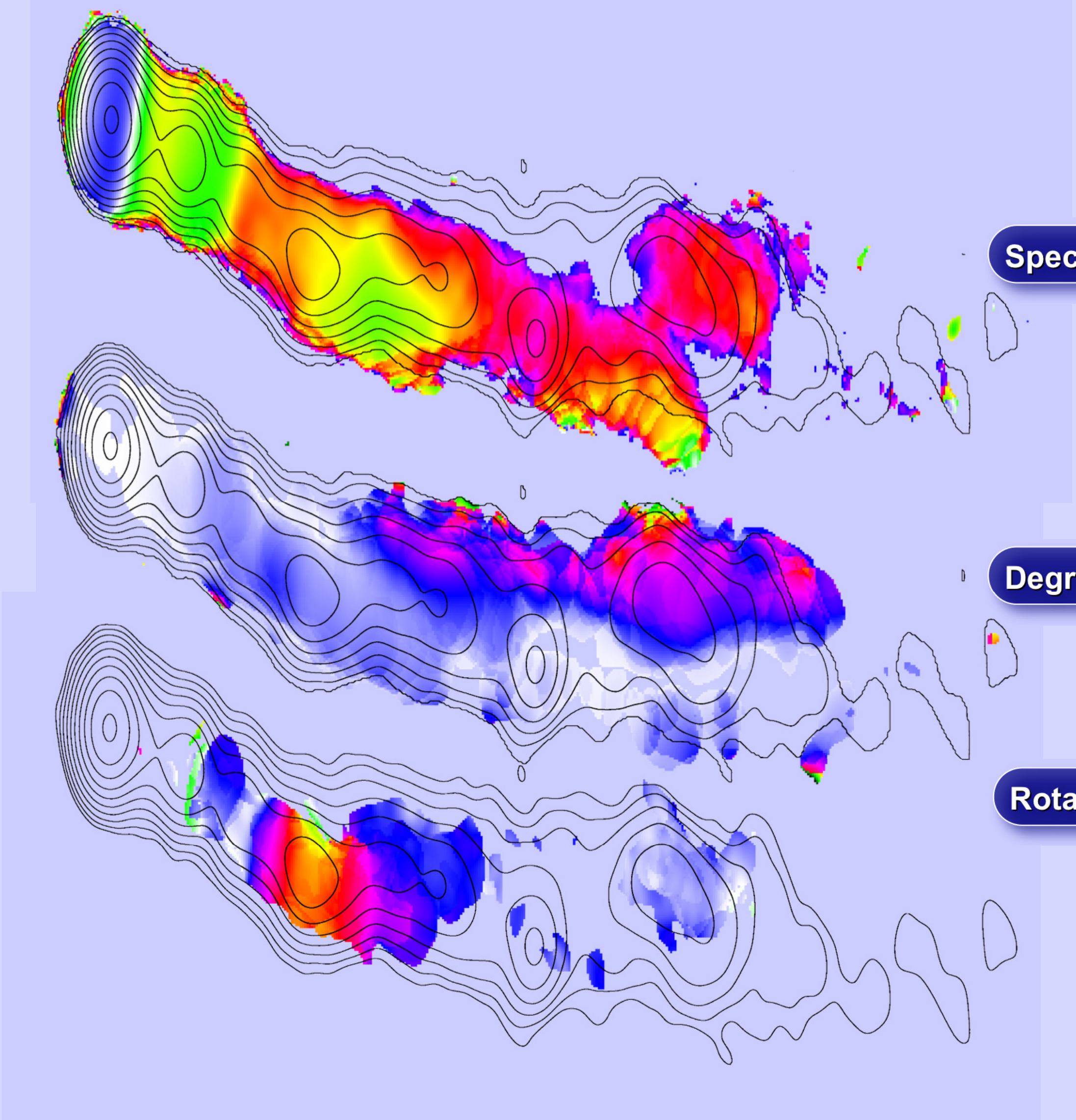
- Confirmed rotation measure across epochs
- Varies with time
- Localized at a particular jet region, mapped by the passing of superluminal components



3C120 Jet-cloud interactions at pc-scales



3C120 — *Jet-cloud interactions at pc-scales*

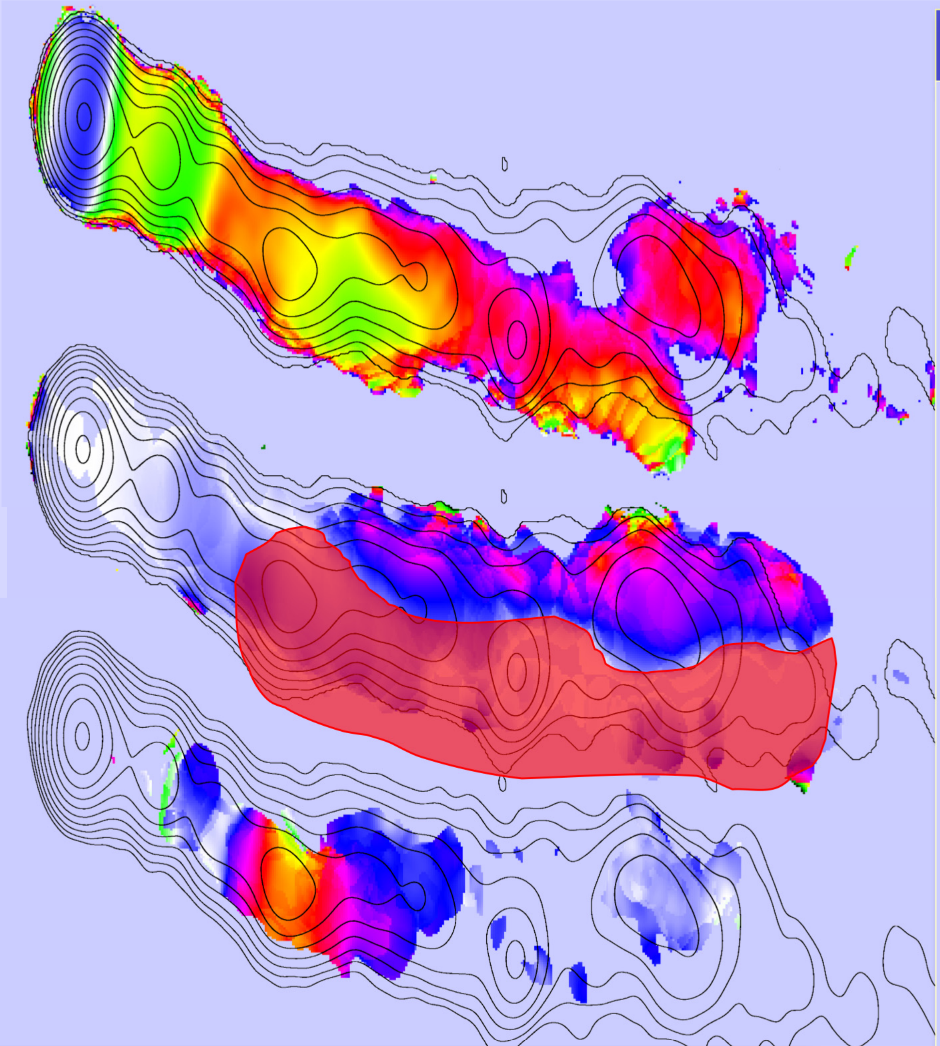


Spectral index 22-43 GHz

Degree of polarization

Rotation measure

3C120 — *Jet-cloud interactions at pc-scales*



But, given the small degree of polarization, could the observed rotation measure be intrinsic to the jet?

A jet-cloud collision?

Would explain:

- Coincidence in position for the increased opacity and RM
- Weak deg. pol. of southern jet (Faraday depolarization)
- Flare of components through the shock produced by the interaction
- Rotation of the EVPAs by Faraday rotation and jet bending
- Rapid fading of components through free-free absorption

The cloud would be located at about 8 pc from the core, and with n_e~5x10^4 cm^{-3}

3C120 — *Jet matter content*

Can we discern whether the jet in 3C120 is composed of "normal" matter or e^-/e^+ pairs? (Marscher et al., in prep)

If the jet, which interacts strongly with the thermal ambient medium, is mainly composed of pair plasma, the positrons entering the medium will thermalize and annihilate, leading to the *emission of the 511 keV annihilation line*.

Time scales

From the inferred density of the cloud of n_e~5x10^4 cm^{-3}, the positrons will thermalized on a time scale of

$$\tau_{therm} \leq 0.6\gamma_i (5\times 10^4\, cm^{-3} / n_e)\ yr$$

where γ_i is initial Lorentz factor of the positrons as they enter the cloud (Pacholczyk 1970).

This, as well as the annihilation time scale (Furlanetto & Loeb 2002)

$$\tau_{an} \sim 100\,(5\times 10^4\, cm^{-3} / n_e)\ yr$$

are a factor of a few smaller than the time for the cloud to move out of the way of the jet, ~300 yr, for a velocity component transverse to the jet of <3000 km s^{-1}.

In addition, 3C120 contains a large amount of kpc-scale gas seen in various lines, with a density in the range of 10$^{3-7}$ cm^{-3} (Axon et al. 1989).

Therefore, a substantial fraction of any positrons in the jet eventually interact with the cloud/external medium.

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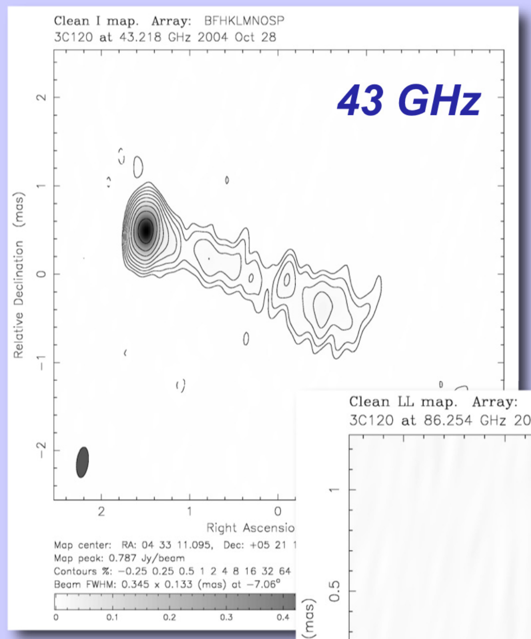
Annihilation line flux

From model-fitting of the images at 43 and 86 GHz, we can estimate the luminosity in the positrons in the case of a pair-dominated jet to be ~3×10^{44} erg s^{-1}.

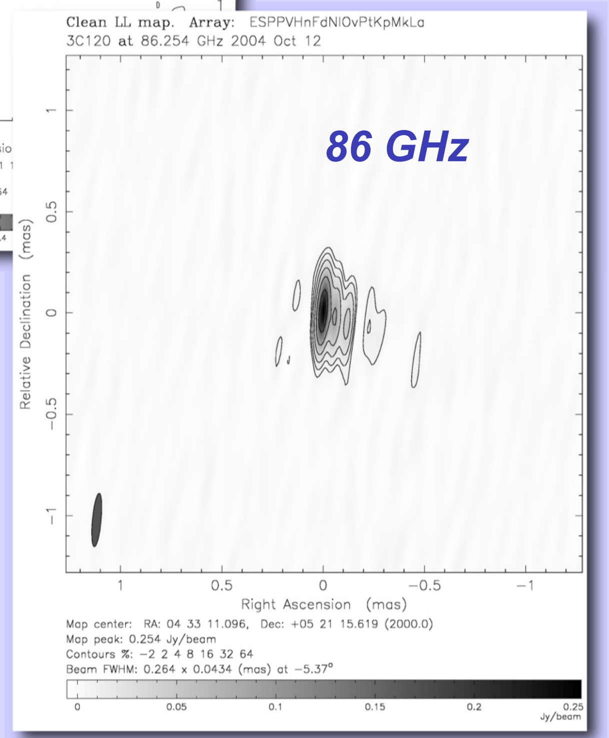
If we assume that a fraction of the positrons *f* interact with the external medium and annihilate, the expected flux of the redshifted 511 keV line is then

$$F\ (511\ \mathrm{keV}) \approx 3\times10^{-4} f \gamma_{\min}^{-1/2}\ \mathrm{photons\ cm^{-2}\ s^{-1}}$$

where $\gamma_{\min}$ is the mean minimum energy of the positrons.



(Marscher et al.)



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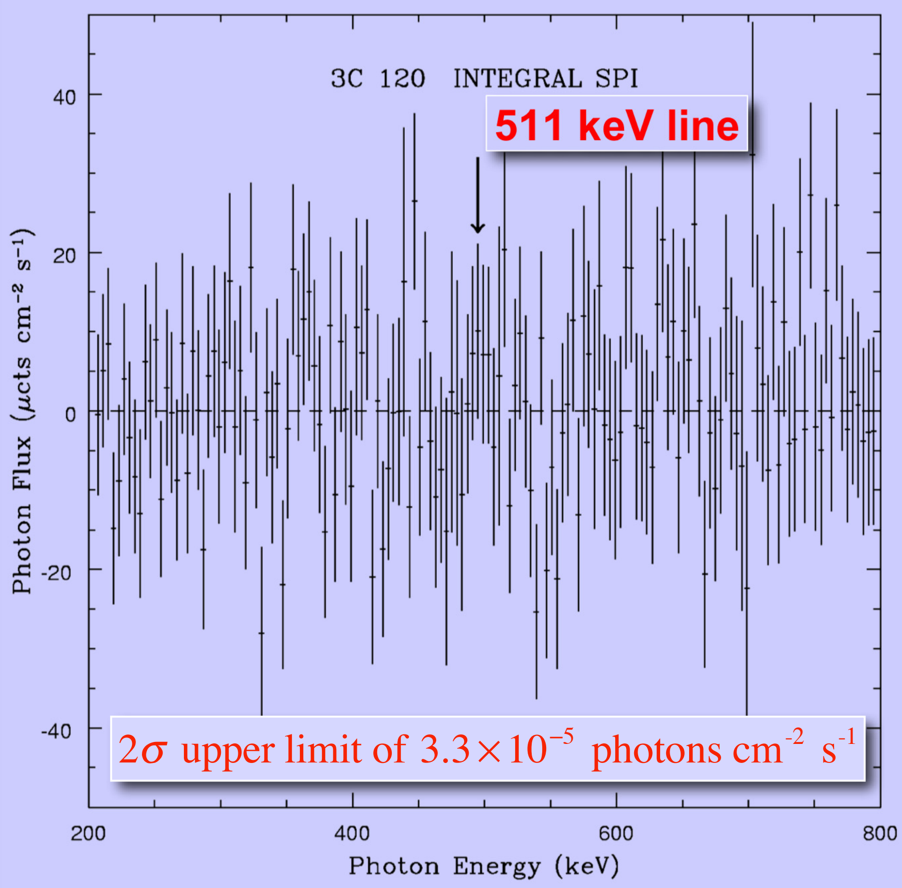
We should be able to detect the annihilation line with INTEGRAL, ***if*** the jet in 3C120 is pair-dominated



Marscher et al. (in prep.)

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Jet composition

Expected line flux:

$$F\ (511\ \mathrm{keV})\ \approx 3\times10^{-4}\, f\gamma_{\min}^{-3/2}\ \text{photons cm}^{-2}\ \mathrm{s}^{-1}$$

Observed line flux:

$$F\ (511\ \mathrm{keV})\ \leq 3.3\times10^{-5}\,\text{photons cm}^{-2}\ \mathrm{s}^{-1}$$

- If f~1 and $\gamma_{\min}$ ~1

  <1/9 of the positive particles are positrons

- For f~0.9-1 we could still have a e^+/e^- pair jet if $\gamma_{\min}$ ~5.

  If $\gamma_{\min}$>>5 internal energy of the e^+/e^- pairs will be transfered to the flow accelerating the jet, which is not observed in the VLBI images

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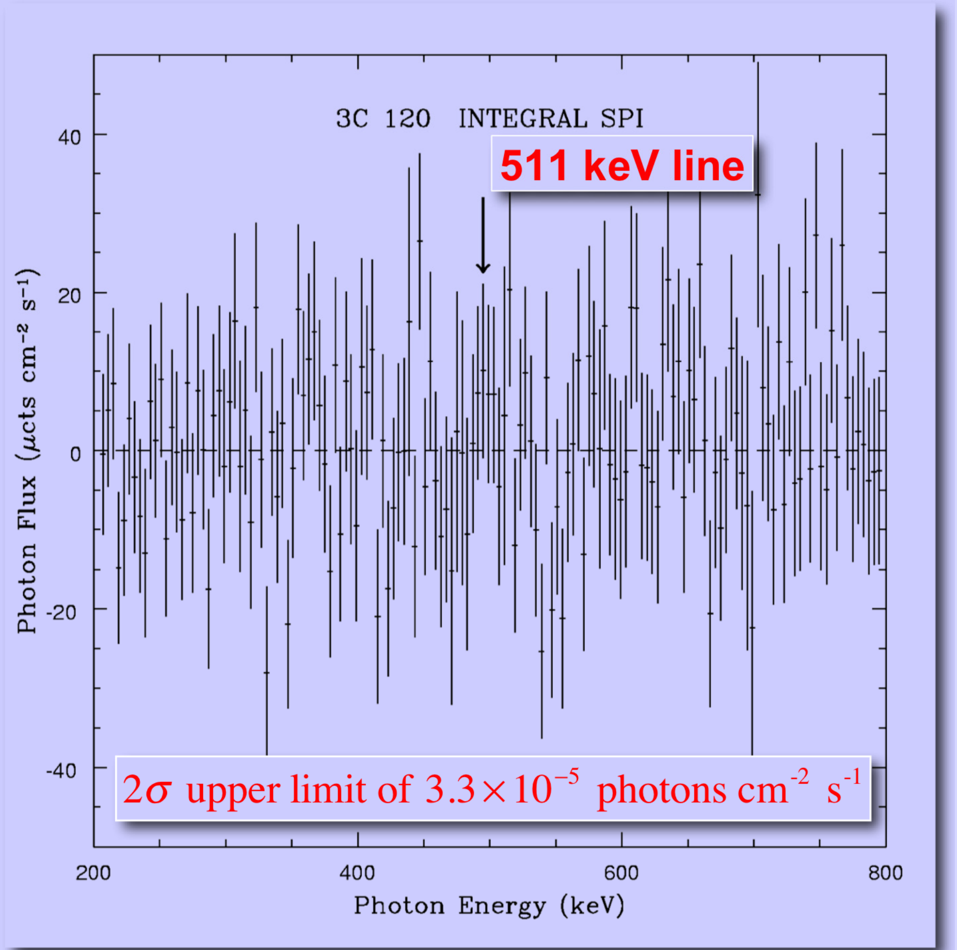
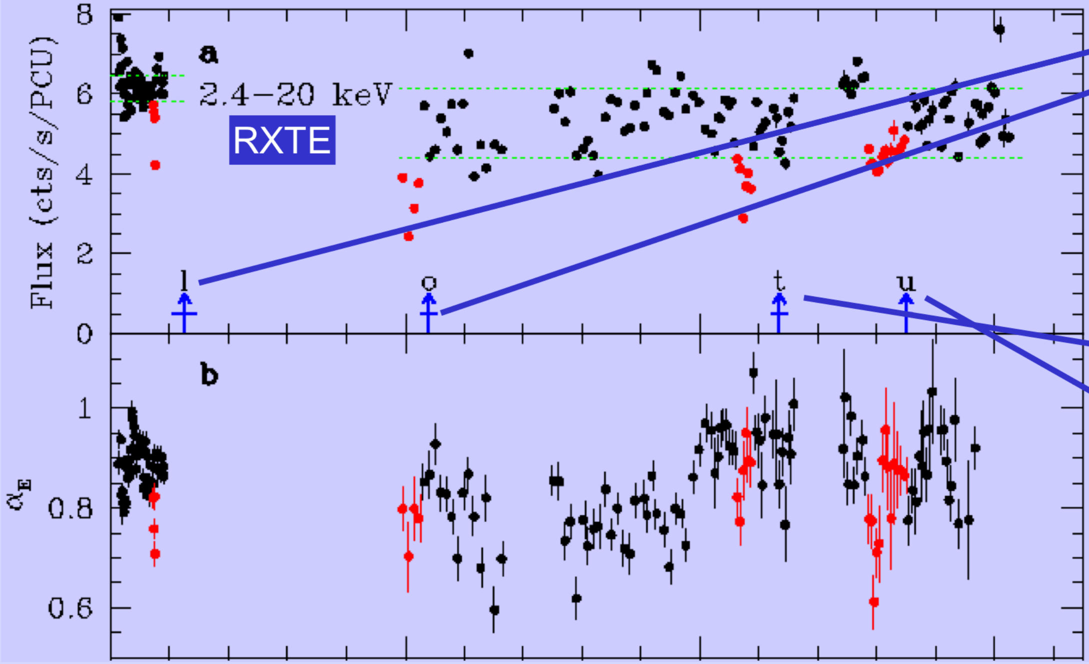
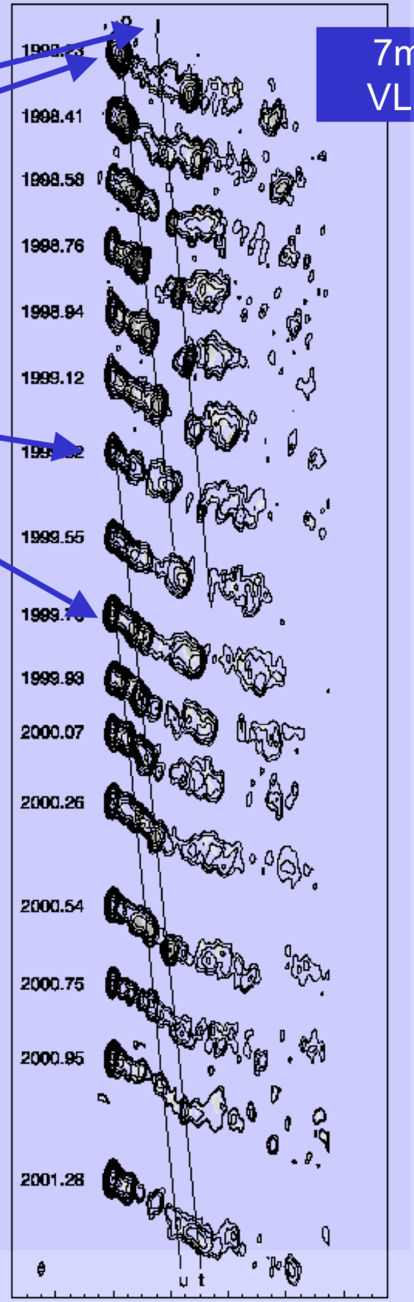


Marscher et al. (in prep.)

3C120 The SMBH+disk+jet connection

Marscher et al. (2002)



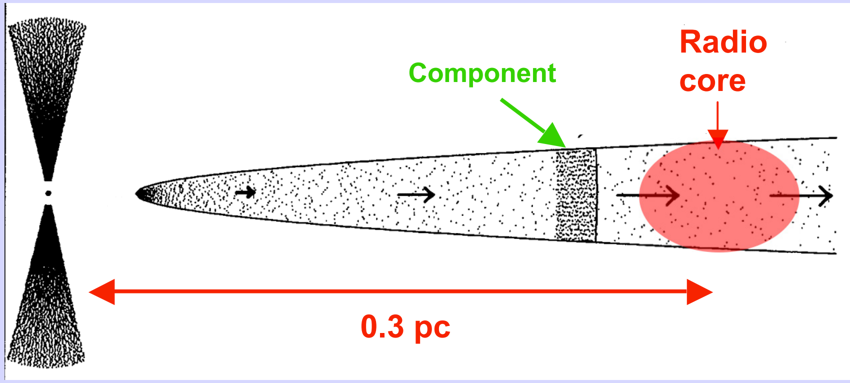


- New superluminal components are observed in the radio jet after the dips in the X-rays, with a constant delay of 0.1±0.03 yrs

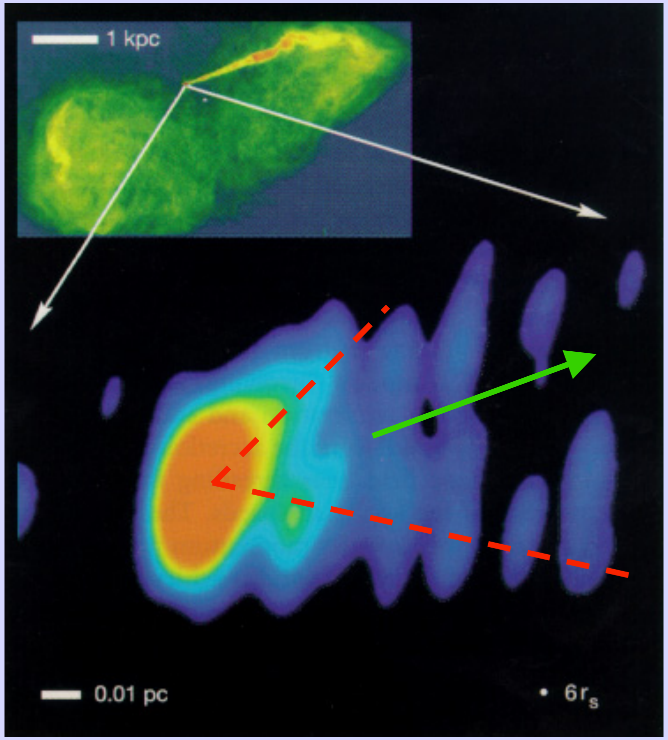
  Part of the inner disk material that is not drawn into the black hole is injected into the jet, leading to the appearance of new superluminal components.

3C120 is the first AGN for which we have observed a similar BH+disk+jet connection as found for μQSO

The inner jet

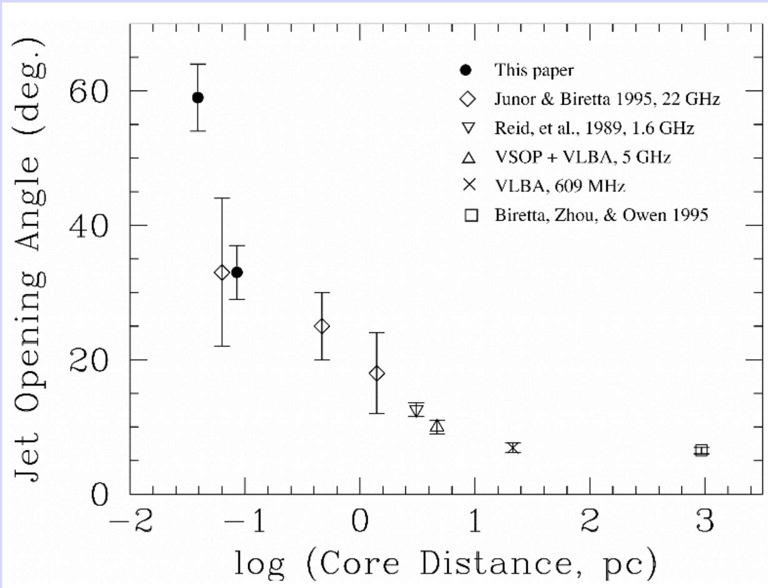


Assuming components move at about 4.7 c, for a viewing angle of 20° ***the radio core is placed at a minimum distance of 0.3 pc from the X-ray source (accretion disk)***



Junor, Biretta & Livio (1999)

This affects the estimated collimation region in M87, which takes place in the inner 30-100 R_s, extending up to 1000 R_s.



SUMMARY

Monitoring of 3C120 at parsec scales

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✓ Formation of components
✓ Kinematics
✓ Jet structure and possible precession
✓ Opacity along the jet

Magnetic field

✓ Intensity and orientation in the jet and components
✓ Testing of shock-in-jet models

- *12 epochs at 15, 22, and 43 GHz in 2001*

External medium

✓ Jet/cloud interactions
✓ Faraday rotation along the jet

- *Bimonthly at 43 GHz since 1999*

Jet-disk system

✓ Correlation between x-rays from the disk and radio from the jet

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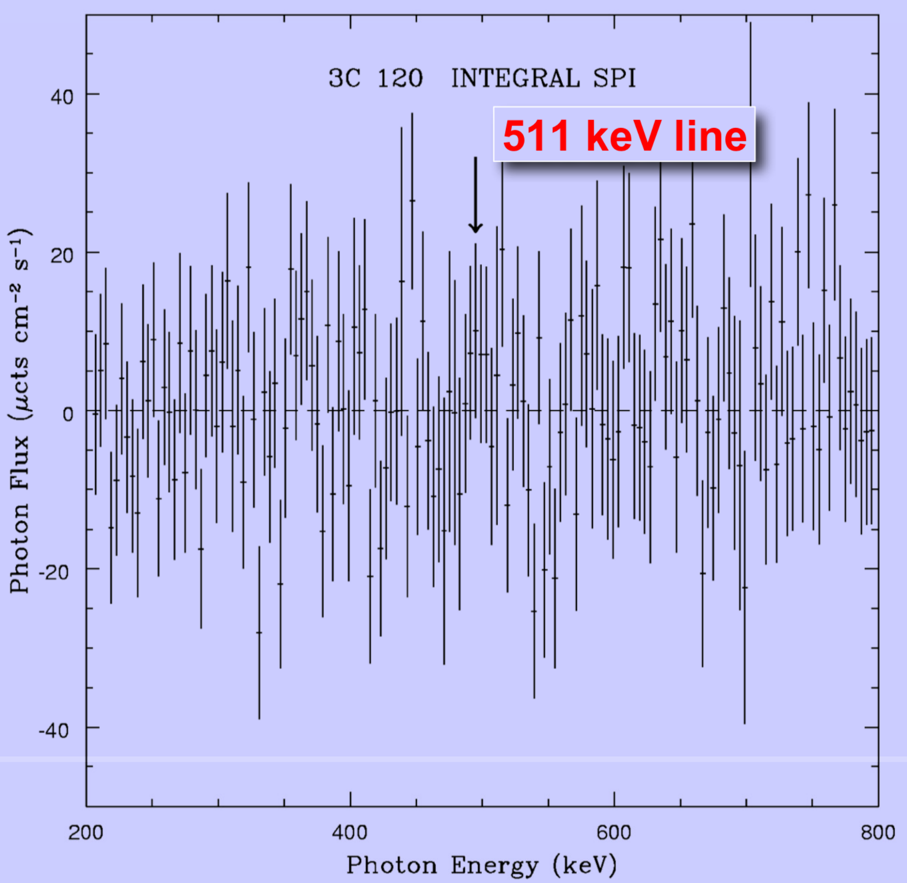
- Jet already collimated and accelerated at sub-pc scales
- No evidence for acceleration of superluminal components
- Evidence for jet precession

- Rapid changes in emission at VLBI scales
- Jet stratification in polarization
- Variable Faraday rotation at pc-scales

Jet/cloud collision?
Perhaps intrinsic to the jet?

- Jets are fed by the inner accretion disk
- Radio core is *NOT* at the jet nozzle

SUMMARY



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Jet/cloud collision?
Perhaps intrinsic to the jet?

- If γ_{min} ~1, <1/9 of the positive particles are positrons

- But, we could still have a e^+/e^- pair jet if γ_{min} ~5.

- Jets are fed by the inner accretion disk
- Radio core is *NOT* at the jet nozzle