Optical continuum flares from the relativistic jet: evidence for non-virial BLR in AGN ?

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Outline

- ❑ Introduction to 3C 390.3

- ❑ Monitoring of individual sources: link between variable optical continuum emission and subparsec-scale jet for 3C 390.3 and 3C120.

- ❑ Statistical analysis: correlation between jet viewing angle and FWHM of Hb broad emission line.

- ❑ A model for the central subparsec-scale region and implications for the BLR structure.

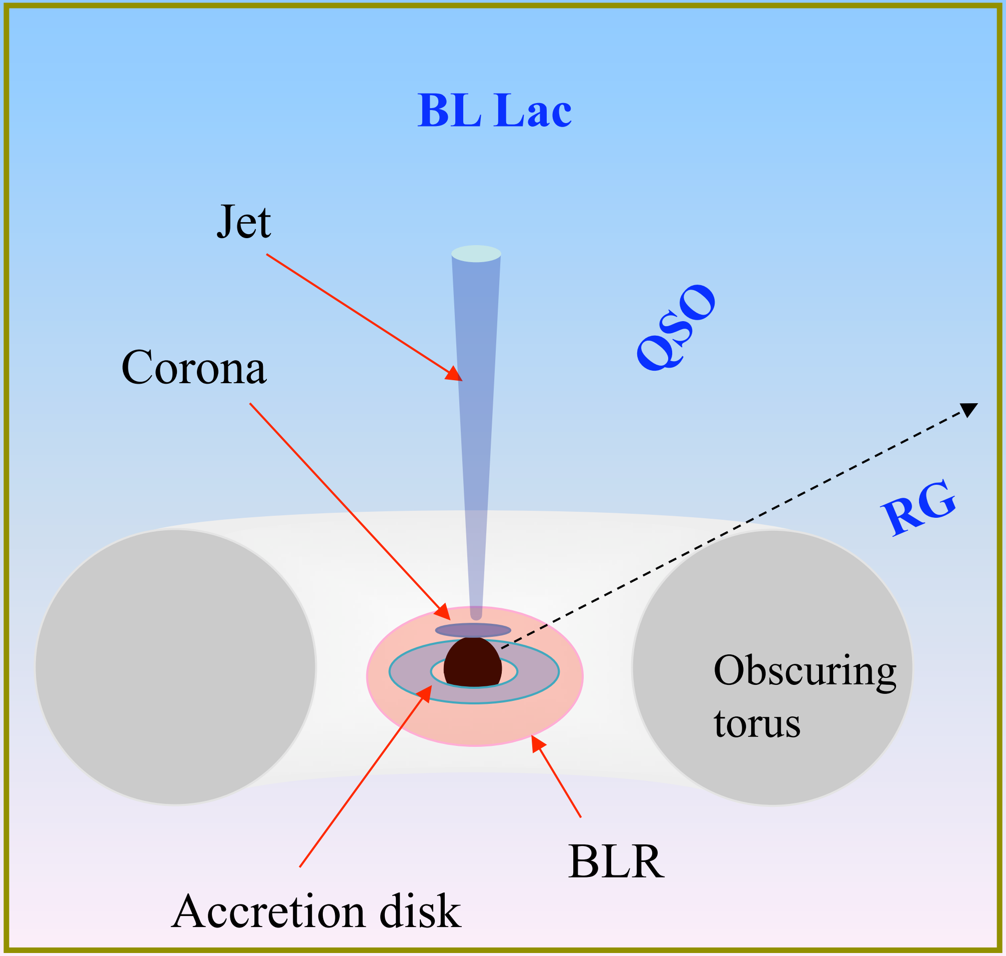
The central engine: unification of radio-loud AGN

- ☐ **BL Lacs:** strong beamed non-thermal continuum emission from the jet is dominant.

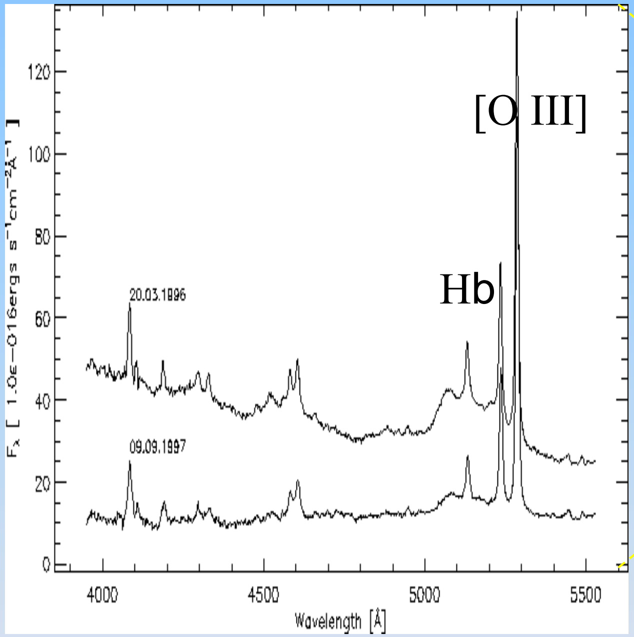
- ☐ **QSOs:** optical thermal continuum emission from accretion disk is dominant; emission from the jet is less beamed (**BLR** is viewed directly).

- ☐ **Broad-line RGs:** accretion disk and BLR are partially hidden by the torus; jet emission can be strong if the jet is relativistic and intrinsically bright.

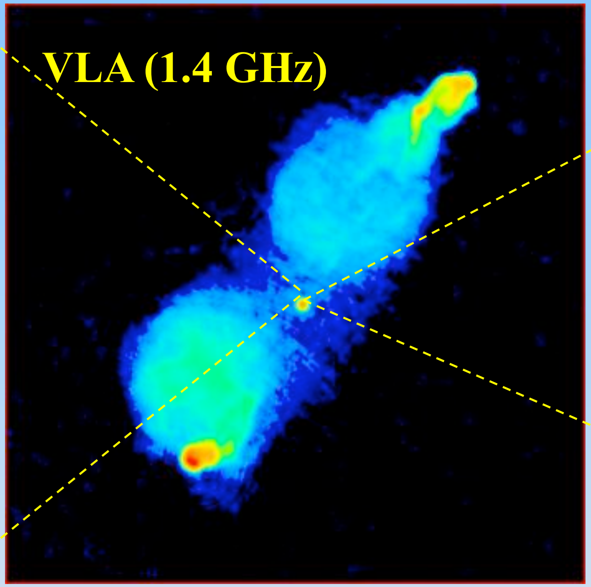
AGN unification



3C390.3: the broad-line radio galaxy

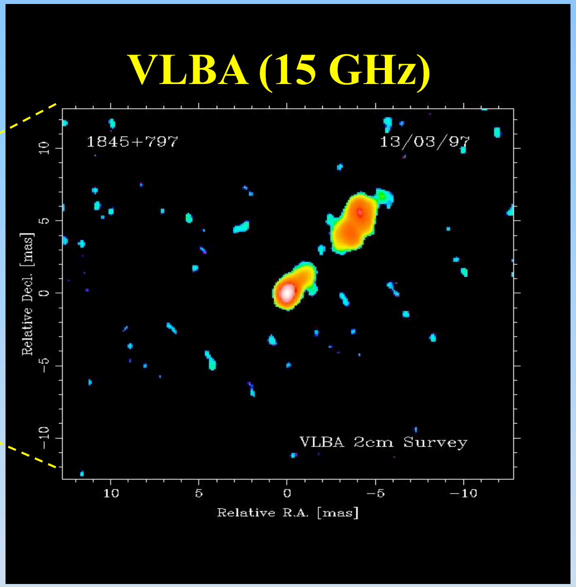


Broad double-peaked Hb emission line (Shapovalova et al. 2001)



Lobe-dominated FR II structure on kpc-scales

Leahy & Perly (1995)



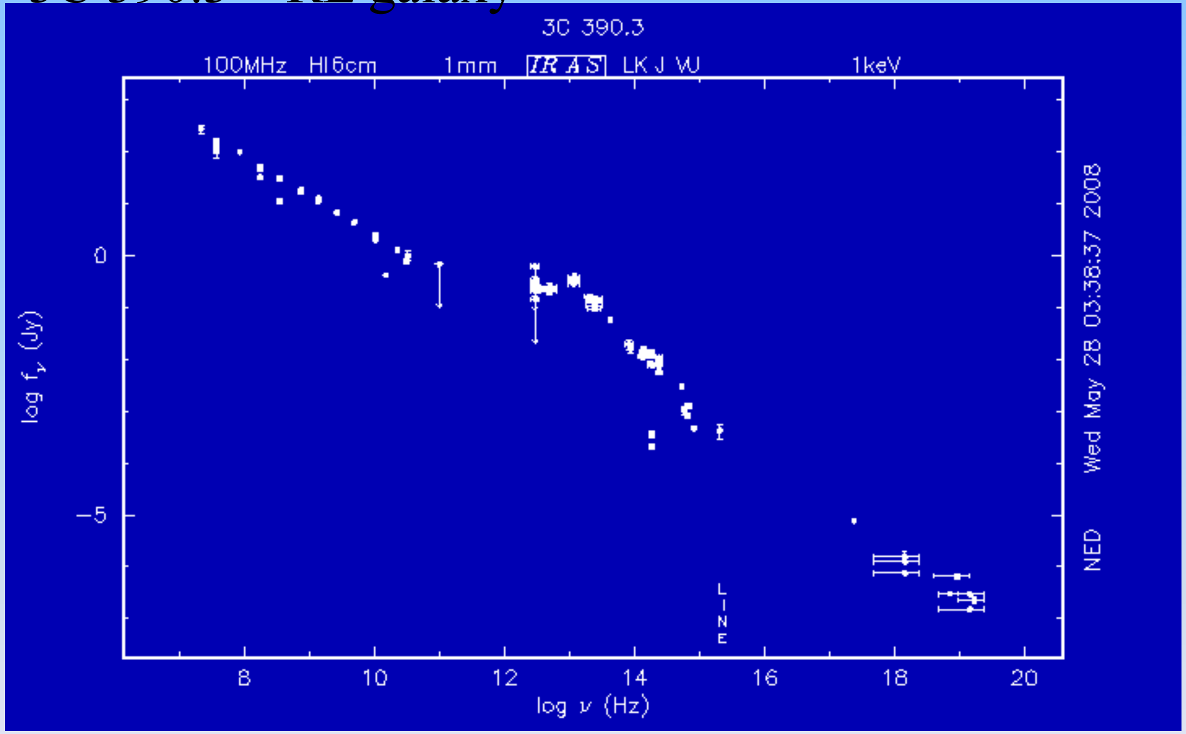
Pc-scale superluminal jet

Kellermann et al. (1998)

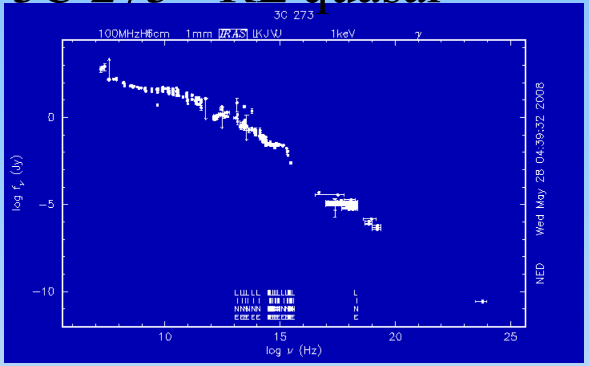
Var. Doppler factor = 1.16
Apparent speed = 1.5*c*
=====================
Jet viewing angle ~ 50
Lorentz factor ~2

3C 390.3: spectral energy distribution

3C 390.3 – RL galaxy



3C 273 - RL quasar

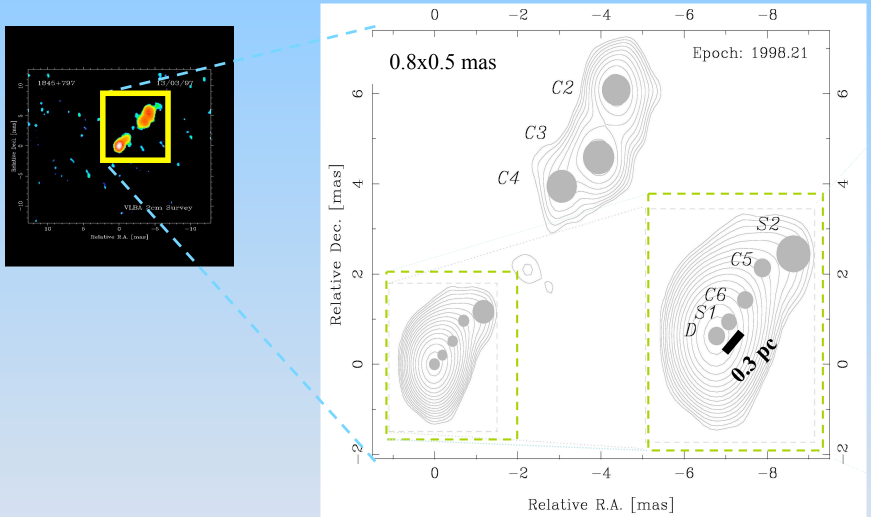


Multiwavelength data over 10 yr: optical component is likely to be opt. thin synchrotron radiation from the core of the jet (Soldi et al. 2008).

- No UV bump (the central disk is obscured)
- Non-thermal emission: radio, optical to X-ray (Wamsteker et al. 1997)

3C390.3: VLBI monitoring at 15 GHz

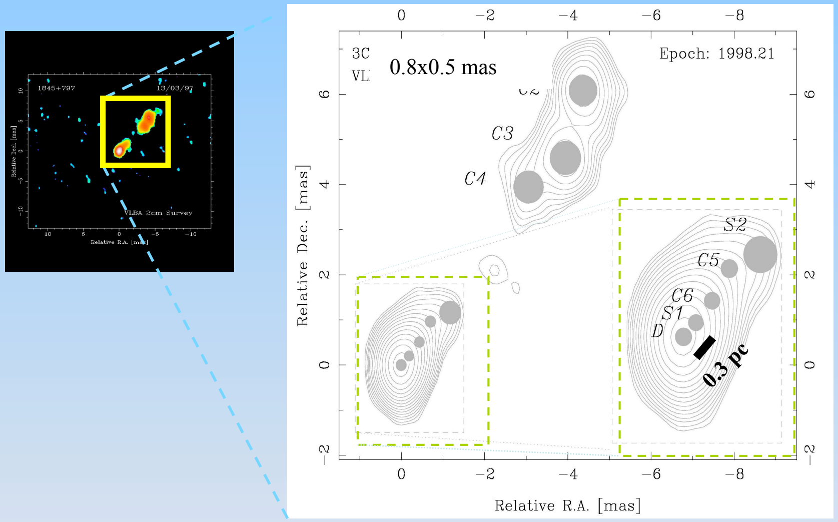
Model fitting of a **single epoch** of the VLBA radio map at 15 GHz
(**1 mas = 1.09 pc**)

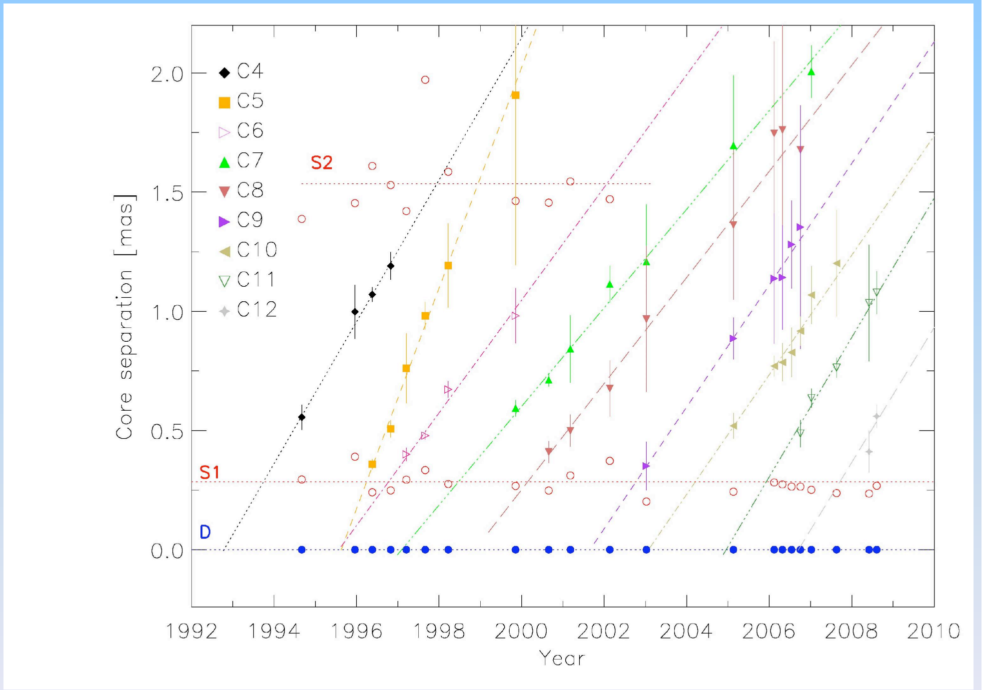


3C390.3: VLBI monitoring at 15 GHz

Model fitting of a **single epoch** of the VLBA radio map at 15 GHz (**1 mas = 1.09 pc**)

Kinematics of ejected jet components (**21 epochs)** during **14 years** period



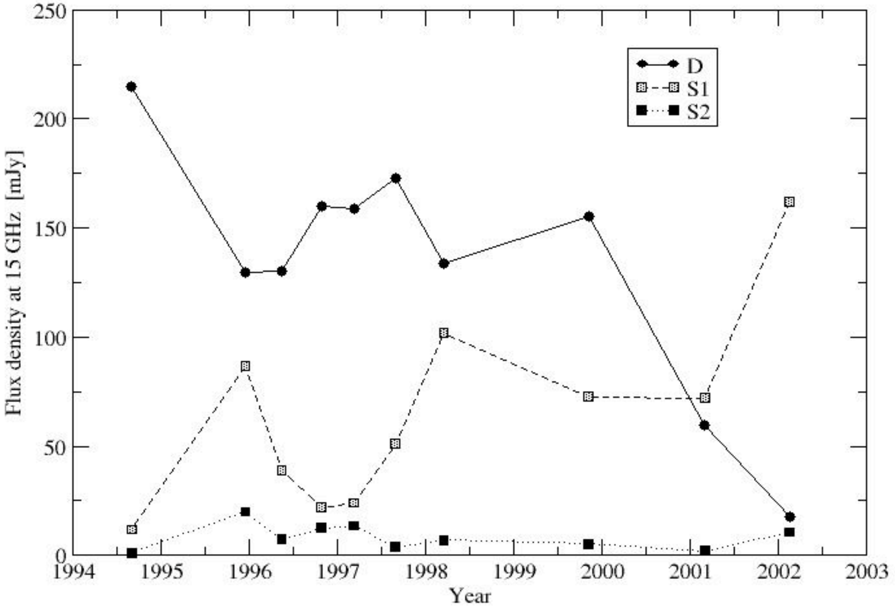


Jet components:
3 stationary radio features (**D, S1** and **S2**)
9 moving jet components (**C4-C12**; apparent speed from 0.7 to 1.5)

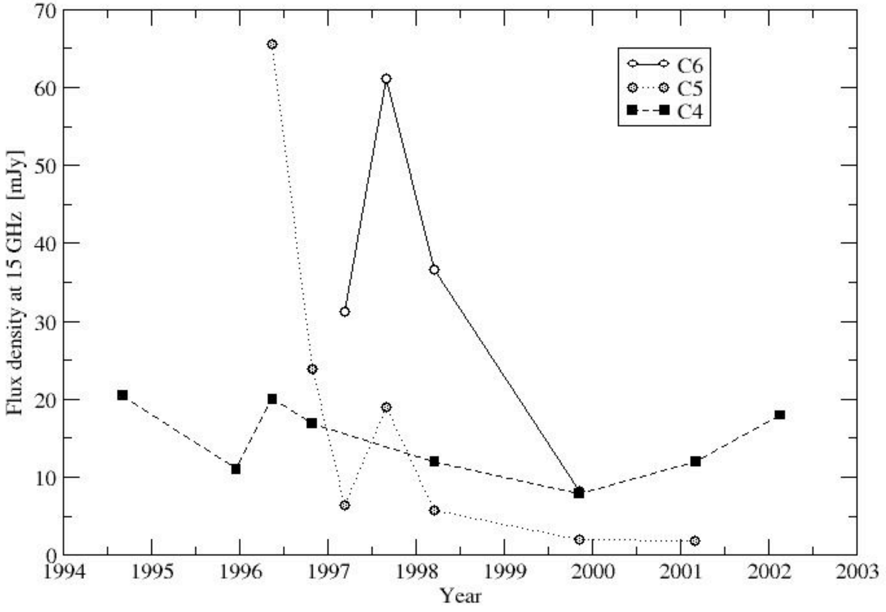
Epochs:
t_D of ejection of moving components at **D**
t_{S1} at which the comp. passes **S1** comp

3C390.3: Flux density variations of the jet components at 15 GHz

Stationary components



Moving components



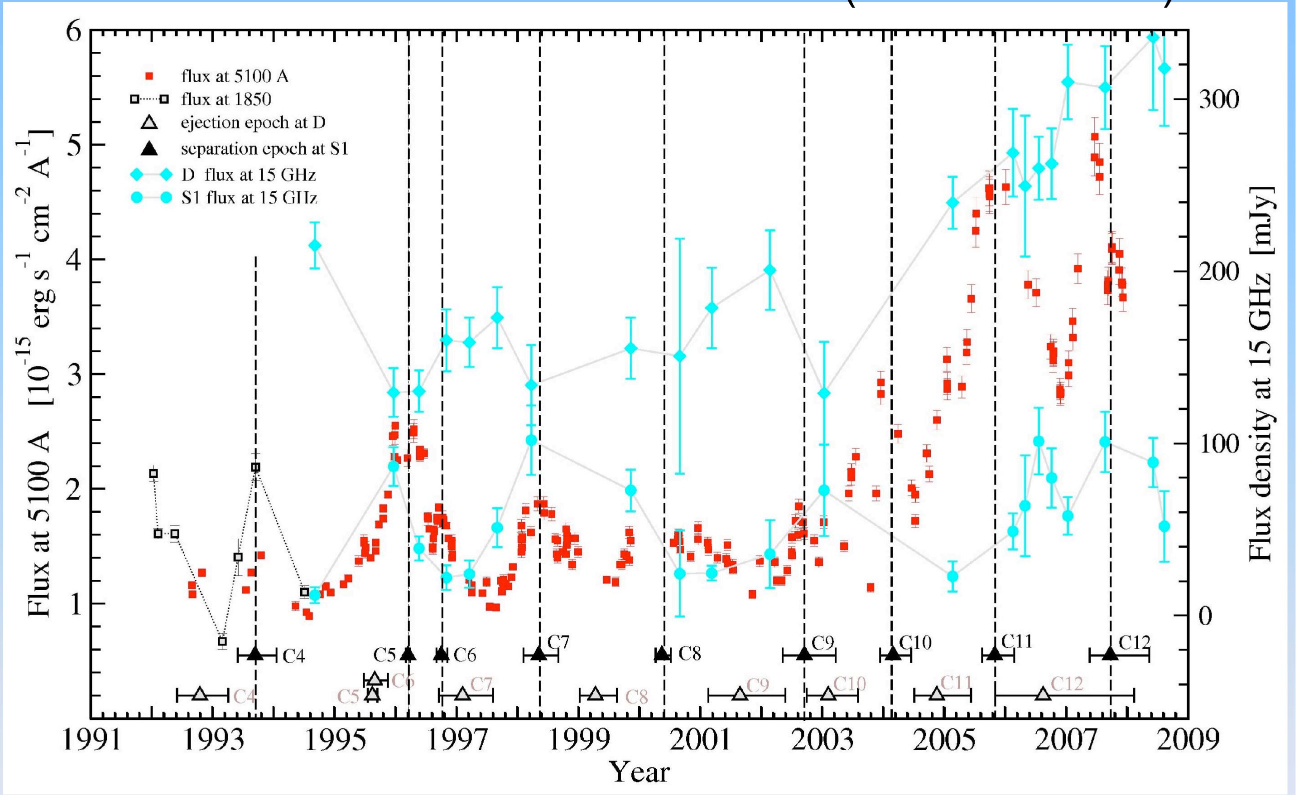
3C390.3: VLBI monitoring at 15 GHz

Resolves the subparsec-scale structure of the jet, its kinematics and measures flux variations of moving jet components

on scales less than one parsec

Link between stationary component S1 and optical flares (1994-2009)

Arshakian et al. 2009 (sub. to MNRAS)



The epochs (t_{S1}) at which radio knots pass through the location of S1 region coincide with time ($t_{opt,max}$) when the optical flares (months-years) are at maximum.

For all 9 ejection events

□ $t_{S1} - t_{opt,max}$ □ ~ 0.1 yr

1. All 9 ejection events are associated with optical flares !
2. Chance probability of this is ~10^{-10} (the correlation is significant at > 99.99 %).
3. Opt. continuum emission rises between component D and component S1

Radio (VLBI) - optical variability (1994-2009)

Variability timescales

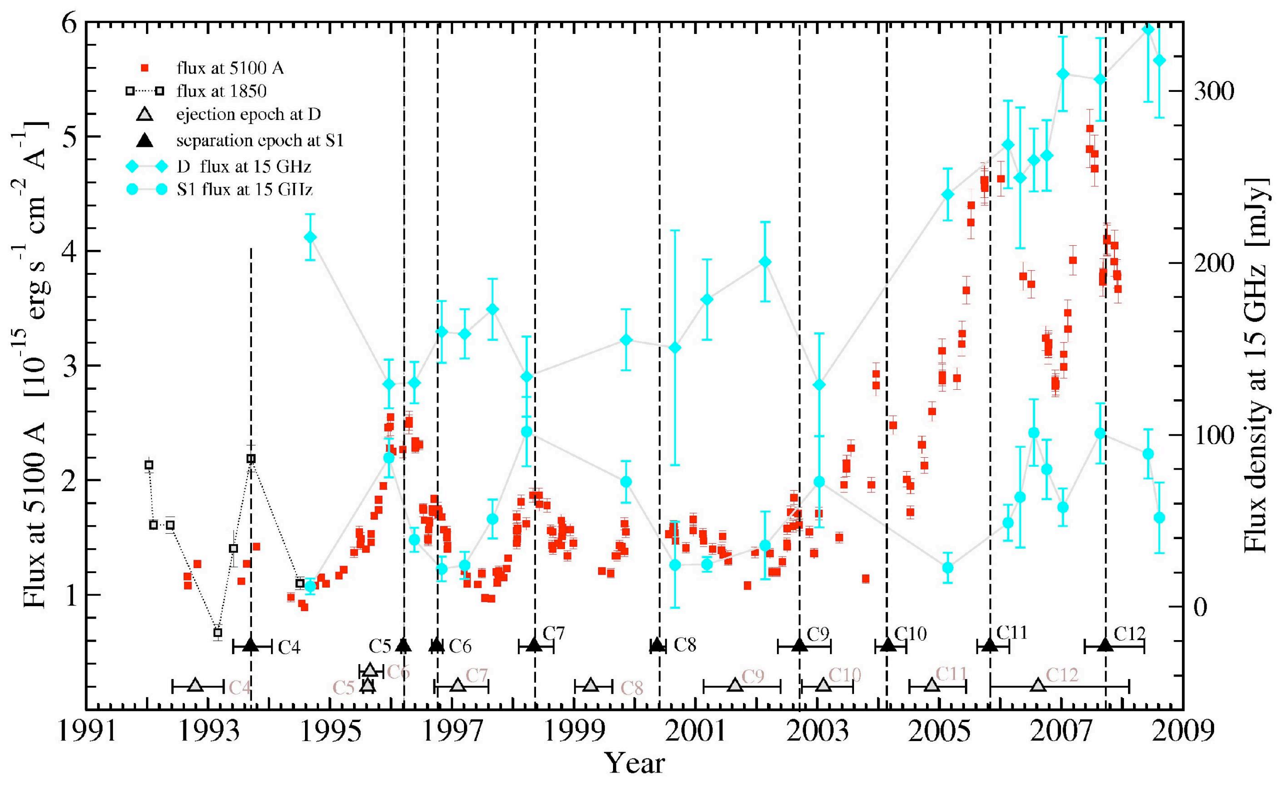
Few decades:
optical variations are related to the radio variability of the component D.

Correlation coefficient:
~0.85±0.1; lag ~ -1 yr.

Few months to few years:
optical flares are coupled with radio flares of the component S1 of the jet

Correlation coefficient:
~0.55 ±0.24; lag ~ -2 months.

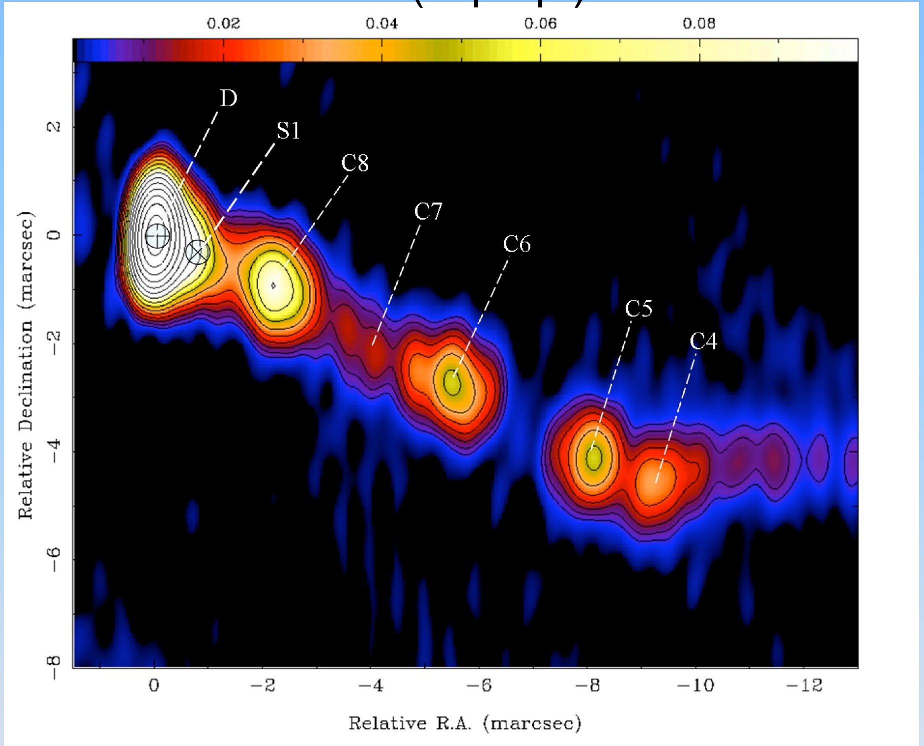
Arshakian et al. 2009 (sub. to MNRAS)



Suggest a correlation BUT uncertantities of correlation coefficient are large

3C 120: radio-loud galaxy (z=0.033)

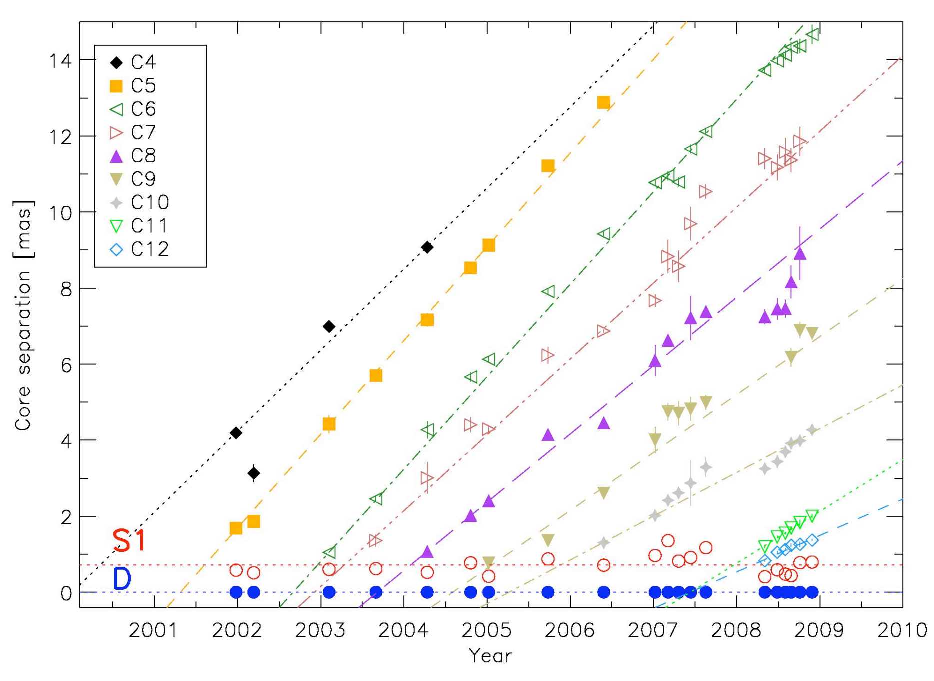
Tavares et al. 2009 (in prep.)

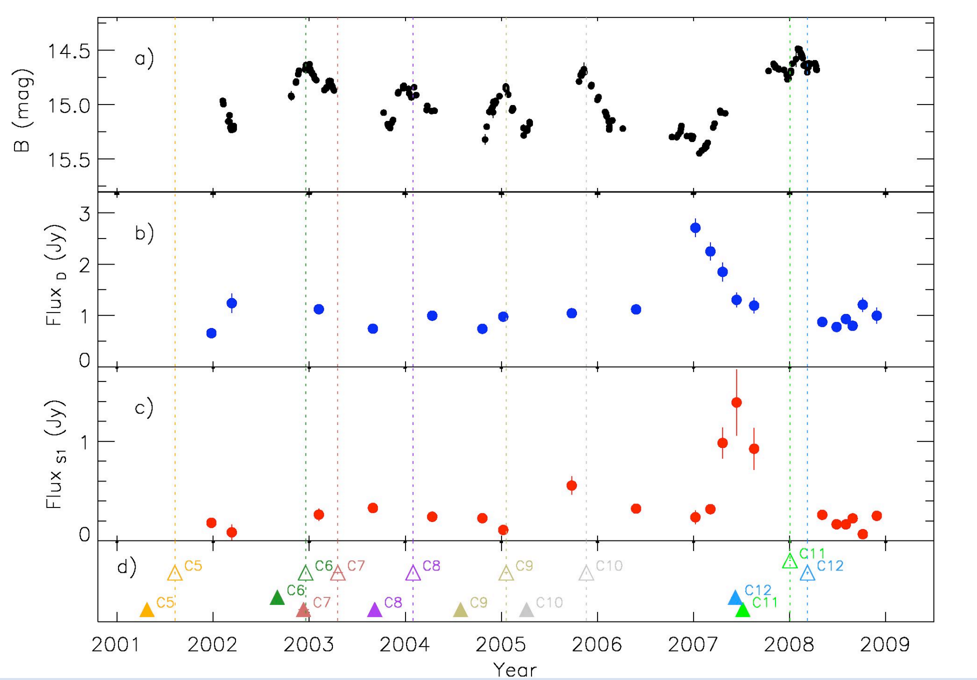


- KPC: broad-line FRII radio galaxy
- PC-scale: bright compact jet
- Apparent speed: ~5.3
- Lorentz factor: ~5 (0.98 c)
- Jet viewing angle: ~10 deg

3C 120: radio-optical monitoring (2002-2009)

Tavares et al. 2009 (in prep.)





Jet components:

2 stationary radio features (**D, S1**) separated by 0.8 mas (0.5 pc).
9 moving jet components (**C4-C12**)

$t_{S1} - t_{opt,max}$ ~ 0.15 yr.

1. Correlation is significant at > 99.9 %
2. Optical emission is enhanced between components D and S1

3C 390.3 and 3C 120

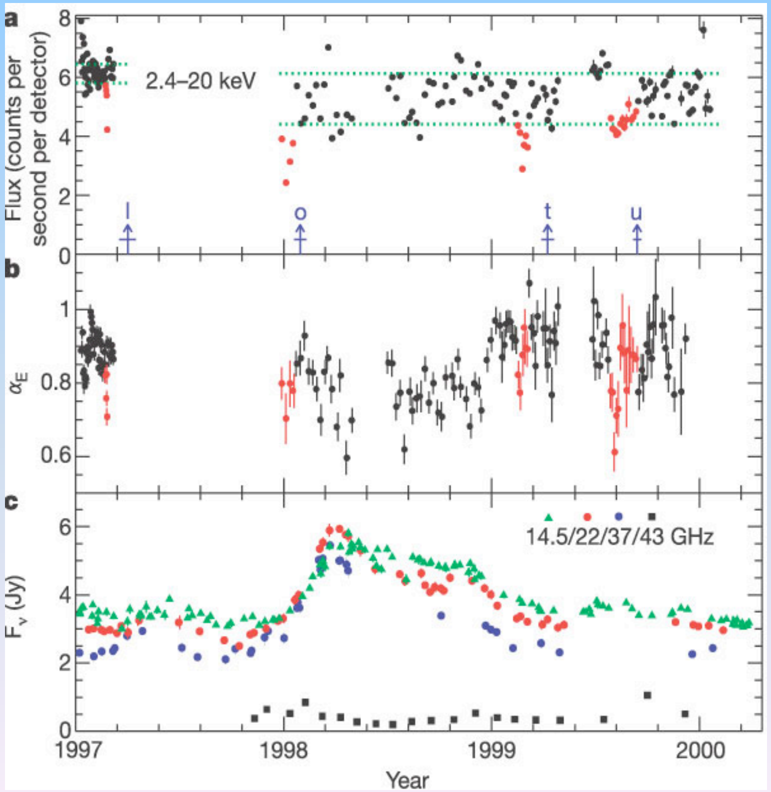
The generation of optical flares
(amplitude, timescale and the frequency)
are likely to be related to the properties
of the subparsec-scale jet:

ejection rate, structure and kinematics

Physical identification of regions D and S1

3C 120: interpretation of the dip in the X-ray light curve

the soft X-ray emitting disk material disappears into the BH and the fraction of it is ejected into the jet.

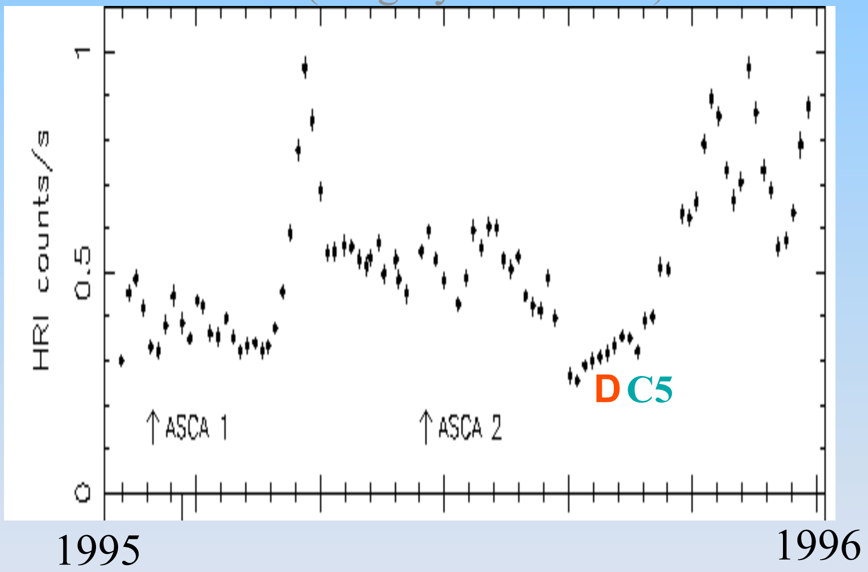


3C 120 (Marscher et al. 2002)

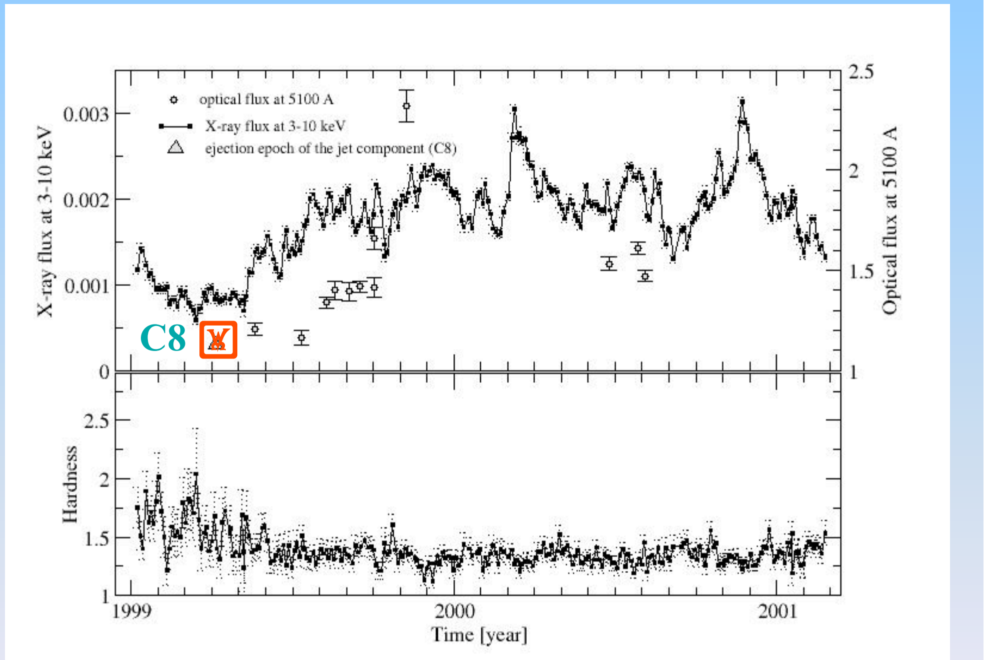
Physical identification of regions D and S1

Evidence from the soft and hard X-ray data

0.5-2 keV (Lieghly et al. 1997)



3-10 keV (Gliozzi et al. 2005)

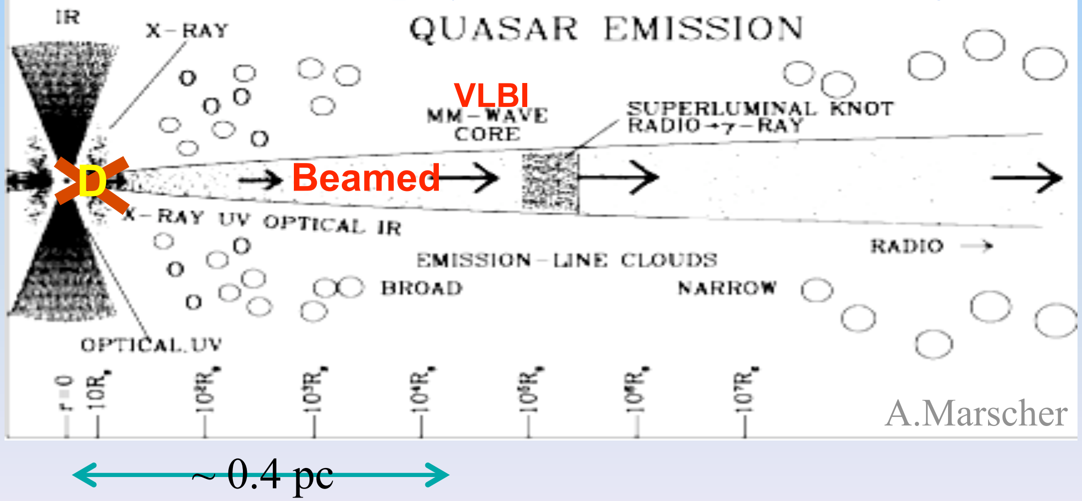


Ejections of **C5** and **C8** components at **D** occurs after a dip in the X-ray and hardening of the spectrum (similar to 3C 120; Marscher et al. 2002).

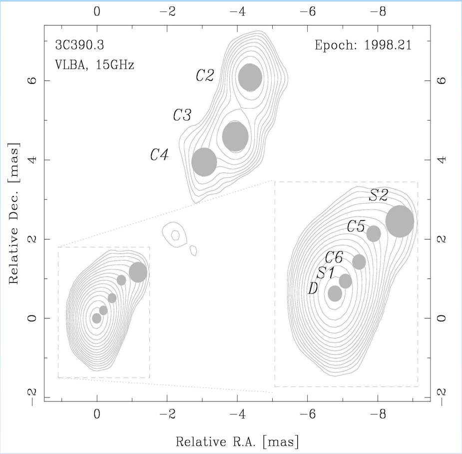
Physical identification of the region D

The component *D* is located near the central BH, and hence it is likely to be associated with the base of the jet

Sketch of physical structure of the jet



A.Marscher

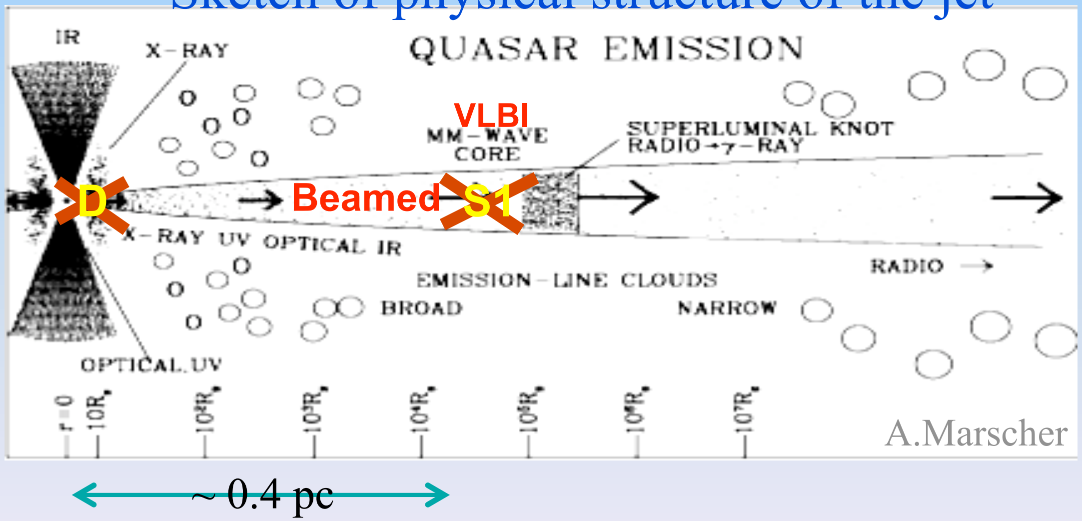


Thermal radio emission can be generated in the **accretion disk** (AD) or above the **hot X-ray corona** at ~200-1000 $\boldsymbol{R}_s$ above the AD (Fabian 2004; Ponti et al. 2005).

Physical identification of the region S1

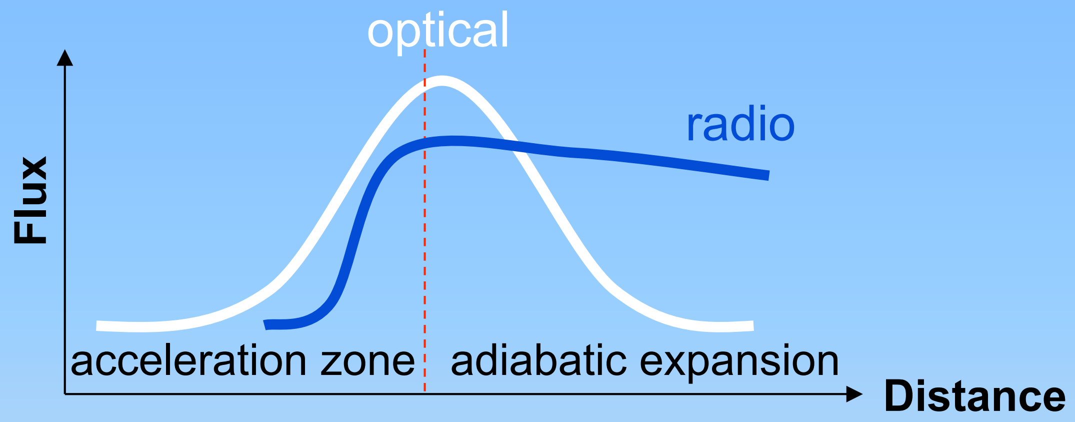
The component *S1* is likely to be associated with a stationary shock (VLBI core) produced in the relativistic continuous flow (Gomez et al. 1995)

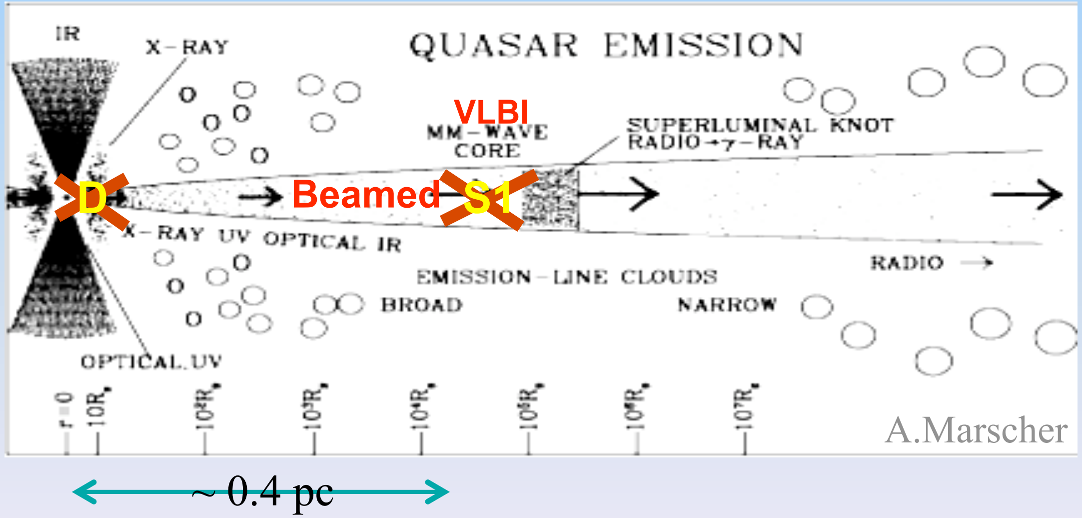
Sketch of physical structure of the jet



The synchrotron radio emission from the core of the jet (**S1**) is beamed in the direction of the jet.

Moving perturbations as the source of variable optical emission





- Continiuos rel. flow generates stationary features D and S1
- Moving perturbations are accelerated between D and S1

Variations of optical continuum drive changes of the H broad-emission line with a time lag of 20-100 days

(Kaspi et al. 2000; Shapovalova et al. 2002)

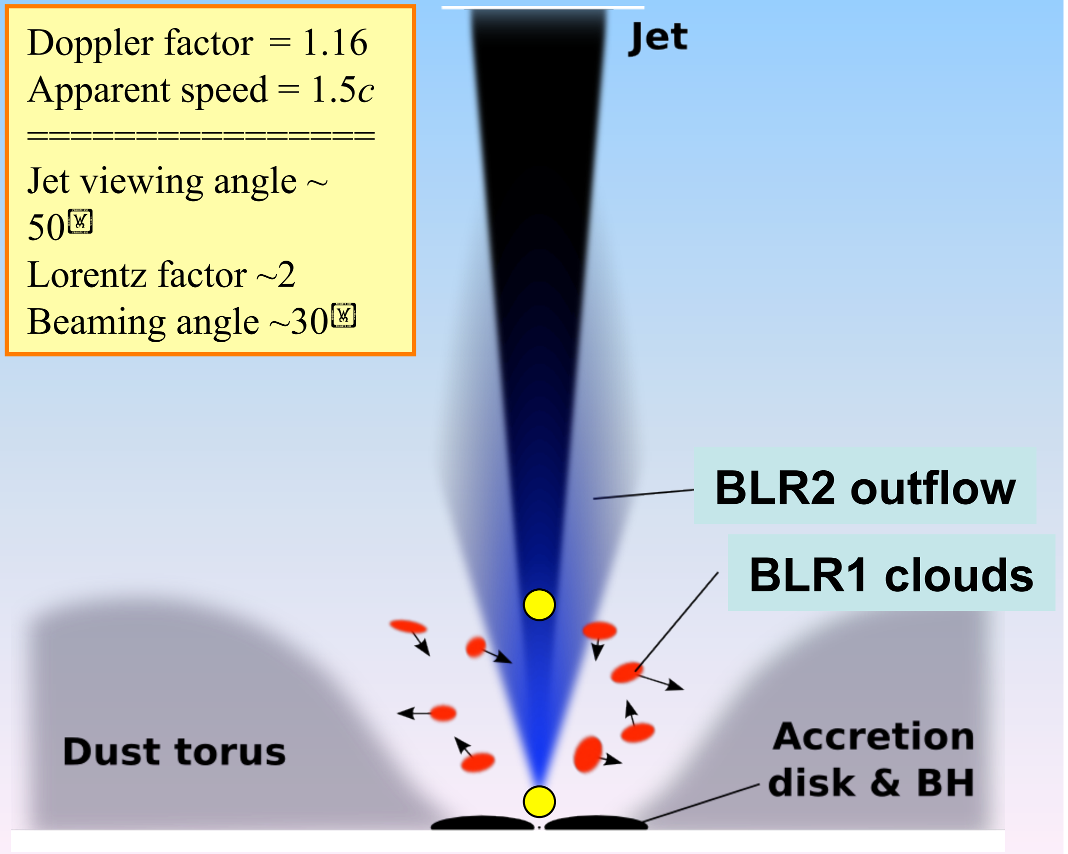
3C 390.3: the sketch of the inner parsec

Structure of the BLR:

- **Conventional BLR1:** virialized clouds ionized by disk/corona.
- **Outflowing and rotating BLR2** ionized by:
  1. Beamed emission from the jet (between **D** and **S1**).
  2. Thermal emission from the disk/ corona.

BLR1/BLR2 are evident around the epochs of minima in the continuum flux, when the jet contribution is small.

BLR2 may be manifested when the jet emission dominates the optical continuum.



Doppler factor = 1.16
Apparent speed = 1.5*c*
=================
Jet viewing angle ~ 50⊠
Lorentz factor ~2
Beaming angle ~30⊠

Challenges of the BLR model

Existence of BLR associated with a gas outflow along the jet questions the assumption of virialized motion of BLR and virial mass estimates of BHs in 3C 390.3, 3C 120 and all superluminal radio-loud AGN

Radio (MOJAVE) - optical project

MOJAVE (**M**onitoring **O**f **J**ets in **A**ctive galactic nuclei with **V**LBA **E**xperiments) is a long-term program to monitor radio brightness and polarization variations in jets associated with active galaxies (http://www.physics.purdue.edu/MOJAVE).

The MOJAVE program is currently observing over 200 compact AGN (core+jet) to study their **morphology, variability, kinematics and evolution**:

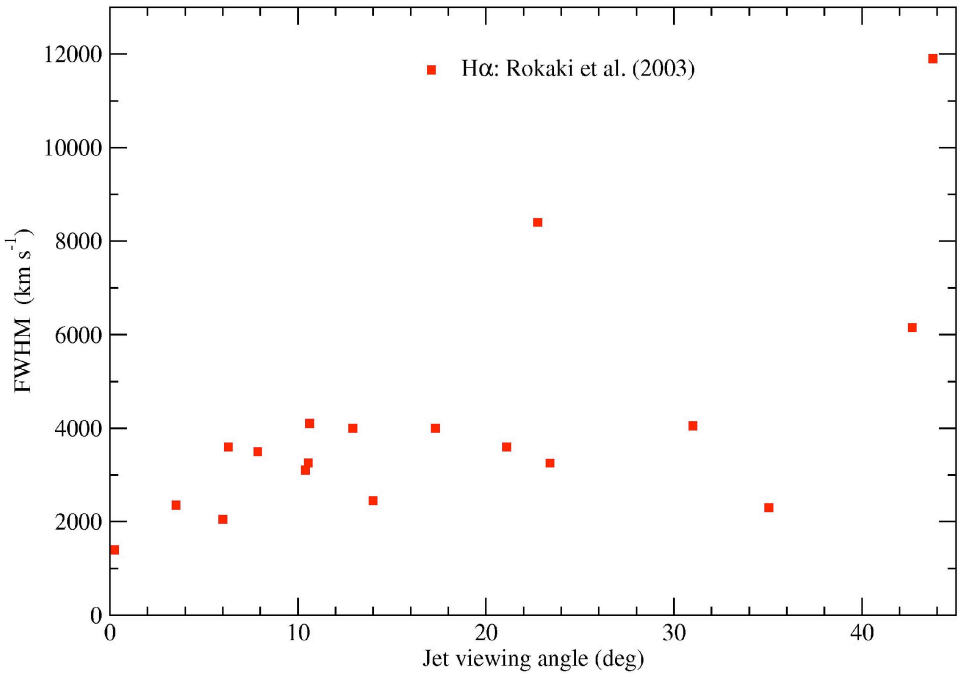
- Radio flux, fractional polarization
- Brightness temperature
- Kinematics and trajectory of ejected jet components
- Doppler factor, viewing angle of the jet

We combined radio data with data available from the optical spectroscopy of AGN (~150 AGN; 2 m class telescopes in Mexico).

1. **Locate the region of energy release and identify the radiation mechanism.**
2. **Study the link between jet parameters and characteristics of the central engine** (variable continuum and line emission, broad-line emission, BHs, Eddington ratios, BLR).

Jet viewing angles and FWHM of broad emission lines for RL AGN

Jet viewing angle (apparent speed and Doppler factor of the jet), and
FWHM (Hα) for 18 RL galaxies and quasars with compact jets (Rokaki et al. 2003).



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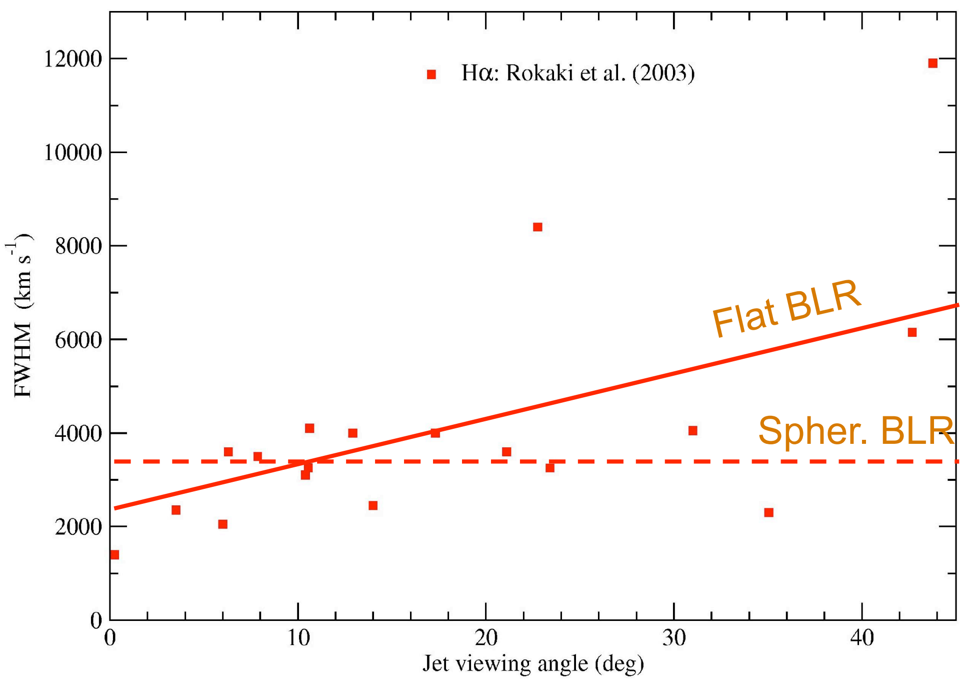
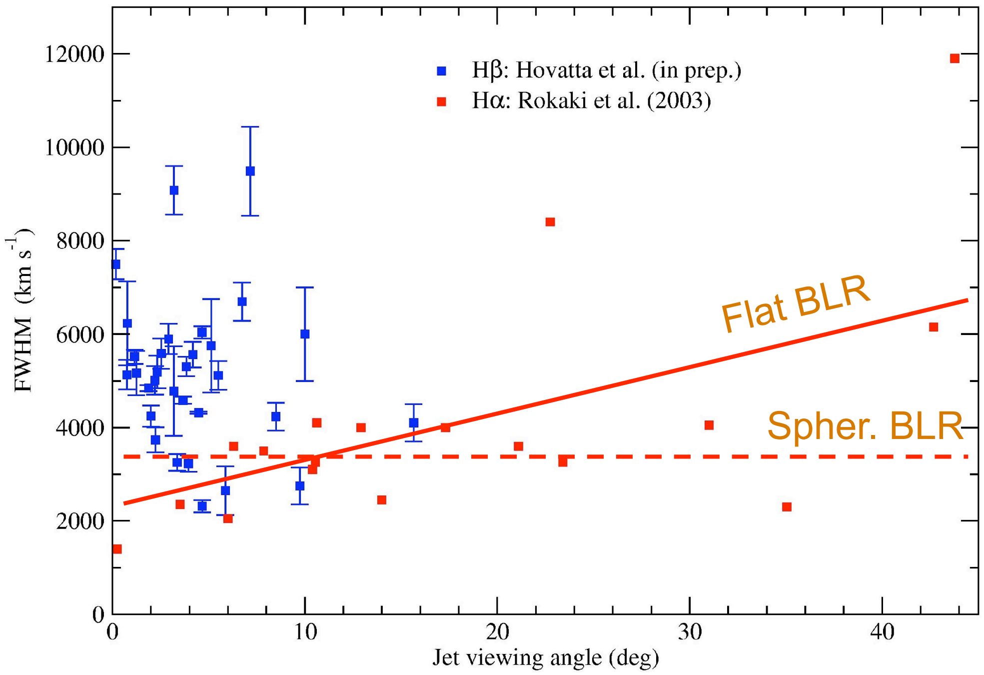


Jet viewing angles and FWHM of broad emission lines for RL AGN

Jet viewing angle (apparent speed and Doppler factor (Hovatta et al. 2009)), and **FWHM (Hβ)** (Torrealba, PhD thesis).

N (RL AGN) = 37 (jet viewing angle ≤ 10°)

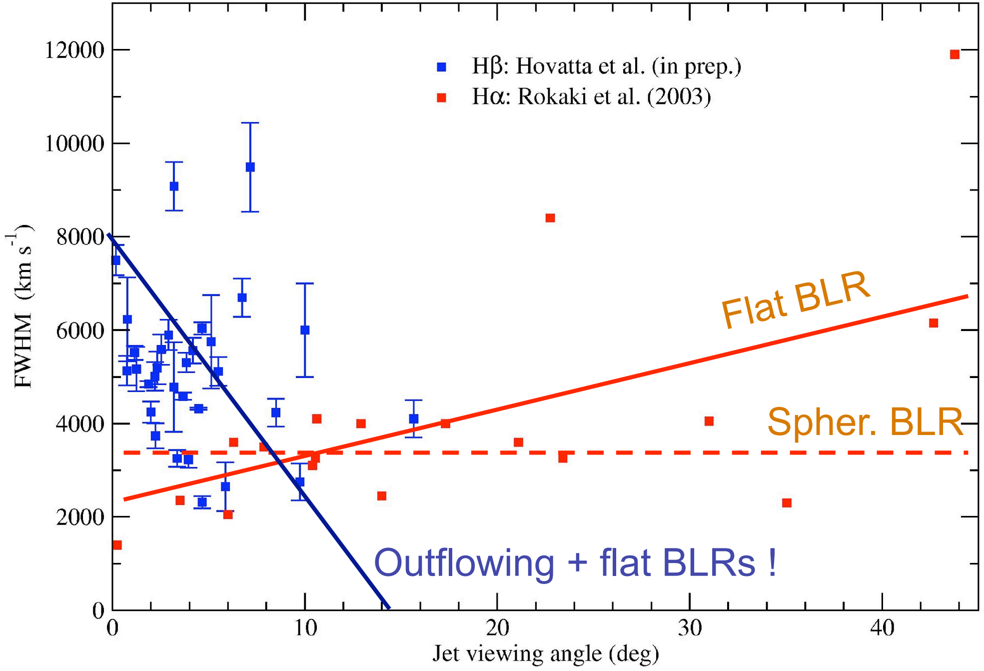


Jet viewing angles and FWHM of broad emission lines for RL AGN

Jet viewing angle (apparent speed and Doppler factor (Hovatta et al. 2009)), and **FWHM (Hβ)** (Torrealba, PhD thesis, 2009).

Negative correlation:

r = 0.38, correlation is significant at 98 % cl

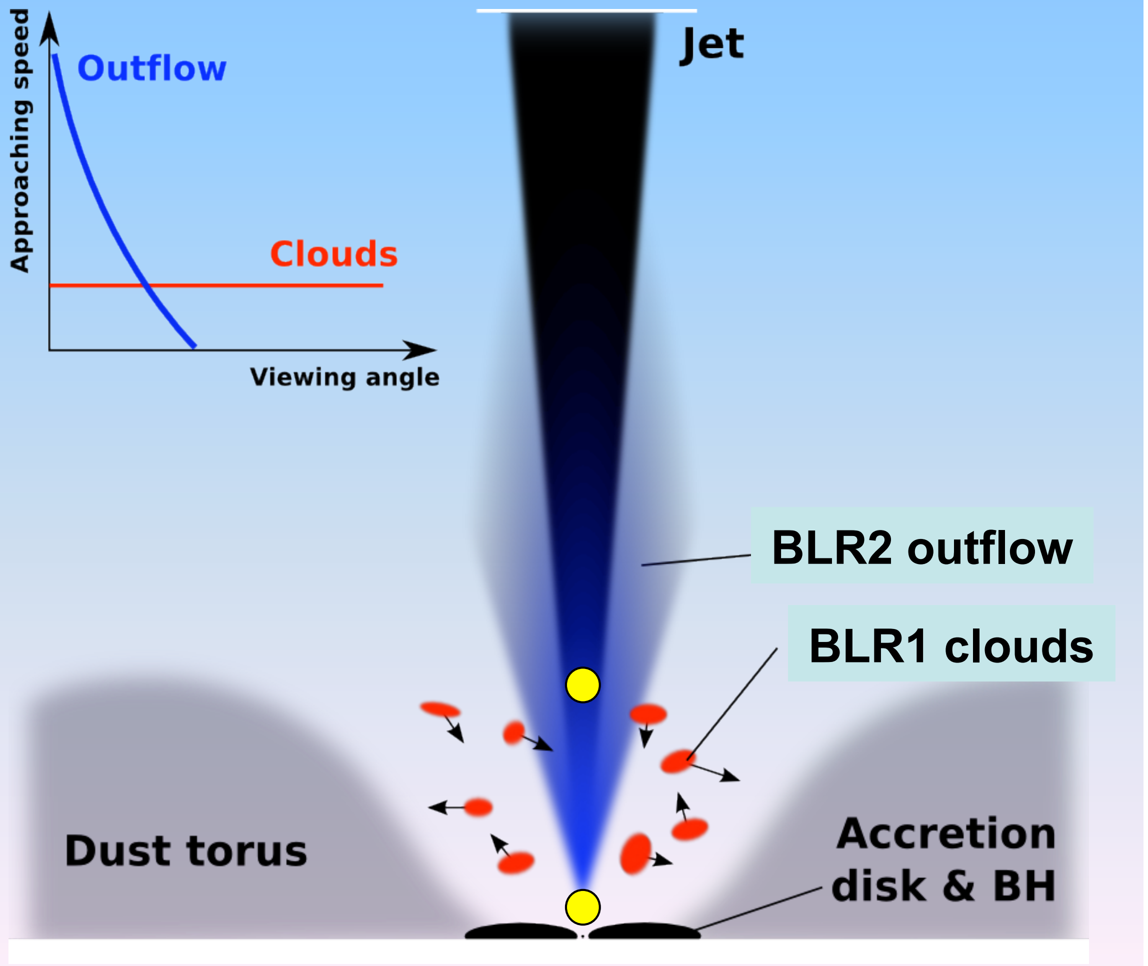


Strtification of the outflowing BLR ?

FWHM(H[illegible], outflow) ~< 4000 km/s

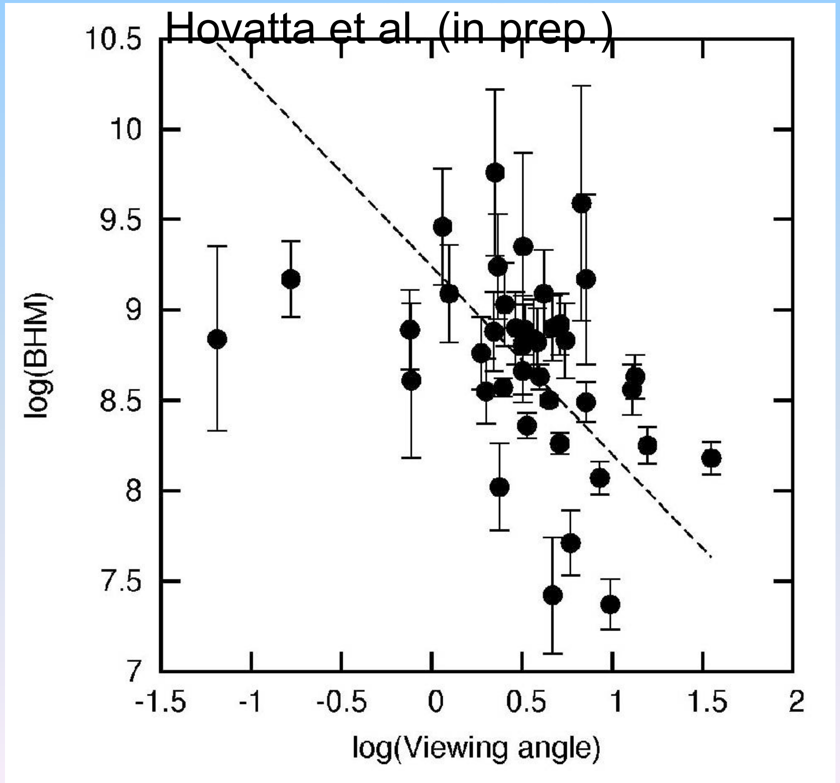
Outflowing BLR

Outflow speed of the broad-line emitting gas is stratisfied within angle of ~10^0 from the jet: faster layers are near the spine of the jet (~4000 km/s).



Jet viewing angles and BH masses for RL AGN

Jet viewing angle (apparent speed and Doppler factor of the jet), and
BH mass (line luminosity and FWHM of H□; Torrealba, PhD thesis, 2009).

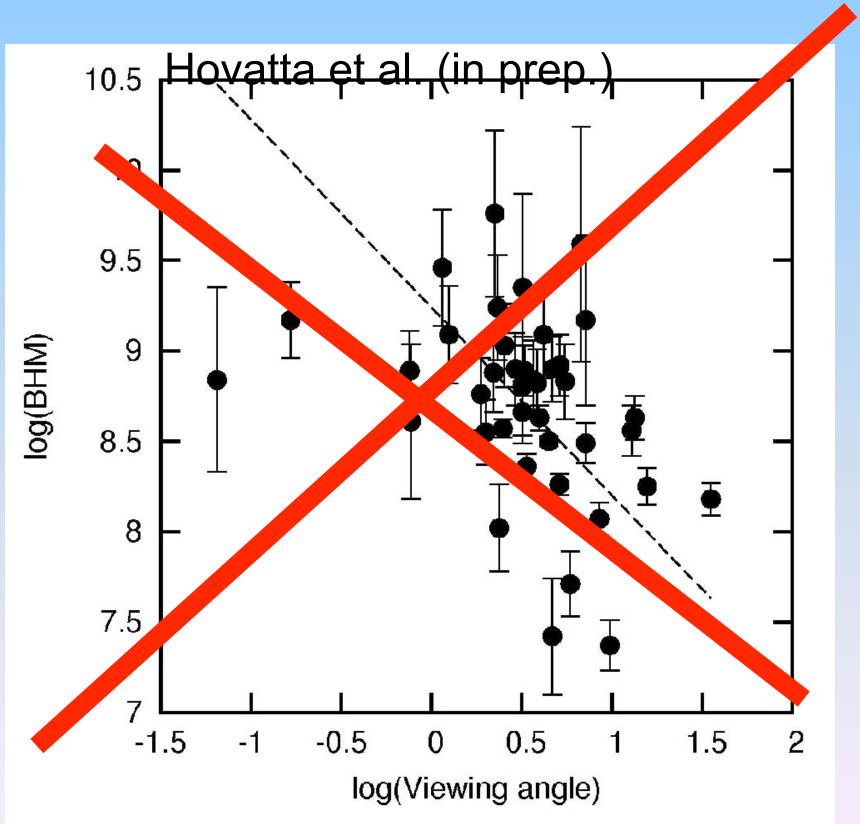

Hovatta et al. (in prep.)

For jet viewing angles □ 10°

- Nice correlation at 99 % cl.

Jet viewing angles and BH masses for RL AGN

Jet viewing angle (pparent speed and Doppler factor of the jet), and
BH mass (line luminosity and FWHM of Hβ, MgII and CIV; Torrealba, PhD thesis, 2009).



For jet viewing angles [illegible] 10°

- Nice correlation at 99 % cl.
- BH masses can be overestimated by factor of <~ 100.

Summary

❑ The structure and kinematics of relativisitic jets are resolved in two radio-loud galaxies (3C 390.3 and 3C 120) on scales less than one parsec.

❑ For these, we found a link between optical flares (on timescales of few monts to few years) and kineamatics of the subprsec-scale jet.

❑ We suggest a model for the inner nucler region:

- **Location** of the source of optical flares: non-thermal emission from the subparsec-scale jet.
- **Properties** of optical flares (timescale, amplitude and frequency) depends on kinematics and ejection rate of the jet.
- **Complex BLR structure**: conventional BLR and rotating outflow-BLR stratisfied within ~10 degrees from the jet.

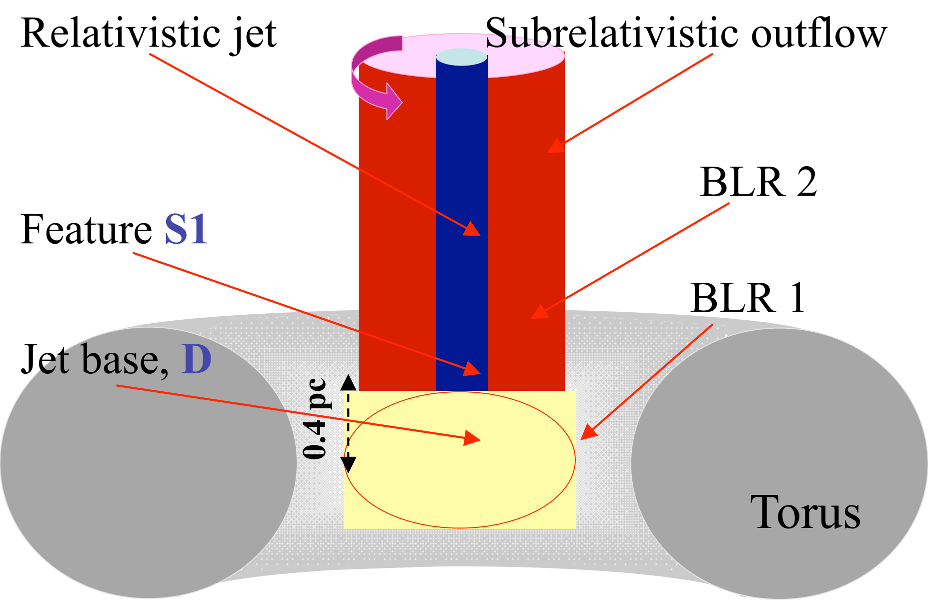
❑ **Existence** of non-virial outflowing BLRs challenges the BH mass and Eddington ratio estimates for radio-loud compact AGN.

3C 390.3: the nuclear region

A sketch of the inner parsec

BLR - two component structure:

- **Virilized BLR1** ionized by disk/ corona (**D**)
- **Outflow BLR2** ionized by the non-thermal beamed emission from the jet near the VLBI core (**S1**)



Jet parameters

BLR1 is evident around the epochs of minima in the cont. flux (the jet contribution is small)
BLR2 may be manifested when the jet emission dominates the optical continuum.

Var. Doppler factor = 1.16
Apparent speed = 1.5*c*
====================
Jet viewing angle ~ 50°
Lorentz factor ~2
Beaming angle ~30°
Distance ~0.4 pc=0.3/sin(50°)