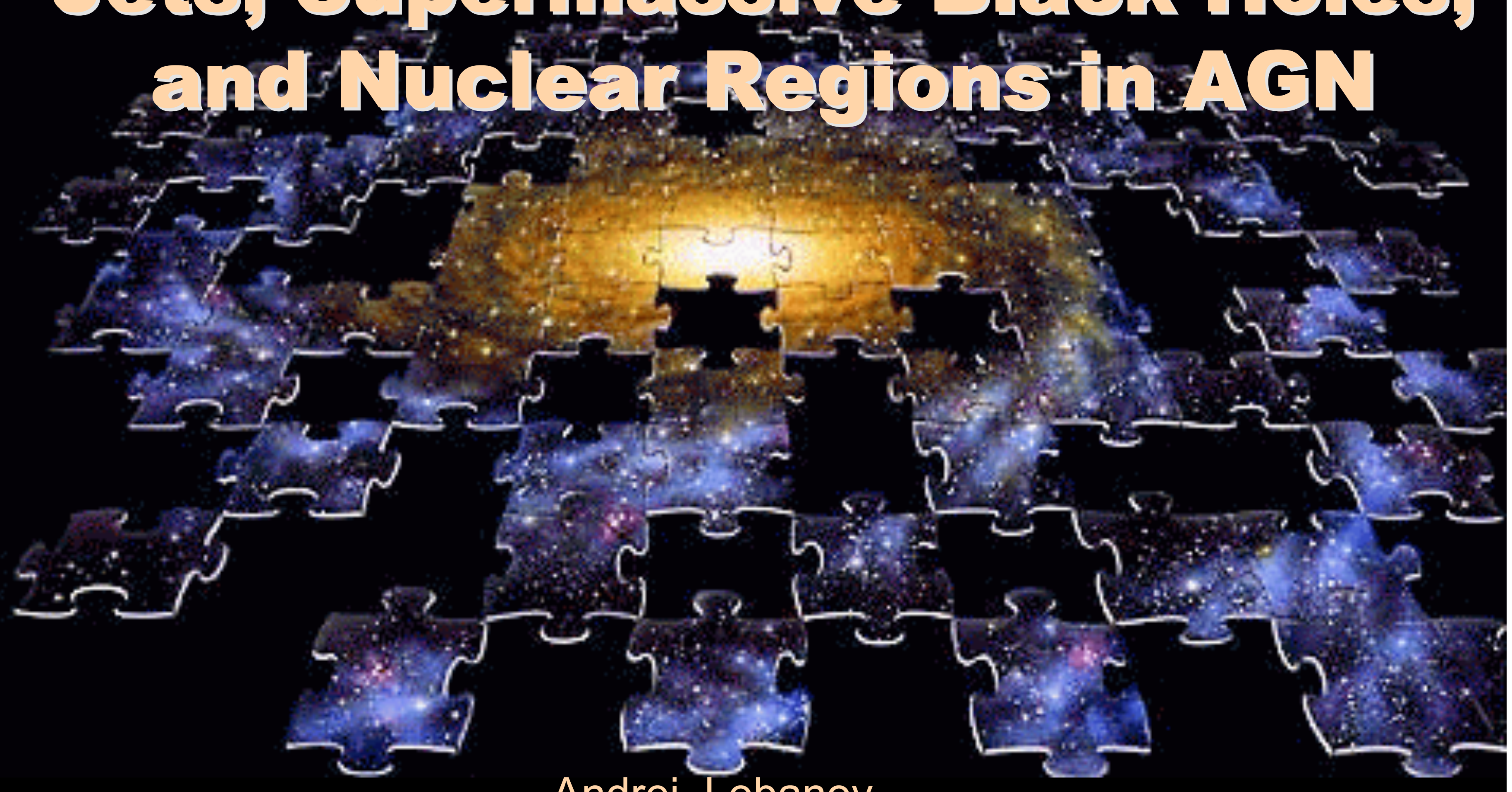
Relation between Ultracomact Jets, Supermassive Black Holes, and Nuclear Regions in AGN



Andrei Lobanov

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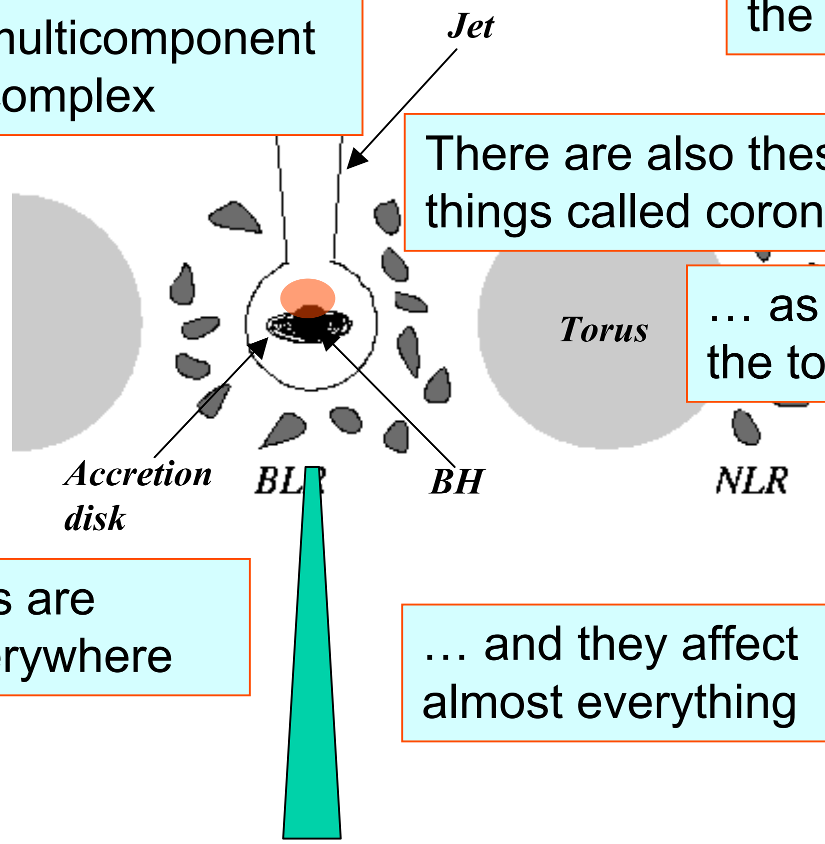
(Changing) AGN Paradigm



The BLR is a multicomponent complex

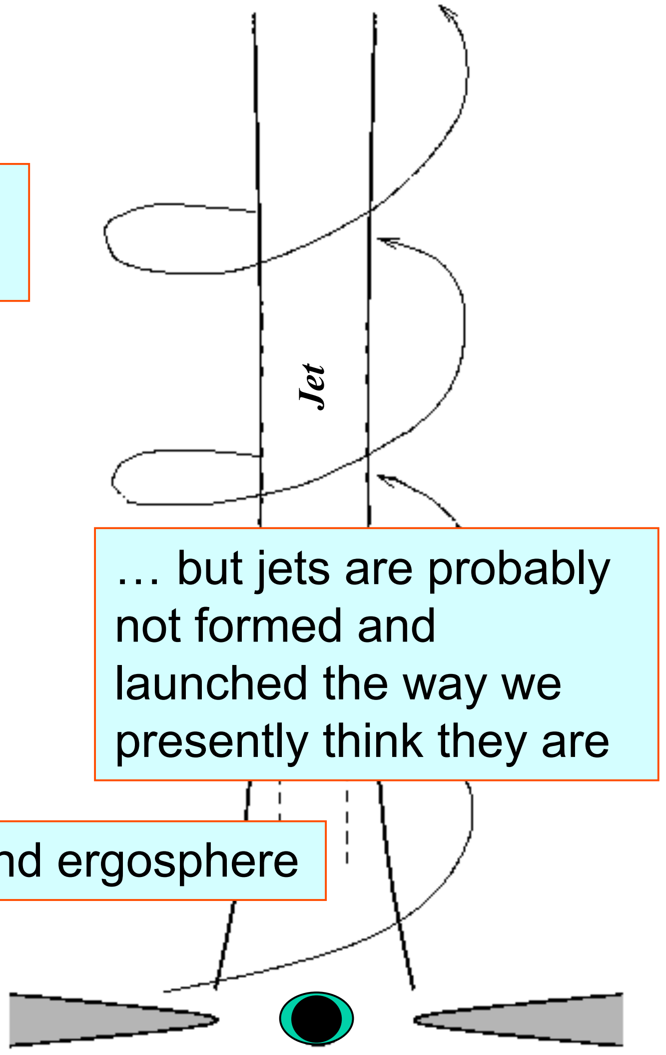
… and so is the NLR

There are also these things called corona…

… as well as the torus

Jets are everywhere

… and they affect almost everything



… but jets are probably not formed and launched the way we presently think they are

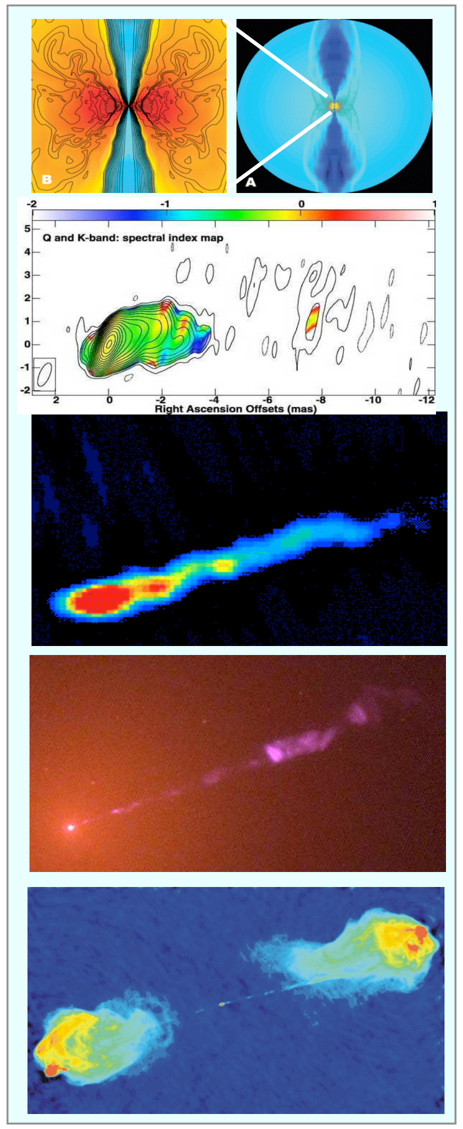
… and ergosphere

Anatomy of Jets

Jet Scales

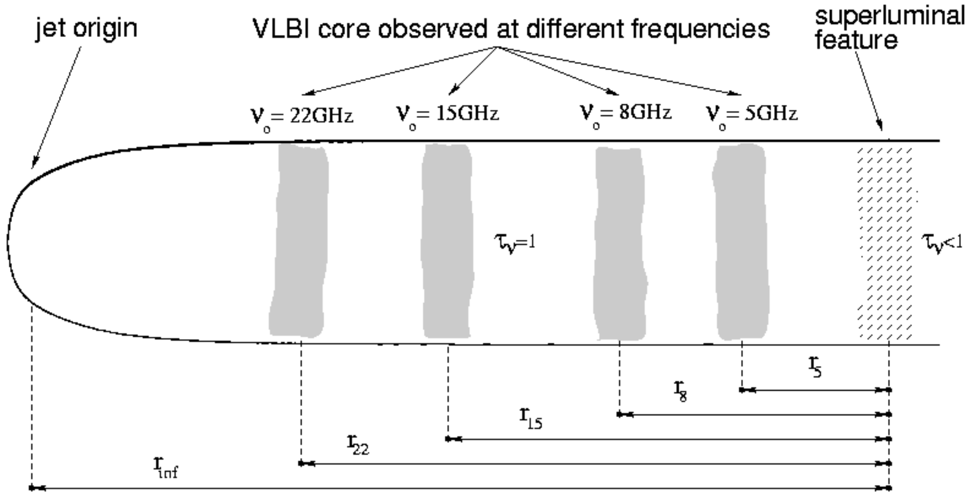
- ☐ **Launching Region: The Accretion Flow;**
  ~10 – 100 R_g (0.5 – 5 mpc; 5 – 50 μas)
  - Probably unresolved or slightly resolved
- ☐ **MHD Acceleration/Collimation Region:**
  ~10 – 10^3 R_g (1 – < 100 mpc; 10 μas – < 1 mas)
  - The Jet “Nozzle”
- ☐ **Transition Region:**
  ~10^3 R_g (< 0.1 pc; < 1 mas)
  - Poynting-Flux-Dominated (PFD) → KFD
- ☐ **Kinetic-Flux-Dominated (KFD) Jet:**
  ~10^3 – 10^9 R_g (0.1 – 10^5 pc; 1 mas – 20’)
- ☐ **Hot Spot/Lobe:**
  ~10^9 R_g (~100 kpc; or 20’)
  - Outer jet is Kinetic-Flux-Dominated

For a 10^9 M_{sun} black hole at a 20Mpc distance ~ M87(Virgo A)



Ultracompact Jets

- ☐ The „core“ of a VLBI jet is located in a region where emission turns optically thin at a given frequency. Shocked(?) emitting regions downstream.



Optical depth in the jet

$$\tau_s(r) = C(\alpha) N_1 \left(\frac{e B_1}{2\pi m_e}\right)^{\epsilon} \frac{\delta^{\epsilon}\phi_o}{r^{(\epsilon m+n-1)}\nu^{\epsilon+1}}$$

The condition τ_s=1 determines the location of the core

$$r[\mathrm{pc}] = (B_1^{k_b} F/\nu)^{1/k_r}$$

Can be estimated from observed “core shift”

$k_r = 1$ → Synchrotron self-absorption

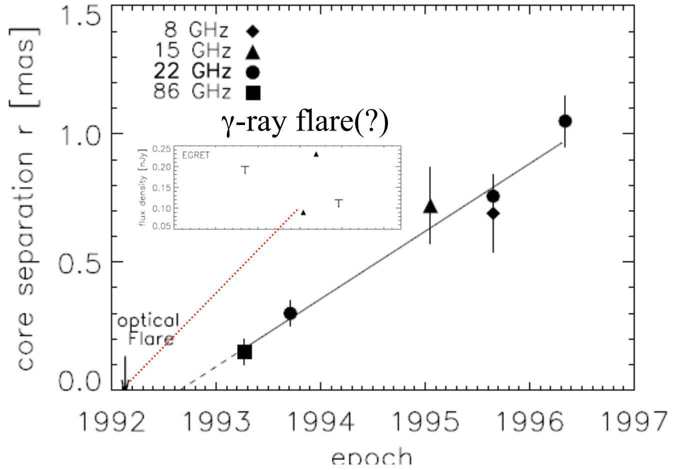
$k_r > 1$ → Synchrotron self-absorption + Gradients in pressure
→ Synchrotron self-absorption + External absorption (i.e. free-free absorption in the broad-line region

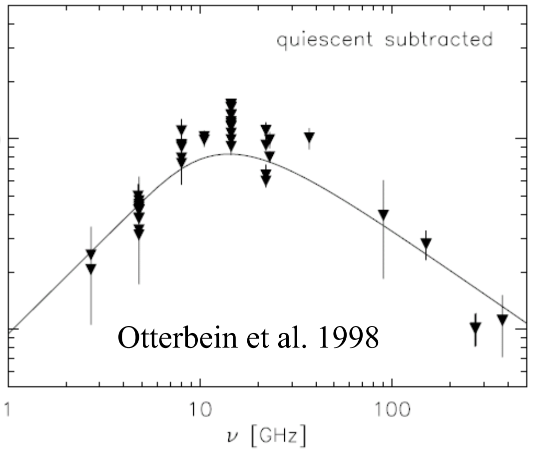
(Lobanov 1998)

Jet Shocks in γ-rays

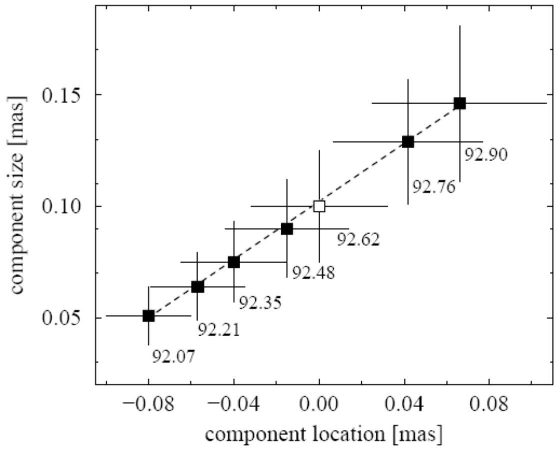
❑ Shocks in ultracompact jets are likely source of γ-ray flares

EGRET & VLBI on 0836+710

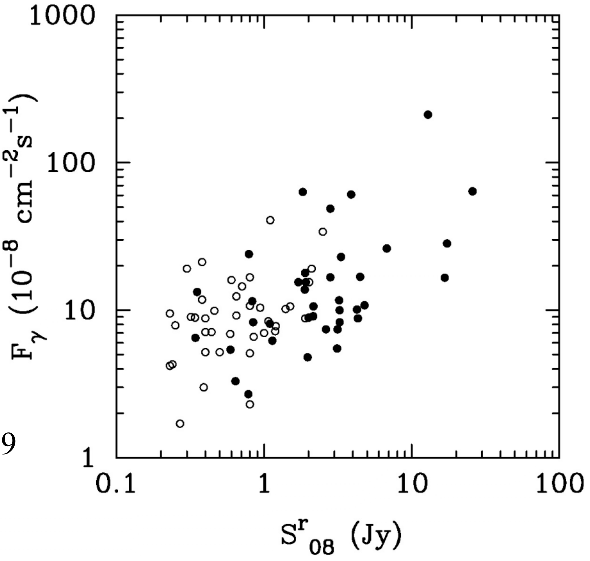




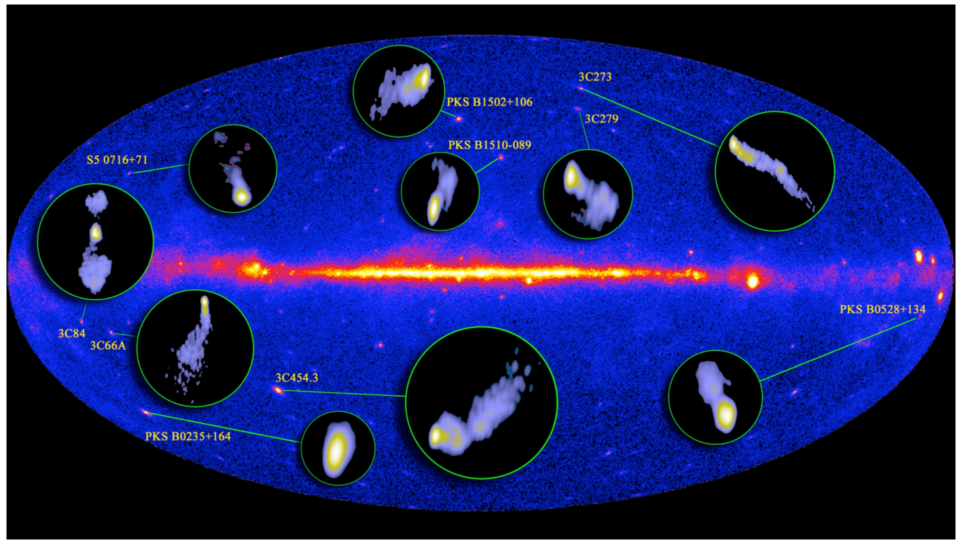
Otterbein et al. 1998



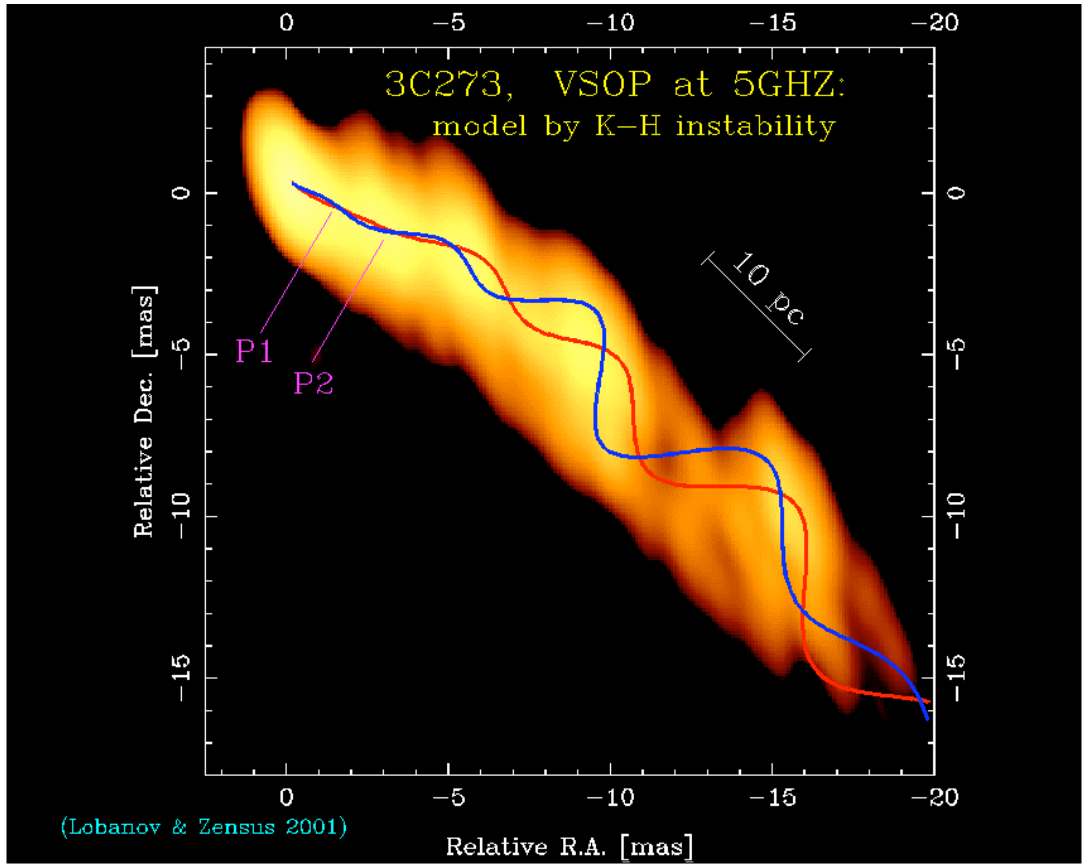
Fermi:
detections



Kovalev et al. 2009



Shocks and K-H Instability

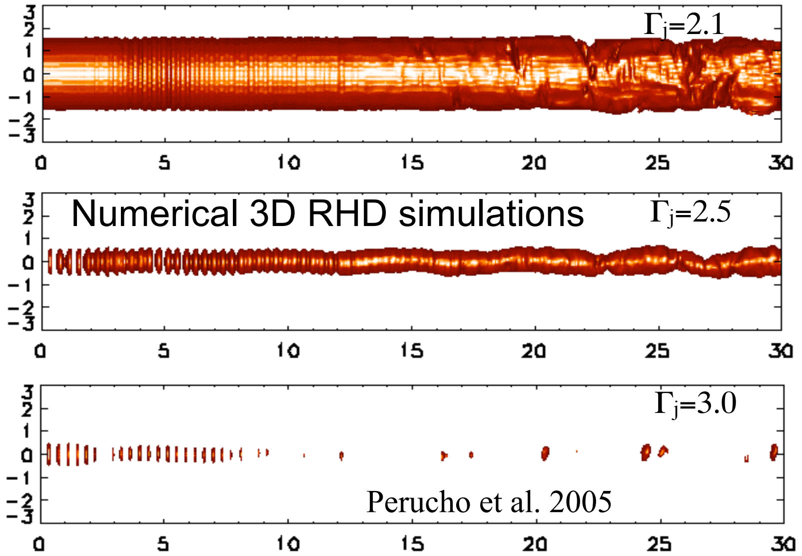


(Lobanov & Zensus 2001)

Wavelengths of the modes:
$\lambda_{Hs}=18.0$, $\lambda_{Es}=12.0$, $\lambda_{Eb1}=4.0$, $\lambda_{Eb2}=1.9$ [mas]

Jet parameters:
$G_j=2.1$, $M_j=3.5$, $\eta=0.02$, $a_j=0.53$, $v_w=0.21$

❑ Shocks dissipate rapidly, giving way to Kelvin-Helmholtz instability as the major factor determining the morphology and dynamics of the flow. The instability develops in a non-linear regime

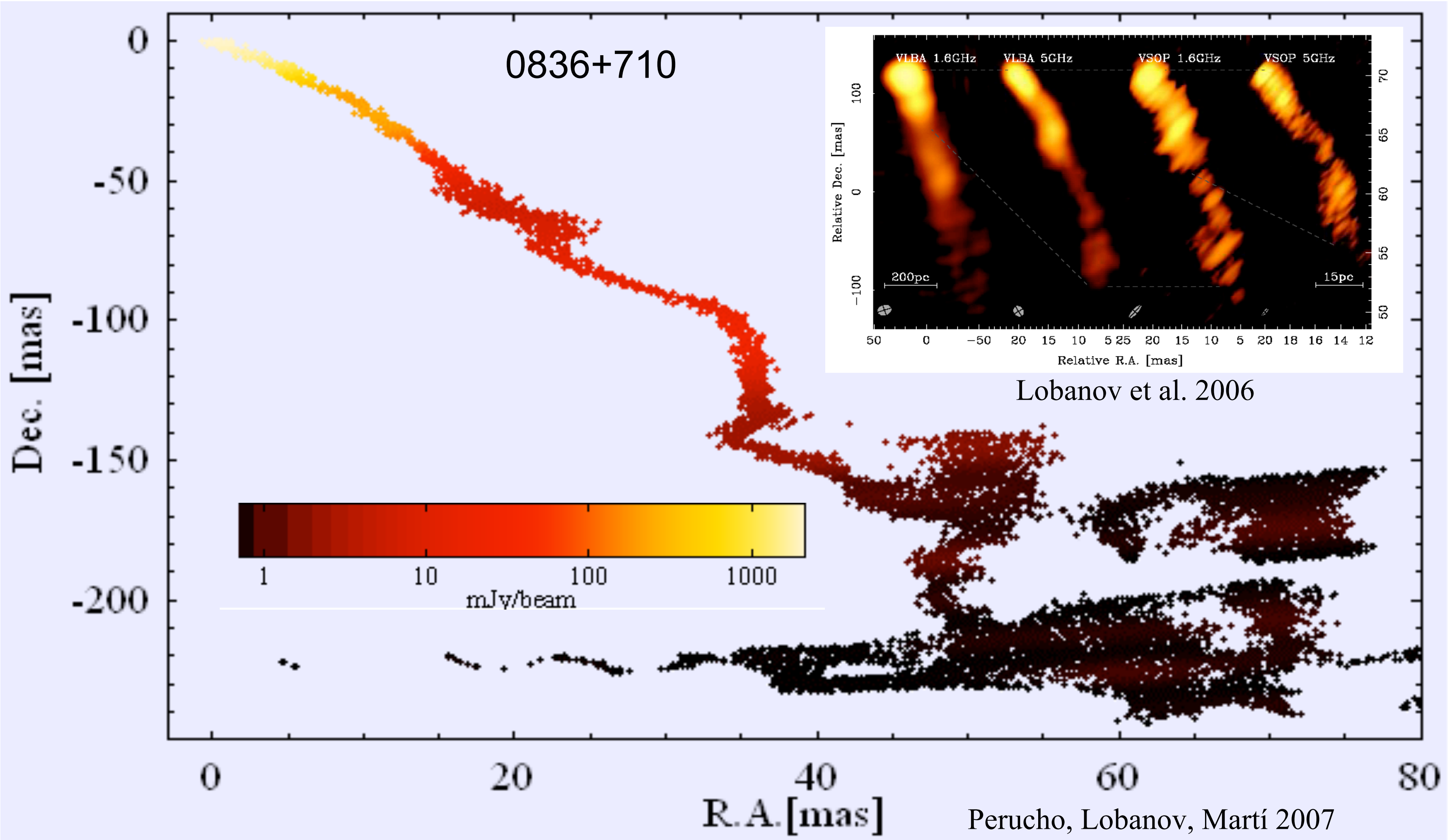


Numerical 3D RHD simulations

Perucho et al. 2005

Jet Disruption

☐ Helical mode of K-H instability can disrupt large-scale jets



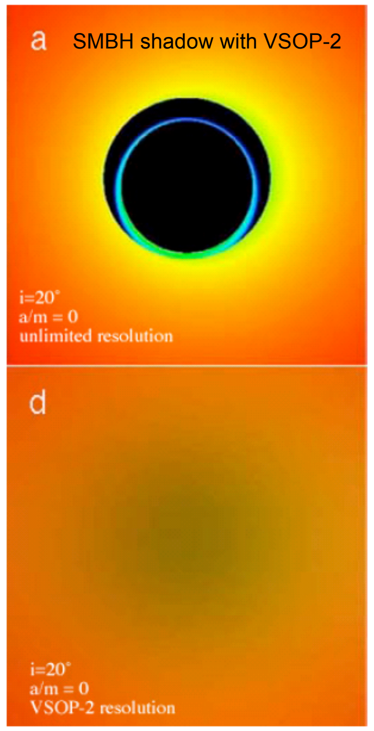
Lobanov et al. 2006

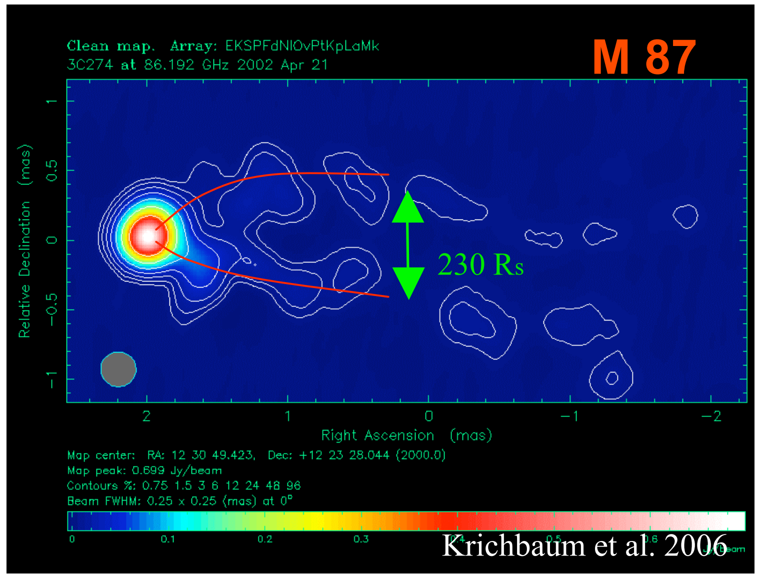
Perucho, Lobanov, Martí 2007

Jets and SMBH Vicinity

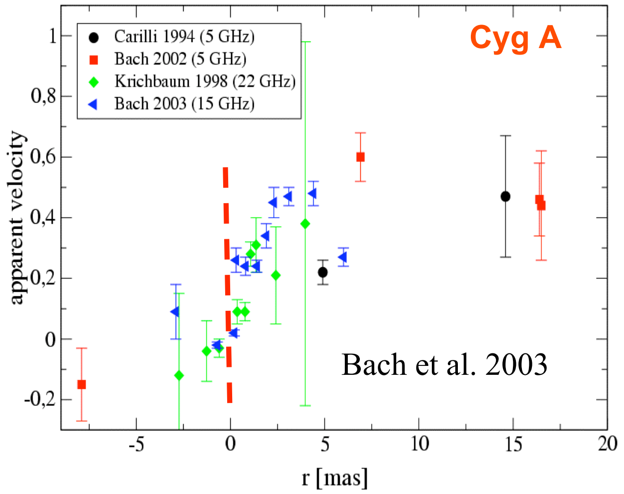
VLBI on BH Vicinity

- Direct imaging of hot material in accretion disks in the vicinity of SMBH
  - **Sgr A***: R_S ~ 10 μas; **M87**: R_S ~ 4 μas; a BH “shadow” size ~26 μas.
  - **VSOP-2:** ~40 μas @ 43 GHz; **mm-VLBI:** 20 μas @ 215 GHz;
  - **RadioAstron:** ~10 μas @ 22 GHz.
- Formation, acceleration, collimation and internal structure of relativistic jets.





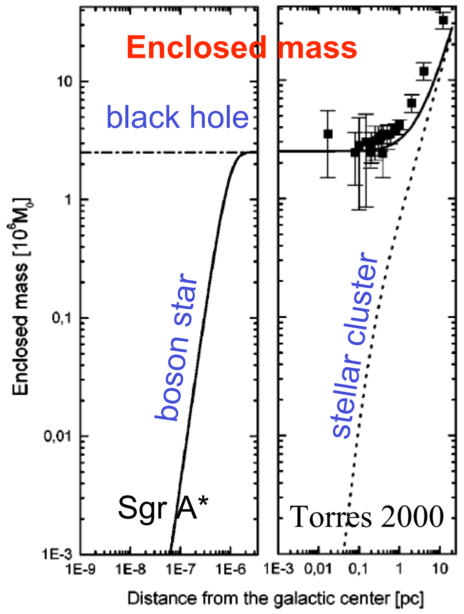
Krichbaum et al. 2006

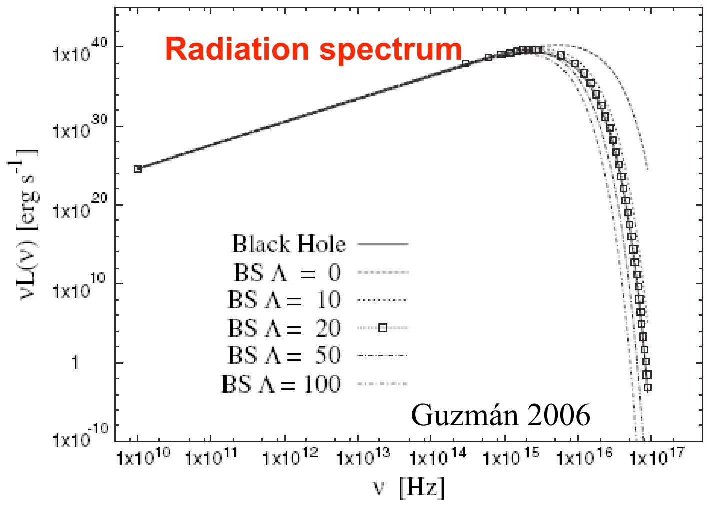


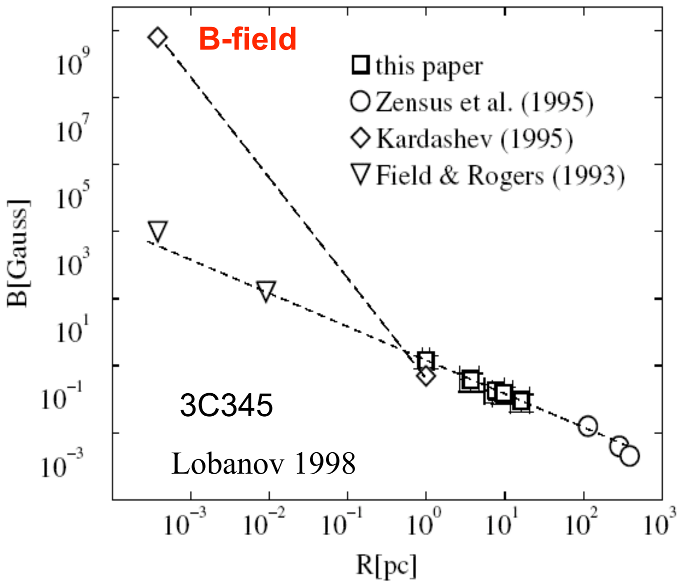
Bach et al. 2003

How Black is Black?

- ☐ Present evidence does not strictly prove existence of black holes...
- ☐ Need to devise instruments and experiments to distinguish effectively between BH and their alternatives:
  - – **stellar orbits:** (S1, Sgr A*) good enough for BH vs. ν condensate tests
  - – **radiation spectrum:** high energies (BH vs. BS), ELF (BH vs. MECO)
  - – **gravitation waves:** BH vs. anything (but need accurate templates)
  - – **VLBI:** 2D imaging (BH vs. BS/MECO?), B-field measurements (BH vs MECO)

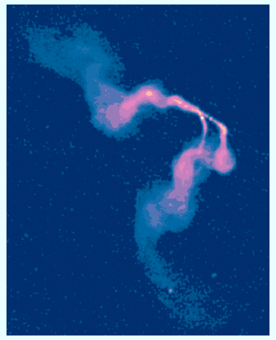


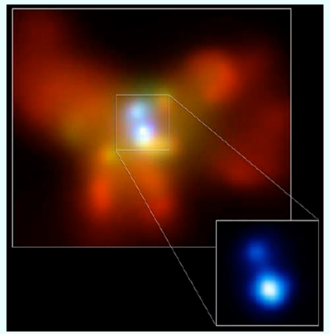




Supermassive BBH

☐ BBH are an important consequnce of galactic mergers, but evidence for their existence is indirect, especially for systems with parsec-scale separations.

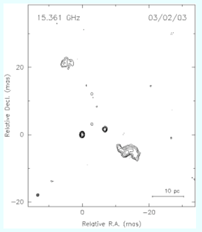




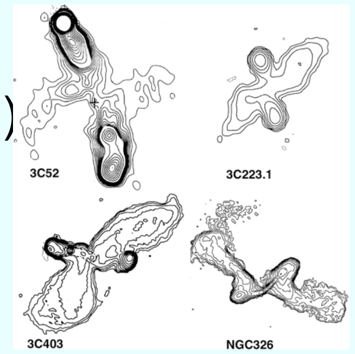
☐ Optical variability: OJ287 (Valtonen et al. 1997)

☐ Kinematics of radio jets:
0420-014 (Britzen et al. 2001)
3C273, 3C120 (Abraham & Romero 2002,2004),
3C345 (Lobanov & Roland 2005),

☐ Double nuclei in interacting galaxies:
3C75 (Owen et al. 1985),NGC 6240 (Komossa et al. 2003),
Mrk 463 (Bianchi et al. 2008),1536+0441 (Wrobel & Laor 2009)



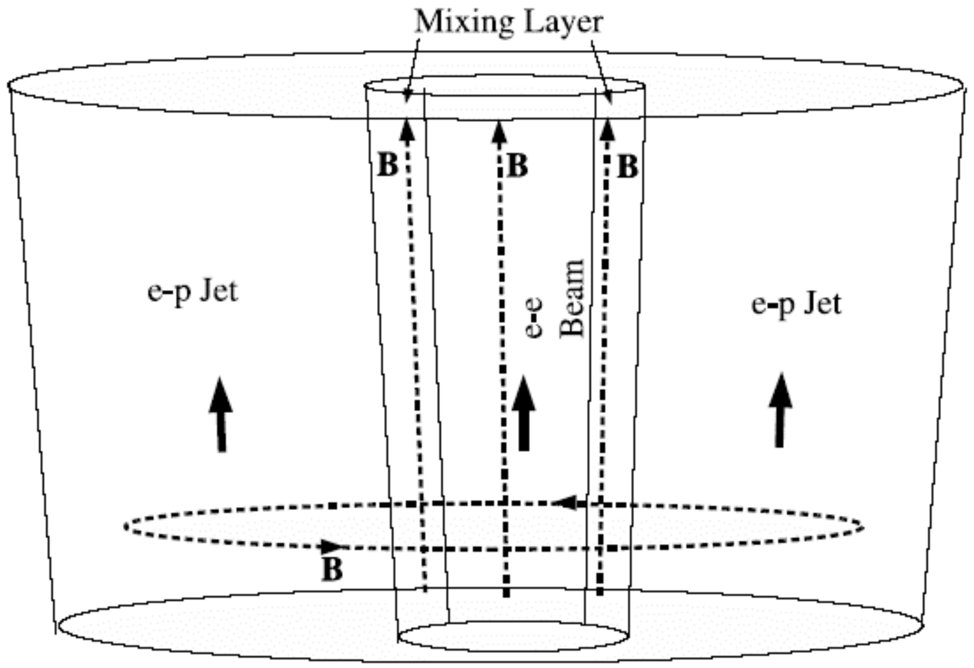
☐ Double nuclei on parsec scales: 0402+379 (Manness et al. 2004)

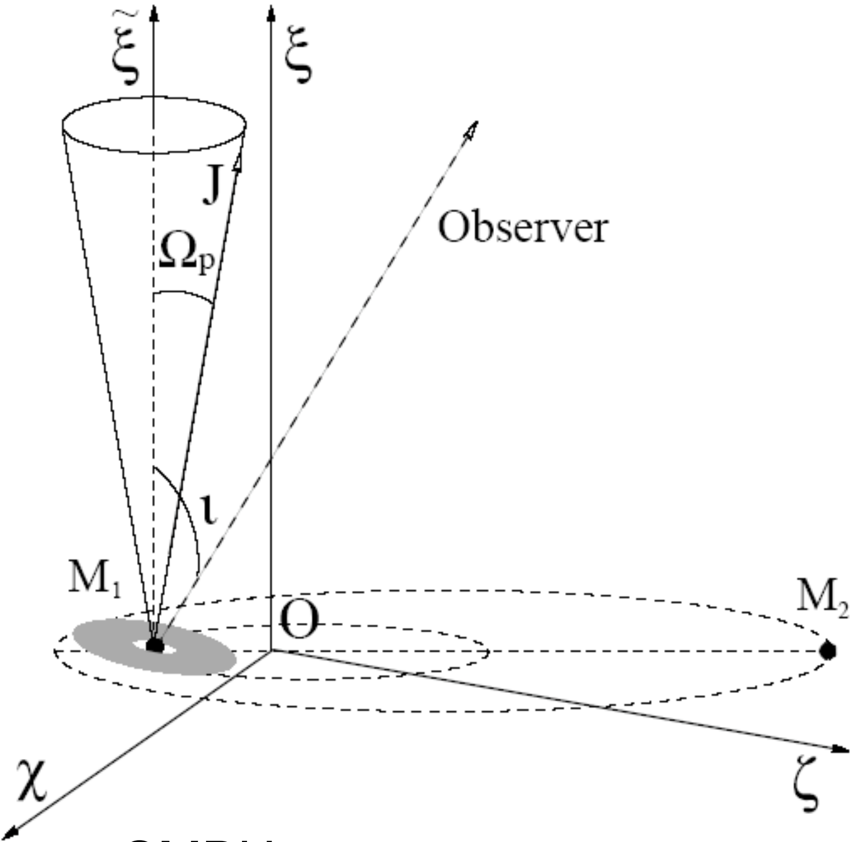


☐ Other evidence:
-- double-peaked broad lines (Eracleous & Halpern 1993)
-- double optical lines (Boroson & Lauer 2009)
-- X-shaped radiosources (Merritt & Ekers 2002)

see poster by
Mar Mezcua

Jets from binary black holes





Sol, Pelletier, Asséo (1989), Lobanov & Roland (2005)

- Magnetically confined outflow from a binary SMBH.
  Jet components are produced by perturbations in the beam
- Explains both evolution of a feature in the jet and optical variability
- Jet contains information about the dynamic state of the binary

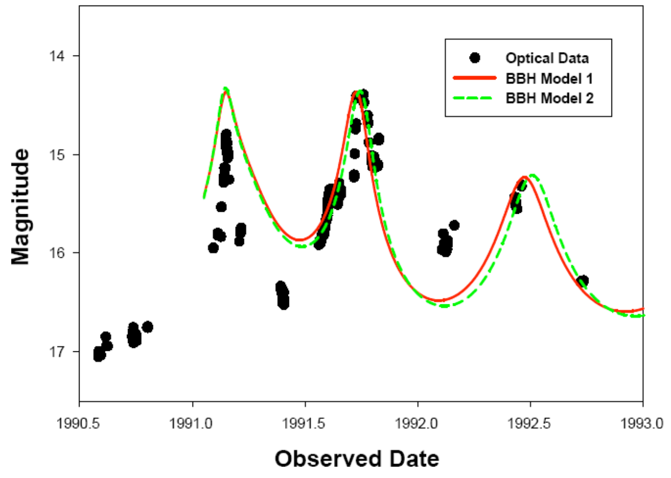
Properties of BBH in 3C345

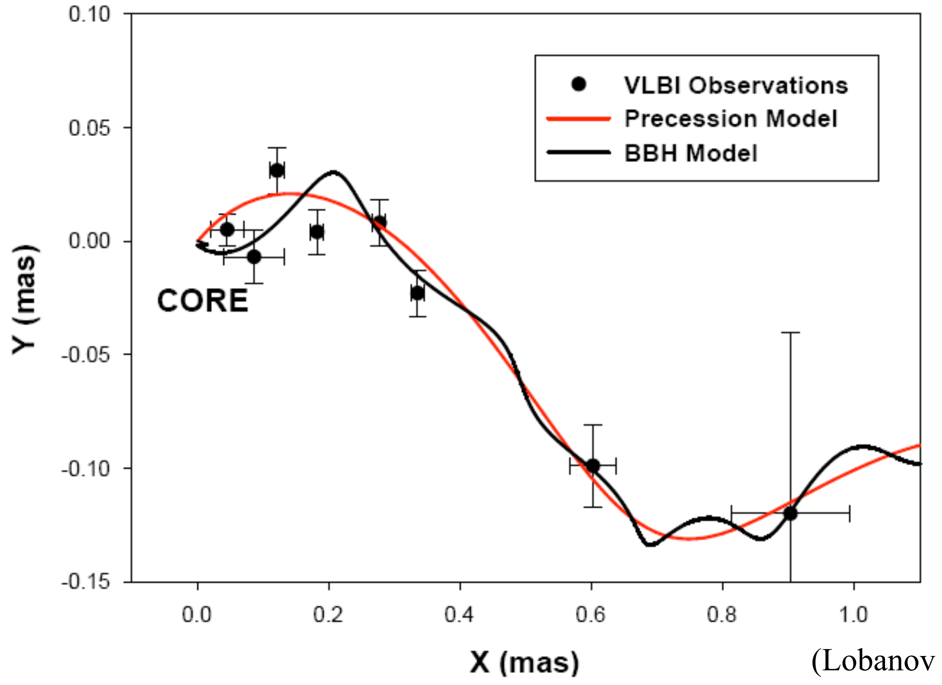
$$M_1 = 7\cdot 10^8\,\mathrm{M_{sol}},\quad M_2 = 7\cdot 10^8\,\mathrm{M_{sol}}$$

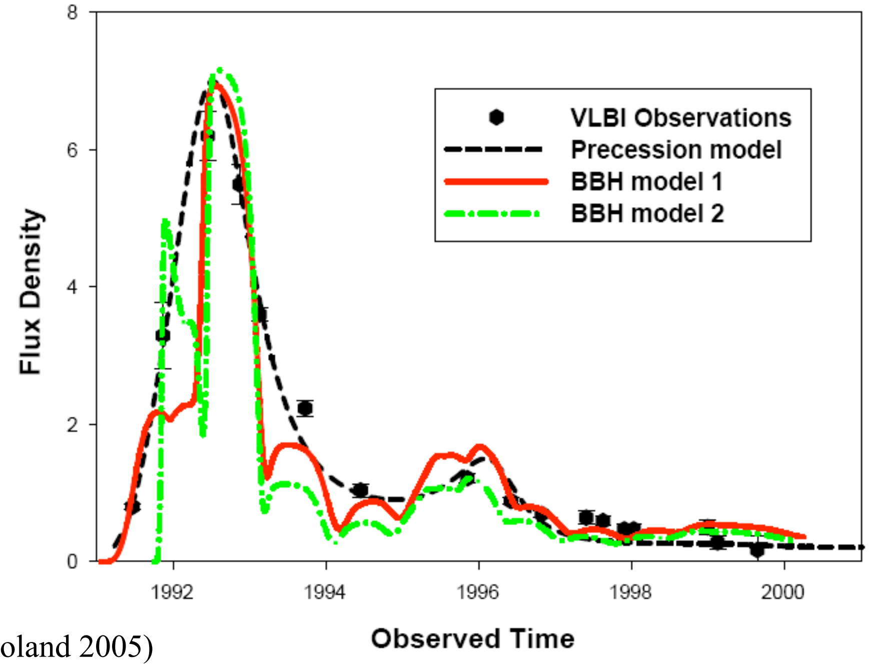
$$a_{\mathrm{maj}} = 0.33\mathrm{pc}\,(0.07\ \mathrm{mas}),\quad e = 0.1$$

$$P_{\mathrm{orb}} \approx 480\,\mathrm{years},$$

$$P_{\mathrm{prec}} \approx 2500\ \mathrm{years}$$





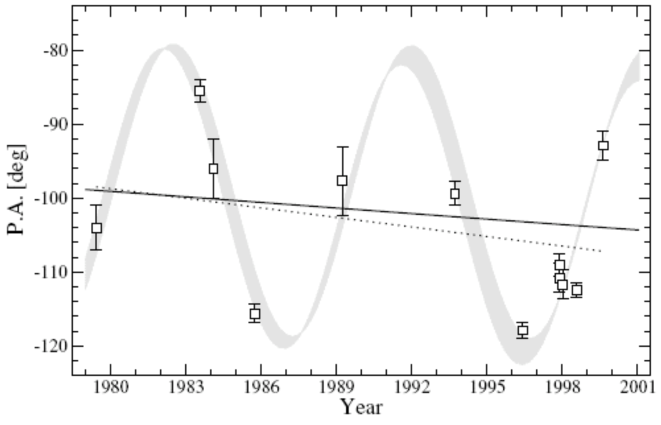


(Lobanov & Roland 2005)

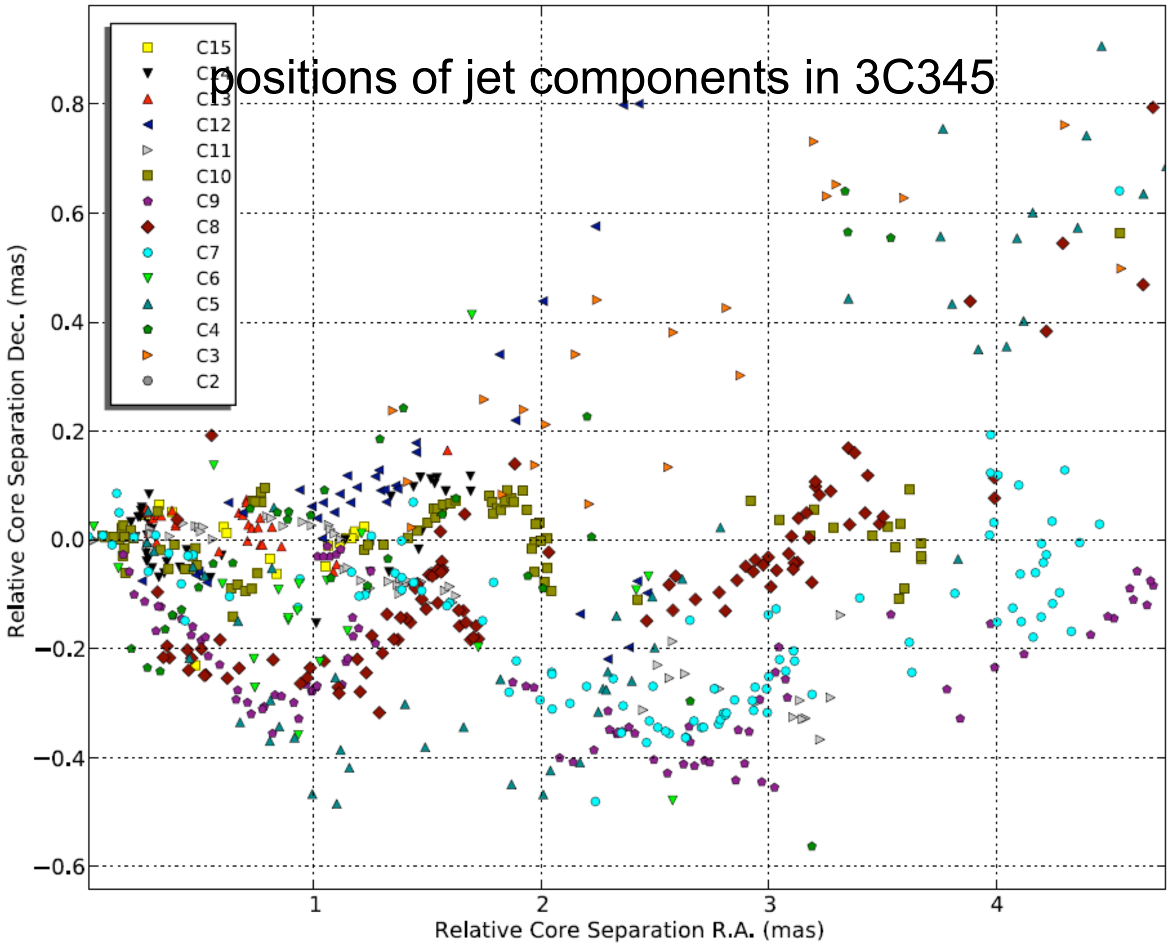
Evolution of the jet in 3C345

- ❑ Combining short-term and long-term evolution of compact jets is arguably the best way to make viable assessments of the properties of putative binary SMBHs in AGN

ejection P.A. of jet components



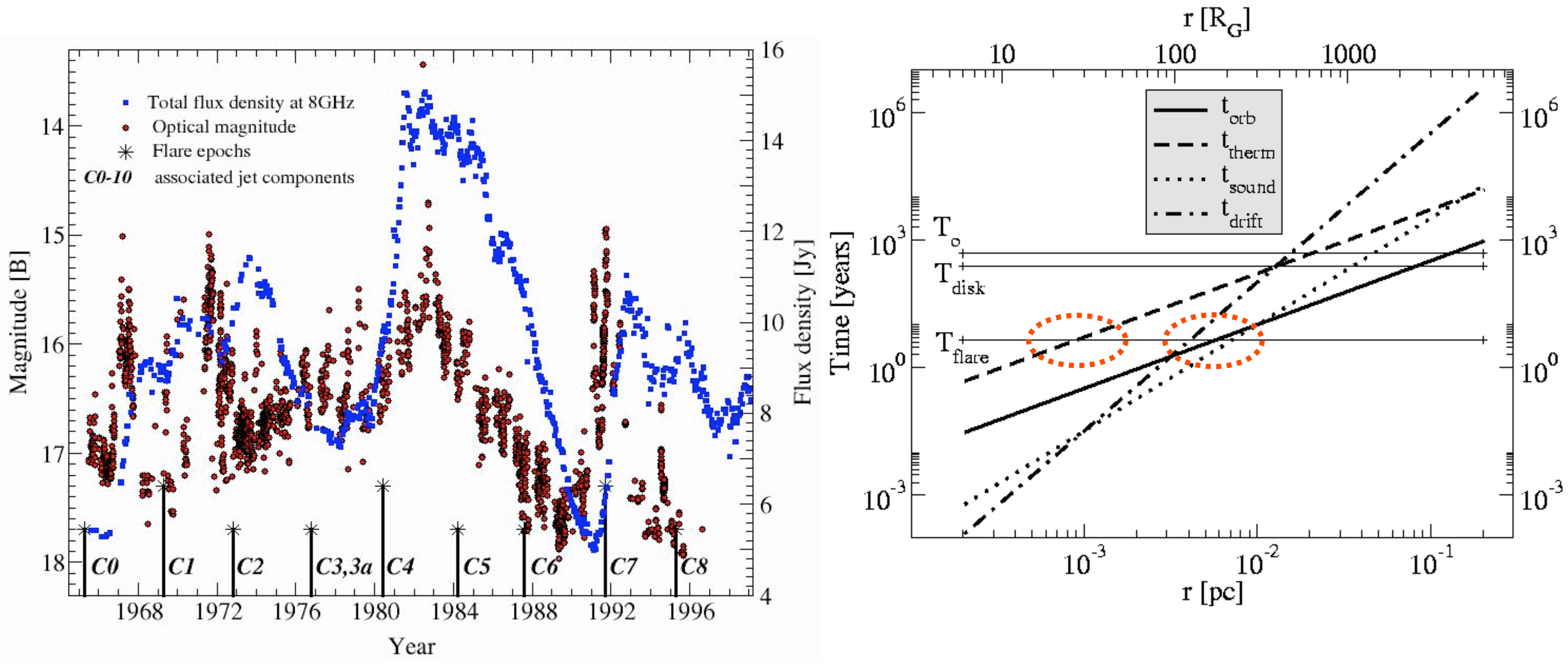
Lobanov & Roland 2005


positions of jet components in 3C345

Schinzel et al. (in prep.)

Jet-Disk Connection

- Flares and ejections of new jet components in 3C345 may be related to the characterstic instability timescales in the disk at 20-200 R_g

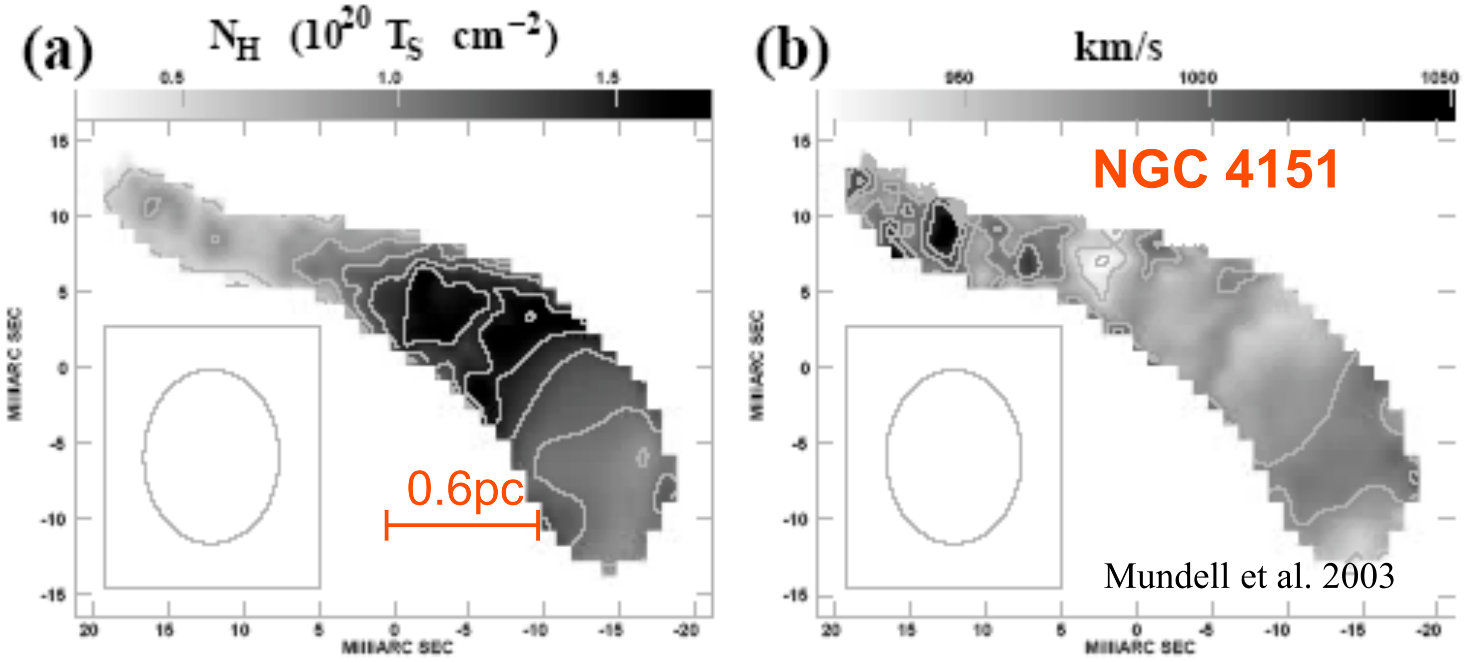


Lobanov & Roland 2005

Jets and Thermal Material in the Nuclear Regions of AGN

Nuclear Absorption

- ☐ Absorption due to several species, most notably HI, CO, OH, HCO^+
- ☐ HI absorption toward compact jets is an excellent tool to probe nuclear regions on parsec scales (Peck & Taylor 2001)
- ☐ Good indicator of physical conditions of the neutral gas (Pedlar 2004)



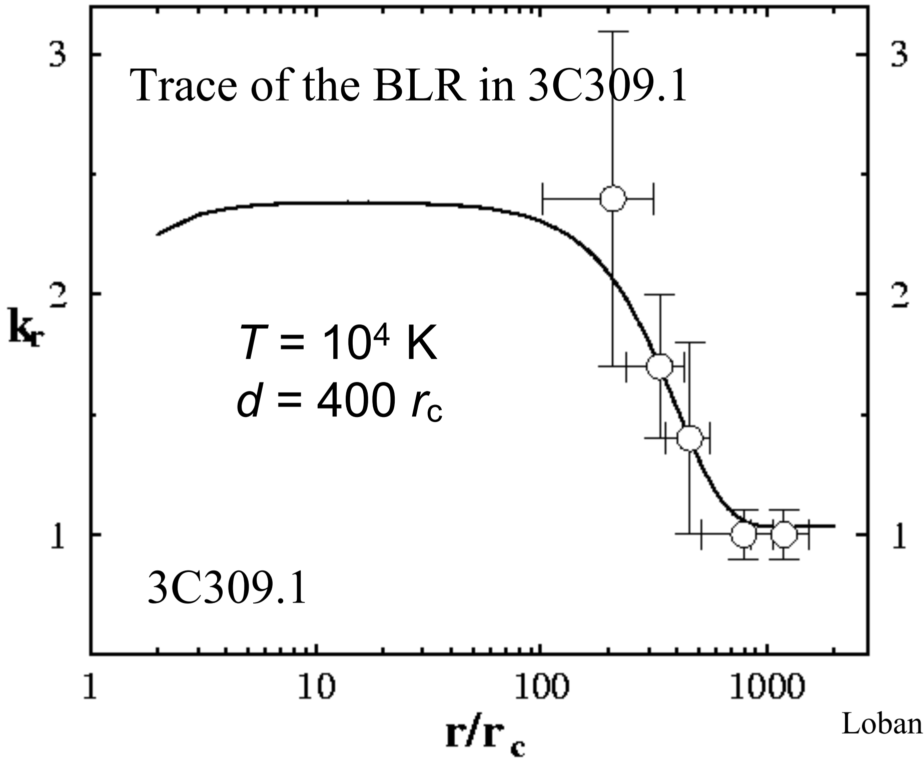
Mundell et al. 2003

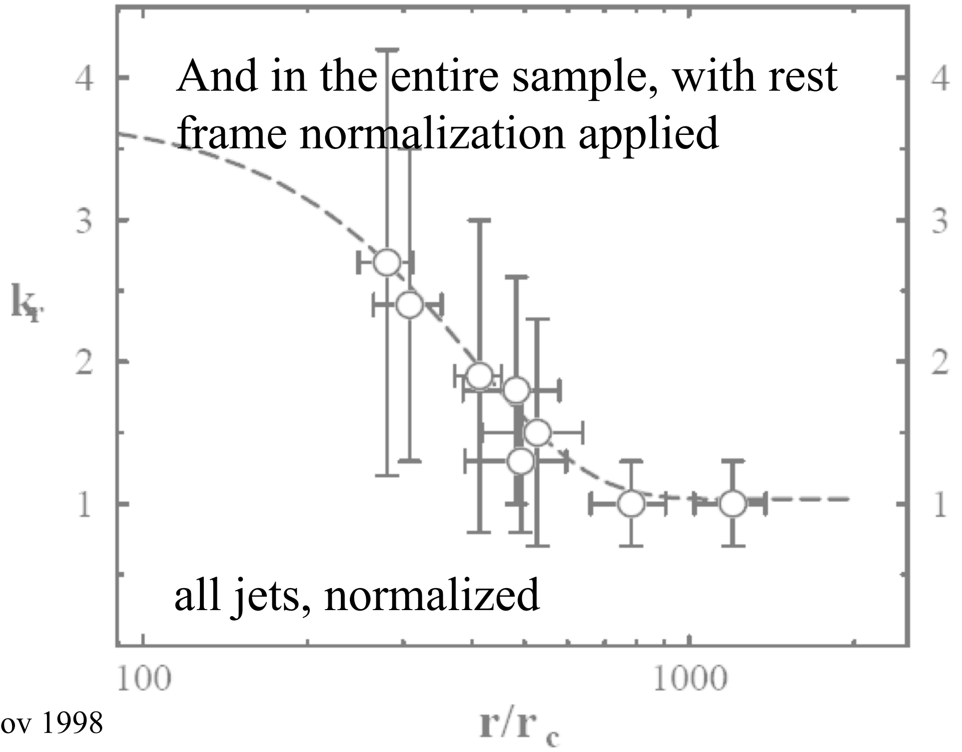
BLR Density Profile

Pressure gradients due to BLR clouds: $p(r) = p_0 \exp(-r^2/d^2)$

Resulting variable core shift index k_r traces effectively these gradients.

Core shift
measurements in a
sample of 7 AGN



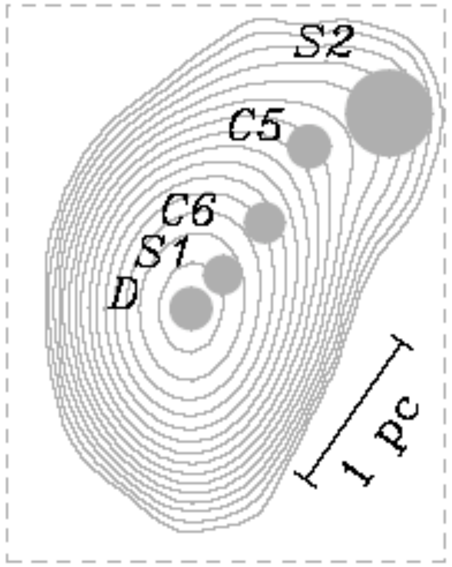


Lobanov 1998

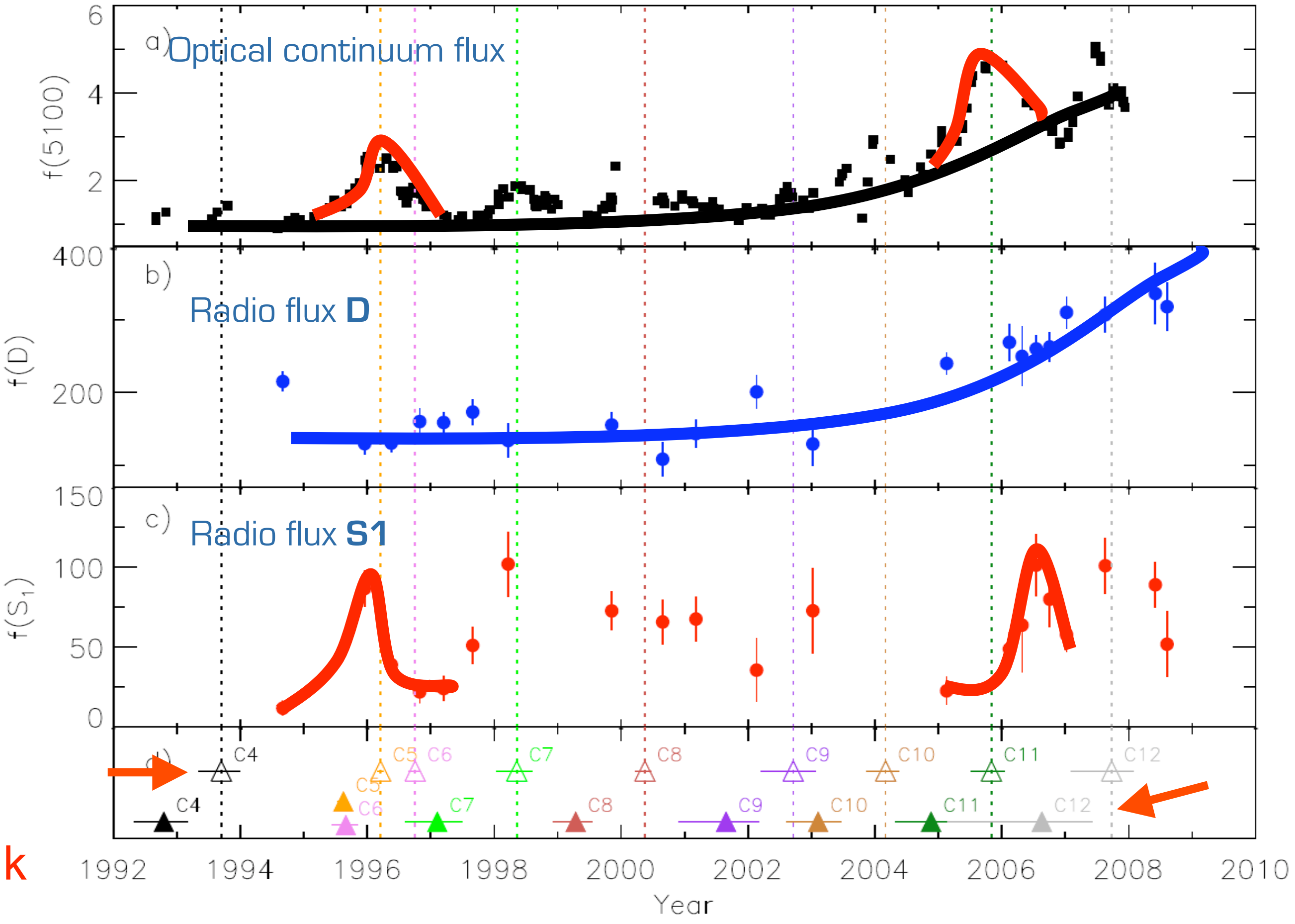
Jet-BLR Connection

- ☐ BLRG 3C390.3, 3C120: jet produces a large fraction of non-thermal continuum
- ☐ This continuum excites line emission from outflowing (non-virialized!) material

3C390.3: radio structure on sub-parsec scales



further discussion in talk by Tigran Arshakian



Arshakian et al. 2007, Tavares et al 2009

Summary

- Jets are effective probes of the fundamental nature of black holes and physical conditions in their vicinity.
- Connections between jets, accretion disks, and BLR exist and should be investigated in detail.
- The possibility of the jet continuum emission exciting a non-virialized component of the broad-line emission has strong implications for SMBH mass estimates and AGN studies in general.
- Nuclear opacity can be used to determine basic properties of the flows themselves and study the physical conditions in the vicinity of SMBH.

- ❑ …