# Determination of the characteristics of the BBH system using VLBI observations

3C 273, 1994, J Roland, R Teyssier & N Roos

0420-014, 2001, S Britzen, J Roland, J Laskar, K Kokkotas, R Campbell & A Witzel

3C 345, 2005, A Lobanov & J Roland

1803+784, 2008, J Roland, S Britzen, N Krudryavtseva & A Witzel

1823+568, C Glueck, S Britzen & J Roland

3C 279, C Fromm, J Roland & E Ros

3C 273 and 3C 454.3

VLBI observations show that the jet is not ejected along a straight line, but seems to be precessing.

We explain the precession of the VLBI jet by a BBH system in the nucleus of the radio galaxy.

A BBH system produces three perturbations of the VLBI ejection:

- due to the precession of the accretion disk,
- due to the motion of the BH ejecting the VLBI jet around the gravity center of the BBH system,
- due to the slow motion of the BBH system around the gravity center of the galaxy

# *The BBH model*


$\Omega$ = 0 : VLBI ejection do not follow a straight line

- BBH system induces a motion of M1 and M2
- BBH system moves around the gravity center of the galaxy

## *Consequences of the BBH model*

If the two BH eject VLBI components:

- 2 families of trajectories (different Omega, …)

  3C 273, 1823+568 ...

- a possible offset of the origin of the VLBI ejection

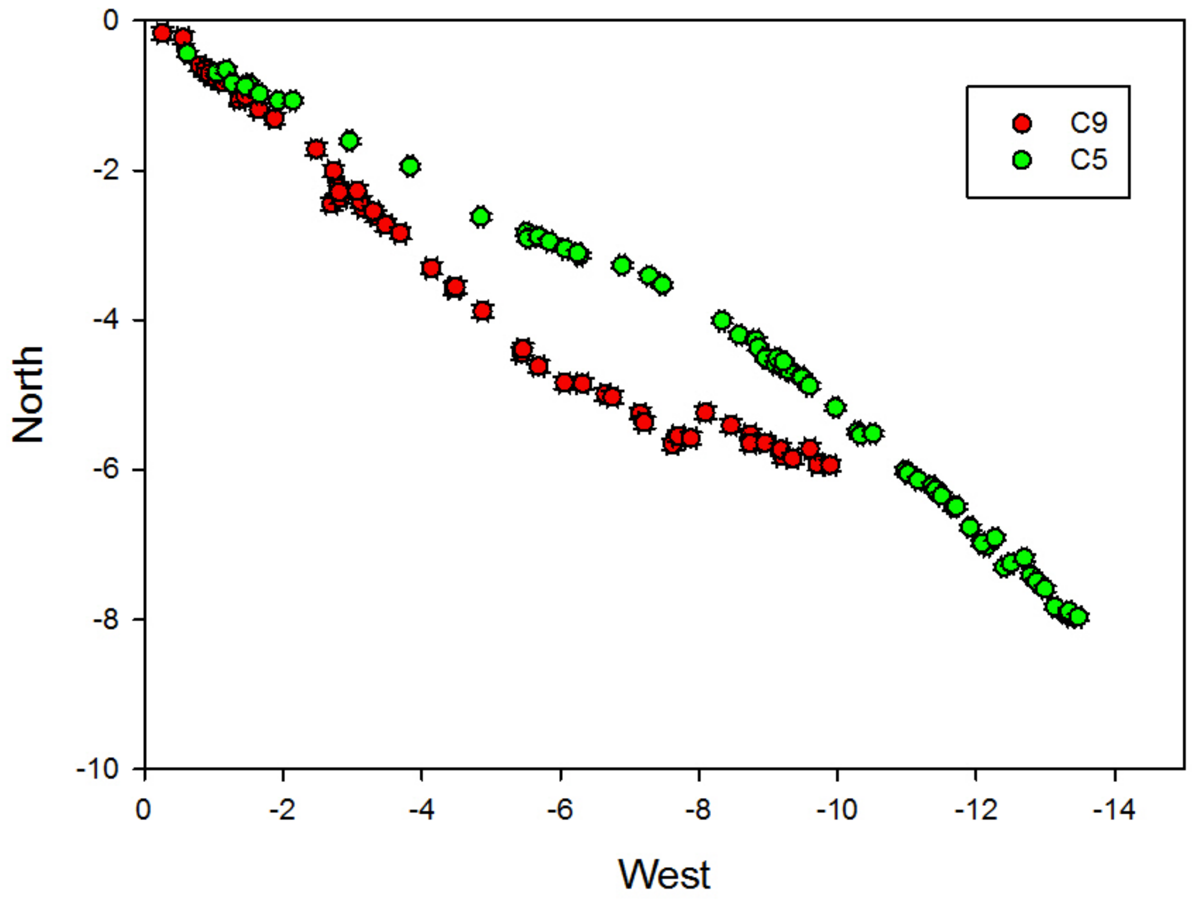
  (VLBI ejection is different from the VLBI core)

  → detection of the Radius of the BBH system and

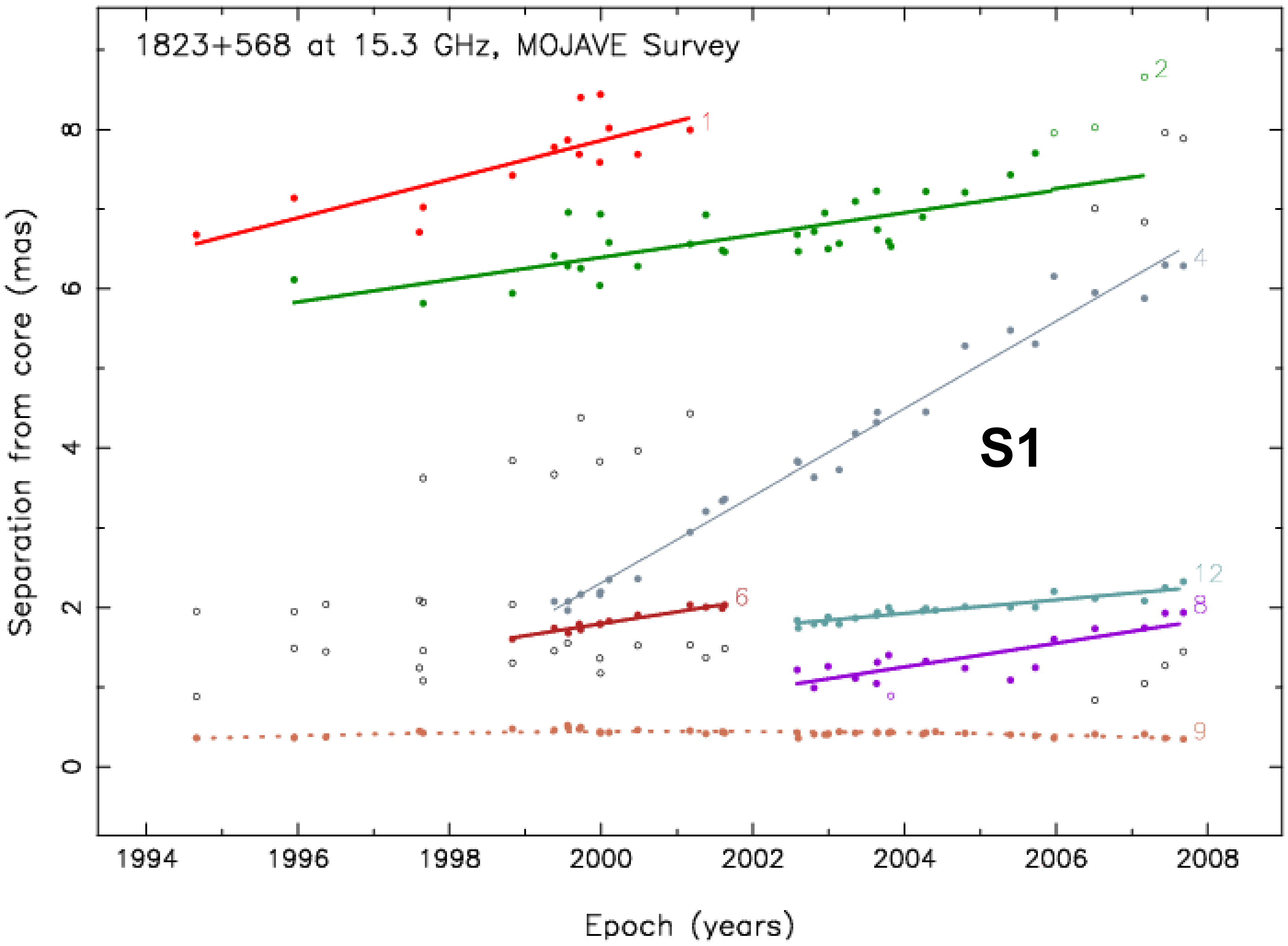
  the positions of the 2 BH

  1823+568, 3C 279 – C5, 3C454.3 – R3

# 3C 273 : components C5 & C9



# 1823+568 : Two fast moving components S1 and S2



# The model (geometrical model)

The plasma ejected relativistically follows the magnetic field lines, which are perturbated by :

- the precession of the accretion disk,
- the motion of the black hole in BBH system,
- the motion of the BBH system around the Gravity Center of the galaxy (few mas wiggles)

The amplitude of the perturbation increases at the beginning and is latter damped.

So the coordinates are given by :

$$x(t)=(R_o(z)\cos(\omega_p t-k_p z+\phi)+x_1(t)\cos(\omega_b t-k_b z+\psi))\exp(-t/T_{beam})$$

$$y(t)=(R_o(z)\sin(\omega_p t-k_p z+\phi)+y_1(t)\sin(\omega_b t-k_b z+\psi))\exp(-t/T_{beam})$$

$$z(t)=z$$

Where $$R(z)=\frac{R_o z(t)}{a+z(t)}$$

and $$x_1(t)=\frac{M_2}{M_1+M_2}\left[\frac{T_b^2}{4\pi^2}G(M_1+M_2)\right]^{(1/3)}$$ e = 0

From, $$v^2=\left(\frac{dx}{dt}\right)^2+\left(\frac{dy}{dt}\right)^2+\left(\frac{dz}{dt}\right)^2$$

we obtain $$A\left(\frac{dz}{dt}\right)^2+B\left(\frac{dz}{dt}\right)+C=0$$

equation which allow to calculate the trajectory, the flux, the relativistic effects ...

Indeed : $$\delta(t)=1/(\gamma[1-\beta\cos(\theta)])$$

where $$\cos(\theta)=\left(\frac{dy}{dt}\,sini_o+\frac{dz}{dt}\,cosi_o\right)/v$$

From VLBI observations, we have X(t) and Y(t) for VLBI components:

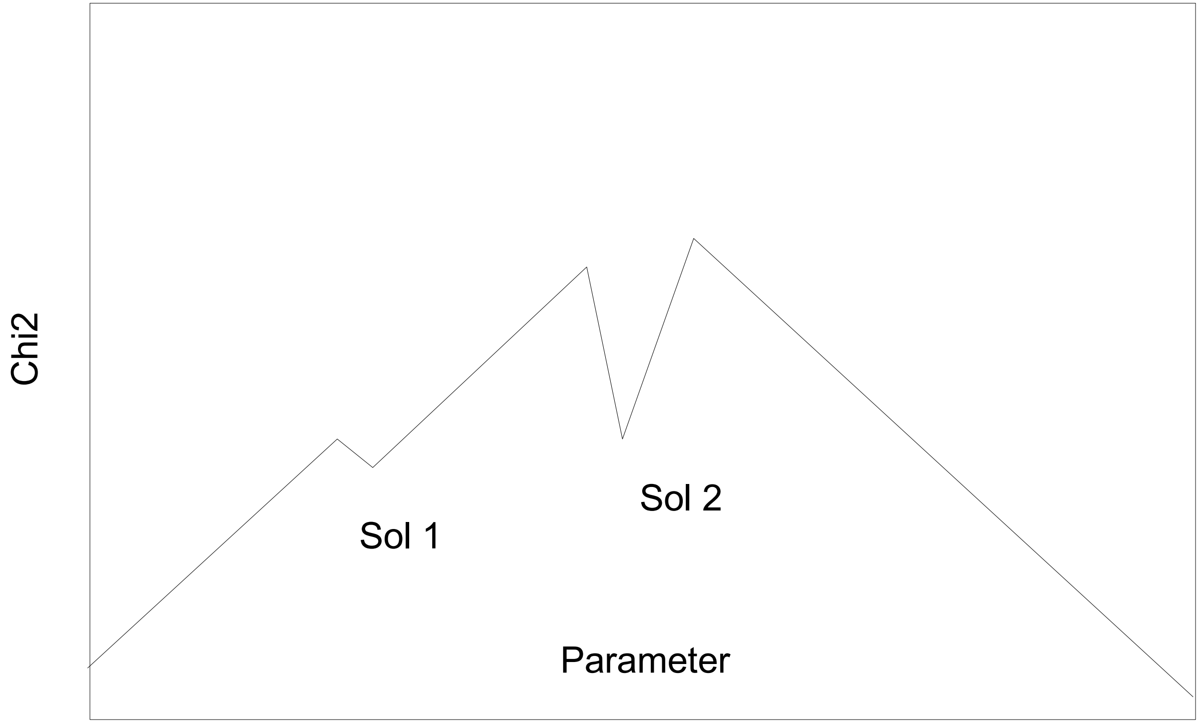
→ the trajectory and the cinematic are known

→ we can find the inclination angle and the bulk Lorentz factor

→ we can find the characteristics of the BBH system in the nucleus (generally, there is not a unique solution, but a family of solutions)

We calculate the Chi2 between the model and the VLBI data and we minimize the function Chi2(Parameters).

- Problem 1: How to find the concave parts of the surface Chi2 ?
- Problem 2: How to obtain all the possible solutions ?
- Problem 3: How to get the most robust solution ?



- the inclination angle,
- the phase of the precession at t = 0,
- the rotation angle in the plane perpendicular to the line of sight,
- the opening angle of the precession cone,
- Ro the maximum amplitude of the perturbation,
- Tp the precession period of the accretion disk,
- Td the characteristic time for the damping of the beam perturbation,
- M1 the mass of the black hole ejecting the radio jet,
- M2 the mass of the secondary black hole,
- the bulk Lorentz factor of the VLBI component,
- the phase of the BBH system at t = 0,
- Tb the period of the BBH system,
- to the origin of the ejection of the VLBI component,
- Va the propagation speed of the perturbations,
- the extension of the VLBI component along the beam.

The final solution for 1823+568 is characterized by:

io = 2.5, gamma = 18.7
omega = 0.1°

Tp/Tb = 7.05, Rbin = 0.066, M1/M2 = 0.25

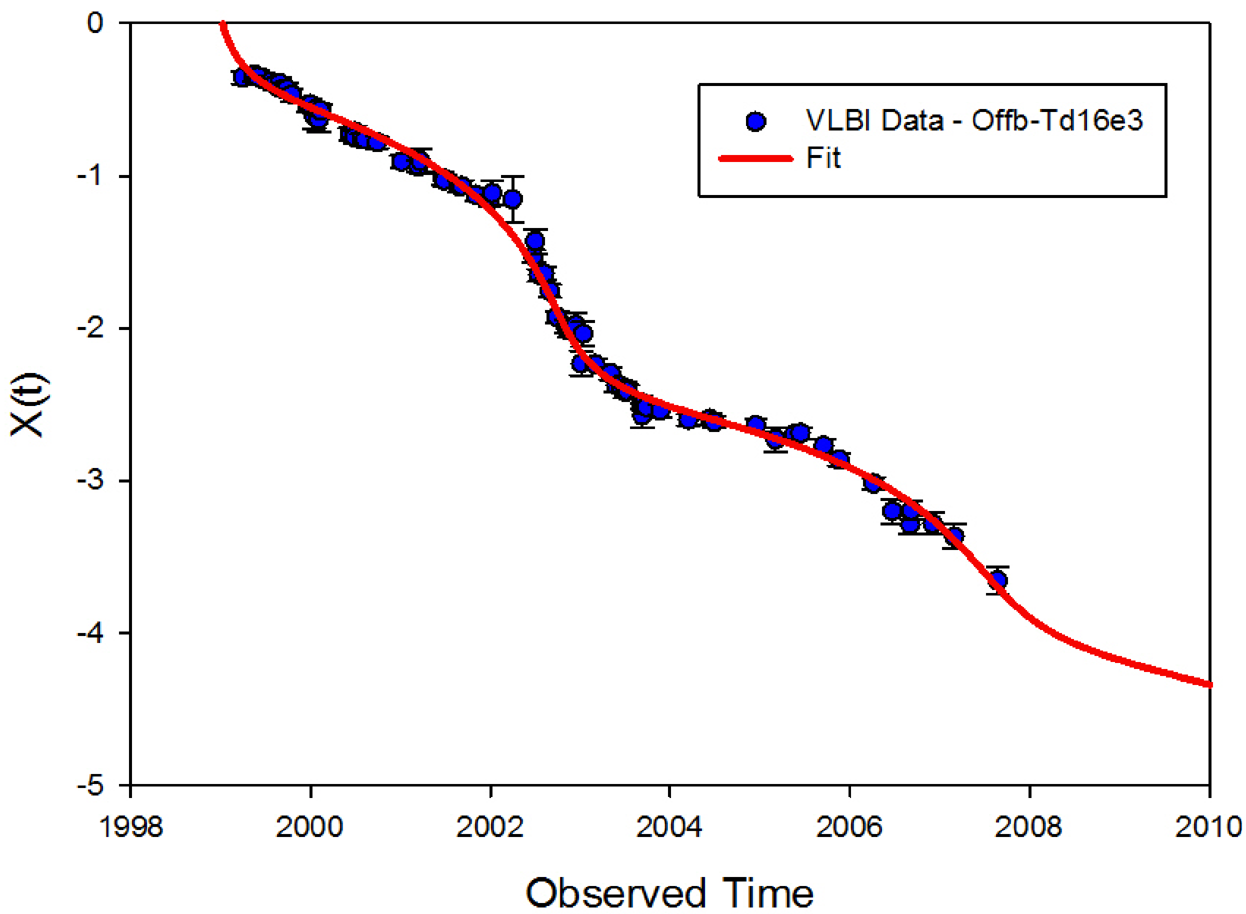
10^3 < Tb < 7 10^4,  2 10^8 > M1+M2 > 10^5

Examples of large Offset :

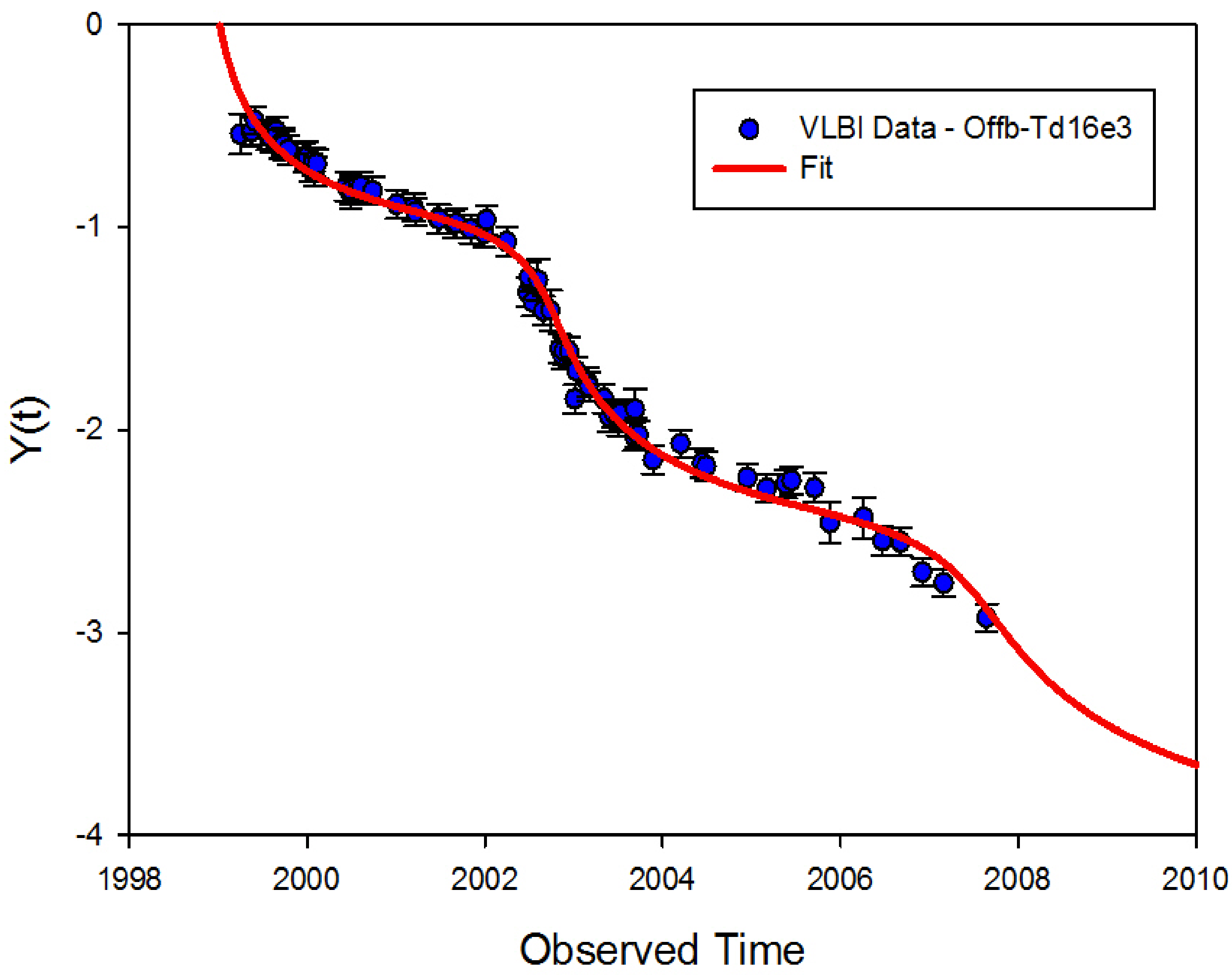
3C 279 – Component C5 (Mojave data)
X_Offset = +0.330 mas
Y_Offset =  -0.010 mas
BBH radius = 0.330 mas

3C 454.3 – Component R3 (Mojave data)
X_Offset = +0.670 mas
Y_Offset =  +0.250 mas
BBH radius = 0.715 mas

# 3C 279 – Component C5 - X(t)



# 3C 279 – Component C5 - Y(t)



## Origin of the VLBI ejection

0917+624 – 1823+568 – 3C 273 – 3C 279 – 3C 454.3

In the case of 1823+568 we are able to detect an offset of 66 $\mu$as

VLBI Observations mm (15 GHz for 1823+568, ...)

- At 15 GHz : Resolution : 0.5 mas; positions : 40 $\mu$as
- At 43 GHz : positions : > 25 $\mu$as ?

Within 1 mas with a resolution of 25 $\mu$as, one can expect to be able to find BBH systems in most of nuclei of radio sources

→ **Link between local Reference Frame and distant radio sources - GAIA (25 $\mu$as)**