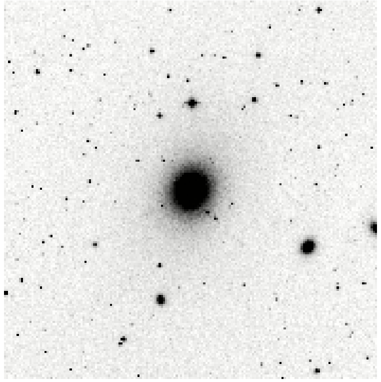
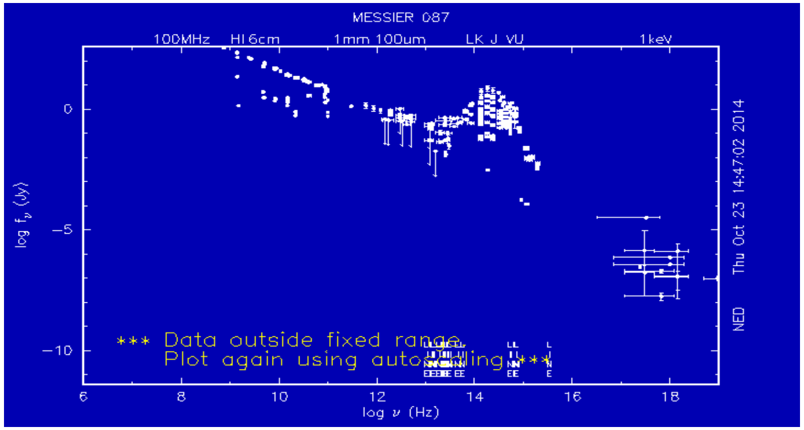
Structure of nuclei of extragalactic radio sources and the link with GAIA

J Roland, IAP & S Lambert, SYRTE

I – General properties of extragalactic radio sources

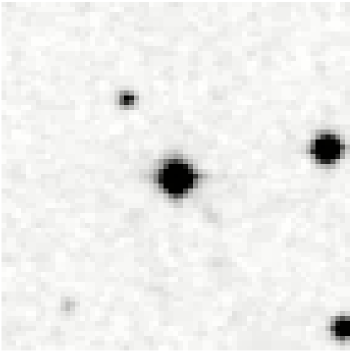
Radio galaxies : associated with elliptical galaxies

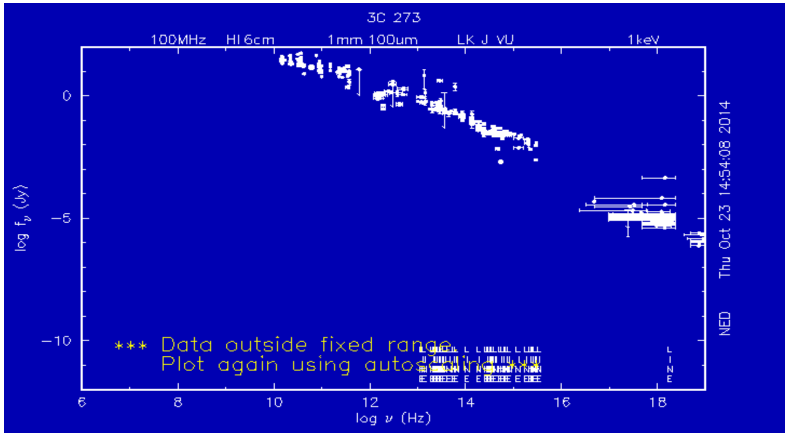




M 87

Quasars : quasi stellar radio sources ≠ QSOs





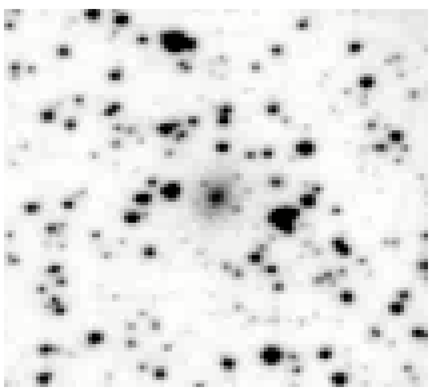
3C 273

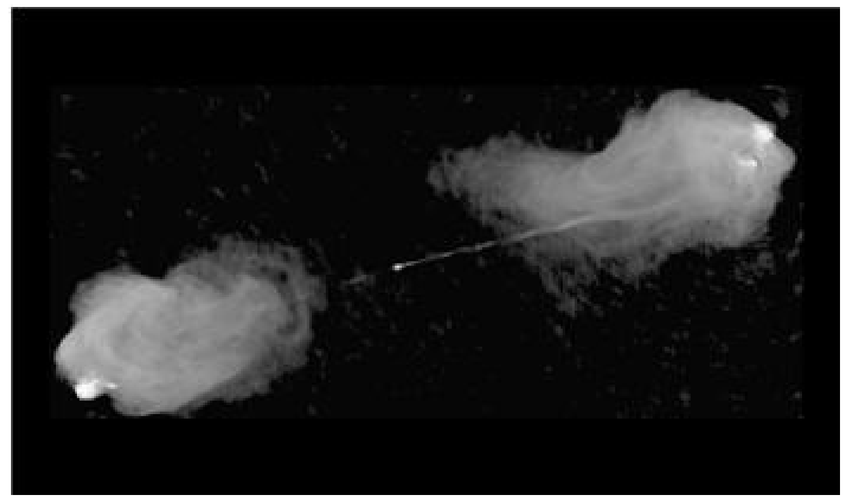
The optical spectrum of quasars is dominated by non-thermal processes

II – What is ejected by the nucleus ?

Extended radio sources

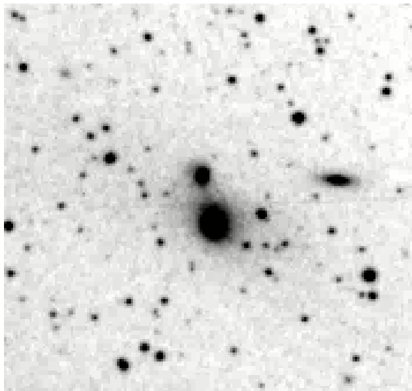
Cygnus A type radio sources

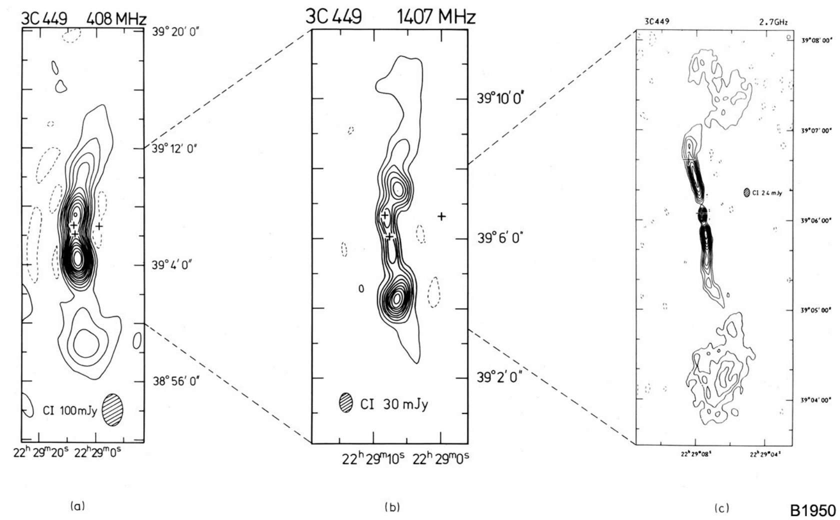




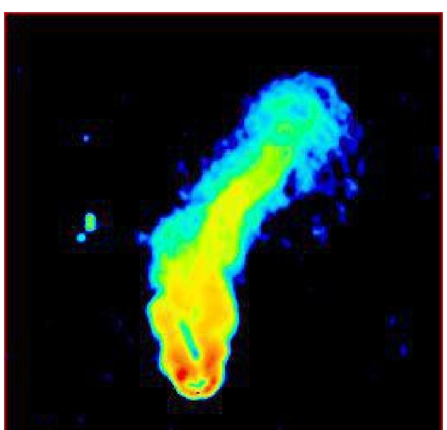
- supersonic jets with a weak radio emisson → formation of strong radio hot spots when the jet interacts with the intergalactic medium (formation of a strong shock at the end of the jet and a bow shock between the intergalactic medium and the hot spots),
- the speed of the jets is : $v < 0.4$ c.

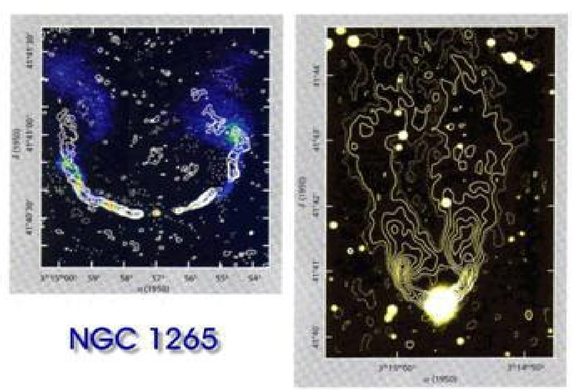
3C 449 type radio sources





- subsonic radio jets with a relatively strong radio emission → no radio hot spots when the jet interacts with the intergalactic medium (the jet pervades the intergalactic medium and dissipates its energy via turbulence),
- the speed of the jets is : v < few 1000 km/s.

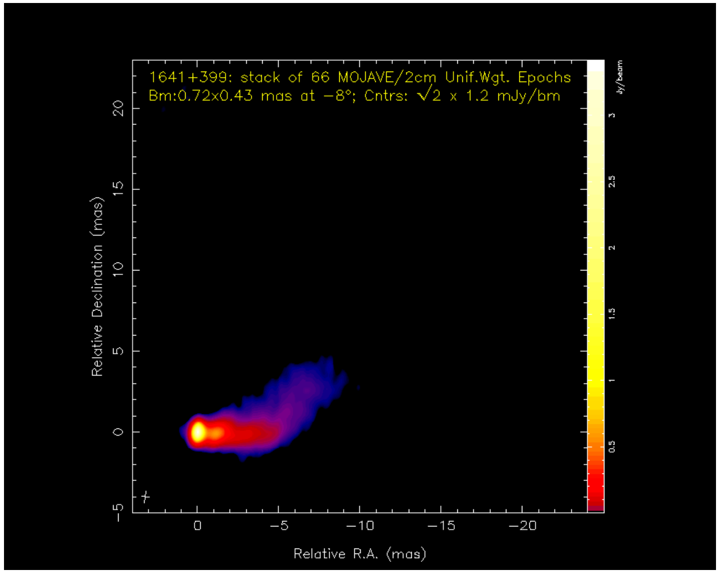




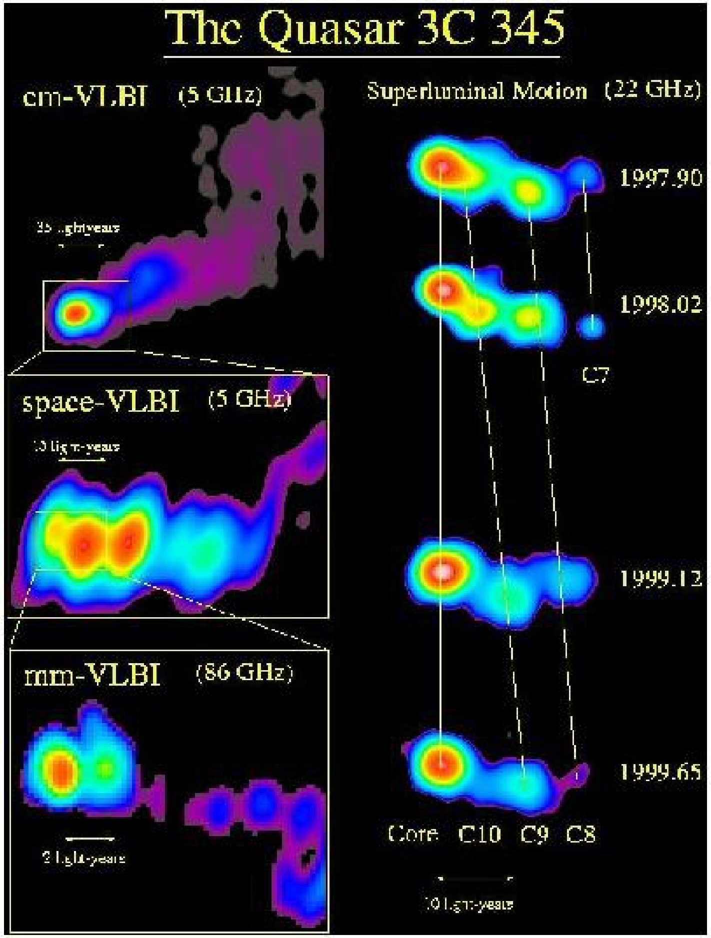
NGC 1265

Head-tail radio galaxies

Compact radio sources



3C 345

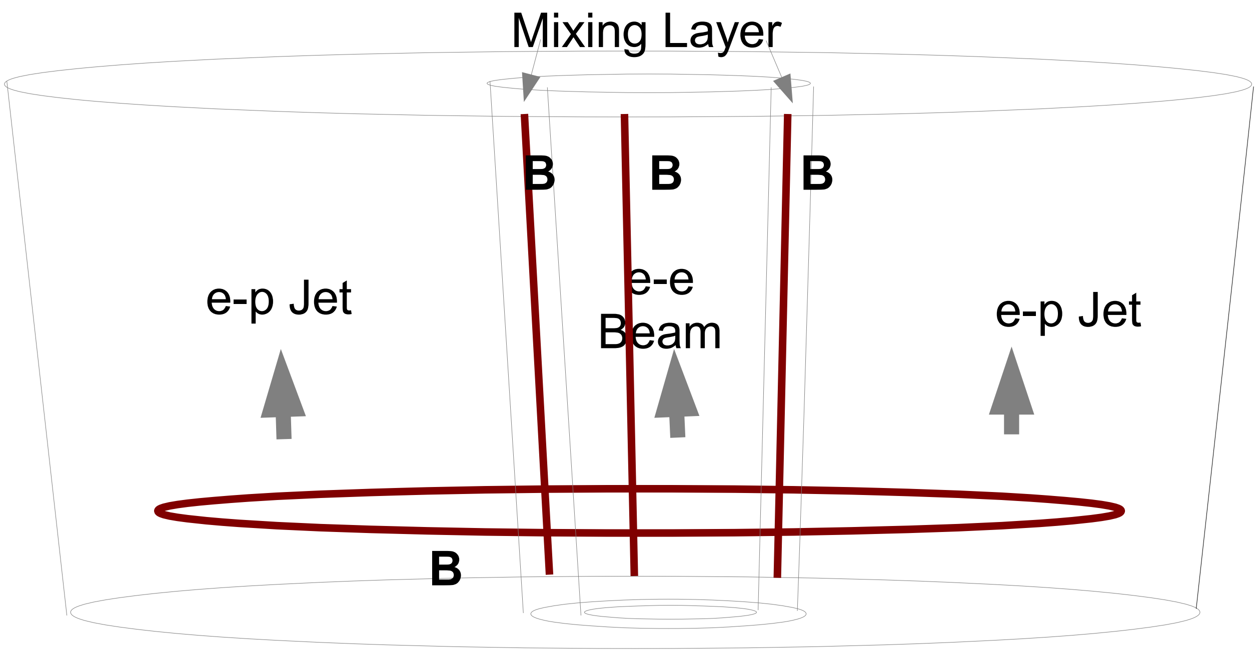


On the milli arc sec scale one observes a quasi continuous flow. It is the synchrotron emission of blobs of plasma (VLBI components) showing superluminal motion (apparent motion).

As the emitting plasma is ejected relativistically, the emission is anisotropic (Doppler boosted).

The ejection of a VLBI component corresponds to an increase of the density of the relativistic particles ejected relativistically.

The two-fluid model



We will assume that nuclei of radio sources eject two fluids:

- an e^{-} - p plasma (*jet*), which speed is : $v_j \leqslant 0.4\,c$
- an e^{-} - $e+$ plasma (*beam*), which speed is : $v_b \approx c$

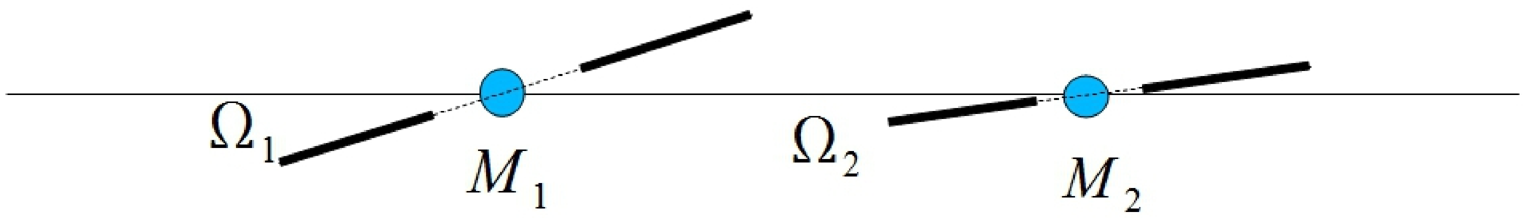
The beam can propagate inside the jet if : $\gamma_b \leqslant 30$

The jet carries most of the mass and the kinetic power ejected by the nucleus, it is responsible for the formation of kpc jets, hot spots and extended lobes.

The beam is responsible for the formation of superluminal sources and their emission from radio to γ-ray.

III – Structure of nuclei of extragalactic radio sources

VLBI observations of compact radio sources show that the ejection of VLBI components does not follow a straight line, but wiggles. These observations suggest a precession of the accretion disk. To explain the precession of the accretion disk, we will assume that the nuclei of radio sources contain BBH systems (binary black hole).



A BBH system produces three perturbations of the VLBI ejection due to

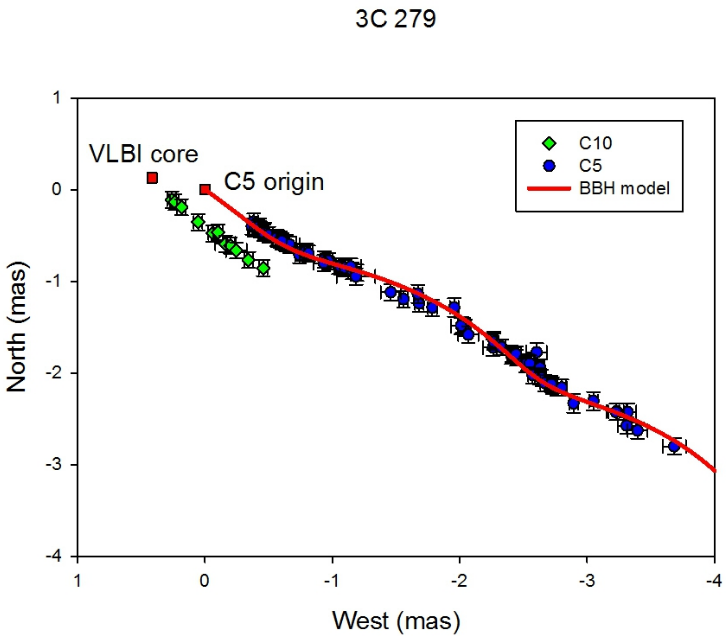
- the precession of the accretion disk,
- the motion of the two black holes around the gravity center of the BBH system, and
- the motion of the BBH system around something.

Consequences of the BBH model

1) – Even if Ω = 0, the VLBI component does not follow a straight line,

2) – If the two BH eject VLBI components, we can observe

- 2 families of trajectories (different Omega, …), 3C 273, 3C 279 ...
- a possible offset of the origin of the VLBI ejection, (the origin of the VLBI ejection is different from the VLBI core), → detection of the radius of the BBH system and the positions of the 2 BH, 3C 279 ...



One fits the coordinates X(t) and Y(t) of an ejected VLBI component assuming that it follows the magnetic tube of the beam which is perturbed by
- the precession of the accretion disk, and
- the motion of the BHs of the BBH system.

Important remark concerning the solution

When we fit one VLBI component, the solution is not unique but is degenerate.

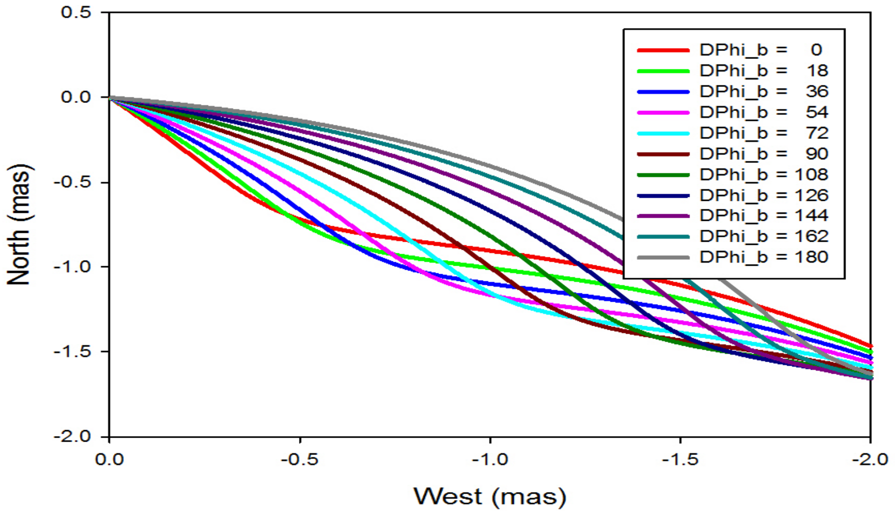
However, if we have 2 VLBI components ejected by the same BH, they only differ by the precession phase, the binary system phase, the origin time of the ejection and the bulk Lorentz factor.

Knowing the difference to1- to2, and the time compression factor, we can deduce the phases of the second component.

→ we can deduce the Mass of the BBH system.

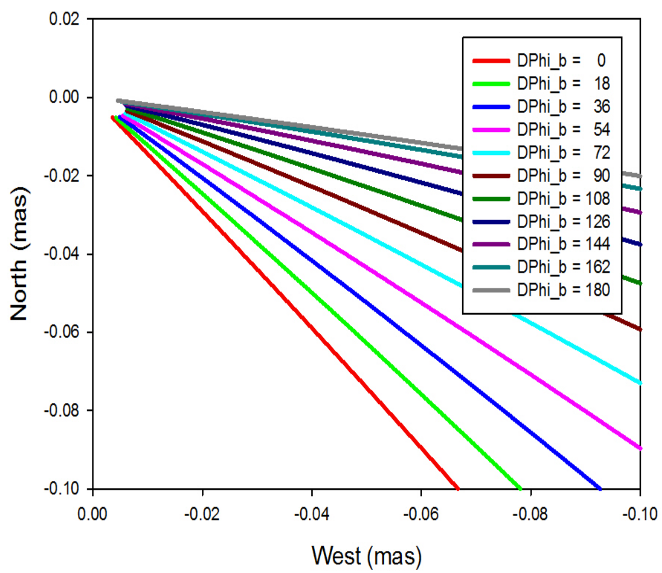
Example of a family of trajectories
3C 279 Component C5

Each VLBI component ejected by the same BH of a BBH system will follow a different trajectory due to the change of the phases (precession and binary system) → family of trajectories.



An important consequence for astrometry :

The position of the « core » ejecting VLBI components of the same family will change
- along the direction of the ejection and
- in the direction of the ejection.



- All VLBI jets show wiggles indicating at least a precession of the accretion disk,

→ this may indicate that all radio sources contain BBH systems,

- Every time that we had enough data to model VLBI ejections, we found that nuclei of extragalactic sources contain a BBH system

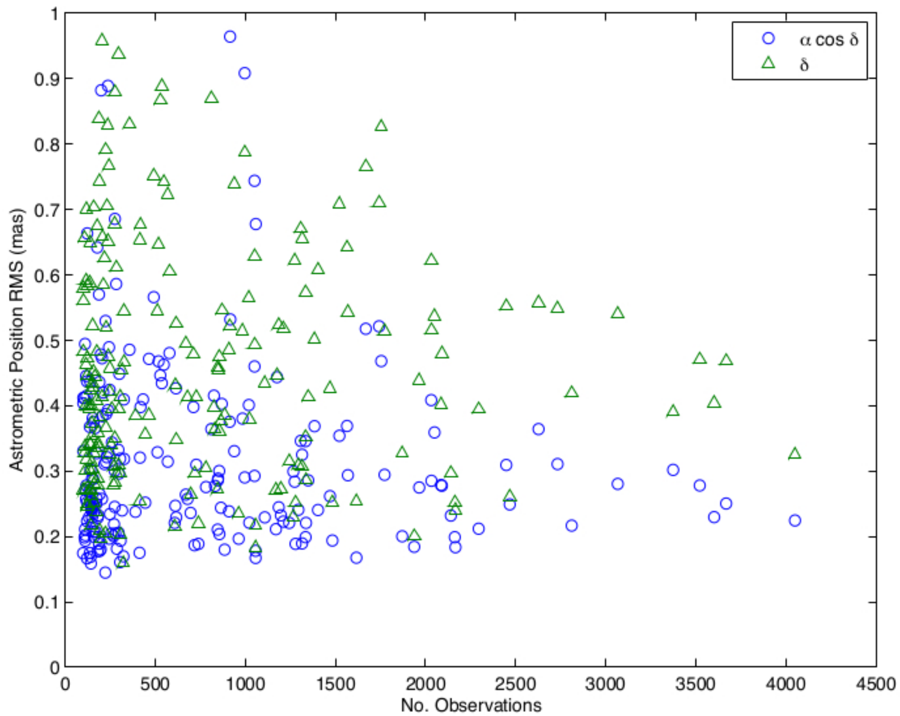
- If nuclei of extragalactic radio sources contain BBH systems, one can understand
  - why extragalactic radio sources are associated with elliptical galaxies,
  - why more than 90% of QSO are not radio sources.

0.2 pc < Rbin < 1.5 pc → **0.1 mas < Rbin < 1 mas**

The two BH are not always detected in radio

The two BH are often detected, but they are not recognized :
(OJ 287, BL Lac, Rbin ≈ 0.2 mas)

IV – Possible link between the structure of nuclei and the RMS time series of the ICRF2 survey



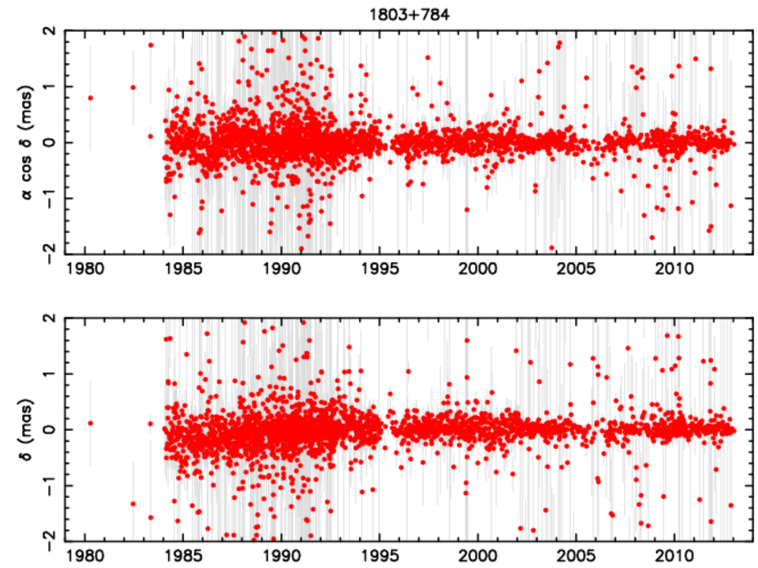
They are only few sources with ΔRMS < 250 µas, that is, very stable sources.

The RMS time series of the ICRF2 survey (VLBI international celestial reference system) > 150 µas.

We found a correlation between the size of the BBH system and the RMS time series of the ICRF2 survey .

For instance, 1803+784 has been observed 2681 times and the RMS of the time series for the coordinates are ≈ 0.17 mas and ≈ 0.18 mas.

It has been shown that the nucleus of 1803+784 contains a BBH system which size is ≈ 0.100 mas (Roland & al. 2008)



	Results	Time series RMS
PKS 0420-014	contains a BBH system : Rbin ≈ 0.12 mas (Britzen et al 2001)	0.33 * 0.60
3C 345	contains a BBH systen (Lobanov & Roland 2005)	0.65 * 1.10
S5 1803+784	contains a BBH system : Rbin ≈ 0.1 mas (Roland et al 2008)	0.17 * 0.18
1823+568	contains a BBH system : Rbin ≈ 0.06 mas (Roland et al 2013)	0.18 * 0.22
3C 279	contains a BBH system : Rbin ≈ 0.42 mas (Roland et al 2013)	0.64 * 0.94
PKS 1741-03	contains a BBH system : Rbin ≈ 0.18 mas (work in progress)	0.24 * 0.41
1928+738	contains 2 BBH system : Rbin ≈ 0.22 mas (Roland et al 2015)	0.33 * 0.36
3C 345	contains 3 BH or 2 BBH systems (work in progress)	0.65 * 1.10
3C 273	contains a BBH system : Rbin ≈ 1.0 mas (work in progress)	0.86 * 2.26

V – Link between VLBI observations and GAIA

GAIA is able to provide a very precise position but has a low resolution, compared to VLBI

- Precision of the position ≈ 25 µas for magnitude ≈ 15

- Precision of the position ≈ 100 µas for magnitude ≈ 18

Important problems for GAIA : the opacity effect and the nature of the radiation detected

-) What is the distance between the VLBI core and the central black hole ???

-) What is the relation between the optical detection of GAIA and the radio core ???

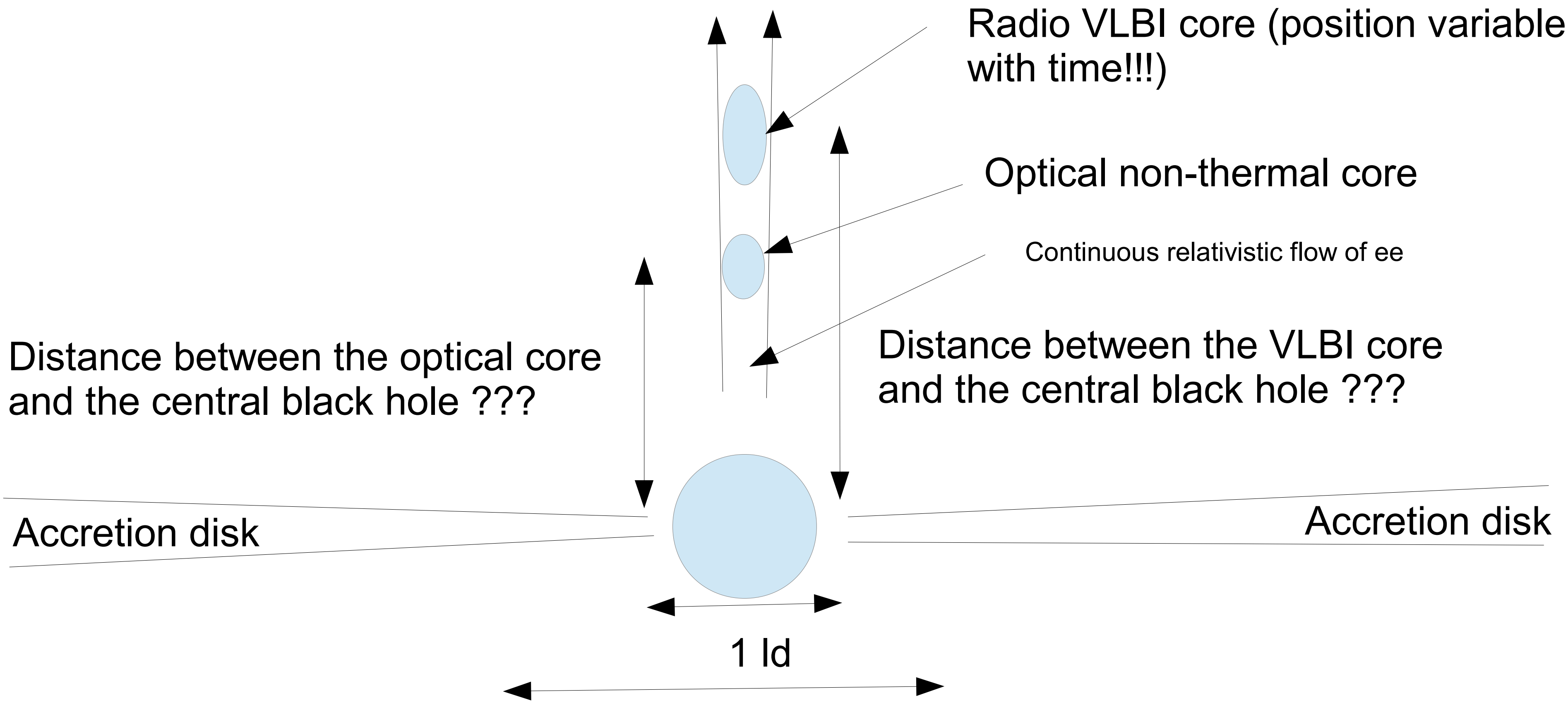
What is the VLBI core ???

Radio VLBI core is the region where the flow becomes tranparent to the synchrotron radiation (frequency dependence).

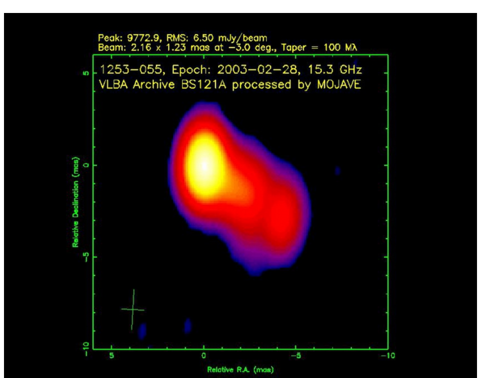
Remark : the opacity effect depends on the inclination angle. Opacity is proportional to sin(io)

If the inclination angle is very small, the opacity effect is very small !

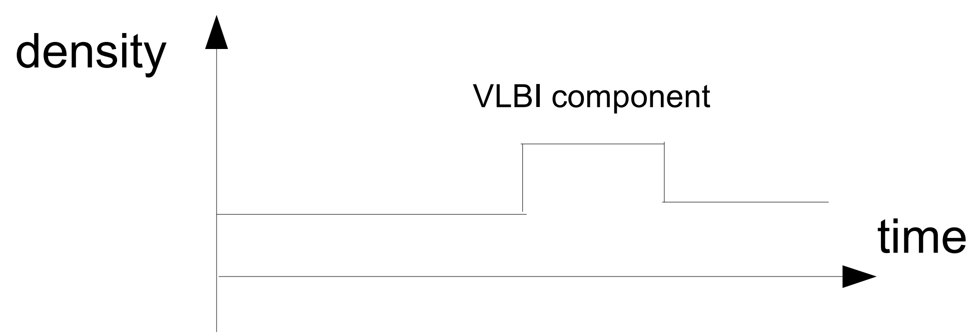
Where the optical emission come from ???



Black body emission - 30 ld = 10 μas

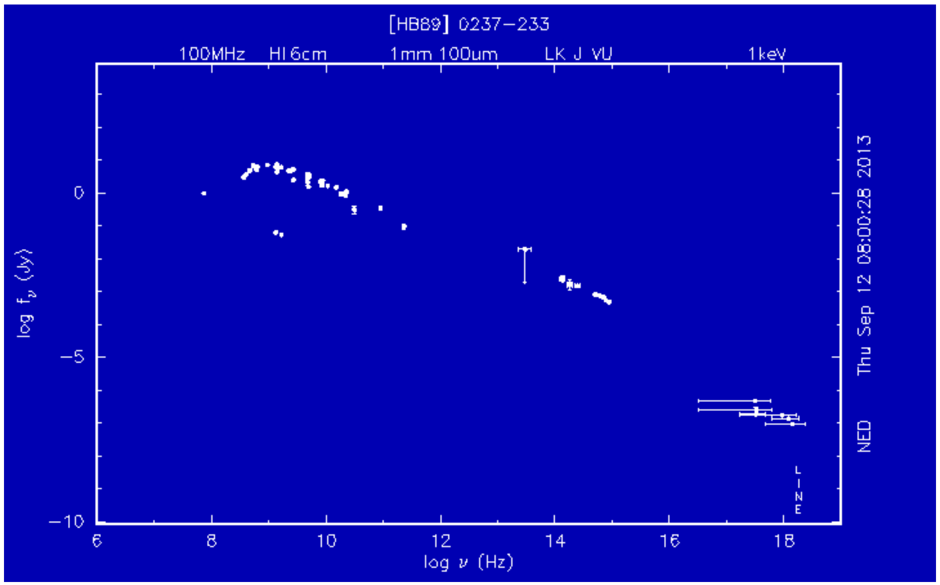


VLBI core

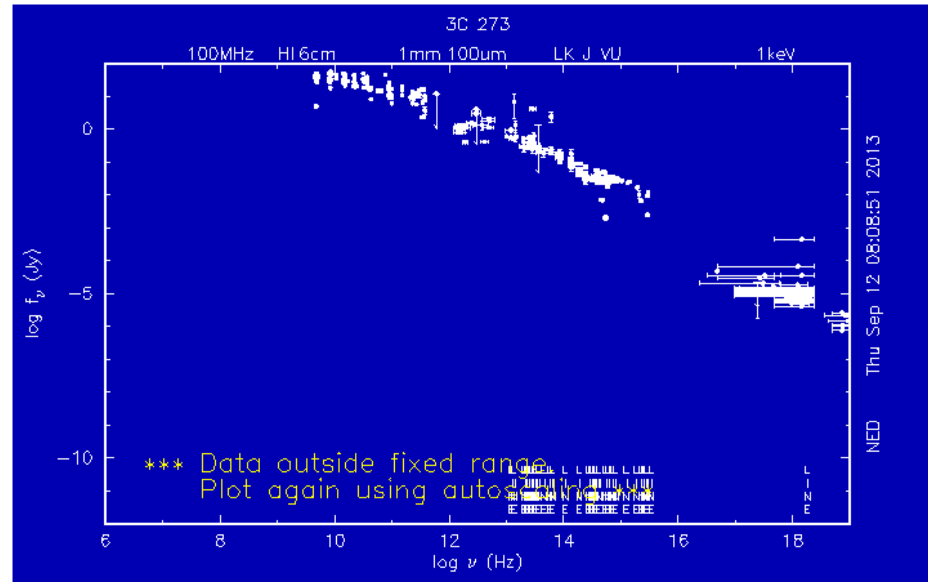


The optical spectrum of a radio quasar is dominated by non-thermal radiation (synchrotron + IC)

This is shown by the power law distribution and the linear polarization



PKS 0237-233



3C 273

Optical emission = optical non-thermal core (synchrotron + IC) +
black body emission of the central parts of the accretion disk +
BL region emission +
stellar emission …

→ **Distance between the radio core and the optical core ???**
(the optical core is not the central black hole !!!)
Problems if you have a BBH system with the two BH ejecting VLBI components ???

Problems if you have a BBH system

with the two BH ejecting VLBI components

If you have two ejecting black holes, 3 different cases can happen :

- 1) the radio core and the optical core are associated with the same BH : the distance between the radio core and the optical core depends on the opacity effect which will be small if the inclination angle is small,

- 2) the radio core and the optical core are associated with different black holes : the distance between the radio core and the optical core is more or less the size of the BBH system (corrected by the possible opacity effect),

- 3) the two black holes are emitting in the optical : GAIA will provide a mean position between the two optical cores ! Which will be different from the positions of the two radio cores.

- Remark : as quasars are strongly and rapidly variables, during the years of observations of GAIA, the 3 different cases can happen for a given source !

Conclusion

- The best radio sources to link the ICRF survey with GAIA survey are the quasars because their optical emission is dominated by non-thermal processes and comes from the optical core. The best quasars are those with the smallest ΔRMS and io.

- The nearby quasars, the bright one, are poor astrometric sources, that is, they have very large ΔRMS. For instance, for 3C 273, $\Delta RMS_\alpha \approx 0.86$ mas and $\Delta RMS_\delta \approx 2.26$ mas.

- The very stable quasars with small ΔRMS are the distant one, that is, the faint one.

The link between GAIA observations and distant radio quasars with errors < 150 μas may be very difficult because within 100 μas, all the quasars will appear as double sources and not as point sources and the radio and the optical observations can come from different regions.