

RADIO QUASARS AND THE LINK WITH GAIA

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ABSTRACT. Modeling VLBI ejections of nuclei of extragalactic radio sources, indicates that their nuclei contain a binary black hole system. One can derive the distance and the positions of the two black holes in the plane of the sky. We can also use the RMS of the time series of the ICRF2 survey to obtain an estimate of the structure and the size of the nuclei. We will discuss the possible problems to link VLBI observations and GAIA optical observations of radio quasars if they contain a binary black hole system.

1. STRUCTURE OF COMPACT RADIO SOURCES MODELING VLBI EJECTIONS

VLBI observations of compact radio sources show that the ejection of VLBI components does not follow a straight line but undulates. These observations suggests a precession of the accretion disk. To explain the precession of the accretion disk, we will assume that the nucleus of radio sources contains a binary black hole system (BBH system) .

A BBH system produces 2 main perturbations of the VLBI ejection due to:

1. the precession of the accretion disk and
2. the motion of the two black holes around the gravity center of the BBH system.

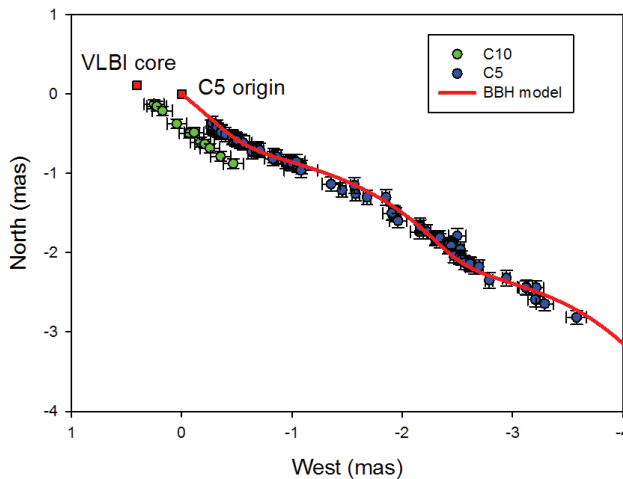


Figure 1: Using the MOJAVE data (Lister & al 2009), we plot the trajectories of C5 and C10. Component C10 is ejected by the VLBI core and component C5 is ejected with a large offset from the VLBI core. Components C5 and C10 follow two different trajectories and are ejected from different origins, indicating that the nucleus of 3C 279 contains a BBH system.

The presence of a BBH system, induces several consequences, which are:

1. the 2 black holes can have accretion disks with different angles with the plane of rotation of the BBH system and can eject VLBI components; in that case we will observe two different families of trajectories, a good example of a source showing 2 families of trajectories is 3C 279 (see Figure 1),

2. if the VLBI core is associated with one black hole and if the ejection of the VLBI component comes from the second black hole, there will be an offset between the VLBI core and the origin of the ejection of the VLBI component; this offset will correspond the radius of the BBH system.

We model the ejection of the VLBI component using a geometrical model taking into account the two main perturbations due to the BBH system. We determine the free parameters of the model comparing the observed coordinates of the VLBI component with the calculated coordinates of the model.

Modeling the ejection of VLBI components using a BBH system has been developed in previous articles, Britzen & al. 2001 modeled 0420-014, Lobanov & Roland 2005 modeled 3C 345, Roland & al. 2008 modeled 1803+784, and Roland & al. 2013 modeled 3C 279 and 1823+568.

Results concerning 3C 279 are shown in Figure 1.

2. STRUCTURE USING THE RMS OF THE TIME SERIES OF THE ICRF2 SURVEY

The ICRF2 Survey (International Celestial Reference Frame) has been obtained using about 6.5 millions of VLBI observations of about 3400 radio sources (Fey & al. 2010).

Important information concerning the structure of the nucleus can be obtained using the RMS of the time series of the ICRF2 survey (Lambert 2013 and <http://ivsopar.obspm.fr/>). To begin, let us take the example of the source 1803+784. The RMS time series of 1803+784 are presented in Figure 2.

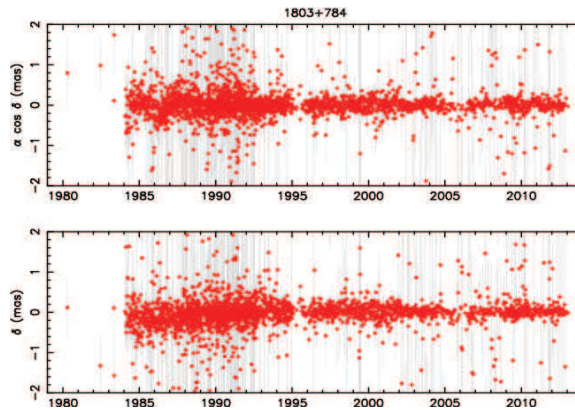


Figure 2: The RMS time series for the coordinates of 1803+784 are ≈ 0.12 mas and ≈ 0.12 mas. It has been shown by Roland & al 2008 that the nucleus of 1803+784 contains a BBH system of size ≈ 0.10 mas.

More generally, using the results obtained from the modeling of VLBI ejections, it can be shown that the RMS time series are correlated with the structure of the nucleus (see Table 1). Indeed, the RMS of the time series is always larger than the size of the BBH system deduced from modeling VLBI ejections.

Table 1 : Structures of compact sources and RMS time series

| Source | Structure | RMS time series |
|--------------|--|-----------------|
| PKS 0420-014 | BBH system : $R_{bin} \approx 0.12$ mas (Britzen et al 2001) | 0.32 * 0.47 |
| 3C 345 | BBH system : (Lobanov & Roland 2005) | 0.71 * 0.69 |
| S5 1803+784 | BBH system : $R_{bin} \approx 0.10$ mas (Roland et al 2008) | 0.12 * 0.12 |
| 1823+568 | BBH system : $R_{bin} \approx 0.06$ mas (Roland et al 2013) | 0.16 * 0.21 |
| 3C 279 | BBH system : $R_{bin} \approx 0.42$ mas (Roland et al 2013) | 0.90 * 1.11 |
| PKS 1741-03 | BBH system : $R_{bin} \approx 0.18$ mas (Work in progress) | 0.20 * 0.23 |
| 1928+738 | BBH system : $R_{bin} \leq 0.23$ mas (Work in progress) | 0.22 * 0.35 |
| 3C 345 | 3 BH or 2 BBH systems (Work in progress) | 0.71 * 0.69 |

The ICRF survey has been done at 8 GHz and the smallest RMS time series found are ≈ 0.1 mas at this frequency. The ICRF survey is now going to be done at 22 GHz and 32 GHz and one can expect to reach for point source sources RMS time series of 0.03 mas. If the smallest RMS time series at these frequencies are, say, ≈ 0.08 mas, this will mean that the sources are not point sources but contain BBH systems which sizes are $R_{bin} \approx 0.07$ mas.

So we can use the RMS time series to look for compact radio sources.

3. LINK BETWEEN VLBI OBSERVATIONS AND GAIA

GAIA will be able to provide a very precise position but has a relatively low resolution (compared to VLBI). For point sources which magnitude is $m_v \approx 15$ the precision of the position will be ≈ 0.02 mas, but for point sources which magnitude is $m_v \approx 18$ the precision of the position will be ≈ 0.10 mas.

The optical emission from a radio quasar can be due to

- the non thermal core (optical emission of the ultra relativistic e^-e^+ ejected relativistically),
- the black body radiation of the central parts of the accretion disk,
- broad line region and
- the stars.

The optical emission of radio quasars is dominated by the non thermal emission (synchrotron and/or inverse Compton emissions). This result is indicated by the power law distribution of the spectrum from the radio to the Xray emission and the linear polarization of the emission (see the spectrum of 3C 273 shown in Figure 3).

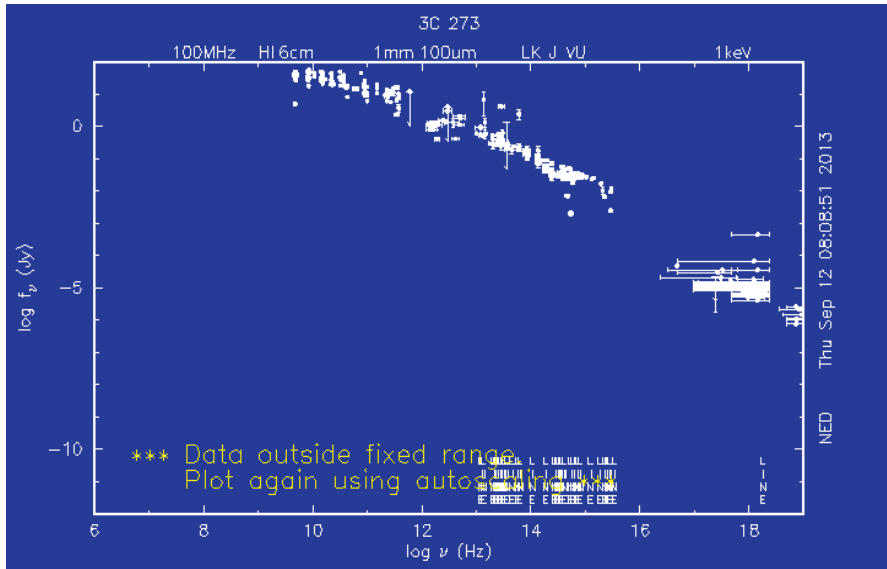


Figure 3: The spectrum of 3C 273. The spectrum shows a power law distribution between the radio to X and γ rays, indicating a non thermal origin. The radiation is linearly polarized. This caption is from the NASA/IPAC Extragalactic Data Base (<http://ned.ipac.caltech.edu/>)

Due to opacity effect, the optical core and the radio core positions are not the same. However, if the inclination angle of the source is very small, i.e. $i_o \leq 3^\circ$, opacity effect will be small. The position of the black hole emitting the VLBI jet is not the same that the positions of the optical core and the radio core.

If the nucleus of the radio quasar contains a BBH system and if the two black holes are active, three different cases can happen:

1. the radio core and the optical core are associated with the same BH, then 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, then 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), and
3. the two black holes are emitting in the optical, then GAIA will provide a mean position between the two optical cores ! This position will be different from the positions of the two radio cores.

as quasars are strongly and rapidly variables, during the 5 years of observations of GAIA, the 3 different cases can happen for a given source !

4. CONCLUSION

To link, with a precision of $\leq 150 \mu\text{as}$, the Local Reference Frame obtained by GAIA and the Reference Frame provided by distant radio quasars, one has to use radio quasars which magnitude is $m_v \leq 18$ and which are a priori the most compact.

Ideally, one has to define a sample of at least 10 radio quasars characterized by:

- $m_v \leq 18$,
- a RMS of the time series $RMS \leq 200 \mu\text{as}$ and
- a declination $-90^\circ \leq \delta \leq 90^\circ$,

which is currently not possible. Indeed, if we look for sources which have a RMS of the time series $RMS \leq 200 \mu\text{as}$, we find only 10 sources with a declination $\delta > 0^\circ$. To obtain sources with $\delta < 0^\circ$, one has to look to sources with a RMS of the time series $RMS \leq 500 \mu\text{as}$! This is due to the lack of VLBI observations in the south hemisphere.

Modeling VLBI ejection using sources from this sample can be done if each VLBI component has been observed at least 20 times and if the component can be followed on a path long enough. It has the advantage to provide the size of the BBH system, the positions of the two black holes and the inclination of the radio source.

During the five years of GAIA observations it will be crucial to improve the number and the quality (UV coverage) of VLBI observations of radio sources with negative declinations in order to model the VLBI ejections and to reduce significantly the RMS of the time series.

5. REFERENCES

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