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Linking VLBI astrometric measurements of extragalactic radio-sources to astrophysical phenomena

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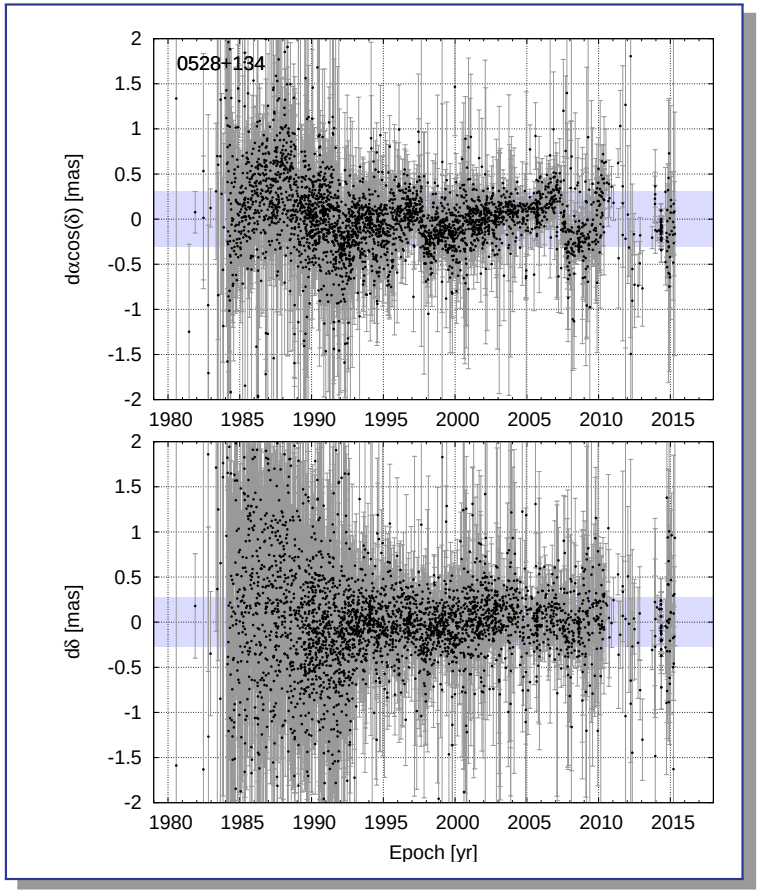
VLBI astrometric measurements of AGNs

→ In geodetic VLBI, hundreds of extragalactic sources are observed, some of them since nearly 40 years. Their absolute astrometric positions are adjusted simultaneously with station positions, Earth rotation and several other parameters.

→ These observations, correlations and data analysis are made under the coordination of the International VLBI Service for astrometry and geodesy [IVS].

→ During the data reduction, it is possible to compute absolute astrometric position time series of the observed AGN.



Astrometric variability of AGNs

→ The interest for geodetic VLBI is to observe sources with the less astrometric variability as possible.

But,

→ There is often a perceptible astrometric variability in the source position time series Gattano et al. [2018].

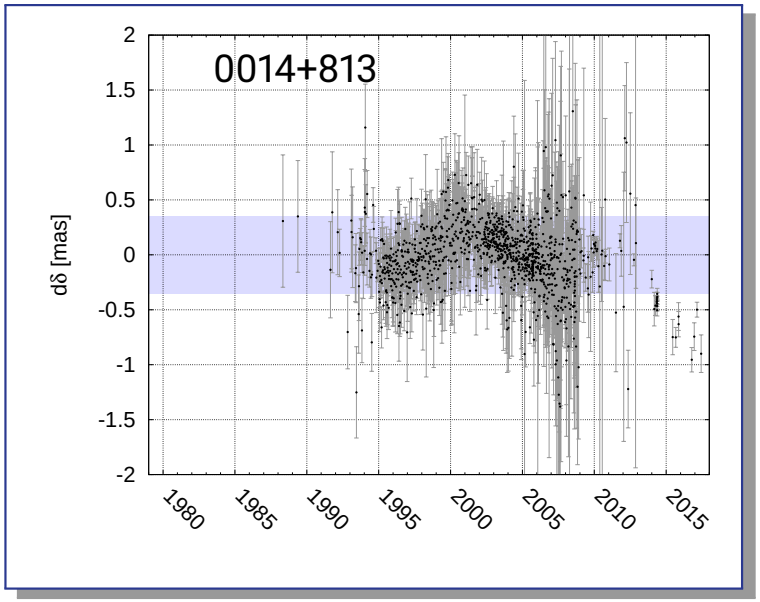
- extrinsic causes : e.g. observing system

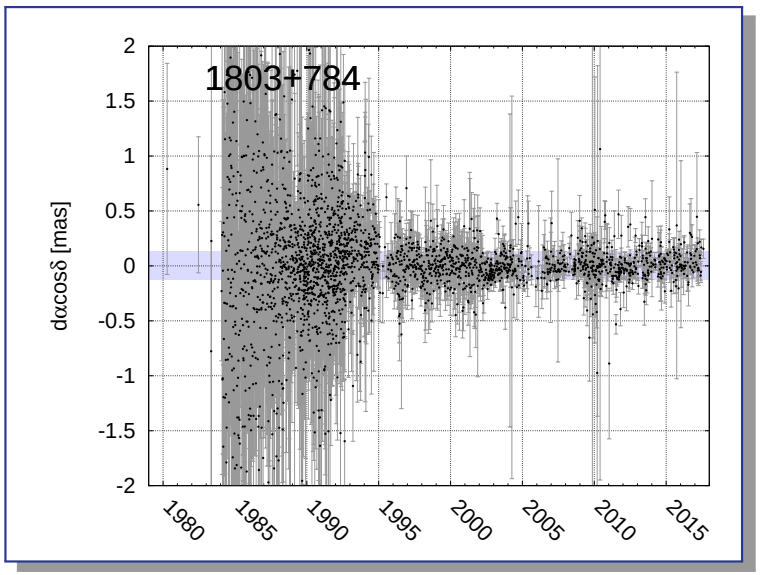
  inhomogeneity of the observing network, atmospheric propagation model

- intrinsic causes : physical phenomena of the source

  e.g. radio knots moving from the main core along the jet, main core instability, supermassive binary black hole

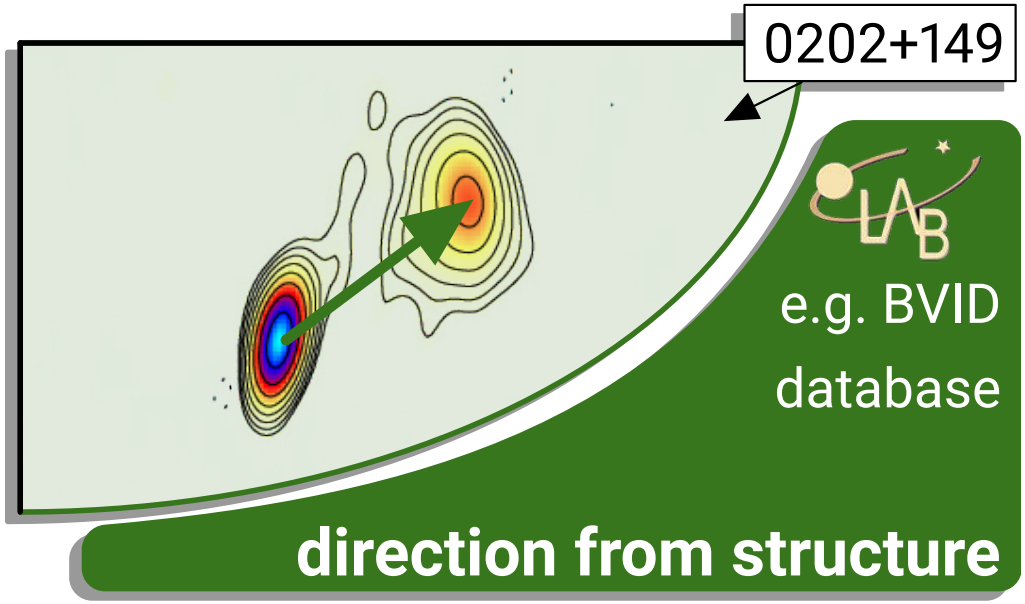
→ Correlation of the photometric and astrometric variabilities favors intrinsic causes [Shabala et al., 2014].





Directional analysis : different observations

- VLBI core located within the AGN jet
- structure direction = AGN jet direction

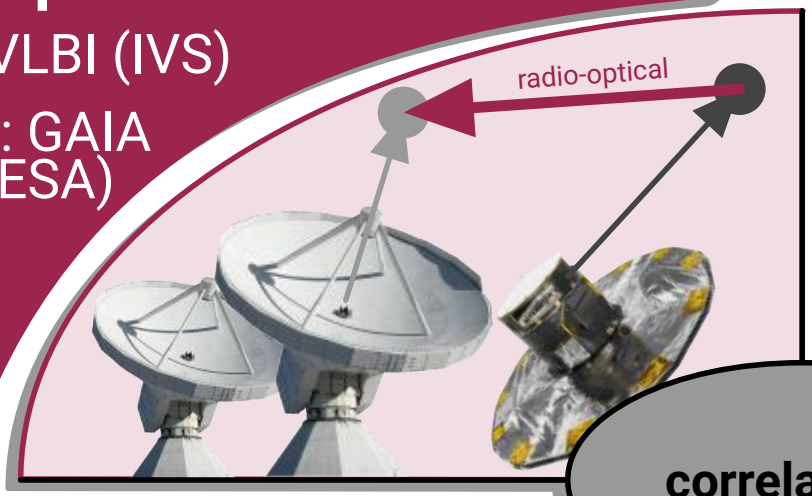


Directional analysis : different observations

radio-optical direction

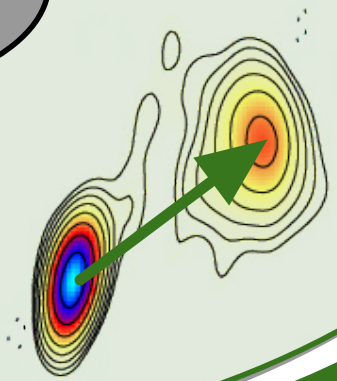
radio : VLBI (IVS)

optical : GAIA (ESA)



correlation ?

0202+149



e.g. BVID database

direction from structure

- VLBI core located within the AGN jet
- structure direction = AGN jet direction
- optical centroid $\rightarrow$ within the jet ? accretion disk ? host galaxy ?

$\rightarrow$ VLBI-Gaia offsets are preferentially oriented along the structure direction.

Kovalev et al. [2017], Petrov and Kovalev [2017a,b]

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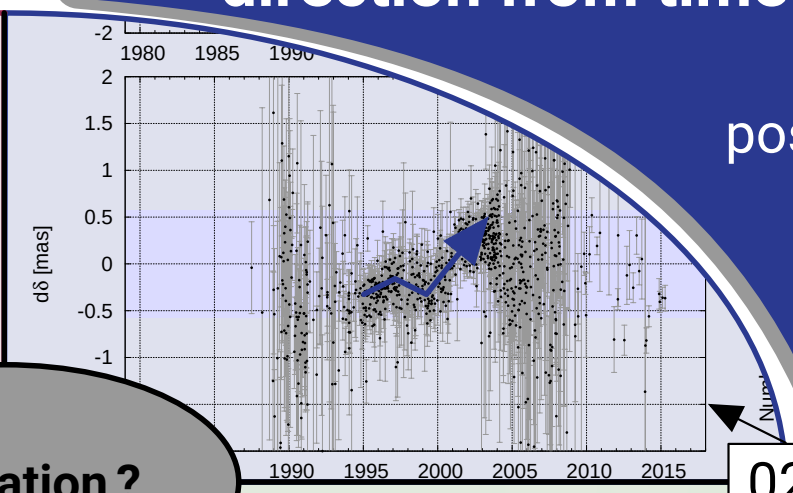
direction from time series

possibililty

?



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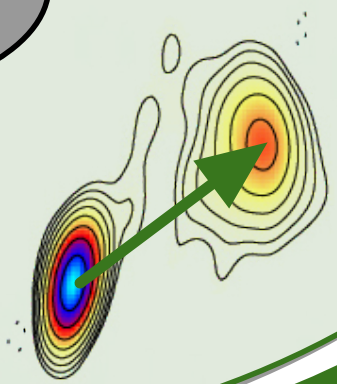

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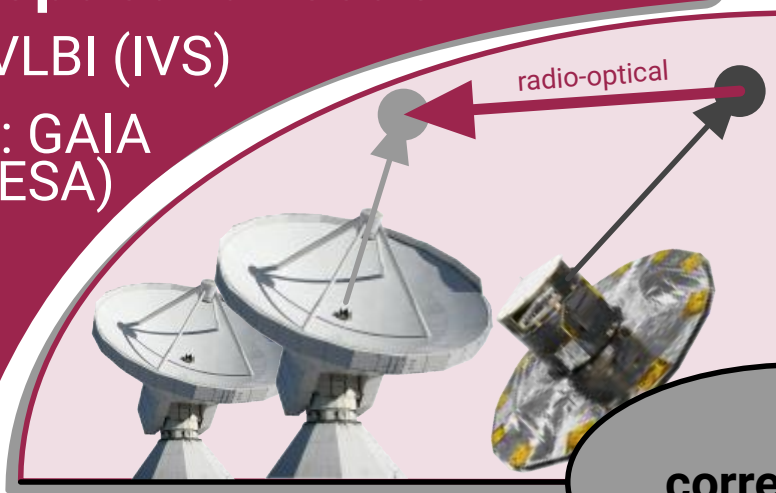
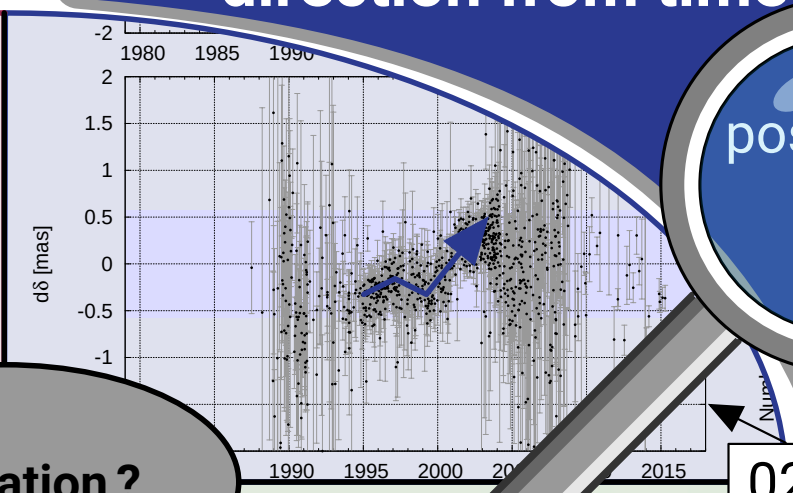


direction from time series



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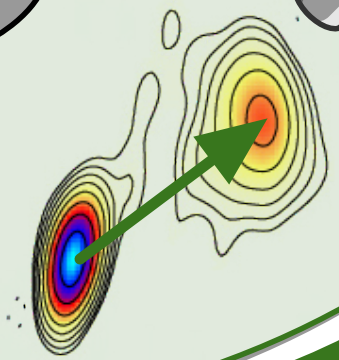

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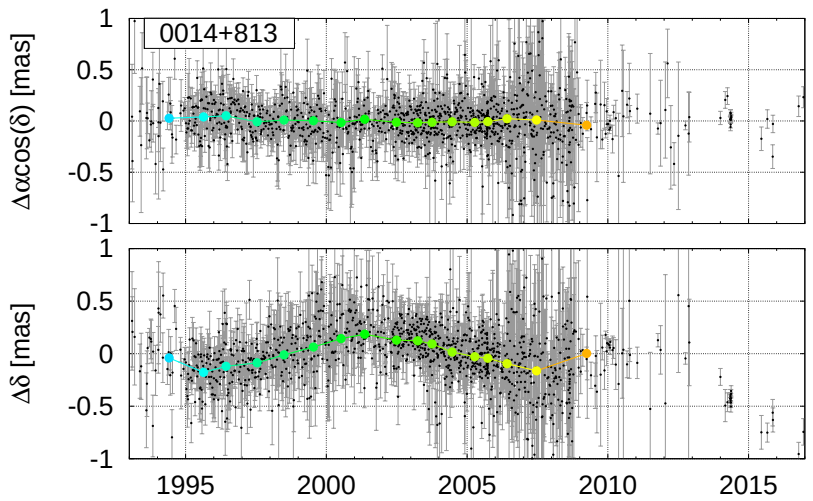
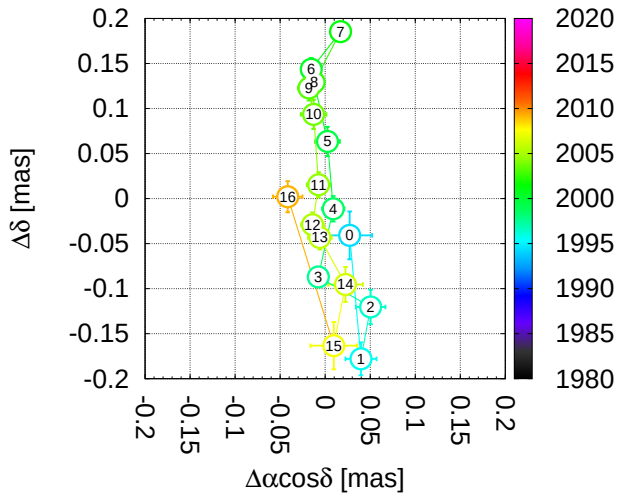
Extract a direction from astrometric variability
→ Proposed methodology

1) Reduction of data series by averaging :

one averaged point
=
50-100 original points

2) Conversion of successive points on the local plane into vector (θ, ρ).





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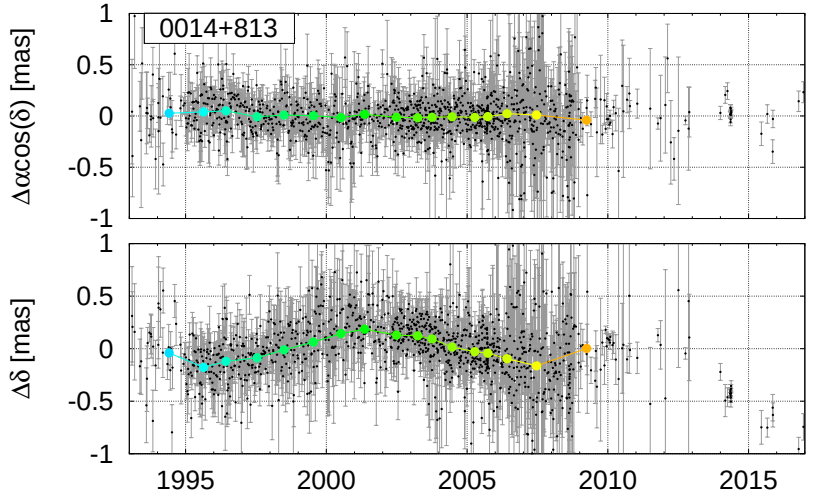

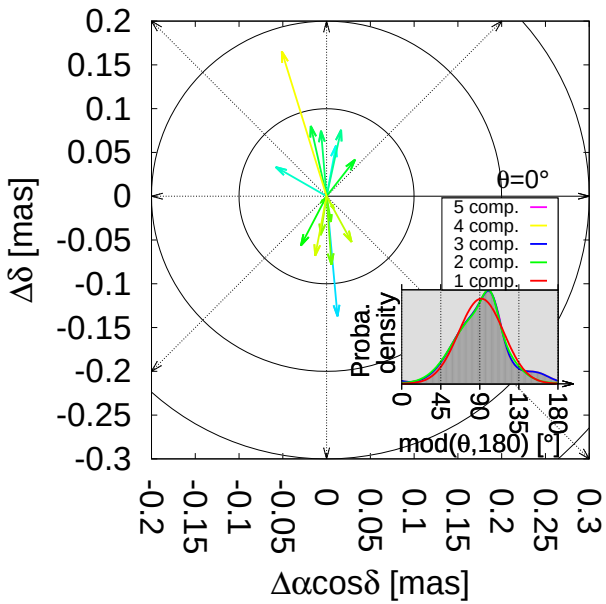

2) Conversion of successive points on the local plane into vector (θ, ρ).

To each vector is associated a gaussian function for which :

the center	is the value θ of the vector angle
the width	is related to the computed uncertainty σ_θ
the amplitude	is the ratio between the length ρ of the vector and its computed uncertainty σ_ρ.

3) Computation of the direction Probability Density Function [PDF] by summing all the gaussian functions.

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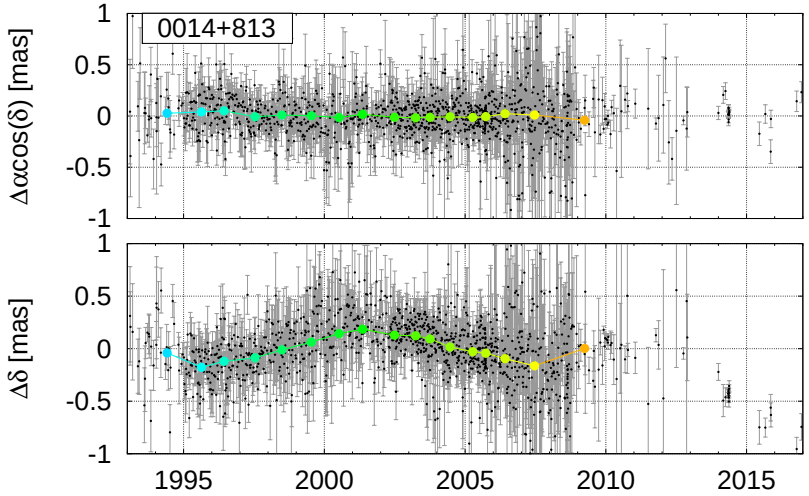

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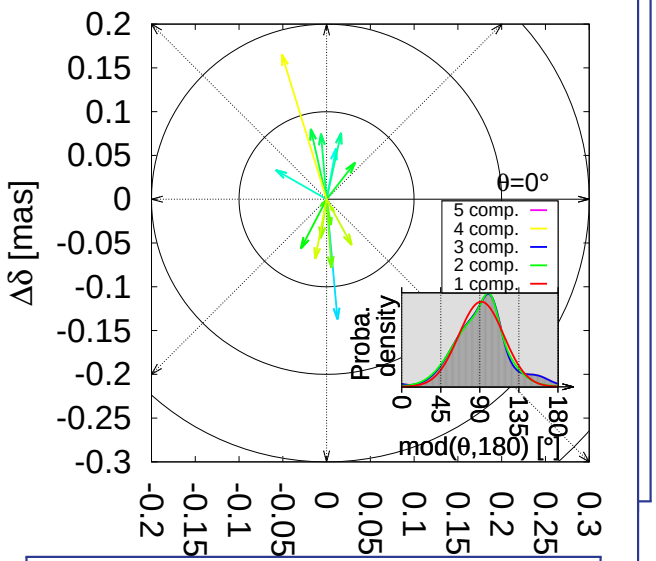

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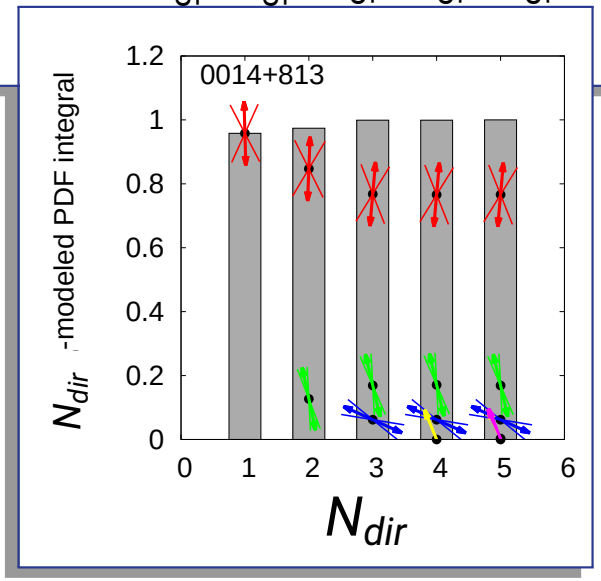
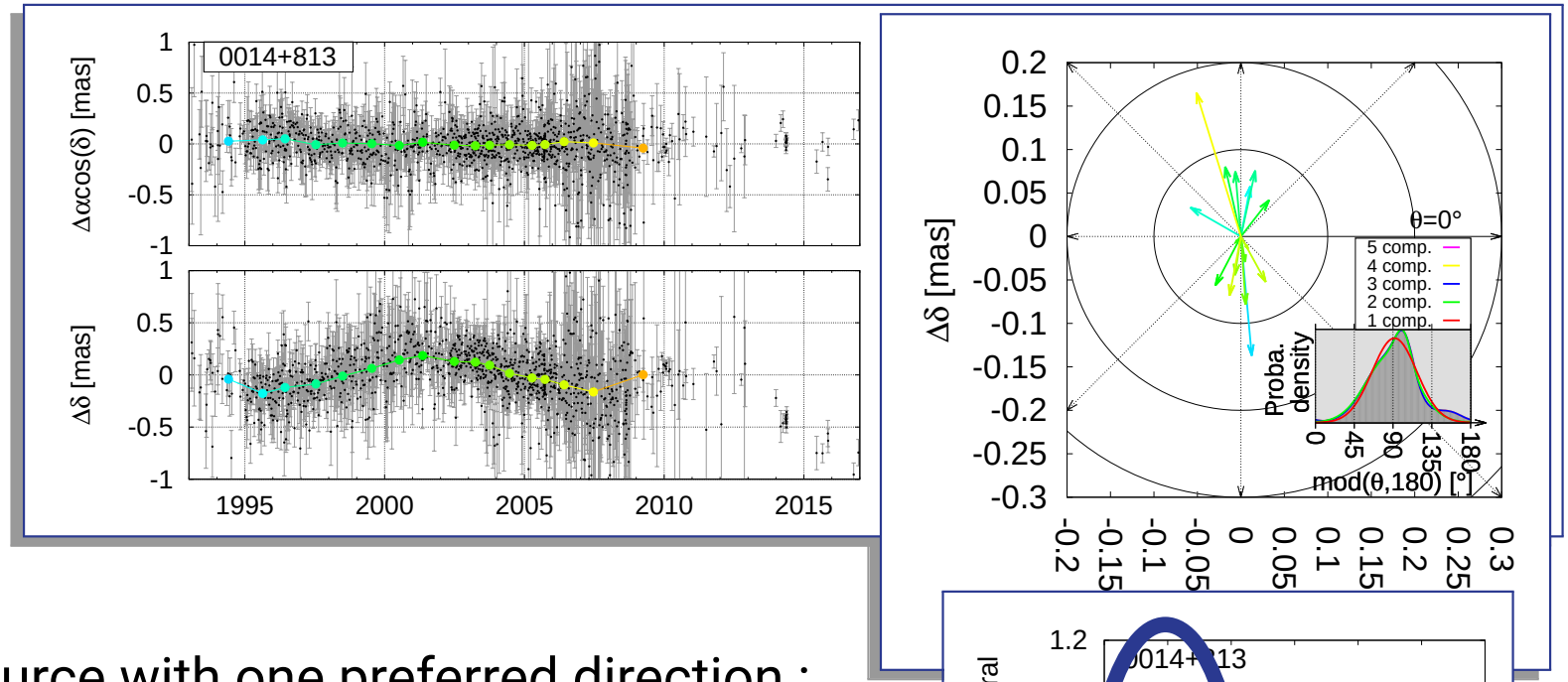
4) Adjustments of 1-5 gaussian function(s) from the PDF.

Θ_i are the preferred directions and σ_{Θ_i}, their uncertainties

the relevance of the adjusted model is given by the closeness of its integral to 1.

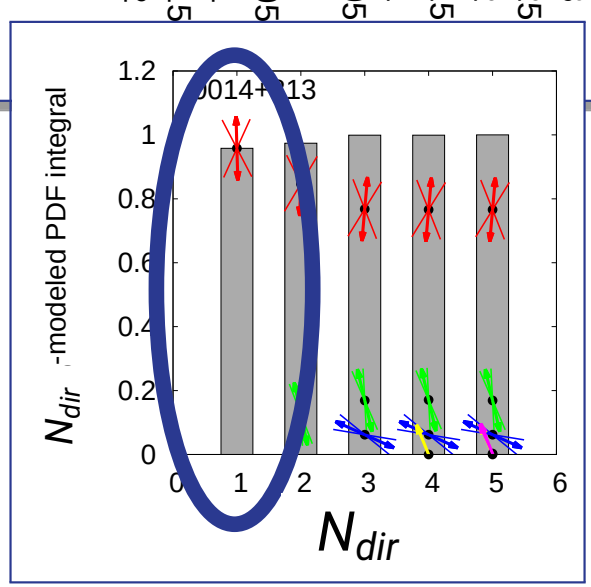


Extract a direction from astrometric variability
→ Proposed methodology

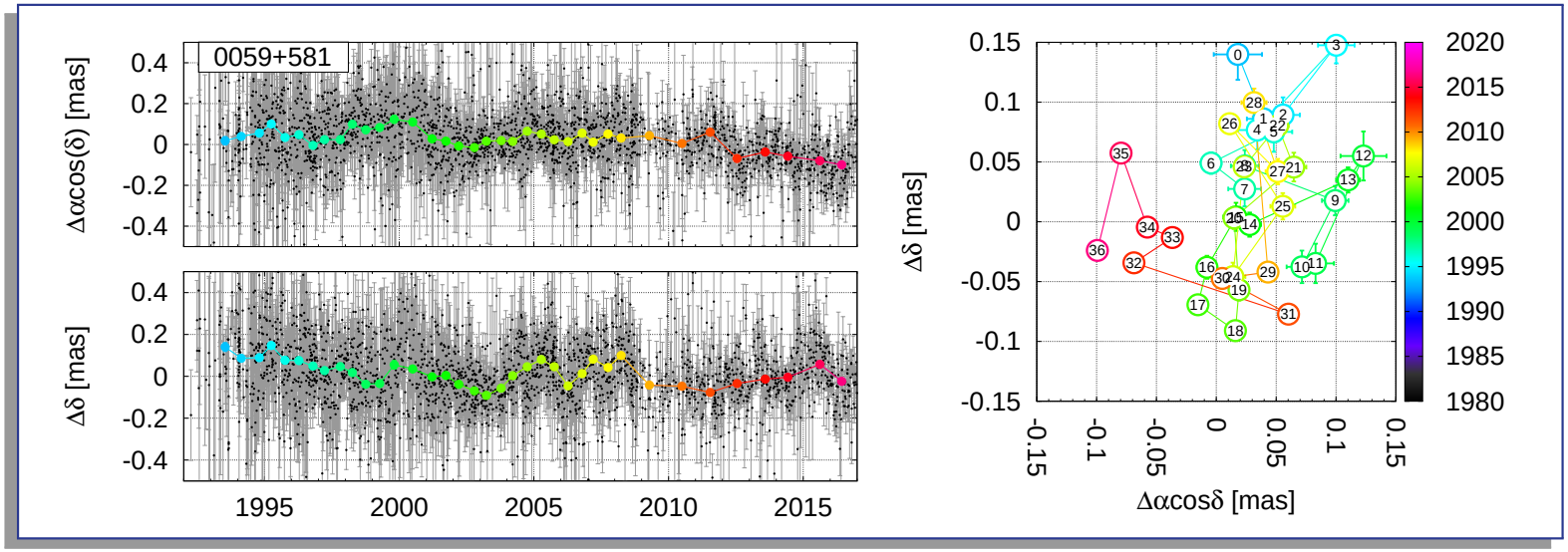


Example of a source with one preferred direction :

→ 0014+813 : $N = 1, \quad \Theta_1 = 92 \pm 25°$.

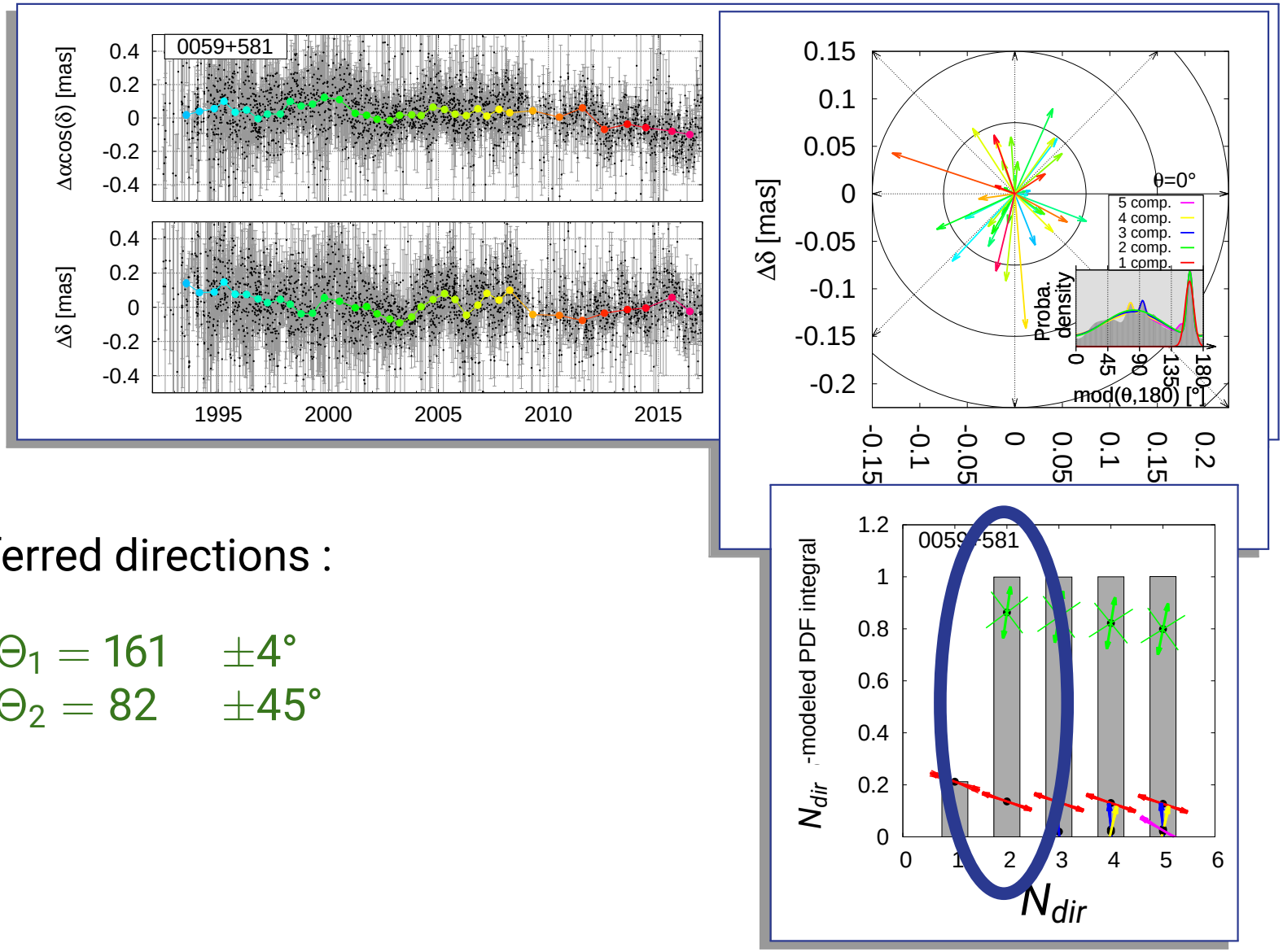


Extract a direction from astrometric instabilities → Another example



Case with 2 preferred directions :

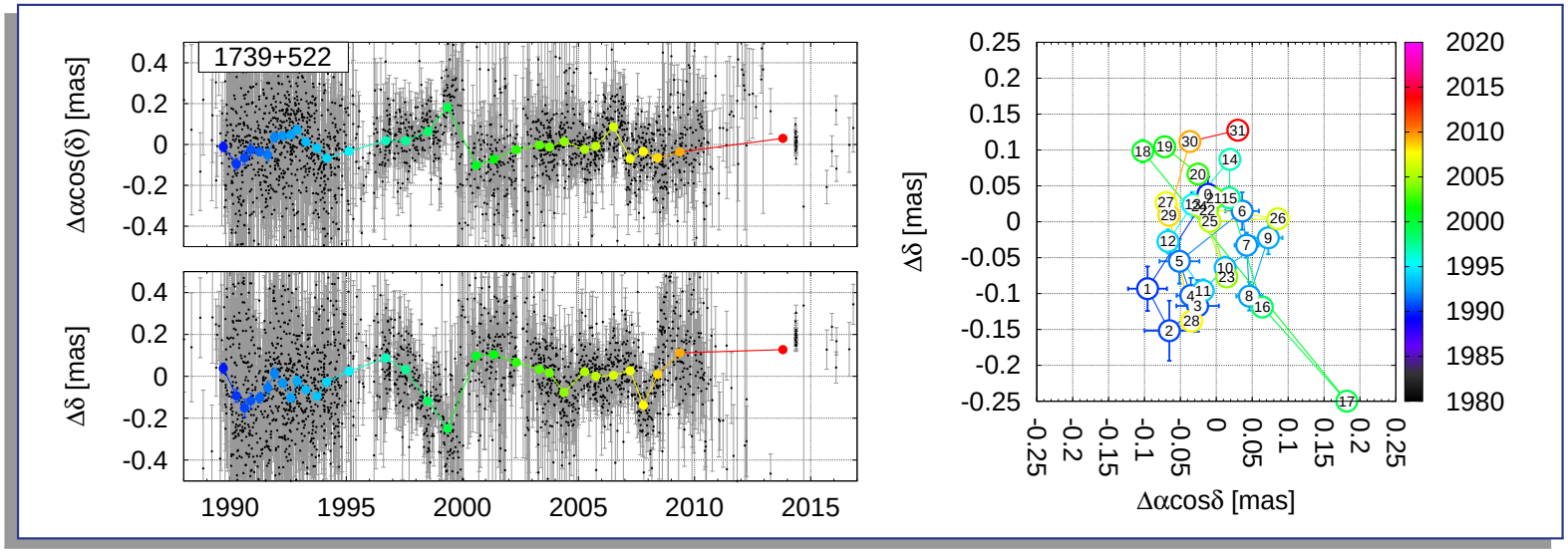
Extract a direction from astrometric instabilities → Another example



Case with 2 preferred directions :

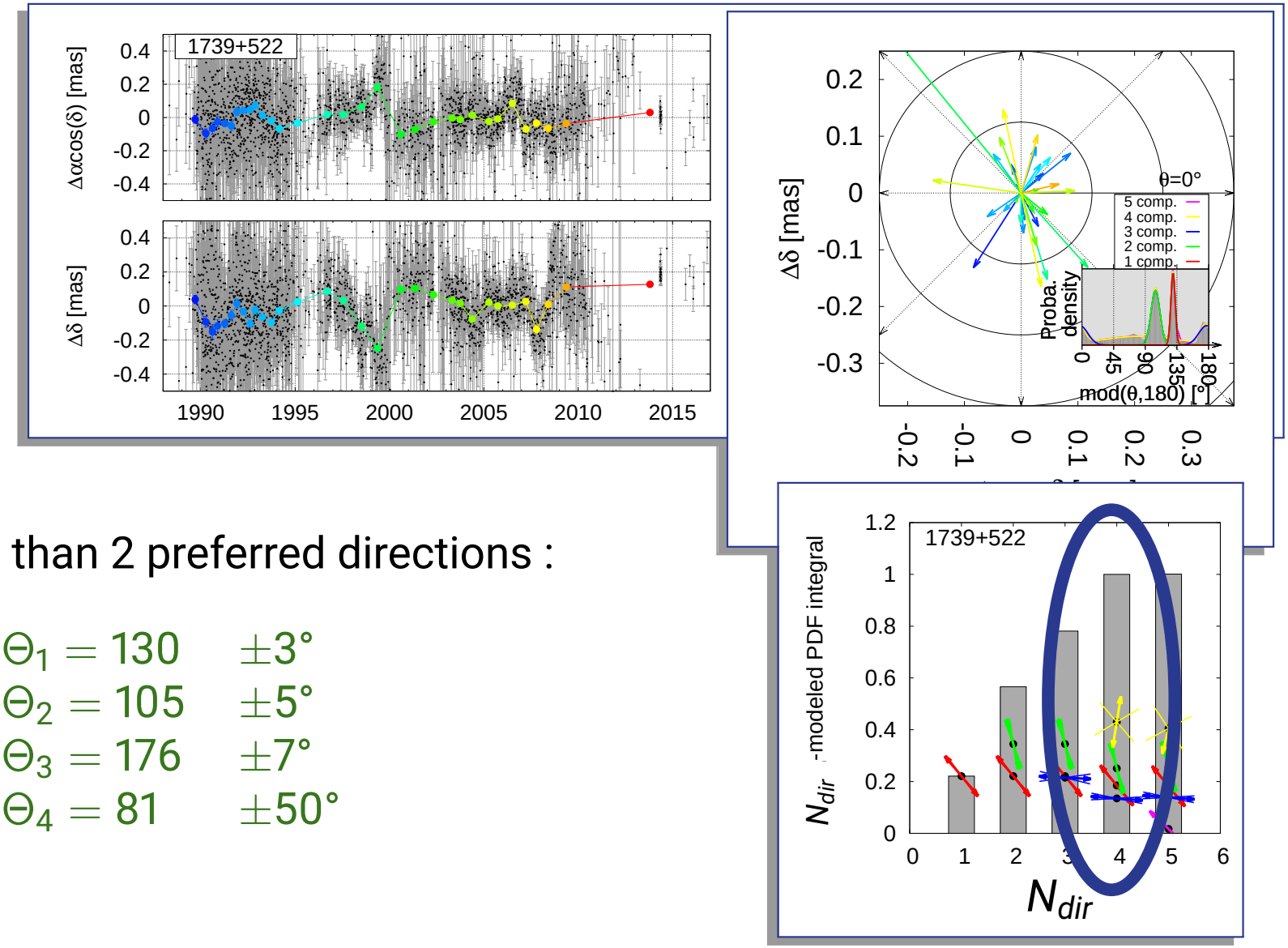
→ 0059+581 : $\Theta_1 = 161 \quad \pm 4°$
$\Theta_2 = 82 \quad \pm 45°$

Extract a direction from astrometric instabilities → Another example



Case with more than 2 preferred directions :

Extract a direction from astrometric instabilities
→ Another example

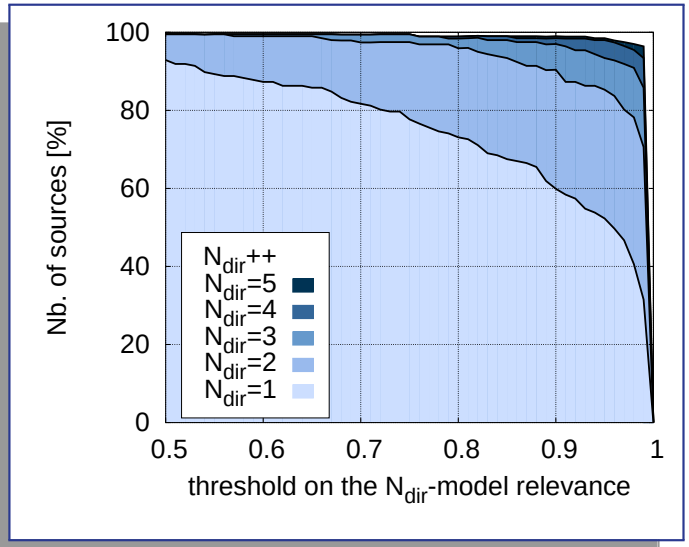


Case with more than 2 preferred directions :

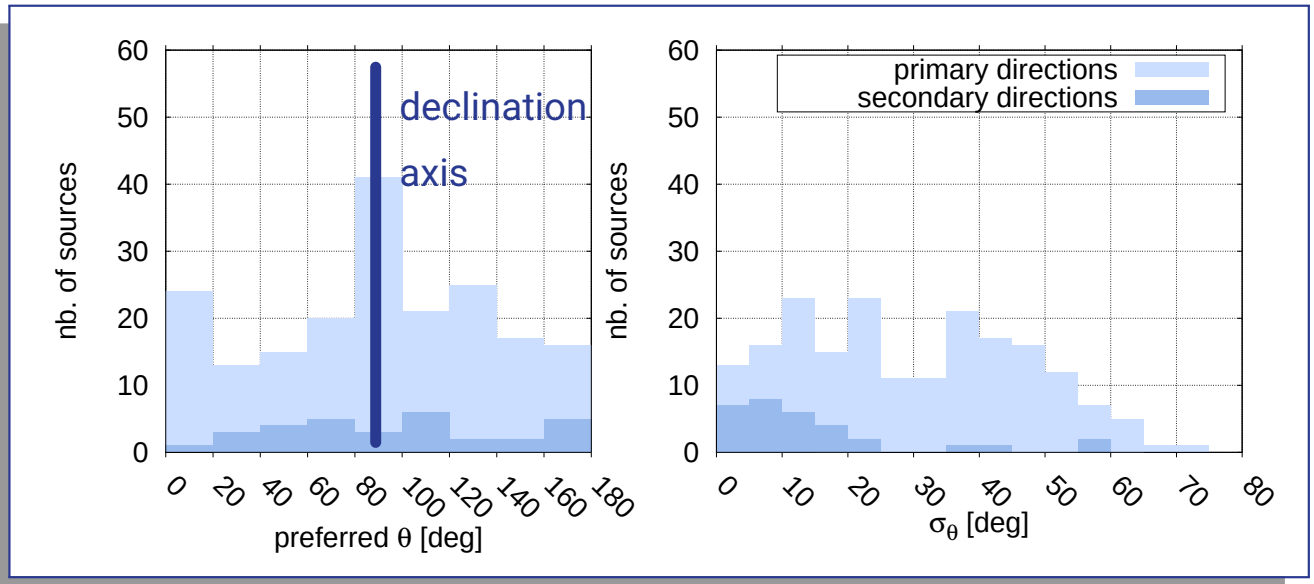
→ 1739+522 :

$$\Theta_1 = 130 \quad \pm 3°$$
$$\Theta_2 = 105 \quad \pm 5°$$
$$\Theta_3 = 176 \quad \pm 7°$$
$$\Theta_4 = 81 \quad \pm 50°$$

Extract a direction from astrometric instabilities → Overvall result

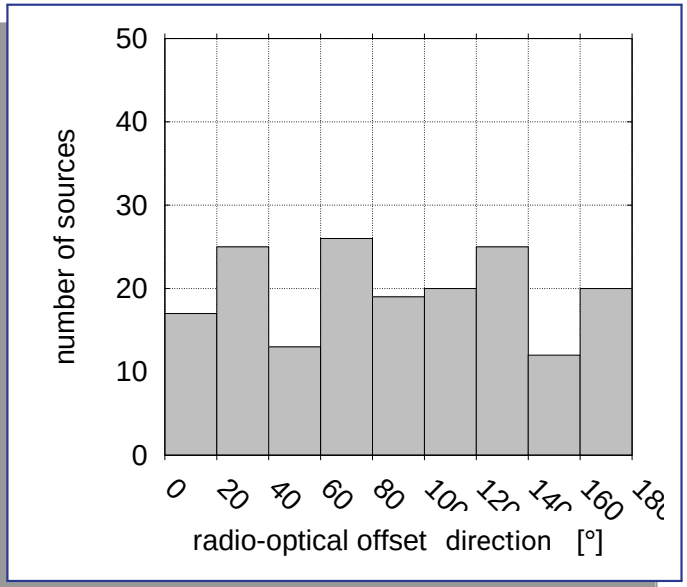


- The method provides a preferred direction for a majority of the 197 sources studied.
- Resulting uncertainties are 10-60° for the primary directions, smaller for the secondary directions.
- Excess of directions around 90° (along the declination axis) → astrophysical effect unlikely ! effect from the observing system ?



- Up to ∼20% sources may be subjected to two directions.

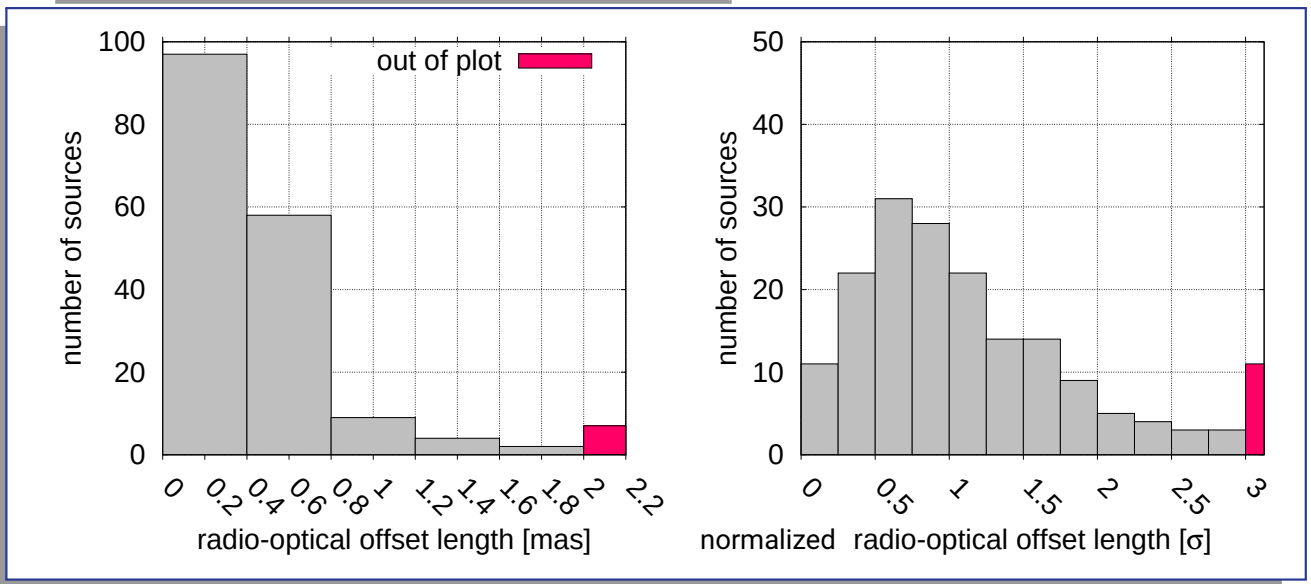
Extract a direction from radio-optical offsets
→ Overall result



- Among the 197 sources most observed by VLBI, 177 have an optical counterpart detected by Gaia-DR2.

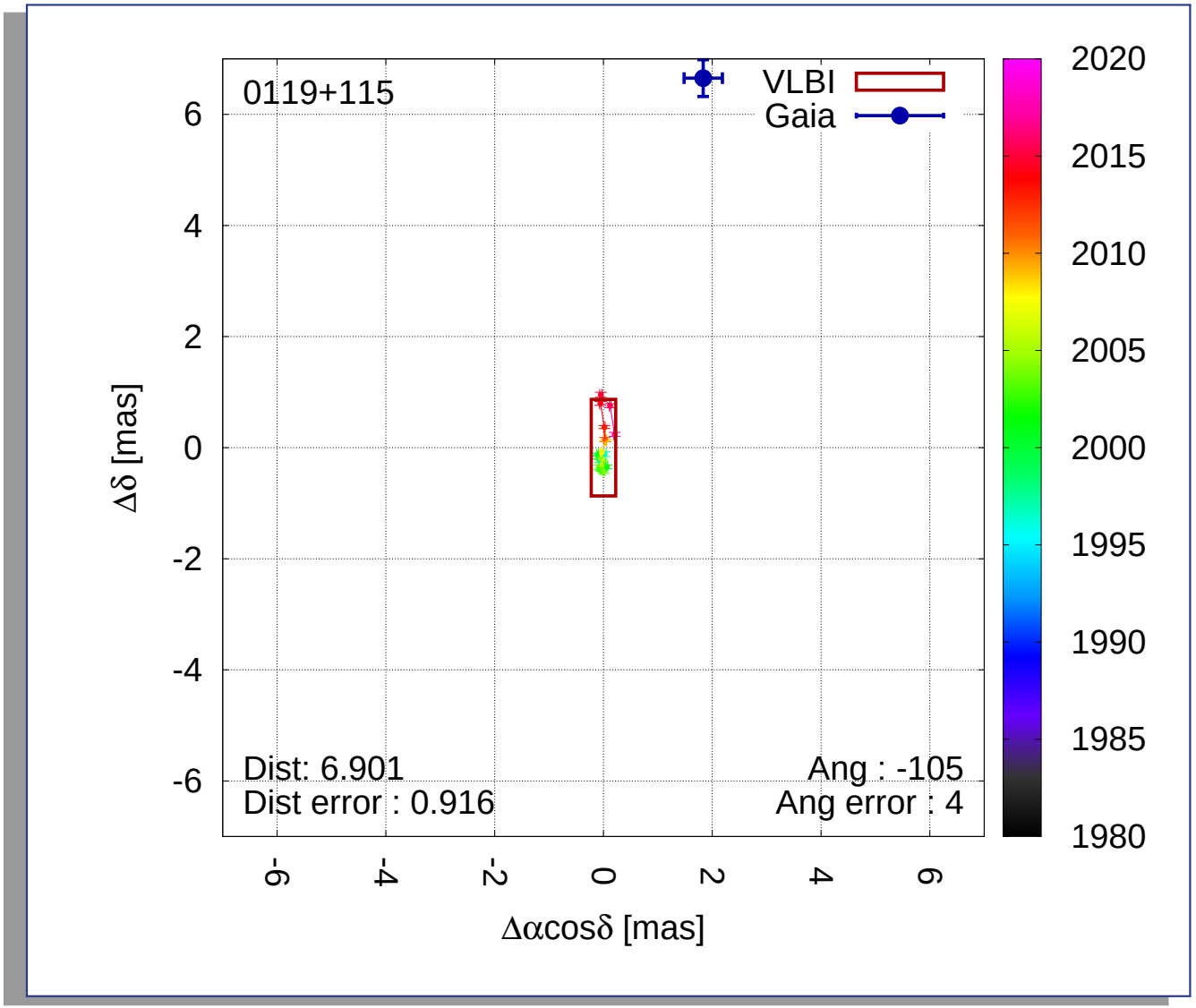
→ Study their radio-optical offset.

- Preferably small radio-optical offset ($\leq$0.8 mas)



- Only 11 sources have significant (3σ confidence) offset
- Homogeneous direction distribution.

Comparison of the two directions
Examples



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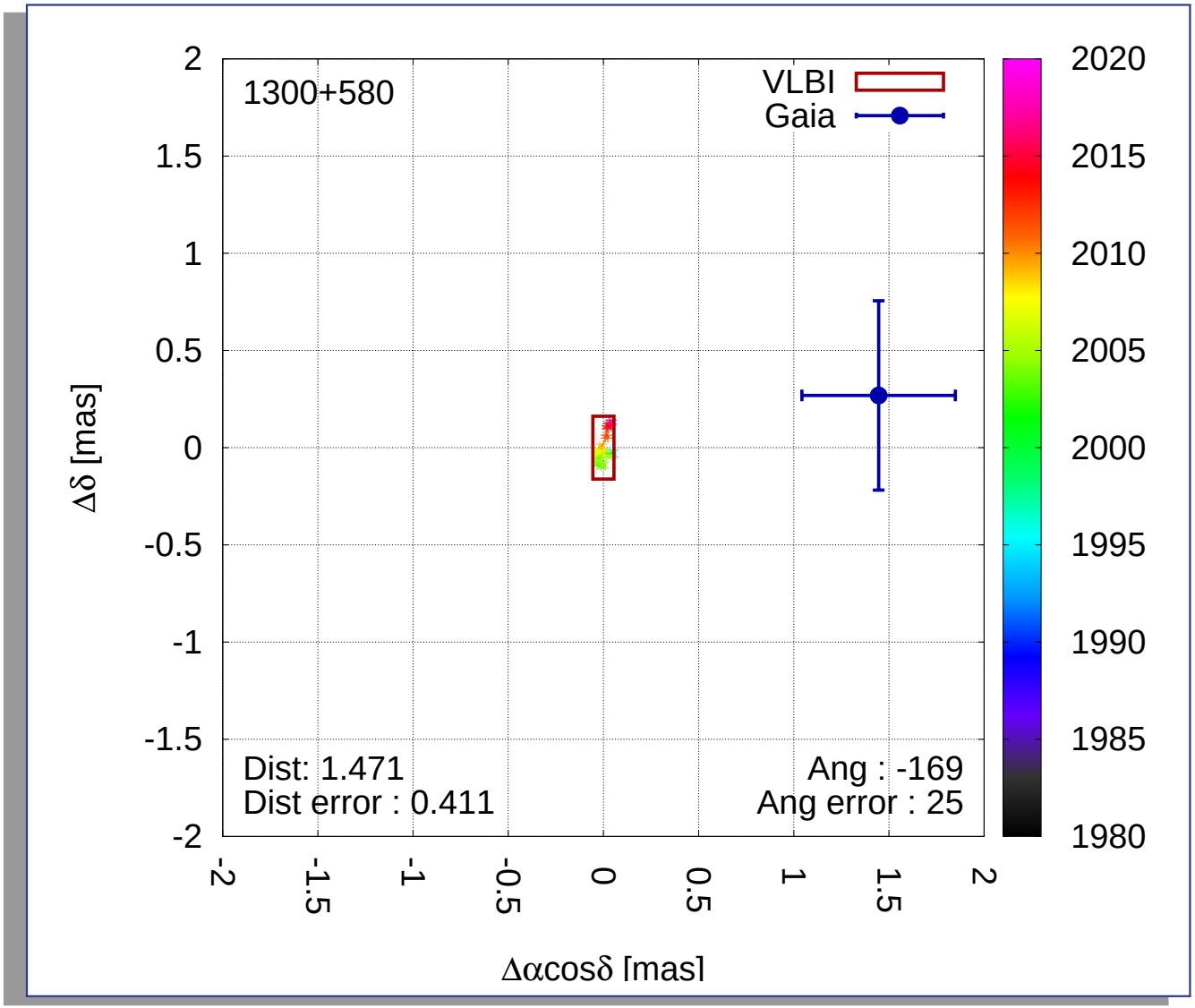
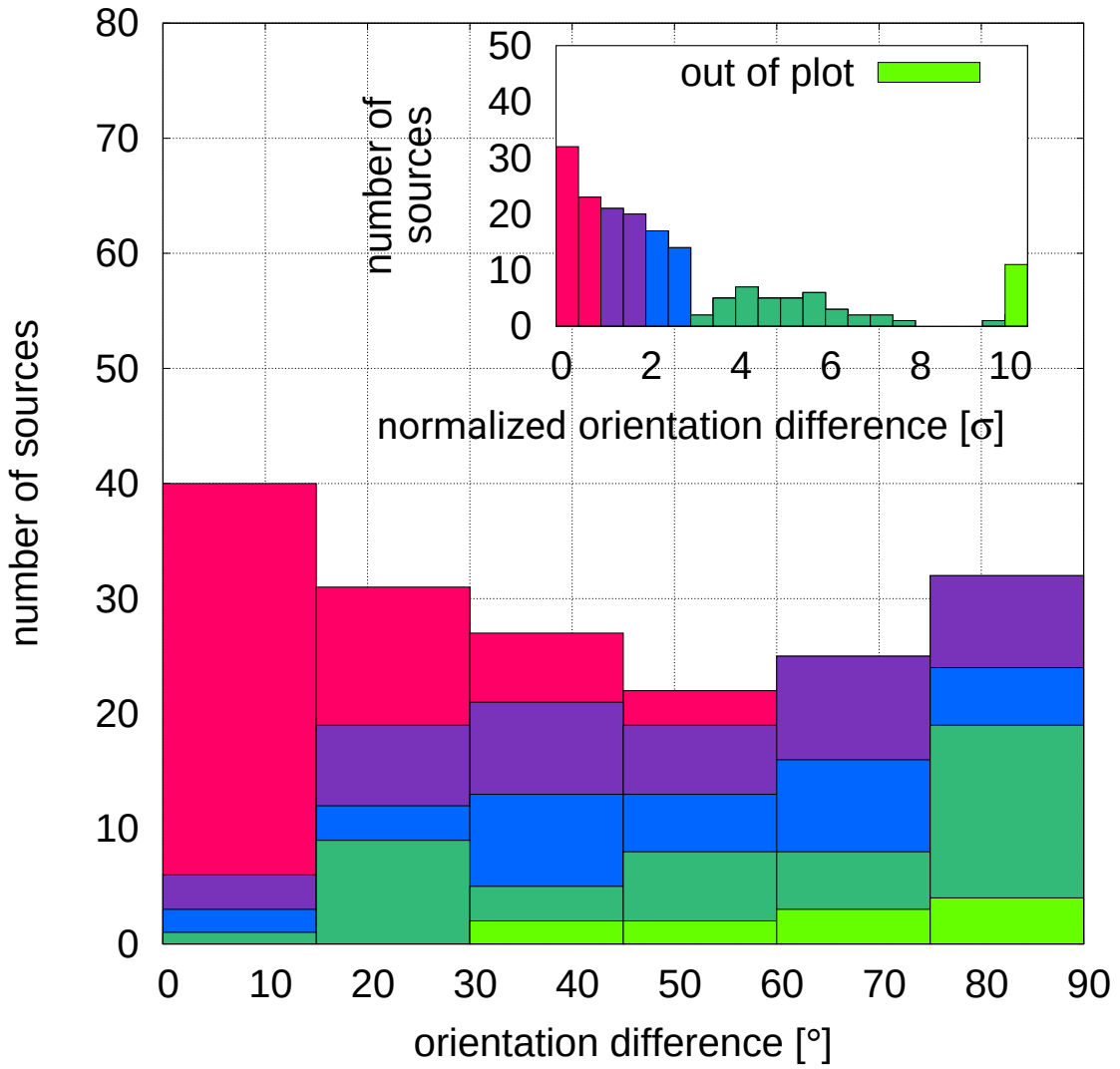


Comparison of the two directions
Result



Two configurations :

1) Aligned directions
(diff. close to 0°)

2) Perpendicular directions
(diff. close to 90°)

- Assuming astrometric variability along the jet, radio-optical offset across the jet. ⇒ Accretion disk or host galaxy may dominate the optical part of the source.
- Assuming VLBI-Gaia offset along the jet, astrometric variability is happening across the jet.

Conclusion and perspectives

- It is possible to extract a directional information from geodetic VLBI astrometric time series with good uncertainties ($\sigma_\theta \sim 10°$) and sometimes large uncertainties ($\sigma_\theta \sim 60°$).
- Two directions needed to characterize ∼20% of sources observed with geodetic VLBI $\rightarrow$ hints for binary black holes ?
- Radio-optical analysis reveals two configurations, sources with the direction of the astrometric variability aligned with the radio-optical offset or perpendicular.

$\rightarrow$ forthcoming : add the jet direction computed from the Bordeaux VLBI Image Database.

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