Bias of core shift effect measurement in the blazars jets

I.N. Pashchenko(*)(1), A.M. Kutkin(1) & Y.Y. Kovalev(1,2,3)

(1) Astro Space Center of Lebedev Physical Institute, Russia, (2) Moscow Insitute of Physics and Technology, Russia, (3) Max-Planck-Institut für Radioastronomy, Germany

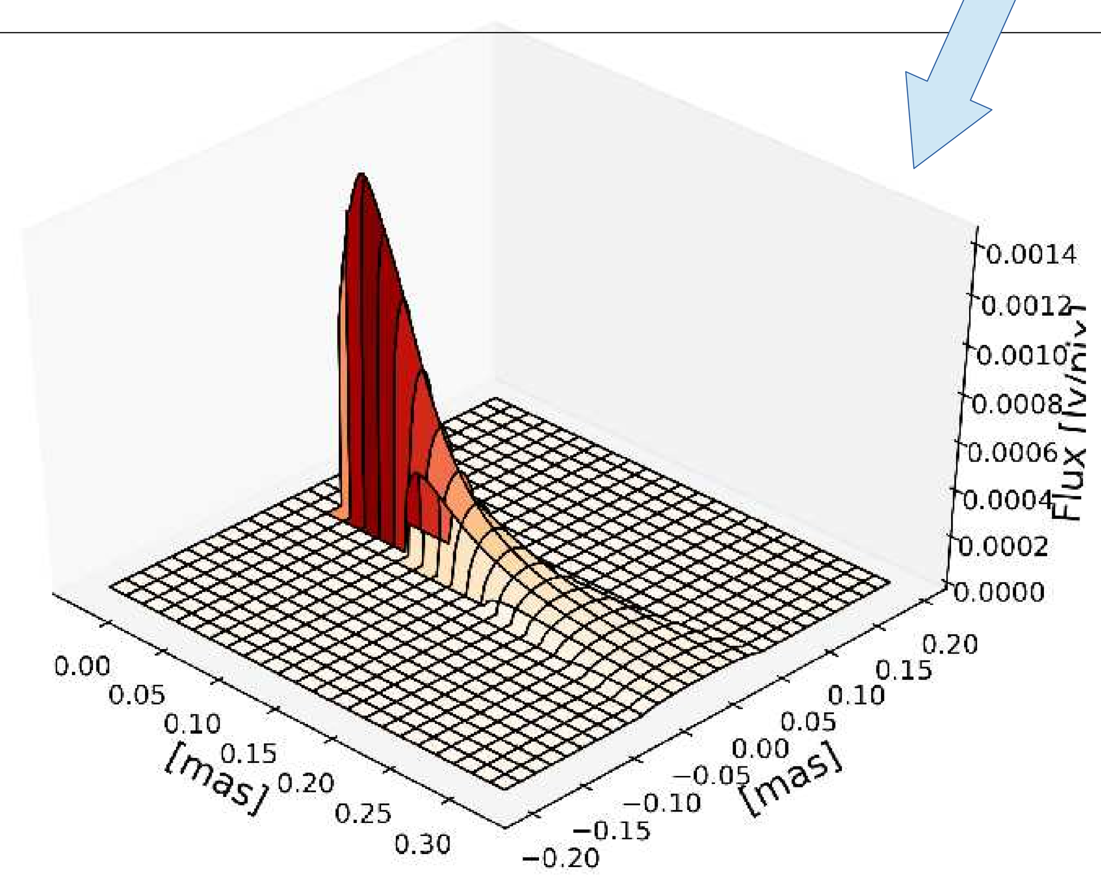
(*) in4pashchenko@gmail.com

The effect

The observed *VLBI core* in quasars is $\tau_{ssa} \approx 1$ surface and its position changes with frequency ν [1]. The value of the shift allows to estimate the magnetic field at 1 pc: $B_1 \sim (\Delta r_{\nu 1\text{-}\nu 2})^{3/4}$ assuming equipartition [2] and $B_1 \sim (\Delta r_{\nu 1\text{-}\nu 2})^5$ without [3]. It also can be used to constrain the flow speed in core region [4, 5] that occurred to be higher than estimated using kinematics of the jet components.

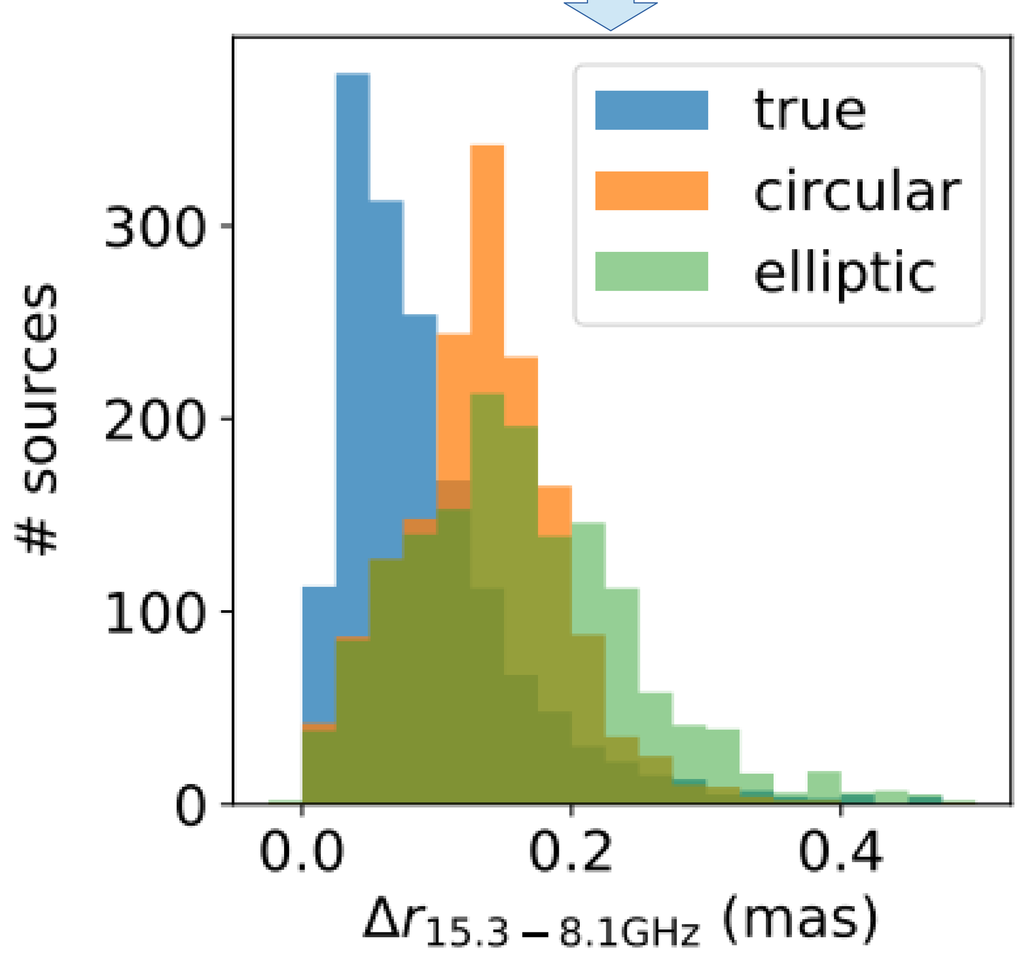
The problem is that ...

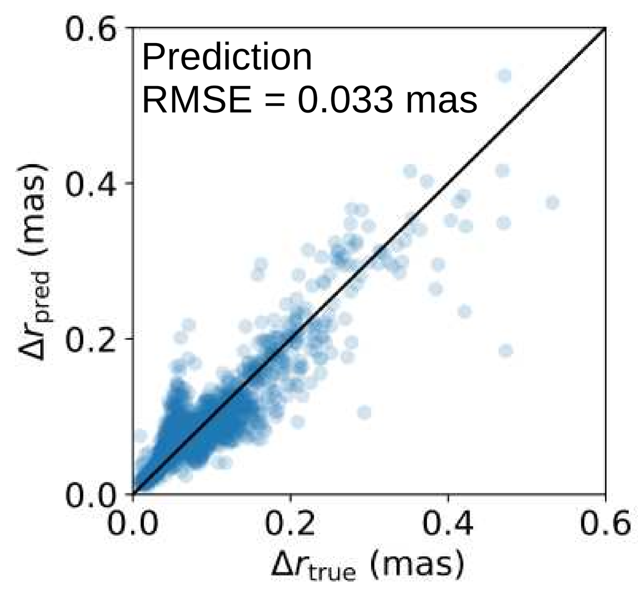
... to measure the core shift one needs to know core position at different frequencies. Core is fitted with a Gaussian, but jet model [1] has *more complex shape*. Oversimplification brings biased estimates.
Is that bias significant?



Method

To assess the bias one needs to know the true model. We created *artificial sample* of ~1.5k sources using BK model [1] on a grid of the parameters conditioned on the observed MOJAVE sample (Luminosity Function [6], apparent opening angles [7] and speeds [8]). Using noise and *uv*-coverage of the real data we compared *true* values of the core shift Δr with those one would estimate by *difmap* modelfitting with circular and elliptic core model .

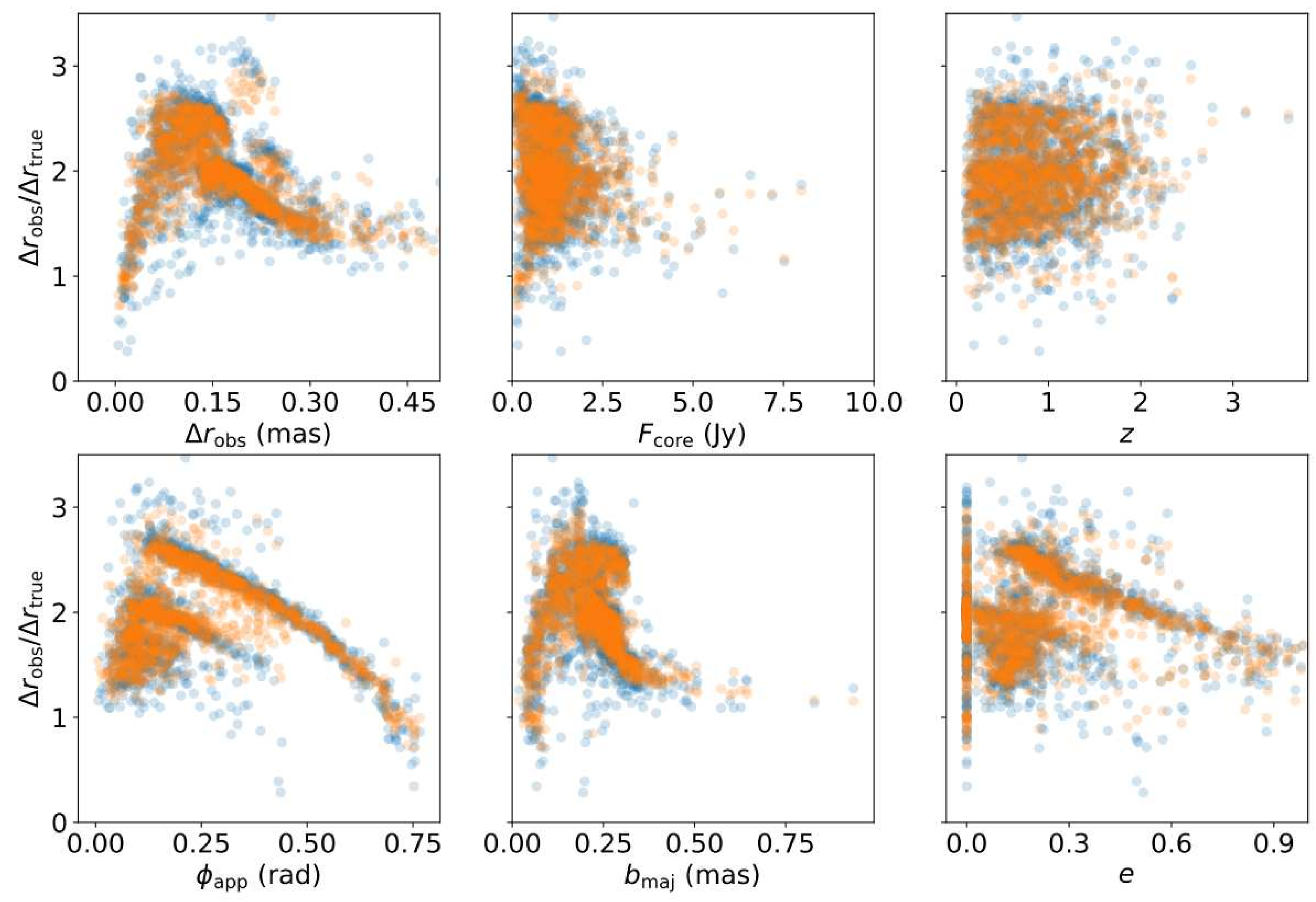


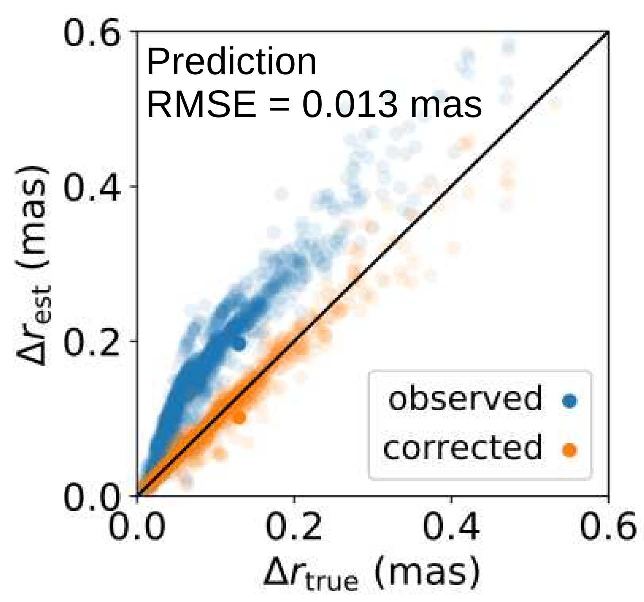


Upper: 15.3-8.1 GHz core shifts predicted by Random Forest trained on the artificial sample vs true shifts.

Results

Core shift estimates are biased by a typical factor $\approx$ 2, but it depends on the observed core parameters in a highly non-linear way. Bias can be corrected using the flexible model trained on the results of simulations. Estimates of k from core shift frequency dependence ($\Delta r \sim \Delta\nu^{-1/k}$) are unbiased if core is represented with equal number of components at each band.





Upper: Observed in simulations and predicted with Random Forest dependence of the observed-to-true 15.3-8.1 GHz core shift ratio on the VLBI observables.

Left: Estimated vs. true 15.3-8.1 GHz core shifts both uncorrected and corrected for bias using the obtained model (see above).

Implications

- B_1 estimated assuming equipartition [2] are ~2x biased upward.
- Without equipartition assumption [3] ~ 1-2 orders of the mag.
- Reconciles B estimates from SED modelling and core shifts [9].
- Problem for MAD scenario [10].
- [3] found $\langle B_{\mathrm{noeq}}[3]/B_{\mathrm{eq}}[2] \rangle \approx$ 1.6 for blazars ($\approx$0.033 after correcting for bias) and $\approx$0.05 for radiogalaxies (we found them to have practically unbiased core shift estimates).
- Brings flow speed estimates [4, 5] closer to the kinematical ones.

By the way...

Using artificial sample we show that jet model [1] allows to estimate the (*unbiased*) core shift using VLBI-observables only at a single frequency.

Conclusions

Core shifts in blazars are typically overestimated. Therefore, magnetic fields deduced from the core shifts are also overestimated by a factor of $\approx$2 (with) or ~10-100 (w/o equipartition assumption). Frequency dependence of the core shift is not biased if the core is modelled with the same number of components at each frequency.

References:
1. Blandford, R. D.; Königl, A., AJ 232, p.34, 1979
2. Lobanov A. P., A&A 330, p. 79, 1998
3. Zdziarski A.A., Sikora M. *et al.*, MNRAS 451, p.927, 2015
4. Kutkin A.M., Pashchenko I.N. et al., MNRAS 475, p.4994, 2018
5. Kutkin A.M., Pashchenko I.N. et al., eprint arXiv:1809.05536
6. Cara M., Lister M.L., ApJ 674, p.111, 2008
7. Lister M.L. et al., AJ 138, p.1874, 2009
8. Clausen-Brown E. et al., A&A 558, A144, 2013
9. Nalewajko K. et al., ApJ 796, L5, 2014
10. Zamaninasab M. et al., Nature 510, p.126, 2014

Data used:
This research has made use of data from the MOJAVE Database that is maintained by the MOJAVE team (Lister et al., 2009, AJ, 137, 3718)

Acknowledgements:
This work is supported by Russian Science Foundation grant 16-12-10481.