Masachika A. Kijima: Application of Geodetic VLBI Data to Obtaining Long-term Light Curves for Astrophysics,
IVS 2010 General Meeting Proceedings, p.266–270
http://ivscc.gsfc.nasa.gov/publications/gm2010/kijima.pdf

Application of Geodetic VLBI Data to Obtaining Long-term Light Curves for Astrophysics

Masachika A. Kijima

(1) SOKENDAI (The Graduate University for Advanced Studies) and (2) National Astronomical Observatory of Japan

e-mail: masachika.kijima@nao.ac.jp

Abstract

The long-term light curve is important to research on binary black holes and disk instability in AGNs. The light curves have been drawn mainly using single dish data provided by the University of Michigan Radio Observatory and the Metsähovi Radio Observatory. Hence, thus far, we have to research on limited sources. I attempt to draw light curves using VLBI data for those sources that have not been monitored by any observatories with single dish. I developed software, analyzed all geodetic VLBI data available at the IVS Data Centers, and drew the light curves at 8 GHz. In this report, I show the tentative results for two AGNs. I compared two light curves of 4C39.25, which were drawn based on single dish data and on VLBI data. I confirmed that the two light curves were consistent. Furthermore, I succeeded in drawing the light curve of 0454-234 with VLBI data, which has not been monitored by any observatory with single dish. In this report, I suggest that the geodetic VLBI archive data is useful to obtain the long-term light curves at radio bands for astrophysics.

1. Introduction

Long-term light curves and VLBI images are useful to investigate the physics of AGNs, binary black holes, and disk instability [1][2][3]. The most extensive monitoring campaigns have been conducted by two observatories, the University of Michigan Radio Observatory (UMRAO) and the Metsähovi Radio Observatory (MRO). The UMRAO has observed over 170 sources at 4.8, 8.0, and 14.5 GHz for over three decades [4]. At higher frequencies, the MRO has published observational measurements at 22, 37, and 87 GHz of over 200 extragalactic radio sources, many of which have been observed for over 10 years [5][6][7]. The studies of AGN variability have been mainly based on the data obtained by the UMRAO and the MRO.

Geodetic VLBI has been conducted for 30 years. The numbers of sources are above 1000 and 3000 at X- and S-band, respectively. Geodetic VLBI archive data can also allow us to draw the long-term light curves as well as hitherto single dish observations.

2. Data Reduction

2.1. Procedure

In this section, the procedure to estimate total flux density is described briefly (Fig.1). The detail and parameters used in each program module are described in the next section.

- “Raw-data” is the archive-data file publicly available at the IVS Data Centers. The number of the files is above 20,000.

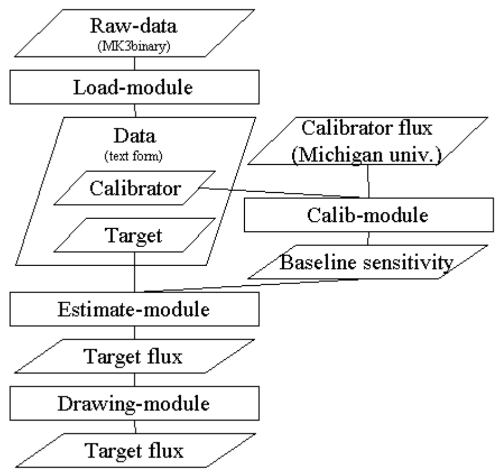

Figure 1. The schematic flow. The parallelograms and rectangles indicate data files and program modules, respectively.

- "Load-module" converts the data format from MK3binary to text form. The module also extracts and collects observational parameters into the one file. The observational parameters are observing date, time, names of the two antennas comprising the baseline, name of the target source, spatial frequencies (u, v, and w), and normalized correlation coefficient (hereafter $\rho_{i,j}$). i and j are ith- and jth-antenna, respectively.
- "Calibration-module" estimates baseline sensitivity ($SEFD_{i,j}$). The sensitivity is estimated with Eq.(1).

$$SEFD_{i,j} = \frac{S^{calibrator}_{UMRAO}}{\rho^{calibrator}_{i,j}} \tag{1}$$

  The sources which have been observed frequently are chosen as flux calibrators. The total flux density ($S^{calibrator}_{UMRAO}$) of the calibrator with a long period is provided by the UMRAO. $\rho^{calibrator}_{i,j}$ is the normalized correlation coefficient of the calibrator obtained by geodetic VLBI observations.
- "Estimate-module" estimates the correlation flux of the target source ($S^{target}_{i,j}$) with Eq.(2) for each baseline.

$$S^{target}_{i,j} = SEFD_{i,j} \times \rho^{target}_{i,j} \tag{2}$$

  $\rho^{target}_{i,j}$ is the normalized correlation coefficient of the target obtained by geodetic VLBI observations.
- "Drawing-module" estimates the total flux density of the target with the correlation flux densities of all baselines ($S^{target}_{i,j}$ for all i,j). The module divides data by time-bin, draws histograms of $S^{target}_{i,j}$. The total flux density (S^{target}) is estimated with the most frequent value (mode) of the histogram.

2.2. Example

In this section, the calculation and parameters of each module are described with a schematic example (Fig. 2).

Load-module: In the analysis so far, the source structure of the targets and the calibrators is not considered. The visibility data with uv-distance less than “uv range”, set to 50 Mλ in this example, is selected.

Calib-module: The $S_{UMRAO}^{calibrator}$ separated within the interval of the “polate range” are interpolated, and re-sampled at the rate of 1 day. The module makes pairs of $S_{UMRAO}^{calibrator}$ and $\rho_{i,j}^{calibrator}$, and calculates $SEFD_{i,j}$ with Eq.(1).

Estimate-module: The $SEFD_{i,j}$ within the interval “calib range” of $\rho_{i,j}^{target}$ are averaged. The module makes pairs of $SEFD_{i,j}$ and $\rho_{i,j}^{target}$, and calculates $S_{i,j}^{target}$ with Eq.(2).

Drawing-module: The module collects $S_{i,j}^{target}$ separated within the interval of “estim range” for all baselines, and draws histogram of $S_{i,j}^{target}$. The most frequent value (mode) of the histogram is estimated as S^{target}.

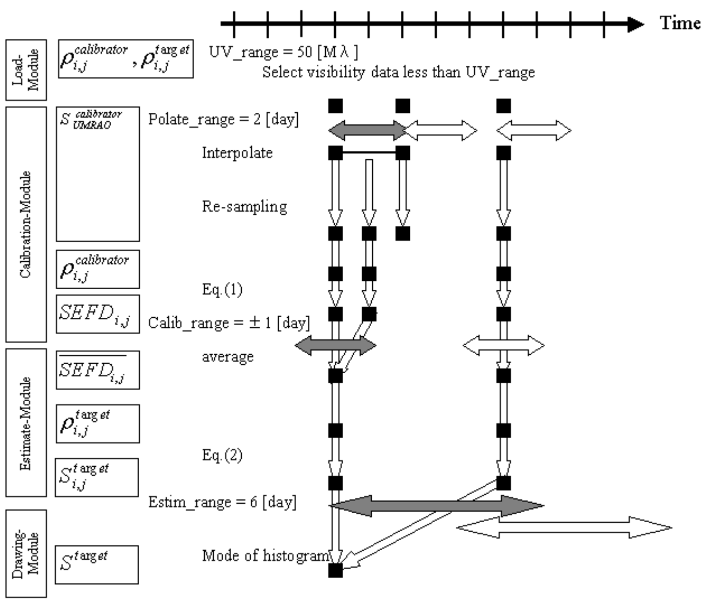

Figure 2. Schematic example. The filled square, the downwards-double arrow, and the left-right-double arrow express the data point, the calculation, and the range of parameter, respectively.

3. Preliminary Results

Initial results are shown in Fig. 3 and 4. For 4C39.25 (Fig. 3), we can see that the black and the gray light curves are consistent with each other. This result implies that we can use the VLBI data as well as single dish data to draw a light curve. For 0454-234 (Fig. 4), the UMRAO has

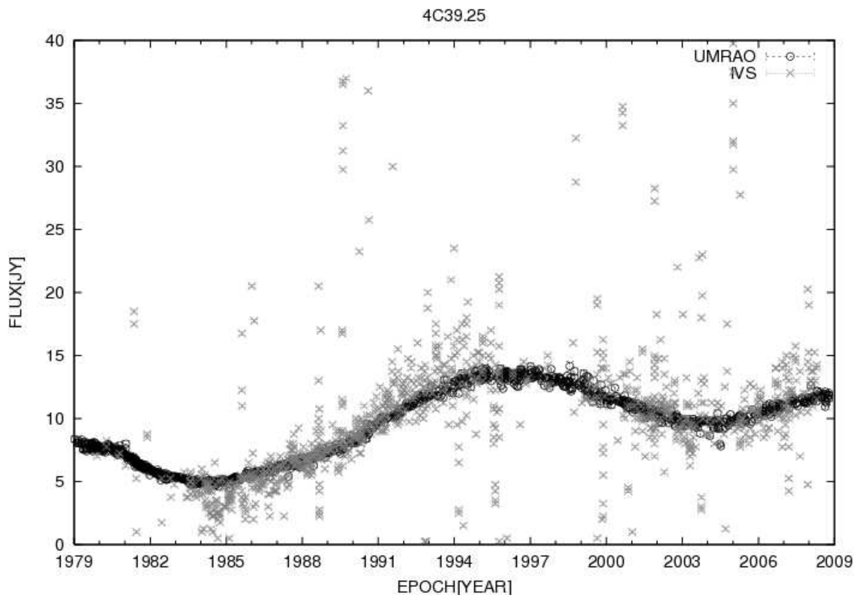

Figure 3. The light curves of 4C39.25. The black light curves are drawn with single dish data provided by the UMRAO at 8 GHz (private communication). The gray light curves are drawn with IVS data, estimated with my analysis at 8 GHz. Please note, the bar of the gray plot is not the error bar. The bar is the class interval width of the histogram drawn by the "Drawing-module", see text.

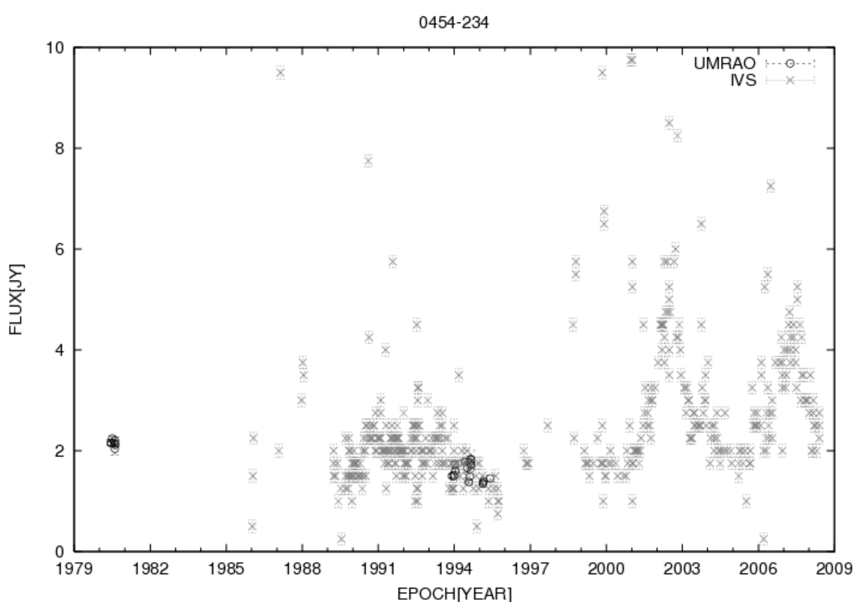

Figure 4. The light curves of 0454-234. The symbol usage is the same as in Fig. 3.

observed this source in 1980 and 1994 only. Based on IVS data, we can find two outbursts in 2002 and 2007. I suggest that the geodetic VLBI archive data is useful for obtaining the long-term light curves at radio bands for astrophysics.

4. Acknowledgements

This study could not have been conducted without the IVS community. I am much obliged for the tireless observations, analyzing, and archiving conducted by the community. My program partially uses MK3TOOLS provided by Thomas Hobiger, National Institute of Information and Communications Technology. This research has made use of data from the University of Michigan Radio Astronomy Observatory which has been supported by the University of Michigan and by a series of grants from the National Science Foundation, most recently AST-0607523. My participation in the "Sixth IVS General Meeting" was partially supported by "Foundation for Promotion of Astronomy". I would like to thank K. Yamashita for support and helpful discussions.

References

[1] Mutel R.L., Su Bumei, Buccuferro R.R., Phillips R.B., 1990, ApJ 352, 81

[2] Caproni A., Abraham Z., 2004b, MNRAS, 349, 1218

[3] Ohsuga K., 2006, ApJ, 640, 923

[4] Aller, M. F., Aller, H. D., & Hughes, P.A. 1985, ApJ, 298, 296

[5] Teräsranta H. et al., 1998, A&AS, 132, 305

[6] Teräsranta H. et al., 2004, A&A, 427, 769

[7] Teräsranta H.,Wiren S K. P., Saarinen V., Hovatta T., 2005, A&A, 440, 409