Classifying Maser features with Fortran and shell script for proper motion study of Water masers in W49N

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Abstract. The 22-GHz Water masers in the W49N star-forming region are one of the richest and most luminous sources in our Galaxy, at the distance of 11.11 kpc. Very Long Baseline Interferometric (VLBI) observations allow us to study both physics of these masers and the star formation process. However, observational results often show numerous (up to several thousand) maser spots, making manual data analysis time-consuming. Therefore, we have developed a new software with simple computer codes to classify maser features in this source observed with KaVA by Asanok et al. (in preparation). Fortran computer language and bash shell script are developed and tested by applying to 3 epochs of data sets. The peak flux and relative position of maser spots are measured using AIPS software. The analysis procedures are as follows: (1) the data are extracted to the package in table format (peak flux and x-y relative positions), (2) maser spots are counted under specified rules, (3) the maser feature is calculated by using flux-weighted mean method, and (4) the output results are compared with those obtained from the conventional method. Preliminary results show that these newly developed codes are able to automatically identify up to 30% of those maser features found by the conventional method in a consistent manner. Therefore, further improvement and development are needed for future application.

1. Introduction
The massive star formation processes have been very important and interesting questions for astronomers since the past 20 years. As their processes have short lifetime scales and use much more energy from the burning process, moreover, the star-forming regions (SFRs) contain plenty of gas and dust which being difficult to investigate or observe directly into their centres especially in the short wavelength e.g., visible light. Therefore, it must wait until the centre of the regions have much more temperature to ionising surrounding environment. The signals are emitted and can be observed in longer wavelength such as infrared, radio and microwave.

One of a unique tool for studying the environment of massive star forming regions (MSFRs) is Microwave Amplification by Stimulated Emission of Radiation: MASER. MASER is natural phenomenon similar to LASER (Light Amplification by Stimulated Emission of Radiation) except that their sources are excited and emitted the signal different frequencies. Cosmic masers (hereafter will be called shortly “masers”) are normally found in molecular clouds and dust of MSFRs.
Masers have many types. The most common are hydroxyl radical or called as hydroxyl (OH) 1.6 GHz and Water (H$_2$O) 22 GHz. These two types can be easily detected mainly in the SFRs [1, 2] or other active regions that can be achieved the radiation from emission or collision from other molecules. However, H$_2$O masers have complex energy level states and noise sensitivity to their surrounding environment. They also have the flux variability with time. Therefore, studying the physical properties of H$_2$O masers will be very useful to understand their nature of flux variability.

W49A is a massive star-forming region and inside Aquila constellation. It is one of the most luminous ($10^7L_\odot$) and massive ($10^6M_\odot$) [3] giant molecular clouds in the Milky Way. It contains three main regions which are W49 North (W49N), W49 South (W49S) and W49 South West (W49SW). W49N is a selected region in our case study. However, due to its large distance 11.1±0.7 kpc [4], the kinematics inside the cloud core are still poorly understood. In addition, H$_2$O maser at the central region of W49N is one of the strongest H$_2$O maser sources in our Galaxy [5]. The observational results often show numerous (up to several thousand) maser spots, making manual data analysis time consuming. For solving this issue, we have developed the basic software for analyzing the maser features of H$_2$O masers toward in W49N star-forming region. The data are taken from Asanok et al. (in preparation) in which they observed by using KaVA facility. The statistical conditions were used to analyse the data and to extract the real maser features. Finally, the results from developed software (DS) will be compared with the conventional method (CM) obtained from previous work for discussion the efficiency of this software and also affected to upgrade its quality for using in other studies in the future.

2. Methodology

2.1. Observation

H$_2$O masers were observed at 22 GHz during February to April 2017 by using KaVA$^1$ facility. The data were recorded at the frequency at 22235.080 MHz (rest frequency) with 1024 channels. In each channel has velocity resolution of 0.42 km s$^{-1}$ which covers the velocity range ±215 km s$^{-1}$ from its reference centre. The data were observed and recorded in 3 epochs separating each session by a month.

2.2. Image processing

The raw data of H$_2$O masers in W49N were calibrated successfully from Asanok et al. (in preparation). The offset position, LSR (Local Standard of Rest) velocities and the peak flux intensity were calculated from Gaussian fitting in the specific software called Astronomical Image Processing System (AIPS). The output files consist of texts and numerical in many rows and columns.

2.3. Process of developing software

After we got the measured data using AIPS software, the Fortran language was used to manage them. The process of developed software can be explained as follows; the first step, the important data were filtered texts out and left only numerical data for analysis further such as the peak flux intensity, x-y relative position offset and LSR velocity. The second step, all of the data were changed to the same units as follows: the peak flux intensity (Jy), x-y relative position offset (milli-arcsecond: mas), LSR velocity (km s$^{-1}$). The third step, the statistical method was used to extract the maser features by counting the same position offset of masers (less than or within 2 mas). To make sure that they are real spots of maser features, those positions must be found in the same position adjacent at least 5 successive channels. Those spot masers from the previous step will be calculated by weight-averaging all values respect to the strongest peak flux intensity and can be explained in the equation (1),

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$^1$This consists of 2 radio observatory arrays i.e. KVN; South Korea and VERA; Japan. The longest baseline is about 2,270 km and the maximum angular resolution in K-band is 2 mas.
\[ x = \frac{\sum_{i=1}^{N} x_i s_i^2}{\sum_{i=1}^{N} s_i^2} \]  

where \( x_i \) is the measured values obtained from the third step such as the offset position and the LSR velocity, \( s_i \) is the peak flux intensity and \( N \) is number of data.

In the final step, the real maser features which are found from all 3 epochs will be selected by DS and compared with CM by using the same conditions such as the offset positions (less than or within 2 mas) and the LSR velocity (less than 2.1 km s\(^{-1}\)).

3. Results

The numbers of spot masers in each epoch are calculated from the DS contain 750, 863 and 889 spots, respectively. The maser features are distributed in a size 4×4 arcsec\(^2\). The LSR velocities cover range [-290:+290] km s\(^{-1}\). The position offsets of maser features in each epoch are shown in figure 1.

![Figure 1](image)

**Figure 1.** The distribution of H\(_2\)O masers in the first, second and the third epoch, respectively. The gradient colour of the LSR velocities represent the strength of velocity in km s\(^{-1}\).

We found only 80 maser features in the same position offsets for all 3 epochs were obtained from DS while CM found 157 maser features. However, the similar maser features from both methods were found only 34 sets as follows; 3 maser features in [-200:-100] km s\(^{-1}\), 8 maser features in [-100:0] km s\(^{-1}\), 20 maser features in [0:+100] km s\(^{-1}\), 2 maser features in [+100:+200] km s\(^{-1}\) and 1 maser features
in [+200:+300] km s\(^{-1}\). The examples of maser features were found in the same position offsets from both methods as shown in Table 1.

The DS method was also used to calculate the displacement of spot masers in W49N by considering the position offset which found in the same sets for all three epochs. Figure 2 shows an example of the H\(_2\)O displacement from epoch 1 to epoch 2. Most of them are moving in the west direction and some of them are in the east direction.

**Table 1.** The examples of maser features were obtained from DS which found in the same criteria with the results of CM.

| maser features | x(mas)   | y(mas)   | LSR (km s\(^{-1}\)) | method |
|----------------|----------|----------|----------------------|--------|
| 1              | 224.402634 | -67.226273 | -18.80              | CM     |
|                | 224.394958 | -66.920563 | -18.62              | DS     |
| 2              | 551.423035 | -199.448776 | -102.13             | CM     |
|                | 552.672058 | -200.065445 | -102.49             | DS     |
| 3              | 1233.677120 | 240.214386 | 58.23               | CM     |
|                | 1233.721440 | 240.426224 | 57.25               | DS     |

**Figure 2.** An example of the H\(_2\)O maser displacements from epoch 1 to epoch 2 with the gradient colour of vectors. The strengths of velocities are explained in figure 1. Their length vectors are proportional to the strength of displacement.

**4. Conclusion**

The strongest maser feature is found at the centre of region about (+1.0,0.0) arcsec and we found the redshifted and the blueshifted LSR velocities are on the east and west directions, respectively. Comparison the results between two methods are found a little number of the same distributions up to 30%. It might be concluded that DS method is needed to improve algorithm especially the considered conditions, the statistical processes and debugs which will be improved and upgraded the efficiency of DS. Moreover, the proper motion algorithm will be added in the finalized version of DS.
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