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Recent Activities in CRL

AN INTRODUCTION TO THE KNIFE (KASHIMA 34 m–NOBEYAMA 45 m INTERFEROMETER) AND RADIO ASTRONOMICAL VLBI OBSERVATIONS

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ABSTRACT

Radio astronomy Very Long Baseline Interferometry (VLBI) Observations started in 1989 using the Kashima 34 m antenna and the Nobeyama 45 m antenna and the experiments are called KNIFE (Kashima Nobeyama Interferometry). The KNIFE observations are mainly done on the 22 GHz and 43 GHz bands and the target objects are compact radio sources including quasars and masers. In this report we give details about the observation system and present some new radio astronomical results for quasars and maser sources obtained during the KNIFE observations.

1. Introduction

CRL has developed VLBI system named K-3 and K-4 and has been conducting VLBI experiments to measure the Earth's dynamics such as the rotation of the Earth and the motion of the tectonic plates[1].

In 1989, in collaboration with the National Astronomical Observatory (NAO), CRL started radio astronomy VLBI experiments which were named KNIFE. The large aperture of the Kashima 34 m[2] (Figure 2) and the Nobeyama 45 m (Figure 1) antennas have high discrimination on the millimeter wave bands and are therefore very effective interferometers for short wavelengths. The first fringe on the 43 GHz band was obtained in October 1989 when observing a SiO (J=1–0, v=1) maser source VY CMa.

The baseline length of the KNIFE system is only about 200 km, but the short wavelength observations provide us with a high spatial resolution comparable to the international VLBI on the 1.6 GHz and 5 GHz bands (the standard radio astronomy VLBI band). Fringe rates of 13 milli-arcseconds on the 22 GHz and 7 milli-arcseconds on the 43 GHz bands have been obtained by the KNIFE experiments. Since the latitude of the two stations is similar the projected baseline changes as the earth rotates. Therefore, we can obtain images of maser sources at high latitude by using only one-baseline observation. The mapping ability is about 1 milli-arcsecond resolution relative to the positions of the maser sources.

In this report we outline the system and the results of observing active galactic nuclei and maser sources in late type stars on the 22 GHz and 43 GHz bands.

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Fig. 1 The 45 m antenna of the Nobeyama Radio Observatory.

Fig. 2 The 34 m antenna of the Kashima Space Research Center.

2. Observation system

In Table 1, we summarize the system noise and the aperture efficiency of the Kashima 34 m and the Nobeyama 45 m antennas. The 43 GHz band receiver at Nobeyama uses a SIS (Superconductor Insulator Superconductor) receiver and the others are cooled HEMT amplifier receivers.

Table 1

Frequency		Kashima 34 m	Nobeyama 45 m
22 GHz	Tsys	150 K	180 K
	ηa	57 ± 5%	65%
43 GHz	Tsys	500–850 K	200–300 K
	ηa	44 ±10%	63 ±3%

The sensitivity of a one bit sampling interferometer is calculated using the following equation,

$$\Delta S = 5.5 \times 10^3 \frac{1}{D_1 \cdot D_2} \left\{ \frac{T_1 \cdot T_2}{\eta_1 \cdot \eta_2 \cdot B \cdot \tau} \right\}^{1/2} \text{(Jy)}$$

D : Antenna Diameter (m)
T : System Noise Temperature (K)
η : Aperture Efficiency
B : Bandwidth (Hz)
τ : Integration Time (second)
1Jy = $10^{-26} Wm^{-2} Hz^{-1}$

Table 2 shows the detection limits on the 22 GHz and 43 GHz bands during 300 seconds' integration. Also the numbers of observable objects are estimated. A signal to noise ratio of higher than 7 is assumed for continuum sources, and 14 for maser sources.

Table 2

Frequency	Continuum Sources (32 MHz)		Maser Sources (0.2 km/s)	
	Detection Limit	No.	Detection Limit	No. (Maser)
22 GHz	>0.10 Jy	2000	>8 Jy	300 (H_2O)
43 GHz	>0.25 Jy	400	>15 Jy	60 (SiO)

We used the K-3 VLBI correlator developed in CRL and the new VLBI correlator named NAOCO[3] developed in NRO for data reduction.

3. Observation results of CSS objects

3.1 Quasars

Quasars are the very distant galaxies that are more than several billion light years away from the Earth. The most prominent feature of quasars is the strong and highly variable radio emission from its core, which suggest the existences of a massive black hole. When observing quasars we see the galaxy it was in the distant past because the light from the quasars was emitted several billion years ago.

The interaction of galaxies is thought to be cause of quasar formation[4]; since it produce a massive, high density core at the galactic center and triggers the formation of massive stars over a very short period.

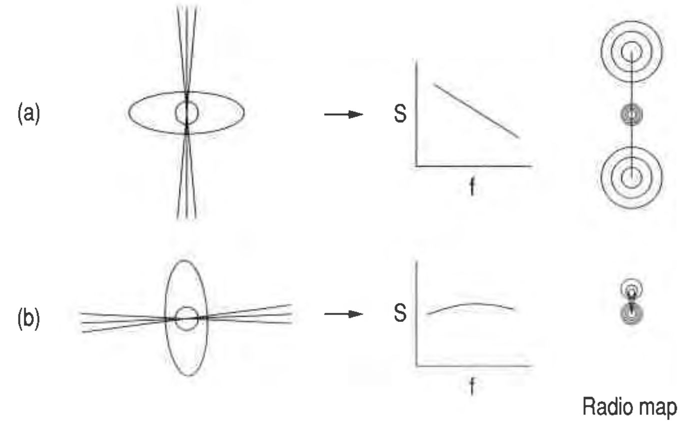

Fig. 3 Models of radio quiet (a) and radio loud (b) quasars.

Some quasars which emit very strong and variable radiation on radio wavelengths are called radio loud quasars. The radio loud quasars exhibit peaks at short centimeter or millimeter wavelengths. However, quasars that emit low radio intensities are called radio quiet quasars. These quasars have a steep spectrum so the radio intensities become weak at higher frequencies.

From recent radio observations using interferometer such as the VLA (Very Large Array) or VLBI, it is thought that quasars have an active nucleus which is composed of a massive black hole, an accretion disk and a high speed plasma jet[(5)]. The differences between radio loud and radio quiet are explained by the different viewing angle of the jet. The coming jet emits very strong synchrotron radiation at centimeter and millimeter wavelengths because of the Doppler amplification and the Doppler beaming effects.

The quasars that exhibit peaks at the centimeter or millimeter wavelengths are radio loud and are compact radio sources which in general exhibit a one sided jet. Whereas extended sources are radio quiet and the radio images reveal a compact core and extended double-lobe components (Figure 3).

3.2 CSS objects

Fanti et al (1988)[(6)] found an unusual group of low activity quasars that exhibit a steep spectrum which have very compact radio cores. They named the group CSS (Compact Steep Spectrum) objects. The CSS objects may be compact active quasars with undeveloped radio-lobes. The high density plasma surrounding with the central cores mask the radio emissions. Therefore, it is better to investigate the characteristics of such quasars at higher frequencies.

We have observed the activity of the CSS objects by using KNIFE on the 22 GHz and 43 GHz bands[(7)]. Figure 4 shows the radio spectra of CSS object 3C380. Although the single dish observations show steep spectra, VLBI spectra peak at the millimeter wavelength. Figure 5 shows the compactness and spectral index of CSS objects by dividing the single dish intensity with the VLBI intensity on the 22 GHz band. It was found that the sources with a large spectral index which indicated the core activity were more compact.

These results strongly suggest that the CSS objects have active cores and have very compact underdeveloped jets. The short wavelength emissions are absorbed by the dense ionized gases

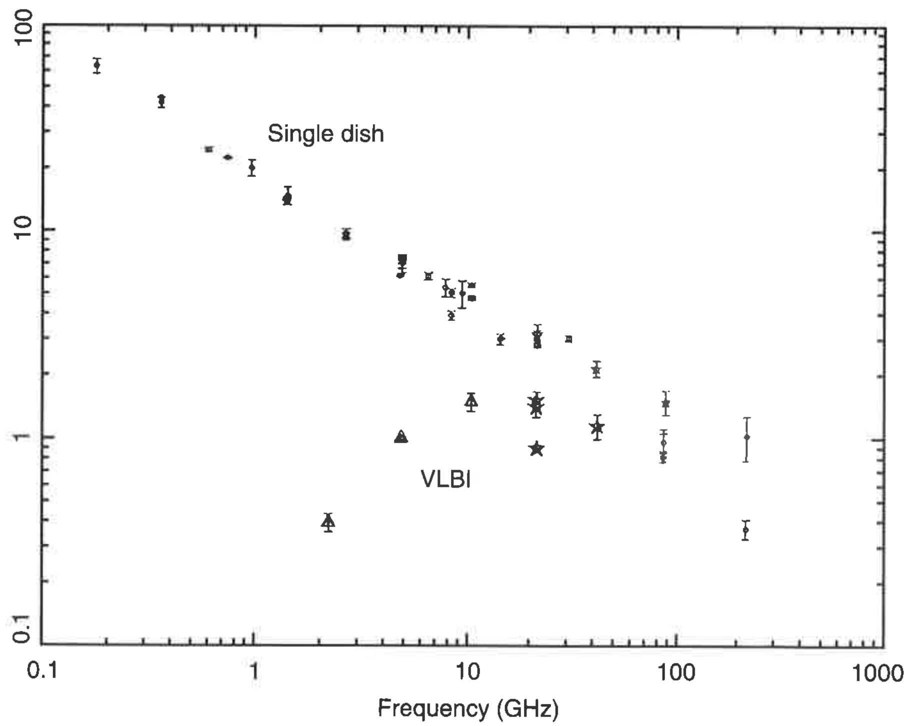

Fig. 4 The radio intensity of CSS (Compact Steep Spectrum) object 3C380. Stars denoted our observations. Single dish spectra shows steep gradient, but the VLBI intensity peaks at centimeter wavelengths.

surrounding the core and steep radio spectra are obtained during single dish observations. It has been said that short wavelength VLBI is the best way to investigate the inside of the core, and our results would seem to support the importance of millimeter wave VLBI.

4. Observational Results of Astronomical Masers

4.1 Masers

Astronomical masers(8) are observed in high density and high temperature gas around proto-stars, mass losing late type stars, and active galactic nuclei. OH masers at 1.6 GHz, CH_3OH masers at 6.7 and 12 GHz, H_2O masers at 22 GHz, and SiO masers at 43 GHz are known as strong maser emission. The pumping mechanism differs for each maser, but strong infrared radiation and post-shock gas compression are generally the input sources for maser excitation.

In VLBI observations, masers are observed as an aggregation of maser spots. Each maser spot is only a few milli-arcseconds in size and is distributed throughout the excitation source.

We are observing the 22 GHz H_2O masers in proto-stars(9), late type stars(10) and galactic nuclei(11), also 43 GHz SiO masers in late type starts(12) using the KNIFE system. Here we describe

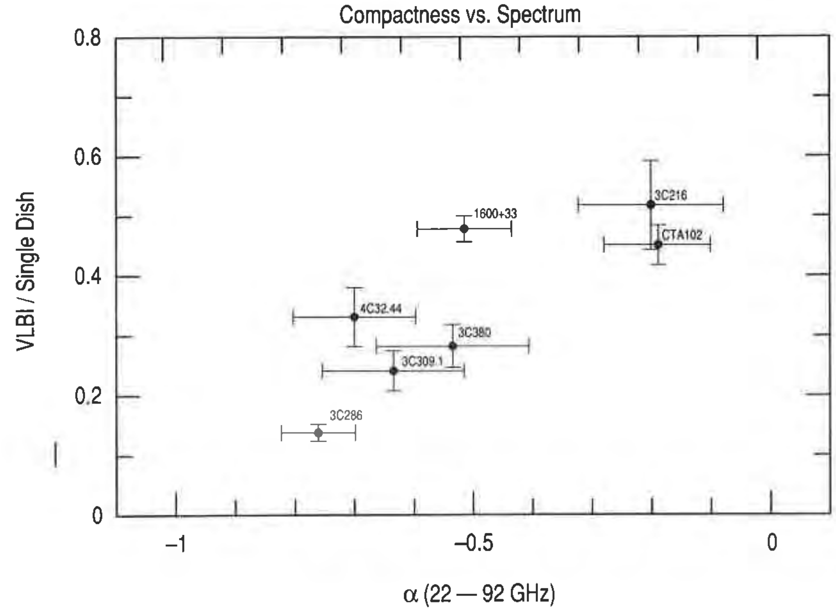

Fig. 5 The compactness of the core and the spectral index of CSS objects. The spectral index were obtained by single dish observations using the 45 m telescope of Nobeyama, the VLBI results were the 22 GHz observations by KNIFE.

the characteristics and some results obtained by KNIFE when observing H_2O and SiO masers in late type stars.

4.2 Spectral evolution of maser in late type stars

By observing H_2O and SiO maser sources using the 34 m antenna at Kashima, we found a systematic change of H_2O maser spectra in late type starts(13). Figure 6 shows the typical H_2O and SiO maser spectra for a visible Mira variable, a near infrared source (IRC/AFGL object), and an obscured far-infrared source (OH/IR star).

SiO masers are emitted within a few stellar radii and the region is highly turbulent because of the supersonic mass loss phenomena and post shock-wave compression. The masers are beamed in the limb direction since maser amplification occurs only when the gas velocity is constant (the maximum maser velocity is the same as the stellar systemic velocity).

However H_2O masers are thought to be emitted due to the interaction of the gases(14) but the emissions are less in the denser regions because of the effect of radiactive decay(15). Accordingly, the H_2O maser emitting region expands as the mass loss increases. The H_2O maser in Mira variables (Figure 6a) comes from almost the same region as the SiO masers and has the same velocity. The double peaked H_2O maser spectrum of IRC/AFGL objects (Figure 6b) comes from areas which are accelerating. This is explained by a model in which the dust forms in regions with its temperature lower than 1500 K and gas/dust expansion is caused by the radiactive pressure(16). In such regions, masers are beamed in a conical direction and are observed to have double peak spectra. In more

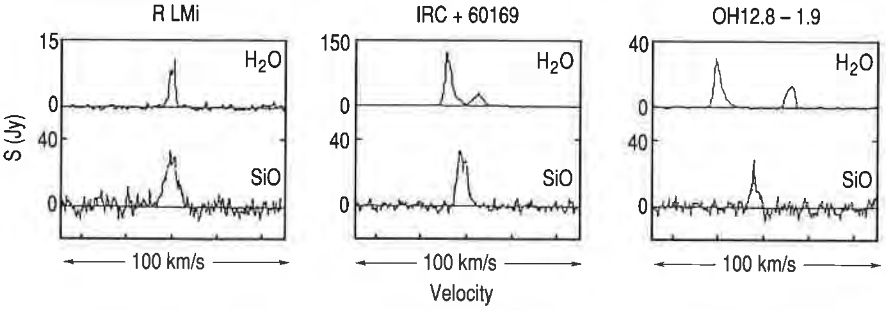

Fig. 6 H_2O (upper) and SiO (lower) maser spectra in a Mira variable (a), an IRC/AFGL object (b), and an OH/IR star (c). The data was obtained after about 10 minutes integration by the 34 m antenna at Kashima using an AOS.

evolved sources (Figure 6c), the maser emitting region expands at a constant velocity because of the decrease in photon pressure. In such cases the maser emissions are highly collimated towards the line of sight. Such beaming effects are well known in OH masers at 1.6 GHz[(8)], but a systematic investigation on H_2O and SiO masers was not conducted before we carried out our observations.

We have also found that the red shifted components are weaker than the blue shifted components, especially, for sources which exhibit double peaked H_2O maser spectra. This is explained easily because the red shifted components come from the opposite side of the star, and therefore some of the maser components must be masked.

4.3 KNIFE observations of masers in late type stars

Figure 7 shows the spatial distribution of maser spots around SiO maser source mu Cephei. A ring-like structure is seen which can be explained by the limb direction beaming model. We also see a small elongation, that suggests the mass loss is not completely spherical but is slightly bipolar.

Figure 8a shows the auto-correlation spectra and Figure 8b shows the VLBI result obtained from H_2O maser source IRC+60169 by KNIFE. The red shifted components are highly resolved and the cross correlation amplitudes are deduced clearly. These results suggest the blocking of the redshifted components, the masking of compact components and that only the expanded components around the star are seen. This object was mapped with the KNIFE and if this hypothesis is correct, we will be able to produce a map with ring like distribution for the red shifted components. Using the blocking model we will be able to develope many new methods to establish the stellar mass loss in late type stars.

5. Conclusion

The KNIFE experiments have produced many new radio astronomical results for compact radio sources such as cores of active galaxies and maser sources. The statistical observations of CSS objects reveal that the short centimeter and millimeter wavelength VLBI observations produce important information about the cores of quasars. The maser observations around late type stars using KNIFE have increased our understandings of the excitation mechanism and the dynamics of mass loss phenomena. We have also carried out KNIFE observations on SiO masers[(12)], which provide us

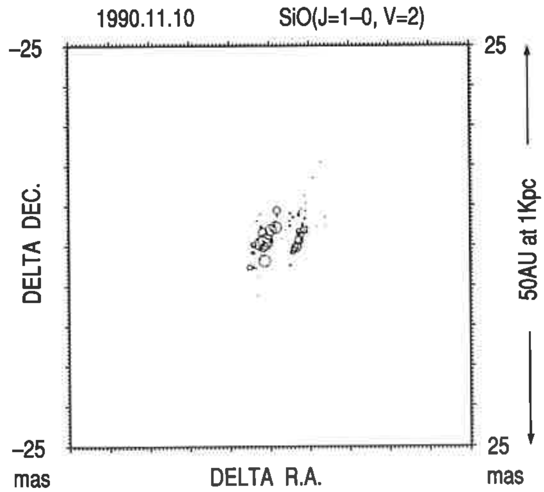

Fig. 7 The distribution of SiO maser spots around mu-Cephei obtained by the KNIFE.

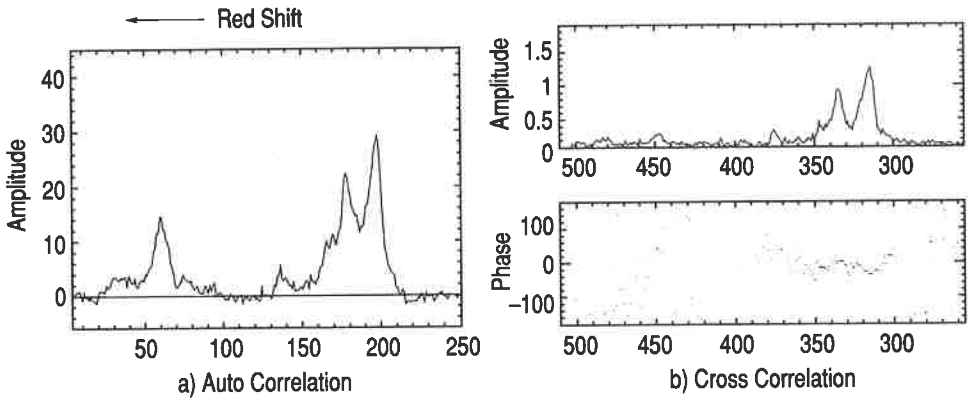

Fig. 8 The auto-correlation (a) and the cross-correlation spectra of H_2O maser source IRC+60169. The red shifted components are highly resolved by KNIFE.

with a new tool for radio astrometry. Several new VLBI antennas for radio astronomy are now being constructed in Japan. The 10 m antenna of Mizusawa observatory and the 6 m antenna at Kagoshima will come on-line in 1993, and the KNIFE will become a large sword with which to cut the universe and open up new research fields.

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