

An Astronomical Observational Plan Using the VERA

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Abstract. National Astronomical Observatory has a future plan to construct a VLBI system named VERA (VLBI for the Earth Rotation study and Astrometry). The VERA has good performance of measuring the position of the radio sources (with the accuracy of an order of ten micro-arcseconds) by phase referencing with distant galaxies and QSOs. Using this system we can measure the parallax of radio sources (masers, etc.) at any place in our Galaxy with the ambiguity of less than 10%. Hence we can measure the distance of sources in our Galaxy with very small ambiguity. The detailed structure of our Galaxy will be studied from new points of view. Proper motions of sources also give us fruitful information of dynamical motion in our Galaxy.

1. Introduction

An Antennacluster-Antennacluster VLBI is a new VLBI method to use for measuring positional difference between radio sources up to several micro-arcseconds. National Astronomical Observatory in Japan has a project “VERA” which will use this kind of technique. We will discuss possible astronomical products by using VERA.

2. VERA and Its Advantage

VERA (VLBI for the Earth Rotation Study and Astronomy) is a project which is optimized to Antennacluster- Antennacluster VLBI observations (SASAO *et al.*, 1993). The system of VERA consists of two sites separated about 2300 km. One site will be at Kitakami mountain and the other will be at an island of Southwestern Islands in Japan.

Each site has four 15 m class antennas which will have six radio bands: S/X for geodesy/earth rotation study, 7 GHz and 12 GHz for astronomy (CH₃OH maser and continuum observations), 22 GHz for Astronomy (H₂O masers/wide band continuum observations)/high frequency geodesy, 43 GHz for (SiO masers/wide-band continuum observations).

If we can measure fringe phases better than 3.6 (360/100) degrees, we can derive positions of radio sources with accuracy of 120, 30, 20, 12, and 6 micro-arcseconds for 2, 7/8, 12, 22, 43 GHz bands, respectively. This means that VERA can derive maser positions with accuracy of better than 12 micro-arcseconds.

The other advantage is the long time integration (more than one hour) of VLBI by phase-referencing using more than two antennas. Two baseline VLBI antennas observe two objects, positional difference of which are smaller than several degrees. After correlation of each baseline data, we can compensate the phase change due to atmosphere by subtracting two data of phases. Then the limit of integration time due to atmosphere becomes longer than one hour. This means that VERA can detect very weak sources. For example, we can detect SiO maser of $S_v \geq 1$ Jy by one hour integration.

3. 10 micro-arcsec Radio Astronomy

Accurate positions of 10 micro-arcsec give us a lot of important information. Linear scale for the distance of 100 pc, 1 kpc, 10 kpc, 100 kpc, and 1 Mpc for 10 micro-arcseconds are 0.001 AU, 0.01 AU, 0.1 AU, 1 AU, 10 AU, and 100 AU, respectively. It means that we can measure trigonometric parallaxes towards distances of 1 kpc and 10 kpc with ambiguity of 1%, and 10%, respectively. So distances of objects in our galaxy are measured directly by using parallaxes with ambiguity of less than 10%. Thus VERA can make detailed map of our Galaxy.

Targets of 10 micro-arcsec radio astronomy are many: late type stars, star forming regions, Galactic center, non-thermal radio stars, pulsars, extragalactic masers/continuum sources, QSO, etc. We will discuss on these targets.

4. Late Type Stars

Some masers (e.g., OH, H₂O, SiO masers) arise at circumstellar envelope of late type stars (e.g., ELITZUR, 1992). SiO masers arise at very inner shell region of the envelopes. The line profiles change with very close relationship with the light curves. Some delays of several ten days in intensity changes of SiO maser line profiles relative to light change indicate that SiO masers are results of mass loss of the central stars. Recent results of VLBI of μ Cep and some sources show patchy ring images indicating some shell structure of about 10 AU (MIYOSHI *et al.*, 1992). The sizes of maser spots are between 0.1 AU to 0.6 AU for Mira variables, and between 0.5 AU to 5 AU for Supergiants (COLOMER *et al.*, 1992). These sizes are suitable for VLBI observations.

H₂O masers arise at region outer than the emitting region of SiO masers. The appearance is similar to those of SiO masers. OH masers arise at the outer region. Line profiles do not change so much, and these are relatively stable. It is not suitable to perform VLBI observations of OH masers because of their large size of about 1000 AU.

If we can derive absolute positions of SiO/H₂O maser spots every months, we can measure trigonometric parallaxes and proper motions of maser spots after VLBI observations during one year. By using parallaxes we can measure distances of the maser spots and also the central stars with accuracy of 1% to 10%. The proper motions of maser spots can be measured more accurate than 0.05 km/s/kpc. Together with LSR velocity of maser spots, we can derive three dimensional positions and

motions. By observations through one pulsation cycle, acceleration and/or rotation of maser spots are determined, and so velocity fields around the central stars will be understood. We can also check the period-luminosity relationship of Mira variables.

Because most of late type stars live longer than 1 Gyr, their current positions are free from their birth places. Therefore, some of them will be trapped in gravitational wells of the spiral arms or the bar which probably exists in the central region of our Galaxy. Therefore, the distribution of late type stars indicates fundamental structure of our Galaxy. The three dimensional distribution of late type stars shows spiral structure and bar structure of our Galaxy. If we succeed to know the three dimensional motion of late type stars, we can evaluate the effects on stars due to the bar potential and the spiral arm potential in our Galaxy.

5. Star Forming Regions

Many kinds of masers arise at star forming regions: OH masers, CH₃OH masers, H₂O masers, NH₃ masers, SiO masers, H₂CO masers. Some of the masers are thought to arise at protoplanetary disk in molecular gas (e.g., SiO masers, and CH₃OH masers). H₂O masers are thought to arise at shocked regions of boundary in molecular outflows. H₂CO masers are thought to be in post shocked regions around compact H_{II} regions.

The high accuracy observations of ten micro-arcseconds of maser positions also show accurate distance of (1% to 10%) from trigonometric parallax and proper motion of 0.05 km/s/kpc. Similar to late type stars, three dimensional positions and motions of the central stars and acceleration and /or rotation of gas disks and molecular outflows are investigated.

There are some interesting aims of our observations.

(1) Check of accuracy of distances derived from statistical parallaxes is important. If statistical parallaxes are accurate enough to derive distances, we can extend the distance ladder.

(2) Distribution of masers shows three dimensional information of the place of star formation. Comparing with distribution of late type stars, we can discuss where star formations are started and stopped in spiral arms. From ensemble average of LSR velocity of maser spots, velocity changes of stars in each spiral arm are measured in one hundred pc resolution.

(3) Giant molecular clouds are accompanied by star forming regions and masers (e.g., KAMEYA *et al.*, 1990). If each giant molecular cloud is accompanied by several maser sources, we can measure three dimensional image of giant molecular clouds by using maser positions like light houses. From LSR velocity data of masers and molecular gas, we can derive their three dimensional internal motion.

6. The Others

(1) Galactic center: There is the VLBI central source Sgr A* which is probably located exactly in the center of our Galaxy (KRICHBAUM *et al.*, 1993). The proper motion of the Sgr A* due to a motion of solar system around the galactic center is

estimated to be about 7 mas/yr. From a relative motion of the Sgr A* relative to background QSOs which are close to the Galactic center, we can derive the proper motion.

If there is periodic local motion of Sgr A* itself, the proper motion contains not only one year motion (parallax) but also the other periodic motion.

(2) Extragalactic sources: Megamasers are sometimes appear in extragalaxies. These masers arise at starburst regions or giant H_{II} regions (e.g., GREENHILL *et al.*, 1993). Because rotation velocities of these masers are a few hundred km/s, 10 micro-arcseconds resolution is good enough to measure this proper motion in one year for neighbor galaxies distances of which are smaller than several Mpc. If there exists more than several masers, we can measure distances from rotating motion.

(3) QSO: By measuring relative positions of QSOs refer to a QSO, an absolute reference frame of QSOs is constructed independently of the earth rotation. Proper motions of QSOs (an order of 0.1 micro-arcsecond/yr for distances of several hundreds Mpc) and that of our Galaxy itself are derived from this reference frame by measuring more than once per year for about 10 years.

(4) Pulsars: Similar to galactic masers, parallax and proper motion of a pulsar were measured. Then distance was derived. We can check a relationship between pulsars and supernova remnants by measuring pulsars. The proper motions and distances of pulsars will give us velocity components which are perpendicular to lines of sights toward pulsars. By comparing the distance with rotation measure of pulsars, we can investigate physical values of interstellar ionized gas averaged over the region between the pulsars and the earth.

Globular clusters contain millisecond pulsars (PRINCE *et al.*, 1991). The motions of the pulsars enable us to find proper motions of globular clusters themselves and their inner motions.

The larger antennas (Diameter ≥ 30 m), and the lower frequency bands (≤ 1 GHz) are necessary to detect weaker sources.

(5) Close binaries: Recently some close binaries are detected by radio wave length (ex., RSCVn, Algol, UX Arietis, CygX3, CygX1, LSI61°303, ScoX1, and SS433). Parallaxes and proper motions of them give us the distances and motions of the stars in our Galaxy.

(6) Gravitational lens effects: HOSOKAWA *et al.* (1993) showed that stellar mass can be determined by measuring gravitational lens effects with the accuracy of 10 micro-arcseconds. Also, stars or space crafts near Jupiter can be a good probe to test relativistic theories of gravitation.

7. Conclusion

The VERA will open a new field of 10 micro-arcsecond astronomy. Especially this will give us detailed maps of the Galactic structure. From these maps we can check stellar motions in the spiral arms or the central bar of our Galaxy.

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