論文内容の要旨

論文題目

Astrometry of the Red Supergiant VY Canis Majoris with VERA ; Parallax Measurements and 3-Dimensional Kinematics of the Circumstellar Envelopes

(VERA による赤色超巨星おおいぬ座 VY 星の位置天文観測 ; 年周視差の計測及び星周ガスにおける運動構造の解明)

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Red supergiants are massive evolved stars. For many years, their location on the HR diagram was not accurately reproduced by stellar evolutionary theory, with the stars characterized as too cool and too luminous to agree with the predictions of the evolutionary tracks. One of the reasons is uncertain distances of the red supergiants, since the luminosity deeply depends on the distance. In recent progress in Very Long Baseline Interferometry (VLBI), we can obtain trigonometric parallaxes of the red supergiants and estimate the luminosity with high accuracy.

High mass loss from the red supergiants release a thick circumstellar envelope of molecular gas and dust. Understanding the mass loss process from red supergiants is important to study their evolutions, as well as the structure of their surrounding envelopes. Strong OH, H_2O and SiO masers are detected in circumstellar environments of the red supergiants. Phase referencing observations of masers are good probes to study the structure and kinematics of the circumstellar envelopes around red supergiants.

We have observed H_2O masers (H_2O $6_{16}-5_{23}$ transition at the rest frequency of 22.235080 GHz), $v = 1$ and $v = 2$, $J = 1 - 0$ SiO masers (at a rest frequency of 43.122027 GHz and 42.820542 GHz, respectively) around the red supergiant VY Canis Majoris (VY CMa) with VLBI Exploration of Radio Astrometry (VERA) for 13 months.

Simultaneous observations for both H_2O masers around VY CMa and a position reference source J0725–2640 were carried out at 10 epochs. The motion of the H_2O maser relative to the

reference source is the sum of annual parallax and proper motion. We successfully detected a trigonometric parallax of 0.87 ± 0.08 mas, corresponding to a distance of 1.15 $^{+0.10}_{-0.09}$ kpc from Sun. With our result, we estimated the luminosity of VY CMa using bolometric flux which is obtained by integrating the observed fluxes at optical and near–IR wavelength. The estimated luminosity is $(3 \pm 0.5) \times 10^5$ $L_\odot$. When we adopt the effective temperature of 3650 K, our result suggests that the location of VY CMa on the HR diagram is consistent with the evolutionary track of an evolved 25 $M_\odot$ and the stellar radius is about 1400 $R_\odot$.

In addition to parallax measurements, proper motions and absolute positions for the H_2O maser features are measured. The proper motions of the H_2O masers show the tendency of expansion. The average of the absolute motions for the H_2O masers is $(\mu_\alpha \cos\delta, \mu_\delta) = (-3.24 \pm 0.16$ mas yr^{-1}, 2.06 ± 0.60 mas yr$^{-1})$. Although we measured the absolute positions and proper motions for the H_2O maser features, stellar position is still uncertain. Therefore, we measured the absolute positions of the SiO maser features, which are located in the closest region from the star, to estimate the position of VY CMa itself.

Since the continuum source J0725–2640 is not bright enough at 43 GHz as a reference for phase referencing analysis, we had to try phase referencing analysis using maser source as a reference, inferred to "inverse phase referencing" in this thesis. We successfully detected J0725–2640 and measured the position of that relative to the one of the SiO maser spots. To evaluate the accuracy of the inverse phase referencing analysis, we compared a positional difference between the result of phase referencing analysis and that of inverse phase referencing analysis at 22 GHz. The difference between two methods of phase referencing is smaller than 30 microarcseconds. We confirmed that the inverse phase referencing is effective method to measure the absolute position of maser source using a weak continuum source. This is the first time to try and evaluate for VERA dual–beam data. We expect that a number of observable samples for VERA will be increased by the inverse phase referencing analysis.

As a result of the inverse phase referencing analysis, we measured the absolute positions of the $v = 1$ and $v = 2$, $J = 1 - 0$ SiO masers. The SiO masers show ring–like distribution, so we assumed that the star lies in the center of the ring and fitted a ring to the distribution of the SiO masers. The radius of the ring was 15 mas, corresponding to 3700 $R_\odot$ at the distance of 1.15 kpc. This result shows that the SiO masers are located in near radii of about 2.6 R_*.

With successful detection of absolute positions of H_2O masers and SiO masers, we compared the distributions for different frequencies of masers without any assumption. We clearly confirmed that the H_2O maser features moved away from the estimated stellar position. Using the

positions on the celestial sphere and the 3–dimensional velocities of the H_2O masers, we consider the 3–dimensional structures and kinematics of the circumstellar envelopes. The 3–dimensional structure and kinematics suggest a bipolar outflow along the line of sight. We also found that velocity of each H_2O maser increases as a function of distance from the star and it means the H_2O masers are accelerated in their environments.