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What can VLBI astrometry tell us about AR Sco?

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Abstract. We proposed to carry out high precision very long baseline interferometry (VLBI) observations of AR Sco, a pulsing white dwarf (WD) - M dwarf (MD) binary, to provide a direct distance measurement with the e-EVN (European VLBI Network) at 5 GHz. By the proposed parallax measurement on AR Sco, not only the precise distance will be determined, but also some physical parameters, such as the luminosity, the mass and the magnetic field will be significantly tightened accordingly, even the gravitational wave amplitude from this unique binary system can be tightly constrained. In addition, the EVN observations will allow us to answer that whether there is an extended emission structure associated with AR Sco, which will help us to explain the stable continuum radio emission observed during the pulse-off state.

Keywords. VLBI, AR Sco, Binary

1. AR Sco – A radio-pulsing white dwarf binary

Recently, pulsed emission on a period of 1.97 minutes in radio, IR, optical and UV bands from a white dwarf (WD) - M dwarf (MD) binary, AR Sco, has been reported by Marsh *et al.* (2016). The brightness of the binary system also varies on a longer period of 3.56 hours due to its binary orbital motion. Marsh *et al.* (2016) argued that the electromagnetic radiation is powered by the spin-down power rather than accretion. AR Sco is the first radio 'white dwarf pulsar' detected so far. The spectral energy distribution of the pulsed emission supports a synchrotron origin. Beside the pulsed emission, AR Sco has much stronger off-pulse continuum emission, ~ 10 mJy at 9 GHz (Marsh *et al.* 2016).

2. Why we need parallax measurement for AR Sco?

A model-dependent distance of 116 ± 16 pc has been reported for AR Sco and the mass of the WD is in the range of $0.81 - 1.29$ $M_\odot$ (Marsh *et al.* 2016). By using the observations of luminosity, the rotation frequency and the frequency derivative of the WD, Franzon & Schramm (2016) found that the WD might have a mass close to 1.29 $M_\odot$ and estimated its radius of ~ 4080 km and the central and surface magnetic fields of $\sim 0.9 \times 10^{13}$ G and $\sim 8.95 \times 10^{11}$ G, respectively. The parameters mentioned above are important for understanding the physical processes on-going in AR Sco, unfortunately, due to the relatively large uncertainty of distance (13%), they can not be tightly constrained.

In order to better understand the unusual features and the possible scenarios presented in literatures, a high precision parallax measurement for AR Sco with VLBI phase-referencing observations is vital to improve its distance determination. The new parallax distance measurement will be expected to have an accuracy of ~ 1 pc, ten times better than the present estimation (116 ± 16 pc). Once the precise distance is determined by the parallax measurement, the typical parameters, such as the physical magnitudes, the mass and the strength of magnetic field will be updated accordingly and the Period-Luminosity relationship of this periodic variable star can be revisited.

Another aspect that will benefit from the distance determination is the amplitude estimation of the gravitational wave coming from AR Sco, the pulsing WD-MD binary system. Using the model-dependent distance of ~ 116 pc, the gravitational wave amplitude for AR Sco was estimated to be $\sim 10^{-(22-23)}$(Franzon & Schramm 2016), which might lead to a detectable signal by LIGO and VIRGO. By applying more precise distance, the gravitational wave amplitude from AR Sco can be tightly constrained, which would help to optimize detecting strategy for the gravitational wave detectors.

In addition, the high-resolution VLBI observations will also allow us to answer that whether there is an extended structure in this unique binary system. This may be a direct sign of the existence of the large-scale shock/interaction formed by the system. Finding them will help us to explain these stable continuum emission observed during the pulse-off status.

3. The pilot e-EVN observations

In order to significantly improve the distance determination for AR Sco, We proposed to run the astrometry observations on AR Sco with the e-EVN at 5 GHz for 4 hours per epoch in the GST time range of 14h – 18h and at four epochs with a separation of a few months. Before carrying out these observations, a short e-EVN proposal to search for nearby phase-referencing sources had been performed at 5 GHz on 2016 Sep 20. The preliminary result shows that PMN J1620-2259, 18 arcmin away from AR Sco, was detected by the e-EVN with a peak flux density of ~ 10 mJy at 5 GHz, indicating that this source can be a good phase-referencing calibrator, given the recording rate of 2 Gbps for the e-EVN observations currently.

For the multi-epoch phase-referencing observations, we expect to achieve a practical image sensitivity better than 0.1 mJy per beam. With the e-EVN beam size, about 5 mas with naturally weighting, we may achieve a position precision probably better than 0.1 mas (1 sigma), which is good enough to precisely measure the large parallax (~ 9 mas) of AR Sco.

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