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MHD Simulations of the SS433 jet: from the central region to the terminal region

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SS433 is one of the famous X-ray binary located at the center of the radio nebula W50. SS433 seems to consist of the compact star and A-type red supergiant. The most obvious feature is the bipolar precession jets with 0.26c (c is the light speed) based on the Doppler effect of the Hα and iron emission lines in the central region[1]. The SS433 jet has a spiral structure with a 0.1 pc scale structure observed in the radio continuum. Radio continuum from jet itself is no longer observed father than 1 pc, but X-ray emissions called "e1" and "w1" are then observed at a distance of 20 pc. In recent years, gamma-ray emission has also been reported at the same region of "e1" and "w1", although the gamma-ray emission cannot detect around the central region[2]. Terminal region of the SS433 jets form the elongated region of W50. SS433 jets have different characteristics depending on the observed scale. Clarifying the W50 formation in a self-consistently from the ejection of SS433 jets is a very important task, but it is difficult to deal with a billion times scale of the ejecta region in one step. So, we will divide the characteristic scale for the numerical simulation.

We separate the calculation region; one is the close to the central compact object (region 1), and the other is the whole structure of the W50 (region 2).

For region 1, we carried out the two-dimensional radiative magneto-hydrodynamic simulation because of the super critical accretion flow for SS433. We assume the initial torus with magnetic fields. To reveal the formation mechanism of W50, we carried out MHD simulation including the molecular cooling effect for the region 2. The density distribution for the background is sloped to incorporate the density gradient from the galactic plane. The high-density side is set as a negative vertical coordinate. We set in the flow nozzle whose velocity is 0.26c (c is the speed of light). Numerical calculations incorporate the molecular cooling effect in order to reproduce the situation where the gas swept into the jet aggregates due to the effect of molecular cooling that exceeds a critical value.

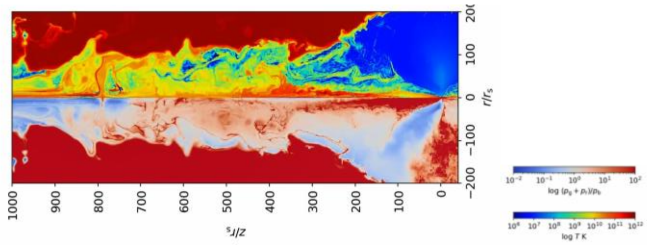

Figure 1 Snap shots of Temperature (top) and Plasma β (bottom) Magnetic pressure-dominant jets are ejected intermittently. The temperature tends to be slightly lower in the radiation-dominant region.

Figure 1 shows the snap shot of the temperature (top) and plasma β defined by the ratio of gas pressure plus radiation pressure to magnetic pressure (bottom) in region 1. We found that the jets are steadily accelerated by the radiative pressure, but a magnetized torus are formed every few tens of rotational periods and magnetized jets are launched repeatedly.

Figure 2 shows the density (right) and velocity (left) distribution for region 2. The tendency of the velocity and whole structure is similar to the previous study[3], but as the result of molecular cooling, the intermediate region between bow shock and contact discontinuity cools down and high density region are formed around the contact discontinuity surface. In the positive z-direction (east side), the gas density increase is small because the critical value is not exceeded, leaving an uncooled region. This situation tends to be consistent with the situation in the east, where a few molecular clouds are observed.

References
[1] Margon, Bruce (1984), "Observations of SS 433", ARA&A, 22: 507-536
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[3] Ohmura et al, "Continuous Jets and Backflow Models for the Formation of W50/SS 433 in Magneto-hydrodynamics Simulations" 2021 ApJ 910 149

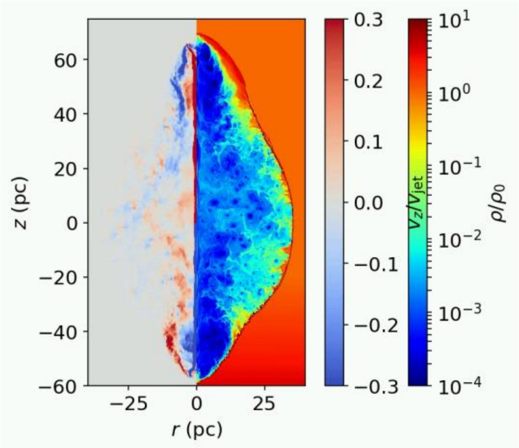

Figure 2 Snap shots for density (right) and vertical velocity (left) for region 2. The density shows the turbulence in the cocoon. The surface region of cocoon, the density increases as the results of the cooling.