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太陽と質量降着を受ける若い星における磁気エネルギーの爆発的解放
Explosive magnetic energy release on the Sun and accreting young stars

高棹真介 [1]
Shinsuke Takasao[1]
大阪大学 [1]
Osaka University[1]

1 Background

Magnetic field plays many essential roles in the entire life of stars. During star formation, the magnetic field removes angular momentum to drive accretion onto stars. When angular momentum removal is sufficiently rapid, accretion flows can be supersonic and produce strong accretion shocks on the stellar surfaces. In addition, protostars and main-sequence stars such as the Sun produce explosions (flares) driven by magnetic reconnection. Those processes are related to turbulent magnetic fields. Performing 3D MHD simulations, we are investigating such explosive magnetic energy release events.

2 Flares powered by magnetic reconnection

Protostars, baby stars growing in mass, are known to produce large X-ray explosions called protostellar flares. Protostellar flares should be powered by magnetic reconnection. Protostellar flares show some similarities to solar flares, but their energy can be larger than the largest solar flares by a factor of 10^{4-5}. The energy build-up process has been elusive. We performed 3D simulations and found that accreting protostars can produce large flares repeatedly. Accreting flows can efficiently accumulate magnetic energy around the protostars. The accumulated magnetic fields are then ejected to the disk via magnetic reconnection. This energy release corresponds to protostellar flares (Figure 1). We will discuss the energy build-up and release processes.

We have been studying solar flares to understand the fundamental energy release processes of magnetic reconnection. We focus on the region where reconnection outflows collide with flare loops (above-the-loop-top region, ALT region), as this region may be mainly accelerating nonthermal electrons. As an update of our previous 2D models [2], we are performing 3D MHD simulations to investigate the dynamic evolution of the ALT region. As a result, we found that the ALT region is forced to oscillate by reconnection outflows and the oscillation induces turbulence. This behavior may be consistent with observations such as quasi-periodic pulsations in non-thermal emissions and significant non-thermal broadening of emissions lines around flare loop tops.

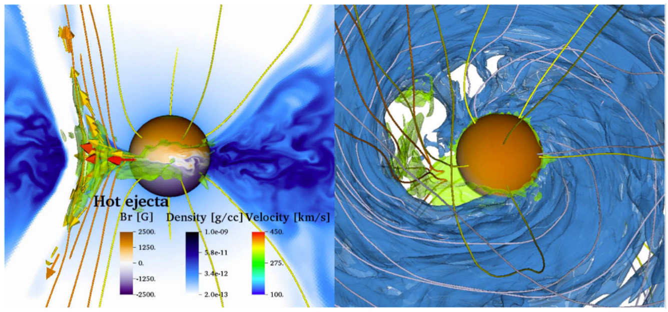

Fig. 1: An example of protostellar flare found in the 3D MHD simulation of Takasao et al. (2019). Left: a side view. The density on the poloidal plane is also displayed. Right: a top view. The blue isosurface indicates a density of 3×10^{-11} g cm^{-3}. In the both panels, the hot plasma ejection is colored in yellow.

3 Accretion flows from a turbulent accretion disk

When angular momentum removal is sufficiently rapid, accretion flows can be supersonic and produce strong accretion shocks on the stellar surfaces. It has been considered that such fast accretion can occur only when the central star is strongly magnetized to develop a stellar magnetosphere. However, observations suggest that weakly magnetized stars also show fast accretion, posing a question to the classical picture. To resolve the problem, we performed a 3D MHD simulation of accretion onto a weakly magnetized star. We found that a part of the disk wind fail to blow and fall onto the star nearly at a free-fall velocity [3] (Figure 2). As the disk wind is driven by the turbulence arising from the magneto-rotational instability, the acceleration is stochastic and the wind velocity is much smaller than the escape velocity around the disk surfaces. Therefore, the wind gas can easily fall onto the star when turbulent magnetic fields lose the angular momentum of the wind gas.

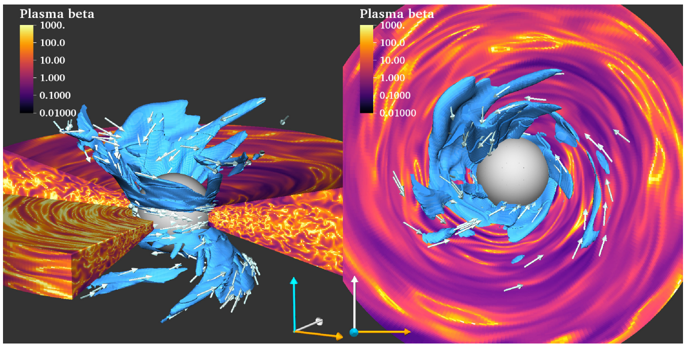

Fig. 2: Accreting star surrounded by the turbulent accretion disk. The color in the disk denotes the plasma beta. Supersonic accreting flows are colored in blue.

References

[1] Takasao et al. 2019, The Astrophysical Journal Letters, 878, L10

[2] Takasao and Shibata 2016, The Astrophysical Journal, 823, 150

[3] Takasao et al. 2018, The Astrophysical Journal, 857, 4