Cyberscience Center
User Research Introduction

Star and Planet Formation Simulation

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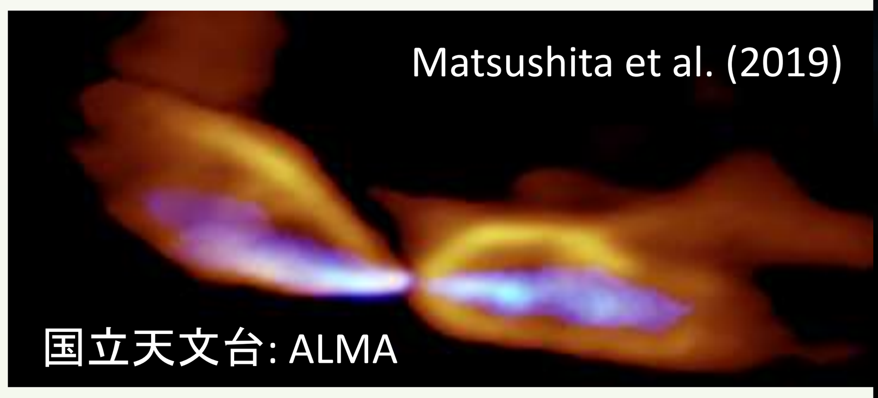
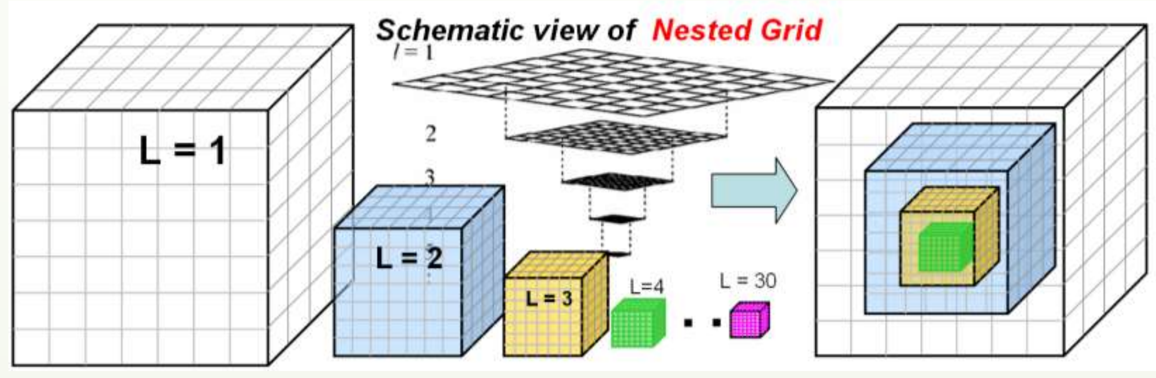
Background

Stars are a most important ingredient in the universe and they are closely related to the material evolution of the universe. When a star is born, the protoplanetary disk evolves around it. In the disk, planets are formed. Thus, the star formation process is important for understanding the planet formation and the origin of life. Recently, ALMA telescope is unveiling the star formation process. We can observe the star forming site with ALMA. In the figures, we can see the protostellar jets, which enclose a protostar (or a baby star). As seen in the figure, when a star is born, the mass ejection occurs. The protostar grows with the mass accretion. Thus, the protostellar jet is consider to be a key to understand the star formation. Recent ALMA observations give us various hints for understanding the star formation. In this study, we simulated the whole process of the star formation using Super Computer SX-ACE. Then, we compared simulation results with observations to unveil the star formation process.



Numerical Method

The molecular cloud core, which is the parent of star, has a size of 10,000au, while the size of the protostar is about 0.01 au, where au means the astronomical unit. Thus, we need to resolve a considerably different spatial scales to simulate both molecular cloud and protostar. To resolve this, we use our nested grid method as shown in below. In this method, several grid is nested to spatially resolve both a large and small objects. Using SX-ACE and Nested Grid code, we executed the star formation simulation.



Basic Equations

We solved the resistive magnetohydro-dynamic equations and protostellar model.

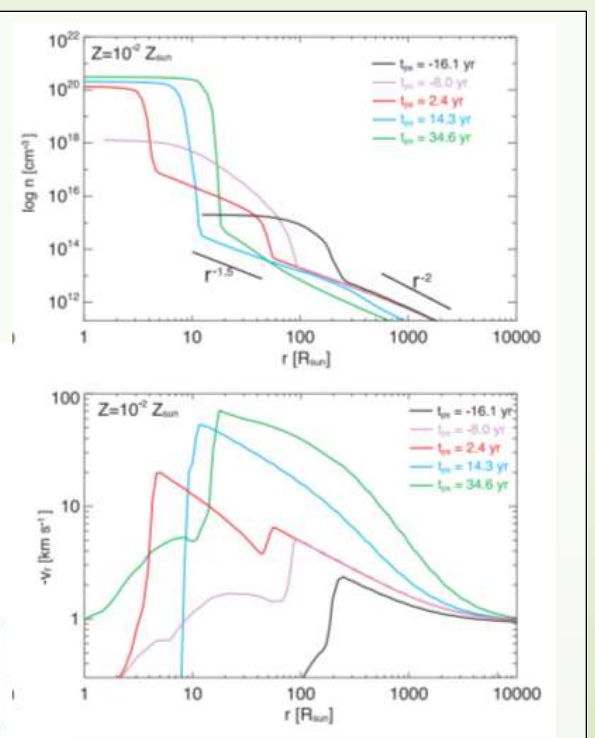
Non-ideal MHD equations

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{v}) = 0,$$

$$\rho \frac{\partial \boldsymbol{v}}{\partial t} + \rho(\boldsymbol{v} \cdot \nabla)\boldsymbol{v} = -\nabla P - \frac{1}{4\pi}\boldsymbol{B} \times (\nabla \times \boldsymbol{B}) - \rho \nabla \phi,$$

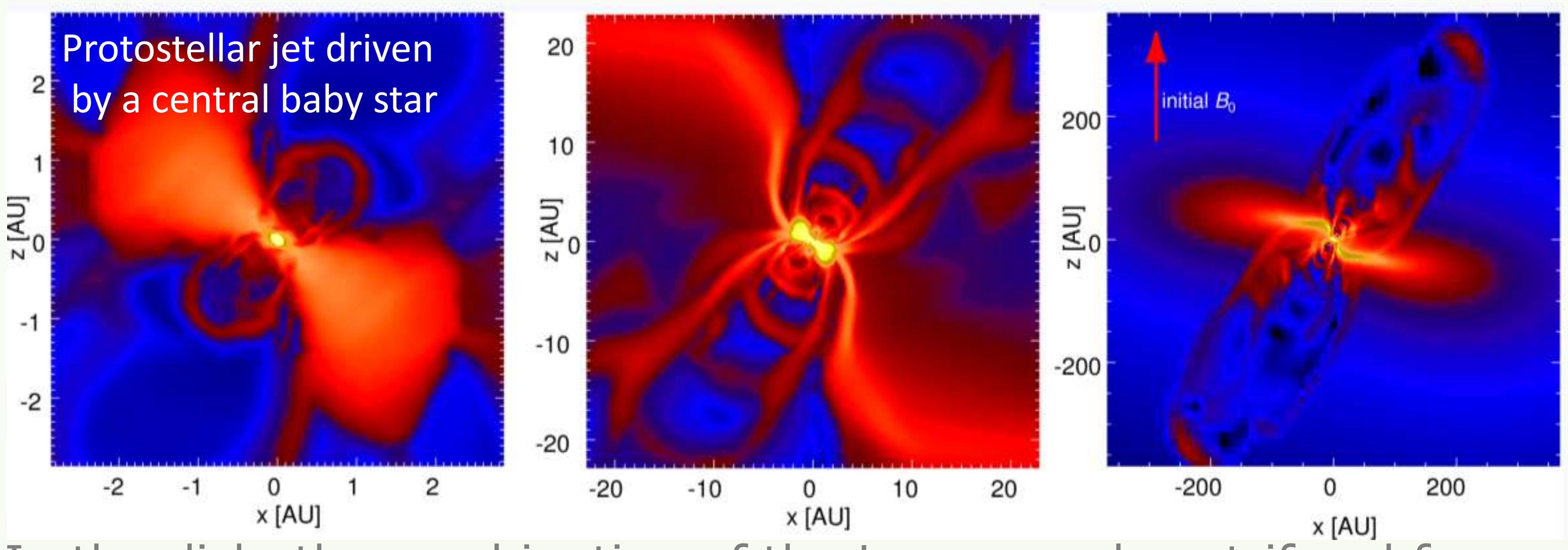
$$\frac{\partial \boldsymbol{B}}{\partial t} = \nabla \times \left[\boldsymbol{v} \times \boldsymbol{B} - \eta_O (\nabla \times \boldsymbol{B}) - \frac{\eta_A}{|\boldsymbol{B}^2|} (\boldsymbol{B} \times (\nabla \times \boldsymbol{B})) \right],$$

$$\nabla^2 \phi = 4\pi G \rho,$$



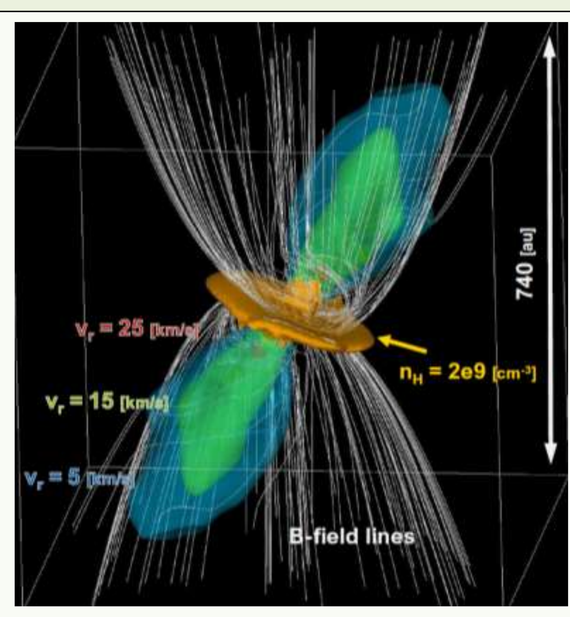
Results and Future Study

We reproduced the protostellar jet seen in observations. When a protostar forms, a parcel of gas with a large angular momentum falls onto the region near the protostar and form a circumstellar disk. The disk exists without falling a central star because the disk is supported by the centrifugal force. However, the protostar growth with accreting matter. Thus, without transporting the angular momentum, the protostar does not grow.

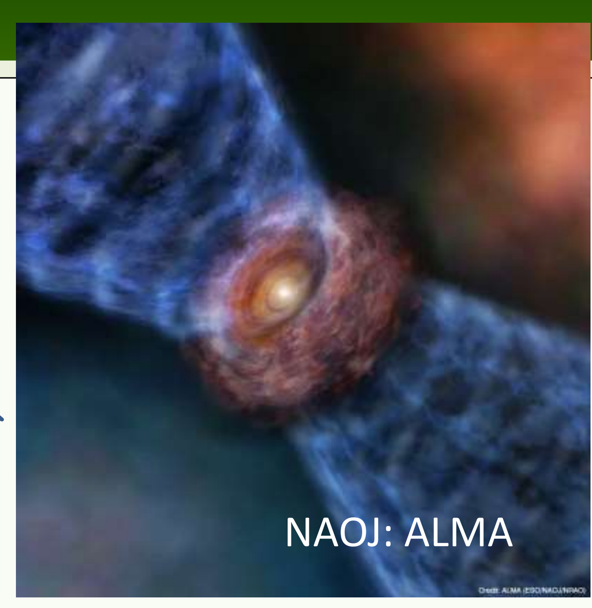


In the disk, the combination of the Lorenz and centrifugal force drive the jet which can effectively transports the angular momentum. Thus, the gas can fall onto the protostar.

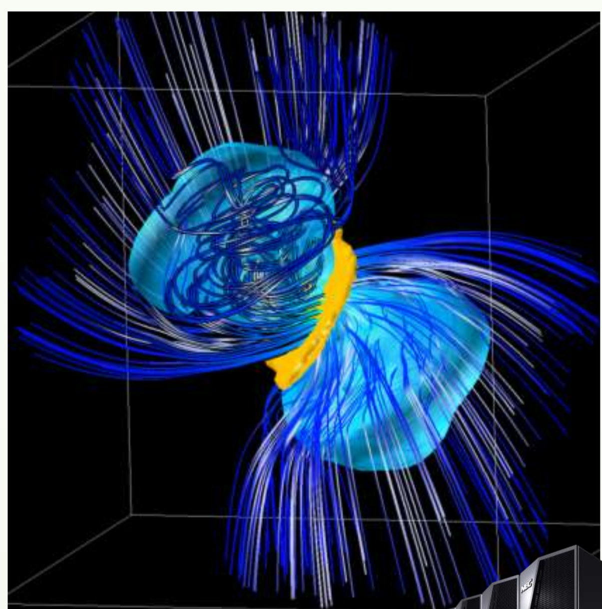
The planet forms in the disk. In our future simulations, we plan to reproduce planets. Further, we will simulate the formation of earth-like planets to unveil the origin of life.



Observation (schematic view)



Numerical simulations



Reference
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