

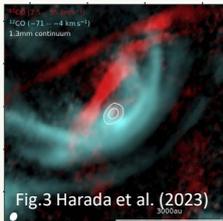
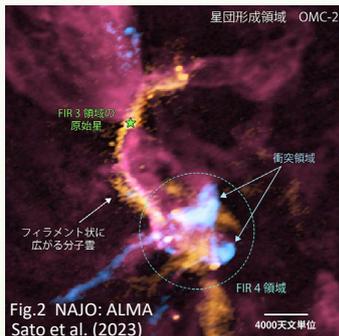
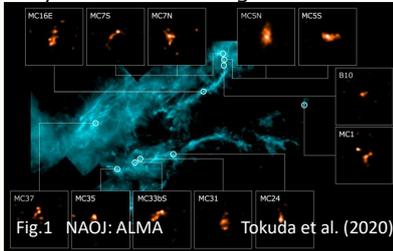
Star and Planet Formation in the Universe

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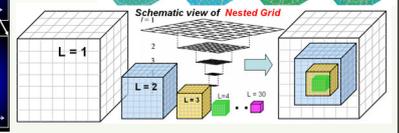
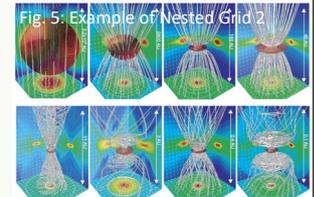
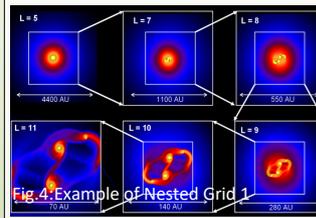
Background

First stars are born in the early universe. Since the first stars are very massive and short-lived, they disappear after occurring supernova explosion. Then, next generation stars form and first galaxies appear and star formation continues. However, the star formation process have not been understood. In addition, planets forms around forming stars. Planet formation has also not be unveiled. The aim of this study is to unveil the star and planet formation process across the universe. Fig. 1 shows the observation of molecular cloud located nearby sun. The dense gas is distributed over the blue region. Red clumps correspond to molecular cloud cores which are direct parents of stars. Fig.2 shows the observation of vary active star-forming region where strong outflows shaken the nascent star-forming clouds. Around the protostars, there exit circumstellar disks where planets form. At the same time, a strong mass ejection occurs from the disk (Fig.3).



Numerical Method

We used Nested Grid code to resolve different spatial scales between molecular cloud core (10,000au) and protostar (0.01 au) and calculated the star formation process using AOBA-A SX-Aurora TSUBASA.



Basic Equations

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

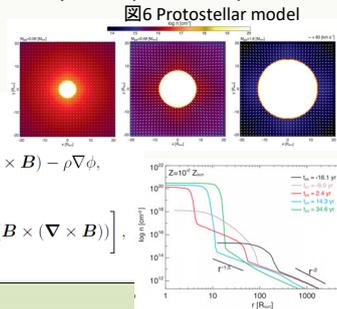
Non-ideal MHD equations

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

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

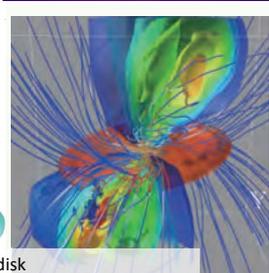
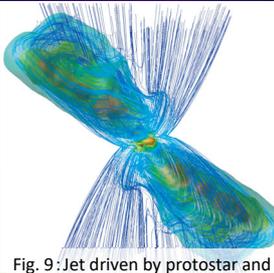
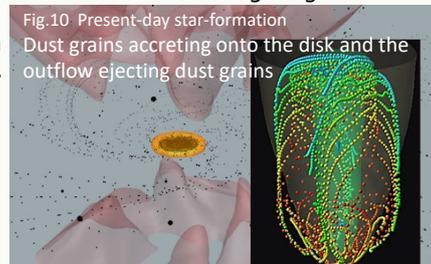
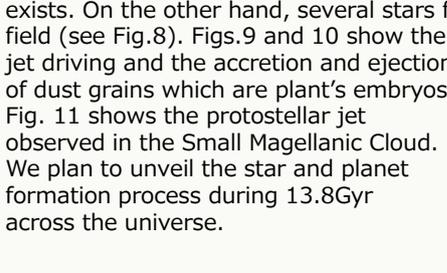
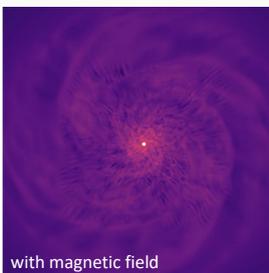
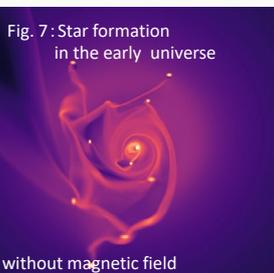
$$\frac{\partial B}{\partial t} = \nabla \times [v \times B - \eta_0 (\nabla \times B) - \frac{\eta_A}{|B|^2} (B \times (\nabla \times B))],$$

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



Results and Future Study

This study focuses on both primordial and present-day star formation. Fig.7 shows that, in the early universe, a single supermassive star, which finally evolves into a supermassive black hole, forms as long as an extremely weak magnetic field exists. (On the other hand, several stars form without considering magnetic field (see Fig.8). Figs.9 and 10 show the jet driving and the accretion and ejection of dust grains which are planet's embryos. Fig. 11 shows the protostellar jet observed in the Small Magellanic Cloud. We plan to unveil the star and planet formation process during 13.8Gyr across the universe.



References
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