Mem. S.A.It. Vol. 88, 795

Memorie della

Revisiting the pre-main sequence evolution of stars: importance of accretion efficiency and deuterium abundance

M. Kunitomo[1], T. Guillot[2], T. Takeuchi[3,4], and S. Ida[5]

[1] Department of Physics, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, Aichi 464-8602, Japan, e-mail: kunitomo@nagoya-u.jp
[2] Laboratoire Lagrange, UMR 7293, Université de Nice-Sophia Antipolis, CNRS, Observatoire de la Côte d'Azur, 06304 Nice Cedex 4, France
[3] Department of Earth and Planetary Sciences, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8551, Japan
[4] Sanoh Industrial Co., Ltd., Japan
[5] Earth-Life Science Institute, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8551, Japan

Abstract. Recent theoretical studies have shown that pre-main-sequence evolution changes significantly with the energy deposited inside the star by accretion. In addition, we find that deuterium burning also regulates the evolution. From the comparison with observation in the Hertzsprung-Russell diagram, we confirm that the luminosity spread seen in young clusters can be explained by models with a somewhat inefficient injection of accretion heat and with low deuterium content. The comparison allows us to exclude some models with extremely inefficient heat injection and low deuterium abundances.

1. Introduction

Recent theoretical studies have shown that pre-main-sequence (pre-MS) evolution of stars can be changed from the classical picture if material loses entropy before or during the accretion onto the star (Mercer-Smith et al. 1984; Palla & Stahler 1992; Hartmann et al. 1997; Vorobyov et al. 2017). Since the low-entropy accretion has strong consequences on the stellar evolutionary tracks, it can be a possible origin of luminosity spread in young clusters (Baraffe et al. 2009, 2012; Hosokawa et al. 2011).

In this article we revisit the pre-MS evolution. We wish to understand what controls the evolution and obtain limits on physically plausible evolutionary tracks from observational constraints.

2. Method

We use the 1D stellar evolution code MESA version 6596 (Paxton et al. 2011). We refer to the Paxton et al. papers and Kunitomo et al. (2017) for full details of the computational method. We calculate the evolution from a 0.01 $M_\odot$ seed with the steady accretion, $10^{-5}\,M_\odot/\mathrm{yr}$. The initial radius is 1.5 $R_\odot$.

We adopt the metallicity to be 0.02. We adopt $X_D = 20$ or 35 ppm, where X_D is the mixing ratio of deuterium in mass. The former

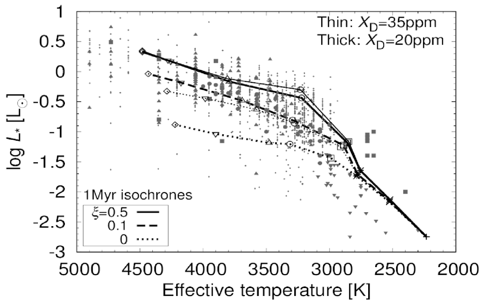

Fig. 1. Comparison of 1 Myr isochrones for the cases $X_D = 20$ (thick lines) and 35 ppm (thin) ranging ξ from 0 (dotted) to 0.5 (solid). The points on each isochrone indicate the stellar mass: pluses, crosses, asterisks, squares, circles, triangles, inverted triangles, and tilted squares for 0.01, 0.25, 0.05, 0.1, 0.3, 0.5, 0.8, and 1 $M_\odot$, respectively. The grey, filled points show the observed stars in young clusters: ONC (small diamonds), ρ Oph (squares), σ Ori (circles), Tau-Aur (triangles), and Tau and Cha I (inverted triangles).

corresponds to the present-day local interstellar value (see, e.g., Prantzos 2007).

We parametrize the heat injected by the accreting material as $\xi L_{\rm acc}$, where $L_{\rm acc}$ is its gravitational energy. Thus we assume that a fraction of the gravitational energy is injected into the star and the rest is radiated to space before the material reaches the star. The accretion heat is assumed to be distributed uniformly in the entire star. Note that if we assume a non-uniform distribution of the accretion heat, the evolution is quantitatively different (see Kunitomo et al. 2017).

3. Isochrones and implications for luminosity spread of young stars

We simulate pre-MS evolutions with various final masses and obtain isochrones by integrating them. Figure 1 shows the coeval isochrones at 1 million years with $X_D = 20$ and 35 ppm ranging ξ from 0 to 0.5. With a fixed X_D, the coeval isochrones with different ξ values have a wide spread. On the other hand, in the $\xi = 0$ cases, the isochrones are sensitive to the assumed X_D. This is because the deuterium fusion also produces lots of energy (5.5 MeV via one reaction). Therefore we conclude that the pre-MS evolution is controlled by both heat injection from the accretion and deuterium content.

Figure 1 also shows that the extent of spread of the isochrones is comparable to the observed spread (~ 1 dex; Kunitomo et al. 2017, and references therein). Therefore, if there is a distribution of the ξ values within a cluster, then the luminosity spread can be created by coeval stars.

Finally we address the constraint on the ξ value. We find that the majority of observed stars lie above the isochrones with $(X_D, \xi) =$ (20 ppm, 0.1) or (35 ppm, 0). We conclude that, by assuming that X_D in the young clusters are not very different from 20 ppm, a majority of stars may be formed with $\xi \gtrsim 0.1$.

Acknowledgements. M.K. has been supported by Grant-in-Aid for JSPS Fellows 24·9296, MEXT Kakenhi grant 23244027 and 16H02160 and Foundation for Promotion of Astronomy.

References

Baraffe, I., Chabrier, G., & Gallardo, J. 2009, ApJ, 702, L27
Baraffe, I., Vorobyov, E., & Chabrier, G. 2012, ApJ, 756, 118
Hartmann, L., Cassen, P., & Kenyon, S. J. 1997, ApJ, 475, 770
Hosokawa, T., Offner, S. S. R., & Krumholz, M. R. 2011, ApJ, 738, 140
Kunitomo, M., et al. 2017, A&A, 599, A49
Mercer-Smith, J. A., Cameron, A. G. W., & Epstein, R. I. 1984, ApJ, 279, 363
Palla, F. & Stahler, S. W. 1992, ApJ, 392, 667
Paxton, B., Bildsten, L., Dotter, A., et al. 2011, ApJS, 192, 3
Prantzos, N. 2007, Space Sci. Rev., 130, 27
Vorobyov, E., Elbakyan, V., Hosokawa, T., et al. 2017, ArXiv e-prints