Midium Project 1
Star Formation History of Solar Neighborhood

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Abstract

Various studies have investigated the statistics of stellar population of the solar neighborhood via multiple techniques. In this work, I take advantage of the *Gaia* data release 2 to construct the star formation history of nearby stars ($r < 100$ pc) based on the present-day mass function and the universal mass-luminosity relation. I find a significant positive star formation rate at ~ 2 Gyr, which is consistent with the "star-burst" revealed by recent works.

Keywords: methods: observational – stars: formation – stars: luminosity function, mass function

1 Introduction

The *Gaia* mission has largely revolutionized our understanding of the dynamics and photometrics of galactic stars and star clusters. For example, recent studies have broadly taken advantage of *Gaia* to investigate the star formation history (SFH) of solar neighborhood or other components of the Milky Way (e.g. Bernard, 2017a,b; Isern, 2019; Sollima, 2019; Mor et al., 2019; Ruiz-Lara et al., 2020).

The above works employed sophisticated methods, including color-magnitude diagram (CMD) fitting, white dwarfs, etc., to derive the IMF with good significance. However, a more intuitive approach is to simply combine the present-day mass function (PDMF) with the universal initial mass function (IMF), since the PDMF stores the memory of star formation. In this work, I first use the *Gaia* data release 2 (*Gaia* DR2) to construct the PDMF of the solar neighborhood within 100 pc, and then derive the SFH by combining the PDMF with a young open cluster, whose mass function can reveal the IMF. The rest of the paper is organized as

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below. In Sec. 2, I describe my methodology in greater detail. I then post my major results in Sec. 3. Finally, I summarize the key points of this work in Sec. 4.

2 Method

2.1 Data Specification

I collect data, including coordinates, parallaxes, g-band magnitudes, and colors, form the *Gaia* DR2 archive[1]. The data of the solar neighborhood contains all 80008 stars with measured distances (derived from parallaxes) within 100 pc, and an apparent magnitude limits of 13. However, since the mass-luminosity relation is simpler and more robust for main sequence stars, I also apply an arbitrary selection criterion to remove post main sequence stars, which are located in the gray region of the CMD (see, left panel of Fig. 1).

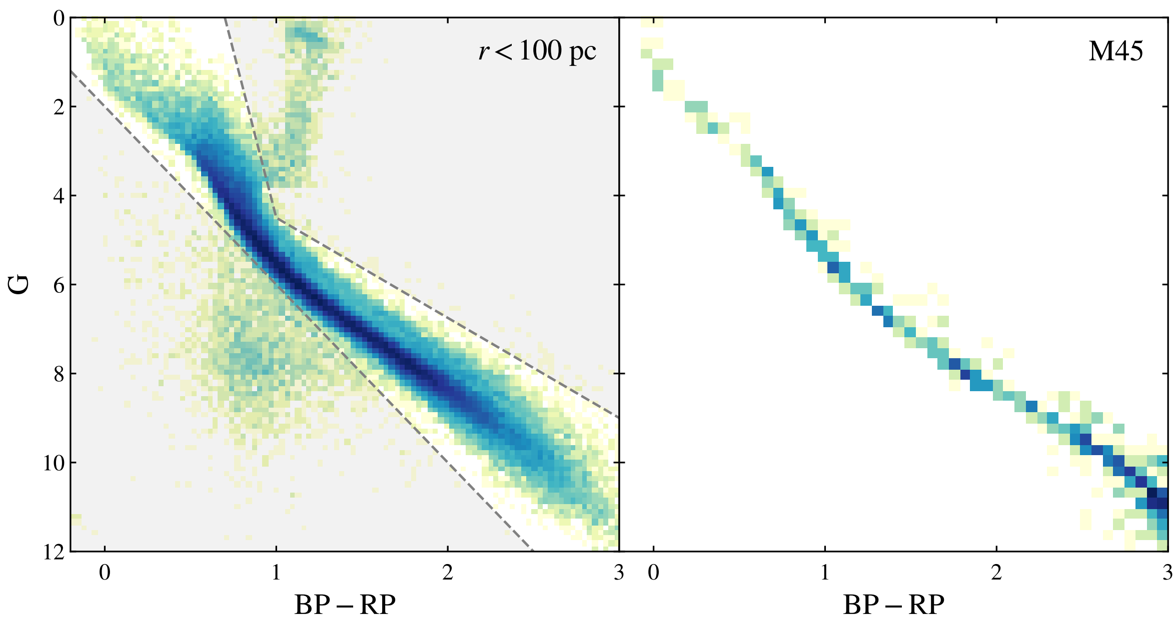

Figure 1: Left: CMD of the solar neighborhood within 100 pc. Only main sequence stars between the two dashed lines are selected for analysis. Right: CMD of the Pleiades.

I also employ the open cluster, Pleiades (M45), as a fiducial cluster. Since the Pleiades is rather young, I can refer to its main PDMF as an analog to the universal IMF. To identify stars from the Pleiades, I first collect data from *Gaia* DR2 with an apparent magnitude limits of 21. Then, I filter the data based on the spatial locations, proper motions, and parallaxes of the Pleiades. Applying the above criteria, 1033 candidate stars are finally selected.

[1] `https://gea.esac.esa.int/archive/`

2.2 SFH from PDMF

Taking into account the stellar evolution, the main sequence PDMF, $f(M)$, can be written as

$$f(M) = \phi(M) \int_0^{\min[T(M),T]} \psi(t)\ dt, \tag{1}$$

where $\phi(x)$ is the universal IMF, $\phi(t)$ is the star formation rate (SFR) at the **look back** time t, $T(M)$ is the lifetime of a star with mass M, and T is the lifespan of the Milky Way. Note that the PDMF and IMF above are normalized such that

$$\int_0^T \psi(t)\ dt = 1. \tag{2}$$

Defining $\eta(M) = f(M)/\phi(M)$, we get the derivative version of Eq. (1):

$$\eta'(M) = \begin{cases} T'(M)\psi \circ T(M), & T(M) < T, \\ 0, & T(M) \geq T. \end{cases} \tag{3}$$

When $T(M) < T$, given the stellar life time,

$$\frac{T(M)}{T_\odot} = \left(\frac{M}{M_\odot}\right)^{-2.5}, \tag{4}$$

where $\odot$ is the lifetime of the Sun; we have

$$\psi \circ T(M) \propto -\eta'(M) \left(\frac{M}{M_\odot}\right)^{3.5}. \tag{5}$$

Additionally, I follow the following steps to calculate the mass functions. Given the main sequence mass-luminosity relation,

$$\frac{M}{M_\odot} = \left(\frac{L}{L_\odot}\right)^{1/3.5}, \tag{6}$$

and the g-band mass-absolute magnitude relation,

$$\frac{L_{\mathrm{G}}}{L_{\mathrm{G}\odot}} = 10^{-(\mathrm{G}-\mathrm{G}_\odot)/2.5}; \tag{7}$$

we can derive that

$$\frac{M}{M_\odot} = 10^{-(\mathrm{G}-\mathrm{G}_\odot)/8.75}, \tag{8}$$

where I assume that $L/L_\odot = L_{\mathrm{G}}/L_{\mathrm{G}\odot}$. Therefore, the mass function can be written in the form of the g-band absolute magnitude function, $f(\mathrm{G})$:

$$f(M) = f \circ M(G) = \left|\frac{f(\mathrm{G})}{M'(\mathrm{G})}\right| = \frac{8.75 f(\mathrm{G})}{\ln 10} 10^{(\mathrm{G}-\mathrm{G}_\odot)/8.75} \tag{9}$$

3 Results

The g-band absolute magnitude functions are shown in Fig. 2, along with the PDMF. As mentioned before, the PDMF of the Pleiades can be regarded as the universal IMF. To meet Eq. 2, I also match the two mass functions at G > 4. I note that there is an apparent discrepancy at G $<\sim 4$, corresponding to $M >\sim 1.5 M_{\odot}$. This is, as expected, due to the death of high-mass main sequence stars.

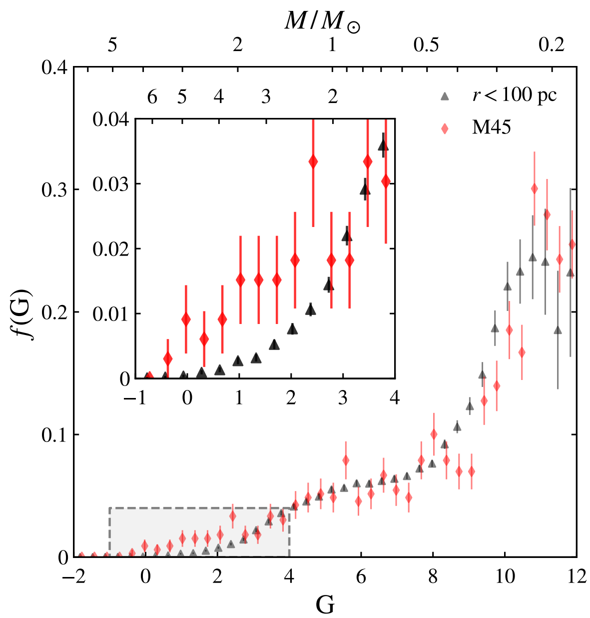

Figure 2: Present-day mass functions of solar neighborhood within 100 pc (black triangles) and the Pleiades (red diamonds). The embedded plot shows a zoom-in view of the shaded region. Uncertainties are estimated by assuming a Poisson distribution.

Applying the techniques in Sec. 2, I plot the SFH in Fig. 3. Although the SFR, $\psi(t)$, is mostly vibrating around 0 within the error range, I note that the SFR at $T(M) > T_{\odot}$ is systematically greater than 0. Moreover, there is a significant off-shore at $M_{\rm c} = 2.01\ M_{\odot}$ and $T_{\rm c} = 0.17\ T_{\odot}$ (or look back time $t \sim 2$ Gyr). Such high SFR agrees with the "star-burst" at 2 Gyr ago revealed by recent works (e.g. Bernard, 2017a,b).

4 Summary

In this work, I produce the SFH of solar neighborhood within 100 pc based on the PDMF. I find a significant non-zero SFR at look back time $t \sim 2$ Gyr, which is consistent with the "star-burst" suggested by recent works.

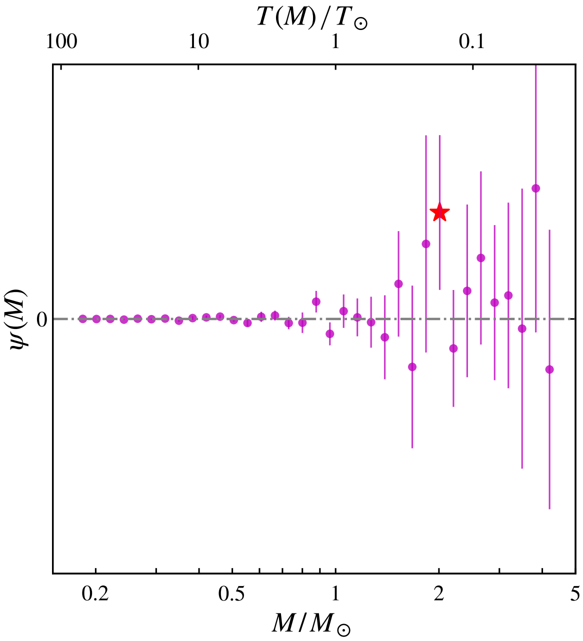

Figure 3: SFH of solar neighborhood within 100 pc. The red star corresponds to $M_c = 2.01\ M_\odot$ and $T_c = 0.17\ T_\odot$. The gray dashed reference line labels the zero SFR.

5 Supplementary Materials

Source code of this work can be found in `https://github.com/EnthalpyBill/ASTRO533/tree/master/project_mid1`.

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