Supplementary materials

Dear Prof. Daniel Stark,

This file mainly introduces my academic experience.

Academic Experiences

Project #1 My first formal research experience came through the College Student Innovation and Entrepreneurship Program, supervised by Prof. Xiaodong Li. Using clustering methods such as Mean Shift, GMM, and DBSCAN, we developed a machine learning–based framework for cosmic web classification. We found that the radial density distribution of the centroid stacked substructures exhibit significant differences in different cosmological parameters sets. This result provides a new approach for identifying erroneous cosmological parameters.

Project #2 <*A new code for low-resolution spectral identification of white dwarf binary candidates*>. This is my bachelor's thesis, I independently developed an artificial-neural-network–based code to fit low-resolution($R \sim 2000$) spectra of close white dwarf binary(CWDB) candidates. The code successfully identify the basic parameters(Effective temperature, surface gravity, mass and radius) of both components of the CWDB candidates based on parallax data from Gaia and absolute flux spectroscopic data from SDSS. It simultaneously fitted both the continuum and the characteristic line profiles (Balmer lines for DA, He lines for DB, different metals or molecules for different MS types) of the target using an ANN-based parameterized spectrum. This method obviates the dependence on expensive and rare high-resolution spectra, paving the way for large-scale spectroscopic identification of CWDBs.

Project #3 In the course *Computational Astrophysics*, I led a three-person team to develop a three-dimensional fluid simulation code from scratch in Python. I was primarily responsible for coding Godunov's first-order algorithm, HLLC Riemann solver and Voronoi tessellation. We validated the code against the solution of SOD shock tube problem. This project deepened my understanding of numerical methods and provided valuable insights into moving-mesh codes such as AREPO, which use similar solvers and tessellations.

Project #4 <*Revealing the Origins of Galactic Globular Clusters via Their Mg-Al Abundances*>. In this paper, we used primordial Mg–Al abundances to distinguish between in situ and accreted globular clusters, identifying a clear chemical dichotomy at [Fe/H] > –1.5. This work highlighted the stability of chemically driven classifications and revealed key discrepancies with dynamical methods. I mainly assisted in stellar population diagnostics and contributed to the paper writing.

Project #5 <*A magnetic white dwarf formed through a binary merger within 35 million years*>. In this work, we reported the discovery of a magnetic white dwarf in the open cluster RSG 5 with an age of only 35 Myr. Its low mass($< 1.05 M_{\odot}$), strong magnetic field (>200 MG), rapid rotation (6.5 min), and circumstellar debris provided compelling evidence for a binary merger origin. My main contribution was the determination of its fundamental stellar parameters, including temperature and surface gravity.

Project #6 Currently, I am working on simulating the formation of multiple stellar populations (MP) in globular clusters. MP problem refers to a star-to-star light alpha element abundances(C-N,Na-O,Mg-Al,etc) anti-correlation in globular clusters, it is theorized to originate from the H-burning product of massive stars. People believe that the 2P stars(the stars with N,Na,Al enriched and C,O,Mg depleted) formed from the primordial gas polluted by massive 1P stars. However, this scenario faces the critical "mass budget problem": The enriched material from 1P stars is neither sufficient to pollute the primordial gas to the observed abundance levels, nor to account for the observed 2P to 1P ratio, which is approximately 1:1. Our work selected massive interacting binaries(MIBs) as the sources of enhanced chemical enrichment to simulate the formation of multiple stellar populations from an isolated giant molecular cloud(GMC). It places critical theoretical constraints on the formation of multiple stellar populations from a star formation perspective, identifies the optimal initial conditions in giant molecular clouds, and establishes a foundational framework for exploring more complex formation scenarios.

I implemented a binary yield model into AREPO-RIGEL code, making it feasible to simulate hydro dynamic, star/binary formation, stellar wind/radiation/SN feedback, chemical enrichment at the same time. Our work identified the "time budget problem: the timing mismatch between pollutant release, turbulent mixing, and star formation strongly limits the fraction of 2P stars(N,Na,Al enriched, C,O,Mg depleted stars): producing substantial 2P material demands higher star formation effeciency, yet the ensuing stellar feedback disrupts the cloud more rapidly, inevitably shortening the star formation duration. This shortened timescale leaves insufficient time window for the release and mixing of enriched ejecta with pristine

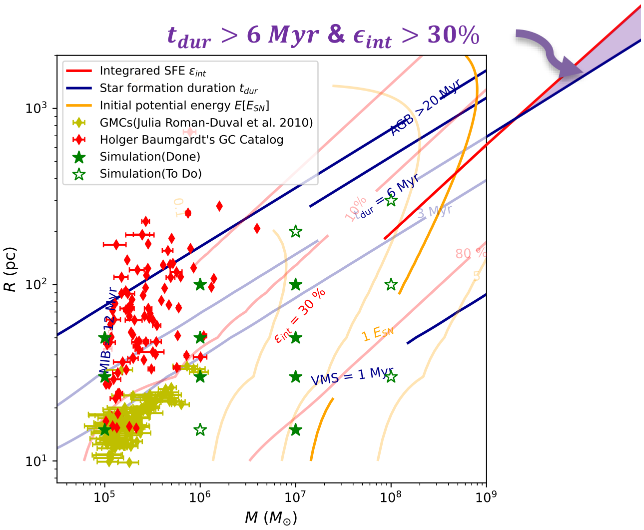

Figure 1: Initial parameter space for GMCs. Red contours: Integrated star formation efficiency ϵ_{int}. Blue contour: Star formation duration t_{dur} and the corresponding yielding timescale of different scenarios(AGB,VMs,MIB). Orange contour: Initial potential energy. Purple translucent area: GMC with SFD > 6 Myr(necessary for MIB yielding) and SFE > 30%(necessary for GC survival).

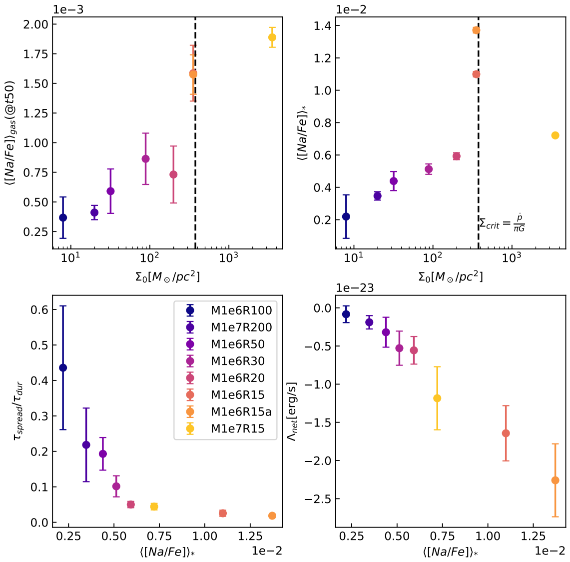

Figure 2: Upper left: Mean [Na/Fe] in gas at the half-mass assembly epoch t_{50} vs. Initial surface density. Upper right: Stellar mean [Na/Fe] vs. Initial surface density. Lower left: diffusion timescale per star formation duration vs. Stellar mean [Na/Fe]. Lower right: Particle- and time-averaged net cooling rate vs. Stellar mean [Na/Fe].

gas, and its subsequent settling into new stars. Isolated GMCs lack effective mechanisms to keep both SFE and SFD high and drop enough 1P stars, MPs in observed GCs cannot be explained without invoking external mechanisms(Figure 1)[1].

We set the yielding timescale to zero, and simulated star formation in GMCs across different initial parameters in order to identify the conditions most favorable for MP formation. Strikingly, the 2P fraction does not scale with GMC initial surface density but instead peaks at the critical surface density(Σ_{crit}) where stellar feedback and gravitational forces are in balance. Despite the denser GMCs ($\Sigma > \Sigma_{crit}$) releasing more 2P gas into the ISM, the resultant fraction of 2P stars does not correspondingly increase. Instead, the 2P fraction exhibits a clear anti-correlation with both the particle- and time-averaged net cooling rate of the cold dense gas and the diffusion timescale per star formation duration(See Figure 2). This indicates that the efficiency of settling 2P gas into stars is modulated by both stellar feedback and mixing processes.

In my future research, I aim to dedicate my efforts to investigating possible progenitors of globular clusters. Using both simulations and observations, I plan to study potential pathways for the formation of multiple stellar populations from a star formation perspective. The presence of multiple stellar populations (MPs) serves as a key distinguishing feature between globular clusters and open clusters, and I believe the key to understanding how MPs formed in GCs, and why they only form in GCs, lies in the special conditions of their progenitors or their host. Therefore, both high-redshift galaxies and regions of extreme star formation are the candiates of my PhD research. Exploring distinctive phenomena of them-such as UV excess, N overabundance, top-heavy IMF and super giant molecular clouds-to uncover the physical links between extreme star-forming environments and the emergence of multiple populations in globular clusters.

I would be greatly appreciate it if you could let me know about the availability of a PhD position in your group. I'm always happy to share more details about my researches anytime.

Sincerely,

Genghao Liu

Attached: Curriculum Vitae

[1] Guided by these foundings, We proposed a cloud–cloud collision scenario as a promising pathway for GC MP formation.During the merger, the pre-existing 1P stars are efficiently scattered, while the 2P gas released by these stars, is retained in the central region and form 2P stars. In this way, most 1P stars are lost, leading to a much higher 2P fraction. Notably, we have already observed spatial distribution differences among stars with different ages, further supporting the potential of the cloud–cloud collision model.