ISSI/ISSI-BJ International Team

"Chemical abundances in the ISM: the litmus test of stellar IMF variations in galaxies across cosmic time"

TEAM REPORT

Abstract

For three decades it has been *speculated* that the stellar initial mass function (IMF) could be more biased towards massive stars in starburst environments, especially in massive galaxies forming at high redshift, but the issue of how/why the IMF should vary in dependence of the environment remained unsettled. In the last few years, however, theoretical and observational evidence has started to pile up in favor of systematic IMF variations as functions of both star formation rate (SFR) and metallicity. The most extreme IMF variations should be seen in large galaxies that shine at high redshifts, with SFRs possibly exceeding 500–1000 $M_\odot$/yr. While classical methods of IMF determination, limited at optical, UV, and near-IR wavelengths, cannot probe such 'monsters' because of their dust obscuration, isotopic abundances measured in their interstellar medium (ISM) at millimeter/submillimeter wavelengths provide fundamental, indirect constraints to the stellar IMF in such extreme objects. In previous work, we demonstrated that some isotopic ratios of CNO elements are indeed excellent probes of the integrated galaxy-wide IMF (IGIMF), thus opening a new window to deduce the stellar IMF in dust-shrouded galaxies using ALMA. The members of our International Team were selected to cover the different expertise and skills necessary to accomplish the following goals: (i) reduce significantly the uncertainties present in abundance measurements, (ii) extend the measurements to different types of galaxies, from dwarfs to ellipticals, at both high and low redshifts, (iii) improve –or develop from scratch– the theoretical tools that are necessary for a full exploitation and interpretation of the data. Our team is composed of ten scientists from five European countries and from China. It includes experts in numerical simulations —semi-analytical models of galaxy formation in cosmological context (Lizhi XIE), pure chemical evolution models (Francesca MATTEUCCI, Donatella ROMANO), state-of-the-art three-dimensional hydrodynamical simulations (Donatella ROMANO)— as well as experts in stellar evolution (Chao LIU, Marco PIGNATARI, Paolo VENTURA), stellar nucleosynthesis (Marco PIGNATARI, Paolo VENTURA), IGIMF theory (Pavel KROUPA), ISM physics and molecular line observations (Rob IVISON, Padelis PAPADOPOULOS, Zhi-Yu ZHANG), data analysis (Zhi-Yu ZHANG). The team also benefited from the interaction with a number of young scientists (Carlo DE MASI, Xiaoting FU, Tereza JERABKOVA, Yan SUN, Zhiqiang YAN) and external experts (Di LI, Junzhi WANG, Yan XU). In order to facilitate the attendance to team members from both European countries and China, the first five-day meeting was held in ISSI, Bern, Switzerland, while the second one was held in ISSI-BJ, Beijing, China.

SUMMARY OF ACTIVITIES

During 7-11 January 2019 and 11-15 November 2019, we organised two team meetings in Bern and Beijing, respectively. In our team meetings, the following topics were covered:

1. Stellar initial mass function (IMF):
    - History and concept of IMF (Kroupa, Jerabkova, Yan)
    - Power-law, log-normal, cut-top functions (Kroupa, Li, Yan, Liu, Romano)
    - Variable IMF (Yan, Jerabkova, Kroupa, De Masi)
    - “Direct” and indirect indications of IMF variations (Ivison, Kroupa, Zhang, Romano)
2. Stars and stellar yields:
    - Binary stars (Liu)
    - Stellar rotation (Pignatari, Romano)
    - Stellar abundance measurements (Fu, Liu, Xu)
    - Stellar evolution, stars in clusters and in the field (Liu, Fu, Xu)
    - Statistics related to IMF (Liu)
    - Nucleosynthesis in single low-, intermediate- and high-mass stars (Ventura, Pignatari, Romano)
    - Nucleosynthesis in nova outbursts (Pignatari, Romano)
3. Measurements of element abundances in the ISM:
    - Molecular chemistry (Zhang, Wang, Li)
    - Optical depth issues (Zhang, Wang, Li)
    - Radiative transfer (Zhang)
    - Mixing of different excitation components (Zhang, Wang, Li, Papadopoulos)
    - Unresolved studies (Zhang, Wang, Ivison)
    - Alpha-enhanced astro-chemistry (Fu, Zhang)
4. Galactic chemical evolution models:
    - Chemical evolution of different types of galaxies (Matteucci, Romano, Xie)
    - IMF transition from top-heavy to bottom-heavy in early-type galaxies (De Masi, Matteucci, Yan, Jerabkova)
    - Degeneracies: variable IMF vs star formation time scales vs galactic outflows (Romano, Xie)
    - Cosmological simulations (Xie)
5. Understanding physics:
    - How stars are formed in molecular gas (Li)
    - How turbulence could impact the IMF and stellar rotation (Zhang, Liu)
    - Establishment and measurement of galactic radial gradients (Romano, Wang, Zhang, Sun)
    - Galactic structure in stars and ISM (Xu, Sun)
    - Physical properties of starburst galaxies and submm galaxies (Ivison, Zhang)

PUBLICATIONS

The discussions held in ISSI and ISSI-BJ and the support from ISSI/ISSI-BJ are acknowledged in the following refereed publications:

1. **Kroupa P., Jerabkova T.,** "*The Salpeter IMF and its descendants"*, 2019, Nat. Astr., 3, 482
2. **Yan Z., Jerabkova T., Kroupa P.,** Vazdekis A., *"Chemical evolution of elliptical galaxies with a variable IMF. A publicly available code"*, 2019, A&A, 629, A93
3. **Romano D., Matteucci F., Zhang Z.-Y., Ivison R., Ventura P.,** *"The evolution of CNO isotopes: the impact of massive stellar rotators"*, 2019, MNRAS, 490, 2838
4. **Yan Z., Jerabkova T., Kroupa P.,** *"The star formation timescale of elliptical galaxies. Fitting [Mg/Fe] and total metallicity simultaneously"*, 2019, A&A, in press
5. Zhang J. S., …, **Romano D., Zhang Z.-Y., Wang J. Z.,** …, *"A systematic study on Galactic interstellar ratio $^{18}O/^{17}O$: I. $C^{18}O$ and $C^{17}O$ J = 1−0 data analysis"*, 2019, ApJ, submitted
6. Li F., **Wang J.,** ..., **Zhang Z.-Y.,** ..., *"Isotopologues of dense gas tracers in nearby infrared bright galaxies"*, 2019, MNRAS, submitted
7. Mendez-Hernandez H., ..., **Zhang Z.-Y.,** ..., *"VALES VI: ISM enrichment in star-forming galaxies up to z~0.2 using $^{12}CO(1−0)$, $^{13}CO(1−0)$ and $C^{18}O(1−0)$ line luminosity ratios"*, 2019, MNRAS, submitted

Further papers are in preparation.