Report on the PhD thesis by Mr. Zhiqiang Yan entitled

Chemical evolution of galaxies with an environment-dependent stellar initial mass function

Report by PhD supervisor

With this thesis, Mr. Zhiqiang Yan has been able to document a masterpiece on one of the most central research problems in modern astrophysics. The thesis analyses how a systematically varying stellar initial mass function (IMF) affects the observable stellar populations of galaxies and their enrichment with metals. The calculations performed and results obtained are extremely significantly important. Mr. Yan for the very first time applies a fully self-consistent formulation of the variation of the IMF in terms of the density and metallicity of the star forming gas as the galaxy evolves in terms of one dimensional chemical evolution models. This has never been achieved before, in particular, since in Mr. Yan's calculations, the IMF is, at every time step, consistent with all known observational constraints on resolved stellar populations and the chemical abundances of the computed galaxies.

In order to perform the research, Mr. Yan developed and published the computer code "GalIMF" (Yan et al. 2017; Yan et al. 2019), therewith being a freely available unique research tool provided for the community. Mr. Yan also invented the correct way of normalising the supernova type 1a rate per star that must be applied when the IMF evolves. This invention is found to be consistent with independent observational estimates, as detailed in his research paper (Yan et al. 2021). In this research paper, which stands as a landmark study, Mr. Yan has, for the very first time ever, solved the problem of why the formation times deduced from stellar population synthesis were consistently significantly longer than those inferred from alpha-element and metal abundances. His work also solves the associated problem that more massive early-type galaxies appear to have more dark matter in their inner regions. According to his models, this "dark matter" is composed of stellar remnants from a galaxy-wide IMF which was overabundant in massive stars. Thus, today we have, as a consequence of Mr. Yan's research, a much more reliable knowledge of how quickly early-type galaxies formed in dependence of their mass.

Mr. Yan's thesis is based on five first-author research papers (he co-authored in total nine) dealing with theoretical problems on how the IMF is to be sampled, how this affects the properties of galaxies, the chemical evolution of massive elliptical and extremely low mass ultra-faint dwarf galaxies, therewith demonstrating that incorporation of the varying-IMF into the calculations is mandatory, as long as this variation fulfils the above mentioned constraints. The calculations are based on the IGIMF theory which encompasses the IMF variation on the scale of molecular cloud cores and propagates this through integration to the galaxy-wide IMF. The IGIMF theory allows to connect the galaxy-wide gas depletion and enrichment to the molecular cloud scale, and Mr. Yan has been one of the very few researchers able to grasp this theory and to apply it and implement it correctly into the calculations. To achieve this, Mr. Yan had to learn and implement stellar-evolution and chemical-yield tables as well as to understand and implement the role of core-collapse and degenerate supernovae.

The thesis is well written and clearly structured and poses an excellent introduction into this important astrophysical topic. Mr. Yan performed all this work largely by himself, he needed very little guidance (which was mostly on how to express the results in English). Mr. Yan convinced me of being a highly talented, extremely capable and independent young researcher with a strong drive and elan to truly understand the natural phenomena. Apart from the outstanding scientific results, Mr. Yan also has a remarkable vita: he came from China to Bonn University to do his MSc, relocated to Charles University for his PhD studies, founded a family (two children) and collided with the COVID era with associated problems.

I very strongly recommend this outstanding thesis to be accepted by the Faculty of Mathematics and Physics for the doctoral degree, which I assess to be of the highest outstanding quality.

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