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Referee report for the PhD Thesis of mgr Gabriele Riccio

The PhD Thesis of mgr Gabriele Riccio titled "**The star formation activity of galaxies: multi-wavelength constraints based on Spectral Energy Distribution fitting**" prepared under the supervision of Dr. hab. Katarzyna Małek, with auxiliary supervision by Dr. Junais, aims to address the long-standing issue of explaining the observed variety and complexity of the galaxy structure through their evolutionary pattern. Neither the exact structure nor the evolution are known in details so far. The author concentrated on the issue of the measuring the star formation activity in galaxies from massive surveys, using the broad band data.

Correspondingly, the Thesis consists of 4 major sections: the Introduction and the three sections presenting the key results. Section 2 is based on the published paper, with 10 co-authors (Małek, K.; Nanni, A.; Boquien, M.; Buat, V.; Burgarella, D.; Donevski, D.; Hamed, M.; Hurley, P.; Shirley, R.; Pollo, A.) . Section 3 is basically a version of the published paper, with 12 co-authors (Paolillo, M. ; Cantiello, M. D'Abrusco, R. ; Jin, X. ; Li, Z. ; Puzia, T.,; Mieske, S. ; Prole, D. J. ; Iodice, E. ; D'Ago, G.; Gatto, M. ; Spavone, M.) . Section 4 contains results which are also about to be published soon, likely with some-co-authors. However, in the two published papers mgr Riccio is the leading author, he will likely be in the third one, so he seemed to have the dominating role in obtaining all these results. Multi-author papers are now characteristic for work done in broad international collaborations, but the leading author is always responsible for the data analysis and the text. The results are summarized in Section 5.

Introduction

The first section reads well, it starts with the onset of astronomy in the ancient times, and with the early recognition of nebulae/galaxies as other Milky Ways only a hundred years ago, but soon after it becomes focused on the material which gives an essential background to the main part of the Thesis. He introduces systematically the concept of the Star Formation Rate (SFR) and Initial Mass Function (IMF), and discuss the sensitivity of various SFR indicators to underlying timescales.

One problematic detail: in Sect. 1.3 the author writes"As the expansion speed-up farther we travel in the Universe, the redshift phenomena is higher at earlier epochs, serving as a time reference for events. " This makes an impression that the accelerated expansion of the Universe is important for having higher redshift at larger distances while the decelerating Universe has the same (qualitative) property. Perhaps this is just unfortunate phrasing.

Considerable attention is payed to presenting the sources of the X-ray emission, including the X-ray binaries and their classification as they are later used as the SFR tracers. The author also discusses in details the X-ray luminosity function (XLF) since it is later used it the Thesis to connect the SFR and X-ray data, and he mentions the issue of including the tail of the otherwise undetected X-ray sources. The use of XLF is however complicated by the strong dependence of the XLF on the surrounding, and in particular the XLF in globular clusters is specific and usually neglected. Next the author discusses several star formation indicators, with particular attention payed to the issue of extinction/attenuation which complicates the use of some indicators. Including the IR into consideration helps to control the amount of radiation absorbed by the dust, as it must be then re-emitted in the IR. Overall, the Introduction is well planned and focused on the topic of the Thesis which is SFR. I have only one more minor comment. It is not easy to understand what is the difference between adopting the best fit as the results of the SED fitting and (adopted in the Thesis) the choice of the SED model with the highest weight. Description at age 24 is not clear, and in addition it does not explain whether the fitting done through iteration or all these elements are fitted as a sequence.

Paper I

There the author demonstrates the possibility of massive SFR determinations with the expected enormous LSST data set using the SED method. These data covers only optical/near-IR bands so the tests are performed using the actual large sample of galaxies with much broader SED. The SFR was estimated from this data, Next, the SEDs were degraded to LSST bands only, and the SFR determination was repeated. It is not surprising that LSST data alone were not giving satisfactory results, particularly for the low redshift galaxies when the lack of rest frame far-UV data did not allow to address reliably the question of extinction. However, two ways out were found. One was the empirical fit which allows to correct the derived SFR as a function of redshift (equation 2.1, page 42). The second one was to connect the expected extinction with the star formation history, and in this way extinction is not an independent parameter, so can be determined from the SED even in the limited band. This is important since it will be rather difficult to match the future impressive LSST galaxy catalog with other spectral band for all objects. Just one comment on my side: the author writes that no UV satellite is planned (page 44). There are some projects, like Israeli ULTRSAT (under construction), with surface area 300 times GALEX, so it might be eventually useful.

The paper is extremely important, the amount of modeling done to achieve the goal is impressive. It provides clear methodological background for SFR determination when the actual LSST data comes.

Paper II

This paper was prepared with the aim to use in the future the X-ray data to infer SFR independently from SED. For the case study the author choose Fornax cluster, as this cluster was extremely well covered with such high spatial resolution instrument as Chandra in X-ray band, and in the optical band with the VLT Survey Telescope. I note that the list of authors in the published version of the paper does not include the supervisor.

In Paper II the amount of data analysis in the optical and X-ray domain, and the final identification of the LMXB in GC and in the field is extremely high and complicated (GC are unresolved etc.), perhaps the co-authors of the paper were of some help, judging from the references, but the created catalog is new, not coming from the literature. It finally contains 82 intra-cluster GC-LMXB and 86 objects hosted by the galaxies. The GC were additionally divided into red and blue to trace the potential effect of metallicity.

The study shows that only a relatively small fraction of LMXB are detected in GC, contributing about 17 % to the total number of LMXB, and about10 % to the total X-ray luminosity of the Fornax cluster. This could be eventually helpful in statistical studies of the relation between the X-ray flux and the SFR in massive studies of galaxies. The high number of intra-cluster GC is interesting *per se*, from the evolutionary aspect, but I am not sure if this is typical for galaxy clusters as this is not discussed in the Thesis. I found one aspect of the data analysis not quite clear: In Fig. 3.3 we see that the red and blue populations are partially overlapping, and I did not see clearly how finally the given GC was assign a color. The author refers to the Gaussian mixture method – does it mean it is random? Does the selection and assignment is repeated several times, and is it checked that the results hold?

Finally, small comment, or perhaps a typo: I am also puzzled what is the hardness ratio between red and blue population of LMXB. Hardness ratio is usually defined as a ratio of the fluxes in a single source, between the two energy bands. I would rather expect a hardness ratio for two populations, with a specified range of hard and soft band limits.

Paper III

This part is devoted to designing the relation between the X-ray luminosity and SFR, thus to some extent building upon Paper II. The goal is to use the eROSITA data. The idea is great, the data in the e-ROSITA Final Equatorial Depth Survey are available. The X-rays are less affected by extinction, which is an advantage, but different contributors to X-ray luminosity scale differently with SFR and its history. Thus the author supplements the X-ray data with other wavelength bands, use the broad-band SED fitting, and finally checks how well the carefully determined SFR correlates with the total X-ray luminosity.

The relation derived by the author shows a correlation between the two, but with a very large scatter. Therefore, the X-ray luminosity is not a good tracer of SFR if no other data are available and SED fitting cannot be performed. The author identifies the sources of scatter as well as the shift of his new relation with respect to the relation obtained by Lermer et al. (2006). He attributes the problem predominantly to the serious incompleteness of the sample (this clearly explains the shift), but the dispersion is hard to limit as the X-ray luminosity couples more to the star formation history, than to the actual SFR. Likely a combination of the study of X-ray source types and more advanced modelling of the star formation history could help in the future to use even the X-ray data alone to probe the SFR.

Summary

Summarizing, the author made an impressive job in data analysis, and interpretation of the results. The results related to LSST are important, and the methodology is ready to use. The experiments with X-rays did not yet result in a clear path to use them as precise SFR tracers, but the directions of the further development were outlined and partially tested. Overall, it is a great and valuable work, and in my opinion the presented Thesis are excellent.

Conclusion

In summary, I consider the doctoral thesis of mgr Gabriele Riccio to be a valuable contribution to the methods of determining such a key parameter of a galaxy as the Star Formation Rate. The Thesis meets the criteria prescribed by the law for a doctoral dissertation. Therefore, I request that this dissertation be admitted to a public defense.

B Czerny

prof. dr hab. Bożena Czerny