CENTRUM ASTRONOMICZNE MIKOŁAJA KOPERNIKA
POLSKA AKADEMIA NAUK

ul. Rabiańska 8
87-100 Toruń

tel. (56) 6219249
fax (56) 6219381

Prof. dr hab. Ryszard Szczerba
Nicolaus Copernicus Astronomical Center
Toruń, Rabiańska 8

Toruń, 23/07/2023

**Review of the doctoral dissertation by Mahmoud Hamed, entitled „Dust Attenuation in Dusty Star Forming galaxies Using Spectral Energy Distribution"**

Mr Mahmoud Hamed's doctoral thesis focuses on problems related to the study of dust attenuation in galaxies with active star formation processes at different redshifts. Despite the fact that dust constitutes only about 1-2% of baryonic matter, it plays a crucial role in specific regions/environments where sufficiently low temperatures enables its formation and/or survival. These areas include envelopes/discs formed during late stages of stellar evolution, the interstellar medium (ISM), and particularly star forming regions with embedded young stellar objects (YSOs). Additionally, tori around central black holes in galaxies with active nuclei (AGN) are also influenced by dust; however, the PhD candidate has not found them in the analyzed samples. In the context of observing distant galaxies observations, where individual dusty environments cannot be resolved, all of them contribute to the global pool of dust that influences the observed light.

The recent observation with the James Webb Space Telescope (JWST) suggest that dust is present in significant amounts already in galaxies that are only about one billion years old (Witstok, J. et al. Carbonaceous dust grains seen in the first billion years of cosmic time. Nature https:// doi.org/10.1038/s41586-023-06413-w 2023). **For this reason alone, research of dust attenuation in galaxies in Mahmoud Hamed's PhD thesis is exceptionally important and timely fits into the dynamically developing branch of modern astrophysics.** The presence of dust is attributed to supernovae and/or the earlier stages of massive stars evolution, rather than to intermediate-mass stars, as observed in evolved galaxies like our Milky Way (even if present they would not have enough time to become dust producers). The detection of the ultraviolet (UV) bump of carbonaceous dust in the near-infrared (IR) domain, made possible by JWST observations, was facilitated by the the Doppler effect in the expanding Universe. This effect causes the radiation from more distant galaxies to be more redshifted. Another aspect of extragalactic astrophysics that requires knowledge of the redshift ($z$) of the observed galaxy to properly convert light to rest-frame wavelengths. The effect of redshift is less pronounced in the IR domain for galaxies at low and intermediate $z$. As a result, the thermal emission of dust, heated by absorption of short-wave radiation, can be directly observed through infrared satellite or radio observations.

Mr Mahmoud Hamed is using the spectral energy distribution (SED) method to investigate proposed forms of attenuation laws in galaxies at different redshifts. This method applies energy balance to reproduce the observed panchromatic SED of galaxies at known redshifts. The method is commonly used in stellar astrophysics, were dust distribution is well constrained. However, for extragalactic applications, especially for dusty star forming galaxies (DSFG), it requires many additional assumptions, such as the presence of stellar populations, star formation history, the present star formation rate (SFR), dust distribution (through the assumed attenuation law), and more. Mr Hamed employs this method with a full understanding of the problems in such research, demonstrating the importance of this method and its potential for understanding the very complicated problem of galaxy evolution.

The PhD thesis is a compilation of three multi-author research papers, two of which are published, and one is currently under review. **In all of them, the candidate is the first author.** However, it is not a simple "staple" of three reprints or preprints (as is a rule in my home Institute), but rather an edited booklet. Similar approaches are used in different countries, particularly in the Netherlands, and this requires additional careful work from the candidate. In the case of the evaluated PhD, it is more comprehensive manual, similar to the older approach. The first chapter contains a comprehensive Introduction. The second chapter is devoted to the dissection of two nearby galaxies in respect to the line of sight at the cosmic noon, while the remaining two chapters deal with large samples of galaxies and are strictly devoted to the influence of different attenuation laws on the SED modelling. I will now evaluate the dissertation chapter by chapter.

Reviewing a dissertation of already published papers is easier in that it does not require a thorough analysis of methodology, used assumptions, or the overall structure of the presented results. Reading Mahmoud Hamed's PhD thesis is a pure pleasure, especially after reading the Abstract and the Introduction, which serve as an excellent guide for the "stellar" reviewer, but also for the scientists already working in the extragalactic astrophysics field. The several-page Introduction to the dissertation is presented very interestingly, and to be honest, it organized my knowledge in this field of research in such significant way that I could analyze the main chapter of the dissertation with full understanding.

In the **Introduction**, Mr Mahmoud Hamed nicely describes the current knowledge about dust in the context of extragalactic investigations. He then demonstrates the complications, but also the power, of panchromatic SED modelling of galaxies resulting from unknown stellar populations, end especially dust attenuation – which is very comprehensively described. He emphasizes the importance and role of dust under the energy balance assumption in the SED modelling. Then he explains the infrared excess (IRX) – attenuation, characterized by the UV slope β, a correlation that is thoroughly investigated in chapter 4. He introduces elaborated methods of estimation of physical properties of galaxies and dust properties necessary for the proper SED modelling, which are so far known and commonly used. Finally, he describes how the physical properties of galaxies are connected/changing during galaxy evolution and summarizes the importance and complexity in understanding dust evolution in the investigated galaxies at different redshifts. Really well done.

**Chapter 2** is based on the paper entitled "Multiwavelength dissection of a massive heavily dust-obscured galaxy and its blue companion at $z\sim2$" that has been published in A&A. The candidate co-authored this paper with a member of the CIGAL core group (L. Ciesla) as a second author, and the PI of the ALMA observations (M. Béthermin) as the third author, among others (including the PhD advisor K. Małek). They conducted a detailed analysis of the system of two galaxies, Astrate and Adonis at $z\sim2$, which has been recently deblended, including in the ALMA observations. The CO mapping shows molecular emission only from Astrate, additionally offset in comparison with the optical images. However, the continuum from VLA observations aligns with the ALMA observations, confirming the reality of the offset. It is a very interesting phenomenon that would be worth investigating further. The SED modelling method based on the CIGALE code is fully utilized in this paper. The candidate also investigates how different attenuation laws influence the derived physical properties of Astrate, a DSFG galaxy, concluding for example that steeper attenuation laws results in the derivation of smaller stellar mass in the galaxy, while shallower ones act in the opposite direction. The SED fitting utilizes a wide grid of free parameters to search for the best fit by minimizing $\chi^2$, sometimes with certain modifications. Usually, the number of free parameters is larger than the number of observational points, but a similar method is commonly used in the SED modelling of YSOs. Despite my "bad feelings" about such an approach, I believe it still provides reasonable results. The most important result of this work seems to be understanding the evolutionary stage of Astrate,  as a quenching through galaxy main sequence (MS) following a starburst epoch.

**Chapter 3** is based on the paper entitled "The slippery slope of dust attenuation curves. Correlation of dust attenuation laws with star-to-dust compactness up to $z$ = 4" that has been recently published in A&A. The candidate co-authored this paper with the PhD advisor as the second author and with a member of the CIGAL core group (L. Ciesla), among others. They investigate the attenuation laws in a sample of carefully selected DSFGs observed in the COSMOS field. The selected 122 galaxies, covering the redshift range $1<z<4$, have up two 24 photometric points, which exceeds the number of free parameters in the approach developed by the candidate in Chapter 3. **Amaizing and congratulations – my concerns from above do not apply**. A novelty in this work is the estimation of the homogeneous effective radii in the UV-optical (to study spatial extent of the stellar population/star forming regions) and in the IR (to study dust extension). This novel approach allows showing that knowledge of the relative sizes is crucial for selecting the best attenuation curve, which mostly influence the estimation of the stellar mass in galaxies. Galaxies with smaller UV-optical/IR sizes prefers (in the sense that the SED fitting gives then smaller $\chi^2$) steeper attenuation laws, while those with relatively large starlight extension require shallower attenuation laws. These results suggest the importance of dust evolution together with galaxy evolution. Worth mentioning, however, is that this does not translate into linear evolution over time, as compactness reaches its maximum at the cosmic noon, as shown by the candidate. It is also worth to underlining that I did not expect the SED fitting using only UV-NIR data predict dust IR emission properly. This probably demonstrates the power of the SED fitting in extragalactic astrophysics.

**Chapter 4** is based on the paper entitled "Decoding the IRX-β dust attenuation relation in star-forming galaxies at intermediate redshift", which has been submitted to A&A. The list of co-authors is unknown to me as the original paper has not been placed in astro-ph. The candidate investigates the factors driving the observed correlation between infrared excess and dust attenuation, measured by the β UV slope of the spectrum. For this purpose, a carefully selected sample of over 1000 galaxies from the VIMOS Public Extragalactic Redshift Survey with a redshift range $0.5<z<0.8$ is utilized. The same method as in Chapter 3 is applied, likely for more than half of the galaxies, with a larger number of photometric data points than the free parameters. The new approach in this chapter involves determining the metallicity of the gas in galaxies using forbidden lines of [O II] and [O III] ratio relative to Hβ. This allowed the candidate to discover a strong influence of gas-phase metallicity on the IRX-β relation. Other physical properties of the investigated galaxies also impact the IRX-β relation, with the galaxies' morphology, stellar mass, and age of dominating stellar populations among the most influential factors. The obtained results are very nicely presented in Figs. 4.6-4.9 in this chapter.

In conclusion, I find Mahmoud Hamed's doctoral dissertation to be highly valuable and far exceeding the criteria set for doctoral dissertations. His thesis aligns with the current trends in astrophysical research and makes a significant contribution to its advancement and development. With full responsibility, I can state that the candidate has demonstrated both the ability to conduct independent scientific research and the knowledge necessary for the proper interpretation of the obtained results. Unfortunately, I am unable to recommend distinguishing his work as I, being a "stellar" reviewer, am not familiar with the current trends and literature in this field. Upon reviewing the citations alone, I noticed that the paper from Chapter 2 is mostly self-cited. Other papers of the candidate, which I believe are much more significant are too recent to have garnered citations yet.

To meet the formal requirements, I recommend the acceptance of Mahmoud Hamed thesis for the public defense.

Signature Not Verified
Dokument podpisany przez Ryszard Szczerba
Data: 2023.07.23 19:34:24 CEST

Ryszard Szczerba