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Review of the doctoral dissertation by Ngân Thi Mý Lê, entitled „Multi-Wavelength observations of the outer Galaxy: Identifying the impact of environment on star formation"

Star formation is one of the most fundamental processes in the universe. Studying star formation is important itself, but also helps us to understand the evolution of galaxies. Stars don't form in isolation: they have a strong impact on their surroundings through processes like radiation, stellar winds, and supernova explosions. This feedback influences the evolution of galaxies and their environments. Taking a closer look, star-forming regions are ideal places for the study of complex chemical reactions and the formation of molecules. This research not only contributes to astrophysics but also has implications for astrobiology. Furthermore, the study of star formation involves the investigation of protoplanetary discs, where planets are born. Understanding this process helps us to explore the formation of planetary systems, potentially uncovering habitable worlds. Hence, research on star formation presented in the Ms. Ngân Lê's doctoral thesis is important and timely fits into this fast developing branch of modern astrophysics, especially taking into account capabilities of the James Webb Space Telescope (JWST).

Ms. Ngân Lê's doctoral thesis focuses on issues related to the study of star formation. Specifically, it attempts to investigate the influence of the environment on this process by selecting star forming regions in the outer Galaxy and comparing their properties with the star forming regions in the Magellanic Clouds, the inner Galaxy or those located nearby. To achieve the goal, she employs observations across the wide range of electromagnetic spectrum. Her work convincingly demonstrates that significant results can be obtained through this modern astrophysical approach. The PhD thesis is a compilation of three multi-author research papers, one of which has been published, and two are in preparation. However, it's important to note that this isn't simply a collection of three reprints or preprints, as is the usual practice in my home Institute. Instead, it takes the form of an edited book, a format employed in various countries, particularly in the Netherlands, which requires the candidate to engage in additional careful work. However, this was not always the case, particularly in as-yet-unpublished articles.

I will now evaluate the dissertation chapter by chapter.

Abstract, Introduction, and Methodology

The main part of the dissertation (Chapters 3-5) is prefaced by an abstract, an introduction and the methodology chapter. Within introduction, Ms Ngân Lê provides a clear overview of the current knowledge concerning star formation and the critical physical processes associated with it, including magnetic field, mass accretion, jets and outflows. She then introduces the reader to the selected star-forming regions from the outer Galaxy that are investigated in the thesis. These regions include Oph-A, a very young, low-mass star-forming area in the L1688 region, and CMa-*l*224, situated in the northern part of the Canis Majoris region, along with its Gy 3-7 cluster. Following this, she provides details about observational characteristics of the instruments used on board of the Stratospheric Observatory for Infrared Astronomy (SOFIA) and the SpeX spectrograph mounted on the NASA Infrared Telescope Facility (IRTF). Finally, in the methodology section she briefly describes the theory that enables the measurement of the magnetic field projection on the plane of the sky using polarized thermal dust emission, and the CO rotational diagram, which allows for the determination of gas temperature (with some additional assumptions). In my opinion, what is missing is an introduction to the Stokes parameters used for determining the polarization characteristics of the incident radiation. In general, the introductory section, spanning several pages, is interesting and well organized. However, the author was unable to entirely avoid minor mistakes or a few unnecessary repetitions, which, however, do not discredit the text.

Chapter 3

In this section, Ms. Ngân Lê attempted to understand the role of the magnetic field in the Oph-A star forming region by using observations from the SOFIA/HAWC+ instrument. This instrument is capable of providing both images and polarimetry of radiation in the far infrared (FIR) wavelengths. Opiuchi-A is an isolated system, and such an approach enables investigations of the magnetic field's influence on star formation. The orientation, as well as the strength of the magnetic field, has been determined at two wavelengths in the FIR for the entire observed region in Oph-A. To assess the importance of the magnetic field, a mass to magnetic flux ratio has been determined. The ratio is much larger than one in the northern part of the cloud, suggesting that this region is experiencing gravitational collapse, and the strength of the magnetic field is insufficient to prevent it. On the other hand, the opposite situation is observed around the position of the S1 star, which influences physical conditions in the eastern part of this molecular cloud. Ms. Ngân Lê determines other indicators of the cloud's physical state and discuss them by comparing them with the similar estimations for different star forming regions. Nice piece of work, which, in my opinion, is ready for publication, except for the final conclusions. These conclusions appear to have been written without fully exploiting the discussion presented. Furthermore, there are several mistakes and repetitions, which suggest that the final part was written too quickly. Additionally, the arrangement of the figures in the appendix does not match their respective captions.

Chapter 4

This chapter is based on the previously published work of Ms. Ngân Lê, so it does not contain the mistakes found in the earlier chapters. The discussion presented regarding the physical conditions in Gy 3-7 cluster is well written, and the available spectroscopic data from SOFIA FIFI-LS instrument are fully exploited. The strong correlation found between

high-J CO and forbidden [O I] lines is convincingly attributed to the presence of C-type shocks influenced by UV photons. Additionally, the physical conditions within the cloud are estimated through modelling. It's worth mentioning that observations from the Torun 32-m radio telescope have detected variable water maser emissions in the direction of this active star forming region. To determine the physical state of the young stellar objects (YSOs) identified within Gy 3-7 molecular cloud, spectral energy distribution (SED) modelling has been performed. The SED fitting utilizes a wide grid of free parameters to search for the best fit by minimizing χ^2, sometimes with certain modifications. Unfortunately, the number of free parameters is very often larger than the number of observational data points. However, despite my "bad feelings" about such an approach, I believe it still provides reasonable results. Finally, using data for Gy 3-7 and other star forming regions, Ms. Ngân Lê and collaborators showed that molecular-to-atomic line cooling (defined as $L_{CO}/L_{[OI]}$) from Galaxy and the Magellanic Clouds do not show dependence on the metallicity.

Chapter 5

This section is devoted to the analysis of near-infrared spectra obtained with the SpeX spectrograph for 33 YSO candidates in the Canis Majoris CMa-*l*224 region. The acquired spectra exhibit atomic and/or molecular spectral features that are characteristic of YSOs. These lines are subsequently used to determine the status and parameters of the observed sources. Specifically, the spectral types of the sources have been determined. Then, various methods of extinction determination are employed, and the estimated extinction is used to quantify the excess continuum emission in the K band, which is interpreted as being due to ongoing accretion. The derived accretion luminosities and mass accretion rates are subsequently compared to those of YSOs in different environments in order to investigate potential dependence on metallicity. However, no evidence supporting such a relationship has been found. This conclusion is reinforced by independent work, which has already been published and co-authored by the candidate, and is based on the VLT/KMOS observations. Again, it is my impression that this part is also ready for submission.

In conclusion, I think that Ms. Ngân Lê's doctoral dissertation is valuable and meets the formal requirements expected of doctoral dissertations. The candidate has demonstrated the ability to conduct scientific research effectively and possesses the necessary knowledge for the accurate interpretation of the obtained results. This leads me to recommend the admission of Ngân Lê to the subsequent stages of the process, including the public defense of her doctoral dissertation.

Signature valid
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