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Review of the PhD Dissertation by M. Z. Mobeen

Dear colleagues,

Mr. Z. Mobeen structured his PhD dissertation as follows. He began with a 50-page introduction, where he clearly presented the motivations behind his work. Directly after this introduction, he included a thematically consistent set of three articles published in *Astronomy & Astrophysics* (rank A), for which he is first author (2021, 2024, and 2025). At the time of writing (29 August), the third publication has appeared on astro-ph but does not yet seem to be formally accepted. Alongside the three articles, several letters were submitted specifying the contributions of each co-author, all of which indicate that Mr. Z. Mobeen carried out the majority of the work.

The entire dissertation focuses on a single astrophysical object of great interest: V838 Mon, the prototype of red novae, corresponding to the merger of two stars whose outburst was observed in 2002. The aim of the PhD is to study the geometry, size, and physical properties of the remnant environment of this highly complex system. To do so, Mr. Z. Mobeen employed the world's two leading interferometers: the Very Large Telescope Interferometer (VLTI) in the Atacama Desert, Chile, and the CHARA Array at Mt. Wilson, California. He also relied on state-of-the-art modeling tools for data analysis.

I will briefly summarize the introduction and the three publications.

In the **introduction**, Mr. Mobeen first reviews the basic principles of interferometry, helping non-specialist readers grasp key concepts such as squared visibilities and closure phases—essential for understanding the subsequent work. He then describes the four interferometric instruments used in his thesis: MATISSE and GRAVITY on VLTI, and MIRC-X and MYSTIC on CHARA. The text continues by outlining two complementary approaches to data analysis: geometric modeling and image reconstruction. He then turns to red novae, and specifically to V838 Mon: its eruption, the stellar merger hypothesis, and previous interferometric studies with PTI, AMBER, MIDI, and ALMA. The introduction concludes with a clear statement of the motivation for the work, together with the roles and contributions of each author in the three papers. As an interferometrist, I found this introduction clear, well-structured, pedagogical, and perfectly suited to framing the three publications.

The **first publication (2021)** presents the first MATISSE observations of V838 Mon in the LMN bands, obtained 16 years after *Lane et al.* with PTI and 7 years after *Chesneau et al.* with AMBER and MIDI. In particular, two L-band measurements were of outstanding quality. Mr. Mobeen analyzed the data using the LITpro tool (Jean-Marie Mariotti Center), building geometric models with simple components such as point sources, disks, Gaussians, and ellipses. This modeling requires balancing the quality of fit against the number of parameters, and the paper carefully details many tested models. The authors report an elongated, disk-like structure of ~3 mas in L band, oriented at –40° on the sky, consistent with prior results in other bands. Closure phases reveal small asymmetries, likely caused by dust inhomogeneities. An attempt at image reconstruction in L band had limited success, as this technique requires much denser uv-coverage. Personally, I found this first paper highly relevant: returning to V838 Mon with MATISSE, seven years after MIDI, was an excellent idea. Olivier Chesneau was a dear friend, and I am glad to see younger generations pursuing novae with the same passion he did. Encouraged by these results, Mr. Mobeen decided to intensify his observational campaign.

The **second paper**, central to the dissertation, is based on observations with MATISSE and GRAVITY at VLTI and with MIRC-X and MYSTIC at CHARA, covering the H, K, L, M, and N bands. Again, squared visibilities and closure phases were geometrically modeled to constrain physical parameters, and high-resolution images of V838 Mon were reconstructed in H and K bands using MIRA and SQUEEZE algorithms. These images reveal a bipolar morphology reminiscent of jets. The central dusty structure, probably an inclined disk, measures ~2 mas in K band and ~1.2 mas in H band, with a clumpy morphology aligned along a PA of –40°, in agreement with the first study. A clump at 1.7 mas from the center may trace jet–environment interactions. Also, spectra show strong CO and H_2O absorption, confirming dense circumstellar material. This study, in my view, will become a reference for the field: indeed only few objects are observed with both VLTI and CHARA using so many instruments, and the dataset is remarkable. The analysis is impressively detailed yet pedagogical, spanning about 15 pages of main text and 20 pages of appendices.

The **third paper** builds on the extensive dataset of the second, now addressing the physics of V838 Mon with the RADMC-3D code. The authors developed a 3D model including jets, a torus, and an ellipsoid. The model reproduces H-band interferometric observables reasonably well but struggles with the very small K-band closure phase deviations. Polarimetric measurements with SAAO-HIPPO show very low intrinsic linear polarization (<2%), consistent with the model. I found this publication particularly valuable: rather than stopping at a geometrical and chemical analysis, Mr. Mobeen attempted to probe deeper into the physics, seeking a genuine understanding of the object's nature.

Overall impression. I believe Mr. Mobeen's thesis will stand as a reference in the field. It is rare to see a single object studied so thoroughly over several years with cutting-edge observations, detailed analysis, and advanced modeling. The results provide a coherent physical picture of the star—one that will surely be refined in the future, but which already represents a solid benchmark. Moreover, Mr. Mobeen has demonstrated mastery of interferometric techniques, which are far from trivial, making excellent use of the tools developed at the Jean-Marie Mariotti Center to broaden access to interferometry. I am confident he is now well-equipped, both observationally and theoretically, to pursue independent research.

Naturally, a thesis raises some questions. I have three:

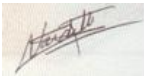
• In the geometrical models of Table 3 (paper 1) and Table A.1 (paper 2), many parameters are involved. Reduced χ^2 values are given, but could there be degeneracies? Did Mr. Mobeen use the χ^2 maps of LITpro to explore them? For example, in model ED(A1) of paper 1, is there correlation between size, PA, and stretch ratio?

• In paper 3, the authors write: "*It is possible that the considered dust analogs are not a good representation of the real dust surrounding V838 Mon. Even more likely, the environment may be constantly producing and destroying dust, which is impossible to model within the static RADMC-3D framework.*" Does Mr. Mobeen have a physical mechanism in mind that could drive continuous dust production? Any ideas on how to test this hypothesis?

• In France, candidates are usually asked to present perspectives for their work. I found this somewhat lacking in the thesis. I would like to know what directions Mr. Mobeen would suggest for a future student, observationally and theoretically. What next steps does he envisage?

In conclusion, I consider Muhammad Zain Mobeen’s dissertation to be a significant and valuable contribution, fully meeting the legal requirements for a doctoral thesis. I therefore recommend that it be admitted to public defense.

Nicolas Nardetto,
Director of Research CNRS



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