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Reviewer's report on PhD thesis "The Role of the Cosmic Web in the Structural and Dynamical Evolution of Dark Matter Subhaloes" by Feven Markos Hunde

The problem of dark matter, its origin, properties and the role in structure formation in the Universe remains one of the major scientific puzzles of present-day astrophysics. The PhD thesis of Ms Hunde comprises an attempt to contribute to the solution of the problem via an analysis of a cosmological simulation of structure formation aimed at understanding the effect of cosmic environment on the properties and evolution of dark matter substructure.

The thesis is composed of six chapters, of which the first two have an introductory character presenting the general background of the thesis and the methodology. The original results of the thesis are presented in chapters 3-5 and the conclusions and outlook follow in chapter 6. The content of chapter 3 has already been published as a paper in Astronomy & Astrophysics, chapter 4 has been submitted as a paper to Physical Review D, while chapter 5 contains as yet unpublished results. The papers are co-authored, but the description of the contributions of the Candidate to the results presented in the thesis appears entirely convincing that her role was dominant in all aspects of the work.

In chapter 3 the Author uses COLOR N-body simulation and the CaCTus cosmic web classification methodology to analyze subhalo populations in host halos of various mass residing in different cosmic web environments. She finds that the environment does imprint systematic effects on the subhalo populations at the present time, for example subhalos hosted by halos in filaments tend to be significantly more abundant than the cosmic mean, while the opposite is true for voids. These results are applied in chapter 4 to calculate the effect of environment on the predictions of the strength of the dark matter annihilation signals. In chapter 5 the Author extends the analysis of substructure to earlier times with the aim to identify the origin of signatures found in chapter 3. She finds that some of the environmental dependence seems to be already established before the subhalos fall into their host, and the subsequent evolution within the host further modifies these signatures through environment-dependent tidal processing.

My major concern about the project is related to the general approach adopted, namely the restriction of the analysis to the purely dark matter simulation performed by one of the

supervisors. It would be more realistic to use simulations with baryonic physics included. While performing such simulations requires substantial know-how and appropriate resources that may not be accessible to the Candidate, there are such simulations available elsewhere. For example, the TNG100-1 simulation of the IllustrisTNG project has a very similar box size and resolution to the COLOR simulation used in the thesis and at the same time includes magnetohydrodynamics, star formation, stellar and AGN feedback etc. In addition, a purely dark matter counterpart of this simulation is available for comparison so the effect of baryons could be disentangled and studied directly. The simulation was already publicly released at the time the Candidate started her work on the PhD thesis so it is really difficult to understand why it was not used, since the PhD student as well as the supervisors must be aware of the importance of the baryonic physics. Indeed, the Candidate states in the introduction and elsewhere in the thesis that the small scale problems of LCDM are solvable once the baryonic physics is taken into account.

Having stated this main concern, below I list detailed comments or questions on the thesis content in order in which they occurred during the reading of the text.

Abstracts: The Polish version of the abstract contains some unfortunate terms like “migawki symulacji” or “satelity środowiskowe”.

Chapter 1: The introduction is rather basic, contains well-known cosmological facts, not really relevant to the content of the thesis. In particular, I believe it was not necessary to include Einstein or Friedmann equations. The constants related to the spherical collapse model are introduced multiple times and not fully consistently. There are some inappropriate terms like “solid body” used in the context of inner density profile shapes, where the Author clearly means just flat profile or one of constant density. The name of the simulation used “COpernicus COmplexio LOw Resolution (COLOR) simulation”, is not fully consistent with the statement that it “provides the high-resolution data”.

Chapter 3: The introductory part of the published paper repeats much of the information that was already included in chapters 1-2. Page 49: it is not explained why the concentration–mass relation of node halos deviates strongly from expectations and why the node environment was excluded from the analysis.

Chapter 4: This chapter is much less developed than the preceding chapters that were already published or submitted for publication. There are a number of inconsistencies and imprecise statements. For example, on page 82 the Author comments on the results shown in Fig. 5.1 stating that “the magnitude of this suppression of the cumulative subhalo mass function increases strongly with host halo mass”, but then says that there is “systematic increase of the survival fraction with host mass”, which has an opposite meaning. The latter trend is explained as related to the fact that lower-mass hosts completed their assembly at earlier epochs when the mean cosmic density was higher and the earlier assembly resulted in longer effective stripping timescales. This is possible, but more massive hosts should strip their subhalos more strongly - why is this not seen? As for the environmental dependence of the same quantity, a few possible reasons were given (page 82 and 84) but none of them was discussed in detail. For the cumulative subhalo velocity function (page 86, Fig. 5.2) the trends with the halo mass and environment seem to be much weaker - why is that? The discussion of

Fig. 5.3 on page 88 is even more confusing: the Author states that “subhalos in filaments show the lowest ratios” of present vs peak mass, while the figure clearly shows the opposite trend.

In summary, I believe the Author’s contribution to understanding the properties and evolution of dark matter substructure and its dependence on environment is substantial, even though the simulations, halo catalogs and cosmic web classifications were not created as part of this thesis, but were provided as pre-existing data products. However, without baryonic physics, the results of the project remain preliminary and difficult to interpret or compare with observations, which is the main shortcoming of the thesis. Overall, the properties of the subhalos seem to be controlled mainly by the host halo mass while the differences due to environment discovered in the thesis are rather small and therefore would probably be subject to changes of comparable or bigger size due to baryonic physics.

I conclude that the presented dissertation meets the formal and customary requirements for doctoral dissertations and I recommend its admission to subsequent stages of the procedure, including the public defense.

Signature Not Verified
Dokument podpisany przez Ewa Łokas
Data: 2026.07.29 13:38:54 CEST

Warsaw, July 29th, 2026

Prof. Ewa L. Łokas

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Konkluzja recenzji rozprawy doktorskiej
(Conclusion of dissertation review)

„The Role of the Cosmic Web in the Structural and Dynamical Evolution of Dark Matter Subhaloes"

Tytuł rozprawy *(Dissertation title)*: .....

Feven Markos Hunde

Autor rozprawy *(Author of the dissertation)*: .....

[X] Pozytywna ocena *(Positive conclusion)*:

Stwierdzam, że przedstawiona mi do recenzji rozprawa spełnia wszystkie wymagania ustawowe i zwyczajowe stawiane rozprawom doktorskim i wnoszę o dopuszczenie jej do dalszych etapów postępowania doktorskiego, uwzględniając publiczną obronę.

*(I conclude that the presented dissertation meets the formal and customary requirements for doctoral dissertations and I recommend its admission to subsequent stages of the procedure, including the public defense.)**

[ ] Ocena negatywna *(negative conclusion)*

Stwierdzam, że przedstawiona mi do recenzji rozprawa nie spełnia wszystkich wymagań ustawowych i zwyczajowych stawianych rozprawom doktorskim i dlatego nie rekomenduję dopuszczenia jej do dalszych etapów postępowania doktorskiego.

*(I conclude that the presented dissertation does not meet the formal and customary requirements for doctoral dissertations and therefore I do not recommend its admission to subsequent stages of the doctoral procedure.)**

Uzasadnienie powyższej oceny znajduje się w raporcie będącym załącznikiem 1.
(The justification of the above assessment can be found in the detailed report in the attachment 1.)

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Data i podpis
(Date and signature)

Załącznik 1: Recenzja rozprawy doktorskiej
(Attachment 1: Review of the dissertation)

**Zaznacz ocenę (Please tick the box with your conclusion)*