



Center for Theoretical Physics
Polish Academy of Sciences
Aleja Lotników 32/46, 02-668 Warsaw
Poland

Department of Astrophysics
Department of Mathematics
University of Vienna

Univ.-Prof. Dr. Oliver Hahn
Türkenschanzstrasse 17
1180 Vienna, Austria

T +43-1-4277-53850
oliver.hahn@univie.ac.at

Re: Evaluation of the thesis manuscript of Feven Markos Hunde

August 15th, 2026

Dear Sir. Dear Madam.

I am following your review request of **Feven Markos Hunde**'s thesis manuscript entitled "**The Role of the Cosmic Web in the Structural and Dynamical Evolution of Dark Matter Subhaloes**".

The thesis' main topic concerns a timely topic in cosmology with relevance also for particle astrophysics: the abundance and properties of clumps of dark matter that are predicted by the cold dark matter paradigm. Specifically, the thesis contains various measurements related to the dependence of the properties (e.g. abundance, density profiles) of sub-structure dark matter clumps orbiting in the host haloes of galaxies of various masses. These clumps are in principle detectable through their effect on gravitationally lensed background galaxies, as well as on the expected annihilation luminosity if the cold dark matter annihilates into standard model particles.

The thesis investigates whether, at fixed host-halo mass, there is an additional dependence on the cosmic-web environment, i.e. whether the host dark-matter halo resides in a filament, wall, void, or other cosmic-web environment. These measurements are important to understand to what extent an additional dependence on the cosmic environment (we know e.g. that our Milky Way resides likely in a low density planar environment) might influence theoretical predictions and interpretations for indirect dark-matter detection and gravitational-lensing applications..

1. ASSESSMENT OF GENERAL THEORETICAL KNOWLEDGE

The dissertation demonstrates broad and adequate knowledge for the award of a doctoral degree in cosmology/astrophysics. The background material necessary for a contextualization of the specific results in the later parts of thesis is presented in the first two chapters. The introductory Chapter 1 of the thesis covers the Λ CDM cosmological standard model, along with the necessary basics on structure formation, the cosmic web, dark matter, dark-matter haloes and their sub-structure, small-scale Λ CDM challenges, and alternative dark-matter paradigms. Chapter 2 presents briefly the numerical and methodological background needed for the research, including N-body simulations,

the COLOR simulations, halo/subhalo identification, and cosmic-web classification with CaCTus. This knowledge forms the foundation for the more technical investigations of the latter chapters.

While concise, the theoretical framing is appropriate for a thesis focused on the analysis of cosmological simulations: the thesis subsequently connects hierarchical structure formation, dark-matter halo evolution, and the large-scale cosmic web of nodes, filaments, walls, and voids. It also explains why subhalo abundance, internal structure, and survival are relevant for probing dark matter physics and indirect-detection signals. Overall, the introductory parts of the dissertation display a sufficient understanding of the theoretical and computational context of the field, the latter parts are thorough and adequate in their use of statistical techniques and means of analysis of the simulations.

2. ASSESSMENT OF INDEPENDENT SCIENTIFIC WORK

The thesis demonstrates the candidate's ability to carry out scientific work independently. It includes one peer-reviewed published article and one submitted manuscript (both in Q1 journals), with Feven Markos Hunde as first author in both cases. The work presented is original and constitutes a significant scientific contribution. In addition, Chapter 5 contains unpublished material that appears to provide a strong basis for an eventual further publication.

Although the simulation data products used in the thesis were pre-existing rather than generated by the candidate, the thesis is centred on original analysis and physical interpretation of these datasets. Given the substantial computational effort involved with analysing high-resolution simulations, this represents a legitimate and substantial form of independent scientific work. The thesis and author-contribution statements indicate that the candidate led the analysis of the N-body simulation data, produced the figures and visualisations, interpreted the results, and wrote the majority of the paper manuscripts. The analysis is thorough and statistically sound. On this basis, I have no doubt that the thesis demonstrates the candidate's ability to conduct independent scientific work at the doctoral level.

Finally, the outlook demonstrates scientific maturity by linking future directions to the limitations of the present work. It acknowledges that the conclusions are based on gravity-only simulations, a single cosmic-web classifier, and finite subhalo resolution, and it identifies hydrodynamical simulations, larger volumes, and extensions to alternative dark-matter scenarios as logical next steps.

3. ASSESSMENT OF ORIGINALITY

The dissertation represents an original contribution through its systematic and quantitative treatment of dark-matter subhalo populations conditioned on cosmic-web environment, and particularly through its environment-dependent modelling of annihilation boost factors. The broad idea that environment matters in structure formation is not itself the main novelty; rather, the originality lies in applying filament/wall/void environmental conditioning to subhalo abundance, internal structure, evolutionary history, and boost-factor predictions within one consistent framework.

Specifically, Chapter 3 investigates how host-halo placement in the cosmic web affects subhalo abundance and their internal density profiles, using the COLOR N-body simulation together with the CaCTus cosmic-web classification framework. Chapter 4 extends this analysis to dark-matter annihilation predictions by incorporating environment-dependent host concentrations, subhalo mass functions, and internal subhalo properties into semi-analytic boost models. The thesis further develops an empirical fitting prescription for the boost factor as a function of cosmic-web

environment, intended for indirect-detection forecasts and halo-population modelling. Finally, Chapter 5 strengthens the originality of the dissertation by tracing whether present-day environmental trends are inherited before infall or amplified through post-accretion tidal evolution.

Thus, the originality is strongest in the environment-conditioned boost-factor prescription, and the quantitative calibration of environmental effects on substructure.

CONCLUSION

In summary, this thesis presents a coherent and original contribution to the study of dark-matter substructure by systematically investigating how the cosmic-web environment affects subhalo abundance, internal structure, evolutionary history, and the predicted effect on dark-matter annihilation signals. A valuable and original aspect is the extension of these environmental trends into semi-analytic annihilation-boost modelling as a function of cosmic-web environment, which provides a practical tool for forecasts and halo-population modelling. As with any N-body-simulation-based study, the conclusions should be understood within the scope of the adopted gravity-only framework, since baryonic processes are not included and may modify subhalo survival, density profiles, and consequently the predicted annihilation boost factors — these points are however directly acknowledged by the author.

Therefore, I conclude that the presented dissertation meets the formal requirements for a Ph.D. thesis and recommend admission of the Candidate to the subsequent stages of the procedure, including the public defense.

Please do not hesitate to contact me in case of any further questions.

Best regards.



Oliver Hahn

Unterzeichner	Oliver Jens Hahn
Datum und Uhrzeit	17.08.2026, 10:15 (GMT+02:00)
 ID Austria	
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Center for Theoretical Physics

Polish Academy of Sciences

Aleja Lotników 32/46, 02-668 Warsaw

Tel. (+48 22) 847 09 20, Fax/Tel: (+48 22) 843 13 69

E-mail: cft@cft.edu.pl, NIP: 525-000-92-81, REGON: 000844815

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):

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.)

15/08/2026

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)