

Meudon, January 29, 2023

On Daniel Procházka's Master Thesis manuscript entitled "Structure of the lunar wake with alpha particles not neglected in the solar wind"

Referee report:

The objective of the thesis is to investigate the effect of the alpha particles transported by the solar wind during the interaction of the latter with the moon. More specifically, how and to what extent, do alpha particles affect the structure and composition of the moon's wake. The motivation stems from the fact that the role of the alpha particles, which only contribute to about 5% to the total number of ions in the solar wind (the remaining 95% being mainly protons), is generally ignored, mostly because this simplifies the already complex problem of a collisionless plasma (the solar wind) interacting with an essentially non-conducting and non-magnetized body. The investigation is done by means of numerical simulations using a so-called hybrid code, which is particularly well suited to capture the kinetic behavior of the ions in a collisionless plasma such as the solar wind. Hybrid codes are significantly more complex and heavy to manipulate than ordinary hydrodynamic codes.

The manuscript is divided in three major parts.

The first part, which includes chapter 1 and 2, presents in details the characteristics of the solar wind and the physics of its interaction with both magnetized and non-magnetized bodies of the solar system. The review is impressive, both in terms of the number of cited publications (up to 100) and in terms of their contextualization, and shows that Daniel Procházka has acquired a clear, vast and detailed knowledge of the subject. This is clearly the strongest part of the thesis which, however, cannot be considered to be central as it does not include Daniel Procházka's own work.

The second part, chapter 3, is a slightly lengthy and not always very clear presentation of the hybrid code Daniel Procházka has been using for the lunar wake studies. The impression, as a reader, is that Daniel Procházka has acquired a good understanding of the code and its limitations.

The third part, Chapter 4, is the really original part of the thesis, where five simulations of the lunar wake are presented and discussed. Unfortunately, as already mentioned, this part is plagued by some weaknesses. For example, the spectra in Fig. 4.12, which show interesting structures, are not really commented. Similarly, the instability analysis in Section 4.4 contains (too) many Figures accompanied by rather minimalistic comments, maybe because

the author has been using incorrect expressions of the instability criterion. Also, I do not understand why there is no discussion of the (possible) role of the Ion Cyclotron Instability, despite the instability being mentioned in many places and particularly at the beginning of Section 4.4. In Section 4.5 Daniel Procházka tests the effect of a conductive shell inside the moon and concludes that the effect is negligible, probably, as suggested by other authors, because the conductivity adopted in the simulation was too small. This section does not bring any new insight, but proves that Daniel Procházka masters all aspects of the simulation.

Summary and conclusions in Chapter 5 are of a good standard, but obviously affected by the weakness of the material presented in Chapter 4.

The main conclusion of the thesis is that the effects of the alphas on the structure of the lunar wake are rather minor. Small effects, on the magnetic structure and a clear difference between the spatial distribution of the protons on one side and the alphas on the other side have been observed. The occurrence of collisionless plasma instabilities such as the mirror and the firehose instability (which are due to anisotropies in the ion temperature parallel and perpendicular to the magnetic field) has been tested in the simulations with no clear conclusions, most likely because of errors in the procedure.

I have been very much impressed by the amount of work which has been presented in the manuscript. Daniel Procházka has visibly gone through an enormous bibliographic work. Overall, but with the notable exception of Chapter 4, the writing is rather clear and generally rigorous. Unfortunately, the comparatively inconsistent chapter 4 is central to the thesis, as it is the place where the personal contribution of Daniel Procházka is presented. This made me opt for grade C on the proposed scale, but I must admit that I have been hesitating between B and C.

In the end, however, I propose rank C (good), for Daniel Procházka's thesis manuscript.

Yours sincerely,

Dr Filippo Pantellini, astronomer at the Paris Observatory

A handwritten signature in black ink, appearing to read 'F. Pantellini', written in a cursive style.