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apl. Prof. Dr. Markus Roth
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Referee Report on the doctoral thesis
"Helioseismic inversios of plasma flows and sound-speed perturbations"
by RNDr. David Korda

The Sun is the only star, which allows us to study astrophysical processes in detail. One of the open questions in astrophysics is how stars generate a magnetic field, and why this magnetic field exhibits strong variations on short time scales. Furthermore, the physics of transient events, i.e. potentially strong ejections of stellar material in combination of local reconfigurations of the magnetic field, can be studied only on the Sun. Therefore, it is of high relevance to study flows of plasma in the solar interior as they must play a relevant role in the respective induction processes.

Helioseismology is the only method that allows studying the dynamical processes inside the Sun. It is based on studying acoustic waves on the Sun. Depending on their frequency and wavenumber, these waves propagate to different depths in the solar interior, which allows to tailor techniques that probe the plasma conditions inside the Sun.

One of these techniques called "time-distance helioseismology" is related to the techniques of geo-seismology. It is based on cross-correlating measurements of the seismic waves at different locations on the Sun. Besides being sensitive for the advection of waves due to flows, this technique allows probing the local sound-speed variations in the solar sub-surface layers. This therefore opens the possibility to access important further physical quantities, e.g. pressure, temperature, and magnetic field.

The PhD thesis submitted by RNDr. David Korda presents highly relevant further developments of the time-distance helioseismology technique. The thesis is written cumulatively, i.e. it is a compilation of three refereed publications in the journal "Astronomy and Astrophysics" that appeared 2019 and 2020 as part of this dissertation. These works are printed in chapter 7. The publications presented build on each other very well and reflect nicely the progress of RNDr. Korda's scientific work. These publications are framed by detailed introductory chapters and a concluding discussion. Those give the non-specialist reader a very good overview on the research field and the open questions solved in the context of the dissertation. In particular Chapter 1, is an excellent summary on the physics of waves in astrophysical plasmas. Furthermore, these chapters provide the necessary insight into the implementation of the inversion methods that RNDr. Korda improved.

In addition to the already published journal articles the thesis is complemented with two further publications, which are in preparation, and an annex consisting of two other publications related to the work and consisting out of one conference proceeding publication and one invited review article. The latter demonstrates the broad background of RNDr. Korda on the application of inversion techniques.

With the first refereed paper, presented in section 7.1, the state-of-the-art of how inversions are done in helioseismology is strongly advanced. In the past, estimates for plasma flows and the sound speed were obtained independently by two separate inversions. The first one based on travel time differences of waves travelling in opposite directions, the second one based on their travel time averages. RNDr. Korda demonstrates clearly that both inversions can be obtained at the same time, when the cross-correlation of the two physical quantities is considered. Therefore, this new approach represents a much better representation of the physical relations of plasma flows and the sound speed variation. Hence, RNDr. Korda is able to significantly improve the information derived on these two quantities from the inversions. Another very relevant further development is the fact, that also the information on the vertical variations of the vector flows is recovered.

As this concept was validated on data resulting from a magneto-hydrodynamic simulation, RNDr. Korda did the next correct step to apply this new methodology to actual helioseismic data obtained from the Helioseismic and Magnetic Imager (HMI) instrument on board the Solar Dynamics Observatory (SDO). The results are presented in the second publication, which is included in section 7.2.1. The comparison of the current techniques with the new methods show that the minimization of the cross-talk is relevant for the vertical flow components, while there is a good agreement for the horizontal components and the sound speed variations.

The third refereed publication that is part of section 7.2.2 describes a second step of applying these techniques to data. Clearly, the potential of the new methodology is demonstrated, when it comes to studying transient events that are connected with solar activity. Here the flow configuration around an eruptive filament is tracked as a function of time, and indications for a change of the flow configuration are found before the filament escapes. This is relevant for understanding solar activity.

The publications in preparation, which are included in the thesis in sections 7.2.3 and 7.3 demonstrate first the applicability of the new methodology for understanding the physics of supergranulation, i.e. the convection in the solar plasma, better, and second present a further development of the technique, which improves the helioseismic estimates in the presence of a magnetic field.

With his work, RNDr. David Korda makes a significant contribution to the understanding of the physics of plasma flows on the Sun. This is of great importance because these plasma flows are the drivers of solar activity and knowledge on them is urgently required to improve the theoretical modelling and the potential to predict solar eruptive events. RNDr. Korda showed for the first time how the full potential of the helioseismic data can be exploited and how the new methodological approach leads to improved inversion results when determining the two dependent physical quantities of the plasma flow vector and the sound speed. RNDr. Korda’s new methodology is now expected to find wide applications in the field. This will then help to decipher how the solar dynamo works, which is why this work represents a great scientific advance.

This thesis proves that RNDr. David Korda has the ability for creative scientific work. Because of this and because of the high scientific relevance, I strongly recommend this thesis for defense and I strongly recommend to award the Ph.D. degree to RNDr. David Korda.

apl. Prof. Dr. Markus Roth