DOCTORAT ASTRONOMIE ET ASTROPHYSIQUE
École Doctorale d'Astronomie et d'Astrophysique d'Ile-de-France

Review provided by : **Robert WIMMER-SCHWEINGRUBER**

In order to allow the PhD defense : **Vratislav KRUPAR**

Title of the PhD dissertation :
« Étude stéréoscopique des émissions radio solaires avec l'instrument S/WAVES embarqué sur les sondes STEREO ».

1) **GENERAL EVALUATION**

In comparison to other recent PhDs in the same field that the referee has personally known, the referee's opinion on the thesis is that it deserves to **be defended to obtain the doctoral degree:**

- **O** No
- **x** Yes (without modification)
- **O** Yes (with major modification)

If yes, is the Ph D

of a scientific level estimated as

- **O** Exceptional
- **x** Excellent
- **O** Very good
- **O** Good
- **O** Satisfactory

with a presentation estimated as

- **O** Exceptional
- **x** Excellent
- **O** Very good
- **O** Good
- **O** Satisfactory
- **O** To be improved

2) **SUMMARY OF THE MAIN POINTS OF THE REVIEW AND REMARKS (in about ten lines)**

This is a well-written thesis with two main results, i.e., a) that the supra-thermal electrons responsible for type III radio bursts travel along the Parker spiral, and, b) that the observed extended source regions are due to scattering in the interplanetary medium. The candidate has published his results as first author in two peer reviewed publications (one of which in the renowned Journal of Geophysical Research), another paper, as well as a co-authored paper. Independently of this review, this demonstrates that Mr. Krupar has achieved the scientific expertise required for a PhD.

Some imperfections in the work hint at some time pressure in finishing the thesis. Nevertheless, they do not merit major rework. Placement of the principal results in a broader context would have enhanced the value of this work.

The thesis is judged to deserve to be defended, to be of 'excellent' value and graded 'très honorable'.

3) **PROPOSED GRADE FOR THE DOCTORAL DEGREE**

In the case where this work seems to you acceptable for a PhD, what do you propose as being the most appropriate grade:

O Honorable

x Très honorable

4) **EXTENDED REPORT**

(please enclose the referee's report with your signature : 3 pages maximum)

Mr. Vratislav Krupar has analysed data from the S/Waves instruments on board the twin STEREO spacecraft and has compared them with data from the Wind spacecraft when the mutual separation was small enough. Type III radio burst can be localized with radio observations by a method called goniopolarimetry (GP) which he uses in his work to tackle a long-standing problem, namely why that type III radio bursts often appear as large, extended sources and not as point sources. His work suggests that scattering of the primary electron beam leads to the observed extended source regions.

The thesis begins with a general introduction to the Sun and solar wind and how they drive radio bursts, the topic of this work. Section 1.3 describes type III radio bursts in some more detail, however, I would have liked Mr.Krupar to be more quantitative here. He mentions that there are several theories that attempt to explain the persistence and conversion of bump-on-tail electron velocity distribution functions (VDFs) and cites them without providing an explanation of their key points and key differences. He does not address whether and how his work could help discern between different models.

Chapter 2 deals with the measurement of radio waves in space. This chapter is important to understand the rest of the thesis and is generally well written. Mr. Krupar focussed mainly on the mathematical aspects of the GP method. I would have expected to see at least a schematic of the S/Waves instrument and how the measured voltages are then converted to physical quantities and how I need to understand the complex amplitude of the voltages used in the subsequent equations. The measured quantity is by necessity real. Later on, in section 2.2.3 he introduces the magnetic field (B_x and B_y) without defining it and explaining how it is measured by S/Waves. He explains the Singular Value Decomposition (SVD) method correctly, but does not explain why it is so well suited for the inversion of radio data. Are the inversion problems often ill-posed (in a mathematical sense)?

The next logical step is taken in chapter 3 on the SVD method for electric radio measurements in which he applies his method to simulated data and performs an inter-calibration between STEREO and Wind. He applies his simulations to the case of a similar instrument to fly on Solar Orbiter in the future and includes real-life 'dirt-effects' such as uncertainties in pointing, length, and flexing of the antennae and their influence on direction finding and inferred source size. This section demonstrates clearly, that Mr. Krupar has full command of the methods appropriate for simulations and understands in great details the importance of the relevant instrument parameters. The following section on data processing demonstrates this once again and contains much of the material I missed in chapter 2. So that 'neglect' is compensated here. However, it would have been helpful to the reader if he had explained the physical meaning of the various matrices, **C**, $\mathbf{M_i}$, and **F**. The data processing is further explained in the following section in which Mr. Krupar provides evidence of the excellent inter-calibration of the two S/Waves instruments as well as with the Waves

instrument on Wind. My principal critique here is that the use of quartiles in comparison is not necessarily justified. It appears to me that a confidence interval on the average would have been more appropriate. I doubt however, that this would have influenced the outcome of the cross correlation in any significant way. In conclusion, this chapter does an excellent job of demonstrating that the methods used in the subsequent analysis are adequate to address the problems addressed.

Chapter 4 discusses some case studies of solar radio bursts observed by STEREO and extends those results in a statistical survey. The chapter is generally well written, although there are some imperfections. The frequency value of the lowest channel is missing on page 51, and it looks to me as if frequencies *decrease* as the source moves farther from the Sun. Nevertheless, the case studies presented here demonstrate unequivocally that the methods explained in the previous chapters work well and allow good triangulation of the source regions of type III radio bursts. These methods are then applied to a total of 156 type II radio bursts observed by STEREO. It would have been interesting to add to Fig.4.12 a panel showing the number of events seen by both STEREO A and B, thus illustrating more clearly table 4.1. Possibly this could have added to the argument about extended source regions. The analysis of the average flux density of these events is (admittedly) crude, but would have benefited from a thorough statistical analysis. What is the reduced Chi-squared? Is the difference between the green and yellow curves statistically significant? Is this all that can be done here? Possibly, a fit of the various models for type III bursts mentioned in the introduction could have shed light on the quality of these models and the physical mechanisms driving type III bursts.

Chapter 5 summarizes the thesis and provides perspectives on future work. Unfortunately, it does not present the results of this work in a broader context and is rather short. A more thorough discussion of the results and their relevance would have been appropriate. Specifically, I would have expected a discussion of the known propagation properties of energetic particles in the heliosphere, and a mention of how the results of this thesis could have implications for perpendicular particle transport, a long-standing problem.

Appendix A presents three first-author publications by Mr. Krupar as well as a co-authored one. Paper I was published in refereed conference proceedings, I do not know about the second. The third paper is the co-authored one and was published in the refereed Astrophysical Journal and Mr. Krupar appears in fifth place. The latest paper with Mr. Krupar as first author has appeared in the Journal of Geophysical Research, one of the foremost journals in this field.

My general impression of this thesis is very positive. While there are some imperfections, some of which no doubt are due to the difficulties of expressing complicated physical phenomena in English, the material is clearly presented and generally well explained. Some other omissions such as missing references (page 28) or missing values (page 51), as well as incomplete literature references (i.e., all books), let me believe that the thesis was finished under considerable pressure, probably due to an imminent deadline. Because the omissions and their remedies are obvious, I don't believe that this thesis requires major rework. The results, i.e., that supra-thermal electrons responsible for type III bursts tend to follow the Parker spiral on their way from the Sun, and that the observed extended source regions are due to enhanced scattering in the interplanetary medium are convincingly presented. While both results are not surprising, this work presents independent evidence for similar results already known from studies of the propagation of energetic particles. The fact that Mr. Krupar has published his results in refereed articles is further evidence that this thesis should be positively received and deserves to be defended.

In conclusion and weighting the excellent results with the few shortcomings of this thesis, I judge the overall work as 'excellent' and grade it as 'très honorable'.

Date : September 5, 2012

Signature :