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MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

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Review of the PhD thesis of Örs Asztalos

"Modell-aided design and interpretation of beam emission spectroscopy measurements on fusion devices"

Magnetic confinement fusion devices are prone to a phenomenon called "profile stiffness": pressure gradients can give rise to microinstabilities (turbulence) which in turn reduce the gradient of the plasma density and temperature profiles, degrading fusion power output. Due to the resulting limit on said gradients, an improved confinement at the plasma edge can lead to a significant increase in performance, and / or a potential reduction of reactor size. For these reasons studying transport phenomena and particularly those at the plasma edge has great importance for magnetic confinement fusion plasmas.

Beam Emission Spectroscopy (BES), the technique discussed in large detail in this thesis, is one of the unique diagnostic tools often employed to gain insight into the behaviour and fluctuations of the edge plasma.

General assessment

The thesis discusses 4 main points (reflected also in the 4 thesis statements) which all connect to BES. They span a wide range of subtopics: determining the ability of the diagnostic to detect fluctuations, optimisations and feasibility studies of several BES systems, model validation, and finally an improvement of the underlying atomic physics model. This is a wide subject area in which the candidate displays a deep understanding of the details and technical issues connected to this field of research.

I have been impressed by the results, which are also published in 11 papers connected to the thesis points. There is a healthy mix of first authored and co-authored publications, demonstrating that the candidate can both be the primary driving force behind a project as well as work as part of a team. The candidate has unquestionably provided great contributions to the field and the results of the thesis work will be further utilised by a large number of researchers at multiple laboratories.

The thesis length is adequate by the number of pages, although I could have imagined an extended version considering the wide range of subjects covered. In particular the introduction, while lists a lot of the background, but perhaps lacks a bit of point to point, inductive, educational discussion of the motivations behind the work.

I have to raise a minor criticism to the general style of presentation: results are sometimes stated rather than explained in context. The author assumes too much of the reader – not everybody working in the field of plasma physics is an expert of BES systems or tokamak scrape-off layer physics. Technical results are sometimes left undiscussed in plain words, for example what does a particular expected photon flux mean in everyday language: good, bad, ...? The logical flow of going from one point to the next is sometimes left to the reader to contemplate. A similar observation goes to citations. The thesis contains an outstanding 280 citations, although at times I felt these are a little more enumerative than explanatory.

The formatting of the thesis is satisfactory, the figures are of great quality and the captions offer good descriptions. I take minor issue with the inconsistencies found in formatting (e.g. when is or is not something in italic), which at times left me thinking whether a particular formatting choice is purposeful to convey a message (unclear at that point), or accidental. These are disruptive to the flow of the reader.

The thesis often uses passive language ("it was done") which at times makes it difficult to linguistically distinguish the candidate's own work from work carried out by co-authors. I believe that every time the work of others are shown the thesis clearly labels them as such. Nevertheless, I'd encourage to use more "I did this" type of phrasing (I calculated, I programmed, I simulated, I invented, ... etc).

Overall I have been very impressed with the work done and the results presented.

Assessment of sections

The introductory sections 1 & 2 discuss background and in larger detail the BES technique. The candidate has a deep understanding of these systems, the MCF devices they are installed on, and has an overall understanding of the minute details of realising these measurements. The candidate also has a broad knowledge of the field, the different approaches used by other groups, the tools they employ, the strengths and weaknesses. I found however that the physics motivation is a little vague. Judging from the thesis BES systems have great promise but are very complex to build, operate and interpret. It is not really emphasised why is it worth going through all this trouble to use BES in the first place, what unique physics insights can be gained. The discussion of the physics phenomena is arguably too brief: the importance of plasma edge or turbulence is not discussed in a significant fashion, it is difficult to follow what "blobs" and "filaments" are beyond buzzwords, and why they are important to study.

Section 3 is an excellent discussion of the issue of spatial localisation and fluctuation response, highlighting the complexities of analysing BES signals.

Section 4 is similarly well written, I found the discussion of the optimisation procedures for a large number of systems on many tokamaks engaging. The candidate continuously displays a deep understanding of the field and provides useful contributions to the community.

Section 5 discusses synthetic BES diagnostics, and an attempt at an experimental validation between data measured with BES and the HESEL code. The limitations of real measurements are carefully explained and great care is taken to consider effects that can make significant contributions to the signals. I found the background description of the statistical methods used (motivation of the choices made and their interpretation) a little lacking: for example, skewness or kurtosis are never defined, neither is why they are interesting quantifiers. There is no discussion of the expected power spectra from turbulence. I don't dispute the results presented in this section, although I would have drawn a different conclusion. To me it seems that once we take all measurement artefacts into account it is difficult to use BES to validate the smaller details of simulated signals. We can surely see whether or not there are big events at the plasma edge, but we have other, more direct measurements to detect such events (such as H-alpha emission). I feel that one could further elaborate the advantages of BES over other possibilities.

Section 6 discusses an extension of the atomic physics model to account for interactions with neutrals. I found this part very interesting and the results are going to be useful for the community and in particular anyone using the updated tools. Again not disputing the results presented, I found it difficult to follow the description of the CTMC method: how this works, why is this good, why is this better than alternatives (if alternatives exist).

Overall the thesis contains great and useful results.

Assessment of the thesis statements

The thesis contains four distinct thesis statements connected to the four separate subtopics covered. I accept these as original works of the candidate. The separation of the thesis points is adequate given the different focus of each: fluctuation response, diagnostic optimisation & trade-offs, synthetic diagnostics, improved atomic physics. The thesis points represent valuable work by the candidate and each are supported by a mix of first-authored and co-authored publications. The only minor criticism I have is with thesis statement III. I'm not sure I'd draw the same conclusions from the results presented as the candidate did (i.e. successful validation). I'd rather argue that this is a clear demonstration of why considering artefacts, noise, and systemic errors is a necessary step in validation; but I'd be careful calling this a finished validation. Analysing one discharge of one tokamak is too low of a statistic for a validation exercise to be considered complete. This of course doesn't reduce the value of the work done by the candidate, but should rather motivate the community to engage more in validation efforts.

Questions to the doctoral candidate

(1) Could you explain in a little more detail what "blobs" and "filaments" are, why they are important to study, and why are the tools used (such as skewness and kurtosis) adequate to characterise them?

(2) Could you elaborate on the unique value of BES in the context of plasma edge physics studies, that justified the great effort in working with this technique?

(3) Could you discuss the differences between the full-f, gyrokinetic, gyrofluid and Braginskii models? Under what assumptions are they valid, what are the advantages and limitations compared to each other, and how do they compare from the perspective of a BES synthetic diagnostic? (i.e. does it matter which one we try to do experimental validation with?)

(4) In figure 5.10 on page 102, The comparison of the simulated and synthetic signal spectra is shown. I'd argue there are two main discrepancies. In figure 5.10a the simulated density fluctuations (red) have a clear peak at $\approx$ 20 kHz, whereas in the experimental signal (green) a peak is found at $\approx$ 5 kHz. In figure 5.10b the shape of the spectrum as a function of frequency is very different between the HESEL density fluctuations and the experimental signals. The power fall-off is often a crucial part of turbulence studies. Can we expect that with adequate synthetic diagnostics these features can be "recovered" from an experimental signal, or do the results indicate that these will be lost due to the process of the measurement?

(5) Page 114, equation (6.2). Perhaps I misunderstood, but how is the cross-section calculated? The text states that b_j are "the corresponding impact parameters randomly chosen following a uniform distribution in $[0; b_{\mathrm{max}}]$." If b_j are random, 2π, T_{N} and b_{max} seem like constants, then how is this formula related to the physics? Which of these quantities comes from the CMTC calculation? How **exactly** is the cross-section derived in the CMTC method?

Conclusions

The results presented in the thesis are of great value to the fusion plasma physics community. The candidate demonstrated a deep understanding in a complex field and had made important contributions in a wide range within BES and fusion plasma physics research. In my assessment the original work included is sufficient for a doctoral degree. I accept the thesis points to be valid and autonomous results of the candidate. I deem the thesis to be suitable for a public defence and sufficient for the awarding of the PhD degree, provided the defence is successful.

Dr. Gergely Papp