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Thesis Changes Log

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PhD Program: Engineering Systems

Title of Thesis: Coronal dimmings associated with coronal mass ejections: evolution, lifetime, and relation to the directivity

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The thesis document includes the following changes in answer to the external review process.
There is a need to precisely define the terms "on-disk" and "off-limb". They are used extensively but are never defined. The definition is added in the beginning of Chapter 3, where the coronal dimmings are introduced. Coronal dimmings can be observed both on the visible solar disk close to the eruption site (referred to as on-disk dimmings) and above the solar limb (off-limb dimmings) from lateral perspective. On-disk dimming observations involve integrating the emission along the line-of-sight of CME propagation, corresponding to a projection of the cross-section of the CME from a top view. Conversely, off-limb dimming observations offer a line-of-sight integration across the CME. **Citation brackets missing: Page 13, 'Chapter 6', Ronca et al. Page 49, starting from Nitta et al. Page 54, Vanninathan et al. Page 71: Hurlburt et al.** Brackets were added. **Page 20, perceived as sunlight: reformulate, it is not clear what that means within the Sun's atmosphere** Deleted this sentence to avoid confusion here. **Most of the solar photosphere, the magnetic field is a few Gauss: that is only partially correct; it is a result of HMI's low resolution. Within the supergranular cells, there is almost no significant magnetic field, that is correct. But the magnetic fields in magnetic elements in the supergranular lanes have magnetic field strength of about 1-1.5 kG – but only diameters of about 100 km, which cannot be resolved by HMI. HMI actually measures not the field strength in Gauss, but the magnetic flux per pixel (area). As HMI has only a plate scale of 0.5", 1-1.5 kG * 100km^2 * pi gives roughly 50-75 Gauss per 0.5"x0.5" HMI pixel. Therefore, be careful when talking about weak quiet Sun magnetic fields. Better say the average magnetic field density is small instead of the magnetic field density low: page 21, 'For most of the solar photosphere…', o page 27, first sentence o page 28, 'Typical magnetic field strength'** Thanks a lot for such an elaborate explanation. I edited the sentences mentioning the average magnetic field or 'as detected by HMI'.

Page 22, 1st paragraph: the density in the transition region decreases by about 4 orders of magnitude, while the temperature increases by 2 orders of magnitude. See also Figure 1-2.

Fixed the typo and made a reference to the Figure 1-2.

Try to avoid the discussion of wave heating and reconnection heating of the corona. Both models have their advantages and disadvantages, and both are still studied by different parts of the community. Wave heating using Alfven waves works well if we do not assume a uniform corona but one which has density fluctuations – and measurements show that we have these. Also, some scientists argue that microflare heating cannot provide sufficient power. You are also right about that your arguments are in the scientific debate; it is a controversial topic. For a PhD thesis, I would advise to not take any side here.

I rephrased the text in order to introduce both theories and not to take any side in this very complex question.

Page 28, the table: What do you mean with unipolar in ephemeral (unipolar) active regions? Ephemeral active regions are typically bipolar. Maybe you mean pores in the sense of ephemeral sunspots?

The initial intent was to mention temporary unipolar regions. However, the choice of the term 'ephemeral regions' was inappropriate, as this definition already exists for bipolar regions. Unipolar regions can evolve into pores or sunspots, while their magnetic fields undergo significant changes throughout their existence. To prevent misinterpretation, this line has been omitted.

Page 31, Paragraph 'It takes several days for shocks in the solar wind to reach the Earth. ….. . It feels like not fitting in the text flow. Wasn't that also discussed in more detail already in the above paragraphs?

I Agree. This paragraph was deleted as I mentioned the same effects in the example events descriptions.

Page 41: CME fronts reveal an angular width of about 30-65 degrees; but in the next sentence you write Halo CMEs extending to nearly 360 degrees. I guess that the extension does not relate here to the angular width described above. This should be made clear as it appears to relate to the angular width.

Average width of CMEs is 30-65 degrees. I rephrased the next part as "Halo CMEs, extending to nearly 360 deg **for the view from LASCO**,…". In the next sentences I describe that usually such width is a geometric projection effect, but studies also show that some events were seen as halo also from STEREO point of view.

Page 42, In general, the mass of a CME falls…: averaged at -> with an average of. Averaged at means that you or someone averages something; but here you mean the average of the CME mass, so the physical average of features.

Fixed this.

Page, 2.2.5: Can also be the pushing slow solar wind behind the CMEs be a driver so that slow CMEs below the escape velocity leave the Sun?

Close to the Sun the magnetic reconnection is believed to be the dominant driver of the initial propagation of a CME, while aerodynamic drag takes over only at larger heights. However, some studies (e.g., Lewis and Simnett, 2002) claim that the ambient solar wind can be a prime force for a slow CME

acceleration, even independently of the magnetic energy amount in the pre-event corona. Added this information to the text.

Some figures are not at the top of the page, which appears strange: Figure 2-4, 2-8, 2-9, 2-10;
Page 54: 'transitional coronal holes' or 'transient coronal holes'? Look up the exact term, transient means something different than transitional;
Page 57, Fe XVI and Mg IX …, representing temperatures of 1 and 2 MK. The order is wrong. Fe XVI -> 2 MK, Mg IX: 1 MK. Make the relation clear;
General: Units are written in roman, variables in italic: Page 58, 1 arcmin2;
Page 66, "Key features of the SDO mission": verb missing;
Page 74, 'were located on the other side of the solar sphere' -> on the back side of the solar sphere;

Fixed.

Page 69, description of STEREO instruments. WAVES, IMPACT, PLASTIC are mentioned, but the description is indifferent. Although they are not used in the thesis, they should either be described with a meaningful sentence, i.e., how the instrument generally works, or the instruments should be entirely skipped.

General information was added to the description of these instruments.

Page 76: 'median filter can be applied to the obtained seed pixels (3x3 square)'. Physicists who know about image processing can guess what you mean with (3x3 square), but others not. Describe that in a better way, using an additional sentence.

A sentence with explanation was added: This filter functions optimally within a 3x3 square window, evaluating the median pixel intensity in local neighborhoods.

Page 86, formula 4.14: why Phi+ + abs(Phi-) /2? I.e., why /2? I guess since you assume closed loops. If so, that should be stated.

Yes, we assume close loops, following Indicated this in the text. Assuming closed loops , we can calculate the total unsigned magnetic flux as the mean of the absolute values of the reconnection fluxes in both polarity regions (Tschernitz et al. 2018).

Page 86, threshold of 10 Gauss for the magnetic flux estimation. It is not clear whether you use the HMI 45s or 720s magnetograms. For the 45s magnetograms, the noise level at disk center is about 7 Gauss, at the limb, it is even higher (I guess 10-20 Gauss). Thus, the threshold corresponds to less than 1.5 sigma, which seems quite a low threshold. If you use such a low threshold, you should reason why this is still fine without affecting the flux derivation in your study.

We use the 720s LOS magnetograms from HMI because of the better signal-to noise ratio. The sentence was rephrased: According to Couvidat et al. 2016, the HMI 720 s LOS magnetograms have a photon noise of 3 G at the solar disk center. To address the increasing noise levels toward the limb, we use a threshold of 10 G (similar to Tschernitz et al. 2018).

Page 87, Section 4.3.5: I understand that you want to introduce the analysis methods for the recovery times later; but if you mention it here, a bit more information, at least in 1-2 sentences, would be helpful. E.g., give a very general description of the approach here, and then say details will be discussed later.

The paragraph describing different metrics for the recovery definition was added to Section 4.3.5.

Page 88, ‘P is a pixel the area which we’. This sentence seems wrong.

Typo was fixed.

Page 126, Figure 6-6. I think you mean Figure 6-1.

Fixed, there were repeating labels in latex.

In several chapters, you repeat paragraphs with almost identical information. It looks like some of them were still from a previous version of your PhD thesis which you forgot to delete. Or maybe you wanted to give an introduction to a subsection, but forgot that you gave the same information in the paragraphs right before. Please revise your thesis by removing paragraphs containing information that was given already (right) before.

The repeating parts were deleted. Introduction in chapter 5 was reduced.

Page 198: ‘to investigate the investigate’. Double investigate

Fixed. Now just one investigate.

Particularly Section 3.4 gives too less information on dimming-CME relationship. At the moment, it is a list of statements from papers, but without explaining the physical causes and effects. Why did you choose not to do that like in the previous Sections and Chapters, where you really gave nice descriptions on the physics? I would recommend to rewrite this section, not using a list style – you will discuss some of these papers anyway again in the introductions of Section 4, 5, and 6 – but in a narrative style where you explain the physical causes and effects of the dimming-CME relationships.

Chapter 3 is created to give very general information on coronal dimmings and what can we learn from observing them, while the next chapters focus deeply on various aspects of dimmings research. The list format allows side-by-side comparison of existing approaches, highlights the different approaches and processing of data before introducing our own methodology in the next chapter.

p. 12. I don't think Solar requires capitalization

Fixed.

p. 20. Sunspots don't occur in "pairs", but groups, and often are solitary. Hoyt & Schatten didn't invent this morphology.

The sentence was reformulated “Usually, they occur in pairs of opposite magnetic polarity.”

p. 37. Thermal instability doesn't explain the lack of a filament.

Deleted this part from the sentence, not to speculate about thermal instability.

Sect. 2.3. Should cite the “implosion” conjecture (Hudson 2000) for initiation, since this is closely related to the reconnection physics

A paragraph about implosion conjecture was added to Section 2.3.

Fig. 3.3. caption should include date Fig. 3.4. caption needs citation of source

Date and source were added.

p. 73. Need to explain HEEQ

A description of HEEQ abbreviation was added.

Eq. 4.5. Needs punctuation; please check other math in this regard

Punctuation for Eq. 4.5 was added, as well as in other equations where it was missed.

p. 84. The Dissauer citation has a misplaced bracket. Please check other citations for other cases where the name should be parenthetical

Fixed for this and other cases.

Eq. 4.12, should define t_dur

The typo was fixed.

Fig. 5.2. This is the first example of (k,d) listing in the figure legend. The caption should therefore repeat the definition and note that subsequent such figures are coming.

A sentence was added to the caption of Fig. 5.2: For this and subsequent correlation plots: the correlation coefficient c is given in the top left corner; the fit parameters k, d of the linear regression log(y) = d + k log(x) are given in the bottom right corner.

Fig. 5.5. What is the one-to-one relation?

Rephrased: The orange line is the identity line y=x.

p. 113. "[60..." garbled

Fixed.

Sect. 5.4.2. The comparison between on-disk and off-disk dimmings is not motivated very well: these in principle are different projections of something that is not geometrically simple.

This is described in the second paragraph of Section 5.5 and after the results summary, where advantages and drawbacks of each observation perspective are listed and why they complement each other. The outcomes from the comparison analysis provide insights into the nature of detected dimming regions and how to accurately attribute the extracted characteristics to estimate the parameters of CMEs.

p. 125. Isn't the Attrill idea a non-starter? Interchange reconnection does not really diminish the open flux, does it? In addition this summary does not mention loop retraction, for which there is literature e.g. by Wang & Sheeley, Simnett and others.

There is no one confirmed theory on this point, while the interchange reconnection is one of the main theories on the dimming recovery, supported by a number of studies. More research will be needed to prove or deny the existing concepts.

p. 167. The Aschwanden height estimation for hard X-rays is probably wrong. The only direct height observation is that of Martinez Oliveros (2012ApJ...753L..26M) and is quite inconsistent.

Direct height estimates like in Oliveros paper are rarely available. Aschwanden et al. 2002 relation provides us an estimation, which was also used in other studies (e.g. forward-fitting for RHESSI). Indeed, there is some uncertainty in these estimates, but for current study we only use it to make the rotation to the other spacecraft more accurate than using the radius of the photosphere.

Figure 7-11. GOES does not observe 25 keV. The figure is showing HXR, not SXR, presumably from STIX?

Typo was fixed, STIX instrument was mentioned in description of panel (e). The confusion came from misplacement of SXR and STIX labels in latex document, now fixed.

p. 177. confusion of SXR and HXR

Fixed.

Figure 7-13. Is the croissant really plausible at the base of the corona? The footpoint regions shown don't seem to correspond to anything in the direct EUV images. Does this discrepancy affect the conclusions?

The croissant is reconstructed on a certain height, while the source location and locations of the footpoints are the output of the model, thus they can be shifted from the AR due to uncertainties of GCS and assumption of radial propagation. This is in general a drawback of the GCS model, where use of the coronal dimmings may help.

Separating the preamble Thesis Objectives from the Introduction Chapter, which has more to do with heliophysics, is a choice that can be discussed. In fact, the thesis could have been organized as follows: Introduction that would give a brief overview of the field of research and state some of the current outstanding questions and research gaps, which would then lead to the statement of the research question and the outline of the thesis manuscript; this would be followed by a Part I Basic of heliophysics, which would contain the current version of Chapter 1 and Chapter 2 merged with Chapter 3; Part II where the actual research work is developed at length would contain the current Chapters 4, 5, 6, and 7. The thesis would then end with the current Chapter 8.

More elaborated overview was added before the thesis objectives. Together they were integrated into the Introduction preamble. Chapter 1 was renamed into 'Basics of Heliophysics'. Upon careful consideration, it was concluded to maintain the singular structure of the thesis without dividing into two parts.

In relation to the above point, while this is not an issue per se, given the small size of Chapter 3, I believe it would be fine to merge it with Chapter 2, which could be renamed Coronal mass ejection and coronal dimming. The resulting chapter would not be too bulky and would be comparable with other chapters in terms of length.

Initially, Chapters 2 and 3 were connected, but as the thesis was developed, a decision was made to emphasize Chapter 3 as a distinct and separate section.

In the reference section, DOIs are given for some references but not for others. This should be fixed either by giving all DOIs with links (preferred option) or removing them all (ok, but not preferred).

All DOIs were added where possible, otherwise links to the source were indicated.

The introduction section would benefit from more precise indication of the problem statement, novelty, relevance, and positions advocated for defense.

The overview part was expanded as a plain text including information on all the mentioned points.

To better check the content of Chapter 1. Some of the content seems to be written in a rush, etc. such as the "four million tons of energy" typo. Enhancing the scientific content of this chapter by also incorporating additional references is advised.

The small typos were fixed, the paragraphs of the chapter were revised.

On page 23, the citation to Figure 1-7 could be inaccurate.

The citation was fixed.

The final paragraph on page 34 is lacking clarity and may benefit from a more precise articulation of concepts.

This paragraph underscores the significance of space weather research and its acknowledgement by society. The sentences have been clarified a bit.

On page 47, the usage of "close relationship" is identified as non-scientific terminology.

Changed for ‘close association’.

The reference to Figure 5.9 is absent on page 114.

The reference was added.

Chapter 7 presents an event dated October 28, 2021, which is initially referenced. But later it is followed by the introduction of an additional event from 2011, which can be confusing for the reader.

An additional paragraph about the second study was added to the project summary.

It is recommended that a more explicit indication of achievements and emphasis on novelty be integrated for the conclusions in each chapter. While external references can validate results, a balanced approach that underscores the originality of the results is encouraged.

Separate conclusion sections were added to Chapters 6 and 7. The Conclusion Chapter was edited to highlight novelty and importance of the results.