Solar Eruptive Events:

Coronal Dimming and a New CubeSat Mission

by

James Paul Mason

B.S., University of California at Santa Cruz, 2009

M.S., University of Colorado at Boulder, 2012

A thesis submitted to the

Faculty of the Graduate School of the

University of Colorado in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

Department of Aerospace Engineering Sciences

2016

This thesis entitled:

Solar Eruptive Events:
Coronal Dimming and a New CubeSat Mission
written by James Paul Mason
has been approved for the Department of Aerospace Engineering Sciences

Dr. Thomas Wooods

Prof. Xinlin Li

Prof. Scott Palo

Dr. Amir Caspi

Prof. Jeffrey Forbes

Date

The final copy of this thesis has been examined by the signatories, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the above mentioned discipline.

Mason, James Paul (Ph.D., Aerospace Engineering Sciences)

Solar Eruptive Events:

Coronal Dimming and a New CubeSat Mission

Thesis directed by Dr. Thomas Wooods

Often the abstract will be long enough to require more than one page, in which case the macro “\OnePageChapter” should *not* be used.

But this one isn’t, so it should.

Dedication

To my late father, who inspired me from an early age to come this far.

Acknowledgements

First and foremost, my deepest thanks to Tom Woods. Through the projects he's introduced me to – in solar physics, in sounding rockets, and in small satellites – I've discovered a career path that excites me and that provides continuous opportunities to learn and contribute. Moreover, he's an excellent role model: dedicated and passionate about his work, patient with everyone without seeming to have to try, and exceptionally reliable. All of the above combined has made my time in graduate school likely to be, upon reflection long from now, one of the highlights of my life. Thank you to my committee for guidance and support, most of whom I've been fortunate to work with closely: Xinlin Li, Scott Palo, Amir Caspi, and Jeff Forbes. Finally, I couldn't have struggled through without the support of my peers, especially Allison Youngblood, whose work ethic inspires me and whom I've been extremely lucky to find. Oh, and my dog, Nessie, who requires three walks a day, has turned out to provide the periods of relaxation away from a screen that have aided in my ability to actually comprehend the work I'm doing.

Contents

Chapter

Tables

Table

Figures

Figure

Chapter 1

Introduction

This sample document illustrates how to use the `thesis` class, originally written by John P. Weiss. Some requirements of the Graduate School are written into that file; page size, line spacing, appropriate placement of captions for tables and figures, etc. Revisions by Hongcheng Ni make it possible to use the (optional) `\usepackage{hyperref}` command to enable internal hyperlinks in the final PDF document. Other tasks of conforming to the requirements are left to other existing LaTeX packages. For example, a common problem is to insert graphics — figures and tables — into the body of the thesis. For this one should use the `graphicx` package, which is part of the standard TeX distribution. Likewise, the Grad School specs say that a large table may be displayed in landscape mode at reduced size, but its caption must also be in rotated position, in the same font and size as the normal text in the body of the thesis. To accomplish this, the user must invoke the `rotating` package, available online.

Figure 8.1 shows an image from a PDF file imported into this document using the `graphicx` package. The command `\usepackage{graphicx}`, which appears near the very top of the main LaTeX file, reads in this package which defines the `\includegraphics{}` macro.

In `thesis` class (for Colorado University), lists are defined so that nested lists will be numbered or marked appropriately. First, an itemized (non-enumerated) list prefaces each item with a bullet. Nested itemized list use asterisks, then dashes, then dots. These lists are typed between the `\begin{itemize}` and `\end{itemize}` commands.

- This is “itemized” item A.

Figure 1.1: This diagram of a cylinder and various measurements and quantities was actually made using **xfig**, a freeware drawing program for Unix systems. Diagrams can be exported directly to PDF files, the preferred format for vector graphics. Vector graphics can be magnified indefinitely without degradation, whereas bitmap images (JPG and PNG) must be pretty high-resolution if you don't want them looking all pixellated when magnified.

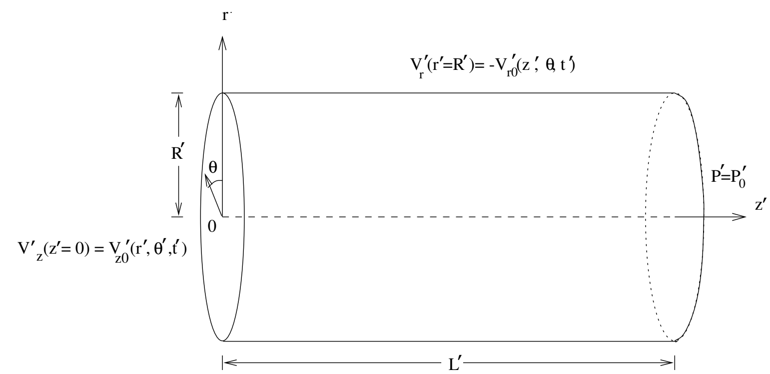
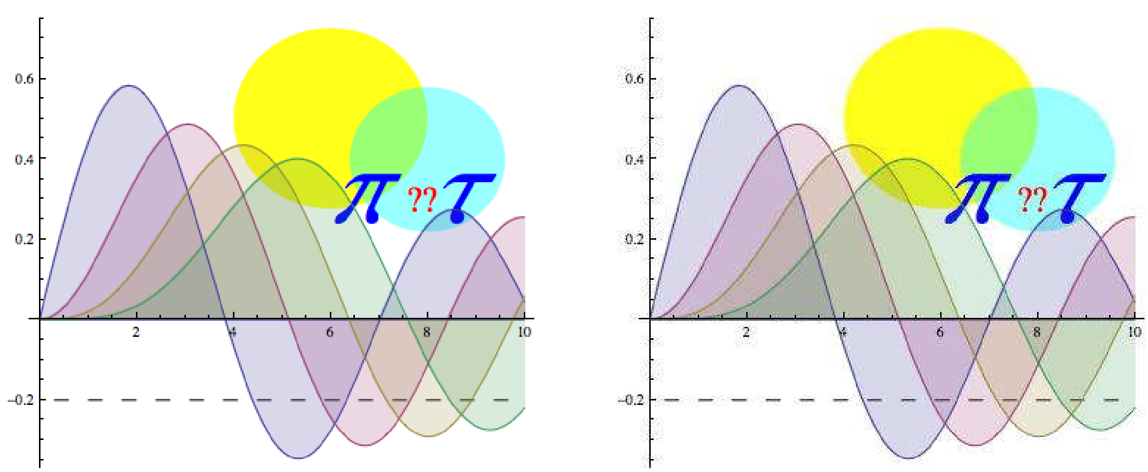


Figure 1.2: The JPEG bitmap format is great for photos but crummy for diagrams (including drawings, graphs, charts) because it can't gracefully handle sharp edges. Note the same bitmap image below from a PNG file and from a JPG file; the latter shows characteristic "ringing" at sharp edges – including text! Seriously, magnify and look closely at the JPG's awful lines and edges. Vector-format PDF is the best for diagrams, but if you must use a bitmap image, let it be PNG. (Left: file *drawing.png*. Right: file *drawing.jpg*.)



- This is “itemized” item B.
- This is “itemized” item C.
    - ∗ This is “itemized” subitem A.
        - – This is “itemized” subsubitem A.
            - · This is “itemized” subsubsubitem A.
        - – This is “itemized” subsubitem B.
    - ∗ This is “itemized” subitem B.
- This is “itemized” item D.

Enumerated lists use the commands `\begin{enumerate}` and `\end{enumerate}`, and nested enumerations appear like this.

(1) This is “enumerated” item A.

(2) This is “enumerated” item B.

(3) This is “enumerated” item C.

    (a) This is “enumerated” subitem A.

        (i) This is “enumerated” subsubitem A.

            (i.a) This is “enumerated” subsubsubitem A.

        (ii) This is “enumerated” subsubitem B.

    (b) This is “enumerated” subitem B.

(4) This is “enumerated” item D.

The work presented here[1] is an extension of Lao**?** and Lao et al.**?**, fictional references that are in the bibliographic source file `refs.bib`.

[1] Footnotes are handled neatly by LaTeX.

Table 1.1: Here is an example of a table with its own footnotes. Don't use the `\footnote` macro if you don't want the footnotes at the bottom of the page. Also, note that in a thesis the caption goes **above** a table, unlike figures.

wave form	S (kVA)	P (kW)	Q^* (kVAr)	$D^\dagger$ (kVAd)
Fig. 8.1a	25.48	25.00	-2.82	4.03
Fig. 8.1b	25.11	18.02	-9.75	14.52
Table 2.1	24.98	22.26	9.19	6.64
Table 8.1	23.48	15.00	6.59	16.82
Fig. 2.1	24.64	22.81	-0.44	9.3

*kVAr means reactive power.
†kVAd means distortion power.

Chapter 2

Relevant Background

The objective of this fake thesis document is to demonstrate a multitude of LaTeX features as well as features specific to the thesis class. We start by giving one short formula, and one big hairy multi-line formula (one of the non-dimensional Navier-Stokes equations):

$$A = \pi r^2 \tag{2.1}$$

$$\begin{aligned}
\rho\left[\frac{DV_r}{Dt} - M\epsilon^2\frac{V_\theta^2}{r}\right] \quad = \quad & -\frac{\delta^2}{\gamma\ M}\frac{\partial P}{\partial r} + \frac{M\ \delta^2}{Re}\left\{2\frac{\partial}{\partial r}\left[\mu\left(\frac{\partial V_r}{\partial r} - \frac{1}{3}\nabla\cdot\overline{\mathbf{V}}\right)\right]\right. \\
& + \frac{1}{r}\frac{\partial}{\partial\theta}\left[\mu\left(\frac{1}{r}\frac{\partial V_r}{\partial\theta} + \epsilon\frac{\partial V_\theta}{\partial r} - \epsilon\frac{V_\theta}{r}\right)\right] \\
& + \frac{\partial}{\partial z}\left[\mu\left(\frac{1}{\delta^2}\frac{\partial V_r}{\partial z} + \frac{\partial V_z}{\partial r}\right)\right] \\
& \left. + 2\ \frac{\mu}{r}\left[\frac{\partial V_r}{\partial r} - \frac{\epsilon}{r}\frac{\partial V_\theta}{\partial\theta} - \frac{V_r}{r}\right]\right\},
\end{aligned} \tag{2.2}$$

2.1 Solar Corona

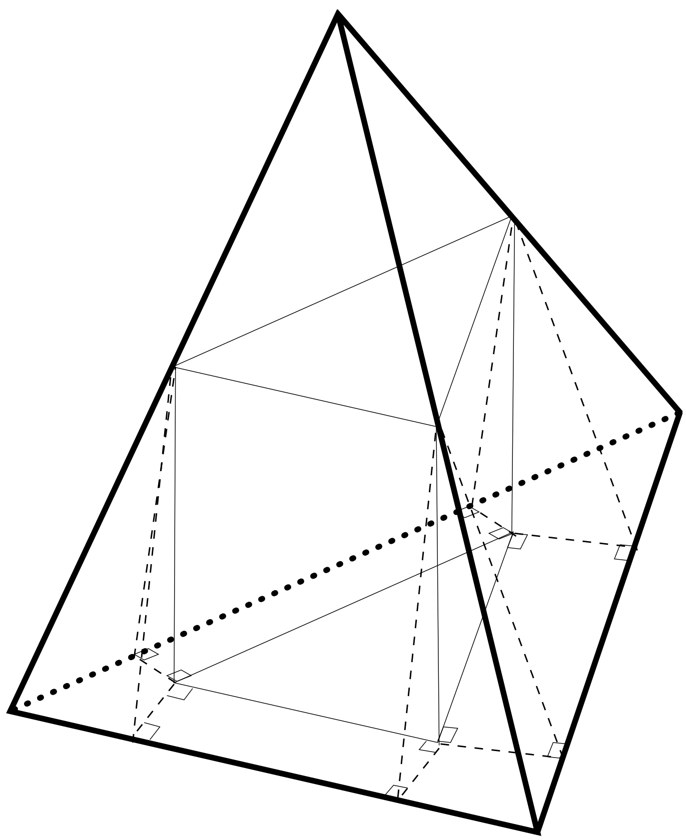
The latter equation is non-dimensionalized using the following definitions:

$$r = \frac{r'}{R'}, \quad z = \frac{z'}{L'}, \quad t = \frac{t'}{t'_a}, \quad \kappa = \frac{\kappa'}{\kappa'_0}, \quad \mu = \frac{\mu'}{\mu'_0}, \quad C_V = \frac{C'_V}{C'_{V0}},$$

where P'_0 is the initial static pressure in the cylinder, and ρ'_0 and T'_0 are the density and temperature of the fluid being injected from the sidewall.

Here is an example of using the macros `\singlespacing` and `\doublespacing`:

Figure 2.1: A triangular pyramid may be cut up as shown, to yield one top pyramid (with one-eighth the volume of the full pyramid), three bottom corner pyramids (which, when joined, are congruent to the top pyramid), three prisms along the bottom edges (the area of whose bottom faces total $B/2$) and the large central prism (volume $= (B/4)(h/2) = Bh/8$). The image, from PDF file "pyr.pdf", was read in using the `\includegraphics` command, from the `graphicx` package.



This paragraph was preceded by the command `\singlespacing`. See the Specifications of the Grad School for instructions about when single spacing is appropriate in a thesis.

And now, here is an example of using the macros `\begin{singlespace}` and `\end{singlespace}`; another way to get single-spacing.

Two cases are studied in the present work which differ only in the boundary conditions. Each different boundary condition model a different source of instability. The boundary of the first case consists of a steady, axisymmetric sidewall radial velocity boundary and a time-dependent, non-axisymmetric endwall axial velocity boundary. The second case is studied with a fixed impermeable axial velocity along the endwall and a combination axisymmetric steady and non-axisymmetric unsteady radial velocity along the sidewall.

Usually you want to use a table produced by some other software, such as Excel, rather than try to do it using LaTeXmacros. If the table is saved/printed to a PDF file, then it can be displayed using the `\includegraphics` macro inside a `table` environment:

Some of the boundary conditions are:

$$z = 0; \qquad V_z = \begin{cases} 0, & t \le 0 \\ \\ \widetilde{F}_{zw}(r, \theta, t), & t > 0 \end{cases} \tag{2.3}$$

$$z = 0; \qquad V_\theta = V_r = 0 \tag{2.4}$$

$$r = 0; \qquad P, \rho, T, V_r, V_\theta, V_z \text{ finite}, \tag{2.5}$$

$$r = 1; \qquad V_r = F_{rws}(z), \tag{2.6}$$

$$r = 1; \qquad V_z = V_\theta = 0, \tag{2.7}$$

and solutions must be periodic in θ.

If you don't believe this stuff, check out Mulick**?** and Baylor**?**.

2.2 Physics of Solar Eruptive Event Initiation

2.2.1 Just meaningless text to test lines per page

According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document

Table 2.1: This table wasn't constructed with LaTeX commands, but resides in PDF file (`tableD.pdf`) created by some other software.

n	**n^2**	**n^3**	**n^4**	**n^7**	**n^{13}**
2	4	8	16	128	8192
3	9	27	81	2187	1594323
4	16	64	256	16384	67108864
5	25	125	625	78125	1220703125
6	36	216	1296	279936	13060694016
7	49	343	2401	823543	96889010407

conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform? According to the Grad School specs. there should be 24–27 lines of print per page of a thesis. This should be true whether the font size is 10, 11, or 12. Count them up; does this document conform?

What is it? This is a labelled paragraph. The heading of the paragraph is emphasized. This is a labelled paragraph. The heading of the paragraph is emphasized.

2.2.2 Space Weather

This is a subsection. Filler filler filler filler filler filler filler filler. Filler filler filler filler filler filler filler filler.

2.2.3 This is another subsection

This is another subsection. Filler filler filler filler filler filler filler filler. Filler filler filler filler filler filler filler filler.

This is paragraph number 2. It used a `\paragraph{}` header, which are always inlined (with extra space) and boldfaced.

This is the third paragraph of the subsection. Filler filler filler filler filler filler filler filler. Filler filler filler filler filler filler filler filler.

2.2.3.1 This is a subsubsection (1)

This is the first paragraph of the subsubsection. Whether it is numbered or inlined depends on the option selected at the beginning of the thesis.

By default, a `\subsubsection` heading is numbered and set off on a separate line, left-justified.

However. Using the `inlineh4` option, subsubsection headers are inlined. And using the `nonumh4` option suppresses numbering of the subsubsections. Together they make subsubsection headings just the same as paragraph headings.

2.2.3.2 This is another subsubsection (2)

Once again, whether its heading is numbered and/or inlined depends on the class options chosen at the start.

There is no "subsubsubsection" entity, and "subparagraph" gets no special treatment in **thesis** class.

2.3 EUV Emission

Finally, this is the end. The bibliography starts on the next page. Note how the `\hyperref` package (mentioned in chapter **??**) also makes hyperlinks from references (e.g., Mulick**?**) to entries in the bibliography.

Chapter 3

Mechanisms of Coronal Dimming

This chapter details the physics of coronal dimming. There are theoretically many physical processes that can lead to an uncareful observer identifying "dimming", which may have little to do with coronal mass ejection (CME). Traditionally, the term "coronal dimming" has been assumed to refer to the void left in the corona after a CME departs. This is one cause of a transient hole in the corona, and is of the greatest concern to space weather forecasters. Typically, a single dimming-sensitive wavelength or band will be observed and analyzed. However, changing temperatures, common during solar eruptive events, cause ionization fraction shifting, resulting in some emissions dimming while others brighten. Additionally, dark material (e.g., a filament) can pass between a bright region (e.g., flaring loops) and the observer, causing a transient dip in emission. Third, solar eruptive events sometimes have associated waves that propagate across the solar disk. These waves are observed as narrow bright fronts with a trailing dark region. The trailing dark region is another way to achieve a transient dimming of emission. Next, there are two ways that Doppler effects can cause transient dips in emission. The first is called Doppler dimming and results from fast moving plasma being sufficiently Doppler-shifted to reduce resonant fluorescence from the solar emission line sources; a phenomenon which is independent of the observation angle. The second occurs if eruptive plasma is moving fast enough in the line-of-sight to shift its emissions outside the bandpass of an observing instrument, which we have named "bandpass shift dimming". The physics, instrument effects, and mitigation strategies for each of these types of theoretically observable dimming are summarized in Table 3.1 and are discussed in detail in the sections that follow.

Table 3.1: Summary of physical processes that can manifest as observed dimming

Short Name	Physical Process	EVE Observational Identifiers	AIA Observational Identifiers
Mass loss (Fig. ??)	Ejection of emitting plasma from corona	Simultaneous intensity decrease in multiple coronal emission lines, with percentage decrease indicative of percentage mass lost	Area over and near the erupting active region (AR) darkens
Thermal (Fig. ??)	Heating raises ionization states (e.g., a fraction of Fe IX becomes Fe X); cooling does the opposite	Heating: Emission loss in lines with lower peak formation temperatures and near simultaneous emission gain in lines with higher peak formation temperatures; vice versa for cooling	Heating: Area near AR darkens in channels with lower peak formation temperature and near simultaneous brightening in channels with higher peak formation temperatures; vice versa for cooling
Obscuration (Fig. ??)	Dim feature (e.g., filament material) moves into line-of-sight over a bright feature (e.g., flare arcade)	Drop of emission lines proportional to their absorption cross section in the obscuring material	Direct observation of this obscuration process
Wave (Fig. ??)	Wave disturbance propagates globally, causing compression/rarefaction of plasma as wave passes by	No effects have been identified	Direct observation of this wave process, especially apparent with difference movies
Doppler	Fast moving plasma Doppler shifts away from resonant fluorescence with solar emission lines	Doppler wavelength shift of emission lines and change in intensity, possibly also observed as line broadening	Change in intensity of moving plasma as its velocity changes
Bandpass	Emissions from fast moving plasma have Doppler wavelength shift	Emission line shifts in wavelength or has broadening	Doppler shift convolves with band-pass sensitivity to cause apparent reduction in emission

3.1 Mass-loss Dimming

3.2 Thermal Dimming

Temperature evolution of emission lines is only interpreted as observed dimming if one is not careful to observe co-spatial emission lines at different peak formation temperatures. As plasma is heated or cooled, the ionization fraction changes, necessarily causing the emission intensity to change (Figure 3.1). For example, heating causes some Fe IX to become Fe X and thus, in the absence of competing physical processes, 171 Å emission drops while 177 Å rises. This pattern was identified observationally in Figure 6 of Woods et al. (2011) using SDO/EVE data, Robbrecht and Wang (2010) using STEREO/EUVI, Jin et al. (2009) and Imada et al. (2007) with Hinode/EIS. It can also be observed in the standard composite (multi-wavelength) movies produced by the AIA team; indeed, this is one of the prime purposes for the composites. The initiation time and duration of temperature evolution tends to be quite similar to mass-loss dimming, as they are typically both responses to the rapid release of magnetic field energy in active regions and require several hours of recovery time. Thus, thermal processes could be mistaken for mass loss if only a single spectral line was observed. Ideally, unblended emission lines from an entire coronal ionization sequence (e.g., Fe I to Fe XVIII) could be used to mitigate this convolution of dimming observations. However, as we will show in Section 4.3, it may be sufficient to have observations of two sufficiently separated ionizations states to differentiate between thermal evolution and mass-loss dimming. This is due, in part, to the fact that hotter lines (e.g., Fe XV and above) are primarily emitted from confined loops near the flare and are thus not strongly impacted by mass-loss dimming. Multi-wavelength Doppler studies have shown that while all (measured) emission lines become blue-shifted (indicating an outflow), the magnitude of the shift is strongly directly proportional to the lines peak formation temperature (Imada et al., 2007; Jin et al., 2009). Figure 3.2 shows this dependence for a plage region with a dimming during an X-class flare. In particular, Fe IX 171 Å emission can be depressed further after open magnetic field lines from the departing CME close down and cause another bout of heating; causing e.g., Fe IX to become Fe X and beyond, which propagates outward as a "heat wave dimming" (Robbrecht and Wang, 2010). It may even be that cool emissions like Fe IX 171 Å are simply moving too slow to account for mass depletion and that warmer lines, such as Fe XII 195 Å better represent the mass being ejected (Robbrecht and Wang, 2010). However, Mason et al. (2014) found that the onset time, slope, and duration of dimming are comparable in SDO/AIA 171 Å and 193 Å[1] and in SDO/EVE 171Å and 195 Å (described in Chapter 4).

Figure 3.1: Schematic depicting the observational difference between dimming and non-dimming emission lines. Relative to a pre-eruption time (left), the Fe IX emission drops while the Fe XIV emission increases (right) due to heating of the plasma and redistribution of ionization states.

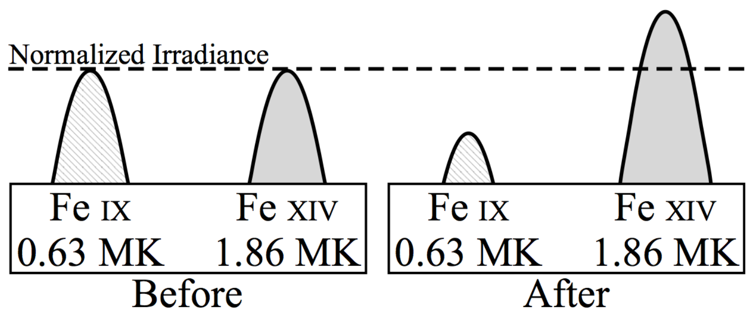
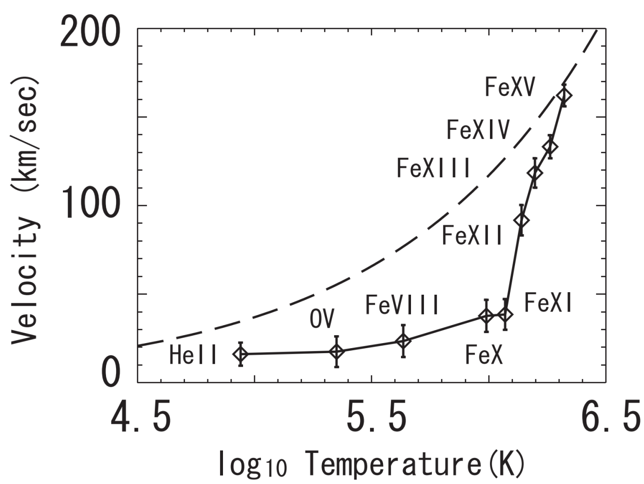


Figure 3.2: Outflow velocity vs emission line peak formation temperature for a dimming region near a plage. Adapted from Imada et al. (2007).



It is important to note that, in general, the magnitude of total observed dimming in a given

[1] Note that the SDO/AIA 193 Å band encompasses 195 Å

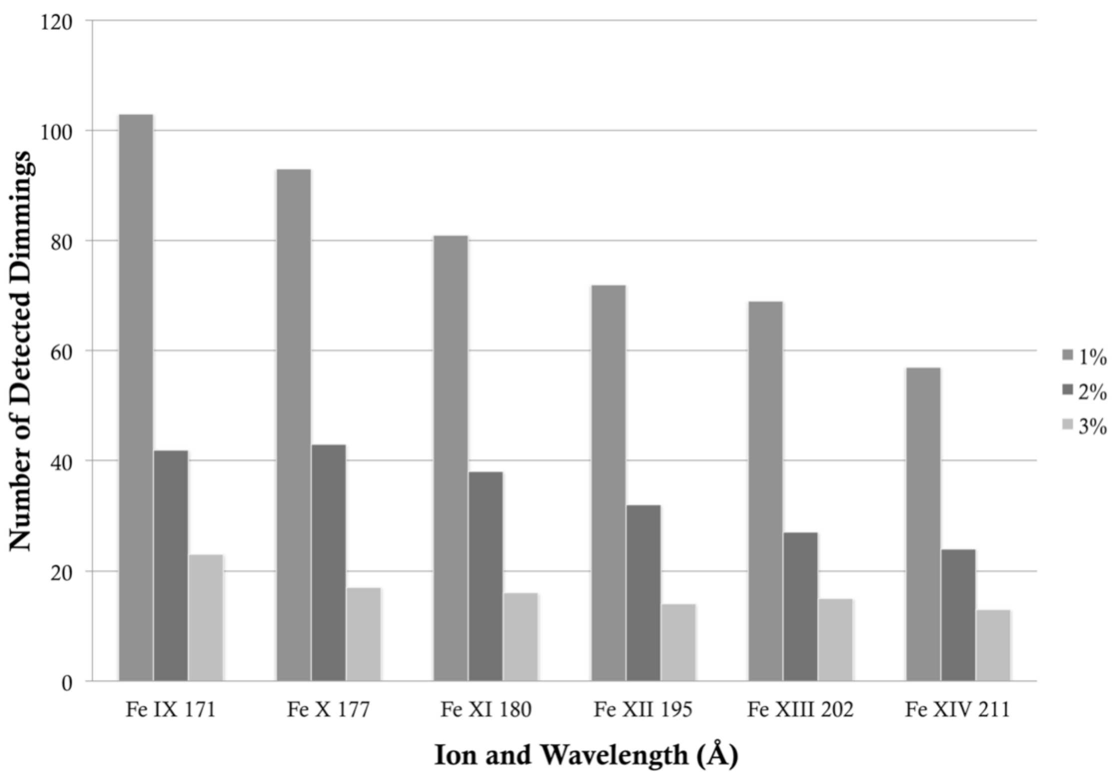
line in EVE spectra is inversely proportional to its peak formation temperature, which can be inferred from Figure 3.3. This figure was generated using a simple algorithm that searched all EVE/MEGS-A data for relative irradiance decreases greater than a specified threshold (1%, 2%, 3%) of flares exceeding GOES X-ray class of C1. The window of time searched was bounded by the GOES event start time and the sooner of either 4 hours after the start time or the next GOES event start time. This algorithm was applied to all EVE data from mission start (2010 February 10) to the failure of the MEGS-A instrument (2014 May 26). MEGS-A takes the measurements of all wavelengths studied here. Figure 3.3 shows that the number of dimmings dramatically decreases as the magnitude threshold is increased, and decreases slightly with higher peak formation temperature. This latter effect is partially due to flare heating adding emission in the higher temperature, higher ionization state, lines that partially offsets the mass-loss dimming. Additionally, these trends indicate that at sufficiently high peak formation temperature, no dimming may be observed at all, even at the lowest detection threshold, which is consistent with the hotter lines being restricted to the confined flare loops and hence experiencing no mass loss. In other words, the higher the peak formation temperature, the greater the relative contribution of more confined loops to the measured emission.

An instrument with spatial resolution like AIA can be used to isolate the confined flaring loops and create a time series of just the dimming region, and this is a procedure carried out in Chapter 4. AIA too has its own limitations: relevant in this case is the relatively lower spectral resolution that blends together emission from several ionization states of Fe. With EVE and AIA combined, it is possible to analyze thermal dimming but the idea instrument for fully characterizing this phenomenon would be a high-resolution hyperspectral imager in the EUV.

3.3 Obscuration Dimming

The physical process that results in apparent dimming here is material that is dark in a particular wavelength (e.g., a filament) moving between bright material (e.g., flare arcade) and the observer (Figure 3.4). In optically thick wavelengths, the dark plasma absorbs some of the bright

Figure 3.3: Number of identified dimmings in EVE for six spectral lines using different percentage dimming depths as the threshold for a detection. There were 263 flares used to trigger an automated search for dimming in EVE. Note the decrease in detections with increasing ionization state (i.e. peak formation temperature).

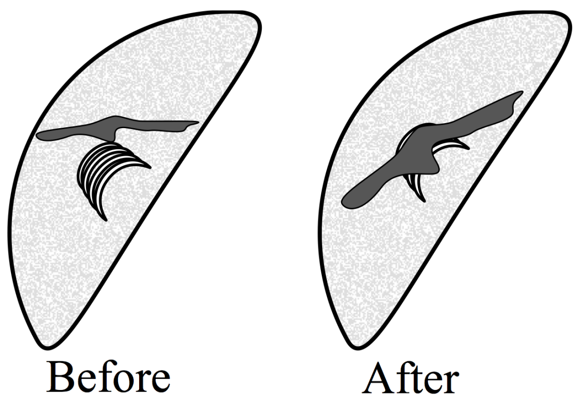


emission, resulting in an apparent decrease in emission. The slow draining of plasma back to the corona can obscure underlying emission for hours, and absorption can be observed in both coronal and chromospheric lines (e.g., Gilbert et al. (2013)). Although the obscuration dimmings can exhibit time and spatial scales comparable to the more short-lived mass-loss dimmings, it is fairly straightforward to identify absorption signatures in the EUV images. It may also be possible to identify this phenomenon with EVE using the He II 256 Å and 304 Å chromospheric emission lines and knowledge of the absorption cross-section through filamentary plasma. Figure 3.5 shows the photoionization cross-sections of the dominant species in the solar corona. Hydrogen and helium contribute an order-of-magnitude more absorption than metals[2] , and thus the effect of metals can

[2] "Metals" in the astrophysical sense

be ignored. The cross-sections are quite steep in the wavelength range of interest here (roughly 150-310 Å). This means that approximately twice as much He II 256 Å than He II 304 Å emission will come through a filament. Furthermore, the mass-loss dimming sensitive lines (e.g., Fe IX 171 Å and 195Å) will be less affected by this obscuration, but a 1% effect would be sufficient to cause a "false" detection. It may be possible to identify obscuration dimming with EVE's 256 Å and 304 Å measurements and determine that an obscuration dimming has occurred. However, further analysis of this type of dimming is required before any conclusions can be drawn.

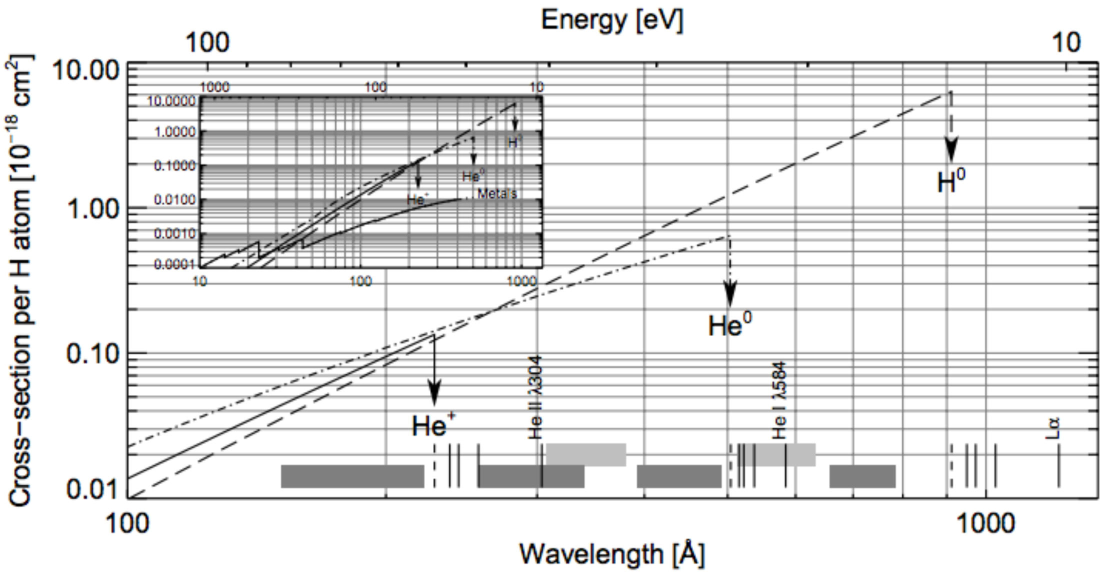
Figure 3.4: Schematic depicting the process of obscuration dimming. A filament previously obscuring only the quiet Sun (left) expands and moves in front of a flare arcade (right). This results in a decreased observed emission from the flare arcade in wavelengths where the filament is optically thick.



3.4 Wave Dimming

The debate about the physics of coronal EUV waves continues (e.g., Zhukov and Auchère (2004); Muhr et al. (2011); Liu and Ofman (2014)) but one of the simplest explanations of the observations is that plasma is compressed as a longitudinal wave passes through the medium. Traveling (i.e., not static) rarefactions are sometimes observed following the compression (Muhr et al., 2011), the compressed regions having higher densities resulting in increased emission, and vice versa (Figure 3.6). Alternatively, some models suggest that the observed phenomenon is not a wave at all, but rather the impact of the CME departing on the global magnetic field (Chen

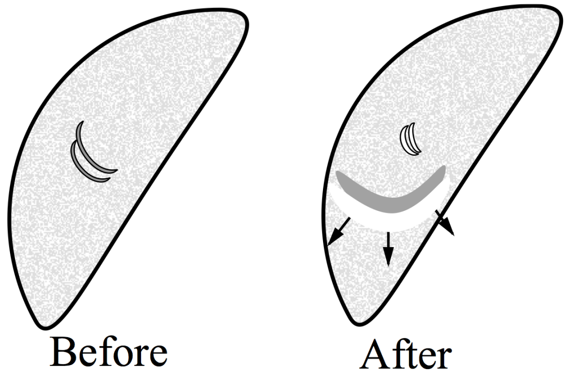
Figure 3.5: Photoionization cross-sections for He I (dot-dashed line), He II (solid line), and H (dashed line) per hydrogen atom. The inset shows a wider wavelength range of the same data but with metals shown for comparison. The dashed vertical bars at the bottom indicate the edges of respective continua. The grey regions at the bottom are not pertinent here as they correspond to specifics of the SOHO/CDS instrument. Adapted from Andretta et al. (2003).



et al., 2002, 2005). Regardless of the physical process responsible, the observation is the same. The EUV waves emanating from an eruption can be seen to cause dimmings and brightenings elsewhere in the solar EUV images, often very far from the original eruption site, particularly near other active regions. We refer to these dimmings that are non-local to the erupting site as sympathetic dimmings.

It is important to distinguish between the wave-caused dimmings and other causes of remote dimming, such as large-scale disappearing loops that are visible in soft X-ray images but only have visible EUV changes at their footpoints (Pohjolainen et al., 2005). EUV wave dimmings are unlikely to be easily identified in full-disk spatially-integrated instruments like EVE because the enhanced emission nearly cancels out the dimmed emission when summed. However, the global nature of these events has the potential to trigger eruptive events in distant regions (Schrijver and Higgins, 2015), potentially leading to further dimming. This is quite likely to occur if a distant active region has significant potential energy stored when the disturbance reaches it – the wave

Figure 3.6: Similar to Figure 3.4, but depicting the process of wave dimming. After an eruptive event, a wave propagates and expands through the corona. The compressed plasma of the wavefront results in enhanced emission, while the rarefied trailing region is dimmed.



propagating across the magnetic field lines acts as a catalyst.

3.5 Two Possible but Unobserved Dimming Mechanisms

Chapter 4

Coronal Dimming Case Study

This sample document illustrates how to use the `thesis` class, originally written by John P. Weiss. Some requirements of the Graduate School are written into that file; page size, line spacing, appropriate placement of captions for tables and figures, etc. Revisions by Hongcheng Ni make it possible to use the (optional) `\usepackage{hyperref}` command to enable internal hyperlinks in the final PDF document. Other tasks of conforming to the requirements are left to other existing LaTeX packages. For example, a common problem is to insert graphics — figures and tables — into the body of the thesis. For this one should use the `graphicx` package, which is part of the standard TeX distribution. Likewise, the Grad School specs say that a large table may be displayed in landscape mode at reduced size, but its caption must also be in rotated position, in the same font and size as the normal text in the body of the thesis. To accomplish this, the user must invoke the `rotating` package, available online.

Figure 8.1 shows an image from a PDF file imported into this document using the `graphicx` package. The command `\usepackage{graphicx}`, which appears near the very top of the main LaTeX file, reads in this package which defines the `\includegraphics{}` macro.

4.1 Lists in `thesis` class

In `thesis` class (for Colorado University), lists are defined so that nested lists will be numbered or marked appropriately. First, an itemized (non-enumerated) list prefaces each item with a bullet. Nested itemized list use asterisks, then dashes, then dots. These lists are typed between

Figure 4.1: This diagram of a cylinder and various measurements and quantities was actually made using **xfig**, a freeware drawing program for Unix systems. Diagrams can be exported directly to PDF files, the preferred format for vector graphics. Vector graphics can be magnified indefinitely without degradation, whereas bitmap images (JPG and PNG) must be pretty high-resolution if you don't want them looking all pixellated when magnified.

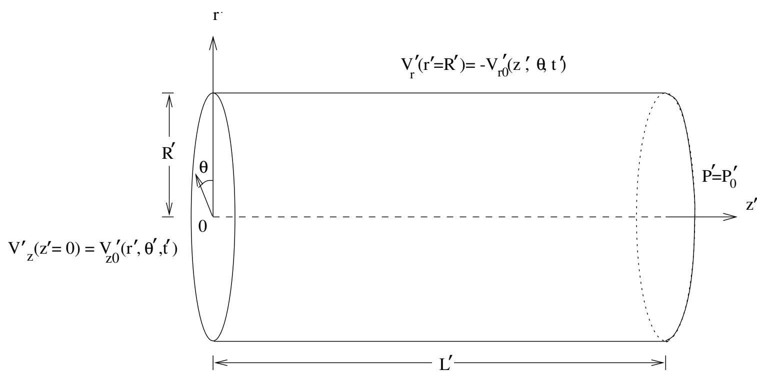
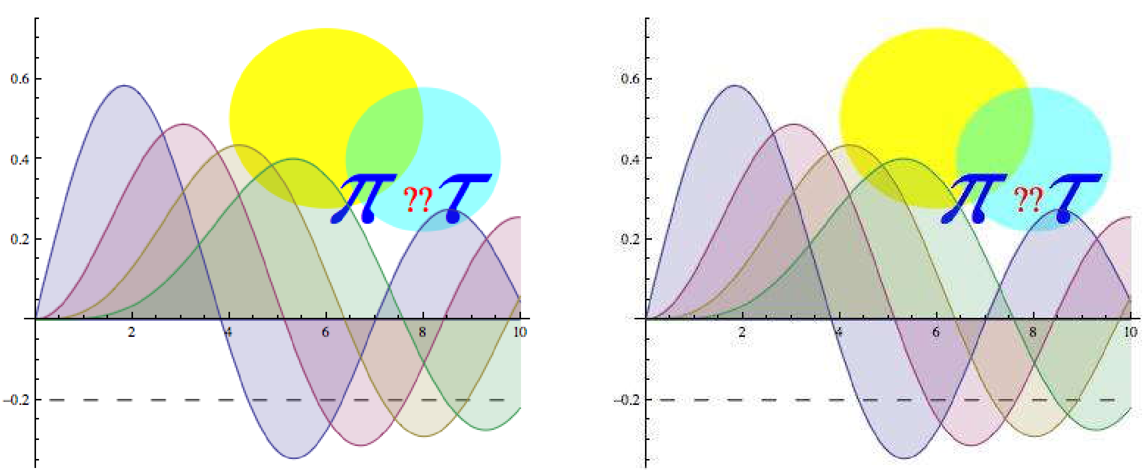


Figure 4.2: The JPEG bitmap format is great for photos but crummy for diagrams (including drawings, graphs, charts) because it can't gracefully handle sharp edges. Note the same bitmap image below from a PNG file and from a JPG file; the latter shows characteristic "ringing" at sharp edges – including text! Seriously, magnify and look closely at the JPG's awful lines and edges. Vector-format PDF is the best for diagrams, but if you must use a bitmap image, let it be PNG. (Left: file *drawing.png*. Right: file *drawing.jpg*.)



the `\begin{itemize}` and `\end{itemize}` commands.

- This is "itemized" item A.
- This is "itemized" item B.
- This is "itemized" item C.
  - ∗ This is "itemized" subitem A.
    - – This is "itemized" subsubitem A.
      - · This is "itemized" subsubsubitem A.
    - – This is "itemized" subsubitem B.
  - ∗ This is "itemized" subitem B.
- This is "itemized" item D.

Enumerated lists use the commands `\begin{enumerate}` and `\end{enumerate}`, and nested enumerations appear like this.

(1) This is "enumerated" item A.

(2) This is "enumerated" item B.

(3) This is "enumerated" item C.

  (a) This is "enumerated" subitem A.

    (i) This is "enumerated" subsubitem A.

      (i.a) This is "enumerated" subsubsubitem A.

    (ii) This is "enumerated" subsubitem B.

  (b) This is "enumerated" subitem B.

(4) This is "enumerated" item D.

The work presented here[1] is an extension of Lao**?** and Lao et al.**?**, fictional references that are in the bibliographic source file `refs.bib`.

Table 4.1: Here is an example of a table with its own footnotes. Don't use the `\footnote` macro if you don't want the footnotes at the bottom of the page. Also, note that in a thesis the caption goes **above** a table, unlike figures.

wave form	S (kVA)	P (kW)	Q^* (kVAr)	$D^\dagger$ (kVAd)
Fig. 8.1a	25.48	25.00	-2.82	4.03
Fig. 8.1b	25.11	18.02	-9.75	14.52
Table 2.1	24.98	22.26	9.19	6.64
Table 8.1	23.48	15.00	6.59	16.82
Fig. 2.1	24.64	22.81	-0.44	9.3

*kVAr means reactive power.
†kVAd means distortion power.

[1] Footnotes are handled neatly by LaTeX.

Chapter 5

Semi-Statistical Study of Coronal Dimming

This sample document illustrates how to use the `thesis` class, originally written by John P. Weiss. Some requirements of the Graduate School are written into that file; page size, line spacing, appropriate placement of captions for tables and figures, etc. Revisions by Hongcheng Ni make it possible to use the (optional) `\usepackage{hyperref}` command to enable internal hyperlinks in the final PDF document. Other tasks of conforming to the requirements are left to other existing LaTeX packages. For example, a common problem is to insert graphics — figures and tables — into the body of the thesis. For this one should use the `graphicx` package, which is part of the standard TeX distribution. Likewise, the Grad School specs say that a large table may be displayed in landscape mode at reduced size, but its caption must also be in rotated position, in the same font and size as the normal text in the body of the thesis. To accomplish this, the user must invoke the `rotating` package, available online.

Figure 8.1 shows an image from a PDF file imported into this document using the `graphicx` package. The command `\usepackage{graphicx}`, which appears near the very top of the main LaTeX file, reads in this package which defines the `\includegraphics{}` macro.

5.1 Lists in `thesis` class

In `thesis` class (for Colorado University), lists are defined so that nested lists will be numbered or marked appropriately. First, an itemized (non-enumerated) list prefaces each item with a bullet. Nested itemized list use asterisks, then dashes, then dots. These lists are typed between

Figure 5.1: This diagram of a cylinder and various measurements and quantities was actually made using **xfig**, a freeware drawing program for Unix systems. Diagrams can be exported directly to PDF files, the preferred format for vector graphics. Vector graphics can be magnified indefinitely without degradation, whereas bitmap images (JPG and PNG) must be pretty high-resolution if you don't want them looking all pixellated when magnified.

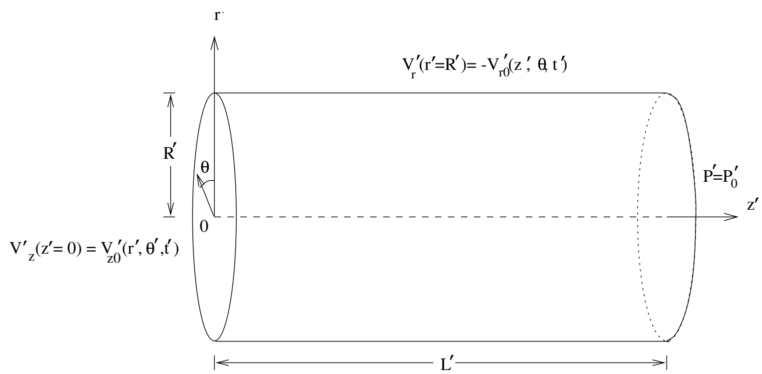
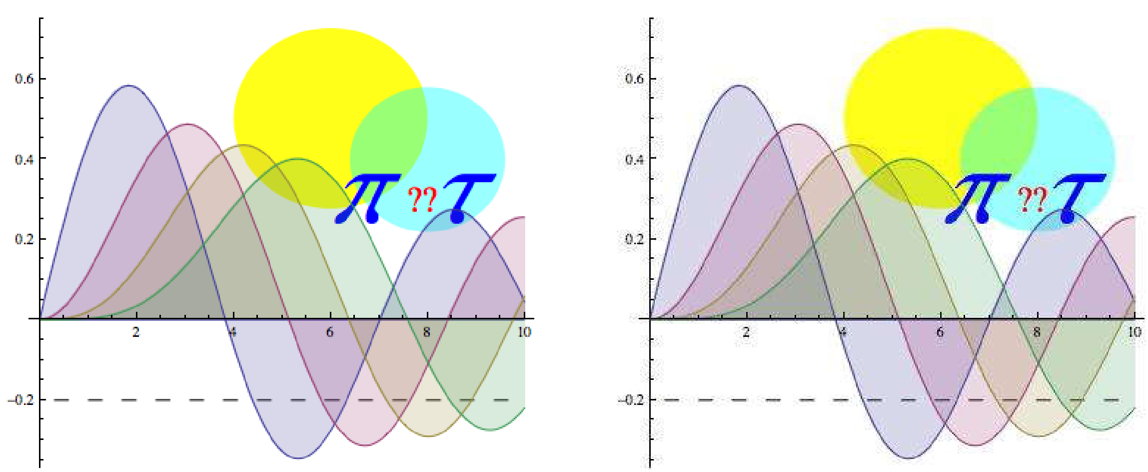


Figure 5.2: The JPEG bitmap format is great for photos but crummy for diagrams (including drawings, graphs, charts) because it can't gracefully handle sharp edges. Note the same bitmap image below from a PNG file and from a JPG file; the latter shows characteristic "ringing" at sharp edges – including text! Seriously, magnify and look closely at the JPG's awful lines and edges. Vector-format PDF is the best for diagrams, but if you must use a bitmap image, let it be PNG. (Left: file *drawing.png*. Right: file *drawing.jpg*.)



the `\begin{itemize}` and `\end{itemize}` commands.

- This is “itemized” item A.
- This is “itemized” item B.
- This is “itemized” item C.
    - ∗ This is “itemized” subitem A.
        - – This is “itemized” subsubitem A.
            - · This is “itemized” subsubsubitem A.
        - – This is “itemized” subsubitem B.
    - ∗ This is “itemized” subitem B.
- This is “itemized” item D.

Enumerated lists use the commands `\begin{enumerate}` and `\end{enumerate}`, and nested enumerations appear like this.

(1) This is “enumerated” item A.

(2) This is “enumerated” item B.

(3) This is “enumerated” item C.

    (a) This is “enumerated” subitem A.

        (i) This is “enumerated” subsubitem A.

            (i.a) This is “enumerated” subsubsubitem A.

        (ii) This is “enumerated” subsubitem B.

    (b) This is “enumerated” subitem B.

(4) This is “enumerated” item D.

The work presented here[1] is an extension of Lao**?** and Lao et al.**?**, fictional references that are in the bibliographic source file `refs.bib`.

Table 5.1: Here is an example of a table with its own footnotes. Don't use the `\footnote` macro if you don't want the footnotes at the bottom of the page. Also, note that in a thesis the caption goes **above** a table, unlike figures.

wave form	S (kVA)	P (kW)	Q^* (kVAr)	$D^\dagger$ (kVAd)
Fig. 8.1a	25.48	25.00	-2.82	4.03
Fig. 8.1b	25.11	18.02	-9.75	14.52
Table 2.1	24.98	22.26	9.19	6.64
Table 8.1	23.48	15.00	6.59	16.82
Fig. 2.1	24.64	22.81	-0.44	9.3

*kVAr means reactive power.
†kVAd means distortion power.

[1] Footnotes are handled neatly by LaTeX.

Chapter 6

Overview of MinXSS Solar CubeSat

This sample document illustrates how to use the `thesis` class, originally written by John P. Weiss. Some requirements of the Graduate School are written into that file; page size, line spacing, appropriate placement of captions for tables and figures, etc. Revisions by Hongcheng Ni make it possible to use the (optional) `\usepackage{hyperref}` command to enable internal hyperlinks in the final PDF document. Other tasks of conforming to the requirements are left to other existing LaTeX packages. For example, a common problem is to insert graphics — figures and tables — into the body of the thesis. For this one should use the `graphicx` package, which is part of the standard TeX distribution. Likewise, the Grad School specs say that a large table may be displayed in landscape mode at reduced size, but its caption must also be in rotated position, in the same font and size as the normal text in the body of the thesis. To accomplish this, the user must invoke the `rotating` package, available online.

Figure 8.1 shows an image from a PDF file imported into this document using the `graphicx` package. The command `\usepackage{graphicx}`, which appears near the very top of the main LaTeX file, reads in this package which defines the `\includegraphics{}` macro.

6.1 Lists in `thesis` class

In `thesis` class (for Colorado University), lists are defined so that nested lists will be numbered or marked appropriately. First, an itemized (non-enumerated) list prefaces each item with a bullet. Nested itemized list use asterisks, then dashes, then dots. These lists are typed between

Figure 6.1: This diagram of a cylinder and various measurements and quantities was actually made using **xfig**, a freeware drawing program for Unix systems. Diagrams can be exported directly to PDF files, the preferred format for vector graphics. Vector graphics can be magnified indefinitely without degradation, whereas bitmap images (JPG and PNG) must be pretty high-resolution if you don't want them looking all pixellated when magnified.

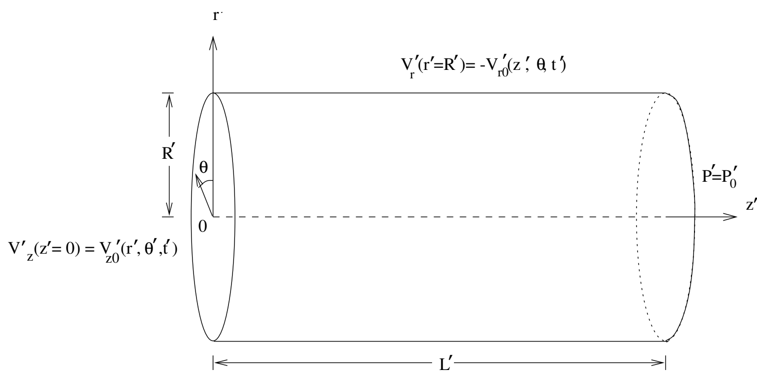
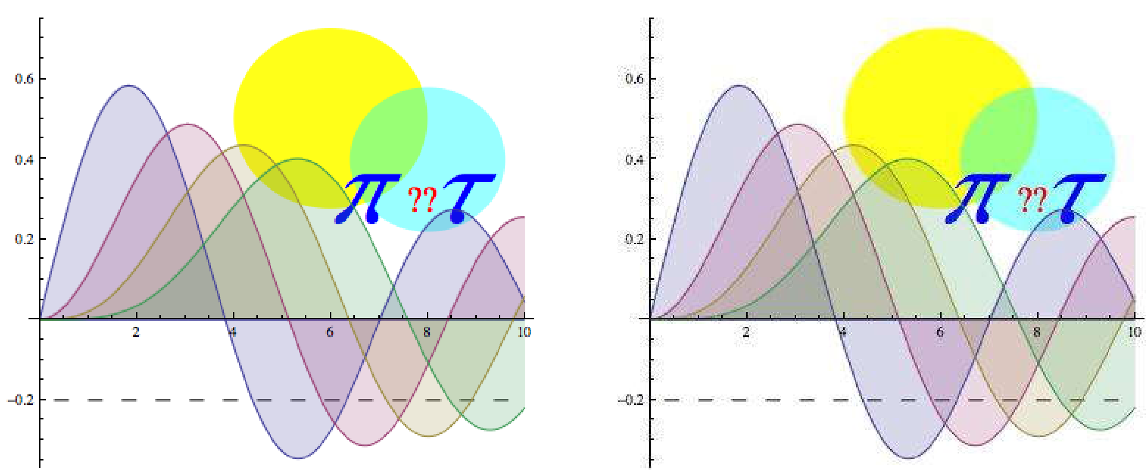


Figure 6.2: The JPEG bitmap format is great for photos but crummy for diagrams (including drawings, graphs, charts) because it can't gracefully handle sharp edges. Note the same bitmap image below from a PNG file and from a JPG file; the latter shows characteristic "ringing" at sharp edges – including text! Seriously, magnify and look closely at the JPG's awful lines and edges. Vector-format PDF is the best for diagrams, but if you must use a bitmap image, let it be PNG. (Left: file *drawing.png*. Right: file *drawing.jpg*.)



the `\begin{itemize}` and `\end{itemize}` commands.

- This is “itemized” item A.
- This is “itemized” item B.
- This is “itemized” item C.
  - ∗ This is “itemized” subitem A.
    - – This is “itemized” subsubitem A.
      - · This is “itemized” subsubsubitem A.
    - – This is “itemized” subsubitem B.
  - ∗ This is “itemized” subitem B.
- This is “itemized” item D.

Enumerated lists use the commands `\begin{enumerate}` and `\end{enumerate}`, and nested enumerations appear like this.

(1) This is “enumerated” item A.

(2) This is “enumerated” item B.

(3) This is “enumerated” item C.

  (a) This is “enumerated” subitem A.

    (i) This is “enumerated” subsubitem A.

      (i.a) This is “enumerated” subsubsubitem A.

    (ii) This is “enumerated” subsubitem B.

  (b) This is “enumerated” subitem B.

(4) This is “enumerated” item D.

The work presented here[1] is an extension of Lao**?** and Lao et al.**?**, fictional references that are in the bibliographic source file `refs.bib`.

Table 6.1: Here is an example of a table with its own footnotes. Don't use the `\footnote` macro if you don't want the footnotes at the bottom of the page. Also, note that in a thesis the caption goes **above** a table, unlike figures.

wave form	S (kVA)	P (kW)	Q^* (kVAr)	$D^\dagger$ (kVAd)
Fig. 8.1a	25.48	25.00	-2.82	4.03
Fig. 8.1b	25.11	18.02	-9.75	14.52
Table 2.1	24.98	22.26	9.19	6.64
Table 8.1	23.48	15.00	6.59	16.82
Fig. 2.1	24.64	22.81	-0.44	9.3

*kVAr means reactive power.
†kVAd means distortion power.

[1] Footnotes are handled neatly by LaTeX.

Chapter 7

Thermal Balance Analysis for a CubeSat

This sample document illustrates how to use the `thesis` class, originally written by John P. Weiss. Some requirements of the Graduate School are written into that file; page size, line spacing, appropriate placement of captions for tables and figures, etc. Revisions by Hongcheng Ni make it possible to use the (optional) `\usepackage{hyperref}` command to enable internal hyperlinks in the final PDF document. Other tasks of conforming to the requirements are left to other existing LaTeX packages. For example, a common problem is to insert graphics — figures and tables — into the body of the thesis. For this one should use the `graphicx` package, which is part of the standard TeX distribution. Likewise, the Grad School specs say that a large table may be displayed in landscape mode at reduced size, but its caption must also be in rotated position, in the same font and size as the normal text in the body of the thesis. To accomplish this, the user must invoke the `rotating` package, available online.

Figure 8.1 shows an image from a PDF file imported into this document using the `graphicx` package. The command `\usepackage{graphicx}`, which appears near the very top of the main LaTeX file, reads in this package which defines the `\includegraphics{}` macro.

7.1 Lists in `thesis` class

In `thesis` class (for Colorado University), lists are defined so that nested lists will be numbered or marked appropriately. First, an itemized (non-enumerated) list prefaces each item with a bullet. Nested itemized list use asterisks, then dashes, then dots. These lists are typed between

Figure 7.1: This diagram of a cylinder and various measurements and quantities was actually made using **xfig**, a freeware drawing program for Unix systems. Diagrams can be exported directly to PDF files, the preferred format for vector graphics. Vector graphics can be magnified indefinitely without degradation, whereas bitmap images (JPG and PNG) must be pretty high-resolution if you don't want them looking all pixellated when magnified.

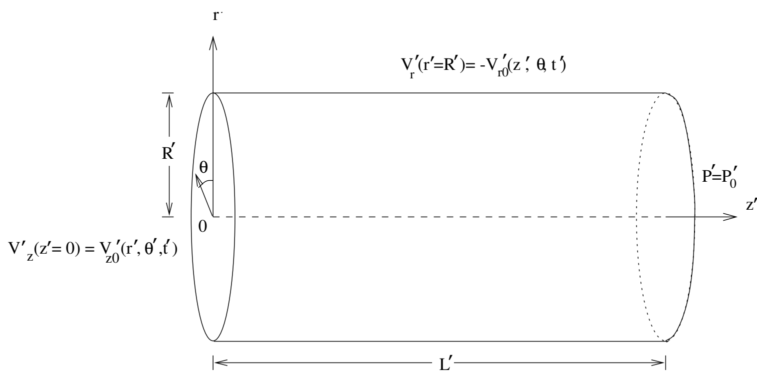
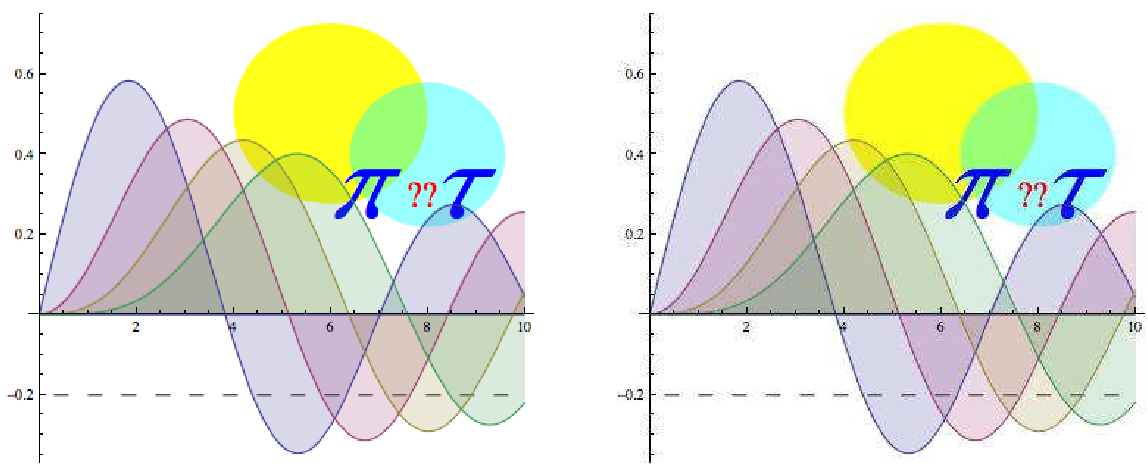


Figure 7.2: The JPEG bitmap format is great for photos but crummy for diagrams (including drawings, graphs, charts) because it can't gracefully handle sharp edges. Note the same bitmap image below from a PNG file and from a JPG file; the latter shows characteristic "ringing" at sharp edges – including text! Seriously, magnify and look closely at the JPG's awful lines and edges. Vector-format PDF is the best for diagrams, but if you must use a bitmap image, let it be PNG. (Left: file *drawing.png*. Right: file *drawing.jpg*.)



the `\begin{itemize}` and `\end{itemize}` commands.

- This is “itemized” item A.
- This is “itemized” item B.
- This is “itemized” item C.
  - ∗ This is “itemized” subitem A.
    - – This is “itemized” subsubitem A.
      - · This is “itemized” subsubsubitem A.
    - – This is “itemized” subsubitem B.
  - ∗ This is “itemized” subitem B.
- This is “itemized” item D.

Enumerated lists use the commands `\begin{enumerate}` and `\end{enumerate}`, and nested enumerations appear like this.

(1) This is “enumerated” item A.

(2) This is “enumerated” item B.

(3) This is “enumerated” item C.

  (a) This is “enumerated” subitem A.

    (i) This is “enumerated” subsubitem A.

      (i.a) This is “enumerated” subsubsubitem A.

    (ii) This is “enumerated” subsubitem B.

  (b) This is “enumerated” subitem B.

(4) This is “enumerated” item D.

The work presented here[1] is an extension of Lao? and Lao et al.?, fictional references that are in the bibliographic source file `refs.bib`.

Table 7.1: Here is an example of a table with its own footnotes. Don't use the `\footnote` macro if you don't want the footnotes at the bottom of the page. Also, note that in a thesis the caption goes **above** a table, unlike figures.

wave form	S (kVA)	P (kW)	Q^* (kVAr)	$D^\dagger$ (kVAd)
Fig. 8.1a	25.48	25.00	-2.82	4.03
Fig. 8.1b	25.11	18.02	-9.75	14.52
Table 2.1	24.98	22.26	9.19	6.64
Table 8.1	23.48	15.00	6.59	16.82
Fig. 2.1	24.64	22.81	-0.44	9.3

*kVAr means reactive power.
†kVAd means distortion power.

[1] Footnotes are handled neatly by LaTeX.

Chapter 8

Summary and Future Work

This sample document illustrates how to use the `thesis` class, originally written by John P. Weiss. Some requirements of the Graduate School are written into that file; page size, line spacing, appropriate placement of captions for tables and figures, etc. Revisions by Hongcheng Ni make it possible to use the (optional) `\usepackage{hyperref}` command to enable internal hyperlinks in the final PDF document. Other tasks of conforming to the requirements are left to other existing LaTeX packages. For example, a common problem is to insert graphics — figures and tables — into the body of the thesis. For this one should use the `graphicx` package, which is part of the standard TeX distribution. Likewise, the Grad School specs say that a large table may be displayed in landscape mode at reduced size, but its caption must also be in rotated position, in the same font and size as the normal text in the body of the thesis. To accomplish this, the user must invoke the `rotating` package, available online.

Figure 8.1 shows an image from a PDF file imported into this document using the `graphicx` package. The command `\usepackage{graphicx}`, which appears near the very top of the main LaTeX file, reads in this package which defines the `\includegraphics{}` macro.

8.1 Lists in `thesis` class

In `thesis` class (for Colorado University), lists are defined so that nested lists will be numbered or marked appropriately. First, an itemized (non-enumerated) list prefaces each item with a bullet. Nested itemized list use asterisks, then dashes, then dots. These lists are typed between

Figure 8.1: This diagram of a cylinder and various measurements and quantities was actually made using **xfig**, a freeware drawing program for Unix systems. Diagrams can be exported directly to PDF files, the preferred format for vector graphics. Vector graphics can be magnified indefinitely without degradation, whereas bitmap images (JPG and PNG) must be pretty high-resolution if you don't want them looking all pixellated when magnified.

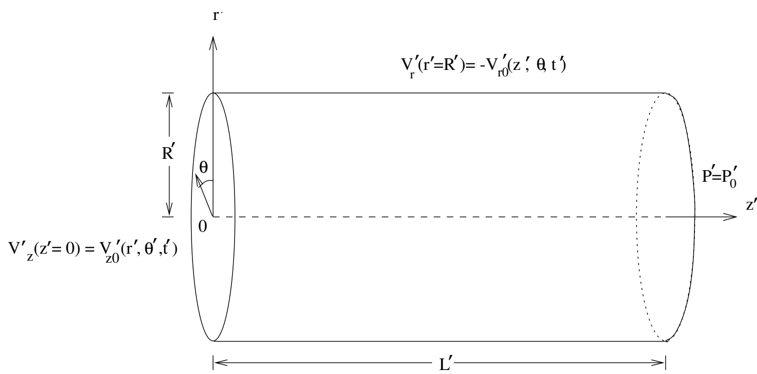
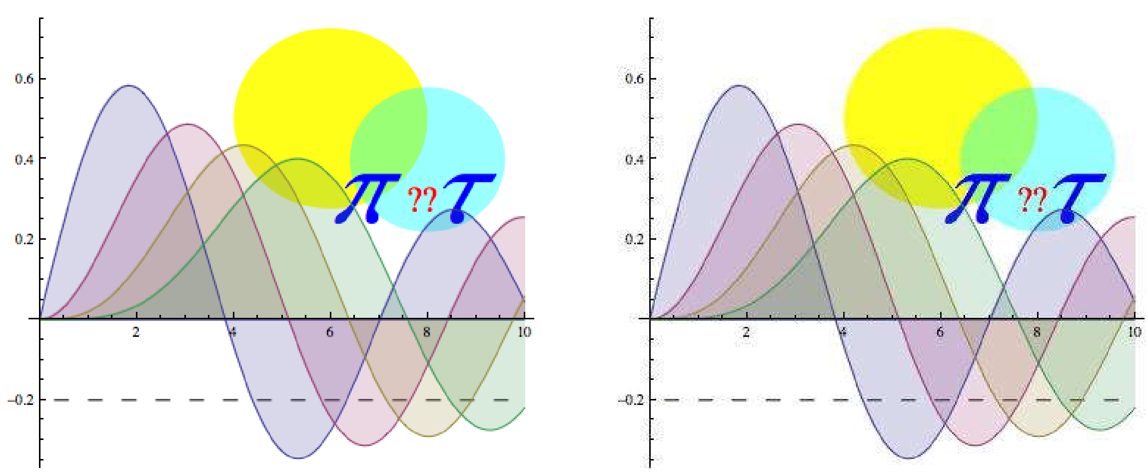


Figure 8.2: The JPEG bitmap format is great for photos but crummy for diagrams (including drawings, graphs, charts) because it can't gracefully handle sharp edges. Note the same bitmap image below from a PNG file and from a JPG file; the latter shows characteristic "ringing" at sharp edges – including text! Seriously, magnify and look closely at the JPG's awful lines and edges. Vector-format PDF is the best for diagrams, but if you must use a bitmap image, let it be PNG. (Left: file *drawing.png*. Right: file *drawing.jpg*.)



the `\begin{itemize}` and `\end{itemize}` commands.

- This is “itemized” item A.
- This is “itemized” item B.
- This is “itemized” item C.
    - ∗ This is “itemized” subitem A.
        - – This is “itemized” subsubitem A.
            - · This is “itemized” subsubsubitem A.
        - – This is “itemized” subsubitem B.
    - ∗ This is “itemized” subitem B.
- This is “itemized” item D.

Enumerated lists use the commands `\begin{enumerate}` and `\end{enumerate}`, and nested enumerations appear like this.

(1) This is “enumerated” item A.

(2) This is “enumerated” item B.

(3) This is “enumerated” item C.

  (a) This is “enumerated” subitem A.

    (i) This is “enumerated” subsubitem A.

      (i.a) This is “enumerated” subsubsubitem A.

    (ii) This is “enumerated” subsubitem B.

  (b) This is “enumerated” subitem B.

(4) This is “enumerated” item D.

The work presented here[1] is an extension of Lao**?** and Lao et al.**?**, fictional references that are in the bibliographic source file `refs.bib`.

Table 8.1: Here is an example of a table with its own footnotes. Don't use the `\footnote` macro if you don't want the footnotes at the bottom of the page. Also, note that in a thesis the caption goes **above** a table, unlike figures.

wave form	S (kVA)	P (kW)	Q^* (kVAr)	$D^\dagger$ (kVAd)
Fig. 8.1a	25.48	25.00	-2.82	4.03
Fig. 8.1b	25.11	18.02	-9.75	14.52
Table 2.1	24.98	22.26	9.19	6.64
Table 8.1	23.48	15.00	6.59	16.82
Fig. 2.1	24.64	22.81	-0.44	9.3

*kVAr means reactive power.
†kVAd means distortion power.

[1] Footnotes are handled neatly by LaTeX.

Bibliography

Andretta, V., Del Zanna, G., and Jordan, S. D. (2003). The EUV helium spectrum in the quiet Sun: A by-product of coronal emission? Astronomy and Astrophysics, 400(2):737–752.

Chen, P. F., Fang, C., and Shibata, K. (2005). A Full View of EIT Waves. The Astrophysical Journal, 622(2):1202–1210.

Chen, P. F., Wu, S. T., Shibata, K., and Fang, C. (2002). Evidence of EIT and Moreton Waves in Numerical Simulations. The Astrophysical Journal, 572(1):L99–L102.

Gilbert, H. R., Inglis, a. R., Mays, M. L., Ofman, L., Thompson, B. J., and Young, C. a. (2013). Energy Release From Impacting Prominence Material Following the 2011 June 7 Eruption. The Astrophysical Journal, 776(1):L12.

Imada, S., Hara, H., Watanabe, T., Kamio, S., Asai, A., Matsuzaki, K., Harra, L. K., and Mariska, J. T. (2007). Discovery of a Temperature-Dependent Upflow in the Plage Region during a Gradual Phase of the X-Class Flare. Publications of the Astronomical Society of Japan, 59(sp3):S793–S799.

Jin, M., Ding, M. D., Chen, P. F., Fang, C., and Imada, S. (2009). CORONAL MASS EJECTION INDUCED OUTFLOWS OBSERVED WITH HINODE /EIS. The Astrophysical Journal, 702(1):27–38.

Liu, W. and Ofman, L. (2014). Advances in Observing Various Coronal EUV Waves in the SDO Era and Their Seismological Applications (Invited Review). Solar Physics, 289(9):3233–3277.

Mason, J. P., Woods, T. N., Caspi, A., Thompson, B. J., and Hock, R. A. (2014). MECHANISMS AND OBSERVATIONS OF CORONAL DIMMING FOR THE 2010 AUGUST 7 EVENT. The Astrophysical Journal, 789(1):61.

Muhr, N., Veronig, A. M., Kienreich, I. W., and Temmer, M. (2011). Analysis of Characteristic Parameters of Large-Scale Coronal Waves Observed by the Solar-Terrestrial Relations Observatory/Extreme Ultraviolet Imager. The Astrophysical Journal, 89:89.

Pohjolainen, S., Vilmer, N., Khan, J. I., and Hillaris, A. E. (2005). Early signatures of large-scale field line opening Multi-wavelength analysis of features connected with a halo CME event. Astronomy & Astrophysics, 434:329–341.

Robbrecht, E. and Wang, Y.-M. (2010). The Temperature-Dependent Nature of Coronal Dimmings. The Astrophysical Journal Letters, 720:88–92.

Schrijver, C. J. and Higgins, P. A. (2015). A Statistical Study of Distant Consequences of Large Solar Energetic Events. Solar Physics, 290(10):2943–2950.

Woods, T. N., Hock, R. A., Eparvier, F. G., Jones, A. R., Chamberlin, P. C., Klimchuk, J. A., Didkovsky, L., Judge, D., Mariska, J. T., Warren, H. P., Schrijver, C. J., Webb, D. F., Bailey, S. M., and Tobiska, W. K. (2011). New Solar Extreme-Ultraviolet irradiance Observations During Flares. The Astrophysical Journal, 739:59.

Zhukov, A. N. and Auchère, F. (2004). On the nature of EIT waves, EUV dimmings and their link to CMEs. Astronomy & Astrophysics, 427:705–716.

Appendix A

Coronal Dimming Event List and Ancillary Data

About appendices: Each appendix follow the same page-numbering rules as a regular chapter; the first page of a (multi-page) appendix is not numbered. By the way, the following are supposedly authentic answers to English GCSE exams!

(1) The Greeks were a highly sculptured people, and without them we wouldnt have history. The Greeks also had myths. A myth is a female moth.

(2) Actually, Homer was not written by Homer but by another man of that name.

(3) Socrates was a famous Greek teacher who went around giving people advice. They killed him. Socrates died from an overdose of wedlock. After his death, his career suffered a dramatic decline.

(4) Julius Caesar extinguished himself on the battlefields of Gaul. The Ides of March murdered him because they thought he was going to be made king. Dying, he gasped out: Tee hee, Brutus.

(5) Nero was a cruel tyranny who would torture his subjects by playing the fiddle to them.

(6) In midevil times most people were alliterate. The greatest writer of the futile ages was Chaucer, who wrote many poems and verses and also wrote literature.

(7) Another story was William Tell, who shot an arrow through an apple while standing on his sons head.

(8) Writing at the same time as Shakespeare was Miguel Cervantes. He wrote Donkey Hote. The next great author was John Milton. Milton wrote Paradise Lost. Then his wife died and he wrote Paradise Regained.

(9) During the Renaissance America began. Christopher Columbus was a great navigator who discovered America while cursing about the Atlantic. His ships were called the Nina, the Pinta, and the Santa Fe.

(10) Gravity was invented by Issac Walton. It is chiefly noticeable in the autumn when the apples are falling off the trees.

(11) Johann Bach wrote a great many musical compositions and had a large number of children. In between he practiced on an old spinster which he kept up in his attic. Bach died from 1750 to the present. Bach was the most famous composer in the world and so was Handel. Handel was half German half Italian and half English. He was very large.

(12) Soon the Constitution of the United States was adopted to secure domestic hostility. Under the constitution the people enjoyed the right to keep bare arms.

(13) The sun never set on the British Empire because the British Empire is In the East and the sun sets in the West.

(14) Louis Pasteur discovered a cure for rabbis. Charles Darwin was a naturalist who wrote the Organ of the Species. Madman Curie discovered radio. And Karl Marx became one of the Marx brothers.

Appendix B

MinXSS CubeSat Mass/Power Tables

(Data, Stardate 1403827) (A one-page chapter — page must be numbered!) Throughout the ages, from Keats to Giorchamo, poets have composed "odes" to individuals who have had a profound effect upon their lives. In keeping with that tradition I have written my next poem . . . in honor of my cat. I call it. . . Ode. . . to Spot. (Shot of Geordi and Worf in audience, looking mystified at each other.)

Felus cattus, is your taxonomic nomenclature
an endothermic quadruped, carnivorous by nature?
Your visual, olfactory, and auditory senses
contribute to your hunting skills, and natural defenses.
I find myself intrigued by your sub-vocal oscillations,
a singular development of cat communications
that obviates your basic hedonistic predilection
for a rhythmic stroking of your fur to demonstrate affection.
A tail is quite essential for your acrobatic talents;
you would not be so agile if you lacked its counterbalance.
And when not being utilized to aid in locomotion,
It often serves to illustrate the state of your emotion.

(Commander Riker begins to applaud, until a glance from Counselor Troi brings him to a halt.) Commander Riker, you have anticipated my denouement. However, the sentiment is appreciated. I will continue.

O Spot, the complex levels of behavior you display
connote a fairly well-developed cognitive array.
And though you are not sentient, Spot, and do not comprehend
I nonetheless consider you a true and valued friend.

Appendix C

MinXSS Thermal Model Parameter Tables

(Data, Stardate 1403827) (A one-page chapter — page must be numbered!) Throughout the ages, from Keats to Giorchamo, poets have composed "odes" to individuals who have had a profound effect upon their lives. In keeping with that tradition I have written my next poem . . . in honor of my cat. I call it. . . Ode. . . to Spot. (Shot of Geordi and Worf in audience, looking mystified at each other.)

> Felus cattus, is your taxonomic nomenclature
> an endothermic quadruped, carnivorous by nature?
> Your visual, olfactory, and auditory senses
> contribute to your hunting skills, and natural defenses.
> I find myself intrigued by your sub-vocal oscillations,
> a singular development of cat communications
> that obviates your basic hedonistic predilection
> for a rhythmic stroking of your fur to demonstrate affection.
> A tail is quite essential for your acrobatic talents;
> you would not be so agile if you lacked its counterbalance.
> And when not being utilized to aid in locomotion,
> It often serves to illustrate the state of your emotion.

(Commander Riker begins to applaud, until a glance from Counselor Troi brings him to a halt.) Commander Riker, you have anticipated my denouement. However, the sentiment is appreciated. I will continue.

> O Spot, the complex levels of behavior you display
> connote a fairly well-developed cognitive array.
> And though you are not sentient, Spot, and do not comprehend
> I nonetheless consider you a true and valued friend.