Introduction to Lab #2

Information and Documents on the Class Homepage

▾ 4th Week (Oct 3~)
Lab2 Document (Due: 4pm, Oct 31)
Link to Group Membership and Policy
Reference Paper on OH Sky Lines
Document on "How to write reports in AST326-326"
Example Lab Report from Previous AST325-326
Lab Report Marking Rubric

Lab Group Membership

AST325

Group A: Jiaren Tan, Sandy Chen, Peikun Guo, Chenguang Kuang, Rain Wang

Group B: Isabella Armstrong, Katerina Benevides, Nicholas Evans, Matthew Kustec, Ainsley Poles

Group C: Xinpeng Xing, Wanshi(Sia) Liang, Colin McCurdy, Jacob Alstrup, Rohan Ashar

Group D: Habiba Zaghloul, Kate Wagner, Ruth Huang, Theresa Drobnik, Anthony Cheung

Group E: Ava Spurr, Phoenix Paing, Danica Bortenstein, Anson Chow, Shashvat Varma

Group F: Ali Ahmed, Ziyyad Ali, Emily Crawley, Utkarsh Gupta, Jonathan Isenberg

Group G: Anntara Khan, Nenguro Kuang, Timothy Ma, Kahah Smith

Group H: Victoria Spada, Morgan Watson, Jessie Wu, Maximilian Zabrodski

AST326

Group Z: Jessica Tran, Adi Khandelwal, Huson Liang, Inaki Fonso Reyes, Diana Korotun

Group Y: Siwoo Lee, Alexander Spencer London, Mayank Shenoy, Jillian Henkel, Sam Lakerdas-Gayle

Group X: Ernest Chang , Fuzo Yoshikawa , Patrice Yee, Sean Yin, Ethan Shore

Group W: Connor MacKeigan, Arianna Lasinski, Kyoka Stone, Christopher Collings, Andrew Li

Group V: Maxwell Fine, Raina Irons, Zara Zaman, Tory Liu, Louie Lu

Group U: Nan Jiang, Hannah Guo, Peter Lyu, Aryamann Rao, Ivan Tockovski, Jimmy Yang

Note:

- If you don't see your name, you need to contact the instructor ASAP.
- The group membership may still change as the class evolves.
- Most of the groups have 5 students other than the groups G, H (which have 4 students) and U (which has 6 students).
- If you don't know the emails of your labmates, you should contact the instructor.
- **Although you collaborate with your labmates in the data reduction, analysis, modelling, discussion, etc, the final products that you provide in your lab reports must be your own. You need to write Python codes yourself (otherwise, you don't really learn coding) and produce your own plots/figures included in your report. Of course, you need to write your own report.**

<u>Group-led Discussion Policies and Schedule (under development)</u>

Date	Groups	Discussion topics to be included (bold fonts: must be included)
Oct 17	A, B, C, D	**Wavelength solution of 1-d Neon spectrum, Blackbody temperature**, Wavelength solution of 2-D OH skylines, etc.
Oct 24	E, F, G, H	**Wavelength solution of 2-d OH skylines, Doppler shift measurements of [Fe II] lines**, Reduction of spectra from the campus telescope, etc.

Note:

- Each group has 7 minutes of group-led discussion time. This includes the presentation and follow-up Q/As. A typical combination is 4-5 minutes of presentation and 2-3 minutes of a Q/A session.
- **All the groups to present need to send their presentation file (in PDF or PowerPoint format) to the instructor (moon@astro.utoronto.ca) by 3pm on the presentation day.** Extra time during the class caused by not sending the presentation file in advance will be taken away from the 7 minutes.
- Group-led discussion should start with a short summary of the group's progress, clearly showing that the group has achieved the minimum progress milestones above (and potentially more). And then you can focus on some specific issues that you've encountered and/or overcome.
- The presentation/discussion time should be equally shared among the group members.
- You can find the following information in the class syllabus about Group-led discussions:

4.3 Group-led Discussions for Lab 2 and 3: On intermediate dates between the start and completion of a given lab, we may have presentations and discussions, termed "Group-led discussions," by lab groups. Each week, a different lab group will facilitate this discussion and presentation. When your group is tasked with leading the discussion, you are required to meet with your team prior to class to decide on a list of discussion topics. These topics may include common sticking points, potential sources of error, and avenues for exploration outside of those in the lab handout. ***You will be graded on the quality of your chosen discussion topics, the unique insights you bring to the discussion, your presentation style, and the degree to which you stimulate class participation.*** *More information will be given during the class on this.*

Lab #2 "Introduction to Spectroscopy"

Lab report is due at 4pm on Oct 31 (Monday). Submission on Quercus.

Of all objects, the planets are those which appear to us under the least varied aspect. We see how we may determine their forms, their distances, their bulk, and their motions, but we can never know anything of their chemical or mineralogical structure; and, much less, that of organized beings living on their surface...
Auguste Comte, The Positive Philosophy, Book II, Chapter 1 (1842)

1. Overview and Goals

Spectroscopy is a fundamental tool used by all physical sciences. For astrophysicists, spectroscopy is essential for characterizing the physical nature of celestial objects and the universe. Astronomical spectroscopy has been used to measure the chemical composition and physical conditions (temperature, pressure, and magnetic field strength) in planets, stars, and galaxies, as well as their velocities. One of the key aspects of spectroscopy is wavelength calibration. In this lab, you will conduct two types of wavelength calibrations, one with Neon lamp for 1-dimensional spectra and the other with OH telluric sky lines on a 2-D dispersed image, to determine the temperature of a blackbody spectrum and velocity of ionized iron gas from a supernova explosion. In addition to the wavelength calibration, you will attend a campus telescope session to have an experience in obtaining spectra of stars (or planets) and reducing them.

Schedule: This is a four-week lab between October 3 and October 31. There will be no class on October 10 for Thanksgiving. Group-led discussions will happen on October 17 and 24. (More information on Group-led discussion will be given separately.)

2. Key Steps

1. Understand how spectroscopy is done, especially wavelength calibration.
2. Obtain a wavelength solution (= mapping solution between the detector pixels and wavelengths) of Neon spectrum taken with a spectrograph equipped with a 1-dimensional detector (= linear detector) using the known wavelengths of Neon lines.
3. Apply the wavelength solution to determine the temperature of a perfect blackbody spectrum assumed to have been taken with the same spectrograph.
4. Obtain a wavelength solution of OH sky lines for a 2-dimenaional dispersed image in the near infrared.
5. Apply the wavelength solution to obtain the velocity of ionized iron gas by comparing the intrinsic wavelength of [Fe II] 1.644 micron and the measured wavelength.
6. Attend one of the telescope sessions at the campus observatory to obtain spectra of bright astronomical objects (e.g., Vega, Jupiter, etc).
7. Reduce the data of the bright objects that you obtained at the campus telescope to extract their spectra and discuss the nature of the observed objects on the spectra.
8. Write a report on your work. (See the document on lab report writing.)

2.1 Wavelength solution of 1-dimisional Neon spectrum and blackbody temperature

Figure 1 shows a simple laboratory setup for spectroscopy: *the left panel shows the entire setup, while the right panel shows the interior of the spectrograph USB4000*. Photons from the light source (e.g., Neon lamp, blackbody source) are transferred to the entrance of the USB4000 spectrograph by optical fiber. Inside the spectrograph, the entered photons are dispersed by grating (component ⑤) before they are recorded in 1-dimensional detector (component ⑨). The detector has **1024 pixels**. (Note that there are other optical components inside the spectrograph that reflect, collimate, and focus the photons.) The spectrograph is configured to be sensitive to photons roughly in the range of 500–800 nm.

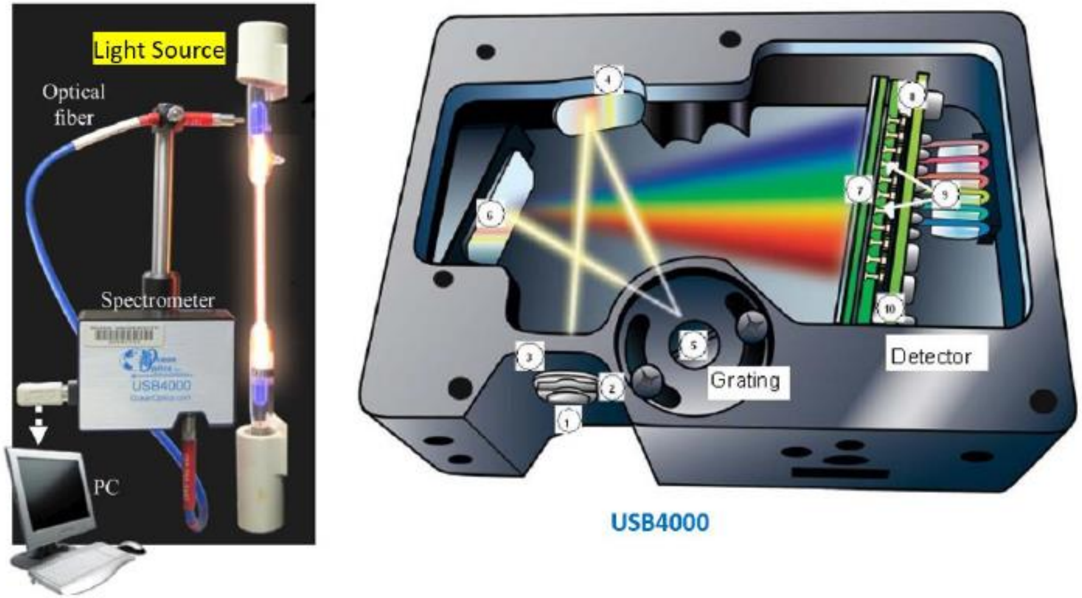


Figure 1. (Left) Experimental setup for laboratory spectroscopy using USB4000 spectrograph. (Right) Internal configuration of the USB4000 spectrograph.

The final goal of this experiment is to determine the temperature of a blackbody source by analyzing its spectrum obtained with the same spectrograph. In the folder linked to the following address

https://drive.google.com/drive/folders/1rEH9VUJx6dikh-P9YDvAWjA6OfMf1Ejf?usp=sharing

you can find a file named "**Group_?_BB.dat**" which is the spectrum of the blackbody source for your group. If you plot the spectrum, it looks like the following

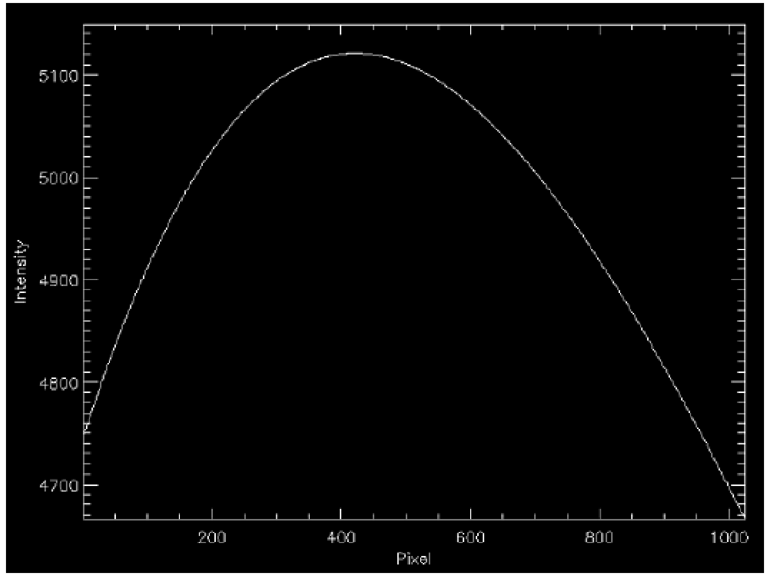


Figure 2. Example spectrum of the blackbody source obtained with the spectrograph.

In order to estimate the temperature of your blackbody source, you need to obtain the wavelength solution since temperature determines the wavelength depednecy of a blackbody spectrum. In the same web page above, you can find a file named "**Ne_calib.dat**," and it is a spectrum of a Neon lamp obtained with the same specrtrograph. Its spectrum looks like the following

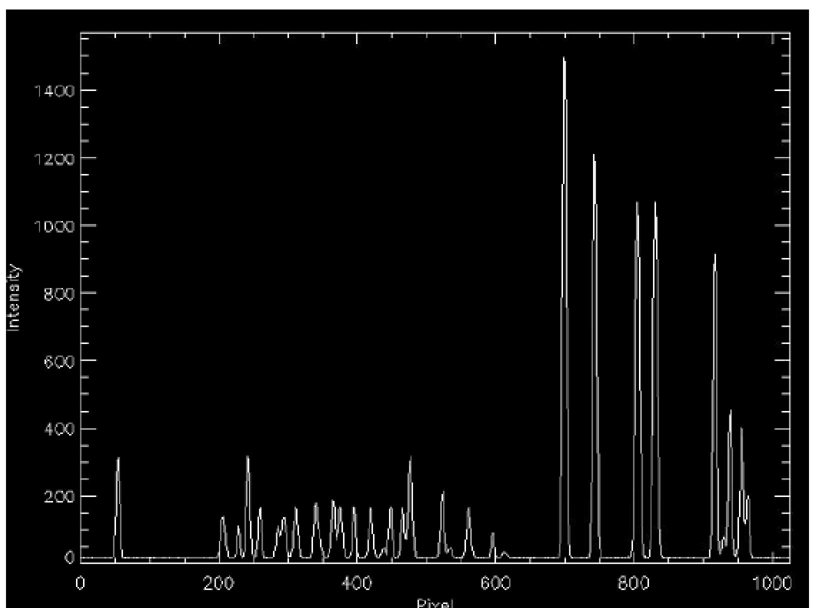


Figure 3. Spectrum of a Neon lamp in "Ne_calib.dat."

Neon has many line transitions in the wavelength range of 500–800 nm as listed in Figure 4,

511.367	640.225
511.650	650.653
540.056	653.288
576.441	659.895
582.015	667.828
585.249	671.704
588.189	692.947
594.483	703.241
597.553	717.394
602.000	724.512
607.433	743.890
609.616	747.244
612.884	748.887
614.306	753.577
616.359	754.404
621.728	837.761
626.649	849.536
630.479	878.375
633.442	1117.752
638.299	1152.275

Figure 4. Wavelengths (in nm) of bright Neon lines. (The source is https://www.oceaninsight.com/globalassets/catalog-blocks-and-images/manuals--instruction-old-logo/wavelength-calibration-products-v1.0_updated.pdf)

and the relative strengths of these lines are shown in Figure 5.

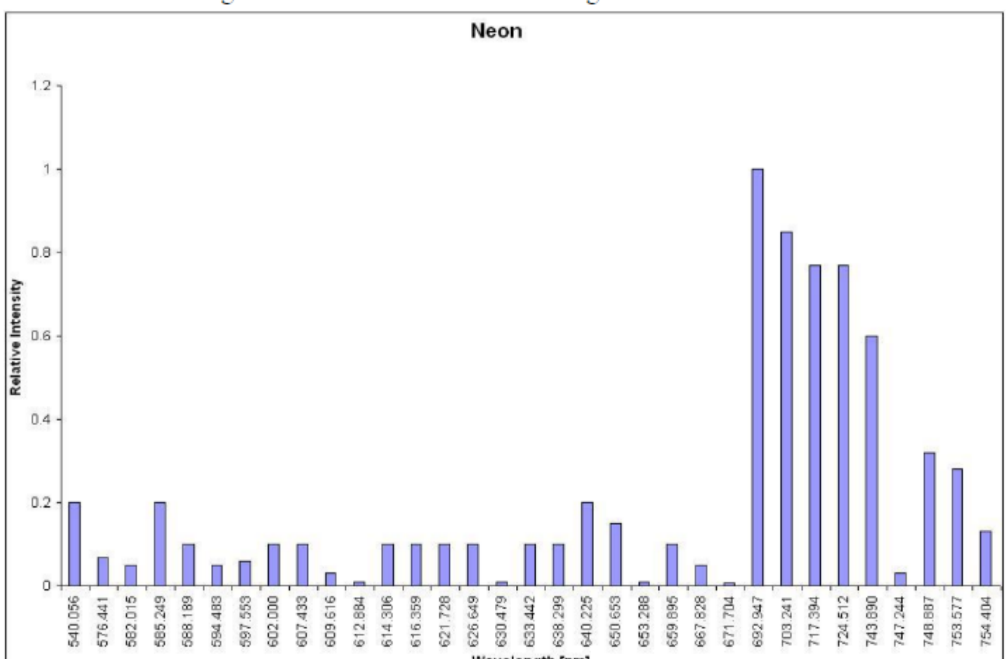


Figure 5. Relative intensities of the Neon lines above. This plot is from the same source as Figure 4.

Now you can obtain the wavelength solution of the spectrum in Figure 3 and determine the temperature of your blackbody. You need to follow the following steps for this.

1. Identify the wavelengths of the Neon lines in Figure 3 as many as possible using the information in Figure 4 and 5. Some nearby lines may overlap.
2. Determine the *centroids* (i.e., pixel positions) of the lines. (There could be many different ways to do it.)
3. Obtain a linear least square fitting between the pixel positions of the Neon lines that you identified and their wavelengths. How good is the fitting? The linear fitting is the wavelength solution.
4. Apply the wavelength solution that you obtained in step 3 above to your blackbody spectrum. Now you know the wavelengths of the blackbody spectrum. What is the temperature of your blackbody?

2.2 Wavelength solution of 2-dimisional dispersed image using OH sky lines and the velocity of ionized iron gas

As we learned in the class, one convenient way to obtain a wavelength solution in the near-infrared waveband is to use the OH sky telluric emission lines. So, let's apply this method to real data. In the same web page above, you can download a file named "**Near-Infrared.fits**" which is a real data file of a 2-dimensional dispersed image of ionized iron gas (= Fe II) from a supernova explosion saved in the FITS (= Flexible Image Transport System) file format. (The FITS format is the standard data format in astronomy.) The file looks like the following if you use a FITS viewer program like DS9 available at https://sites.google.com/cfa.harvard.edu/saoimageds9. *(Note that adjusting scale and changing contrast is important to see images in DS9. You can try ZScale and move mouse on the image with the right button pressed to adjust contrast.)*

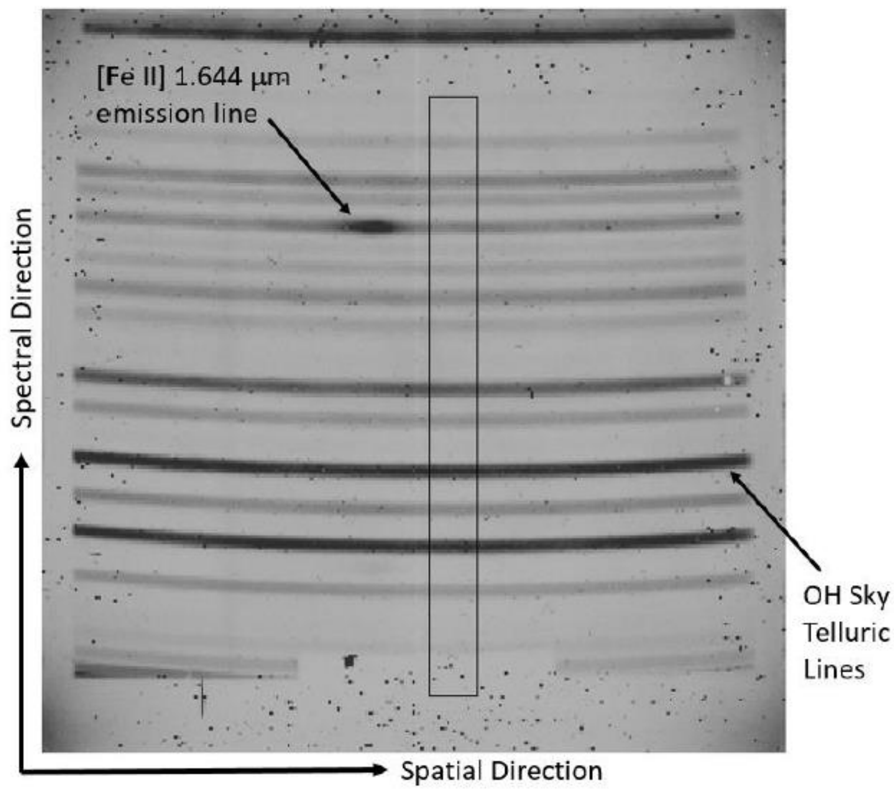


Figure 6. Dispersed image of ionized iron gas from a supernova explosion.

You can see that it is dominated by the OH sky lines, but there exists clear [Fe II] 1.644 micron emission almost overlapping with one of the OH lines. Figure 7 is a spectrum of the OH lines in Figure 6 created by using the area in the rectangle Figure 6 by taking the median value of each row in the rectangle.

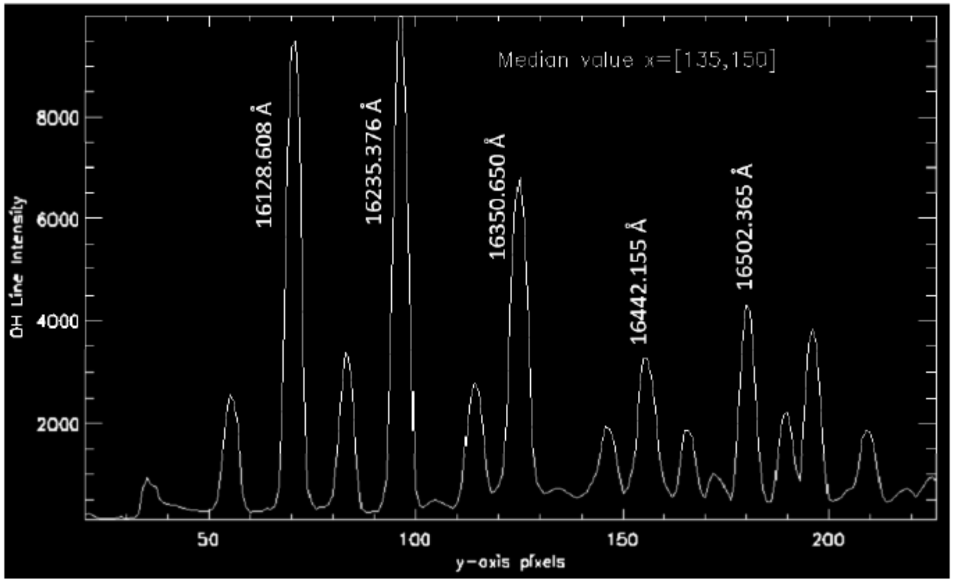


Figure 7. Spectrum of the OH telluric sky lines in Figure 6. Five bright lines are identified with their wavelengths.

Five bright OH sky lines are easily identifiable using the relative intensities of the known OH lines in Figure 8.

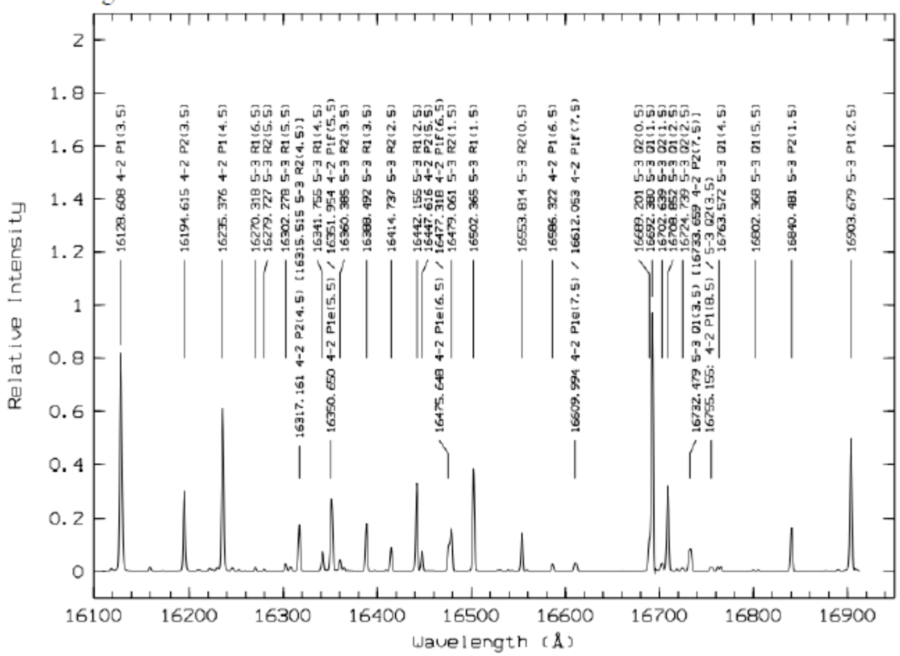
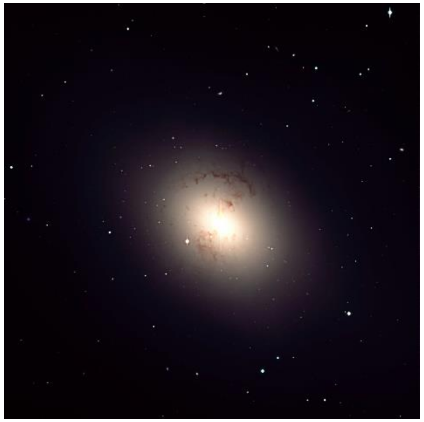


Figure 8. Relative intensities of known the OH telluric sky lines in the wavelength range of 1.610-1.690 micron from the paper of Rousselot et al. 2000. (Note that this paper is linked in the class web page.)

How to find a centroid?



$$x_{\rm cent} = \frac{\sum x_i I_i}{\sum I_i}, \;\; y_{\rm cent} = \frac{\sum y_i I_i}{\sum I_i}$$

I_i : pixel intensity

- The summation, i, runs over a region in the vicinity of the object.
- Note that this is a **weighted average** of positions with the weight determined by pixel intensities.
- This can be applied to the determination of the center of 1-D line profiles.

How to find a centroid?

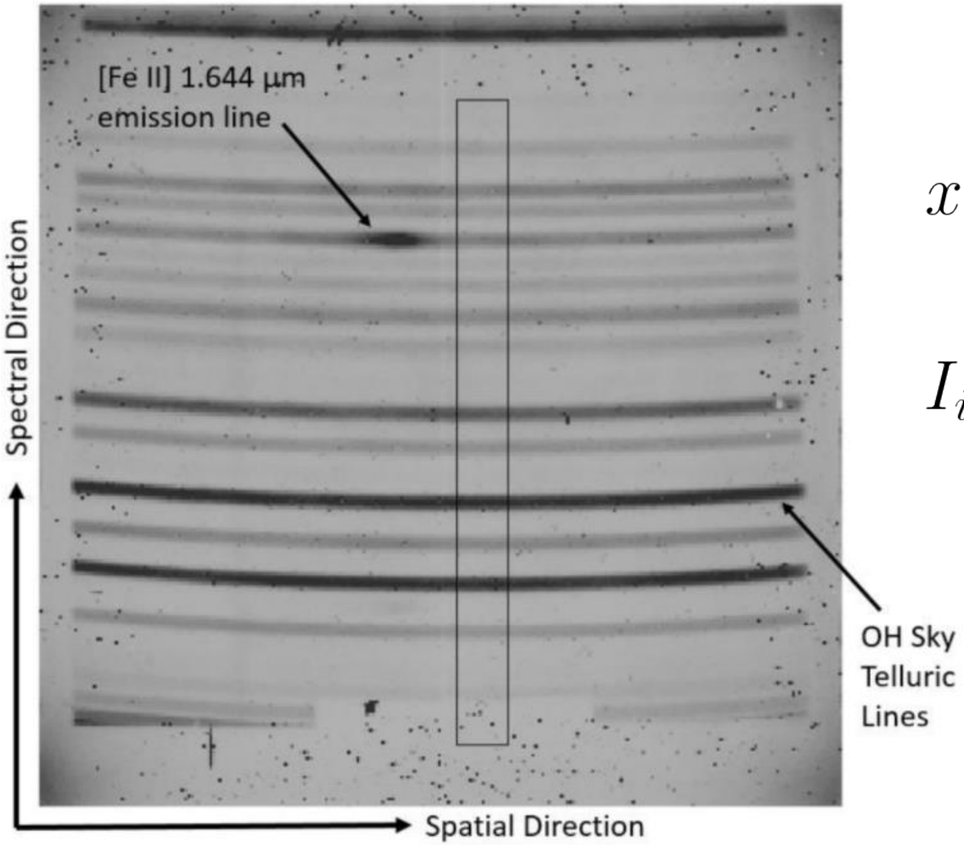


Figure 6. Dispersed image of ionized iron gas from a supernova explosion.

$$x_{\mathrm{cent}} = \frac{\sum x_i I_i}{\sum I_i}, \ y_{\mathrm{cent}} = \frac{\sum y_i I_i}{\sum I_i}$$

I_i : pixel intensity

Now you can calculate the velocity of the iron gas in Figure 6 using the observed wavelength of the [Fe II] 1.644 micron line. You need to follow the following steps for this:

1. In addition to the five already identified OH lines, identify as many more OH lines as possible from a region near the [Fe II] emission (e.g., the rectangular box) in Figure 6.
2. Determine the central positions (in terms of y-axis pixel numbers) of the identified lines, and then conduct polynomial fitting of the central positions to the wavelengths. This gives a wavelength solution, which is mapping between the pixel positions and wavelengths. You can choose the degree of the polynomial fit between 1 (= linear least fit) and 3.
3. How good is your wavelength solution, or what is the uncertainty of your wavelength solution?
4. Determine the central position of the [Fe II] emission in Figure 6 in y-axis, and then apply the wavelength solution that you already obtained above using OH sky lines to estimate the wavelength of [Fe II] emission in Figure 6. The intrinsic wavelength of the [Fe II] 1.644 μm line emission is 1.6439981 μm. What's the velocity of the gas emitting the [Fe II] emission in Figure 6?

3. Nighttime Observing with the Campus Telescope

We will conduct real astronomical observations to obtain spectra of bright objects (e.g., Vega, Jupiter, Albireo, Scheat, etc) using a spectrograph on the campus telescope located on the 16^{th} floor of the McLennan Physics tower. Michael Williams (williams@astro.utoronto.ca), who is in charge of the lab equipment and telescope operation, will be there to set up the telescope and spectrograph and help you collect your data. We will use *Shelyak Alpy* spectrograph for the observations. The spectrograph information is available from this link:

https://www.shelyak.com/produit/alpy-600/?lang=en

We will extract spectra of the observed objects after applying the standard data reduction process, including subtraction of dark (bias), flat-fielding, and wavelength calibration. **A guideline of how to conduct the data reduction process will be given during lecture hours. Also, the details of the logistical issues of the nighttime observing session will be posted and explained later on the calss homepage and during lecture hours.**

(Tentative) Nighttime Observing Schedule/Plan

Oct 17 (Mon, 8:15–9:30pm)	A
Oct 17 (Mon, 9:45–11:00pm)	B
Oct 18 (Tue, 8:15–9:30pm)	C
Oct 18 (Tue, 9:45–11:00pm)	D
Oct 19 (Wed, 8:15–9:30pm)	E
Oct 19 (Wed, 9:45–11:00pm)	F
Oct 20 (Thr, 8:15–9:30pm)	G
Oct 20 (Thr, 9:45–11:00pm)	H

Oct 24 (Mon, 8:15–9:30pm)	Z
Oct 24 (Mon, 9:45–11:00pm)	Y
Oct 25 (Tue, 8:15–9:30pm)	X
Oct 25 (Tue, 9:45–11:00pm)	W
Oct 26 (Wed, 8:15–9:30pm)	V
Oct 26 (Wed, 9:45–11:00pm)	U
Oct 27 (Thr, 8:15–9:30pm)	Open
Oct 27 (Thr, 9:45–11:00pm)	Open

Open: For the students who get a special permission to attend.

(Tentative) Nighttime Observing Schedule/Plan

- The nighttime observing sessions for spectroscopy is regardless of the weather condition.
- In the case that weather condition is poor, you will still have a chance to see how the operation is made.
- The standard data set will be distributed at the beginning of the sessions.
- Each group can choose to reduce the standard data set or the data that it has obtained. (The letter is more desirable.)
- The attendance will be checked.
- More information will be given before the start of the sessions.

Lab 2 report needs to be written in a paper-style form!

Writing a lab report

An experiment is only finished when you have written up your findings, so in some sense writing your lab report is the most important step. Your lab report must communicate your findings clearly and convincingly—the purpose of this document is to help you accomplish these goals.

1. Lab Report Contents

A lab report is a written description of your activities and findings that comprises:

- The title of the experiment.
- The date, your name, email address, and other contact information. Include the names of your lab group partners in the introduction with a description of any division of labor that occurred.
- An **Abstract** that summarizes the objectives, methods, and principal conclusions and results of your experiment.
- An **Introduction** section that outlines and motivates the problem you are exploring and any necessary background material.
- A section on **Data** or **Observations** that give a description of the origin of the data. *If you acquired the data*, describe how and when the data have been acquired with a specific description of the equipment that you used and information relevant to the experiment (time, date, personnel involved). There is no need to quote extensively from lab handouts. This section would include a log or summary of observations (e.g., a table). Also, include a description of any anomalies or systematic errors that might be present in the data. *If the data were given to you*, just provide a simple statement for it.
- A section on **Data Reduction & Methods** that describes the data reduction methods and algorithms. Explain what statistical methods were used to analyze or combine the data into your final results. Describe how you estimated the uncertainty in data.
- A section on **Data Analysis & Modelling, which performs a comparison of the results,** achieved with theoretical expectations and an exploration of any deviations. This section outlines the analysis techniques used in the experiment and any models that were used to deduce the results and conclusions of the experiment.
- A **Discussion** section explores the meaning of your experimental results and their impact and importance. The discussion section explores the results and experimental setup with evidence-based critical thinking and deduction. This section is where you discuss the limitations of your experiment and error analysis and future work that would aid in this experiment or other experiments.
- A summary of **Conclusions** that synthesize the results and interpretation.
- An **Appendix** section can be used to include information on the reductions or analysis that would otherwise clutter the whole of the paper. It is often used to put essential pieces of code or detailed descriptions of the experiment. The key point of an appendix is that it gives more detail to the reader if needed, but if it was removed, it should never impact the flow or purpose of the whole paper.

ASTRO 325/6 lab reports should not exceed **ten pages** (including tables and figures.) These ten pages do not include appendix sections that include key portions of your code used in your reductions and analysis. Use **single spaced lines and 12-point Times font and 1-inch margins**. Please print your reports using the duplex option so that both sides of the paper are used.

2. Getting Started

A blank page can be intimidating. Always start with an outline—you can use the one above in §1. When you have sketched an outline, you have a map of where you are going and a way to estimate how much time and effort will be needed to finish your task. The outline will also help you figure out if you have forgotten any important steps. Here are some ideas to help you get started and follow through to a satisfying conclusion.

- Set out your thoughts in an outline that organizes and directs the logical flow from introduction to conclusions.
- Some people write outlines and then fill in the details as they proceed: others may or may not follow the outline, or even consult it as they write; however, thinking through the structure and logic of your report will help focus your writing and lead to text that is easier to read. The first outline does not have to be complete—you can refine and expand it as you proceed.
- When you have an outline, you do not have to work sequentially from start to finish. You can start the outline before you complete the experiment. Even if you do not know what your conclusions are, you can still write a bullet that says "Conclusions."
- Think before you write! Clear thinking precedes clear writing. The clearer the ideas are in your head, the clearer they will be on the page. Thinking through your report should leave you with a solid understanding of what you want to say.
- Be explicit. A lab report is not a drama or a mystery where the story is resolved at the end. Never assume that the reader knows what you mean or where you are going. State your objectives and methods early on.
- State the principal results, both the intermediate ones and the final ones. Results are not just a table of numbers—describe the results in the text. Although a table may contain the actual answer, the reader will need help interpreting these results—hence the need for a description. We do not just want the answer: we want to see how you got there! You are writing for a critical (but not antagonistic) reader. You need to convince the reader that at each step you have likely done the right thing. Finally, never quote a number without stating the uncertainty and the units.
- Get your lab partners to read your report. Don't be proud. Remember, you are not just writing for yourself.

3. Style of Lab Report

A lab report is a narrative recording your activities. In a lot of writing style is an important consideration. Clarity trumps style in scientific writing; the clearer your report, the easier it will be for the reader to understand and follow your logic and writing. If you cannot explain what you have done clearly it probably means that you do not understand it either—and you certainly will not convince anyone else that you know what you are talking about. Some tips for clear writing include:

- Work from a plan or outline (see §2). You may find it helpful to flush out each item in your outline into several concrete subtopics. Each topic in the outline will likely deserve a section heading in your report. Use subsections to refine your direction and purpose.
- Flush out your thoughts into paragraphs. Use a topic sentence to focus each paragraph so that reader knows what is coming next.
- Keep it simple. Write to express, not to impress! This means writing in short, simple sentences using common vocabulary and syntax. Use simple verbs and place them next to their subjects. Do not get tied down in complex clauses or language that may be ambiguous.

- Brevity enhances clarity. Try to convey the maximum information in the minimum number of words. Avoid wordiness—eliminate unnecessary determiners and modifiers; change phrases into single words; change unnecessary that, who, and which clauses into phrases; use active rather than passive verbs; replace circumlocutions with direct expressions. Watch out for weasel words and phrases, e.g., "it is known that… ," "experience shows … ." You can find examples at:

  http://owl.english.purdue.edu/owl/resource/572/01/

  These techniques will give you more room to convey important information.
- Read what your write and seek criticism! Talk about your ideas with others at different stages of writing your report. Get your roommate, lab partner, TA, professor, friend, sibling, or parent, to read your work. Remember, you should be your own severest critic. Finish your lab report a day early (!) and then reread at least eight hours later.
- Conventional spelling and grammar counts. Use the spell checker.
- Avoid colloquial and informal language. Do not use contractions. Use acronyms sparingly, and define them on first use.
- Use bullets sparingly! Save them for making important points.

The most enjoyable way to learn about clear writing is to read those who practice it well. Here are some examples: Carl Sagan: "Cosmos"; "Demon Haunted World"; "Pale Blue Dot". Sagan remains one of the best and most influential science writers. John McPhee: "Annals of the Former World," "The Curve of Binding Energy." McPhee writes on many topics, but his essays and books on geology are superb. Other science writers to watch out for are Elizabeth Kolbert, Timothy Ferris, Richard Dawkins ("The Selfish Gene"; "The Blind Watchmaker"), Peter Galison ("Einstein's Clocks, Poincare's Maps"), Stephen Jay Gould ("Wonderful Life").

3.1 Equations, Figures, & Tables

Equations, figures, and tables are key elements of your report. In the main body of the report, show all relevant equations that you used. Equations should be labeled with equation numbers so that you can refer to them in the text. If you quote an equation without derivation, cite the reference. Use equations as you present the explanation of what you did. When you include an equation, the text preceding and following it will explain in words what the equation means. Equations are delineated by punctuation because they are part of sentences. For example, put a period after an equation if it ends a sentence. The text preceding or following an equation should always define any new symbolic quantities that are used for the first time.

Put tables and graphs in the text close to where they are referenced instead of attaching them at the end. This way it is easier to link the discussion to the data. Equations, figures, and tables must have numbers so that they can be referenced in the text. LaTeX allows automatic cross-referencing of document elements and update figure and equation numbers as new elements are added to the document.

Figures and tables must be labeled. Plots must have axis labels specifying quantity and units, and each figure and table should have a text caption that describes what is shown. A figure or table important enough to include in the report should be discussed and referred to by figure number in the body of the report. Figures and tables that are not mentioned in the text will be ignored.

It is preferable to do all figure labeling in Python, but not required. It is better to have a graph labeled by hand than not at all. You will find it faster and more accurate if you learn how to do this on the computer. Use the `MATPLOTLIB` options `TITLE`, `XTITLE` and `YTITLE`.

4. Collaboration & Cooperation

Collaboration is an essential aspect of lab work. Working together is also an effective way of learning. However, when it comes to writing your report and presenting your data, this must be an individual effort. You can and should discuss getting data and understanding it. But the act of presenting it must be your own effort. It is easy to cut and paste text and figures from one report to another: such activities will not be tolerated from either party. If you include a figure or plot generated by another student, you must give credit to the source in the figure caption. Presentation of figures from other students should only be used for the purpose of comparison with you own work.

Lab Report Rubric

All lab reports must be written by you alone – you may share measurements and analysis efforts from your team, but the overall content and presentation of your report should be unique. Each lab is worth a total of 75 points (pts):

- Overall Lab Quality & Participation [20 pts]:
    - Overall structure, Style, & Depth — 15 pts
    - Format — 5 pts
- Lab report sections [55 pts]:
    - Abstract — 5 pts
    - Introduction — 10 pts
    - Observations & Data (or Data) — 5 pts
    - Data reduction & Methods — 10 pts
    - Data analysis & Modeling — 10 pts
    - Discussion — 10 pts
    - Appendix (presentation of code and/or detailed analysis) — 5 pts

The following tables explain the grading schemes for lab reports. Please review each table so you are familiar with what is expected of you.

Overall Structure & Style [15 pts]	
15	The lab report reads as a narrative describing the group's and individual's activities. The overall goal and methods are clear from the beginning and serve as a key driver throughout the text. The report follows a logical structure on all scales, from sentences, to paragraphs, to sections, to subsections, and conveys the maximum amount of information in the minimum number of words. The activities described demonstrate initiative and creativity on the part of the individual.
12	The overall structure of the report, including the experimental goals and methods, are clear throughout, though perhaps uninspiring. The text is mostly clear, but the balance between sections may be slightly off, or some phrases may be awkward. The report is complete but contains no new or surprising insights.
9	The report as a whole contains significant organizational flaws. The experiment purpose may be buried, or key results may be inadequately described. The text may not flow well, or may be confusing at times.
6	The lab report is poorly structured. The experimental purpose may be unclear. Key figures or tables may be present but without explanation.
3	Organization and logical structure are absent. The experimental purpose is unclear, and the lab is incomplete.

Format [5 pts] – Each column is the total # points for each topic	
1	Contains title, date, name, contact information, lab group, and any division of labor.

1	Does not exceed 10 pages (including tables and figures).
1	Minimum 10-point font is used.
1	Proper spelling is used throughout the report
1	Proper grammar is used throughout the report. Complete sentences are required, unless a list or table is identified. Grammar and spelling will be considered in the overall structure & style of the report rubric as well.

Abstract [5 pts]	
5	Succinctly states the objectives, methods, and principle conclusions of the experiment.
4	Less succinct, may contain some off-topic statements but states the key objectives, methods, and conclusions.
3	Verbose, lacks focus, may be missing key components of the lab summary.
2	Verbose, follows the lab handout extremely closely, conveys only a tenuous understanding of the lab's purpose.
1	Verbose, does not reflect the actual purpose of the lab, contains details or irrelevant information.

Introduction [10 pts]	
10	Concisely motivates the problem and introduces the methods used in pursuing it.
8	Less concise, may contain irrelevant information that detracts from the central purpose but states the overall goal and the key methods.
6	Verbose, lacks focus, the purpose of the lab is not central, and the key methods may not be introduced.
4	Verbose, draws excessively from the lab handout, methods are not introduced.
2	Verbose, the purpose of the lab is not clear, methods are not introduced.

Observations & Data (or Data) [5 pts]: (Note that in the case the data were simply given to you, not all the details below may apply. You can provide only relevant parts.)	
5	Describes the equipment used and how the data were acquired or obtained. If necessary, provides a clear log or summary of the observations, containing the observation times, dates, personnel involved, etc. If necessary, summarizes any anomalies or systematic errors that may be present in the data.
4	All important information for the data acquisition is present, but there may be organizational or logical lapses. Potential anomalies and systematic errors are described.
3	Mediocre organization, some relevant observational information may be missing or not adequately described. Possible systematic errors are not described.

2	Poor organization, key observational information needed to reproduce the experiment may be missing, anomalies are not described.
1	Poor organization, the given information is inadequate for the reader to successfully repeat the experiment, anomalies are not described.

Data Reduction & Methods [10 pts]	
10	Describes data reduction methods/algorithms, as well as statistical methods used to analyze the data or combine it into the final results. Methods used to estimate uncertainties in the data are clearly explained. The reader is adequately led through intermediate to final results with each consecutive step clearly explained.
8	Data reduction and uncertainty estimation techniques are present, but each step may not be fully explained. The reader may not be fully convinced that the results and uncertainties are correct.
6	Some data reduction techniques are listed, but the description lacks organization and clarity. Uncertainty estimates may be missing or incorrect.
4	Data reductions steps are only partially described, and some steps may be incorrect. Uncertainty estimates are absent or in error.
2	Key steps in the data reduction process are not described in the text. Error estimates are absent. The reduction steps are likely in error.

Data Analysis & Modeling [10 pts]	
10	Demonstrates complete understanding of the physical principles underlying the experiment. Intermediate calculations with plots or tables appear in a logical sequence throughout and are sufficient to convince the reader that the final results are correct. All equations used appear in the text with equation numbers and references. Equations are described and explained as part of sentences within the context of the experiment, and all new symbolic quantities are defined. Figures and tables have clear captions, numbers, and labels, are referred to in the body of the report, are placed in the text close to where they are referenced, and are used to support key arguments in the text.
8	Demonstrates nearly complete understanding of physical principles. Intermediate calculations are present, and the organization is fairly clear. All equations used are listed and mostly explained. Figures and tables are used throughout to support key arguments in the text. Calculations appear generally correct and complete, but may contain some minor errors.
6	Shows partial understanding of the relevant physical principles. Intermediate calculations may be sparse, and organization may be lacking. Equations are listed but may not be adequately explained. Figures and tables may appear without reference in the text. Important calculations may be absent or contain major computational errors.
4	Shows limited understanding of the relevant physical principles. Intermediate calculations may be absent, and organization is unclear. Key equations may be missing, poorly explained, or in error. Key figures and tables may be absent, or demonstrate major computational errors.

2	Shows very little understanding of the relevant physical principles. No attempt at the end result may be present, let alone intermediate calculations. Organization is unclear, equations are missing or in error, and important figures or tables are absent without explanation.

Discussion [10 pts]	
10	Synthesizes, analyzes, and interprets the results in the context of the experimental purpose. Compares results achieved with theoretical expectations. Explains discrepancies between theory and results appropriately in terms of errors in measurement and technique. Describes remaining ambiguities, uncertainties, and avenues for future investigation. Includes an insightful summary of conclusions.
8	Reiterates the main results with some ties to the experimental purpose. Compares results achieved with theoretical expectations. Explains discrepancies between theory and results but may contain omissions or oversights. The summary may needlessly repeat information described previously in the report without revealing new insights.
6	Reiterates the main results with some ties to the experimental purpose. Compares results achieved with theoretical expectations but explanations for discrepancies may be vague or wordy. The summary may needlessly repeat information described previously in the report without revealing new insights.
4	Main results may not be clear, or may not be tied to the original purpose of the experiment. Comparison with theory may be excluded or may contain significant errors. Concluding remarks may be absent.
2	Main results are not given, and the text is not tied to the introduction. Comparison with theory and concluding remarks may be sparse or completely absent.

Appendix [5 pts]	
5	The appendix should include a presentation of code that was written in-house (i.e. by members of your group) to perform pertinent reductions and analysis in the lab activity. Essential pieces of the code should be presented in the appendix with brief text that *well describes and presents the key portion of the code used in the lab*. The main body of the text should refer to these sections in the appendix.
4	The appendix includes the essential in-house code used in the lab activity, but the text in the appendix weakly describes and presents the code relating to the lab results.
3	The appendix includes minimal portions of the essential in-house code used in the lab activity, and the text weakly describes and presents the code relating to the lab results.
2	The appendix includes minimal portions of in-house code used in the lab activity, and poorly describes and presents the code relating to the lab results.
1	The appendix does not include in-house code used in the lab activity, and minimally describes any of the code and lab results.

Example Lab Report

AST325H1F Lab 1: Photon Counting

Emily Deibert
emily.deibert@mail.utoronto.ca

5 October 2015

Abstract

In this report, the statistical properties of photons are examined through the use of a photomultiplier tube (PMT) which relies on the photoelectric effect. Datasets taken with varying parameters from the PMT are compared to both Poisson and Gaussian distributions in order to study inherent characteristics of photon counting statistics. By testing various lengths and numbers of integrations of the PMT, it will be shown that an increased number of samples per trial results in a lower standard deviation, and thus a lower error in the calculated mean photon count. Further, the mean count and variance for a series of datasets with increasingly long integration times are shown to exhibit a linear relationship, indicative of a Poisson distribution. As the number of counts per trial increases, the data are increasingly well-matched with the continuous Gaussian distribution. Various avenues of error analysis and reduction techniques are also explored.

1 Introduction

The quantum nature of light is such that there is a certain probability that a photon will be released from an excited atom at a given moment in time. For astrophysicists, whose primary goal is almost always to study light gathered from distant sources, methods and limitations of light detection and measurement are of the utmost importance. In this experiment, we attempt to quantify the probability of photon detection by examining the statistics of photons counted by a photomultiplier tube (PMT). While it can be shown using calculations that for ultraviolet and visible wavelengths photons are well-modelled by Poisson statistics (see [1]), our experiment attempts to prove this claim empirically, as well as to investigate the relationship of photon statistics to a Gaussian distribution. Methods of reducing spread in the measured photon count values will also be explored.

Work for this experiment was split evenly between the author (Emily Deibert) and lab group partners Vivian Tan and Fei Fan Wu. In particular, the methods and codes used to obtain and analyze data were a collaboration between all three group members. Individual members ran their own trials of the PMT device to gather data, and produced their own unique plots of these results.

Practical assignments take long.

So start early!