WPI | Department of Physics

Application of Rotational Motion

1110 Lab 5

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I Abstract

The astronaut Tim Peake, featured in the international space station (ISS) video's we will analyze later, is a good example himself of circular moment. He, in the ISS, was kept in a nearly circular orbit around the planet for nearly six months due to gravity. In his demonstrations tension often plays the role of that center force that gravity was for the ISS.

An object can move around in a circle with a constant speed, but still be accelerating because it's direction is constantly changing. This acceleration, which is always directed towards the center of the circle, is called centripetal acceleration.

this

Lab Objectives

- Practice designing an experiment to compare data from the International Space Station (ISS) to at home conditions
- Think carefully about rotational motion.

Lab Materials

- Camera.
- Tracker or Logger Pro Software [?].
- Items to create one's own rotational motion video.

Link for this lab

Please use this link to download the reference ISS video: http://astroacademy.org.uk/resources/circular-motion/

Introduction

In this lab we are asking you to analyze an ISS video, and try to recreate it. You will, at the end, produce directions on how you performed your homemade experiments, a graph comparing your experiment to the ISS one you modeled it on, and a reflection on this experiments. Thank you for a lovely semester, and we enjoyed having you all in lab.

We recommend you watch the introduction video to circular motion at the National Space Academy's (NSA) website here [?].

As they say, Newton's first law means that a ball on a string wishes to go off in a straight line. The string applies a tension force, and that causes the ball to rotate. The tension force at a right angle of the ball's instantaneous direction of travel means that the ball will follow a circular orbit. That ball's velocity will always be changing, although it's speed is constant. This is because it's direction is changing as it rotates around the tension.

Whenever there is circular motion there must be a force directed inwards to keep the object moving on an axis.

I.1. Historical Perspective on the development of Kepler's Laws

In order to refresh the concepts related to circular motion please revisit your lectures. The name planet comes from a Greek word meaning "wanderer," and indeed the planets continuously change their positions in the sky relative to the background of stars. One of the great intellectual accomplishments of the 16th and 17th centuries was the threefold realization that the earth is also a planet, that all planets orbit the sun, and that the apparent motions of the planets as seen from the earth can be used to determine their orbits precisely.

The first and second of these ideas were published by Nicolaus Copernicus in Poland in 1543. The nature of planetary orbits was deduced between 1601 and 1619 by the German astronomer and mathematician Johannes Kepler, using precise data on apparent planetary motions compiled by his mentor, the Danish astronomer Tycho Brahe. By trial and error, Kepler discovered three empirical laws that accurately described the motions of the planets.

Johannes Kepler began as an assistant to the Danish astronomer Tycho Brahe. Brahe ran the first great observatory in Europe, and made measurements of the planets that were so exact they are still valid today. After Brahe's death Kepler inherited his data[1], and ultimately made several observations that overthrew his preconceptions of how the planets rotated. For example, he ultimately had to fight through his conception that planets moved in perfect circles when Brahe's data said they move in ellipses.

Kepler was familiar with Galileo's work on inertia and accelerated motion, but did not apply them to his work with satellites. He believed that the force on a moving body was always in the same direction as the body's motion. Galileo thought differently, he he also never accepted that planets moved in anything but perfect circles [**?**]. Because of the mismatch in their understanding, it took Newton to consolidate their ideas.

I.2. Kepler's Laws

Kepler's Laws

1. Each planet moves in an elliptical orbit, with the sun at one focus of the ellipse.
2. A line from the sun to a given planet sweeps out equal areas in equal times.
3. The periods of the planets are proportional to the 32 powers of the major axis lengths of their orbits.

Kepler's second law directly relates to conservation of momentum. The fact that the sector velocity is constant means that the angular momentum is constant [**?**].

Using Kepler's second law we know:

$$|\frac{dA}{dt}| = \frac{1}{2}r\nu\ sin\phi \tag{1}$$

Where ϕ is the angle between r and v. $r\nu sin\phi$ is the magnitude of the vector product $\overrightarrow{r}x\overrightarrow{\nu}$, which is 1/m times the angular momentum $\overrightarrow{L} = \overrightarrow{r}xm\overrightarrow{\nu}$ of the planet with respect to the sun. Therefore we have

$$\frac{dA}{dt} = \frac{1}{2m}|\overrightarrow{r}\ X\ m\overrightarrow{\nu}| = \frac{|L|}{2m} \tag{2}$$

Which is just Kepler's second law. For a circular orbit momentum is conserved, so L becomes

$$L = m\nu r \tag{3}$$

II Part I: National Space Academy Rotational Motion

Once again we are asking you to download an ISS video and compare it to a video you make yourself. You may download the video from their website, which is in the reference section. Not all of the videos have Tracker files, and we suggest you only use the ones that do.

This time we will ask you to download one video, and create one video to compare. You can find a table of the video's you can compare your data too in the bottom of this lab.

After you have picked which video you wish to recreate, please download it and open it in either Tracker or Logger Pro. Then you should track the mass that the astronaut is spinning. Your software will then give you the option to look at the rotational velocity, acceleration and momentum. To update the momentum you must enter a mass of the spun object, which has been provided in the table above.

Please plot the angular momentum versus time of the ISS video.

III Part II: Making your own Rotation Video

With a known length of string, attach an item to the end of that string. We suggest you take inspiration from the NSA's video, and attach a cup of water to the string, but only if one is outside.

[1] Inherited might not be the right word. Stole might be more appropriate [**?**]

Holding the end of the string rotate the item attached to it, while recording. Be sure to have your object of known length in the frame for calibration later. Then analyze that video with Tracker.

In Part I you analyzed a rotational videos taken at the ISS. In part II we will now design our own experiments, and compare it to the data in part I. Please create an experiment to compare with the NSA video. We understand that you are operating in very different circumstances from astronauts, and we hope that you attempt your best. Your video should include at least one rotation, and you should be able to calculate the rotational momentum in your analysis. This means you need to know

- The radius of your string.
- The rotational velocity of the system ω.
- Mass of the rotating object.

Question 1 **Experimental Method**

For your experiment write a set of directions for how to perform the rotation experiment you just recorded. What materials did you use? How did you go about setting up the experiment? (4-5 sentences) Please number all your steps.

1.
2.
3.
4.
5.

Here is a wonderful example of a rotational video performed by Professor Kafle.

Question 2 **Results**

Compare and contrast the rotation observed in these video's.

You will create two plots, and graph both data sets from the two video's.

These plots should include include the angular momentum versus time of the ISS video and your own video. Please follow all graph formatting rules.

For an example of a a good graph please see fig. 9

Please calculate the maximum, minimum and mean rotational momentums for the ISS video and your own.

You can use the momentum function on Tracker to think about angular momentum, as the radius of these swinging objects are constant.

Question 3 *Please indicate which space video you used and include a link to the videos you made as a drop box link, unlisted youtube video, or google drive link. Your video should be accessible to your Lab Instructor, and we will not chase you down to request permissions to view this video.*

Question 4 *Reflecting on the experiment you designed and videotaped to compare to the astronaut's video, was there anything you wish you did differently? (1-2 sentences)*

IV Conclusion

Question 5 *What conclusions are you able to make based on the data you collected for this lab? Back up your conclusions with evidence, use equations, measurements, references to figures, etc when appropriate. If you are not sure where to start, you will want to use the words conserved and/or not conserved in your conclusion.*

After you finish this lab please fill out out a TA evaluation form. The survey is linked on the Canvas site. You can find it under the quiz "Lab Instructor Evaluation". After you complete the evaluation form on another site you will receive a completion code. Please enter that completion code into the "Lab Instructor Evaluation" quiz.

V Extra Credit

For 2 points of extra credit please submit a blooper video of you performing your own experiment. Tries that do not pan out are an essential part of doing physics. Submit it as either a youtube link, dropbox link, or google drive link. Bloopers can be from this week's experiment or a previous video you made for Tracker. Please include a sentence on why it did not work out if it is not obvious.

VI Appendix

VI.1. Propagation of Uncertainties review from Lab 1

For an example of how to do this in Python please also see the Appendix. When estimating the systematic uncertainty to be propagated please think about the refinement of the time and position divisions you are able to achieve with the Tracker software. [**?**].

Perhaps the dots you place on Tracker are perfect. It is unlikely that they are, and therefore there is a slight error inherent in the data from your Tracker files. That article, by Rhett Allain who now writes for Wired [**?**], suggests a useful technique for investigating systematic error. They suggest trying to track the same point multiple times, and seeing if there are differences in the points and values from them.

This is similar to how in the first lab we asked you to compare your measurements of your ID to other's measurements of their ID's. They were measurements of the same things, but with slightly different values.

Systematic uncertainty on the masses can be estimated at around 5%. If lab was in person we would have you measure the mass of the balls several times, and use the variation to think about the systematic uncertainty. In the post-covid era, however, please just propagate that error as 5% of whatever mass was given.

Using the mean we just calculated find the area of your ID. Area is length times width, but what about the uncertainties? The error propagation is not the same as when we added our length together because we are multiplying our measurements rather than adding them. This method is valid for both multiplication and division of measurements with uncertainties. The formula is

$(\delta A)/(|A|) = (\delta x)/(|x|) + (\delta y)/(|y|)$

where A is the area, x is the length, y is the width, δx and δy are the uncertainties associated with the length and width respectively. $\delta A$is the propagated uncertainty of the area.

Exporting data from Tracker

After you have downloaded the Tracker software here and tracked your moving object you will want to export your data for your analysis software.[2]

The first way to export your data is to go 'File' to 'Export' to 'All Cells' to 'Save As...' That will save all the data you can see on your data table, which is in the bottom right corner in Fig. 1.

[2] Please remember to use any analysis software aside from Excel or Google Sheets. Matlab, Python, C++, Stata, R are all great software's to use

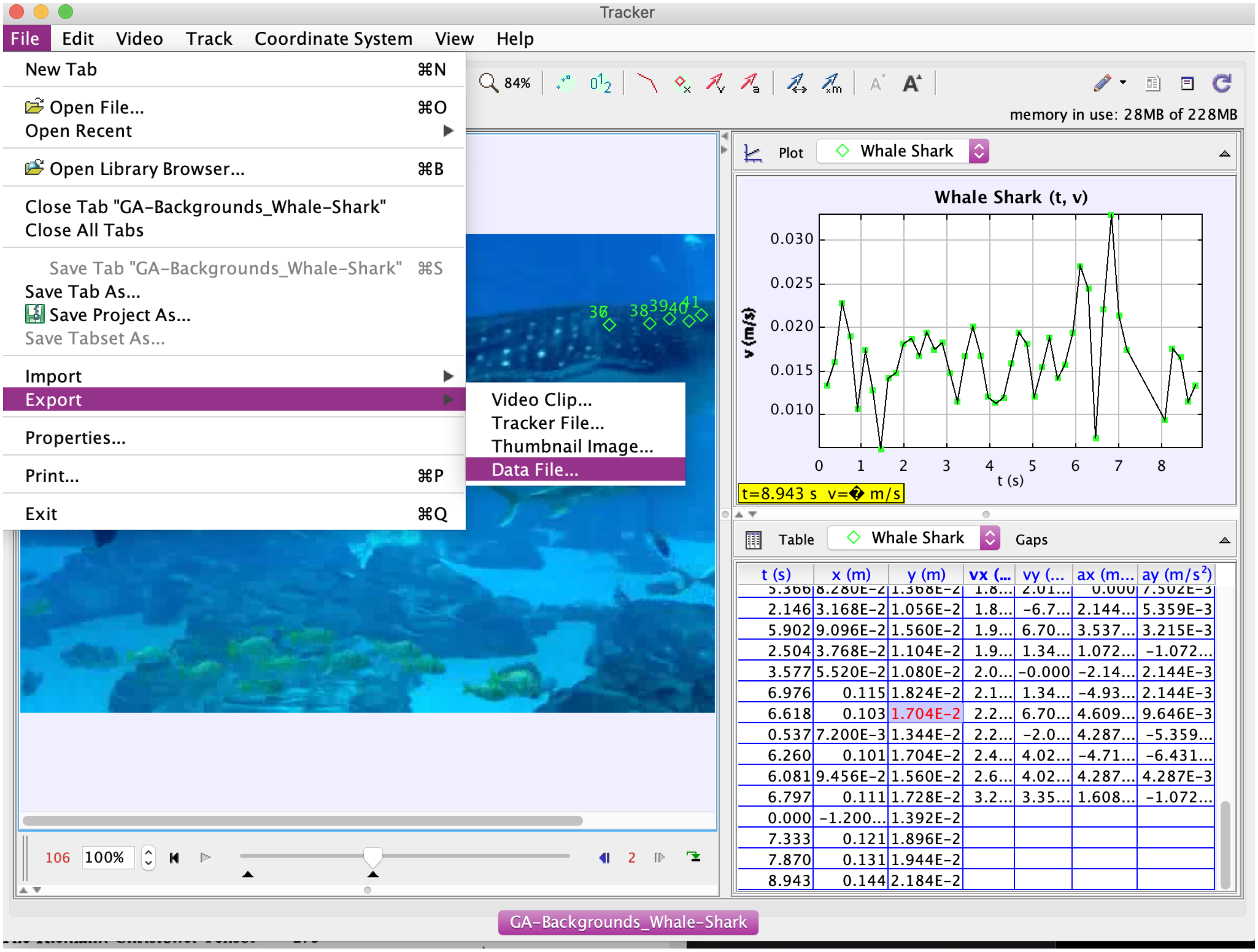

Figure 1: The first way to export your data is to go 'File' to 'Export' to 'All Cells' to 'Save As...' That will save all the data you can see on your data table, which is in the bottom right corner in this image.

Then you want to save all cell's as in Fig. 2. You will only save the data displayed on the chart, so if you wish to change what data you see click the Tables button as in Fig. 3.

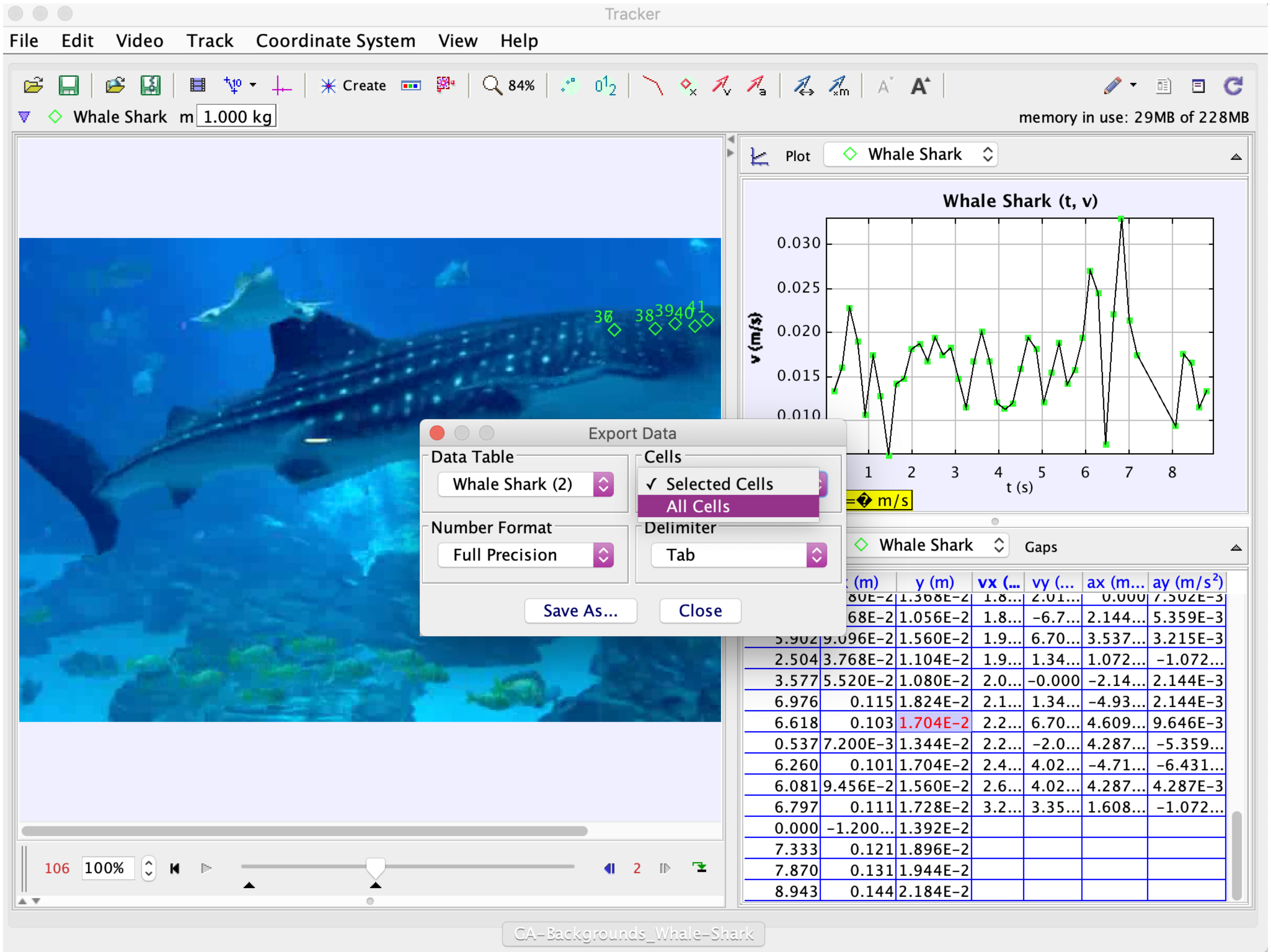

Figure 2: Choose 'All Cells' and 'Full Precision' when saving your data.

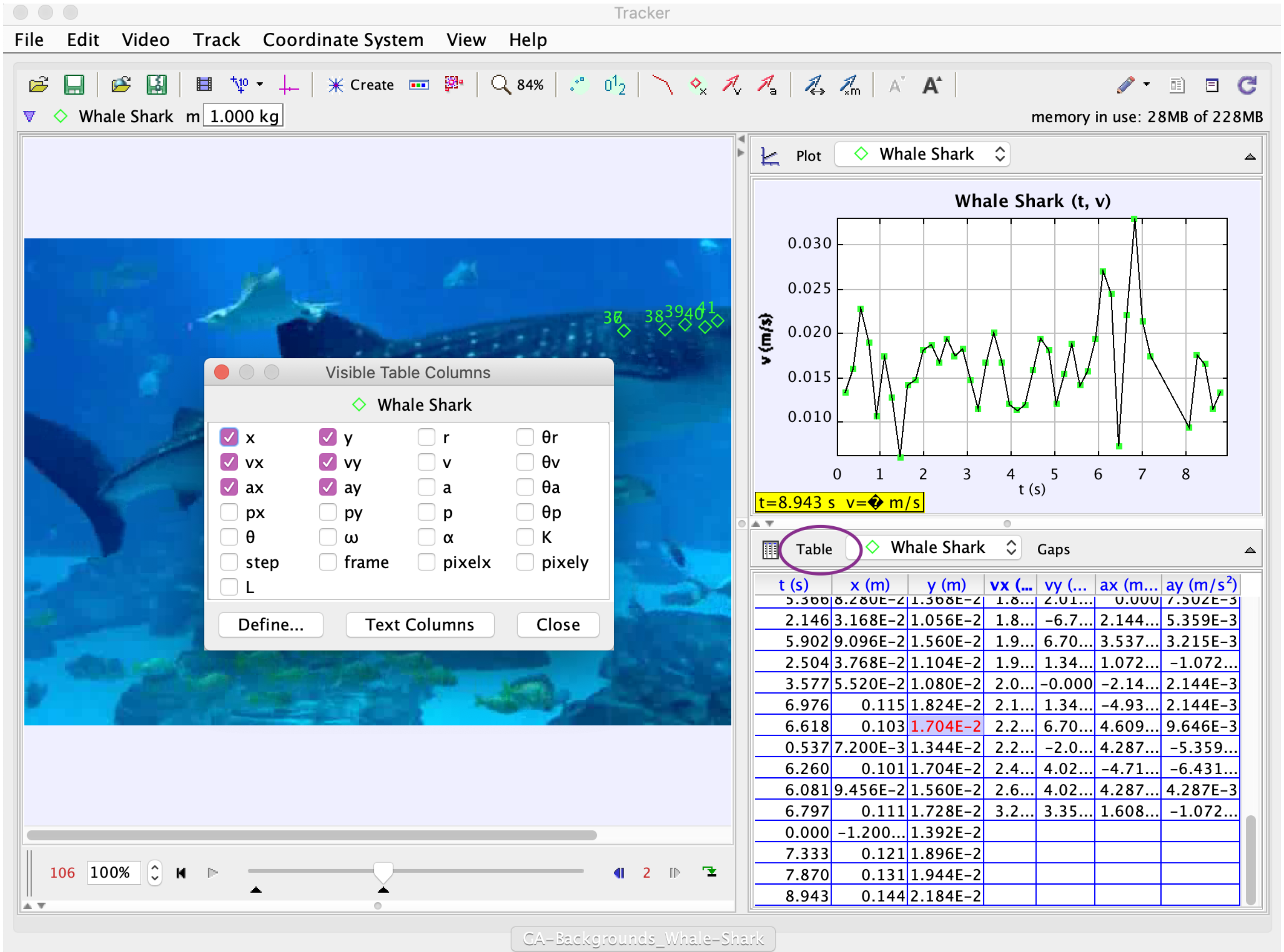

Figure 3: Clicking on the table icon allows you to choose which data you wish to see on your table, and therefore what date you wish to export.

The second way to export data is right click on your chart, choose 'Analyze' and then export from the file tab. You can see the Analysis button appear in Fig. 4, and then where to export from in Fig. 5.

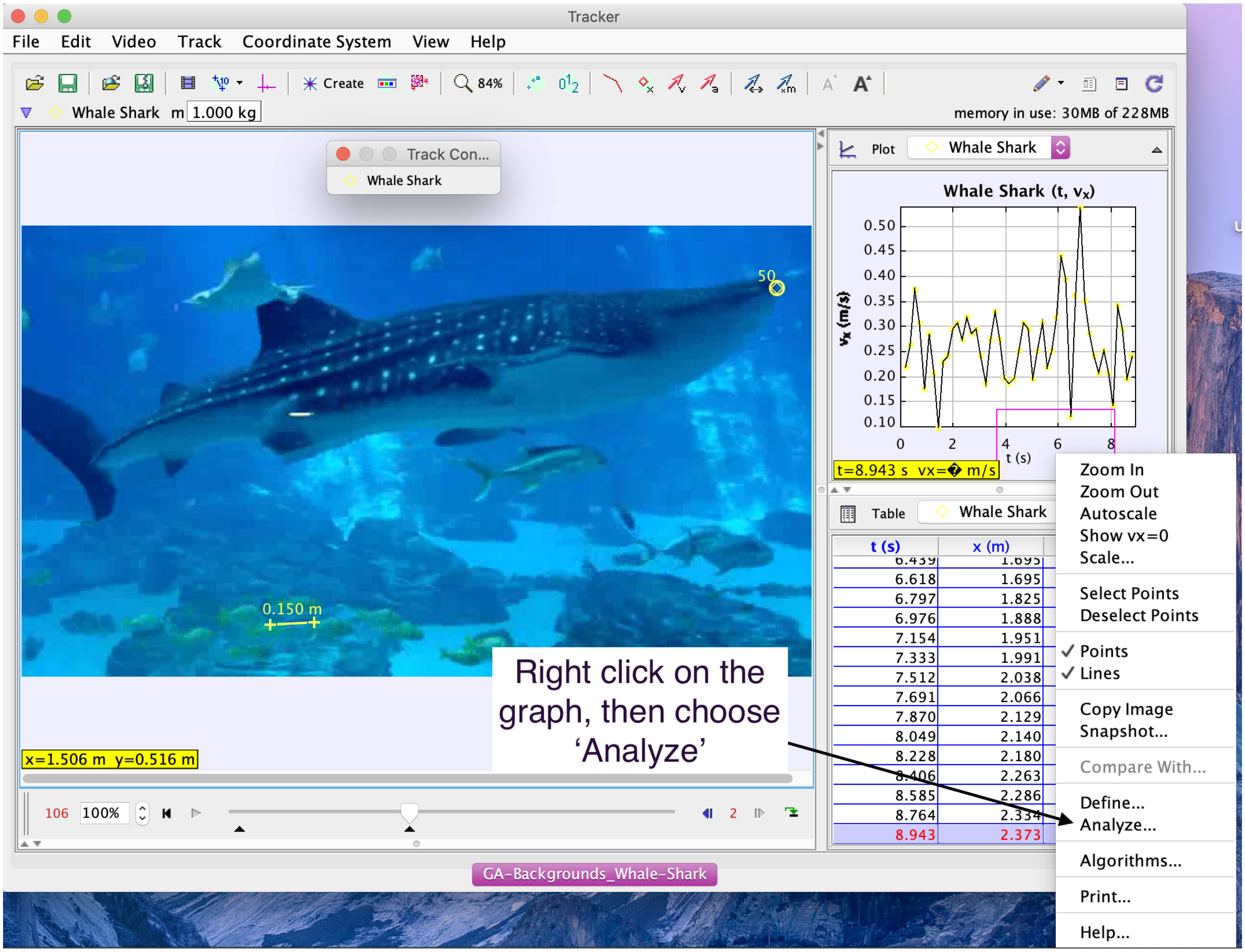

Figure 4: The analysis function can be very helpful when you want to see the Tracker plot clearer.

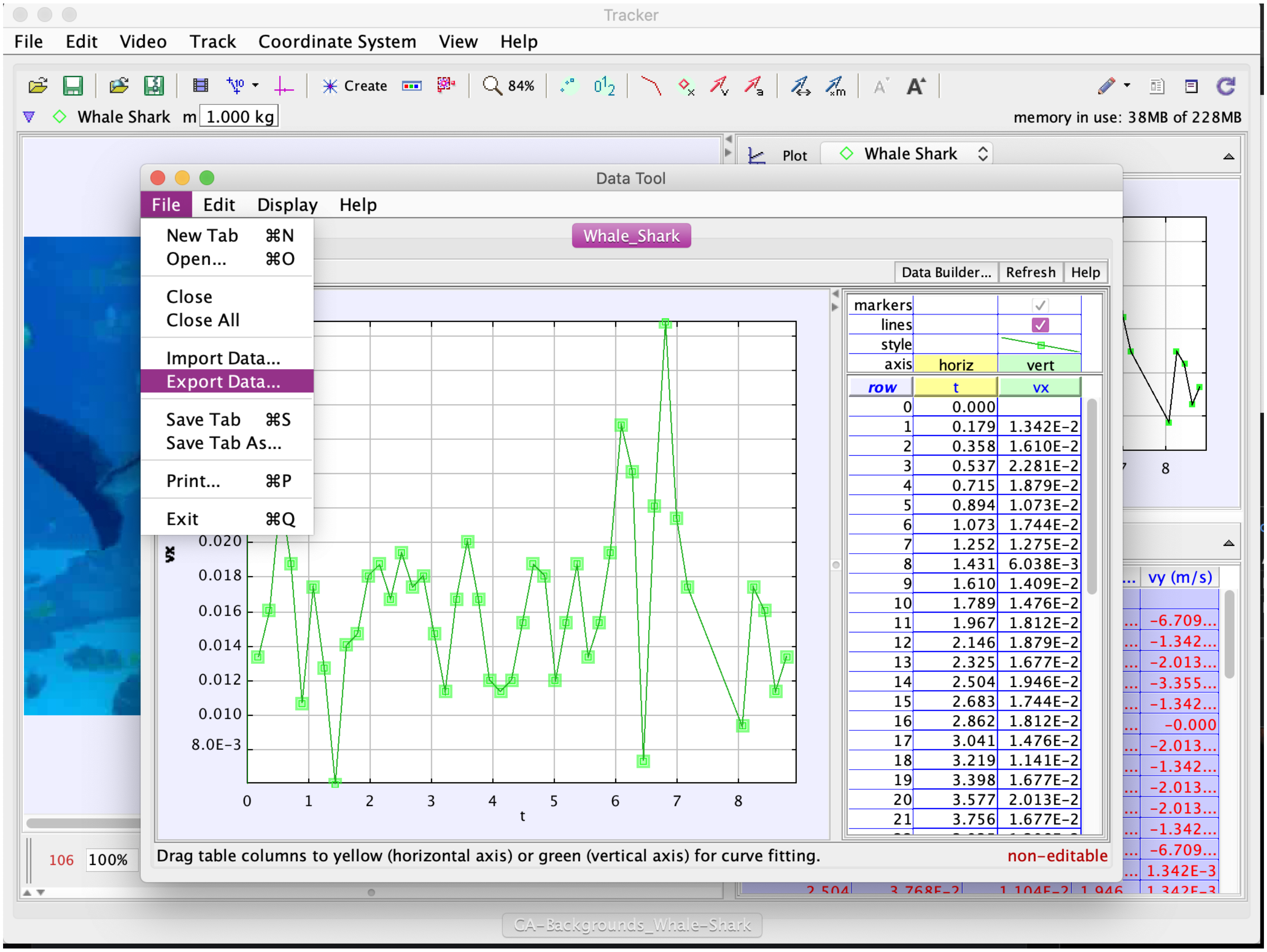

Figure 5: You can also export from the analysis function.

The Figures and Caption Rules

There are a few very important aspects to creating a proper figure and caption. If you follow these rules, not only will you get points on your physics lab grades, you will impress your instructors and peers in the future.

The Caption

- The caption should start with a label so you can reference the figure from other places in your paper/report. For this course you should use "Figure 1", "Figure 2", etc.
- The caption should allow the figure to be standalone, that is to say, by reading the caption and looking at the figure, it should be clear what the figure is about and why it was included without reading the whole paper.
- The caption should contain complete sentences and be as brief as possible while still conveying your information clearly (this is not always easy).
- Please add captions to your tables as well, otherwise we will not know what we are looking at.

The Figure

- **Make sure that the resolution is high enough to not be pixelated at its final size.**
- Check that any text is readable at the final size (Using a smaller graph in Logger Pro will cause the text to be larger in relation to the graph when inserted into another program).

- For graphs, ensure that the axes are labeled (including units) and that there is a legend if you have multiple data sets on the same graphs.

Tables

- The first row of the table should be a header, where each item is labeled with what is contained in that row. If it is a physical measurement it should have the correct units.
- For tables include a short caption of what is contained in the table, or what was examined.
- The caption should start with a label so you can reference the figure from other places in your paper/report. For this course you should use "Table 1", "Table 2", etc. For an example of a good table caption please see Figure 6.

Table 1. Baseline characteristics of study participants

Variables	Intervention group (n=14)	Control group (n=15)
Women (no [%])	7 (50)	5 (33)
Median age (range)	22.0 (19 – 58)	21.0 (18 – 70)
First winter in icy conditions (no [%])	—	1 (7)
Previous falls on ice (no [%])	8 (57)	11 (73)
≥ 1 fall this winter (no [%])	4 (29)	7 (50)
Injury from fall this winter (no [%])	1 (7)	—
Time been walking this route (no [%]):		
<6 months	3 (21)	2 (13)
6–12 months	9 (64)	9 (60)
>12 months	2 (14)	4 (26)

Figure 6: An example table from the paper Lianne Parkin, Sheila M Williams, and Patricia Priest, "Preventing Winter Falls: A Randomised Controlled Trial of a Novel Intervention" 122, no. 1298 (2009): 9.

Python

According to IEEE Spectrum, Python is the most popular programming languages. Python is a free, general purpose, cross discipline programming language that has moved to the forefront of many disciplines.

If you decide to use Python your TA's will help you troubleshoot your code. While they might be able to help you troubleshoot when you use a different program or code, be aware of the fact that they are not familiar with all programming codes. There are many languages (R, Matlab, Opal, Julia, etc.) out there that are just as useful as Python, but we have chosen to use Python here. You may use any programming language you wish, but not Excel or Google Sheets.

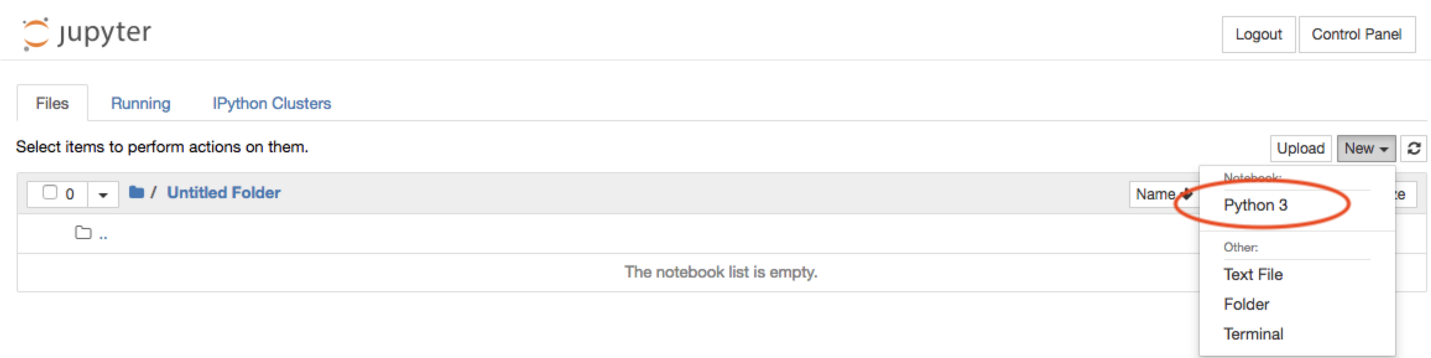

Figure 7: Navigate to `jupyterhub.wpi.edu/hub/login` and sign in with your WPI email address and password, choose an instance to spawn (either is fine) and create a new Python 3 file as shown here

We have set up a Jupyter notebook you may use. The website is https://jupyterhub.wpi.edu/hub/login.[3] There are many ways to learn Python, including reading a book, asking a friend, working through examples, or googling furiously when problems arise. We encourage you to discover which approach works best for you. Going forward this class will provide basic Python examples, but feel free to iterate upon the template we provide. What we provide is a stripped down version, and

[3] If you cannot log in please email WPI's IT department, and they will be happy to help polite students. The first thing they will tell you, however, is to check to make sure you don't have to change your password and try a VPN if you are off campus.

elaboration is encouraged. See this Github repository for our examples. We hope at the end of this term you will be able to add to your resume "Proficient in Python".

Jupyter uses a cell based system and evaluated variables carry over to the next cell. There are a few different types of cells, Figure 8 shows 2 kinds, the code cell, which we will be using most of the time, and the markdown cell, which you can use to add nicely formatted notes to you file.

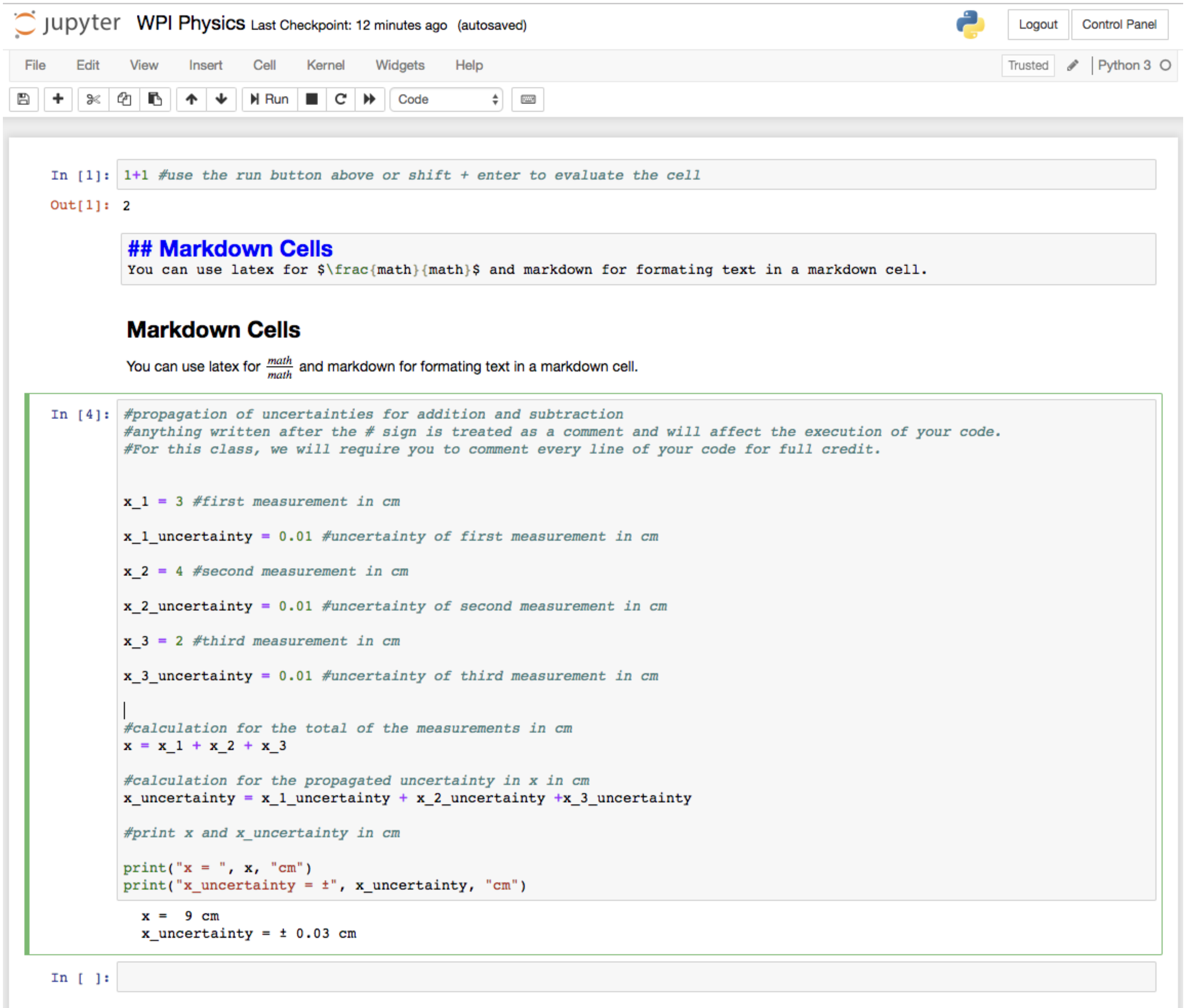

Figure 8: Above is the code that you could use use to propagate uncertainty for values that are added or subtracted. Always remember to comment your code.

If you prefer to work through a book or examples we recommend Mark Newman's book, which is available for free on his website [?]. Chapter Two is a basic introduction to the syntax for Python. Chapter Three covers graphs and visualizations, and we hope you will look into it if you learn best from a book. If you wish to get a head start in this class we recommend reading this book.

If you wish for a more advanced textbook there is a compilation of free online computational physics books here.

Error

Humans can often be a source of error, but describing one's total error as 'human error' does little to illuminate the subject. Humans can contribute error to a system, but it is not their mere presence, often, that causes that error. That error is contributed by a specific action, or lack of action of the operator and you should always be specific. If we ask for why there might be error in a system, and someone responses with just human error without explaining what, specifically, that answer will not receive credit.

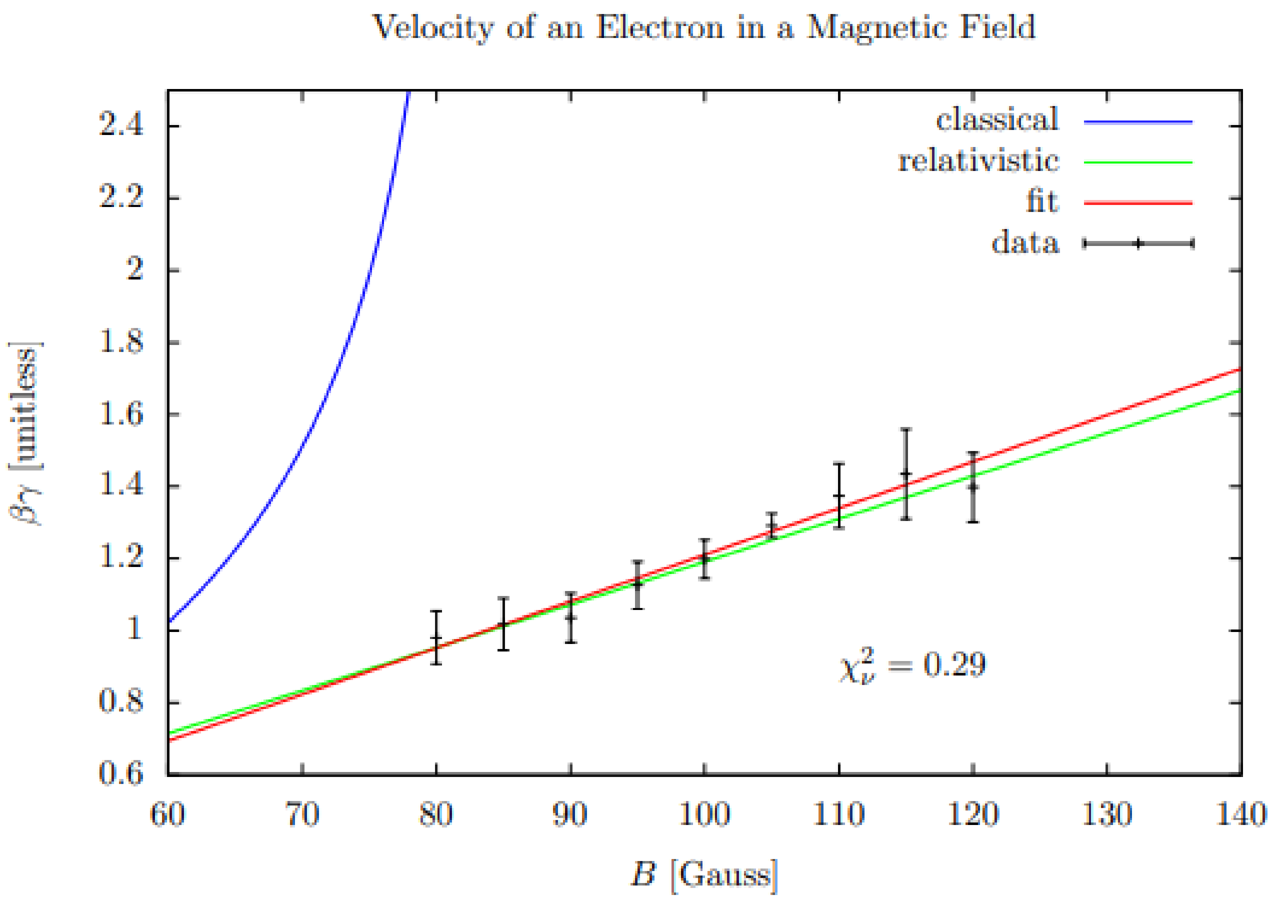

Figure 9: Example of a good figure with excellent error bars and a label. Figure from Philip Ilten of University College Dublin [?].

Collisions Video Summary		
Video File Name	Summary of Movement	Mass
V1 Ball on tether released - horizontal plane	A side on view of Tim spinning the ball on a tether in a horizontal plane and then releasing it	1kg [4]
V2 Ball on tether released - vertical plane	A side on view of Tim spinning the ball on a tether in a vertical plane and then releasing it	1kg
V3 Vertical ball in hoop - Tim holding	A side on view of a ball travelling in a vertical circular held by Tim loop at 8x speed	1kg
V4 Horizontal ball in hoop - Tim holding	A side on view of a ball travelling in a horizontal circular loop with Tim holding it	1kg
V5 Vertical ball in hoop - clamped	A side on view of a ball travelling in a vertical clamped circular hoop nearing (having already been travelling for several minutes)	1kg
V6 2 balls in circular track air resistance	A side on video of two balls of differing size rolling around a vertical clamped circular track	1kg and 0.05kg
Extra 1 Ball on tether - Tim hits the camera	A bonus video of Tim spinning the ball on a tether and aiming it to hit the camera!	1kg