Astrophysics II: Laboratory 1

Superluminal Motion and Quasar Jets

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1 Objectives:

- Gain some working familiarity with MATLAB.
  - Plot familiar and unfamiliar equations.
  - Write and run functions (.m files).
  - Explore parameter space via visualization.

- Measure superluminal motion and estimate the lower bound speed for bulk motion in the jet of 3C 279.

2 Procedure

2.1 Intro to MATLAB

1. Open Matlab. Notice the sections of the window: editor, command line, history, data window, etc.

2. Go to http://www.astro.umd.edu/~mavara/ and download two files: <lab1plot.m> and <lab1func.m>. Save them into a new folder you create on the desktop with your last name, followed by "lab1".

3. Open each of these files into the editor in Matlab and read through them. Pay close attention to the comment made at the end of each line telling what that command instructs matlab to do.

4. Run <lab1plot.m> by typing "lab1plot" at the command line. Note that you may have to change the matlab current directory to the folder you created in order for matlab to find those files when you execute this command at the prompt.

5. Now, try a few of the commands inside these matlab function files out for yourself at the command line. See <simpleCommands.html> for guidance.

6. Now try making adjustments to these files and run them again with the same command as before. Note any differences. What change did you make and what effect did it have? I suggest simple changes each time, so that you can tell exactly what the change was. (We call this changing one parameter at a time in physics and it's useful in many areas including programming!) Note that you will need to save the file after each change you make before it will take effect when you run the function file at the command line.

7. Now let's turn the heat up. Open the editor window with <lab1func.m> and choose a new function to define in this function file. Examples: sin(), cos(), exp(), 1/x, etc... Save and run command lab1plot.

8. Once you have your new function plotted try the more complicated function, with two input parameters, that we derived which expresses β_T:

$$\beta_T = \frac{\beta sin\theta}{1 - \beta cos\theta} \tag{1}$$

Choose a value of β relatively close to 1 and use the standard procedure to plot the function. Note that you'll want to change the range values in <lab1plot.m> if you haven't already to 0...π for the x axis signifying the range in values of theta.

9. By increasing the value of beta to very close to unity convince yourself that it approaches γ. Recall that

$$\gamma = \frac{1}{\sqrt{1 - \beta^2}} \tag{2}$$

2.2 Measuring Superluminal Motion

1. From Newtonian (and as it turns out, General Relativity gives the same answer) Cosmology we arrive at the equation

$$v \approx H_0 D \tag{3}$$

where $H_0 = 74.2 \pm 3.6 km/s/Mpc$.

There is also a relation in cosmological physics between the redshift z of light from distant objects and the velocity at which that object is receeding, the same velocity as in equation 2.

$$z \approx \frac{v}{c} \tag{4}$$

Use these relations to find the distance to 3C 279 if $z = 0.5362$.

2. Now, use this distance to find the scale between angle on the sky measured in arcseconds and distance at 3C 279. Your answer will have units pc/arcsec. Check your answer against that listed in the Nasa/IPAC Extragalactic Database (NED) if you have time by searching for the NED main page and searching for 3C 279 on that page. These values are listed under the "Quantities Derived From Redshift" section. If your answer does not agree with theirs what might be causing the discrepancy?

3. Now, study the handout image of the jet of 3C 279 showing it's change over time. Use a ruler or other method to approximate the change in position of the brightest knot over time measured in miliarcsec per second.

4. Use your conversion scale you derived before using the redshift in order to measure the transverse velocity of the knot.

5. Convert your speed into units of c, the speed of light. What do you get as the transverse velocity of the jet knot? Is it reasonable as a superluminal speed? (note that google offers a valuable resource for checking your conversions and doing quick math, but I would like you to use MATLAB for any numerical calculations, and don't keep more significant digits than you're allowed by the accuracy of your measurements!)

6. Use your knowledge of the relation between β, β_T, and θ in order to get a lower estimate of the velocity of the material in this jet. (Hint: Can you use the high-velocity limit explored in 2.1.9 in this case to simplify your calculations?)

3 Questions

Now let's think about the usefulness of what we've learned.

How can we increase our precision of the measurement of the transverse velocity of the jet knot?

What are the errors in the values we used in our calculations? Which are well confined and which, alternatively, have large errors?

How might we measure the value of theta for the jet in 3C 279 and thereby collapse the degeneracy in our value of jet velocity? Recall that in order to obtain the jet velocity we must constrain two of the three variables β, β_T, and θ.