SURP Computing Project - Simon Smith

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Stars form in dense gas in molecular clouds. Dense gas in molecular clouds tends to be organized in filaments, and stars form in even denser 'cores' of gas within and along these filaments. When we look at the velocities of the gas in these structures, we find that some filaments appear to have multiple components - that is, they themselves may be made up of even smaller, narrower filaments moving at slightly different velocities. The goal of this project is to identify the different components of a filament in the Taurus molecular cloud using several different techniques. Taurus was mapped in emission from ammonia (NH_3) and other lines (including HC_5N) by the Green Bank Ammonia Survey (GAS). From this, we will investigate how this filament formed, and hopefully say something about how dense gas evolves from cloud to star-forming core in Taurus. First, however, we need to explore our data.

Section 1 - Statistics of data cubes

1. Begin by downloading the Taurus HC2 data for the HC_5N $J = 9 - 8$ line from the link in our Notion project page. You will want the *maps.tgz file. Untar the file. Using the `astropy` package, specifically `astropy.fitsio`, read in the cube 'HC2_HC5N_9-8_all_rebase3_trim.fits'. Documentation can be found at `https://docs.astropy.org/en/stable/io/fits/`.

2. Explore the data. What are the dimensions of the cube? From the header, describe the overall size of the map in degrees, the pixel scale and the angular resolution. What is the velocity resolution in the third axis? If we assume a distance of 140 pc to the region, what is the map size, pixel scale and angular resolution in pc? In au? You should write a short function to output these numbers.

3. Next we want to investigate some of the statistics of the data. Astronomical observations always contain noise from various sources. Here, we have already removed signals that could cause systematic errors in the data. In the radio, interference from terrestrial sources can be a big problem, but is thankfully not an issue at the wavelength used

here. As a result, the noise in the data can be thought of as random fluctuations of some amplitude, across wavelength (or velocity). At each pixel in x and y, calculate the standard deviation along the v axis in the cube. Plot the result as a map of noise across the x and y dimensions. What do you see? **Note: since the observed maps are not rectangular, parts of the cube outside the observed regions may contain zero values, or NaNs. Be sure to omit these from your calculations!**

4. The noise map created above likely has some structure in it. To remove this, we need to mask (or simply remove from our calculation) parts of the v axis where there is line emission to better calculate the noise. Think about how to make a simple mask that can apply to the whole cube, rather than a detailed mask that needs to be revised at each pixel x and y. It will help to plot a spectrum - that is, plot the amplitude as a function of v for a particular pixel (x,y) that shows a bright emission line. Do this and make a new image of the improved result.

5. From your noise map, make a histogram of the noise values. Calculate the mean. Does the mean accurately represent the overall level of noise in the data? What about the median? On your histogram, show the mean and median values you calculated.

Section 2 - Moment maps

1. A quick way to visualize and analyse the emission in data cubes is to calculate the spectral moments. For some background, see `https://www.atnf.csiro.au/people/Tobias.Westmeier/tools_hihelpers.php#moments`. Write a function to calculate the zeroth, first, and second moments for this cube. Consider how you might use your calculations for the noise in the data, and/or your mask, to improve the signal-to-noise of your moments. Plot your images to show the results! Be sure to describe what the moment maps can tell us about the properties of the HC_5N gas in HC2.