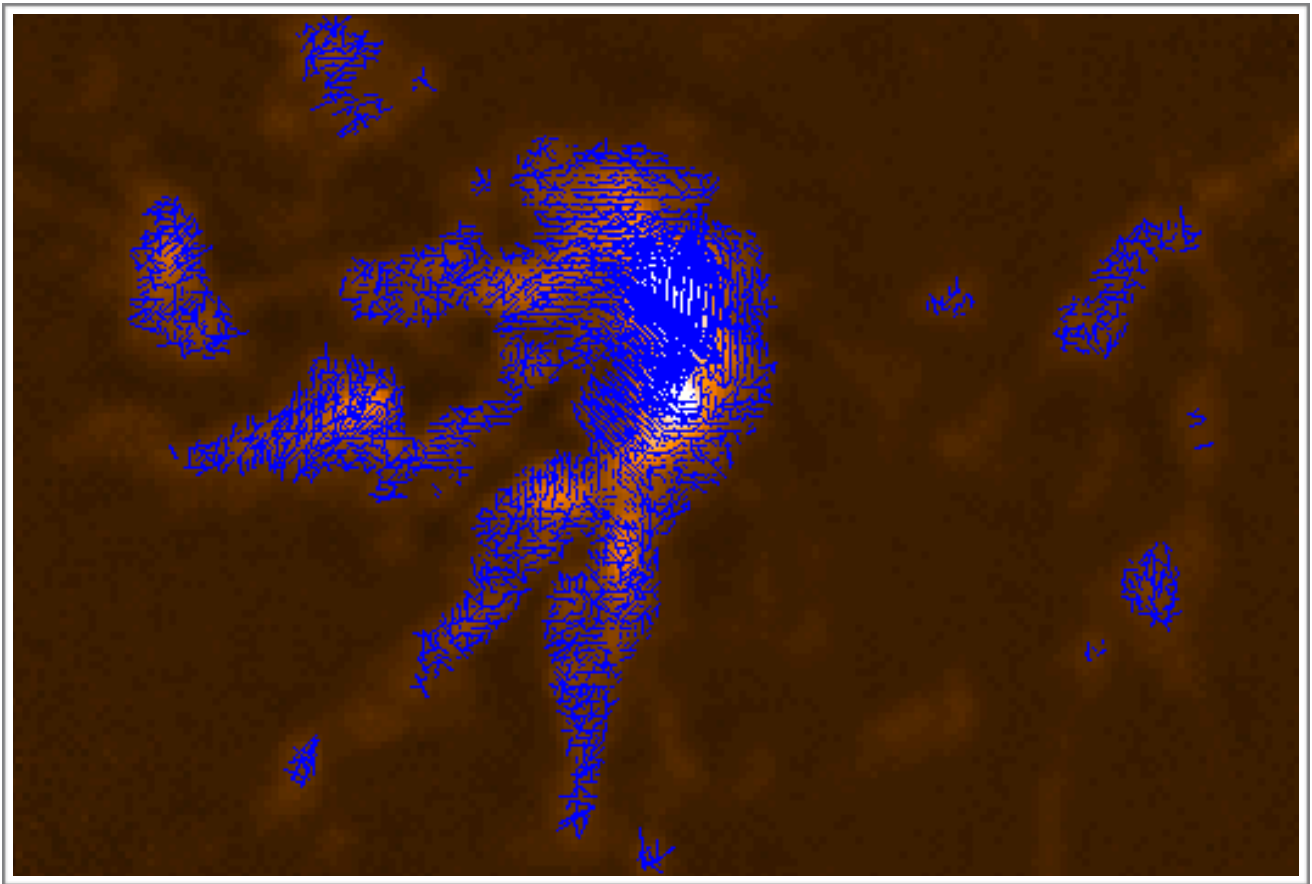


# Assignment 5

## *Magnetic Jellyfish*



ASTR 351L

Spring 2019

# Measuring B-Fields

## *Polarimetry at Submillimetre Wavelengths*

Link to Introductory Slides:

[https://www.eaobservatory.org/~s.mairs/ASTR351/slides/ASTR351L\\_Jellyfish.pdf](https://www.eaobservatory.org/~s.mairs/ASTR351/slides/ASTR351L_Jellyfish.pdf)

### Procedure:

#### Part I

1. Download the file (9 MB):

<https://www.eaobservatory.org/~s.mairs/ASTR351/assignments/Jellyfish.tar.gz>

This is a compressed file containing a directory called “Jellyfish” that is home to 3 SCUBA-2/POL-2 (850 micron, continuum) maps of an area of the sky affectionately known as the Jellyfish Nebula. The 3 maps contain the Stokes I, Q, and U data. Additionally, there is a polarisation vector catalogue called “VectorCat.FIT” along with a Jupyter notebook that will come in handy for Part II of this lab.

2. Copy this file to a suitable directory to work in (e.g. your local Desktop directory, `~/Desktop` , in the following example):

```
%cp Jellyfish.tar.gz ~/Desktop
```

3. Switch to the working directory using “cd”, unzip the file using “gunzip” and untar the file using “tar -xvf”. Change to the newly-created directory containing the data:

```
%cd ~/Desktop  
%gunzip Jellyfish.tar.gz  
%tar -xvf Jellyfish.tar  
%cd Jellyfish
```

Check the contents of this directory by using the linux command: `%ls`

4. Load the Starlink Software:

```
%export STARLINK_DIR=/opt/star-2018A
%source $STARLINK_DIR/etc/profile
```

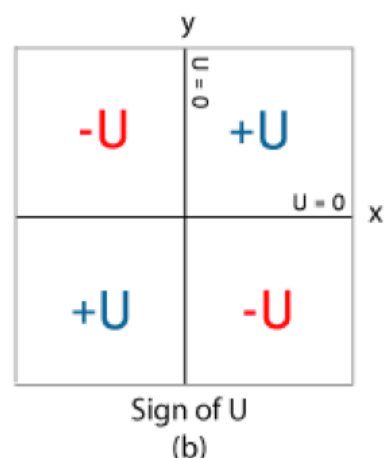
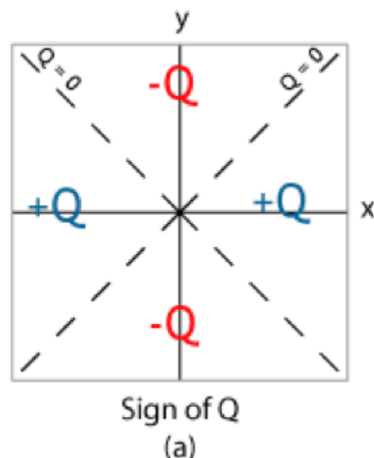
Then, take a look at the Intensity map with Gaia:

```
%gaia Jellyfish_I.sdf
```

**Make a note of the units of this map.** Play around with the stretch a little bit and get familiar with the data. Despite what the rest of the header information will tell you (it is displaying information from just one of the scans included in this map), this is a co-added map including data taken during several different times. Since you are all experts at searching for data using the CADC now (see assignments 3 and 4), you can find more information about the data that was included in this map by searching the following information:

Project Code	UT Date (YYYY-MM-DD)	Scan/Obs Numbers
M16AD002	2017-06-07	29, 37, 38, 43, 44, 48
M16AD002	2017-08-01	23, 24
M17BP084	2017-08-10	13, 14, 19, 21
M17BP084	2017-09-25	11, 12

5. POL-2 is only sensitive to linear polarisation. That means that out of the 4 Stokes parameters, I, Q, U, and V, we only care about the first 3 ( $V = 0$  for this detector). Along with the intensity map that you looked at, also use Gaia to look at the Q and U maps, “Jellyfish\_Q.sdf” and “Jellyfish\_U.sdf”. Keep in mind this useful graphic from wikipedia, as you do! **Why is the signal so weak in these maps?**



6. Now, we are going to have some fun plotting the magnetic field over the dusty, gaseous star-forming structures we see at 850 microns. First, re-open the Intensity map (I) with Gaia.

```
%gaia Jellyfish_I.sdf
```

With your map open in Gaia, click on “Image Analysis” (drop-down menu) —> “Polarimetry Toolbox”. In the box that pops up, click “File —> open” and select “VectorCat.FIT”. This vector catalog was generated through the POL-2 data reduction process. It saves information such as the I, Q, and U parameters for each pixel, but also the measured polarisation angle of the light and the polarisation percentage of the incoming light.

Set the vector length to be “PI” (the polarised intensity, or, the intensity multiplied by the polarisation percentage) and set the vector scale to be 0.5 just because it looks good. Then, set the “rotation” to be 90 degrees. Remember, the magnetic field angle is 90 degrees rotated from the polarisation angle!

There are a *lot* of vectors that pop up as every pixel in the image has polarisation information attached to it. Let’s clean this up a bit by only looking at the pixels with a highly significant intensity value (10 sigma). Conveniently, the vector catalogue contains both the intensity information (I) and the uncertainty in that intensity (DI). Click on the *Selecting* tab, and set the *Expression* field to be the following:

```
$I/$DI<10
```

(the dollar signs tell Starlink to find the columns labelled ‘I’ and ‘DI’ in the loaded catalogue). After setting the expression, press enter. This will select all the polarisation vectors that have an intensity less than 10\*sigma. Select “Edit —> Cut”. This will leave you with a nice map of polarisation vectors overlaid on the image. Finally, click “File —> Save As” and save this version of the catalogue as “TrimmedCat.FIT” (in the bottom box of the “Save As” window, rename the file.)

**Describe any general trends in the magnetic field lines. Are they generally parallel or perpendicular to filamentary structures? Can you see multiple dust components by looking only at the magnetic field structure? What other expressions might be useful to enter to trim the catalogue and analyse robust information?**

7. Next, we are going to make a quick, fun plot in the terminal using the Trimmed Catalogue you created in step 6, above.

First, make sure the kappa and polpack packages are loaded:

```
%kappa  
%polpack
```

This command sets up a postscript (image) file called Jellyfish.ps to write your results to:

```
%gdset Jellyfish.ps/acps
```

Next, we are going to ask Starlink to create some contours for us on a subset of our region. The subset is defined by square brackets immediately following the image name - it uses the form:

[x~Size\_of\_Box\_centered\_on\_x, y~Size\_of\_Box\_centered\_on\_x], for pixel (x,y).

We will base the contours on percentiles present in the image (The value where 60% of the data is brighter, 65%, 70%...). I have put together a style file for you called “sty” that specifies the way in which to draw the contours (included in Jellyfish.tar.gz).

```
%contourJellyfish_I\(-30~130,-5~150\) mode=perc  
percentiles=\[60,65,70,75,80,85,90,92,95\] style=^sty key=no
```

Then, we will plot the vectored from TrimmedCat.FIT, following the style specified in “vsty” (also included in Jellyfish.tar.gz).

```
%polplot TrimmedCat.FIT axes=no clear=no style=^vsty vscale=20 key=no
```

Finally, we convert the postscript file to a more friendly pdf file and view it using the image software “gimp”:

```
%ps2pdf Jellyfish.ps Jellyfish.pdf  
%gimp Jellyfish.pdf
```

**Attach this (or a similar) image to your lab report. Feel free to play around with the contouring, the subsections, or the style files to make the image your own. Comment on whether you think this is a useful set of contours, or how you would improve (or improved!) this image for clarity.**

## Part II:

1. Now we are going to do a bit of fancy physics to derive some physical conditions/properties of the Jellyfish nebula. For this section, follow along and complete the the Jupyter notebook “jellyfish.ipynb” included in Jellyfish.tar.gz.

## Questions/Plots:

### Part I

1. What are the units of the Intensity map?
2. What is the total exposure time that went into the creation of this map? (Note: CADC has a column for exposure time for each scan listed in the table in Part 1. It is important to search for the **RAW DATA** to get these numbers right).
3. Why is the signal so weak in the Q and U maps in comparison to the I map?
4. Describe any general trends in the magnetic field lines after applying the  $I/DI > 10$  criterion to the vector catalogue. Are the magnetic fields generally parallel or perpendicular to filamentary structures? Can you see multiple dust components by looking only at the magnetic field structure? What other expressions might be useful to enter to trim the catalogue and analyse robust information?
5. Attach the contour+vector catalogue image you created in step 7. Feel free to play around with the contouring, the subset, and the style files to make the image your own. Are there other ways you might improve (or did improve) this image for clarity?

### Part II

6. Plot a histogram (with reasonable bins) of the **magnetic field orientation** for all vectors with  $I/DI > 10$ . Find the average and the standard deviation of the distribution.
7. Plot a histogram of the **magnetic field orientation** for a single filament and find the mean and the standard deviation. Compare these values to your answer in question 6.
8. What is the value you calculated for “n” in the central Hub? Include each step of your calculation (or attach your code, as long as it is properly commented with units!).
9. What is the FWHM velocity dispersion you calculated for the central Hub? Include each step of your calculation (or attach your code with units!).
10. Using the Davis-Chandrasekhar-Fermi method, calculate the magnetic field strength of the central hub! Include your calculation and remember units!

## References to use:

- ★ Slides from the lab:

[https://www.eaobservatory.org/~s.mairs/ASTR351/slides/ASTR351L\\_Jellyfish.pdf](https://www.eaobservatory.org/~s.mairs/ASTR351/slides/ASTR351L_Jellyfish.pdf)

- ★ POL-2 Cookbook:

<http://starlink.eao.hawaii.edu/docs/sc22.pdf>

- ★ Pattle, K. Et al. (See Equation 1 in Section 3!)

<https://ui.adsabs.harvard.edu/#abs/2017ApJ...846..122P/abstract>