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AST425 PROPOSAL: WHAT LOCAL MAGNETIC FIELDS CAN TEACH US ABOUT A POSSIBLE SUPERNOVA REMNANT (G182.5-4.0)

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ABSTRACT

This proposed study focuses on classifying a currently unknown object which we refer to as G182.5-4.0. From current studies, it is believed that this object falls into one of two categories; an old supernova remnant or filaments in the interstellar medium produced by one or more supernova remnants which have retained their shape due to an interstellar magnetic field. We say that the object is a possible supernova remnant because of its highly unusual shape which does not comply with any current and commonly known geometries of supernova remnants. We believe that the unusual shape is connected and can be explained from the properties of the interstellar magnetic field which is suspected to permeate the object, and also the surrounding neutral hydrogen fibers. Neutral hydrogen fibers are known to align with interstellar magnetic fields so we propose that if a connection can be made between the orientations of the neutral hydrogen fibers (hence the interstellar magnetic field) and the unusual shape of the object, this can then provide strong evidence in order to classify G182.5-4.0. To do this, we intend to use an algorithm known as the Rolling Hough Transform which quantifies the linearity and spatial coherence of neutral hydrogen structures. We have a reason to qualitatively suspect a connection between the orientations of the neural hydrogen fibers and the filaments of the object through visually observing image data sets. In order to further quantify this prediction, we aim to dissect the data given by the Rolling Hough Transform to confirm or disconfirm the connection between the major orientations we wish to study (magnetic field/neutral hydrogen fibers, and the filaments of G182.5-4.0).

1. MOTIVATION

Magnetic fields are presumed to be pervasive in all parts of the Universe and are spread through almost all celestial objects and the medium in between (Han, 2017). For the case of large scale objects (and so to the scale of objects considered in astronomical observations), magnetic field strengths are generally on the order of a few μG (Ferriere, 2012) and are often in very complex orientations. This implies that these magnetic fields are difficult to quantify when attempting to conduct observations directly. The outstanding questions are then what other techniques can we use in order to better understand these magnetic fields? What can they tell us about the objects which are permeated by them?

1.1. *Background*

In this research project, the aim is to answer these questions for a possible new supernova remnant (SNR) located near the Crab Nebula, but unassociated due its the distance and size, called G182.5-4.0 (see Fig. 1) (West et al., 2020). G182.5-4.0 displays characteristics of being a shell that is very compressed, thin, and straight. These qualities disagree with the characteristics that conventional SNRs demonstrate (Igumenshchev et al., 1992). Typically, SNRs in the interstellar medium (ISM) frequently display characteristics of either disk symmetry (shell elongated in a disk structure) or spheroid attributions (shell extending in all directions exhibiting a somewhat closed spherical shape) (Igumenshchev et al., 1992). However, SNR geometry is not just limited to the previous two cases. It is possible for SNRs to exhibit all kinds of shapes and sizes. One thing that is usually common between most SNRs is the fact that their shape typically forms some kind of a closed structure (Lopez, 2013). In this research, G182.5-4.0 can be seen as having open ends which directly distinguishes its unique filament structure. The two prevailing hypothesis for what this object can possibly be are as follows:

1. An Old SNR: The object is in a bizarre configuration consisting of thin and elongated filaments. If this object indeed is a SNR, then it would suggest that its shell is very compressed and is due to its presence in an unusual environment (West et al., 2020).

2. Filaments in the ISM: This object could also be a product of a very old or multiple SNRs which have

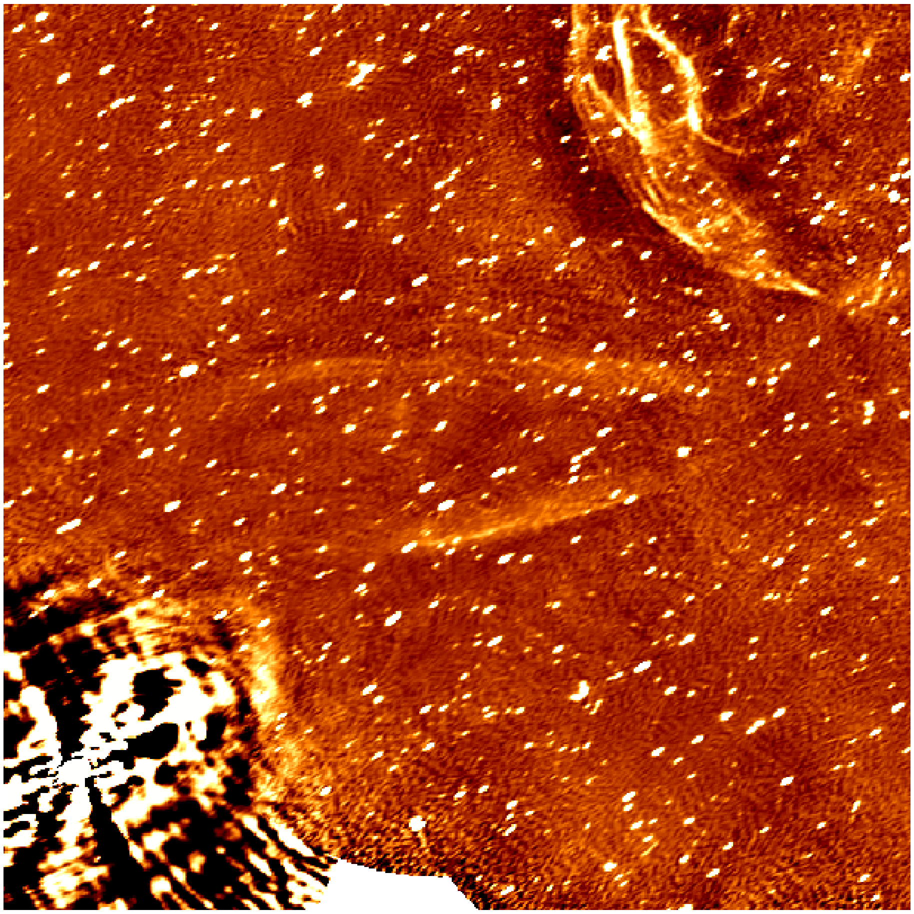


Figure 1. An image of the new SNR candidate G182.5-4.0 near the Crab Nebula. This finding is a radio observation conducted by the Dominion Radio Astrophysical Observatory Synthesis Telescope (DRAO-ST). This image is a Stokes I total intensity measurement at 1420 MHz with a resolution of 1'. In this image, we can see some identifiable structures. One being the Crab Nebula which is located near the bottom-left and the other being S147 which is a faint shell type SNR (Xiao et al., 2008) located near the top-right. The object of interest lies in the center of the image perceived as unusual structure with a very compressed, thin, and straight shell. The bright intensity point sources in this image are due to external background galaxy intensity emissions and are ignored for the examination of this object.

achieved their elongated shape due to a Galactic magnetic field (West et al., 2020).

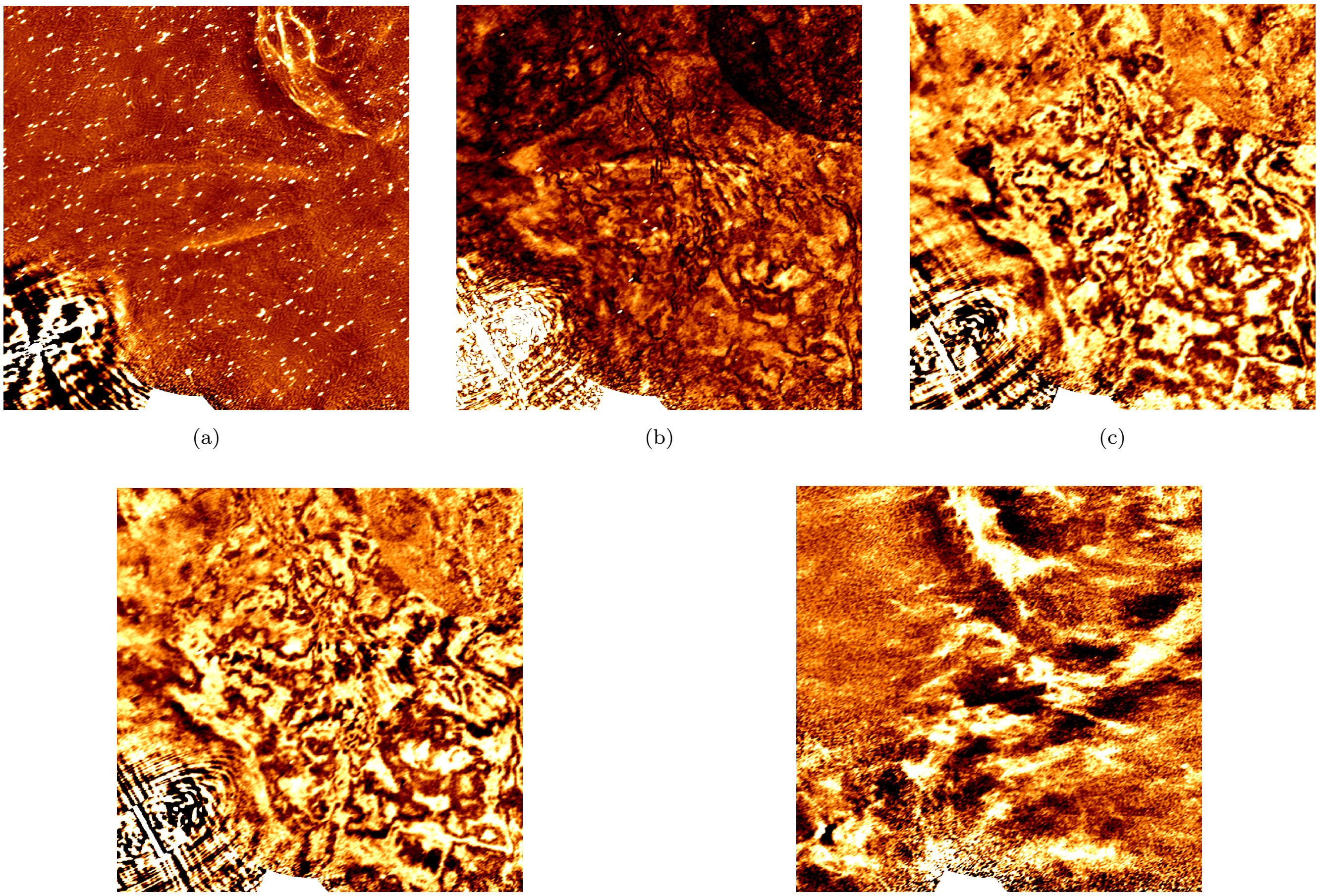
1.2. *Connection to Synchrotron Radiation*

One way to provide conclusive evidence for the presence of a Galactic magnetic field is to study radio synchrotron radiation. Synchrotron radiation is the electromagnetic radiation emitted when charged particles are accelerated in a direction which is perpendicular to their velocity (Newton-McGee, 2009). Synchrotron radiation observed in galaxies originates from relativistic electrons in magnetic fields (Han, 2017). Therefore, if synchrotron radiation is observed, we know that there is a magnetic field present. Another connection between SNRs and synchrotron radiation is that the dominant radiation emitted for SNRs is in fact synchrotron radiation which is intrinsically polarized (Han, 2017). From this, the object of study will be the most visible (highly intense) through radio observations. As is described in Sec 2.1, the main observations for the possible SNR in this study heavily relies on the DRAO-ST radio observation for G182.5-4.0 through various polarized and unpolarized Stokes parameters (Fig. 1 & Fig. 2).

1.3. *Connection With Neutral Hydrogen Fibers*

In the best case scenario, we would like to understand everything about the magnetic field which we believe is encompassing this object. This includes its magnitude (strength) and orientation (direction). One of the ways in which one can begin to understand the orientation of the magnetic field is to study in particular the neutral hydrogen (HI) fiber regions coexisting with the object (see Fig. 2(e)).

We know that there is a confirmed presence of a wind-blown HI bubble in the vicinity of this object (Wallace et al., 1999). When HI fibers are present in a magnetic



(a) (b) (c) (d) (e)

Figure 2. The Stokes parameters captured by DRAO-ST within the same region. (a) & (b) represent the I and PI Stokes parameters respectfully. (c) & (d) represent the Q and U Stokes parameters respectfully. (e) represents one slice of the HI cube data. In general, the HI cube of data contains multiple 2-dimensional data sets (images). All of the images (a)-(e) were captured at a frequency of 1420MHz and a resolution of 1'.

field, they are known to align themselves along the direction of the interstellar magnetic field (Clark et al., 2014). This means that it is then possible to apprehend the orientation of the magnetic field. If this is the case and we have an indication of the orientation of the magnetic field, this can be compared to the orientation of the object which in turn will provide valuable evidence for the explanation of what this object may be (further discussed in Sec. 2.2).

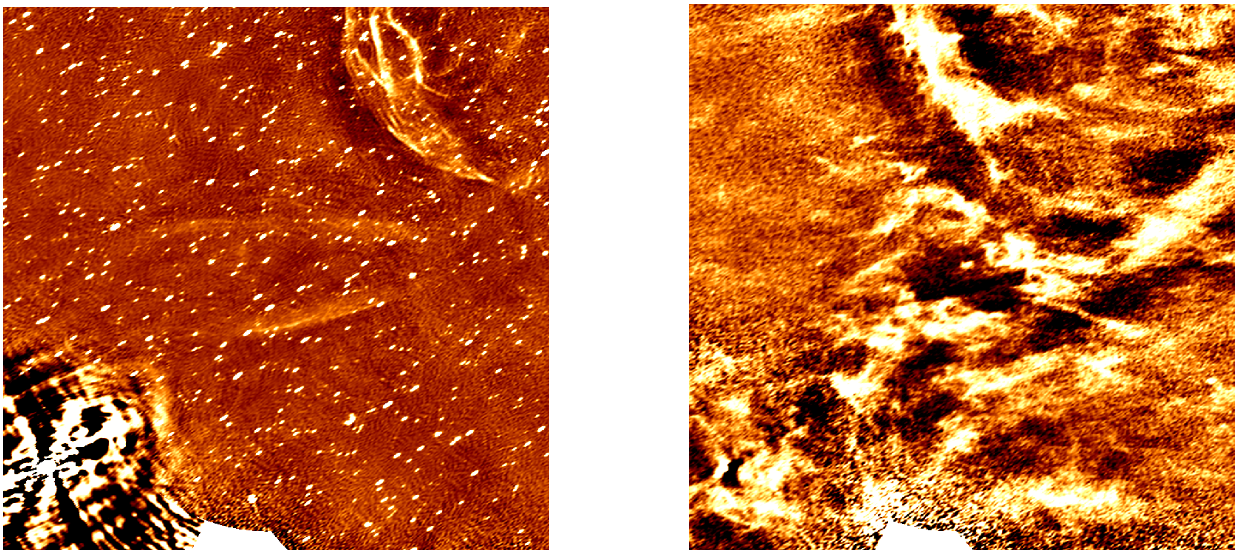
2. RESEARCH

2.1. *DRAO Observations & Data*

Using the DRAO-ST radio study on G182.5-4.0, a single data set containing five image products was derived at a resolution and frequency of 1' and 1420 MHz respectfully. The five image products correspond to a Stokes total intensity (I) image (as in Fig. 1), a Stokes polarized intensity (PI) image, the Stokes linear polarized parameters (Q and U), and compiled series of HI images (see Fig. 2). Together, these image products (Fig 2(a)-(d)) constitute the Stokes parameters. Stokes I is a measurement of the total intensity of the polarized radiation, Stokes Q and U together describe the linearly polarised components of this radiation, and Stokes PI is a combination of the previous Stokes parameters to describe the polarized intensity as a single quantity (Newton-McGee, 2009).

2.2. *Method*

As we began to explain in Sec 1.3, HI fibers are known to have a deep connection with magnetic fields. In particular, it is known that in the presence of a magnetic field, regions where HI is present will undergo a shift in orientation such that they are then aligned with the magnetic field (Clark et al., 2014). This is an extremely useful property that can aid in determining the presence of magnetic fields that would otherwise be difficult to observe and study directly.



(a) (e)

Figure 3. Here we can qualitatively observe Stokes I (a) and the HI data slice (e). These are the same figures as used in Fig. 2 however, they have been enlarged to highlight the importance of comparison between these two images. In (e), we can see abundant HI fibers in some sort of alignment which we believe to be a possible magnetic field. On the other hand in (a) we can see the Stokes I filaments of G182.5-4.0 and compare this to the orientation of the HI fibers in order to come up with promising evidence that both may be permeated by a similar magnetic field.

Using the DRAO-ST radio study, observations have already been made in the form of image products where the HI fibers can be detected and seen (Fig. 2). We would like to have a more quantitative way to monitor and provide some sort of analysis for these fibers. For this, we introduce the Rolling Hough Transform (RHT). The RHT is a way to quantify the linearity and spatial coherence of HI structures (Clark et al., 2014). It does so through running a specific algorithm through the coding software Python which is able to detect these fibers in a data set and then presents a new data set which traces their orientation (Clark et al., 2014).

Since HI fibers have the unique property of aligning with the magnetic field, we can infer details about the orientation of such a magnetic field and begin to understand some of its spatial properties. Once we have some sort of idea about the features of the magnetic field, we can then determine if G182.5-4.0 has any type of relation to the encompassing HI fibers and therefore to the magnetic field orientation. Before using the RHT to gain quantitative results, we can attempt to partially answer this question qualitatively.

We already know that HI fibers align a certain way in a magnetic field, so we have a data set cube image of the HI abundance for the area of study. We also have other image sets ((a)-(d) from Fig. 2) which focus more on the filaments and their observed and hypothesized orientation. So one beginning method for determining the presence of a magnetic field is to compare both of these images (HI and lets say Stokes I) to see if there are any matches between the two.

This is done in Fig. 3, where we can see a side by side view of the total intensity and the HI images. From this comparison, the abundance of HI fibers around G182.5-4.0 indicate first the confirmed presence of a magnetic field. Second, it can be observed that since the filaments of G182.5-4.0 also lie closely to the aligned HI fibers, this would indicate and interaction between the magnetic field and the object. From these reasons we conclude that further quantitative analysis (such as the RHT) will promise results which closely tie to the hypothesis of this object and its interaction with the present magnetic field.

3. OUTCOMES OF RESEARCH

In this research project, we would like to classify G182.5-4.0 in some form. Currently, it is believed that this object is a possible SNR. The significance of the proposed research in this project is to determine whether this assumption is true, or if we should classify this object as being something entirely different. Through studying the HI fibers which are believed to be encompassing this object and employing the RHT, we would like to derive properties of magnetic field such as its orientation. The significance of studying the magnetic field would be to narrow down the two current hypothesis (as described in Sec. 1.1) to one, or to conclude that the object does not fit into any of these hypothesis in which case further analysis would be required.

The major expected outcome for this project is a connection between the alignment of the filaments to the alignment of the HI fibers. From Fig. 3, we can observe the filaments and the HI fibers side-by-side. It is highly anticipated that there is a connection between the orientations between the two. This is because qualitatively the HI fibers seems to outline/trace the path of the filaments or vice-versa. From this, we can expect that this is caused by the local interstellar magnetic field which requires substantial attention.

4. RESEARCH PLAN

The project steps are as follows:

1. For the remaining of the month of October, the time will be spend towards getting familiar with the tools which are going to be used in this project. This includes running and understanding the input/output parameters for the RHT on sample data which is unrelated to this project. Also, any remaining doubts of the student for this project will be resolved. The beginning of October was spent doing supplementary readings provided by the advisor and gaining background knowledge in order to move forward with the proposed project.

2. For the month of November, the major goal is to get completely familiar with how to use the RHT. During this month, the RHT will be employed for this project from the experience gained in the previous month. If there are any issues with any of the understanding for the RHT, we would like to handle it during this month.

3. Since the month of December will be relatively shorter than the other months, more time will be spent running the RHT for the collected data and ensuring that it is done correctly. Applying the RHT is the bulk of the project so it has to be made sure that this process is done as correctly as possible.

4. Once the RHT is correctly employed, the months of January and February will focus on comparing the data gained for the HI fibers through the RHT to the already present G182.5-4.0 Stokes parameters data. During these months, we will be able to draw conclusions from the collected and present data from the previous months in order to classify the object G182.5-4.0.

5. The month of March will focus on gathering the conclusions of this project to write the final report.

REFERENCES

Clark, S. E., Peek, J. E. G., Putman, M. E., 2014, APJ, 1-2, 4

Ferriere, K., 2012, EAS, 24

Han, J.L., 2017, ARAA, 112, 136-138

Igumenshchev, I. V., Tutukov, A. V., Shustov, B. M., 1992, SOVAST, 245

Lopez, L. A., arXiv:1306.2638, 2-3

Newton-McGee, K. J., 2009, School of Physics University of Sydney, 6-7, 21

Wallace, B.J., Landecker, T. L., Kalberla, P. M. W., Taylor, A. R., APJS, 3

West, J., Kothes, R., Safi-Harb, S., 2020, University of Toronto, Dunlap Institute for Astronomy & Astrophysics

Xiao, L., Furst, E., Reich, W., Han, L. J., 2008, A&A, 1