Submillimeter Polarimetry and the Galactic Center Magnetic Field

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Abstract. We summarize recent Galactic center submillimeter polarimetry results from both the Hertz polarimeter operating at the Caltech Submillimeter Observatory and the SPARO polarimeter operating on the Viper telescope at the South Pole. Using a $5'$ beam, SPARO has found the large scale field within the central 200 parsecs to be parallel to the plane of the Galaxy, suggesting a toroidal field. On smaller ($20''$) scales, the Hertz data within the central 50 parsecs show a field that is more complex. In denser regions, the field is generally parallel to the plane, consistent with the field observed by SPARO. In less dense regions, the field is generally perpendicular to the plane, consistent with the field traced by the brightest long, thin synchrotron structures known as the non-thermal filaments (NTFs). These results support the idea that an initially poloidal field in the Galactic center is sheared by differential rotation into a toroidal configuration in regions where the gravitational energy density is greater than that of the magnetic field. In addition, we present new Hertz data on the Dust Ridge, an arched structure of submillimeter emission extending from the Galactic center Radio Arc to Sagittarius B2.

1. Introduction

The role of magnetic fields in our Galactic center is not well understood despite its suspected importance in the dynamics of the region. In turn, the Galactic center offers the most detailed view of the physical conditions and processes at the centers of active galaxies.

As new instruments come online, far-infrared/submillimeter polarimetry is beginning to provide new information concerning the magnetic fields in the cold dust that permeates these regions. In this contribution, we summarize recent submillimeter and far-infrared polarimetry of the Galactic center and present new data with a preliminary analysis.

2. The Large Scale Field

The inferred magnetic field vectors shown in Figure 1 are from Novak et al. (2003). They were obtained with the SPARO 450 μm polarimeter at the South Pole's Viper telescope. The angular resolution of each data point is $5'$. The contours in Figure 1 are 850 μm continuum emission (Pierce-Price et al. 2000), and the background image is 90 cm continuum emission (LaRosa et al. 2000).

Novak et al. (2003) point out that the field as measured by SPARO is generally parallel to the plane of the Galaxy in projection. This is in stark contrast to the direction of the field that is traced by the brightest non-thermal filaments that run perpendicular to the plane in the radio emission. Novak et al. (2003) suggest that these two fields can coexist in a scenario in which an initially poloidal field is sheared into a toroidal one in regions where the gravitational energy density is greater than the magnetic energy density.

This model, originally conceived by Uchida, Shibata, & Sofue (1985), predicts that the magnetic field component that is parallel to the line-of-sight should change signs in adjacent quadrants of the Galactic coordinate system. Novak et al. (2003) reference a sample of Faraday rotation measurements of NTFs in the central molecular zone (CMZ) that support this argument.

3. Sagittarius A

On smaller spatial scales, the inferred magnetic field is more complex. The left hand side of Figure 2 shows magnetic field vectors from Chuss et al. (2003) that span selected regions of the central 50 parsecs of the Galaxy. The vectors are inferred from various studies of far-infrared and submillimeter polarimetry (Dotson et al. 2000; Novak et al. 2000; Chuss et al. 2003).

The projected magnetic field direction varies across the central 50 parsecs. In some areas, the small scale field follows the large scale field measured by Novak et al. (2003). In other regions, the field deviates significantly from this toroidal configuration. Chuss et al. (2003) find that the field direction and the submillimeter flux (which is a measure of mass) are related in the following way. In regions of low submillimeter flux, they find the field tends to be oriented perpendicular to the plane. In regions of higher submillimeter flux, the field is generally parallel to the plane.

Chuss et al. (2003) explain this correlation using a similar idea to that invoked by Novak et al. (2003). In this case, they note that the central 50 parsecs consists of regions of matter of varying density. In the underdense regions, the magnetic field energy density can support itself against gravitational forces, and thus the primordial poloidal field is preserved. In overdense regions (the molecular clouds), the field is weaker than the other forces in its environment and gets sheared by the forces local to the molecular clouds. Because a majority of the cloud motions lie close to the plane in projection, a large fraction of these fields get sheared into a direction parallel to the plane.

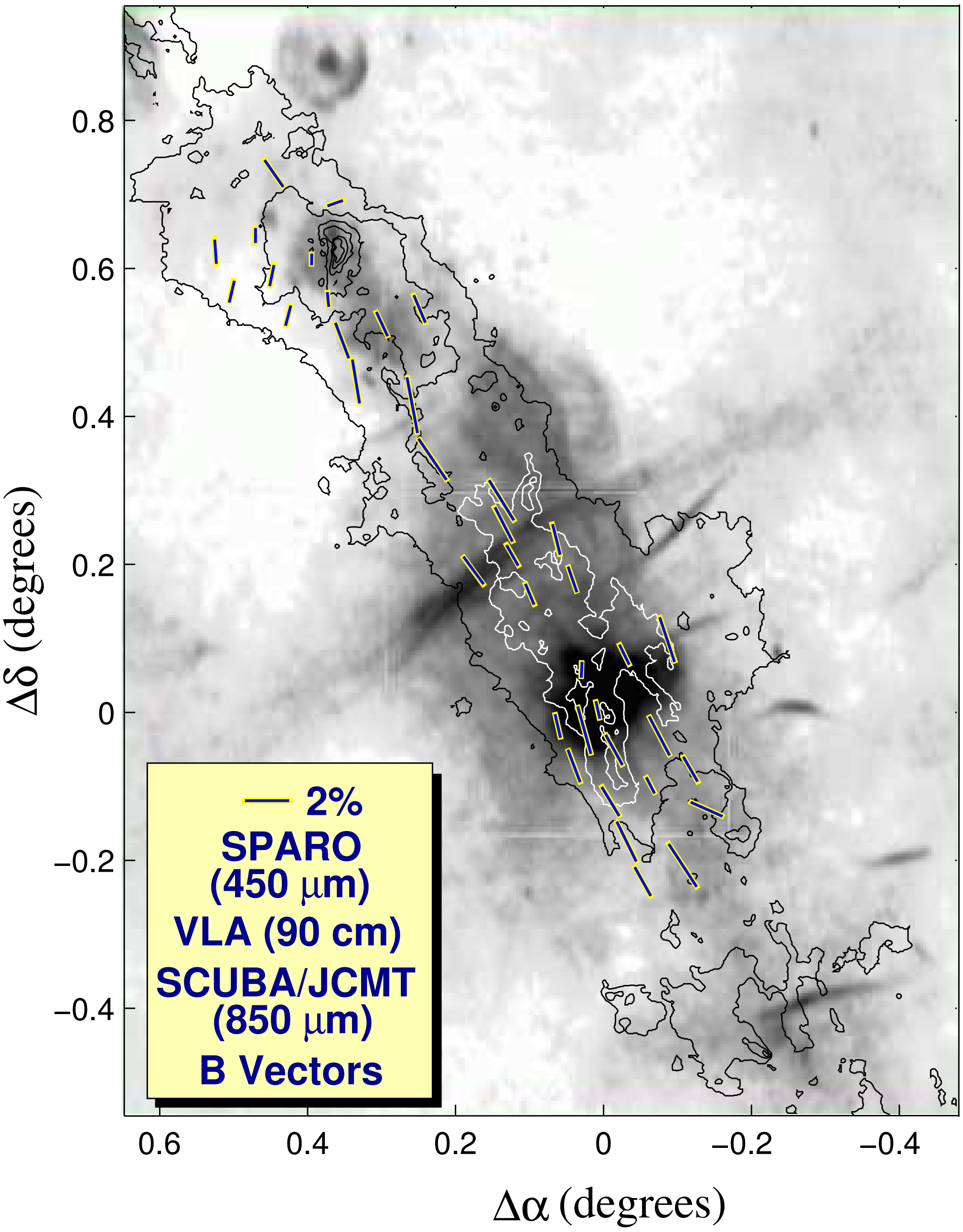

Figure 1. The SPARO Galactic center data set (Novak et al. 2003) is superposed on a 90 cm continuum image (LaRosa et al. 2000). The contours represent dust emission as measured by SCUBA at 850 μm (Pierce-Price et al. 2000). The vectors represent the magnetic field directions as inferred from 450 μm polarimetry with a 5′ beam. The coordinate system is centered on Sagittarius A*.

4. New Observations

The inferred magnetic field lines shown on the right hand side of Figure 2 were obtained at the Caltech Submillimeter Observatory using the University of Chicago's Hertz Polarimeter (Schleuning et al. 1997). The angular resolution of a Hertz beam is $20''$, and the bandpass is 350 μm with a $\Delta\lambda/\lambda$ of 10%. The vectors shown in Figure 2 each have a polarimetric signal-to-noise greater than 3.

A detailed interpretation will be given for these data in a future paper. In the following sections, we give preliminary impressions on how these data fit in the context of the previously published data.

4.1. The Dust Ridge

The Dust Ridge is a string of molecular clouds that extend from just north of the Radio Arc to Sagittarius B2. The magnetic field seems to have a coherent structure across the length of the Dust Ridge. It starts out at the southwestern end aligned parallel to the Galactic plane. As the Dust Ridge arches away from the plane, the field vectors rotate to a perpendicular configuration and then back to a parallel structure as the Dust Ridge bends back towards Sagittarius B2 and the Galactic Plane.

These new data suggests that the field in the Dust Ridge is part of a global Galactic center magnetic field. The field seems to be parallel to the plane in the regions closer to the Galactic plane. As Galactic latitude increases, the field returns to a poloidal configuration. This large scale coherence of the field is consistent with the results from the Sagittarius A region.

4.2. Sagittarius B2

Sagittarius B2 is a giant H II region/molecular cloud complex located at the edge of the central molecular zone. At $\sim 10^7$ $M_{\odot}$(Tsuboi, Handa, & Ukita 1999), it is the most massive molecular cloud complex in the Galactic center and the site of significant star formation.

The magnetic fields inferred from submillimeter polarimetry are shown on the right hand side of Figure 2. Sagittarius B2 is the large emission region in the upper left hand side of the panel. The field lines in the case of Sagittarius B2 appear to have a spiral shape. Such a geometry indicates that the field in this region is dominated by the local gravitational effects of the Sagittarius B2 complex. In the context of a global magnetic field that can be locally sheared by gravitational effects, Sagittarius B2 may offer an extreme example of local forces dominating the field structure.

5. Summary

We have presented preliminary submillimeter polarimetry results for both the Dust Ridge and Sagittarius B2. These new data complement previously published far-infrared and submillimeter polarimetry data of the Galactic center and continue to shed light on the structure of the Galactic center magnetic field.

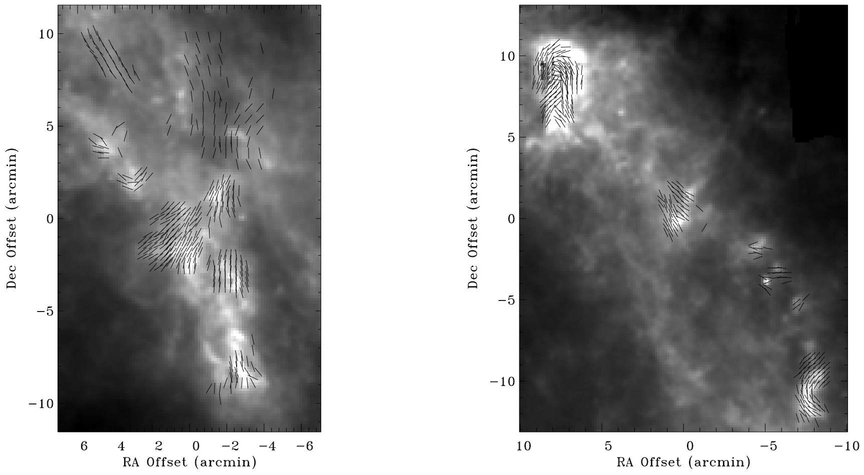

Figure 2. The figure on the left shows the magnetic field vectors in the Sagittarius A region as given in Chuss et al. (2003). The origin of the coordinate system is $\alpha = 17^{\mathrm{h}}45^{\mathrm{m}}50\overset{\mathrm{s}}{.}6, \delta = -28^{\circ}57'23''$. The figure on the right shows the new data in Sagittarius B. The origin of the coordinate system is $\alpha = 17^{\mathrm{h}}46^{\mathrm{m}}45\overset{\mathrm{s}}{.}2, \delta = -28^{\circ}31'52''$. In both cases, magnetic field vectors are superposed on 850 μm flux (Pierce-Price et al. 2000).

Future observations with greater spatial and spectral coverage offer a promising tool for providing further insight into the role of magnetic field in our Galactic center.

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