A Magnetic Field Study Using Polarized Emission from Dust of Nearby Starburst Galaxies

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Abstract. We present $350\,\mu$m polarization observations of dust in the nearby starburst galaxies M 82 and NGC 253, that were obtained with the SHARP instrument on the Caltech Submillimeter Observatory in Hawaii. The SHARP data allow a "penetratred" view of the dense, optically dark regions of these galaxies nuclear regions, enabling field structures, both within the star-forming nuclear disk and galactic halo. Therefore, the observations allow an examination of field components predicted by magnetic-dynamo and dynamo-regeneration theories or a blow out of fields by rapid star-formation in these galaxies.

1. Introduction

Nearby disk galaxies as well as our own galaxy are observed to have large-scale magnetic field structures with strengths on the order of a few micro-Gauss (e.g., Beck 2000; Rand & Kulkarni 1989). The generation of such magnetic field structures and strengths has yet to be fully explained. Some sort of magnetic dynamo mechanism is probably in place within these galaxies capable of generating and amplifying "seed" magnetic fields. The actual nature of such dynamos, their interaction with and importance to other galaxy phenomena (e.g., spiral arms, connectivity between diffuse and dense clouds, and star formation), and the origin and strength of the "seed" magnetic fields are in the early stages of being understood. Observations of the large-scale magnetic field structure in galaxies, particularly of galaxies in different phases of development, will help constrain galactic dynamo models.

We undertook a program with the SHARP instrument (Novak et al. 2004) on the Caltech Submillimeter Observatory (CSO) in Hawaii in order to observe the magnetic field structure in two nearby submillimetre (submm) galaxies undergoing starbursts, M 82 and NGC 253. Such periods of vigorous star formation may enhance magnetic field generation and amplification (Balsara et al. 2004). To date, the program observations have mapped submm continuum emission that is polarized $> 0.5\%$ from the nuclear disks in M 82 and NGC 253; and future submm mapping of these and similar galaxies should aim to provide polarization maps $> 3\sigma$, both within the star-forming nuclear disk and in the galactic halo. As described below, such new observations will help discriminate between dynamo/dynamo-regeneration theories vs. blow-out of fields by rapid star-formation.

2. Observationally Studying Galactic Magnetic Field Structures

Edge-on galaxies provide an opportunity to study the magnetic field structure orthogonal to the plane of the disk of a galaxy. The ratio of the strengths of the halo magnetic field to the disk field in a galaxy should be proportional to the ratio of that galaxy's cyclonic motion to differential rotation (Ruzmaikin et al. 1988). Beck (2000) observed edge-on galaxies at radio wavebands and summarized that in general these have relatively weak polarized synchrotron emission near the planes of their disks, probably due to depolarizing effects such as tangled fields along the line-of-sight and Faraday rotation, and not all galaxies have observable halos in the radio. Those that do show bright extended halos are usually harboring active starbursts to some degree; two in particular are the starburst galaxies M 82 and NGC 253. The polarized synchrotron emission in the halo of NGC 253 implies magnetic field lines, which are predominantly parallel to the plane of the disk (Beck at al. 1994). However, Reuter et al. (1994) found that the magnetic fields in the inner halo near the center of M 82 were more poloidal in nature. In regards to M 82, the poloidal field structure may not be due to dynamo effects; the field structure may be caused by gas outflows from the starburst in M 82 (Reuter et al. 1994). But, this seems not to be happening in the starburst NGC 253. However, there is some near-IR polarization evidence (after effects of scattering are removed) in M 82, that there is a large-scale poloidal field in the nuclear region of the galaxy and a toroidal field in the plane of the disk further out (Jones 2000). Our preliminary data of M82 (Figure 1 left), which are not contaminated by scattering, additionally imply a toriodal field in the halo of M82. The radio, near-IR, and submm polarimetry presented here are filling in different parts of the magnetic field geometry; however, deeper submm observations and the resulting polarization vectors that should be possible with future more sensitive instruments on SOFIA (http://www.sofia.usra.edu/) and ALMA (http://www.almaobservatory.org/) are still required.

3. The Uniqueness of the Current Submm Polarimetry of M 82 and NGC 253

Both NGC 253 and M 82 exhibit very low synchrotron polarizations within the planes of their disks, especially in their nuclei. This could be due to the depolarizing influences exacerbated by the starbursts. In an attempt to measure the magnetic field structure within the planes and nuclei of these galaxies, we we undertook SHARP/CSO observations of the polarized dust emission at 350 μm in these regions. The 350-μm emission does not suffer from Faraday rotation and suffers less from line-of-sight effects than synchrotron emission, since the 350-μm emission is more localized in the nuclei of these galaxies than is the synchrotron emission. In addition, the SHARP/CSO beam at 350 μm is smaller than the effective beamsizes of the synchrotron polarization maps.

Polarimetry mapping of NGC 253 and M 82 in the submm can directly image the magnetic fields aligning cold dust grains that emit polarized continuum. The data could thus allow a determination of whether the magnetic field lines in the halos of these galaxies trace dynamo-regeneration of fields or fields blown out by rapid star formation in the ring, that are respectively predicted to be parallel or perpendicular to the plane of the galaxy (Han 2008; Reuter et al. 1994). With reasonably high spatial resolution observations and the optically-thin nature of the submm continuum, the data can allow a "penetrated" view of the dense, optically dark regions of NGC 253's and M 82's nuclear regions, enabling spatial mapping of the galaxy's magnetic field structure within its star-forming disk or inner, nuclear region. The presented preliminary data already and incomplete show that the submm continuum from patches in the dense, nuclear region and below and above the disk is polarized, suggesting that the fields in some areas of the disk and inner halo are very ordered; and, if mapped at significant ($\geq 3\sigma$) signal to noise with future more sensitive instruments, the maps can be compared to the field directions predicted by theory.

Recently, Balsara et al (2004) described how starbursts can provide fast dynamo environments, enabling magnetic field growth at rates faster than those possible using mean-field dynamo models, the dynamo model usually associated with normal, disk-galaxy environments. Starbursts could be a crucial link in the growth of proto-galaxy "seed" fields to the field strengths seen in normal galaxies today. As mentioned above, deeper submm observations and the resulting polarization vectors of M 82 and NGC 253 and similar galaxies, that should be possible with future more sensitive instruments on SOFIA and ALMA, should provide observational evidence of such a link in the growth of proto-galaxy "seed" fields to the field strengths seen in normal galaxies today.

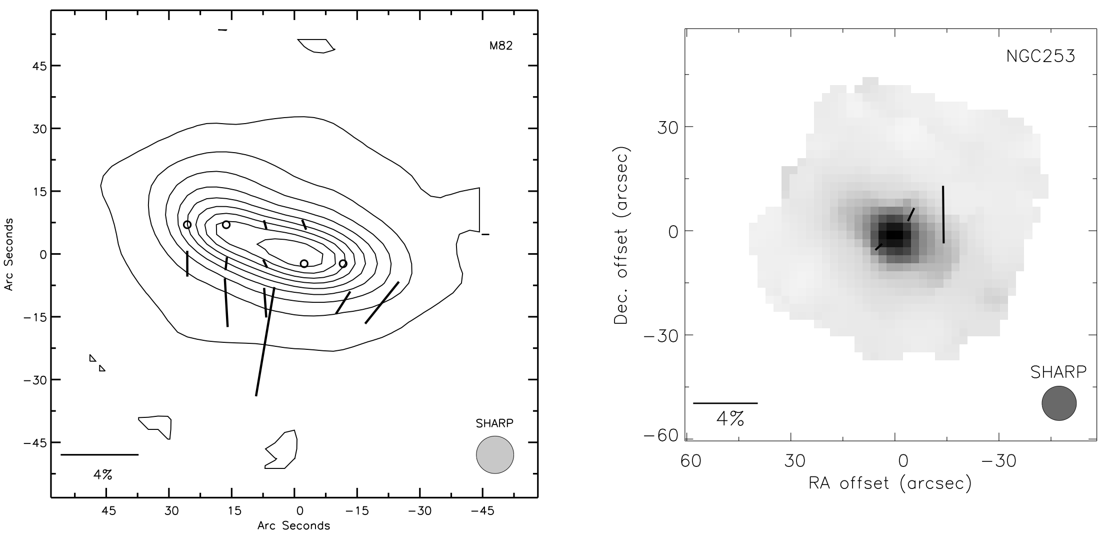

Figure 1. *Left:* Preliminarily reduced $\sim 3\,\sigma$ polarization vectors of the 350 μm continuum emission of M 82 obtained with SHARP. The overlaid circles indicate polarization 2σ upper limits $< 0.75\%$. *Right:* Two to 2.7 sigma polarization vectors of the 450 μm continuum emission of NGC 253 obtained with SHARP. The keys in both figures represent a polarization vector of 4% and the SHARP beam of $9''$. Contours *(left)* and gray-scale *(right)* are als from SHARP.

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Facilities: Caltech Submillimeter Observatory

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