ASKAP Study of Cosmological Origin of Magnetic Fields in Spiral Galaxies [1]

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ABSTRACT

We propose ASKAP Faraday RM (rotation measure) mapping of magnetic field configurations in spiral galaxies. We aim at clarifying the cosmological origin model of the S (bisymmetric Spiral), R (Ring) and V (central Vertical) magnetic fields, which are superposed by D (dynamo) fields. We strategize the observations into Faraday RM mapping of the

(1) Central V fields in nearby spirals;

(2) Global S and R fields, and S-R transition;

(4) Connection of S field to intergalactic magnetic field;

(3) Tight D (dynamo) fields and their fraction in SR fields.

Subject headings: Magnetic fields, Rotation measure, spiral galaxies, linear polarization

1. GALACTIC MAGNETISM

The origin of large-scale magnetic fields in spiral galaxies is a mystery for its topological uniqueness. Two major ideas to explain the origin of magnetic fields have been suggested: dynamo amplification of seed field and primordial origin (Sofue, et al 1987; Beck et al. 1996). Large-scale magnetic fields in galactic disks of spiral galaxies show bisymmetric spiral (BSS; hereafter S), ring (R) or axisymmetric (ASS) configuration (Fig. 2). The R and ASS field configurations are topologically the same, unless there exists a magnetic monopole for ASS, and we represent these two cases as R. The central global fields are vertical (V). On these global fields, D (dynamo) fields are superposed, which are fluctuations and random fields due to dynamo mechanism.

The S, R, D fields are deeply coupled with the interstellar physics, star formation, gaseous spiral structure, and accretion processes, because of the comparable magnetic and gaseous energy densities in the ISM. They play crucial roles in the disk-halo connection and galactic-scale circulation of gas via magnetic inflation and local jets. Central V field energy often exceeds the gaseous kinetic energy, accelerating the angular momentum loss and accretion, and produce galactic scale outflows and cosmic jets.

2. PRIMORDIAL - S, R, V - FIELDS

2.1. S (Spiral) Field

If the S field is a structure open to the intergalactic space, it can uniquely be understood as due to the winding up mechanism of larger-scale primordial magnetic field. A large scale uniform magnetic field wound up with the rotation of the diskis maintained at a constant pitch angle by reconnection among the field lines near the neutral sheets, regulated in a time scale determined by Alfven speed on the order of $t \sim 2 \times 10^7$ years, shich is shorter than the rotation period of the galaxy.

2.2. R (Ring) Field

It may happen that the primordial magnetic field before galaxy formation was not uniform.

[1] † Everybody is welcome for collaboration, or joint observations would be possible with similar proposals.

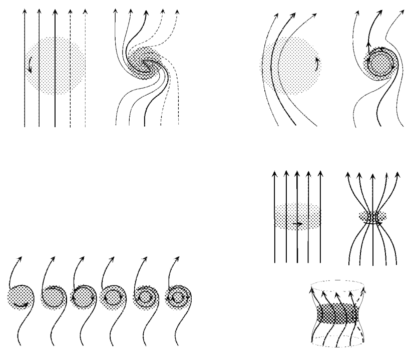

Fig. 1.— Cosmological origin of the topology of S (tl), R (tr), R amplification (bl) and V (br) fields.

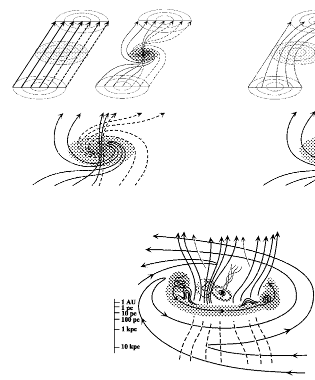

Fig. 2.— Cosmological unified origin of the topology of S, R and V fields (Sofue et al. 2009)

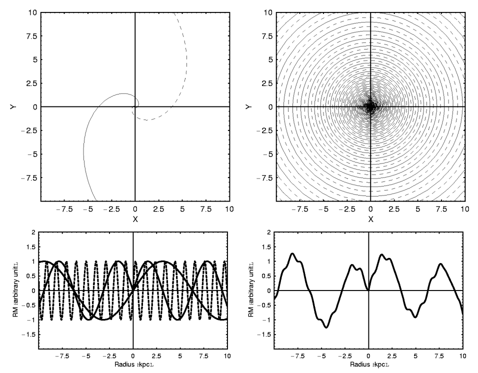

Fig. 3.— A seed field is wound up to maitain an S field (tl), on which tight D fields are superposed (tr). Schematic RM variations along the major axis (or along an anulus) for S(symmetric oscillation), R (antisymmetric), and D (tight oscillation) (bl), and their sum with amplitudes 1, 0.25 and 0.1 for S, R and D (br).

Then, part of the amplified S field will be reconnected and create an R field inside a certain radius. Once a ring field is created, it will shrink to attain smaller radius due to the magnetic tension and disk gas accretion toward the center. Accordingly, the bisymmetric component, left over in the outer disk, will be wound again by the differential rotation of the galaxy. When it is wound further, another reconnection takes place, and creates a second ring. Thus, the R field strength is amplified, as the galaxy rotates and contracts.

2.3. V (Vertical) Field

The strong vertical field in the Galactic Center (e.g. LaRosa et al. 2000) has been a mystery, since the dynamo mechanism cannot create a field stronger than the equipartition value. The nearby spirals M31, M81 (see Beck 2008) and M104 show vertical central fields (Krause et al. 2008). NGC 253 shows "whole plane Vertical filaments", linking the disk and deep halo (Sofue et al. 1994). A unique explanation of V field is to attribute it to the fossil of primordial vertical field trapped to the forming galactic disk. The difusion time of the V field accross the disk is $t \sim 5 \times 10^8$ years, much longer than the rotation time. Thus, the field is secularly accumulated to the center, being twisted to cause angular momentum loss of the disk gas, further accelerating the disk accretion and field amplification. The magnetic energy density becomes comparable to the kinetic energy of gas. In fact, a V field as strong as a few mG is observed in the Galactic Center, having energy density as high as that of the rotation energy density. Such strong twisted field produces vertical cosmic jets.

2.4. Unified Model of S, R and V Fields

The principal question to the above primordial hypothesis is why the two or three different topologies, S, R and V, are observed simultaneously in the same galaxy. This question is answered if we consider a tilted original magnetic field (Fig. 3). The strength of the vertical component is amplified simply obeying $B_{\rm v} \sim B_{0{\rm v}}(R/R_0)^{-2}$, where R is the radius and R_0 is the original radius within which the original field was enclosed. When $B_{\rm v}$ reaches a certain critical strength, the tension of the field will become strong enough so that the steroidal (spiral) field is slipped off from the disk plane to catch up the original tilted off-plane field.

The amplified vertical field is further accumulated to produce strong V field in the central disk. Thus, the outer field is wound up to form S configuration, and a V field appears in the central region at the same time.

2.5. D Field with Tight Reversals

The $\alpha\omega$ dynamo amplifies the field strength in the gas disk. The dynamo amplifies seed fields, which are dominated by cloud size fields with scales ~ 100 pc whose directions are random. Unless an ordered (therefore cosmological) field existed, the dynamo can create only tightly reversing fields, keeping the averaged field flux (e.g. in ~ 1 kpc) to be zero. Such reversing fields may be observed by high-resolution observations with resolution better than about ten parsecs.

3. TECHNICAL REQUIREMENTS: FARADAY RM POLARIMETRY

3.1. THE PURPOSE

We propose Faraday RM Mapping of nearby spiral galaxies. We observe wide fields centered on large-size galaxies like NGC 253. We stress that such a wide field mapping of a galaxy is very difficult with the narrow FoV of VLA.

We aim at clarifying the:

(1) Central V fields and their connection to halo field at high angular resolution;

(2) Global S-R field transition in the disk at medium/low resolution;

(3) Topological connection of S field to intergalactic (primordial) magnetic field at high-sensitivity;

(4) Tight D fields (dynamo) vs primordial origin ratio by high-angular resolution.

3.2. FARADAY POLARIMETRY with RM SYNTHESIS

We use the ASKAP Faraday polarimeter at 1.8 (or 1.4) GHz to map the intrinsic magnetic vectors in the galaxies. A Faraday polarimeter consists of multi-narrow band polarimeters with appropriate band separation, so that the Faraday rotation angles among the bands are within $\pi/2$, in order to avoid the *pi* rotation ambiguity of RM determination.

As the rotation measure is expected to be large in the galactic centers, the band resolution (separation) $\Delta\lambda$ must be as narrow as $\Delta\phi = RM\Delta\lambda^2 < \pi/2$, or $\Delta\nu < \pi\nu/(4RM\lambda^2)$. So, we require a band separation of $\Delta\nu \sim 50 - 100$ kHz for $RM \sim 1000$ rad m^{-2}, and 500 MHz for 100 rad m^{-2}. ALso, in order for the internal band depolarization to be samll enough, the RM resolution (bandwidth) must be accordingly narrow, e.g. 50 kHz for 1000 rad m$-^2$, and 500 kHz for 100 rad m^{-2}. We then determine the RM (line of sight B vector) and intrinsic polarization angle ϕ_0 (intrinsic B-vector direction + 90$\circ$) by the RM synthesis ($\phi - \lambda^2$ plot) without ambiguity of π rotation.

3.3. TARGET GALAXIES

We list large-size nearby galaxies in Table 2. We put priority to brighter and larger galaxies, e.g. NGC 253, M83, M104, NGC 55, and NGC 300. As the ASKAP FOV is much larger than those for individual galaxies, we may be able map the galaxy-intergalactic connection, depending on the integration time. The list and requested time are provisional, and should be fixed according to the ASKAP final status before observations.

3.4. OBSERVING TIME REQUESTED

In order to obtain 0.02 K rms polarization maps with $30''$ synthesized beam, we require 160 hours integration time for one frequency per one galaxy. The required parameters are listed in Table 1. The total time requested is approximately 800 hours, given the number of target galaxies is 5. The number of targets may be negotiated for the alocated time. We observe in the order of the priority as given in the target list.

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Table 1: OBSERVATION PARAMETERS

Obs. Mode	Faraday polarimetry with RM Synthesis
Frequencies	1.8 GHz or 1.4 GHz
Bandwidth	50 - 500 kHz
No. of pol.	4 (I, Q, U)
Synth. beam	$30''$
Sensitivity (rms)	0.02 K
Survey Time	
Integ. time	160 h per galaxy
Survey speed	One FOV per galaxy
No. of galaxies	5
Total obs. time	800 h

Table 2: TARGETS Nearby Big Galaxies

Galaxies	(RA, δ) (J2000.0) , Size (degxdeg)*
NGC 253	00h47m33.120s -25d17m17.59s, 2x1
NGC 300	00h54m53.48s -37d41m03.8s , 1x1
NGC 55	00h14m53.60s -39d11m47.9s, 1x1
M83	13h37m00.950s -29d51m55.50s, 0.5x0.5
M104	12h39m59.4318s -11d37m22.996s, 0.5x0.5

* Size including halo and outskirts, two to three times the optical disk.