

Uncovering star formation feedback and magnetism in galaxies with radio continuum surveys

Fatemeh S. Tabatabaei^{1,2,3}

¹ Instituto de Astrofísica de Canarias, Vía Láctea S/N, E-38205 La Laguna, Spain

² Departamento de Astrofísica, Universidad de La Laguna, E-38206 La Laguna, Spain

³ Max-Planck-Institut für Astronomie, Königstuhl 17, 69117 Heidelberg, Germany

Abstract

Recent studies show the importance of the star formation feedback in changing the energetic and structure of galaxies. Dissecting the physics of the feedback is hence crucial to understand the evolution of galaxies. Full polarization radio continuum surveys can be ideally performed to trace not only star formation but also the energetic components of the interstellar medium (ISM), the magnetic fields and cosmic ray electrons. Using the SKA precursors, we investigate the effect of the massive star formation on the ISM energy balance in nearby galaxies. Our multi-scale and multi-frequency surveys show that cosmic rays are injected in star forming regions and lose energy propagating away from their birth place. Due to the star formation feedback, cosmic ray electron population becomes younger and more energetic. Star formation also amplifies the turbulent magnetic field inserting a high pressure which is important in energy balance in the ISM and structure formation in the host galaxy.

1 Introduction

To understand the evolution and appearance of galaxies it is crucial to study the ISM/star formation interplay in galaxies. Most of our information about the ISM relates to its massive component, the gas and its various phases. Its interplay with star formation can be addressed through the famous Kennicutt-Schmidt relation [4, 7] between the rate of star formation and the gas density. The Herschel and Spitzer space telescopes have made major breakthroughs in this area, by mapping the emission from dust and the gas content of galaxies. However, not much is known about the connection of star formation and the most energetic ISM components, the cosmic rays and magnetic fields, and their role in structure formation in galaxies. As an extinction-free tracer of star formation, the radio continuum emission provides crucial complementary information about magnetic fields and cosmic ray electrons (CREs).

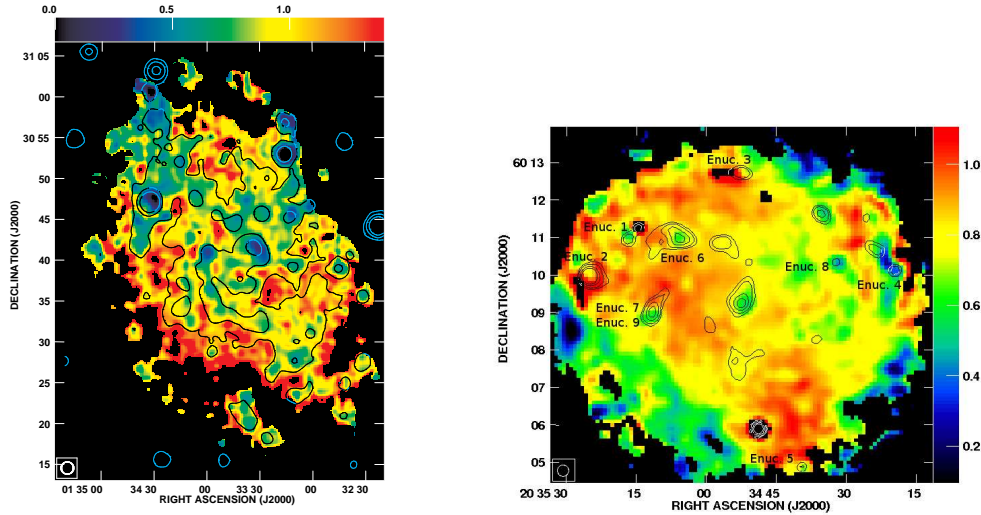


Figure 1: *Left:* M33- The nonthermal spectral index (α_n) map obtained from the nonthermal radio fluxes at 3.6 and 20 cm. The spiral arms and giant HII regions are indicated by contours of the total radio emission at 3.6 cm superimposed. *Right:* NGC 6946- α_n mapped using the same method as in M33. The 9 giant HII regions are indicated. The bars show the α_n values.

New developments in radio correlators and polarimeters will revolutionize radio astronomy in the next years. Radio continuum observations with the forthcoming SKA and its pathfinders such as VLA, GMRT, and LOFAR are paramount to study the production and propagation of CREs, the star formation–ISM interplay, and the role of magnetic fields in structure formation and energy balance in galaxies.

In this proceeding, I present parts of our studies performed on resolved scales as well as globally in nearby galaxies as ideal laboratories for studying astrophysical processes that regulate the evolution of galaxies, among them the interplay between the star formation and the ISM.

2 Resolved nonthermal emission from galaxies

The radio continuum emission from galaxies observed in cm-waves is mainly due to two different radiation mechanisms, the nonthermal synchrotron emission and the thermal free-free emission. The nonthermal emission depends on the magnetic fields and CRE number density. Therefore, separating the thermal and nonthermal emission is key to understand the sources

of CREs and their distribution in galaxies and in estimates of the magnetic field strength. The classical method requires accurate absolute measurements of the brightness temperature at high and low radio frequencies and needs a prior knowledge of the nonthermal spectral index (α_n , $S_\nu \sim \nu^{-\alpha_n}$). Propagating and interacting with matter and energy in the ISM, CREs cool and their energy spectrum changes depending on the environment. Hence, a fixed α_n is not a correct assumption when obtaining the distributions of the nonthermal emission and the CREs/magnetic fields across galaxies. For M33, we developed a thermal/nonthermal separation method based on a thermal radio template (TRT) leading to the first map of the pure nonthermal spectral index in a galaxy [8]. In star forming regions, the nonthermal spectrum is flatter ($\alpha_n \sim 0.6$, typical spectral index of supernova remnants) than in the inter-arm regions and outer parts of M33 ($\alpha_n \sim 1.0$, typical spectral index of synchrotron/inverse Compton loss), in agreement with the energy loss theory of CREs propagating from their places of birth (Fig. 1). The mean α_n across M33 is 0.95. Separating the thermal and non-thermal emission in other nearby galaxy with higher SFR, NGC 6946, a flatter spectrum is obtained ($\alpha_n \sim 0.8$) [10]. If this is due to the star formation feedback and if a general dependency exists in galaxy samples have been impossible to address based on the classical separation method. This is investigated in detail in our global study (see Sect. 4).

3 Distribution of the magnetic field strength in galaxies

The equipartition magnetic field strength depends on the nonthermal intensity and spectral index α_n [1] and hence its local variation can be investigated using the maps of the pure nonthermal emission. The TRT separation technique has allowed mapping the magnetic field strength in M33 [9] and NGC 6946 [10]. In both galaxies, the magnetic field strength is correlated with the SFR surface density (Fig. 2). This correlation is more likely due to the turbulent component of the magnetic field, as the SFR surface density has a tight correlation with the turbulent field. This shows an enhancement of the turbulent magnetic field due to star formation feedback, such as supernova and strong shocks. As a possible mechanism, small-scale magnetic fields could be amplified in star forming regions by a turbulent dynamo mechanism where kinetic energy converts to magnetic energy (see e.g., [2] and [3]).

We note that there is no correlation between the large-scale, ordered magnetic field and SFR surface density in galaxies, as in the case of M33 and NGC 6946 (Fig. 2). Studying a sample of non-interacting/non-cluster galaxies, we found a correlation between the large-scale magnetic field strength and the rotation speed of galaxies (Fig. 3) which shows the effect of the gas dynamics in ordering the magnetic fields in galaxies [11].

4 Radio SEDs of galaxies

Studying the spectral energy distribution (SED) provides significant information on the origin, energetics, and physics of the electromagnetic radiation in general. We have performed a coherent multi-band survey of the mid-radio (1-10 GHz, MRC) SEDs in a statistically meaningful galaxy sample, the KINGFISH (Key Insights on Nearby Galaxies; a Far-Infrared

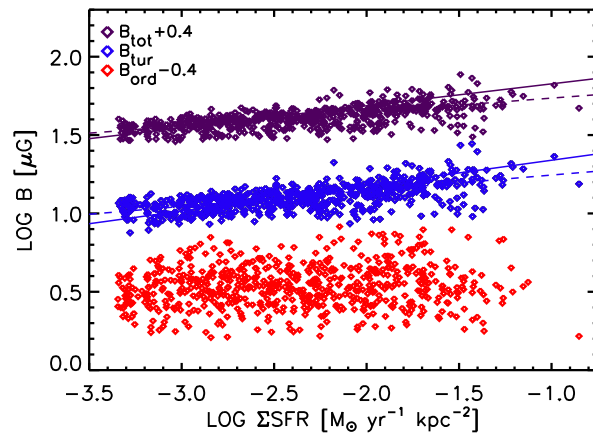


Figure 2: Resolved magnetic field strength vs. the star formation rate in NGC 6946 [10]. Blue symbols show the turbulent magnetic field, red symbols the ordered magnetic field (shifted by -0.4 along the Y axis), and purple symbols the total magnetic field (shifted by +0.4 along the Y axis). The ordered magnetic field does not correlate with the SFR.

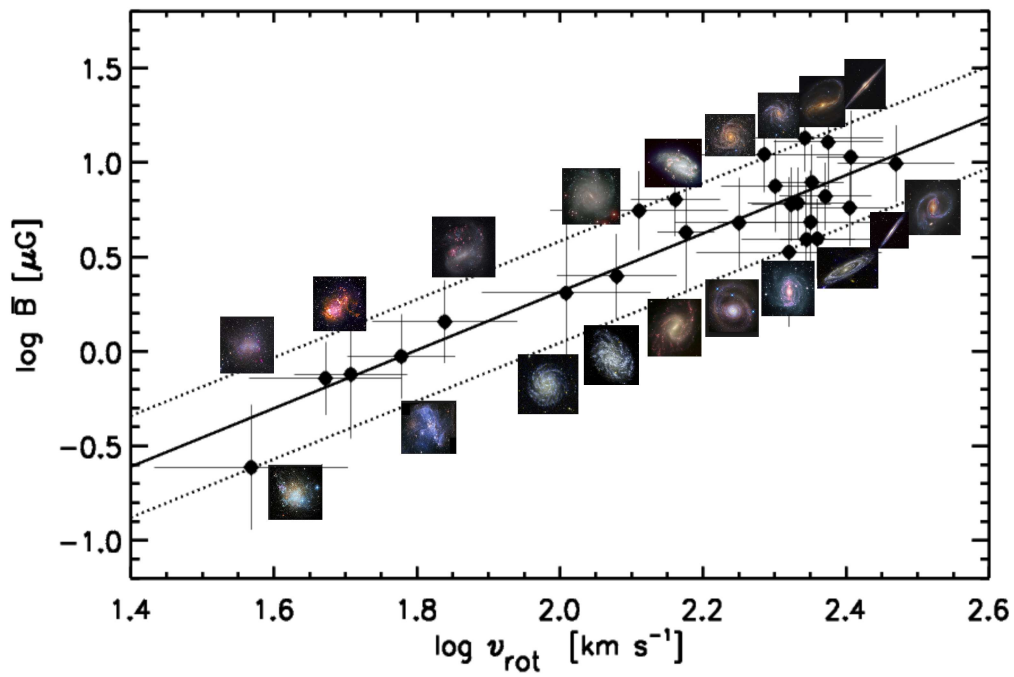


Figure 3: Strength of the large-scale magnetic field versus the rotation speed in nearby galaxies [12].

Survey with Herschel [5]) with the 100-m Effelsberg telescope (PI: E. Schinnerer). The Effelsberg observations at 1.4 GHz, 4.8 GHz, 8.5 GHz combined with archive data at 10.5 GHz [6] allow us, for the first time, to determine the MRC bolometric luminosities and further present calibration relations for the MRC versus the monochromatic radio luminosities, and as a SFR tracer [12]. The radio SED is fitted using a Bayesian Markov Chain Monte Carlo (MCMC) technique leading to measurements for the global nonthermal spectral index α_n and the thermal fraction. α_n is found to decrease with increasing the SFR surface density in galaxies, in agreement with our local studies. Hence, due to the star formation feedback, the CRE population is dominated by young and energetic particles in galaxies with high SFR.

Acknowledgments

FST acknowledges financial support from the Spanish Ministry of Economy and Competitiveness (MINECO) under grant number AYA2013-41243-P.

References

- [1] Beck, R., & Krause, M., 2005, *Astronomische Nachrichten*, 326, 414
- [2] Beck, R., & Hoernes, P., 1996, *Nature*, 379, 47
- [3] Gressel, O., Elstner, D., Ziegler, U., Rüdiger, G., 2008, *A&A*, 486, L35
- [4] Kennicutt, Jr., R. C., 1998, *ARA&A*, 36, 189
- [5] Kennicutt, Jr., R. C., Calzetti, D., Aniano, G., et al., 2011, *PASP*, 123, 1347
- [6] Niklas, S., Klein, U., Wielebinski, R., 1997, *A&A*, 322, 19
- [7] Schmidt, M., 1959, *ApJ*, 129, 243
- [8] Tabatabaei, F. S., Beck, R., Krügel, E., et al., 2007, *A&A*, 475, 133
- [9] Tabatabaei, F. S., Krause, M., Fletcher, A., Beck, R., 2008, *A&A*, 490, 1005
- [10] Tabatabaei, F. S., Schinnerer, E., Murphy, E. J., et al., 2013, *A&A*, 552, 19
- [11] Tabatabaei, F. S., Martinsson, T. P. K., Knapen, J. H., et al., 2016, *ApJ*, 818, L10
- [12] Tabatabaei, F. S., Schinnerer, E., Krause, M., et al., 2016, *ApJ* in press (arXiv:161101705)