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Tracing star formation with radio emission

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Abstract. Synchrotron emission from cosmic rays, produced in supernova remnants, contains information about a galaxy's star formation rate (SFR). For a quantitative estimate, we construct a model of non-thermal galactic radio flux, including the effect of free-free absorption. The latter can lead to a breakdown of the relation between the SFR and the radio flux at low frequencies and high gas densities. We employ our model to local disk and starburst galaxies and discuss the evolution of SFR-radio relations with redshift.

1. Introduction

Local star-forming galaxies typically lie on the far-infrared (FIR) - radio correlation, a linear relation between the 1.4 GHz and the 60 μm luminosity (Yun et al. 2001). This can be leveraged to derive a relation between the radio flux and the SFR (Murphy et al. 2011), by using well established FIR-SFR relations (e.g. Leitherer et al. 1999). It is, however, unclear if such correlations hold in all types of galaxies and at different cosmic times. In this article we discuss the physical background of radio-SFR relations, suggest scaling relations for various types of galaxies, and present limitations of such relations.

2. A model for galactic radio spectra

Fig. 1 shows schematically how galactic radio emission is related to the SFR. Depending on the stellar initial mass function, the SFR is connected with the supernova rate. Supernovae produce cosmic rays which lose energy on the one side via free-free emission when interacting with the ionized gas, and on the other side via synchrotron radiation in the magnetized interstellar medium. Additionally, supernova shocks drive turbulence which affects the interstellar magnetic field. Especially at low frequencies and high gas densities, the radio flux can be suppressed as a result of free-free absorption. We take this effect into account when modelling galactic radio spectra.

The total galactic radio flux depends on a number of free parameters, including the gas density, the interstellar radiation field, the ionization degree, the galactic magnetic field, galactic winds, and of course the SFR.

Based on two fiducial models, a Milky Way like galaxy (for SFRs below 10 $M_{\odot}$/yr) and a M 82 like starburst core (for higher SFRs), we calculate radio spectra and radio-SFR relations at various observing frequencies.

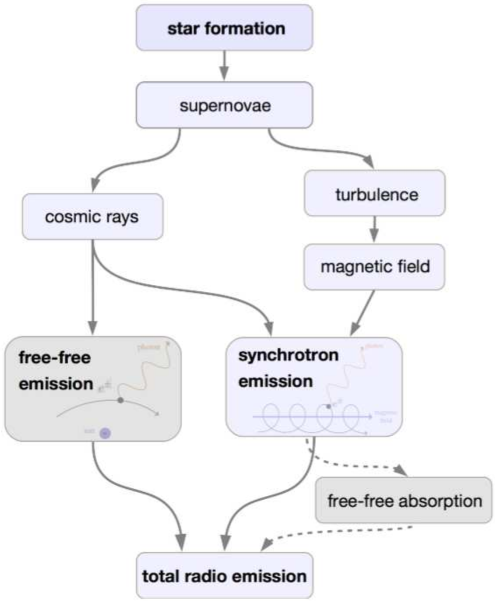

Fig. 1. Flowchart illustrating the origin of a relation between the SFR and the radio flux.

3. Results

3.1. Radio-SFR relations

Using a semi-analytical galaxy model we find the following scaling relations for Milky Way like galaxies:

$$\frac{\dot{M}_\star}{M_\odot\ \mathrm{yr}^{-1}} \approx \begin{cases} 3.20 \times 10^{-5}\ \dfrac{60\ \mathrm{MHz}\ L_{60\ \mathrm{MHz}}}{L_\odot} \\ 2.29 \times 10^{-5}\ \dfrac{200\ \mathrm{MHz}\ L_{200\ \mathrm{MHz}}}{L_\odot} \\ 1.63 \times 10^{-5}\ \dfrac{1.4\ \mathrm{GHz}\ L_{1.4\ \mathrm{GHz}}}{L_\odot}. \end{cases}$$

As the gas density in the starburst core of M 82 is high, such relations can only hold at higher observing frequencies. At 1.4 GHz we find

$$\frac{\dot{M}_\star}{M_\odot\ \mathrm{yr}^{-1}} \approx 1.39 \times 10^{-4}\, \frac{1.4\ \mathrm{GHz}\ L_{1.4\ \mathrm{GHz}}}{L_\odot}.$$

The results for our fiducial models can be extrapolated to explore a large range of galactic parameters (see Schober et al. 2017).

3.2. Critical frequencies

The synchrotron flux, being proportional to the number of cosmic rays, increases with increasing SFR. However, at low frequencies radio flux is absorbed by free-free processes. As a result, non-thermal radio emission is unsuitable as a tracer for the SFR below a critical frequency ν_{crit}, which depends on the density and the ionization degree of the interstellar medium. In Schober et al. (2017) we find $\nu_{\mathrm{crit}} \approx 7.3 \times 10^6$ Hz for Milky Way like galaxy and $\nu_{\mathrm{crit}} \approx 8.7 \times 10^8$ Hz for M 82.

3.3. Galaxies at high redshifts

With high redshift galaxies being typically denser than their local counterparts, ν_{crit} becomes large in the galaxys rest frame. As, however, spectral features move to lower frequencies in the observational frame, radio-SFR relations can often be employed for young galaxies (see Schober et al. 2017).

4. Conclusions and outlook

Based on a set of free parameters, we have derived relations between the SFR and the galactic non-thermal radio luminosity, which can be an important tool for future ultra-deep radio surveys. We provide explicit scaling relations for a Milky Way like galaxy and a starburst core similar to M 82. As these relations can vary in different individual galaxies, we are currently preparing an online calculator, named RAISE.

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References

Yun, M. S., et al. 2001, ApJ, 554, 803
Leiterer, C., et al. 1999, ApJS, 123, 3
Murphy, E. J., et al. 2011, ApJ, 737, 67
Condon, J. J. 1992, ARA&A, 30, 575
Schober, J., et al. 2017, MNRAS, 468, 946