The Diffuse Extragalactic Radio Background and the implications for gamma-ray astrophysics

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Abstract

Radio emission from normal galaxies and radio galaxies is due to synchrotron radiation by relativistic electrons accelerating helically in the presence of a magnetic field. At low frequencies (in the kHz to GHz frequency band), the radio emissions accumulate over cosmological time to form a diffuse background that is similar to the cosmic microwave background (CMB). This background is known as the diffuse Extragalactic Radio Background (ERB). In this work, we produce an updated Protheroe and Biermann (1996) ERB model and test it against radio survey data at different redshifts using the evolution of galaxies with cosmic time. We conclude by presenting the implications for gamma-ray astrophysics, and therefore use our resulting ERB model to calculate the opacity of ultrahigh-energy gamma-rays in the universe.

The Synchrotron Spectra

Reasons for low frequency cut-off at kHz - MHz:

- Low energy cut-off in the cosmic-ray energy spectrum. (For NGs, see Aguilar et al., 2019)
- Effects of synchrotron self-absorption.
- In the case of NGs, thermal absorption by free electrons.

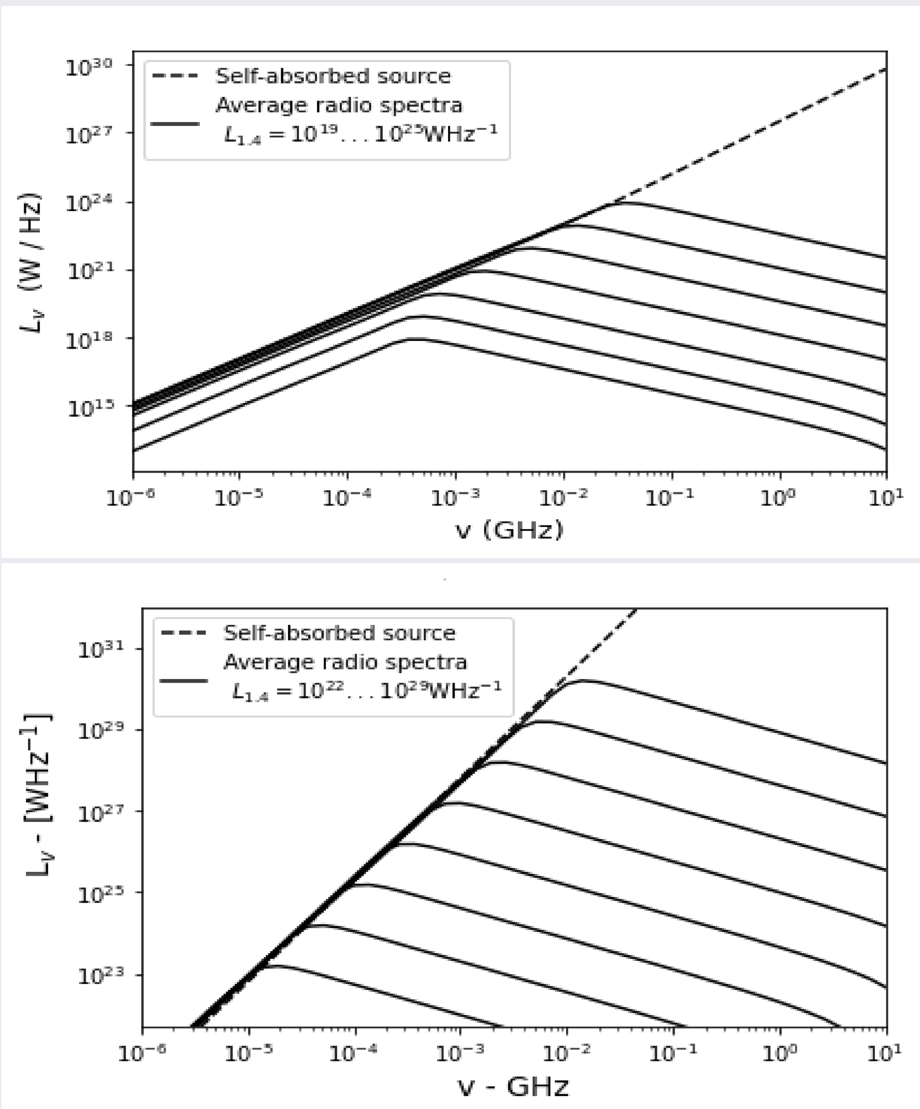

Figure 1. The average synchrotron radio spectra for (a) NGs with 1.4 GHz luminosity $L_{1.4} = 10^{19}...10^{25}$ W/Hz and (b) RGs with 1.4GHz luminosity $L_{1.4} = 10^{19}...10^{25}$ W/Hz W/Hz, including the effects of synchrotron self-absorption - solid curves. The dashed line shows the maximum luminosity of a completely self-absorbed source.

References

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Introduction

The radiation from galaxies fills up the universe and is accumulated over cosmic time to form a background similar to the cosmic microwave background. The intensity of this background depends on different factors such as:

- the number of galaxies,
- the evolution of galaxies with cosmic time,
- the luminosity distribution of the galaxies,
- and in the case of normal galaxies, the radio-infrared correlation

The ERB helps us to study the evolution of different types of galaxies observed at various radio frequencies, the star-formation rate in normal galaxies, the implications for ultra-high energy γ-ray propagation in the universe etc.

Infrared-radio correlation

Normal galaxies are very transparent to infrared wavelength observations due to the presence of HII regions where star formation occurs. A strong correlation exists between infrared and radio luminosities of star forming galaxies, particularly between the luminosities at 1.4 GHz and 60 μm (Yun, M.S. et al., 2001)

$$log(L_{1.4}) = [0.99{+}0.01]log(L_{60}/L_{\odot}){+}12.07{\pm}0.08 \quad (2)$$

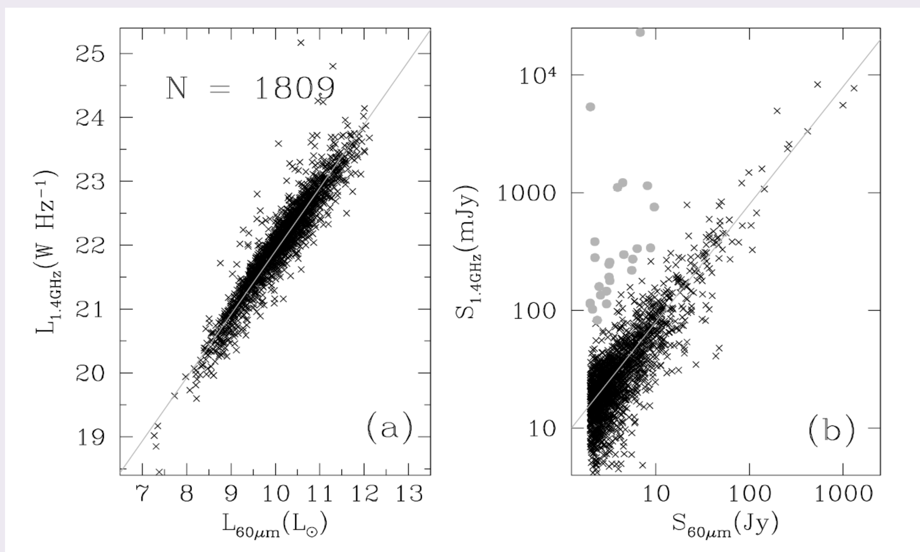

Figure 4. The correlations between: (a) luminosity at 1.4 GHz and 60 μm, (b) flux density at 1.4 GHz and 60 μm for the IRAS 2Jy sample. **Credit:** Yun, M.S. et al., 2001

Results

We have established a new model for the extragalactic radio background by updating the Protheroe and Biermann(1996) methodology.

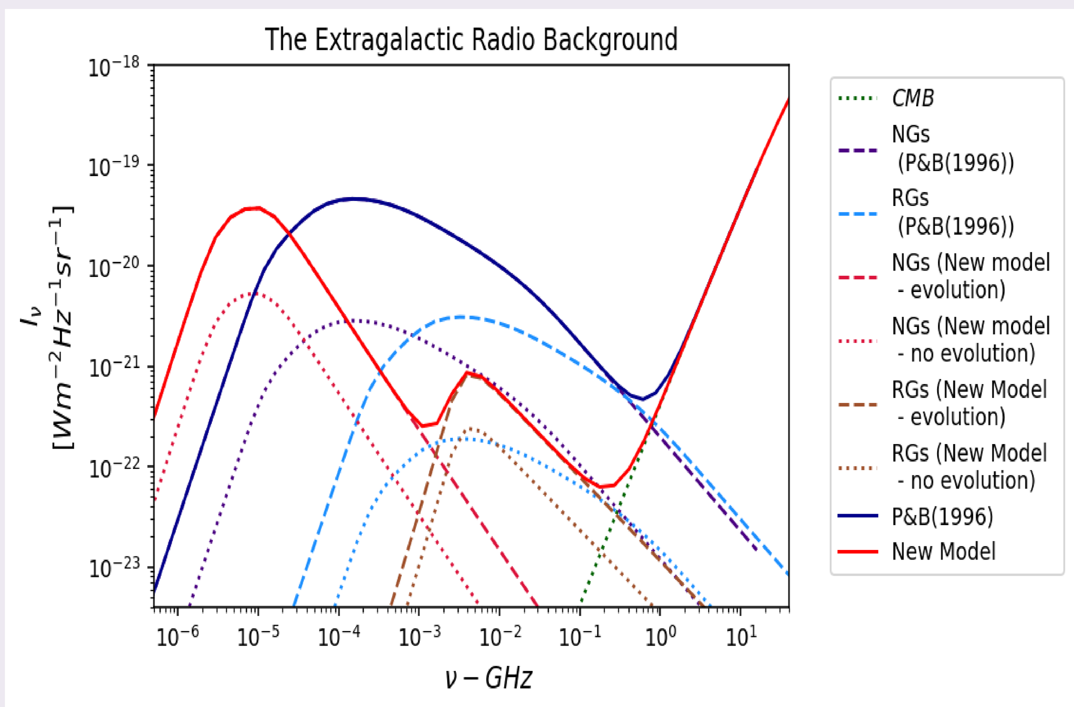

Figure 5. The new extragalacitc radio background intensity from normal galaxies (red curves), the radio galaxies (brown curves) and the CMB (green curve) compared to the current 1996 model (blue curves). Dashed lines: Evolution applied. Dotted lines: No evolution.

Acknowledgements

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Radio luminosity function

The luminosity function (LF) represents the number of galaxies per unit luminosity range at redshift z.

$$\rho\left(L/f(z), z=0\right) = g(z)\rho_0\left(L/f(z), z=0\right) \quad (1)$$

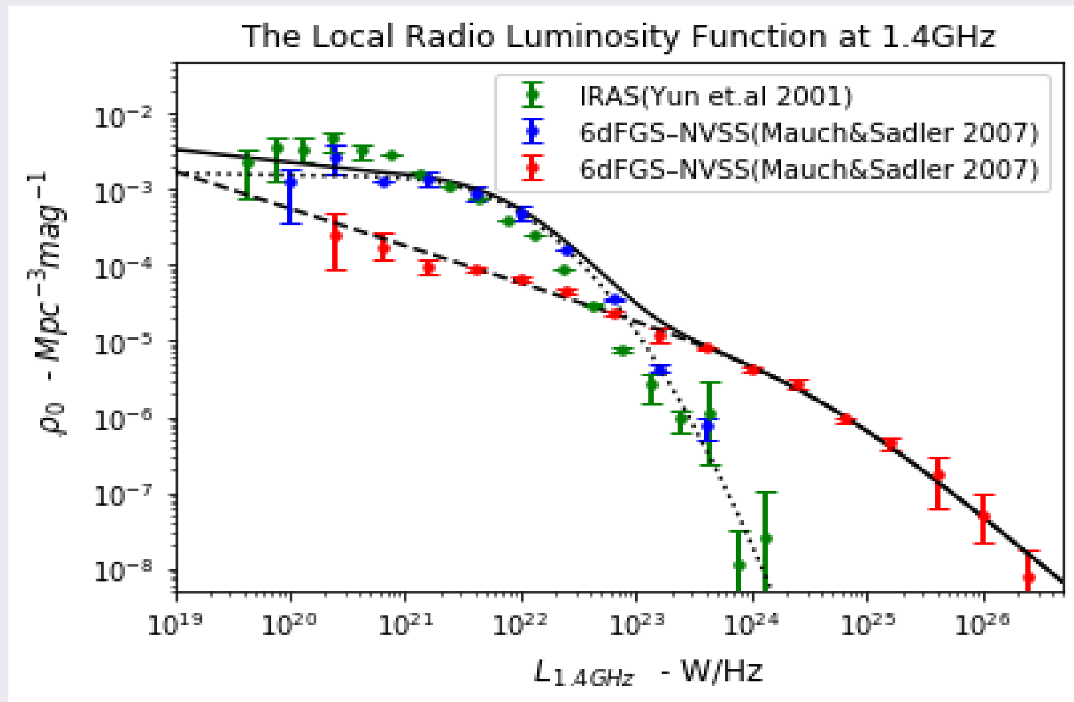

Figure 2. The radio luminosity function for normal galaxies (dotted curve) and radio galaxies (dashed curve).

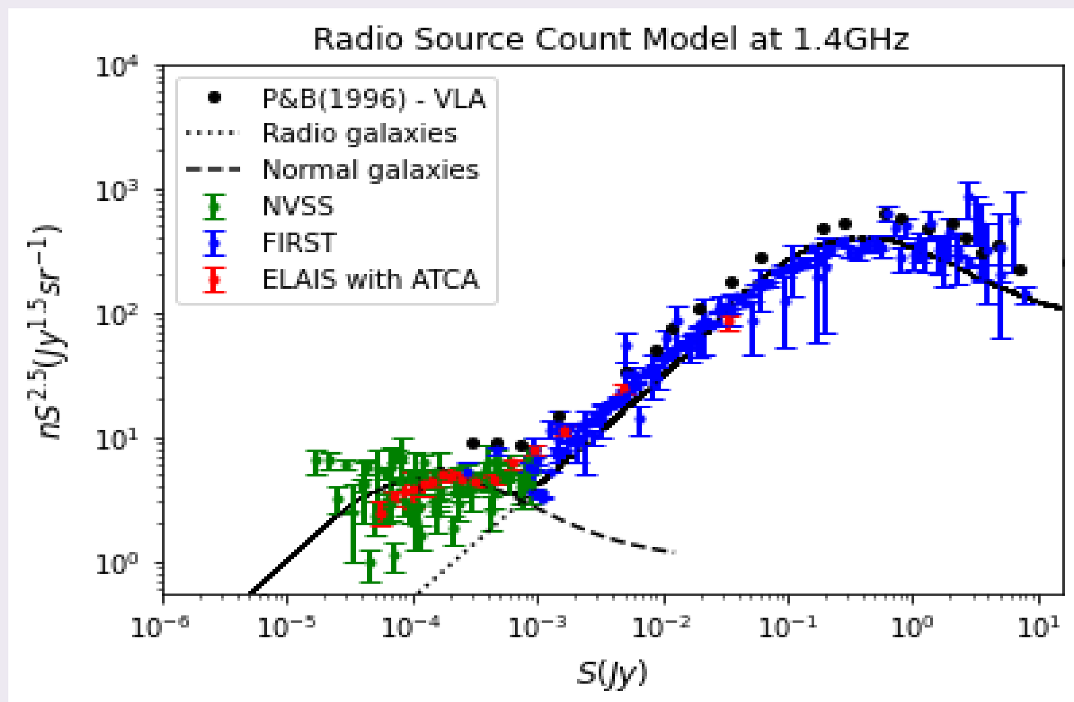

Figure 3. The source count model for normal galaxies (dashed curve) and radio galaxies (dotted curve).

* $\rho_0(L) \equiv$ local luminosity function, $f(z) \equiv$ the source luminosity evolution function, $g(z) \equiv$ the source density evolution function. See Yuan et al.(2017)

Conclusions

- The radio intensity from normal galaxies dominates the extragalactic radio background at low frequencies and reaches a peak ~10kHz.
- At low frequencies, the new estimate for the radio background surpasses the previous model by (Protheroe and Bierman, 1996). The background radiation drops faster at high radio frequencies than in the previous model.
- We have also addressed the uncertainties presented by the new model: (1) Recent adaptation of the radio-infrared correlation(Yun, M.S. et al., 2001) (2) The radio spectra of galaxies. (3) The luminosity evolution produced source counts consistent with observational data from De Zotti(2009).
- What next? Using our result, investigate the implications of γ-ray propagation in the radio background.