

# A Re-analysis of the WMAP Data to Determine the Detailed Characteristics of the Galactic Synchrotron Emission

Gimhanie Kehelpannala

University of Botswana

Rhodri Evans

Botswana International University of Science and Technology

Moletlanyi Tshipa

University of Botswana

AfAS 2026 Conference

24.03.2026



## Introduction

The Cosmic Microwave Background (CMB) provides us with countless information regarding the early stages and the evolution of the Universe. Hence, investigating the CMB is one of the most important studies in Astronomy. For better results, any contaminations restricting the investigations must be removed. Therefore, further studies of each contamination is a must. Among the contaminations there are Galactic foregrounds, extragalactic foregrounds and instrumental/systematic effects (Bennett *et al.*, 2003). In this poster presentation, our focus is one of the emissions that contributes to the Galactic foregrounds; synchrotron emission.

1

## Galactic Foreground Emission

- Galactic foreground emission provides information regarding the physical process in the magnetized interstellar medium and is the main obstacle in obtaining a clean full sky map of the cosmic microwave background to investigate the early stages of the Universe (Bershanskii, 2025)
- The main foreground emissions are:
  - Synchrotron emission
  - Free-free emission
  - Dust emission

2

## Synchrotron Emission

- When a charged particle moves through a magnetic field at an angle, it has two velocity components; parallel velocity and perpendicular velocity (to the magnetic field). The two velocities result in the particle moving in a helical (spiral) motion in the direction of the magnetic field lines at a constant speed which in turn result in a centripetal acceleration. This acceleration causes the charged particle to emit a radiation (Hean, 2023; Rybicki and Lightman, 1979).
- Synchrotron emission is such a radiation radiated by relativistic electrons spiraling in the large-scale magnetic field of the Galactic (Rybicki and Lightman, 1979; Gold *et al.*, 2009; Gold *et al.*, 2011).
- Synchrotron emission arise from; “electrons trapped in the magnetic fields of discrete supernova remnants and diffuse emission from cosmic-ray electrons spread throughout the Galaxy” (Bennett *et al.*, 2003).
- According to Rybicki and Lightman (1979), as well as Lai *et al* (2025), synchrotron emission (as other foreground emissions) follows the power law;

$$I_\nu \propto \nu^{-\beta}$$

specific intensity,  $I_\nu$   
frequency,  $\nu$   
spectral index,  $\beta$

- Spectral index of the synchrotron emission was found to be in a range from -2.5 to -3.3 (Patel *et al.*, 2026; Fuskeland *et al.*, 2021; Juvela *et al.*, 2018).
- Thus, synchrotron emission is dominant in low frequencies and submissive at higher frequencies.
- Since the power law is linear in intensity, synchrotron emission could only be measured in Rayleigh-Jeans antenna temperature (Rybicki and Lightman, 1979).
- Default WMAP data are usually in thermodynamic temperature and must be converted to RJ antenna temperature when analyzing synchrotron emission (and other foregrounds) by using the equation;

$$T_{RJ}(\nu) = \frac{T_{CMB}}{g(x)}$$

where

$$g(x) \equiv \frac{x^2 e^x}{(e^x - 1)}$$

and

$$x \equiv \frac{h\nu}{kT_{CMB}}$$

RJ antenna temperature,  $T_{RJ}$   
thermodynamic temperature,  $T_{CMB}$   
Planck's constant,  $h$   
frequency,  $\nu$   
Boltzmann's constant,  $k$

3

## Methodology

- All nine years of data from the Wilkinson Microwave Anisotropy Probe (WMAP) were used (DR5).
- WMAP has observed the CMB for a nine years using five different bands; K Band (23.0 GHz), Ka Band (33.0 GHz), Q Band (41.0 GHz), V Band (61.0 GHz), and W Band (94.0 GHz) (Bennett *et al.*, 2003).
- By using Python, all bands were smoothed to the same resolution of 1 degree and were converted into antenna temperature before saving them as FITS files.
- Synchrotron emission maps were generated by using the full multi-component model;

$$T(\nu) = T_{CMB} + T_{syn}(\nu) + T_{ff}(\nu) + T_{dust}(\nu)$$

$$T(\nu) = T_{CMB} + T_{syn}(\nu_0) \left(\frac{\nu}{\nu_0}\right)^{\beta_{syn}} + T_{ff}(\nu_0) \left(\frac{\nu}{\nu_0}\right)^{\beta_{ff}} + T_{dust}(\nu_0) \left(\frac{\nu}{\nu_0}\right)^{\beta_{dust}}$$

observed temp at freq  $\nu$ ,  $T(\nu)$   
CMB component,  $T_{CMB}$   
synchrotron component,  $T_{syn}$   
free-free component,  $T_{ff}$   
dust component,  $T_{dust}$   
frequency,  $\nu$   
reference frequency (K Band),  $\nu_0$   
spectral index  $\beta$

where the spectral index of dust emission and free-free emission were kept constant (1.7 and -2.15 respectively), while changing the spectral index of synchrotron emission within the range -2.7 to -3.3. K Band (23 GHz) was chosen as the reference frequency.

4

## Results

- The emission of the cosmic microwave background (CMB) and the foregrounds are shown in Figure 1.

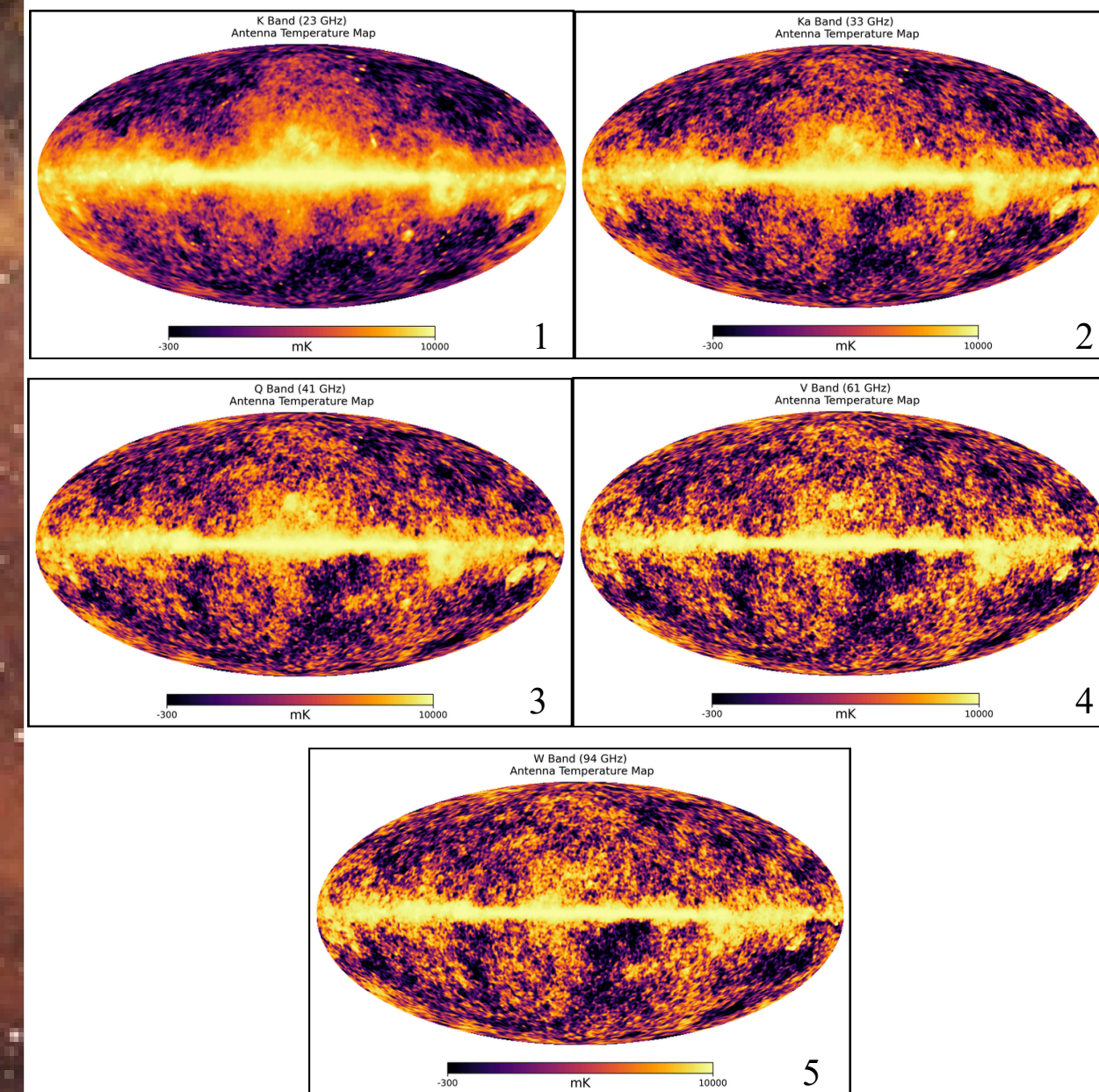


Fig 1: Showing the emission of the CMB and the foregrounds in RJ antenna temperature units at; 1) K Band, 2) Ka Band, 3) Q Band, 4) V Band and 5) W Band.

5

- The synchrotron emission maps (where the spectral indices are -2.7, -3.0 and -3.3) of the Ka band (33 GHz) and W band (94 GHz) are shown in Figure 2.

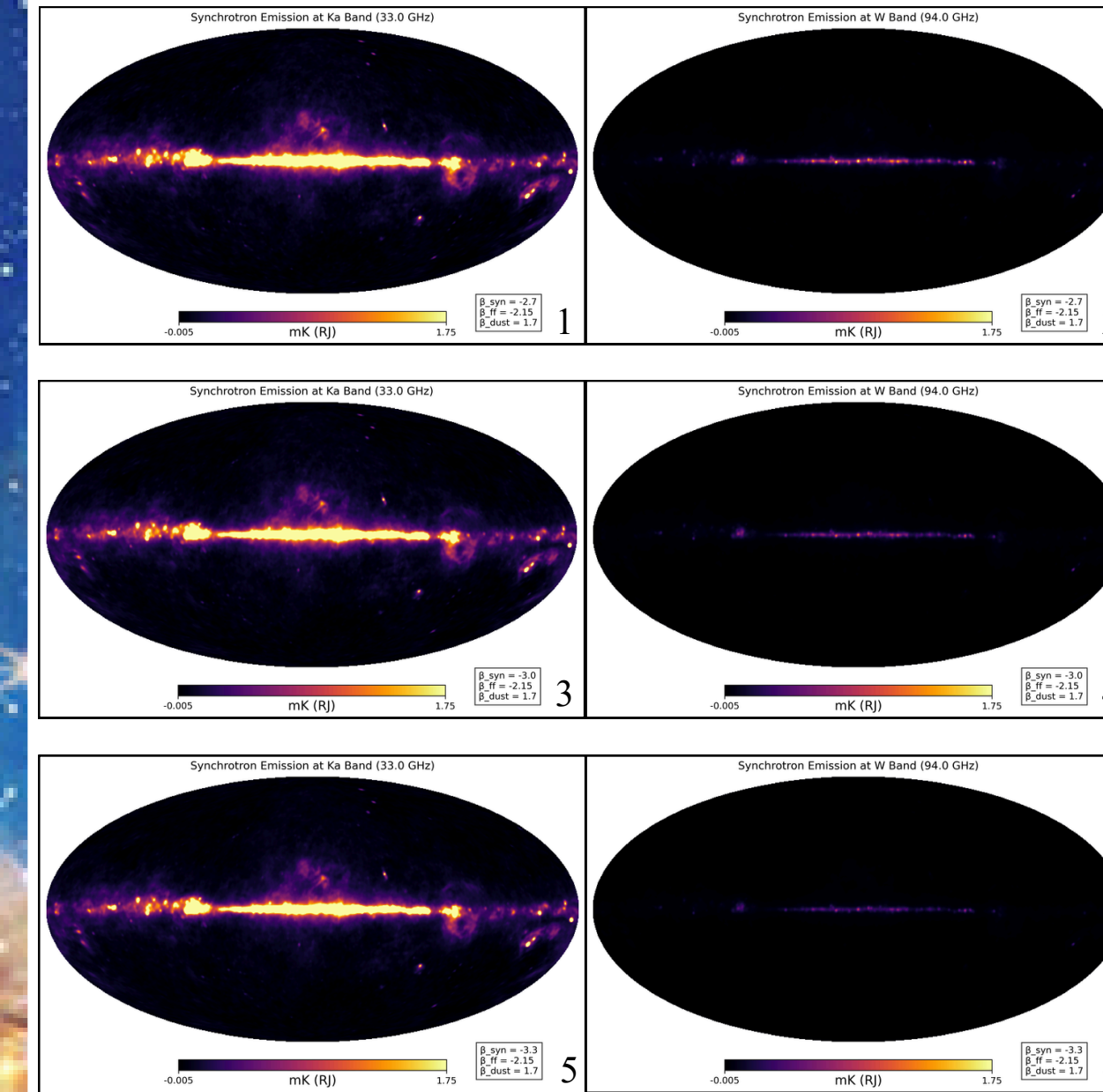


Fig 2: Showing the synchrotron emission at spectral indices -2.7 [1] Ka Band & 2) W Band], -3.0 [3] Ka Band & 4)W Band], and -3.3 [5] Ka Band & 6) W Band].

6

- The plot of synchrotron emission vs galactic latitude and the plot of synchrotron emission vs galactic longitude are shown in Figure 3 and Figure 4 respectively.

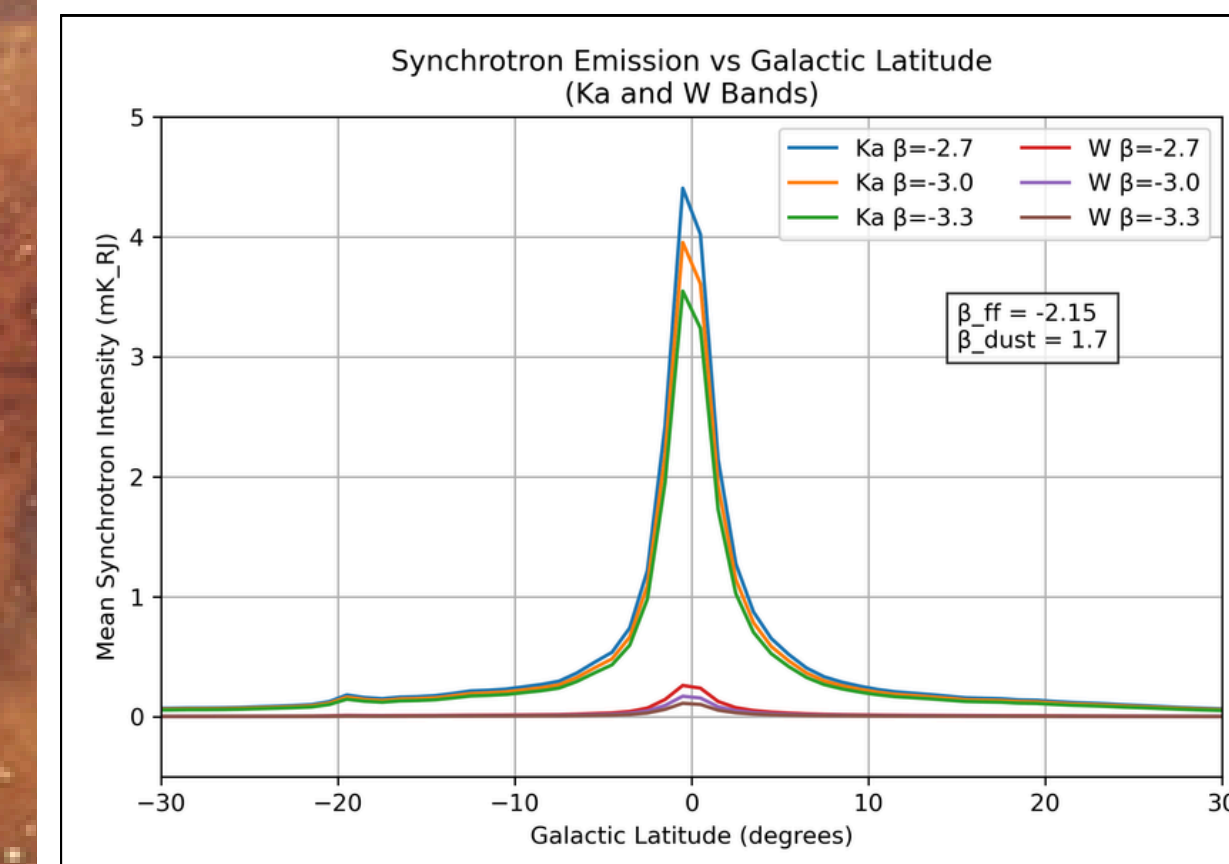


Fig 3: Showing the synchrotron emission vs galactic latitude of Ka & W Bands for spectral indices -2.7, -3.0, and -3.3.

7

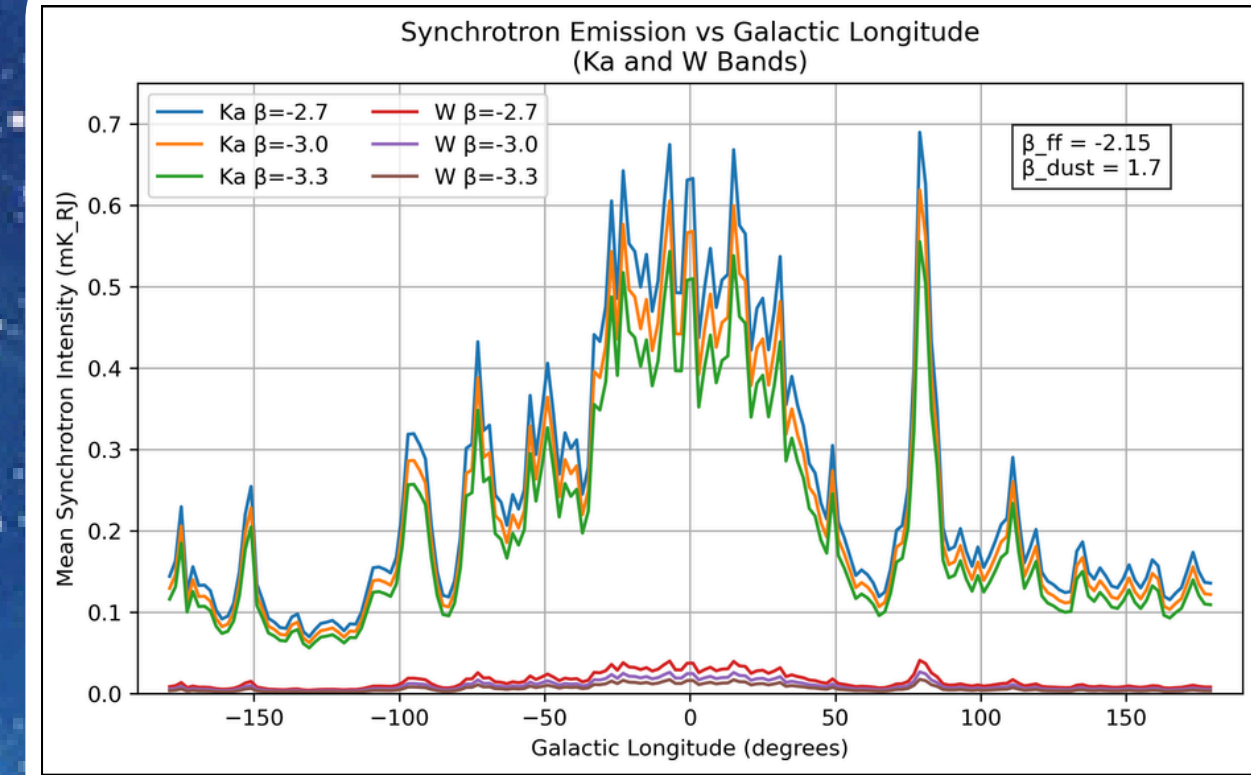


Fig 4: Showing the synchrotron emission vs galactic longitude of Ka & W Bands for spectral indices -2.7, -3.0, and -3.3.

8

## Analysis and Conclusion

- Figure 1 shows that higher the frequency, the more details we can see in the maps.
- Figure 2 shows that synchrotron emission is dominant at low frequency (Ka Band- 33 GHz) and submissive at high frequency (W Band- 94 GHz).
- Figure 3 and 4 show that the synchrotron emission is dominant at the low frequency (Ka Band- 33 GHz), and that its strongest at the Galactic (0 deg in the x-axis in both plots).
- In conclusion, synchrotron emission is detected at low frequencies and dominant at the Galactic.

9

## References

Bennett, C. L., ..... Wollack, E. (2003). First-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Foreground Emission. *The Astrophysical Journal Supplement Series*. Vol. 148. (pp. 97-117).

Bershanskii, A. (2025). Galactic Foreground Emissions Randomization Due to Chaotic/Turbulent Dynamics of Magnetized Plasma Dominated by Magnetic Helicity.

Fuskeland, U., ..... Wehus, I. K. (2021). Constraints on the Spectral Index of Polarized Synchrotron Emission from WMAP and Faraday-Corrected S-PASS Data. *Astronomy and Astrophysics*. Vol. 646.

Gold, B., ..... Wright, E. L. (2009). Five-Year Wilkinson Microwave Anisotropy Probe Observations: Galactic Foreground Emission. *The Astrophysical Journal Supplement Series*. Vol. 180. (pp. 265-282).

Gold, B., ..... Wright, E. L. (2011). Seven-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Galactic Foreground Emission. *The Astrophysical Journal Supplement Series*. Vol. 192.

Lai, P. C. W., ..... Kong, A. K. H. (2025). Spectropolarimetry of Synchrotron Radiation from Relativistic Electrons with Anisotropic Pitch-Angle and Various Energy Distributions. *Monthly Notices of the Royal Astronomical Society*. Vol. 542.

Patel, S. K., ..... Samal, P. K. (2026). Probing Foreground Residuals in Cleaned CMB Temperature Maps from Planck. *The European Physical Journal C*. Vol. 86.

Rybicki, G. B., Lightman, A. P. (1979). *Radiative Processes in Astrophysics*.

Juvela, M., ..... Yoo, H. (2018). Herschel and SCUBA-2 observations of dust emission in a sample of Planck cold clumps. *Astronomy and Astrophysics*. Vol. 612.

10