The Case For A Bright Radio Background

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The Radio Sky

Measured Temperature: $21 \pm 3$ K
Plane-Parallel Component: $6 \pm 1$ K
Isotropic Residual: $15 \pm 3$ K

Over half of the polar brightness results from an isotropic component:

This is not a minor fitting error!
Isotropic Component

Spectrum consistent with synchrotron emission

\[ T = 1.26 \pm 0.09 \text{ K} \ (\nu/1 \text{ GHz})^{-2.6} \]

Known from radio surveys, but assumed to be Galactic

Where’s Waldo?

Existence of isotropic component known for 50 years. The question is, where does it originate?

3 Possibilities for Isotropic Emission

• Small patch (centered on sun)
• Big patch (Galactic halo)
• Extragalactic background

Simplest choice: Emission originates within Galaxy (somewhere)
Galactic Halo

2-component model for Galactic radio emission

- Disk
  - Semi-major axis = 2.1
  - Semi-minor axis = 0.4
- Halo
  - Radius = 1.8

(in units of the solar circle)

Adjust volume emissivity to match radio data

Good fit to radio maps, but is such a bright halo likely?

Halo Search in Edge-On Spirals

Model prediction: If Milky Way is a typical spiral galaxy, then edge-on spirals should show similar bright halo

Model Prediction at 1500 MHz

6% and 12% contours

NGC 4517 at 1500 MHz
Halo Search in Edge-On Spirals

Model prediction: If Milky Way is a typical spiral galaxy, then edge-on spirals should show similar bright halo.

Model Prediction at 1500 MHz

Measure ellipticity for 32 edge-on spirals
32 of 32 are more elliptical than halo model
No evidence for bright halo
Local Emission from Spherical Patch

Localized enhancement ~ 600 pc radius
- Cosmic ray density?
- Magnetic field?
- Sun is close enough to center for isotropy

Test Using Synchrotron Polarization

Large-Scale Polarization

WMAP 23 GHz polarization
Negligible Faraday rotation

Observed polarization dominated by smooth regular field even in faint regions of the sky
Polarization From Small Patch

If we were inside small patch with uniform field ...

- Expected polarization $\sim 165 (f/0.75) \, \mu K$ at 22 GHz
- Observed value $< 9 \, \mu K$
- Fractional polarization $f < 0.04$ for each line of sight
Synchrotron Depolarization

Synchrotron emission is intrinsically polarized ... \[ f = P/I \sim 0.75 \]

... But the observed emission is strikingly de-polarized

Faintest third of sky: \[ \langle f \rangle = 0.045 \pm 0.011 \]
Synchrotron Depolarization

Simulate magnetic field with Kolmogorov power spectrum

Compare polarized to unpolarized synchrotron intensities for uniform volume emissivity

Getting \( \langle f \rangle = 0.045 \) requires over \( 10^5 \) magnetic domains

Domain size < 0.001 pc
Multi-Messenger Tests

Radio / Far-IR Correlation

One of tightest correlations in astrophysics
Persists on scales 50 pc to 15 kpc

Estimate polar cap brightness from radio / FIR correlation

1) DIRBE FIR * <q> from external galaxies
   \[ T = 5.9 \pm 3.5 \, \text{K at 408 MHz} \]
2) DIRBE FIR * <q> from local (Milky Way) correlation
   \[ T = 4.8 \pm 1.5 \, \text{K at 408 MHz} \]

Factor of 4 below observed value (20 K)

Either Galaxy is outlier at 5--10 standard deviations,
or the isotropic component is not Galactic in origin
Extragalactic Origin?

Galactic origin for isotropic emission requires multiple anomalies
  • Bright radio halo
  • Radio/FIR correlation
  • Magnetic field structure

Extragalactic origin removes anomalies
  • No need for radio halo
  • Restores normal radio/FIR correlation
  • Higher fractional polarization / larger domains (few pc)

\textbf{BUT} need new faint source population
Cosmic Radio Background

![Cosmic Radio Background Diagram](image)

- **Energy Density** $\nu I_\nu$ (nW m$^{-2}$ sr$^{-1}$)
- **Frequency (Hz)**
  - **CMB**
  - **CIB**
  - **COB**
  - **CXB**
  - **CRB**
Source Counts

How many sources does it take 'till we know
That too many photons have fried

-- Bob Dylan, "Blowin' In The Wind"

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Need a boatload of faint sources
Not yet seen, but certainly possible!

Condon et al 2012
Multi-Messenger Hints?

Radio / X-Ray Connection

Cosmic rays Compton scatter photons to soft X-ray energies

Need mechanism to enhance synchrotron while not over-producing X-ray background

Isotropic component must originate from region with $|B| > 1 \mu G$

Sources? What Sources?

Requirements for extragalactic background:

A lot of faint sources ...
Bright in synchrotron ...
With a high magnetic field ...
But without appreciable far-IR emission

Early Universe?

- Supernova from black hole formation
- Large number of potential source sites
- High magnetic field
- Zero metalicity: No dust $\rightarrow$ minimal FIR

Potential new source population at sub-$\mu$Jy levels

Bierman et al. 2013, MNRAS
Tests for Radio Background

Source counts at nJy levels

Millimeter polarization maps

Absolutely-calibrated sky surveys at 100-200 GHz