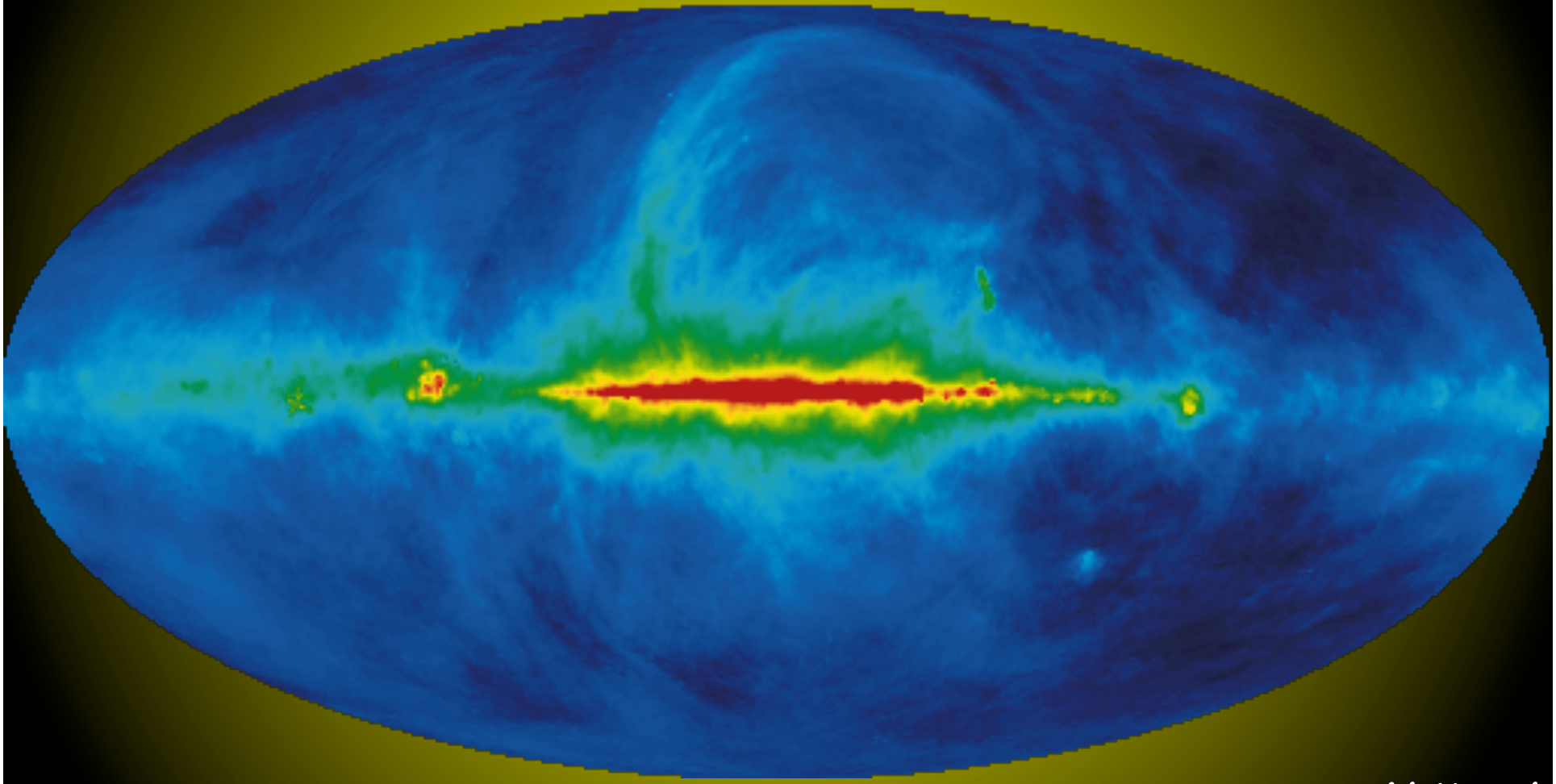
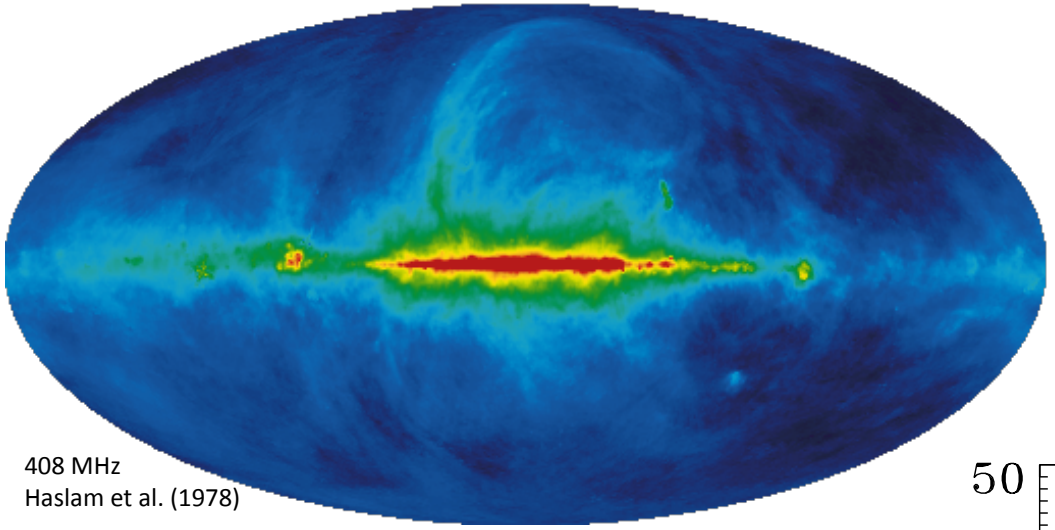
The Case For A Bright Radio Background



Al Kogut
Goddard Space Flight Center

The Radio Sky



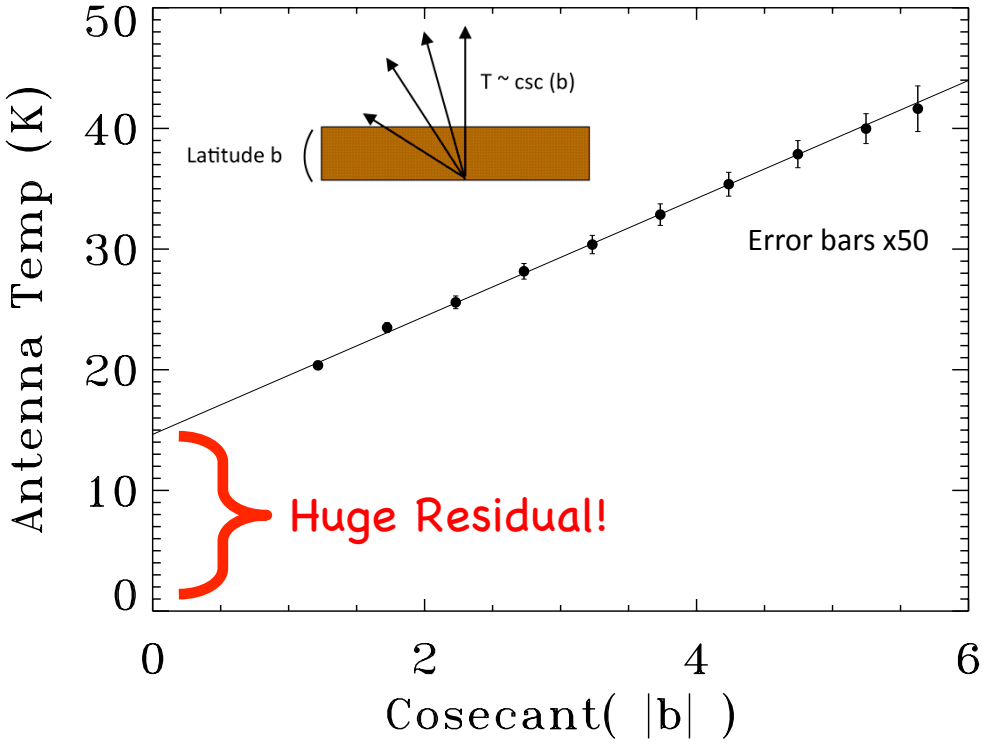
408 MHz
Haslam et al. (1978)

Simplest model of high-latitude sky

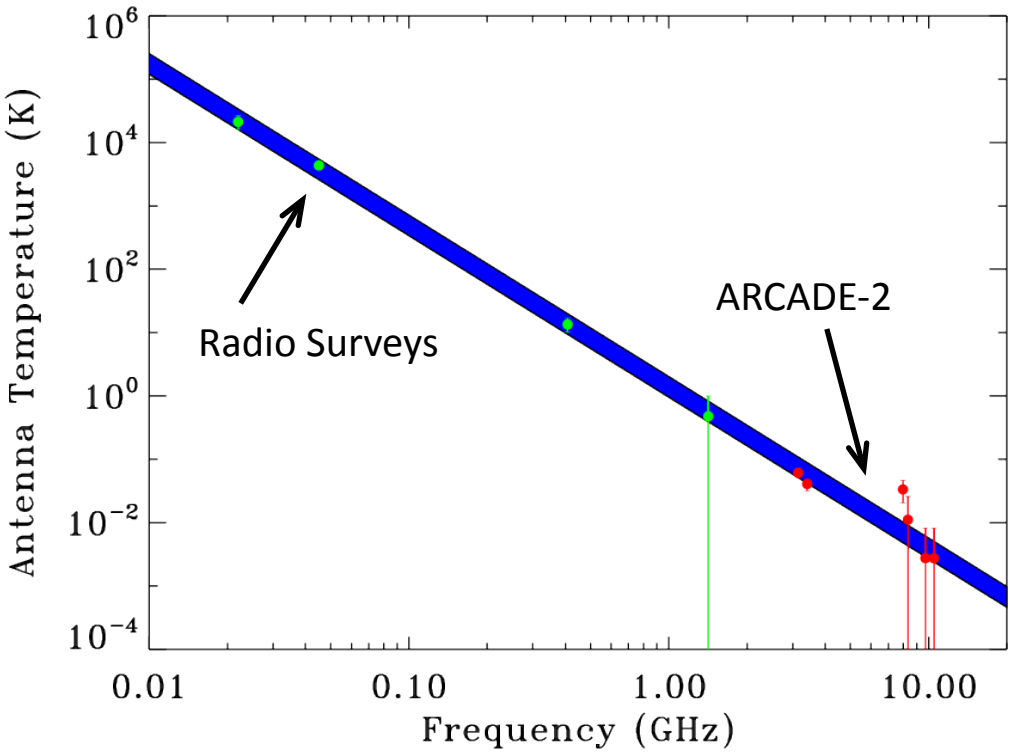
Measured Temperature: 21 ± 3 K
Plane-Parallel Component: 6 ± 1 K
Isotropic Residual: 15 ± 3 K

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

This is not a a minor fitting error!



Isotropic Component



Spectrum consistent with synchrotron emission

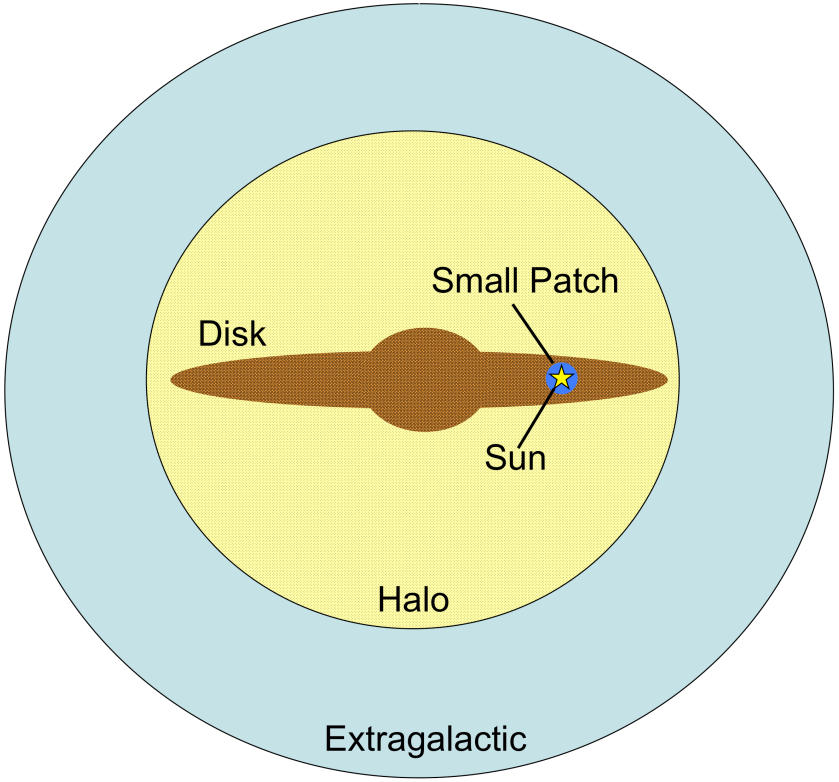
$T = 1.26 \pm 0.09\ K\ \ (\nu\ /1\ GHz)^{-2.6}$

Known from radio surveys, but assumed to be Galactic

Kogut et al 2011, ApJ, 734, 4
Fixsen et al. 2011, ApJ, 734, 5

Where's Waldo?

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

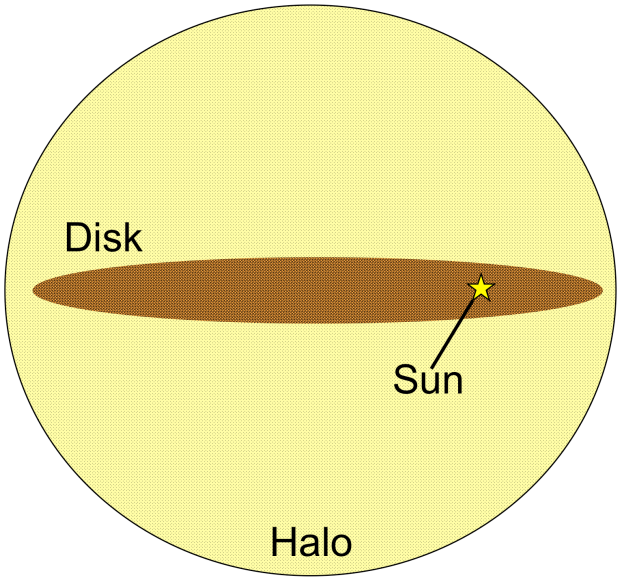


3 Possibilities for Isotropic Emission

- 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

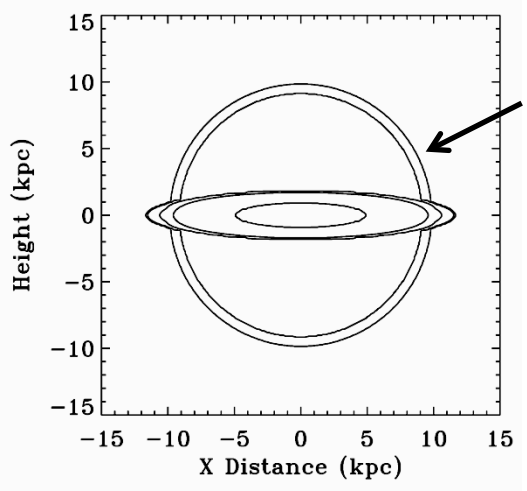
Good fit to radio maps, but is such a bright halo likely?

Subrahmanyan & Cowsik 2013, ApJ, 776, 42

Halo Search in Edge-On Spirals

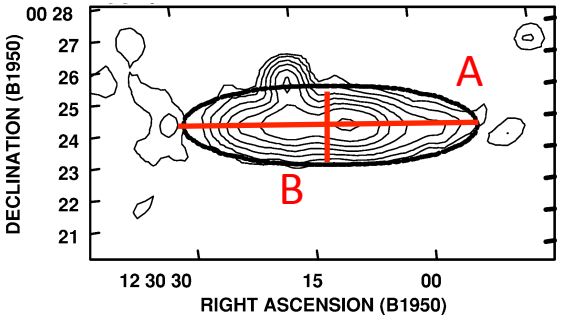
Model prediction: If Milky Way is a typical spiral galaxy,
then edge-on spirals should show similar bright halo

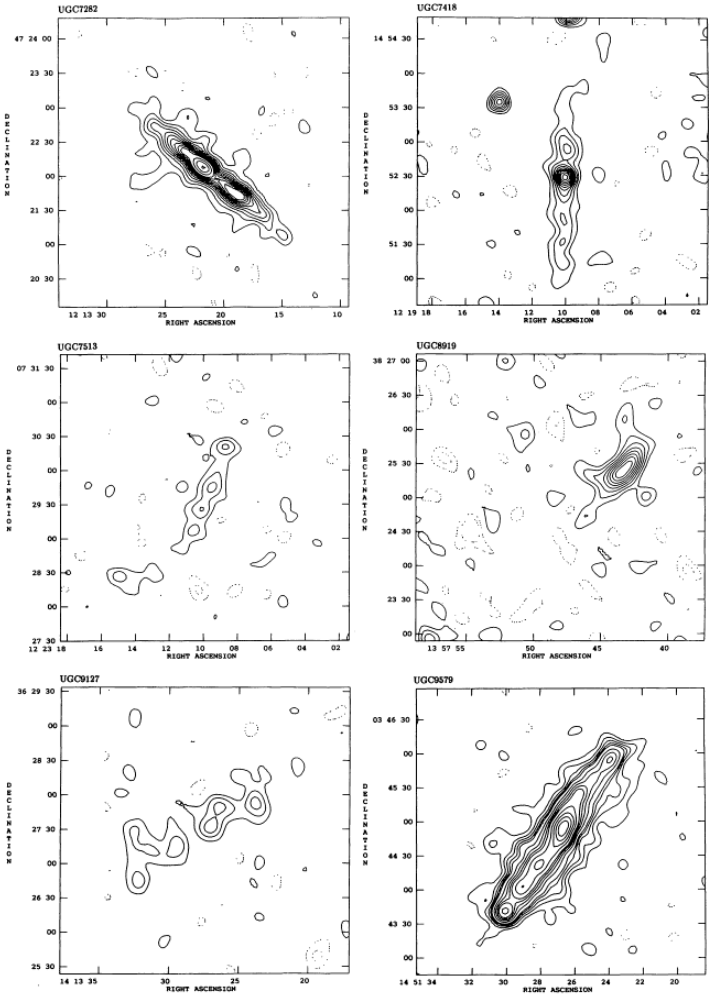
Model Prediction at 1500 MHz



6% and 12% contours

NGC 4517 at 1500 MHz





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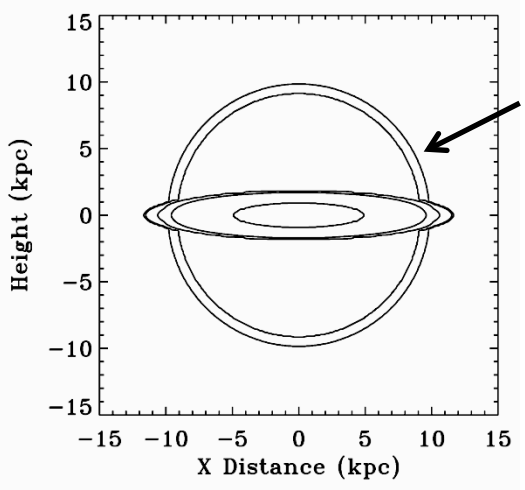

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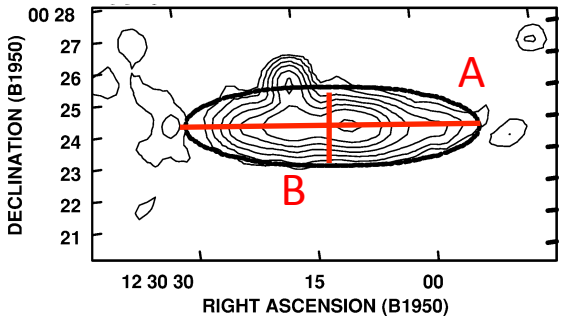
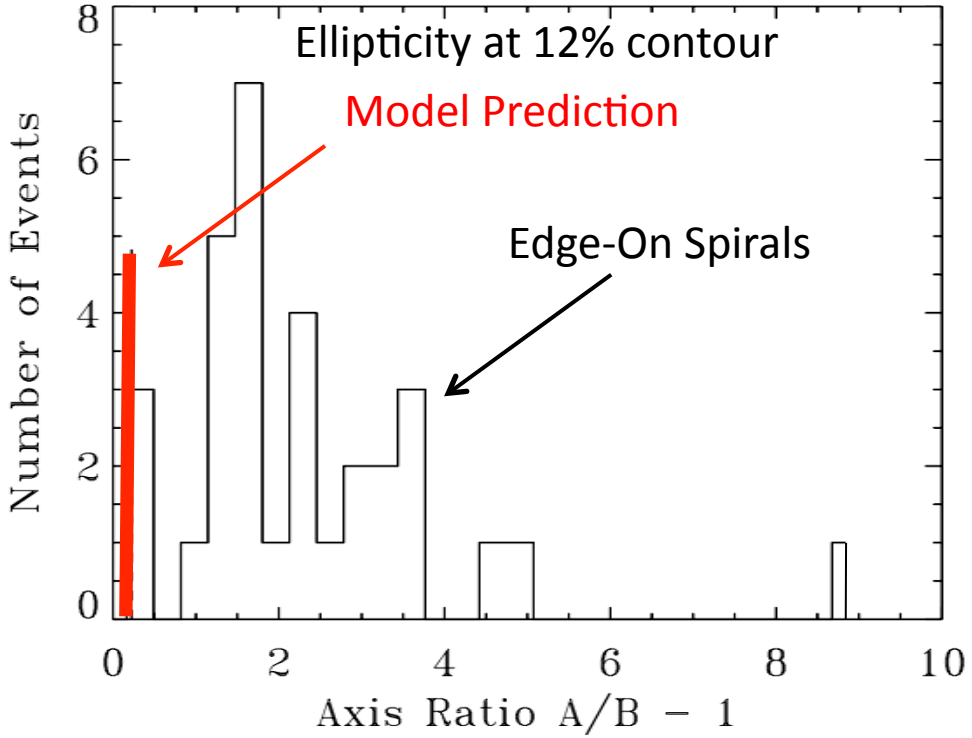


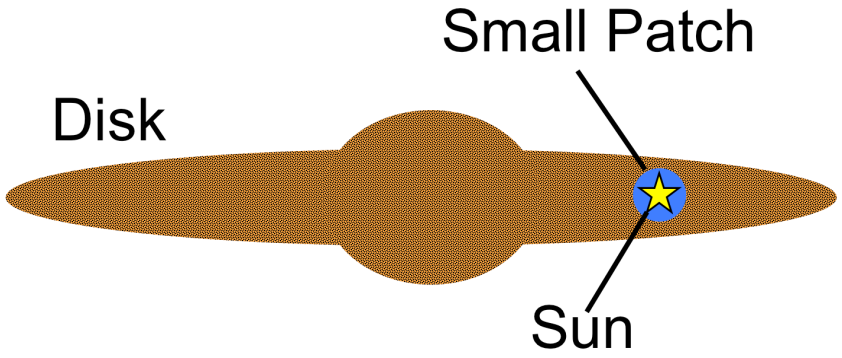
Measure ellipticity for 32 edge-on spirals

32 of 32 are more elliptical than halo model

No evidence for bright halo



Local Emission from Spherical Patch



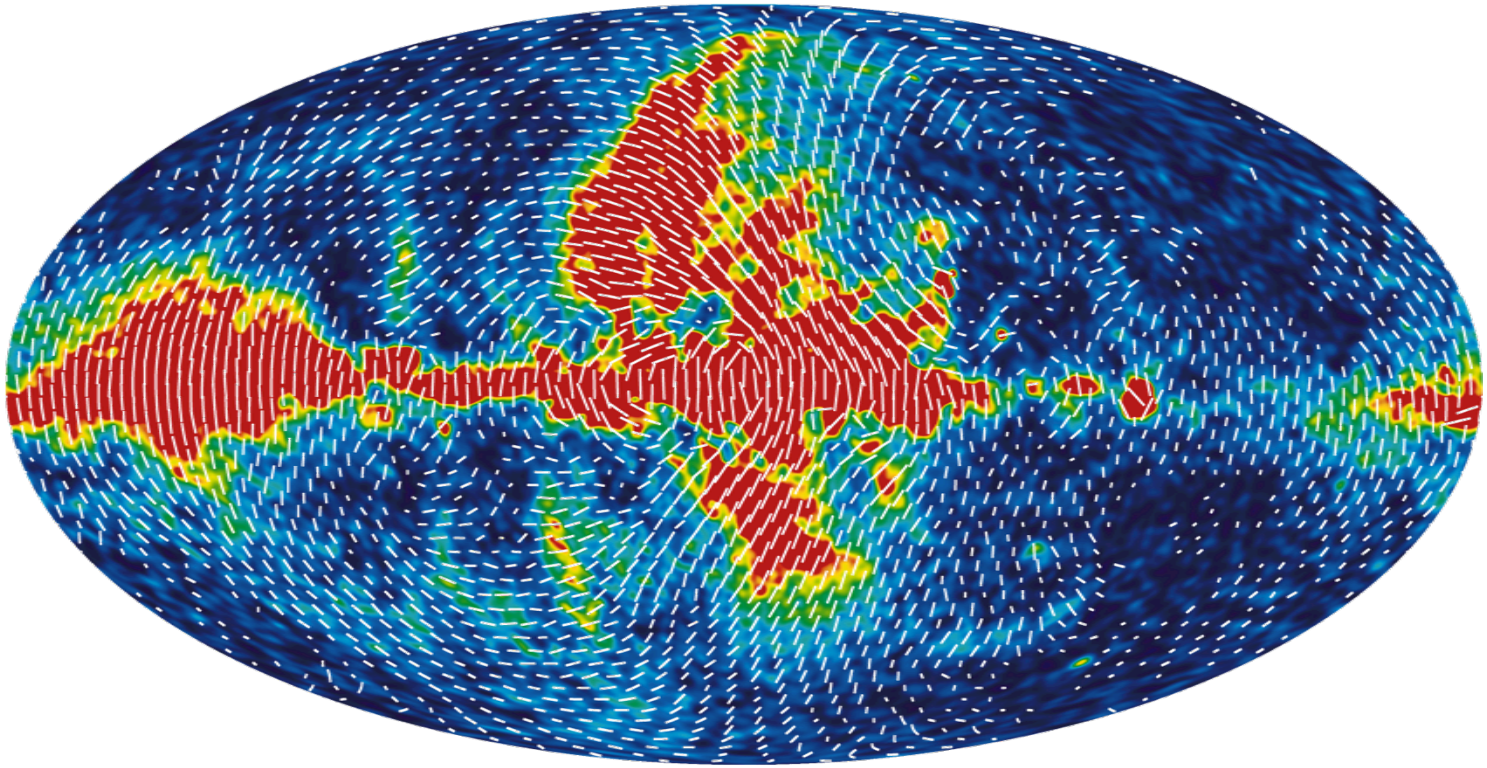
Localized enhancement ~ 600 pc radius
- Cosmic ray density?
- Magnetic field?

Sun is close enough to center for isotropy

Test Using Synchrotron Polarization

Sun et al. 2008, A&A 477, 573

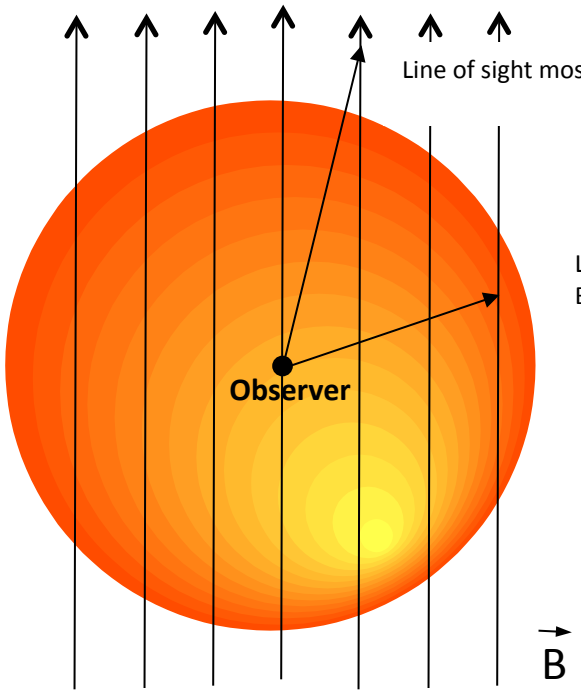
Large-Scale Polarization



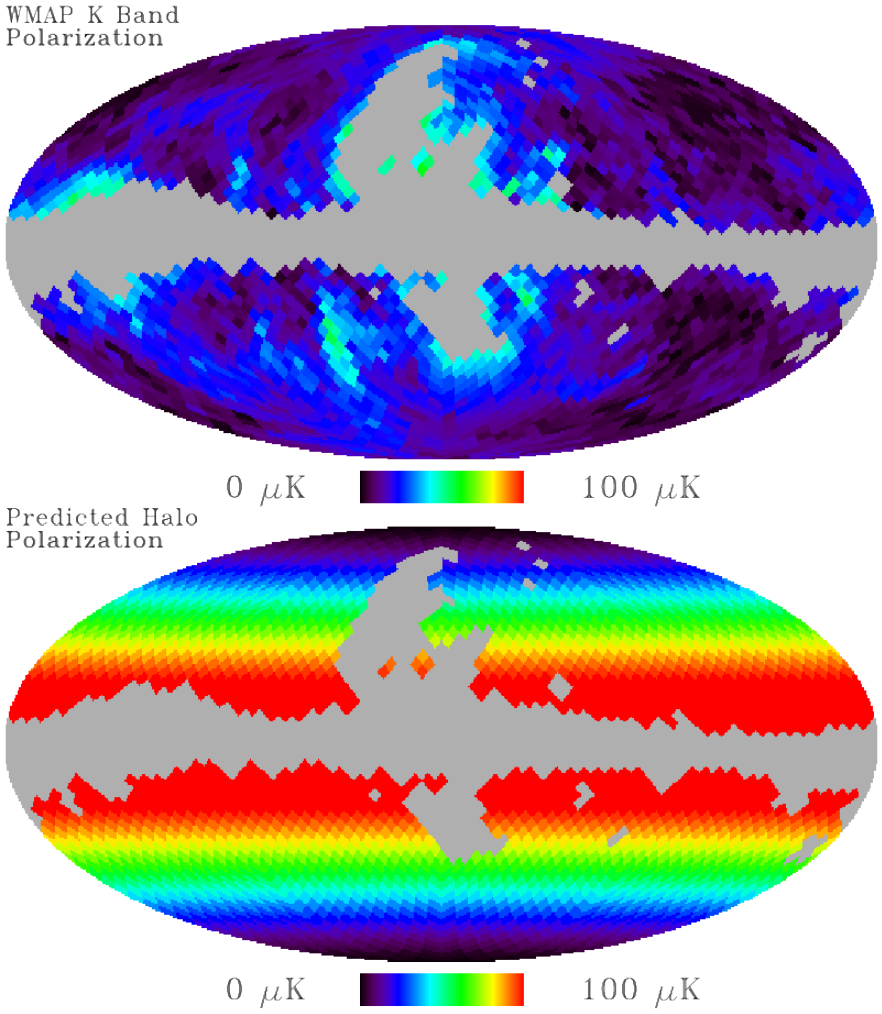
WMAP 23 GHz polarization
Negligible Faraday rotation

Observed polarization dominated by smooth regular field
even in faint regions of the sky

Polarization From Small Patch



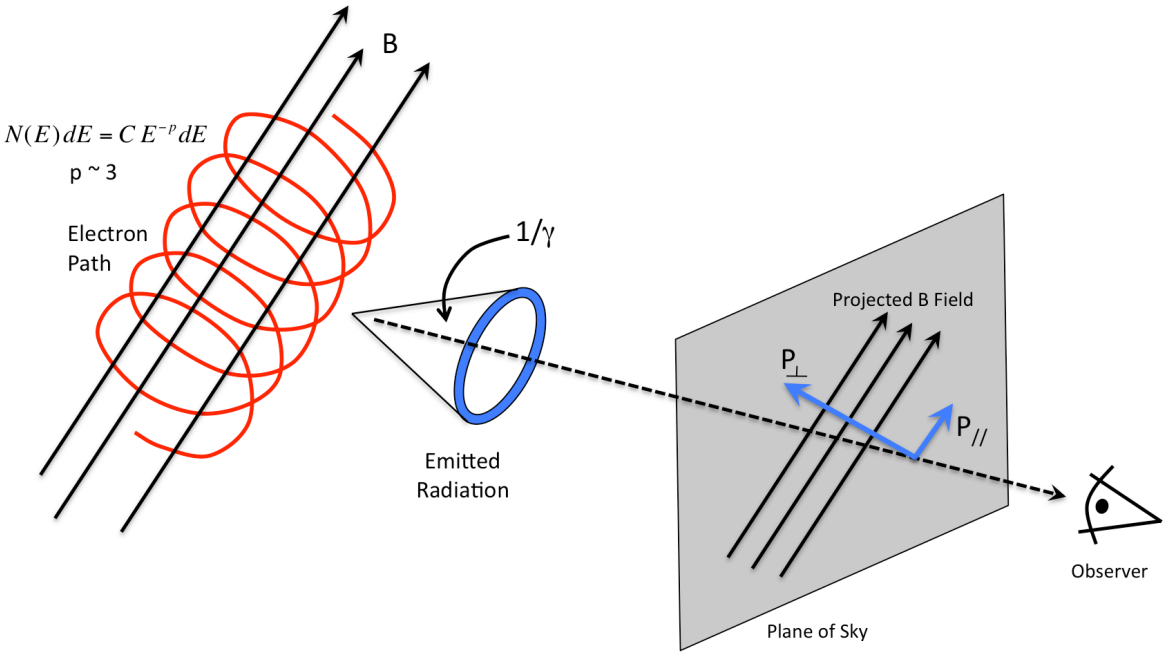
Polarized synchrotron ∝ $B_{\perp}$



If we were inside small patch with uniform field …

- Expected polarization ~165 (f/0.75) μK at 22 GHz
- Observed value < 9 μK
- Fractional polarization f < 0.04 for each line of sight

Synchrotron Depolarization

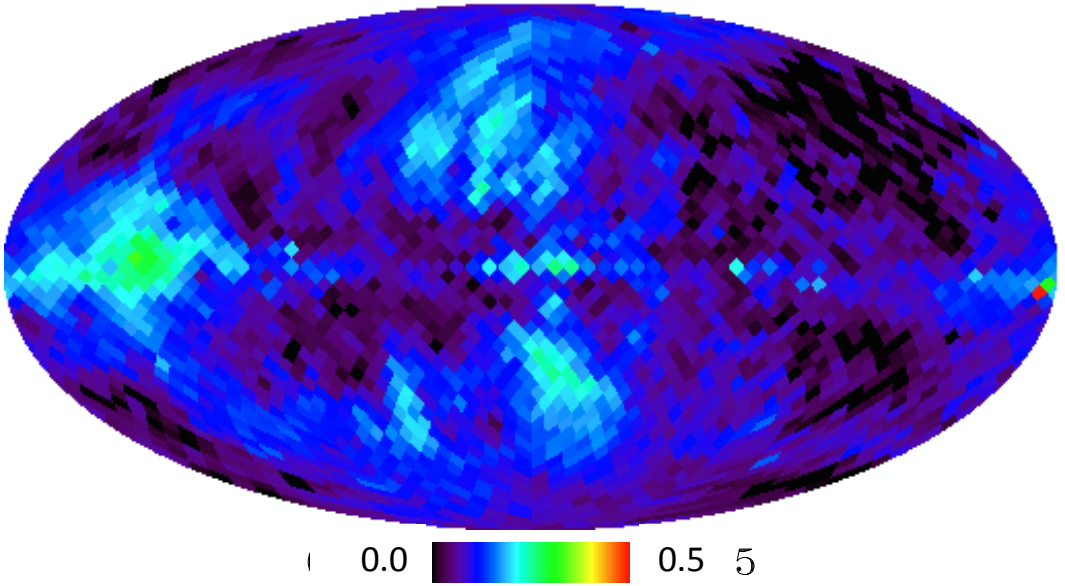


Synchrotron emission is intrinsically polarized …

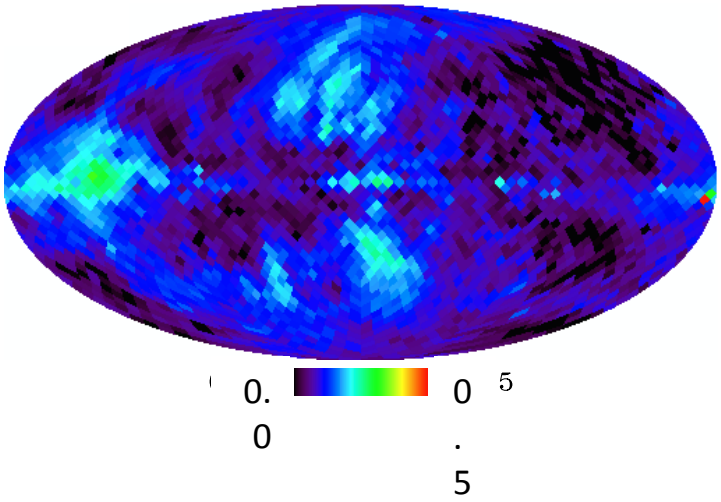
f = P/I ~ 0.75

… But the observed emission is strikingly de-polarized

Faintest third of sky:
<f> = 0.045 ± 0.011



Synchrotron Depolarization



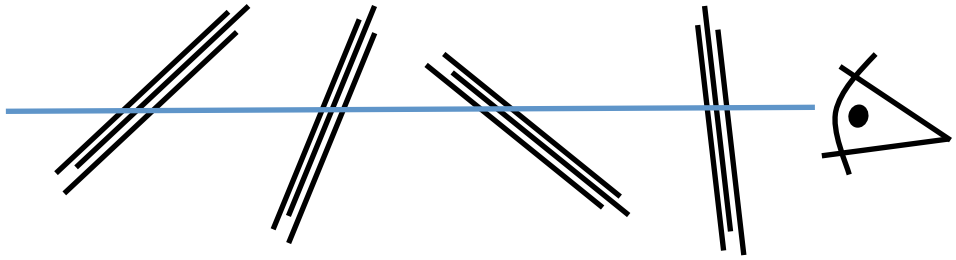
Simulate magnetic field with Kolmogorov power spectrum

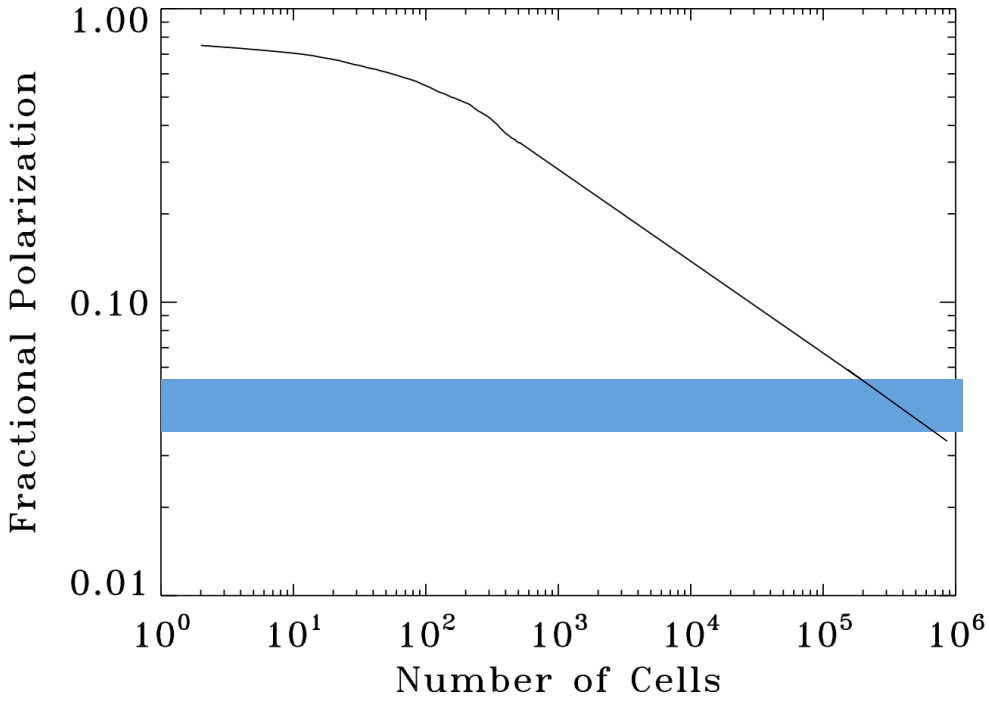
Compare polarized to unpolarized synchrotron intensities for uniform volume emissivity

Getting <f> = 0.045 requires over 10^5 magnetic domains

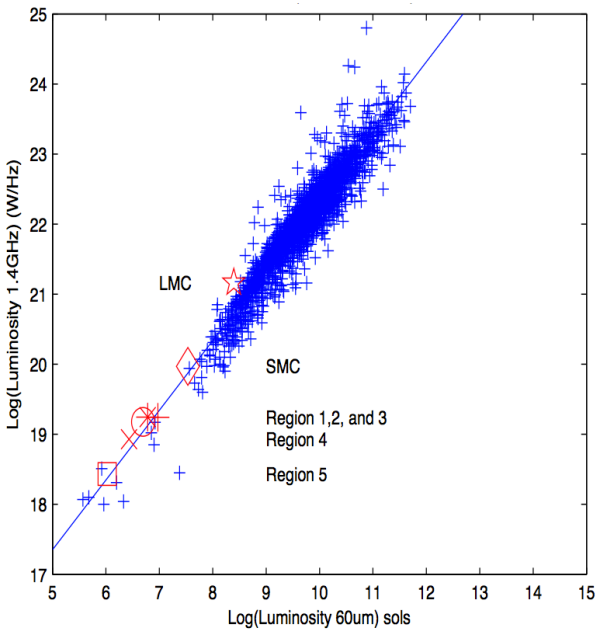
Domain size < 0.001 pc

De-polarization from random isotropic magnetic field



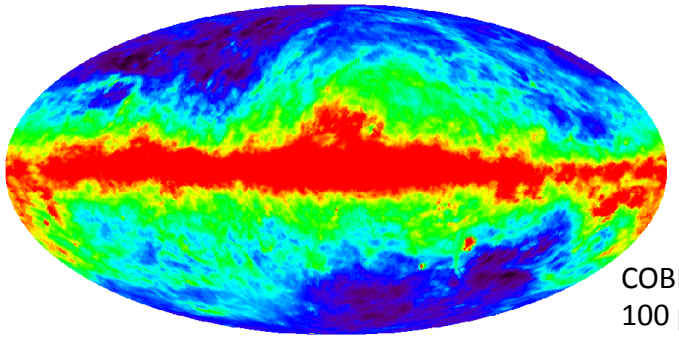


Multi-Messenger Tests



Radio / Far-IR Correlation

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



COBE/DIRBE
100 μm

Estimate polar cap brightness from radio / FIR correlation

1) DIRBE FIR * <q> from external galaxies
   T = 5.9 ± 3.5 K at 408 MHz
2) DIRBE FIR * <q> from local (Milky Way) correlation
   T = 4.8 ± 1.5 K at 408 MHz

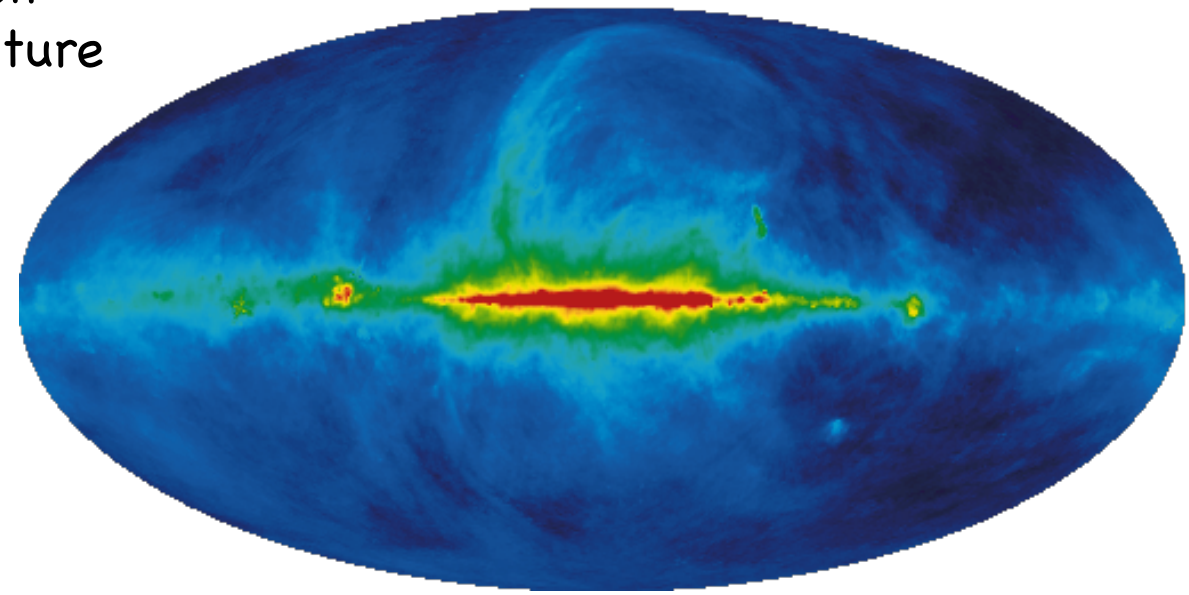
Factor of 4 below observed value (20 K)

**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

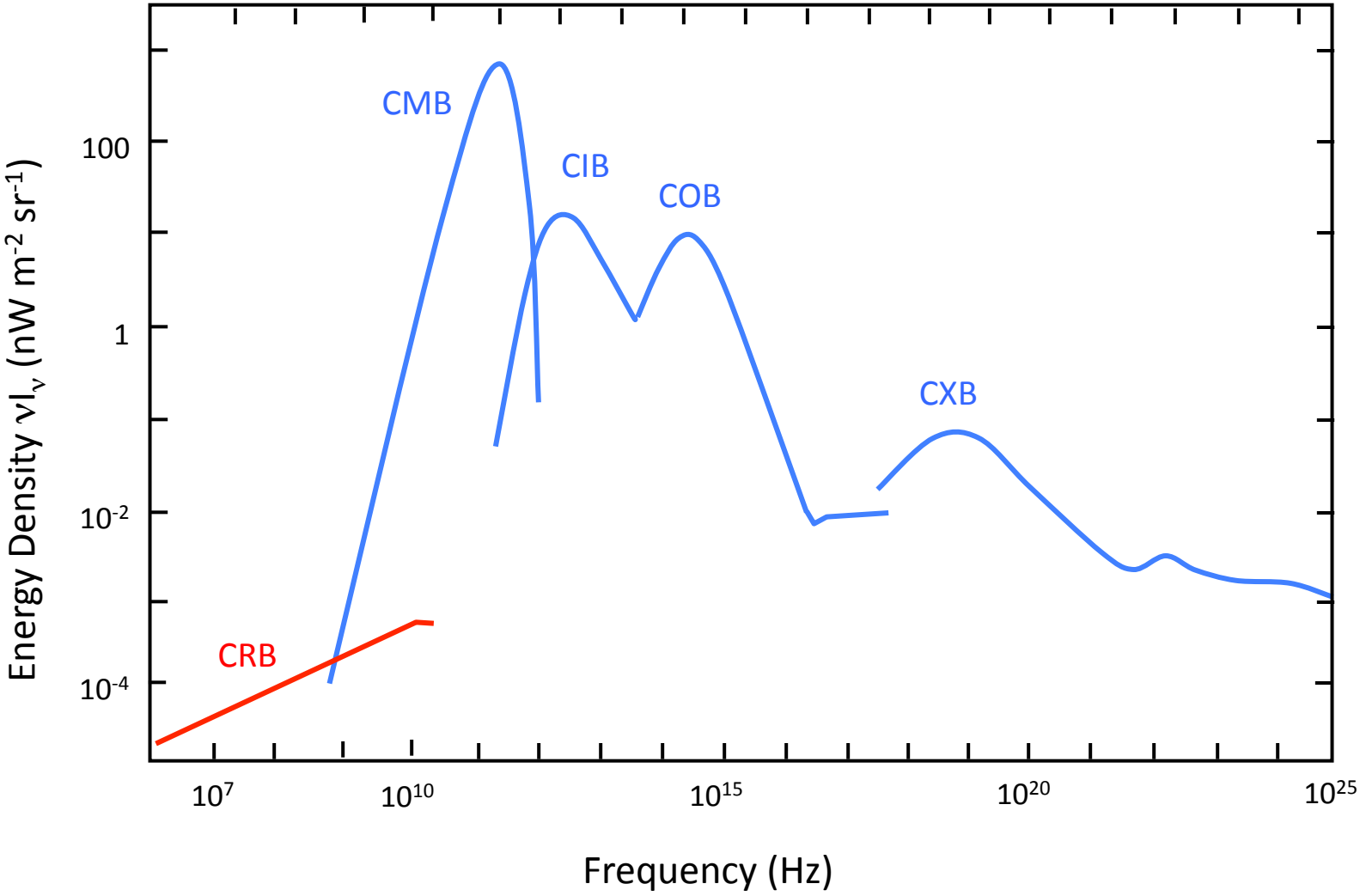


Extragalactic origin removes anomalies

- No need for radio halo
- Restores normal radio/FIR correlation
- Higher fractional polarization / larger domains (few pc)

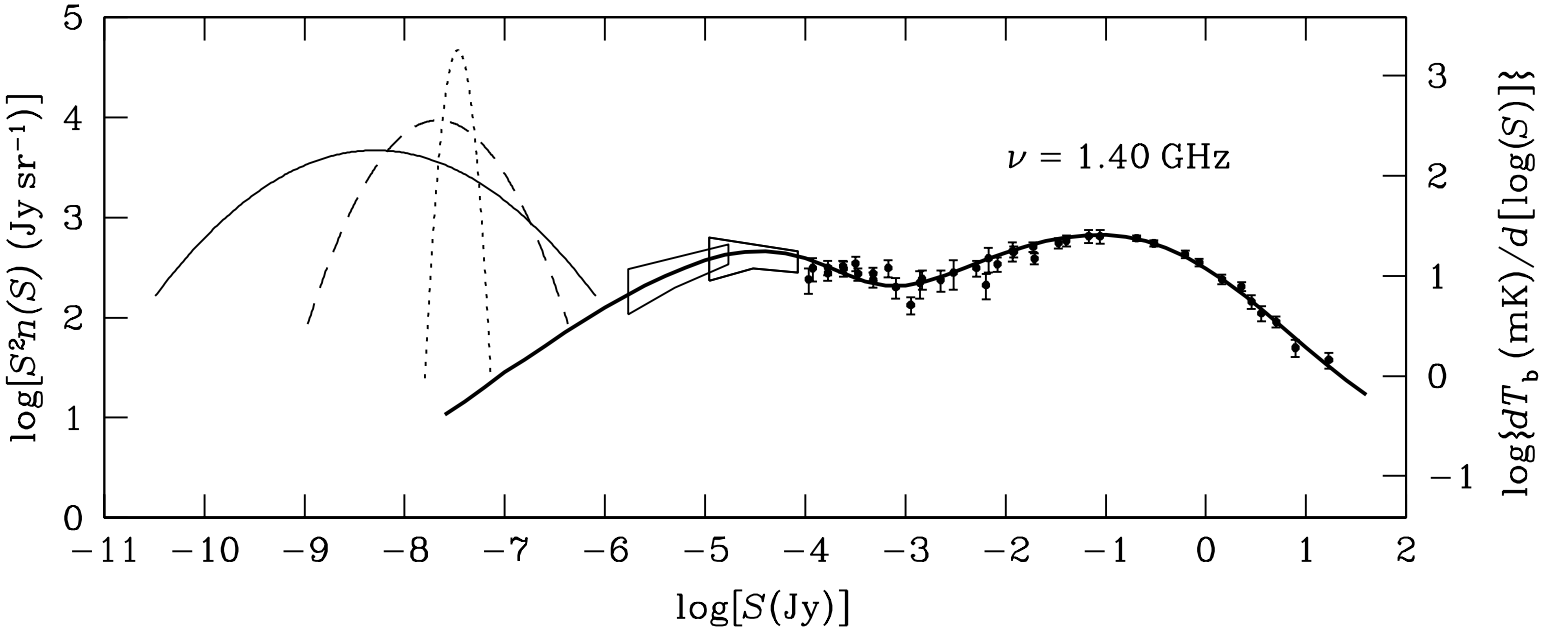
BUT need new faint source population

Cosmic Radio Background



Source Counts

How many sources does it take 'till we know
That too many photons have fried
-- Bob Dylan, "Blowin' In The Wind"

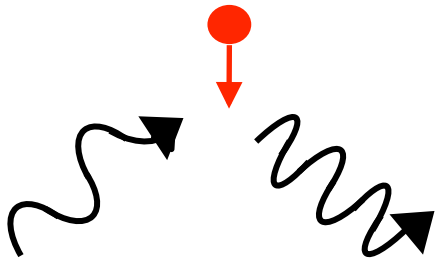


Need a boatload of faint sources
Not yet seen, but certainly possible!

Condon al 2012

Multi-Messenger Hints?

Radio / X-Ray Connection



Compton Scattering

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 μG

Singal et al 2010, MNRAS, 409, 1172

Sources? What Sources?

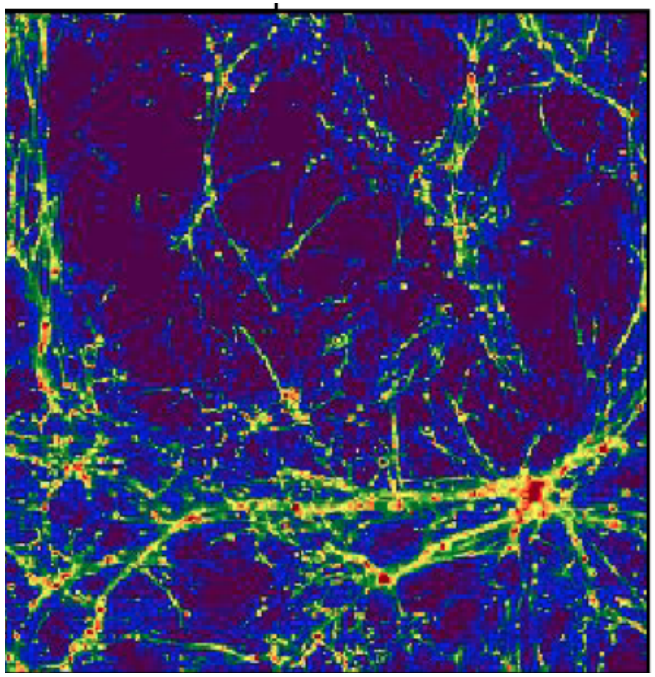
Requirements for extragalactic background:

A lot of faint sources …

Bright in synchrotron …

With a high magnetic field …

But without appreciable far-IR emission



Bierman et al. 2013, MNRAS

Early Universe?

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

Potential new source population at sub-μJy levels

Tests for Radio Background

Source counts at nJy levels

Millimeter polarization maps

Absolutely-calibrated sky surveys at 100-200 GHz