The WMAP Haze Excess and WIMP Annihilations

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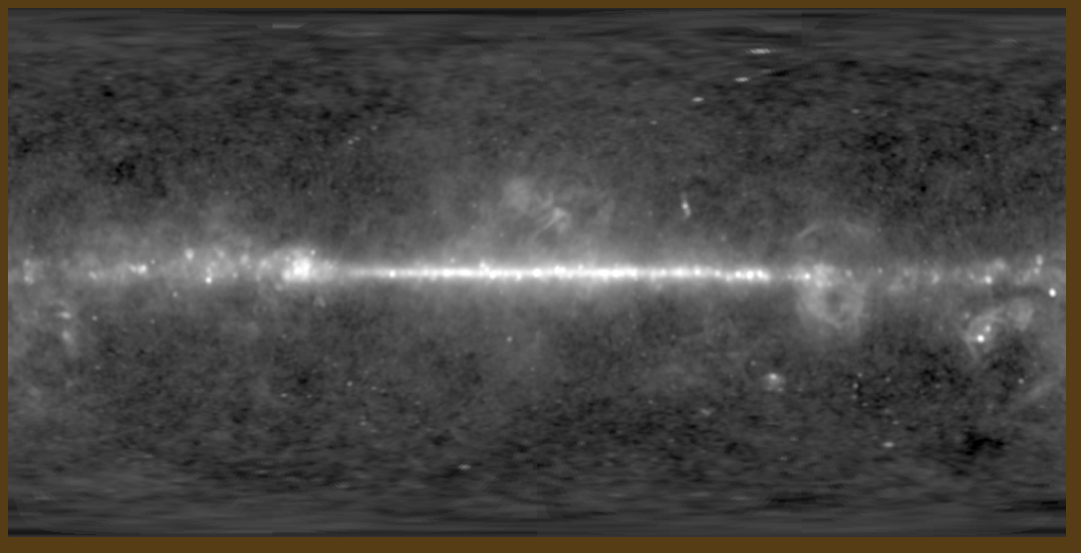
Roadmap

CMB FOREGROUNDS ⟷ **DARK MATTER**

- WIMP annihilations produce gamma rays
- WIMP annihilations *also* produce e^+e^- (cosmic ray electrons)
- Number dens□ity is high in the Galactic center (GC)
  => many e^+e^- injected
- Significant **B** field in GC
- B field + many electrons = synchrotron radiation
- ~10-100 GHz => WMAP

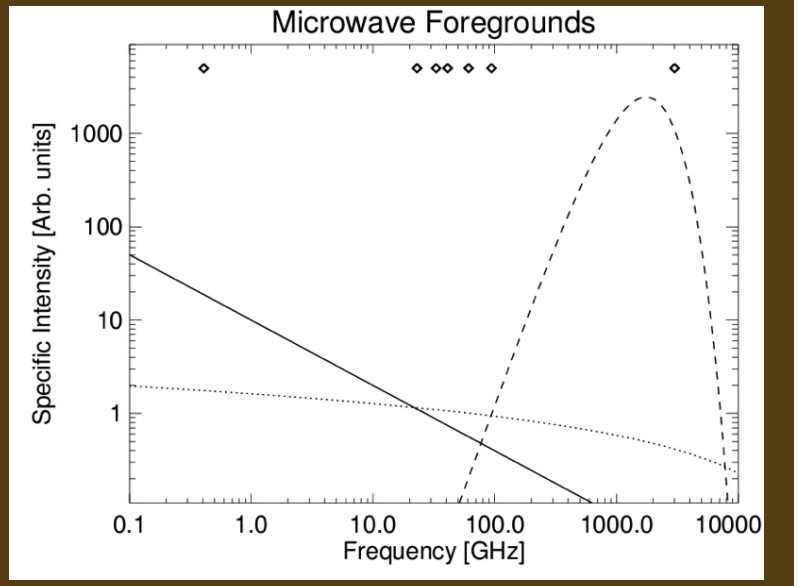
WMAP

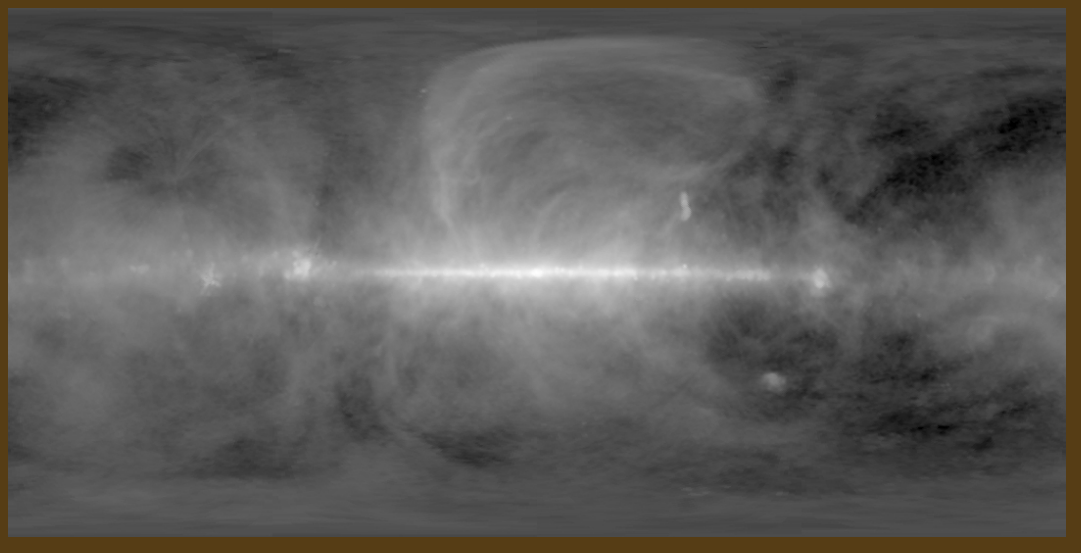
- Goal is to measure CMB fluctuations at $1/10^5$ (mK)
- Frequency coverage: 23-91 GHz
- Full sky map, 3 years of data
- Substantially "contaminated" by foregrounds



4 WMAP Foregrounds
Synchrotron

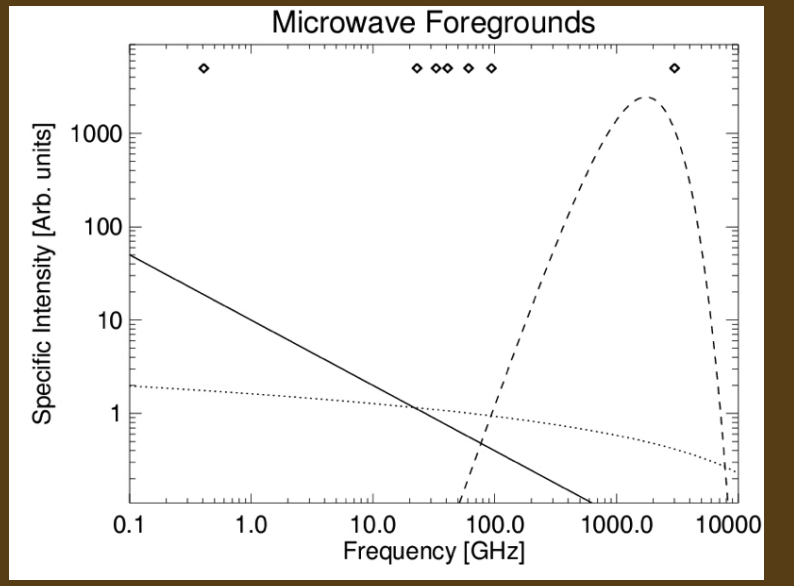
- Synchrotron from SN shock accelerated electrons + **B** field
- Dominant at low frequencies
- Well described by $I_\upsilon \propto \upsilon^{-1.0}$ (kJy/sr)
- Morphology traced by Haslam 408 MHz map (Haslam et al., 1982)

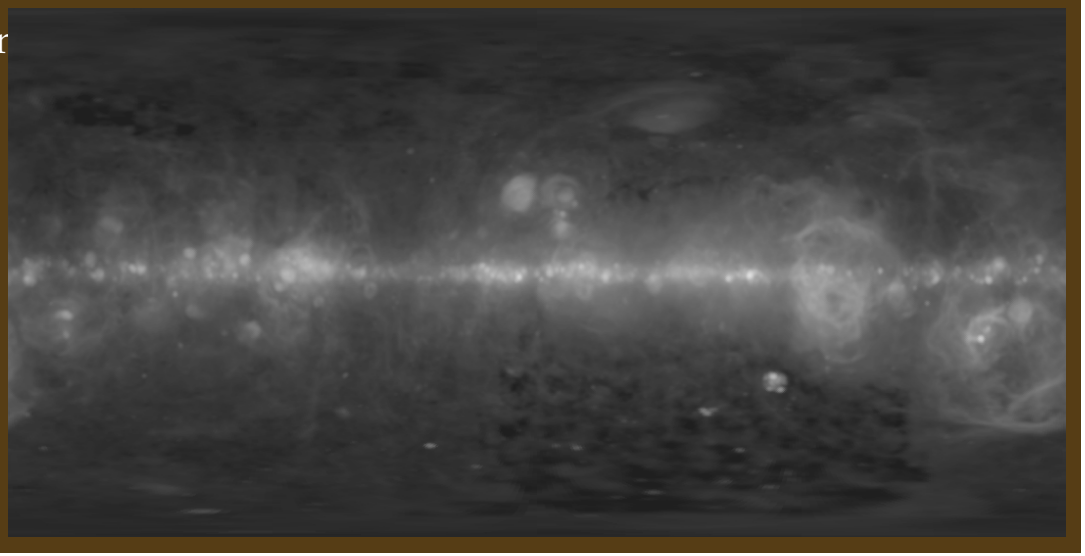




4 WMAP Foregrounds
Free-Free

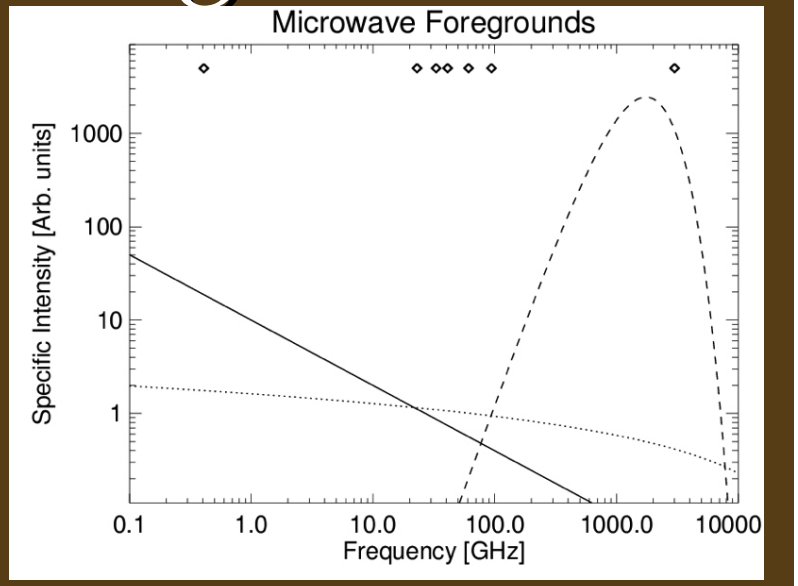
- Hot gas electron/ion thermal brehmstraalung
- Low and intermediate frequencies
- Well described by $I_\upsilon \propto \upsilon^{-0.1}$ (kJy/sr)
- Morphology traced by Hα recombination line map (Finkbeiner 2003)

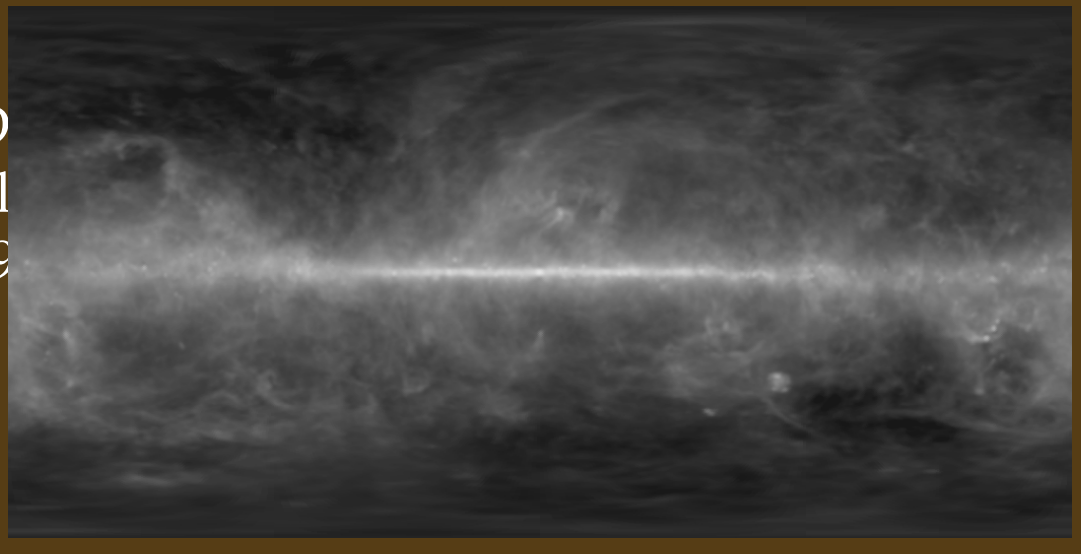




4 WMAP Foregrounds
Thermal and Spinning Dust

- At high frequencies dust grains vibrating in equilibrium with the radiation field: "thermal" dust
- Well described by $I_\upsilon \propto \upsilon^{3.7}$ (kJy/sr)
- Below 61 GHz, spectrum *rises* with *decreasing* frequency: "spinning" dust
- Morphology traced by the SFD (Schlegel et al., 1998) dust map eval at 94 GHz by Finkbeiner et al., 19





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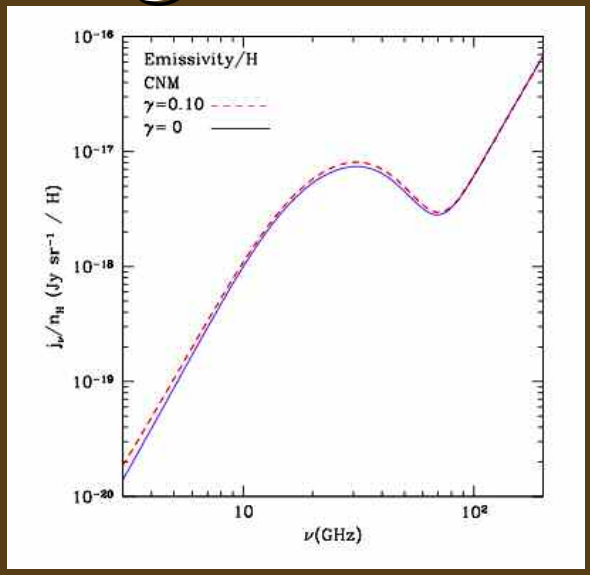
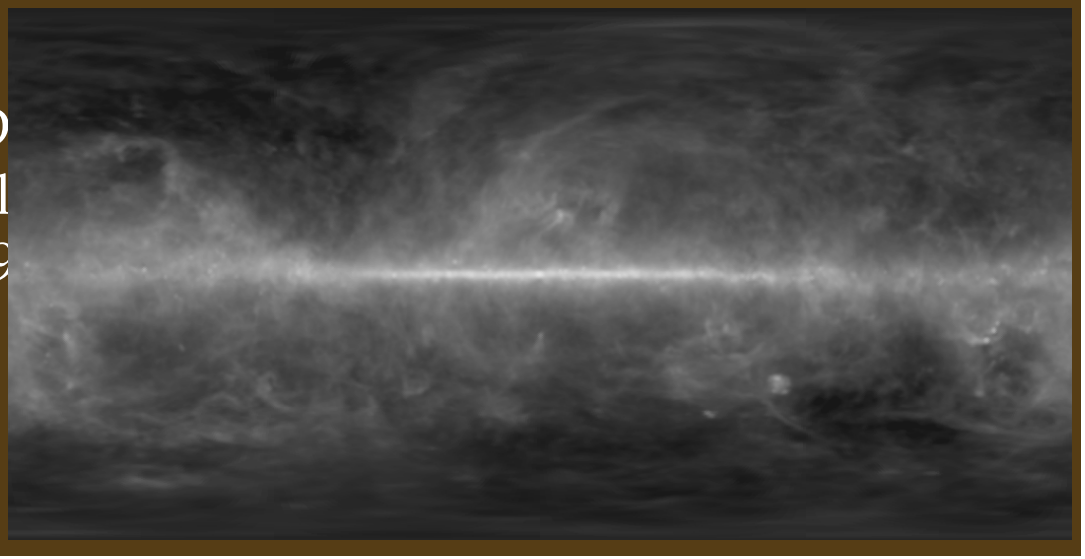
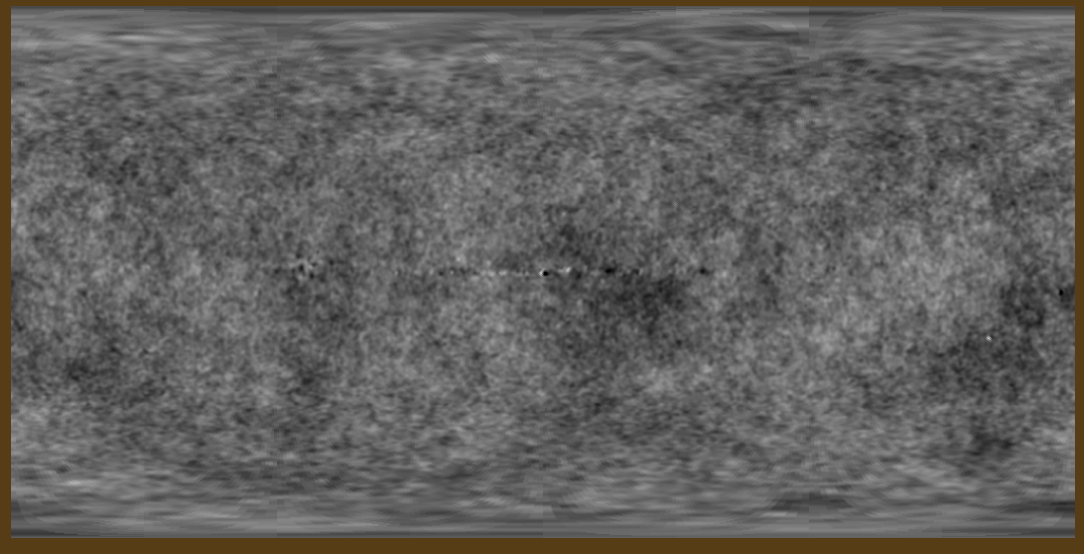


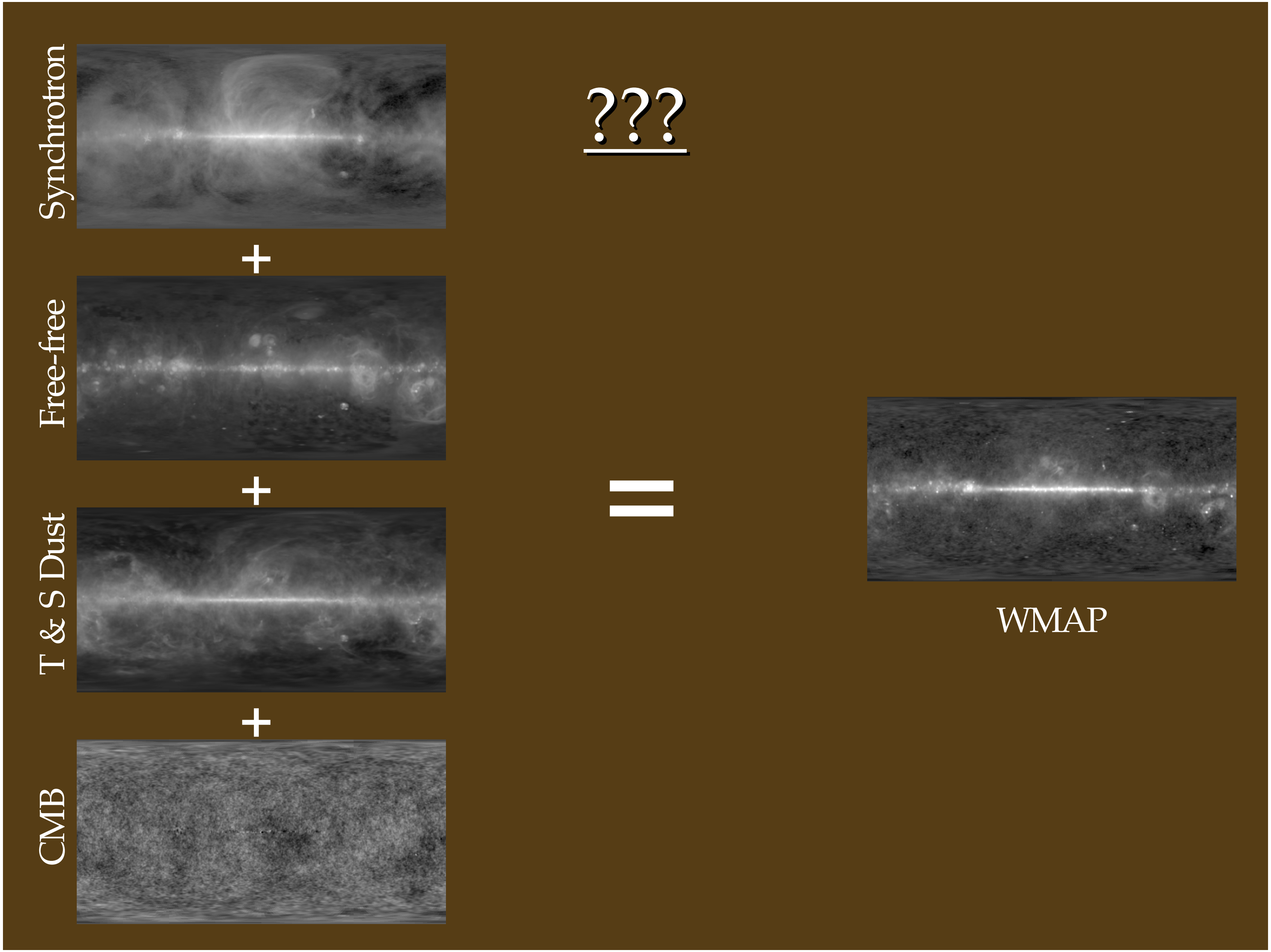
Draine & Lazarian, 1998



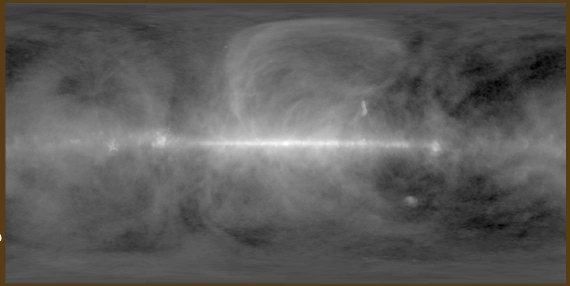
CMB

- For Galactic foregrounds, CMB is the *biggest* source of noise!
- Foregrounds can be ***approximately*** canceled via an internal linear combination (ILC) of WMAP bands




Synchrotron
Free-free
T & S Dust
CMB
???
WMAP

Synchrotron



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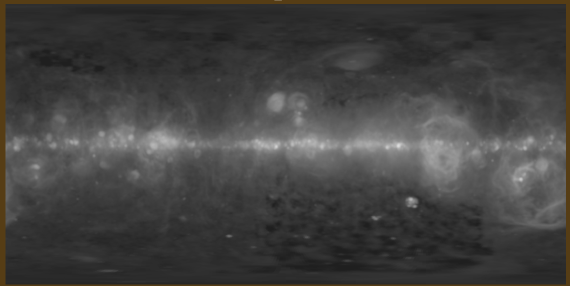
Free-free



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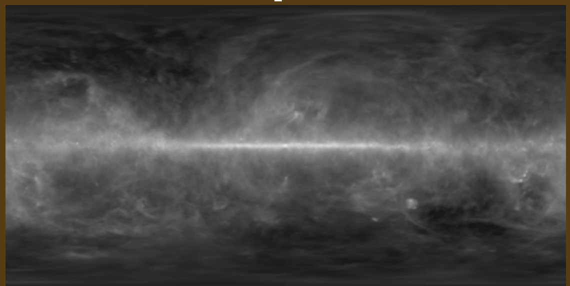
T & S Dust



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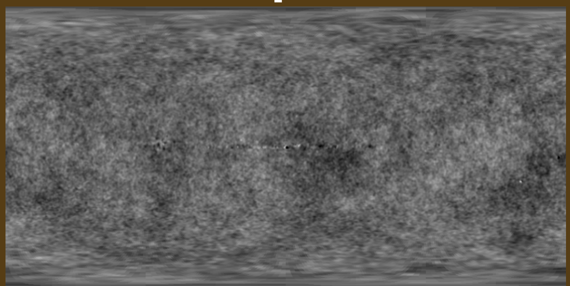
CMB



No!

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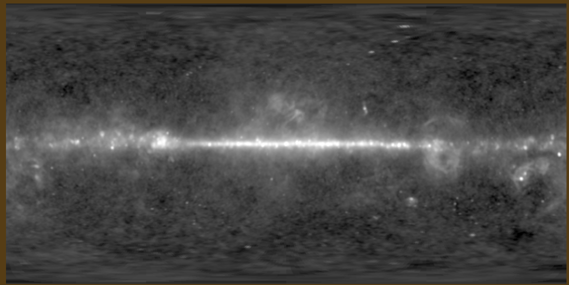
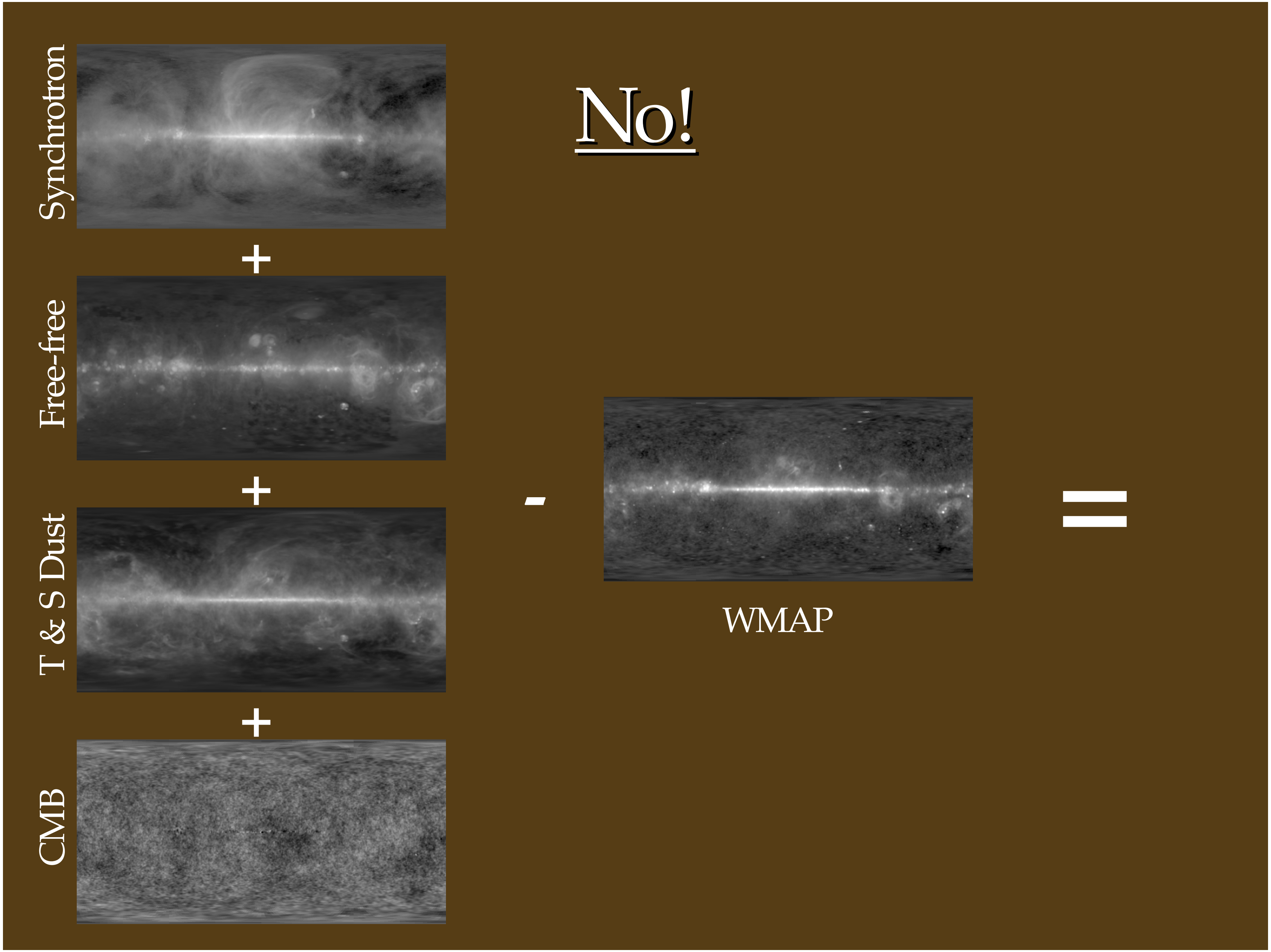
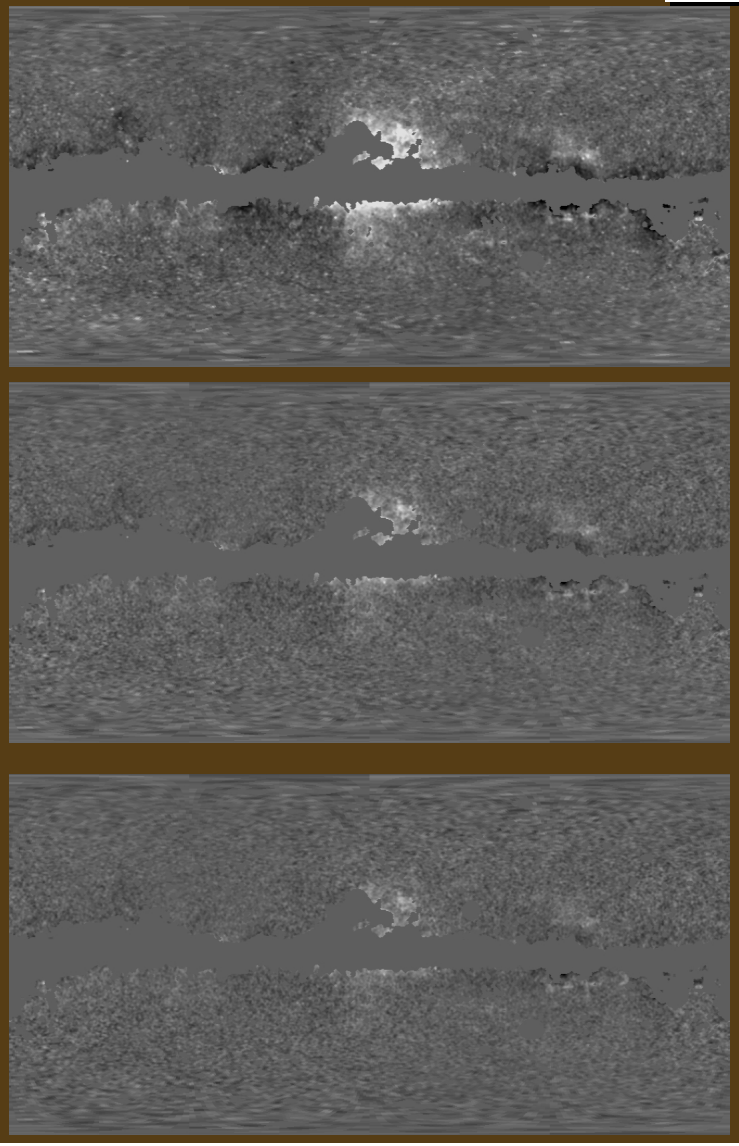


WMAP



No!
Synchrotron
+
Free-free
+
T & S Dust
+
CMB
-
WMAP
=

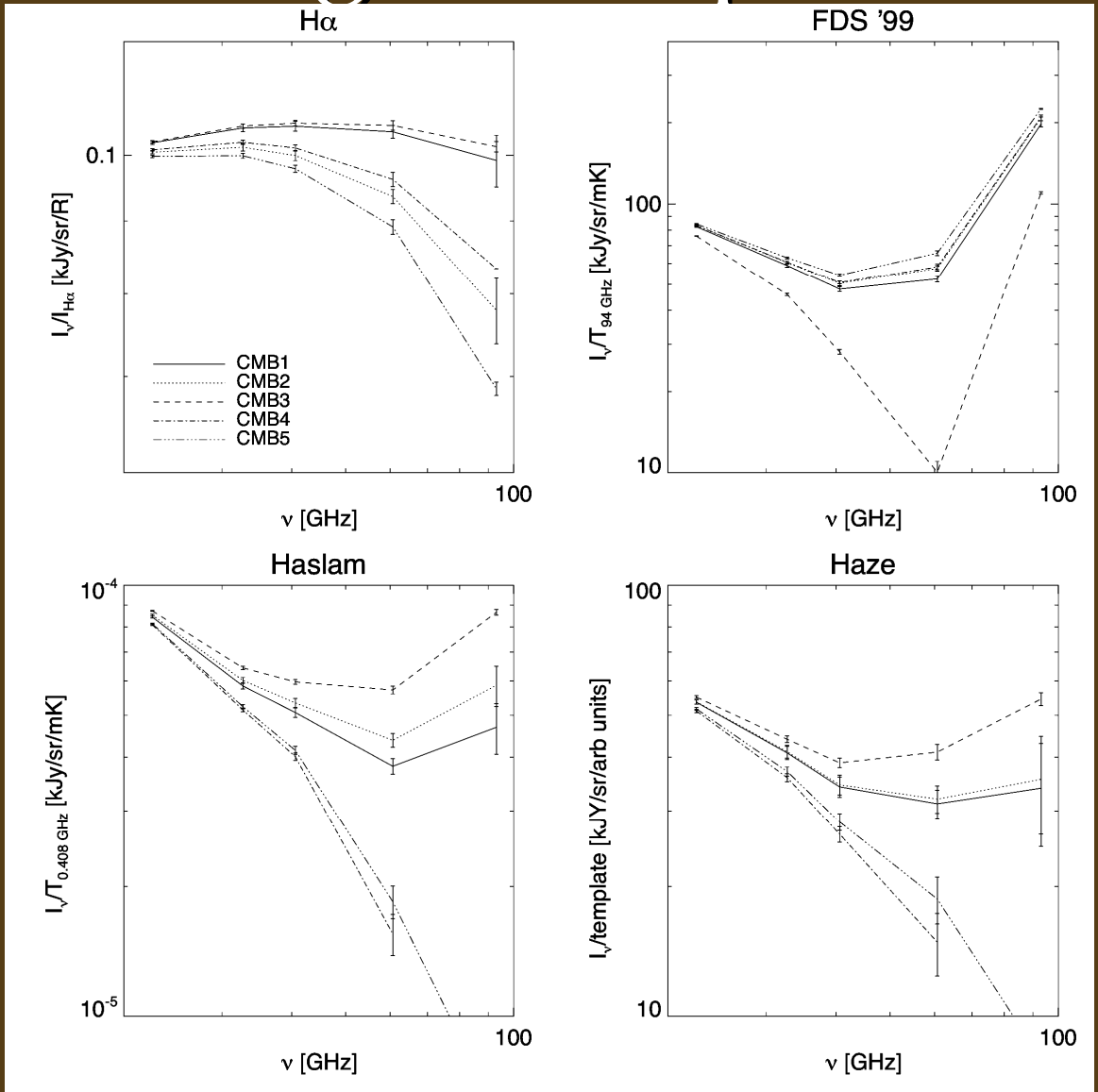
A 5th Foreground: the Haze



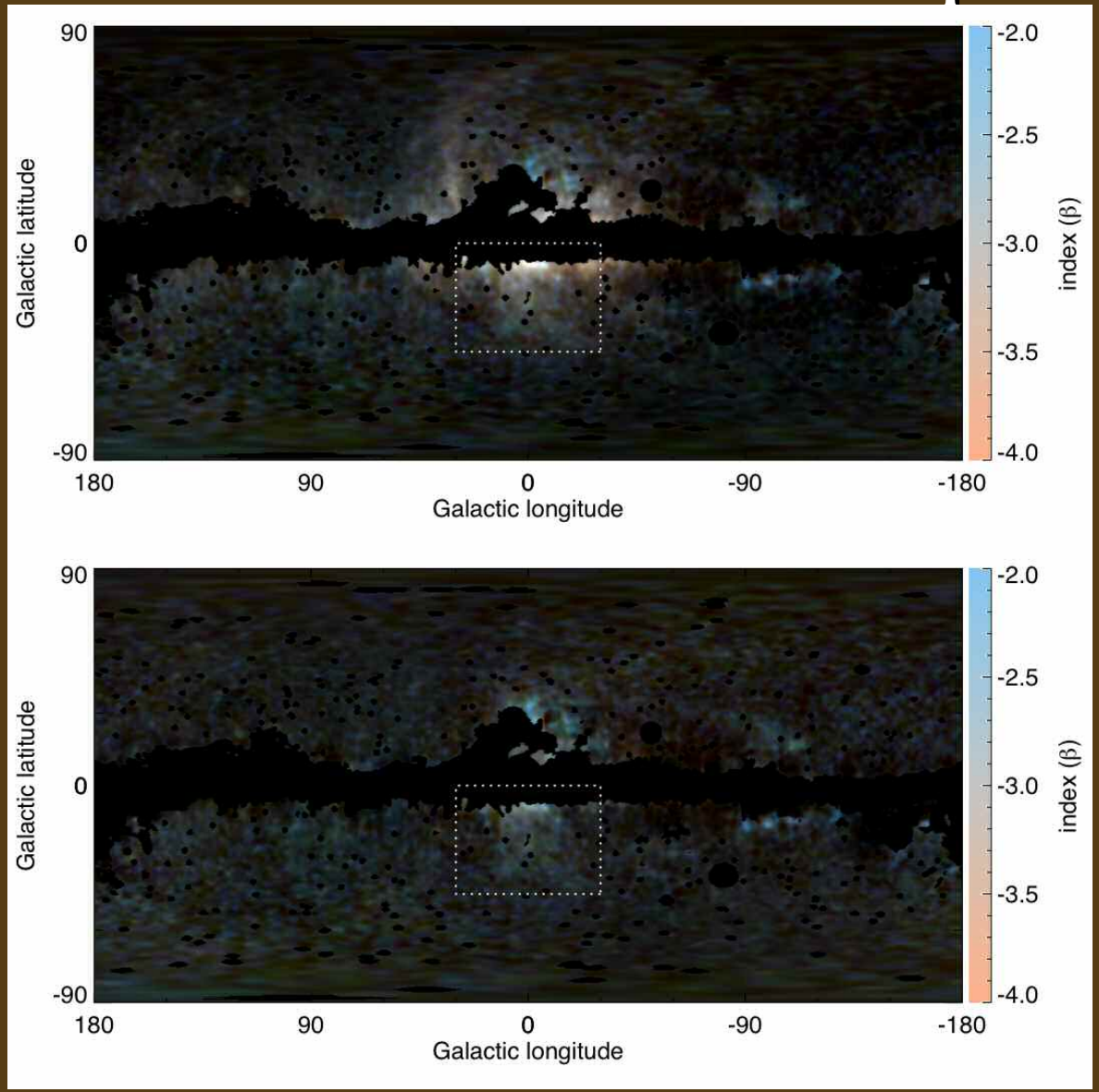
- Multi-linear regression fit
- Excess towards the GC
- What is it?
  - No structure in Hα map
  - No significant X-ray emission
    => not free-free
- What is its spectrum?
  - Take $T(r) \sim 1/r$
  - Relax stress on fit
  - Residuals are ideally mean zero

Dobler & Finkbeiner, 2007

Foreground Spectra



The Haze Spectrum

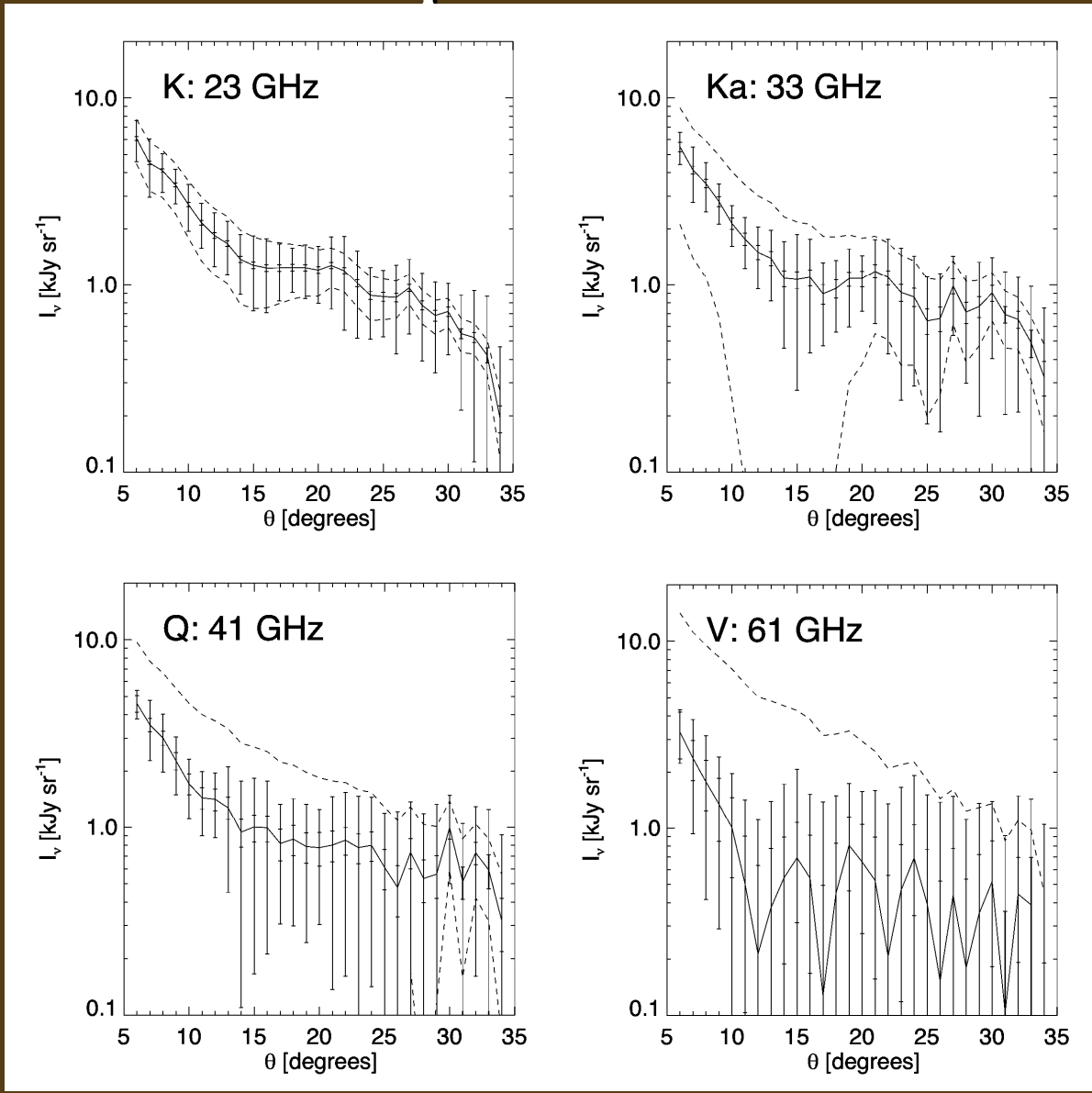


- Looks like synchrotron but with a very hard spectrum, $E^2 dN/dE \propto E^{0.1\text{-}0.2}$
- If it is synchrotron, it requires
  - hard e^+e^- spectrum
  - extended emission
- Very difficult to produce astrophysically

Dobler & Finkbeiner, 2007

The Haze: an explanation

- WIMP annihilation produces very energetic electrons (>50 GeV)
- Halo annihilation towards the GC is *extended* injection (i.e., a point source)
- Can it explain the haze data towards the south Galactic center?



The Haze: an explanation

- Galactic/baryon parameters:
  - Magnetic field, $B = 10$ μG
  - Diffusion constant, $K(E) \sim 10^{28}$ cm^2/s
- Dark matter parameters
  - DM halo profile, $\rho = \rho(r)$
  - WIMP mass, $M \sim 100\text{-}800$ GeV
  - Annihilation cross section, $\sigma v \sim 3 \times 10^{-26}$ cm^3/s
  - Annihilation mechanisms (e^+e^-, $\mu^+\mu^-$, etc.)

Diffusion Equation

$$\frac{d}{dt}n(E,\mathbf{x}) = \nabla \cdot (K(E,\mathbf{x})\nabla n) + \frac{\partial}{\partial E}\left[b(E,\mathbf{x})n\right] + Q(E,\mathbf{x})$$

*K(E,**x**)* = diffusion coefficient

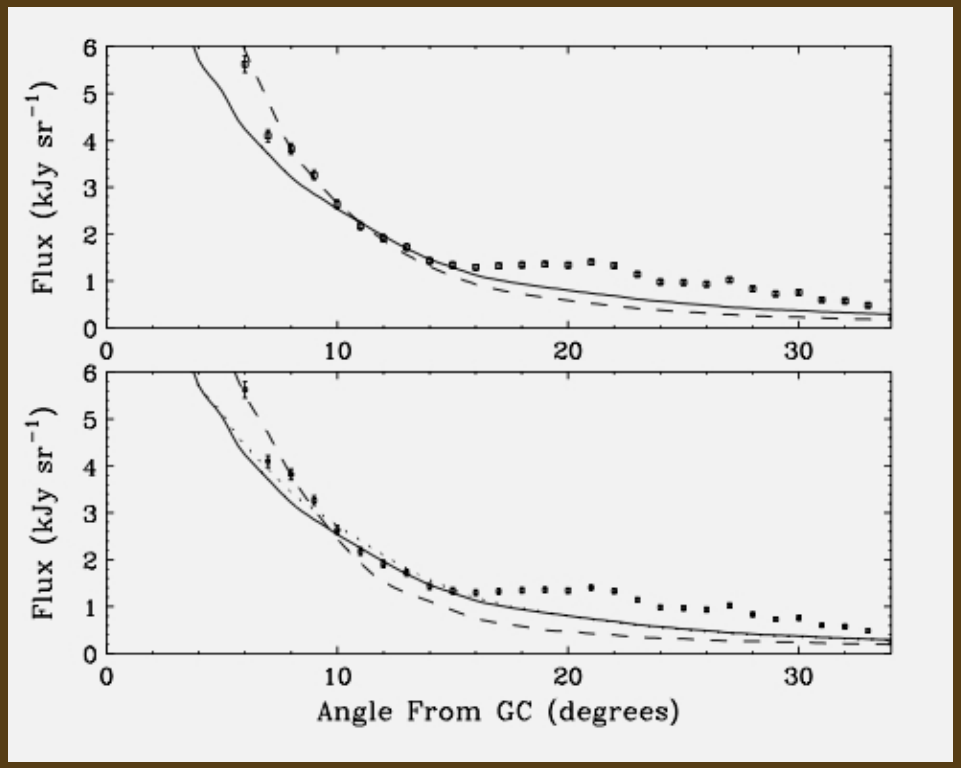
*b(E,**x**)* = energy loss coefficient

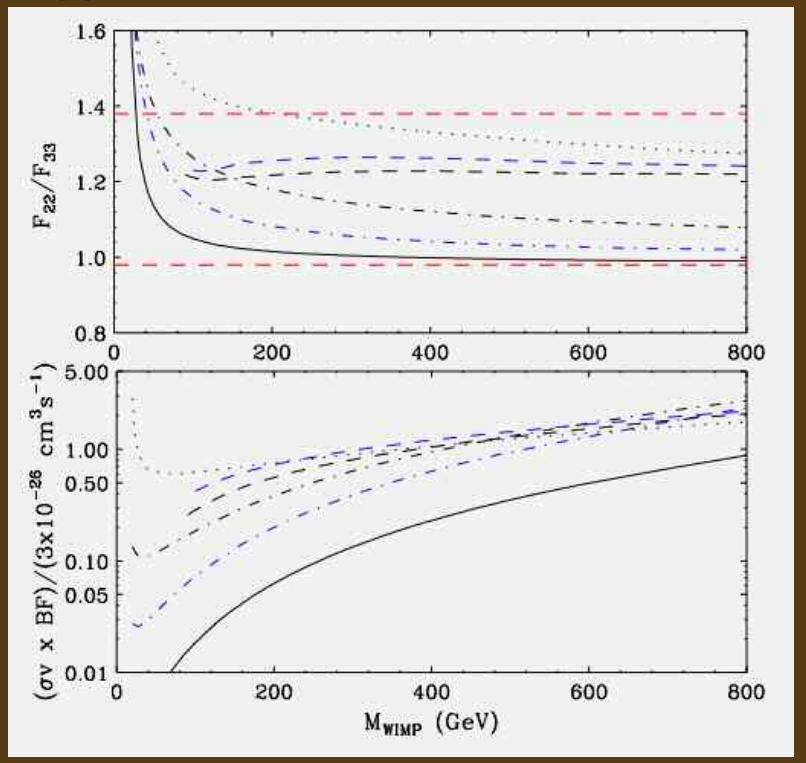
*Q(E,**x**)* = source term

Assuming steady state and isotropic diffusion and energy loss =>

$$-K(E)\nabla^2 n - \frac{\partial}{\partial E}\left[b(E)n\right] = Q(E,\mathbf{x}).$$

The Haze: an explanation





- $\rho(r) \sim r^{-1.2}$ favored, consistent with a contracted NFW profile
- **No** boost factor (due to substructures) is required
- Multiple annihilation channels are consistent with 23-33 GHz spectrum

Hooper, Finkbeiner, & Dobler, 2007

Conclusions

- Excess microwave emission is observed towards the GC
- The haze is ***extended,*** ($R \leq 20$ degrees)
- Consistent with synchrotron radiation from a hard spectrum cosmic ray electron population.
  - $E^2\, dN/dE \propto E^{0.1\text{-}0.2}$
- A simple WIMP annihilation model fits the data reasonably well
  - $M \sim 100$ GeV
  - $\sigma v \sim 3x10^{-26}$ cm^3/s
  - $\rho(r) \sim r^{-1.2}$ favored
- Future prospects:
  - GLAST: inverse Compton gammas from e^+e^-, possible prompt gammas
  - PLANCK: will mostly eliminate uncertainties in the haze spectrum