THE COSMIC RADIO BACKGROUND

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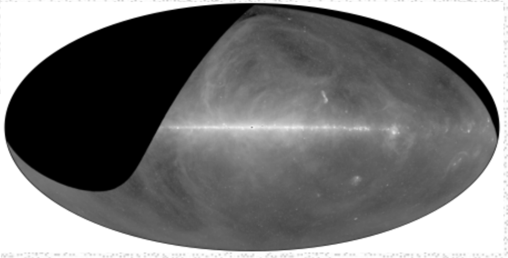
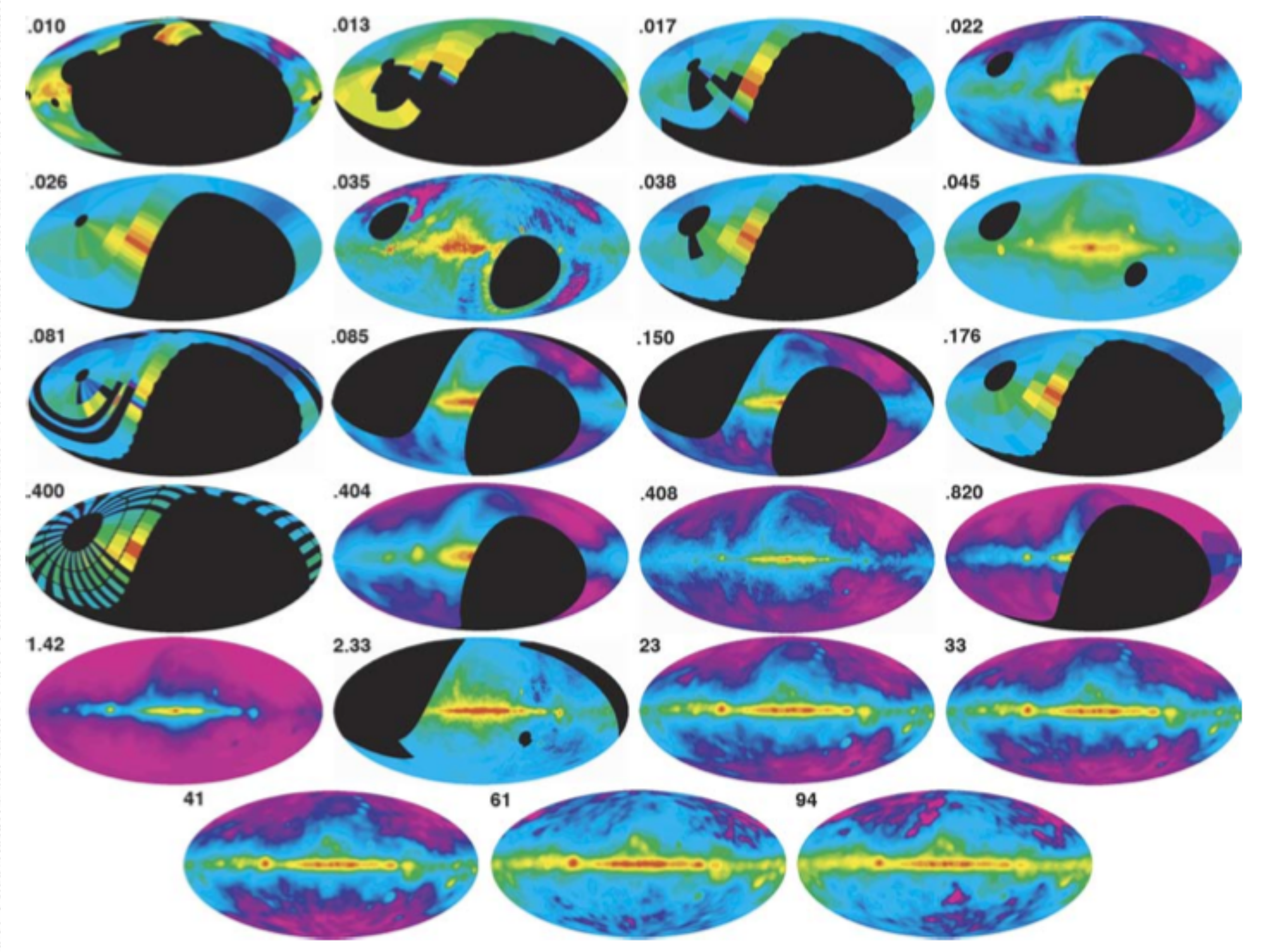
All-sky images of the CRB

1.42 GHz



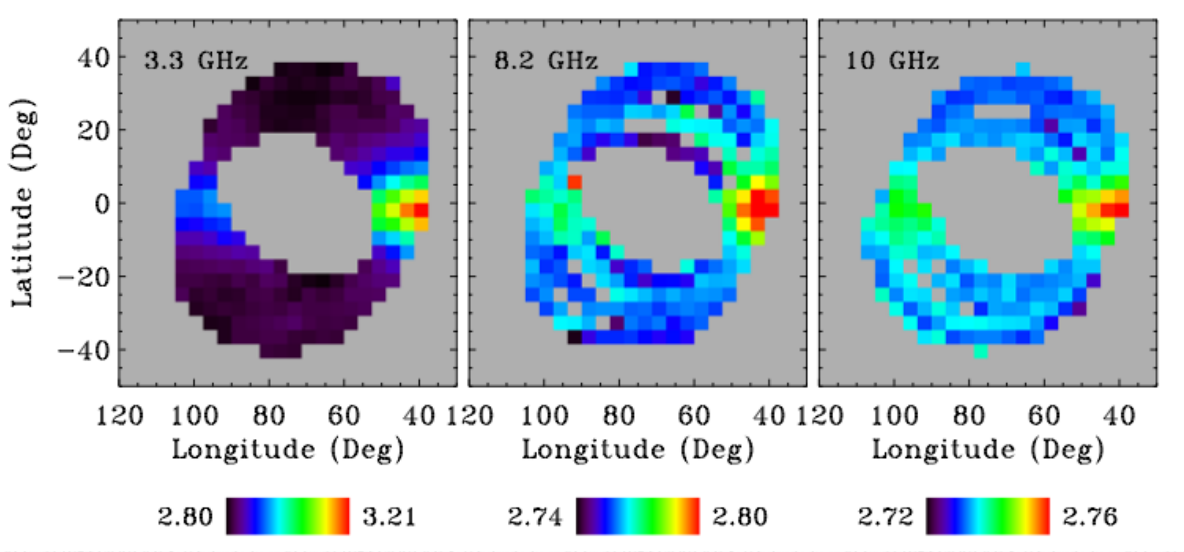
[Calabretta ++ 2013]



[de Oliveira-Costa ++ 2008]

- Sky coverage
- Maps made with Absolute and Differential radiometers
- Errors in zero point and scale
- Scanning errors

At higher radio frequencies: ARCADE 2 measurements of the absolute brightness of the CRB



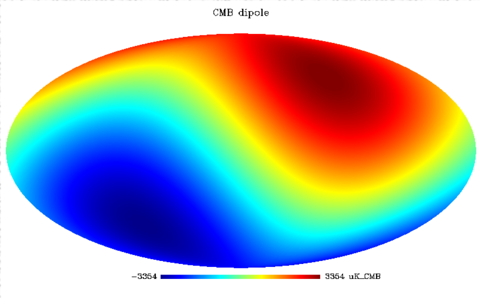
[Kogut ++ 2011]

Dominated by CMB monopole.

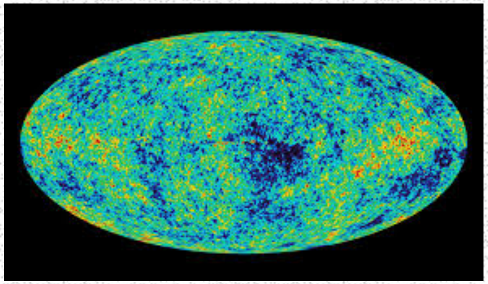
Galactic emission is seen in all three images.

Components of the CRB

- Relic radiation: CMB
  - Almost uniform 2.7 K black body spectrum
  - Excepting for the 3.3 mK dipole



  - And micro K CMB anisotropies



- Extragalactic
  - Discrete radio sources
  - Distribution is expected to be uniform, with some clustering
- Galactic emission
  - Thermal & non-thermal radio sources and diffuse structures in the Milky Way
  - Expected to be anisotropic, excepting for any local `bubble` of emissivity

Simplest model for the Galactic emission

A plane parallel slab model for the galaxy [Kogut ++ 2011]

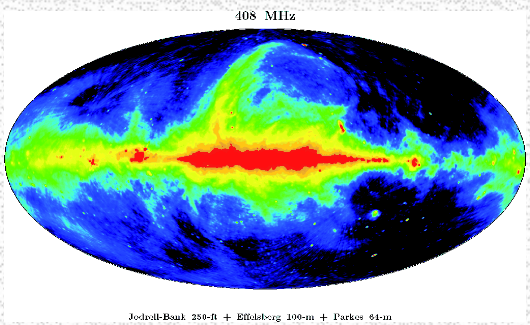
$$T_A(|b|) = a_0 + a_1 \csc(|b|)$$

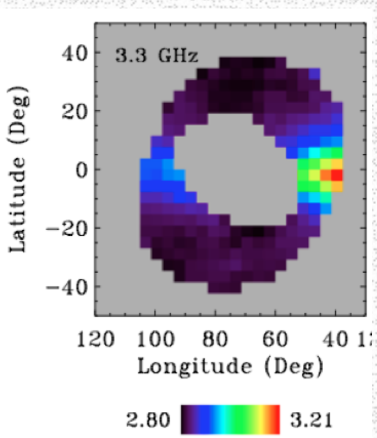
a1 is the slab brightness towards the Galactic pole

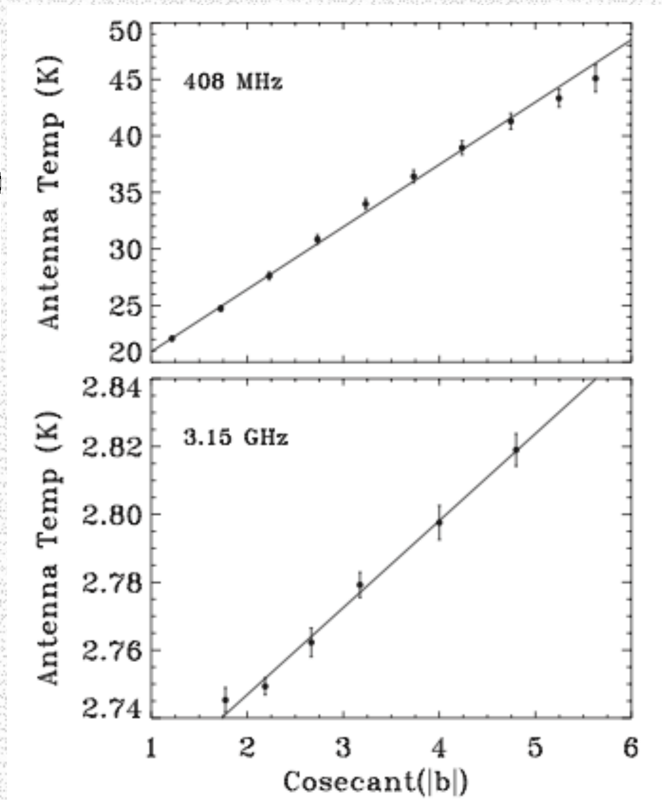
a0 is the ‘constant’ brightness of the remainder:

= Brightness of the uniform component of CRB.

Extragalactic and any Local bubble







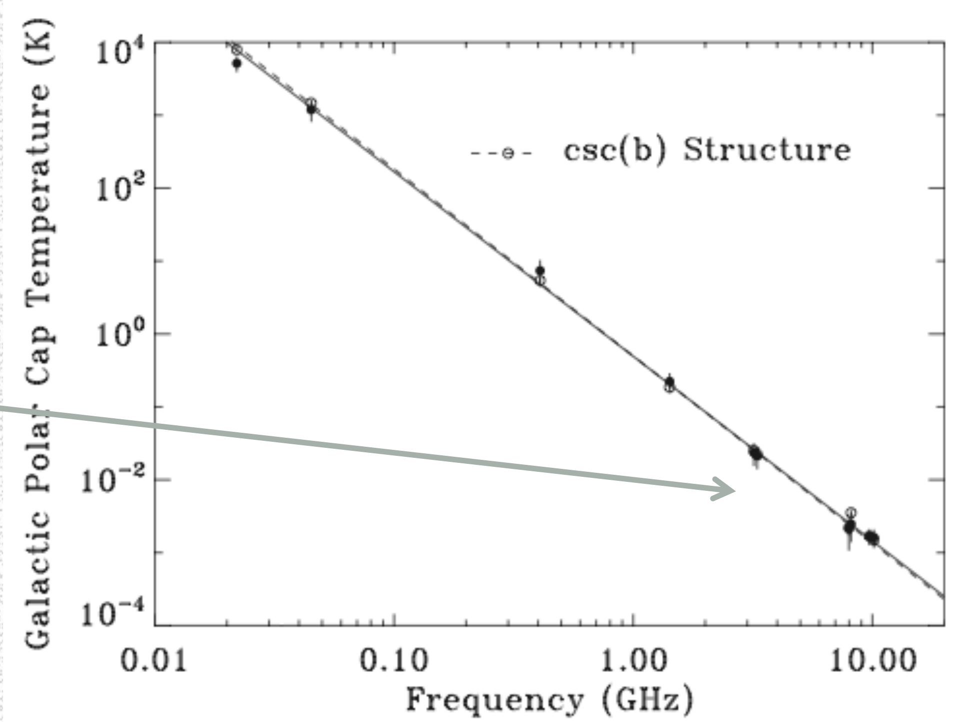
Slab model for the Galactic emission

[Kogut ++ 2011]

a1 = Brightness of the slab model towards the Galactic pole

Computed using all-sky images at 22, 45, 408, 1420 MHz

Apart from the ARCADE data

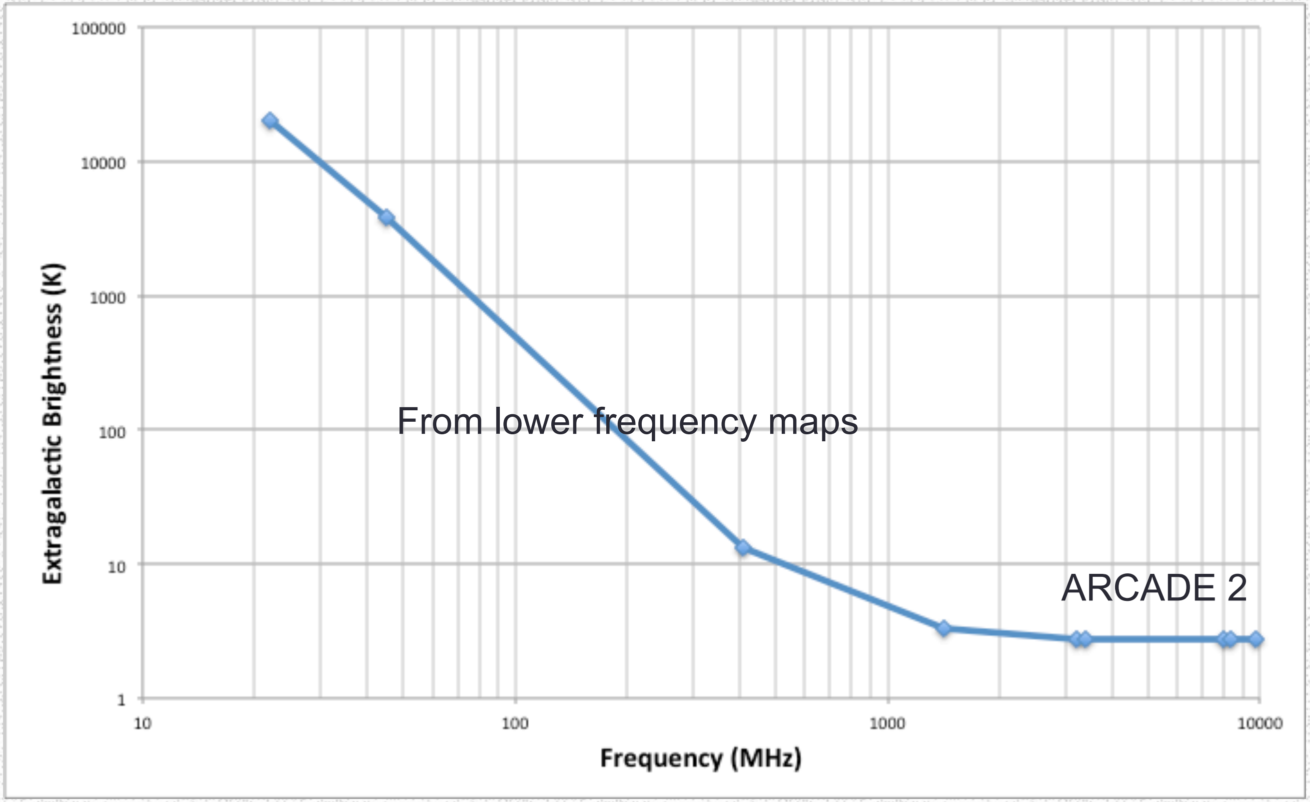


$T = 209\ \mathrm{mK}\ (f\ /\ 1400\ \mathrm{MHz})^{-2.55}$

The remainder ought to be isotropic components of the CRB

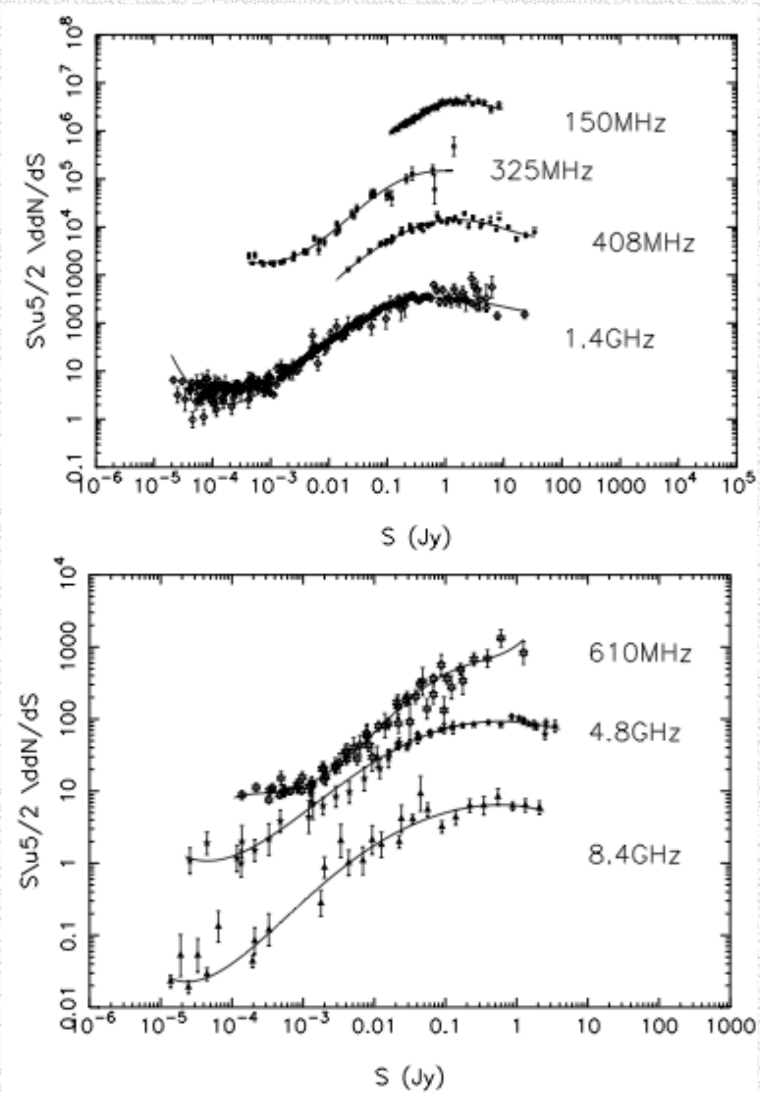
An unaccounted for excess uniform background?

Take the absolute brightness of the CRB (from ARCADE + low frequency maps)
Subtract the slab model for the Galaxy (from Kogut ++ 2011)
To get an ‘extragalactic’ brightness temperature.



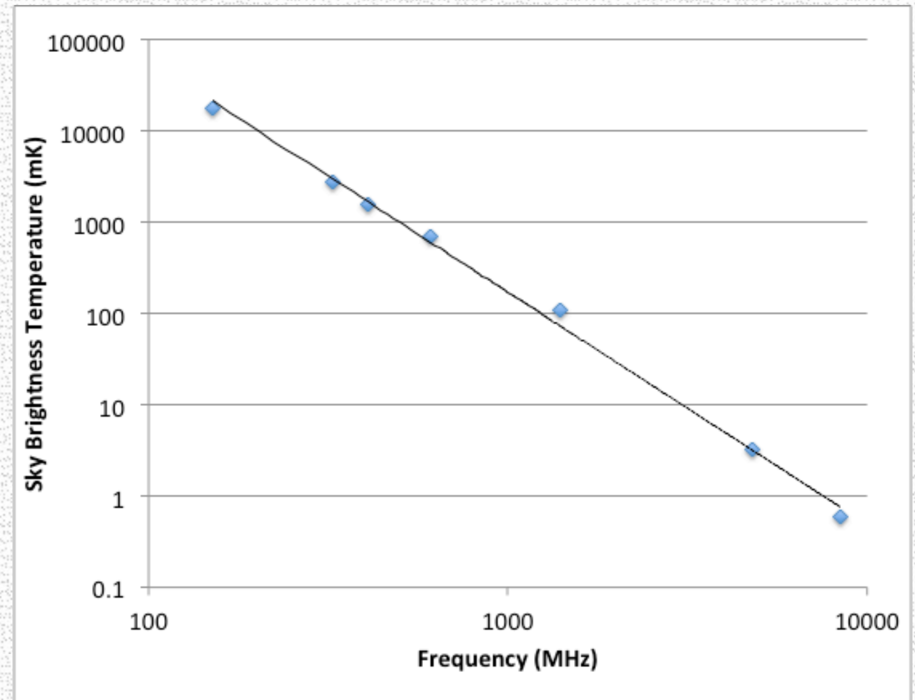
[Fixsen ++ 2011; Seiffert ++ 2011]

Extragalactic discrete radio sources



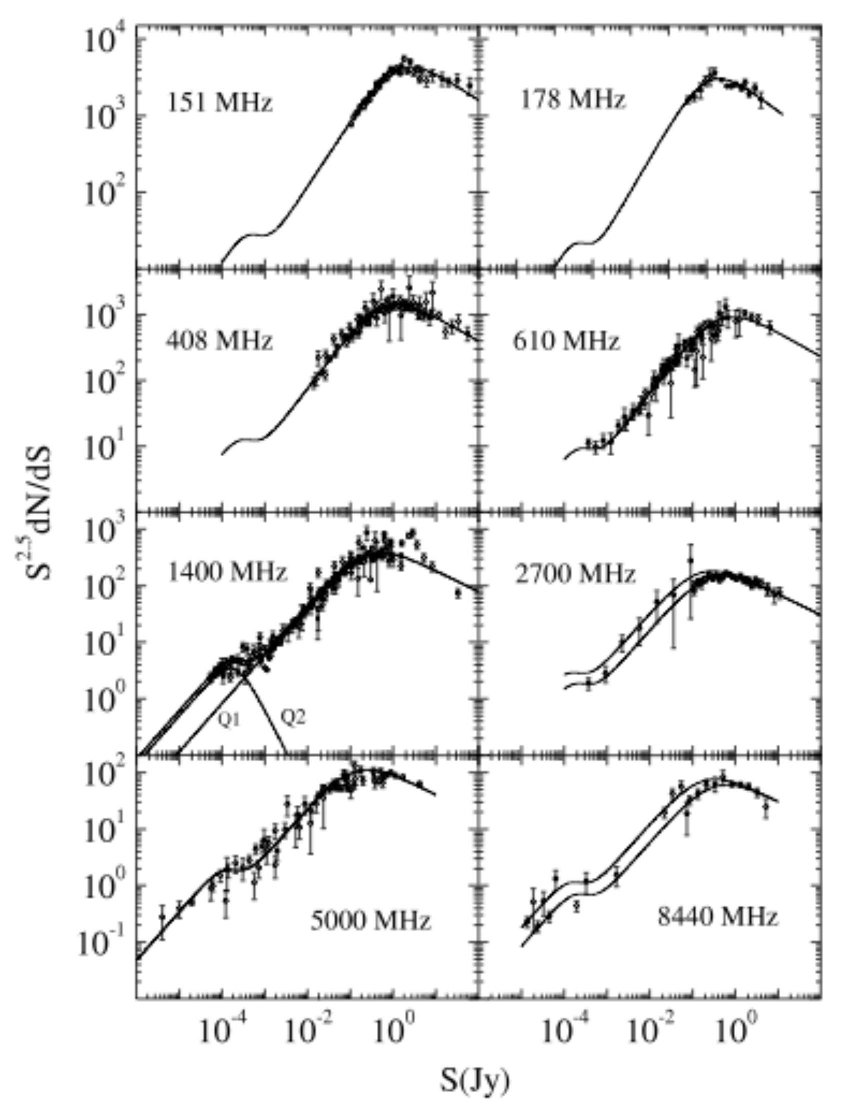
[Vernstrom ++ 2011]

Integrating over just the flux density range over which sources have been detected:



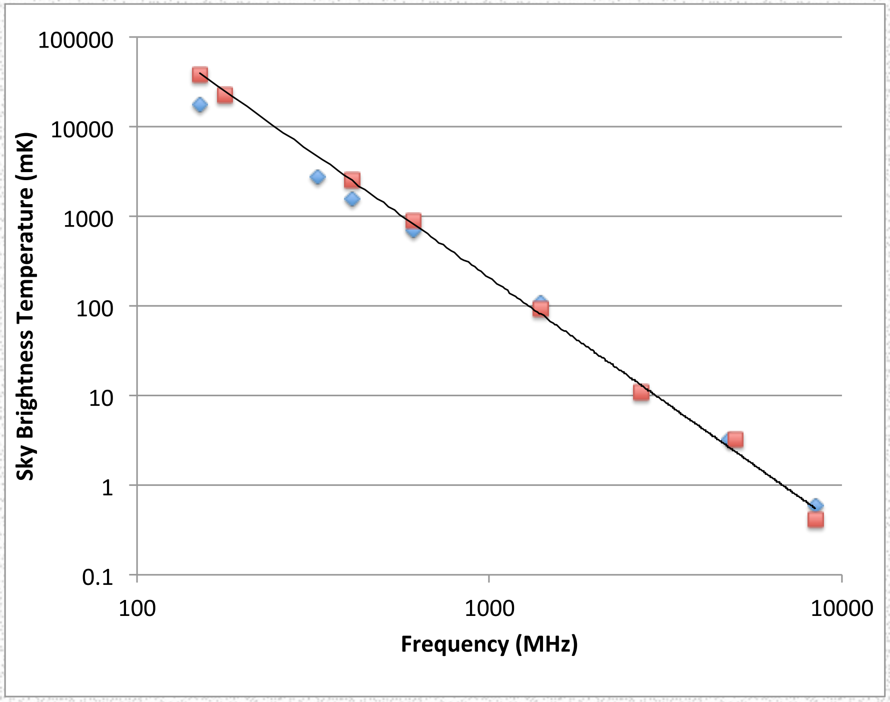
$$T = 74\text{ mK }(f / 1400\text{ MHz})^{-2.54}$$

Extragalactic discrete radio sources



[Gervasi ++ 2008]

Integrating the model fit down to microJy level:



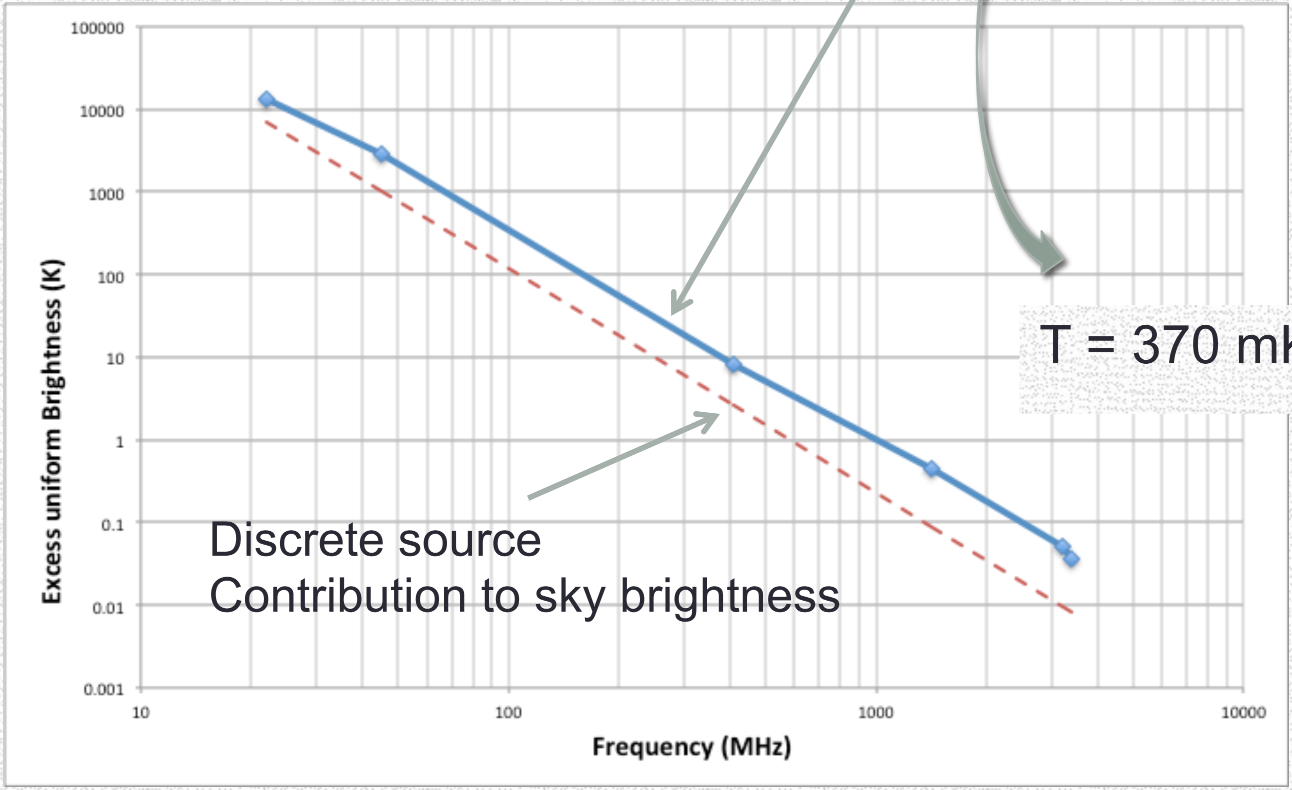
$$T = 92\ \text{mK}\ (f\ /\ 1400\ \text{MHz})^{-2.71}$$

An unaccounted for excess uniform background?

Subtract the brightness corresponding to discrete radio sources and CMB from the Extragalactic background

Unaccounted excess – which is a uniform radio background – is a factor 2-5 more than the background from known populations of discrete sources.

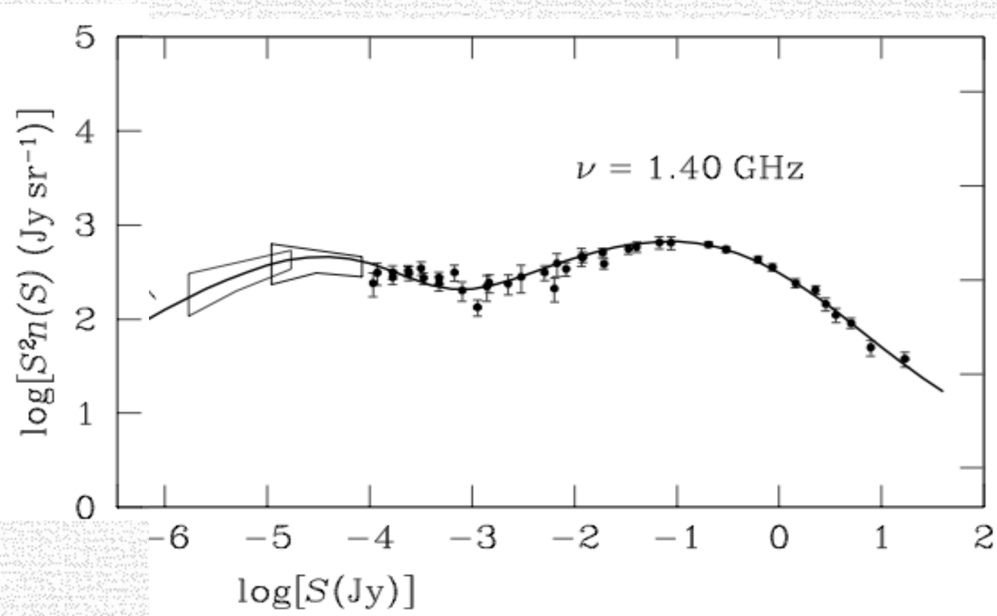
[Fixsen ++ 2011; Seiffert ++ 2011]



$T = 370 \text{ mK } (f / 1400 \text{ MHz})^{-2.57}$

Discrete source
Contribution to sky brightness

The ‘excess’ motivated a Deep EVLA survey



[Condon ++ 2012]

EVLA deep survey at 3 GHz

Down to 1 microJy rms noise

Extend the source counts to 1 microJy at 1.4 GHz

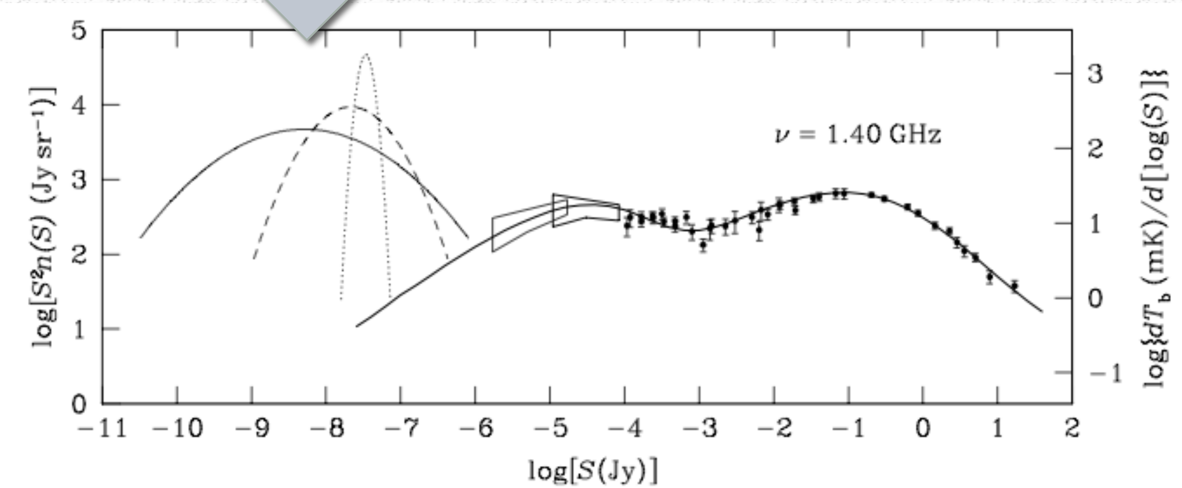
Integrating the source counts (extrapolated to nanoJy)

gives 100 mK sky brightness at 1.4 GHz

Models for the ‘excess’

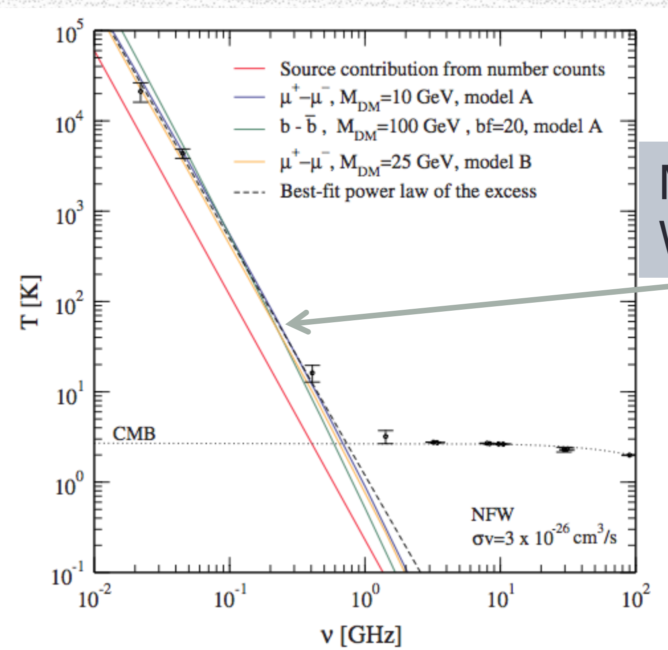
New sub-microJy source population?

[Condon ++ 2012]



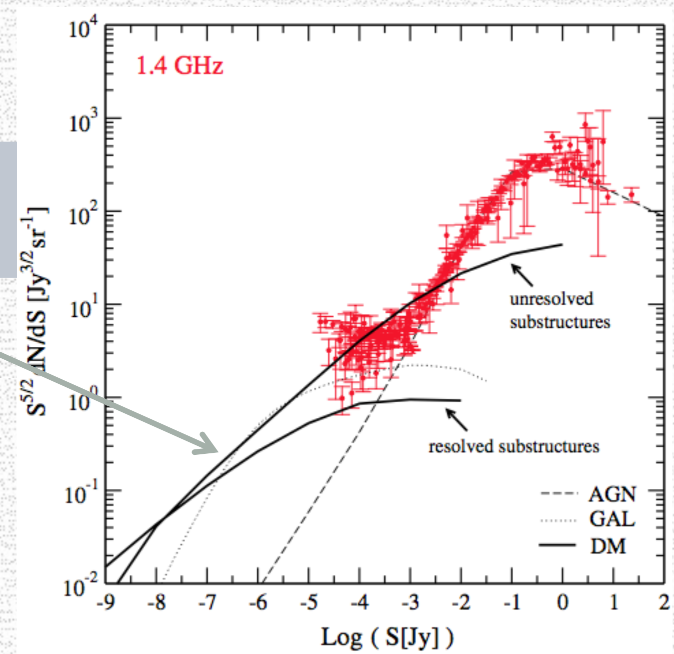
Is the ‘excess’ a relic of creation of primordial black holes?

[Biermann & Harms 2013]



[Fornengo ++ 2011]

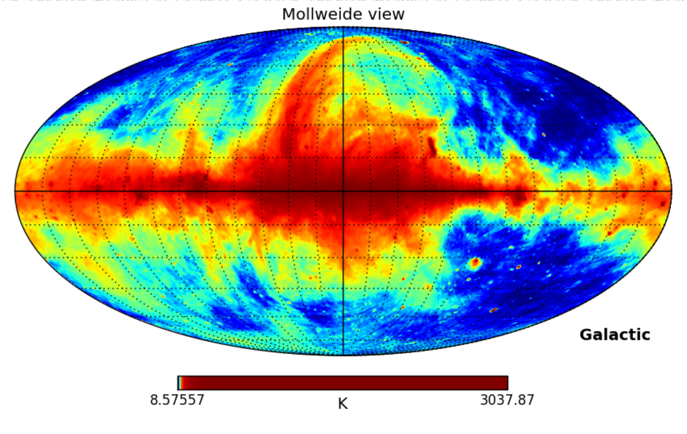
Models for decaying WIMP DM

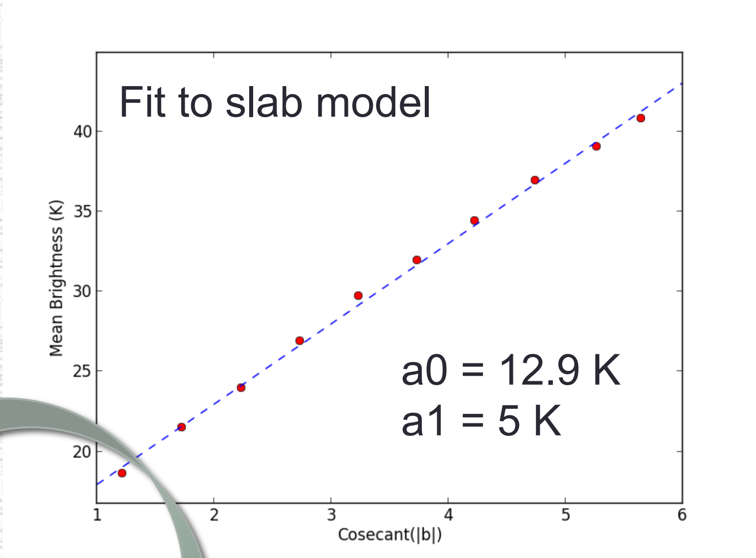


[RS & Cowsik 2013]

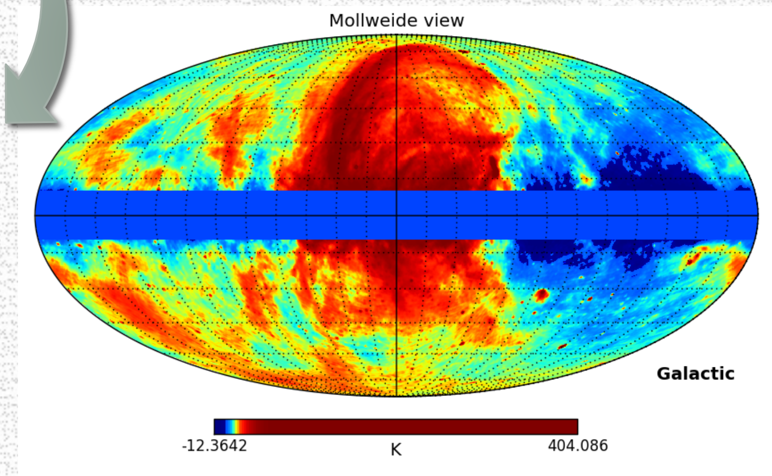
Slab model for the Galactic emission - revisited

408 MHz all sky survey





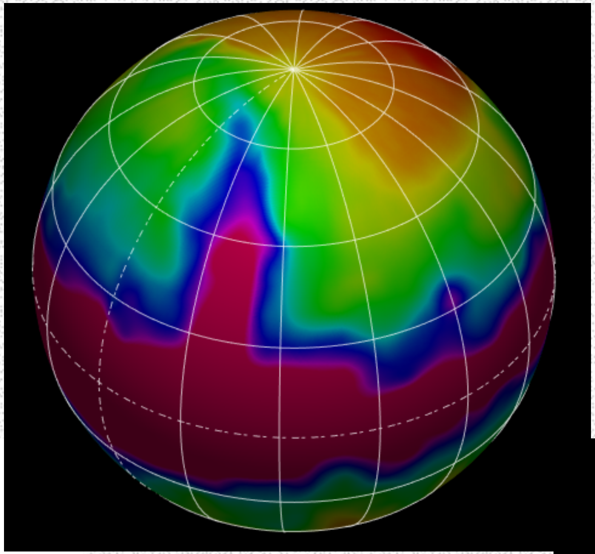
- a0 in the fit = average of the residual brightness.
- The average residual is *not* the uniform extragalactic brightness
- Galactic emission does have complex structure – loops & spurs – that is a contaminant in the residual.
- The average of the residual is an overestimate of the uniform brightness.



Residual after subtracting the slab model

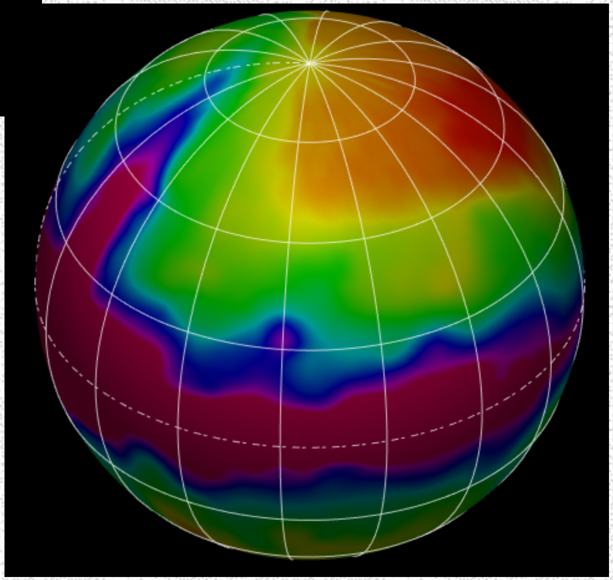
An effective model for the Galactic emission

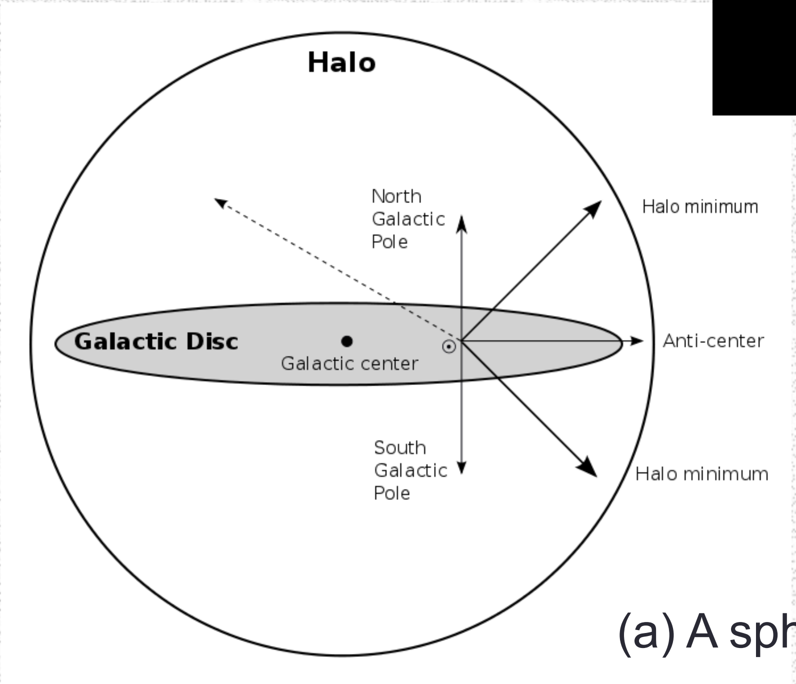
[RS & Cowsik 2013]



Minimum is offset from the poles and towards the galactic anti-center

Suggests a spherical halo model component





6 components
Plus
Map of loops & spurs

(a) A spherical halo component

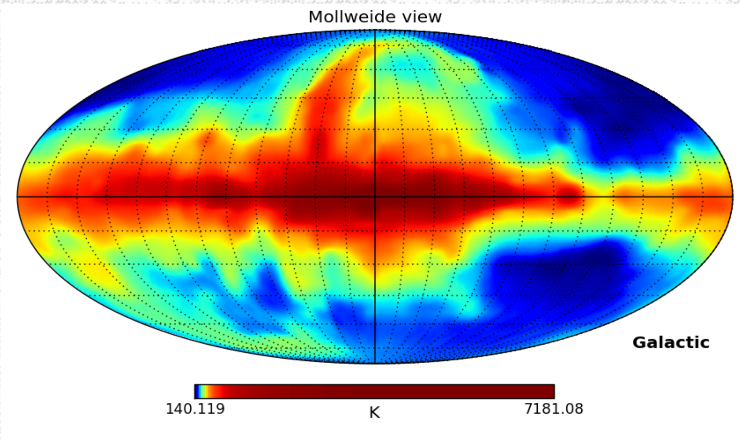
(b) A highly flattened spheroid (oblate spheroid)

(c) A complex distribution representing the loops & spurs

PLUS (d) uniform component (Extragalactic brightness)

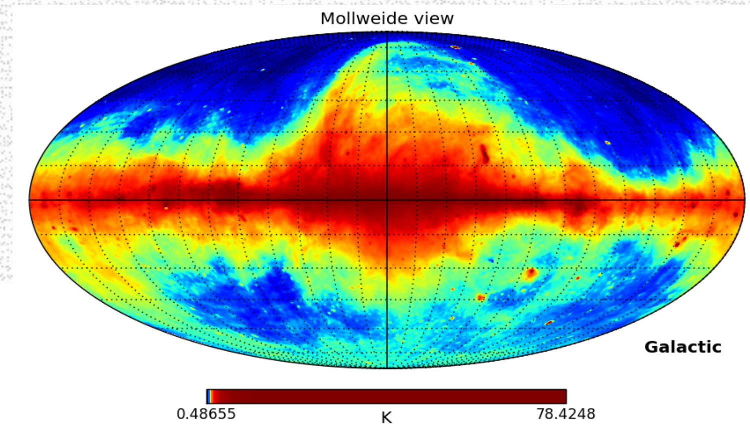
[RS & Cowsik 2013]

Model fit maps at 150, 408 & 1420 MHz separately

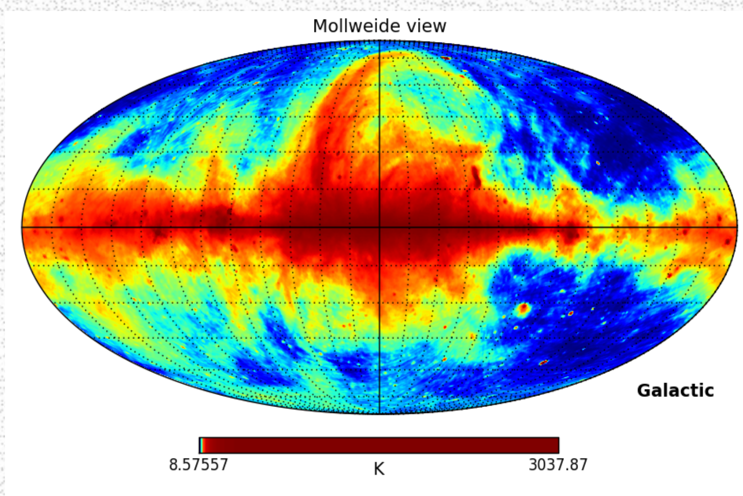


150 MHz: Landecker & Wielebinski (1970)

Healpix R8 format
2.2 deg beam at 150 MHz
1 deg beam at 408 & 1420 MHz



1420 MHz: Reich & Reich (1986)
Reich ++ (2001)



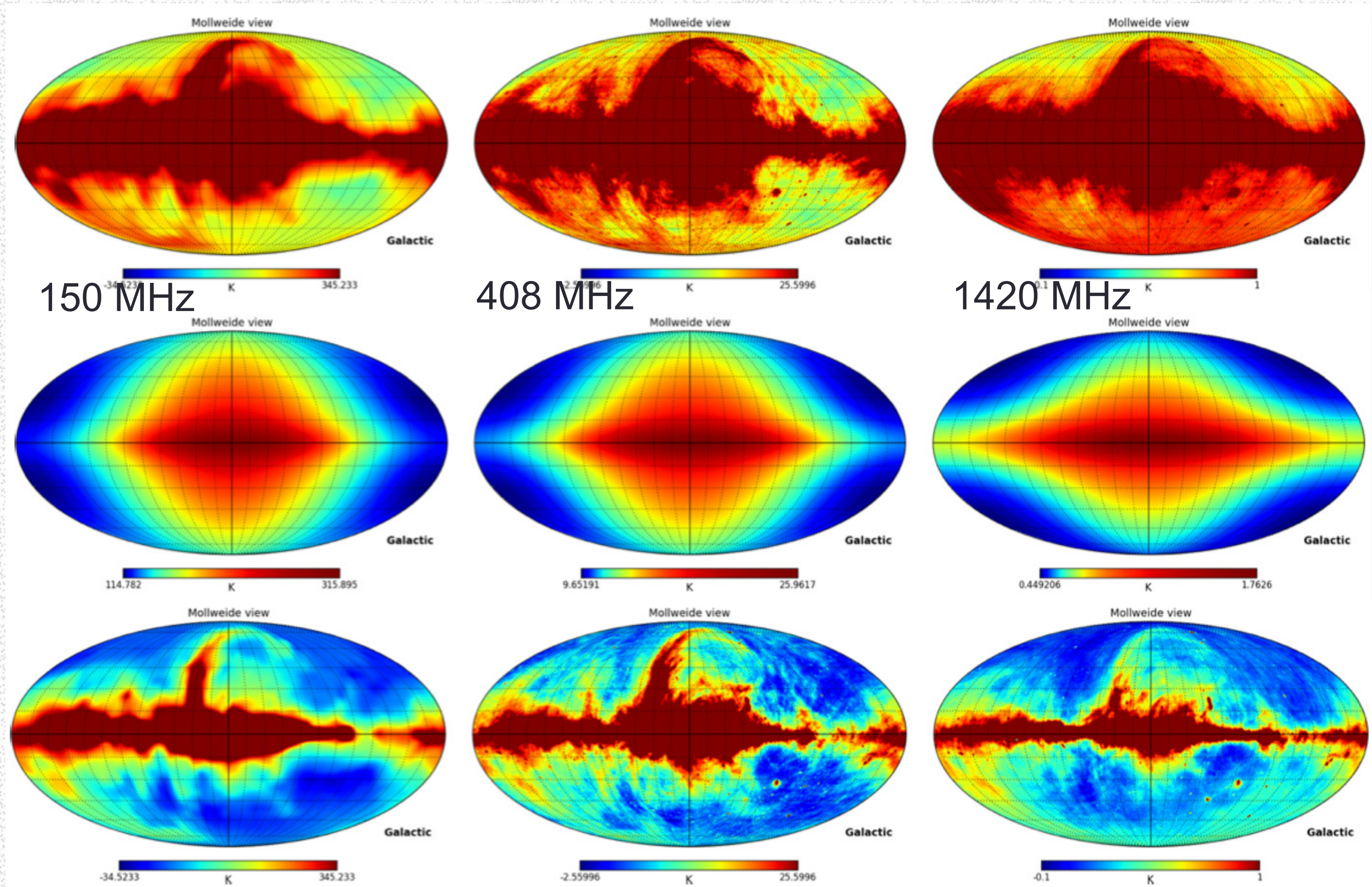
408 MHz: Haslam ++ (1982)

CMB monopole of 2.725 K
subtracted before fitting

[RS & Cowsik 2013]

Simulated Annealing => Simplex – model parameters

Constrain loops & spurs image to have minimum sky area + strongly exclude negatives (Loops & Spurs image is treated like a radio astronomy image of ‘sources’)

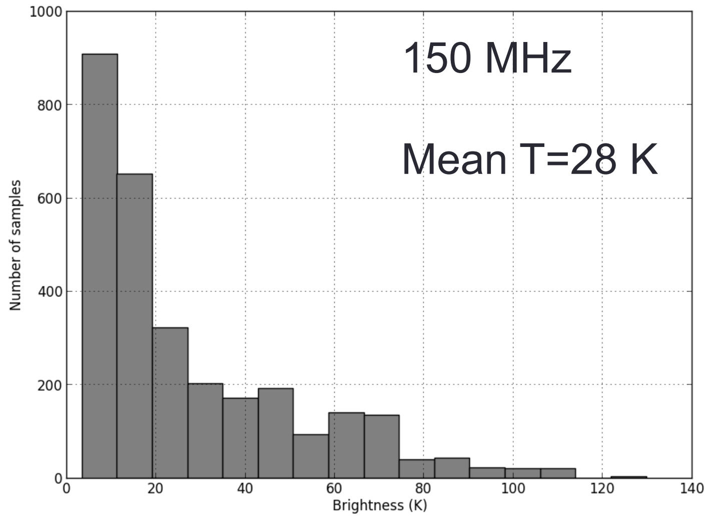


Fit parameters

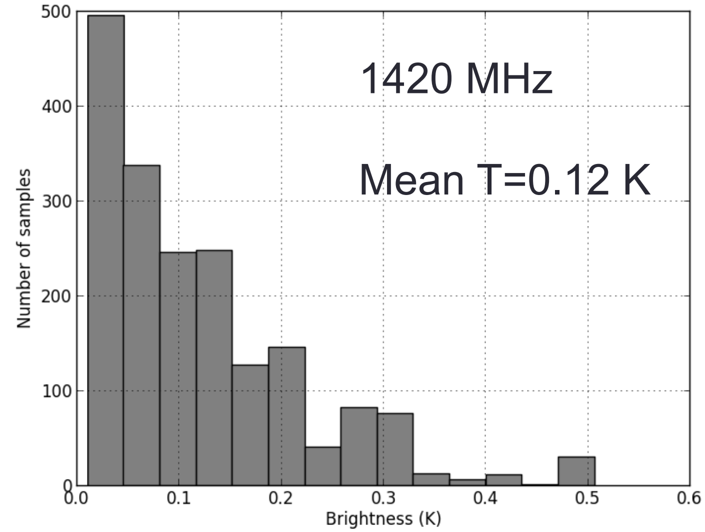
	150 MHz	408 MHz	1420 MHz
Slope a_1 for a slab model	69 K	5.0 K	0.17 K
Intercept a_0	143 K	13 K	0.62 K
Semi-major axis[a] of the spheroid	1.60	1.56	2.1
Semi-minor axis[a] of the spheroid	0.29	0.24	0.37
Radius[a] of the sphere	2.39	2.14	1.8
Axial ratio of the spheroid	5.6	6.4	5.6
Brightness of spheroid in the plane[b]	69 K	7 K	0.79 K
Brightness of spheroid toward the poles[b]	12 K	1.1 K	0.14 K
Brightness of the sphere[b]	129 K	6.9 K	0.30 K
Background brightness from the optimization	21 K	4.5 K	0.14 K

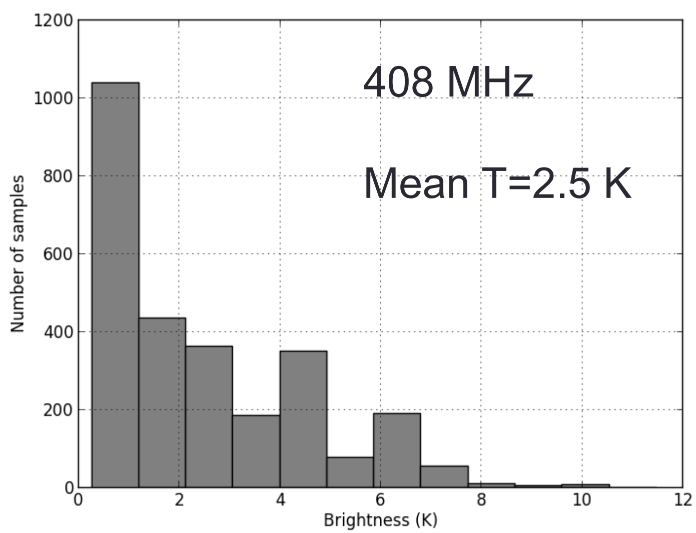
[RS & Cowsik 2013]

Markov Chain Monte Carlo (MCMC) analysis of the distribution in model parameters



Used the MCMC Hammer [Goodman & Weare 2012; Foreman-Mackey ++ 2013]





No compelling case for an unaccounted excess uniform radio background!

Largest uncertainty arises from errors in zero points of the images!