THE COSMIC RADIO BACKGROUND

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CAASTRO
All-sky images of the CRB

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

[de Oliveira-Costa ++ 2008]

[Calabretta ++ 2013]

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

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]

\[ T_A(|b|) = a_0 + a_1 \csc(|b|) \]

\( a_1 \) is the slab brightness towards the Galactic pole
\( a_0 \) 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

\( a_1 = \text{Brightness of the slab model towards the Galactic pole} \)

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

Apart from the ARCADE data

\[ T = 209 \text{ mK} \left( \frac{f}{1400 \text{ MHz}} \right)^{-2.55} \]

The remainder ought to be isotropic components of the CRB

[Kogut ++ 2011]
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

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

\[ T = 74 \text{ mK} \left( \frac{f}{1400 \text{ MHz}} \right)^{-2.54} \]
Extragalactic discrete radio sources

Integrating the model fit down to microJy level:

\[ T = 92 \text{ mK} \left( \frac{f}{1400 \text{ MHz}} \right)^{-2.71} \]
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.

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

[Fixsen ++ 2011; Seiffert ++ 2011]
The ‘excess’ motivated a Deep EVLA survey

![Graph showing source counts at different frequencies.]

*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
New sub-microJy source population?  
[Condon ++ 2012]

Models for the ‘excess’

Is the ‘excess’ a relic of creation of primordial black holes?  
[Biermann & Harms 2013]

Models for decaying WIMP DM  
[Fornengo ++ 2011]
Slab model for the Galactic emission - revisited

- \(a_0\) 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.

- \(a_0 = 12.9\) K
- \(a_1 = 5\) K
An effective model for the Galactic emission

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

Suggests a spherical halo model component

(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)
Model fit maps at 150, 408 & 1420 MHz separately

150 MHz: Landecker & Wielebinski (1970)

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

408 MHz: Haslam ++ (1982)

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

CMB monopole of 2.725 K subtracted before fitting
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’)

[RS & Cowsik 2013]
### Fit parameters

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

$^a$ Units are in microns; $^b$ unitless.
Markov Chain Monte Carlo (MCMC) analysis of the distribution in model parameters

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

150 MHz
Mean T=28 K

408 MHz
Mean T=2.5 K

1420 MHz
Mean T=0.12 K

No compelling case for an unaccounted excess uniform radio background!

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

[RS & Cowsik 2013]