Sources of CMB Spots in Closed Hyperbolic Universes

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(January 9, 2019)

Abstract

The results of a previous paper by the author [Astrophys. J. 470, 43 (1996)] are improved, through a more reliable technique for finding the location of sources whose images are on the surface of last scattering.
I. INTRODUCTION

Some years ago Cayón and Smoot \[1\]; hereafter CS, identified a number of ‘cold’ and ‘hot’ spots in the COBE maps of the cosmic microwave background (CMB), as patches of physical density fluctuations (rather than noise) on the surface of last scattering (SLS). A cold (hot) spot, interpreted as gravitational Sachs-Wolfe effect plus fluctuation of radiation temperature on the SLS, corresponds to an increase (decrease) of matter density \[2\]. These results were used by the author \[3\]; henceforth Paper I, in connection with the possibility of the universe’s spatial section being a closed hyperbolic 3-manifold (CHM).

Tables 1a-b list the galactic coordinates in degrees \((-180 < l \leq 180, -90 \leq b \leq 90)\) for the positions of the six overerdense \((C1 - C6)\) and the eight underdense \((H1 - H8)\) CS spots. Given the comoving nature of cosmic geometry, it was argued that those spots, for example the overdense ones, might have evolved into galaxy superclusters which are - or may become - observable in our epoch. The underdense spots would have evolved into the relative voids in the observed structure of the large-scale matter distribution.

| Spot | \(l\)  | \(b\)  |
|------|-------|-------|
| C1   | -99.0 | 57.0  |
| C2   | 85.0  | 40.0  |
| C3   | -21.0 | -45.0 |
| C4   | 73.0  | -29.0 |
| C5   | 81.5  | -59.0 |
| C6   | -86.0 | 33.0  |

| Spot | \(l\)  | \(b\)  |
|------|-------|-------|
| H1   | -24.0 | 51.0  |
| H2   | 46.0  | -32.0 |
| H3   | 96.0  | -28.0 |
| H4   | 120.0 | -36.6 |
| H5   | 172.0 | 29.0  |
| H6   | -81.0 | -33.0 |
| H7   | 141.0 | -73.5 |
| H8   | -82.0 | -58.0 |

Since the CMB spots are the result of using the COBE satellite’s wide-angle detectors, they represent a smearing of density inhomogeneities on the scale of about ten arc degrees. But we may expect that the small angle detectors in the planned projects MAP and Planck will produce spots that cluster in a way consistent with COBE’s maps. In the bottom-
up model of structure formation \[4\] these fine-grained overdense spots would evolve into galaxies, which would later produce clusters and superclusters. Therefore the original idea that COBE spots become superclusters (or large-scale voids) seems basically sound.

The purpose of Paper I was to fit a number of CHM’s to the CS spots. Since these are interpreted as density inhomogeneities in the fundamental polyhedron (FP) for the manifold, we hoped the positions of the latter, when compared with those of observed structures and voids, might favor some of those CHM’s as the real cosmic space. This task is of course far from simple: there are infinitely many CHM’s, Earth might be located anywhere inside them, with any orientation with respect to the real sky, not to mention the uncertainties about \(\Omega_0, H_0\), and now also \(\Lambda\)!

But we may expect this situation to improve: the parameters’ ranges will be narrowed, and the several proposals for topology determination (cf. Weeks’s \[5\] and Roukema’s \[6\] talks in this Session) will eventually indicate what manifolds are the most likely candidates for representing the cosmos.

II. THE SEARCH FOR SEEDS IN THE FUNDAMENTAL POLYHEDRON

In Paper I a lopsided method was adopted to choose a possible source for a given CS spot. The sources shown in Fig. 3 and Tables 2 and 3 of Paper I are usually concentrated in narrow bands of galactic latitude \(b\). Another problem with Paper I was that we looked for sources inside the maximum injectivity FP, with basepoint at the center (which is the standard in SnapPea \[7\]) and the observer displaced from the center; this produces an asymmetry in the distances of the found candidate sources.

Here I make two improvements on this research, both with the help of our geometer guru, Jeff Weeks. One of them is that now \(FP\) is chosen with basepoint on the observer’s position, which makes the source distribution centered on the the observer. The other one is in the search procedure, which will now be discussed.

Fig. 1 is a crude sketch of \(FP\) for a CHM isometric to a quotient space \(H^3/\Gamma\) as usual, with the basepoint and observer at \(FP\)’s center \(O\), and the spherical SLS.

With a point \(P'\) (the center of a spot) \(\in SLS\) we want to find the pre-image \(P\) of \(P'\) in \(FP\), that is, \(P' = \gamma P\) for some \(\gamma \in \Gamma\). Let \(\{g_k, k = 1 - n\}\) be the set of face-pairing
generators corresponding to the \( n\)-face \( FP \). Points \( P \) and \( P' \), and cell \( FP' = \gamma(FP) \) are also shown in Fig. 1.

The computer search for \( P \) and \( \gamma \) is shown in Fig. 2 as a flow chart, where \( d(A,B) \) means comoving distance between points \( A \) and \( B \); \( g \) is represented by \( G \), \( g_k \) by \( G_k \), and \( \text{inv}(G) \) is the inverse of \( g \). Referring to this figure, note that (i) if the result is \( \gamma = g = 1 \), then \( P = P' \in FP \), which means that \( FP \) is large enough to intersect \( SLS \); and (ii) the calculation of \( \gamma \) is not necessary, but is useful for checking: it must be \( P' = \gamma P \).

The search for sources was done in Paper I for the ten smallest known CHM’s, numbered HW1-10; they are described in [8]. For each of these the observer’s position and space orientation were chosen randomly, but, as said above, not so randomly distributed sources were found. Here we get better results, as shown for manifold \( m007(+3,1) \) or HW3 in Table 2. The observer is at position (0.3, 0.0, 0.0) in Klein coordinates relative to the standard \( FP \) in SnapPea, and axes rotated by (4.5669, 0.1078, 5.3451) in Euler angles in radians, with respect to the axes obtained for the displaced basepoint. (It is interesting to observe that the standard \( FP \) has 20 faces, against 24 faces in our example.) Table 2 shows \( (Z, l, b) \) and the path \( g = \gamma^{-1} \) from the spot to its source, as a word in the generators \( (g_1 - g_{24} \) are here labeled \( G_{00} - G_{23} \), as in the computer printout). We adopt the values \( \Omega_0 = 0.3 \) and \( Z_{SLS} = 1300 \).

The idea to pursue, which is illustrated in Paper I, is to vary these positions and orientations randomly, until we get sources that match data in catalogs of galaxy superclusters and voids - which, for this to become possible, should reach much deeper space than the present limit of about \( Z = 0.12 \) in Einasto et al.’s [8] list of superclusters.
Table 2. Sources for CS spots in m007(±3,1) universe.

| Spot | Source   | Motion from spot to source |
|------|----------|---------------------------|
| C1   | Z 1.133  | l −51.3  b 12.0           |
|      |          | G01G12G08G06              |
| C2   | Z 0.638  | l −94.4  b 79.4           |
|      |          | G07G14G06G04G01           |
| C2   | Z 0.490  | l 63.4  b −29.9           |
|      |          | G00G20G13G06G03           |
| C4   | Z 1.370  | l 145.0  b −22.4          |
|      |          | G00G04G02G01              |
| C5   | Z 1.294  | l 177.7  b 4.8            |
|      |          | G06G23G04G02G21G07G05G01  |
| C6   | Z 0.477  | l −142.1  b −50.0         |
|      |          | G05G18G06G03G00           |
| H1   | Z 1.026  | l 42.0  b −36.3           |
|      |          | G02G21G13G05              |
| H2   | Z 0.925  | l −91.3  b 52.6           |
|      |          | G10G07G04G02G01           |
| H3   | Z 0.564  | l −62.8  b 35.0           |
|      |          | G01G15G10G02G01           |
| H4   | Z 1.158  | l 31.5  b 5.3             |
|      |          | G04G01G21G14G03G01        |
| H5   | Z 0.931  | l 28.3  b −0.1            |
|      |          | G02G01G13G02              |
| H6   | Z 1.027  | l −158.8  b 21.4          |
|      |          | G10G02G00G17G06G00        |
| H7   | Z 0.917  | l 90.8  b −54.4           |
|      |          | G03G18G06G04              |
| H8   | Z 0.361  | l 128.1  b −37.6          |
|      |          | G06G04G02G00              |

ACKNOWLEDGEMENTS

I am grateful to Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP-Brazil) for a grant to allow my participation in this Meeting. Also to Jeff Weeks for his continued assistance on geometry matters, and to Laerte Sodré Jr. for a conversation on superclusters.
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\[ P' \text{ on SLS} \]
\[ G = 1 \]

\[ k = 1 \]

\[ P = G_k \times P' \]

\[ d(P, O) < d(P', O)? \]

\[ k = k + 1 \]

Yes

\[ P = P' \text{ on FP} \]
\[ \gamma = \text{inv}(G) \]

No

\[ k = n? \]

Yes

No

Figure 2