# Apparent evidence for Hawking points in the CMB Sky

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#### Dedicated to the memory of Stephen Hawking

This paper presents powerful observational evidence of anomalous individual points in the very early universe that appear to be sources of vast amounts of energy, revealed as specific signals found in the CMB sky. Though seemingly problematic for cosmic inflation, the existence of such anomalous points is an implication of conformal cyclic cosmology (CCC), as what could be the Hawking points of the theory, these being the effects of the final Hawking evaporation of supermassive black holes in the aeon prior to ours. Although of extremely low temperature at emission, in CCC this radiation is enormously concentrated by the conformal compression of the entire future of the black hole, resulting in a single point at the crossover into our current aeon, with the emission of vast numbers of particles, whose effects we appear to be seeing as the observed anomalous points. Remarkably, the B-mode location found by BICEP 2 is at one of these anomalous points.

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### Outline of the CCC proposal

Conformal Cyclic Cosmology (CCC) was put forward by one of us [1–4] in 2005 as a possible theoretical scheme that could account for the strange imbalance between the apparently thermal nature of matter and radiation in the early universe, as opposed to the very low gravitational entropy, as evidenced by the universe's initial uniformity and suppression of gravitational degrees of freedom. In CCC, this comes about from our big bang having been the conformal continuation of the remote future of a previous aeon whose own big bang had arisen from an aeon prior to that, etc., and the suppression of initial gravitational degrees of freedom at the big bang of each aeon is a conformal consequence of this. Likewise, our own aeon's remote future conformally continues to become the big bang of a succeeding aeon, and so on.

It is argued that the crossover from aeon to aeon is physically plausible, despite the enormous differences in densities and temperatures at each crossover 3-surface X, because the physics on both sides of X is dominated by conformally invariant processes carried out by effectively massless particles: at each big bang, by particles whose kinetic energy totally dominates their mass, and at each aeon's remote future by photons. Black holes eventually disappear by Hawking evaporation. To deal with the relatively tiny number of massive particles surviving to each aeon's eternity, a hypothesis of eventual mass fade-out is adopted at very late times, to enable the strict application of the equations of CCC (see [3, 4]). This also raises an issue of how much of the energy in a galactic cluster's physical material will accompany that of the Hawking radiation itself into the following acon. To avoid addressing this uncertainty we simply phrase our arguments as though the Hawking radiation is the dominant effect but this is not actually essential to the arguments of the paper.

The dynamics of each aeon is otherwise governed by standard physics, and most particularly, by Einstein's equations, with positive  $\Lambda$  taken to be unchanging from aeon to aeon. The only significant deviation from currently standard cosmology is that there is no cosmic inflation in CCC, the roles for which inflation has importance in conventional cosmology being taken over by the  $\Lambda$ -driven exponential (self-similar) expansion of the previous aeon, somewhat in the spirit of the earlier cosmological scheme of Gasperini and Veneziano [5]). The crossover 3-surface X is spacelike, because  $\Lambda > 0$  [6]. The dynamics through X is driven largely by a requirement that  $\Lambda$  be constant throughout the evolution at crossover, and by the reciprocal hypothesis, whereby the conformal factor becomes (minus) its reciprocal after crossover [3, 4]. There remain some relatively minor ambiguities that do not concern us here. See [3] for details. It should, however, be made clear that CCC is consistent with current  $\Lambda$ CDM cosmology, but without inflation.

#### CCC's current observational status

Up until now, the main observational case for CCC has rested on CCC's prediction that gravitational wave signals from collisions between supermassive black holes in the aeon prior to ours should lead, after crossover, to impulsive initial motions in the dark-matter of our current aeon that would appear as specific signals in our own CMB. These would be circular rings of lower temperature variance than the background, and (usually) where the average temperature around the ring is significantly larger or smaller than that of a concentric ring just outside it. Such rings often occur in concentric sets, since these collisions would be frequent within the same previous-aeon galactic cluster.

The observational status of these signals has been controversial (unsurprisingly, owing to CCC's unconventional nature). Nevertheless, the published results of two independent groups, using very different methods of analysis, have presented observational cases that such implications or CCC are actually present in our CMB. Using standard simulation-based tests, it was argued in [7] that CCC-predicted features are present in the WMAP data, with 99.7% confidence and, in [8], present in the Planck data with 99.4% confidence. In [3], the WMAP data was examined for evidence of concentric sets (of 3 or more) low-variance rings, and numerous examples were found, the significance of which being argued for by the fact that the signal dropped dramatically if the identical search were for elliptical shapes instead. Moreover, the distribution of the centres of these low-variance circular triples is manifestly clustered, this being consistent with CCC but hard to understand on the basis of standard inflation. The latter feature was even more prominently demonstrated in an analysis of the Planck data, as shown in [9]. An independent analysis of the WMAP data was carried out in [10], and although the pictures obtained were essentially identical with those of [3], the authors argued that the features obtained could well be a chance effect. Nevertheless, no explanation from within conventional cosmology has been provided as to how, on the basis of a quantum-random inflationary origin for CMB temperature fluctuations, the observed clustering could arise. Though clustering was not a CCC prediction, it is easily accommodated in CCC, as a consequence of a surprising degree of inhomogeneity in the supermassive black-hole distribution in the previous aeon, seemingly more than is, as yet, directly observed in our own aeon.

Since the conception of CCC, it has always been a key ingredient that the black holes of each aeon should evaporate away entirely by Hawking radiation within the entire history of the aeon. The actual presence of black holes at crossover would cause difficulties with the smooth transition from aeon to aeon. But since this transition is to take place at what would be regarded as infinite time (according to standard time measures of general relativity), all black holes should have evaporated away by crossover, despite estimated timescales of some  $10^{100}$  years for the ultimate size of some supermassive black holes. We must bear in mind that despite Hawking radiation being of an absurdly tiny temperature, over the aeon's whole history the entire mass-energy of the hole will be finally radiated away and, in the conformal picture, this will take place within what would effectively be a single point H, which we refer to as a Hawking point, only infinitesimally beneath X. Being mainly in the form of photons (and some neutrinos) this radiation comes directly through Xto heat the initial dark matter of the succeeding aeon enormously just to the future of H, virtually depositing the hole's entire mass-energy there. This heated region would gradually spread out in our aeon until reaching the decoupling 3-surface D, providing something like a Gaussian distribution on D centred at a point G on D, just to the future of H in the conformal picture, where the spread, duly constrained by the speed of light, should be fairly small from our vantage point, and certainly less than the maximum causally allowed diameter of around  $4^{\circ}$  (i.e. a radius < 0.035 radians). What we see from our current vantage point would be the intersection of our past light cone C with this small distribution on D, which appears to us as a small Gaussian distribution centred at the Hawking point H, having spread out to subtend an angular distance of no greater than 0.035 radians on either side of G (i.e. within H's light cone). The actual temperature profile depends on the masses and wavelengths of particles involved - for higher masses and higher energies it should appear to us like a Gaussian with maximum temperature at H (i.e. at G), and cooling off as it spreads out to something less than the causally allowed maximum of  $2^{\circ}$  radius (less, because C would normally not quite pass through G) and it is the sort of range that we appear to see in the data.

## The significance of the Planck data

The procedure that we applied in the present case is identical to the one described in detail in [7] and [8], with excluded Galactic equatorial belt, imposed masks etc. with one crucial difference. In the previous cases (i.e. looking for the ring-type structures) the assumed profile consisted of two concentric rings, the inner with negative weight and the outer with positive weight. The convolution of the profile (with different angular radii and widths of the rings) with the actual temperature  $\delta T$  was calculated in different directions in the sky. Such calculations were performed both for the real maps as measured by WMAP and Planck (70 GHz, SMICA, SEVEM...) and for a 1000 artificial maps generated with the observed CMB power spectrum. Then the CDF's of the results were compared using the procedure described in [11]. The results showed that in some cases none of artificial maps out of a 1000 performed better (i.e. had larger absolute values of the convolution in the extreme right and extreme left parts of the CDFs) than the real map.

In the present case we are looking for the slopes of  $\delta T$  around a given direction for a ring of inner angular radius  $r_1$  and width  $\varepsilon$ . The slope in a given direction was calculated by the formula (minimizing  $\sum (\delta T_i - a x_i - b)^2$  with respect to a and b)

$$a = \frac{n \sum (x_i \,\delta T_i) - (\sum x_i)(\sum \delta T_i)}{n \sum x_i^2 - (\sum x_i)^2} \tag{1}$$

where  $x_i$  is the angular distance of point *i* from the given direction,  $\delta T_i$  is the temperature at this point and *n* is the number or points in the ring. The sums run over all points in a ring around the given direction. Having the slopes for all directions on the sky we create the CDF

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for a given map. Then we create a theoretical CDF by averaging the CDFs of all 1000 artificial maps and use the formula from [11] to calculate 2 numbers describing extremal, positive and negative, parts of CDF. Then we check how many artificial maps outperform the real map, separately for positive and negative slopes.

The results for smallest rings are given below in table I. The inner rings and widths are given in the first and second columns, respectively. The third column shows the number of artificial maps outperforming the real map with large positive slopes and the fourth column the number of artificial maps outperforming the real map with large negative slopes. The zeroes in the fourth column show that for rings of widths 0.02 or 0.03 (with inner radius 0.01) there are no artificial maps outperforming the real map with large negative slopes i.e. with the temperature decreasing outwards. The probability of the purely random appearance of such disks can be estimated to be no more than 0.001 and should actually be smaller since we obtained the zeroes of  $N_{-}$  in these two cases also for an additionally created independent set of 1000 artificial maps.

TABLE I: # of artificial maps outperforming the real map

$r_1$	ω	$N_{+}$	$N_{-}$	$r_1$	ω	$N_+$	$N_{-}$
0.0	0.01	921	242	0.0	0.02	710	186
0.01	0.01	952	139	0.01	0.02	734	0
0.02	0.01	215	831	0.02	0.02	384	110
0.03	0.01	625	905	0.03	0.02	258	978
0.04	0.01	182	910	0.04	0.02	991	921

$r_1$	ε	$N_{+}$	$N_{-}$	$r_1$	ε	$N_{+}$	$N_{-}$
0.0	0.03	681	63	0.0	0.04	608	6
0.01	0.03	875	0	0.01	0.04	779	968
0.02	0.03	756	601	0.02	0.04	289	513
0.03	0.03	180	666	0.03	0.04	749	597
0.04	0.03	162	412	0.04	0.04	42	378

In table II, the galactic coordinates (in radians, latitude from the North Galactic Pole) of the disks with the most significant negative slopes are given for innerradius 0.01 and widths 0.02 and 0.03 (some of the points in both tables correspond to one and the same point on the map, for example  $(\theta, \phi) = (2.219, 0.012)$ ). The slopes are startingly large apparently pointing to some novel phenomenon. The center of the BICEP2 window, that we call *B*2, is remarkably close to the point on the list  $(\theta, \phi) = (2.678, 5.388)$ .

The difference between the temperatures of the outer and inner boundaries for the most significant ring (0.01, 0.02)

TABLE II: galactic coordinates of 10 rings with most negative slopes  $(T_{\rm CMB}/{\rm rad})$ left:  $r_1 = 0.01$ ,  $\varepsilon = 0.02$ , right:  $r_1 = 0.01$ ,  $\varepsilon = 0.03$ 

$T_{\rm CMB}/{\rm rad}$	θ	$\phi$	$T_{\rm CMB}/{\rm rad}$	$\theta$	$\phi$
-0.01403	2.219	0.012	-0.01033	0.204	2.405
-0.01266	0.204	2.405	-0.00891	2.962	0.056
-0.01215	0.703	2.777	-0.00804	2.219	0.012
-0.01166	2.988	4.908	-0.00735	0.140	4.783
-0.01164	2.545	0.051	-0.00721	2.383	0.744
-0.01154	2.949	0.052	-0.00701	2.795	2.705
-0.01151	2.678	5.388	-0.00677	0.799	0.785
-0.01129	0.716	3.698	-0.00662	2.949	0.052
-0.01113	0.689	0.844	-0.00660	2.756	5.209
-0.01103	0.799	0.785	-0.00658	2.545	0.051

is  $-2.8 \cdot 10^{-4}$  K and for (0.01, 0.03) it is  $-3.1 \cdot 10^{-4}$  K i.e. more than an order of magnitude more than the average CMB fluctuation.

## The BICEP2 anomalous point: a double co-incidence?

In March 2014, the BICEP 2 team announced the discovery of B-modes in photon polarization in a certain location in the CMB sky [12], appearing to indicate the presence of primordial gravitational waves at that location. Although later considerations of cosmic dust [13] indicated that these observations were untrustworthy, they had nevertheless initially caused a worry for CCC, because that scheme demands the absence of such primordial gravitational waves. Accordingly, an alternative proposal for BICEP 2's B-modes had been considered, arising out of an idea due to K.P. Tod (see [15]) that primordial magnetic fields might arise in CCC as coming through X from galactic clusters in the previous aeon (the surviving material of the cluster itself having ultimately dispersed through mass fade-out), and such primordial magnetic fields could certainly produce B-modes (for observational analysis see [14]). On the basis that such a galactic cluster ought to have contained a supermassive black hole which could well have swallowed several others, we might expect concentric rings centred on that location, in accordance with our earlier considerations. These would have to be neither red- nor blueshifted i.e. greenish in the colour-coding of [3] in order that the final moments of that cluster should lie on C's intersection with D. An examination of Figure 3a of [3] indeed revealed a triple of rings, greenish in the colour-coding, and centred on the point B2, which had already been noticed [16] as something of an apparent coincidence. But this is also precisely the condition for a Hawking point, and it was remarkable to find the actual presence of B2 among our anomalous points, this appearing to provide some unexpected additional support for CCC. A search for other examples of this phenomenon should be rewarding.

#### Outlook

It seems to us that anomalous points provide an important new input to cosmology, irrespective of the validity of CCC. It is hard to see, however, that they find a natural explanation in the currently conventional inflationary picture.

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