Proceedings of the 7th International Conference on Gravitation and Cosmology (ICGC2011) IOP Publishing
Journal of Physics: Conference Series **484** (2014) 012040 doi:10.1088/1742-6596/484/1/012040

Probing the anisotropic expansion history of the universe using CMBR

R K Mohapatra, P S Saumia*, and A M Srivastava

Institute of Physics, Sachivalaya Marg, Bhubaneswar 751005, India

E-mail: *saumia@iopb.res.in

Abstract. We have proposed a technique to detect any anisotropic expansion in the universe from the beginning of inflation to the last scattering. Any anisotropic expansion in the universe would deform the shape of the primordial density perturbations in the universe, and a shape analysis of the super-horizon fluctuations in CMBR will detect this shape deformation. Using this analysis, we have constrainted any anisotropic expansion in the universe to be less than 35%.

1. Introduction

Observations have shown that the present universe is homogeneous and isotropic. One of the most important observational evidences for the homogeneity and isotropy of the universe is the highly smooth and uniform Cosmic Microwave Background (CMB) radiation. This does not rule out the possibility of an initial anisotropic expansion of the homogeneous universe, which tend to isotropic expansion later [1]. The question we would like to ask, here, is: Whether we can detect any such transient anisotropic expansion in the history of the universe in a model independent way? We have proposed that an analysis of the shapes of the super-horizon sized fluctuations in the CMB can detect any anisotropic expansion in the universe, starting from inflation to the surface of last scattering. Our technique is very general. The only assumption, here, is that there is some mechanism in the early universe, which generates the density fluctuations of super-horizon scales. However, for definiteness, we have used the picture of an early inflationary stage of the universe, which is responsible for the generation of density fluctuations. Any early anisotropic expansion in the universe will deform the fluctuations.

We have discussed two different ways of identifying shape deformations of density fluctuation patches: (i) We have generated patches by considering some threshold value for over-density (or under-density) of CMBR fluctuations in a given region on the surface of last scattering (excursion sets). We then have studied shape deformation of these patches in this region using either the Fourier transform, or detected it directly in the spatial patch. Both these methods can detect the shape deformations. However, the shape analysis with spatial region has specific advantages, which we have discussed later. (ii) We have also analyzed simulated density fluctuations of specific geometrical shapes, such as spheres, and ellipsoids. This helps us in analyzing the strengths of these two techniques in differentiating various scenarios, such as anisotropies arising from initial conditions, or anisotropies arising from the anisotropic expansion, etc.

2. The analysis

The main idea underlying our analysis is the following: If the density perturbations generated initially (say during inflation) were statistically isotropic, then they would continue to have an average spherical shape (statistically), if the expansion of the universe was always isotropic. But if the universe ever went through an anisotropic expansion, then these perturbations would get deformed [2]. For example, if the universe ever expanded differently in one direction from the other two, then the *average* shape of these perturbations will become ellipsoidal. This average deformation will survive the later isotropic expansion till the time the size of the perturbation remains super-horizon. This means that any anisotropic expansion from the beginning of inflation to the surface of last scattering will leave their signature in the shapes of super-horizon perturbations in the CMBR.

We have used WMAP-7 data (ILC map) for the analysis, and chosen thin strips of the sky along the great circles so as to avoid the galaxy contamination along the equator, and also chosen the convenient pixel arrangement of HEALPix. We have done this by rotating the sky along z-axis at different angles. A strip of width $\pm 10^\circ$ along this rotated equator has been chosen, and we have chosen CMBR fluctuations above/below a particular value, thereby, forming the excursion sets. Figure 1 (a) shows a small $20^\circ \times 20^\circ$ region in this equatorial belt. Filled patches correspond to temperature anisotropies of magnitude (0.02 - 1)$\times(\Delta T)_{max}$, where $(\Delta T)_{max}$ is the maximum magnitude of CMBR temperature anisotropy in this patch. As one can see, the patches appear randomly shaped and sized. Such patches are projected on a plane to calculate the X and Y extents.

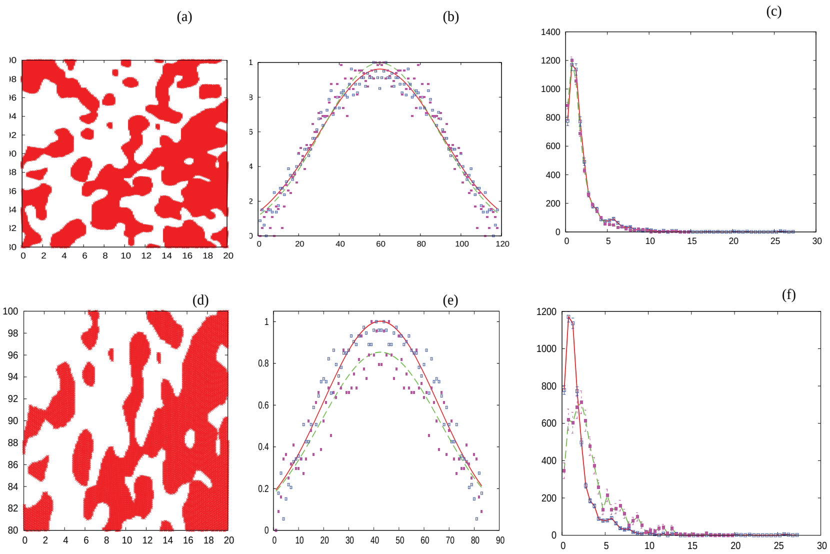

Figure 1. (a) X-axis corresponds to $(\sin\theta)\ \phi$ (degrees) and the Y-axis shows θ (degrees). The figure shows the excursion sets in a $20^\circ \times 20^\circ$ region in the equatorial belt of CMBR sky. (b) Shows the histograms in the two directions for the 2D Fourier transform. Solid and dashed curves are best fits to these histograms. (c) Shows plots of these histograms of the widths of filled patches with corresponding $(\sqrt{N})$ error bars. Distribution for width along X-axis (angle ϕ) is shown by solid plot and distribution for width along Y-axis (angle θ) is shown by the dashed line. (d), (e) and (f) correspond to (a), (b) and (c) in the case $\alpha = 2.0$

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2.1. Fourier transform method

Detection of shape anisotropies using Fourier transforms can be done in different ways depending on what criterion one adopts to characterize the anisotropy. We have followed the approach used in [3] for analyzing anisotropic deformations in metallography. Here, one uses a digitized image of the material and then calculates the 2D Fourier transform of the image, which is thresholded to levels 0 and 1. Anisotropy in the Fourier space is then determined by the ratio of the widths of the histograms in the two directions. (See [4] for more details). Figure 1 (b) shows the plots of the histograms in the two directions corresponding to the 2D Fourier transform. The two plots completely overlap showing the statistical isotropy of the excursion sets in Figure 1 (a).

2.2. Analysis in the physical space

We have now described our technique for detecting shape deformations directly in the physical space. What we want to find out is the average widths of the fluctuations in X-direction, and compare it with the average widths in the Y-direction for the sky as given in Figure 1 (a). For this, we have proceeded as follows: We have divided the entire 20° wide equatorial belt into thin slices (varying from 0.05° - 1°) in X- and Y-directions (to increase statistics). Using these slices, we have determined the X and Y extents of various filled patches. We have then plotted the frequency distributions (histograms) of X and Y widths of the intersections of all the patches with these slices in this equatorial belt. For the isotropic case, we expect the X and Y histograms to almost overlap. Any relative shift, or difference, between the X and the Y histograms will imply the presence of an anisotropy, such as an anisotropic expansion. We mention that this fine slicing of the equatorial strip is done to simplify the analysis and improve the statistics. The solid and dashed curves in Figure 1 (c) shows the X and Y histograms, and they overlap showing an isotropic expansion as also shown by the Fourier transform plots.

3. Constraining the anisotropy

To determine the level of isotropy, which is implied by the overlap of the two histograms in Figures 1 (b) and 1 (c), we have introduced artificial stretching in the CMBR patches as follows and repeated the above analysis for this *stretched* data. To *simulate* stretching by a factor α, we have simply multiplied the Y-coordinate (i.e., θ) for each point in the equatorial strip used above by a factor $\alpha \times \frac{|y|}{10^\circ}$. This stretching represents an anisotropic expansion of the universe along the polar axis compared to the expansion in the equatorial plane by a factor α. Note again that this simple scaling expression works approximately fine for a relatively thin strip along the equator. For strips having larger widths along the longitudes, the Y-coordinates of different patches will be scaled by a more complicated factor.

Figure 1 (d) shows these artificially stretched patches corresponding to the patches shown in Figure 1 (a). The stretching factor is $\alpha = 2$ for Figure 1 (d). We have now repeated the analyses as described above for these patches. Figure 1 (e) shows the histograms calculated for the 2D Fourier transform for the stretched patches of Figure 1 (d). We have seen that these histograms do not overlap showing the anisotropy arising from the stretching in Figure 1 (d). Similarly, Figure 1 (f) shows the histograms resulting from the analysis in physical space applied to Figure 1 (d). We have seen, here, also that the two histograms do not overlap and the difference is significant. Note incidentally that the peak in the dashed curve (θ histogram) has shifted to larger widths by almost a factor of 2, which is the factor of stretching of patches for Figure 1 (d). We have tried to put stronger constraint on the anisotropic expansion factor α by repeating the analysis with different values of α (including values of $\alpha < 1$). Figures 2 (a) and 2 (b) show the cases of $\alpha = 1.35$ and 1.3. We have seen that the two histograms corresponding to X and Y widths of patches are clearly separated for $\alpha = 1.35$. However, for $\alpha \leq 1.3$, the differences in the two histograms are insignificant. It is important to note, here, that the most important, qualitative, signature of anisotropic expansion in our technique is the relative lateral

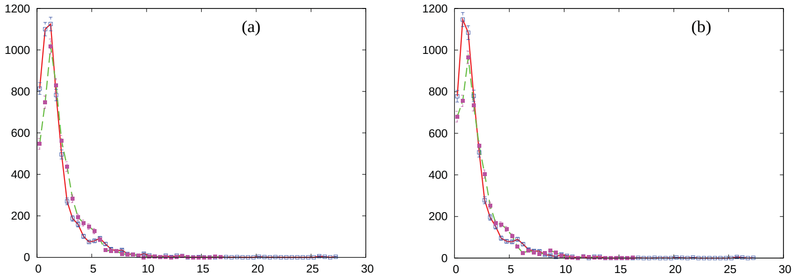

Figure 2. Plots (a) and (b) are the frequency distributions for CMBR data with stretch factor $\alpha = 1.35$, and 1.3 respectively. ϕ and θ width distributions are shown by solid and dashed curves.

shift of the curves of the X and Y frequency distributions. This is clearly seen in Figure 2 (a), which represents larger length scales in one direction compared to the other direction. This automatically is correlated with change in relative heights of the peaks. Thus, in Figure 2 (a), though peak height are very different, our focus on detecting anisotropic expansion (here, with $\alpha = 1.35$) is in the shift of the overall curve towards right. When we use smaller values of α, this lateral shift is not significant. With this, it seems reasonable to conclude that with our analysis technique, and with the present CMBR data, one can put a conservative upper bound of $\alpha < 1.35$ on the anisotropic expansion in the entire history of the universe. We have also repeated the analysis by using under-density patches in CMBR sky and the results are the same.

To demonstrate the strength of the technique, we have repeated the analysis using simulated patches with well defined geometric shapes. The isotropic case is represented by circles, whereas anisotropic case by ellipses. For this, we have created a 3 dimensional cubic region in which over-densities of constant magnitude and specific geometric shapes are created at different locations. This represents a part of the universe enclosing the CMBR sky. We have then determined the shapes of the over-density patches by embedding a surface of two-sphere (representing the CMBR sky) in this cubic region and recording the patches, which are intersected by this S^2. We have repeated the analyses, and noticed that for isotropic case, the histograms in both the analyses overlap, but for anisotropic case, they do not, and here also, for the analysis in physical space, there is a peak shift which quantifies the stretch factor or the anisotropy factor. (See [4] for the figures). We can also show with simulated patches that our technique can also distinguish fluctuations, which are created deformed with the ones, which are deformed due to anisotropic expansion. It can also be shown that the analysis in physical space has more advantages, since it can quantify the shape deformation of fluctuations, but is not sensitive to any other type of anisotropy, say anisotropic distribution of patches, whereas the Fourier transform method detects all anisotropies and cannot distinguish them in a qualitative manner.

4. Conclusions

We have emphasized the most important part of our results, that a simple technique of shape analysis is able to answer an important question in an almost model independent manner. That is whether the universe ever expanded anisotropically almost from the beginning of inflation near $t \simeq 10^{-35}$ sec. up to the stage of last scattering when the universe was 300,000 years old. Even with our qualitative approach of comparing the histograms in the two directions, we can conclude that our technique can rule out any anisotropic expansion of the universe in the past to less than 35%, apart from any sufficiently early stages of inflationary universe, which are followed by very long, isotropic inflationary stage. In particular, any anisotropic expansion stage after the end of inflation is certainly restricted to $\alpha < 1.35$. With PLANCK data, one should be able to do shape analysis of patches with high resolution. A major drawback of our present analysis is its restriction to relatively small angular scale. Thus, claims of anisotropy at quadrapole level in the literature are not examined by our analysis at present. We are working on improvement of our techniques for larger angular scales, and also trying to get better control on statistical fluctuations in our plots.

Acknowledgements
We acknowledge the use of the Legacy Archive for Microwave Background Data Analysis (LAMBDA), and HEALPix package.

References

[1] See Chapter XI *General Relativity - An Einstein Centenary Survey* 1979 eds S W Hawking and W Israel (Cambridge University Press)
[2] Buniy R V, Berera A and Kephart T W 2006 *Phys. Rev. D* **73** 063529
[3] Holota and Nemecek 2002 *Applied Electronics* p 88
[4] Mohapatra Ranjita K, Saumia P S and Srivastava Ajit M [arXiv:1111.2722] *and references therein.*