### Project Summary

We have recently shown that the remarkable temperature maps of the microwave background space made by Planck and WMAP can be used to infer the four dimensional structure of the Universe – expressed as a map of the gravitational potential - on the largest linear scale, specifically and conservatively on a scale of ~ ten billion light years. We have implemented this process to produce 3D maps that are valid when the Universe was roughly four hundred million years old, and are evolvable from the time of inflation to the present day. From tests on both real and simulated data this map-making method seems to be robust, so long as the initial fluctuation spectrum truly has the general form – almost scale-free power law, Gaussian and adiabatic – that has been inferred elsewhere from the observations.

Having established this proof of concept, we now aim to extend our general approach, improving the map’s resolution. This will be done in a staged manner by, first, carefully adding, higher resolution and polarimetric Planck data. Then, we will set up the theoretical methodology to combine the CMB data with that from many existing, local surveys of galaxies and quasars. Finally, we will explore how to handle the even richer datasets that are expected from WFIRST, Euclid, Epoch of Reionization studies and many other probes of large scale structure to come.

The goal of mapping the present structure and history of the actual universe that we inhabit provides a useful complement to the methodology practiced in much of contemporary cosmology, where the emphasis is on inferring fundamental physics principles from the statistical properties of an *ensemble* of universes, either imagined or realized in a multiverse. Nonetheless, if this program is successful it can impact these physics investigations through providing important “prior” information that will improve the statistical analyses, and through testing for self-consistency in the assumptions that have gone into the map-making. In particular, by tracing the modes that we measure back to the time of inflation, we can check if their phases are random as is predicted.

Increasing our map resolution in this fashion will require carrying out a much more careful approach to the microwave background data, and tackling the challenge of combining quite heterogeneous datasets such as those associated with the WISE satellite, the Hubble–COSMOS survey, the SDSS/BigBOSS and DES surveys. Residual features associated with our galaxy will also have to be handled carefully. The practical limits of this project are not yet known but it is proposed to determine them using existing data. It is then proposed to test our approach by predicting what should be learned from future observations. The promise of future data for this general approach is considerable.

We will also carry out an ancillary investigation in which the nesting of equipotentials inferred on the surface of last scattering is represented as a tree. The properties of this tree allows additional tests of the Gaussianity that we have assumed. This investigation can be extended in interesting ways to include polarization and the three-dimensional structure itself.

Mapping the universe on the largest scales has broad popular appeal as well as scientific utility. Even at low resolution, the images of previously undetected cosmic structure are likely to be of great interest, and we are exploring a variety of public presentation techniques including movies, modern graphics and three dimensional printing. The research is being prosecuted in the open at

<http://github.com/rogerblandford/Music>, where contributions are invited from all-comers.