CLUSTERS OF GALAXIES AS STANDARD CANDLES FOR GLOBAL OBSERVATIONAL COSMOLOGY

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As the largest gravitationally collapsed objects, and as objects with a relatively low space density, clusters of galaxies offer one of the best sets of standard candles for trying to measure basic cosmological parameters such as the injectivity diameter \(2r_{\text{inj}}\) (the shortest distance between two topologically lensed images of any object, e.g. cluster) and the out-diameter \(2r_+\) (the maximum ‘size’ of the Universe). Present constraints indicate that either of these may be smaller or larger than the horizon diameter.

1 Global observational cosmology versus local observational cosmology

As was noticed by Karl Schwarzschild, the three-dimensional space that we live in may or may not be curved, and it may or may not be multiply connected. Two-dimensional examples of flat and curved spaces include the infinite flat plane and (the surface of) a sphere, respectively; examples of simply connected and multiply connected spaces include the infinite flat plane and a cylinder, respectively.

Curvature is a local property; connectedness (topology) is a global property.

The advent of general relativity and the Friedmann-Lemaître-Robertson-Walker (FLRW) model led to little change in empirical constraints on these properties for most of the twentieth century. For a recent general introduction to the subject, see Luminet & Roukema or Roukema.

Different definitions of the size of an FLRW universe are possible and are presented in §5.1 of ref. in particular the injectivity diameter \(2r_{\text{inj}}\) (the shortest distance between two topologically lensed images of any object, e.g. cluster) and the out-diameter \(2r_+\) (the maximum ‘size’ of the Universe). For example, the injectivity diameter of a cylinder universe is its circumference, but its out-diameter is infinite.

Constraining \(2r_{\text{inj}}\) and \(2r_+\) is a fundamental goal of observational cosmology. The basic principle underlying nearly all methods of constraining these parameters is the existence of multiple, topologically lensed images of a single object (e.g. think of the multiple spatial geodesics on a cylinder joining an arbitrary point \(A\) to the observer at \(B\)), where the object is either a physically collapsed extragalactic object such as a cluster of galaxies or a quasar, or a patch of plasma which emits microwave background radiation.

For a compact and recent classification of the numerous different approaches, see ref.

2 Using X-ray clusters to constrain local observational cosmology

Several contributors to this meeting have presented work on using observations of clusters of galaxies, particularly as detected in X-rays, in order to see to what extent these can or cannot
constrain local cosmological parameters such as the matter density parameter $\Omega_m$ and the cosmological constant $\Omega_\Lambda$.

3 Using X-ray clusters to constrain global observational cosmology

Gott\textsuperscript{1} found that the lack of topologically lensed images of the Coma cluster closer to the observer than Coma itself implied a minimum value of $2r_+ \approx 60h^{-1}\text{Mpc}$.

Lehoucq, Luminet & Lachièze-Rey\textsuperscript{2} used a catalogue of Abell and ACO clusters to demonstrate a statistical method of searching for pairs of topological images in a catalogue with negligible selection effects.

Roukema & Edge\textsuperscript{9} pointed out that since the formation time of the most massive X-ray clusters is similar to the age of the Universe, these objects should be much closer to a “standard candle” (once formed) useful for searching for multiple topological images than other extragalactic objects, such as quasars.

Using archival data, Roukema et al.\textsuperscript{9,8,7,4} have investigated a serendipitous hypothesis for the global topology of the Universe, corresponding to one of the simplest multiply connected models possible, a “2-torus” model, in which the Coma cluster, and the clusters RX J1347.5-1145 and CL 09104+4109 are three images of a single, physical cluster. Since the archival data is of insufficient quality to provide strong constraints, an observational programme is underway in order to provide serious constraints on this working hypothesis.

The arguments of Gott\textsuperscript{1} and Roukema & Edge\textsuperscript{9} remain valid for all future candidate 3-manifolds (“topologies”): possibly the best way to test a candidate 3-manifold detected in cosmic microwave background data from the MAP and/or Planck satellites will be to conduct X-ray searches for clusters of galaxies at the angular positions and redshifts predicted by the candidate model. The model should then be quickly confirmed or falsified given sufficient telescope time.

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