Erratum: Effect of inhomogeneities on high precision measurements of cosmological distances [Phys. Rev. D 90, 123536 (2014)]

Austin Peel,[1,*] M. A. Troxel,[1,2,†] and Mustapha Ishak[1,‡]

[1] *Department of Physics, The University of Texas at Dallas, Richardson, Texas 75080, USA*
[2] *Jodrell Bank Center for Astrophysics, School of Physics and Astronomy, University of Manchester, Oxford Road, Manchester M13 9PL, United Kingdom*

(Received 1 July 2015; published 20 July 2015)

DOI: 10.1103/PhysRevD.92.029901 PACS numbers: 98.80.Es, 95.30.Sf, 98.80.-k, 99.10.Cd

We correct and clarify a few points from the discussion in our previous paper regarding distances and magnifications in a Szekeres Swiss-cheese model of the Universe. The main conclusion of the paper remains unchanged, but the correct quantity we should have considered in our statistical analysis is the magnification m instead of the shift in the distance modulus $\Delta\mu$. We, thus, provide here the necessary clarifications. We denote the magnification by m here to avoid confusion with the common μ notation. Indeed, for transparent lenses, it is the magnification that is expected to be conserved when considering averages over sources, while it is the reciprocal magnification that is conserved when averaging over directions from the observer. That is,

$$\langle m \rangle_A = 1 \quad \text{and} \quad \langle m^{-1} \rangle_\Omega = 1 \tag{1}$$

using the notation of [1] for source averages $\langle \ldots \rangle_A$ and direction averages $\langle \ldots \rangle_\Omega$. For recent extensive discussions, see Refs. [1–3]. The argument for conservation of the magnification was originally posed by Weinberg [4], and the conclusion that there is no mean amplification of fluxes in an inhomogeneous universe follows from photon conservation. An important assumption of the argument is that the area of a constant-redshift surface is not affected by lensing, and while this is not strictly true, the authors of [1] have shown that changes to the area are negligible in practice.

From our definition of $\Delta\mu = \mu_{\mathrm{FLRW}} - \mu_{\mathrm{SC}}$ in our previous paper, the magnification of a source along a particular line of sight is given by

$$m = \left(\frac{D_A}{d_A}\right)^2 = 10^{2\Delta\mu/5}, \tag{2}$$

where D_A and d_A are the angular area distances in a pure Friedmann-Lemaître-Robertson-Walker (FLRW) model and the Swiss-cheese model, respectively; see Eq. (29) of our previous paper. Equation (2) here follows from the definition of magnification as the ratio of actual-to-unlensed flux densities for a source at a given redshift. We can, therefore, translate our results in our previous paper into statistics for the magnification, or actually m^{-1}, which is appropriate for our model, since we propagate light rays away from the observer in different chosen directions. The result is that indeed $\langle m^{-1} \rangle_\Omega = 1$ to high accuracy for sources at redshifts out to 1.5 and with different sizes of intervening holes. For example, $\langle m^{-1} \rangle_\Omega - 1 = (0.33, 0.25, -3.37, -8.98) \times 10^{-4}$ for respective source redshifts $z_{\mathrm{src}} = (0.25, 0.50, 0.75, 1.00)$ with 30 Mpc sized holes and 1000 lines of sight each. Similarly small deviations from $\langle m^{-1} \rangle_\Omega = 1$ result for the larger hole sizes we considered in our previous paper.

As shown in Fig. 1 below, we have also examined the probability distributions of m^{-1} that are analogous to the plots in Fig. 7 of our previous paper. We see in the figure that, apart from being centered on $m^{-1} = 1$ instead of $\Delta\mu = 0$, the corresponding distributions do not look significantly different, which is due to the small spreads in both quantities. In sum, although the reciprocal magnification is unbiased, this does not mean that the distance itself need be unbiased, since these quantities are not linearly related. However, for the constructions we have considered, changes to the mean distances away from the smoothed FLRW value remain negligible, with fractional differences not exceeding 10^{-3} at any of the redshift considered.

*austin.peel@utdallas.edu
†michael.troxel@manchester.ac.uk
‡mishak@utdallas.edu

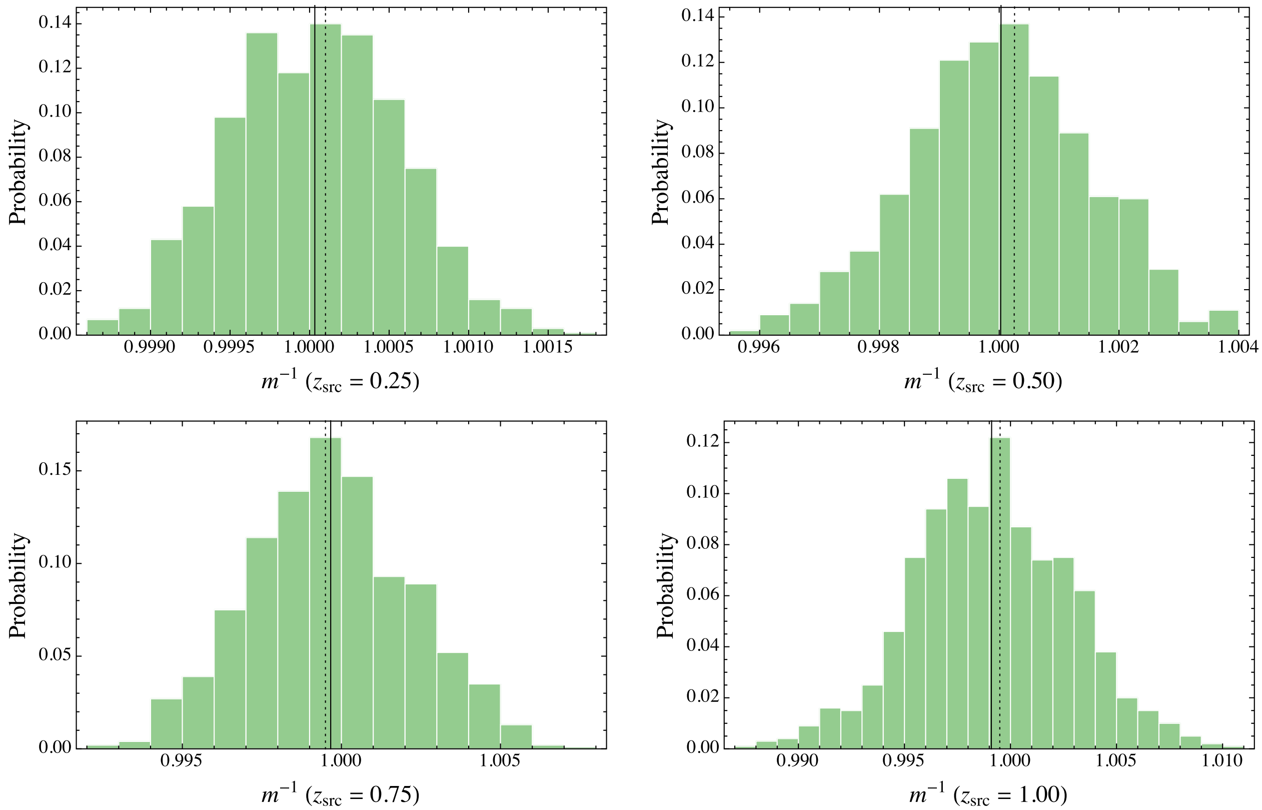

FIG. 1 (color online). Histograms showing the probability distributions of reciprocal magnification m^{-1} in a Szekeres Swiss-cheese model using 30 Mpc holes. Mean values are represented by solid vertical lines and modes by dotted vertical lines. The figure is the analogue of Fig. 7 in our previous paper. The means are all close to 1, reflecting the conservation of photon flux in the model. As discussed in the text, although the reciprocal magnification is unbiased, this does not mean that the distance itself need be unbiased, since these two quantities are not linearly related.

[1] N. Kaiser and J. A. Peacock, arXiv:1503.08506.
[2] T. W. B. Kibble and R. Lieu, Astrophys. J. **632**, 718 (2005).
[3] C. Bonvin, C. Clarkson, R. Durrer, R. Maartens, and O. Umeh, arXiv:1504.01676.
[4] S. Weinberg, Astrophys. J. **208**, L1 (1976).