Erratum: Swift follow-up of gravitational wave triggers: results from the first aLIGO run and optimisation for the future

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Erratum: *Swift* follow-up of gravitational wave triggers: results from the first aLIGO run and optimisation for the future

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There was an error in equation (7) of Evans et al. (2016). That equation contains the normalising term N_P, which is the total number of pixels in the gravitational wave (GW) localisation probability map. The paper states: "*N_P is the number of pixels in the map, and $L_{\rm tot}$ is the total catalogued galaxy luminosity within the GW volume, so $\frac{L_g N_P}{L_{\rm tot}}$ gives the ratio of the actual luminosity in pixel p compared to that expected if the galaxies were homogeniously distributed on the sky, i.e. the relative probability of this pixel hosting a merger event compared to any other pixel.*". While this is true, it results in an incorrect overall normalization of the probability that the GW event is in a known galaxy ($= P_{\rm gal} = \sum_p(\mathcal{P}_{{\rm gal},p})$) compared to not being in such a galaxy ($= P_{\rm nogal} = \sum_p(\mathcal{P}_{{\rm nogal},p})$; P refers to the total probability, $\mathcal{P}_p$ is the probability in pixel p).

The correct formulation should result in $P_{\rm gal} = \bar{C}$, $P_{\rm nogal} = 1 - \bar{C}$, where $\bar{C}$ is the mean completeness of the galaxy catalogue employed at the distance of the GW event. Since $P_{\rm gal}$ is simply the sum over all pixels, p, of equation (7) in Evans et al. (2016), one should find:

$$N \sum_p \left(C_p \mathcal{P}_{{\rm GW},p} \frac{L_p}{L_{\rm tot}} \right) = \bar{C} \tag{1}$$

where N is the normalization constant we are seeking, C_p is the galaxy catalogue completeness to the GW distance should the event lie in pixel p (equation 5 of Evans et al. 2016) and $\mathcal{P}_{{\rm GW},p}$ is the original GW probability in that pixel. L_p is the sum over all galaxies in pixel p of the galaxy luminosity multiplied by the probability that the galaxy is the same distance as the GW event. $L_{\rm tot}$ is the sum of L_p over all pixels. It will be seen that $\frac{L_p}{L_{\rm tot}}$ corresponds to the summation in the original equation (7), but here N_P has been replaced with N and taken outside of the sum (since it is constant). Thus:

$$\begin{aligned} N &= \frac{\bar{C}}{\sum_p \left(C_p \mathcal{P}_{{\rm GW},p} \frac{L_p}{L_{\rm tot}} \right)} \\ &= \frac{\sum_p \mathcal{P}_{{\rm GW},p} C_p}{\sum_p \left(C_p \mathcal{P}_{{\rm GW},p} \sum_g \left(\mathcal{P}(g|P_p[D]) \frac{L_g}{L_{\rm tot}} \right) \right)} \end{aligned} \tag{2}$$

$\mathcal{P}(g|P_p[D])$ is defined in equation (9) of Evans et al. (2016).

Hence, the correct formulation for equation (7) in Evans et al. (2016) should be:

$$\mathcal{P}_{{\rm gal},p} = \mathcal{P}_{{\rm GW},p} C_p N \sum_g \left(\mathcal{P}(g|P_p[D]) \frac{L_g}{L_{\rm tot}} \right) \tag{3}$$

with N as defined in equation (2).

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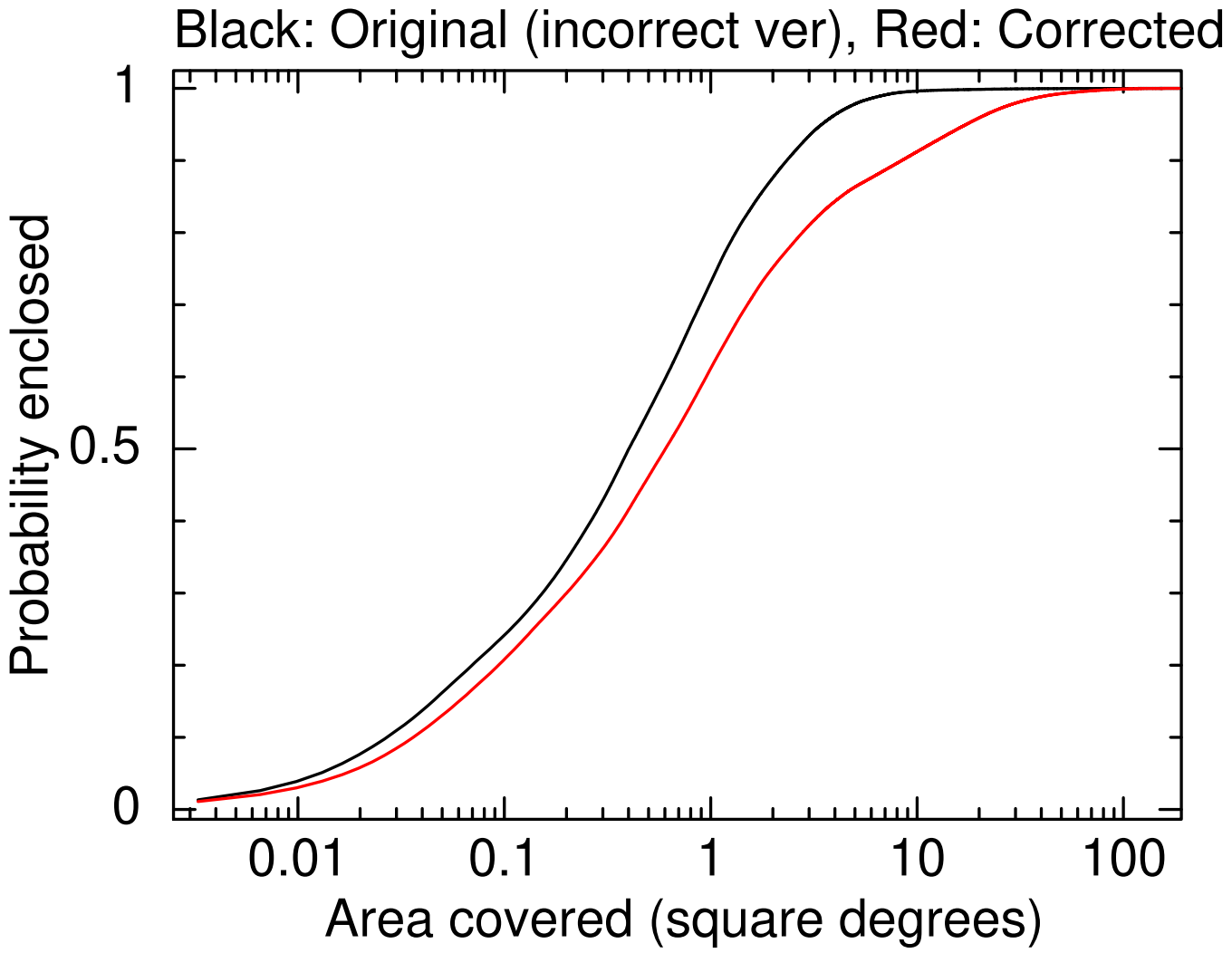

Figure 1. The cumulative probability within the galaxy-convolved GW skymap of GW 170817 as a function of area. The black curve is calculated using the incorrect normalization of Evans et al. (2016) whereas the red curve uses the values from this erratum. The effect is not large, but increases as the fractional probability enclosed becomes high.

The impact of this error is modest. The incorrect formulation resulted in the over-emphasis of catalogued galaxies within the GW error region. The only GW event to date for which this may have had an impact was GW 170817 (e.g. Abbott et al. 2017), for which the GW merger was in a catalogued galaxy, thus this error if anything aided the search. Fig. 1 demonstrates quantitatively the impact of the error. Here we show the cumulative probability in the galaxy-convolved skymap as a function of area enclosed (summing over pixels in decreasing probability order). The original equation (7) shown in black clearly overestimates the enclosed probability as a function of area; the discrepency being worse as the fractional probability enclosed becomes high.

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