Constraining Short, Hard Gamma-Ray Burst Beaming Angles From Gravitational Wave Event Rate Measurements

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Abstract

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GRB Beaming Angles From Coalescence Rate Measurements

Assuming that at least some fraction of sGRBs are due to compact binary coalescence, the observed rate of sGRBs may be written,

$$\mathcal{R}_{\mathrm{grb}} = \epsilon\mathcal{R}(1-\cos\theta), \tag{1}$$

$$p(\theta,\epsilon) = p(\mathcal{R},\epsilon)\left|\left|\frac{\partial(\mathcal{R},\epsilon)}{\partial(\theta,\epsilon)}\right|\right|, \tag{2}$$

where the Jacobian matrix is given by,

$$\frac{\partial(\mathcal{R},\epsilon)}{\partial(\theta,\epsilon)} = \begin{bmatrix} \frac{\partial\mathcal{R}}{\partial\theta} & \frac{\partial\mathcal{R}}{\partial\epsilon} \\ \frac{\partial\epsilon}{\partial\theta} & \frac{\partial\epsilon}{\partial\epsilon} \end{bmatrix}. \tag{3}$$

$$p(\theta) = \int_\epsilon p(\theta,\epsilon)\,\mathrm{d}\epsilon, \tag{4}$$

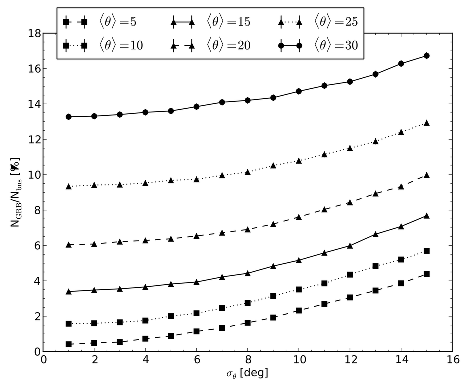

Figure 1: Figure caption

Prior on GRB Efficiency, ϵ

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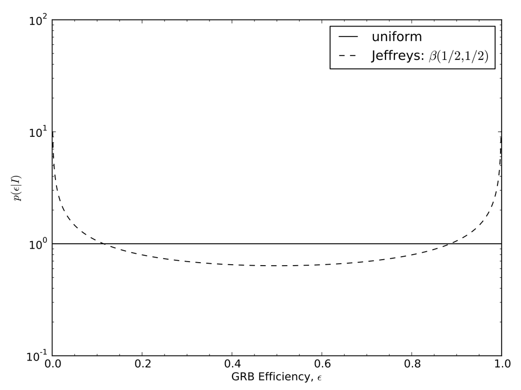

Figure 2: Figure caption

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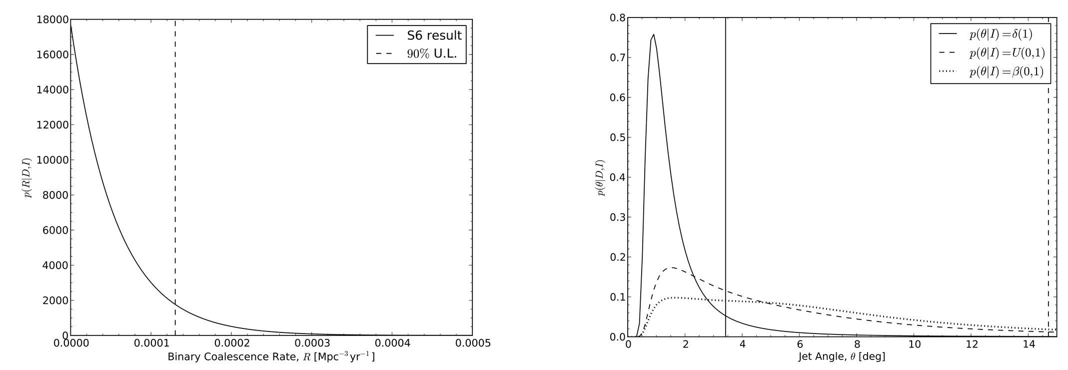
Constraints From The Initial Detector Era

Constructing The Rate Posterior

$$p(\mathcal{R}|C_L(\rho^*),T,\Lambda) \propto p(\mathcal{R})\left[\frac{1+\Lambda C_L(\rho^*)T}{1+\Lambda}\right]e^{-\mathcal{R}C_L(\rho^*)T} \tag{5}$$

Jet Angle Posterior



(a) Rate Posterior

(b) Jet Posterior

Figure 3: S6 results

Constraints In The Advanced Detector Era

Constructing The Rate Posterior

So let $b = 10^{-2}\,\mathrm{yr}^{-1}$. From there, we can get the detection rate posterior using equations 14.10–14.12 of Gregory. The measured rate r consists of two components, one due to a signal of interest, s, and the other a known background rate, b:

$$r = s + b\begin{cases} s = \text{signal rate} \\ b = \text{background rate}\end{cases} \tag{6}$$

Since the background rate is known,

$$p(s|n,b,I) = p(r|n,b,I), \tag{7}$$

where n is the number of gravitational wave (GW) detections. From eq 14.8 of Gregory, we get to:

$$p(s|n,b,I) = C\frac{T\left[(s+b)T\right]^n e^{-(s+b)T}}{n!}, \tag{8}$$

where,

$$C^{-1} = \frac{e^{-bT}}{n!}\int_0^\infty \mathrm{d}(sT)(s+b)^n T^n e^{-sT} \tag{9}$$

$$= \sum_{i=0}^{n}\frac{(bT)^i e^{-bT}}{i!}. \tag{10}$$

In particular, the detection rate for a given type of binary coalescence in LIGO-Virgo is given by equation 1 in [?],

$$s = \mathcal{R}\times N_G, \tag{11}$$

where $\mathcal{R}$ is the coalescence rate of that type of binary per galaxy and N_G is the number of galaxies accessible with a search for the relevant binary type. N_G is well approximated at large distances by,

$$N_G = \frac{4}{3}\pi\left(\frac{D_{\mathrm{horizon}}}{\mathrm{Mpc}}\right)^3(2.26)^{-3}(0.0116). \tag{12}$$

The reader is directed to [?] for a discussion of the numerical factors in the equation above.

Finally, we recognise that N is the signal rate s in equation ?? so that we arrive at the desired posterior on the binary coalescence rate,

$$p(\mathcal{R}|N_{\mathrm{det}},I) = p(s|N_{\mathrm{det}},I)\left|\frac{\mathrm{d}s}{\mathrm{d}\mathcal{R}}\right| \tag{13}$$

$$= N_G\cdot p(s|N_{\mathrm{det}},I) \tag{14}$$

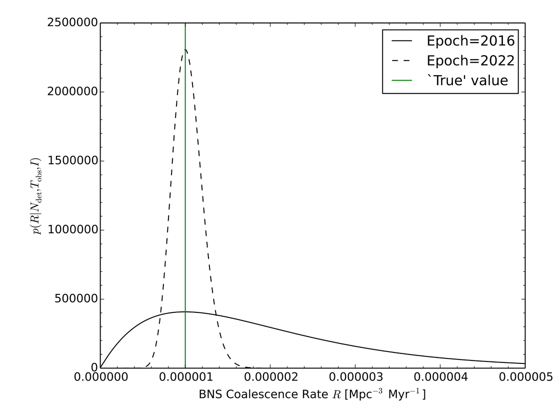


Figure 4: Figure caption

Jet Angle Posterior

Conclusions

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Acknowledgements

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