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

James A. Clark[1], Ik Siong Heng[2] & Martin Hendry[2]

1. Georgia Institute of Technology
2. University of Glasgow

Georgia Tech Center for Relativistic Astrophysics College of Sciences

University of Glasgow

Abstract

Sed fringilla tempus hendrerit. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Etiam ut elit sit amet metus lobortis consequat sit amet in libero. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Phasellus vel sem magna. Nunc at convallis urna. isus ante. Pellentesque condimentum dui. Etiam sagittis purus non tellus tempor volutpat. Donec et dui non massa tristique adipiscing. Quisque vestibulum eros eu. Phasellus imperdiet, tortor vitae congue bibendum, felis enim sagittis lorem, et volutpat ante orci sagittis mi. Morbi rutrum laoreet semper. Morbi accumsan enim nec tortor consectetur non commodo nisi sollicitudin. Proin sollicitudin. Pellentesque eget orci eros. Fusce ultricies, tellus et pellentesque fringilla, ante massa luctus libero, quis tristique purus urna nec nibh.

This Work

1. Lorem ipsum dolor sit amet, consectetur.
2. Nullam at mi nisl. Vestibulum est purus, ultricies cursus volutpat sit amet, vestibulum eu.
3. Praesent tortor libero, vulputate quis elementum a, iaculis.
4. Phasellus a quam mauris, non varius mauris. Fusce tristique, enim tempor varius porta, elit purus commodo velit, pretium mattis ligula nisl nec ante.
5. Ut adipiscing accumsan sapien, sit amet pretium.
6. Estibulum est purus, ultricies cursus volutpat
7. Nullam at mi nisl. Vestibulum est purus, ultricies cursus volutpat sit amet, vestibulum eu.
8. Praesent tortor libero, vulputate quis elementum a, iaculis.

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,

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

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

where the Jacobian matrix is given by,

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

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

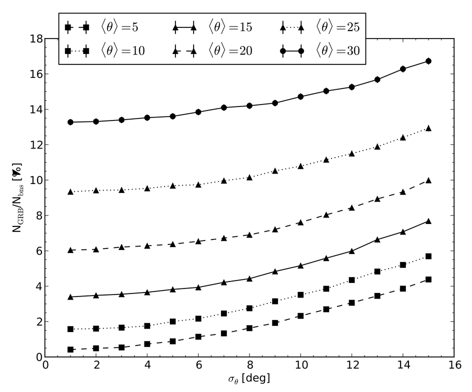


Figure 1: Figure caption

Prior on GRB Efficiency, ϵ

Sed fringilla tempus hendrerit. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Etiam ut elit sit amet metus lobortis consequat sit amet in libero. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Phasellus vel sem magna. Nunc at convallis urna. isus ante. Pellentesque

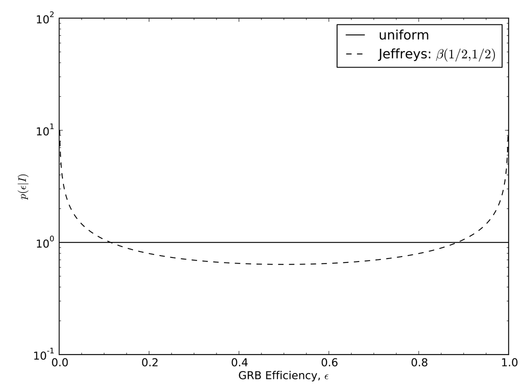


Figure 2: Figure caption

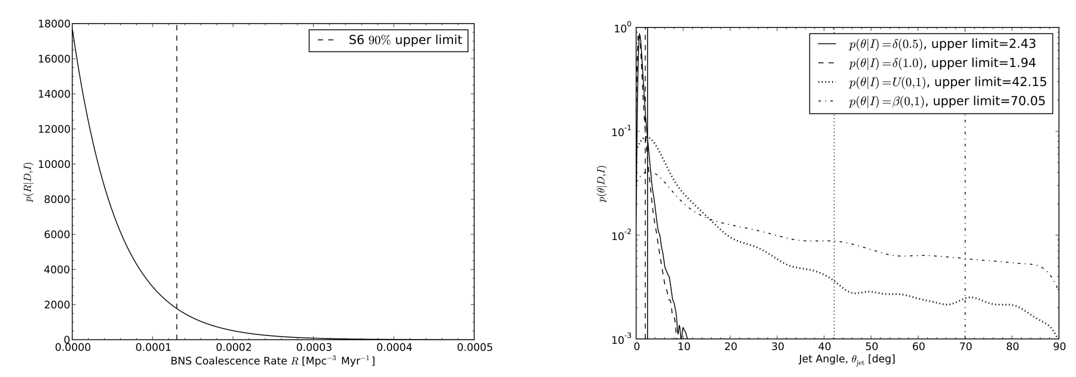
Sed fringilla tempus hendrerit. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Etiam ut elit sit amet metus lobortis consequat sit amet in libero. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Phasellus vel sem magna. Nunc at convallis urna. isus ante. Pellentesque condimentum dui. Etiam sagittis purus non tellus tempor volutpat. Donec et dui non massa tristique adipiscing. Quisque vestibulum eros eu. Phasellus imperdiet, tortor vitae congue bibendum, felis enim sagittis lorem, et volutpat ante orci sagittis mi. Morbi rutrum laoreet semper. Morbi accumsan enim nec tortor consectetur non commodo nisi sollicitudin. Proin sollicitudin. Pellentesque eget orci eros. Fusce ultricies, tellus et pellentesque fringilla, ante massa luctus libero, quis tristique purus urna nec nibh.

Constraints From The Initial Detector Era

Constructing The Rate Posterior

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

Results



(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,

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

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

Finally, we recognise that $\dot{N}$ is the signal rate s in equation **??** so that we arrive at the desired posterior on the binary coalescence rate,

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

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

Results: Validation

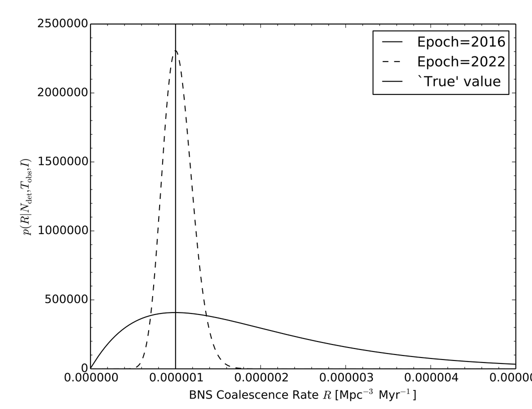
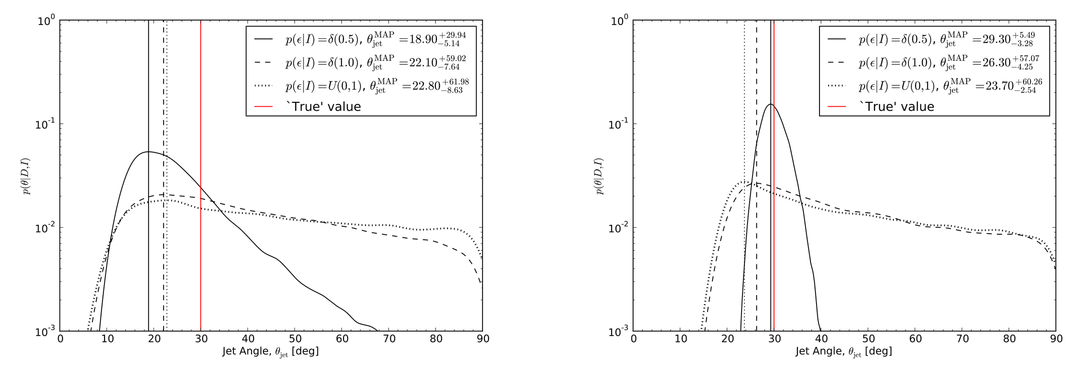


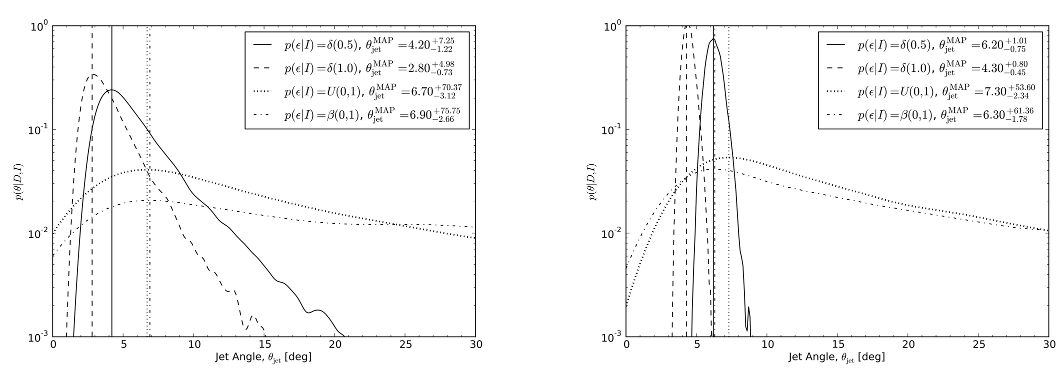
Figure 4: Figure caption



(a) Rate Posterior (b) Jet Posterior

Figure 5: Example results for $\theta_{\rm jet} = 30^\circ$ and binary coalescence rates in [?] to derive a 'simulated' GRB rate.

Results: Predictions



(a) Rate Posterior (b) Jet Posterior

Figure 6: Results in ADE assuming $\mathcal{R}_{\rm grb} = 3\times10^{-9}\,\mathrm{Mpc}^{-3}\mathrm{yr}^{-1}$ and binary coalescence rates in [?].

Conclusions

- Pellentesque eget orci eros. Fusce ultricies, tellus et pellentesque fringilla, ante massa luctus libero, quis tristique purus urna nec nibh. Phasellus fermentum rutrum elementum. Nam quis justo lectus.
- Vestibulum sem ante, hendrerit a gravida ac, blandit quis magna.
- Donec sem metus, facilisis at condimentum eget, vehicula ut massa. Morbi consequat, diam sed convallis tincidunt, arcu nunc.
- Nunc at convallis urna. isus ante. Pellentesque condimentum dui. Etiam sagittis purus non tellus tempor volutpat. Donec et dui non massa tristique adipiscing.

Acknowledgements

Etiam fermentum, arcu ut gravida fringilla, dolor arcu laoreet justo, ut imperdiet urna arcu a arcu. Donec nec ante a dui tempus consectetur. Cras nisi turpis, dapibus sit amet mattis sed, laoreet.