Distinguishing GRB Progenitors using Gravitational-Wave Observations

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Motivation

Gamma ray bursts (GRBs) are the most electromagnetically luminous astronomical events in the universe. They come in at least two classes: Long bursts (LB > 2 seconds) and short hard bursts (SHB < 2 seconds). In both cases the resulting jet, which is seen as a GRB, is launched along the polar axis of the progenitor. The progenitors of these different kinds of bursts are believed to be different: LB are strongly believed to be associated with hypernovaes and SHB are thought to be produced by mergers of Neutron star-Neutron star (NS-NS) binaries. They are also one of the most promising gravitational-wave (GW) sources; Here, we illustrate how joint GRB and gravitational-wave (GW) observations can test these and other progenitor models, using Maximum entropy technique (Maxent, [1]).

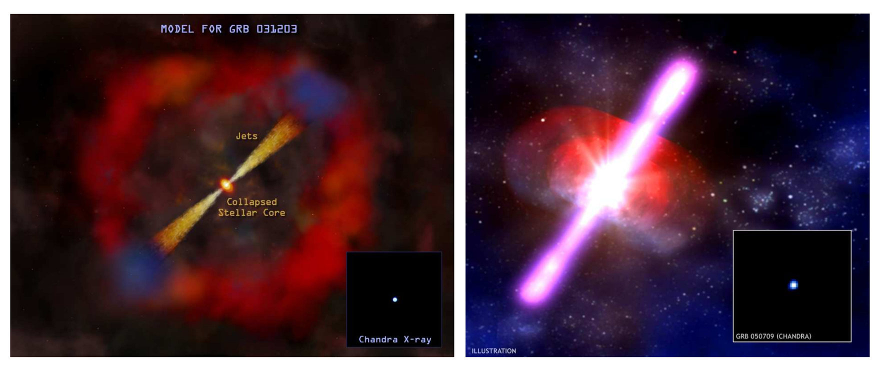

FIGURE 1: An artist's depiction of Long GRB (left) and short GRB (right). In both cases, the jet is emitted along the polar axis of the progenitor (Image courtesy Chandra)

How can GW observations be used to distinguish between progenitors ?

One way to distinguish GRB progenitors is from the degree of axi-symmetry. In general NS-NS mergers radiate angular momentum and are strongly non-axisymmetric, whereas hypernova are much closer to axisymmetry. Axisymmetric systems emit linearly polarized (LP) radiation; Non-axisymmetric systems emit circularly polarized (CP) radiation; Hence, corresponding measurement of polarizations associated with GRBs can help in distinguishing progenitor models.

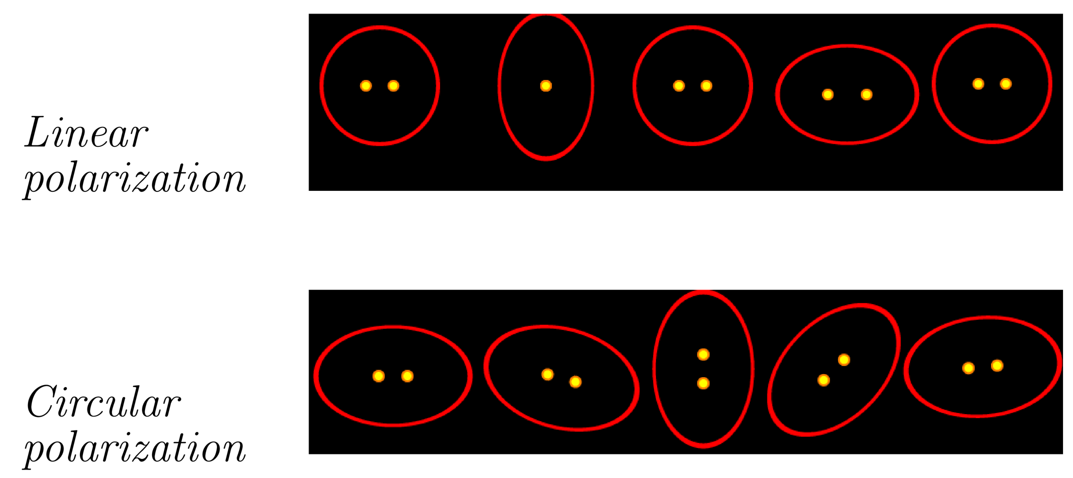

FIGURE 2: An illustration of linear polarization (h_+, top figure) and circular polarization (bottom figure) of a GW.

Polarization measurements through Stoke's parameters

The polarization state of a GW can be determined by calculating its Stoke's parameters, which measure it's $+$, $\times$ and circular polarizations amplitudes of a GW. If $\tilde{h}_+$ and $\tilde{h}_\times$ represent Fourier transforms of the inferred amplitudes of a GW, then the Stoke's parameters can be written as:

$$\begin{aligned} I &= \tilde{h}_+\tilde{h}_+^* + \tilde{h}_\times\tilde{h}_\times^* \\ Q &= \tilde{h}_+\tilde{h}_+^* - \tilde{h}_\times\tilde{h}_\times^* \\ U &= \tilde{h}_+\tilde{h}_\times^* + \tilde{h}_\times\tilde{h}_+^* \\ V &= \tilde{h}_\times\tilde{h}_+^* - \tilde{h}_+\tilde{h}_\times^* \end{aligned} \quad (1)$$

The degree to which a GW is linearly polarized is measured by $\sqrt{Q^2 + U^2}$ and **the degree of circular polarization** is found from $|V|$.

A linearly polarized wave would have $|V| = 0, (Q^2 + U^2)^{1/2} = 1$, whereas a circularly polarized wave has $|V| = 1, Q = U = 0$.

Coherent techniques like Maxent will enable GW detector networks to measure GW polarization

To illustrate how well a GW detector network can measure the degree of polarization, we have embedded circularly polarized sine-Gaussian waveforms into noisy data-streams. Using Maxent (see accompanying poster by Finn et al.), we have extracted the waveforms and computed Stoke's parameters using these inferred waveforms.

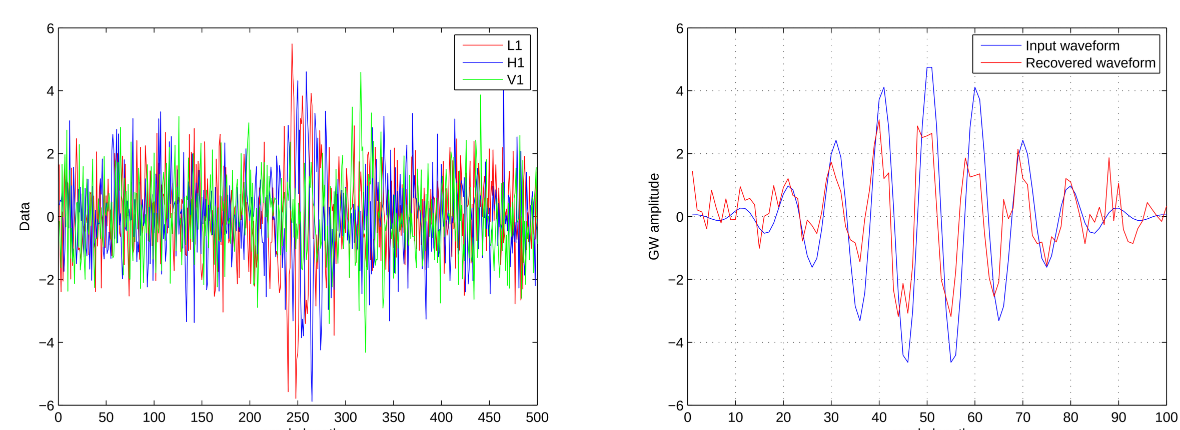

FIGURE 3: *Left:* A plot showing L1, H1 & V1 detector data for a peak input amplitude of $5\times$ rms noise . *Right:* Input GW amplitude (blue) and recovered amplitude (red) using Maxent.

The following figures show the sensitivity to circular polarization for a combination of Livingston (L1), Hanford (H1), VIRGO (V1) and a 3 Km detector at the location and with arm-orientation similar to TAMA. We show the sensitivity improvement in measuring the circular-polarization over all sky, when additional detectors are added to the network for peak amplitudes of 5 and $20\times$ rms noise level.

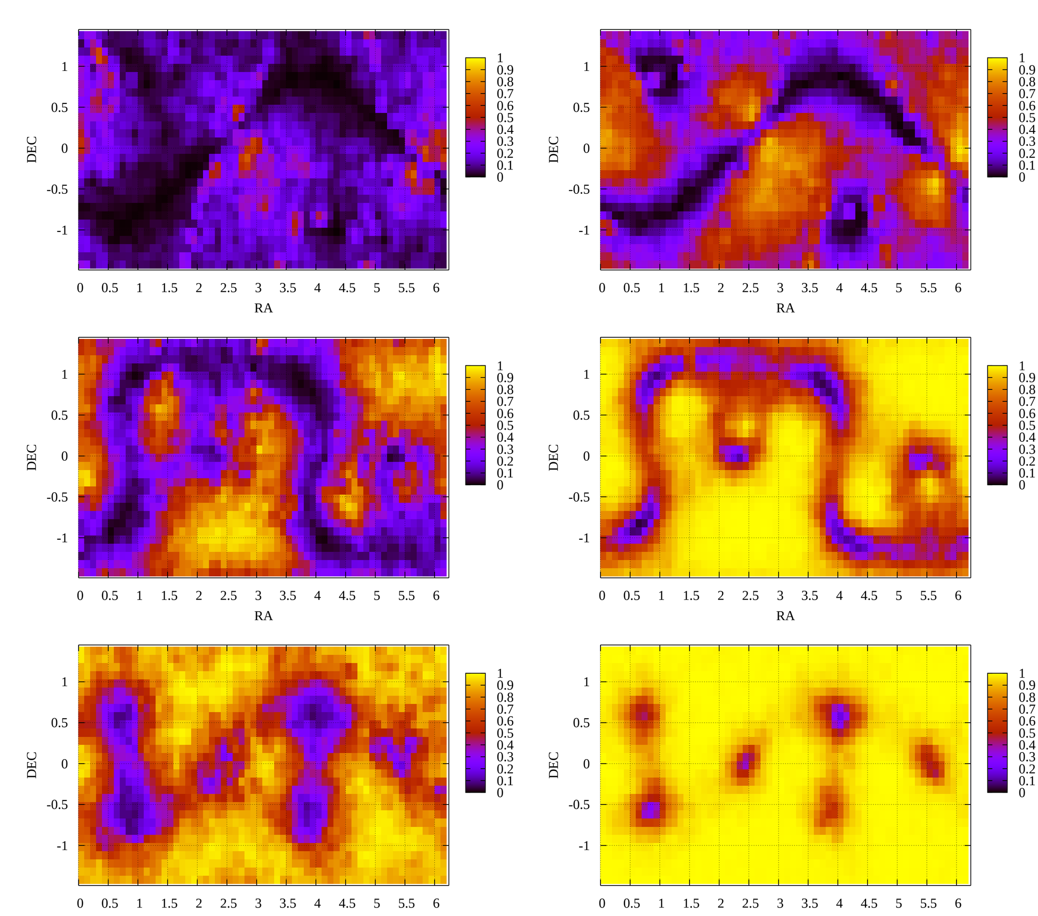

FIGURE 4: An all sky map of Stokes V parameter for a (1) L1-H1 (first row) (2) L1-H1-V1 (second row) and (3) L1-H1-V1-T1 (third row) detector network.

Going beyond

- *Polarization measurements can determine the orientation of the beaming axis* [2]. Since the jet from a GRB is emitted along the polar axis, GWs will be circularly polarized when viewed down this axis and linearly polarized when viewed along the equatorial plane.
- *GW observations can detect GRBs with unfavorable orientations which otherwise would not be detected.*

References

[1] Summerscales, T. Z. et al. (2008), ApJ, 678, 1142
[2] Kobayashi & Meszaros. (2003), ApJ, 585, L89

Acknowledgements

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