The Swift short gamma-ray burst rate density: implications for detecting neutron star mergers by ALIGO

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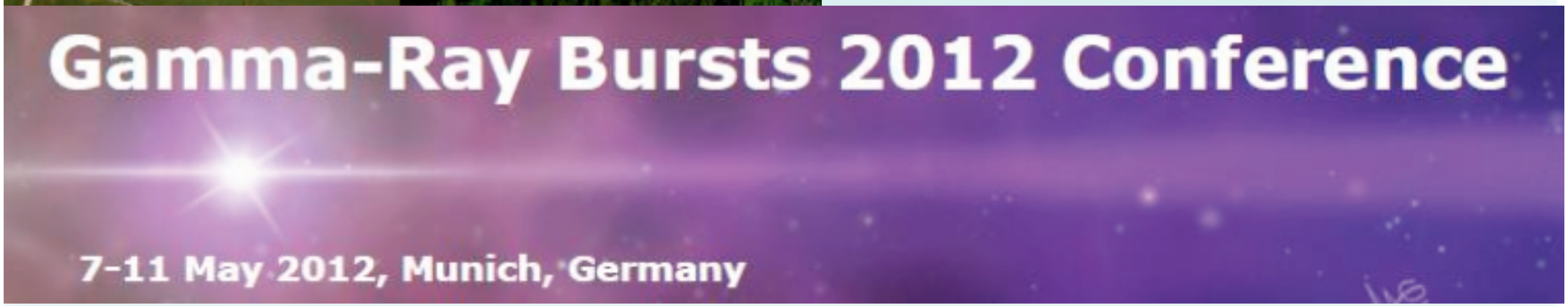
on behalf of 8 co-authors

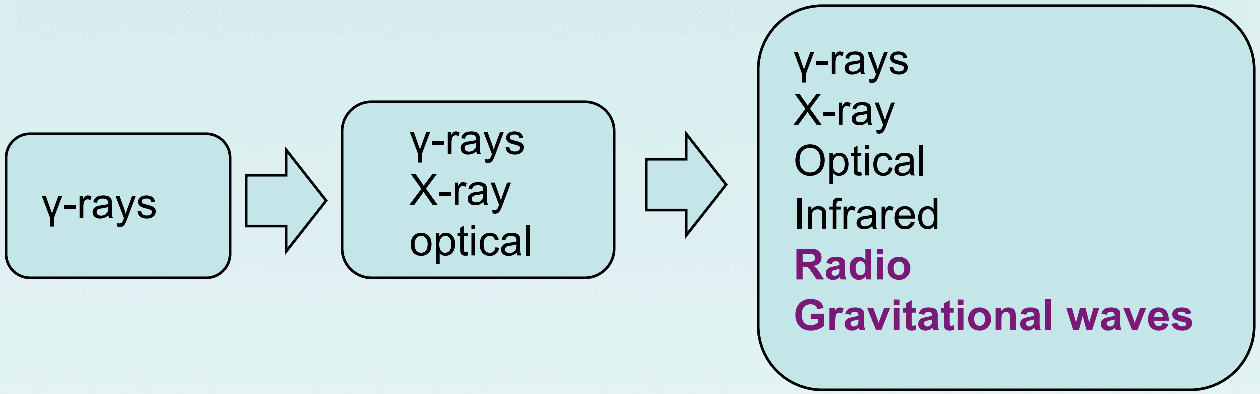


Presentation Overview

- Why pan-spectral EM + GW astronomy
- SGRBs selection effects
- Intrinsic SGRB rates at small-z
- Inferred rate of detections by ALIGO/Virgo
- The Future

Why SGRB rate density is important: GW + EM = paradigm shift

- Increases confidence of first GW detections.
- Increases the GW search sensitivity horizon distance
- Constrain models for SGRB -> maybe not even the EM counterparts of NS mergers!
- History tells us from the GRB experience that perseverance will pay off (enabled by new facilities)



Two methods to estimate binary NS merger rates

1. Galactic binary pulsar rate or simulations extrapolated **out** to extra-Galactic distances.
   Abadie et al. (2010) review gives a NS merger rate of (10-1000) Gpc^{-3} yr^{-1}.
   ALIGO binary merger detection rate predictions based on method 1.

2 Observed SGRB rate extrapolated in to small-z volumes.

Main problems with using SGRBs to constrain binary NS mergers

- Small number statistics
- Beaming angle distribution uncertain
- Fraction of NS mergers actually lead to SGRBs (magnetar formation)?
- Selection effects

…But SGRB instrinsic rates can potentially provide **independent** constraints on binary mergers (with similar uncertainties to method 1).

Method

Small number statistics imply simplest model
We avoid:

SGRB luminosity function
models for progenitor rate evolution
beaming angle distribution
All have large uncertainties.

We focus on observed and measured parameters:

- Redshift
- GRB peak flux
- Limits on beaming from X-ray afterglow – noting that jet angles are model dependant. We use n = 1 cm^{-3} (Kopac et al. 2012)

We aim to use SGRB rate density estimates to infer a detection rate of binary NS mergers by Advanced LIGO (ALIGO) and Virgo interferometers.

Simplest model possible…must include selection effects

Flux and band limited detector and triggering procedure reduces sensitivity. Shown dramatically by comparison of BATSE to Swift SGRB detection rate.

About three dozen SGRBs had been localized by Swift

About 50% have optical detections
One third have redshift determinations based on host galaxy spectroscopy (similar to long bursts)

- Strong Malmquist bias – optical detections biased to smaller volumes

- Bias towards measuring smaller jet angles (because of dependence on time of jet break)

- Calculated rate needs to be boosted by the fraction of missing redshifts

Poisson rate density for the sample of SGRBs using method 2 corrected for known selection effects.

$$R_{\rm SGRB} = \sum_{i}^{n} \frac{1}{V_{\rm i(max)}} \frac{1}{F_r} \frac{1}{T} \frac{1}{\Omega} R_{B/S} B_i(\theta_{\rm j}) {\rm P}_{i(T90;{\rm P_L})}$$

V_{max} is the maximum volume for a burst to be detected and P_i is the probability of a burst being short: see Bromberg et al. (2012).

F_r is the fraction of measured redshifts, to Swift detected SGRBs

$$d_{\rm max} = \sqrt{\frac{F_p k(z)}{F_{\rm Lim} k(z_{\rm Lim})}} d_L(z)$$

The smallest V_{max} (small peak flux and redshift) contribute most to the rate density.

SGRB sample with redshifts
See arXiv:1202.2179

SGRB	T_{90} (s)	θ_j (deg)	z	peak flux (ph s^{-1} cm^{-2})
101219A*	0.6	-	0.718	4.1
100816A*	2.9	$> 12^{\dagger}$	0.803	10.9
100117A*	0.3	-	0.92	2.9
090510A*	0.3	-	0.903	9.7
080905A	1.0	-	0.122	6.0
070724A	0.4	$> 11^{\dagger}$	0.457	2.0
061217A	0.2	-	0.827	2.4
060502B	0.1	-	0.287	8.5
051221A*	1.4	7^{a}	0.547	12.0
050509B	0.73	-	0.225	3.7

SGRBs with Extended Emission excluded from sample and rate density calculated separately

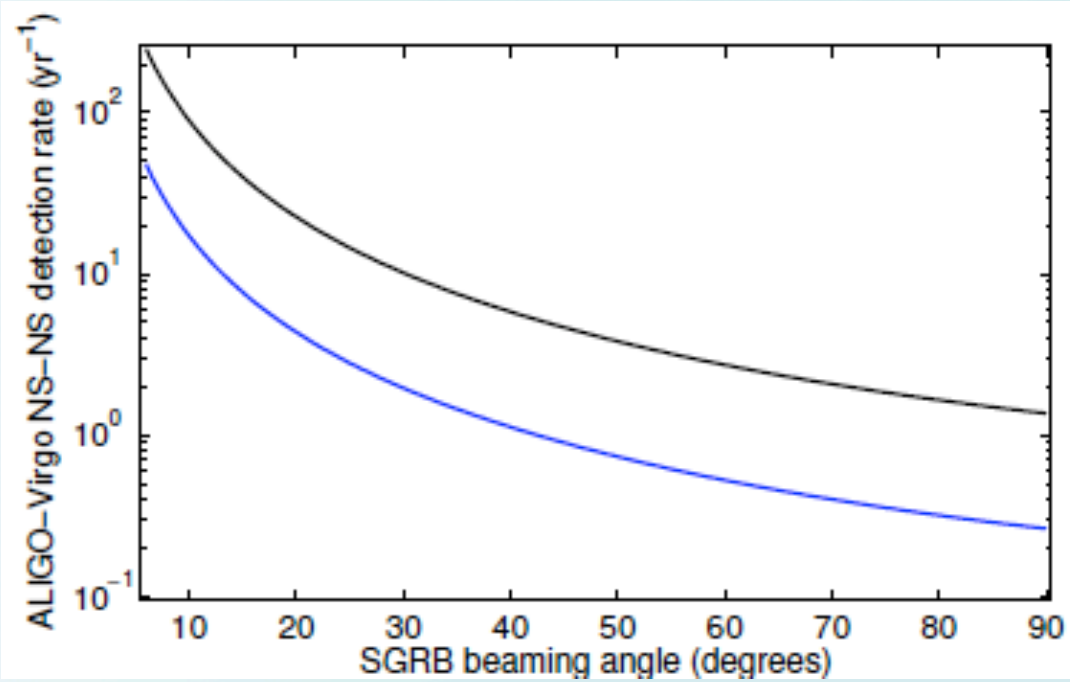
SGRB	$P_{i(T_{90};P_L)}$	lower rate $\mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$	upper rate $\mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$
101219A	0.95	0.04	7.2*
100816A	0.24†	0.005	0.2
100117A	0.98	0.036	6.6*
090510	0.98	0.019	3.4*
080905A	0.92	5.3	960*
070724A	0.51	0.0.39	21
061217	0.98	0.18	34*
060502B	0.99	0.48	88*
051221A	0.33	0.01	1.4
050509B	0.84	1.8	330*
Total rate		$8.2^{+5.7}_{-3.8}$	1500^{+1000}_{-660}

SGRB intrinsic rate density

The beaming-corrected SGRB rate densities with Poisson uncertainties using the observed constraints on theta, and scaled by the probability of a burst being an SGRB.

Lower rate estimates assume isotropic emission, and upper rates use the observed beaming angle constraints shown, or the smallest observed beaming angle in the sample i.e. 7 degrees

ALIGO detection rate of NS mergers based on SRGB intrinsic rate density



$$R(\theta_j) = \frac{4\pi}{3} D_h^3 R_{\rm Low} B(\theta_j)$$

D_h = 197 Mpc for a single ALIGO detector (Lower curve)

D_h = 341 Mpc for two ALIGO detectors in a coincidence search (Upper curve)

Summary of Results (Uncertainty)

Intrinsic SGRB rate density in relatively local Universe:
Lower rate (isotropic emission) = 8 Gpc^{-3} yr^{-1}
Higher rate ($\sim 7^o$) = 1500 Gpc^{-3} yr^{-1}
Significant Poisson uncertainty: (+1000 -660) Gpc^{-3} yr^{-1}

ALIGIO (2 detector) binary NS merger detection rate (not beamed) ~ 2 yr^{-1}
Higher rate ($\sim 7^o$) ~ **200 yr^{-1} (more realistic)**
Significant Poisson uncertainty

If mergers follow SFR, rate density can decrease by a factor of 2.

Take home message
Binary neutron star merger detections likely by ALIGO
Coincident EM + GW observations could provide the most detailed probe of NS mergers.

The Near Future

➢EM follow-up of ALIGO Alerts

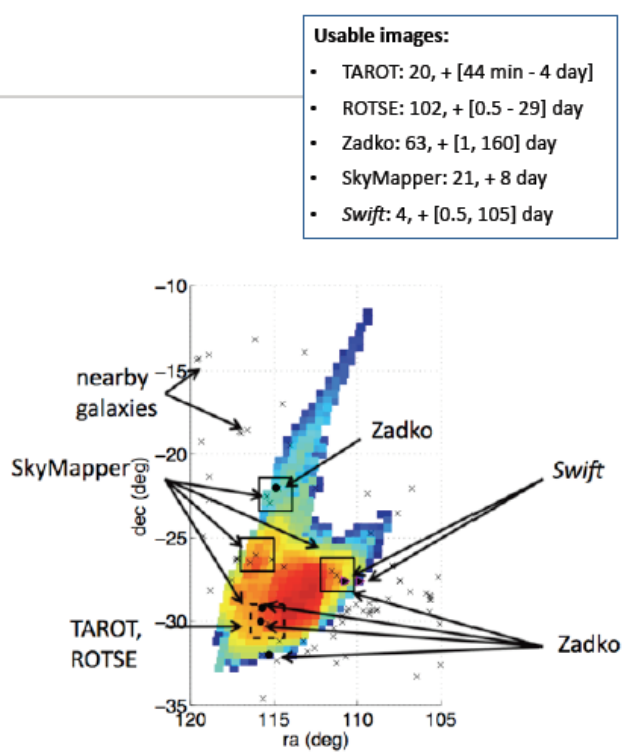
If beaming angles are small: ALIGO detection rate high…but EM detections less likely

If beaming angles are large: ALIGO detection rate low…but EM detections more likely

One small **"Elephant in the lounge room"**

➢ALIGO source localisation is > several degrees:

➢New strategies for joint EM+GW need developing

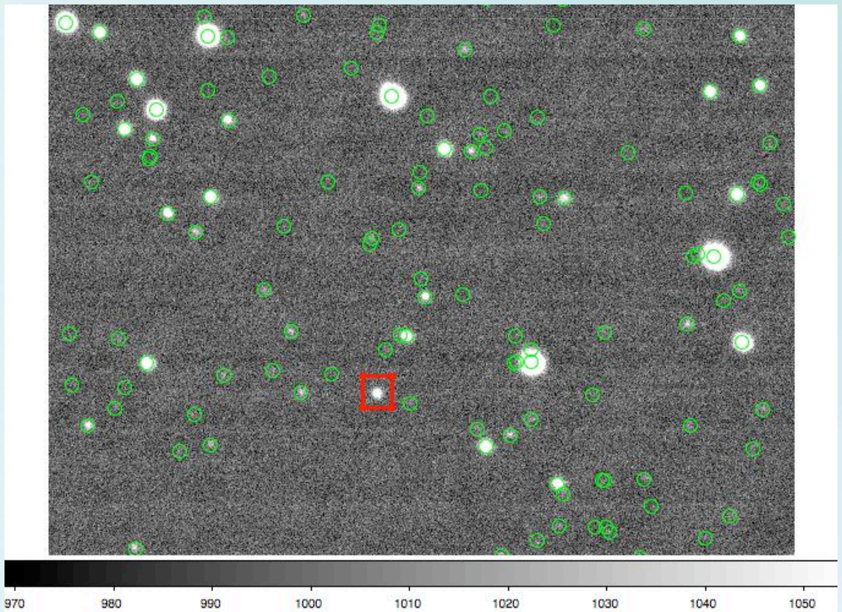


➢The Era of Pan-spectral astronomy is arriving soon

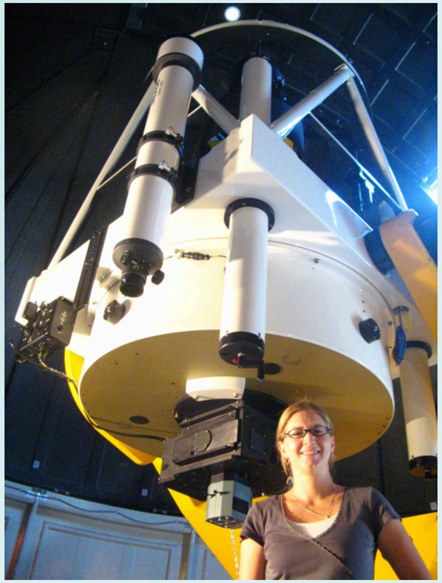
THE END

Thanks to the organizers

GRB101024 trigger + 200 s



Zadko Telescope
1-m robotic



SGRB-EE rate density

SGRB-EE		
071227	0.038	0.97
070714B	0.0036	0.66
061210	0.0034	0.16
061006	0.0088	1.6
060614	0.073	3.3
050724	0.03	0.32
Total rate	$0.16^{+0.15}_{-0.088}$	$7.1^{+6.9}_{-4}$