Using short GRBs to forecast GW detections at Advanced LIGO*

(*How I learnt to stop worrying and embrace ignorance)

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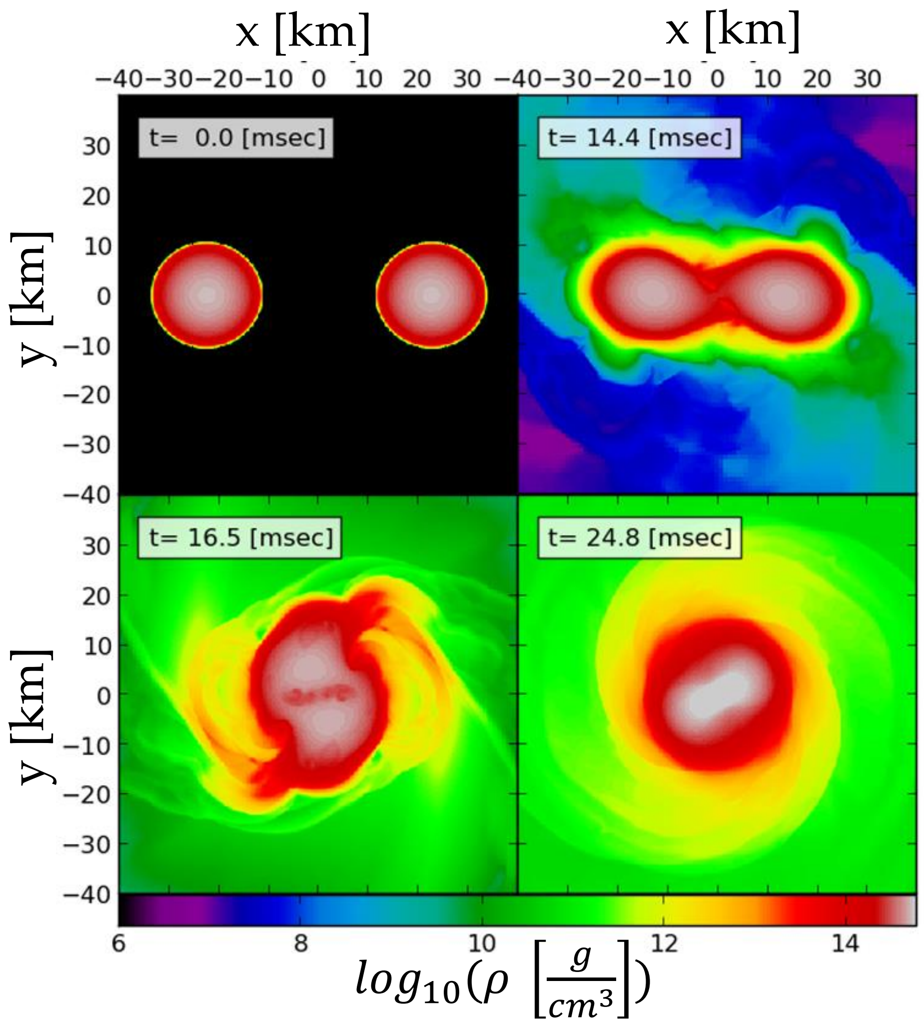
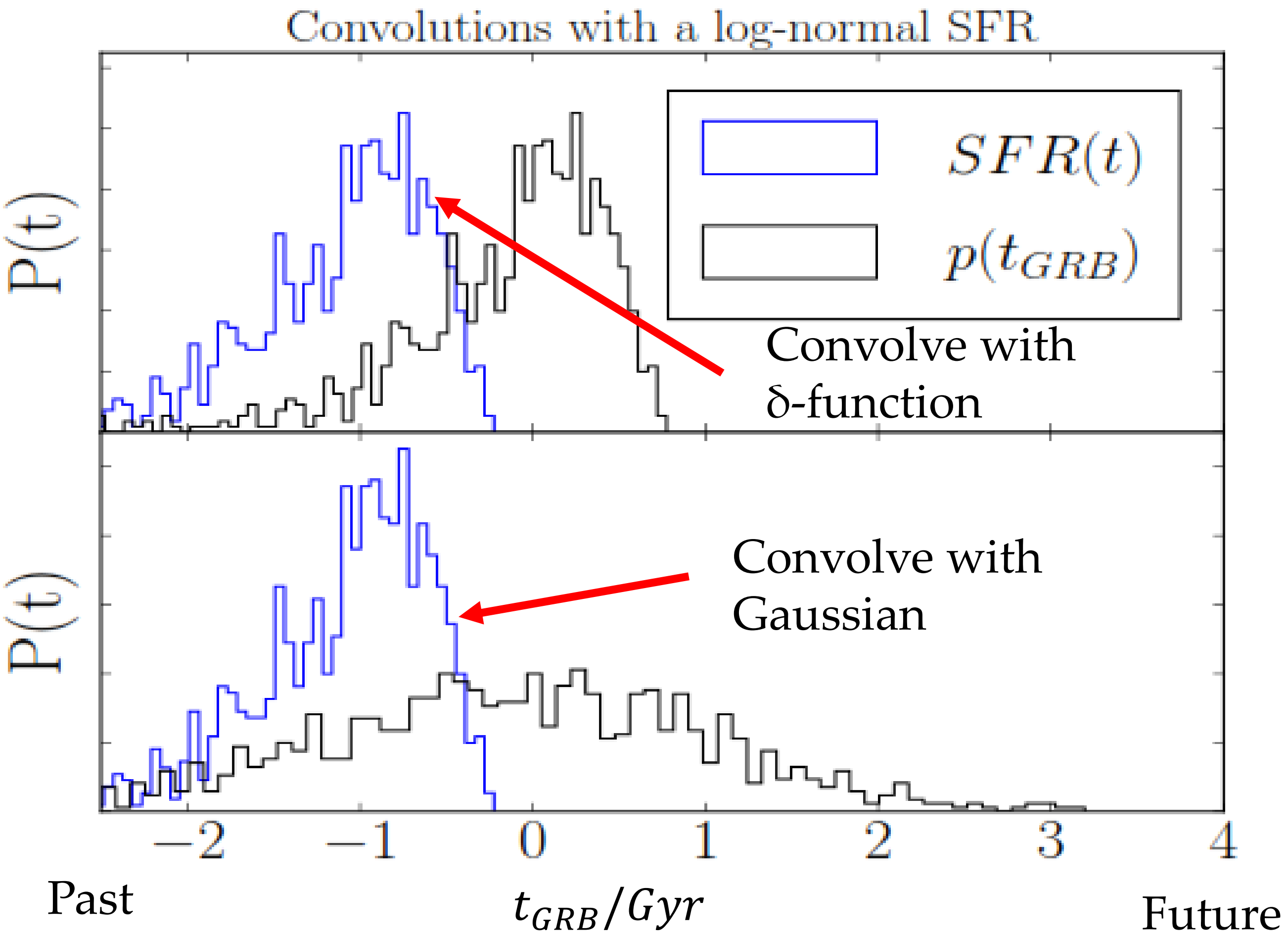
Short VS long gamma-ray bursts (GRBs)

	Short GRB	Long GRB
Duration	<2s	>2s
γ-rays	Hard	Soft
Progenitor	Merging compact object binaries	Rapidly rotating core collapse SN
Optical/X-ray afterglows	Yes	Yes
Gravitational waves?	**YES!** The theoretical GW signal for these events is well understood.	**Yes…** But the signal might be different for each burst. Less promising GW progenitors.



Simulation of merging neutron stars in a binary.
(Max Planck Institute for Gravitational Physics).

What is the time delay distribution?



<u>Contention in the field</u>

- Virgili et al (2011) :

Delay ~ $N(\mu = 2Gyr,\ \sigma = 1Gyr)$

VS

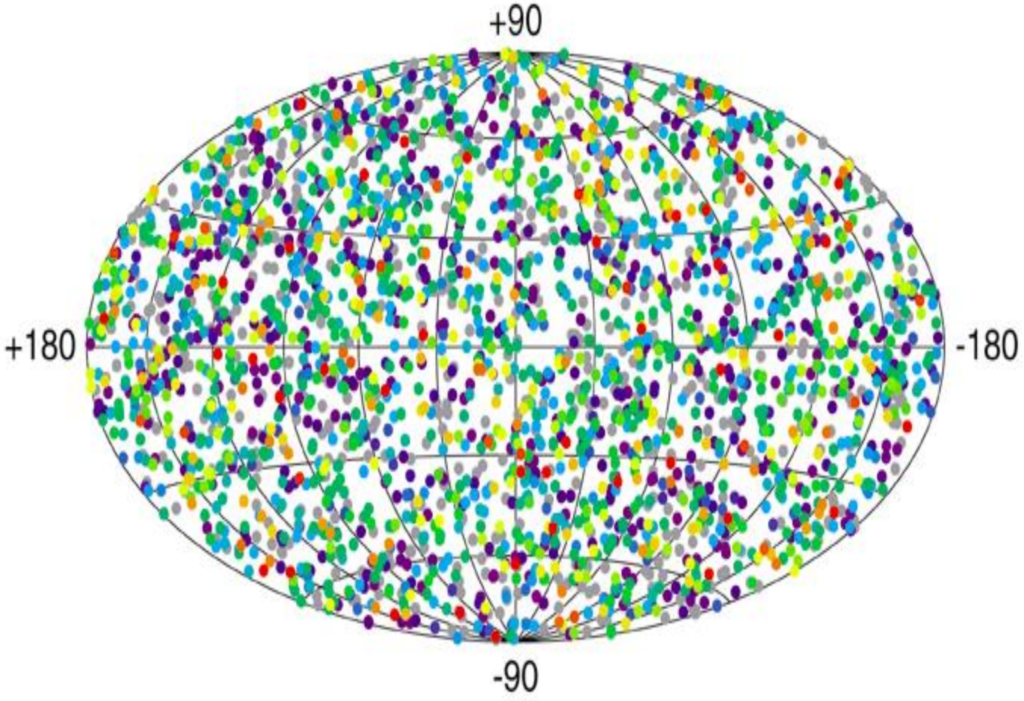
- Wanderman & Piran (2014):

Delay ~ $\delta(t - \tau)$

$\tau \approx 2.9Gyr$ OR $\tau \approx 3.9Gyr$ (SFR dependent).

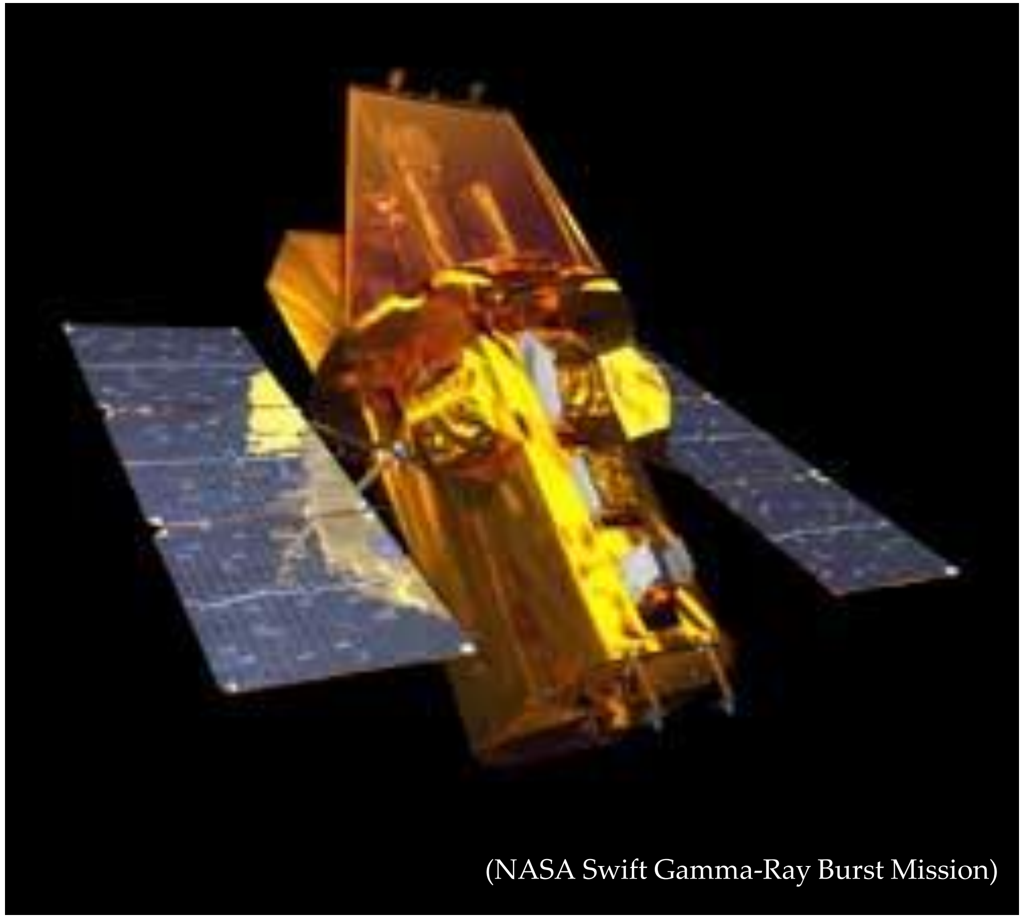
Observing GRBs

Past GRB detections



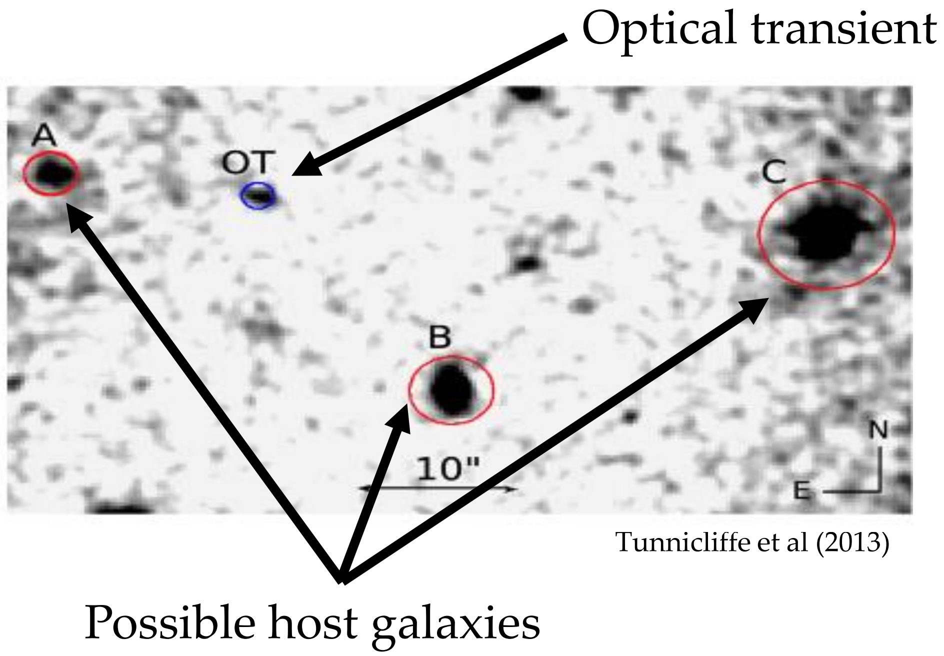
(NASA's Godard Space Flight Centre).

Swift (2004 - Present).



The factors limiting inference

- Small number stats.; we only know *z* for ~40% of the detected sGRBs.
  - ➢Observing constraints, dark afterglows and host galaxy confusion.
- Sample contamination from collapsars (LGRBs).
  - ➢Skew inference to shorter time delays.



Tunnicliffe et al (2013)

- Selection effects on…
  - ➢The optical afterglow; dark GRBs reside at *high z*.
  - ➢The GRB itself; dark GRBs reside at *low z*.

Recipe: Testing the robustness of inference of the delay time distribution.

From the Kitchen of: Riley, Giblin et al (in prep.)

- Convolve your delay time distribution(s) with an SFR → the distribution of sGRBs in time.

- Apply observational constraints: adopt/fit a GRB luminosity function, to derive $p(observed|t_{GRB})$.

- Maximum likelihood estimation for the parameter(s) (τ) of the delay time distribution: $\mathcal{L}(\tau) \propto \prod_i [p_{SFR}(t_i, \tau) * p_{delay}(\tau)]\ p(obs|t_i)$

- Check if the answers change (a lot) when you model contamination/selection effects.

Our Scenarios

- Scenario I: The sample is pure and unbiased.

- Scenario II: The sample is unbiased but has collapsar contaminants: amend the time delay distribution.

$$p_\tau(\tau) = f\delta(\tilde{\tau} - \tau) \; + \; \underbrace{(1 - f)\delta(\tilde{\tau})}_{\text{New term accommodates collapsars}}$$

$f \equiv f_{merger}$= fraction of sample that are mergers

($\tilde{\tau}$ = the dummy integration parameter)

Our Scenarios (cont'd)

- Scenario III: The sample is pure, but the afterglows are subject to Malmquist bias.
  - Missing high-z GRBs from sample → Randomly assign z to dark GRBs from U($2 < z < 4$) distribution.

- Scenario IV: The sample is pure, but the GRB itself is subject to Malmquist bias.
  - All GRBs are at low-z → Randomly assign z to *all* unknown redshift GRBs from U($z < 1$) distribution.

The Results

		Results	
Scenario	**Description**	**δ-function**	**Gaussian**
I	Pure, unbiased sample	$\tau \leq 1.77$ Gyr	$\mu = (3.84 \pm 0.80)$Gyr
II	Contaminated, unbiased	$\tau = (4.02 \pm 0.90)$Gyr $f_{merger} = 0.81 \pm 0.17$	N/A
III	Malmquist bias on afterglow	$\tau = 0.0_{-0.0}^{+0.02}$Gyr	$\mu = 0.0_{-0.0}^{+0.2}$Gyr
IV	Malmquist bias on GRB	N/A	$\mu = (3.69 \pm 0.35)$Gyr

Bottom line: these rows illustrate how we're *very* sensitive to high-z GRBs… **Contamination** or **afterglow Malmquist bias** could ruin everything!

And it's likely contamination is a problem…

Take Home Message:

- We want to infer the time delay distribution to forecast GW detections at advanced LIGO.
- BUT inference faces considerable limitations.
- We get very different time delay distributions when we (crudely) model contamination and afterglow Malmquist bias.
- Unlikely to accurately forecast GW detections using short GRB observations.

Suggested Question…

"Is there a sensible way to eliminate collapsar contaminants from our sample of mergers?"

Contention with literature…

- Wanderman & Piran (2014): constant delay of $(2.9 \pm 0.4)Gyr$ OR $(3.9 \pm 0.5)Gyr$ → Inconsistent with results for δ-function: $\tau \leq 1.77$ Gyr

  When we omit the (probably a contaminant) high-z GRB, we get more consistent results;

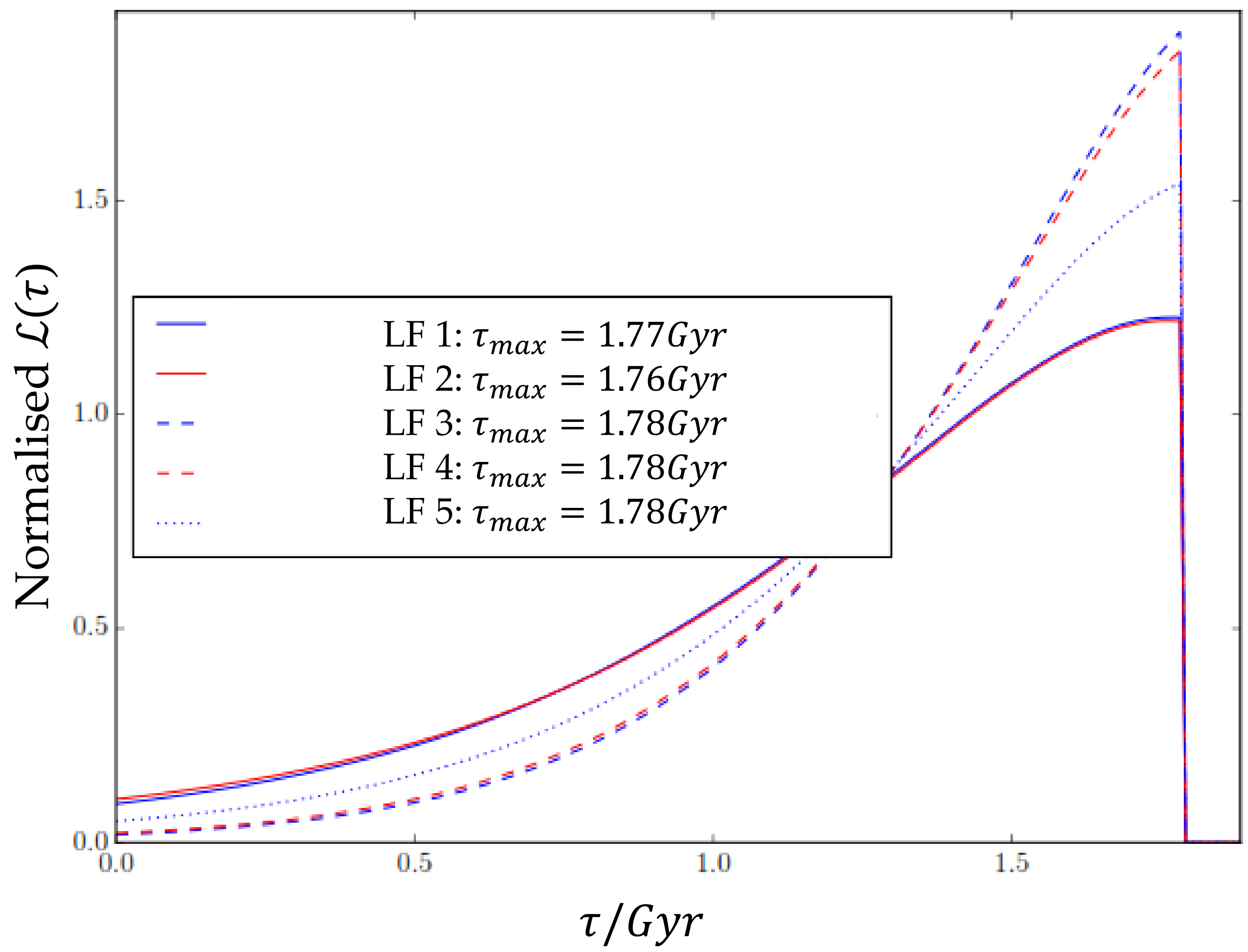
  $$(3.84 \pm 0.80)Gyr$$

  Their contamination estimate of ≈20-40% is also consistent with this work.

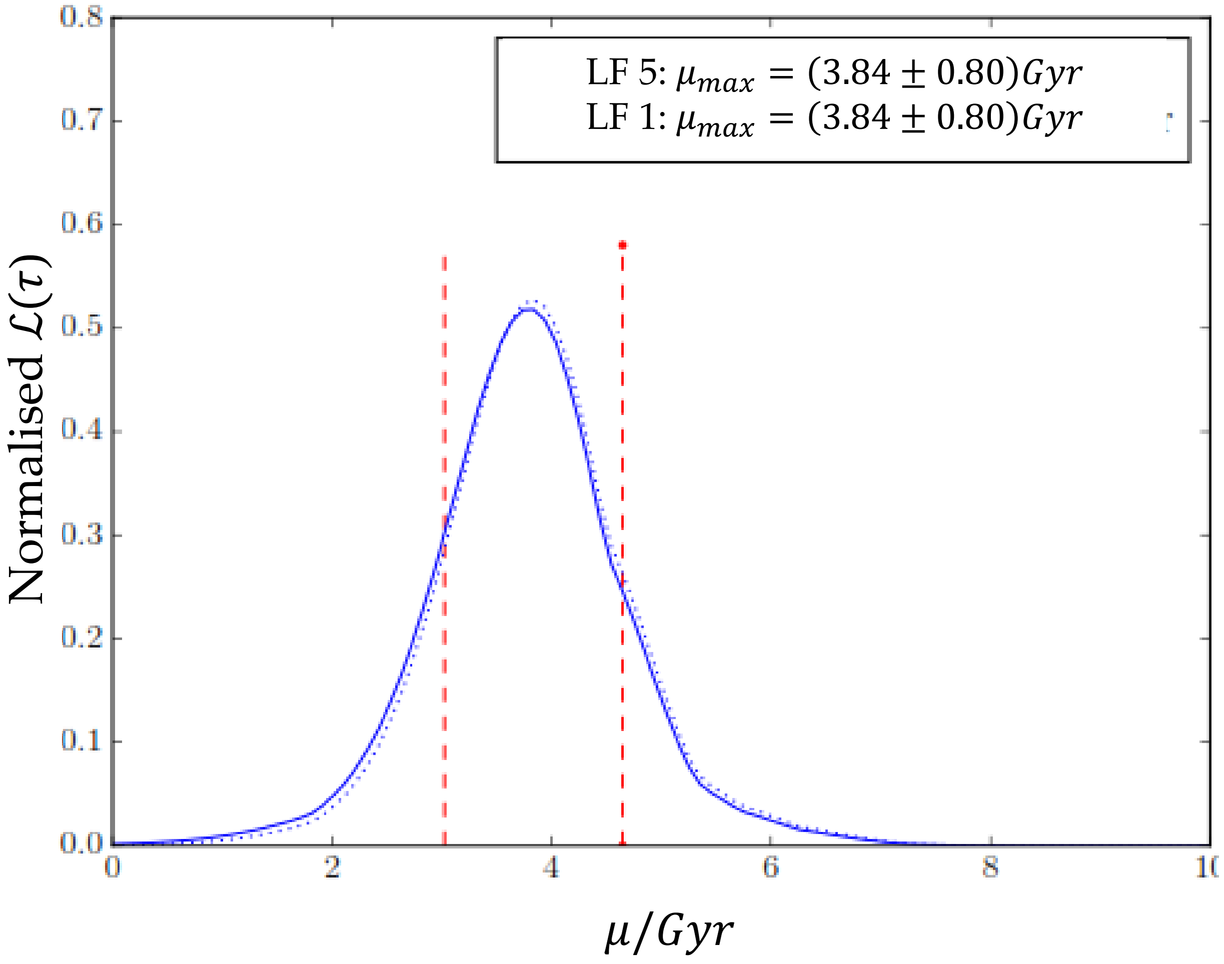
- Virgili et al (2011): delay ~ $N(\mu{\sim}2Gyr,\ \sigma{\sim}1Gyr)$ → Inconsistent with our results for Gaussian, assuming a pure unbiased sample: $\mu = (3.84 \pm 0.80)\mathrm{Gyr}$

Scenario I: The sample is pure & unbiased

Constant τ delay (delay ~ δ-function)



delay ~ $N(\mu, \sigma = 1Gyr)$



Scenario II: The sample is unbiased but contaminated

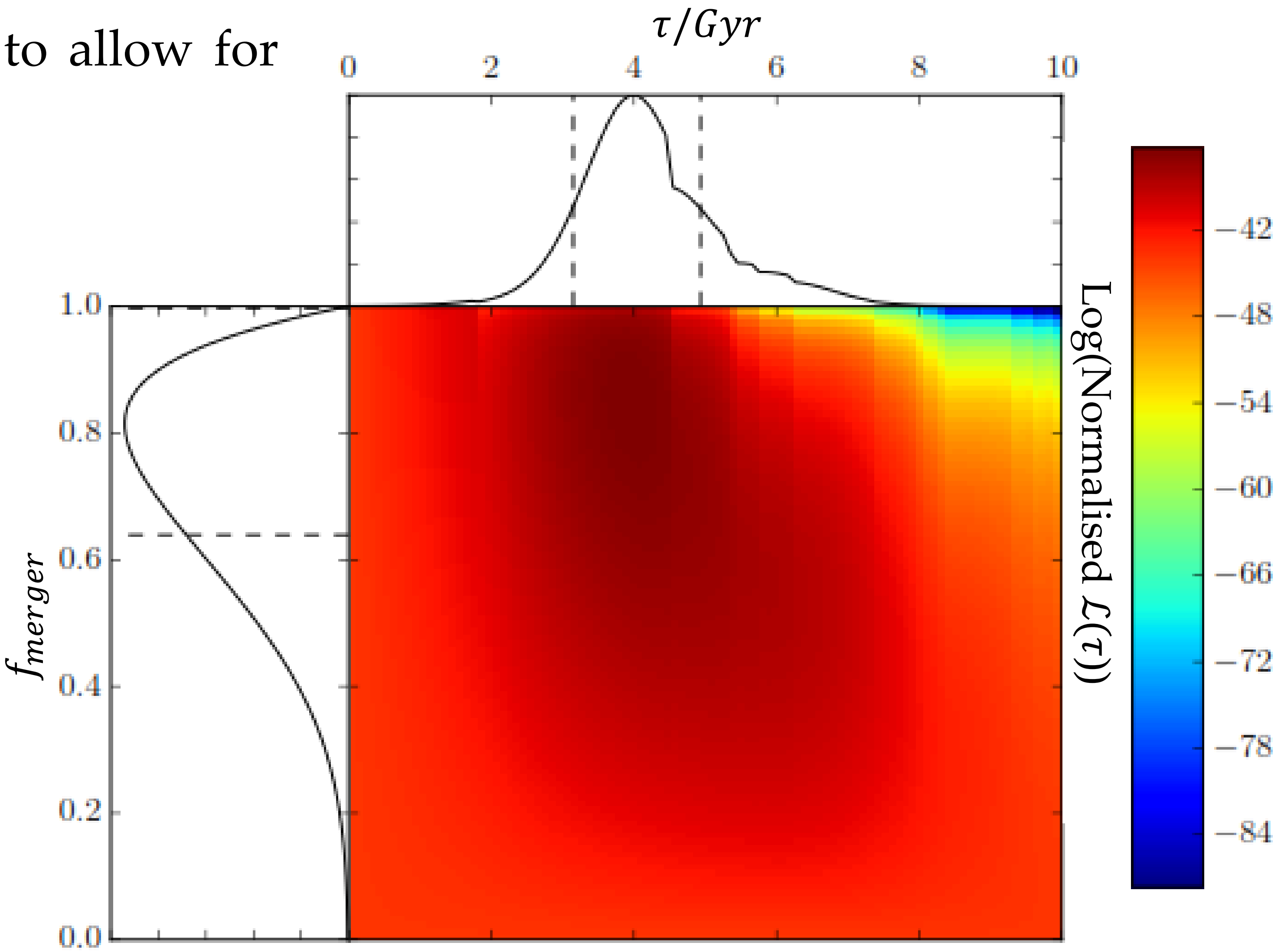
Amend the δ-delay time distribution to allow for collapsars with ~no delay:

$$p_\tau(\tau) = \underbrace{f}_{\substack{f \equiv f_{merger} = \text{fraction of sample} \\ \text{that are mergers}}}\,\delta(\tilde{\tau} - \tau) + \underbrace{(1 - f)\delta(\tilde{\tau})}_{\substack{\text{New term accommodates} \\ \text{collapsars}}}$$

($\tilde{\tau}$ = the dummy integration parameter)

Result:

$$\tau = (4.02 \pm 0.90)Gyr$$
$$f_{merger} = 0.81 \pm 0.17$$



Scenario III: The sample is pure, but the afterglows are subject to Malmquist bias

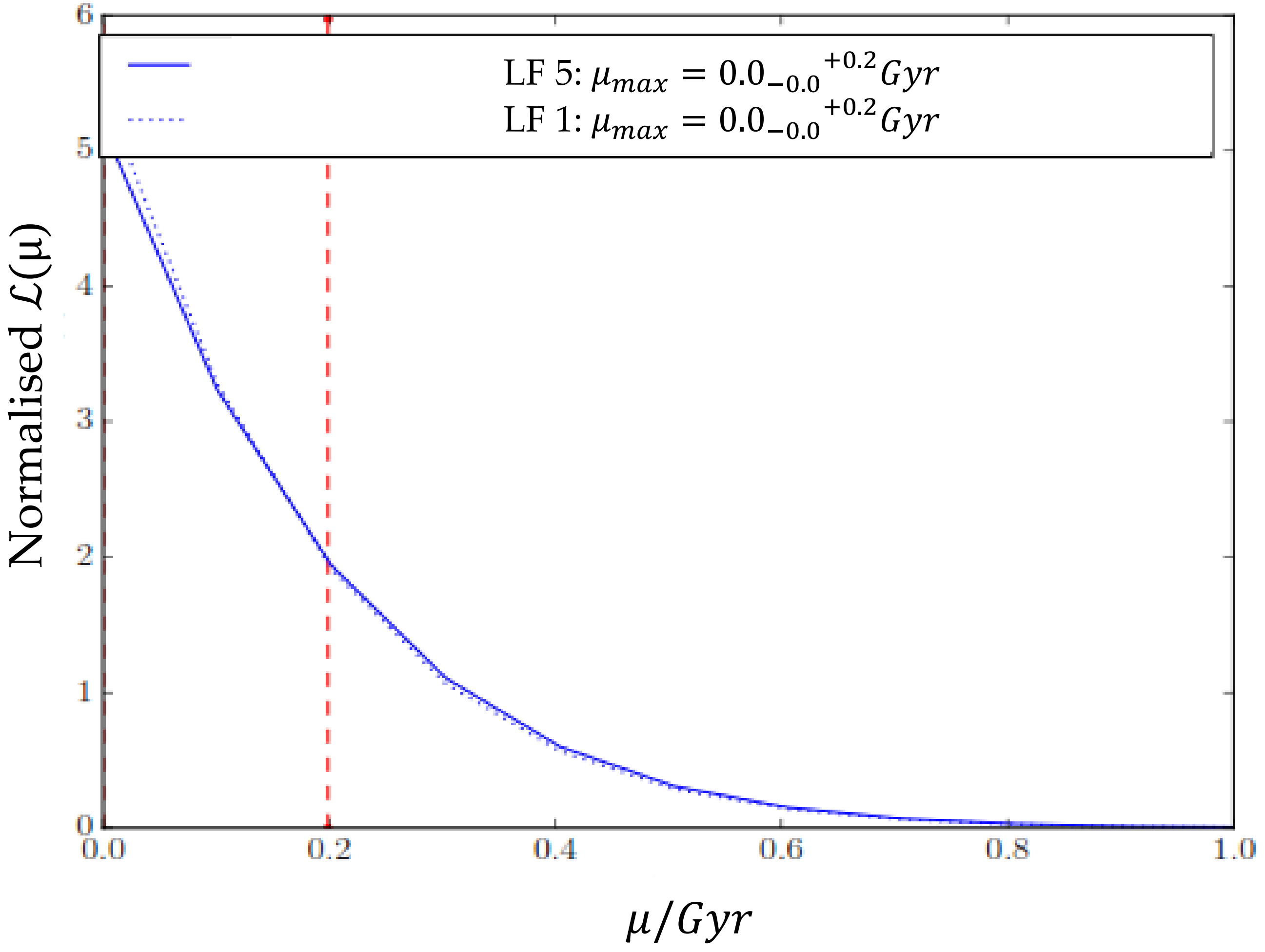
Assume the reason we failed to see afterglows for “dark” GRBs, is because they were at high-z. Consider *extreme* case;
→ Randomly assign z to dark GRBs from U(2 < z < 4) distribution.

Results:

- Constant τ delay (delay ~ δ-function)

$$\tau = 0.0_{-0.0}{}^{+0.02}Gyr$$

- delay ~ $N(\mu, \sigma = 1Gyr)$



Scenario IV: The sample is pure, but the GRBs themselves are subject to Malmquist bias

Assume that in order to observe a GRB, it must be at low redshift; *Extreme* case:
→ Randomly assign z to *all* unknown redshift GRBs from U(z < 1) distribution.

Results:

- Constant τ delay (delay ~ δ-function)

N/A: intrinsic limit on maximum delay time.

- delay ~ $N(\mu, \sigma = 1Gyr)$