

Short GRBs and Mergers: Astrophysical constraints on a BH-NS and NS-NS origin

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[V. Kalogera, C. Kim, K. Belczynski, T. Fragos]

APS, April 16, 2007

Outline

- Short GRBs : A Review
 - Intersection with LIGO
- Population synthesis predictions
 - Milky Way
 - Universe
- Could short GRBs be mergers?
 - Detection rates consistent?
 - Redshift distribution, hosts?

astro-ph/0610076; 0609465

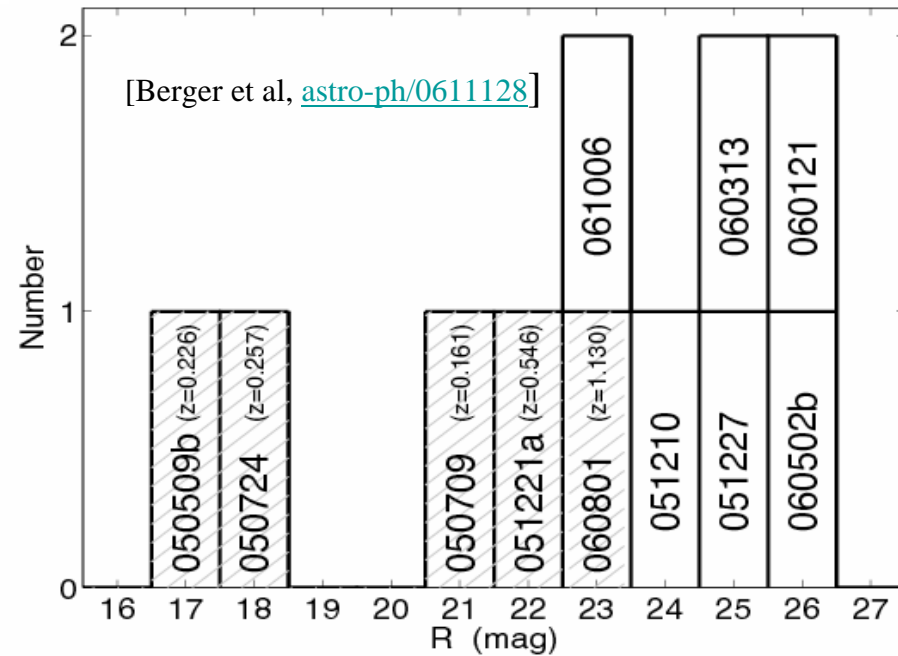
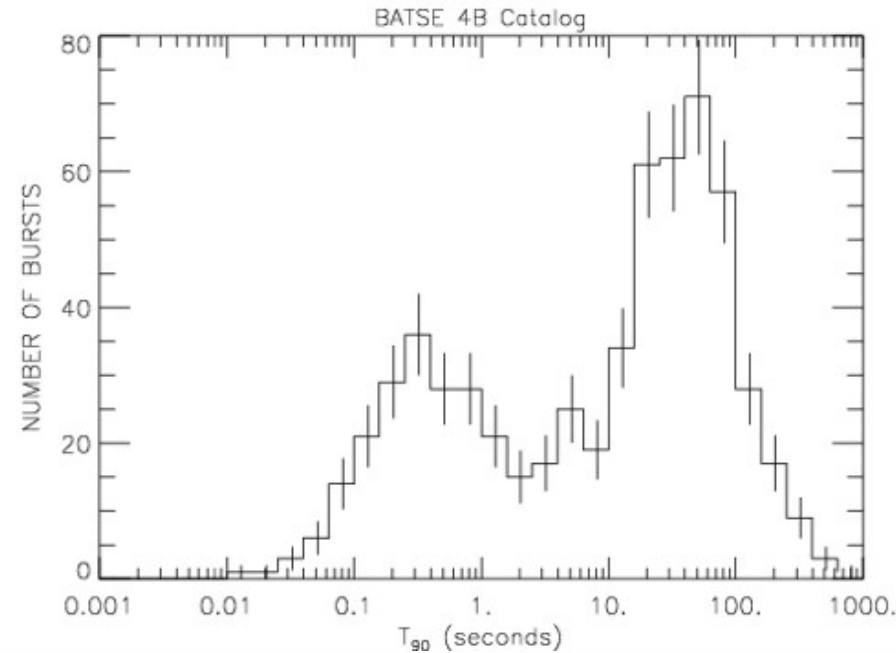
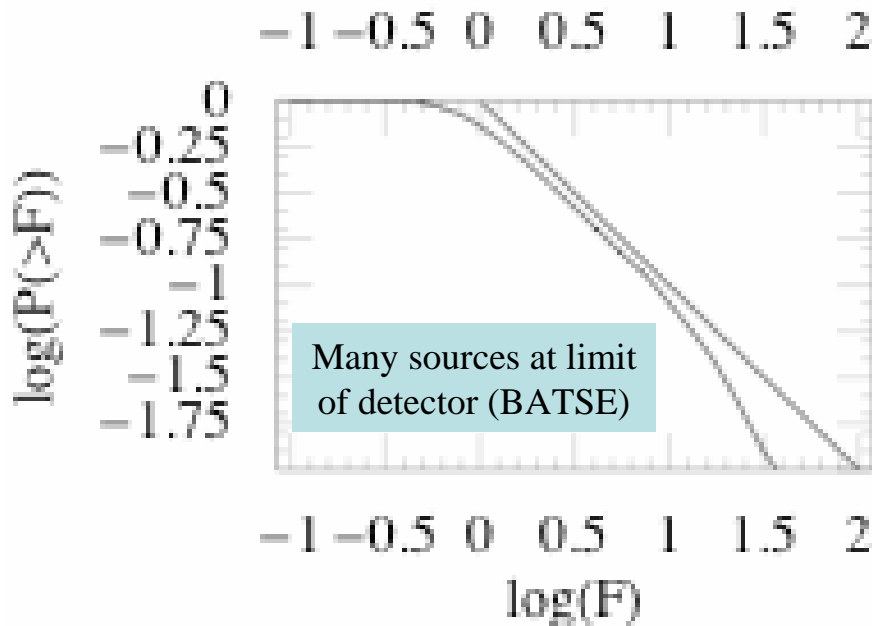
Short GRBs: A Review

Short GRBs

- One of two (?) classes
- Cosmological distances
 - Low redshift **selection effect?**
- Hard: often peaks out of band
- Flux power law

$$dP/dL \sim L^{-2}$$

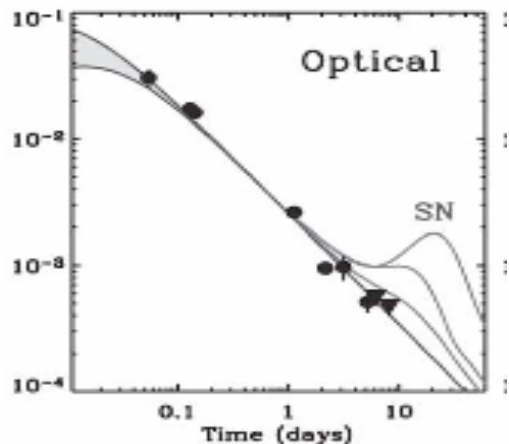
--> **most** (probably) **unseen**



Short GRBs: A Review

Merger motivation?

- No SN structure in afterglow



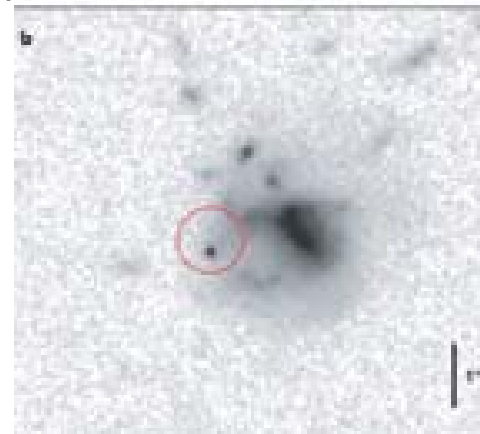
GRB 051221 (Soderberg et al 2006)

- In both **old**, young galaxies

Selected short GRBs			
GRB	Host	L/L_*	SFR M_{\odot}/yr
050509b	E	3	< 0.1
050709b	Sb/Sc	0.1	0.2
050724	E	1.5	< 0.03
051221	S	0.3	1.4
060502	E	1.6	0.6

(Nakar, 2006 : Table 3)

- Occasional host **offsets**



GRB 050709 (Fox et al Nature 437 845)

- Young NSs are *some* (known)

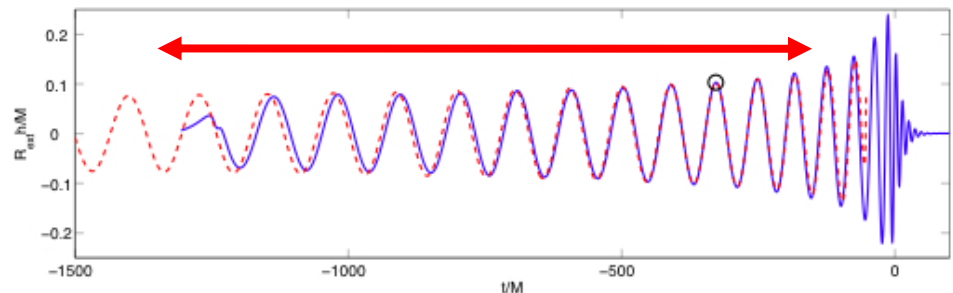
Energetics suggest not **all**

Short GRBs: Review

- Gravitational waves essential

- Central engine? : Certainty requires gravitational waves

- See inspiral
- Check masses



- Coincident observation powerful

[e.g., merger-burst delay time; opening angle constraints; masses; NS radius; ...]

- Nondetection still useful

[e.g., find fraction of short bursts from NS alone nearby]

- Short GRBs : potentially powerful tool?

- Constrain channels: Short GRBs $\gg 10/\text{yr}$; $\#(\text{NS-NS})=4$

Popsyn and Milky Way

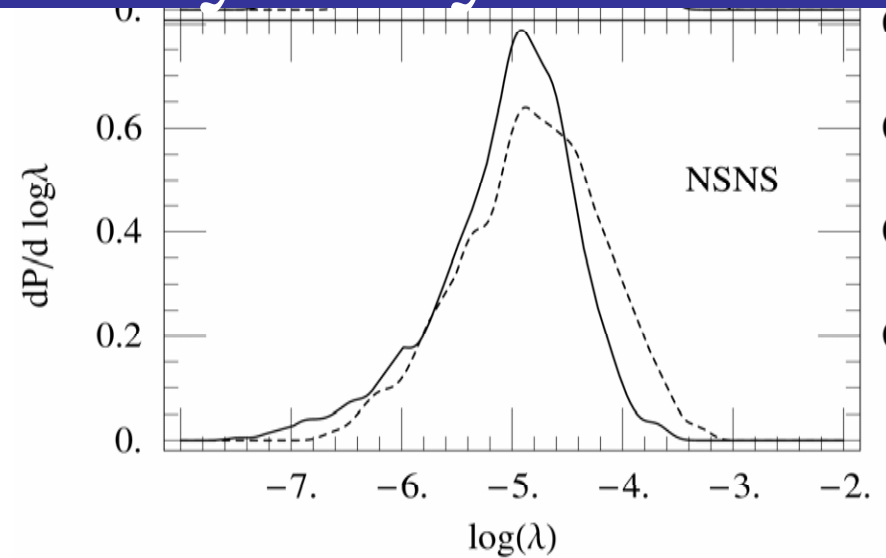
Population synthesis

- *Controlled* uncertainties
--> wide but *limited* range of predictions

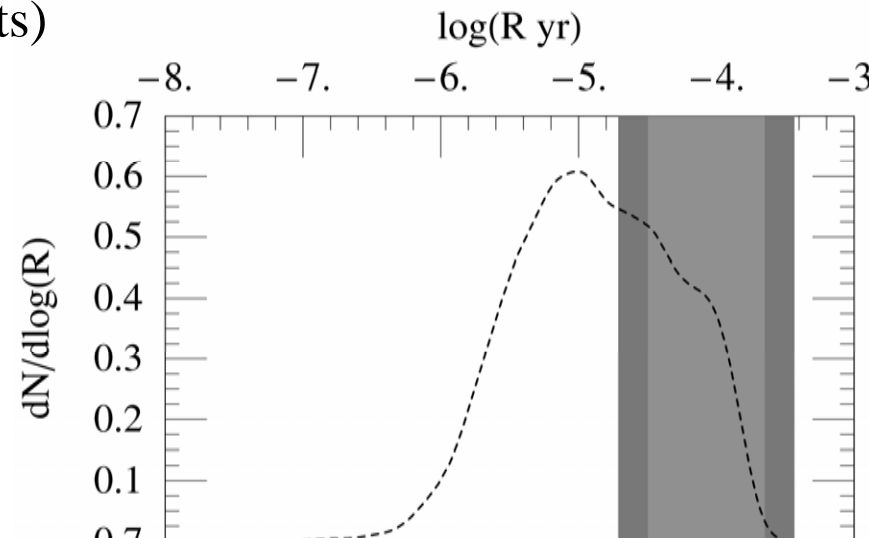
Milky Way: A test

- ~ steady state system (average merger rate)
- Compare to observations (several Kim et al)
(NS-NS binaries + **known** selection effects)
 - Observation: shaded
 - Theory: dotted curve
 - Systematics : dark shaded
- **Limited** set (9%) consistent
 - Complicated, extended 7d volume
 - Lots of physics can be mined

[astro-ph/0610076](https://arxiv.org/abs/astro-ph/0610076)



More binaries/mass

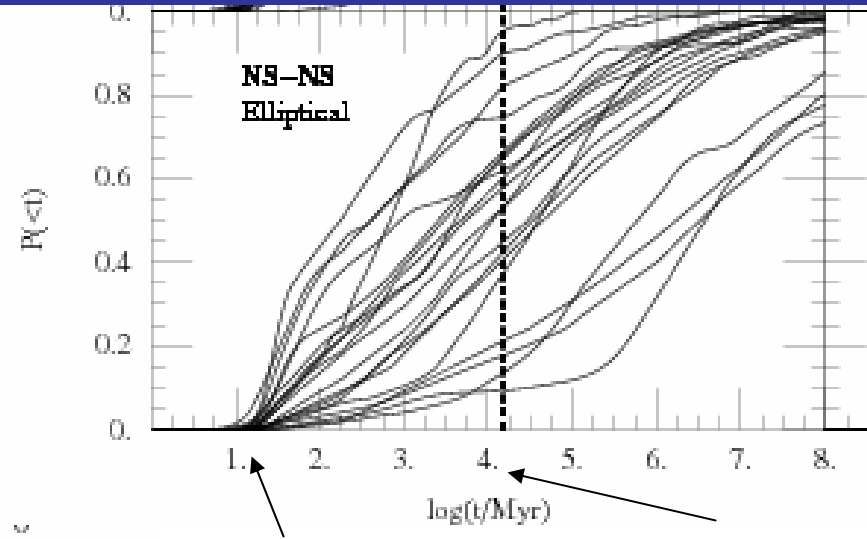
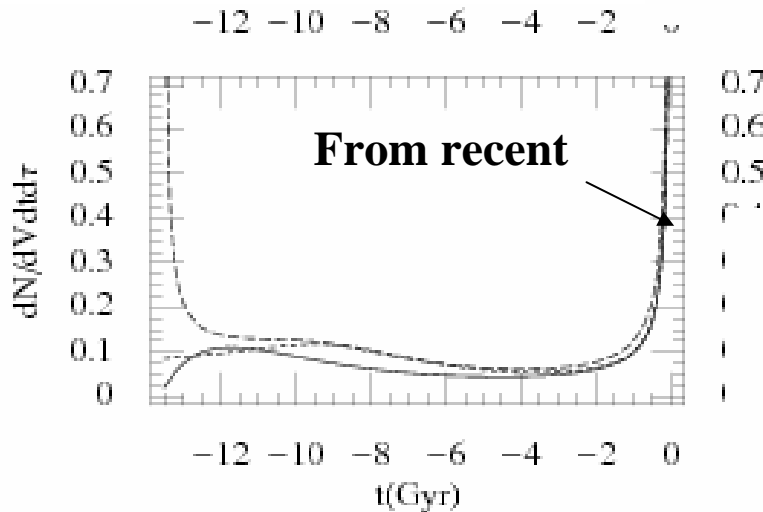


Popsyn and Universe

Inhomogeneous universe: The reality

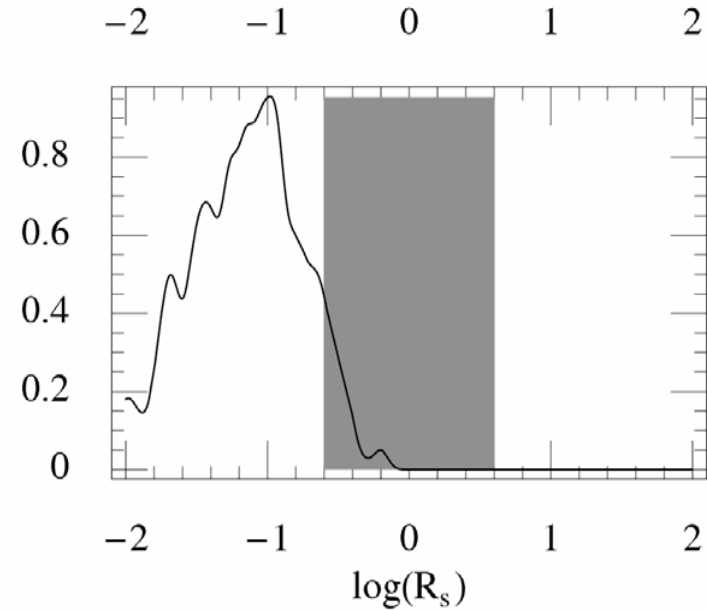
- Time-dependent, multicomponent SFR
- Use delay time distribution ($dP/dt \sim 1/t$)
- Long delays matter

Plot:
Birth time for
present-day mergers



Merging after 2nd
supernova

Merging after
10 Gyr



Sample multicomponent predictions:

- Merger rate in spirals
(NS-NS)

Can short GRBs be mergers?

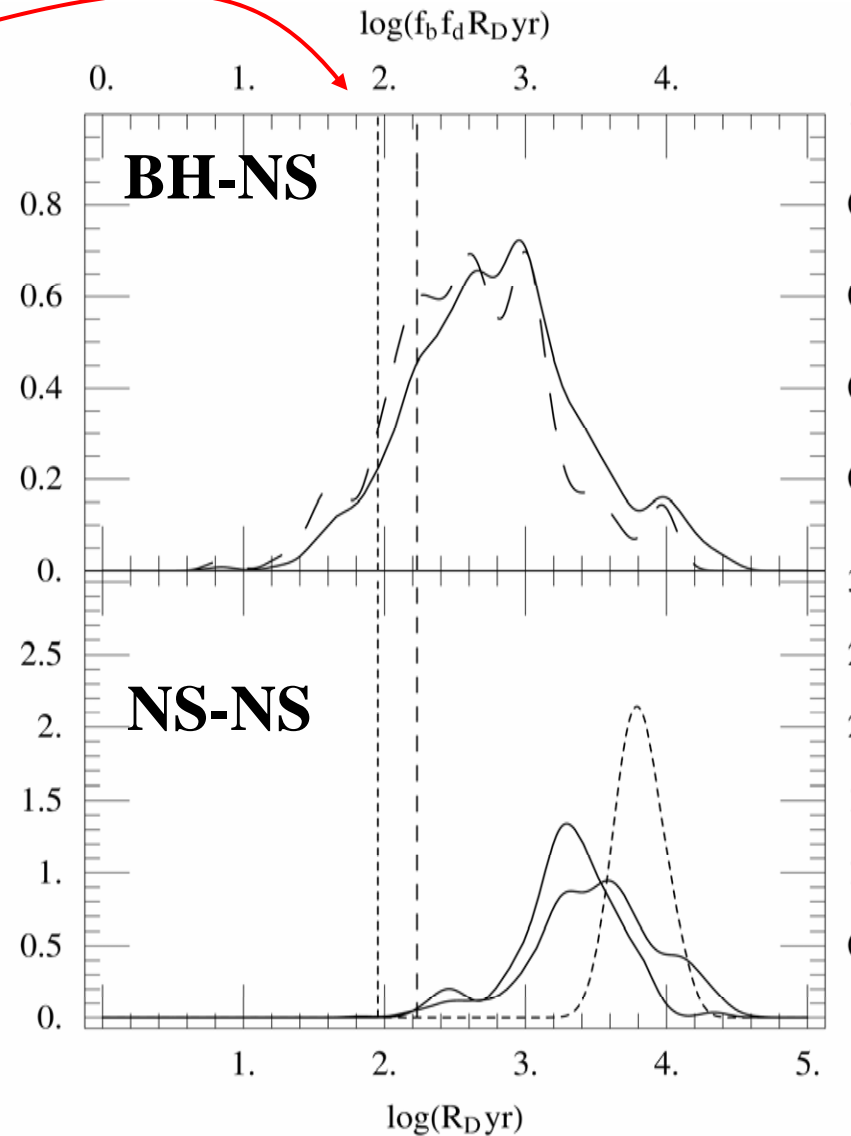
Test 1: Are there enough mergers?

... so far, usually yes:

- Plot: All-sky detection rate vs predictions, if
 - + No bursts fainter than seen
 - + All sky coverage & no beaming

... but

surprising if detectors
“fine-tuned”
many *should be* missed

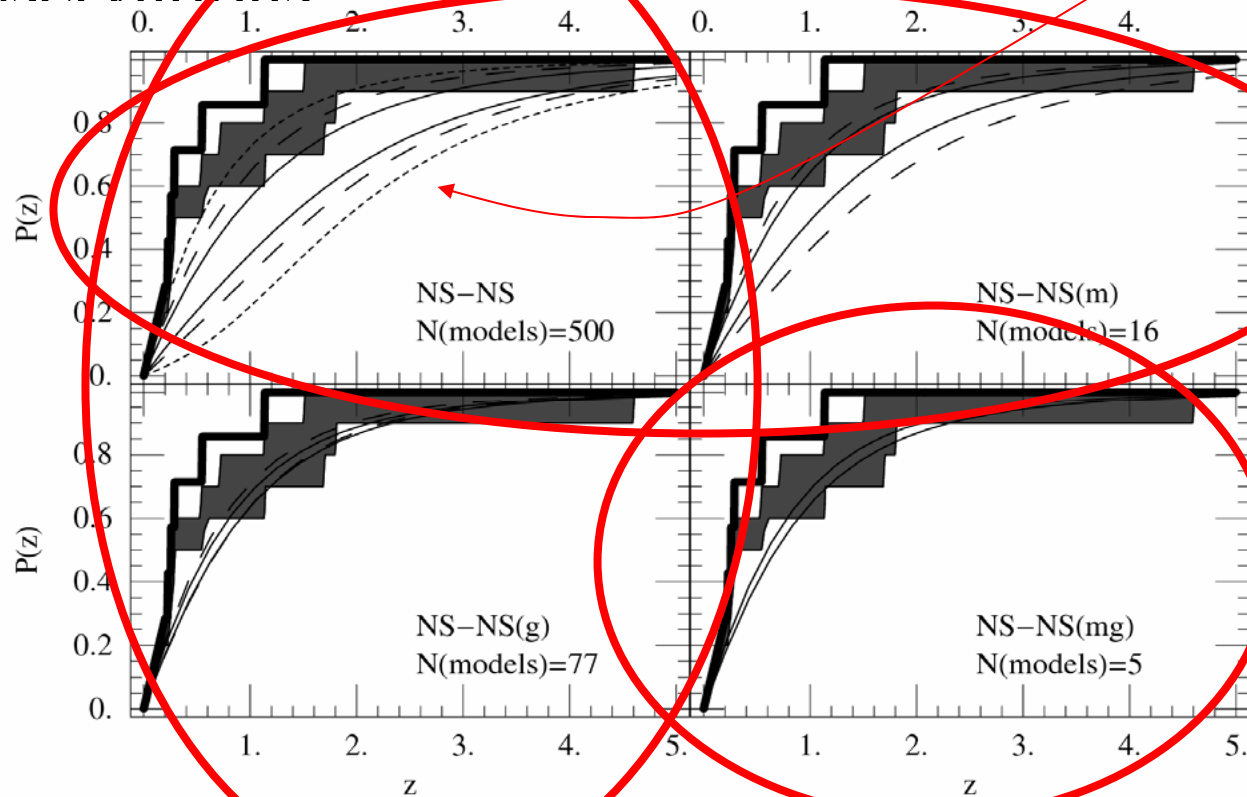
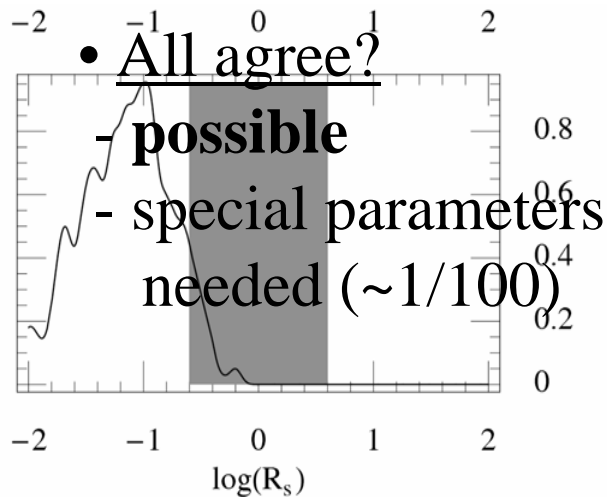


Can short GRBs be mergers?

Test 2: Are they distributed consistently in redshift? (NS-NS shown)

- Predictions & observations
- Matching redshifts
- Observed NS-NS (Milky Way)

Key
 Solid: 25-75%
 Dashed: 10-90%
 Dotted: 1%-99%



O'Shaughnessy et al (in prep)

Can short GRBs be mergers?

NS-NS?:

- Physical interpretation

- Observations : GRBs

- Dominated by **recent** events

- Expect:

- Recent spirals dominate or
- **or** Ellipticals dominate, with long delays

Plot: f_s : fraction of mergers in spirals ($z=0$)

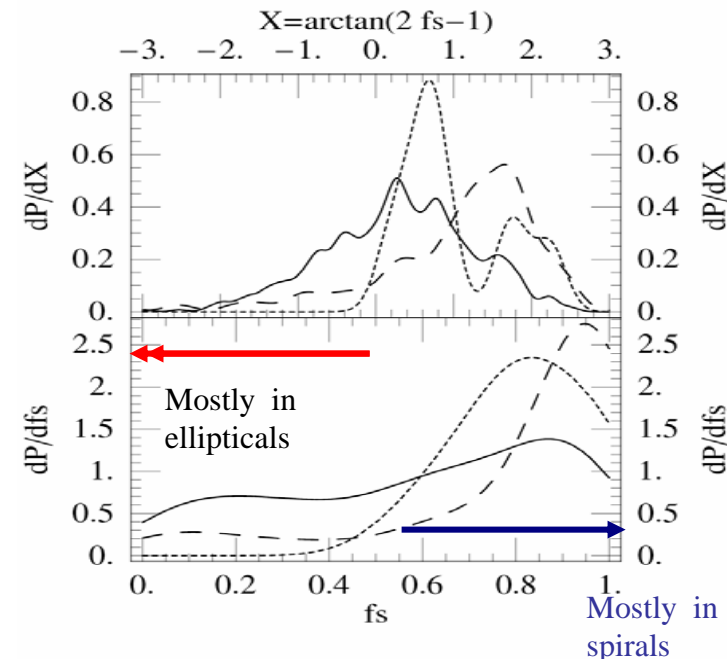
- **Consistent** so far

- Observations: Galactic NS-NS

- High merger rate

- Expect

- High merger rate in spirals



Conclusions

- Useful comparison method **despite** large uncertainties
- Preliminary results
 - Via comparing to pulsar binaries in Milky Way
 - Via comparing to short GRBs?
 - Conventional popsyn **works** : weak constraints-> standard model ok
 - Expect GRBs in **either host** : spirals form stars now
 - Spirals now favored; may change with new redshifts!
 - Short GRBs = NS-NS? **hard** : few consistent ellipticals
 - Short GRBs = BH-NS? **easier** : fewer observations
- Observational recommendations

Supporting slides follow

- LIGO and short GRBs : Nondetection still useful
- Swift detection biases

Nondetection still useful

SGRs are GRBs

- Known galactic/nearby source : SGR 1806
- *Unknown* (small?) contribution to short GRB rate

LIGO can “distinguish”:

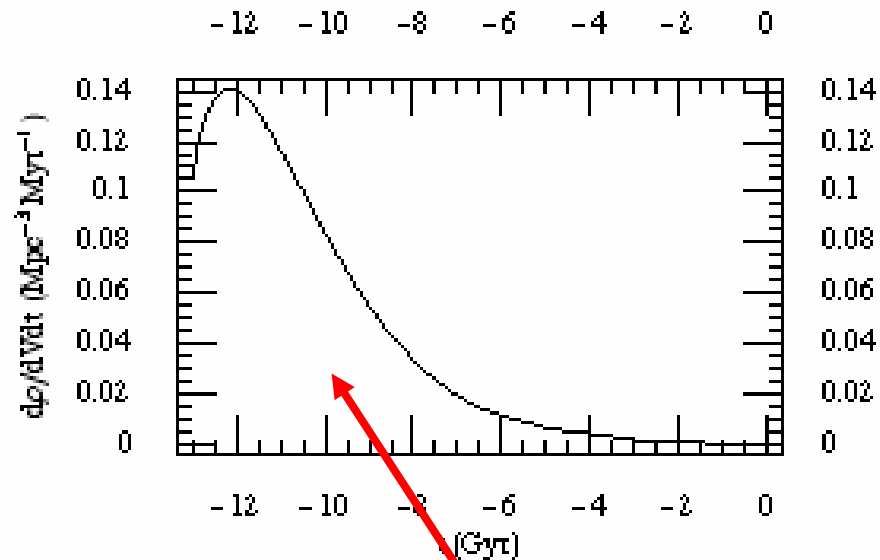
- Short GRB nearby (e.g., <15 Mpc)
 - Merger : Detectable
 - SGR : Marginally/not detectable
- **Application**
 - **Assist** host galaxy searches (i.e., minimum distance to merger)
 - **estimate** SGR contribution

Importance of early SFR

Long delays allow mergers in ellipticals now

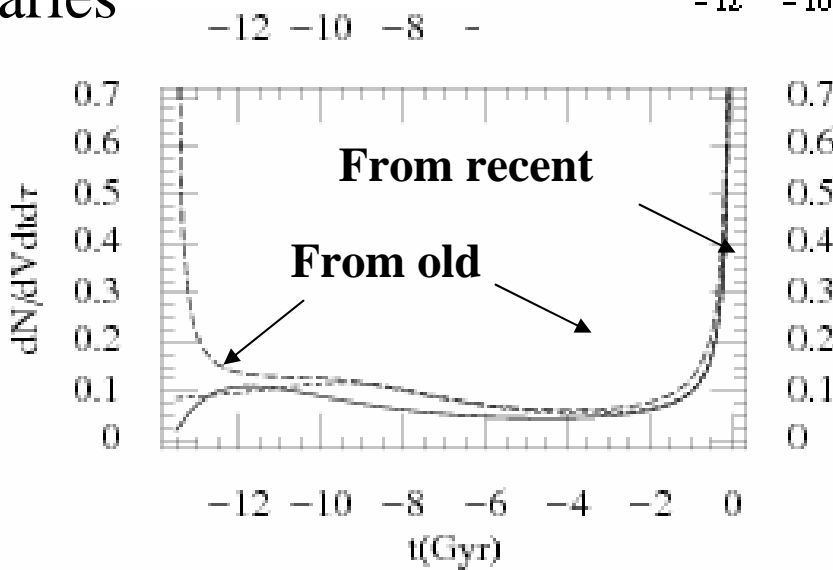
- Merger rate from starburst: $R \sim dN/dt \sim 1/t$
- SFR higher in past:

- Result:
 - Many mergers *now* occur in ancient binaries



Nagamine et al [astro-ph/0603257](https://arxiv.org/abs/astro-ph/0603257)

ancient SFR
= **ellipticals**
(mergers, ...)



Plot:

Birth time for present-day mergers

Outline

- Predictions and Constraints: Milky Way
- Why Ellipticals Matter
- Predictions and Constraints Revisited
- GRBs
 - Review + the short GRB merger model
 - Short GRB observations, the long-delay mystery, and selection effects
 - Detection rates versus L_{\min}
 - Predictions versus observations:
 - If short GRB = BH-NS
 - If short GRB = NS-NS
 - Gravitational waves?
- Conclusions

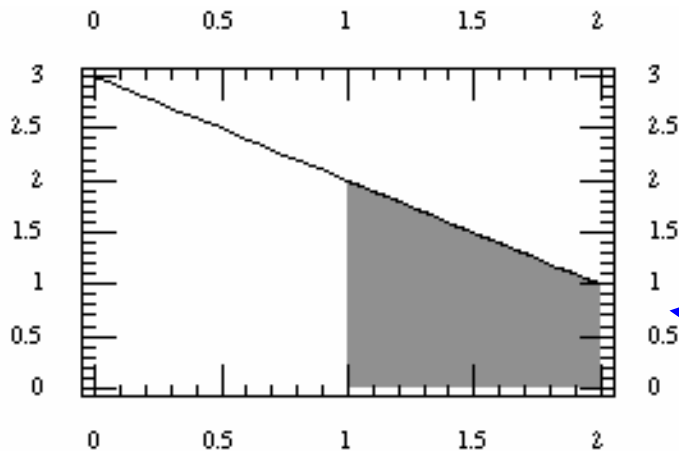
Observables: Detection rate?

Binary pulsars

- Many (isolated) observed
- **Minimum luminosity** ~ known
- Observed number
--> **rate** (+ 'small' error)

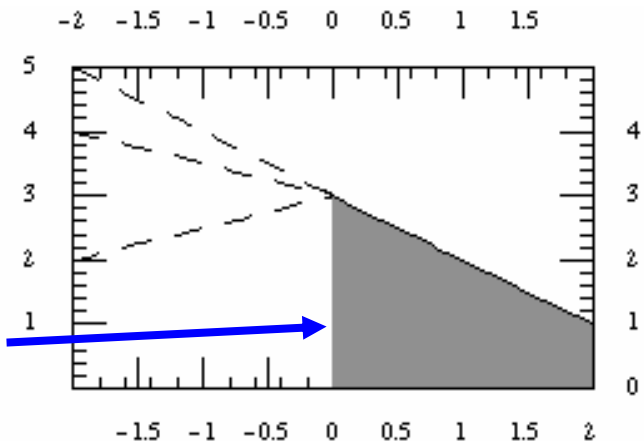
Short GRBs

- Few observations
- **Minimum luminosity** ~ **unknown**
- Observed number
--> **rate upper bound**



Plots:
Cartoon on L_{\min}

observed



Conclusion:

The number (rate) of short GRB observations is a weak constraint on models

Merger predictions \leftrightarrow short GRBs?

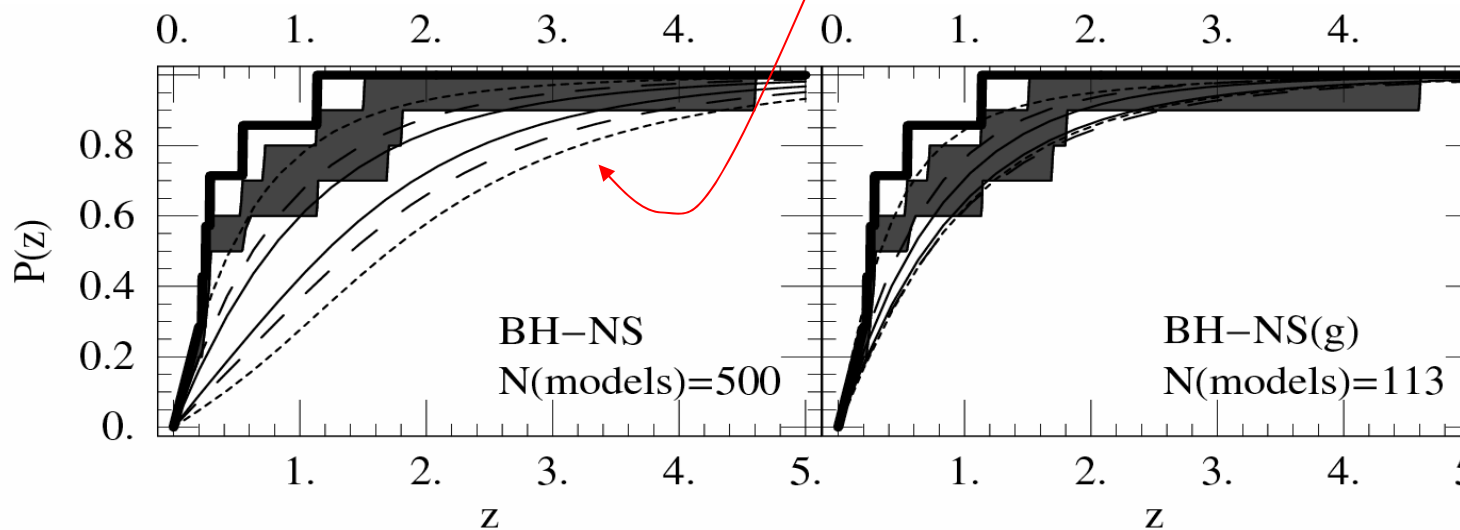
BH-NS?

- Predictions:
 - 500 pairs of simulations
 - Range of redshift distributions

- Observations:

- Solid: certain
- Shaded: possible

Key
Solid: 25-75%
Dashed: 10-90%
Dotted: 1%-99%

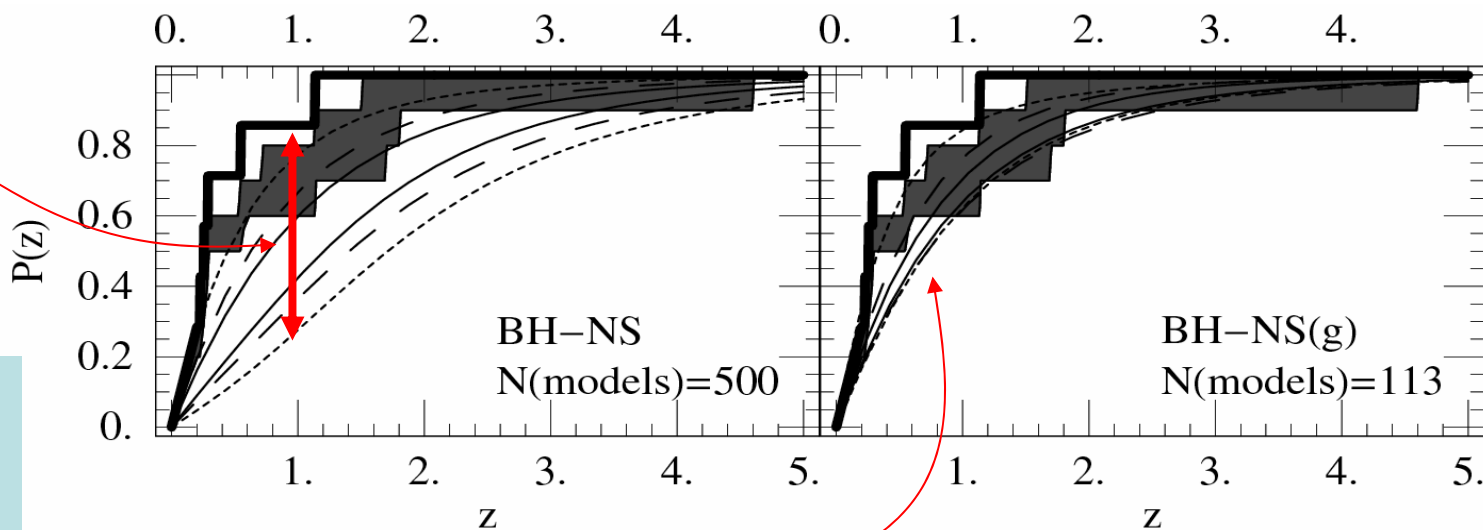


O'Shaughnessy et al (in prep)

Merger predictions \leftrightarrow short GRBs?

BH-NS?

- Predictions that agree?
 - Compare *cumulative distributions*:
 - maximum difference < 0.48 everywhere [95% Komogorov-Smirnov given GRBs]
 - Compare to **well-known** GRB redshifts since 2005 [consistent selection effects]
 - dominated by low redshift



Result:
Distributions
which agree
= mostly
at *low* redshift

O'Shaughnessy et al (in prep)

Merger predictions \leftrightarrow short GRBs?

BH-NS?:

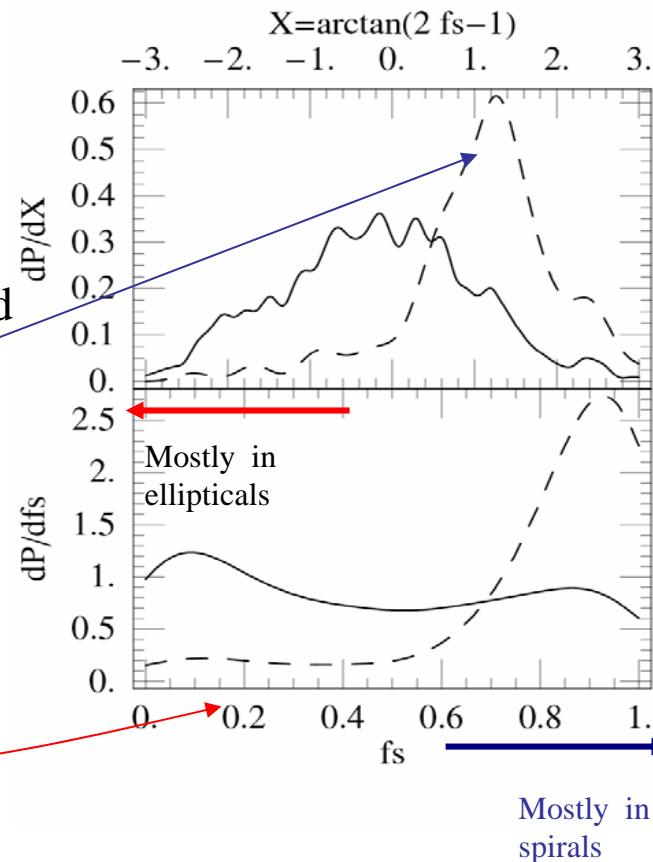
- Physical interpretation

- Observations : Dominated by **recent** events

- Expect:

- Most mergers occur in spirals (=recent SFR) and High rate (per unit mass) forming in spirals
- **or** Most mergers occur in ellipticals (=old SFR) and High rate (per unit mass) forming in elliptical and **Extremely** prolonged delay between formation and merger (**RARE**)

Plot: f_s : fraction of mergers in spirals ($z=0$)



O'Shaughnessy et al (in prep)

Conclusions

Future (model) directions:

- More comparisons

- Milky Way

- Pulsar masses
- Binary **parameters** (orbits!)
- Supernova kick consistency?

- Extragalactic

- Supernova rates

- Broader model space

- Polar kicks?

- Different maximum NS mass

- [**important**: BH-NS merger rate sensitive to it!]

- Different accretion physics

Goal:

- show predictions *robust* to physics changes
- if changes matter, understand why
(and devise tests to constrain physics)

Some examples:
Belczynski et al. (in prep)

