Review of SHORT GRBs

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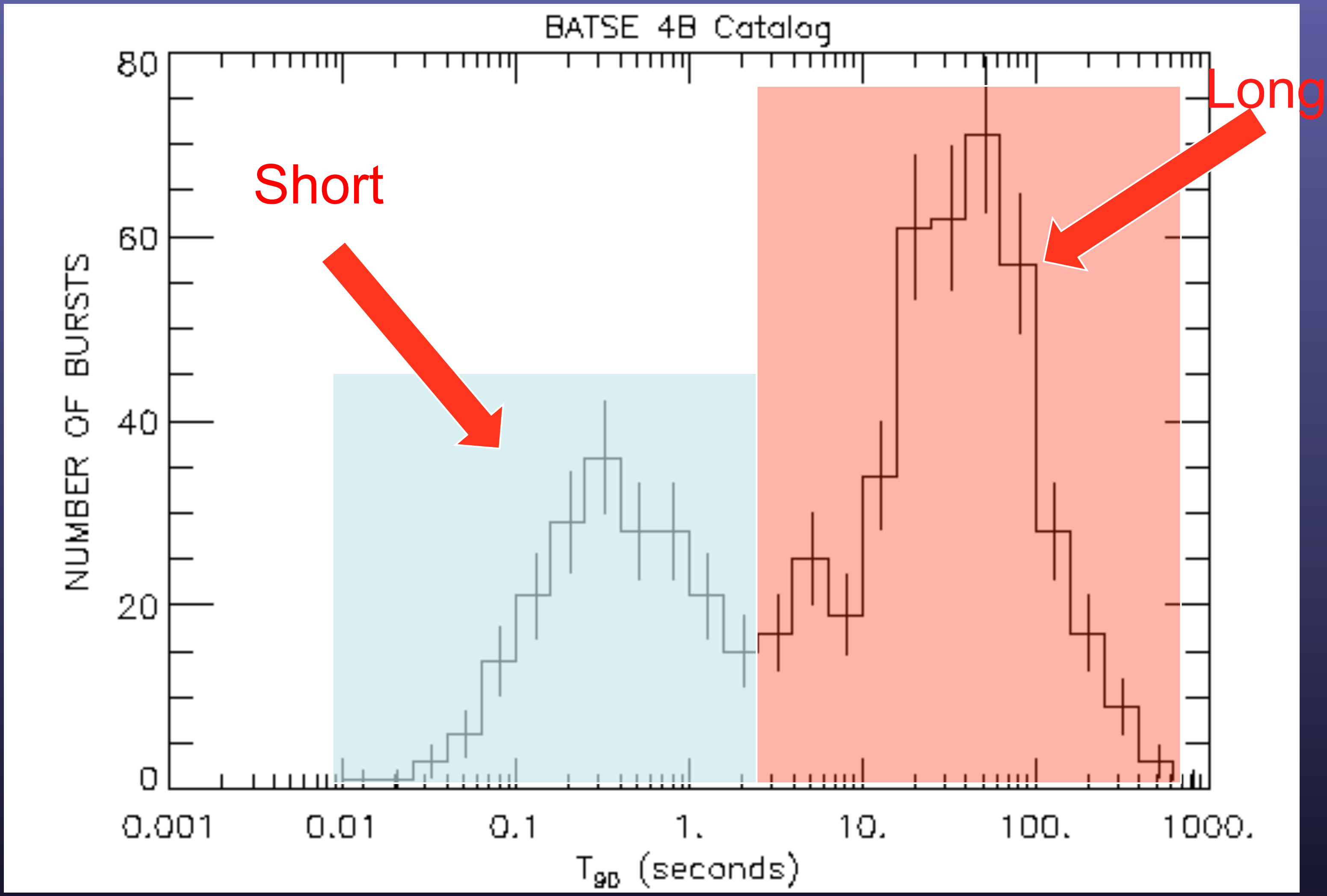
OUTLINE

- Observations of Short GRBS:
  - 'Standard' prompt emission
  - 'Other' emission
  - Afterglow emission
  - Host galaxies, z distribution, offsets…
- Progenitor models of Short GRBs:
  - Binary mergers:
    - Numerical simulations of merger
    - Predicted properties (z-distr., offsets, hosts)
    - Magnetar remnant
- Looking at the future: SGRBs & GWs

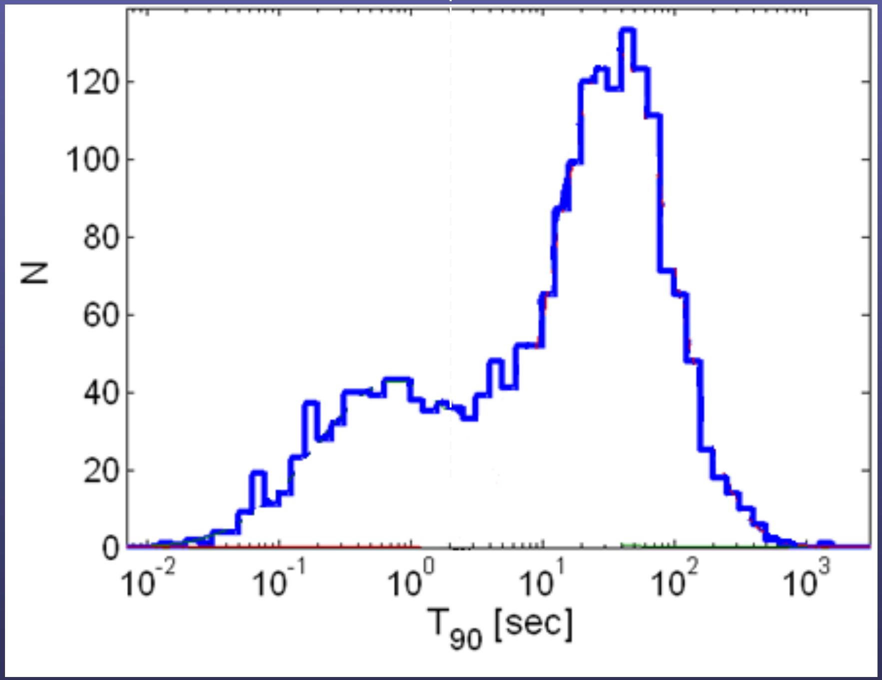
Bimodal distribution of durations



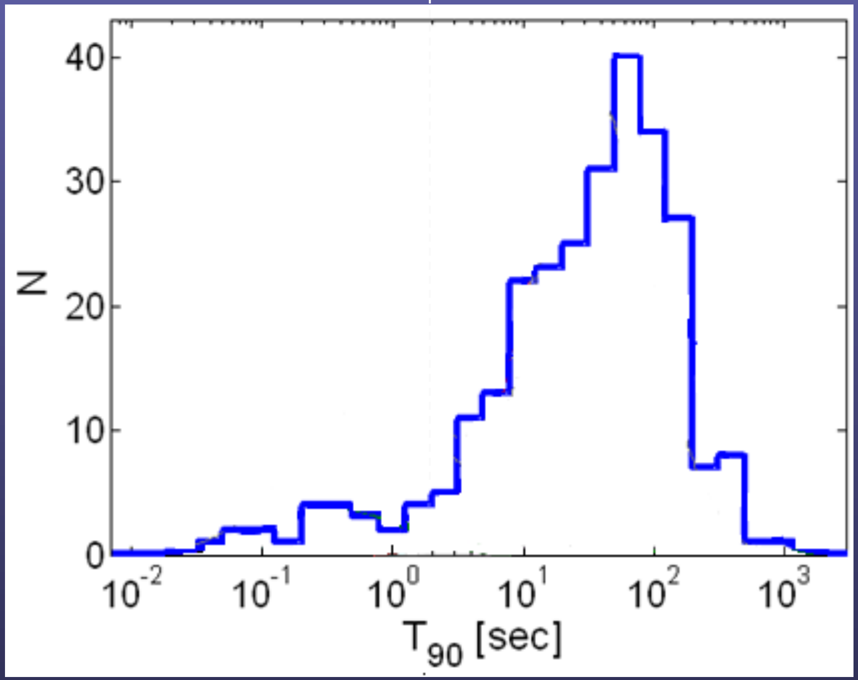
http://www.batse.msfc.nasa.gov/batse/grb/duration/

Note that GRB classification is instrument dependent

BATSE T_{90} (50 - 300 keV)



Swift T_{90} (15 - 350 keV)



[figure credit: E. Nakar]

Threshold duration for the Swift sample estimated to be shorter than for BATSE sample, 0.6-0.7sec instead of 2 sec

[Bromberg et al. 2012]

Another hint at bimodality: *short-hard & long-soft*

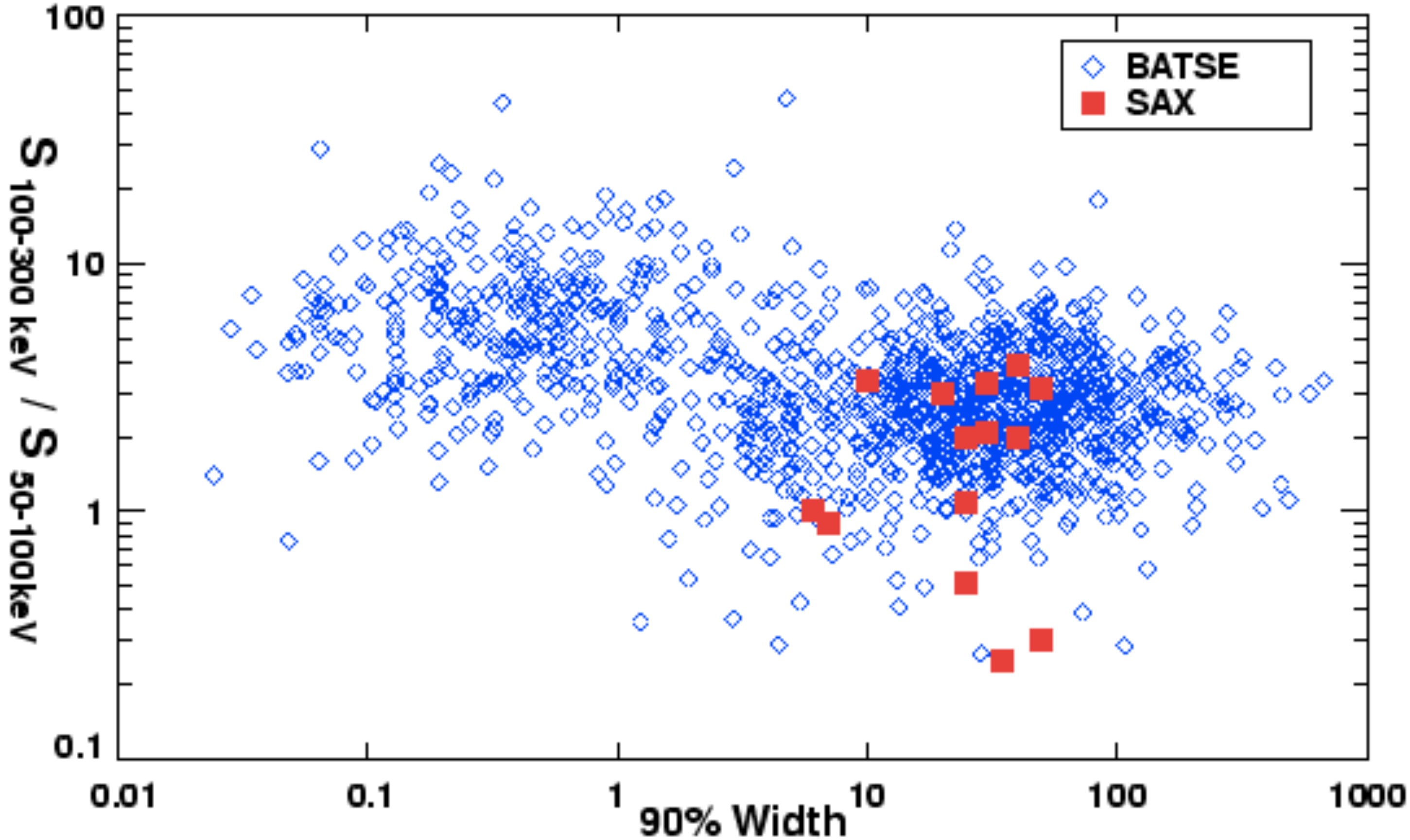
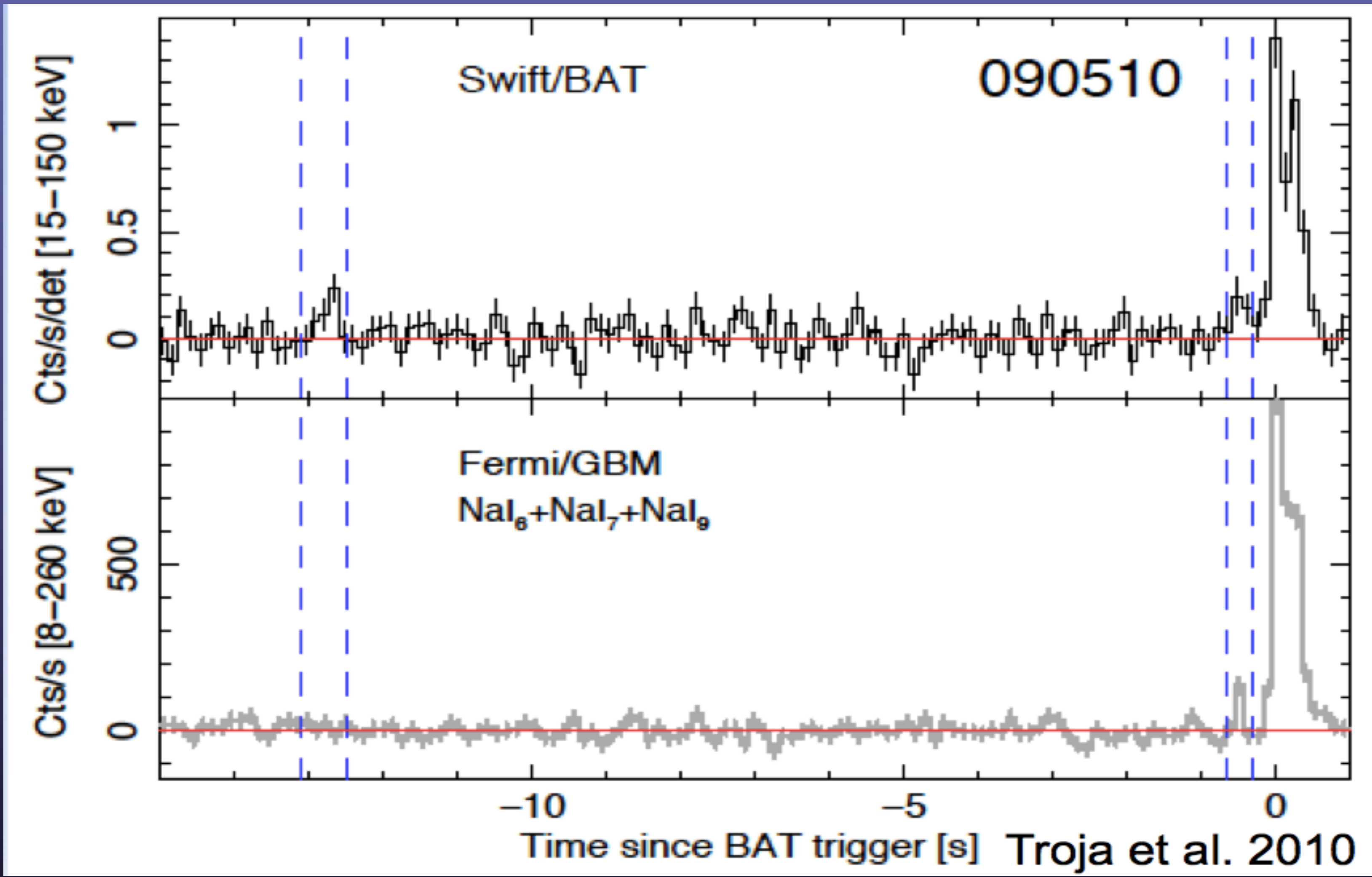


Figure: HR-Duration (T_{90}) Correlation of GRBs. The squares spot the

http://www.batse.msfc.nasa.gov/batse/grb/4bcatalog/

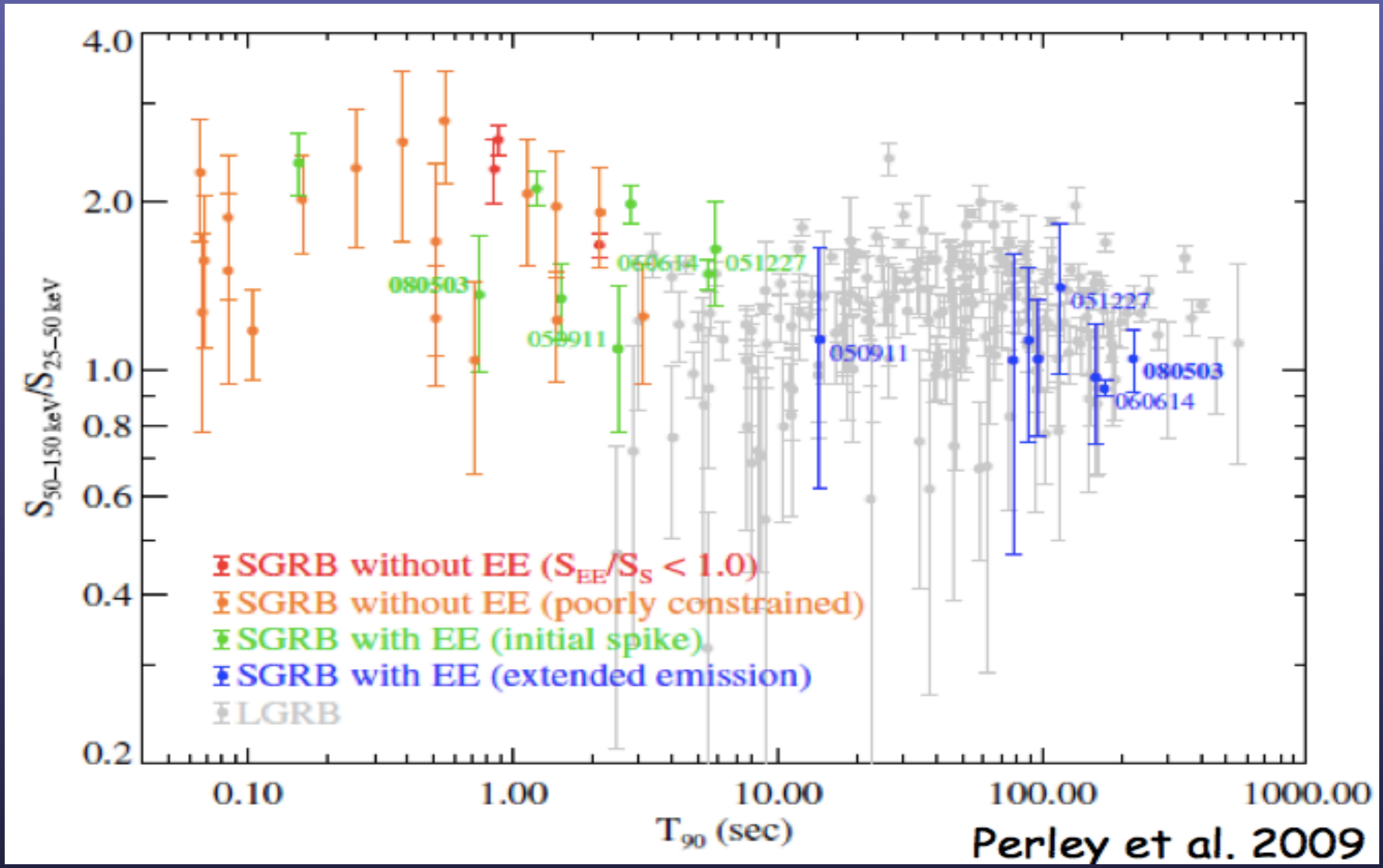
Are short GRBs really short?

PRECURSORS



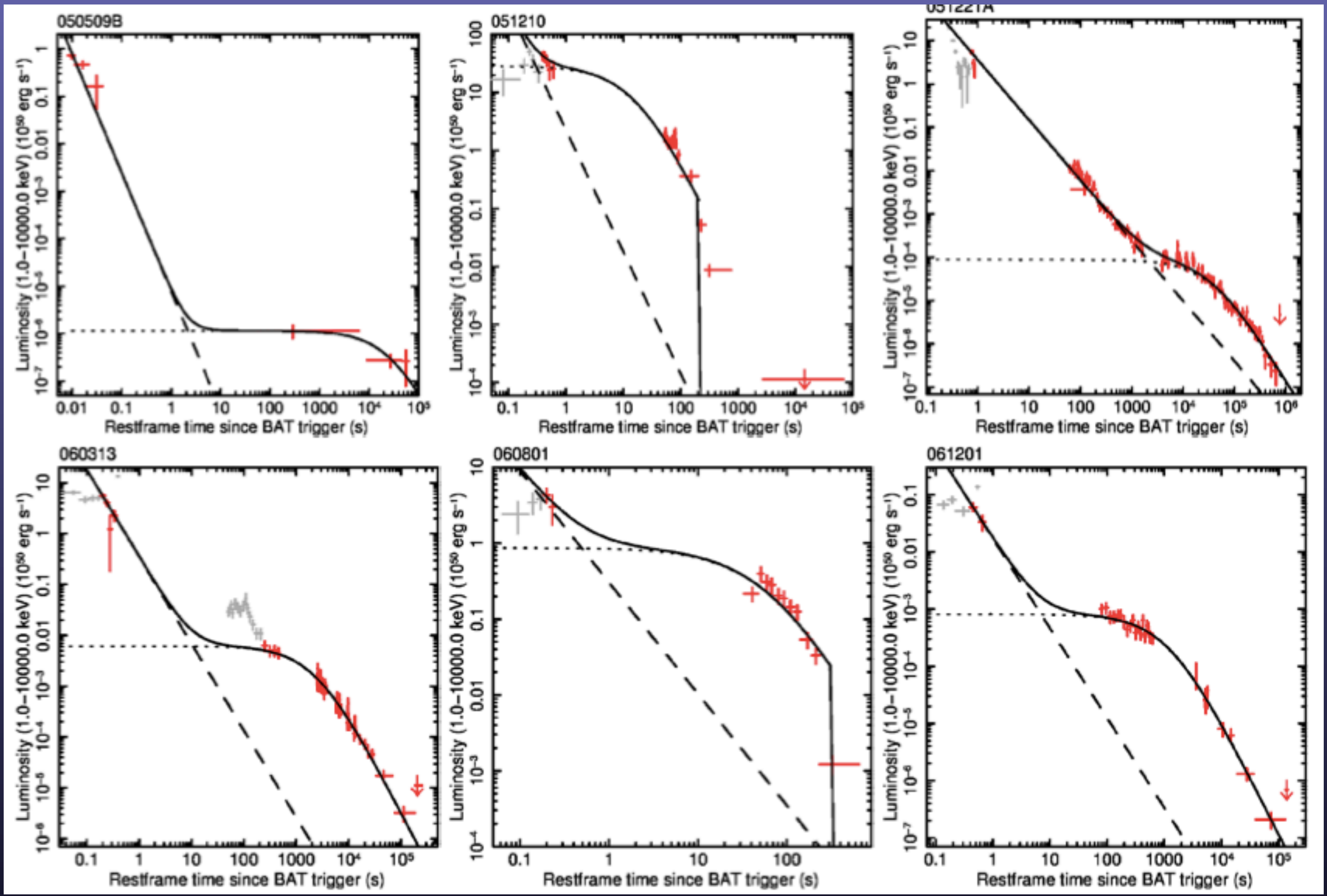
Out of 49 Swift bursts, 5 potential candidates

EXTENDED EMISSION



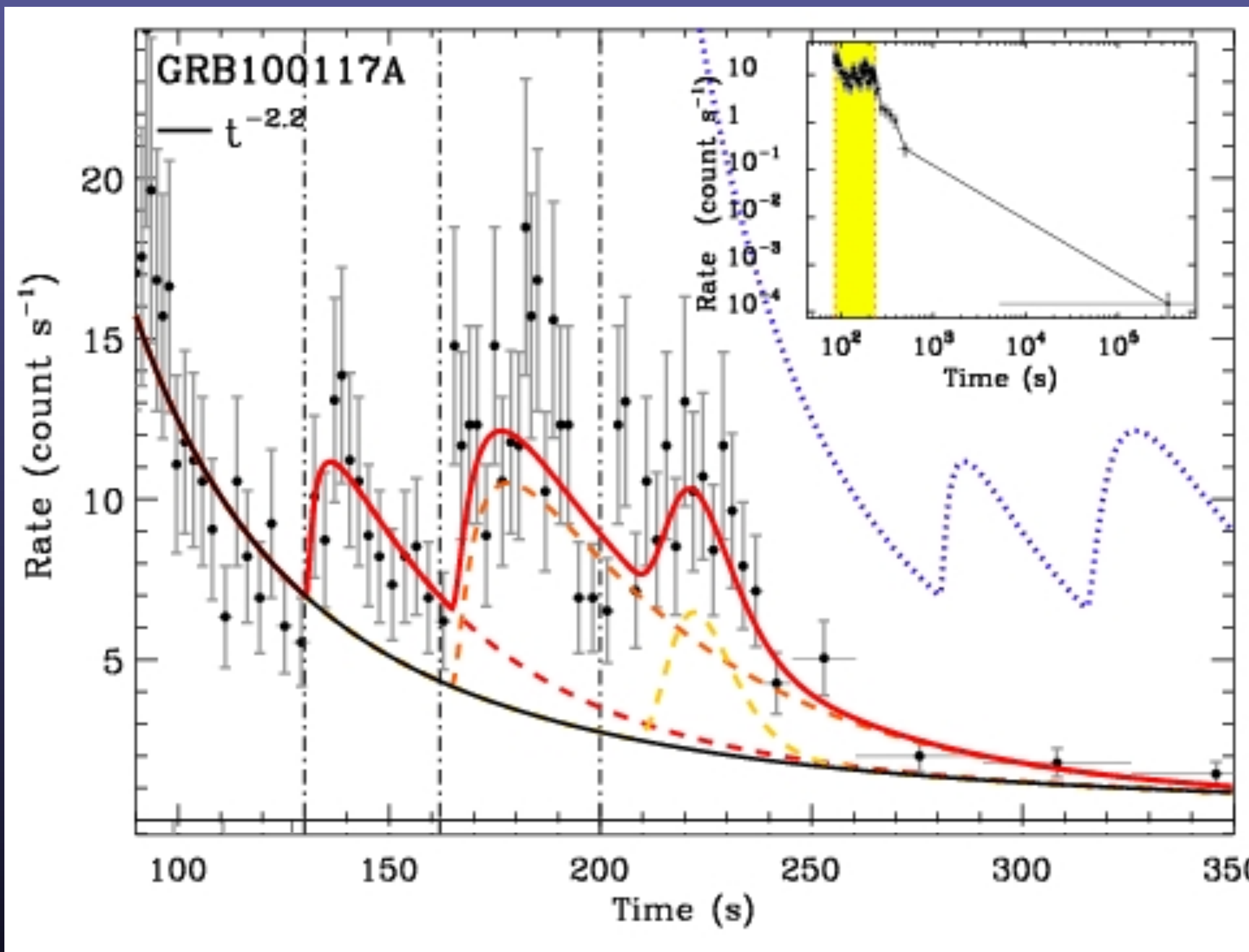
Softer than the prompt emission; lasts about 10-100 sec; sometimes delayed onset; observed in about 25% of events [Norris et al 2010]

PLATEAUS



About half of all Swift detected SGRBs appear to show a plateau phase [Rowlinson et al 2013]

FLARES



Displayed by a number of short GRBs

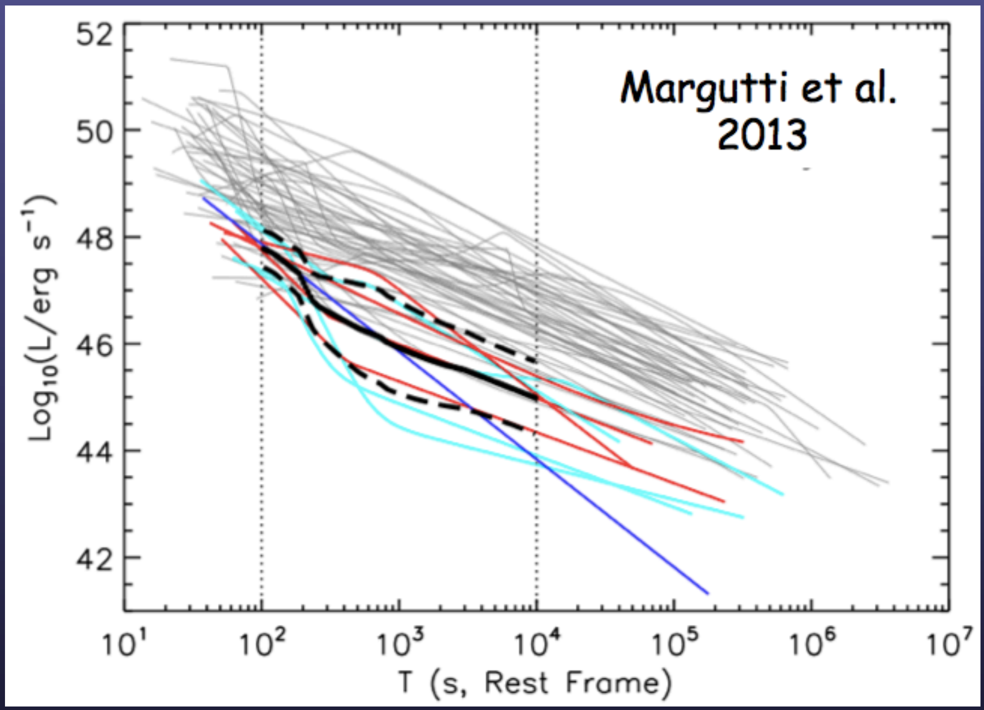
GRB 100117A

[Margutti et al. 2011]

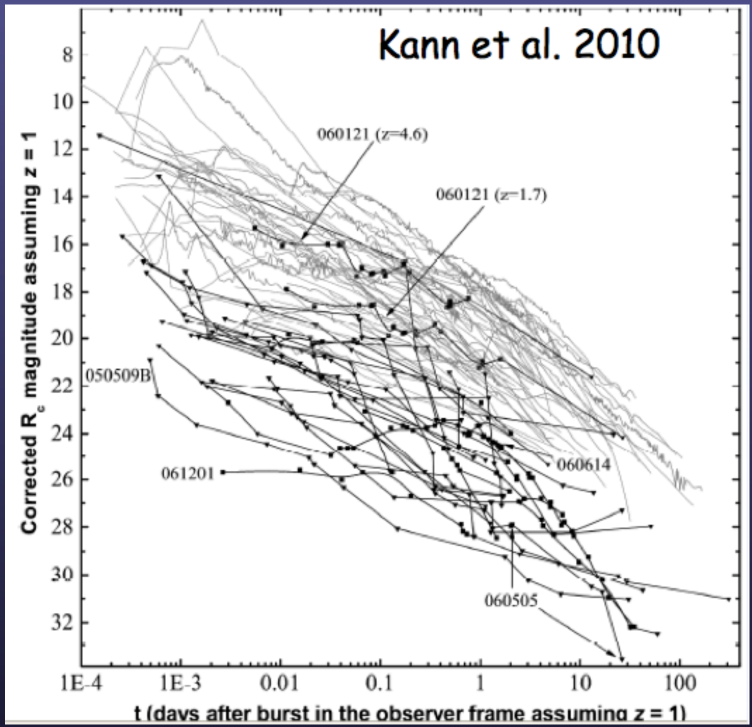
Afterglow properties:

Comparing the short vs the long GRBs

X-rays

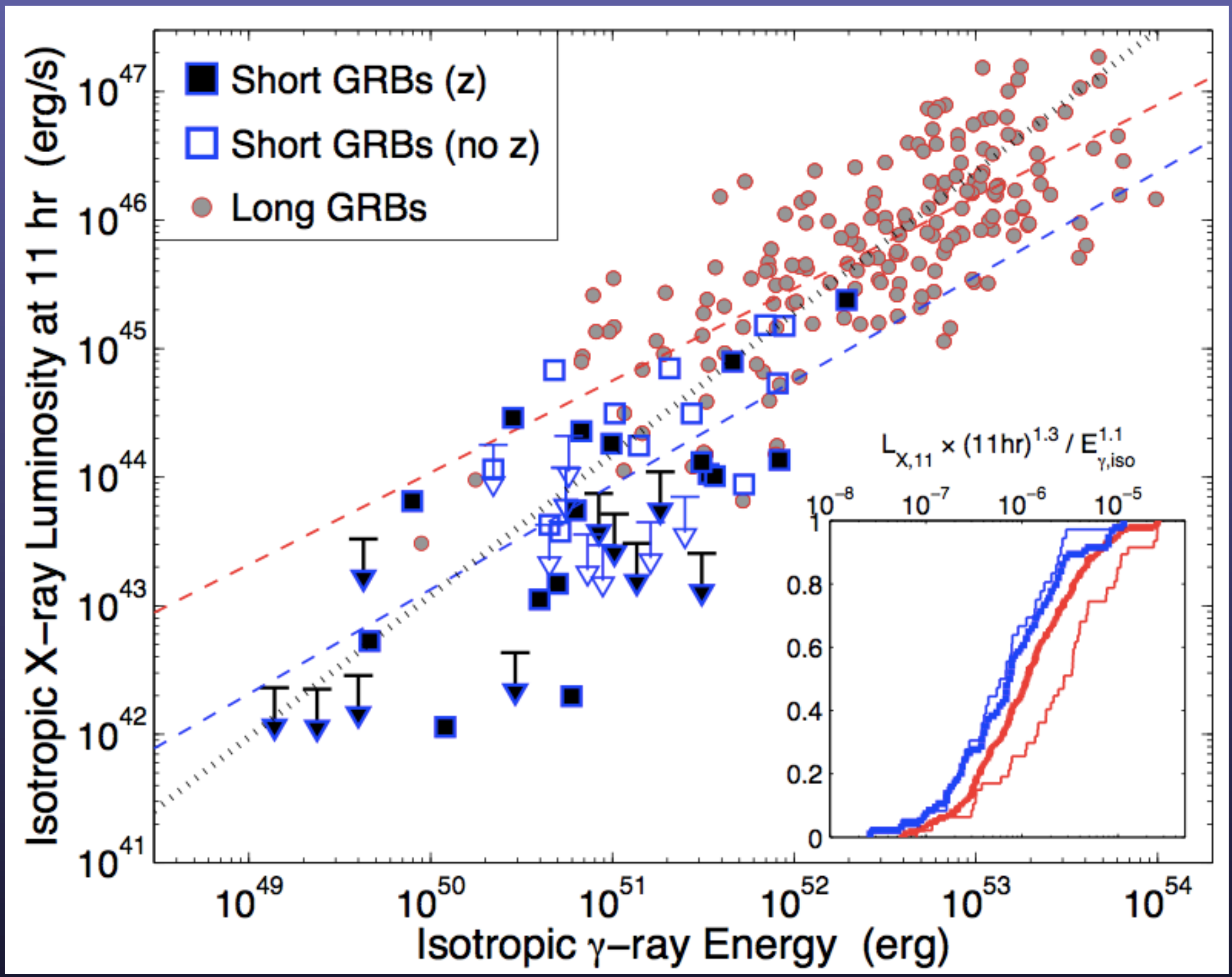


Optical



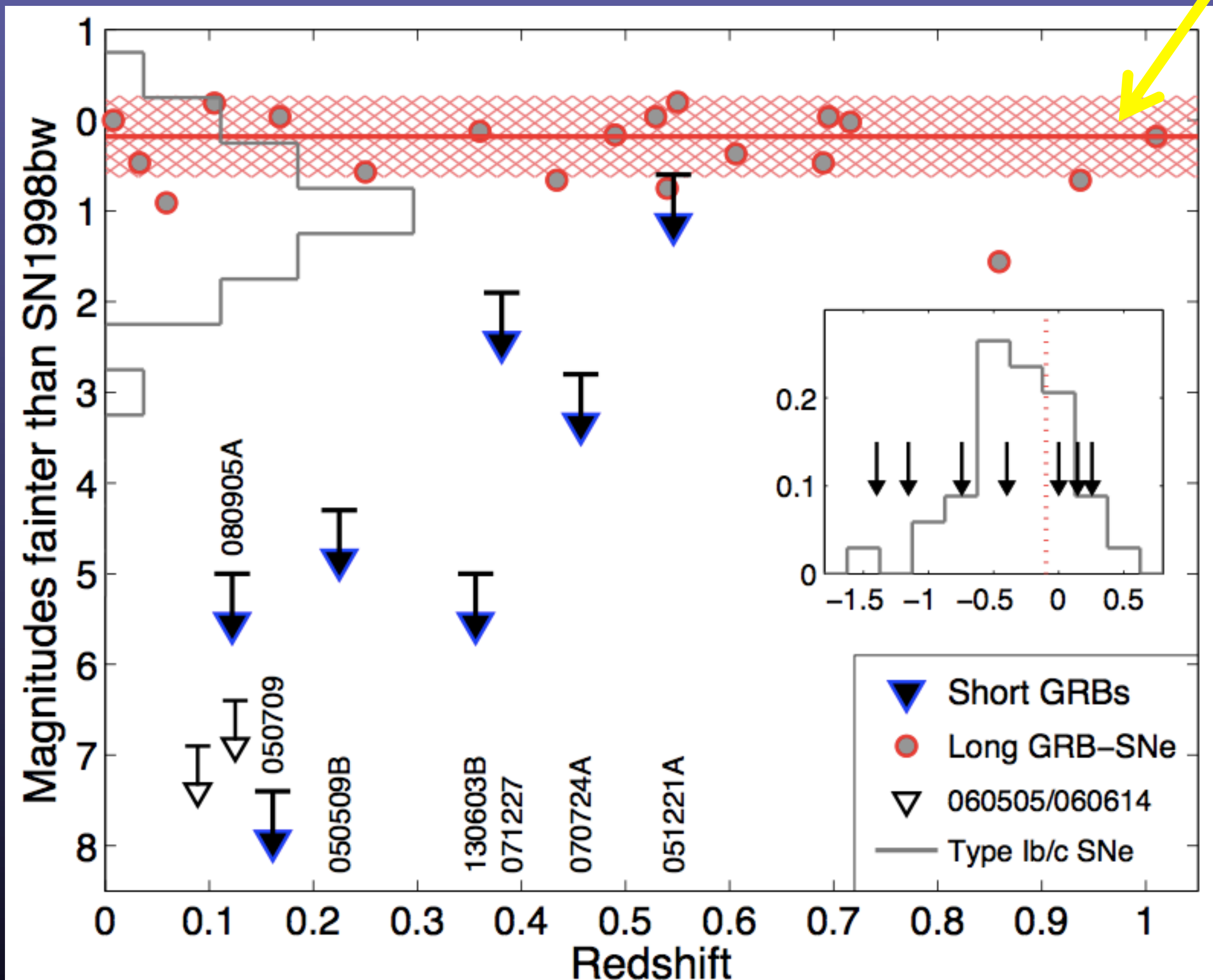
Afterglows of SGRBs *dimmer* than those of LGRBs

ENERGETICS



SGRBs *less energetic* than LGRBs

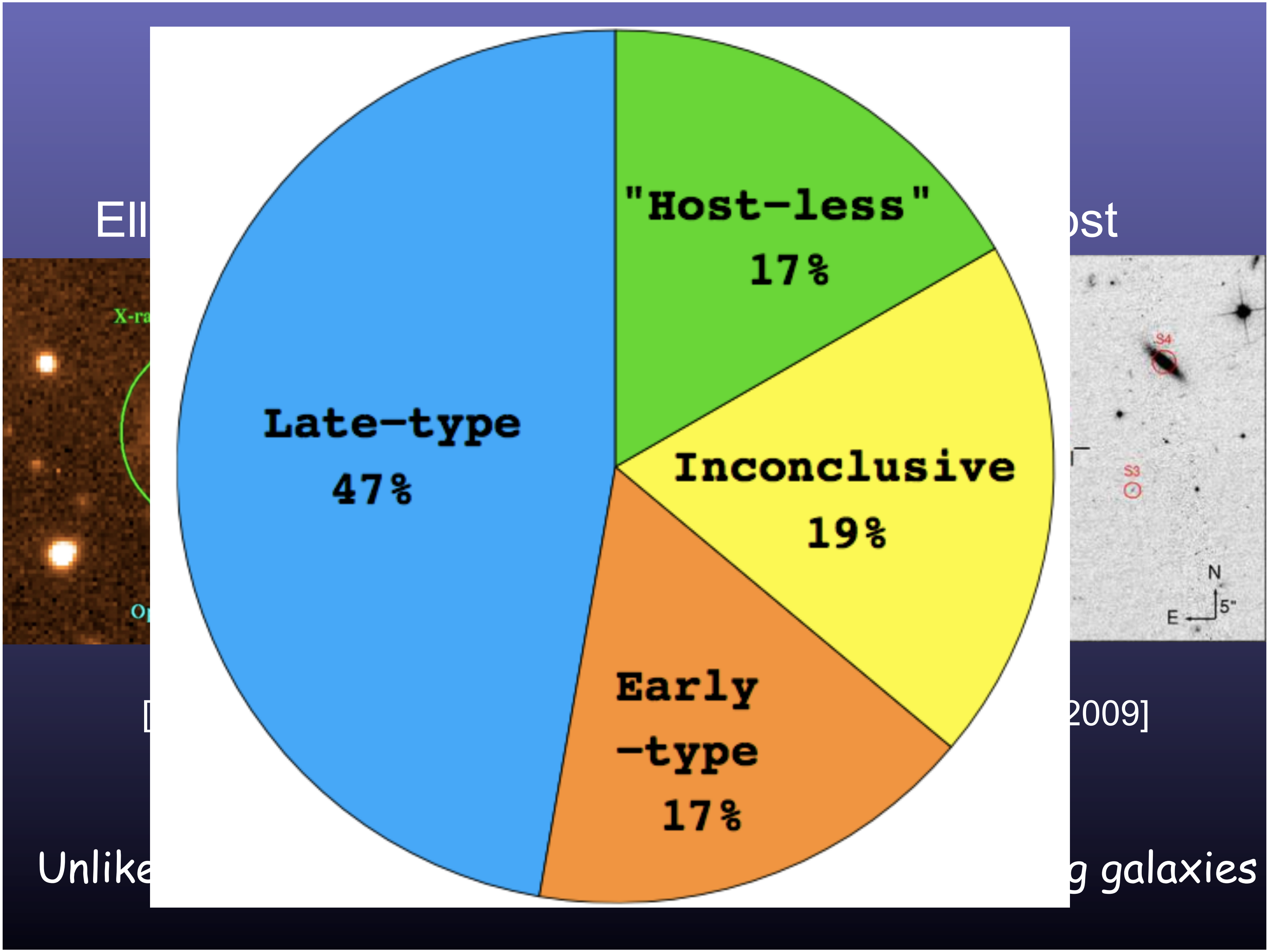
NO SN ASSOCIATION



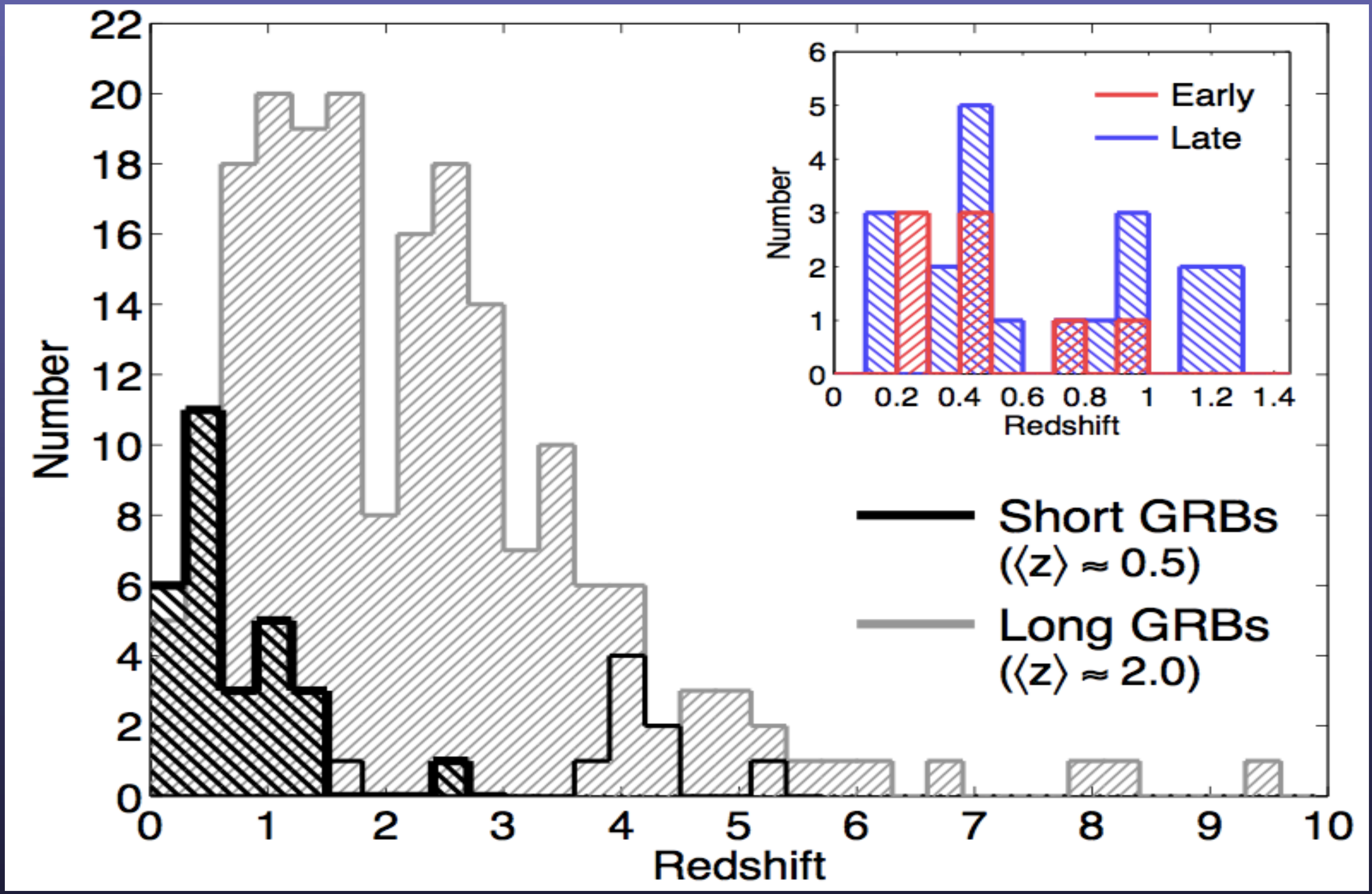
SN peak magnitudes for Long GRBs

Limits for Short GRBs relative to SN1998bw

[Berger 2014]


"Host-less"
17%
Inconclusive
19%
Early
-type
17%
Late-type
47%

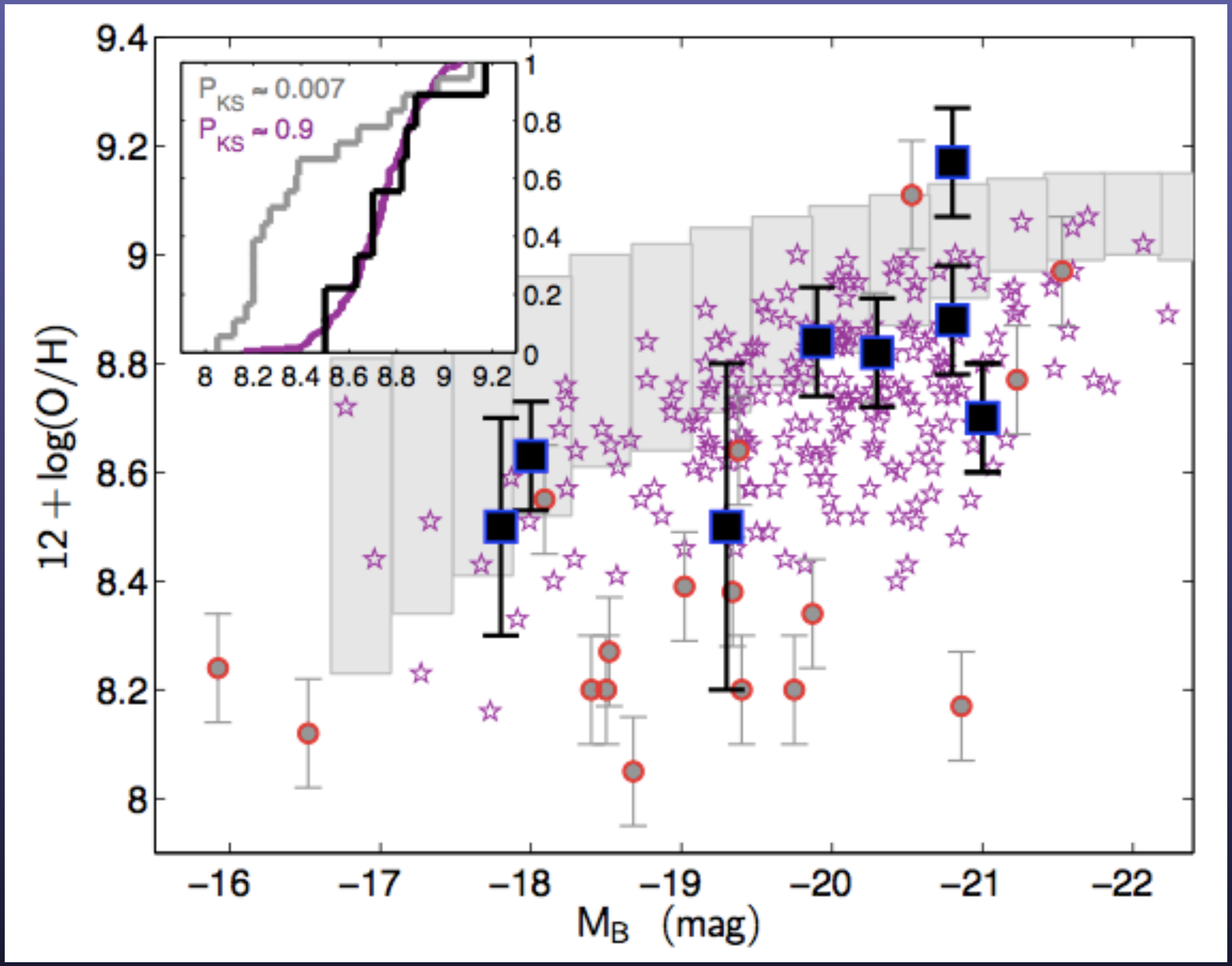
Redshift distribution



[Berger 2014]

SGRBs have systematically *lower* redshifts than LGRBs

HOST GALAXY METALLICITIES

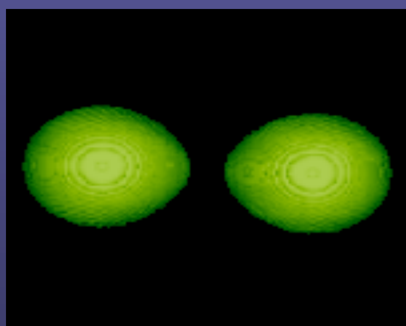


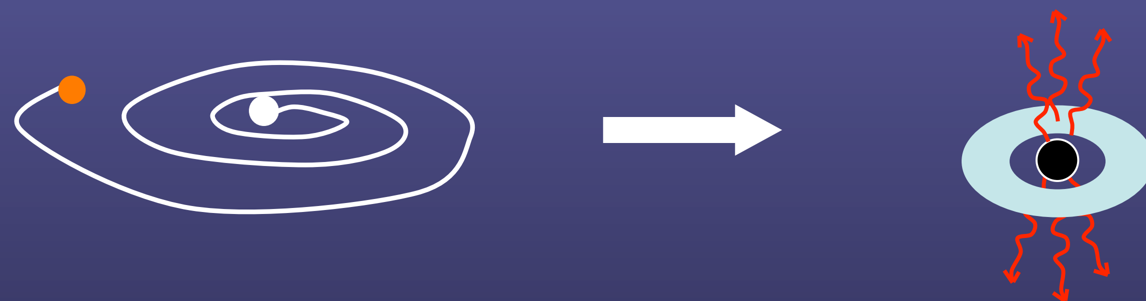
[Berger 2014]

Consistent with those of field galaxies at similar redshifts (unlike LGRBs)

PUTTING IT ALL TOGETHER……

(likely) Progenitor models



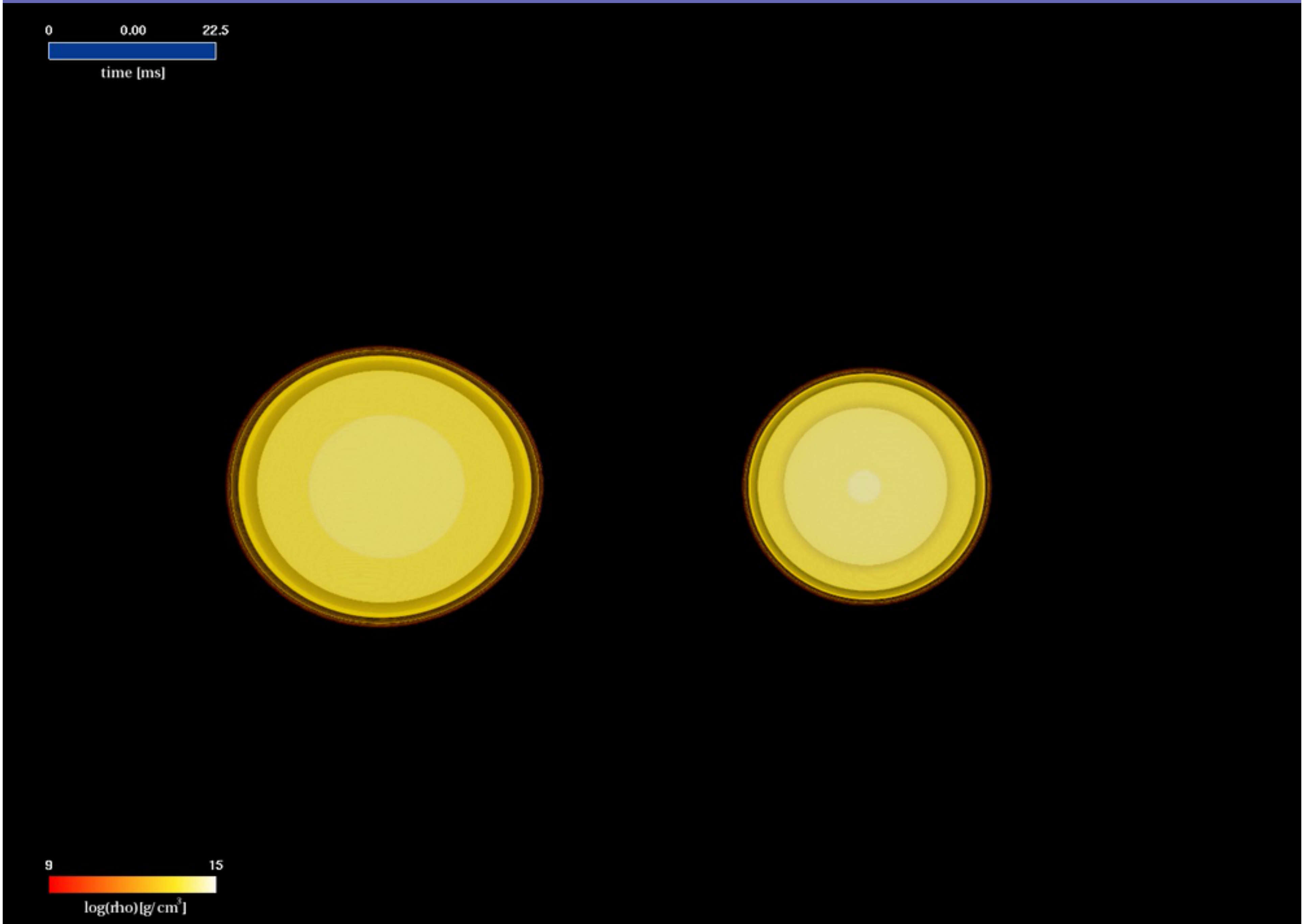


Corroborative pieces of evidence:

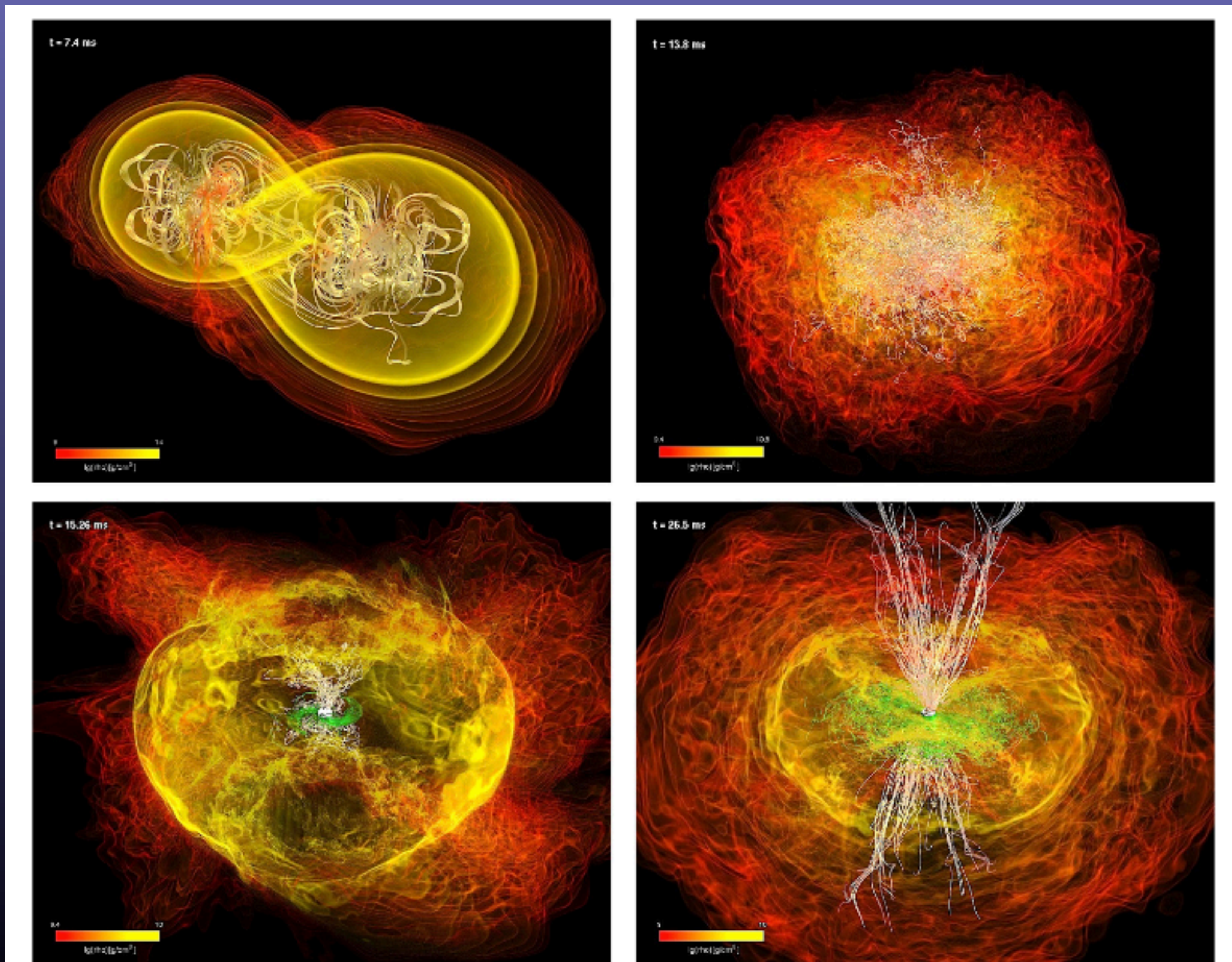
- No SN ever found associated with a short GRB
- Energies a factor of 10 or more lower than for long GRBs
- Generally associated with early type galaxies, with low star-formation, unlike long GRBs, associated with regions of high star formation.
- Average redshift lower than for long GRBs

SHORT GRBs – connection with binary mergers supported by numerical simulations [e.g. Sekiguki et al 2011; Rezzolla et al 2011; Bauewein & Janka 2012; Etienne et al 2012; Palenzuela et al 2013; Deaton et al. 2013; Paschalidis et al. 2013; Read et al. 2013; Hotokezaka et al. 2013; Rosswog et al 2013; Bauswein et al 2014; ………]

Following movie:
Visualization by Giacomazzo, Koppitz, Rezzolla with data by Rezzolla et al. (2010)

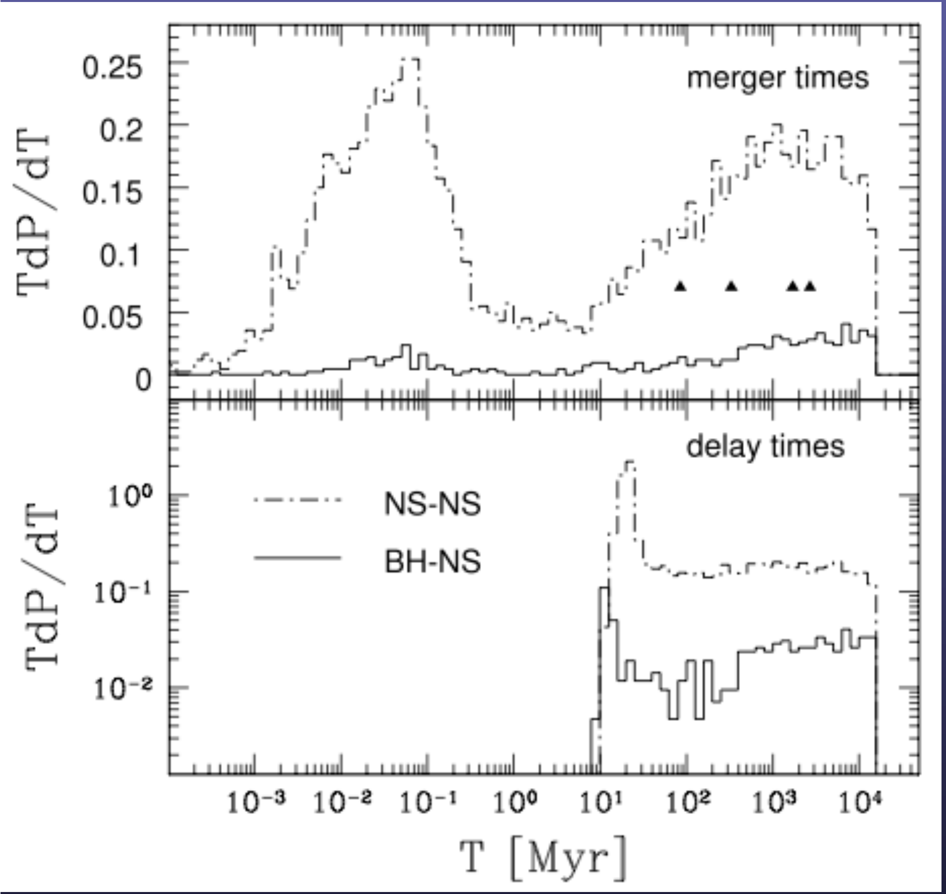

0
0.00
22.5
time [ms]
9
15
log(rho)[g/cm³]

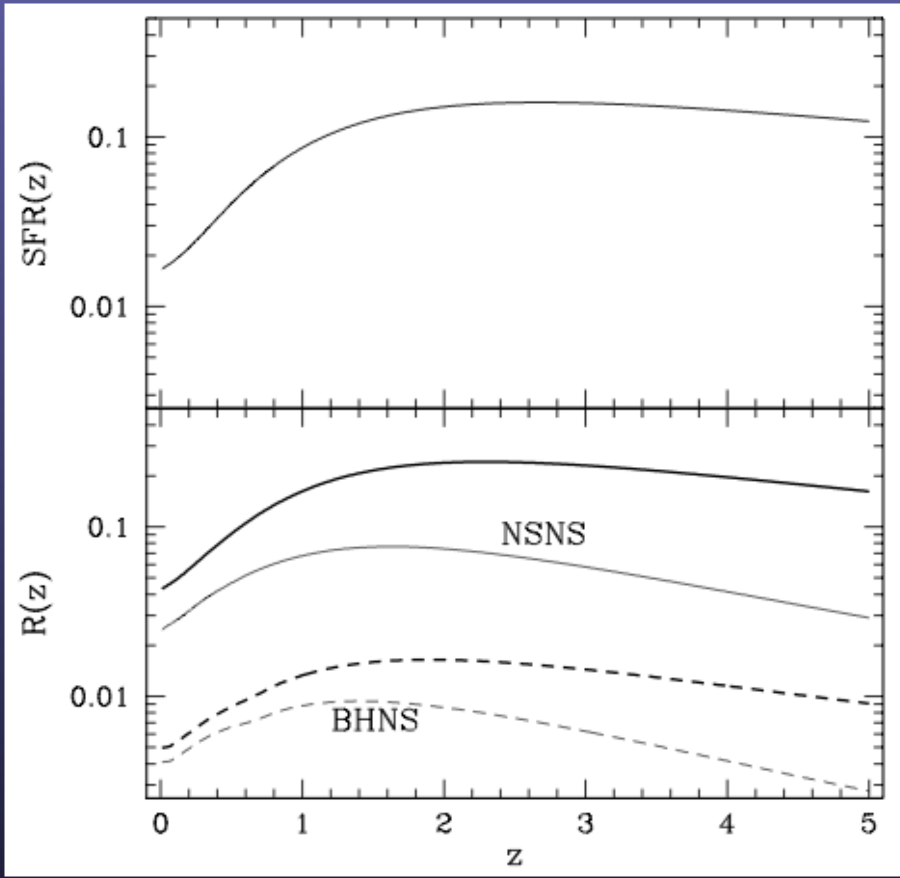
Evidence for possible formation of a jet [Rezzolla et al. 2011]



Theoretical expectations for SGRBs from binary mergers:
Merger & delay times – redshift distribution

[Perna & Belczynski 2002; Belczynski, Perna et al. 2006]

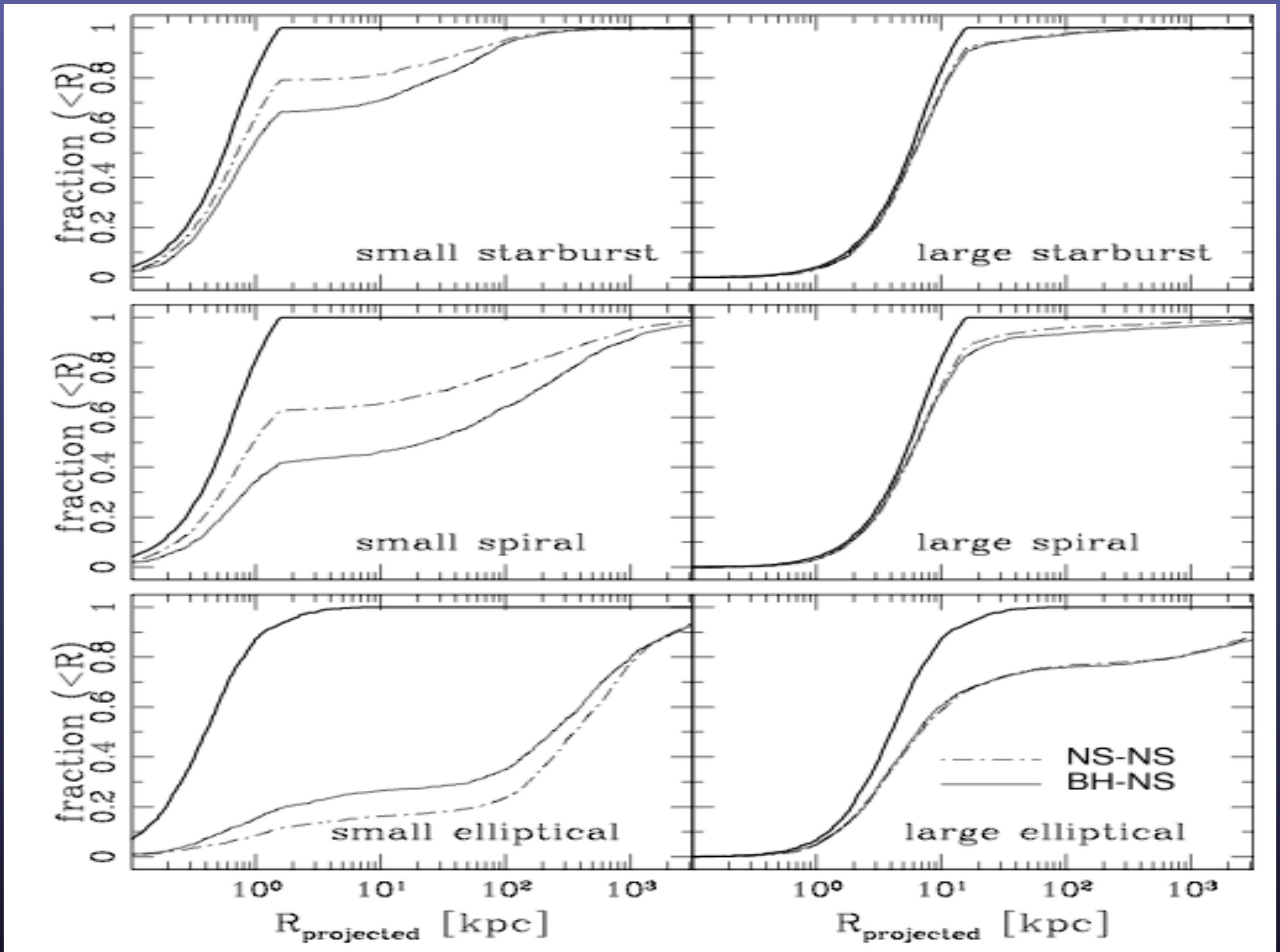




$$\tau_{GW} \propto a^4/(\mu M^2)$$

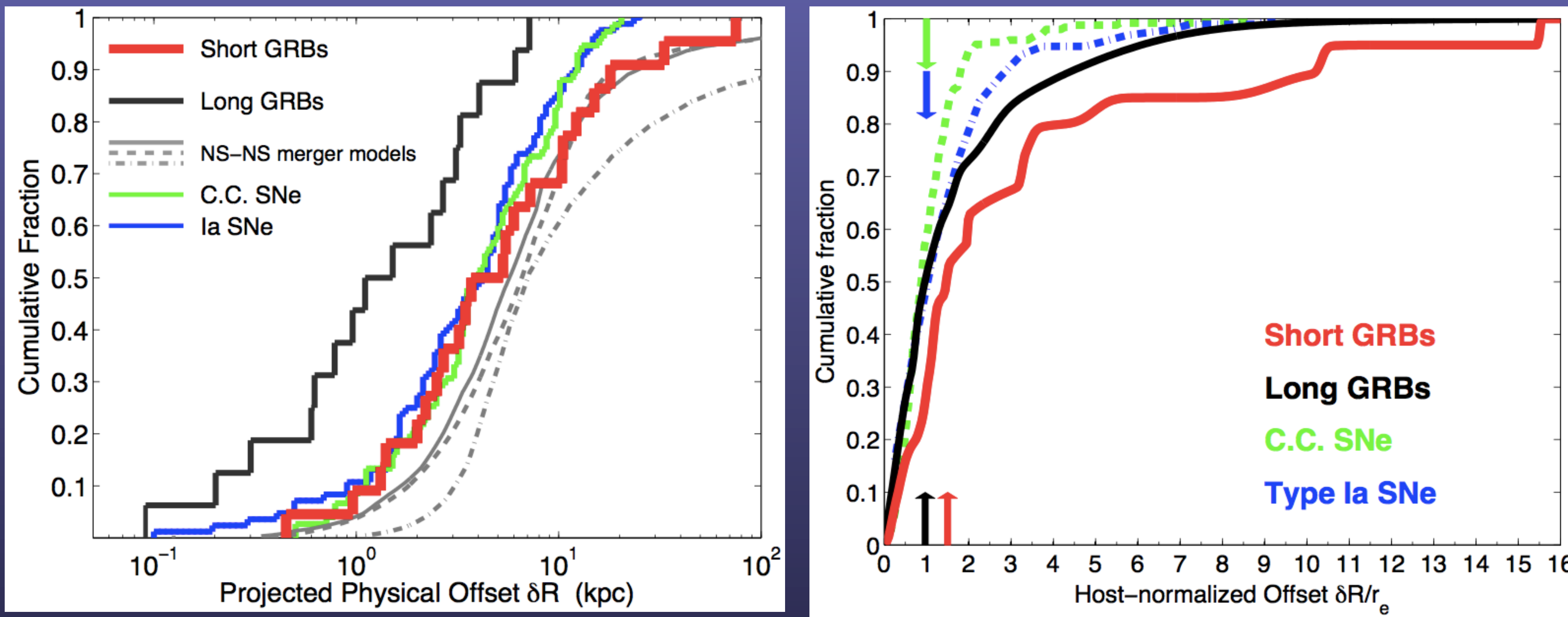
Merger times (due to GW emission) spread wide range of values:

Theoretical expectations for SGRBs from binary mergers: Galactic offsets distribution



[Perna & Belczynski 2002; Belczynski, Perna et al. 2006]

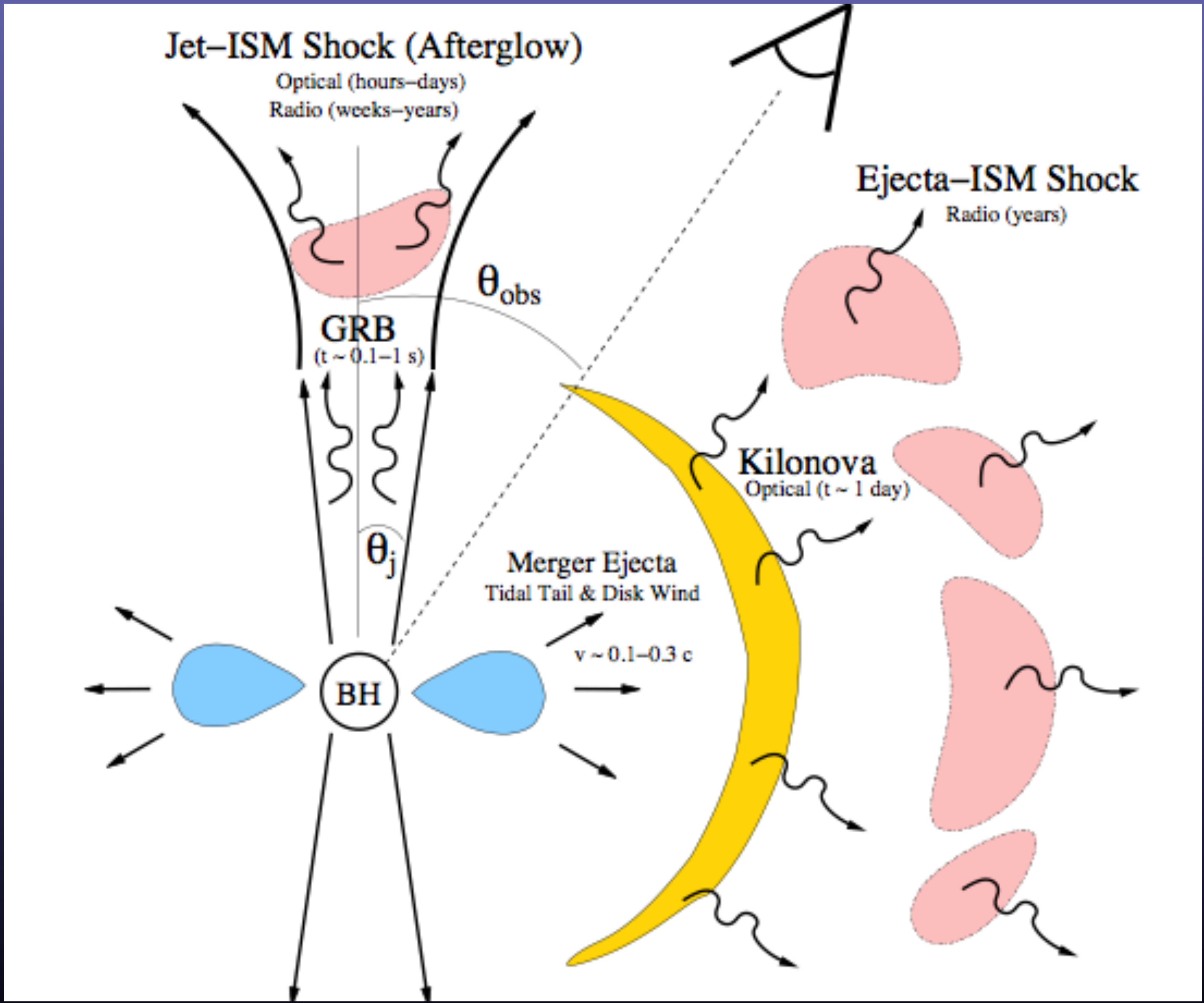
Galactic offsets: Observations



[Fong & Berger 2013]

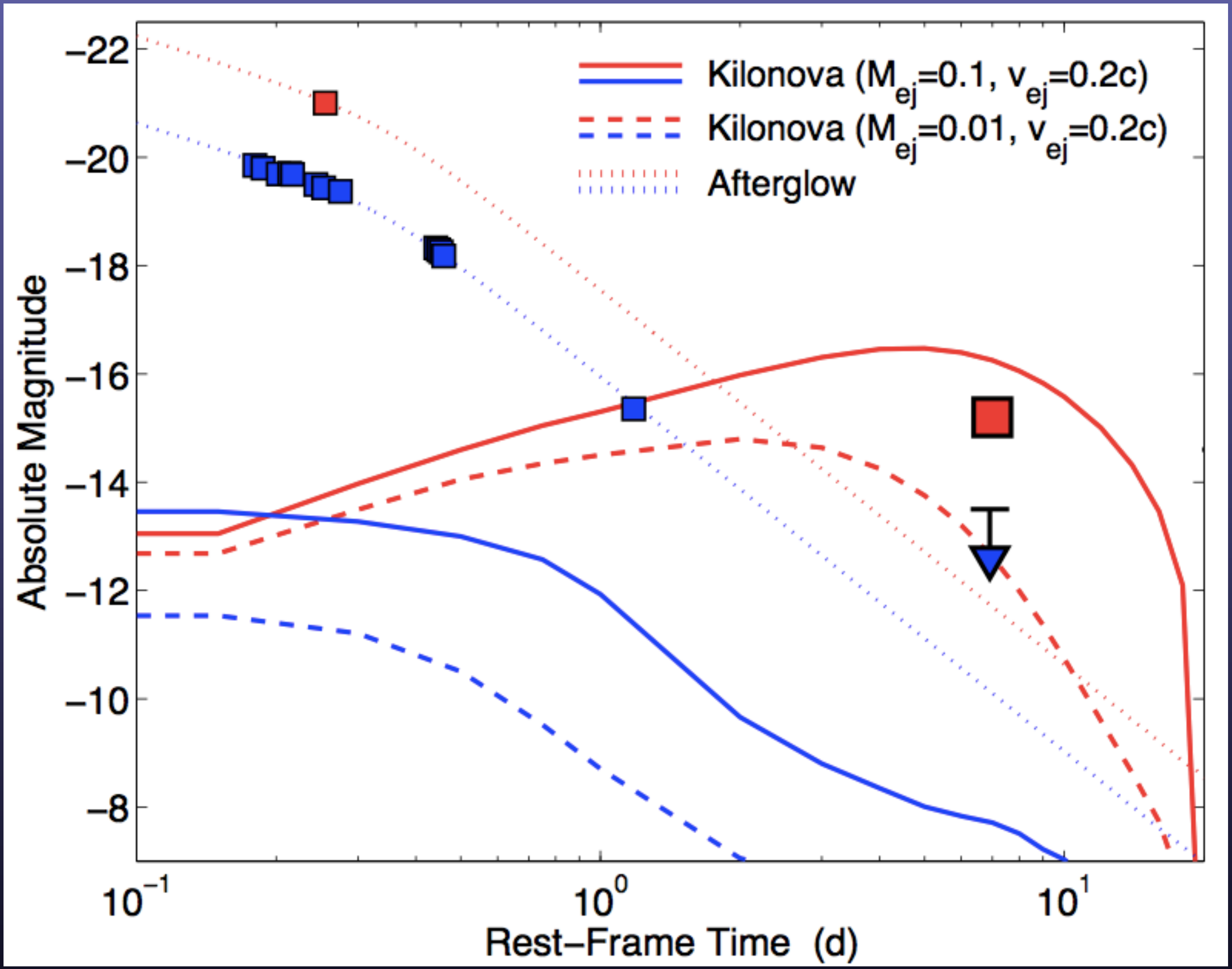
SGRBs have systematically larger offsets than LGRBs
SGB offsets broadly consistent with merger models

EM counterparts from binary mergers are more than just SGRBs



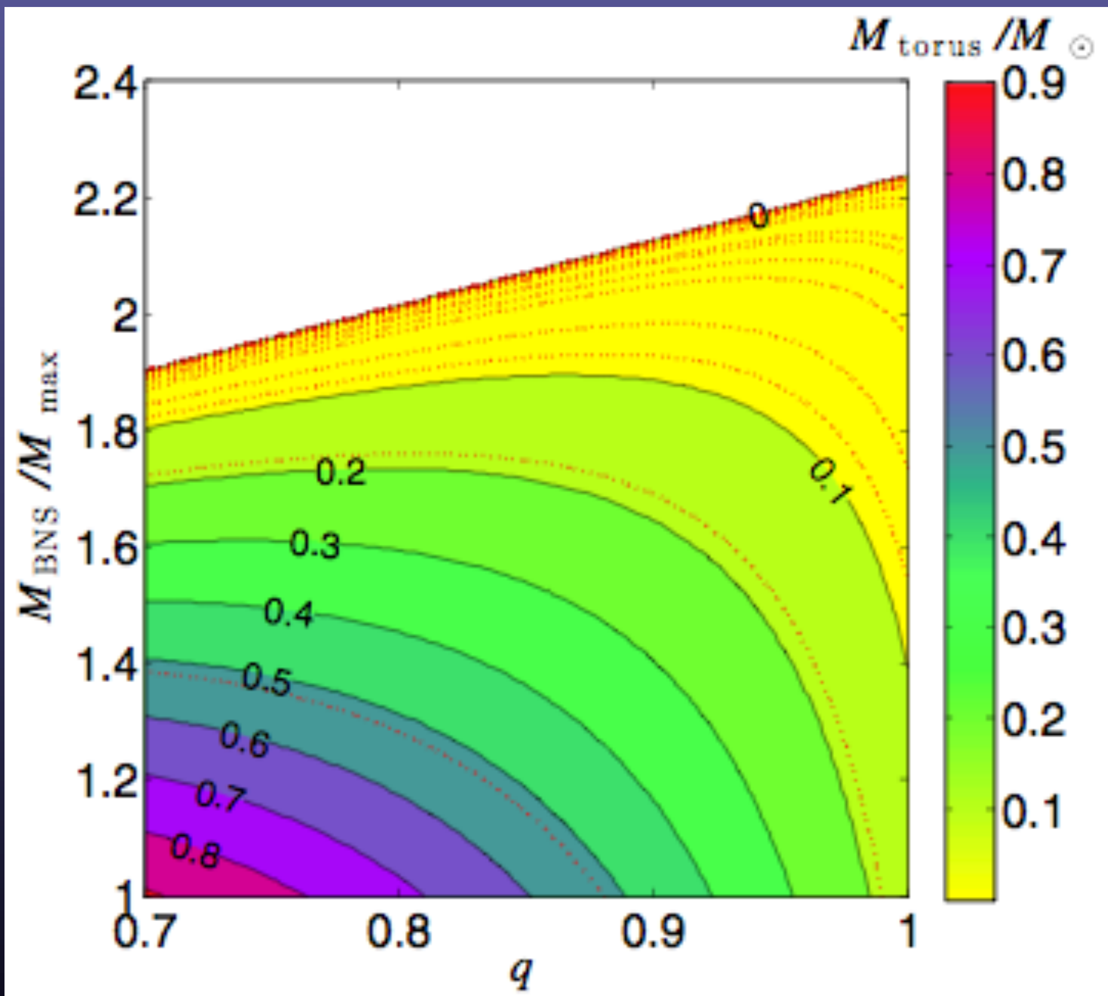
[Metzger & Berger 2012]

Possible KILONOVA signature in GRB130603b?



[Berger et al. 2013]

If short GRBs are indeed associated with binary mergers, then a comparison between numerical simulations and current data can already be informative.



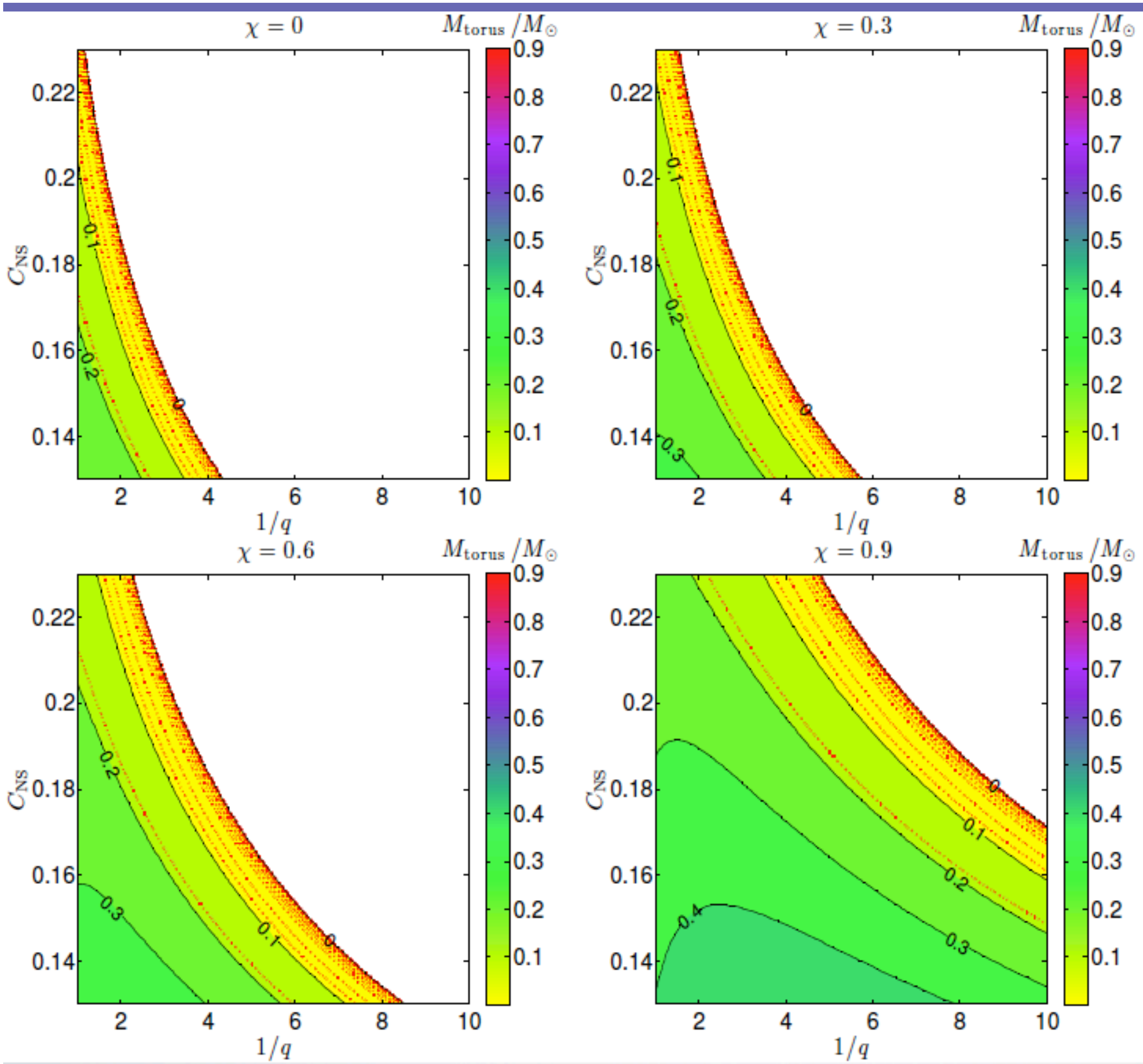
[Giacomazzo, Perna et al. 2013]

NS-NS merger

Predicted torus masses for different binary properties, compared to torus masses inferred for specific GRBs

→ 'High-mass' binary mergers are favored

[see Giacomazzo's talk]



NS-BS mergers

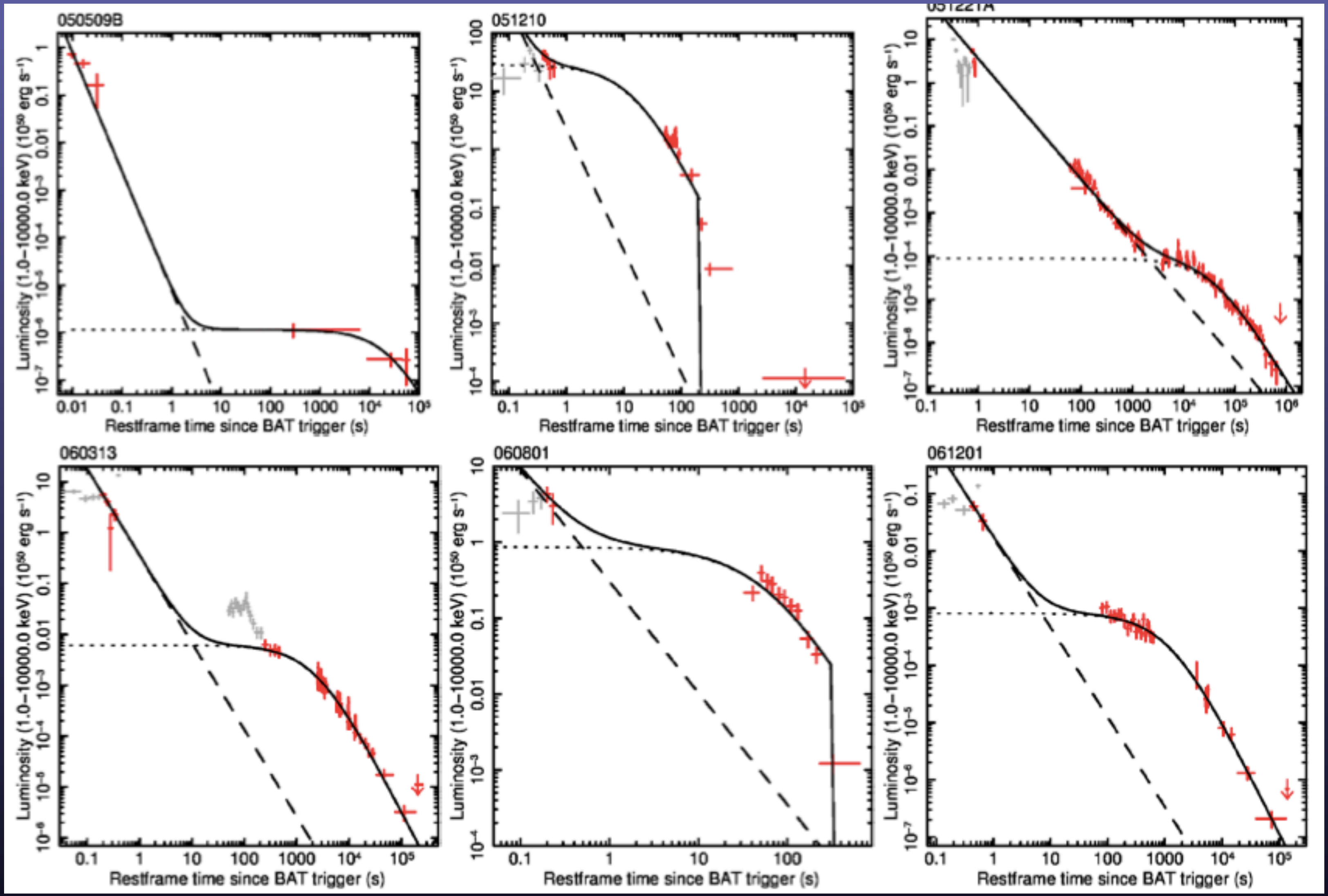
Population synthesis calculations predict 1/q ~ 7 – 10 [Belczynski et al 2008]

High-BH spins are favored

[Giacomazzo, Perna, et al. 2013]

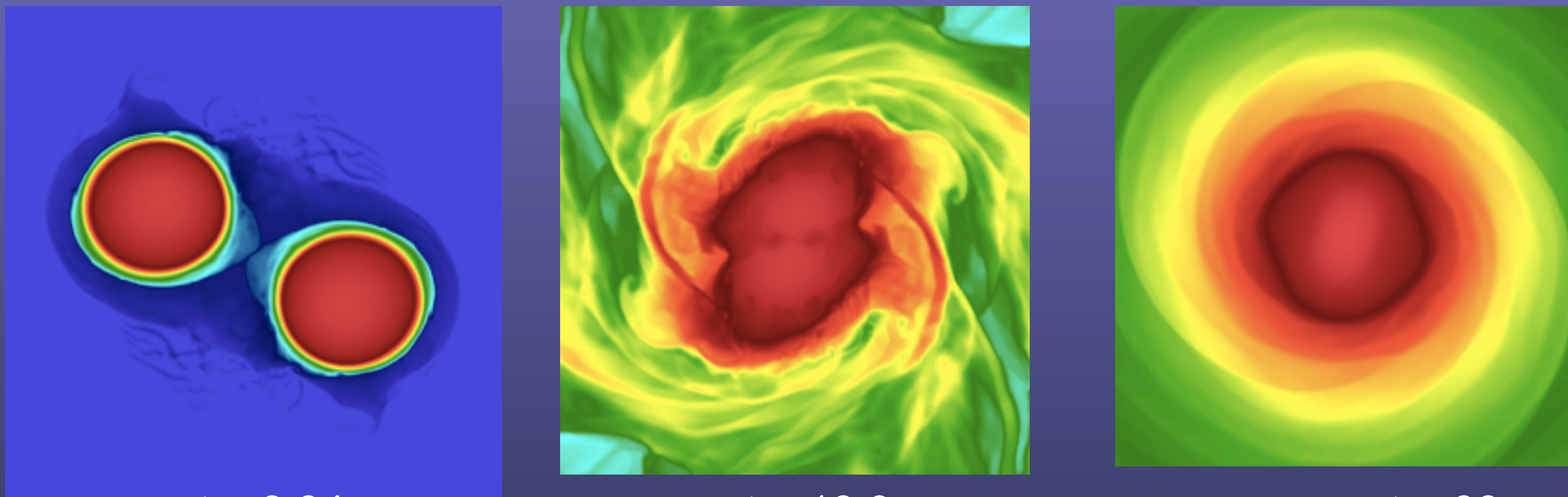
[see Giacomazzo's talk]

Plateaus could be interpreted with the presence of a stable or unstable magnetar

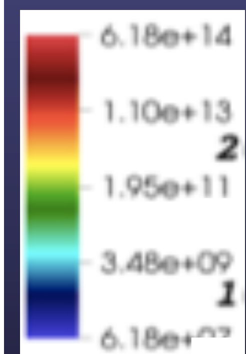


[Rowlinson et al 2013]

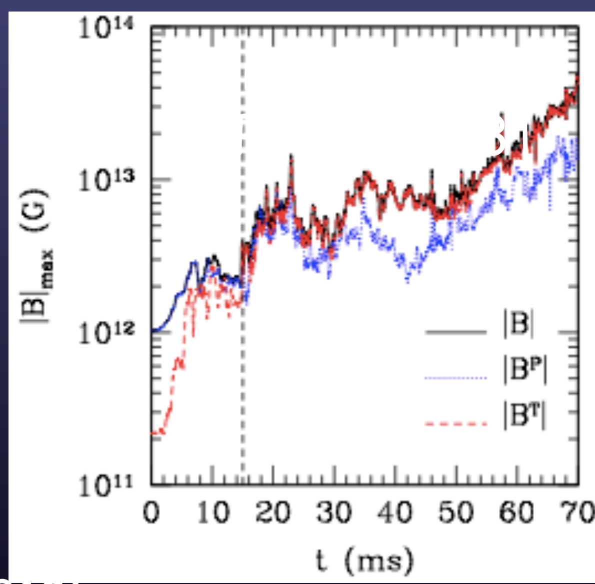
Magnetar formation via NS-NS mergers?



t = 8.34 ms   t = 18.9 ms   t = 66 ms



B ampl. also seen in local simulations by by Zrake & MacFadyen (2012)



GR MHD simulations of the merger of two 'small' NSs showed that a stable NS *can* be formed, and the B field is amplified during the merger

→ Magnetar formation may result from NS-NS merger

[Giacomazzo & Perna 2013]

Extended emission can be explained through the formation of a rapidly rotating magnetar [Metzger et al 2008; Bucciantini et al 2012]; heating from r-process nucleosynthesis which momentarily halts accretion onto the central object [Metzger et al 2010]; interaction of the relativistic outflow with a non-degenerate stellar companion [MacFadyen et al 2005]

Precursors could be due to the transition of the fireball to the optically thin regime [Lazzati et al 2005]; magnetospheric interactions between the compact objects [Hansen & Lyutikov 2001]; resonant scattering of neutron star crusts prior to merger [Tsang et al. 2012], accretion and propeller around a millisecond magnetar [Bernardini et al. 2013; Gompertz et al. 2014]

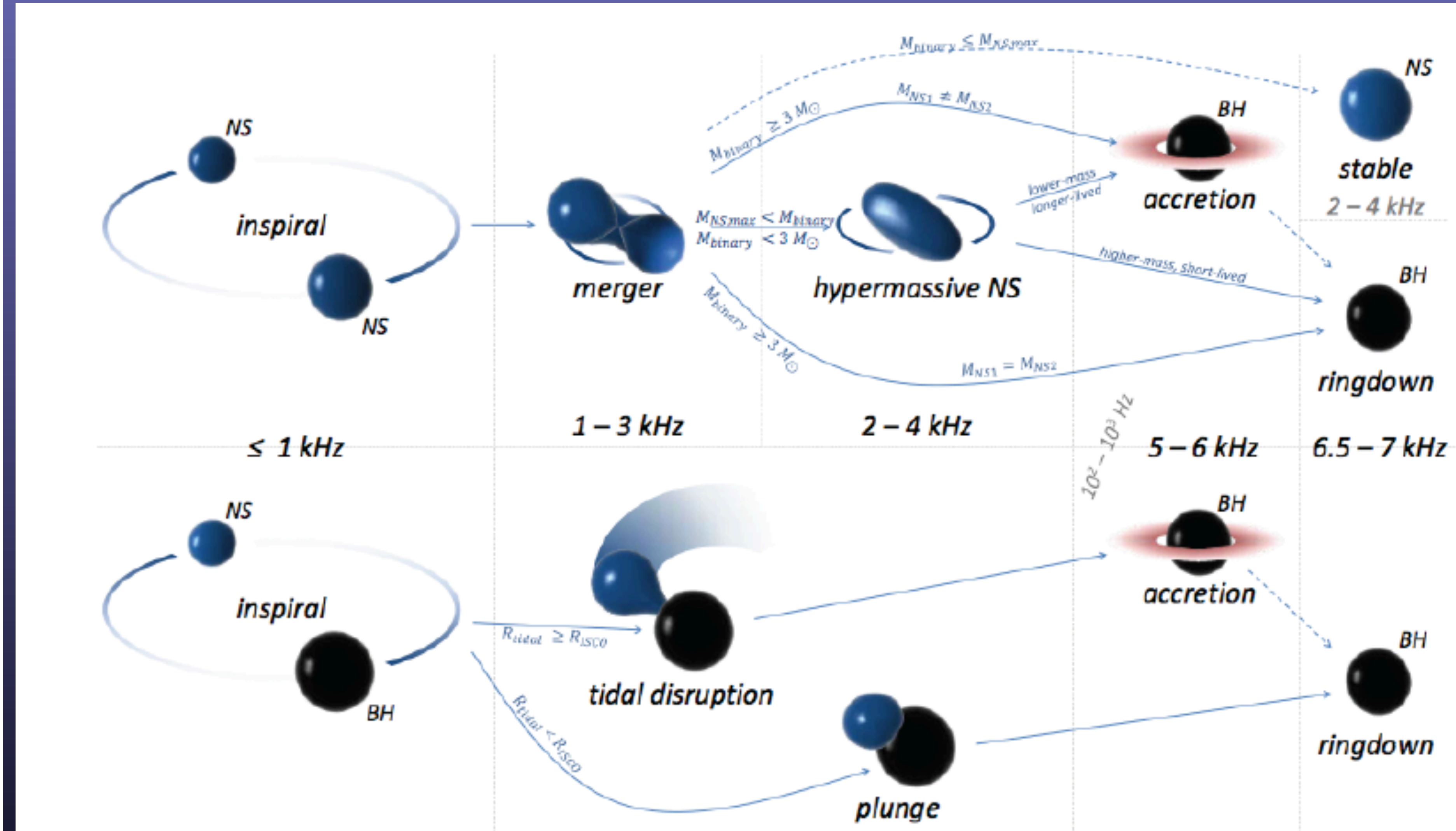
X-ray flares could have an origin in the accretion disk formed after the merger [Perna et al 2006; Proga & Zhang 2006]; delayed fallback of material after the merger [Rosswog 2007]; magnetic recoonection within a magnetized outflow [Giannios 2006]

How can we obtain independent diagnostics of the progenitors of short GRBs? (in the binary merger scenario)

GRAVITATIONAL WAVES!

GWs from Binary Mergers

[Bartos et al. 2013]

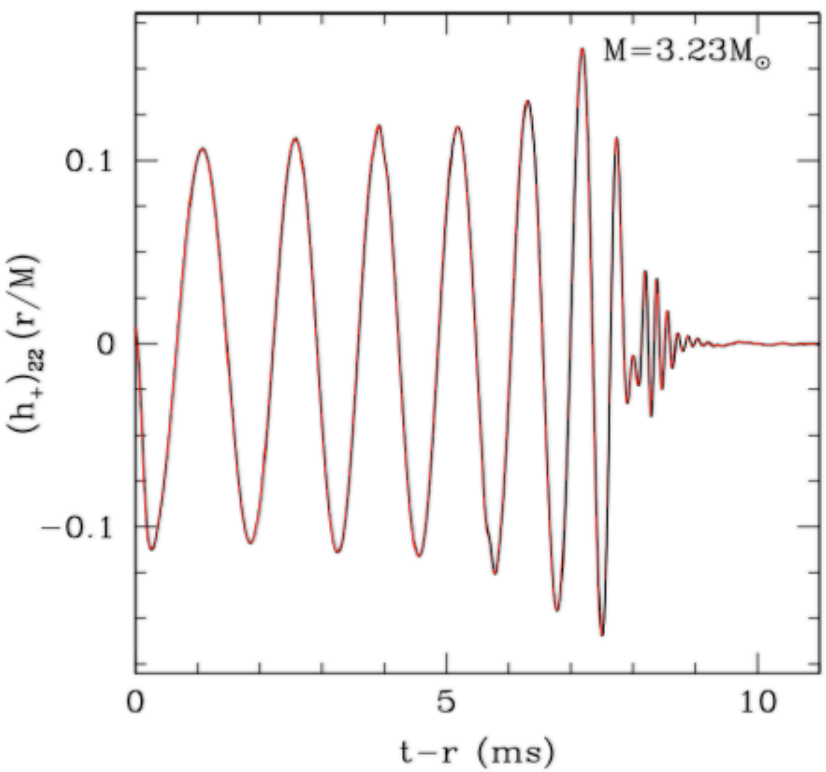


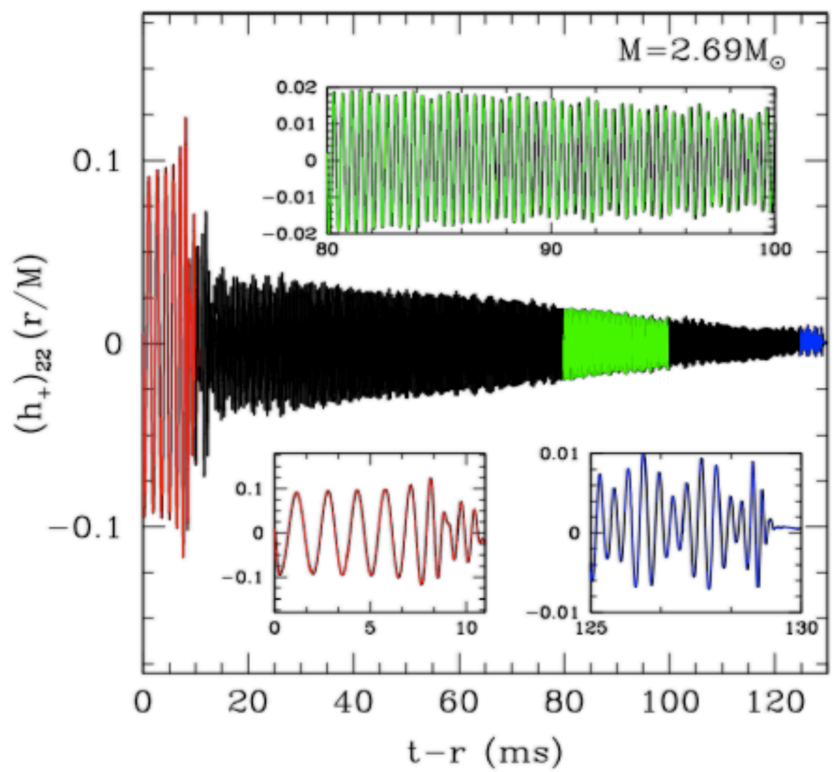
GW emission associated to various phases of the merger

Independent diagnostics of SGRB binary progenitor

"low-energy" SGRBs
(<~1e51 erg)
↓
"high-mass" BNSs

"high-energy" SGRBs
(>~1e51 erg)
↓
"low-mass" BNSs





[Andersson et al. 2010 with data from Rezzolla et al. 2010]

SUMMARY

- Observations of SGRBs in the last decade have provided a wealth of data
- Several indirect pieces of evidence point towards a binary progenitor merger (redshift distribution, galaxy offsets, no SN association, host types, ...)
- Numerical simulations of binary mergers support a link to the phenomenology of SGRBs
- Detection of GWs in association with SGRBs will firm their association to mergers, and help constrain their progenitor properties