Gravitational waves and GRBs

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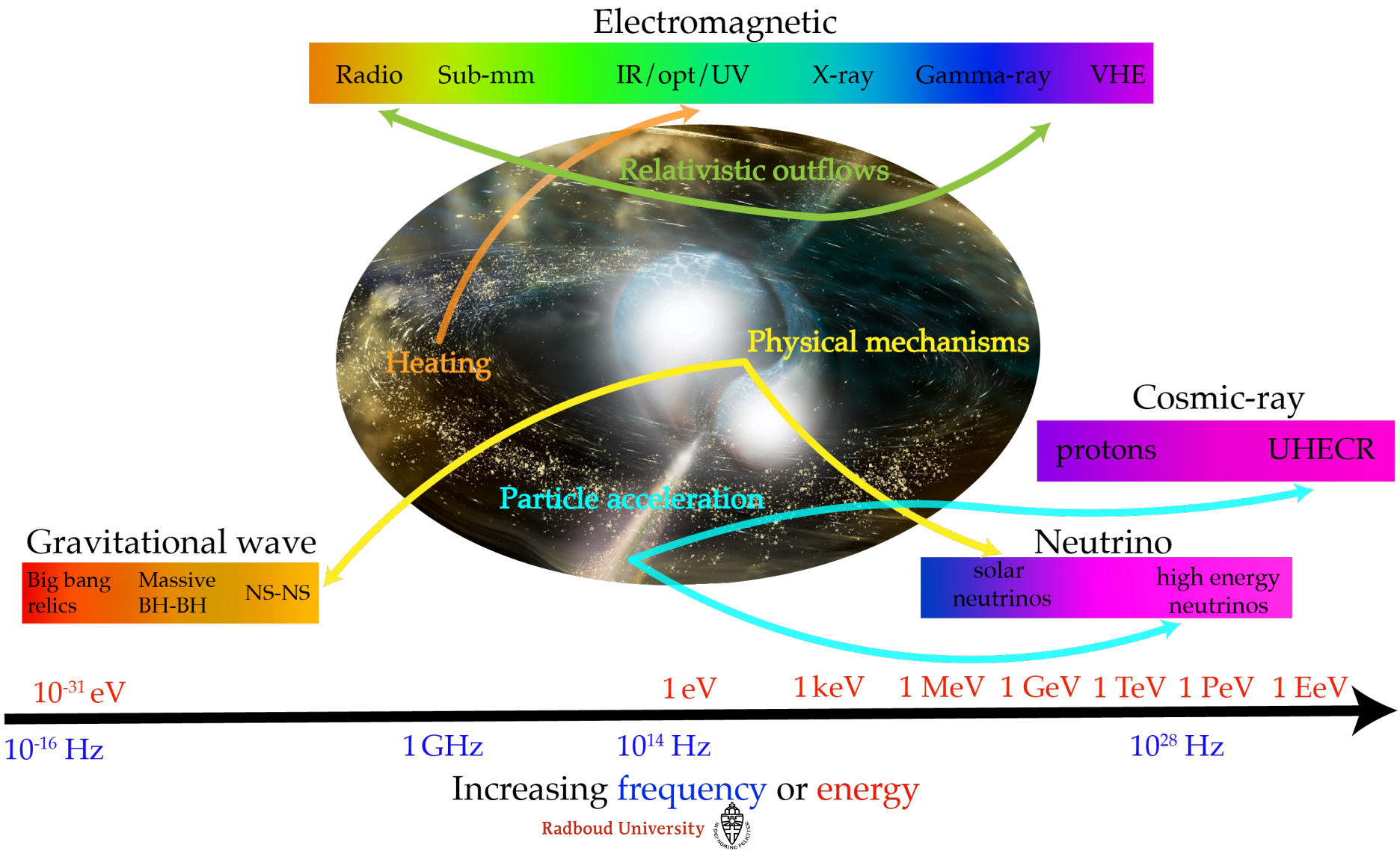
Electromagnetic
Radio
Sub-mm
IR/opt/UV
X-ray
Gamma-ray
VHE
Relativistic outflows
Heating
Physical mechanisms
Particle acceleration
Cosmic-ray
protons
UHECR
Neutrino
solar neutrinos
high energy neutrinos
Gravitational wave
Big bang relics
Massive BH-BH
NS-NS
10-31 eV
1 eV
1 keV
1 MeV
1 GeV
1 TeV
1 PeV
1 EeV
10-16 Hz
1 GHz
1014 Hz
1028 Hz
Increasing frequency or energy
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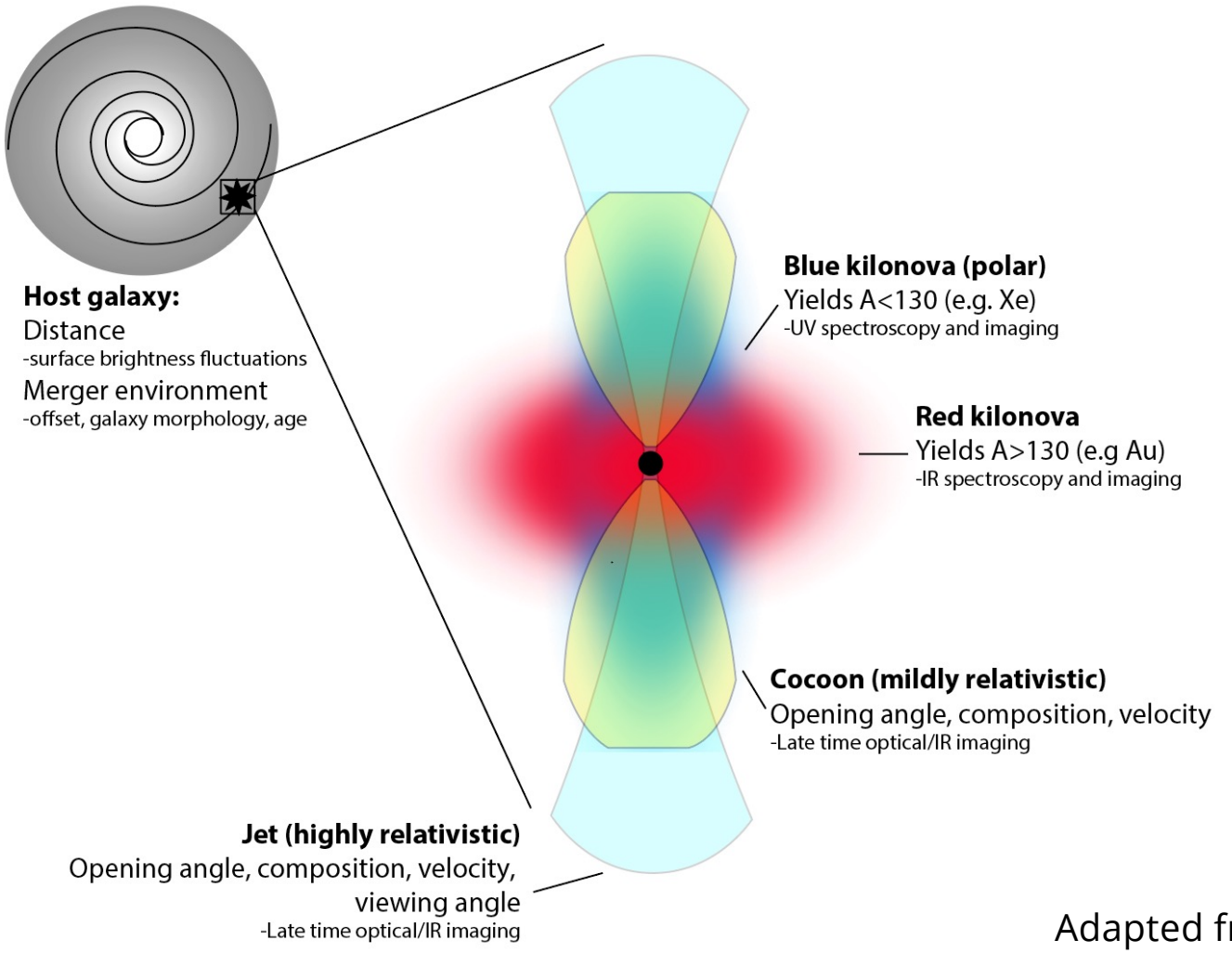
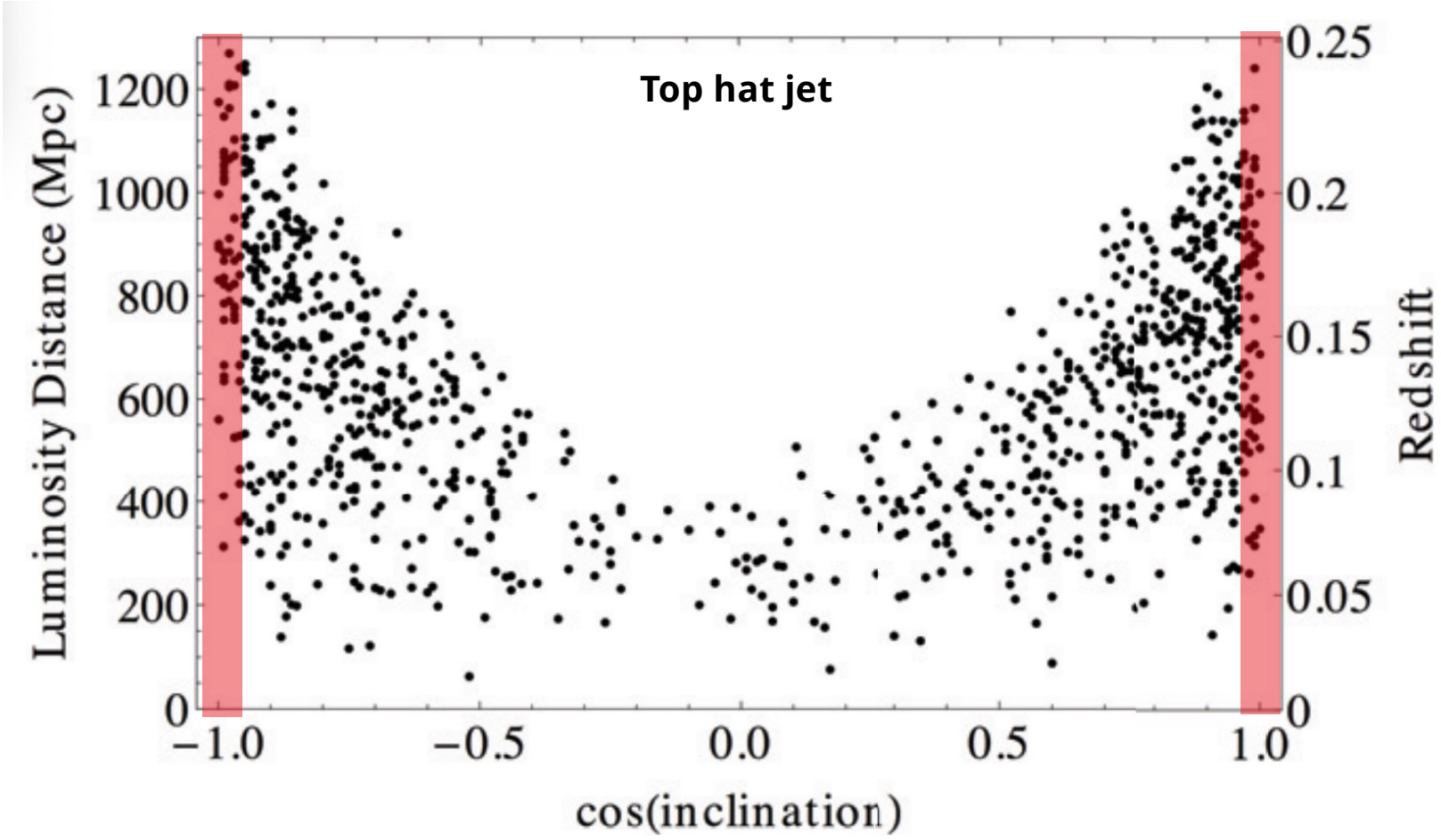
Possible multi-messenger and GRB signals



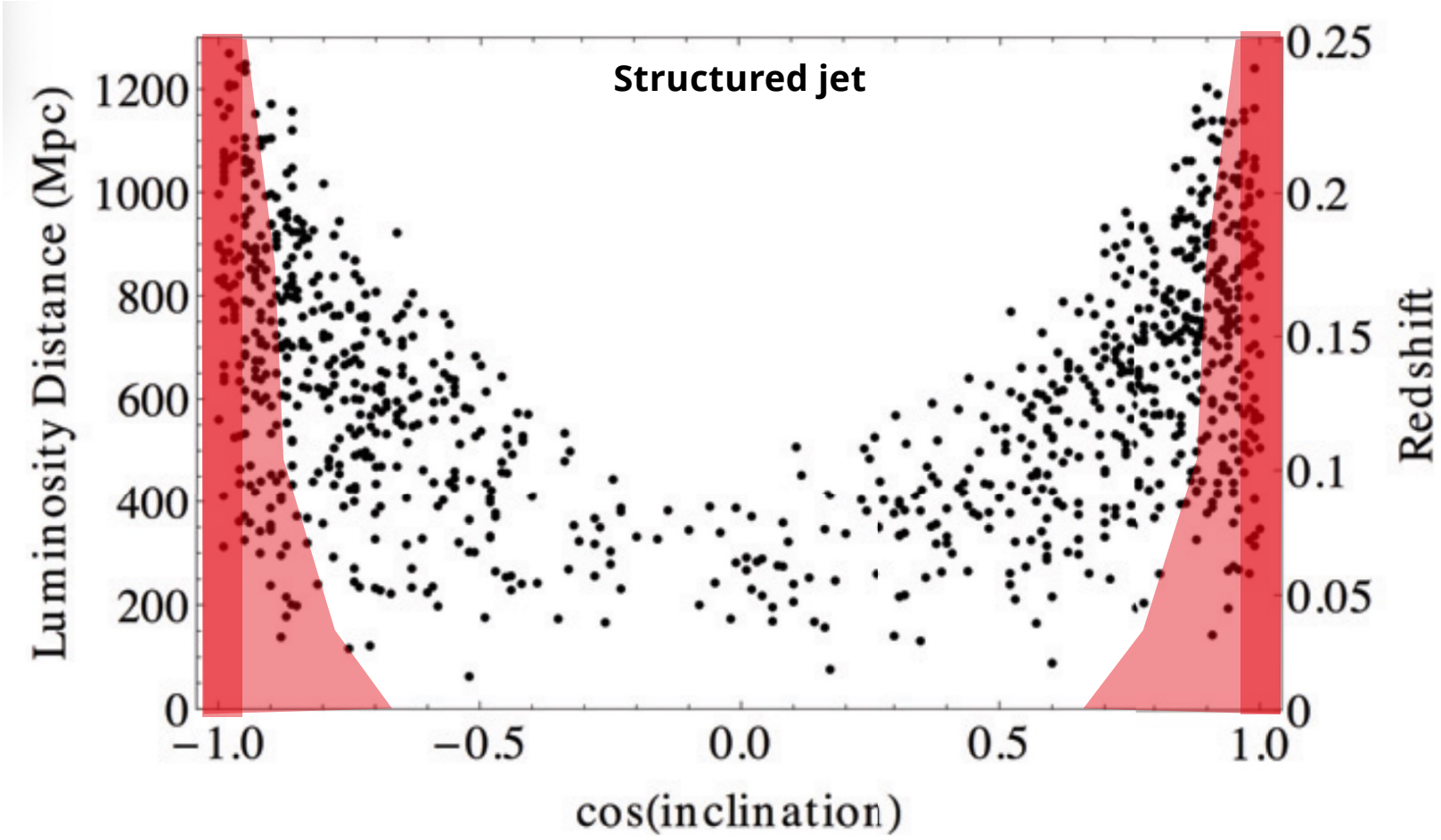
Adapted from Metzger 2017

GRB detectability in a compact object merger



Nissanke et al. 2011

GRB detectability in a compact object merger



Nissanke et al. 2011

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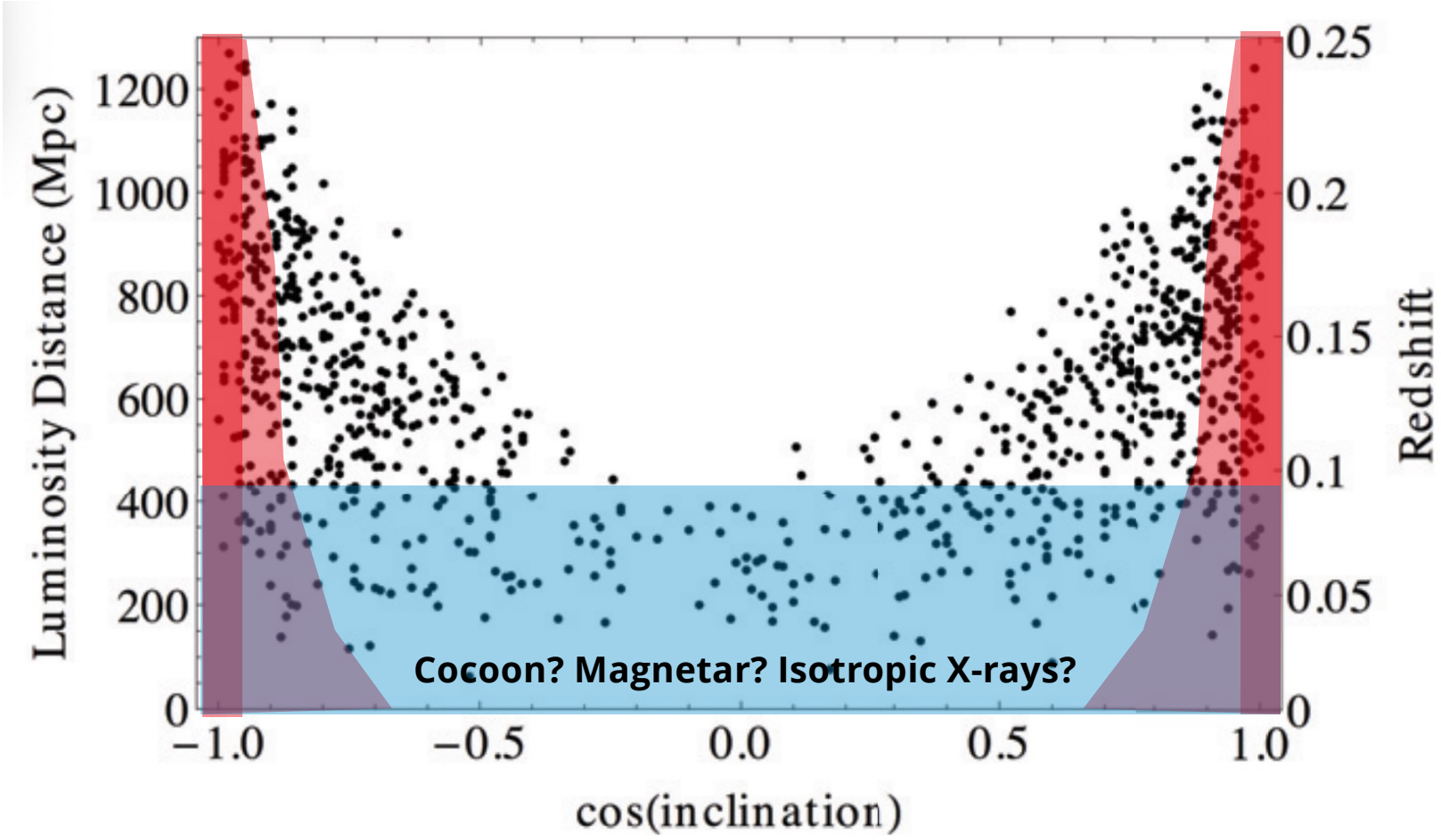
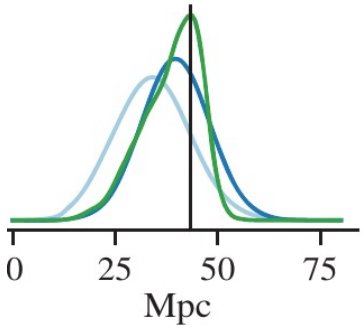
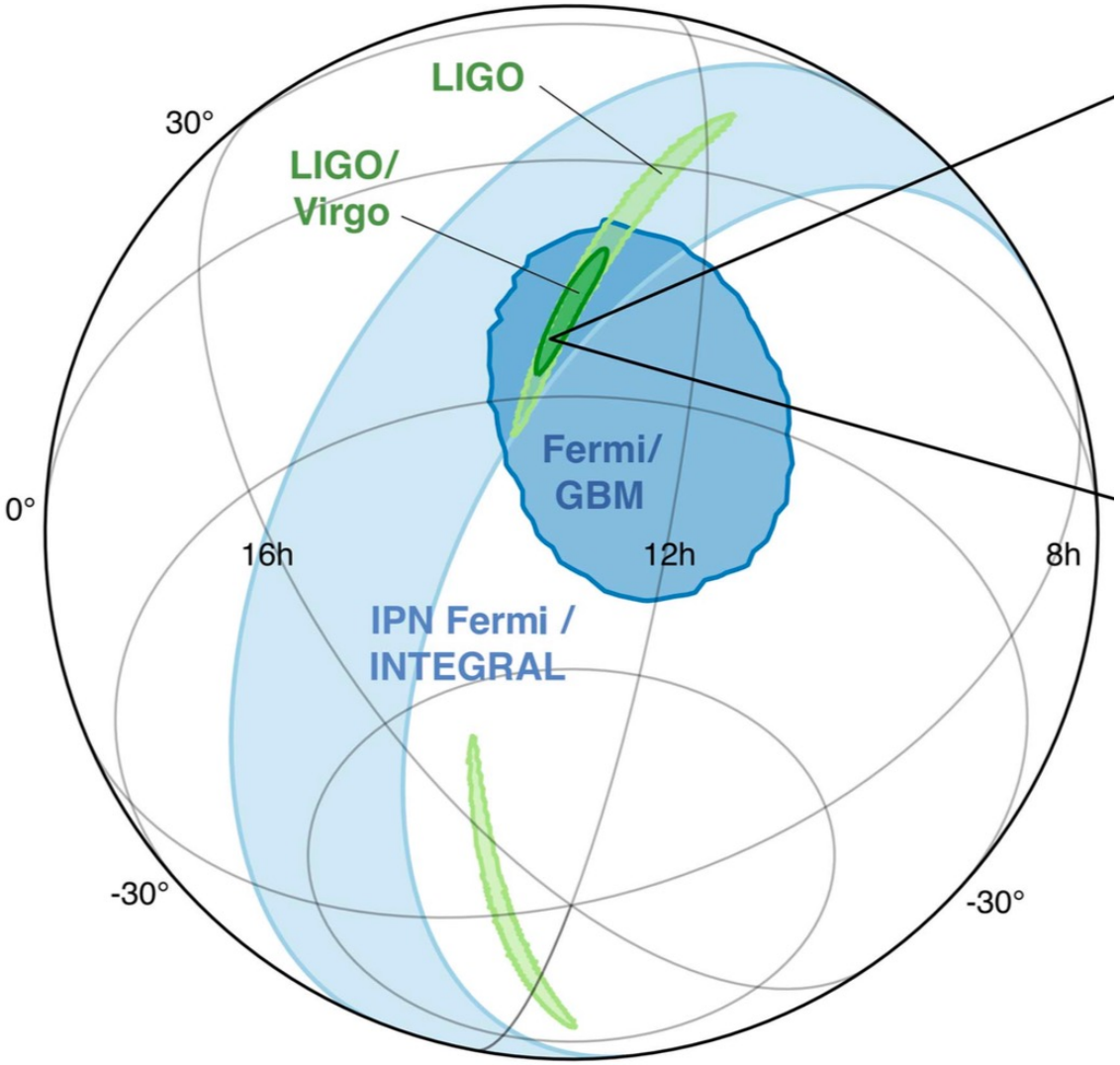


Nissanke et al. 2011

Sky localisation

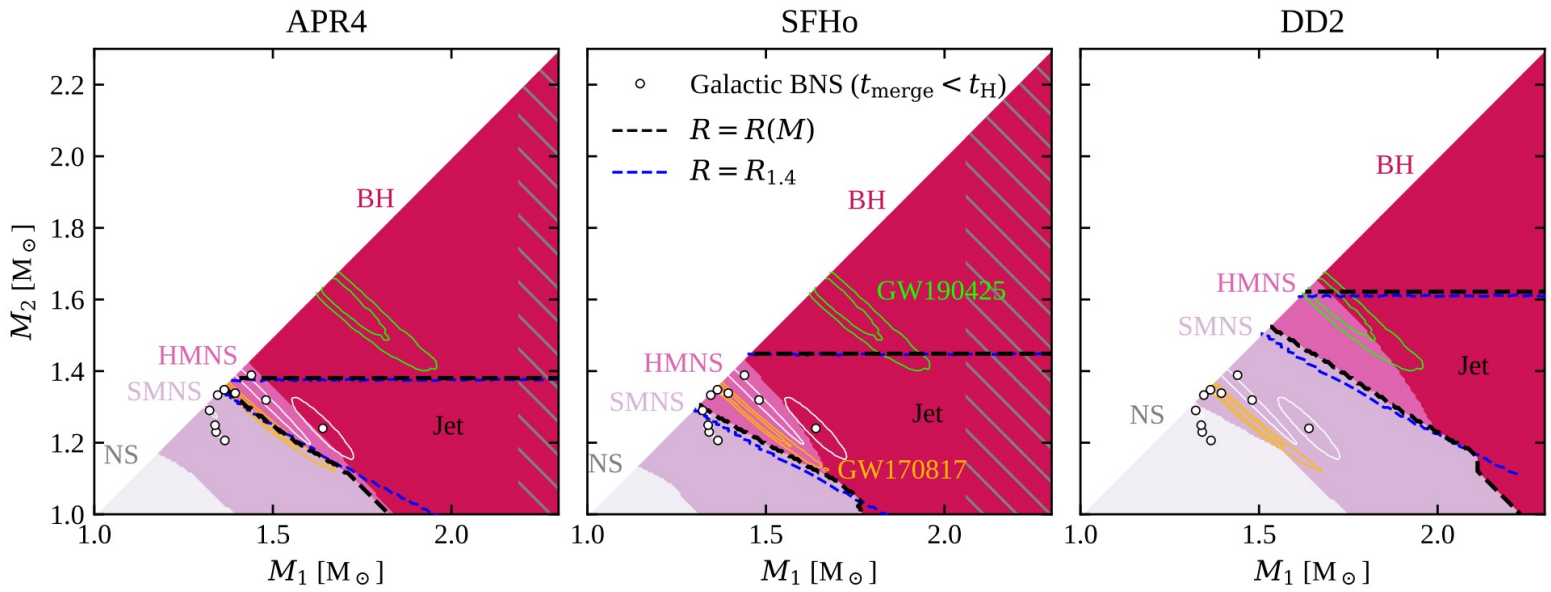
Fermi, GECAM etc – 100’s sq. degrees
EP, SVOM (prompt), 10’s sq. arcmin
Swift, EP FXT, arcsec





Which progenitors produce which GRBs?

Do all compact object mergers (with mass outside innermost stable orbit) produce a GRB?



Salafia et al. 2022

What is the luminosity function of the associated GRBs? What parts of this are intrinsic or viewing angle dependent?

What is the duration of the GRBs? How can we identify GRBs from mergers?

Which progenitors produce which GRBs?

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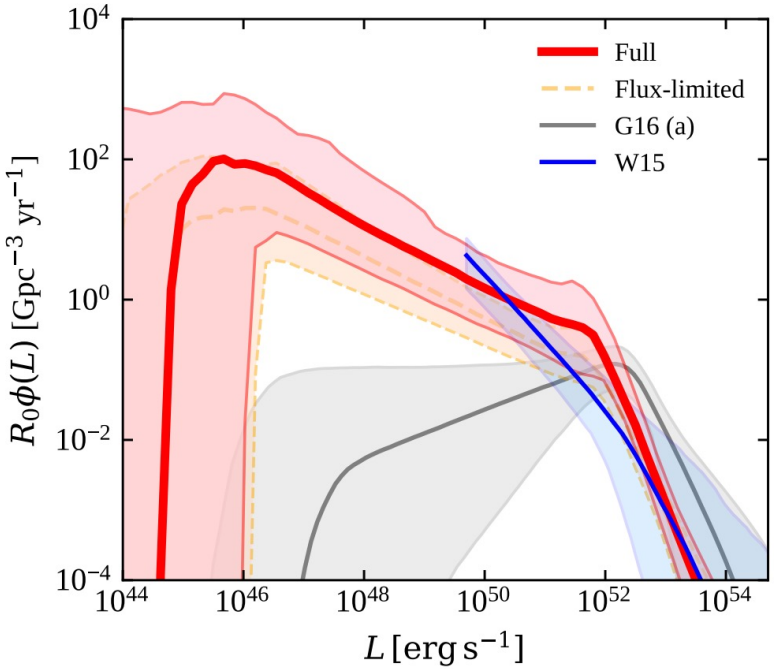

Salafia et al. 2023

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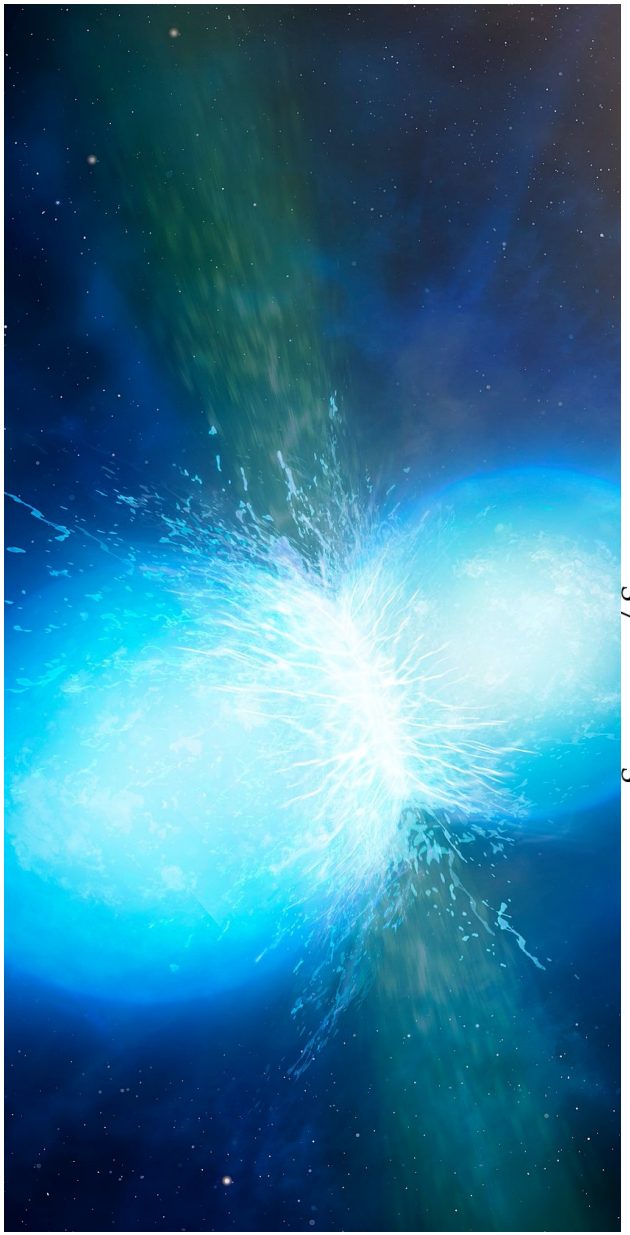
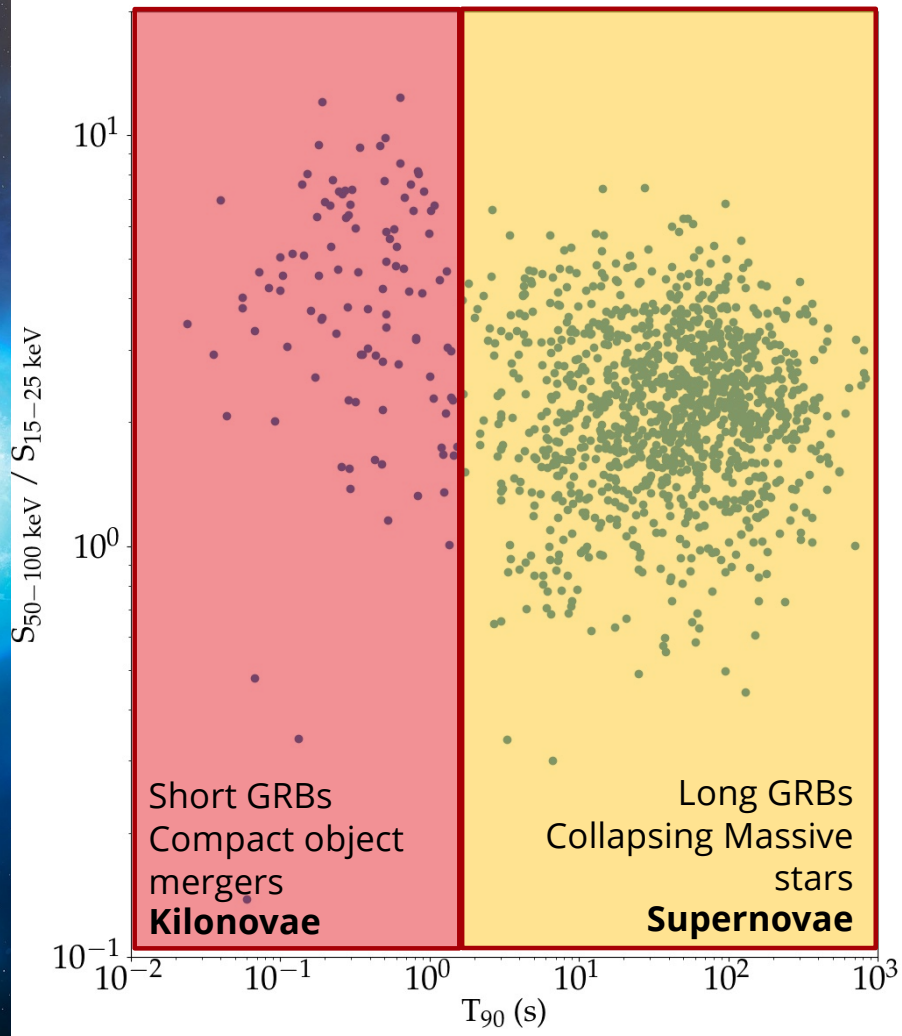
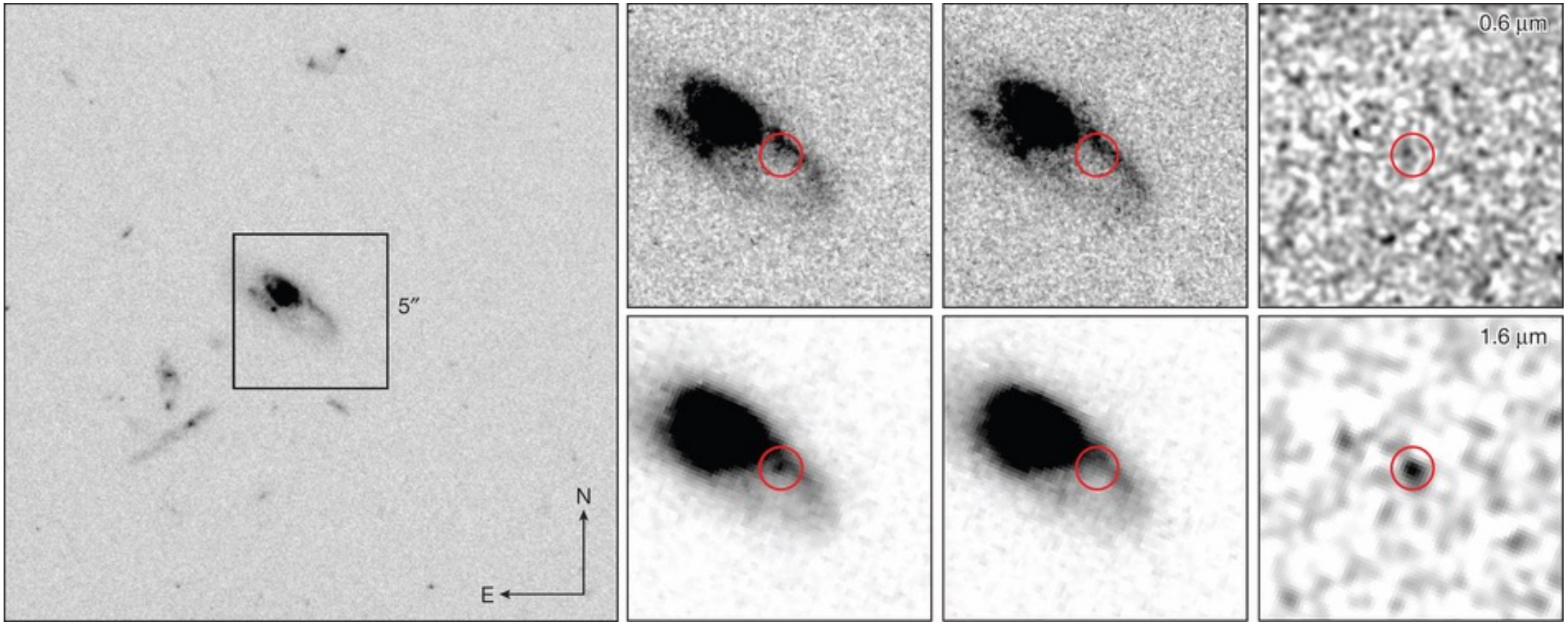


The classical GRB progenitor paradigm



Short GRB progenitors – kilonovae



Tanvir et al. 2013

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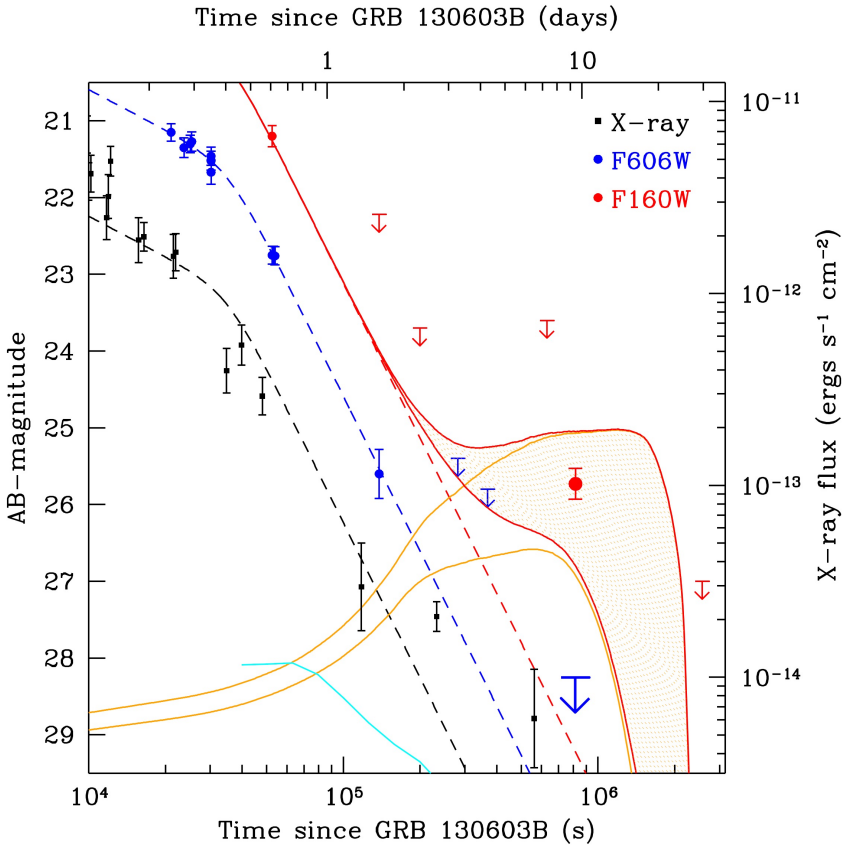
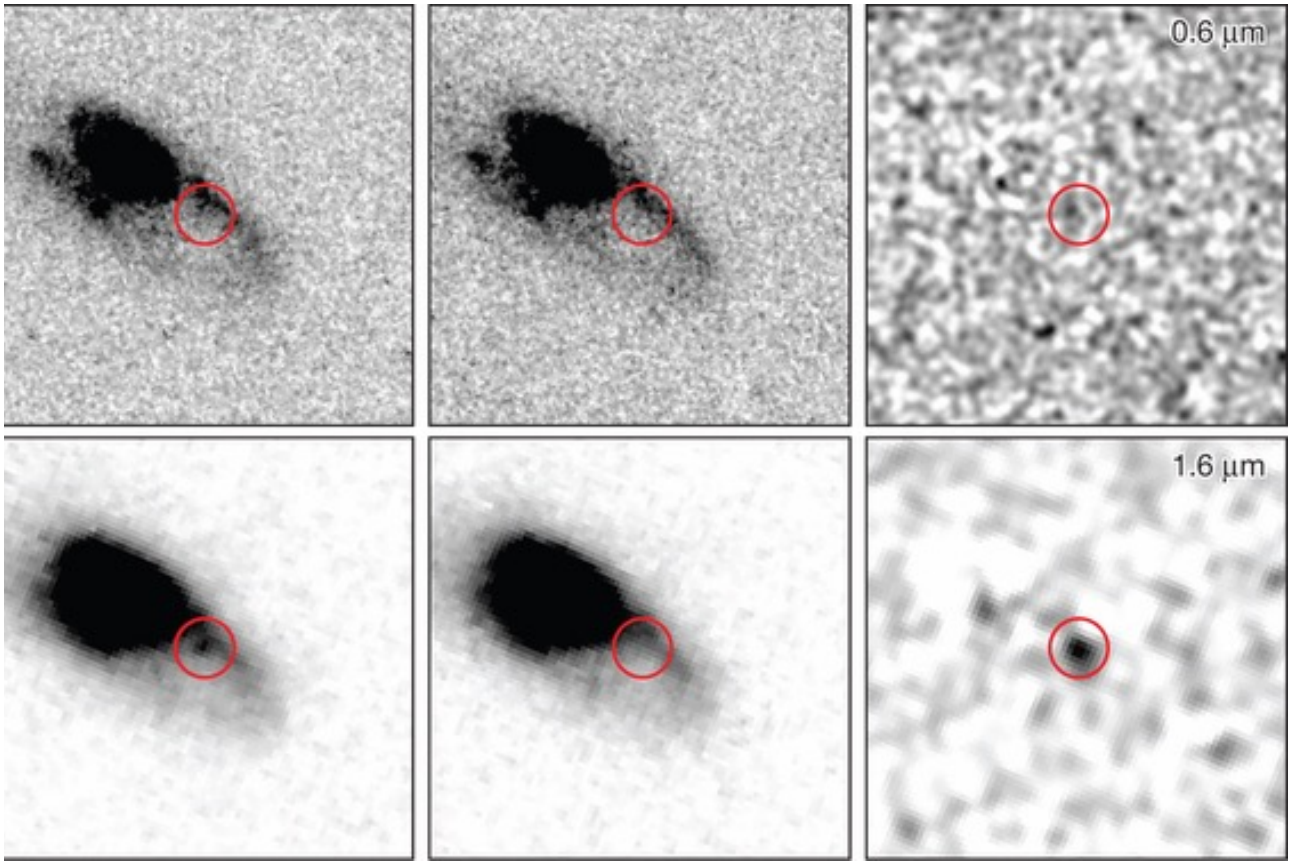
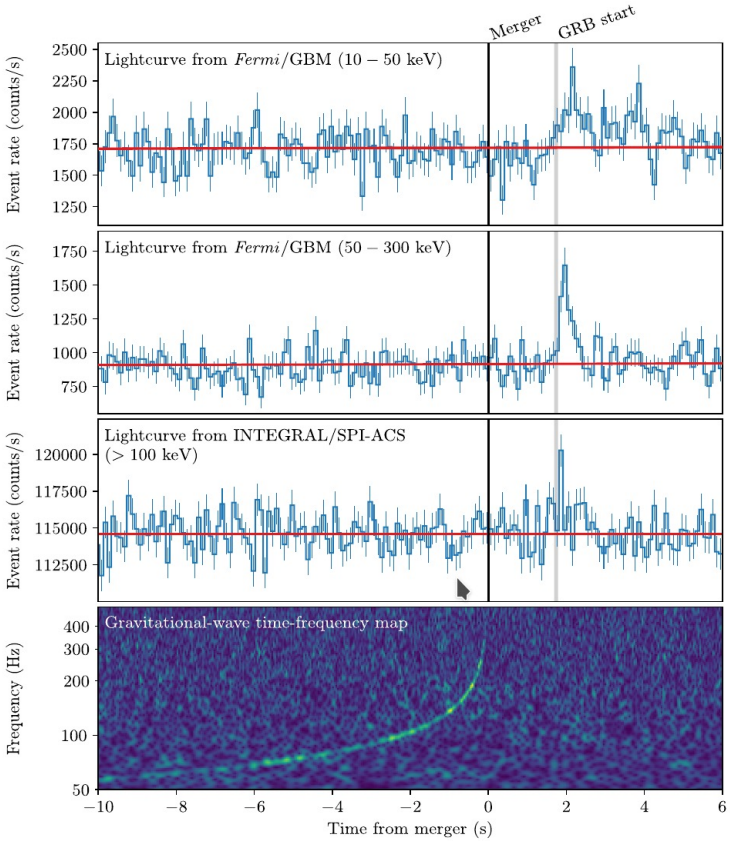
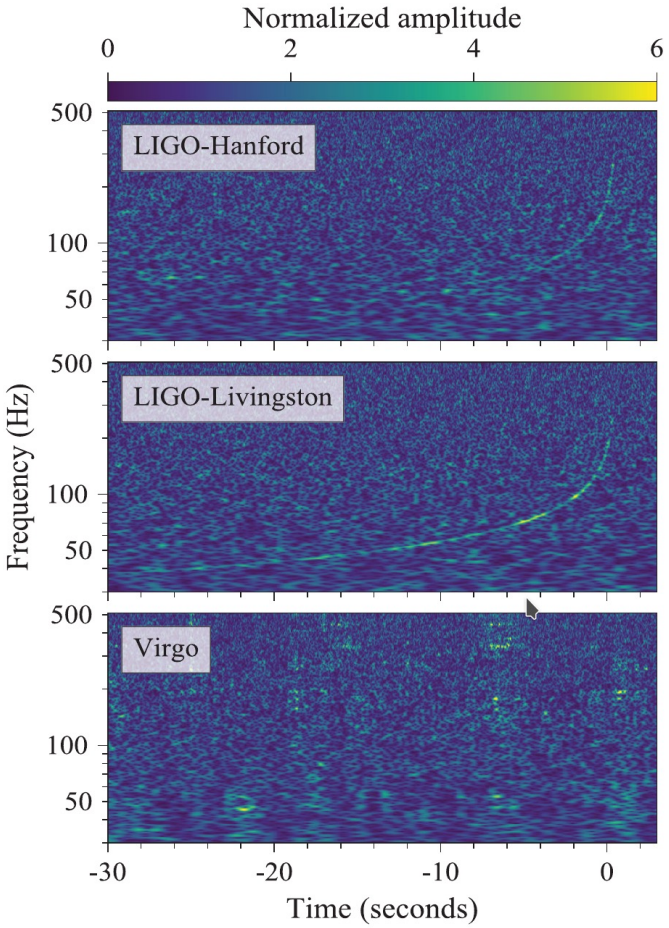


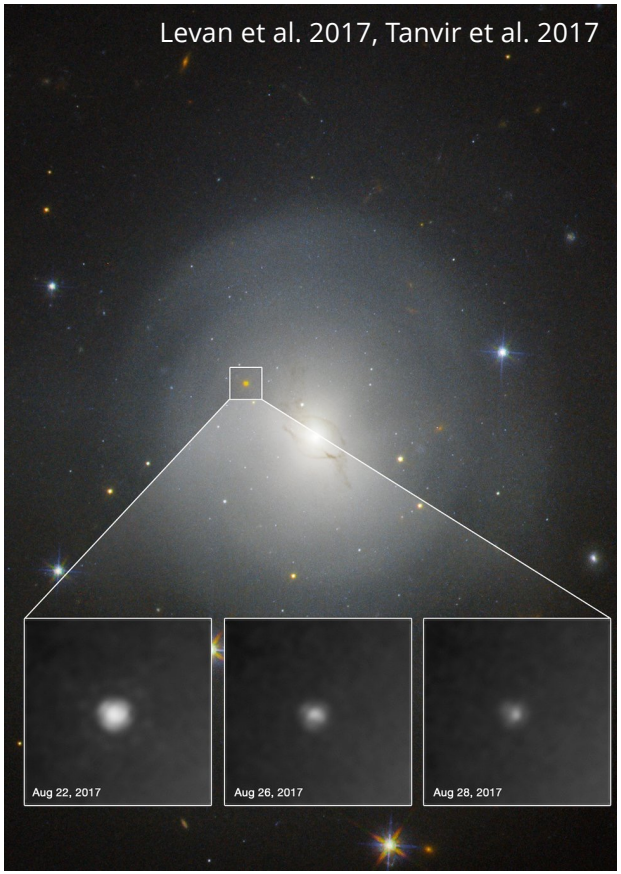


Tanvir et al. 2013

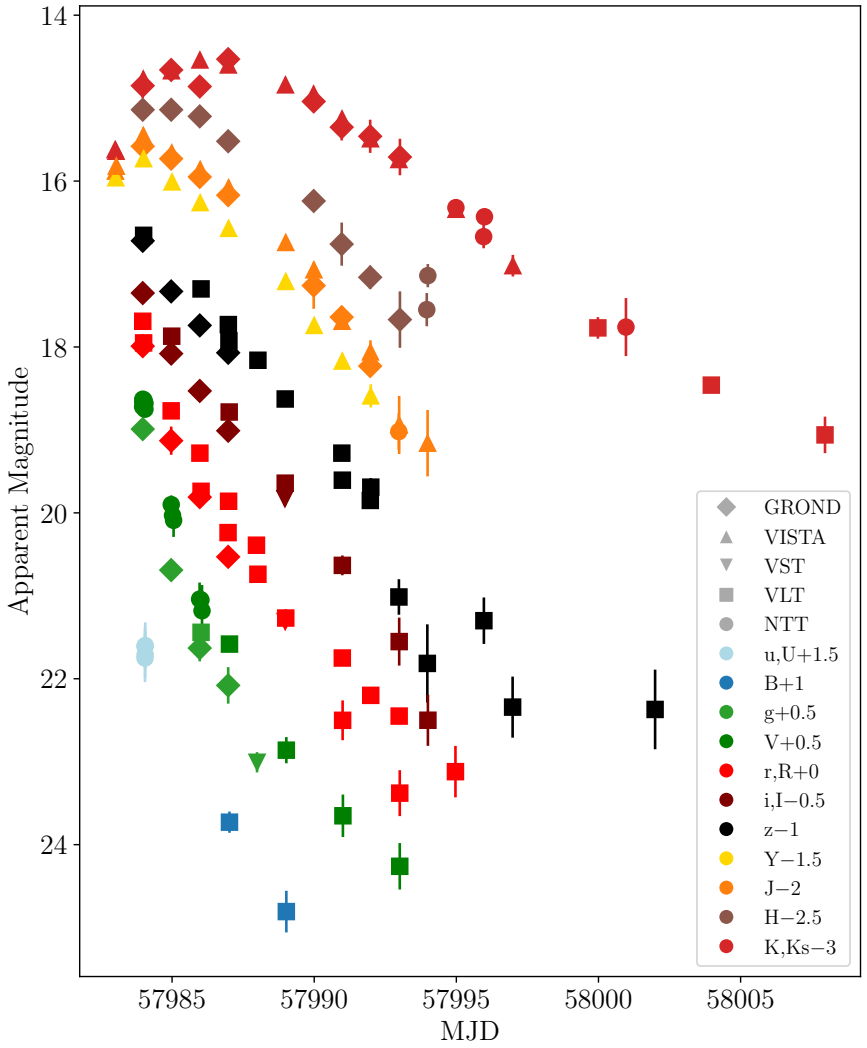
Short GRB progenitors secured

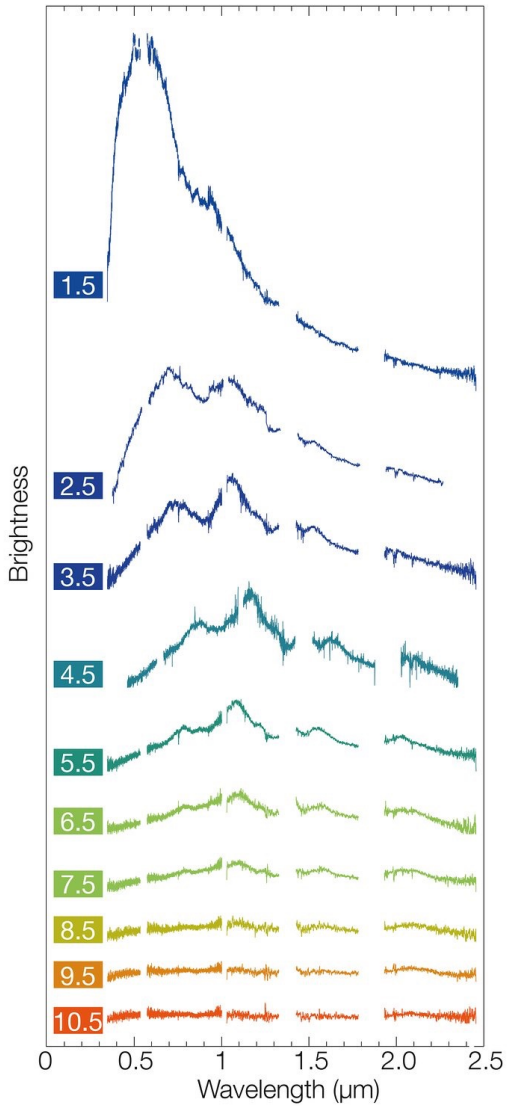






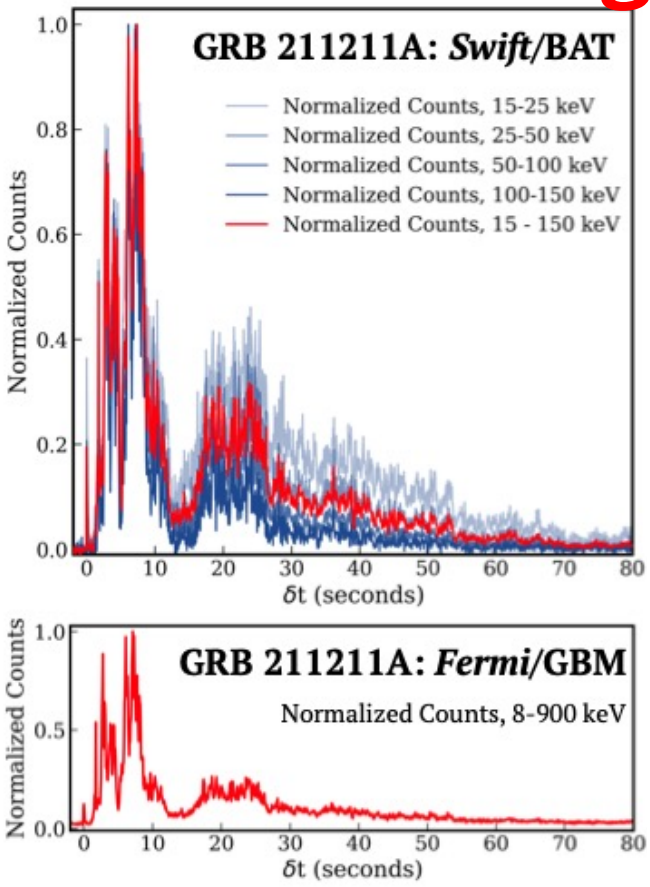
Abbott et al. 2017

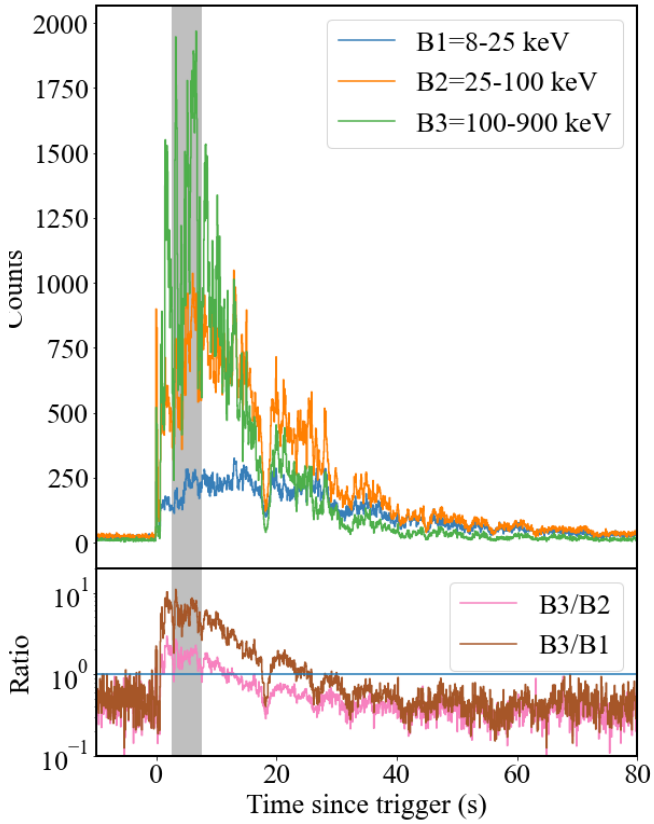


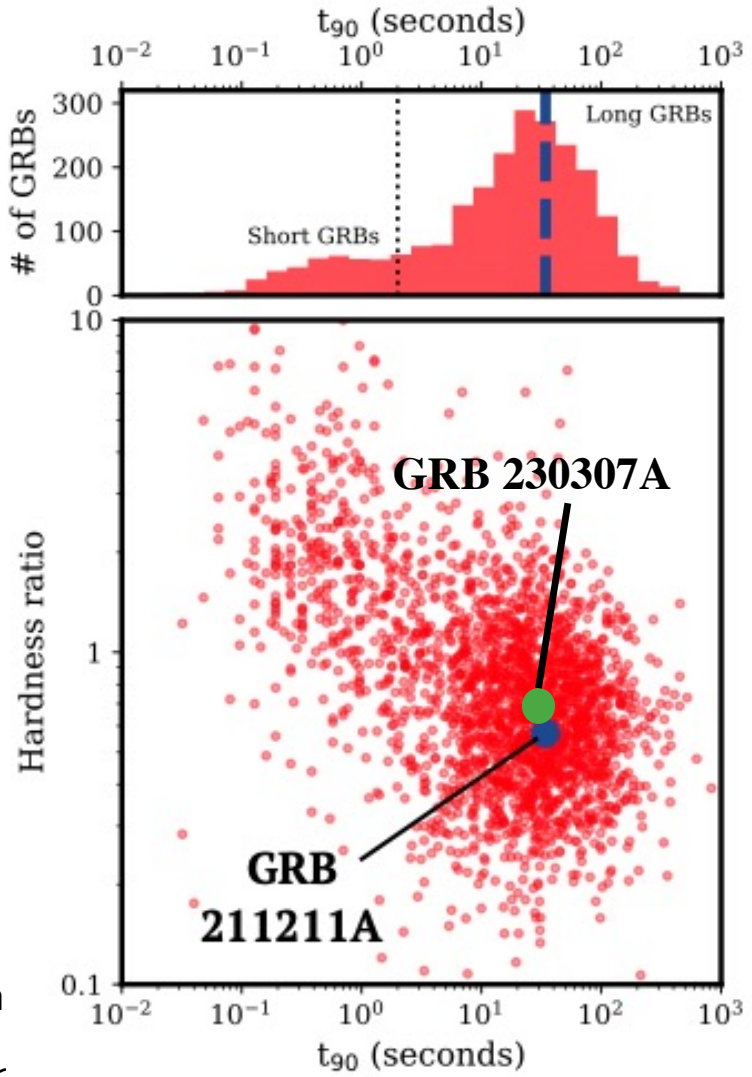


LVC et al. 2017 ApJL
See also:
Arcavi et al. 2017, Cowperthwaite et al. 2017, Chornock et al. 2017, Drout et al. 2017 Nicholl et al. 2017, Haggard et al. 2017, Hallinan et al. 2017, Kasliwal et al. 2017, Levan et al. 2017, Lipunov et al. 2017, Margutti et al. 2017, Smartt et al. 2017, Soares-Santos et al. 2017, Tanvir et al. 2017, Troja et al. 2017, Valenti et al. 2017

“Normal” long GRBs?

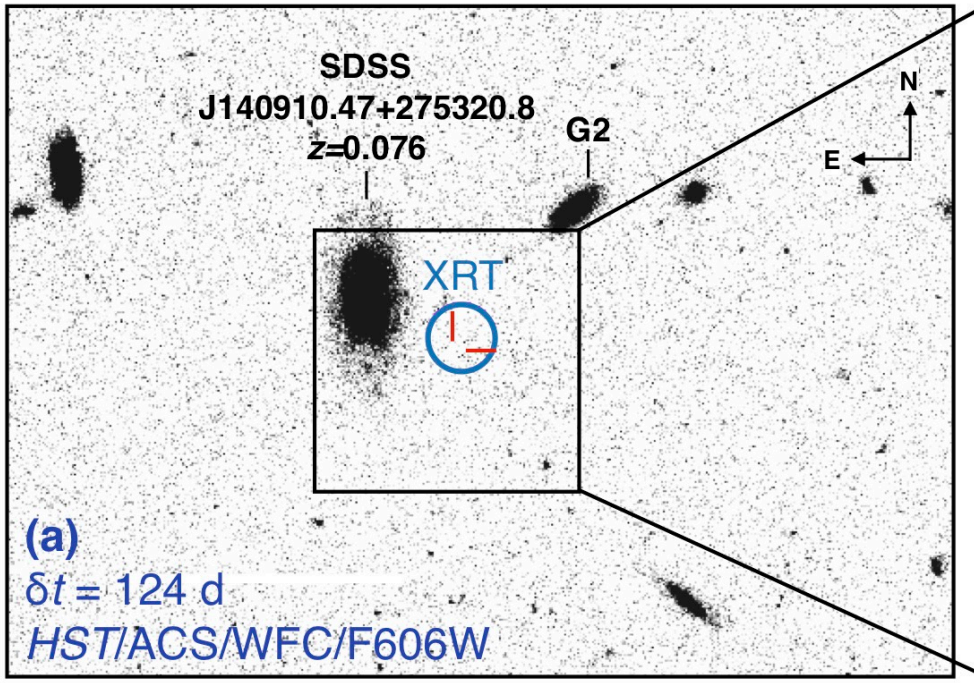


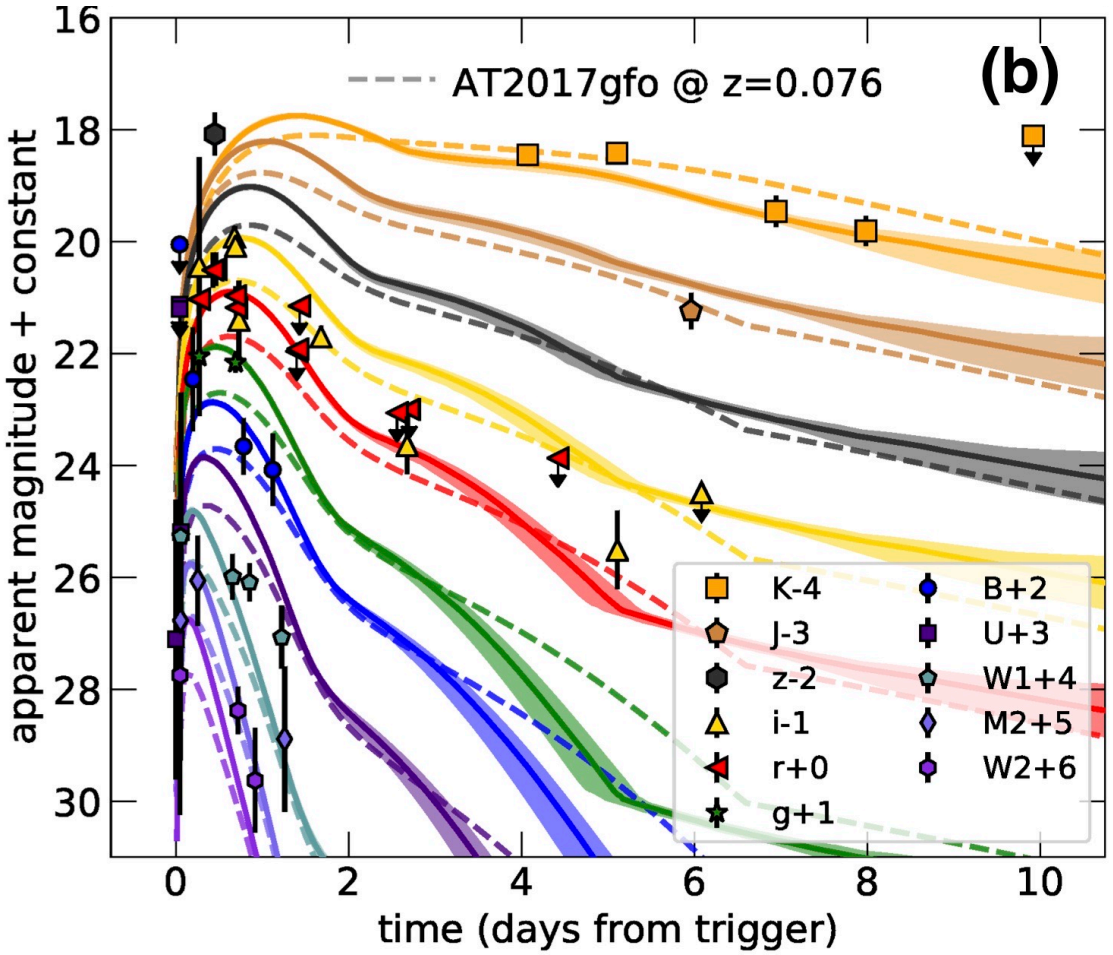




Rastinejad et al. 2022 Nature 612 223, Troja et al. 2022 Nature 612 228, Yang et a 2022 Nature 612 232, Levan et al. 2024 Nature 626 737 Yang et al. 2024 Nature 626 742 Sun et al. 2023 arXiv:2307.05689, Gillanders et al. 2023 arXiv: 2308.0063

GRB 211211A



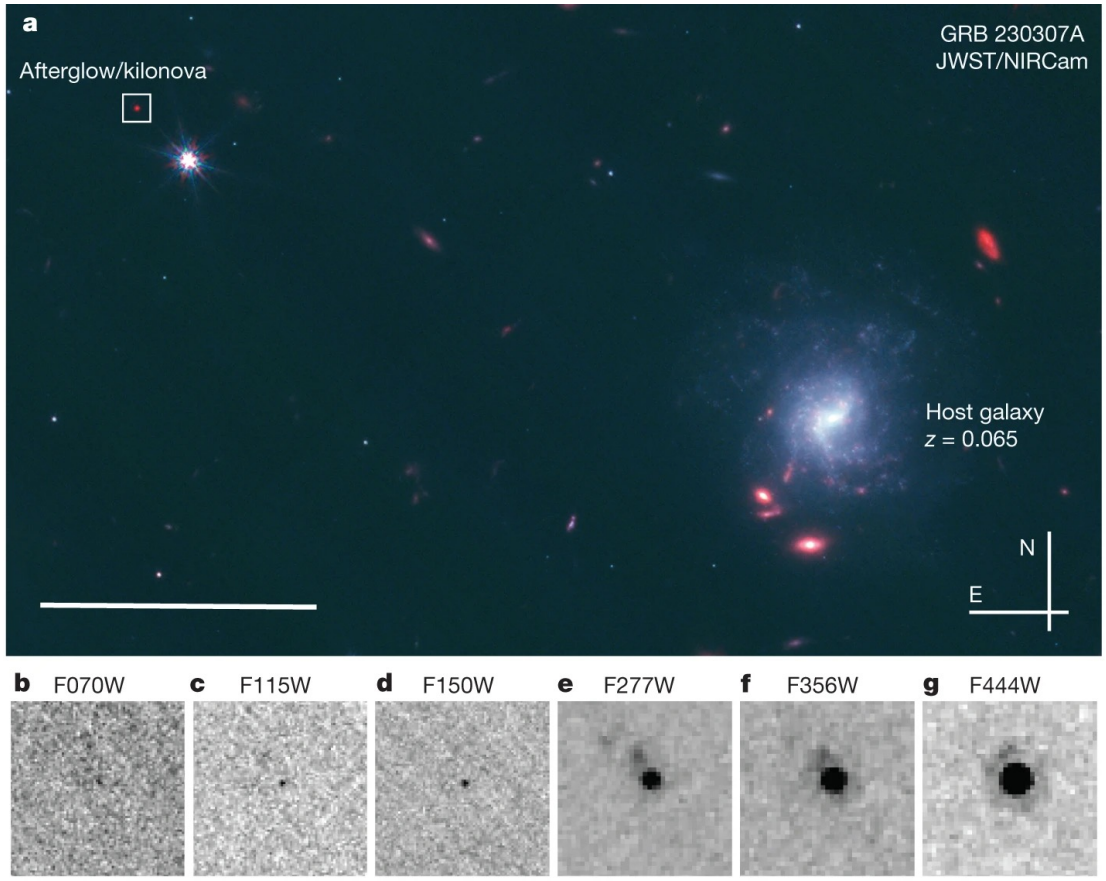


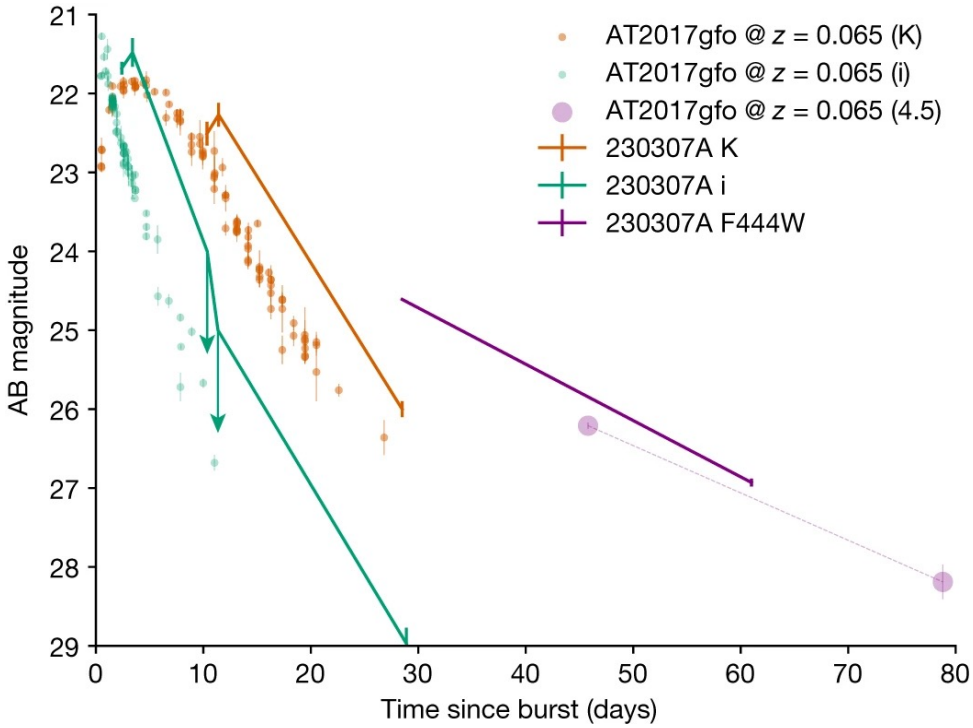
Long duration gamma-ray bursts can form kilonovae ➔ merging compact objects

Rastinejad et al. 2022 Nature 612 223, Troja et al. 2022 Nature 612 228, Yang et al. 2022 Nature 612 232

GRB 230307A

second brightest GRB of all time





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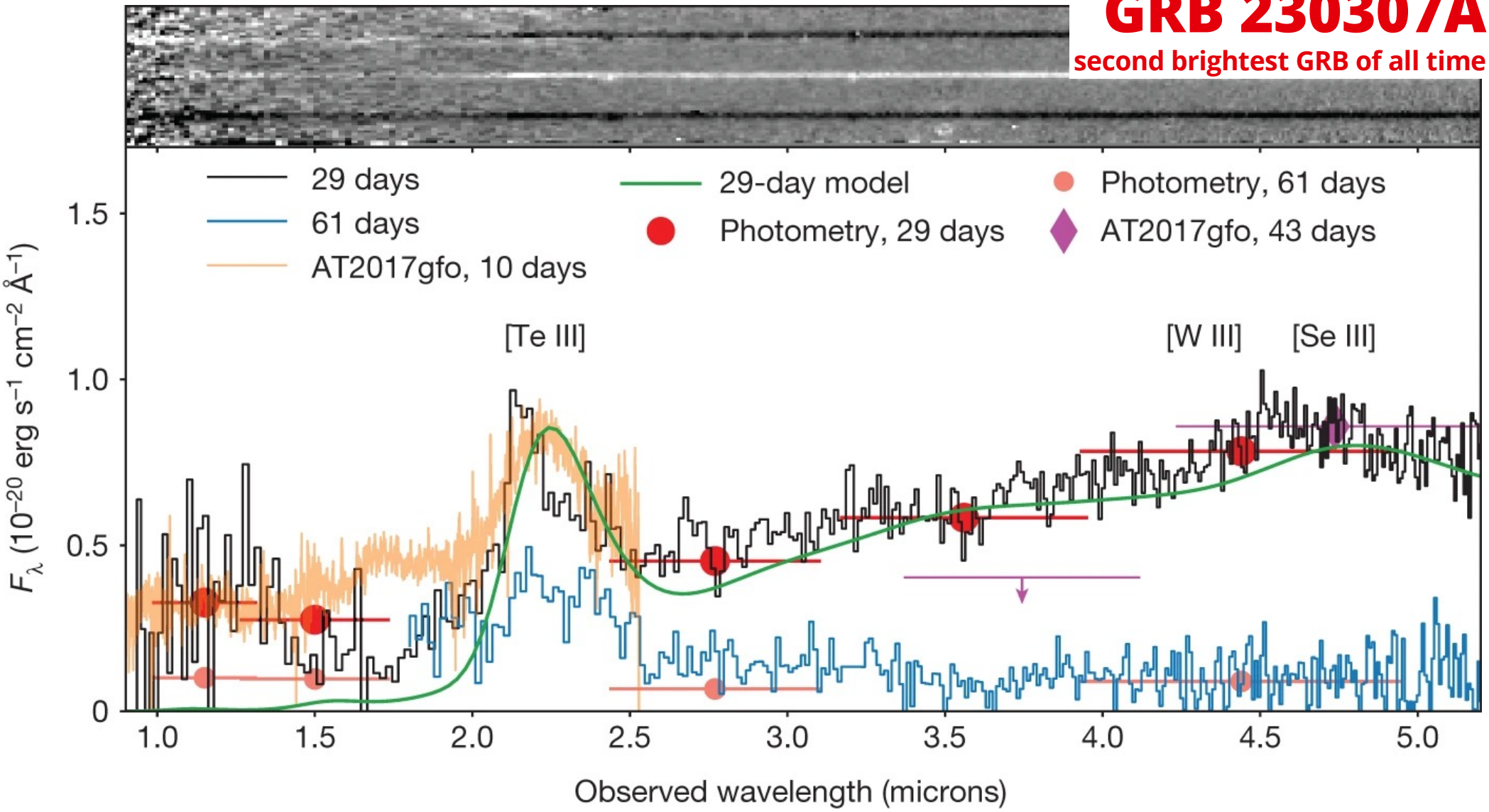
Levan et al. 2024 Nature 626 737

GRB 230307A

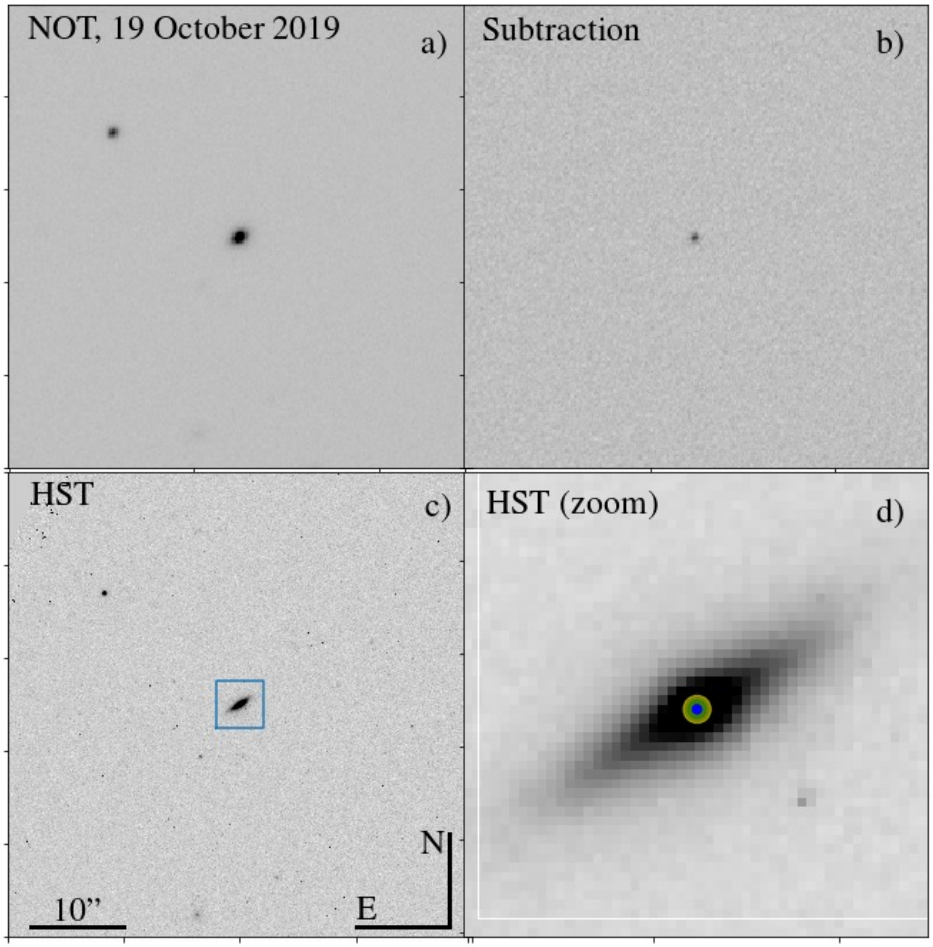
second brightest GRB of all time

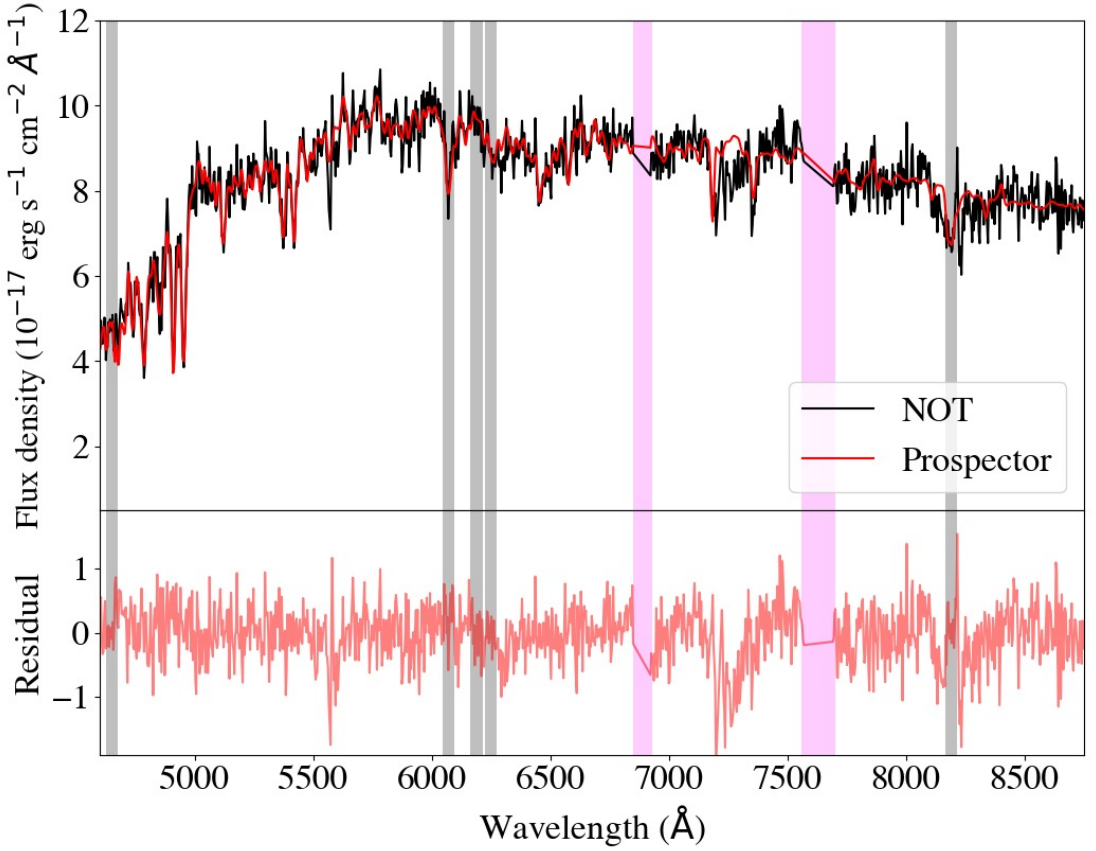


Levan et al. 2024 Nature 626 737, Gillanders et al. arXiv: 2308.00633

GRB 19109A

(T_{90} = 65s, no short spike, no supernova (<0.05 SN 1998bw)

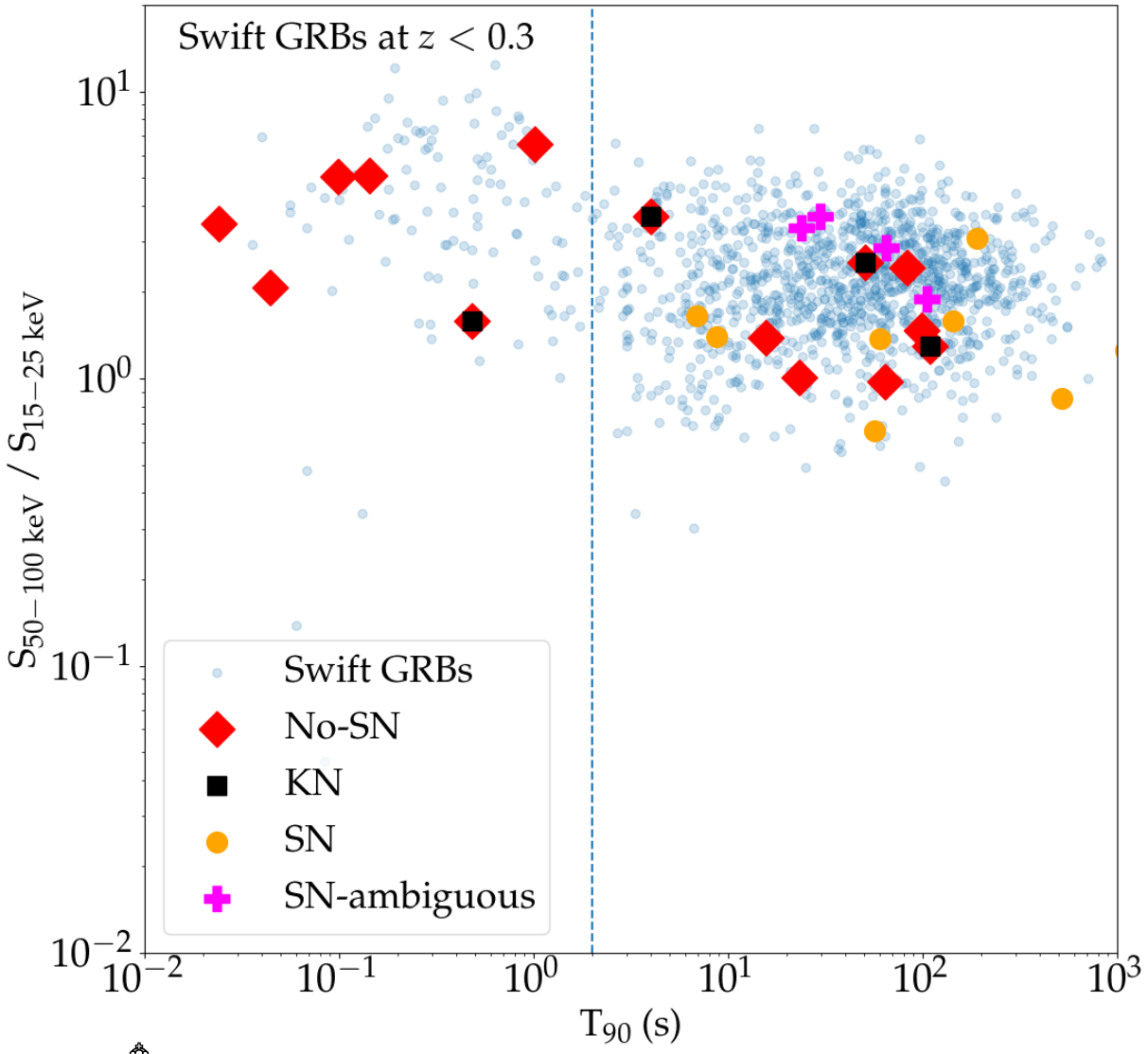




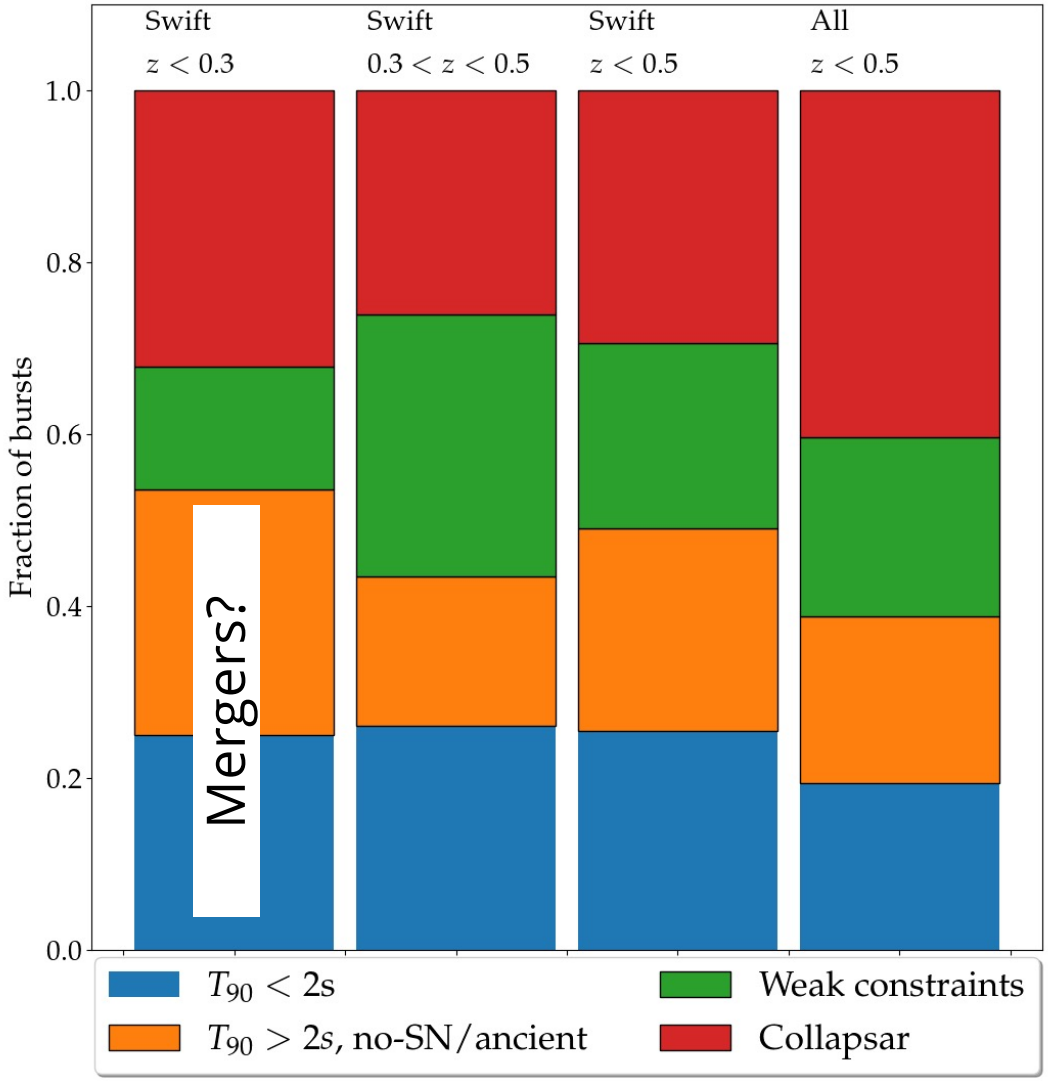
Is GRB 191019A the first example of dynamical merger? Is it in an AGN disc?

Levan et al. 2023 Nature Astronomy, 7, 976,Lazzati et al. 2023 ApJ 950 20

Long GRBs from mergers?



There can be a substantial contribution from compact object mergers to long GRBs



The population of mergers at relevant distances for GW detectors

400 Mpc – on-axis, BNS, LVK

GRB 170817A(S) – GW KN
GRB 111005A(L) – no SN
GRB 230307A(L) - KN
GRB 211211A(L) - KN
GRB 051109B(L) – no SN
GRB 060505(L) – no SN, possible KN

800 Mpc – on-axis, BH-NS, LVK

GRB 080905A(S) – no SN
GRB 150101B(S) – possible KN
GRB 050709(S) – no SN
GRB 060614(L) –possible KN
***GRB* 160821B(S) - KN**

Mostly detected by Swift, 1/6th of sky at any moment, 30% redshift complete. All sky rate likely 10-20 times higher.

Is the best route to getting more GW-EM events narrower deeper, further down luminosity function, or wider shallower but getting all events?

In the local Universe, there are more long GRBs possibly from mergers than short GRBs.

But rates start to become problematic with the non-detection of BNS mergers in O4

800 Mpc is also close to the limit where we might reliably find kilonova without precise positions, even with VRO/LSST.

Summary

GRBs were the first seen GW-EM signal (even if only by a few hours) and remain a prime route to identify multi-messenger signals

While a GRB time co-incidence alone is enough to claim association, the big gains come if GRBs can also provide precise localization => multi-wavelength counterparts, host galaxies, redshifts, energetics, cosmology etc etc.

Surprisingly, recent evidence suggests that long GRBs can also form via compact object mergers, and in the local Universe may contribute equally (or even more) than short GRBs to the volumetric rate.

Given beaming, it is likely that only a modest fraction of GRBs will be associated with GW events unless there is some broad or isotropic component. In the LVK era wide-field surveys for counterparts and kilonovae may be more important (but may also not be).

In the longer term future for Einstein Telescope/Cosmic Explorer GRBs are likely to be the tool of choice.