VULCANO WORKSHOP 2024

Frontier Objects in AstroPhysics and Particle Physics

May 26th - June 1st, Ischia, NA, Italy

Observations of Kilonovae

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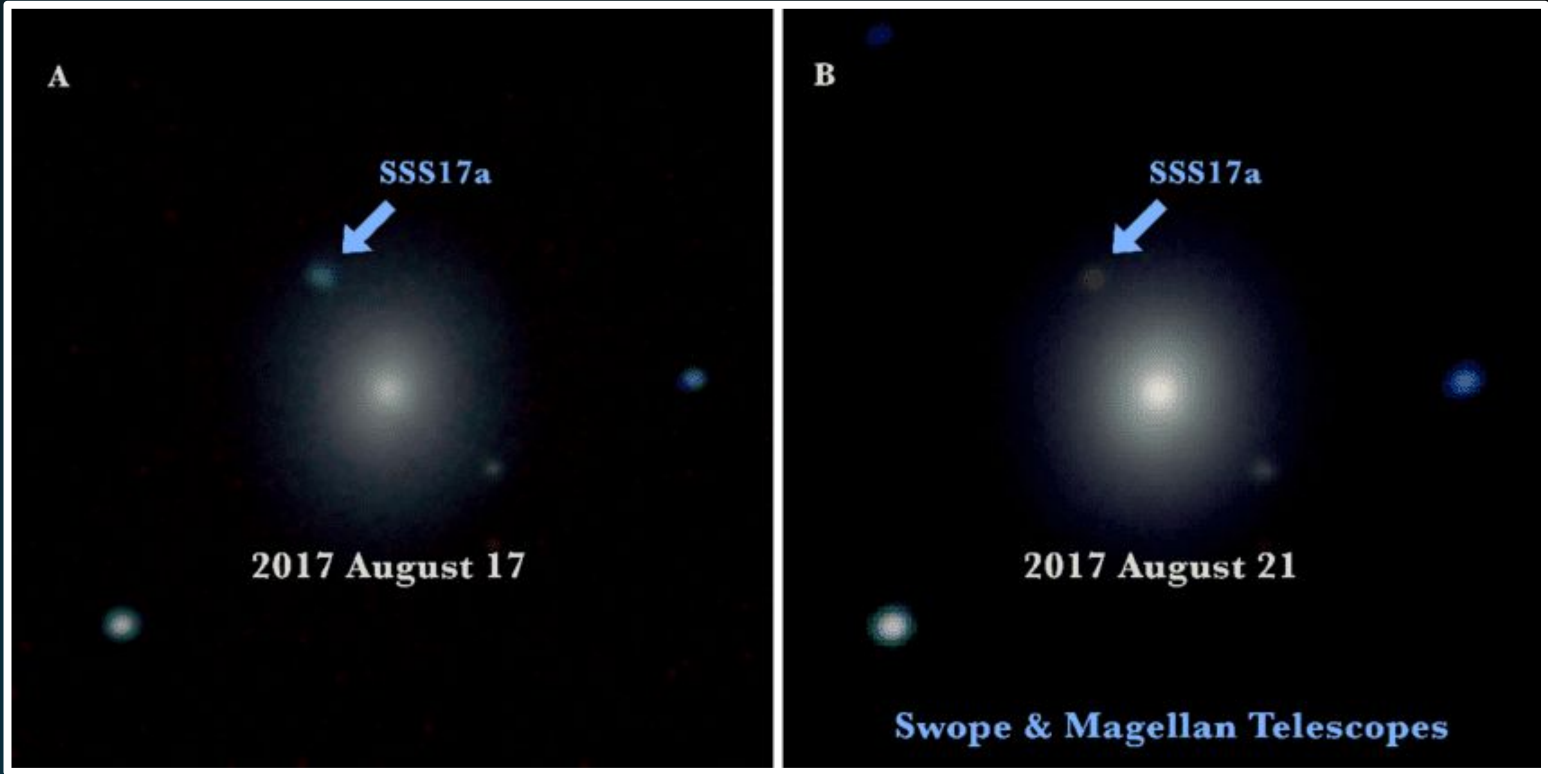
OAS BOLOGNA

cred. E. Holbeck

NSMs can make at least the lanthanides (*r*-process elements)



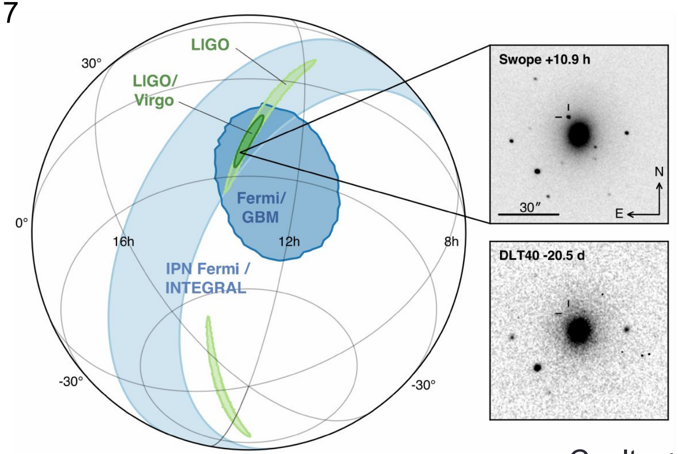
Villar+ (ApJ, 2017)

Lawrence Livermore National Laboratory

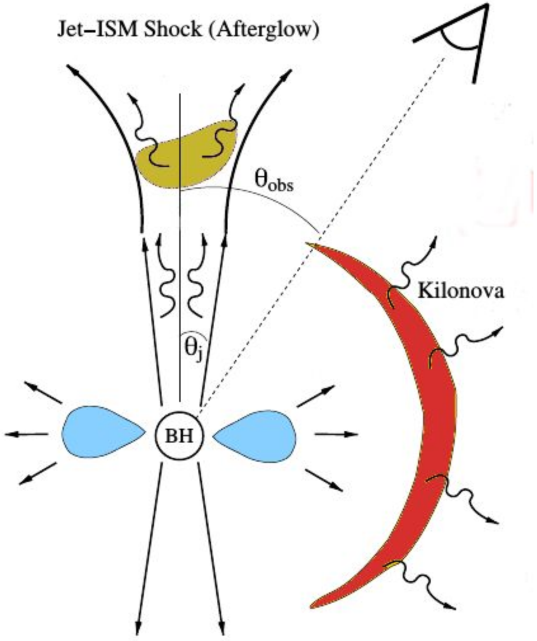
Gamma ray bursts and mergers

Three-In-One Event:
GW 170817, a short GRB, and a kilonova

Abbot+17

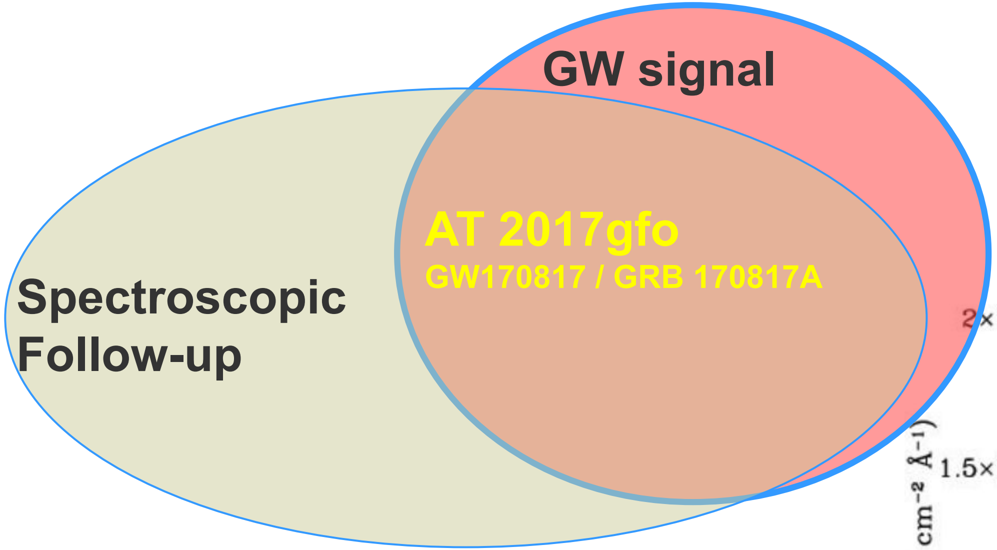


Coulter+17



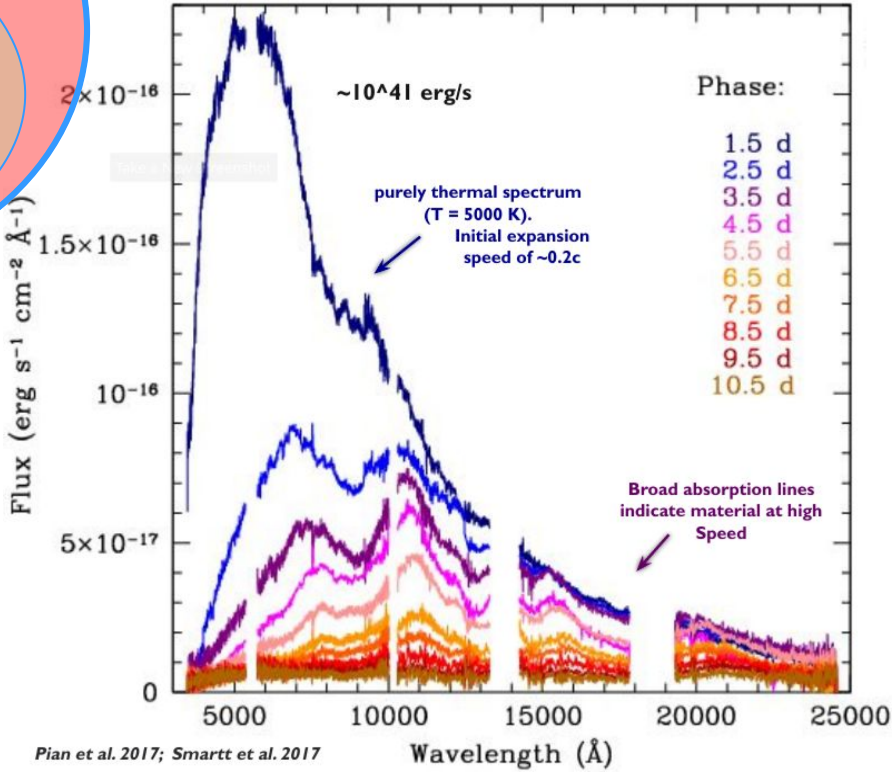
Metzger & Berger 2012

Discovery of the AT2017gfo



Kilonova (KN):

thermal emission powered by the radioactive decay of heavy elements formed via r-process nucleosynthesis



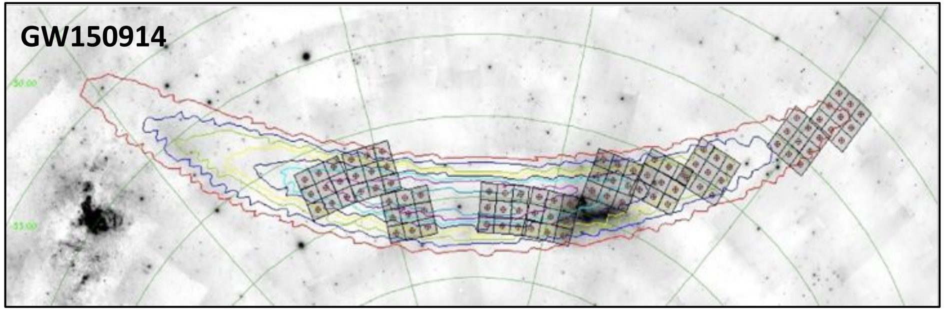
Pian et al. 2017; Smartt et al. 2017

Observational strategies to find EM counterparts

Expected multi-band follow-up counterparts are kilonovae and off-axis afterglows

1. **Tiling the GW sky localization area** using large FoV instruments

⇨ not optimal for faint transients

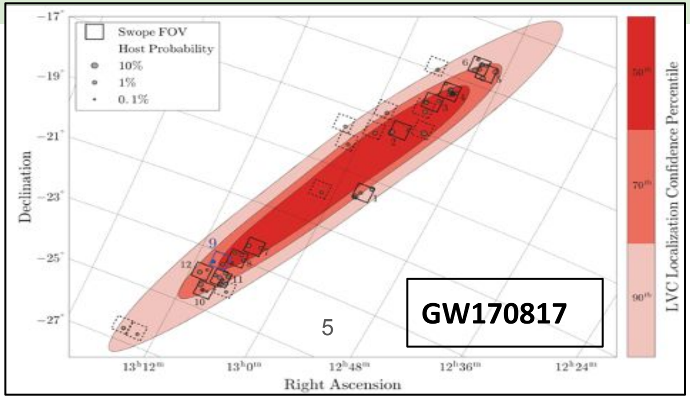


Brocato et al. 2018

Example of 90 deg^2 coverage with the VLT Survey Telescope of the 310 deg^2 90% cred. Area of GW150914 at 410 Mpc

2. **Galaxy Targetting** using small FoV instruments

⇨ biased by galaxy catalog completeness



Coulter et al. 2017

Example of galaxy targeting with 1-mt class telescope within the 31 deg^2 90% cred. Area of GW170817 at 40 Mpc

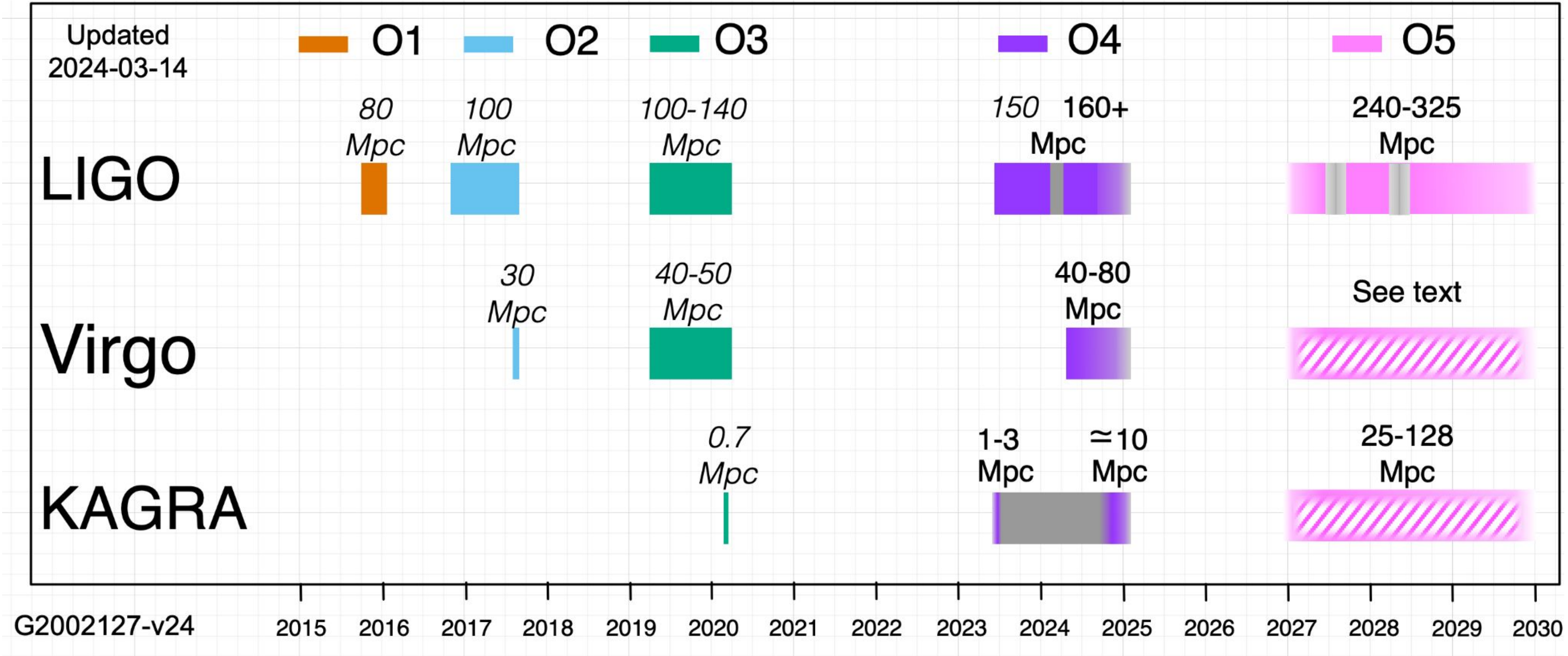
IDENTIFY THE E.M. COUNTERPART CANDIDATES OF GW SOURCES

LVK GW source sky localization still > tens of deg^2

Hundreds of optical candidates will be identify in sky surveys

Guaranteed telescope time to follow-up the most promising counterparts and characterize/ identify their nature

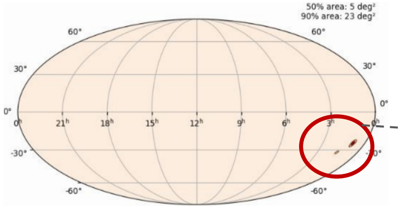
IDENTIFY THE E.M. COUNTERPART CANDIDATES OF GW SOURCES



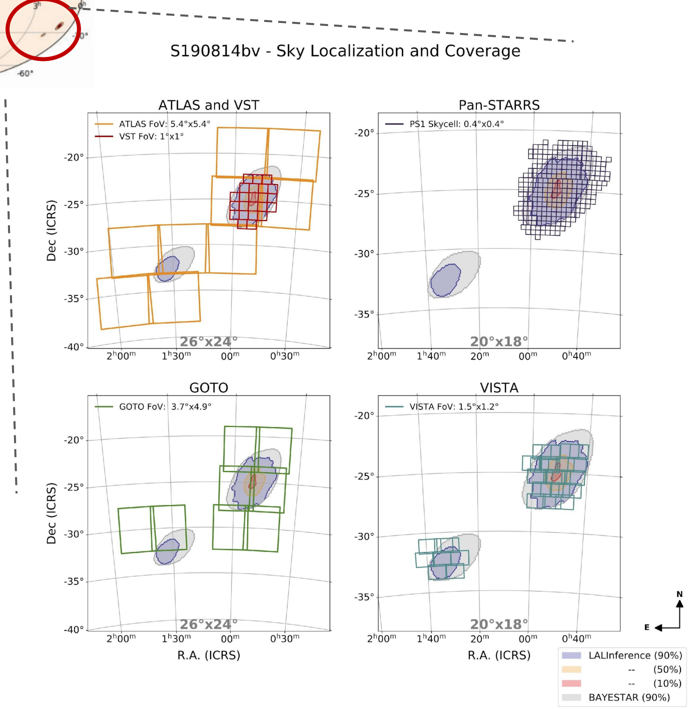
GW190814bv: NS-BH merger

Ackley et al. 2020 A&A 643, A113, including several OAS members

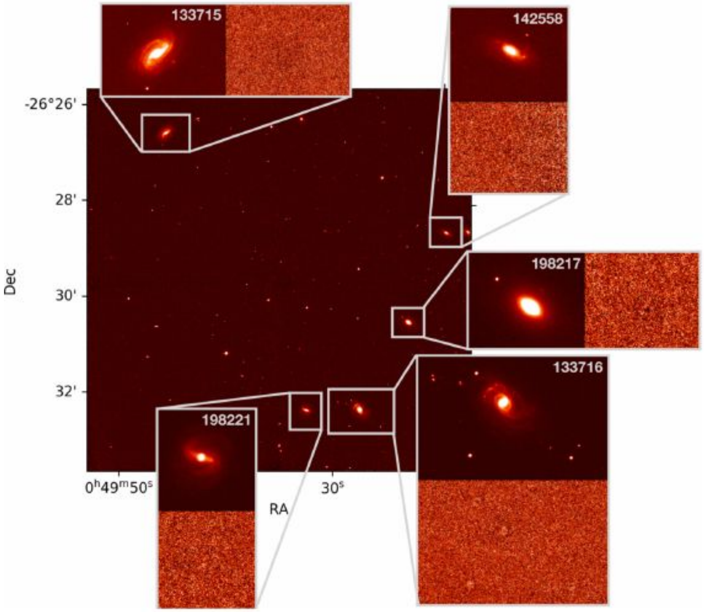
large distance 267±52 Mpc



Wide-field survey



Targeted search of galaxies



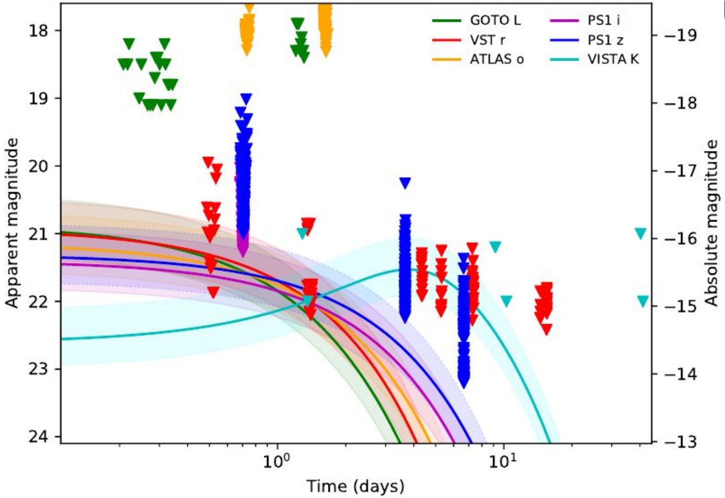
GW190814bv: NS-BH merger

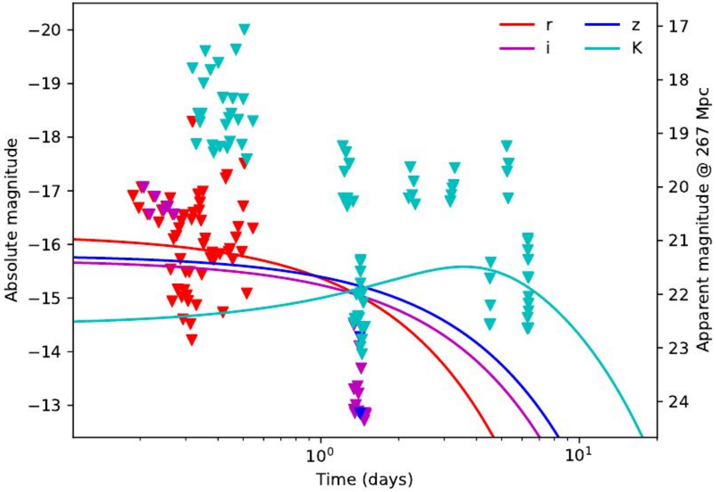
Ackley et al. 2020 A&A 643, A113, including several OAS members

Wide-field survey

Targeted search of galaxies

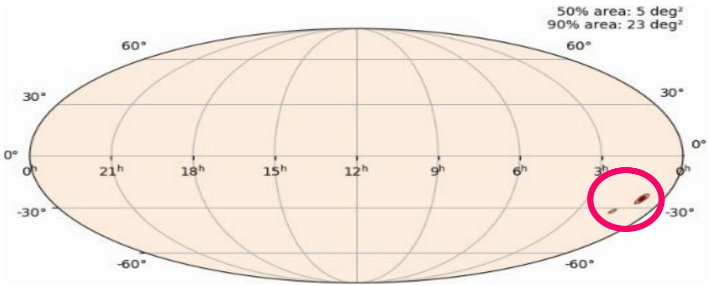
Upper limits compared to AT2017gfo light curves



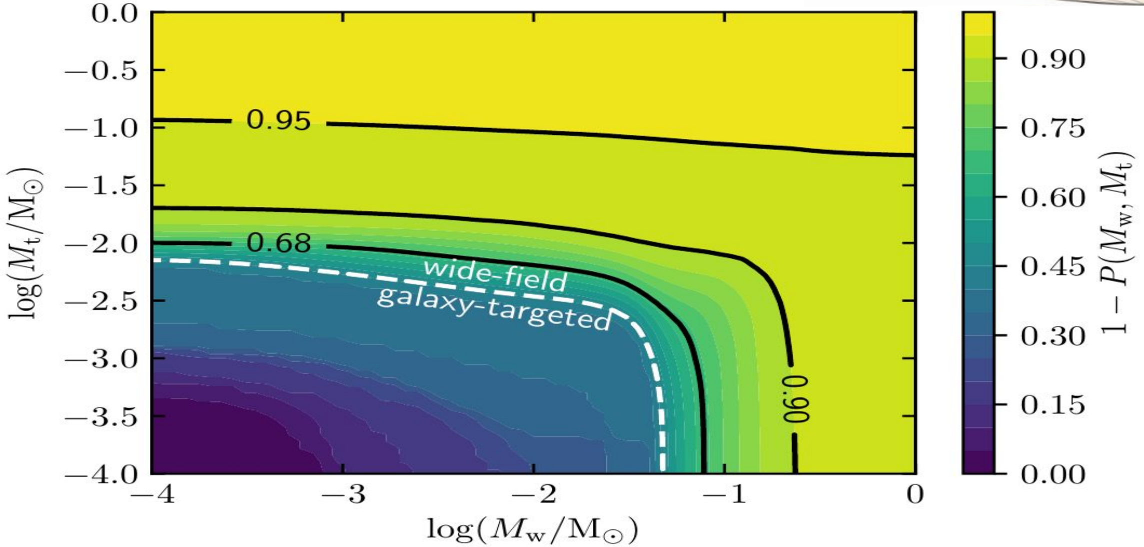


Exclude a KN with large ejecta mass M>0.1 Msun
no AT2017gfo but some brighter GRB/KN

RESULTS GW190814bv (~270Mpc)



Lower mass



Tightest constrain

- **Limits on the tidal ejecta mass (Mt) and secular disk wind mass (Mw) obtained by comparing with the NS-BH KN model from Barbieri+19**

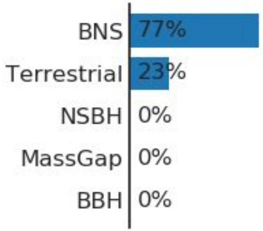
Ackley et al. 2020 A&A 643, A113
See also Thakur et al., 2020 MNRAS 499, 3868

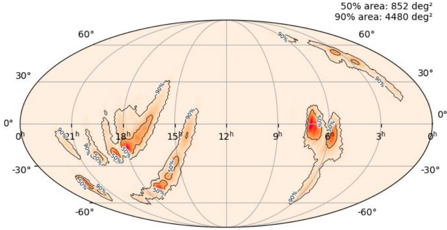
RESULTS S191213g

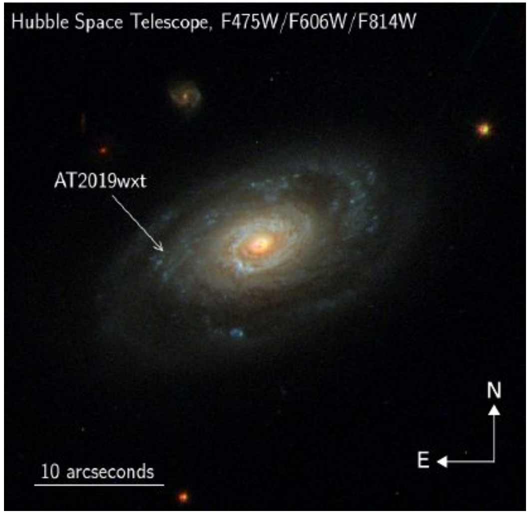
- BNS event at ~200 Mpc

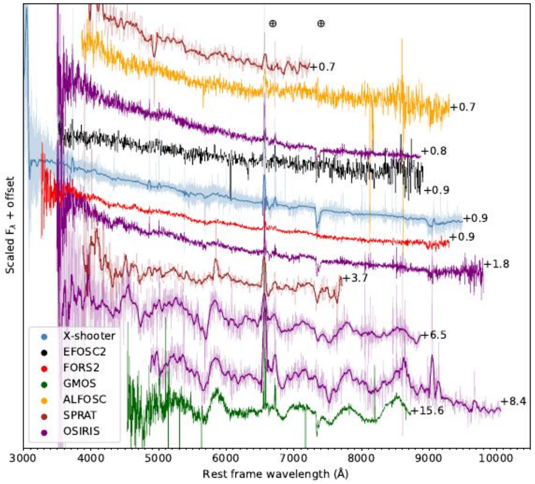
- **SN2019wxt:** ultra-stripped SN resulted from the s
  KN candidates discovered by Pan-STARRS1:

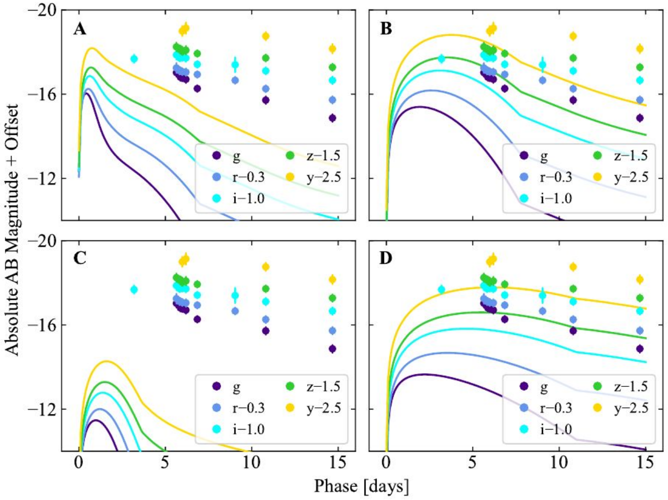
"Panning for gold, but finding helium"





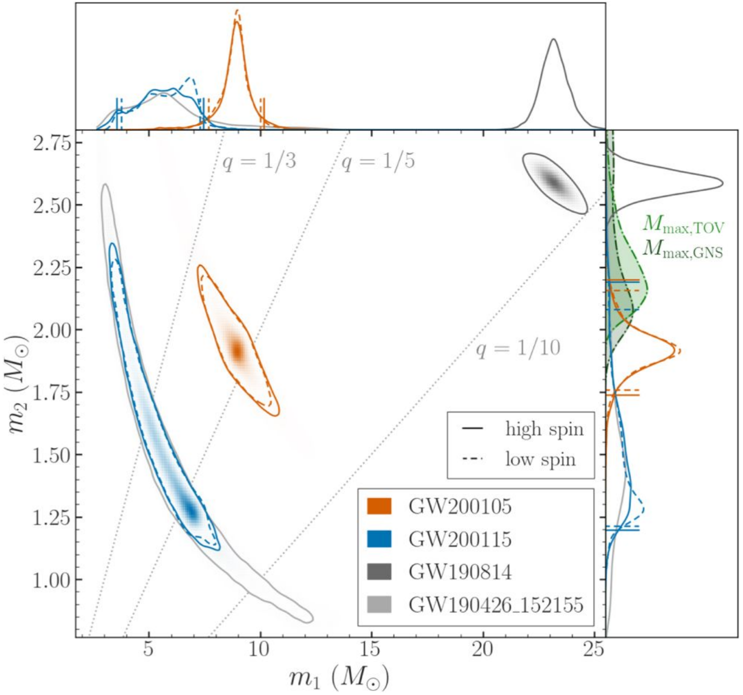




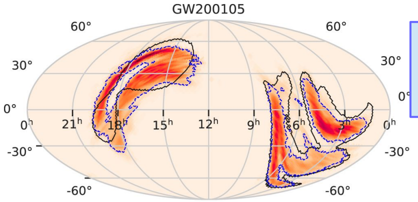


Agudo, et al.: A&A 675, A201 (2023)

First NSBH events: GW200115 and GW200105

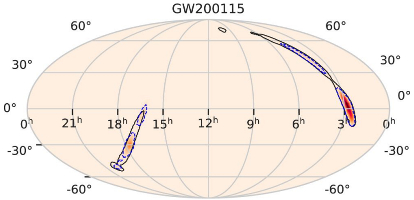


LVK 2021, ApJ, 915L, 5A



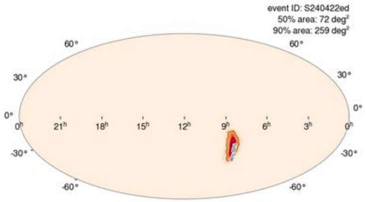
Initially: Terrestrial 97%
Large area

~300 Mpc



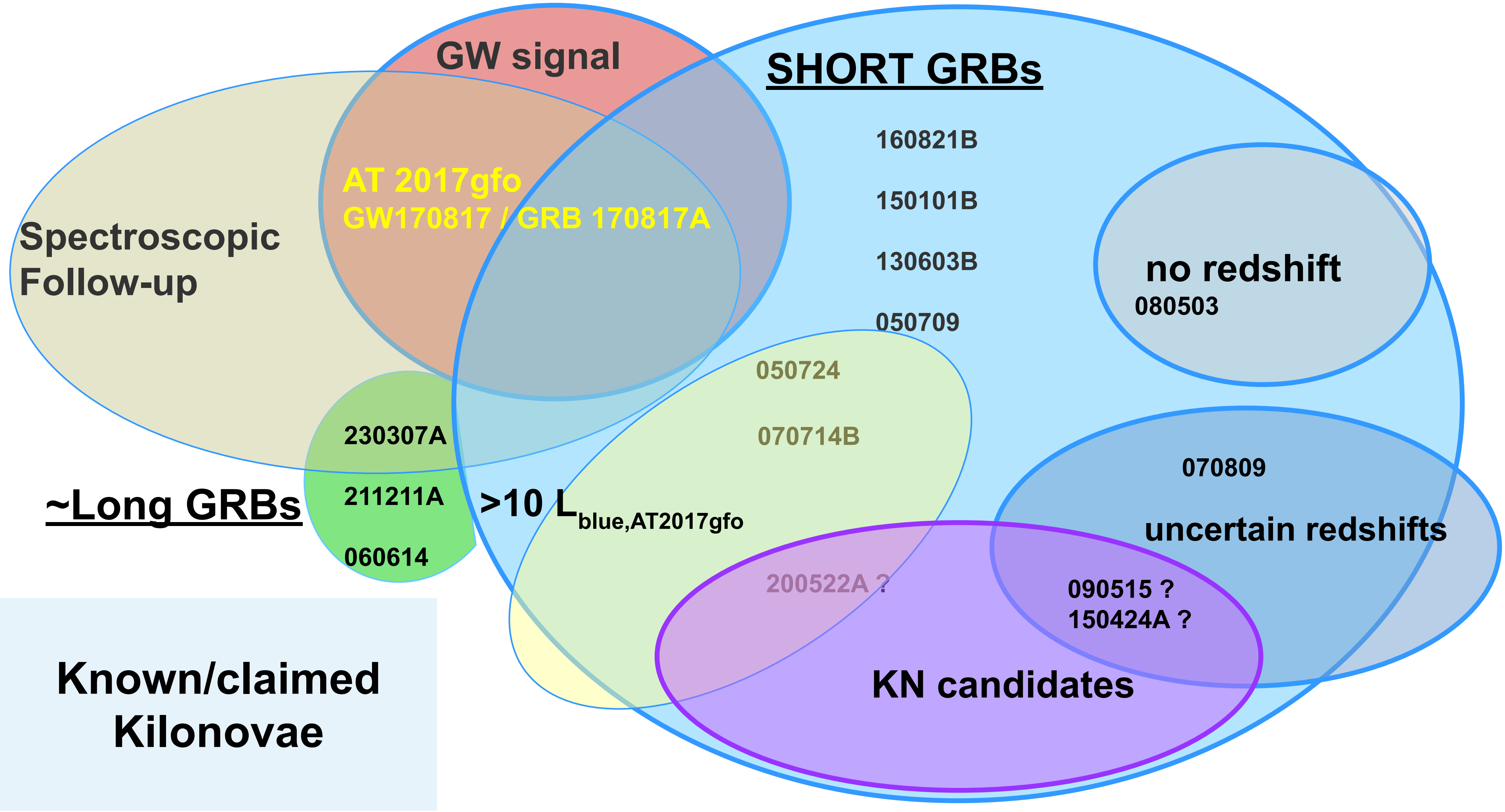
Initially: MassGap 99%
Bad observability from ground

Anand+21,: <50% EM coverage



AV>1 in most of the skymap

O4b:S240422ed



GW signal
SHORT GRBs
160821B
150101B
130603B
050709
AT 2017gfo
GW170817 / GRB 170817A
Spectroscopic
Follow-up
no redshift
080503
050724
070714B
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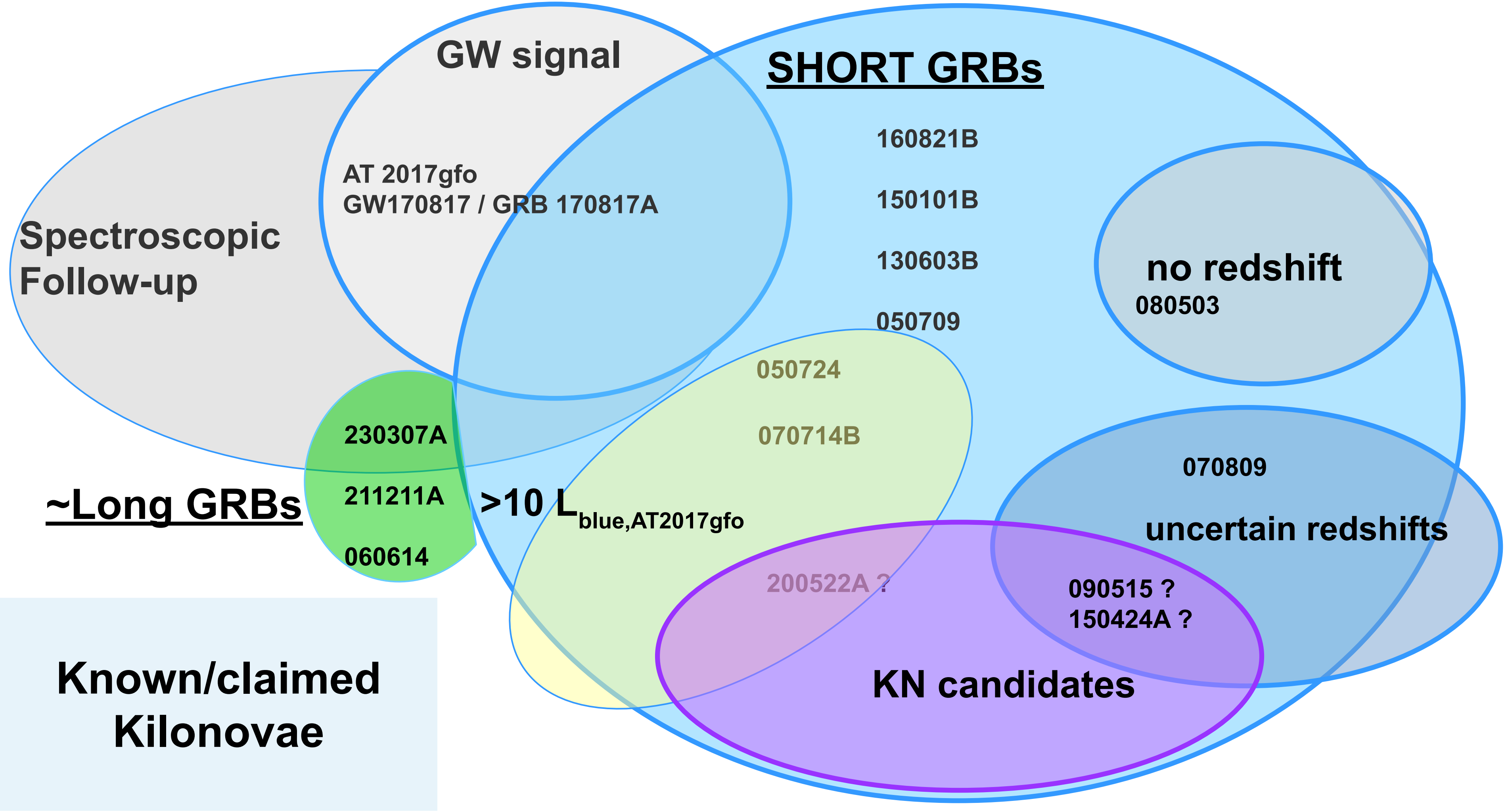
uncertain redshifts
200522A ?
090515 ?
150424A ?
KN candidates
Known/claimed
Kilonovae



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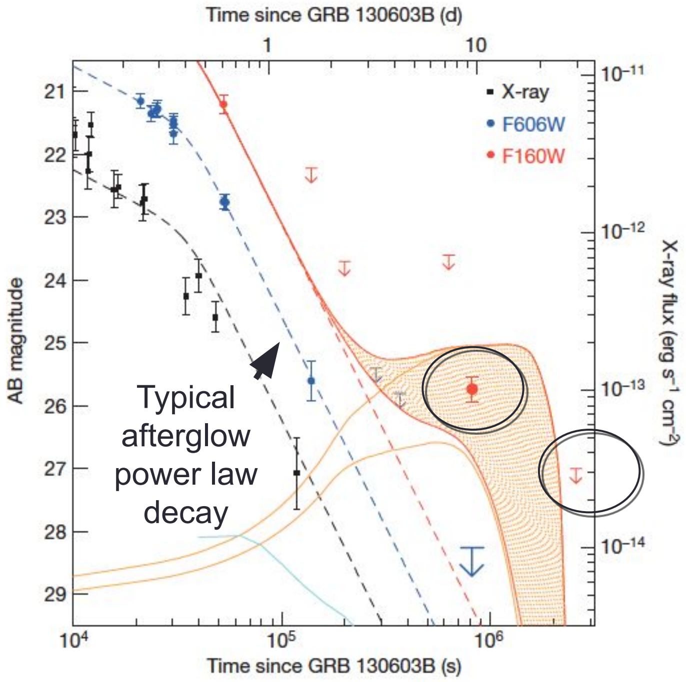
What can we learn from short GRBs

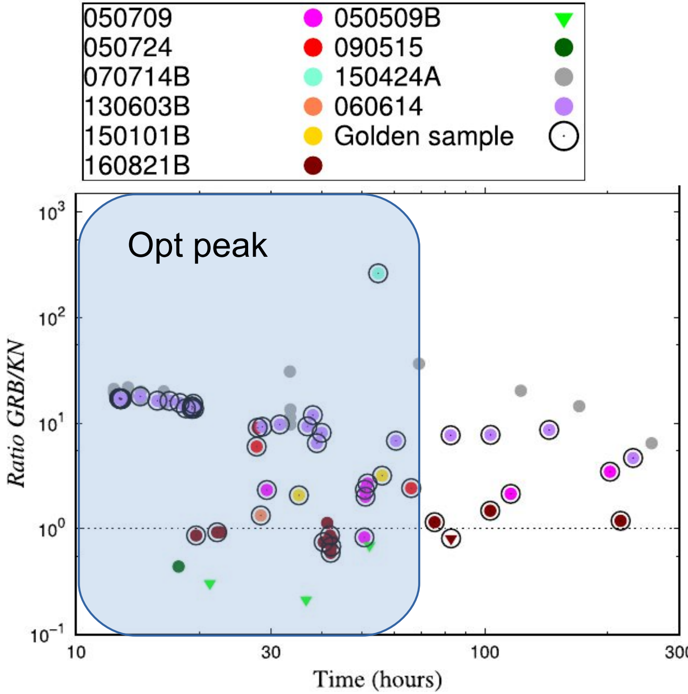


Tanvir+2013

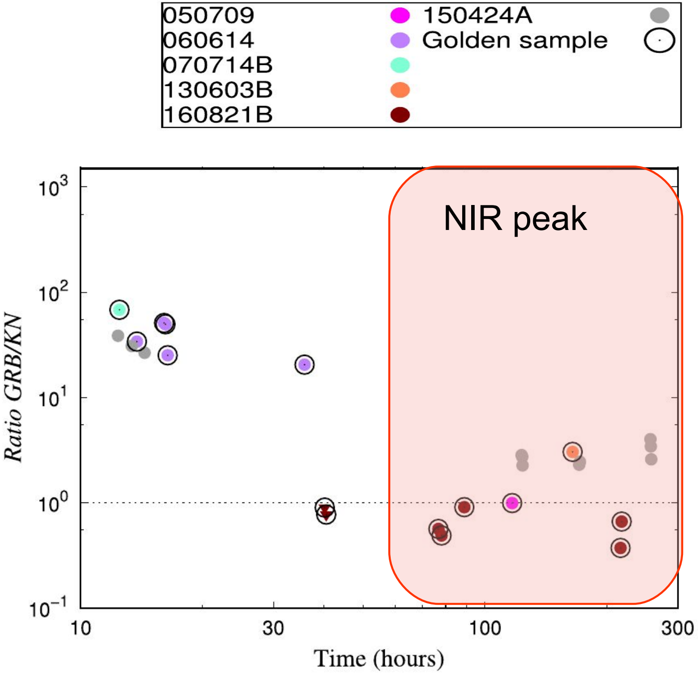
- Precise localization of the EM counterpart of BNS/NS-BH mergers.
- We know the inclination of the system!
- **The afterglow can dominate over the kilonova …**

  … but is at least possible to put constraints on KN properties

Constraints on kilonova properties



Cases with possible or confirmed KN



Large range of blue KN luminosity

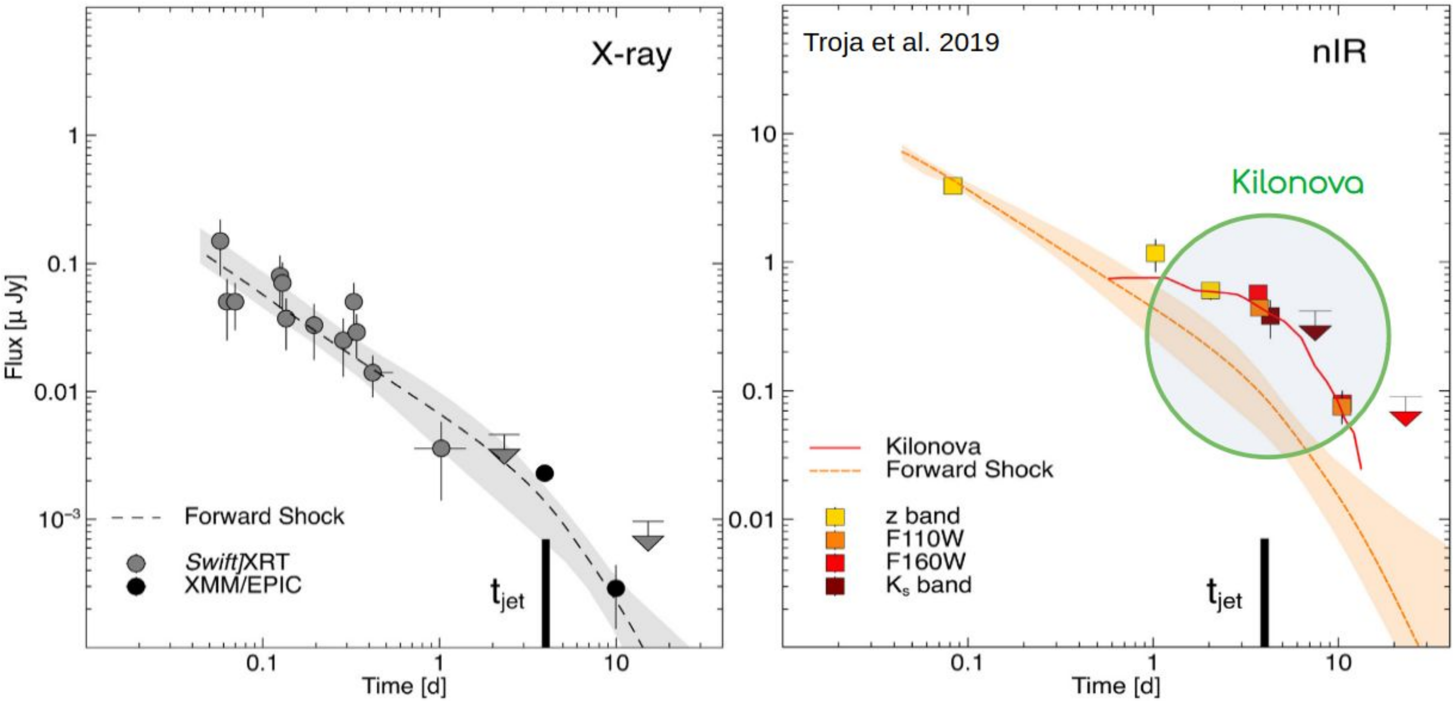
- NIR component similar to AT2017gfo

Rossi+20

Constraints on kilonova properties

Modelling of electromagnetic counterparts in the X-ray and UV/Optical/NIR bands

See also Ascenzi +19 on few cases



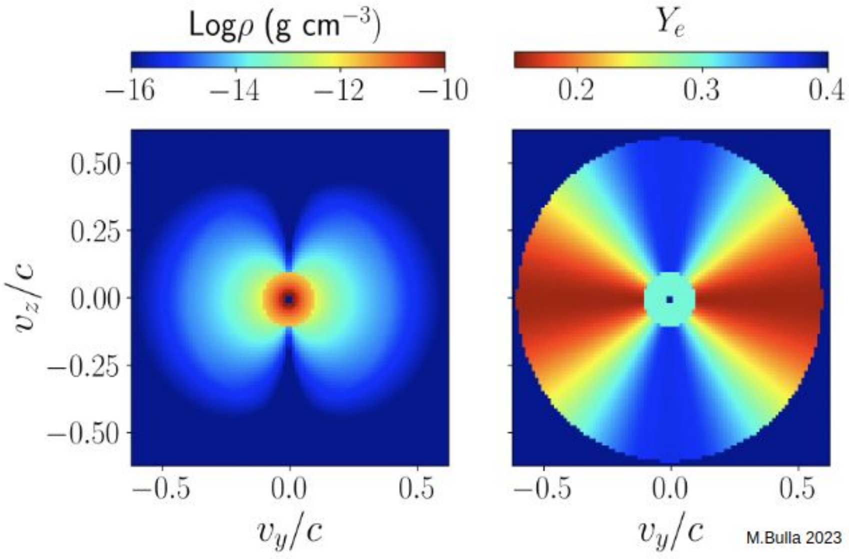
Future improvements: multi-wavelength modelling

State of the art models to explore the Kilonova parameter space, NMMA (pang+22), Redback (Sarin+23), Bajes (Breschi+21), see also xkn (Ricigliano+24)

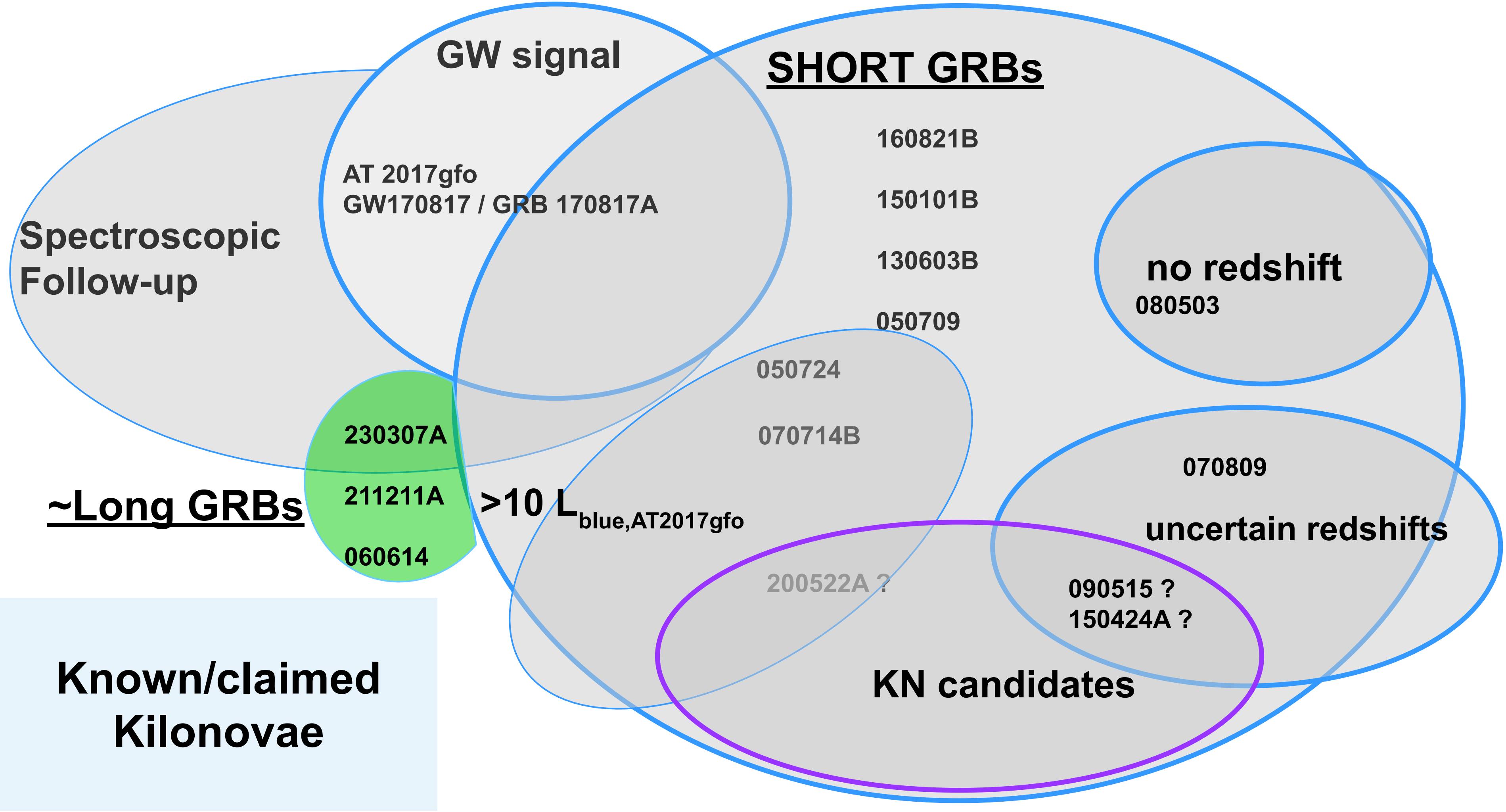
via e.g. POSSIS (Bulla, 2023), RT (Kawaguchi+21), Kasen+18, Wollaeger+21, Metzger (18) …

POSSIS

- 3D Monte Carlo radiative transfer code.
- Depends on the local values of density, electron fraction and temperature.
- Dynamical ejecta and post-merger disk wind.
- vwind = [0.05, 0.10, 0.15] c
- mwind = [0.010, 0.050, 0.090, 0.130] M☉
- vdyn = [0.15, 0.20, 0.25] c
- mdyn = [0.001, 0.005, 0.010] M☉
- Ye = [0.15, 0.20, 0.25]



Density and electron fraction distribution



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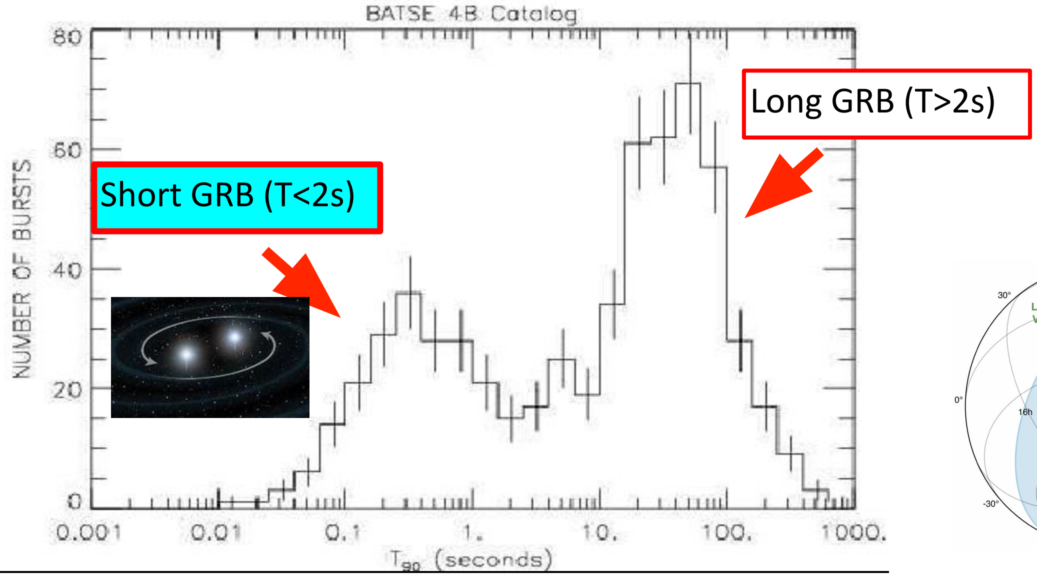
Gamma ray bursts and mergers

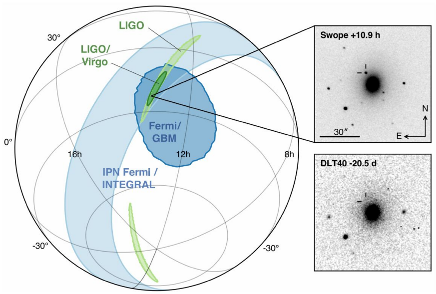
The burst duration shows a bimodal distribution interpreted to be (indirect) evidence of two classes of progenitors



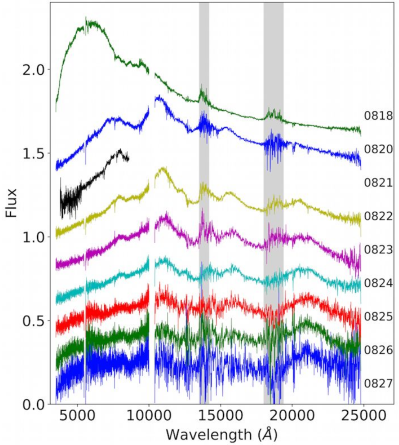
BATSE data *Kouveliotu et al. 1993*

The duration as indicator of the origin of a GRB

GRB 170817A, GW170817



Abbot+17



Pian et al., 2017

Coulter+17

Gamma ray bursts

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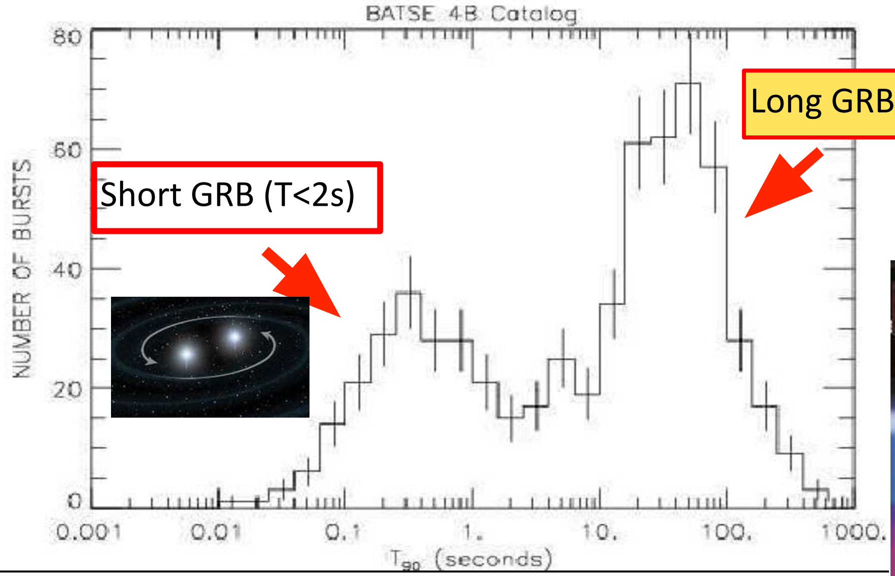
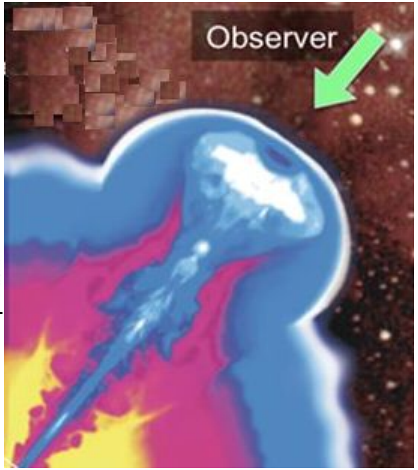


BATSE data *Kouveliotu et al. 1993*

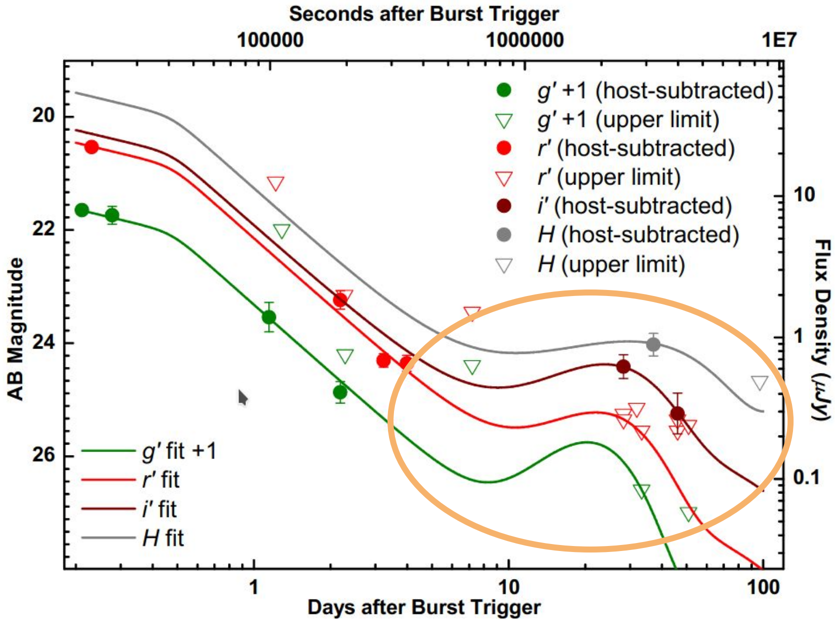
Is the simple duration an indicator of the origin of a GRB?
The 2 distributions overlap
(e.g., Horvath+02, Levesque+10)

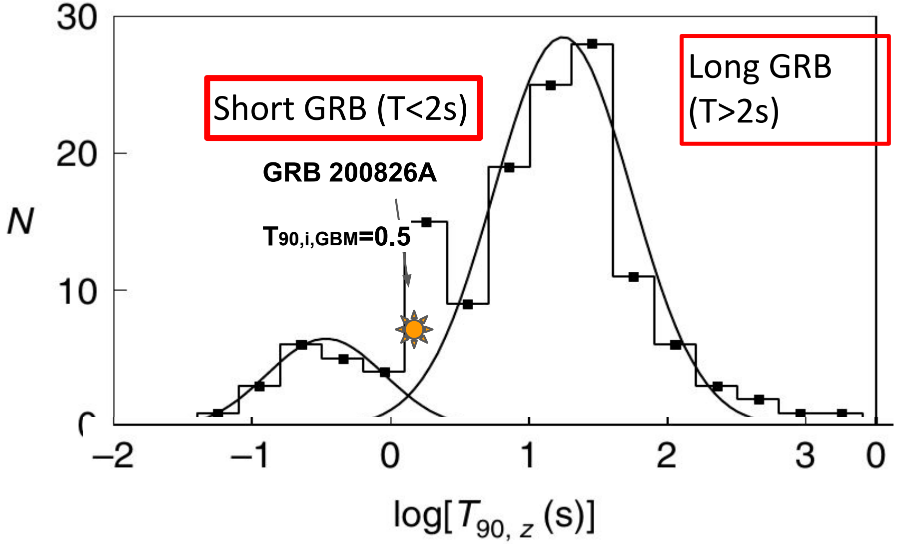


Bromberg+11,12,13:
The limit of 2s is valid for BATSE bursts.

- 0.8s is more suitable for Swift BAT
- 1.7s for FERMI GBM

GRB 200826A: the shortest collapsar event



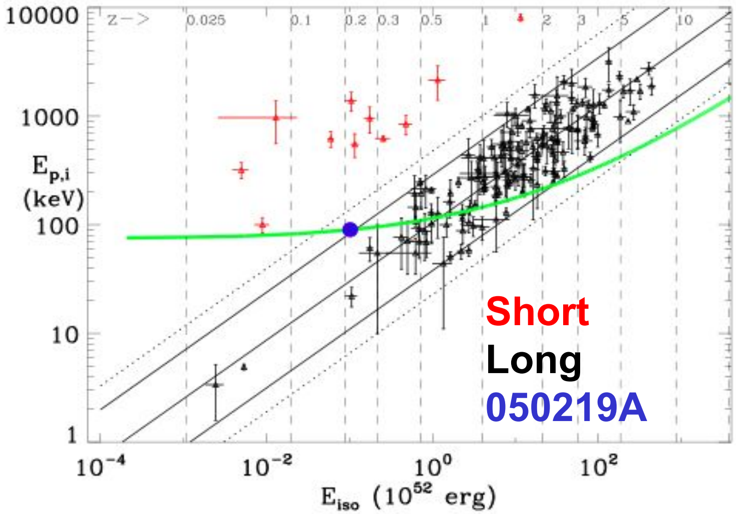


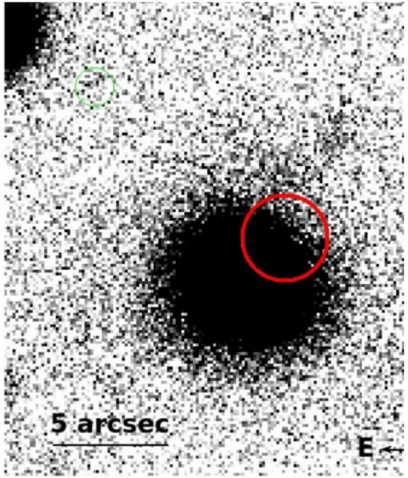
Rest-frame duration $T_{90,i}$=0.5 s

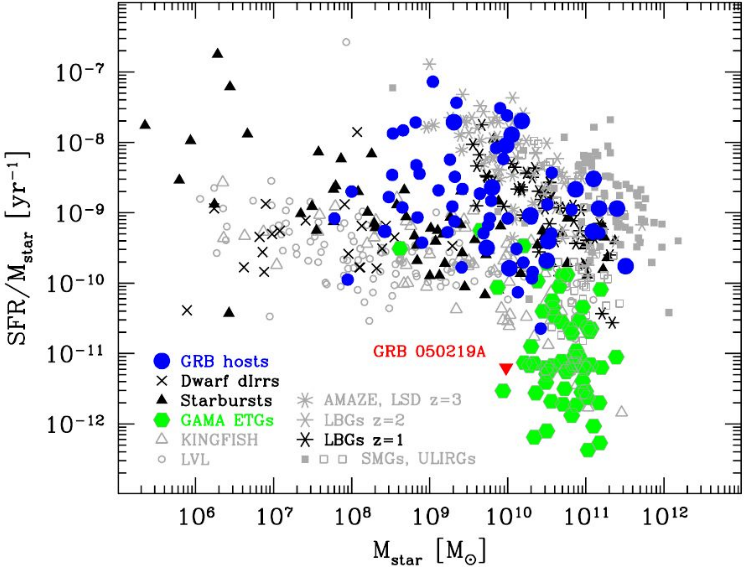
Rossi et al., 2022, ApJ, 932, 1

GRB 050219: a long GRB in a passive galaxy

Rossi et al.: The host galaxy of GRB 050219A (z=0.211)



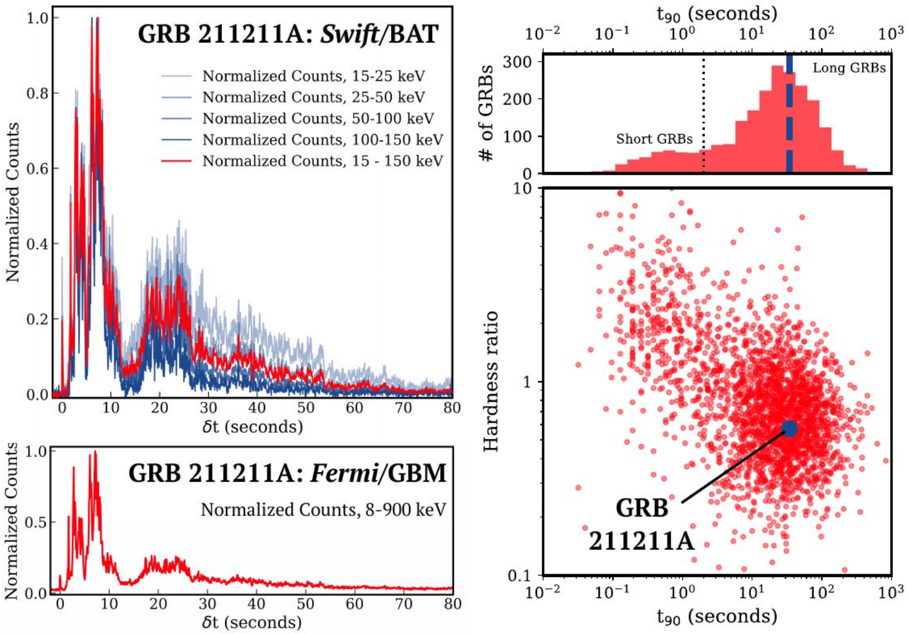


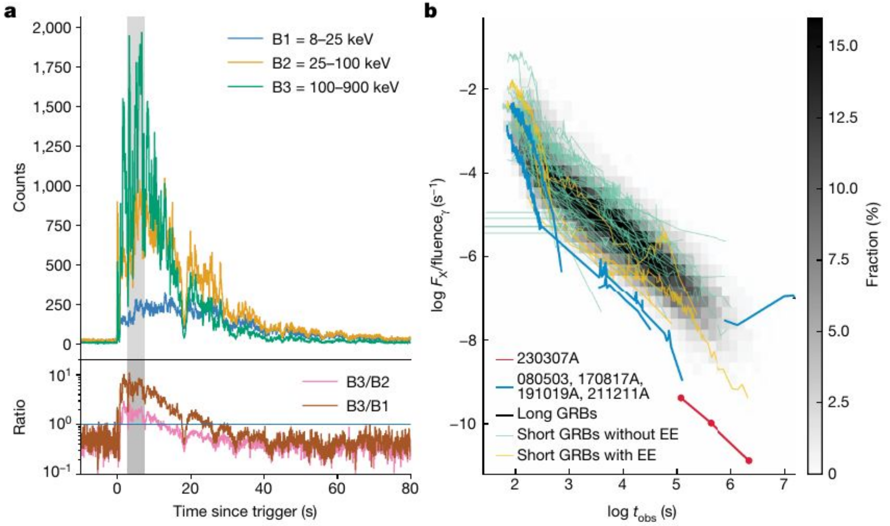


see Amati 2006

(adapted from Hunt et al. 2014)

GRB 211211A and 230307A: “*long*” GRBs followed by a KN



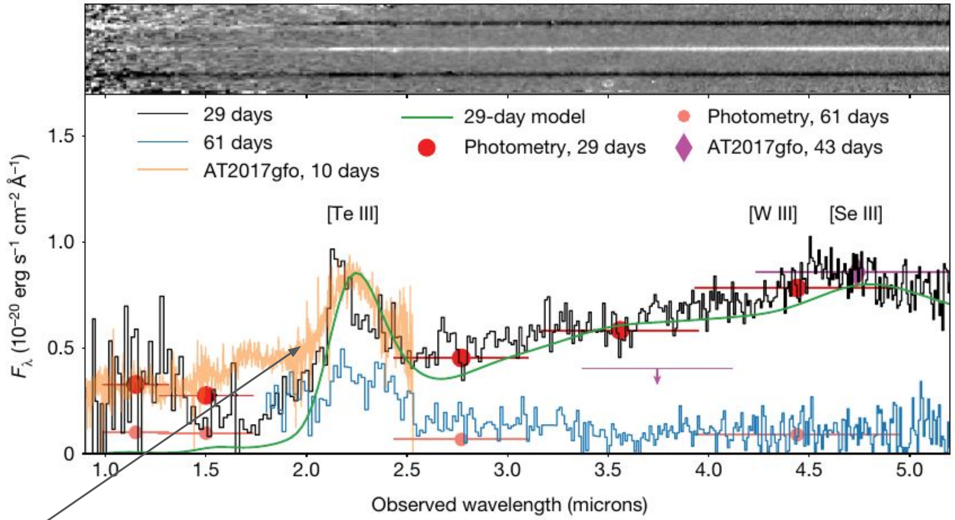


~40kpc (in projection) offset from its host

see also e.g., Gillanders+23, Yang+23

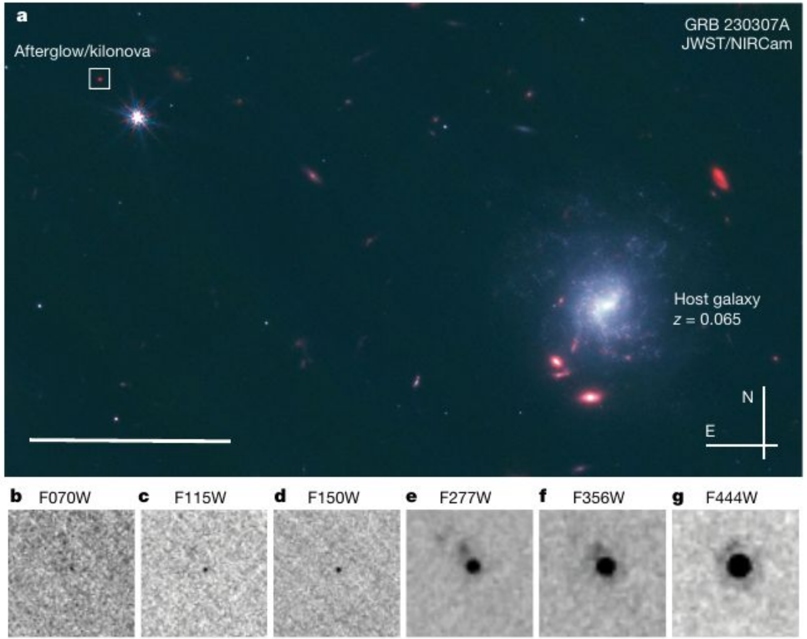
Levan et al., 2024, *Nature* **626**, 737

GRB 230307A: a "*long*" GRB followed by a KN



Clear emission at both 29 and 61 days, consistent with the expected location of [Te III] (Hotekezaka+18). This line is also clearly visible in the scaled late-time spectrum of AT2017gfo (Gillanders+23,Hotekezaka+22)

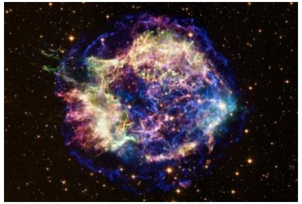
Levan et al., 2024, *Nature* **626**, 737

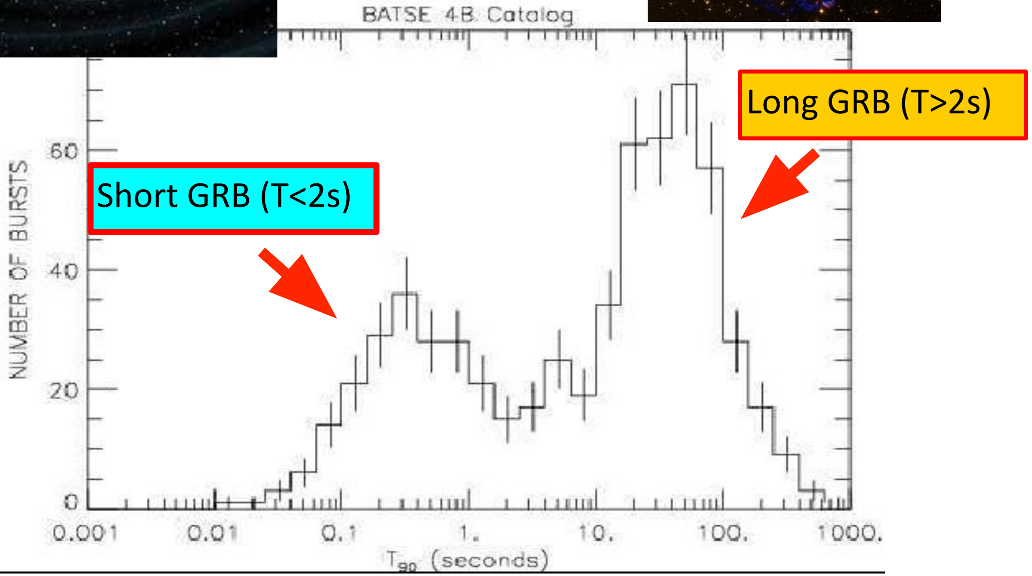


~40kpc (in projection) offset from its host

see also e.g., Gillanders+23, Yang+23

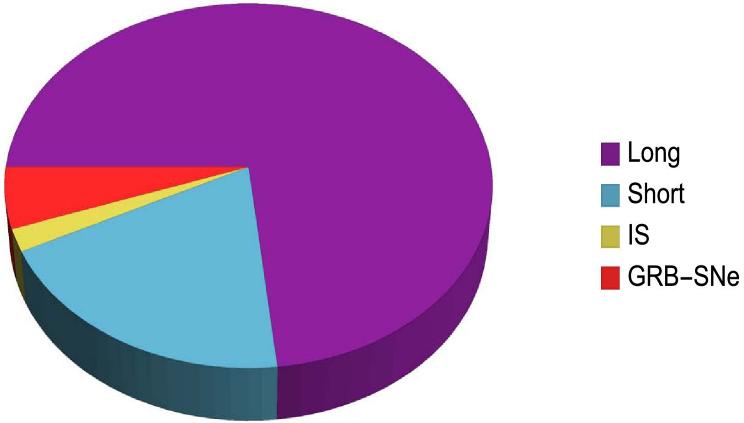
New (missed) population of merger events





BATSE data *Kouveliotu et al. 1993*

The duration is not an indicator of the origin of a GRB.

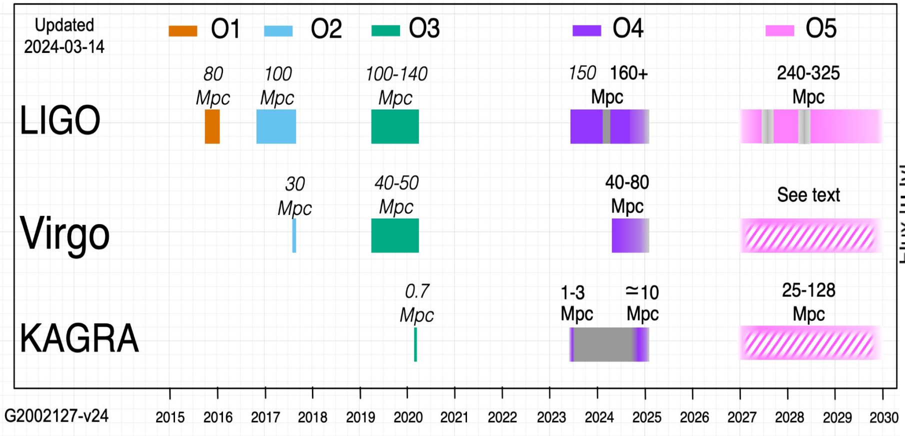


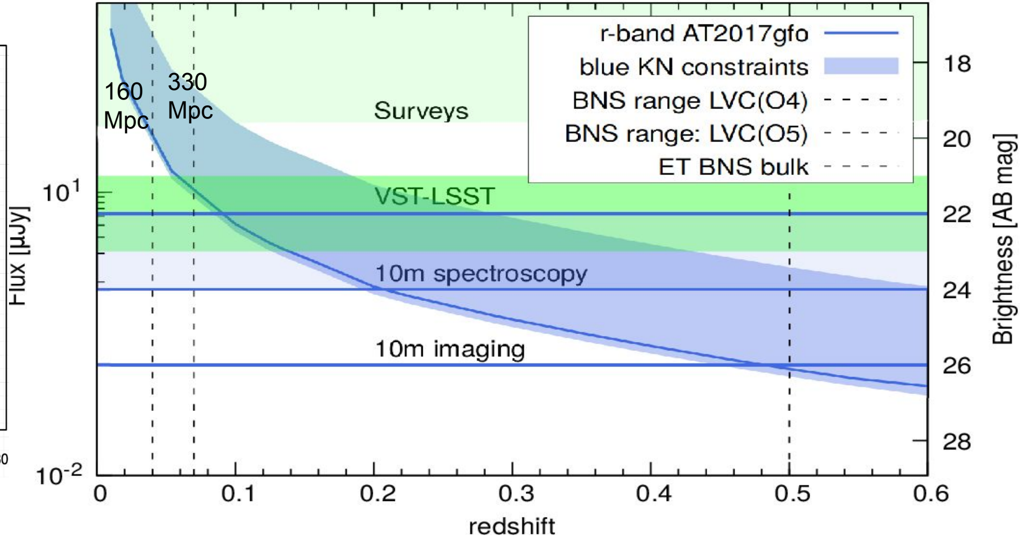
Petrosian, Dainotti +24

FUTURE PERSPECTIVES during O4 and O5 and ET

The problem is to localize EM counterparts, not their follow-up

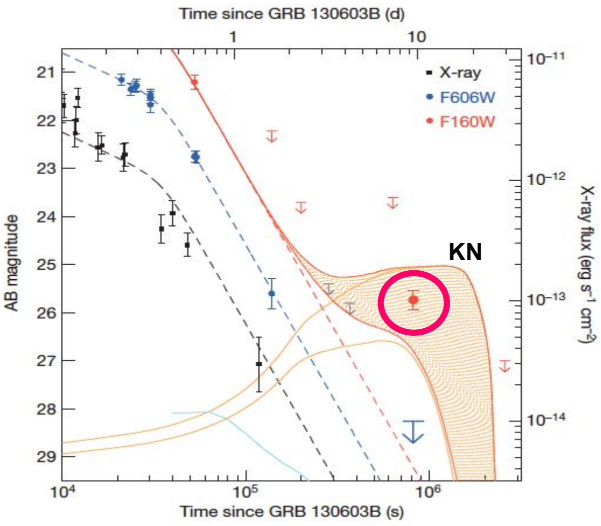
Peak luminosity vs redshift

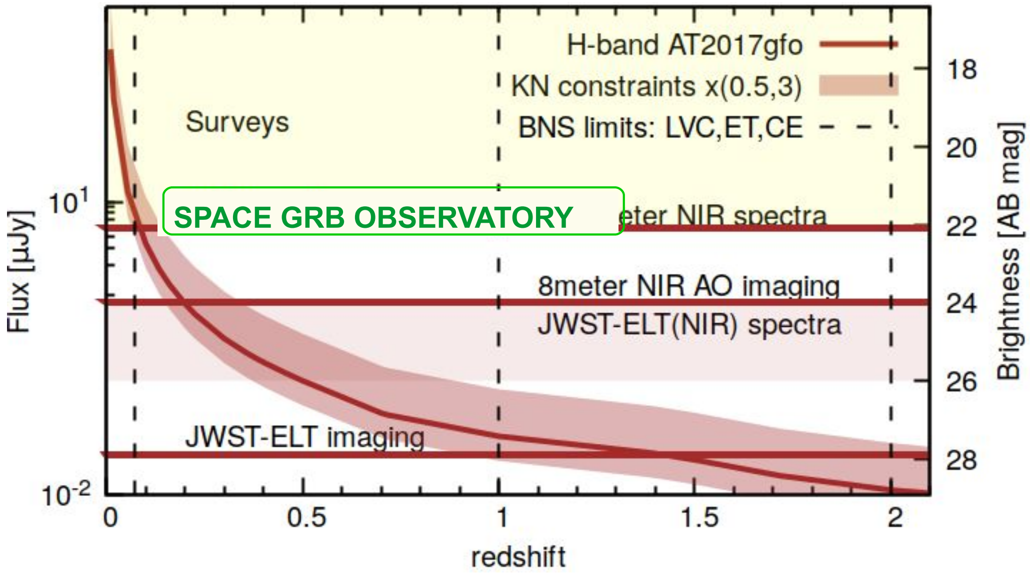




Moving on from
Rossi et al., 2020, MNRAS 493, 3379

FUTURE PERSPECTIVES in the 30s during 3G interferometers and ELT/JWST

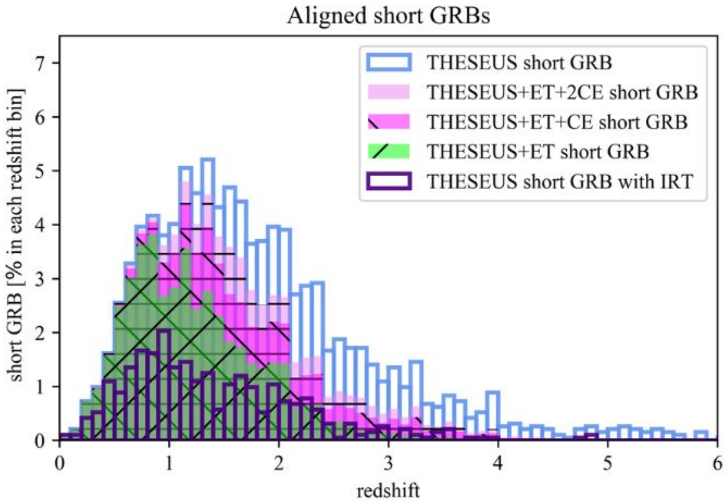


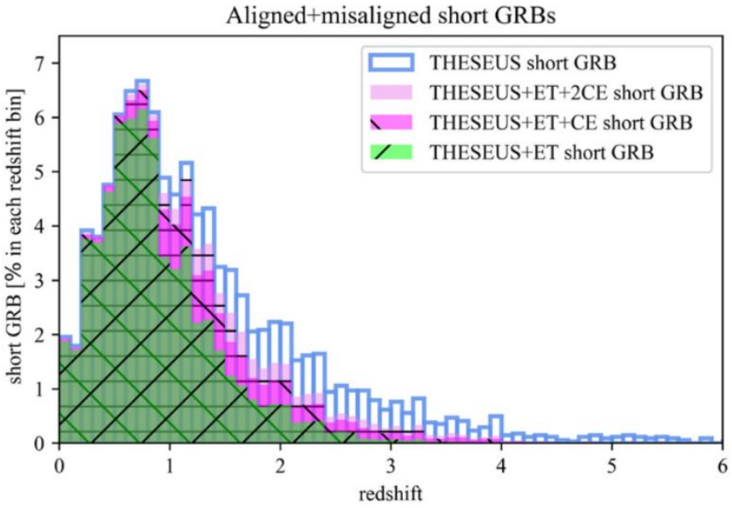


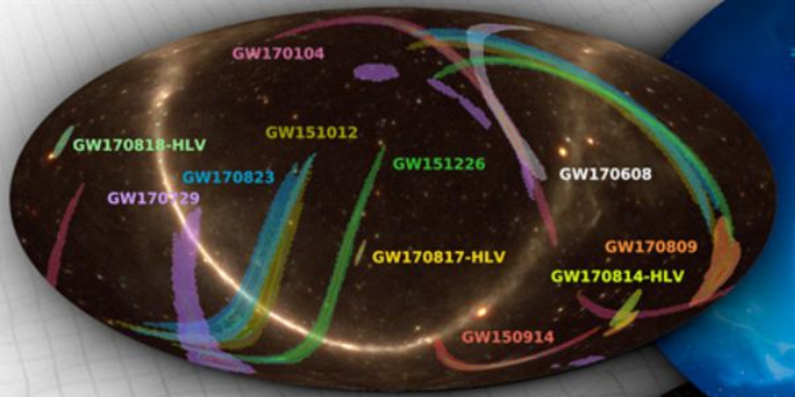
- A space observatory can detect the associated
- GRB and its afterglow (if on-axis)

- See also Rastinejad +21

- Afterglow brighter than KN, ok for smaller telescopes
- Spectroscopic caracterization by JWST/ELTs
- Redshift : from afterglow / host

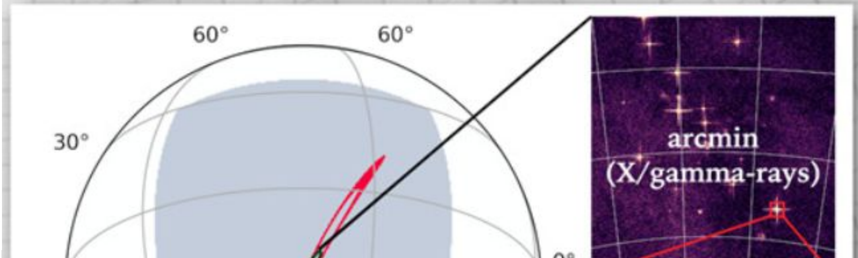






THESEUS ensures:

- Immediate coverage of gravitational wave and neutrino source error boxes
- Real time sky localizations
- Temporal & spectral charaterization from NIR to gamma-rays



Summary

- **The study of GRBs+Kilonovae allows to constrain physical properties of the merger**
  - progenitor (without GW signal), NS_NS vs NS-BH
  - KN and GRB geometry and ejecta properties (masses, velocities, Ye)
  - r-process abundances (cosmic chemical enrichment)

- **New scenarios: (missed) population of merger-long GRBs**
  - The simple duration is NOT an indicator of the origin of a GRB
  - keep an eye on missing SN, merger-like host-galaxy, offset from the host, GRB properties
  - **We should expect a rate of GRBs from mergers larger than current estimates?**

- **Future perspectives: GRB missions in the 30s**
  - GRBs allow a precise localization of the EM counterpart of GW-merger signals

THANK YOU