Identifying Electromagnetic Counterparts to NS-NS Mergers

Dr. Dario Carbone (TTU)

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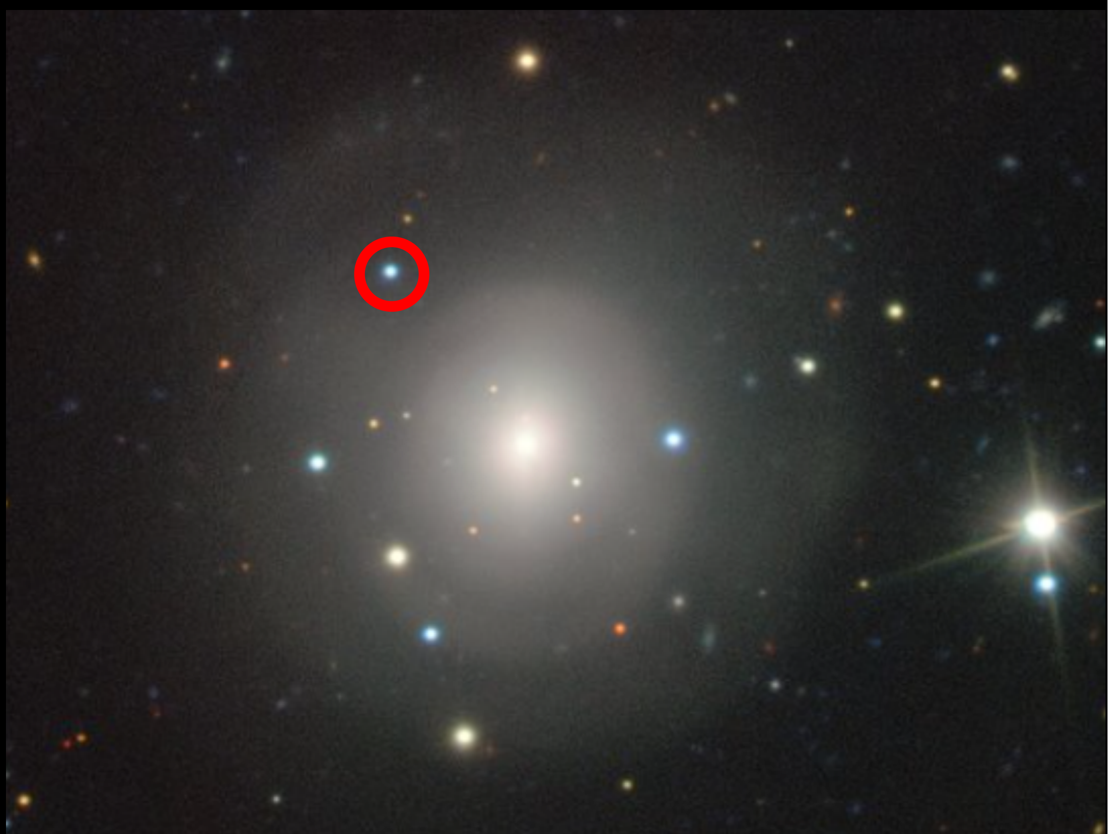
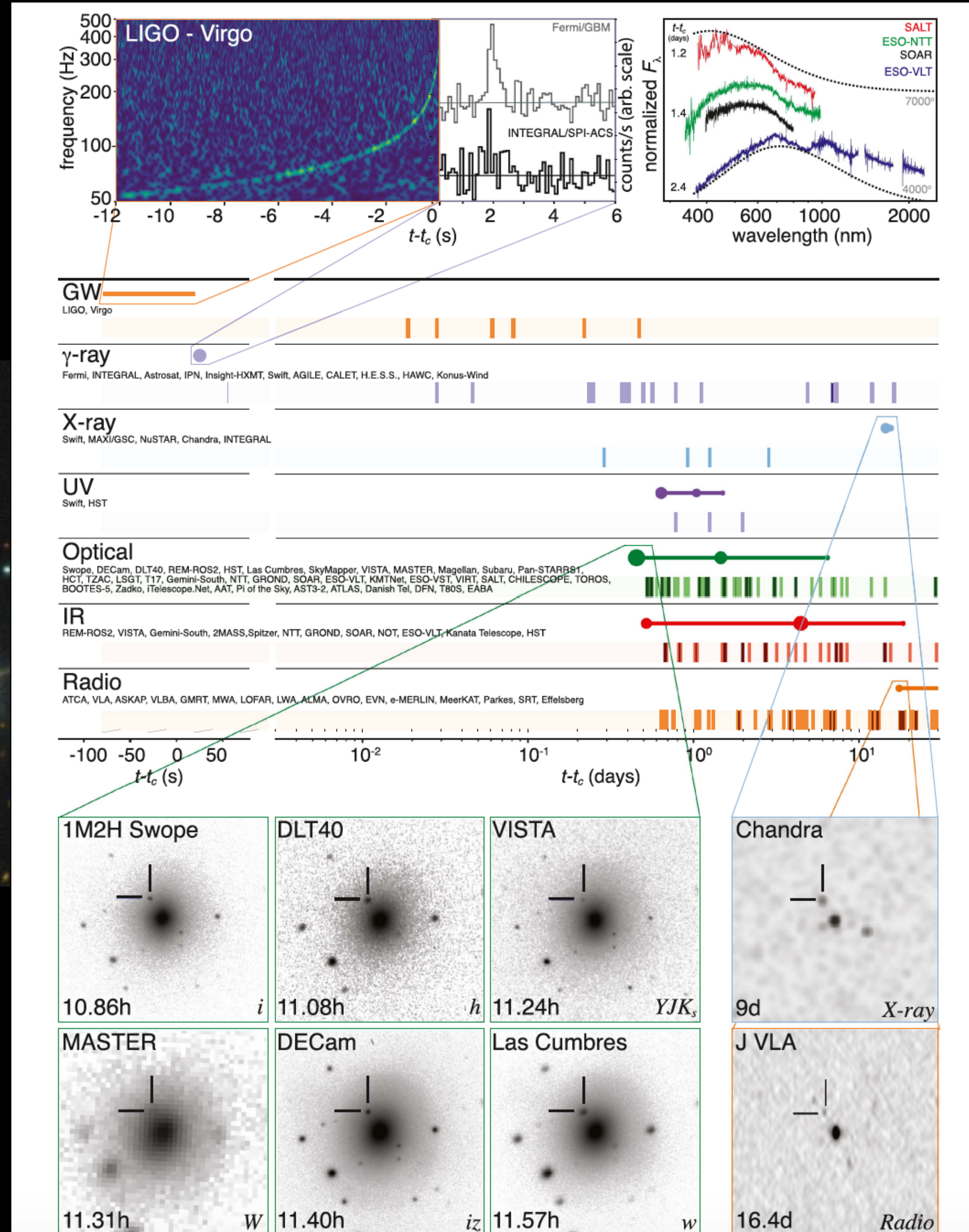
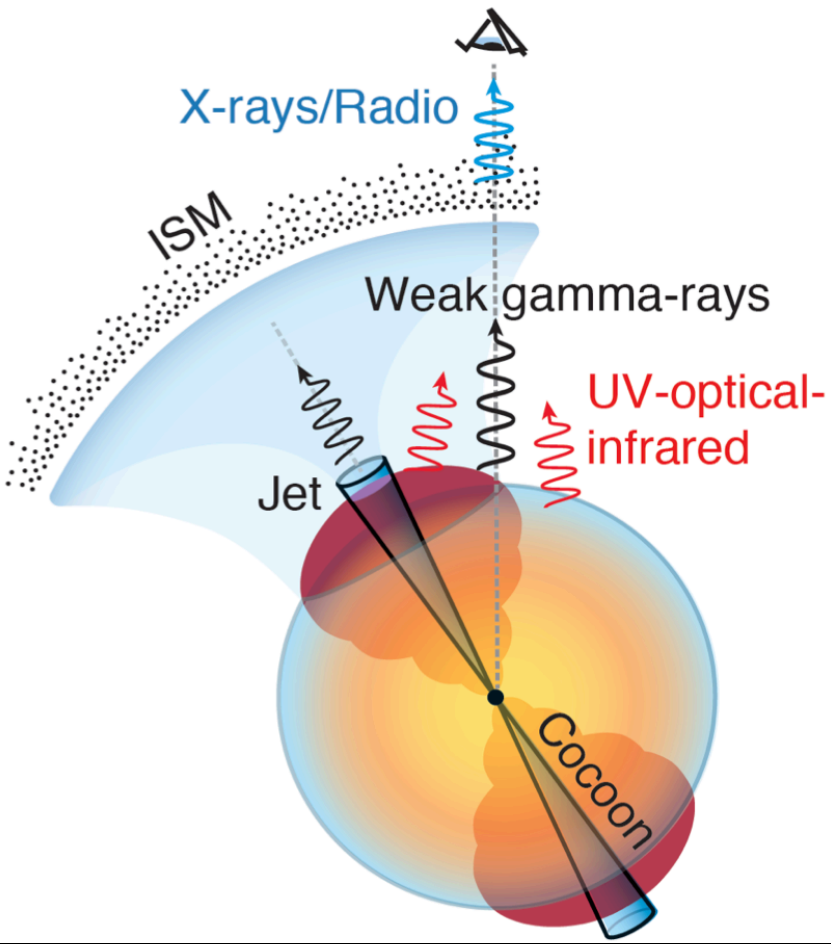


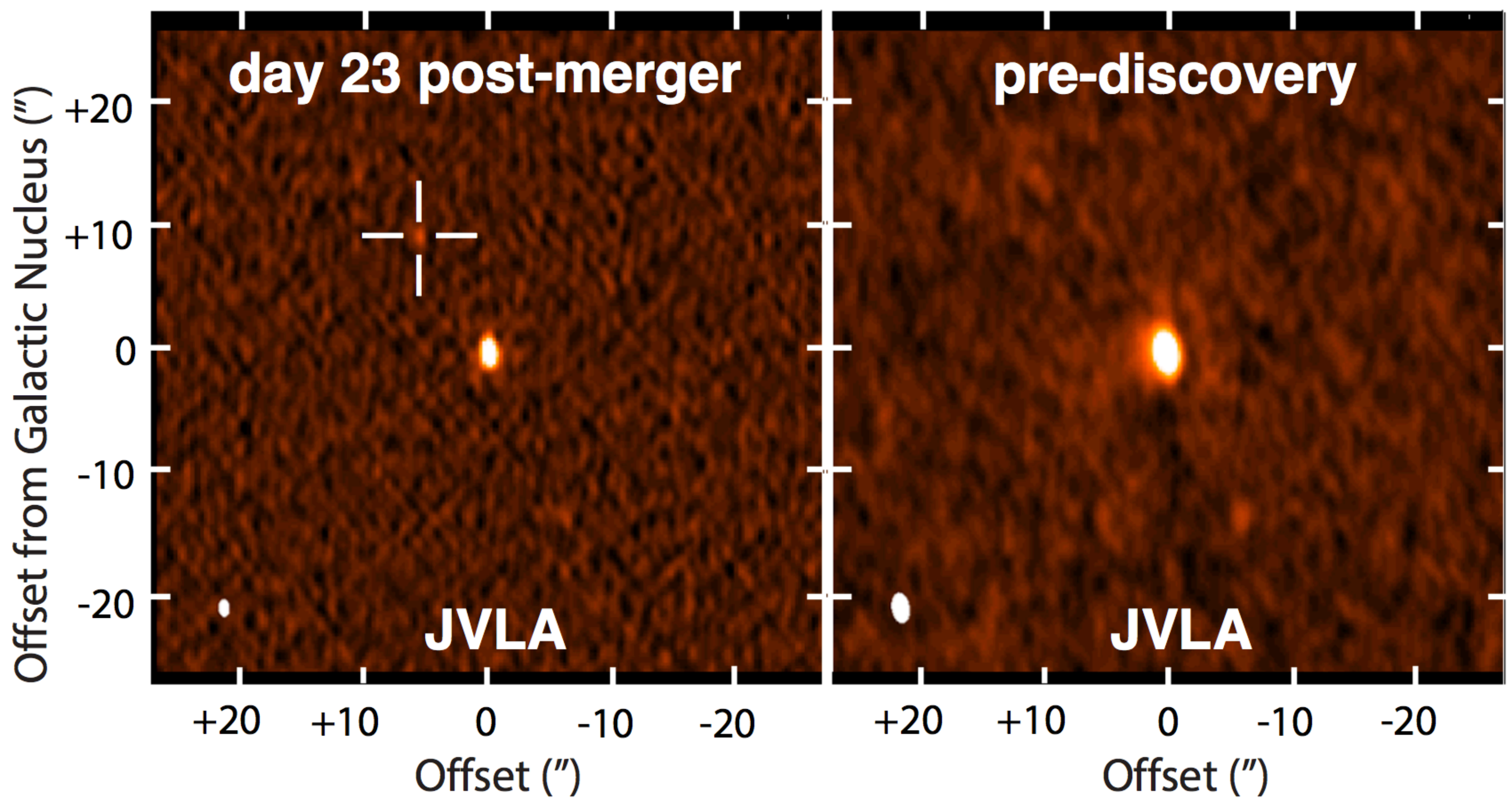
Credit: European Southern Observatory
Very Large Telescope

Abbott et al., ApJL, 848:L12, 2017



... all the way to radio!





Hallinan, Corsi, et al. 2017, Science,
0.1126/science.aap9855

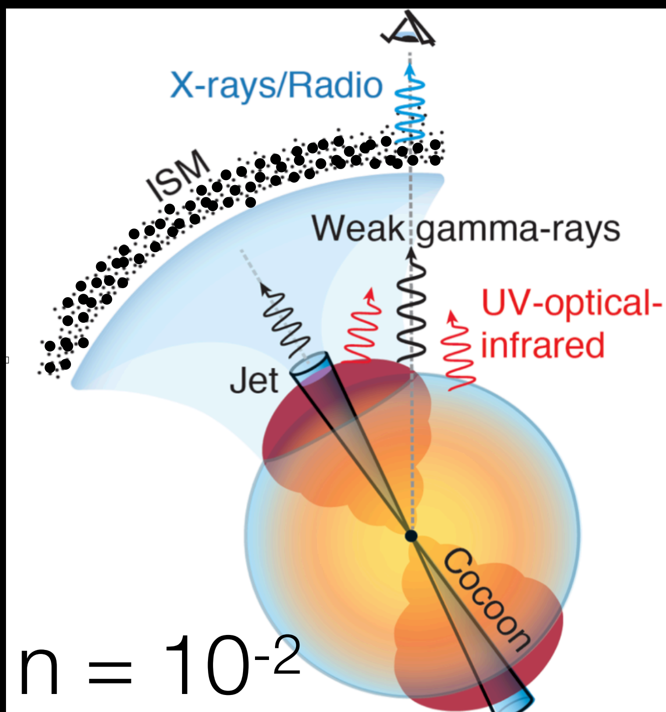
Motivation

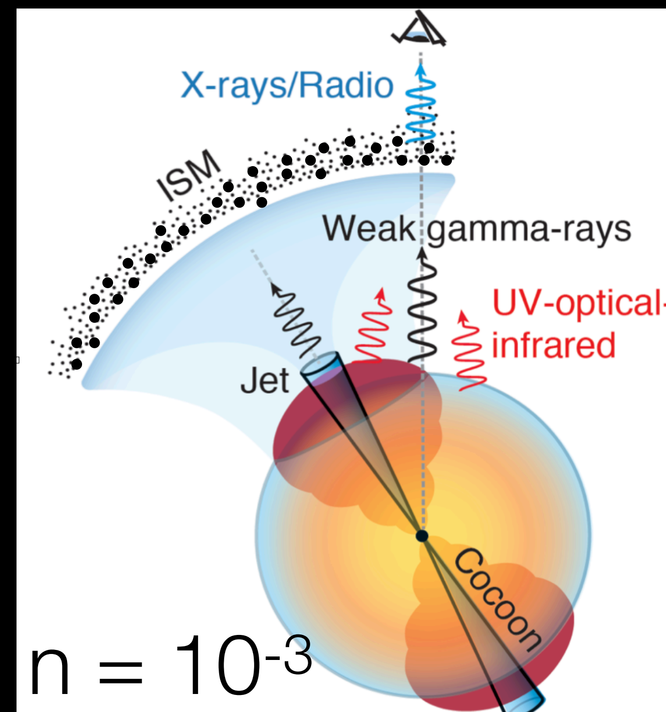
- NS-NS mergers will be routine - be prepared!
- Use radio because:
  - Ubiquitous - independent of the geometry.
  - Tracks different components than UV/opt/IR.
  - Maps speed distribution in the dynamic ejecta.
- Determine best follow-up strategy with lowest number of observations.

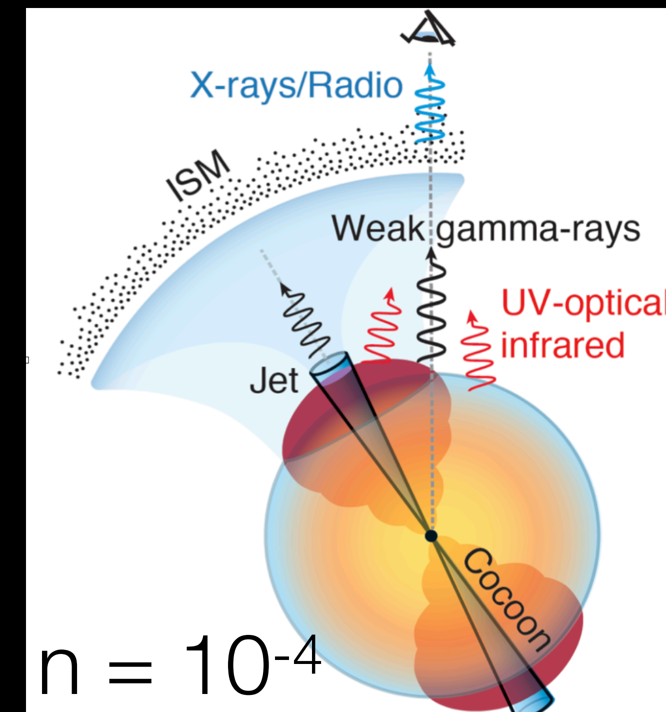
Method - Simulated Sources

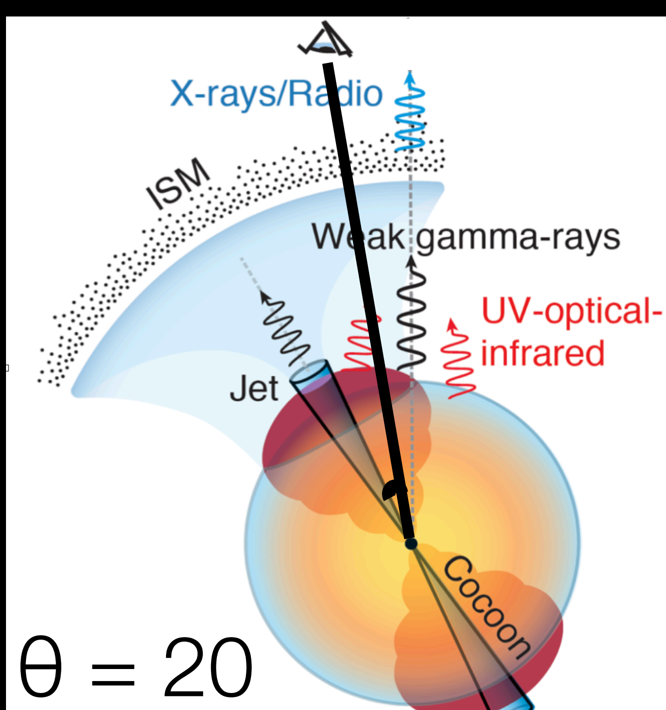
- We simulated off-axis short GRBs @40 Mpc.
  (van Eerten et al., ApJ, 79:44, 2012)
- $n = 10^{-2}, 10^{-3}, 10^{-4}\ cm^{-3}$.
- Off-axis angle = 20, 30, 45 degrees.
- We simulated 10^4 sources per type.
- We have included contaminant sources such as off-axis long GRBs.

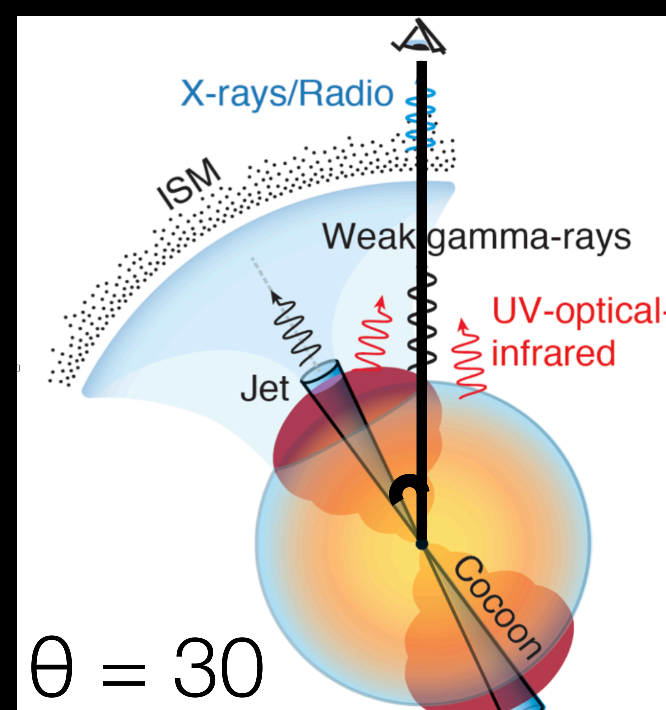
Different densities and viewing angles

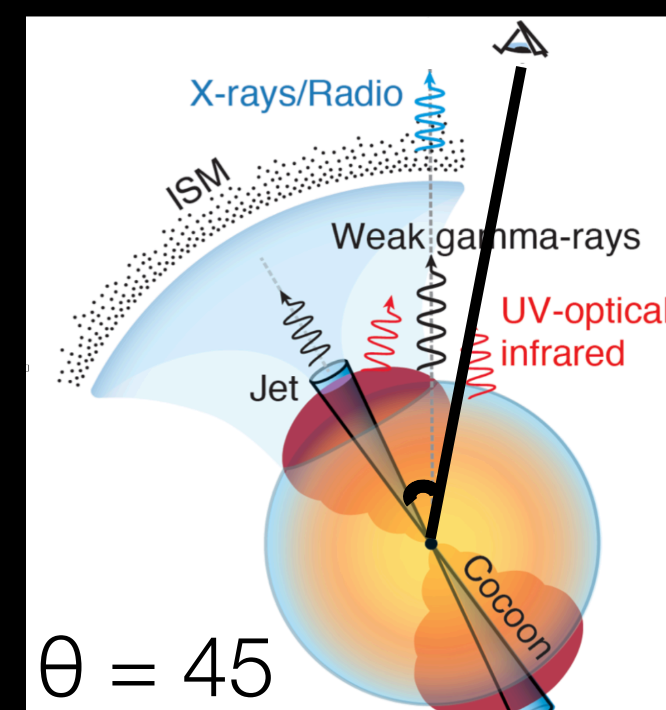








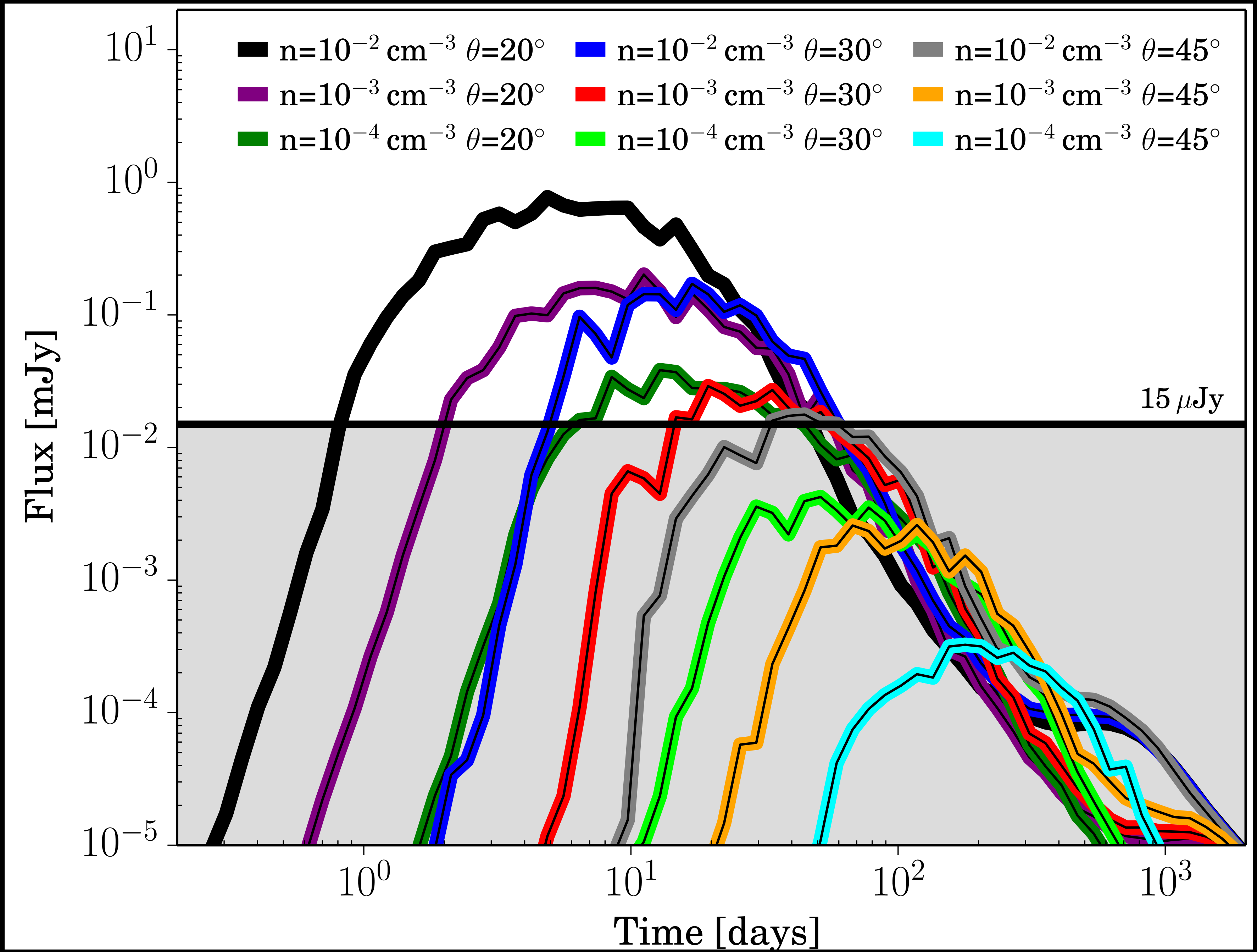




Simulated LC

E = 10^{50} erg

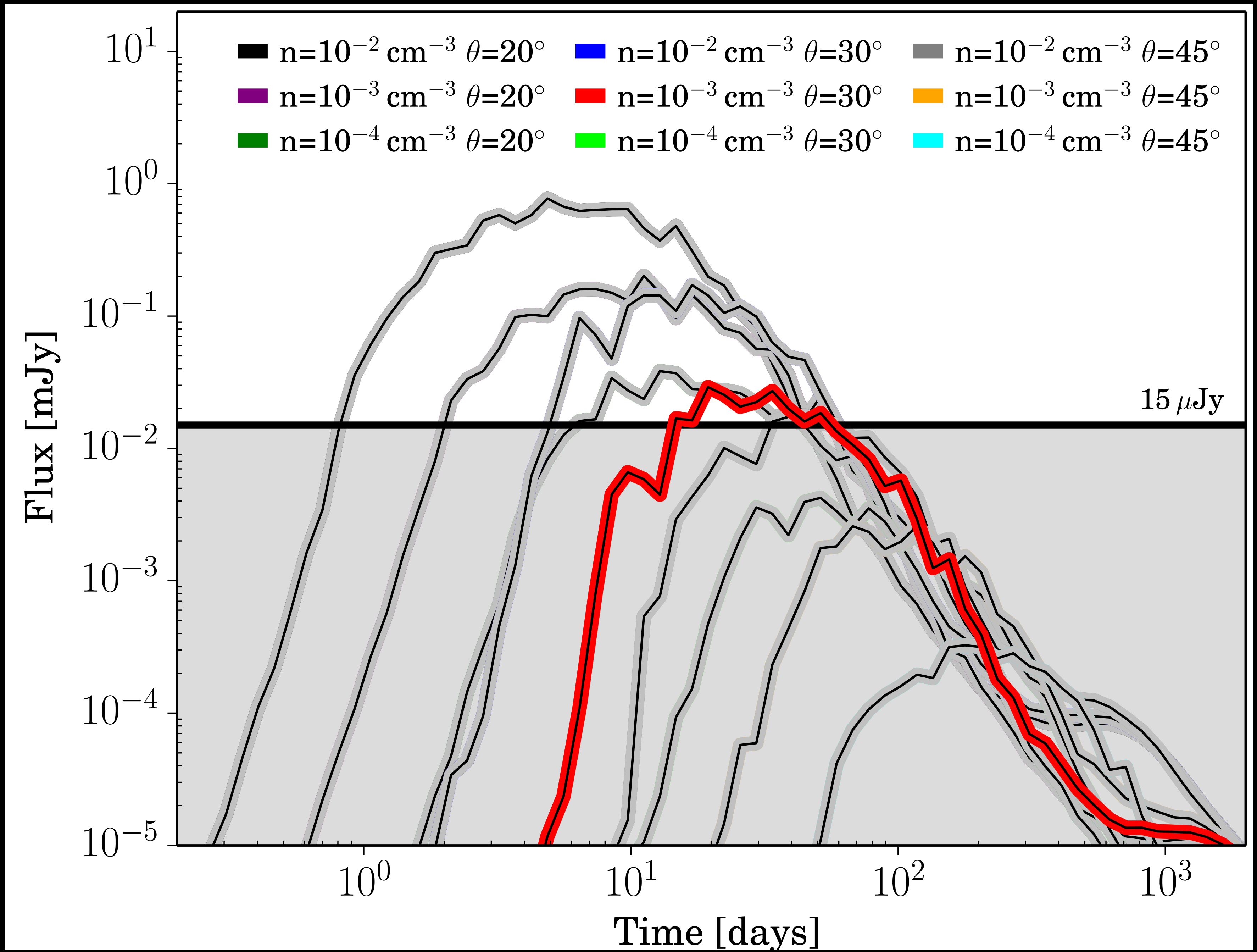
Jet half-opening angle = 12^{O}



Simulated GW170817-like LC

E = 10^{50} erg

Jet half-opening angle = 12^{O}



Method - Radio Observations

- We simulated radio observations performed by the VLA at 5 GHz, with 4 GHz of bandwidth.
- Each observation has total time of 2h and reaches a 3σ sensitivity of 15 μJy.
- The maximum number of observations per event is set by expected event rate and typical VLA-1 year time allocation (~max 50h).
- Light curve association to physical model done by comparing measured flux to expected flux.

Results

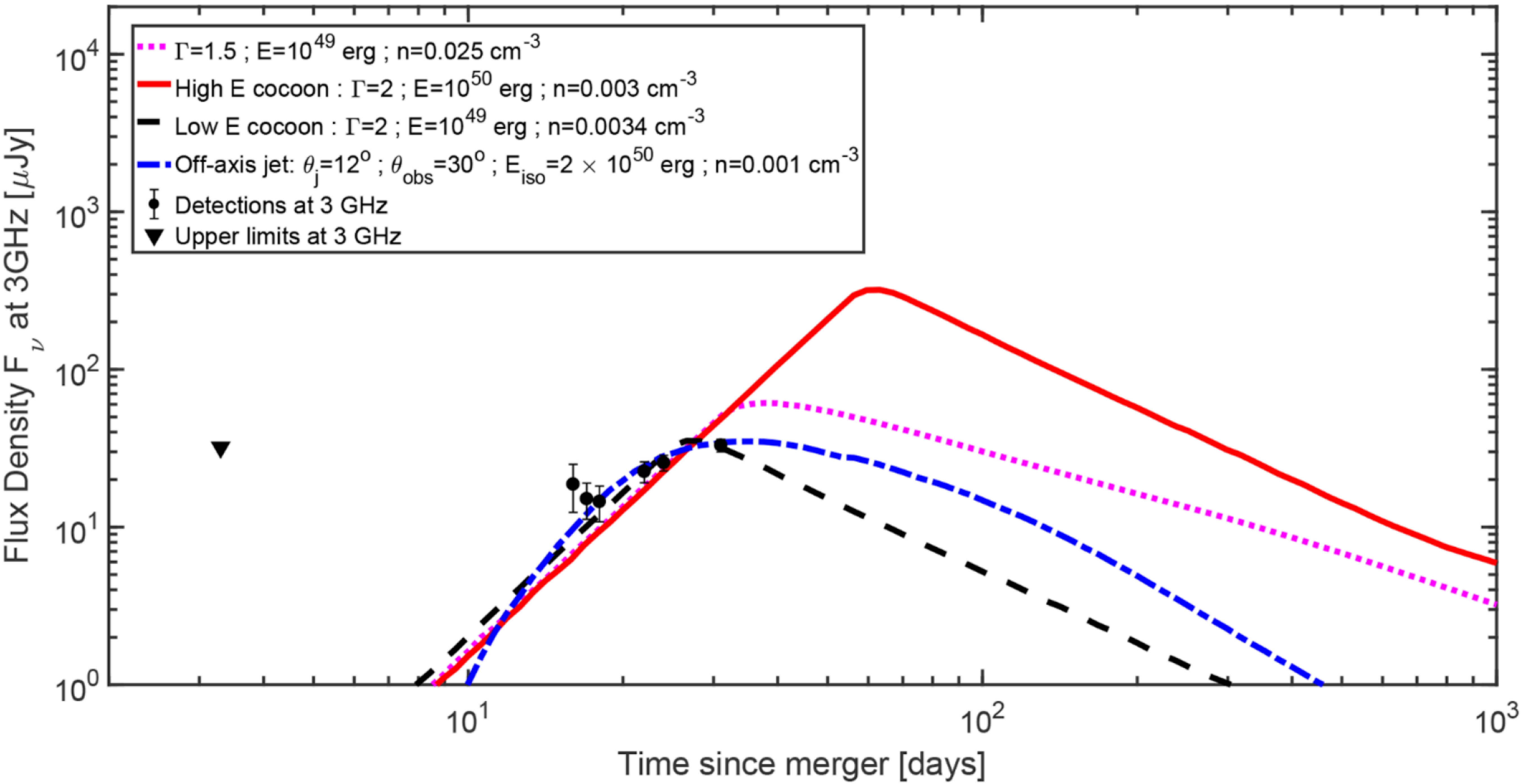
- The parameter we maximized is the probability to discover a source and correctly/uniquely identify its physical parameters.
- The optimal observational setup and efficiency depend on the available observing time.

Number of Observations	Efficiency (GW170817-like)	Epochs (days after the first observation)
4	73% (0%)	6, 8, 24
7	81% (85.2%)	2, 4, 6, 8, 24, 32 4, 6, 8, 24, 30, 32
8	83% (99.9%)	2, 4, 6, 8, 24, 30, 32

Conclusions

- We can correctly and uniquely identify the physical parameters of radio counterparts to NS-NS mergers for several combinations of these parameters.
- Future is bright & exiting!
  - LIGO O3 cycle will start in Fall 2018.
  - More events to be discovered (~5 per year).
  - ngVLA pushes the horizon much further
    (for GW170817: 55 Mpc, now, to 176 Mpc, with ngVLA).

The unfolding radio story…



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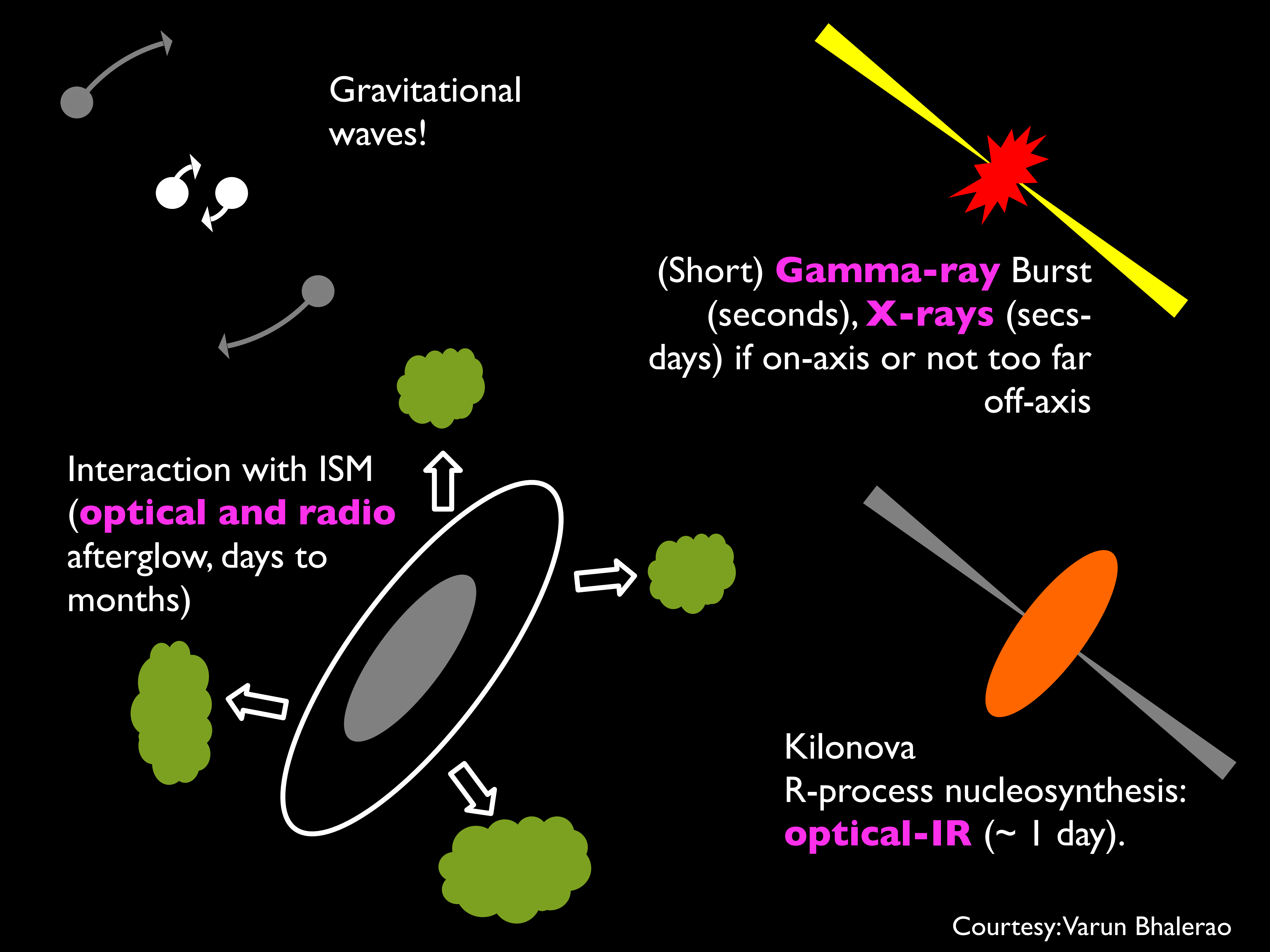
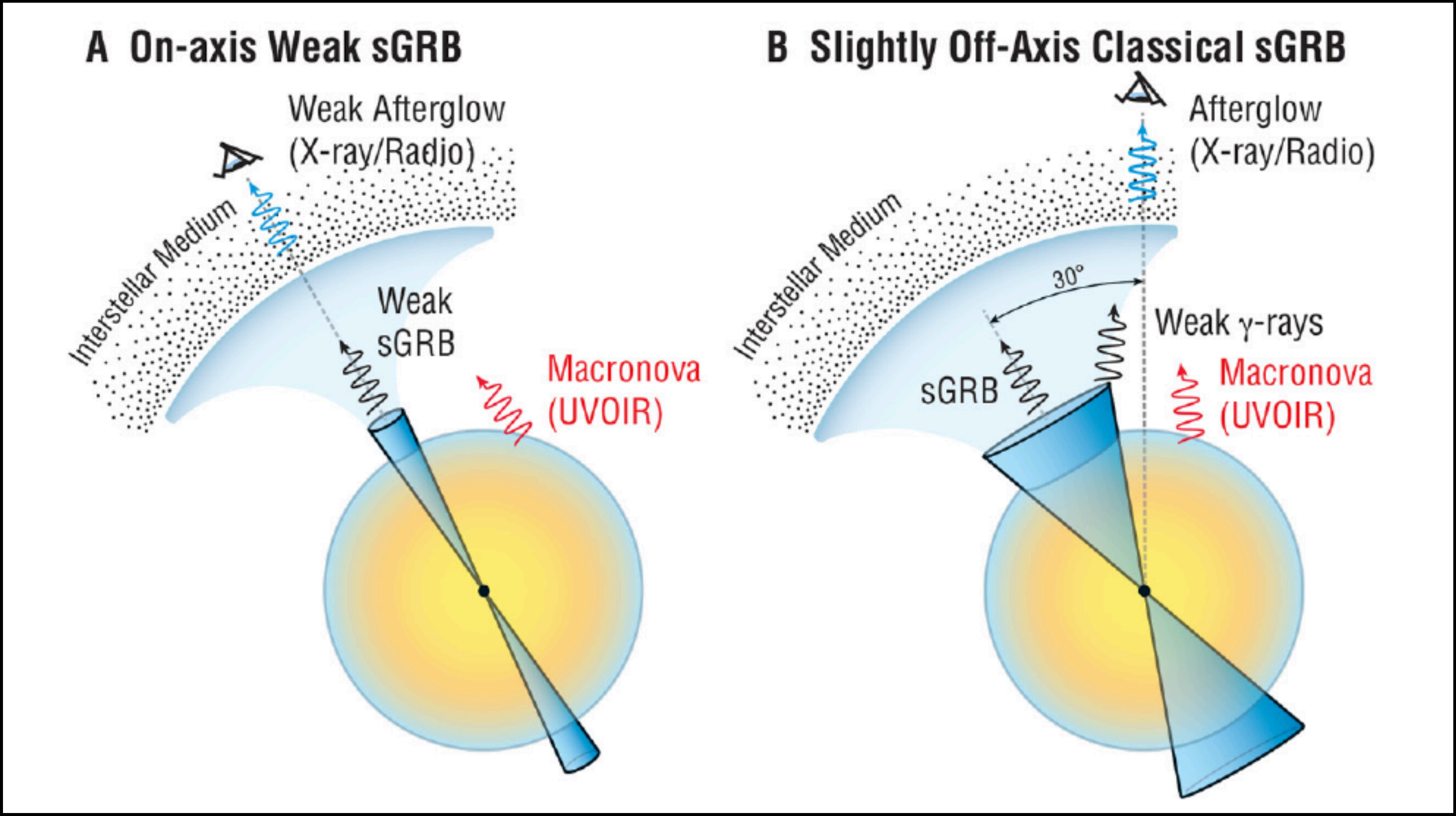


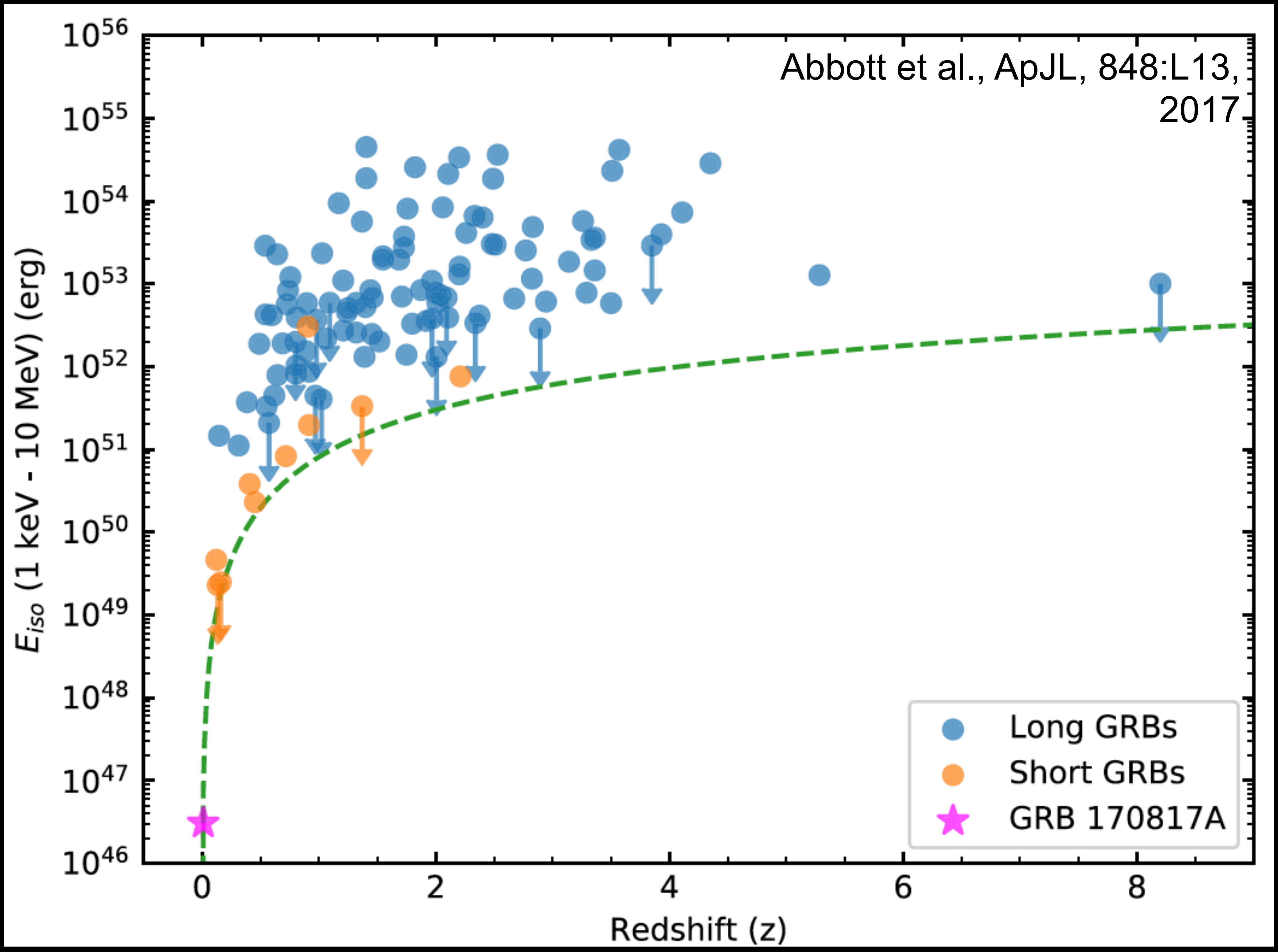
Gravitational waves!
(Short) Gamma-ray Burst (seconds), X-rays (secs-days) if on-axis or not too far off-axis
Interaction with ISM (optical and radio afterglow, days to months)
Kilonova
R-process nucleosynthesis: optical-IR (~ 1 day).
Courtesy: Varun Bhalerao

Why so dim?



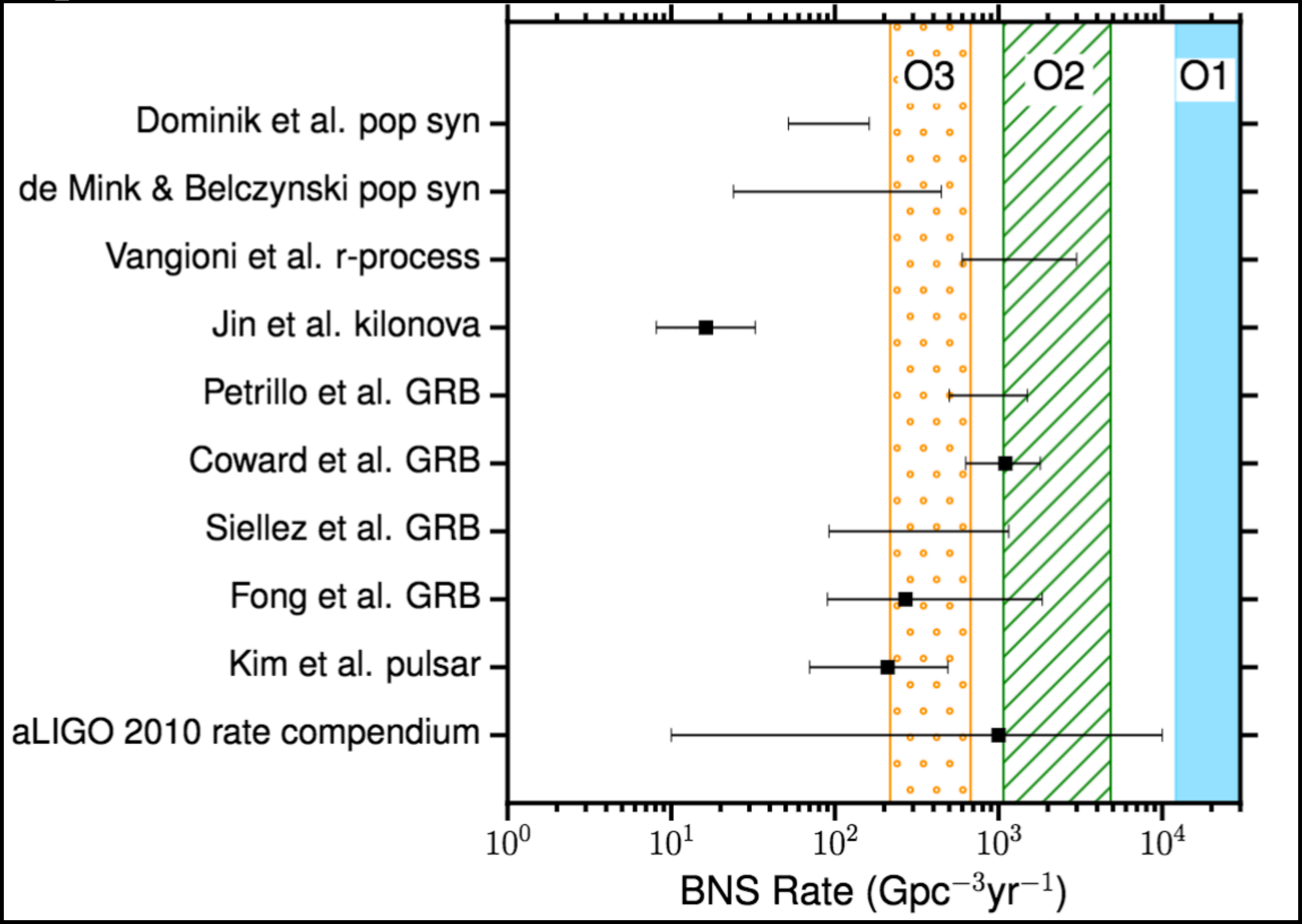
M. M. Kasliwal *et al.*, *Science* 10.1126/science.aap9455 (2017)

GRB170817: A dim outlier!

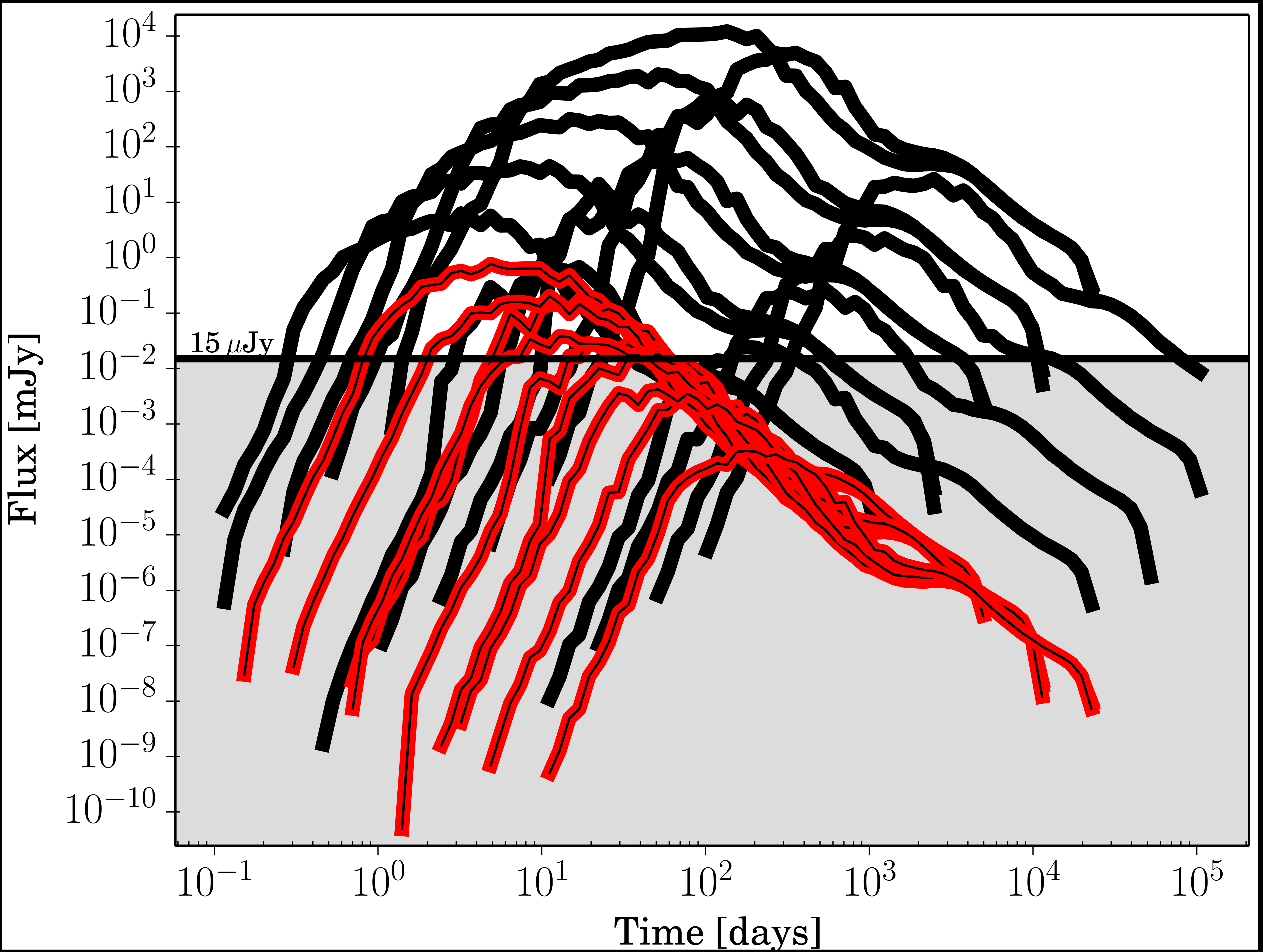


Source Type	Horizon win VLA (Mpc)	Horizon with ngVLA (Mpc)
short_2_20	288	910
short_3_20	147	465
short_4_20	64	203
short_2_30	136	429
short_3_30	56	176
short_4_30	21	67
short_2_45	44	138
short_3_45	17	53
short_4_45	6	19

Pre-GW170817 expectations: NS-NS rates



Abbott et al. 2016, ApJ, 832, L21


Flux [mJy]
Time [days]
15 μJy
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}