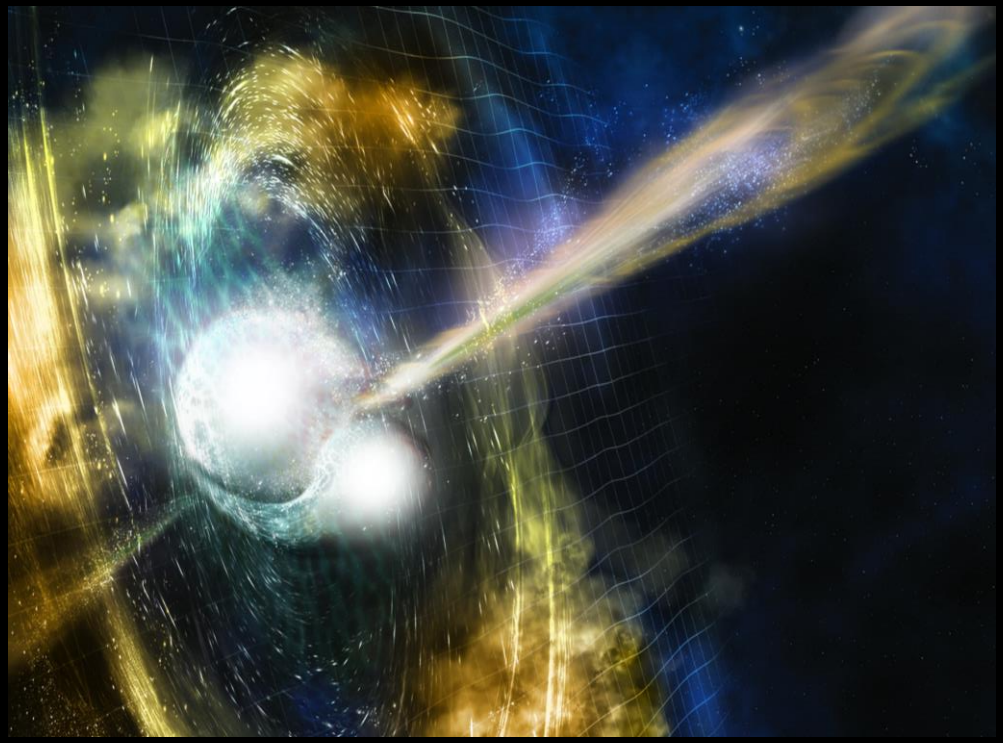
A Late-Time Galaxy-Targeted Search for the Radio Counterpart of GW190814



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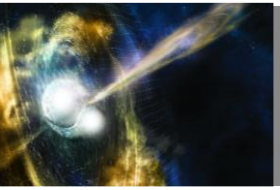
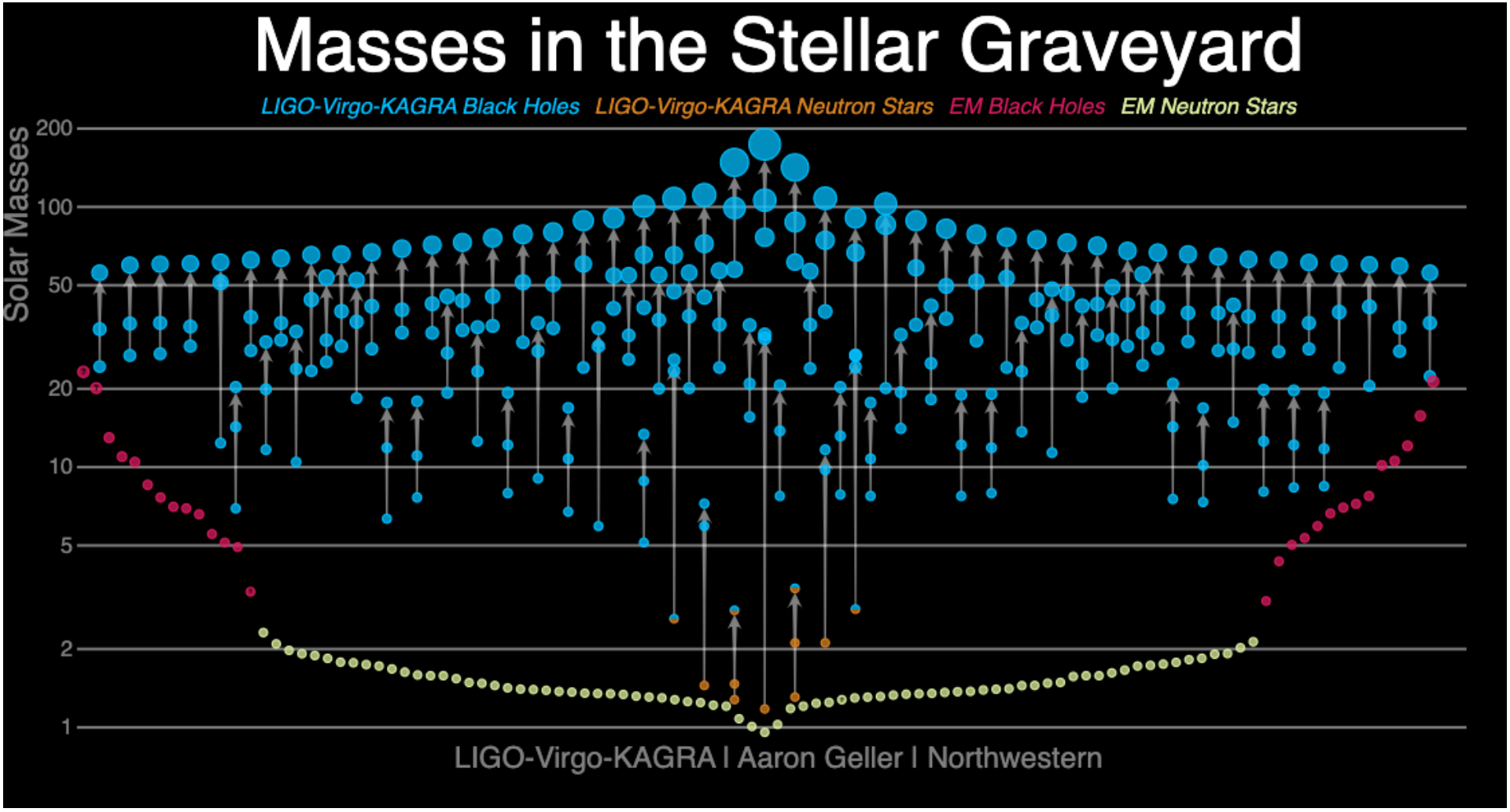
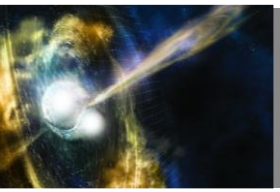
Rare Gems in Big Data, May 20, 2024



Gravitational Waves Reveal Compact Objects





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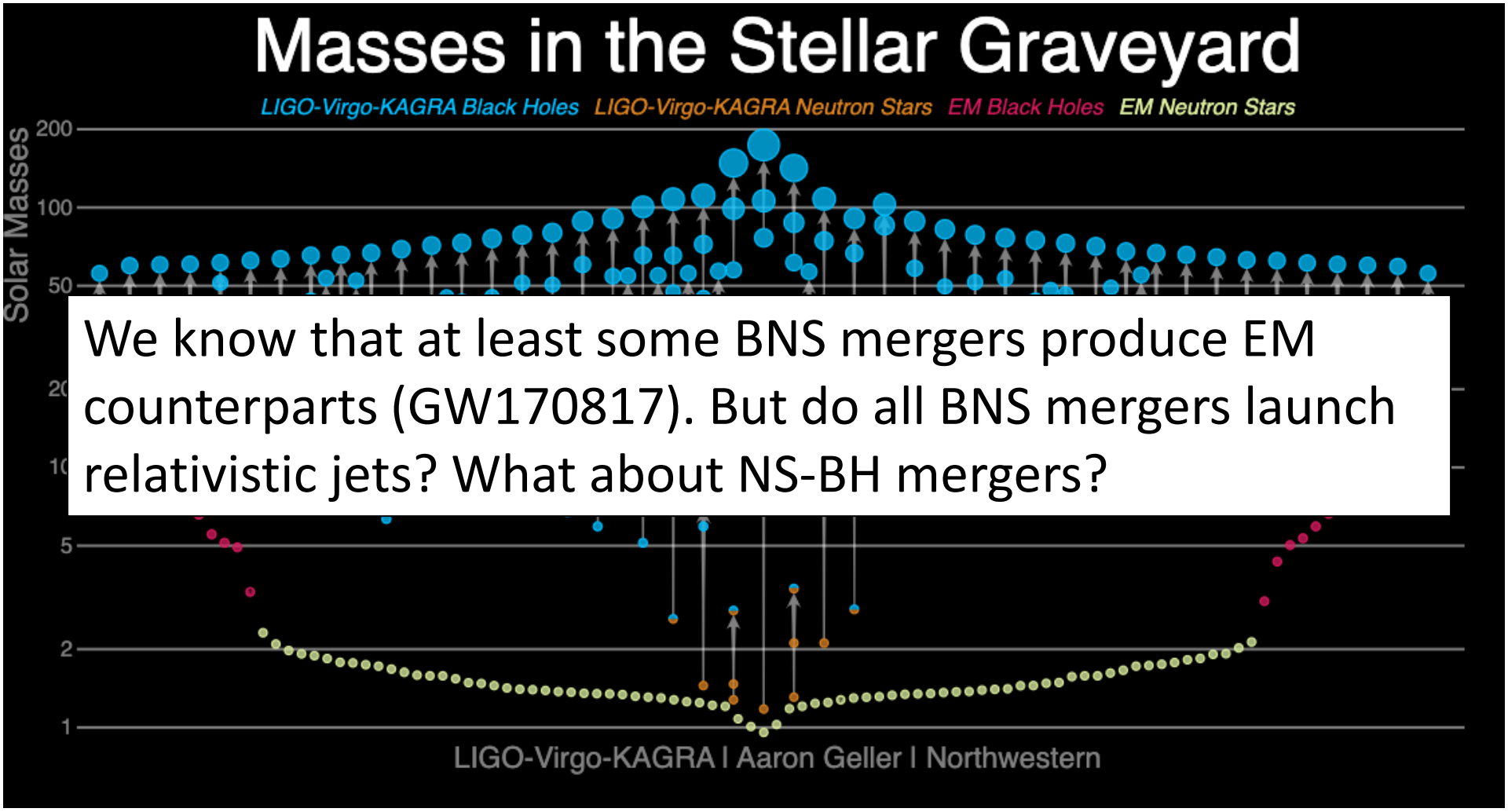
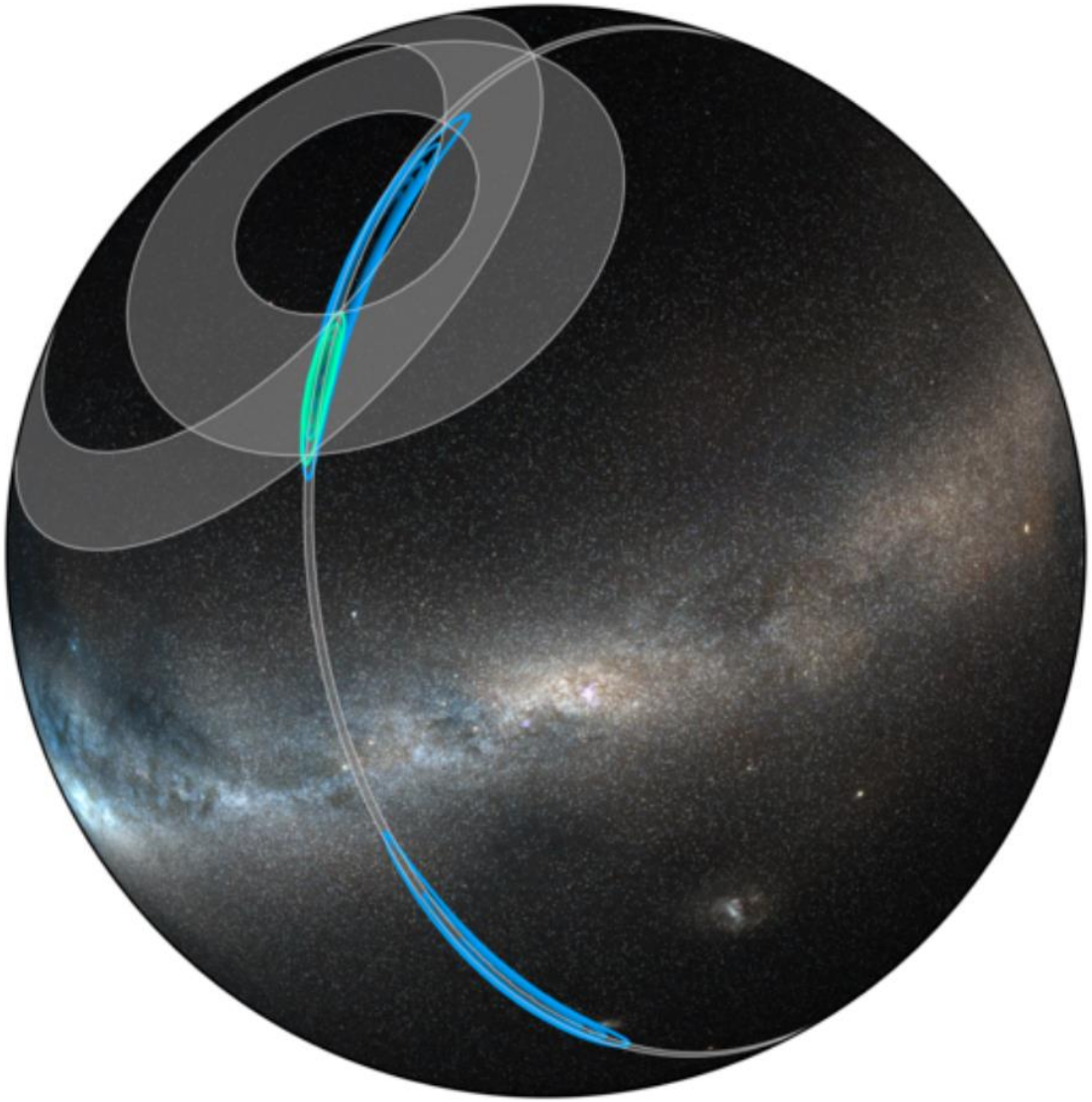


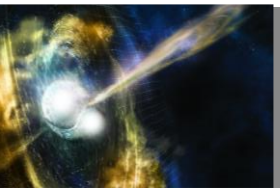
We know that at least some BNS mergers produce EM counterparts (GW170817). But do all BNS mergers launch relativistic jets? What about NS-BH mergers?

But we got lucky the first time…

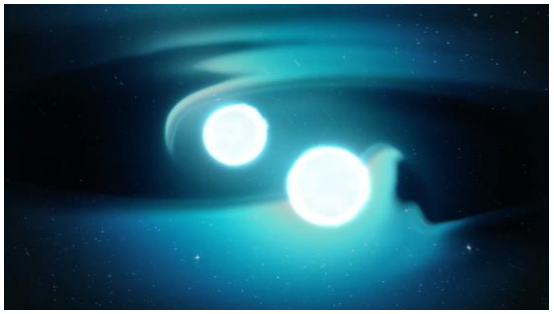


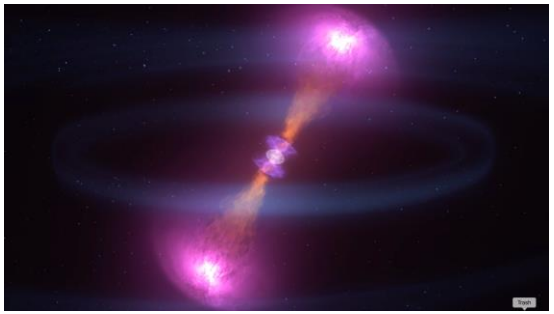
Credit: LIGO/Virgo/NASA/Leo Singer (Milky Way image: Axel Mellinger)

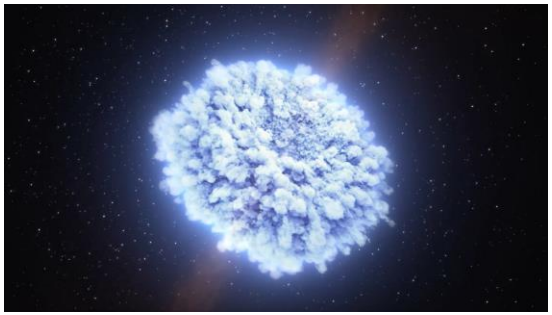
- **GW170817 was:**
  - Nearby (40 Mpc) = bright optical transient!
  - Well-localized (28 deg^2)
  - Visible at night
- How do we adapt our observing strategies to find events where none of these may be true?



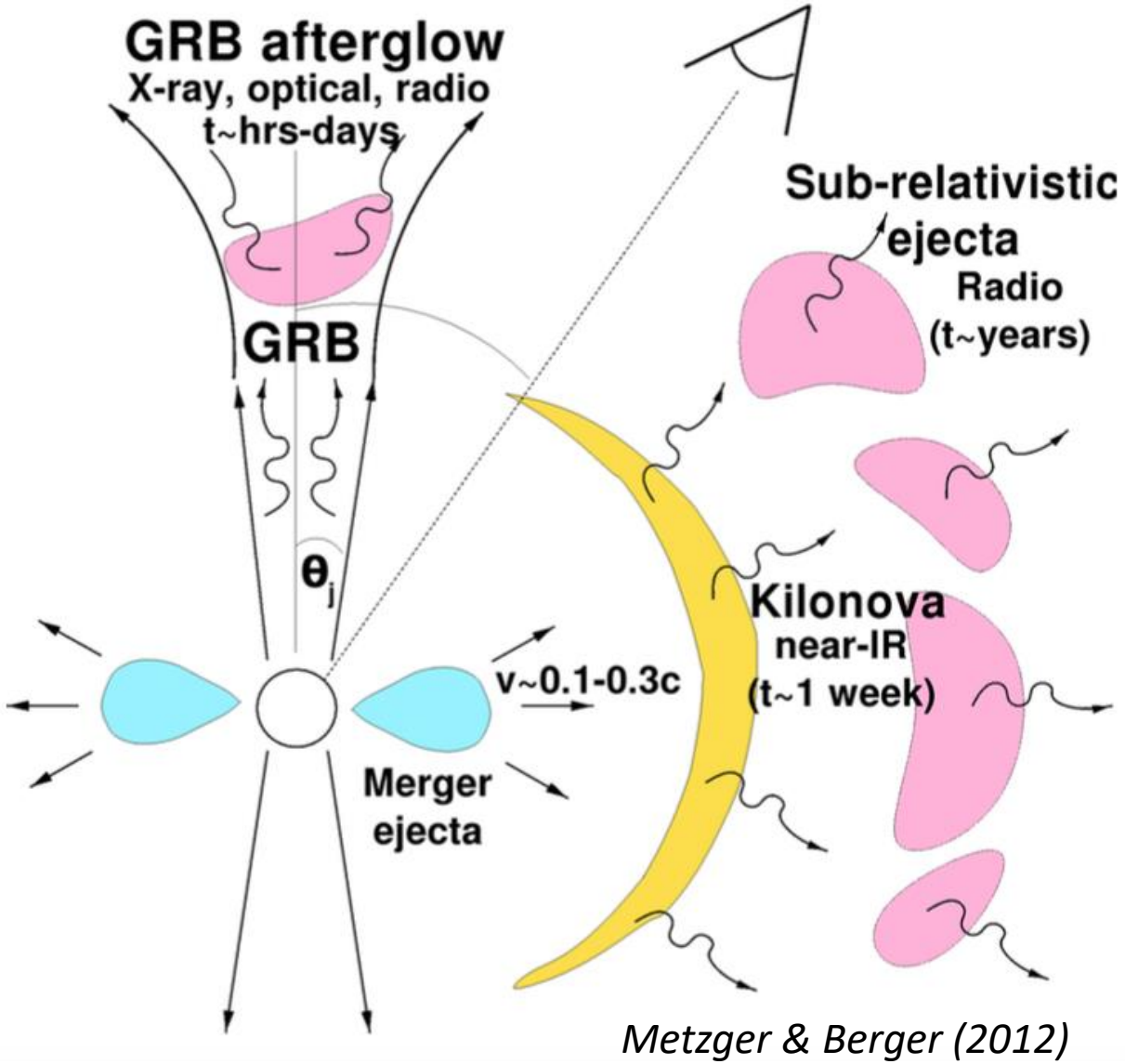
Other types of EM emission







NASA

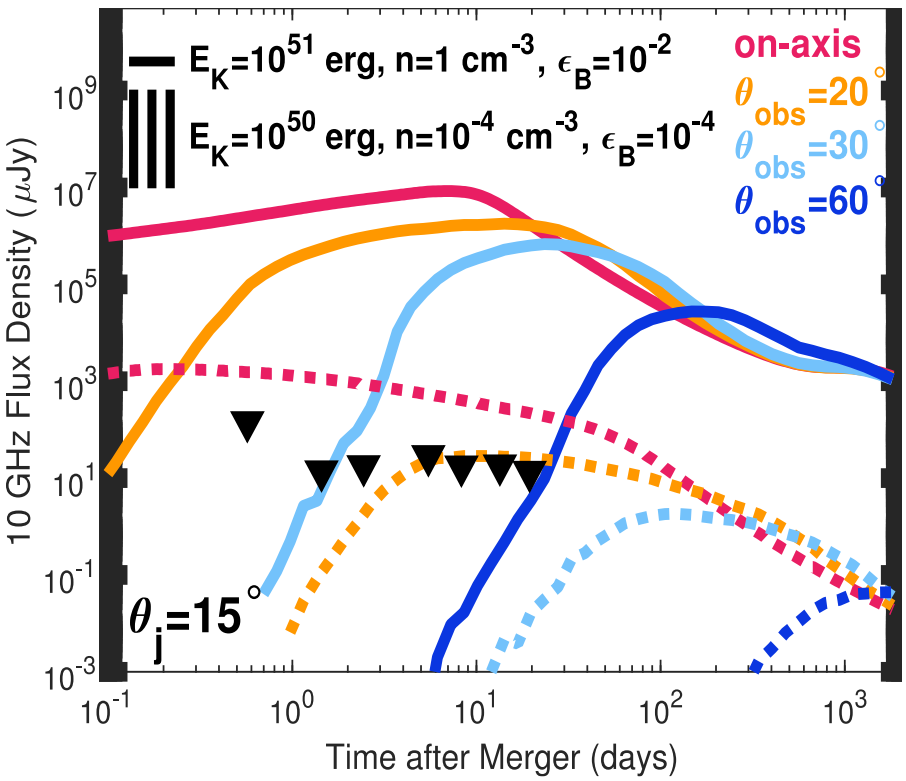


Metzger & Berger (2012)

Radio Emission

- Radio emission directly measures key physical properties of the system (e.g. ejecta energy and velocity, jet viewing angle, ISM density)
- Can observe in the daytime!
- Emission may be delayed by months or years and evolves slowly at late times, so searches must be long-duration

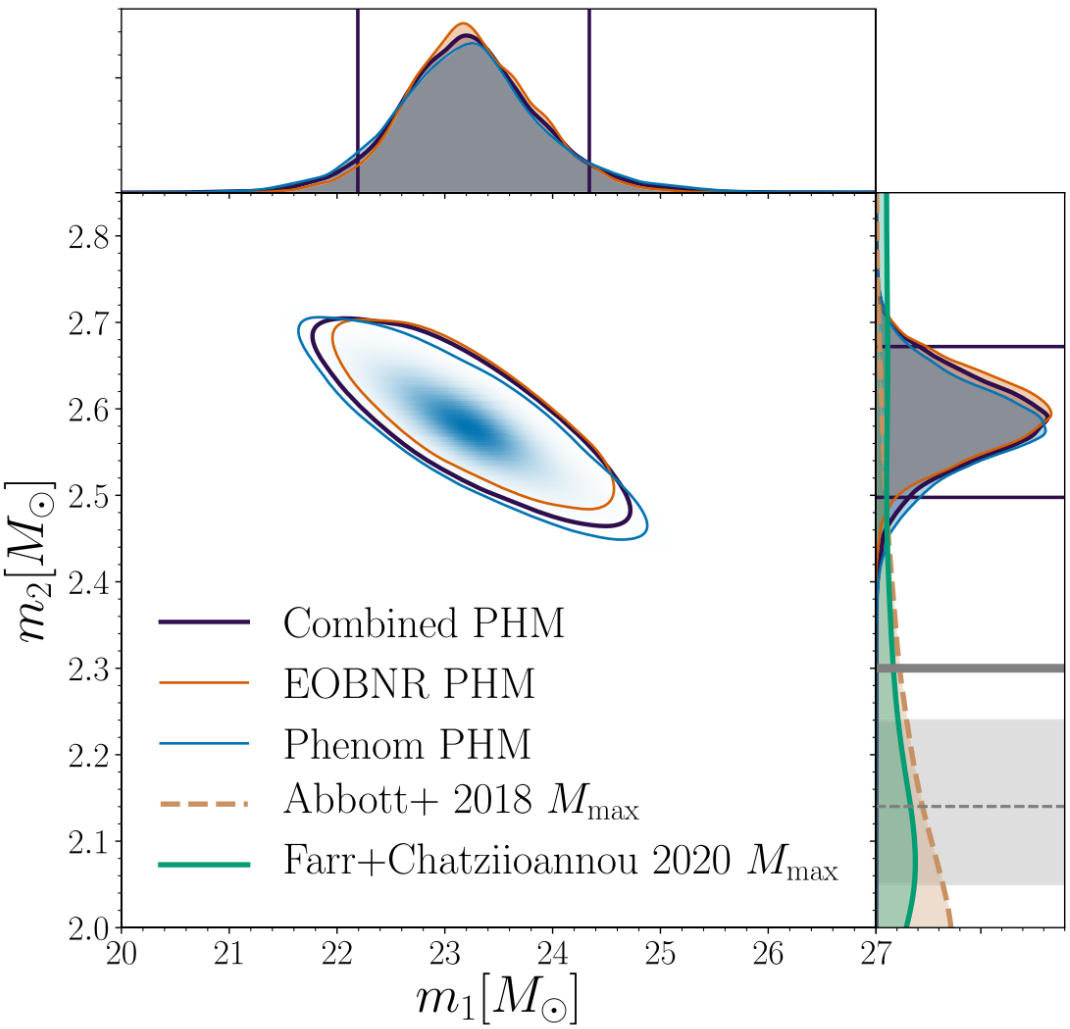
Alexander et al. (2017)



How do we find radio transients today?

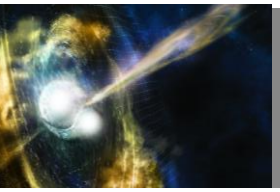
- To obtain sufficient resolution and sensitivity generally need **radio interferometers**
  - VLA, ATCA, ALMA, LOFAR, MWA, ASKAP, MeerKAT, etc.
- Recent improvements in survey speed, field of view, and computational speed have made radio transient searches feasible and productive
  - The radio sky is much quieter than the optical sky – biggest contaminant on timescales of interest is AGN
  - Large FoV telescopes optimal for blind searches (e.g. Dobie et al. 2019, 2022)
  - For small FoV telescopes, galaxy-targeted searches are more efficient, can focus on higher frequencies (where sky is even quieter)

The test case of GW190814

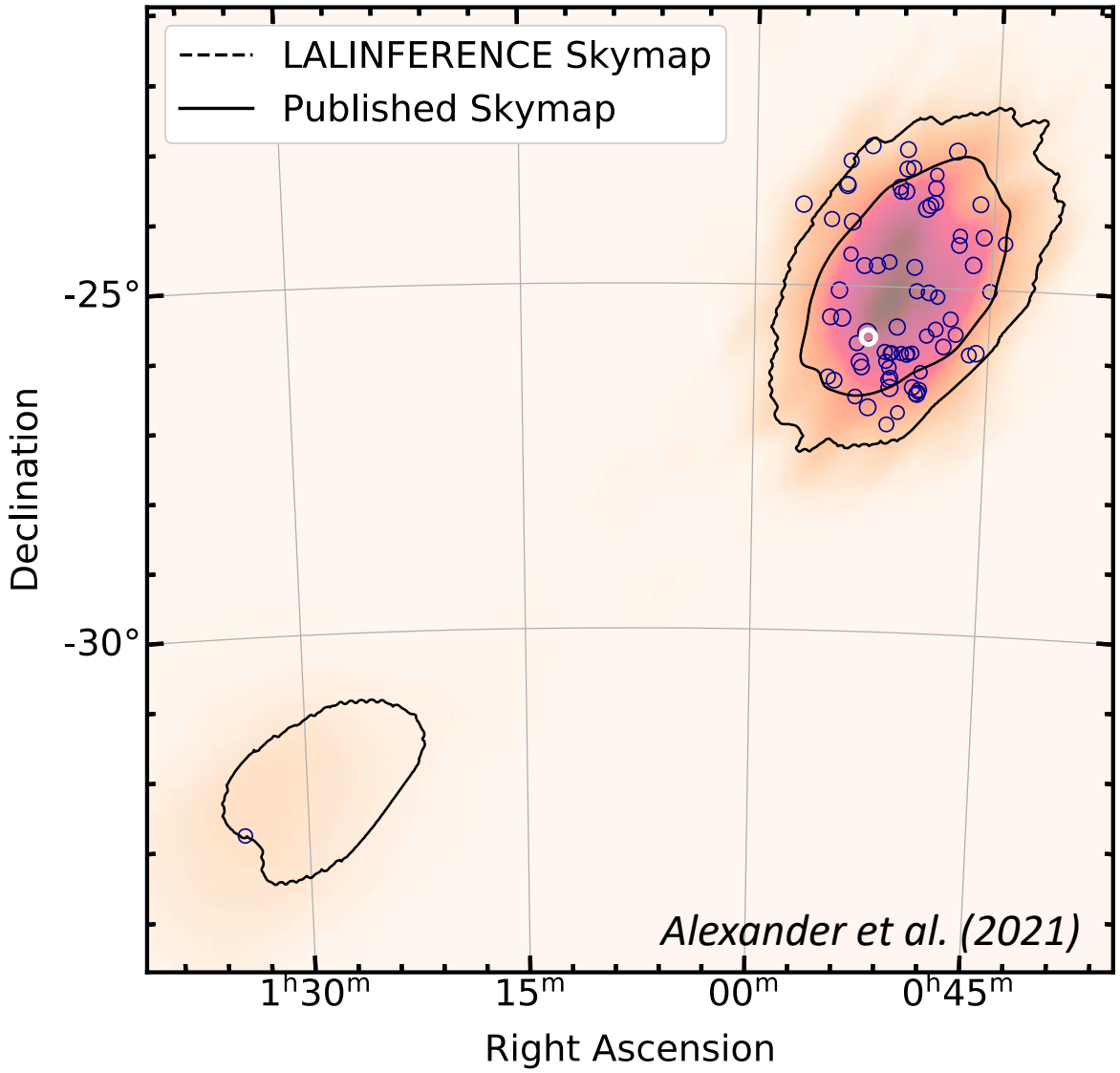


Abbott et al. (2020)

- High-significance candidate NS-BH or BBH merger
- Very well localized (18.5 deg^2)
- No optical, high-energy, or radio counterpart found at early times



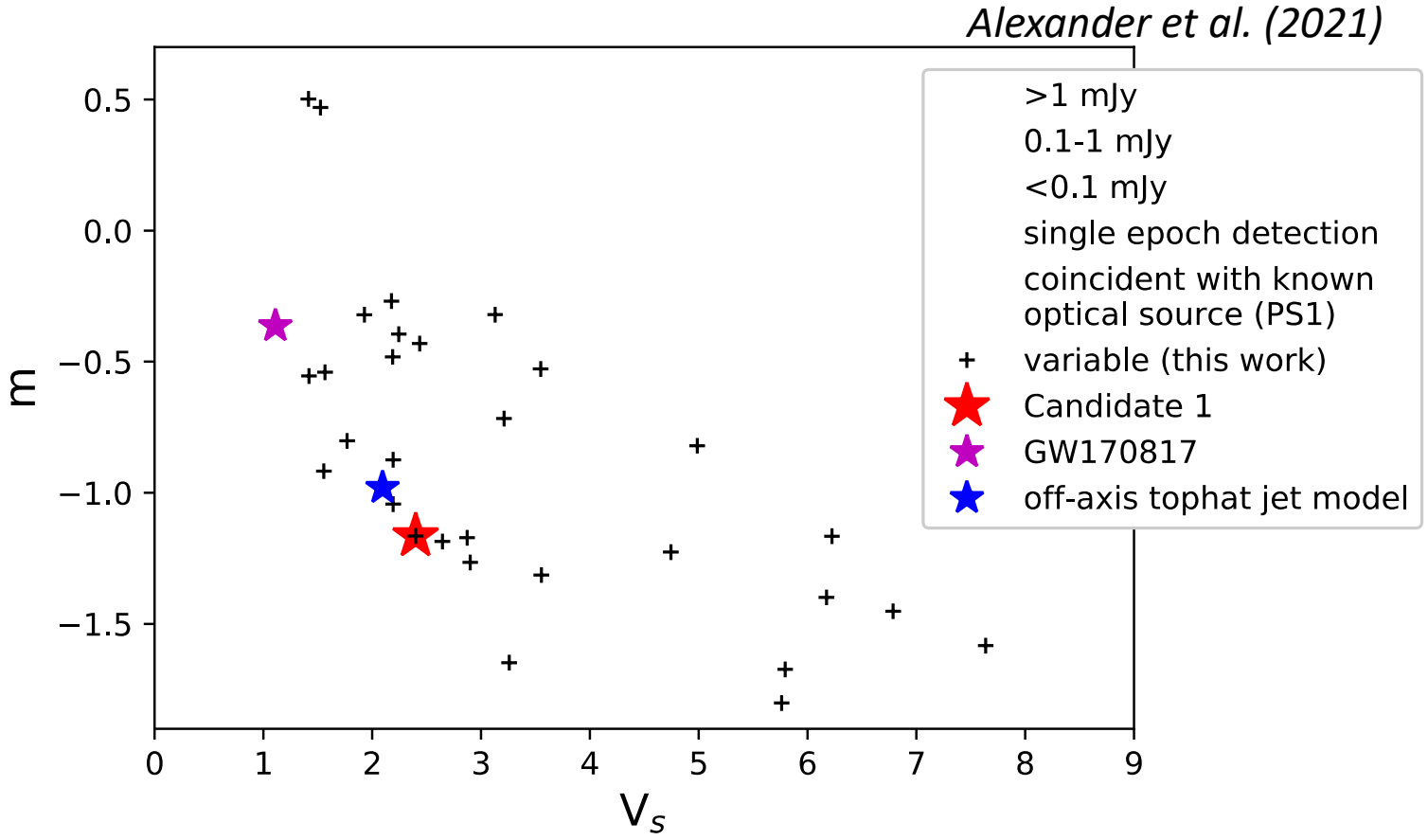
Radio search for late-time emission



- 75 galaxies from the GLADE catalog, containing ~32% of the stellar mass in the final localization volume
- Observed 1 & 6 months post-merger
  - Pre-merger measurement of host galaxy radio emission from the VLA Sky Survey

Variable candidates

Alexander et al. (2021)

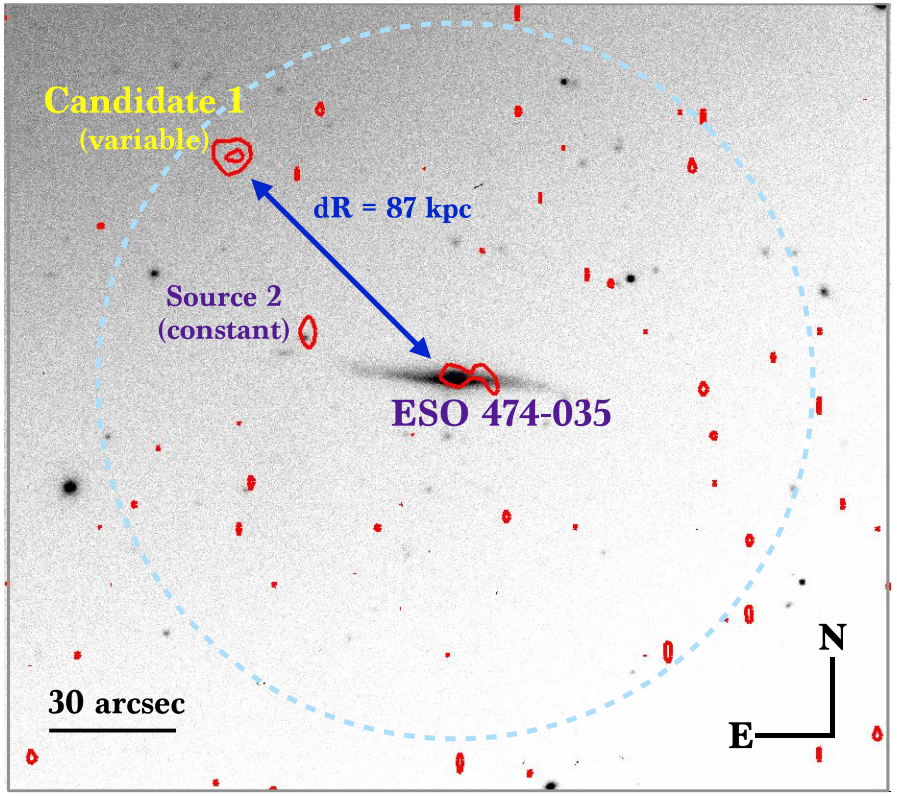


- 30 variable sources detected, 24 with optical counterparts in pre-merger imaging
  - More than half would have been missed by previously used variability cuts
  - Host, AGN contamination more significant than in wide-field surveys

Candidate 1: a background AGN

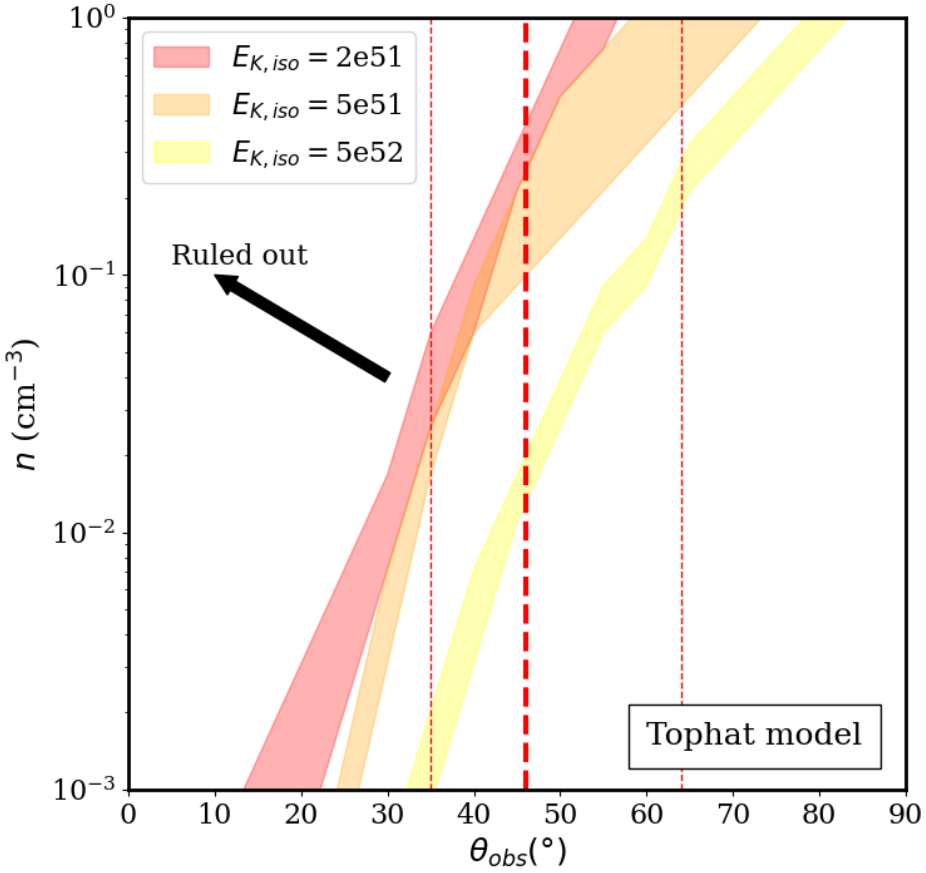
- Optical observations revealed no transient or persistent optical counterpart to radio Candidate 1
  - No bright kilonova
  - If background AGN, then must be at z > 2
- Multi-frequency radio observations confirm AGN origin
  - Resolved dual-lobed structure at higher frequencies
  - Synchrotron modeling would require high energy & density

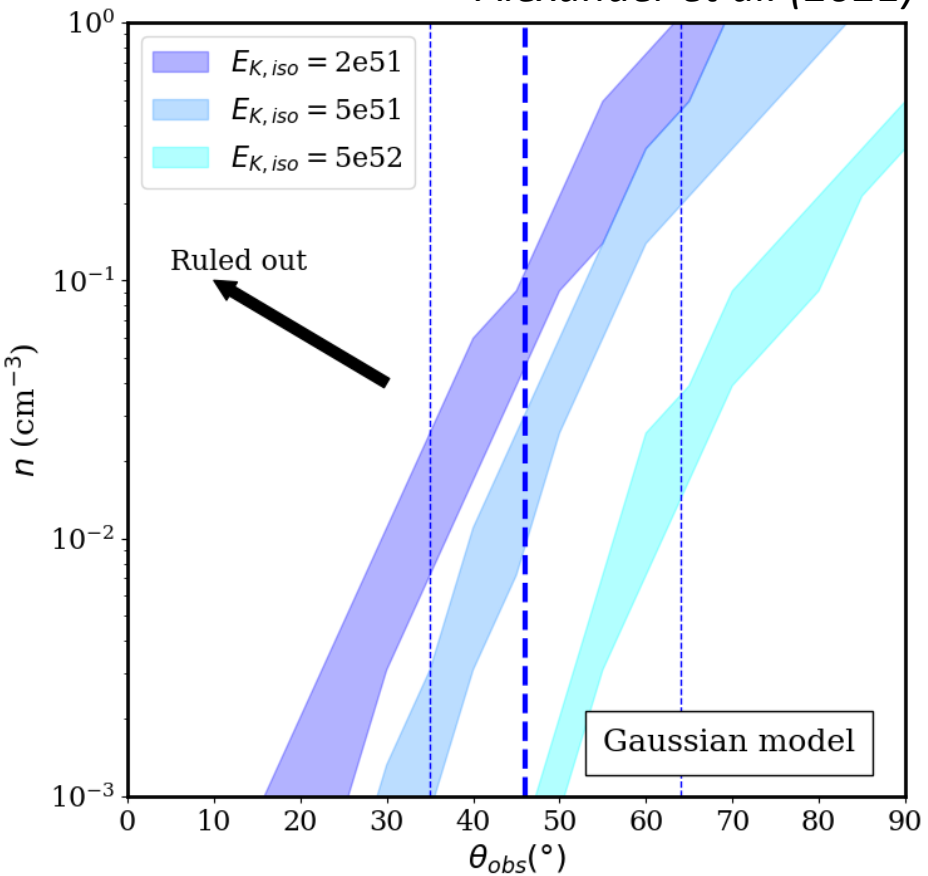
Alexander et al. (2021)



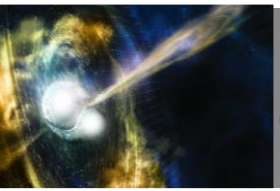
Limits on a relativistic jet

Alexander et al. (2021)





Assuming the merger location was included in our search region, we can rule out an energetic off-axis relativistic jet in a dense ISM (assuming p = 2.2, ε_e = 0.1, and ε_B = 0.01).



Summary (see Alexander et al. 2021 for more)

- We can rule out an energetic off-axis jet for GW190814 within our observed area
  - Caveat: assumptions about shock microphysics required
- Contamination from e.g. AGN variability may have been previously underestimated, but for some events radio will be the only possible way to observe
  - Important to coordinate follow up efforts
  - Galaxy-targeted searches need better galaxy catalogs and template images → LSST/Rubin and precursor missions, VLASS, VAST, and other radio surveys
  - New radio facilities with larger field of view (e.g. ASKAP) will complement galaxy-targeted searches
  - Large potential for automating aspects of vetting process