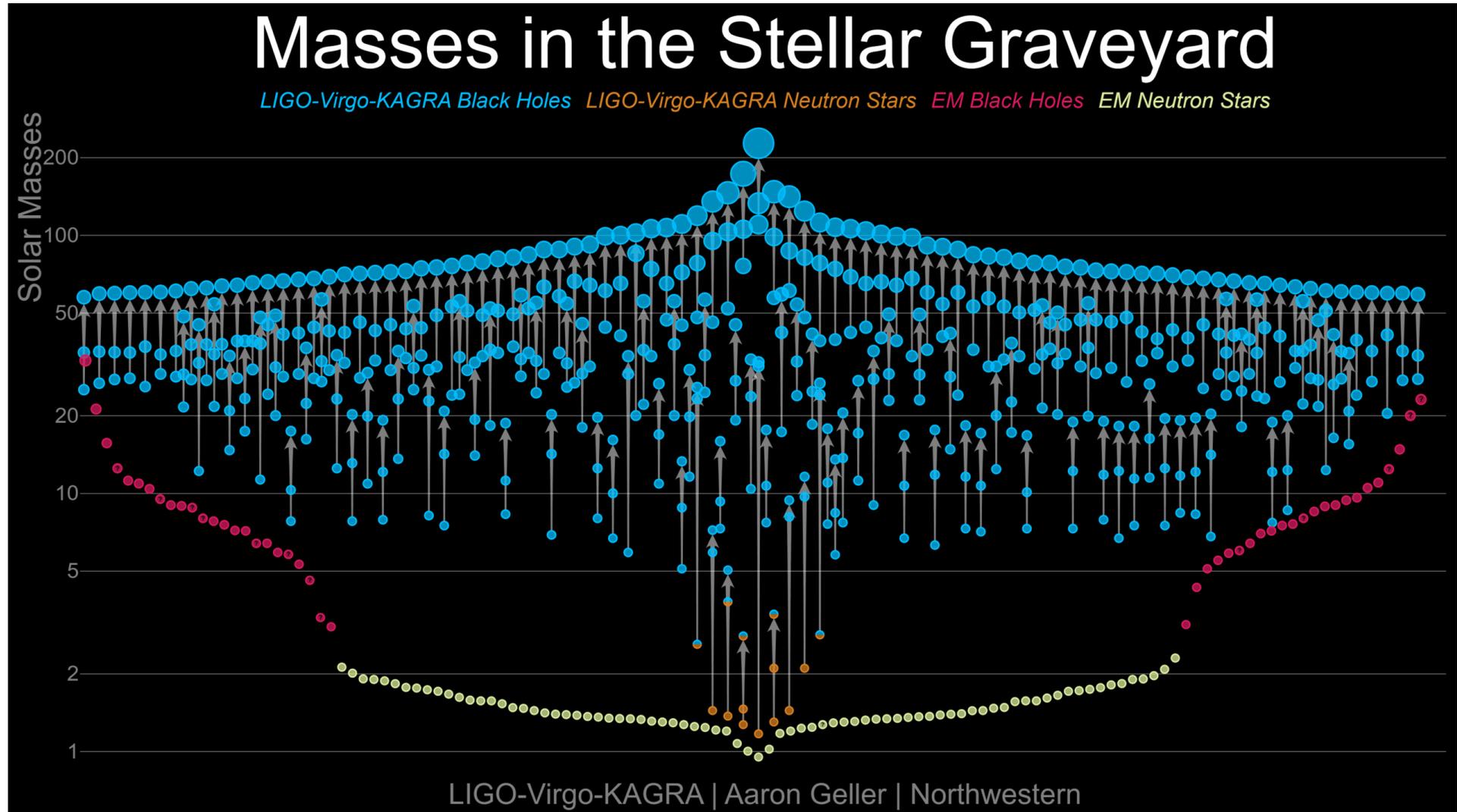


Compact Object Mergers Observing Plan

TDAMM, Huntsville, AL

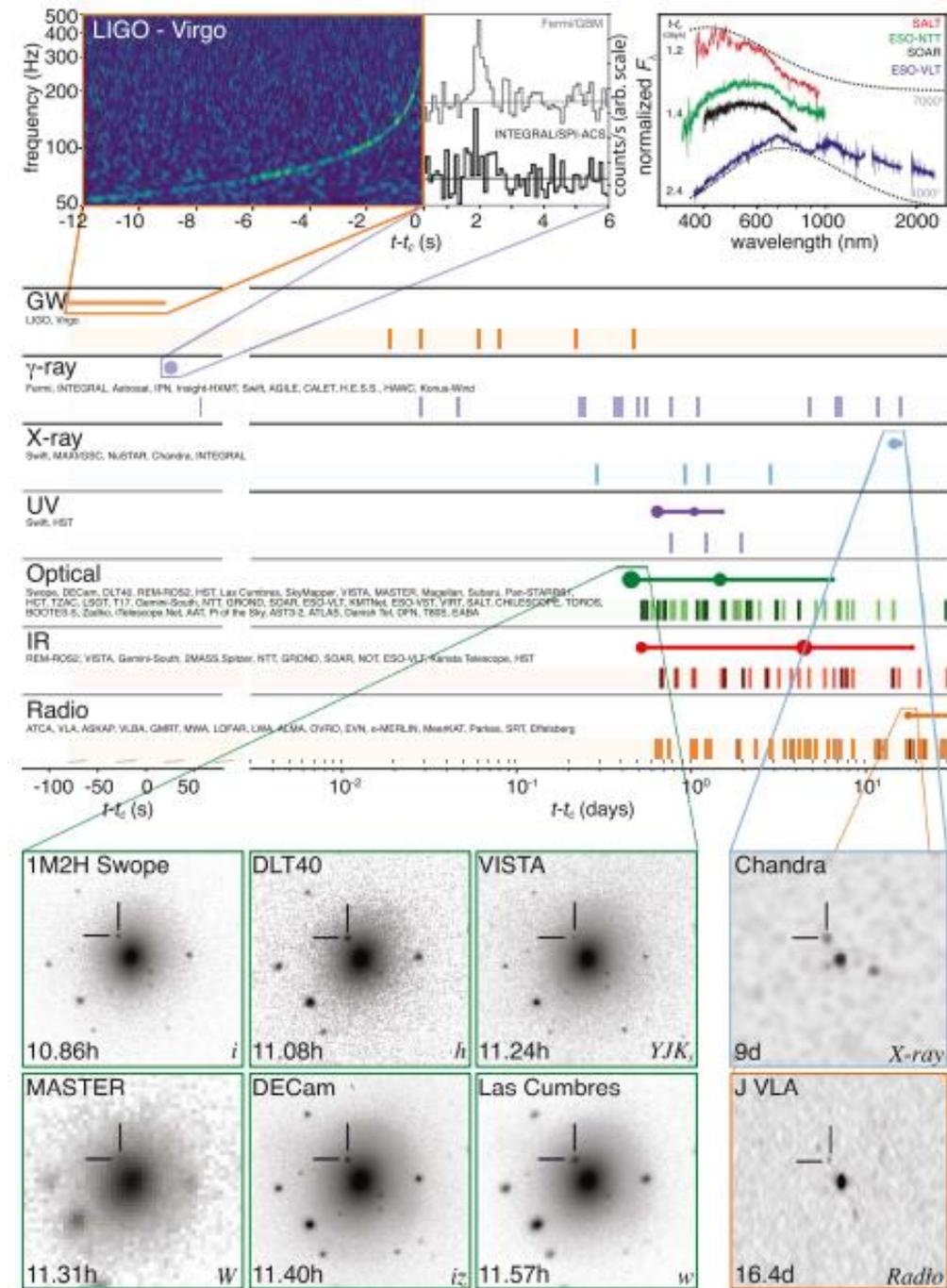
October 28, 2025

Compact Object Mergers are Common



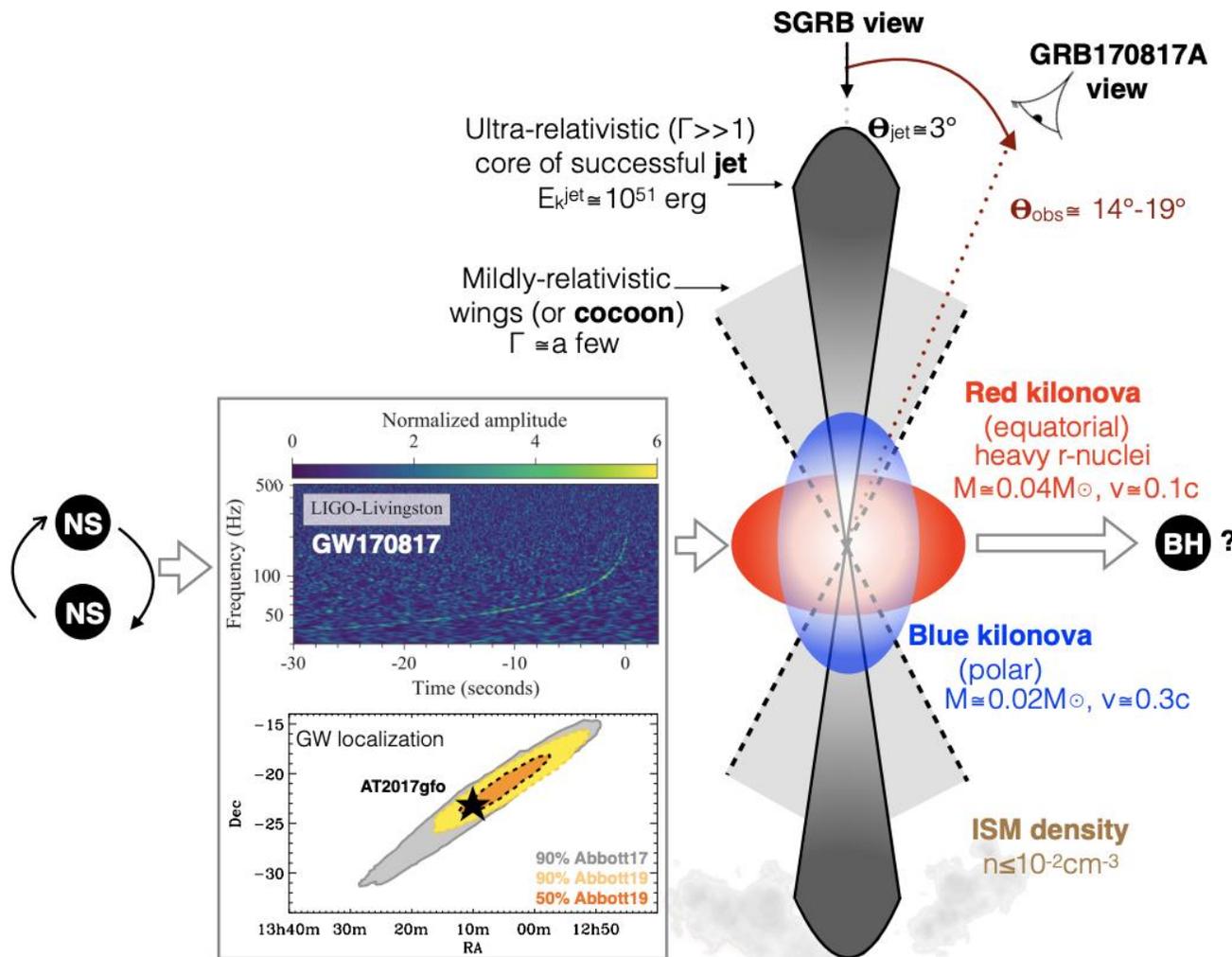
But EM counterparts are not

- We have exactly one multi-messenger compact object merger, GW170817
- This event was a (literal) goldmine – extensively studied across the EM spectrum, from gamma-rays to radio
 - Equation of state of dense neutron-star matter, properties of heavy nuclei e.g. actinides, the mechanism of gamma-ray bursts, BH accretion physics, the origin of r-process elements, cosmology, ...



What did we learn from GW170817?

Margutti & Chornock 2020:



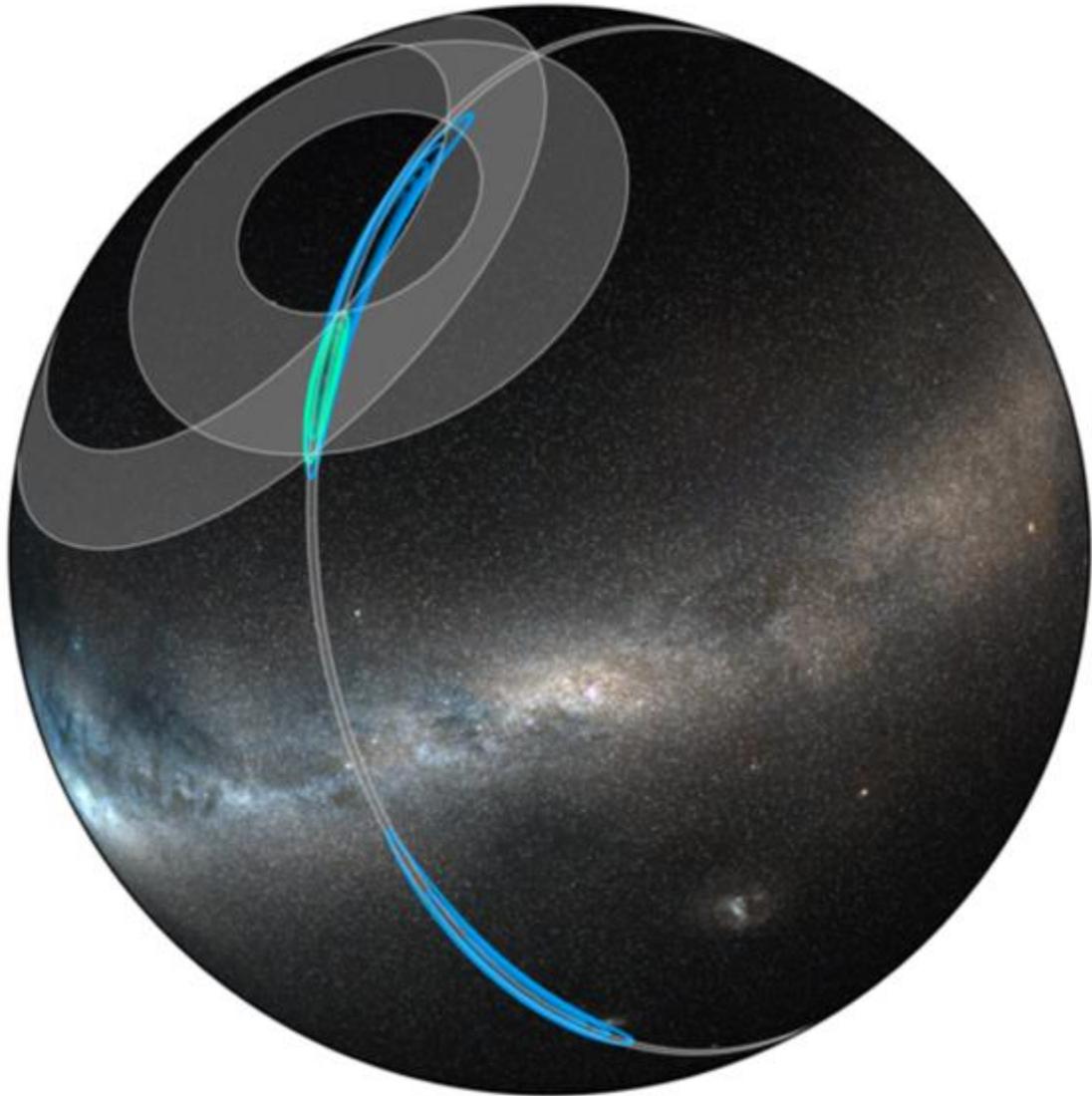
- The detection of a spatially coincident weak burst of γ -rays (GRB 170817A) 1.7 s after the merger constituted the first electromagnetic detection of a gravitational wave source and established a connection between at least some cosmic short gamma-ray bursts (SGRBs) and binary neutron star mergers.

- A fast-evolving optical and near-infrared transient (AT 2017gfo) associated with the event can be interpreted as resulting from the ejection of $\sim 0.05 M_\odot$ of material enriched in r -process elements, finally establishing binary neutron star mergers as at least one source of r -process nucleosynthesis.

- Radio and X-ray observations revealed a long-rising source that peaked ~ 160 d after the merger. Combined with the apparent superluminal motion of the associated VLBI source, these observations show that the merger produced a relativistic structured jet whose core was oriented $\approx 20^\circ$ from the line of sight and with properties similar to SGRBs. The jet structure likely results from the jet interaction with the merger ejecta.

- The electromagnetic and gravitational wave information can be combined to produce constraints on the expansion rate of the universe and the equation of state of dense nuclear matter. These multimessenger endeavors will be a major emphasis for future work.

GW170817: beginner's luck?

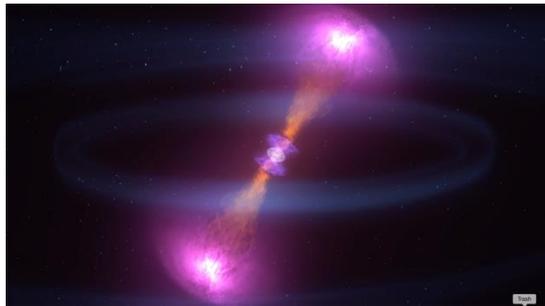
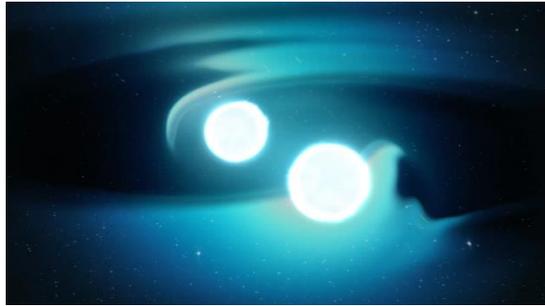


- **GW170817 was:**
 - Nearby (40 Mpc) = bright optical transient!
 - Well-localized (28 deg²)
 - Visible at night
- How do we adapt our observing strategies to find events where none of these may be true?
- When would a community observing plan help?
 - The uniquely rich dataset for GW170817 is a huge win for the community...but future compact object mergers will almost certainly be more elusive

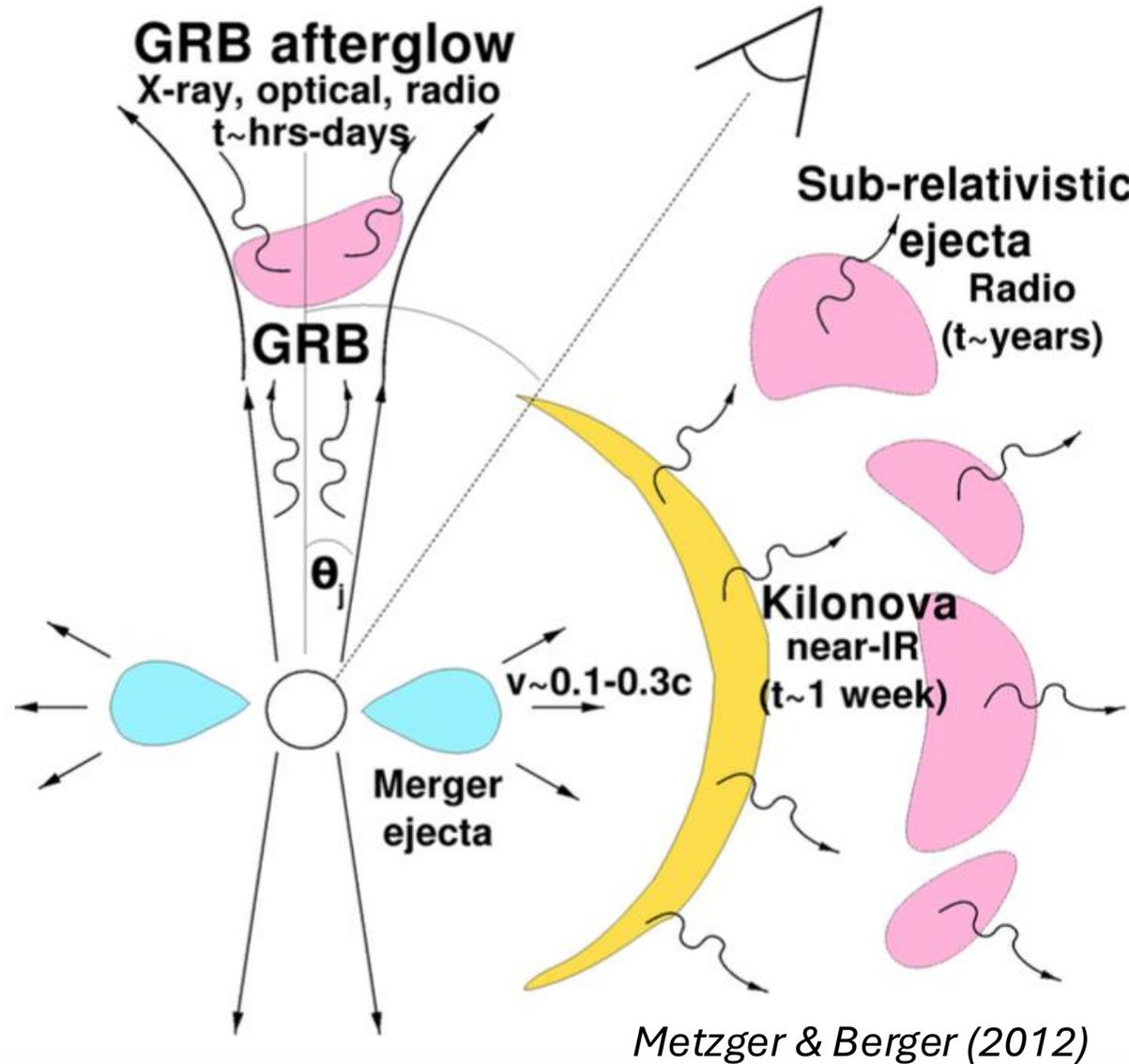
What are (some of) the challenges?

- large GW localization volumes
 - Sometimes not all visible at night, or from a single facility's location
- larger event distances = **faint** counterparts
- Need to learn to identify counterparts in new data streams (e.g. Rubin/LSST)
- Need to respond quickly (kilonovae evolve fast) **and** sustain monitoring over a long time (radio + X-rays can be delayed by months and last years)
- difficulty of ruling out contaminants (e.g. young supernovae) in a timely manner
- community duplication of effort

Expected EM counterparts and rates



NASA



- We are most confident in the existence of counterparts to neutron star-containing mergers (BNS or NS-BH)
- Rates are uncertain but low. From Abbott et al 2023: BNS: 10 to 1700 $\text{Gpc}^{-3} \text{yr}^{-1}$, NSBH: 7.8 to 140 $\text{Gpc}^{-3} \text{yr}^{-1}$
- Relevant timescales are seconds to months/years after the merger

Triggering Criteria: GWs

The past 10 years of LVK operations have revealed that NS-containing mergers are very rare. Given the high scientific return, **any** NS-containing GW merger should likely trigger a search for a counterpart. The exact sequence of observations to be triggered will depend on a number of factors:

- On-sky localization and distance – mergers that are poorly localized will require a large investment of telescope time to search the entire possible localization area. Similarly, distant mergers will have fainter counterparts and more potential host galaxies, complicating counterpart discovery efforts and follow up.
- Time to counterpart identification (dependent on point 1 above)
- Mass ratio – NSBH with a high BH to NS mass ratio will have very little mass-ejection and may not be worth following-up. (but we probably will anyway?)
- Binary inclination angle – highly off-axis mergers will have much fainter X-ray and radio emission, which may be delayed by ~months. On-axis mergers will have prompt bright gamma-rays (short GRB).

Triggering Criteria: Other

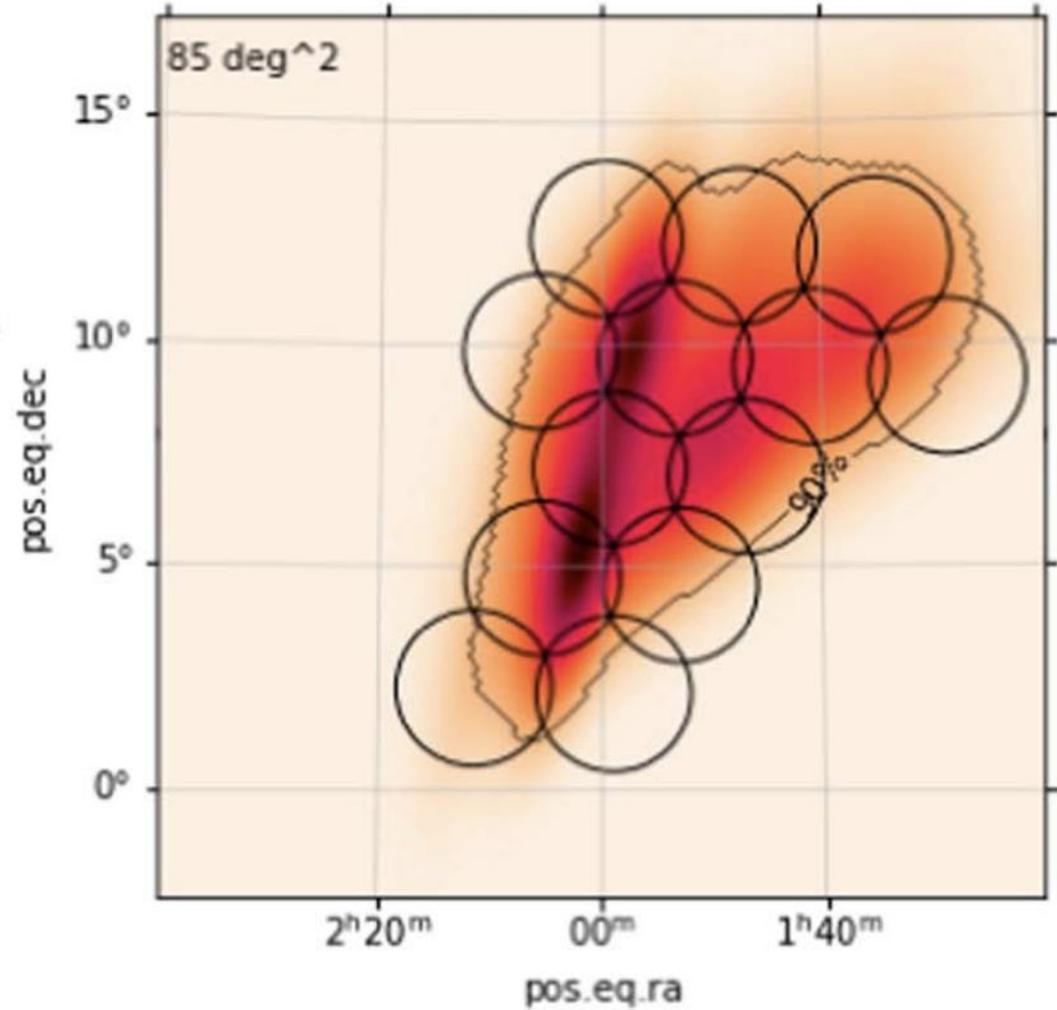
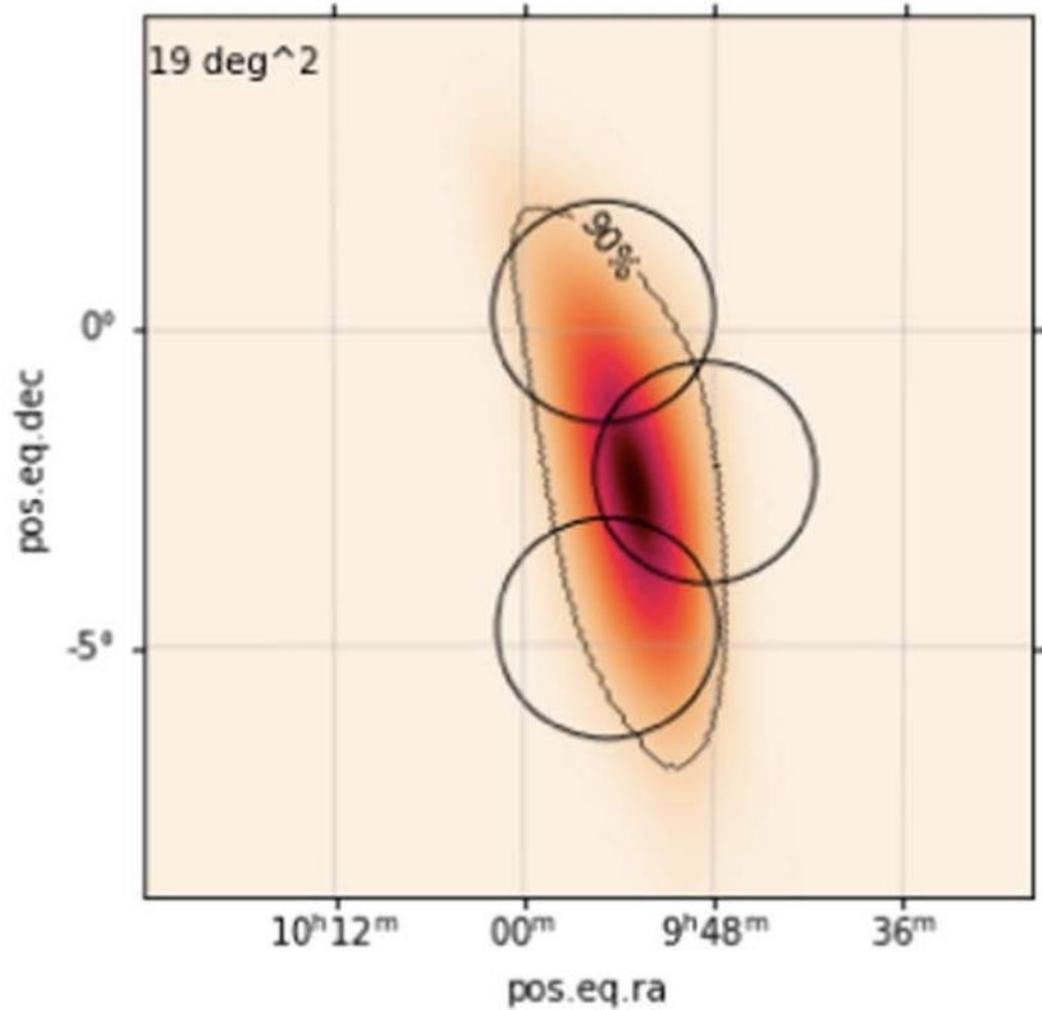
- A few possible KNe have also been identified in conjunction with GRBs, suggesting a possible GW-independent method of identifying these rare events.
- New wide-field optical surveys like Rubin's LSST may also possess the sensitivity to independently discover kilonovae.
- Nevertheless, the expected event rate across all of these discovery methods is no more than a few per year at most (and likely $< 1/\text{yr}$).
- Current draft community observing plan focuses on identifying a counterpart in the GW case (but open to discussion!) and on observations desired after an unambiguous counterpart is found

What observations do we need?

- T0 + 0–1 hr: Rapid-response triggers (gamma-ray, X-ray)
- T0 + 1–24 hr: Optical/NIR spectroscopy and imaging (wide-field imaging to search for candidate counterparts, spectroscopy to vet them)
- T0 + 1–24 hr: UV/Optical/NIR spectroscopy and imaging of ID'd counterpart
- T0 + 1–14 days: Multi-epoch coverage across UV/optical/IR/radio/X-ray
- T0 + weeks–months: Monitor ejecta and environment evolution (radio/X-ray/optical)

Observatory	Wavelength/Coverage	Unique Capability	Ideal Use Case
HST	UV/Optical	High-resolution imaging	Late-time optical follow-up
JWST	NIR/MIR	KN spectroscopy, deep IR imaging	Bright, nearby events (spectroscopy) or distant events with a clear counterpart (late-time imaging)
Swift	UV/X-ray	Rapid follow-up	Early-time monitoring
Rubin	Optical (Wide-field)	High-cadence surveys	GW-independent KN identification; deep imaging of LVK localization regions
Large ground-based optical telescopes (e.g. Keck, Gemini)	Optical	KN spectroscopy, deep optical imaging in multiple bands	events with a clear counterpart
VLA, MeerKAT, ATCA, GMRT	Radio	Jet and ejecta studies	Late-time synchrotron afterglow
ASKAP	Radio	Wide-field radio imaging	Radio counterpart identification; monitoring of late-time synchrotron afterglow
Chandra	X-rays	Jet and ejecta studies	Late-time synchrotron afterglow

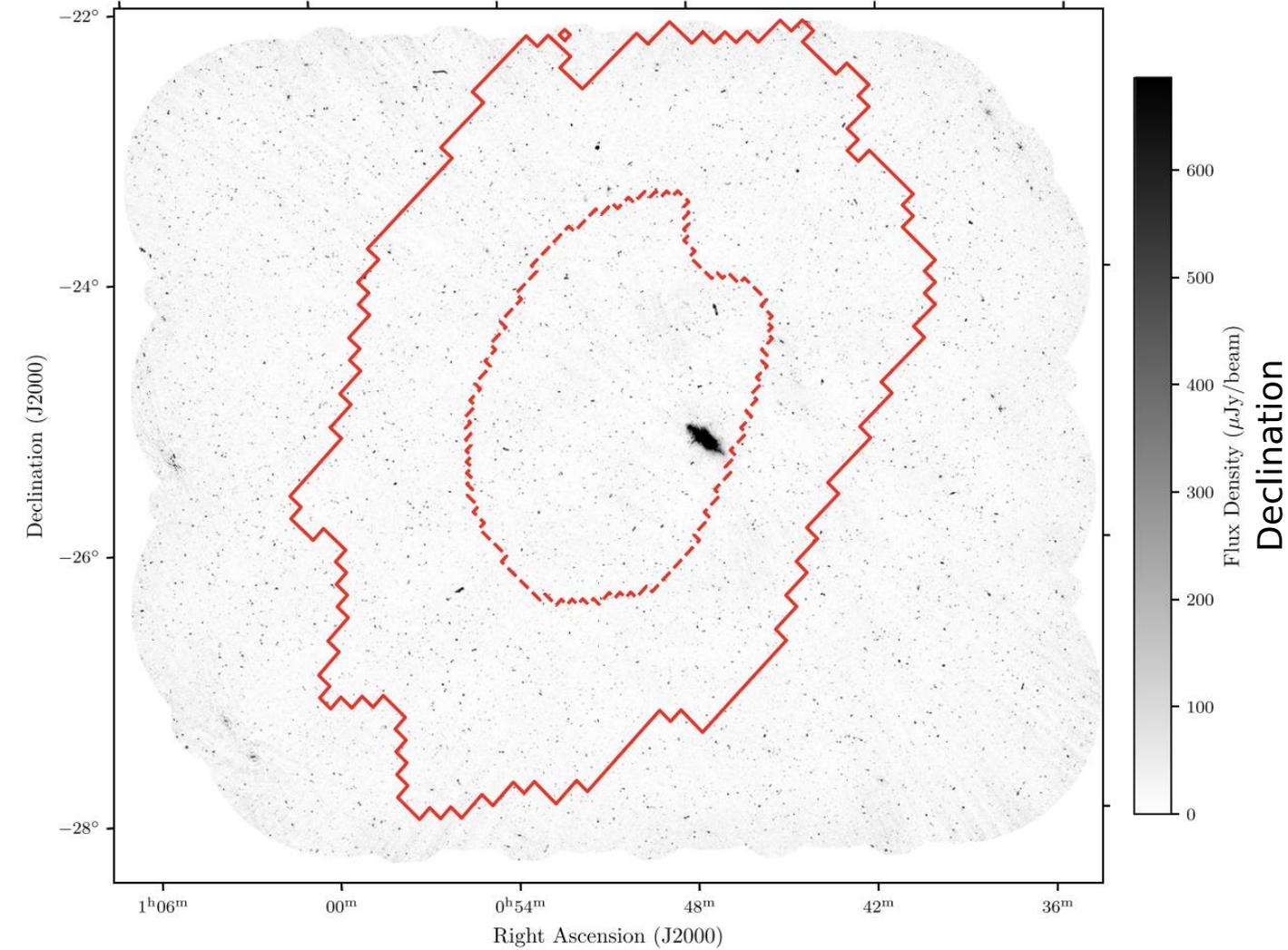
Finding a counterpart: A Key Role for Rubin



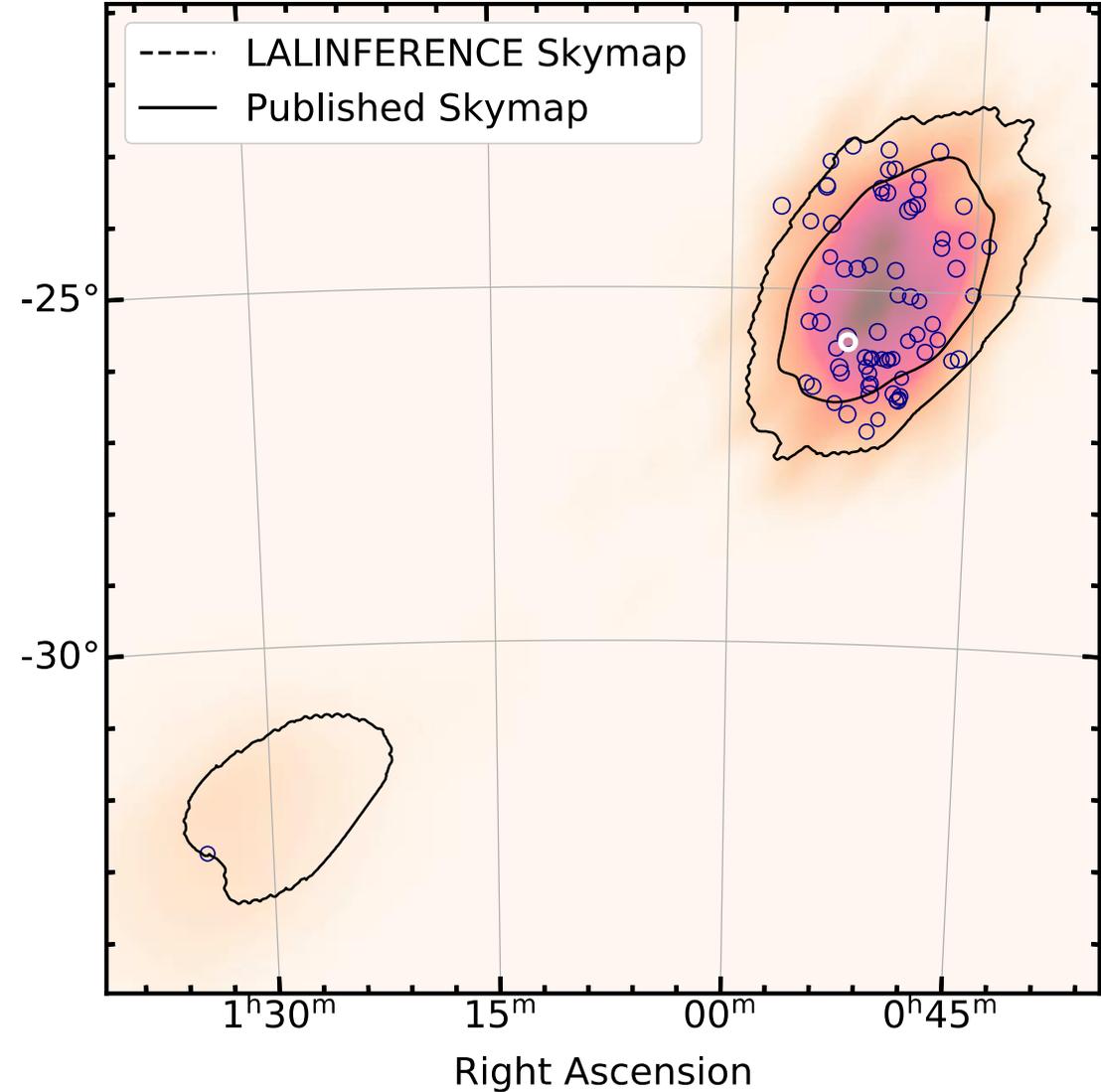
Andreoni et al. (2022)

Radio counterpart searches

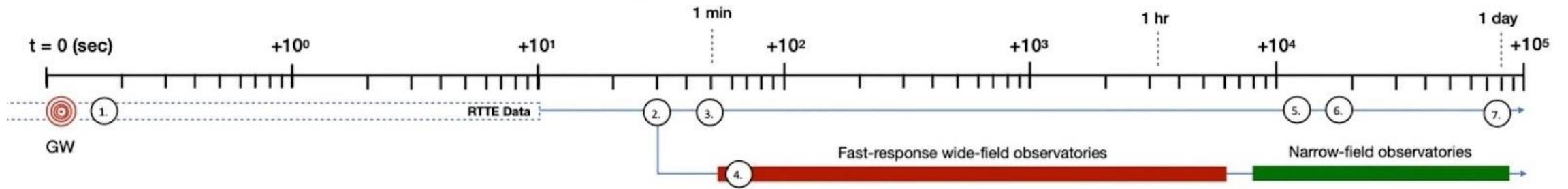
Alexander et al. (2021)



Dobie et al. (2019)



Example observing timeline



1. LVK detects merger
2. Detection circulated by GCN
3. Automated rapid-response observations triggered (e.g. Swift)
4. Fast-response wide-field observatories begin search
5. Narrow-field observatories used to help confirm counterpart (e.g. targeted spectroscopy of promising candidates)
6. Narrow-field observatories begin detailed monitoring (optimistic case)
7. Narrow-field observations may be delayed by >1 day or more if counterpart is not found quickly

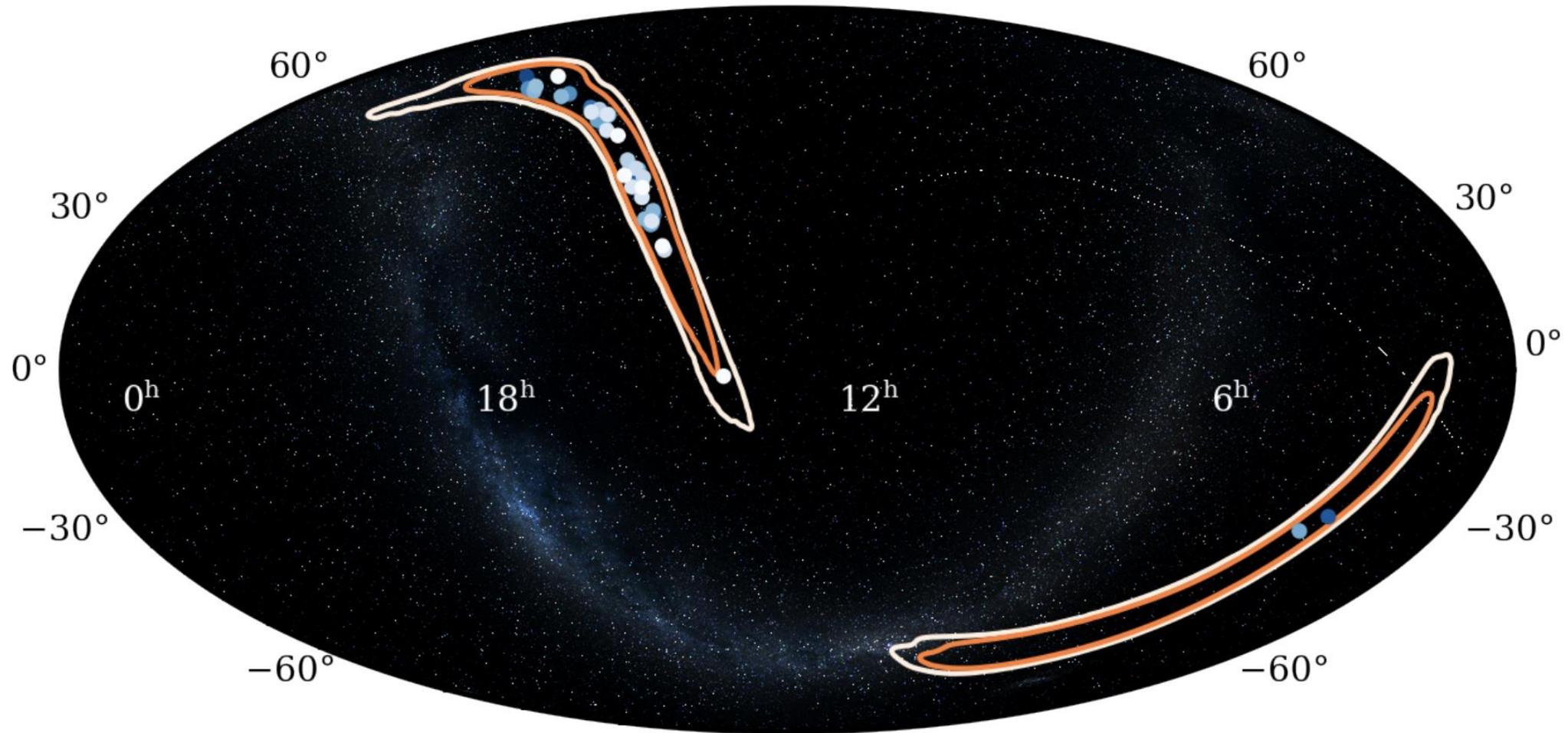
What observations do we need? Rapid ID Case

Timescale	Observatory	Capability/Wavelength	ToO Triggering Criteria
T0	Fermi / Swift	Gamma-ray detection	Automatic trigger on GRB detection
T0 + 1 hour	Swift	X-ray detection (for on-axis/nearly on-axis events)	Automated observations based on GRB detection
T0 + 1 to 24 hours	Swift	Wide-field X-ray, UV, Optical imaging	GW localization < XX deg ² , distance cut?
T0 + 1 to 48 hours	ground-based optical (e.g., Rubin, ZTF, LS4)	Deep wide-field optical imaging to search for kilonova	GW localization < XX deg ² , distance cut?
T0 + 1 to 48 hours	Swift, HST, ground-based optical (e.g., ZTF, Gemini)	X-ray, UV, Optical imaging	Requires detection of optical counterpart
T0 + 6 to 24 hours	Gemini, Keck, VLT	Optical/NIR spectroscopy	Requires detection of optical counterpart
T0 + 1 to 7 days	ALMA, SMA, NOEMA	mm and sub-mm afterglow follow-up	Based on well-localized optical/X-ray afterglow
T0 + 1 day to 12 months	VLA, ATCA(?), MeerKAT, GMRT	Long-term radio afterglow follow-up	Based on well-localized optical/X-ray afterglow. Longer-term follow-up can be proposal-based or scheduled
T0 + 7 days to months	HST, Chandra, JWST	Late-time imaging/spectroscopy in UV/IR/X-ray	Proposal-based ToO or scheduled follow-up

Community coordination needs

- Who Needs to Be Alerted: Missions, ground-based observatories, coordination networks.
- Preferred Alert Channels: GCN – also AMON, VOEvent, Slack, etc?
- GW triggers and candidate coordinates + early photometry need to be made public ASAP, as extremely rapid turnaround is essential for this science.
- It would also be ideal to publish what observations are being made where and when, to minimize duplication and coordinate coverage of the full GW localization regions across different teams (as attempted by the Treasure Map)
- Public real-time scoring of published candidates (see e.g. TROVE talk tomorrow by N. Franz)

S250818k: a recent example where it is clear not all possible candidates are being found (or followed)...



Open questions

- Should we ever trigger on binary black hole mergers? (Particularly close and/or well-localized ones?) What about high mass ratio NSBHs?
- Should we skip BNS mergers that have an extremely poor localization or are too far away? (What's too far?)
- Sometimes, it may take several days or longer to ID a counterpart. Is it appropriate to trigger valuable community resources (e.g. HST, JWST) even if there is still some doubt as to a candidate's validity? What level of proof is sufficient? Who decides?
- More coordinated wide-field observing would help, but how to decide who should observe what? How do we ensure that lower-probability portions of large localization areas are not entirely missed?
- What observatories / types of observations have we not yet discussed?