NASA/IPAC Extragalactic Database

How Can NED Support LISA?

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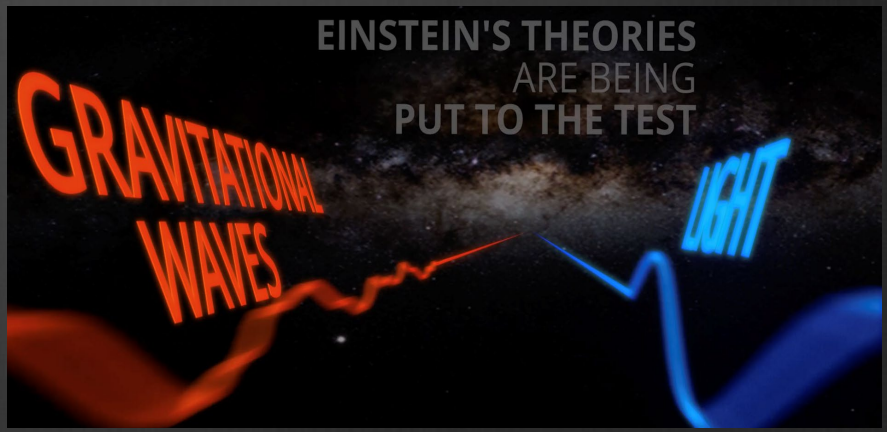
LISA – Merging MBHs

- "Loud" transient signals
  - Massive black hole binaries (MBHBs)
  - $M_{BH} \sim 10^4 - 10^7\ M_\odot$
  - z ~ all redshifts
  - Detectable for hours – days
- Will probe MBHs across cosmic history!
- Combined with EM or host identification:
  - MBH-host co-evolution
  - BH accretion physics
  - Cosmology

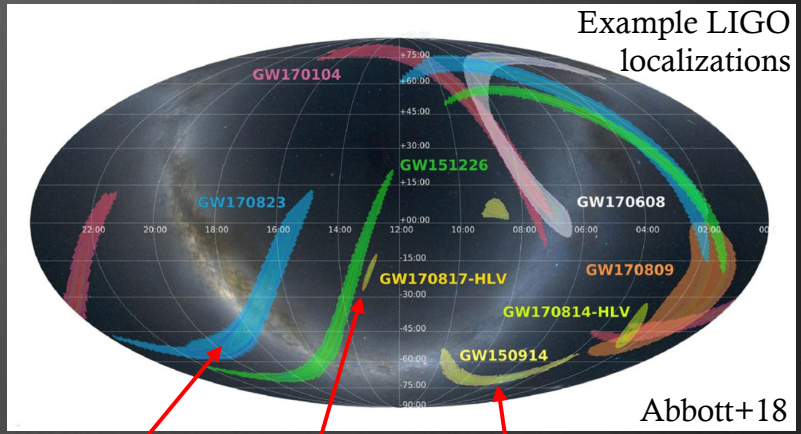


courtesy: A. Weinstein

Finding Hosts is Difficult…

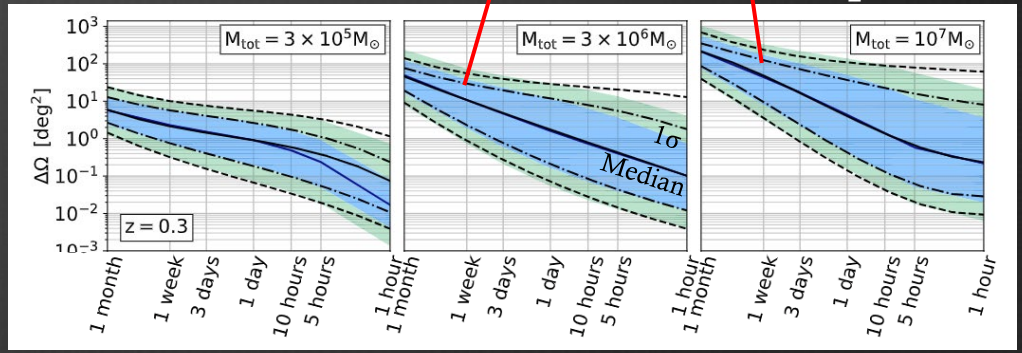
- Even in the Local Universe and a week to merger…
  1. Sky areas are likely large
     - z=0.3: 10s – 1000 deg^2
     - z=1: 10s – 1000s deg^2
  2. Larger volumes and more host candidates (Lops+23)
     - N(z=0.3) ~100s – 1000s
     - N(z=1) ~10^5
  3. Merger rates are uncertain
     - tenths – tens per year (e.g., Katz+20a, Chen+22, Li+22, DeGraf+24)

- Lessons from LIGO/Virgo/KAGRA (LVK)
  - Host galaxy prioritization…

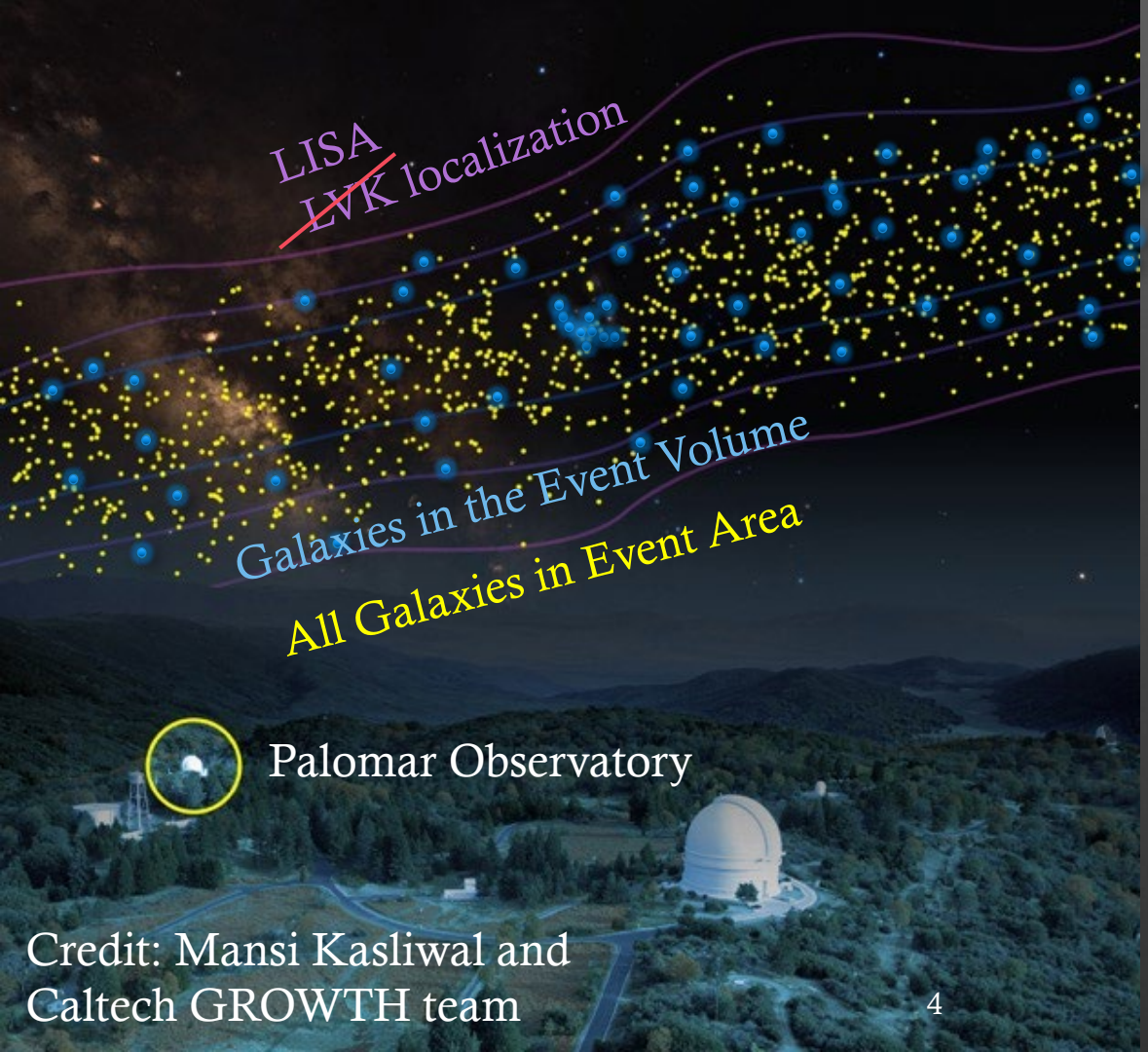


z~1

Dwarfs MW-like Ellipticals



Mangiagli+20 (see also Katz+20b)



Credit: Mansi Kasliwal and Caltech GROWTH team

How Do Galaxies Help?

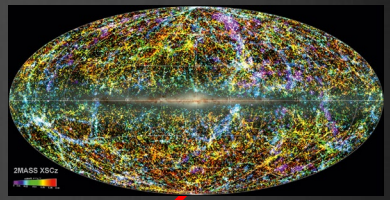
1. Prioritize follow-up efforts for galaxies in the event volume
2. Weed out contamination foreground and background
3. Optimize tiling strategies based on density of galaxies
4. Prioritize likely hosts. based on
   - Host and/or BH properties

What is NED?

- Compiles and cross-matches data from:
  - Literature
    - >135,000 papers since 1990
  - Surveys
    - 2MASS, Chandra , DESI-EDR, GALEX, SDSS, WISE, +more
- Data:
  - N_{tot} ~1.1B objects
  - Names, positions, fluxes, diameters
  - Redshifts: N(w/z) = 11M
  - Redshift-independent distances: N=150k
- NED is updated continually

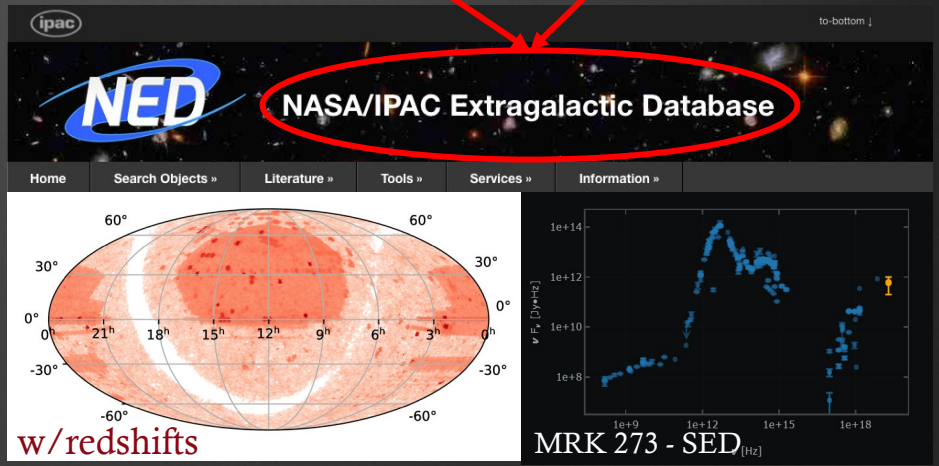
Literature

Surveys



2MASS-XSC
Jarrett+00

Public database of extragalactic objects



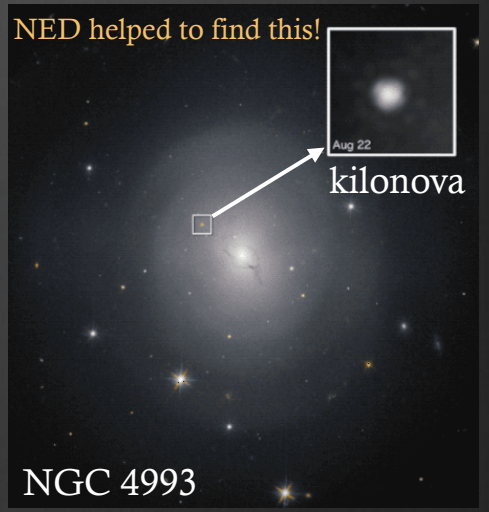
https://ned.ipac.caltech.edu/

NED Supports GW Follow Up Today

- Binary Neutron Star (BNS) Merger event: GW170817
  - Galaxy strategy used to find only EM counterpart
  - Coulter+17 cite the usage of NED in discovery paper

- Gravitational Wave Follow-up Service (NED-GWF):
  - https://ned.ipac.caltech.edu/NED::GWFoverview/
  - 3D cross match NED with event HEALPix map
  - Provides: Galaxy lists and prioritization metrics (within mins of alert)
  - Responded to ~2700 GW events since 2019
    - Host candidates published via NASA GCN
    - i.e., S250206dm – NSBH event; NED list (GCN 39235) used by other groups (GCN 39196, 39286, 39311, 39355 , 39545)
  - Additional support: extra vetting, some priority ingestion, physical properties ($M_\star$, SFR)

GW170817



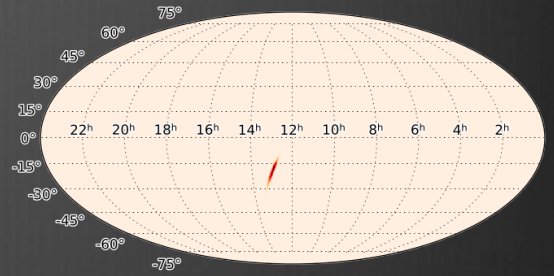
Coulter+17

Prioritization Metrics

- Joint Prob = $P_{3D} \times P_{host}$ (HEALPix, Singer+16, Arcavai+17)
- For LVK,
  - Merger rate ∝ SFH * τ_{delay} (Adhikari+2020)
  - τ_{delay} > Gyr: GW170817 host NGC 4993 is old and massive (see also Nugent+22)
  - NED provides multiple prioritization metrics
- LISA data provides distance and M_{BH},
  - Simulations are providing glimpses at host properties
    - Izquierdo-Villalba+23, Dong-Páez+23, Bardati+24a,b, etc.
  - Additional constraints from observations are needed…

GW170817

Final Localization (31 deg^2)



N(in Vol)= 46

Final Sky Map (31 deg^2)

Galaxy	Rank	$P_{M_\star} \times P_V$
NGC 4763	1	4.34e-02
NGC 4970	2	3.08e-02
NGC 4830	3	2.83e-02
IC 4197	4	2.26e-02
IC 4180	5	2.07e-02
NGC 4993	6	1.81e-02
MCG -02-33-036	7	1.56e-02
NGC 4968	8	1.30e-02
ESO 508- G 033	9	8.67e-03
ESO 575- G 029	10	8.37e-03

Mass

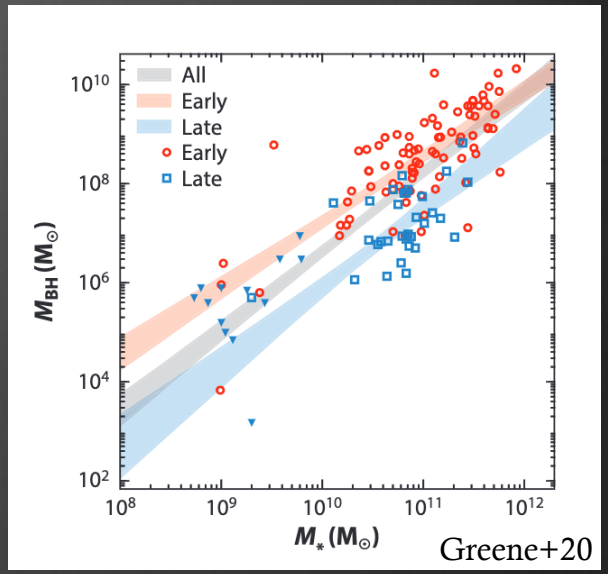
Galaxy	Rank	$P_{\mathrm{sSFR}^{-1}} \times P_V$
NGC 4970	1	5.12e-02
NGC 4830	2	3.97e-02
NGC 4993	3	8.69e-03
IC 4197	4	5.69e-03
ESO 575- G 061	5	4.16e-03
WISEA J125732.70-194200.8	6	4.04e-03
WISEA J125251.08-152929.7	7	3.07e-03
MCG -02-33-036	8	2.16e-03
IC 4180	9	2.02e-03
2MFGC 10461	10	1.85e-03

sSFR

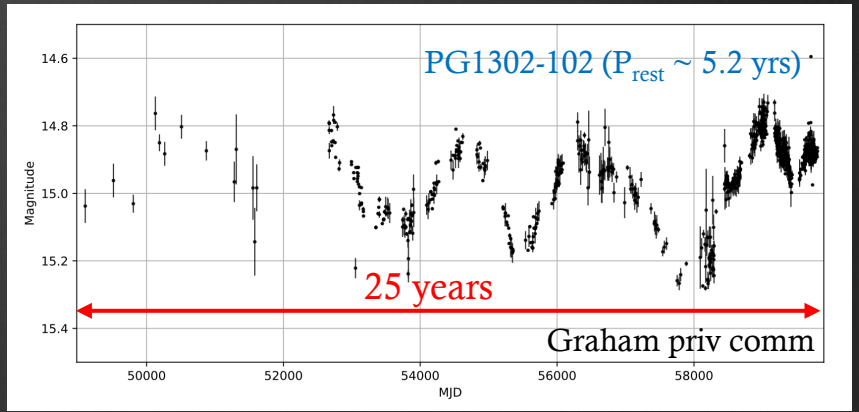
Cook+23

Additional Constraints for LISA

- By M_{BH}
  - Virial M_{BH} estimates from spectra (SDSS, DESI, etc.)
  - $M_{BH} - \sigma$ (or $- M_{\star}$)
    - Host $M_{\star}$ provides constraints on M_{BH}
- By merger time (τ_{merger})
  - Orbital properties from periodicity searches in time series (ZTF, Rubin, Roman, etc.) constrain τ_{merger}
  - Need long baselines (>5-10 cycles; Vaughan+16)
    - Robust identification & periods



Greene+20



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NASA/IPAC Extragalactic Database

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Home » Services » Gravitational Wave Followup » Events

Gravitational Wave Followup Events

LIGO-Virgo Event GW170817 **Type** 3-Update

IMPORTANT: All names that begin with "MS" are mock/test events ("Mock Superevent"; only the 5 latest will be displayed).
Only names that begin with "GW" or "S" are possible real GW events ("Superevent").
For more information, see the Gravitational Wave Candidate Event Database.

Note: The NED and Census of the Local Universe (CLU) projects are issuing a joint notice of candidate galaxies for each LIGO GW trigger. While a large fraction of the galaxies in CLU catalog come from NED, there are galaxies in CLU that have not yet been ingested into NED, and NED is continually updating its holdings. Thus, some of the CLU top 20 galaxies listed in the GCN notices may not be in the NED list on this website. In addition, the NED service sorts its galaxies differently than CLU. However, the overall composition of the CLU and NED galaxy lists will be similar.

Sky Localization for GW170817-3-Update Cross-Matched with Galaxies in NED

NOTICE: This is an historical event for demonstration purposes only.

GW Event Information From LIGO

graceID	EventDate	Instruments	HasNS	HasRemnant	FAR
GW170817	17-08-17 12:41:04 (UTC)	H1,L1,V1	1.0	1.0	1 per 8.000e+04 years

Table columns: graceID is the LIGO designation and is a link to the GraceDB entry for this event. EventDate is the date and time of the GW event in UTC. Instruments indicates which facilities were involved in detecting the GW event. HasNS is the probability that at least one object in the binary has a mass consistent with a neutron star. HasRemnant is the probability that a nonzero mass was ejected outside the central remnant object. FAR is the false alarm rate for the GW event given as the number of instances per year that a noise fluctuation is expected to occur with the strength of this event in each of the detectors at the same time.

NED-GWF for LISA

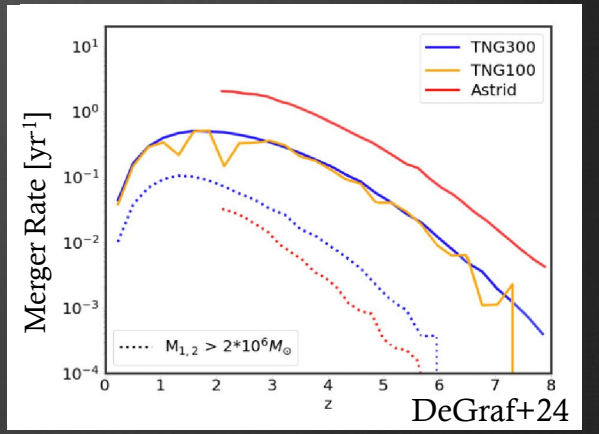
- Goal: optimize rapid EM follow-up to each GW event
  - Listen for events, crossmatch to NED → prioritized galaxy list
  - Timescale ~ mins
- Prioritizations:
  - Keep: in 90% volume
  - Cut: outside of M_{BH} range
  - Cut: with known long periods (won't merge)
- What data are needed?
  - Host & BH properties
  - Current list of multi-MBH systems & properties
  - Links to time-series

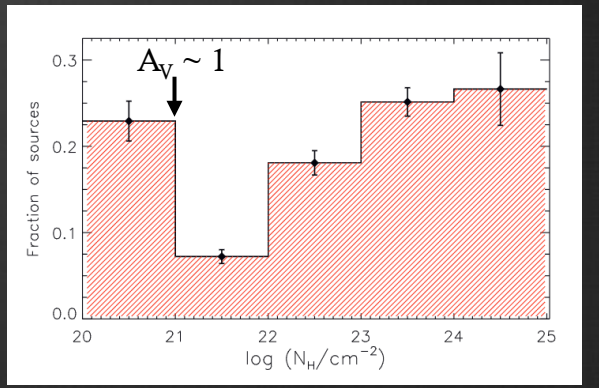
Challenges to Overcome

1. LISA events will be at larger distances than for LVK
   - Candidates will be fainter and more of them

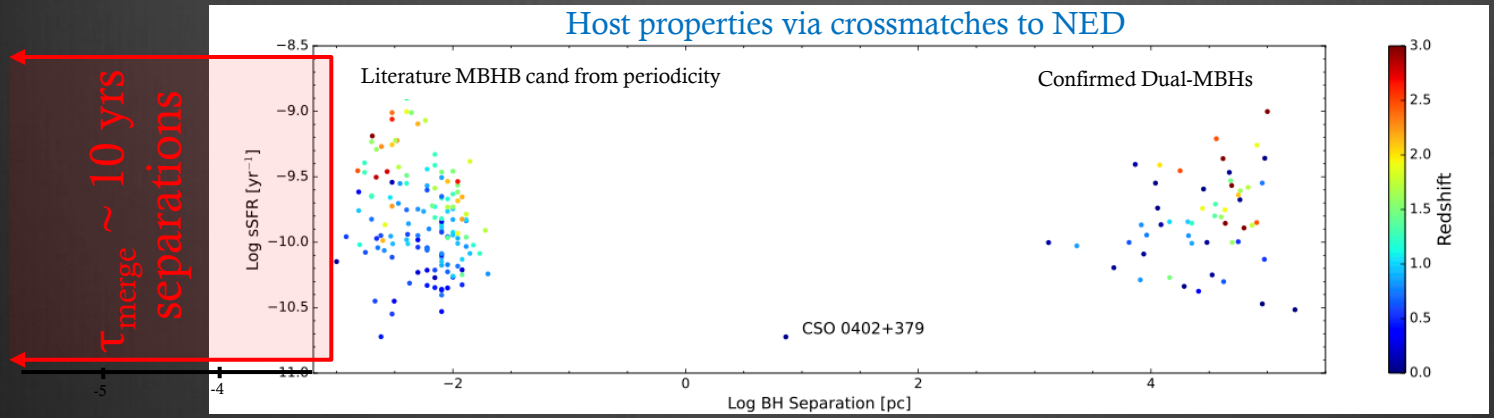
2. "Dark" mergers
   - Heavy obscuration and/or low BH accretion
   - ~20-30% AGN are Compton thick (Buchner+15, Ricci+15)
   - Host properties will be key

- Many host strategies can be facilitated by NED
  - NED will continue to:
    - Ingest extragalactic objects, redshifts, etc.
    - Redshift catalogs of interest: DESI (40M), Euclid (50M), SphereX (500M)
    - Make robust cross matches
    - Calculate host properties (SFR, $M_{\star}$, etc.)
  - NED will need to:
    - Ingest or Estimate BH properties (M_{BH}, separation, orbital periods, etc.)





LISA Science Gaps - NASA



- LISA Science Gap - MBHB2: Between MBHB Mergers ←→ Dual AGN
  - Dual-AGN/MBH provide an anchor to understanding the evolution to small separations
    - Confirmed: Big MAC catalog (Pfeifle+24)
  - Host studies across this gap are key
- LISA Science Gap - MBHB3: Improve Periodicity searches in time-domain surveys
  - Merger separations → P < 200 days (Rubin, ZTF)
  - Provide both merger candidates and constraints on host properties
- 10 years to fill these gaps…

Summary

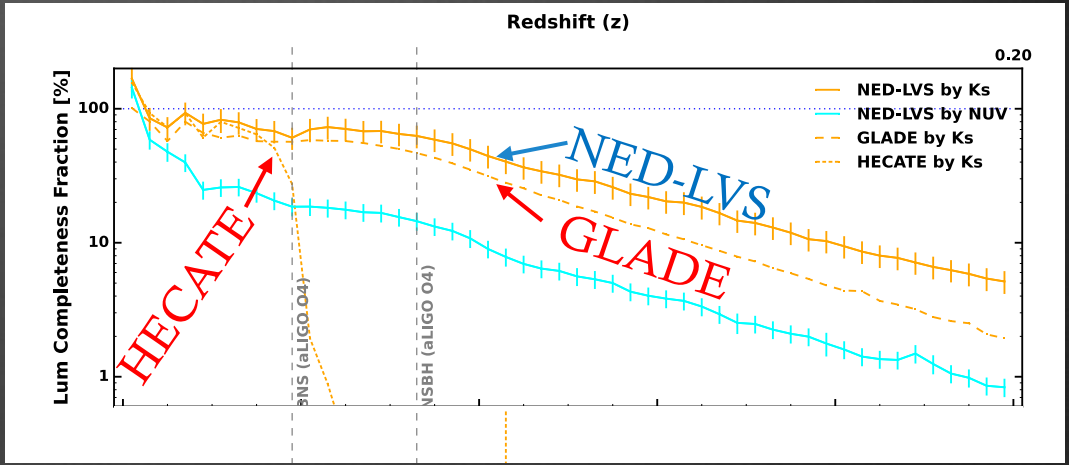
- The direct detection of MBHs from LISA will yield many discoveries
  - Many discoveries can only happen via host ID
- Finding MBH hosts will be difficult
  - Search strategies utilizing hosts will be key
- NED is an on-going project to collect & combine extragalactic data
  - From literature and surveys
  - N=1.1B objects and N=11M with redshifts
  - Currently supports rapid follow up to LVK GW events
  - These data, tools, and strategies can be applied to LISA MBH events
- NED Future:
  - Continued ingestion of catalogs containing more higher-z data
  - Data in NED are a natural foundation for LISA follow-up tools

Extra Slides…

Completeness of NED-LVS

- NED-LVS Completeness
  - $= \frac{\sum L(galaxies)}{j_L(Vol)}$; j_L = predicted luminosity density
  - 70% by NIR flux (D<350 Mpc)
- Comparison to others
  - By Lum:
    NED ~10 – 15% more complete
  - By Num:
    NED ~20 – 45% more galaxies
- Quality of the Sample
  - Nearby objects → z-Independent distances
  - Redshifts → 71% are spec-z
  - Additional cleaning of stars, bad photo-z, etc.

Cook+2023

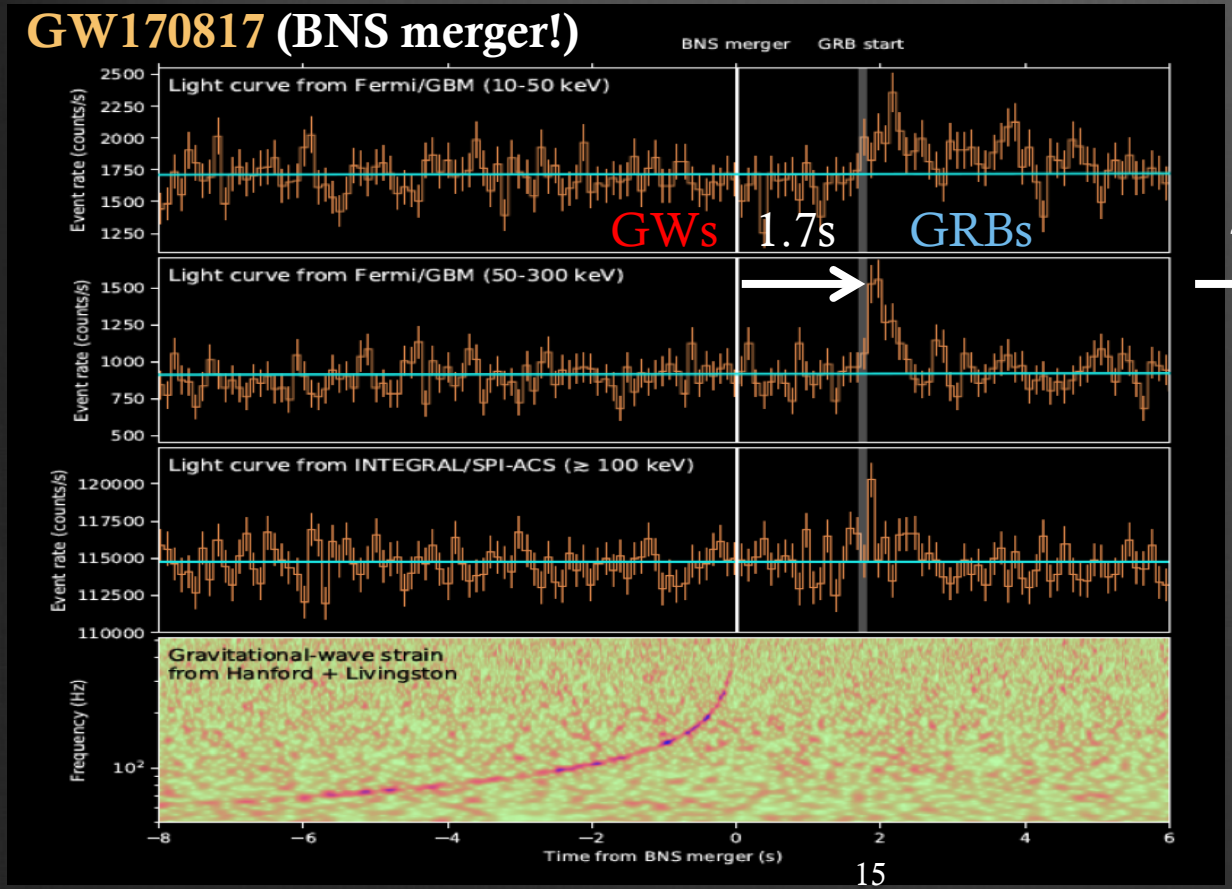


Comparison of Galaxy Catalogs

	HECATE (D<200 Mpc)	NED-LVS (D<200 Mpc)	GLADE (D<1000 Mpc)	NED-LVS (D<1000 Mpc)
N (Total)	204,733	297,998	1,703,812	2,073,597
N ($M_\star$)	46.0%	74.5%	0.0%	84.7%
N (SFR)	65.0%	75.7%	0.0%	84.9%

Multi-Messenger Astronomy

GW170817 (BNS merger!)



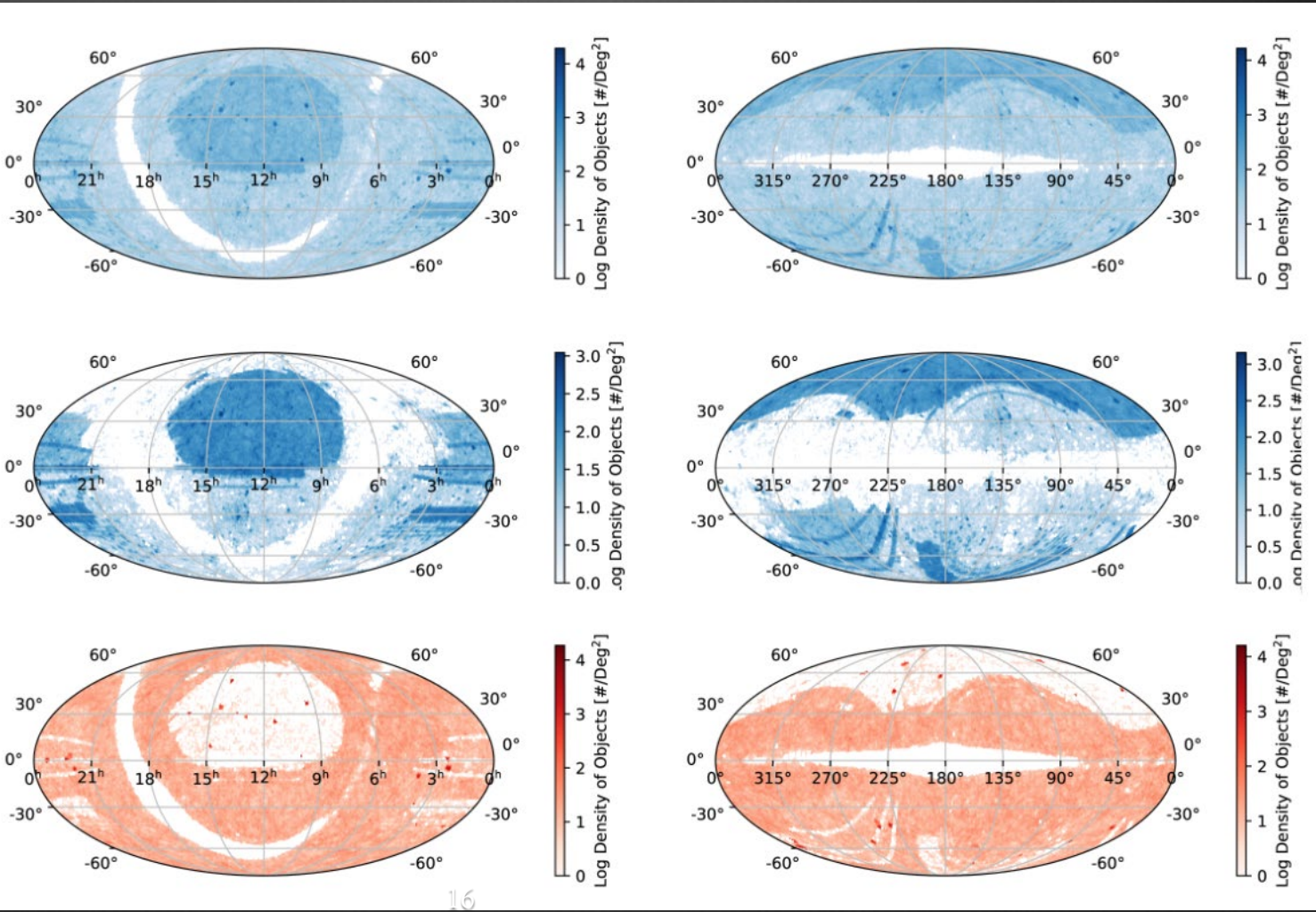
~11 hrs

kilonova

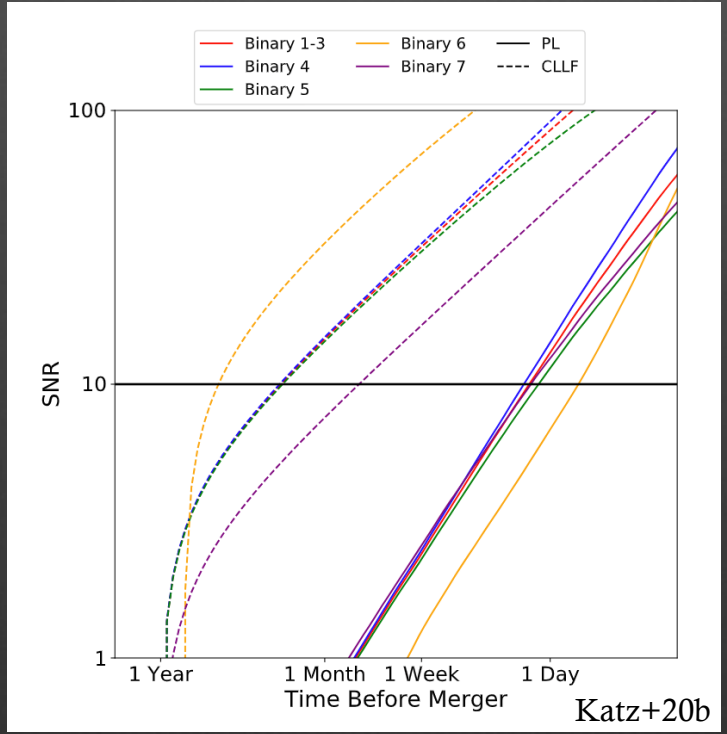
Coulter+17

LVC, Fermi, Integral *Astrophys. J. Lett., (2017)*

Sky Coverage



LISA old/new Design



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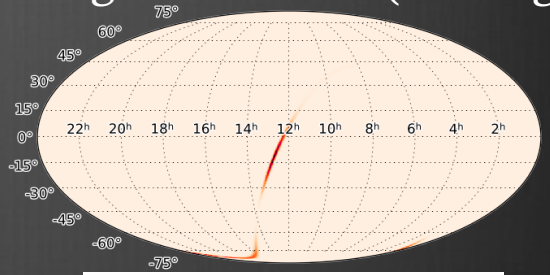
GW170817

No Virgo Constrains (187 deg^2)



N(in Vol)= 211

Galaxy	Rank	$P_{M_*} \times P_V$
NGC 5061	1	5.03e-02
NGC 4763	2	2.13e-02
NGC 5114	3	1.87e-02
NGC 3976	4	1.65e-02
NGC 4970	5	1.64e-02
NGC 4830	6	1.58e-02
NGC 5967	7	1.43e-02
IC 4197	8	1.30e-02
NGC 4993	9	1.18e-02
IC 4180	10	1.10e-02

Mass

Galaxy	Rank	$P_{\mathrm{sSFR}^{-1}} \times P_V$
NGC 4970	1	4.34e-02
NGC 4830	2	3.54e-02
IC 0874	3	2.89e-02
UGCA 289	4	1.57e-02
NGC 5048	5	1.37e-02
NGC 5114	6	1.33e-02
MCG -02-32-026	7	1.26e-02
NGC 5061	8	1.09e-02
NGC 4993	9	9.02e-03
IC 4197	10	5.24e-03

sSFR^{-1}

Cook+23