Post-bacc (Quarterly?) Update

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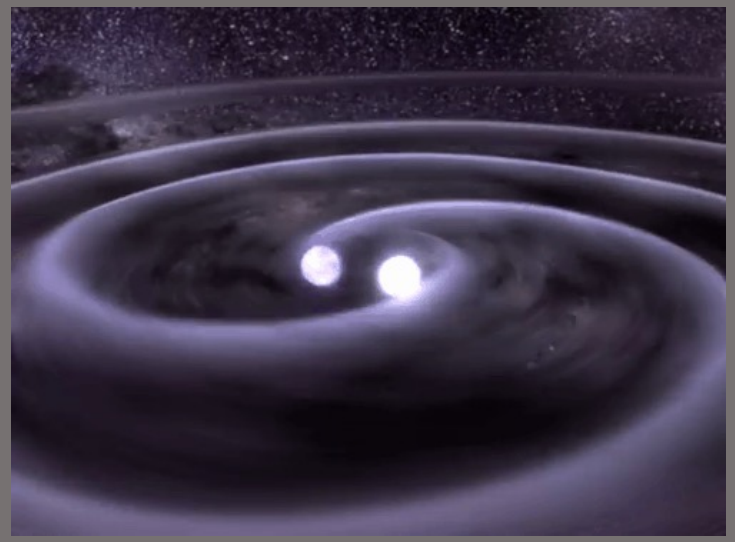
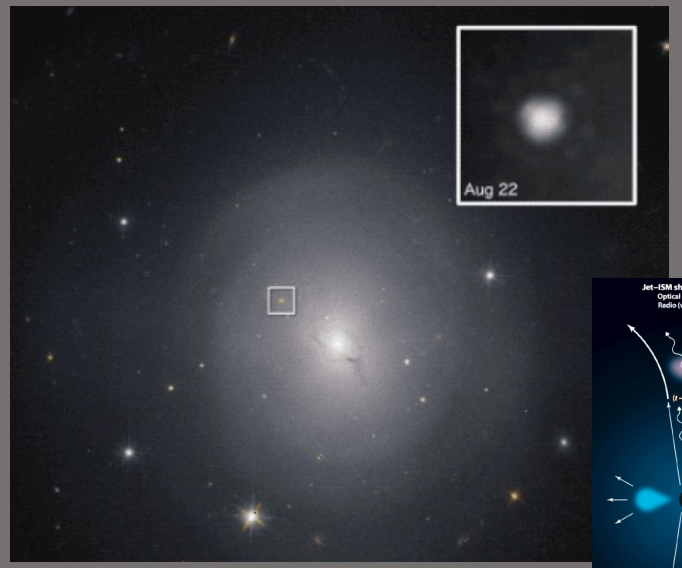
Outline of talk

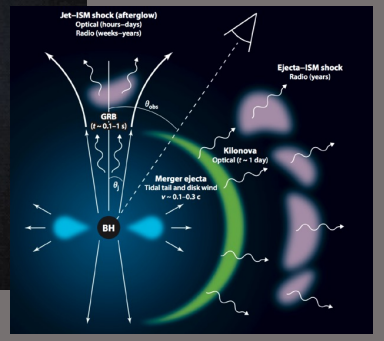
- Intro to Gravitational Waves and science questions
- Observing Scenarios project/efforts
- Training dataset data development for Kilonova classification
- Extracurriculars



Gravitational Waves



Kilonovae!



Electromagnetic Waves

Multimessenger Astronomy rising

- Only one GW event with observed EM counterpart
- Fueled many efforts in support of gravitational wave (GW) follow-up campaigns (ZTF, LSST)
- KN science cases include
    - Neutron star equation of state constraints
    - Hubble constant calculations
    - r-process nucleosynthesis

What does the future hold??

Observing Scenarios

In Collaboration with Weizmann Kiendrebeogo, Leo Singer, Michael Couphlin, and more.

- Goal

To maximize ToO observations during upcoming LIGO, Virgo, KAGRA observing runs (O4 mid-late May?!)

- We develop “observing scenarios” to support these efforts by simulating the detection (ZTF, LSST) and localization of GW events to provide accurate predictions and statistics for upcoming observing runs O4 and O5
- Distances, detection rates, sky localizations, KN lightcurves, H_o and EoS constraint

Observing Scenarios

Nuclear Multimessenger Astronomy (NMMA) software framework, bilby

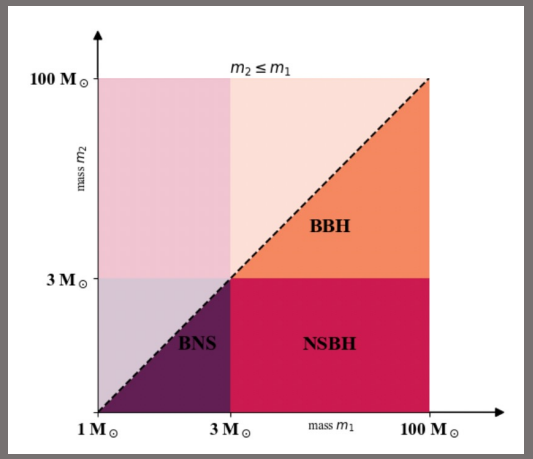
Bayesian multi-messenger pipeline for GW+EM analyses

KN models

light curve fitting

Property estimation (BNS, NSBH)

Population component masses



Spin magnitudes

m < 2.5 M_{sun}, [0,.4]

m >2.5 M_{sun}, [0,1]

- GWTC-3 distribution

Drawn from model describing full population of CBC's and their component mass and spin distribution (10^6 total sample)

- Split populations based on mass and spin thresholds
- Maximum sensitive distances, assign sensitive co-moving volumes for each sample
- Draw distances and sky localizations (ligo.skymap code for LIGO, Virgo, KAGRA), and extrinsic parameters (lat, long, incl.)
- Apply SNR cuttoff (>8) to realize detected events (bayestar)
- Calculate Summary statistics

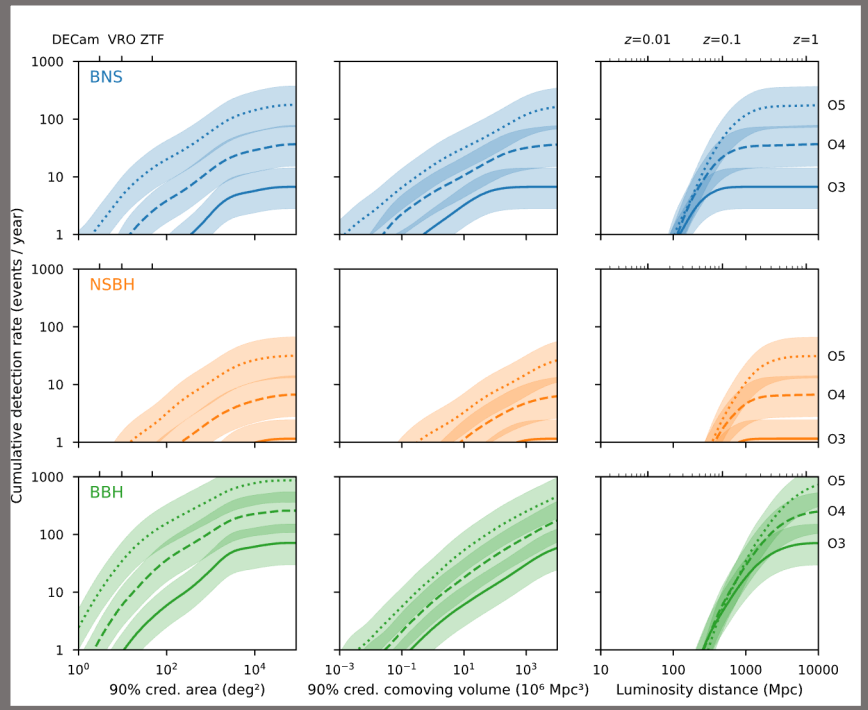
Summary statistics

Run	Dist.	BNS	NSBH	BBH
Median 90% credible area (deg^2)				
O4	LRR	2100^{+150}_{-220}	2090^{+130}_{-130}	653^{+53}_{-36}
	GWTC-3	1860^{+250}_{-170}	2140^{+480}_{-530}	1428^{+60}_{-55}
O5	LRR	2050^{+100}_{-160}	2110^{+100}_{-100}	682^{+25}_{-30}
	GWTC-3	2050^{+120}_{-120}	2000^{+350}_{-220}	1256^{+48}_{-53}
Median 90% credible Comoving Volume (10^3 Mpc^3)				
O4	LRR	$46.5^{+6.6}_{-7.0}$	159^{+26}_{-16}	207^{+21}_{-20}
	GWTC-3	$67.9^{+11.3}_{-9.9}$	232^{+101}_{-50}	3400^{+310}_{-240}
O5	LRR	240^{+29}_{-26}	785^{+68}_{-62}	857^{+63}_{-60}
	GWTC-3	376^{+36}_{-40}	1350^{+290}_{-300}	8580^{+600}_{-550}
Median Luminosity Distance (Mpc)				
O4	LRR	349^{+12}_{-14}	564^{+15}_{-13}	1102^{+33}_{-32}
	GWTC-3	398^{+15}_{-14}	770^{+67}_{-70}	2685^{+53}_{-40}
O5	LRR	619^{+15}_{-19}	1007^{+20}_{-22}	1948^{+34}_{-24}
	GWTC-3	738^{+30}_{-25}	1318^{+71}_{-100}	4607^{+77}_{-82}
Sensitive volume : detection rate / merger rate: (Gpc^3)				
O4	LRR	$0.1011^{+0.0066}_{-0.0064}$	$0.403^{+0.021}_{-0.020}$	$1.861^{+0.077}_{-0.074}$
	GWTC-3	$0.172^{+0.013}_{-0.012}$	$0.78^{+0.14}_{-0.13}$	$15.15^{+0.42}_{-0.41}$
O5	LRR	$0.507^{+0.027}_{-0.026}$	$1.809^{+0.070}_{-0.068}$	$7.62^{+0.19}_{-0.19}$
	GWTC-3	$0.827^{+0.044}_{-0.042}$	$3.65^{+0.47}_{-0.43}$	$50.7^{+1.2}_{-1.2}$

Detection/data overload approaching!!

- More detections than reasonable to handle by follow-up capabilities
- Detector sensitivity increasing! Localization not so much…

Cumulative Histogram, Public Alert Rate



Annual detection rates

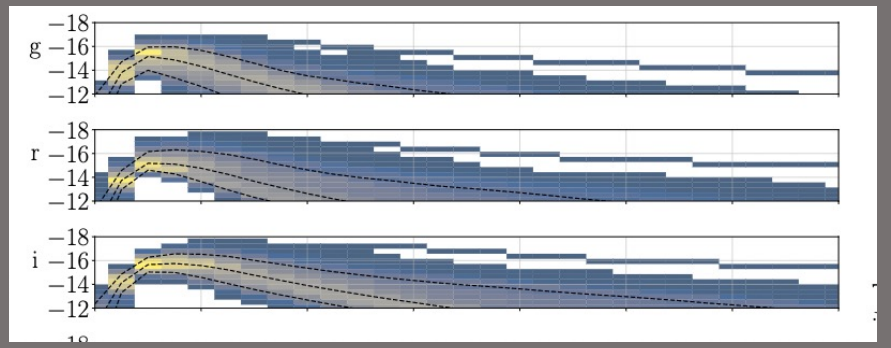
Run	Distribution	BNS	NSBH	BBH
Annual number of detections				
O4	LRR	17^{+35}_{-13}	10^{+18}_{-8}	46^{+23}_{-17}
	GWTC-3	36^{+49}_{-22}	6^{+11}_{-5}	260^{+330}_{-150}
O5	LRR	86^{+171}_{-59}	48^{+71}_{-30}	190^{+80}_{-58}
	GWTC-3	180^{+220}_{-100}	31^{+42}_{-20}	870^{+1100}_{-480}

Run	Dist.	BNS		NSBH	
		Telescopes			
		ZTF	LSST	ZTF	LSST
O4	GWTC-3	10.06 %	90.34 %	2.72 %	60.87 %
O5	GWTC-3	2.6 %	69.4 %	0.28 %	30.62 %

In collaboration with Ari Sravan and more

BNS, O4, ZTF

KN identification



- Bottlenecks/motivations

KNe are faint and transient (<1week in optical)

Localization regions are very big and include tens of contaminating transients

Real-time classification is crucial to maximize observational resources and scientific return, especially given the large detection rates for O4 and O5 paired with little to no localization improvement!

Past observing runs have relied on humans for classification – not reasonable.

Solutions/ML

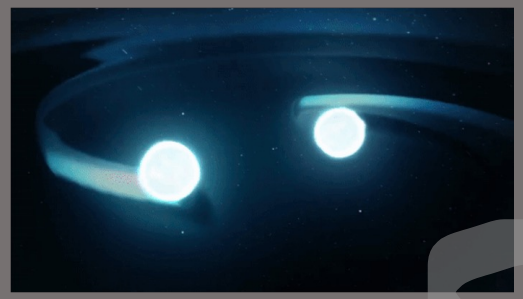
Need for accurate autonomous, real-time classification algorithms!

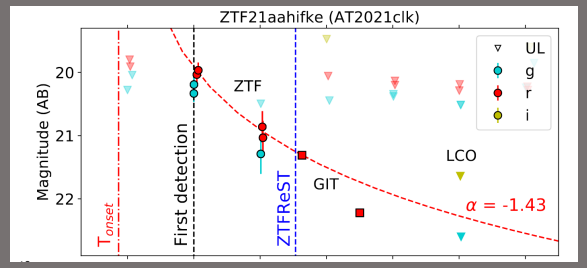
My data set

- Comprehensive (GW+EM, O4 and O5) training set considering full low-latency EM follow-up capabilities (ZTF) based on LIGO, Virgo, KAGRA detectors.
- Useful to a wide range of folks to train on/incorporate in prep for next observing runs

Autonomous Real-Time Decision-Making with Ari

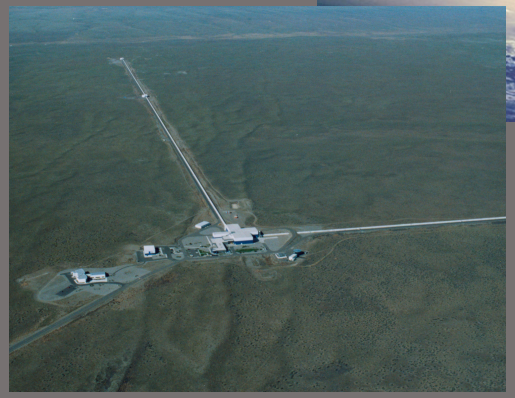
- Implement on agent used to strategize follow-up, identify, and characterize KN



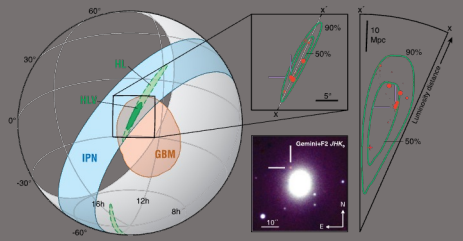


Before KN fades!

Automated vetting
- ML classifier's
- Evolution rate



Public GCN alert



~mins

~mins-hrs

Data Generation

Observing scenario simulated injections/realistic populations to produce foundation

GCN Alert content training data

- Observation ID
- Event Significance: estimated FAR
- CBC Sky localization

BAYESTAR algorithm --> Healpix projection

- CBC Inference: source classification and properties

P-Astro: BNS, NSBH, BBH

EMBright: HasNS, HasRemnant

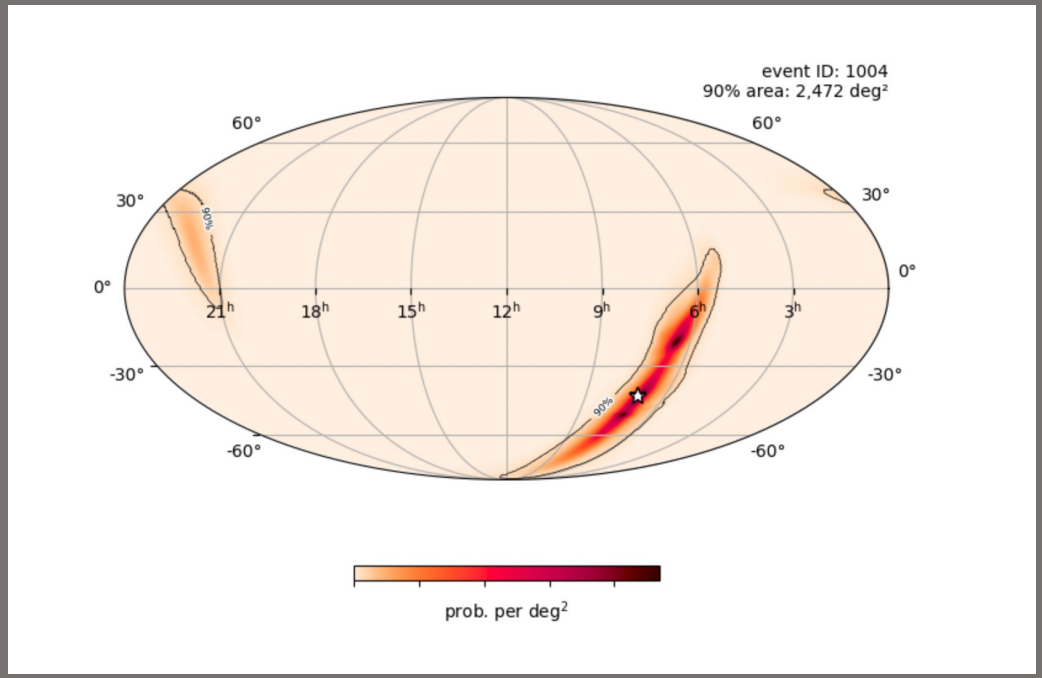
+

KN light curves

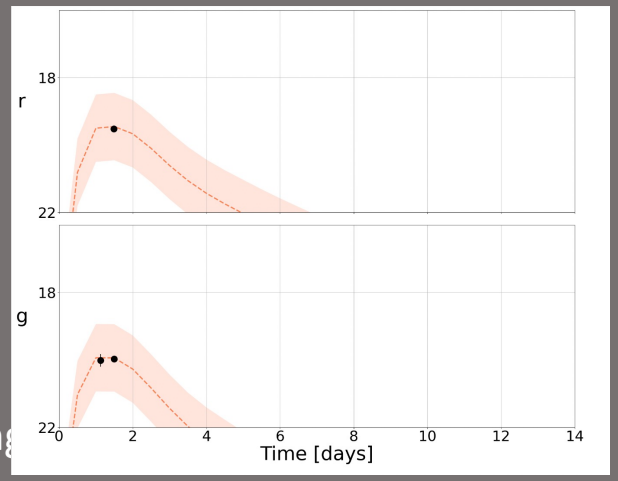
KN ejecta properties

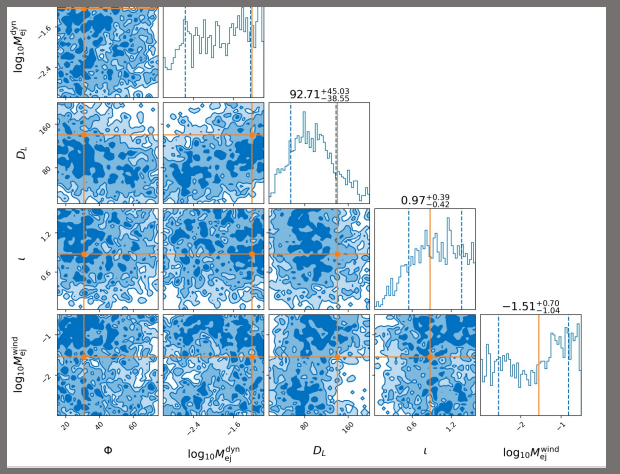
Bulla Kilonova model (dynamical and disk wind ejecta, opening angle, observation angle)

Localization



Lightcurve posteriors





Challenges and Looking Forward…

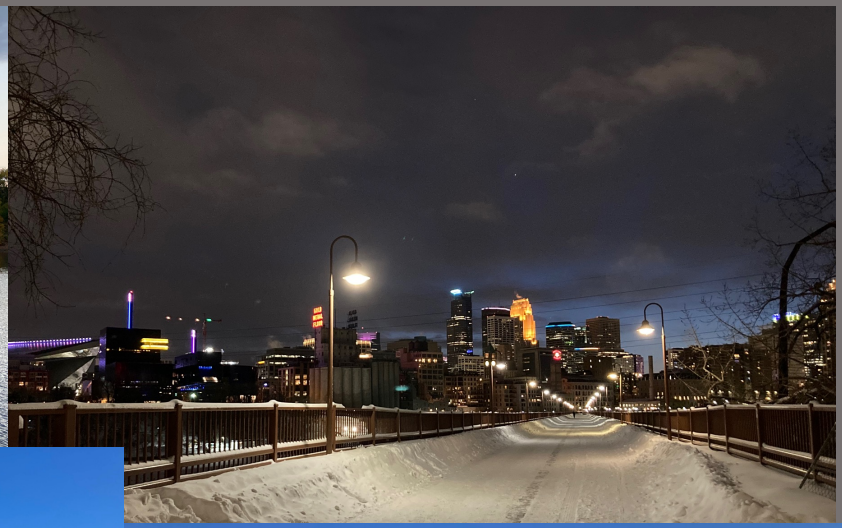
- Scaling challenges (20,000 skyamps per population for reasonable training), condor jobs, sanity checks

- Spectra
- Host galaxy image stamps
- Ari to incorporate skymaps and lightcurves narrow agent ~May
- Others to use on classifyers

- Wrapping up observing scenario paper. Data is released.

Extracurriculars

- Not really, but…
  - Science talks given at Mifa!
  - Helping with telescope night
- Some real ones
  - Surviving Minnesota winters
  - Swimming and running a lot
  - Hanging out with cool office mates
  - Jumping into lakes
  - Exploring the city (music!) and River



Thank you!