The Role of Archives for Future GW events

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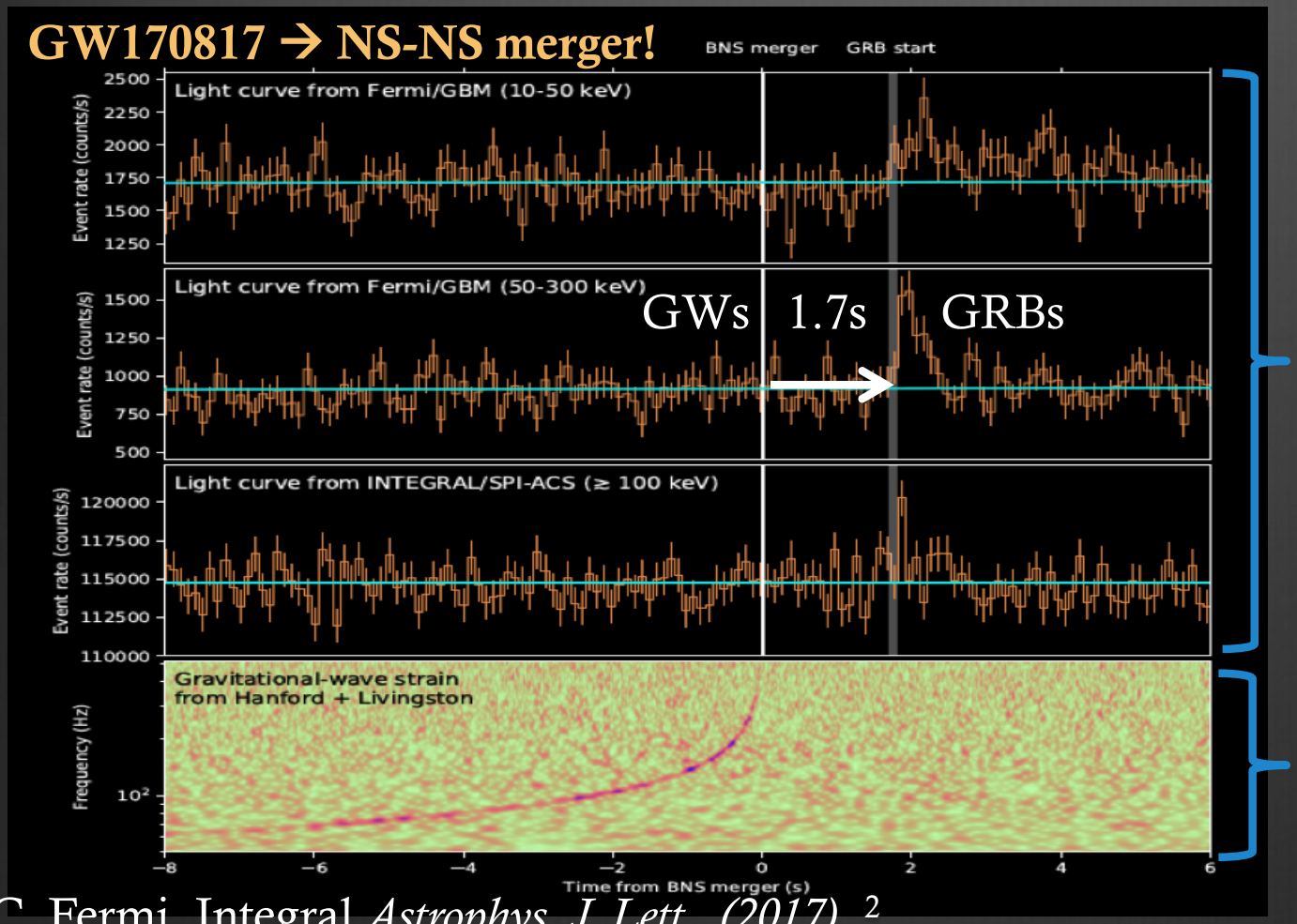
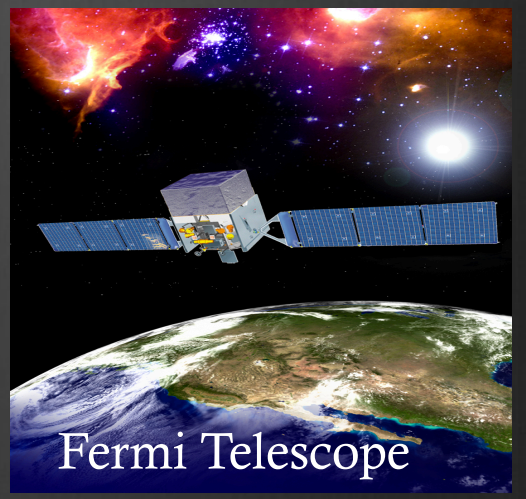
AstroData2020s Conference
December 6, 2018

Multi-Messenger Astronomy

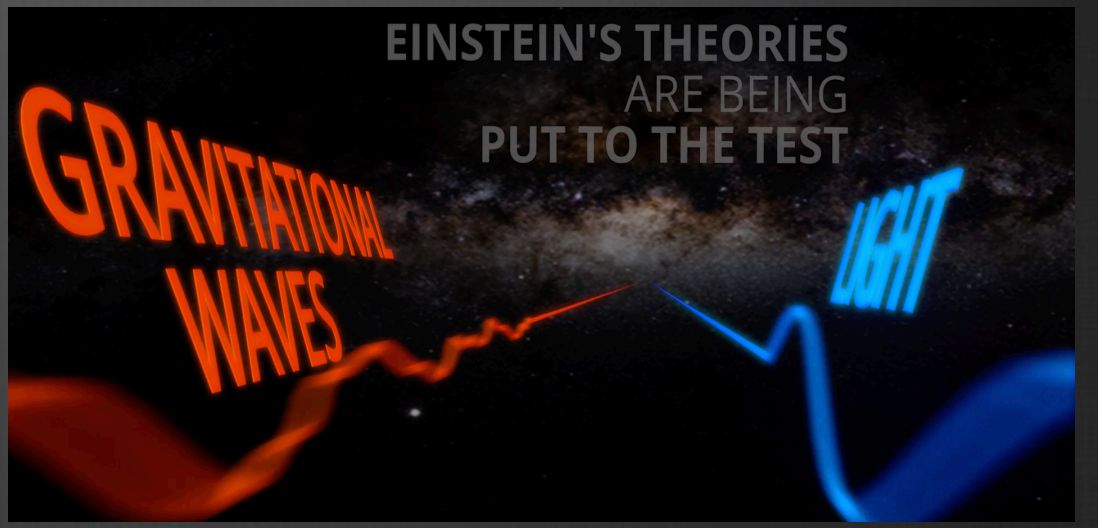




LVC, Fermi, Integral *Astrophys. J. Lett., (2017)* [2]

Multi-Messenger Discoveries

- Science impacts
  - Some short GRBs are associated with NS-NS mergers
  - GWs travel at the speed of light
  - Much of the elements heavier than Fe are made in such events
- **EM follow-up is key for above**
- Future?
  - Science: many new opportunities
  - Focus: How to maximize this science by leveraging astronomy archives?

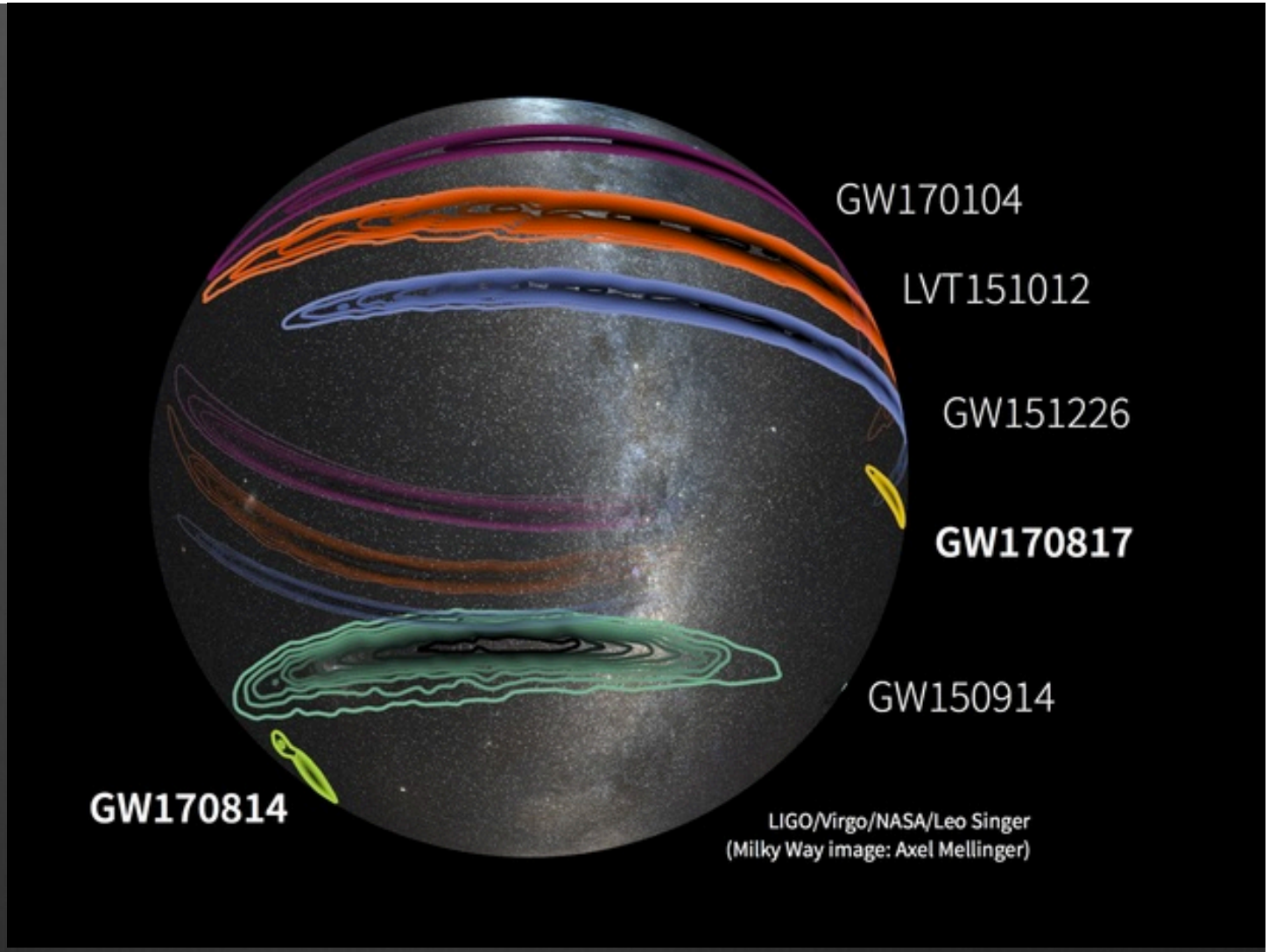


courtesy: A. Weinstein

May have skipped a few steps here…

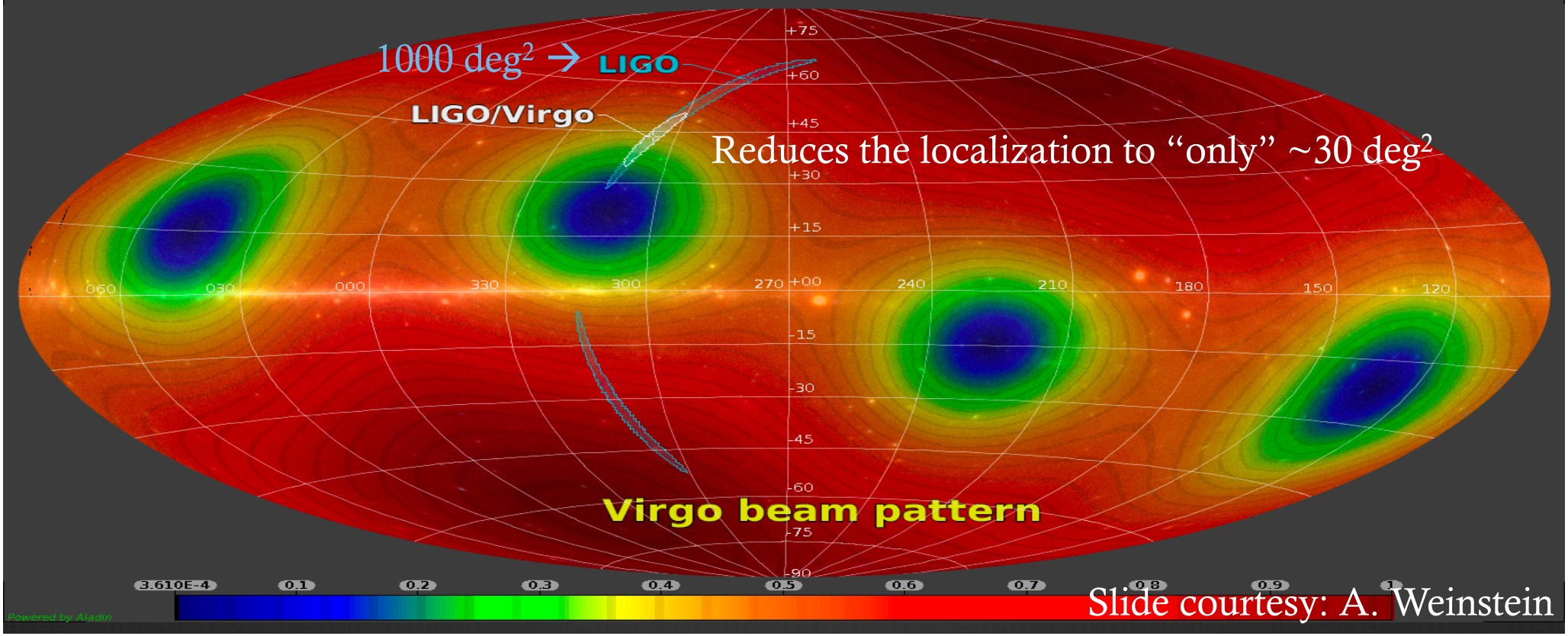
Electromagnetic (EM) Follow-up

- Large sky localization
  - 100s-1000 deg^2
- Very difficult to tile entire area
- If you could…
  - other transient contaminants
- Answer: Galaxies



Virgo "non-detection"

It appears that the signal was in Virgo's "blind spot"



Slide courtesy: A. Weinstein

GCN CIRCULAR #21519 – LIGO/Virgo G298048: Nearby Galaxies in the Localization Volume

David O. Cook (Caltech), Angela Van Sistine (UW Milwaukee), Leo Singer (NASA/GSFC), M. M. Kasliwal (Caltech), and David Kaplan (UW Milwaukee)

*Report on behalf of the GROWTH collaborations

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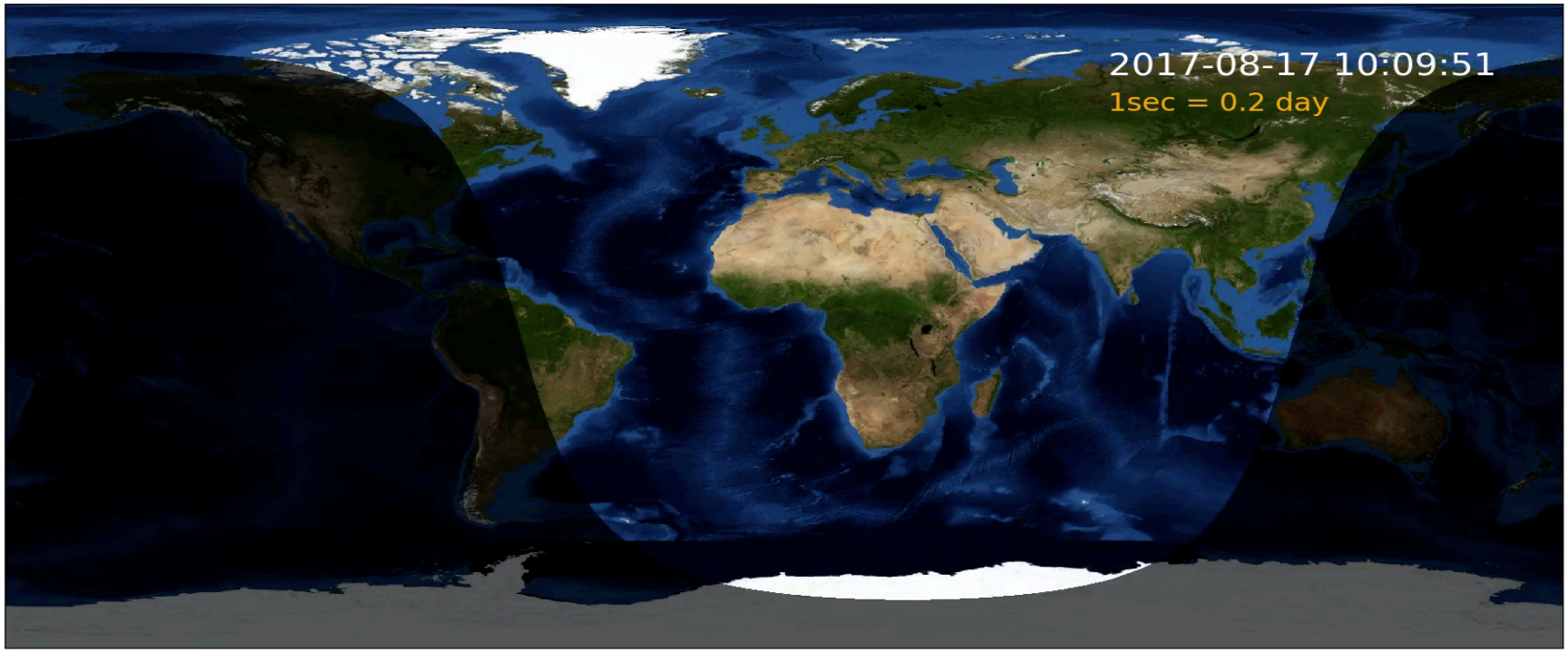
NGC 4970	196.8906	-24.0086	46.50	nan	10.42	33.34
NGC 4830	194.3663	-19.6913	47.90	1.419	10.41	33.40
NGC 4993	197.4487	-23.3839	41.66	nan	10.26	33.10
NGC 4968	196.7749	-23.6770	42.24	0.626	10.25	33.13
IC 4197	197.0180	-23.7969	43.24	nan	10.24	33.18
IC 4180	196.7354	-23.9171	42.46	-0.623	10.17	33.14
ESO 508- G 033	199.0969	-26.5614	45.59	0.199	9.95	33.29
MCG -02-33-036	193.1066	-15.5172	53.87	-1.130	9.86	33.66
ESO 508- G 010	196.9080	-23.5790	43.04	nan	9.51	33.17
MCG -03-33-023	194.2521	-17.3202	56.79	nan	9.33	33.77
ESO 575- G 053	196.2705	-22.3839	36.37	-0.856	9.33	32.80
2MASX J12525109-1529300	193.2130	-15.4916	52.26	nan	9.31	33.59
2MASX J12505229-1454238	192.7180	-14.9066	52.96	-0.855	9.29	33.62
2MASX J12573271-1942006	194.3863	-19.7002	52.39	-1.788	9.25	33.60
ESO 576- G 003	197.6488	-21.7482	42.04	nan	9.18	33.12
UGCA 331	197.6914	-23.8657	40.82	nan	9.17	33.05
IC 3825	192.6544	-14.4828	51.04	-0.985	9.17	33.54
ESO 575- G 055	196.6663	-22.4561	44.49	-0.975	9.07	33.24
ESO 508- G 003	196.6000	-24.1641	40.52	nan	9.06	33.04
ESO 508- G 019	197.4663	-24.2391	41.79	nan	8.98	33.11
ESO 575- G 029	193.9986	-19.2691	45.21	nan	8.96	33.28
2MASX J13073768-2356181	196.9071	-23.9384	49.73	nan	8.92	33.48
2MFGC 10461	197.1774	-23.7756	41.39	nan	8.90	33.08
2MASX J13061939-2258491	196.5805	-22.9804	41.51	-1.129	8.83	33.09
UGCA 327	196.9370	-22.8579	37.29	nan	8.81	32.86
GALEXASC J125520.46-170546.9	193.8364	-17.0966	56.69	-1.151	8.67	33.77

EM follow-up is a Global Effort



Credit: V. Bhalerao
From GROWTH team (PI: Kasliwal)

Future: LIGO + Archives

- GW events will be public!
  - LIGO O3 run starts ~April 2019
- How can archives help with EM follow-up?
  - Galaxy lists for all to observe
  - Produce source catalogs based on archive images (light curves)
  - Incorporate transient alert streams for the public
  - Cloud platforms with jupyter notebooks
    - Supported data processing modules for instruments
    - Observing tools (optimized tiling)
    - Transient finding tools (image subtraction)
  - All of this needs to be fast

Sky Localization for GW20190322 CrossMatched Against NED Galaxies

Download NED Galaxies

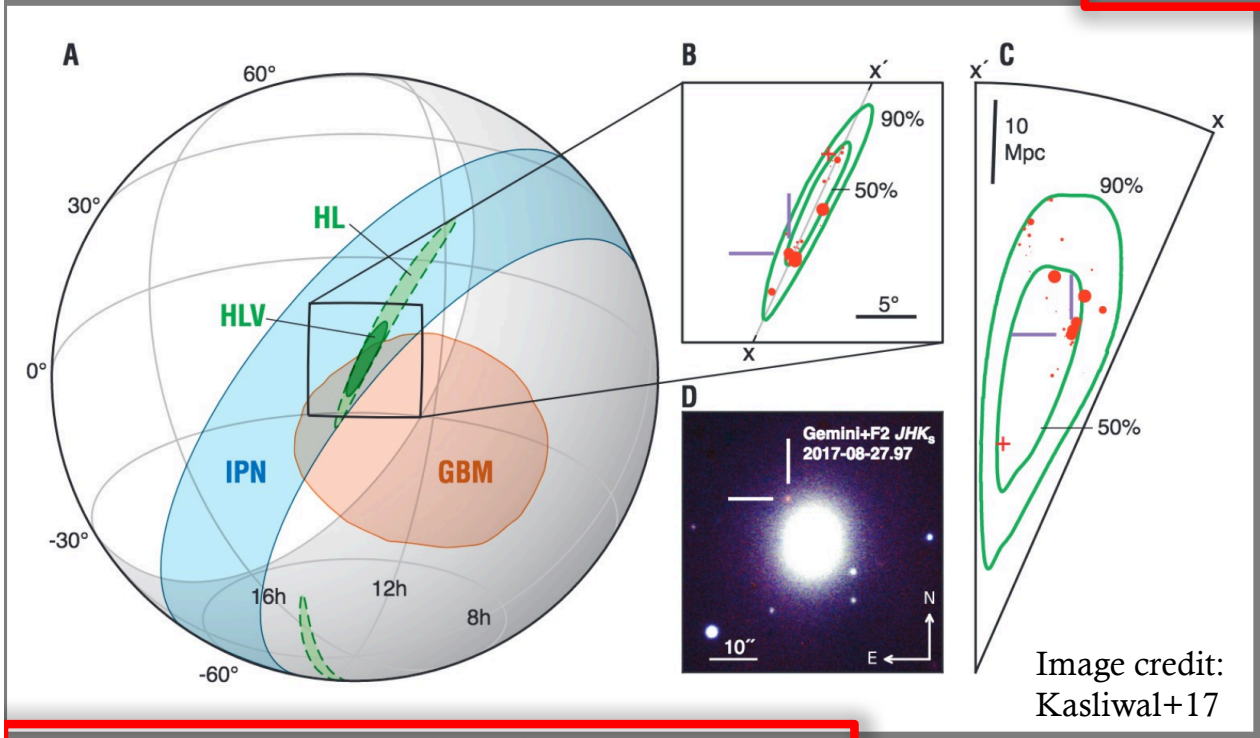


Image credit: Kasliwal+17

name_NED	ra	dec	distmpc	logsfr_fuv	logmstar	dm_kin	P
NGC 4970	196.8906	-24.0086	46.5	nan	10.42	33.34	0.67982512378
NGC 4830	194.3663	-19.6913	47.9	-1.419	10.41	33.4	0.751692025898
NGC 4993	197.4487	-23.3839	41.66	nan	10.26	33.1	0.406381229308
NGC 4968	196.7749	-23.677	42.24	0.626	10.25	33.13	0.505916529441
IC 4197	197.018	-23.7969	43.24	nan	10.24	33.18	0.484445523125
IC 4180	196.7354	-23.9171	42.46	-0.623	10.17	33.14	0.601966463045
ESO 508- G 033	199.0969	-26.5614	45.59	0.199	9.95	33.29	0.825983269095
MCG -02-33-036	193.1066	-15.5172	53.87	-1.13	9.86	33.66	0.877644438005

EM-GW Service at NED

- Being developed for O3
- Goal: optimize rapid EM follow-up to each GW event
- Auto download sky localization
- Crossmatch to NED
- Visualizations like this
- Alert community via Gamma-ray Coordinates Network (GCN)
- Latency ~ mins

Follow-up Timescales

- GCN times for GW170817

Table 6
Gamma-ray Coordinates Network (GCN) Notices and Circulars related to GW170817 until

Telescope	UT Date	Δt (days)	Obs. Wavelength	References
Fermi/GBM	2017 Aug 17 12:41:20	0.0	gamma-ray	24666471, Fermi-GBM (2017)
LIGO-Virgo/–	2017 Aug 17 13:21:42	0.03	gw	21505, LIGO Scientific Collaboration & Virgo Collaboration et al. (2017a)
Fermi/GBM	2017 Aug 17 13:47:37	0.05	gamma-ray	GCN 21506, Connaughton et al. (2017)
INTEGRAL/SPI-ACS	2017 Aug 17 13:57:47	0.05	gamma-ray	GCN 21507, Savchenko et al. (2017a)
IceCube/–	2017 Aug 17 14:05:11	0.06	neutrino	GCN 21508, Bartos et al. (2017a)
LIGO-Virgo/–	2017 Aug 17 14:09:25	0.06	gw	GCN 21509, LIGO Scientific Collaboration & Virgo Collaboration et al. (2017d)
LIGO-Virgo/–	2017 Aug 17 14:38:46	0.08	gw	GCN 21510, LIGO Scientific Collaboration & Virgo Collaboration et al. (2017e)
IceCube/–	2017 Aug 17 14:54:58	0.09	neutrino	GCN 21511, Bartos et al. (2017c)
LIGO-Virgo/–	2017 Aug 17 17:54:51	0.22	gw	GCN 21513, LIGO Scientific Collaboration & Virgo Collaboration et al. (2017b)
Astrosat/CZTI	2017 Aug 17 18:16:42	0.23	gamma-ray	GCN 21514, Balasubramanian et al. (2017)
IPN/–	2017 Aug 17 18:35:12	0.25	gamma-ray	GCN 21515, Svinkin et al. (2017b)
–/–	2017 Aug 17 18:55:12	0.27	gamma-ray	GCN 21516, Dalya et al. (2016)
Insight-HXMT/HE	2017 Aug 17 19:35:28	0.29	gamma-ray	GCN 21518, Liao et al. (2017)
–/–	2017 Aug 17 20:00:07	0.3	gamma-ray	GCN 21519, Cook et al. (2017a)
Fermi/GBM	2017 Aug 17 20:00:07	0.3	gamma-ray	GCN 21520, von Kienlin et al. (2017)
–/–	2017 Aug 17 20:12:41	0.31	gamma-ray	GCN 21521, Cook et al. (2017b)
ANTARES/–	2017 Aug 17 20:35:31	0.33	neutrino	GCN 21522, Ageron et al. (2017a)
Swift/BAT	2017 Aug 17 21:34:36	0.37	gamma-ray	GCN 21524, Barthelmy et al. (2017)
AGILE/MCAL	2017 Aug 17 22:01:26	0.39	gamma-ray	GCN 21525, Pilia et al. (2017)
AGILE/GRID	2017 Aug 17 22:22:43	0.4	gamma-ray	GCN 21526, Piano et al. (2017)
LIGO-Virgo/–	2017 Aug 17 23:54:40	0.47	gamma-ray	GCN 21527, LIGO Scientific Collaboration & Virgo Collaboration et al. (2017c)
Fermi/GBM	2017 Aug 18 00:36:12	0.5	gamma-ray	GCN 21528, Goldstein et al. (2017b)
Swope/–	2017 Aug 18 01:05:23	0.52	optical	GCN 21529, Coulter et al. (2017a)
DECam/–	2017 Aug 18 01:15:01	0.52	optical	GCN 21530, Allam et al. (2017)
DLT40/–	2017 Aug 18 01:41:13	0.54	optical	GCN 21531, Yang et al. (2017a)
REM-ROS2/–	2017 Aug 18 02:00:40	0.56	optical, IR	GCN 21532, Melandri et al. (2017a)
ASAS-SN/–	2017 Aug 18 02:06:30	0.56	optical	GCN 21533, Cowperthwaite et al. (2017a)

The Astrophysical Journal Letters, 848:L12 (59pp), 2017 October 20

NED Galaxies (Future)

6 Hours

Glade Galaxies

CLU Galaxies

7 Hours

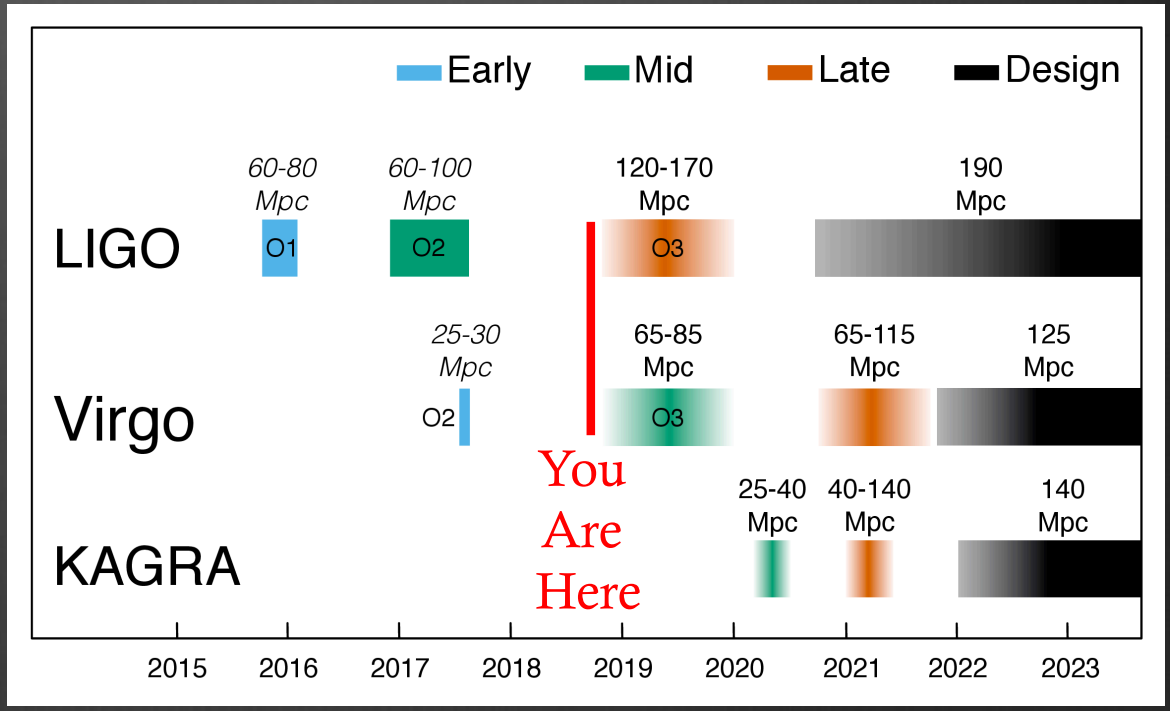
CLU Galaxies

12 Hours

Optical Counterpart

Future capabilities of LIGO

- O3 (2019)
  - LIGO-Virgo (3 detectors)
    - 1-50 NS-NS events
- In the 2020s
  - KAGRA (2020-2022)
  - LIGO-India (2024+)
  - 5 detectors in 2024+
    - 11-180 NS-NS events



Abbott+18 (arXiv:1304.0670)

Discussion Time…

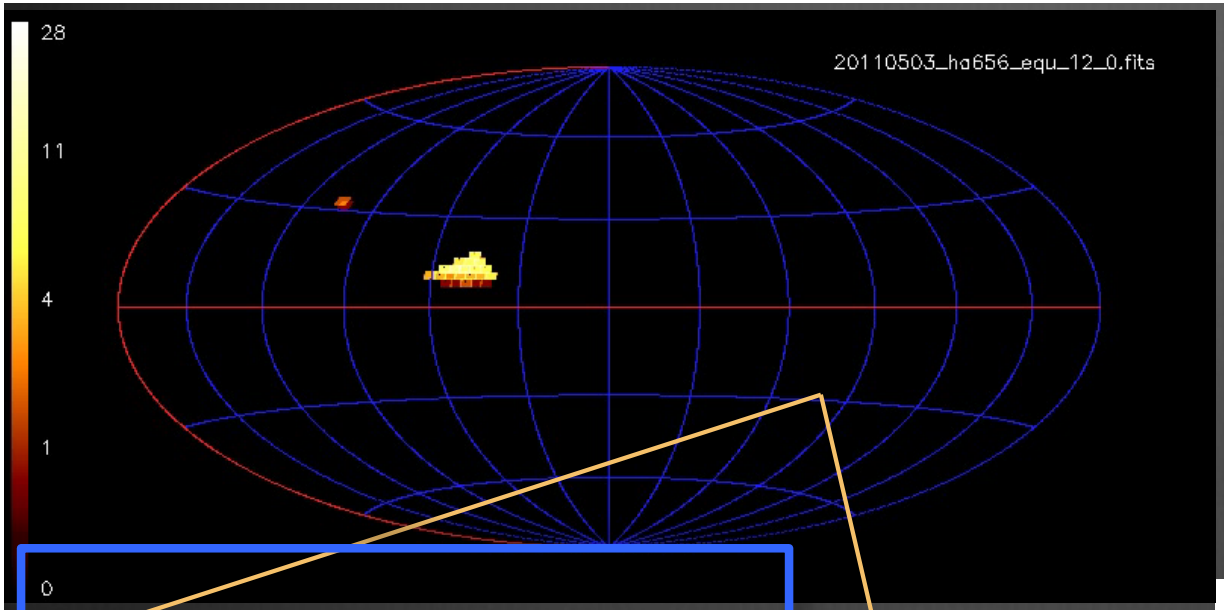
1. What improvements to current archive services “Should” be implemented?

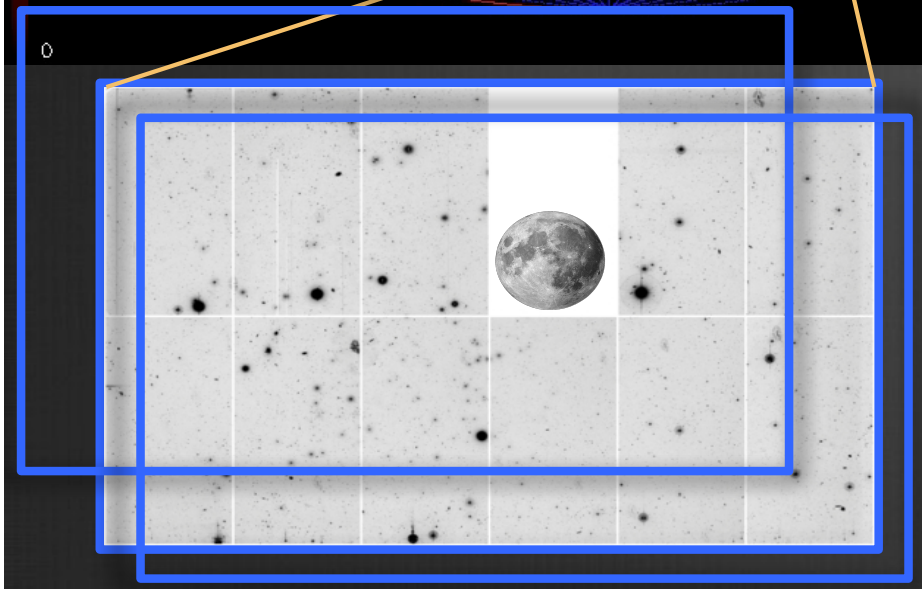
2. What new services “Need” to be implemented in the 2020s?

3. “Thematic” vs “Mission” archives

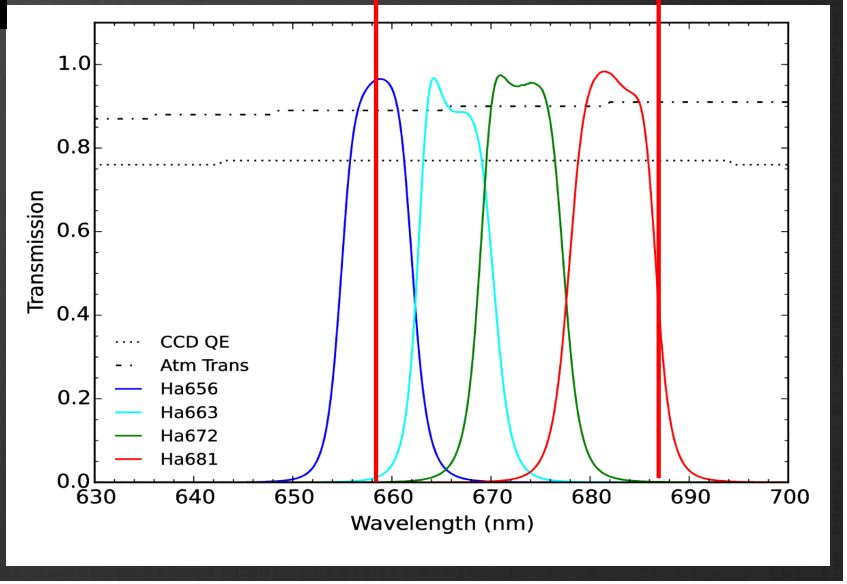
CLU Hα

- 3π of the sky (26,470 deg^2) on 48" at Palomar Observatory
- 1" pixel scale
- 4 narrow-band filters
- Constrain distance via Hα at different redshift





Cook+ (submitted)



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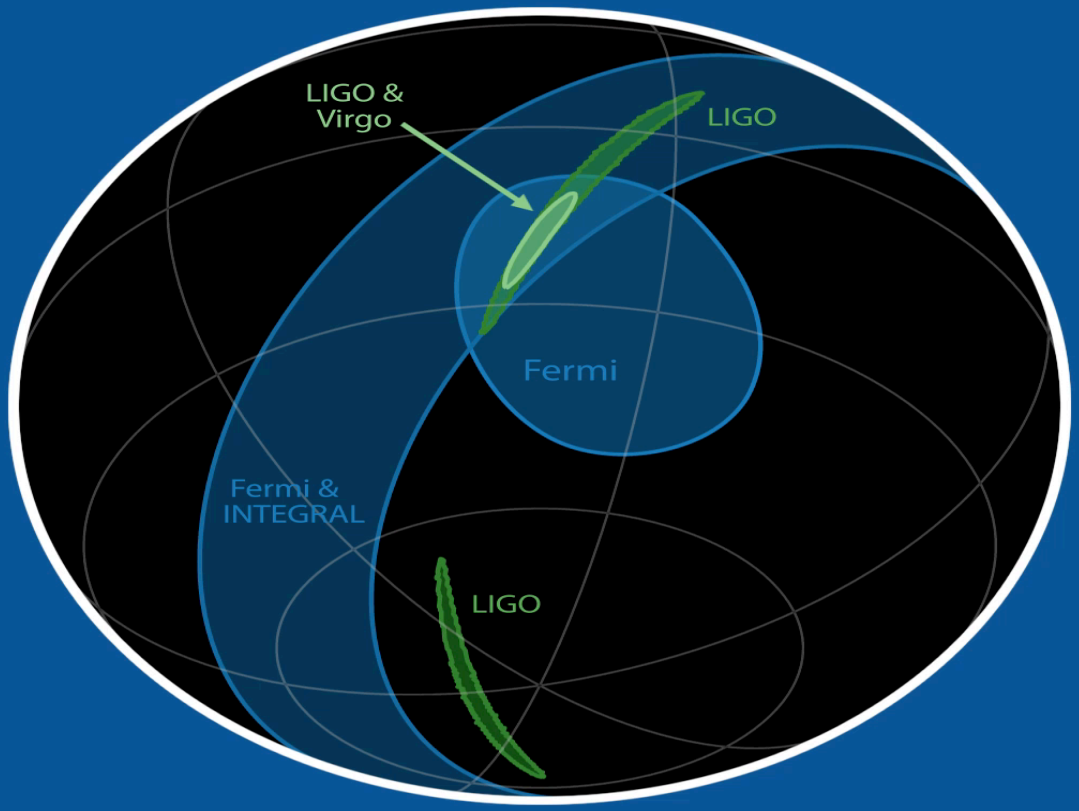
Step 1: Find the Galaxy…



Credit: R. Hurt