Searching for Kilonovae:
Using DECam and the DESGW Data Pipeline in Pursuit of Optical Counterparts to Gravitational Wave Events

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DESGW Overview

- Hubble Tension
  - Early- vs. late-universe H_0 discrepancy
- DESGW H_0 measurements
  - Standard Sirens
  - Independent of tradition
  - EM and GW
- GW signal
  - Detectable by LIGO/Virgo/KAGRA (LVK)
  - Event distance

2026

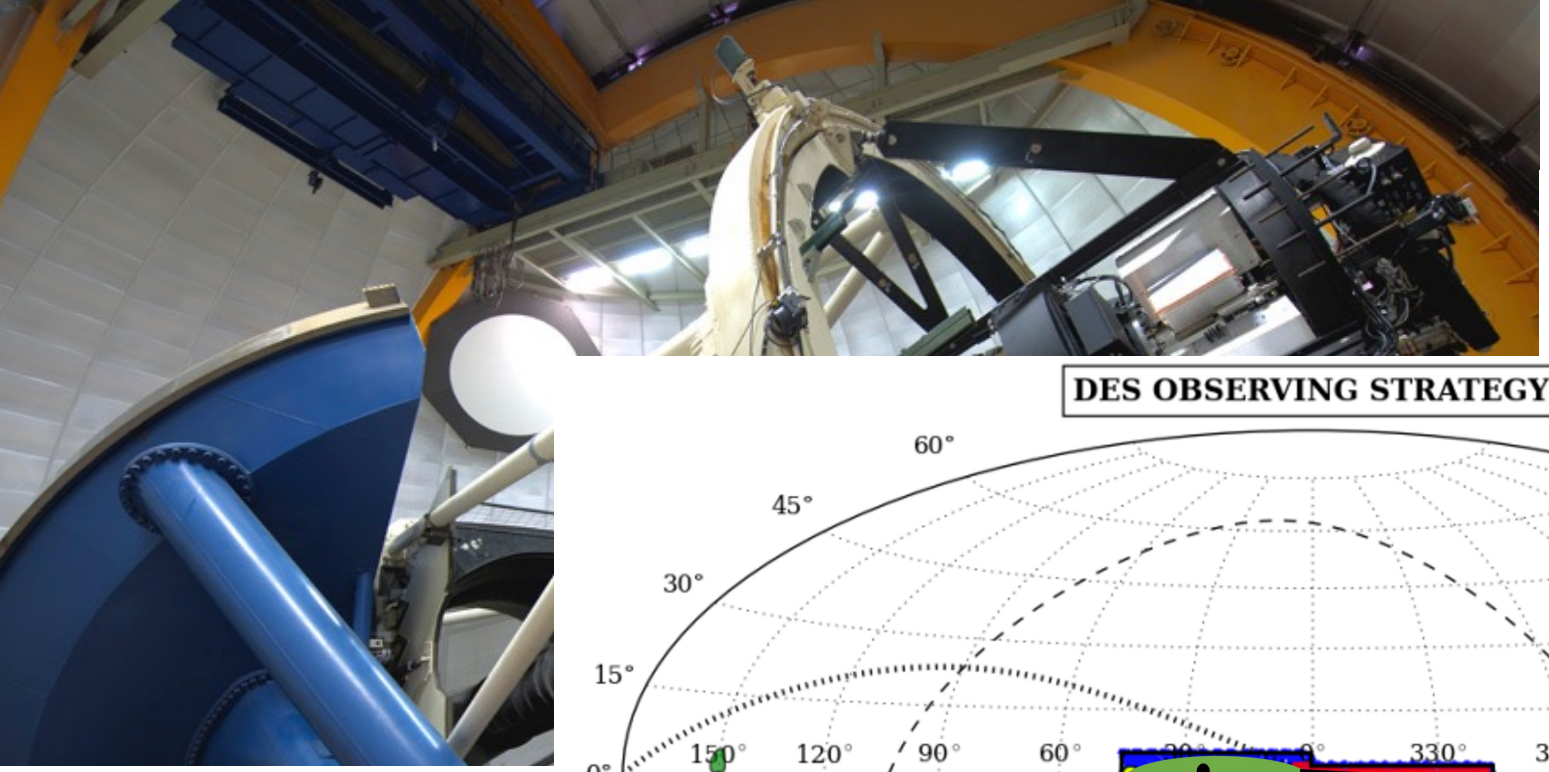
50 BNS: 2% H_0 Uncertainty

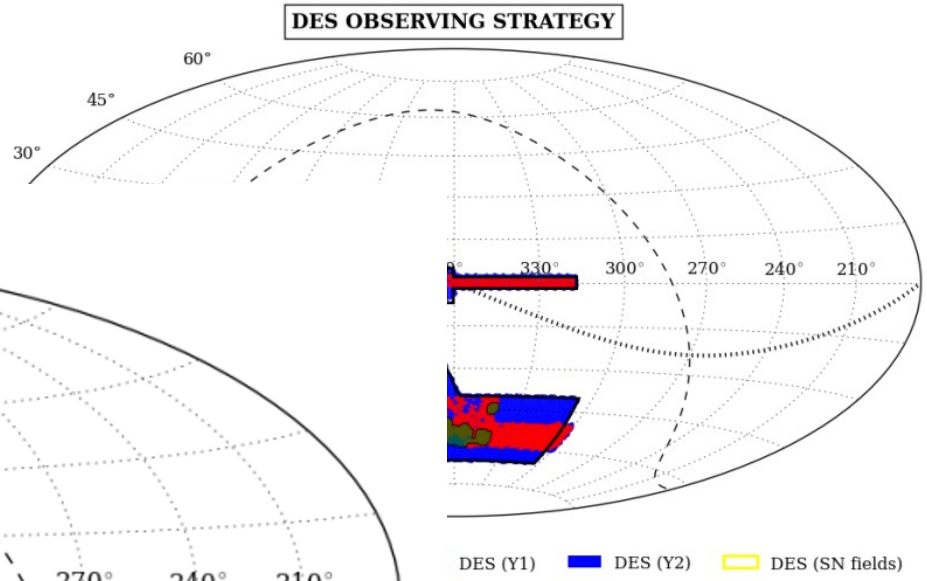
100 BNS: 1% H_0 Uncertainty

Chen et al. 2018

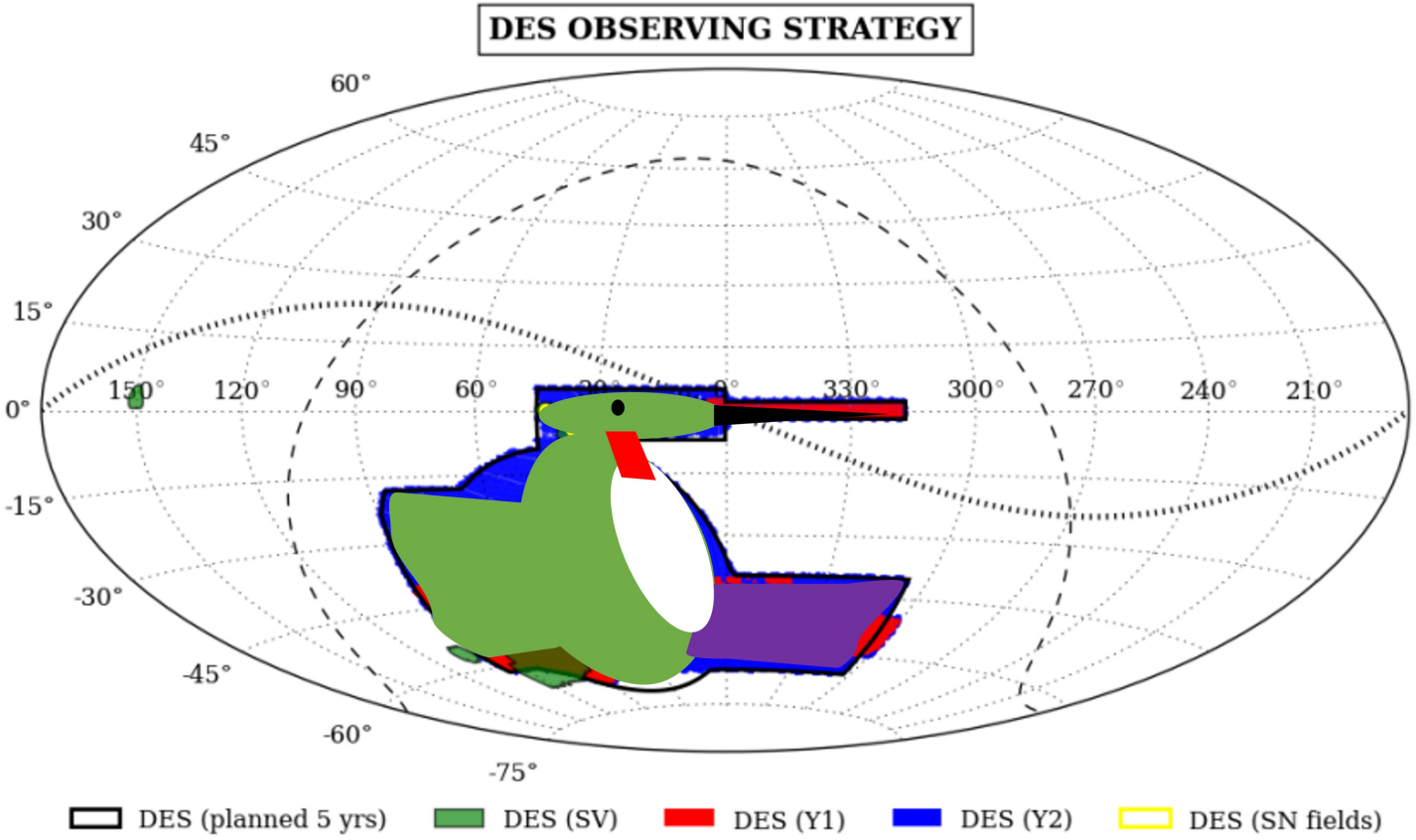
- EM signal
  - Binary neutron star, neutron star / black hole collisions
  - d to a host galaxy
  - data
  - detected
  - 70817
  - DESGW and other groups discovered
- GW170817 H_0 measurement
  - 70 $km/s/Mpc$
  - Uncertainty too large

Overview: DECam





rmilab); right: Lahav et al. 2016



- Location:
  - Cerro Tolo
    American
    (CTIO), Chi
- 4m Victor M.
  telescope

print

g^2

ngbird

Overview: Follow-up and the DESGW Data Pipeline

Main Injector

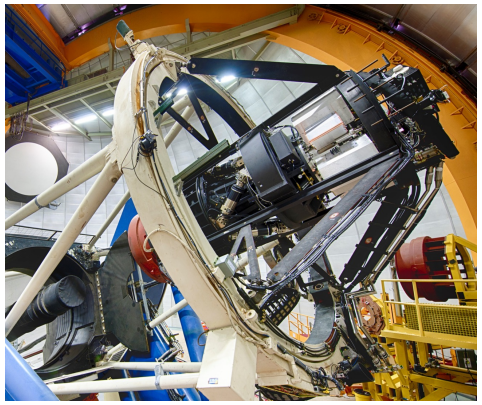
Overview: Follow-up and the DESGW Data Pipeline

The Main Injector

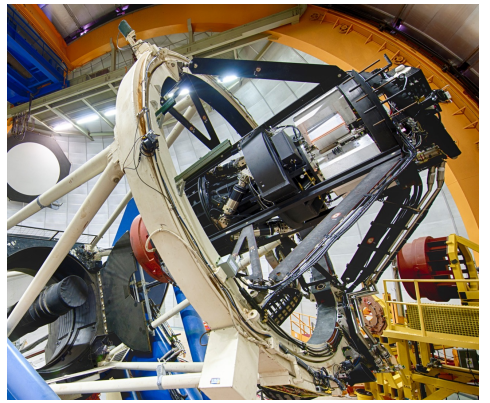
Collects LVC trigger data

Creates probability maps

Generates DECam pointing instructions



Overview: Follow-up and the DESGW Data Pipeline



Main Injector

Image Processing

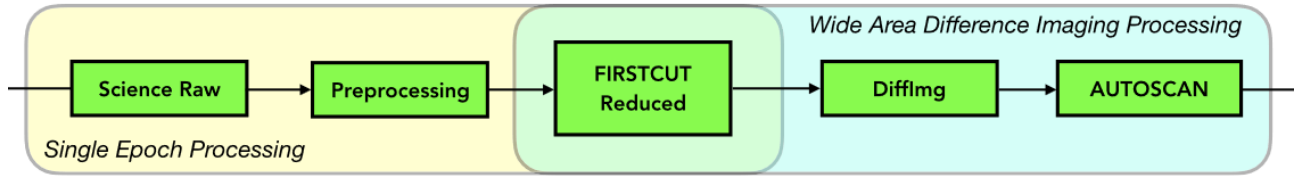
Overview: The Data Pipeline

The Main Injector

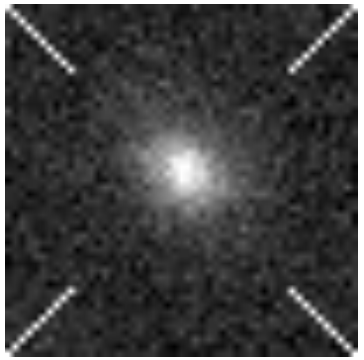
Image Processing

Single Epoch Processing: refines, corrected images

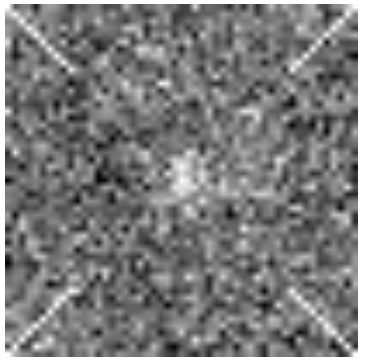
Difference Imaging: Subtracts SE-processed images; Highlights optical transience



Template



Search



Difference

Overview: Follow-up and the DESGW Data Pipeline

Main Injector

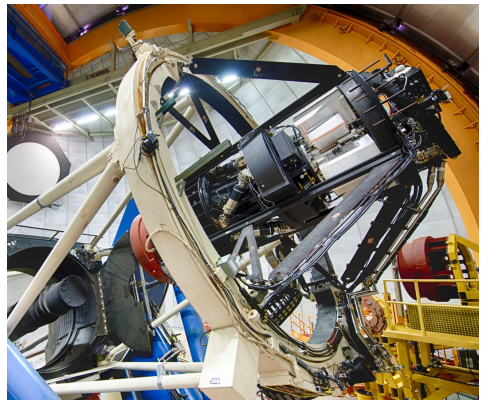
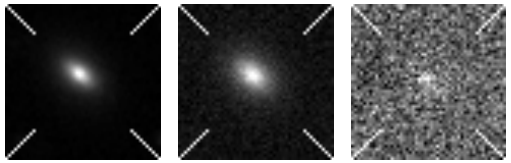
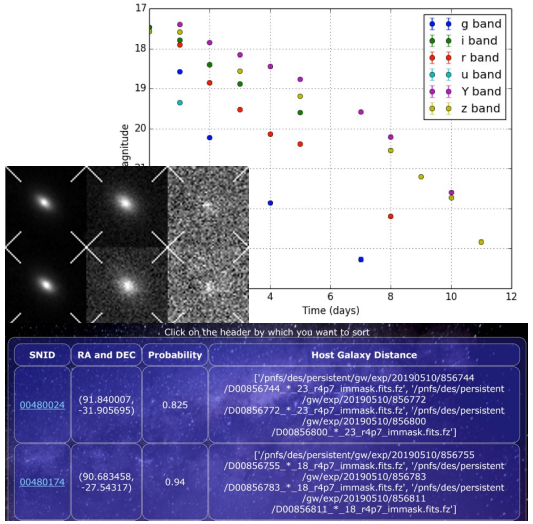


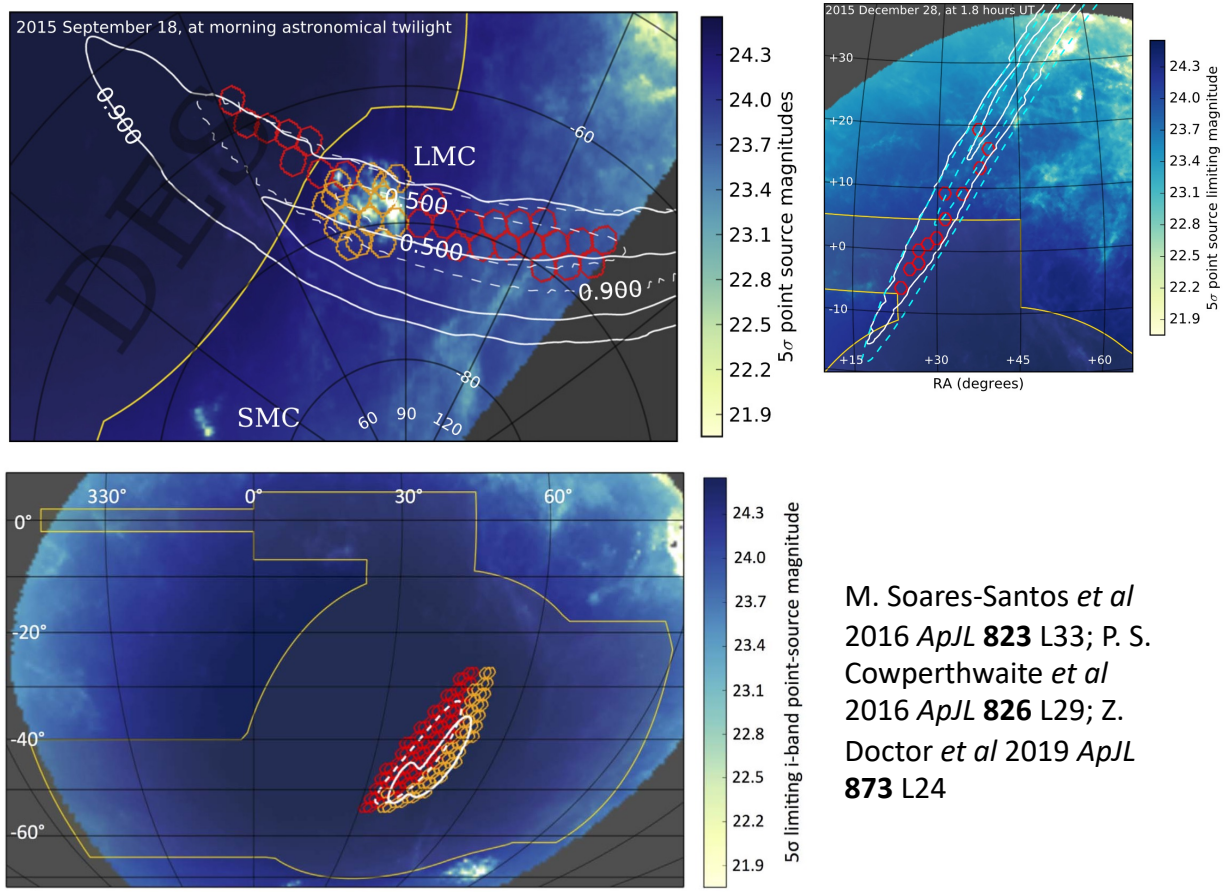
Image Processing



Post-Processing



DESGW Follow-ups O1 – O3



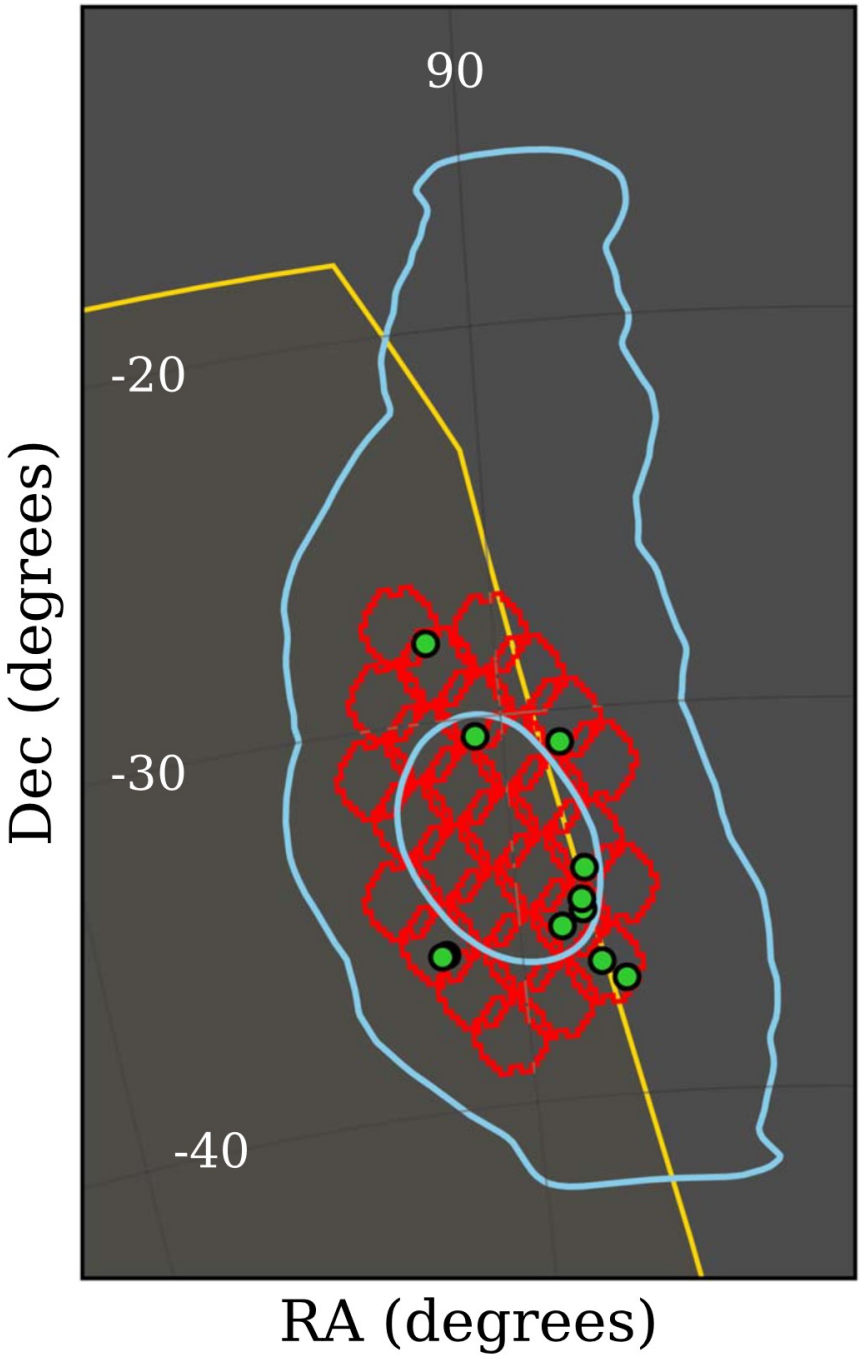
M. Soares-Santos *et al* 2016 *ApJL* **823** L33; P. S. Cowperthwaite *et al* 2016 *ApJL* **826** L29; Z. Doctor *et al* 2019 *ApJL* **873** L24

Event Name	Distance (Mpc)	Sky Localization (deg^2)	Prob. Area Search (%)	Search Depth (i-band mag)
GW150914	440^{+150}_{-170}	310	38	21.5
GW151226	450^{+180}_{-190}	1033	2	22.2
GW170104	990^{+440}_{-430}	921	10	24.0
GW170814	600^{+150}_{-220}	87	86	23.0
GW170817	40^{+8}_{-8}	87.2	81	22.0
S190510g	227^{+92}_{-92}	1166	65	21.7 (r-band)
GW190728	870^{+260}_{-370}	400	81	23.0 (r-band)
GW190814	239^{+43}_{-43}	23	80	23.5 (r-band)
GW200224	1710^{+490}_{-640}	50	85	23.2

A DESGW Search for the Electromagnetic Counterpart to the LIGO/Virgo Gravitational-wave Binary Neutron Star Merger Candidate S190510g

Garcia, et al. *ApJ* 903, 75 (2020)

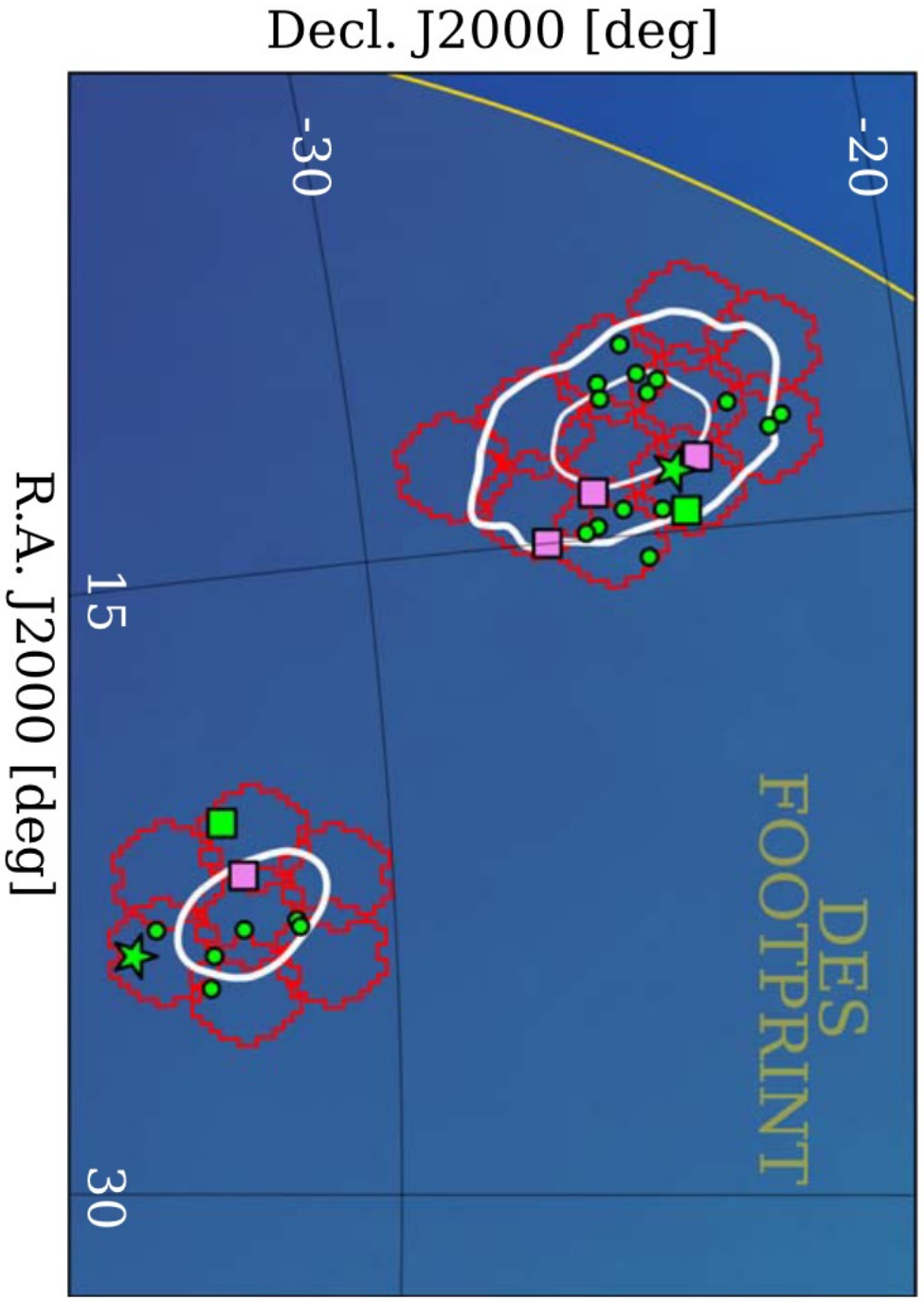
- Binary Neutron Star Merger
  - 1166 deg^2
  - 227^{+92}_{-92} Mpc
- DESGW Search
  - Used GROWTH data
  - ~65% of the probability area
  - ~1.5hr of observing
  - *g, r, z* bands
- Observed 2 nights, 84 deg^2
- 1,165 total candidates -> 11 final candidates
- Event redacted
  - Terrestrial source
- Findings:
  - Increased image depth/exposure times decrease number of follow-ups to discover kilonovae



Constraints on the Physical Properties of GW190814 through Simulations Based on DECam Follow-up Observations by the Dark Energy Survey

Morgan, et al. *ApJ* 901, 83 (2020)

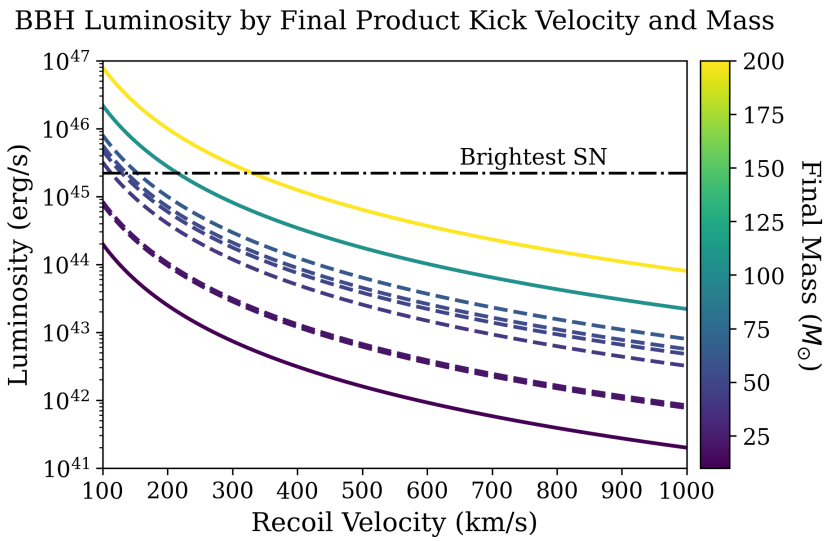
- Well-localized NSBS
  - 23 deg^2
- 6 nights of observing over 16 days post-merger
- 33,571 counterpart candidates
- Sensitivity analysis
  - KN efficiency constraints

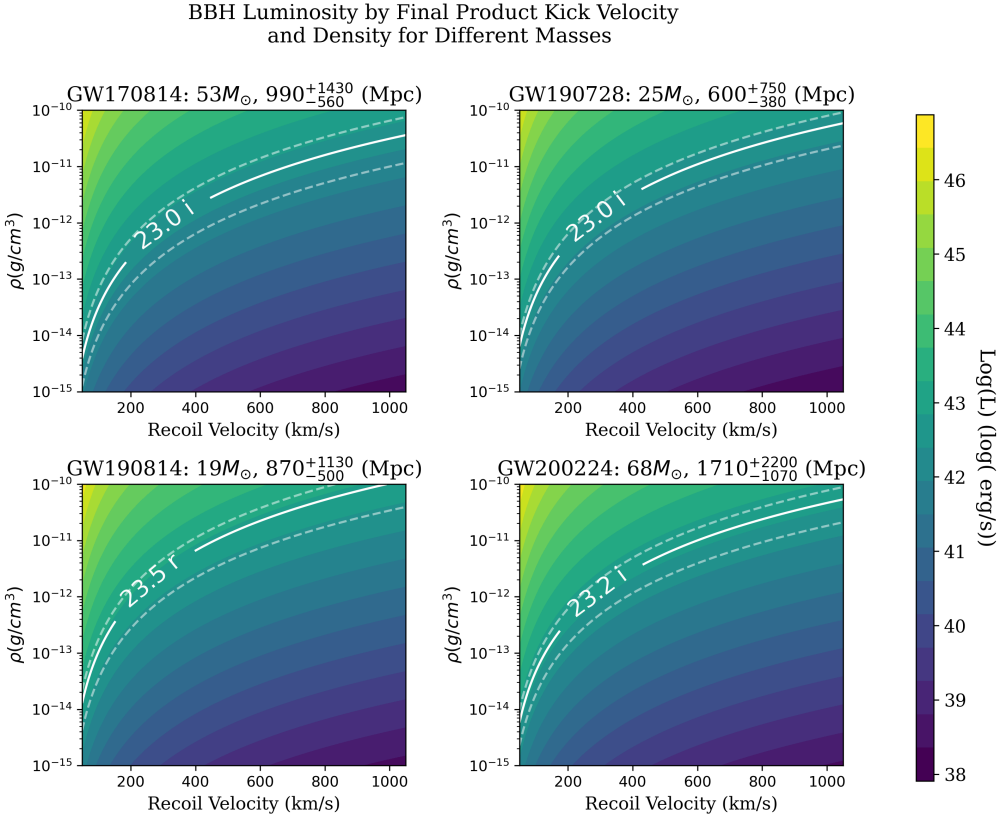


Searching for EM-Bright Binary Black Hole Mergers in Dark Energy Survey Data

Sherman, et al. *in preparation* (2022)

- Binary Black Hole Mergers (BBHs)
  - Thought of as optically dark
  - Used for dark sirens analysis
- EM Bright BBHs
  - Reveal new astrophysics
  - Enhance cosmological measurements
- Search
  - Reprocess DESGW BBH searches considering EM emission models
- Analysis
  - Model, simulate BBH EM emission
    - Evaluate search criteria
    - Deduce frequency of detection
    - Study properties
    - Put limits on physical parameters





DESGW Ongoing Analyses & Improvements to the DESGW Data Pipeline

- Strategy Paper
  - Improve DESGW's search strategies, maximize probability of kilonova detection
  - Exposure times
  - Filters
- Main Injector
  - Improve, speed up observing plan calculations
  - Consider updated strategy
- Image Processing + Post-Processing
  - Elise Kesler (UMich), Dana Yaptangco (UCF)
  - Significantly improve automation of pipeline
- Website
  - Pipeline and processing status
  - Improved visual inspection methods
  - Integration with Spectro follow-up teamc

Summary

- A standard sirens measurement of H_0 could resolve the Hubble Tension
- DESGW searches for kilonovae, relying on DECam and the DESGW data pipeline
- GW170817
  - The only kilonova discovered
- Significant improvements to the DESGW procedures/data pipeline to enhance discovery
  - Optimization of strategy
  - Updates to automization

Thank you!

Collaborators:

The DESGW Team

Questions?