Improvements to Image Processing to Identify GW Counterparts

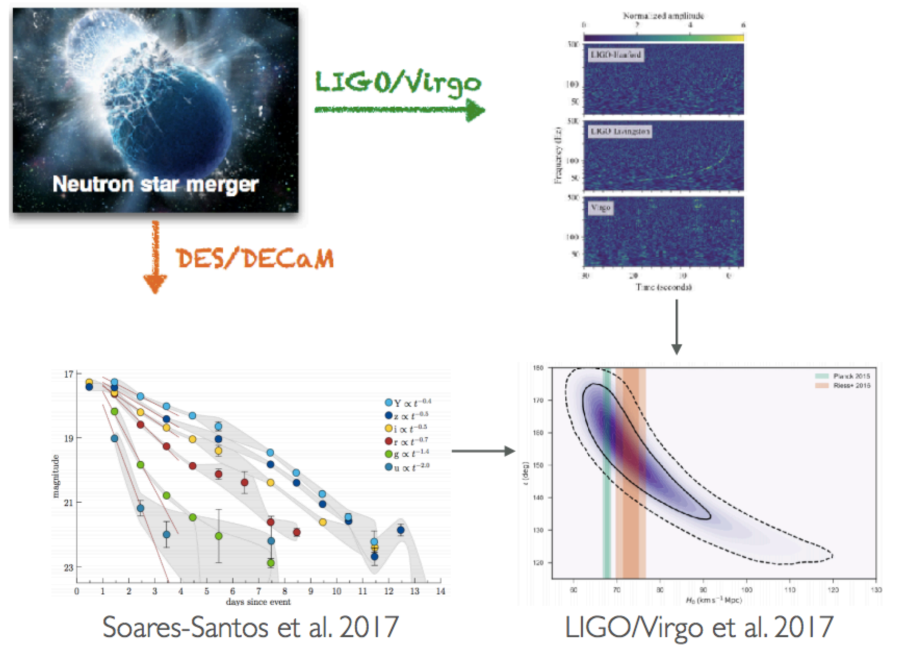
Noemi Glaeser, *University of South Carolina, Columbia, SC*

UNIVERSITY OF SOUTH CAROLINA

Binary neutron star (BNS) mergers emit both gravitational waves (GW) and electromagnetic (EM) signals. Upon a Laser Interferometer Gravitational-Wave Observatory (LIGO) detection of a BNS event, the Dark Energy Survey GW group (DES-GW) attempts to locate and observe the EM counterpart. We employ a series of computer programs known as the DES-GW pipeline to capture and process Dark Energy Camera (DECam) images with the goal of identifying the location and characteristics of the EM counterpart and shedding light on the nature of dark energy. Here we describe image processing improvements for LIGO Observing Run 3 (O3).

Introduction

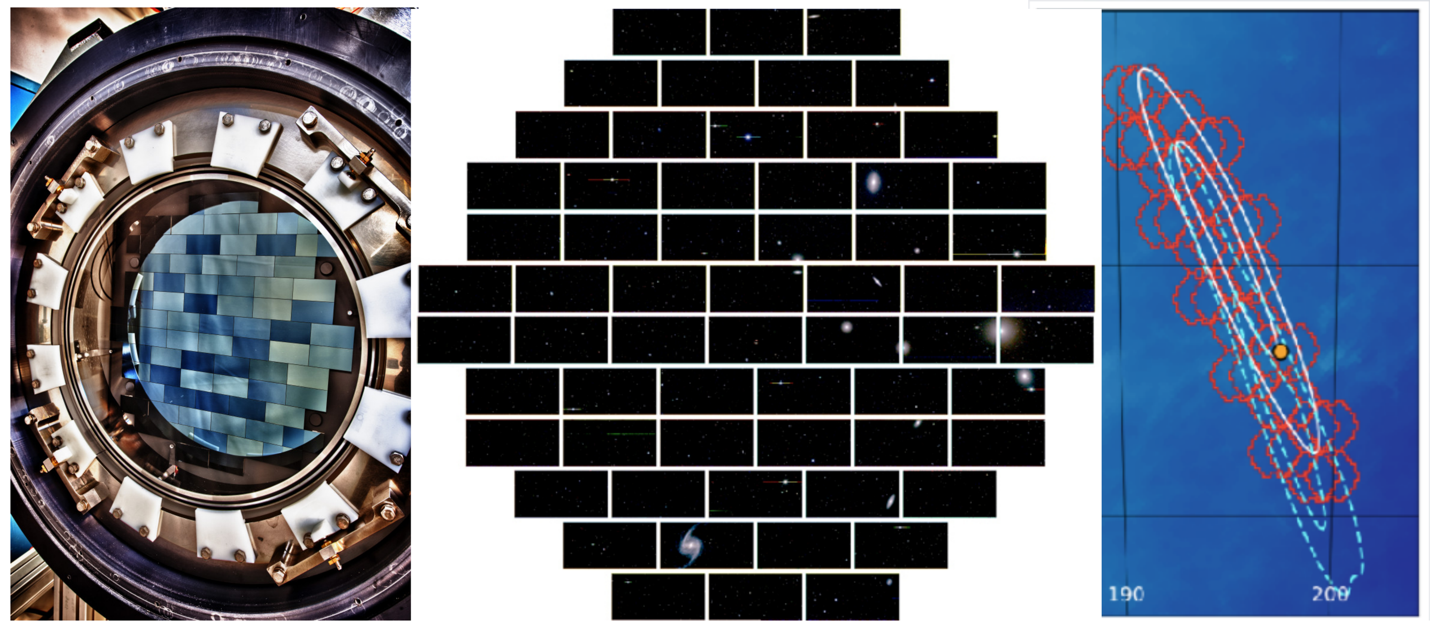
By observing GW emitted by distant mergers of massive objects, LIGO provides an independent distance measurement directly to these events. Observing the same object in the optical range (called a kilonova), allows us to gather additional information such as redshift. Using a distance-redshift plot, we obtain an independent measure of the Hubble constant, improving its known bounds.



Right: Process of determining the Hubble constant using GW170817 counterpart observation (Credit: Soares-Santos et al.)

Methods

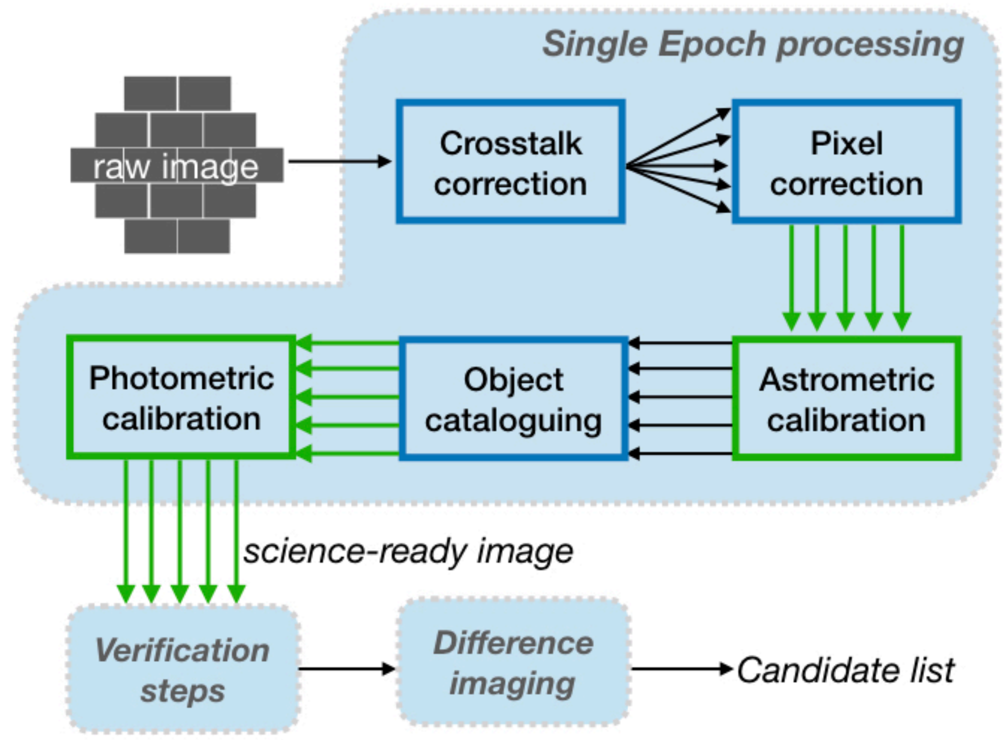
DECam



Left: DECam **Center:** DECam image consisting of 62 CCDs **Right:** LIGO probability area for GW170817 counterpart (Credit: DES Collaboration)

- 570 megapixel 2.2-deg. FOV camera with 6 filters
- On 4m Blanco telescope at Cerro Tololo Inter-American Observatory (CTIAO) in Chile
- Will cover 500-sq. deg. DES footprint 10x in 4 bands

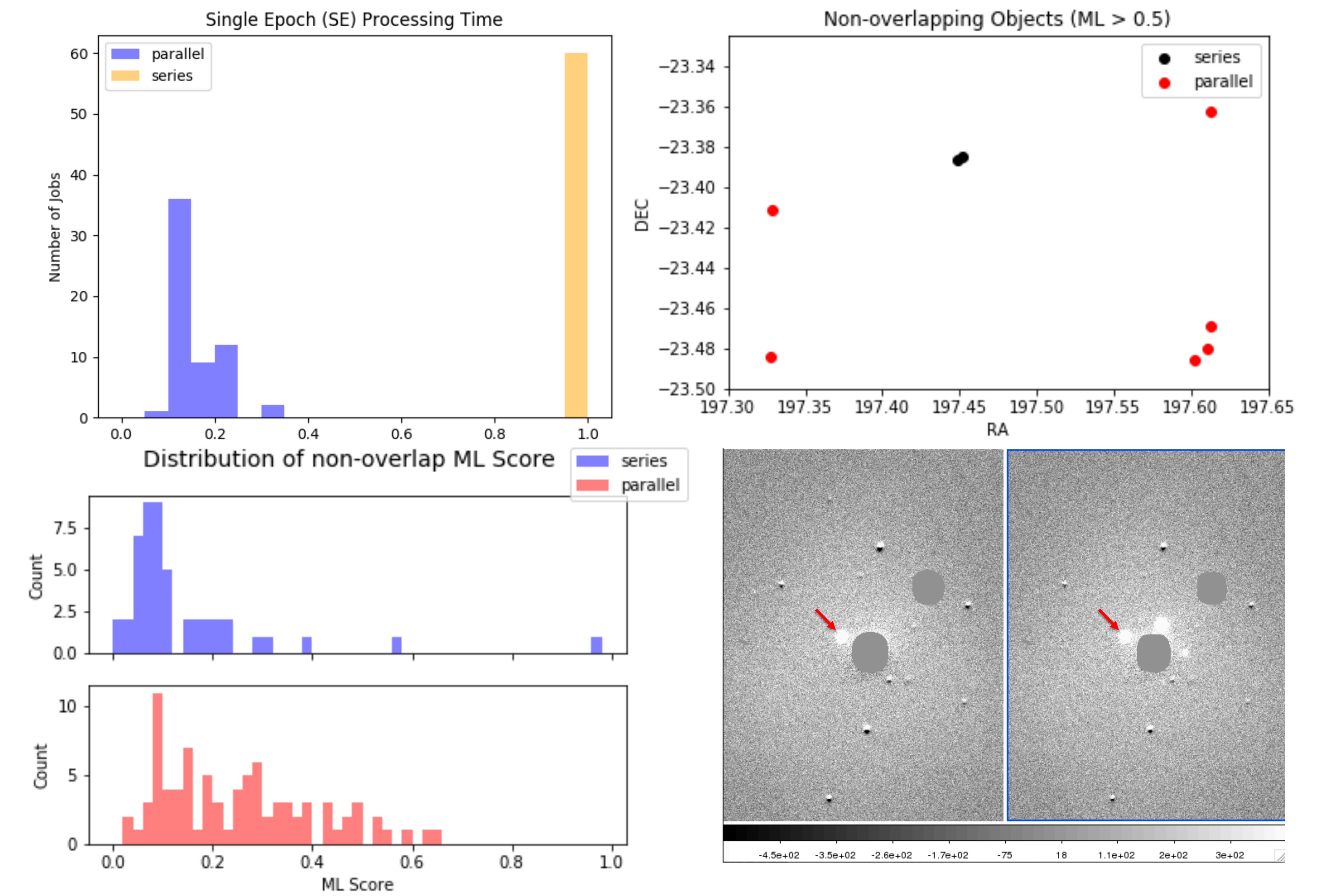
The Image Processing Pipeline



DES-GW Image Processing Pipeline (new changes in green)

- Parallel astrometric & photometric calibration
- GAIA-DR2 star catalog instead of 2MASS
- Tested on GW170817 images to ensure counterpart was still identified

Results & Conclusion



Clockwise from top left: (1) SE parallelization speedup (series: 0.9625 h; parallel: μ=0.15, median=0.13, σ=0.05). **(2)** Only 8 candidates with ML>0.5 were not identified both before and after, only 1 with ML>0.7. (ML=0.96) **(3)** Difference images for parallel (left) and series (right), counterpart (red arrow) is present in both. **(4)** Distribution of ML scores of candidate non-matches.

The full image processing pipeline runtime, from raw image to candidate list, decreased from ~5-8 h to an estimated 1 h. The new pipeline will be used in LIGO O3 in early 2019 to identify more GW counterparts and provide an independent Hubble constant measurement. It will also play a key role in fast counterpart identification, which is crucial in enabling early, detailed spectroscopic follow-up.

References

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THE DARK ENERGY SURVEY LIGO