Searching for Optical Counterparts to Gravitational Wave Events with the Catalina Sky Survey

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ABSTRACT

On 17 August 2017, the era of multi-messenger, gravitational wave astronomy began with the discovery of the optical counterpart to the gravitational wave event GW170817. In this poster, we outline our software and strategy for discovering optical counterparts to future gravitational wave events using data from the Catalina Sky Survey (CSS). With this strategy we will be able to tile 60 deg^2 within 30 minutes with four separate visits to remove moving objects. We will also be running the data through our transient detection pipeline in real time to detect transient candidates as soon as possible.

STRATEGY

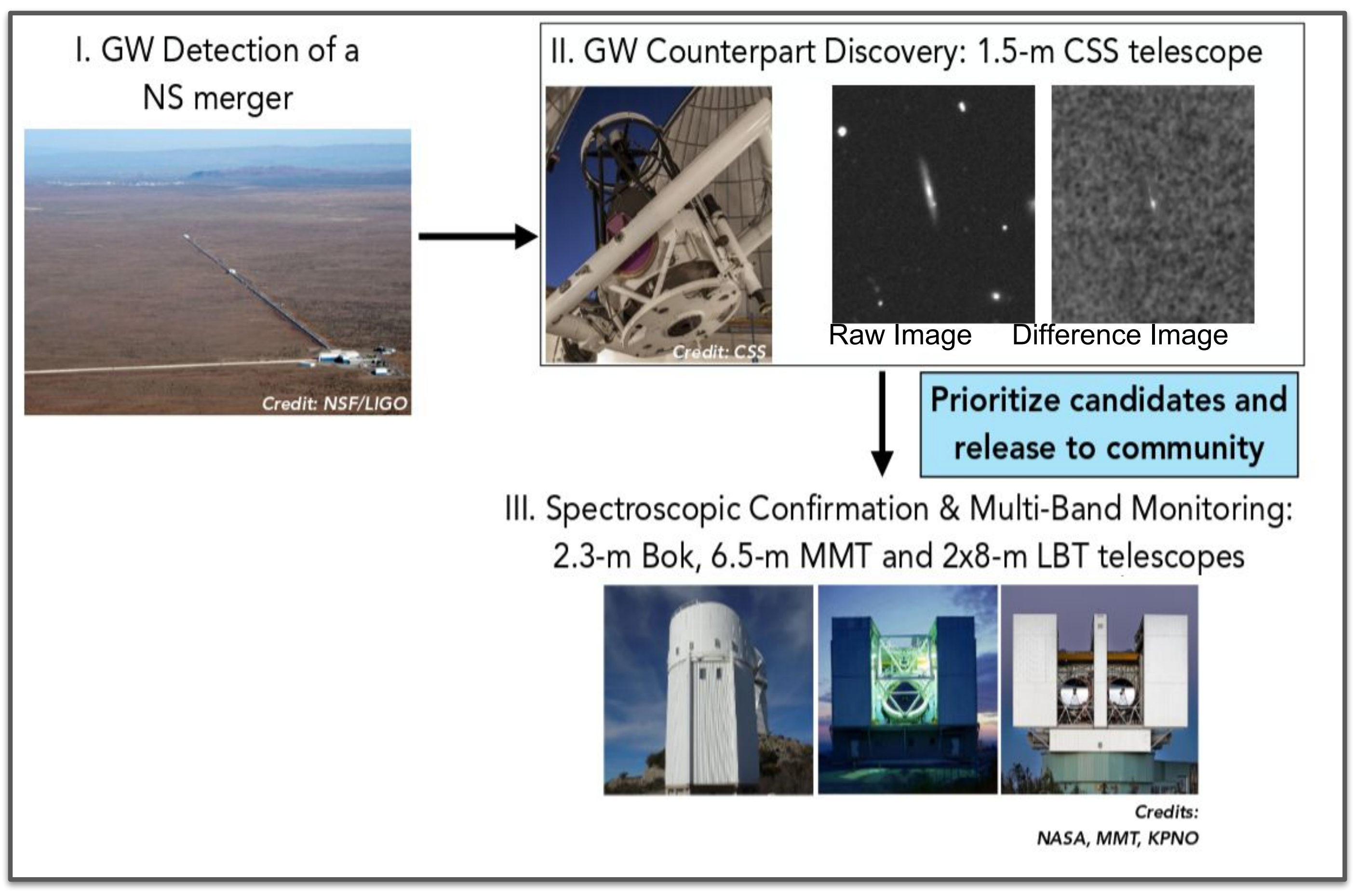
Our strategy is to piggyback on the Catalina Sky Survey's search for near earth asteroids to search for optical counterparts to gravitational wave events using data from the CSS 1.5-meter G96 telescope. We will request CSS to observe their standard fields with the highest probability for containing the optical counterpart based on the event localization. The observations must also be useful for their ongoing science asteroid survey.

Catalina Sky Survey

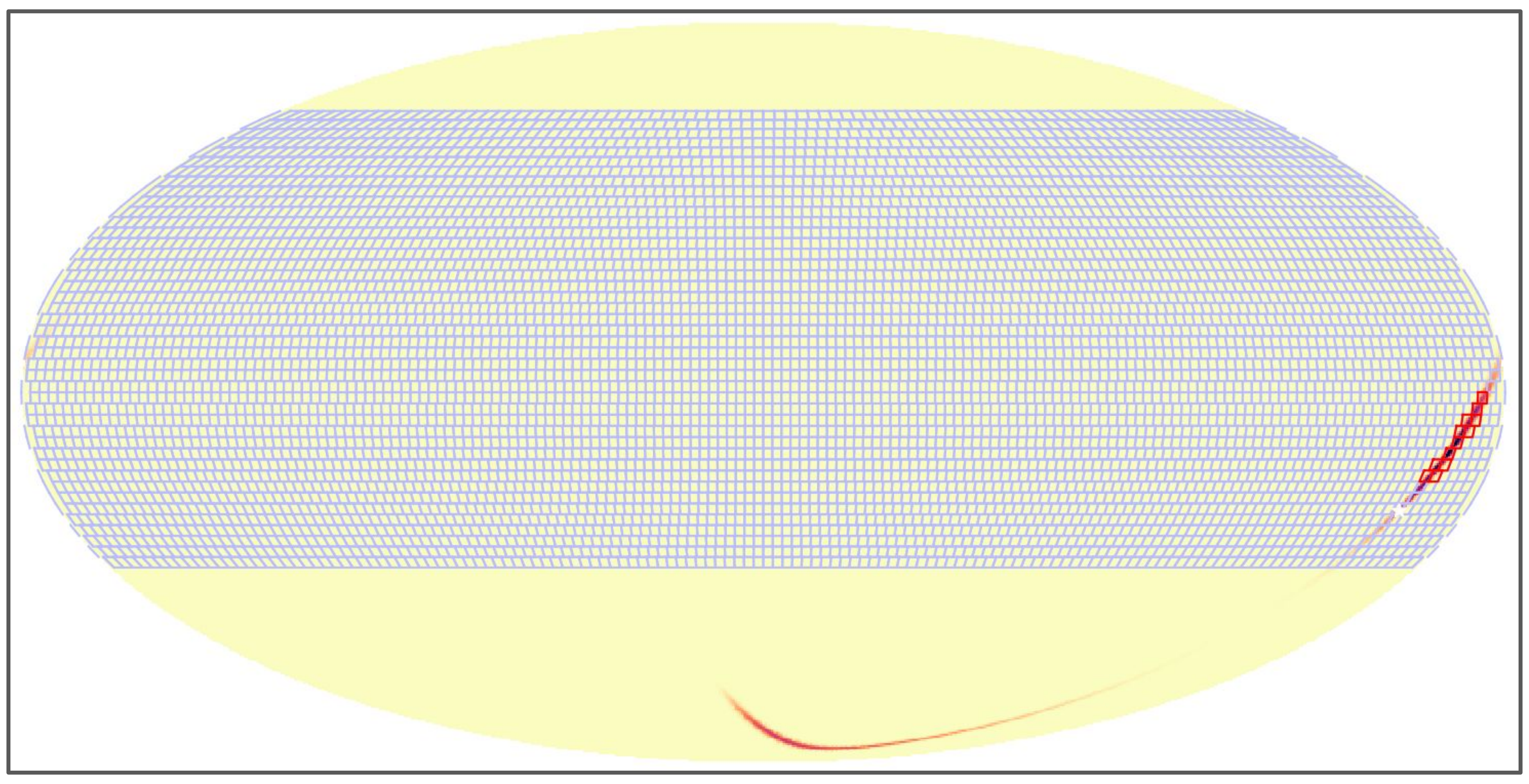
The Catalina Sky Survey uses three telescopes in the Santa Catalina Mountains near Tucson, Arizona. These telescopes include a 1.5-meter G96 telescope and 1.0-meter on the summit of Mt. Lemmon as well as a 0.7-meter telescope on Mt. Bigelow. CSS telescopes operate 24 nights per lunar cycle with a 4-5 day break surrounding the full moon. The imager for the 1.5-meter G96 telescope that we will be utilizing delivers a 5.0 deg^2 field of view to a limiting magnitude of V~21.5 mag in 30s exposures allowing for 1000 deg^2 to be covered per night.

CSS Triggering

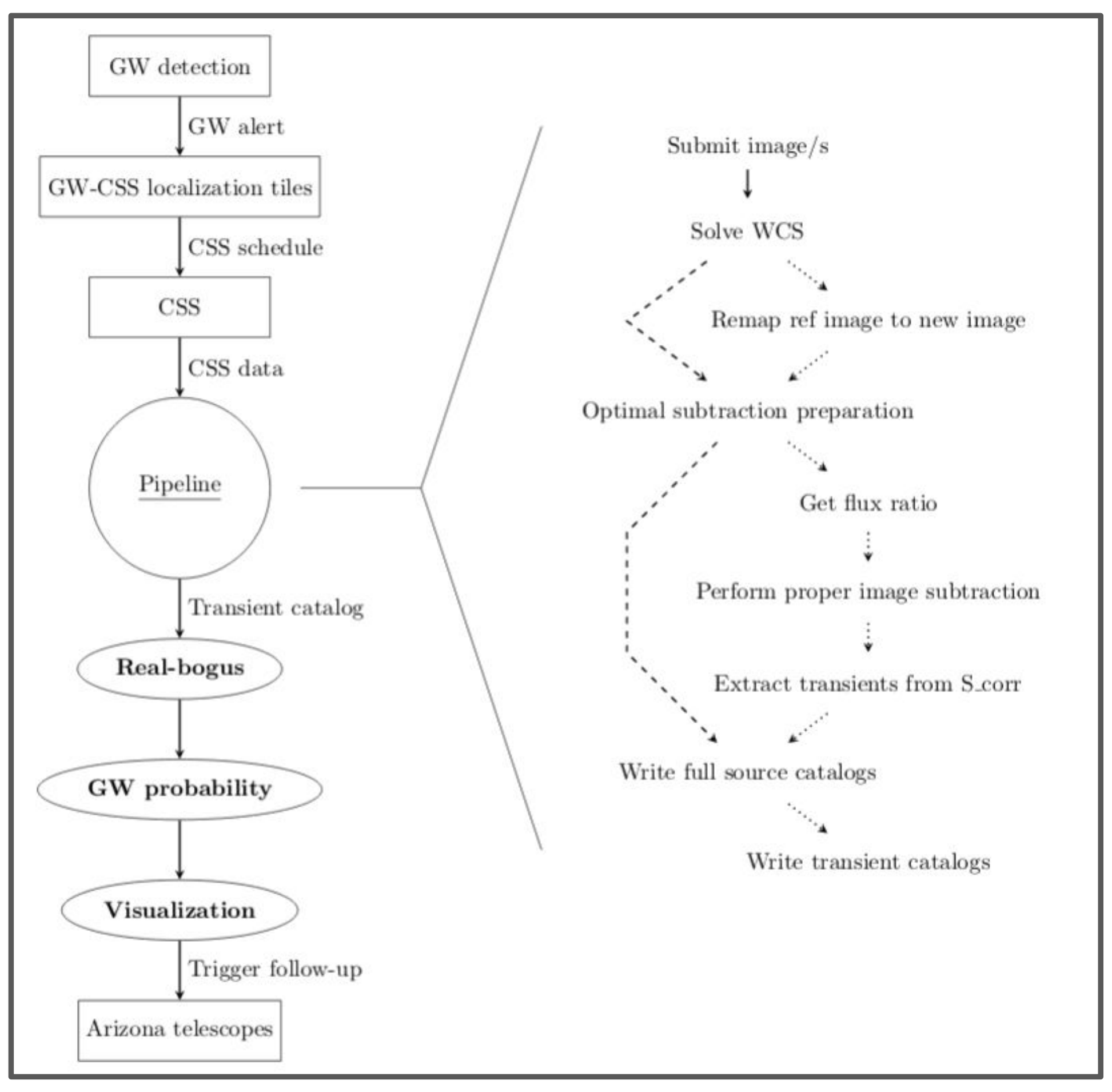
We have developed software to trigger CSS observations using the pygcn package by Leo Singer. Once we have the gravitational wave alert, we will determine the fields with the highest probability of containing the gravitational wave optical counterpart. Currently this is set up to send an email containing the fields to be observed to the telescope, but soon it will automatically load the fields into the CSS queue scheduler.



The use of CSS allows rapid tiling of the highest probability regions shortly after the gravitational wave is detected. This enables rapid follow-up observations with larger facilities. In particular, we are leveraging our access to telescopes in southern Arizona for follow-up observations.



All-sky plot of the GW170817 initial LIGO localization overlaid on the grid of the CSS fields in blue. A selection of the ten fields with the highest probability are boxed in red for reference. The kilonova is indicated with a white star. In this case, LIGO without VIRGO, the optical counterpart is not within the ten highest probability fields. Note that to maintain the asteroid survey, we only request fields that are adjacent to one another.

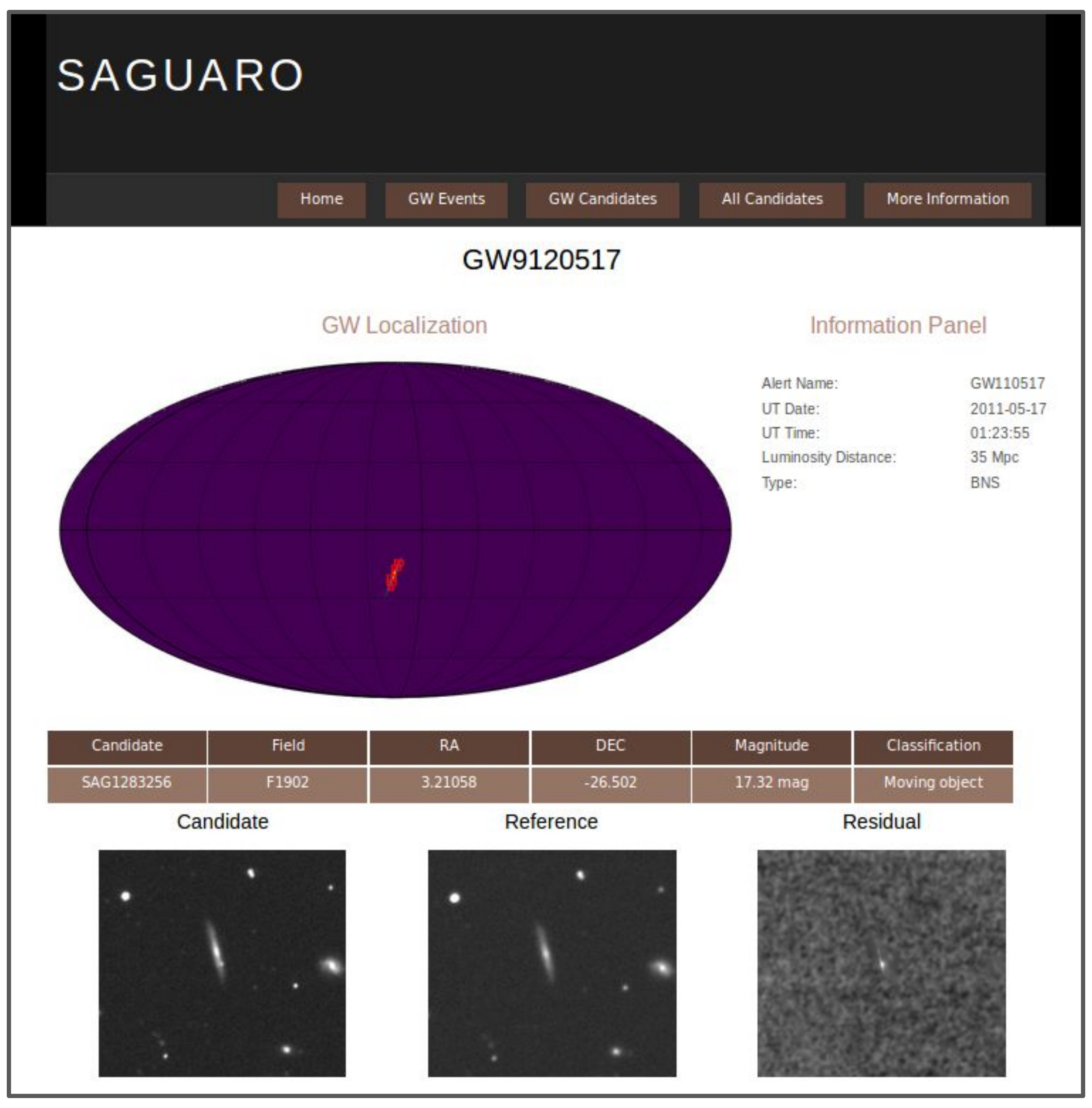


Pipeline

We use the reduction pipeline developed by Paterson et. al (2018, in prep) for MeerLICHT and BlackGEM (Bloemen et al. 2016) to analyze the CSS data as it is received.

The pipeline performs basic reduction steps, such as debasing, flat fielding, gain correction, cosmic ray cleaning, and bad pixel masking for each image. The image subtraction part of the MeerLICHT pipeline makes use of the image subtraction method by Zackay, Ofek and Gal-Yam (ZOGY; see Zackay, Ofek, & Gal-Yam 2016).

ZOGY uses statistical principles to derive the optimal statistic for transient detection. Instead of a convolution kernel, ZOGY uses the PSF across the reference and new images during the photometric alignment, typically providing an improved representation of the sources in the image compared to the convolution kernel fit using HOTPANTS (Becker 2015). ZOGY uses the derived PSFs, along with an estimate of the background standard deviation and flux ratios, to perform the image subtraction by using Fast Fourier Transforms. The difference image is then used to create a significance and a corrected significance image representing the significance of all pixels in the difference image, with the corrected significance image including corrections for source noise and astrometric error.



GW9120517

GW Localization

Information Panel

Alert Name: GW110517
UT Date: 2011-05-17
UT Time: 01:23:55
Luminosity Distance: 35 Mpc
Type: BNS

Candidate	Field	RA	DEC	Magnitude	Classification
SAG1283256	F1902	3.21058	-26.502	17.32 mag	Moving object

Candidate

Reference

Residual

Candidate Visualization

We are currently developing an internal website for candidate vetting and early analysis. This website will run on a Flask web application and use python to query a PostgreSQL database containing information about the LIGO-VIRGO Alert, the CSS fields that were triggered, and the pipeline dataproducts. This is an example GW candidate page from the internal website. For each GW alert, this internal webpage shows information from the alert, a plot of the localization probability map with the CSS fields over-laid, and lists of candidates from the pipeline. Once the candidates have been vetted to remove false positives due to cosmic rays, moving objects, or variable stars, a list of qualified candidates will be made available to the public.