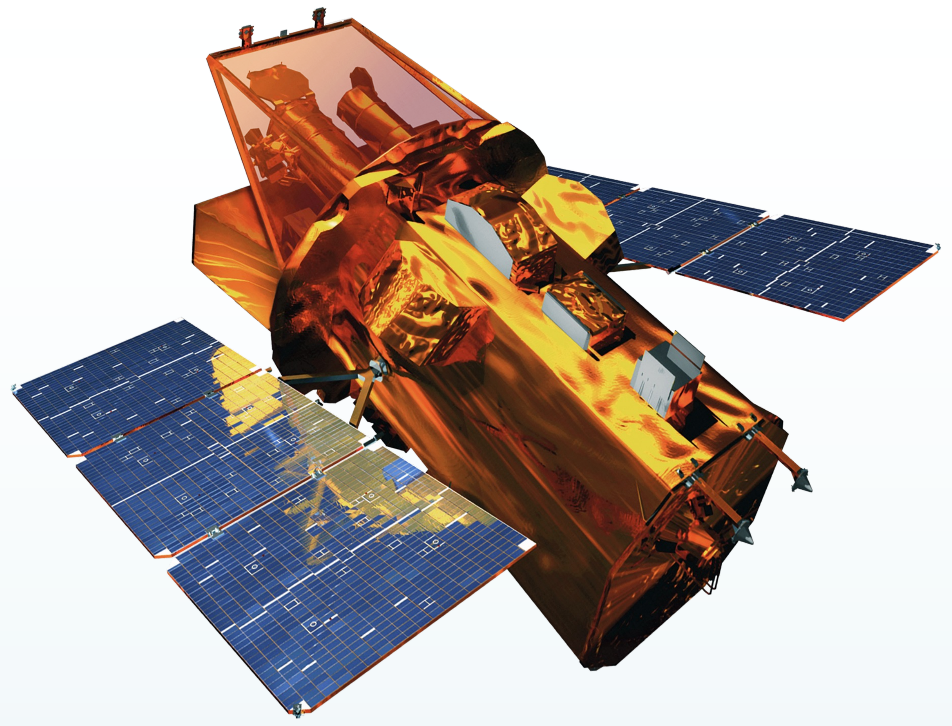


The UVOT Image Subtraction Pipeline

Asmita Korde-Patel [1], Noel Klingler [1,2,3], Frank Marshall [1], Brad Cenko [1]

[1] NASA Goddard Space Flight Center, [2] University of Maryland Baltimore County, [3] CRESST II

Motivation

The detection of faint optical transients is a critical component of gravitational wave (GW) follow-up efforts. Compact object mergers (e.g., binary neutron stars) produce kilonovae – thermal transients powered by the radioactive decay of r-process elements. Unlike GRB jets, kilonovae are comparatively isotropic and thus may offer a higher likelihood of detection. However, their faintness and location within host galaxies make their detection challenging, as galactic diffuse emission can obscure the transient signal. To address this, we present a new pipeline for automated image subtraction of UVOT GW follow-up data. By utilizing high-quality template images, the pipeline effectively removes the galactic background, enabling the detection of faint transients embedded within host galaxies. When complete, the pipeline will greatly aid in searches for electromagnetic counterparts to gravitational wave events, as well as searches for serendipitous UV/optical transients.

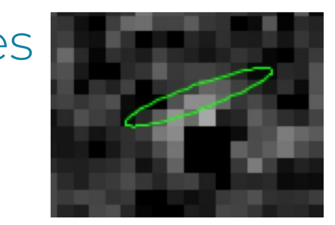
Algorithm

Upon receiving an input UVOT (U-band) image, the pipeline will:

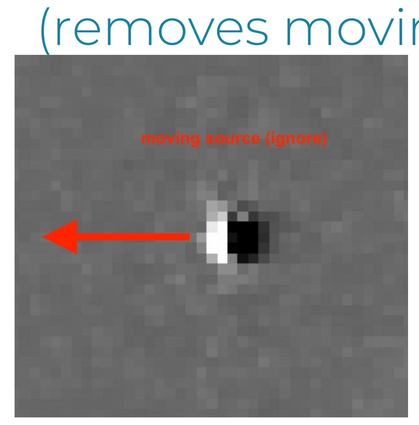
1. queries the UVOT archive for a suitable reference image (>30 sec exposure, covering the same region of sky), and downloads either the longest exposure or the most recent (user-specified)
2. normalize the images (based on exposure time)
3. subtract the reference image from the input image (using uvotimsum)
4. run source detection (using uvotdetect)
5. apply filtering criteria (to remove false-positives, variable sources, etc.)
6. produce thumbnails of each "valid" transient (showing the reference image, new image, and differenced image)
7. upload the "valid" transient thumbnail images to a webpage for human vetting

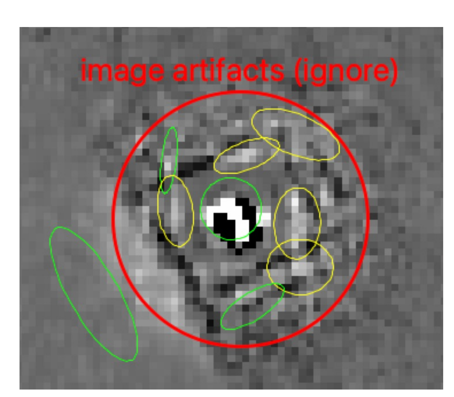
Filtering Criteria

1. check if candidate transient is near (within 2") of image boundary; (removes false-positives from sources at FOV edge)
2. check candidate ellipticity (PSF check): semi-major < 4 pix, semi-minor > 0.3 pix, semi-major / semi-minor < 4 (prevents noise / non-sources from being falsely flagged)



3. check candidate significance: ratio of ct rate / ct rate error > 5 (prevents false positives from noise)
4. check if candidate exists in both reference and input images (within 2 arcsec): eliminate if within both (screens out variable sources)
5. check if candidate is a known transient: SIMBAD query (prevents false-flagging of already-known transients that Swift intended to observe)
6. check uvotdetect flags: 0, 1, and 2 are okay; screen out the rest (remove spurious sources)
7. check sum of counts in vicinity != 0: (removes moving sources)



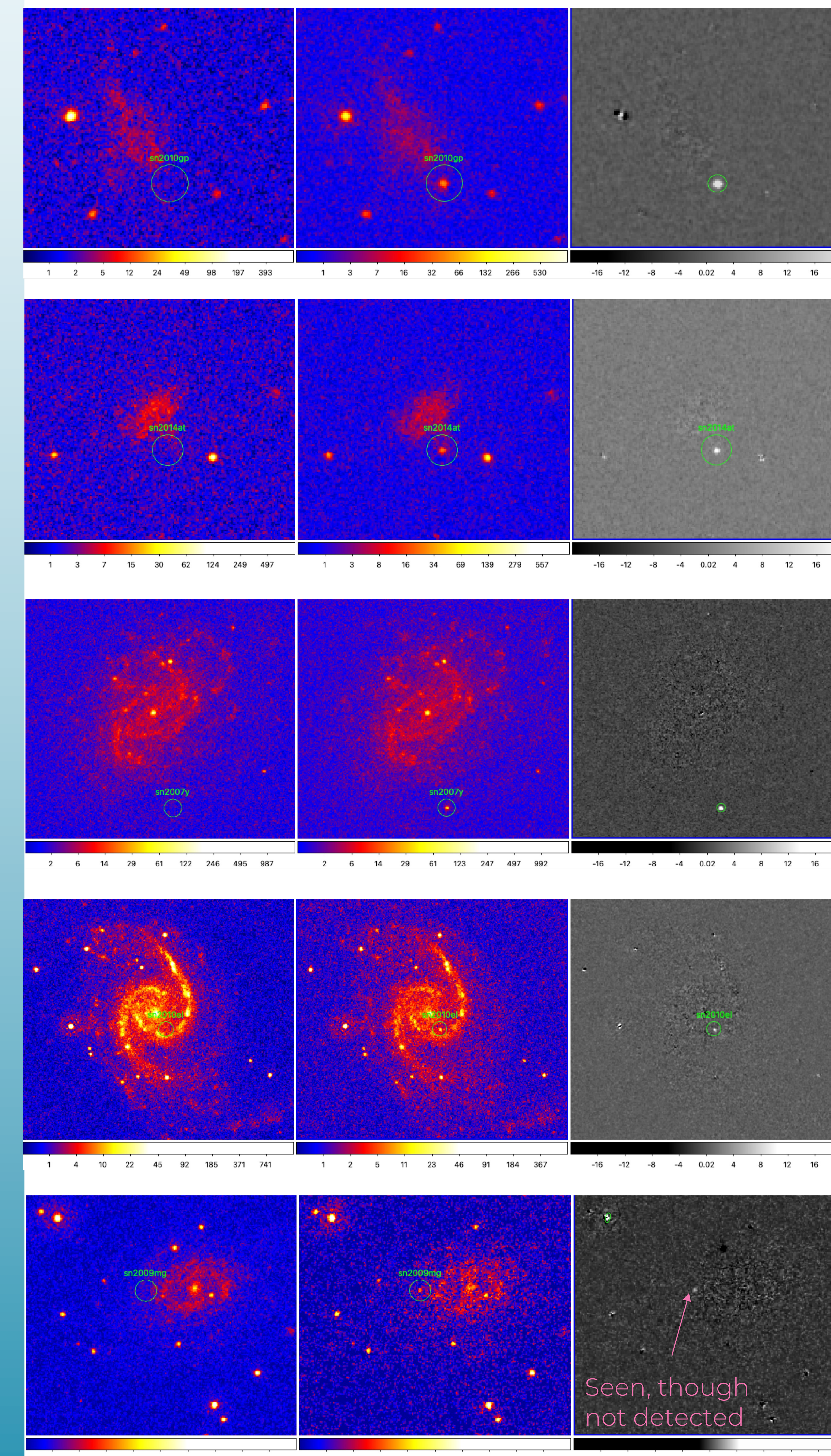


8. ignore candidates within 18" of bright sources (>10 cts/s): removes image artifacts caused by bright sources

Image Subtraction:

Some examples from our testing:

ref. img, input img, subtracted img



As shown, the pipeline effectively removes Galactic diffuse emission, and detects (most) transients at the moment.

Current Results

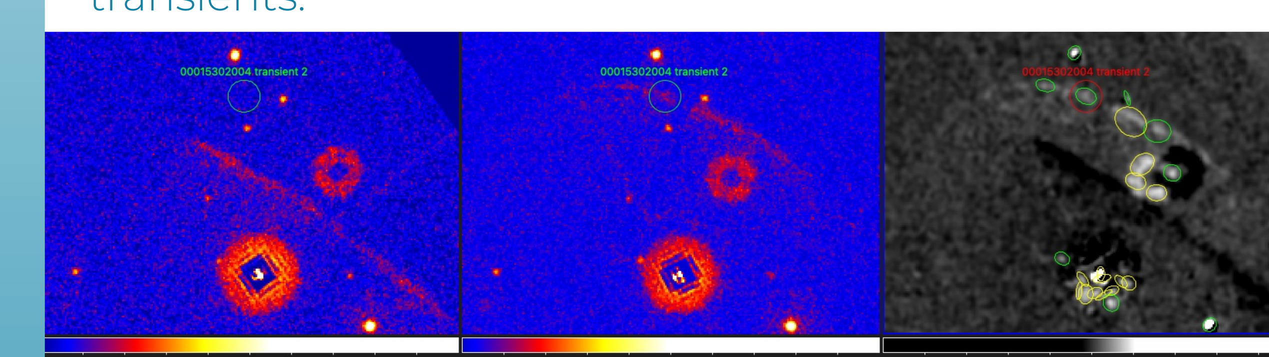
We are use a sample of 17 transient image sets for pipeline testing and calibration. The sample images consist of transients (mostly supernovae) from Swift's Optical/Ultraviolet Supernova Archive (SOUSA; Brown et al. 2014, Ap&SS, 354, 89). Our sample transients are located near galaxies, or are embedded within galactic diffuse emission, as these represent the environments we can expect kilonovae to reside in.

Currently, the pipeline detects ~53% (9/17) of the real test transients. (Can be increased to ~80%, but with high false-positive rate).

The false-positive rate is 0.70 sources per field.

Current and Future Work

Our goal is to maximize the fraction of our test (real) transients that the pipeline detects, while minimizing the rate of false/spurious transients reported. We also want to ensure that faint sources in galactic environments (a proxy for kilonovae) are consistently detected. We are testing what values of criteria and source detection (uvotdetect) parameters maximize our results, while minimizing the reporting of false transients.



The largest source of false-transients are image artifacts (example shown above). We are developing scripts to predict the location of image artifacts based on the position of bright sources and the roll angle, so we may effectively flag these out.

In the near future we will have the pipeline run automatically on gravitational-wave follow-up images, then Swift monitoring campaigns (e.g., weekly SMC tiling), and eventually all U-band observations, in order to detect serendipitous transients.