Spot the Difference: Searching for Cosmic Explosions

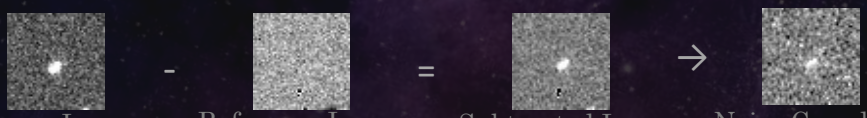
R.Cutter*, D.Steeghs, GOTO Collaboration†

Background

The detection of Gravitational Waves (GWs) in 2016[1] and the discovery of the first neutron star merger along with the richness of its Electromagnetic emission[2], has firmly delivered on the promises of multi-messenger astronomy. The Gravitational wave Optical Transient Observatory (GOTO) is optimised to find transient counterparts in a large sky area quickly. To achieve this, a high cadence survey is conducted ensuring a recent reference image is always available. Real time location of these transients is crucial, as phenomena, like kilonovae, associated with GWs last but a few days. Finding them quickly allows for more detailed investigation before they vanish.

GOTO under the Milkyway

GOTO has a wide field of view, with 4 telescopes it covers 20deg^2. With plans of adding an additional 12 we expect to see over 100000 sources per typical field. The goal is to promptly locate changes in these fields. With image subtraction, the process takes minutes. After comparing multiple image subtraction pipelines, we found a python implementation of ZOGY[3] to be quite promising. ZOGY is a statistical interpretation of image subtraction. By taking the Point Spread Function (PSF) and registration of two images showing the same field, a clean subtraction can be completed. ZOGY offers an additional step that conventional subtraction methods do not in the form of correlated noise matching. This step further cleans the subtraction by removing artefacts caused by noise and poor PSF matching.



Science Image — Reference Image — Subtracted Image — Noise Correlated

The transient stayed and the artefact was removed!

Caveats

ZOGY is critically dependant on a good PSF estimation and image registration. If the PSF is wrong, sources are convolved incorrectly. If the registration is poor sources are not subtracted from each other and instead will create 'butterflies' seen in figure 2.

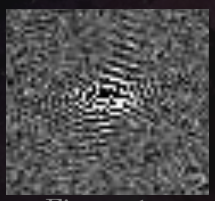
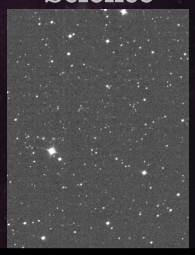


Figure 1
Poor PSF estimation

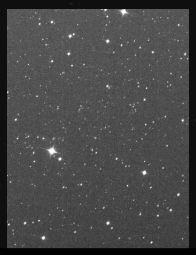
Figure 2
Poor image registration

Science



Spot the Difference

Reference



Spoilers!

While more computationally expensive than other methods, image subtraction offers more concrete extraction of transients. ZOGY in comparison to other pipelines, such as the LSST stack and HOTPANTS, has demonstrated key strengths, both in the noise correlation step and in speed. Images need to be subtracted within minutes to prevent the pipeline getting backed up with data and to allow for real time follow-up. ZOGY delivers on these requirements. For busy fields, more complex PSF models need to be established. Typically we find 4 transients per 5deg^2 in under 4 minutes; highlighting ZOGY's efficacy.

* R.Cutter@Warwick.ac.uk

† The GOTO collaboration is a collaboration between: Warwick University, Monash University, Leicester University, Armagh Observatory, NARIT, and Sheffield University, The University of Turku‡, and The University of Manchester‡
‡membership pending

[1] Abbott, B. P., et al. 2016. PRL, *116*(6), 061102.
[2] Abbott, B. P., et al. 2017 ApJ 848.2, L12.
[3] Zackay, B., et al. 2016 ApJ, *830*(1), 27.

https://goto-observatory.org

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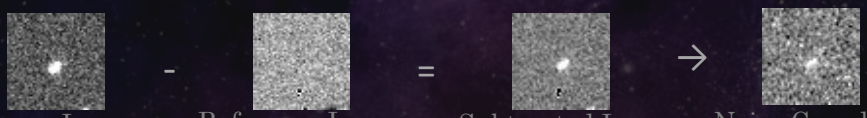

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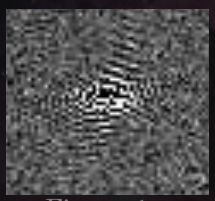

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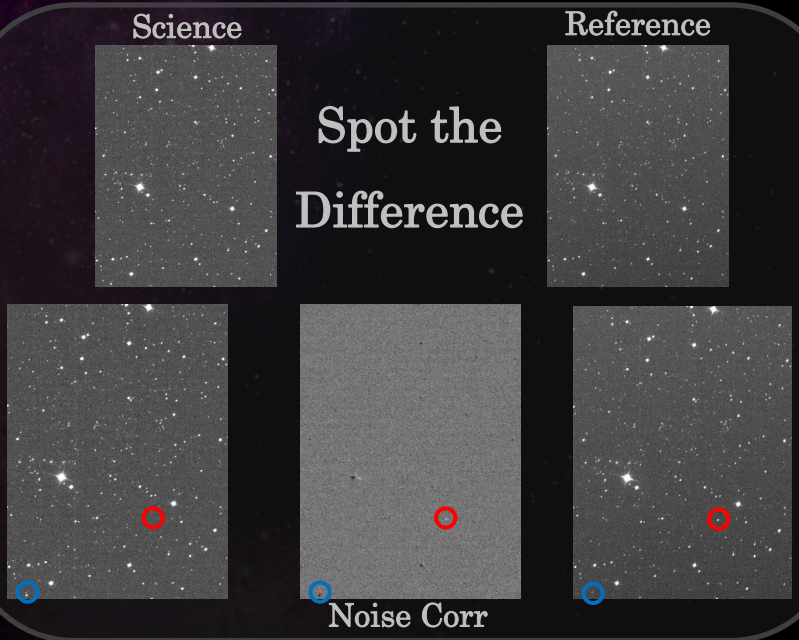

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