MW-Gaia STSM

Finding electromagnetic counterparts to gravitational wave events with Gaia

Dr Zuzanna Kostrzewa-Rutkowska from the Leiden University spent 5 days (25-29/11/2019) at the University of Cambridge thanks to a GP1 STSM grant to collaborate with Dr. Simon Hodgkin.

The main aim of this STSM visit was a study of the ESA-Gaia mission usage to search for electromagnetic counterparts to gravitational wave events. The recent discoveries of gravitational wave events and in one case also its electromagnetic counterpart allow us to study the Universe in a novel way. The increased sensitivity of the LIGO and Virgo detectors has opened new possibilities for serial detections of transient events from stellar remnant mergers. The gravitational wave sources are expected to have sky localisation up to a few hundred square degrees, thus Gaia as an all-sky multi-epoch photometric survey seems to be a perfect tool to search for these events and study them.

From September 2014 onwards new transients from Gaia have been made publicly available after manual vetting of candidate transients detected by the Gaia Science Alerts (GSA) team. To this end, AlertPipe - dedicated software for data processing, transient searching, and candidate filtering was employed. Accurate photometry and low-resolution spectroscopy should allow for a robust classification and reduce the rate of false positives. Hence, we have been planning to implement a new approach to detect candidate transients related to gravitational wave events within the Gaia Alerts stream.

The visit focused on finding the most robust way to discover the electromagnetic counterparts to gravitational wave events with Gaia. Although, the current system has allowed to find many interesting transients the specific of the gravitational wave events (rare events, fast and faint) requires a special approach to increase the sensitivity of the alerting system.

Work carried out during the visit:

- learning the structure of the current transient detection pipelines to discover transients in Gaia – we studied the design of AlertPipe, the order of data processing and filtering, the parameter space;
- discussion on implementation and testing of a new pipeline to detect electromagnetic counterparts in Gaia - using results from already performed tests on the Gaia data we discussed a possible approach to implement a new detection algorithm and possible difficulties (eg. increase in processing time, conflicts with current detection algorithm);
- study of potential false positives coming from the new detector - the new alert stream will increase the number of detected candidate transients, however, due to enhanced sensitivity, the number of possible false positives will also increase - we also considered the ways of filtering the data by fine tuning current filters or designing a standalone approach;
- discussion on features of alerted transient sample (including both electromagnetic counterpart candidates and false positives) - the new detections

will leave us with many candidate transients that we would like to study in details - we examined the possible usable features coming from the Gaia data.

Main achievements

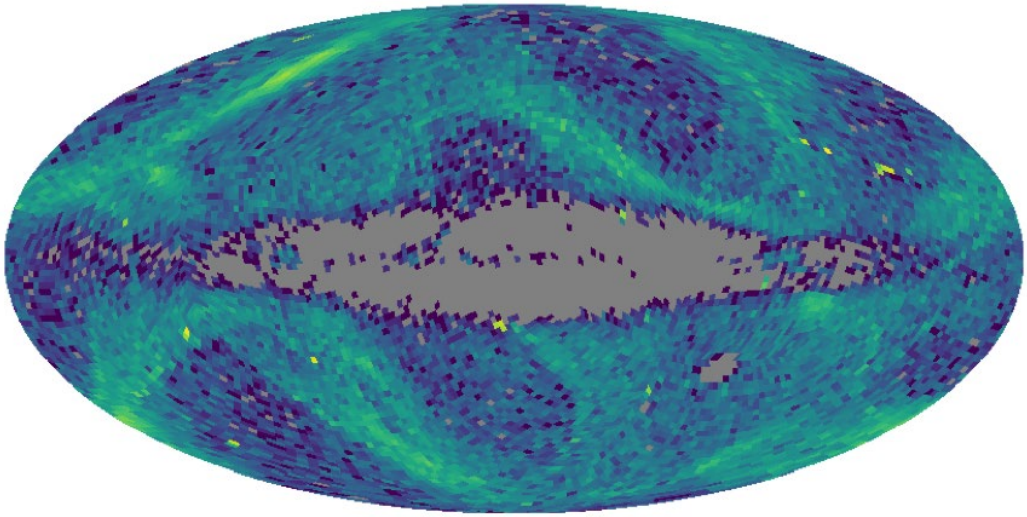
The proposed algorithm led to an increase of the number of Gaia-detected electromagnetic counterparts to gravitational wave events. The tests on the new detection algorithm and first attempts to make use of it for previous gravitational wave events were described in a publication:

- ✓ "Electromagnetic counterparts to gravitational wave events from Gaia" Z. Kostrzewa-Rutkowska, P.G. Jonker, S.T. Hodgkin et al. MNRAS 493, 3264 (2020) https://arxiv.org/abs/2002.04853

They planned the schedule of the new software implementation to be ready it as soon as possible when LIGO and Virgo are operational. It was envisaged that the new alert stream would be available early following year and then the validation process might start. They aimed to use the current system of filtering and eyeballing in order to scrutinise the obtained candidate transient sample. These tests outcomes were the basis of following steps.

The publication strategy for the new alert stream was also agreed.

The proposed algorithm to detect GW counterparts in the Gaia Alerts stream was implemented and tested in real time as can be seen in this Gaia image of the week: https://www.cosmos.esa.int/web/gaia/iow_20210825



The all-sky distribution of candidate transients detected during the year 2018 using the GaiaX algorithm (Kostrzewa-Rutkowska et al. 2020). The map resolution is HEALPix of nside 32. The plot is in Galactic coordinates.

Another paper from the collaboration has been recently accepted:

- ✓ "Preparing for Gaia Searches for Optical Counterparts of Gravitational Wave Events during O4" S. Biswas, Z. Kostrzewa-Rutkowska et al. MNRAS accepted (2023) https://arxiv.org/abs/2307.05212

The LIGO-Virgo-Kagra gravitational wave detectors started to observe in May 2023 and Gaia Alerts are planning to provide EM counterpart candidates during these observations.

On-going collaboration on implementation and testing of the new algorithms for searching for electromagnetic counterparts to gravitational wave events in the Gaia transient stream.