Individual External Collaborator Project Proposal

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WG(s) involved in the project:

TDA, Galaxies, Compact Objects

Scientific Project description (up to two pages, all included):

The vast majority of Ultraluminous X-ray sources (ULXs) are accreting at rates such that the accretion disc locally reaches the Eddington limit. As a result of detecting pulsations (Bachetti et al. 2014; Fuerst et al. 2017; Israel et al. 2017a, b; Carpano et al. 2018; Sathyaprakash et al. 2019), we know that ULXs likely contain a mixture of neutron stars and stellar mass black holes (Middleton & King 2017), although the exact proportion remains unknown and a major question in astronomy today. As some ULXs will one day evolve into gravitational wave (GW) sources (as the resulting compact object binary in-spirals: Marchant et al. 2017), determining the make-up of the ULX population will be important for understanding the GW event rate, as well as for testing our understanding of binary evolution. eROSITA's repeated scans will provide the most complete view of the X-ray sky and are ideal for detecting and studying the ULX population *en-masse*. Whilst eRASS might allow us to detect new neutron star ULXs for pulse searches (see the associated proposal by Prof. Tim Roberts), eRASS provides other exciting new routes to understanding the underlying population of ULXs.

ULX spectral population studies:

Observations of ULXs indicate a continuum of X-ray 'states' (see Middleton et al. 2015a) which are best explained by the super-critical model of Shakura & Sunyaev (1973) with the addition of radiative transfer and geometrical beaming in an optically thick wind-cone (e.g. Poutanen et al. 2007; King 2009). For a given population, the distribution of ULXs as a function of spectral hardness (hard flux/soft flux) should be uniform for a random (evenly-distributed) likelihood of inclinations, with any deviations from this resulting from the geometry of the accretion flow/outflow across the population. Such deviations should mostly result from geometrical beaming (collimation) and can be compared to theoretical, semi-analytical models of radiatively driven winds which are dependent on the mass accretion rate from the secondary star. These models are being developed in collaboration between my team and the Remeis observatory (recently supported by an AHEAD-funded visit by PI Middleton).

Whilst our latest ULX catalogue (see Earnshaw et al. 2018), indicates that the known ULX population out to 100 Mpc is around a few hundred, eRASS will likely discover new, previously undetected ULXs. The reasons for this are three-fold. Firstly, the current ULX catalogue is based on good but not complete coverage of local galaxies. In the DE consortium portion of the sky alone, 100 local galaxies not covered in the Earnshaw et al. (2018) ULX catalogue will be observed. Whilst most of these will be low surface-brightness dwarfs, the ULX rate is higher as a function of star formation per unit mass in such galaxies (Walton et al. 2011). Secondly, the ULX inflow is expected to precess due to a variety of effects (Lense-Thirring effect, radiative warps, tidal precession), all of which lead to a time-dependent view of a given source (spectrum and brightness). Precession periods can be very long (10s-100s of days), whilst the time at peak luminosity may be short (Dauser et al. 2017). We have been performing calculations based on population synthesis codes (Wiktorowicz et al. 2018) to determine how many observations are necessary to detect all of the Lense-Thirring precessing ULXs (to the 99% level of completion: Khan et al. in prep). This has indicated that many may spend much of their time edge-on and X-ray dim but ~8 observations - an excellent match to eRASS - are needed to obtain a complete census of the observable ULX population.

Methodology: As the ULX population is a mixed demographic (comprised of black holes and neutron stars), we should expect some form of skewed distribution in spectral hardness vs luminosity due to the fact that neutron stars should be more beamed than black holes in order to appear as ULXs (> 10^{39} erg/s) for the same mass transfer rate. In collaboration with members of the eROSITA consortium (T. Dauser, J. Wilms) we are currently developing a bespoke spectral model that includes the numerical effects of beaming calculated via ray-tracing. This is a first step towards a publicly available analytical model for spectral-fitting to ULXs and can be used to predict the distribution of ULX hardness versus luminosity. We will simulate our model for a range of underlying mass distributions (and assuming random inclinations); by making subsequent comparisons to the largest available population of ULXs through the combination of ERASS (which will sample the sky with high enough cadence to have an almost complete census of the population – see above) and our own catalogue (Earnshaw et al. 2018), we will thereby constrain the compatible range of NS-ULXs within the observed population.

Required data, supporting datasets and/or tools:

Access to eRASS1, NRTA and eROSITA simulation software. Together with a student, Dr Middleton will contribute to the ULX search by providing selection criteria for ULX, updates on the ULX catalogue, and contribute the models necessary for the interpretation of the ULX spectra and their variability, as well as the expertise for the modeling of the ULX population as a whole.

List of Potential Collaborators within eROSITA_DE

Arne Rau
Joern Wilms
Thomas Dauser
Stefania Carpano
Chandreyee Maitra

There are also connections to work done in the nearby galaxy group (Frank Haberl and the collaborator proposal on X-rays from nearby galaxies)

Expected Outcome

The 2019/2020 year of the EC status corresponds to the first year of the eRASS survey. This year will be devoted to refining the ULX detection parameters , which we derived using XMM data and simulations, with the real data. This will result in a first publication that will be devoted to verifying the population and variability models with the initial data.

Expected duration of the project

One year. Future EC status requests are foreseen as the full science potential of this project will only be realized with access to the final, full eRASS products. Initial access to the data is required, however, in order to formulate and refine the trigger criteria and transient characterization.

Once the initial work is done as described above, the work in the following years will go towards the characterization of the ULX variability and ULX in nearby galaxies, in expectation of the full eRASS.