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Extragalactic panel
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Extragalactic counterparts of serendipitous X-ray transients

Abstract

Motivated by the discovery of two X-ray transients in the Chandra Deep Field-South, with characteristics suggestive of magnetar remnants from neutron star mergers, we made an exhaustive search for similar transients in the Chandra archive which produced 10 further viable extragalactic candidates. Archival imaging (DSS, PanSTARRS, DES, WISE) has allowed us to pinpoint tentative host galaxies for 6 candidates. For the remaining 4, we only have shallow or moderate depth photometric upper limits. We propose multi-band photometry with the MPE 2.2m GROND instrument for the four candidates which lack optical/NIR counterparts, as well as three candidates which lack NIR photometric constraints, in order to gain insight into the properties of their hosts, as well as their possible progenitors. Characterizing the host galaxies of this new X-ray transient population is a crucial step to understand the emission mechanisms of this new X-ray transient population and a possible relation with sGRBs.

Observing Blocks

Instrument/Telescope	Req. time	Min. time	1^{st} Option	2^{nd} Option
GROND/MPG 2.2-m	1 nights	1 nights	September Any	August Any

CoIs

Name	Institution	e-mail	Observer?
Franz Bauer	PUC	fbauer@astro.puc.cl	True

Status of the project

- Past nights: 0
- Future nights: 3
- Long term: False
- Large program: False

- Thesis: False

List of Targets

ID	RA	DEC	Mag
IdY118	03:01:04.14	-77:52:51.42	r>23.1
IdY108	01:03:44.54	-21:48:45.79	r>23.7
IdY97	06:00:01.08	-52:42:54.07	r>23
Id41	05:07:06.76	-31:52:11.28	r>23.6
IdY60	21:12:30.350	-63:29:56.904	r>23.2
Id36	00:46:48.66	-11:50:51.54	r=21.4
Id37	00:47:06.01	-11:48:56.20	r=21.7

SCIENTIFIC AIM AND RATIONALE

The near simultaneous detection of the neutron star merger event GW170817 (by LIGO/VIRGO) and GRB170817A (by Fermi/INTEGRAL) rapidly ushered in the multi-messenger astronomy era [1], and in the next days and weeks ∼70 telescopes around the world caught glimpses of an electromagnetic counterpart and characterization of the host galaxy. This detection answered several open questions: *i*) binary systems of neutron stars emit gravitational waves; *ii*) Fermi and INTEGRAL detected a short gamma-ray burst (sGRB) associated with GW170817 [4]; *iii*) during the next hours and days multiple teams detected for the first time clear and unambiguous signs of kilonova (Kn) emission at UV/opt/NIR wavelengths ([2], [7], [8]); and *iv*) ∼10 days after the merger, X-ray and radio telescopes detected the delayed afterglow emission, which helped constrain the environment of the binary ([11]), as well as its geometry and jet structure. Nevertheless, many questions remain to be answered in the coming years and decades.

In parallel, Bauer et al. (2017;[3]) and Xue et al. (2019;[13]) identified unusual fast X-ray transients (FXRTs), denoted "XT1" and "XT2", respectively, from the 7 Ms Chandra Deep Field-South (CDF-S) dataset. Constraints on XT1 imply an origin either as an off-axis sGRB or a tidal disruption event (TDE) around an intermediate-mass black hole (IMBH), while XT2 exhibits properties suggesting a magnetar wind origin related to the merger of neutron stars, similar to GRB 160821B (Troja et al. 2019). Such events were predicted by Zhang (2013), who proposed a type of GRB-less X-ray transient resulting from the merger of neutron stars considering a rapidly spinning magnetar-like remnant for lines of sight off-axis from the sGRB jet. Following from this, Sun et al. (2017; [10]) simulated X-ray emission from neutron star mergers considering possible magnetar remnants and different observer viewing angles, finding that the light curve shapes depend strongly on viewing angle, magnetar spin-down time, "transparent" (optical depth, $\tau>1$) time, and collapse time. More recently, several efforts were made to specifically explain XT2 and its possible massive magnetar progenitor (e.g., Lu et al. 2019 [5]; Xiao et al. 2019 [12]), while XT1 has been proposed to come from a magnetar remnant of a neutron star merger viewed at a larger off-axis angle [10].

As such, FXRTs like XT1 and XT2 appear to share some common progenitor traits with GW 170817-like events and sGRBs, and it is thus important to understand how all of these transients might relate to each other, particularly given the ongoing LIGO/VIRGO campaign (O3) and the modest sample of well-characterized sGRBs. Unfortunately, a sample of only two extragalactic FXRTs is insufficient to build a definitive scenario for how neutron star mergers relate to FXRT emission properties. The discovery of more and/or stricter limits on the number density and properties of such extragalactic FXRTs can thus place valuable constraints on the unknown electromagnetic properties of sGRBs and off-axis neutron star mergers. We recently expanded the search for XT-like transients (Quirola et al. 2019, in prep), narrowing down a sample of ∼220,000 Chandra sources to arrive at **a sample of 10 new viable extragalactic FXRT candidates (see Figs. 1 and 2).** Each is securely detected by *Chandra* (30–155 X-ray counts) and shows $>3\sigma$ variability within 5–10 ks (Fig. 2). Cross-matching to optical/NIR archival imaging, six (IdY59, IdY60, IdY84, Id36, Id37, Id44) have R=19.8–23.1 counterparts (estimated $z_{\rm ph}\approx1.4\pm0.8$, 0.9 ± 0.4 and 0.4 ± 0.1 for IdY59, IdY60 and IdY84, respectively; see Figs. 1), while four only have upper limits (IdY97, IdY108, IdY118, IdY41).

We propose multi-band photometry with the MPE 2.2m GROND instrument for the four candidates which lack optical/NIR counterparts (see Figs. 1), as well as three candidates (IdY60, Id36, and Id37) which lack NIR photometric constraints, in order to gain insight into the properties of their hosts, as well as their possible progenitors. While the sample is admittedly small, it will increase the overall number of known extragalactic FXRTs by a factor of 6 and serves as an important pilot program for understanding this emergent transient

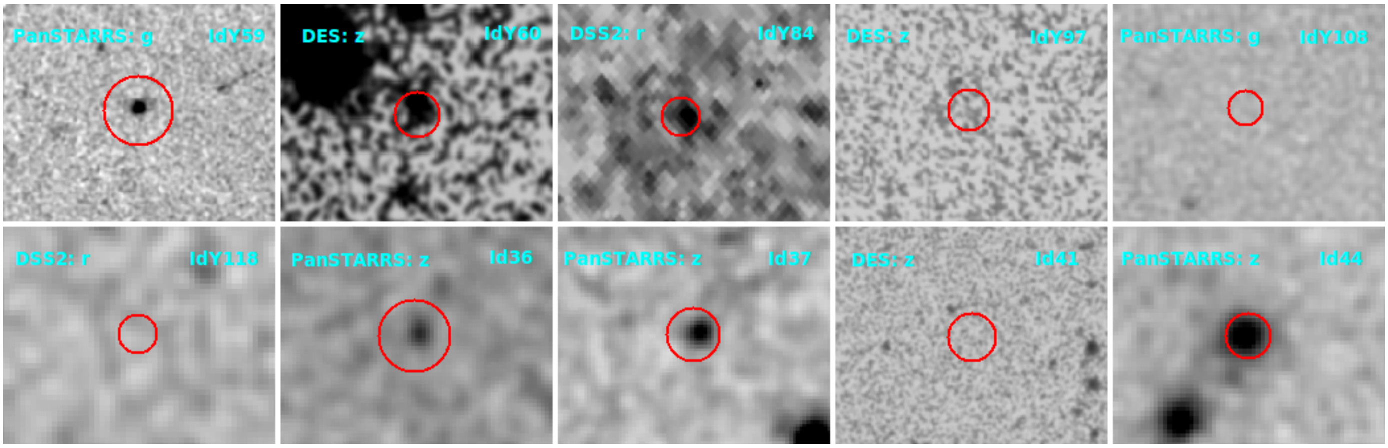

Figure 1: Optical (DES, PanSTARRS, DSS2) images of the FXRT fields. Red circles denote 3σ Chandra errors in astrometric position, while telescope+filter and FXRT ID name are shown in the left and right corners, respectively. Specifically, IdY97 is undetected in DES (g >25.0, r >24.0, z >23.0), IdY108 is undetected in PanSTARRS/DES (g >22.2, r >24.2, z >24.0), IdY118 is undetected in DSS2 (b >21, r >20.5), and Id41 is undetected in DES (r >23.6).

#	Name	IdObj	RA	DEC	Opt/count.	Mag
1	IdY59	5814	334.80906	-18.85415	PanStarrs	r=19.801±0.025
2	IdY60	5885	318.12646	-63.49914	DES	r=23.126±0.142
3	IdY84	9841	175.00503	-31.91743	DES	r=21.10±0.03
4	IdY97	12264	90.00452	-52.71502	DES	r>23.0
5	IdY108	13454	15.93559	-21.81272	DES	r>23.7
6	IdY118	15113	45.26725	-77.88095	DECam/NSC	r>23.1
7	Id36	2565	11.70274	-11.84765	PanSTARRS	r=21.35±0.25
8	Id37	2565	11.77505	-11.81561	PanSTARRS	r=21.66±0.32
9	Id41	4062	76.77816	-31.86980	DES	r>23.6
10	Id44	5814	334.78498	-18.74922	PanSTARRS	r=19.893±0.057

Table 1: FXRT candidates obtained from Chandra Source Catalog for this proposal, as well as their magnitud (or upper limits) using optical catalogs.

population and their hosts. The results from this program are critical to inform future follow-up as we expand our search to other archives to build up further statistics.

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References

[1] Abbott et al. 2017a, ApJ, 848(2), L12.

[2] Abbott et al. 2017b, ApJ, 850(2), L39.

[3] Bauer et al. 2017, MNRAS, 67(4), 4841–4857.

[4] Goldstein et al. 2017, ApJ, 848(2), L14.

[5] Lu et al. 2019, arXiv e-prints.

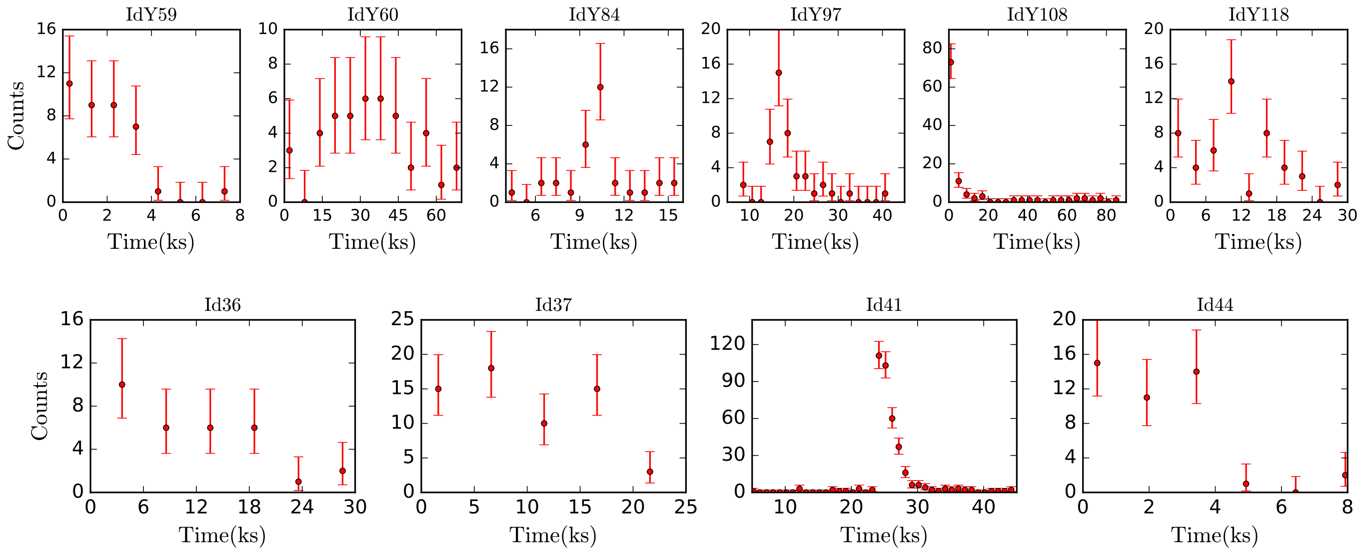

Figure 2: X-ray light curves of the FXRTs; note that the X-ray backgrounds have not been subtracted from the light curves.

[6] Pandey et al. 2019, MNRAS, 485(4), 5294-5318.

[7] Pian et al. 2017, Nature, 551(7678), 67–70.

[8] Smartt et al. 2017, Nature, 551(7678), 75–79.

[9] Sun et al. 2017, ApJ, 835(1), L7.

[10] Sun et al. 2019, arXiv e-prints.

[11] Troja et al. 2017, Nature, 551(7678), 71–74.

[12] Xiao et al. 2019, ApJL, 879(1), L7.

[13] Xue et al. 2019, Nature, 568(7751), 198–201.

[14] Yang et al. 2019, MNRAS, 487, 4721-4736.

[15] Zhang 2013, ApJ, 763(1), L22.

CURRENT STATUS OF THE PROJECT

This follow-up will form an important part of J. Quirola's PhD project, where the main goal is to identify and characterize fast extragalactic X-ray transients (FXRTs), possibly related with merger of neutron stars, hidden in the Chandra and XMM-Newton archives. Yang et al. (2019) developed a simple algorithm to find "XT"-like events in X-ray data, and applied it to 19 Ms of *Chandra* observations from six relatively uniform survey fields with deep ancillary data. While XT1 and XT2 were easily "rediscovered", they found no additional viable candidates and placed stronger limits on the number densities. We recently expanded this search, applying both the Yang et al. algorithm and a matched filter method taking into account the light curve shape of XT1 and XT2. Our FXRT sample was selected by analyzing ~220,000 sources with $|b|>10°$ ("extragalactic") from the Chandra Data Release 2.0 (equivalent to ~200 Ms) using the above methods and rejecting stellar high-Galactic latitude stars via multi-wavelength cross-matching (e.g. from DES, PanSTARRS, VHS, AllWISE, Gaia catalogs) and long-term light curve analysis. This resulted in 10 viable extragalactic FXRT candidates. This observational proposal consists of obtaining imaging for the 4 FXRTs which lack optical/NIR counterparts in several archival catalogs, and 3 FXRTs with incomplete NIR photometry. The project has four different steps: *i*) find X-ray transients and X-ray archive; *ii*) characterize their X-ray (and if possible multi-wavelength) properties; *iii*) study in detail their host galaxies; and *iv*) compare with well-known transients such as short gamma-ray bursts, new LIGO/VIRGO detections, etc. These observations form a crucial portion of the project; in order to enable the study and characterization of the host galaxies, it is necessary to obtain photometric and spectroscopy information of them.

The related experience of the authors began with the very first discovery of this class of X-ray transients roughly 2 years ago. The list of relevant refereed publications detailing our involvement is summarized as follows:

1. Yang, G., Brandt, W. N., Zhu, S. F., et al. (2019) "Searching for fast extragalactic X-ray transients in Chandra surveys," MNRAS, 487, 4721-4736.

2. H., Li, Y., Zhang, B., et al. (2019) "A unified binary neutron star merger magnetar model for the Chandra X-ray transients CDF-S XT1 and XT2," arXiv.

3. Xue, Y. Q., Zheng, X. C., Li, Y., et al. (2019) "A magnetar-powered X-ray transient as the aftermath of a binary neutron-star merger," Nature, 568, 198-201.

4. Kim, S., Schulze, S., Resmi, L., et al. (2017) "ALMA and GMRT Constraints on the Off-axis Gamma-Ray Burst 170817A from the Binary Neutron Star Merger GW170817," ApJL, 850, L21.

5. Smartt, S. J., Chen, T.-W., Jerkstrand, A., et al. (2017) "A kilonova as the electromagnetic counterpart to a gravitational-wave source," Natur, 551, 75-79.

6. Abbott, B. P., Abbott, R., Abbott, T. D., et al. (2017) "Multi-messenger Observations of a Binary Neutron Star Merger," ApJL, 848, L12.

7. Bauer, F. E., Treister, E., Schawinski, K., et al. (2017) "A new, faint population of X-ray transients," MNRAS, 467, 4841-4857.

TECHNICAL DESCRIPTION

Our goals are to identify any nearby counterparts brighter than $R \sim 26$ and place color/redshift constraints on them. Our choice of depth here is motivated by the fact that while the counterpart of XT1 [m_{F606W}=27.51, m_{F125W}=27.3, z_{ph}=2.23 (0.39–3.21 @95% interval)] falls 1.5 mags below this limit, the counterparts of XT2 (m_{F606W}=25.35, m_{F140W}=23.85, z_{sp}=0.738) and our 6 other FXRTs lie above it. We only have weak redshift constraints ($z_{\rm ph}\sim$0.3–2.2) or galaxy types ($B-R\sim$0.4–2.0) for the 6 FXRTs with counterparts, which are comparable to host galaxies of CDF-S XT1 and XT2 ($B-R\sim$0.2–1.0, respectively). Therefore, we can anticipate that our targets will have photometry consistent with similarly red host galaxies.

MPE 2.2m GROND imaging is requested to identify the host galaxies of the four FXRTs (IdY97, IdY108, IdY118 and Id41) which lack counterparts to $r>$23.0–23.7, as well as NIR imaging for IdY60, Id36, and Id37. Due to its unique features, especially simultaneous imaging in different filter-bands, GROND is essential to efficiently characterize and study our FXRT candidate hosts and to measure their spectral energy distribution.

For the 4 FXRTs which lack counterparts, we request 2.2 hours per target to observe the four targets including overheads (total request 8.8 hr), while for the 3 FXRTs in need of NIR imaging, we request 28 min each (total request 1.5 hr). We expect good quality photometry ($\pm$4 days from New Moon and airmass<1.5, with nominal La Silla extinction coefficients) under a seeing of $\sim 1.0''$, enabling an imaging depth of $r'\approx$25.5 (in the case of a better seeing of $\sim$0.6”, we can probe to $r'\sim$6.5 (using table from http://www.mpe.mpg.de/ jcg/GROND/operations.html). In the other filters, the time requested per target will be sufficient to probe magnitudes of $g<$25.0, $i<$25.5, $z<$25.1, $J<$22.6, $H<$22.1 and $K<$21.4, or approximately XT2-like hosts. In total, we request 10.3 hrs, or 1 full night.

All of our targets will be optimally visible from La Silla in September 2020. Most will also be visible in August, while only a subset (3-4) will be visible earlier than this at airmass $\lesssim$2.