# Report of the Chandra Time Domain Working Group

**Chairs:**

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|---|---|---|
| Jon M. Miller | University of Michigan | jonmm@umich.edu |
| Rodolfo Montez | SAO | rodolfo.montez@cfa.harvard.edu |

**Members:**

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| Brad Cenko | NASA/GSFC |
| George Chartas | College of Charleston |
| Nathalie Degenaar | University of Amsterdam |
| Wen-fai Fong | Northwestern University |
| Daryl Haggard | McGill University |
| Thomas Maccarone | Texas Tech University |
| Rachel Osten | Space Telescope Science Institute |
| David Pooley | Trinity University |
| Enrico Ramirez-Ruiz | University of California, Santa Cruz |
| Nanda Rea | Institute of Space Sciences (CSIC) Barcelona |

**Executive Summary**

The TDWG was convened by the Chandra Director, Patrick Slane, with the charge of reviewing and evaluating how Chandra serves the community of users that make time-domain and time-constrained observations. The TDWG engaged in this with a clear view of three key facts: (1) Chandra has a growing number of observing constraints related to spacecraft health and safety, (2) time-domain and time-constrained observations often happen at the expense of other programs (or at least their scheduling) and adds burdens to Chandra personnel, and (3) the field is on the cusp of a rapid acceleration in the number of detected transient events and multi-wavelength efforts that will benefit from Chandra observations.

The TDWG examined proposal statistics and observing statistics, talked with our communities, and discussed several key questions at some length. The data, discussions, and recommendations are presented in more detail in the report that follows. The key points and recommendations from our efforts are as follows: (1) Chandra continues to do an excellent job of serving the time-domain user community, even as the mission ages, and despite difficult circumstances (COVID-19, etc.); (2) retaining proprietary rights for Chandra observations - including time-domain observations - is likely key to achieving optimal science returns, and may also serve the goal of promoting diversity, equity, and inclusion within the user community; (3) in the exceptional case of gravitational wave follow-ups, it may be possible to solicit white papers and to convene a panel to decide on an observing strategy, later inviting users to propose to use a shared pool of funding; this may serve as a test-case for future efforts in other science areas.

To assist the mission and the CDO, the TDWG has attempted to compile an exhaustive list of use cases where Chandra adds unique information, and to identify the nature of related observations (e.g., TOO, DDT, time-constrained, etc.). This table is appended at the end of our report.

## 1. Review of Proposal Data and Observing Data

The working group gathered and scrutinized proposal data and observation data from prior Chandra cycles. Specifically, we examined the time requested in time-constrained categories (TOO, DDT, and observations fixed in time for any reason) versus the time available/awarded, as a function of scientific category, requested response time, and as a function of observing cycle. As the mission has progressed, observatory constraints have become a key factor in approving and scheduling time-constrained observations, so we also examined the number of constraints requested versus the number available, again across scientific categories, response times, and observing cycles. Please see Tables 1-4, and Figures 1-4. Please also see Appendix 1 for a set of unique use cases, and the categories of time-constrained observations that they may require.

Within the limits of the data, we find that the scientific areas that participate in time-constrained observations are all served well by current Chandra policies and procedures. The process appears to be equitable in that proposal success is proportional to proposal pressure (e.g., the fraction of time approved relative to time available appears to be relatively consistent). In some scientific categories, there are now fewer requests for time-constrained Chandra observations than in earlier mission cycles; in these areas, it is possible that a proposal may not have been awarded in recent cycles, but this appears to be consistent with small numbers and expected variations. There is no clear evidence that any scientific area is “shut out” by current policies and procedures.

Follow-up observations to identify X-ray counterparts to gravitational wave events mark a unique use case for Chandra, with growing importance. The Director noted for the TDWG that this is a category that poses specific challenges for the CDO and review panels, in that it is difficult to distinguish between several very similar requests. The TDWG looked at this issue at some length, and discussed it in detail. It is clear that difficulties posed by GW transients are not unique to this scientific area, but they are the most extreme and immediate. We suggest that the Chandra mission and the GW community could be better served if a unified observing scheme yielding immediately public data is adopted through a white paper process, with users proposing to the peer review to use an allocation of funding for specific analysis goals. For example, the funding could be an extension of the archival funding category. In the future, this process could be adapted to other categories, factoring in lessons learned from this effort.

The TDWG also attempted to examine how well the time-constrained community understands the rules and policies that affect the evaluation of their proposals, and the execution of their observations. In general, the documentation is excellent, and there appears to be a strong understanding within the community. Nevertheless, we feel that it is important to ensure that the goals of diversity, equity, and inclusion are highly prioritized. It is possible that the barriers to entry are higher in this category of Chandra observations, relative to others. Chandra workshops and presentations at large meetings are an effective tool for communication to the users, and we suggest that sessions dedicated to time-domain astronomy with Chandra (e.g., overviews of scheduling constraints, rules, and guidelines for proposal preparation) that reach out to underrepresented communities could have a positive impact.

### Recommendations:

- While mission operations were largely beyond the purview of this committee, it is nonetheless clear the mission works hard to maximize capabilities for time-domain observations (e.g., response time, target-of-opportunity interrupts, coordinated observations) and to clearly communicate opportunities and challenges to the community. If additional resources would help to augment (or even maintain at the current level) these capabilities in future cycles, the TDWG urges the mission to request such support in upcoming NASA reviews.
- We recommend that GW transient follow-ups be handled in a special manner, with the goals of (1) allowing the CDO to focus on the mission and (2) ensuring that science drives observations and allocations for the GW community. The observing strategy for a suitable (e.g., double neutron star), localized GW event could be decided *in advance* by an anonymous peer review of white papers from the community. Individual PIs and teams could then propose for funding to analyze the related data, or to pursue related theoretical investigations, in each cycle. The funding could be an augmentation to the archival category, but there are likely many avenues and specifics of this kind are best left to the CDO.
- We recommend that the mission clarify to proposers and proposal reviewers that there should be no advantage (e.g. no augmentation in score) when proposers request that data be made public immediately. There are numerous reasons why proposers may require a proprietary period, not least because a student, postdoctoral researcher, or other early career scientist is involved.
- We recommend that the mission plan sessions within workshops and larger astronomy meetings to focus on how users can make time-domain observations with Chandra (see below). We encourage the mission to make appropriate efforts to engage communities that are underrepresented within the field for these sessions, with the goal of diversifying the set of users that make time-domain observations.
- The TDWG recognizes that the DDT program places a burden on the CDO, but the flexibility this category provides to the mission is potentially very important to opening new fields and realizing special scientific opportunities. We recommend that this category be retained and kept vibrant.

### 2. Is there any scope for the CXC to rapidly report on some aspects of a time-domain or time-constrained observation? What are the impacts on data rights, individual users, the user community, and the science in question?

There are certain circumstances that require the fast release of some of the information that Chandra might provide. These circumstances are always related to transient events and the need for a fast circulation of important data that might allow a larger community to react quickly. A clear example is the organization of large multi-band campaigns, especially on very short reaction times, when often crucial data on specific events are missing because facilities could not be prompted in-time. Fast multi-band follow-up from as many facilities as possible to enhance the global scientific return of a transient event can only be achieved by releasing crucial info to a large community on a short timescale. For those specific topics the fast Chandra release of any possible information that might allow a better and faster planning of other facilities should be envisaged. Given the exquisite Chandra angular resolution and effective area, the information that might be disclosed are mainly: *accurate X-ray positions, and X-ray fluxes.*

The impact on the data rights of the individual users should be left to the proposal PI. The main factors to consider likely include: (1) the specific science case of the data where the transient event is detected, (2) the nature of the discovery: serendipitous or from a pointed TOO or DDT, (3) the scientific expertise of the proposing group wrt the observed transient event, (4) the presence of students and young postdocs in the PI group. Each of these things, and a host of other considerations, may factor into PI decisions.

The impact of rapid information release on the community is undoubtedly very significant. For discoveries arising from dedicated TOOs and DDTs, in many circumstances the fast release of the accurate X-ray position and flux can help the multiwavelength community to better tune their observations, to choose the correct strategy, and react more rapidly.. For serendipitous events detected in GO programs, this approach will increase the number of transient detections, pushing PIs of accepted proposals to have a first look at the data quickly after the observation is performed.

**Recommendations (valid for TOO, DDT or GO observations where a transient is found):**

- The committee perceives many difficulties in balancing the need of proprietary periods with the importance of having certain information released quickly to a wider community. The PIs of all proposals should be encouraged to search in their data on possible field transients and to rapidly report results, or to grant permission to the CDO (or any facilitator within the CXC) to search for the data as quickly as possible. The PIs of time-domain proposals should be encouraged to search their data and to rapidly report accurate positions and fluxes from their targeted transient event.
- The committee recommends that any CDO or CXC assistance be accepted through an "opt-in" strategy. Such a policy would allow for serendipitous transients to be reported quickly in order to facilitate follow-up, without jeopardizing PI science. The committee recommends placing the opt-in/opt-out question on the observation parameter forms issued after the proposals are reviewed, rather than on the proposal forms, in order to ensure that this does not unduly affect panel decisions.

### 3. What are the scientific impacts of exclusive-use periods and who is impacted positively or negatively by the reduction or elimination of exclusive-use periods?

The working group has identified several specific negative impacts that could occur if proprietary periods were eliminated. The committee suggests that caution be exercised in eliminating or reducing proprietary rights, but that a system like that recommended for GW follow-up observations could be implemented in other special cases.

The time pressure that would result from making data public immediately could cause undue stress and present obstacles both for junior scientists (including students) and for faculty/senior scientists who may be untenured, have a small group, or are trying to break into a new field. That stress could lead to hasty analyses and poor science. At a time when mental health and work-life balance are finally becoming part of the conversation in astronomy, creating additional stress would seem to be a step in the wrong direction.

On the positive side, having no proprietary period would allow for quick results to be published and independently verified, which may help some fields to progress. It may also help to plan future monitoring of interesting targets with other facilities.

The TDWG suggests that a one-size-fits-all approach is unlikely to work. The CDO may wish to establish standards and/or a process through which subfields could communicate a consensus view in favor of eliminating proprietary periods. If a white paper process is developed and a common set of observations are made for a period, it may be important to evaluate the efficacy of that step and a means of reversing it if the outcomes are not positive.

**Recommendations:**

- The committee strongly recommends retaining exclusive use periods. The committee also recommends that the CXC strongly (but informally) encourage data sharing for groups that wish to pursue independent investigations with the same data set (e.g. if a team is only looking at diffuse emission from a galaxy, another team could simultaneously analyze the point sources).
- If the CDO agrees that the proprietary or public nature of a program should have no bearing on its approval, we urge that this be clearly communicated to proposers and reviewers.

### 4. How can Chandra best enable time-domain subfields and their early-career scientists?

The TDWG discussed this topic at length, and in detail. How leaders are cultivated, and how they are encouraged to lead, will determine the advancement of the mission. The consensus that emerged is that Chandra is in a position to positively affect the careers of scientists that are just getting started, but that meaningful support may require more than simply opening doors. Training and funding opportunities that are specifically targeted at early career scientists have the potential to increase participation in the time-domain astronomy that is unique to Chandra, and important to many fields. The TDWG is particularly enthusiastic for efforts that can bring scientists who primarily work in other wavelengths into the Chandra user's community, and efforts that can improve the diversity of the Chandra time-domain community.

**Recommendations:**

- **Training:** While it is acknowledged that the CXC provides several training opportunities for the community, TOO proposals are a special brand of proposal. The committee recommends that the CXC explore training workshops for how to write TOO proposals and all of the necessary components. This type of meeting could work virtually, or be a session at an AAS meeting (in which early-career attendance is typically very large). This could be performed in conjunction with overall leadership training of early-career scientists, in concordance with NASA's overall mission to diversify the pool of PIs.

- **Specific funding calls:** Funding is essential for early career scientists and can often help to level the playing field. One way to broaden the base of early-career researchers engaged in *Chandra* data is to provide funding for use of archival data, specifically for early-career researchers. This could be even further extended: for gravitational waves, if proprietary periods are waived on certain proposals perhaps a pool of funding could be available that early-career researchers could also apply for to engage in publicly-available data. There could also be additional funding provided to student PI's (akin to the NRAO Student Observing Support program).

- **Co-PI's:** It is crucial to truly engage students in high-impact time-domain science. It is difficult to do that without allowing students to PI proposals. By serving as PI on a proposal, the student will be able to learn crucial decision-making on when and how to trigger observations, and be the first point of contact when the data are available. However, we recognize that for highly-competitive science areas that require large team efforts (e.g., gravitational wave astronomy), it is often impossible to attribute the work to a *singular* lead, and instead the leadership load is shared between a junior and senior person (e.g., student and advisor). Following the *HST* model of having an option for co-PI's could open doors for junior researchers who might not ever get to PI time-domain proposals, while also allowing senior PI's to be in the loop. This option will also allow for due credit and name recognition, both of which are crucial in this field.

Table 1. Number of all proposals by category for Cycles 10-22.

| **Category (Cycles 10-22)** | **N_prop** | **N_approved** | **N_observed** |
|---|---|---|---|
| ACTIVE GALAXIES AND QUASARS | 1420 | 406 (28.6%) | 371 (91.4%) |
| SN SNR AND ISOLATED NS | 1129 | 425 (37.6%) | 376 (88.5%) |
| CLUSTERS OF GALAXIES | 978 | 246 (25.2%) | 246 (100.0%) |
| STARS AND WD | 919 | 286 (31.1%) | 276 (96.5%) |
| BH AND NS BINARIES | 900 | 403 (44.8%) | 301 (74.7%) |
| NORMAL GALAXIES: X-RAY POPULATIONS | 338 | 99 (29.3%) | 97 (98.0%) |
| NORMAL GALAXIES: DIFFUSE EMISSION | 226 | 50 (22.1%) | 48 (96.0%) |
| WD BINARIES AND CV | 208 | 69 (33.2%) | 68 (98.6%) |
| EXTRAGALACTIC DIFFUSE EMISSION AND SURVEYS | 150 | 43 (28.7%) | 41 (95.3%) |
| GALACTIC DIFFUSE EMISSION AND SURVEYS | 98 | 31 (31.6%) | 27 (87.1%) |
| SOLAR SYSTEM AND EXOPLANETS | 35 | 16 (45.7%) | 15 (93.8%) |
| GRAVITATIONAL WAVE EVENT | 8 | 4 (50.0%) | 3 (75.0%) |
| **All Totals** | **6409** | **2078 (32.4%)** | **1869 (89.9%)** |

Table 2. Number of TOO proposals by category for Cycles 10-22.

| **Category (Cycles 10-22)** | **N_prop** | **N_approved** | **N_observed** |
|---|---|---|---|
| BH AND NS BINARIES | 291 | 178 (61.2%) | 80 (44.9%) |
| SN, SNR AND ISOLATED NS | 252 | 129 (51.2%) | 82 (63.6%) |
| ACTIVE GALAXIES AND QUASARS | 85 | 45 (52.9%) | 12 (26.7%) |
| WD BINARIES AND CV | 39 | 9 (23.1%) | 8 (88.9%) |
| STARS AND WD | 23 | 16 (69.6%) | 7 (43.8%) |
| EXTRAGALACTIC DIFFUSE EMISSION AND SURVEYS | 16 | 11 (68.8%) | 9 (81.8%) |
| GALACTIC DIFFUSE EMISSION AND SURVEYS | 10 | 8 (80.0%) | 4 (50.0%) |
| SOLAR SYSTEM AND EXOPLANETS | 7 | 3 (42.9%) | 2 (66.7%) |
| GRAVITATIONAL WAVE EVENT | 4 | 2 (50.0%) | 1 (50.0%) |

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|---|---|---|---|
| NORMAL GALAXIES: DIFFUSE EMISSION | 3 | 2 (66.7%) | 0 (0.0%) |
| NORMAL GALAXIES: X-RAY POPULATIONS | 3 | 2 (66.7%) | 0 (0.0%) |
| **TOO Totals** | **733** | **405 (55.3%)** | **205 (50.6%)** |

Table 3. Number of DDT proposals by category for Cycles 10-22.

| **Category (Cycles 10-22)** | **N_prop** | **N_approved** | **N_observed** |
|---|---|---|---|
| BH AND NS BINARIES | 121 | 68 (56.2%) | 67 (98.5%) |
| SN, SNR AND ISOLATED NS | 94 | 62 (66.0%) | 62 (100.0%) |
| ACTIVE GALAXIES AND QUASARS | 53 | 35 (66.0%) | 34 (97.1%) |
| WD BINARIES AND CV | 29 | 18 (62.1%) | 18 (100.0%) |
| STARS AND WD | 20 | 13 (65.0%) | 12 (92.3%) |
| NORMAL GALAXIES: X-RAY POPULATIONS | 12 | 2 (16.7%) | 2 (100.0%) |
| CLUSTERS OF GALAXIES | 8 | 1 (12.5%) | 1 (100.0%) |
| SOLAR SYSTEM AND EXOPLANETS | 6 | 5 (83.3%) | 5 (100.0%) |
| NORMAL GALAXIES: DIFFUSE EMISSION | 4 | 0 (--) | 0 (--) |
| GRAVITATIONAL WAVE EVENT | 3 | 1 (33.3%) | 1 (100.0%) |
| GALACTIC DIFFUSE EMISSION AND SURVEYS | 2 | 1 (50.0%) | 1 (100.0%) |
| **DDT Totals** | **352** | **206 (58.5%)** | **203 (98.5%)** |

Table 4. Number of Time-Constrained GO proposals by category for Cycles 10-22.

| **Category (Cycles 10-22)** | **N_prop** | **N_approved** | **N_observed** |
|---|---|---|---|
| BH AND NS BINARIES | 191 | 57 (29.8%) | 56 (98.2%) |
| STARS AND WD | 181 | 49 (27.1%) | 49 (100.0%) |
| ACTIVE GALAXIES AND QUASARS | 164 | 42 (25.6%) | 42 (100.0%) |
| SN SNR AND ISOLATED NS | 128 | 59 (46.1%) | 58 (98.3%) |
| NORMAL GALAXIES: X-RAY POPULATIONS | 57 | 22 (38.6%) | 22 (100.0%) |
| WD BINARIES AND CV | 15 | 2 (13.3%) | 2 (100.0%) |
| CLUSTERS OF GALAXIES | 14 | 1 (7.1%) | 1 (100.0%) |
| SOLAR SYSTEM AND EXOPLANETS | 11 | 6 (54.5%) | 6 (100.0%) |

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|---|---|---|---|
| NORMAL GALAXIES: DIFFUSE EMISSION | 10 | 0 (--) | 0 (--) |
| EXTRAGALACTIC DIFFUSE EMISSION AND SURVEYS | 10 | 1 (10.0%) | 1 (100.0%) |
| GALACTIC DIFFUSE EMISSION AND SURVEYS | 9 | 3 (33.3%) | 3 (100.0%) |
| GRAVITATIONAL WAVE EVENT | 1 | 1 (100.0%) | 1 (100.0%) |
| **TC-GO Totals** | **791** | **243 (30.7%)** | **241 (99.2%)** |

Distribution figures. These figures are generated by compiling the number of proposals by a given PI both requested and successful, then sorting by number of proposals (many to fewer) to calculate the normalized cumulative distribution. You can read off these graphs, for example, that half of the awarded proposals go to N number of PIs.

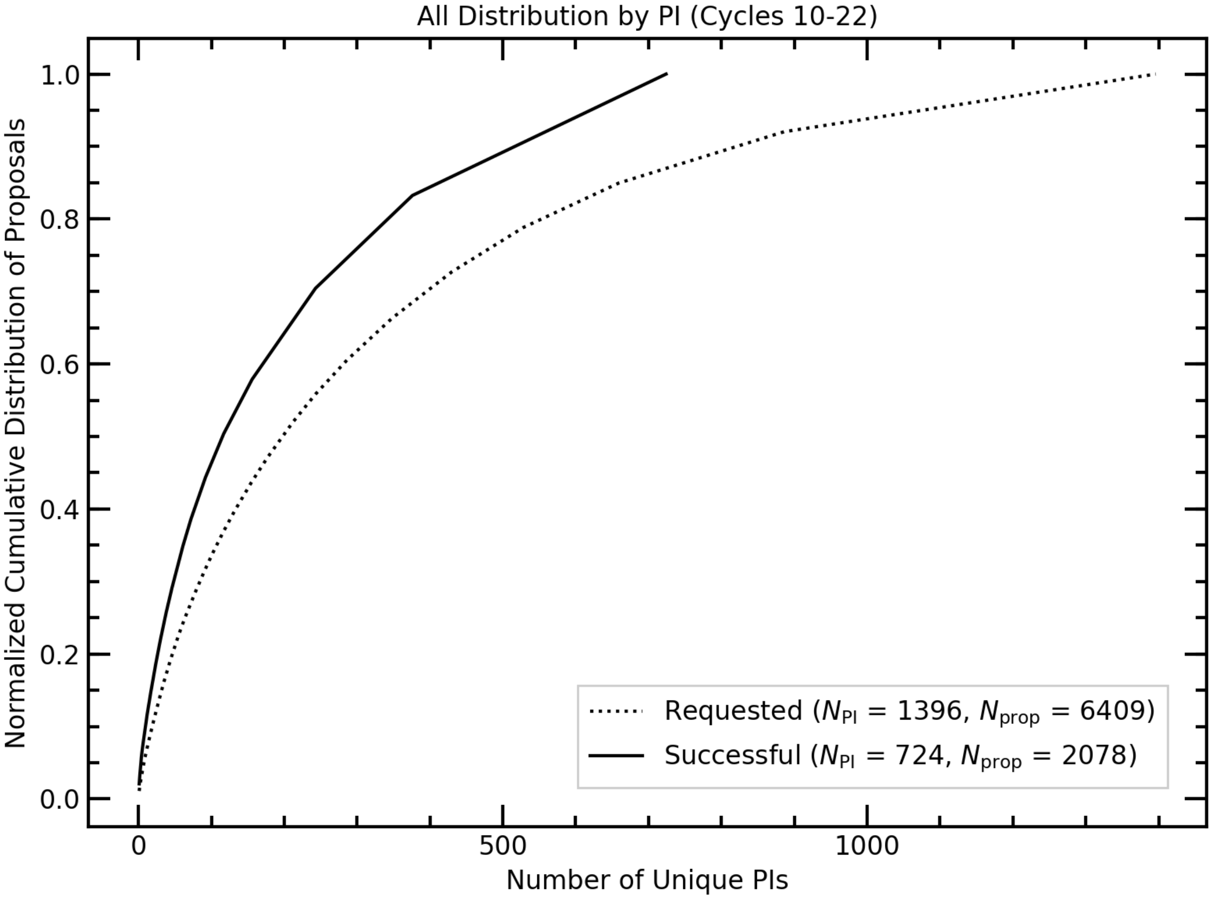

Figure 1. All Distribution by Unique PIs.

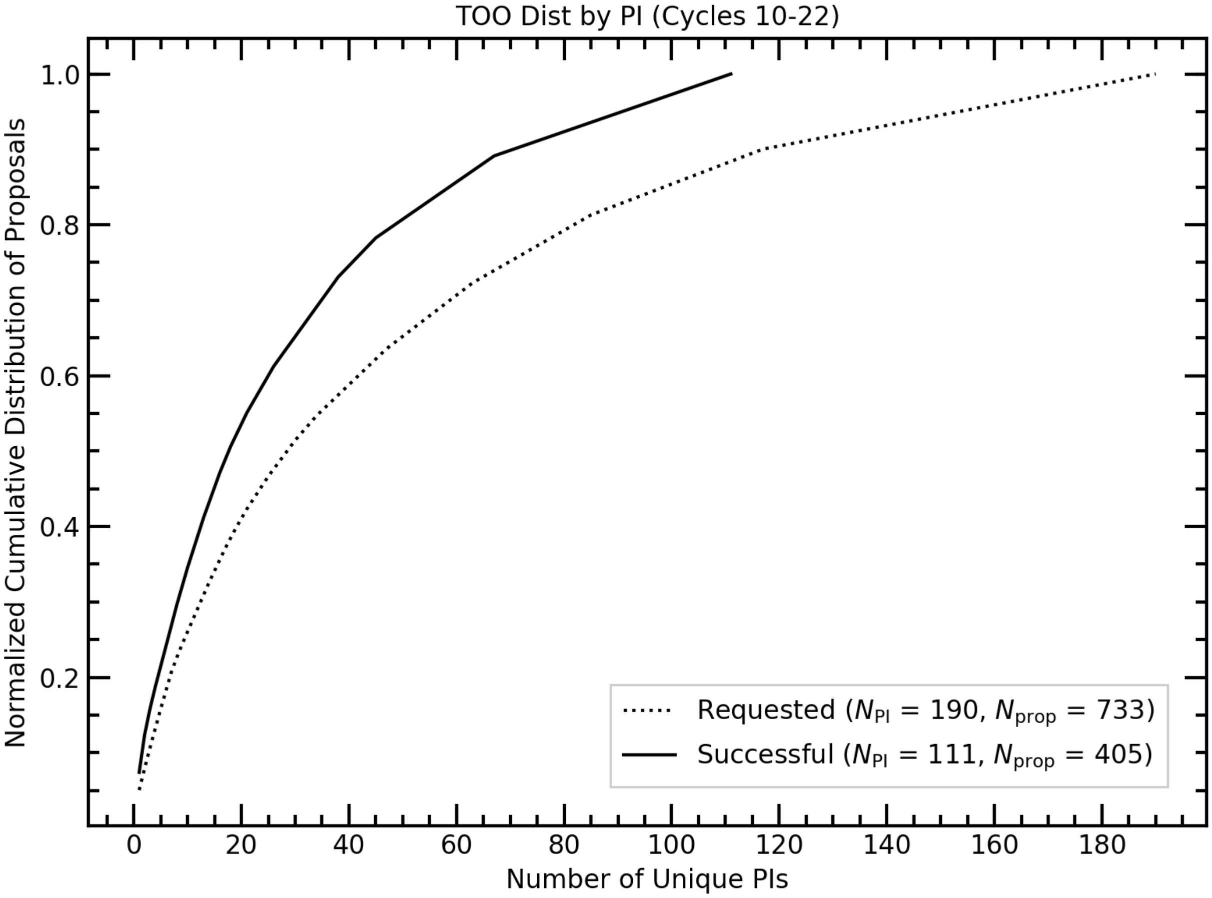

Figure 2. TOO Distribution by Unique PIs.

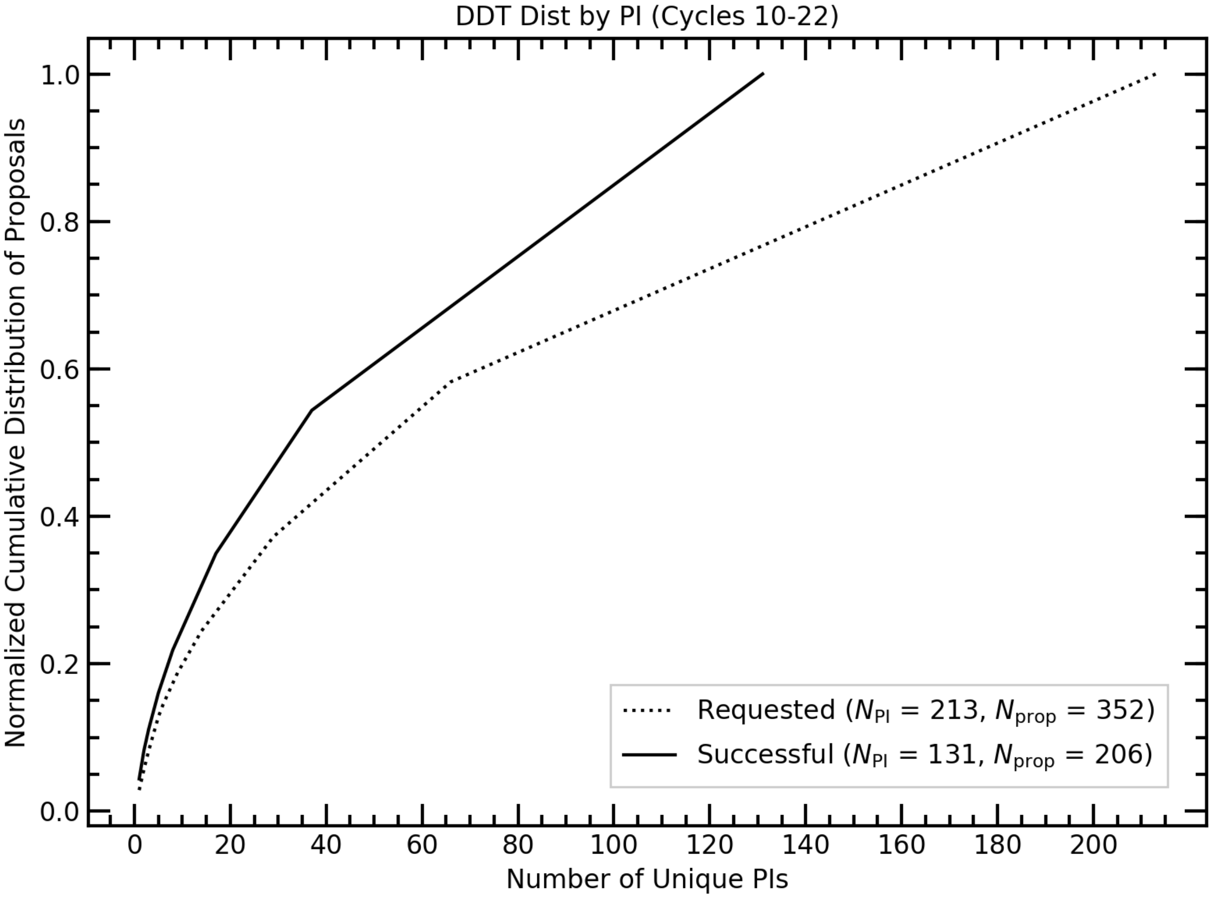

Figure 3. DDT Distribution by Unique PIs.

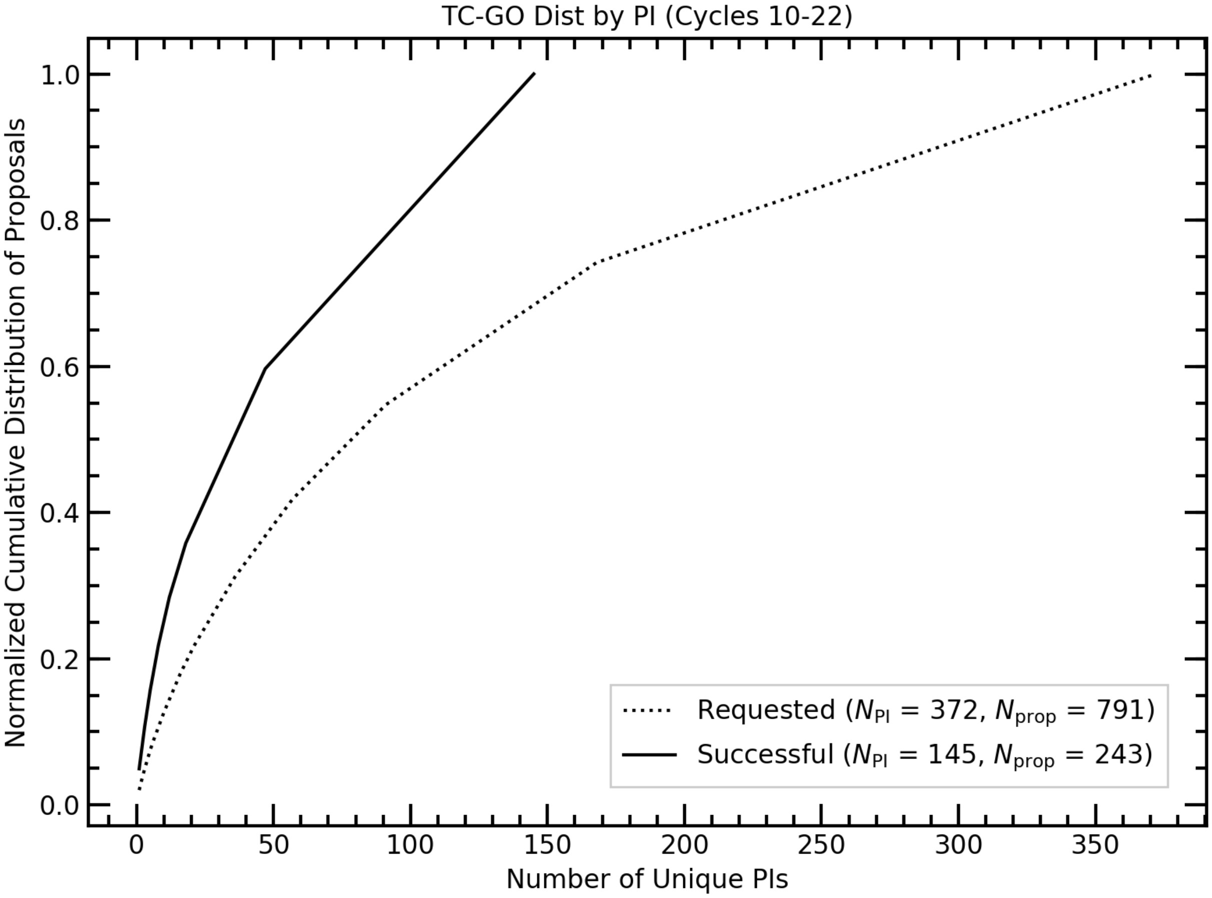

Figure 4. TC-GO Distribution by Unique PIs.

Appendix: Unique use cases.

| **Source category** | **TD category (1 = TOO, 2 = DDT, 3 = monitoring, 4 = constrained in time/phase, 5 = coordinated** | **Special notes.** |
|---|---|---|
| Quasar lenses | 1,2,3,4,5 | Chandra can spatially resolve many lenses. Monitoring reveals the inner geometry. XMM cannot do this. Athena may struggle. |
| Glob. populations | 1,2,3,4,5 | Chandra can identify sources in outburst within crowded GC fields. Stellar density makes this difficult or impossible in optical. Swift is likely insufficient. This is also true in the inner parts of the Galaxy and a few other places like spiral arm tangent points. In globular clusters, known periodicities can help identify new outbursts with previous transients. Chandra should be a "last resort" for just identifying new outbursts. |
| Galactic center | 1,2,3,5 (4?) | Only Chandra can spatially resolve individual X-ray point sources in the crowded Galactic center (Sgr A*, binaries, magnetars); multi-wavelength observations are often important and necessitate coordinated obs |
| GW counterparts | 1,2,3,4,5 | The spatial resolution and sensitivity of Chandra are likely required to see NS-NS and possibly BH-NS mergers. Most may be too faint even for Chandra. |
| AGN jets | 3,4,5 | Chandra can resolve knots close to the nucleus in jets such as M87, and their motions. It is the only X-ray angle on this. -- no, also disk-jet connection in LLAGN, using X-rays to isolate disk. |
| Dust scattering halos | 1,2,3 | Some of this work can be done with lower angular resolution, but most cannot. |
| YSO variability | 1,2,3,4?,5 | Crowding is severe. Strong potential for ALMA coordination. |
| Extragalactic X-ray binary variability | 3 | Crowded; even without crowding, better positions important for secure globular cluster associations; JWST will be able to follow some up, so precise positions are even more important. |
| X-ray binaries | 1,2,3,4,5 | The HETGS will be unsurpassed until the launch of XRISM, and then potentially still the best option for F > 0.2 Crab (appx). |
| Magnetars | 1,2,3,4,5 | Chandra can resolve the sources when embedded in crowded regions (i.e. Galactic center) or having bright PWN or SNR around (i.e. PSR1119, RXW103, and others). Chandra can also resolve small scale scattering halos due to the outbursts. Chandra has a better visibility window for Galactic plane transients, that XMM can observe only twice a year, and Swift has insufficient effective area. |

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|---|---|---|
| Supernovae | 1,2,5 | Since it will generally be follow-up, a lot can be done with lower angular resolution missions, but really special objects may benefit from pointing flexibility. Chandra is an important component of SN follow-up; about half of the Swift/XRT detections are partially or entirely due to unrelated sources (a lot of core collapse SNe have a nasty habit of exploding in regions where X-ray binaries like to hang out). |
| GRBs | 1,2,3,4,5 | Chandra can pinpoint the early X-ray afterglow with the good spatial resolution needed to avoid confusion with other X-ray emitters in distant Galaxies (HMXB or AGNs). Follow-up often requested to detect the possible jet break (only Chandra can go that faint in flux). |
| Classical novae | 1,2 | LETGS is important for these objects; XMM visibilities are often a problem; rates are growing dramatically for extincted objects, but they are rare enough for cases where sub. 0.5 keV can be seen that just relying on XMM/Athena may mean very low rates |
| Massive stars/colliding wind binaries | 3,4,5 | The spatial and spectral capabilities can be very important in these systems. |
| Low mass stars | 3,4,5 | Chandra offers unique capabilities, both for long-term monitoring and catching special phases. |
| Neutrino events/VHE cosmic rays | 1 | If there are some nearby candidates, it will be helpful to know not just which AGN is flaring, but which knot in its jet |
| Kilonovae | 1,2,3,4,5 | These may usually be associated with either a GW source or a GRB, but it is also possible that the KNe itself and associated afterglow(s) may be detected independently, which would merit Chandra obs to identify X-ray emission, jets/outflows, etc. These events are flagged for a special proposal round in the main report. |
| Tidal disruption events | 1, 2, 3, 4, 5 | Angular resolution is important in some cases (e.g., to distinguish nucleus from off-nuclear sources). For bright events spectral resolution is important. The long-wavelength coverage of the LETG is unique and suited to events that are naturally very soft. |
| Fast radio bursts | 1,2,3,4,5 | Angular resolution is important in some cases (e.g., to distinguish nucleus from off-nuclear sources). |
| Fast blue optical transients | 1,2,3,4,5 | Perhaps falls under the "supernova" category, but it is unclear what the central power source is. Spatial resolution and sensitivity are important. |