OBSERVING REQUEST
University of Arizona Observatories

Year: 2017 **Term:** Jul–Dec **Proposal type:** short-term*

AZTEC: Arizona Transient Exploration and Characterization

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CoI(s): G. Grant Williams (SO), Peter Milne (SO), Tom Matheson (NOAO), Dennis Zaritsky (SO), Paul Smith (SO), Jennifer Andrews (SO), Wen-Fai Fong (SO), Max Moe (SO), Charles Kilpatrick (UCSC), Christopher Bilinski (SO)

Abstract of Scientific Justification

We propose to continue the ongoing study of explosive transient science at Steward. The study of astronomical transient and variable sources (supernovae, GRBs, stellar eruptions, tidal disruption flares, binary stars, etc.) is of fundamental importance to astronomy, and a primary area of future effort as emphasized by the decadal review and the construction of LSST. In the time leading up to LSST, this is a regime where small and moderate-sized telescopes with broad-band photometry and single-object spectroscopy can make critical advances, because valuable new insight derives from physical properties of transients provided by nature. Arizona is unique among US institutions in its access to a diverse suite of telescopes. AZTEC marshalls our small and large telescopes in Arizona to obtain photometry and spectra of a wide variety of transients, and we leverage the flexible queue scheduling of UKIRT to enhance the cadence and wavelength coverage of this diverse program. We will take advantage of the sensitivity afforded by LBT and MMT to obtain low- and high-resolution spectra of particularly faint (old) objects. **We emphasize that AZTEC combines several different projects (at least 10 distinct programs) with different science cases under one umbrella program, to allow better and more flexible scheduling to follow transient events. It is not just one proposal with one PI, which is the cause of the apparently large time request for a single proposal. This program represents all observational studies of explosive transients at Steward.** So far, AZTEC time granted in the last 2 yr has yielded 25 publications; we hope to continue this track record in 2017B. We also enable frequent undergraduate student observing and undergrad research projects with data from all telescopes.

Summary of observing runs requested for this project

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling Optimal	Scheduling Acceptable	Sharing Poss.	Sharing Adv.
1	MMT	f/9	Blue			4	grey	Sep–Dec	Aug–Dec	no	no
2	MMT	f/9	Blue			4	dark	Sep–Dec	Aug–Dec	no	no
3	90	f/9	BCSpec			8	grey	Sep–Dec	Aug–Dec	no	no
4	61	f/9	Mont4k			6	dark	Sep–Dec	Aug–Dec	no	no
5	UKIRT	f/9	WFCAM			5	any	Sep–Dec	Aug–Dec	yes	yes
6	UKIRT	cass	UFTI			5	any	Sep–Dec	Aug–Dec	yes	yes
7	LBT	f/9	MODS			2	dark	Sep–Dec	Aug–Dec	yes	yes
8	MMT	f/5	MMTCam			1	grey	Sep–Dec	Aug–Dec	yes	yes
9	MMT	f/5	MMIRS			2	bright	Sep–Dec	Aug–Dec	no	no

Scheduling constraints and unusable dates *(up to 4 lines)***:** We ask nights to be staggered evenly to facilitate transient monitoring. Please schedule single nights. Please try to avoid scheduling more than 2 telescopes (especially Kuiper/MMT/Bok) on the same night if possible.

no text past this line

A $\star$ appended to the proposal type indicates a continuation proposal; a $\star$ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a $*$ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	SN 2017abc	00 00 00.00	+30 00 00.00	V <= 20.0, to be discovered

Approval for Instrument Use from PI: N/A

Graduate students *(provide the following information if student is PI on the cover page or if this is a 2nd-year or Thesis program. Send confirmation email to TAC chair in place of signature.)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis
Christopher Bilinski	N. Smith		no	yes

Scientific Justification

There is a wide variety of supernovae (SNe) and other astrophysical explosions, resulting from various stellar initial masses, metallicities, multiplicity, explosion mechanisms, and evolutionary paths. Some are traditional core-collapse SNe, some produce GRBs, some may be failed SNe or weak SNe formed by fallback onto a black hole, some are pre-SN eruptions (a.k.a. luminous blue variables, LBVs), and some are thermonuclear explosions like Type Ia SNe and pair-instability SNe. All of these are of interest in this proposal, where we aim to harness Steward's array of telescopes to obtain followup broad-band photometry (i.e., light curves) and spectroscopy of explosive transients. Transients offer unique windows into stellar evolution, allowing us to dissect inner layers of stars as they are peeled away, and to directly measure the mass and energy in their violent death throes. Our aim is to characterize transients that are discovered by other surveys (amateur astronomers, PTF, the Lick Observatory SN search, CRTS, ASASSN, PanSTARRS, etc.). We will follow a subset in specific categories that align with our primary scientific interests as described below.

Here we propose to continue our "poor man's queue" for Steward's telescopes that we call the Arizona Transient Exploration and Characterization (AZTEC) program. This is an umbrella program with several diverse science goals. In the next subsection, we describe each of these primary science goals and identify the lead investigator. The TAC really should think of AZTEC as at least 10 separate programs, which we need to merge together into one large program because of the time-dependent nature of our science. We must do this in order to pool our efforts on various telescopes to enhance scheduling flexibility, to facilitate more regular monitoring, and to maximize the scientific return of our diverse telescope system for the study of transient sources. *AZTEC was approved in 2015A-2016A; things are working logistically very well now. This time we place a stronger emphasis on late-time spectroscopy with MMT and LBT. These observations are the most essential to our overall program, since explosions generally reveal their most important secrets (total ejecta mass, composion, structure, distant CSM, dust formation) as they fade from view when we can see deep into the interior of the ejecta.*

Specific Science Goals - 10 differnet programs:
(1) SNe with dense circumstellar material (Type IIn). PI = N.Smith. About 9% of core-collapse SNe are classified as Type IIn (Smith et al. 2011). The "n" means that they have narrow H lines in their spectrum arising when the SN shock crashes into slow and dense circumstellar material (CSM). These objects are of particular interest because their dense CSM is ejected in violent eruptive mass loss events before the SN, indicating the presence of an instability that is a prelude to core collapse and may affect the core collapse mechanism itself (Smith & Arnett 2014). Spectra of these events can constrain the expansion speed and kinetic energy of the SNe, but can also measure the speed and mass-loss rate of the progenitor star eruptions because the pre-shock gas is illuminated. The instability causing these pre-SN outbursts is still unidentified, so understanding the diversity in physical parameters is essential to diagnose it. Since SNe IIn have narrow lines, higher spectral resolution is needed, and strong CSM interaction can continue for years as the SN fades. A recent example of this is the remarkable case of SN2005ip, which is still going strong (Smith et al. 2016, Fig. 1). This is one of our primary science drivers for MMT time with Bluechannel.

(2) Thermonuclear SNe with strong CSM interaction; or SNe Ia-CSM. PI=Milne/Kilpatrick. Similar to SNe IIn in terms of CSM interaction and observed diagnostics, but in Type Ia SNe. The fact that some SNe Ia crash into dense H-rich CSM has extremely important implications for cosmology, since it proves that some SNe Ia progenitors are single degenerate rather than 2 merging white dwarfs (see Kilpatrick+16).

(3) Nearby SNe with an HST-detected progenitor star (PI = N.Smith). Any normal type of core-collapse SN can become extremely valuable in the rare nearby cases when we are lucky enough to have pre-explosion archival HST detections of a progenitor star. More than a dozen reliable detections of progenitor stars are known (Smartt 2009; with several more added recently). In these cases, precise estimates of the SN ejecta mass, abundances, and kinetic energy derived from spectra are extremely valuable since they can be compared with the estimated mass and type of star that exploded. N. Smith is a co-I on an HST program that has triggered observations of 3 of these.

(4) Type Ia SNe. PI = P.Milne. Swift discovered that the normal Type Ia SNe used as cosmological distance indicators can be divided into two classes, based on their NUV-optical colors (Milne et al. 2013), and that the

ratio between these classes changes with redshift (Milne et al. 2015). This potentially impacts the amount of dark energy inferred. The M4K camera has excellent blue sensitivity and will categorize nearby events as NUV-red or NUV-blue. UKIRT photometry will constrain extinction toward normal Ia's and will spot super-Chandrasekhar candidates (Kilpatrick & Milne, in prep.).

(5) Late-time spectroscopy of Type Ia supernovae in elliptical galaxies. PI = M.Moe. The progenitors of SNe Ia remain hotly debated. In most cases observations fail to reveal signatures of a donor star, but pre-explosion images of a 2002cx-like SN Ia provided evidence for a He star donor (McCully et al. 2014). There has been a growing consensus that He stars, main-sequence stars, giants, and white-dwarf donors all contribute to the overall SN Ia rate, but producing different subclasses of SN Ia. In particular, sub-luminous SN Ia that preferentially explode in elliptical galaxies may contain giant donors (Ruiz-Lapuente et al. 1993). Radio, optical, and X-ray observations taken near maximum light provide only weak upper limits for the amount of H (Chomiuk et al. 2016), but late-time optical spectroscopy 150-250 days after explosion can firmly rule out or confirm the giant donor hypothesis based on the absence or presence of Hα emission (Maguire et al. 2016). A nearby ($<$100 Mpc) SN Ia explodes in an elliptical galaxy each month, and then subsequently fades to V=18-19 mag after 150-250 days. We plan to obtain late-time spectra with MMT of 6 SNe Ia during the 2016B observing semester (6-12 hours total).

(6) Spectropolarimatry of SNe. PI = G.Williams. This program aims to understand the asymmetry for a wide variety of SNe using SPOL on the MMT, Bok, and Kuiper. SPOL observations will be submitted separately. With AZTEC, we will obtain non-polarization spectra and photometry to place specpol data in context.

(7) Eruptive non-SN transients (LBVs and related phenomena). PI = N.Smith/Andrews. In addition to SNe IIn that result from a SN crashing into CSM created by a pre-SN eruption (above), we also aim to study the pre-SN eruptions directly. This is a class of transient events that are non-terminal stellar eruptions, such as LBVs like η Car that are sometimes called “SN impostors”. Studying the luminosity and spectral evolution provides critical clues about unsteady mass loss in the late evolution of massive stars (see review by Smith 2014). These can last for years and undergo subtle spectroscopic changes (Smith et al. 2016).

(8) Core-collapse SNe with dust formation and IR Echoes. PI = J.Andrews. Core-collapse supernovae (ccSNe) may be crucial players in the dust budget of galaxies, especially at high-redshift where only higher mass stars have enough time to enrich the ISM. The mechanism and the efficiency of dust condensation is not well understood. When dust forms in SNe, it can be measured using a combination of optical/IR photometry and spectroscopy: (1) a sudden decrease in continuum brightness in the optical (Kuiper phot.), (2) a brightening in the IR as new dust grains re-emit in the IR (UKIRT phot.), and (3) the development of asymmetric, blue-shifted emission-line profiles, caused by new dust preferentially extinguishing redshifted emission (MMT/LBT spectra). If dusty CSM already exists around the object, there may also be enhanced IR flux due to absorption and re-emission of the initial SN flash, called an “IR echo”. Therefore observing IR echoes can be an invaluable tool for reconstructing the evolution and characteristics of the progenitor.

(9) GRBs and their SNe. PI=W-F.Fong. Long-duration gamma-ray bursts (GRBs) have two optical counterparts: the afterglow, which is the relativistic jet interacting with the circumburst medium, and a Type Ic SN. At present, differences between Type Ic SNe with or without GRBs are poorly understood. To date, only ≈ 10 GRB-SNe have been spectroscopically confirmed, due to the paucity of low-redshift ($z \lesssim 0.7$) long GRBs. While the afterglow emission fades below the capabilities of ground-based facilities in $\sim$1 week, the SN emission is often detectable $\gtrsim$3 weeks after the burst. Our program provides a unique opportunity for constraining their expansion velocities and ejecta masses.

(10) Infrared-only transients. PI=N.Smith/Andrews. Smith, Andrews, & Milne are co-investigators on a current Spitzer large program to discover and study transient sources in the IR (PI=M Kasliwal), called “SPIRITS: Spitzer Infrared Transient Search”. These are either obscured SNe, or unusual dusty stellar mergers or transients associated with star formation. IR spectra and images (UKIRT) are needed because these sources are faint optically.

AZTEC won't cover everything related to transients. For example, ToO interrupts for GRBs may still be needed for timescales shorter than our cadence, and programs that seek numerous high-redshift SNe or studies of host galaxies will not be covered by AZTEC.

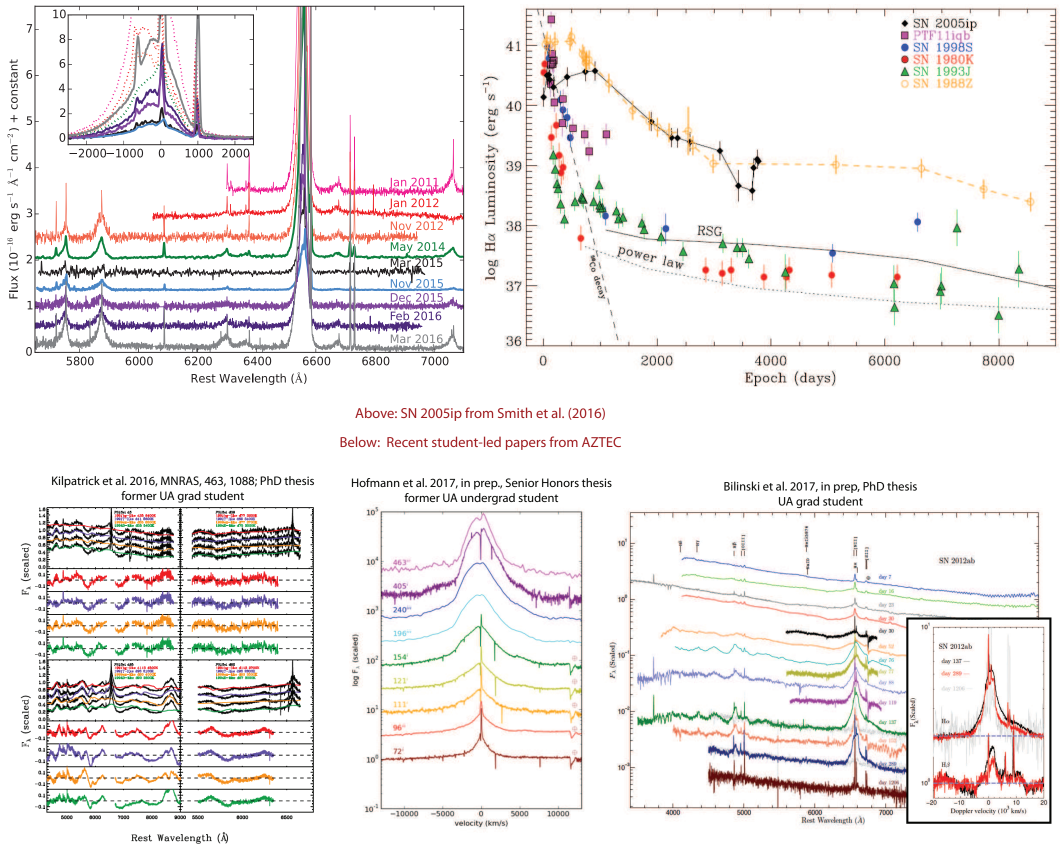

Figure 1: **TOP.** Left: a series of late-time spectra of SN2005ip taken over the past 2 years with AZTEC, typical of our studies of SNe IIn evolution. Right: A plot of the Hα luminosity with time for SN 2005ip, compared to a few other nearby SNe with strong interaction. This ongoing interaction requires a CSM shell of 15-20 $M_\odot$ lost 1000 yr before explosion (from Smith et al. 2016, in press.). **BOTTOM.** Examples of figures from recent AZTEC papers led by students. *Left:* The Type Ia-CSM supernova PS15si. Kilpatrick et al. 2016 compared the spectra to a series of templates and showed that this was a specific subtype of Type Ia SNe that was interacting with several $M_\odot$ of CSM. *Middle:* The Type IIn supernova PSNJ13522, from Hofmann et al. 2016. This shows the Hα line profile evolution, used to decipher the forward shock speed, luminosity, and mass of CSM. This is the typical evolution over several hundred days. *Right:* Spectra of SN2012ab from Bilinski et al. 2016 (in prep.). Although this was a Type IIn with *narrow* lines, it was extremely unusual in that at very late times it also showed very *broad* line wings out to almost 20,000 km s^{-1}.

REFERENCES • Chomiuk et al. 2016, ApJ, 821, 119 • Fong, W., Milne, P., Smith, N., & Andrews, J. 2014, GCN Circular, 16826, 1 • Kilpatrick, C. & Milne, P.A., in prep. • Maguire et al. 2016, MNRAS, 457, 3254 • McCully et al. 2014, Nature, 512, 54 • Milne et al. 2013, ApJ, 779, 28 • Milne et al. 2015, ApJ, 803, 20 • Smartt 2009, ARAA, 47, 63 • Smith 2014, ARAA, 52, 487 • Smith & Arnett 2014, ApJ, 785, 82 • Smith, N., et al. 2011, MNRAS, 412, 1522 • Smith et al. 2016, MNRAS, 455, 3546 • Smith et al. 2016, MNRAS, 458, 950

Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science.* ***(up to one page)***

This proposal aims to observe diverse explosive transients that have not yet been discovered and that continually fade at sometimes unpredictable rates, so we cannot provide a traditional estimate of the exposure times needed for a set number of targets of known flux as one might do for a standard survey program. Our time request is guided by two principles: (1) Establishing a *cadence* for monitoring transients that is frequent enough to provide adequately-sampled light curves and spectroscopy, essential to understand the temporal evolution of any explosion. (2) Typical exposure times required for a minimal number of targets that can continue to address the science cases outlined above.

The 1-page limit does not permit a detailed time justification for each telescope. As an example, consider the time needed for MMT spectroscopy, which is our most important resource for this science. Above we outlined 10 separate science cases that have been put into one large proposal to facilitiate monitoring. Let's say that we will try to follow the detailed evolution of 1 target for each of these science cases. Each target requires 5-10 spectra to monitor the changes in spectral evolution as they fade over a semester. Typical exposure times for a 19-21 mag source to achieve adequate signal to noise in the higher resolution setting (1200 lpm grating) are always about 1-2 hour per target per epoch. Spread over 5-10 epochs, this means that one target will require the equivalent of about 1 full MMT night - but it is of course 10 epochs of 0.1 nights. The only practical way to accomplish this is to combine all transient programs together and make one big request. Since there are 10 separate programs combined into one, the total needed is about 10 MMT nights. Our request of 8 nights with MMT/Bluechannel is therefore conservative (not including weather losses, which have been terrible). Below we describe how each facility fits into our overall science program.

MMT/Bluechannel: Bluechannel on the MMT will emphasize higher resolution spectra (1200 lpm grating; 4 gray nights), for SNe and transients with narrow lines (Type IIn SNe and LBV eruptions). Higher resolution will also be used to study the Na I D absorption. We will also use Bluechannel to obtain low-res spectra of fainter targets, like SNe after they fade (4 dark nights). *Scheduling: Please stagger these MMT nights evenly through the semester as single nights.*

LBT/MODS: We request 2 nights for dark-time spectroscopy with MODS, reserved for our very faintest targets at late times. These will be single-object long-slit observations. Some of our late-time targets are way too faint for the MMT guider camera, and even blind offsets can be problematic. In order to measure reliable line fluxes in the late nebular phases (like the always critical Hα flux, which is a direct diagnostic of the pre-SN mass-loss rate in CSM interacting SNe), we must be sure that the source is positioned correctly in the slit. Our faintest targets are usually too faint for MMT in any case, especially in the blue. *Since we are focussed on very late times, scheduling is flexible, but please try to avoid the same nights as MMT.*

Bok/B&C: The B&C spectrograph on the Bok will provide low-resolution spectra, required for all transients near maximum luminosity (typically 16th to 19th mag). Usually 30min - 1 hour exposures per target (more as they fade), including overheads with standard stars. 1-2 nights per month to achieve a suitable cadence to obtain 4-6 spectra for a typical SN.

Kuiper/Mont4k: Used to obtain broad-band UBVRI light curves, essential to understand the basic energetics of any transient. We use the robotic super-LOTIS telescope for high cadence photometry at peak.

UKIRT: The JHK photometry is needed for studies of dust formation and IR echoes, IR-only transients (SPIRITS), Type Ia supernovae, and for evaluating extinction in all transients. We typically require a total of 0.5-1 hr per target (19-20 mag) per epoch, with several epochs over a few months as a SN fades.

MMT/MMTCam: We request the equivalent of 1 night with MMTCam, to occur as several 5-20 minute blocks of single targets in queue observing mode. The purpose is to obtain photometry of fainter transients with DEC above +60; *beyond Kuiper's DEC pointing limit.*

MMT/MMIRS: IR spectroscopy is needed for studies of dust formation (its effect on line profiles) and the IR-only transients discovered with SPIRITS. Dust formation begins at late times when SNe have faded.

Summary of Time Requested and Awarded *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in. (**up to one page**)*

Studying transients is fundamentally different from many other types of programs in terms of approach. Our targets come and go with time as provided by Nature, and we respond, so study is perpetual and ongoing. Because this is a somewhat non-traditional program, we attempt here to answer questions that we have recieved from the TAC in the last cycle, or hypothetical questions that we anticipate:

Q: SNe are bright. Why does AZTEC need MMT and LBT? A: While we mainly focus on explosive transients that are fairly bright at peak (17-19 mag), all these transients fade by many magnitudes as their ejecta cool and recombine. When this happens the ejecta become transparent and we can see deep into the guts of the star that exploded, allowing us to measure the mass, abundances, kinetic energy, density profile, etc. For this reason, the most important physical information is obtained from late-time spectra, when our targets have faded from 17th mag to about 21-23 mag. This is the chief reason we need MMT and LBT.

Q: Why is Nathan requesting so much time? A: Because **AZTEC is actually a combination of at least 10 different transient science programs led by several PIs, which are combined into AZTEC for the practical necessity of scheduling**. Each of these individual science cases is asking for the equivalent of less than 1 MMT night and only 1-2 hours of LBT time total. We hope the TAC appreciates that AZTEC represents *all explosive transient science at Steward*, which is a major branch of modern astronomy and a main motivation for building LSST. We are not asking for all the time we might like, but the minimum we need. We prioritize in real time as we track the evolution of our targets.

Q: Why so much time? A: Because our targets change with time, and we need to observe them over and over again. It takes small portions of many many nights to build up the dataset needed to study the evolution of a single SN as it fades, and late times when the SNe are faint (requiring long exposures on MMT and LBT) are the most important in terms of uncovering the physics. As a result, our program is requesting a large amount of time on many different telescopes.

Q: Why so many targets each semester? Why not 1 or 2 to accomplish the same science? A: The answer is that we need more like 100 SNe of various types in order to begin to understand the statistics of the diverse subtypes of explosions, but Nature only gives us 5 new ones each semester (some we follow for many semesters) that fit our criteria (bright enough to also observe at late times) and are of the type we are interested in. We must be patient and persistent, and over time we build up statistics.

Q: When will it end? Will this go on forever? A: Honestly, it will end when the informative surprises end. So far this has not happened. Our community is still at a relatively early phase of exploring the transient sky when large surveys like PTF are finding many new and bizarre transients all the time. These discoveries hold critical new clues to understanding the latest phases in the evolution of massive stars and binary stars, their connection to the diversity of explosions, and the physics of explosions in general. When we have so many transients studied in detail that we can clearly separate them into well-defined recognizeable subgroups, then we will begin doing statistics on the diversity. This will be one of the main efforts in the LSST era; right now we are just learning how to recognize the difference between all these transients and what their important physical parameters are.

We are focused mainly on *followup* of transients discovered by other means (i.e. this is a followup program, not a transient search). We collaborate directly with the Lick Observatory Supernova Search (LOSS) at Berkeley and the Palomar Transient Factory (PTF) at Caltech; these are the main dedicated search engines that discover, obtain early photometry, and initially classify the transients.

Our followup is highly multi-wavelength in order to evaluate the complete picture of the explosions we study. AZTEC observations proposed here cover the essential optical/IR spectra range. We have ongoing accepted programs to study the late time evolution of SNe at radio (VLA) and X-ray wavelengths (Swift and Chandra programs), as well as the UV evolution with Swift/UVOT.

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). (**up to one page**)*

⋆ PI N. Smith. AZTEC was approved in 5 previous semesters. Previous semesters usually had a similar amount of time as in the present request. Although we were plagued by weather early on, we are now seeing a steady stream of publications in (or to be submitted to) refereed journals. All our AZTEC data up to the end of 2016B have been reduced, and many papers are in prep. Papers led by undergrad or graduate students are noted below. Hopefully our publications make a case that we are being productive. Please forgive the small font.

Published or accepted AZTEC papers in Past 2 yr:

1. Andrews, J.E., Smith, N., & Mauerhan, J.C. 2015, MNRAS, 451, 145, "Late-time spectrocopy of SN 2002hh: A continued light echo and no shock interaction yet"
2. Drozdov, D, Leising, M.D., Milne, P.A., Pearcy, J., Riess, A.G., Macri, L.M., Bryngelson, G.L., & Garnavich, P.M. 2015, ApJ, 805, 71. "Detection of a Light Echo from the Otherwise Normal SN 2007af"
3. Jencson, J.E., and SPIRITS team (including J.E. Andrews & N. Smith) 2017, ApJ, 837, 167, "SPIRITS 15c and SPIRITS 14buu: Two Obscured Supernovae in the Nearby Star-Forming Galaxy IC 2163"
4. Kilpatrick, C., Andrews, J.E., Smith, N., Milne, P.M., et al. 2016, MNRAS, 463, 1088. "An optical and near-infrared study of the Type Ia/IIn Supernova PS15si" [**** former UA grad student**]
5. Lau, R.M., and SPIRITS team (including N. Smith) 2016, ApJ, 830, 142, "Rising from the ashes: Mid-infrared re-brightening of the impostor SN 2010da in NGC300"
6. Milne P, Foley R, Brown, Narayan 2015, ApJ, 803, 20. "The Changing Fractions of Type Ia NUV-Optical Subclasses with Redshift"
7. Milne PA, et al. 2017, ApJ, 835, 100, "Multi-epoch Spectropolarimetry of SN 2011fe"
8. Porter, A.L., Leising, M.D., Williams, G.G., Milne, P., Smith, P., Smith, N., Bilinski, C., Hoffman, J.L., Huk, L., and Leonard, D.C. 2016, ApJ, 828, 24, "Asymmetries in Sn 2014J near maximum light revealed through spectropolarimetry" [**non-UA grad student**]
9. Smith N, Andrews JE, Mauerhan JC, et al. 2015, MNRAS, 449, 1876. "PTF11iqb: cool supergiant mass-loss that bridges the gap between Type IIn and normal supernovae"
10. Smith N, et al. 2016, MNRAS, 455, 3546. "The persistent eruption of UGC 2773-OT: Finally, a decade-long extragalactic Eta Carinae analogue"
11. Smith N, et al. 2016, MNRAS, 458, 950. "Massive-Star Mergers and the recent Transient in NGC4490: A More Luminous Cousin of V838 Mon and V1309 Sco"
12. Smith N, Andrews JE, Mauerhan JC. 2016, MNRAS, 463, 2904, "Massive stars dying alone: The extremely remote environment of SN2009ip"
13. Smith N, Kilpatrick C, et al. 2017, MNRAS, 466, 3021. "Endurance of SN 2005ip After a Decade: X-rays, Radio, and Hα Like in SN1988Z Require Long-Lived Pre-Supernova Mass Loss".

Submitted or in prep. AZTEC papers:

14. Andrews, J.E., Smith, N., et al. 2017, MNRAS, in prep. "Late interaction in the Type IIn supernova SN2013L"
15. Andrews, J.E., Smith, N., et al. 2017, MNRAS, in prep. "A Study of Hα line-widths in a sample of early-time Type IIn SNe"
16. Bilinski, C., Smith, N., Williams, G.G., et al. 2017, MNRAS, almost submitted. "SN2012ab: A Peculiar Type IIn Supernova SN2012ab" [**** UA grad, thesis**]
17. Bilinski, C., Smith, N., Andrews, J.E., et al. 2017, MNRAS, in prep. "The Type IIn supernova SN2014ab" [**** UA grad, thesis**]
18. Bilinski, C., Smith, N., Williams, G.G., et al. 2017, MNRAS, in prep. "The asymmetry of Type IIn supernovae" **** UA grad, thesis**]
19. Bullivant, C., Smith, N., Andrews, J.E., et al. 2017, submitted. "The Type IIn supernovae SN 2013fr and SN 2013fs" **** UA undergrad**]
20. Bullivant, C., Smith, N., Andrews, J.E., et al. 2017, in prep. "The supernova impostor NGC 5775-OT" **** UA undergrad**]
21. Hoffman R.A., Smith, N., et al. 2017, MNRAS, in prep. "The bright Type IIn supernova PSN J13522411+3941286 in NGC 5337" [**** former UA undergrad, Senior Honors Thesis**.]
22. Jencson JE, and SPIRITS team (including J.E. Andrews, P. Milne, & N. Smith) 2017, in prep., "SPIRITS 16tn: Discovery of a Highly Obscured Supernova in the Nearby Star-forming Galaxy M108"
23. Johansson J, and SPIRITS team (including P. Milne & N. Smith) 2017, in prep., "SN2014dt: a Type Iax SN with an IR surprise"
24. Kilpatrick, C.D., Andrews, J.E., Smith, N., Milne, P., Shivvers, I., Zheng, W., Filippenko, A.V. 2017, in prep. "Mapping the Circumstellar Environment Around the Type IIn Supernova MASTER OT J044212.20+230616.7" [**** former UA grad**.]
25. Kilpatrick, C. & Milne, P.A., 2017, in prep. "UV-OPT-NIR Photometric Comparisons between super-Chandrasekhar candidates and other broad type Ia Supernovae" [**** former UA grad**]
26. Milne, P.A., et al. 2017, in prep. "Two Groups of Narrow-Peaked Type Ia Supernovae Revealed by the NUV-Optical Colors"
27. Shivvers, I., Andrews, J.E., Smith, N., et al. 2017, submitted, "The Type Ibn supernova SN2015G"
28. Smith N., Andrews J.E., et al. 2017, in prep. "The unusually persistent Type IIn supernova SN 2011iw"
29. Smith, N., et al. 2017, in prep. "PTF10vyq: A decade-long outburst from a new LBV in M33"
30. Smith, N., et al. 2017, in prep., "SN 2016bkv and its LBV progenitor detected by HST"
31. Smith, N., et al. 2017, in prep., "SNhunt 225 in NGC2403 and its HST progenitor"
32. Williams, G.G. et al. 2017, in prep. "Evolution of Asymmetries in the Type IIn SN 2010jl"

AZTEC also yielded numerous ATel announcements of SN spectral type IDs, in support of Swift/UVOT SN studies. Note: Due to space limitations, please see other co-I proposals for their publications.

Other Information *Provide any additional program-related information including, for example, relation of current program to externally funded research, to the development of expanded capabilities for UA telescopes, or to individual timescales (e.g. PI is finishing postdoc appointment and this request would complete program). (**up to one page**)*

The scientific projects described in the justification section of the AZTEC proposal are funded by several grants, including two AAG NSF grants (3 NSF grants if you include the SPOL project, which is ending soon), two NASA Einstein Postdoctorial Fellowships (co-Is W.F. Fong and M. Moe), and numerous smaller HST and Swift grants. For all of these, continual ground-based spectroscopic and photometric followup of transient sources is absolutely essential to the success of these projects. There are also NASA grants at other institutions for which AZTEC members are co-Is (for example, Smith and Andrews are co-Is on A.V. Filippenko's ongoing multi-cycle HST SNAP program to study old supernobvae and S. Van Dyk's ongoing multi-cycle HST program to study SN progenitors). Smith, Andrews, and Milne are also co-Is on the funded SPIRITS program (Spitzer Infrared Transient Search), which is a large Spitzer program led by M. Kasliwal, for which AZ pledged ground-based support, and for which we received funding to contribute to upgrading UA facilities.