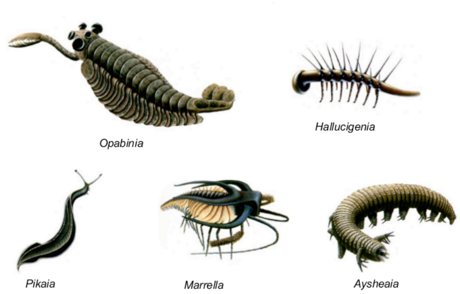
Boutiques & Experiments: 2015

Caltech Campus, August 28–29, 2015



Why This Workshop?

By all accounts we are now in the era of wide-field surveys. Surveys can be tremendously amplified by using three strategies: cross-comparing with other surveys, combining imaging surveys with massively multiplexed spectroscopic programs and repeated visits to the sky ("Time Domain Astronomy", TDA). The last topic is the subject of this small workshop.

The routine parameters of a synoptic survey are the following: the observing band, the expected (end-of-survey) depth and the extent of the sky coverage. In contrast, for TDA science, the *cadence* – the mean time between visits to the same piece of sky in the same band – matters. Indeed, one may say that TDA surveys are, first and foremost, characterized by cadence. Other parameters are depth (single epoch sensitivity), choice of bands and choice of sky pointings. Too often, in the opinion of this writer, synoptic surveys designed with a "Universal" cadence end up providing a cadence that is universally unsatisfactory (from a TDA perspective).

Many flagship synoptic surveys appear to be driven by cosmography and large scale structure studies. This strong bias has and will continue to motivate TDA astronomers to develop surveys optimized for TDA science. As noted above TDA surveys have several parameters and so one is naturally led to a motley mix of TDA surveys, which are optimized for different TDA survey parameters.

The motivation of this workshop is to critically examine the value, and then forecast the future, of specialized surveys, bearing in mind the development of flagship projects (such as DES, HSC, LSST, EUCLID and WFIRST), in the coming decade.

An explanation of terminology now follows. "Boutique" surveys are surveys which deliberately make drastic choices (which could be rooted in financial issues or a deliberate focus of the PI) in the survey parameters (listed above). The ASAS (All Sky Automated Survey) and the on-going ASASSN (ASAS SN) are exemplars of a boutique survey. Both are widely considered to be highly effective projects and extremely cost effective.

"Experiments" are imaging surveys which are focused on a single or a well defined goal. The CFHT Legacy Survey (CFHTLS) was focused strongly on Ia supernova cosmology and was considered to be an extremely successful survey. The Catalina Sky Survey (CSS) is focused on finding near-earth asteroids (NEOs) and the choice of filter (white light) and cadence is tuned for NEO discovery. CSS dominated the discovery of NEOs and has now been overtaken by projects with significantly larger capitalization and running costs. PanSTARRS-2 (PS2), owing to sponsor desires, is also an experiment (for NEO studies).

Well known examples of "Non TDA but Boutique" are Low Surface brightness surveys, Narrow-band surveys (Hα, other nebular lines) and Polarization surveys. Micro-lensing surveys and planet occultation studies are most certainly TDA experiments. It is rather curious that these experiments appear not have gained much traction in the larger TDA community. However, Kepler-2 (K2) is being driven entirely by user demand and TESS has a phenomenal grasp and it is quite likely that there will be a stronger coupling between the larger TDA community and these two missions.

Why Now? A survey of the astronomical market shows a dramatic growth in TDA projects. Clearly, this workshop is timely. However, it would be useful to examine what factors are driving this growth in TDA projects (with a view of understanding how long this growth may persist). The growth is the most dramatic in optical TDA projects and this can be attributed to the decreasing cost of basic components (detectors, lenses) and sub-systems (telescope mounts, computing). Projects such as Evryscope and ASAS-SN rely entirely on Commercial Off-the-Shelf (COTS). The high-end amateur astronomy market has led to a market which can provide high quality CCDs, data reduction packages, telescope mounts, domes – all at increasingly affordable costs. These developments have fueled many exoplanet transit TDA projects (for instance).

In the past science grade sensors (CCDs; stable performance and low read noise) used to cost a fortune. However, the cost in COTS science-grade CCDs has led to ”telescope arrays” instead of a single telescope. The sweet spot for these facilities is “wide+shallow”. Examples include ATLAS, GOTO and BlackGEM. It is hard to beat the cost-effectiveness of telescope arrays (relative to a single telescope but with a large number of detectors).

The increasing ease of combining electrical, electronic and mechanical systems (“electromechanical”) has led to the rise of robotic telescopes (or retreading of existing telescopes for robotic operations). This development makes it possible to decrease the latency of follow up, allow operations at remote sites (and thereby widen longitude coverage) and also to decrease operational costs. Examples include RATIR and STELLA. The increase in internet bandwidth and ease of on-site computing means that robotic telescopes can be easily linked. “Whole Earth” telescopes are no longer exercises in heroism. These developments explain the rise of LCOGT, GROWTH and other such facilities.

Taken together all these technological advances (at lower costs) have also made it possible to undertake focused surveys such as surveys dedicated to low surface brightness imaging (Dragonfly), narrow band (e.g. SHASSA) and single goal projects (STELLA, Robo-AO).

Radio Astronomy. Radio astronomy has finally come of age in the TDA world. At low frequency the facilities naturally have large FOV. Inexpensive computation makes it possible to image the entire available FOV. At decimetric frequencies new designs – large N, small diameter (LNSD) and phased array feeds – increase the mapping speed of interferometers by an order of magnitude (or more). Finally, increasingly inexpensive computing is now making it possible for existing arrays and telescopes to fully process large chunks of the radio spectrum in multiple ways. For example, the primary strength of the VLA is aperture synthetic imaging. However, the signals from the 27 antennas can be combined to yield multiple beams on the sky to search for pulsars or SETI signals. Such extensive digital signal processing would have been prohibitively expensive in the past but has now become possible. This has given rise to "commensal"[1] observing. We are fortunate that several leaders in radio astronomy were able to sign up for the meeting and participate.

Goals. There are two goals for this small one and half day invitational workshop. First is to understand the role and value of smaller surveys once larger surveys get going. The proponents of large surveys have (naturally) been known to claim that large etendues allow for a wide range of cadences to be undertaken. This may well be true but it would be good to have a scholarly discussion keeping squarely in mind the issue of cost to benefit.

The second goal is to review emerging methodologies in TDA. It is our opinion that some of these emerging methodologies may have a profound effect (multiplicative effect) on TDA surveys. So being alert to these developments will be well worth our time.

For instance, as noted earlier low frequency radio arrays, by the virtue of the physics of dipole elements, result in wide field imaging and this naturally opens up the possibility for another facility to rather easily undertake "coordinated" observations. Some facilities such as Gaia, Kepler, TESS, Swift/BAT have large FOV and coordinated observing with wide-field ground based facilities can provide unique TDA data. In a similar fashion commensal observing is likely to reshape the use of the VLA. A third development is robotic telescopes. Such telescopes allow astronomers to leverage wide-field imagers (e.g. GRB detectors) with narrow field follow up telescopes (e.g. RAPTOR). Robo-AO has proved its value for the Kepler mission. Ultra-low resolution spectroscopy ($\lambda/\Delta\lambda \approx 100$), if shown to provide reliable spectral classification, can lead to dramatic changes in the field of transient object astronomy.

At optical wavelengths integrating detectors (films, CCDs) have been the sensors of choice. A typical integration time for CCDs (in TDA surveys) is 30 s to 60 s. Apart from some odd balls such as pulsars there are no known sources (nor for that matter, even hints) of more rapid transients and variables. However, the history of modern astronomy consists of astronomers being surprised and astounded by entirely unexpected findings. Nature has had 13.8 Gyr to develop all sorts of weird sources and phenomena and modern astronomical history is only one hundred years old. Fortunately, recent developments now allow for faster sensors (e.g. CMOS, EMCCD) and these in turn open up new phase space for TDA surveys. These technical advances favor smaller surveys (their lower capitalization allows rapid changes) over existing or planned behemoths.

Like many TDA meetings this workshop focuses primarily on data generation and methodologies to accelerate analysis. However, the primary reason why astronomers undertake projects is not to generate data. Data is not equal to understanding. In fact, one may even argue (with reason) that many TDA projects lack proper end-to-end planning. Nonetheless, our excuse for holding this workshop is that TDA is currently in ferment and

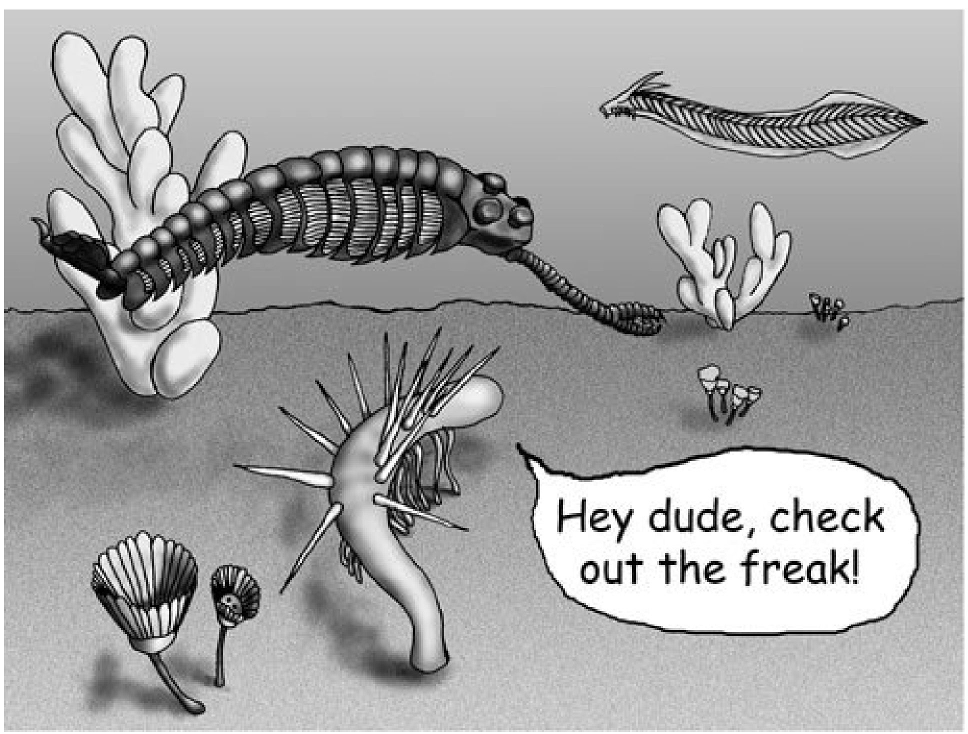
[1]This word is currently radio astronomy street slang. In ecology, commensalism is a class of relationships between two organisms where one organism benefits from the other without affecting it. In this context commensal observing means the same observation can benefit multiple projects.

so a focus on data generation is not unreasonable. However, a future meeting is planned to be held whose focus will be on the science returns and cost-benefit analysis of various TDA projects.

It is rather unfortunate that the timing of the workshop precluded the attendance of several key PIs (who were keen to attend the meeting): Tonry, Chambers and Pollaco. In any case, we hope that this small workshop will catalyze new ideas and take TDA astronomy to dizzying heights over the next few years!

I would like to thank Lars Bildsten for help and guidance in selecting the speakers and invitees, Anna Ho and Vikram Ravi for proof reading and Sterl Phinney for comments. Caltech Optical Observatories provided the financial support for this workshop. I would like to thank Lin Yan, Yi Cao, Bronagh Glaser and Linda Donnelly for help with logistics.

S. R. Kulkarni | August 21, 2015 (v.2)
Pasadena



Tuesday, just after lunch, five hundred and thirty-six million years ago: First appearance of chordates.

Notes to Speakers

The purpose of this workshop is to get discussions going. This is the primary advantage of an in-person meeting (otherwise we could all hear talks as YouTube segments). In order to achieve this singular goal we are making three requests of you.

1. All talks are assigned 20 minutes. We request that you apportion as follows: 15 minutes for the talk and 5 minutes for Q&A. All too often speakers consume their Q&A time – which is a loss to both speaker (feedback from audience) and the audience (inability to engage speaker in new directions).

   So we humbly request that you exercise discipline and finish your talk in 15 minutes.

2. We want the audience to definitely get the big picture. However, an advantage of the meeting is that experts attend and you (the speaker) could get specific feedback. In order to accommodate the needs for both the lay audience and the expert we request that you begin and end your talk with a summary and outstanding issues.

3. We request that you provide us with (i) a 1-page summary (pdf) and (ii) a pdf version of your talk ONE WEEK PRIOR TO THE MEETING. We realize that this request flies in the face of the tradition in our field (namely talks are prepared on airplane en route to the meeting).

   However, having the talk in advance will help students and those who are interested in becoming familiar with the subject ahead of the meeting. This way they are in a better position to -listen- to you rather than being overwhelmed by new content.

   Please take time to write a thoughtful summary. Also it is best if you keep your presentation simple (dynamic tools in the talk do not translate well to pdf file)

ps. We believe that the workshop has value beyond the group attending the workshop. *So we will be videotaping the proceedings and linking the presentations and video proceedings it to the iPTF homepage (following the workshop).* In view of our plans we request that you please use your discretion in what you wish to display in your ppt and what you wish to say in your talk (e.g. unpublished information).

Figure 1: The 18-inch "Schmidt" telescope (P18) was the first telescope at the Palomar Observatory. The moving force behind this project was Fritz Zwicky (pictured above) who was the first astronomer and astrophysicist appointed at Caltech (in anticipation of the 200-inch project). Through fellow astronomer Baade, Zwicky came to learn of a new design that allowed for wide field imaging with a reflecting telescope (Schmidt corrector). To our knowledge P18 was the first astronomical Schmidt telescope to go into operation. The current 48-inch Oschin telescope (P48) at Palomar (famous for the Palomar Observatory Sky Surveys) is the successor to the 18-inch telescope.

Note: Interesting details including vintage photographs and achievements of P18 can be found at `www.astro.caltech.edu/palomar/media/vintagemedia.html` and `www.astro.caltech.edu/palomar/about/telescopes/decommissioned.html#p18const`.

Figure 2: The P18 is now an exhibit at the Museum of the Palomar Observatory. The restoration was made possible by the generosity of astronomer and asteroid hunter par excellence Dr. "Glo" Helin. The Museum and the Observatory are well worth a visit!

Notes to Readers

What follows in this brochure are 1-page summaries provided by the speakers which in most cases were provided *ahead of the meeting*. The participants were expected to have read the abstracts (and viewed presentations, if available) also ahead of the meeting. The logic was that the participants would become sufficiently familiar with the basic material and thus focus on the more subtle or substantive issues. Following the meeting the collection of presentations will be available at the following URL: `http://www.ptf.caltech.edu/page/meetings/BoutiquesExperiments2015.html`

Figure 3: Fritz Zwicky (left) and Walter Baade (right). Several astronomers had recognized that some novae were much brighter than the well studied (Galactic) novae and had suggested names (giant nova, exceptional nova and Hauptnova). However, in a seminal paper in 1934 Baade & Zwicky clarified the distinction between routine novae and the brighter nova (and found in other galaxies, routinely) and called the latter "supernova" [see D. Osterbrock, BAAS 33, 1330 (2001)].

"I soon became convinced... that all the theorizing would be empty brain exercise and therefore a waste of time unless one first ascertained what the population of the universe really consists of."

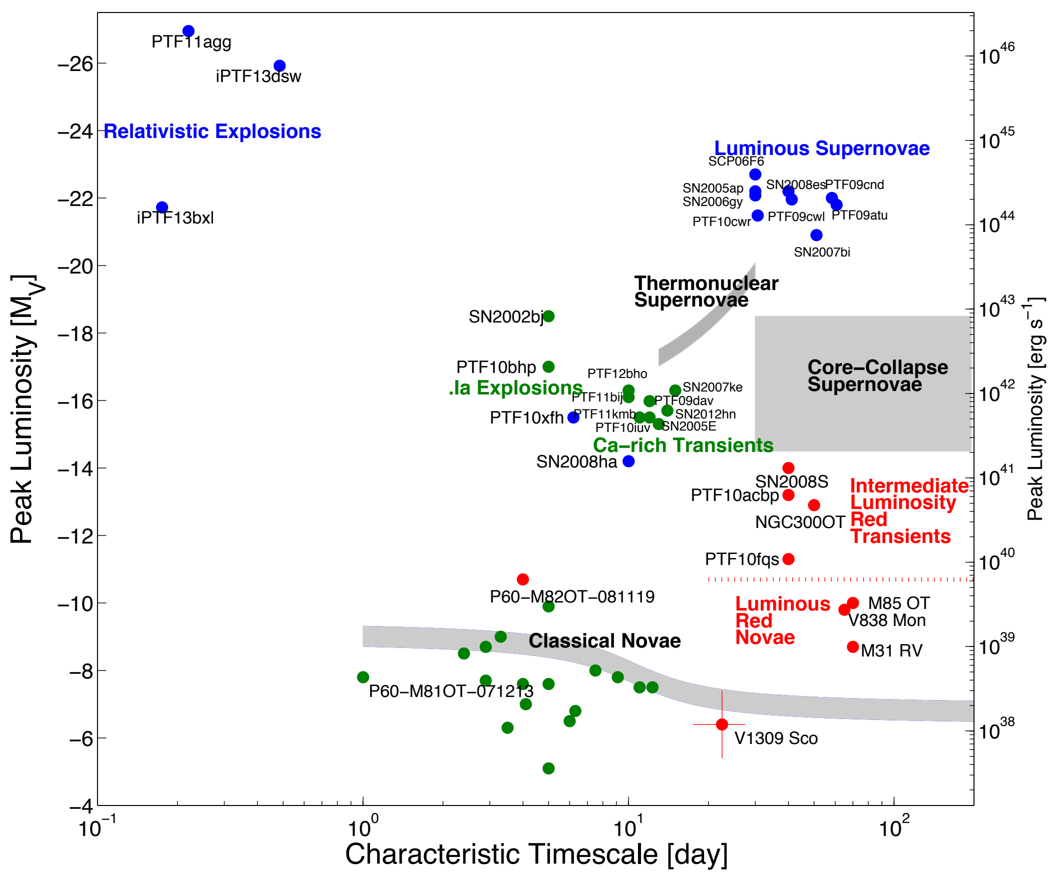


Figure 4: Phase space of cosmic explosions. The clear distinction between "classical" novae and "super-novae" of Baade & Zwicky has now been blurred by the discovery of several classes and sub-types of supernovae and entirely new classes of explosions such as gamma-ray bursts, stellar mergers and super luminous supernovae. Figure provided by M. Kasliwal

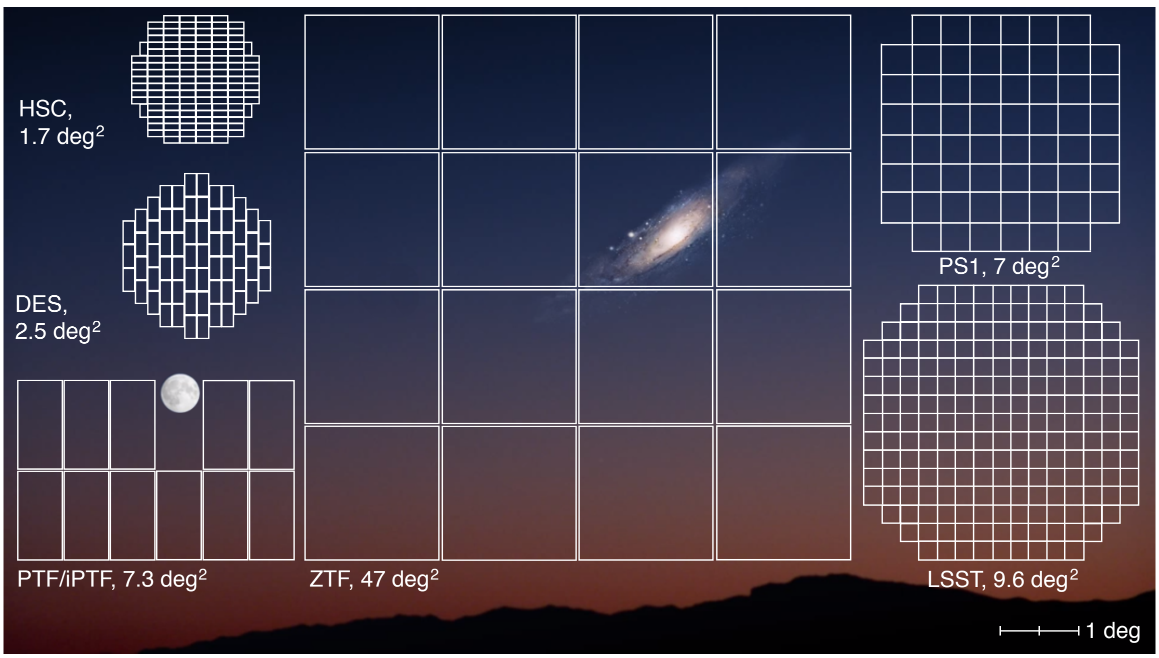


Figure 5: A schematic view of some of the large astronomical imagers: Hyper-Suprime Camera (HSC), Dark Energy Survey (DES), Palomar Transient Factory (PTF), Zwicky Transient Facility (ZTF), PanSTARSS (PS) and Large Synoptic Survey Telescope (LSST). Figure provided by J. Johansson, OKC, Sweden.

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Hyper-Suprime Camera (HSC), with a field-of-view of 1.5 degrees, is a formidable imager. It is mounted at the prime focus of the Subaru 8.2-m telescope. The sensor is a 116-mosaic of red-sensitive CCDs supplied by Hamamatsu Photonics.The imaging camera is impressive: the diameter of the first lens is 82 cm and the the length of the lens barrel (seven lenses) is 165 cm (and weighs nearly a metric ton!). The point spread function delivered by this imager is smaller than 0.2 arc-sec (FWHM) in worst case which is the would sharpest lens among this class of the corrector lens for astronomy.

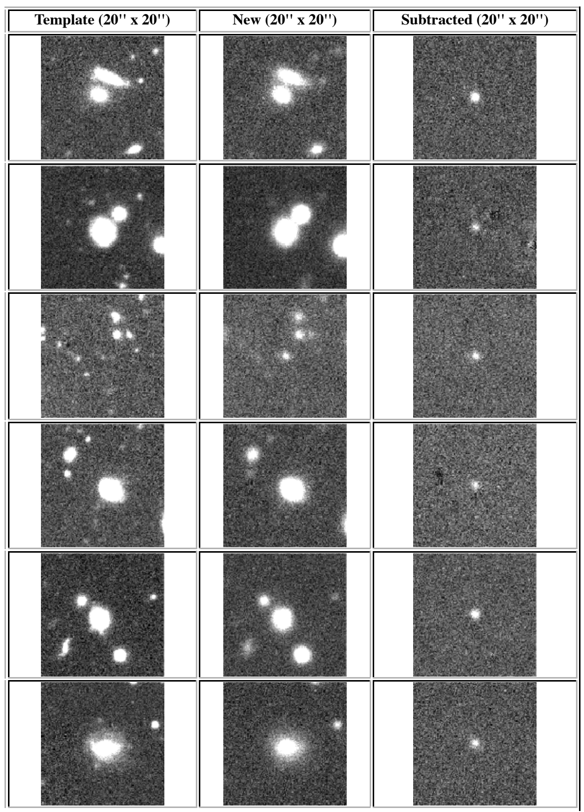


Figure 6: Ten supernovae candidates (of which we display only seven) identified from a single night of observations with the HSC. The excerpt from Atel#7297 (dated 19 August 2015) reads as follows "... *Our Subaru/HSC open-use observations were performed on 19 Aug 2015 UT, under poor weather condition with 1.1-1.5 arcsec seeing. The candidates were detected in real time using a quick image subtraction system (ATel #6291). Candidate screening was performed by incorporating machine learning techniques into the system. The reference images were obtained with HSC on 2 and 3 Jul 2014 UT."*

Chapter 1

Session A: Ongoing Projects

A.1 Evryscope (Most of the Sky, All Night Long) by N. Law

A.2 PanSTARRS (Two Powerful Imagers At Once) by H. Flewelling

A.3 PTF, ZTF (Systematic Exploration of Night Sky) by E. Bellm

A.4 TDA with DECAM (LSST LITE) by A. Rest

A.5 ASAS-SN (The Night Sky, Once a Night) by B. Shappee

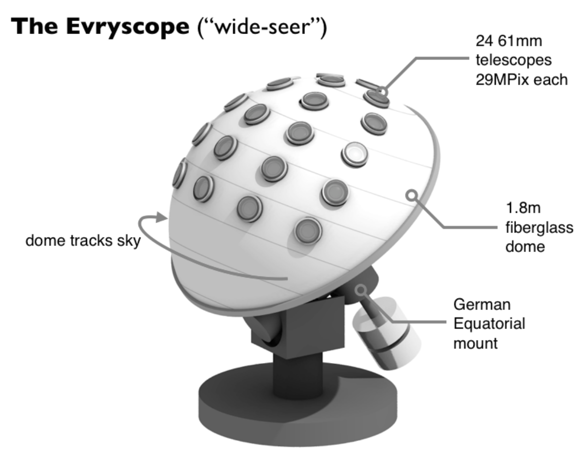


Figure 1.1: Schematic representation of Evyrscope. This instrument aims, using a large number of smaller imagers, to cover the entire night sky, at any given instant. Figure supplied by N. Law.

The Evryscope: the first full-sky gigapixel-scale telescope

The Evryscope is a new type of telescope which covers the entire accessible sky in each exposure. Its 8000-square-degree field-of-view 691 MPix telescope is sensitive to exoplanet transits and other short timescale events not discernible from existing large-sky-area astronomical surveys. The telescope, which places 27 separate individual telescopes into a common mount which tracks the entire accessible sky with only one moving part, is building 1%-precision, many-year-length, high- cadence light curves for every accessible object brighter than ~ 16th magnitude. The camera readout times are short enough to provide near-continuous observing, with a 97% survey time efficiency. The Evryscope has the largest survey grasp of any current ground-based survey, and is the only existing survey within an order of magnitude of LSST's étendue.

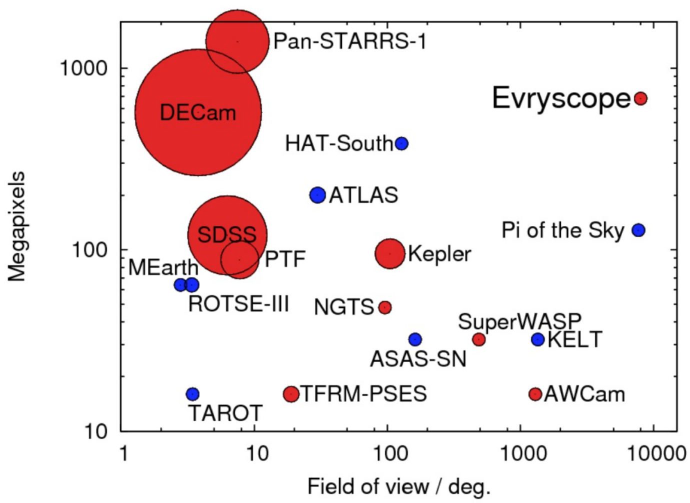


Figure 1: The Evryscope's unique location among operating sky surveys, covering an order of magnitude in FoV and data rate. Points are sized by telescope aperture (with a minimum size for the small apertures, for visibility). Red and blue points are single- and multiple-site surveys, respectively.

The Evryscope is producing a night-by-night, two-minute-cadence, record of all Southern sky events down to at least 16th magnitude, enabling searches for rapid-timescale variability phenomena ranging from exoplanet transits to gamma-ray-bursts; its enormous field of view allows us to simultaneously monitor very large numbers of targets that would otherwise require individual targeting by dedicated telescopes. The system is sensitive to transiting exoplanets around white dwarfs, M-dwarfs, and the nearest and brightest stars, and is the first to be able to rapidly monitor most of the sky for nearby-star microlensing events. The Evryscope obtains precise and high-cadence eclipse timing for all Southern eclipsing binaries brighter than 16th magnitude, simultaneously monitors a host of compact-object pulsation and accretion phenomena, and is searching for young stars by their photometric activity. When relatively rare transients events occur, such as gamma-ray bursts (GRBs), nearby supernovae, or even gravitational wave detections from the Advanced LIGO/Virgo network, the telescope will return minute-by-minute light curves and upper limits without needing pointing towards the event as it occurs. By co-adding images, the system will reach V~19 in one-hour integrations, enabling the monitoring of faint objects. Finally, by recording all data, the Evryscope will be able to provide pre-event imaging at two-minute cadence for bright transients and variable objects, enabling the first high-cadence searches for optical variability before, during and after rapid events detected at other wavelengths.

We deployed the Evryscope, funded by NSF/ATI, at CTIO in late May 2015. The system has already produced hundreds of thousands of images and over 20TB of data, is meeting our image quality goals, and is achieving at least 5 mmag photometric precision in light curves. As we build the data analysis systems for the first Evryscope, we are also developing designs for further systems: an Antarctic Evryscope which takes advantage of the continuous winter darkness to achieve much higher detection efficiency for long-period exoplanets; a world-wide network of telescopes which could cover most of the entire sky continuously 24 hours-a-day; and larger-aperture systems which would be capable of rapidly detecting faint extragalactic events.

Notes for Law's talk (abstract on opposing page)

PanSTARRS (Two Powerful Imagers At Once)

Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) is a set of 2 wide field survey telescopes each with the largest digital cameras ever built. This talk will describe the characteristics of the 2 telescopes, the PS1 survey which just completed as well as some information about the public data release, and the ongoing PS1 + PS2 NEO survey.

Pan-STARRS1 (PS1) is a 1.8 m Ritchey-Chretien telescope with a 7 square degree field of view, a 1.4 gigapixel camera, ~0.25 arcsec pixels, average seeing of 1 arcsec, and is located at Haleakala, Hawaii. PS1 uses g,r,i,z,y,w filters, these are similar to the SDSS filters. It has been in operation since 2009.

Pan-STARRS2 (PS2) is very similar in design, with similar optics, filters and camera, and is currently in commissioning. It is located next to PS1, and shares the support building.

PS1 Survey (2009-2014)

During 2009 and 2014, PS1 surveyed the skies in order to do key science projects spanning from the inner solar system to the large scale structure of the universe. There are several surveys, but the majority of the observing time was spent on the 3pi and Medium Deep surveys, and so I will focus on those.

The 3pi survey, done in g,r,i,z, and y filters, covers 3/4ths of the sky and everything with a declination greater than -30 degrees. The median 10 sigma depths for this survey are between 20.5 and 22.5, depending on the filters. This survey provides precision photometry and astrometry with accuracies below the 1% level.

The Medium Deep survey consists of 10 fields with cadence and exposure times chosen primarily for supernovae searches, but can be used for other time domain astronomy. This survey is done in g,r,i,z,y bands, with long (120-240s) exposures. A sequence of 8 exposures per filter, a few filters per night is done for the medium deep fields that are currently visible. Five sigma depths for stacks ranges between ~24^{th} and ~26^{th} mag. Data from the 3pi and the Medium Deep survey will be publicly released soon, and will be available from STScI. The pixels will be available through MAST and there will be a query-able database (similar to SDSS Sky Server).

Science results from PS1 survey are too many to count, and impossible to describe in a 15 minute talk. Please search for Pan-STARRS on NASA ADS for more information.

PS1+PS2 NEO Survey (2014-2017)

Currently PS1 and PS2 are focused on finding NEOs. The survey is done in w band, covering 26,000 square degrees and excludes the galactic plane and the ecliptic poles. According to MPC (http://www.minorplanetcenter.net/iau/lists/YearlyBreakdown.html), PS1 has found 2/3rds of all of the PHAs discovered in 2015, and PS2 has found a PHA, a comet, and several other asteroids and NEOs while in commissioning.

Notes for Flewelling's talk (abstract on opposing page)

PTF & ZTF: Systematic Exploration of the Night Sky

Eric Bellm

From its inception in 2009, the Palomar Transient Factory (PTF) has sought to explore untapped areas of time-domain astronomy. The original PTF survey prioritized simplicity and spectroscopy: it used a secondhand camera on the Palomar 48" Schmidt telescope, observed mainly in a single filter, and used an extensive but ad-hoc network of larger telescopes for followup.

The returns on this strategy proved remarkable. The headlining discovery was of PTF 11kly (SN 2011fe), the youngest Type Ia supernova ever observed. PTF's blind survey strategy also helped identify several new classes of transients in the peak magnitude–decay timescale phase space, including superluminous supernovae, Ca-rich gap transients, and the unusual fast-decaying transient PTF 11agg.

The Intermediate Palomar Transient Factory (iPTF) era (2013–present) has featured continual improvements in pipeline algorithms and data processing. The survey has pursued focused observing programs at specific cadences. An emphasis on high-cadence observations with same-night spectroscopic followup has lowered the raw transient discovery rate, as less sky area is observed nightly, but has opened new scientific frontiers. With iPTF 13ast (SN 2013cu), iPTF pioneered "flash spectroscopy" of core-collapse supernovae, identifying fast-fading spectral signatures of the supernovae progenitor in its ionized circumstellar wind. High cadence observations likewise enabled the discovery of iPTF 14yb, the first gamma-ray burst discovered without a high-energy trigger.

With an ever-growing database of well-calibrated photometry, the PTF dataset has shown increasing value for studies of variable sources and solar system objects. Productive uses have included searches for Galactic Halo substructure with RR Lyrae tracers, identification of large samples of Young Stellar Objects, and creation of the largest sample of asteroid rotation periods. iPTF has also embarked on a systematic variability survey of the Northern Galactic Plane, already the largest extant, laying the groundwork for a wide variety of stellar and compact binary science.

In 2017, the Zwicky Transient Facility (ZTF) survey will commence using a purpose-built camera designed to maximize the survey speed possible with the 48". Sixteen wafer-scale CCDs combined with fast readout electronics will provide an instantaneous field of view of 47 deg^2 and more than an order of magnitude increase in survey speed relative to PTF. This enhanced capability will enable ZTF to find the fast and the rare by observing at high cadence while maintaining wide areal coverage.

ZTF will discover a supernova less than 24 hours after explosion every night it surveys, identify tens of relativistic transients each year, and perform systematic searches for electromagnetic counterparts to gravitational wave detections. With hundreds of epochs in each field per year across the entire Northern sky, ZTF will be a premiere dataset for variability studies and enable a highly sensitive search for streaking Near Earth Asteroids.

As new surveys, including ZTF, ATLAS, and Evryscope, are now capable of surveying the entire visible sky in a single night, essentially all slow, bright transients will be quickly identified. Increasing survey depth is thus the only means of increasing the raw discovery rate, but the fainter transients discovered this way are less useful due to their costly followup. New and creative approaches will be needed to find productive niches in the years ahead.

Notes for Bellm's talk (abstract on opposing page)

TDA with DECam

DECam is the only publically available wide-field imager on a medium-size telescope in the southern hemisphere. I'll describe some of the exciting time-domain projects that are now possible with targeted, purposed surveys using this new capability.

Light Echoes of Historic Supernovae (SNe) and Eruptions: We have discovered light echoes of 3 SN Ia in the LMC, the Cas A SN, Tycho's SN, and Eta Car's Great Eruption. With the spectra of these light echoes, we can determine the type of explosion. In addition, LEs offer the unique opportunity to observe the same event from different lines of sight, providing a direct probe of the asymmetry of the explosion. A ``sweet spot'' search area for finding light echoes, where the echoes are expected to be brightest due to a more favorable combination of geometry and forward scattering efficiency, is for a scattering angle smaller than 135 degree. This search area depends on the age of the SN and its distance, and varies widely from SN to SN. With DECam, we are now able to search for light echoes of historic supernova with large search areas, like RCW 86, SN 1006, and Crab Nebula.

High cadence SN light curves with the Kepler Telescope: The 30-min cadence of Kepler Telescope observations provide the best rise-time information ever obtained for a thermonuclear supernova and tightly constrain the shock breakout of a core collapse event. No current or planned supernova search will have the cadence and continuous coverage that we have, which is essential for the detection and study of the first hours after a supernova explosion. Kepler data is downloaded with a significant delay (sometimes upwards of 6 months), limiting quick detection of the SN and subsequent triggering of follow-up. To circumvent this problem, we use DECam to monitor the galaxies every 2-3 days. This allows us to detect the SN early, so that we can trigger subsequent ground-based follow-up in a useful time frame.

LIGO Gravitational Waves Follow-up: The first science run of the Advanced LIGO/Virgo detector network is scheduled for Sep–Dec 2015 and may lead to the first direct detection of gravitational waves (GW) from compact-object binary mergers. In the current configuration, NS-NS mergers will be detectable to $\approx$ 80 Mpc with a localization of $\sim$ 200 deg^2. The most promising electro-magnetic counterpart is a "kilonova" – an optical transient powered by the radioactive decay of r-process elements synthesized in the merger ejecta. At 80 Mpc kilonovae are expected to be dim and fast-evolving, requiring large wide-field telescopes for detection in the large localization region. DECam is the only instrument in the southern hemisphere capable of such follow-up.

High-redshift Superluminous SNe (SLSNe): SLSNe are a recently discovered class of astrophysical transient with absolute magnitudes in the range -21 to -23, some 50 times brighter than normal supernova types. Ongoing transient searches in their current design are unable to detect many SLSN events due to their rarity and long duration light-curves. SUDDS, a DECam survey, will provide a large sample of these events. The improved quality and quantity of light curves and spectroscopy will allow us to probe the theories of the their origin, and constrain their progenitors.

Notes for Rest's talk (abstract on opposing page)

The All-Sky Automated Survey for Supernovae

There is no optical survey that frequently images and records the entire celestial sphere (both northern and southern hemispheres), seeking out the transient, variable, and sometimes violent events that mark the evolution and transformation of our Universe. We are changing that with our "All-Sky Automated Survey for Supernovae" (ASAS-SN), which automatically surveys the entire visible sky every other night and is already producing a steady stream of discoveries.

The major scientific goal of ASAS-SN is to produce the first complete and unbiased census of bright, nearby supernovae, and to study these events in detail. Supernovae are extremely important in many areas of astrophysics (massive star evolution; galaxy formation and evolution, including chemical enrichment; dark energy etc.), and yet we do not have a good understanding of their progenitor stars and their explosion mechanisms. Bright and nearby SNe, discovered early by our high-cadence survey, are especially valuable, as they and their host galaxies are easy to study using relatively modest size, 1-m to 4-m diameter telescopes. As shown in Figure 1, ASAS-SN is discovering almost two-thirds of all the bright ($<$ 17 mag) SNe on the sky, and recovering most of the remaining. ASAS-SN's has currently discovered 208 SNe: 158 Type Ia, 38 Type II, 8 Type Ib/Ic, 3 Untyped and the most luminous SLSN ever discovered (Dong et al. 2015). Finally, ASAS-SN discovered the nearby and bright Type Ia ASASSN-14lp, detecting it less than day after first light (Shappee et al. 2015).

By virtue of simply observing the sky, ASAS-SN has also proven to be a gold mine for both Galactic and extragalactic, non-SN transients. We have discovered 475+ new cataclysmic variables (CVs), detected many hundreds of outbursts of known CVs, 41 strong M-dwarf flares (with $\Delta V \gtrsim 4$), many strong blazar and AGN outbursts, and the three closest candidate tidal disruption event (TDE) discovered to date at optical wavelengths. Based on these discoveries, we have published papers on the unusual AGN outburst in NGC 2617 (Shappee et al. 2014a), two extreme ΔV $\sim$ 9 mag M-dwarf flares (Schmidt et al. 2014, Simonian et al. 2014), a rare EX Lupi-type accretion event (Holoien et al. 2014c), ASASSN-14ae, a candidate TDE at roughly 200 Mpc (Holoien et al. 2014a), ASASSN-14li, a candidate TDE at roughly 90 Mpc (Holoien et al. 2015).

ASAS-SN transients are discovered and announced in real-time to the astronomical community, through our transients website, ASAS-SN Twitter feed, VSNET alerts, and ATels.

There are other projects, current or planned, to survey the variable sky, but none offer the combination of sky coverage, survey depth, saturation magnitude, ease of study, time sampling, and fully automated pipeline that ASAS-SN has, and some are at least one (e.g., ZTF) or two (e.g., LSST) orders of magnitude more expensive to build, to operate and, perhaps most importantly, to follow-up. As such, I expect ASAS-SN to be on the cutting edge of scientific discovery for many years to come, especially given our flexible and modular approach to studying the variable universe, and our dedication to eventually making all of our data public in real time.

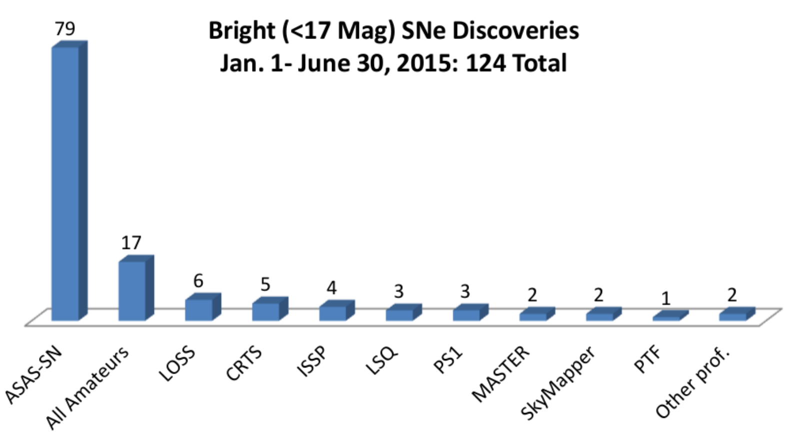


Figure 1: Number of supernova discoveries with $V \lesssim 17$ mag, from January to June 30 2015, by different surveys, including amateur astronomers.

Notes for Shappee's talk (abstract on opposing page)

"To eliminate the discrepancy between men's plans and the results achieved, a new approach is necessary. Morphological thinking suggests that this new approach cannot be realized through increased teaching of specialized knowledge. This morphological analysis suggests that the essential fact has been overlooked that every human is potentially a genius. Education and dissemination of knowledge must assume a form which allows each student to absorb whatever develops his own genius, lest he become frustrated. The same outlook applies to the genius of the peoples as a whole."

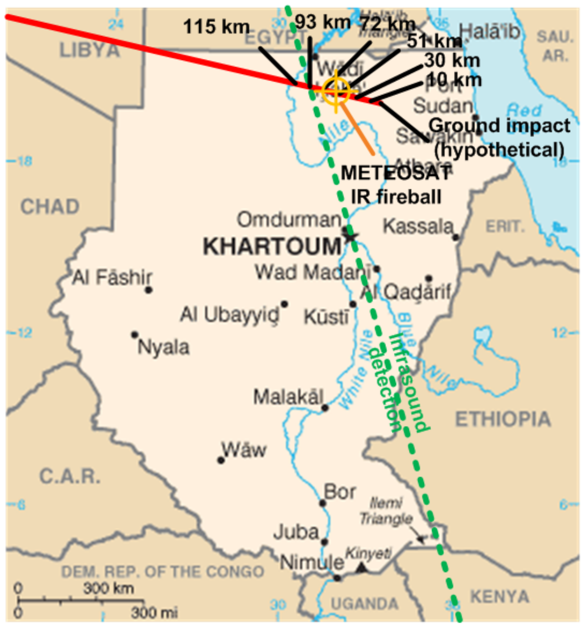


Figure 1.2: The entry path of NEA 2008TC$_3$. This is the first time that an asteroid impact was predicted to good precision prior to entry into our atmosphere. 2008TC$_3$, identified by the Catalina Sky Survey, entered Earth's atmosphere on October 7, 2008 and exploded at an estimated attitude of 37 km above the Nubian Desert in the then country of Sudan. Some 600 meteorites weighing a total of 10.5 kg (out of an estimated 80 tons) were recovered. As noted in the `Wikipedia` "many of these belonged to a rare type known as ureilites, which contain, among other minerals, nanodiamonds." In detail "586 astrometric and almost as many photometric observations were performed by 27 amateur and professional observers in less than 19 hours and reported to the Minor Planet Center, which issued 25 Minor Planet Electronic Circulars with new orbit solutions in eleven hours as observations poured in." By any metric this was the cheapest Sample Return Mission!

Chapter 2

Session B: Boutiques

B.1 Low Surface Brightness (Dragonfly) by P. van Dokkum

B.2 Narrow Band Survey (PTF/Hα) by D. Cook

B.3 Catalina Sky Survey (NEOs and Public Transients) by A. Mahabal

B.4 Rapid Response (Raptor Responds) by T. Vestrand

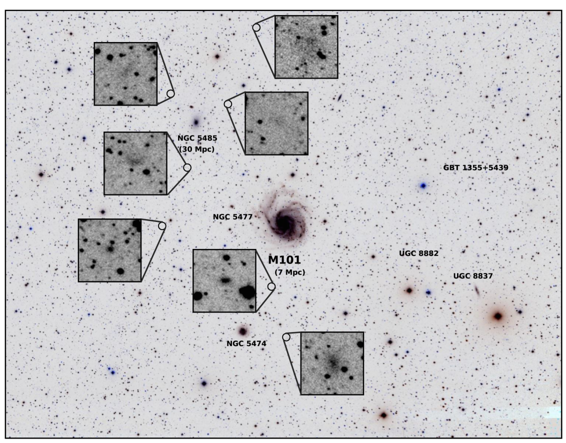


Figure 2.1: Discovery of faint galaxies made by the Dragonfly robotic telephoto facility (located near Cloudcroft, NM). Eight Canon telephoto lenses are co-mounted and co-pointed, each with its own science-grade commercial CCDs. The FOV is 2.6° × 1.9° and equivalent aperture is 40 cm. Figure provided by A. Merritt.

The Dragonfly Telephoto Array

Pieter van Dokkum, Roberto Abraham, Allison Merritt, JieLai Zhang

In the past ~40 years there has been tremendous improvement in our ability to detect the light of point sources. Owing to increases of the size of telescopes, placing them in orbit, and (particularly) the evolution from photographic plates to CCDs, the limiting magnitude for imaging has gone from ~25 to ~30 and for spectroscopy from ~21 to ~26. However, this factor of 100 increase in point source sensitivity has not been matched by an equivalent increase in sensitivity to low surface brightness emission: photographic plates in the 1970s reached ~29 mag arcsec^{-2}, and this has remained the practical limit of standard telescopes. The science that lies just beyond is rich: we could discover and characterize the faintest dwarf galaxies, measure the stellar halos and tidal streams around galaxies to similar limits as from Local Group star counts, as well as study Galactic cirrus, intracluster light, comets, and light echoes from supernovae in an entirely new regime.

The reasons for the lack of progress in reaching fainter limits have to do with the dynamic range of the night sky emission, combined with the design choices that make large telescopes possible. The use of mirrors rather than lenses, and large secondary mirror assemblies which obstruct the light path, conspire to create complicated point spread functions (PSFs). As shown in Slater et al. (2009), even with the best reflecting telescopes, the wings of the PSFs of stars and galaxies essentially cover the entire sky beyond ~29.5 mag arcsec^{-2}.

We have constructed a telescope, the Dragonfly Telephoto Array (Abraham & van Dokkum 2014), that is optimized for the detection of spatially-extended low surface brightness emission. The array consists of high-end telephoto lenses, which have perfect baffling, do not suffer from the scattering (due to dust and microroughness) associated with mirrors, and have an unobstructed light path. Furthermore, the latest generation of these lenses have sub-wavelength nano-fabricated optical coatings which minimize scattered light and ghosting. As shown in Abraham & van Dokkum (2014), the Dragonfly PSF has wings that are a factor of ~10 reduced compared to those of the best reflecting telescopes, enabling imaging down to ~32 mag arcsec^{-2} (or beyond, with careful PSF modeling and subtraction). We are presently completing a survey of the companions and stellar halos of galaxies in an attempt to address both the “missing satellite” and “missing substructure” problems of galaxy formation, and to explore the disk-halo interface.

Currently the array consists of 10 Canon 400 mm f/2.8 II lenses, and “behaves” as a refractor with a 45 cm aperture, a focal ratio of 0.89, and a field of view of 6 square degrees. It is fully robotic and semi-autonomous, and is operating every clear night at the New Mexico Skies telescope facility. Early results include the discoveries of seven new dwarfs around M101, the lack of a stellar halo around that galaxy, and a large population of “ultra diffuse” galaxies in the Coma cluster (UDGs have morphologies like dwarf spheroidals but sizes like the Milky Way). We are in the process of upgrading the array to ~50 lenses, which will turn it into the largest refractor in existence (with an aperture of 101 cm and an extremely fast focal ratio of 0.40).

Notes for van Dokkum's talk (abstract on opposing page)

Census of the Local Universe (CLU)

The Palomar Transient Factory has been undertaking the CLU survey to complete our census of galaxies in the local universe out to 200 Mpc. CLU deploys four contiguous narrow-band filters to search for extended, emission line (Hα) sources across 3π of the sky. The estimated 5σ limiting flux for a point source is 2×10^{-17} erg s^{-1} cm^{-2} (Rau et al., 2009), which corresponds to a SFR of $\sim 10^{-4}$ M$_\odot$ yr^{-1} at a distance of 200 Mpc; given the prescription of Kennicutt (1998). Thus, the CLU galaxy catalog will capture 85% of the B-band light and 92% of the Hα luminosity out to 200 Mpc.

CLU assists the discovery of local Universe transients by providing a secure host galaxy redshift range to channel follow-up. For example, if a candidate transient is spatially coincident with a CLU galaxy, we could infer its luminosity and hence, distinguish a rare, young supernova from an old, background supernova. Nearby galaxies occupy less than 1% of the area on sky. Thus, when searching for electromagnetic counterparts in coarse localizations of hundreds of square degrees (e.g., gravitational wave triggers from advanced LIGO), CLU can promptly narrow-down the list of candidate counterparts by over two orders of magnitude.

CLU will also advance our understanding of galaxy evolution by providing a more accurate anchor point for the local star formation rate density (ρ). Emission line studies of nearby and high redshift galaxy have found that the ρ increases with redshift until z$\sim$1$-$2 and then plateaus or decreases (Lilly et al., 1996). A major source of scatter on this relationship derives from cosmic variance in studies probing small volumes of space. The CLU local SFR measurement will be derived from the largest area on the sky yet studied in the nearby universe, thus providing a robust anchor point for the relationship between cosmic SFR density and redshift. In addition, matching CLU and GALEX sources will better constrain the discrepancy between Hα- and UV-derived SFRs in low-SFR galaxies (Lee et al., 2009; Meurer et al., 2009) by adding many more low-SFR galaxies. Better number statistics in the low-SFR regime may help to discriminate between different theories proposed to account for these SFR discrepancies, which will have implications on the stellar IMF, stellar population models, and luminosity-derived physical properties of galaxies.

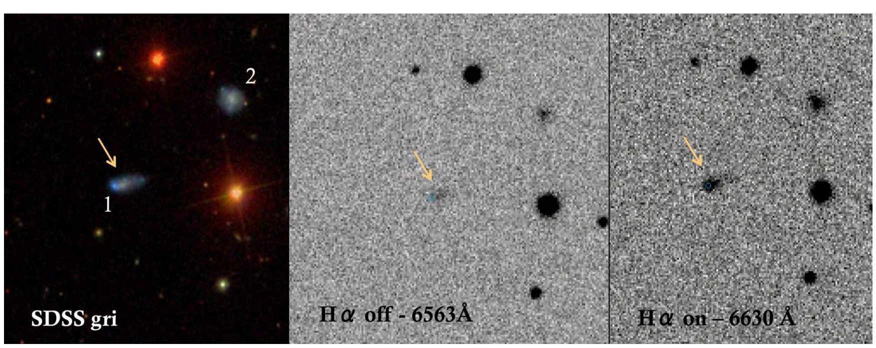


Figure 1: Two newly discovered nearby galaxies in the Census of Local Universe (CLU) narrow-band survey. Shown above (left-to-right) is the SDSS gri color composite, the PTF Hα-off image (z$\sim$0, 6563Å), and the PTF Hα-on image (z$\sim$0.01, 6630Å). The galaxy marked with an arrow was spectroscopically confirmed to be at z=0.015 with SDSS/BOSS. CLU will uncover tens of thousands of nearby galaxies out to z=0.05 using a four filter narrow-band survey with PTF.

Notes for Cook's talk (abstract on opposing page)

Catalina Sky Survey and Catalina Real-time Transient Survey

The Catalina Sky Survey (CSS; PI: Eric Christensen, UA/LPL) searches for Near Earth Objects (NEOs). It has been a very highly successful survey finding close to 6000 NEOs so far, almost half of all known, and continues to find about two per day. It is the only survey that has discovered Earth-impacting asteroids before the impact (2008 TC3 and 2014 AA, both ~3m in diameter). Currently two telescopes are used by the CSS: the 0.7m Schmidt at Mt. Bigelow and the 1.5m Prime Focus telescope at Mt. Lemmon, both in Arizona, US. For several years, the 0.5m Uppsala Schmidt at Siding Spring telescope in Australia was used to cover the Southern hemisphere. CSS uses unfiltered CCDs, and is roughly calibrated to the V band. The current 4kx4k CCDs are soon to be replaced by 10.5kx10.5k CCDs increasing the FOV from 1.2 sq. deg to 5.0 (Mt. Lemmon) and 8.2 sq. deg. to 19.4 (Mt. Bigelow). A remotely operated 1.0m telescope is used for NEO astrometric follow-up. The survey operates by taking 4 images separated by 10 min for a set of fields, and revisits them on the tim scales ranging from days to years.

The Catalina Real-time Transient Survey (CRTS; PIs: S. George Djorgovski and Andrew Drake; Caltech), started in 2007, uses the same data streams to search for astrophysical transients and variables outside the Solar system. CRTS has so far discovered over 10,000 high-amplitude transients (http://crts.caltech.edu/), while monitoring the brightness of some 500 million sources over a total area of over 33000 sq. deg, with time baselines of up to 10 years, and typically a few hundred epochs per pointing. In order to maximize the scientific returns and benefits for the entire community, CRTS has an open data policy: all transients are published in real time as VOEvents, and all data are publicly available through the survey website, and from IUCAA, in Pune, India (http://crts.iucaa.in).

Among the high amplitude transients, CRTS has discovered thousands of SNe, including a number of hyper-luminous or otherwise peculiar events, thousands of CVs, and other types of flaring sources. In addition, archival studies have been used to discover tens of thousands of periodic variable stars, including RR Lyrae of all sub-types, used to map the Galactic halo, Long Period Variables, AGNs, discovery of a characteristic time of stochastic quasar variability, and periodically variable quasars, which are candidates for binary supermassive black holes. There are orders of magnitude more low-amplitude variables of all types.

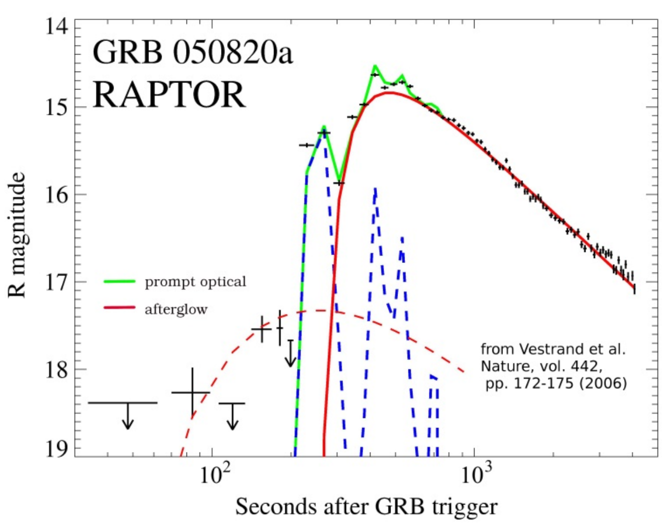
Automated classification of transients and light-curves of variable sources is critical for optimizing the scientific returns from synoptic sky surveys. We employ a variety of domain-knowledge informed features to go with the large number of characterization and classification techniques we use. These include Decision Trees, Random Forests, Bayesian Networks, Probabilistic Structure Functions, Symbolic Regression, and various feature selection methods. We have been also working on applying domain adaptation techniques to diverse datasets (surveys/domains) e.g. CRTS, LINEAR, and PTF for richer and quicker returns from newer datasets.

Notes for Mahabal's talk (abstract on opposing page)

*RAP*id *T*elescopes for *O*ptical *R*esponse (RAPTOR): Shaving off response seconds can enable discoveries

The RAPTOR telescope program at Los Alamos National Laboratory is a "boutique effort" in the sense that it has to make drastic design choices that are driven by the goal of observing astrophysical explosions as fast as possible while meeting the tight financial constraints imposed by a small budget. Our primary scientific focus is the measurement of optical emission from gamma-ray bursts (GRBs), with a particular emphasis on observations while the gamma-rays are being emitted. GRBs can arrive from any direction, at any time, and most have durations of less than 100 seconds. The Burst Alert Telescope (BAT) on NASA's Swift satellite currently provides the best real-time GRB alerts; providing high precision localization (< 4 arcmin) with temporal latencies of ~20 seconds. So, to have a reasonable chance of observing the optical emission during the gamma-ray emitting interval, one needs to construct a telescope that is capable of slewing to any point in the sky and observing in less than ~10 seconds after receipt of GRB localization. To meet that goal, one has to construct telescopes that accelerate/decelerate and slew at rates that are about 10 times faster than conventional fast slewing telescopes. And, since human operators are just too slow, the telescopes must be autonomous robots.

RAPTOR employs a telescope ecosystem approach to the follow-up of cosmic explosions. The workhorse follow-up telescopes in the ecosystem are RAPTOR-S, RAPTOR-T, and RAPTOR-Z. All three employ 0.4-0.5 meter telescope tubes and are carried on mounts that can slew at 30 deg/sec, accelerate at 30 deg/sec^2, and start observing the GRB in less than six seconds. RAPTOR-T employs four co-aligned 0.4-m telescopes with synchronized imagers that collect simultaneous 4-color Sloan filter (g'r'i'z') photometry. And, RAPTORs S and Z collect high-cadence photometry and (soon) polarization measurements. The rapid response measurements are complimented by observations from four full-sky persistent monitors, with a 3σ sensitivity of R≈10 mag. in 10 seconds, located in New Mexico, Hawaii, and on Kwajalein Atoll. These monitors, which cover the full Swift field-of-view, allow us to search for both bright emission before the response telescopes are on target and for precursor emission before the GRB trigger.



Observations taken during the prompt gamma-ray emitting interval have revealed two distinct components of the optical emission: (1) so-called "prompt" optical emission correlated with prompt gamma-ray emission, and (2) early optical afterglow emission uncorrelated with the prompt gamma-ray emission. In context of the standard fireball model, the prompt optical emission is attributed to internal shocks in an ultra-relativistic jet outflow generated by the central engine and the afterglow emission to external shocks generated by interaction with the surrounding medium. The prompt optical emission therefore reflects the impulsive energy injection into the jet and the early afterglow emission measures the response of the jet/environment system to the energy injection. Exploring the color evolution, polarization evolution, and temporal lags between the prompt optical and gamma components provide important probes of the GRB engine and the nature of the ultra-relativistic jet.

Notes for Vestrand's talk (abstract on opposing page)

"I have a good idea every two years. Give me a topic, I will give you the idea!"

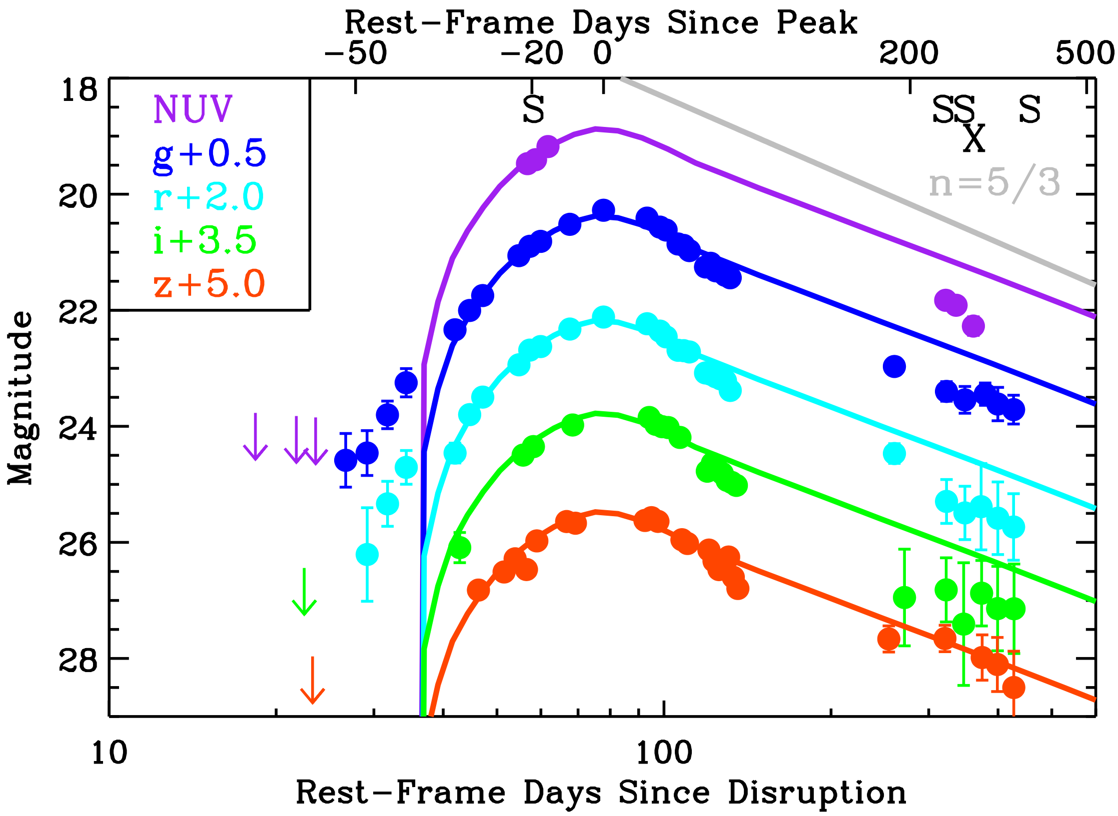


Figure 2.2: The optical and Galex/UV light curves of PS1-10jh, a transient widely regarded as a benchmark of tidal disruption events. PanSTARRS-1 (PS-1) and the UV mission Galex undertook coordinated observations. The 3-day cadence of the PS1 Medium-deep survey and the characteristic strong UV emission greatly aided the discovery and follow up of PS1-10jh. From Gezari et al. (Nature, 2012).

Chapter 3

Session C: Theorists Dream

C.1 Exploring the boundary between neutron stasr and blackh holes by T. Piro

C.2 AICs: What we know and, maybe, how to find them by J. Schwab

C.3 New stellar insights from precision SNe data by L. Bildsten

C.4 Breaking News: The Dynamic Thermal IR Sky by M. Kasliwal

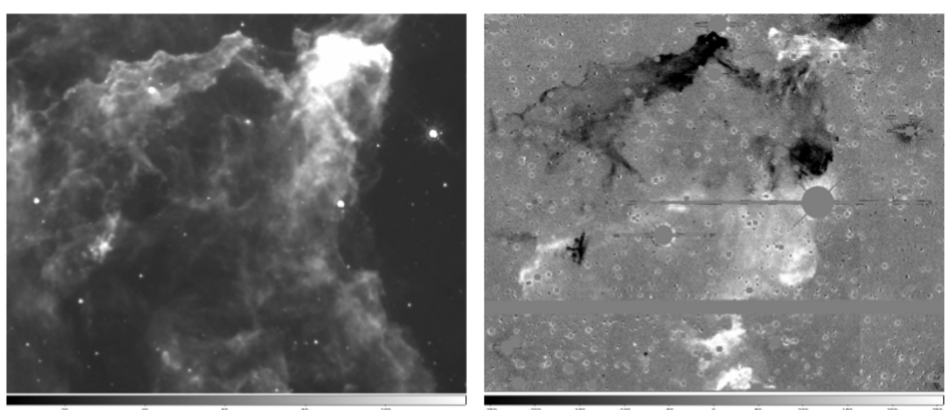


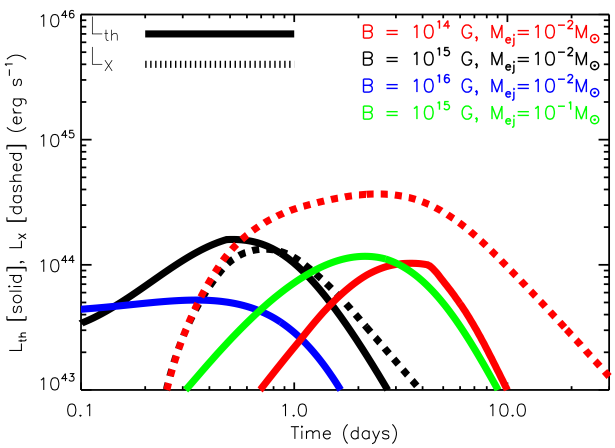
Figure 3.1: Light echoes from η Car Great Eruption of 2003. Left: Spitzer 8 μm image Right: Difference image between a DECam image from 2013 and Mosaic II image from 2003. The black structures are light echoes as observed in 2003, and the white structures are the echoes as 2013. The box has a length of about 8 arcmin on the side. Figure supplied by A. Rest.

Exploring the Boundary Between Neutron Stars and Black Holes

Even though our Galaxy houses plenty of stellar mass black holes, the actual events that give rise to them is poorly understood. In this talk, I explore two avenues for investigating the boundary between the formation of black holes and neutron stars: (1) the electromagnetic events that may accompany massive stars that die as black holes rather than neutron stars, and (2) the signatures when two merging neutron stars form a massive neutron star rather than a black hole.

In the first case, the key insight was by Nadezhin (1980). He realized that in the time before a newly born neutron star becomes a black hole within a massive star, it can radiate multiple tenths of a solar mass in neutrinos. This generates a low energy shock which can unbind the loosely bound hydrogen envelope of a red supergiant, subsequently leading to both a long-lasting shock breakout (Piro 2013) and a very low energy supernova (Lovegrove & Woosley 2013). Combining this mechanism with the observed black hole masses in our Galaxy strongly suggests that black hole formation abruptly begins above $\sim 20\,M_\odot$ (Kochanek 2014; Clausen, Piro & Ott 2014). This is enticingly similar to the upper limit found for Type II-P progenitors (Smartt et al. 2009). This cutoff also implies that no more than $\sim 10\%$ of massive stars die as black holes for a normal IMF (Clausen, Piro & Ott 2014).

In the second case, the hope is that observing the unique signatures of a long lasting neutron star following a neutron star merger would help us infer the maximum mass of neutron stars. This would be an important equation of state constraint. Such models take advantage of the general idea that the large amount of angular momentum associated with the merger would generate a quickly rotating magnetar. This magnetar then spins down, generating what amounts to a very high energy analog of the pulsar wind nebulae observed for young pulsars in our galaxy. At early times, this generates a bright X-ray flash from synchrotron emission and a bright optical supernova from some fraction of absorbed X-rays, both lasting about a day (Metzger & Piro 2014, see the figure). On longer timescales of months, the synchrotron emits at longer wavelength and could be observed as a radio transient (Piro & Kulkarni 2013). Ideally, the gravitational waves prior to such electromagnetic events could be observed by LIGO, which would provide strong evidence that indeed a neutron star was born out of the merger.



Optical (solid) and X-ray (dashed) light curves for the scenario of a quickly rotating magnetar spinning down within the remnant material of a neutron star merger (Metzger & Piro 2014). The various colors correspond to different magnetic field strengths and masses of ejecta, as summarized within the figure.

This is only a subset of the electromagnetic signatures that have been predicted near the boundary between neutron stars and black holes (for example, see Piro & Ott 2011, Dexter & Kasen 2013, Kashiyama & Quataert 2015), but hopefully the sample presented here provides strong motivation that there are a variety of signatures to be searching for over a wide range of electromagnetic wavelengths.

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Notes for Piro's talk (abstract on opposing page)

Accretion-Induced Collapses: What we know and, maybe, how to find them

A massive oxygen-neon white dwarf (WD) will undergo accretion-induced collapse (AIC) to a neutron star (NS) when the central density of the WD exceeds a critical threshold (corresponding to a mass around 1.38 $M_\odot$). The simplest signature of AIC is the emission caused by the collapse and subsequent explosion, analogous to a core collapse supernova. However, the ejecta mass is much smaller and only a small amount of Ni-56 ($\sim 10^{-3}\,M_\odot$) is likely to be synthesized in the explosion (Woosley & Baron, 1992; Dessart et al., 2006). Since a massive WD is compact, this signature will be faint and fast ($t \approx 1\,\text{day}$, $M_V \gtrsim -14$).

Two primary AIC channels have been invoked: the single-degenerate channel, where a WD accretes from a non-degenerate companion star, and the double-degenerate channel, where a massive WD is created by the merger of two WDs. A better understanding of the observable properties of AIC progenitor systems (especially for the double degenerate scenario; Schwab et al., 2012, Schwab et al. in prep.) provides the opportunity to place observational limits on the existence of pre-AIC systems in our own galaxy.

A more secure understanding of the signature of AIC rests on understanding (at least) three things: (i) whether realistic progenitor systems have additional material that can interact with the explosion; (ii) whether other aspects of the post-collapse evolution lead to the synthesis of Ni-56 (or other radioactive material); and (iii) whether the newly formed neutron star is a magnetar.

In the single degenerate scenario, since the AIC occurs when the WD reaches the critical mass, there is not material associated with the WD at larger radii. However, if the mass donor is a Roche lobe-filling red giant, a signature of the interaction of this companion with the explosion may be expected (Kasen, 2010; Piro & Thompson, 2014). This produces a transient with a higher peak luminosity and longer duration ($t \approx 3\,\text{days}$, $M_V \approx -17$).

In the double degenerate channel, since the total mass of the merging WDs may be in excess of the critical mass, the explosion may be enshrouded by additional material ($\sim 0.1\,M_\odot$). If this material is at small radii ($\sim 10^9$ cm) it lengthens the duration of the lightcurve without substantially changing the peak luminosity. If it is at large radii ($\sim 10^{13}$ cm), perhaps as a result of the post-merger evolution, it can also increase the peak luminosity.

In both scenarios (accretion and merger), the massive WD may be rapidly (differentially?) rotating. This can lead to the synthesis and ejection of additional Ni-56 ($\sim 10^{-2}\,M_\odot$; Metzger et al., 2009). Additionally, the rapidly rotating WD may collapse to form a rapidly rotating ($P \sim 10$ ms) magnetar, able to power a radio, optical, and x-ray transients (Piro & Kulkarni, 2013; Metzger & Bower, 2014; Metzger & Piro, 2014).

The continued non-detection of these aforementioned signatures provides limits on the rates of AIC and/or the correctness of these models. The rate of AIC is typically estimated to be $\lesssim 1\%$ of the Type Ia rate, with estimates from population synthesis (single-degenerate channel; Yungelson & Livio, 1998) and observations of the white dwarf merger rate (double-degenerate channel; Badenes & Maoz, 2012). If AIC is a site for nucleosynthesis by the r-process, then additional rate constraints are provided by the total observed abundance of this material.

Notes for Schwab's talk (abstract on opposing page)

New stellar insights from precision supernova data

We have known for quite a while that massive stars explode as supernovae at the end of their lives, and we have now witnessed a remarkably large diversity in observable outcomes. However, there is one kind of supernova where the data are plentiful, many progenitors are known and our astrophysical understanding is reasonably secure: Type IIP supernova. Lasting more than 100 days at a nearly constant plateau luminosity, these common hydrogen-rich supernovae are caused by energy released from core collapse in hydrogen rich red supergiants of masses ranging from $8 - 15 M_{\odot}$ (Smartt 2015).

For this rather common class, the combination of more accurate and flexible stellar and shock evolution modeling (Paxton et al. 2015, Morozova et al. 2015) with the plethora of photometric and spectroscopic data (e.g. Faran et al. 2014) opens up new opportunities for scientific exploration. In particular, nearly independent of the exact core collapse mechanism (Morozova et al. 2015) the traversal of the star by the shock wave (Matzner & McKee 1999) leads to calculable (Popov 1993) outcomes in the resulting light curves (e. g. Kasen & Woosley 2009, Dessart & Hillier 2011). Namely, we know the physics of shock waves, ejecta evolution and radiative transfer well enough that we can turn the problem around and use the supernovae data to constrain stellar evolution. Recent theoretical work in this vein has begun (e.g. Dessart et al. 2013, Morozova et al. 2015). Just as we have learned from the asteroseismic revolution enabled by the Kepler mission (Aerts 2015), highly accurate data combined with theoretical work can lead to fundamental new probes of interior stellar properties (e.g. rotation, burning state, and magnetism) previously unmeasurable.

In my talk, I will expose a few possible paths of immediate theoretical exploration, highlighting the possibility of probing the outcomes of the Rayleigh-Taylor induced (Chevalier 1976) mixing at the H/He boundary during and after shock traversal within the star. Recent three-dimensional simulations of the extent of mixing (Wongwathanarat et al. 2015) motivate a suite of one dimensional ejecta models that can be coupled to the radiative transfer computations needed for accurate light curve and spectral modeling. This holds the promise of probing the extent of the mixing at this boundary as well as aiding in the observational inference of the ejected mass and eventually, the distribution of ^{56}Ni in the deeper regions of the ejecta.

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Notes for Bildsten's talk (abstract on opposing page)

SPIRITS: SPitzer InfraRed Intensive Transients Survey

The dynamic infrared sky is hitherto largely unexplored. We are undertaking the SPitzer InfraRed Intensive Transients Survey (SPIRITS) to systematically uncover infrared transients in nearby galaxies. SPIRITS is a three-year survey (2014–2016) that searches 190 nearby galaxies within 20 Mpc, on timescales ranging between a week and a year, to a depth of 20 mag in the two Spitzer/IRAC channels of 3.6 and 4.5 μm. Concomitantly, the SPIRITS team undertakes extensive ground-based monitoring of these galaxies in the optical and near-infrared.

SPIRITS is finding over 40 transients and over 1200 strong variables annually. SPIRITS has uncovered unusual infrared transients in the luminosity gap between novae and supernovae (Kasliwal et al. in prep). These transients occur in grand spirals, emit predominantly in the infrared and have no optical counterparts whatsoever. These transients are neither detected in our concomitant optical surveys with Palomar, Swope and LCOGT nor are they detected in deep HST imaging. Infrared colors suggest very cold effective blackbody temperatures spanning 250 K to 3000 K. These transients cannot be classical novae as the mid-infrared luminosities are much higher than Eddington. The colors and luminosity cannot be explained simply as extremely dust obscured supernovae. The photometric evolution is diverse and spans slow rise, flat evolution and fast decline. We speculate these may represent diverse physical origins such as the birth of a massive star binary, electron-capture induced collapse of an extreme AGB star, outflows in mass-losing binaries and stellar mergers.

Next, we discuss the specific case of SPIRITS 14ajc which we interpret as the birth of a massive star binary. Located in a spiral arm of M 83, SPIRITS 14ajc has a [3.6] luminosity of −11 mag and a [3.6]−[4.5] color of 0.7 mag (i.e. 900 K). Neither an optical nor a near-infrared counterpart is detected to $I > 25.5$ mag and $H > 22$ mag. A K-band spectrum of SPIRITS 14ajc with Keck I/MOSFIRE shows five emission lines of excited molecular hydrogen. The line velocities match the underlying CO velocity map of M 83 from NMA. The relative line intensities of four 1-0 ro-vibrational lines correspond to a shock temperature of ∼1000 K. (However, the 2-1 line is stronger and suggestive of an alternate pumping mechanism such as fluorescence.) Dynamical interactions in small groups of massive stars orbiting each other in non-hierarchical multiple systems are subject to violent rearrangements that tend to produce capture-formed close binaries, and runaway, high-velocity stars (as in OMC1; see Bally et al. 2011). This birth of a massive star binary could drive shocks in the molecular cloud with velocities, temperature and luminosity consistent with SPIRITS 14ajc.

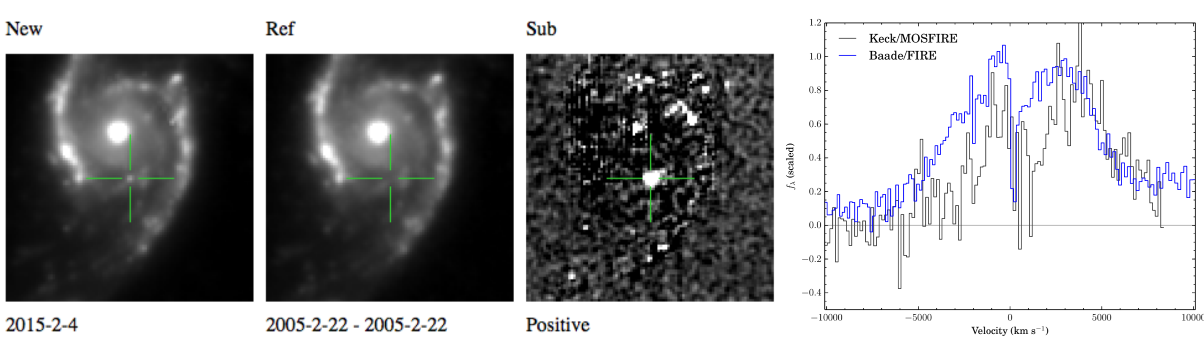


Figure 1: Yet another puzzling new infrared transient is SPIRITS 15C in IC 2163. It is extremely red ([3.6]−[4.5] = 3.1 mag i.e. 250 K) with a luminosity in the gap between novae and supernovae (−14.9 mag at [4.5]). *Left:* Discovery Image *Left Middle:* Reference Image from the Spitzer Heritage Archive. *Right Middle:* Difference Image. *Right:* Near-IR spectroscopy shows a solitary emission line (Helium?) with width 8000 km s^{-1} five months after first detection. No current model can simply explain the observations: Helium emission at late-time yet a cold SED, high velocity at late-time yet slow photometric evolution, located in the spiral arm yet no massive star progenitor in HST imaging (and possibly a rate as high as once per year). [Jencson et al. in prep]

Notes for Kasliwal's talk (abstract on opposing page)

"With all reserve we advance the view that a super-nova represents the transition of an ordinary star into a neutron star, consisting mainly of neutrons. Such a star may possess a very small radius and an extremely high density. As neutrons can be packed much more closely than ordinary nuclei and electrons, the gravitational packing energy in a cold neutron star may become very large, and, under certain circumstances, may far exceed the ordinary nuclear packing fractions. A neutron star would therefore represent the most stable configuration of matter as such." Baade & Zwicky in "Cosmic Rays from Super-Novae", PNAS (1934).

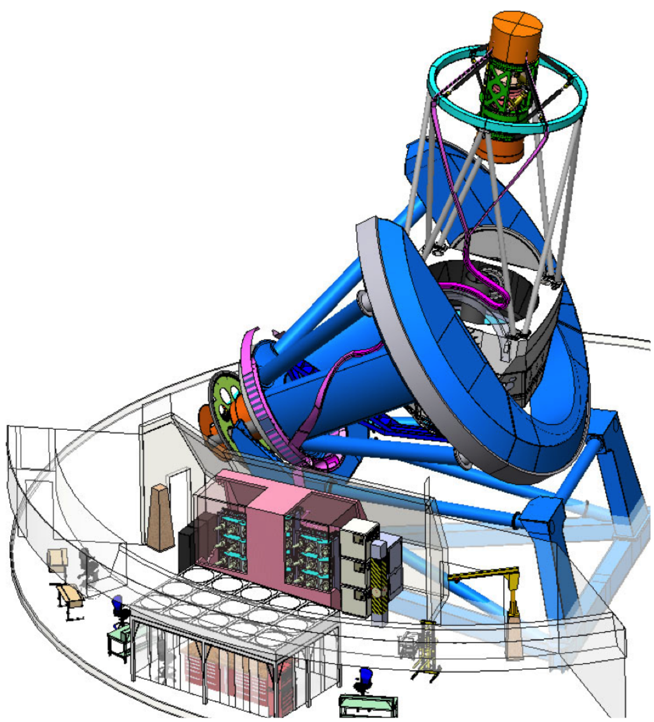


Figure 3.2: The *Dark Energy Spectroscopic Instrument* (DESI) is a massively-multiplexed spectrograph with 5000 spectroscopic channels. This amazing spectrograph will be mounted at the prime focus of the Kitt Peak Mayall 4-m telescope and expected to start operating in 2019. While the primary purpose is cosmography the instrument has the ability to accelerate time domain astronomy by pre- or post-observations of host galaxies of cosmic explosions.

Chapter 4

Session D: In Development

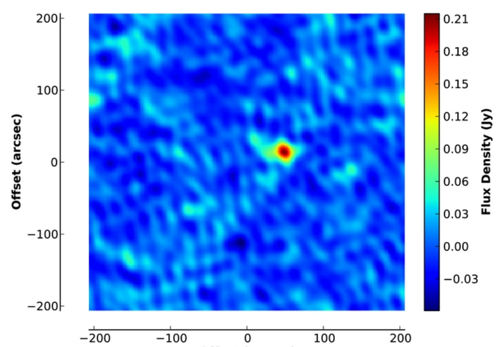


Figure 4.1: Very Large Array (VLA) image of a single, de-dispersed pulse of the rotating radio transient (RRAT) J0628+0909. The integration time was a mere 10 ms (Law et al. 2012). An ongoing VLA campaign with 5-millisecond integration times promises to provide arcsecond localization for FRBs and thereby unambiguously solve the question of whether they are of cosmological, galactic, or terrestrial origin.

The BlackGEM project is a wide-field telescope array dedicated to measure the optical emission from pairs of merging neutron stars and black holes. A few hours prior to the optical emission, these violent events should also emit copious amounts of gravitational radiation in the form of gravitational waves; ripples in the fabric of space-time itself. Since the gravitational wave events detected by aLIGO and Virgo are expected within a sphere of ~200 Mpc radius, many will be located on or near resolved galaxies, and be faint. Spatial resolution is therefore doubly essential: to resolve out the night-sky background (sensitivity to points sources), and to accurately locate the event on top of its host galaxy.

The BlackGEM array will comprise 15 telescopes, each of 65cm diameter, to be located at ESO La Silla, a site with excellent seeing ($\sim 1''$). The optical design gives a field-of-view of 2.7 square degrees per telescope (a 40 square degrees FOV for the full array) and be seeing limited: each telescope will be equipped with a 10.5k x 10.5k pixel CCD of 10 micron pixel size. With the focal length of the telescope (f/5.5) this will lead to a sky sampling of $0.56''$/pix, well matched to the seeing on La Silla. Each telescope will be equipped with a 6-filter wheel (u,g,y,r,i,z), where the y-filter runs from 4400 - 7200 Å.

The array mode of BlackGEM is uniquely suited to match the pointing of the telescope to the shape of the gravitational wave errorboxes. These are often split and elongated in shape, which makes a monolithic telescope design less suited than the BlackGEM array approach. In case of a detected counterpart, all telescopes can be pointed at the specific position (target mode), in which case the array functions as a single 3.6m telescope with a 2.7 square degree field of view. Given the fact that counterparts are expected to be fainter than the sky background (~21 magnitude/square-arcsecond) the additional read-out-noise of 15 detectors is not the limiting factor.

When BlackGEM is not doing followup of gravitational wave triggers, BlackGEM will do an All Sky Survey, a survey in the all bands (u,g,y,r,i,z) down to 22nd magnitude of the full Southern Sky. BlackGEM will also do a high-cadence survey to characterize fast transients (< 1 day) down to 23rd magnitude as a function of magnitude, time scale, color (g,r,i) and sky location.

BlackGEM is expected to be operational at the end of 2016.

Notes for Groot's talk (abstract on opposing page)

WALOP: Wide Field Polarimetry

Tim Pearson and Tony Readhead

Interstellar polarization Observations of linear polarization can be used to trace the distribution of interstellar dust and magnetic fields. Dust residing within a magnetized environment makes linearly polarized light in two ways: through thermal emission, and through partial absorption of the starlight from background stars. The polarization of dust emission and the polarization of starlight induced by dust absorption are complementary effects of the same astrophysical process: the alignment of dust grains with the magnetic field threading the interstellar region where they reside. Dust grains are preferentially aligned with their short axes along the magnetic field. Dust grains emit with the electric field preferentially aligned with their long axes; their long axes are aligned perpendicular to the magnetic field, so dust emission (typically at submillimeter and far infrared wavelengths) is partially polarized perpendicularly to the magnetic field, while starlight absorbed by dust has its electric field component along the long grain axis preferentially attenuated, and the light that makes it through is partially polarized along the magnetic field.

Polarization of starlight is thus complementary to the recent all-sky maps of submm-wavelength polarized emission from *Planck*, and other tracers of magnetic field such as the rotation measures of extragalactic radio sources. But because the stars are distributed throughout the Galaxy, they can provide 3D tomography of dust and magnetic fields. The *Gaia* mission will measure parallaxes for $\sim 10^9$ stars, with $\sim 10^6$ brighter than 16 mag. Polarization measurements of these stars will yield a unique 3-dimensional information cube on dust and magnetic field properties.

Goals We are exploring the feasibility of an instrument that could yield accurate polarization measurements of at least 20 stars/deg^2 over a large fraction of the sky (this is a 20-fold increase over the current average, even in the best-mapped areas of the sky), with systematic errors controlled down to 0.2% so that polarization properties can be confidently measured even in the areas of the sky with the lowest dust emission.

Such a dataset will be a valuable contribution to, e.g., (1) Physical models of interstellar dust, its emission and absorption, and polarization properties. (2) Mapping the Galactic magnetic field; (3) Physically-motivated predictions of the dust-emission polarization at various microwave frequencies, that can be used to help model the dust emission at CMB-dominated frequencies, as is needed for reliable detection of primordial *B*-modes. (4) Models of the formation of star-forming molecular clouds. (5) MHD instabilities. (6) The “Galactic fountain” model for the gas enrichment of the Galaxy. (7) Back-tracing the sources of ultra-high-energy cosmic rays.

Instrument concept With A. N. Ramaprakash (IUCAA) we are designing a pathfinder (WALOP: Wide Area Linear Optical Polarimeter) that can explore the potential and pitfalls of wide-field polarimetric imaging. It is based on the very successful RoboPol instrument which has no moving parts and uses a beam splitter, super-achromatic half-wave retarders, and Wollaston prisms to form 4 simultaneous images of each star, from which Stokes I, Q, and U can be extracted. RoboPol has been in operation on a 1.3 m telescope at Skinakas (Crete) for 2.5 years. The new instrument will have a 30 arcmin field of view, and the optics will separate the images onto four separate 4096×4096 CCD detectors. The major design issues are: (1) Sensitivity: on a 1.3 m telescope we should be able to get 0.2% accuracy for a 2% polarized source with $R = 16.4$ in a 10-min exposure; (2) Stability of instrumental polarization, which will be measured by scanning standard stars across the field; (3) Sky coverage, which is limited by available telescope time and budget. We have guaranteed time on the Skinakas telescope, and we are exploring collaborations with a number of groups to obtain observing time on small telescopes in both the northern and southern hemispheres.

Notes for Pearson's talk (abstract on opposing page)

Wide Field CMOS/EMCCD

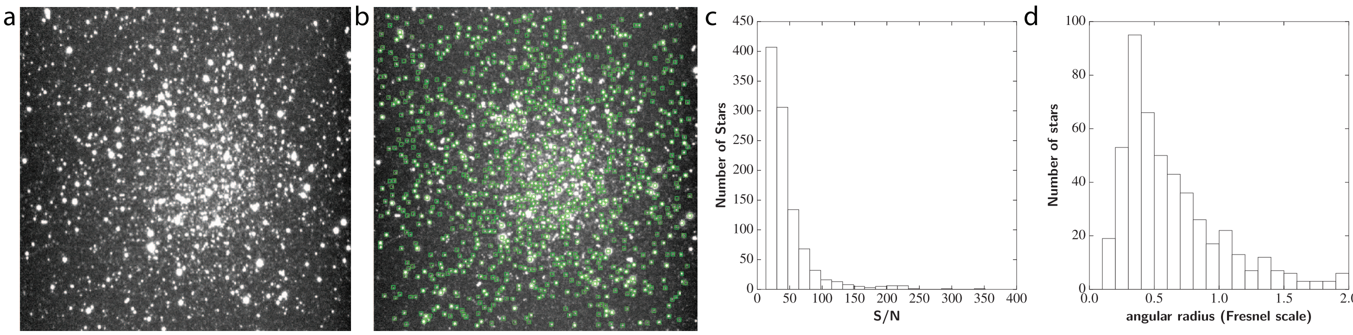


Figure 1. **a.** A single 25 ms Sloan i' band frame of M22 taken with the red channel of CHIMERA on July 24, 2014 during commissioning observations. **b.** The first 1000 stars identified using the DAOPHOT task daofind at a threshold of 10 sigma above the background are highlighted. **c.** The distribution of the SNR for the same 1000 stars highlighted in panel b. **d.** Based on the known distance of M22 and using publicly available optical (UCAC) and NIR (2MASS) catalogs, we determine the angular radii of 540 of the 1000 stars, with the angular radius given as fraction of the Fresnel scale calculated at 40 AU. Stars with angular radius below a Fresnel scale are needed for detection of a diffraction pattern during occultation.

CCDs have been the preferred detector for the focal planes of telescopes for decades, but can suffer from large amounts of output amplifier noise at higher read out rates. With the advent of the electron-multiplying CCD (EMCCD) (Jerram et al. 2001), extremely low noise ($<$ 1 e- rms), high-speed clocking, has become possible. EMCCD's differ from conventional CCDs in that they possess a so-called high gain or electron multiplying (EM) register, which is an additional stage containing a large signal output. In this region, electrons can be amplified by avalanche multiplication, thereby delivering much higher SNR, albeit at the proportional reduction in pixel charge capacity. EMCCDs have enabled fast imaging on modest fields of view with very low effective noise.

CMOS technology, on the other hand, offers an alternative path to high-speed large format sensors. Indeed, the current and incoming generation of CMOS sensors come equipped with the necessary readout electronics to push to much larger sensors than currently possible for EMCCDs, while maintaining very high full frame readout rates. However, CMOS noise can be more difficult to characterize than CCD noise because of additional pixel and column amplifier noise, as well as non-linearities in the charge-to-voltage conversions (Holst et al. 2011), and calibration of early CMOS sensors for astronomical application has proved challenging.

The CHIMERA Instrument: Both EMCCD and CMOS sensors have been extensively tested on the 5.1 m Hale telescope at the Palomar Observatory via the Caltech High-Speed Multi-color Camera (CHIMERA) instrument. CHIMERA was designed for high-speed, wide-field, dual-band imaging and is currently capable of imaging a 5 x 5 arcminute field of view simultaneously in two bands at 50 frames/sec, using two 1K x 1K EMCCDs to deliver very low read noise, with much higher frame rates possible on windowed sub-fields. CHIMERA will eventually expand in capability to image the entire 24 x 24 arcminute field of view available from the prime focus of the Hale telescope, making use of a 4K x 4K CMOS sensor that is currently under development.

CHIMERA was designed to characterize the size distribution of Kuiper Belt objects (KBOs) of diameter ≤ 1 km. Objects smaller than about 10 km in radius are too faint to be detected in reflected light but can be detected indirectly via occultation of background stars. For sub-km-sized KBOs, occultations typically last of order a tenth of a second and diffraction effects become important, requiring very fast sampling of ~ 40 Hz. Meanwhile, the rate is $< 10^{-7}\,s^{-1}$ per star (Schlichting et al. 2009, 2012), so a wide-field is necessary to maximize the number of stars simultaneously monitored. Both EMCCDs and large format CMOS sensors are well matched to this challenge. CHIMERA's EMCCDs can deliver full-frame imaging at the cadence required to critically sample diffraction-dominated occultations (Figure 1). Moreover, the wavelength dependent nature of the associated diffraction pattern in two photometric bands can be used to eliminate false positives such as scintillation. By targeting dense fields near the ecliptic, CHIMERA can monitor 1000s of stars simultaneously and detect multiple occultations per night.

CHIMERA is just one of a new generation of instrument that will employ EMCCDs and CMOS sensors for wide-field imaging to open up uncharted parameter space in the transient sky on short timescales. For example, CHIMERA has also been used to develop and test the technique of synthetic tracking for detection of small near-Earth asteroids (see talk of Mike Shao). Possible applications include surveys of the galactic plane and bulge for short duration transient events associated with magnetic reconnection and compact object accretion as well as systematic surveys for short period white dwarf binary systems.

Notes for Hallinan's talk (abstract on opposing page)

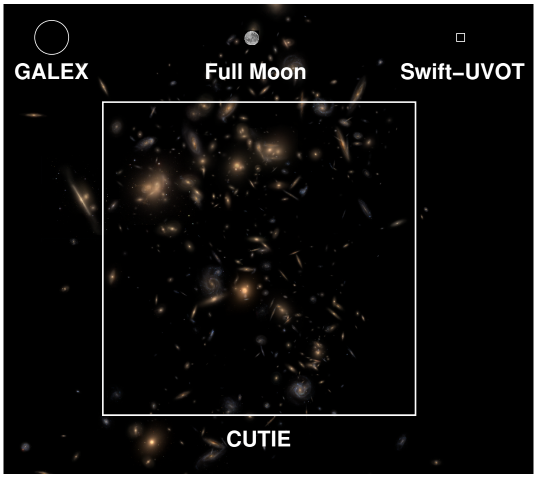
A Constellation of Cubesats to Detect NEOs

Often in science, the availability of new technology enables observations that otherwise are impractical. In addition, new technology often enables observations at a much lower cost. When several new technologies are brought together, one can get both. Observations of moving objects, such as NEOs (near-Earth asteroids) with a single CCD exposure are limited in sensitivity when the object moves more than one PSF/pixel. This limitation to sensitivity can be overcome by taking multiple short exposures and shifting subsequent images to effectively unstreak a longer exposure image, a technique we call synthetic tracking. For this technique to be useful, the camera has to be able to take fast exposures (a few Hz) with low read noise ~1e. In addition, since we do not know which direction the object is moving or its velocity, we need a fast computer (a GPU) try the shift/add operation for 1,000's of velocity vectors. The combination of these two technologies led to the detection of a previously unknown H~29mag NEO (23 Vmag) with the Palomar 5m. Conversely, synthetic tracking enables small telescopes to detect moving objects that otherwise would require much larger telescopes using normal CCDs.

Cubesats are spacecraft that use components that conform to the 10cm cube form factor. The main advantage of Cubesats is their extremely low cost both in production and launch services. Current commercial Cubesat components have the lifetimes of over 3 years for LEO. Synthetic tracking enables very small (10cm class) telescopes to detect moving NEOs with the same sensitivity as that for the much larger telescopes. Space-based searches for NEOs are expensive, and CubeSat-based telescopes can reduces the cost dramatically. However, the cost of a CubeSat is so low, that one can consider a constellation of Cubesats in solar orbit instead of just one. We conducted a simulation of several cubesat constellations conducting a survey of NEOs that would impact the Earth. Typically a NEO has to come within 0.4~0.6AU of a telescope to be detected. A 5 CubeSat constellation in solar orbit ~0.8AU can find 90% of H=22mag (140m) NEOs in ~3 years of observing, much faster than any single observatory. A more advanced 8 CubeSat-based constellation with 15cm optics and a 10sqdeg FOV could find 90% of H=24.2 mag (50m) NEOs in ~5yrs, versus ~14 years for a combined LSST and IR satellite in a 0.7AU orbit.

Notes for Shao's talk (abstract on opposing page)

CUTIE: Cubesat Ultraviolet Transient Imaging Experiment



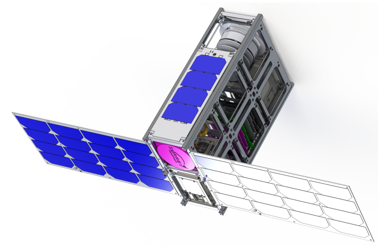


Figure 1: *Left: SDSS image of the Virgo galaxy cluster. With its 121 deg^2 field of view (orders of magnitude larger than any modern UV mission), CUTIE would conduct a time-domain survey for astronomical transients and variables. Above: Model of the CUTIE spacecraft.*

In this talk, I present an overview of the Cubesat Ultraviolet Transient Imaging Experiment (CUTIE), a mission concept designed to open the UV bandpass to truly synoptic science for the first time. **These capabilities represent orders of magnitude improvement in both areal coverage and monitoring cadence over past UV imagers.**

CUTIE At A Glance

Aperture	8 cm
Field of View	121 deg^2
Survey Area	1700 deg^2
Bandpass	260–320 nm
Resolution (FWHM)	$\lesssim 38''$
Sensitivity (5σ in 165 s)	19 mag (AB)
Cadence	≈ 95 min

I will describe the scientific motivation behind CUTIE, as well as the instrument and spacecraft design we have chosen to meet these objectives. Our innovative design in a 6U cubesat form factor would enable tremendous cost savings though heavy use of commercial off-the-shelf (COTS) components and an accelerated timeline from conception to on-sky operation. Such missions are ideally suited to train young scientists to develop the next generation of pioneering NASA missions.

Prioritized CUTIE Scientific Objectives

- *Core-Collapse Supernova Progenitors:* Double the number of known CCSNe with robust progenitor identifications via the detection of the short-lived shock breakout/cooling phase.
- *Tidal Disruption Events:* Double the number of TDEs with well-sampled light curves, thereby probing the properties (mass, possibly spin) of super-massive black holes at the centers of distant, quiescent galaxies.
- *Active Galactic Nuclei (AGN) Variability:* Constrain fundamental properties of the accretion disk and correlate observed variability with host galaxy properties for thousands of well-sampled AGN.
- *Orphan Gamma-Ray Burst (GRB) Afterglows:* Identify "orphan" GRB afterglows, either resulting from viewing angle effects (*i.e.*, off-axis geometry) and/or baryon loading of the jet.)

Notes for Cenko's talk (abstract on opposing page)

DESI and Transient Surveys

The Dark Energy Spectroscopic Instrument (DESI) will be a new multi-object spectrograph for the NOAO Mayall telescope which will perform a massive galaxy redshift survey of the Northern hemisphere. The main scientific goal of DESI is to increase our knowledge of dark energy and dark matter by at least an order of magnitude compared with today's constraints. DESI will possess 5000 fibers over an 8 sq. deg. field-of-view, feeding 10 SDSS-like spectrographs to obtain spectra for $r \simeq 22$ mag galaxies in just 45 minutes of observation. DESI is planning to have first light in 2018 with the main survey starting in 2019 lasting at least 5 years.

DESI is planning two main galaxy surveys. First is a high-redshift survey using 18 million emission-line galaxies (ELGs; $0{:}6 < z < 1{:}6$) over 14,000 deg_2, combined with a few million luminous red galaxies ($0{:}4 < z < 1$) and quasars. The other survey is called the Bright Galaxy Sample (BGS) that is targeting approximately 10 million lower-redshift galaxies over the same area of the sky but to a fixed magnitude limit of $r < 19{:}5$ mag. We can expect to find SNe in all the DESI galaxy redshift surveys, however, the BGS will likely be the main source of useable DESI SNe given its brighter magnitude limit ($r < 19{:}5$ mag) and thus lower redshift range. A basic calculation, scaling from the detection rate of SDSS, suggests DESI will find ~1000 SNe Ia and ~150 core-collapse SNe. In addition, DESI should find ~100 tidal disruption events during the survey period in the BGS sample alone.

The next generation of optical transient surveys will find millions of transients (LSST, ZTF, PanSTARRS). When new transients are discovered and announced DESI may already have relevant observations of nearby objects (e.g., spectra of potential host galaxies), which could be useful to the transient community, in near real-time, to help classify the objects. Beyond providing archival data of new discoveries, DESI may wish to consider more active follow-up of new transient objects. For example, if a new transient was discovered in a region of the sky scheduled for near-term DESI observations (the next few nights), that DESI field could be prioritized for immediate observations and could include dedicated fibers for the transient and nearby galaxies. Such a "Target-of-Opportunity" mode could be accomplished by utilizing on of the ~100 “sky” fibers used for calibration in each of the 8 sq. deg. DESI pointings.

DESI can play a key role in supporting LSST and ZTF supernova science by dedicating a subset of its fibers per field to such an ancillary program of host galaxies of transient events. The Dark Energy Survey (DES) is following this approach using the AAOmega instrument on the AAT (“OzDES") and through repeat observations (sometimes up to 15 separate visits to the same galaxy) can obtain redshifts for $r \simeq 24$ host galaxies (typically associated with $z \sim 1$ SNe Ia. Based on the cosmologically or physically useful sample of LSST supernovae and all of the ZTF discovered SNe, ~100 targets per DESI pointing would be required to obtain host redshifts for these SNe which is still a small compared to the total number of fibers per field (2%).

By the time DESI is commissioned (2018), searches for optical counterparts for gravitational wave (GW) sources detected by LIGO+VIRGO will be underway. The positional error boxes for the first GW detections will be large (tens of square degrees) meaning finding a likely optical counterpart will be difficult, as such an area should be surveyed in real-time (ideally within hours of the GW source). ZTF would be able to screen such fields to discover several hundred optical transients over this error box while DESI could then spectroscopically target these objects in just a few pointings. While this could be carried out during bright-time with minimal impact to the survey, interrupting the nominal dark-time DESI program would require more discussion and study.

Notes for Nugent's talk (abstract on opposing page)

Status of LCOGT

The Las Cumbres Observatory Global Telescope Network is a facility designed, constructed, and now operating to provide unique capabilities for time-domain follow-up studies. Already in place are two 2-meter, nine 1-m, and three 40-cm telescopes, with two more 1-m and four more 40-cm telescope deployments planned for the 12-18 months. The network provides complete coverage in the south, and will soon in the north also. The telescopes are robotic and are equipped with optical imagers. The 2-m telescopes also have low-dispersion spectrographs, and a set of high-dispersion, fiber-fed spectrographs are being built for the 1-m telescopes. Observations are assigned to telescopes by a single software scheduler, which optimizes the schedule over the entire network.

Network time is allocated to astronomers represented by the LCOGT Science Collaboration, which includes the site partners and a few other institutions that have helped us get started. Each telescope contributes approximately 2000 hours of usable time per year, so quite large projects are possible. Research supported includes three key projects (supernovae, microlensing, and AGN reverberation-mapping) as well as about 50 smaller projects, ranging from tens to hundreds of hours each. Users request observations at any time through a web form or an API, which can be integrated into project-specific software.

Robotic operation means that each site has the ability to determine when it is appropriate to open, and that telescopes and instruments configure themselves and take data according to a queue that they have downloaded from headquarters. Each night's observation plan includes calibration frames, focus runs, and observations of standard stars. Data are transmitted over the internet back to headquarters, where they are pipeline processed and transferred to our data archive at IPAC.

The sixteen months of full science operations have been very successful. Weather and downtime statistics have been consistent with expectations. Our strategy of slightly underallocating the expected hours has resulted in almost all planned observations being obtained and all allocated time being used. We have demonstrated the capability to do continuous monitoring over several days as well as response as quick as 2 minutes to targets of opportunity requests. Relative photometry at the millimag level has been achieved for bright stars.

Current improvement work is aimed at maintaining a high level of data quality – flat fielding, image quality, etc. Additional capabilities are planned for the scheduler, including better feedback on unsuccessful observations, ability to better constrain acceptable conditions for a given observation request, and more precise control over relative priority of observations for a project.

LCOGT is actively seeking additional partners. These may range from purchase of a few tens of hours of network time to groups or communities who wish to join our Science Collaboration.

Notes for Boroson's talk (abstract on opposing page)

"Every evening, I come home tired and have just enough energy to fill out the endless tax forms, to pay bills, not to let my house neglected and to hear the radio concert for an hour."

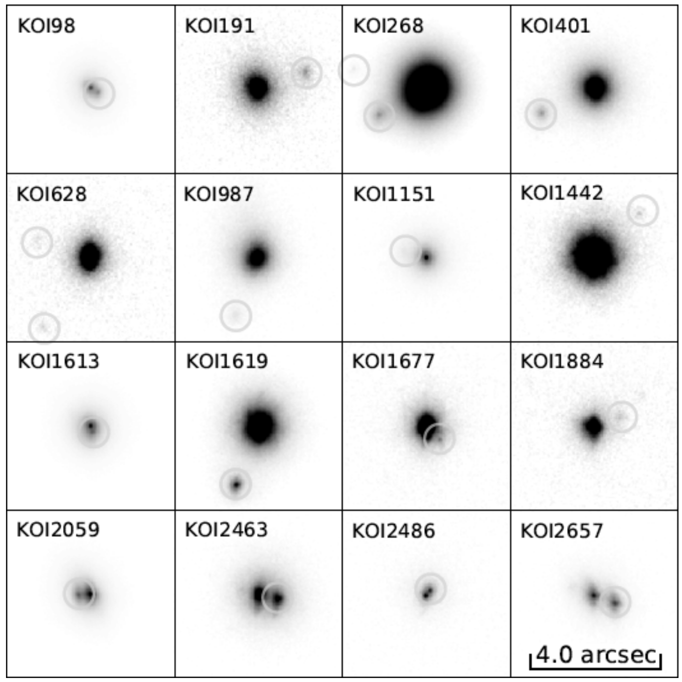


Figure 4.2: Optical images of some "Kepler Objects of Interest" (KOI). This group of KOI are stars hosting candidate exoplanets. Two of these systems, KOI-191 and KOI-1151, exhibit interesting architectures and are best explained by the hypothesis that the Kepler identified exoplanet candidates are shared between the two stars resolved by Robo-AO. The images were obtained with Robo-AO, the first fully autonomous laser adaptive optics and imaging system, which routinely observes over 200 objects per night with an acuity 10 times sharper at visible wavelengths than typically possible from the ground. Single-handedly, Robo-AO has imaged 3,300 Kepler candidate exoplanet hosts, and has found over 450 nearby sources diluting the Kepler light curves, which may be physically associated and/or responsible for transit false positives. The above figure shows 16 of the Kepler candidate exoplanet hosts with contaminating sources discovered by Robo-AO. Figure supplied by C. Baranec.

Chapter 5

Session E: TESS & Kepler Missions

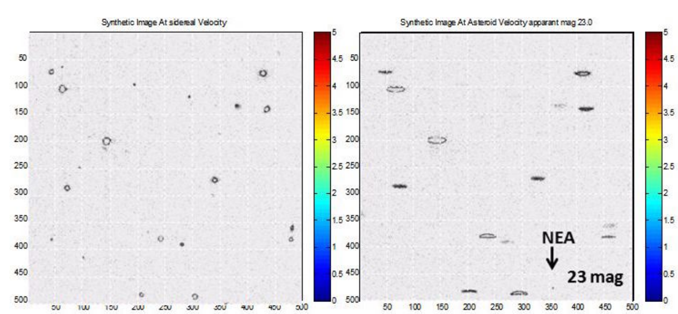


Figure 5.1: The immense gains obtained by synthetic tracking. A total of 450 images were recorded at a rate of 15 frames/second. (Left) The images are combined assuming no special motion (other than sidereal). (Right) The images are combined for an assumed angular velocity of 0.29″/second, leading to a detection of a 23 mag NEA. The NEA was found by "trying" 10,000 angular velocities. Image supplied by M. Shao.

The Transiting Exoplanet Survey Satellite (TESS): Opportunities for Commensal Survey Science

The Transiting Exoplanet Survey Satellite (TESS) will discover thousands of exoplanets in orbit around the brightest stars in the sky. In its two-year prime survey mission, TESS will monitor more than 200,000 bright stars in the solar neighborhood for temporary drops in brightness caused by planetary transits. This first-ever spaceborne all-sky transit survey will identify planets ranging from Earth-sized to gas giants, around a wide range of stellar types and orbital distances.

TESS stars will typically be 30-100 times brighter than those surveyed by the Kepler satellite; thus, TESS planets will be far easier to characterize with follow-up observations. For the first time it will be possible to study the masses, sizes, densities, orbits, and atmospheres of a large cohort of small planets, including a sample of rocky worlds in the habitable zones of their host stars.

An additional data product from the TESS mission will be full frame images (FFI) with a cadence of 30 minutes or less. These FFI will provide precise photometric information for every object within the 2300 square degree instantaneous field of view of the TESS cameras. These objects will include more than 1 million stars and bright galaxies observed during sessions of several weeks. In total, more than 30 million objects brighter than I=16 will be precisely photometered during the two-year prime mission. In principle, the lunar-resonant TESS orbit could provide opportunities for an extended mission lasting more than a decade, with data rates in excess of 100 Mbits/s.

Table 1 is a compilation of potential targets for which TESS could provide commensal survey results. The brighter TESS stars will potentially yield valuable asteroseismic information as a result of monitoring at a rapid cadence of nominally 20 seconds.

An extended survey by TESS of regions surrounding the North and South Ecliptic Poles will provide prime exoplanet targets for characterization with the James Webb Space Telescope (JWST), as well as other large ground-based and space-based telescopes of the future.

TESS will issue data releases every 4 months, inviting immediate community-wide efforts to study the new planets, as well as commensal survey candidates from the FFI. The TESS legacy will be a catalog of the nearest and brightest main-sequence stars hosting transiting exoplanets, which will endure as the most favorable targets for detailed future investigations.

TESS is targeted for launch in 2017 as a NASA Astrophysics Explorer mission.

Table 1: Commensal Target Classes for TESS Full Frame Images

Low Mass Eclipsing Binaries Peculiar Eclipsing Binaries -Extremely short periods -Highly eccentric orbits Variable stars -Eclipsing variables -Pulsating variables RR Lyrae Stars Flare Stars	Active Galactic Nuclei T Tauri Stars White Dwarfs -Transiting Planets -Stellar Pulsations Neutron Stars Emission line stars (Be stars) Microlensing Events Cepheids	Gyrochronology in clusters Young/X-ray bright stars Supernovae -Pre-Discovery -Post-Discovery Solar System Objects -Near Earth asteroids -Comets Gamma-ray Bursts

Notes for Ricker's talk (abstract on opposing page)

Bridging Type Ib/c Supernovae And Wolf-Rayet Stars With Asteroseismology

Wolf-Rayet stars (WRs) have long been speculated to be progenitors of Type Ib/c supernovae (SNe), as they show large mass loss rates indicating that they have lost their hydrogen envelope. Through the traditional method of fortuitous pre-explosion imaging, however, only one progenitor candidate of a Type Ib supernova has been found (Cao et al. 2015; see Smartt 2015 for a recent review). Even if the candidate disappears in the post-explosion image and is confirmed as the supernova progenitor, it is still difficult to tell whether it is a WR star. Therefore, other tests are needed to compare the nature of Type Ib/c supernova progenitors and WRs. Asteroseismology provides accurate measurements to stellar mass and structure and serves as a unique tool to test the WR progenitor scenario.

First, asteroseismology of WRs can measure stellar masses more accurately. The current estimates of WR masses are based on stellar evolution models and therefore have very large uncertainties, except for those WRs in binary systems (Crowther 2007). One problem in the WR progenitor scenario is that the typically inferred WR masses between 10 and 15 solar masses are too large compared to the ejecta masses of typical Type Ib/c SNe between 3 and 5 solar masses. Recent studies by Piro & Morozova (2014) and Wheeler et al. (2015) show that the supernova ejecta masses inferred from their lightcurve shapes around maximum light may be underestimated and that a few solar mass of helium could hide in the ejecta. So if WR masses measured accurately from asteroseismology are less than those inferred from stellar evolution models, then WRs can keep their progenitor candidacy. Otherwise, we can safely rule out WRs as progenitors of Type Ib/c SNe based on this mass problem.

Furthermore, if multiple oscillation modes could be detected from WRs, then we could use them to infer the poorly constrained stellar structure beneath their photospheres. Should such a WR explode, our knowledge about the stellar structure together with metallicity measurements from spectroscopic observations can be used to calculate the expected early-time lightcurve of its resulting SN, because the early-time lightcurve is determined purely by the explosion energy and the structure of its outer ejecta until energy released by ^{56}Ni radioactive decay diffuses to the surface (e.g., Rabinak & Waxman 2010, Piro & Nakar 2013). The predicted early-time lightcurve can subsequently be compared to the observed early-time lightcurves of Type Ib/c SNe from rapid-cadence time-domain surveys (iPTF/ZTF, ASAS-SN, etc.). This comparison provides an independent test to the WR progenitor scenario.

Pulsations of WRs are expected to have periods shorter than a day (Glatzel & Mehren 1996; Glatzel et al. 1999). However, due to their rarity in the sky and the short pulsation periods, the time variability of only very few WRs have been well studied. Lefévre (2005) analyzed the light variability of WR123 with MOST 38 day uninterrupted observations and found a stable 9.8 hour period. The origin of this period is still in debate (Townsend & MacDonald 2006; Dorfi et al. 2006). A large sample of WRs are needed to examine whether the 9.8 hour oscillation is common in WRs and to identify pulsation modes for mass estimation.

So far, 433 Galactic WRs (Rosslowe & Crowther 2015), 134 in the Large Magellanic Cloud (Breysacher et al. 1999) and 12 in the Small Magellanic Cloud (Massey et al. 2003) have been identified. Most of them are bright enough for both K2 and TESS. The ongoing K2 survey will have 33 WRs in its Campaign 9 fields. The time variability of these WRs can form a piloting study in preparation for TESS. In the future, the all-sky coverage of TESS will provide a complete sample of WRs down to $\simeq$16 magnitude. Lightcurves of these WRs will be sampled by TESS 30-minute full frames. Many of them are actually bright enough to qualify faster-cadence observations (2 minutes or even 20 seconds). Given the facts that the rate of Type Ib/c SNe in the Milky Way is about one every four hundred years (Li et al. 2011)[1], and that the typical lifetime of a WR is about 10^5 years (Meynet & Maeder 2005), if WRs are progenitors of all Type Ib/c SNe, it is not unreasonable that one of the WRs in our sample will explode in the speaker's lifetime.

[1]The specific event rate is higher in an irregular galaxy than in a spiral galaxy by about 50%

Notes for Cao's talk (abstract on opposing page)

TESS Transient Survey

The TESS full frame images (FFIs) will survey a 2300 deg^2 region of the sky, almost continuously, with a cadence of 30 min or less. These images not only present an opportunity to study known sources (e.g., stellar variability), but they will also present a tremendous opportunity for transient science as well.

At first glance, it might seem that TESS is shallow when compared to ground based transient surveys (GBTS). However, if you compare TESS at the precision and cadence feasible for GBTS, a more fair comparison can be made. TESS will be capable of producing 1% photometry for 16th magnitude sources and better than 10% photometry for 18th magnitude sources every hour. Ignoring the confusion limit, one could get $\sim 10\%$ photometry for source at about ~ 19.5 mag by stacking 12 hours of TESS data. This is deeper than ASAS-SN and approaching the limiting magnitude of ZTF. TESS also has a faster cadence although it has significantly less sky coverage.

The depth and cadence of TESS will often allow it to obtain high precision light curves for bright transients before they are discovered by GBTS. However, bright, large-amplitude transients will be discovered by GBTS before the TESS data is downloaded. This will allow early-time multi-band photometry and spectroscopy which would not be possible if the transient was discovered only in TESS data.

What will the rates of interesting transients be? Let's scale from the nearby SN rate. There have been ~ 80 SNe so far in 2015 brighter than 16^{th} magnitude. Scaling to TESS, we would expect to catch $\sim 6-7$ SNe per year at least ~ 3.5 mag below peak. However, the rarer, brighter events are even more interesting. There have been ~ 6 SNe Ia so far in 2015 with SN Ia $V \lesssim 14.0$, so one would expect ~ 1 SN Ia in the 2 year primary mission lifetime to be caught more than 5 mag below peak in the TESS data. This depth is interesting because it would constrain the SN Ia light curve within the first day of first light and place strong constraints on its progenitor system (e.g., Kasen 2010). This is similar to recent Kepler SNe (Olling et al. 2015), except, the TESS SN would also be extensively observed by ground-based observatories.

Finally, a transient source detection pipeline could be constructed for the TESS FFIs which would leverage its unique combination of photometric precision, cadence, and large sky coverage. TESS's large pixels pose a difficulty, but, the ASAS-SN pipeline has shown that this can be overcome. The most constraining characteristic of TESS for a transient search would be its 13.7 day orbit and any additional time needed to reduce the FFIs. This would mean that any transient would likely be several days old before it was announced.

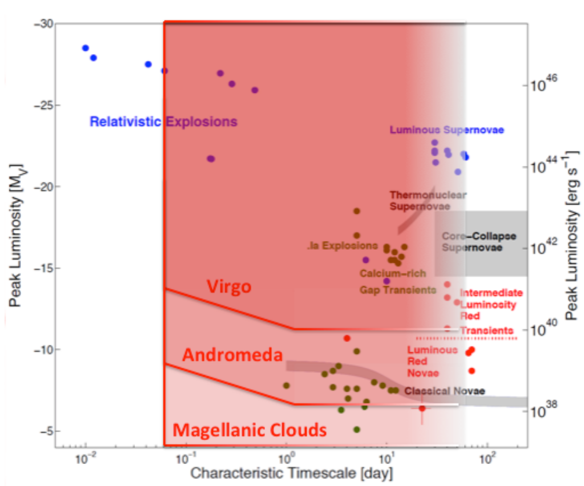


Figure 1: Characteristic timescales and luminosities for known classes of transients with rough regions for TESS overlain for Virgo, Andromeda, and the Magellanic Clouds. Plot Credit: Mansi Kasliwal

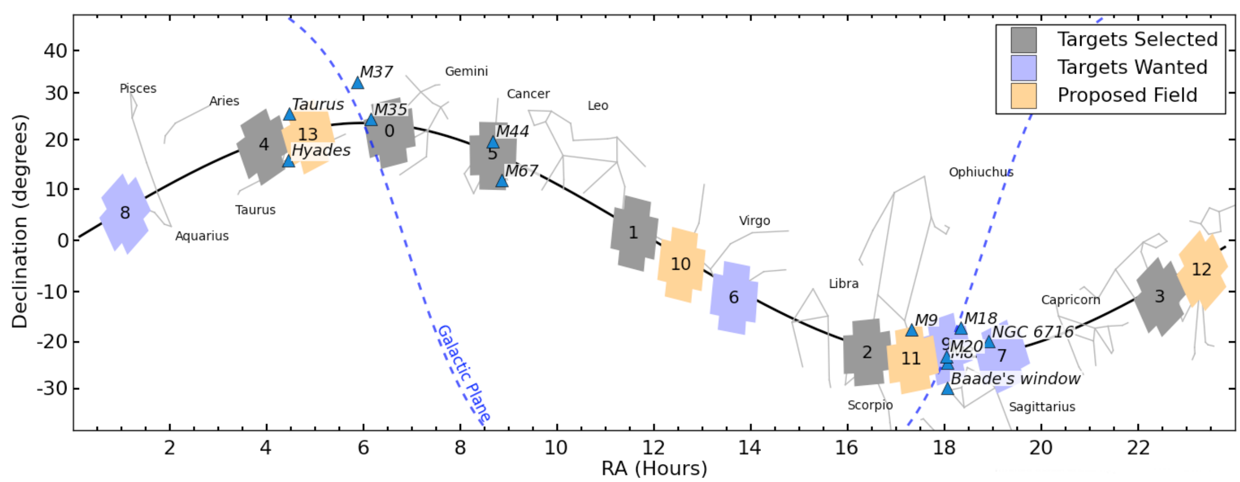
Notes for Shappee's talk (abstract on opposing page)

The NASA K2 Mission

Extending Kepler's Legacy to the ecliptic

Thomas Barclay - NASA Ames Research Center

The K2 mission provides an opportunity to continue Kepler's ground-breaking discoveries in the field of exoplanets and expand its role into new and exciting astrophysical observations. K2 is founded on the proven value of long-baseline, high-cadence, high-precision photometry and exploits a large field of view to simultaneously monitor tens of thousands of targets. K2 is limited to pointing near the ecliptic plane, sequentially observing fields as it orbits the sun. This observing strategy regularly brings new, well-characterized target fields into view, enabling observations of scientifically important objects across a wide range of galactic latitudes in both the northern and southern skies. K2 has performed a series of long, ecliptic-pointed campaigns to collect data for the astrophysical community that have been informing their understanding of planet formation processes, young stars, stellar activity, stellar structure and evolution, and extragalactic science.



K2 is into it's second year of observations, having already observed six full-length 80-day long campaigns. Future campaigns include a field aimed towards the galactic bulge dedicated to microlensing science (C9) and the potential for an extra-galactic science focused campaign in 2017.

In the first year of operations K2 observations have focused on exoplanet science and stellar astrophysics with a smaller extra-galactic program searching for supernovae. In April 2016 we will perform a campaign (C9) in the forward velocity-vector direction enabling simultaneous space and ground-based observations. The primary science focus of C9 will be observing a parallax between microlensing events observed from Earth and from Kepler. In 2017 there is potential for another forward-facing field at high-galactic latitudes focused on extra-galactic science.

Notes for Thomas' talk (abstract on opposing page)

Kepler & Other Surveys:
Using *The Cannon** to Exploit the Overlap Between *Kepler* & APOGEE

Terminology note: I use the term "labels" to refer collectively to the full set of properties that describe a star, including stellar parameters and chemical abundances.

The overlap between *Kepler* and large spectroscopic surveys presents an opportunity to measure a comprehensive set of labels for stars in the Milky Way. From *Kepler* light curves, asteroseismology can be used to estimate surface gravities (log*g*), masses (*M*), and radii (*R*) for red giant stars. From high-resolution spectroscopic data, survey pipelines can determine effective temperatures (T_{eff}), log*g*, metallicities (*[Fe/H]*), and a suite of chemical abundances ([*X/H*]). This information is complementary, e.g. *M* cannot (yet) be directly determined from spectra, and a value of T_{eff} is necessary for inferring *M* and *R*.

This is the motivation behind APOKASC (Pinsonneault 2014), a joint effort between the APOGEE (APO-) spectroscopic survey and the *Kepler* Asteroseismology Science Consortium (-KASC) to compile spectroscopic and asteroseismetric labels for objects in the *Kepler* fields. In this talk, I will focus on the potential of the APOKASC catalogue as a "training set" to fit for a spectral model that can directly compute from a spectrum quantities that formerly were accessible only to asteroseismology.

To determine this spectral model, we use *The Cannon*. *The Cannon* (Ness et al. 2015) is a new data-driven method for determining stellar labels from stellar spectra in the context of large spectroscopic surveys. The method is described in detail in Ness et al. (2015). In short, *The Cannon* makes two assumptions: that the spectra of stars with identical labels look identical, and that spectra vary smoothly with label changes. In other words, the continuum-normalized flux at each pixel in a spectrum is a smooth function of the labels that characterize the star. The "spectral model" is thus a function that maps each pixel of the spectrum to an object's labels, and *The Cannon* fits for this spectral model within a "training set" of objects: a collection of spectra and corresponding labels. This model can then be applied to spectra both inside and outside the training set.

We use APOGEE spectra and five APOKASC labels (T_{eff}, log*g*, *[Fe/H]*, *[α/Fe]*, and *M*) to train *The Cannon* model. For validation, we show that we can reproduce these labels for all of the objects in the training set. More interestingly, we show that the model can calculate physically plausible labels for objects *outside* the training set (APOGEE objects *not* measured by Kepler). Furthermore, we can investigate which regions of the spectrum are being used to determine which labels, because *The Cannon* model returns a set of coefficients for each pixel of a spectrum. For mass, we are finding that particularly informative spectral regions correspond to carbon and nitrogen features.

A significant limitation to *The Cannon* is that the model is only as reliable and comprehensive as the training set. In January, APOKASC is releasing 8,000 new objects, which will dramatically push the current boundaries of the label space, including many more low-log*g*, metal-poor stars. This dramatically diversified training set will help us continue to exploit the full wealth of information in stellar spectra.

* Named after Annie Jump Cannon, who pioneered stellar classification without stellar models.

Notes for Ho & Kupfer's talk (abstract on opposing page)

Breaking News: The Dynamic Radio Sky

Faced by many challenges, breakthroughs in the synoptic study of the transient radio sky have been scarce to date and certainly lag efforts at optical and gamma-ray wavelengths by a decade or more. Interferometers to date have lacked the survey speed for routine detection of the populations accessible at higher energies, specifically the various classes of supernovae targeted by optical surveys and the highly relativistic outflows of gamma-ray bursts (GRBs) targeted by space-based gamma-ray observatories. Furthermore, the rise and decay timescale for such events is typically very long at the frequencies ($\lesssim 5\,\mathrm{GHz}$) accessible to current and planned radio survey instruments requiring survey strategies spanning many years for robust measurement of event rates.

Nonetheless, the potential science return from synoptic radio surveys remains highly motivating. Radio observations, unlike optical, can penetrate the dusty environments of obscured supernovae. Similarly, the late-time, sub-relativistic radio afterglows of GRBs are largely isotropic, offering a means to an unbiased measure of their true rate and a path to identification of the electromagnetic counterpart to gravitational wave triggers offered by Advanced-LIGO and Advanced-VIRGO. In addition, a myriad of galactic phenomena produce transient radio emission, with an increasing propensity for coherent radio emission at lower frequencies, the latter being a powerful diagnostic of local magnetic field strength and plasma density.

A transformation is underway - interferometers are being developed that will offer enormous increases in survey speed, both at GHz frequencies (ASKAP, MeerKAT, APERTIF, SKA) and MHz frequencies (LOFAR, MWA, LWA). Meanwhile, the Jansky Very Large Array (VLA) has undergone a substantial upgrade delivering a 10-fold increase in survey speed, bringing the extragalactic explosive afterglow population within reach with modest time allocation. I will present results from the Caltech-NRAO Stripe 82 Survey (CNSS), a dedicated radio transient survey that takes advantage of the VLA's increase in sensitivity.

The Caltech-NRAO Stripe 82 Survey

While sensitive to many classes of transients, both Galactic and extragalactic, the CNSS was proposed and designed to enable detection of the radio afterglows associated with the extragalactic explosive population. For this reason, CNSS uses the VLA to image the entire 270 sq. degrees of the Sloan Digital Sky Survey (SDSS) southern equatorial Stripe 82 on each of five epochs spanning 18 months, using a frequency of 3 GHz. Stripe 82 was chosen due to the deep SDSS five-band photometry, as well as spectra from the Baryon Oscillation Spectroscopic Survey (BOSS) survey, for this region of the sky, originally obtained as part of the SDSS supernova survey. BOSS spectroscopy and/or photo-z determination from SDSS photometry, allows rapid identification and distance determination for transients associated with galaxies in the local universe. These data are further complemented by the plethora of ancillary survey data for Stripe 82 from radio to X-ray (eg., VLA, SDSS, UKIRT, Galex, CFHT, VISTA, WiggleZ, Herschel).

With the equivalent of 6,000 individual pointings per epoch, and 1000 frequency channels, the CNSS presented enormous challenges. To enable the VLA to survey to a shallow depth in each epoch without losing a large amount of time to slewing the dishes, an "on-the-fly" (OTF) mode of operation was commissioned that allowed us to slew the telescope continuously and step in phase electronically. A custom developed pipeline for data calibration and imaging, source extraction, cataloging of transients and triggering of follow-up observations was developed at Caltech, and implemented on dedicated hardware deployed to the NRAO DSOC at Socorro (Mooley et al. 2015). Transients were detected typically within 6 hours of completing an observation block, allowing follow-up with the VLA, Swift, Palomar and Keck observatories.

I will present the initial results from the first 3 epochs of the CNSS, including the discovery of an exciting new population of radio transients, likely due to the late time, sub-relativistic afterglow of initially relativistic jetted explosions. I will also briefly discuss the upcoming VLA Sky Survey (VLASS), a concept initially motivated by the capabilities demonstrated by the CNSS. The VLASS will survey 30,000 sq. degrees three times over 7 years and will be the deepest radio transient survey until the advent of the SKA.

Notes Hallinan's talk (abstract on opposing page)

From `urbandictionary.com`

`An individual with few redeeming characteristics. Stems from the fact that spheres appear exactly the same when viewed from any perspective. The phrase is commonly attributed to astronomer Fritz Zwicky.`

e.g. Scooby's a spherical b—–d, since no matter how you look at him, he's still a b—–d.

Figure 5.2: Ten newly discovered local Universe galaxies found in the Census of the Local Universe (CLU) survey via PTF narrow-band imaging. Shown above are the SDSS gri color composite images for each galaxy. The properties of these galaxies span a wide range in color and Hα equivalent width, and all ten have been spectroscopically confirmed to be local via BOSS/SDSS. Given the estimated PTF Hα sensitivity of L(Hα) $\sim 10^{39.8}$ erg s^{-1} we anticipate an 85% completeness at 200 Mpc resulting in the discovery of tens of thousands of new nearby galaxies. Figure supplied by D. Cook & M. Kasliwal.

Chapter 6

Session F: New Tools & Methodologies

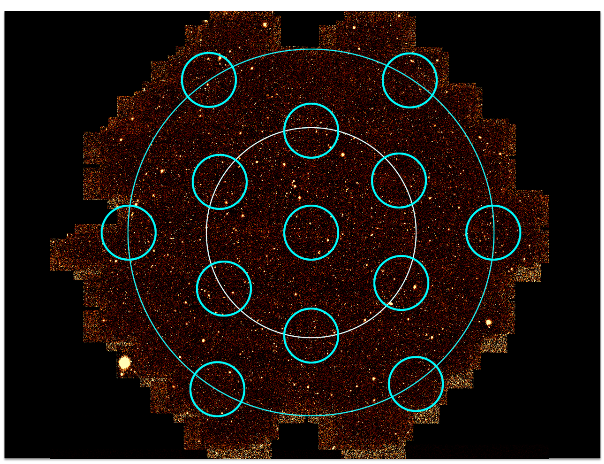


Figure 6.1: The field-of-view of the Dark Energy Camera (DECAM; about 3 deg^2) imposed on the the thirteen beams of the Parkes 1.4 GHz multi-beam receiver. In 20 s DECAM achieves $m_g \sim 24$ mag) with a read time of only 17 s. With this "Deep Wide & Fast" astronomers are searching for extragalactic counterparts to the most mysterious Fast Radio Bursts (FRBs) observed at Parkes or Molonglo. The program brings in Swift Observatory on timescales of minutes. Figure supplied by J. Cooke.

Deeper, Wider, Faster

Detecting counterparts to the fastest bursts in the sky

Transient events fully populate the conventional magnitude vs. duration space, which probes timescales of roughly 1 – 100 days. Theory predicts a large number of events resulting from a variety of physical mechanisms occurring on timescales of seconds-to-hours. Fragmented observational efforts on such timescales have uncovered phenomena such as 'bursty' gamma-ray bursts, new classes of novae, evidence for supernova shock break-out, tidal disruption events, kilonovae, and the recently discovered fast radio bursts (FRBs; radio bursts on millisecond timescale) that are likely extragalactic in origin but whose physical mechanisms are currently unknown.

These fast events are typically rare, requiring wide field searches, and are best detected, or perhaps only detectable, at certain wavelengths. In addition, some of the observed and theorized events have complicated and/or unknown light curve behavior. Extragalactic detection of these events (out to z ~ 1 for FRBs) requires deep observations. As a result, effectively probing the short transient time domain requires simultaneous deep, wide, and fast observations at multiple wavelengths. The large data sets generated by fast time sampling of wide areas, and the unknown nature of some transient event profiles, create an environment best tackled by data science and machine learning techniques.

Our Deeper, Wider, Faster (DWF) program attacks these challenges head-on by coordinating simultaneous observations with an array of observatories from the radio to gamma ray. Anchored by the real-time (confirmation within seconds) FRB detection capability of the Parkes radio observatory, the program leans on our optical observations using DECam at CTIO, capitalizing on its unique combination of wide field, high sensitivity, and quick 20s readout time, and rapid Swift satellite coverage in the UV/x-ray/gamma-ray via our Cycle 11 program. Finally, the observations are strongly enhanced by coordinated simultaneous observations with the Molonglo and VLA radio observatories and an array of optical and infrared telescopes for spectroscopic follow-up (with others being added with time). As such, DWF is capable of detecting rapid transients over the full range of wavelengths in wide fields on a seconds-to-hours timescale and to m ~ 24 – 27 (20s – 2 hrs) in the optical.

The Parkes data is processed and analysed in real time (seconds). The DECam data is processed and analysed in real time (minutes) partially manipulated at the observatory and transferred and processed on the supercomputer at Swinburne University. The data are then assessed in real time (1) visually, (2) using conventional source detection software and machine learning techniques to identify rapid ToO triggers and (3) processed thoroughly for archival detections and study after the observations. DWF is providing a strong framework for future gravitational wave counterpart searches. The challenges that remain are improving the efficiency and efficacy of rapid data analysis and multi-observatory rapid photometric and spectroscopic follow-up.

Notes for Cooke's talk (abstract on opposing page)

Front-line Transient Classification: The SED Machine

The SED Machine (SEDM) is designed to be the front-line classification engine for the Zwicky Transient Factory (ZTF), capable of producing transient type classifications within hours of discovery for objects brighter than 20.5 V magnitudes. It consists of a lenslet array IFU (30"x30" FOV) with a low-resolution (R ~ 100), high-throughput, optical (365-1000nm) spectrograph in parallel operation with a 4-filter (SDSS ugri, 5' x 5' FOV each) direct imaging camera (Rainbow Camera, RC). The SEDM is mounted on the Palomar 60-inch (P60) telescope and will eventually be robotically controlled and marshaled by a transient priority-scheduling engine that will queue new targets automatically. All data reduction will take place as soon as images are acquired with the end result being a host-subtracted, flux-calibrated spectrum suitable for uploading to the PTF Marshal and subsequent input into fitting and classification programs such as SNfit.

We report on the progress of commissioning the SEDM and present results from a recent run (17,18,19 August 2015) where the pointing model was explored, the throughput was characterized and the classification capabilities of the SEDM were demonstrated (see Figure 1). We also present our plans for integrating a scheduling engine for the SEDM with the existing robotic operation of the P60 telescope using software already proven with the GRBCam and currently used for iPTF on the P48 telescope.

Figure 1 below shows the RC r-band acquisition image and the result of a fit to the IFU spectrum of transient PTF15ccs, discovered on 19 August 2015 and observed with SEDM the same night. The transient was reported to be 19.3 mag in the SDSS g-band. The IFU observations consist of two pair of 30-min exposures offset on the IFU by seven arcseconds (RA & Dec) for sky removal. The images were reduced and the spectrum was run through SNfit producing a very good fit to a Type Ia SN at +10 days. The spectrum and the classification were uploaded to the PTF Marshal within an hour of final data acquisition. This is a significant milestone in the commissioning of the SEDM and demonstrates its potential as a front-line classification engine.

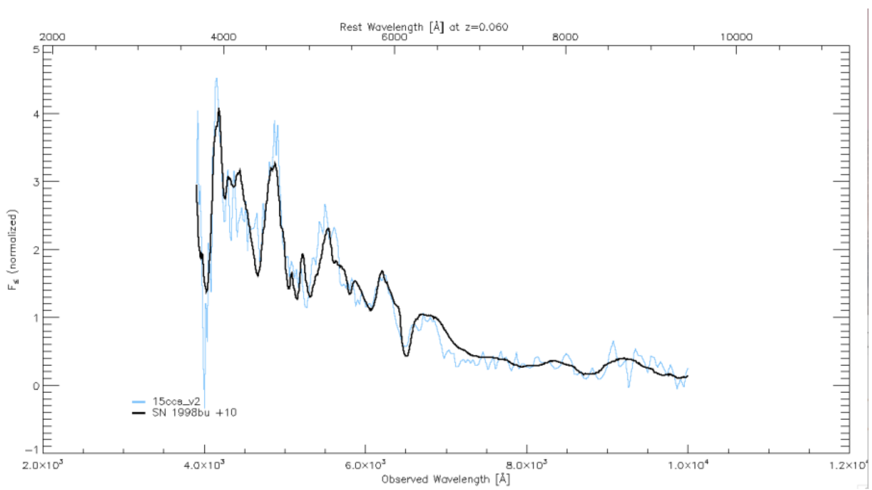
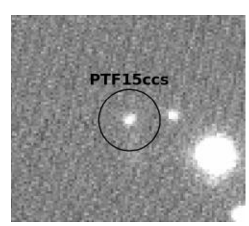


Figure 1. PTF15ccs IFU spectrum and Template SN Ia fit (right). RC r-band 30s image (below).



Notes for Konidaris' talk (abstract on opposing page)

Commensal and Triggered Observing at the Karl G. Jansky Very Large Array (JVLA) by Dale A. Frail, AD New Mexico Operations

The JVLA is a workhorse for time-domain astronomy. It has a suite of capabilities and observing modes that allow it to function as a stand-alone imager, a fast survey telescope or as a sensitive follow-up instrument for discoveries made at other wavelengths. Of the approximately 350 science programs executed at the JVLA each year, 15 to 20% involve time-sensitive observations. The diversity of time domain science is large. In any given semester the JVLA may be used to image electron beams in the Sun's corona at 100 millisecond resolution, follow up recent gamma-ray bursts and supernovae, and image the expanding shells of old novae and supernova remnants. In this talk I will outline two new time domain capabilities that have recently been implemented, driven by community interest. (1) The JVLA is now able to automatically respond to external triggers (e.g. ZTF, Swift, etc.) and rapidly slew to targets. (2) The JVLA is increasingly being used in commensal or "piggy-back" mode. In one case the JVLA is being used with multiple back ends, with one instrument using the prime focus (VLITE) while the other (WIDAR) uses the Cassegrain focus. In a second mode (under development) the main WIDAR correlator is used to collect standard image data with seconds-long integrations, while simultaneously looking for millisecond fast radio bursts.

Notes for Frail's talk (abstract on opposing page)

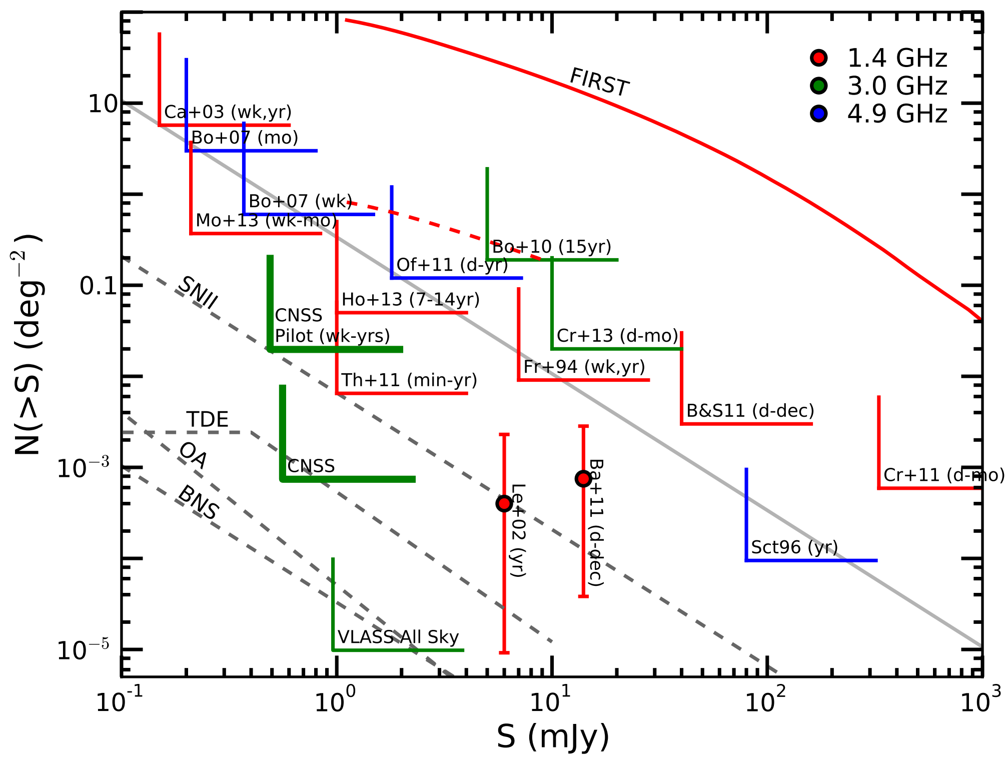


Figure 6.2: The logN-logS phase space of radio transients. The majority of the surveys to date have revealed a fairly quiet radio sky at GHz frequencies. However, the newly-developed on-the-fly (OTF) mapping at the Jansky VLA has facilitated surveys that have started probing the phase space of exotic transients such as core-collapse supernovae, non-thermal tidal disruption events (TDE), new classes of stellar sources with strong non-thermal emission and long-lived transients of unknown origin. Next generation radio facilities with their large mapping speed are well suited to exploring the dynamic radio sky. From Mooley et al. 2015 (ApJ, accepted).

Chapter 7

Session G: Resurgent Radio Astronomy

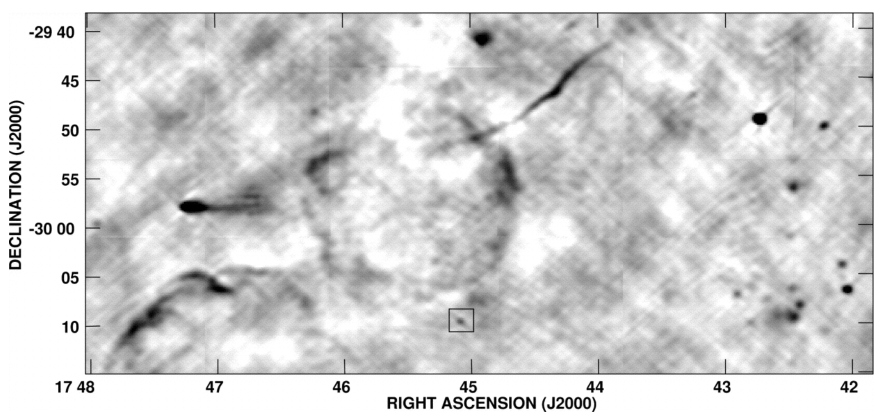


Figure 7.1: GCRT J1745−3009 is a source (located towards the Galactic center; marked by an open box) found at meter-wavelengths (Hyman et al. 2005). It has one of the steepest spectral index, the emission is nearly pure circularization and exhibits a period of 78 minutes. Astronomers are *clueless* about the origin of this source despite being it being discovered two decades ago.

Status of Low Frequency Radio Facilities: With a Focus on Transients

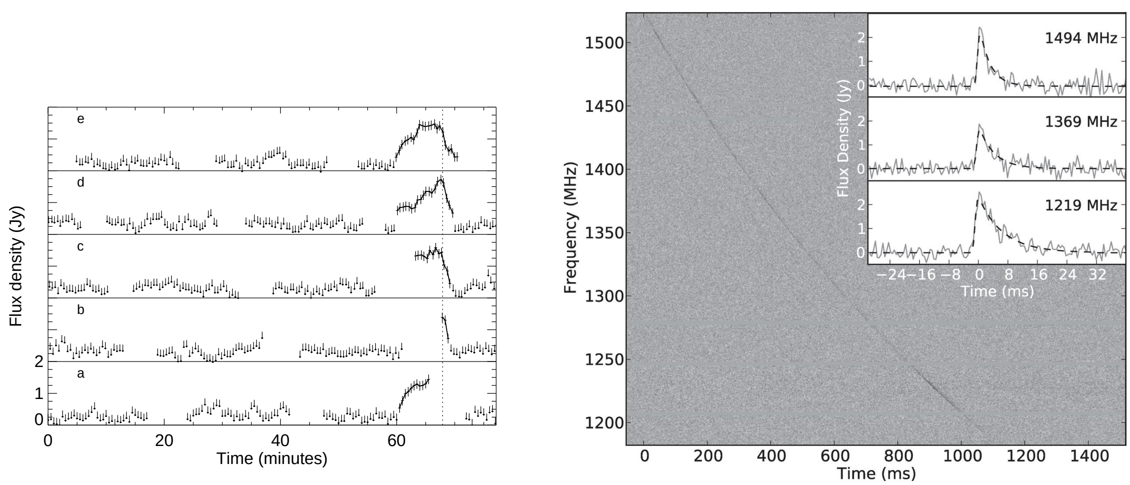
Joseph Lazio (JPL, Caltech)

Synoptic Surveys: Boutique & Experiments, Pasadena, CA; August 28–29

Abstract

Transient radio sources are necessarily compact and usually are the locations of explosive or dynamic events, therefore offering unique opportunities for probing fundamental physics and astrophysics. In addition, short-duration transients are powerful probes of intervening media owing to dispersion, scattering, and Faraday rotation that modify the signals. Searches for radio transients have a long history, and a wide variety of radio transients are known, ranging from extremely nearby to cosmological distances. In addition, motivated by analogy to known objects or applying known physics, there are a number of classes of hypothesized classes of transients.

In this presentation, I focus on the capabilities of the emerging suite of low radio frequency facilities (operating below 1 GHz) to probe the dynamic radio sky. These facilities include the Giant Metrewave Radio Telescope (GMRT), the V-LITE capability on the Very Large Array (VLA), the Low Frequency Array (LOFAR), the Murchison Widefield Array (MWA), and the various instances of the Long Wavelength Array (LWA). I begin by reviewing the different classes of transients that might be expected and arguing that incoherent transients are unlikely to be numerous at low frequencies, as is apparently being borne out by experience. I then suggest the classes of coherent transients most likely to be the focus of future investigations.



Two examples of transients that may be numerous at low radio frequencies. (*Left*) The folded light curve for GCRT J1745−3009, an as-yet unidentified transient discovered at 330 MHz. It may represent a slowly rotating magnetized body. (*Right*) A highly dispersed transient, a.k.a. a Fast Radio Burst (FRB). Although discovered at 1.4 GHz, the frequency dependence of dispersion suggests that FRBs may be several seconds long at lower frequencies, if absorption effects are not significant.

Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Notes for Lazio's talk (abstract on opposing page)

Fast Radio Transient Surveys with CHIME

Vicky Kaspi, McGill University
on behalf of CHIME/FRB and CHIME/Pulsar Collaborations

CHIME is a new 80-m $\times$ 100-m radio telescope being currently being built in Penticton, British Columbia as part of a collaboration between University of British Columbia, McGill University and University of Toronto. CHIME will operate in the 400-800 MHz radio band in two linear polarizations and will have no moving parts: it consists of 4 parallel cylindrical paraboloids arranged North-South (each measuring 20 m x 100 m) to act as a transit telescope. Thanks to 256 feed antennas per cylinder, equispaced along the axes, CHIME will act as a 'software' telescope, having a field of view of 240 deg^2 tiled by 1024 simultaneous beams, observing 24/7. This is achieved by combining the low-noise amplified analog signals from each feed antenna, after digitising at 800 MHz, in a backend software correlator that processes the data using a combination of FPGAs and GPUs. First light for full CHIME is expected in 2016.

CHIME is designed to map the Northern sky in the redshifted light of the neutral Hydrogen 21-cm line in order to measure the effect of baryon acoustic oscillations. Using HI intensity mapping, CHIME will make a 3D map of the large-scale structure of the Universe between redshifts of 0.8 and 2.5. The experiment is designed to observe the period in the Universe's history during which the standard ΛCDM model predicts that dark energy began to dominate the energy density of the Universe and when decelerated expansion transitioned to acceleration.

However, CHIME will also be very useful for studying the transient radio sky, thanks to its sensitivity and large field-of-view. Of particular relevance is the puzzle of Fast Radio Bursts, few-ms radio bursts having dispersion measures far larger than are expected from our Galaxy and suggesting cosmological distances. The origin of FRBs is presently unknown. Current best estimates of FRB rates, together with reasonable assumptions regarding spectral indices and degrees of scattering suggest CHIME could detect dozens of FRBs per day. To accomplish this, the CHIME correlator is being modified to produce, alongside its nominal data stream, 1-ms resolution "filterbank" data having 4096 channels, each with 8 bits and having polarization summed. This will be fed into a backend system funded by CFI and currently under design but likely consisting of several hundred commercially available GPUs which will incoherently dedisperse the data stream at a large range of trial dispersion measures, then search for peaks in the resulting time series using boxcar filters of different widths, all in real time. Different proposed algorithms for achieving this as efficiently as possible – and hence to cover as much sky as our local power limitations impose – are presently under study.

CHIME will also be useful for monitoring radio pulsars, as its large collecting area and bandwidth, hence great sensitivity, will enable detection of nearly every known radio pulsar in the Northern sky. This will be useful for monitoring rotating radio transients (RRATs), eclipsing pulsars, relavistic binaries, nullers, and mode changers. Regular pulsar monitoring will also enable detailed studies of interstellar medium effects, which will be particularly useful to Pulsar Timing Arrays and their effort to detect nanohertz-frequency gravitational waves. A separate pulsar backend is currently under construction at McGill University and will enable the simultaneous observation of 10 independent positions on the sky, 24/7, each coherently dedispersed.

Notes for Kaspi's talk (abstract on opposing page)

Molonglo: Refurbished & Resurgent

Among all electromagnetic wavebands, transient and variable phenomena in the radio sky may be uniquely difficult to characterize. Radio astronomers wade through a mire of instrumental instabilities, human-generated radio-frequency interference (RFI), and atmospheric phenomena. In order to ultimately establish that a source is astrophysical, the plane-wave nature of its emission must be demonstrated. For time-variable sources, this requires interferometry. However, the computational cost of correlating signals between *n(n-1)/2* pairs of antennas in an *n*-antenna system often means low *n*'s, and time-variable artefacts caused by sparsely filled apertures.

We have refurbished the 50-year-old Molonglo Observatory Synthesis Telescope, a project we term UTMOST. The UTMOST interferometer has a mile-long (11.6 m across) reflecting surface. Radio signals in a 30 MHz band centered on 843 MHz are received and digitized at 352 points along the telescope, providing a data rate of 22 GB/s. These data are processed in real time by a system of FPGA-based spectrometers and a 54-GPU supercomputer. The data can also be recorded to disk for future processing.

UTMOST is designed and poised to hunt down radio transients and variables on all timescales. On millisecond timescales, UTMOST will detect isolated bursts from Galactic neutron stars, as well as the possibly cosmological and so far unidentified Fast Radio Bursts (FRBs). Indeed, the large field of view (approx. 8 deg^2) and substantial sensitivity combine to imply a detection rate of better than one FRB per week. As all FRBs have so far been detected with individual radio antennas, an UTMOST detection will provide the strongest evidence yet for the astrophysical origin of FRBs, along with a 47'' by 2 deg localization. We expect UTMOST to collate a statistically significant FRB sample. On longer timescales, UTMOST will be sensitive to variability in existing radio sources, such as AGN, and to a plethora of transients, such as outbursts from Galactic compact object systems, stellar flares, radio supernovae, and otherwise unidentified events such as the Galactic Center transients.

Currently, UTMOST is in the final stages of refurbishment and commissioning. As the UTMOST frequency band coincides with a commonly used mobile phone band, we identify and excise most RFI in real time. We have developed a real-time GPU-based fast transient detector to search for events such as FRBs in any of up to 704 synthesized "beams", or pixels (see Fig. 1). This detector ('Heimdall') will trigger the recording of the rawest (baseband) data. We also produce aperture-synthesis radio images (see Fig. 2). Outstanding issues include completing the hardware upgrade, and developing techniques to search for minute- to hour-long variability. In summary, UTMOST provides the means to monitor the Southern radio sky on any timescale of interest, with interferometric resolution, over a wide field, and with substantial sensitivity. So look out, sky!

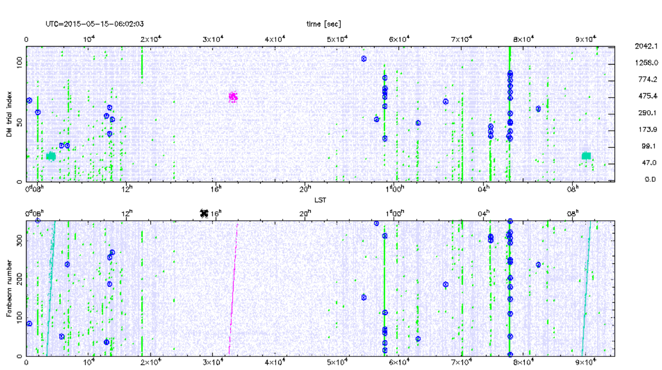


Fig. 1: Pilot fast transient drift-scan search, with pulsar transits and candidate events.

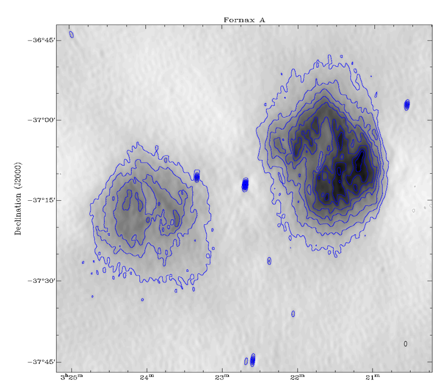


Fig. 2: UTMOST commissioning image of the radio galaxy Fornax A.

Notes for Ravi's talk (abstract on opposing page)

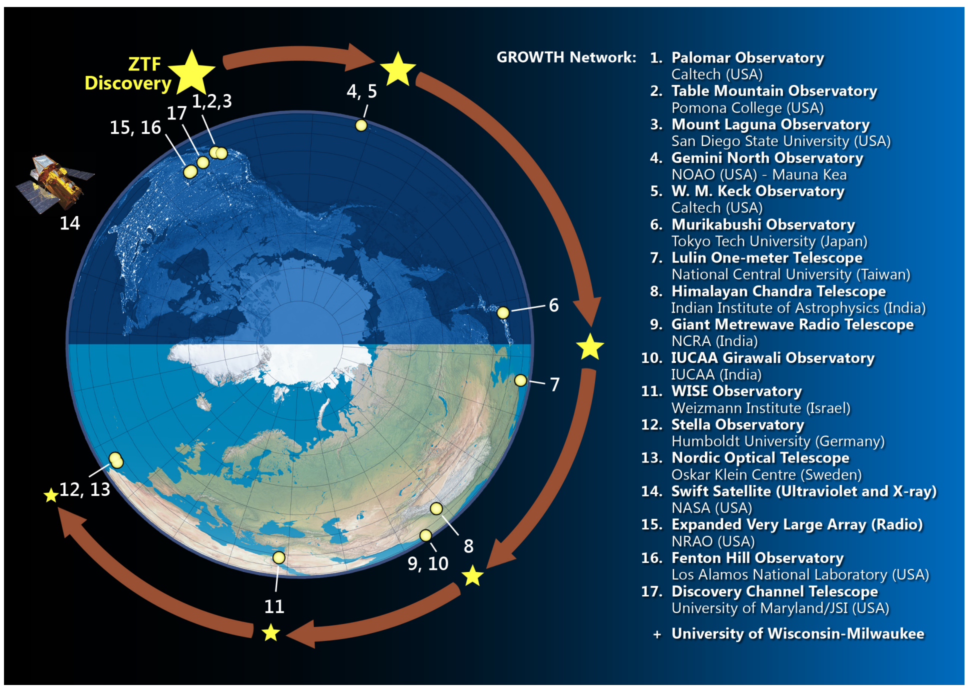


Figure 7.2: GROWTH (Global Relay of Observatories Watching Transients Happen) is a co-ordinated northern network of astronomers and telescopes unbeaten by sunrise. As the transient fades and the earth rotates, the baton to collect follow-up data is relayed from country-to-country (orange arrows). Image supplied by M. Kasliwal, the Principal Investigator for GROWTH.

Appendix A

Participants

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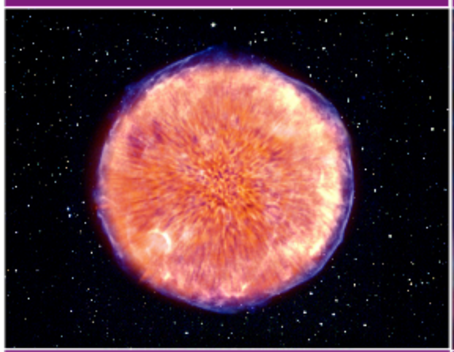
B. Shappee, Carnegie
P. Szkody, UW
P. van Dokkum, Yale
T. Vestrand, LANL
R. Walters, Caltech
S. Weinreb, JPL
A. Weinstein, Caltech
L. Yan, Caltech
A. Janzen, Caltech

Acknowledgements: The quotes from Zwicky are drawn from `www.brainyquote.com`. Credits for photographs: Figure 1 is from Caltech archives; Figure 3 is from `www.scienceblogs.com`; Figure 1.2 is from `Wikipedia`. The curious creatures from the Cambrian era (including with five eyes!) is from `http://earthlearningidea.blogspot.com`. The cartoon on the Cambrian explosion is from `http://conservationbytes.com/`.

A wide-field explorer that will unveil the dynamic UV sky

INVESTIGATION GOALS

Goal 1: How do the lives of massive stars end?



OBJECTIVES

(1) Determine the state of the star prior to supernova
(2) Measure explosion parameters
(3) Determine how initial conditions affect SN type
(4) Determine the pre-explosion evolution of massive stars
(5) Constrain shock breakout models

Goal 2: Masses and Environments of Black Holes

OBJECTIVES

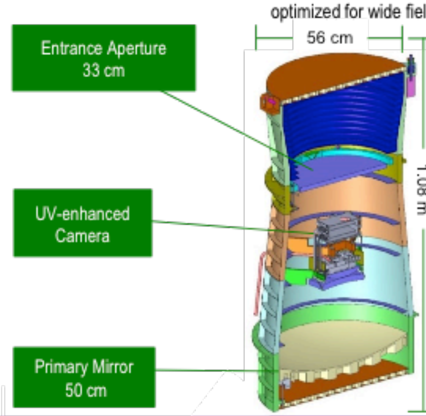
(1) Measurement of black hole masses for redshifts to $z \lesssim 0.35$
(2) Measure size of accretion disk and map geometry of the Broad Line Region

MISSION SYSTEM

- 2 year mission operating in GEO Graveyard Orbit
- Proven S/C supplier (IAI) with 100% track record of success
- Free-flyer, 1.2m x 1.2m x 0.6m, 162 kg
- Stares at the same patch of sky for six month intervals; 2 in the Northern Hemisphere and 1 in Southern Hemisphere
- Continuous communications through commercial ground stations

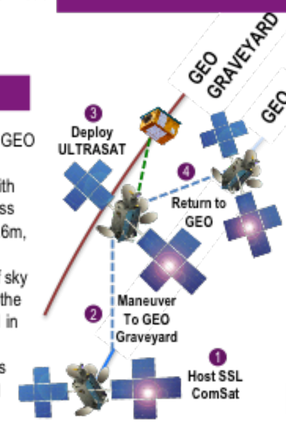
PAYLOAD SYSTEM KEY CHARACTERISTICS

ULTRASAT's Schmidt telescope and UV camera are optimized for wide field observations.

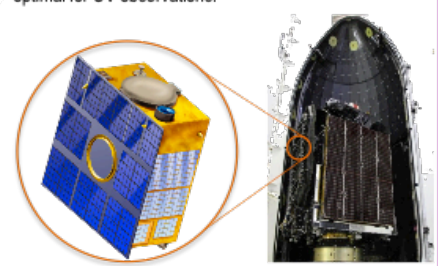


Mass	45.3 kg
Continuous Imaging	Nearly orthogonal to sun direction
FoV	210 deg^2
Band	220 – 280 nm
Detector	Delta-doped e2v CCD 42-80
FPA	Mosaic of five 2k x 4k CCD 42-80
Cadence	900 sec (3x300 s)
Limiting Mag	21.5 mag (AB), 5 σ
Alert	< 1 hr

HOSTED LAUNCH



ULTRASAT's "taxi" to space with Loral Space Systems provides low cost, low risk insertion via SSL's proven Lightband system to its GEO graveyard orbit, which is optimal for UV observations.



GROUND-BASED SCIENCE OBSERVATIONS

ULTRASAT's rapid transient alerts, in concert with committed ground based follow-up, provides a treasure trove of science to the global astronomy community.

ULTRASAT is a proposed joint mission between the Israeli Space Agency & Caltech/JPL