LSST TVS RoadMap Document (Draft in progress)

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NOTE:

The paper is organized as follows: The four main sections are

- Time sensitive science cases: these are science cases that require prompt identification and trigger of follow up resources.
- Non-time sensitive science cases: these are science cases that can be developed on the annual data releases. Some of these science cases may assume that the sample is pure, i.e. that prompt identification or characterization has been achieved.
- Deep Drilling Fields
- Mini Surveys

  Each of these section is further subdivided into:

  - Extrinsic transients and variability: including geometric transients such as microlensing, eclipsing binaries, and transiting planets.
  - Intrinsic galactic and Local Universe transients and Variables: including stellar eruptions, explosions, pulsations.
  - Intrinsic extra-galactic transients: including supernovae, GRB.

Each of these section should include multiple science cases. Each science case should include:

Figure 1: Structure of the paper. Click on the blue nodes to see the subsections and subsection editors. Click on the white nodes to collapse the subsections. A larger, zummable version of this structure tree is available at http://cosmo.nyu.edu/~fb55/vizs/RoadmapOutline/tree.html

- Low hanging fruits
- Pie in the sky

Each section should identify tasks (including but not limited to):

- Observations needed ahead of LSST to narrow the space of relevant variables

- Theory development to generate predictions on LSST observables
- Computational advancements and infrastructure required to handle LSST data volume
- Data integration progress to incorporate multiwavelength/context/other time scale data
- Facilities upgrades and development to support follow-up

Introduction

Chapter Editors: RS and FBB

LSST on the horizon, scale of project and data products will be entirely new and require advanced preparation in order to be ready in time to maximize the science return.

LSST Data Products – An Overview

Author and Editor: M. L. Graham

The Large Synoptic Survey Telescope (LSST) is an astronomical project designed to generate significant advances in four science areas: cosmology (dark matter and dark energy); the Solar System (with a focus on potentially hazardous asteroids); the Milky Way Galaxy; and transient phenomena. To do this, the LSST will deliver a deep survey that covers $\sim 1.8 \times 10^4$ square degrees in the southern sky and will detect ~ 40 billion stars and galaxies (**?**). A total of ~ 825 visits to each part of the sky within this area will be made in six filters, *ugrizy*, over 10 years. About 10% of the observing time will be devoted to community-proposed special programs that extend the areal coverage, depth, and/or sampling cadence (e.g., mini-surveys, deep drilling fields). The LSST currently estimates that full operations will begin in late 2022.

The LSST will acquire ∼20 terabytes of raw data each night and process it in real time, distributing alerts on objects that vary in brightness or position within 60 seconds, delivering processed images and updated object catalogs within 24 hours, and releasing a yearly reprocessed data set including deep image stacks (**?**). To enable science with this massive data set, the LSST Data Management System includes the Science Platform: a web-based service for data access, analysis, and processing that includes software tools and computational resources (**?**). We discuss the Prompt and Data Release data products in further detail in Sections and 0.3, respectively.

Potential of LSST for time domain science

(phase space diagram)

Purpose of document

- Stimulate research and preparations for LSST
- Outline areas of necessary work (theoretical and practical)
- Identify weaknesses and strengths of different LSST observing strategies for time domain science
- Identify areas of research and infrastructure which are currently underprepared.

Science cases covered by V1 of this document

Science cases NOT covered by V1 of this document

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  - Intrinsic/Extrinsic extra-galactic transients: including supernovae, GRB, blazars.

Time Critical science

LSST *Prompt* data products

Editor and Author: Melissa Graham

Every standard visit image ($\sim$ 30s integration) acquired by the LSST will be immediately reduced, calibrated, and processed with Difference Image Analysis (DIA), wherein a template image (a deep stack of previously obtained images) is subtracted to generate a difference image. All sources detected in the difference image represent the time-variable components of transient phenomena (e.g., supernovae), variable stars (e.g., RR Lyrae), and moving objects (e.g., asteroids). For all difference-image sources detected with a signal-to-noise ratio (SNR) of at least 5, an alert packet containing information about the source (location, fluxes, derived parameters, and $\sim 6'' \times 6''$ cutouts) will be generated and released within 60 seconds of the end of image readout. Alerts are world public and can be shared with anyone, anywhere. It is expected that alerts on moving objects will be integrated into the Minor Planet Center. Due to the very high bandwidth of the LSST Alert Stream it will only be delivered in full, in real-time, to 4-7 Alert Brokers (**?**), who will serve them to their communities (some brokers plan to provide public access, e.g., **?**). All other prompt data products (e.g., visit, template, and difference images, catalogs of difference-image objects) will be made available to LSST members via the Science Platform within 24 hours, but are subject to a two-year proprietary period, after which time they can be shared with anyone, anywhere, worldwide. LSST members will also have access to the LSST Alert Filtering Service where they may define filters and receive alerts on their targets of interest in real-time, and access to a queryable database of alerts.

Quantities of Particular Importance to Time-Domain Studies – There are four Prompt data types and quantities that we want to highlight which will be specifically useful for time-domain astronomy. First, all detected difference-image sources for which there was no variable source previously detected will have forced photometry performed at their location in the last $\sim$30 days of difference images in order to, e.g., look for faint precursor events. This is commonly referred to as precovery photometry and will be available within 24 hours (as are all Prompt data products). Second, all objects that were detected in difference images within the past ∼12 months will have forced photometry performed at their location in the new difference image in order to, e.g., continue to monitor known objects as they fade. This forced photometry will be available within 24 hours. Third, the catalog of difference-image sources will contain some light curve characterization parameters for, e.g., periodic and non-periodic features. The exact nature of these parameters is to be determined, but they will be updated to include new observations within 24 hours. Fourth, all difference-image sources will be associated with the nearest static-sky objects from the Data Release data products (see Section 0.3), so that the potential host galaxy and/or longer-term information about the variable star can be easily obtained. These associations will be included in the alerts and also the difference-image source catalogs.

See also **?** for a full and complete description of the LSST data products.

Science Cases using LSST *Prompt* data products

0.1 Extrinsic Transients

Editor: Rachel Street

Microlensing

Authors: Rachel Street, Marc Moniez

Microlensing occurs when a foreground object (lens) passes directly between the observer and a luminous background source**?**. A review of the microlensing formalism can be found in **?**. The gravity of the lens deflects light from the source with a characteristic radius, R_E, causing the source to brighten and fade as they move into and out of alignment, with a timescale, t_E that is proportional to the square root of the lens mass (years for BHs, days to weeks for planets and stars). Assuming a single point-like lens of mass M located at distance D_L is deflecting the light from a single point-like source located at distance D_S, the characteristic radius (Einstein radius) R_{E} is given by:

$$R_{\mathrm{E}}=\sqrt{\frac{4GM}{c^2}D_S x(1-x)} \simeq 4.54\ \mathrm{AU.} \left[\frac{M}{M_\odot}\right]^{\frac{1}{2}} \left[\frac{D_S}{10kpc}\right]^{\frac{1}{2}} \frac{[x(1-x)]^{\frac{1}{2}}}{0.5}, \tag{1}$$

where G is the Newtonian gravitational constant, and $x = D_L/D_S$. If the lens is moving at a constant relative transverse velocity v_T, the characteristic lensing time scale is given by:

$$t_{\mathrm{E}} \sim 79\ \mathrm{days} \times \left[\frac{v_T}{100\,km/s}\right]^{-1} \left[\frac{M}{M_\odot}\right]^{\frac{1}{2}} \left[\frac{D_S}{10\,kpc}\right]^{\frac{1}{2}} \frac{[x(1-x)]^{\frac{1}{2}}}{0.5}\ . \tag{2}$$

The so-called simple microlensing effect (point-like source and lens with rectilinear motions) has the following characteristic features. Given the low probability of the alignment, the event should be singular in the history of the source (as well as of the deflector); the magnification, independent of the color, is a simple function of time depending only on three parameters, with a symmetrical shape; as the source and the deflector are independent, the prior distribution of the events' impact parameters must be uniform; all stars at the same given distance have the same probability of being lensed; therefore the sample of lensed stars should be representative of the monitored population at that distance, particularly with respect to the observed color and magnitude distributions.

Since this phenomenon doesn't require light to be detected from the lens itself, it is capable of exploring populations which are otherwise hidden from view due to their distance and/or intrinsic luminosity.

LSST offers two complementary opportunities for microlensing discoveries: by extending the Wide-Fast-Deep survey to cover the Galactic Plane, and by conducting coordinated observations of a Deep Drilling

Field located on the WFIRST Bulge survey region. Here we explore the scientific yield from both observing strategies.

- Low hanging fruits

  a) **Galactic Plane Survey: Galactic population of single and binary black holes**
  Stellar evolution models imply that there should be millions of black holes residing in our galaxy **?**. Those with masses below $\sim 20\,\mathrm{M}_\odot$ are the expected products of stellar evolution **?**, but recent gravitational wave detections suggest an unforeseen population of more massive ($>20\,\mathrm{M}_\odot$) BHs, which result from BH-BH mergers **?**, **?**, **?**. These may be produced by stellar evolution, or formed in the very early Universe from the clumps of non-barionic dark matter: primordial BH e.g., **?**, **?**. The mass function of the BH is still very poorly known. A recent analysis of 8 years of OGLE-III photometric time-series data **?** yielded 13 candidates for dark objects found via the microlensing method, indicating a continuation of mass spectrum of black holes from $3\,\mathrm{M}_\odot$ upwards.

  The past and present microlensing surveys all suffered from a drastic decline of the detection efficiency for events with durations t_E larger than a few years, which are expected from massive lenses ($M > 20.M_\odot$). This is the reason why the published limits on the contribution of compact objects to the Galactic dark matter are not very constraining beyond this mass. With 10 years of continuous observations, the light-curves measured by LSST will allow one to reach the sensitivity either to detect heavy black holes up to $1000.M_\odot$ and measure their Galactic density, or to exclude their contribution to a significant fraction of the Galactic hidden matter.

  The main condition to succeed in this task is to ensure a time-sampling of the Galactic fields and of LMC/SMC that spans the entire LSST survey duration and avoids very long gaps within the light-curves (apart the inevitable inter-seasonal gaps). The final efficiency to long timescale events will not be sensitive to the details of the cadencing, as long as long gaps are avoided. In this search, the past and present surveys databases will add precious information to confirm or not microlensing candidates found with LSST alone.

  Such LSST will complement the results from LIGO since it is capable of directly measuring the properties of single as well as binary, lenses. LSST will reach fainter magnitudes than OGLE ($\sim$23 mag vs $\sim$20 mag), so we expect that by monitoring a few billion stars in the Galactic Plane it will detect hundreds of BH events.

  b) **Galactic Plane Survey: Self-lensing in the Magellenic Clouds**
  By including the Magellenic Clouds in the Wide-Fast-Deep survey, LSST will be able to detect microlensing events where both the lens and source lie in the Clouds, and hence explore stellar and stellar remnant populations in another galaxy. By conducting a long duration, self-consistent survey including the Milky Way Bulge, Galactic Disk and both Magellanic Clouds (LMC, SMC) LSST will compare the populations in different local environments.

  c) **Galactic Plane Survey: Galactic Population of Planets and Low-mass Stars**
  Despite outstanding discoveries from Kepler and other surveys, the vast majority of known exoplanets lie within 1 kpc of the Sun **?**. Variations in star formation, metallicity and stellar density and ages across the Galaxy mean we cannot assume that planets are ubiquitous, and comparing their occurrence rates in different populations will offer insights into their formation processes. Microlensing can probe to much greater distances ($\leqslant$8.5 kpc) and is sensitive to objects of all masses **???** in orbits between $\sim$1–10 AU. The microlensing rate for surveys outside the Bulge has been estimated **?** based on the minion_1016 OpSim *with minimal coverage of Plane fields*. They found an average rate of 15 events deg^{-2} year^{-1} in the disk and 400 events deg^{-2} year^{-1} in the Bulge. **This detection rate can be doubled if the cadence is increased from 6 d to 2 d.** Our proposed strategy ensures regular coverage of the Magellanic Clouds. The "edge-on" orientation of the SMC results in a higher probability of self-lensing (where both source and lens lie within that galaxy), raising the possibility of **detecting stellar and perhaps even planetary**

companions in a galaxy other than the Milky Way ?. LSST is predicted to detect 20–30 events year^{-1} **?**, provided the galaxy is monitored at least once every few days.

- Pie in the sky

  a) **Galactic Plane Survey: Mesolensing**
  R_E is inversely proportional to the lens distance, $\sim D_L{}^{-3/2}$, so nearby objects traveling at relatively high velocities are more likely to lens background stars than a similar, more distant objects **? ?**. LSST will investigate the mass distribution of faint objects in the local neighborhood such as low mass dwarfs, stellar remnants, and free-floating planets.

  b) **Galactic Plane Survey: Predicted Lensing**
  LSST proper motions will be valuable for predicting future microlensing events, as has been done from Gaia and Pan-STARRS 1 data (to shallower limiting magnitudes than LSST), **?**(Neilsen Bramich 2018).

0.2 Galactic and Local Universe transients and variables

Editor: Paula Szkody

EXor/FUor

Authors: Teresa Giannini,Rosaria (Sara) Bonito, Simone Antoniucci

An intense accretion activity is a defining feature of the large majority of all the Pre-Main Sequence (PMS) stars. Albeit a small and irregular photometric variations (typically 0.2-1 mag) caused by disk accretion variability is commonly seen in the light curves of many classical T Tauri stars (CTTSs), some young sources display powerful UV-optical outbursts of much larger intensity (up to 4-6 mag). So far, only $\sim$ 20 objects have been recognized as 'genuine' eruptive protostars **?** and even less have been long-term monitored. Depending on the different properties (bursts duration, recurrence time between subsequent bursts, accretion rate, presence of absorption or emission lines), young eruptive protostars are classified either as FUors **?** or EXors **?** Observationally, FUors and EXors are very different objects. FUors are characterized by bursts of long duration (tens of years) with accretion rates of the order of 10^{-4}-10^{-5} $M_\odot$/yr and spectra dominated by absorption lines, while EXors undergo shorter outbursts (months-one year) with a recurrence time of months to years, have accretion rates of the order of 10^{-6}-10^{-7} $M_\odot$/yr, and are characterized by emission line spectra.

For both classes of objects it is believed that bursts are due to accretion of material that piles-up at the inner edge of the disk **?**. However, the mechanism responsible for the burst triggering is not known: proposed scenarios **?** involve gravitational or thermal instabilities inside the disk or perturbation by an external body (orbiting planets or close encounters with nearby stars). At the moment, however, *none of the proposed models is able to provide a realistic view of the observed burst phenomenology*, also because the scarcity of the observations prevents to put tight constraints to the physical parameters involved.

The unprecedented sensitivity, spatial coverage and, even more importantly, observing cadence of LSST will allow for the first time a *statistical* approach for the discovery and monitoring of eruptive protostars. In particular, both the telescope lifetime and the sky coverage cadence, will permit to optimally monitor EXor-type variables. Furthermore, discovery of many new FUors/EXors is highly probable.

- Low hanging fruits

  a) **Hugely improve the number of new EXor candidates in our Galaxy.**
  Only about $\sim$ 20 EXors are known so far, mostly found serendipitous during observational campaigns dedicated to different scientific aims. With LSST we will have the un-precedent occasion to hugely improve this number. Considering an r-band limiting magnitude of 24.4 for a single

visit, we will observe all the stars with r $\sim$ 15 even in obscured regions (with $A_V \leq 10$ mag). Our selection criteria will be: 1) location in a star formation region; 2) shape of the Spectral Energy Distribution in and out of the high brightness phase; 3) light-curve analysis: rising/declining time of typical duration of months and speed of about 0.05 mag/day; burst amplitude between 2 and 4-5 mag in g-band; burst duration: months/few years, recurrence: months/years; 4) LSST color-color analysis: during burst, a significant excess emission in the UV is expected **?**. The LSST [g-r] vs. [u-g] color-color diagram represents therefore a powerful diagnostic tool for selection of EXor candidates. Investigation of public surveys (ASASSN, Gaia, iPTF, ZTF), as well as photometric monitoring (e.g.VST/OmegaCAM) of selected star forming regions are in order ahead of LSST to refine the above diagnostic tools. We remark that EXor/FUor bursts occur in timescales of months. In case of alert we need to investigate the past history of the source to reconstruct the light curve in the precedent quiescence phase. We need therefore access to all the LSST photometric data, that must be stored in a dedicated repository. Optical/near-infrared spectroscopic follow-up is needed to confirm the presence of emission lines in the spectrum and to measure the mass accretion rate. Depending on the source brightness and visibility, we will activate ToO observations at the ESO facilities (SoXS, X-shooter), LBT (MODS, LUCI), and TNG (GIARPS, Dolores, NICS) . Prompt follow-up in X-ray is also envisaged. In this respect, we remark that we will have access to GTO time for SoXS. Also, we have submitted a program for observation with e-Rosita (Stelzer, Giannini, Bonito 2018) to study the X-ray emission and its variability in accretion bursts. eROSITA All-Sky Survey will operate for 4 yrs beginning in 2019, therefore also simultaneous observations with LSST will be analyzed. Multi-epoch observations, when available, will be used to also explore the variability of these sources in X-rays, thus allowing us to perform a multi-band study of variability. We will also take advantage of magnetohydrodynamic numerical simulations and laboratory experiments **?** to investigate the multi-band properties of accretion shocks in standard and eruptive scenario. Given the optimal sky coverage and cadence of LSST we expect to increase the number of EXor candidates of about an order of magnitude since the first year of observations.

b) **Monitor known objects to identify and characterize both their low- and high-brightness states.**
The LSST main survey cadence of a couple of visits per months is ideal to properly sampling the light curves of the known objects, since it allows us to follow the rising/declining phases as well as the short amplitude variability characteristic of the quiescent phases. Our goals are: 1) to construct a library of light curves of known objects to be used as a reference for the identification of other potential members of the EXor class; 2) to measure the physical parameters and the mass accretion rate during different phases of the source activity by means of optical/near-infrared spectroscopic follow-ups. Since bursts occur typically every five-ten years, we expect to be able to observe at least one burst in a temporal range of 3-10 years.

- Pie in the sky

a) **Discover new FUors and follow their rising phase.**
With a telescope lifetime of about a decade, it is reasonable to detect new FUors. Prompt optical and near-IR spectroscopic as well as X-ray observations are needed to characterize the physical parameters and the mass accretion rate during the rising and peak phases. FUor outbursts occur typically on time-scales of 100 years. Therefore,it is likely that all the telescope lifetime is needed to discover a reasonable number of FUor events.

b) **Investigate the occurrence of EXor/FUor-like phenomena in evolutionary phases earlier than pre-main sequence.**
The large majority of EXors/FUors are PMS stars with age about 10^7 yr. In principle, however, nothing prevents the existence of eruptive variables younger than PMS stars (the so-called Class I sources, age about 10^{5-6} yr). Detection of very young eruptive variables is however challenging:

being still immersed in their natal environment, they are heavily extincted at the UV and optical bands, i.e. in the photometric bands where the accretion burst is more intense. According to the model by **?**, a 1 $L_\odot$ Class I source at a distance of 140 pc (Taurus, the closest star formation region) has g $\sim$ 16 mag. Considering the g-band limiting magnitude of 24.7 per single visit, we will be able to detect a burst of 6-7 mag of such sources provided that the local visual extinction does not exceed 15 mag. In case of detection, prompt follow-up of near-infrared imaging/spectroscopy will be activated. Such a discovery would be also a case of interest for observations with JWST, to study the accretion variability in the mid-infrared. In the assumption that Class I sources undergo EXor events in timescales similar to pre-main sequence EXor, we expect to observe significant bursts in the first 1-3 years of the telescope lifetime.

Compact Binaries: Cataclysmic Variables (CVs)

Authors: Paula Szkody and Elena Mason

Accretion onto compact objects represents a powerful probe of binary evolution and accretion physics, particularly those in tight orbits with late-type donor stars. Several types of systems comprise compact binaries. Cataclysmic variables (CVs) have accretion onto a white dwarf and include novae with 10-15 magnitude outbursts caused by thermonuclear runaways on the white dwarf, dwarf novae with 2-9 mag outbursts caused by disk instabilities and novalikes which have high and low states of accretion. Low mass x-ray binaries (LMXBs) encompass accretion onto a neutron star (NS) or a black hole (BH). They also experience rare outbursts due to disk instabilities but also vary between intermediate and quiescent states. With a record of different accretion states among these compact binaries, it has become critical to map the accretion history of each class of objects to correctly frame their evolutionary scenario.

Accretion onto compact objects requires that the binary system loses angular momentum. Mechanisms of angular momentum loss have been identified as magnetic braking in the donor star and gravitational radiation loses. Which mechanism is driving the angular momentum loss depends on the nature of the compact binary and its evolutionary phase. It is known that MSPs, LMXRBs and CVs can change their accretion states by stopping mass transfer, or switching from high to low accretion regimes and vice-versa. The timescale for large accretion state variations is of the order of days to months for LMXRBs and MSPs, and of weeks to years for CVs.

The need for time-critical data on CVs is listed below.

- Lowhanging fruits:

  1. **Find new novae.**
     Unknown new novae can be found by their amplitude and the community notified so that the early rise can be followed spectroscopically to determine the type of nova (from CO ad Ne lines) that is related to the mass of the white dwarf.

  2. **Identify Recurrent Novae Outbursts.**
     New outbursts of a known nova will allow the properties of recurrent novae to be compared to classical novae through immediate followup.

  3. **Identify low states of known Novalikes.**
     Spectroscopic identification of the underlying stars can be made during low states of accretion in known novalike systems. These low states can only last for weeks and are the only time when the accretion disk disappears and the stars can be seen and masses measured in these high accretion rate systems.

  4. **Find new high amplitude dwarf novae.**
     Early identification of high amplitude (greater than 5 mag i.e. superoutbursts) dwarf novae allows followup with high cadence photometry during their 2-3 week bright phases to determine superhump periods that enables a mass ratio and clues to their evolution history.

- Pie in the sky

    1. **Find new CV eruptive behavior.**
    While several types of outbursts are known for CVs, new types and forms of the outburst behavior are still possible. Since the rise times are short (less than 1-2 days) and the entire outburst might not last long, early identification can provide followup that ensures a correct classification.

Compact Binaries: Neutron Star Binaries

Author: Elena Mason

Neutron star binaries with a milli-second pulsar (MSP) are found either in the accretion state (AMSP, mostly discovered during outburst), or in the rotational powered state (RMSP, typically discovered in radio survey and more recently also in the γ energies by Fermi). According to the so-called *recycled scenario* (Alpar et al. 1982, Nat, 300, 728), MSPs are neutron stars (NSs) that have been spun-up by a Gyrs-long accretion phase as Low Mass X-ray Binaries (LMXBs), once the mass transfer has dropped enough to allow the activation of the (radio) MSP powered by the rotation of magnetic field.

Transitional milli-second pulsar (tMSPs) are NS binaries that have been observed to switch from an accretion to a rotation powered state or vice-versa on time scale of months to decades (e.g. Papitto et al. 2013, Nat. 501 517; Archibald et al. 2009, Sci. 324 1411; Stappers et al. 2014 ApJ 790 39; Patruno et al. 2014, ApJ 781 L3; de Martino et al. 2010, A&A 515, 25, de Martino et al. 2013, A&A 550 89; Bassa et al. 2014, MNRAS 441 1825). Hence, they demonstrate, at a time, the connection between LMXPs and MSP (confirming the recycled scenario), as well as the fact that the transition might be driven also by mass transfer variations. Only a few transitional systems are currently known. They have been observed in outburst (only one case) and in an intermediate sub-luminous state where an accretion disk is present (Archibald et al. 2015, ApJ 807 62; Papitto et al 2015, MNRAS 449 26). These are the only LMXBs that have been observed to be high energy Gamma-ray emitters (as revealed by the Fermi-LAT, de Martino et al. 2010). Radio, and X-ray observations performed during the intermediate states reveal an anti-correlated behavior between these two bands indicative of jet emission (e.g. Patruno et al. 2014, ApJ 781, L3; de Martino et al. 2010, A&A 515 25; de Martino et al. 2015, MNRAS 454 2190, see also Papitto et al. 2014, MNRAS 438 2105, Papitto & Torres, 2015 ApJ 807 33). Additionally, the observation of optical pulses during the intermediate sub-luminous state (Ambrosino et al. 2017, Astron.Nat. 1, 854, Papitto et al. 2019, arXiv1904.10433) argue against accretion and it seems that the majority of the accretion disk material is expelled.

- Lowhanging fruits:
  Observe changes of state of any MSP, LMXBs and tMSP, known and/or new discovered:

  The multi-color photometry of the LSST main survey will enable to alert in real time about any change of state of the known systems (whether MSP, LMXB or tMSP) as well as of the yet to be discovered systems (that will be discovered combining LSST survey with other next generation sky surveys – e.g. THESEUS or eROSITA). This will, at a time,

    1. provide a census of the transitional systems among MSPs thus helping framing the evolutionary phase of each accreting NS, and
    2. produce dedicated follow-up that will allow determining the system parameters and/or characterizing the physical mechanisms behind each observed phenomenology.

  Any change of state reported (and alerted) by LSST main survey might trigger dedicated follow up observations aimed at solving the binary system parameters. In particular a binary entering in one or the other state will trigger time-resolved optical spectroscopy to determine the donor star and/or the disc parameters. For those with unknown orbital periods it will be possible to trace the secondary and, in case of accretion disk, the primary orbital motions. If a LMXB-to-RMSP transition occur the observations will be crucial to trigger optical spectroscopy and multi-band optical photometry to derive the donor spectral type, the effects of pulsar irradiation and orbital parameters. These low-states will enable to trigger radio pulsar searches (eg MeerKAT and SKA) . The binary orbital parameters are crucial to perform searches for pulses in the Gamma-ray and X-ray regimes. Hence, it will be of utmost importance to promptly alert for any system entering in a sub-luminous state before it enters its radio state or resume full accretion. Time resolved optical follow up of systems in the MSP state will be needed to establish binarity and constrain the companion star and the mass function of the binary.

- Pie in the sky:

  Unexpected transitions or transition frequencies, if observed, will imply revision of current evolutionary scenarios.

Compact Binaries: Black Hole Binaries (BHBs)

Authors: Michael Johnson, Poshak Gandi

- Low hanging fruits:
- Pie in the sky

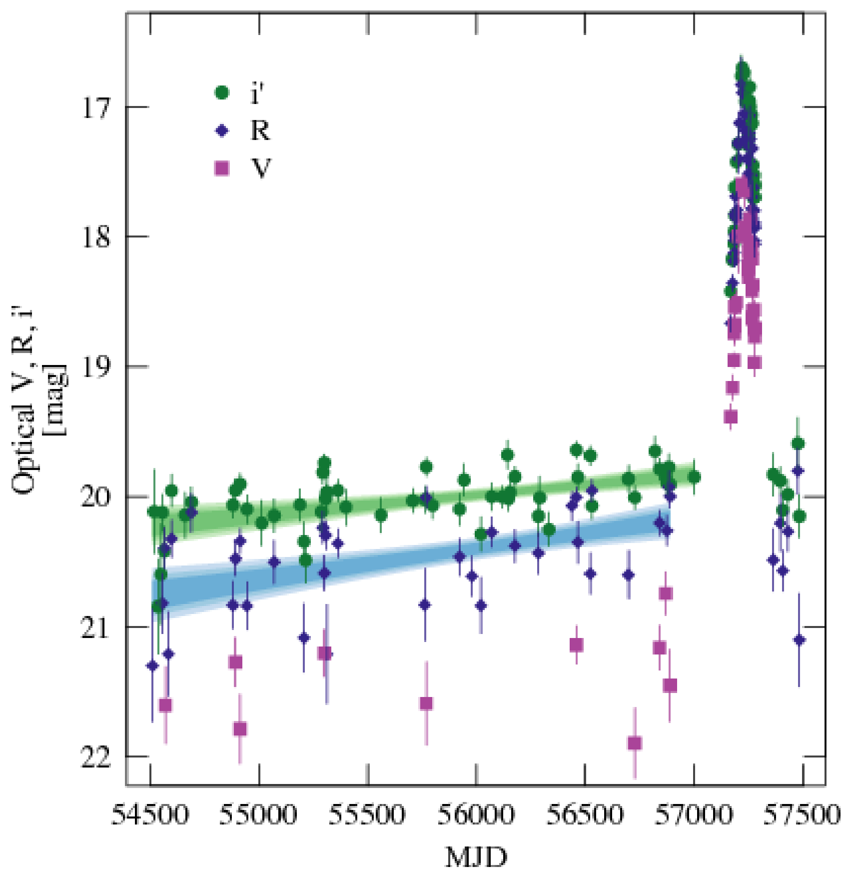

Figure 2: Long term optical lightcurve of an outburst from BHB GS 1354-64.

- Low hanging fruits:
  Observing the increase in luminosity of known BHBs that occurs prior to the outburst can be used to trigger dedicated follow-up in order to characterise the event. So far, only the brightest tip of the population has been followed up in detail in the optical, therefore increasing these statistics is vital to better our understanding of these outbursts. LSST will also likely observe outbursts in undiscovered

systems, the redder filters of LSST will be particularly suited to this as the faintest systems will be those that are with heavy extinction. As many may only be visible with the current generation of telescopes during outburst, follow-up must be triggered promptly.

- Pie in the sky:
  Characterising the long term trends of BHB outburst may be the key to predicting their occurrence, allowing us to trigger follow-up *before* the event. Additionally, the long term outburst trend is what distinguishes the optical signature of LMXBs from other systems which also exhibit ellipsoidal modulation, such as cataclysmic variables. Therefore, characterisation of this trend may also allow for the classification of LMXBs, without the need for X-ray follow-up. However, this characterisation would require additional detailed observations of BHBs throughout their outburst phases as well as associated analysis.

Extra Galactic transients

Editor: ?

Intermediate-Luminosity Optical Transients (ILOTs)

Authors: Andrea Pastorello & Elena Mason

Intermediate-Luminosity Optical Transients (ILOTs; e.g. Kasliwal 2007, Berger et al. 2009, ApJ, 699, 1850) form a class of astrophysical objects identified through their faint absolute luminosity. Their absolute magnitudes are in fact intermediate between those of core-collapse supernovae (SNe) and classical novae ($-10 > M_V > -15$). They have been studied in depth only in recent years, hence our knowledge on their nature is still incomplete. This because we collected high-quality and well-sampled data sets for only a limited number of ILOTs. In addition, despite the observables of different species of ILOTs are very similar, they can be produced by a wide variety of physical mechanisms and different progenitor stars. Although a fraction of SNe have actually in the same magnitude range as ILOTs, incl. low-luminosity stripped-envelopes SNe (SNe Iax, Ca-rich transients, .Ia candidates, or other faint SNe I; e.g. Kasliwal 2013, IAU Symposium 2013; Valenti et al. 2009, Nature, 459, 674), and low-luminosity Type II-P events (Pastorello et al. 2004, MNRAS, 347, 74; Spiro et al. 2014, MNRAS, 439, 2873), our group is mostly interested in non-terminal stellar transients.

- Science Cases

  1. **Ordinary Luminous Blue Variable (LBV) outbursts (S Dor-like)**
     LBVs are very bright sources, and among the most massive stars detectable in galaxies. Famous examples in our Galaxy are AG Car and HR Car. In the nearby Universe, we can also mention: AE And and EF And in M31, Var C and Romano's Star (GR 290) in M33, along with several well-studied LBVs in NGC 2403. During S Dor-like outbursts, stars experience erratic brightness variability over timescales of several months to a few years, with ΔM of a couple of magnitudes, but without a significant change in the bolometric luminosity (Humphreys & Davidson, 1994; Smith et al., 2011; Humphreys et al. 2017). In this phase, LBVs moves to the right of the Hertzprung-Russell diagram, becoming redder and cooler, to then come back to the left side in quiescence.
     The full range of variability of a classical LBV can be comfortably monitored with single shot LSST observations up to about 30 Mpc, but with periodic stacks we can largely exceed this distance limit. For known LBVs, using also literature and archive data, we aim at obtaining light curves with baselines of many decades. Multiple survey strategy may reveal different types of variability, which develop on different timescales. Well-studied LBVs will become reference objects, as we expect to find with LSST new LBV candidates in outbursts.

  2. **Giant Eruptions/outbursts of LBVs and other massive stars**

Massive LBVs may also experience major eruptions, becoming the most luminous objects in their hosts. Eta Car, in the Milky Way (MW), experienced a Giant Eruption in the mid-19th Century. During a giant eruption (which lasts years to decades), LBVs may show multiple outbursts whose individual peaks reach $M_V \approx -14$ mag (Wagner et al. 2004, Smith et al. 2011, 2017; Pastorello et al. 2010, 2013). LBVs and other hypergiants may also experience single short-duration outbursts (with M_V similar as giant eruptions; Smith et al. 2010, 2011; Tartaglia et al. 2016a). Although their massive progenitors survive the outbursts, these ILOTs may resemble (as energetics and spectral appearance) true SN explosions. Hence extragalactic LBV-like outbursts are frequently dubbed SN impostors (Van Dyk et al. 2000).
A growing number of SN impostors were seen to herald true SN explosions a few months or years later. These SNe show signature of interaction with circum-stellar material (CSM), and are usually of Type IIn (Mauerhan et al. 2013; Margutti et al. 2014; Fraser et al. 2013a, 2013b, 2015,Tartaglia et al. 2016; Elias-Rosa et al. 2016, 2018; Thöne et al. 2017; Pastorello et al. 2013, 2018), although in one case an outburst of a massive star was observed before the explosion of a SN Ibn (SN 2006jc; Pastorello et al. 2007; Foley et al. 2007; Maund et al. 2016).

We aim at monitoring SN impostor light curves with LSST, as well as discovering ejecta-CSM interacting SNe with evidence of pre-SN outbursts. Understanding if pre-SN outburst events are common in the pre-SN stages (as claimed by Ofek et al. 2014) is a major goal of our research. In addition, a wide database of objects well-followed until very late phases is an essential tool to observationally discriminate SN impostors from faint ejecta-CSM interacting SNe.

3. **(Luminous) Red Novae and non-degenerate stellar mergers**
The most spectacular transient phenomenon induced by stellar binary interaction is the coalescence of two stars. The nature of Red Novae (RNe), such as V838 Mon, V4332 Sgr and M31-RV, was debated until V1309 Sco was discovered. A combination of spectroscopic data and a well-sampled light-curve proved it to be a stellar merger (Tylenda et al. 2011; Mason et al. 2010). Recent discoveries of extra-galactic counterparts, the so-called Luminous Red Novae (LRNe; Blagorodnova et al. 2017; Goranskij et al. 2016; Smith et al. 2016) have extended the LRN zoo to much higher luminosities and masses. RNe/LRNe show multi-peaked light curves, and spectra that progressively transition from intermediate-type stars to M-type stars. TiO and VO molecules are usually detected in very late spectra of stellar mergers.

Stellar mergers are common (e.g., de Mink et al. 2014), with the rates tightly depending on their luminosity: Kochanek et al. (2014) estimated a Galactic rate of a few $\times 10^{-1}$ yr^{-1} for V1309 Sco-like events ($M_V \approx -4$ mag); ~ 0.03 yr^{-1} for V838 Mon-like events ($M_V \approx -10$ mag), $\sim 10^{-3}$ yr^{-1} for NGC4490-2011OT-like events ($M_V \approx -14$ mag). Although low-luminosity RNe are quite frequent, only about 15 RNe/LRNe have been observed in the Galaxy and in the Local Universe so far. They have absolute magnitudes at peak ranging from −4 to −15 mag. This is probably because they are not always easily discernible from other types of eruptive variables. LSST, with the different survey strategies, is expected to find many more candidates. A large sample of objects with good-quality data is essential to unveil the mechanisms triggering the RN outbursts, the fate of the binary systems (coalescence or not), and will finally allow us to provide more robust occurrence rate estimates.

4. **Intermediate-Luminosity Red Transients (ILRTs)**
Their spectra are initially quite blue, but they become redder with time. They show prominent H and Ca II lines, incl. the typical [Ca II] 7291, 7323 Ådoublet in emission. In ILRTs, the doublet is detected at all phases. Their light curves are reminiscent of those of sub-luminous Type II-L SNe (e.g. SN 2008S and NGC300-2008OT1; Prieto et al. 2008, Bond et al. 2009; Botticella et al. 2009, Smith et al. 2009, Berger et al. 2009, Humphreys et al. 2011) or even Type II-P SNe (e.g. M85-2006OT1 and PTF10fqs; Kulkarni et al. 2007; Pastorello et al. 2007b; Kasliwal et al. 2011), and – when observed – the late-time decline rate is roughly consistent with the

^{5}6Co decay. In quiescence, the progenitors of ILRTs, usually remains undetected in the optical and near-infrared bands, while they are fairly luminous in the mid-IR domain. The progenitors of ILRTs are moderately massive stars (8-15 $M_\odot$), enshrouded in dusty cocoons. ILRTs are proposed to be electron-capture SNe from Super-Asymptotic Giant Branch (S-AGB) stars (e.g. Botticella et al. 2009; Pumo et al. 2009; Pastorello et al. 2007; Thompson et al. 2009). Although this interpretation is disputed (see, e.g., Smith et al. 2011), recent observational arguments seem to favor the terminal SN explosion scenario for ILRTs (Adams et al. 2016).

The increasing number of ILRTs discovered in nearby galaxies suggests that these transients are relatively frequent (about 20% of the local core-collapse SN rate, according to Thompson et al. 2009). LSST will greatly increase the number of new discoveries, providing light curves from the explosion to very late phases. All of this is essential to determine the presence of classical SN signatures, such as the shock breakout, the light curve ^{56}Co tail). In addition, stack frames collected before and years after the explosion will provide high-quality images of the ILRT location which (in combination with deep infrared images collected with other facilities) are fundamental to characterize the progenitor stars and their final fate.

- Low-hanging fruits

  1. The study of the canonical variability (the S Dor phase) of known luminous blue variables in the Milky Way, LMC and SMC, and nearby Galaxies is a key instrument to unveil the role of binary interaction. The moderate-cadence of the main survey (with one observation every a few days and in different filters) allows us to investigate modulations and/or periodicity features in the light curves. Through the light and color curves and using supporting spectroscopic information, we can determine correlations among the observable parameters.
  2. The LSST main survey cadence is expected to help finding new transients of all species. Assuming an r-band limiting magnitude of 24.4 for a single visit, and an absolute peak magnitude of -10 for an ILOT at early phases, we can detect young ILOTs up to about 80 Mpc. High-quality data sets can be obtained for objects in nearby galaxies.
  3. The planned LSST cadence will allow the collection of homogeneously sampled light curve and colors of different ILOT sub-types (major LBV eruptions, luminous red novae, intermediate-luminosity red transients). The availability of well-sampled templates will greatly favor the classification of new objects, as well as the comparisons and the interpretation of the various transients. The additional color information will in particular allow us the determination of preliminary physical parameters (e.g. temperature and radius).
  4. Precise estimates of the rates of the different ILOT types are still incomplete or even missing. With the main survey, we aim at increasing the precision of volumetric rate estimates for the different family of transients.

- Pie in the sky

  1. The magnitude and colour information inferred from the inspection of LSST archive images will help constraining the progenitor parameters of new ILOTs, and allow us to detect variability patterns before the onset of the main transient event. When stellar counterparts are not obviously found in single-visit images, the periodic stacks with allow us to go much deeper in magnitude, greatly increasing the probability to detect the quiescent progenitor.
  2. The fate of ILOTs some year after the outbursts. Above the observations, the interpretation of the real nature of many ILOT species is still controversial. For ILRTs and some LBV-like eruptions, for example, it is still debated whether the star survived the eruptive even or not. For some LRNe, the fate of the binary system after the common envelope ejection is still controversial (final merger vs. surviving binary). The existence of a large image database, allow us the creation of deep stacks that allow us to monitor the source in the optical bands up to very late phases. This is essential

to follow the decline to below the luminosity threshold of the quiescent progenitor, eventually observing the complete disappearance of the source. Supporting IR observations, however, are necessary to constrain the dust formation affecting the optical photometry.

3. Increasing the statistics of well-sampled ILOTs is a key goal to determine possible correlations (1) among observed parameters such as the peak absolute magnitude, the temperature evolution and the velocity of the ejected material; (2) between observables and other physical parameters such as the energy released in the outburst and/or the progenitor mass; (3) to correlate the physical parameters with the properties of the environments (stellar population, metallicity).

- Tasks
- Outcome in commissioning, 1, 3, 10 years

GRB

Authors: Maria Drout? Eric Bellm? Antonino Cucchiara

Gamma-ray Bursts (GRBs) have been identified in the late 60's by the Vela spy satellites. After more than fifty years we know now that some GRBs are among the brightest cosmic explosion in the Universe. The majority of their emission occur in the high-energy regimes (Gamma rays), while a low-energy emission (the *afterglow*), is produced in the aftermath of the GRB explosions.

Two classes of GRBs are currently identified: the *long* (LGRBs) and *short* (SGRBs), based on the duration of the gamma-ray emission. LGRBs have a duration equal or longer than 2-seconds, while SGRBs emission last less than two seconds. While early GRB studies focus only on the properties of the gamma-ray prompt emission, the launch of the Neil Gehrels Swift Observatory (formerly known as *S*wift) has shifted the attention to the early (first minutes to few hours) afterglow emission, in particular from X-ray to Optical.

LGRBs are thought to be produced by the explosion of single massive ($\gtrsim 10 - 30 M_{\odot}$) star, while SGRBs are the byproduct of the merging process of two compact objects like neutron-star binaries (NSB), black hole binaries (BHB), or Neutron star - white dwarf pairs. SGRBs are also connected with the production of Gravitational Wave (GW) signals, as recently discovered by the adLIGO-VIRGO experiments experimens.

On the other end, LGRBs are likely connected with the earliest generation of massive stars produced in the Universe. A few GRBs (GRB 090423, GRB 090429B, GRB 120923) have been either spectrocopically or photometrically confirmed at redshifts $z \gtrsim 7$, representing the furthest stellar objects ever discovered. These events, not only represent a unique laboratory for stellar evolution, but also pinpoint towards host galaxies independently of their intrinsic mass or luminosity. Such objects become complementary to, e.g., Hubble Ultra Deep Field samples and represent unique targets for future high-redshift Universe explorers like James Webb Space Telescope and WFIRST.

GRB emission

LGRBs and SGRBs produce, after the initial gamma-ray radiation, a jetted emission that interacts with the surrounding inter-stellar medium (ISM). The afterglow is generated by the synchrotron emission produced by the interaction of the ultra-relativistic blastwave with the ISM. Optical/infrared rapid spectroscopy of GRB afterglow reveals the properties of the GRB host ISM as well as the presence of intervening systems. Absorption spectra have been key to investigate the cosmological metal content up to redshift $z \approx 6$. This also include constraints on the neutral hydrogen fraction, and the dynamics of re-ionization.

Also, rapid (within minutes of the GRB discovery) and timely spaced spectroscopic observations have revealed the presence of varying fine-structure transitions which hint at the interaction of the surrounding medium with the GRB emission and/or with ISM particles ionized by the surrounding stellar UV background.

LGRB Orphan Afterglows

The *Swift* satellites detects on average 100 GRB^{-1}, but the number of actual event is poised but the uncertainty in the jet opening angle of the initial gamma-ray emission ($\theta_{\rm jet}$). If the viewing angle (the angle between the jet axis and the observer line of sight) $\theta_{\rm view} > \theta_{\rm jet}$ we will not be able to detect the prompt emission, but, thanks to the deceleration of the blastwave and the subsequent decrease in Lorentz factor Γ, we will be able to to detect the low-energy afterglow emission. These **orphan afterglow** can be a factor $\propto (1 - \cos\theta_{\rm jet})^{-1} \sim 200$. The peak of the detectable emission, occurring likely days post-burst is in the MHz-GHz regime, but the LSST single visit depth ($r \approx 24.5$) enables the detection of such event. Assuming typical microphysical parameters for the GRB emission, LSST should be able to identify roughly 50 orphan afterglow GRBs per year.

The incoming
GRBs as GW electromagnetic counterparts
Short GRBs are due to the merger of two compact objects. At 200 Mpc radius, NS-NS mergers and subsequent Kilonova emission can be detected up to 1 week at the single visit, assuming a i-band observation is included.

The availability of LSST data in real time will allow us to:

- Short GRBs and Kilonovae emission (see also GW-EM counterpart section)
- Low hanging fruits
- Pie in the sky

0.2.1 Blazars

Authors: Claudia M. Raiteri, Barbara Balmaverde, Maria Isabel Carnerero, Filippo D'Ammando, Chiara Righi

Active galactic nuclei (AGNs) include a broad variety of sources that share the common property of emitting persistent huge luminosities from a very compact region (~ 1 pc). Their power is thought to come from accretion of matter onto a supermassive black hole (10^6–10^{10} $M_\odot$). Some AGNs are very powerful radio sources, with twin jets of plasma extending up to Mpc distances from the central engine. When one of the jets is oriented close to the line of sight, its emission is amplified by relativistic effects and these beamed sources are called "blazars". Therefore, blazars are the most suitable objects to investigate the physics of the inner parts of extragalactic jets.

Blazars include flat spectrum radio quasars (FSRQs) and BL Lac objects (BL Lacs). The classical separation between the two classes depends on the spectroscopic properties, BL Lac showing only weak emission lines, if any.

Blazars emit at all wavelengths, from the radio to the gamma-ray band, and their flux is variable on all the observable time scales, from minutes to years. The variability can be due to both geometric effects (i.e. variations of the viewing angle of the emitting regions, see e.g. Raiteri et al. 2017, Nature 552, 374) and intrinsic (i.e. energetic) processes. Orientation changes can be produced either by magnetohydrodynamic instabilities developing inside the jet or by orbital motion in a binary black hole system or by a precessing jet. Energetic processes include injection and acceleration of particles and formation of shock waves.

Blazar radiation is polarized and both the polarization degree and angle are variable too. Indeed the low-energy radiation, from radio to UV or X-rays, is well explained as synchrotron radiation produced by relativistic electrons in the magnetized jet, while the origin of the high-energy radiation is still debated. According to leptonic models, it is produced by inverse-Compton scattering of soft photons from the same relativistic electrons. Alternatively, hadronic models can explain the high-energy emission as due to synchrotron radiation produced by protons and muons and to particle cascades (e.g. Boettcher et al. 2013, ApJ, 768, 54). They also predict the production of neutrinos. In this respect, the recent detection by IceCube of ultra-high-energy neutrinos that can possibly be associated with blazars opens an exciting new observing window on these sources (Aartsen et al. 2013, Science, 342, 1242856). Righi et al. (2017, A&A, 598, A36) estimated that the future neutrino experiment KM3Net will be able to detect the signal of several BL Lacs in a few years. In this context, the LSST continuous mapping of the sky will be a formidable tool to establish such connections.

The availability of LSST data in real time will allow us to:

- Low hanging fruits
  1. monitor blazar flux variations to trigger follow-up observations every time an interesting event (usually a flare) is detected, and to immediately react to the detection of PeV neutrinos with IceCube or of high-energy flares with satellites or ground-based Cherenkov facilities. Follow-up observations may include optical observations in polarimetric and spectroscopic mode and observations at other wavelengths, in particular with the Swift satellite and MAGIC telescopes and, in the future, CTA and SKA. Multifrequency light curves will allow us to study cross-correlations and time delays between changes in different bands and this in turn will shed light on the emission mechanisms and location of the various emitting regions in the jet;
  2. monitor colour changes as well as changes in the broad-band spectral energy distribution as a test for theoretical models for blazar emission (particle acceleration/cooling mechanisms, shock waves, orientation effects);
  3. search for optical counterparts of unidentified gamma-ray sources observed by Fermi (and in the future CTA) among the transient/variable sources observed by LSST
- Pie in the sky
  1. compare the predicted blazar neutrino flux with the ultra-high-energy events revealed by IceCube (and in the future KM3NeT) to verify possible associations and probe the jet emission physics;
  2. reveal periodic flux changes that would suggest that the central engine is a binary black hole system (BBHS). Indeed, radio-loud AGN (as e.g. blazars) are among the best sources to search for BBHS as they are hosted in giant elliptical galaxies that are thought to result from galaxy mergers. According to the binary black hole models of Lehto & Valtonen (1996, ApJ, 460, 207) and Sundelius et al. (1997, ApJ, 484, 180), when a secondary black hole impacts the accretion disk of the primary black hole, a periodic optical outburst signal is produced. The outburst timing gives strong constraints on the two BH masses involved and a measurement of the spin of the primary black hole. This model has been successfully applied to the quasi-periodic light curve of the BL Lac object OJ 287, which shows double-peaked outbursts every ~ 12 years (Valtonen et al. 2016, ApJL, 819, L37). In contrast, Villata et al. (1998, MNRAS, 293, L13) proposed a scenario where the two jets launched by the two SMBHs of the binary system are bent by the interaction with the ambient medium and their axes precede, so that the orientation of the outflow varies quasi-periodically in time. The two models can be discerned with polarimetric measurements. Since LSST will monitor a large portion of the sky for ~ 10 years, we expect that it will be able to detect several BBHSs, with important implications also for the gravitational waves astronomy.

EM counterparts of GW events

Authors: Enzo Brocato, Raffaella Margutti?

- Low hanging fruits
- Pie in the sky

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0.3 Broker interaction

Broker interaction and possibilities enabled by brokers depending on the broker output complexity.

Facility requirements

The blazar science case would highly benefit from a support telescope of the meter class equipped with a polarimeter to monitor the polarimetric behaviour of selected objects, especially during active states. Polarimetry can distinguish between non-thermal and thermal phenomena and is expected to give information on the jet magnetic field.

Computational requirements.

Describe briefly the computational requirements

Non Time-Critical science

LSST Data Release products (for time domain)

Editor and Author: Melissa Graham

After the first half-year of operations, and on an annual basis thereafter, LSST will reprocess and release all of its data via the Science Platform. This will include all of the data products associated with difference imaging analysis (DIA; i.e., the Prompt data products discussed in Section), the raw and calibration images, deeply coadded all-sky image mosaics in each filter, and object catalogs with measurements and parameters derived from both the visit and coadded images (including catalogs of moving-object orbits based on LSST data alone). Object catalogs of forced photometry in all direct images for the union set of all objects detected in any image (or image stack) will also be provided. In general, for time-domain studies the annual data release will be the most highly *characterized* set of data products, and will be best suited for e.g., population studies and events rates analyses.

0.4 Extrinsic transients and variables

Editor: Michael Lund, Josh Pepper

Transiting exoplanets

Authors: Michael Lund, Josh Pepper

Surveys searching for transiting planets generally are only able to look at a limited parameter space of host stars. Most searches that look at large areas of sky are constrained to relatively nearby stars as these surveys tend to focus on brighter stars. Some searches probe deep, but only in a single region of sky, such as the *Kepler* field. This trade-off in survey design is a result of the two ways that planet yields can be improved. LSST, in contrast, is not designed with transiting exoplanets in mind, and so provides a different sort of a challenge, as well as opportunity. The deep-drilling fields are very limited, but have a similar cadence to ground-based planet searches. The wide-fast-deep fields are at a lower cadence, but will cover half the sky much fainter than most surveys that are focused on exoplanet detection. The result is that for these fields the detection efficiency will be lower, but the range of stars being searched will include populations not normally prioritized in transiting planet searches, such as red and white dwarfs, stars in the galactic bulge, and stars in clusters. This opens the door to LSST providing some insight into planet occurrence (and formation) rates around stars of varying mass, metalicity, and stage of stellar evolution.

- Low hanging fruits

1. The faint end of TESS host stars may overlap with the bright end of stars observed by LSST. With TESS optimized for detecting short period planets, LSST's detection efficiency could be calibrated by trying to recover exoplanets that are found by TESS around stars in the magnitude overlap

- Pie in the sky

  1. The occurrence rate of planets around white dwarfs currently only has upper limits, and a search hasn't yet been conducted on a very large number of white dwarfs, as there are few white dwarfs bright enough to have been included in previous planet searches. As even an earth-sized planet transiting a white dwarf will block a significant amount of light, these events will be detectable with only a few points in transit.
  2. The Magellanic Clouds will be within the LSST footprint. While they are at great distance, if they are included in deep-drilling fields and have on order of 10,000 observations, solar-mass (or slightly larger than solar-mass) main sequence stars in the Magellanic Clouds may have enough data that it will be possible to detect large transiting planets in short orbits. This would not just represent some of the most distant exoplanets discovered, but could then provide information about planet occurrence rates in a very different stellar environment.

Eclipsing binary stars

Authors: Andrej Prsa

- Low hanging fruits
- Pie in the sky

Microlensing

Authors: Marc Moniez

- Low hanging fruits
  a) Optical depth, event rate and t_E distribution
  The microlensing optical depth towards a given source is the instantaneous probability for that source to lie behind the Einstein ring of a lens. It only depends on the mass density along the line of sight, from the observer to distance D_S of that source:

$$\tau(D_S) = \frac{4\pi G D_S^2}{c^2} \int_0^1 x(1-x)\rho(x) u dx\,, \tag{3}$$

where $\rho(x)$ is the mass density of deflectors at distance xD_S. When considering a sample of N_{obs} sources observed during a duration T_{obs}, the probability for any source to lie behind a lens has to be averaged on the D_S distribution to be connected with the event frequency and duration estimates through the expression:

$$\tau = \frac{1}{N_{obs}T_{obs}} \frac{\pi}{2} \sum_{events} \frac{t_{\rm E}}{\epsilon(t_{\rm E})}, \tag{4}$$

where $\epsilon(t_{\rm E})$ is the average detection efficiency of microlensing events with a time scale $t_{\rm E}$. This number is conventionally defined as the ratio of the number of detected microlensing events with duration $t_{\rm E}$, to the expected number of events where the source gets behind the Einstein ring of a lens during T_{exp}. The optical depth can be considered as a probe that brings information about the mass density distribution of compact objects towards a given direction. The distribution of the microlensing durations t_E allows in addition to probe the kinematics of the population of compact objects. The optical depth determination and the best use of the microlensing durations both require a careful estimate of the detection efficiency $\epsilon(t_{\rm E})$. This estimate needs the simulation of events in a domain of the parameter space that exceeds by a large amount the expected domain of sensitivity, and averages are computed over all the parameters other than t_E (impact parameter, source luminosity, colour and distance, time of maximum magnification...). The estimate of this efficiency is a hard point of the microlensing interpretation, since identified sources of bias (like blending, parallax of finite source effects...) may be complicated to take into account. When analyzing a set of past data, these biases are untargeted, in the sense that they do not vary during the event progress, and the efficiency studies are similar for all microlensing surveys. If a broker is used in LSST to trigger follow-up observations, then the bias becomes targeted, since the observation strategy may vary during the progress of each event, depending on its characteristics. Such an adaptative strategy allows to increase the chances to detect the strong potential events (fast varying magnification, anomalies...), by aggregating external data to the LSST information. The impact of this targeted aggregation on the detection efficiency will need a specific simulation, taking into account possible human decision bias, to properly estimate final efficiencies. The difficulties here come from the fact that an efficiency results from an averaging, and the singularisation of events, as expected from an alert system, hampers the collective behaviour.

0.5 Intrinsic Galactic and Local Universe transients and variables

Editor: Kelly Hambleton

Pulsating stars

Authors: Kelly Hambleton, Keaton Bell, Massimo Dall'Ora, Ilaria Musella, Maria Ida Moretti, Marcella Di Criscienzo

Stars in many stages of evolution experience global pulsations. These oscillations propagate through and are affected by the details of the stellar interiors. They manifest as photometric variations in the time domain with frequencies equal to the eigenfrequencies of stars. By measuring these frequencies, we can constrain the interior stellar structures, which are otherwise not accessible in non-pulsating stars. This is one of the most powerful methods for probing stellar structure, which would be otherwise impossible. Global properties (e.g., luminosities, radii, masses) obtained from asteroseismology (pulsation analysis) also enable many types of science, such as standardizing candles for distance determinations and revealing the absolute sizes/masses of exoplanets and binary companions. The detection of stellar pulsations helps us to understand the driving mechanisms, making the pulsation frequencies more readily interpretable.

- Low hanging fruits

  1. The classification of a large number of pulsating stars. While it is not expected that this will be complete, it will include Cepheids, RR Lyraes, subdwarf B stars, gamma Doradus stars, Delta Scuti stars and pulsating white dwarf stars. The different colors provided by LSST will enable the temperature determinations of these objects by identifying the average color of each object in several different bands. When combined with distances, it will be possible to obtain luminosities. Thus LSST will provide the opportunity to generate a pulsational H-R diagram of an extreme number of stars in the Southern hemisphere. Additionally, the large spatial coverage will allow for population studies where positional variations can be taken into account and considerations such as the association with the thin and thick disk can be statistically analyzed. Typical pulsation timescales can be measured from, e.g., computing structure functions (record of typical magnitude differences at different time lags, as often employed in quasar analyses).

     The minisurveys and deep drilling fields can also provide additional support for this goal, as the reliable classification of pulsating stars in a smaller field with a higher cadence could, in principal, provide a training set for training machine learning algorithms to classify further pulsating stars in the main survey.

Representative samples of each class of pulsating variable star should be identified in existing survey data (e.g., stars with time domain photometry from PTF/ZTF, colors from SDSS, and distances from Gaia), to define initial classification algorithms. Different summary statistics (rms scatter, structure function turnover time lag, etc.) from other time domain surveys (PTF, ZTF, Pan-STARRS, ASAS-SN, etc.) should be considered to identify the features that best discern the variable subclasses and relate to physical properties of interest. To store the catalog data, computing facilities are required with large amounts of memory ∼Tb. Additionally, a server and the infrastructure to host an online version of the catalog would be a long term service goal.

The generation of such a catalog would begin during the commissioning phase but would be limited to the longer period variables until enough data has been acquired to identify shorter period variables. The catalog will grow incrementally with each additional data release.

The identification and cataloging of known variables (within the field and magnitude range of LSST) can begin prior to first light, as can the development of classification algorithms. Furthermore, the tools to determine the temperature and luminosity of the pulsating stars can undergo development prior to data acquisition.

Upon commissioning, the first H-R diagram can be created, which can be built upon from subsequent data releases.

- Pie in the sky

  1. The classification and period determination of multi-periodic variables and variables with short periods (such as white dwarfs and delta Scuti stars) for asteroseismological studies.

     Comparing the amplitudes of variation in different filters may help to constrain (at least statistically) the geometries (spherical degree) or types (gravity or pressure as restoring force) of pulsation modes. This is better suited to deep drilling fields.

     An analysis of the limitations placed by the spectral window of the main survey strategy is necessary to understand where seismic results may be reliable. The development of tools that enable the propagation of frequency aliases into the asteroseismic solution space may revive the potential to seismically constrain stellar interiors with LSST data, at least at the population level.

     Since the majority of identification will be undertaken by assessing the scatter in the data (combined with color and temperature information) it is unlikely that significant headway will be made until the nominal mission is well underway due to the large number of data points needed.

     The most scientifically compelling pulsating star discoveries made from the LSST data (e.g., new variable classes, planet hosts, those with extreme pulsational characteristics or that belong to important stellar populations) can be targeted for follow-up with high-speed cameras on large telescopes to obtain data sets suitable for full asteroseismic analyses. SCORPIO on Gemini-S is one example of an instrument with high-speed capabilities that will be able to probe the LSST survey volume.

Cepheids and RR Lyrae stars

Authors: Ilaria Musella, Marcella Marconi, Maria Ida Moretti, Silvio Leccia, Roberto Molinaro, Vincenzo Ripepi, Giulia de Somma

During the last 2 decades an extensive and detailed theoretical scenario for several classes of pulsating stars, including Cepheids and RR Lyrae, has been built on the basis of nonlinear convective pulsation models (see e.g. **????????**). These models allow us to derive all the observables, for example, boundaries of the instability strip, light curves, periods, amplitudes, mean magnitudes. They cover a large range of mass, luminosity, metallicity and Helium content, and thus represent a robust and unique theoretical tool to interpret the observed behavior of different classes of pulsating stars and to fully exploit their crucial role as distance indicators and stellar population tracers. In this context, multi-band time series data collected by LSST, combined with its very accurate parallaxes and proper-motion measurements, will provide a fundamental benchmark extending Gaia capabilities to a five magnitudes fainter, thus allowing us to observe variable stars not only in the Milky Way but also in external galaxies. On this basis, it will also be crucial for the the next generation of ground-based extremely large telescopes and for complementing near-infrared surveys from space-based observatories.

- Low hanging fruits

  1. **Building of a complete theoretical scenario for Cepheids and RR Lyrae in the LSST bands**.
     In the next year, before the LSST commissioning, we need to build a complete theoretical scenario for Cepheids and RR Lyrae in the LSST bands to compare the observed pulsation properties of these pulsators with our models. In order to do this, we plan to enlarge the already computed extensive sets of nonlinear convective pulsation models for Cepheids and RR Lyrae at varying chemical composition (Z and Y), masses and luminosities (see e.g. **??????**, for pulsational models in the Johnson-Cousins filters) and to transform these pulsational models into the LSST photometric ugriyz bands. The ugriyz light curves, mean magnitudes and colours, pulsation amplitudes and colour–colour loops will be derived, together with periods and analytical relations connecting pulsational to intrinsic stellar parameters (e.g. period-luminosity, period-luminosity-color and Wesenheit relations) and in turn their possible dependence on the metal content. Analogous works has been already developed to study the theoretical intrinsic properties of RR Lyrae and Cepheids in the SDSS bands **??** and of Cepheids in the HST/WFC3 filters typically used to study these variables (F555W, F606W and F814W, F160W; **?**). LSST observations will provide a very large database of pulsators hosted in different environments and characterized by different chemical compositions, allowing us to test the accuracy and reliability of our models and also to modify and/or refine the input physical parameters to get a very good agreement between theoretical and observational properties.
  2. **3D structure of the studied systems**
     Preliminary results about distance measurements and 3D distributions of variables in stellar systems will be obtained in three years after the commissioning phase through the comparison between our models and the observed light curves. The LSST data will be combined with all the other public multiwavelenght datasets.
  3. **Constraining to an unprecedented level of accuracy the coefficients of period-luminosity (PL) and period-luminosity-color (PLC) relations of Cepheids and RR Lyrae**
     This result will be obtained after the 10 years survey. Indeed, the collected data will allow us to get firm conclusions on the metallicity dependence of these relations, with relevant applications for our knowledge of the 3D structure of the investigated stellar systems and of the extragalactic distance scale.
  4. **Very accurate estimates for stellar masses**
     Very accurate estimates for the stellar masses of the studied variable stars will also be obtained through the comparison between the very extensive and accurate LSST light curves and the theoretical ones. Stellar masses are crucial to derive firm constraints on the efficiency of non canonical phenomena (such as overshooting and mass loss in stellar evolution models), on the pulsation-convection coupling and on the very debated, but fundamental, parameters such as the helium to metal enrichment ratio. Indeed, this ratio has a key role in several fields of stellar and galactic astrophysics and has been shown to affect the predicted metallicity dependence of Cepheid PL relations (see e.g. **?**, and references therein).

- Pie in the sky

1. **Definitive constraints on the physical and numerical assumptions adopted in the pulsation models**
   As final and very ambitious goals, we aim, on the theoretical field, to put definitive constraints on the physical and numerical assumptions adopted in the pulsation models (e.g. the adopted opacity tables or the treatment of convection and overshooting) and on the observational one, to firmly establish the calibration of the extragalactic distance scale to understand the current tension in the H_0 determination derived by Planck and that obtained using distance indicators.

Long Period Variables

Authors: Nicolas Mauron, Marcella Di Criscienzo....

Long period variables (LPVs) are cool giants with periods or timescale of 100-3000 days, and V-band peak-to-peak amplitude of $\sim$ 0.1-4 mag. Being in the so-called asymptotic giant stage (AGB), they comprise a degenerate core, composed of oxygen and carbon (or neon), a 3α burning zone and a region with CNO nuclear activity. This compact core (size 1/100 $R_\odot$) is surrounded by the convective "envelope" (size 100-500 $R_\odot$, surface $T \sim 3000-4000$K). The surface chemistry of these stars may be altered by Hot Bottom Burning (HBB) and Third Dredge-Up (TDU), whose efficiency depends on initial mass and metallicity. In addition to convection and chemistry, pulsation and mass-loss are critical. Intense mass ejection creates an expanding, dust-productive low-density envelope. Despite recent progress on AGB evolution **?**, it still remains a challenge to establish a consistent link between evolution, convection, chemistry, pulsation, shocks, dust formation, and mass loss. LSST is at a pivotal place by providing multicolor lightcurves and constrain pulsation models.

- Low hanging fruits

1. **Pulsation** is observationaly proven but the physical understanding is in an embryonic state, despite its tremendous importance for Miras used as standard candles (Huang, Riess et al. 2018). OGLE and MACHO experiments have shown that in the Period-Luminosity diagram LPVs form six distinct parallel sequences.We know that membership of each of the sequences depends on the pulsation mode responsible for their variability **?** but understanding which of these relationships is good as a standard candle is not a simple question. However LPVs are multiperiodic and normally only the primary period (that with higher amplitude) is used in the PL diagram. **?**showed that, as the star evolves, specific overtone modes gradually become stable and the primary mode shifts towards lower radial orders. In particular, the star initially rises on the PL diagram while traversing these sequences from left to right. Since LSST will measure thousands of LPV lightcurves either for Galactic disc stars or stars in external galaxies, with a range of metallicity and age, studies comparable to those of OGLE and MACHO will be achievable.
   Theoretical predictions of pulsation properties as a function of stellar parameters along the AGB need to be refined. While the commissioning and first year should be enough to detect most LPVs within a few Mpc, 5-10 years will be necessary to firmly establish the longest periods (mostly $\sim$ 2 yrs) and eventually their long secondary periods.

2. **LPVs in galaxies** are dominant for the enrichment in dust (silicates, carbon dust), and some elements like carbon or lithium. Due to their large mass loss rates and cool temperatures, the AGB winds are a favorable site for dust production, via condensation of gas molecules into solid grains. Recent investigations by **????** and **?** set the theoretical framework to model dust formation in expanding AGB winds. LSST will measure the pulsation periods or multi-period character of AGBs. It will also provide multicolor time-dependent information helping to understand optical absorption/scattering by grains. An exquisite knowledge of circumstellar dust, at all metallicities, is basic for the SED fitting of LPVs having huge mass-loss, because they dominate the Dust Production Rate of the host galaxy, with a special importance at high redshifts. *LSST would need to have filters to discriminate C/O chemistry (arXiv:1903.06834).*

*Infrared surveys (from $\sim$ 1 μ to 30 μ), started with Spitzer (DUSTINGS program,**??**, must be pursued to have (at least) some temporal information in phase with LSST.*

- Pie in the Sky

1. **Long secondary periods** (LSP) happen for about 25-30 % of LPVs, as shown by the LMC/SMC surveys. The LSP is the reddest sequence in the PL diagram (called D sequence), and has an unknown origin. It cannot be radial fundamental pulsation since the period is $\sim$ 4 times longer than the fundamental period. The most favored explanations are binarity and non radial g modes, but not without significant problems. The link between LSP and mass loss via dust driven winds was raised by **?**. They showed that LSPs display some mid-IR excess compared to stars without LSPs. LSPs cause mass ejection from giant stars. This mass and accompanying circumstellar dust is most likely in either a clumpy or a disk configuration. The 10 years of LSST activity will be fundamental to understand how the presence of LPS depends on environment or binarity quantifying the percentage of LPVs that show this type of secondary variability.

2. **Symbiotic stars** (SySt) are composed of a giant and an accreting white dwarf. They can play a role as progenitors of supernovae of type I. LSST will help detect them through their peculiar ugriz colors **?**. LSST will measure their AGB period and/or provide typical, often enigmatic lightcurves, such as those shown by **?**. By surveying part of the Galactic disk, the halo and nearby dwarfs, LSST will bring complementary information on StSy populations and evolution. Note that only 250 Galactic and 70 extragalactic StSy are known so far (**?**), and LSST will contribute to narrow the very uncertain number of SySts in the Galaxy. A systematic search of lightcurves typical of SySt in available databases (OGLE, Catalina, ATLAS) should be carried out to prepare LSST characterization.

3. **Multicolor lightcurves** given by LSST for thousands of LPVs will be exploited to refine pulsation and shock waves models, since each star will have a path in the *ugrizy* space. This science is starting with Gaia 2-filter photometry. But LSST will surpass Gaia not just because it will last about twice as long, but because its hugely better time sampling and its multicolor facility. To our knowledge, there is no model of this aspect of pulsation, although it has the potential to identify large tendencies with metallicity, luminosity, dust production, etc.

   *We need high resolution spectral monitoring of a few dozen periodic LPVs (of diverse origin) to help constrain gas hydrodynamics and shocks and to complement LSST photometry. Feasibility is proven in **?**. This task must last $\sim$ 10 years. However, the 1st year of data will provide 2-3 periods for pulsators with $P \sim$ 100-200 days.*

4. **LPV as standard candles** is an essential LSST goal, and every possible study should be attempted to narrow and optimize the choice of Miras suitable for this science. The Mira infrared P-L relation has a scatter that is competitive with that of Cepheids, but documentation on the infrared ($\sim 1-4\mu$) lightcurves is scarce. In addition, dust can be involved either in emission or in absorption in IR lighcurves.

   We need deep-learning software to search for subgroups of OGLE and future LSST Miras that would decrease the P-L relation scatter. A theoretical/empirical link between LSST optical lightcurves and 2μ lightcurves must be achieved. It is only after $\sim$ 5-10 yrs of operation that we shall have this information, provided a significant number of $\sim$ 2μ lightcurves are achieved with ground based-telescopes.

Variability in Ultra-cool dwarfs/BDs

Authors: Markus Rabus

Photometric monitoring of brown dwarfs has shown that these objects show a time-dependent variability. The general theory is that this variability is due to global weather phenomena in the atmosphere. This observation has initiated the beginning of an insight into weather patterns in substellar objects outside of our Solar System. While cloudy atmospheres could explain the observed variabilities, see e.g. **?**, many problems can only partially be explained, as e.g. resurgence of FeH absorption.

Therefore other theories have been brought forward. One theory argues for non-uniform temperature profiles or perturbations in the atmosphere's temperature structure causing brightness fluctuations in UCDs **?**. Another theory by **?** argues for thermochemical instabilities that cause the observed variability in UCDs. Chemical abundance variations can form non-uniform surface opacities causing variabilities in the observation.

Further variability effects might be introduced through lightning and auroral activities. Several works by amongst others, **?**, **?** and **?** discuss the possibility and detection of lightning effects in the BD's atmosphere. While the possible detection of lightning has been discussed theoretically, auroral activities in a BD have been detected by **?**. Finally, a favorable alignment between a putative planetary orbit and the observer's line of sight could cause a periodic transit-shaped variability (for details see [**Reference to transit section**]).

However, the sample of substellar objects monitored for variability is still very small to draw a meaningful conclusion. In addition, the difficulties to detect and monitor these objects shows the example of Luhman 16 AB, which is the closest substellar object not belonging to our Solar System. Despite being very close to us, it was discovered only recently in 2013, but on the other hand, it has also become a benchmark system (see e.g. **?**, **?**and **?**) to study variabilities in brown dwarfs.

A major problem of these objects is their low intrinsic brightness. However, only a few variability surveys have been conducted, most of them in the NIR bands. Unfortunately, the difficulties to obtain high-precision light curves in the NIR wavelength range combined with a short observations span hampered a robust conclusion. So far, the longest observing span has been done by **?**. The authors observed Luhmann-16 in the optical band with the LCO 1-m telescope network for 42 days. Instead observing confirmed UCDs one-by-one, we will take advantage of LSST's very huge etendue. This will allow us to observe many of these faint UCDs with a large range of spectral type. We will be able to monitor many objects for a larger range of time then just a few hours. Given the faintness of these objects and the planned photometric precision of LSST, this facility will be the perfect way to photometrically monitor many UCDs at once in an efficient way. Moreover, the large aperture of LSST will permit to extent a robust sample of monitored UCDs down to even cooler spectral types, as e.g. Y-type.

The discovered and monitored objects will help us to gain a better understanding of cool atmospheres. Furthermore, they will serve as precursor for atmosphere studies with the future generations of gigantic telescopes and advanced space missions.

Besides, probing the atmosphere of UCDs we will also extent and improve the statistical significance of the IMF of UCDs in the galactic plane. This region has been avoided in the past due to crowding and increased confusion with other objects, like e.g. 'O'-rich and 'C'-rich Long Period Variable (LPV) asymptotic giant branch (AGB) stars, distant highly reddened luminous early-type main-sequence/giant branch stars and Young Stellar Objects (YSOs). However, these objects are shared with other group members [**see other science drivers**], as opposed to pure UCD surveys, where these objects are simply rejected. Therefore, only few limited searches for UCDs in the galactic plane has been conducted, see e.g. **?**, **?** and **?**. All authors confirm a similar space density of UCDs as in higher galactic latitudes (see e.g. **?**).

EXor/FUor

Authors: Teresa Giannini,Sara Bonito, Simone Antoniucci
An intense accretion activity is a defining feature of the large majority of all the Pre-Main Sequence (PMS) stars. Albeit a small and irregular photometric variations (typically 0.2-1 mag) caused by disk accretion variability is commonly seen in the light curves of many classical T Tauri stars (cTTSs), some young sources display powerful UV-optical outbursts of much larger intensity (up to 4-6 mag). So far, only ~ 20 objects have been recognized as 'genuine' eruptive protostars **?**, and even less have been long-term monitored. Depending on the different properties (bursts duration, recurrence time between subsequent bursts, accretion rate, presence of absorption or emission lines), young eruptive protostars are classified either as FUors **?** or EXors **?**. Observationally, FUors and EXors are very different objects. FUors are characterized by bursts of long duration (tens of years) with accretion rates of the order of 10^{-4}-10^{-5} $M_{\odot}$/yr and spectra dominated by absorption lines, while EXors undergo shorter outbursts (months-one year) with a recurrence time of months to years, have accretion rates of the order of 10^{-6}-10^{-7} $M_{\odot}$/yr, and are characterized by emission line spectra.

For both classes of objects it is believed that bursts are due to accretion of material that piles-up at the inner edge of the disk **?**. However, the mechanism responsible for the burst triggering is not known: proposed scenarios **?** involve gravitational or thermal instabilities inside the disk or perturbation by an external body (orbiting planets or close encounters with nearby stars). At the moment, however, *none of the proposed models is able to provide a realistic view of the observed burst phenomenology*, also because the scarcity of the observations prevents to put tight constraints to the physical parameters involved.

- Low hanging fruits

  1. **Define the statistical impact of eruptive vs non-eruptive mass accretion in pre-main sequence stars.**
     It is presently unknown whether EXors and FUors are peculiar objects or rather they represent a short and recurrent phase that all the pre-main sequence stars experience during their evolution. To answer this question, we need to compute the percentage of eruptive vs. non-eruptive pre-main sequence stars in different star forming regions. In particular, at least two outbursts episodes should be seen to classify a source as an EXor-type variable. Present observations indicate that only about 2% of PMS are eruptive variables, mostly found serendipitous during observational campaigns carried out to pursue different scientific aims. We expect, therefore, that the percentage of eruptive vs. non eruptive PMS is largely underestimated. A statistical study based on Spitzer/WISE data was already performed by our group **?**, but now, in preparation of LSST observations, we intend to exploit the present public surveys to explore the topic in the optical domain, where bursts are by far more intense. With LSST we expect to reach a statistically significant sample of eruptive protostars within 3 years.

  2. **Discriminate between intrinsic (EXor) and extrinsic (UXor) pre-main sequence variables.**
     The classification of a source as an EXor is often uncertain. Indeed, the observed properties (burst amplitude, cadence, optical/IR colors) are often attributable to accretion as well as to eclipse events related to orbiting bodies, evaporation/condensation of circumstellar dust, or ejected material by powerful outflows that move along the line of sight (UXors variables, **?**). Also, many young variables obey to both mechanisms, whose mutual prevalence depends on the level of activity. Hence, it is becoming clearer and clearer that, more than to merely classify an object as EXor or UXor, it is crucial to infer on the variation of the mass accretion rate, the time dependence of visual extinction A_V, and, more importantly, the possible existence of (inter-)relationships between accretion and extinction events. A secure discrimination between an EXor and an UXor can be achieved through a light curve monitoring of at least 1-3 yr. This is needed to separate light curves of long periods of quiescence with superposed accretion bursts (EXors) from quasi-periodical dimmings from a constant (high) brightness level (UXors). Optical/near-infrared

spectroscopic follow-ups are in order to confirm the indications retrieved from the light curves, since EXors and UXors differ as for the shape of the continuum and the emission/absorption lines present in the spectrum. Systematic monitoring on known objects is presently on-going at LBT (**?**; **?**; **?**; **?**), with the aim, among others, to construct template spectra of EXor and UXor sources, which will be a reference for spectroscopic follow-ups of LSST observations. We intend to use our SoXS GTO time for the same purpose.

3. **Provide clues on the mechanism triggering the outburst.**
   From the comparison of the light curves in a statistically significant sample of objects, we will give observational clues on the mechanism(s) triggering the outburst. LSST observations would represent unvaluable testbeds for the exisisting models. For example, periodicity in the light-curve, burst duration, or asymmetries in the rising/declining time, would represent observational constraints able to discriminate thermal or gravitational instabilities inside the disk (slow rising, non-periodic light curves), from perturbations induced by external bodies (fast rising and periodic light curves). To reach this goal we need a long monitoring of the objects, and therefore we expect to reach significant results in 10 years at least.

- Pie in the sky

  1. **Understand whether and how eruptive accretion can solve the 'luminosity problem'**
     .
     The identification of a statistically significant sample of EXors (and possibly FUors) will allow us to understand the role of eruptive mass accretion in a more general context of star formation studies. In a classical star-formation scenario for low-mass objects, about 90% of the final mass is accreted onto the star in about 10^5 yr, with typical mass accretion rates of 10^{-7}-10^{-5} $M_\odot$/yr. Then, the accretion progressively fades to rates of 10^{-9}-10^{-10} $M_\odot$/yr. In this quasi-stationary scenario, however, protostellar luminosities should be largely higher than observed (the so-called 'luminosity problem', **?**). Variable (and possibly eruptive) accretion has been proposed as a way of reconciling the observed star formation time and the mean protostellar luminosity **?**. **?** also found that episodic accretion can contribute a significant fraction of the stellar mass. LSST main survey will give the opportunity to systematically cover and monitor most of the known star forming regions. These are the ideal conditions to determine the *true* percentage of eruptive variables, at least in regions where the extinction is not prohibitive. To solve the luminosity problem, however, we should demonstrate not only that eruptive PMS variables are much more common than presently expected, but also that bursts frequency and amplitude produce an increase of the accretion luminosity high enough to compensate the low values observed during the much longer fainter states. All the telescope lifetime is needed to reach such an ambitious goal.

Compact Binaries: Cataclysmic Variables (CVs)

Authors: Paula Szkody

The variability of cataclysmic variables involves timescales ranging from days to 30 years and amplitudes from one magnitude to 15 magnitudes. While the time-critical studies will address some science goals related to immediate discoveries (see Cataclysmic Variables section under Time-Critical Science), there are many aspects that need the 10 yr coverage afforded by LSST. Long term studies of CVs from the LSST archive starting from year one and continuing to the full ten years of the survey will involve the following science goals.

- Low hanging fruits:

  1. **Discover and classify new dwarf novae** from light curves, color and amplitude to determine their number density in the galaxy as a function of galactic latitude to compare with population models. This will require followup spectroscopic observations on a large telescope to confirm the classifications. The full 10 years of the survey will provide the best number density as the majority

of objects are expected to have long (decades) timescales between outbursts. Better population models are needed to provide comparison of the resulting number densities with expectations from evolution.

2. **Monitor the length of time that known novalikes spend in low versus high states** in order to understand the mass transfer rates and angular momentum losses in these systems. This will require the long timebase of 10 years.

3. **Find candidate systems for containing magnetic white dwarfs** (polars and intermediate polars) from the shape of the light curves and colors in order to better understand the ultimate evolution of high magnetic field systems after common envelope evolution. Confirmation of the magnetic nature will require circular polarimetry and/or medium resolution spectroscopy. While results will be found on a yearly basis, the full 10 years is needed to determine final numbers of magnetic versus non-magnetic systems and how they are distributed in the galaxy.

4. **Find candidate eclipsing systems** that would allow inclinations (from light curve modeling) and the masses of the stars (from radial velocity studies) to be determined. Will require followup for high time resolution light curves and time-resolved spectra to obtain radial velocity curves.

- Pie in the sky:

  1. **Determine the orbital period distribution of candidate dwarf novae** from follow-up photometric and spectroscopic studies to allow comparison with population models. Determine the mass of the secondary for the shortest period systems to find those after the period bounce as predicted by models. This will require time-resolved spectra on large telescopes.

  2. **Determine the spin and orbital periods of candidate intermediate polars** from high cadence (sec-min) observations to confirm their classification and understand the properties of magnetic binary evolution.

  3. **Accomplish followup polarization studies of candidate polars** to determine the magnetic fields of the white dwarf in order to confirm their classification and understand the evolution of the highest field white dwarfs in binaries compared to isolated single white dwarfs.

Compact Binaries: Neutron Star Binaries

Authors: Elena Mason

The study of tMSPs, MSPs and LMXBs (in other words, accreting neutron stars – see Time Critical Science section: Compact binaries: neutron star binaries for an introduction) is not limited to the LSST alerts (see Time Crtical Science section). Instead it will greatly benefit from the all-sky survey, long term monitoring characteristics of the project.

- Low hanging fruits

  1. **A census of tMSPs, MSPs and LMXBs:**The multi-band deep LSST observations will be combined/cross-matched with the data from other next generation surveys such as, for example, THESEUS or eROSITA allowing the discovery of new accreting NS. The resulting census will allow population analysis also of complete samples once the LSST data are cross matched with GAIA parallaxes and proper motion.

     Note in particular, that for the new MSPs discovered via radio surveys, finding the X-ray and/or optical counterpart is crucial to properly characterize the population of MSP binaries in its various subclass (e.g. black-widows with degenerate donors, and redbacks with non-degenerate donors).

     In a similar way, known and new LMXBs will be identified and monitored at optical wavelengths thanks to the LSST observations.

2. **Long term monitoring of all known tMSPs, MSPs and LMXBs:**The LSST light curves of known objects will allow assessing the long term variability of each system, properly framing the MSP population in the context of LMXB and helping answering to the question whether *a)* all MSPs turn transitional and *b)* the tMSP is possibly an evolutionary phase preceding total exhaustion of the donor star.

   Known systems (MSPs, tMSPs and LMXBs) will be part of the monitoring program starting with the commissioning observations. New systems will enter the monitoring program once early LSST data sets will be combined and cross-correlated with candidate MSPs, tMSPs and LMXBs from the coming radio and X-ray surveys within the SKA and X-ray surveys. From the beginning to the end of the LSST mission the database of accreting NS will gradually increase in light curve extension and sample size, eventually culminating in a 10 yr long multi-color light curve for each system.

   Mapping of the variability patterns displayed by interacting compact binaries will be invaluable to tackle the history of the mass accretion rate of each object and to frame the correct evolutionary scenario for each subclass of compact binaries. This is particularly compelling for the accreting NS and, among these the tMSPs (Arcibald et al. 2009; de Martino et al. 2010, Papitto et al. 2013) which are MSPs that have recently been discovered to change from a state of radio pulsar to that of LMXBs or vice-versa, also displaying intermediate states where a subluminous accretion disk seems associated to the launch of jets.

   While the change of state of an accreting NS might trigger follow up observations (see Time Critical Science section), the long term (multi-color) light curve of each system will allow to determine time scale of changes as well the duration of each states and the driving factor for the change of state. Is the change of state depending solely on the change in the mass transfer rate? does the mass transfer rate depend on the nature of the secondary star or other system parameters? are tMSP a specific evolutionary phase between the LMXBs and the MSP or can any system virtually turn into a tMSP? This is particularly timely in the recent years given that the number of known MSPs has more than triplicated since 2010 thanks to both radio surveys and blind searches in the *Fermi-LAT* sky scans that discovered a number of pulsar-like γ sources eventually confirmed to be MSPs. The number of such systems is expected to increase even more dramatically once SKA will be in operation (enabling much improved timing precision of binary pulse) and next generation X-ray missions will permit discovery and high S/N modeling of X-ray pulsed signal.

- Pie in the sky

Compact Binaries: Black Hole Binaries(BHBs)

Authors: Michael Johnson, Poshak Gandhi

Of the millions of stellar-mass black holes formed through the collapse of massive stars over the lifetime of the Milky Way, only 20 have masses that have been dynamically confirmed through spectroscopic measurements (e.g., **?**). Expanding this the sample of black hole masses could aid in answering many questions central to modern astrophysics.

There is expected to be a large population of black hole binaries (BHBs) in quiescence with low X-ray luminosities from 10^{30}– 10^{33} erg s^{-1}. Such systems can be identified in the optical as variables that show unique, double-humped ellipsoidal variations of typical peak-to-peak amplitude 0.2 mag due to the tidal deformation of the secondary star, which can be a giant or main sequence star. In some cases, analysis of the light curve alone can point to a high mass ratio between the components, suggesting a black hole primary; in other cases, the accretion disk will make a large contribution to the optical light which results in intrinsic, random, and fast variations in the light curve. The disk contribution to optical light can vary over time, and several years of data is required to properly subtract the accretion disk contribution in order to properly fit ellipsoidal variations (?). As a result, data products generated by LSST for studying the ellipsoidal variability of BHBs will begin to become useful around the 3 year mark, allowing for some probe of the variability, however the results will be much improved after the full 10 year survey. The characteristic ellipsoidal modulation of X-ray binaries can also be observed in other classes of binary systems. Therefore, X-ray follow-up observations are required in order to classify X-ray binaries, this follow-up to the majority of the discovered systems should be possible with the next generation of X-ray telescopes (e.g. Athena ?).

BHBs typically spend most of their time in quiescence, where the optical emission is dominated by the companion star. However, many systems undergo periods of outburst, thought to be triggered by instabilities in the accretion disc ?. These outbursts are characterised by very rapid and dramatic increases in optical luminosity and during outburst, the disc becomes the dominant component in the optical luminosity and the characteristic ellipsoidal modulation can no longer be observed.

LSST is expected to discover many unknown BHBs, therefore additional observations pre-LSST (i.e. prior to discovery) will be superfluous. The brighter sources will be spectroscopically observable with the current generation of 4-m to 10-m telescopes to dynamically confirm new black holes; spectroscopy of all candidates should be possible with the forthcoming generation of large telescopes. Thus, LSST would trigger a rich variety of observational investigations of the accretion/outflow process through studies of this large, dark population.

- Low hanging fruits: Period Determination and Quiescnet Magnitude Observations

  Many BHB candidates have currently only been observed during outburst as they are too faint to be observed without sufficiently optically sensitive follow-up which has not been possible for most of these systems. LSST should be able to observe a large fraction of the population of these systems in quiescence for the first time during the first year of LSST operations. As the companion star cannot always be observed during outburst, this will allow for counterpart identification for many of these systems.

  The period determination of a meaningful fraction of the black hole binary population. The majority of Galactic BHBs will likely be too faint to be observed by LSST. However, the fraction which LSST should be able to observe through ellipsoidal variability (approximately 1/3 ?), should prove to be statistically significant with regards to the population studies of BHBs. The current computational techniques are capable of determining the period through ellipsoidal variability and due to the low expected total population of LMXBs in the Milky Way ($\sim$1300; ?), period determination of a fraction of this population would require enough storage to host all images for each of the objects (or at least the regions in which they are contained) and computing resources to generate $\sim 10^5$ power spectra per system. Figure 3 shows results for the period determination of BHB with LSST over a broad range of parameter space when using different observing strategies from ?.

- Pie in the sky: Binary Component Mass Measurement

  ?, investigate the relation between parameters of BHB optical light curves and physical parameters of the system, such as binary component mass or orbital inclination. Therefore, LSST could be used to place constrains on these physical parameters in BHBs that are observed in quiescence. Potentially, this information could then be used to answer questions such as: which stars produce black holes and which neutron stars; whether there is a true gap in mass between these two types of compact object; whether supernova explosions result in large black hole kicks. However, these techniques will have to be investigated further, while using simulated LSST data in order to determine their applicability.

ILOTs

Authors: Jorick Vink

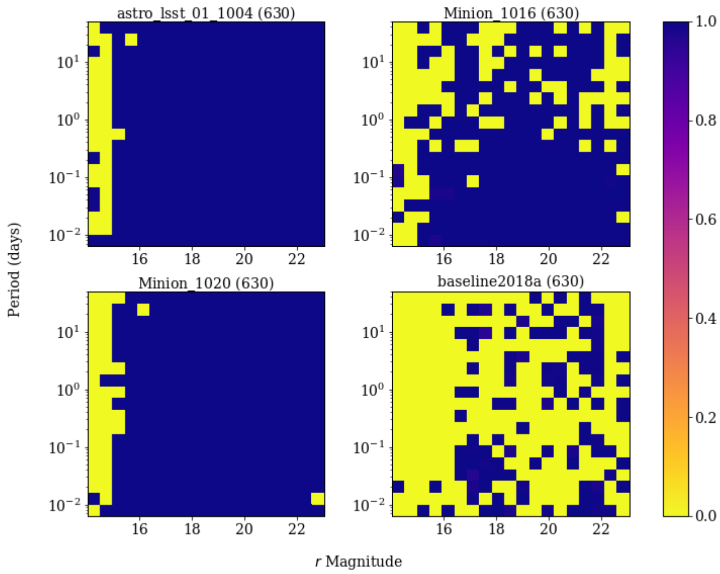

Figure 3: Colour maps displaying the period determination of LMXBs possible with observing strategies astro_sim_01_1004, Minion_1016, Minion_1020 and baseline2018a. All observations used were of LSST field 630 which is in the Galactic Plane Y axis denotes the orbital period in days, X axis r mag before adding contributions from ellipsoidal modulation, flaring and noise. The colour denotes the significance of the period detected. If the measured period differed from the actual period by more than 5%, then the significance was set to zero.

LBVs are very bright sources, and among the most massive stars detectable in galaxies. Famous examples in our Galaxy are AG Car and HR Car. In the nearby Universe, we should also mention: S Doradus in the LMC as this is the proto-type of the class. Other famous examples include AE And and EF And in M31, Var C and Romano's Star (GR 290) in M33, along with several well-studied LBVs in NGC 2403. During S Dor-like outbursts, stars experience erratic brightness variability over timescales of several months to a few years or decades, with ΔM of a couple of magnitudes, typically $\Delta M = 1 - 2$. Traditionally it had been assumed there was no significant change in the bolometric luminosity **?**, but this has more recently been challenged **??**. During outburst, S Doradus LBVs move to the right of the Hertzprung-Russell diagram, becoming redder and cooler, to then come back to the left side in quiescence. The reason for the HRD excursion is as yet unknown although envelope inflation due to the proximity to the Eddington limit is the main contender **?**.
The full range of variability of a classical LBV can be comfortably monitored with single shot LSST observations up to about 30 Mpc, but with periodic stacks we can largely exceed this distance limit. For known LBVs, using also literature and archive data, we aim at obtaining light curves with baselines of many decades. Multiple survey strategy may reveal different types of variability, which develop on different timescales. Well-studied LBVs will become reference objects, as we expect to find with LSST new LBV candidates in outburst.

- Low hanging fruits

  1. **Observations of Ordinary Luminous Blue Variable (LBV) outbursts (S Dor-like)**
     Known S Dor variables will automatically be observed and this will greatly enhance the baseline and quality of reference objects. In addition, some LBVs are known to undergo multiple giant

outbursts. An example of such a restless LBV is SN2000ch the LBV in NGC 3432 **?**. Some LBVs may already be identified in the first year of LSST observations, but given that the average time-scale of S Dor variations is about a decade, the sample will only start to be complete after 3 and 10 years.

- Pie in the sky

  1. **Determination of the Evolutionary State of LBVs**
     Using the "reference frame" known objects, new S Dor variables will be discovered with LSST in a variety of environments. Ultimately it is the need for completeness of LBVs in comparison to ordinary Blue supergiants which will determine the duration of the LBV phase and thus the evolutunary status of LBVs **?**. This is the main science goal.
     In addition to relying on observed reference objects, theoretical development on envelope inflation and atmosphere modelling is needed to predict a range of LBV colours as a function of metal contents.
     The need for modelling is particularly clear when one considers the fact that known transients show a rather wide range of behaviour **?**, which makes the value of simply using templates rather more limited.

0.6 Intrinsic/Extrinsic extragalactic transients and variables

Editor: Claudia M. Raiteri/Chiara Righi

Blazars

Authors: Claudia M. Raiteri, Barbara Balmaverde, Maria Isabel Carnerero, Filippo D'Ammando, Chiara Righi

While the detailed study of the jet emission variability in blazars is time-critical because it requires simultaneous multiwavelength observations especially during active states, other studies on blazars are non time-critical. These include statistical analysis of the properties of the whole blazar class or of blazar subclasses (BL Lacs and FSRQs). Of particular interest is the analysis of the blazar luminosity function and its relationship with that of radiogalaxies, which represent the unbeamed parent population of blazars according to unified models of AGN. Another important topic is the study of the environment of the blazar host galaxies. Blazars are commonly hosted by giant elliptical galaxies mostly located in dense environments, but the picture needs to be investigated further with a large sample of objects covering a wide range of redshifts. With LSST data we plan to:

- Low hanging fruits

  1. perform a statistical study of blazar variability to detect characteristic behaviours of the different blazar classes;
  2. build diagnostic diagrams to identify new blazars;
  3. explore the blazar optical luminosity function on a much wider population;
  4. make a more detailed evaluation of the neutrino background due to these sources;
  5. study the environment of the blazar host galaxies.

- Pie in the sky

  1. check theoretical predictions against observations to discriminate among emission and variability mechanisms in blazars;
  2. define the cosmic evolution of blazar populations;

3. check Unification Models for AGNs.

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Science cases that require *User Generated Data* Products

Science Case 1

- Low hanging fruits
- Pie in the sky

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Deep Drilling Fields science cases

0.7 Extrinsic transients and variables

Editor: Andrej Prsa

Eclipsing binary stars

Authors: Andrej Prsa

- Low hanging fruits
- Pie in the sky

Microlensing

Author: Rachel Street

- Low hanging fruit

a) **Bulge Deep Drilling Field: Exoplanets**
One of our most powerful tools for understanding planetary formation is to compare the actual planet population with that predicted by simulations, but there remain important gaps in our planet census. Low-mass planets in orbits between ∼1–10 AU are of particular interest, because the core accretion mechanism predicts a population of icy bodies (e.g. Ida & Lin 2013) in this region. Evolutionary models further predict that gravitational interactions between migrating protoplanets should result in some being ejected from their systems (Mustill 2015, Chatterjee 2008). However, this parameter space coincides with a gap in the sensitivity of the planet-hunting techniques used to date, leading to it being sparsely sampled. Microlensing offers a way to test both of these predictions, being capable of detecting planets down to $\sim 0.1\,M_{Earth}$ at orbital separations of ∼1–10 AU. It is also capable of detecting free-floating planets that have been ejected from their formation star systems. The effectiveness of this technique has now been demonstrated by the discovery of three candidate FFP events (Mroz et al. 2017, Mroz et al. 2018).

A survey of the Galactic Bulge region where the rate of microlensing events is highest is one of the main goals of NASA's WFIRST Mission (Spergel et al.2015). The spacecraft will discover ∼1400 bound planets and will provide a dataset ideal for detecting FFPs (Penny et al. 2018). The physical properties of bound planets should be constrained by direct measurement of the light from the lensing system, but this technique cannot be applied for FFPs. Microlensing models suffer from a number of degeneracies, and the physical properties of the lens are extremely hard to measure without an additional constraint on the event parallax. For long timescale events (>30 d) this can be derived from a single lightcurve thanks to the orbital motion of the observer, but WFIRST data alone cannot measure the parallax for short timescale ($t_E \leqslant 30$ d) events. Thanks to the $\sim$0.01 AU separation between LSST and WFIRST (at L2), the observatories will measure different magnifications and times of maximum, enabling us to derive the physical and dynamical properties of short timescale events.

LSST will substantially improve constraints on the lens properties, particularly the FFP mass function, distances and kinematics, by simultaneously observing a Deep Drilling Field covering the WFIRST Bulge survey region. LSST will also complete event lightcurves that remain partially sampled by WFIRST. WFIRST will observe $i \sim 19$–25 mag stars in the Bulge for a total of $\sim$432 d spread over 6 'seasons'. But the spacecraft can only monitor the field for $\sim$72 d at a time due to pointing constraints. Since microlensing events can peak at any time, and have durations t_E $\sim$1–100 d, many WFIRST lightcurves will be incompletely sampled. This will make it difficult to measure the parallax (and hence physical properties) for even long timescale events, and raises the probability that anomalous features (and lens companions) will be missed in the inter-season gaps.

- Pie in the sky

0.8 Intrinsic Galactic and Local Universe transients and variables

Editor: Markus Rabus

Pulsating stars

Authors: Kelly Hambleton,Massimo Dall'Ora, Ilaria Musella, Maria Ida Moretti, Keaton Bell, Robert Szabo

- Low hanging fruits

  Cepheids and RR Lyrae stars: identification, period, color, period variations, detection of modulations of the light curve, statistics of the occurrence of modulations, identification of multi-mode pulsation

  Observation of RR Lyrae stars in globular clusters, dwarf galaxies, Magellanic Clouds, etc.

- Pie in the sky

  1. Cepheids and RR Lyrae stars: detection of low-amplitude additional modes, other dynamical phenomena (like period doubling), Blazhko (modulation) period distribution, detection of multiple modulations for a given object

     Cepheids/RR Lyrae stars in binary or even eclipsing systems (low chance, especially for RR Lyrae stars)

  2. detection of low (sub)stellar mass companions to the pulsating stars

  3. If the additional observations of the deep drilling fields are carried out at a higher (possibly continuous; **?**) cadence, accurate period solutions could be obtained for many multi-periodic variables. The internal structures of these objects could be constrained by full asteroseismic analyses, and these well characterized variables could provide a reliable sample for training machine learning models to classify variables in the main survey.

Variability in Ultra-cool dwarfs/BDs

Authors: Markus Rabus

As mentioned ...

- Low hanging fruits

1. Detect rotational variability in L/T dwarfs due to global weather phenomena in the atmosphere. Beginning of an insight into weather patterns in substellar objects outside of our Solar System. It is still not clear what causes this variability. Clouds, non-uniform temperature profiles or perturbations in the atmosphere's temperature structure can cause brightness fluctuations. The discovered and monitored objects will help us to gain a better understanding of cool atmospheres. Furthermore, they will serve as precursor for atmosphere studies with the future generations of gigantic telescopes and advanced space missions.

- Pie in the sky

  1. Multi-filter photometric monitoring to reveal a possible filter-dependent phase shift and amplitudes.
  2. Possible variability effects through lightning and auroral activities.
  3. Variability in Y dwarfs.

compact binaries: NS binaries (in quiescence and outburst)

Authors: Elena Mason

Deep drilling fields in the contest of LMXBs, MSPs, tMSPs will work similarly to the LSST main survey although they cadence and filter choice and sequence will be different. Hence, DDF data could both produce alerts (see Time Critical Science section) and, most important, light curve and colors (see non-Time-Critical Science section).

- Low hanging fruits

  1. **Period search in know and new discovered accreting NS:**
     The higher cadence foreseen for DDF will enable complementary science/analysis with respect to the LSST main survey. In particular, they will allow performing period search (especially orbital period search) of the monitored systems, once a sufficient number of data points will have been piled-up.
  2. **Census of accreting NS in crowded field:**
     The different stellar environment explored by the DDF surveys will enable comparison of the accreting NS populations and how they are affected by their environment (whether it is star density or metallicity etc).
  3. **Change of states and outbursts alerts:**
     Alert from DDF survey are in principle possible and will enable us to trigger follow-up observations of accreting NS binaries that enter a state which allow probing the binary parameter and/or physical mechanism responsible of the observed phenomenology.

- Pie in the sky

ILOTs

Authors: Andrea Pastorello & Elena Mason

See DDF Section

- Low hanging fruits
- Pie in the sky
- Tasks
- Outcome in commissioning, 1, 3, 10 years

0.9 Intrinsic/Extrinsic Extragalactic Transients

Editor: Maria Isabel Carnerero Martin

Blazars

Authors: Claudia M. Raiteri, Barbara Balmaverde, Maria Isabel Carnerero Martin, Filippo D'Ammando, Chiara Righi

Among the population of the about 4000 known blazars, only a few tens of bright objects have been the targets of densely sampled observing campaigns aiming to study the flux variability in details. The vast majority of blazars are faint sources, with magnitude less than 17. Intranight variability has often been detected in bright and variable blazars during flaring states. DDFs would allow us to investigate whether these fast flux variations are a common property of blazars.

Among the four already approved DDFs (see Fig. 2), only COSMOS contains known blazars. These are two faint BL Lac objects, which have not shown particular variability in the optical band, although the available light curves are affected by large errors. To exploit the LSST potentialities for blazar studies, additional DDFs could be proposed. In particular, DDFs including candidate neutrino sources would be highly valuable, considering that detection of a high-energy neutrino comes with a large uncertainty on the sky location (of the order of 1 degree). Possible examples are shown in Fig. 3. All the possible new DDFs contain a neutrino source candidate plus a few other fainter blazars of various type and redshift. Since the candidate neutrino sources are bright, observations of one of these DDFs would require smaller exposure times than a normal visit, or observations in star trail mode (Thomas & Kahn 2018, ApJ, 868, 38), therefore it could suit all the scientific cases where very fast transients are involved.

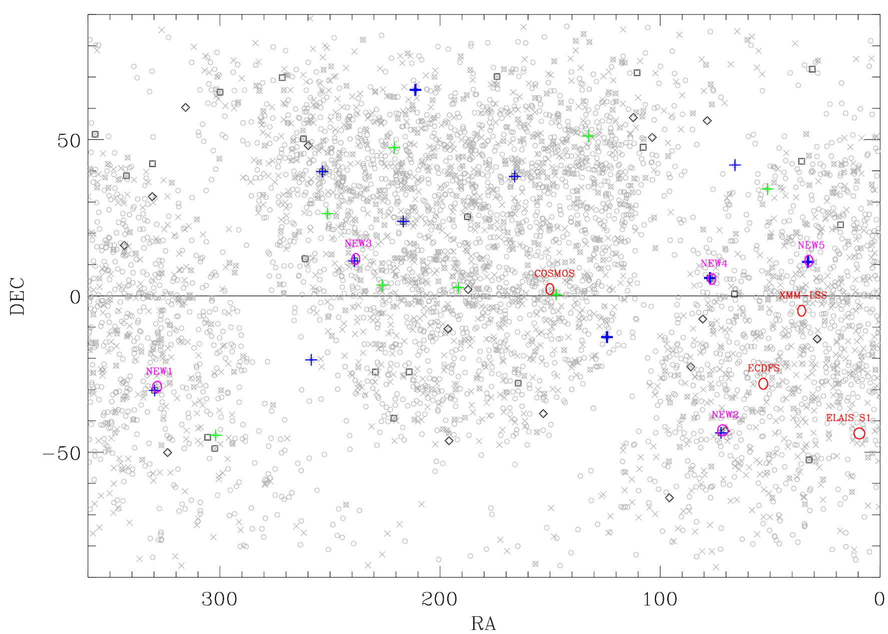

Figure 4: Distribution of blazars from the BZCAT5 (circles) e 2WHSP (crosses) catalogues in the sky. The regions of the four approved LSST DDFs are circled in red. Black squares/diamonds mark the brightest (R<15) BL Lacs/ FSRQs in BZCAT5. Blue plus signs represent candidate neutrino sources and green plus signs gamma-loud (and radio-loud) narrow-line Seyfert 1 galaxies (NLSy1) that show a blazar-like behaviour. Possible choices for new DDFs are indicated in purple.

The proposal of these new DDFs would allow to:

- Low hanging fruits
  1. perform intense monitoring of interesting blazars to study extragalactic relativistic jets;
  2. detect the shortest variability time scales, i.e. the smallest emission regions in the jet;
  3. trigger immediate follow-up observations of important events, in particular at very high energies;
  4. study the environment of the blazar host galaxies.
- Pie in the sky
  1. establish the possible correspondence with high-energy neutrinos, which would shed light on the jet emission mechanisms (leptonic vs hadronic models);
  2. identify the faintest blazar population.

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Minisurvey science cases

0.10 Extrinsic transients and variables

Editor: Marc Moniez

Eclipsing binary stars

Authors: Andrej Prsa

- Low hanging fruits
- Pie in the sky

Interstellar scintillation towards LMC and SMC

Author: Marc Moniez

Stars twinkle because their light propagates through turbulent atmosphere. Of order of one percent light modulation due to scintillation is expected to happen at a few minute time scale when remote stars are observed through an interstellar turbulent cloud, but it has never been observed at optical wavelengths. The time scales of the weak optical intensity fluctuations resulting from the wave distortions induced by a turbulent medium (visible nebulae or hidden molecular gas) are accessible only now to the current technology. LSST is the ideal setup to search for this signature of gas thanks to the fast readout and to the wide and deep field. As a first result, the detection of such a signal would provide a new tool to measure the inhomogeneities and the dynamics of nebulae. Our long term objective is to search for *cold transparent* molecular H_2 *dust-free* clouds, which are the last possible candidates for the missing baryons **?**, **?** representing $\sim 50\%$ of the Milky Way baryons **?**.

We propose to take long series of consecutive images of the same field toward LMC or SMC during two nights through the "moving mode". This "micro-survey" could be done during the commissioning of the camera, but does not need all the mechanical functionalities of the telescope mount, since the telescope should point at the same direction during the full nights.

It has been suggested that a hierarchical structure of cold H_2 could fill the Galactic thick disk **?** or halo, providing a solution for the Galactic dark matter problem. This gas should form transparent (dust-free) "clumpuscules" of 10 AU size, with a column density of $10^{24-25}\,\mathrm{cm}^{-2}$, and a surface filling factor smaller than 1%. Such clumpuscules are invisible to the direct observations since they do not emit or absorb light, but only increase the total optical path of the light by $5-50cm$; as a consequence, the diffractive and refractive scintillation caused by their turbulence - similarly to the well known radio scintillation - is the only way to detect them.

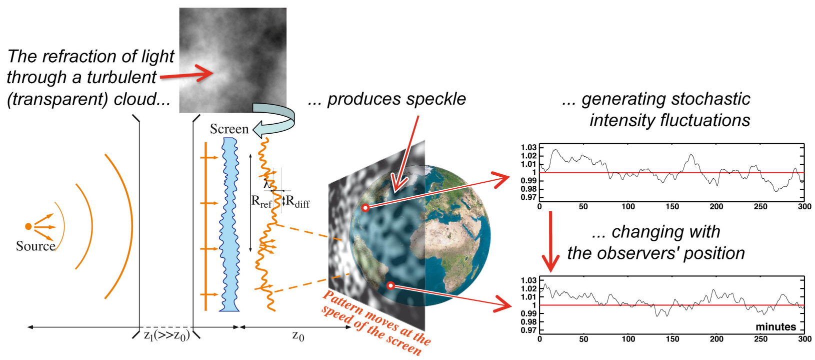

Figure 5: Up: simulation of a 2D stochastic phase delay (grey scale) caused by the column of gas affected by Kolmogorov-type turbulence. Down: the propagation of light from a stellar source (left) after crossing the cloud (represented as a phase screen) and the resulting illumination pattern on Earth. The distorted wavefront produces structures at scale $R_{ref} = 3086km \times [\lambda/1\mu m]\,[z_0/100\,pc]\,[R_{diff}/1000\,km]^{-1}$. As a consequence, two telescopes distant by a few thousand kilometers are differently illuminated at a given time. These structures sweep the Earth at the transverse speed of the screen (typically a few $10's$ of km/s), producing uncorrelated illumination fluctuations at a few minute time scale. The configuration simulated here corresponds to a scintillating star of half the solar size, located at $1\,kpc$, seen through a turbulent cloud at $160\,pc$ with $R_{diff} = 1000\,km$ translating at $V_T \sim 17\,km/s$ with respect to the line of sight. The two telescopes are $10,000\,km$ away (the GEMINI telescopes are at $9430\,km$ linear distance).

Fig. 5 shows how refraction through an inhomogeneous transparent cloud produces an irregular illumination on Earth **?** and **?**. The turbulence strength of the refractive medium is quantified by the diffraction radius $R_{diff}(\lambda)$, defined as the transverse separation for which the rms of the phase difference is 1 radian at λ. The refractive medium, located at distance z_0 from Earth, and moving with transverse velocity V_T relative to the line of sight, is responsible for stochastic intensity fluctuations of the light received from the star at a typical **characteristic time scale of a few minutes**, scaling as:

$$t_{ref}(\lambda) = 5.2\,minutes \left[\frac{\lambda}{1\mu m}\right] \left[\frac{z_0}{100\,pc}\right] \left[\frac{R_{diff}(\lambda)}{1000\,km}\right]^{-1} \left[\frac{V_T}{10\,km/s}\right]^{-1}, \tag{5}$$

with a typical **intensity modulation index** $m_{scint.} = \sigma_I / < I >$ **of a few** %, limited by the source spatial coherence, thus decreasing when the angular stellar radius θ_r increases, according to:

$$m_{scint.} = 0.05 \left[\frac{\lambda}{1\mu m}\right] \left[\frac{z_0}{100\,pc}\right]^{-1/6} \left[\frac{R_{diff}(\lambda)}{1000km}\right]^{-5/6} \left[\frac{\theta_r}{\theta(Sun\ at\ 10kpc)}\right]^{-7/6}. \tag{6}$$

Since the illumination on Earth depends on the position (Fig. 5-right), we expect variations of the light-curves observed from two telescopes to decorrelate when their distance increases. This signature – incompatible with an intrinsic source variability – points to a propagation effect.

One should notice that the signal cannot be confused with atmospheric scintillation - that induces fast PSF variations but negligible intensity variations within a large aperture **?**, **?** and **?** - or with atmospheric absorption fluctuations, that can be precisely taken into account in the analysis, by the simultaneous monitoring of all stars in the field.

- Low hanging fruits

  Using the LSST, two runs (either with neutral filter, to benefit from a maximum of light, or with g filter) of a few hours towards a given direction (LMC or SMC to benefit from the wide field), taking series of 15s consecutive exposures, will allow to obtain a few tens of millions of light-curves with 1-2 thousands of measurements each at the requested high rate (~ 3 per minute) and the requested photometric precision (better than 1% on stars with $M_V = 20.5$). Such a harvest of data would allow to efficiently search for a scintillation signal down to optical depth of order of 10^{-6}.

  1. If no scintillation is discovered, a strong upper limit of the molecular gas contribution to the Galactic mass will be established (following the analysis of **?**).
  2. If a scintillation signal is suspected, it could be confirmed thanks to the repetition of the observations during two different nights (which do not need to be consecutive). Moreover, if a trigger is available at the time of observations (based on simple peak-to-peak variation threshold), complementary observations could be simultaneously done with remote telescopes, allowing to test the decorrelation of the stochastic fluctuations between distant locations.
  3. If enough twinkling stars are discovered, the decrease of the modulation index when the size of the source increases could also be measured, as a check of the properties of the scintillation process.

  Fig. 6 shows the configurations (source magnitude and turbulence strength expressed in R_{diff}) that should produce detectable scintillation with LSST observations (upper-right zone). The ultimate sensitivity corresponds to $R_{diff} \sim 16,000km$, which is typically associated to a medium with density fluctuations as low as $2 \times 10^7\ cm^{-3}$.

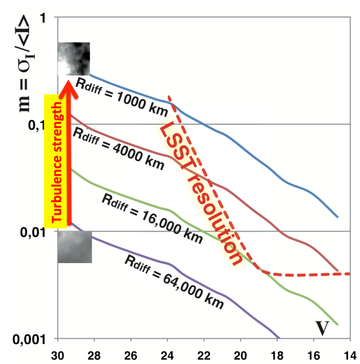

Figure 6: The expected modulation index m in I, as a function of the source apparent magnitude V, for 4 different turbulence strength parameters R_{diff} (smaller R_{diff} corresponds to stronger turbulence). The screen is at $z_0 = 1Kpc$ (invisible halo clumpuscule typical case), the source is at $z_1 = 55Kpc$ (within LMC). The instrumental photometric precision (dashed line) is taken from the LSST science book **?**. We see that few percent precision observations already allow a sensitivity to a medium with relatively low strength turbulence, characterized by $R_{diff} < 16,000km$, that should induce scintillation detectable for stars with $16 < V < 22$.

- Pie in the sky

  1. The database produced by such a "movie mode" will certainly be useful for many other science subjects like the searches for planetary transits, the detailed study of eclipsing binaries (to refine the knowledge of the LMC distance), the microlensing searches for hidden very low mass compact

objects and for microlensing caustic crossing if observations are coordinated with the microlensing networks.

0.11 Intrinsic Galactic and Local Universe transients and variables

Editor: Keaton Bell

Pulsating stars

Authors: Kelly Hambleton, Keaton Bell, Massimo Dall'Ora, Ilaria Musella, Maria Ida Moretti, Robert Szabo, Marcella Di Criscienzo

- Low hanging fruits

  1. The identification and classification of multi-periodic variables and low-amplitude, relatively high-frequency variables (such as delta Scuti Stars, Gamma Doradus stars, and pulsating white dwarfs). The ability to identify such variables will significantly increase if any minisurveys provide a faster cadence and a greater number of observations, especially of the Galactic Plane. These variables have periods on the order of minutes (white dwarfs), hours (delta Scuti stars) and days (gamma Doradus stars).

     For the purpose of asteroseismology, radial velocity follow-up observations will provide a more detailed look into the pulsational nature of the objects and will allow for thorough pulsational modeling. The required spectroscopy must be high resolution with high cadence (to obtain several spectra per pulsational cycle). This becomes significantly more difficult for higher frequency pulsations, as shorter exposures are required and thus the largest telescopes will be needed to reach the high magnitude limits of LSST. For known objects in the field, spectroscopic observations can begin prior to the commencement of the survey observations.

     Studying the potential problems caused by aliasing by the observational window function of different minisurvey strategies will inform the realistic limitations for asteroseismology for these better studied fields. Ideally, the minisurveys will be designed to minimize aliasing, possibly even using the past history of field visits to strategically time revisits to reduce existing aliases (https://arxiv.org/abs/1812.03142).

     Information on adopted survey strategies will enable more specific anticipation of science results and the associated tools and resources that they will require. The classification will commence with the first data release and will continue incrementally as the data are released. The infrastructure to store and host the catalog is required. Furthermore, the creation of an online catalog to provide the data to the community in a user-friendly format is desirable.

  2. Faster cadence may allow the detection of finer details in the light curves, i.e. additional low amplitude modes in classical pulsators (RR Lyrae, Cepheids), as well as main-sequence pulsators (β Cep, γ Dor, δ Sct). For RR Lyrae stars and Cepheids, the color and temporal behavior of the additional, low-amplitude modes is not well known.

- Pie in the sky

  1. The asteroseismology of red giant stars. Red giant stars are stochastic pulsators. They pulsate with periods on the order of days to hours. As their pulsations are stochastic in nature, the resolution of their pulsations is proportional to 1/(2T) where T is the duration of observations. Furthermore, a high cadence is required to enable the detection of the red giant peaks and thus a dithering strategy that reduces aliasing (or at least provides a predictable window pattern) is also needed. The colors will provide temperatures which are necessary for the determination of radii and masses from the use of scaling relations. By considering red giants from several mini-surveys, population studies of red giants can be performed, including the consideration of their

fundamental parameters. An assessment of the scaling relations as a function of location and thus metallicity can also be preformed. If this is possible, it will only be possible at the end of the data acquisition period because of the need for a long observational baseline. With a 10-year baseline, it may be possible to detect solar-like oscillators with lower frequencies of maximum oscillation power than were detected from Kepler data.

RR Lyrae stars in the inner bulge

Authors: Massimo Dall'Ora, Giuseppe Bono, Michele Fabrizio, Giuliana Fiorentino, Alessia Garofalo, Kelly Hambleton, Davide Magurno, Silvia Marinoni, Paola Marrese, Tatiana Muraveva

- Motivation
  Despite all the efforts so far, we still lack a clear knowledge of the old stellar population in the Galactic inner bulge, mainly because of the strong reddening. However, RR Lyrae stars are well-known pulsating stars typical of the old stellar populations and sound standard candles, since they follow well-defined NIR period-luminosity relations. As standard candles, in the GAIA DR2 era they can provide individual distances with an accuracy better of 3%. Moreover, they also follow reddening-free Weseheneit functions, of great interest in environments affected by strong and/or differential reddening. With these tools we can measure the density profile of the old population, the 3D structure of the bulge and of the bar, and get fundamental observables to constrain the MW formation models. The use of three bands *iZy*, together with *JHK* (VVV survey) measurements, will allow us to provide new individual estimates of distance, reddening and metallicity.
- Low hanging fruits
  1. discovery and classification of pulsating variable stars. The project is focused on RR Lyrae stars, but the proposed cadence will be tuned also to discover SX Phe stars and Anomalous Cepheids, typical of old/intermediate stellar populations and well-known distance indicators. Typical periods go from 0.1 (SX Phe stars) to 2 days (Anomalous Cepheids).
  2. individual distances of the RR Lyrae stars, of the SX Phe stars and of the Anomalous Cepheids
- Pie in the sky
  The collected database of individual distances, and reddening and metallicity estimates of the RR Lyrae stars will allow us to:
  1. put constraints on the 3D model and density profile of the old population of the inner bulge
  2. compare the derived profiles with the results from other stellar population tracers (red clump stars, etc.), and a comparison with the theoretical models of the bulge formation

Variability in Ultra-cool dwarfs/BDs

Authors: Markus Rabus

- Low hanging fruits
  1. Detect rotational variability in L/T dwarfs due to global weather phenomena in the atmosphere. Beginning of an insight into weather patterns in substellar objects outside of our Solar System. It is still not clear what causes this variability. Clouds, non-uniform temperature profiles or perturbations in the atmosphere's temperature structure can cause brightness fluctuations. The discovered and monitored objects will help us to gain a better understanding of cool atmospheres. Furthermore, they will serve as precursor for atmosphere studies with the future generations of gigantic telescopes and advanced space missions.
- Pie in the sky

1. Multi-filter photometric monitoring to reveal a possible filter-dependent phase shift and amplitudes.
2. Possible variability effects through lightning and auroral activities.
3. Variability in Y dwarfs.

Variables in LMC,SMC

Authors: Paula Szkody

The Magellanic Clouds contain a large range of variables and transients, all at the same distance, with low extinction and low metalicity. Thus, a minisurvey/deep drilling survey of the Clouds provides the ability to collect a large statistical sample of both known and unknown variability. To obtain light curves covering the full range of periodic variability from 30 sec to 10 years as well as transient and eruptive objects will require observations ranging from continuous 15 second exposures in a single filter (to catch short period variables such as δScuti and pulsating white dwarfs) to multiple (30-300) visits in gri filters depending on the type of periodic variable, and to catch transient or eruptive variables. The optimum cadence will need to be developed prior to the start of LSST. As some variables will benefit from multiwavelength (X-ray, UV, IR) observations, the dates of observations of the Clouds should be advertised to facilitate simultaneous or contemporaneous observing time of the fields with LSST.

- Low hanging fruits
  1. Use novae to determine how the differences in metalicity affect the rate and location of novae compared to the Milky Way.
  2. Fully characterize variable stars in the MCs with a much higher cadence of observations in g and r filters to determine the ranges of variability between 15 sec and 3 days that are missed in the main survey.
  3. Determine accurate periods for all regularly variable objects down to approximately absolute magnitude of 6.5 (assuming a limit for variability of apparent magnitude of 25).
- Pie in the sky

compact binaries: NS binaries (in quiescence and outburst)

Authors: Elena Mason

Mini surveys will support and serve our studies of binary NS of the type LMXBs, MSP and tMSP in an identical way than the main LSST and deep drilling survey but in different patches of sky. Again, they potentially probe different stellar environment compared to the LSST main survey and the DDF one (see previous sections). The smaller total number of visits foreseen for the mini surveys will however produced somewhat more poorly sampled light curves and less timely alert.

- Low hanging fruits
  1. **Change of states and outbursts alerts:**
     Alert from DDF survey are in principle possible and will enable us to trigger follow-up observations of accreting NS binaries that enter a state which allow probing the binary parameter and/or physical mechanism responsible of the observed phenomenology. Note that, being the follow up a soft target of opportunity in any case, the non timely alert might be not critical, although it might depend of individual cases.
- Pie in the sky

Intermediate Luminosity Optical Transients (ILOTs)

Authors: Andrea Pastorello & Elena Mason

- Low hanging fruits

  1. Mini-surveys or DDFs targeting the Local Universe, LMC/SMC and crowded fields in the Milky Way can discover ILOTs caught at very early phases. A higher, multi-band cadence allows us to characterize the stellar variability and (including the data obtained with the main survey) constrain the variability history and the nature of the progenitor system. This strategy allowed the OGLE survey to detect the famous Red Nova V1309Sco (Tylenda et al. 2011).

  2. Reliable rate estimates for the different ILOT types are still incomplete or even missing. With the main survey, we aim to precisely constrain the frequency with which the different families of transients may occur in the surveyed galaxies (in particular, Milky Way, SMC, LMC and M31).

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  1. The photometric monitoring of new and/or known contact binaries allows us to find new LRN precursor candidates (e.g. KIC 9832227, Molnar et al. 2015, 2017). The identification of binary systems whose photometric period declines with time indicates inspiraling motions that can lead to a common envelope ejection. The common envelope may rearrange the geometry of the stellar system or lead the two stars to merge. The monitoring of such stellar systems would require a cadence of one shot every several hours.

  2. Dedicated surveys on nearby galaxies (within 30 Mpc) and with a higher cadence can provide high-quality light curves. High-precision photometry of bright objects is crucial to identify lower-contrast modulations superimposed on the well-known larger variability of LBVs. This is a key step to constrain the presence of binary LBV companions.

  3. High-cadence observations reveal fast-evolving transients, including new species of ILOTs and faint, fast-evolving supernovae. In particular, studying the rapid photometric evolution of some types of ILOTs (e.g. putative SN impostors or ILRTs) during the very early phases may reveal shock-breakout signatures, which may enable us to unequivocally discriminate terminal (faint) SN explosions from non-terminal outbursts.

- Tasks

- Outcome in commissioning, 1, 3, 10 years

Young stars and their variability

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We aim at investigating stellar variability of single objects or in statistical samples in stellar clusters. We plan to analyze variability due to: stellar activity; accretion process, also in eruptive bursts (FUors and EXors); rotation; etc.. Our goals include identify specific fields and targets and the proper cadence to pursue the study of variability for young stars in general. We will: investigate the feasibility to optimize the cadence required, as the stellar variability range is different in different context; take advantage of data collected in existing surveys ad previous programs (Gaia-ESO Survey, Chandra, etc.) to characterize the interesting fields and objects also using a multi-wavelength approach. Stellar variability due to stellar activity, to accretion process also in eruptive bursts (FUors and EXors), to rotation, etc., will benefit from higher cadence exploring different properties as clusters with different ages, metallicity, and location. The Galactic Plane should be investigated with a cadence higher with respect to the Main Survey to follow the variability of stars. Analysis of available data from previous surveys as well as the development of diagnostic tools will be used to investigate the proposed issue.

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  Photometric variability, on short- (hours), mid- (days, months), and long-term (years) timescales, is part of the definition of classical T Tauri stars (CTTSs; Joy 1945). Young stellar objects (YSOs) are characterized by photometric variability caused by several distinct physical processes: mass accretion events from circumstellar disks, presence of warps in envelopes and disks, the creation of new knots in stellar jets, stellar rotation, starspots, magnetic cycles, and flares. We can study all these phenomena if we acquire both short-term and long-term lightcurves of a statistically significant sample of YSOs. With a sparse coverage it will be possible to quantify long-term secular variability, also adequate for identifying sudden changes caused by large accretion events such as FU Ori and EX Ori outbursts (see Sect. EXor/FUor). In CTTSs, blue band fluxes rise more strongly during accretion events. The analysis of long-term color magnitude-diagrams (CMDs) as r vs. g-r will allow us to identify the weak T Tauri stars (WTTSs) members of the cluster, while a bluer spread characterizes the CTTS members, as the blue band excess is related to the accretion activity only present in CTTSs. Therefore, an important discrimination between WTTS and CTTS among the cluster members can be performed.

  We have data from previous programs, as DECam observations of Carina at the CTIO 4-m that reached depths similar to those proposed for LSST. Venuti et al. 2014 already explored the mid-term variability in clusters and measured the UV excess (and correspondingly computed the mass accretion rate) from each observing epoch during the CFHT r-band (and u-band) monitoring of young cluster NGC 2264, from which we can deduce properties of young stars with accretion process at work. We will take advantage of data collected in existing surveys and with previous programs (as many team members are involved in Gaia-ESO Survey, Chandra, etc.) to characterize the interesting fields and objects also using a multi-wavelength approach. In fact, Feigelson et al. 2011 also find thousands of X-ray sources dispersed outside of compact clusters. A large accretion event is also a powerful way to select interesting systems for further observations with other instruments. For example, after an accretion event one could look for evidence of a newly-created jet knot. Classifications based on color can be confirmed spectroscopically with, for example, FLAMES observations of the H alpha emission line (see also Bonito et al. 2013 and Bonito et al. in preparation). We also applied for a programme of observations of EX Ori type stars with e-Rosita (Stelzer, Giannini, Bonito). Accretion process in young stars have also been investigated with detailed 3D magnetohydrodynamic (MHD) models (Kurosawa & Romanova 2013; see also the role of the local absorption for other wavelength emission in Bonito et al. 2014 and Revet et al. 2017). Our current hardware resources are not proper to handle LSST data volume. Therefore, updated computational resources are required to keep up with the increased data-flow rate (already seen with Gaia) that will become available in the near future with LSST. LSST with its unprecedented sensitivity, spatial coverage, and observing cadence will allow us to employ a statistical approach for the first time to the comprehension of star formation processes.

  Outcome in early phase and in 1 yr - 3 yr: The observation of the same region in a subsequent year has the potential to uncover period changes that may arise from stellar differential rotation, and amplitude variations indicative of stellar cycles.

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  Young stars exhibit short-term photometric variability caused by mass accretion events from circumstellar disks, the presence of dusty warps within the inner disks, starspots that rotate across the stellar surfaces, and flares. A cadence of 30 minutes every night for one week per year is necessary to clarify the nature of both the short-term and long-term variability of the thousands of young stars in Carina region (more details if the White Paper submitted in response to the call for LSST Cadence Optimization and in Bonito et al. 2018, http://adsabs.harvard.edu/abs/2018arXiv181203135R). This approach will allow us to relate the observed variability to stellar properties such as mass, age, binarity, and to environmental properties such as location within or exterior to the H II region, and to the presence or absence of a circumstellar disk. Large samples are needed to quantify how the various physical processes depend upon stellar properties, environmental conditions, and the evolutionary stages of the stars. LSST will allow us to survey an outstanding collection of star forming regions (SFRs) in the Southern hemisphere: the closest low-mass , the intermediate-mass, and massive (Carina) SFRs. Therefore, we plan to target one major SFR every year. We plan to start with observations of the Carina Nebula, which is well-placed for observations from Chile with LSST, and guarantees a large number of sources (11,000 members identified; Townsley et al. 2011). Different sources of variability (e.g. stellar flares, accretion bursts, absorption due to warped disks, rotational modulation due to spots) can be discriminated from their significantly differing observational characteristics. A dense coverage of SFRs with LSST will allow us to characterize different class of light curves (LCs) (see Fig. 1, Bonito et al. 2018: http://adsabs.harvard.edu/abs/2018arXiv181203135R), including light curves dominated by accretion bursts (Stauffer et al. 2014), periodic or quasi-periodic flux dips (associated to rotating inner disk warp occulting the stellar emission, Bouvier et al. 2007a; Alencar et al. 2010). As young stars with variability undergo significant and rapid color changes owing to both accretion processes and extinction variations, so it is important to include multiple filters in any dense coverage campaign, as g, r, and i bands. Data in each band (changing every 30 minutes g, r, and i filters) gives its own lightcurve, making it possible to follow how the colors vary with phase: 140 photometric points in each filter should be collected to populate the phases well enough. Variability in different colours helps to discriminate between hot spots, cold spots, and circumstellar extinction. Flaring in WTTS can also be monitored, though the rapid decline of chromospheric flares requires a rapid cadence to capture correctly.

Considering previous DECam 60-sec r-band images of Carina, we derived that it is possible to get very good photometry. Monitoring the accretion events can be used to trigger an alarm to observe the same objects with other instruments and in different bands (from X-rays to IR). We plan to ask for spectroscopic data for the entire duration of the high-cadence observing. Contemporaneous spectroscopy, e.g. with FLAMES, will be performed. Detailed 3D MHD models of the infalling material have been developed to investigate the accretion process in young stars. These models account also for the observed variability in the inverse P-Cygni line profiles as we view accretion streams along the line of sight to the star (Kurosawa & Romanova 2013; Bonito et al. 2014; Revet et al. 2017). Models suggest accretion cooling timescales of 30 min to several hours in accordance with observations of the shortest bursts in BP Tau (0.6 h; see discussion in Siwak et al. 2018). Support for new hardware (both computing facilities and disk storage) will be crucial to handle the enormous rate of information and rapid stream of data provided by LSST.

Outcome in the early phase - 1 yr: At the beginning of LSST operations we argue that a targeted test field (Carina Nebula) should be observed in the above manner to illustrate what can be done with LSST in this mode.

Outcome in 3 yr: In subsequent years, we will either choose a different region or possibly return to the same regions to monitor slow changes in periods or amplitudes that may arise from differential rotation or starspot cycles.

Outcome in 10 yr: Combining a densely-packed short-interval dataset with a sparse but long baseline study maximizes the scientific return for both methods, and allows LSST to address all of the accretion and rotational variability associated with young stars.

0.12 Intrinsic/Extrinsic Extragalactic Transients

Editor: Barbara Balmaverde

Blazars

Authors: Barbara Balmaverde, Claudia M. Raiteri, Maria Isabel Carnerero, Filippo D'Ammando, Chiara Righi

The discovery of new AGNs (and in particular blazars) with LSST would greatly benefits from ancillary multi-wavelength data. In the optical band the emission from low luminosity blazars in many cases is diluted by the thermal continuum of the galaxy light. Faint blazars could not be pinpointed using statistical tools alone to measure their intrinsic variability in optical images. In theses cases different techniques should be used in synergy to select blazars candidates, measuring for example the ratio between the optical with respect to the X-ray or radio luminosity (alpha$_{ox}$, alpha$_{or}$) or their near IR colours in the WISE bands (Massaro et al. 2012). The four Deep Drilling Fields already proposed, ELAIS-S1, XMM-LSS, CDF-S and Cosmos, are small regions of the sky (covering an area of $\sim$9.6 deg^2) that have been chosen for the rich multivalength dataset available. However, to discover new blazars candidates, we need wider area because blazars are intrinsically rare objects (in fact only two known blazar falls in these fields).

There are other rich datasets regions actually included in the LSST Wide, Fast, Deep Survey. For example the stripe 82 is a wide equatorial region of the sky (between 20h 24m < R.A. < 04h 08m and -1.27 deg <Dec <+1.27 deg, $\sim$300 deg^2), imaged between 80 and 120 times to explore intrinsic objects variability and to reach deeper magnitudes than any single Sloan Digital Sky Survey (SDSS) scan. For the full field we have optical spectroscopic observations from SDDS and SDSS BOSS, mid-infrared *WISE* coverage, near-infrared coverage from UKIDSS and VHS, ultraviolet coverage from *GALEX*, radio coverage from FIRST, far-infrared coverage from *Herschel* and X-ray point source catalogues from *Chandra* and *XMM* observations.

Furthermore, a promising sky area for our science case is the Northern Ecliptic Region (NEOs) Mini survey. Blazars are strong radio emitters and therefore the informations on the radio properties of potential candidates are crucial. Up to now, only the FIRST radio survey (Faint Images of the Radio Sky at Twenty-cm) provides a good compromise between depth and coverage. The survey area has been chosen to coincide with that of the Sloan Digital Sky Survey (SDSS) and covers mainly the Northern Emisphere. The NEOs mini survey will be complemented by the FIRST radio point source catalogue.

In particular the discovery of low-power BL-Lacs objects will allow us:

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  to discover possible new TeV emitters that in the future may be detected by the Cherenkov Telescope arrays *CTA*. In fact we expect that most of the objects observed at the highest energies (in the TeV band) will be BL Lacs and in particular HBL (high energy peaked BL Lacs).

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  to explore the behaviour of the jet formation and emission processes at the lowest levels of accretion.

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Tasks

Editors: FBB,RS Tasks broken down by science area

Classification

L3

Classification

Classification

L3

L3

Classification

State of the classification and implication for TVS science

User Generated data products to be developed

User generated data products that we need to develop and their relation with other data products

Key infrastructure elements

Computational infrastructure, observing facilities

Summary and next steps

Including areas and science cases that are neglected in this V1