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THE VARIABLE SKY IN THE MULTI-MESSENGER ERA: A CHALLENGE FOR OHP

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Abstract. With the many on-going sky surveys, dozens of variables and transients are detected every night, most of which remain unclassified due to the shortage of telescope time for follow-up. Besides classical variables, many Supernovae (SNe) are discovered, some of which are peculiar, super-luminous or under-luminous, and their energy source and explosion mechanism is not yet understood. With the recent detection of gravitational waves, we need also to understand the production rates and sources of binary neutron stars or massive black holes, and the relations between SNe and Gamma-rays bursts. The origin of high-energy neutrinos and fast radio bursts also remains elusive. All this requires more classification of transients in general and SNe in particular, to identify the specific cases of interest and study them in details. Similarly, the follow-up and interpretation of changing look quasars is crucial for a better understanding of the properties of their central regions. Telescopes of the 2m class (or more...) can play an important role in this quest by allowing a larger number of classifications to be done, provided they are equiped with efficient low-dispersion spectrographs, like the one under study for the 1.93m at OHP. Getting such an expertise in classifications is fundamental to be able to exploit later the thousands of transients which will be provided by the LSST.

Keywords: Transients, Supernovae, AGN's, Spectroscopy

1 Introduction

In the recent years, many surveys have started to cover large fractions of the sky with a cadence of a few nights, discovering large numbers of variables or transients. To mention only a few, the earlier Palomar Transient Factory (PTF) has now evolved into Zwicky Transient Factory with an improved detector and cadence, reaching 20th magnitudes in a few seconds exposures. In Hawaii, the PanStarrs, with its two 2m telescopes, is reaching 21th magnitude also, while ATLAS is concentrating on brighter objects (typically 18th magnitude). The ASAS-SN survey is operating both in Hawaii and in Chile to detect bright transients (typically 17th mag), while OGLE is observing from LasCampanas in Chile. These are surveying all the sky reachable from their observatory. Many other, small telescopes operate already since quite some time in rapid response to Gamma-Rays Bursts (GRB's) alerts, like Tarot, Rem, Zadko, etc...In space, the ESA-GAIA satellite, although its primary mission is about astrometry, because it is scanning the sky repeatedly is also generating alerts on photometric variability with a limiting magnitude of about 19. All these surveys provide a lot of interesting targets to identify and eventually follow-up, but only a small fraction is classified in practice, due to lack of telescope time. The diversity of targets, briefly described below, should provide a good incentive for "older" telescopes to play again a significant role if equiped with modern instrumentation.

2 The variety of transients

2.1 Supernovae and alike

Since the early recognition by Minkowski (1941) that two different types of SNe existed, the types I with no hydrogen in their spectra and the types II with hydrogen, the diversity of SNe has increased, and they can now be distributed in physical categories. The types Ia are believed to result from the explosion of a white dwarf in a binary system, while the types Ib,c and II result from the collapse of a massive star (see Filippenko (1997) for a review), even if all the details of the explosion mechanisms are not yet fully understood. But some other

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cases are emerging outside those categories. For instance, a transient was detected by Kulkarni & al. (2007) in M85, where it was not clear if the object was an under-luminous SN, or an over-luminous Nova. Similarly, super-luminous SNe were recently recognised, exceeding by more than a factor of ten the luminosity of classical SNe (e.g. Quimby & al. (2011) and their source of energy is not yet understood (e-p annihilation, magnetar or other). Thanks to an EU-wide effort to classify some of the many transients now discovered, a few more cases have been found by the PESSTO observations (Smartt & al. (2015)) with the ESO-NTT telescope from LaSilla, progressively filling the parameter space of Absolute Magnitude versus Evolution Time, as shown in Fig.1. But this concerns only a fraction of the discovered transients and in the southern hemisphere only. A similar EU-wide effort in the northern hemisphere is still missing.

Long Duration Gamma-Rays Bursts (GRB's) are often associated with a Ic SN appearing a few days after the detection of the GRB. Those Ic's seem to usually have broader lines than standard Ic's and the reason for this is not yet clear (faster ejection velocities? Mixing of several lines?). But conversely, as GRB's are only detected when their jet is properly oriented towards the observer, it is important to get better statistics on the occurence of Ic SNe in general, as this would give an indication on the opening angle of the GRB and the occurence of "orphan"events: here also, more observations and classifications are necessary to detect those SNe.

The detection of the first Gravitational Wave (GW) events since 2015 has opened a new window in the exploration of the universe. While the first events were interpreted as due to the merging of binary blackholes (e.g. Abbott & al. (2016)), a new milestone has been covered with the event detected last year, GW170817 (Abbott & al. (2017)), also detected in Gamma-Rays and associated with a kilonova in the optical. This firm association confirmed the long-suspected existence of kilonovae (merging of a binary neutron star), but also raised the question of the frequency of occurence of such events. The optical counterpart was quite bright, about 17th magnitude at discovery and would/should have been easely discovered independantly of the GW by the various optical surveys, provided their cadence was fast enough. Indeed the lightcurve of the kilonova is decreasing rapidly, as shown by Arcavi & al. (2017), much faster than even the fastest known SNe (see Fig.2). This is thus also calling for faster reaction and spectral classification of newly discovered transients, independantly of GW events: even if the sensitivity of the GW detectors will have improved for the O3 run starting in 2019, optical surveys could bring an answer to the question of the rate of occurence of kilonovae, if they are properly recognised.

2.2 *Active Galactic Nuclei*

AGN's are known to be variable, by small amounts, presumably due to changes in the accretion rate on the central black hole. In some, rare, cases, the changes can be larger, reaching one magnitude or more, and spectral changes are reported also (change from type 1 to type 2, or vice and versa). An early example is NGC7582 (Aretxaga & al. (1999)). More recently, systematic searches have revealed a dozen cases of 'changing look" quasars (MacLeod & al. (2016)), with changes in the broad lines and in the colour of the continuum, the interperation of which is still under debate. Changes in obscuration seem to have too long timescales, while changes in the ionisation flux may also require changes in the BLR structure to reproduce the observed variations and timescales (MacLeod & al. (2016)). More spectroscopic observations at regular intervals are needed to establish the real timescale of those changes: the apparent timescales being of order of months or even years, this is not puting strong constraints on observing schedules, like would the Targets of Opportunity mentioned before. A simultaneous assesment of the X-rays properties would be very valuable to estimate possible changes in the absorbing column density. The eRosita X-rays mission, to be launched soon, will also detect many cases of variability to be followed from the ground. Ultimately, when a nuclear Alert is produced, the question will be to identify it as AGN variability, a classical SN, or a Tidal Disruption Event.

2.3 *Other targets*

As other examples of multi-wavelength astronomy targets, sources of astrophysical neutrinos are still awaiting to be identified, apart from the Sun and SN1987A. This is clearly due to the limited sensitivity and angular resolution of presently active detectors (Antares in the Mediterranean Sea, or IceCube at the South Pole), but should improve with the next generation of detectors. As an illustrative example, the 2015 trigger by Dornic & al. (2015), where a Swift follow-up identified a flaring X-rays source in the field, revealed to be only an unrelated, "classical", flaring G-K star, once a classification spectrum had been obtained (de Ugarte Postigo & al. (2015)). This clearly shows the need to correctly know the probability of chance occurence, in a given error box, of an unrelated astrophysical transient, and hence to increase the efforts of classification of the var-

ious classes of transients to provide these statistics. More recently*, the detection of a high-energy neutrino, IceCube-170922A, in spatial coincidence with a γ -rays emitting blazar (IceCube & al. (2018)) , suggests that blazars may be a significant source of high-energy neutrinos.
Fast Radio Bursts (FRBs) present another challenge: they are radio bursts of millisecond-duration, at extragalactic distances (as seen from their dispersion measure) but of unknown physical origin. While several of them are known (Petroff & al. (2016)), only one of them, FRB121102, has been finally located within a dwarf galaxy (Tendulkar & al. (2017) thanks to its repeatability, which allowed VLBI observations to be scheduled. The operating mechanism is still under debate, more identifications are awaited for.
Many other, more "classical", variables are of course detected, like RCorBor, Cepheids, FU-Or, TTaurii, Be stars, Dwarf Novae, etc., each with their own specificities and interest, providing targets for many astronomers. This is also a unique opportunity to estimate the occurence rate of each of those, provided they are properly caracterised upon discovery. The ESA-Gaia satellite is providing a large fraction of candidates (`http://gsaweb.ast.cam.ac.uk/alerts/`), but here also only a small fraction is classified in practice. Last, but not least, many asteroids are also detected as transients, and require a fast follow-up to establish a preliminary orbit (otherwise they will be lost again), as described elsewhere in this volume (Thuillot & al. (2018)).

3 Instrumentation

The instruments needed for classification and follow-up are of two kinds: spectrographs for initial classification and then to follow the spectral evolution; photometers to establish and fill-in the light curve when the sampling from the surveys is irregular or uncomplete (e.g. Gaia) or the object becomes too faint to be followed by the surveys themselves. Many "small" telescopes (1m class) can be enroled in the photometric follow-up, if they are equiped with modern CCD cameras, as exemplified by the GAIA-FUN-SSO network of telescopes established to follow-up asteroids (see Thuillot & al. (2018) in this volume). A modest field of view is required (typically 10'-20') and combined observing runs can follow asteroids as well as other photometric variables, as we do with the 1.2m telescope at OHP. Establishing the lightcurve of SNe is important for a clear classification, but requires monitoring over several weeks after maximum. For a typical Ia SN, the magnitude at maximum can be reconstructed (which is essential for their use in cosmology), even if the maximum was not observed, and the light curve sampling was irregular, thanks to fiting with templates as done for example by Jha et al. (2007).
For spectroscopy, a long-slit spectrograph with modest spectral resolution (R $\sim$1000) is sufficient in most cases, the most important factor being a wide spectral coverage rather than the resolution itself. As an example, the SPRAT at the Liverpool telescope in LaPalma has been developed specifically for classification of transients (`http:\telescope.livjm.ac.uk/Telinst/Inst/SPRAT/`) and provides a spectral resolution of about 350, covering the range 4000-8000 Å . This is believed to be sufficient to classify SNe which usually have broad lines. The french community has no such instrument available on any of its northern telescopes, neither OHP nor TBL nor CFHT, only high resolution spectrographs. It has thus been decided to start by equiping the T193 at OHP with a clone of the SPRAT, with some improvements however like a better spectral resolution (R $\sim$700) and a wider spectral coverage (see Adami & al. (2018) in this volume for a detailed description). There are indeed many cases where narrow lines are seen in SNe also, if only from the CSM and, of course, many other objects require a better resolution to classify, for instance to resolve Halpha from [NII]. Expected limiting magnitudes go down to 19-20 with a 2m telescope, which should allow classification of many targets. More complex instruments would of course be interesting (like IFU's or a coverage including the near-IR), but are falling outside the available budget. When the object gets fainter, a larger telescope is required for the follow-up, and the Mauna Kea Spectroscopic Explorer would be interesting also. Even if transients are usually single in such a wide field instrument, it should be easy to insert one transient as "interloper" into a different program.

4 Conclusions

The variety and number of targets (transients, or variables) provided by the various sky-surveys is opening a new era in Astrophysics, the one of the "Variable Sky". A large effort of classification and follow-up is necessary to fully exploit this resource and understand the various physical mechanisms at play. This requires spectroscopy (primarily low-dispersion) for the classification and photometry to establish the light curves. "Small" telescopes, even older ones, can play an important role in this game, provided they are equiped with

*This was announced after the SF2A meeting itself

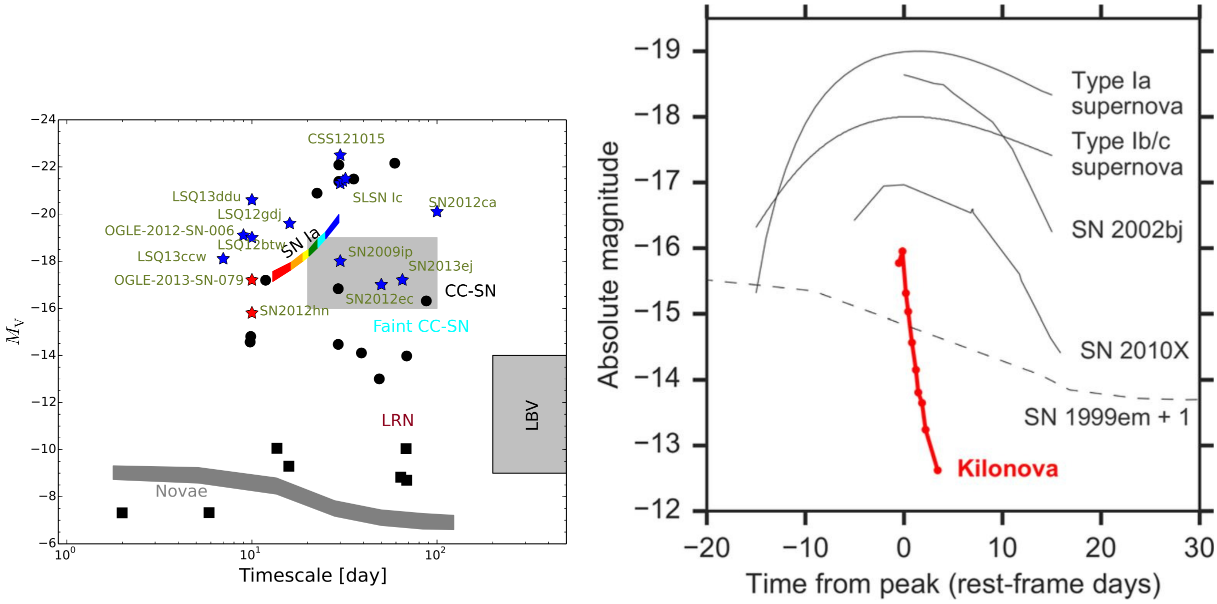

Fig. 1. Left: Transients from Pessto lying outside the classical locations (Smartt et al. 2015, adapted from Kulkarni et al. (2007)) **Right:** The kilonova associated to GW170817 (from Arcavi et al. 2017) evolves much faster than any known SN, even the fastest ones known.

state-of-the-art instrumentation: 1m class for photometry, 2-4m class for spectroscopy. While some resources are available to the french community in the southern hemisphere thanks to ESO, nothing is available in the North. The rapid completion of the Mistral project for the 1.93m at OHP is therefore essential, and the Mauna Kea Spectroscopic Explorer would be an asset. Specially so in the perspective of many more, and fainter, targets, later to be provided by the Large Synoptic Survey Telescope.

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