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The Pan-Starrs-1 and the recent SN Science

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Abstract. The search for transient phenomena in the Universe has entered a new era. In the next decade new all-sky surveys will provide a vast amount of astronomical survey data. These data will address issues in many of the astronomical fields. In the Supernova field, we will have for the first time the possibility to discover SNe without most of the observational bias present in the previous SN searches. Here we report the status of the transients study in one of the new on-going all-sky surveys: the Panoramic Survey Telescope & Rapid Response System-1 (PanStarrs-1).

Key words. Surveys: General, PanStarrs Supernovae: General

1. Introduction

The fondamental role of Surveys for astronomical objects over large areas of the sky is undoubt. Unlike targeted observations of specific objects, they make possible statistical studies without making prohibitively lengthy observations and allow interesting or rare examples of phenomena to be found and studied in greater detail. They are indeed largely used to discover and studies variable phenomena as Supernovae, comets and planets.
In the next section we briefly summarize some important use of surveys for the SN field, while in Section 3, we shortly describe the PanStarrs survey and summarize the status of the survey. Finally, in Section 4, we will describe some of the important goals of the future surveys in the SN field.

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2. Surveys and SNe in the last decade

The first goal of SN Surveys is to discover new and interesting SNe. The most efficient strategy to discover new transients is the *pointed survey strategy* in which a sample of galaxies is selected and each of them is individually observed with a cadence of a few days and scanned for new SNe. In the past the majority of SNe have been discovered with this technique. For example most of the SNe discovered by amateur astronomers are found with this technique, monitoring bright galaxies in the local universe. This technique is also used with great success by the Lick Observatory Supernova Search (LOSS) scanning a catalogues of 7500-14000 nearby galaxies ($z \lesssim 0.04$) with a cadence of 3-5 days (Leaman et al. 2010; Li et al. 2010a,b).

This strategy produces huge numbers of SNe, since the most luminous galaxies are also the most prolific ones. But, at the same time, it is biased against low-louminous galaxies that are likely to be metal poor (we will discuss this point later). A further drawback of the

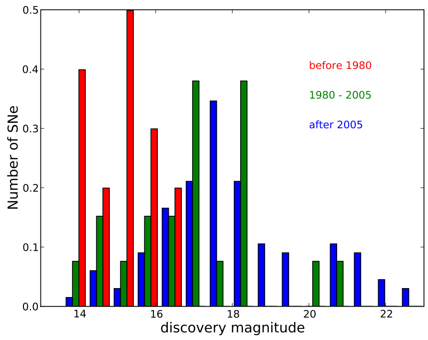

Fig. 1. Distribution of discovery magnitudes for SNe type IIP (data from the Asiago catalogues). Due to the plateau phase in type IIP SNe, The discovery magnitude of this SNe is a good estimate of the limit magnitude for SN discoveries.

past SNe surveys is that most of them had a magnitude limit close to $\sim$ 19. This is clearly visible in Fig. 1 where the histogram of the of the discovery magnitude[1] of SNe type IIP is shown for different time windows. Before 2005 in the local Universe, most of the SN have been discovered at a magnitude brighter than $\sim$ 19. Only recently we started to discover SNe with a magnitude fainter than 19. With this limit, until 2005, the most faint transient (mag $\lesssim$ -14) could have been discovered only within $\sim$ 35 Mparsec.

Building on the *pointed survey strategy*, a SN Search can be also achieved with wide-field cameras. The Texas Supernova Search (Quimby et al. 2005; Yuan et al. 2007), for example, with a wide field of 1.85 square degree is focused on finding nearby SNe while monitoring hundreds-to-thousand galaxies. A new step further has been the construction of wide-field optical telescopes with field of view from 5 to 10 square degrees used in dedicated survey mode (e.g. Catalina Real-Time Transient Survey, The Palomar Transient Factory, Pan-STARRS-1). The latter will be described in detail in the next section.

The other way to get a statistically significant number of SNe, without using a particularly large field of view, is going deeper in magnitude. This is usually the approach of SN Surveys at high redshift. They generally have smaller fields of view, but they go much deeper in magnitude in order to have comparable search volumes to the other surveys. The main goals of these surveys are the following: study the SN rates as a function of redshift (e.g. Cappellaro et al. 2005; Botticella et al. 2008); study the evolution and the SN diversities as a function of redshift and constrain the cosmological models using the SN (mainly thermonuclear) as standard candles (e.g. Astier et al. 2006). One of the most important result in the SN field obtained from two supernova surveys at redshift $0.15 \leq z \leq 0.83$. In 1998 two groups reported plausible evidence that the expansion of the universe is accelerating (Riess et al. 1998; Perlmutter et al. 1999). From then on, several new surveys of SNe Ia at high redshift have been done in order to constrain better the cosmological parameters (e.g. The SDSS Supernova Survey (Kessler et al. 2009), ESSENCE (Wood-Vasey et al. 2007), SNLS (Astier et al. 2006), GOODS/HST transient search (Riess et al. 2004)). New promising result at very high redshift, can be obtained with dedicated surveys using new generation of telescopes (e.g. see Della Valle et al. 2005).

3. PanStarrs-1

The Panoramic Survey Telescope & Rapid Response System-1 (Pan-STARRS-1) is an innovative design for a wide-field imaging facility developed at the University of Hawaii's Institute for Astronomy and partially funded by US Airforce.

PanStarrs-1 will observe the entire available sky several times each month. The primary goal is to discover and characterise Earth-approaching objects, both asteroids & comets, that might pose a danger to our planet.

[1] data from the asiago catalogues (http://graspa.oapd.inaf.it/index.php?option=com_content&view=article&id=62&Itemid=78) We used the discovery magnitude of type IIP, because it is a good approximation of the brightest magnitude reached by the discovered SN independently of the discovery epoch

But the huge amount of collected data will also be fundamental in other research area as for example in the studies of transient objects.

This prototype single-mirror telescope (PS1) is now operational on Mount Haleakala. Ten research organisations around the word, the PS1 Science Consortium (PS1SC), are funding the PS1 operations from the beginning of 2009. As a guide line, the PS1SC selected 12 key projects that will be investigated using the PS1 data.

The PS1 key projects are:

1. *Populations of objects in the Inner Solar System*
2. *Populations of objects in the Outer Solar System*
3. *Low-Mass Stars, Brown Dwarfs, and Young Stellar Objects*
4. *Search for Exo-Planets by dedicated Stellar Transit Surveys*
5. *Structure of the Milky Way and the Local Group*
6. *A Dedicated Deep Survey of M31*
7. *Massive Stars and supernova progenitors*
8. *Cosmology investigations with Variables and Explosive Transients*
9. *Galaxy Properties*
10. *Active Galactic Nuclei and High Redshift Quasars*
11. *Cosmological Lensing*
12. *Large Scale Structure*

A number of other smaller projects have also been selected and are also part the PS1SC science that will be addressed with PS1 data.

To achieve these goals, the PS1 telescope time has been divided in 5 large surveys. Each of these has a different observational strategy:

– **3Π Survey:** This is the main survey of PS1 with allocated 56% of the observational time. It has a sky area of 30000 square degree covering the full sky at a declination ≥ -30 degree. The whole area will be covered 4 times a year in all filters (g,r,i,z,Y). Each night we are observing on average ∼ 2000 square degree.
– **Medium Deep Survey:** This survey has been allocated 25% of the observational time. Ten fields already observed by other surveys (SDSS, COSMO, CDFs, etc) have been selected and are observed every 4 days in all the filters (g,r,i,z,Y). The nightly depth is set to reach SNIa at z ≥ 0.5 .
– **Solar System Sweet Spot Survey:** Each lunation approximately 500 square degrees in each of two *sweet spots* will be observed twice a night, separated by approximately a half hour *Transient Time Interval*. This region is scheduled to be re-observed three times a lunation, preferably spaced by about 4 days. The observations are in the i band and 5% of time is allocated for this survey.
– **Stellar Transit Survey:** The goal of the Stellar Transit Survey (STS), is to find 100 Hot Jupiters by detecting the transit of such an object in the light curves of millions of stars visible in the proposed survey fields. The 3 STS Campaigns are pointing the Hyades, the Praesepe and a field in the Galactic bulge. For this Campaign there will be three adjacent GPC1 footprints.
The observations are in the r band and 4% of time is allocated for this survey.
– **Deep Survey of M31:** The Deep survey in M31 (PAndromeda) will be in the r filter with 2 visit per nights with a separation of 0-5 h. Additional exposures in gizY are also observed. The time allocated for this survey is 2%.

3.1. PS1 Status

From the beginning of 2009, a period of 18 months was used for commissioning. During this period several sets of data were taken and used to test the telescope performance, to improve the image quality, sensitivity and observing efficiency. A huge effort has been made to improve the data quality in order to satisfy the key projects requests. This has been done both at an hardware level (e.g. replacing some CCDs, decreasing the background noise, etc), but also improving the Pan-STARRS Image Processing Pipeline (IPP). The PS1 camera indeed is the largest camera ever built with 1.4 gigapixel (GPC1). The camera has 60 chips, with 8x8 cells in each chip and 584x591 pixel in each cell. Each GPC1 image is ~3 GigaByte and PS1 produce 1-2 Tbyte of data every night, processed everyday.

The IPP has been developed and improved during commissioning time and is now able to process and release to the Consortium most of the data product requested by the different key projects. These include: processed images (single exposure, nightly stack and difference images) and detection tables. Due to the amount of data some of the key projects download from Hawai only the catalogues produced every day by IPP and access image subsets through an image server located in Hawai (*Postage Stamp Server*). At the beginning of May 2010, PS1 mission started following the Design Reference Mission and it will proceed until the end of 2012 and possibly further.

3.2. The Queen's University involvement in the transient key projects (KP7 and KP8)

The Transient key projects KP7 and KP8 are mainly interested in the data products from the 3Π Survey and the Medium Deep Survey. At Queen's University, we download 3 different data products: the Medium Deep stack images, the Medium Deep catalogue detections of variable sources from the difference images, and the 3Π source catalogues from single exposure 3Π-images. In the future, instead of the 3Π sources catalogues, we will download the 3Π catalogues of detections of variable sources from the difference images (when these will be available[2]).

While the MD images are downloaded mainly for testing and as a storage backup, the main work is done on the catalogues. From the huge amount of data collected by PS1 and processed by the IPP, we are getting every night 10^5 detections. All of these are ingested in the *Transient Science Server* (TSS) developed by our Collaboration of Queens -IfA - Harvard - JHU and located at Queen's. The goal of the TSS is to clean from the tables false detections and divide the transients in categories trough a cross-correlation of all the detections with a set of published available catalogues and build tune series light curves from all assimilated detections.

For the MD Survey, the candidates are crossmatched with all the available catalogues for the observed sky area (e.g. 2MASS, SDSS, NED, etc) and divided in one of the following categories: AGN, SN, variable stars and orphan (not matching with any catalogues). Additional cuts are applied after visual inspection of the image stamps, their light curve and the number of occurrences. Finally some of these are selected as good transients, observed and spectroscopically classified. The Transient Science Server is able to ingest and process all the 10^5 detections that IPP produces every night. Up to now, about 1000 of real transient have been discovered in the MD Survey, with ~ 100 of them spectroscopically confirmed. The spectroscopic confirmation is one of the crucial requirements of all the new sky surveys, we will come back to this point in the conclusion. Some of these SNe turned out to be quite interesting and they have been studied in detail (Botticella et al. 2010; Gezari et al. 2010; Narayan et al. 2010).

For the 3Π Survey the transient search can not be executed yet in the same way of the Medium Deep Survey. A full sky coverage has yet to be completed in order to have the reference images that are necessary to detect variable objects. In Fig. 2 the r-band coverage of PS1 observations from February to August 2010 is shown. At the beginning of 2011, a full static-sky will be available in all the bands and the IPP will start to produce extra catalogues of variable sources in the 3Π Survey in a similar way as is done for the Medium Deep Survey. At that point we will be able to apply to the 3Π detections catalogues a similar algorithm that is applied now to the Medium Deep detections catalogues.

[2] The IPP is actually already producing some 3Π catalogues of detections in difference images, but at the moment the difference images are computed using single exposure observed the same night. This data product is very useful to trace moving objects but for most of the variable transients with variability on a timescale longer than hours. On the other hand this data product could be useful to discover a small number of SNe at the shock breakout (a few are expected in the full 3-years PS1 mission)

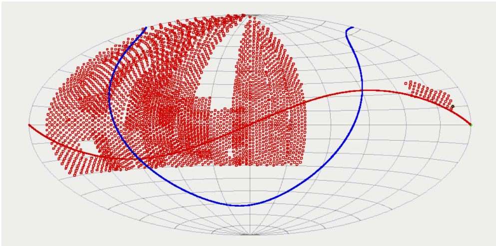

Fig. 2. The r band sky-coverage of PS1 in six months of observations from February to August 2010. Similar coverage has been obtained in the same period for the other bands: ugizY.

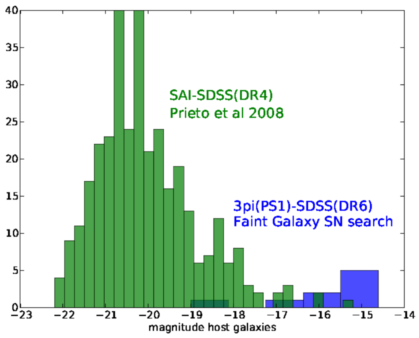

Fig. 3. Magnitude distribution of host galaxies of classified SNe in the 3Π faint galaxy survey compared with the magnitude distribution of the host galaxies of a set of good classified SNe occurred in SDSS galaxies (Prieto et al. 2008). The SNe we discovered are clearly occurring the faint galaxies.

During the first year, while waiting for the full 3Π images coverage, we are running a transient search on the SDSS area called the *3Π Faint galaxy supernova survey* (Valenti et al. 2010). The transient search has been performed cross-correlating the SDSS and the PS1 magnitudes catalogues, restricted only to the faint SDSS galaxies. All the objects that appear in the PS1 images significantly brighter than the SDSS magnitude are selected and further investigated. Even though with this approach we are not able to detect the vast amount of SNe we will discover once the full sky 3Π images will be available, it has several advantages: first, it is easier indeed to detect transients in faint galaxies than in bright galaxies (without using the difference image technique); second, it gives us the possibility to discover SNe in those galaxies (low-luminosity, dwarf, irregular galaxies) that were not monitored by the previous surveys.

During the first 4 months, with this technique, we discovered few dozen of transients and spectroscopically classified 12 of them: 9 SNe in faint galaxies and 3 AGNs. The bias of previous surveys against finding SNe in faint galaxies is evident by comparing the absolute magnitude distribution of these SNe with those of the other SNe discovered so far in SDSS fields (see fig. 3). These were mainly discovered in luminous, high metallicity galaxies.

4. Conclusions

We are now entering a new era, in which new all-sky surveys are starting to discover a huge amount of transients (see Fig. 4). In the last 5 years, the increasing number of transients has had a big impact in the SN field. We were able to perform interesting statistical works on *common* SNe (type Ia and IIP), to understand better *less common* SNe (stripped envelope CC), but also to discover several *rare* explosions never observed before: Ultra-bright SNe in faint galaxies (Gal-Yam et al. 2009; Young et al. 2010; Quimby et al. 2009; Pastorello et al. 2010), faint hydrogen rich SNe (Prieto et al. 2008; Berger et al. 2009; Bond et al. 2009; Botticella et al. 2009; Smith et al. 2009) and faint hydrogen poor SNe (Valenti et al. 2009; Foley et al. 2009, 2010). The discussion on these *rare* transients just started and new explosive scenarios have been proposed.

The transients in faint galaxies are particularly interesting since it is known that faint galaxies are likely to be metal poor and the vast majority of CC SNe that have occurred in low-metallicity environments have up to now remained undetected. On the other hand, metallicity is one of the key parameters in stellar evolution and it has been investigated in most stellar evolution model sets and explosion models, but still not for the final stages of the stellar evolution: the death of a star. As an example, the study of stripped envelope CC SNe in metal poor galaxies may have a big impact

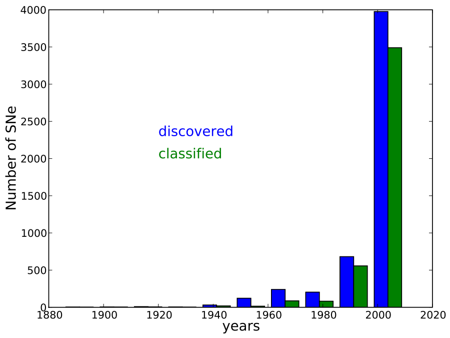

Fig. 4. Number of discovered (and classified) SNe as a function of time. Data from Asiago Catalogues[1].

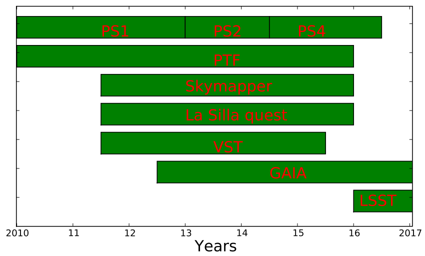

Fig. 5. The timeline of the current and upcoming surveys, each of which is capable of producing thousand of transient per year.

on our understanding of the progenitor of these SNe and their connection with GRBs.

While, it is clear that in the next decade the number of discovered transient will significantly increase (thanks to the new upcoming surveys, see Fig. 5), it is still not clear how to handle such numbers of new transients. It will be a challenge, not only to spectroscopically classify them, but also to select the interesting ones for dedicated follow-up.

It is clear indeed that with the current facilities the spectroscopic classification of transient is a challenge. New spectroscopic facilities or a different classification method (photometric classification has been already tested to classify some SNe) is one the next goals for the next decade.

[3] http://graspa.oapd.inaf.it/index.php?option=com_content&view=article&id=62&Itemid=78

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References

Astier, P., et al. 2006, A&A, 447, 31
Berger, E. et al. 2009, ApJ, 699, 1850
Bond, H. E., et al. 2009, ApJ, 695, L154
Botticella, M. T. et al. 2008, A&A, 479, 49
Botticella, M. T. et al. 2009, MNRAS, 398, 1041
Botticella, M. T. et al. 2010, ApJ, 717, L52
Cappellaro, E. et al. 2005, A&A, 430, 83
Della Valle, M. et al. 2005, arXiv:astro-ph/0504103
Foley, R. J. et al. 2009, AJ, 138, 376
Foley, R. J., et al 2010, ApJ, 708, L61
Gal-Yam, A. et al. 2009, Nature, 462, 624
Gezari, S. et al. 2010, ApJ, 720, L77
Kessler, R. et al. 2009, ApJS, 185, 32
Leaman, J., Li, W., Chornock, R., & Filippenko, A. V. 2010, arXiv:1006.4611
Li, W. et al. 2010, arXiv:1006.4612
Li, W., et al. 2010, arXiv:1006.4613
Narayan, G. et al. 2010, arXiv:1008.4353
Pastorello, A. et al. 2010, arXiv:1008.2674
Perlmutter, S. et al. 1999, ApJ, 517, 565
Prieto, J. L., Stanek, K. Z., & Beacom, J. F. 2008, ApJ, 673, 999
Prieto, J. L. et al. 2008, ApJ, 681, L9
Quimby, R. M. et al. 2005, Bulletin of the American Astronomical Society, 37, 1431
Quimby, R. M. et al. 2009, arXiv:0910.0059
Riess, A.G. et al. 1998, AJ, 116, 1009

Riess, A. G. et al. 2004, ApJ, 607, 665
Smith, N. et al. 2009, ApJ, 697, L49
S. Valenti, et al. 2010, The Astronomer's Telegram, 2668, 1
Valenti, S. et al. 2009, Nature, 459, 674
Wood-Vasey, W. M. et al. 2007, ApJ, 666, 694
Young, D. R. et al. 2008, A&A, 489, 359
Young, D. R. et al. 2010, A&A, 512, A70
Yuan, Fang et al. 2007, Bulletin of the American Astronomical Society, 38, 929