PESSTO: The Public ESO Spectroscopic Survey of Transient Objects

Stephen J. Smartt[1]
Stefano Valenti[2,3,4]
Morgan Fraser[1,5]
Cosimo Inserra[1]
David R. Young[1]
Mark Sullivan[6]
Stefano Benetti[2]
Avishay Gal-Yam[7]
Cristina Knapic[8]
Marco Molinaro[8]
Andrea Pastorello[2]
Riccardo Smareglia[8]
Ken W. Smith[1]
Stefan Taubenberger[9]
Ofer Yaron[7]

[1] Astrophysics Research Centre, School of Mathematics and Physics, Queen's University Belfast, United Kingdom
[2] Osservatorio Astronomico di Padova, INAF, Italy
[3] Las Cumbres Observatory Global Telescope Network, Goleta, USA
[4] Department of Physics, University of California Santa Barbara, USA
[5] Institute of Astronomy, University of Cambridge, United Kingdom
[6] School of Physics and Astronomy, University of Southampton, United Kingdom
[7] Benoziyo Center for Astrophysics, Weizmann Institute of Science, Rehovot, Israel
[8] INAF–Osservatorio Astronomico di Trieste, Italy
[9] Max-Planck-Institut für Astrophysik, Garching, Germany

Team members:
Joe P. Anderson[1], Christophe Balland[2], Charles Baltay[3], Cristina Barbarino[4], Franz E. Bauer[5,6,7], Sylvain Baumont[2], David Bersier[8], Sebastian Bongard[2], Maria Teresa Botticella[9], Filomena Bufano[10], Mattia Bulla[11], Enrico Cappellaro[12], Flora Cellier-Holzem[2], Ting-Wan Chen[11], Michael J. Childress[13], Alejandro Clocchiatti[5,6], Massimo Dall'Ora[9], John Danziger[14], Massimo DellaValle[9], Michel Dennefeld[15], Patrick El Hage[2], Nancy Elias-Rosa[12,16], Nancy Elman[3], Mathilde Fleury[2], Elisabeth Gall[1], Santiago Gonzalez-Gaitan[17], Laura Greggio[12], Ellie Hadjiyska[3], Wolfgang Hillebrandt[18], Simon Hodgkin[19], Isobel M. Hook[20,21], Phil A. James[8], Anders Jerkstrand[11], Erkki Kankare2[2], Rubina Kotak[11], Laurent Le Guillou[2], Giorgos Leloudas[23,24], Peter Lundqvist[23], Kate Maguire[1], Ilan Manulis[25], Steven J. Margheim[26], Seppo Mattila[22], Justyn R. Maund[11], Paolo A. Mazzali[8], Matt McCrum[11], Ryan McKinnon[3], Matt Nicholl[11], Reynald Pain[2], Joe Polshaw[11], Maria Letizia Pumo[12], David Rabinowitz[3], Emma Reilly[11], Cristina Romero-Cañizales[5,6], Richard Scalzo[13], Brian Schmidt[13], Steve Schulze5[6], Stuart Sim[11], Jesper Sollerman[23], Giacomo Terreran1[1,12], Massimo Turatto[12], Emma Walker[3], Nicholas A. Walton[19], Fang Yuan[13], Luca Zampieri[12]

[1]ESO, [2]CNRS-IN2P3, [3]Yale Univ., [4]Sapienza Univ. Roma, [5]PUC, [6]Millennium Center for Supernova Science, [7]SSI, Boulder, [8]Liverpool John Moores Univ. [9]INAF – Obs. Capodimonte, [10]Univ. Andrés Bello, [11]Queen's Univ. Belfast, [12]INAF Obs. Padova, [13]RSAA, ANU, [14]OATS–INAF, [15]IAP, [16]ICE, Bellaterra, [17]Univ. de Chile, [18]MPA, [19]IoA, Cambridge, [20]Univ. Oxford Astrophys., [21]INAF – Obs. Roma, [22]FINCA, [23]Stockholm Univ., [24]Dark Cosmology Centre, [25]Weizmann Institute of Science, [26]Gemini

PESSTO, which began in April 2012 as one of two ESO public spectroscopic surveys, uses the EFOSC2 and SOFI instruments on the New Technology Telescope during ten nights a month for nine months of the year. Transients for PESSTO follow-up are provided by dedicated large-field 1–2-metre telescope imaging surveys. In its first year PESSTO classified 263 optical transients, publicly released the reduced spectra within 12 hours of the end of the night and identified 33 supernovae (SNe) for dedicated follow-up campaigns. Nine papers have been published or submitted on the topics of supernova progenitors, the origins of type Ia SNe, the uncertain nature of faint optical transients and superluminous supernovae, and a definitive public dataset on a most intriguing supernova, the infamous SN2009ip.

The science goal of PESSTO[1] (Smartt et al., 2013) is to extend our knowledge of unusual and rare transient events that are now challenging our understanding of the two standard explosion mechanisms which have held for several decades: core-collapse and thermonuclear. For some supernovae we are unsure whether they are thermonuclear or core collapse in origin. Supernovae in the nearby Universe ($z < 0.05$) allow critical measurements to constrain the physics, such as progenitor detections and multi-wavelength (X-ray to radio) follow-up. This offers a powerful way to probe both the explosion mechanisms and shock physics. The first important data that PESSTO takes is a classification spectrum, which gives an immediate measurement of redshift and initial supernova type. These targets are prioritised for classification if they are nearby (within about 40 Mpc, e.g., Figure 1), are discovered shortly after explosion (within a few days), are intrinsically more luminous or fainter than the bulk of the canonical supernova population, have unexplained properties (such as pre-explosion outbursts) or are fast declining supernovae. The latter are difficult to find and follow-up in detail, as all currently running optical surveys have found.

PESSTO targets and strategy

To feed PESSTO, an alliance has been made with the two major wide-field southern hemisphere surveys that have survey strategies that produce large numbers of young targets in PESSTO's sensitivity range (mag < 20.5). The La Silla QUEST survey searches for supernovae over 1000 square degrees on a 1–2 day cadence, providing PESSTO with 5–10 supernova candidates per night for classification. The rapid cadence allows for young objects to be identified for immediate follow-up and this has been the major feeder survey for PESSTO to date. The SkyMapper telescope is another powerful survey which has just started sky survey operations in earnest in September 2013 and promises a harvest of targets, and accompanying multi-colour light curves. The PESSTO science teams also scour the Catalina Sky Survey public discoveries, and, recently, the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS1) survey discoveries for appropriate targets. PESSTO also welcomes early alerts from amateur supernova hunters who can inform us as quickly as possible when they find southern hemisphere and equatorial targets.

A critical component of PESSTO is communicating discovery and target details from all input surveys to ~ 120 science members, allowing them to comment, prioritise and ensure that the observers at the New Technology Telescope (NTT) get rapid and reliable information for the night's work. Speed is of the essence, as delays can lead to a scientifically critical epoch being missed. We have developed the PESSTO Marshall (based on input from Palomar Transient Factory [PTF] and Pan-STARRS1 software development) which assimilates all target information, displays interactive webpages and records comments, classifications and plans in a database. The Marshall talks to the La Silla QUEST, SkyMapper and Pan-STARRS1 databases directly, shares information and also pulls in publicly posted targets from the Catalina Sky Survey and amateur International Astronomical Union (IAU) posted targets. PESSTO developed a data reduction pipeline that allows a one command full reduction and calibration of spectra within seconds of data being taken. New classification spectra are publicly released within about 12 hours after the end of the night. These spectra are accompanied by an instant announcement to the Astronomer's Telegram, reporting target details and classifications.

The PESSTO observing team is typically made up of two observers at La Silla, and one or two people acting as a support team in Europe or Chile who take over the data release and telegram posting at the end of the Chilean night. This gives an excellent opportunity for students to be trained at the telescope in

Figure 1. The PESSTO image of SN2013ej in M74 (Valenti et al., 2013), taken with EFOSC2 on the NTT. The supernova is the bright object in the bottom left corner. This nearby SN had pre-explosion images of the galaxy, allowing a direct search for the progenitor star (ESO Picture of the Week, 2 September 2013).

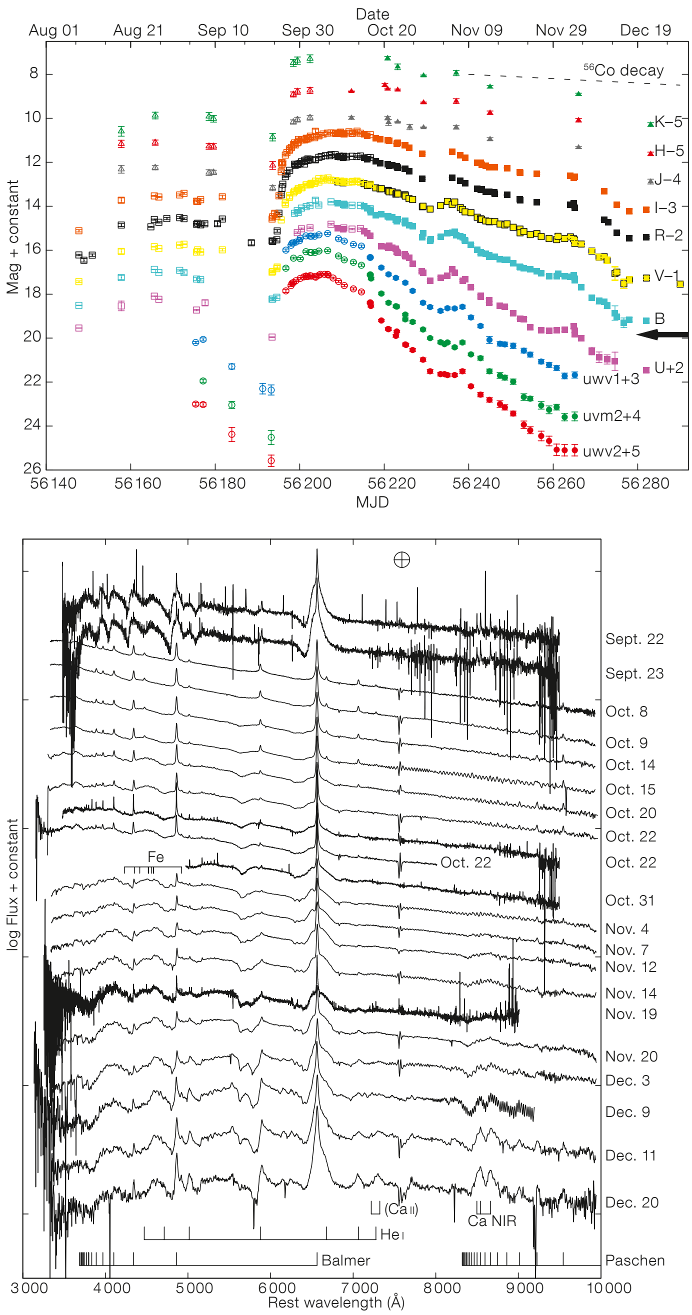


Figure 2. PESSTO light curve (upper) and spectral sequence (lower) for SN2009ip (Fraser et al., 2013), showing the initial explosion or eruption in August 2012 and rapid rise to maximum in September 2012. It is still not known if the star underwent core collapse.

making real decisions, communicating with a large science team, reducing data instantly and working out how to optimise the nights observing. PESSTO observing slots are allocated a year in advance and the younger scientists in the collaboration are keen to get this invaluable experience. PESSTO members coordinate observations with other facilities, such as the VLT, the Telescopio Nazionale Galileo (TNG), the William Herschel Telescope (WHT) and a host of 1–2-metre facilities for light-curve monitoring (e.g., Liverpool Telescope, Panchromatic Robotic Optical Monitoring and Polarimetry Telescopes [PROMPT], Small and Moderate Aperture Research Telescope System [SMARTS], Las Cumbres Observatory Global Telescope [LCOGT]).

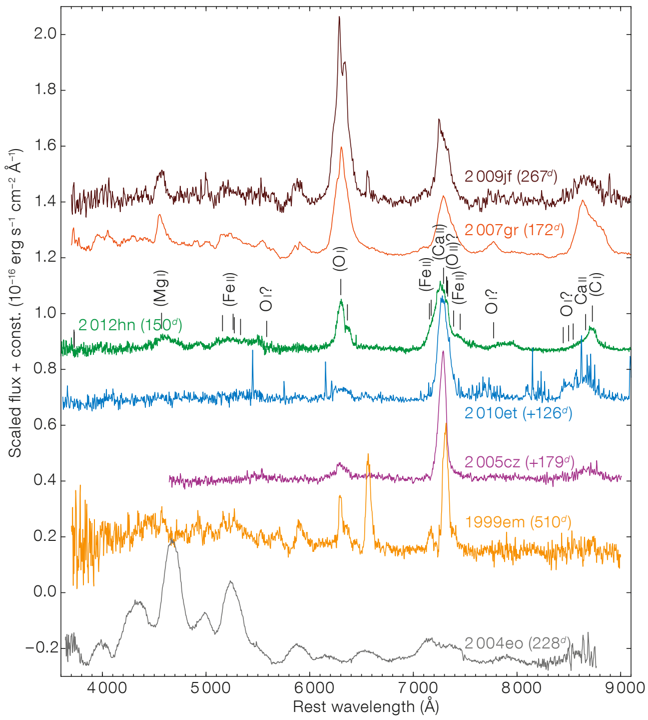
PESSTO first-year science highlights

A successful first year of PESSTO led to the identification of 33 supernovae as scientifically interesting for detailed follow-up, and work on these is either complete or in preparation by team members. The highlight of the year was the spectacular rise in luminosity of a supernova known as SN2009ip. A transient was first discovered in 2009 in NGC 7259, which turned out to be the giant outburst of a star in the luminous blue variable stage. Although it was labelled a supernova and given the IAU name, it had not catastrophically exploded, but returned to a state of restless variability during the next three years. The star was monitored frequently (Pastorello et al., 2013) before a spectacular double peaked rise to supernova-like luminosities in August and September 2012 (Figure 2); it has been classified as a type "IIn" supernova, which means narrow hydrogen lines are visible. PESSTO monitored the outburst from the rise to peak until solar conjunction in 2013 and is now observing it during the second season (Fraser et al., 2013; Fraser et al., in prep).

This is the first time in history that a star has been monitored for years, photometrically and spectroscopically, before its explosion as a supernova. It is still not clear if the massive progenitor star has actually undergone core collapse or if the observed luminosity is powered from colliding shells which were ejected by the star in eruptive phases, such as through the pulsational pair-instability process. It is certainly a "super"-nova simply from its observed luminosity and the similarity with other type IIn explosions at larger distances. This type of instability may be quite common for these events. PESSTO produced a public optical and near-infrared dataset for SN2009ip and continues to do so with the hope that the second season data can detect (or set limits on) the nucleosynthetic products expected if core collapse occurred.

Other PESSTO highlights include a joint VLT X-shooter project for high resolution spectra of type Ia supernovae to look for interstellar absorption signatures that could shed light on the decades long progenitor system debate (Maguire et al., 2013). The detection of an excess of blue-shifted components led Maguire et al. to suggest that this is due to mass-loss signatures in the single degenerate scenario and that there are two distinct populations of normal, cosmologically useful SNe Ia. There are a growing number of supernovae for which we are struggling to explain their physical mechanisms and in many cases it is ambiguous whether or not a core collapse or thermonuclear explosion has occurred. One example is the group of faint type I supernovae, which, by definition, have no observable hydrogen or helium, but show conflicting signs of having a massive star or white dwarf origin. PESSTO studied SN2012hn, which is a faint type I supernova that lies 6 kpc from an E/SO host (Valenti et al., 2013a). There is no sign of star formation at its location, but spectra show strong oxygen, calcium and carbon lines after 150 days which are more indicative of nucleosynthesis in core-collapse supernovae (Figure 3).

Another supernova with an ambiguous origin is SN2012ca. Studies of this object, which build on previous work, show that distinguishing between the type Ia SNe and core collapse when there is interaction with circumstellar material is not easy (Inserra et al., 2013). These events are significant for determining how many physical channels could produce the cosmologically important type Ia SNe. The new class of superluminous supernovae has caught the attention of the community as the source of the luminosity is still not understood. PESSTO classified four of these in its first year at redshifts around $z = 0.2$ and the first detailed study was submitted by Benetti et al. (2013). These supernovae cannot be powered by ^{56}Ni, which is the mechanism powering normal type Ia and Ibc SNe as they decay too fast. Two models have emerged as candidates, magnetar-powered and shock breakout from a dense and extended circumstellar shell or dense wind. Future multi-wavelength observations of the nearest events are likely to be the best way to distinguish between the models. Finally PESSTO has studied very nearby (< 20 Mpc) supernovae to determine their progenitor origins through early and frequent spectroscopic monitoring combined with archive images of the progenitor explosion site (Maund et al., 2013; Childress et al., 2013; Valenti et al., 2013b).



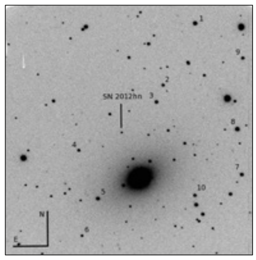


Figure 3. PESSTO image showing the position of the faint type I supernova 2012hn, at 6 kpc away from its host galaxy NGC 2272. Left: Nebular spectrum of SN2012hn (green) compared to other SNe. Prominent lines of forbidden O, Ca and Mg are visible, similar to those seen in core-collapse SNe, while the [Fe II] features typical of type Ia SNe are weak or missing; see Valenti et al. (2012a) for more details.

SSDR1 and outlook

PESSTO provides reduced classification spectra within 12–24 hours of the data being taken and releases these publicly through the Weizmann Interactive Supernova data REPository[2] (WISeREP) and an Astronomer's Telegram announcement. The final reduced data products which are now available as SSDR1 (Spectroscopic Survey Data Release 1) contain better reductions (telluric correction and fringe frame correction, more accurate flux calibration). All follow-up spectra with EFOSC2 and SOFI are available. We are also releasing all intermediate data products that may be useful to the community in the Italian Astronomical Archives (INAF IA2) in Trieste[3]. PESSTO releases 2D flux-calibrated and wavelength-calibrated frames as associated data products so that users can re-extract signal (either the transient or background galaxy) for objects with high levels of background contamination. In addition, all images taken with EFOSC2 and SOFI are reduced, astrometrically calibrated and photometrically calibrated (as far as the small fields will allow) within SSDR1.

On the technical side, the future outlook for PESSTO is to improve the absolute flux calibration of spectra (see Smartt et al., 2013) in SSDR2 and beyond. On the science side, PESSTO is trying to minimise the time between transient discoveries in the partner surveys and the first spectra being taken to look for novel signatures of the explosion mechanisms that can constrain physical models and also to probe the parameter space of rapidly varying extragalactic transients. With a large spectroscopic survey sample, statistical studies of the transient population along with host galaxy properties will be possible. With all the major ESO community supernova groups on board, PESSTO has rapidly evolved into a prodigious science survey in its first year, with great promise for its future years.

References

Benetti, S. et al. 2013, MNRAS, submitted, arXiv:1310.1311
Childress, M. J. et al. 2013, ApJ, 770, 29
Fraser, M. et al. 2013, MNRAS, 433, 1312
Inserra, C. et al. 2013, MNRAS, in press, arXiv:1307.1791
Maguire, K. et al. 2013, MNRAS, 436, 222
Maund, J. R. et al. 2013, MNRAS, 431, 102
Pastorello, A. et al. 2013, ApJ, 767, 1
Smartt, S. J. et al. 2013, A&A, in prep.
Valenti, S. et al. 2013a, MNRAS, in press, arXiv:1302.2983
Valenti, S. et al. 2013b, MNRAS, in press, arXiv:1309.4269

Links

1 PESSTO web page: http://www.pessto.org
2 WISeREP: http://www.weizmann.ac.il/astrophysics/wiserep
3 INAF IA2 data archive: http://ia2.oats.inaf.it/