PESSTO SSDR1 : ESO Phase 3 Data Release Description

Data Collection	PESSTO
Release Number	1
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Abstract

The European Southern Observatory selected PESSTO (Public ESO Spectroscopic Survey of Transient Objects) is a public spectroscopic survey which began in April 2012. PESSTO is carried out on the New Technology Telescope with the instruments EFOSC2 and SOFI to provide optical and NIR spectroscopy and imaging. We typically target supernovae and optical transients brighter than 20.5^m for classification, with a goal of classifying supernovae as close to the explosion epoch as possible. Science targets are selected for detailed follow-up based on the PESSTO science goal of extending knowledge of the extremes of the supernova population. We use standard EFOSC2 setups providing spectra with resolutions of 13-17Å between 3680-10320Å. A subset of the brighter science targets are selected for SOFI spectroscopy with the blue and red grisms (resolutions 23-33Å) and imaging with broadband JHK_s filters. This first data release (SSDR1) contains flux calibrated spectra for all targets taken during the first year, between April 2012 and April 2013. We estimate the absolute accuracy of the flux calibrations for EFOSC2 across the whole survey in SSDR1 to be 15%, although data will be provided in readily accessible format to reduce this to a few per cent with extra tailored steps. The standard NIR reduction process does not produce high accuracy absolute spectrophotometry but synthetic photometry with accompanying JHK_s imaging will improve this. Future data releases will focus on improving the automated flux calibration of the data products, providing calibrated lightcurves and target catalogues. This release only includes the spectral data products. The EFOSC2 images and SOFI images will be provided in an extended data release in January 2014.

Overview of Observations

PESSTO has been allocated 90 nights per year, in visitor mode, on the ESO NTT. There are no observations planned during the months of May, June and July due to the Galactic centre being at optimal right ascension. These three months make it more difficult to search for extragalactic SNe and there is large time pressure from the ESO community for Milky Way stellar science. PESSTO typically has been allocated 10 nights per month split into three sub-runs of 4N, 3N and 3N. Typically the middle sub-run is dark time, while the two others are grey/bright with the moon up for around 50% of the time. The instruments used are EFOSC2 and SOFI and both spectroscopy and imaging modes are employed. The PESSTO collaboration host public webpages with much useful information on night reports, observing conditions, observing with the NTT, the data reduction pipeline. This information will be updated during the survey and users should read this document with the information on www.pessto.org and the wiki pages that the homepage points to. A summary of the spectroscopic data setups is given in Tables 1 and 2. The science target selection strategy is described in detail in Smartt et al. (2013)

Table 1. PESSTO settings for EFOSC2 spectroscopy. The blocking filter OG530 is used only (and always) for Gr#16. The 1" slit projects to 3.5 binned pixels. The column headed Arclines indicates the number of lines used. The RMS is the typical residual for the wavelength calibration solution.

Grism	Wavelength (Å)	Filter (blocking)	Dispersion (Åpix^{-1})	Resolution (Å for 1" slit)	Arclines (number)	RMS (Å)
#13	3684 - 9315	none	5.5	17.7	13-15	0.10-0.15
#11	3380 - 7520	none	4	13	9	0.10-0.15
#16	6015-10320	OG530	4	13	11-14	0.05-0.10

Table 2. PESSTO settings for SOFI spectroscopy. The 1" slit projects to 3.4 pixels FWHM, measured from arc lines. The column headed Arclines indicates the number of lines used. The RMS is the typical residual for the wavelength calibration solution. The order blocking filters used are 0.925μm (GBF) and 1.424μm (GRF) "cut-on" filters.

Grism	Wavelength (μm)	Filter (blocking)	Dispersion (Å pix^{-1})	Resolution (Å for 1" slit)	Arclines (number)	RMS (Å)
Blue	0.95 - 1.64	GBF	6.96	23	12-14	0.1-0.2
Red	1.53 - 2.52	GRF	10.22	33	7-8	0.2-0.7

Release Content

PESSTO observes single targets in long-slit mode and selects targets for two purposes as described in Smartt et al. (2014). The first is to classify targets as early as possible after discovery. The main feeder survey for PESSTO is the La Silla QUEST survey (LSQ), as described in Baltay et al. (2013), but PESSTO takes targets from many different public surveys. These "classification" spectra are taken with Grism#13 and typically we aim for signal-to-noise in the continuum between 10-20 depending on the magnitude of the source. The main purpose is to reliably screen targets to determine their classification and redshift. The science goal of PESSTO (Smartt et al. 2014) is detailed follow-up and time series spectroscopic monitoring of supernovae at the extremes of the known population e.g. the most luminous, the faintest, the fast declining etc. Hence the screening classification spectra are necessarily kept short in order to minimize the time observing normal supernovae and maximize the time available for scientific follow-up.

In the first year, PESSTO has taken spectra of 298 distinct objects. From this list, 41 supernovae were picked as interesting science targets and these were scheduled for follow-up time series EFOSC2 optical spectroscopy, with the brightest also having SOFI spectra. A summary of the first year of PESSTO Key Science targets and the spectral data sets taken is given in Table 3. The total number of spectra released for these 41 "PESSTO Key Science" targets are 516 EFOSC2 spectra and 95 SOFI spectra (a total of 611). These EFOSC2 numbers include the first classification spectra taken.

PESSTO has used EFOSC2 in imaging mode to take acquisition images of all targets before a spectrum is taken and in some cases multi-colour photometry is taken. Smartt et al. (2014) describes the rationale for lightcurve construction for PESSTO science targets, which are typically bright enough to be done with smaller aperture facilities. SOFI imaging is always taken when SOFI near infra-red spectra are taken.

In total the SSDR1 contains 18GB of data and the numbers of images and spectra are given in Table 4. In total there are 814 EFOSC2 spectra released. These include the 516 EFOSC2 spectra of Table 3. The remaining 298 EFOSC spectra relate to 257 objects for which we took spectra but did not pursue a detailed follow-up campaign. There are more spectra than objects simply due to the fact that in some cases PESSTO took more than one spectrum for classification due to either low signal-to-noise in the first spectrum, or ambiguous classifications that needed further spectra to allow a secure analysis. Generally, the first spectrum taken of an object was enough for a classification. However there were circumstances in which further spectra were needed due to either low signal-to-noise, or a real ambiguity. The most common cause of ambiguity in classification are objects showing featureless blue continua. These are usually young type II SNe, but can be Galactic CVs, tidal disruption candidates, or moderate redshift superluminous supernovae. In these cases further spectra usually show spectral features to allow redshift and classifications. The classifications released by PESSTO are based on the set of early spectra taken. A full catalogue of classification targets with details of redshifts, host galaxies, types, epochs is planned for the second release (likely to be SSDR2).

There are also more acquisition images than individual spectra, since in some cases a deeper acquisition image was taken, or the object was not visible. These are generally released as calibrated science images. The vast majority of objects observed have both spectra and images. But there are 65 individual images that have no spectrum counterpart, and 12 spectra that have no image counterpart.

Table 3: PESSTO Key Science targets. These targets were selected for detailed follow-up, initially with EFOSC2 and with SOFI when possible. The numbers refer to the numbers of epochs of spectra taken with each Grism. Gr11, GR13 and Gr16 refer to the EFOSC2 grisms and GB, GR refer to the SOFI grisms. There are 516 EFOSC2 spectra and 95 SOFI spectra of these Key Science Targets.

Target	**Type**	**Number of spectra**	**Comments**
SN2009ip	IIn	18xGr11, 2xGr13, 16xGr16 8xGB, 6xGR	Fraser et al. (2013)
SN2012fr	Ia (very early)	15xGr11, 15xGr16 10xGB, 9xGR	
SN2012ec	II-P (progenitor)	12xGr11, 2xGr13, 11xGr16 11xGB, 4xGR	Maund et al. (2013)
SN2013K	IIP	6xGr11, 15xGr13, 7xGr16 1xGB	
LSQ13fn	IIn	13xGr11, 9xGr13, 6xGr16	
SN2012dy	IIb	12xGr11, 6xGr13, 9xGr16	
SN2012hs	IIb	7xGr11, 7xGr13, 7xGr16 3xGB, 1xGR	
LSQ12dwl	Ic	2xGr11, 7xGr13, 2xGr16 5xGB, 4xGR	PTF12gzk
SN2013ao	Ia (CSM search)	9xGr11, 1xGr13, 9xGr16	Maguire et al. (2013)
SN2012ca	IIn (Ic or Ia + CSM)	11xGr13 5xGB, 2xGR	Inserra et al. (2013)
LSQ12gdj	Ia (super-Chandra)	7xGr11, 7xGr16 1xGB, 1xGR	Scalzo et al. (2013)
LSQ12hxg	IIn	5xGr11, 8xGr13, 3xGr16	
LSQ12dyw	Tidal disruption event?	1xGr11, 13xGr13, 1xGr16	
SN2013ak	IIb (radio, mm, x-ray)	4xGr11, 4xGr16 3xGB, 3xGR	
SN2013ai	II (progenitor cluster)	3xGr11, 11xGr13	
SSS130221-133330-194457	IIn	7xGr11, 6xGr13	
OGLE-2012-SN-006	Ibn	1xGr11, 6xGr13, 1xGr16 2xGB, 2xGR	
SSS120810-231802-560926	SLSN Ic	12xGr13	
CSS130403-150213+103846	Ia (remote location)	7xGr11, 1xGr13, 3xGr16	Far from any host
OGLE-2012-SN-040	IIn	3xGr11, 3xGr13, 3xGr16 1xGB, 1xGR	
OGLE-2013-SN-016	Ia (sub-luminous)	9xGr11, 1xGr13, 1xGr16	
LSQ12heq	IIn	4xGr11, 5xGr13, 2xGr16	Nuclear event
CSS121015-004244+132827	SLSN Ic/II	10xGr13	Benetti et al. (2013)
SN2012hr	Ia (CSM search)	3xGr11, 1xGr13, 3xGr16 2xGB, 1xGR	Maguire et al. (2013)
LSQ12hot	IIn	1xGr11, 9xGr13	
SN2013am	II	4xGr13 3xGB, 3xGR	

LSQ12dlf	SLSN Ic	1xGr11, 7xGr13, 1xGr16	
LSQ12fxd	Ia (remote location)	4xGr11, 1xGr13, 4xGr16	Far from any host
LSQ12gpw	Ia (super-Chandra)	4xGr11, 1xGr13, 4xGr16	
PSNJ15213475-0722183	IIn (2008s-like or SN imposter)	6xGr11, 1xGr13, 2xGr16	
SN2012ht	Ia (CSM search)	3xGr11, 3xGr16 2xGB, 1xGR	Maguire et al. (2013)
SN2013bb	IIb (energetic)	4xGr11, 1xGr13, 4xGr16	
LSQ12fhs	Ia (super-Chandra)	3xGr11, 4xGr13	
SN2012hn	Faint type I	3xGr11, 1xGr13, 3xGr16	Valenti et al. (2013)
SN2013aj	Ia (CSM search)	3xGr11, 1xGr13, 3xGr16	Maguire et al. (2013)
SSS130404-102043-062657	Ia (remote location)	2xGr11, 3xGr13, 2xGr16	Far from any host
LSQ13sj	II	7xGr13	
SN2013U	Ia (CSM search)	3xGr11, 3xGr16	Maguire et al. (2013)
SN2012hd	Ia (CSM search)	2xGr11, 1xGr13, 2xGr16	Maguire et al. (2013)
LSQ12gxb	I (peculiar)	3xGr11, 1xGr13, 1xGr16	
OGLE-2013-SN-019	IIn	4xGr11, 1xGr13	

Table 4: Total number of science files released in the various formats described here. The image data are not yet included in this release. They are scheduled for release in January 2014 and the numbers are given here for information.

File type	Format	Number of files	Data Volume
EFOSC2 1D spectra	Binary Table format	814	39Mb
EFOSC2 2D spectral images	FITS image	814	2.7Gb
EFOSC2 images (of which ACQ)	FITS image	2681 (1072)	12.0Gb (4.2Gb)
SOFI 1D spectra	Binary Table format	95	4.5Mb
SOFI 2D spectral images	FITS image	95	298Mb
SOFI image weights	FITS image	246	2.0Gb
SOFI images	FITS image	246	2.0Gb
TOTAL		**4991**	**18GB**

Data Reduction, Calibration and Quality

1. EFOSC2 Spectroscopic calibration data and reduction

Bias calibration: A set of 11 bias frames are typically taken each afternoon of PESSTO EFOSC2 observations and are used to create a nightly master bias. This nightly master bias frame is applied to all EFOSC2 data taken, including the spectroscopic frames, the acquisition images and any photometric imaging. The frame used for the bias subtraction can be tracked in the header keyword.

```
ZEROCOR = 'bias_20130402_Gr11_Free_56448.fits
```

The file name gives the date the bias frames were taken, the Grism and filter combinations for which it is applicable (of course for biases this is not relevant but the pipeline keeps track with this nomenclature) and the MJD of when the master bias was created. The dark current is less than 3.5 e− pix^{-1} hr^{-1}, hence with typical PESSTO exposures being 600-1800s, no dark frame correction is made.

Flat field calibration : The PESSTO survey takes sets of spectroscopic flatfields in the afternoons at a typical frequency of once per sub-run of 3-4 nights. Five exposures are taken with maximum count levels of 40,000-50,000 ADU for each of the grism, order sorting filter, and slit width combinations that we use (8 combinations in total). Each of these is combined to give a masterflat which can be associated with the appropriate science observations from the sub-run.

```
FLATCOR = 'nflat_20130413_Gr11_Free_slit1.0_100325221_56448.fits'
```

The EFOSC2 CCD#40 is a thinned chip, hence has significant fringing beyond 7200Å and the severity depends upon the grating used. The only way to remove fringing (in spectroscopic mode) is to take a calibration flat field lamp exposure *immediately after or before* the science image and use this to divide into the science spectrum. PESSTO always takes internal lamp flats (3 exposures of typically 40,000 ADU maximum count level) after taking any science spectra with Gr#16. More details on the exact methods used are given in Smartt et al. (2014).

Cosmic ray removal : The PESSTO pipeline incorporates a modified version of the *python* implementation of LaCOSMIC (Van Dokkum 2001) to remove cosmic rays in the central 200 pixels around the object (i.e. central pixel ±100 pixels).

Arc frames and wavelength calibrations: Arc frames are taken in the evening before observing and in the morning after the night finishes. EFOSC2 has helium and argon lamps and PESSTO uses both of these lamps turned on together. No arc frames are taken during the night to reduce overheads. Although EFOSC2 suffers from significant flexure as the instrument rotates at the nasmyth focus (which can be 4 pixels over 200 degrees in rotation), the flexure causes a rigid shift of the wavelength frame. Hence we apply the calibration determined from the evening arc frames and adjust this with a linear offset as measured from either the skylines or atmospheric absorption lines. Relatively high order Legendre polynomial fits (5-6) are needed to fit the EFOSC2 arc lines with a fit which produces no systematic residuals. The number of arc lines used for the dispersion solution of each object, along with the RMS error, are given in the header of the reduced spectra by the keywords `LAMNLIN` and `LAMRMS` respectively. The formal RMS values are probably too small to realistically represent the uncertainty in the wavelength calibration at any particular point, given the FWHM of the arclines is 13-17Å. Hence this might suggest over-fitting of the sampled points. As a comparison, Legendre polynomials with order 4 produced obvious systematic residuals and RMS values of between 0.4-1.0Å for a 1.0" slit and 1-1.8Å for a 1.''5 slit. For exposures longer than 300 s, the linear shift applied to the dispersion solution is measured from the night sky emission lines. For shorter exposures such as spectrophotometric standards, the night sky lines are not visible, and the shift is instead measured from the telluric absorptions in the extracted 1D spectrum. The linear shifts are typically in the range of 6-13 Å for Gr#11 and Gr#13. In the case of Gr#16 spectra the shifts were usually smaller, usually 4-9 Å. This value of linear shift is recorded in the header keyword SHIFT. The linear shifts are calculated by cross-correlating the observed spectrum (sky or standard) with a series of library restframe spectra which are off set by 1Å. The library spectrum which produces the minimum in the cross-correlation function is taken as the correct match and this shift is applied. This method limits the precision of the shift to 1Å, which is roughly 1/4 of a pixel and less than 1/10 of a resolution element. This value of 1Å is recorded in the header as the systematic error in the wavelength calibration (SPEC_SYE).

Spectrophotometric standards and flux calibration: PESSTO uses a set of 9 spectrophotometric standard stars for (see Smartt et al. 2014) and we typically observe an EFOSC2 spectrophotometric standard three times per night (start, middle and end), although if there are significant SOFI observations or weather intervenes then this may be reduced. Generally, the three observations will include 2 different stars and a set of observations is taken with all grism, slit and filter combinations used during the nights observing. From September 2012 to November 2012 the standard EG21 was frequently observed. We later realised however that the photometric flux tables for this star did not cover the full, telluric corrected regions for Gr#16 and Gr#13 and hence stopped using it after 2012-11-21. We have only used it to calibrate PESSTO data taken with Gr#11 in SSDR1. To remove any second order contamination in the flux standards, PESSTO always takes Gr#13 data for these stars with and without the filter GG495, to allow correction for the effect during pipeline reductions. Flux standards are always observed unless clouds, wind or humidity force unexpected dome closure. Hence even during nights which are not photometric, flux standards are taken and the spectra are flux calibrated; we deal with the issue of the absolute flux reliability below. A sensitivity function is derived for each EFOSC2 configuration from the spectrophotometric standards observed. These were averaged to create a master sensitivity function for each month, which was then applied to the final reduced spectra. In a few instances, a master sensitivity curve was not created for a particular configuration on a given month, as there were no appropriate standards observed. In these cases, the sensitivity function from the preceding or following month was used.

The standard method of ensuring spectra are properly flux calibrated is to compare synthetic photometry of the science spectra with contemporaneous calibrated photometry and apply either a constant, linear or quadratic multiplicative function to the spectra to bring the synthetic spectra into line with the photometry. For PESSTO SSDR1 this is not yet possible for all spectra since the photometric lightcurves are not yet finalised for many of the science targets and the classification spectra do not have a photometric sequence. However it is useful to know what the typical uncertainty is in any flux calibrated PESSTO spectrum, and this is encoded in the header keyword FLUXERR. PESSTO observes through non-photometric nights, and during these nights all targets are still flux calibrated. Hence the uncertainties in flux calibrations come from transparency (clouds), seeing variations that cause mismatches between sensitivity curves derived using standards with different image quality, and target slit positioning. Finally, photometric flux is generally measured with point-spread-function fitting which inherently includes an aperture correction to determine the total flux whereas spectroscopic flux is typically extracted down to 10 per cent of the peak flux (a standard practice in IRAF's *apall* task). All of this means that large percentage variations are expected and we carried out tests as to how well this method works and what is the reliability of the absolute flux calibration in the spectra. In Smartt et al. (2014) we describe these quantitative tests, deriving Fig. 1 reproduced here. We find that the RMS scatter in the absolute spectroscopic flux calibration is 15.2% and this is recorded in the headers of all spectra.

```
FLUXERR =                  15.2 /Fractional uncertainty of the flux [%]
```

Science users should use this as a typical guide, if the seeing (as can be measured on the 2D frames and acquisition images) and night conditions (from the PESSTO wiki night reports; see Smartt et al. 2014) are reasonable. In future data releases we plan to significantly improve on the flux calibration scatter and reduce both the failures and intrinsic scatter.

Telluric absorption correction: PESSTO uses a model of the atmospheric absorption to correct for the H_2O and O_2 absorption (see Smartt et al. 2014 for details). This is carried out for all grism setups. The intensities of H_2O and O_2 absorptions in the atmospheric absorption model are first Gaussian smoothed to the nominal resolution of each instrumental setup, and then rebinned to the appropriate pixel dispersion. The pipeline then scales the model spectrum so that the intensities of H_2O and O_2 absorptions match those observed in the spectrophotometric standards, hence creating multiple model telluric spectra per night. Each science spectrum is than corrected for telluric absorption, by dividing it by the smoothed, rebinned, and scaled absorption model which is most closely matched in time i.e. closest match between the standard star observation time and the science observation time.

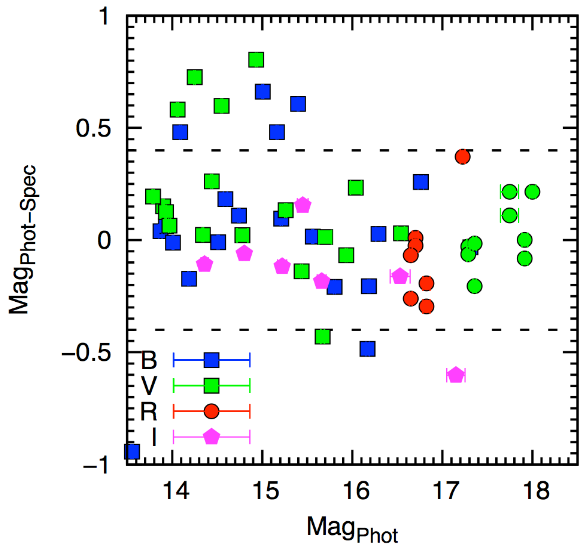

Fig 1: Synthetic magnitudes as measured from flux-calibrated spectra (Gr#11 and Gr#16) compared to the photometric magnitude at the same epoch for SN2009ip (Fraser et al. 2013) and SN2012fr (Childress et al. 2013, and Conteras et al., in prep.). Additionally, the synthetic magnitudes from Gr#13 observations compared to photometry of SN2013ai (Fraser et al. in prep) are plotted. Mag_{Phot} is the calibrated photometric magnitude and the y-axis is the difference between this and the synthetic photometry measured from the flux calibrated spectra. Colours indicate filters, square symbols are Gr#11, pentagons are Gr#16 and circles are Gr#13.

2. EFOSC2 Imaging calibration data and reduction

As noted in the abstract of this data release description. This release only includes the spectral data products. The EFOSC2 images and SOFI images will be provided in an extended data release in January 2014.

EFOSC2 is used in imaging mode for PESSTO to provide supporting photometry for some targets. Much of the photometric lightcurve data is provided by PESSTO scientists through their access to other facilities such as the SMARTS 1.3m, Liverpool Telescope, the Faulkes Telescopes, the SWOPE 1m, Asiago Telescopes and PROMPT. However EFOSC2 is also used for supporting data, particularly when the targets are fainter than around 19.5 ^{m}. The detector setup is exactly the same as for the spectroscopic observations (above and Smartt et al. 2014). We use the filters *U*#640, *B*#639, *V*#641, *R*#642, *g*#782, *r*#784, *i*#705, *z*#623, typically with *UBVRi* or *Ugriz* sequences depending on the science target . Additionally, an acquisition image is taken through a *V*-band filter before every spectroscopic exposure to identify the target and allow it to be placed on the slit. These are also processed in a similar manner to the photometric science frames. These acquisition frames are available as SSDR1 archive data products.

Bias and flat-fielding: As the EFOSC2 CCD is read out in the same mode for both imaging and spectroscopy the CCD characteristics are the same and the bias subtraction calibration is carried out in a similar way. Twilight sky flat-fields for imaging are typically taken once per sub-run of 3-4N and a master flat is created and used as close as possible to the science, or acquisition frames. The master flat and bias frames used is found listed by the header keywords. The naming nomenclature is similar to that for the spectroscopic calibration frames but without the grism and slit names.

```
ZEROCOR = 'bias_20130402_56463.fits'
FLATCOR = 'flat_20130401_R642_56463.fits'
```

In constructing these, the individual flats are checked and those with a high number of visible stars are rejected and not included in the masterflat. The masterflats commonly show a feature of apparent "dots" in a straight line (along X) in the central pixel area of [200:700,530:590] in filters *Vgrz* (it is also faintly visible in *B*). These are common, but transitory, and it is not clear if they are illumination ghosts and hence not present in the science frames. However, the counts level of these patterns differ by only 1% from the average level of the masterflat and as a consequence we assume they do not impinge on science frame calibrations. Imaging fringe frames are constructed for the *i*-band filter from a collection of NTT *i*-band images taken between Jan. 2010 and Apr. 2012.

Photometric calibration: For standard fields (see Table 3 of Smartt et al. 2014) taken during PESSTO time the image products in the archive have zeropoints calculated directly with the Landolt or SDSS magnitudes of the stars in the field, and this is recorded in the header. The pipeline also calculates ZPs for science frames if the fields are in the SDSS DR7 footprint and uses reference stars from that catalogue to set the ZPs. If the science frame is observed with filters *g*#642,*r*#784 or *z*#623 the ZPs are provided in the SDSS AB system. If the science frame is observed with filters *U*#640,*B*#639,*V*#641,*R*#642, or *i*#705 the magnitudes of the stars in the SDSS DR7 catalogue are converted to the Landolt system using the equations from (Jester et al. 2005) and ZPs are provided in Landolt system. When the field is in the DR7 footprint, the ZPs are calculated for reference stars matched to DR7 stars and are reported for an airmass=0 using the extinction coefficient reported in Table 4 of Smartt et al. (2014). The ZP is computed as the mean of all ZPs obtained for all the stars that have catalogue matches.

For images which do not fall in the SDSS DR7 footprint, we generally do not have photometric reference stars in the EFOSC2 4.1 x 4.1 arcmin field. Hence we adopt and report the average PHOTOZP which we have measured and recorded in Table 4 of Smartt et al. (2014). If the night was photometric, then the error in the PHOTZP is recorded as the error reported in Smartt et al. (2014) Table 4 (PHOTZPER) allowing the user to use the PHOTOZP with some degree of confidence within the observed spread of the average measurement. If the night was not photometric then PHOTZPER is always set to 2.0. This is likely the maximum extinction we would tolerate when taking photometric science frames for PESSTO, hence caution should be used when this value is 2.0. The record of photometric and non-photometric nights are recorded by the observers on the PESSTO wiki and in Smartt et al. (2014). In this way the keyword FLUXCAL is always set to ABSOLUTE, but users should be cautious of the validity of this. The PESSTO pipeline adds the following keywords which describe the data product, the measurements of which are described in full in Smartt et al. (2014)

```
PSF_FWHM=            1.32371928 /Spatial resolution (arcsec)
ELLIPTIC=                 0.131 /Average ellipticity of point sources
PHOTZP =                  25.98 / MAG=-2.5*log(data)+PHOTZP
PHOTZPER=                   2.0 /error in PHOTZP
FLUXCAL = 'ABSOLUTE'            /Certifies the validity of PHOTZP
PHOTSYS = 'VEGA     '           / Photometric system VEGA or AB
ABMAGSAT=     13.34036948729493 /Saturation limit for point sources (AB mags)
ABMAGLIM=     19.86138704080803 / 5-sigma limiting AB magnitude for point sources
```

Science users can then employ the ZPs to calibrate photometry of stars in the field using the following equation (and with the calibration caveats described above) :

where $COUNTS_{\mathrm{ADU}}$ is the measured signal in ADU and K_{filter} is the average extinction coefficient listed in for each filter in Table 4 of Smartt et al. (2014). The other terms are as defined in the FITS headers.

Astrometric calibration : The astrometric calibration was derived using the USNO B1 and 2MASS reference catalogues, and a distortion model described by a second order polynomial. A typical scatter of 0.4-0.5 arcsec was been found for the science frames with around 15 stars usually recognised by the catalogue in the EFOSC2 frame. This typically improves to an rms ~0.2-0.3 with ~>30 stars.. The information on the RMS of *RA* and *DEC* and the number of stars used for the calibration are given by the header keyword `ASTROMET`. Details for the other astrometric keywords are provided in Smartt et al. (2014).

3. SOFI Spectroscopic calibration data and reduction

Similar to PESSTO observations and reductions for EFOSC2, we aim to homogenise the SOFI observations and calibrations and tie them directly to what is required in the data reduction pipeline. A standard set of PESSTO OB for calibrations and science are available on the PESSTO wiki and the following sections describe how they are applied in the pipeline reduction process.

Bias, dark and cross-talk correction: The detector bias offset and structure is subtracted along with the sky background, as is standard procedure with his chip. The SOFI detector suffers from cross talk, where a bright source on either of the two upper or lower quadrants of the detector will be accompanied by a "ghost" on the corresponding row on the opposite two quadrants. This cross-talk effect is corrected for within the PESSTO pipeline by summing each row on the detector, scaling by a constant value, and subtracting from the opposite quadrants.

Flat field calibration: The lamp-off flats are subtracted from the lamp-on flats, to remove the thermal background of the system. These subtracted flat fields are combined and normalized and used to correct for the pixel to pixel variations in detector sensitivity in the science and standard star frames. The amplitude of the variability in the flat field is ~4% for the red grism and ~6% for the blue grism. Two normalized red grism flat fields taken ~5 months apart show exactly the same structure, demonstrating that the flat field is stable, and that the use of monthly calibrations is justitifed (see Smartt et al. 2014).

Arc frames and wavelength calibrations : wavelength calibration is performed using spectra of a Xenon arc lamp. To fit the dispersion solution of the arc spectra without any systematic residuals requires a 4th order polynomial fit (see Table 2 for details of numbers of lines and RMS). This dispersion solution is applied to the two dimensional spectra and the sky lines are cross-correlated with an accurately calibrated template sky. A linear shift is applied to the wavelength calibration and recorded in the header keyword SHIFT. As with the EFOSC2 correction, the precision of the wavelength correction is limited to 1Å, due to the scale of the shifts in the library sky spectra employed. Hence this value of 1Å, is again recorded as the systematic error in the wavelength calibration (SPEC_SYE).

Sky subtraction and spectral extraction : SOFI spectra for PESSTO are taken in an ABBA dither pattern. This pattern consists of taking a first (A_1) exposure at a position 'A', then moving the telescope so that the target is shifted along the slit of SOFI by ~5-10 " to position 'B'. Two exposures are taken at 'B' (B_1 and B_2), before the telescope is offset back to 'A' where a final exposure (A_2) is taken. The pipeline subtracts each pair of observations (i.e, A_1-B_1, B_1-A_1, B_2-A_2, A_2-B_2) to give individual bias- and sky-subtracted frames and shifts these sky-subtracted frames so that the trace of the target is at a constant pixel position, and the frames are then combined. Finally, the spectrum is optimally extracted interactively.

Telluric absorption correction : A"telluric standard" is observed immediately prior to or following the science spectrum, and at a similar airmass. The spectrum of the telluric standard is then divided by an appropriate template spectrum of the same spectral type, yielding an absorption spectrum for the telluric features. The absorption spectrum is then divided into the science spectrum to correct for the telluric absorption. As part of PESSTO, we observe either a Vega-like (spectral type A0V) or a Solar analog (G2V) telluric standard for each SOFI spectrum. The PESSTO pipeline uses the closest (in time) observed telluric standard to each science or standard star spectrum.

Spectrophotometric standards and flux calibration : The process for correcting the spectrum for the telluric absorption also provides a means for flux calibration using the Hipparcos I or V photometry of the solar analogs and Vega standards used. The flux of the observed telluric standard spectrum is scaled to match the tabulated photometry, with the assumption that the telluric standards have the same color (temperature) as Vega or the Sun. When possible, a second step is performed to flux calibrate the spectra using a spectrophotometric standard. The spectrophotometric standard is reduced and corrected for telluric absorption using a telluric standard, with the same technique as used for the science targets. This corrected standard spectrum is then compared with its tabulated flux, and the science frame is then linearly scaled in flux to correct for any flux discrepancy. There are only a handful of spectrophotometric standard stars which have tabulated fluxes extending out as far as the *K*-band. We do observe these standards (listed in Table 2 of Smartt et al. 2014) as far as possible when SOFI spectra are taken, but nonetheless there are a significant number of nights where no flux standard was observed in the NIR. For these nights the spectra will still have an approximate flux calibration performed against the accompanying telluric standard. All SOFI spectra have the following keyword which denotes which telluric standard was used for both the telluric correction and the initial flux calibration.

```
SENSFUN = 'TSTD_Hip109796_20130417_GB_merge_56478_1_ex.fits' /tell stand frame
```

If one of the spectrophotometric flux standards from Smartt et al. (2014; Table 3) has been used to additionally scale the flux then the keyword SENSPHOT is added to the header, with the spectrum used to apply the flux calibration. This file has the name of the standard clearly labelled. In this way, users can distinguish which method has been applied.

```
SENSPHOT= 'sens_GD71_20130417_GB_merge_56478_1_f.fits' / sens used to flux cal
```

To check the flux calibration of SOFI spectra, we would ideally have a large number of targets with both well sampled NIR lightcurves and SOFI spectra. At this time, the NIR lightcurves for most of the PESSTO science targets are not complete and not calibrated reliably enough to allow a large scale comparison. We have used a well observed type Ia SN (SN 2012fr Childress et al. 2013) to determine the accuracy and reliability of the SSDR1 flux calibrations. Synthetic *J*-band photometry was performed on the blue grism spectra, and *H*-band photometry on the red grism spectra. The difference between the synthetic magnitudes and the *JH* photometry from (Conteras et al., 2013, in prep) is plotted in Fig. 3. Not surprisingly, a fairly large spread of magnitude offsets is seen, with the distribution having a mean of 0.04^m and a standard deviation of 0.37^m. Although this is quite a significant scatter, it can be improved upon by users by employing the JHK_S imaging that is normally done when SOFI spectra are taken. Synthetic photometry will allow more accurate scaling of the absolute flux levels. This correction is not in SSDR1, but in future PESSTO data releases, the flux calibration of SOFI spectra will be cross checked against the JHK_S photometry of the target taken closest to the observations.

This uncertainty in the absolute flux calibration is recorded in the headers of all SOFI spectra with the following header keyword (as done for EFOSC2) :

```
FLUXERR =                34.7 /Fractional uncertainty of the flux [%]
```

4. *SOFI imaging calibration frames and reduction*

As noted in the abstract of this data release description. This release only includes the spectral data products. The EFOSC2 images and SOFI images will be provided in an extended data release in January 2014.

Bias, cross-talk and flat calibration : SOFI imaging is carried out as default when spectroscopy is done, providing images with a 4.9 arcmin field of view (0.29 arcsec pix^{-1}). The cross talk effect is first corrected as for the spectra and all images are then flat fielded using dome flats, which are typically taken on an annual basis. Pairs of flats are taken with the dome screen illuminated and un-illuminated; the latter are then subtracted from the former to account for bias and thermal background. Multiple flats are combined, and then used to reduce the science data. An illumination correction is also applied, to account for the difference between the illumination pattern of the dome flats and the actual illumination of the night sky. The illumination correction is determined by imaging a bright star at each position in a 4×4 grid on the detector. The intensity of the star is then measured at each position, and a two-dimensional polynomial is fitted. This polynomial is normalised to unity, so that it can be applied to the imaging data as a multiplicative correction

Sky subtraction : For targets that are in relatively uncrowded fields, a dither pattern is employed where the telescope is moved to four offset positions on the sky, while keeping the target in the field of view ("on-source sky subtraction"). To determine the sky background, the four frames are then median combined *without* applying offsets, rejecting pixels from any individual image which are more than a certain threshold above the median. This *initial* sky image is subtracted from each individual frame in order to obtain a *initial* sky-subtracted images. These frames are used to identify the positions of all sources and create a mask frame for each science image. For each set of four images, the frames are then median combined *again without* applying offsets and using the masks created previously to reject all sources and produce the *final* sky image. The *final* sky background image is then subtracted from each of the input frames. The sky-subtracted images are then mosaiced together to create a single image using the swarp package (Bertin et al. 2002).
For targets which are in a crowded field, or where there is extended diffuse emission (such as nearby galaxies), PESSTO observations alterntae between observing the target, and observing an uncrowded off-source field around ~5 arcmin from the target (typically four frames on source, then four frames off source are observed, dithering in each case). The off-source frames are then used to compute a sky frame in the same way as for the "on-source sky subtraction". The off-source sky frame is then subtracted from each of the on-source images of the target, which are then combined to create the final image. Since the field of view of SOFI is rather small (4.9 arcmin) the astrometry is not set for single images. Instead, *sextractor* is run to detect sources in individual frames, and to check the nominal dither. The images are then mosaiced together using swarp. Finally, an astrometric calibration is made, by cross correlating the sources detected by sextractor with the 2MASS catalogue, in the same fashion as for the EFOSC2 frames. The instrumental aperture magnitudes of the sources in the field as measured by daophot are then compared to their catalogued 2MASS magnitudes to determine the photometric zeropoint, which is recorded in the header of the image as `PHOTZP`. The other photometric keywords are similar to EFOSC2 (see Smartt et al., 2014 for details)

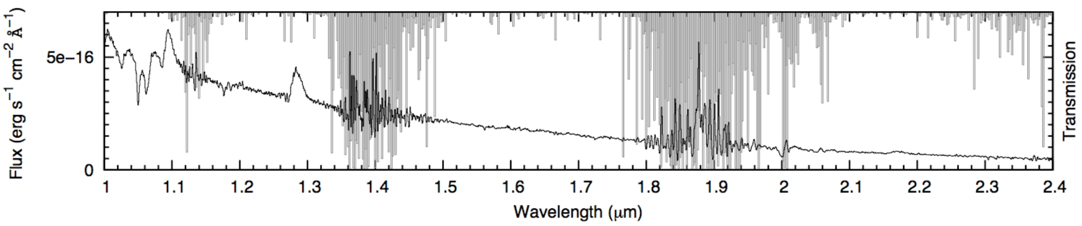

Fig 2. Combined blue and red grism SOFI spectra of SN 2012ec taken on 2013 September 24. Overplotted in grey is the atmospheric transmis- sion, showing the correspondence between regions of low transparency and poor S/N in the spectrum.

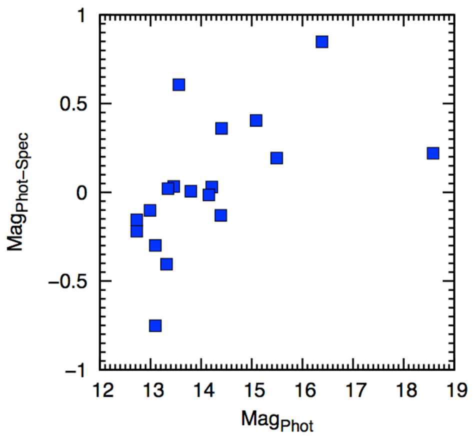

Fig 3: Comparison of observed and synthetic *JH* magnitudes for SN 2012fr. The standard deviation of the distribution is 34.7%, which is a measure of the uncertainty of the absolute spectroscopic flux scale of the calibrated SOFI spectra.

Previous Releases

This is the first spectroscopic survey data release for PESSTO.

Data Format

EFOSC2 data file types and naming

One one-dimensional flux calibrated spectra are released as binary FITS table format as the standard SSDR1 data products. These conform to the ESO Science Data Products Standard (Retzlaff et al. 2013), refered to as the spectrum binary table format. The binary table FITS file consists of one primary header (there is no data in the primary `HDU` so `NAXIS=0`), and a single extension containing a header unit and a `BINTABLE` with `NAXIS=2`. A unique FITS file is provided for each individual science spectrum. The actual spectral data is stored within the table as vector arrays in single cells. As a consequence, there is only one row in the `BINTABLE`, that is `NAXIS2=1`.

Information associated with the science spectrum is also provided within the same binary table FITS file resulting in a table containing one row with four data cells. The first cell contains the wavelength array in angstroms. The other three cells contain the science spectrum flux array (extracted with variance weighting), its error array (the standard deviation produced during the extraction procedure) and finally the sky background flux array. Each flux array is in units of erg cm^{-2} s^{-1} $Å^{-1}$.

The science spectrum has a filename of the following form, object name, date of observation, grism, filter, slit width, MJD of data reduction date, a numeric counter (beginning at 1) to distinguish multiple exposures taken on the same night, and a suffix `sb` to denote a spectrum in binary table format.

```
SN2013ak_20130412_Gr11_Free_slit1.0_56448_1_sb.fits
```

In the few cases where the object name is longer than 20 characters, it is truncated within the filename to ensure the filename does not exceed the 68 character limit enforced by ESO. The full object name is always recorded in the OBJECT keyword.

They can be identified as having the data product category keyword set as

```
PRODCATG = SCIENCE.SPECTRUM /Data product category
```

The 2D spectrum images which can be used to re-extract the object as discussed above are released as associated ancillary data in SSDR1. They are associated with the science spectra through the following header keywords in the science spectra files. The file name is the same as for the 1D spectrum, but the suffix used is `i` to denote an image.

```
ASSOC1 = ANCILLARY.2DSPECTRUM         /Category of associated file
ASSON1 = SN2013ak_20130412_Gr11_Free_slit1.0_56448_1_si.fits /Name of associated file
```

These 2D files are wavelength and flux calibrated hence a user can re-extract a region of the data and have a calibrated spectrum immediately. Users should note the value for `BUNIT` in these frames means that the flux should be divided by 10^{20} to provide the result in erg cm^{-2} s^{-1} $Å^{-1}$.

The reduced acquisition images and multi-colour photometric imaging frames, astrometrically calibrated and photometrically calibrated are also released as science data products in SSDR1. The photometric calibration is described above, and varies significantly from field to field, given the small size of the EFOSC2 field of view. These may be useful for improving on flux calibration in the future, if reference stars in the field can be accurately calibrated. These are reduced as discussed in Sect.4 and again can be identified as follows. Again the date in the filename refers to the date of observation, followed by the filter and date reduced

```
acq_SN2011hs_20120422_R642_56462_2.fits
```

and product categories labelled as :

```
PRODCATG = SCIENCE.IMAGE /Data product category
```

All EFOSC files have the following keyword set to show which data release version the file belongs to (in this case SSDR1):

```
DATA_REL = SSDR1 /Data Release Version
```

SOFI data file types and naming

The data products for SOFI are similar to those described above for EFOSC2. The spectra are in binary table FITS format, with the same four data cells corresponding to the wavelength in angstroms, the weighted science spectrum and its error and the sky background flux array. Again, each flux array is in units of erg cm^{-2} s^{-1} $Å^{-1}$. The SSDR1 FITS keywords described Smartt et al. (2014) are again applicable here. A typical file name is

```
SN2009ip_20130417_GB_merge_56478_1_sb.fits
```

Where the object name is followed by the date observed, the grism (GB for the blue grism, or GR for the red grism), the word “merge” to note that that the individual exposures in the ABBA dither pattern have been co-added, the date the file was created, a numeric value to distinguish multiple exposures on the same night and a suffix `sb` to denote a spectrum in binary table format. As with EFOSC2, this science spectrum can be identified with the label :

```
PRODCATG = SCIENCE.SPECTRUM /Data product category
```

We also provide the 2D flux calibrated and wavelength calibrated file so that users can re-extract their object directly, as described with EFOSC2. The identification of the 2D images follow the same convention as for EFOSC2, with the suffix `si` to denote a spectral image.

```
ASSOC1 = ANCILLARY.2DSPECTRUM           /Category of associated file
ASSON1 = SN2009ip_20130417_GB_merge_56478_1_si.fits /Name of associated file
```

There is no acquisition frame taken for SOFI spectra, hence the equivalent data product for EFOSC2 does not exist, but in nearly all cases where PESSTO takes a SOFI spectrum, imaging in JHK_s is also taken. These images are flux and astrometrically calibrated and released as science frames rather than associated files. They are labeled as follows where K_S labels the filter and the `merge` denotes that the dithers have been co-added.

```
SN2013am_20130417_Ks_merge_56475_1.fits
```

We also release the image weight map as described in (Retzlaff et al. 2013). The definition in this document is the pixel-to-pixel variation of the statistical significance of the image array in terms of a number that is proportional to the inverse variance of the background, i.e. not including the Poisson noise of sources. This is labelled as

```
ASSOC1 = ANCILLARY.WEIGHTMAP          /Category of associated file
ASSON1 = SN2013am_20130417_Ks_merge_56475_1.weight.fits /Name of associated file
```

As with the EFOSC files, all SOFI file have the following keyword set to show which data release version the file belongs:

```
DATA_REL = SSDR1 /Data Release Version
```

Catalogue Columns

No catalogues are released with SSDR1, but future releases will include catalogues of the PESSTO classification and science follow-up targets.

Acknowledgements

If using these data, please cite this paper

Smartt S.J., et al., 2014, A&A, (to be submitted): *PESSTO : survey description and products from the first data release of the Public ESO Spectroscopic Survey of Transient Objects*

And please also add the following acknowledging statement in your articles

Based on data products from observations made with ESO Telescopes at the La Silla Paranal Observatory under programme 188.D-3003: PESSTO (the Public ESO Spectroscopic Survey for Transient Objects).

References

Bennetti S., et al., 2013, MNRAS, submitted, arXiv:1310.1311
Bertin, E., Mellier, Y., Radovich, M., et al. 2002, *in Astronomical Society of the Pacific Conference Series, Vol. 281, Astronomical Data Analysis Software and Systems XI, ed. D. A. Bohlender, D. Durand, & T. H. Handley, 228*
Childress et al. 2013, ApJ, 770, 29
Fraser M., et al. 2013, MNRAS, 433, 1312
Inserra, C., et al. 2013, MNRAS, 770, 128
Jester et al. 2005, AJ, 130, 873
Maguire K., et al. 2013, MNRAS, 436, 222
Maund J.R. et al. 2013, MNRAS, 431, L102
Retzlaff et al. 2013, GEN-SPE-ESO-33000-5335, Issue 5
Scalzo R., et al. 2013, MNRAS, to be submitted,
Smartt S.J. et al., 2014, A&A, to be submitted
van Dokkum, P. G. 2001, PASP, 113, 1420