A young stellar environment for the superluminous supernova PTF12dam

C. C. Thöne,1† A. de Ugarte Postigo,1,2 R. García-Benito,1 G. Leloudas,2,3 S. Schulze4,5 and R. Amorín6

1Instituto de Astrofísica de Andalucía, Glorieta de la Astronomía s/n, E-18008 Granada, Spain
2Dark Cosmology Centre, Niels-Bohr Institute, University of Copenhagen, Juliane Maries Vej 30, DK-2100 København Ø, Denmark
3Department of Particle Physics & Astrophysics, Weizmann Institute of Science, Rehovot 76100, Israel
4Instituto de Astrofísica, Facultad de Física, Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, 7820436 Macul, Santiago, Chile
5Instituto de Astrofísica, Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, 7820436 Macul, Santiago, Chile
6INAF – Osservatorio Astronomico di Roma, via Frascati 33, I-00040 Monteporzio Catone, Roma, Italy

Accepted 2015 April 2. Received 2015 March 27; in original form 2014 November 4

ABSTRACT
The progenitors of superluminous supernovae (SLSNe) are still a mystery. Hydrogen-poor SLSN hosts are young, highly star-forming dwarf galaxies and the majority belongs to the class of ‘extreme emission line galaxies’. Here we present a resolved long-slit study of the host of the hydrogen-poor SLSN PTF12dam probing the kiloparsec environment of the SN site to determine the age of the progenitor. The SN occurred in a star-forming region in the head of a ‘tadpole’ galaxy with largely uniform properties. The galaxy experienced a recent starburst superimposed on an underlying old stellar population (SP). We determine a very young SP at the SN site of ~3 Myr and a metallicity of 12+log(O/H)=8.0 but do not observe any Wolf–Rayet features. The progenitor of PTF12dam was likely a massive star of >60 $M_\odot$ and one of the first stars exploding as an SN in the most recent starburst episode.

Key words: supernovae: individual: PTF12dam – galaxies: abundances – galaxies starburst.

1 INTRODUCTION
Superluminous supernovae (SLSNe) are a recently identified class of stellar explosion with peak magnitudes of $<-21$ mag (for a review see Gal-Yam 2012). Like traditional SNe they are divided into Type I and II, depending on the presence of H in their spectra. H-rich SLSNe resemble Type IIn SNe and their energy probably stems from interactions of the SN ejecta with H-rich circumstellar material (CSM; Gal-Yam 2012). The energy source of SLSNe I (identified by Quimby et al. 2011) remains a topic of debate. Circumstellar interaction (Chevalier & Irvin 2011) could explain their light curves (Chatzopoulos, Wheeler & Couch 2013) but the typical narrow lines are absent (Pastorello et al. 2010; Quimby et al. 2011). Alternatively, they could be powered by magnetar (e.g. Kasen & Bildsten 2010) or black hole engines (Dexter & Kasen 2013). A third proposed class are Type R (Gal-Yam 2012); also H-poor, these events show a faster light curve decline and could be pair-instability SNe (Gal-Yam et al. 2009). However, this distinction has been debated based on observations of PTF12dam (Nicholl et al. 2013) which could unify the two classes. Nicholl et al. (2013) favour a magnetar model, but Chen et al. (2014) shows that it would need fine-tuning to fit the late-time data. A CSM interaction model provides an acceptable fit but requires large masses for the ejecta and the CSM.

The hosts of SLSNe are distinctively different from other SN hosts. Following a few early studies (e.g.Neill et al. 2011), Leloudas et al. (2014) and Leloudas et al. (2015) recently published two large SLSN host samples. They conclude that SLSN-I hosts are low-luminosity low-mass objects with low metallicities and high specific star formation rates while Type II hosts are more massive and metal-rich (Leloudas et al. 2015), suggesting a different progenitor. While Leloudas et al. (2014) claim a similarity between long GRB (LGRB) and SLSN-I hosts, Leloudas et al. (2015) argue that SLSN-I hosts are more extreme and most belong to the class of extreme emission line galaxies (EELGs, selected in galaxy surveys by their unusually strong emission line EWs; Amorín et al. 2014).

In this Letter, we analyse different parts of the host of PTF12dam and derive conclusions on the progenitor. PTF12dam at $z = 0.107$ was detected by the Palomar Transient Factory on 2012 April 20 (Quimby et al. 2012) and classified as Type R or I (Nicholl et al. 2013). Its host is a ‘tadpole galaxy’ (Sánchez-Almeida et al. 2013) with a compact core consisting of several star forming (SF) regions, in one of which the SN was located, and a fainter tail. Global spectra of the host have been presented by Chen et al. (2014), Leloudas et al. (2014) and Leloudas et al. (2015) showing very strong emission lines and a low metallicity which point to recent starburst. Throughout the Letter, we use a Planck cosmology with $\Omega_m = 0.315$, $\Omega_{\Lambda} = 0.685$ and $H_0 = 67.3$.  

* Based on data taken under programs GTC67-13B, GTC69-14A (PI C. Thöne) and GTC48-14A (PI A. de Ugarte Postigo)
† E-mail: ethoene@iaa.es

© 2015 The Authors
Published by Oxford University Press on behalf of the Royal Astronomical Society
2 OBSERVATIONS

We obtained long-slit spectra using OSIRIS at the GTC (Cepa et al. 2003) at two different slit angles (see Fig. 1) on 2014 February 28 and April 30. Both slits cover the SN position, slit 1 was put at parallactic while slit 2 was placed across the tadpole. At each epoch, we used the R2000B and R2500R grisms that cover the wavelength range from 3950 to 7700 Å and provide resolutions of 2165 (0.85 Å pixel\(^{-1}\)) and 2475 (1.04 Å pixel\(^{-1}\)) respectively. Exposure times were 3×400 s for slit 1 and 4×400 s for slit 2. Relative flux calibration was obtained using the standard stars G191 and GD143 at epoch 1 and 2. The seeing was 1.2 and 0.9 arcsec in the two nights, respectively. The spectra are then divided into three spatial bins each and analysed separately. The bins have a width of 8–12 pixels to cover different parts of the galaxy (see Fig. 1). We also extract the integrated spectrum for both slit positions.

On 2014 August 4, we observed the field around PTF12dam using tunable narrow-band filters at OSIRIS/GTC. 5 × 750 s exposures were taken using a 12 Å filter in steps of 8 Å around the wavelength of H\(\alpha\) at the redshift of PTF12dam. An additional 200 s continuum image was taken, scaled to the flux of each narrow band filter and subtracted from the frames after PSF (point spread function) matching.

3 RESULTS

The spectra show a multitude of emission lines (see Table A2 and Fig. 2). Besides strong nebular and auroral lines of [O\(\text{iii}\)], O\(\text{iii}\), H\(\alpha\), [N\(\text{ii}\)] and [S\(\text{ii}\)], we detect 16 lines of the Balmer series in emission, several transitions from He\(\text{i}\), [Ne\(\text{iii}\)], [Fe\(\text{ii}\)] and [Ar\(\text{iv}\)], the \(T_e\) sensitive [O\(\text{iii}\)]\(\lambda\) 4363, [O\(\text{i}\)]\(\lambda\) 6300 and most of the permitted transitions of He\(\text{i}\). He\(\text{i}\), [Ar\(\text{iv}\)] and [Fe\(\text{ii}\)] require a hard radiation field to be ionized as e.g. provided by Wolf–Rayet (WR) stars. [O\(\text{i}\)] is indicative of shocks and can be used to distinguish between excitations by AGNs and H\(\text{ii}\) regions. The location in the diagnostic diagram of log(O\(\text{i}/\text{He}\)) versus log([O\(\text{iii}/\text{H}\beta\)]) confirms its origin in a normal H\(\text{ii}\) region (see e.g. Kewley et al. 2001).

The host has EWs of [O\(\text{iii}\)] = −945±2 Å and H\(\alpha\) = −814±9 Å (rest-frame, integrated spectrum of slit 1). This defines it as an EELG like ~50 per cent of SLSN-Type I/R hosts (Leloudas et al. 2015) and in fact the most extreme galaxy in this respect within in the sample of Leloudas et al. (2015).

3.1 Abundances, star formation and extinction

We determine metallicities in the different parts of the galaxy using the strong line parameters of N2 and O3N2 with the most recent calibration of Marino et al. (2013) as well as by direct abundance measurements using the electron temperature \(T_e\) sensitive line of [O\(\text{iii}\)]\(\lambda\)4363 (see Table 1). We also determine the relative abundances of N, Ne, Ar, Fe and H\(\alpha\) (see Table A2 in the appendix).

The metallicity overall is low with values of 12+log(O/H) = 8.04–8.09 or \(\sim 1/4\) Z\(_\odot\) and the results from different metallicity calibrators match surprisingly well. The host does not show an enhancement in the N/O ratio as some green pea galaxies1 (GPs; Amorín, Pérez-Montero & Vílchez 2010), but has abundances of Ne, Ar, H\(\alpha\) and Fe very similar to those galaxies (Amorín et al. 2012a). The high-ionization level is comparable to the most extreme EELGs (Jaskot & Oey 2013), indicating a hard radiation field and young stellar population (SP; e.g. Martín-Manjón et al. 2010). There is very little variation of metallicity and abundances along the slits except for some lower values in the tail of the tadpole, though the values are within the errors of the methods. The extinction derived using the linear fit to the Balmer decrements of H\(\alpha\), H\(\beta\), H\(\gamma\) and H\(\delta\) shows some low extinction in the head of the tadpole, in the rest of the galaxy the extinction is consistent with zero. The Galactic extinction in the line-of-sight is \(E(B−V) = 0.01\) mag.

The SFR derived from H\(\alpha\) (Kennicutt 1998) is 4.3 M\(_\odot\) yr\(^{-1}\) for both slit positions. Most of the SF comes from the tadpole head where the SN exploded. The luminosity- and mass-weighted specific SFR is 24 M\(_\odot\) yr\(^{-1}/L/L^*\) and 1.39 Gyr\(^{-1}\), taking the B-band magnitude and stellar mass derived in Leloudas et al. (2015) that used the spectrum of slit 1 scaled to the photometry of the entire galaxy. These are some of the highest values of the sample in Leloudas et al. (2015) and on the upper end of the distribution for EELGs.

3.2 Age of the stellar population

Several diagnostics can be used to constrain the age of the underlying SP and hence the mass and age of the progenitor star. This is the first time that we are able to put very tight limits on the age of a SLSN progenitor based on several indicators. In the following we use the spectra of the tadpole head that cover the SN site as we are interested in the SP at the SN location.

The EW of the H\(\alpha\) and H\(\beta\) emission lines strongly depend on the SP age in the first 10–20 Myr both for an instantaneous burst (ib) and continuous star formation (csf), and somewhat on the metallicity of the gas. Due to the young age no considerable absorption in the Balmer lines has to be taken into account. At a metallicity of 12+log(O/H)~8.0 (Z = 0.004) adopting new models generated by Levesque et al. (2013) using STARBUST99 (Leitherer et al. 1999) we get ages of 4 (ib) and 10–15 Myr (csf). Another strong age indicator

---

1 GPs are EELGs at 0.112 < z < 0.360 selected from the SDSS DR7 by their green colour in colour composite images (Cardamone et al. 2009).
is He I (Gonzalez-Delgado, Leitherer & Heckman 1999) which is only present in emission up to 5 Myr after the starburst (ib). The EWs of the He I λλ3810, 4026, 4471 and 4922 lines consistently give an age of 3 Myr (ib) or 5–10 Myr (csf).

Very young starbursts further show the Balmer continuum in emission instead of a Balmer break in absorption (Sánchez Almeida et al. 2012). Higher order Balmer lines are quickly affected by stellar absorption and disappear in emission, e.g. Hβ would be dominated by absorption for an age of >5 Myr (ib) (González Delgado et al. 1999). We note some low-level absorption in the high-order Balmer lines, but the centre part of the galaxy clearly shows the Balmer series in emission down to the Balmer break putting a maximum age of 5 Myr. The spectral energy distribution (SED) has a large upturn of the Balmer break and is detected by GALEX (Chen et al. 2014), supporting a very young population.

We perform star formation history (SFH) modelling at the SN site using the spectral continuum. For this we use the STARLIGHT code (Cid Fernandes et al. 2005) fitting a spectrum with a non-parametric linear combination of single stellar population (SSP) models. Dust is accounted for using a Calzetti reddening law with R_V = 3.1, emission lines are masked out. The SSP base was built from the Granada (González Delgado et al. 2005) and MILES (Vazdekis et al. 2010) libraries, covering a metallicity range log Z/Z⊙ from −2.3 to −0.4, ages of 0.001–14 Gyr and assuming a Salpeter IMF. All spectra present a very similar SFH (see Fig. 3): a young component of <10 Myr and old component >1 Gyr. This has also been found in similar objects with recent star formation like BCDs (Pérez-Montero et al. 2010) and GPs (Amorín et al. 2012a). An intermediate component is seen in the southern part of slit 1 and the tail.

To explore the possibility that the current starburst in the host of PTF12dam was triggered by interaction we observed the field around the host with narrow-band tunable filters centred at Hα at z = 0.107. The use of etalon filters results in a shift in wavelength with distance from the optical axis such that with the five steps covered in our observations we can detect Hα in emission in a field-of-view (FoV) of ~2 arcmin (244 kpc) around the optical axis.

In an FoV of 2arcmin we detect only three emitting sources (see Fig. 1 in the appendix): G1 is at a distance of 139 kpc with an emission peak at −315 km s^{-1} and has an SDSS photo-z of 0.188 ± 0.1341. G2 had also been covered by slit 1 and has emission-line redshift of z = 0.443. G3 has two emission peaks which could correspond to Hα and [N II] in a high-metallicity object and has a photo-z of 0.118 ± 0.064. None of the objects are interacting with PTF12dam, excluding a merger event as trigger for the recent starburst.

\[ \text{Table 1. Properties along the two slit positions. } N2 \text{ and } O3N2 \text{ metallicities are from Marino et al. (2013), the ionization parameter } U \text{ is derived from the models described in Pérez-Montero (2014) using several strong emission lines. For the extinction from the Balmer decrement we use a linear fit to the ratio from } H\alpha, H\beta, H\gamma \text{ and } H\delta \text{ and assume a case B recombination and temperatures and densities of } 12000 \text{ K/100 cm}^{-3}. \text{ EWs are in rest frame.} \]
3.4 Kinematics

Using intermediate resolution spectra Amorín et al. (2012b) found that the emission lines of GPs consist of a narrow and a broad component with an FWHM of up to 600 km s⁻¹. Such components have also been detected in other compact starbursts (Izotov, Thuan & Guseva 2007; James et al. 2009) and extragalactic H II regions (e.g. Firpo et al. 2011) and might trace outflows from WR/stellar winds or SN explosions. We analyse the structure of Hα and [O III] using the NGAUSFIT routine in IRAF (see Fig. A1 in the appendix).

The emission lines show surprisingly little kinematic features. Across the tadpole we see no sign of rotation and the centroid differ only by 28 km s⁻¹, although this is likely an issue of spectral resolution. All lines are best fitted with a combination of a narrow and a wide component. Comparing with a single Gaussian fit results in positive residuals in the wings indicating that the broad component is actually present. The narrow components are barely resolved with an FWHM of 120–140 km s⁻¹ (the spectral resolution is ~100 km s⁻¹) while the broad components have an FWHM of 180–200 km s⁻¹. The two components are both centred at 0 km s⁻¹ except [O III] in slit 2 while Amorín et al. (2012b) found considerable shifts between line centroid for GPs. Full width zero intensity (FWZI) is ~400 km s⁻¹, which is larger than the rotation of a dwarf galaxy and could indicate stellar winds or outflows.

4 DISCUSSION

The host of PTF12dam is a very young starburst exceeding many EELGs in terms of [O III] EW, SSFR and ionization. It is one of the most star-forming SLSN hosts detected so far and the only one showing He i emission, although this might be an effect of S/N. However, its metallicity is not extremely low and SP modelling reveals an old population of several Gyr followed by a long, quiet period and a recent starburst with an age of a few Myr. The properties are largely uniform throughout the galaxy while Sánchez-Almeida et al. (2013) observe abundances 0.5 dex higher in the tail of nearby tadpoles. The tail of the PTF12dam host might host an older SP than the head, but the metallicity is similar. Galaxy interaction is largely excluded as trigger for the recent starburst and in fact most tadpoles are isolated galaxies. Sánchez-Almeida et al. (2013) propose the inflow of cold, metal-poor gas on to the tadpole head as SF trigger which could be an appealing option for the PTF12dam host.

Despite its young age, we do not detect WR features in the host of PTF12dam while it shows strong He ii lines. However, the fraction of starbursts with WR features drops with metallicity and at 12+log(O/H)< 8.0 only 50 per cent show WR features (Shirazi & Brinchmann 2012), which could be explained by weaker stellar winds at low metallicity or a more homogeneous evolution of massive stars. Within WR galaxies, He ii emission and WR features can be spatially separated, hence He ii emission does not need to be connected to WR stars (Kehrig et al. 2013). Not all GPs show WR features (Jaskot & Oey 2013) although this could be an issue of S/N. Our limits on the number of WR stars at 3 Myr and a metallicity of 12+log(O/H) = 8.0 are slightly higher than what would be expected (see Lopéz-Sánchez & Esteban 2010, figs 7 and 8), so their non-detection is consistent with the models.

Lunnan et al. (2014) claimed that SLSN-I and LGRB hosts belonged to similar galaxy populations while Leloudas et al. (2015) proposes younger hosts for H-poor SLSN. Some nearby LGRB hosts do show evidence for WR features (Han et al. 2010) and metallicities are usually subsolar but all of them have 12+log(O/H) > 8.0 and the sites of z < 0.3 LGRB hosts even have 12+log(O/H)
> 8.2 (Levesque et al. 2010). Most SLSN-I host have metallicities of ~1/4 solar with some even going down to 1/10 solar.

For PTF12dam we are able to set strong limits on its progenitor age and hence its mass from its environment. SP modelling and high-excitation lines suggest that it was formed in the most recent starburst with an age of ~3 Myr corresponding to a star of ~60 M⊙ (e.g. Meynet & Maeder 2005). Chen et al. (2014) derived an age of 30–40 Myr using the Hα EW and SP modelling of the SN-subtracted host spectrum, although based on a much lower EW and uncertain removal of the SN contribution. Lunnan et al. (2013) put a limit of 5 Myr for the progenitor of PS1-10bzj based on the Hβ EW and broad-band SP modelling. Likewise, Christensen et al. 2008, Ostlin et al. 2008 and Thöne et al. 2014 found ages of 5–6 Myr for the SP surrounding GRB sites using high-angular resolution photometry, integral-field spectra and SP modelling. IFU observations of SN locations show that SN Ibc progenitors are stars with masses of <40 M⊙ with a few exceptions (Kuncarayakti et al. 2013).

The high progenitor mass of PTF12dam suggests that SLSNe might be some of the most massive stars, superseding even GRBs. The CSM interaction model proposed by Chen et al. (2014) would require large masses for the ejecta and the H-poor CSM (29 and 13 M⊙, respectively), consistent with the progenitor mass derived in this work. Whatever the exact model for this SN, its progenitor likely was a very massive star created in the recent SF episode and one of the first stars of that starburst that exploded as an SN. Further high-angular resolution studies are needed to determine the population of H-poor SLSN progenitors.

**Acknowledgements**

Based on observations made with the GTC, installed in the Spanish ORM (IAC) on the island of La Palma. CCT and AdUP acknowledge a Ramón y Cajal fellowship of the Spanish MINECO and partial support from AYA2012-39362-C02-02. AdUP is further supported by FP7-PEOPLE-2012-CIG 322307. DARK is funded by the DNRF. RGB acknowledges support from AYA2010-15081, SiS from CONICYT-Chile FONDECYT 3140534, Basal-CATA PFB-06/2007 and IC120009. RA acknowledges the FP7 SPACE project ASTRODEEP (Ref. No: 312725) of the EC.

**References**

Amorín R. O., Pérez-Montero E., Vilchez J. M., 2010, ApJ, 715, L128

Amorín R., Pérez-Montero E., Vilchez J. M., Papaderos P., 2012a, ApJ, 749, 185

Amorín R., Vilchez J. M., Hägg G. F., Firpo V., Prez-Montero E., Papaderos P., 2012b, ApJ, 754, L22

Amorín R. et al., 2014, A&A, preprint (astro-ph/14033441)

Brinchmann J., Kunth D., Durrell F., 2008, A&A, 485, 657

Cardamone C. et al., 2009, MNRAS, 399, 1191

Chatzopoulos E., Wheeler J. C., Couch S. M., 2013, ApJ, 776, 129

Cepa J. et al., 2003, Proc. SPIE, 4841, 1739

Chen T.-W. et al., 2014, MNRAS, preprint (astro-ph/14097728)

Christensen L., Vreeswijk P. M., Sollerman J., Thöne C. C., Le Floc’h E., Wiersma K., 2008, A&A, 490, 45

Cid Fernandes R., Mateus A., Sodré L., Stasińska G., Gomes J. M., 2005, MNRAS, 358, 363

Chevalier R. A., Irwin C. M., 2011, ApJ, 729, L6

Dexter J., Kasen D., 2013, ApJ, 772, 30

Firpo V., Bosch G., Hägg G. F., Díaz Á. I., Morrell N., 2011, MNRAS, 414, 3288

Gal-Yam A., 2012, Science, 337, 927

Gal-Yam A. et al., 2009, Nature, 462, 624

Gonzalez-Delgado R. M., Leitherer C., Heckman T. M., 1999, ApJS, 125, 489

González Delgado R. M., Cerviño M., Martins L. P., Leitherer C., Hauschildt P. H., 2005, MNRAS, 357, 945

Han X. H., Hammer F., Liang Y. C., Flores H., Rodrigues M., Hou J. L., Wei J. Y., 2010, A&A, 514, A24

Izotov Y. I., Thuan T. X., Guseva N. G., 2007, ApJ, 671, 1297

James B. L., Tamanai Y. G., Barlow M. J., Westmoquette M. S., Walsh J. R., Cuisinier F., Exter K. M., 2009, MNRAS, 398, 2

Jaskot A. E., Oey M. S., 2013, ApJ, 766, 91

Kasen D., Bildsten L., 2010, ApJ, 717, 245

Kehrig C. et al., 2013, MNRAS, 432, 2731

Kennicutt R. C., Jr, 1998, ARA&A, 36, 189

Kewley L. J., Ellison S. L., 2008, ApJ, 681, 1183

Kewley L. J., Heisler C. A., Dopita M. A., Lumsden S., ApJ, 132, 37

Kuncarayakti H. et al., 2013, AJ, 146, 31

Leitherer C. et al., 1999, ApJS, 123, 3

Levesque E. M., Leitherer C., 2013, ApJ, 779, 170

Levesque E. M., Kewley L. J., Berger E., Zahid H. J., 2010, AJ, 140, 1557

Leloudas G. et al., 2015, MNRAS, 449, 917

López-Sánchez A. R., Esteban C., 2010, A&A, 516, A104

Lunnan R. et al., 2013, ApJ, 771, 97

Lunnan R. et al., 2014, ApJ, 787, 138

Luridiana V., Morisset C., Shaw R. A., 2015, MNRAS, 451, 8.2 (Levesque et al. 2010)

Marino R. et al., 2013, A&A, 559, A114

Martin-Manjón M. L., García-Vargas M. L., Moll M., Díaz A. I., 2010, MNRAS, 403, 2014

Meynet G., Maeder A., 2005, A&A, 429, 581

Neff J. D. et al., 2011, ApJ, 727, 15

Nicholl M. et al., 2013, Nature, 502, 346

Ostlin G., Zackrisson E., Sollerman J., Mattila S., Hayes M., 2008, MNRAS, 387, 1227

Pastorello A. et al., 2010, ApJ, 724, L16

Pettini M., Pagel B. E. J., 2004, MNRAS, 348, L59

Pérez-Montero E., 2014, MNRAS, 441, 2663

Pérez-Montero E., García-Benito R., Häggé G. F., Díaz Á. I., 2010, MNRAS, 404, 2037

Quimby R. M. et al., 2001, Nature, 474, 487

Quimby R. M. et al., 2012, Astron. Telegram, 4121, 1

Sánchez Almeida J., Terlevich R., Terlevich E., Cid Fernandes R., Morales-Luis A. B., 2012, ApJ, 756, 163

Sánchez-Almeida J., Muoz-Tun C., Elmegreen D. M., Elmegreen B. G., Mnež Abreu J., 2013, ApJ, 767, 74

Shirazi M., Brinchmann J., 2012, MNRAS, 421, 1043

Thöne C. C., Christensen L., Prochaska J. X., Bloom J. S., Gorosabel J., Fynbo J. P. U., Jakobsson P. Fruchter A. S., 2014, MNRAS, 441, 2034

Vazdekis A., Sanchez-Blazquez P., Falcn-Barroso J., Cenarro A. J., Beasley M. A., Cardiel N., Gorgas J., Peletier R. F., 2010, MNRAS, 404, 1639

**Supporting Information**

Additional Supporting Information may be found in the online version of this article:

PTF12dam_MNRAS_rev2_supplement.pdf

Please note: Oxford University Press are not responsible for the content or functionality of any supporting materials supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.

This paper has been typeset from a TEX/LATEX file prepared by the author.