Monthly Notices
of the
ROYAL ASTRONOMICAL SOCIETY

MNRAS **431**, 2050–2062 (2013)
Advance Access publication 2013 March 28

doi:10.1093/mnras/stt202

Supernovae and radio transients in M82

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Accepted 2013 January 31. Received 2013 January 17; in original form 2012 July 6

ABSTRACT

We present optical and near-infrared (NIR) photometry and NIR spectroscopy of SN 2004am, the only optically detected supernova (SN) in M82. These demonstrate that SN 2004am was a highly reddened Type II-P SN similar to the low-luminosity Type II-P events such as SNe 1997D and 2005cs. We show that SN 2004am was located coincident with the obscured super star cluster M82-L, and from the cluster age infer a progenitor mass of $12^{+7}_{-3}\,\mathrm{M}_{\odot}$. In addition to this, we present a high spatial resolution Gemini-North Telescope *K*-band adaptive optics image of the site of SN 2008iz and a second transient of uncertain nature, both detected so far only at radio wavelengths. Using image subtraction techniques together with archival data from the *Hubble Space Telescope*, we are able to recover a NIR transient source coincident with both objects. We find the likely extinction towards SN 2008iz to be not more than $A_V \sim 10$. The nature of the second transient remains elusive and we regard an extremely bright microquasar in M82 as the most plausible scenario.

Key words: supernovae: general – supernovae: individual: SN 2004am – supernovae: individual: SN 2008iz – galaxies: individual: M82 – galaxies: starburst – infrared: galaxies.

1 INTRODUCTION

In the nuclear regions of M82 and other nearby starburst galaxies, one core-collapse supernova (CCSN) is expected to explode every 5–10 years and a number of young supernova remnants (SNRs) have been revealed in these regions by radio observations (Kronberg, Biermann & Schwab 1985). However, due to the high dust extinction in the nuclear starburst regions most of the actual SNe have remained undetected (e.g. Mattila & Meikle 2001). Searches working at near-infrared (NIR) wavelengths have discovered SNe in the nuclear and circumnuclear regions of a few nearby starburst galaxies and luminous infrared galaxies (LIRGs) (e.g. Maiolino et al. 2002; Mattila et al. 2007; Kankare et al. 2008; Miluzio & Cappellaro 2010; Kankare et al. 2012). Furthermore, optical searches have been able to discover a few SNe in normal nearby spiral galaxies with several magnitudes of visual extinction (e.g. SNe 2002hh, 2002cv; Di Paola et al. 2002; Pozzo et al. 2006).

The first claim of a detection of a SN at optical or NIR wavelengths in M82 was by Lebofsky et al. (1986), who reported the discovery of SN 1986D in 2 μm observations. However, it was later shown by Gehrz et al. (1986) that the source identified as SN 1986D was already present in their 2.2 μm images obtained 3 years earlier and has not varied significantly in brightness since then. This source was designated as the feature K2 by Dietz et al. (1986). SN 2004am in M82 was discovered (Singer, Pugh & Li 2004) by the Lick Observatory SN Search (LOSS) on images from 2004 March 5.2 UT, but it was already present in their earlier images from 2003 November 21.6. Being on a bright spot in M82 caused their detection software to initially miss the new object. On 2004 March 6.9, SN 2004am was spectroscopically classified as a highly reddened Type II event showing some spectral similarity to the Type II-P SN (SN II-P) 1995V (Mattila et al. 2004). Radio non-detections of SN 2004am on 2003 November 14 (8.4 and 15 GHz) and on 2004 March 9 (5 GHz) were reported by Beswick et al. (2004). SN 2004am is still the only SN ever *discovered* at optical/IR wavelengths in M82.

Being a prototypical starburst galaxy at a distance of 3.3 ± 0.3 Mpc (from the Cepheid distance to the M81 group; Freedman et al. 2001) means that there is a wealth of ground- and space-based imaging of M82. Identification of progenitors in both *Hubble Space Telescope* (*HST*) and ground-based images has now become frequent (e.g. Smartt et al. 2004; Li et al. 2006; Mattila et al. 2008b; Maund & Smartt 2009; Fraser et al. 2011; Van Dyk et al. 2012). Furthermore, in M82 the compact star population has been

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studied extensively (e.g. McCrady, Gilbert & Graham 2003; Smith et al. 2006; Bastian et al. 2007; Lançon et al. 2008). Hence, SN 2004am is interesting not only because it is the first SN discovered in M82 in the optical and NIR, but also because its physical association with the well-studied super star cluster (SSC) M82-L allows a mass estimate of the progenitor star. In one recent case, SN 2004dj in NGC 2403, the explosion was coincident with a young compact star cluster (Maíz-Apellániz et al. 2004; Wang et al. 2005). The spectral energy distributions of the host cluster suggest ages and masses of 13–20 Myr and (2.4–9.6) × 10^4 $M_{\odot}$, respectively. If we assume that the stellar population in the cluster is coeval, then this leads to estimates of the progenitor mass of 12–15 $M_{\odot}$. Vinkó et al. (2009) produced an improved study of the host cluster once SN 2004dj faded using extensive data from the ultraviolet (UV) to NIR. They estimated a most likely turn-off mass in the range 12–20 $M_{\odot}$. SN 2004dj was a Type II-P event (Vinkó et al. 2006), and the estimate of the progenitor mass from the turn-off age is consistent with the mass estimates from the direct detection of SN II-P progenitors on pre-explosion images (Smartt et al. 2009).

Over the last 30 years, there have been four detected radio transients in M82 which have been suggested to be SNe. The source 41.5+59.7 (Kronberg & Sramek 1985) was seen in 1981 February at 5 GHz with a flux density of 7.07 ± 0.24 mJy, but by April of the following year had faded below the detection limit of 1.5 mJy. Another transient 40.59+ 55.8 (Muxlow et al. 1994) was detected at one epoch with the Multi-Element Radio Linked Interferometer Network (MERLIN) at 5 GHz with a flux density of ∼1.23 mJy in 1992 July. Neither of these two sources was detected by Fenech et al. (2008) to a flux limit of ∼20 μJy suggesting them to be transient sources, as opposed to sources with variable nature.

More recently, a bright (∼100 mJy) radio transient in the nuclear regions of M82 was discovered by Brunthaler et al. (2009a) in 22 GHz images from the Very Large Array (VLA) obtained in 2008 March. Over an year's time the source faded by a factor of 10, showing a spectral index of about −0.8 in the VLA (1.4–43 GHz) observations from 2009 April, indicating an optically-thick synchrotron spectrum. Furthermore, very long baseline interferometry observations from 2008 May and 2009 April revealed a ring-like structure expanding by ∼23 000 km s^{-1} (Brunthaler et al. 2010). These observations definitely confirmed the SN nature of the transient designated as SN 2008iz. Monthly monitoring of M82 with the 25 m Urumqi radio telescope at 5 GHz led to the detection of SN 2008iz as a flare on top of the M82 radio emission (Marchili et al. 2010). The SN peaked with a flux of ∼160 mJy on 2008 June 21, while modelling of its light curve yielded an accurate explosion date of 2008 February 18.

In 2009 May, another new radio transient was discovered in the nuclear regions of M82 by means of MERLIN observations (Muxlow et al. 2009). Following Gendre et al. (2013) we call it the 43.78+59.3 transient. This source reached a peak intensity of 0.72 mJy at 5 GHz in early 2009 May, and 1.7 mJy at 1.6 GHz on 2009 May 20. The nature of this object is still unknown due to its peculiar low luminosity, its longevity (still observed after 19 months of its discovery), its position with respect to the dynamical centre of the galaxy, and tentative evidence of proper motion and expansion. At the moment, the most viable explanation for its nature appears to be a microquasar (Muxlow et al. 2010; Joseph, Maccarone & Fender 2011) displaying a high ratio of radio to X-ray luminosity. For instance, the source Cygnus X-3, which is one of the strongest Galactic microquasars, has a radio luminosity exceeding its X-ray luminosity by an order of magnitude (Nipoti, Blundell & Binney 2005). Thus, a similar scenario could also be plausible in the case of the 43.78+59.3 transient.

In this paper, we present photometric and spectroscopic observations of SN 2004am which despite its small distance has remained unstudied due to the high line-of-sight dust extinction and the fact that it occurred coincident with the nuclear SSC M82-L. We make use of this coincidence to infer an initial mass for the progenitor. We use deep, high spatial resolution imaging from the Gemini-North Telescope to search for NIR counterparts of SN 2008iz and the 43.78+59.3 transient and make use of these to investigate their nature and the line-of-sight extinctions towards these sources. Finally, we discuss the nature of the radio transients in M82 making use of existing radio observations and compare these with the expectations from the SN rate estimates.

2 SN 2004AM: OBSERVATIONS AND RESULTS

2.1 Observations and data reduction

SN 2004am was observed with the NIR imager and spectrograph LIRIS on the William Herschel Telescope (WHT). LIRIS spectra covering *zJ* bands were obtained on two epochs, 2004 March 6 and 2004 November 25. The observations included in this study are listed in Table 1. The NIR imaging data were reduced using standard IRAF routines and the spectroscopy using the FIGARO package as a part of the Starlink software. SN 2004am appears coincident with the SSC M82-L in these images [with seeing full width at half-maximum (FWHM) ∼ 1.5 arcsec], and therefore, all the photometry was performed on subtracted images. The ISIS2.2 package (Alard & Lupton 1998) was used to convolve the better seeing image to the poorer seeing one, and to match the intensities and background prior to the image subtraction. The 2004 November 25 JHK_s images were used as the image subtraction references for the LIRIS images, as they provided a smooth subtraction and a further K_s epoch on 2005 January 30 indicated that the SN was no longer detectable in the November 25 K_s frame.

In addition, we recovered optical images containing the site of SN 2004am from the *HST* archive. The pipeline-reduced products from the *HST* archive were used. SN 2004am was observed with the Advanced Camera for Surveys (ACS) HRC instrument in the *F*555*W* and *F*814*W* filters on 2004 July 5 (SNAP 10272; PI: A. Filippenko). The site of SN 2004am was covered also with the ACS WFC instrument in the *F*814*W* filter on 2004 February 9 (PID 9788; PI: L. C. Ho) and 2006 March 27 . Unfortunately, SN 2004am was saturated in the image from 2004 February 9 and therefore we could not make use of it for reliable photometry. However, we were still able to use it for precise relative astrometry of SN 2004am (see Fig. 1). We attempted to detect SN 2004am in the ACS/HRC images using images obtained with the same instrument and filters on 2002 June 7 as reference for the image subtraction with the ISIS2.2 package. However, no significant source was detected at the location of M82-L in the difference images and we conclude that SN 2004am had already faded below the detection limit of *HST* by the 2004 July 5 epoch of observation (see Fig. 2).

2.2 Photometry of SN 2004am

Photometry of SN 2004am was performed in the subtracted LIRIS images using the aperture photometry procedure in the GAIA image analysis tool (Draper 2004). The JHK_s magnitudes from 2MASS for three bright field stars covered in the LIRIS field of view were used

Table 1. Optical and NIR photometry of SN 2004am. The epochs are assuming the first observation of the SN by LOSS was 2 weeks after the explosion (see Section 2.3). Between 14 and 118 days unfiltered CCD magnitudes are from Singer et al. (2004). The 'und.' label means the SN was undetected at these wavelengths with any significance in comparison to the coincident host cluster.

Date (UT) (2004)	Epoch (days)	*V*	*unfilt*	*I*	*J*	*H*	*K*	Instrument/reference
November 21.5	14	–	16.0	–	–	–	–	Singer et al. (2004)
November 23.5	16	–	16.1	–	–	–	–	Singer et al. (2004)
December 28.4	51	–	16.3	–	–	–	–	Singer et al. (2004)
January 2.5	56	–	16.4	–	–	–	–	Singer et al. (2004)
January 17.4	71	–	16.4	–	–	–	–	Singer et al. (2004)
January 21.4	75	–	16.4	–	–	–	–	Singer et al. (2004)
January 30.3	84	–	16.4	–	–	–	–	Singer et al. (2004)
February 5.3	90	–	16.4	–	–	–	–	Singer et al. (2004)
March 5.2	118	–	17.0	–	–	–	–	Singer et al. (2004)
March 6.9	120	–	–	–	12.95 ± 0.08	12.49 ± 0.16	12.03 ± 0.14	WHT/LIRIS
June 5.9	211	–	–	–	–	–	13.06 ± 0.12	WHT/LIRIS
July 5.3	241	und.	–	>20.3	–	–	–	*HST*/ACS/HRC
November 25.2	384	–	–	–	und.	und.	und.	WHT/LIRIS

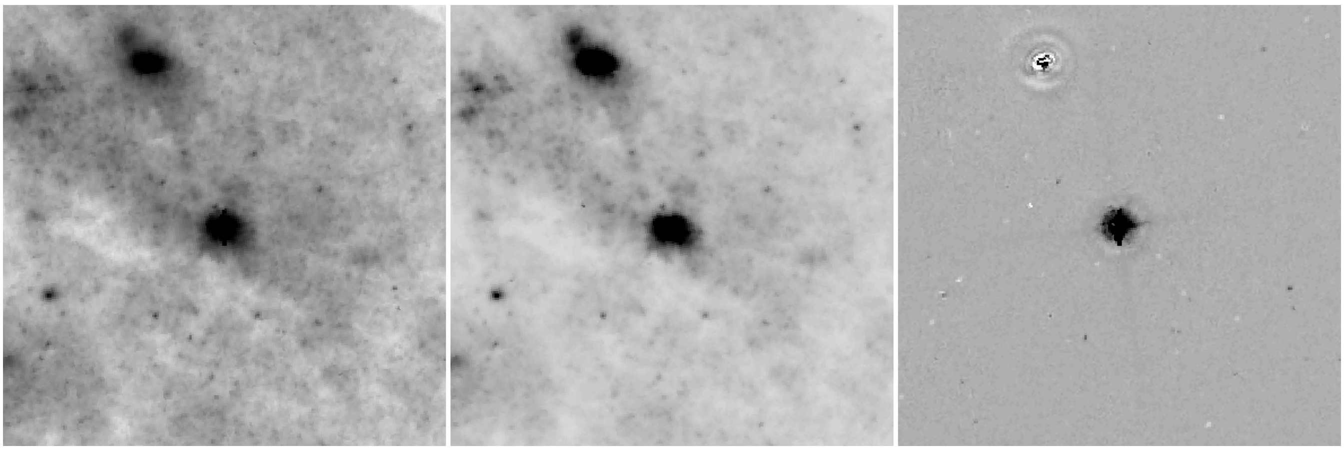

Figure 1. 10×10 arcsec^2 sections of ACS/WFC *F*814*W* images (north is up and east to the left) showing the SSCs M82-L (in the middle) and M82-F (to the north-east from the centre) obtained on 2004 February 9 (left-hand panel) and 2006 March 27 (middle panel) and the subtraction between the two obtained using ISIS2.2 (right-hand panel). The images are shown with an inverted intensity scale and the first two with log scaling. A positive saturated image subtraction residual is visible in the subtracted image at the location of M82-L.

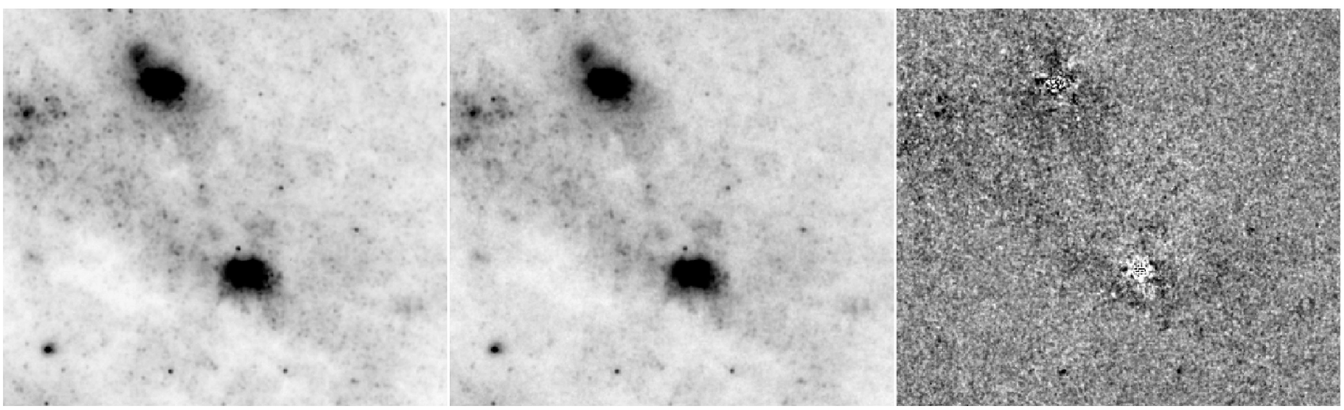

Figure 2. Sections of ACS/HRC *F*814*W* images (north is up and east to the left) showing the SSCs M82-L (to the south-west from the centre) and M82-F obtained on 2004 July 5 (left-hand panel) and 2002 June 7 (middle panel) and the subtraction between the two obtained using ISIS2.2 (right-hand panel). The first two are shown with an inverted intensity scale. Positive image subtraction residuals are visible in the subtracted image at the location of M82-L, but there is no evidence of a point source, indicating that the SN has faded below the *HST* detection limit.

for the photometric calibration. The average of the zero-point magnitudes obtained was adopted for the calibration and their standard deviation as the photometric uncertainty. The statistical uncertainty in the photometry as estimated by GAIA was in all cases negligible.

The residual noise from the flux of M82-L leaves no obvious point source in the subtracted *HST*/ACS HRC images from 2004 July 5 (see Fig. 2). Aperture photometry was performed on the residuals using GAIA. For this we used a 0.25-arcsec-radius aperture and a sky annulus between 1.5 and 2.0 times the aperture radius. No suitable point sources were present within the ACS/HRC field of view and thus we adopted an aperture correction from 0.25 arcsec to infinite aperture from Sirianni et al. (2005). Application of the appropriate Vegamag zero-point yielded $m(F814W) = 20.3$, which we adopt as an upper limit for the brightness of SN 2004am at this epoch.

2.3 The type and extinction of SN 2004am

The spectra of SN 2004am at both epochs are contaminated by the SSC. We subtracted the high-signal-to-noise spectrum of M82-L (provided by Lançon et al. 2008) from both epochs. This spectrum was manually scaled and the simple subtraction procedure resulted in an apparently flat spectrum with the SSC continuum removed in the first epoch (2004 March 6). However, the subtraction from the second epoch left no identifiable SN features and we conclude that SN 2004am had faded below the detection limit of the spectral signal.

In Fig. 3, the subtracted SN 2004am spectrum is compared to the spectra of three SNe II-P: 2004et (Maguire et al. 2010), 1995V (Fassia et al. 1998) and 1997D (Benetti et al. 2001). All spectra were dereddened (by the values quoted in the original publications) and scaled to the continuum level at 1.3 μm of SN 2004am. SN 2004am was dereddened with $A_V = 3.7$ and $R = 2.4$ as found for M82-L by Lançon et al. (2008). SN 2004am has a similar spectrum to SNe II-P at the end of the plateau phase. The ejecta velocity from the P Cygni troughs in the metal lines (e.g. Sr II, Fe II, and C I) indicates that SN 2004am appears more similar to the low-velocity and low-luminosity SN 1997D, than the other two. Cross-correlation and fitting Gaussians to the centroids of the sharpest P Cygni profiles show that the velocity difference between SNe 2004am and 1997D is negligible, while the line troughs of SNe 1995V and 2004et

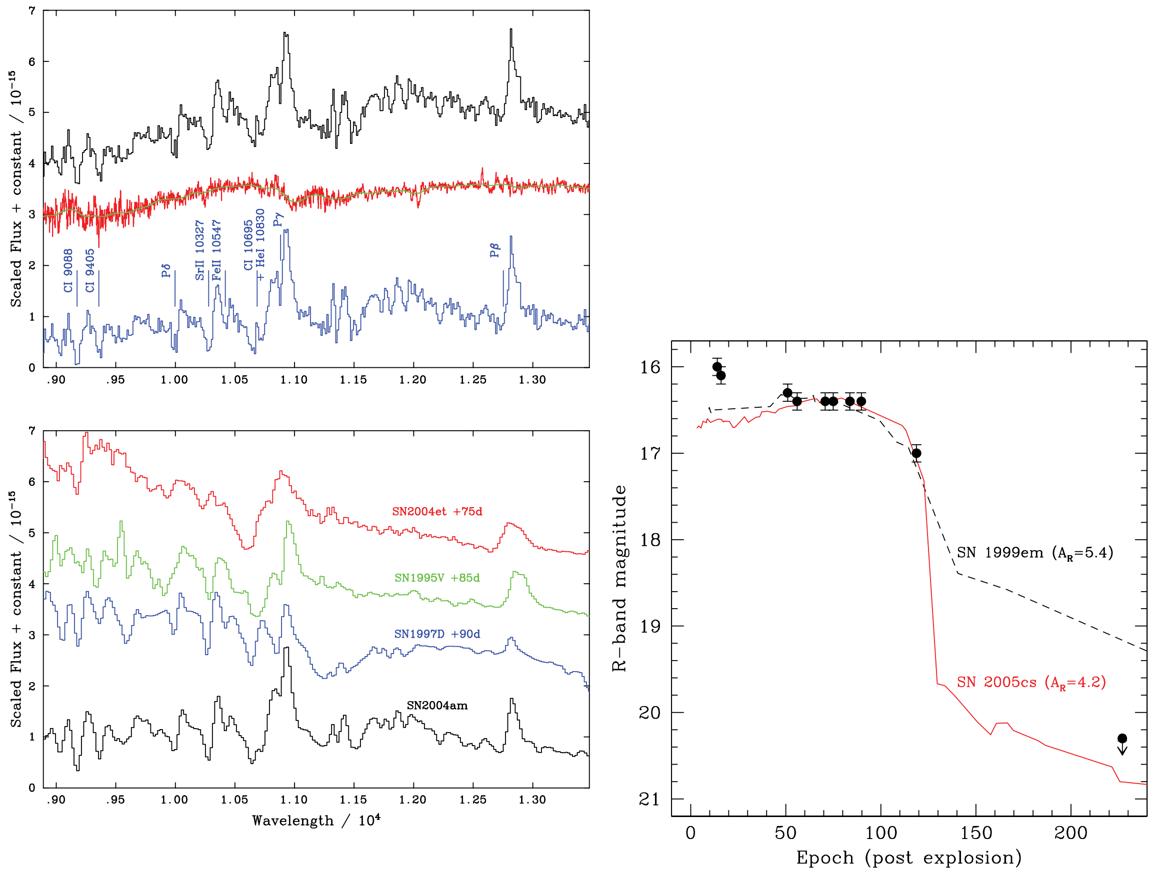

Figure 3. Left-hand top panel: a comparison of the SN 2004am *zJ* spectra obtained on 2004 March 6 (black) with the spectrum of the SSC M82-L from Lançon et al. (2008) shown in red (along with a Gaussian smoothed spectrum overlaid in green). The pre-discovery spectrum of M82-L was scaled and subtracted from the 2004 March 6 spectrum to leave a clean spectrum of SN 2004am. The major features are marked at the positions of the probable P Cygni absorption troughs. Left-hand lower panel: a comparison of the SN 2004am *zJ* spectrum with that of three other well-studied SNe II-P near the end of the plateau phase. All spectra were dereddened and scaled to match the flux of SN 2004am at 1.3 μm (see text). As the spectra were taken with a diversity of resolutions, all were broadened (with a Gaussian FWHM of 40 Å) and rebinned (to 20 Å pixel^{-1}) to the lowest resolution for a meaningful comparison. The SN 2004am spectrum was dereddened with $A_V = 3.7$ and $R = 2.4$ as found for M82-L by Lançon et al. (2008). Right-hand panel: the light curve of SN 2004am compared with the *R*-band light curves of two SNe II-P. The comparison light curves were scaled to a distance of 3.3 Mpc and dimmed to correspond to host galaxy extinctions of $A_R = 5.4$ and 4.2 for SN 1999em and 2005cs, respectively. The plateau points are unfiltered CCD magnitudes from Singer et al. (2004), and the upper limit at 241 days is an estimated limit from the *F814W HST* image. An epoch of explosion of 14 days before the first observations by LOSS was adopted for SN 2004am to yield a good match with the post-plateau drop in the light curves of SNe 1999em and 2005cs.

are blueshifted by $1000 \pm 500\,\mathrm{km\,s^{-1}}$. Furthermore, the spectral features of SNe 1995V and 2004et are visually broader (see Fig. 3).

The classification of SN 2004am as a Type II-P event is supported by its unfiltered light curve shown in Fig. 3, compared with the *R*-band light curves of two different II-P events: SNe 1999em and 2005cs (Elmhamdi et al. 2003; Pastorello et al. 2009). The plateau points of SN 2004am are unfiltered CCD magnitudes from Singer et al. (2004), and the upper limit at 241 d has been estimated from the *F*814*W* *HST* images. The light curves of the two SNe have been scaled to the same distance as SN 2004am, and have been dimmed to correspond to host galaxy extinctions of $A_R = 5.4$ and 4.2 mag, respectively. For this we adopted a distance of 11.7 Mpc for the host galaxy of SN 1999em based on Cepheids (Leonard et al. 2003) and 8.4 Mpc for the host galaxy of SN 2005cs based on the application of the Expanding Photosphere Method for SNe 2005cs and 2011dh in the same host galaxy (Vinkó et al. 2012). The total (host galaxy + Galactic) extinctions of $A_V = 0.31$ and 0.43 were adopted for SNe 1999em and 2005cs, respectively, following Smartt et al. (2009) and a Galactic extinction of $A_V = 0.53$ (Schlegel, Finkbeiner & Davis 1998) towards M82. Assuming an epoch of explosion of 14 d before the SN was first observed by the LOSS was found to yield a good match with the post-plateau drop in the light curves of SNe 1999em and 2005cs. If the extinction towards SN 2004am is similar to that found for M82-L by Lançon et al. (2008), then its absolute magnitude is fainter than that of the low-luminosity Type II-P SN 2005cs. SN 2004am is only likely to be a normal SN II-P if the extinction is higher than $A_R \simeq 5$. Also, the spectrum analysis indicates that SN 2004am has a low ejecta velocity and is similar to SNe 1997D and 2005cs. Furthermore, SN 2004am is not visible in the late deep image from the *HST*/ACS at 241 days, allowing a conservative detection limit of $I \simeq 20.3$ to be set. The corresponding *R*-band limit would be fainter than this due to the red $R - I$ colour of SNe II-P at such epochs and the likely high extinction towards SN 2004am. Fig. 3 shows this is too faint to be compatible with the nebular phase of SN 1999em, but is compatible with a SN that ejected a low amount of ^{56}Ni such as SN 2005cs (Pastorello et al. 2009).

Comparison of the unfiltered SN photometry from Singer et al. (2004) on March 5 with our *K*-band photometry on March 7 yields a SN colour of $(m_{\mathrm{CCD}} - K) \simeq +5.0$. Typical $R - K$ magnitudes around 100 days for SNe II-P are in the range 0.8–1.6 (Maguire et al. 2010); hence, this supports a host galaxy extinction of around $A_V \simeq 4$–5. The NIR colours $J - K = 0.9 \pm 0.2$ and $H - K = 0.5 \pm 0.2$ also support a large extinction for SN 2004am. Given the evidence that low-luminosity SNe show a large NIR excess which changes rapidly at around 100 days (Pastorello et al. 2009), the JHK_s colours are compatible with extinctions in the range $A_V \simeq 3$–6.

2.4 SSC M82-L and the progenitor of SN 2004am

The *HST*/ACS WFC *F*814*W* (*I*-band) image (0.05 arcsec pixel^{-1}) of M82 obtained on 2006 March 27 was aligned with the *HST*/ACS WFC *F*814*W* image from 2004 February 9. We measured the centroid positions for 30 point-like sources visible in both the images using the IRAF APPHOT package. A general geometric transformation function was derived for the pairs of coordinates using the IRAF GEOMAP task. The astrometric uncertainty was estimated from the rms of the residuals from fitting the transformation function to the data points. The uncertainties in both *x* and *y* estimated this way were about 4 milliarcseconds (mas).

To measure the position of SN 2004am, we first subtracted the aligned 2006 image from the 2004 image using the ISIS2.2 package. This revealed SN 2004am as a positive saturated point source at the location of M82-L. To minimize the biasing effects of the saturation, the position of the SN was measured in the subtracted image making use of point spread function (PSF) fitting within the SNOOPY[1] package based on IRAF's DAOPHOT. We also applied three different methods within the IRAF's APPHOT package viz. centroiding, two-dimensional Gaussian fitting and optimal filtering in order to estimate a conservative uncertainty for the position of SN 2004am. The standard deviation of the four different measurements was found to be 20 mas in *x* and 142 mas in *y* (the large uncertainty in the *y* direction was due to a strong spike in the PSF). We therefore find that the SN is located 32 ± 20 mas in *x* and 19 ± 142 mas in *y* from the centroid position of the SSC in the ACS image (see Fig. 1).

Higher resolution images of the field around M82-L and M82-F are available from the *HST*/ACS HRC (0.025 arcsec pixel^{-1}) and we have also employed the *F*814*W* filter image in measuring the cluster's radial profile. These were taken on 2002 June 7 and presented in Bastian et al. (2007). In the high-resolution *HST*/ACS HRC *F*814*W* image, the SSC is resolved, but it has a fairly sharp core compared to the nearby M82-F and two other nearby, fainter clusters (Bastian et al. 2007). The core has a half width at half-maximum (HWHM) of approximately 30 mas, but the wings of the radial profile are broad and the half width at zero-intensity is 380 mas. M82-F by comparison has a broader core with a HWHM of 70 arcsec, but a similar spatial extent of approximately 400 mas. The best measured position for SN 2004am therefore falls within the half-light radius of the cluster M82-L and we conclude that SN 2004am is spatially coincident with the SSC M82-L and that its progenitor was most likely a cluster member.

M82-L has been extensively studied in the optical and the NIR, with the first attempt at an age determination offered by Gallagher & Smith (1999). Their spectra of M82-L only included red wavelengths, resulting in a somewhat uncertain estimate of the cluster age. However, they suggest an age of around 60 Myr, similar to that obtained for M82-F, as these clusters display comparable Ca II triplet line strengths. Space Telescope Imaging Spectrograph (STIS) spectra of M82-L were analysed by Smith et al. (2006) with the spectral synthesis code STARBURST99 (Leitherer et al. 1999). A spectroscopic age for the cluster of 65^{+70}_{-35} Myr and extinction of $E(B - V) = 1.87 \pm 0.39$ were derived. The large error bars arise mostly from the fact the *U* band was not covered and hence the extinction and age become difficult to disentangle.

The more recent study of Lançon et al. (2008) presented a medium-resolution ($R \simeq 750$), high-signal-to-noise ratio, 0.8–2.4 μm spectrum of M82-L. They used the stellar population synthesis code (PÉGASE.2), with a library of observed red supergiant spectra to produce single stellar population spectra with ages in the range 8–60 Myr. In all cases, near-solar metallicity is assumed, along with a Salpeter initial mass function (IMF). An impressive fit to the JHK_s spectra of M82-L is obtained for a single stellar population of age 18^{+17}_{-8} Myr. The age of the cluster provides a strong constraint on the mass of the progenitor star, if we assume that the cluster formed coevally and that the cluster age is representative of that of the progenitor. Smartt et al. (2009) employed the stellar evolutionary tracks of Eldridge & Tout (2004) to determine stellar

[1] SNOOPY, originally presented in Patat (1996), has been implemented in IRAF by E. Cappellaro. The package is based on DAOPHOT, but optimized for SN magnitude measurements.

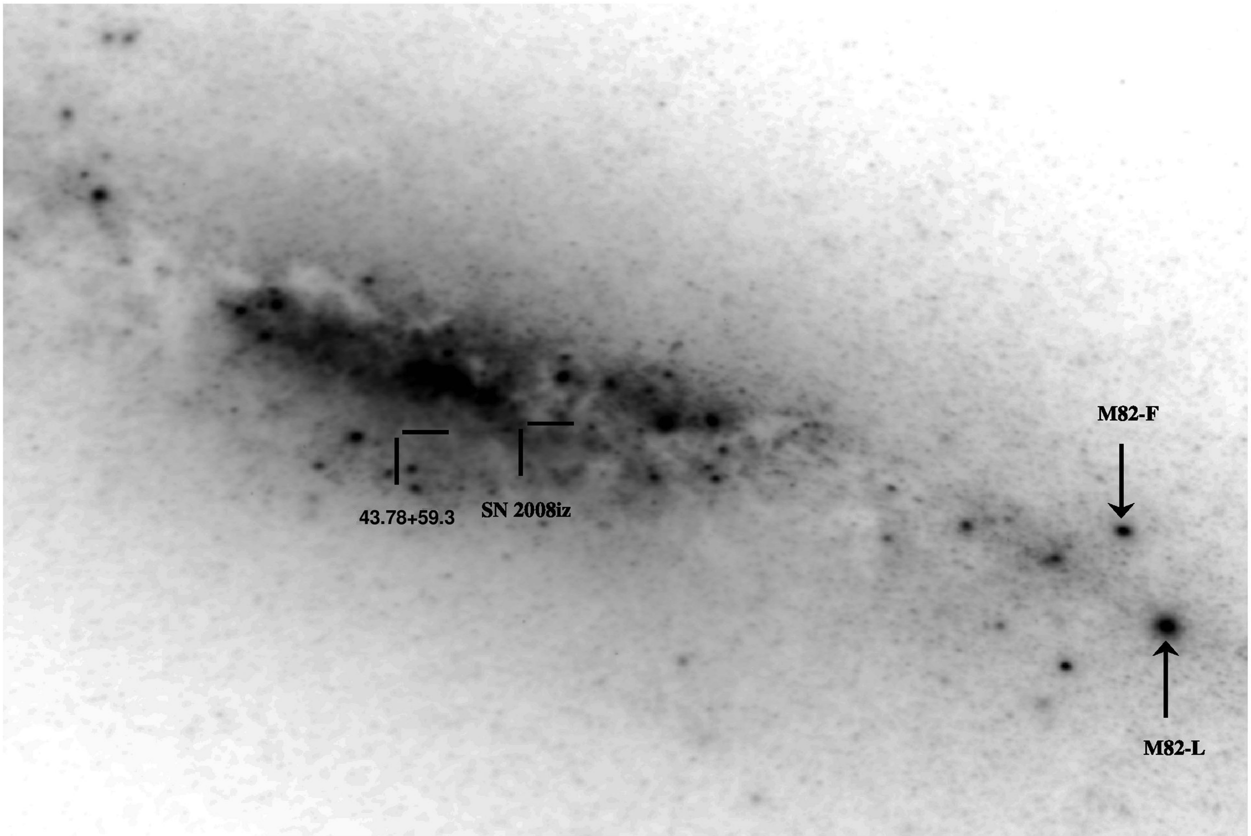

Figure 4. A 50 × 33 arcsec^2 region of the *K*-band Gemini-North Telescope Altair/NIRI image of the M82 nuclear regions (north is up and east to the left). The locations of SN 2008iz, the 43.78+59.3 transient and the SSCs M82-L and M82-F are indicated.

masses of SN II-P progenitors. Using these tracks (to allow a consistent comparison), we find that an age of 18^{+17}_{-8} Myr corresponds to lifetimes of stars of initial masses $12^{+7}_{-3}\,M_{\odot}$. The models in the single stellar population analysis of Lançon et al. (2008) were those of Bressan et al. (1993) and the age–mass relationships in both codes are quite similar.

3 SN 2008IZ AND THE 43.78+59.3 TRANSIENT – OBSERVATIONS AND RESULTS

3.1 Observations and data reduction

The sites of SN 2008iz and the 43.78+59.3 transient were observed on 2009 June 11 using the Near-Infrared Imager (NIRI) with the ALTAIR AO system on the Gemini-North Telescope, as part of our SN progenitor identification programme.[2] The f/14 camera was used, giving 0.05 arcsec pixels over a 51 × 51 arcsec^2 field of view. While typically in AO observations of SNe, the SN itself is used as a natural guide star (or a tip-tilt star together with a laser guide star), this is only possible for bright (V < 15 mag) SNe. Hence, for these observations obtained in the natural guide star mode we used the nearby cluster M82-F as the natural guide star. During the observations the seeing was exceptionally good, mostly FWHM < 0.4 arcsec (as measured by ALTAIR), yielding a reasonable AO correction quality (FWHM ∼ 0.2 arcsec), despite M82-F being an extended source. An integration time of 60 s was used per pointing and separate sky frames were obtained. The image shown in Fig. 4 has a total on-source integration time of 30 min and was reduced using standard techniques (sky subtraction and masking of bad pixels) for NIR imaging with the IRAF GEMINI package.

As neither SN 2008iz nor the 43.78+59.3 transient was immediately visible at their position from the radio observations (Fraser et al. 2009), we attempted to perform image subtraction to identify any faint transient source or low-level variability at the site of either transient. We obtained pre-explosion observations from *HST*+NICMOS via MAST[3] to use as reference images for the image subtraction. For SN 2008iz, the images used were a 448 s exposure with the NIC2 camera (pixel scale 0.075 arcsec pixel^{-1}) in the *F*222*M* filter and a 1408 s exposure in the *F*237*M* filter obtained using the same camera. For the 43.78+59.3 transient, the templates used were a 448 s exposure in *F*222*M* and a 1408 s exposure in *F*237*M*. All the NICMOS images were taken on 1998 April 12; the pipeline-reduced products from the *HST* archive were used.

3.2 Alignment and SN identification

As the field of view of both the NIRI (51 × 51 arcsec^2) and the NICMOS (19 × 19 arcsec^2) images is small compared to the angular size of M82, we employed a bootstrap technique to obtain accurate astrometry for our data. We first identified SDSS sources in an *F*814*W*-filter *HST*/ACS mosaic (Mutchler et al. 2007) of M82, which allowed us to calibrate the world coordinate system (WCS)

[2] GN-2009A-Q-32.

[3] http://archive.stsci.edu

Table 2. Reported coordinates of the transients in M82 discussed in this paper. All coordinates are in J2000.

Transient	RA	Dec.	Reference
SN 2004am	9:55:46.61	+69:40:38.1	Singer et al. (2004)
SN 2008iz	9:55:51.55	+69:40:45.792	Brunthaler et al. (2009b)
	9:55:51.55	+69:40:45.788	Beswick et al. (2009)
43.78+59.3 transient	9:55:52.5083	+69:40:45.420	Muxlow et al. (2009)

of this image to a high degree of accuracy, and subsequently used this frame as an astrometric reference for all other images.

The ACS mosaic of M82 was downloaded from the *HST*/MAST high-level science products web pages.[4] This mosaic image has been corrected for the geometric distortion of ACS, and its internal astrometric accuracy is extremely good, with residuals in the alignment of the input tiles to the mosaic of ∼0.1 pixels, corresponding to 5 mas. We identified 51 point sources which are in the Sloan catalogue (Abazajian et al. 2009) with an *r* magnitude < 21 mag. The coordinates of these sources were measured with the IRAF PHOT task. Using the pixel coordinates of the sources, together with the Sloan catalogue celestial coordinates, we refit the WCS for the ACS mosaic using IRAF CCMAP and CCSETWCS. A general transformation was allowed, consisting of translation, rotation, scaling and a polynomial term. Three sources were discarded at this stage as outliers. The rms error in fitting the new WCS was 48 and 41 mas in RA and Dec., respectively.

Next, we identified 26 sources in common between our NIRI *K*-band image and the ACS *F*814*W*-filter mosaic. We measured the pixel coordinates of these as before with IRAF PHOT, and fitted the matched coordinate list with a general transformation using IRAF GEOMAP. We rejected two sources as clear outliers from the fit. The rms error in the fit was 20 and 22 mas in RA and Dec., respectively. The NIRI image was transformed to match the ACS image, and the two frames compared by eye to verify the transformation.

Using the Sloan-calibrated WCS, and using the values of RA and Dec. from radio observations given in Table 2, we identified the pixel coordinates of SN 2008iz and the 43.78+59.3 transient in the ACS image. These coordinates were then transformed to the NIRI image using the transformation determined previously with the GEOXYTRAN task.

Unfortunately, the sites of SN 2008iz and the 43.78+59.3 transient are on different NICMOS images, and so each had to be aligned to the NIRI image separately. In each case, we matched between 10 and 20 common sources, and transformed the NICMOS image to the pixel coordinates of the NIRI image using IRAF GEOMAP and GEOTRAN.

For SN 2008iz, we used the ISIS2.2 package to convolve the *F*222*M*- and *F*237*M*-filter NICMOS images to match the PSF and flux level of the NIRI *K*-band image. We then subtracted the convolved *F*222*M* and *F*237*M* images from the *K* image, and searched for residual flux at the site of the radio SN. As an additional test, we subtracted the *F*222*M* image from the *F*237*M* image to see if a colour difference could produce a source.

The results of these subtractions are shown in Figs 5 and 6. As can be seen, there is a clear detection of a source coincident with the radio coordinates of SN 2008iz in the subtractions between the NIRI and NICMOS images. The source in the difference image consists of positive flux, implying a brightening since 1998 April. The source is clearest in the subtraction between the NIRI *K* and NICMOS *F*222*M* images (which is unsurprising given the good match between the bandpasses of the filters, as shown in Fig. 7), although it is still significant in the subtraction with the *F*237*M* image. No source is detected at the site of the SN in the subtraction between the *F*222*M* and *F*237*M* filters, indicating that there is not a point source with a large *F*222*M* − *F*237*M* colour at this location that could account for the source in the other subtractions.

We repeated the same procedure for the 43.78+59.3 transient, again finding a source at the radio position of the transient in the difference image. As the detection was not as clear as in the case of SN 2008iz, we repeated the convolution and subtraction process using HOTPANTS,[5] but obtained the same result.

We measured the pixel coordinates of both sources in the difference images obtained with ISIS2.2 and the *F*222*M* template image using the optimal filter centring algorithm in IRAF PHOT. In the case of SN 2008iz, we find an offset of 0.68 pixels (34 mas) between the expected and measured positions of the transient, while for the 43.78+59.3 transient there is a 1.62 pixel (81 mas) offset. While this is slightly outside the combined rms error of the alignment (70 mas), we nonetheless consider the association convincing, given that the transient source is detected at a relatively low signal-to-noise ratio. We identified nine other point sources which appeared in a 12 × 12 arcsec^2 region in the difference image for the 43.78+59.3 transient; from this we calculate a probability of a variable or transient source coincident to less than 81 mas as ∼0.1 per cent.

3.3 Photometry of SN 2008iz and the 43.78+59.3 transient

For SN 2008iz and the 43.78+59.3 transient, we performed both PSF fitting and aperture photometry in the *K* − *F*222*M* difference images. To set the zero-point for the photometry, we measured the most isolated and point-like SSCs 6, c, d, F and L in the NIRI frame, adopting their *F*222*M* magnitudes from McCrady et al. (2003). As no bright enough individual stars were covered within the NIRI field of view, also the PSF was determined using the SSCs. According to McCrady et al. (2003) these SSCs have their projected half-light radii less than ∼0.09 arcsec, i.e. are unresolved in our NIRI images with spatial resolution of FWHM ∼ 0.2 arcsec and are within ∼30 arcsec from SN 2008iz and the 43.78+59.3 transient. The average value and the standard deviation of the zero-points obtained with the different clusters were adopted to be used for the photometric calibration and its associated uncertainty. We also attempted to use 2MASS sources in the NIRI field of view to set the zero-point, but unfortunately there were an insufficient number of isolated sources with reliable 2MASS *K*-band magnitudes covered by the field of view. As a consistency check, photometry was also obtained from a subtracted image where the NIRI frame was scaled to match the flux units of the NICMOS template prior to the

[4] http://archive.stsci.edu/prepds/m82/

[5] http://www.astro.washington.edu/users/becker/hotpants.html

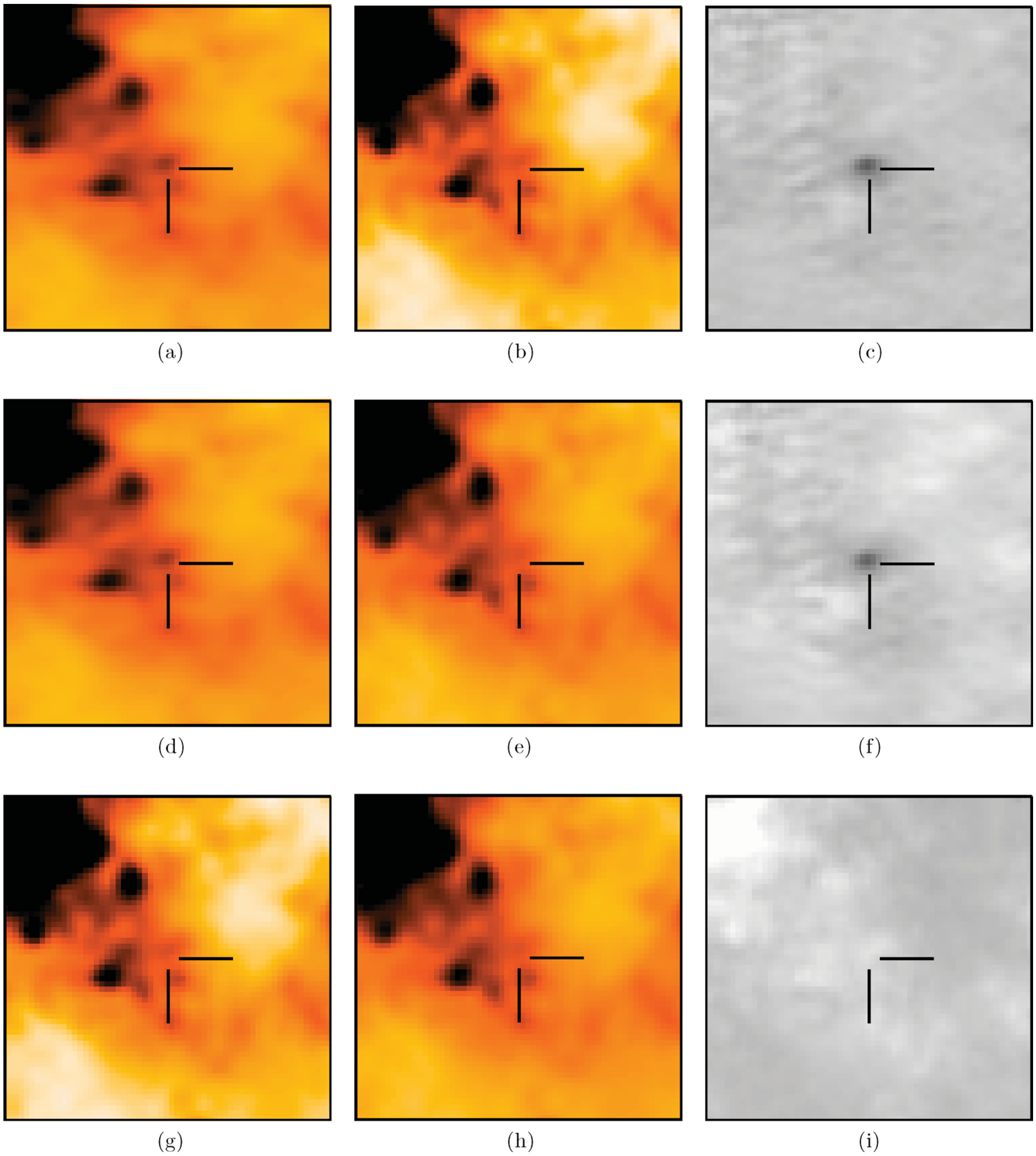

Figure 5. Gemini post- and *HST* pre-explosion images of the site of SN 2008iz, together with difference images obtained with ISIS2.2. In all cases, the images are centred on the radio coordinates of the transient, with north up and east left. All images are 3 × 3 arcsec^2. (a) Gemini+NIRI (*K*) post-explosion. (b) *HST*+NICMOS (*F222M*) pre-explosion, transformed to match the NIRI image. (c) Subtraction of (b) from (a) using ISIS2.2. (d) Gemini+NIRI (*K*) post-explosion. (e) *HST*+NICMOS (*F237M*) pre-explosion, transformed to match the NIRI image. (f) Subtraction of (e) from (d) using ISIS2.2. (g) *HST*+NICMOS (*F222M*) pre-explosion. (h) *HST*+NICMOS (*F237M*) pre-explosion. (i) Subtraction of (g) from (h) using ISIS2.2.

subtraction. Using the PHOTFLAM value in the FITS header of the latter yielded a *K* magnitude for SN 2008iz within ∼0.1 mag from the one obtained using the SSCs.

Using PSF fitting for SN 2008iz gives a magnitude of *F222M* (∼*K*) = 15.91 ± 0.16 where the error is dominated by the uncertainty in the zero-point magnitude (±0.14 mag). The photometric uncertainty was estimated via PSF fitting to artificial sources placed close to the SN position after subtracting the PSF fit at the SN position. For comparison, using a photometric aperture with an 8 pixel radius for SN 2008iz gives a magnitude of 16.03. In this case, the zero-point was obtained using aperture photometry (8 pixel radius) of the five SSCs. Varying the photometric aperture by a few pixels causes the photometry of SN 2008iz to vary by up to 0.2 mag. The measured magnitude is also dependent on the region used to measure the sky background at the SN location. The convolution used in the image subtraction will also affect the noise properties of the subtracted image. For these reasons, we adopt a conservative error of ±0.3 mag for our aperture photometry which is larger than would be implied by Poissonian statistics.

For the 43.78+59.3 transient, we obtain a magnitude of *F222M* = 17.87 ± 0.28 by PSF fitting. For the aperture photometry, we used a smaller aperture with a 4 pixel radius to avoid including flux from an image artefact to the south of the transient in the difference image (as can be seen in Fig. 6c). Using the zero-point from aperture photometry (4 pixel radius) of the five SSCs, we find a magnitude of *F222M* = 17.59, with the same conservative error of ±0.3 mag

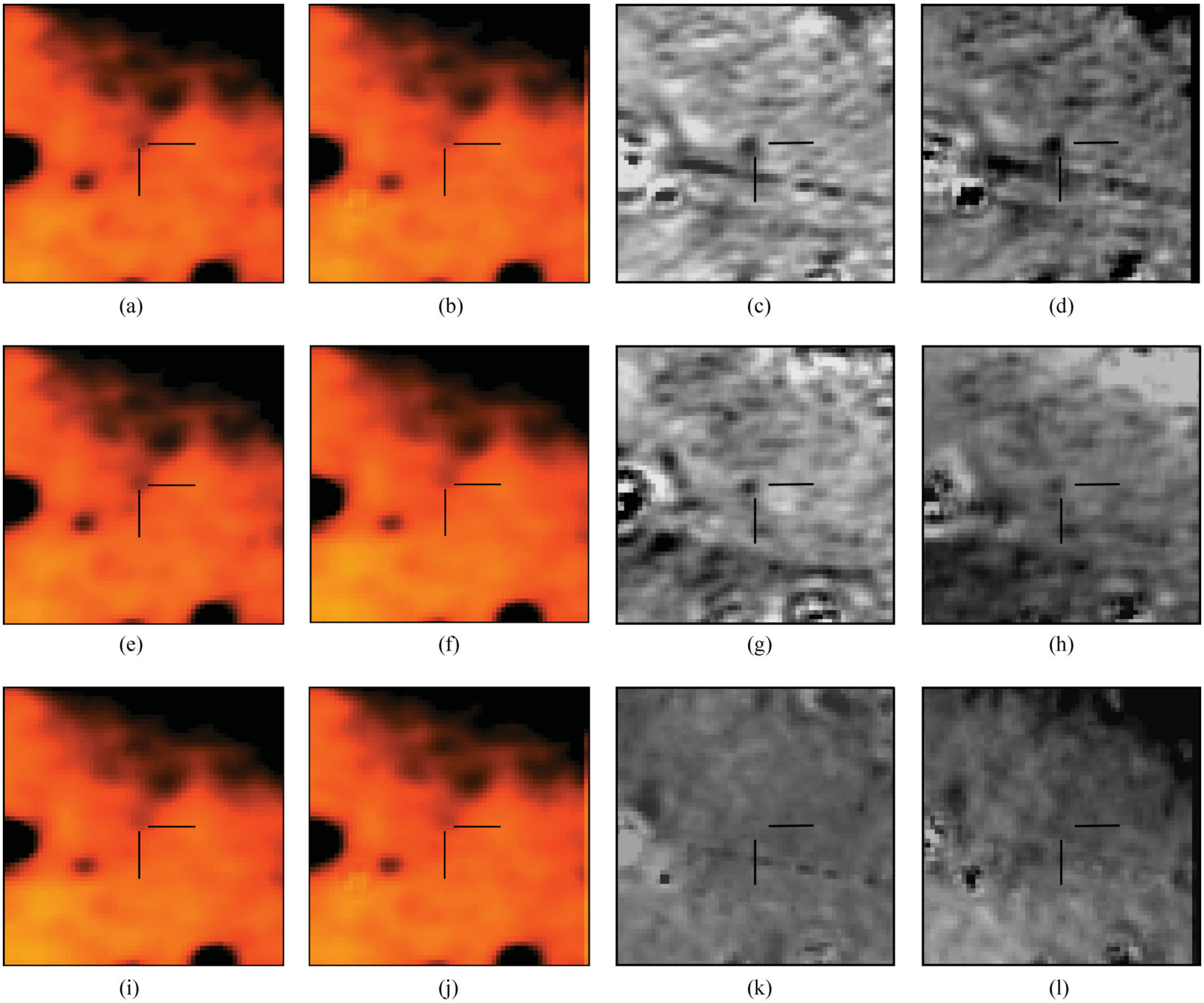

Figure 6. Gemini post- and *HST* pre-explosion images of the site of the 43.78+59.3 transient, together with difference images obtained using ISIS2.2 and HOTPANTS. In all cases, the images are centred on the radio coordinates of the transient, with north up and east left. All images are 3 × 3 arcsec^2. (a) Gemini+NIRI (K_s) post-explosion. (b) *HST*+NICMOS (*F222M*) pre-explosion, transformed to match the NIRI image. (c) Subtraction of (b) from (a) using ISIS2.2. (d) Subtraction of (b) from (a) using HOTPANTS. (e) Gemini+NIRI (K_s) post-explosion. (f) *HST*+NICMOS (*F237M*) pre-explosion, transformed to match the NIRI image. (g) Subtraction of (f) from (e) using ISIS2.2. (h) Subtraction of (f) from (e) using HOTPANTS. (i) *HST*+NICMOS (F237M) pre-explosion, transformed to match the NIRI image. (j) *HST*+NICMOS (F222M) pre-explosion, transformed to match the NIRI image. (k) Subtraction of (j) from (i) using ISIS2.2. (l) Subtraction of (j) from (i) using HOTPANTS.

as estimated for SN 2008iz. As a check on the effect of the small aperture on our photometry, we used the same 4 pixel radius to measure the magnitude of SN 2008iz, and found a value which differs only by 0.2 mag from that found through the 8 pixel aperture. As this difference is smaller than our errors, we do not regard this as a significant source of error.

From now on we adopt the PSF-fitting-based magnitudes as the most accurate ones to be used in this study. We note that these are also consistent with the magnitudes obtained through aperture photometry but have smaller uncertainties. As a final test, we used SYNPHOT to calculate the $F222M - K$ colour of a range of blackbodies between 100 and 50 000 K. For temperatures hotter than 500 K, we find that the colour difference between the two filters is negligible (0.02 mag or less). While the difference does become large (>0.1 mag) for $T < 400$ K, if the flux in SN 2008iz was coming from dust at this temperature, then it would be emitting in the mid-IR rather than the *K* band (Mattila et al. 2008a).

4 DISCUSSION

4.1 SN 2004am

SN 2004am is the only SN ever discovered at optical/IR wavelengths in the prototypical starburst galaxy M82. It occurred spatially coincident with the obscured SSC M82-L and suffers from a host galaxy extinction of $A_V \simeq 5 \pm 1$ which is consistent with the extinction derived for M82-L. From the compiled photometry and our NIR spectra, it is clearly a SN II-P, which one would expect to come

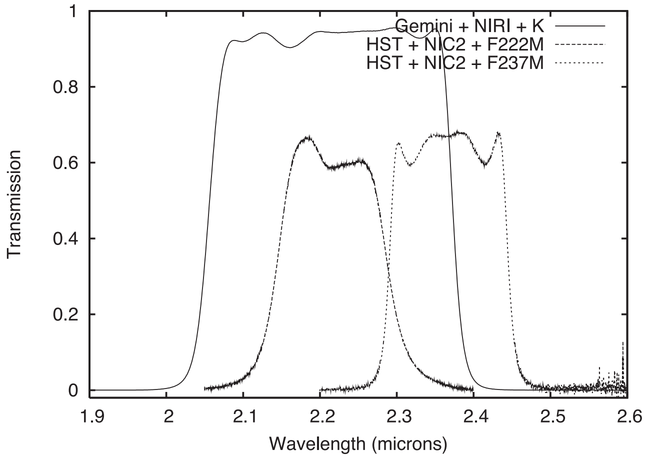

Figure 7. Transmission curves for *HST* (telescope + instrument + filter) and Gemini (filter only) used for the pre- and post-explosion imaging of SN 2008iz and the 43.78+59.3 transient.

from a red supergiant progenitor star. It is likely a low-luminosity SN II-P and these have been proposed to come from stars towards the lower mass range that will produce core collapse (Smartt et al. 2009).

Lançon et al. (2008) and McCrady & Graham (2007) show that the NIR spectra of M82-L are dominated by the spectral features of red supergiant stars. The viral mass of the cluster is estimated to be $(4 \pm 0.6) \times 10^6\,M_\odot$ (McCrady & Graham 2007) which agrees with the mass estimate from the cluster luminosity by Lançon et al. (2008). Assuming the best-fitting age of around 18 Myr (Section 2.4) for M82-L, the single stellar population models of Lançon et al. (2008) suggest there are likely to be of the order of 100–260 red supergiants in the cluster, depending on the IMF and lower mass limit used. Clearly there is a rich population of red supergiants as potential progenitors of SNe II-P.

In fact M82-L is the most massive host cluster of a SN that has been accurately measured in the nearby Universe. Nearby SNe do not tend to be discovered coincident with the most massive unresolved clusters. In the volume-limited sample of 20 SNe II-P reviewed by Smartt et al. (2009) which have high-resolution pre-explosion images available, only two fall on compact clusters. This may be a little surprising; however, Pellerin et al. (2007) show that in NGC 1313 75–90 per cent of the UV flux is produced by stars outside the dense clusters. They propose that the late O and early B-type stars (that will eventually produce 8–30 $M_\odot$ red supergiants) are diffusely spread throughout a galaxy due to infant mortality of stellar clusters (Lada & Lada 2003). Crockett et al. (2008) have shown that Type Ic SN 2007gr exploded on the edge of a bright object in NGC 1058 and suggested that this may be a host cluster. This is one of the 12 SNe Ib/c studied by Eldridge et al. (2013) at high resolution and is the only one possibly associated with a stellar cluster, again supporting an approximate figure of 10 per cent.

The mass range that we suggest is appropriate for the progenitor ($12^{+7}_{-3}\,M_\odot$) is in agreement with the masses of red supergiants directly detected in nearby galaxies. Smartt et al. (2009) present a full list of a volume- and time-limited search for SN progenitors, and find the likely progenitor population of SNe II-P are red supergiants of initial masses 8–17 $M_\odot$. The mass of the progenitor of SN 2004am is consistent with this mass range. The fact that it was in a cluster with such a rich red supergiant population further supports the idea that this stellar evolutionary phase directly gives rise to SNe II-P. However, we note that Fraser et al. (2011) suggest a lower mass range of 8–9 $M_\odot$ for the progenitors of sub-luminous SNe II-P, and if SN 2004am was one of these events, it is also in agreement with the expected progenitor mass range within the 1σ uncertainty.

4.2 SN 2008iz

In Fig. 8, we compare the radio luminosities of SN 2008iz and the two radio transients in M82 (41.5+59.7 and 40.59+55.8) of unknown nature with the peak spectral radio luminosities of SNe with different types. The luminosities of the two transients are comparable with those of SNe II-P, such as SNe 1999em and 2004dj. The peak luminosity and time to reach the peak make SN 2008iz very similar to the well-observed Type IIb SN 1993J, thus suggesting that also their progenitor stars might be similar. However, the expansion velocity of ∼20 000 km s^{-1} observed for SN 2008iz (Brunthaler et al. 2010) was somewhat higher than the one for SN 1993J (∼15 000 km s^{-1}; Marcaide et al. 1995).

At a distance of 3.3 Mpc, SN 2008iz has an absolute magnitude of $K = -11.68 \pm 0.16$ for zero host galaxy extinction. The first detection of SN 2008iz at radio wavelengths was in 2008 March, with a best estimate for the explosion epoch of 2008 February 18, implying that at the time of our NIRI observation the SN was already ∼480 days old. Unfortunately, there are few SNe with NIR light curves for comparison at this late phase. However, SN 1987A had an absolute magnitude of $K = -12.2$ (Suntzeff & Bouchet 1990) at +450 days, while at 300 days SN 2004et had an absolute magnitude of $K = -13.35$ (Maguire et al. 2010). These magnitudes are comparable to that of SN 2008iz with a modest amount of extinction ($A_K \lesssim 1$ mag).

Brunthaler et al. (2010) estimated the extinction towards SN 2008iz to be $A_V = 24.4$ mag, using the intensity of the ^{12}CO ($J = 2 \rightarrow 1$) line from Weiß et al. (2001), together with the CO

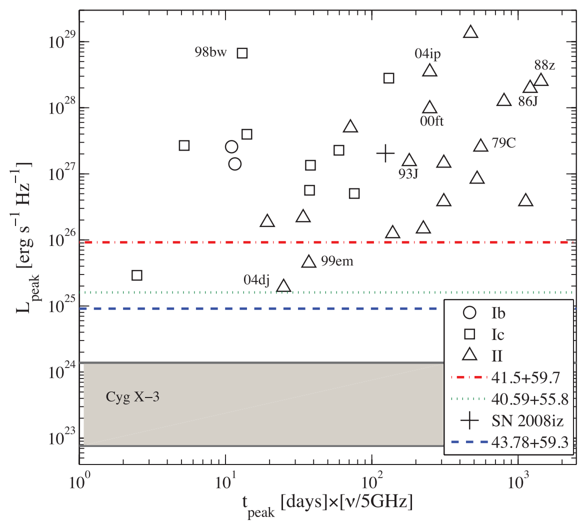

Figure 8. Peak spectral radio luminosity versus time to reach the peak (normalized to 5 GHz) for different types of CCSNe. The four M82 transients have been added to allow comparison with historic radio SNe. SN 2008iz is represented by a cross, whereas the rest of the transients, for which the peak epoch is unknown, are represented as the dot–dashed (41.5+59.7), dotted (40.59+55.8) and dashed (43.78+59.3) lines. The grey region represents the range that the galactic microquasar Cygnus X-3 has been observed to reach in major flare states at radio wavelengths (Waltman et al. 1995).

to H_2 ratio and the relation of Güver & Özel (2009) between hydrogen column density and extinction. We find, however, that when using the same data and relations as Brunthaler et al. (2010), we obtain a total extinction of $A_V = 48.9$ mag. This is exactly twice the value found by Brunthaler et al. (2010), and we suggest that these authors may have neglected to multiply the value of $N(H_2)$ by 2 to convert to hydrogen nuclei before applying the hydrogen nuclei to the extinction relation of Güver & Özel (2009).

$A_V = 48.9$ mag implies an extinction in K of ∼5.5 mag (Cardelli, Clayton & Mathis 1989). Such a high extinction would put SN 2008iz at an absolute magnitude of $K \sim -17$ mag, which is uncomfortably high for a SN at such a late phase. While a late-time NIR excess has been observed for several SNe, and attributed to dust formation in the cool, dense shell located between the forward and reverse shocks (e.g. Fox et al. 2009), a K-band excess of this magnitude is quite unusual. Furthermore, such excesses are most commonly seen in SNe IIn, which are intrinsically rare. For example, adopting a distance of 18.6 Mpc (assuming the Virgo+GA+Shapley corrected recession velocity from NED and $H_0 = 70$ km s^{-1} Mpc^{-1}) for SN IIn 1998S, its absolute K-band magnitude (Pozzo et al. 2004) at an epoch of ∼480 days was ∼−17.5. A more likely explanation of the apparent discrepancy between the extinction for SN 2008iz as derived from the H_2 column density, and that expected for a SN at that phase, is that much of the H_2 lies behind the site of SN 2008iz. If the SN was located behind one-fifth of the total H_2 column, then its derived extinction would be closer to $A_V \sim 10$ mag, bringing the late-time magnitude into agreement with that of SNe 1987A and 2004et.

4.3 The 43.78+59.3 transient

One of the possible explanations advocated for the 43.78+59.3 transient by Muxlow et al. (2010) and Joseph et al. (2011) was that it was an extragalactic microquasar. Microquasars are the stellar analogues to quasars, and are believed to arise from a compact object accreting matter from a stellar companion, and in the process forming a relativistic jet. They typically display strong and variable radio and X-ray emission. In Fig. 8 we compare the radio luminosity of the 43.78+59.3 transient with the range of luminosities that the Galactic microquasar Cygnus X-3 has been observed to reach in major flare states (Waltman et al. 1995). Only if Cygnus X-3 would increase its highest observed radio luminosity by a factor of ∼10, the 43.78+59.3 transient would be comparable in brightness. We note that recently Batejat et al. (2012) have proposed that three rapidly variable radio sources within the nuclear regions of the ultraluminous IR galaxy Arp 220 having their radio luminosities a factor of ∼100 times larger than the luminosity of the 43.78+59.3 transient could be associated with highly beamed microquasars. The apparent magnitude of the 43.78+59.3 transient is $K \sim 17.9$, corresponding to an absolute magnitude of $K \sim -9.7$ if assuming no host galaxy extinction. Such a bright absolute magnitude would make the 43.78+59.3 transient the brightest known example of a microquasar by quite some margin; for comparison, the Galactic microquasar SS433 has an absolute magnitude which varies between $K = -5.7$ and -6.4 (Kodaira, Nakada & Backman 1985; Blundell & Bowler 2004).

The 43.78+59.3 transient was first detected in the radio 40 days prior to the epoch of the Gemini image. From the templates presented in Mattila & Meikle (2001) at +40 days, we would expect a normal, unextinguished SN in M82 to have an apparent magnitude of $K \sim 9.6$. Clearly the observed magnitude of the 43.78+59.3 transient appears difficult to reconcile with a SN. If, however, the first detection of the 43.78+59.3 transient did not mark the explosion epoch, but was instead late time radio emission, then the faint absolute magnitude is less puzzling. Similarly, ∼70 mag of extinction in V would bring the observed and expected K magnitudes into agreement. However, even with a high extinction or an earlier explosion epoch, its observed radio flux density evolution (Gendre et al. 2013; Rob Beswick, private communication) points to a non-SN origin for this source.

The absolute magnitude of the 43.78+59.3 transient is comparable to the quiescent magnitude of luminous blue variables (LBVs). LBV eruptions, also termed 'supernova impostors' (Van Dyk et al. 2000), can reach an absolute magnitude of ∼−12 to −16 in V. The SN impostors SN 2009ip and UGC 2773 OT2009-1 have upper limits on their 8 GHz radio luminosity of $<1.3 \times 10^{26}$ erg s^{-1} Hz^{-1} and $<2.6 \times 10^{26}$ erg s^{-1} Hz^{-1}, respectively (Foley et al. 2011). These limits are an order of magnitude higher than the peak radio luminosity of the 43.78+59.3 transient, and hence the luminosity of the latter is not inconsistent with the limited information on the properties of SN impostors at radio wavelengths.

The NIR magnitude of the 43.78+59.3 transient is also reminiscent of that of a nova at peak. Most common novae fade rapidly after the outburst, but from the template light curves presented in Strope, Schaefer & Henden (2010) either an F- or D-class nova could still be bright at ∼+40 days. However, classical novae are not usually strong radio sources, and the peak of the radio light curve tends to be later than the optical maximum; hence, the MERLIN detection would appear incongruous with this scenario.

The nature of the 43.78+59.3 transient remains elusive, and on the basis of the limited data available, we regard an extremely bright extragalactic microquasar as the most plausible scenario, perhaps from a high-mass X-ray binary such as LS 5039 (Clark et al. 2001), but with a high ratio of radio to X-ray flux. A bright extragalactic microquasar was proposed as the most likely explanation by Muxlow et al. (2010) and Joseph et al. (2011). We concur with that conclusion although it would mean that the NIR luminosity is a factor of about 30 higher than Galactic microquasars.

4.4 Comparison with the expected SN rate

SNe 2004am and 2008iz are still the only SNe detected at optical/NIR wavelengths in M82. This is perhaps somewhat surprising, given the SN rate estimates of around 7–9 per century (Fenech et al. 2008; Fenech et al. 2010), the small distance and the appeal of this galaxy as a target in SN searches. It is very likely that extinction has hampered the discovery of recent SNe in the past decade (for estimates of extinctions towards the radio SNRs of M82, see Mattila & Meikle 2001). Over the last ∼20–30 years during which M82 has been regularly monitored at radio wavelengths, the detection of two confirmed SNe (SNe 2004am and 2008iz) and the two radio transients (41.5+59.7 and 40.59+55.8) with a possible SN origin is in reasonable agreement with the expectation. However, the discoveries of SNe 2004am and 2008iz have important lessons for attempts to find heavily extinguished SNe in more distant starburst galaxies. While SN 2008iz was recovered at a comparable magnitude to the two SNe found by Kankare et al. (2012) in their NIR LIRG SN search, it is of note that Fraser et al. (2009) originally reported a non-detection for both SN 2008iz and the 43.78+59.3 transient. We have only recovered these transients with a careful analysis using a posteriori knowledge of the source positions from radio observations. Without these data, it is likely that SN 2008iz would have remained undiscovered in the NIR.

Recently Mattila et al. (2012) studied the fraction of CCSNe missed by rest-frame optical SN searches and found an average local value of ∼20 per cent increasing to ∼40 per cent of CCSNe missed at $z \sim 1$–2. These estimates highlight the need for a better control of the SN activity in the obscured environments such as the nuclear regions of nearby starburst galaxies and LIRGs. Unless properly accounted for, such systematic effects can dominate the uncertainties in the CCSN rates at high redshift (e.g. Dahlen et al. 2012; Melinder et al. 2012).

5 CONCLUSIONS

SN 2004am was the first optically detected SN in M82 when discovered by LOSS (Singer et al. 2004), and remains the only transient discovered in the optical. We show that it is most likely to have been a subluminous, highly reddened Type II-P event coincident with the obscured nuclear SSC M82-L. From the cluster age we inferred a progenitor mass of $12^{+7}_{-3}\,\mathrm{M}_{\odot}$ which is within the uncertainties in agreement with the expected progenitor mass range for such events. Making use of high spatial resolution *K*-band imaging, we detected NIR counterparts for both SN 2008iz and the 43.78+59.3 transient, previously detected only at radio wavelengths. Our late-time *K*-band magnitude rules out an extremely high extinction towards SN 2008iz. The nature of the 43.78+59.3 transient still remains elusive, an extremely bright microquasar in M82 being the most plausible scenario.

ACKNOWLEDGEMENTS

We thank an anonymous referee for several useful suggestions, Ariane Lançon for providing the NIR spectrum of M82-L, Catherine Walsh for helpful discussions on extinction and atomic and molecular column densities, Robert Greimel and Rubina Kotak for carrying out some of the WHT observations, Andrea Pastorello for helpful discussions, and Rob Beswick for providing information on the 43.78+59.3 transient. The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP7/2007-2013) ERC Grant agreement n° [291222] (PI : S. J. Smartt). SM and CR-C acknowledge financial support from the Academy of Finland (project: 8120503) and MF acknowledges support from the UK's STFC.

Based on observations obtained as part of programme GN-2009A-Q-32 at the Gemini Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the NSF on behalf of the Gemini partnership. Also based on observations made with the NASA/ESA *HST*, obtained from the Data Archive at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555.

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