Signatures of an eruptive phase before the explosion of the peculiar core-collapse SN 2013gc

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ABSTRACT

We present photometric and spectroscopic analysis of the peculiar core-collapse SN 2013gc. The light curve shows an early maximum followed by a fast decline and a phase of almost constant luminosity. At +200 days from maximum, a brightening of 1 mag is observed in all bands, followed by a steep linear luminosity decline after +300 d. From archival images taken between 1.5 and 2.5 years before the explosion, we found that a weak source is visible at the supernova location, with mag ≈ 20. The early supernova spectra show Balmer lines, with a narrow (∼ 560 km s\(^{-1}\)) P-Cygni absorption superimposed on a broad (∼3400 km s\(^{-1}\)) component, typical of type IIn events. Through a comparison of colour curves, absolute light curves and spectra of SN 2013gc with a sample of supernovae IIn, we conclude that SN 2013gc is a member of the so-called type IId subgroup (Benetti 2000). The complex profile of the H\(\alpha\) line suggests a composite circumstellar medium geometry, with a combination of lower velocity, spherically symmetric gas and a more rapidly expanding bilobed feature. This distribution of the circumstellar medium has been likely formed through major mass-loss events, that we directly observed from 3 years before the explosion of SN 2013gc. The modest luminosity of SN 2013gc at all phases, the very small amount of ejected \(^{56}\)Ni (of the order of \(10^{-3} M_{\odot}\)), the major pre-supernova stellar activity and the lack of prominent [O i] lines in the late-time spectra support a fallback core-collapse scenario for the massive progenitor of SN 2013gc.

Key words: supernovae: general, supernovae: individual: SN 2013gc, SN 1994aj, SN 1996al, SN 1996L, SN 2000P

1 INTRODUCTION

Major astronomical surveys, such as the Asteroid Terrestrial-impact Last Alert System (ATLAS; Tonry et al. 2018), the All Sky Automated Survey for SuperNovae (ASAS-SN; Shappee et al. 2014) and the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS; Chambers et al. 2016) are discovering a growing number of peculiar stellar transients that display a wide range of photometric and spectroscopic properties. A fraction of them show supernova (SN) features, with high velocity gas. Some exhibit also signatures of interaction between fast-moving ejecta and circumstellar medium (CSM), which is revealed through multi-component line profiles in the spectra. In particular, supernovae (SNe) showing narrow H emission lines likely produced in the unshocked photoionised (Chevalier & Fransson 1994; Chugai & Danziger 1994) are classified as type IIn (Schlegel 1990). A well-studied member of this class

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is SN 1988Z (Turatto et al. 1993; Statidakis & Sadler 1991; Aretxaga et al. 1999; Smith et al. 2017).

Dense H-rich CSM is generally produced through mass-loss events from the progenitor star, which occurred from tens to thousands years before the SN explosion. However, in some cases, H-rich CSM grows through eruptive episodes which they lose a considerable amount of material (up to 10⁴ solar masses). The best followed GE of an LBV in Carinae in the mid 19th century. It lasted a few decades, during which the star grew up to absolute magnitude $M \sim -14$ (Smith & Frew 2011). An LBV GE which occurs in a distant galaxy can be confused with an under-luminous type IIn SN. For this reason, extra-galactic GEs (or major outbursts) of hypergiants are sometimes dubbed as "SN Impostors" (Van Dyk et al. 2000).

LBVs may exhibit an extreme variability, with oscillations exceeding 5 mag, over periods of many years. These outbursts sometimes are premonitions of subsequent type II SN explosions. This was directly observed in SN 2009ip (Mauermann et al. 2013; Smith, Mauerhan & Prieto 2014); LSQ13zm (Tartaglia et al. 2016), SN 2016bdu (Pastorello et al. 2018); SNhunt151 (Elias-Rosa et al. 2018). The progenitor of SN 2009ip had a non-terminal outburst in 2009. Other outbursts of the same object were observed in the following years, until a much brighter event occurred in summer 2012, which was claimed to be the signature of the final core-collapse. The sequence of events observed in SN 2009ip indicated that the progenitor was likely an LBV. Multiple outbursts accompanied by major mass loss allow the formation of a dense H-rich cocoon around the star. Hence, when the star finally exploded, it showed up as a type IIn SN.

In the vast array of displays of SNe IIn, a group exhibits peculiar "double" (broad and narrow) P-Cygni profile in the H lines, signatures of SN ejecta and CSM, respectively. For this spectral property, these peculiar type IIn events are labelled as "type IId" (see the review of Benetti 2000). This category includes SN 1994aj (Benetti et al. 1998), SN 1996L (Benetti et al. 1999) and SN 1996al (Benetti et al. 2016). These objects are quite rare, and this paper discuss the case of a possible new member, SN 2013gc.

The structure of the paper is as follows: we introduce the discovery of SN 2013gc, the physical properties of the host galaxy, including a discussion on the reddening and the distance, in Sect. 2. Information of the instrumentation used and a description on the data reduction techniques are reported in Sect. 3. An analysis of the light curve is provided in Sect. 4, while in Sect. 5 we analyse the reddening-corrected colour and absolute magnitude curves. In Sect. 6 we present robust evidence of progenitor variability before the explosion. The spectral features and evolution of Hα profile are discussed in Sect. 7. A discussion on the progenitor and the physics of the explosion is presented in Sect. 8. Finally, the conclusions are summarized in Sect. 9. In appendix A, we present the photometric measurements and the spectra of another SN IIn/IId 2000P, which has been used as a comparison object in this paper.

## 2 DISCOVERY

SN 2013gc (=PSN J08071188-2803263) was discovered on 2013 November 7 at RA=$08^h07^m11.8^s$ and Dec=$-28^\circ 03'26''.32$ (J2000), 43.3° east and 18.0° south of the nucleus of the galaxy ESO 430-20 (a.k.a. PGC 22788, Antezana et al. 2013). The discovery chart is in Fig. 1.
The discovery was done by the CHilean Automatic Supernova search survey (CHASE; Pignata et al. 2009), using the Panchromatic Robotic Optical Monitoring and Polarimetry Telescopes (PROMPT; Reichart et al. 2005), at the Cerro Tololo Inter-American Observatory (CTIO).

The original spectral classification indicated it was SN IIn (Antezana et al. 2013). The spectrum, discussed in Sect. 7, was obtained soon after the discovery with the Las Campanas 2.5-m du Pont telescope (WFCCD), and cross-correlated with a library of SN spectra using the "Supernova Identification" code (SNID; Blondin & Tonry 2007). SN 2013gc appeared as a type IIn SN similar to SN 1996L (Benetti et al. 1999) at about two months after the explosion.

### 2.1 The SN environment

The host galaxy ESO 430-20 is a member of a small group of galaxies (Crook et al. 2007). The morphological classification, from the RC3 Catalogue (De Vaucouleurs et al. 1991), is SAB(s)cd. Details on the galaxy obtained from the NASA/IPAC Extragalactic Database (NED)\(^1\) are summarized in Tab. 1. The type II SN 2013ak was also discovered in this galaxy, on 2013 March 9 (Carrasco et al. 2013), at a magnitude of 13.5. The location of SN 2013gc is far from the galaxy center: with a distance of 12.37 Mpc, the SN is located at 2.81 kpc from the nucleus, while the radius of the galaxy is 3.4 kpc. Due to the relatively large radial distance from the galaxy center, the local dust contamination is likely small.

### 2.2 Distance

The distance of ESO 430-20 is controversial. The Virgo+Great Attractor+Shapley velocity (\(v = 942 \pm 20\) km s\(^{-1}\), Tab. 1), assuming \(H_0 = 73\) km s\(^{-1}\)Mpc\(^{-1}\), provides a distance \(d = 12.90 \pm 0.27\) Mpc, hence \(\mu = 30.55 \pm 0.05\) mag. Crook et al. (2007) determine a distance of 13.36 Mpc, equal to \(\mu = 30.63\) mag. The HyperLeda catalogue reports a radial velocity corrected for Virgo Cluster infall \(V_{\text{vir}} = 793 \pm 2\) km s\(^{-1}\), a distance \(d = 12.0^{+0.6}_{-0.6}\) Mpc and \(\mu = 30.40 \pm 1.37\) mag.

Theureau et al. (2007) give three different distance estimates of the host galaxy through photometry in 3 NIR bands, and applying the Tully-Fisher (TF) relation: \(d = 11.4\) Mpc in \(J\), \(d = 11.5\) Mpc in \(H\), \(d = 12\) Mpc in \(K\), with \(\mu\) of 30.29\(\pm\)0.46, 30.31\(\pm\)0.47, 30.40\(\pm\)0.45 mag, respectively.

More recently, Tully et al. (2016) estimated \(d = 6.95\) Mpc for ESO 430-20, corresponding to \(\mu = 29.21 \pm 0.54\) mag, obtained from the TF relation, calibrated on a sample of galaxy clusters. The discrepancy with the previous determinations is very large, so we do not take it in account this result in the choice of the distance to adopt.

For the distance, the mean of the three TF determinations obtained by Theureau et al. (2007), and the two kinematical velocities reported in Tab. 1 were considered. We hence adopt \(d = 12.37 \pm 1.07\) Mpc and \(\mu = 30.46 \pm 0.19\) mag through-out this paper.

### 2.3 Reddening

The Galactic reddening \(A_V\) reported in Tab. 1 is from Schlafly & Finkbeiner (2011). Assuming \(R_V = 3.1\) (Fitzpatrick 1999), a colour excess \(E(B-V) = 0.404\) mag is derived. We adopt the Cardelli, Clayton & Mathis (1989) extinction law. The extinction is quite large due to the low galactic latitude of the galaxy (\(\sim 2.3\)°). This makes the reddening value very uncertain. We warn that the inaccuracy of the Schlafly extinction maps can lead to inaccuracy on the intrinsic distance and absolute magnitude of the object.

On the other hand, we are not able to estimate the internal reddening of the host galaxy. We notice that the spectra do not show the narrow Na\(D\) doublet features of the host galaxy, because the modest flux of the continuum at these wavelengths. The host galaxy reddening is hence assumed to be negligible, which is consistent with the remote location of the SN in the host galaxy.

### 3 SETUP AND DATA REDUCTION

Johnson-Cousins \(BVRIJK\), Sloan grizy and unfiltered photometric images were obtained with a large number of observing facilities, whose technical notes are here summarized. For the photometry, we used:

- The PROMPT facility, located at CTIO, which consists of six 0.41-meter robotic telescopes (Reichart et al. 2005)\(^2\).
- The TRAnsiting Planets and Planetesimals Small Telescope (TRAPPIST) is a robotic 0.5-meter Ritchey-Chrétien telescope located at ESO La Silla Observatory\(^3\).

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\(^1\) http://nedwww.ipac.caltech.edu/

\(^2\) The optical imagers, made by Apogee, use back-illuminated E2V 1024×1024 CCDs, with a 2′ field of view and a pixel scale of 0.6′/pixel. Sloan u′g′r′i′z′ and Johnson \(BVRI\) filters are available.

\(^3\) The telescope is equipped with a Fairchild 3041 back-illuminated 2k×2k CCD. The pixel scale is 0.64′/pixel. The field of view of the camera is 22′×22′. Johnson-Cousins \(BVRI\) filters are available.
Photometric nights were used to calibrate the magnitudes of reference stars in the SN field, through the observations of Landolt (1992) standard fields with the same instrumental setup. This local sequence was used to correct the instrumental zero points in non photometric nights. Photometric errors were estimated through artificial star experiments, combined in quadrature with the uncertainties derived from the PSF-fitting returned by DAOPHOT. Finally, we calibrated the final instrumental magnitudes of the SN in the Johnson-Cousins and Sloan photometric systems, using differential photometry. For the calibration of the PS1 survey images, we followed the prescriptions of Magnier et al. (2016).

The few Sloan r and i (apart for those from PS1 survey) magnitudes were transformed in the Johnson-Cousins photometric system following the equations of Chonis & Gaskell (2008). Clear filter magnitudes from PROMPT were treated as Cousins R-band magnitudes, because the wavelength efficiency peak of the detector is similar to that of the R filter response curve.

Only a single epoch of J, H and K imaging of the SN, along with a few additional NIR frames of the SN field taken before the explosion, are available. Clean sky images were obtained by median-combining multiple dithered images of the field, and consequently subtracted to individual images. Sky-subtracted images were finally combined to increase the SNR. PSF-fitting photometry was also performed on the NIR sources, and the final SN magnitudes were calibrated using the 2MASS catalog as reference.

4 LIGHT CURVE

Our photometric campaign spans 7 years, starting from March 2010. The first detection of the SN is on 2013 August 26, hence ~1.5 months before the discovery announcement. With only one observation during the rising phase, it is not possible to precisely determine the explosion epoch. The last non-detection is dated 2013 June 19, and the SN must be exploded between the above two dates. As detailed in Sect. 8, we assume 2013 August 16 (MJD 56520) as explosion date. The object was then followed for about 2 years, up to June 2015. Pre-explosion images and those obtained at very late phases are unfiltered. The multi-band optical magnitudes are reported in Tab. A3 and in Tab. A4 for the infrared (IR), while unfiltered magnitudes are listed in Tab. A5.

The photometric coverage of the SN evolution in the BVRIJHK and gizy bands is shown in Fig. 2. Magnitudes are not corrected for the line of sight extinction. We assume MJD 56544±7 as an indicative epoch for the maximum luminosity, that is 4 days before the brightest V band magnitude (MJD 56548) and 20 days before the brightest point in I band (MJD 56564). This agrees with the estimate of Antezana et al. (2013).

The light curve shows a fast linear decline after maximum, with a rate of 6.6 ± 0.2, 7.5 ± 0.3 and 6.1 ± 0.2 mag (100 d)^{-1} in the V, R and I bands, respectively. Such decline rates are typical of the ‘Linear’ subclass of type II SNe (Valenti et al. 2016). Two ESO/SC observations were performed only 3 and 4 days after our maximum estimate, when the SN was at V = 15.1 mag (hence, M_{V} ~ −16.6 mag near maximum).

4.1 Data reduction

For the photometric data reduction we used a dedicated pipeline called SNooPy (Cappellaro 2014). The optical images were corrected for bias, overscan and flat-field, using standard IRAF tasks. If several dithered exposures with the same instrumental configuration were taken on the same night, they were combined to increase the signal-to-noise ratio (SNR). The SNooPy package is used for astrometric calibration and seeing determination on the images. The PSF-fitting technique was used to determine the instrumental SN magnitude. For each image, we built a PSF model using the profiles of bright, isolated stars in the field. We subtracted the sky background fitting a low-order polynomial (typically a second-order). Then, the modelled source was subtracted from the original frames, a new estimate of the local background is performed and the fitting procedure is repeated. If the source is not detected, an upper limit to the luminosity is established.

Photometric nights were used to calibrate the magnitudes of reference stars in the SN field, through the observations of Landolt (1992) standard fields with the same instrumental setup. This local sequence was used to correct the instrumental zero points in non photometric nights. Photometric errors were estimated through artificial star experiments, combined in quadrature with the uncertainties derived from the PSF-fitting returned by DAOPHOT. Finally, we calibrated the final instrumental magnitudes of the SN in the Johnson-Cousins and Sloan photometric systems, using differential photometry. For the calibration of the PS1 survey images, we followed the prescriptions of Magnier et al. (2016).

The few Sloan r and i (apart for those from PS1 survey) magnitudes were transformed in the Johnson-Cousins photometric system following the equations of Chonis & Gaskell (2008). Clear filter magnitudes from PROMPT were treated as Cousins R-band magnitudes, because the wavelength efficiency peak of the detector is similar to that of the R filter response curve.

Only a single epoch of J, H and K imaging of the SN, along with a few additional NIR frames of the SN field taken before the explosion, are available. Clean sky images were obtained by median-combining multiple dithered images of the field, and consequently subtracted to individual images. Sky-subtracted images were finally combined to increase the SNR. PSF-fitting photometry was also performed on the NIR sources, and the final SN magnitudes were calibrated using the 2MASS catalog as reference.
The linear decline is followed by a slower decline in all bands. This phase, lasting ~20 days, is well sampled in the $R$ band with a slope of $1.02 \pm 0.11$ mag (100 d)$^{-1}$. This decline slope is consistent with that expected from the decay rate of $^{56}$Co into $^{56}$Fe. The second decline ends at phase ~90 days. This short fraction of the light curve will be used to guess an upper limit on the $^{56}$Ni mass ejected by SN 2013gc (see Sect. 8).

Then the light curve shows a sort of plateau at around 20.5, 19.0 and 18.5 mag in the $V$, $R$ and $I$ bands, respectively. The plateau lasts about 70 days. We believe that the abrupt stop of the luminosity decline at +120 d marks the onset of a new, stronger ejecta-CSM interaction episode, that hereafter will become the primary source of energy for the SN. Later on, a rebrightening in the $R$ and $I$ bands is observed, with a rise of 1 mag. A secondary peak in I-band is reached on MJD 56738 (+194 days). Then, the light curve rapidly fades.

From +300 to +630 days the light curve presents a well-defined linear decay, with a slope of $0.43 \pm 0.05$ mag (100 d)$^{-1}$, flatter than the decay rate of $^{56}$Co. However, the SN is detected only in the $R$ band. Around 2 years after the explosion, due to the faintness of the object, the photometric measurements are very close to detection limits.

The SN field was imaged again by the DECam Plane Survey (DECaPS; Schlafly et al. 2018), with the 4-meter ‘V. Blanco’ telescope at CTIO, between January and April 2017. From this survey we collect 3 images in the Sloan $grz$-bands, one of which is shown in Fig. 5. The images are calibrated using the PANSTARRS DR1 catalog. We detect a faint source at the position of SN 2013gc at $g = 23.57 \pm 0.22$ mag, $r = 22.63 \pm 0.18$ mag, $z = 22.62 \pm 0.24$ mag. These detections are over 1 mag fainter than those of the outbursts observed in 2010 to 2013, and this can be used as an argument to support the terminal explosion of the progenitor star.

### 5 COLOUR AND ABSOLUTE LIGHT CURVES: COMPARISON WITH SIMILAR OBJECTS

#### 5.1 Colour curves

We compare the $(B - V)_0$, $(V - R)_0$ and $(R - I)_0$ colour curves of SN 2013gc with those of type IId SN 1994aj (Benetti et al. 1998), SN 1996L (Benetti et al. 1999), SN 1996al (Benetti et al. 2005) and SN 2000P in Fig. 3. The photometry of SN 2000P is published in this paper for the first time, and is reported in appendix A. For SN 1996al, we used the reddening and the distance reported in Benetti et al. (2016) ($\mu = 31.80 \pm 0.2$ mag, $E(B - V) = 0.11 \pm 0.05$ mag), while for SN 1994aj, SN 1996L and SN 2000P we adopted the reddening and the luminosity distances reported in NED for the respective host galaxies (SN 1994aj: $\mu = 35.72$ mag, $A_V = 0.115$ mag; SN 1996L: $\mu = 35.76$ mag, $A_V = 0.255$ mag; SN 2000P: $\mu = 32.75$ mag, $A_V = 0.209$ magn). All values are obtained with the assumption $H_0 = 73$ km s$^{-1}$ Mpc$^{-1}$.

Soon after maximum, the objects have colour indices around 0 mag. At early phases the $(B - V)_0$ and $(V - R)_0$ colour curves of our SN IId sample shows an evolution to redder colours faster up to about 60 days, then slower until 150 days, from $\sim 0$ to $\sim 1$ mag. $(R - I)_0$ for SN 1996al, SN 1996L, SN 2000P and SN 2013gc remains almost flat. At late phases ($\sim 240$ days), $(B - V)_0$ increases rapidly (30 days) from 0 to 0.7 mag in SN 2013gc, as expected from a cooling photosphere (see Fig. 3). Meanwhile, $(V - R)_0$ has not a monotonic trend, showing significant oscillations of 0.3 mag at later phases, whilst $(R - I)_0$ has a flatter evolution, stabilizing around 0 mag.

#### 5.2 Absolute light curves

With the distance adopted in Sect. 2 and the extinction reported in Tab. 1 for SN 2013gc, we obtain $M_V \sim -16.5 \pm 0.25$ mag for the brightest observation (not considering the error on the reddening and on the host galaxy extinction). This value is close to the mean luminosity of ‘normal’ SNe IIL $\langle M_V \rangle = -16.8 \pm 0.5$ (Valenti et al. 2016) but, as discussed before, our brightest detection is not coincident with the real maximum.

The $R$-band absolute light curves of SN 2013gc and the type IId SNe 1996al, 1996L, 1994aj and 2000P are compared in Fig. 4. From this comparison, we note that the whole absolute light curve of SN 2013gc is fainter than those of comparison SNe by about 2 mag. However, the decline (between 40 and 70 days after maximum) of SN 2013gc is quite similar to the average of the sample.

Because of the low Galactic latitude of the host galaxy, the Milky Way extinction is uncertain. Shifting upwards SN 2013gc by 2 mag, a fair agreement between SN 2013gc and other SNe IId would be found, with the exception of the late rebrightening of 1 mag (lasting 40 days) which remains a distinctive feature of SN 2013gc.

The source detected in the DECam images in 2017, with $M_V \approx -8.9$ mag and an intrinsically colour $(g - r)_0 \approx 0.5$ mag, can be a contaminant background H I region or even a residual signature of the SN.

### 6 ANALYSIS OF PRE-SN DATA

The SN field was sparsely monitored for more than 3 years before the explosion. We found several archival images taken between 2010 and early 2013 with a detection of a source at the SN position, although in some cases with large error bars. This is very likely an indication that the SN 2013gc progenitor experienced a phase of long-lasting luminosity variability, most likely a major eruption started a few years before the SN explosion. Selected secure detections, along with images witnessing the principal phases of the SN evolution, are shown in Fig. 5.

The PS1 survey sparsely monitored the field between 2010 and 2013. The first images from PS1 in March 2010, in $g$ and $y$ bands, show a source with a magnitude of about 20. Then, a stack of the nine best-quality frames taken between 2010 December 2 and 2011 January 14 from the PTF survey (Rau et al. 2009) has been produced. In this image, we detect a very faint source at $R \sim 21.8$ mag, which is close the bona fide limiting magnitude of the survey. The absolute magnitude of the source is only $M_R \sim -9.65$ mag. From the same survey, we combine the images obtained from 2011 January 17 to 19, and from 2011 January 21 to 27. The seeing in those nights was quite poor (3 arcsec), and only upper limits are obtained.
Figure 2. Optical and NIR light curves of SN 2013gc. Top: the full 7-year coverage. For sake of clearness, error bars are not reported here. A blow-up on the light curve of the transient during the 2012 variability period (see Sect. 6) is shown in the top-right inset. The purple, dashed vertical lines mark the epochs imaged in the panels in Fig. 5. The horizontal line indicates the magnitude of the brightest detection of 2017, showing that the object has faded with respect to the pre-SN eruptive-phase. Bottom: blow-up on the post-explosion evolution. The purple, dashed lines mark the epochs of the available spectra, while the black dot-dashed line marks the date of the assumed maximum. Upper limits are indicated as empty symbols. For each band, a different symbol is used.

We found a few images taken later in 2011, with only one detection on 2011 March 06 (MJD 55626). For this event we estimate an $R$-band absolute magnitude of $-11.74 \pm 0.35$ mag, although we cannot constrain the duration of the outburst. In fact, in frames obtained 12 days before and 6 days after the burst nothing is visible at the same limiting magnitude.

On early 2012, the field was well monitored, and a few additional sparse detections are registered (see the top-right box in Fig. 2). This is another evidence of the long-lasting instability of the SN progenitor. The faintest detections are at 21 mag, corresponding to an $R$-band absolute magnitude of $\sim -10.5$ mag, but in other cases the source has an apparent mag between 20 and 21. The source has also been detected by PS1 on 2011 October 20 in the $y$ band, at 19 mag, which is almost 3 mag brighter than the faintest PTF detection measured 9-10 months before. We now describe a remarkable sequence of events: on 2012 February 25 (MJD
An eruptive phase heralded the type IId SN 2013gc

Figure 3. Colour curves of SN 2013gc (blue circles), corrected for extinction, shown with those of the comparison SNe 1996al (green squares), 1996L (red triangles), 1994aj (black triangles) and 2000P (purple diamonds). The phase of SN 2000P is from the discovery date, not from the maximum, that probably was not observed (Fig. A1 in appendix). \( B - V \) is in the upper panel, \( V - R \) in the middle and \( R - I \) in the bottom panel. Error bars are reported for all objects.

Figure 4. Absolute \( R \)-band light curves of SN 2013gc (blue circles) and comparison objects. Error bars are reported. The different symbols indicate the same SNe as in Fig. 3.

55982), the source is hardly visible. The day after, the object is in flare, showing a brightening of 1 mag. Then, on 2012 February 27, the transient has faded again by 0.5 mag. This sequence highlights a scenario with a short-duration flares occurring during a long eruptive phase. The absolute magnitude estimated for this flare is \( R = -11.41 \pm 0.40 \) mag, similar to that observed in sole LBV-like outburst, such as SN 2000ch (Pastorello et al. 2010). The upper limits measured in a number of lower-quality images are not very deep (<20 mag), hence they are not very constraining.

After some months without images due to the heliac conjunction, the monitoring campaign restarted in late 2012, and the object was detected in several frames. In one of them, on 2012 December 1, the object reached \( M_R = -11.51 \pm 0.50 \) mag. In March 2013, the explosion of SN 2013ak in the same galaxy triggered a vast observational campaign, and tens of multi-band images of the field are hence available. In one of those images, taken with the Gemini South telescope, a brightening is clearly revealed on 2013 May 4 at \( R = 20.45 \) mag (\( M_R \sim -11.00 \pm 0.23 \) mag). Also this event is probably a short-duration flare. In fact, the source is not detected in images taken one day before and one day after. However, the quality of these images, taken with the PROMPT telescopes, is lower than the image of the Gemini South telescope. We remark that the peak luminosity of the four events described above is very similar. After June 2013, the region was again in heliac conjunction. Then, when the field became again visible at around mid-August 2013, the SN was already visible.

7 SPECTROSCOPY

We obtained 5 optical spectra of SN 2013gc with the following two instrumental configurations:

- The 4.1-meter “SOAR” telescope at CTIO, with the Goodman Spectrograph\(^{12}\) (PI F. Bufano).
- The Du Pont telescope at Las Campanas Observatory with the WFCCD/WF4K\(^{13}\) (PI P. Lira).

The pointing images of these instrument were also used for photometry. The first spectrum, taken one day after the discovery, was used for the spectral classification. The second spectrum is dated 2013 November 17, during the first dimming phase. The last two spectra were obtained after the second luminosity peak, on 2014 May 5 and May 12. On 2014 May 12 a medium resolution spectrum around the H\(\alpha\) region was also taken. Technical details of the five spectra are reported in Tab. 2.

\(^{12}\) It has a 7.2 arcmin diameter FOV, with a 0.15 arcsec/pixel scale. We used the Red Camera. The Spectrograph can also do imaging with SDSS and Bessell filters. The Red Camera is equipped with a 4096×4112 pixel, back-illuminated, E2V CCD. (http://www.ctio.noao.edu/soar/content/goodman-red-camera)

\(^{13}\) The camera covers a 25' field, with a scale of 0.484 ''/pixel. The detector has 4064×4064 pixels. (http://www.lco.cl/telescopes-information/irenee-du-pont/instruments/)

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Figure 5. Images of the field of SN 2013gc obtained at selected crucial phases. Panel a) the stacked December 2010 frames from PTF survey. b) The 2011 March 6 brightening. c) The 2012 February 26 flare. d) The Gemini image of the 2013 May 4 detection. e) The $I$-band luminosity peak. f) An $I$-band image during the plateau. g) The $I$-band image at the second peak. h) A late $R$-band detection after the second peak. i) The post-explosion $r$-band image of the DECaPS survey.

Table 2. Basic information of the 5 spectra of SN 2013gc. The phase is with respect to the adopted maximum (MJD 56544). To evaluate the instrumental resolution, we measured the FWHM of the [O i] night sky lines.

| Date           | MJD    | Phase (d) | Instrument          | sky lines spectral range (Å) | exp. times (s) |
|----------------|--------|-----------|---------------------|----------------------------|---------------|
| 2013 November 8| 56604.20 | +60       | WFCCD+blue grism    | 3620-9180                  | 2×900         |
| 2013 November 17 | 56613.17 | +69       | Goodman Spectrograph | 3765-8830                  | 2×3600        |
| 2014 May 5     | 56782.09 | +238      | WFCCD+blue grism    | 3630-9200                  | 2×1000        |
| 2014 May 11    | 56788.98 | +245      | Goodman Spectrograph | 4050-8940                  | 2×2700        |
| 2014 May 12    | 56789.05 | +245      | Goodman Spectrograph | 6250-7500                  | 2700          |

7.1 Spectroscopic reduction and line identification

All spectra were pre-reduced and calibrated using routine IRAF packages. The 2-dimensional frames were corrected for bias and flat-field, then the 1-dimensional spectra were extracted, and sky lines and cosmic rays were removed. On that spectrum, we performed wavelength and flux calibrations, using arc lamps and spectrophotometric standard stars. The spectral fluxes were scaled according to the $R$-band photometry of the nearest night. The spectra were also corrected for the strongest telluric absorption bands. The five spectra were corrected for redshift and reddening, adopting the values of $z$ and $A_V$ given in Tab. 1. The calibrated low-resolution spectra, with line identification, are shown in Fig. 6, while the medium-resolution spectrum is plotted in the bottom panel.
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Figure 6. Top: the 4 low-resolution spectra of SN 2013gc, corrected for redshift and reddening. Bottom: The mid-resolution spectrum of SN 2013gc, dated 2014 May 12. The spectrum covers 1200 Å around the Hα line. The main lines are identified in figure.

A weak, red continuum ($T_{bb} \sim 4000$ K) is present in the early spectra. Absorption features of metals, and Balmer lines in emission are also observed. Hα is the most prominent feature in all spectra, and its profile is described in detail in Sect. 7.3. Hβ has a similar profile as Hα. Hγ is not clearly detected, although the spectra have a low SNR at blue wavelengths. Helium lines are weak in early spectra, but become more intense later. He I $\lambda 7065$ is the strongest line, followed by $\lambda 6678$ and $\lambda 4922$. He I $\lambda 5876$ is blended with the Na I D doublet in emission.

To evaluate the evolution of He lines, we measure the fluxes ratio Hα/He I $\lambda 7065$ in all spectra. We choose the He I $\lambda 7065$ line because it is isolated and not significantly blended with other lines. In the first two spectra the ratio is around $90 \pm 10$, but the flux measurement of the He line is difficult due to its faintness. In the $+238$ d spectrum the ratio is lowered to $\sim 30$, and in the $+245$ d spectra is only $18 \pm 2$.

We identify Fe II features (multiplets 40, 42, 46, 48, 49, 199). The Fe II (46) $\lambda 6113$ line is observed in absorption at early phases, while it is in emission at late epochs. A blow-up of the first and last spectrum in the region 4800-5600 Å, with the identified lines of Fe II multiplets, is shown in Fig. 7.

At late phases, the flux contribution of the spectral continuum is negligible, and the line profiles have changed. We identify the Ca II IR triplet lines, detected as broad emission. The FWHM of the Ca II $\lambda 8662$ line is $3400 \pm 100$ km s$^{-1}$. There is a possible detection of O I $\lambda 7774$ in the first spectrum. More in general, we note an increasing number of emission lines, especially from forbidden transitions. In particular, we identify: [O III] $\lambda \lambda 4959,5007$ and possibly $\lambda 4363$ lines, [N II] $\lambda \lambda 6548,6584$ lines (although blended with the Hα line), [S II] $\lambda \lambda 6716,6731$ lines. Narrow [Si II], [N II] and [O III] lines likely arise from unresolved background contam-
7.2 Comparison with similar objects

Our spectra are compared with those of SN 1996al, SN 1996L, SN 1994aj and SN 2000P obtained at around the same phases. All spectra of SN 2000P are presented in this paper for the first time (see Appendix A).

The early spectra of SN 2013gc are similar to those of SN 1994aj, SN 1996al and SN 1996L taken at 60-70 days after maximum, in particular with respect to the H$\alpha$ profile and the Na$\text{i}$ D P-Cygni line. In all these SNe, H$\alpha$ and H$\beta$ show a narrow P-Cygni absorption over a broader P-Cygni component. The main difference at early times is that SN 1996al and SN 1996L have a hotter continuum, peaking around 5000 Å, giving a black-body temperature $T_{bb}$ of $\sim 6000$ K and $\sim 5000$ K, respectively.

One of the most interesting comparison is with SN 2000P, which has an excellent spectroscopic dataset. As for SN 2013gc, H$\alpha$ is characterized by a very narrow P-Cygni absorption and an extended Lorentzian red wing. H$\beta$ also has a similar narrow P-Cygni feature. Many bumps, likely due to Fe$\text{ii}$, are observed in the spectra of both objects. It is worth comparing the spectra and the H$\alpha$ profile evolution of SN 2000P (Fig. A2) with those of SN 1996al (Fig. 5 and 7 of Benetti et al. 2016). In the spectra of SN 2000P obtained a very few days after the maximum light, the blue continuum indicates an high temperature of gas. H$\alpha$ and H$\beta$ show a double P-Cygni feature, along with a broad emission from He$\text{i}$ λ5876 and Na$\text{i}$ D lines. At phase $\pm 30$ days, many bumps from metals arise and the Ca$\text{ii}$ triplet becomes well visible. From this epoch, a blue-shifted H$\alpha$ bump starts to develop at an intermediate-width, and grows in strength with time. One year after the maximum, H$\alpha$ is nearly the only observable feature, and the blue-shifted component is more prominent than that at the rest frame.

The late-time spectra of SN 2013gc and SN 2000P are not sufficiently close in phase to make a reasonable comparison. A comparison of the spectra of SN 2013gc with other SNe IId at similar phases is provided in Fig. 8. In the comparison of early-time spectra, we note that H$\beta$ is quite prominent, with the Balmer decrement H$\alpha$/H$\beta$ being higher in SN 2013gc than in other SNe IId. In particular, for SN 1996al at $\sim +60$ days, (Benetti et al. 2016) found an H$\alpha$/H$\beta$ ratio of 5, while in SN 2013gc we infer a ratio of around 10. In late spectra the ratio has increased to $\sim 20$. This comparison with SN 1996al supports the possibility that the reddening in the direction of ESO 430-20 may have been underestimated.

7.3 The H$\alpha$ profile

The analysis of H$\alpha$ profile can provide information on the CSM around the SN. The H$\alpha$ profile is complex, and consists of multiple components (see Fig. 9). In early spectra, a narrow P-Cygni absorption is superposed on a broad component. The line is asymmetric with an extended red wing. The simultaneous presence of a broad component from the fast ejecta and a narrow P-Cygni profile from slow circumstellar wind is a characterizing feature of type IId SN spectra. The H$\alpha$ profile shows an evolution from the early (+60 d) to the late (+245 d) epochs, with the velocities of the broader components progressively decreasing with time. In order to identify the different line components, we deblended the H$\alpha$ profile, following Benetti et al. (2016). We considered the spectra obtained +69 and +245 days. The results are illustrated in Fig. 10, and the velocities of the different line components are reported in Tab. 3.

At the early epoch, the relatively broad H$\alpha$ component has a velocity of 3400 km s$^{-1}$, which is very similar to the full-width-at-half-maximum (FWHM) velocity ($v_{FWHM}$) of the Ca$\text{ii}$ λ8662 line. The FWHM of this component can be considered representative of the SN ejecta velocity. In the late spectrum, H$\alpha$ has been deblended using 3 distinct intermediate-width emission components, with comparable
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Figure 8. Comparison of the +60 (top) and +245 (bottom) days spectra of SN 2013gc with those of comparison objects at approximately the same phase. On the right panel the same comparison is done for H\textalpha profiles at the same epochs.

Table 3. FWHM and central wavelengths of the various components of the H\textalpha profile obtained in all spectra. For the P-Cygni component the velocity of the minimum respect to the rest-frame is reported.

| Phase | (Em)\textsubscript{broad} | (Em)\textsubscript{narrow} | (Ab)\textsubscript{P-Cygni} | Red Wing | Blue Wing |
|-------|-----------------|-----------------|-----------------|----------|----------|
|       | v\textsubscript{FWHM}; \lambda (km s\textsuperscript{-1});(Å) | v\textsubscript{FWHM}; \lambda (km s\textsuperscript{-1});(Å) | Min. vel. v\textsubscript{FWHM}; \lambda (km s\textsuperscript{-1});(Å) | v\textsubscript{FWHM}; \lambda (km s\textsuperscript{-1});(Å) | v\textsubscript{FWHM}; \lambda (km s\textsuperscript{-1});(Å) |
| +60   | 3400±100; 6559  | 300±15; 6561.7  | 560             | 1800±50; 6598 | 6540     |
| +69   | 3450±100; 6557  | 340±20; 6561.7  | 470             | 1650±50; 6598 | 6542     |
| +238  | 1600±50; 6565  | 420±20; 6561.2  | 420             | 1600±50; 6598 | 6540     |
| +245  | 1600±50; 6566  | 350±20; 6563.5  | 460             | 1650±50; 6598 | 6542     |
| +245  | 1550±50; 6566  | 120±5; 6561.8   | 380             | 1300±30; 6600 | 1550±50; 6539 |

$v_{FWHM}$ ranging between 1300 and 1800 km s\textsuperscript{-1}. These components correspond to 3 distinct emitting regions: a first (blue shifted from the rest-wavelength) moving towards the observer, a second (red shifted) one which is produced by receding gas, and a third, centered at the rest-frame.

In principle, from the velocities of the ejecta and the CSM, one can infer the time of ejection of the CSM which later interacts with the SN ejecta. We adopt the velocities derived from the first spectrum, because it is the closest to the explosion available. We adopt 3400 km s\textsuperscript{-1} for the ejecta (from the FWHM of the broad component), and 560 km s\textsuperscript{-1} for the wind (from the minimum of the narrow P-Cygni component). Although the velocity at the explosion should be used for freely expanding ejecta, those of SN 2013gc are likely shocked already soon after the explosion, hence the value inferred from the first spectrum is a fair approximation of the ejecta velocity. The explosion epoch is unknown, but it is constrained between MJD 56463 (the last non-detection) and MJD 56530 (the first SN detection). Assuming that the collision of the SN ejecta with a dense circumstellar shell marks the onset of the light curve plateau (MJD 56640±10), the material would have been ejected between MJD ∼55560 (December 2010-January 2011) and MJD ∼55970 (February 2012) for the above two constraints on the explosion epoch, respectively. On the other hand, at about MJD 56720±10 we note a major brightening of the light curve, which is an evidence of enhanced CSM-ejecta interaction. With the same velocities and the explosion time interval, the second shell would have been ejected between MJD ∼55150 (November 2009) and MJD ∼55560 (December 2010-January 2011). The above constraints on the mass loss epochs are consistent with the timing of the pre-SN detections, and favour an explosion that occurred soon after the last non-detection (Sect. 6 and Fig. 2, top panel). From March 2010 we di-
We calculated the pseudo-bolometric light curve of SN 2013gc, correctly witnessed the outbursts that produced the SN CSM and determined the type IIn/IId observables.

8 DISCUSSION

The composite Balmer line profiles, with the simultaneous presence of broad and narrow components with P-Cygni profiles, makes SN 2013gc a member of the IId sub-class of type IIn SNe (Benetti 2000). This fact is supported by the comparison of the colour and absolute light curves of SN 2013gc with those of the known SNe IId which show a similar evolution. In particular, the onset of strong ejecta-CSM interaction (between 120 and 140 days after the explosion in SN 2013gc), is compatible with that observed in similar SNe (typically between 100 and 150 days, Benetti 2000).

8.1 Bolometric luminosity and the \(^{56}\)Ni mass

We calculated the pseudo-bolometric light curve of SN 2013gc accounting for the contribution in the BVRI bands only. For epochs without photometry in some bands, we made an interpolation to the available data using the R-band light curve as reference, and assuming a constant colour index. We fixed the explosion date on MJD 56520, about 10 days before the first SN detection. This implies a rise-time of 23±7 days from the explosion to the maximum. Then a first steep decline is observed. However, in order to estimate an upper limit to the ejected \(^{56}\)Ni mass, we focus on the light curve portion having a decline rate similar to that of \(^{56}\)Co. We identify a very short time interval during which the decline slope is compatible with the \(^{56}\)Co decay rate, i.e. between 97 and 118 days after explosion.

As a comparison, we selected the classical core-collapse SN 1987A, and a type II SN with a shorter a plateau, SN 2012A (Tomasella et al. 2013). SN 1996al is also considered as a comparison object. The bolometric light curves of the four objects are compared in Fig. 11, with a blow-up on the portion of the SN 2013gc light curve with a decline rate consistent with the \(^{56}\)Co decay.

The estimated \(^{56}\)Ni mass of SN 1987A is 0.085 \(M_{\odot}\) (Utrobin & Chugai 2011), while for SN 2012A the estimate is 0.011±0.004 \(M_{\odot}\) (Tomasella et al. 2013). We calculated and averaged the bolometric luminosity ratio of SN 2012A and SN 2013gc at three epochs after the explosion, at +112, +118 and +135 days. The \(M_{\text{Ni}}\) is obtained from the following relation:

\[
\frac{L_{\text{bol}}(2012A)}{L_{\text{bol}}(2013gc)} = \frac{M_{\text{Ni}}(2012A)}{M_{\text{Ni}}(2013gc)} = 2.5 \pm 0.6
\]

From this value, and propagating the errors, the \(^{56}\)Ni mass estimated for SN 2013gc is 5.0(±2.7)\(\times\)10^{-3}\(M_{\odot}\). We remark that this value is inferred assuming that the SN 2013gc light curve at 100-120 d is powered by \(^{56}\)Co decay only. This is not necessarily true, because all other observables indicate that the ejecta-CSM interaction is operating at all phases. For this reason, the \(^{56}\)Ni mass calculated above must be considered as an upper limit. It is worth noting that for SN 1996al Benetti et al. (2016) constrained an upper \(^{56}\)Ni mass limit of 0.018 \(M_{\odot}\), a factor of about 4 higher than that inferred for SN 2013gc.

This \(^{56}\)Ni mass constrained for SN 2013gc is definitely modest, also accounting that other photometric indicators (in particular the plateau and the second brightening) suggest that the main luminosity powering mechanism is the interaction between the SN ejecta and surrounding material. For this reason, we can safely estimate that the \(^{56}\)Ni mass ejected by SN 2013gc is very low, comparable with that inferred for some under-luminous type II SNe (Pastorello et al. 2004; Spiro et al. 2014).

8.2 The progenitor star

The interest for SN 2013gc lies in the fact that a prolonged variability phase was observed in the progenitor site before the SN explosion. So far, a possible eruptive event was claimed for the progenitor of a SN IId, and was limited to a single detection of a luminous source at the position of SN 1996al in archival Hα images obtained 8 years before the SN explosion (Benetti et al. 2016). For SN 2013gc the indications of pre-SN stellar activity are much more robust, and we witnessed a complex eruptive phase prior to the explosion. As seen in Sect. 6, the variability of the progenitor in 2010-2012 resembles those observed in other SN impostors. In particular, the pre-SN stages of SN 2009ip (Mauerhan et al. 2013) and SNhunt 151 (Elias-Rosa et al. 2018), and the current evolution of SN 2000ch (Pastorello et al. 2010). The bright absolute magnitude of the source in pre-SN images (\(M \sim -11\) mag) rules out the possibility that the progenitor was in a quiescent phase.

The deconvolution of the Hα profile, in particular from the last spectrum, allows us to reconstruct the structure of the CSM and to constrain the physics of the explosion, and the nature of progenitor star.

The fast initial (50-80 d) drop of the light curve implies...
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Figure 10. Decomposition of the Hα profile through multiple components. Left: In the +69 days spectrum the profile is well fitted using a gaussian broad emission (blue), on top of which stands a narrow Lorentzian emission (red) and a gaussian absorption for the P-Cygni (green). The bump due to the Hei λ6678 is also fitted with a gaussian emission (purple). Right: In the +245 days medium-resolution (FWHM=1.7 Å) spectrum the Hα profile is decomposed with an intermediate-width gaussian emission (blue), a narrow Lorentzian emission (red) and a gaussian absorption for the P-Cygni (green). Two additional gaussian components are required, a red-shifted (purple) and a blue-shifted (orange). In both graphs the sum of the 4 components is shown with a black dashed line. Residuals between the data and the fit are reported.

Figure 11. Quasi-bolometric BVRI light curves of SNe 1987A, 1996al, 2012A and 2013gc. In the box, a blow-up of the region between 95 and 145 days after the explosion, in which there is evidence of $^{56}$Co radioactive decay. The decay slope of $^{56}$Co (0.98 mag (100 d)$^{-1}$) is reported with a purple line for comparison.

Figure 10. Decomposition of the Hα profile through multiple components. Left: In the +69 days spectrum the profile is well fitted using a gaussian broad emission (blue), on top of which stands a narrow Lorentzian emission (red) and a gaussian absorption for the P-Cygni (green). The bump due to the Hei λ6678 is also fitted with a gaussian emission (purple). Right: In the +245 days medium-resolution (FWHM=1.7 Å) spectrum the Hα profile is decomposed with an intermediate-width gaussian emission (blue), a narrow Lorentzian emission (red) and a gaussian absorption for the P-Cygni (green). Two additional gaussian components are required, a red-shifted (purple) and a blue-shifted (orange). In both graphs the sum of the 4 components is shown with a black dashed line. Residuals between the data and the fit are reported.

Figure 11. Quasi-bolometric BVRI light curves of SNe 1987A, 1996al, 2012A and 2013gc. In the box, a blow-up of the region between 95 and 145 days after the explosion, in which there is evidence of $^{56}$Co radioactive decay. The decay slope of $^{56}$Co (0.98 mag (100 d)$^{-1}$) is reported with a purple line for comparison.

8.3 The explosion scenario

From the decomposition of the Hα profile, we can constrain the geometry of the CSM. The presence of multi-component Hα line profiles both in early and late-epoch spectra reveals that the CSM-ejecta interaction is likely active from the early phases of the SN evolution, suggesting that progenitor’s mass loss has continued until a very short time before the SN explosion. In this context, the above claim is supported by the evidence that the progenitor in outburst was observed until May 2013, only ~100 days before the SN explosion. The light curve plateau and the rebrighten-
ing at about 200 days have to be considered as enhanced interaction with a denser CSM regions.

The Hα profile in the late spectra has a composite profile, with three intermediate-width components (with \( v_{\text{FWHM}} \) exceeding \( 10^3 \) km s\(^{-1}\)): a blue-shifted component peaking at \(-1000\) km s\(^{-1}\), a redshifted one centered at \(+1600\) km s\(^{-1}\), and a third one in the middle, centered at the rest wavelength of the transition, atop of which a narrow emission is observed with \( v_{\text{FWHM}} \) of a few \( 10^2 \) km s\(^{-1}\). This suggests a complex and structured CSM geometry.

The two components shifted from the rest wavelength reveal a bipolar emitting structure of the CSM, expanding with a core velocity in the range 1300-1800 km s\(^{-1}\). The difference of the measured expansion velocities can be explained with an intrinsic difference in the ejection velocity of the two lobes, or possibly by a mismatch between the line of sight and the polar axis of the bipolar nebula. Similar spectral features were observed in the SN IIn 2010ip, although in that case a jet-like explosion in a nearly spherically symmetric CSM was proposed (Smith et al. 2012), and the velocities involved were in fact one order of magnitude larger. The kinetic energy of SN 2013gc is much smaller, and is consistent with a fall-back SN scenario (see Sect. 8.2). A spherically symmetric CSM expanding at much lower velocity is revealed through the presence of a narrow Hα component, while a nearly spherical shell, shocked by the interaction, produces the central, intermediate-width component. The material shocked by the ejecta is optically thick, and hides (at all epochs) the underlying SN features.

This CSM configuration shares some similarity with that proposed by Benetti et al. (2016) for SN 1996al, consisting of an equatorial circumstellar disc producing the Hα profile with two emission bumps shifted from the rest wavelength. That material was surrounded by a spherical, clumpy component producing the Hα emission at zero velocity. The clumpiness of the SN 1996al CSM was deduced from the evolution of the He lines, that became more prominent with time. In analogy with SN 1996al, the spectra of SN 2013gc show an increasing strength of the He lines from the early to the late phases, which may indicate the presence of high-density clumps heated by the SN shock in its lower-density, spherically symmetric CSM component. We also note that the radial velocities of the Hα bumps of SN 1996al and SN 2013gc are comparable, supporting an overall similarity in the gas ejection scenarios for the two objects. SN 1996al was characterized by low ejecta mass and a modest kinetic energy. The ejecta interaction with a dense CSM embedding the progenitor determined the light curve features at all phases, and was still active 15 years after the explosion. The proposed CSM structure around SN 2013gc is composed by an equatorial disc with a complex density profile, and ejecta-CSM interaction being always present. When the ejecta reach the first CSM equatorial density enhancement, the conversion of kinetic energy into radiation gives rise to the observed plateau, while the encounter with an outer layer with higher density powers the second peak. Later on, ejecta-CSM interactions weakens and the SN light curve finally starts the fast decline.

9 CONCLUSIONS

SN 2013gc is a member of the type IId SNe class, a subgroup of type IIn SNe whose spectra are characterized by double, broad and narrow, P-Cygni Hα components. SN 2013gc can be considered a scaled-down version of SN 1996al, triggered by the same physical process: a fall-back SN from a highly massive star, possibly an LBV. SN 2013gc is the first object of this class showing a long-duration progenitor’s eruptive phase lasting a few years (at least, from 2010 and 2013), and continued until a very short time before the SN explosion. The object showed significant variability, with oscillations of 1-2 mag in very short time-scales (days from months). The multiple flares and the long-duration major eruption are best suited with a massive progenitor in its final evolutionary stages, very likely an LBV. The outbursts formed a structured CSM around the progenitor (and very close to it), and the SN ejecta interact with it from soon after the SN explosion. When the ejecta collide with denser CSM layers, the interaction powered the observed light curve plateau and the second peak. The CSM is likely clumpy, as deduced from the evolution of the He lines, and is composed of a spherically symmetric component, two denser shells and a further bipolar CSM component. The fall-back scenario of a massive star is supported by the low \(^{56}\)Ni mass found, the low luminosity of the SN, the lack of [O II] lines in the spectra and the detection of numerous pre-SN outbursts from the progenitor.

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APPENDIX A:

A1 Light curves and spectroscopic sequence of SN 2000P

SN 2000P was discovered on 2000 March 8 by the amateur astronomer R. Chassagneat at R.A. = 13°07′9.88 and Dec. = −28°13′50.3′ (J2000). The SN is located about 16° east and 21° south of the center of the spiral galaxy NGC 4030.
Figure A1. Optical and NIR light curve of SN 2000P, spanning about 3 years of observations. The magnitudes are not corrected for line-of-sight extinction. The red arrow indicates an upper limit in the $R$ band.

The $UBVRIJHK$ photometry of SN 2000P is presented in Tab. A1, the technical informations on the spectra are provided in Tab. A2. In Fig. A1 we give the optical and NIR light curve of SN 2000P, while in Fig. A2 we plot the spectral sequence and the evolution of the $H\alpha$ profile.
Table A1. Optical and NIR photometric measurements for SN 2000P. For completeness, amateur astronomers measurements are also included.

| Date       | MJD     | phase \(^a\) | U  | B  | V  | R  | I  | J  | H  | K  | Telescope \(^b\) | Observation PI |
|------------|---------|--------------|----|----|----|----|----|----|----|----|-------------------|----------------|
| 2000-03-08 | 51611.03| 0.0          | 14.10(04) |    |    |    |    |    |    |    | 0.3 meter        | Chassagne      |
| 2000-03-09 | 51612.12| 1.1          | 14.57(05) |    |    |    |    |    |    |    | Pic du Midi      | Colas           |
| 2000-03-10 | 51614.18| 3.2          | 14.31(03) | 15.20(02) | 15.01(02) | 14.76(02) | 14.61(02) |    |    |    | Dan Turatto       |                |
| 2000-03-12 | 51616.24| 5.2          | 14.68(03) | 15.30(02) | 15.10(02) | 14.86(02) | 14.64(02) |    |    |    | Dan Turatto       |                |
| 2000-03-13 | 51616.64| 5.6          | 15.17(05) |    |    |    |    |    |    |    | ?                 | Kiyota          |
| 2000-04-04 | 51638.01| 27.0         | 15.30(10) |    |    |    |    |    |    |    | Dan Turatto       |                |
| 2000-04-07 | 51641.08| 30.1         | 15.82(05) | 15.98(05) | 15.52(02) | 15.20(03) | 14.98(07) |    |    |    | KAIT Li et al. (2002) |                |
| 2000-04-09 | 51643.04| 32.0         | 15.67(10) |    |    |    |    |    |    |    | EF2               | Pastorello      |
| 2000-04-14 | 51654.00| 43.0         | 17.48(03) | 17.60(03) | 17.04(03) | 16.56(02) | 16.39(02) |    |    |    | KAIT Li et al. (2002) |                |
| 2000-04-26 | 51661.25| 50.2         | 17.12(10) |    |    |    |    |    |    |    | KAIT Li et al. (2002) |                |
| 2000-05-23 | 51687.00| 76.0         | 19.14(05) | 18.96(02) | 18.37(02) | 18.17(05) | 17.55(24) | 17.44(21) | 16.69(20) | SOFI Salamanca    |                |
| 2000-05-25 | 51690.95| 79.9         | 19.23(10) |    |    |    |    |    |    |    | SOFI Grobol       |                |
| 2000-05-27 | 51691.95| 79.9         | 19.23(10) |    |    |    |    |    |    |    | SOFI Grobol       |                |
| 2000-06-05 | 51699.50| 88.5         | 21.22(02) |    |    |    |    |    |    |    | KAIT Li et al. (2002) |                |
| 2000-12-06 | 51884.60| 273.6        | 21.22(02) |    |    |    |    |    |    |    | HST Li et al. (2002) |                |
| 2001-01-02 | 51942.37| 331.3        | 21.65(08) | 21.80(09) | 21.51(08) | 20.56(03) | 21.20(06) |    |    |    | EF2               | Pastorello      |
| 2001-03-17 | 51985.35| 374.3        | 22.17(10) | 21.69(08) | 20.62(04) | 21.26(26) |    |    |    | Dan Pastorello    |                |
| 2001-03-18 | 51986.29| 375.2        |    |    |    |    |    |    |    |    | Dan Pastorello    |                |
| 2001-04-09 | 52008.30| 397.3        |    |    |    |    |    |    |    |    | Dan Pastorello    |                |
| 2001-06-26 | 52117.02| 506.0        | 22.49(04) | 22.33(05) |    |    |    |    |    |    | VLT1              | Cappellaro      |
| 2002-08-31 | 52518.15| 907.1        |    |    |    |    |    |    |    | 21.72*           | EF2 Pastorello   |
| 2003-05-20 | 52779.02| 1168.0       | 24.67(29) | 24.10(16) | 23.36(11) | 22.78(18) |    |    |    | VLT2              | Zampieri        |

\(^a\) Days from the discovery

\(^b\) Dan = ESO Danish 1.54m+DFOSC, EF2 = ESO 3.6m+EFOSC2, TNG = TNG 3.6m+OIG, SOFI = ESO NTT+SOFI, VLT1 = VLT (UT1) 8.2m+FORS1, VLT2 = VLT (UT4) 8.2m+FORS2

\(^c\) HST+F555W

\(^d\) HST+F814W

\(^e\) Upper limit
Figure A2. Left: Time sequence of optical spectra of SN 2000P, spanning about 3 years of observations. The flux of the spectra are scaled according to the $R$-band or, if not available, to the $V$-band photometry of the nearest night. The spectra plotted in red color are taken from CfA Supernova Data Archive (https://www.cfa.harvard.edu/supernova/SNarchive.html), to fill the time gap of our sequence. Right: Evolution of the Hα profile in the same spectral sequence. The logarithm of the specific flux is reported on the $y$-axis. The velocity respect to the rest-frame is shown. In both graphs the phase is relative to the discovery.

Table A2. Spectroscopic observations of SN 2000P.

| Date       | MJD   | phase$^a$ | Range    | Resolution$^b$ | Telescope | Instrument |
|------------|-------|-----------|----------|----------------|-----------|------------|
| 2000-03-11 | 51614.2 | 3.2       | 3900-6840 | 4.7            | ESO 1.54m | DFOSC (gr7) |
| 2000-03-13 | 51616.3 | 5.3       | 3350-9800 | 9.3            | ESO 1.54m | DFOSC (gr4+gr5) |
| 2000-03-14 | 51617.2 | 6.2       | 3860-6820 | 5.1            | ESO 1.54m | DFOSC (gr7) |
| 2000-04-07 | 51641.1 | 29.1      | 3370-9800 | 16             | ESO 3.6m  | EFOSC2 (gr11+gr12) |
| 2001-02-02 | 51942.3 | 331.3     | 3360-7450 | 9              | ESO 3.6m  | EFOSC2 (gr11) |
| 2001-07-27 | 52117.0 | 506.0     | 4230-8920 | 11             | VLT UT1 8.2m | FORS1 |
| 2003-05-20 | 52779.0 | 1168.0    | 3400-9600 | 10             | VLT UT4 8.2m | FORS2 |

$^a$ Days from the discovery

$^b$ FWHM of the night sky lines.
An eruptive phase heralded the type IId SN 2013gc

Table A3. Optical Johnson-Cousins and Sloan photometry of 2013gc.

| Date       | MJD   | B     | V     | R     | I     | g     | z     | y     | Telescope |
|------------|-------|-------|-------|-------|-------|-------|-------|-------|------------|
| 2010-03-02 | 55257.32 | >19.57 | 0.37  | PS1   |
| 2010-04-04 | 55290.24 | >20.32 | 0.15  | PS1   |
| 2010-11-02 | 55517.61 | >20.11 | PS1   |
| 2010-11-17 | 55517.61 | >18.90 | PS1   |
| 2010-12-24 | 55544±22 | 21.78(0.40) | PTF |
| 2011-01-18 | 55579±1 | >20.42 | PTF |
| 2011-01-24 | 55585±3 | >18.96 | PTF |
| 2011-03-25 | 55645.24 | 19.47(0.30) | PS1 |
| 2011-10-20 | 55854.65 | 19.06(0.16) | PS1 |
| 2011-11-14 | 55879.60 | 21.06(0.20) | PS1 |
| 2012-02-10 | 55967.37 | 19.76(0.08) | PS1 |
| 2012-04-04 | 56021.24 | >19.72 | PS1 |
| 2012-10-29 | 56229.63 | 20.64(0.31) | PS1 |
| 2012-10-30 | 56230.65 | >19.62 | PS1 |
| 2012-12-28 | 56289.54 | >20.19 | 0.18(0.18) | PS1 |
| 2013-03-11 | 56362.28 | >18.83 | NTT   |
| 2013-03-19 | 56370.16 | >19.39 | NTT   |
| 2013-03-29 | 56380.98 | >18.55 | >18.65 | >18.44 | >18.31 | PROMPT |
| 2013-04-01 | 56383.18 | >18.37 | PROMPT |
| 2013-04-01 | 56383.89 | >19.21 | >18.56 | >18.64 | >18.13 | PROMPT |
| 2013-04-02 | 56384.14 | >20.33 | NTT   |
| 2013-04-02 | 56384.98 | >18.30 | >18.52 | >18.13 | >17.91 | PROMPT |
| 2013-04-04 | 56386.97 | >19.00 | >18.76 | >18.52 | >18.26 | PROMPT |
| 2013-04-05 | 56387.98 | >19.95 | >18.82 | >17.91 | PROMPT |
| 2013-04-06 | 56388.08 | >20.58 | NTT   |
| 2013-04-07 | 56389.01 | >20.07 | >19.61 | >18.94 | >18.97 | PROMPT |
| 2013-04-08 | 56390.00 | >20.22 | >18.84 | >19.22 | >18.09 | PROMPT |
| 2013-04-08 | 56390.97 | >17.58 | >17.79 | >17.66 | NTT   |
| 2013-04-10 | 56392.98 | >19.71 | >18.85 | >18.82 | >18.26 | PROMPT |
| 2013-04-11 | 56393.97 | >18.33 | PROMPT |
| 2013-04-12 | 56394.98 | >20.28 | PROMPT |
| 2013-04-13 | 56395.05 | >20.35 | NTT   |
| 2013-04-14 | 56396.04 | >18.87 | >18.97 | >19.28 | >18.34 | PROMPT |
| 2013-04-14 | 56396.96 | >18.81 | >18.00 | >18.27 | >18.78 | PROMPT |
| 2013-04-16 | 56398.96 | >19.25 | >19.56 | >19.35 | >18.78 | PROMPT |
| 2013-04-19 | 56401.02 | >20.29 | NTT   |
| 2013-04-19 | 56401.98 | >20.99 | >20.52 | >20.24 | >19.72 | PROMPT |
| 2013-04-20 | 56402.96 | >20.42 | >20.59 | >20.58 | >19.98 | PROMPT |
| 2013-04-22 | 56404.05 | >20.87 | >19.09 | >19.15 | >18.60 | PROMPT |
| 2013-04-25 | 56407.98 | >19.42 | >19.33 | >19.67 | >19.25 | PROMPT |
| 2013-04-28 | 56410.08 | >17.64 | PROMPT |
| 2013-04-28 | 56410.96 | >17.99 | >18.34 | PROMPT |
| 2013-04-29 | 56411.96 | >18.70 | PROMPT |
| 2013-05-01 | 56413.95 | >19.30 | PROMPT |
| 2013-05-04 | 56416.06 | >19.64 | >18.20 | PROMPT |
| 2013-05-04 | 56416.96 | >20.45(0.14) | GEMINI |
| 2013-05-05 | 56417.99 | >20.74 | >18.84 | PROMPT |
| 2013-05-07 | 56419.01 | >20.48 | >19.16 | >19.07 | PROMPT |
| 2013-05-11 | 56423.96 | >20.66 | >21.07 | >20.43 | >20.29 | PROMPT |
| 2013-05-15 | 56427.96 | >19.80 | >19.99 | >18.71 | PROMPT |
| 2013-05-19 | 56431.96 | >19.99 | >20.23 | >18.71 | PROMPT |
| 2013-05-20 | 56432.97 | >20.13 | >19.67 | PROMPT |
| 2013-05-22 | 56434.97 | >20.90 | PROMPT |
| 2013-05-23 | 56435.96 | >19.44 | >20.99 | PROMPT |
| 2013-05-24 | 56436.96 | >20.12 | >19.30 | PROMPT |
| 2013-05-29 | 56441.96 | >18.96 | >20.13 | >20.75 | >19.17 | PROMPT |
| 2013-06-03 | 56446.94 | >18.15 | PROMPT |
| 2013-06-12 | 56455.95 | >19.06 | >19.79 | PROMPT |
| 2013-06-19 | 56462.94 | >18.23 | >18.66 | PROMPT |
| 2013-08-26 | 56530.39 | 18.21(0.08) | SOAR |
| 2013-09-12 | 56547.36 | 15.16(0.02) | NTT   |
| 2013-09-13 | 56548.36 | 15.14(0.04) | NTT   |
| 2013-09-28 | 56563.38 | 15.95(0.05) | PROMPT |
| 2013-09-29 | 56564.40 | 14.66(0.14)b | 15.91(0.06) | PROMPT |
| 2013-10-08 | 56573.29 | 16.59(0.05) | NTT   |
### Table A3 – continued Optical Johnson and Sloan photometry of 2013gc.

| Date       | MJD   | B      | V      | R      | I      | g      | z      | y      | Telescopea |
|------------|-------|--------|--------|--------|--------|--------|--------|--------|------------|
| 2013-11-04 | 56600.65 | 19.93(0.04) | 18.75(0.08) | 16.71(0.02) | 16.60(0.03) | PS1    |
| 2013-11-06 | 56602.28 | 17.67(0.11)b | 17.18(0.08)b | 19.54(0.08) | 16.83(0.06) | PROMPT |
| 2013-11-08 | 56604.30 | 18.07(0.04) | 17.41(0.10) | TRAP    |
| 2013-11-12 | 56608.31 | 18.29(0.05) | 17.53(0.10) | SARA    |
| 2013-11-16 | 56612.26 | 18.40(0.06) | 19.01(0.06) | SOAR    |
| 2013-11-18 | 56614.25 | 20.86(0.37) | 20.04(0.13) | SARA    |
| 2013-11-26 | 56622.28 | 19.01(0.06) | 18.41(0.11) | TRAP    |
| 2013-12-29 | 56655.17 | 19.02(0.24) | 18.44(0.21) | TRAP    |
| 2014-01-02 | 56659.22 | 18.96(0.22) | 18.49(0.12) | TRAP    |
| 2014-01-12 | 56669.19 | 20.22(0.19) | 18.85(0.05) | TRAP    |
| 2014-02-02 | 56690.17 | 18.83(0.07) | 18.52(0.07) | TRAP    |
| 2014-02-03 | 56718.11 | 17.38(0.04) | 18.01(0.08) | SMARTS  |
| 2014-03-22 | 56738.05 | 17.38(0.04) | 18.01(0.08) | SMARTS  |
| 2014-04-02 | 56749.00 | 19.91(0.09) |            | TRAP    |
| 2014-04-04 | 56781.24 | 20.86(0.37) | 20.04(0.13) | SARA    |
| 2014-05-05 | 56810.91 | 19.79(0.11) | 19.41(0.09) | SARA    |
| 2014-05-09 | 56876.99 | 18.66(0.15)b | 18.43(0.30)b | 20.59(0.33) | 17.72(0.30) | PROMPT |
| 2014-05-11 | 56878.98 | >20.52 | 20.09(0.14) | 18.38(0.09) | TRAP    |
| 2014-05-11 | 56879.99 | 18.77(0.06) |            | SOAR    |
| 2014-05-16 | 56930.98 | 20.82(0.27) | 20.13(0.14) | 20.58(0.23) | TRAP    |
| 2014-05-27 | 56894.96 | 20.54(0.33) | 19.93(0.20) | 18.52(0.10) | SARA    |
| 2014-05-30 | 56897.96 | 20.91(0.16) | 18.83(0.10) | 18.56(0.08) | SMARTS  |
| 2014-06-01 | 56899.97 | 20.91(0.16) | 20.01(0.13) | 18.67(0.11) | 18.18(0.20) | TRAP    |
| 2014-06-10 | 56890.17 | 19.28(0.19) | 18.84(0.23) | TRAP    |
| 2014-06-26 | 56834.97 | >21.01 | >21.00 | >19.46 | TRAP    |
| 2015-02-22 | 57075.05 | >21.21 | >20.94 | 20.84(0.46) | >20.34 | TRAP    |
| 2015-04-02 | 57144.02 | >20.45 | >20.54 | 20.95(0.32) | >19.93 | TRAP    |
| 2015-05-01 | 57143.99 | >21.26 | >21.26 | 21.04(0.18) | >20.13 | TRAP    |
| 2015-05-12 | 57154.00 | 21.04(0.18) | 21.26(0.18) | 20.13(0.18) | >20.12 | TRAP    |
| 2015-05-20 | 57163.00 | >20.78 | >20.78 | >22.63(0.18) | >20.12 | TRAP    |
| 2015-06-11 | 57185.00 | >20.78 | >20.78 | >22.63(0.18) | >20.12 | TRAP    |
| 2017-03-04d | 57816±47 | 23.57(0.22) | 22.62(0.24) | DEC      |

$^a$ NTT = ESO 3.6-meter NTT+EFOSC2, SOAR = 4.1-meter ‘SOAR’+Goodman Spectrograph, TRAP = 0.5-meter TRAPPIST, SMARTS = CTIO 1.3-meter+ANDICAM, SARA = CTIO 0.6-meter+ARC, GEMINI = 8.1-meter Gemini South+GMOS-S, PTF = 1.2-meter ‘S. Oschin’ Schmidt+PTF survey, PONT = Las Campanas 2.5-meter ‘Du Pont’+WFCCD/WF4K-1, PS1 = Haleakala 1.8-meter+Pan-STARRS1 Survey, DEC = CTIO 4-meter ‘V. Blanco’+Dark Energy Camera (DECaPS survey).

$^b$ Converted from Sloan to Johnson photometric system.

$^c$ For this epoch we also report $r = 22.63(0.18)$.

$^d$ PS1 i band magnitude, not converted to I.

### Table A4. NIR photometry of 2013gc.

| Date       | MJD   | J      | H      | K      | Telescopea |
|------------|-------|--------|--------|--------|------------|
| 2013-03-18 | 56370.00 | >19.70 | >18.02 | >18.32 | SOFI       |
| 2013-04-04 | 56386.02 | 19.29(0.33) | 18.84(0.32) | 18.08(0.19) | SOFI       |
| 2013-04-12 | 56394.05 | 19.39(0.26) | 18.74(0.40) | 17.91(0.25) | SOFI       |
| 2013-04-18 | 56400.05 | 19.46(0.27) | 18.81(0.33) | 18.54(0.37) | SOFI       |
| 2014-05-30 | 56807.98 | 17.29(0.16) | 17.15(0.18) | 17.55(0.30) | SMARTS     |

$^a$ SOFI = ESO 3.6-meter NTT+SOFI, SMARTS = CTIO 1.3-meter+ANDICAM.
### Table A5. Clear photometry of 2013gc, treated as Johnson $R$.

| Date       | MJD     | clear magnitude | Telescope |
|------------|---------|-----------------|-----------|
| 2013-01-27 | 55588.07| $>18.99$         | PROMPT    |
| 2013-02-01 | 55593.08| $>19.32$         | PROMPT    |
| 2013-02-20 | 55612.10| $>19.72$         | PROMPT    |
| 2013-03-06 | 55626.06| 19.70(0.15)      | PROMPT    |
| 2013-03-12 | 55632.03| $>19.68$         | PROMPT    |
| 2013-05-02 | 55683.08| $>19.57$         | PROMPT    |
| 2013-09-14 | 55818.37| $>19.01$         | PROMPT    |
| 2013-09-25 | 55829.34| $>19.57$         | PROMPT    |
| 2013-10-17 | 55851.28| $>19.08$         | PROMPT    |
| 2013-10-22 | 55856.35| $>18.49$         | PROMPT    |
| 2013-11-02 | 55867.24| $>19.47$         | PROMPT    |
| 2013-01-04 | 55930.10| $>19.16$         | PROMPT    |
| 2013-01-07 | 55933.19| 20.36(0.36)      | PROMPT    |
| 2013-01-10 | 55936.20| $>19.27$         | PROMPT    |
| 2013-01-14 | 55940.21| 20.42(0.27)      | PROMPT    |
| 2013-01-18 | 55944.18| $>20.01$         | PROMPT    |
| 2013-02-24 | 55950.15| $>19.95$         | PROMPT    |
| 2013-02-27 | 55953.15| 20.46(0.41)      | PROMPT    |
| 2013-02-29 | 55955.13| $>19.72$         | PROMPT    |
| 2013-02-01 | 55958.20| 20.93(0.41)      | PROMPT    |
| 2013-02-03 | 55961.16| $>19.58$         | PROMPT    |
| 2013-02-06 | 55963.12| $>19.57$         | PROMPT    |
| 2013-02-08 | 55965.14| 19.89(0.45)      | PROMPT    |
| 2013-02-10 | 55967.11| 19.93(0.37)      | PROMPT    |
| 2013-02-12 | 55969.10| 20.35(0.34)      | PROMPT    |
| 2013-02-21 | 55978.10| $>20.16$         | PROMPT    |
| 2013-02-24 | 55981.07| $>19.39$         | PROMPT    |
| 2013-02-25 | 55982.09| 21.09(0.50)      | PROMPT    |
| 2013-02-26 | 55984.09| 20.87(0.26)      | PROMPT    |
| 2013-02-27 | 55984.09| 20.65(0.26)      | PROMPT    |
| 2013-02-03 | 55988.09| $>19.64$         | PROMPT    |
| 2013-02-05 | 55991.07| $>19.90$         | PROMPT    |
| 2013-02-07 | 55993.05| $>19.19$         | PROMPT    |
| 2013-02-09 | 55995.07| 19.96(0.37)      | PROMPT    |
| 2013-03-11 | 55997.06| $>19.26$         | PROMPT    |
| 2013-03-13 | 55999.05| $>19.95$         | PROMPT    |
| 2013-03-14 | 56000.06| $>18.70$         | PROMPT    |
| 2013-03-16 | 56002.05| 21.27(0.46)      | PROMPT    |
| 2013-03-18 | 56004.04| $>20.14$         | PROMPT    |
| 2013-03-26 | 56012.03| $>20.12$         | PROMPT    |
| 2013-03-31 | 56017.01| 20.29(0.47)      | PROMPT    |
| 2013-04-06 | 56023.01| $>19.63$         | PROMPT    |
| 2013-10-11 | 56211.30| $>19.67$         | PROMPT    |
| 2013-10-14 | 56214.29| $>19.71$         | PROMPT    |
| 2013-11-27 | 56258.22| $>19.72$         | PROMPT    |
| 2013-12-01 | 56262.25| 19.93(0.32)      | PROMPT    |
| 2013-12-04 | 56265.30| $>19.43$         | PROMPT    |
| 2013-12-06 | 56267.29| $>19.75$         | PROMPT    |
| 2013-12-09 | 56270.15| $>19.09$         | PROMPT    |
| 2013-12-13 | 56274.20| $>19.86$         | PROMPT    |
| 2013-12-16 | 56277.12| $>19.80$         | PROMPT    |
| 2013-12-21 | 56282.12| 20.47(0.42)      | PROMPT    |
| 2013-12-24 | 56285.16| 20.41(0.39)      | PROMPT    |
| 2013-12-27 | 56288.23| 20.10(0.44)      | PROMPT    |
| 2013-12-31 | 56292.22| $>19.69$         | PROMPT    |
| 2013-01-04 | 56296.21| $>19.48$         | PROMPT    |
| 2013-01-13 | 56305.22| $>19.62$         | PROMPT    |
| 2013-01-16 | 56308.12| $>19.69$         | PROMPT    |
| 2013-01-23 | 56315.35| $>19.36$         | PROMPT    |
| 2013-01-26 | 56318.14| $>19.37$         | PROMPT    |
| 2013-02-02 | 56325.21| $>19.56$         | PROMPT    |
| 2013-02-08 | 56331.30| $>19.62$         | PROMPT    |
| 2013-02-15 | 56338.15| $>20.02$         | PROMPT    |
| 2013-03-09 | 56360.23| $>19.79$         | PROMPT    |
| 2013-03-10 | 56361.12| $>19.50$         | PROMPT    |
| 2013-03-11 | 56362.14| $>19.01$         | PROMPT    |
| 2013-03-14 | 56365.18| 20.49(0.33)      | PROMPT    |
| 2013-03-18 | 56369.22| $>19.08$         | PROMPT    |
| 2013-03-28 | 56370.19| $>19.66$         | PROMPT    |