

Decadal pre-explosion activity and circumstellar interaction in a supernova

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Massive stripped stars are expected to become unstable before core collapse, but direct evidence linking such activity to the material shaping the ensuing explosion remains rare. Here we report optical observations of SN 2026gzf, a broad-lined Type Ic supernova associated with the Einstein Probe X-ray transient EP260321a, beginning just 1.25 hours after the X-ray trigger. Lulin Observatory discovered the optical counterpart and captured a luminous blue first-day excess that cannot be reproduced by a radioactive-powered model alone. Hydrodynamic modelling indicates that interaction with approximately $0.02 M_{\odot}$ of compact circumstellar material accounts for this early emission. Archival Pan-STARRS imaging reveals variable emission at the explosion site over the preceding ~ 12 years, with enhanced luminosity during the final ~ 3 years before explosion, broadly consistent with increased mass loss during late oxygen burning. To our knowledge, this is the first stripped-envelope supernova progenitor with repeatedly detected pre-explosion variability spanning more than a decade. Together, these observations provide the first direct connection in a stripped-envelope supernova between long-term pre-explosion activity, compact circumstellar material, an X-ray shock-breakout signal and the first hours of optical emission. SN 2026gzf therefore shows how late-stage instability in a stripped progenitor system can shape the immediate environment into which the star explodes.

The final years of massive-star evolution are poorly observed, particularly for stripped-envelope progenitors. Shock breakout provides one of the few direct probes of the stellar surface and nearby circumstellar material at the moment of explosion. It occurs when radiation trapped behind the blast wave escapes, either at the stellar surface or within optically thick circumstellar material. For progenitor radii of $0.1\text{--}1000 R_{\odot}$, the resulting transient lasts from seconds to hours, with emission that evolves rapidly from X-ray to optical wavelengths as the shocked ejecta expand and cool. Such events are difficult to detect because of their short duration, especially for compact stripped-envelope Type Ib and Ic SNe, whose progenitors have lost their hydrogen envelopes and, in Type Ic events, lack prominent helium features. X-ray shock-breakout detections from stripped-envelope SNe remain rare; the best-known examples are SN 2006aj(1; 2; 3) and SN 2008D(4; 5), both discovered almost two decades ago.

On 21 March 2026 at 12:23 UTC (MJD 61120.516; hereafter T_0), the Einstein Probe (EP) satellite(6) detected the fast X-ray transient EP260321a(7), a luminous soft X-ray source consistent with SN shock breakout(8; 9, see Methods 1). Within 1.25 hours of the trigger, we began optical

follow-up observations with Lulin Observatory(10) as part of the Kinder program(11) (Methods 2).
 In these images, we detected a blue, rising transient at $\alpha = [09:59:42.88]$, $\delta = [+00:25:06.30]$
 (Fig. 1, upper panel). The transient is coincident with a resolved galaxy at $z = 0.0345$ (12) and with
 a blue point-like source visible in archival Panoramic Survey Telescope and Rapid Response Sys-
 tem (Pan-STARRS) images(13). Our dense photometric monitoring during the first night showed
 that the source brightened by 0.66 mag in the r band within 4.68 hours, confirming it as the opti-
 cal counterpart of EP260321a(10; 14; 15). We continued monitoring the event over the following
 weeks with multiple ground-based telescopes, tracing the rise, peak and decline of the optical light
 curve (Fig. 1, lower panel). All photometry was measured after subtraction of host-galaxy template
 images to isolate the transient flux. Instrument configurations are described in Methods 3.

Spectroscopic follow-up classified the transient as a broad-lined Type Ic SN at a redshift
 consistent with the nearby galaxy(16; 17; 18; 19), directly linking the X-ray flash to the onset of
 a stripped-envelope explosion. The object was reported to the International Astronomical Union
 Transient Name Server and designated SN 2026gzf*. We obtained optical and near-infrared spec-
 tra with NOT/ALFOSC, ANU 2.3-m/WiFeS, LOT/UVEX, Keck II/NIRES and IRTF/Spex. The
 spectra are similar to those of broad-lined Type Ic SNe, especially SN 2006aj(2; 20; 21) (Fig. 2).
 Radiative-transfer modelling with TARDIS(22) reproduces the main optical and near-infrared
 spectral features of SN 2026gzf and supports the line identifications. The models indicate that Fe-
 group, Si and Ca features dominate the optical spectra, with He I $\lambda 10830$ contributing mainly in the
 near-infrared (Methods 4). SN 2026gzf is therefore unusual among SNe Ic-BL: it was discovered
 through its X-ray shock-breakout signal and followed almost immediately at optical wavelengths.

The redshift measured from the spectrum of SN 2026gzf is consistent with that of the nearby
 galaxy, but the SN position is more closely associated with an underlying blue compact source
 visible in Pan-STARRS (Fig. 1, upper panel), Sloan Digital Sky Survey(23) and Dark Energy
 Spectroscopic Instrument Legacy Imaging Surveys (DESI-LS) images(24) (see Methods 5). Di-
 rect aperture photometry of archival Pan-STARRS, ZTF, Subaru and DESI-LS images shows a
 persistent baseline source with mutually consistent fluxes across surveys and blue optical colours.
 This source could be a compact star-forming region or an unresolved dwarf galaxy. A foreground
 star is disfavoured by the absence of measurable proper motion in Gaia Data Release 3(25). The
 probability of chance alignment with an unrelated point source of comparable brightness is also

*<https://www.wis-tns.org/object/2026gzf>

low: $< 10^{-4}$ in the r band for our fiducial calculation, and $< 1.4 \times 10^{-3}$ under conservative assumptions. The archival blue compact source, Pan-STARRS precursor residuals, and later SN positions are mutually consistent within the astrometric uncertainties, supporting a common physical origin.

Archival photometry indicates that the blue compact source varied before the SN explosion. We analysed 60 epochs of Pan-STARRS imaging in the broad optical w filter obtained between 2015 and 2026, using a deep stack of earlier Pan-STARRS images as the reference (see Methods 5). Image subtraction shows variable excess flux at the SN position over the 12 yr before the EP trigger, with the signal also detected in independent r -band images. The residual flux shows significant pre-explosion variability, with no evidence for periodicity (Fig. 3). This behaviour further disfavors an ordinary foreground variable star and supports pre-explosion activity from the SN progenitor system, probably embedded in or associated with the blue compact star-forming source.

The precursor became brighter toward the final years before explosion. Its average brightness was $w \approx 22.8$ mag, corresponding to $M_w \approx -13.2$ mag at $z = 0.0345$, between -12 and -3 yr before explosion. During the final ~ 3 yr, it brightened to $w \approx 22.2$ mag ($M_w \approx -13.8$ mag), corresponding to a luminosity increase by a factor of ~ 1.7 . This long-timescale brightening suggests enhanced mass ejection during the final years before core collapse, broadly consistent with the expected duration of oxygen burning in a $\sim 15 M_\odot$ progenitor (26; 27). For a progenitor of similar mass, silicon burning lasts only ~ 18 d; an additional mass-loss episode on this shorter timescale could have produced more compact material, although no observations cover that final interval. The X-ray peak timescale of ~ 700 s implies a characteristic breakout radius of $\sim 3 \times 10^2 R_\odot$ (9). This radius is substantially larger than expected for the surface of a compact stripped star, favouring shock breakout in CSM close to the progenitor. At the same time, it is compact on circumstellar scales, suggesting that the relevant material was ejected only shortly before explosion. Together, the decade-long variability, final-years brightening and compact breakout scale provide the observational basis for linking the earliest emission to recent pre-explosion mass loss at the same site.

The earliest Lulin observations sampled the transition from the high-energy breakout emission to the initial optical rise of SN 2026gzf (Fig. 1, lower panel). These first optical data cannot be explained by a standard radioactive SN rise alone. The main rise to peak can be powered by radioactive ^{56}Ni decay (28), whereas the first hours may also include shock-cooling emission from

the outer ejecta. For the compact progenitors of Type Ic SNe, however, this shock-cooling component is expected to be faint and short-lived(29). The first Lulin points place SN 2026gzf more than 1 mag above the prediction of a hydrodynamic model without nearby CSM (Fig. 1, lower panel). Because the same model reproduces the main peak, the first-hour excess requires an additional power source (see Methods 6). This independent optical evidence strengthens the case that the breakout occurred not at the bare surface of a compact stripped star, but in dense CSM close to the progenitor.

We modelled the early light curve with a simple spherical hydrodynamic calculation in which the SN ejecta interact with dense CSM. Guided by the EP shock-breakout signal, we adopted a compact CSM radius of 3×10^{13} cm, comparable to the breakout scale inferred from the X-ray duration and blackbody emission(9). The blue first-day excess of SN 2026gzf can be reproduced with a wind-like CSM density profile if the CSM mass is $\sim 0.02 M_{\odot}$ (Methods 7). For a wind velocity of 1000 km s^{-1} , typical of Wolf-Rayet stars and often invoked for stripped-envelope progenitors, this radius corresponds to material ejected during the final ~ 3.5 d before explosion, implying a mass-loss rate of $2 M_{\odot} \text{ yr}^{-1}$. Such an extreme rate is far above that expected from standard line-driven winds(30), suggesting a dynamical mass-ejection process(31). Independently, a simple ^{56}Ni -powered MOSFiT model reproduces the main multi-band light curve but not the first-day excess (Methods 8), supporting a picture in which radioactive heating powers the main peak while ejecta–CSM interaction accounts for the earliest optical emission.

This mass-loss estimate assumes spherical symmetry and should therefore be regarded as an order-of-magnitude value. Some broad-lined Type Ic SNe are associated with GRBs and collimated relativistic jets, but the early X-ray and optical emission of SN 2026gzf does not resemble a typical GRB afterglow. Independent analysis finds no evidence for a relativistic jet in this event(19). Dense CSM could also suppress a jet by causing it to stall(32). Alternatively, energy deposited by a choked jet into the surrounding material could produce cocoon emission and contribute to the early optical excess(33). Thus, although the geometry and detailed power source of the earliest emission remain uncertain, all scenarios considered here require dense material at a compact radius. Such material also provides a natural explanation for the unusually long duration of the soft X-ray flash, if shock breakout occurred in extended CSM rather than at the stellar surface. This robust requirement for compact CSM links the earliest emission to recent pre-SN mass loss. The same site showed prolonged pre-explosion variability, suggesting that the material

inferred from the X-ray and optical data was part of a broader history of progenitor activity rather than an isolated circumstellar structure. Figure 4 presents a schematic illustration of this scenario. Additional possible evidence for structured CSM, possible shells associated with stronger precursor episodes, is discussed in the Methods 9.

This sequence distinguishes SN 2026gzf from most previously observed stripped-envelope explosions. The early emission of Type Ic SNe is heterogeneous (see Methods 10): some events, such as SN 2020lao(34), show no shock-cooling signature, whereas others, such as SN 2018gep(35), exhibit a luminous early excess. SN 2018gep also showed precursor emission from the progenitor system, but only during the weeks immediately before explosion, rather than over years. Around maximum light, SN 2026gzf resembles luminous broad-lined Type Ic SNe such as SN 2006aj(36). Most comparable events, however, are discovered either through GRB follow-up, where afterglow emission complicates the early SN light curve, or by wide-field optical surveys, which usually do not precisely constrain the explosion time. The soft X-ray discovery of EP260321a and rapid Lulin follow-up therefore provide one of the best-constrained explosion times and earliest optical light curves for a broad-lined Type Ic SN.

SN 2026gzf is also exceptional in its pre-explosion behaviour. Possible precursor emission has previously been reported for the broad-lined Type Ic SN PTF11qej, for which archival PTF imaging suggested a candidate outburst of $M_r \approx -13$ mag approximately 2.5 yr before explosion(37). Together with the weeks-long precursor of SN 2018gep, this shows that eruptive pre-explosion activity can occur in broad-lined Type Ic progenitor systems. However, these earlier cases involved either an isolated candidate outburst or activity confined to the final weeks before explosion.

The precursor of SN 2026gzf reaches ~ -14 mag, comparable in luminosity to the remarkably bright precursor of SN 1961V(38), while its short-timescale fluctuations resemble the strong variability seen in SN 2009ip(39), with variations of > 0.5 mag and up to ~ 3 mag (see Methods 11). Although SN 1961V and SN 2009ip likely arose from different, hydrogen-rich progenitor channels, they demonstrate that violent pre-explosion variability can reach similar luminosities in other massive-star systems.

To our knowledge, SN 2026gzf is the first stripped-envelope SN progenitor system with

repeatedly detected pre-explosion variability spanning more than a decade. The lack of previous detections may reflect both the intrinsic rarity of such events and observational selection: at an apparent magnitude of ~ 23 mag, the precursor lies below the depth routinely reached by most current wide-field surveys. SN 2026gzf therefore offers a timely preview of the long-baseline precursor science that Rubin/LSST is expected to enable, allowing us to test whether such activity is genuinely rare or has largely remained hidden below previous survey limits.

The local environment of SN 2026gzf is consistent with this picture of a young stripped progenitor. We obtained WiFeS integral-field spectroscopy to characterize both the host galaxy and the compact star-forming source associated with the SN position. Spectral-energy-distribution modelling with PROSPECTOR(40) (see Methods 12) gives stellar masses of $\log_{10}(M_*/M_\odot) = 9.04^{+0.09}_{-0.08}$ for the larger galaxy and $\log_{10}(M_*/M_\odot) = 8.09^{+0.23}_{-0.07}$ for the blue compact source, showing that the latter is the less massive component. The global host properties indicate a low-metallicity star-forming system, with a dust-corrected star-formation rate of $0.37 \pm 0.08 M_\odot \text{ yr}^{-1}$ and a gas-phase metallicity of $12 + \log(\text{O}/\text{H}) = 8.00 \pm 0.03$. A spectrum extracted at the SN position, although contaminated by SN light, gives a similarly low metallicity of $12 + \log(\text{O}/\text{H}) = 8.05 \pm 0.04$ and a local star-formation rate of $0.17 \pm 0.04 M_\odot \text{ yr}^{-1}$. These local values are based on a 3×3 -spaxel extraction, and the blue compact source cannot be cleanly separated from surrounding host emission. They should therefore be interpreted as representative of the SN vicinity rather than the exact SN sightline. Nevertheless, the WiFeS data show that SN 2026gzf exploded in a blue, low-metallicity star-forming environment, with a local metallicity of $\sim 0.23 Z_\odot$ and a high specific star-formation rate of $\sim 1.37 \text{ Gyr}^{-1}$. This places the SN site at the low-metallicity end of the broad-lined Type Ic SN host population(19; 41; 42).

Taken together, our rapid-response optical observations of SN 2026gzf, the EP shock-breakout detection and deep archival imaging provide a rare view of activity associated with a stripped-envelope SN progenitor system from the decade before explosion to the moment of core collapse. Rather than representing disconnected observables, the decade-long precursor variability, X-ray flash, blue first-day excess and compact CSM point to a single physical sequence in which the progenitor system became increasingly active before collapse and exploded into nearby material produced shortly beforehand. The historical light curve shows strong pre-explosion variability, with a clear increase in precursor luminosity during the final ~ 3 yr, suggesting enhanced mass ejection on a timescale comparable to late oxygen burning. The compact CSM required by the

239 X-ray and early optical data likely formed later, during an even shorter mass-loss episode shortly
240 before explosion, possibly associated with the final silicon-burning phase. SN 2026gzf provides
241 direct evidence that pre-SN instability and early circumstellar interaction are physically linked in
242 at least some broad-lined Type Ic explosions. More broadly, it shows that broad-lined Type Ic
243 SNe can be highly heterogeneous at the earliest times. Rapid optical follow-up of X-ray-selected
244 explosions will be critical for determining how often this sequence occurs(43), while deep time-
245 domain surveys such as Rubin/LSST will test whether long-term precursor activity is a common
246 but previously hidden feature of stripped-envelope SN progenitors.

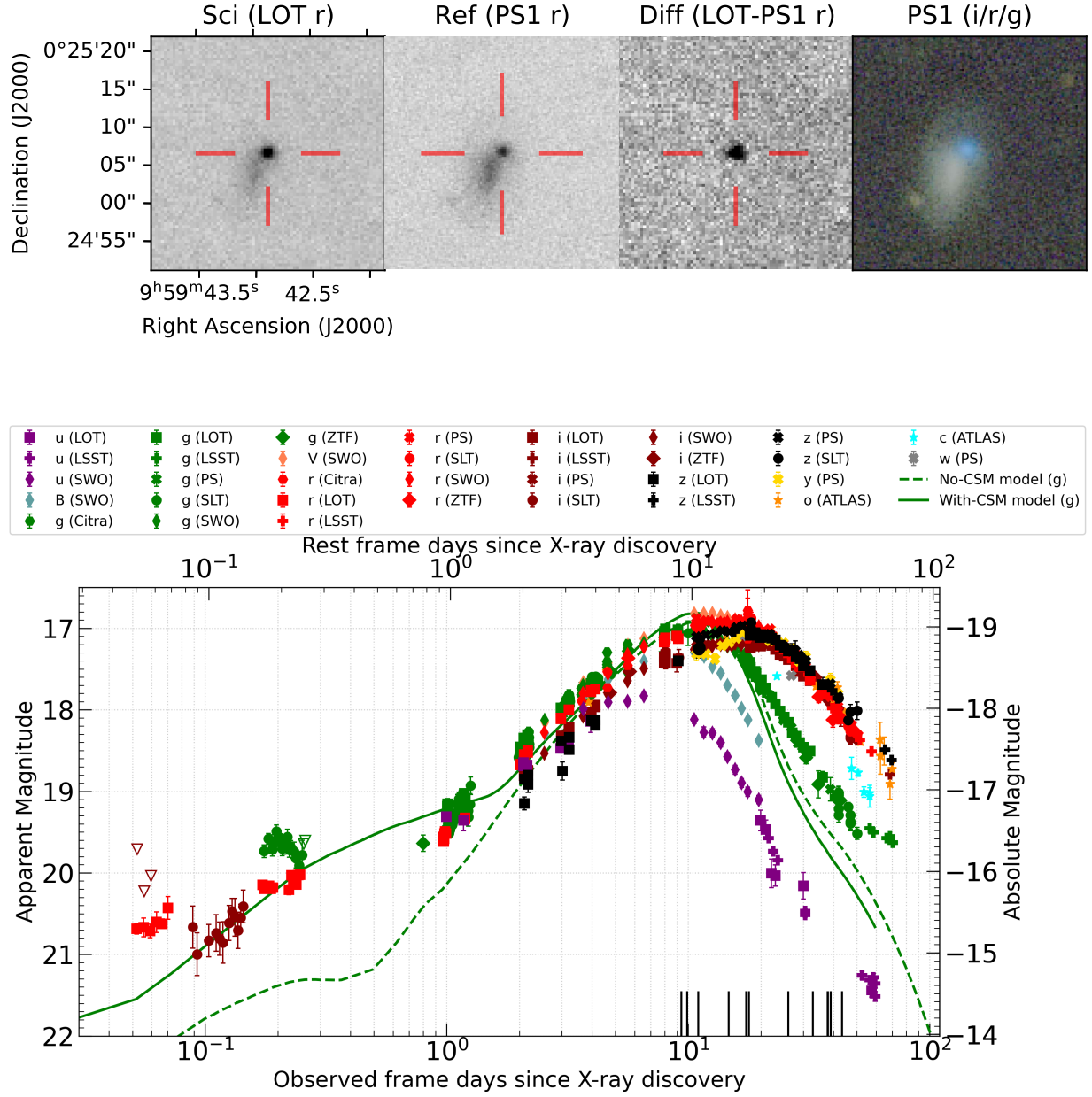


Figure 1: **Discovery and early optical evolution of SN 2026gzf.** **Upper panel,** From left to right: the LOT r -band discovery image obtained by Kinder, the Pan-STARRS r -band reference image, the corresponding difference image, and a Pan-STARRS colour composite ($i/r/g$). The red cross marks the position of SN 2026gzf. The transient position is coincident with a blue compact source. **Lower panel,** Multi-band light curves of SN 2026gzf, including the earliest Lulin follow-up observations and later survey photometry. The logarithmic x-axis highlights the high-cadence first-day light curve and the rapid early optical rise following the X-ray trigger. All the magnitudes in this figure are corrected for galactic extinction assuming $A_V = 0.067$ mag. Upper limits in corresponding filters are shown by downward pointing triangles. **The g -band hydrodynamic models with and without CSM are also indicated.**

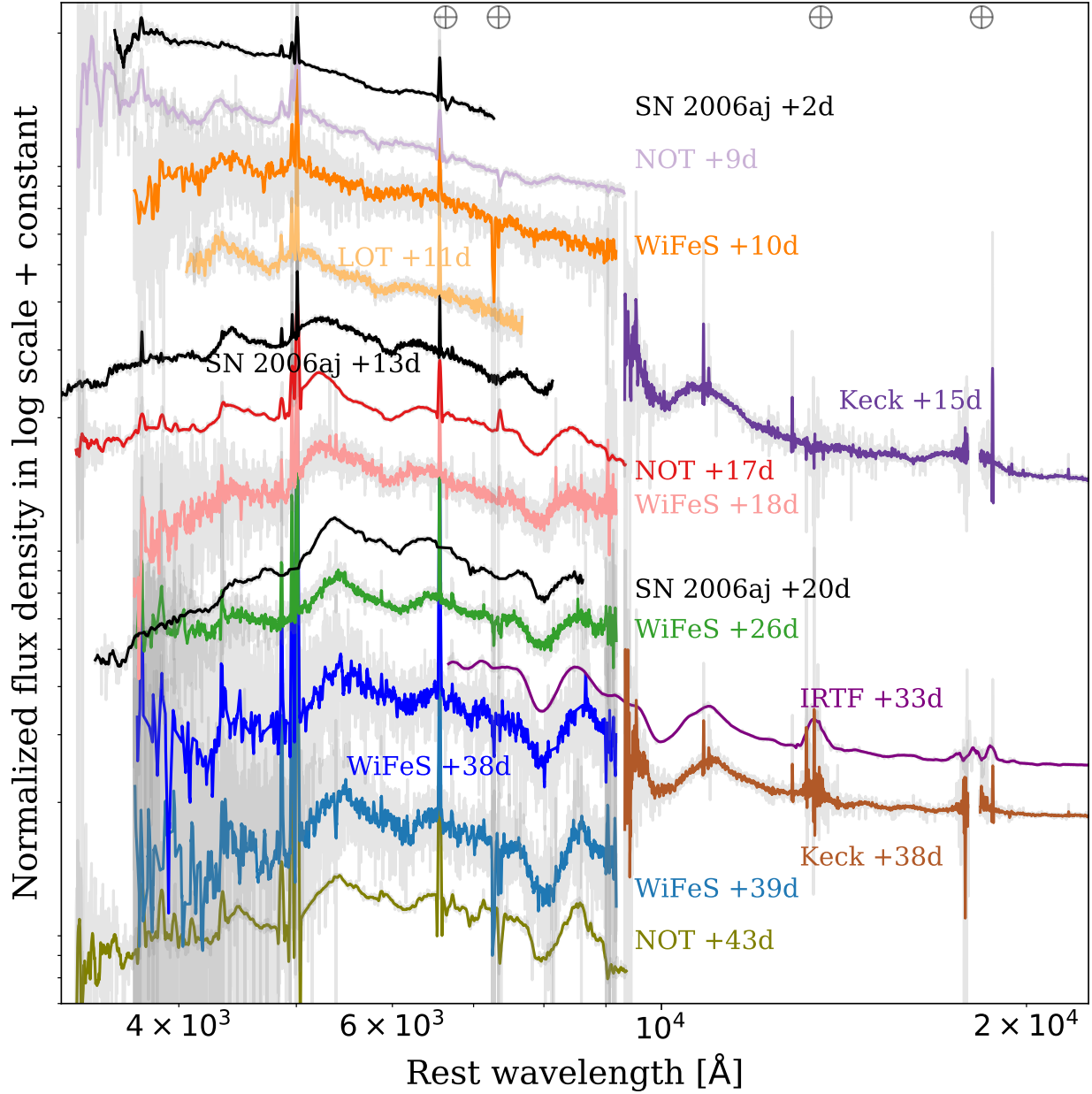


Figure 2: **Spectroscopic evolution of SN 2026gzf.** Rest-frame spectral sequence of SN 2026gzf from +9 to +43 days relative to the X-ray trigger ($T_0 = \text{MJD} = 61120.516$). Optical spectra from NOT, ANU 2.3-m/WiFeS and LOT are shown together with NIR spectra from Keck II/NIRES and IRTF/SpeX. All spectra are normalized and vertically offset for clarity. The coloured curves show the displayed binned spectra, while the grey curves indicate the original unbinned data. Earth symbols mark wavelength regions strongly affected by telluric absorption. Narrow host-galaxy HII-region emission lines are superposed on the SN features. Spectra of SN 2006aj at similar phases are overplotted for comparison.

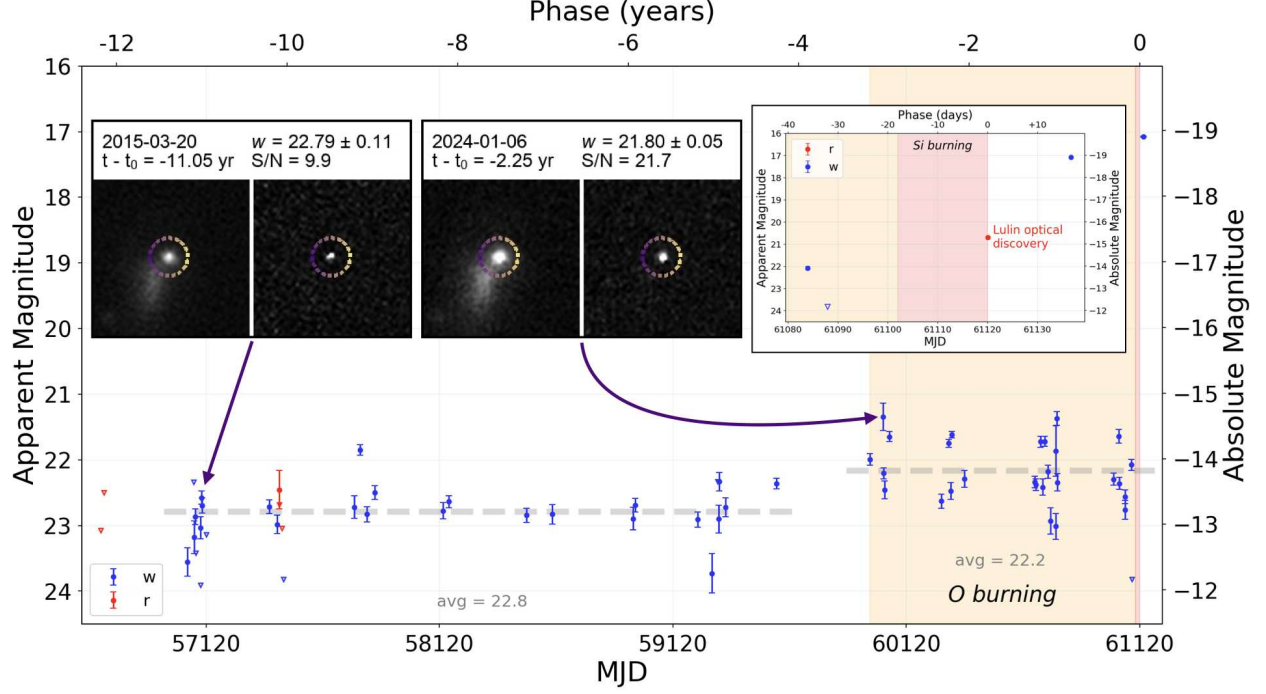


Figure 3: **Precursor activities of SN 2026gzf.** Historical Pan-STARRS w -band data show variability at the progenitor site over the final ~ 12 years before the SN explosion. Owing to the lack of earlier w -band coverage, we cannot exclude the possibility that similar activity was already present at earlier times. The precursor brightened from an average $w \approx 22.8$ mag ($M_w \approx -13.2$ mag) during -12 to -3 yr before explosion to $w \approx 22.2$ mag ($M_w \approx -13.8$) over the final ~ 3 yr. This is consistent with enhanced mass loss on a timescale comparable to late oxygen burning in a $\sim 15 M_\odot$ progenitor. An additional, more compact mass-loss episode during the final silicon-burning stage (~ 18 d) may have produced the dense nearby circumstellar material responsible for the X-ray shock-breakout signal, although this period is not covered by our observations. The upper inset panels show $0.28' \times 0.28'$ science and template-subtracted images at the site of SN 2026gzf for selected Pan-STARRS w -band data (north up, east to the left).

A precursor and early CSM interaction in the Type Ic-BL SN associated with EP260321a

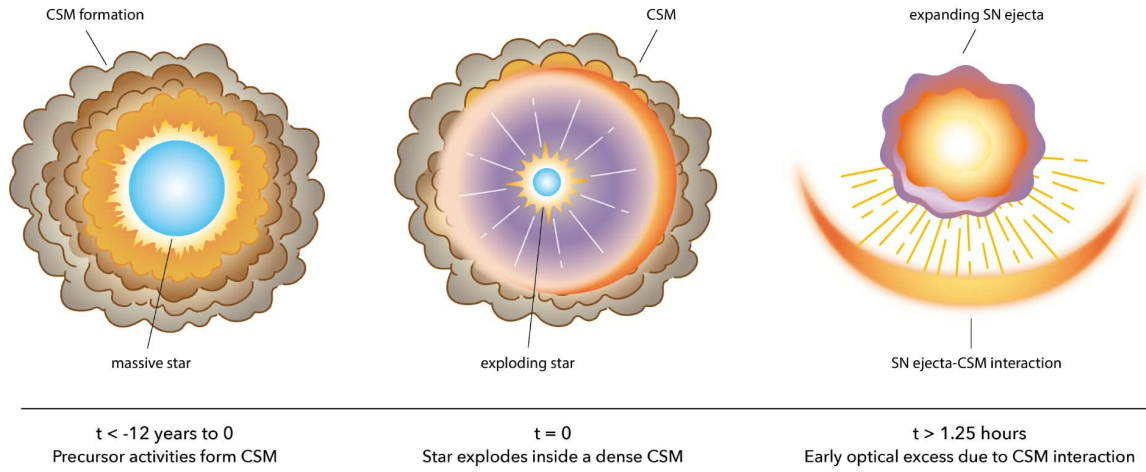


Figure 4: **Schematic scenario for SN 2026gzf.** **Left**, long-term precursor variability indicates sustained activity in the progenitor system and may have produced extended or structured CSM. **Middle**, shortly before explosion, an additional episode of mass loss forms compact dense material close to the star. At $t=0$, the star explodes inside this nearby dense CSM, giving rise to the soft X-ray flash detected by Einstein Probe. **Right**, by $t > 1.25$ h, interaction between the rapidly expanding SN ejecta and the nearby CSM contributes to the bright, blue first-day optical excess. The schematic therefore links the decade-long precursor variability, the EP X-ray trigger, the optical counterpart discovery at 1.25 h, the blue first-day excess, and the subsequent rise into a normal Ic-BL SN.

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Methods

1 X-ray shock breakout

Einstein Probe (EP)(6) is a space X-ray mission designed to monitor the soft X-ray sky for transient phenomena and to perform rapid onboard follow-up of newly discovered events. By combining the Wide-field X-ray Telescope (WXT) with the more sensitive Follow-up X-ray Telescope (FXT), EP is optimized for the discovery and early characterization of short lived high energy transients. EP260321a was discovered by EP-WXT on 21 March 2026, 12:23:07 UTC (MJD 61120.516; T_0) as a fast, soft X-ray transient(7; 9). The initial WXT exposure lasted only ~ 432 s before being interrupted by the spacecraft’s autonomous follow-up sequence triggered by the transient itself, and thus represents only a lower limit on the true duration of the X-ray emission. Follow-up observations with the onboard EP-FXT started 12 min later and revealed a previously uncatalogued, rapidly fading X-ray source within the WXT localization region. The X-ray spectra are well described by absorbed blackbody models with temperatures of 164^{+40}_{-29} eV and 121^{+3}_{-3} eV in the WXT and FXT data, respectively. A galaxy at $z = 0.0345$ lies within the refined X-ray position; if associated, the transient reached a luminosity of $\sim 2.2 \times 10^{44}$ erg s $^{-1}$. These properties make EP260321a a compelling candidate for the shock breakout phase of a SN(8).

2 Discovery of the optical counterpart

The search for the optical counterpart to EP260321a began immediately after the EP trigger. Our Kinder/Lulin campaign obtained the first optical discovery of the counterpart to EP260321a, starting only 1.25 hr after the X-ray detection(10). In these earliest Lulin observations, we identified a blue source at $\alpha, \delta = 09^{\text{h}}59^{\text{m}}42^{\text{s}}88, +00^{\circ}25'06''3$ (J2000), projected near a galaxy (SDSS J095942.99+002504.0) within the EP localisation region (Fig. 1). We noted that this SDSS galaxy has a redshift of $z = 0.034$, as independently measured in the 2dF and DESI Legacy Survey DR1 spectroscopic catalogues. At first, this source was plausibly interpreted as an unrelated variable star, as no unambiguous new optical transient had yet emerged and several contemporaneous observations reported only upper limits(10; 49; 50; 51). However, the picture changed over the following day. Our continued optical monitoring showed that the source brightened(14), while independent detections from other facilities established a consistent counterpart at the same position(53; 54). Together with the early optical evolution(55), these data suggested that the initial emission was not dominated by a persistent variable star, but instead traced a rapidly evolving transient associ-

ated with EP260321a(15). Subsequent spectroscopy confirmed this interpretation(57). Broad SN-like features were identified at the redshift of the nearby galaxy, excluding a Galactic origin and demonstrating that the optical counterpart was an emerging broad-lined Type Ic SN(16; 17; 18). The combined X-ray and optical behaviour therefore supports a picture in which SN 2026gzf was discovered at an exceptionally early phase, when the SN emission was only beginning to emerge.

We note that a variable blue source at the same position as SN 2026gzf was previously identified in Pan-STARRS1 imaging (internally named PS18csa) on MJD 58465.55 (2018 December 13) with a w -band magnitude, 21.66 ± 0.15 mag. This detection was subsequently reported to the International Astronomical Union Transient Name Server as AT 2018mtl. This detection corresponds to one of the episodes of precursor variability of SN 2026gzf (see Fig. 3).

3 Photometric and Spectroscopic data

Our analysis is built on the high-cadence optical light curves obtained with the Lulin Observatory telescopes (LOT and SLT), which provide the core dataset of this work and capture the earliest evolution of SN 2026gzf. To improve the temporal coverage and mitigate weather-related gaps, we supplemented the Lulin data with additional imaging from Pan-STARRS, ATLAS, LSST, and public ZTF observations. At the earliest phases, we further included data from the Citra telescope and the Swope telescope obtained through POISE, which help bridge gaps in coverage caused by longitudinal separation.

In addition to the imaging data, we obtained optical spectra of SN 2026gzf near maximum light with the WiFeS, the NOT, and the LOT spectrographs. The WiFeS integral-field unit (IFU) spectroscopy also provides spatially resolved information on the host galaxy environment, enabling investigation of the nearby H II region and the local environment of the SN. We further include NIR spectra obtained with Keck II/NIRES and IRTF/Spex.

Logs of the photometric and spectroscopic observations are provided in Tables 2 and 1, and the extinction-corrected spectra are presented in Fig. 2. All spectra reported here have been uploaded to WISEREP(61). We use AB magnitudes in this work. We adopt a flat Λ CDM cosmology with parameters $H_0 = 67.4 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_m = 0.315$, and $\Omega_\Lambda = 0.685$, from the *Planck* 2018 collaboration (62). Thus the distance modulus $\mu = 35.98$, luminosity distance = 156.54 Mpc. The Milky Way extinction is $A_V = 0.067$ mag(63).

The details of the instrument configuration are as follows:

Kinder We initiated follow-up observations of EP260321a as part of the Kinder collaboration(11) using the Lulin One-meter Telescope (LOT), equipped with the SOPHIA 2048BX camera, and the 40-cm Seisi Lulin Telescope (SLT)[†], equipped with an Andor EMCCD camera. The data were processed with a custom-built pipeline[‡] that performs standard bias, dark, and flat-field corrections. Unless explicitly stated otherwise, all photometric measurements were performed using a homogeneous approach, including template subtraction. Whenever the observed filter matched the Pan-STARRS system, we used the corresponding Pan-STARRS image(13) as the subtraction template, in which we used Pan-STARRS stacked images as templates. For *u*-band measurements, the template and calibration were from SDSS. The SN brightness was then measured with point spread function (PSF) photometry on the subtracted images using AUTOPHOT(66), and the resulting magnitudes were calibrated using field stars from the ATLAS Refcat2 catalogue(67). To preserve the highest possible temporal resolution, we performed photometry directly on the individual exposure images. However, the observations obtained near peak ($\sim$ MJD 61129 and MJD 61131) were affected by moonlight, so the individual images were combined to improve the signal-to-noise ratio (see details in the observing log).

Follow-up optical spectra were obtained with the LOT using the Shelyak UVEX spectrograph. The instrumental setup, consisting of a 300 line mm^{-1} grating, a 50 μm slit, and the ASI533MM Pro CMOS camera under bin-2 readout mode, provides a resolving power of ~ 300 , a wavelength coverage of 4200–7950 Å, and a dispersion of 2.49 Å pixel^{-1} . Standard reductions were applied, including bias and dark subtraction, flat-field correction with tungsten-illuminated dome flats, wavelength calibration using the internal ArNe lamp, and flux calibration with spectrophotometric standards GD 108 observed at similar airmass to the target. We adopted the A-B dithering pattern during the observation of the spectra, with an offset of 5'' along the R.A. direction, for a better background subtraction.

Citra We obtained images with the 0.5-m Citra Space Corporation’s PlaneWave telescope in New Mexico, which is equipped with a CMOS camera and a Sloan filter set. The CMOS camera Moravian C5A-150M has a 1.2×1.9 degrees field of view, with a pixel scale of 1''. Observations were carried out in *g* and *r* filters, with individual exposure time of 60 seconds. The raw data were

[†]“Seisi” is a word from the Tsou, an Indigenous people of Taiwan, referring to a minivet. The telescope is named in recognition of the longstanding connection between Lulin Observatory and its Tsou resident assistants.

[‡]<https://hdl.handle.net/11296/98q6x4>

processed following standard calibration procedures, including bias and dark subtraction as well as flat-field corrections.

Pan-STARRS We undertook a multi-band (*grizyw*) observational follow-up campaign of SN 2026gzf with Pan-STARRS (PS), commencing on MJD 61131.3. The PS telescope system consists of two 1.8-m telescopes (Pan-STARRS1 and Pan-STARRS2) located at the summit of Haleakala on the Hawaiian island of Maui(13), and employs an SDSS-like filter system denoted as *grizy*, as well as a broad *w* filter, which is a composite of the *gri* filters(68). The imaging system provides a pixel scale of 0.26'' and a field of view of 7 deg²(13). All target images of SN 2026gzf were obtained with Pan-STARRS2, and were processed with the standard Pan-STARRS pipeline. Target images were astrometrically and photometrically calibrated, before having a historical Pan-STARRS1 3π reference image subtracted to produce a final difference image, from which we measure PSF photometry(69; 70; 71).

ATLAS Asteroid Terrestrial-impact Last Alert System (ATLAS) is a four-unit, 0.5-m wide-field survey system that monitors the entire sky(72). The transient is listed internally as ATLAS26dgs. The available ATLAS data were obtained in the cyan (*c*) and orange (*o*) bands, which roughly corresponds to the combined Pan-STARRS/SDSS $g+r$ and $r+i$ bands, respectively. We obtained the ATLAS points(73) from the forced photometry service(74).

Rubin/LSST The Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST) is a deep, wide-field optical time-domain survey that will scan the southern sky using an 8.4-meter telescope and a 3.2-gigapixel camera, driving unprecedented discoveries in time-domain astronomy (75). To construct the optical light curves, we retrieved the photometric data for LSST object ID 314003014107006318 utilizing the Lasair broker (76).

ZTF Zwicky Transient Facility (ZTF) is a wide-field optical synoptic survey carried out with the Palomar 48-inch telescope, using a 47 deg² camera and g, r , and i filters for time-domain discovery and monitoring(77; 78). We supplemented our follow-up photometry with public forced ZTF measurements retrieved from the Lasair broker(76). The transient is internally designated ZTF26aaonmha, and the available public light curve consists of g - and r -band observations.

WiFeS The Wide-Field Spectrograph (WiFeS) is an Integral Field Unit mounted on the Australian National University (ANU) 2.3m Telescope(79), located at Siding Spring Observatory in Coonabarabran, Australia. WiFeS spectroscopy of SN 2026gzf was originally obtained on the 31st of

March 2026 near maximum light, using the Nod and Shuffle mode for three 1800s exposures, each made up of 900s on source and 900s on sky. We utilised the B3000 and R3000 gratings, along with the RT560 dichroic to produce $R \sim 3000$ spectra from 3300–9200 Å. The data were reduced using the PYWIFES pipeline(80). We further acquired an additional 4 WiFeS observations under darker sky conditions, and stacked the resulting datacubes to use in the spectral analysis of host galaxy properties.

PRESTO and NUTS2 Three optical spectra of SN 2026gzf were obtained with the 2.56-m Nordic Optical Telescope (NOT)(81) at the Roque de los Muchachos Observatory on La Palma, Spain, one as part of the PRESTO project and two by the NOT Unbiased Transient Survey 2 (NUTS2)(82). The observations were carried out with the Alhambra Faint Object Spectrograph and Camera (ALFOSC) and the data were reduced following standard procedures and flux calibrated using observations of spectrophotometric standard stars obtained on the same nights.

POISE Optical *ugriBV* imaging was obtained as part of the Precision Observations of Infant SupernovaE (POISE) programme (83) using the Swope 1-m telescope at Las Campanas Observatory and reduced using the Carnegie Supernova Project (CSP) photometric pipeline (84). The reductions included bias subtraction, flat-field correction, astrometric registration, and PSF photometry measured relative to a local sequence of field stars. The local sequence was calibrated using stars from the Refcat2 catalogue (72) transformed to the natural system of the Swope telescope. Host-galaxy contamination was removed through image subtraction using Pan-STARRS1 (PS1) reference images. Specifically, PS1 *g*-band images were used for subtraction of the *B*, *V*, and *g*-band data, while PS1 *r*- and *i*-band images were used for subtraction of the corresponding *r*- and *i*-band observations, respectively. Image subtractions were performed with the ImageMatch subtraction software[§]. No template subtraction was applied to the *u*-band imaging.

HISS Three NIR spectra were obtained on the 10-m W. M. Keck Observatory Telescope II (Keck II) with the Near-Infrared Echellette Spectrometer (NIREs)(85) and the 3.2-m NASA Infrared Telescope Facility (IRTF) with the SpeX Spectrograph(86) at Maunakea, Hawaii. The observations are as part of the Hawaii Infrared Supernova Study (HISS)(87; 88; 89; 90). The data were reduced using the methods outlined in (87).

[§]<https://code.obs.carnegiescience.edu/Algorithms/imagematch>

HSC-SSP The Hyper-Suprime Cam (HSC)(91) is a powerful wide-field mosaic camera mounted on the prime focus of the Subaru 8.2-m telescope, which consists of 104 $2k \times 4k$ scientific CCDs with a mean pixel scale of $0.168''$. It has an effective field of view of 1.5 degrees in diameter, with a modified sloan *griz* filter system. We collected the survey data under the framework of the Hyper-Suprime Cam Subaru Strategic Program (HSC-SSP)(92), a wide-field survey designed to address a broad range of cosmological and galaxy-evolution questions. In the latest HSC-SSP Public Data Release version 3 (HSC-SSP PDR3)(93), we retrieved 43 calibrated 'CORR'-level HSC exposures obtained over 14 nights.

DESI Legacy Imaging Surveys Historical pre-explosion imaging of the SN 2026gzf site was obtained with the Dark Energy Camera (DECam)(94) mounted on the Víctor M. Blanco 4-m telescope at the Cerro Tololo Inter-American Observatory. We retrieved archival pipeline-reduced science images in the g , r , i , and z bands through the NOIRLab Astro Data Archive. These public archival data primarily consist of observations from the DESI Legacy Imaging Surveys(24) and earlier DECam programmes. The dataset comprises a total of 55 individual exposures, spanning from April 2013 to February 2020. These long-term multi-band observations provide critical data for assessing the precursor activity at the explosion site prior to the Einstein Probe trigger.

4 Spectral analysis of SN 2026gzf

Figure 2 presents the rest-frame spectral sequence of SN 2026gzf from 9 to 43 d relative to the EP X-ray trigger time (MJD 61120.516; T_0), based on optical observations obtained with NOT/ALFOSC, ANU 2.3-m/WiFeS and LOT/UVEX, together with NIR spectra from Keck II/NIRES and IRTF/SpeX. For visual comparison, the spectra are normalized and arbitrarily offset. The optical sequence exhibits broad absorption and emission features characteristic of broad-lined Type Ic SNe (SNe Ic-BL). Superposed on these are strong, narrow host galaxy H II-region emission lines, including prominent $H\alpha$, $H\beta$, and $[O III] \lambda\lambda 4959, 5007$. The NIR spectra extend our wavelength coverage to $\sim 2.4 \mu m$, and provide additional constraints on the spectral energy distribution (SED) and line identifications. For context, we also over-plot spectra of SN 2006aj at comparable epochs(2; 20; 21), illustrating the close resemblance in spectral evolution.

To better understand the properties of SN 2026gzf, we undertake spectral modelling of a subset of our spectral sequence. For this, we employ the open-source TARDIS code(99) (specif-

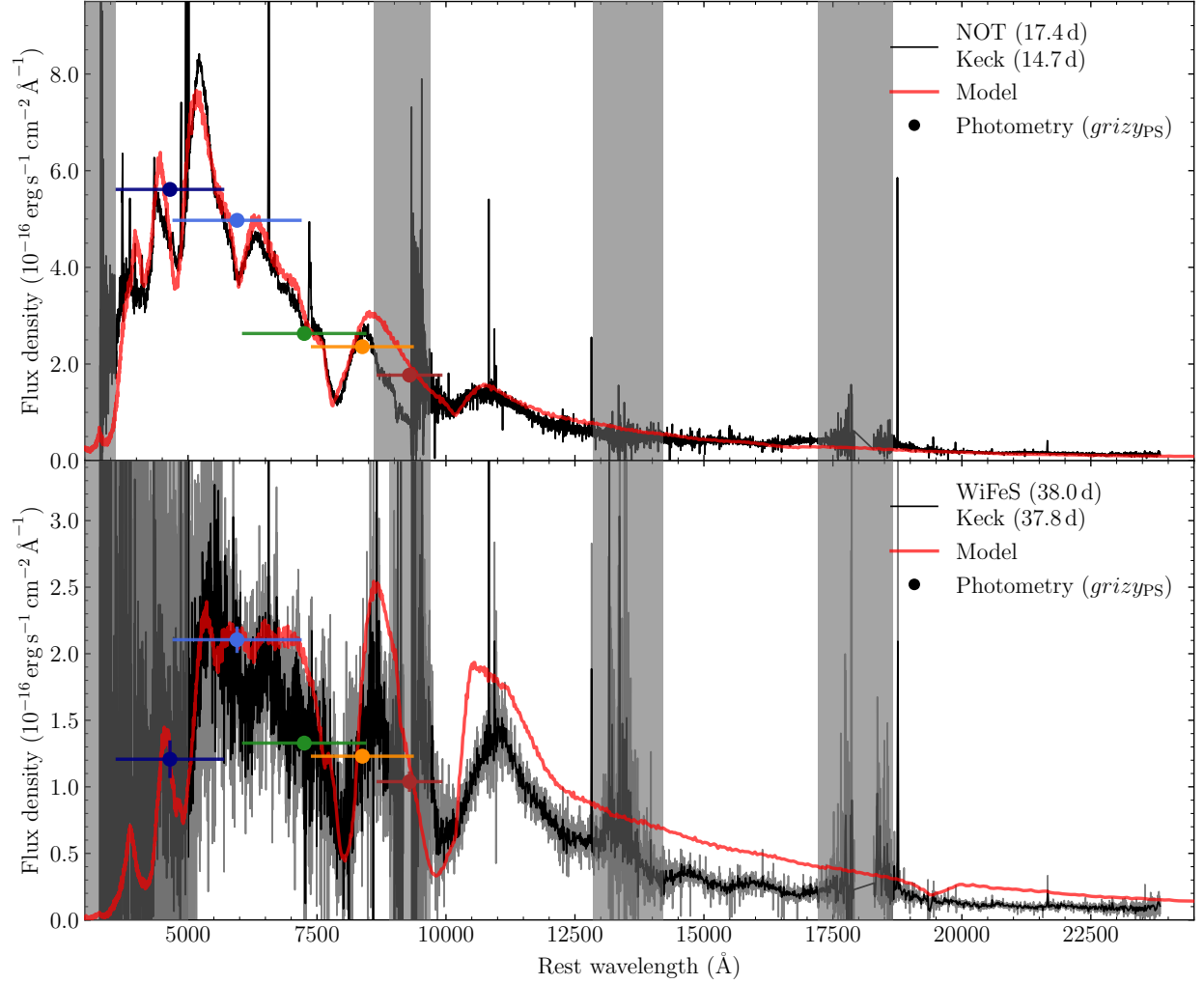


Figure 5: Comparison between our best-fitting TARDIS models and the optical NOT and WiFeS spectra obtained 17.4 and 38.0 (observer-frame) days post-explosion. We also plot the similar-phase NIR Keck spectra for comparison to our model spectra. Finally, we over-plot the Pan-STARRS photometry that was used to flux-calibrate the spectra. All observational data has been de-reddened and shifted to the rest frame, for ease of comparison to our model spectra. Regions corresponding to poor data quality or strong telluric absorption are masked by vertical grey bands. The spectra in the lower panel have been re-binned ($5\times$) for clarity.

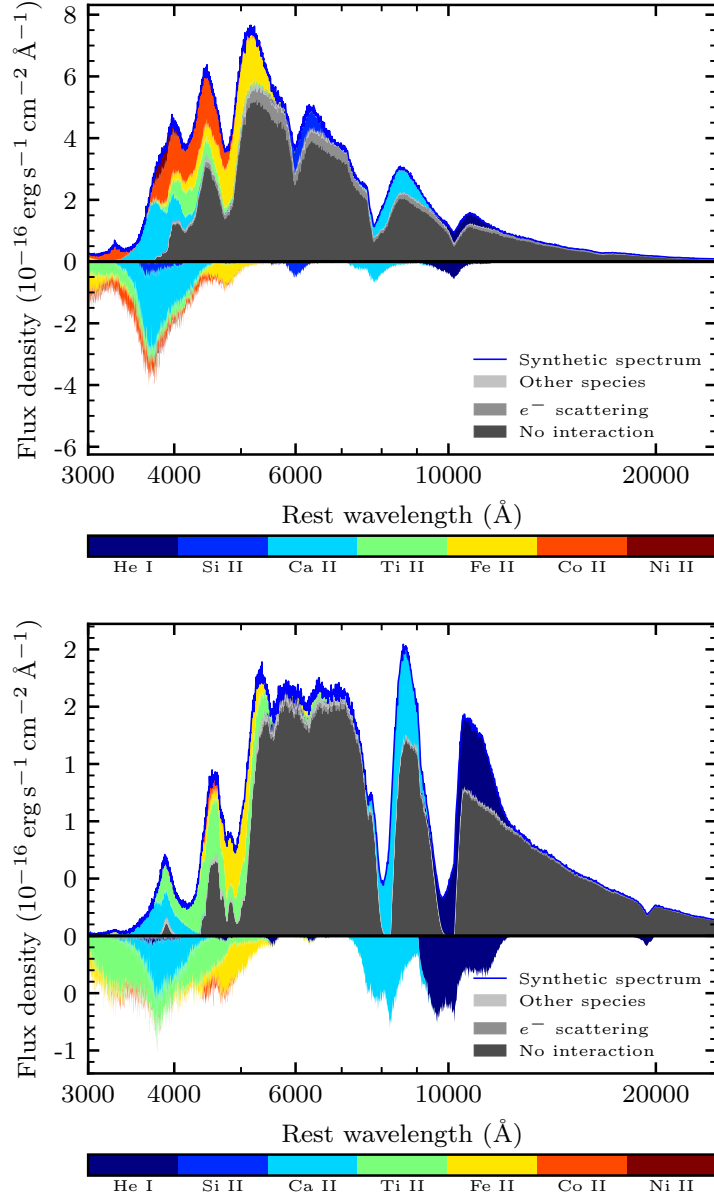


Figure 6: *Top*: Model decomposition plot for our best-fitting TARDIS model of the 17.4 d NOT spectrum, illustrating the strongest contributions to the SED. Contributions from specific ions are colour-coded; absorption is represented by shaded regions below Flux = 0, while emission is represented by shaded regions above Flux = 0. *Bottom*: Same as *Top*, but for our best-fitting model of the 38.0 d WiFeS spectrum.

ically v2025.05.25). TARDIS is a 1D Monte Carlo radiative transfer code that is capable of rapidly synthesising model spectra for a range of explosive transient types, including SNe Ic and Ic-BL(100; 101; 102; 103). The code approximates the ejecta from some stellar explosion as a homologously expanding, uniform sphere, with the ejecta discretised into two zones: an inner opaque region, and an outer line-forming region that is discretised into shells. The inner region of the ejecta is assumed to be completely optically thick, within which all energy deposition is assumed to occur (and assumed to completely thermalise). The *outer* boundary of this optically thick region represents the *inner* boundary of the computational domain, and thus it represents a sharp photosphere beneath the line-forming region. At the beginning of a simulation, some number of photon packets are spawned at this inner boundary, with random propagation directions and frequencies randomly sampled from a single-temperature blackbody (whose temperature is derived from the model luminosity). These photon packets are then propagated through the ejecta, and the code records each instance of interaction (via free e^- scattering or bound-bound transitions). The simulation progresses until all photon packet paths have terminated; at this point the emergent packets are used to construct a model spectrum that can be compared to data. The user controls the position of the inner and outer boundaries of the line-forming region, as well as the density profile, composition and luminosity. While the code is time independent (i.e., each simulation represents a single snapshot in time), it is possible to construct a series of self-consistent models that can then be compared to a series of observations.

For our modelling efforts, we focus on reproducing the SED and prominent features in the 17.4d NOT and 38.0d WiFeS optical spectra. First, we flux-calibrate the spectra to the near-contemporaneous ($\Delta\text{MJD} < 0.9\text{d}$) Pan-STARRS *griz* photometry. The data were then dereddened (assuming $A_V = 0.067$; Section 3) and shifted to the rest frame (assuming $z = 0.0345$; Section 2). In Figure 5 we overlay our Pan-STARRS photometry onto these observed spectra, demonstrating excellent agreement.

Next, we generate TARDIS models to reproduce these two spectra. For our model setup, we utilise the `nebular`, `dilute-lte` and `macroatom` treatments for ionisation, excitation and line interactions, respectively. Additionally, to better reproduce the observed He features in the NIR spectra, we adopt the He NLTE treatment outlined by Ref. (104). By approximately accounting for non-thermal excitation processes, we can more accurately recover He feature strengths in our model spectra. We stress that this is a simple, empirically derived approximation, and as such our inferred He masses should not be over-interpreted as true mass estimates.

From our model fitting, we endeavour to uncover the ions that are responsible for the prominent absorption and emission in the spectra. For our models, we assume a power law density profile, of the form:

$$\rho(v, t) = \rho_0 \left(\frac{v}{v_0} \right)^{-\Gamma} \left(\frac{t_{\text{exp}}}{t_0} \right)^{-3}, \quad (1)$$

where $\rho_0 = 6 \times 10^{-11} \text{ g cm}^{-3}$, $v_0 = 10000 \text{ km s}^{-1}$ and $t_0 = 2 \text{ d}$ are normalisation constants for the density profile. These constants define a reference point in velocity space and time at which $\rho(v, t)$ has a specified value. The parameter t_0 is therefore only a reference epoch for the density normalisation, and should not be interpreted as a fitted physical timescale or as the explosion epoch. We adopt $t_0 = 2 \text{ d}$ because this is the default reference value used in our TARDIS setup; choosing a different reference epoch would be equivalent provided the density normalisation is rescaled consistently. From this parameterisation, we compute a consistent density at any other point in space and time. We assume $\Gamma = 6$, motivated by prior works modelling SNe Ic-BL(100; 102). We fix our t_{exp} values to be the (rest-frame) time between EP detection and the epoch of spectral observation. Finally, we assume an outer boundary velocity, $v_{\text{outer}} = 50000 \text{ km s}^{-1}$. We compare our best-fitting TARDIS models to the observations in Figure 5. We also compare to the 14.7 and 37.8 d Keck NIR spectra to check model agreement with the NIR properties of SN 2026gzzf. We note that these spectra have not been flux-calibrated, and the phases do not perfectly match those of our TARDIS models; however, we find that our model continua and He I $\lambda 10830$ features closely match the data. We summarise our best-fitting model properties in Table 4.

To fit the data, we invoke a three-zone composition profile comprised of He, Si, Ca, Ti and radioactive ^{56}Ni (which decays, providing ^{56}Co and ^{56}Fe). Our full composition profile is presented in Table 3. We note that this composition does not encompass all elements expected to be synthesised and ejected by a SN Ic-BL; our focus here was on line identification and general reproduction of the continuum, enabling approximate ejecta properties to be ascertained. We find that the spectral features, through the optical and NIR, can be replicated by our models including just these seven elements. The specific contributions of each element are highlighted in Figure 6.

We note an apparent inconsistency in our composition profile between 17.4 and 38.0 d. We invoke a higher Ca mass fraction at 17.4 d than at 38.0 d ($X[\text{Ca}]_{32000-18000 \text{ km s}^{-1}} = 8 \times 10^{-3}$ vs. $X[\text{Ca}]_{32000-18000 \text{ km s}^{-1}} = 10^{-4}$; see Table 3). A relatively large Ca mass fraction at 17.4 d is required by our models to match the data. At this phase, Ca II exists as a trace ion in our model; as such, we are extremely sensitive to the exact temperature profile. A modest tweak on the order of

a few 100 K may lead to substantial changes in the ion balance of Ca. To overcome this, we inflate the Ca mass fraction so as to provide our model with enough Ca II to produce a prominent P-Cygni feature at $\sim 8000 \text{ \AA}$. While this may appear to result in some uncertainty in the quantity of Ca in the ejecta, we note that the Ca II mass fraction (the only Ca ion to which we are sensitive) evolves as anticipated; i.e., our model at 38.0 d contains more Ca II than our 17.4 d model ($2.1 \times 10^{-5} M_{\odot}$ versus $7.4 \times 10^{-7} M_{\odot}$; see Table 4).

The species identifications and expansion velocities extracted from our sequence of best-fitting models match those inferred from similar analyses of other SNe Ic-BL (e.g., Ref. (100)). While our modelling indicates the presence of a small amount of He ($\sim 0.072 M_{\odot}$), this does not clash with the proposed ‘Ic-BL’ classification. SN classification schemes are typically based on the presence (or absence) of *optical* absorption features; in the case of SN 2026gzf, our models indicate that He only contributes substantially to the data at $\approx 1 \mu\text{m}$, through its $\lambda 10830$ transition. Finally, we note that SN 2026gzf is not the first SN Ic-BL to possess He features. Optical He features have been identified in e.g., the Ic-BL SNe 2012ap and 2016coi (105; 106).

5 Pre-burst activities

Astrometric registration and source localisation We quantified the positional association between SN 2026gzf and the historical blue compact source, by which we mean the persistent blue source visible in archival direct images prior to explosion, rather than the later Pan-STARRS difference image residuals. In the present analysis we used archival direct images from DECam, Subaru/Hyper Suprime-Cam, SDSS, and Pan-STARRS, and compared these with representative post-explosion SN positions shown in Fig. 7 and listed in Table 5. Each archival image was tied to the *Gaia* DR3 astrometric frame using nearby reference stars retrieved through VizierR (I/355/gaiadr3), retaining stars brighter than $G = 20$ mag and excluding objects close to the image boundaries. For each image, the astrometric solution was refined in two stages. We first estimated a bulk translational offset by searching for the nearest local peaks around the WCS-predicted *Gaia* positions within a coarse search radius of 30 pixels, using a centroid box with a half-size of 7 pixels. The resulting shifts were sigma-clipped at the 3σ level to derive a robust global offset for each frame. We then carried out a finer local search within 10 pixels and fitted an affine transformation between the predicted and observed reference star positions. Only matches within 4 pixels of the shifted prediction were retained in the affine fit, and a residual clip of 2.5 pixels was applied. The astrometric uncertainty for each image includes the rms residual of this

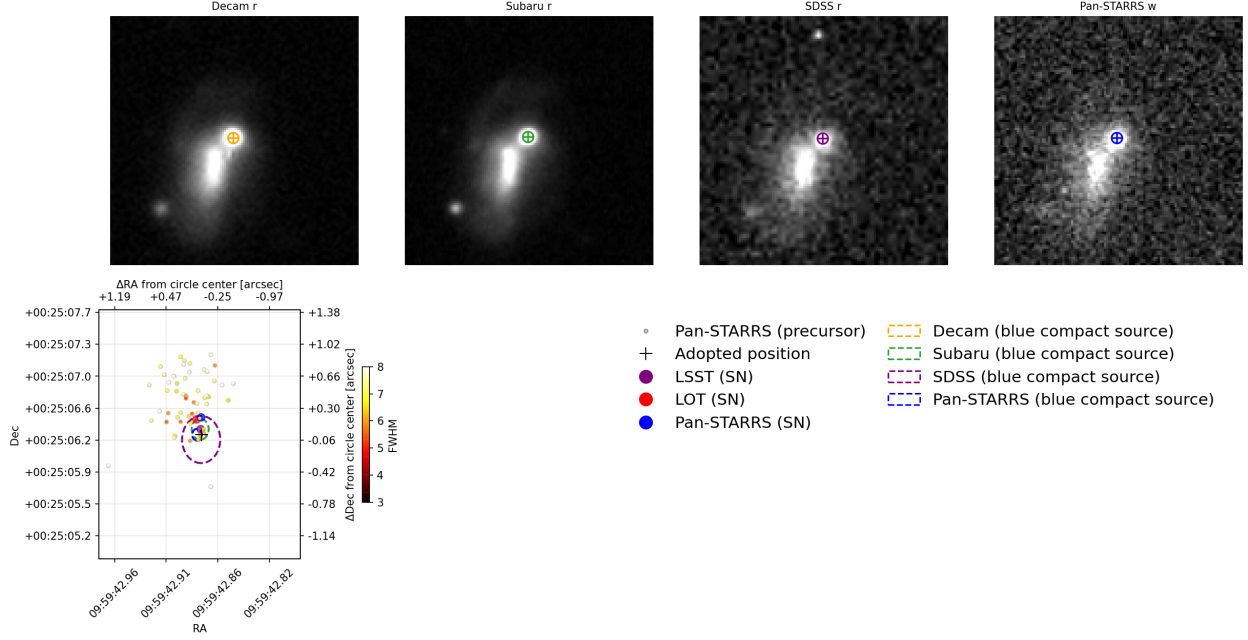


Figure 7: **Astrometric association between the historical blue compact source, the Pan-STARRS precursor residuals, and SN 2026gzf.** Top, archival cutouts of the explosion site from DECAM r , Subaru r , SDSS r , and Pan-STARRS w , registered to a common astrometric frame. The coloured crosshairs mark the independently measured centroid of the blue compact source in each dataset. Bottom, sky coordinate comparison of the measured source centroids. The small open circles show the individual Pan-STARRS precursor positions measured from w -band difference image residuals, with the colour indicating the image seeing at each epoch. Filled coloured circles mark representative later SN positions from optical imaging. The dashed ellipses indicate the astrometric uncertainty of the blue compact source centroid in each archival dataset. The best-seeing precursor residuals lie very close to the SN and blue compact source positions, while small offsets are expected because the centroid measured from a difference image residual depends to some extent on the adopted reference frame. Overall, the pre-explosion source, the precursor residuals, and the SN positions are consistent within the astrometric uncertainties, supporting a common origin.

609 local affine solution.

610 We measured the centroid of the historical blue compact source in each archival direct im-
611 age using `photutils`, extracting a small cutout around the target position, estimating the local
612 background from the border pixels of the cutout, subtracting this background, setting negative
613 pixel values to zero, and computing the centroid from the remaining flux distribution. The cen-
614 troid uncertainty was estimated from the weighted second moments of the source light distribution
615 and combined in quadrature with the local astrometric rms. For archival images in which a sta-
616 ble local centroid could not be recovered, we retained the Gaia-registered prior-projected position
617 rather than forcing an unstable centroid solution. The adopted pre-explosion position was defined
618 from the archival direct image centroids of the blue compact source alone, and not from the Pan-
619 STARRS precursor residuals or the later SN positions. The latter are shown separately in Fig. 7
620 and Table 5 as consistency checks. The Pan-STARRS precursor positions were measured from
621 w -band difference image residuals and are therefore expected to show small centroid shifts that
622 depend to some extent on the adopted reference frame and subtraction template. Likewise, the
623 later SN positions are not used to define the pre-explosion centroid, but instead to test whether the
624 explosion occurred at the same site.

625 Using the weighted mean of the archival direct image centroids listed in Table 5, we adopt a
626 pre-explosion astrometric reference position of $\alpha = [09:59:42.88]$, $\delta = [+00:25:06.3]$ (J2000). The
627 corresponding uncertainties are $\sigma_{\text{RA,sky}} = 0.0268$ arcsec and $\sigma_{\text{Dec}} = 0.0232$ arcsec. All archival di-
628 rect image centroids of the blue compact source are mutually consistent with this adopted position
629 within the quoted astrometric uncertainties, and the later SN positions are consistent with the same
630 site to within the overall astrometric error budget. Unless otherwise noted, we use this adopted
631 astrometric reference position throughout the paper as the fiducial coordinate of the explosion site.

632 **Archival aperture photometry and flux homogenisation** To characterise the long-term be-
633 haviour of the explosion site, we measured circular aperture fluxes at the fixed adopted
634 source position on archival images from Pan-STARRS1, ZTF, Subaru/Hyper Suprime-Cam,
635 and DECam. All images were analysed with the same aperture photometry procedure using
636 `photutils.aperture_photometry`, in order to minimise survey dependent systematics.
637 ZTF images were retrieved from IRSA, while the Pan-STARRS1, Subaru, and DECam images
638 were taken from the corresponding survey or archival image products used throughout this work.

639 For each frame, the source aperture radius was scaled to the image quality and set to

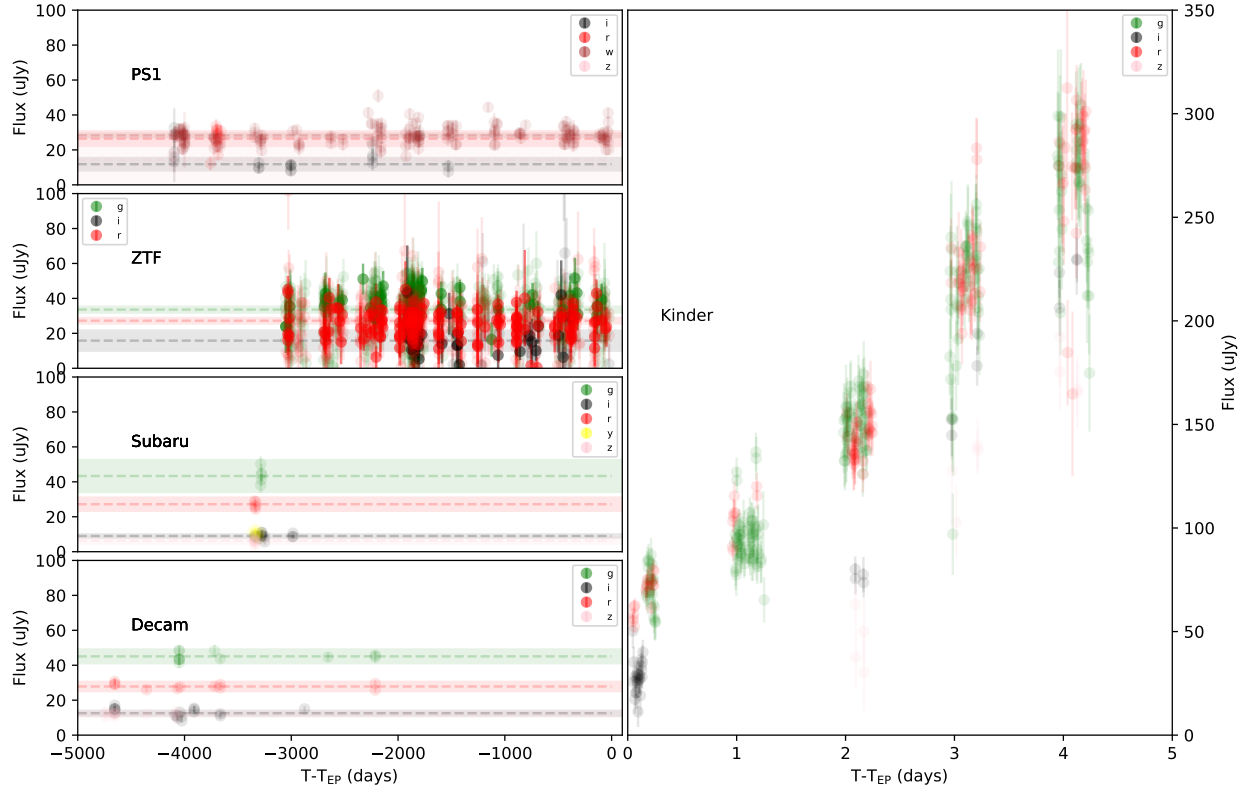


Figure 8: **Long-term pre-explosion variability and the early rise of SN 2026gzf.** Left, historical photometry measured at the explosion site from Pan-STARRS, ZTF, Subaru, and DECam. The pre-explosion measurements are based on direct aperture photometry at a fixed position and without template subtraction, in order to track the total flux at the site of the blue compact source in a survey consistent way. For each epoch, the source aperture radius was set to $0.8 \times \text{FWHM}$ and the local background was estimated from a concentric annulus with inner and outer radii of $1.0 \times \text{FWHM}$ and $1.5 \times \text{FWHM}$, respectively. The dashed lines and shaded bands indicate the mean pre-explosion flux level and its uncertainty in each band. Right, the rapid optical rise measured by the Kinder/Lulin follow-up during the first days after EP260321a. The strongest pre-explosion activity is seen in the blue bands, indicating that the explosion site was not fully quiescent before the final outburst.

0.8 $\times$ FWHM, while the local background was estimated from a concentric annulus with inner and outer radii of 1.0 $\times$ FWHM and 1.5 $\times$ FWHM, respectively. We adopted this relatively local background estimate because the source is projected on a structured host environment, so larger annuli risk incorporating unrelated galaxy substructure. The background level was estimated from sigma-clipped annular pixels, and the aperture-sum uncertainty was combined with the local background rms to obtain the final photometric uncertainty. To minimise calibration offsets, all measurements were expressed in flux-density units (μ Jy) and calibrated against the same local Pan-STARRS1 field-star sequence, using nearby unsaturated stars and the closest available Pan-STARRS1 bandpass for each image filter. This common calibration strategy was applied consistently to Pan-STARRS1, ZTF, Subaru and DECam images, so that the measured differences primarily reflect source variability, bandpass mismatch and host-background structure rather than differences in the adopted photometric reference system. We did not apply explicit S-corrections across surveys; any remaining inter-survey offsets are therefore treated conservatively as arising from a combination of bandpass mismatch, seeing differences and structured host-background contamination. For the pre-explosion analysis, we used direct aperture photometry rather than PSF photometry on template subtracted images. Because a blue compact source is already present at the explosion site before outburst, the residual flux in a difference image depends sensitively on the adopted reference frame. In practice, different reference images can produce different residual amplitudes, making small long-term variations difficult to interpret robustly. Direct aperture photometry at a fixed position therefore provides a more stable and survey consistent way to assess the baseline flux level and flux variance of the unresolved pre-explosion source.

The long-lived activity of the source site is also independently suggested by the fact that the PS1 team reported the source in 2018 as PS18csa (later TNS name AT 2018mtl[¶]), discovered on 2018 December 13 at a w -band magnitude of 21.66. This motivated our closer examination of the pre-explosion variability in the Pan-STARRS1 data. However, because the direct aperture photometry used here measures the total flux at the site without template subtraction, we do not use it alone to quantify the amplitude of the precursor variability. Instead, in the following subsection we analyse the Pan-STARRS1 pre-explosion images with template subtraction and PSF-based photometry to confirm and characterise the variability more directly.

Independent aperture photometry from Pan-STARRS1, ZTF, Subaru, and DECam yields broadly consistent baseline fluxes at the source position (Table 6). In particular, the mean r -

[¶]<https://www.wis-tns.org/object/2018mtl>

band fluxes measured from the four surveys are mutually consistent within the expected survey-to-survey scatter, while the source is systematically brighter in the blue than in the redder optical bands. Table 6 also lists the corresponding AB magnitudes, computed from $m_{\text{AB}} = 23.9 - 2.5 \log_{10}(f_{\mu\text{Jy}})$. In the following subsection, we use the band-specific *Average* AB magnitudes listed in the final row of each filter group to define the magnitude ranges of the comparison samples in the chance-alignment calculation.

Chance-alignment probability of an unrelated foreground source To quantify the probability that the pre-explosion blue compact source is an unrelated source projected by chance onto the position of SN 2026gzf, we estimated the local surface density of catalogue sources with comparable apparent brightness in a control field centred on the explosion site. Our primary calculation used the Pan-STARRS1 DR2 mean-source catalogue within a radius of 5 arcmin around the adopted astrometric reference position, excluding the immediate host region with a circular mask of radius 5 arcsec. For each optical band, the fiducial apparent magnitude of the blue compact source was taken from the band-specific *Average* AB magnitudes listed in Table 6. Comparison samples were then selected within a magnitude interval of ± 0.5 mag around the corresponding value for the fiducial calculation.

For a given comparison sample, the chance-alignment probability was computed analytically as

$$P = 1 - \exp(-\pi r_{\text{match}}^2 \Sigma),$$

where r_{match} is the adopted matching radius and Σ is the local surface density of comparison sources in units of arcsec^{-2} . Because the formal astrometric uncertainty of the adopted pre-explosion position is much smaller than the scatter among the pre-explosion and post-explosion positional measurements, we adopted a deliberately conservative matching radius of $r_{\text{match}} = 0.3$ arcsec for the fiducial calculation. We report two related probabilities: P_{any} , using all catalogue sources of comparable apparent brightness, and P_{point} , restricting the comparison sample to unresolved point-like sources selected from the Pan-STARRS1 catalogue using PSF–Kron compactness criteria.

For the fiducial case (Run A in Table 7), the inferred probabilities are low in all optical bands, with the smallest values obtained in the blue. Representative values are $P_{\text{any}} = 3.70 \times 10^{-5}$ in g and 2.07×10^{-4} in r , while restricting the comparison sample to point-like sources yields $P_{\text{point}} = 1.50 \times 10^{-5}$ in g and 8.90×10^{-5} in r . The corresponding probabilities in the redder

bands are somewhat larger because the sky density of comparable sources is higher. As robustness tests, we repeated the same calculation with a substantially larger matching radius of $r_{\text{match}} = 0.5$ arcsec (Run B), and then with both $r_{\text{match}} = 0.5$ arcsec and a wider magnitude interval of $\Delta m = \pm 1.0$ mag (Run C). As expected, the inferred probabilities increase under these deliberately more conservative assumptions, but remain low and do not alter the qualitative conclusion (Table 7). As an independent cross check, we also estimated the same probability by Monte Carlo sampling. We drew 10^5 random sky positions uniformly within the same 5-arcmin control field, rejected points falling inside the excluded host mask, and measured the fraction whose nearest comparison object lay within r_{match} . The Monte Carlo results are consistent with the analytic surface density estimates, supporting the robustness of the calculation.

These single band probabilities are themselves conservative, because they condition only on positional coincidence and comparable brightness in one filter at a time. The pre-explosion source is also unusually blue, and requiring a comparison object to match both the position and the observed colour of the blue compact source would reduce the chance-alignment probability further. We therefore regard the quoted single band values as conservative upper limits on the probability that the pre-explosion blue compact source is an unrelated foreground-like object.

Photometry on Pan-STARRS pre-explosion images All Pan-Starrs pre-explosion images were stacked on a nightly basis using SCAMP(107) for astrometric refinement and SWarp(108). Stacked science and template images were then processed through the AutoPhOT pipeline(109). Astrometric calibration was performed using `astrometry.net`(110) to align the World Coordinate System to the Gaia DR3 reference frame(25). Template images were aligned to the science frame using SCAMP(107) for astrometric refinement and SWarp(108) for resampling onto the science pixel grid, with distortion corrections. Alignment quality was verified through the rms scatter of matched sources. The PSFs were constructed empirically using PhotUtils(112) from isolated, high signal-to-noise stellar sources identified by SExtractor(113). Image subtraction was performed using the Sparse Field Flux Transport algorithm(114), which determines an optimal convolution kernel to match the template PSF to the science image. The template was convolved to match the science PSF such that transient sources retain the science frame characteristics in the difference image. SFFT operates in either sparse-field or crowded-field mode depending on the stellar density. Photometric calibration was propagated through the subtraction process, and difference image quality was assessed via background statistics and photometric consistency of non-variable sources.

Photometric calibration was performed using synthetic photometry from Gaia DR3 spectrophotometry. Reference star magnitudes in the target filter system were derived using GaiaXPy(115) to convolve the Gaia low-resolution spectra with filter transmission curves obtained from the Spanish Virtual Observatory (SVO) Filter Profile Service(116). This approach provides accurate synthetic magnitudes for calibration stars across a wide range of colours and spectral types, enabling consistent zero-point determination for each image. However, the magnitudes of the precursors represent a lower limit, as the contribution of the progenitor to the total light from the blue compact source at the time of the reference stack is unknown.

Limiting magnitudes were determined using a photometric injection and recovery framework. Artificial point sources with magnitudes spanning the expected detection threshold were generated using the empirical PSF and added at random positions across the difference image. The 3σ limiting magnitude was defined as the faintest injected magnitude at which sources were recovered with signal-to-noise ratio ≥ 3 and positional accuracy within 0.5 pixels.

Figure 3 shows a subset of w -band differences images. For the majority of w -band images, a clear detection is seen at the position of SN 2026gzf.

Search for periodicity in the archival variability To test whether the historical variability could be explained by an ordinary periodic variable star, we searched for coherent periodicity in the pre-explosion Pan-STARRS1 light curve using the P4J periodogram package(117). We restricted the analysis to pre-trigger measurements and removed entries with non-finite times, fluxes, or flux uncertainties, as well as measurements with non-positive uncertainties. The periodogram was evaluated over trial periods between 1 and 1000 days.

The resulting periodogram shows no significant peak over this range. In particular, no peak exceeds the adopted significance threshold, indicating that the archival PS light curve does not show convincing evidence for coherent periodic modulation. We therefore disfavor an ordinary periodic stellar variable as the origin of the pre-explosion variability.

6 Early luminosity excess of SN 2026gzf

Optical follow-up of EP260321a started at Lulin Observatory 1.25 h after the EP-WXT trigger, using the 1-m LOT and the 40-cm SLT, as part of the Kinder (Kilonova Finder) programme(11; 118). The first observations began on 2026 March 21 at 13:38:02 UT (MJD 61120.568079), with

SLT following 23 s later. In this first epoch, LOT obtained six 300 s r -band exposures, while SLT obtained 24 separate 300 s i -band exposures. LOT later secured two additional r -band observing blocks. The second LOT block started at 4.15 h after T_0 and comprised six 300 s r -band exposures. After a ~ 44 min gap, LOT obtained a third block of seven 300 s r -band exposures. During this later epoch, SLT obtained 24 frames of 300 s g -band exposures. The resulting high-cadence light curve during the first hours is shown in the zoomed-in panel of Fig. 1. The observing log is given in Table 1. In particular, the r -band source brightened by 0.66 mag (from ~ 20.7 to ~ 20.1 mag) over 4.68 h. The g -band data also shows a rising trend, while the i -band measurements are broadly consistent with early brightening despite the sparser sampling. During these early stages, the SN exhibited very high temperatures, indicated by $(g - r)$ colours of ~ -0.5 mag. These data demonstrate that the source was still emerging and brightening rapidly during the first five hours of optical follow-up, and show that SN 2026gzf was caught during the transition from the high-energy breakout phase to the earliest optical emergence of the SN. Over the following days, the source continued to brighten and evolved to redder colours.

7 Hydrodynamic light curve modelling with STELLA

We computed synthetic light curves to estimate explosion and CSM properties of SN 2026gzf by using the one-dimensional multi-frequency radiation hydrodynamic code STELLA(119). Motivated by the photometric and spectroscopic similarities to SN 2006aj, we assumed the same ejecta mass ($2 M_\odot$) and explosion energy (2×10^{51} erg)(3). We adopted the $3.85 M_\odot$ C+O star progenitor model of (121) and set the mass cut at $1.85 M_\odot$ to obtain the assumed ejecta mass. The wind-like dense CSM $\rho_{\text{CSM}} = 10^{-3}(r/10^{10} \text{ cm})^{-2} \text{ g cm}^{-3}$ is attached on top of the progenitor. The progenitor radius is $9 \times 10^9 \text{ cm}$ and the CSM density near the progenitor surface is about $10^{-3} \text{ g cm}^{-3}$. The radius of the dense CSM is assumed to be $3 \times 10^{13} \text{ cm}$ given the CSM radius estimate based on the X-ray flash(9). The CSM mass is $0.02 M_\odot$ and the required mass-loss rate to form the dense CSM is $2 M_\odot \text{ yr}^{-1}$ assuming the wind velocity of 1000 km s^{-1} .

The light-curve models with and without CSM are shown in Fig. 1. In this scenario, the CSM is sufficiently dense to produce shock breakout at its outer surface, and the duration of the X-ray flash corresponds to the light-travel time across the CSM. A ^{56}Ni mass of $0.5 M_\odot$ is required to match the peak brightness, and significant outward mixing of ^{56}Ni in the ejecta is needed to reproduce the observed rise time of SN 2026gzf.

8 Semi-analytic light-curve modelling with MOSFiT

To independently estimate the explosion parameters that explain the main light curve peak, we fit the multi-band optical photometry with the Modular Open Source Fitter for Transients (MOSFiT)(122). We use a basic ^{56}Ni -heated model following the Arnett formalism(28), and assume a blackbody spectral energy distribution with absorption at blue wavelengths to mimic the effects of line blanketing(124; 125): $L_\lambda(\lambda) = L_{\lambda,\text{BB}}(\lambda/\lambda_{\text{cut}})^\alpha$, where α and λ_{cut} are free parameters. The other physical parameters of the model are the ejecta mass M_{ej} and velocity v_{ej} , the ^{56}Ni fraction f_{Ni} , the temperature at late times T_{min} , and the gamma-ray trapping opacity κ_γ (we fix the photon diffusion opacity at $\kappa = 0.1 \text{ cm}^2 \text{ g}^{-1}$). Since our model does not include shock cooling, we do not fit to any data points prior to MJD 61123 (i.e. within the first ≈ 3 days of explosion). Given this simplification and the approximate nature of the model, we do not fix the explosion date to exactly match the EP detection, but instead make this a free parameter within a small window of 5 days. Finally, we include a white noise parameter σ in the likelihood function following (122). We use flat or log-flat priors for all parameters.

The fitting results are shown in Fig. 9. We obtain an excellent fit to the light curve in all bands, with broad metal line absorption significantly affecting the spectrum only below $\approx 4500 \text{ \AA}$ (u and g bands). The estimated explosion date is within 2 days of the true date from the EP detection. We find $M_{\text{ej}} \approx 1 M_\odot$, $v_{\text{ej}} \approx 11,000 \text{ km s}^{-1}$, and $M_{\text{Ni}} \approx 0.4 M_\odot$. Although the statistical errors on these parameters are $\sim 10\%$, given the exquisite data, this is a highly simplified model and the systematic errors are likely much larger (see e.g. discussion in Ref of (126)) and we suggest that given the degeneracies visible between the main physical parameters, these numbers are likely reliable only to within a factor ~ 2 . The best-fit velocity is consistent with the observed spectra, and the masses of the ejecta and ^{56}Ni are consistent with those in the hydrodynamic models based on the similar event SN 2006aj(3), further motivating their use to study the early light curve.

9 On the presence of the CSM shells and the epochs of CSM interaction

Our hydrodynamic modelling suggests that the early excess in the light curves can be attributed to the presence of dense CSM. The formation of CSM is supported by the precursor activities that started ~ 12 years before the X-ray detection (Fig. 8). There have been incidences when the precursor activities have been linked to the formation of CSM or an extended environment. As a robust example of Type Ic-BL SNe with precursor activity, SN 2018gep showed detection about 15

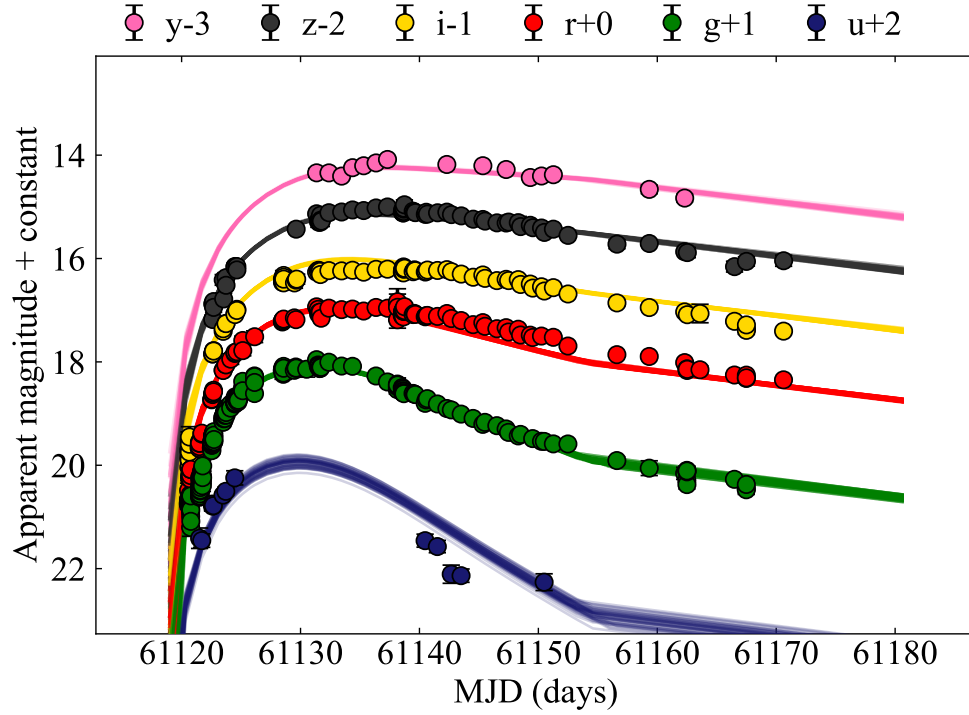


Figure 9: **MOSFiT fit to the multi-band optical light curve of SN 2026gzf.** The points show the observed photometry, while the solid curves show the best-fit ^{56}Ni -powered model based on the Arnett formalism. Data earlier than MJD 61123 were excluded from the fit because the model does not include shock-cooling or circumstellar-interaction emission. The model reproduces the main peak well in all bands and yields an explosion date within ~ 2 days of the EP trigger, with representative parameters $M_{\text{ej}} \approx 1 M_{\odot}$, $v_{\text{ej}} \approx 11,000 \text{ km s}^{-1}$, and $M_{\text{Ni}} \approx 0.4 M_{\odot}$.

days before its explosion (35). The pre-SN detections of SN 2018gep were close to -14 mag and were rather attributed to eruptive mass losses than a quiescent progenitor. Given the position of EP260321a in its host galaxy, a quiescent progenitor can be less favored. In Figure 3, we identify six w -band kinks at MJDs 57779.5, 60021.3, 60315.5, 60696.5, 60761.3, and 61053.5. These kinks possibly mark more rigorous activities following stronger eruptions which eventually would have formed denser CSM shells. Assuming a wind velocity of 1000 km s^{-1} for Wolf-Ray stars, we used equation 5 of (35) to estimate the radii of corresponding CSM shells. Corresponding to the above-mentioned six major eruptions, there would be CSM shells with radii $\sim 5.8 \times 10^{14}$, 3.1×10^{15} , 3.7×10^{15} , 6.9×10^{15} , 9.5×10^{15} , and 2.9×10^{16} cm.

Next, we adopted a broken power-law distribution to the velocity evolution (of Si II) for Type Ic-BL SNe of the form presented in (128) and estimated the tentative epochs of CSM interactions corresponding to the presence of CSM shells with the above-mentioned radii. The tentative epochs of CSM interaction for the last five eruptions (starting from the one at MJD 61053.5, only ~ 67 days before the X-ray detection) would be $\sim +1\text{d}$, $+14\text{d}$, $+18\text{d}$, $+93\text{d}$, and $+2350\text{d}$ (MJD 60021.3 eruption). For the eruption at MJD 57779.5, the CSM shell radius is 2.9×10^{16} cm, thus, the SN-ejecta would eventually be too slow to reach there. With the tentative epochs of CSM-interactions estimated, the day-1 early excess in our light curves can indeed be associated to the presence of CSM resulting from the latest eruption. There were no reported radio observations close to the other predicted epochs of CSM interactions. Despite having optical spectra close to $+18\text{d}$, we hardly see any interaction features. This can be attributed to the lower resolution of the spectrograph. Additionally, we can not rule out the possibility of the older mass loss episodes resulting with different wind velocities than the simplified assumption of 1000 km s^{-1} , hence the locations of CSM shells and the epochs of interaction might be uncertain corresponding to those episodes. Nevertheless, even if interaction happens at these radii, the signatures could be subtle, Ic-BL SNe are not known to show strong interaction features.

10 Comparison with other X-ray outburst stripped-envelope supernovae

Figure 10 shows the rest-frame absolute light curves of broad-lined Type Ic SNe that were discovered sufficiently early to probe their initial emission, including SNe 1998bw(129), 2006aj(36), 2018gep(35), 2020bvc(131), 2020lao(34), and the recent EP-discovered events (also Ic-BL) SNe 2024gsa(133), 2025kg(134) and 2025wkm(135). We also include SN 2008D(4), although it was a Type Ib rather than an Ic-BL, because it remains one of the best-studied stripped-envelope

SNe with an X-ray shock-breakout signal and exceptionally early follow-up data. We note that SN 2008D is known to suffer substantial host-galaxy extinction, with $A_V \approx 2$ mag(4; 5). No correction for host-galaxy extinction has been applied to any of the SNe except for SN 1998bw(129) as given in this plot.

Panel (a) shows that the g -band luminosity evolution of SN 2026gzf is broadly consistent with that of luminous Ic-BL events, with a peak luminosity close to those of SN 2006aj and SN 2020bvc, but with unusually luminous measurements already present during the first day. Panel (b) shows the same behaviour in the r band: the later rise and peak are similar to those of the comparison Ic-BL sample, whereas the earliest data points lie above the smoother monotonic rise expected for an ordinary radioactive-powered light curve. Panel (c) shows that SN 2026gzf is also very blue ($g-r \sim -0.5$) at the earliest epochs and then reddens steadily with time, broadly following the colour evolution seen in SN 2006aj and SN 2020bvc. Taken together, the three panels show that although the later photometric evolution of SN 2026gzf is broadly typical of luminous Ic-BL SNe, its earliest emission includes a distinct bright, blue first-day excess suggestive of interaction with nearby CSM.

11 Comparison of the precursor activity of SN 2026gzf with other transients

We compare the long-term pre-explosion variability of SN 2026gzf with a small, non-exhaustive sample of transients for which precursor activity has been reported, including SNe 1961V(38), 2006jc(138), 2009ip(39), 2015bh(140), 2018gep(35), 2023fyq(141), and UGC 2773-OT(142), see Fig. 11. In terms of absolute magnitude, the precursor of SN 2026gzf is among the most luminous in the sample, reaching $M \approx -14$ mag. The only clearly comparable case in this figure is SN 1961V, whose precursor was also extremely bright and likewise persisted for more than a decade before the main event; it has been interpreted as a pulsational pair-instability event from a very massive progenitor of roughly $100\text{--}115 M_\odot$ (143). Although SN 2026gzf is unlikely to arise from such an extreme progenitor channel, this comparison emphasizes that its long-term precursor activity was unusually luminous for a stripped-envelope SN progenitor.

Moreover, the precursor of SN 2026gzf also shows pronounced short-timescale variability superposed on the longer-term evolution. Similar erratic behavior was seen in SN 2009ip, although that object was a hydrogen-rich Type II event rather than a stripped-envelope SN. The analogy is therefore not one of progenitor class, but of phenomenology: both objects show evi-

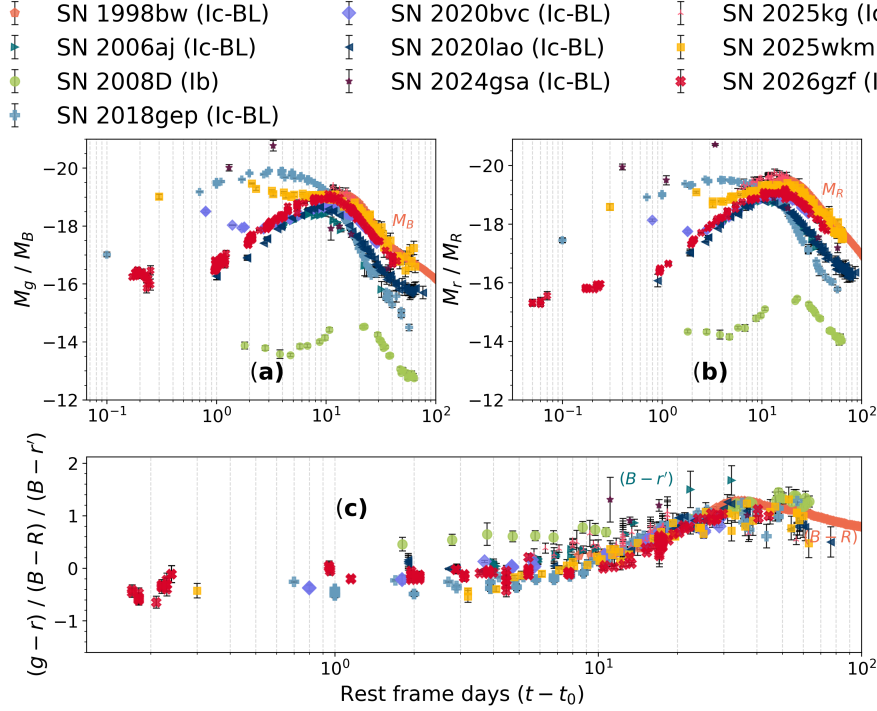


Figure 10: **Lightcurve evolution of SN 2026gzf and comparison with other SNe.** The upper panels, (a) and (b), compare the rest-frame red- and blue-band light curves of SN 2026gzf with those of the Ic-BL SNe 1998bw, 2006aj, 2018gep, 2020bvc and 2020lao, together with the recent EP-discovered events SNe 2024gsa, 2025kg and 2025wkm. SN 2008D is also shown, although it was a Type Ib SN. All light curves are plotted relative to T_{burst} . The lower panel, (c), shows the corresponding colour evolution. SN 2026gzf rises rapidly at early times and exhibits unusually blue colours, consistent with excess early emission shaped by interaction with nearby CSM.

dence for violent variability shortly before explosion. This suggests that such eruptive behavior may not be limited to extended hydrogen-rich progenitors, but could also occur in compact stripped progenitors such as Wolf–Rayet-like stars.

12 Host galaxy environments

SN 2026gzf lies in a disturbed system (Fig. 1, right panel), consisting of the larger galaxy SDSS J095942.99+002504.0 and a nearby blue compact source, SDSS J095942.88+002506.2. The SN is spatially coincident with the latter, indicating that this blue compact source is its most likely immediate host. The larger system has a spectroscopic redshift of $z = 0.0345$, independently measured by the 2dF Galaxy Redshift Survey (2dFGRS; TGN352Z077) and DESI Legacy Survey spectroscopy (target ID: 39627799320858502). With an absolute magnitude of about $M_r = -16.6$ mag, the blue compact source could plausibly be a compact dwarf galaxy(144) or a particularly luminous star-forming region, possibly associated with or orbiting the larger disturbed galaxy. Because young clusters in interacting galaxies can be very luminous(145), we do not attempt to distinguish among these possibilities given the available spatial resolution and signal-to-noise ratio, and therefore adopt the neutral term “blue compact source” throughout this paper.

To characterize the host galaxy and the local environment of SN 2026gzf, we analysed WiFeS integral-field spectroscopy. Due to poor S/N, we stacked two of our WiFeS observations that were taken during dark-time (on 2026-04-08 and 2026-04-16) to improve our data quality. We defined a flux-limited aperture (see Figure 12) to extract a global host spectrum from these stacked IFU cubes, measuring a Balmer decrement of 3.67 ± 0.35 , corresponding to $E(B - V) = 0.25 \pm 0.09$ mag assuming a CCM extinction law with $R_V = 3.1$. The dust-corrected $H\alpha$ luminosity implies a star-formation rate of $0.37 \pm 0.08 M_\odot \text{ yr}^{-1}$, and the gas-phase metallicity derived from the O3N2 diagnostic (146) is $12 + \log(\text{O}/\text{H}) = 8.00 \pm 0.03$. We also extracted a spectrum from a 3x3-spaxel (1'' per spaxel) aperture corresponding with the blue compact source at the SN position. This spectrum is contaminated by SN light, but provides a local estimate of the surrounding environment, with a Balmer decrement of 3.42 ± 0.40 , $E(B - V) = 0.18 \pm 0.11$ mag, a dust-corrected star-formation rate of $0.17 \pm 0.04 M_\odot \text{ yr}^{-1}$, and $12 + \log(\text{O}/\text{H}) = 8.05 \pm 0.04$. When deriving maps of the host galaxy from the stacked WiFeS datacubes, there remain significant spaxel-to-spaxel fluctuations. We therefore produce maps by extracting spectra from a 3x3 sliding aperture centred on each spaxel, as seen in Figure 12. Given the limited data quality, properties

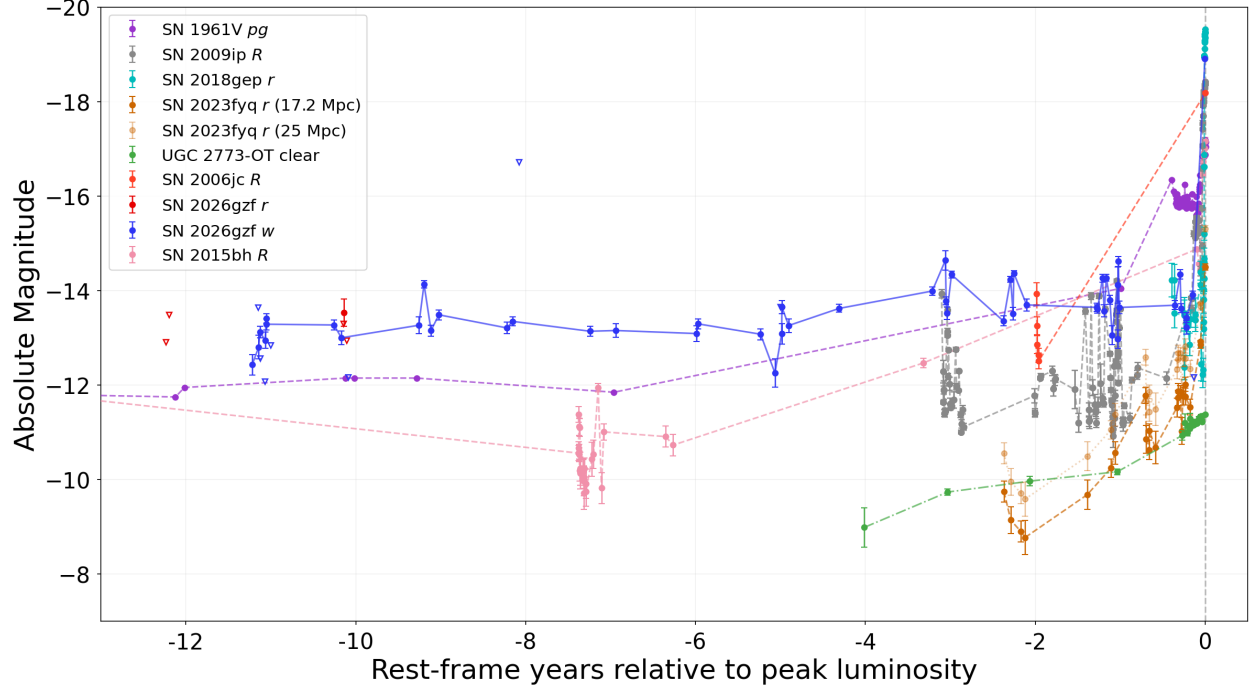


Figure 11: **Comparison of the long-term precursor activity of SN 2026gzf with other transients.** Absolute magnitude is shown as a function of rest-frame time in years relative to the peak luminosity of the main eruption or SN light curve of each object. Time 0 marks the peak, so all points shown correspond to precursor activity before the main event. The blue and red points show the archival Pan-STARRS w - and r -band measurements of SN 2026gzf. For comparison, we also show the reported precursor variability of SNe 1961V, 2006jc, 2009ip, 2015bh, 2018gep, 2023fyq, and UGC 2773-OT. SN 2023fyq is shown for two assumed distances because the distance to its Virgo-cluster host remains uncertain; the two tracks illustrate how this uncertainty affects the inferred absolute magnitude of the precursor. Among these objects, the precursor of SN 2026gzf is one of the most luminous, reaching $M \approx -14$ mag, and also exhibits substantial variability on both year-long and shorter timescales.

derived for a given spaxel should be treated as indicators of a local region surrounding that spaxel, rather than properties directly within the sightline of the spaxel.

Although our dust map suggests elevated host extinction near SN 2026gzf, several independent indicators point to little extinction along the direct SN sightline. In particular, the Balmer decrement measured from the LOT spectrum is close to the Case B recombination value of 2.86, suggesting minimal local extinction. This is further supported by the absence of red colours in the SN peak photometry and the lack of Na I D absorption in the SN spectra, consistent with the SN lying on the near side of the system along our line of sight. Independent MUSE observations likewise indicate little or no dust extinction at the SN position(19). The discrepancy with our estimate may arise because the blue compact source is not fully resolved from the larger galaxy in our data.

We modelled the spectral energy distribution for both larger galaxy (SDSS J095942.99+002504.0) and the blue compact source (SDSS J095942.88+002506.2) considered as the host of SN 2026gzf. We characterized the host galaxy using archival ultraviolet-to-infrared imaging from the Galaxy Evolution Explorer (GALEX), Pan-STARRS and unWISE. Using HOSTPHOT(148), matched-aperture photometry was constructed across all bands using an aperture defined from the Legacy Survey r -band image. Specifically, we adopted an aperture size of $11.729'' \times 7.022''$ for the larger galaxy and $1.015'' \times 0.999''$ for the blue compact source. The SED fitting was performed with PROSPECTOR(40), with posterior sampling carried out using DYNESTY. We adopted the `Prospector- $\alpha$` model, which includes nebular line and continuum emission as well as dust emission. We adopted a log-uniform prior on the total stellar mass (`total.mass`), covering $10^8 < M/M_\odot < 10^{12}$, and model the stellar metallicity (`logzsol`) with a top-hat prior ranging from $-2 < \log(Z/Z_\odot) < 0.19$. The star-formation history (SFH) is modeled non-parametrically via the `z_fraction` prescription, complemented by a Beta continuity prior to ensure smooth transitions in the star-formation rate across cosmic time. For dust attenuation, the diffuse dust optical depth (`dust2`, $\hat{\tau}_2$) is assigned a uniform prior in the range $[0, 4.0]$. Additionally, we account for IR dust emission using the (150) templates, governed by the minimum radiation field intensity ($0.1 < U_{\min} < 25$), the PAH mass fraction ($0.5 < Q_{\text{PAH}} < 7.0$), and the mass fraction of dust exposed to a high-intensity radiation field (`dust_gamma`, γ), for which we assume a prior range of $0.001 < \gamma < 0.15$. Figures 13 and 14 show the host-galaxy broadband photometry and the corresponding best-fitting PROSPECTOR model. From the posterior medians and 1σ uncertainties, we infer $\log_{10}(M_*/M_\odot) = 9.04^{+0.09}_{-0.08}$ for the larger galaxy and $\log_{10}(M_*/M_\odot) = 8.09^{+0.23}_{-0.07}$ for the blue compact source. Its stellar mass is thus about an order of

946 magnitude lower than that of the larger galaxy, consistent with a dwarf-companion interpretation.
947 By combining stellar mass with the star-formation rate derived above, we can calculate the specific
948 star-formation rate. This yields $\sim 0.34 \text{ Gyr}^{-1}$ for the larger galaxy and $\sim 1.37 \text{ Gyr}^{-1}$ for the blue
949 compact source. Additionally, their A_V values calculated from `dust2` are 0.076 and 0.043 mag,
950 respectively.

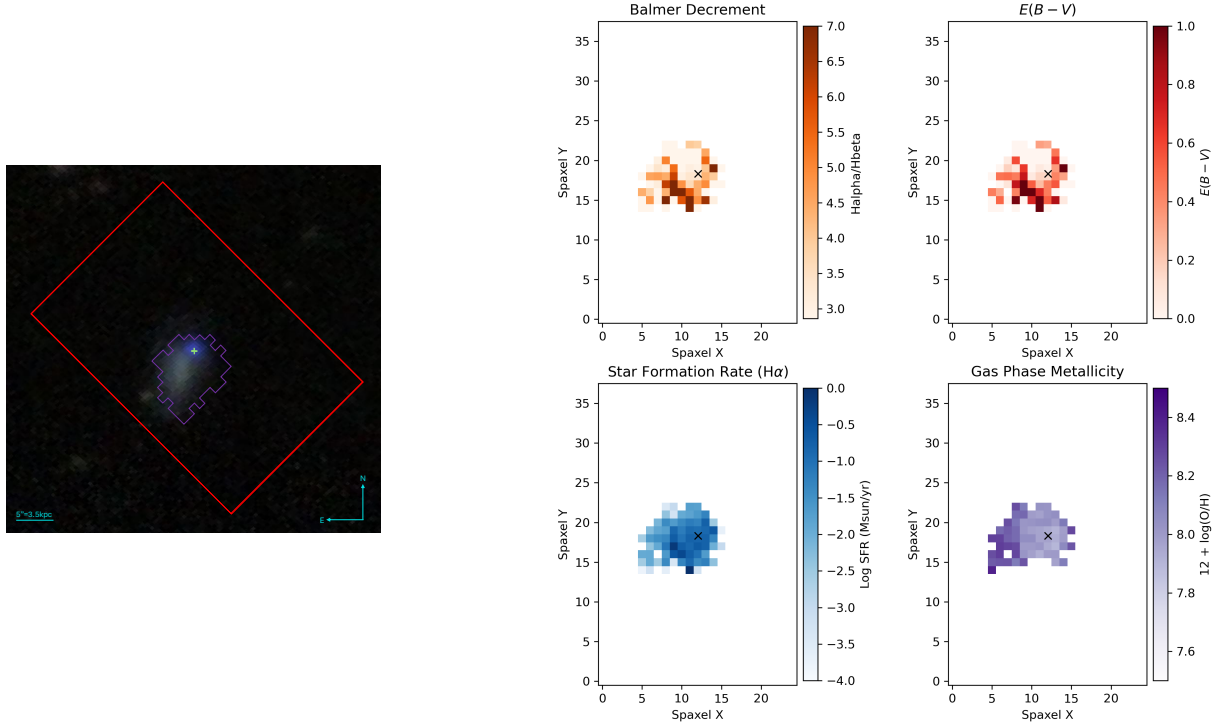


Figure 12: **Host-galaxy colour image and WiFeS IFU maps of the host galaxy of SN 2026gzf.** *Left:* SDSS colour image of the host galaxy of SN 2026gzf, with the red rectangle representing the WiFeS FoV for our observations, and the position of the SN marked as a green cross. The region in purple contains sufficient WiFeS S/N per spaxel for host-property estimation, and this region was used to extract global properties of the host galaxy. *Right:* WiFeS IFU maps of the host galaxy of SN 2026gzf, constructed using a sliding 3×3 aperture on stacked datacubes from our dark-time observations (2026-04-08 and 2026-04-16). When rotated by the 45° position angle of the WiFeS observations, these maps correspond to the purple region in the left-hand panel. Shown are the Balmer decrement (upper left), $E(B - V)$ (upper right), $H\alpha$ -based star-formation rate (lower left), and gas-phase metallicity (lower right). The SN position is marked with a black “ $\times$ ”. Owing to the limited signal-to-noise ratio and spatial resolution, the maps provide only smoothed estimates of the local host properties, and the compact blue source at the SN position is not cleanly separable from the surrounding host emission.

Table 1: Log of optical photometric observations. This table presents a representative sample of the dataset, displaying only the initial observational epochs from various instruments to illustrate the data format and content.

MJD	m	σ_m	Filter	Telescope	Exptime (s)
61120.568	20.74	0.06	r	LOT	300.0
61120.568	>19.8		i	SLT	300.0
61121.316	19.70	0.17	g	P60	30.0
61123.052	18.34	0.01	r	SWO	320.0
61124.122	17.82	0.07	g	Citra	60.0
61124.377	17.98	0.06	o	ATLAS	30.0
61131.349	16.96	0.03	g	PS2	60.0
61136.021	17.01	0.00	r	LSST	30.0

Table 2: Spectroscopic observing log of SN 2026gzf. T_0 is defined as MJD 61120.516 (the EP-WXT trigger time).

Date	MJD	$T_{\text{start}} - T_0$ (days)	Telescope	Instrument	Grating	Exp. time (seconds)	Slit (")	Resolution	Wavelength Range (Å)
2026-03-30	61129.897	9.38	NOT	ALFOSC	Grism 4	1600	1.3	710	3001–9637
2026-03-31	61130.440	9.92	ANU 2.3 m	WiFeS	B3000/R3000	900×3	IFU	3000/3000	3500–5700/5400–9500
2026-04-01	61131.530	11.02	LOT	UVEX	300	600×12	1.29	300	4200–7950
2026-04-05	61135.240	14.72	Keck II	NIRES	-	120×4	0.55	2700	9648—24666
2026-04-07	61137.922	17.41	NOT	ALFOSC	Grism 4	1800	1.3	710	3001–9637
2026-04-08	61138.387	17.87	ANU 2.3 m	WiFeS	B3000/R3000	900×3	IFU	3000/3000	3500–5700/5400–9500
2026-04-16	61146.543	26.03	ANU 2.3 m	WiFeS	B3000/R3000	900×3	IFU	3000/3000	3500–5700/5400–9500
2026-04-23	61153.369	32.85	NASA IRTF	SpeX	-	120×12	0.8	2000	6905–25450
2026-04-28	61158.341	37.83	Keck II	NIRES	-	120×8	0.55	2700	9648—24666
2026-04-28	61158.471	37.96	ANU 2.3 m	WiFeS	B3000/R3000	900×1	IFU	3000/3000	3500–5700/5400–9500
2026-04-29	61159.466	38.95	ANU 2.3 m	WiFeS	B3000/R3000	2700×3	IFU	3000/3000	3500–5700/5400–9500
2026-05-03	61163.953	43.44	NOT	ALFOSC	Grism 4	2042	1.0	710	3001–9637

Table 3: TARDIS model compositions.

Element	Mass fraction		
	$\geq 32000 \text{ km s}^{-1}$	$32000 - 18000 \text{ km s}^{-1}$	$< 18000 \text{ km s}^{-1}$
He	0.68	0.68	0.00
Si	0.12	0.12	0.12
Ca	4×10^{-4}	$10^{-4} (8 \times 10^{-3})_{\odot}$	10^{-4}
Ti	0.00	10^{-3}	10^{-3}
$^{56}\text{Ni}^*$	0.20	0.20	0.88

We define a ^{56}Ni mass fraction at $t = 0$ days. The code then computes the Ni, Co and Fe mass fractions at $t = t_{\text{exp}}$, following the $^{56}\text{Ni} \rightarrow ^{56}\text{Co} \rightarrow ^{56}\text{Fe}$ radioactive decay sequence.

At 17.4 d we invoke an inflated Ca mass fraction of 8×10^{-3} (see text for details).

Table 4: TARDIS input model parameters, and selected output model properties.

	Epoch 1 (17.4 d NOT)	Epoch 2 (38.0 d WiFeS)
Inputs		
t_{exp} (days)	16.82	36.73
L_{ph} ($10^{42} \text{ erg s}^{-1}$)*	9.0	5.5
v_{inner} (km s^{-1})	18000	15000
Outputs		
T_{ph} (K) $_{\odot}$	7110	4390
M_{LF} ($M_{\odot}$) $^{\square}$	0.106	0.188
M_{He} ($M_{\odot}$)	0.072	0.072
M_{CaII} ($M_{\odot}$)	7.4×10^{-7}	2.1×10^{-5}

Luminosity of the inner boundary/photosphere.

Temperature of the inner boundary/photosphere.

Total mass contained within the line-forming region of the simulation. This number should be $\ll M_{\text{ej}}$, as it only accounts for ejecta material that lies above v_{inner} .

Table 5: **Astrometric measurements at the site of SN 2026gzf.** The upper section lists the archival direct-image centroids of the blue compact source used to define the adopted pre-explosion position. The lower section lists representative later SN positions shown for comparison only; these are not used in the weighted mean.

Dataset	RA (deg)	Dec (deg)	$\sigma_{\text{RA,sky}}$ (arcsec)	σ_{Dec} (arcsec)
DECam r	149.9286600	0.4184164	0.030	0.025
Subaru r	149.9286680	0.4184338	0.118	0.119
SDSS r	149.9286642	0.4184014	0.266	0.266
Pan-STARRS w	149.9286802	0.4184167	0.067	0.067
Adopted position	149.9286637	0.4184170	0.027	0.023
LSST SN	149.9286667	0.4184342	-	-
LOT SN	149.9286830	0.4184660	-	-
Pan-STARRS SN	149.9286701	0.4184176	-	-

Table 6: **Mean pre-explosion photometry measured at the site of SN 2026gzf.** For each survey and band, we list the mean flux density and statistical uncertainty, together with the corresponding AB magnitude and propagated uncertainty, computed using an AB zeropoint of 23.9 for flux densities expressed in μJy . Within each filter group, the “Average” row gives the inverse-variance weighted mean flux across surveys and the weighted scatter in flux space. For the w band, only one survey measurement is available, so the listed uncertainty is the measurement uncertainty rather than an inter-survey weighted scatter.

Survey	Band	Mean flux (μJy)	Uncertainty (μJy)	AB mag	Uncertainty (mag)
PS1	w	28.33	0.23	20.269	0.009
Average	w	28.33	0.23	20.269	0.009
PS1	r	26.46	0.88	20.344	0.036
ZTF	r	27.23	0.35	20.312	0.014
Subaru	r	27.18	0.80	20.314	0.032
DECam	r	27.84	0.57	20.288	0.022
Average	r	27.29	0.36	20.310	0.014
PS1	i	11.82	0.75	21.218	0.069
ZTF	i	15.82	1.19	20.902	0.082
Subaru	i	9.02	0.22	21.512	0.026
DECam	i	12.55	0.32	21.153	0.028
Average	i	10.36	1.82	21.361	0.190
PS1	z	14.40	2.75	21.004	0.207
Subaru	z	6.36	0.38	21.891	0.065
DECam	z	12.05	0.36	21.198	0.032
Average	z	9.40	2.87	21.467	0.331
ZTF	g	33.58	0.37	20.085	0.012
Subaru	g	43.32	1.85	19.808	0.046
DECam	g	45.09	0.83	19.765	0.020
Average	g	35.74	4.43	20.017	0.135

Table 7: **Chance-alignment probabilities for the pre-explosion blue compact source under different matching assumptions.** The probabilities were computed from the local surface density of PS1 DR2 catalogue sources in a 5-arcmin control field centred on the explosion site, excluding the inner 5-arcsec host region. For each band, the fiducial apparent magnitude was taken from the band-specific Average AB magnitude listed in Table 6. P_{any} uses all catalogue sources of comparable apparent brightness, while P_{point} restricts the comparison sample to unresolved point-like sources selected using PSF–Kron compactness. Monte Carlo random position tests gave consistent results and are not listed separately here.

Run	r_{match} (arcsec)	Δm (mag)	Band	P_{any}	P_{point}
A	0.3	± 0.5	g	3.70×10^{-5}	1.50×10^{-5}
A	0.3	± 0.5	r	2.07×10^{-4}	8.90×10^{-5}
A	0.3	± 0.5	i	1.16×10^{-3}	3.42×10^{-4}
A	0.3	± 0.5	z	7.70×10^{-4}	1.93×10^{-4}
B	0.5	± 0.5	g	1.03×10^{-4}	4.17×10^{-5}
B	0.5	± 0.5	r	5.75×10^{-4}	2.47×10^{-4}
B	0.5	± 0.5	i	3.21×10^{-3}	9.50×10^{-4}
B	0.5	± 0.5	z	2.14×10^{-3}	5.36×10^{-4}
C	0.5	± 1.0	g	2.75×10^{-4}	1.22×10^{-4}
C	0.5	± 1.0	r	1.59×10^{-3}	5.72×10^{-4}
C	0.5	± 1.0	i	5.41×10^{-3}	1.34×10^{-3}
C	0.5	± 1.0	z	3.03×10^{-3}	8.08×10^{-4}

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1186 Supplementary Information

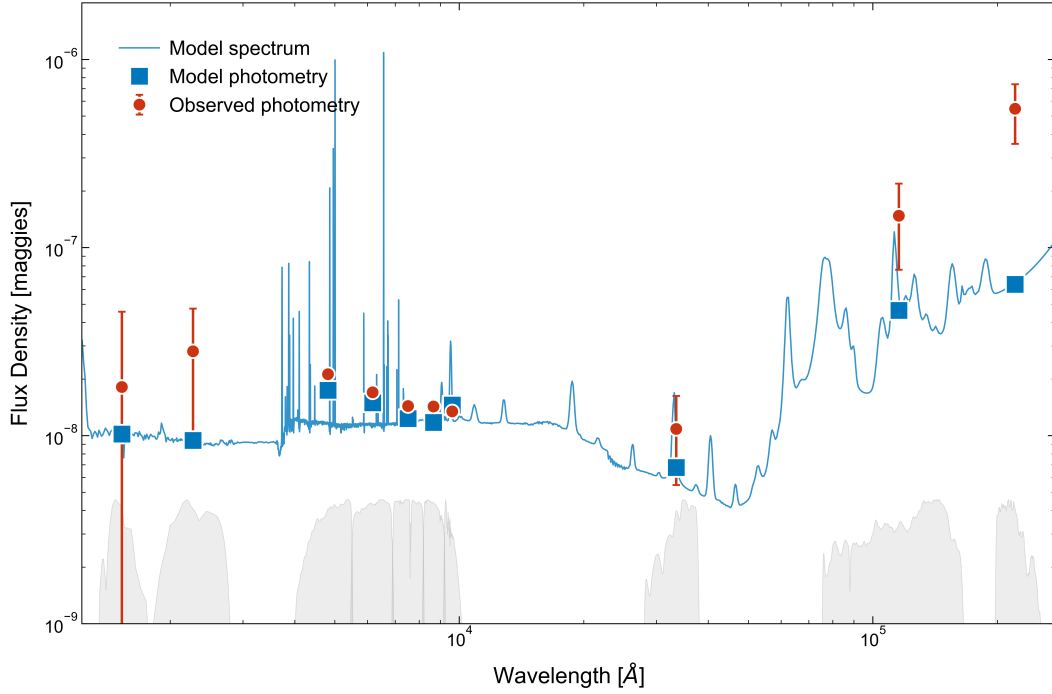


Figure 13: **Best-fit SED focusing specifically on the blue compact source hosting SN 2026gzf.** By utilizing photometry restricted to the blue compact source, the model characterizes the stellar population and dust properties of the host component while minimizing light contamination from the larger primary galaxy. The blue solid line represents the best-fit model spectrum, while red circles with error bars denote the observed multi-band photometry. Blue squares indicate the model-predicted photometry integrated over the respective filter bands. The gray shaded regions at the bottom illustrate the transmission curves of the filters used in the fitting process. The fit covers a broad wavelength range from the UV to the mid-IR to constrain the integrated physical properties of the combined system.

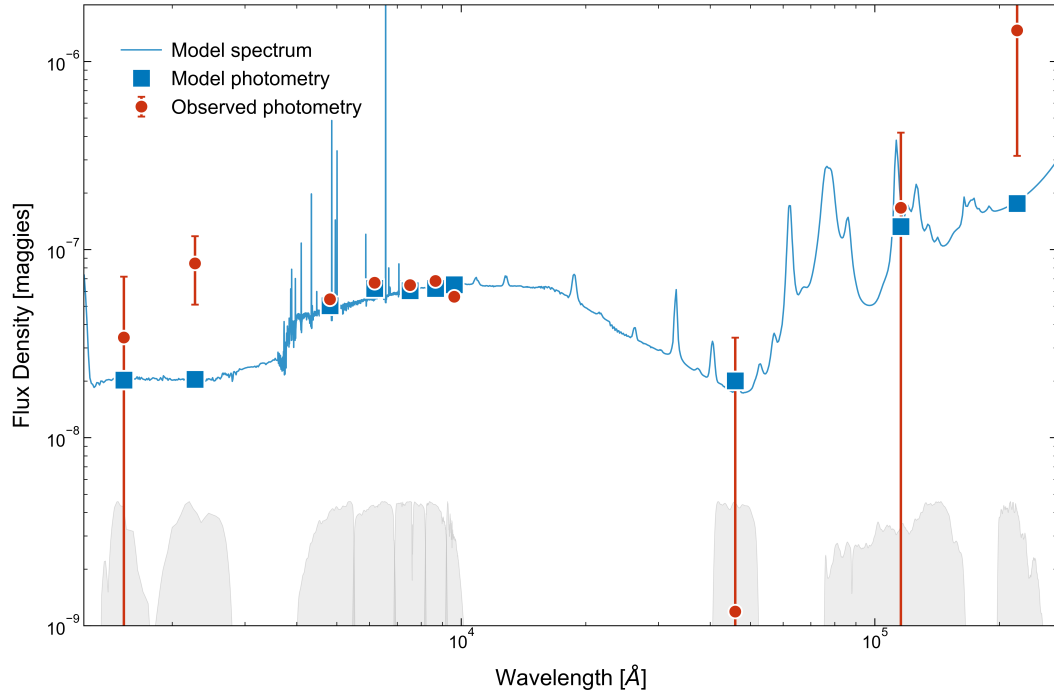


Figure 14: **Best-fit SED for the entire galaxy system.** This system consists of a larger primary galaxy and a smaller companion hosting SN 2026gzf. Symbols and colour schemes are identical to those in Figure 13.

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Contributions T.-W.C. led the project, coordinated the follow-up campaign, and is the primary author of the manuscript. A.A. led the optical data reduction and photometric analysis, and contributed to the Lulin/Kinder discovery and follow-up observations. S.Y. contributed to the data analysis, astrometric and source-association analysis, and spectroscopic interpretation. S.J.S. contributed to the interpretation of the source association and precursor activity, provided archival survey data products, and assisted with scientific coordination with related teams. T.J.M. led the hydrodynamical light-curve modelling and circumstellar-interaction interpretation. S.J.B. contributed to the analysis of the precursor activity and performed photometry on the archival precursor images. M.D.S. contributed to the POISE photometric, NUTS and HISS spectroscopic data and stripped-envelope supernova context. B.M. and B.P.S. contributed to the WiFeS observations and host-environment analysis. M.N. performed the semi-analytic light curve modelling and contributed to the interpretation and writing of the manuscript. J.H.G. contributed to Pan-STARRS follow-up, spectroscopic classification and interpretation, and the TARDIS spectral modelling. A.K.H.K. contributed to the Lulin follow-up and shock-breakout interpretation. A.D. led light curve comparison with other SNe. C.-H. Lai performed the prospector fitting. Y.-H.L. contributed to precursor comparison. Y.-C.C., C.-H.L., Y.-H.L., Z.-Y.C., K.N.T.H., M.-H.L., C.-C.N., Y.-C.P., A.S.K., T.M., S.S., D.-C.Q., Z.-N.W., J.-L.Y. and Z.Z. contributed to the Lulin/Kinder observations, data processing and early counterpart identification. K.A., A.M., C.L., and L.R. contributed to the WiFeS observations. M.E.H., K.W.S., K.C.C., S.J.S., T.d.B., C.-C.L., T.B.L., E.A.M., G.S.H.P., and R.W. contributed to Pan-STARRS observations, archival imaging, calibration, data products and survey infrastructure. E.K., T.L.K. and T.M.R. contributed to NOT spectroscopic observations. H.K. contributed to spectroscopic interpretation. C.-J.L. and J.T. contributed to host-environment interpretation. C.-H. Lee contributed Citra observations and data products. C.A., W.B.H.,

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1294 **Competing Interests** There are no competing interests to declare.

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1297 Sheng Yang (email: sheng.yang@hnas.ac.cn).

1298 **Data Availability** The optical spectra of SN 2026gzf that support the findings of this study will be
1299 made available via the WISeREP archive (<https://www.wiserep.org/object/30455>). The
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1301 a public source (<https://fallingstar-data.com/forcedphot/>), ZTF and LSST points are
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1304 **Code Availability** Upon request, the corresponding author will provide code used to produce the figures.