International Journal of Astronomy and Astrophysics, 2024, 14, 220-229
https://www.scirp.org/journal/ijaa
ISSN Online: 2161-4725
ISSN Print: 2161-4717

Swift XRT Analysis of Type II-P Supernova SN 2008ij

SH. M. Shehata*, Ahmed M. Fouad, R. M. Samir, A. A. Shaker

National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Egypt
Email: *sherehan.shehata@gmail.com

How to cite this paper: Shehata, SH.M., Fouad, A.M., Samir, R.M. and Shaker, A.A. (2024) Swift XRT Analysis of Type II-P Supernova SN 2008ij. *International Journal of Astronomy and Astrophysics*, **14**, 220-229.
https://doi.org/10.4236/ijaa.2024.143014

Received: July 11, 2024
Accepted: September 7, 2024
Published: September 10, 2024

Abstract

This study investigates the X-ray properties and evolution of Type II supernovae (SNe II) observed by Swift, examining variations among supernovae and exploring their X-ray characteristics over time. We present the first X-ray study of the Type IIp supernova SN 2008ij using data from the Swift X-ray mission. This investigation focuses on its spectral properties, identifying an X-ray flux of 1.20 (+0.11, −0.10) × 10^{-13} erg/cm^2/s and a plasma temperature of 4.76 (+1.22, −0.83) keV. Our study marks an advancement in understanding SN 2008ij, providing crucial results into its X-ray emission characteristics. These results lay the groundwork for future studies of Type IIp supernovae, offering a foundation for exploring their evolutionary and physical processes.

Keywords

X-Ray Core Collapse Supernova, Swift (XRT) Observations

1. Introduction

X-ray observations of supernovae provide a unique opportunity to explore their early evolution and the underlying physical processes driving their explosions. X-rays, high-energy photons emitted during the shock-heating phase, occur as the ejected material interacts with the surrounding circumstellar and interstellar medium. A study by [1] investigated the X-ray emission and light curves of all known supernovae (SNe) to study the nature of the medium into which they are expanding. The results indicated that many young SNe, particularly those of Type IIn Sne, which are the brightest X-ray luminosity class, do not appear to be expanding into steady winds.

Some Type IIn SNe showed very steep X-ray luminosity declines, suggesting density declines much steeper than r^{-2}. However, other Type IIn SNe exhibited constant or even increasing X-ray luminosity over periods of months to years.

Many other SNe did not have declines consistent with expansion in a steady wind. Therefore, the expansion and density structure of the circumstellar medium must be investigated before assuming steady wind expansion. [2] conducted a comprehensive study of the X-ray emission from a grid of hydrodynamical simulations of Type II supernovae during phase two. They analyzed the X-ray luminosity and its dependence on various physical parameters, including progenitor structure and explosion energy.

Reference [3] studied the X-ray emission from the Type II supernova SN 2013fs during phase two using X-ray observations with the Chandra X-ray Observatory. They analyzed the X-ray luminosity and its temporal evolution, along with other multi-wavelength data, to investigate the energy sources and properties of the circumstellar medium. The study found high X-ray luminosity, indicating a strong interaction between the supernova shock and the dense circumstellar material.

The expansion of a supernova (SN) shock wave into the surrounding medium results in a structure consisting of forward and reverse shocks, with a contact discontinuity in between, as described by [4]. These shocks raise the temperature of the medium, leading to X-ray emission. The X-ray emission originates from thin shell with a radius between the forward and reverse shocks. In cases where both the SN ejecta and the circumstellar medium (CSM) density profiles follow power laws, the evolution remains self-similar, even if the wind may not have been constant.

2. Identification and Characterization of the SN 2008ij

SN 2008ij is a notable Type II supernova that caught the attention of astronomers upon its appearance in 2008. Type II supernovae occur when massive stars reach the end of their life cycles and explode. SN 2008ij is located in the galaxy NGC 6643 in the constellation Draco; it provided valuable information about the behavior and traits of these celestial occurrences.

SN 2008ij was discovered in the NGC 6643 galaxy on December 19th 2008, located at RA, Dec = (18:19:51.811, +74:33:54.90). **Table 1** presents the fundamental details of SN 2008ij and its host galaxy, including its position, redshift, type and other parameters as gathered from previous studies. Reference [5] utilized 12 epochs of Swift X-Ray Telescope (XRT) observations from December 23, 2008, to January 27, 2009, totaling 45.1 ks of exposure time. A point source was detected at the supernova's optical position with a 3.1-sigma significance, showing a PSF count rate of (3.6 ± 1.1) E−04 cts/s, corresponding to an unabsorbed X-ray flux of (1.9 ± 0.6) E−14 erg/cm^2/s and a luminosity of (1.0 ± 0.3) E39 erg/s for a thermal plasma spectrum with a temperature of kT = 10 keV. The Galactic foreground column density was N_H = 5.56E+20 [6], and the supernova's distance was 21 Mpc (z = 0.004950, [7]). The X-ray source faded from 1.6 E39 erg/s to 6.7 E38 erg/s (0.2 - 10 keV) during the Swift XRT observations. No X-ray source was visible in pre-SN Swift XRT or Chandra ACIS-S observations. The positional coincidence, fading X-ray source, and lack of pre-SN X-ray emission indicates that the X-ray emission is likely from the interaction of the SN shock with circumstellar material from the progenitor's stellar wind. Additional Chandra and Swift observations are planned.

Table 1. Parameters of SN 2008ij and its host galaxy.

Parameter	Value	Ref.
RA (J2000)	18:19:51.811	[11]
Dec (J2000)	+74:33:54.90	[11]
Gal coord. (J2000)	105.53220 + 28.16859	[12]
Discovery Date (UT)	2008/12/19.45 UT	[11]
Discovery Mag	15.9 (unfiltered)	[11]
Magnitude at Max	15.4 (V)	[13]
Type	SN II-P	[14]
Host Galaxy Center offset	23"E & 11"S	[11]
Mostly similar to	1999 em	[14]
Host Galaxy	NGC 6643	[11]
RA (J2000)	18:21:13.44	[15]
Dec (J2000)	+74:32:36.6	[15]
Distance (Tully-Fisher)	19.3 (Mpc)	[16]
Redshift	0.00495	[17]
Radial Velocity (Heliocentric)	1484 (km/s)	[17]
Historical SNe	SN 2008bo	[18]

Further VLA searches on January 29, 2009, at 1.425 GHz, also detected no radio emission, with a 3-sigma upper limit of 0.18 mJy (resolution 4.9"). Due to weak and declining X-ray flux and lack of radio detection, further radio searches for SN 2008ij were discontinued [8]. Reference [9] compared the nebular spectra of SN 2008ij with the models developed by [10]. They found that the spectra of SN 2008ij matched the model for a progenitor star with an initial mass M ZAMS = 15 $M_\odot$.

3. Methodology

3.1. Swift Pipeline

Swift used the X-ray Telescope (XRT) to observe the area in the 0.3 to 10 keV range in photon-counting mode and WT mode. It was detected at position coordinates (274.9659, 74.5653) at T_0 229013462.0006. The data were analyzed using the UK Swift team's online tools with HEASOFT version 6.32, following methods described by [19] [20].

SN 2008ij was observed in multiple instances, with the median 3σ count-rate limit for all observation periods being 0.005 counts per second (0.3 - 10 keV).

Utilizing the dynamic rebinning feature in the Swift online tools, the 3σ count-rate limit is enhanced to a median value of 0.002 counts per second. The summary of the X-ray properties of the supernova is shown in **Table 2**. **Figure 1** shows the image from Swift/XRT in the energy range 0.3 - 10.0 keV for the SN 2008ij.

Table 2. The X-ray properties out of the Swift pipeline for the SN2008ij.

Parameter	Value
N_H	1.3 (+0.4, −0.4) × 10^{21} cm^{-2}
z	0.005
Photon Index	1.98 (+0.15, −0.15)
Flux (0.3 - 10.0) keV (observed)	1.20 (+0.11, −0.10) × 10^{-13} erg·cm^{-2}·s^{-1}
Flux (0.3 - 10.0) keV (unabsorbed)	1.53 (+0.12, −0.11) × 10^{-13} erg·cm^{-2}·s^{-1}
Counts to flux	3.41 × 10^{-11} erg·cm^{-2}·ct^{-1}
Counts to flux (unabsorbed)	4.34 × 10^{-11} erg·cm^{-2}·ct^{-1}
C_stat	310.45 (357)
Spectrum exposure	384.7 ks

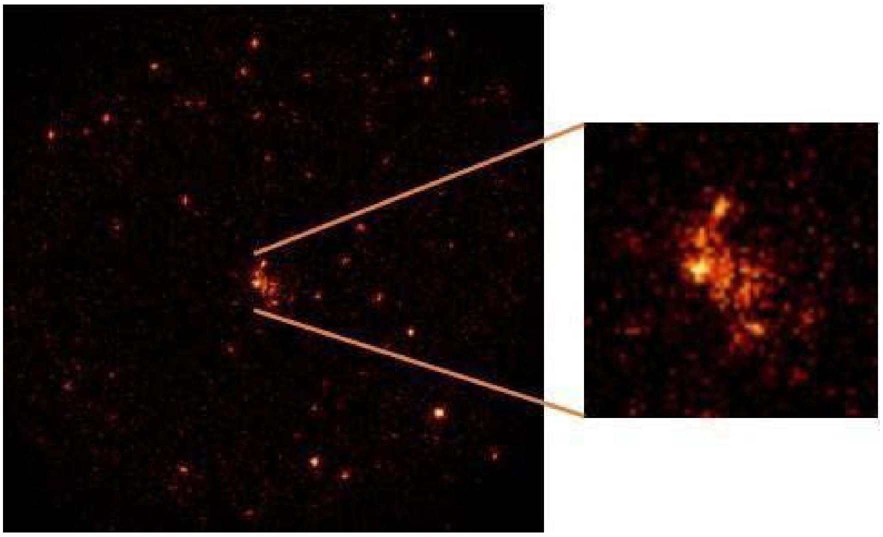

Figure 1. SWIFT (XRT) image of SN2008ij in the energy range 0.3 - 10.0 keV. The supernova is too faint.

We calculated the observed and unabsorbed flux for all the observations, powerlaw photon index using the Galactic neutral hydrogen column density of 1.3 (+0.4, −0.4) × 10^{21} cm^{-2}. The median count-rate limit corresponds to an unabsorbed flux of less than 1.53 (+0.12, −0.11) × 10^{-13} erg·cm^{-2}·s^{-1} erg·cm^{-2}·s^{-1} between 0.3 and 10 keV for the PC mode.

We used powerlaw, BlackBody and Apec models to fit data and to obtain e.g. index, effective temperature and plasma temperature. **Figure 2** shows the spectral fit of the powerlaw model for the joint spectra of all the observations detected by Swift/XRT for both modes WT and PC, while Figure 3 illustrates the fit of the thermal model Apec for the same observations. Figure 4 displays the spectral fit of the Blackbody model applied to the combined spectra from all observations detected by Swift/XRT, encompassing both WT and PC modes.

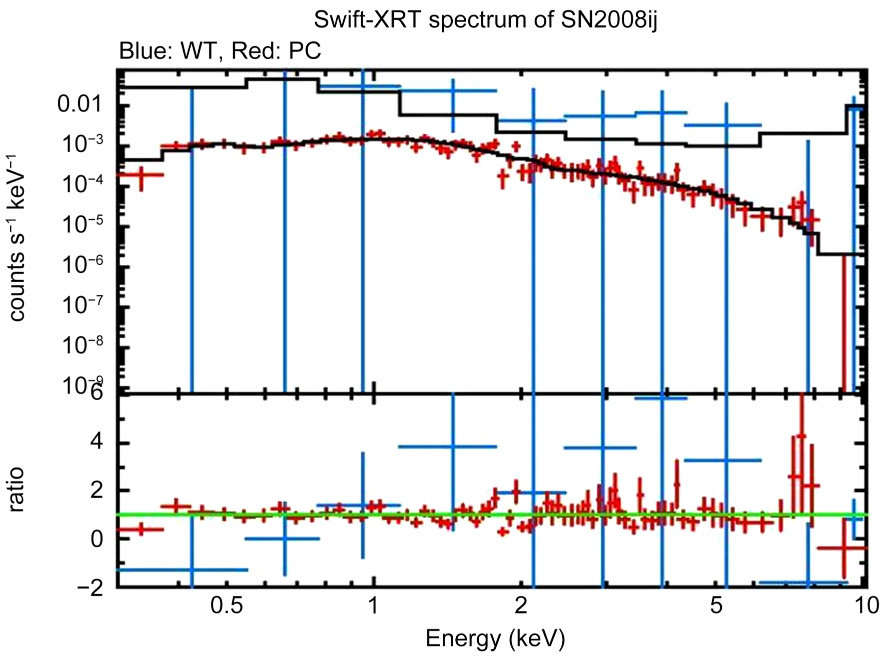

Figure 2. The joint spectrum for all the observations detected by SWIFT/XRT for the powerlaw model with w_stat 310.45/(357).

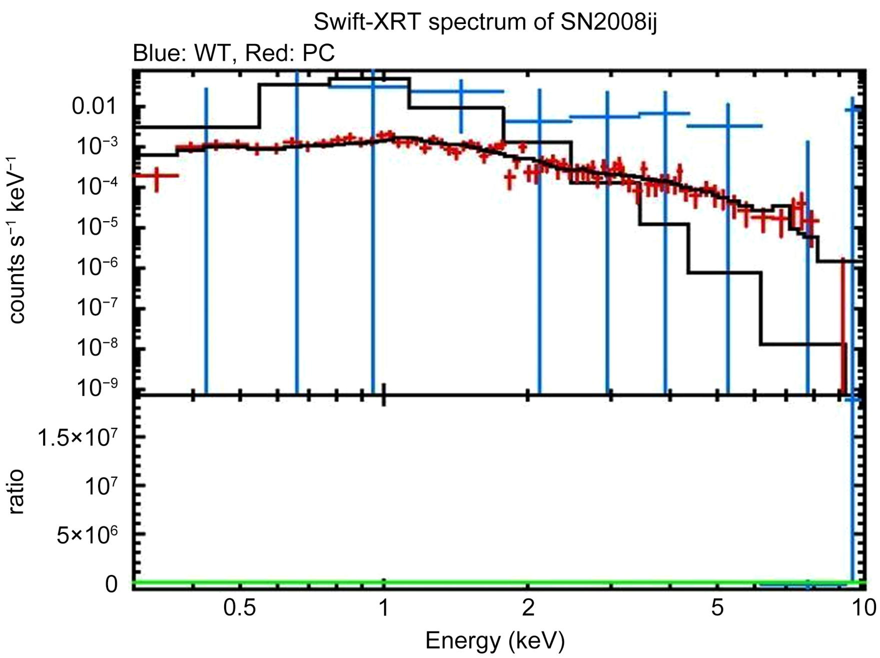

Figure 3. The joint spectrum for all the observations detected by SWIFT/XRT for the APEC model with w_stat 324.50/(357).

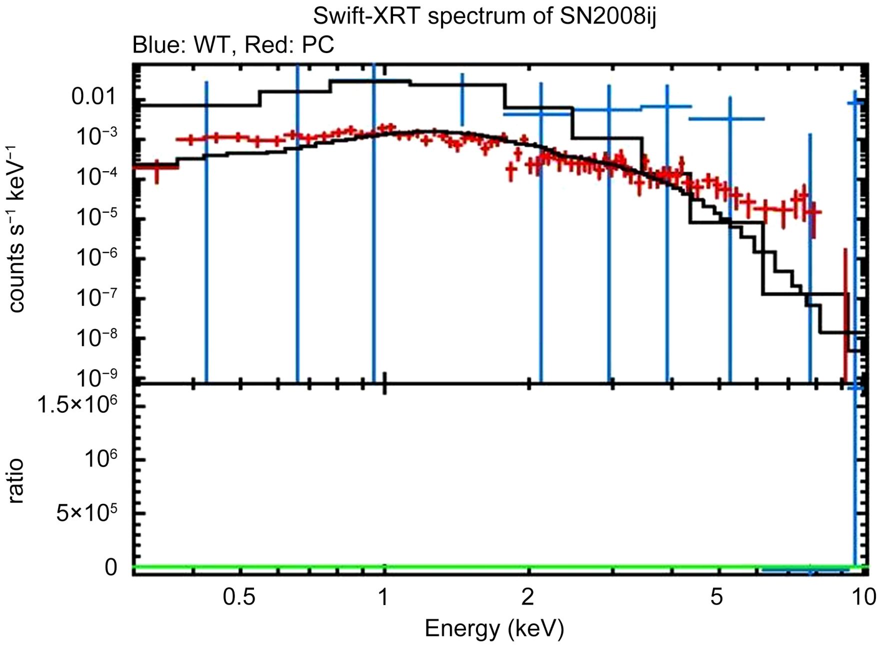

Figure 4. The joint spectrum for all the observations detected by SWIFT/XRT for the BlackBody model with w_stat 493.81/(357).

3.2. Swift/XRT Reduction and Analysis

SN 2008ij was the focus of all Swift/XRT observations from 23rd December to 14th Feb. We analyzed three epochs that have Observational ID 00031314001, 00031314002 and 00031314008 related to the age 5, 7 and 30 days since the explosion of Swift/XRT for the supernova's position. The event data file, acquired in photon counting mode, was retrieved from the Swift online archive. The photon counting mode data was then processed using the xrtpipeline tasks.

The data were fitted in the energy range of 0.3 - 8.0 keV after background subtraction. The spectrum was successfully modeled using XSPEC with the zpowerlaw model, after fixing the hydrogen column density to the Galactic value [21] [22]. For analyzing all observations, we applied Cash statistics [23] and utilized the tbabs absorption model. **Table 3** presents X-ray results estimated from the analysis of the three epochs observed by SWIFT/XRT.

Table 3. The results of the analysis of the observation of SWIFT/XRT.

obs_id	age	Flux erg·cm^{-2}·s^{-1}	luminosity erg/s	Index	kT (keV)
31314001	5	1.18E−11 +/− 5.5E−12	6.3E41 +/− 0.5E40	1.6 +/− 0.4	3.80 +/− 1.1
31314002	7	1.57E−11 +/− 4.2E−12	8.4E41 +/− 0.3E41	1.64 +/− 0.3	7.05 +/− 0.9
31314008	30	1.25E−11 +/− 4.3 E−12	6.8E41 +/− 2.4E40	1.70 +/− 0.2	3.60 +/− 1.2

4. Summary and Discussion

In this paper we have presented a study of X-ray properties of the SN2008ij Type II supernova, which exploded in the nearby galaxy NGC 6643 in the constellation

Draco. Swift/XRT detected the SN at position coordinates 274.9659, 74.5653 several times using both modes. In this study, an automatic selection program was developed to select useful supernova data out of over 97 observations.

It is undeniable that each supernova has its own unique characteristics. Even among supernovae of the same type, factors such as environmental differences, stellar compositions, stellar wind, and shock wave properties undoubtedly impact X-ray emissions. Finding a single model that can perfectly explain all features of X-ray supernova spectra is challenging. The prevalence of powerlaw models in matching most cases serves as evidence of this difficulty. With this in mind, we conducted various analyses on luminosities. The results indicate that the majority of supernova luminosities fall within the range of 6.4E37 erg/s. We examine the X-ray emission resulting from the interaction between the supernova ejecta and the surrounding circumstellar material. The X-rays produced during this interaction provide insights into the density and distribution of the circumstellar material, the size of the shock front, and the processes responsible for particle acceleration and radiation [24] [25].

We focused on Swift/XRT observations spectally PC mode that gave good fit with the three spectral models powerlaw, Black body and Apec. In this study, an automatic selection program was developed to select useful supernova data out of over 97 observations. In order to determine a supernova's effective photosphere's temperature, one must fit its continuum spectrum to a chi-squared blackbody curve. We obtained the effective temperature of the SN2008ij 0.540 (+0.021, −0.030) keV. On the other hand, the absorbed apec model gives plasma temperature 4.76 (+1.22, −0.83) keV.

X-rays can also be generated through inverse Compton emission, where the cooling effect of photospheric photons may play a significant role. Type II supernovae are typically found in star-forming regions of spiral galaxies. They are thought to occur due to the explosion caused by the core-collapse of massive stars, most likely red supergiants. X-rays provide the most direct evidence of circumstellar interaction thus, we tried to investigate the X-ray properties of core-collapse supernovae.

Since this paper focuses on X-ray emission, we will provide a brief overview of the observational results. Several observations have been detected by Swift/XRT ~3 of them in the first phase have good quality to be studied. We interpret the X-ray emission within the framework of the circumstellar interaction model for Type IIP SNe, as discussed by [26] and references therein. Thus, three epochs from Swift/XRT were analyzed from day 5 to 30 since the explosion of the SNe. Some parameters were estimated from the analysis such as Flux, Luminosity, photon index from the powerlaw model. Moreover we obtained the plasma temperature from the Apec model.

The high X-ray luminosity that we obtained from the analysis indicates a higher density. The luminosity was increasing rapidly in the first few days after the shockwave. Then, during the photospheric phase (day 7 to 30), it declines from 8.4 ±

0.3 to 6.8 ± 0.24 (E41 erg/s). This result agrees with [1] who showed that the X-ray luminosity (Lx) and time (t) is described by the power law equation ($Lx \propto t^{-a}$). The temperatures in the first two observations are approximately 6.27×10^7 K average which falls within the range where the reverse shock is expected to be non-radiative, with free-free emission being the dominant process which agrees with [27]. This is also in agreement with [28] who studied SN 2004dj that was detected by Chandra in August 2004, likely two months after the explosion, and it had a temperature of approximately 7 keV.

Acknowledgements

We acknowledge the use of public data from the Swift data archive.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Dwarkadas, V.V. and Gruszko, J. (2011) What Are Published X-Ray Light Curves Telling Us about Young Supernova Expansion? *Monthly Notices of the Royal Astronomical Society*, **419**, 1515-1524. https://doi.org/10.1111/j.1365-2966.2011.19808.x

[2] Dessart, L., John Hillier, D. and Audit, E. (2017) Explosion of Red-Supergiant Stars: Influence of the Atmospheric Structure on Shock Breakout and Early-Time Supernova Radiation. *Astronomy & Astrophysics*, **605**, A83. https://doi.org/10.1051/0004-6361/201730942

[3] Margutti, R., Chornock, R., Metzger, B.D., Coppejans, D.L., Guidorzi, C., Migliori, G., *et al.* (2018) Results from a Systematic Survey of X-Ray Emission from Hydrogen-Poor Superluminous Sne. *The Astrophysical Journal*, **864**, Article 45. https://doi.org/10.3847/1538-4357/aad2df

[4] Chevalier, R.A. (1982) Are Young Supernova Remnants Interacting with Circumstellar Gas. *The Astrophysical Journal*, **259**, L85. https://doi.org/10.1086/183853

[5] Immler, S., Pooley, D., Brown, P.J., Milne, P., Immler, S., Pooley, D., Brown, P.J. and Milne, P. (2009) Swift XRT Detection of Supernova 2008ij in X-Rays. https://ui.adsabs.harvard.edu/abs/2009ATel.1918....1I/abstract

[6] Dickey, J.M. and Lockman, F.J. (1990) H I in the Galaxy. *Annual Review of Astronomy and Astrophysics*, **28**, 215-259. https://doi.org/10.1146/annurev.aa.28.090190.001243

[7] Haynes, M.P., Hogg, D.E., Maddalena, R.J., Roberts, M.S. and van Zee, L. (1998) Asymmetry in High-Precision Global H I Profiles of Isolated Spiral Galaxies. *The Astronomical Journal*, **115**, 62-79. https://doi.org/10.1086/300166

[8] Stockdale, C.J., Weiler, K.W., Immler, S., Williams, C.L.M., Panagia, N., van Dyk, S.D., Ryder, S., Marcaide, J.M., Pooley, D., Sramek, R.A. and Kelley, M.T. (2009). Radio Non-Detections of Type IIP Supernovae 2008ij (NGC 6643) 2009H (NGC 1084), and 2009N (4487). https://ui.adsabs.harvard.edu/abs/2009ATel.1915....1S/abstract

[9] Silverman, J.M., Pickett, S., Craig Wheeler, J., Filippenko, A.V., Vinkó, J., Marion, G.H., *et al.* (2017) After the Fall: Late-Time Spectroscopy of Type IIP Supernovae. *Monthly Notices of the Royal Astronomical Society*, **467**, 369-411. https://doi.org/10.1093/mnras/stx058

[10] Jerkstrand, A., Smartt, S.J., Fraser, M., Fransson, C., Sollerman, J., Taddia, F., *et al.* (2014) The Nebular Spectra of SN 2012aw and Constraints on Stellar Nucleosynthesis from Oxygen Emission Lines. *Monthly Notices of the Royal Astronomical Society*, **439**, 3694-3703. https://doi.org/10.1093/mnras/stu221

[11] Nakano, S., Kadota, K., Kryachko, T. and Korotkiy, S. (2008) Supernova 2008ij in NGC 6643. https://ui.adsabs.harvard.edu/abs/2008CBET.1626....1N/abstract

[12] Barbon, R., Buondi, V., Cappellaro, E. and Turatto, M. (2008) VizieR Online Data Catalog: Asiago Supernova Catalogue. CDS/ADC Collection of Electronic Catalogues. https://ui.adsabs.harvard.edu/abs/2008yCat....1.2024B/abstract

[13] Kryachko, T. and Korotkiy S. (2008) SN in NGC6643. http://www.astroalert.su/2008/12/19/sn-in-ngc6643/

[14] Challis, P. and Challis, P. (2008) Supernova 2008ij in NGC 6643. https://ui.adsabs.harvard.edu/abs/2008CBET.1627....1C/abstract

[15] Jarrett, T.H., Chester, T., Cutri, R., Schneider, S., Skrutskie, M. and Huchra, J.P. (2000) 2MASS Extended Source Catalog: Overview and Algorithms. *The Astronomical Journal*, **119**, 2498-2531. https://doi.org/10.1086/301330

[16] Theureau, G., Hanski, M.O., Coudreau, N., Hallet, N. and Martin, J.-M. (2006) Kinematics of the Local Universe. *Astronomy & Astrophysics*, **465**, 71-85. https://doi.org/10.1051/0004-6361:20066187

[17] Falco, E.E., Kurtz, M.J., Geller, M.J., Huchra, J.P., Peters, J., Berlind, P., *et al.* (1999) The Updated Zwicky Catalog (UZC). *Publications of the Astronomical Society of the Pacific*, **111**, 438-452. https://doi.org/10.1086/316343

[18] Nissinen, M. and Oksanen, A. (2008) Supernova 2008bo in NGC 6643. https://ui.adsabs.harvard.edu/abs/2008CBET.1324....1N/abstract

[19] Evans, P.A., Beardmore, A.P., Page, K.L., Tyler, L.G., Osborne, J.P., Goad, M.R., *et al.* (2007) An Online Repository of *Swift*/XRT Light Curves of γ-ray Bursts. *Astronomy & Astrophysics*, **469**, 379-385. https://doi.org/10.1051/0004-6361:20077530

[20] Evans, P.A., Beardmore, A.P., Page, K.L., Osborne, J.P., O'Brien, P.T., Willingale, R., *et al.* (2009) Methods and Results of an Automatic Analysis of a Complete Sample of Swift-*XRT* Observations of GRBs. *Monthly Notices of the Royal Astronomical Society*, **397**, 1177-1201. https://doi.org/10.1111/j.1365-2966.2009.14913.x

[21] Dickey, J. (1990) H I in the Galaxy. *Annual Review of Astronomy and Astrophysics*, **28**, 215-261. https://doi.org/10.1146/annurev.astro.28.1.215

[22] Howk, J.C., Sembach, K.R. and Savage, B.D. (2003) Ionized Gas in the First 10 Kiloparsecs of the Interstellar Galactic Halo. *The Astrophysical Journal*, **586**, 249-267. https://doi.org/10.1086/346262

[23] Cash, W., Charles, P., Bowyer, S., Walter, F., Ayres, T.R. and Linsky, J.L. (1979) Discovery of X-Rays from the 40 Eridani System. *The Astrophysical Journal*, **231**, L137. https://doi.org/10.1086/183020

[24] Chevalier, R.A. and Fransson, C. (2006) Circumstellar Emission from Type Ib and Ic Supernovae. *The Astrophysical Journal*, **651**, 381-391. https://doi.org/10.1086/507606

[25] Chakraborti, S., Ray, A., Smith, R., Margutti, R., Pooley, D., Bose, S., *et al.* (2016) Probing Final Stages of Stellar Evolution with X-Ray Observations of Sn 2013ej. *The Astrophysical Journal*, **817**, Article 22. https://doi.org/10.3847/0004-637x/817/1/22

[26] Chevalier, R.A., Fransson, C. and Nymark, T.K. (2006) Radio and X-Ray Emission as Probes of Type IIP Supernovae and Red Supergiant Mass Loss. *The Astrophysical*

Journal, **641**, 1029-1038. https://doi.org/10.1086/500528

[27] Misra, K., Pooley, D., Chandra, P., Bhattacharya, D., Ray, A.K., Sagar, R., *et al*. (2007) Type IIP Supernova SN 2004et: A Multiwavelength Study in X-Ray, Optical and Radio. *Monthly Notices of the Royal Astronomical Society*, **381**, 280-292. https://doi.org/10.1111/j.1365-2966.2007.12258.x

[28] Pooley, D. and Lewin, W.H.G. (2004) Supernova 2004dj in NGC 2403. International Astronomical Union Circular 8390 (2004): 1.