Proceedings of the 4th International Conference on Mathematical Physics and Computational Simulation
DOI: 10.54254/2753-8818/2026.35287

Studying Cosmology with Supernovae

Chenyu Liu

College of Liberal Arts and Sciences, University of Illinois Urbana-Champaign, Urbana-Champaign, USA
chenyul8@illinois.edu

Abstract. Supernovae connect stellar evolution, high-energy transient astronomy, and observational cosmology. This review examines how supernova physics and survey design together determine the cosmological value of supernova observations. It distinguishes Type Ia thermonuclear supernovae, which are standardizable luminosity-distance indicators, from Type II and other core-collapse supernovae, which probe massive-star evolution, circumstellar interaction, compact-remnant formation, and multi-messenger signals. The discussion first reviews the physical mechanisms of Type Ia and Type II explosions, emphasizing that spectral classification and explosion mechanism should not be conflated. It then surveys representative low-, intermediate-, and high-redshift programs, including the Nearby Supernova Factory, Foundation Supernova Survey, Sloan Digital Sky Survey-II Supernova Survey, Pan-STARRS1, Zwicky Transient Facility, High-z Supernova Search Team, Supernova Legacy Survey, and Dark Energy Survey. Core-collapse follow-up programs, X-ray monitoring, and neutrino observatories are also discussed because they clarify the astrophysical diversity that must be separated from the Type Ia cosmology program. Finally, the review explains how Type Ia Hubble diagrams support late-time cosmic acceleration and why future progress depends less on sample size alone than on calibration, selection effects, dust, host-galaxy correlations, population evolution, and cross-probe consistency. The central conclusion is that supernova cosmology remains powerful precisely because it joins empirical standardization with explicit treatment of astrophysical and observational systematics.

Keywords: supernovae, Type Ia supernovae, cosmology, dark energy, core-collapse supernovae

1. Introduction

Supernovae provide a rare bridge between the life cycle of stars and the large-scale history of the universe. Their explosions release enormous energy, synthesize heavy elements, and create compact remnants, while their light curves and spectra allow astronomers to infer distances, progenitor properties, explosion mechanisms, and cosmological parameters. A clear treatment of supernovae therefore requires both an astrophysical and a cosmological perspective.

This paper argues that the cosmological use of supernovae depends on a careful separation between classification, physical mechanism, and observational purpose. A supernova type defined

DOI: 10.54254/2753-8818/2026.35287

spectroscopically is not automatically a cosmological standard candle, and a survey that discovers many transients is not automatically optimized for dark-energy inference. The most important cosmological subclass is Type Ia, whose luminosities can be standardized through empirical light-curve corrections. Type II and other core-collapse supernovae are less central as standard candles but are essential for understanding massive-star deaths, early-time transients, circumstellar material, neutrino emission, and the broader astrophysical context of time-domain surveys.

This review is therefore organized around three linked questions. First, what physical mechanisms distinguish thermonuclear Type Ia explosions from hydrogen-rich core-collapse events? Second, how do observational programs at different redshifts serve different functions, such as calibration, redshift bridging, high-redshift cosmology, and rapid early-time classification? Third, how do Type Ia supernova distances enter the evidence for cosmic acceleration, and what systematic uncertainties limit the next generation of measurements?

The paper proceeds as follows. Section 2 reviews the main physical differences between Type Ia and Type II supernovae, while also noting the limitations of overly simple classification. Section 3 summarizes representative observational programs and compares their scientific purposes. Section 4 discusses how Type Ia supernovae constrain the expansion history and dark energy. Section 5 concludes by identifying the main limitations and future directions.

2. Supernova physics

Classical supernova classification is based primarily on spectral features, especially the presence or absence of hydrogen lines. Type II supernovae show prominent hydrogen, while Type I supernovae do not. Historically, this spectral distinction was useful because it separated many hydrogen-rich massive-star explosions from hydrogen-poor events. However, the physical interpretation of the classification requires caution. Type Ia supernovae are thermonuclear explosions, whereas Type Ib and Type Ic supernovae are usually core-collapse explosions of stripped massive stars. For cosmological applications, the relevant subclass is Type Ia rather than Type I as a whole [1, 2].

This distinction is not a minor terminology issue. If all Type I events are treated as thermonuclear standard candles, the resulting discussion confuses spectral taxonomy with explosion physics. A rigorous supernova review should therefore move from spectra to mechanisms: hydrogen absorption identifies Type II events; silicon features near maximum light are characteristic of Type Ia events; and the absence of hydrogen in Type Ib/Ic events reflects envelope stripping rather than a thermonuclear origin.

2.1. Type Ia thermonuclear supernovae

Type Ia supernovae are generally associated with the thermonuclear disruption of carbon-oxygen white dwarfs in binary systems. In the classical scenario, a white dwarf approaches the Chandrasekhar mass, approximately 1.4 solar masses, through accretion from a companion star or through interaction with another white dwarf. Under appropriate density and temperature conditions, carbon and oxygen burning becomes explosive and unbinds much of the star [1]. The Chandrasekhar-mass picture is important historically, but it should not be presented as the only possible progenitor channel; double-degenerate mergers and sub-Chandrasekhar detonation scenarios are also relevant to the diversity of Type Ia events.

The energy scale of a typical Type Ia explosion is roughly 10^51 erg. Much of this energy becomes kinetic energy of the expanding ejecta, while the observed optical and near-infrared luminosity is powered mainly by the radioactive decay chain 56Ni to 56Co to 56Fe. The amount and

DOI: 10.54254/2753-8818/2026.35287

distribution of synthesized 56Ni influence the peak luminosity, color evolution, and decline rate of the light curve. This is why the physical details of burning, mixing, opacity, and ejecta structure matter even when Type Ia supernovae are treated empirically as distance indicators.

Observed Type Ia light curves are not perfectly identical, but they are standardizable. Empirical relations among light-curve width, color, and luminosity allow distances to be inferred with relatively small scatter [3]. The width-luminosity relation means that broader, slower-declining light curves are generally more luminous, while color corrections account for dust and intrinsic color variation. These corrections are the foundation of the distance modulus estimates used in supernova Hubble diagrams.

The word standardizable is essential. Type Ia supernovae should not be described as perfectly uniform standard candles. Their usefulness comes from a calibrated procedure that converts heterogeneous events into a standardized distance scale. This procedure introduces model dependence through light-curve fitting, calibration, intrinsic scatter, and host-galaxy corrections.

This standardizability is the foundation of Type Ia supernova cosmology. After calibration, the comparison between apparent magnitude and redshift provides a luminosity-distance relation over cosmological scales. Type Ia supernovae are therefore used in estimates of the Hubble constant, tests of the Friedmann equation framework, and measurements of the late-time expansion history of the universe [4].

The remaining theoretical problem is that Type Ia explosions are not fully understood from first principles. The transition between deflagration and detonation, the diversity of progenitor channels, metallicity effects, and asymmetries in the explosion may all influence luminosity calibration. Three-dimensional simulations have improved the physical picture but remain computationally demanding and sensitive to uncertain microphysics [5]. For precision cosmology, these astrophysical uncertainties should be treated as potential systematic errors rather than as irrelevant details.

2.2. Type II core-collapse supernovae

Type II supernovae arise from the gravitational collapse of massive stars that retain hydrogen-rich envelopes at the time of explosion. Their progenitors typically have initial masses above about eight solar masses. Unlike Type Ia events, Type II supernovae do not have a single characteristic progenitor mass or a single standardized luminosity scale. Their observed diversity reflects variations in progenitor mass, radius, metallicity, rotation, binary interaction, circumstellar material, and mass-loss history [2, 6].

The light curves of Type II supernovae often show a plateau phase caused by hydrogen recombination in the expanding envelope. At early times, the emission is influenced by shock heating and cooling. At later times, radioactive decay, especially 56Co to 56Fe, contributes to the luminosity. Ejecta velocities are typically several thousand kilometers per second and depend on explosion energy and envelope mass. The explosion releases most of its gravitational binding energy as neutrinos rather than electromagnetic radiation, making core-collapse supernovae essential targets for multi-messenger astronomy [7, 8].

The theoretical mechanism of core-collapse explosions remains a central problem in astrophysics. The favored paradigm is neutrino-driven shock revival: after core bounce, the outward shock stalls, and a fraction of the neutrino luminosity from the proto-neutron star heats material behind the shock. Convection and the standing accretion shock instability can increase the dwell time of matter in the gain region, helping the shock revive and produce an explosion [8].

The core-collapse mechanism illustrates why Type II supernovae are scientifically important even though they are not the primary tools of modern dark-energy inference. They connect stellar

DOI: 10.54254/2753-8818/2026.35287

evolution, nuclear-density matter, neutrino transport, hydrodynamic instability, and compact-object formation. Their diversity also warns against treating any supernova class as astrophysically simple merely because it has a useful observational classification.

3. Observational programs

Supernova observation differs by scientific purpose. A survey should be evaluated not only by the number of transients discovered but also by the redshift range, photometric calibration, cadence, spectroscopic completeness, follow-up strategy, and control of selection effects. Low-redshift Type Ia surveys are crucial for calibration and nearby population studies; intermediate-redshift surveys bridge local samples and high-redshift cosmology; high-redshift programs test cosmic acceleration; and core-collapse programs focus on progenitors, explosion physics, circumstellar interaction, and multi-messenger signals.

Table 1 summarizes the main role of representative programs discussed in this review. The table clarifies how survey design maps onto scientific purpose and cosmological inference.

Table 1. Representative supernova programs and their main roles

Program or facility	Approximate role	Main contribution	Main limitation or caution
Nearby Supernova Factory	Low-redshift Type Ia calibration	Spectrophotometric light curves and standardization tests	Nearby calibration still depends on selection and photometric consistency
Foundation Supernova Survey	Homogeneous low-redshift anchor	Pan-STARRS-based light curves and improved local sample	Needs connection to higher-redshift samples
SDSS-II Supernova Survey	Intermediate-redshift bridge	Well-sampled multiband light curves over Stripe 82	Spectroscopic follow-up and classification completeness matter
Pan-STARRS1 and ZTF	Large time-domain discovery	High-cadence imaging and large transient samples	Discovery efficiency is not the same as cosmological precision
High-z Team, SNLS, DES	High-redshift cosmology	Evidence and constraints for cosmic acceleration and dark energy	Dominated increasingly by calibration and population systematics
Rubin/LSST, Einstein Probe, IceCube	Future population and multi-messenger studies	Large samples, X-ray shock breakout, and neutrino alerts	Requires rapid follow-up and careful classification

3.1. Low-redshift Type Ia calibration

Low-redshift Type Ia observations provide the calibration foundation for cosmology. Nearby events are bright enough for detailed spectroscopy and multiband photometry, so they define the empirical light-curve relations applied to more distant samples. The Nearby Supernova Factory was designed to obtain high-quality spectrophotometric observations of nearby Type Ia supernovae, helping calibrate light-curve properties, color relations, and the standardization procedure [9].

The Foundation Supernova Survey had a similar calibration motivation but placed special emphasis on a homogeneous low-redshift sample. It used Pan-STARRS photometry and modern light-curve fitting to replace older heterogeneous nearby samples. Its first data release included more than two hundred Type Ia light curves, with a large subset satisfying cosmological quality cuts, and it substantially improved the local anchor used in dark-energy and Hubble-constant analyses [10].

DOI: 10.54254/2753-8818/2026.35287

The main lesson from these nearby surveys is that local supernovae are not merely a convenience sample. They set the zero point and empirical standardization relations for the entire cosmological distance ladder. If the nearby sample is heterogeneous, poorly calibrated, or drawn from a different host-galaxy population than the distant sample, the inferred cosmology can be biased even when the high-redshift observations are precise.

3.2. Automated discovery and early-time follow-up

Automated transient discovery and rapid follow-up have become increasingly important in the era of high-cadence surveys. The BTSbot-nearby program uses Zwicky Transient Facility alerts and autonomous spectroscopic follow-up to identify very young nearby supernovae. Its example of SN 2024jlf is a Type IIP event, not a Type Ia cosmology object, but it demonstrates how low-latency automation can capture short-lived early-time spectral features such as flash-ionization lines [11].

For this reason, BTSbot-nearby is best understood as a core-collapse and rapid-response example rather than as evidence for Type Ia standard-candle calibration. This distinction matters because early-time Type IIP spectroscopy probes circumstellar material and progenitor mass loss, whereas Type Ia cosmology depends mainly on calibrated light-curve distances and population control.

Rapid automation nevertheless has indirect importance for cosmology. Future surveys will generate extremely large alert streams, and human classification alone will not be sufficient. Automated vetting, prompt spectroscopy, and machine-learning classifiers can reduce latency and improve sample completeness. However, classification algorithms must be validated carefully, because contamination by non-Ia transients or peculiar Ia events can introduce selection bias into cosmological samples.

3.3. Intermediate-redshift surveys

At intermediate redshifts, the Sloan Digital Sky Survey-II Supernova Survey repeatedly imaged Stripe 82 and obtained well-sampled multiband light curves of Type Ia supernovae in the approximate range $0.05 < z < 0.35$. This survey filled an important redshift gap between local calibration samples and high-redshift cosmology samples. It used repeated drift-scan imaging, image subtraction, automated candidate detection, visual screening, photometric classification, and spectroscopic follow-up with a network of telescopes [12, 13].

The SDSS-II survey was important not only because it increased the number of supernovae but also because it improved the continuity of the Hubble diagram. A cosmological inference based only on very nearby and very distant objects is vulnerable to calibration offsets and unrecognized sample differences. Intermediate-redshift data help connect the local distance scale to the redshift range where acceleration becomes measurable.

Pan-STARRS1 also contributed substantially to time-domain astronomy. Its wide-field imaging strategy, multiple filters, image-processing pipeline, stacking, and difference imaging enabled the discovery and characterization of large numbers of Type Ia supernovae and other transients [14]. Pan-STARRS1 samples have been used in cosmological analyses because they provide a broad redshift baseline and relatively homogeneous photometry, although their cosmological value depends on calibration, classification, and selection modeling.

The Zwicky Transient Facility expanded the speed and scale of transient discovery with a wide field of view, high cadence, real-time image differencing, and alert distribution [15, 16]. ZTF is especially valuable for young supernovae, rare transients, tidal disruption events, active galactic nuclei, and solar-system objects. For Type Ia cosmology, however, discovery power must be converted into a well-characterized sample with known selection functions and reliable photometric calibration.

3.4. High-redshift Type Ia cosmology surveys

High-redshift supernova programs made Type Ia supernovae decisive tools for cosmology. The High-z Supernova Search Team used ground- and space-based facilities to discover and follow distant Type Ia supernovae. Together with related work by the Supernova Cosmology Project, these observations showed that distant Type Ia supernovae were fainter than expected in a matter-dominated decelerating universe, implying late-time cosmic acceleration [17-19].

The logic of the high-redshift result is simple but powerful. In a universe dominated by matter, gravity should decelerate expansion, and distant supernovae at a given redshift should appear brighter than they do in an accelerating universe. The observed faintness of distant Type Ia supernovae therefore indicated that the expansion history could not be explained by ordinary matter alone. When interpreted within the Friedmann-Robertson-Walker framework, the result required a dominant component with negative pressure, commonly called dark energy.

The Supernova Legacy Survey used a rolling-search strategy with the Canada-France-Hawaii Telescope to discover and monitor high-redshift Type Ia supernovae in multiple optical bands. By combining distant supernovae with nearby samples and fitting light curves with empirical standardization models, it provided stronger constraints on matter density and the dark-energy equation-of-state parameter [20].

The Dark Energy Survey supernova program used the Dark Energy Camera on the Blanco telescope to monitor repeated fields in several optical bands. Its goal was to discover and characterize large numbers of Type Ia supernovae for dark-energy constraints while also building a legacy dataset for other transients, including core-collapse and superluminous supernovae [21]. DES illustrates the modern direction of the field: large samples are useful only when survey cadence, photometric calibration, host-galaxy redshifts, classification probabilities, and selection functions are modeled together.

3.5. Observations of Type II and core-collapse supernovae

Type II supernovae are especially valuable because they can often be connected directly to their progenitor stars. Deep pre-explosion imaging of nearby galaxies has identified several Type II-P progenitors as red supergiants with initial masses of roughly 8 to 17 solar masses. This has led to the red-supergiant problem: the apparent lack of high-mass red-supergiant progenitors in observed Type II-P samples [6].

The diversity of core-collapse supernovae includes Type II-P, Type II-L, Type IIn, and Type IIb events. Type II-P events show a plateau, Type II-L events decline more linearly, Type IIn events exhibit narrow emission lines from strong circumstellar interaction, and Type IIb events evolve from hydrogen-rich to helium-dominated spectra. This diversity reflects differences in envelope mass, mass loss, binary interaction, metallicity, and circumstellar environment [7].

Flash spectroscopy, rapid-response photometry, and early-time ultraviolet or X-ray observations reveal circumstellar material and mass loss shortly before explosion. These observations are especially important for distinguishing whether observed diversity arises from single-star evolution, binary stripping, eruptive mass loss, or environmental effects [7].

The Vera C. Rubin Observatory Legacy Survey of Space and Time will discover enormous samples of supernovae and other transients, enabling population-level studies. At this scale, the main challenge will not be discovery but classification, follow-up prioritization, and physical interpretation. The Core Cosmology Library supports precision predictions for cosmological observables relevant to Rubin-era analyses, including galaxy clustering and weak lensing [22]. Although this library is not a supernova survey, it belongs in the discussion because future dark-energy tests will combine supernova distances with other cosmological probes.

The Einstein Probe, with wide-field soft X-ray monitoring, may detect shock-breakout events and circumstellar interaction from nearby core-collapse supernovae [23]. Shock breakout is short-lived and difficult to observe, but it directly constrains progenitor radius, explosion energy, and envelope structure. X-ray emission at later times traces the interaction between the ejecta and circumstellar material, providing a record of mass loss in the final stages of stellar evolution.

Neutrino detectors such as IceCube and coordinated alert systems are crucial for the next Galactic core-collapse supernova [24]. The neutrino burst arrives before most electromagnetic signals and provides a direct view of the collapsing core. A future Galactic event observed in neutrinos, gravitational waves, and electromagnetic radiation would test the neutrino-heating mechanism, nuclear matter physics, and explosion asymmetry far more directly than optical light curves alone.

4. Cosmological implications

4.1. Type Ia standardization and the Hubble diagram

The cosmological significance of Type Ia supernovae rests on the relation between apparent brightness, intrinsic luminosity, and distance. Once Type Ia light curves are standardized using empirical width and color corrections, the resulting Hubble diagram gives luminosity distance as a function of redshift [25, 26]. This method directly probes the expansion history and is complementary to probes based on the growth of structure.

In practical terms, supernova cosmology estimates a distance modulus from the observed peak magnitude after corrections for light-curve shape, color, and nuisance parameters. Modern analyses often use light-curve models such as SALT2, combine photometric calibration data across surveys, and model intrinsic scatter. The residuals around the best-fitting Hubble diagram, sometimes called Hubble residuals, are then examined for dependence on redshift, host-galaxy properties, color, and survey selection.

This technical layer is essential. The evidence for acceleration is not obtained by simply comparing raw brightnesses. It requires a calibrated chain from photometry to light-curve parameters, from light-curve parameters to standardized luminosities, and from standardized luminosities to cosmological distances.

4.2. Cosmic acceleration and dark energy

The key discovery of the late 1990s was that distant Type Ia supernovae appeared fainter than expected in a decelerating universe. Within the Friedmann-Robertson-Walker framework, this result indicates that the expansion of the universe has accelerated during the past several billion years. The simplest explanation is a cosmological constant with equation-of-state parameter $w = -1$, although dynamical dark energy and modified gravity remain possible alternatives [26-28].

The physical interpretation is that matter alone cannot account for the observed distance-redshift relation. Matter produces gravitational attraction and therefore deceleration. A component with sufficiently negative pressure can instead drive accelerated expansion. Einstein's cosmological constant is the simplest such component, but its required energy density is extraordinarily small

DOI: 10.54254/2753-8818/2026.35287

compared with naive quantum-field-theory expectations, producing the cosmological constant problem [28].

Supernova evidence is strongest when combined with other probes. Cosmic microwave background measurements constrain spatial curvature and the early-universe density budget, while baryon acoustic oscillations provide standard-ruler distances at intermediate redshift. The combination of supernovae, cosmic microwave background, and baryon acoustic oscillations supports a spatially flat universe dominated at late times by a dark-energy component [27-29].

Supernovae are especially valuable in this combination because they measure relative distances over the redshift range where the transition from deceleration to acceleration occurs. They do not by themselves determine every cosmological parameter, but they strongly constrain the shape of the late-time expansion history. This is why supernova data remain central even in an era of cosmic microwave background, baryon acoustic oscillation, weak-lensing, and galaxy-clustering surveys.

4.3. Systematic uncertainties and alternative explanations

Precision supernova cosmology is limited not only by sample size but also by systematic uncertainties. Important concerns include photometric calibration, dust extinction, color corrections, host-galaxy dependence, selection effects, gravitational lensing scatter, possible population evolution, and uncertainty in light-curve models. Because Type Ia supernovae are standardizable rather than perfectly standard, these issues must be modeled explicitly [25, 29].

Dust is a natural alternative explanation for faint distant supernovae because dust makes objects dimmer. Ordinary dust also reddens light, so multiband photometry can test for it. Grey dust that dims without strong reddening is harder to exclude but is constrained by the absence of corresponding far-infrared signatures and by the consistency of supernova colors and light-curve shapes across redshift. These tests do not remove every uncertainty, but they make a simple dust-only explanation implausible [25, 29].

Population evolution is another concern. The stellar populations that produce Type Ia supernovae at high redshift may differ in age, metallicity, and host-galaxy environment from nearby populations. If these differences change standardized luminosities, they could bias cosmological inference. Modern analyses therefore examine host-mass steps, color-luminosity relations, redshift trends in Hubble residuals, and spectroscopic similarity between nearby and distant events.

Several cross-checks strengthen the cosmological interpretation. Observed light-curve time dilation by a factor close to $1 + z$ supports the expanding-universe interpretation. Multi-band observations constrain ordinary dust reddening and grey-dust scenarios. Comparisons across host-galaxy types and redshift ranges test whether luminosity evolution could mimic acceleration. Although none of these tests removes all uncertainty, together they make the acceleration result difficult to explain by a single astrophysical contaminant [25, 26, 29].

Selection effects must also be treated explicitly. Magnitude-limited surveys preferentially discover brighter objects near the detection threshold, producing Malmquist-type biases. Spectroscopic follow-up can introduce additional biases if candidates are selected by brightness, host galaxy, color, or observing conditions. Large samples do not automatically solve these problems; they can make systematic biases statistically significant unless the survey selection function is modeled.

DOI: 10.54254/2753-8818/2026.35287

4.4. Future surveys and dark-energy tests

The next stage of supernova cosmology aims to reduce systematic uncertainties to the sub-percent level. Large ground-based surveys such as the Legacy Survey of Space and Time will provide very large statistical samples, while space-based and near-infrared observations can reduce dust-related uncertainty and improve calibration. The major scientific goal is to determine whether dark energy is exactly consistent with a cosmological constant or instead shows time variation in w [28, 29].

Future progress will require more than discovering more supernovae. It will require homogeneous calibration, well-defined selection functions, spectroscopic or high-quality photometric classification, host-galaxy information, improved light-curve models, and joint analysis with other cosmological probes. Near-infrared observations are particularly valuable because dust extinction is reduced and Type Ia supernovae may be more uniform at longer wavelengths.

If future supernova, weak-lensing, cluster, and baryon-acoustic-oscillation measurements agree on both geometry and growth of structure, they will further strengthen the Lambda cold dark matter model. If they disagree, the discrepancy may indicate unmodeled systematics, evolving dark energy, or a breakdown of general relativity on cosmological scales. Supernovae therefore remain central to fundamental physics as well as observational astronomy.

A balanced conclusion is therefore neither that supernovae have solved dark energy completely nor that their systematics make them unreliable. Their strength lies in the fact that they provide a direct distance-redshift measurement, while their weakness lies in the astrophysical complexity of the objects used as distance indicators. The field advances by making that complexity explicit.

4.5. How survey design enters cosmological inference

A useful way to connect the observational and cosmological parts of the paper is to view each survey as controlling a different term in the error budget. Nearby programs mainly determine calibration and the absolute or relative zero point of the distance scale. Intermediate-redshift programs test whether the same standardization relation holds when the observed bands, host populations, and selection thresholds change. High-redshift programs provide the strongest leverage on acceleration, but they are also more sensitive to selection bias, K-corrections, dust, and classification uncertainty. This division of labor explains why a cosmological supernova sample is usually a compilation rather than a single survey product.

Because the observed flux is measured through finite filters, K-corrections are needed to compare rest-frame supernova light emitted at different wavelengths and observed at different redshifts. This correction is straightforward in principle but difficult in practice because it depends on spectral templates, color evolution, and calibration across instruments. A small cross-survey calibration offset can mimic a cosmological signal when samples from different redshift ranges are stitched together.

Spectroscopic completeness is another central issue. Spectroscopically confirmed Type Ia samples are cleaner but expensive, especially at high redshift. Photometrically classified samples are much larger but require probabilistic treatment of contamination. A modern analysis therefore needs both a large sample and a transparent classification model. The cosmological result should not depend on an implicit assumption that every candidate with a Type Ia-like light curve is genuinely Type Ia.

A further reason to keep the survey comparison explicit is that different observing strategies produce different missing data patterns. A rolling high-redshift search can obtain well-sampled light curves but may have limited spectroscopy. A nearby rapid-response program can secure early spectra

DOI: 10.54254/2753-8818/2026.35287

but may not provide a cosmologically representative sample. A wide-field alert stream can discover rare events but may require aggressive filtering before follow-up. These design choices affect the final scientific conclusion, so they should be stated rather than hidden behind the phrase "large supernova sample."

The same point applies to core-collapse surveys. A sample optimized for shock breakout or flash spectroscopy will favor nearby, young, rapidly followed events, while a survey optimized for population statistics will emphasize completeness and classification over the earliest spectra. Thus, the observational strategy determines which physical question can be answered: progenitor radius, mass-loss history, explosion rate, luminosity function, or cosmological distance.

Detailed survey material is valuable when it explains calibration, cadence, redshift coverage, and follow-up design rather than simply listing disconnected project summaries.

4.6. Relation to the Hubble constant tension

Type Ia supernovae also enter the local distance ladder used to infer the Hubble constant. In this application, nearby Type Ia supernovae are calibrated by independent distance indicators such as Cepheids or the tip of the red-giant branch, and then used to extend the distance scale to galaxies in the smooth Hubble flow. This use differs from high-redshift dark-energy inference but shares many of the same vulnerabilities: photometric calibration, host-galaxy environment, light-curve standardization, and sample selection.

The Hubble constant tension illustrates why the treatment of systematics is not merely technical. If local distance-ladder measurements and early-universe inferences disagree, the explanation could be new physics, but it could also involve hidden calibration or population effects. Supernovae sit at the center of this debate because they translate local calibrators into cosmological distances. A careful paper should therefore avoid claiming that supernovae simply "measure the Hubble constant" without explaining the ladder structure behind that measurement.

5. Conclusion

Supernovae are powerful laboratories for both stellar evolution and cosmology. Type Ia supernovae provide standardized luminosity distances and remain essential for measuring cosmic acceleration and dark-energy parameters. Type II and other core-collapse supernovae reveal the final stages of massive-star evolution, the physics of shock revival, circumstellar interaction, and multi-messenger signals. The strongest version of a supernova review therefore distinguishes carefully between spectral classification, explosion mechanism, and cosmological utility.

Low-redshift surveys calibrate Type Ia supernovae; intermediate-redshift surveys connect local and distant samples; high-redshift surveys test cosmic acceleration; and core-collapse programs provide the astrophysical context for massive-star explosions and rapid-transient follow-up. The comparison shows that different surveys answer different scientific questions and should not be collapsed into a single list of discoveries.

Future progress depends on improved calibration, rapid follow-up, homogeneous samples, theoretical modeling, and cross-probe consistency. Large time-domain surveys and multi-messenger observatories will transform the field from individual case studies to statistical population science. At the same time, the use of Type Ia supernovae in precision cosmology will require increasingly careful treatment of astrophysical diversity and observational systematics.

DOI: 10.54254/2753-8818/2026.35287

References

[1] Nadyozhin, D. K., & Imshennik, V. S. (2005). Physics of supernovae. International Journal of Modern Physics A, 20, 6597-6611. https: //doi.org/10.1142/s0217751x05029630

[2] Woosley, S. E., & Weaver, T. A. (1986). The physics of supernova explosions. Annual Review of Astronomy and Astrophysics, 24, 205-253. https: //doi.org/10.1146/annurev.aa.24.090186.001225

[3] Jha, S. W., Maguire, K., & Sullivan, M. (2019). Observational properties of thermonuclear supernovae. Nature Astronomy, 3(8), 706-716.

[4] Wang, Y., Freese, K., Gondolo, P., & Lewis, M. (2003). Future Type Ia supernova data as tests of dark energy from modified Friedmann equations. The Astrophysical Journal, 594, 25-32. https: //doi.org/10.1086/376899

[5] Janka, H.-T., Melson, T., & Summa, A. (2016). Physics of core-collapse supernovae in three dimensions: A sneak preview. Annual Review of Nuclear and Particle Science, 66, 341-375. https: //doi.org/10.1146/annurev-nucl-102115-044747

[6] Smartt, S. J. (2009). Progenitors of core-collapse supernovae. Annual Review of Astronomy and Astrophysics, 47(1), 63-106.

[7] Modjaz, M., Gutierrez, C. P., & Arcavi, I. (2019). New regimes in the observation of core-collapse supernovae. Nature Astronomy, 3(8), 717-724.

[8] Yamada, S., Nagakura, H., Akaho, R., Harada, A., Furusawa, S., Iwakami, W., & Sumiyoshi, K. (2024). Physical mechanism of core-collapse supernovae that neutrinos drive. Proceedings of the Japan Academy, Series B, 100(3), 190-233.

[9] Aldering, G., Adam, G., Antilogus, P., Astier, P., Bacon, R., Bongard, S., & Wood-Vasey, W. M. (2002). Overview of the nearby supernova factory. In Survey and Other Telescope Technologies and Discoveries. SPIE.

[10] Foley, R. J., Scolnic, D., Rest, A., Jha, S. W., Pan, Y. C., Riess, A. G., & Willman, M. (2018). The Foundation Supernova Survey: Motivation, design, implementation, and first data release. Monthly Notices of the Royal Astronomical Society, 475(1), 193-219.

[11] Rehemtulla, N., Jacobson-Galan, W. V., Singh, A., Miller, A. A., Kilpatrick, C. D., Hinds, K. R., & Kulkarni, S. R. (2025). The BTSbot-nearby discovery of SN 2024jlf: Rapid, autonomous follow-up probes interaction in an 18.5 Mpc Type IIP supernova. The Astrophysical Journal, 985(2), 241.

[12] Frieman, J. A., Bassett, B., Becker, A., Choi, C., Cinabro, D., DeJongh, F., & York, D. (2008). The Sloan Digital Sky Survey-II supernova survey: Technical summary. The Astronomical Journal, 135(1), 338-347.

[13] Sako, M., Bassett, B., Becker, A., Cinabro, D., DeJongh, F., Depoy, D. L., & Snedden, S. A. (2008). The Sloan Digital Sky Survey-II supernova survey: Search algorithm and follow-up observations. The Astronomical Journal, 135(1), 348-373.

[14] Chambers, K. C., Magnier, E. A., Metcalfe, N., Flewelling, H. A., Huber, M. E., Waters, C. Z., & Wyse, R. (2016). The Pan-STARRS1 surveys. arXiv preprint arXiv: 1612.05560.

[15] Bellm, E. C., Kulkarni, S. R., Graham, M. J., Dekany, R., Smith, R. M., Riddle, R., & Zolkower, J. (2019). The Zwicky Transient Facility: System overview, performance, and first results. Publications of the Astronomical Society of the Pacific, 131(995), 018002.

[16] Graham, M. J., Kulkarni, S. R., Bellm, E. C., Adams, S. M., Barbarino, C., Blagorodnova, N., & Zolkower, J. (2019). The Zwicky Transient Facility: Science objectives. Publications of the Astronomical Society of the Pacific, 131(1001), 078001.

[17] Schmidt, B. P., Suntzeff, N. B., Phillips, M. M., Schommer, R. A., Clocchiatti, A., Kirshner, R. P., & Ciardullo, R. (1998). The high-Z supernova search: Measuring cosmic deceleration and global curvature of the universe using Type Ia supernovae. The Astrophysical Journal, 507(1), 46-63.

[18] Filippenko, A. V., & Riess, A. G. (1998). Results from the high-z supernova search team. Physics Reports, 307(1-4), 31-44.

[19] Tonry, J. L., Schmidt, B. P., Barris, B., Candia, P., Challis, P., Clocchiatti, A., & Suntzeff, N. B. (2003). Cosmological results from high-z supernovae. The Astrophysical Journal, 594(1), 1-24.

[20] Astier, P., Guy, J., Regnault, N., Pain, R., Aubourg, E., Balam, D., & Walton, N. (2006). The Supernova Legacy Survey: Measurement of Omega_M and w from the first year data set. Astronomy & Astrophysics, 447(1), 31-48.

[21] Dark Energy Survey Collaboration, Abbott, T., Abdalla, F. B., Aleksic, J., Allam, S., Amara, A., & Zuntz, J. (2016). The Dark Energy Survey: More than dark energy-an overview. Monthly Notices of the Royal Astronomical Society, 460(2), 1270-1299.

[22] Chisari, N. E., Alonso, D., Krause, E., Leonard, C. D., Bull, P., Neveu, J., & Wagoner, E. L. (2019). Core Cosmology Library: Precision cosmological predictions for LSST. The Astrophysical Journal Supplement Series,

DOI: 10.54254/2753-8818/2026.35287

242(1), 2.
[23] Yuan, W., Zhang, C., Chen, Y., & Ling, Z. (2022). The Einstein Probe mission. In Handbook of X-ray and Gamma-ray Astrophysics. Springer.
[24] Ishihara, A. (2019). The IceCube Upgrade. Proceedings of Science, ICRC2019, 1031.
[25] Leibundgut, B. (2001). Cosmological implications from observations of Type Ia supernovae. Annual Review of Astronomy and Astrophysics, 39, 67-98.
[26] Perlmutter, S. (2012). Measuring the acceleration of the cosmic expansion using supernovae. Reviews of Modern Physics, 84(3), 1127-1143.
[27] Frieman, J. A., Turner, M. S., & Huterer, D. (2008). Dark energy and the accelerating universe. Annual Review of Astronomy and Astrophysics, 46, 385-432.
[28] Caldwell, R. R., & Kamionkowski, M. (2009). The physics of cosmic acceleration. Annual Review of Nuclear and Particle Science, 59, 397-429.
[29] Goobar, A., & Leibundgut, B. (2011). Supernova cosmology: Legacy and future. Annual Review of Nuclear and Particle Science, 61, 251-279.