Observing the Next Nearby Supernova

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Proprietary Period: 0

Cycle 12 primary orbits: 33

Abstract

If a neutrino-producing supernova (SN) explodes in the Galaxy, the Large or Small Magellanic Clouds, or a close member of the Local Group, it will be detected first by operating neutrino experiments: Super-Kamiokande, SNO, MACRO, and AMANDA. The supernova neutrino early warning system will notify photon observers throughout the world within an hour of the neutrino detection. Although the per-year probability of observing a neutrino SN (within 100 kpc) is small, the detection would be importantly scientifically and of widespread interest. The optical counterpart could be much brighter than normal extragalactic SNe. A bright nearby supernova detected by other means would also be of great interest and should activate this proposal. We propose unique STIS ultraviolet spectroscopic observations to measure the principal metallic lines, and hence the composition, velocity, and physical state, of the outermost atmosphere of the exploded star. In addition, we propose narrow- and broad-band imaging to provide information about the stellar environment and early morphology unobtainable from the ground. The data, especially images, will be valuable for public outreach and will be released immediately by NASA.

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CoI	Prof. Mark Vagins	University of California - Irvine	USA/CA

Number of investigators: 17

Observing Summary:

Target	RA	DEC	V	Config/Mode/SEs	Flags	Orbits
GALSNE-ASAP	00 00 0.00	+00 00 0.00	0.0	STIS/CCD/Spectroscopic/G230LB, G230MB, G430M, G750M	TOO	3
GALSNE-ASAP	00 00 0.00	+00 00 0.00	0.0	ACS/HRC/Imaging/F250W, F330W, F435W, F658N, F814W, F502N	TOO	1
GALSNE-ASAP	00 00 0.00	+00 00 0.00	0.0	ACS/WFC/Imaging/F435W, F555W, F625W, F814W, F658N, F502N	TOO	2
GALSNE-ASAP	00 00 0.00	+00 00 0.00	0.0	NIC1/Imaging/F108N, F110W, F160W, POL0S, POL120S, POL240S	TOO	1

Target	RA	DEC	V	Config/Mode/SEs	Flags	Orbits
GALSNE-ASAP	00 00 0.00	+00 00 0.00	0.0	ACS/HRC/Imaging/CORON/F502N, F658N, F330W, F475W, F606W, F814W	TOO	1
GALSNE-visit2	00 00 0.00	+00 00 0.00	0.0	STIS/CCD/Spectroscopic/G230LB, G230MB, G430M, G750M	TOO	3
GALSNE-1week	00 00 0.00	+00 00 0.00	0.0	STIS/FUV-MAMA/Spectroscopic/E140H, E140M, G140L, G140M	TOO	2
GALSNE-1week	00 00 0.00	+00 00 0.00	0.0	STIS/NUV-MAMA/Spectroscopic/E230H, E230M, G230L, G230M	TOO	2
GALSNE-1week	00 00 0.00	+00 00 0.00	0.0	STIS/CCD/Spectroscopic/G230LB, G230MB, G430M, G750M	TOO	2
GALSNE-1week	00 00 0.00	+00 00 0.00	0.0	ACS/HRC/Imaging/F220W, F330W, F435W, F814W, F658N, F660N	TOO	1
GALSNE-1week	00 00 0.00	+00 00 0.00	0.0	ACS/HRC/Imaging/CORON/F220W, F330W, F435W, F814W, F658N, F660N	TOO	0
GALSNE-1month	00 00 0.00	+00 00 0.00	0.0	STIS/FUV-MAMA/Spectroscopic/E140H, E140M, G140L, G140M		1
GALSNE-1month	00 00 0.00	+00 00 0.00	0.0	STIS/NUV-MAMA/Spectroscopic/E230M, G230L, G230M		1
GALSNE-1month	00 00 0.00	+00 00 0.00	0.0	STIS/CCD/Spectroscopic/G230MB, G230LB, G430M, G750M, G430L		1
GALSNE-1month	00 00 0.00	+00 00 0.00	0.0	ACS/HRC/Imaging/F220W, F330W, F502N, F658N, F555W, F814W		1
GALSNE-1month	00 00 0.00	+00 00 0.00	0.0	NIC1/Imaging/F108N, F110W, F160W, POL0S, POL120S, POL240S		1
GALSNE-1month	00 00 0.00	+00 00 0.00	0.0	ACS/HRC/Imaging/CORON/F220W, F555W, F658N, F502N, F555W, F814W		0
GALSNE-6months	00 00 0.00	+00 00 0.00	0.0	STIS/FUV-MAMA/Spectroscopic/E140H, E140M, G140L, G140M		1
GALSNE-6months	00 00 0.00	+00 00 0.00	0.0	STIS/NUV-MAMA/Spectroscopic/E230M, G230L, G230M		1
GALSNE-6months	00 00 0.00	+00 00 0.00	0.0	STIS/CCD/Spectroscopic/G230LB, G230MB, G430L, G430M, G750M		1
GALSNE-6months	00 00 0.00	+00 00 0.00	0.0	ACS/HRC/Imaging/F220W, F330W, F555W, F658N, F502N, F814W		1
GALSNE-6months	00 00 0.00	+00 00 0.00	0.0	ACS/HRC/Imaging/CORON/F220W, F330W, F555W, F658N, F502N, F814W		0

Target	RA	DEC	V	Config/Mode/SEs	Flags	Orbits
GALSNE-6months	00 00 0.00	+00 00 0.00	0.0	NIC1/Imaging/F108N, F110W, F160W, POL0S, POL120S, POL240S		1
GALSNE-1year	00 00 0.00	+00 00 0.00	0.0	STIS/FUV-MAMA/Spectroscopic/E140H, E140M, G140L, G140M		1
GALSNE-1year	00 00 0.00	+00 00 0.00	0.0	STIS/CCD/Spectroscopic/G230LB, G230MB, G430L, G430M, G750M		1
GALSNE-1year	00 00 0.00	+00 00 0.00	0.0	STIS/NUV-MAMA/Spectroscopic/G230L, G230M, E230M		1
GALSNE-1year	00 00 0.00	+00 00 0.00	0.0	NIC1/Imaging/F108N, F110W, F160W, POL0S, POL120S, POL240S		1
GALSNE-1year	00 00 0.00	+00 00 0.00	0.0	ACS/HRC/Imaging/F220W, F330W, F435W, F814W, F658N, F502N		1
GALSNE-1year	00 00 0.00	+00 00 0.00	0.0	ACS/HRC/Imaging/CORON/F220W, F330W, F435W, F814W, F658N, F502N		0
				Total orbit request:		33

Scientific Justification

SN 1987A may have been the most intensively investigated astronomical event of the past century, as telescopes of all types focused on the debris of the explosion. Two detectors, Kamiokande and IMB, detected 20 neutrino events [5, 8, 10]. Much was learned from SN1987A, both about the astrophysics of SN explosions and about the physics of neutrinos [1, 3].

In 1987, the neutrino signal was extracted after the first optical observation. The situation will be different next time. Neutrino physicists are now prepared and have much bigger detectors. The neutrino signal emerges promptly from a SN's core, so the detection of the neutrino burst from the next SN in the Galaxy, the Large or Small Magellanic Clouds, or nearby in the Local Group (including Sculptor, Carina, Sextans, Ursa Minor, Draco, and Sagittarius) will be the earliest signal of a stellar collapse. The neutrino signal will provide an early warning for astronomers [12] and a crude direction good to perhaps 5^0 [4]. A growing consortium of neutrino experiments is prepared to notify amateur and professional astronomers, who will quickly locate the precise optical counterpart.

We propose observations of Galactic or nearby SN which only *HST* can perform. For this proposal, 'nearby' means within 100 kpc, the range of the neutrino detectors.

Will there be a detected nearby SN that *HST* can observe in Cycle 12 ? Probably not. The rate of neutrino explosions in the Galaxy has been estimated to lie somewhere between one every 10 yr [2] (based on the death rate of massive stars in the Bahcall-Soneira Galaxy model) to one per 300 yr (based on the historical record of 6 naked-eye SN or 'guest stars' in the last two millenia, most of which were brighter than -3 mag). Rate estimates based on radio SN remnants range from one per 20 to one per 150 yr [14]. The conservative probability range, for a bright, nearby SN in Cycle 12, is 0.3 to 10 percent.

Despite the low rates, the scientific rewards of observing a nearby SN with *HST* are so great that we feel it is essential to prepare in advance. Because the optical counterparts may be extremely bright, it is necessary to make special plans (different from the SINS program for more distant galaxies) for observing with *HST*. Special care is necessary in planning the observations since the possible flux range covers more than a factor of 10^8, from $V = -6$ to $V = +15$.

There will be no proprietary period for data obtained with this proposal. We will work with STScI to make the data publicly available in a convenient form, for both scientists and the interested public, as soon as possible.

1 Neutrinos from supernovae

When the core of a massive star collapses at the end of its life, less than 1 percent of the gravitational binding energy of the neutron star is expected to be released in the form of optically visible radiation and kinetic energy of the expanding remnant. The remainder is radiated in neutrinos, of which ~ 1 percent will be electron neutrinos from an initial "neutronization" burst and the remaining 99 percent will be neutrinos from the later cooling reactions, distributed evenly among the flavors. Average neutrino energies are expected to be about 12 MeV for ν_e, 15 MeV for $\bar{\nu}_e$, and 18 MeV for all other flavors. The neutrinos are emitted over a total timescale of tens of seconds, with about half emitted during the first 1-2 s, and with the spectrum softening over time. References [3, 6] summarize the expected neutrino signal. Table 1 summarizes the detectors with SN neutrino detection capability. In addition, gravitational wave detectors such as LIGO may record

Detector	Type	Mass (kton)	Location	# of events @10 kpc	Status
Super-K	H_2O Č	32	Japan	4400	online
MACRO	scint.	0.6	Italy	150	online
LVD	scint.	0.7	Italy	170	online
SNO	H_2O, D_2O	1.7 1	Canada	350 430	running
AMANDA	long string	$\sim$ 2 per PMT	Antarctica	N/A	running
Baksan	scint.	0.33	Russia	70	running
BOREXINO	scint.	1.3	Italy	$\sim$200	2001
KamLAND	scint.	1	Japan	300	2001
OMNIS	high Z	$\sim 10^5$	USA	$\sim$1000	2001

Table 1: Some specific SN neutrino detectors. All of these detectors are expected to be connected to the SNEWS eventually. A status of "online" means "running and also already connected to SNEWS."

prompt signals from nearby asymmetric stellar collapses.

2 The Neutrino Coincidence Network

Several of the neutrino detectors already have stellar collapse monitor software running; this software searches the data stream in real time for evidence of neutrino bursts. The Supernova Neutrino Early Warning System (SNEWS), a prototype inter-experiment network to monitor for coincidences and coordinate burst alarms, has been running since May 1998 [7]. Currently SNEWS is capable of disseminating alerts within one hour or less; further improvement down to several minutes may be possible in the near future. Table 1 lists the detectors which are or are going to be on SNEWS; three are connected and SNO is expected to join within months.

If the SN is distant and only weak signals are recorded, a coincidence between signals from different detectors effectively increases the sensitivity, by allowing a reduction in the alarm threshold for a given false alarm rate. An average rate of false alarms of less than 1 per century is practical for two experiments in coincidence. By requiring three or more experiments in coincidence, the false alarm rate can be made completely negligible.

How will we know where to point *HST*? The next nearby SN may be discovered by conventional optical observations, which will pinpoint the target. A neutrino signal from Super-Kamiokande, confirmed by information from other neutrino detectors, will provide an error box with a radius 5°. The SNEWS collaboration has established connections with other observing groups to make certain that alerts are sent out immediately to amateur and professional astronomers, including variable star observers and gamma-ray burst and SN search teams, so that the precise direction can be determined quickly.

3 HST Observations

Multi-epoch *HST* observations of a neutrino SN are necessary for ultraviolet (UV) spectroscopy and high resolution imaging. The spectroscopy will be used to determine the chemical composition and thermodynamic state of the fastest-moving material; this cannot be done from the ground because most of the strong metal lines appear in the UV. The imaging, besides producing exciting public outreach materials, will be used to explore the environment of the SN, where high spatial resolution is necessary for subtraction of the point source contribution to see the supernova's neighbors. A wide field image, constructed from ACS/WFC and ACS/HRC images will create an press release image of the bright supernova in context with its environment. We also are planning IR observations with NICMOS, to provide high resolution imaging in the IR, and also, if the supernova is extrememly reddened, NICMOS observations may be the only instrument which will be effective with *HST*.

Fairly low-resolution UV spectroscopy with the STIS CCD and FUV-MAMA will be used to measure lines from, e.g., C, N, O, S, Mg, Fe, all of which have strong absorption lines in the UV. The supernova spectroscopy does not need to be at high resolution because the lines will be broadened through expansion by 1000 to 30,000 $\mathrm{km\,s^{-1}}$. The strengths and shapes of these lines help determine the chemical composition and velocity structure of the supernova atmosphere. These abundances are crucial in understanding the late stages of stellar evolution and the role of SNe in creating and distributing metals in the interstellar medium. Medium and High (when possible) resolution observations will also be made to study the interstellar medium along the line of sight, and perhaps the circumstellar medium of the supernova.

The G230LB grating on the CCD and the G140L grating on the FUV-MAMA will provide spectroscopy with a resolution of $\sim 500\ \mathrm{km\,s^{-1}}$ over the entire spectral range from 1150 to 3100 Å. Because the SN will be bright, high signal-to-noise is easy to obtain. The only concern is saturation of the detectors, which can be prevented with the neutral-density filters and short exposure times. The graduated observing strategy designed to obtain safe high signal-to-noise STIS observations is explained in "Description of the Observations" below.

Data taken with ACS/WFC, ACS/HRC and NICMOS will provide high resolution images of the immediate environment of the SN, even when the SN is quite bright. If the SN is significantly brighter than $V = 6$ mag, it would saturate and bleed even at the shortest exposure times, reducing the science value of the images. The recent ACS/HRC images of 3c 273 have shown the value of using the coronagraph on ACS/HRC to image the faint surrounding near bright point sources, in this case revealing the host galaxy of the quasar. Images will be taken in broad-band and narrow-band filters, and sometimes with the coronagraph, when possible (see "Descriptions of the Observations," below), with narrow-band filters centered on the lines expected to be strong in the nebula.

The imaging provides a measurement of the environment of the SN and therefore information about the stellar population from which the SN progenitor is drawn. These images will probe closer to the SN itself than any ground-based images because of *HST* 's angular resolution. Early-time, high-resolution images may be essential for understanding if the progenitor star is in, e.g., an H II region or a dusty environment. Images will make it possible to measure motions of the ejecta, with the images taken early providing a zeroth epoch baseline for comparison with later images. If the ejecta expand radially at $10^4\ \mathrm{km\,s^{-1}}$, the apparent diameter increases at 0.4 arcsec $\mathrm{yr^{-1}}$ at 10 kpc.

If the SN is subject to strong extinction in the optical or in a crowded field of foreground stars, the *HST* images may provide the only reliable data for photometry.

In order to obtain the unique and important ultraviolet data for the next nearby supernova, we request that the first visit be scheduled with the fast (24-hour) response and be subject to the fixed overhead charge. The observing sequence will then continue with a second visit to be taken during that first week. Then, two visits in the second week after discovery, followed by visits at first+1 month, first +6 months, and first+1 year.

References

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Description of the Observations

The first observations will be imaging, if possible, then spectra, both for studying the supernova and its circumstellar environment and for the interstellar medium along the line of sight. Wherever possible, we will take pictures that can be released quickly by NASA and which will help provide a public context for this unique event. We have worked closely with our cycle 9, 10 and 11 contact scientist and have run extensive tests with the STIS ETC to construct a safe observing plan for phase II.

We have detailed plans for the first two weeks of STIS observations, depending upon the observed optical magnitude. We have used dereddened IUE UV spectra of SN1987A, SN 1993J and a T 12000 degree blackbody (E(B-V)=0) as inputs to the STIS exposure calculator to produce safe STIS/MAMA exposures with low dispersion (G140L) and higher dispersion gratings (G140M,E140M) for the second week of observations after discovery. Special care had to be taken in evaluating the STIS/MAMA observations in the ultraviolet. For details, we refer the energetic reviewer to the STScI proposal archive for ID9429, PI Bahcall.

Imaging plan:

In the first visit, ACS/WFC observations will be taken to create a spectacular true color images of the supernova and its surroundings. We will also use ACS/HRC and NICMOS with various filters, including some with the coronagraph for a higher resolution images. If the supernova is very bright, WFPC2 may the best to create the wide field image. WFPC2 can be used in the same amount of time to take a series of images on and off target. Short exposures on the supernova and long exposures off target to get the fully beauty of the field, can be mosaiced togethor. This scenario will create a wide field picture for press, to show the bright supernova in context with it's neighborhood.

Further photometric imaging (1 orbit each) will be done once the second week, then at +1 month, +6 months and +1 year. The exact details of these observations will most likely change depending on the exact target brightness and distance.

Spectra plan:

The spectra plan is broken up into three sections. What can be done safely the first week ?, What should be done the second week ?, and thirdly, What are the best continuing UV spectral observations ?

During the first week we will only use the STIS/CCD, except if the target is faint $V > 13$. Each visit is a series of exposures that will fit into a 2-4 orbit visit. Each STIS visit includes a combination of grating, neutral density filters, and exposure time to obtain a S/N ratio of 50 in each observation. If the UV flux is 10 times brighter the CCD will not saturate, and if the UV flux is 10 times dimmer we still get some signal.

As it happens, in any of the STIS combinations to get an exposure with S/N ratio of 50, either the observation can be done with a short exposure, or the exposure time becomes too large (> 2 orbits) and therefore are not used. With these short exposures the orbits can be efficiently packed with many different configurations. We considered all possible UV emission lines, ranked them in importance, then picked those configurations which covers the most important lines. In every case the low dispersion UV spectrum with G230LB can be obtained in the first visit.

The second visit in week one will be the exact same observation plus the next dimmer visit. If this object's UV flux fades like SN 1987A or SN 1993J, we'll still get a good measure of the UV spectrum.

During the second week we will make two more visits to observe the changing UV spectrum. By measuring the UV flux from the first STIS observation we will be able to determine the UV flux level for the observations in the far UV region (1100-1600A). This regime is very interesting, but requires known flux for safe observations.

A complete set of safe visits have been created to obtain a S/N ratio of 50, in the 1100-3500 spectral region. We used the STIS ETC with 12K BB (basically flat continuum in FUV) and normalized the flux at 1400A. For example: If we predict the flux will be 3E-12 @ 1400A, then we would use visit 61 whose exposures are set for 5E-12 @ 1400$\AA$. All STIS/MAMA visits are below a global count of 10,000 counts/sec and we never approach the limit of 75 counts per sec per pixel.

A repeat visit in week two will continue to monitor the changing UV spectrum. We have included, mostly to pack the orbits (but not to create additional orbits), optical gratings to observe any circumstellar interactions at high spatial resolution.

The spectra observations at +1 month, +6 month, and +1 year will be in the UV. The exact details will be depend on the flux and type of supernova. These phase II details can be written and entered into the schedule after the second week observations. We will use information from the earliest *HST* and groundbased observations to determine the observing details for the subsequent observations because the SN emission changes very rapidly as it cools, and because dust reddening is potentially of great importance in planning the observations.

Many of the UV modes for a very bright target will use unsupported STIS observing modes, whose calibration is best done after the initial supernova observations are made and we know which modes require calibration.

Special Requirements

The range of initial magnitudes covered by this proposal is $V = -6$ to $V = +15$. This enormous range required great care in constructing a program that passed all the safety checks. For details of an earlier embodiment of this program, see Cycle 11 proposal 9429, PI Bahcall. We are grateful to Dr. N. Walborn (STScI) for a thorough investigation of the safety issues.

The ultraviolet light decayed extremely rapidly for SN1987A, orders of magnitude within one week (see Pun et al. 1995, Fig. 12). Therefore, we request that the first visit be scheduled with the first 24-hour response time.

The estimated rate for visual SNe occurring in the Galaxy is somewhere between every 10 and 300 years. Thus the probability that this TOO proposal would be activated in Cycle 12 is small, ~ 0.3 to 10 percent. However, if a SN does go off in the Galaxy, or in a neighboring galaxy, it will be an historic opportunity for astronomy in general and *HST* in particular.

Coordinated Observations

This *HST* proposal may be unique in that it is coordinated with neutrino observations from Super-Kamiokande (for which Prof. Totsuka is spokesperson), SNO (for which Prof. McDonald is director), MACRO (for which Prof. Barish is spokesperson), and AMANDA (for which Prof. Barwick is the US Co-spokesperson). It is also coordinated with gravity-wave observations from LIGO (for which Prof. Barish is PI). SNEWS will notify amateur and professional astronomers around the world working in the optical, radio, and infrared. We have established arrangements with existing SNe and optical transient discovery teams (represented here by Profs. Filippenko, Kirshner and

Kulkarni) and amateur astronomy associations (represented here by Drs. Mattei, Robinson and Fienberg) to provide them with the available information as soon as cross checks have established with certainty that a nearby supernova has been detected. One or more of these teams will perform the precise localization of the SN upon which this proposal depends.

The process may be reversed if the next supernova detected within 100 kpc is a type SNIa. In this case, the initial discovery will probably be made by optical astronomers and afterwards the neutrino scientists will use the observed direction and approximate time of the explosion to search carefully for the possible existence of a weak neutrino signal from a SNIa.

Justify Duplications

There are no other previously accepted *HST* programs which propose to observe new Galactic or nearby (within 100 kpc) SNe. An earlier version of the program was approved in Cycle 8 as DD/GO 8404, Cycle 9 GO 8646, Cycle 10 9108, and Cycle 11 9429 PI Bahcall.

The extreme range of possible brightnesses considered here for nearby SNe distinguishes this proposal from the SINS program to observe supernova in more distant galaxies.

Previous Related HST Programs

The PI's accepted *HST* proposals include 1018, 1019, 1022, 1025, 2424, 3034, 3040, 3042, 3068, 3088, 3092, 3111, 3156, 3157, 3158, 3159, 3220, 3221, 3222, 3227, 3418, 3981, 3992, 4000, 4017, 4027, 4028, 4044, 4117, 4118, 4581, 4799, 4817, 4818, 4939, 5081, 5099, 5225, 5343, 5603, 5664, 5687 5849, 8404, 8646, 9108, 9429. 8404, 8646, 9108, and 9429 are directly related to the current proposal.

The above proposals have resulted in many publications, including: ApJ 377 5 (1991); ApJ 386 L1 (1992); ApJ 387 56 (1992); ApJ 392 L1 (1992); ApJ 394 51 (1992); ApJ 397 68 (1992); PASP 104 678 (1992); AJ 103 1047 (1992); ApJ 398 495 (1992); AJ 104 959 (1992); ApJS 87 1 (1993); ApJS 87 45 (1993); ApJ 400 L51 (1992); ApJ 402 69 (1993); ApJ 405 491 (l993); AJ 104 1790 (1992); ApJS 88 53 (1993); ApJ 413 116 (1993); ApJ 409 28 (1993); ApJ 420 110 (1994); AJ 106 1 (1993); ApJ 441 200 (1995); ApJ 457 19 (1996); AJ 107 1745 (1994); ApJ 444 64 (1995); ApJ 436 33 (1994); PASP 106 646 (1994); AJ 108 1786 (1994); ApJ 435 L11 (1994); ApJ 435 L51 (1994); ApJ 435 L59 (1994); ApJ 440 91 (1995); ApJS 99 1 (1995); ApJ 450 486 (1995); ApJ 452 L91 (1995); ApJ 465 759 (1996); ApJ 447 L1 (1995); ApJ 457 557 (1996); AJ 111 267 (1996); ApJ 468 469 (1996); ApJ 470 L11 (1996); ApJ 479 642 (1997); AJ 113 669 (1997); ApJ 503 798 (1998); ApJS 118 1 (1998); AJ 116 1757 (1998); ApJ 506 1 (1998); and ApJ 520 67 (1999). This list is incomplete.