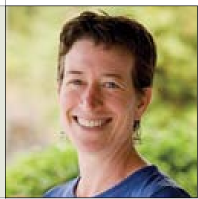

Nancy A. Levenson

Science Highlights

From standard candles to the serendipitous use of one of the most distant known supernovae to study the interstellar medium in very distant galaxies, learn about four of Gemini's most recent contributions to the understanding of our universe.

The Best Standard Candle for Cosmology

Exploding stars offer some of the most precise measurements of cosmic distances. Astronomers have long used observations of these supernovae at visible wavelengths for this purpose and they provide the basis for the 2011 Nobel Prize in Physics. Supernovae do have some intrinsic differences in visible light, however, so the observations must be corrected; that is, to standardize the candles (to the same absolute luminosity). Visible light also suffers from the complication of attenuation by dust anywhere along the line-of-sight, from the supernova's host galaxy to our vantage point in the Milky Way.

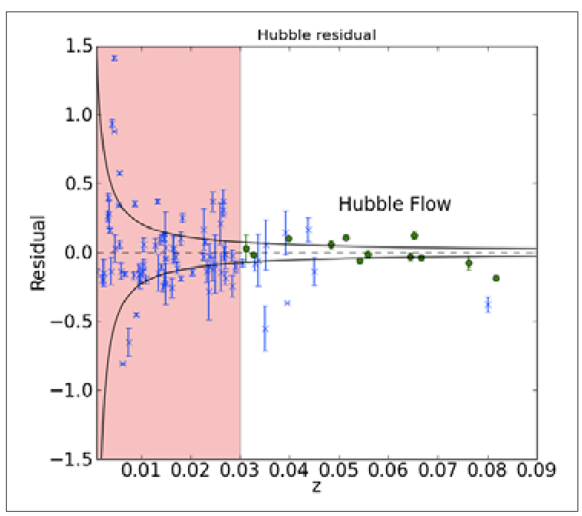

Figure 1.
The residual Hubble diagram for supernovae observed in the H band (green), compared with previous NIR samples (blue). The deviation of each measurement from the overall mean is plotted against redshift, z, which indicates distance.

In contrast, at near-infrared wavelengths, Type Ia supernovae serve as the best "standard candle" for these determinations. As Rob Barone-Nugent (University of Melbourne, Australia) and colleagues show in the *Monthly Notices of the Royal Astronomical Society*, Type Ia supernovae are intrinsically more consistent in their peak luminosity when viewed in the near-infrared (NIR), so they do not require these corrections. Because of this characteristic, the team can measure cosmological distances to an accuracy of 5 percent (Barone-Nugent *et al., Monthly Notices of the Royal Astronomical Society*, **425**: 1007, 2012). Such precise mea-

Figure 2.
Microwave (orange), optical (red, green, blue), and ultraviolet (blue) image of Phoenix Cluster. Image courtesy of the Chandra X-ray Observatory.

surements are essential to the study of the expansion history of the universe and hence to constrain the nature of dark energy.

The supernovae used in the study, discovered with the Palomar Transient Factory, were confirmed as ordinary Type Ia supernovae by subsequent spectroscopy and by using the Near-Infrared Imager and Spectrometer (NIRI) on the Gemini North telescope to follow the characteristic fading of the NIR emission and determine the peak brightness.

One further important selection criterion was to restrict the study to supernovae at distances large enough so the overall expansion of the universe (the Hubble flow) determines the motion of their host galaxies, independent of local peculiar motions; *i.e.*, redshifts $0.03 < z < 0.09$ (Figure 1). While earlier work had already indicated the greater uniformity of supernova emission in the NIR, this is the first large study to obtain high-quality measurements of more distant supernovae. Although these observations are more difficult because the distant supernovae appear fainter, this avoids the complication of local motions and results in the most precise known standard candle for cosmological measurements.

Beginning to Solve the Cooling Flow Problem

Clusters of galaxies are full of hot gas that emits copious X-ray radiation. This emission should lead to a "cooling flow," whereby cooling material sinks to the dense center of the cluster. In turn, we expect this inflowing reservoir of relatively cool gas to stimulate star formation in the galaxy located at the cluster's core, rather than result in runaway cooling of the cluster gas. The problem, until now, is that observations of such central galaxies have revealed them to be quiescent, showing little evidence for ongoing star formation.

Michael McDonald (Massachusetts Institute of Technology) and colleagues have now detected the first evidence for significant cooling-flow-induced star formation in a central cluster galaxy (McDonald *et al.*, 2012 *Nature*, **488:** 349). The cluster itself, designated SPT-CLJ2344-4243, was detected with the South Pole Telescope. Follow-up spectra obtained using the Gemini Multi-Object Spectrograph (GMOS) at Gemini South provided some of the first hints that the central galaxy was unlike the red, well-formed elliptical galaxies typical of cluster cores. The researchers also used additional measurements of other cluster members to determine the baseline redshift ($z = 0.6$) for comparison of other observations.

The more complete analysis of the so-called "Phoenix Cluster" and its central galaxy (Figure 2) emerges from observations spanning X-ray to far-infrared energies. The central galaxy possesses an active nucleus in addition to star formation at a rate of 740 M_{Sun}/year. The star formation rate is still too low to prevent runaway cooling, given the measured cooling flow rate of 3800 M_{Sun}/year, suggesting that the feedback mechanism is not fully established in this example. Nonetheless, the high star formation rate points to this mode of star formation from intracluster gas as an important element of galaxy formation, in addition to galaxy mergers, which had been widely considered previously. The team continues to use observations with GMOS-S to complement the South Pole Telescope survey, so more exciting results should be forthcoming.

Populating the "Brown Dwarf Desert"

Formation of multiple stellar systems tends to favor objects of roughly the same mass, whereas planets tend to be much less massive than their central stars. The result is a "desert" in the population distribution, with few brown dwarfs as companions of stars, or equivalently, few systems showing mass ratios of 1-10 percent. Markus Janson (Princeton University) and colleagues report finding several more candidates in this sparse region (*The Astrophysical Journal*, **758**: L2, 2012), but raise new questions at the same time.

The newly-identified targets have masses in the range of 45-95 times the mass of Jupiter. They also lie at relatively large distances from their central stars (angular separations of 0.35-1.83 arcseconds, which corresponds to about 40-200 astronomical units). Thus, mass alone does not distinguish their formation history, and the large separations open additional pathways. Their origin may be similar to those of standard stellar systems (formation in common collapse of dense cloud cores), planets (mass build-up through accretion), or none of the above (through capture of free-floating external bodies).

The team obtained the high-angular-resolution images of the targets in the young (10-12 million year) Scorpius-Centaurus (Sco-Cen) stellar association using the Near-Infrared Coronagraphic Imager on Gemini South, with multiple observational epochs to demonstrate genuine association through common proper motion (Figure 3). Additional spectroscopy using ESO's Very Large Telescope confirmed their classification.

Probing the Distant Interstellar Medium

The emission of material between the stars of distant galaxies is often too feeble to detect directly, so a useful technique is to observe the absorbing effect of this material on the light from a background source. Typically, distant quasars and gamma-ray bursts (GRBs) have effectively served as these sources. Now, Edo Berger (Harvard-Smithsonian Center for Astrophysics) and colleagues demonstrate the utility of extremely luminous supernovae for this work, using PS1-11bam, one of the most distant confirmed supernovae, as their subject (*The Astrophysical Journal Letters*, **755**: L29, 2012). In addition to expanding the number of galaxies in the early universe that may be probed, the new class of sources hints at differences among the galaxy environments of supernovae, GRBs, and ordinary star formation.

PS1-11bam was discovered in the Pan-STARRS1 imaging survey, with spectroscopy showing characteristic features of ultraluminous supernovae, likely due to the core collapse of a massive star. Subsequent observations using GMOS at Gemini North confirm that it is very distant, with redshift ($z = 1.566$). More importantly, galactic emission and narrow metal absorption lines appear at the same redshift, revealing the host galaxy's interstellar medium (Figure 4). The

Figure 3.
NICI images of three low-mass companions to stars in the Sco-Cen region. The first two are likely brown dwarfs, and the third is probably a very low-mass star.

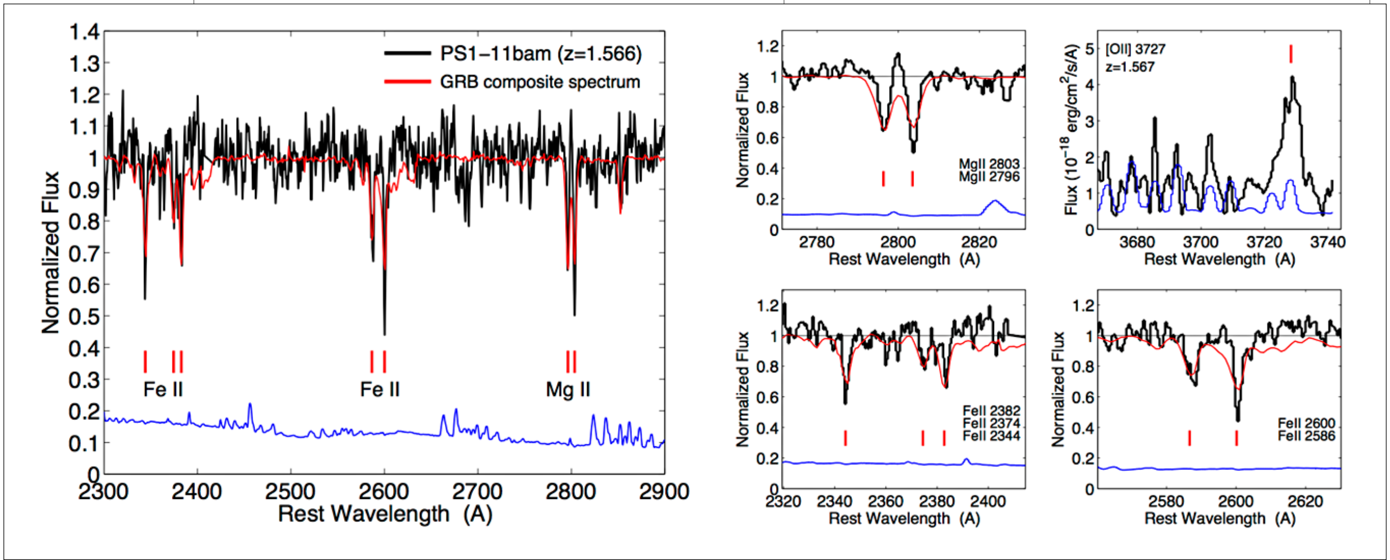

Figure 4.
Left: *Portion of a Gemini spectrum of PS1-11bam containing several interstellar absorption features of Fe II and Mg II at z = 1.566 (black). The error spectrum is shown in blue, and for comparison, the composite GRB spectrum in red.* ***Right:*** *A zoom-in on the relevant Fe II and Mg II lines demonstrates the similarity to GRB absorption spectra. The host galaxy also appears in the emission of [O II] 3727.*

equivalent widths of Mg II and Fe II in this case are intermediate between typical observations of quasars (which tend to probe galaxy outskirts) and GRBs (which tend to probe the central regions of galaxies), and they are much lower than those of star-forming galaxies at the same redshift.

This first direct demonstration that ultraluminous supernovae can reveal distant galaxies suggests that the next generation of imaging surveys and spectroscopy from extremely large telescopes could be applied to galaxies in the earliest days of the universe.

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