Amateur, NOAO, HST, and Chandra Observers Team Up to Search for Supernova Progenitor

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A team of Arizona-based amateur astronomers, an NOAO observer at Kitt Peak National Observatory (KPNO), and users of the Hubble Space Telescope (HST) and the Chandra X-Ray Observatory have combined their efforts in search of a progenitor star for an unusual and potentially important supernova (SN). The supernova, of Type Ib, was discovered in the Arp 299 system of interacting galaxies.

The supernova was discovered by amateurs Jack Newton and Tim Puckett, during the course of their Puckett Observatory Supernova Search. Using automated telescopes in Georgia and Arizona, this team images about 800 galaxies every clear night. The new star was identified by Newton on the morning of 24 January 2010 when he blinked CCD frames taken the previous night with his 16-in telescope in Portal, AZ. The Puckett team promptly notified the community of the discovery through the Central Bureau for Astronomical Telegrams (Newton & Puckett 2010), and it was designated SN 2010O.

SN 2010O exploded in a spectacular pair of interacting galaxies, cataloged as NGC 3690, also called Arp 299. Due to its active star formation, Arp 299 is a "supernova factory," having produced eight known supernovae (SNe), including SN 2010O, in the past 20 years.

Supernovae come in two flavors, classified according to the absence (Type I) or presence (Type II) of hydrogen in their spectra. Type II SNe are now understood as being due to core collapses in massive young stars, usually occurring when the stars have evolved to become luminous red supergiants. Among the H-deficient Type I SNe, there are three subclasses: Ia (having Si II absorption), Ib (no Si II absorption, but He is present), and Ic (no Si II or He). Type Ia SNe are not associated with young stars and are believed to be white dwarfs in binaries that reach the Chandrasekhar limit and explode. However, the Type Ib and Type Ic SNe do appear to be core collapses, occurring in massive stars that have lost their H envelopes (and He in the Type Ic ones) before the explosion. Until recently, however, the observational evidence supporting this picture in the form of actual images of stars that then subsequently exploded as SNe was scant.

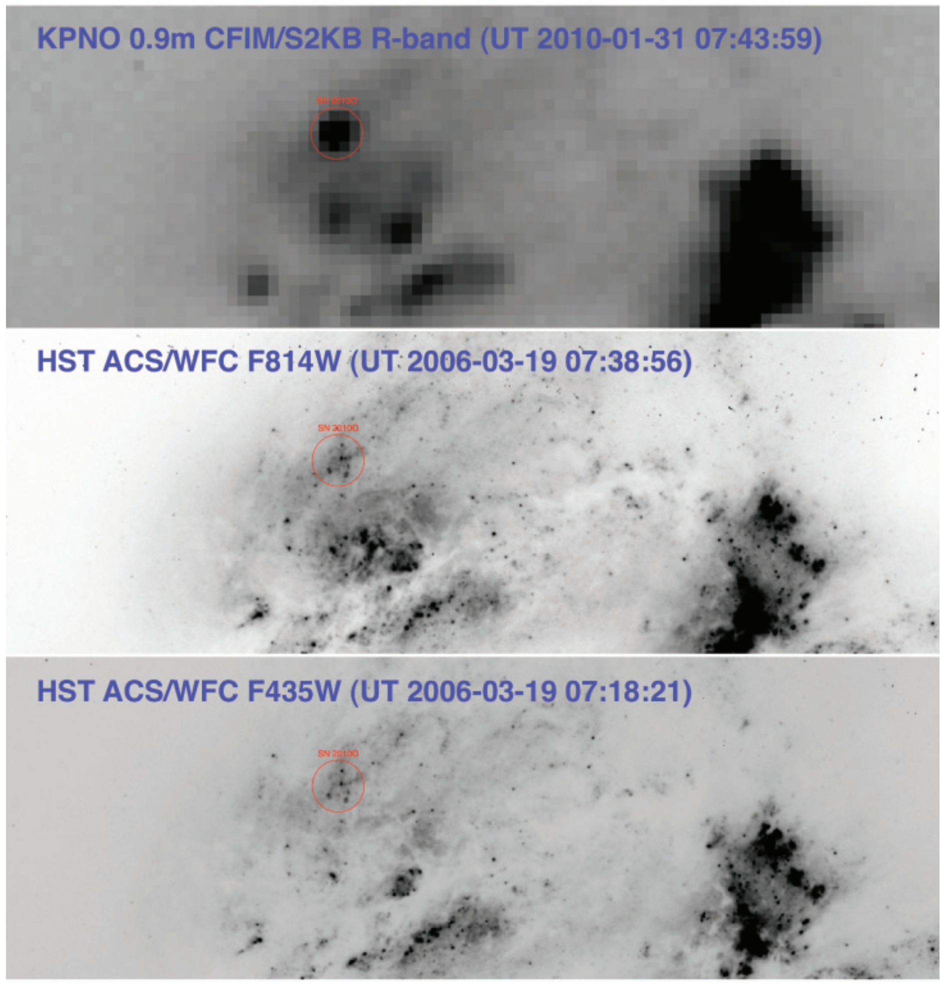

Figure 1: (Top) A portion of the KPNO image, with SN 2010O circled in red. The middle and bottom images are the pre-explosion HST frames, taken with the Advanced Camera for Surveys in 2006.

The situation has changed dramatically since the early 1990s, primarily due to the advent of HST high-resolution imaging and Hubble's ever-increasing archive of deep images of nearby galaxies. The current status of searches for SN progenitors has been reviewed by Smartt (2009). There are now enough detections of resolved progenitor stars in pre-explosion images to confirm unambiguously that most Type II SNe do in fact arise from red supergiants.

The situation is not so good for the H-deficient Type Ib and Type Ic SNe that occur in young populations. As summarized in Smartt's review,

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there are 10 Type Ib or Type Ic SNe that had pre-outburst deep images, but not one of them had a detected progenitor.

There are two main evolutionary scenarios to account for H-deficient core-collapse SNe: (1) they arise from massive Wolf-Rayet (WR) stars that have lost their H envelopes through stellar winds before the explosion occurred, or (2) they come from lower-mass stars that have lost their H through mass transfer in close binaries.

There is extensive pre-explosion imaging of Arp 299 available in the HST archive, ranging from the ultra-violet (UV) to the optical and near-infrared (IR). Moreover, the galaxy has been observed by the Chandra X-ray satellite before the SN outburst. After the discovery announcement for SN 2010O appeared, a team of astronomers using the Nordic Optical Telescope obtained spectra showing it to be of the relatively rare Type Ib (Mattila et al. 2010). This finding opened up the possibility of an unprecedented multi-wavelength search for a Type Ib progenitor, using the archival HST and Chandra data.

The first step is to locate the SN site as precisely as possible in the space-based images. This is not feasible with the amateur images, which do not have the necessary depth and resolution required for registration with HST frames. The team, therefore, used the WIYN 0.9-m telescope on Kitt Peak to obtain deeper CCD images, with the best ones being acquired by Katy Garmany on January 31.

Figure 1 (top) shows a portion of the KPNO image, with SN 2010O circled in red. The middle and bottom images are the pre-explosion HST frames, taken with the Advanced Camera for Surveys in 2006. The team was excited to see that a blue object, most probably a compact star cluster, lies very close to the SN position. Based on the UV/optical/IR spectral-energy distribution of the cluster, combined with theoretical models, Roeland van der Marel estimated the cluster's age to be 14 Myr, implying a turnoff mass of 14 M_{sun} (see Bond et al. 2010 for further details). Such a relatively low mass would favor the close-binary scenario, rather than a more massive WR progenitor. Further support of an interacting-binary origin comes from the Chandra pre-explosion observations, which reveal that there was a transient X-ray source located near the SN position in 2005, but not in 2001 (Nelemans et al. 2010).

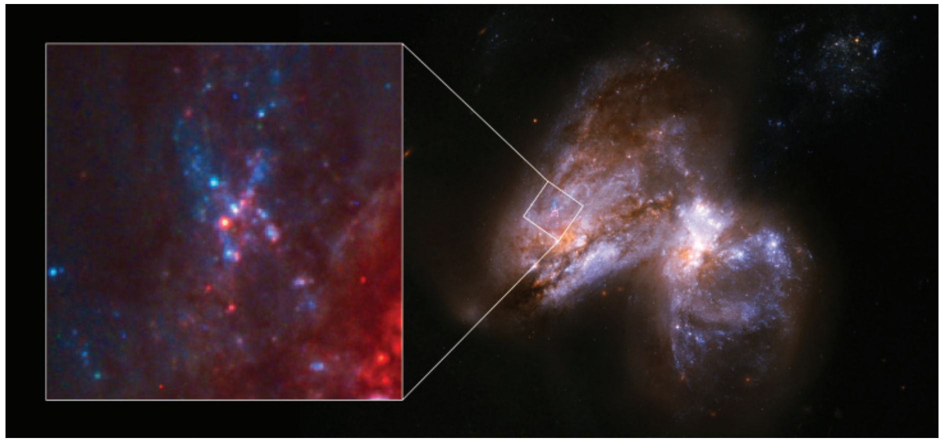

Figure 2: The image on the right-hand side shows the interacting galaxy pair Arp 299 (NGC 3690) in Ursa Major, as observed with the Hubble Space Telescope and Advanced Camera for Surveys in March 2006. Active star formation has been triggered by this galactic collision; eight supernovae, including SN 2010O, have been detected in Arp 299, which lies at a distance of about 50 Mpc (150 million light-years). The inset on the left is taken from images obtained with HST's new Wide Field Camera 3 on 24 June 2010; it shows SN 2010O as the bright, reddish star at the center. The angular size of the inset is 8 × 8 arcsec, or about 1.8 × 1.8 kpc at the distance of Arp 299. The supernova lies about 0.35 arcsec, or about 80 pc, southeast of the pair of compact young clusters described in the text. (Image credits: wide-angle view: NASA, ESA, the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration, and A. Evans; inset: NASA, ESA, and H. Bond.)

Based on these findings, the team proposed for new HST observations, which they hoped to obtain while the SN was still detectable. Images were acquired on 24 June 2010 using the new Wide Field Camera 3 (WFC3) and U, B, and I filters. Figure 2 shows a color rendition of our WFC3 images. SN 2010O is the bright, reddish star at the center. Lying about 0.35 arcsec to the northwest (upper right) is the compact cluster discussed above (which, at the higher resolution of WFC3, actually resolves into two clusters of contrasting colors).

Unfortunately, the SN proved not to lie at the location of the compact clusters, but it is still possible to say something about the progenitor based on the colors of the pre-outburst light at the true explosion site. The team is also investigating the precise location of the transient X-ray source to see whether we can argue that it was a progenitor binary. But in the meantime, our work demonstrates the power of combining the small telescopes of amateurs, the facilities at Kitt Peak, and the space-based observatories to shed new light on the explosions of massive stars.

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