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In principle, historical supernovae could still be visible as scattered-light echoes even centuries later [1, 2]. Searches for surface brightness variations using photographic plates have not recovered any echoes in the regions of historical Galactic supernovae [3]. Using differenced images, our SuperMACHO collaboration has discovered three faint new variable surface brightness complexes with high apparent proper motion pointing back to well-defined positions in the Large Magellanic Cloud (LMC). These correspond to three of the six smallest (and likely youngest) supernova remnants believed to be due to thermonuclear (Type Ia) supernovae [4]. A lower limit to the age of these remnants and echoes is 200 years given the lack of any reported LMC supernovae until 1987. The discovery of historical supernova echoes in the LMC suggests that similar echoes for Galactic supernovae such as Tycho, Kepler, Cas A, or SN1006 could be visible using standard image differencing techniques.

Over 100 years ago, a rapidly expanding nebula was photographed by Ritchey around Nova Persei 1901 [6] which was interpreted as a light echo from the nova explosion [7]. Later modelling of the physics of the scattering and the geometry that leads to apparent superluminal expansion confirmed this interpretation [8]. Since then, light echoes (whereby we mean a simple scattering echo rather than fluorescence or dust re-radiation) have been seen in the Galactic nova Sagittarii 1936 [9] and the eruptive variable V838 Monocerotis [10]. Echoes have also been observed from extragalactic supernovae, including SN 1991T [13, 14], 1993J [15, 16], 1998bu [17], with SN1987A being the most famous [11,12].

By simple scaling arguments based on the visibility of Nova Persei [1,2,18] light echoes from supernovae as old as a few hundred to a thousand years could be detected, especially if the illuminated dust cloud has regions of high dust densities, exceeding a particle concentration of 10^{-8} cm^{-3}[19]. More sophisticated models of scattered light echoes have been published [5,20,21] but a predicted late-time light echo surface brightness is not calculated.

The few targeted surveys searching for echoes from supernovae [3,22] and novae [23,24] have not been successful. However, these surveys did not use digital image subtraction techniques to remove the dense stellar and galactic backgrounds. Even the bright echoes near SN 1987A [12] at V~ 21.3 mag arcsec^{-2} are hard to detect relative to the dense stellar background of the Large Magellanic Cloud (LMC).

As part of the SuperMACHO microlensing survey, we have been monitoring the central portion of the LMC every other night for three months each year over the last four years (2001-2004) using the CTIO 4m Blanco telescope with the facility 8Kx8K MOSAIC imager. The survey covers 24 square degrees in 68 pointings in an approximate rectangle 3.7° by 6.6° aligned with the LMC bar. The images are taken through our custom "*VR*" filter (λ_c=625nm, $\Delta\lambda$=220nm) with exposure times of 60s to 200s, depending on the stellar densities. Using an automated pipeline, we subtract point spread function matched template images from the recent epoch image to search for variability. The resulting difference images are remarkably clean of the stellar background and are ideal for searching for variable objects. Our pipeline detects and catalogs the variable objects.

The echo of SN1987A shown in Figure 1 was trivial to recover with our pipeline. The *VR* surface brightness varies from 19.8 to our limit of ~24 mag per sq-arcsecond with one knot as bright as 19.3. The echo can be seen as far out as 7.3' from the explosion site. A quick inspection of the difference images showed no other obvious ring structures in the LMC. To search for very faint variable echoes, we have examined by eye all the variable objects discovered by our automatic pipeline. We found a number of very faint linear structures that had high proper motions with vector directions inconsistent with the 1987A echo. For each structure, we estimated a vector direction as shown in Figure 2. The vector was defined to be perpendicular to a linear fit to an echo segment, with the direction given by the proper motion. Typical proper motions range from 0.5-2.4” yr^{-1} which, at the angular scale of the LMC of 0.77 light-year $arcsec^{-1}$ makes many of these structures have apparent superluminal velocities. The surface brightness ranges from 22.3 down to our limit of detection.

Figure 3 shows the echo vectors extrapolated backward in time pointing to three well-defined positions as the origins of the echo complexes. We have estimated the position of the crossing point of the vectors by calculating the crossings of all pairs of vectors in each group excluding any echo pair with a separation of less than 10 arcseconds. The origins of the four echo complexes are listed in Table 1. The error in the centroid was estimated from the averaged vector crossings. Rather surprisingly, the three unidentified echo origins correspond within arcminutes of the positions of known supernova remnants (SNRs) [25]. Even more surprisingly, these three origins correspond to three of the six youngest SNRs [4] and these three are precisely the three that are classified as likely Type Ia events based on the X-ray emission spectra!

Given the positional match with young SNRs and the high apparent proper motions of the diffuse light, we conclude that the three echoes discovered in this work are likely to be scattered light echoes from Type Ia supernovae in the LMC. Planned spectroscopy of the brightest knots in the three echo complexes should allow us unambiguously to type the supernovae and confirm the classifications from the X-ray studies.

Supernova echoes can be used to measure the structure and nature of the interstellar medium [20, 28] and, in principle, can be used to measure geometric distances [27]. The geometric relationship is relatively straightforward, given by [30]

$z = \frac{D^2\alpha^2}{2ct} - \frac{ct}{2}$ where z is the distance from the light source (supernova) to the dust sheet, t is the time since peak brightness of the source, and alpha is the measured angular separation between the source and the observed echo. The speed of light c and the distance between Earth and the source D (effectively the distance to the LMC) are taken as known quantities. In the case of SN 1987A, where t is known, the echoes in Figure 1 can be used to map out the structure of the dust [30].

Without a date of explosion, we cannot estimate the distance of the scattering clouds surrounding the supernovae. A Type Ia SN would reach V~ −0.5 mag and would be the second or third brightest star in the southern sky for a few weeks. The sizes of these remnants provide lower limits to their ages of >300yrs (assuming an unrealistic constant shock velocity of 10,000 km s^{-1}) which means they predate the modern astronomical records in the southern hemisphere which started with the establishment of the Royal Observatory at the Cape in 1820. The best ages for these remnants from optical and X-ray observations are upper limits of <1000 to 1500 years [26]. If one can determine the distance z between the SN and the dust or between two dust sheets producing an echo arc (for example, either from correlation with the dust sheets of SN1987 or other observations, such as radio observations of HI gas), then one could in principle determine the dates of explosions of these SNe, which would provide tight constraints on the modelling and improve our understanding of these events

Also intriguing is the opportunity they provide for directly observing the spectral light from the historical supernovae themselves as Zwicky suggested in 1940 [29]. Precise image subtraction techniques on nearby galaxies and in our own Galaxy with modern digital images can reach much fainter surface brightness limits than the early photographic surveys and allow us to find echoes from supernovae up to 1000 years old. With the discovery of a bright echo knot, we could today take a spectrum of the Tycho, Kepler, SN1006, or Cas A supernova.

Style tag for received and accepted dates (omit if these are unknown).

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Figure 1. The light echoes from SN 1987A. The data, taken at the CTIO 4m Blanco telescope with the MOSAIC imager in the *VR* filter, were used to make this difference image with epoch 2004.97 minus 2001.95 data, representing 17.8 and 14.8 years after the explosion. The field is 13.8' by 18.4' with N up and E left. White represents flux enhancements in the 2004 image and black in

the 2001 image. Faint echo arcs can be seen as far out as 6.6' and 7.3' from the explosion site, or 0.9 and 1.1kpc in front of SN 1987A.

Figure 2. Example of new light echo in the LMC at RA, Dec=(05:16:06,-69:17:07, J2000), part of echo complex #2 in Table 1. Each panel is 80" on a side with N up and E to the left. Panel 1 (upper left) shows the unsubtracted (template) image which includes the cluster Hodge 243. Panel 2 (upper right) shows how cleanly the field subtracts with data taken 50d earlier. The next three panels show the echo motion 1, 2, and 3 years after the template date. White represents positive flux in the present epoch image and black in the template image. The vector motions are plotted in Panel 6 (lower right). Each echo is fit with a straight line (red). The apparent proper motion is given by the yellow vector and extrapolated backwards (blue). The size of the yellow vector is proportional to the length of the echo segment fit. Saturated stars are masked out with grey circles. A number of faint variable stars appear as black or white spots.

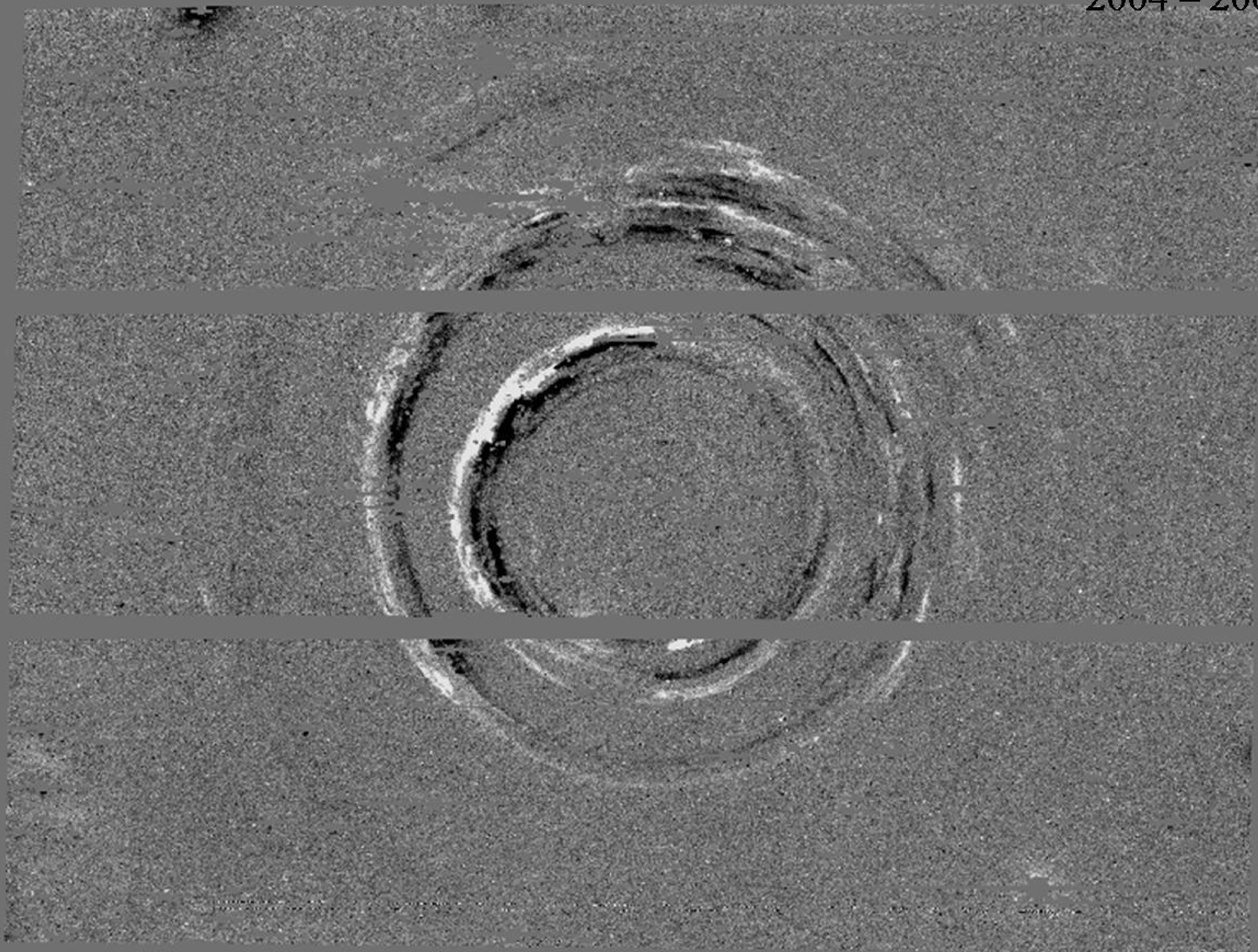
Figure 3. A plot of the light echo vectors in the LMC. The vectors have the same meaning as in Figure 2. The centres of the echo complexes are indicated by yellow circles. The lengths of the yellow vectors are 100x the length of the echo arc. The source on the left marked with a star is SN1987A. The green circles are the location of historical novae, and the red circles are the supernova remnant locations [25]. Evidently, the three unknown echo complexes point to three catalogued supernova remnants.

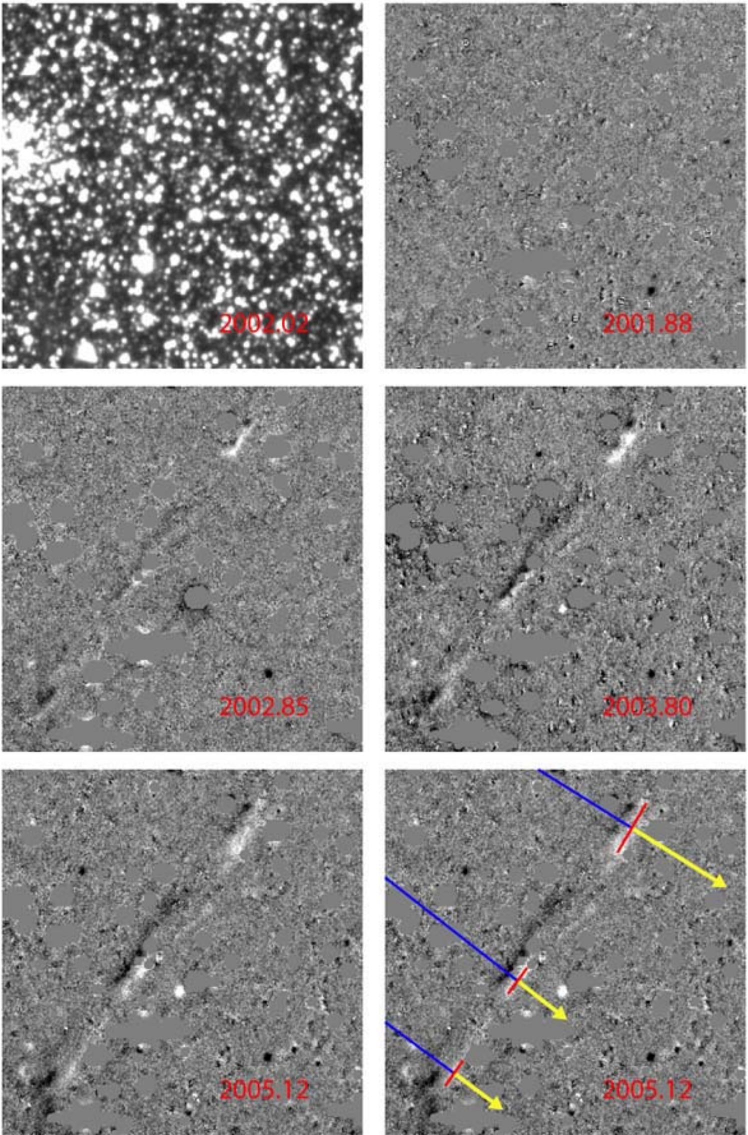
Table 1: Positions of Supernova Echo Origins in the LMC

Echo complex	RA	dec	position error δr	SNR name

1	05:35:30	-69:16	0.1	0.2	SN1987A
2	05:19:14	-69:04	1	2.5	0519-69.0
3	05:11:17	-67:31	1	10.0	0509-67.5
4	05:09:19	-68:42	2	2.3	0509-68.7 (N103B)

Position errors, based on the intersection of the echo vectors, are given in arcminutes. δr, the distance between the tabulated echo origin and SNR, is given in arcminutes. Coordinates are equinox J2000.


2004 – 2001


2002.02
2001.88
2002.85
2003.80
2005.12
2005.12