Light Echoes of Ancient Transients

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BACKGROUND

Our discovery of light echoes of Tycho's SN, Cas A, Eta Car's Great Eruption, and 3 SNRs in the LMC has given us the unique opportunity to directly observe the light of long gone ancient events. Furthermore, multiple light echoes allow us to see the same explosion from different directions, providing the only way to directly asymmetry. In favorable cases, we can even obtain a spectro-photometric time-series, e.g., for Eta Car's eruption and Tycho's SN. We also found a new application of light echoes: the distance measurement to these historic transients using recently available E(B-V) 3D map of Green et al.(2015).

SN Name	RA	Dec	Date	Dist. (kpc)	Type	Search Radius (deg)	Search Area (deg^2)	Discovery Telescope	Discovery Reference
Cas A	**23:23**	**+58:48**	**1680**	**3.4**	**SN IIb**	**5**	**66**	**KPNO4m, LaSilla3.6m**	**Rest+08, Krause+08**
Tycho	**00:25**	**+64:09**	**1572**	**2.3**	**Normal SN Ia**	**10**	**287**	**KPNO4m**	**Rest+08**
0509-67.5 (LMC)	**05:11**	**-67:31**	**~1600**	**50**	**Overlum. SN Ia**	**1**	**3**	**CTIO4m**	**Rest+05**
0519-69.0 (LMC)	**05:19**	**-69:04**	**~1400**	**50**	**SN Ia**	**1**	**3**	**CTIO4m**	**Rest+05**
N103B (LMC)	**05:09**	**-68:42**	**~1000**	**50**	**SN Ia**	**1**	**3**	**CTIO4m**	**Rest+05**
Eta Car	**10:45**	**-59:41**	**~1840**	**2.4**	**Great Eruption**	**3**	**36**	**CTIO4m**	**Rest+12**
SN 1181	02:05	+64:49	1181	2.6	?	17	2400		
P Cygni	20:17	+38:02	1600	1.6	Great Eruption	31	3000		
Crab Nebula	05:34	+22:01	1054	1.9	SN II?	31	3000		
W49B	19:11	+09:06	1000	8.0	Core-collapse	6	113		
Kepler	17:30	-21:29	1604	2.9	Peculiar SN Ia?	7	140		
SN 1006	15:02	-42:06	1006	2.2	SN Ia	27	2300		
RCW 86	14:43	-62:28	0185	2.8	SN Ia/II?	43	6000		

Table 1: A list of ancient transients/remnants from the last 200 years in our Galaxy and the LMC. We have found light echoes for the first 6 in this list, and we are searching for light echoes from the other 7 transients/remnants.

The Search for New Light Echoes

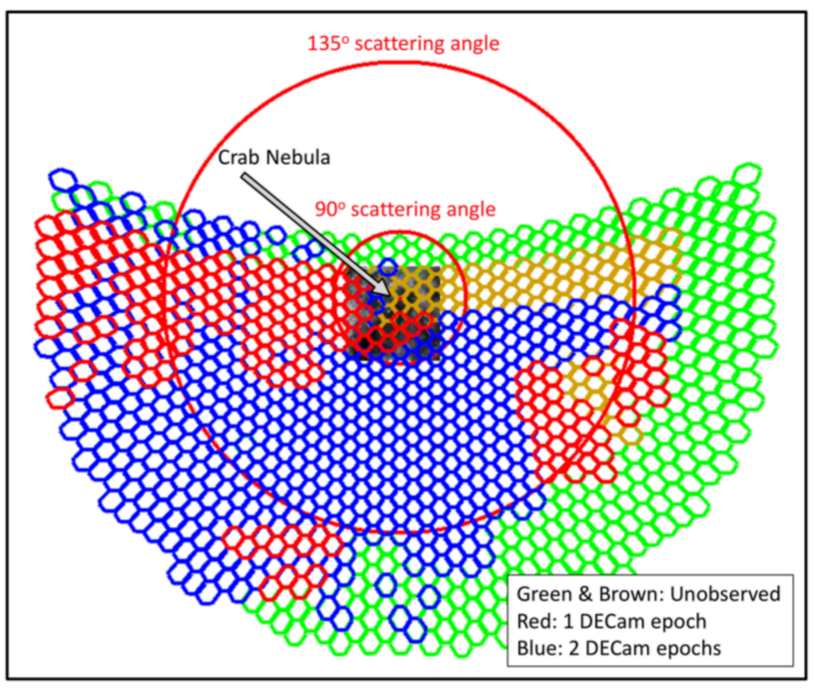

Fig. 1: Fields of the Crab Nebula observed with DECam on the CTIO 4m Blanco telescope. Green and brown hexagons are unobserved fields. Red (173 fields) and blue (472 fields) hexagons indicate fields that have one and two epochs, respectively. The big red circles indicate 90 degree and 135 degree scattering angles.

- In previous years, we found light echoes of Cas A, Tycho, 3 SNe in the LMC, and Eta Car (see Table 1).
- Remaining 7 targets have large search areas.
- We use DECam (FOV 3 deg^2) for our search.
- Focus on areas w/ scattering angle <135 deg.
- We have covered ~5000 deg^2, e.g, 1500 deg^2 south of the Crab Nebula (see Fig. 1).
- Reductions are ongoing. We have candidate SN echoes (Fig. 2), but no confirmation yet.

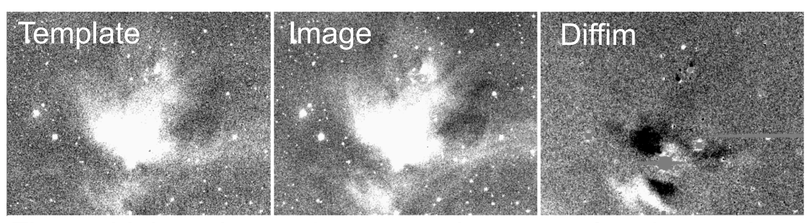

Fig. 2: Light echoes close to a dusty star-forming region. Follow-up observations will determine if these are light echoes of a SN or the close-by bright star.

Exceptionally Fast Ejecta in Eta Car's Great Eruption

- Light Echoes provide spectrophotometric time series of Eta Car's Great Eruption (Rest+12, Prieto+14. Smith+18a,b).
- Hα profile from narrow line to a broader and asymmetric line with P Cyg absorption (see Fig. 3).
- Hα develops extremely broad emission wings out to −10,000 km/s on the blue side of the line, and 20,000 km/s to the red.
- These SN-like speeds indicate explosive energy source rather than a stellar wind cause the Great Eruption (Smith+18a,b).

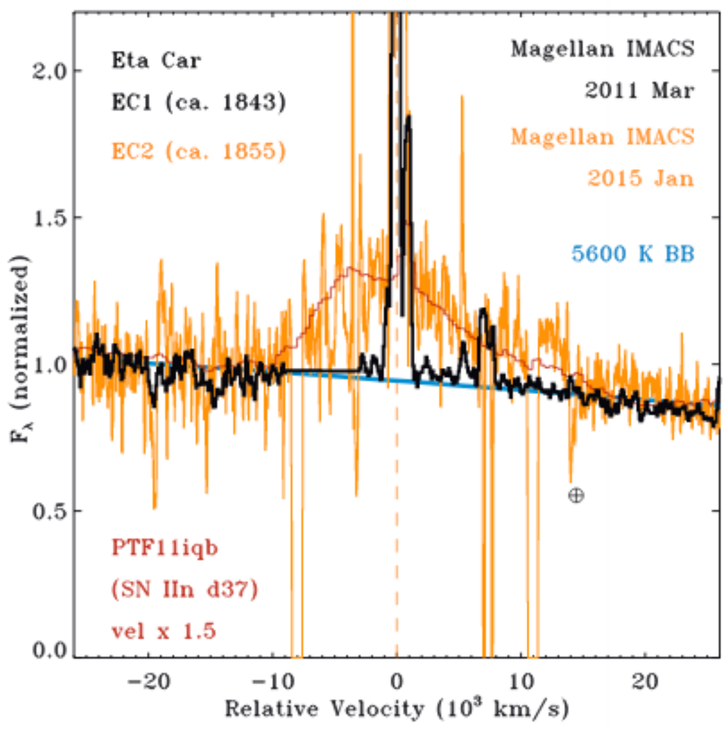

Fig. 3: Red: light echo spectra corresponding to late times in the plateau phase of Eta Car's Great Eruption, showing very broad Halpha line wings (Smith+18a,b). Black: light spectrum of a different echo that traces the peak of the Great Eruption (Rest+12, Prieto+14), which does not show broad lines. Therefore the fast material seems to have appeared at late phases in the eruption. Merely as an illustrative comparison, we also show the broad component in the TypeIIn/II-L core-collapse supernova PTF11iqb from Smith et al. (2015), with velocities multiplied by 1.5.

Mystery Light Echoes in the LMC

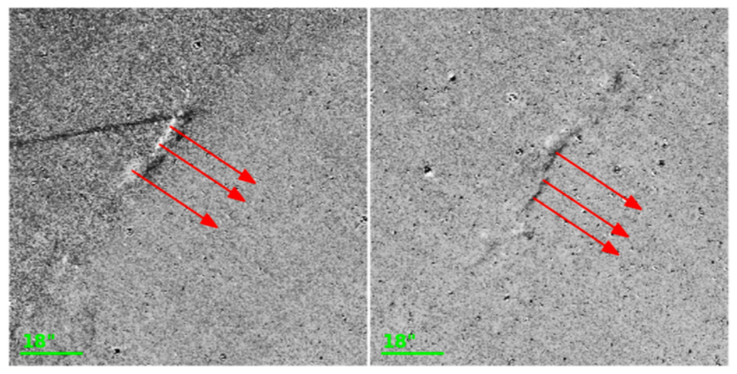

Fig. 4: The two panels show two light echo arclets discovered in an HST ACS difference image from the LMC 30 Dor region. Vector arrows point toward the source origin (opposite to their proper motion).

- We discovered two light echoes in the LMC 30 Dor regions (Fig. 4, Johnson+19).
- Similar surface brightness, size, apparent motion to the other light echoes of ancient SN in the LMC (Rest+05,08).
- 5 SNR are consistent with light echo apparent motion, but are too old (Fig. 5)!
- **Light echoes could come from a yet undiscovered SN remnant!**

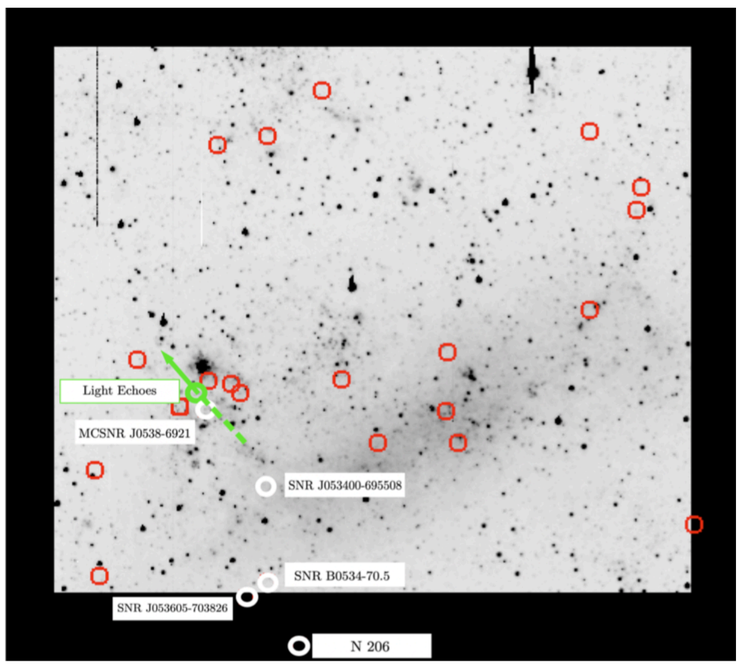

Fig. 5: Red circles identify LMC supernova remnants, white labeled circles identify the 5 candidates to be associated with the light echoes, and a green circle identifies the light echoes with an arrow indicating their apparent motion.