STATEMENT OF PREVIOUS AND CURRENT RESEARCH

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Light attenuated by dust limits our ability to interpret the local and distant universe, i.e., the Type Ia supernova (SN) cosmology, which uses Type Ia SNe as the most accurate distance indicators at redshifts out to $\sim$2. Amazingly, this accuracy is achieved without knowing even approximately the distribution of various progenitors. My thesis work is focused on our ongoing polarimetric monitoring at both early and late phases of Type Ia SNe with the *HST* and VLT to study the progenitor system and probe the optical properties of dust in nearby extragalactic environments using the light echoes resulted in the supernova-lit interstellar material (ISM).

Light Echo: more than a time machine. Light echoes are from scattered light of a transient event arise from dust clouds. They are known as 'astronomical time machines' by preserving the information of the original explosion. However, they also reveal the optical properties of the scattering dust since photons scattered by the dust reach the observer in a slightly different path. The trajectories followed by the scattered photons are confined in an ellipsoid. This iso-delay ellipsoid expands over time, mapping out the dust traversed, and preserves the explosion information. Such events have already provided substantial and exciting scientific opportunities. Examples are probing the progenitor properties of historical transients (Davidson & Humphreys, 2012; Rest et al., 2008) and in some cases the three-dimensional structure of the explosion, see the examples of η Carinae (Rest et al., 2012), SN 1987A (Sinnott et al., 2013) and Cassiopeia A (Grefenstette et al., 2014). Additionally, polarized light echoes provide a unique opportunity to derive an independent geometric distance, i.e., as for the galactic star V838 Monocerotis (Sparks et al., 2008). My current work focuses on the echoing dust near and far from the SN by taking advantage of the scattered light.

Resolved Interstellar Echoes through multi-band imaging: testing the optical properties of the dust. Interstellar extinction caused by dust affects most astronomical observations. Currently a widely-used approach in determining the extinction is the 'pair method' - comparing spectrophotometry of two sources with the same spectral energy distribution, one of which has negligible foreground extinction. However, information acquired through this pair method is limited to single sightlines. The scattering nature of the extragalactic dust grains is poorly understood. Resolved light echoes provide additional information on interstellar dust extinction because they literally reflect light-scattering properties and reach the observer through multiple different paths. Therefore, observations of the SN and resolved light echoes provide a unique opportunity to measure the extinction properties of the dust along the line of sight and the scattering properties independently.

We have obtained multi-epoch and multi-color images with *HST* at very late phases after the SN 2014J explosion, and we are able to directly convert 2D images into maps of the optical properties of the dust responsible to the light echo signals. I have detected different wavelength-dependencies of scattering in different ISM components: a small $R_V \sim 1.4$ in a dense layer of dust and a Milky Way-like $R_V \sim 3$ in a diffuse, tenuous dust cloud. This suggests that these two different ISM components exhibit different grain size distributions (Yang et al., 2016a), and this is consistent with a correlation between the host galaxy extinction A_V and their measured R_V (Mandel et al., 2011). The dense layer of dust may also be responsible for most of the extinction towards the SN 2014J. This study reveals the R_V fluctuation of the extragalactic dust on parsec scales. We deduce that systematically steeper extinction laws towards Type Ia SNe do not have to represent the average behavior of the extinction law in the host galaxy.

Unresolved Circumstellar Echoes with late-time polarimetry: Probing the pre-explosion evolution. Observations of the polarized scattered light and its time evolution can be an effective way of studying the circumstellar material (CSM). Type Ia SNe are intrinsically very little polarized in broad-band observations ($\lesssim 0.2\%$, Wang & Wheeler, 2008), but the scattered light from CSM can be highly polarized. As a SN fades, the portion of the scattered light coming from CSM increases and can contribute significantly to the total flux observed from the SN. Light scattered at large angles can be polarized at $\sim 50\%$. For a spatially unresolved source, the scattered light can contribute significantly to the total integrated light and the polarization of the integrated light can evolve rapidly with time after the supernova evolves past optical maximum (Wang & Wheeler, 1996).

I tested the circumstellar environment of SN 2014J by monitoring its late-time polarization with the imaging polarimetry mode of the *HST* ACS/WFC. I found the polarization of Type Ia SN 2014J shows conspicuous deviation at day 277 from other epochs (Kawabata et al., 2014; Patat et al., 2015). I developed a model to calculate the amount of CS dust constrained by the deviations of polarization of Type Ia SNe. This model was applied to the observed data to deduce the amount of dust needed to produce the observed polarization at day 277. I found the time-deviations of polarization can result from light scattered by a silicate dust ejecta of $\gtrsim 10^{-6} M_{\odot}$ located $\sim 5 \times 10^{17}$ cm (0.5 light years) to the SN based on Mie scattering and dust models from Draine & Lee (1984); Laor & Draine (1993); Weingartner & Draine (2001). The location of this matter then constrains the time history of the mass ejection and is consistent with an episode of nova-like ejection ~160 years before the SN explosion for a typical speed of 1,000 km/sec. The mass of ejecta and the time-delay between the mass ejection and the explosion of the SN are consistent with most of the double-degenerate scenarios discussed in Margutti et al. (2014) and references therein. To summarize, the principle fact enabling late-time polarimetry as an effective tool to constrain the CSM is that the fraction of polarized flux from any asymmetric CS dust increases substantially as the the SN dims sufficiently.

Polarimetry as a unique tool to study the progenitor system. Early observations before the ejecta wipe out most of the traces of the pre-explosion configuration is critical to study the progenitor systems, especially for Type Ia SNe. When the blast wave hits a major obstacle such as a companion, an accretion disk or other CSM, the signature of this interaction is temporarily detectable before it is left so far behind the expanding photosphere. Polarimetry probes the mass-loss history and the geometrical asymmetry. If the footprint on the photosphere of the distribution of the dust particles is asymmetric, the integrated polarization can be quite large.

My efforts include Target of Opportunity programs using the VLT to obtain spectropolarimetric data for Type Ia SNe at very early phases (VLT 096.D-0144, PI: Wang). My discovery of a low level of continuum polarization ($<0.2\%$) of SN 2015ak as early as 11 days before the maximum is inconsistent with the merger-induced explosion scenario (Bulla et al., 2016). Moreover, intrigued by the explosion mechanism of ASASSN-15lh - the most luminous supernova ever discovered (Dong et al., 2015, 2016), I requested *HST* Directors Discretionary Time observations to obtain imaging polarimetry of this target. Three orbits for a single visit in multi-band were awarded (*HST* 14348 PI: Yang). I have conducted the calibration of the ACS/WFC polarimeters F435W/POLUV and F775W/POLV independently based on the most recent calibration program (*HST* 13964, PI: M. McMaster) to provide stringent constraints on the asymmetries of the event. My measurement suggests that this hydrogen-poor superluminous supernova event at z$\sim$0.23 has a small asymmetry on the sky (Brown et al., 2016). Current and next generation surveys will probe the time-domain universe in unprecedented cadence, depth, and sky coverage. The uniqueness of polarimetry makes it a promising tool for understanding both the physics of the progenitor itself, and the properties of the dust illuminated by the transient event, by looking tomographically, and by looking back in time.

Antarctic site testing as pathfinders for further astronomical studies. Antarctic sites are proving to be excellent sites for optical, NIR, and THz astronomical observations. To understanding and make the use of the long ‘winter night’ as well as other remarkable observation conditions is one of the essential topics for future astronomy.

I am leading two data reduction and analysis programs on Antarctic site testing (Yang et al., 2016b, and Yang et al. 2017 in prep). Given the nature of the wide-field design and combined with no sidereal tracking system, non-negligible effects needed to be modeled to effectively process the data. From continuous monitoring data at the highest point on the Antarctic plateau in a $90^\circ \times 90^\circ$ Field-of-View with a fisheye lens, I built a data reduction pipeline and calibrated the BVR sky brightness, the cloud coverage, and estimated the aurorae statistics from 60,000 raw frames. Light curves of ~ 2600 stars brighter than 7.5 in V for a consecutive 120 days have also been obtained. These results are shown in Yang et al. (2016b). I am continuing my work on Antarctic site testing with the photometric and spectral data obtained by Gattini UV South Pole experiment (Moore et al., 2012) to measure and categorize the optical night sky brightness at the very blue wavelengths. My work on Antarctic site testing will be continuing in the future.

References

Brown et al. 2016, ApJ, 828, 3
Bulla et al. 2016, MNRaS, 455, 1060
Davidson et al. 2012, Nature, 486, E1
Dong et al. 2015, ATEL, 7774
–. 2016, Science, 351, 257
Draine et al. 1984, ApJ, 285, 89
Grefenstette et al. 2014, Nature, 506, 339
Kawabata et al. 2014, ApJL, 795, L4
Laor et al. 1993, ApJ, 402, 441
Mandel et al. 2011, ApJ, 731, 120
Margutti et al. 2014, ApJ, 790, 52
Moore et al. 2012, SPIE, 8444E, 1QM
Milne et al. 2001, ApJ, 559, 1019
Patat et al. 2015, A&A, 577, A53
Rest et al. 2008, ApJ, 680, 1137
Rest et al. 2012, Nature, 482, 375
Sinnott et al. 2013, ApJ, 767, 45
Sparks et al. 2008, AJ, 135, 605
Wang et al. 1996, ApJL, 462, L27
–. 2008, ARAA, 46, 433
Weingartner et al. 2001, ApJ, 548, 296
Yang et al. 2016a, arXiv:1610.02458
Yang et al. 2016b, arXiv:1610.10094