OBSERVING REQUEST
University of Arizona Observatories

Year: 2015 **Term:** Jan–Jun **Proposal type:** short-term⋆

Investigation of the Luminosity Evolution of Type Ia Supernovae from the Ages of Nearby Early-Type Host Galaxies

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Abstract of Scientific Justification

The luminosity evolution of Type Ia supernovae (SNe Ia) and dust extinction play major roles in the systematic uncertainties of the SN cosmology. In order to overcome these obstacles, we propose to continue our spectroscopic survey using MMT-BCS to take spectra for early-type and passive host galaxies of SNe Ia in the northern hemisphere. Using these spectra, we will measure Lick indices to estimate their luminosity-weighted mean ages and metallicities by employing population synthesis models. This data set will be used to investigate the luminosity evolution of SNe Ia with respect to look-back time, or redshift, which is a crucial test required in the SN cosmology. Our sample comes from our own SN catalogue which has three SN light-curve fitters and their Hubble residual (HR) values. Since we are dealing with early-type and passive galaxies, this project is also less affected by dust extinction. Our preliminary result, based on a small sample of bright host galaxies in the southern hemisphere, shows an interesting trend between the host galaxy population age and HR, in the sense that SNe Ia in younger galaxies are fainter than those in older galaxies. Taken at face value, this age (evolution) effect can mimic a large fraction of the HR used in the discovery of the dark energy. However, our preliminary result is significant only at $\sim 1.5\sigma$ level, and therefore, further observations are urgently required to confirm this trend. As the feasibility test performed in our previous observing run with MMT-BCS showed very promising results, this project will eventually provide more robust constraints on the nature of dark energy.

Summary of observing runs requested for this project

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling Optimal	Scheduling Acceptable	Sharing Poss.	Sharing Adv.
1	MMT	f/9	Blue			3	dark	Jan	Jan–Feb	no	no

Scheduling constraints and unusable dates *(up to 4 lines)*: None

no text past this line

A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a ∗ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	SDSS J005011.17+004032.5	00:50:11.18	+00:40:32.6	V=19.2g, z=0.1893, Passive
2	NGC 0382	01:07:23.87	+32:24:13.9	V=14.22, z=0.0174, E
3	SDSS J 011304.03-003223.9	01:13:04.03	-00:32:24.0	V=18.3g, z=0.1186, Passive
4	NGC 0495	01:22:56.00	+33:28:18.0	V=13.93, z=0.137, SB0/a
5	2MASX J01344182-0036154	01:34:41.84	-00:36:15.2	V=17.3g, z=0.0785, Passive
6	2MASX J01372378-0018422	01:37:23.78	-00:18:42.2	V=17.1g, z=0.0549, Passive
7	NGC 0759	01:57:50.33	+36:20:35.2	V=13.84, z=0.0156, E
8	2MASX J02050352+0010309	02:05:03.56	+00:10:30.4	V=17.5g, z=0.0766, Passive
9	PGC 010738	02:50:08.84	+12:50:37.0	V=15.40, z=0.0343, compact
10	SDSS J030711.02+010711.9	03:07:11.2	+01:07:12.0	V=19.5g, z=0.1290, Passive
11	NGC 1275	03:19:48.16	+41:30:42.1	V=12.64, z=0.0176, cD
12	SDSS J032331.34+004002.2	03:23:31.35	+00:40:02.2	V=18.4g, z=0.1284, Passive
13	2MASX J03260105+4041403	03:26:01.07	+40:41:40.5	V=17.30, z=0.0140, S/S0?
14	SDSS J033444.49+002119.8	03:34:44.49	+00:21:19.8	V=19.0g, z=0.1226, Passive
15	PGC 017176	05:21:49.79	+06:40:37.3	V=17.41, z=0.0321, SA0-:
16	UGC 06609	11:38:29.46	+20:31:39.8	V=14.33, z=0.0257, E
17	NGC 3873	11:45:46.10	+19:46:26.2	V=13.85, z=0.0181, E
18	NGC 4070	12:04:11.30	+20:24:35.4	V=14.14, z=0.0241, E
19	NGC 4493	12:31:08.37	+00:36:49.3	V=14.5g, z=0.0232, SA0-
20	CGCG 189-024	13:07:54.81	+34:05:13.6	V=14.8g, z=0.0337, E
21	CGCG 190-050	13:45:34.99	+35:36:40.1	V=14.4g, z=0.0237, S0?
22	NGC 5490	14:09:57.29	+17:32:44.0	V=12.9g, z=0.0162, E

Approval for Instrument Use from PI: N/A

Graduate students *(provide the following information for* ***each*** *student named as PI or CoI on the cover page. Have the advisor's signature(s) appear on* ***all*** *submitted copies)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis
Young-Lo Kim	Young-Wook Lee		no	yes
Yijung Kang	Young-Wook Lee		no	yes

Scientific Justification

Type Ia Supernovae (SNe Ia) cosmology is currently providing the only direct evidence for the presence of dark energy (Figure 1) [1, 2]. The distance measurement using SNe Ia is based on the assumption that the look-back time evolution of SNe Ia luminosity, after light-curve shape and dust extinction corrections, would be negligible. A strong support for this assumption was the apparent insensitivity of SNe Ia distances with the host galaxies having different morphological types, where SNe Ia are believed to arise from old and young progenitors.

However, two recent compilations of SNe Ia data show a systematic difference in the Hubble residual (HR). HR is defined as the difference between the distance modulus determined from SN Ia and that from the host galaxy redshift based on the cosmological model. A negative HR means brighter SNe Ia. The average HR of SNe Ia in Scd/Sd/Irr hosts is 0.14 (+/- 0.07) mag larger than that in E/S0 hosts at low-redshift (Figure 2), and SNe Ia in late-type hosts has HR of 0.18 (+/- 0.09) mag larger than those in early-type hosts at high-redshift [3, 4]. This morphological difference is believed to be originated from the difference in the population ages. Sullivan et al. (2010) [5] also report a systematic difference in HR of 0.08 (+/- 0.02) mag between the high and low mass host galaxies. They showed that this difference could shift the dark energy equation of state, w, by 0.17. All of these results might indicate that the light-curve fitters used by the SNe Ia community cannot quite correct for a large portion of the population age (and therefore the evolution) effect.

In order to investigate this effect more directly, we propose to measure Lick indices of early-type and passive host galaxies in the redshift range $0.01 \leq z \leq 0.2$ using MMT-BCS for the northern targets. Meyers et al. (2012) [6] reported that the reliable age and metallicity may not be obtained when the signal-to-noise ratio (S/N) is less than 50. Accordingly, we will take the galaxy spectra with $S/N \geq 50$. Early-type and passive galaxies are preferred because they are less affected by dust reddening and also their ages can be measured from the Balmer absorption lines. We are using YEPS (Yonsei Evolutionary Population Synthesis) model, together with TMB03 and Schiavon07 SSP models, to estimate host galaxy population ages and metallicities [7, 8, 9]. Light-curve shape and reddening corrected SNe Ia distances, based on MLCS2k2, SALT2, and SNooPy methods will be measured using SNANA (SuperNova ANAlysis) package [10] to investigate the correlations between the HR and the population age of host galaxies.

Our preliminary result, based on the observations made with a small telescope (LCO du Pont 2.5m) for the relatively bright southern targets, shows interesting trends between host galaxy population age and Hubble residual (Figure 3). Black solid line indicates the posterior median estimation of the regression line derived using MCMC method. The range of these slope is from -0.16 to -0.38 mag/10Gyr. Blue shade regions denote the 2σ confidence intervals on the regression lines in MCMC method. Any combination of the population synthesis models and the light-curve fitters shows that SNe Ia in younger galaxies have positive residuals compared to those in older galaxies. This is indicating that the light-curve corrected SNe Ia in younger hosts are indeed fainter. This result is independent of the choice of the population synthesis models and light-curve fitters. Our preliminary result, which is significant at $\sim 1.5\sigma$ level, shows a possibility that the evolution of SNe Ia luminosity would replace some of the HR used in the discovery of dark energy. Since the magnitude difference used in the discovery of the dark energy is only ~ 0.2 mag, this correlation, if any, will introduce a serious systematic error in cosmological analyses, which should be corrected for the better determination of the equation of state of dark energy. In order to confirm this at 3σ level, we urgently need more sample of host galaxies spectra with $S/N \geq 50$ in the northern hemisphere.

References

[1] Riess, A. G., Filippenko, A. V., Challis, P., et al. 1998, AJ , 116, 1009

[2] Perlmutter, S., Aldering, G., Goldhaber, G., et al. 1999, ApJ , 517, 565

[3] Hicken, M., Wood-Vasey, W. M., Blondin, S., et al. 2009, ApJ , 700, 1097

[4] Suzuki, N., Rubin, D., Lidman, C., et al. 2012, ApJ , 746, 85

[5] Sullivan, M., Conley, A., Howell, D. A., et al. 2010, MNRAS , 406, 782

[6] Meyers, J., Graves, G., Aldering, G., et al. 2012, American Astronomical Society Meeting Abstracts #219, 219, #143.11

[7] Chung, C., Yoon, S.-J., Lee, S.-Y., & Lee, Y.-W. 2013, ApJS , 204, 3

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[9] Schiavon, R. P. 2007, ApJS , 171, 146

[10] Kessler, R., Bernstein, J. P., Cinabro, D., et al. 2009b, PASP , 121, 1028

[11] Smith, M., Nichol, R. C., Dilday, B., et al. 2012, ApJ , 755, 61

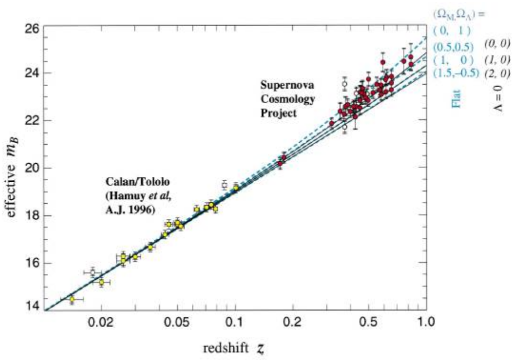

Figure 1: Hubble diagram for 42 high-redshift SNe Ia from the Supernova Cosmology Project and 18 low-redshift SNe Ia from the Calan/Tololo Supernova Survey after correcting both sets for the SN Ia light-curve width-luminosity relation [2]. This figure shows that SNe Ia at high-redshift are fainter than those at low-redshift. This is suggesting that SNe Ia at high-redshift is farther than expected from open CDM. This discovery has been interpreted as an evidence for the accelerating expansion of the Universe.

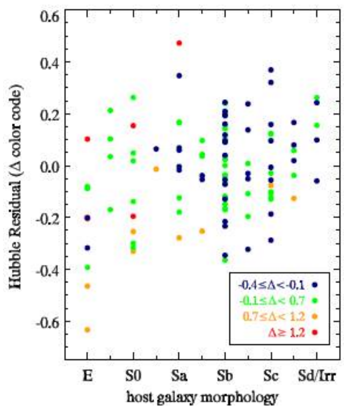

Figure 2: MLCS17 Hubble residual vs. host galaxy morphology diagram [3]. Δ is the shape parameter of SNe Ia in MLCS17 model, and fainter SNe Ia have higher value of Δ. There is a $\sim 2\sigma$ difference in Hubble residuals between the E-S0 and Scd-Irr galaxies.

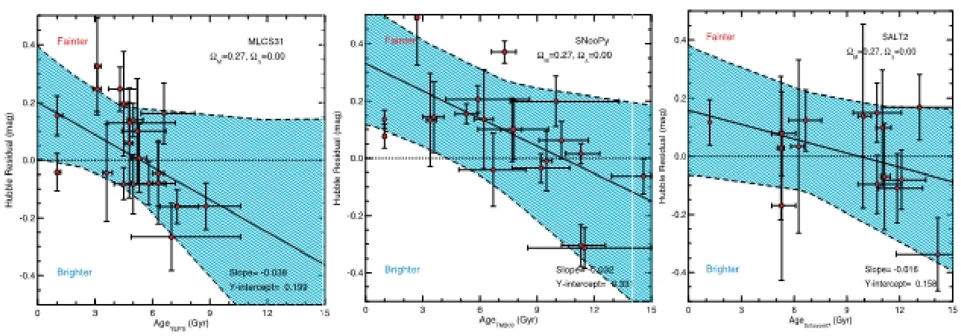

Figure 3: Correlations between the host galaxy population age vs. Hubble residual from our preliminary result. All three panels show a negative trend between host age and HR. This is indicating that SNe Ia in younger galaxies (i.e., at high-redshift) are fainter compared to those in older galaxies (i.e., in local universe). This is significant at $\sim 1.5\sigma$ level.

Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science.* ***(up to one page)***

The main goal of this project is to investigate possible evolution of SNe Ia luminosity with respect to redshift. Since the direct age dating of SNe Ia progenitor itself is impossible, the best approach is to estimate population ages of their host galaxies. As some SN progenitors may not follow the global properties of host galaxies, a large sample ($\sim$ 60) of host galaxies would be required for better statistics.

We selected early-type and passive host galaxies from our own SN catalogue (see above), where morphological classification was drawn from NED[1] and Smith et al. (2012) [11] . They are distributed at $0.01 \leq z \leq 0.2$ in the apparent magnitude range of $12 \leq V \leq 20$.

We will use MMT-BCS 300 grating which provides a dispersion of 1.96 Å/pixel and a resolution of 6.47 $\AA$. The wavelength range will be 3800 - 7000 $\AA$ with $S/N \geq 50$ at 5500 $\AA$. We will obtain Balmer lines (Hα and Hβ), where Hβ will be measured for the population age estimation and Hα will be used for the emission line correction. In addition, Lick/IDS index lines (Mgb, Fe5270, and Fe5335) will be taken to estimate the metallicities of host galaxies.

Based on the previous observing run at MMT, the optimal exposure times per target are 45 minutes (3 $\times$ 900 sec) for the brighter samples (V $\leq$ 17) and 2 hours (3 $\times$ 2400 sec) for the fainter targets (17 $<$ V $\leq$ 20). For the calibration frames, additional time of 5 minutes is required for each target. For this observing run as a second phase of our survey, we suggest to observe 22 targets, so we need at least 31 hours, (12 $\times$ 50) minutes + (10 $\times$ 125) minutes, only for the target observations. Therefore, in total, we require about 36 hours (3 nights) of observation time, including 2 hours for overhead and another 3 hours for calibration stars and galaxies. Dark nights are required to secure the high $S/N (\geq 50)$ spectral data.

[1] http://ned.ipac.caltech.edu

Summary of Time Requested and Awarded *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in. (**up to one page**)*

(1) This is our second observing run at UAO. We had 1 successful night for the feasibility test last year and we are asking 3 nights for this observing run. In order to complete this project, we need 2 more nights to get ~ 60 host galaxies in the northern hemisphere.

(2) We are using du Pont 2.5m telescope at LCO for the brighter southern targets. These brighter samples will be combined with UAO data for the final analysis.

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with \command). (**up to one page**)*

⋆ We had 1 successful night for the feasibility test last year. We obtained 8 host-galaxy spectra under a good seeing condition and dark night. We are currently analyzing these spectra, and preliminary results confirmed that MMT is an ideal instrument to obtain spectra with $S/N \geq 50$ for the host galaxies up to z $\sim$ 0.2.