Photometric Observation and Analysis of Supernova J081659.74+511233.7, Search for New Supernovae in Multi-Galactic Fields, and Call for a New Type Ia Width-Luminosity Relation Model for Supernovae Observations in Luminance Magnitudes.

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Abstract

Photometric observations of supernovae J081659.74+511233.7, ASASSN-15la, ASASSN-15li, and ASASSN-15ln were obtained with BSU's 14" telescope and Apogee Alta U47 CCD on clear nights between February 27th, and July 13th, 2015. Images were processed in MaxIm DL and lightcurves of the supernovae generated using MaxIm DL's differential photometry tool. A Gaussian fit to the early redshift-corrected lightcurve of type Ia supernova J081659.74+511233.7 with RMS 0.9951 reveals a luminance decline of 0.27 magnitudes from peak to phase +15. We present light curves for each type Ia supernova target. Multi-galactic fields were imaged between May 22nd and July 11th, 2015 with no cataclysmic variables detected. Future work includes comparison of our luminance filter data to RVB passband data gathered for ASASSN-15la and -15li to attempt to determine a width-luminosity relationship for type Ia supernovae in luminance magnitude.

Introduction

Type Ia supernovae are of paramount importance as standardizable candles to probe cosmological distances and geometry. Most observations of these targets are short-term, done by large observatories near maximum light in UBVRI bands or full-spectrum. Observatories with low observing power or less than ideal viewing conditions often forego these measurements due to their time-consuming nature. However, an issue in the field of type Ia research is too few observers – thousands of supernovae per year go unstudied.

In February 2015, BSU students Ben Lombard and Sarah Peck began observing supernova J081659.74+511233.7 (hereafter SN1) at the BSU Observatory using a clear luminance filter sensitive to light wavelengths between 350 and 750 nm, with the most significant transmittance in blue and green light. This filter was used to increase the signal from dim targets, and therefore the BSU observatory's chance of detection. Lombard and Peck produced a preliminary lightcurve that showed a clear decline in SN1's luminosity as expected. This showed that the BSU Observatory can observe these dim targets.

Data Acquisition and Processing

Instrumentation and Software:

- 14" EdgeHD on Paramount ME robotic mount controlled with TheSky 6 and TPoint
- Apogee Alta U47 CCD (D2 body) and FW50 filter wheel
- Astrodon standard UBVRI and Luminance filters
- Shelyak Star Analyzer 200 diffraction grating
- MaxImDL
- AAVSO Variable Star Plotter

Observations:

- SN1:
  - All images 120s in length
  - Imaged with luminance filter on 21 nights from 2/27 to 6/13/2015
  - BVR images taken on 7 nights during the same period
  - Spectrum imaged on 5/22 and 5/30
- ASASSN-15la, ASASSN-15li, and ASASSN-15ln:
  - Imaged with luminance and BVR filters on five nights from 6/24 to 7/11
  - Additional observations for 15li on 6/19, plus spectroscopic images
  - Exposure times primarily 30s (some 60s)
- Multi-galactic fields in the regions of IC4304 and NGC5228 were imaged along with M101's field from 5/22 – 7/11
- Flat and dark calibration images taken each observing night when possible. Bias calibrations taken four times throughout duration of observing period.

Processing:

- MaxIm DL's built-in calibration protocols used with most appropriate bias, dark and flat images for each date and exposure length.
- No usable flat calibration images were obtained between 3/10 and 4/12. Flats from 3/9 were chosen to calibrate images during this period after testing flat-correction options for best agreement among reference and check star magnitude variations.
- Flat fields were dark-calibrated with exposure-time-matched dark frames to avoid scaling the dark current.
- Best ten SN1 images from each observing night sum-stacked in MaxIm DL to generate data images with effective exposure times of 20 minutes. Criteria for choosing images to stack: preferential exclusion of images with egging, low signal-to-noise, and background anomalies. (The third condition could not always be met due to a flat-calibration issue that left cross-hatch and dust-donut patterns in images, particularly those with long exposure lengths).
- BVR and luminance images of ASASSN targets stacked to shorter effective exposure times of 5 and 10 minutes.
- All spectroscopic stacked images of a single target were stacked for any given observing night.

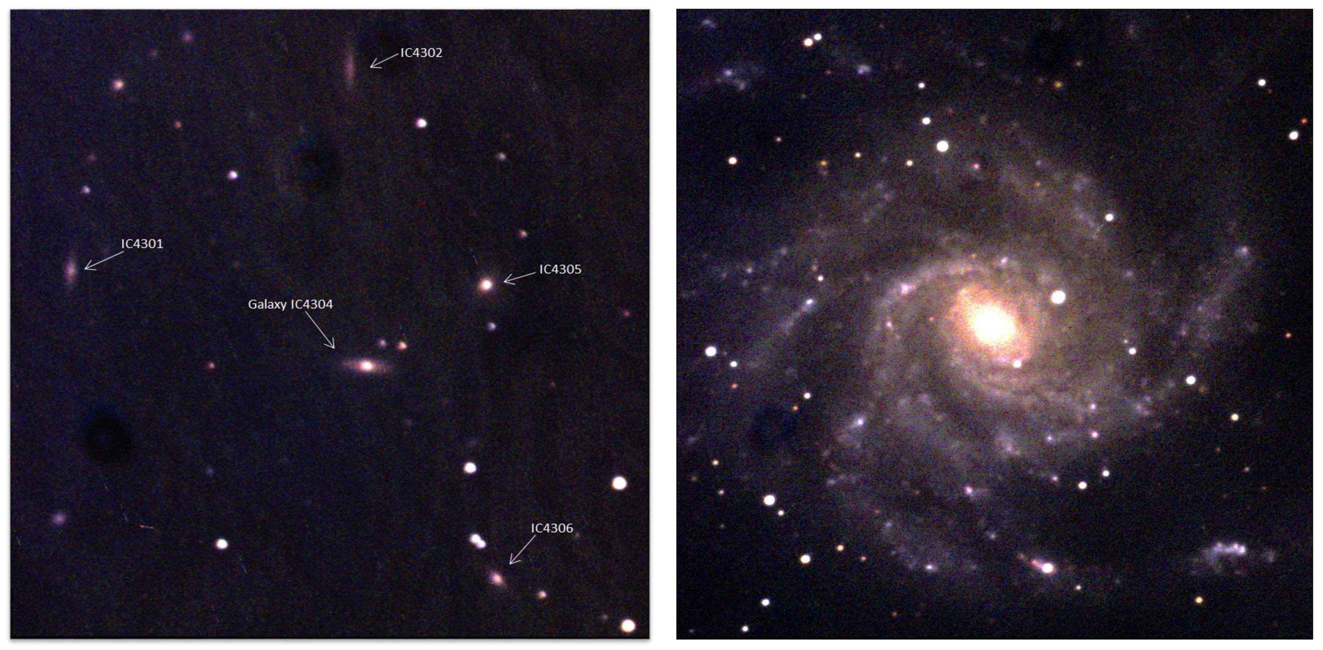

Figure 1: Color composite image of IC4304's multi-galactic field *(Left)* and Galaxy M101 *(Right)*.

Analysis

Differential Photometry:

- Used MaxIm DL 6's aperture photometry tool (Fig. 1).
- Supernova targets' magnitudes compared to a chosen reference star in each image.
- Reference stars chosen for magnitude stability (by comparison with additional check stars) and comparable FWHM to supernova targets when possible.
- Reference star vs. check star magnitude stability used as confirmation of acceptable image calibration.
- ASASSN 15-ln's images rejected (low signal-to-noise), but identified as type II supernova at Asiago T.C.P.

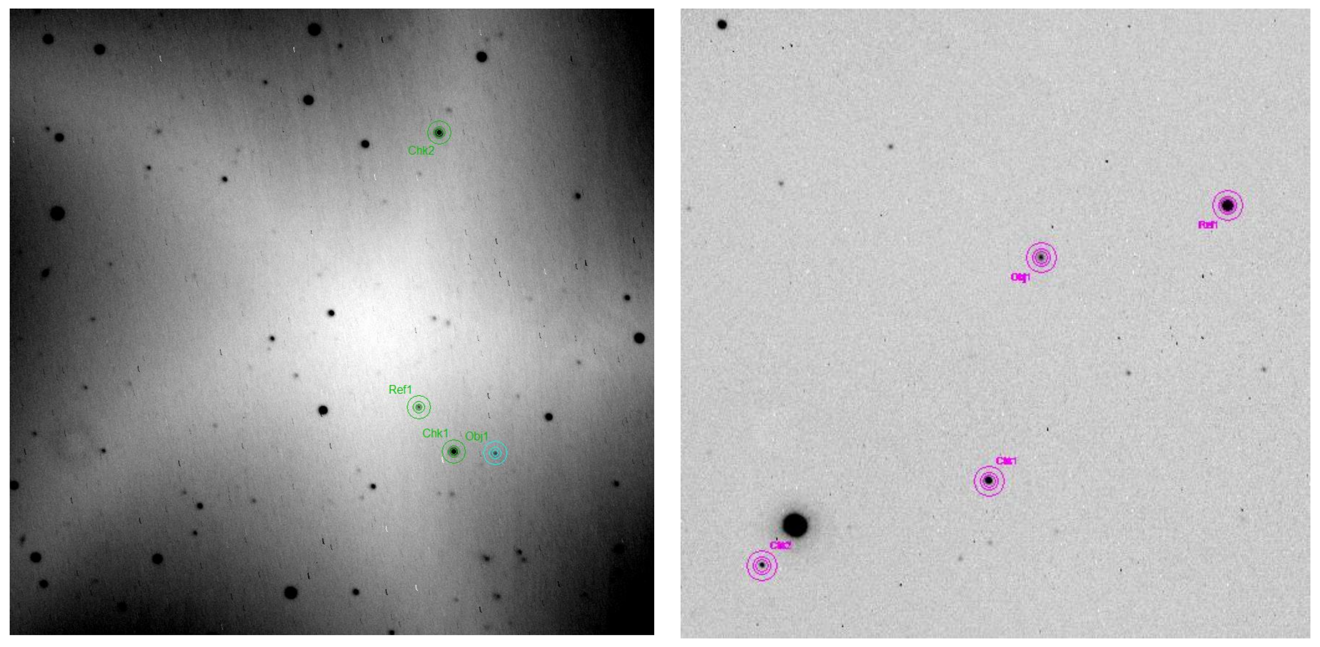

Figure 2: Supernova J081659.74+511233.7's field (left) and ASASSN-15la's field (right). The target, reference star, and two check stars are labeled in each. The star-like pattern in the left field is due to calibration with short-exposure flats from 3/9/15.

Early Lightcurve Fitting:

The early declining lightcurve of a type Ia supernova in its rest frame is well-described by a Gaussian Distribution[2]. We constructed a gaussian fitting program in excel (described by Eq.1), which was used as a tool make comparisons between synthetic type Ia light curves and our own pre-inflection lightcurves. This allowed us to determine how well our observational data fit the model Type Ia profile while finding the moment of peak brightness necessary to measure the supernova's intrinsic brightness.

$$m = m_{max} e^{\left(\frac{-(t-t_0)^2}{2\sigma^2}\right)} \qquad \text{Eq. (1)}$$

In Eq. 1, m is the apparent relative magnitude of the target, m_{max} is the apparent relative magnitude of the target at peak brightness, t is time in Julian Days, t_0 is the time of peak brightness, and σ is the FWHM of the fit in days.

Cosmological Corrections:

Because our targets are cosmologically distant, redshift causes a significant time dilation effect in the shape of the lightcurve and an overall dimming effect in addition to changes in apparent color. Other effects – e.g., reddening due to dust in our own galaxy and the object's host galaxy –also have significance. Spectroscopic images obtained at BSU were too dim compared to background noise to measure the redshift, so redshift measurements obtained from larger observatories (e.g. Palomar)[5] were used in

$$\Delta t_{em} = \frac{\Delta t_{ob}}{(1+z)} \qquad \text{Eq. (2)}$$

Eq. 2, the time dilation correction. This relates the time between measurements in the supernova's rest frame (Δt_{em}) to the time between observations here (Δt_{ob}) and the redshift z[1]. This effectively squeezes each light curve by a factor of 1/(1+z) on the time axis.

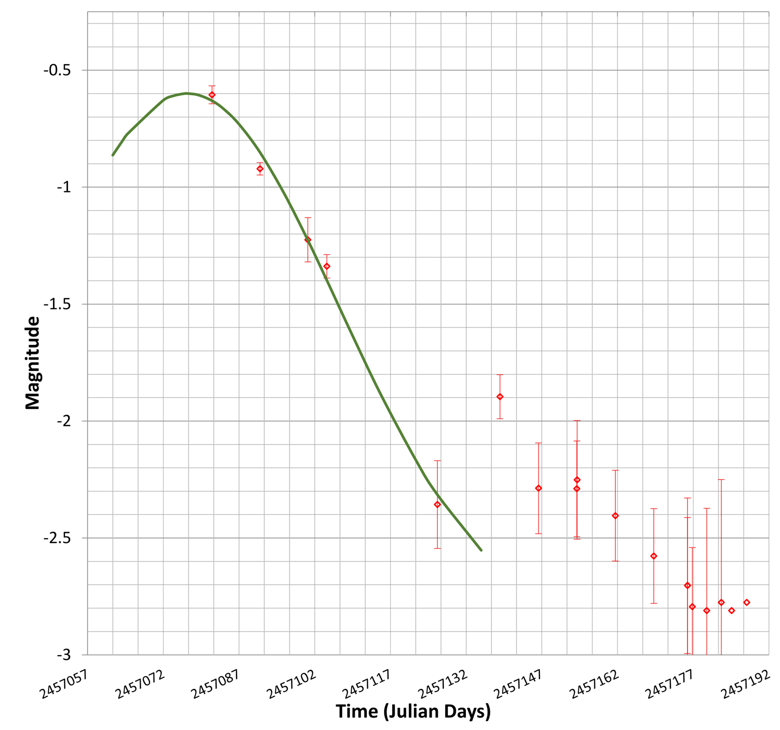

Figure 3*:* Supernova J081659.74+511233.7's z-corrected luminance lightcurve (z=0.05) and fit to early decline rate. Red diamonds are instrumental magnitude compared to the reference star. The green curve is the best (RMS 0.9951) fit to the early lightcurve (first 5 data points) with a peak of -0.59 mag and decline of 0.27 mag from peak to phase +15.

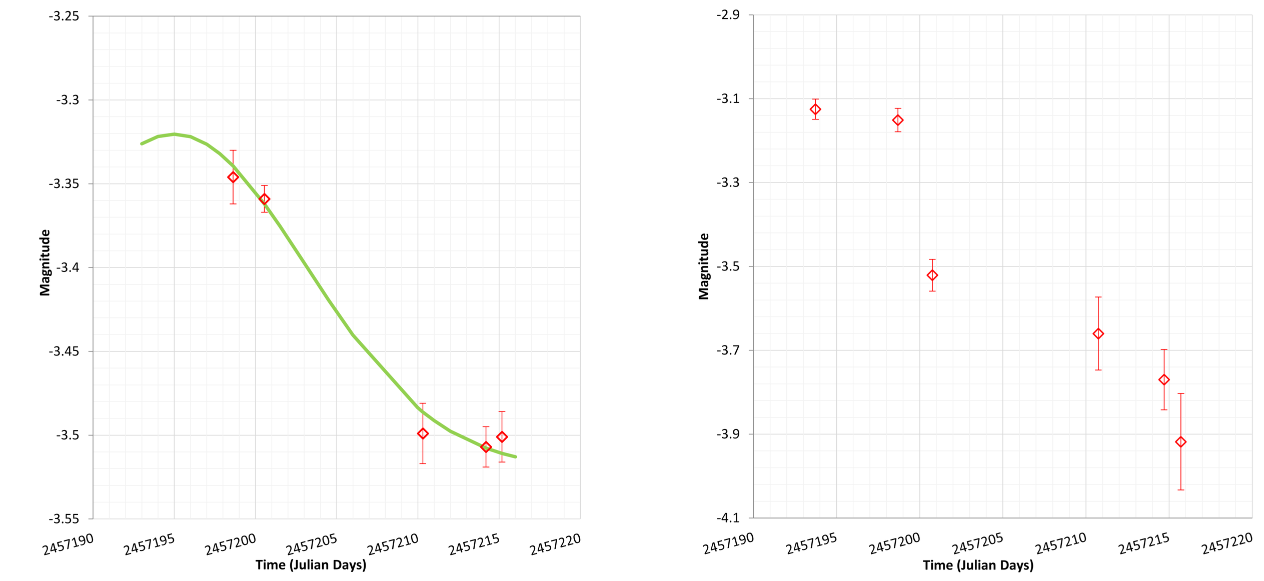

Figure 4: *Left:* ASASSN 15-la's corrected B-band lightcurve (z=0.027) and fit (RMS 0.9883) to early decline rate with peak of -3.32 mag and Δm_B=0.16. *Right*: Uncorrected B-band lightcurve of ASASSN 15-li (redshift as yet undetermined).

Conclusions

- SN1's luminance magnitude declined by 0.27 from peak to phase +15 with fit RMS 0.9951.
- ASASSN 15la's 15-day B-band decline is measured at 0.16 magnitudes.
- Both values above must be corrected for reddening (extinction).
- ASASSN 15li's B-band decline was detected but must be corrected for redshift and extinction.
- Supernovae can be successfully observed with the BSU Observatory's telescope and imaging equipment. More specifically, this is true for observations of distant transient objects such as SNe during early pre and post maximum light phases (typically the first 30+ days or so) in UBVRI bands, and for early and late phase in the luminance filter.
- The observatory's diffraction grating, it was not useful for spectral classification of these dim targets, and is limited to targets brighter than ~18th magnitude.

Future Work

- Corrections for dust absorption
- A flux calibration to standard reference magnitudes is necessary to get measurements of absolute magnitude independent of known width-luminosity relationships.
- A new width-luminosity relationship should be defined for luminance magnitudes if identified.
  - This may help other small observatories observe these faint targets successfully.
  - More observers are needed in this field, so making observations easier is worth pursuing.
- A measurement of luminosity distance can be obtained with the luminance filter if properly flux calibrated using Eq. (4). $L = \frac{4\pi {D_L}^2}{(1+Z)} F$ Eq.(4)
- Measure M_B for type Ia targets based on Eq. (5) (the width-luminosity relationship defined by Phillips[3]).
  $$M_{max}(B) = -21.726 + 2.698\Delta m_{15}(B) \qquad \text{Eq. (5)}$$
- Study late light-curve of SN1 to determine if shape reveals type Ia subtype.

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