USING THE LANDOLT SELECTED AREAS (SAs) FOR PHOTOMETRIC IDENTIFICATION OF FAINT SUPERNOVAE AND OPTICAL COUNTERPARTS TO GAMMA-RAY BURSTERS

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Abstract

We propose to use the Landolt Selected Areas (SAs) as convenient photometric fields to calibrate magnitudes and colors of faint supernovae and optical counterparts or "flashes" associated with transient gamma-ray bursts (GRBs). The spacing of and established photometric sequences in the SAs makes them convenient reference fields to interleave with CCD images of suspected time-variable objects for transformation of instrumental magnitudes and colors to standardized systems.

1. Introduction

We are performing a photometric calibration of a 0.5-m computer-controlled telescope with an Apogee CCD camera and Harris BVR filter set at the Highland Road Park Observatory (HRPO) near the Louisiana State University campus in Baton Rouge, Louisiana. We are systematically surveying a number of the Landolt Selected Areas (SAs) to: 1) monitor variability of various of the existing photometric standards; and 2) extend the UBVRI standard sequence in selected fields to a fainter limiting magnitude. We anticipate also being able to respond quickly to communications regarding rapidly varying optical sources (such as the optical counterparts to gamma-ray bursters) and provide time-resolved magnitudes and colors on a standard photometric system.

2. The Landolt Selected Areas

The Landolt Selected Areas (SAs) represent a widely-spaced set of stellar fields along the celestial equator with established Johnson UBVRI photometric sequences (Landolt 1973, 1983, 1992). The SAs are used for a wide variety of stellar studies requiring well observed, accessible fields with ongoing photometric monitoring.

Even with the relatively small fields of view of most telescope-CCD camera combinations (6–20 arcmin), a significant number of photometric standards can be observed in a single frame by judicious choice of a subfield. An entire SA field can be reproduced, if necessary, by mosaicing overlapping CCD images.

Reduction of instrumental magnitudes and colors to a standard photometric system can be accomplished in almost real-time with the system at HRPO, in that a dedicated computer system handles the telescope and instrument control and a separate, networked computer is available for local and remote data reduction and analysis using a variety of software.

3. Photometric Monitoring and Calibration of Time-Variable Stellar Objects

A unique opportunity is developing to obtain photometric observations of pre- and post-maximum optical events associated with supernovae and gamma-ray bursts (GRBs). With the increasing number of concerted satellite and ground-based observing networks being established, the notification time for the appearance of a faint supernova or a gamma-ray burst is dropping from hours to minutes. In addition to providing an optical identification of a detected X-ray or gamma ray (and neutrino) source, modest telescopes equipped with a standard filter set and a CCD camera can provide multicolor, high time resolution observations of these objects, especially as they reach and then fade from maximum light. Rather then merely reporting instrumental magnitudes and colors, by interleaving CCD frames of a standard Landolt SA, observers can transform instrumental measurements to a standard photometric system (UBVRI), without laboriously observing all-sky photometric standards.

Once a satellite position and error box have been relayed for an interesting source, we can easily identify the nearest SA field to use for photometric sequencing. Thus, we envision the capability of rapidly responding to a GRB alert, quickly imaging the field around the best position in multiple filters, and then offsetting to the nearest subfield of a Landolt SA where we have previously calibrated photometric standards. This observing sequence will be repeated to provide high time resolution light curves (V) for the optical counterpart and simultaneously provide valuable color indices, such as (B-V) and (V-R).

As part of the calibration program, a 2.0-second (unfiltered) CCD image of a 9' x 9' subfield of SA 98 is shown in Figure 1, taken with the HRPO 0.5-m telescope and Apogee CCD camera. This night (02-06-2000 UT) was only marginally photometric, with large flaring in the seeing occasionally blurring the images of SA 98–185 and SA 98–193 together, as they are only 30" apart, accounting for gaps in the differential light curve (Figure 2). We have been monitoring SA 98–185 to verify reported claims of variability.

4. Rapid Photometric Reduction

We currently use the MaxIm DL™ software for the CCD camera control data acquisition and initial data reduction (dark subtraction, flat field division, and synthetic aperture photometry). For final data analysis, however, we deliberately chose to use Microsoft Excel© as it is nearly universally installed on a wide variety of computer platforms. It is a practical software spreadsheet tool, especially for many amateur astronomers who may not wish to bear the cost of a site license for more expensive applications.

We briefly summarize the data reduction process for corrected (*i.e.,* out of atmosphere) instrumental magnitudes, primarily to emphasize the ease with which the process may be carried out with Excel. Detailed discussions and examples of complete photometric reductions can be found in Henden and Kaitchuck (1982), Sterken and Manfroid (1992), Budding (1993), and Martinez and Klotz (1998). From frame-by-frame synthetic aperture photometry using Maxlm DL™, the (object + sky) intensities, I_{os}, and proximate sky intensities, I_s, are determined for the object of interest (in this case the suspected variable "standard" SA 98–185) and a suitable comparison star (another nearby standard, SA 98–193).

In an Excel workbook, raw instrumental magnitudes, m, are then calculated from Pogson's equation:

$$m = a - 2.5 \log(I_{os} - I_s) \tag{1}$$

where a is an arbitrary constant. Atmospheric extinction is determined by calculating the secant of the zenith angle, z, from which the airmass, X, is then determined for each observation:

$$\sec(z) = [(\sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)\cos(h)]^{-1} \tag{2}$$

$$X \approx \sec(z) - 0.0018167(\sec(z) - 1) \tag{3}$$

where ϕ = observatory latitude, δ = stellar declination, and h = stellar hour angle.

Using nightly (or mean) values of the extinction coefficient, k, appropriate for the filter used, corrected magnitudes, m_o, are calculated from Bouguer's equation:

$$m_o = m - kX \tag{4}$$

Differential magnitudes are then determined by

$$\Delta m = (m_v - m_c)_o \tag{5}$$

and a light curve results from plotting Δm versus universal time (UT). The reduction process is summarized in Table 1 and the differential light curve for SA 98–185 and SA 98–191 is displayed in Figure 2.

Similar results are seen for the eclipsing cataclysmic variable UX UMa in Figure 3. This particular night (UT 04-10-2000) was photometric, as evidenced by the much smaller scatter of the comparison star magnitudes (σ = 0.003 mag).

5. Conclusion

We anticipate that small (amateur and professional) observatories are increasingly poised to make significant photometric contributions by rapidly responding to satellite alerts of transient X-ray and gamma ray sources. Rather than just reporting visual magnitudes or raw instrumental determinations of brightness, we can reliably transform instrumental quantities into standard photometric magnitudes and colors.

References

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Table 1. CCD Photometry of Landolt SA 98.

Highland Road Park Observatory Baton Rouge, Louisiana				*Longitude = 89°W Latitude = 30°N Extinction Coefficient: k_{NF} = 0.110*			
Object: SA 98–185		*Comparison: SA 98–193*		*Frame Exposure: 2.0 seconds*		*Filter: No filter*	
UT Time (hours)	*UT Date (days)*	*LST (hours)*	*Object (V) (mag)*	*Comparison (C) (mag)*	*Δ m(V-C) (mag)*	*sec(z)*	*Airmass, X*
2.90	6.12	16.90	15.13	14.68	0.44	1.14	1.14
2.97	6.12	16.97	15.12	14.69	0.43	1.15	1.15
3.04	6.13	17.05	15.16	14.70	0.46	1.15	1.15
3.11	6.13	17.12	—	—	—	1.16	1.16
3.18	6.13	17.20	15.15	14.71	0.44	1.17	1.17
3.25	6.14	17.27	15.12	14.67	0.44	1.18	1.18
3.32	6.14	17.35	15.13	14.68	0.45	1.19	1.19
3.39	6.14	17.42	15.12	14.67	0.44	1.20	1.20
3.46	6.14	17.50	15.13	14.69	0.44	1.21	1.21
3.53	6.15	17.57	—	—	—	1.22	1.22
3.60	6.15	17.65	—	—	—	1.23	1.23
3.67	6.15	17.72	—	—	—	1.24	1.24
3.74	6.16	17.80	—	—	—	1.26	1.26
3.81	6.16	17.87	—	—	—	1.27	1.27
3.88	6.16	17.95	—	—	—	1.29	1.29
3.95	6.16	18.02	15.13	14.69	0.44	1.30	1.30

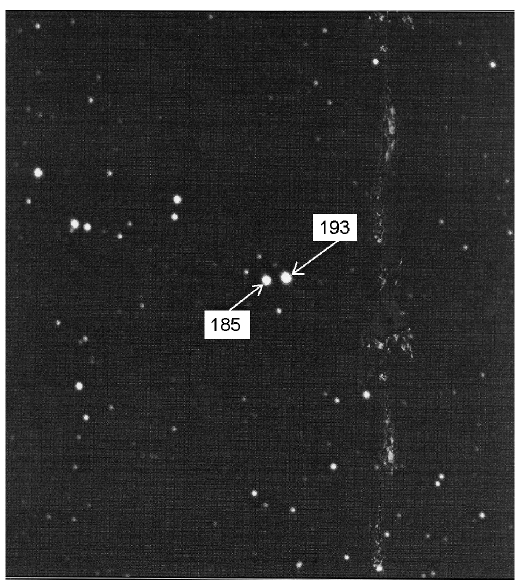

Figure 1. A 2.0-sec unfiltered CCD image taken with the HRPO 0.5-m reflector showing a 9' x 9' portion of the original Landolt SA 98. The image has been reduced (dark subtracted and flat fielded).

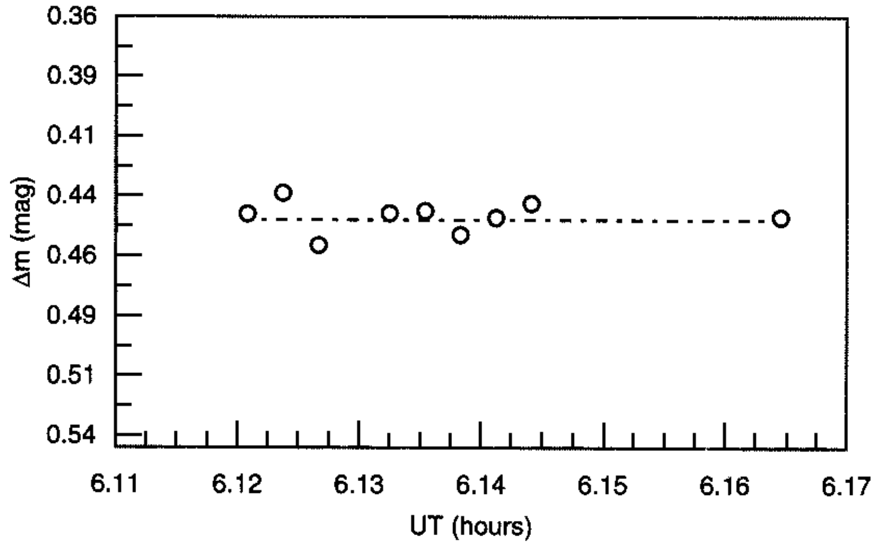

Figure 2. Differential CCD photometry on UT 02-06-2000 obtained with the HRPO 0.5-m telescope to check reported variability of SA 98–185. This night was a relatively poor one, as the standard deviation is $\sigma = 0.011$ mag, relative to the comparison SA 98–193, using an extinction coefficient, $k_{NF} = 0.110$.

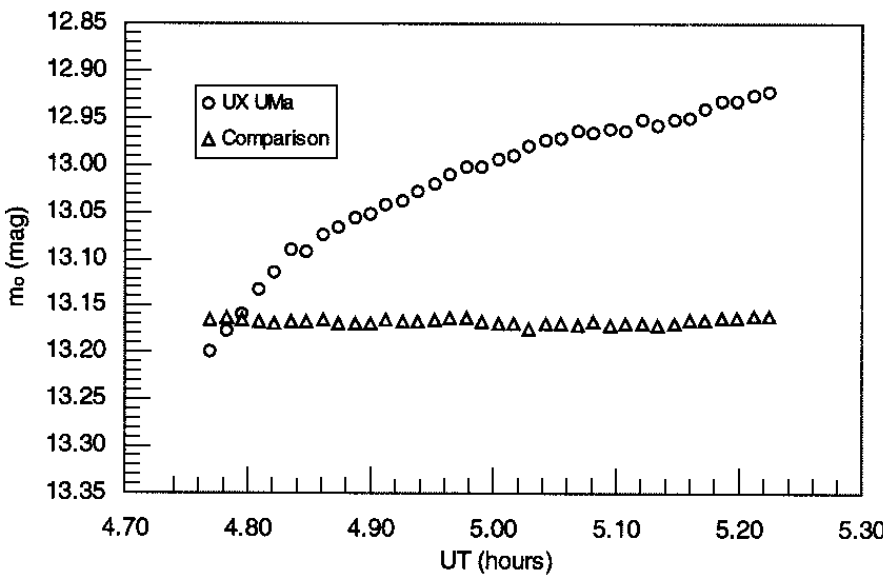

Figure 3. CCD photometry on UT 04-10-2000 of the cataclysmic variable UX UMa during egress from eclipse and a nearby comparison star. The standard deviation of the comparison is $\sigma = 0.003$ mag, using an extinction coefficient, $k_{NF} = 0.100$.