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The Complete Visual Light Curve of SN 1987A: Thirteen Months of FES Observations

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ABSTRACT

Visual brightness measurements of SN 1987A are being obtained with the IUE acquisition camera and star tracker (Fine Error Sensor, or FES) as part of each ultraviolet observation. Due to IUE's around-the-clock operation and lack of clouds, the FES record of SN 1987A is perhaps the most complete set of visual photometry of the supernova made by any single instrument. These data illustrate the photometric limitations of the FES (± 0.03 mag). Use of differential photometric methods are recommended for IUE observers desiring accurate photometry from FES measurements made during their observing shifts.

Keywords: Supernovae, visual light curves, differential photometry

1. INTRODUCTION

The IUE Fine Error Sensor plays an integral role in the target acquisition for each spectral observation made by the satellite's spectrograph/camera systems (Refs. 1 and 2). Prior to each exposure of the supernova, as for virtually all exposures of objects $14 \text{ mag} < V < -1 \text{ mag}$, the target's center of light is positioned at a standard position (the "Reference Point") in the telescope field of view. From the Reference Point canned slews are used to accurately position the target in the spectrograph aperture. The process of positioning the supernova's center of light produces a mean brightness measurement. These FES counts have been recorded for each observation of SN 1987A at GSFC

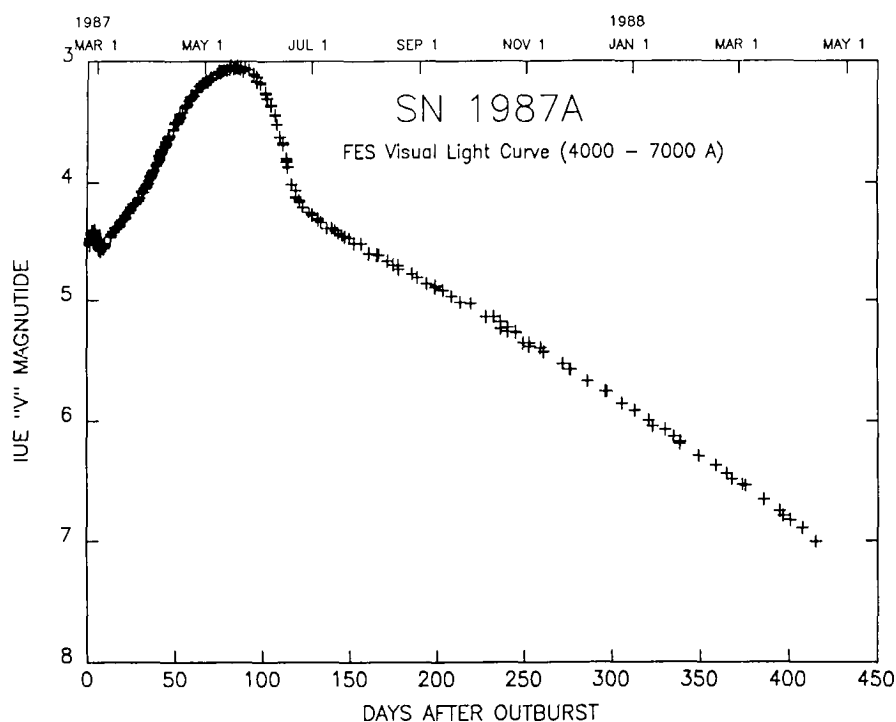


Figure 1 IUE "V" magnitude light curve for the SN 1987A outburst through 18 April 1988

to produce a database with over 520 entries as of 18 April 1988. The complete IUE light curve for SN 1987A is shown in Figure 1, which includes all corrections discussed below.

The FES is an image disector with an unfiltered S20 photocathode, and therefore has a very broad spectral response ($\sim 4000\text{-}7000 \text{ \AA}$). Despite its moderate photometric precision it has proved to be very useful because it is available 24 hours per day and is not vulnerable to bad weather or seeing conditions.

2. OBSERVATIONS

The first FES measurements of SN 1987A were made on 24.812 February 1987, about 1.5 days after the outburst began. The time of outburst is taken to coincide with the Kamiokande-II and IMB neutrino detections (23.316 February 1987, Refs. 3, 4). SN 1987A was observed daily by IUE from 24 February through late May 1987, approximately every other day during June, July, and August, and with decreasing frequency since then. Observations are now obtained every 7-10 days. During each observing period FES counts for SN 1987A were measured with the supernova accurately positioned at the Reference Point as part of the normal process of obtaining UV spectra.

The FES was used in the Underlap Mode (used for $m_V < 4.8$) for all observations of SN 1987A prior to mid-July. Measurements were made in both Underlap and Overlap modes through March 1988, and only in Overlap thereafter. Collection of FES data in both scan modes was continued as long as possible so as to build up a unique data base of FES measurements which will improve the FES photometric calibration. All data to date have been in the Fast Track scan rate.

The FES calibration of Imhoff (Ref. 5) was used to derive FES V magnitudes, which includes a correction for time-dependent changes in the FES sensitivity. No correction has been made for the small (B-V) dependence in the calibration. A significant part of the loss of sensitivity appears to be due to a "fatigue spot" on the FES aperture plate located precisely at the Reference Point. The origin of this fatigue spot is unknown, but might plausibly arise from long-term damage to the Reference Point's location of the photocathode due to 10 years of accumulated target acquisition activity. This effect accounts for the majority of the sensitivity change (Ref. 6)

The Underlap data for SN 1987A was found to have low scatter ($\pm 0.03 \text{ mag}$). However, the Overlap data obtained at the same time had much larger scatter, even though every precaution was taken to ensure that the target was properly centered at the Reference Point. Beginning in early October 1987 a star of similar brightness and color close to the supernova was observed with the FES within an hour of the SN 1987A measurements so that differential methods could be used. The comparison star was HD 45669 (K5 III, $V=5.56$, $(B-V)=1.51$). A moderately red star was chosen as an approximation to the general spectral distribution of SN 1987A, even though there are significant differences between a K star and the supernova's spectrum (most notably the strong emission lines).

Figure 2 shows the variation in FES counts for HD 45669 from October 1987 to April 1988. Two points should be noted: First, there is a long-term decline in mean brightness of about 7-8%. During this time period, the supernova's FES counts decreased from about 18000 to 4000. Second, there is a large short-term variability. The latter appears to be instrumental because the FES counts of SN 1987A vary in exactly the same manner. Figure 3 shows the uncorrected FES magnitudes for SN 1987A. In Figure 4 is shown the same data when the FES counts for SN 1987A are increased or decreased for the day to day fluctuations about the mean for HD 45669 (the solid line in Figure 3). This procedure results in a significant improvement in the scatter, comparable to that in Underlap mode. The corrected magnitudes shown in Figure 4 are an expanded version of the data in Figure 1.

The long-term decline in counts for HD 45669 is believed to be due to the FES fatigue spot. The origin of the day to day variations is unknown, but instrumental effects are suspected. The short-term changes actually occur on a time scale of hours (Ref. 7).

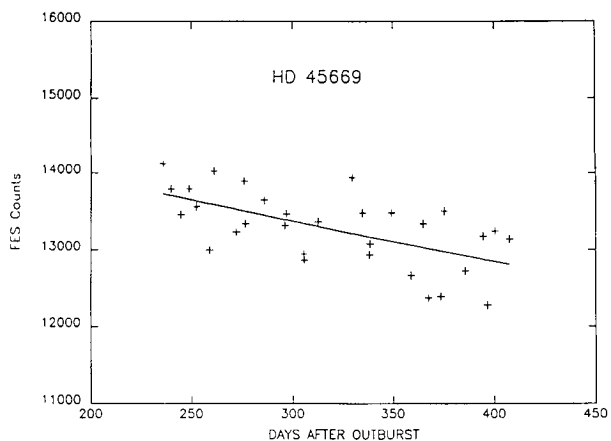


Figure 2 FES counts (fast track, overlap mode) for the SN 1987A comparison star, HD 45669. The solid line is a linear least-squares fit to the data, which defines the long-term change in mean brightness due to FES sensitivity (fatigue spot) losses

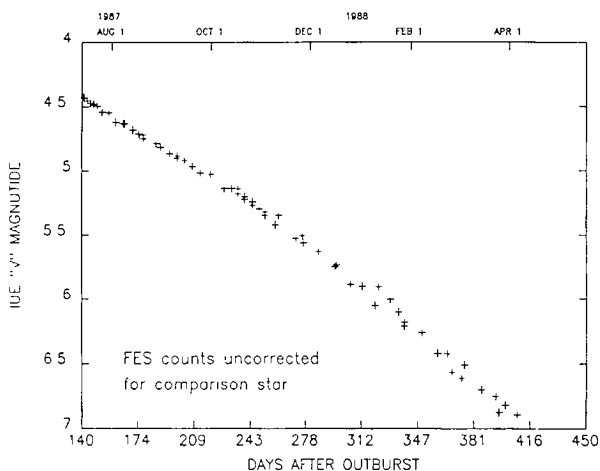


Figure 3 IUE "V" magnitudes for SN 1987A as computed with the calibration from Ref. 5. No correction for (B-V) has been made

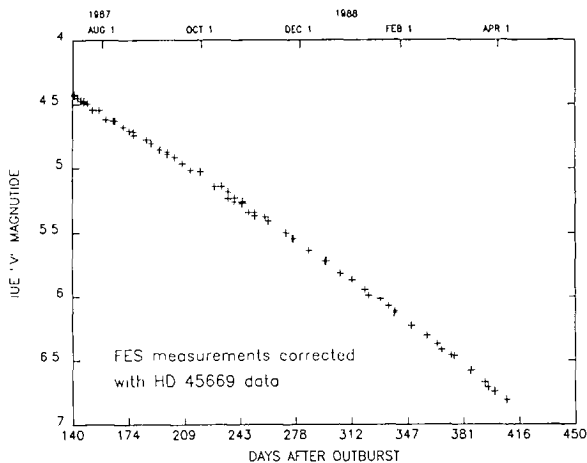


Figure 4 IUE "V" magnitudes for SN 1987A corrected for day-to-day fluctuations of the comparison star HD 45669 about its mean brightness (see Fig. 2). Note the significant improvement in scatter, compared to Fig. 3.

3. DISCUSSION

The SN 1987A light curve has been widely discussed (e.g. Refs. 8-10). The IUE FES data agrees well with ground-based measurements. The data clearly shows the exponential decay portion between days 140-210. After that, however, there is a gradual deviation from a linear (in magnitudes) decay rate as the supernova becomes fainter at a slightly faster rate. This first became evident in the IUE data in early January 1988 (Ref. 11). Looking back at the data, the non-exponential decrease was underway by late November (~ day 250), corresponding closely to the emergence of gamma rays from the supernova ejecta (Refs. 12-15).

The deviation from an exponential decline is now quite large (over 0.5 mag). Figure 5 shows the deviation from the exponential decay light curve predicted from days 140-210. If the FES bandpass closely approximates the bolometric light curve, then this implies that over 30% of the gamma-ray energy is escaping, either as gamma rays or at slightly lower energies in the X-ray spectrum, and is not contributing to the visual spectrum.

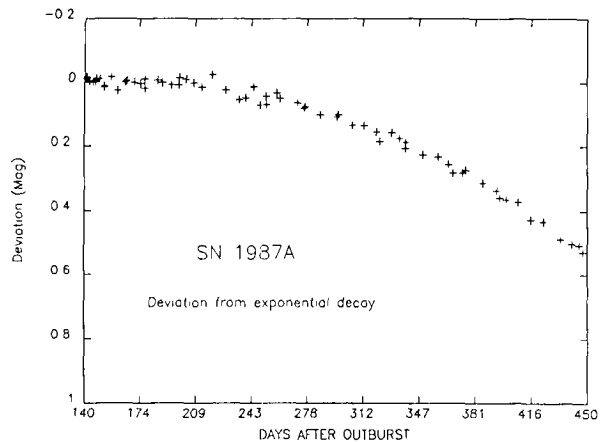


Figure 5 Deviation of the IUE SN 1987A FES light curve from the exponential decay measured between days 140-210.

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