Probable Optical Identification of LMC X-4

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Among the five X-ray sources known to exist in the Large Magellanic Cloud, none has up to now been positively identified with an optical object. However, this situation may change in the near future as X-ray satellites point to the source known as LMC X-4. The existence of this source was announced in 1972 as a result of the first X-ray survey of the sky by the UHURU satellite; it was also detected by the Ariel 5 and SAS-3 satellites and there is now definite evidence for variability, including flares. The rotating modulation collimator system aboard SAS-3 determined the position of LMC X-4 to one arc minute. Inside the error box a large number of stars are visible on the ESO QBS plate (field 86). Very deep objective-prism Schmidt plates taken at Cerro Tololo by N. Sanduleak and A. G. D. Philip showed an OB star near the centre of the error box. A spectrum of this star was taken by E. Maurice in January 1977 with the Echelec spectrograph of the 1.5-m telescope at La Silla; it showed the star to be indeed an early-type luminous object. During our runs at La Silla in February and March 1977 we started a systematic study of this object. One of us (C.C.) measured it photometrically at the 1-m telescope while the other took 124 Å/mm spectra at the 1.5-m using also the Echelec and the Lallemand electronographic camera. In the course of a first run in February at the 1-m we found the star to be variable by 0.1 magnitude from night to night and by a few per cent in the course of the night. Concurrently, W. Hiltner, working at Cerro Tololo, also discovered the variability of this star. In the course of seven consecutive nights in March we obtained *simultaneous* photometric and spectroscopic data. This was supplemented by a few

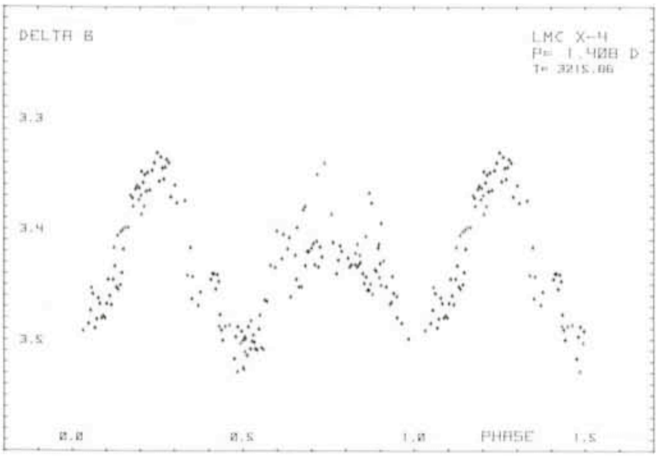

Fig. 1.

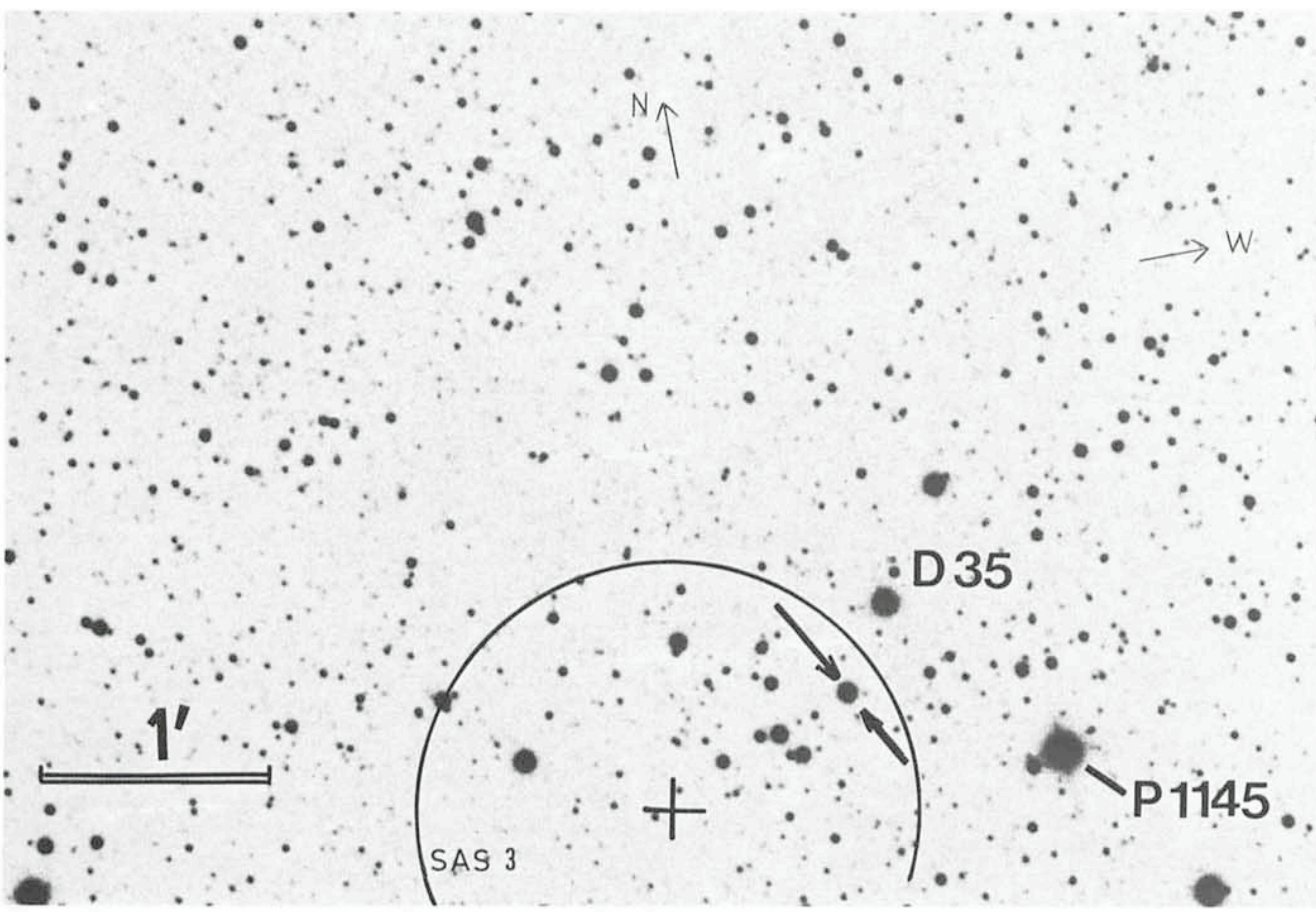

Fig. 2. — *The region of the LMC that includes LMC X-4. The probable candidate star is indicated by the double arrow. SAS-3 one-arc minute radius error circle, Westerlund D 35 star and galactic star P 1145 (Fehrenbach's catalogue) are indicated. Plate taken at the prime focus of the ESO 3.6-m telescope by S. Laustsen.*

nights at the ESO 50-cm during the new moon. The reduction of the photometric data was completed in April and a statistical analysis showed the presence of a regular variation with a period of $1^d.408 \pm 0^d.002$ and an amplitude of 0.15 magnitude. The light curve is double-humped with one maximum being variable in intensity (Fig. 1). Twenty-one electronographic spectra of this star were reduced using the PDS computer-controlled microphotometer of Nice Observatory (CDCA). The spectrum shows H, He I and He II in absorption; the spectral type is about O8 and the mean radial velocity confirms LMC membership. The λ 4686 He II line is also present in emission and it exhibits periodic radial-velocity variations in phase with the light curve. A preliminary value for the semi-amplitude is 450 ±50 km/s. Maximum recession velocity occurs at the time of the variable maximum in the light curve. The underlying λ 4686 absorption line shows approximately constant radial velocity to within ±50 km/s. The optical light curve of this star resembles strikingly those of Vela X-1, SMC X-1, Cen X-3, and Cyg X-1, all positively identified binary X-ray sources with OB-type supergiant companions. However, the orbital period of the LMC X-4 candidate is shorter and the radial velocity of the λ 4686 emission line is larger than in these other systems. In this sense the object is remarkable. Except in Cyg X-1, X-ray eclipses have been found in all the above systems and we hope that future X-ray observations will reveal whether they exist in LMC X-4. If so, the identification will have been confirmed beyond doubt.

A Search for Anomalous Tails of Short-period Comets

Should any future comet display a spectacular sunward spike like the one Comet Arend-Roland exhibited in late April 1957, it would not surprise observers any more. Recent dynamical studies of cometary dust by Z. Sekanina at the Centre for Astrophysics of the Harvard College and Smithsonian Astrophysical Observatories led to the understanding of the behaviour of the sunward, "anomalous" tails or "antitails", to the recognition of the rules that determine the conditions of visibility of these phenomena, and thus to the possibility of their routine predictions.

The astrophysical significance of the anomalous tails is determined by the fact that they are composed of relatively heavy dust particles, whose sizes vary typically from about 100 microns to a few millimetres. The millimetre-sized grains correspond to meteoroids that give rise to the meteor phenomenon, primarily to the one detectable by radar techniques. The submillimetre-sized particles are believed to contribute most significantly to the mass of the interplanetary dust cloud (zodiacal cloud). It thus becomes obvious that studies of anomalous tails are relevant to many aspects of the comet-meteor relationships and to the evolutionary problems of the zodiacal cloud.

Successful Prediction of Antitails

Since Sekanina's formulation of the criteria of visibility in 1973, predictions of anomalous tails have been published by him for two nearly-parabolic comets: Kohoutek 1973 XII and Bradfield 1975 XI. Both predictions were confirmed by observations. The application of the criteria to the past instances led to successful identifications of antitail observations for a number of nearly-parabolic comets, but no positive reports seem to exist for the short-period comets in spite of plentiful opportunities. The apparent absence of anomalous tails among the short-period comets is difficult to reconcile with the well-established associations of meteor streams with a number of these comets, and particularly with the occasional occurrences of the remarkable "meteor storms".

The zodiacal cloud is self-destructive. As shown by F. L. Whipple, it requires a continuous input rate of 10^7 grammes/sec to replenish the mass lost by dissipation. The source that provides the mass input is unknown. However, the mass cannot be supplied by asteroidal collisions as recent investigations of the dust population in the asteroid belt have shown. Likewise, the mass cannot be provided by nearly-parabolic comets, since virtually all dust they release escapes from the solar system to interstellar space. The short-period comets are regarded as another inadequate source, but the present estimates are hardly meaningful. They are based on highly doubtful premises, such as a linear relation between the intrinsic brightness of the comet and its large-particle emission rate. It appears that the detection and photometric investigation of anomalous tails is the only ground-based technique that can resolve the problem of the short-period comets as a potential supplier of the required mass.

The ESO Schmidt Telescope Observes Comet d'Arrest

The absence of reports on anomalous tails of the short-period comets in the past suggests that such formations must be very faint and that only fast cameras might have a chance to detect them. This kind of reasoning led to a collaboration—a very fruitful one, as it turned out later—between Dr. Sekanina and Dr. H.-E. Schuster, who is in charge of the ESO 1-metre Schmidt telescope. Dr. Sekanina's list of the short-period comets with favourable conditions for observing anomalous tails shows almost two dozen cases between the years 1976 and 2000. Periodic Comet d'Arrest, the first comet on the list, was south of the Sun when it developed favourable conditions in October 1976; they persisted as long as the comet could be followed, well into 1977. The anomalous tail was to point to the west of the nucleus. Dr. Schuster took the first plate in mid-November, a 45-minute exposure on a panchromatic emulsion combined with a GG 385 filter. The image of the comet was large and circular. Direct inspection showed no trace of the anomalous tail, but a densitometer scan revealed a definite extension in the anticipated direction at angular distances from the nucleus exceeding 10 arcminutes. Most of the visible coma was apparently due to C_2 which was not filtered out and which entirely obliterated the minor contribution from dust near the nucleus. It became obvious that in order to obtain a more convincing evidence, it was necessary to use a more restrictive filter (a red one) which in turn required a