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NGC 1068, 3C 273, AND SCORPIUS X-1: CIRCULAR POLARIZATION DISPUTED

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ABSTRACT

Null results to within 0.05 percent were obtained for the circular polarization of NGC 1068 and 3C 273; and similarly for Sco X-1 except possibly on one occasion.

I. INTRODUCTION

In a paper submitted contemporaneously (Kemp, Wolstencroft, and Swedlund 1972) we describe a survey over the past 18 months of a variety of stellar objects for optical circular polarization, generally down to a level of 0.05 percent or below. Data for three objects of unusual interest—the Seyfert galaxy NGC 1068, the quasar 3C 273, and the X-ray source Sco X-1—are discussed in the present Letter. It has recently been claimed or strongly suggested that all of these have large circular polarization, of the order of 1 percent (Severny, Nikulin, and Kuvshinov 1971; Nikulin, Kuvshinov, and Severny 1971). In contrast, for NGC 1068 and 3C 273 we have obtained unambiguously null results with upper limits about 0.05 percent in each case. For Sco X-1 we found no statistically significant polarization on three nights, and only some marginal evidence for a fluctuating or transient polarization on one night; but in the latter case the value is an order of magnitude smaller than the typical values mentioned by Nikulin *et al.*

The accuracy of these measurements is governed by (1) noise and (2) the incidental linear-circular conversion (LCC) in the polarimeter. The former is ultimately the photon shot noise, which produces a standard deviation in the fractional polarization given by $\sigma_q = N^{-1/2}$, where N is the number of photons received in the measuring interval. In fact, σ_q is larger if there is excess noise, e.g., from flickering of the source, from Bose-Einstein coherence effects in the case of extraordinarily hot sources, or from the polarimeter electronics. Noise aspects are carefully dealt with below in connection with 3C 273 and Sco X-1. Our polarimeter has an LCC coefficient of about 3×10^{-3}, slowly varying with λ; but an effective coefficient at least a factor of 3 smaller than this can be achieved by periodic rotation of the apparatus (Kemp *et al.* 1971). Thus LCC was not a factor in the present data, although attention was always paid to the linear polarization of the objects and tests for LCC effects were made.

II. RESULTS

All the work was done at Cassegrain focus on the 88-inch (224 cm) telescope at Mauna Kea. The polarimeter, briefly described in earlier papers, is covered in Kemp *et al.* (1972). The circular polarization data are tabulated in table 1. Wavelength pass-

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bands are given in terms of the half-transmission points λ_{min} and λ_{max}, controlled variously by the transmittances or ranges of the Polaroid analyzer, the photomultiplier, the atmosphere, and in one measurement a cut-on filter. In the cases for which $\lambda_{min} = 3400$, a special HPN'B ultraviolet/visual Polaroid was used. Although the interest is in broad-band effects such as from thermal magnetoemission or synchrotron radiation, we cannot be sure that any real polarization is weakly λ-dependent; the chance exists that $q(\lambda)$ alternates in sign, for example, and might cancel out when integrated over some wide band. Aware of this, we varied the passbands somewhat, as noted.

For NGC 1068 the clearly null results were obtained on two occasions 1 year apart, with different angular apertures (both centered on the nucleus) and different passbands. To us, further efforts on this object do not seem useful, except with an order-of-magnitude increase in integration time or perhaps with an attempt to resolve the object into regions. It seems doubtful that large polarization from a local region of extent, say, 1 square arc second, could be so diluted or canceled out that we would not see some hint of it in the present data.

The 3C 273 and Sco X-1 data are given in table 1 as time averages over periods as long as 3 hours. These average q-values are all very small with maybe one exception. Certainly in 3C 273 there is no case for q as large as 0.2 percent. The only questions are those of sporadic effects, which of course we may miss; and short-time effects. The well-known intensity fluctuations in Sco X-1 do bring to mind such possibilities as flarelike events producing a temporary net magnetic field. Though 3C 273, however, is said to have a quiet power spectrum (Lawrence, Ostriker, and Hesser 1967), apart from long-term brightness changes, we worked under the assumption that the power spectrum of its circular polarization $q(t)$ might not be quiet.

More detailed data for 3C 273 are shown in figure 1 and table 2. Our instrument records q in terms of 30-s averages. To compare fluctuations we have also analyzed the records into standard periods of 15 minutes, over which fairly small values can be measured, of order 0.1 percent. Columns (6) and (7) of table 1 are the rms fluctuations

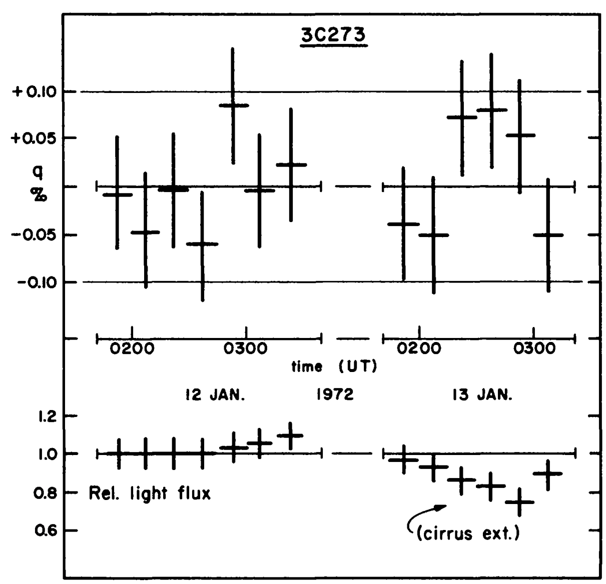

FIG. 1.—Search for fluctuating circular polarization in 3C 273. *Abcissae*, Universal Time. Upper portion is percent circular polarization; lower portion is relative light flux (d.c. in polarimeter photomultiplier). The q data, recorded one reading each 30 s, are presented here as 15-minute averages. Second night had varying extinction due to cirrus layer.

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TABLE 1

CIRCULAR POLARIZATION DATA FOR NGC 1068, 3C 273, AND SCORPIUS X-1

Object (1)	Visual Magnitude (2)	Linear Polarization (percent) (3)	Date* (4)	λ† (5)	Stop Diameter (seconds) (6)	Integration Time (minutes) (7)	q (percent) (8)
NGC 1068........	9–10.6	1–5	1970 December 8	4100–6300	7	10	0.00±0.10
	...	...	1971 December 23	3400–6300	10	62	0.00±0.04
3C 273...........	12.8	0.7±0.3‡	1971 February 21	4100–6300	10	42	0.00±0.02
	...	...	1971 December 22–23	3400–6300	10	134§	+0.06±0.07
	...	...	1972 January 12–13	3400–6300	10	190§	0.00±0.01
Sco X-1..........	13.2±0.2	1.0±0.2‖	1971 May 21	4100–6300	23	120#	+0.14±0.03
	12.6±0.2	...	1971 May 22	4100–6300	23	60#	+0.04±0.04
	...	...	1971 May 22	5300–6300	23	15	+0.05±0.07
	13.0±0.2	...	1972 February 10	3400–6300	23	68	−0.01±0.03
	13.0±0.4	0.5±0.2‖	1972 February 11	4200–6300	10	30	0.00±0.06

* Universal Time.

† Approximate passband in Å between half-transmission points, governed by type of Polaroid used, photomultiplier response, and filter if used.

‡ Perhaps somewhat controversial; see Liller 1969.

§ Total integration times for two nights of each observing run, with two-night averages for q. See also table 2 and fig. 1.

‖ Our own brief measurements, possibly contaminated by night sky on 1971 May 21; value of 1972 February 11 agrees roughly with Landstreet and Angel 1971.

Time averages; see also fig. 2.

TABLE 2

DETAILED CIRCULAR POLARIZATION DATA FOR 3C 273 AND COMPARISON STARS

Object	Approx. Visual Magnitude	Date (UT)	λ (Å)	Total Integration Time (minutes)	σ_q(15 min), (percent)*		q(percent), Time Average†
					Meas.	Ideal	
3C 273	12.8	1971 February 21	4100–6300	42	0.05	0.05	0.00±0.02
	...	1971 December 22	3400–6300	34	0.11	0.04	+0.15±0.08
	...	1971 December 23	3400–6300	100	0.13	0.04	−0.03±0.05
	...	1972 January 12	3400–6300	100	0.05	0.04	0.00±0.02
	...	1972 January 13	3400–6300	90	0.06	0.04	+0.01±0.03
Star a‡	13.1	1971 December 22	3400–6300	6	0.17	0.05	+0.13±0.28
Star X‡	12.8	1972 January 12	3400–6300	25	0.08	0.04	−0.10±0.06
Star 1‡	12.5	1972 January 13	3400–6300	120	0.06	0.03	−0.02±0.02
Star 2‡	12.5	1972 January 13	3400–6300	65	0.04	0.03	0.00±0.02

* Root mean square fluctuations of q over 15-minute intervals, as expected from measured 30-s fluctuations, compared with theoretical photoelectron shot noise.

† Errors based on *measured* σ_q(30 s), times $(30\ \mathrm{s}/T)^{1/2}$.

‡ Selected for magnitudes comparable with 3C 273 but otherwise at random. Stars a, X from field near 3C 273; linear polarization not measured. Stars 1, 2 were in direction of the Hyades cluster and had linear polarization 1.0 and 1.7 percent, respectively.

σ_q for 15-minute averages obtained respectively in two ways: (*a*) The measured σ_q(15 min) was derived from the actual record by first calculating σ_q(30 s) and then assuming $\sigma_q(15 \text{ min}) = \sigma_q(30 \text{ s})/\sqrt{30}$. (*b*) The ideal σ_q(15 min) is $N_e^{-1/2}$, where N_e is the number of photoelectron pulses in 15 minutes. (Though our system does not have pulse counting, we determine N_e indirectly.) In table 2 and also in table 1 we have used such $\sigma_q(T)$ derived from 30-s intervals in the records to specify the errors. These errors are evidently conservative, because $q(t)$ might have an intrinsic power spectrum of its own, added to the shot noise. Any signal standing out over such errors would indicate a real q varying over characteristic times much longer than 30 s. Further checks on the fluctuations are furnished by data from records for four miscellaneous stars comparable in magnitude to 3C 273, listed in table 2. Notice that excess noise in σ_q(meas) of 3C 273 in the December run also shows up in star *a;* it was clear upon data reduction that some kind of excess electronic noise was present during the entire run. (Tests with an artificial calibrating light also bore this out.) Allowing for this, we conclude that *all* the recorded fluctuations of $q(t)$ for 3C 273 are within the normal statistics.

Similar analysis has been applied to the Sco X-1 data, with a slightly more interesting result. The expected $\sigma_q(T)$ have again been conservatively computed from σ_q(30 s) of the recorded data and used for the vertical error bars in figure 2. The latter shows what must on the surface be called a polarization flare, on the night 1971 May 21. Some sky effects were an issue in that measurement. Though there was no moon nor twilight, with the large stop the sky flux contribution was about 20 percent of the total. This probably contaminated the linear polarization (see note || to table 1), but probably not the circular polarization. A check on a star-free adjacent region the next night showed negligible circularly polarized flux, and sky polarization should not vary greatly. However, in any case, (*a*) the maximum q recorded for the object was quite modest, ~0.25 percent; and (*b*) no significant values $|q| \gtrsim 0.1$ percent were found in any of the 15-minute intervals on the following night May 22, or on the nights 1972 February 10 and 11.

III. DISCUSSION

In our view the cases for sizable circular polarization of NGC 1068 and 3C 273 should be dismissed. As for Sco X-1, it can be added that Landstreet and Angel (1972), in the course of work on the linear polarization, detected no circular component. We do not claim our single instance of an apparent real effect as a discovery, because although

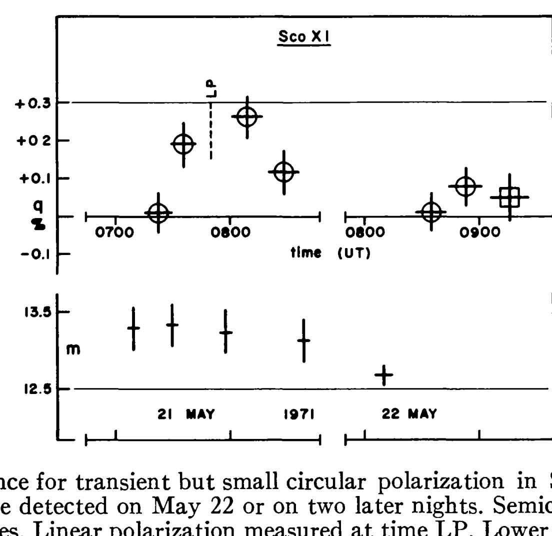

FIG. 2.—Some evidence for transient but small circular polarization in Sco X-1 on 1971 May 21. No cases $|q| > 3\ \sigma$ were detected on May 22 or on two later nights. Semicontinuous q data shown as 10- or 15-minute averages. Linear polarization measured at time LP. Lower section shows approximate visual magnitude. Circled q points were for $\lambda\lambda$4100-6300; squared point had passband $\lambda\lambda$5300–6600.

the event lies well outside probabilities for random noise we cannot rule out an instrumental artifact. If real, the event (fig. 2) implies a fluctuating q on a timescale $T \sim 1$ hour. There is some incentive to look for more events and to be prepared to relate them to changes in brightness and perhaps in linear polarization.

As to why the Russian group found such large q-values, the chance that they observed real but transient effects in all three objects is very remote. Our only suggestion is that they may not have dealt thoroughly enough with linear-circular conversion, even though they discuss this at length. Nevertheless, their upper limits for many interesting objects are a valuable contribution for the planning of future work.

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