A New Distance Indicator for Spiral Galaxies?

E. GIRAUD, ESO

1. Introduction

With an observed dispersion of 0.45–0.55 mag, the Tully-Fisher (T-F) relation between the maximum rotation velocity V_M, deduced from H I profiles at 21 cm, and the luminosity of spiral galaxies is a good method for determining relative distances of clusters of galaxies. However, the scatter in the relation is larger than can be accounted for by observational errors only. In particular the B-band T-F relation is probably not single-valued (i.e. an Sb with a maximum rotation velocity equal to that of an Sc is fainter in the blue than the Sc). It is generally thought that the use of infrared magnitudes (H band at 1.6 μm) tends to reduce the scatter. But a major disadvantage at H is the absence of a system of diameters (H magnitudes are measured within a standard aperture ratio, fixed at ~ 31 % of the isophotal blue diameter at 25 mag arcsec^{-2} [Fig. 1]).

In view of this, it was expected that significant improvement would be obtained if isophotal magnitudes could be measured in a band where:

(a) the sensitivity of CCD detectors is good

(b) the corrections for galactic and internal reddening are quite small

(c) the luminosity is a reliable indicator of the mass in stars.

The red I-band was chosen as a compromise between these constraints. One of its disadvantages is the brightness and the noise of the sky background. But this is not a major problem because accurate sky subtraction can be made on CCD frames. A programme of CCD surface photometry in the I-band was started for this initial purpose.

2. Observations

Nine nights in two runs (September 1986 and May 1987) at the 1.5-m Danish telescope were allocated to the project. Unfortunately, poor weather conditions were encountered during a large fraction of the observing time. Useful observations under photometric conditions could be performed in I and B or V for about $2\frac{1}{2}$ nights. The data were acquired with CCD # 1 in September 1986 and CCD # 3 in May 1987. Series of dome flat fields were taken for every filter at the beginning of each night. Standard stars from the catalogue of Landolt were observed alternately with galaxies.

3. Reduction

The reduction of raw data was carried out with IHAP at ESO, Garching. The sky background was measured by taking the mean of pixel values within disks of specified centres and radii. The disks were centred to avoid stars and extended galaxy light. Isophotic levels were deduced for each frame from the standard stars. Then elliptical isophotes were obtained visually by overlaying ellipses of given centre, major axis, position angle and ellipticity onto high contrast images. Most often the isophotes can be fairly well approximated by ellipses, but in general not all of them have the same centre, ellipticity and position angle. An example of the shift of the isophotes is shown in Figure 2 for NGC 4522. Non-concentric isophotes were encountered in the case of very dusty galaxies. This is illustrated in Figure 3 for the edge-on galaxy I3322A. For this galaxy bright contours were forced on a symmetric profile. The apparent magnitudes were measured within various isophotal diameters and the magnitude–line width relation was tested for each of them.

4. Results

It turned out that the reduction of the spread in the Tully-Fisher relation is only marginal. However, the surface brightness was identified as an irreducible source of scatter. More precisely it was found that the surface brightness of galaxies of similar line widths can be different. At this point one possibility would be to consider that kinematic and photometric data describe a plane given by $L \propto V_M^x S^y$ where the luminosity L and the mean surface birghtness S are measured at some isophote. The pend-

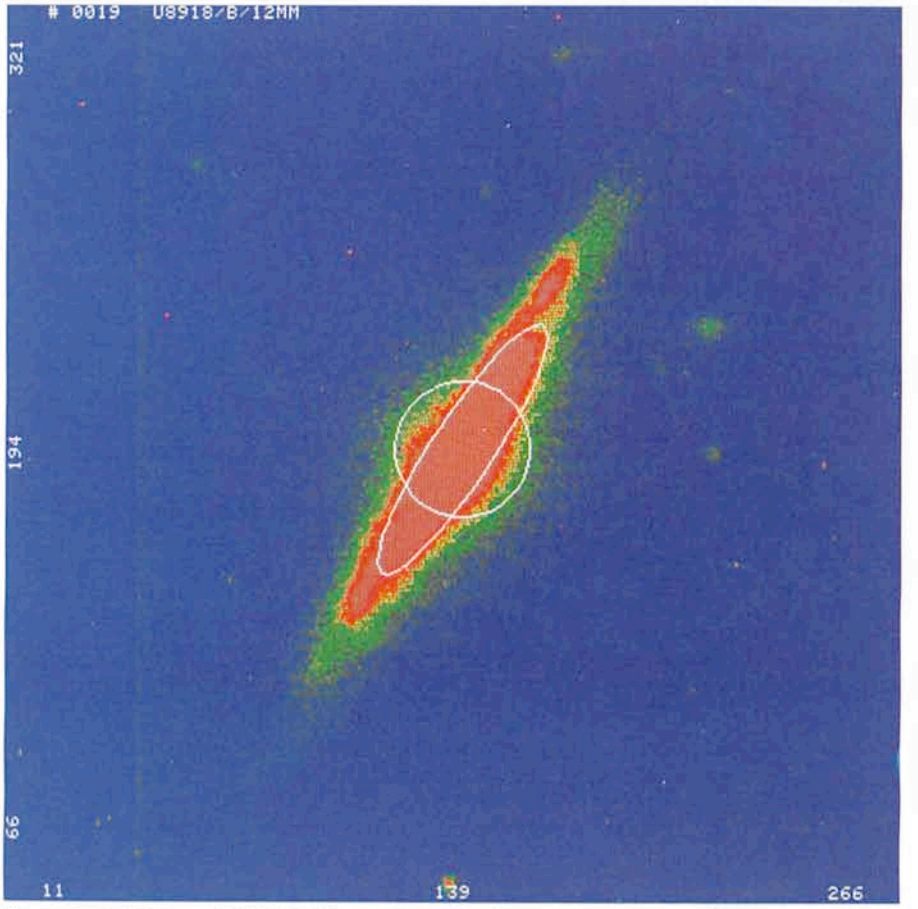

Figure 1: *A B-frame of UGC 8918, an edge-on galaxy at v = 4070 km s^{-1}, obtained with the 1.5-m Danish telescope at La Silla (exposure time 12 minutes, CCD # 3). Superimposed are the standard circular aperture at log A/D (O) = – 0.5 of the infrared system and the elliptical contour used in the I-band (in the case of a rotation velocity V_M = 167 km s^{-1}).*

Detailed Spectra at z = 4.11

The hitherto most distant known object in the Universe is Q0000-26, a 17.5-mag quasar in Sculptor with redshift 4.11. Spectra by J. Webb with the ESO 3.6 m + CASPEC (480–660 nm, 0.06 nm resolution, >12 hr integration time) show many absorption lines around z = 4 and an intervening galaxy at z = 3.39 (ESO PR 13/87).

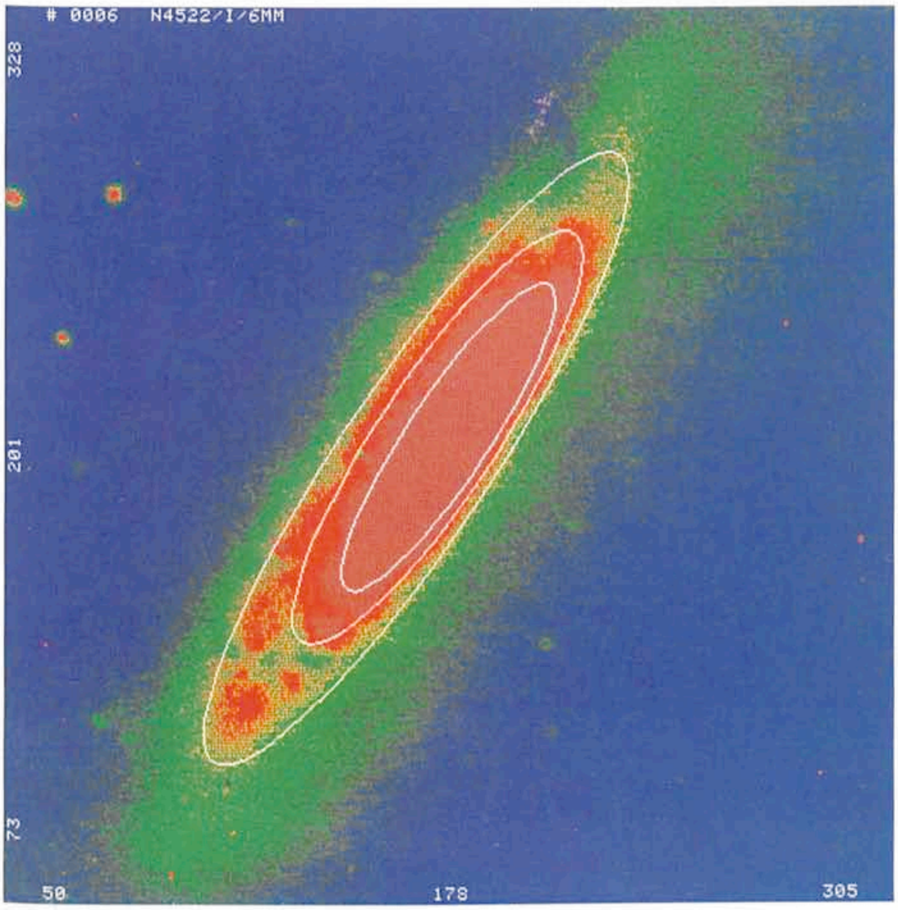

Figure 2: *An I-frame of NGC 4522, a galaxy in Virgo, showing a shift in the isophote contours. (1.5-m Danish telescope, CCD # 3, exposure time 6 minutes.) The luminosity and the surface brightness of this galaxy were measured near the outermost elliptical contour.*

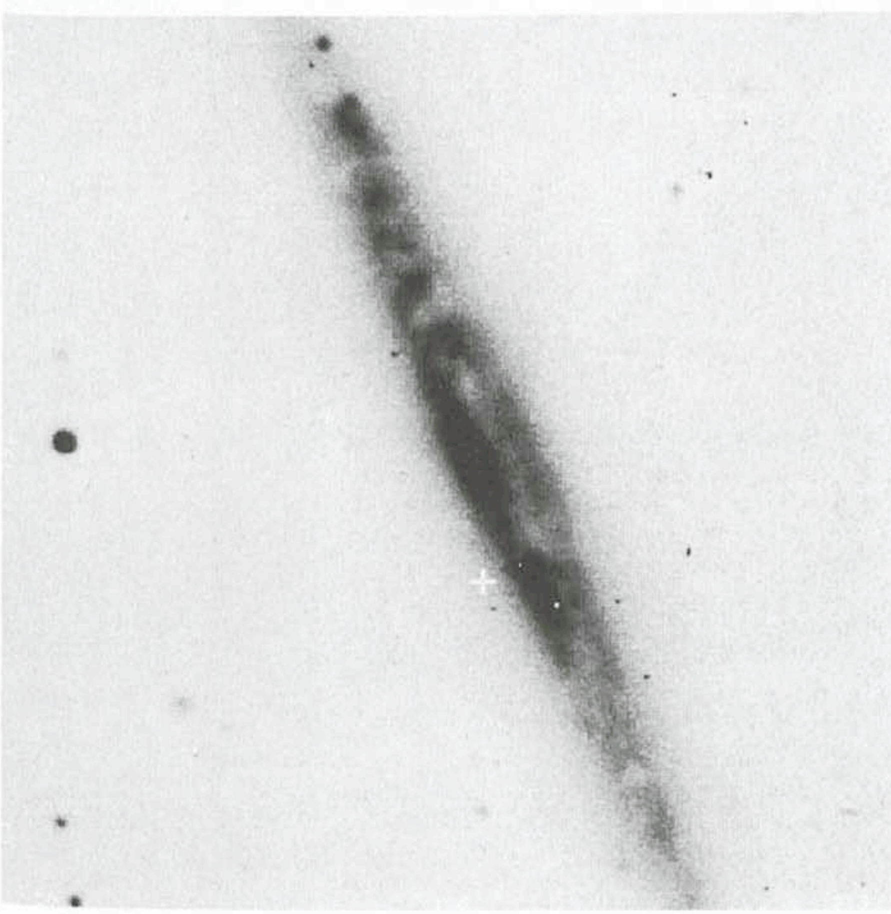

Figure 3: *Image of the edge-on Scd(?) galaxy I3322A in Virgo showing a strong line of dust in its plane.*

A NEW LUMINOSITY INDICATOR ?

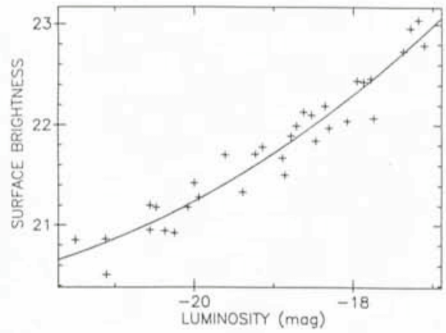

Figure 4: *The luminosity-surface brightness relation.*

ing question would be to determine it. In fact, the synthetic rotation curves pictured by Rubin et al. (1985) indicate that the maximum rotational velocity of bright galaxies is generally reached within a small fraction of their diameter, while for small galaxies the rotation velocity increases more slowly along the radius. From this argument, a relation between luminosity, rotation velocity and surface brightness would not involve a single isophote for all galaxies.

To take full advantage of the surface photometry the luminosity and the surface brightness have been measured within isophotes deduced from an empirical linear relation where brighter isophotes are used for galaxies of progressively higher rotation velocity. Apparent magnitudes and diameters were corrected for galactic absorption and internal reddening by using the equations of the RC2 with a maximum of $A_I = 0.28$ mag for edge-on galaxies and $A_I/A_B = 0.35$.

The relative distances have been derived from the Hubble flow by assuming that the motion of the Local Group in the frame of the cosmic microwave background is the composition of the infall of the Local Group toward Virgo and of the L.S.C. toward Hydra-Centaurus.

The basic result of this approach is illustrated in Figure 4 which presents the luminosity-surface brightness relation.

From this first test, I get a dispersion of 0.18 mag in the relation luminosity → surface brightness and 0.35 mag in the relation surface brightness → luminosity.

This result, which is much better than the Tully-Fisher relation, is quite impressive because the spatial distribution and the environment of the set of data are very heterogeneous. (There are some objects in Virgo, Pegasus I, Z 74-23 and

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The area around the Horsehead Nebula, reproduced from a 120-minute ESO Schmidt plate (IIIa−F + RG630). Contrast control by B. Dumoulin and J. Québatte, ESO. ▸

in the field!) In particular, if this sample is representative of the real world, the cosmic scatter must be very small. Moreover it seems possible to improve the accuracy of the method by balancing the weight of the errors in each photometric variable. A solution is to choose brighter isophotes for massive galaxies in order to increase the range in surface brightness. A more complete analysis of the data is now in progress.

To conclude, an accuracy level of 12–15 % in extragalactic distances seems to be within arm's reach by this new luminosity indicator. It would be very important to confirm the result with a sample of ~ 100 galaxies, to calibrate the zero-point of the relation and to start the study of galaxy streamings at kinematic distances smaller than 8,000–10,000 km s^{-1}.

References

Rubin et al., 1985, *Astrophys. J.*, **289**, 81.

A New Device for Performing High-Speed Polarimetric Measurements

K. METZ, D. KUNZE, M. ROTH, Universitäts-Sternwarte München, F.R. Germany
D. HOFSTADT, ESO

Introduction

The explosion of the supernova SN 1987A in the LMC on February 23, 1987, was such an exceptional event for the present generation of astronomers that all possible efforts are justified that could allow a deeper insight into the somewhat spectacular results obtained for the supernova. It is not our purpose to review here the descussions that were triggered by the observation of two different neutrino showers that raised the question as to whether the precursor of SN 1987A is now a black hole or a neutron star. If we assume the latter, it should be possible to carry out linear as well as circular polarization measurements synchronous with the perhaps fast rotating central star, as soon as the pulsar becomes visible. With respect to the distance modulus of SN 1987A, which is of the order of $18^{m}_{.}5$, it is evident that we cannot directly observe in the visible domain the polarization of a central object in the supernova. However, it will perhaps be possible to measure the interaction of a strong and quickly varying magnetic field with the shell surrounding the pulsar. To derive a correlation between polarization and magnetic field, it must be possible to measure the polarization synchronously with the rotation of the neutron star. This can be implemented in a simple way also in the relatively slow ESO polarimeter PISCO. The intended modification has to be carried out in such a way that absolutely no interferences with the usual functions of the instrument can occur (Stahl et al., 1986). Therefore the proposed changes mainly have to be shifted onto the software facilities of the instrument. Since it requires much work to prepare the requisite programmes at a computer we have to start our modifications immediately and therefore at a time we are by no means certain about the usefulness of our efforts. However, once created, the intended modification can also be used for measuring fast varying objects like polars of DQ Her type.

Performance of the Modification

The multichannel analyzer described by K. Metz (1984) will be replaced by the ESO Time Series System (TSS) that allows data to be collected in four channels each msec and to write them in a special way onto a magnetic tape. For synchronizing the channels, the system additionally provides a 1 kilohertz signal from a CERME clock display unit that is connected with the ESO Universal Time to read out the UT. In describing the principle of the proposed modification of PISCO, all details of the phase plates and the polarizing prism that were described by K. Metz (1984, 1986) shall be omitted for the moment. Then the count-rates of the photomultipliers are proportional:

$$I +/- (Q \times \cos(4\delta(t)) + U \times \sin(4\delta(t)) \quad (1)$$

I, Q, U are the Stokes parameters to be measured (if the quarterwave instead of the half-wave plate of the compensator is used, Q, U describe the circular polarization of the signal), +/– stands for the two multiplier channels 1 and 2 respectively, $\delta(t)$ is the instantaneous position angle of the optical axis of the continuously rotating phase plate.

Since the two channels of the polarimeter can work independently, only one channel (with sign +) will be considered for the following:

for $\delta(t)$ =

0°.0	the multi-	I+Q	(a)
22°.5	plier count	I+U	(b)
45°.0	rate is	I–Q	(c)
67°.5	proportional	I–U	(d)

Since one rotation of the modulating half-wave plate yields four identical measurements of the polarization, the Stokes parameters measured for a certain angle $\delta(t)$ repeat modulo 90°.

The basic idea of the modification is then very simple: If one wishes a polarization measurement for a certain phase position X of the pulsar than one has to wait for a coincidence of the pulsar phase X and the necessary half-wave plate position angles (a), (b), (c), (d), each modulo 90°. The times of the coincidences are indicated by the clock pulses of the TSS and the 32 pulses generated in the polarimeter in order to indicate the instantaneous position angle of the rotating half-wave plate.

Time Resolution

The time resolution of the proposed modification cannot be described in a general way since it depends not only on the fixed rotation frequency of 6 Hz of the modulating half-wave plate but also on the period of the pulsar in question. Since the rotation of the half-wave plate cannot be adjusted to a fractional number of the pulsar period two entire compromises have to be met:

(1) For the selected pulsar phase X a certain deviation has to be tolerated (however, the deviation should not far exceed 10 % of the pulsar period).

(2) The positions (a), (b), (c), (d) of the axis of the rotating phase plate can be selected only with an accuracy of $11^{\circ}_{.}25$, corresponding to the distance of two subsequent clock pulses generated in the polarimeter during one rotation of the modulating phase plate. If P is the period of the pulsar, d = 5.21

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