GLOBAL EXTINCTION IN SPIRAL GALAXIES
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ABSTRACT
Magnitude-limited samples of spiral galaxies drawn from the Ursa Major and Pisces Clusters are used to determine their extinction properties as a function of inclination. Imaging photometry is available for 87 spirals in the B, R, I, and K' bands. Extinction causes systematic scatter in color-magnitude plots. A strong luminosity dependence is found. Relative edge-on to face-on extinction of up to 1.7 mag is found at B for the most luminous galaxies but is unmeasurably small for faint galaxies. At R the differential absorption with inclination reaches 1.3 mag, at I it reaches 1.0 mag, and at K' the differential absorption can in the extreme be as great as 0.3 mag. The luminosity dependence of reddening can be translated into a dependence on rotation rate, which is a distance-independent observable. Hence, corrections can be made that are useful for distance measurements. The strong dependence of the corrections on luminosity act to steepen luminosity–line width slope correlations. The effect is greatest toward the blue, with the consequence that luminosity–line width slope dependencies are now only weakly a function of color.

Key words: galaxies: ISM — galaxies: photometry

1. INTRODUCTION
It is evident that there is optical obscuration in spiral galaxies, yet the quantitative amount of the dimming due to obscuration is disputed. There is a displacement in the photometric properties of edge-on and face-on galaxies. If distance considerations are taken into account, then in a set of similarly sized galaxies the more edge-on ones will tend to be fainter, or in a set of galaxies of the same luminosity the more edge-on ones will tend to be bigger.

This opening statement touches on the two outstanding problems that confront efforts to quantify the level of obscuration in galaxies. To begin with, there is more than one good explanation for the photometric separation of galaxies with inclination: galaxies of the same intrinsic size and luminosity might appear dimmer toward edge-on because of increased path lengths through the obscuring material, or they might appear larger toward edge-on because surface brightnesses are enhanced by the increased path lengths. The second big problem arises out of uncertain relative distances with most samples since luminosities and dimensions scale differently with distance; hence, distance uncertainties add noise to tests.

A nice review of previous research is provided by Huizinga (1994). At one extreme, galaxies were accepted to be completely transparent and corrections were made only to dimensions in the Reference Catalogue of Bright Galaxies (de Vaucouleurs & de Vaucouleurs 1964). At the other extreme, galaxies were proposed to be optically thick at all observable radii by Valentijn (1990), to the extent that González-Serrano & Valentijn (1991) posited that the obscuring material could resolve the “dark matter” problem. The current generally accepted viewpoint is intermediate. Spiral galaxies probably have high opacities near their centers but are relatively transparent at their visible extremities.

We have a utilitarian need to understand the global obscuration properties of spiral galaxies. A primary consideration for us is the need to correct for inclination effects with luminosity–H I profile line width distance estimators (Tully & Fisher 1977). Inclination dependencies also have to be understood when we use photometric information in statistical studies of galactic structure (cf. Tully & Verheijen 1997). In these cases, it may be enough to know the overall and statistical effects of projection from an empirical evaluation. An alternative approach is to try to develop a physical model of what is happening. However, a realistic model would have many parameters and require a lot of information as constraints. There have been attempts in this direction (Wainscoat, Freeman, & Hyland 1989; Byun, Freeman, & Kylafis 1994; Bianchi, Ferrara, & Giovanardi 1996). To date, there has not been any study with both the information content per object needed for elaborate modeling and the large number of objects needed for a statistical evaluation of the norm and range of obscuration properties.

What we bring that is new is imaging photometry over a substantial optical-infrared baseline: large-format BRI CCD imaging and K' imaging with a 256 × 256 HgCdTe detector. Our sample is not really large, but it has nice qualities with respect to the distance problem and with respect to completion. We are using data from two clusters, and hence objects are at either of two discrete distances and there is a measure of completion to well-specified limits.

Our primary sample is drawn from the Ursa Major Cluster. The photometric data have been published by Tully et al. (1996). There are 62 galaxies in a window on the sky and in redshift that are brighter than 14.7 mag at B. Optical photometry is available for all 62, and K' photometry is available for 60. Observations and reductions of the optical components were done by M. J. P., M. A. W. V., and R. B. T. Observations and reductions of the K' material were carried out by J.-S. H., M. A. W. V., and R. B. T. The Ursa Major Cluster is a loose, irregular cluster with normal

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spiral and few gas-poor systems. It is probably dynamically young. The constituents may be representative of typical galaxies outside of dense regions. Our sample is complete down to roughly the luminosity of the Small Magellanic Cloud, at $M_B \approx -16.5$ mag. Unfortunately, there is a paucity of extremely luminous galaxies in this sample.

Our supplemental sample is drawn from what has been called the Pisces Cluster, part of the Perseus-Pisces filament (Haynes & Giovanelli 1988) and an entity that has frequently been used in studies of distances and flows (Aaronson et al. 1986; Han & Mould 1992). Sakai, Giovanelli, & Wegner (1994) have discussed an overlapping part of the region and refer to subunits as the NGC 383 and NGC 507 groups. We consider candidates within the window $00^h49^m < a < 01^h32^m$, $28^\circ < \delta < 34^\circ$, and $4300 \, \text{km} \, \text{s}^{-1} < V_{hel} + 300 \, \text{sin} \, l \, \cos \, b < 6400 \, \text{km} \, \text{s}^{-1}$. There are a couple of knots in the region dominated by early-type galaxies, but spirals are scattered about in an irregular fashion. We take galaxies detected in the H I 21 cm line at Arecibo (Giovanelli & Haynes 1985, 1989; Wegner, Haynes, & Giovanelli 1993), typed as spirals, and with cataloged axial ratios $b/a \leq 0.5$. The Arecibo telescope gives a high detection rate for spirals at 5000 km s$^{-1}$, so there is reasonable completion (at $\delta < 33^\circ$) to a magnitude limit of $B = 15.7$. This limit is $M_B = -19$ mag after corrections, roughly the magnitude of the Local Group galaxy M33. Cases in which the H I signals may be confused are avoided. This Pisces sample has the disadvantages that our axial ratio limit excludes very face-on examples and, for observational reasons, it is not as rigorously complete as the Ursa Major sample (details in next section). However, it contains a substantial number of intrinsically luminous spirals. The optical photometry was acquired and reduced by M. J. P. and R. B. T. The $K'$ photometry was obtained by P. L. W., W. S., and R. B. T. There are 38 galaxies in the Pisces sample.

The information we have available allows us to escape the problems that have plagued efforts to calibrate the levels of obscuration in galaxies. We will describe tests that decouple luminosities and dimensions. The cluster nature of the samples essentially eliminates scatter due to uncertain relative distances. The sample completeness features are important.

Two different tests have been considered. It turns out that the most sensitive test involves deviations as a function of inclination from the mean correlation in color-magnitude plots where one passband is $B$, $R$, or $I$ and the other passband is $K'$. Another test gives consistent but less statistically significant results. It involves deviations with inclination from the mean correlations between luminosities and H I profile line widths. The latter test requires kinematic information as well as photometric and cannot include very face-on cases because of the large uncertainties in the deprojected kinematic parameter. Hence, fewer galaxies are available for the second test and the inclination baseline is truncated. Also, the ratio of reddening scatter to the intrinsic luminosity scatter in the relations is somewhat more favorable in the first test compared with the second.

Between the two clusters, we have 101 galaxies with BRIK' information in our magnitude-limited sample. It will be seen that the statistical effects of obscuration are quite evident. The question becomes, how complex a description of the obscuration do the data afford? The simplest case would be the definition of a single coefficient for some analytic dependency on inclination or ellipticity in each bandpass. However, it has been suggested that there are dependencies on such additional parameters as type (de Vaucouleurs et al. 1991; Han 1992) and luminosity (Giovanelli et al. 1995). Indeed, it will be shown that there is a strong dependence of obscuration on luminosity in our sample. As Giovanelli et al. (1995) point out, the correction procedure that is adopted affects the slope of the luminosity–line width correlation and hence, potentially, distance estimates based on that correlation. The challenge to us is to generate a description of the luminosity dependence with our relatively limited sample. One needs enough cases in a bin to sample a broad inclination range and characterize the scatter. Then the luminosity dependence has to be transformed to a distance-independent parameter, like the profile width, to be useful for distance measurements.

It would also be nice to further our understanding of how the obscuring material is distributed in galaxies. For example, Giovanelli et al. (1994) and Peletier et al. (1995) contend that there is a strong radial dependence, with considerable obscuration near the centers of galaxies and little at the outer edges. It would be possible to investigate that kind of effect with two-dimensional color decompositions with our data. However, that study is beyond the scope of this paper.

2. THE COMBINED UMA AND PISCES DATA SETS

The Ursa Major data set is the larger of the two cluster samples and has more rigorous completion limits. The cluster membership was defined by windows on the plane of the sky and in velocity, as discussed by Tully et al. (1996). The photometric data are provided in that paper for the 79 galaxies accepted as cluster members. The census of the cluster within the prescribed window constraints is considered to be complete to $B = 14.7$, or, after preliminary corrections for inclination and assuming a distance modulus of 31.33 mag (18.5 Mpc), $M_B^{Um,h} \approx -16.5$ mag at the faint limit. Some photometric, kinematic, and dynamical properties of these galaxies were discussed by Tully & Verheijen (1997) and Verheijen (1997).

The distance to UMa was determined by the luminosity–line width methodology (Pierce & Tully 1988, 1992; Tully 1998). For intercomparisons within the UMa sample, the distance choice is irrelevant; the only issue is the validity of the assumption that all the distances are the same. The intercomparisons between the UMa and Pisces samples requires knowledge of the relative distances of the two groups, but the zero-point calibration of the distance estimator is irrelevant. Moreover, it will be shown that our primary color-magnitude test is quite insensitive to modest relative distance errors. Hence, the data are transformed to absolute magnitudes to facilitate the intercomparison between clusters but the results are insensitive to uncertainties in distances.

All our color-magnitude comparisons are made with $K'$ magnitudes and colors that stretch to $K'$ from one of $B$, $R$, and $I$. This choice is made because $K'$ is almost free of reddening, and hence, overwhelmingly, the obscuration effects are found in the color term only. The $B$-band completion limit is found to translate to a $K'$ limit of $M_B^{Um,h} = -19.2$ for the UMa Cluster. The superscripts indicate that corrections have been made for reddening within our own
Galaxy (latitude $b$) and for the redshift spectral displacement ($k$-correction), although both are negligible for the UMa systems. These corrections are small but not completely negligible for the Pisces systems to be discussed next. The Galactic reddening corrections are taken from Burstein & Heiles (1984) in the following ratios between bands: $B = 1.00$, $R = 0.62$, $I = 0.41$, $K' = 0.08$. The spectral displacement adjustments ($k$-corrections) are $\sim 0$ for UMa galaxies, and for Pisces galaxies are $\sim 0.03 \pm 0.03$ mag at $B$ (Pence 1976) and $\lesssim 0.01$ mag at $R$, $I$, and $K'$. The bands are Johnson $B$, Cousins $RI$, and a filtering of the $K$ infrared atmospheric window that damps thermal noise.

After tiny Galactic and $k$-corrections (but not inclination corrections) have been applied, there are 63 galaxies in the magnitude-limited sample (complete except for two galaxies missing $K'$ photometry: the Sm galaxy UGC 6628 and the Sa galaxy UGC 7129). Ten of these are classified S0 or S0/a. Our tests fail to demonstrate that there is any extinction in this small subset of early-type galaxies. Hence these galaxies earlier than Sa are excluded from further consideration. The magnitude limit excludes any galaxy of type Im. The UMa sample thus provides our analysis with 53 spirals typed Sa to Sm.

Unfortunately, the UMa Cluster lacks extremely luminous members. The brightest galaxy at $K'$ is NGC 3953, an Sbc system with $M_{K'}^{b.c.} = -24.35$ mag, $M_B^{b.c.} = -20.88$, and a maximum rotational velocity $V_{\text{max}} = 219$ km s$^{-1}$ (these values have been corrected for inclination effects in ways to be described). This system is comparable to our Galaxy and considerably smaller than Andromeda. If extinction is a function of luminosity (Giovanelli et al. 1995), then the sample needs to be extended to larger systems. The Pisces region sample suits our needs.

The Pisces Cluster galaxies selected for this study lie within the space and velocity windows described in the previous section, have cataloged axial ratios $b/a < 0.5$ (nominally, inclinations greater than 60°), are classed as spirals, and have been detected in the H$\alpha$ radio line. Giovanelli & Haynes (1989, pp. 633–634) claim "reasonable[ly] complete[ion] for spiral galaxies ... larger than 1°" as reported in the Uppsala General Catalogue (Nilson 1973) and "more than 90%" completion of spirals brighter than 15.7 mag in the Catalogue of Galaxies and of Clusters of Galaxies (Zwicky et al. 1961–1968).

The Pisces sample is taken to be at a distance of 60 Mpc, $(m - M)_0 = 33.88$ mag. 2.55 mag more distant than UMa. This distance is determined from a recalibration of the luminosity–line width relations (Tully 1998) reviewed in §6. The differential UMa-Pisces distance comes from the superposition of the data from these two regions. It will be explained further along why our primary test is not very sensitive to relative distance uncertainties. At this assumed distance, the equivalent $K'$-band completion limit for our sample is $M_{K'}^{b.c.} = -21.4$ mag (Galactic and $k$-corrections applied but not inclination corrections). We have four-band photometry for 34 galaxies brighter than the completion limit. The most luminous galaxy in this Pisces sample has $M_{K'}^{b.c.} = -25.20$ mag, $M_B^{b.c.} = -21.79$ mag, and a maximum rotational velocity $V_{\text{max}} = 259$ km s$^{-1}$, properties resembling the Andromeda galaxy.

In summary, our analysis will be conducted with 87 galaxies: 53 spirals in UMa with $-24$ mag $\lesssim M_{K'}^{b.c.} \lesssim -19$ mag and 34 spirals in Pisces with $-25$ mag $\lesssim M_{K'}^{b.c.} \lesssim -21$ mag. The UMa systems cover a full range of inclinations, but systems oriented toward face-on were not observed in Pisces.

3. Deviations from Color-Magnitude and Line Width-Magnitude Correlations

Color-magnitude diagrams are shown in Figure 1 for $B - K'$ versus $M_{K'}$, $R - K'$ versus $M_{K'}$, and $I - K'$ versus $M_{K'}$. The different symbols distinguish the UMa and Pisces samples. Galactic and $k$-corrections have been applied but not corrections for obscuration as a function of inclination. The lines in Figure 1 are regressions with uncertainties in colors. Obscuration as a function of tilt essentially only affects the colors.

Our expectation is that systems that are more edge-on would be reddened by extinction and tend to lie to the right in the color-magnitude diagrams. In fact, this expectation is
Fig. 2.—Deviations in color from the mean relations of Fig. 1 as a function of axial ratio \( b/a \). The top row of panels illustrates deviations at \( B - K' \), the middle row illustrates deviations at \( R - K' \), and the bottom row illustrates deviations at \( I - K' \). The left column of panels isolates the fraction of the sample with \( M_K < -23.5 \) mag (nine galaxies in Ursa Major and 12 galaxies in Pisces), the panels second from left show data for galaxies with \( -23.5 \text{mag} < M_K < -22.5 \text{mag} \) (11 galaxies in Ursa Major and 11 galaxies in Pisces), the panels second from right show data for galaxies with \( -22.5 \text{mag} < M_K < -21 \text{mag} \) (13 galaxies in Ursa Major and 11 galaxies in Pisces), and the right set of panels shows data for galaxies with \( -21 \text{mag} < M_K < -19.2 \text{mag} \) (20 galaxies in Ursa Major and none in Pisces). *Filled circles:* Ursa Major; *open circles:* Pisces. The solid line in each panel gives the best fit for the analytic expression \( \gamma_4 \log (a/b) \) with the requirement that the dependence on \( b/a \) be nullified.
met for the high-luminosity cases but is not clearly met for the faintest galaxies. Galaxies with $M_B^k < -23$ mag have considerable extinction, and galaxies with $M_B^k > -20$ mag have negligible extinction. The evidence is shown in Figure 2. After some experimentation, it was decided the best we could do with the present information was to separate the data into four luminosity zones. Deviations from the mean $B-K'$, $R-K'$, and $I-K'$ versus $M_K^k$ fits are plotted as a function of axial ratio in the four separate bins.

We adopt a standard empirical description of the extinction, $A_{\lambda}$, as a function of inclination, $i$, in the passband $\lambda$:

$$A_{\lambda}^{-0} = \gamma_{\lambda} \log \left( \frac{a}{b} \right).$$

(1)

The nomenclature in the superscript, $i - 0$, implies corrections are to face-on orientation but do not account for extinction in a face-on system. Inclinations are related to axial ratios, $b/a$, through

$$\cos i = \sqrt{\frac{(b/a)^2 - r_0^2}{1 - r_0^2}},$$

(2)

where $r_0$ is the axial ratio of a system viewed edge-on. For the purposes of this discussion we take $r_0 = 0.20$, although values as low as $r_0 \approx 0.1$ can be entertained and the choice is not important here. Our corrections, $A_{\lambda}^{-0}$, do not depend on the choice of $r_0$, only on $b/a$.

Optimal values of $\gamma_{\lambda}$ were found for each of the four luminosity bins and the three passbands $\lambda = B, R, I$. The optimal values satisfy the requirement that, with these corrections to magnitudes, there are no color-magnitude residuals with axial ratio. The uncertainties that are recorded correspond to corrections that yield slopes that differ by 1 standard deviation from no correction. Account has to be taken of the fact that extinction is not entirely negligible at $K'$. In this analysis, we assume that $A_K$ is 15% of $A_B$, 21% of $A_R$, and 25% of $A_I$. These choices might sound surprisingly high. They were arrived at iteratively and will be justified in §5.

The best fits are shown in Figure 2. As expected, the amplitude of extinction drops from $B$, through $R$, to $I$. It is evident that the amplitude of extinction within any of these bands also drops in passing from high to low luminosity. By the lowest luminosity band, the correlation with axial ratio is so weak that it is not statistically significant. The information in the three passbands is not entirely independent, since the samples are the same and all colors share the same $K'$ information. These results are summarized by the placement of the squares in Figure 3.

A similar analysis can be performed with the residuals of line width–magnitude correlations. This test is not quite as sensitive as the one already described, for the reasons mentioned in §1. Since fewer galaxies are available, we consider three bins instead of four: $M_K < -23.4$ mag (21 galaxies), $-23.4 \leq M_K \leq -22.0$ mag (25 galaxies), and $M_K > -22.0$ mag (16 galaxies). The results from these tests are recorded by the triangles in Figure 3.

The evidence from the two tests is consistent and clearly indicates a falling trend of $\gamma_{\lambda}$ toward the fainter galaxies. Before we draw conclusions, though, let us compare these results with what others have found.

4. COMPARISON WITH ABSORPTION PARAMETERIZATIONS
IN THE LITERATURE

Most of the early work involving large data sets used $B$ material, or photographic magnitudes transformed to $B$. In the Third Reference Catalogue (de Vaucouleurs et al. 1991), extinction is described by the familiar parameterization $A_K^{-0} = \gamma_B \log (a/b)$, where $\gamma_B$ is described as type-dependent. It is a maximum value for type Sc at $\gamma_B = 1.5$ and decreases symmetrically with type steps toward earlier or later morphologies to $\gamma_B = 1.0$ at types Sa and Sm. There is a strong correlation between type and luminosity, especially for Sbc and later (later types tend to be fainter), so it can be expected that the alternative dependencies of extinction on type or luminosity are manifestations of the same phenomenon. The Third Reference Catalogue description is in the mid to upper range of the effect that we see. It is possible that high-luminosity early-type spirals have less obscuration than late types of the same luminosity, as the Third
Reference Catalogue corrections would suggest. The statistics with our sample are too slim to test this possibility, with only ~25% of our spirals typed Sa–Sb. From our limited information, we concur with the Third Reference Catalogue that extinction appears to be negligible in S0 systems.

Bottinelli et al. (1995) find a slightly larger $\tau_B = 1.67$ for pure disk systems, galaxies that would be typed Sc–Sd. These corrections are substantial and correspond to relatively opaque systems. Bottinelli et al. (1995) argue that $\tau_B \sim 1$ as far out in the galaxies as radii corresponding to a $B$ surface brightness of 25 mag arcsec$^{-2}$. As a consequence, they argue, diameters at that isophote are insensitive to inclination. Our results seem to be in reasonable agreement with their claim on an analysis of the Ford, & Buch-Mathewson, 1992 data set at $B$. Tentatively, we suppose that if Giovanelli et al. had $B$ and $R$ data for their large sample then they would have found greater extinction than we find. The dotted lines in the $B$ and $R$ panels assume augmentations above the solid lines such that at the luminosity of the brightest galaxy in our sample $\gamma_i$ is enhanced by 2% over what we find and such that $\gamma_i$ goes to zero 1 mag fainter than found with our data. These conditions are roughly consistent with what is found at $\lambda = I$.

Our comparisons would not be complete without mention that Willick et al. (1996) explicitly discount a luminosity dependence for extinction corrections. They base their claim on an analysis of the Mathewson, Ford, & Buchhorn (1992) data set at $I$ and also their own material at $r_{\text{Gunn}}$ for which Courteau 1996 finds $\gamma_i = 0.95$. Their analysis is more indirect, asking if there are residuals in distance estimates as a combined function of inclination and luminosity. They find no such correlation in residuals, but the plots have a lot of scatter. Our tests and those by Giovanelli et al. (1995) are more direct and less buried in other components of scatter.

The extinction in the faintest galaxies in our sample is so low that it is not significantly above our measurement capability, though other authors find evidence for absorption at low luminosities or late types. Our complete sample in UMa extends roughly as faint as the Small Magellanic Cloud. The other data sets that have been discussed draw from galaxies at larger redshift and contain relatively few galaxies as faint. The status of extinction in low-luminosity galaxies is not yet on a good footing.

The equations that describe the dotted lines in Figure 3 and, hence, represent the corrections we advocate are [with $h_{80} = H_0/(80 \text{ km s}^{-1} \text{ Mpc}^{-1})$]

$$\gamma_B = -0.35(15.6 + M_B^{k,i} + 5 \log h_{80})$$

or $\gamma_B = 0$ if $M_B^{h,k,i} > -15.6$ mag;

$$\gamma_R = -0.24(16.2 + M_R^{k,i} + 5 \log h_{80})$$

or $\gamma_R = 0$ if $M_R^{h,k,i} > -16.2$ mag;

$$\gamma_I = -0.20(16.9 + M_I^{k,i} + 5 \log h_{80})$$
or \( \gamma_I = 0 \) if \( M_{R^I,k,i} > -16.9 \) mag; and
\[
\gamma_K = -0.045(18.3 + M_{R^K,k,i} + 5 \log h_80)
\] (6)
or \( \gamma_K = 0 \) if \( M_{R^K,k,i} > -18.3 \) mag.

The adjustments specified by the absorption model that have been discussed have been applied to the color-magnitude diagrams that are shown in Figure 4. The luminosity amplitude dependency illustrated by the dotted lines in Figure 3 is applied. Hence the faintest galaxies have little correction. Because of this luminosity dependence to the corrections, the color-magnitude correlations become very steep. As a consequence, these relationships are not useful as distance estimators, contrary to the hopes of Tully, Mould, & Aaronson (1982). However, the weak dependence of the color-magnitude relations on distances means that relative uncertainties in the distances of UMa and Pisces of the color-magnitude relations on distances means that Mould, & Aaronson However, the weak dependence (1982).

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As an aside, it can be noted that the luminosity-dependent extinction corrections cause the bluer bands to be steeper than they appear in the absence of such a depen-

**Fig. 4.—**Color-magnitude diagrams corrected for absorption effects as a function of inclination. *Filled circles:* Ursa Major; *open circles:* Pisces; *asterisks:* types earlier than Sa. Straight lines are regressions with errors in colors to types Sa and later.
dency in the corrections. Hence, there is a much weaker color term in the slope than has been found in the past. Also, the differential correction with luminosity acts to eliminate curvature in the logarithmic luminosity–line width correlations.

The relations between $\gamma_j$ and $M_j$ presented in equations (3)–(6) can now be recast to replace $M_j$ terms with $W_R^j$ terms. The extinction parameter $\gamma_j$ can go to zero but cannot be negative:

$$
\begin{align*}
\gamma_B &= 1.57 + 2.75(\log W_R^i - 2.5), \\
\gamma_R &= 1.15 + 1.88(\log W_R^i - 2.5), \\
\gamma_I &= 0.92 + 1.63(\log W_R^i - 2.5), \\
\gamma_K &= 0.22 + 0.40(\log W_R^i - 2.5).
\end{align*}
$$

Fortunately, absorption values $A_j^{i-o} = \gamma_j \log (a/b)$ are stabilized against inclination uncertainties because an error drives the $\gamma_j$ and $\log (a/b)$ terms in offsetting senses.

The properties of the luminosity–line width correlations and the measurement of distances are not our direct concern in this paper, but the fits in Figure 5 do strongly constrain the relative distances of the Ursa Major and Pisces Clusters. The best distance is obtained by minimizing the residuals of each cluster separately to the mean line and taking the average of the four passbands. $B$ is given a relative weight of 0.7, in proportion to the square of the increased dispersion in that band. The relative distance modulus difference (Pisces minus UMa) is 2.55 $\pm$ 0.10 mag. The relative moduli in the different bands agree with that value with $\pm$ 0.03 mag rms dispersion. The rms scatter about the mean relationships is 0.42–0.43 mag at $R$, $I$, and $K'$ and 0.55 mag at $B$. The uncertainty of 0.10 mag in the distance estimate is the quadrature sum of the separate standard deviations of the two clusters in each of the $R$, $I$, and $K'$ bands.

If the distance modulus of the Ursa Major Cluster is taken to be 31.33 mag (Tully 1998), then Pisces is at 33.88 mag, or 60 Mpc. The cluster was given a velocity in the frame of the cosmic microwave background of $V_{\text{CMB}} = 4771$ km s$^{-1}$ by Han & Mould (1992). The inferred value for the Hubble constant is $H_0 = 80$ km s$^{-1}$ Mpc$^{-1}$.

7. CONCLUSIONS

Though our sample is moderate in number (pared to 87 spirals in the final analysis), it is reasonably well defined in terms of completion limits, and we have photometric images in four bands ranging from $B$, where there is considerable absorption, to $K'$, where there is minuscule absorption. Inclination effects of the sort attributable to extinction are seen in the scatter of line width–magnitude and color-magnitude correlations. Galaxies that are more edge-on are fainter and redder in the mean. Plots of deviations from the mean as a function of inclination provide a quantitative measure of the amplitude of absorption. Similar results are found whether the residuals in line width–magnitude or color-magnitude relations are considered. The statistical significance of the results is better with the color-magnitude analysis, so we concentrate on those tests.

We confirm the claim by Giovanelli et al. (1995) that the extinction in spirals is luminosity dependent. Galaxies with $M_{K'}^{i-o}$ reaching $-25$ mag ($M_B^{i-o} \sim -22$ mag) have up to $\sim 1.7$ mag of differential absorption between face-on and

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**Fig. 5.**—Luminosity–line width relations in the four passbands after corrections for inclination. **Filled circles:** Ursa Major; **open circles:** Pisces. Straight lines are regressions with errors in line widths.
edge-on (1.3 mag at R, 1.0 mag at I, 0.25 mag inferred at K’). However, the amplitude of extinction drops off rapidly with decreasing luminosity, becoming unmeasurable at $M_B \approx -20$ mag ($M_B \approx -17$ mag). The corrections reach higher values than we entertained in the past (Tully & Fouqué 1985). We arrived at our old corrections from data on relatively nearby galaxies that have low luminosities in the mean. Samples such as those studied by Giovanelli et al. (1994, 1995) have larger mean redshifts, and hence larger mean luminosities, and it can now be understood why such samples lead to larger absorption corrections. Extinction corrections have been formulated in terms of the distance-independent variable, line widths, so they can be applied to distance estimators. The data assembled in this paper suggest $H_0 = 80$ km s$^{-1}$ Mpc$^{-1}$.

Sadly, Peter Witchalls passed away a few days after this paper was submitted for publication.

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