EXTINCTION STUDIES IN M31

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Abstract.
In this paper we examine the gas-to-dust ratio in M31 galaxy combining radio emission data on neutral hydrogen (HI) and carbon oxide (CO) with the recent extinction estimates of young stellar groups (OB associations and open clusters). The fraction of sightlines where the observed N(HI)/2E_{B-V} ratio is outside the typical Galactic range is only 1/10; however, the correlation between these two quantities remains weak. A radial dependence of this ratio, twice flatter than previous estimates, indicates absence of a strong metallicity gradient. Detection of objects behind the disk of M31 allow pencil beams estimates of the total extinction. The results confirm the plausibility of a disk model with exponentially decreasing optical thickness in radial direction.

Nearly constant gas–to–dust ratio in the Galactic interstellar medium in the few kpc vicinity of the Sun [1] shows that dust and gas are well mixed and the grain properties do not vary essentially. One comes to this conclusion taking into account the existing tight correlation between the star light extinction and the observed total gas column density N(HI+2H_2). Local Galactic value of the gas-to-dust ratio is often adopted for regions outside the Solar neighborhood or in other spiral galaxies; yet, it is difficult to prove directly its universal applicability. One promising test is to perform comparison between the properties of dust and gas in nearby galaxies.

The nearest giant spiral, M31, is an attractive target for comprehensive study of the ISM. Its proximity allows for construction of a detailed picture of stars', dust, and gas distributions. However, any extensive survey is time-consuming because of the large angular size of M31 (4.5°×1.5°; see Fig. 1).

The new CO(1$\rightarrow$0) map [2] with an angular resolution of 23″ at λ=2.6 mm, combined with the HI map of [3], yields excellent opportunities for comparative studies of dust and cool gas, representative for the whole body of M31. We examine here the gas-to-dust ratio in M31 galaxy using pencil beam columns from these maps toward the centers of young stellar groups (OB associations and open clusters) and new mean extinction estimates, based on HST observations. Extinction data are summarized in Table 1. Their radial distribution is shown in Fig. 2, compared with the averaged radial distribution of the total gas column density. Because of the large extinction spread, even within a single stellar group, no clear pattern is evident.

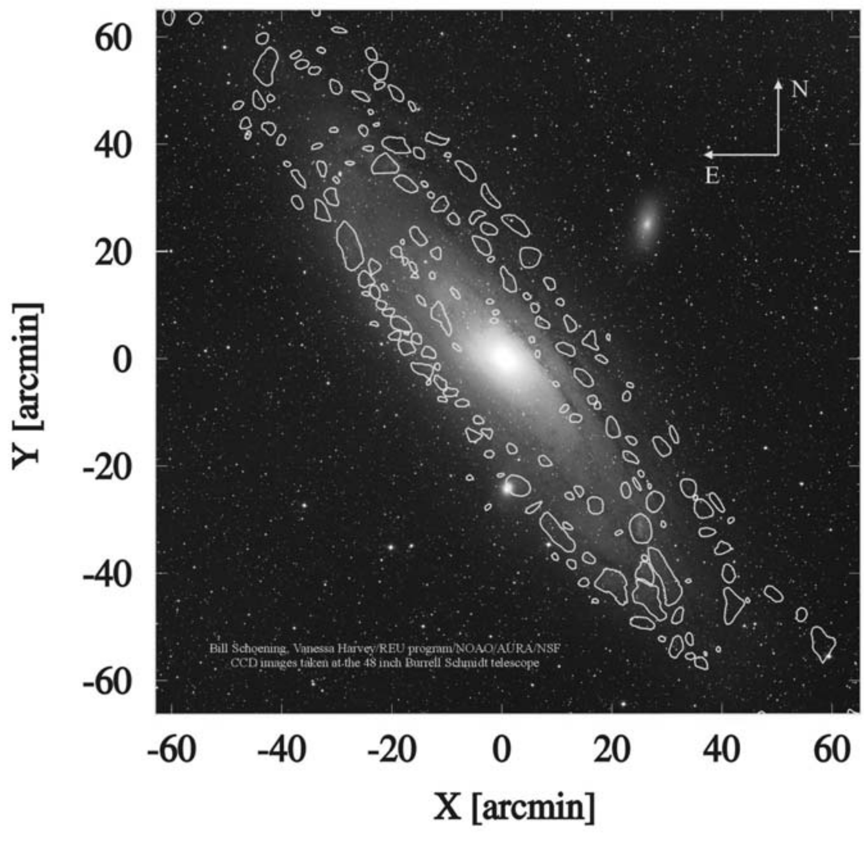

Figure 1: OB associations in M31 (as outlined by van den Bergh /1964/) superimposed on a mosaic CCD image, obtained by Bill Schoening. Note the striking overlap between their boundaries and the dark clouds which testifies that young stars and dust are well mixed.

The corresponding relationships `atomic gas-dust' and `total gas-dust' are illustrated in Fig. 3. A constant gas-to-dust ratio in M31 would yield a good correlation within an expected range, delineated with dashed lines on Fig. 3. This is the case in the Milky Way (cf. Fig. 2 in [1]). Although the fraction of sightlines with observed N(HI)/2E_{B-V} ratio outside the Galactic range is only 1/10, these quantities do not correlate. Several reasons for a weakened correlation were pointed out in [11]. First, the gas-to-dust ratio may depend on the galactocentric distance. Increase of metallicity toward the center of M31 is expected to be inversely proportional to the gas-to-dust ratio. The check of this possibility showed, however, that the radial gradient of the 2E_{B-V}/N(HI) ratio is much flatter than that of metallicity. Second, the fraction of gas density associated with dust may vary locally (not exactly 1/2) – stellar groups, located in front of or behind the disk mid-plane, will exhibit strong deviation from the mean gas-to-dust ratio. Yet there is no doubt that young stellar groups are located at or close to the mid-plane of M31 disk. The poor angular resolution of the neutral gas maps is inappropriate for individual extinction estimates of a star or a cluster but would not influence severely the correlation in case the stellar groups' sizes are of the same order. Despite the fact that ~300 "higher resolution values" of the gas-to-dust ratio, extracted from Fig. 4 in [4], fall within the Galactic range, the correlation is still absent, even on a log-log graph. It was in [12] also found that the 2D extinction map based on CCD photometry of OB stars exhibits neither correlation nor anticorrelation when directly compared with the distributions of cold dust emission and gas column density.

Table 1. Modern extinction data for stellar groups in M31 galaxy

Stellar group type	Total number of estimates	Technique	References
OB-associations	7	Isochrones method	[4]
Brightest stars	5	Q-method + spectroscopy	[5]
OB-associations	80	SFH (MATCH package)	[6]
Young clusters	29	SFH (MATCH package)	[7]
OB-associations	9	SFH (MATCH package)	[8]
OB-associations	4	Q-method (+ Strömgren	[9]

		vby photometry)	
OB-associations	20	Fitting of the MS + varying R_v	[10]

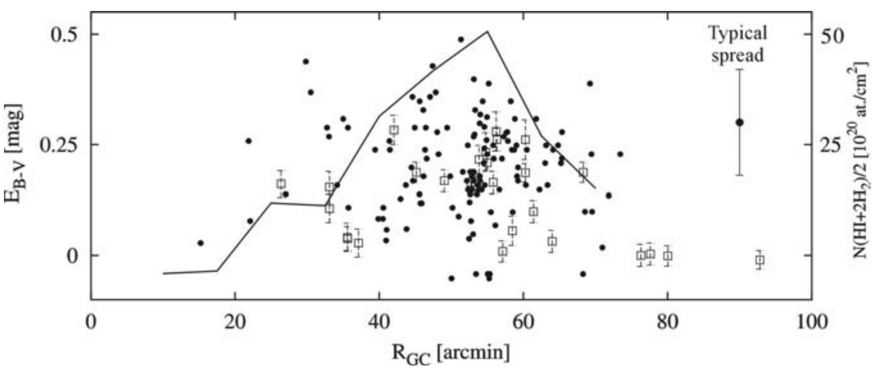

Figure 2: Radial distribution of the mean internal extinction in M31 stellar groups, listed in Table 1. The values for OB-associations ([4,5,6,8,9,10]; filled circles) and for the young clusters [7]; open squares) are plotted; the typical spread within the associations is given at the top right corner. The averaged radial distribution of the total gas column density is drawn with thick line for comparison. No clear pattern could be traced due to the significant extinction variations even within a single stellar group.

The most plausible explanation for the lack of correlation remain the limitations of the techniques applied and hence the rough extinction estimates. For example, when a modeled optical thickness is considered, the distribution of the individual extinction estimates seems to confirm an opaque disk, at least in the spiral arms of M31. Thus, the average extinction could not be representative for the true optical depth along the sightlines toward young stellar groups. The exponentially decreasing total optical thickness outward the galactic center, as obtained by [13] is represented in Fig. 4 with filled circles. The most direct way to check the model is to compare its predictions with extinction estimates, equivalent to pencil beam optical

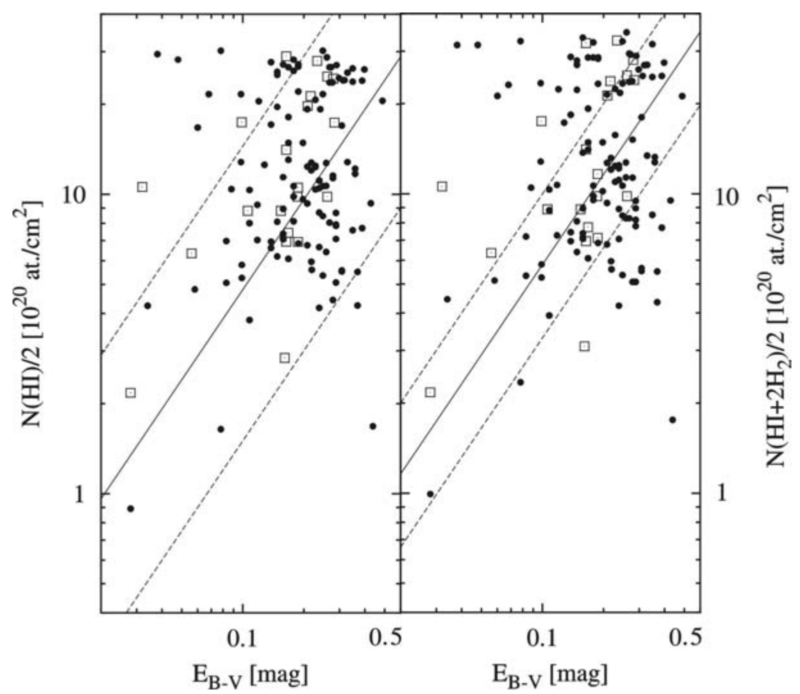

Figure 3: The relationships 'hydrogen (left: atomic; right: total) column density - mean extinction' in young stellar groups in M31 (see also Table 1 and Fig. 1). Mean Galactic gas-to-dust ratios (thick line; [1]) and the expected range of values (dashed) are shown. Note the quite weak correlation.

depths, for objects behind the disk (Fig. 4). Such objects are: distant galaxies beyond the M31 outskirts [14]; globulars, probably lying behind the disk [15]; the "remarkable" globular 037-B327, seen through one of the western spiral arms [16] and a cluster of galaxies [17], hidden behind the NE part of M31. Not all optical depths detected confirm the model of exponentially decreasing optical thickness, especially the globulars in [15] at distance $R_{GC}<50'$, which can be explained with the clumpiness of ISM leading to a selection bias: only globulars along less obscured sightlines have been detected first. We note also that the extinction value of [14] at $R_{GC}=115'$ indicates a smaller radial scale-factor of exponential decrease of the extinction than the model of [13].

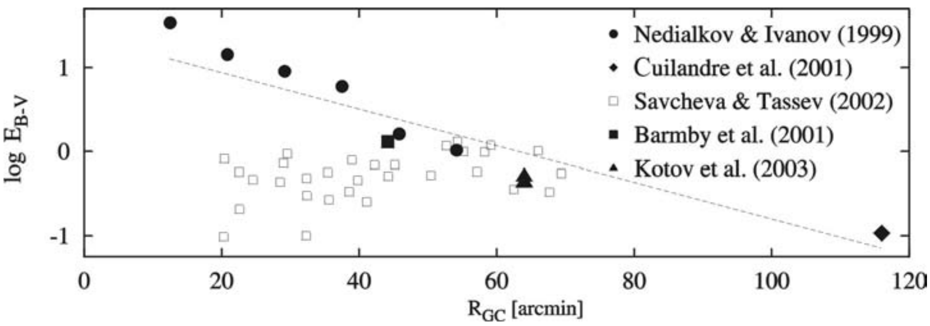

Figure 4: Total optical thickness of M31 disk versus projected galactocentric distance. Filled circles represent the predicted exponential decrease, according to Nedialkov & Ivanov (1999). Other pencil beam optical depths are given with different symbols as indicated in the figure. The dashed line fits all data, denoted with filled symbols (see text for details).

Significant optical thickness of the inner disk of M31 galaxy and deficiency of both atomic and molecular gas seems a quite unrealistic combination. The only natural explanation is that most of the hydrogen might be in molecular phase, frozen on dust grains at temperatures not very different from the temperature of the cosmic microwave background [18].

Acknowledgments

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