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Probing the M 31 Opacity through Galaxies behind Its Disk

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Abstract.

We obtain IR CCD images with 1.83 m Vatican Advanced Technology Telescope (VATT) at Mt. Graham International Observatory, USA and carry out a HK photometry for a sample of 21 galaxies seen through the disk of M 31. Most of the galaxies exhibit prominent bulges and the sample is representative for two mean galactocentric distances: $20'$ (7 galaxies) and $90'$ (14 galaxies) well within the standard isophotal diameter D_{25}. Reasonable consistency between the colors derived by us and the 2MASS colors was found. The neglect of the k-corrections and assumption of a fixed intrinsic color for a typical elliptical leads to E_{B-V} estimates not correlated with the gas column densities. Such a contradiction can be overcome if chemically consistent evolutionary models are taken into account.

1 Introduction

The dust in a galaxy attenuates the light of extragalactic sources. Recent studies [1] pointed that the early type spirals are more opaque and show more extinction at radius larger than R_{25} in B-band while Sd and LSB galaxies are almost transparent. Because dust is not uniformly distributed in galactic disks their opacity is also nonuniform. A detailed study of morphologically representative samples of spirals shows that dust opacity of a disk arises from two distinct components: first, optically thicker ($\tau_V = 0.8 \div 8^m$) and radially dependent component, associated with the spiral arms and second, relatively constant optically thinner disk ($\tau_V \sim 1^m$), associated with the inter-arm regions and outer parts of the disk.

The proximity of the giant spiral galaxy M 31 gives us the opportunity for comprehensive study of the stars and the ISM. Radial distribution of the opacity in M 31, at least in the spiral arms, using individual estimates of OB stars shows that the opacity exponentially decrease away from the galactic buldge [2]. A study of 41 globular clusters in M 31 indicates the absence of radial extinction gradient with the galactocentric distance [3]. Another way to obtain the true opacity of the disk and to test the previous models without any preliminary assumptions is to measure carefully the colors from the reddening of background galaxies behind the disk of M 31. The opacity in the outskirts of M 31 was derived by [4] just by the use of background galaxies. They found semi-transparent disk ($\tau_B \sim 1$) at distance of $1.2(D_{25}/2)$. In this paper we will present opacity estimates representative for galactocentric distance of $0.25(D_{25}/2)$ and $0.9(D_{25}/2)$ using background ellipticals.

2 Observations and Data Reduction

We obtained $H\&K$-bands imaging of a sample of 21 background galaxies in the field of M 31, which comprises a heterogeneous selection from: visual inspection of DSS, plates from NOAO archive and dropouts from a search for globulars [5]. Although, the galaxies lack morphological classification, most of them are ellipticals or at least exhibit prominent buldges. The observations were performed at 17 different positions (see Figure 1) located well within standard diameter D_{25} where the active starformations still took place. The images was obtained with the near IR camera ARNICA [6] at 1.8m Vatican Advanced Technology Telescope on Mt. Graham. The instrument is equipped with a NICMOS 3 (256×256 pixels) detector array with scale of 0.505 arcsec/pixel.

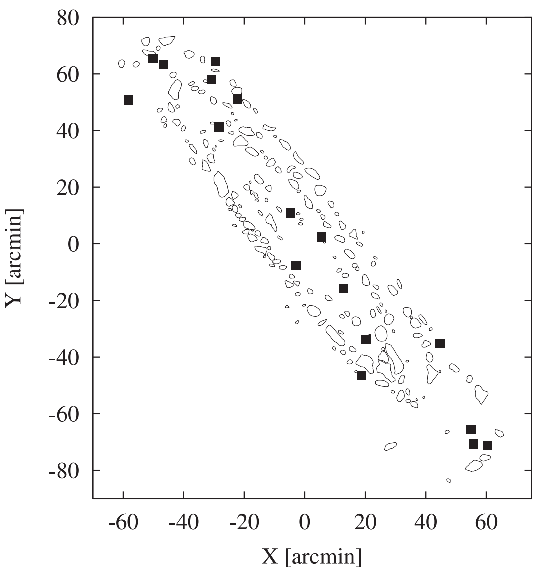

Figure 1. Positions of 17 program fields (solid squares) together with the superimposed boundaries of OB complexes of [7] in M 31. Each field covers area of $2.15' \times 2.15'$ and the total number of background galaxies within them is 21.

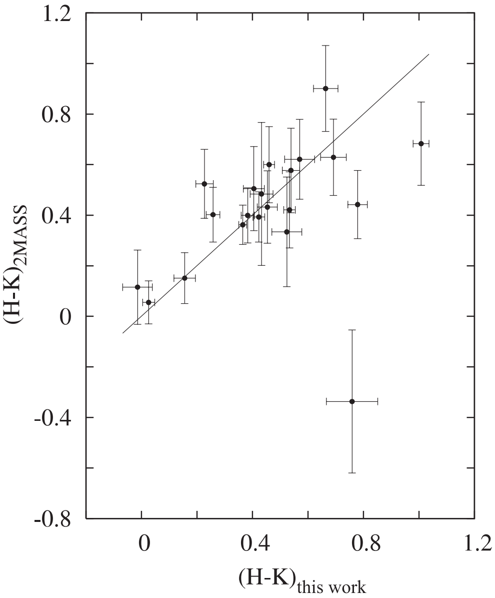

Figure 2. Comparison between the colors as derived in this work and the 2MASS colors. The deviating point is galaxy at $RA(J2000.0) = 00^h 43^m 09.67^s$ $DEC(J2000.0) = 41°27'21.25''$.

For each image, we removed the background by subtracting "sky" image and then divide the resulting image to the flat-field images created from the science frames. After that, all individual images in every filter/field were aligned and median-combined to eliminate "negative" stellar images, cosmetic defects, and cosmic rays.

Non-photometric conditions during most of the observing nights (typical seeing of $2.5''$ for every filter/night and presence of thin cirrus clouds) forced us to use 2MASS stars for the photometric calibration (typical, 4–10 stars per field). No color dependence was found in the calibration equations, and the typical r.m.s. of the photometry zero-point varied between 0.04 and 0.2 for the both bands.

3 Results

3.1 Colors of the background galaxies

For all of the background galaxies 4 arcsec circular aperture photometry in each band was performed with IRAF [1] The derived colors show (see Figure 2) a reasonable consistency with the colors from the 2MASS point source catalog. The

[1] IRAF is the Image Analysis and Reduction Facility made available to the astronomical community by the National Optical Astronomy Observatories, which are operated by AURA, Inc., under contract with the U.S. National Science Foundation.

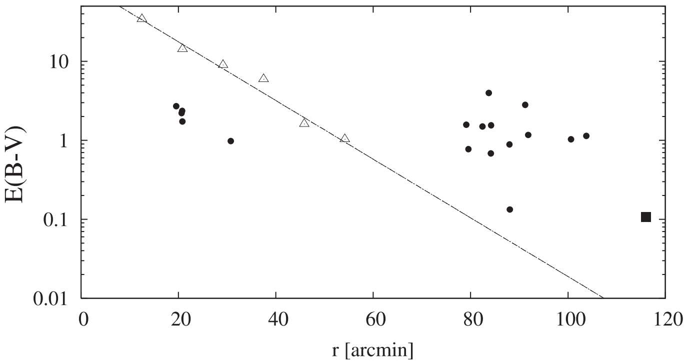

Figure 3. Radial distribution of the opacity of M31 disk in terms of E_{B-V} as obtained in this work (solid circles), by [2] – in the spiral arms regions and by [4] – for the M 31 outskirts.

most direct way to derive opacity of the disk is to assume for all galaxies a constant intrinsic color $(H - K)_0 = 0.22$ mag typical for an almost motionless elliptical galaxy [8] and to subtract it from the observed color, taking into account the Galactic extinction according to [9].

Radial distribution of the derived opacity do not show any trend of decreasing with r (see Figure 3) in comparison with the strong radial decrease of opacity in the spiral arms obtained by [2] using OB stars. A probable explanation is that our background galaxies are representative for the inter-arm regions where the opacity of the disk stays relatively law and constant with the galactocentric distance [1]. Large E_{B-V} spread suggests possible variations of the associated gas column densities along the sightlines toward the studied galaxies. Thus we tried to correlate these two quantities in order to improve the reliability of the derived opacities.

3.2 Correlation with gas column densities

We used HI map of [10] for pencil beam estimates of atomic Hydrogen column density. Since this map has better coverage over the entire M 31 disk than the available map of molecular gas we prefer to use it. Unfortunately, its angular resolution is only $24'' \times 36''$ and exceeds several times our photometric apertures of $4''$. Only 6 of 16 background galaxies positioned inside the HI map boundaries fall within expected range of the galactic gas-to-dust ratio and the observed correlation is poor. This may indicate that some fraction of all total excess of $H - K$ colors is due to the redshift and more sophisticated approach is needed. Another possible explanation is a bias in the selection of our targets - indeed, it is easier to find background galaxies in regions with lower extinction. This possibility is facilitated by the clumpy dust distribution.

3.3 True colors accounted for z and new opacities

We used GALEV evolution models [11] in terms of K *vs.* $(H - K)$ for E, Sa and Sb morphological types over the redshift range $z = 0 \div 0.25$ to obtain true colors of studied galaxies (see Figure 4). Some of them exhibit colors bluer than the models (curves on Figure 4) and hence no extinction can be derived. Their color suggests presence of young population. The rest are Sa or E-galactics. To find their true colors we used the slope of the reddening vector and slide back the points to the nearest "zero-reddening" sequence. For the galaxies with a previous lack of dust-gas correlation the situation remains the same. Let us note that some highly extincted galaxies are observed at very law gas column density position. The lack of correlation may be caused by the insufficient map resolution if only small clouds are located along sightlines. Again, only 6 galaxies fall within expected range of the galactic gas-to-dust ratio, but this time the observed correlation is much tighter (see Figure 5).

The mean $N(HI)/A_V = 4.0[10^{21}$ atom/cm$^2]$ is quite close to the Galactic one in Solar vicinity [12] indicating similar metallicities. The main effect of accounting for the z-origin of the $H - K$ colors from our photometry is that the derived extinctions correlate much better with the gas columns.

The new redefined values of E_{B-V} vary from 0.1 to 0.6 mag and are representative for the opacity of the optically thinner disk of M 31. This is not unexpected result having in mind that studied background galaxies are observed along sightlines across the inter-arm regions of M 31 disk.

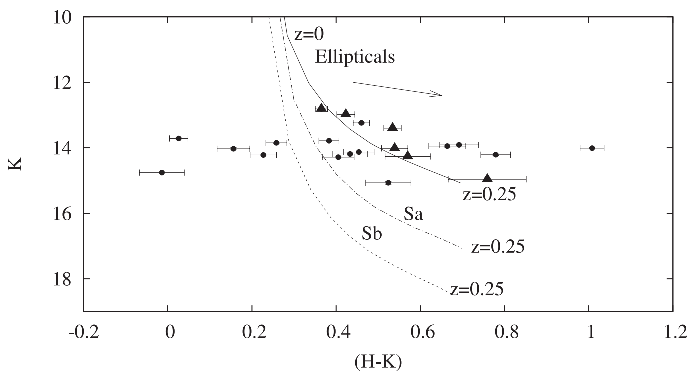

Figure 4. Color-magnitude diagram K *vs.* $(H - K)$ for 21 background galaxies. GALEV evolution models for ellipticals, Sa and Sb galaxies at different z are shown with curves. Triangles – 6 galaxies with correlation between N(HI) and E_{B-V}. The arrow represents reddening vector of 0.5^m in K.

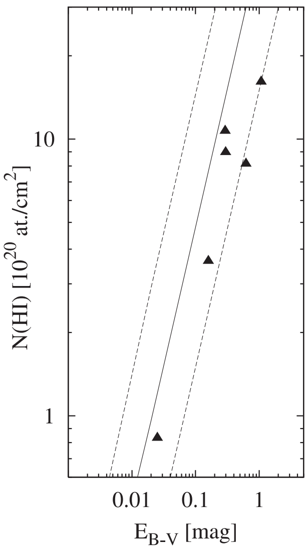

Figure 5. Atomic Hydrogen column density versus extinction: mean Galactic gas-to-dust ratio (thick line; [12]) and the expect range of values (dashed lines) are shown; data for 6 successfully derived opacities of the M 31 disk are marked with solid triangles.

4 Conclusions

We obtain a reliable extinction estimates for six distant galaxies behind the disk of M31 within blue isophotal diameter D_{25} . Taking into account redshifts corrections the final opacities E_{B-V} derived for the disk of M 31 are within the range $(0.1 \div 0.6)^m$. The points spread in E_{B-V} indicates nonuniform dust distribution and absence of any radial gradient. Averaged opacities in terms of τ_V for the two galactocentric distances are 0.9 mag and 1.2 mag correspond to semi-transparent thinner disk representative for inter-arm regions and outer parts of the disk [1].

Acknowledgments

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