How ESO-LV did and did not (?) look through the Galaxy

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Abstract. Recent results on the opacity of external galaxies are compared to results of extinction studies of the Galaxy. If our local environment has a similar opacity as found for ESO-LV Sb/Sc's, we would expect a total face-on optical depth $\tau \sim 1.3$. Galactic extinction maps and galaxy counts suggest an extinction towards the Southern Galactic hemisphere which is larger than in the Northern direction. In total, reddening due to cirrus could account for about $\tau = 0.5$. If one insists on the Galaxy to conform to ESO-LV Sb/Sc's, then cold molecular clouds should obscure a significant part of the Southern sky.

1. Introduction

Recent discussions about the degree of transparancy of the outer regions of Sb and Sc galaxies were triggered by the studies of Disney *et al.*(1989) and Valentijn (1990, hereafter V90). Here, we focus on the regions in the radial range between one exponential scale length and the outer regions of spiral galaxies, say at the 25^{th} or the 26^{th} blue isophote and discuss how results of external galaxies could possibly be matched with data of the Galaxy.

Often, the question arises: 'if galaxies like our Galaxy behave opaque, how is it then possible that we can observe from Earth a significant part of the Universe?'. Here, we address this question, along lines which were originally presented in Valentijn 1991 (hereafter V91).

The resolution of this issue is still speculative, but I want to present some of our findings to the participants of this conference as the results might help to resolve a number of poorly understood extinction properties of the Galaxy. One outstanding problem again showed up at this conference in the presentation by B. Burton: 'on one hand the Leiden/Dwingeloo Survey of HI shows a tight correlation between HI column density and IRAS 100 μm flux on small scales, while on the other hand, at large radii, the radial 100 μm flux density falls off much quicker than the HI column density'. This is perhaps one of the most important questions, which needs a better physical understanding.

The Galactic HI survey might learn us about the radial variation of gas to dust ratios and what we might expect in external galaxies – vice versa, the statistical extinction studies of external galaxies, might learn us what to expect for the radial variation of star to dust ratios in the Galaxy. Here, we address the latter question and in order to quickly show the various steps that are undertaken in the statistical evaluations I have compiled Figure 1. This graph shows the

Figure 1.

great number of steps before arriving at a model for the Galaxy, and even when the last step is not correct, for instance in the case that our local environment in the Galaxy is different from the average Sb-Sc spiral, then this does not say much about the validity of the previous steps.

2. The Opacity Study Ladder

Figure 1 summarizes the various steps that are used in statistical evaluations of the mean opacity of the disks of spirals. After obtaining a sample of galaxies with detailed surface photometry (ESO-LV in our work) both a parameter and a sample have to be selected. It is then investigated how, observationally, the parameter value is related to the inclination angle of the galaxy on the sky.

Already at the very first step of the process (obtaining accurate photometry) the first debate starts. Huizinga and van Albada (1992, see also Huizinga's thesis, 1994) deduce transparent outer regions by assuming that the original visual diameter estimate of Lauberts was incorrect and that the ESO-LV value of the diameter at the 25^{th} isophote (D_{25}) is correct, in spite of the notion by the authors of the ESO-LV catalogue that due to a technicality an artificial inclination dependency was introduced in the D_{25} listed in ESO-LV. Valentijn (1994, hereafter V94) presents a recipe for a small correction to D_{25}, which is confirmed photometrically by Peletier *et al.* (1994b) and numerically by Rönback and Bergvall (1994). After applying this recipe, the corrected ESO-LV D_{25} values are in a very good agreement with the original visual estimates for all inclinations. Both diameter values do not show any significant correlation with inclination and thus conform the expectations for optically thick outer regions. Unfortunately, the conclusions of Huizinga and van Albada are caused by neither using the original visual diameters, nor the corrected ESO-LV values.

Both Burstein *et al.* (1991) and V94 extensively discussed the problems with various sample/parameter combinations, the second step on the ladder. Burstein *et al.* rightfully warn against combinations which use as a parameter the apparent diameter or the apparent magnitude and for the sample selection a criterion which is also distant dependent. When redshifts are available such problems can be circumvented and, doing so, Burstein *et al.* conclude high optical thickness in the outer regions of spiral galaxies, confirming the V90 results, but objecting against his method. However, these objections are not relevant as in V90 the, distant independent, local surface brightness was used as the parameter, which does not suffer from the suspected ambiguities. This is further illustrated in V94, in which for a variety of sample selections, the same result is obtained: a very modest inclination dependency of the local surface brightness of Sc and Sc galaxies, at least at their effective radius.

When redshifts of the samples are known, indeed a number of problems can be circumvented, see also the interesting approach presented by Bottinelli *et al.* at this conference. Another way to trace distant dependent selection effects is to determine V/V_{max} values of the sample, while varying the cutoff limit of the sample. This way, V94 demonstrated that incomplete samples, with $V/V_{max} < 0.5$, exhibit an increase of isophotal diameters with increasing inclination angle, a property of transparent outer regions. On the other hand, complete samples with $V/V_{max} = 0.5$, which have been cut at a higher limit, do not show any significant increase of isophotal diameters with inclination angle, now conform the expectations for optically thick outer regions.

I conclude, that the current literature of Sb,Sc galaxies still strongly supports the view that both their Blue isophotal diameters and local surface brightness hardly depend on inclination. For a simple slab model with a homogeneous mix of stars and absorbers, or for a sandwich model with a more transparent outer region, the hitherto determined regressions (values of C) correspond to optical depth listed in Table 1.

Table 1. Very global face-on B band opacity values of Sb galaxies

Center	C $\sim$ 0	$\tau \sim$ 5-30
effective radius	C $\sim$ .2	$\tau \sim$ 1-2
D_{25},D_{26}	C $\sim$ .2-.4	$\tau \sim$ 1

Note, that at this state of the process (fourth box on the ladder, Figure 1) we need not yet to define the nature of the absorbers, we only assume them to be well mixed with the stars.

However, as outlined in V90, the tabulated radial variation of τ is approximately a factor 10 less than the radial variation of the emitted star light. Thus, the data suggest an absorbing component with an exponential scale length larger than that of the stars (this was actually the motivation for the alternative two-disk rotation curve solution presented by González and Valentijn, 1991). In a recent study, comparing the near infra-red K band scale length with that in the Blue band, for a representative sample of 38 spiral galaxies, Peletier *et al.* (1994a,b) find indeed that the ratio (B/K) is in the range 1.3-1.9. A detailed application of a radial version of the equation of radiation transfer resulted in detailed spatial models for the absorbing components. The observed B/K scale length ratios, together with the noted absence of a diameter increase with inclination, support a two component model for the absorbing material: one component which follows the distribution of the stars (as indicated by the K photometry) and one component which ought to have at least a two times larger scale length than that of the stars.

The dust component that follows the stars, is nearly transparent at the effective radius and its spatial distribution matches to the dust as detected by IRAS. Note, that Bothun and Rogers (1992) also claim the IRAS detected dust to be essentially transparent at the visual bands.

The second component, with a scale length larger than that of the stars, ought to have a dust temperature $< 20K$ and escaped from detection by IRAS. The inclination studies for simple sandwich models indicate at the effective radius a value of $\tau \sim 1.3$, which corresponds to $A_B \sim 0.6$. In V90 it was proposed that cold molecular clouds could largely contribute to absorption by this second component.

So if, after all, we wish to evaluate whether the opacity studies of external galaxies could match to the local properties of the Galaxy, we have to evaluate the question whether a local value of $\tau = 1.3$ is appropriate, taking into account that it should contain one component with a scale length equal to that of the stars (with τ =0.3-0.4) and one component associated with cold dust with a scale length much larger than that of the stars (with τ around 0.9).

3. The Galaxy as an Sbc with $\tau = 1.3$

Of course, our Galaxy could be special, or our local environment could be special, allowing for better local transparency than suggested by the inclination tests of external galaxies. But, it seems unsatisfactory to close the issue with such a statement. Let us now explore the possibilities that actually the local Galaxy behaves like typical ESO-LV disks.

The ESO-LV data base itself contains valuable information about the extinction in the Galaxy, which data have the unique property that they have been acquired in a very homogeneous fashion over a large part of the Southern Galactic Hemisphere and for a significant part of the Northern Galactic Hemisphere. (See V91 for a preliminary report on this Section).

By applying statistical techniques to measured surface brightness values of about 12000 ESO-LV galaxies Choloniewski and Valentijn (1991, hereafter CV91) have obtained a Galactic extinction map. The map corresponds to the results of an alternative, more conventional approach, using the B-R reddening. The map also closely corresponds to the IRAS map obtained at the South Pole by Boulanger *et al.* Remarkably, however, the map suggests a much higher extinction towards the South Pole than towards the North. Given the homogeneity of the data acquisition, it is difficult to see how this could have entered our data in an artificial way. Thus, the data suggest that the Sun is located slightly above the main absorbing (cirrus) layer of the Galaxy and actually shows $A_B = 0.2{-}0.3$ towards the South Pole. In Table 2 these 'reddening' values are listed together with the corresponding values of τ for a homogeneous slab model.

Table 2. The local Galaxy with total $\tau = 1.3$

	A_B		τ	
	North	South	North	South
Reddening (CV 1991)	0.05	.2 - .3	0.1	0.4
Molecular clouds	0.15	.25	0.3	0.5

Fig 2. shows the count rate (number of galaxies per square degree) of ESO-LV galaxies, as a function of Galactic latitude. We have made many of such plots, for instance excluding Abell cluster galaxies, or poor group galaxies, taking different cross cuts through the sky (separated in RA), but it is always found that there is a higher count rate in the North than in the South.

Fig 3. presents the differential count rate normalized with a Euclidian world model. Evidently, the count rate is a factor 1.6 higher in the North than in the South, which value is reproduced when plotting the count rate of the faint background galaxies, which have been recorded on the ESO-LV images.

The count rate difference North/South is NOT correlated with the reddening difference North/South obtained by CV91, and thus the variation in count rate can not be caused by the component that is responsible for the reddening (see V91 Fig 5)!

It is possible, that we are observing the effect of an intrinsic overdensity of galaxies in the Northern Hemisphere, essentially due to the Hydra and Centaurus clusters, but this seems not directly to match to the repetition of the count rate

Figure 2. The count rate (number of galaxies per square degree) of ESO-LV galaxies as a function of Galactic latitude, selecting galaxies not identified with clusters or rich groups of galaxies ($N_{gal} < 5$).

Figure 3. Differential counts normalized with a Euclidian world model of the ESO-LV galaxies and background galaxies found in the ESO-LV survey (in bins of 0.3^m total B magnitude). Squares for the Northern Galactic hemisphere, triangles for the Southern hemisphere.

difference at faint magnitudes (18-20) or when neglecting rich cluster galaxies. This item deserves a more extensive investigation by extending galaxy counts further towards the North.

It is interesting, but speculative, to assign the count rate difference to the effects of molecular clouds, as suggested by the inclination studies. In order to create a count difference North-South of 1.6 in a disk with total $\tau = 1.3$ (with 0.5 being caused by cirrus type of dust) the presence of molecular clouds in the Northern hemisphere should result into an effective $\tau = 0.3$, while in the Southern hemisphere this value is then 0.5. Numerical experiments with randomly distributed clouds indicate that a value of $\tau = 0.5$ would imply for an observer located in the disk that about 40-50% of the sky will be obscured at Galactic latitudes 20-40^0, and 20% of the sky will be obscured at latitudes $> 40^0$. However, these numbers are subject to strong statistical fluctuations, (e.g. one nearby cloud could obscure half of the sky).

At this conference, I wanted to present these puzzling results, as your comments might help progress in this complicated field. Indeed there is an answer to the question: 'if galaxies like our Galaxy behave opaque, how is it then possible that we can observe from Earth a significant part of the Universe?'. This answer is tabulated in Table 2. Also the spatial distribution of the reddening component (IRAS seen) and the cold component (larger than that of the stars) seems to obey the results of extinctions studies of external galaxies. But the implication would be that we are missing a significant fraction of galaxies in our surveys, without noticing it. That is not an attractive conclusion.

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