Bull. Astr. Soc. India (2000) **28**, 423-428

Photometric studies of starburst galaxies

Aparna A. Chitre

Physical Research Loboratory, Ahmedabad 380 009, India

Abstract. We present the results of a detailed morphological analysis of a sample of Markarian starburst galaxies. CCD surface photometry of those galaxies was carried out based on observations made in U BV RI and Hα. The morphology of the sample objects was studied using isophotal contours and colour images. The radial variations of the surface brightness, ellipticity, position angle and the colour profiles were constructed using ellipse fitting techniques. We find that the star formation activity is not confined to the central region alone, but it also occurs at various other locations like the ends of bars, along circum-nuclear rings or even globally in a few cases. The luminosity profiles show an exponential nature in the outer region. Strong isophotal twisting is observed in almost all the S0 galaxies in our sample. In a few cases, this is accompanied by boxiness, indicating a strong interaction or merger. Blue light is more centrally concentrated as compared to red light in early type galaxies while the reverse holds for spirals. The scale lengths in B and R are comparable. Composite models were constructed and ages between 10^6 and 10^7 years and burst strength between 1% to 5% were able to explain the observed colours.

Key words : Galaxies, starburst, surface photometry

1. Introduction

The term "starburst" was first coined by Weedman (1973) to describe galaxies experiencing episodes of star formation that are too intense to be sustained over the lifetime of the galaxy. The burst of star formation produces a large number of massive stars which completely dominate the luminosity of the galaxy. The essential characteristic of a starburst is the conversion of a large amount of gas into stars in a time much shorter than the evolutionary timescale. A variety of mechanisms have been proposed to explain the starburst phenomenon (Schweizer 1986; Scalo & Struck-Marcell 1986). The onset of a starburst in the central regions of galaxies requires a high concentration of gas in this region, which in turn requires a large-scale dynamical disturbance to cause the gas in the galaxy to lose angular momentum and fall rapidly towards the center. Numerical simulations have confirmed the effectiveness of tidal interactions (Icke 1985; Noguchi & Ishibashi 1986), bars (Schwarz 1984; Combes & Gerin 1985) as well as bar within a bar (Shlosman et al. 1989) in fueling the central region. A spatially resolved study through various spectral bands is necessary to study the detailed photometric properties of the galaxies, the locations and distribution of the star forming regions with respect to the underlying galaxy.

2. Observations and data reductions

The sample of starburst galaxies for the present study was drawn exclusively from the Markarian lists of uv-excess objects (Markarian 1983 and references therein). Starburst galaxies with visual magnitudes brighter than $14^m.5$ and angular sizes greater than 20" were selected. The observations were made at the Cassegrain focus of the 1.2m telescope at Gurushikhar, Mt. Abu. On chip binning of 2x2 was employed and the resultant resolution obtained was 0.63" per pixel. CCD images of the sample galaxies were obtained during several observing runs between October 1996 and April 1997 through broad-band *UBVRI* and narrow-band Hα filters. Each observation was broken up into 3 to 5 exposures. Standard stars from Landolt were observed to calibrate the data.

Standard procedures of bias subtraction and flat fielding were used to reduce the data. The transformation equations were set up using the standard stars observations and the coefficients thus obtained were used to calibrate the images. Individual exposures in each filter were aligned and combined using average sigma clipping. The sky background was computed from the mode of the histogram and subtracted from the images. Pure emission line images were constructed by estimating the underlying continuum from off-band images and subtracting it from the on-band image. Corrections for galactic extinction and extinction in the program galaxy were applied. The rms noise in the sky corresponded to 24.5, 23.9, 23.8 and 23.0 mag/arcsec^2 in the *B, V, R* and *I* images respectively.

3. Optical morphology

Starburst galaxies are a very inhomogeneous morphological class of galaxies. Observations of star forming galaxies reveal an obvious relation between the star formation rate and dynamical features. The association between nuclear activity and galaxy morphology has been studied by several workers (Sersic & Pastoriza 1967; Simkin et al. 1980). Numerical simulations now reproduce many original features of starburst galaxies, including their disturbed morphologies and gas inflows fueling the starburst (Toomre & Toomre 1972; Borne 1984; Aguilar & White 1986). Though gravitational interactions and mergers seem to play a major role in triggering starbursts, violently interacting galaxies are not necessarily the seat of starbursts (Bushouse 1986) and most starbursts are isolated (Coziol et al. 1997).

Analysis of the galaxy images and their isophotes reveals that the sample can be split into three major morphological types: the S0's and ellipticals, the spirals, and the irregulars/peculiars. The S0's and ellipticals generally show smooth outer isophotes. However, distortions are seen in the form of disturbed inner isophotal contours or off-centered outer isophotes. The sample contains 10 spirals out of which 8 are barred spirals. Star formation is seen in the nuclear region and at the ends of bars in most cases. Mrk 332 and Mrk 449 are the two spirals which do not show the presence of a bar. In case of Mrk 332, intense star forming activity is seen along a ring like structure tracing the spiral arms. The arms show a disturbed morphology and are embedded in a smooth outer envelope. Mrk 1194 and Mrk 213 show indications of a nuclear bar or oval distortion misaligned with the primary bar. Only one spiral, Mrk 1379 forms a part of an interacting system of galaxies. We classify three galaxies viz. Mrk 363, Mrk 439 and Mrk 1134 as irregulars/peculiars because of their highly disturbed isophotal contours. The Hα isophotal contours do not trace the optical contours and the peak of Hα emission also does not coincide with the optical nucleus in Mrk 363 and Mrk 439. The colour maps show that star formation is generally concentrated in the central region in all galaxies. In general, the regions with intense Hα emission corresponds to the bluest regions seen in the colour maps.

Simulated concentric aperture photometry of the Hα images shows that the emission peaks in the central region and falls off nearly exponentially outwards. A pseudo equivalent width (E.W.) was defined as the ratio of the intensity in the emission image to that of the underlying continuum taken through a filter with the same bandwidth but with the peak transmission outside the emission line region. We find that the radial distribution of pseudo E.W. does not show a uniform behaviour indicating that though intensity of the line emission is maximum at the center, burst strength with respect to the underlying population is not always the highest in the central region.

4. Structural properties

One of the primary tool for studying the structure of galaxies is surface photometry i.e. the measurement of the brightness distribution. In order to study the nature of the galaxy hosting the starburst and to provide a quantitative description of the morphological aspects, we explored the sample galaxies to look for structures known to be associated with the starburst phenomenon. The structure of the galaxies in the sample was studied using ellipse fitting techniques (Jedrzejewski 1987). Based on the radial variations of the luminosity, ellipticity and position angle, various structural details like the presence and extent of bars, isophotal twists, deviations from the isophotes from perfect ellipticity were studied. Using this technique, it was possible to qualitatively separate the effects of reddening due to dust and redder stellar populations (Prieto et al. 1992 a,b). Fine structure which may be hidden in the overall signal of the galaxy was extracted by subtracting a smooth model constructed by interpolation of the isophotal analysis profiles.

The luminosity profiles are made up of multiple components. The early type galaxies showed luminosity profiles made up of an inner steep part corresponding to the region in which the burst dominates and an outer exponential part which corresponds to the underlying disk. The outer disk was marked and fitted by the exponential law. Strong isophotal twisting was detected in most of these galaxies. A few showed boxiness in the inner regions. The spirals showed an intermediate plateau in the luminosity profiles corresponding to the bar in these galaxies. The colour profiles were modulated by the star forming regions and dust in the spirals. Many of these galaxies showed a double peaked ellipticity profile. We detected the presence of an inner bar having a different position angle with respect to the primary bar in two galaxies, Mrk 213 and Mrk 1194. The half-light radius in each band was derived from the total magnitudes. A plot of the half-light radius in B (a_{eb})) versus the half-light radius in R (a_{er}) is shown in Fig. 1. It is evident that the blue light is more centrally concentrated in case of S0's/E's. The spirals

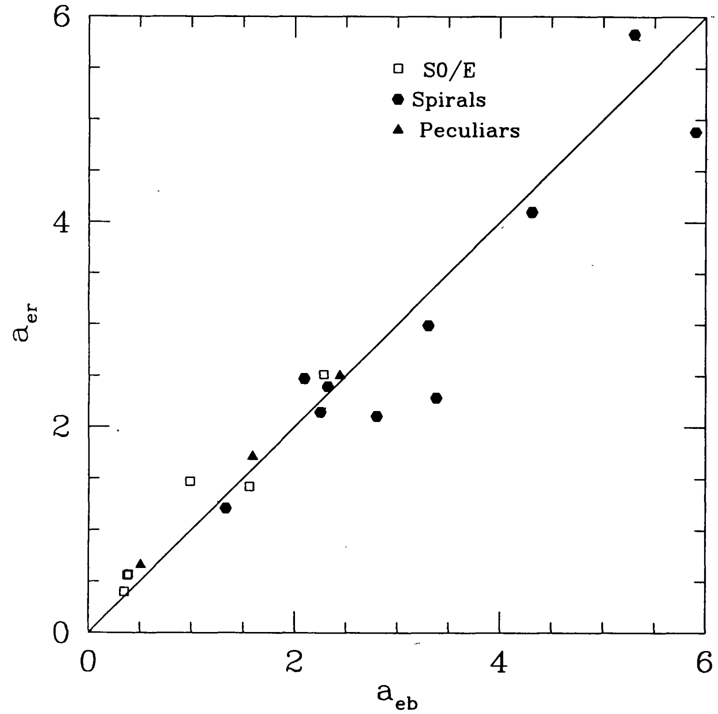

Figure 1. Comparison of the half-light radii in B (a_{eb}) and R (a_{er}). Both the axes are in units of kpc. The solid line is the locus of a_{eb}=a_{er}.

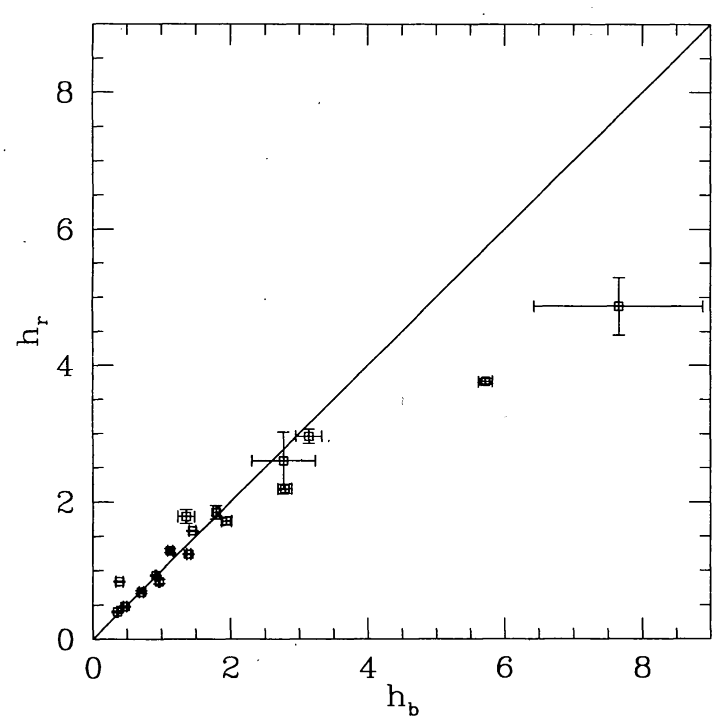

Figure 2. Comparison of the scale lengths in B (h_b) and R in (h_r). Units of kpc are used for both axes. The solid line is the locus of h_b=h_r.

in the sample have $a_{eb}>a_{er}$ in general as many of these objects show strong extranuclear star formation which contributes to the total blue light in the galaxy. Figure 2. shows the comparison between the disk scale lengths in *B* and *R*. We find that the scale lengths are comparable in the two filters.

5. The age and strength of the burst

Evolutionary population synthesis models aim at predicting the observed properties of a stellar population at different times of its evolution. Composite models were constructed to derive the burst ages and strengths. This basically involved adding a burst component to an old galaxy population (Larson & Tinsley 1978) and tracing its evolution in colour with time. Both an actively evolving and a passive underlying population were considered. The burst was assumed to be instantaneous. The burst ages were varied from 1 Myr to 5 Gyr and the burst strengths varied from 1% to 5%. A grid of models were constructed in this manner and the observed colours compared with the model colours. In most cases, we find that the model values compare very well with the observed values and we derive ages ranging from 10^6 to 10^7 years for these cases.

6. Conclusions

A detailed study of the morphological and the structural properties of a sample of Markarian starburst galaxies has revealed the following: Starbursts occur in a variety of morphological environments. Activity is not confined to the central regions alone, but is also found in the form of circumnuclear rings, at the ends of bars or even globally. The S0's/E's in the sample show strong isophotal twists accompanied by boxiness in a few cases indicating a strong interaction or merger. The half-light radii in *B* are smaller than the half-light radii in *R* for early-type galaxies in the sample while the reverse holds for the spirals studied. The scale lengths in these two bands are comparable indicating that the starburst has not affected the underlying disk to a great extent. Ages between 10^6 and 10^7 years and burst strengths between 1% to 5% are able to explain the observed broad band colours in these galaxies.

This work was done at the Physical Research Laboratory under the supervision of Prof. U.C. Joshi.

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