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CCD imaging of Seyfert galaxy NGC 1068

B. Lokanadham[1], G. S. D. Babu[2] and Y. Ravi Kiron[3]

[1] *Centre for Advanced Study in Astronomy, Osmania University, Hyderabad 500 007, India*

[2] *Indian Institute of Astrophysics, Koramangala, Bangalore 560 034, India*

[3] *B. M. Birla Science Centre, Adarsh Nagar, Hyderabad 500 063, India*

Abstract. CCD observations of NGC1068 have been obtained in BVRI filters with 2.34 meter Vainu Bappu Telescope of Kavalur in India. The contours of the indices B-V, B-I and V-I of the galaxy indicate the presence of the star-forming region in the circumnuclear ring. The excitation mechanism of the star forming complexes is explained in the light of multi-wavelength observations of the galaxy.

Key words : Galaxies - Seyferts - NGC1068 - Structure

1. Introduction

NGC1068 is a bright well studied galaxy originally considered as the Seyfert type 2 prototype. Its proximity (18.1 Mpc, $H_0 = 75$ kms^{-1}Mpc^{-1}) allows a detailed study of the different emissive regions, and thus of the interaction between the nuclear activity and the host galaxy. The existence of a Seyfert 1 nucleus has been suggested by Antonucci and Miller (1985) who have shown that broad polarized Fe II and Balmer emission lines are present in the nuclear spectrum. The non-thermal radiation source should then be obscured along the line of sight by atoms of material allowing the emission to escape only in a cone having an axis close to radio axis. Most of the ionized gas observed in the galaxy NGC1068, at radial distances larger than 1 Kpc ($11''.4$) is associated with bright H II regions powered by OB stars. The hot phase in NGC 1068 is detectable in emission due to its high density, and this could be a characteristic of regions undergoing very active stellar formation where the gas content and the supernova rate are very high. Koyama et al. (1989) observed the hard X-rays from NGC1068 and revealed the presence of obscuring torus and the nucleus. However, we can view the emission from NGC1068 from a less obscured narrow line region (NLR) in the optical and UV light and thereby we can obtain information on the geometry and nature of NLR. In view of this, we have taken observations of NGC1068 in the optical region covering BVRI filters.

2. Observations and data reductions

The optical imaging was done at the prime focus (f/3.25) of 2-34-meter VBT. Kavalur, India on the night of 24th November 1998. The detector used was a liquid nitrogen cooled CCD of the format 1024 × 1024 with a pixel size of 24μm × 24μm. This yields a scale of 0.6″ per pixel at the prime focus of VBT. This galaxy was observed in Johnson-Cousins BVRI filters with an exposure of 300 sec. in B and V filters and 120 sec. in R and I filters. The Standard Areas of Landolt (1992)viz., SA94 were observed in order to obtain accurate transformation coefficients and also the extinction coefficients. The object was sandwiched between the observations of the standard stars. Seeing was around 2″ of arc. Several sky flats and bias frames were taken for pre-processing the CCD data. Conditions remained photometric throughout the night.

Preliminary CCD data reduction steps for imaging (bias subtraction, flat fielding, cosmic ray removal and sky subtraction etc.) were carried out using standard tasks within the IRAF[1] to obtain clean images of the galaxy. Dark current is very small in modern CCD detectors and was negligible.

The longer the exposure time is, the better the S-N ratio will be. However, because of the contribution of the sky and the fast saturating bright stars, very long exposures were not advisable. The solution was to split the exposure time into two or more shorter exposures. As a result, we had to realign the frames. In general, alignment needs translation and rotation of frames. *Geomap* and *Geotran* tasks of IRAF were used to align the frames. After aligning, the *Imcombine* task was used to combine the aligned frames of the object in a given filter. The frames in different filters were normalized to a uniform exposure time.

After pre-processing steps, the instrumental magnitudes had to be converted to standard magnitudes, so that they can be compared with the observations carried out by others. A large CCD has an advantage of observing several stars simultaneously. If a region containing many standard stars is chosen, a large number of data points are obtained for the standardization. Keeping this in view, we selected the Landolt stars. The magnitudes were corrected for atmospheric extinction. Then the colour indices were obtained by taking the difference of magnitudes in two filters.

3. Results

After processing the images and standardising them, the corrected and total magnitudes and colour indices of the nuclear region of NGC1068 obtained are listed in Table 1.

Table 1. Magnitudes and colour indices of the nucleus of NGC 1068

Filter	Magnitude	Filter	Magnitude
B	11.71	B-V	0.91
V	10.80	B-I	1.99
R	10.23	B-R	1.48
I	9.27	V-I	1.08

[1]Image Reduction and Analysis Facility is distributed by the National Optical Astronomy Observatories (NOAO), which is operated by the Association of Universities, Inc. (AURA) under co-operative agreement with the National Science Foundation.

The contour maps of the circum-nuclear region of NGC1068 in B-V, B-I, B-R and V-I are presented in figure 1.

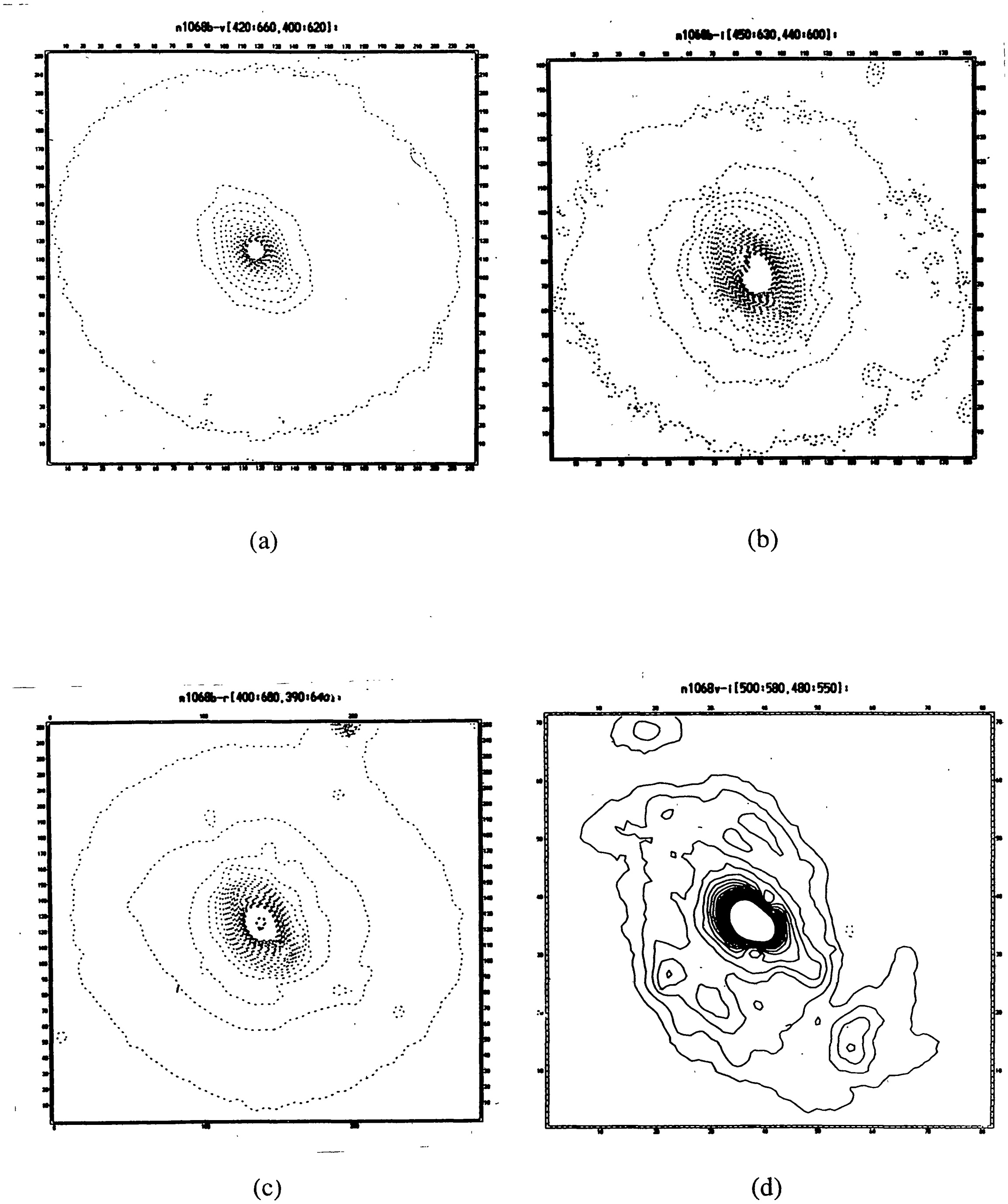

Figure 1. The contour maps of NGC1068 in B-V, B-I, B-R and V-I colours

In order to emphasize the distribution of the star forming regions and the dust lanes, we have divided the blue image (B) by the near infrared image (I) as shown in Figure 2. Blue is indicated by black and red is shown as white. The redder nucleus consisting of dust as well as the evolved stars, is prominently visible and the star forming regions are seen around the nucleus as deep dark patches. The dust patterns are easily discernible in this picture as gray lanes.

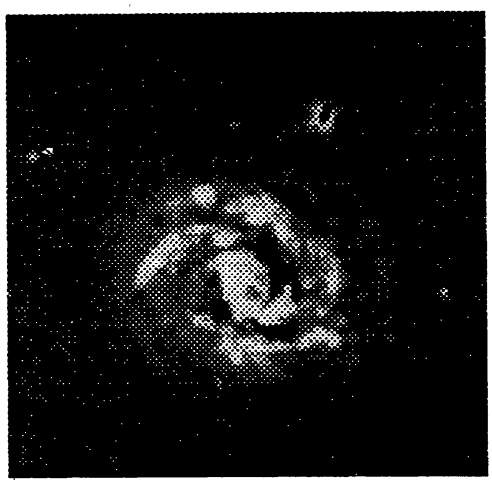

Figure 2. Colour Index picture of NGC1068 obtained by dividing B image by I image. The circum-nuclear ring and star formation regions are very prominent.

4. Discussions

The contour maps of the galaxy show the presence of very young star forming regions dominating the circum-nuclear part of the galaxy. The same is more clearly depicted as predominantly blue region shown as black patches in the colour index image (figure 2), which undoubtedly indicate the presence of young hot stars. The outer spiral arms also contain more regions of red than the blue part along with some dust regions which are shown as gray patches in the disk. A detailed photometric study by Smith et al. (1982) also revealed that the bright inner disk of NGC1068 is bluer than that of most Sb galaxies, and that the outer spiral arms are the reddest part of the disk.

Antonucci and Miller (1985) found that the spectrum of NGC1068 is linearly polarized light. They proposed that the galaxy contains a Seyfert 1 nucleus blocked from direct view by a thick torus, but rendered visible through scattering by a cloud of electrons along the axis of the torus. Miller et al. (1991) have inferred an electron temperature of $< 3 \times 10^5$ K from the scattering cloud from limits to broadening of Hβ by the scattering.

Wilson et al. (1992) studied the X-ray spectrum of NGC1068. The images show a compact nuclear source, circum nuclear extended (diameter = 1.5 Kpc) emission, and emission on a scale (diameter = 15 Kpc) similar to that of a starburst disk. They favoured thermal emission from a hot (10^{6-7} K), out flowing wind as the source of the nuclear and circum nuclear emission. The X-ray spectrum of the starburst disk is found to be harder than that of the nucleus. Emission from the starbursts rather than the electron-scattered Seyfert nucleus, may be responsible for much of the hard spectrum emission from NGC1068 in the 2-10KeV band.

Lutz et al. (1999) studied this galaxy in the infrared wavelength (2.4-45μm). They measured the mid infrared line profiles and concluded that the lines are mostly dominated by emission from the star forming arms.

Ulvestad (1994) found that the radio core emission in Seyferts is quite weak, usually much less than 100mJy at 6 cm wavelength. Gallimore et al. (1999) inferred from the observations that the radio continuum of NGC1068 is dominated by thermal free-free processes. The result of simple photo-ionization calculations is that the torus receives a smaller flux of ionizing photons than does the central engine.

Moorwood (1996) suggested that there is thus a growing body of evidence to suggest a) that circum-nuclear starburst activity is more common in Seyfert 2 and b) that the starburst activity in the Seyfert 2 is older than in pure starburst galaxies. There is no obvious reason why this should be in the standard unification model, which is based solely on the orientation of the obscuring torus to the line of sight. This could, however, be taken as an evidence of an evolution from starburst to Seyfert 2.

5. Conclusions

The B/I image clearly indicates some intense blue regions around the nucleus, where star forming is taking place. The contour maps of the colour indices B-V, B-I, B-R and V-I also indicate the presence of star forming regions in the circum-nuclear ring. All these observations, analysis and discussions suggest that most of ionized gas in the circum-nuclear regions of NGC1068 is associated with HII regions powered by hot stars. If we assume that the energy generation in the AGN is only by the super massive blackhole mechanism as suggested by Blandford (1988), then the massive stars in the circum-nuclear regions also produce comparable amounts of radiant energy over a period of time.

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