# The Mid-Infrared Color of NGC 1313, NGC 6946, and IC 10

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## Abstract

A mid-infrared color and surface brightness study is performed on NGC 1313, NGC 6946, and IC 10. Images taken by the Infrared Space Observatory (ISO) using the LW2 (6.75 $\mu$m) and LW3 (15 $\mu$m) filters generally recover the structure seen optically in these mildly inclined, late-type galaxies. Though their global $\frac{F_\nu(15\mu m)}{F_\nu(6.75\mu m)}$ flux ratios are equivalent and typical of normal galaxies, their trends with surface brightness differ significantly. The run of $\frac{F_\nu(15\mu m)}{F_\nu(6.75\mu m)}$ with surface brightness increases more dramatically in NGC 1313 and IC 10 than seen in the disk of NGC 6946. This discrepancy illuminates the range of drivers of surface brightness variations in normal galaxies: brighter locations in NGC 1313 and IC 10 represent regions of increased heating intensity, whereas surface filling factors govern surface brightness fluctuations in the disk of NGC 6946.

## 1. Introduction

The unprecented sensitivity at infrared wavelengths afforded by ISO allowed studies of the dust emission in galaxies other than IR-bright starburst and ultraluminous systems. The US Key Project on Normal Galaxies was designed to sample the interstellar medium in galaxies whose luminosity is primarily governed by star formation, the dominant factor locally in galaxy evolution. Thanks to their proximity and favorable inclinations, IC 10, NGC 1313 and NGC 6946 were selected from the Normal Galaxy sample to be studied in detail using a variety of instruments aboard ISO. Probing to fainter surface brightness levels than heretofore possible, ISOCAM was used to construct spatially-resolved mid-IR maps of these three galaxies. Such data provide for the first time clues to the sources of infrared surface brightness variations within normal galaxies.

## 2. The Data

Mid-IR maps were carried out using the raster scan mode, with a set of 8×8 pointings for NGC 6946 and a set of 4×4 pointings for both NGC 1313 and IC 10. Integrations were between 340 and 840 seconds. The LW2 and LW3 frames have been registered and smoothed to a similar resolution ($\sim 9''$).

### NGC 1313

Located at a distance of $\sim$4 Mpc, NGC 1313 is an isolated barred Sd galaxy. Star forming regions are evident along the bar and arms of the galaxy (Ryder et al. 1995), and preliminary evidence supports an East-to-West star formation gradient across the galaxy (Wells et al. 1996).

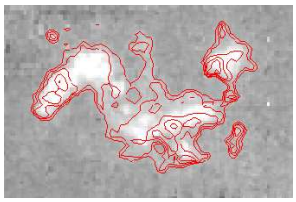

**Figure 1a** The contours of the NGC 1313 $\frac{F_\nu(15\mu m)}{F_\nu(6.75\mu m)}$ color map overlayed on its 15 $\mu$m image. Contour separations signify color changes of 0.5. Significant color variations are located near sites of recent star formation.

### NGC 6946

NGC 6946 is a barred Scd galaxy at a distance comparable to that of NGC 1313. Outside the starburst nucleus, mid-IR arm/interarm studies show that (i) non-ionizing radiation is a significant factor in heating the disk's dust (Malhotra et al. 1996) and (ii) filling factor fluctuations play a key role in its mid-IR surface brightness variations (Helou et al. 1996).

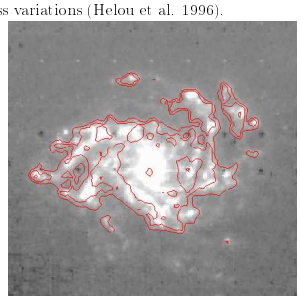

**Figure 1b** Similiar to Figure 1a, but for NGC 6946. The color in the disk varies little.

### IC 10

Classified as a Magellanic-type dwarf irregular, IC 10 is considered to be a member of the Local Group (van den Bergh 1994). Wilcots & Miller (1998) show this galaxy is still in a formative stage, and contains many pockets of active star formation. In fact, Massey & Armandroff (1995) find the global surface density of Wolf Rayet stars in IC 10 is the highest in the Local Group.

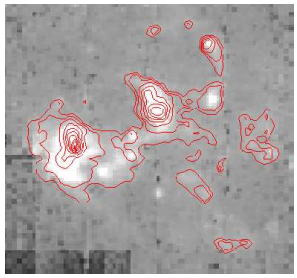

**Figure 1c** Similiar to Figure 1a, but for IC 10.

## 3. Infrared Surface Brightness

What drives infrared surface brightness fluctuations in normal galaxies? Is the mid-IR emission governed mainly by young, hot stars, or is the distribution of dust the dominant factor? A simple model for the infrared surface brightness in normal galaxies is $\mathbf{\Sigma_{ir} \propto N_d \cdot \langle U \rangle}$ where $\mathbf{N_d}$ is the dust column density and $\langle \mathbf{U} \rangle$ signifies the heating intensity. The $\frac{F_\nu(15\mu m)}{F_\nu(6.75\mu m)}$ color maps provide an indication of heating intensity variations within the galaxies since

- IRAS observations showed the $\frac{F_\nu(60\mu m)}{F_\nu(100\mu m)}$ ratio increases with increased star formation activity (Helou 1986); and
- recent ISO data suggest a correlation between $\frac{F_\nu(15\mu m)}{F_\nu(6.75\mu m)}$ and $\frac{F_\nu(60\mu m)}{F_\nu(100\mu m)}$ above a certain $\frac{F_\nu(60\mu m)}{F_\nu(100\mu m)}$ threshold (Helou et al. 1999).

## 4. Results

Figure 2 displays the run of average $\frac{F_\nu(15\mu m)}{F_\nu(6.75\mu m)}$ color with mid-IR surface brightness. Important features of the data include the broad stretch in observable surface brightness and the large discrepancies between the three trends. In contrast to what is seen in the disk of NGC 6946, the data for NGC 1313 and IC 10 show relatively large increases in mid-IR color at moderate surface brightness levels. To understand these differences, consider the scenarios for the model curves within the inset of Figure 2.

Curve 1: A constant $N_d$ combined with increasing $\langle U \rangle$. The curve does not rise until a threshold $\langle U \rangle$ is surpassed (§ 3).

Curve 2: Same as for curve 1, but at a higher $N_d$.

Curve 3: Both $N_d$ and $\langle U \rangle$ increasing.

Curve 0: There are two possibilities:
(i) Same as for curve 1, but at an increased *hardness* of the UV field, which leads to the destruction of aromatic band carriers.
(ii) A decreasing $N_d$ and increasing $\langle U \rangle$, with $N_d \cdot \langle U \rangle$ increasing.

Do these help explain the different trends in these galaxies? First, the average dust column density for NGC 6946 is a factor of 10 larger than that seen in NGC 1313 and IC 10. This is consistent with its trend turning over at a comparatively large surface brightness level (cf. curve 2). Second, a relatively steep trend is expected from a galaxy with a large fraction of young stars (cf. IC 10 and curve 0).

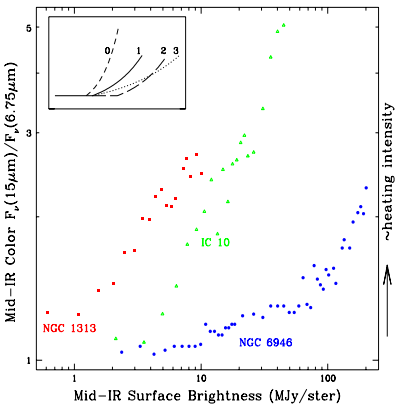


**Figure 2** The average $\frac{F_\nu(15\mu m)}{F_\nu(6.75\mu m)}$ color ratio as a function of mid-IR surface brightness. The model curves drawn in the inset are discussed in Section 4.

## 5. References

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