RevMexAA (Serie de Conferencias), **3**, 173–176 (1995)

DUST IN STARBURST GALAXIES: INSIGHTS FROM NEAR-INFRARED SPECTROSCOPY

Daniela Calzetti[1]

Space Telescope Science Institute, 3700 San Martin Dr., Baltimore, MD 21218, USA

RESUMEN

Se estudia la distribución geométrica del polvo en regiones de formación estelar para una muestra de 13 galaxias, usando los cocientes de las líneas de recombinación de hidrógeno ópticas e infrarrojas. A partir de nuevos datos infrarrojos en las bandas J y K, he medido las líneas de emisión Paβ y Brγ en la región central de la galaxia. Las medidas infrarrojas son complementadas con datos de las líneas de Balmer, Hα, Hβ y Hγ obtenidos en programas anteriores. Infiero que el polvo asociado con el brote de formación estelar puede modelarse como una pantalla antepuesta (grumosa). El mismo modelo de distribución del polvo fue usado para explicar la extinción de los espectros ultravioleta de las galaxias con brote estelar (Calzetti et al. 1994). Estos descubrimientos apoyan el escenario de que el polvo, responsable por el enrojecimiento del espectro desde el UV al infrarrojo, se produce fuera de la región de brote estelar. La presencia de polvo opticamente grueso no queda excluida, pero su presencia solo puede ser revelada con datos en longitudes de onda mayores.

ABSTRACT

The geometrical distribution of dust in starburst regions for a sample of 13 galaxies is studied, using ratios of the hydrogen recombination lines at optical and near-infrared wavelengths. From new infrared spectroscopic data in the J and K bands, I measure the Paβ and Brγ line emission from the galaxies' central regions. The infrared measurements are supplemented by data on the Balmer line emission Hα, Hβ, and Hγ, obtained during previous programs. I infer that the dust associated with the burst of star formation can be modeled as a foreground (clumpy) screen. The same dust distribution model was used to explain the obscuration properties of the ultraviolet spectra of starburst galaxies (Calzetti et al. 1994). These findings support the scenario that the dust responsible for the reddening of the UV-to-near-IR starburst spectra is outside the starburst region. The presence of optically thick dust is not excluded, but its presence can be revealed only by data at longer wavelengths.

Key words: **DUST, EXTINCTION — GALAXIES: STARBURST — INFRARED: GALAXIES**

1. INTRODUCTION

The determination of a galaxy global properties, such as the total luminous mass, the chemical composition, the star formation rate, etc., finds its first obstacle in the poor knowledge of the galaxy's dust content and distribution. Dust is the most elusive source of continuous opacity, lacking in general features that can help to quantify its effects on the emerging radiation. The complex geometry of the dust in galaxies is an added complication: studies of the effects of dust on the galaxy's radiation indicate that the "net"

[1]Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, which is operated by AURA, Inc., under cooperative agreement with the National Science Foundation.

reddening strongly depends on the dust distribution (Natta & Panagia 1984; Witt, Thronson, & Capuano 1992; Calzetti, Kinney, & Storchi-Bergmann 1994). Finally, the dust composition and grain-size distribution, the dust formation/destruction processes, and the details of the interaction of the dust with the surrounding environment are not yet fully constrained from either a theoretical or observational point of view (e.g., Mathis & Whiffen 1989; Draine 1990; Sofia, Cardelli, & Savage 1994; Jones et al. 1994; Jura 1994; Kim & Martin 1995).

The spectra of the starburst nuclei of galaxies show the emission lines from the H II regions surrounding the massive stars. Lines emitted at different wavelengths suffer different amounts of dust obscuration, with the bluest lines more extincted than the reddest lines. Since the dust is, in principle, distributed in and between the emitting regions in galaxies, we expect that the red lines probe larger optical depths than the blue lines. Therefore, multiwavelength information can be used to study the geometrical distribution of the dust in galaxies. In this respect, the ratios of the hydrogen recombination lines, which are weakly dependent on the physical parameters of the emitting gas (Osterbrock 1989), provide a means to characterize the dust distribution.

The infrared hydrogen emission lines Paβ(1.282 μm) and Brγ(2.166 μm) of the nuclei of 13 starburst galaxies are used here, in conjunction with information from optical spectra obtained in a previous study (Calzetti et al. 1994), to study the dust distribution in starbursting regions. The main properties of the 13 galaxies (IC 1586, IC 214, NGC 1569, NGC 1614, NGC 4194, NGC 4385, NGC 4861, NGC 5860, NGC 6052, NGC 6090, NGC 7250, NGC 7673, NGC 7714) are summarized in Calzetti et al. (1994) and Storchi-Bergmann, Calzetti, & Kinney (1994). The present investigation uses infrared and optical spectra taken in closely matched apertures, in order to sample comparable regions within each galaxy.

2. ANALYSIS AND RESULTS

The J and K spectra of the 13 starburst galaxies were obtained with the long slit cryogenic spectrometer at the 1.3-m Kitt Peak telescope during April and September 1994. Details on the observations, data reduction and flux calibration can be found in Calzetti, Kinney, & Storchi-Bergmann (1995). In order to closely match the aperture of the optical observations (a circular aperture of 13$''$.5 diameter and a rectangular aperture $10'' \times 20''$, cf. McQuade, Calzetti, & Kinney 1995; Storchi-Bergmann, Kinney, & Challis 1995), the infrared spectrometer's slit was opened to 6$''$.9 and a window $6''.9 \times 20''$ was extracted from the frames.

For all the galaxies, the hydrogen recombination lines Paβ(1.282 μm) and Brγ(2.166 μm) are measured, and these data are joined with the measurements of the Hα(0.656 μm) and Hβ(0.486 μm) emission lines from the optical spectra (Calzetti et al. 1994). The extinction curves of Seaton (1979) and Landini et al. (1984) in the optical and infrared, respectively, are used to convert line ratios into color excess E($B-V$). The curves are used purely for scaling purposes. The Hα and Hβ emission lines are corrected for the underlying stellar absorption using the Hγ(0.434 μm) line (McCall, Rybski, & Shields 1985).

The color excesses E($B-V$) derived from Paβ/Brγ and from Hβ/Brγ are compared with E($B-V$) from Hα/Hβ in Figures 1 and 2, respectively. The Hα/Hβ line ratio is the most commonly used ratio to derive extinction values for extragalactic objects. The infrared line ratio Paβ/Brγ probes regions of larger optical depth than the optical line ratio does. However, because of the small extinction both lines suffer, the uncertainties of the color excess are large. The Hβ/Brγ line ratio offers a long wavelength baseline with well-detected lines; the long baseline reduces the uncertainties of the E($B-V$) values. Three models for the dust distribution are plotted with the data: 1) a foreground homogeneous dust screen; 2) a foreground slab of Poissonian distributed dust clumps, with an average of $N=10$ clumps along the line of sight; and 3) a homogeneous mixture of dust and emitting gas (see Calzetti et al. 1994). The data are bracketed by the first two models, suggesting that the obscuration in bursts of star formation is dominated by dust located between the observer and the emitting region.

3. CONCLUSIONS

The hydrogen emission line ratios of starburst nuclei at optical and near-IR wavelengths suggest that most of the reddening of the massive stars' radiation is due to dust located outside the bursting region. A similar conclusion was reached by Calzetti et al. (1994) for the dust obscuration at ultraviolet wavelengths.

Far-infrared data support the same scenario. The *IRAS* data on the starburst galaxies indicate that, on average, about 70% of the far-infrared dust emission can be attributed to foreground dust heated by massive stars (Calzetti et al. 1995).

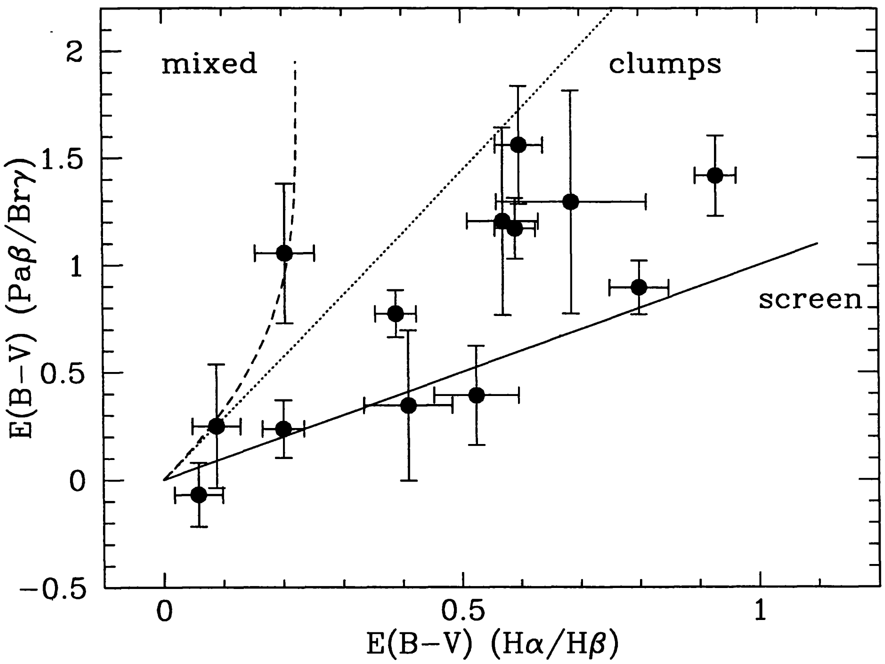

Fig. 1. The color excess E($B-V$) derived from the line ratio Paβ/Brγ is shown as a function of E($B-V$) from Hα/Hβ for the 13 starburst galaxies. The error bars are 1σ uncertainties. The three curves correspond to three models for the dust's geometrical distribution: a foreground homogeneous dust screen (continuous line); a foreground clumpy dust distribution (dotted line); and a homogeneous mixture of dust and gas (dashed line).

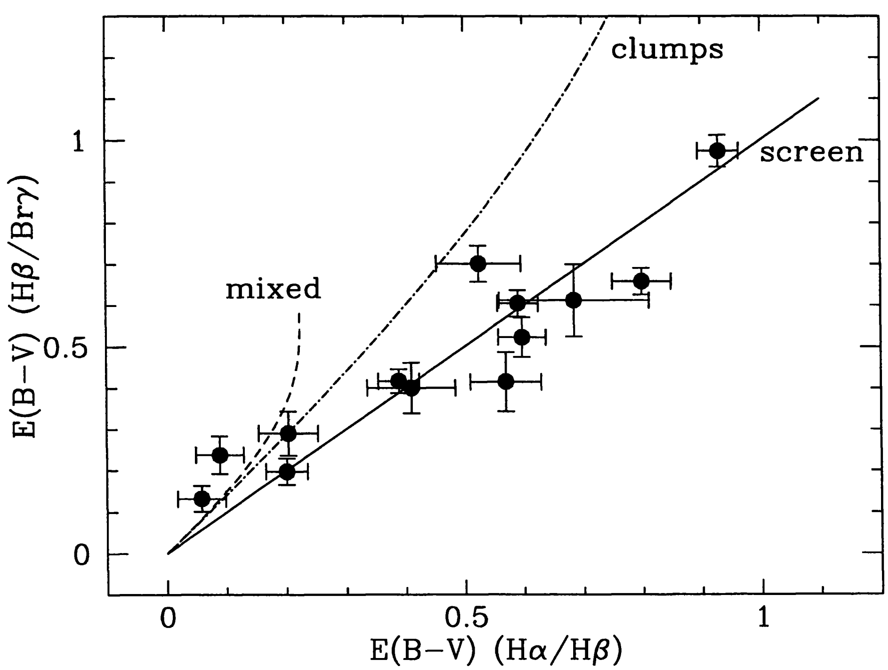

Fig. 2. As in Figure 1, for the line ratio Hβ/Brγ.

The combination of ultraviolet, optical, near-infrared and far-infrared data suggests that most of the diffuse dust is outside the bursting region. This conclusion may be not surprising. A starburst environment is characterized by increased supernova activity, large UV energy densities, and outflows from supernova shocks and hot star winds (superwinds; see Heckman, Armus, & Miley 1990). All these processes may interfere with the dust formation/destruction mechanisms and/or may eject a fraction of the ISM/dust outside the region (De Young & Heckman 1994). As a net result, dust grains may be more efficiently destroyed/removed in a starburst region than in a "quiescent" interstellar environment (Draine & Salpeter 1979; Draine 1990; Jones et al. 1994; Boulanger et al. 1988).

The fact that the dust responsible for most of the obscuration of the emerging radiation is located outside the bursting region does not necessarily imply that *all* the dust is outside the region. Indeed, the presence of thick dust clouds inside the starburst is not excluded, and hydrogen recombination lines further into the infrared may reveal their presence (e.g., Kawara, Nishida, & Phillips 1989; Puxley 1991; Puxley & Brand 1994).

The author acknowledges support from the NASA Grant NAGW-3757 during this research.

REFERENCES

Boulanger, F., Beichman, C., Désert, F. X., Helou, G., Pérault, M., & Ryter, C. 1988, ApJ, 332, 328
Calzetti, D., Bohlin, R. C., Kinney, A. L., Storchi-Bergmann, T., & Heckman, T. M. 1995, ApJ, 443, 136
Calzetti, D., Kinney, A. L., & Storchi-Bergmann, T. 1994, ApJ, 429, 582
———. 1995, in preparation
De Young, D. S., & Heckman, T. M. 1994, ApJ, 431, 598
Draine, B. T. 1990, in The Evolution of the Interstellar Medium, ed. L. Blitz, ASP Conference Series, v. 12, 193
Draine, B. T., & Salpeter, E. E. 1979, ApJ, 231, 438
Heckman, T. M., Armus, L., & Miley, G. 1990, ApJS, 74, 833
Jones, A. P., Tielens, A. G. G. M., Hollenbach, D. J., & McKee, C. F. 1994, ApJ, 433, 797
Jura, M. 1994, ApJ, 434, 713
Kawara, K., Nishida, M., & Phillips, M. M. 1989, ApJ, 337, 230
Kim, S. -H., & Martin, P. G. 1995, ApJ, 442, 172
Landini, M., Natta, A., Oliva, E., Salinari, P., & Moorwood, A. F. M. 1984, A&A, 134, 284
Mathis, J. S., & Whiffen, G. 1989, ApJ, 341, 808
McCall, M. L., Rybski, P. M., & Shields, G. A. 1985, ApJS, 57, 1
McQuade, K., Calzetti, D., & Kinney, A. L. 1995, ApJS, 97, 331
Natta, A., & Panagia, N. 1984, ApJ, 287, 228
Osterbrock, D.E. 1989, Astrophysics of Gaseous Nebulae and Active Galactic Nuclei, (Mill Valley: University Science Books)
Puxley, P. J. 1991, MNRAS, 249, 11P
Puxley, P. J., & Brand, P. W. J. L. 1994, MNRAS, 266, 431
Seaton, M. J. 1979, MNRAS, 187, 73P
Sofia, U. J., Cardelli, J. A., & Savage, B. D. 1994, ApJ, 430, 650
Storchi-Bergmann, T., Calzetti, D., & Kinney, A. L. 1994, ApJ, 429, 572
Storchi-Bergmann, T., Kinney, A. L., & Challis, P. 1995, ApJS, in press
Witt, A. N., Thronson, H. A., & Capuano, J. M. 1992, ApJ, 393, 611