ISOPHOT Observations of Narrow-Line Seyfert 1 Galaxies

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Abstract

Broad infrared spectra (7–200 \(\mu\)m) of four NLS1 galaxies, obtained with the imaging photo-polarimeter (ISOPHOT) on board the Infrared Space Observatory (ISO), are presented. The infrared luminosities and temperatures, opacities and sizes of the emitting dust components are derived.

A comparison between the observed infrared spectra and the optical emission line fluxes of a sample of 16 NLS1 galaxies suggests that these objects suffer different degrees of dust absorption according to the inclination of the line of sight with respect to the dust distribution.

Key words: galaxies: Seyfert; galaxies: photometry; infrared: galaxies

1 Introduction

The dust properties in NLS1 galaxies may play a key role in explaining their peculiar properties. Indeed, the relative weakness of low density forbidden line emission and the absence of broad hydrogen wings in NLS1 galaxies may be understood if most of the ionizing flux is absorbed in the inner forbidden line region, thus reducing the amount of ionizing radiation reaching the low density clouds, and absorbing the internal broad line region (BLR) emission. The presence of dust is indicated by several observations. Spectropolarimetry observations suggest that dust scatters the optical photons in several NLS1 galaxies \cite{1}, and soft X-ray observations indicate the presence of a dusty warm absorber along the line of sight to some NLS1 galaxies \cite{2}. However, in the far-infrared (FIR) domain, NLS1s show a high degree of similarity with normal Seyfert 1 galaxies \cite{3}, \cite{4}, suggesting that their dust properties are not unique among Seyfert galaxies. Our purpose is to investigate the dust properties in NLS1 galaxies through the analysis of their infrared (IR) emission, a direct tracer of dust \cite{5}, \cite{6}. 

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The spectral energy distribution (SED) from near-IR (NIR) to millimetre wavelengths of four NLS1 galaxies (TONS180, RXJ0323−49, IRAS13224−3809, and PG1404+226) are analyzed here and shown in the objects’ rest-frames in Fig. 1. The grey body radiation model was used to fit the observed SEDs.

![Fig. 1. Spectral energy distribution of PG1404+226 (a), IRAS13224−3809 (b), TONS180 (c) and RXJ0323−49 (d). Dotted lines represent single grey body components at the indicated temperature, and the solid line the composite spectrum obtained summing each single component. The dashed line represents the power law obtained fitting data between 3 and 60 µm. Arrows indicate 5σ upper limits (3σ for millimeter data). Diamonds represent ISOPHOT data, squares IRAS data, and circles IRAC1, SEST and IRAM data.](image)

The parameters of the model are the radius $r$ of the projected source, the dust temperature $T$, and the dust optical depth $\tau_d$. The observed IR SEDs are smooth, describable by several grey body components characterized by different temperatures and opacities. Since the data do not permit us to constrain $\tau_d$, we fixed it at two extreme values and then we derived the other parameters of the model. First, we fixed $\tau_d$ at one of the highest hydrogen column density values measured in Seyfert galaxies ($1.8 \times 10^{24}$ atoms cm$^{-2}$), and, secondly, we chose $\tau_d$ corresponding to the optical extinction estimated from the Balmer decrement of each object (see best fitting curves in Fig. 1). In the case of large opacities, the estimated sizes of the dust emission regions vary from 0.2 pc for the hottest component (1000 K), to $\sim$500 pc for the coldest.
one (20 K), and in the case of low opacities, the minimum estimated size is 0.3 pc, and the maximum 20 kpc. The comparison between the temperatures and sizes measured in the two extreme regimes, and the observed values in Seyfert galaxies suggests that the cold dust is characterized by low opacity, while the warm/hot dust may be more opaque. As a consequence, the IR radiation at long wavelengths (T ≤ 60 K) will be isotropic, and orientation-independent. Conversely, at shorter wavelengths (T > 60 K) the dust may self-absorb its emitted radiation, and the observed emission may depend on orientation.

3 The role of the dust in NLS1 galaxies

The steepness of the power law obtained by fitting all the IR data at wavelengths shorter than 60 µm, where the effects of opacity become important, is an indicator of dust extinction. We compared the Balmer decrement values (Hα/Hβ), indicators of extinction at optical wavelengths, of the NLS1 galaxies studied here with the slope of the power law obtained by fitting the observed data between 3 and 60 µm (see best-fit power laws in Fig. 1). The measured power law slopes range between 0.99 and 1.77, which corresponds to a range in the visual extinction of 61 mag, provided that all objects have the same intrinsic IR power law. The variation in the Hα/Hβ values corresponds instead to a range in the visual extinction of only 2.8 mag. Such a difference indicates that all the emitting dust can not be responsible for the reddening observed in the Balmer lines. However, the two parameters, Hα/Hβ, and α_{3.60 µm}, are strongly correlated (the Spearman’s correlation rank is 1.0, with a null associated probability to obtain such a value from uncorrelated values). The corresponding values and their linear interpolation are shown in Fig. 2a, with filled diamonds and a dashed line, respectively. We selected 12 additional NLS1 galaxies from a sample of 148 objects for which the Balmer decrement and the IR spectrum were measured. The observed correlation is still present for the additional 12 NLS1 galaxies (the Spearman’s correlation rank is 0.61, and the probability to obtain such a value from uncorrelated values is 1.13%), as shown in Fig. 2a (the solid line represents the best fit line obtained considering all the 16 NLS1 galaxies which are marked by empty diamonds). A correlation between α_{3.60 µm} and the line intensity ratio [OIII]/Hβ was also discovered (see Fig. 2b). The corresponding Spearman’s coefficient rank is 0.78, and the probability to obtain such a value from uncorrelated values is 0.04%.

The steepening of the IR power law and the enhancement of the Balmer decrement and of the line ratio [OIII]/Hβ can be interpreted in terms of inclination-dependent obscuration. The central regions of these objects are probably surrounded by a distribution of dust that becomes gradually less opaque along some directions. The BLR must be more extended than the inner hot dust,
Fig. 2. Balmer decrement values (a) and line ratios $[\text{OIII}]/H\beta$ (b) vs the IR spectral index $\alpha_{3.60\mu m}$. Filled diamonds represent the 4 NLS1 observed with ISOPHOT and empty diamonds the 12 additional NLS1 galaxies. The solid line is the best linear fit obtained considering all the 16 NLS1 galaxies, and the dashed line is the best linear fit obtained considering only the 4 NLS1.

since its emission is less absorbed than the “broad” lines. Towards the direction where dust is less opaque, the BLR and the hottest dust component will be directly visible, while towards the direction where dust is more opaque, the broad emission lines and the hottest dust radiation will be partially absorbed. Since the $H\beta$ emission is produced in both the BLR and in the narrow line region, when the BLR is obscured the ratio $[\text{OIII}]/H\beta$ will be higher than in unobscured objects.

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