USING SPITZER DATA TO OBTAIN DUST DISTRIBUTION AROUND THE ACTIVE GALACTIC NUCLEUS NGC 4051

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Abstract We have used the Rees' model of Seyfert I galaxies to make detailed calculations of dust distribution as a function of the slope of the spectral intensity versus frequency curve in the infra-red. From these results and our observations of the active galactic nucleus NGC 4051 with the *Spitzer Space Telescope* Infrared Array Camera (IRAC) we obtain the dust distribution function for this nucleus. Based on this work we present a high school lesson.

INTRODUCTION

AGN is a term that refers to galaxies that have light coming from their nuclei that is greater than the sum total of all the light coming from all the stars in the galaxy. The present model is that the excess light is generated by the accretion disk that surrounds a super massive black hole that lies in the center of the AGN (Figure 1). Generally the thermal radiation from the accretion disk spans wavelengths from the X-rays to the optical. This light then usually gets absorbed by the much cooler dust around the nucleus of the galaxy, and is then re-emitted in the infrared. The focus of this investigation is to obtain the number density distribution function of the dust around the AGN.

Rees et al Model:

The assumptions of the Rees et al [1] model are given in Figure 2. Since the grain is at thermal equilibrium the temperature (T) of the grain will depend upon the distance (r) from the accretion disk and is given by the equation

$$T^{4+\gamma} = \frac{C}{r^2} \qquad (1)$$

The flux (F_ν) of the grains is proportional to and is given by

$$F_\nu \alpha \int_0^{1500} \nu^{3+\gamma} \frac{1}{T^{7+\frac{3\gamma}{2}+\beta(2+\frac{\gamma}{2})}} \frac{1}{\exp(\frac{h\nu}{kT})-1} dT \qquad (2)$$

Rees et al solved the above integral by assuming that the Planck function can be replaced by the frequency at which the function is a maximum. With this assumption Rees et al showed that the spectral index ξ is given by

$$\xi = \frac{1}{2}[2+\gamma-(4+\gamma)(2-\beta)] \qquad (3)$$

We have solved equation (2) numerically and have compared our results to (3) and this is showed in the Figure 3 below.

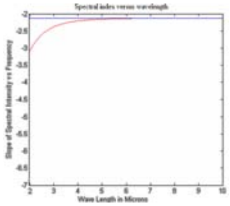

Figure 3: A comparison of Rees formula (3) (Blue line) and our exact evaluation of (2)(Red line). We have used gamma is equal to 1.6 and beta is equal to 0.6. It is clear that the results are indistinguishable after 5 microns

Spitzer Observations of NGC 4051

We have observed NGC 4051 with the *Spitzer Space Telescope* from June 10 2008 to June 20 2008 at 3.6, 4.5, 5.8, and 8.0 microns. The results for June 20 are shown in Figure 4. We measured fluxes with the Aperture Photometry Tool developed by the Spitzer Science Center/JPL/Caltech. From these fluxes we calculated the spectral indices and used our numerical results of (2) to calculate β. NGC 4051 has been monitored in the near infrared by Suganuma et al [2] over a period of 900 days. These authors found that 300-350 days separated the minimum and maximum flux in the K-band. Therefore we assumed that the fluxes could not have changed appreciably during the 11 days of our observation and we used the average flux to calculate the spectral index. Buchanan et al [3] have also made observations of NGC 4051 from 5.0-35 microns. We have used their results to calculate the values of β for 10, 20 and 30 microns. Table I gives the spectral indices and the corresponding β values.

ACTIVE GALACTIC NUCLEI

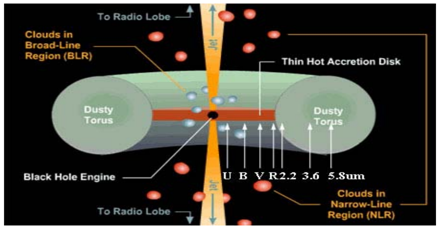

Figure 1: Schematic diagram of an AGN showing the super massive black hole, accretion disk and dust. The goal of this investigation is to calculate the number density distribution function of the dust.

Rees et al Model:

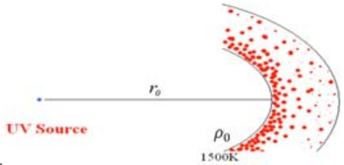

Figure 2: The Rees model is based on the following assumptions:

Grains are in thermal equilibrium

Intensity of light (I_ν) emitted by the grain is given by the power law, $I_\nu = q_{ir}\nu^\gamma B_\nu(T)$

The grains are assumed to be graphite/silicate with γ=1.6

The grains are optically thin to UV radiation

The density distribution of the grains is given by the power law, $\rho = \rho_0(\frac{r}{r_0})^{-\beta}$

Spitzer Space Telescope images of NGC 4051

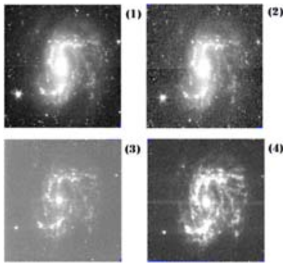

Figure 4: Spitzer Space telescope images of NGC 4051 taken on June 20, 2008
(1) 3.6 microns
(2) 4.5 microns
(3) 5.8 microns
(4) 8 microns

Table I

Range of wavelength (microns)	Spectral Index	Value of β
4.5-3.6	-0.564	1.311
5.8-4.5	-2.279	0.553
8.0-5.8	-1.581	0.799
10.0-8.0	-1.337	0.882
20.0-10.0	-1.23	0.918
30.0-20.0	-1.249	0.911

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LESSON

This lesson is designed for physics students who have taken/taking calculus.
Assumptions: Grains are blackbodies
Grains are distributed uniformly.
Light absorbed by the grain=Light radiated from the grain (condition of thermal equilibrium)

Light radiated from grain= $4\pi a^2 \sigma T^4$

Light absorbed by the grain= $\frac{\pi a^2 L}{4\pi r^2}$

In the above equations is the radius of the grain, σ is Stefan's constant and *L* is the luminosity of the accretion disk. Equating the two equations gives us the analog of (1) for a blackbody which is,

$$T^4 = \frac{C'}{r^2} \qquad (4)$$

The flux should be proportional to,

$$F_\nu \alpha \int_{r_0}^{\infty} \frac{\nu^3}{\exp(\frac{h\nu}{kT})-1} r^2 dr \qquad (5)$$

With the help of (4) students can integrate (5) and the final answer is

$$F_\nu \alpha \nu^3 \sum_{n=1}^{n=\infty} \exp(-nx)\left[\frac{1}{nx}+\frac{5}{(nx)^2}+\frac{20}{(nx)^3}+\frac{60}{(nx)^4}+\frac{120}{(nx)^5}+\frac{120}{(nx)^6}\right] \qquad (6)$$

Where $x = \frac{h\nu}{kT_1}$ and $T_1 = 1500^0 K$

The above equation converges rapidly and in practice there is no need to go above *n*=4

Conclusion:

We have used the Rees' model of Seyfert I galaxies to make detailed calculations of dust distribution as a function of the spectral index in the infra-red. From these results and our observations of the active galactic nucleus NGC 4051 with the *Spitzer Space Telescope* we obtain a dust distribution power-law exponent of 0.8-0.9 over a wavelength of 5.8-30.0 microns. We have assumed that the dust is made up of graphite/silicate grains and that the grains are optically thin to UV radiation. Future work will be directed to removing this assumption

References:

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