New infrared Seyfert galaxies

Q.S. Gu[1,3]**, J.H. Huang**[1,3]**, H.J. Su**[2,3]**, and Z.H. Shang**[2,3]

[1] Department of Astronomy, Nanjing University, Nanjing 210093, China
[2] Purple Mountain Observatory, Nanjing 210008, China
[3] United Lab for Optical Astronomy, The Chinese Academy of Sciences, China

Abstract. We present optical spectra for new infrared Seyfert galaxies obtained with the 2.16m telescope at Beijing Astronomical Observatory (BAO). After wavelength and flux calibration, they are classified by the degree of nuclear activity: nine Seyfert 2 and three Seyfert 3 galaxies. In addition, by using the data from de Grijp et al.(1992), we find that (1) there exists a tight correlation between luminosities of far-infrared (L_{FIR}) and Hα ($L_{H\alpha}$) for both Seyfert and HII-like (starburst) galaxies; (2) the median value of Hα luminosities of Seyfert 1s is one magnitude larger than that of Seyfert 2s and starburst galaxies; (3) the cumulative distributions of FIR luminosities and infrared spectral index $\alpha(100, 60)$ for Seyfert 1s and 2s are similar to that of starburst galaxies. We conclude that most of the far-infrared emission from Seyfert 2 galaxies is due to the violent nuclear/circumnuclear starburst, rather than the nonthermal activity in the nucleus, this may also be the case for many Seyfert 1s as well.

Key words: galaxies: active – galaxies: Seyfert – galaxies: starburst – infrared: galaxies

1. Introduction

Seyfert galaxies have intense nuclear activities and they are strong sources of near and mid-infrared radiation (Rieke 1978). Since the IRAS survey provided the infrared data for over 20,000 galaxies, it is a well established fact that there is a strong $25\mu m$ component in Seyfert galaxies (Dultzin-Hacyan et al. 1988); and de Grijp et al. (1985) presented a new method for detecting hitherto unknown Seyfert galaxies by their flat infrared spectra, where the infrared spectral indices between 25 μm and 60 μm, $\alpha(60,25)$ (defined by $S_\nu \propto \nu^\alpha$, where S_ν is the flux density at frequency ν), are in the range [-1.25, -0.5]. On the other hand, Keel et al. (1988) compared the distribution of the location of stars, normal galaxies and AGN in the palne of $\alpha(60,25)$ vs $\alpha(100,60)$ and found that AGN are located in the area of

$\alpha(60,25)$ in the range [-1.5,0.5] or $\alpha(100,60)$ in the range [-0.8,0.5].

Following de Grijp et al. (1985; 1992), we have selected a large sample of galaxies to search for new Seyfert galaxies from the IRAS Extra-galactic Catalog (EGCAT, 1994) based on their IR properties. Since 1994, we have carried out the survey by using the 2.16m telescope at Beijing Astronomical Observatory (BAO). Gu et al. (1995) presented the spectral results of ten new Seyfert galaxies: one Seyfert 1, three Seyfert 2s and 6 LINERs (also called Seyfert 3 by Veron and Veron,1993).

In this paper, we will present the spectral results of new Seyfert galaxies which we detected in the recent observations. The organization of the paper is as follows. In Sect. 2, we describe our observations and data reduction procedure, and we present the results of the twelve new Seyfert galaxies in Sect. 3. And in Sect. 4, we present three diagnostic diagrams and discuss the far-infrared (FIR) emission in Seyfert galaxies. Finally, the major results of this paper are summarized in Sect. 5.

2. Observation and data reduction

The present mini-sample is selected with $\alpha(60,25)$ in the range of [-1.5,+0.5] and each galaxy has a strong 25 μm emission: that is the flux ratio at 25 μm and 100μm is larger than 0.2. In order to be sure that the objects are not foreground sources (stars, planetary nebulae, etc), we have inspected each one using CDROM of the Digitized Sky Survey [1].

The observing log and some basic data (IRAS flux densities are taken from EGCAT) are presented in Table 1. All spectra were taken with the Carl Zeiss Jena universal Cassegrain spectrograph at the Beijing Astronomical Observatory(BAO) 2.16m telescope, a 300 lines mm^{-1} grating (dispersion is 195 Å/mm,

---

[1] Based on photographic data of the National Geographic Society – Pal Observatory Sky Survey (NGS-POSS) obtained using the Oschin Telescope Palomar Mountain. The NGS-POSS was funded by a grant from the Natio Geographic Society to the California Institute of Technology. The plates were processed into the present compressed digital form with their permission. The Digitized Sky Survey was produced at the Spac Telescope Science Institute under US Government grant NAG W-2166.

Table 1. Observing log and some basic data

Object name	$\alpha(1950)$	Position $\delta(1950)$	S12 Jy	S25 Jy	S60 Jy	S100 Jy	Date
F01518+2705	015153.6	+270505	0.189	0.690	1.224	1.755	Dec.17, 95
F02095−0526	020933.9	−052639	0.107	0.173	0.537	0.642	Dec.20, 95
F02394+0457	023925.3	+045724	0.043	0.159	0.555	1.734	Dec.18, 95
F03077+1709	030746.9	+170949	0.082	0.422	0.880	1.992	Dec.20, 95
F04210+0401	042102.5	+040105	0.084	0.453	0.919	1.491	Oct. 2, 95
F04507+0358	045046.6	+035847	0.362	0.599	0.612	0.041	Nov.28, 94
F04580+0018	045800.3	+001854	0.117	0.216	0.598	0.791	Dec.16, 95
F08216+3009	082137.7	+300907	0.215	0.375	0.441	0.354	Dec.17, 95
F08449+3526	084457.6	+352648	0.038	0.346	0.546	1.240	Jan.17, 96
F09427+4252	094244.5	+425222	0.177	0.290	0.663	0.946	Dec.20, 95
F10285+5834	102834.3	+583456	0.074	0.223	0.624	1.193	Dec.20, 95
F10419+3430	104158.2	+343045	0.050	0.226	0.574	0.647	Dec.16, 95
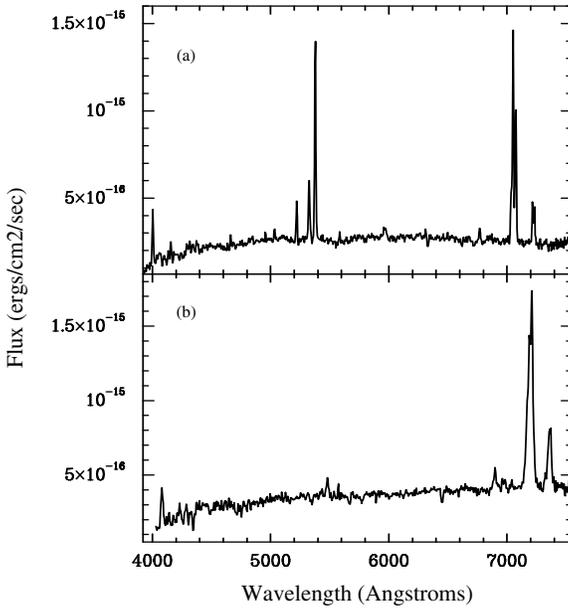
Fig. 1a and b. The spectra of new Seyfert galaxies. **a** F09427+4252, **b** F01518+2705.

equivalently) was used and the width of long slit was about 2.5". The spectral range was from 3800Å to 7600Å with the dispersion of 4.66 Å/pixel and the resolution (FWHM) of 10.96 Å. Standard stars were selected from KPNO standards, and all spectra were reduced using standard IRAF[2] procedures.

---

[2]   IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

3. Results

The observed objects are classified according to their ionization states estimated from the flux ratios between emission lines (Baldwin et al. 1981; Veilleux & Osterbrock 1987), the emission line ratios used are [OIII]λ5007/Hβ, [NII]λ6583/Hα, [SII]$\lambda\lambda$6716,6731/Hα and [OI]λ6300/Hα.

Seyfert 1 galaxies have very broad HI, HeI and HeII emission lines with full widths at half maximum (FWHM) of the order of 1 to 5×10^3 km sec^{-1}, and the forbidden lines such as [OIII]$\lambda\lambda$4959,5007 and [NII]$\lambda\lambda$6548,6583 and [SII]$\lambda\lambda$6716,6731 have the FWHMs of order 500 km sec^{-1} regardless of the narrow line ratios (Osterbrock 1989). The objects with [OIII]λ5007/Hβ>3 and [NII]λ6583/Hα> 0.5 are classified as Seyfert 2, and those with [OIII]λ5007/Hβ< 3 and [NII]λ6583/Hα>0.5 are classified as Seyfert 3. Emission-line objects whose line ratios lie outside the ranges appropriate for Seyfert 2 and Seyfert 3 nuclei are called HII-like galaxies (de Grijp et al. 1992). The objects without [OIII]λ5007/Hβ, were classified as AGN-like if [NII]λ6583/Hα>0.5 and [OI]λ6300/Hα>0.06 or as HII-like if [NII]λ6583/Hα<0.5 and [OI]λ6300/Hα<0.06 (Armus et al., 1989).

According to this classification scheme, we found nine Seyfert 2s and three Seyfert 3s. We show the spectra of a typical Seyfert 2 and Seyfert 3 in Figs. 1a and 1b.
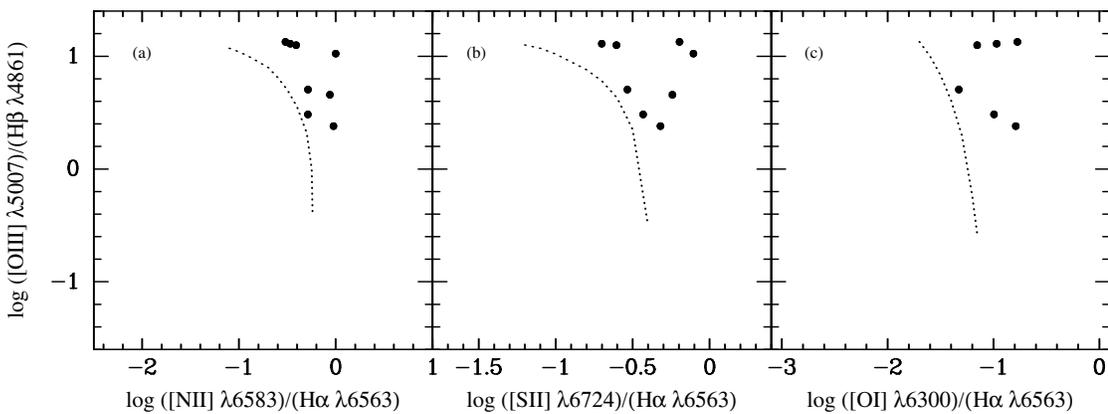
The excitation states, along with the measured redshifts and far-infrared luminosities, of these new Seyferts are given in Table 2. The columns of Table 2 are as follows: column(1), the source name; column(2), the redshifts derived from Hβ, [OIII]λ5007, and Hα; column(3), logarithm of the FIR luminosities in L$_\odot$ from 40 to 120μm, given by Lonsdale et al. (1985)

$$L_{\mathrm{FIR}} = 3.75 \ 10^5 \ D^2 \ (2.58 \ S_{60} + S_{100}), \qquad (1)$$

where S_{60} and S_{100} are the flux densities at 60μm and 100μm in Jy, D is the distance in Mpc and $H_0 = 75 \ km \ sec^{-1} \ Mpc^{-1}$; column(4), the flux ratios of [OIII]λ5007 to Hβ; column(5),

Table 2. Optical and infrared properties of the new Seyfert galaxies

IRAS Name	z	log L_{FIR}	[OIII]/Hβ	[NII]/Hα	[SII]/Hα	[O I]/Hα	Spectral Type
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
F01518+2705	0.095	11.42	2.4	0.947	0.479	0.162	Sy3
F02095−0526	0.041	10.31		1.014	0.849		Sy2
F02394+0457	0.069	10.96	4.553	0.869	0.573		Sy2
F03077+1709	0.065	11.03	10.55	1.000	0.784		Sy2
F04210+0401	0.045	10.67	13.393	0.302	0.637	0.168	Sy2
F04507+0358	0.028	9.88	12.542	0.389	0.248	0.070	Sy2
F04580+0018	0.073	10.87		0.689	0.659		Sy3
F08216+3009	0.025	9.76	12.90	0.338	0.199	0.107	Sy2
F08449+3526	0.057	10.71	3.048	0.515	0.370	0.101	Sy2
F09427+4252	0.074	10.95	5.068	0.516	0.292	0.047	Sy2
F10285+5834	0.091	11.15		0.811	0.815		Sy3
F10419+3430	0.070	10.80		0.656	0.361		Sy2

Fig. 2a–c. Diagnostic diagrams. **a** log([NII]λ6583/Hα) vs. log([OIII]λ5007/Hβ); **b** log([SII]λ6724/Hα) vs. log([OIII]λ5007/Hβ); and **c** log([OI]λ6300/Hα) vs. log([OIII]λ5007/Hβ). The short-dashed line divided NL AGNs from starburst galaxies is taken from Osterbrock(1989).

the flux ratios of [NII]λ6583 to Hα; column(6), the flux ratios of [SII]$\lambda\lambda$6716,6731 to Hα; column(7), the flux ratios of [OI]λ6300 to Hα; and column(8), the spectral type.

4. Discussion

4.1. Diagnostic diagrams

The diagnostic diagrams of the new Seyfert galaxies for which the ratios [OIII]λ5007/Hβ, [OI]λ6300/Hα, [NII]λ6583/Hα, and [SII]λ6724/Hα could be measured , are plotted in Figs. 2a, b and c. All these new Seyferts occupy the AGN portion of the plots where the photoionization by a power-law continuum is the dominant ionization mechanism.

4.2. FIR emission in Seyfert galaxies

FIR emission in Seyfert galaxies can be accounted for by (1) emission by warm dust which is heated in regions of star formation; (2) emission associated with an active galactic nucleus(AGN), either nonthermal flux coming directly from AGN or dust reradiation of nonthermal UV-optical continuum emission from the accretion disk. Most authors assume that FIR emission in Seyferts comes from dust heated by power law continuum or is synchrotron radiation, e.g. Rowan-Robinson (1987). But Rodriguez-Espinosa et al. (1987) analysed a sample of optically selected Seyfert galaxies and suggested that star formation produced the bulk of the FIR emission in Seyfert galaxies. In 1988, Dultzin-Hacyan et al. found a strong correlation between the luminosity at 25 μm and the nuclear Hβ luminosity for Seyfert 2s but not for Seyfert 1s, so they suggested that only Seyfert 2s have FIR emission from dust heated by hot stars, and they also found the ratio of 25 μm to 100 μm for Seyfert 2s was statistically equal to that for starburst galaxies, and suggested again that hot stars are indeed capable of producing hot dust to emit observed 25 μm "excess" in Seyfert 2s (e.g. Vaceli et al., 1993, Mouri and Taniguchi, 1992).

It is generally accepted that FIR emission in starburst galaxies arises from the dust heated by newly formed OB stars and that Hα emission traces the stars producing significant ionizing radiation (OB stars) (Keel, 1991).
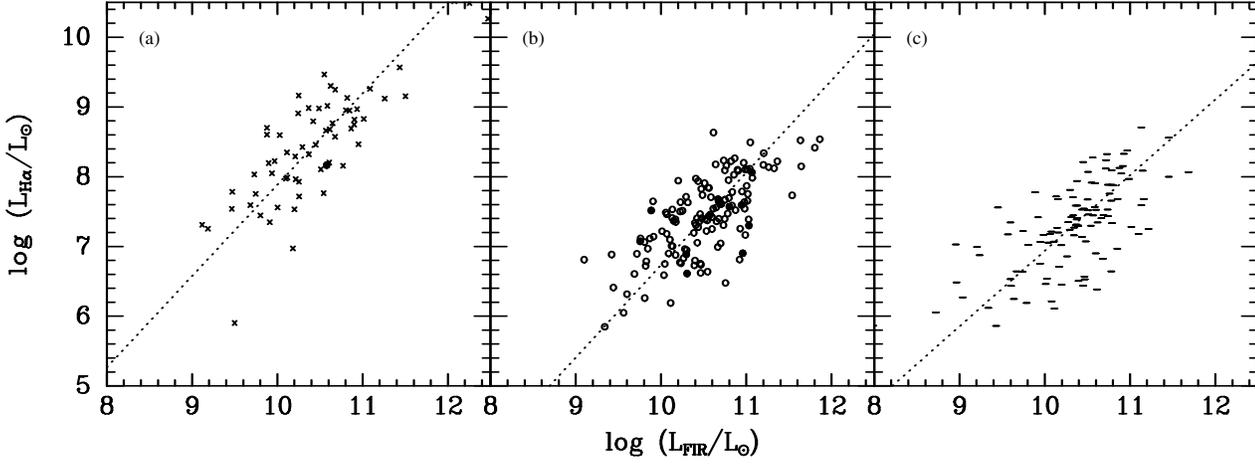
Fig. 3a–c. Correlation between luminosities of far-infrared (L_{FIR}) and Hα ($L_{H\alpha}$). **a** Seyfert 1 galaxies; **b** Seyfert 2 galaxies; and **c** starburst galaxies. In **b**, Seyfert 2 galaxies taken from de Grijp et al.(1992) are plotted by open circles and our new Seyfert 2s by filled circles.

In order to study FIR emission in infrared selected Seyfert galaxies, we picked out all Seyfert and starburst galaxies from de Grijp et al. (1992), together with our new Seyfert galaxies and those in Gu et al.(1995) to build a large, complete infrared-selected Seyfert sample and a starburst galaxies sample for comparison. The number of Seyfert 1s, Seyfert 2s, Seyfert 3s and starburst galaxies is 63(1), 141(12), 17(9) and 114(0), respectively, the digits in parenthesis are the number of our new Seyfert galaxies. We will not discuss the statistical properties of Seyfert 3 sample due to its small sample-size.

Figs. 3a, b and c show the correlation between L_{FIR} and Hα luminosities ($L_{H\alpha}$) for Seyfert 1s, Seyfert 2s and starburst galaxies. The Hα luminosity in logarithm is computed by Devereux & Young (1990),

$$L_{H\alpha} = 2.96 \times 10^{16} F_{H\alpha} D^2 \ [L_\odot], \tag{2}$$

where $F_{H\alpha}$ is Hα flux in units of ergs cm^{-2} s^{-1} and D is the distance in Mpc.

We also plot the regression line in each figure, which minimizes the sum of the square of the perpendicular distances between data points and the line (Isobe et al. 1990), the equations of three regression lines are as follows:

$$Syf\,1s : logL_{H\alpha} = (1.242 \pm 0.009)logL_{FIR} - (4.506 \pm 1.322) \tag{3}$$

$$Syf\,2s : logL_{H\alpha} = (1.191 \pm 0.006)logL_{FIR} - (5.112 \pm 0.883) \tag{4}$$

$$SBs : logL_{H\alpha} = (1.050 \pm 0.005)logL_{FIR} - (3.555 \pm 0.669) \tag{5}$$

The correlation coefficients for Seyfert 1s, 2s and starburst galaxies are 81.7 %, 66.7 % and 66.0 %, respectively. It is shown that there is a tight correlation between L_{FIR} and $L_{H\alpha}$ in starburst galaxies which has been predicted theoretically as both FIR and Hα emission arise from star formation region. But such tight correlation also exists in Seyfert galaxies, and even better than that in starburst galaxies. We notice that the non-linearity is becoming obvious from 1.050 in starburst to 1.191 in Seyfert

Table 3. Median values of $L_{H\alpha}$, L_{FIR} and $\alpha(100, 60)$ for Seyfert 1s , 2s and starburst galaxies

Sample	$logL_{H\alpha}$ $L_\odot$	$logL_{FIR}$ $L_\odot$	$\alpha(100, 60)$
Seyfert 1	8.467	10.368	-0.826
Seyfert 2	7.423	10.532	-0.623
starburst	7.335	10.392	-0.780

2s and 1.242 in Seyfert 1 galaxies, such change of the slope may reflect the increasing contribution to FIR emission from the nonthermal activity in AGN.

We also show the cumulative distributions of $L_{H\alpha}$, L_{FIR} and IR spectral index $\alpha(100, 60)$ in Figs. 4 a, b and c for Seyfert 1s(cross), 2s(open circle) and starburst galaxies(-). The median values of these three parameters for Seyfert 1, 2 and starburst galaxies are given in Table 3.

From Fig. 4b. and 4c, we find that the distributions of L_{FIR} and $\alpha(100, 60)$ are both similar for these three samples which indicate that the circumnuclear starburst is energetic enough to account for FIR emission in Seyfert galaxies. It is very interesting to note that $L_{H\alpha}$ of Seyfert 1 galaxies is about one magnitude larger than that of Seyfert 2 and starburst galaxies. On the other hand, the distribution for Seyfert 2 is almost the same as the one for starburst galaxies. In the view of the unified scheme of AGN (see Antonucci 1993), Seyfert 1 and Seyfert 2 galaxies share the same nuclei and the observed differences are due to obscuration and viewing angle effect and not to intrinsic, physical differences. According to this scheme, the Hα emission in Seyfert 2s from the circumnuclear starburst suffered severe attenuation by the dusty torus around the accretion disk while not in Seyfert 1s. So the observed systematical difference in Hα emission between Seyfert 1s and Seyfert 2s, shown in Fig. 4a, may give another evidence supporting the unified scheme. The optical depth (τ_d) of this dusty torus could be inferred in the following. Assuming
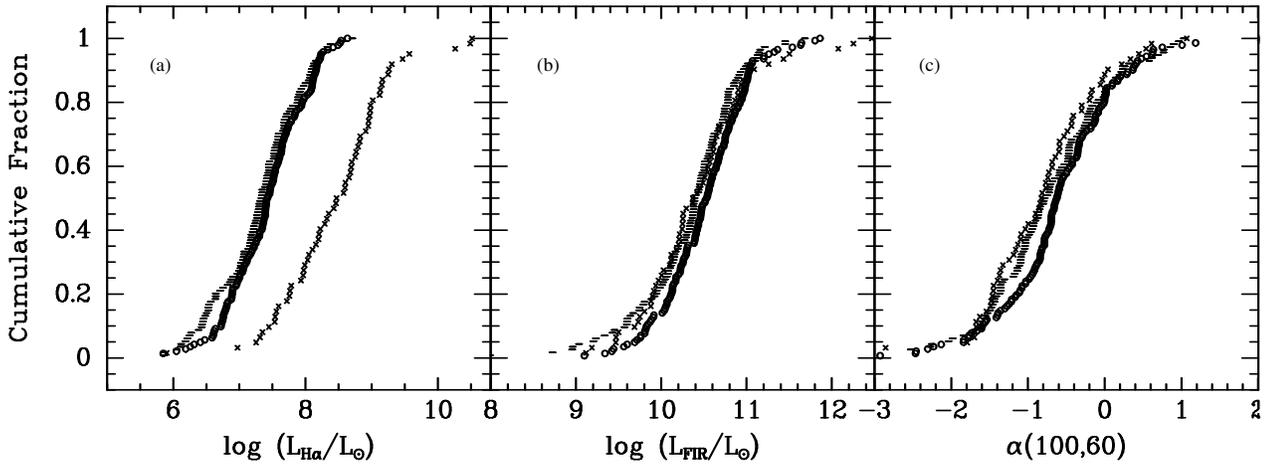
Fig. 4a–c. Cumulative distributions of Seyfert 1, Seyfert 2, and starburst galaxies. **a** $L_{\text{H}\alpha}$; **b** L_{FIR}; and **c** IR spectral index $\alpha(100, 60)$. Seyfert 1 galaxies are shown by cross, Seyfert 2 by open circle and starburst galaxies by a short bar.

the observed Hα intensity from Seyfert 2 to be, $I_{2,\text{obs}} = I_0 e^{-\tau_d}$, then τ_d is approximate to $\ln(10^{8.467-7.423}) = 2.4$.

Now, we could estimate the thermal contribution to FIR emission from the intense circumnuclear starburst in Seyfert 2 galaxies by a very simplified approach. Assuming that the FIR emission in starburst galaxies completely comes from starburst, the FIR-emission percentage contributed by starburst in Seyfert 2s is about $10^{(\frac{7.423-7.335}{1.050}+10.392-10.532)} = 88\%$.

Dultzin-Hacyan et al. (1990) have convincingly indicated that the ratio of I_{25}/I_{100} is the best IRAS tracer of recent star formation. We found that the mean value of I_{25}/I_{100} for Seyfert 2s, 0.3589, is statistically equal to that of Seyfert 1s, 0.3637. So hot stars can also heat dust up to the observed temperature for 25 μm "excess" in Seyfert 1s. It is interesting to notice that this mean value of I_{25}/I_{100} for IR selected Seyferts is statistically the same as that of optically selected Seyfert 1s (Dultzin-Hacyan et al. 1988). Our results confirm previous claims that FIR comes from dust heated by hot stars in Seyfert 2s and we also find that it is the same for Seyfert 1s in our IR selected sample, and possibly for optically selected Seyfert 1s, too.

5. Conclusion

We have presented the results of the slit-spectroscopic observations of 12 new infrared-selected Seyfert galaxies which are classified according to their principle excitation mechanisms as following: nine of them to be Seyfert 2 galaxies and three to be Seyfert 3 galaxies.

By comparing the properties of IR selected Seyfert and starburst galaxies, we obtained the following results:

1. There is a tight correlation between FIR and Hα luminosities for Seyfert and starburst galaxies , which indicates that FIR emission in both Seyfert and starburst galaxies arises from starburst activities.

2. The median value of Hα luminosities of Seyfert 1s is one magnitude larger than that of Seyfert 2s and starburst galaxies, which is consistent with the AGN unified scheme.

3. The cumulative distribution of L_{FIR} for Seyfert galaxies is similar to that of starburst galaxies. A circumnuclear starburst in Seyfert galaxies is energetic enough to account for FIR emission.

4. The cumulative distribution of IR spectral index $\alpha(100, 60)$ for Seyfert galaxies is also similar to that in starburst galaxies, showing that FIR emission in Seyfert galaxies comes from dust reprocessing emission, corresponding to the same temperature as that in starburst galaxies.

Our work gives strong support to earlier claims that the FIR luminosity of Seyfert 2 galaxies is of stellar origin (e.g. Rodriguez-Espinosa et al..,1987; Mouri & Taniguchi 1992; Dultzin-Hacyan & Benitez 1994). Moreover, here we show that this may also be the case for many Seyfert 1 galaxies as well. At least, it is the case for all FIR selected Seyfert 1s in our sample. It is important to notice, however, that our sample is biased towards galaxies with recent bursts of star formation, because it is FIR selected and because all galaxies have relative flat infrared spectra (see Dultzin-Hacyan, Masegosa & Moles 1990).

References

Antonucci R., 1993, ARA&A, 31,473
Armus L., Heckman T. M., & Miley G. K., 1989, ApJ, 347, 727.
Baldwin J. A., Philips M. M., & Terlevich R., 1981, PASP, 93, 5.
Devereux N. A. & Young J. S., 1990, ApJ, 350, L25.

de Grijp M. H. K., Miley G. K., Lub J. & de Jong T., 1985, Nature, 314,240.

de Grijp M. H. K., Keel W. C., Miley G. K., Goudfrooij P. & Lub J., 1992, A&AS, 96, 389.

Dultzin-Hacyan D., Moles M. & Masegosa J., 1988, A&A, 206, 95.

Dultzin-Hacyan D., Masegosa J. & Moles M. 1990, A&A, 238,28

Dultzin-Hacyan D. & Benitez E. 1994, A&A 291, 720

EGCAT, 1994, IPAC, Caltec

Gu Q.S., Huang J.H., Shang Z.H., Su H.J. & Zhu J., 1995, Ap&SS, 229,317

Isobe T.,Feigelson E. D., Akritas M. G. & Babu G. J., 1990, ApJ, 364, 104.

Keel W. C., de Grijp M. H. K.,& Miley G. K., 1988, A&A, 203, 250.

Keel W. C., 1991, Dynamics of galaxies & their molecular cloud distributions, eds. Combes F. et al., p243.

Lonsdale, C.J., Helou, G., Good, J.C., & Rice, W.L., 1985, Catalogued Galaxies and Quasars Observed in the IRAS Survey, Washington D.C.

Mouri H. & Taniguchi Y. 1992, ApJ, 386. 68

Osterbrock, D. E., 1989, Astrophysics of Gaseous Nebulae and Active Galactic Nuclei , Mill Valley, CA, University Science Books.

Rieke G. H., 1978, ApJ, 226, 550.

Rodriguez Espinosa J.M., Rudy R.J. & Jones B., 1987, ApJ, 312, 555.

Rowan-Robinson, M.: 1987, in Star Formation in Galaxies, ed. C.J. Persson, U.S. Govt. Print. Off., Washington, DC, USA, p133.

Vaceli M. S., Viegas S. M., Gruenwald R & Benavides-Soares P. 1993, PASP 105, 875

Veilleux, S., & Osterbrock, D.E., 1987, ApJS, 63, 295

Veron-Cetty M.-P. & Veron P., 1993, ESO Scientific Report, No.13.