Enhanced Star Formation in Seyfert 2 Galaxies

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Abstract

In this paper, we report our preliminary results on enhanced star formation activity in Seyfert 2 galaxies. By re-analysing the Tully-Fisher relation for Whittle(1992)'s sample and for a Seyfert 2s' sample selecting from Veron-Cetty & Veron (1996), we find that (1) almost all Seyfert 2 galaxies with circumnuclear star formation have a ratio of far infrared (FIR) to blue luminosities ($L_{\text{FIR}}/L_B$) to be larger than 1/3; (2) for Seyfert 2 galaxies with $L_{\text{FIR}}/L_B < 1/3$, the Tully-Fisher relation is similar to that of the normal spiral galaxies; while for those with $L_{\text{FIR}}/L_B \geq 1/3$, they are significantly different from the normal ones, which confirms Whittle's suggestion of enhanced star formation activities in the circumnuclear regions of these Seyfert 2 galaxies.

Key Words : Galaxies: kinematics and dynamics — Galaxies: Seyfert — Galaxies: starburst

1 Introduction

There are many debates on the connection between Seyfert activity and starburst in AGN regime. On one hand, in the view of the starburst model for AGN, the Seyfert activity could be accounted for by a central starburst (Terlevich & Melnick 1985 and Terlevich et al. 1992), on the other hand, Norman & Scoville (1988) have suggested that a very compact starburst would provide mass to feed the nuclear black hole (see also Perry & Williams 1994). Recently, the UV-optical observations of four Seyfert 2 galaxies (Heckman et al. 1997; Gonzalez Delgado et al. 1998) present direct evidence of the existence of hot, massive stars (O and B) in the nuclei of these Seyferts. In MKN 477, the contribution by a nuclear starburst (in the Wolf-Rayet phase) to the total intrinsic UV luminosity can be about 25% (Heckman et al. 1997). Wilson (1988) suggested that a number of Seyfert galaxies had low ionization rotating gas disks and the high ionizion Narrow Line Regions (NLRs), such as NGC 1068, NGC 7469, MKN 509 etc., which showed clear evidence for circumnuclear star formation at both radio and IR wavelengths. Now, the growing observed data provided strong evidence indicating the coexistence of Seyfert activity and massive starburst (e.g. Telesco et al. 1984; Rodriguez-Espinosa et al., 1987; Heckman et al. 1989; Neff et al. 1994; Genzel et al. 1995; Oliva et al. 1995; Cid Fernander & Terlevich 1995, and Gonzalez Delgado et al. 1997a).

Colina et al. (1997b) have found that the observed UV fluxes in Seyfert 2 galaxies with circumnuclear star-forming ring, are dominated not by the radiation from AGN, but by emission from clusters of young hot stars located in circumnuclear star-forming regions. Now,
more and more observational evidences suggest that nuclear starburst plays a key role in Seyfert 2 nuclear activity (e.g. Rodriguez-Espinosa et al., 1986; Heckman et al. 1995; Heckman et al. 1997; Maiolino et al. 1995; and Gu et al. 1997).

In examining the basic acceleration mechanisms on the ionized gas in Seyfert's NLRs, Whittle (1992a,b,c) has suggested that the departures of Tully-Fisher and Faber-Jackson relations in Seyfert galaxies from those of normal spirals are due to enhanced star formation in Seyferts. The offset of Faber-Jackson relation is clearly explained by Nelson & Whittle (1996), who have found that Seyfert bulges are kinematically normal, and the offset is due to a lower mean mass-to-light ratio of Seyfert galaxies, either having higher star formation rate or avoiding systems with older stellar populations. In this paper, we report our study on the offset of Tully-Fisher relation of Seyfert galaxies to normal spirals and confirm the Whittle's suggestion of enhanced star formation in Seyferts, by use of the ratio of far-infrared (FIR) to blue luminosities ($L_{\text{FIR}}/L_B$) as an indicator of recent star formation rate (SFR).

The organization of this paper is as follows. In section 2, we discuss $L_{\text{FIR}}/L_B$ as an indicator of star formation rate. Our analyses on the Tully-Fisher relation of Seyfert galaxies for Whittle's sample and for a sample of all Seyfert 2 galaxies in Veron-Cetty & Veron (1996) are presented in section 3. And a summary of our main results is given in section 4.

## 2 $L_{\text{FIR}}/L_B$ : an Indicator of SFR

As is well known, H$\alpha$ emission is a good indicator of massive star formation rate (SFR) in galaxies (see recent review by Kennicutt 1998). However, there are only limited number of galaxies with detected H$\alpha$ emission fluxes (Kennicutt & Kent 1983; Romanishin 1990; Ryder & Dopita 1994; Young et al. 1996; Gonzalez Delgado et al. 1997a and Feinstein 1997) instead, Devereux & Young (1991) have suggested that FIR emission is also an indicator of SFR, by assuming that FIR emission arises from thermal re-radiation of dust heated by massive O, B stars. In three nearest galaxies (M31, M81, and M101), Devereux and his collaborators have found a good spatial correspondence between the deconvolved FIR images and H$\alpha$ emission (Devereux et al. 1994; Devereux et al. 1995 and Devereux & Scowen 1994). Other evidence includes the tight correlation between FIR and H$\alpha$ emission fluxes (Lonsdale Persson & Helou 1987; Devereux & Young 1990). In fact, FIR emission is widely used as an intensive indicator of SFR in analysing the infrared properties of galaxies (e.g. Keel 1993; Combes et al 1994; Helou & Bicay 1993; Kandalian 1997). In his recent review of star formation in galaxies, Kennicutt (1998) has suggested that FIR emission can be a sensitive tracer of the young stellar population and SFR, and presented the diagnostic methods used to measure SFRs including FIR luminosities.

The relation between FIR and radio fluxes is well known to be the best correlation for extragalactic objects. Condon, Anderson & Helou (1991) have found that $Q$, the ratio of infrared to radio fluxes, increases away from a nearly constant value as the galaxy changes from heating by young stars to heating by old stellar populations, Helou & Bicay (1993)
claim that the constant Q is in force for $L_{\text{FIR}}/L_B \geq 1/3$. Recently, in analysing the bar-enhanced star-forming activities in spiral galaxies, Huang et al. (1996) have taken $L_{\text{FIR}}/L_B$ as an indicator of relative star formation rate. Interestingly, they also find a critical value of $L_{\text{FIR}}/L_B \sim 1/3$, and the bar’s enhanced effect on star formation activity is detectable only for galaxies with $L_{\text{FIR}}/L_B \geq 1/3$.

FIR emission in Seyfert galaxies can be accounted for by (1) thermal re-radiation of warm dust heated in star forming regions; (2) emission associated with an AGN, either nonthermal flux coming directly from AGN or dust reradiation of nonthermal UV-optical continuum emission from the accretion disk (Rowan-Robinson 1987). But more and more work performed in UV, optical, mid-infrared, far-infrared and radio wavelengths, supports that most of FIR emission in Seyfert 2 galaxies originates from dust heated by hot, massive (O and B) stars formed in the circumnuclear starburst region (Rodríguez-Espinosa et al. 1987; Dultzin-Hacyan et al. 1988; Vaceli et al. 1993; Gu et al. 1997; and Rodríguez-Espinosa & Perez Garcia 1998).

Table 1 lists all Seyfert 2 galaxies with detectable nuclear/circumnuclear star formation that we collect from literatures. It is very interesting to notice that nearly all these galaxies have $L_{\text{FIR}}/L_B \geq 1/3$ except NGC 5347. According to Gonzalez Delgado et al. (1997b), the numbers of H\ ion regions in the inner and outer part of the disk are 63/46, 28/18, 98/19, 59/105 and 1/32 for NGC 1068, NGC 1667, NGC 3982, NGC 5427 and NGC 5347, respectively. In NGC 5347, there is only one H\ ion region in the inner disk, which might account for the low value of $L_{\text{FIR}}/L_B$, if the majority of dust responsible for FIR emission is located in the nuclear region.

Table 1. Seyfert 2 Galaxies with Circumnuclear Star Formation

| Name       | $L_{\text{FIR}}/L_B$ | Type | Notes       |
|------------|----------------------|------|-------------|
| NGC 262    | 0.465                | .SAS0*| GD97        |
| NGC 1068   | 1.050                | RSAT3..| GD97,CG97b  |
| NGC 1365   | 0.872                | .SBS3..| FN98        |
| NGC 1667   | 0.690                | .SXR5..| GD97,CG97b  |
| NGC 3982   | 0.420                | .SXR3*..| GD97,CG97b  |
| NGC 4303   | 0.472                | .SXT4..| CG97a       |
| NGC 4945   | 0.639                | .SBS6*..| FN98        |
| NGC 5135   | 1.565                | .SBS2..| GD98        |
| NGC 5347   | 0.259                | PSBT2..| GD97        |
| NGC 5427   | 0.450                | .SAS5P..| GD97,CG97b  |
| NGC 5728   | 0.444                | .SXR1*..| CA96        |
| NGC 5953   | 1.910                | .SA.1*P..| CG97b        |
| NGC 6221   | 0.335                | .SBS5..| FN98        |
| NGC 6810   | 0.758                | .SAS2*..| FN98        |
| NGC 7130   | 2.278                | .S..1P..| GD98        |
| NGC 7582   | 1.111                | PSBS2..| FN98        |
| Circinus   | 0.557                | .SAS3*..| FN98        |
| MKN 477    | 1.779                | .S..*P..| HG97        |
From the above considerations, it seems reasonable to adopt \( \frac{L_{\text{FIR}}}{L_{\text{B}}} \) as an indicator of relative star formation rate in Seyfert galaxies, and we will refer \( \frac{L_{\text{FIR}}}{L_{\text{B}}} = 1/3 \) as a threshold of enhanced star formation.

3 The Tully-Fisher Relation in Seyfert Galaxies

Following the notations in Whittle (1992c), we replot the Tully-Fisher relation, the total absolute blue magnitude \( M_B(\text{total}) \) against the normalized, inclination-corrected full rotation velocity \( V_{\text{rot}}^{\text{c}}|Sb \) in Fig 1 for Whittle’s Seyfert galaxies. Fig. 1a is for \( \frac{L_{\text{FIR}}}{L_{\text{B}}} < 1/3 \), and Fig. 1b for \( \frac{L_{\text{FIR}}}{L_{\text{B}}} \geq 1/3 \). The thick dot-dashed lines show the best fit to data, and the thin dashed line illustrates the fit for normal Sb spirals from Rubin et al. (1985), given by,

\[
M_B(\text{total}) = 5.84 - 10.23 \times \log V_{\text{rot}}^{\text{c}}|Sb
\]  

(1)

where \( V_{\text{rot}}^{\text{c}} = V_{\text{rot}}/\sin i \), and \( V_{\text{rot}}^{\text{c}}|Sb = V_{\text{rot}}^{\text{c}} \times 10^{0.053*(T-3)} \), and \( i \), inclination angle, \( T \) is the numerical index of Hubble type.

\( \frac{L_{\text{FIR}}}{L_{\text{B}}} \) is computed with the relation

\[
\log(\frac{L_{\text{FIR}}}{L_{\text{B}}}) = -0.734 + 0.4 \times B^0_T - 0.4 \times M_{\text{FIR}}
\]  

(2)

where \( M_{\text{FIR}} \) and \( B^0_T \) are apparent magnitudes at FIR and blue band, and all the above basic data are taken from the Lyon-Meudon Extragalactic Database (LEDA) and RC3 (de Vaucouleurs et al. 1991).

The Kolmogorov-Smirnov tests indicate that Whittle’s Seyferts with \( \frac{L_{\text{FIR}}}{L_{\text{B}}} < 1/3 \) obey the same Tully-Fisher relation as normal galaxies, shown in Fig 1a, while those with \( \frac{L_{\text{FIR}}}{L_{\text{B}}} \geq 1/3 \) (in Fig 1b) show significant offset from the normal Tully-Fisher relation represented by thin dashed line. Considering our discussion on \( \frac{L_{\text{FIR}}}{L_{\text{B}}} \) in the previous section, the results shown in Fig 1 might imply that the host galaxies of Whittle’s Seyferts with normal star-forming activities show the same properties as the normal spiral galaxies, while those with enhanced star formation do not. The reason is that the massive O, B stars, formed in the enhanced episode of star formation, make a significant contribution to the galactic luminosities but not to masses (Rhee & van Albada 1995).
In order to examine the above arguments, we have constructed a new sample of Seyfert 2 galaxies from Veron-Cetty & Veron (1996). The sample contains 52 sources, due to the limitation of basic data needed for the Tully-Fisher relation, which are extracted from LEDA and RC3. Fig 2a and 2b show the Tully-Fisher relation for this sample with the same definitions as those in Fig 1a and 1b.

The first impression on Fig 2a and 2b, compared with Fig 1a and 1b, is that the new sample of Seyferts show much larger scatters. The main reason is that the Seyfert galaxies in Whittle sample shown in Fig 1 are constrained to those with better data quality (see Whittle 1992c). However, Seyfert 2 galaxies in the new sample are collected from all we can obtained without considering data quality. One example might be indicative. NGC 7319, one outlier in Fig 2a, has been in Whittle’s large sample (Whittle 1992a), it was finally discarded in Whittle (1992c) in analysing Tully-Fisher relation because of its large uncertainty in inclination, which is the main source of uncertainty in the inclination-corrected full rotational velocity. We suspect that the other two outliers in Fig 2a, NGC 5347 and ESO 428-G14, have the same problem as NGC 7319. Statistically, the dot-dashed line in Fig 2a shows the best fit to the data, after discarding the three outliers. The Kolmogorov-Smirnov test indicates that our new sample of Seyfert 2 galaxies with \( L_{\text{FIR}}/L_B < 1/3 \) obey the same Tully-Fisher relation as the normal spiral galaxies.

In constructing our new sample of Seyfert galaxies, we have not included any of Seyfert 1 sources, due to the unclear nature of FIR emission. Indeed, Maiolino et al. (1995) claimed that Seyfert 2 galaxies experience higher level of star formation activities than Seyfert 1s. The analyses by Coziol et al (1998) for their PDS galaxies also derived a higher relative star formation rate for their PDS Seyfert 2 sample than for Seyfert 1s. Gonzalez Delgado et al. (1997b) have listed several Seyfert 1 galaxies with detection of nuclear/circumnuclear star formation. Their relative star formation rates, \( L_{\text{FIR}}/L_B \), are 0.214, 2.790, 0.264, 0.104, and 0.257 for NGC 2639, NGC 7469, NGC 3227, NGC 4639 and NGC 6814, respectively. The majority of them show normal star formation activities, \( L_{\text{FIR}}/L_B < 1/3 \). It might be reasonable then to argue that the FIR emission in Seyfert 1 galaxies is different from that in Seyfert 2s.

4 Conclusions

We have discussed the effect of enhanced star formation in Seyfert 2 galaxies on the Tully-Fisher relation in this paper. The main results are (1) for nearly all Seyfert 2 galaxies with detection of nuclear and/or circumnuclear star formation, the ratio between FIR and blue luminosities is greater than 1/3, and (2) we confirm that the offset of the Tully-Fisher relation in Seyfert 2 galaxies is due to the enhanced star formation in the circumnuclear region. By use of \( L_{\text{FIR}}/L_B \) as an indicator of relative star formation rate, we find that Seyfert 2 galaxies with normal star formation activities, obey the same Tully-Fisher relation as the normal
galaxies.

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Figure Captions:

Figure 1. The Tully-Fisher relation for Whittle’s sample. (a) for Seyfert galaxies with $L_{\text{FIR}}/L_B < 1/3$; and (b) for Seyfert galaxies with $L_{\text{FIR}}/L_B \geq 1/3$. The dot-dashed lines show the best fit to data and dashed line is the fit to normal Sb spiral galaxies from Rubin et al. (1985).

Figure 2. The Tully-Fisher relation for Seyfert 2 galaxies from Veron-Cetty & Veron (1996) sample. (a) for Seyfert galaxies with $L_{\text{FIR}}/L_B < 1/3$; and (b) for Seyfert galaxies with $L_{\text{FIR}}/L_B \geq 1/3$. The dot-dashed lines show the best fit to data and dashed line is the fit to normal Sb spiral galaxies from Rubin et al. (1985).
