

AN EVIDENCE FOR ENHANCED STAR FORMATION RATE IN ARAKELIAN GALAXIES

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(Abstract)

Infrared emission of 182 Arakelian galaxies with high surface brightness included in the IRAS Survey is considered as an evidence for enhanced star formation rate. About 63 % of them have high infrared luminosities $L_{\text{FIR}} \gg 10^{44} \text{ erg.s}^{-1}$ in the region between (1 - 500) μm . The distribution of $\log(f_{60}/f_{100})$ shows that the Arakelian galaxies are warmer than the "normal" S galaxies with clearly definitely peak placed at about 45 K. The galaxies with high surface brightness tend to extend the relation f_{100}/f_{60} versus $L_{\text{IR}}/L_{\text{B}}$ for "normal" S galaxies and emit up to seven times more energy in the infrared region between (40-120 μm). The mean ratio $L_{\text{FIR}}/L_{\text{B}}$ for 145 Arakelian G with infrared radiation and known redshifts is ca. 3.63.

If the dust clouds are optically thin the mean value of the dust mass which radiates at 60 μm $M_{\text{dust}}(60\mu\text{m})$ is ca. $9 \cdot 10^5 M_{\odot}$. The connection between L_{IR} and L_{B} points out that the most galaxies with high surface brightness have constant or increased star formation rate.

1. Introduction

Arakelian galaxies (AknG) are a sample which contains 591 galaxies whose surface brightness are larger than 22 mag per sq arcsec in the system near to this of Holmberg. More than half (~ 300 objects) have emission lines in their spectra and excess in radio flux at 408 MHz, Arakelian (1975). The high surface brightness in the optical region is connected with occurrence of young and blue stars rather than with their compactness. This is the reason for more intensive general radiation field.

The present work considers to the infrared radiation from 182 Arakelian galaxies included in Cataloged Galaxies and Quasars detected in the IRAS survey, 1985. This sample is 32% from the whole Arakelian's list. 145 of them have known redshifts, 36 of them have good determined IRAS fluxes.

2. GENERAL PROPERTIES

We shall suggest that the infrared radiation of the galaxies in question is due of thermal reradiation by dust of the stellar

radiation field. The nature of the IR radiation in Akn G will be discussed in details by Yankulova and Petrov, 1990 (to be published).

Indicators for the "infrared activity" of galaxies are the luminosities in the infrared L_{IR} and the ratio L_{IR}/L_B , where L_B is taken to be equal of νf_ν at $\lambda = 4400 \text{ \AA}$. We have used the calibration of Houck et al. (1984) in the blue region F_B

$$(1) \text{Lg } F_B = -7.54 - m_p / 2.5 \text{ [W/m}^2\text{]}.$$

Note that these fluxes are about 5 times larger than those in standard B-filter Soifer et al. (1987).

Infrared fluxes F_{IR} refer to the infrared emission between 40 and 120 μm which is determined according to Cataloged Galaxies and Quasars Observed in the IRAS Survey, 1985, Appendix B

$$(2) F_{IR} = 1,26 \cdot (2,58 \cdot 10^{12} \cdot f_{60} + 1,00 \cdot 10^{12} \cdot f_{100}) \cdot 10^{-26} \text{ [W/m}^2\text{]},$$

where f_{60} and f_{100} are the IRAS cataloged flux density in [Jy]. In order to have possibility to compare the results with those of other authors for different kinds of objects we'll use this definition.

Following Belfort et al. (1987) we have estimated the total far infrared emission from about 1 to 500 μm F_{FIR} by expression

$$(3) F_{FIR} = 1,75 \cdot 10^{-14} \cdot (12,66 \cdot f_{12} + 5,0 \cdot f_{25} + 2,55 \cdot f_{60} + 1,01 \cdot f_{100})$$

in $[\text{W/m}^2]$, where $f_{\mu\text{km}}$ are the IRAS flux densities in [Jy]. The luminosities L_B , L_{IR} and L_{FIR} are computed for $H = 75 \text{ km/s.Mpc}$.

Figure 1 shows the distribution of the total far infrared luminosities L_{FIR} for the all Arakelian galaxies with known redshifts. They are 145 objects. It should be noted that about 63% of the all Arakelian galaxies with IR radiation have $L_{FIR} > 10^{44} \text{ erg.s}^{-1}$. In fact this means that the Akn galaxies belong to ELIRS (extremely luminous far infrared sources) Harvit et al. (1987) because they have large values of IR radiation between 1 to 500 μm and low ionized optical spectra.

On the figure 2 we have presented the color-indices f_{60}/f_{100} distribution for galaxies with high surface brightness (Akn G). For comparison the same one has been presented for three other samples of galaxies - "normal" spirals from the Virgo cluster galaxies with low surface brightness (LSBG - G. Helou (1985) and blue compact emission line galaxies (BCELG) picked out from the Markarian lists (Kunth and Sevre, 1985). The lower horizontal axis is labeled with $\log(f_{60}/f_{100})$ and upper axis with the corresponding color temperature.

The mean value of the infrared color f_{60}/f_{100} for the sample of Akn G is $\log(f_{60}/f_{100}) = -0.34$ and the mean value of the ratio $L_{IR}/L_B \sim 1.32$.

For comparison the "normal" S galaxies investigated by de Jong et al. (1984) have $\log(f_{60}/f_{100}) = -0.43$ and $L_{IR}/L_B \sim 0.4$. The

distribution of $\log(f_{60}/f_{100})$ shows that the Arakelian galaxies are warmer than the "normal" S galaxies with clearly definitely pick placed about at $T \sim 45$ K . At the same figure we can see that the Arakelian galaxies detected by IRAS have the distribution of temperature color index f_{60}/f_{100} similar to that of the blue compact emission line galaxies Kunth,Sevre (1985).

Figure 3 presents the relation between the infrared color f_{100}/f_{60} versus the index of activity L_{IR}/L_B for the sample consisted of 145 Arakelian galaxies with known redshifts. On this diagram 36 objects whose IRAS fluxes at 60 and 100 mkm are well determined are noted by circles. The region occupied by the "normal" S galaxies picked out the Virgo cluster is drawn by uninterrupted line. On the same diagram the blue compact emission line galaxies would have occupied the upper right region and they continue the same relation for the normal S galaxies Kunth and Sevre (1985).

The ratio F_{IR}/F_B has been adopted by many authors as a convenient way of measuring the infrared activity of galaxies and the mean value of this ratio for 145 Akn G with known redshifts is $L_{IR}/L_B \sim 1.32$. The ratio L_{FIR}/L_B for the same objects is $L_{FIR}/L_B \sim 3.63$. Dust temperature from f_{100}/f_{60} increases and the galaxies become warmer with increasing of the infrared activity (ratio L_{IR}/L_B) which has been discovered by de Jong et al.(1984) for the "normal" S galaxies from the Virgo cluster. The galaxies with high surface brightness tend to extend this relation and so do BCG and at temperature in the range 40 - 50 K they emit up to seven times more energy in the infrared region (between 40 and 120 mkm) than in the blue region. It should be noted that the region occupied by the high surface brightness galaxies coincides with that one occupied by the blue compact galaxies with emission lines.

Maybe this result points out higher rate of star formation in these galaxies than in normal spirals and irregular galaxies.36 Arakelian galaxies which have good determined IRAS fluxes are marked on the two color diagram $\log(f_{60}/f_{100})$ and $\log(f_{12}/f_{25})$ - figure 4. Helou's (1986) model is superimposed there.

Except for galaxies with Seyfert - like nucleus far infrared radiation is a result of thermal radiation from interstellar dust grains heated by starlight. In Helou's model FIR consists of two components: cirrus like component C(7n) which is heated by the general radiation field and warm component A(7n) connected with active star formation regions. Curve D in the Helou's model is from Desert's calculations who calculates the emission from dust particles of various sizes and the heating radiation field which is altered from an intensity comparable to the solar neighborhood (point X) to one similar to that found in a region of active star formation (point Y). The second noted curve H was computed from Helou's two component model and represents the locus of points in the color - color diagram that have equal contributions from the warm and cool components. The circles labeled B and S are the adopted colours of the "starburst" and "seyfert" components used

to synthesize the observed far infrared spectra by Rowan - Robinson, (1987). Most of the galaxies from the sample of 36 Arakelian galaxies with well determined IRAS fluxes are situated between two curves D and H on the Figure 4. This fact points out that those are objects with higher rate of star formation. The ratio IR/B increases from down right corner to upper left corner. Now we will consider some objects which are situated above the curve D.

Akn.312. We find this object to be an interesting one. It lies immediately on the curve D in the region with high SFR. Akn 312 is an elliptical object with jet Arakelian, (1975). The emission lines are very bright - Doroshenko, Terebizh (1975)

Akn.564. This is a known Seyfert galaxy with striking evidence of nucleus of Seyfert galaxies. In the spectrum of this object it is observed strong H α the wide of which is about 100 A - Arakelian et al. (1976).

Akn 381. The radiation of this object in the infrared region exceeds nearly 6 times that one in the visual region. This is an elliptical blue object with an envelope. It is observed that emission line of H α with mean intensity and weak lines of [NII] $\lambda\lambda$ 6548/83 Arakelian et al. (1976).

There is strong emission of H α and mean intensities of [NII] $\lambda\lambda$ 6548/83 and [SII] $\lambda\lambda$ 6717/31 in the spectra of the objects Akn 291, 409, 497, 490, 541 Dibay, Yesipov (1975, 1976) and Dibay et. al. (1976).

The mass of the radiated dust is determined mainly from the lower temperature dust component at T_d from f₆₀/f₁₀₀, because B λ (T_d) decreases rapidly with decreasing of the temperature. For optically thin emission the dust mass emitting at a given wavelength is given by

$$(4) M_{\text{dust}}(\lambda) = 4\pi R_g^2 * f_{\lambda} / 4\pi B_{\lambda}(T_d) * K(\lambda),$$

where R_g is the distance from the Earth to galaxy, f λ is the observed flux density at wavelength λ , T_d is the dust temperature deduced from f₆₀/f₁₀₀, K(λ) = Q(λ)/(4/3)a ζ [cm²/g] is the mass absorption coefficient and Q(λ)~ λ^{-n} is the absorption efficiency of the dust.

We suggest that the dust is a mixture of graphite and Silicate particles with radii a = 10 mkm and densities ζ = 2 g/cm³. Based on the recent grain model of Drain and Lee (1984), we adopt n = 1 and K(60 mkm) = 250 cm²/g. We use the IRAS fluxes at 60 mkm which are well determined at this frequency to estimate the dust mass M_{dust}(60 mkm). We find that the mean value of the dust mass M_{dust}(60 mkm) is ~ 10⁵Mo. The dust mass evaluated by this way is a low limit of the dust clouds which radiate FIR and they are optically thin at 60 and 100 mkm.

It may be expected that there is a correlation between the ratio $L_{\text{IR}}/L_{\text{B}}$ and the dust mass which radiates at 60 and 100 mkm. This relation is shown on Figure 5 and Pearson correlation coefficient is ~ 0.60 .

3. Star Formation Rate

The star formation rate is considered from the point of view of the connection between LIR and LB. This relation for all Arakelian galaxies with infrared radiation is represented on the *Figure 6*.

According to Gallagher and Hunter (1987) the line 2 corresponds to constant SFR and the line 3 corresponds to a burst in the star formation. The most galaxies are situated between the lines 2 and 3 and above the latter. This points out for increased star formation rate in Arakelian galaxies.

Following Gallagher and Hunter (1987) we can make a rough estimation of star formation rate

$$(5) M_{\text{FIR}} = 2.5 \cdot 10^{-10} \beta^{-1} d^{-1} L_{\text{IR}} \text{ [Mo per year] ,}$$

if the mass of the warm stars is ~ 10 Mo. In this expression $\beta \sim 0.5$ and it depends on the newborn star effective temperature T^* and on galaxy's geometry. The part δ of the infrared radiation which is connected with the young stars is $\delta < 1.0$. According to *Figure 4* for Arakelian galaxies we can assume that $\delta \sim 0.75$. As a result we obtain $dM/dt \sim 10$ Mo per year.

4. Conclusion

About 63% from the Arakelian galaxies included in the IRAS survey have large infrared luminosities $L_{\text{FIR}} \gg 10^{44}$ erg.s⁻¹ in the region between 1-500 mkm.

The distribution of $\log(f_{60}/f_{100})$ shows that the Arakelian galaxies are warmer than the "normal" Sgalaxies with clearly definitely pick placed about at $T \sim 45$ K. Arakelian galaxies detected by IRAS have the distribution of temperature color index f_{60}/f_{100} similar to that of the blue compact emission line galaxies.

The mean value of the ratio $L_{\text{IR}}/L_{\text{B}}$ for 145 Arakelian galaxies with IR and known redshifts is $L_{\text{IR}}/L_{\text{B}} \sim 1.32$. The ratio $L_{\text{FIR}}/L_{\text{B}}$ for the same objects is ~ 3.63 . The galaxies with high surface brightness tend to extend the relation f_{100}/f_{60} versus $L_{\text{IR}}/L_{\text{B}}$ for "normal" Sgalaxies and emit up to seven times more energy in the infrared region between (40 - 120 mkm).

The mean value of the dust mass which radiate at 60 mkm $M_{\text{dust}}(60\text{mkm})$ is $\sim 10^5$ Mo.

The connection between L_{IR} and L_{B} points out that the most galaxies with high surface brightness have constant or increased star formation rate.

CAPTIONS FOR FIGURES

Figure 1. Distribution of the total far infrared luminosity between 1 to 500 mkm for the sample of Akn G with high surface brightness.

Figure 2. Distribution of the $f(60\text{mkm})$ to $f(100\text{mkm})$ ratio for the considered sample of Akn G with IR emission (lower panel); blue compact emission line galaxies (BCELG); galaxies with low surface brightness (LSBG); "normal" spirals from the Virgo cluster.

Figure 3. The relation between the infrared color f_{100}/f_{60} versus the index of activity $L_{\text{IR}}/L_{\text{B}}$ for the sample of 145 AknGal with known redshifts. 36 objects whose IRAS flux are well determined are noted by circles. The region occupied by the "normal" S galaxies picked out the Virgo cluster is drawn by uninterupted line de Jong et (1984).

Figure 4. Infrared color - color diagram plotting the ratio $\log(f_{60}/f_{100})$ against the ratio $\log(f_{12}/f_{25})$. Helou's (1986) model is superimposed there. The circles labeled B and S are the adopted colours of the "starburst" and "sefvert" components in Rowan - Robinson (1986).

Figure 5. The dust mass which radiates at 60 and 120 mkm in solar units versus the ratio of infrared luminosity between 40 and 120 mkm to blue luminosity L_{B} .

Figure 6. The infrared luminosity L_{IR} between 40 and 120 mkm versus the blue luminosity L_{B} . According to Gallagher and Hunter (1987) the line 2 corresponds to a constant SFR, the line 3 corresponds to a burst in the star formation.

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