Statistical properties of the faint early-type galaxies sample: possible effects of evolution

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July 24, 2013

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Abstract

Early-type galaxies from CfA catalogue were assotiated with IRAS FSC sources. In given sample IR and optical properties were used to obtain some classification of these objects. The existance of significant classes can be evidence of presence one main type of the dust in each galaxy. Physical interpretation of obtained classes was discussed. The dust mass in two classes of galaxies can be calculated using evolution modelling. In this case we can obtain a estimations for chemical composition and initial mass function in these galaxies.

1 Introduction

The availability of an enormous amount of infrared data, obtained in the IRAS experiment, makes it possible to analyze statistical properties of samples of various celestial objects, including those in which the components of IR emission are expected to be fairly weak. In particular, galaxies of early morphological types (E and S0) may be placed into the latter category. Although the first release of the IRAS Point Source Catalog contained only a small number of such galaxies, the application of additional processing techniques allowed the formation of a large sample of such objects and the investigation of statictical properties of various galaxy physical parameters, obtained both from IR data and from data derived in other spectral regions (Knapp et al. [1], Bally & Thronson [2]). The release of the next catalog of IR sources (Faint Source catalogue v.2, FSC-2, Moshir et al [3]) justifies the studies of general sample properties of early-type galaxies, associated with the sources of this catalog. These studies are also useful because the objects in the IRAS Point Source Catalog (PSC) and FSC-2 Catalog are subject to various selection effects and may exhibit various physical properties. In this work, such an investigation was performed using objects from the CfA catalog (Huhra, [4]), which has associations in the FCS-2 catalog. For the derived sample, the objects were classified by means of the cluster analysis, and physical interpretation of the obtained classes was made.

2 Data and data handling

To analyze possible associations with Faint Source Catalog, the largest available catalog of galaxies - CfA catalog - was used, which containes 38909 objects; morphological type is given for 17008 objects, 4596 objects from them are early-type galaxies (catalog's type $t < 0$). To apply the identification procedure, the following selection criteria were used for objects: the separation between the objects in the CfA and FSC-2 catalogs was within 60 arcsec; the object showed a statistically significant flux (parameter $FQUAL > 2$) in one of the far-IR bands (60 or 100 μm); there was no associations for the source in FSC-2 catalog with other, closer objects from catalogs of other objects. The applied procedure resulted in a sample of 539 galaxies, which was used in the subsequent analysis; 11 galaxies from this list had no previous associations with IR sources. A group of galaxies with statistically significant IR measurements in, at least, three IRAS bands and with measured apparent magnitudes in Johnson's UBV system, as well as with known redshifts, was selected from the general sample. These data were available for 166 E and S0 galaxies. Such selection is required to classify objects by, at least, three parameters. As it is desirable that the selected parameters were independent of the galaxy distance, the flux ratios at 25, 60, 100 μm, and in the B band (f_{25}/f_{60}, f_{100}/f_{60}, f_B/f_{60}) were used for the classification.

Hierarchical clustering algorithm, involving a sequential agglomeration of objects or a group of objects (clusters) using a criterion of any kind, was applied for object classification. After the agglomeration of objects into a single cluster, the maximum number of statistically significant clusters is determined using a criterion of any kind (a set of criteria). In this case, a software program of hierarchical cluster analysis, taken from the STATLIB library (compiled by Murtagh [5]) minimal increase in residual mean square (RMS) in a cluster during agglomeration (Ward's criterion) was used as a criterion for cluster agglomeration; this leads to breaking the hyperspherical form (in classification parameter space) into clusters. To estimate the significance of breaking into clusters, a semi-empirical criterion was applied, based on an analysis of the "dissimilarity - number of cluster" relationship (Mojena & Wishart [6]); according to this criterion, the agglomeration must stop when the growth rate of RMS increases during cluster agglomeration. The requirement that the separation between clusters be larger than RMS within each cluster was used as an additional criterion. The application of both these criteria resulted in breaking the sample into four clusters (object classes), which were subsequently subject to further analysis.

3 Results of Data Processing

To analyze the derived classes of galaxies, some additional physical parameters for each sample object were calculated, including the dust distribution in temperature, dust masses, and the contribution of IR emission to overall emission from galaxies. The limited number of photometric bands require a simple dust model to describe the observational IR photometry:

$$I_\nu = \tau_\nu B_\nu \left(T_{\text{dust}}\right)$$

where $\tau_\nu \propto \nu^\alpha$ is the optical depth, and $B_\nu \left(T_{\text{dust}}\right)$ - the Plank function. Unfortunately this approximation can not give meaningful results for a large number of galaxies in the sample. As a consequence, we have to use a multicomponent dust model:

$$I_\nu = \sum_{i=1}^{n} \tau_\nu^{(i)} B_\nu \left(T_{\text{dust}}^{(i)}\right)$$

A two-component ($n = 2$) model of dust was employed to evaluate the temperature distribution. As three measurements are not enough to determine the complete set of parameters for such a model, the spectral index α in the dependence of absorption coefficient on the frequency and the temperature of one of the component ($T_{\text{d}ust}^{(1)} = 28\text{K}$) were fixed parameters. As a result of the modelling, the temperature of the "hot" component, as well as the "hot"- to-"cold" component ratio was calculated. The "hot" component with temperature $T_{\text{d}ust}^{(2)} > 60\text{K}$

is present virtually in all galaxies, its contribution to overall emission being in the range from 1% to 60%. The mass of dust, as in the paper by Greenhouse et al [7], was calculated from the emission in a wavelength interval of 25 to 300 μm, taking into account the two-component model of dust. Statistical data on classification parameters ($lg(f_B/f_{60})$, $lg(f_{25}/f_{60})$, $lg(f_{100}/f_{60})$) and additional physical parameters, quoted above ($T^{(2)}_{\mathrm{d}ust}, lg(M_{\mathrm{d}ust})$, the contribution of "hot" component to overall emission , as well as the redshift z and morphological type t), were obtained for each selected class of galaxies and are given in Table 1.

Parameter	Cluster1	Cluster2	Cluster3	Cluster4
Redshift z	0.017 ± 0.001	0.010 ± 0.003	0.019 ± 0.003	0.009 ± 0.004
Type t	-2.86 ± 0.21	-2.32 ± 0.25	-2.56 ± 0.26	-2.78 ± 0.35
$\lg(f_B)/f_{60})$	-0.36 ± 0.09	1.34 ± 0.13	0.49 ± 0.11	3.35 ± 0.21
$\lg(f_{25})/f_{60})$	-0.86 ± 0.01	-0.99 ± 0.02	-0.49 ± 0.03	-0.49 ± 0.03
$\lg(f_{100})/f_{60})$	0.23 ± 0.01	0.41 ± 0.01	0.20 ± 0.02	0.53 ± 0.03
$T^{(2)}_{\mathrm{dust}}$	66.41 ± 0.41	69.89 ± 2.02	81.54 ± 1.50	94.49 ± 4.81
$\lg(M_{\mathrm{dust}})$ in $M_\odot$	7.60 ± 0.09	7.15 ± 0.15	7.52 ± 0.12	6.51 ± 0.21
"Hot"/ "Total"	0.37 ± 0.02	0.27 ± 0.05	0.38 ± 0.03	0.13 ± 0.02

To interpret some physical properties of galaxies of various types, the available observations revealing traces of interaction (possible associations with objects from Vorontsov-Vel'aminov's catalod of interacting galaxies), traces of an active nucleus (possible associations with objects from Veron's catalog), and the presence of radio emission, were collected. As a result of the comparison of the above signs, the following interpretation may be provided for the division of early-type galaxy sample into classes:

- Class 1: Galaxies with high abundance of moderate-temperature dust; this class includes all interacting galaxies, galaxies with giant HII zones, and a number of sources emitting in a high-frequency radio range; the above signs imply outbreaks of star formation in this class of galaxies and the existence of UV photons - the main source of dust heating.

- Class 2: Differs from the previous class by a considerably lower dust abundance and by a minimum number of peculiar properties (there are weak traces of nuclear activity in a number of cases); this class appears to include "normal" ellipticals.

- Class 3: Contains mainly galaxies with active nuclei, high-temperature dust (when the amount of optical emission, reradiated in infrared, is small), galaxies with synchrotron radio sources. The dust properties being close to IR properties of galaxies implies that the dust surrounding the nucleus is the main contributor of IR emission in this class of galaxies.

- Class 4: This class of objects has the same properties as class-2 galaxies, except that their dust is warmer. To establish the nature of the additional dust-heating source for this class of galaxies a more thorough investigation of their observed properties in a variety of spectral regions may be required. Another explanation can be offered, if we assume that the spectral index α in the dust model is large. Since α is determined by the size distribution of dust grains, the distruction of large dust particles takes place in these objects. The negative corelation between the temperature and mass of the dust favors the second explanation.

4 Dust and history of galaxies

As a result previous consideration, we can see, that a set of galaxies without significant star formation, nuclear activity and interaction can be selected using by clustering methods. For these objects we can suggest late-type stars in each galaxy as ultimate source of interstellar dust in this galaxy. It provide us to write relations between stellar evolution and dust mass in a galaxy. If the galactic mass is generated mainly in atmospheres of late stars, dust mass can be estimated as:

$$M_{\rm dust} = \zeta(Z)\, t_{\rm dust}\, \dot{\rm M}_{\rm gas}$$

where $\zeta(Z)$ is the content of dust in the stellar wind (depend on chemical composition Z), $t_{\rm dust}$ – lifetime of dust grains, $\dot{\rm M}_{\rm gas}$ - stellar mass loss rates, determined as:

$$\frac{\dot{\rm M}_{\rm gas}}{M_{\rm gal}} = \int_{M_{\rm min}}^{M_{\rm max}} \frac{\dot{\rm M}(M_*)}{M_*} \phi(M_*) dM_*$$

where $M_{\rm gal}$ is total galactic mass, $M_{\rm min}$, $M_{\rm max}$ are minimal and maximal stellar masses, and $\phi(M_*) \propto {M_*}^{-\alpha}$ – stellar mass function. Since $\zeta(Z)$ and $\dot{\rm M}(M_*)$ can be obtained from stellar models, dust mass, obtained from IR-observations can be useful tool to estimate the chemical composition and stellar mass function in the galaxies.

5 Conclusions

1. It is possible to obtain statistically significant groups of galaxies on the basis of IRAS photometry. This fact can be considered as evidence of the existence of one main type of dust in each galaxy.

2. The derived classes of galaxies can be interpreted as: - galaxies with active star formation (class 1); - galaxies with strong nuclear activity (class 3); - "normal" E/S0 galaxies (class 2); - galaxies with large index in the size distribution of grains (class 4).

3. Many galaxies show appreciable (up to 80% of the overall dust mass) amount of hot ($T_{\rm d}{}_{ust} > 60$K) dust.

4. For galaxies from classes 2 and 4 we have an opportunity to estimate the chemical composition and initial mass function from the dust mass.

References

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