Bull. Astr. Soc. India (1993) **21**, 135-138

Isolated pairs of spiral galaxies—a statistical study of far infrared and microwave characteristics

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Received 1992 December 3; accepted 1993 January 25

Abstract. A statistical study of the far infrared and microwave (λ6.3 cm) luminosities of a sample of isolated pairs of spiral galaxies and a comparison sample of non-interacting galaxies selected from the lists given by Wunderlich & Klein (1991) does not reveal any significant difference between the two samples.

Key words : galaxies : interacting spiral galaxies—star burst—infrared and microwave characteristics

1. Introduction

Studies in the infrared reveal aspects of star formation in galaxies (Rowan-Robinson 1991) and galaxy interactions are believed to be responsible for enhancing the rates of star formation and for triggering bursts of star formation (Keel 1991). Presence of a companion galaxy and merging systems are characterised by very high rate of star formation and 'star burst' activity (Keel 1991). Sanders *et al.* (1986) infer that the majority of the most luminous IRAS galaxies with far infrared luminosities greater than $10^{11}\ L_{\odot}$ appear to be strongly interacting systems and those with the highest $L_{FIR}/M(H_2)$ ratios are mergers or close contact pairs. According to de Jong (1986) the fraction of interacting systems among infrared galaxies is significantly higher than among local field galaxies which suggests that (distant) encounters between galaxies may play an important role in triggering bursts of star-formation.

Lonsdale, Persson & Matthews (1984) have observed that, on average, the 10 μm luminosities of interacting galaxies are higher than those of non-interacting galaxies. This observation is in conformity with the conclusion of Cutri and McAlary (1985) that a population of nuclei with extremely luminous 10 μm emission is unique to the interacting sample.

However, Cutri & McAlary (1985) also state that comparisons with suitable control samples indicate that at least 50% of the galaxies in interacting pairs have infrared properties no different from those of non-interacting galaxies and remark that it will be just as important to understand why interactions do not always induce activity. Also, Keel & Van Soest (1992), based on a study of the pairing properties of Markarian starburst galaxies using optical and far infrared data, do not find any clear differences in the global character of starformation between isolated and paired Markarian systems. In view of these disparate results it seemed of interest to make a statistical study of the far infrared and λ6.3 cm radio continuum luminosities of interacting and non-interacting spirals which have been compiled by Wunderlich & Klein (1991) to enable a comprehensive discussion of the radio-FIR relation of interacting and non-interacting spirals.

2. Data for the statistical study

(a) *Interacting spirals*

Wunderlich & Klein (1991) list 36 pairs of interacting galaxies. For compiling this list they used the "catalogue of isolated pairs of galaxies in the northern hemisphere" (Karachentsev 1972). In compiling this list they picked the objects by searching the Palomar Sky survey charts and applied to all galaxies appearing to form a pair criteria for isolation as well as apparent photographic magnitude and differences in radial velocities of the galaxies in the pair. They have also restricted the choice to a limited range of right ascensions.

(b) *Comparison sample*

They list 37 isolated spirals as comparison sample which is part of the sample given by Hummel (1980). In selecting this sample they have used certain brightness criteria while restricting to certain limiting right ascensions and declinations. They have carefully excluded all those galaxies which are noted as members of pairs or groups by others.

(c) *Data for the present study*

For our statistical study we have used the data from Wunderlich & Klein's (1991) table 8 giving the far infrared and monochromatic radio luminosities for the isolated pairs of galaxies and table 9 for the comparison sample. From these two tables we have picked out objects which are almost at the same distance, the difference being ≤ 1 Mpc and for which definite values of far infrared luminosities and the luminosities of the cold component of dust are tabulated. On this basis we have obtained a data sample of 11 pairs of almost equidistant interacting and comparison objects. The average distance and the absolute photographic magnitude of the interacting and comparison sample are approximately the same. These 11 pairs are listed in table 1 along with the distances and the FIR luminosities of the warm dust component.

3. Statistical analysis and results

We have obtained the far infrared luminosity of the warm dust component in each object by subtracting the luminosity of the cold component from the total luminosity in the FIR given in tables 8 and 9 by Wunderlich & Klein (1991). The luminosity of the warm dust component is the result of the heating of the dust particles by recently formed massive (OB) stars and is therefore indicative of the recent OB star formation rate. Many studies have also established the high correlation between the total microwave and far infrared emission of spiral galaxies suggesting that the young massive stars are causally linked to the radio continuum.

Table 1. List of interacting and non-interacting galaxies, their distances and warm dust component luminosities

S. No.	Interacting galaxies non-interacting	Distance D Mpc	$\log L_{FIR}$ (warm)
1	K 218	3.1	36.806
	N 1560	2.6	33.684
2	K 133	3.8	34.552
	N 6503	4.2	34.826
3	K40	6.7	34.975
	N 7640	7.7	35.203
4	K 110	16.9	37.355
	N 7217	16.5	35.971
5	K 210	17.4	36.176
	N 7814	17.2	35.292
6	K 195	23.8	36.759
	N 6643	23.1	36.380
7	K 216	24.6	35.979
	N 2712	25.1	35.776
8	K 132	31.8	36.253
	N 2701	32.3	36.219
9	K 186	35.0	36.387
	N 1169	35.0	35.849
10	K 165	56.2	35.757
	N 1961	55.4	36.917
11	K 68	58.9	36.786
	N 2942	58.8	35.944
	Mean	25.29 (Interacting)	
		25.26 (Non-interacting)	

In order to find out how the far infrared characteristics compare between the sample of interacting (i.e. isolated pairs of) galaxies and the comparison sample (of non-interacting) galaxies we have subjected their warm component luminosities to statistical tests. Applying the rank U test of Mann-Whitney (Chase & Brown 1986) we are led to reject the hypothesis that the two samples are from different populations at the 5% level of significance. Also, since the sample sizes $n_1 = n_2 > 10$ the distribution of U is approximately normal and using the corresponding test statistic we arrive at the same conclusion with the same level of significance. The Wilcoxon signed rank test (Chase & Brown 1986) also confirmed this conclusion.

A similar analysis performed on the cold component luminosities for the two samples also leads to the same conclusion.

We subjected the monochromatic microwave (λ = 6.3 cm) luminosities of the interacting and comparison samples to statistical analysis. In five of the interacting samples and four of the comparison samples only upper limits to the microwave luminosities are given by Wunderlich & Klein (1991). Hence, as treated by Cutri & McAlary (1985) for censored data with upper limits, we carried out the Gehan two-sample test (Eddington 1987). This again, as one would expect because of the tight correlation between radio and FIR luminosities, showed that the distributions of the two samples are not different.

4. Conclusion

Statistical analyses of samples of interacting and non-interacting spiral galaxies selected from the lists given by Wunderlich & Klein (1991) suggest that the far infrared characteristics of these samples of spiral galaxies do not differ significantly. This result seems to be in accordance with the observation of Cutri & McAlary (1985) that at least 50% of the galaxies in interacting pairs have infrared properties no different from those of non-interacting galaxies and also with the conclusion of Keel & van Soest (1992) that they are unable to identify any clear differences in the global character of star formation between isolated and paired Markarian systems.

It may also be noted that the FIR luminosities of the warm dust component in the samples in our study are $\leq 10^{11}L_{\odot}$ and according to Sanders *et al.* (1986) only those with far infrared luminosities $> 10^{11}L_{\odot}$ are strongly interacting systems.

If it is established that the far infrared properties of some interacting spiral galaxies are not significantly different from non-interacting spiral galaxies it is possible that, irrespective of the triggering mechanism, the resulting starburst loses memory of it and the same kind of objects are produced as suggested by Campos-Aguilar & Moles (1991) for blue compact dwarf galaxies. Keel & van Soest (1992) have also noted that they are unable to identify any clear differences in the global character of star formation between isolated and paired Markarian systems and remark that interactions can apparently trigger bursts of star formation but exercise little influence on their properties once triggering has occurred.

It would be interesting to identify the physical parameters which distinguish those isolated pairs of galaxies that differ in their far infrared and microwave characteristics from the non-interacting galaxies and those isolated pairs that do not reveal any differences.

Acknowledgement

We thank Ajit Kembhavi for constructive comments.

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NOTES AND NEWS

IAU Colloquium on the magnetic and velocity fields of solar active regions, September 6-12, 1992

The IAU Colloquium No 143, on 'The magnetic and velocity fields of the solar active regions' held at Beijing, China, was attended by more than 150 scientists from seventeen countries. The scientific program of this colloquium consisted of 22 invited talks, 43 oral contributed papers and 68 poster presentations. The highlight of the colloquium was a friendly debate on 'Strong and weak magnetic fields : Nature of the small-scale flux elements' between J. O. Stenflo and H. Zirin.

The first scientific session was devoted to 'Structure of active regions'. The session began with an invited talk by A. Title on 'Evolution and structure of fine structure magnetic fields'. A. Hofmann gave a detailed account of constructed maps of the Stocks I and V-components having an extreme spatial resolution down to 0.3 arc sec and polarimetric accuracy lower than one percent after eliminating effects of instrumental polarisation and stray light. He showed that magnetic field strength does not vary across dark and bright structures at a given spot radius. From diffraction limited magnetograms, obtained by using speckle interferometric techniques. C. U. Keller found that individual magnetic flux tubes with a diameter of about 200 km do not cover a significantly larger area than the cospatial bright points. Further, he reported that magnetic elements larger than 300 km are mostly darker than the average intensity and the transition between bright and dark elements occurs at diameters of about 300 km. Then six oral contributed papers dealt with very high resolution of 0.3 arc sec observations of magnetic and velocity fields of solar active regions obtained using active optics.

The second session began with the invited talk by T. Sakurai on the techniques of magnetic field computation and their application to solar magnetic fields. He reviewed the potential field models and force-free field models in active region scales, and global models including the source surface. To link the theories of solar dynamo and surface magnetic field, K. Petrovay proposed a model of vertical transport of magnetic flux through the convective zone assuming that the vertical distribution of magnetic fields is determined by dynamical equilibrium of different transport process. From the study of distribution of solar flare energies, peak fluxes and durations E. Lu showed that magnetic reconnection avalanches follows power law and energy release process is fundamentally the same for flares of all sizes.

Techniques of magnetic and velocity fields measurements were discussed in the third session. Guoxiang Ai explained the newly built facility at Huairou solar observatory to obtain the vector magnetograms and filtergrams simultaneously using 9 narrow band filter of 0.15-0.50 passband. H. P. Jones reviewed the techniques and instrumentation for inferring longitudinal, total and vector magnetic fields using a spectrograph and use of narrow band filters to isolate Zeeman-sensitive portions of visible and near infrared spectrum lines. D. Deming discussed the design of a 12-micron Strokes polarimeter using a high resolution Fabry-Perot etalon and large format array detector. Sunspot studies using the 12-micron lines have shown that the sunspot magnetic field extends well beyond the photometric boundary of the sunspot and magnetic filling factor is essentially 100% in mature sunspots. A paper by L. Dame' *et al.* described the details of the experimental set up for SIMURIS which stands for 'Solar Interferometric Mission for Ultrahigh Resolution Imaging and Spectroscopy'. It is a payload project for space station freedom to image the sun simultaneously in ultraviolet with 0.1 arc sec resolution and invisible with 0.05 arc sec resolution, sufficient to resolve the steep gradients across magnetic confinements. In session four, J. O. Stenflo discussed the first definite identification of intrinsically weak (less than KG) fields, using the Stokes V profile of an infrared line pair near 1.56 micron. The weak fields have proven to be much more elusive until last year. From the spectroscopic data H. Zirin concluded the existence of strong magnetic field in quiet and active regions on the sun. Chromospheric fields and study of flare were discussed in sessions 5 and 6. T. Sakao described the hard and soft x-ray images obtained on board YOHKOH since its launch in August 1991. Hard x-ray images (above 23 KeV) in the impulsive phase of the flare show double-source structure at the peaks of impulsive bursts. Each of the double sources is located on either side of the magnetic neutral line. At valleys, hard x-ray emissions between 23 and 33 KeV show single-source structure at the neutral line while higher energy x-rays still remain double sources. Using YOHKOH data T. Kosugi showed that hard x-ray sources vary rapidly in shape and average height of hard x-ray sources is ~ 9000 km above the photosphere in the lowest energy band of 14 KeV, but at higher energies the altitude becomes progressively lower, reaching ~ 6000 km above 60 KeV. K. Shibata talked about the 'jet-like features' in the solar corona as seen in the soft x-ray images of sun obtained from YOHKOH. Typical size of the 'jet' is $5 \times 10^3 - 4 \times 10^5$ km and the apparent velocity is 30-300 km s^{-1}. He showed that many of the jets are associated with flare-like bright points, or flaring emerging flux regions or active regions. Structure of some jets suggests a helical magnetic field configuration along the jet.

The role of magnetic shear in topology in solar active region, structure and effect of emerging flux regions and convection in active regions was discussed in the remaining four sessions. T. G. Forbes showed that observationally defined shear is not necessarily a direct measure of magnetic energy stored in coronal currents. From the study of bipolar magnetic structures K. L. Harvey concluded that the number of active regions increases with decreasing region size, varying roughly as a powerlaw. A paper presented by J. Harvey indicated that the amplitude of 5-minute period p-mode oscillations reduces within active regions compared to the quiet sun but shorter and longer periods tend to enhance within active regions. H. Zirin in his concluding remarks suggested that more observations with high spatial, temporal and spectral resolution must be made to understand to topology and dynamics of active regions and triggering of solar flares.

Visits of the Huairou solar observatory and ancient astronomy observatory at Beijing were very useful and exciting.

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