IV. AGN RELATED PHENOMENA

https://doi.org/10.1017/S0074180900162278 Published online by Cambridge University Press

Alexei Fridman, Leonid Matveenko, Alexander Boyarchuk

Jack Sulentic, Halton Arp, Vahagn Gurzadyan

https://doi.org/10.1017/S0074180900162278 Published online by Cambridge University Press

Active Galactic Nuclei and Related Phenomena
IAU Symposium, Vol. 194, 1999
Yervant Terzian, Daniel Weedman, Edward Khachikian, eds.

Activity in Interacting and Binary Galaxies

Yervant Terzian

Department of Astronomy and National Astronomy and Ionosphere Center, Cornell University, Ithaca, NY, 14853

Abstract.
This is a short review of recent studies and reports on interacting galaxies and binary galaxies. Early studies were primarily made at optical wavelengths, but recent ones have concentrated on observing HI at $\lambda 21$ cm. Application of the Virial Theorem to these observations indicates M/L values of the binary systems of $\lesssim 50$, suggesting the existence of moderate halos around spiral galaxies.

1. Introduction

If gravity is the dominant force at large scales in the Universe, as we believe, then we hope to learn about the large scale structure of the universe, including its mass content and distribution. Such advances are crucial for establishing a credible theory of cosmic evolution.

For more than fifty years one of the outstanding problems of cosmology has been the "missing mass" in the universe (Zwicky 1937). If the physics we have come to understand is universal, then the evidence for dark matter cannot be disputed. On the scale of galaxies, and even clusters of galaxies the need for dark matter is very well established (Ashman 1992). Much less is known about the dark matter needed to support a closed model of the Big Bang universe and this matter, if it exists, is probably nonbaryonic (Bahcall, Lubin and Dorman 1995).

In order to investigate the dynamical masses of galaxies, including their halos, studies of gravitationally bound binary galaxies have been made as discussed in the following sections. Evidence for interacting and merging galaxies has recently been discussed by Schweizer (1996) and Hibbard and van Gorkom (1996), and the dynamics of galaxy interactions by Barnes (1996). HI observations of binary galaxies have been discussed by Nordgren, et al. (1999) and references therein.

2. Interacting Galaxies

The most prominent signature of galaxy interactions is their neutral hydrogen distribution and kinematics (Sancisi, 1998). HI $\lambda 21$ cm observations of binary galaxies or small groups, normally show tidal interactions in the form of HI tails and bridges even when the optical images seem to be undisturbed (Rand, 1994; Nordgren, et. al. 1998). The extended HI features sometimes have a very large

https://doi.org/10.1017/S0074180900162278 Published online by Cambridge University Press

cross section and contribute to the halo material surrounding galaxies. Such extended halos could be the source of the absorption lines seen in the spectra of distant quasars. Sancisi (1998) has argued that major interactions between galaxies of similar masses cause large tidal effects and many lead to mergers and eventually to the formation of elliptical galaxies. Minor interactions are normally those between a normal galaxy and a small dwarf companion, and this leads into gas accretion in the galactic disk and may cause sudden star formation in starbursts. Tidal material falling back into the galaxies is clearly seen in the system NGC7252 mapped in HI with the VLA by Hibbard, et. al. (1994).

From a study of interacting galaxies Sancisi (1998) has concluded that at least 25 percent of field galaxies have undergone some kind of tidal interaction, and a larger percentage of galaxies may have been through one or more mergers.

Two very comprehensive reviews have been prepared in the Saas-Fee Advanced Course 26, in 1996, and appear in a volume *Galaxies: Interactions and Induced Star Formation.* François Schweizer wrote about "Observational Evidence for Interactions and Mergers", and Joshua E. Barnes wrote about "Dynamics of Galaxy Interactions." In the 1950s Fritz Zwicky began the examination of interacting galaxies and concluded that the extended filaments seen from close galaxy pairs must be due to tidal gravitational interactions (Zwicky 1956, 1959). Vorontsov-Velyaminov (1959) also noted the many peculiar, distorted images of galaxies in binary galaxy systems. Soon after, Arp (1966) produced his "Atlas of Peculiar Galaxies" thus documenting many examples of galaxy interactions. Then numerical modeling showed that tidal interactions can indeed produce extended galaxy filaments and bridges, of which the most famous is the galaxy pair NGC4038/4039, known as "The Antennae", successfully modeled by Toomre and Toomre (1972).

The numerical simulations of interacting galaxies have progressed from gravitating two-point masses, each with a disk of particles, to today's N-body simulations with $N{\sim}10^6$ (Schweizer 1996). Tidal drag, fast encounters, dynamical friction, orbit decay, relaxation, and final mergers have now been incorporated in the sophisticated models of galaxy interactions as discussed by Barnes (1996).

A likely outcome of merging spiral galaxies could be the formation of elliptical galaxies, as simulations of merging remnants resemble ellipticals (Toomre and Toomre 1972). Indeed, Hibbard and van Gorkom (1996) have presented a systematic observational study of HI at λ21 cm of a sample of galaxy systems involved in progressive stages of merging. The observations were performed using the VLA and included the systems Arp 295, NGC 4676, NGC 520, NGC 3921, and NGC 7252. Hibbard and van Gorkom conclude that as the merger rearranges the light profiles of the progenitor disk galaxies they evolve into elliptical galaxies. Interacting galaxies often show signs of vigorous star formation, and the Infrared Astronomical Satellite IRAS in 1983 made numerous observations of starbursts in merging galaxies (Sanders 1990).

3. Binary Galaxies

From statistical studies of stellar motions the mass to luminosity ratio M/L ($M_\odot$=1, $L_\odot$=1) in the vicinity of the sun is just a few, and for the entire galaxy could be as high as 20. The flat rotation curves of galaxies indeed indicate M/L values of the order of tens. Small groups of galaxies show M/L values reaching ~100 from the dispersion velocities of their members, and large galaxy clusters show values of a few hundred. In order to have a closed universe one would require an M/L value of about 1500. This missing mass problem has been with us since Zwicky pointed it out in 1937, and remains completely unresolved.

In order to investigate the M/L values in galaxies, including their halos, Page (1952) observed binary galaxies and applied the Virial Theorem to determine if significant dark matter was attached to the luminous galaxies. This method looks simple but has several limitations.

First we must make sure that we are observing real gravitating galaxy pairs and not detached "optical" pairs. In all cases we unfortunately can only measure the projected separation of the two galaxies, and we have no information on the orbital eccentricity and inclination. Hence we need to observe large samples of galaxy pairs to obtain statistical results. The one parameter that we can determine with great accuracy today is the systematic radial velocity of each galaxy in a pair and hence their velocity difference ΔV.

Observations of galaxy pairs at optical wavelengths were done by Page (1952), Arp (1966), Karachentsev (1972) and Turner (1976a, b) among a few others, with ΔV accuracies of ~30 to 50 km/sec. Radio HI observations began with Peterson (Peterson, 1979a, b; Peterson and Terzian 1979) who used large samples of spiral galaxies and who adopted criteria to confine the sample, such as the relative magnitude of the galaxy pair should not exceed 2.5 magnitudes, and an isolation criterion to insure that there were no other nearby galaxies gravitationally distrubing the system. Later Schneider, et.al. (1986) used a more expanded sample and more refined isolation criteria.

In 1993 more detailed studies were performed by carefully selecting the galaxy pairs from galaxy redshift catalogues, thus performing a three dimensional isolation analysis (Chengalur, et.al 1993, 1994, 1995, 1996). In this manner wide pairs as well as close pairs were identified and accurately observed. The wide pairs were observed with the Arecibo radio telescope (beamwidth 3 arc min), and the Parkes radio telescope (beamwidth 14 arc min). The close pairs were observed with the VLA and the Australia Array (angular resolution ~30 arc sec). These studies continued with even more conservative selection criteria, such as identifying pairs in low or medium galaxy density regions (Nordgren, et.al. 1997a, 1997b, 1998). In total 106 wide pairs were observed and 25 close pairs were mapped with synthesis arrays. The velocity accuracy of the radio observations was about 5 km/sec.

The new surveys were statistically complete samples that included only pairs in low and medium galaxy density regions. The results have shown that the distribution of ΔV peaks at zero and decreases smoothly with increasing ΔV, as expected from a random orientation of galaxy pairs (Fig 1. from Nordgren et.al. 1996). The HI maps of close pairs all show tidal interactions in the form of tails, bridges and common envelopes.

For wide pairs, which are isolated, the median ΔV ~30 km/sec and pairs with projected separation as large as 1.0 Mpc have a median ΔV ~50 km/sec and are probably bound pairs, since the random galaxy velocities are of the order of $\geq$200 km/sec. Nordgren, et.al. (1999) argue that as the separation between pairs decreases from ~1.0 Mpc the median ΔV should increase until dynamical friction from dark matter halos forces ΔV to decrease. The data, however, show no such increase in ΔV with decreasing separations, hence they conclude that large dark halos, ~500 pc, exist. These could contribute to the HI line absorption seen in the spectra of quasars as mentioned earlier.

These modern data give a best fit that results into an overall M/L ~ 50, with a mass per spiral galaxy of $\sim 4.5 \times 10^{11}$ $M_\odot$ (Nordgren, et.al. 1999). This value is a few times larger than that derived from rotation curves and strongly suggests moderate dark matter halos. It is to be noted that the matter needed to close the universe does not appear to be distributed in the vicinity of the galaxies.

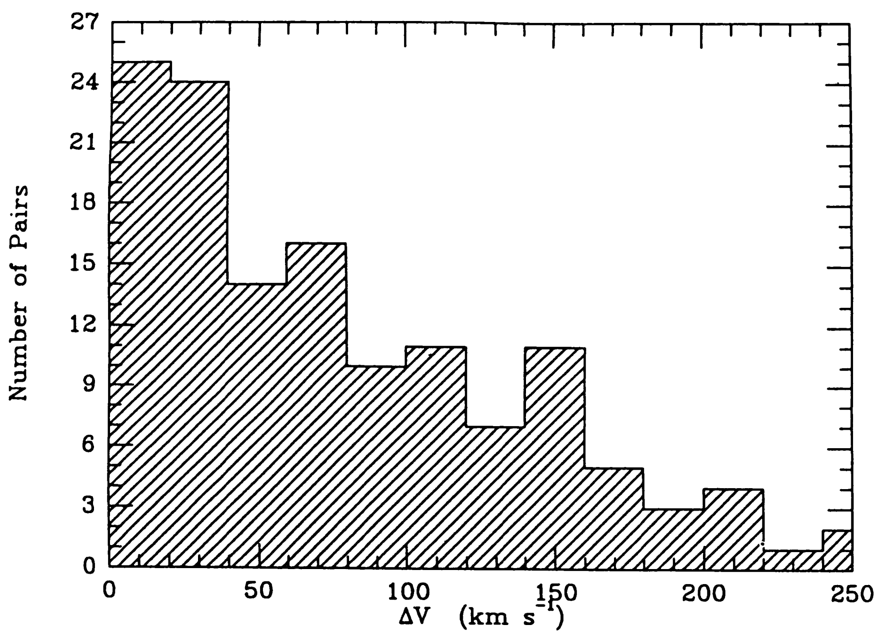

Figure 1. The distribution of velocity differences in galaxy pairs from the sample by Chengular et.al., and Nordgren et.al. cited in the text.

4. Velocity Quantization

In 1976 Tifft (1976) argued that the distribution of redshifts of galaxies shows periodic or quantized intervals separated by ~72 km/sec. Significant literature has been devoted to this potentionally cosmologically very important assertion, and discussion can be found in Tifft and Cocke (1989), Tifft (1996), Napier and Guthrie (1996) and Nordgren et.al. (1996). This last reference provides observational data on the velocity difference between pairs of galaxies. The data is arguably the most accurate set of velocities with errors $\lesssim 5$ km/sec,

https://doi.org/10.1017/S0074180900162278 Published online by Cambridge University Press

and includes ~130 isolated pairs. These observations show that the velocity difference of the pair sample decreases monotonically from zero and there is no indication of any redshift periodically in this sample (shown in Figure 1.).

A detailed analysis for searching for data clustering and periodicities has been given by Newman et.al. (1989, 1994) and by Newman and Terzian (1996). These authors critically discuss the approximate statistical methods used in concluding periodic effects, particularly when the data samples are very limited. Nevertheless, any credible velocity quantization effects, if real, would completely revolutionize our concepts of cosmology.

5. Conclusions

Although very significant new observational and theoretical studies have emerged on merging, interacting, and binary galaxies during the last few decades, much research work remains ahead. In particular detailed velocity structure of close and merging pairs is essential to understand the last phases of the mergers. Studies of small galaxy groups are also important to investigate the mutual gravitational perturbations that occur in these systems.

Acknowledgments. The author wishes to thank his close collaborators on the topics discussed above, who include J. Chengalur, M. Haynes, W. Newman, T. Nordgren and E. E. Salpeter. This work was partiallly supported by the National Astronomy and Ionosphere Center which is operated by Cornell University under a cooperative agreement with the National Science Foundation.

References

Arp, H., 1966, ApJS, 14, 1.

Ashman, K. M., 1992, PASP, 104, 1109.

Bahcall, N. A., Lubin, L. M., Dorman, V. 1995, ApJ, 447, 81.

Barnes, J. E., 1996, *Galaxies: Interactions and Induced Star Formation*, Saas-Fee 26.

Chengalur, J. N., Salpeter, E. E., Terzian, Y., 1993, ApJ, 419, 30.

Chengalur, J. N., Salpeter, E. E., Terzian, Y., 1994, AJ, 107, 1984.

Chengalur, J. N., Salpeter, E. E., Terzian, Y., 1995, AJ, 110, 167.

Chengalur, J. N., Salpeter, E. E., Terzian, Y., 1996, ApJ, 461, 546.

Hibbard, J. E., Guhathakurta, P., van Gorkom, J. H., Schweizer, F., 1994, AJ, 107, 67

Hibbard, J. E., van Gorkom, J. H., 1996, AJ, 111, 655.

Karachentsev, I., 1972, Com. Sp. Aps. Obs. USSR, 7, 1.

Napier, W. M., Guthrie, B. N. G., 1996, Ap&SS, 244, 111.

Newman, W. I., Haynes, M. P., Terzian, Y., 1989, ApJ, 344, 111.

Newman, W. I., Haynes, M. P., Terzian, Y., 1994, ApJ, 431, 147.

Newman, W. I., Terzian, Y., 1996, Ap&SS, 244, 127.

Nordgren, T. E., Terzian, Y., Salpeter, E. E., 1996, Ap&SS, 244, 65.

Nordgren, T. E., Chengalur, J. N., Salpeter, E. E., Terzian, Y., 1997a, AJ, 114, 77.

Nordgren, T. E., Chengalur, J. N., Salpeter, E. E., Terzian, Y., 1997b, AJ, 114, 913.

Nordgren, T. E., Chengalur, J. N., Salpeter, E. E., Terzian, Y., 1998, ApJS, 115, 43.

Nordgren, T. E., Chengalur, J. N., Salpeter, E. E., Terzian, Y., 1999, ApJ, (in press).

Page, T., 1952, ApJ, 116, 63.

Peterson, S. D., 1979a. ApJS, 40, 527.

Peterson, S. D., 1979b. ApJ, 232, 20.

Peterson, S. D., Terzian, Y., 1979, Jour. Roy. Ast. Soc. Can., 73, 215.

Rand, R. J., 1994, AA, 285, 833.

Sancisi, R. 1998. *Galaxy Interactions at Low and High Redshift*, eds. D. Sanders and J. Barnes (Kluwer, Dordrecht).

Sanders, D. B., 1990. *Dynamics and Interactions of Galaxies*, ed. R. Wielen (Springer Verlag, Berlin), 459.

Schneider, S., Helou, G., Salpeter, E. E., Terzian, Y., 1986, AJ, 92, 742.

Schweizer, F., 1996, *Galaxies: Interactions and Induced Star Formation*, Saas-Fee, 26.

Tifft, W. G., 1976, ApJ, 206, 38.

Tifft, W. G., Cocke, W. J., 1989, ApJ, 336, 128.

Tifft, W. G., 1996, Ap&SS, 244, 29.

Toomre, A. and Toomre, J., 1972, ApJ, 178, 623.

Turner, E. L., 1976a, ApJ, 208, 20.

Turner, E. L., 1976b, 208, 304.

Vorontsov-Velyaminov, B. A., 1959, *Atlas and Catalogue of Interacting Galaxies*, (Sternberg Institute, Moscow State University, Moscow).

Zwicky, F., 1937, ApJ, 86, 217.

Zwicky, F. 1956, Ergebnisse d. exakten Naturw., 29, 344.

Zwicky, F. 1959, Handbuch d. Physik, 53, 373.