A&A 451, 817–820 (2006)
DOI: 10.1051/0004-6361:20054497

Astronomy & Astrophysics

Disturbed isolated galaxies: indicators of a dark galaxy population? *(Research Note)*

I. D. Karachentsev[1], V. E. Karachentseva[2], and W. K. Huchtmeier[3]

[1] Special Astrophysical Observatory, Russian Academy of Sciences, N. Arkhyz, KChR, 369167, Russia
e-mail: ikar@luna.sao.ru
[2] Astronomical Observatory of Kiev University, Observatorna 3, 04053 Kiev, Ukraine
[3] Max-Planck-Institut fur Radioastronomy, Auf dem Hugel 69, 53121 Bonn, Germany

Received 9 November 2005 / Accepted 14 January 2006

ABSTRACT

We report the results of our search for disturbed (interacting) objects among very isolated galaxies. The inspections of 1050 northern isolated galaxies from KIG and 500 nearby, very isolated galaxies situated in the Local Supercluster yielded five and four strongly disturbed galaxies, respectively. We suggest that the existence of "dark" galaxies explains the observed signs of interaction. This assumption leads to a cosmic abundance of dark galaxies (with the typical masses for luminous galaxies) that is less than ~1/20 the population of visible galaxies.

Key words. galaxies: interactions

1. Introduction

The paradigm of Lambda-CDM cosmology assumes that apart from dark halos with normal (luminous) galaxies in their centers, completely dark clumps (sub-halos) should also exist with masses $\sim (10^8-10^{11})$ $M_\odot$ (van den Bosch et al. 2003; Tully 2005; Yang et al. 2005). The current understanding of the mass distribution and spatial distribution of such invisible objects so far remains rather uncertain. However, the total number of dark subhalos may be comparable to or even exceed in the number of the usual, luminous galaxies by a factor tens. For instance, within volume of the Local Group, cosmological models of structure formation predict about 300 satellites with masses greater than $\sim 3 \times 10^8$ $M_\odot$ (Klypin et al. 1999). This number is significantly higher than the three dozen satellites actually observed in the Milky Way and Andromeda. A possible explanation for this discrepancy is the physical processes inhibiting star formation especially in low mass clumps, thus implying the existence of a large number of dark satellites.

Apparently, the completely dark "galaxies" (sub-halos) may be detected via gravitational-lensing effects (Trentham et al. 2001). Recently Natarajan & Springel (2004) measured masses of such substructures in five clusters of galaxies utilizing archival Hubble Space Telescope data and applying galaxy-galaxy lensing techniques. They found that the fraction of total cluster mass associated with individual (visible and invisible) sub-halos of $10^{11}-10^{12.5}$ $M_\odot$ ranges from 10–20%. But in practice, this approach is not efficient enough to explore dark objects in loose groups and in the general galaxy field, because the positions of dark galaxies on the sky are unknown a priori. Here, we use another approach mentioned by Trentham et al. (2001), which relies on searching for signs of non-motivated distortion visible on images of spatially isolated galaxies.

2. Interacting and isolated galaxies

As is well known, galaxies in close encounters show a significant signature of gravitational interaction in the form of a distortion of their structure, the presence of tails and bridges, or a common diffuse envelope. All these features have been quantitatively explained based on numerous N-body simulations ever since Toomre & Toomre (1972). Signs of interaction are seen in more than 50% of those binary galaxies where the separation is comparable to the sum of the diameters (Karachentsev 1987). In systems with greater separation, as in triple galaxies, the relative number of interacting galaxies is about 1/4–1/3. In magnitude-limited galaxy catalogs, the fraction of interacting objects is equal to (8 ± 1)% (Karachentsev 1987).

When considering more and more scattered systems of galaxies and single galaxies of the "general field", one can expect a fraction of the interacting objects among them to be nearly zero. This would occur if there were no other objects except the luminous cataloged galaxies. However, if completely dark galaxies (halos) with masses of 10^8-10^{11} $M_\odot$ exist, the phenomena of interaction will occur in the case of extremely isolated galaxies, too. Hence, an asymptotic relative number of peculiar shapes among the most spatially isolated galaxies may be a sensitive tool for estimating the cosmic abundance of massive dark galaxies.

3. Searching for distorted isolated galaxies

To search for such "strange" cases of interaction where the second interacting companion is invisible, we used the "Catalog of Isolated Galaxies" (Karachentseva 1973 = KIG). This catalog contains 1050 galaxies without "significant" neighbors. According to our estimates, the catalog objects do not suffer essential perturbations from neighboring galaxies over some Gyr.

Table 1. List of isolated galaxies with disturbed structure.

KIG	Name	RA(J2000.0)Dec	V_h km s^{-1}	Type	B mag	$a \times b$ arcmin	lg L $L_\odot$	Comments
293	UGC 4722	090023.5+253641	+1794	Sdm	15.2	1.6 × 0.2	8.9	
341	F635-02	093005.4+135821	–	Sa	15.6	1.5 × 0.2	–	
349	UGC 5101	093551.6+612111	+11809	Sb	15.1	0.8 × 0.4	10.3	Sy 1.5
940	UGC11871	220041.4+103309	+7978	Sa	14.5	1.1 × 0.7	10.5	Sy 1.9
946	UGC11905	220554.5+203822	+7522	Sa	14.6	1.5 × 0.9	10.4	II Zw 163
–	ESO539-7	001848.5-190031	+3187	Sm	14.8	1.5 × 1.3	9.5	
–	NGC 244	004546.3-153549	+ 944	S0	13.8	1.2 × 1.0	8.9	Haro 10
–	ESO545-5	022006.1-194503	+2338	Sdm	13.8	2.5 × 0.8	9.7	

Notes:

UGC 4722, RFGC 1465.	LSB tail of 2′ directed from *N*-part of the galaxy to *N*.
F635-02.	Wide curved tail to NW; or a diffuse companion in contact.
UGC 5101.	Jet across the galaxy, longer to the W. Ring on the NW. Merger? But a single nucleus in 2MASS.
UGC 11871, VV 812.	Wide bright loop to S with a projected star. Diffuse extension to NW.
UGC 11905.	Long tail to S slightly curved to W. Loop on the NW, and the LSB horizontal feature above.
ESO 539-7, DDO 1, UGCA 5.	Asymmetric knotted arm at E-side. V_h = +2060 (RC3).
NGC 244, VV 728, UGCA 10.	Asymmetric envelope at E-side with a knot.
ESO545-05.	LSB loop from the core towards NE, short tail on the W. A galaxy 10′ to E has V_h = 7608 km s^{-1}.

As it is a sample of galaxies with $m < 15\overset{m}{.}7$ and declination > $-2°$, the KIG catalog includes only 4% of the CGCG galaxies (Zwicky et al. 1961–1968); i.e. it is a collection of a rather rare kind of galaxies.

All KIG galaxies were inspected by us on the Digital Sky Survey (the blue POSS-II, when accessible). In some cases, we also studied galaxy images in the 2 micron survey (2MASS) to check for the possibility of double-nuclei systems as recent merging remnants. The results of our inspections are presented in the upper part of Table 1. Its columns contain: (1, 2) galaxy numbers in the known catalogs taken from the NASA Extragalactic Database (NED); (3, 4) coordinates for the J2000.0 epoch; (5) heliocentric radial velocity; (6) morphological type; (7, 8) apparent magnitude and angular dimension from the NED; (9) integrated blue luminosity assuming a Hubble parameter H_0 = 72 km s^{-1} Mpc^{-1}; (10) comments relative to nuclear activity. Footnotes to the table list basic signs of peculiarity seen in the structure of the galaxies.

Obviously, there are different factors of observational selection affected the detection of isolated galaxies with peculiar shapes in a sample limited by flux but not by volume. Therefore, we undertook a new search for isolated distorted galaxies in a sample limited by radial velocities, $V_{\rm LG}$ < 3200 km s^{-1}. In this sample of ~7500 galaxies covering the volume of the Local Supercluster, about 60% of the galaxies reside in groups of different populations (Makarov & Karachentsev 2000). The remaining $N \sim 3000$ galaxies are characterized by different degrees of isolation with respect to their neighbors (with known radial velocities). We selected 500 of the most isolated galaxies and inspected their images on DSS. Only 4 galaxies out of 500 show significant signs of interaction. They are listed in the bottom of Table 1. One case here, UGC 4722, turns out to be common with the KIG sample. The DSS images of all 8 peculiar single galaxies found by us are shown in Fig. 1. The field of view in each case is 8′ by 6′.

4. Discussion

Signs of interaction between galaxies are best developed when the objects have similar masses. If the number of completely dark sub-halos with typical masses of $\sim 10^8$–10^{11} $M_\odot$ in any volume approximately corresponds to the number of usual luminous galaxies, then one may expect about 8% interacting galaxies among the isolated ones (interaction with an invisible object). This rough estimate ignores, of course, properties of spatial distribution of dark sub-haloes with respect to the usual galaxies (i.e. the biasing problem). The observed relative number of KIG galaxies with clear features of interaction, 5/1050 = 0.5%, turns out to be at least one order of magnitude lower than expected. Moreover, the observed frequency of disturbed shapes among very isolated galaxies in the Local Supercluster, 4/500 = 0.8%, is consistent with the previous estimate made for the catalog sample. In view of these results, it is rather unlikely that the number of massive dark sub-halos is similar to or even exceeds the number of the usual visible galaxies.

It should be stressed that apart from interaction with a dark galaxy, the observed morphological irregularities of isolated galaxies may different origins: a) there could have been a merger, with the companion now merged and not visible anymore; b) interaction with a companion now far away; c) there could be large gas accretion from cosmic filaments, and asymmetrical accretion could lead to perturbed morphologies (and also starburst and AGN fueling).

In this context, we note that four galaxies out of eight listed in Table 1 are distinguished by their active nuclei. This may be a hint that their peculiar shape is caused by a recent merging event. Moreover, some distorted shapes of dwarf Sm galaxies may be generated by an asymmetric star-formation burst inside the galaxy. Taking this possibility into account, we suggest that the true relative number of isolated galaxies probably disturbed by dark galaxies does not exceed a value of 0.3%.

The data in Table 1 show that peculiar isolated galaxies are distributed over the sky rather inhomogeneously. This may indicate the existence of clumps (filaments, clusters) in the distribution of dark galaxies. The first observational evidence of the presence of a dark cluster was made in the literature (Jee et al. 2005a,b).

As noted by Neil Trentham (personal communication), dark galaxies probably have low masses and negligible dynamical effects on massive galaxies like the ones in the KIG sample. They can have much more substantial effects on the nearby low-mass galaxies seen, for example, in the Catalog of Neighboring

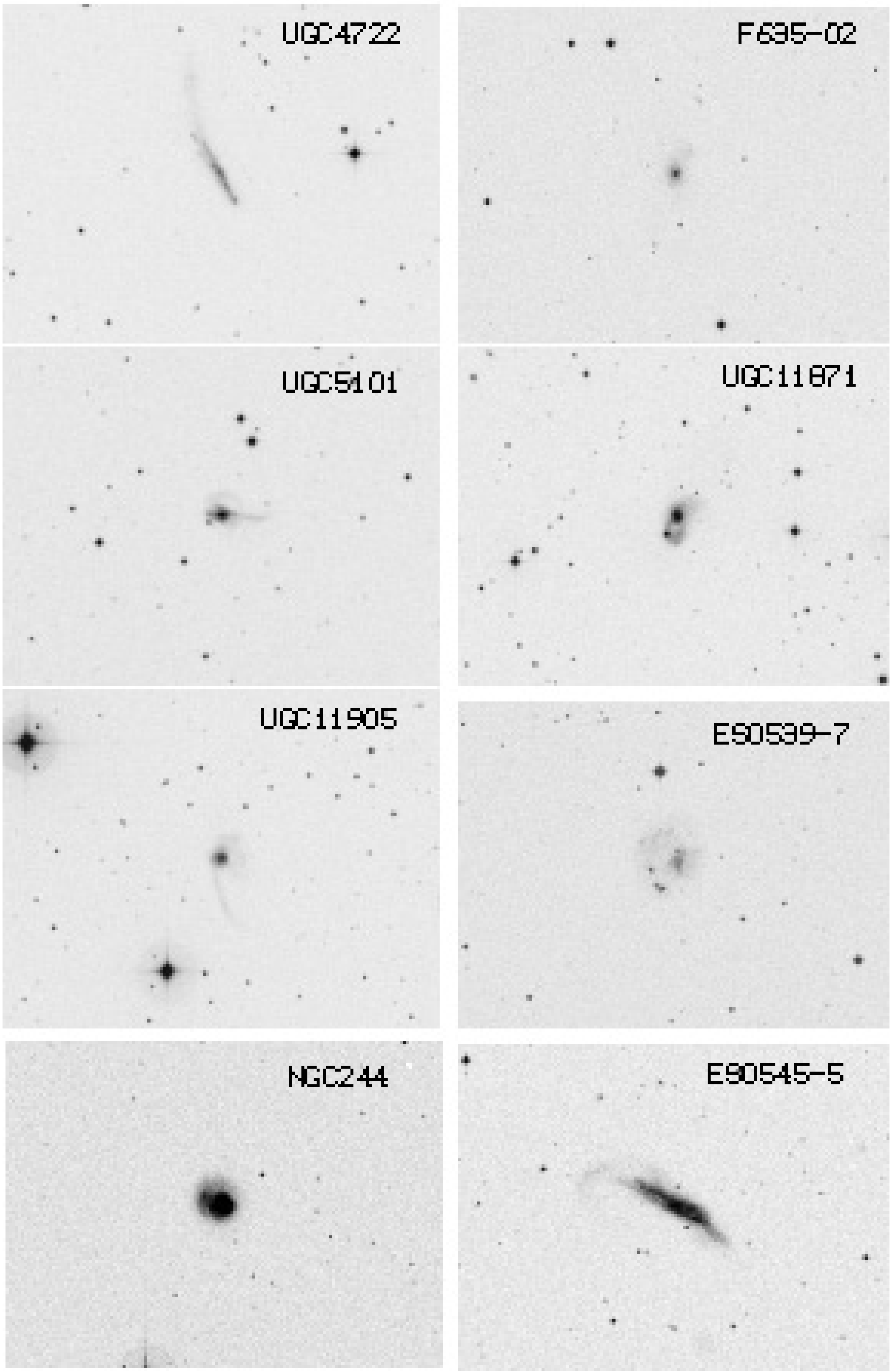

Fig. 1. STScI DSS optical images of the eight disturbed isolated galaxies. East is left and North is up. The FoV is $8' \times 6'$.

Galaxies (Karachentsev et al. 2004). This sample contains 197 quite isolated galaxies with a "tidal index" $\Theta < 0$. (A negative Θ means that the Keplerian cyclic period of the galaxy with respect to its main neighboring disturber exceeds the cosmic Hubble time.) The majority of them (~90%) are low mass dwarfs. Recently, Pustilnik et al. (2005) found that an isolated nearby galaxy, DDO 68 = VV 542 with $M_B = -14.3$ mag and $\Theta = -1.6$, seems to be a disturbed object "with a long curved tail on the South and a ring-like structure at the Northern edge." If DDO68 is a single such object in the Local Volume, it yields a fraction of disturbed isolated galaxies, 1/197 = 0.5%, the same as for the KIG catalog. We inspected DSS images of all 197 isolated galaxies in the Local Volume and found some more examples of distorted objects: NGC 1313 = VV 436 (IRAS source), NGC 2537 = VV 138 (IRAS source), UGC 8837 = DDO 185. But, their peculiar structure could be also understood as the result of galaxy merging or an asymmetric star-formation burst.

Apparently, the cases of isolated galaxies with distorted shapes, as presented above, need special studies of their structure and kinematics. Detailed investigations of such objects may give important information on the population of dark galaxies.

Acknowledgements. The authors thank Neil Trentham, Francoise Combes, and Brent Tully for useful comments. This search has made use of the NASA/IPAC Extragalactic Database (NED), the STScI Digitized Sky Survey (DSS), and the Two Micron All–Sky Survey (2MASS). This work was supported by DFG–RFBR grant 03–02–06010.

References

Jee, M. J., White, R. L., Benitez, N., et al. 2005a, ApJ, 618, 46
Jee, M. J., White, R. L., Ford, H. C., et al. 2005b [arXiv:astro-ph/0508044]
Karachentseva, V. E. 1973, Soobsch. Spec. Astrop. Obs., 8, 3
Karachentsev, I. D. 1987, Binary Galaxies (Moscow: Nauka)
Karachentsev, I. D., Karachentseva, V. E., Huchtmeier, W. K., & Makarov, D. I. 2004, AJ, 127, 2031
Klypin, A. A., Kravtsov, A. V., & Valenzuela, O. 1999, ApJ, 522, 82
Makarov, D. I., & Karachentsev, I. D. 2000, in Small Galaxy Groups, ed. M. Valtonen, & C. Flinn, ASP Conf. Ser., 209, 40
Natarajan, P., & Springel, V. 2004, ApJ, 617, L13
Pustilnik, S. A., Kniazev, A. Y., & Pramskij, A. G. 2005, A&A, 443, 91
Toomre, A., & Toomre, J. 1972, ApJ, 178, 623
Trentham, N., Moller, O., & Ramires-Ruiz, E. 2001, MNRAS, 322, 658
Tully, R. B. 2005, ApJ, 618, 214
van den Bosch, F., Yang, X., & Mo, H. J. 2003, MNRAS, 340, 771
Zwicky, F., et al. 1961–1968, Catalog of Galaxies and of Clusters of Galaxies (California, Pasadena) (CGCG)
Yang, X., Mo, H. J., Jing, Y. P., & van den Bosch, F. 2005, MNRAS, 358, 217