Forty Years of Research on Isolated Galaxies

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Abstract. Isolated galaxies have not been a hot topic over the past four decades. This is partly due to uncertainties about their existence. Are there galaxies isolated enough to be interesting? Do they exist in sufficient numbers to be statistically useful? Most attempts to compile isolated galaxy lists were marginally successful—too small number and not very isolated galaxies. If really isolated galaxies do exist then their value becomes obvious in a Universe where effects of interactions and environment (i.e. nurture) are important. They provide a means for better quantifying effects of nurture. The Catalog of Isolated Galaxies (CIG) compiled by Valentina Karachentseva appeared near the beginning of the review period. It becomes the focus of this review because of its obvious strengths and because the AMIGA project has increased its utility through a refinement (a vetted CIG). It contains almost 1000 galaxies with nearest neighbor crossing times of 1-3Gyr. It is large enough to serve as a zero-point or control sample. The galaxies in the CIG (and the distribution of galaxy types) may be significantly different than those in even slightly richer environments. The AMIGA-CIG, and future iterations, may be able to tell us something about galaxy formation. It may also allow us to better define intrinsic (natural) correlations like e.g. Fisher-Tully and FIR-OPTICAL. Correlations can be better defined when the dispersion added by external stimuli (nurture) is minimized or removed.

1 Introduction

Studies of isolated galaxies can be said to begin at about the same time it was realized that galaxy ‘nurture’ was important (e.g. Sulentic 1976; but see also Tovmassian 1966). I remember well the criticism for suggesting in my thesis that radio emission from interacting galaxies was enhanced. Of course within a decade the role of nurture on galaxy structure and evolution was established (Larson & Tinsley 1978; Stocke 1978; Lonsdale et al. 1984; Cutri & McAlary 1985). There remains some confusion about the nurture mechanism(s) which stems in part from the fact that there are two definitions of nurture: 1) galaxies can be influenced by the local environmental surface density (e.g. clusters to voids) and 2) galaxies in any environment can be influenced by one or more nearby companions (pairs and compact groups). The morphology-density relation (Postman & Geller 1984) formalizes evidence for definition 1 while numerous theoretical and observational studies (e.g. Keel 2009) confirm definition 2. Definition 1 deals largely with the frequency of occurrence of early-type galaxies as a function of environmental density while Definition 2 deals largely with late-types whose non-stellar components manifest most clearly the effects of "one-on-one" nurture at all environmental densities (interacting pairs are found in both clusters.
and voids). It has been argued that all early-types are the product of late-type merging and harassment (e.g. Barnes 1998; Schweizer 2000). We argue here that the evidence (the existence of isolated early-types) does not support this view.

Once it is agreed that galaxy structure and evolution are influenced by environment then the value of a carefully selected isolated sample becomes obvious. Some researchers argue that truly isolated galaxies do not exist but this is often simply a matter of semantics. It is now generally accepted that there is no field galaxy population (Huchra & Thuan 1977, Einasto 1990). Rather than speaking of a specific class of isolated galaxy it is perhaps more useful to speak of identifying the most isolated galaxies that exist. Many attempts to identify these galaxies yielded samples too small for statistical applications. One sample, the Catalog of Isolated Galaxies (CIG: Karachentseva 1973), is large enough (n∼1050) to serve as a useful statistical control for studies seeking to quantify the effects of nurture. In fact the CIG sample serves as a counterpoint to the Catalog of Isolated Pairs of Galaxies published one year earlier (CPG: Karachentsev 1972). I became aware of these catalogs in 1974, too late to use them in my thesis (instead see Stocke 1978). Soviet publications were not available in every university library in the US and there was no internet in the early 70's.

2 Lessons from the 70’s, 80’s and 90’s

Publication of the visually compiled CIG corresponds in time to the first attempts at automated catalog compilation. Surprisingly no automated catalog appeared over the next 30 years that could replace the CIG in quality or completeness. Looking back we appreciate that algorithms cannot select well isolated systems whether singlet, pair, triplet or compact group. There are two main reasons for this limitation: 1) source catalogs used by an algorithm are flux limited and many close companions to candidate isolated galaxies will lie below that limit and 2) close bright companions are sometimes not listed separately in source catalogs. Algorithms work well in terms of (above) isolation definition 1 but the product catalogs include many violations of isolation definition 2 (e.g. Turner & Gott 1975, Vettolani et al. 1986). Visual verification of product catalogs is always necessary and this is why the CIG (and CPG) remain valuable resources to this day. The CPG satisfies definition 1 but completely fails definition 2 while the CIG satisfies both.

The CIG has a large number of strengths: WELL DEFINED: visual application of a precise isolation criterion; SIZE: 800-1050 galaxies depending on how one defines isolation – permitting exploration of the luminosity-morphology domain of isolated galaxies; REDSHIFT: almost complete coverage; ISOLATION: nearest neighbor crossing times tc=1-3Gyr; DEPTH/COMPLETENESS: 80-90% complete to Vr=10000km/s (for detailed analyses of the CIG prior to the AMIGA project see Adams et al. 1980, Karachentseva 1980, Xu & Sulentic 1991). Pre-AMIGA radio line/continuum, optical and infrared studies of various CIG subsets can be found by inserting “isolated galaxies” in the title query panel after entering adsabs.harvard.edu and proceeding to the “astronomy and astrophysics search page. Such a query will also lead one to other lists of isolated
galaxies. Most, including the CIG, contain obvious examples of Definition 2 violations. Visually compiled lists are only as good as the images from which they are compiled—in ∼ 1970 the best image resource was the Palomar Sky Survey (POSS). It is interesting to note the small number of CIG galaxies included in (northern sky overlap) most of the other lists (e.g. Xanthopoulos & de Robertis 1991, 1/8 Seyferts; Morgan et al. 1998, 3/12 spirals; Aguerri 1999, 6/16 barred; Pisano & Wilcots 1999, 0/6 extremely isolated; Marquez & Moles 1996, 1999, spirals 4/22; Colbert et al. 2001, 1/18 early-types; Kornreich et al. 2001, 1/9 SA type; Pisano et al. 2002, 4/22 extremely isolated; Madore et al. 2004, 1/12 ellipticals from Bothun et al. 1977; Reda et al. 2004, 2/13 isolated early-type). The small overlap does not in the majority of cases, reflect isolated galaxies overlooked by the CIG but rather the more stringent isolation criteria used to compile the CIG.

Isolated galaxies have never been a hot topic yet, if real, a proper list would represent a valuable resource. One of the few large pre-AMIGA series of papers dealing with reasonably isolated galaxies involves samples of from 22-203 isolated spiral galaxies (Varela et al. 2004, Marquez et al. 2004 and references back to 1996). While making no claims about sample completeness the authors present interesting comparisons with less-isolated and more-active spirals. They found that isolated spirals tend towards later-types, symmetric morphologies. They may be bluer, smaller and less luminous (but see later). This work also finds tighter Kormendy and Fisher-Tully relations for the isolated galaxies if, as might be expected, nurture adds dispersion to most galaxy measures. Consistent with that assumption they also find a narrower range of disk scale length and effective surface brightness ($\mu_e$) for more isolated galaxies.

3 The AMIGA project

We have summarized the advantages of the CIG but there are also problems, principally that it was compiled from a visual search of the original Palomar Sky Survey (POSS). Visual compilation is less a problem than the low resolution and non-linearity of the POSS data. This means that the originally assigned galaxy types are OK but spiral galaxy bulges appear larger on low resolution images leading to an overestimate of the early-type spiral fraction. Compact spirals can easily be misclassified as E or S0 type. Compact companion galaxies can be overlooked. The strengths of the catalog motivated us to undertake a systematic refinement or “vetting” of the CIG under the AMIGA (Analysis of the Interstellar Medium of Isolated GAaxies http://amiga.iaa.es) project. We expected to reject a significant number of CIG but were confident that a sample large enough for statistical studies would remain. We have focused so far on galaxies with recession velocities $V_r$ greater than 1500km/s. The largely local and largely dwarf galaxy population within 1500km/s deserves separate consideration. Excluding the local objects and non-isolated galaxies yields a final vetted sample of 719 galaxies. We summarize the steps in the AMIGA project that have lead to a refined CIG sample. We also summarize the initial multi wavelength studies of the sample.

- OLF derivation: (Verdes-Montenegro et al. 2005) Application of a $V/V_m$ test suggests that the vetted CIG is ∼90% complete to B∼15.0. The
histogram of heliocentric velocities shows peaks identifiable with local large scale structure components (within 10-15×10⁴ km/s) (see also Haynes & Giovanelli 1983). However underlying the peaks we find that about half of the sample show a quasi-homogeneous distribution. While a galaxy "field" may not exist we identify a very field-like galaxy population. Comparison of the CIG OLF with other derivations indicates that the best fit Schechter M*= -20.1 parameter is as low or lower than previous estimates (except 2dFGRS void).

• Morphology Refinement: (Sulentic et al. 2006) Morphological vetting made use of the POSS2 (using SDSS CCD estimates for 215 galaxies to evaluate accuracy) for the n=1018 galaxies remaining after the optical OLF study. Fully 2/3 of the CIG sample are found to be late-type (i.e. small bulge) Sb-Sc spirals. 15% show later spiral types yielding a late-type fraction of ~86%. N=32 galaxies were identified as interacting (Definition 2 nurture) while an additional 154 were flagged as possibly interacting systems. Perhaps most interesting are the 14% of the sample classified as early-type and distributed approximately equally between elliptical and lenticular galaxies. We find a wide range of luminosities (M_B=-17 to -23) among the Sb-Sc majority with M*= -20.2. Perhaps most surprisingly the E+S0 galaxies show a similar M* with a range M_B= -16 to -21 and only two galaxies near -22. These are perhaps the best candidates for a primordial early-type population since they are low luminosity systems and are found in environments where merging and harassments are improbable (see also Sulentic & Rabaca 1994). We also compare our results with those for several large surveys including 2dFGRS, SDSS, NOG and SSRS2 (see paper for detailed references and discussion). Such comparisons are difficult because different definitions of isolation (i.e. voids) and different selection techniques (Definition 1) were employed. It is interesting to note that the galaxy population in the lowest density bin of 2dFGRS is similar in size to the CIG.

• MIR/FIR Statistics: (Lisenfeld et al. 2007) Mid- and Far-infrared emission from galaxies has proven to be perhaps the most sensitive diagnostic of nurture. The wide dispersion of MIR/FIR values in isolated and interacting samples makes it difficult to improve the accuracy of nurture quantification (Xu & Sulentic 1991). If the vetted CIG is almost nurture free then it offers the possibility to serve as the optimal control sample in such studies. Indeed mean FIR luminosity (logL_{FIR}=9.5L_☉) and FIR - Optical flux ratio (log R= 0.44) for the Sb-Sc majority show among the lowest mean values of any galaxy sample yet studied. The absence of nurture contamination also means that the dispersion in measured values is lower—a desideratum for a good control sample. An internal comparison was made by comparing mean values for vetted CIG and for 14 CIG flagged as interacting during the morphology phase. The latter galaxies showed much higher mean values (9.9 and -0.06 respectively) illustrating the effect of including nurture contaminated galaxies in a control sample.
• Isolation Refinement: (Verley et al. 2007ab) The vetted CIG is shown to be a sample where nearest neighbor crossing times are $t_c \sim 1-3$ Gyr. See contribution by Simon Verley in this volume.

• Radio Continuum Emission: (Leon et al. 2008) The radio detection fraction and derived radio luminosities for detections reveal a very radio-quiet sample. Most detections show radio luminosities in the range $L_{1.4GHz}=20-22$ W Hz$^{-1}$ with only three sources showing a radio/optical flux ratio $R \geq 100$ (i.e. formally a radio-galaxy according to Kellerman et al. (1989) (most detections lie between $R=1-10$). Comparison of detections and fluxes in the NVSS and FIRST surveys suggests that the radio emission arises in most cases from disk emission driven by star formation.

• AGN in Isolated Galaxies: (Sabater et al. 2008) Using various techniques to identify active nuclei yields a list of 89 candidates which implies the lowest AGN fraction that we are aware of. See contribution by Pepe Sabater in this proceeding. See also Deborah Dultzin’s review for discussion of the AGN–nurture question.

• 21cm HI Profiles: (Espada et al. in preparation) The Arecibo HI survey (Haynes & Giovanelli 1980, 1983, 1984; Hewitt et al. 1983) explored HI properties of a large CIG subsample and found that HI mass depends more on galaxy diameter than morphological type. In fact examination of their measures reveals no difference in HI measures between the Sb, Sbc and Sc galaxies which dominate the CIG. The AMIGA HI survey incorporates a much larger sample of old and new data. We find a very low fraction of asymmetric profiles as expected for an isolated sample. For the first time we are able to isolate the intrinsic (non-nurture) asymmetry distribution. See contribution by Dani Espada in this proceeding.

• Studies of Subsamples: More recent photometric/structural analysis using SDSS imagery have focussed on 100 of the Sb-c galaxies in the vetted CIG ($M_i = -19$ to -23). Both surface photometric (Durbala et al. 2008) and Fourier (Durbala et al. 2009) analyses were performed on this ‘prototypical’ isolated sample. Most bulge/total flux ratios were found to lie $B/T \leq 0.2$ with Sersic indices generally $n_{BULGE} \leq 2.5$ which is consistent with the idea that most isolated spirals contain a pseudo bulge. A correlation between $B/T$ and $n_{BULGE}$ is seen only for galaxies visually classified Sb (largest bulge/disk ratios) suggesting that some of these may involve nurtured bulges. Overall more than 90% of the sample may contain pseudo bulges and subjective type Sb may represent a boundary between largely classical and largely pseudo bulge populations. Bar-spiral decomposition was accomplished using Fourier processing of the images. Comparison with the OSUBGS sample (Eskridge et al. 2002) indicates that the CIG contains many more large bars ($l_{bar} \geq 3$ kpc). The analysis reveals a $4 \times$ higher fraction of spirals dominated by $m = 2$ & 3 multiplicity compared to the CSRG sample (Buta 1995). The first step in evaluating H$\alpha$ emission properties of AMIGA-CIG galaxies involves a study of the 45 largest and least inclined spirals (Verley et al. 2007c) where we estimate torques between the gas and stellar mass components.
4 Future Work

This review has unavoidably emphasized results from the AMIGA project and passed over detailed studies of individual isolated galaxies. The size of the sample and the strength of the isolation criterion make it the best place to begin statistical studies involving the low density tail of the two point correlation function and/or morphology density relation. Analysis of automated surveys is fraught with peril until they can be properly vetted with good imagery—SDSS offers great promise. Review of the literature shows that isolation means different things to different people. The label itself is a source of debate. Do isolated galaxies really exist? Have they always been isolated? Rather than using the sobriquet “isolated” we suggest that the AMIGA vetted CIG is simply the best compilation of the most isolated galaxies in the local Universe. Nearest neighbor crossing times of 1-3Gyr are long enough to be interesting. The fact that we find multi wavelength differences with other samples (even those labeled isolated) argues that these galaxies have spent most of their lives in relative isolation. The low luminosity early-type fraction and the large fraction of small bulge spirals cannot have experienced much nurture in their lives. This is the closest we are likely to come to identifying a population of galaxies whose properties are dominated by nature rather than nurture.

Other isolated samples tabulated earlier show little overlap with the CIG. Most of them report little difference when compared to samples in richer environments. These samples appear to contain more luminous early types and spirals with large bulges than found in the CIG. This leads to the possibility that galaxy properties change significantly below a certain density threshold—dare we say “field-like”? There are two ways to explore this possibility: 1) the late-type (Sb-c) spiral majority and 2) the early-type (E+S0) population. The former prototypical population requires testing of the hypothesis that it is dominated by pseudo bulges. This would obviously favor bottom-up spiral galaxy formation. Measures of bulge colors and kinematics can provide direct tests of the pseudo-bulge hypothesis. In the case of the low luminosity early-types we need to confirm that they are indeed E and S0 systems. The relative fractions of these two types needs to be better determined and, finally, spectroscopy to infer their star formation histories. Initial work (Marcum et al. 2004) for nine CIG ellipticals yields mixed results with some showing typical red colors and others much bluer than normal. I see a couple nice thesis projects here!

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