Serb. Astron. J. № 186 (2013), 1 - 14
DOI: 10.2298/SAJ1386001M UDC 524.7–36–42–48–52–54
Invited review

FIELD GALAXIES AND THEIR AGNs: NATURE VERSUS NURTURE

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(Received: May 30, 2013; Accepted: May 30, 2013)

SUMMARY: This review attempts to present most recent findings related to the very controversial question of which processes guide the flow of gas to the galactic centers where the accretion and growth of supermassive black holes occurs. Also, we put this question in the context of influence of the environment (galaxy clusters versus field) onto these processes.

Key words. galaxies: abundances – galaxies: active – galaxies: formation – galaxies: evolution – galaxies: interactions – galaxies: halos

1. INTRODUCTION

One of the biggest successes of the standard Big Bang cosmology is the prediction of the existence and black body nature of Cosmic Microwave Background (CMB). Observations and measurements of the CMB radiation by COBE (COsmic Background Explorer), WMAP (Wilkinson Microwave Anisotropy Probe) and Planck show an almost isotropic blackbody radiation with temperature $T_{CMB} = 2.726 \pm 0.010$ K (Mather et al. 1994) (Universe is very smooth on large scales > 200 Mpc), and show temperature anisotropies on angular scales of $\sim 90°$ (Smoot et al. 1992) (Universe is inhomogeneous on small scales represented by planets, stars, galaxies, clusters and superclusters of galaxies).

As a possible explanation, theory of inflation predicts that the Universe expands exponentially for a brief period of time. During this time, matter distribution is "flattened" and at the end of this inflationary period, it is highly homogeneous on large scales, but is locally perturbed as a consequence of quantum fluctuations (Guth and Kaiser 2005). Hence, quantum fluctuations create a perturbation field that can be described as a Gaussian random field. These primordial density perturbations grow into the gravitational instability scenario through the gravitational Jeans instability, which leads to the formation of the first structures.

1.1. Dark Matter Halos

The first objects that grow through perturbations are those consisting of dark matter, since dark matter is made of collisionless particles that interact very weakly with the rest of matter and with the radiation field (Rubin et al. 1980, Lynden-Bell et al. 1988). The self-gravity of dark matter in overdense regions eventually wins against the expansion of the Universe, dark matter collapses, experiences a violent relaxation and quickly reaches virial equilibrium forming bound objects called dark matter halos (DMH) (Bardeen et al. 1986, Eisenstein and Loeb 1995, Sheth et al. 2001). The inner structure of DMH has been investigated through numerical simulations by Navarro et al. (1997) who have found that DMH density profiles have a universal shape, independent of the halo mass, the initial density fluctuation spectrum and the cosmological parameters.

1.2. Proto-galaxies

Dark matter halos are the only objects forming as long as the gas is ionized. Formation of the first "baryon objects" or proto-galaxies is much more complicated. The exact physics of galaxy formation depends on which process is dominant (star formation, mechanical and radiative physics, turbulence, etc.). Since first galaxies form very early, observational constrains are insufficient. Numerical simulations have a large problem because of the enormous dynamical range that has to be addressed simultaneously from ~ 1 AU up to hundreds of kiloparsecs.

It starts with recombination (the time at which the electron fraction has dropped to 0.1) which occurs at $z_{\rm rec}\sim 1100$ and neutral atomic hydrogen forms. Perturbations in the gas component finally start growing at the centers of already formed dark matter halos (Peebles et al. 1993). Next, the gaseous component virializes in a way similar to the virialization of dark matter and the first bound gas objects form. Before the collaps, dark matter halos acquire angular momentum. Because of this, during the collapse, baryons with low specific angular momentum can cool down, accrete onto the inner regions, cause central starbust which in turn forms central spheroid. Baryons with higher specific angular momentum form galactic disks (White and Rees 1978, Fall and Efstathiou 1980, Mo et al. 1998). Meanwhile, the gas in halo develops shocks and gets reheated to a temperature at which pressure support can prevent further collapse. At the same time, dynamical friction acting on clumps of gas, dissipates their orbital energy and deposits it in the dark matter, which gets heated and pushed away from the center (Moore 1994, Flores and Primack 1994, El-Zant et al. 2001).

This leads to the, already mentioned above, universal density profile in virialised objects (Navarro et al. 1997, hereafter NFW). Inside some characteristic radius Rs, density profile has a power law with a slope of 2. It becomes shallower and tends to a slope of 1 toward the centre. The violent relaxation process builds the inner structure of halos with a shallow density profile while the secondary accretion gives rise to a steep outer density profile (Ciardi and Ferrara 2005).

1.3. Disk Galaxies - Late Type

Due to tidal interactions dark matter halos are always born with a rotation which is further increased in gas as baryons fall into potential wells of these halos while conserving their angular momentum to some degree (White and Rees 1978, Fall and Efstathiou 1980). As rotation drains angular momentum along rotation axis, gas cloud flattens and disk forms.

When observed disks are compared to disks formed in numerical simulations, it has been noticed that the observed disks have specific angular momentum smaller by a factor of two while their radial scale-length is larger by a factor of ten. In other words, disks formed in simulations lose too much angular momentum, are much more compact and resemble bulges rather than disks (Navarro and Steinmetz 2000). First part of the problem is numerical in nature. Simulations with improved numerical resolution (Governato et al. 2004, Naab et al. 2007, Mayer et al. 2007) and better numerical conservation of angular momentum (Okamoto et al. 2005) have improved the situation. Second part of the problem is physical. Gas cooling in numerical simulations leads to excessive fragmentation. In order to prevent the gas to cool too much, a natural feedback mechanism is provided by the stellar evolution. Energy radiated in supernovae and by OB stars prevents disk from collapsing and decreases bulge-to-disk ratio (Robertson et al. 2004, Heller et al. 2007).

1.4. Galaxy Growth through Mergers

Structure formation dictates that dark matter halos form in the early universe and hierarchically merge into larger bound objects. As dark matter halos merge, the gas-rich galaxies at their centers also merge and so each merger brings a fresh supply of gas to the center of the galaxy. Mergers can be major if the mass ratio of merging galaxies is > 0.33 or > 0.25 and minor if this ratio is < 0.1). If merger occurs between gas rich galaxies then it is defined as a "wet" merger, otherwise it is a "dry" merger. Mergers can be multiple when more than two galaxies are involved.

Mergers dominate the way that structures form at high redshift (merger rate $\sim (1+z)^p$). However, structures are not uniformly distributed. There are regions of space almost totally devoid of galaxies and their are high density regions. Cosmic Microwave Background (CMB) spectrum tells us that some regions of Universe are overdense. That is where dark matter collapses to form halos first. As these regions have higher density, the gravity they create pulls other halos together to form first galaxy clusters. High concentration of halos and large gravitational potential leads to numerous halo mergers over the Hubble time. Less dense regions (voids) have isolated halos with galaxies growing in isolation with almost no mergers (field galaxies). Because of this, value of the exponent p has a large scatter. $p \sim 6$ in clusters (van Dokkum et al. 1999) and ~ 3 in the field (Le Fevre et al. 2000). If we focus on major mergers only, then $p \sim 3.5$ for clusters and ~ 2 for the field galaxies (Rawat et al. 2008). Numerical simulations predict merger rate close to 3.

Since first galaxies are gas-rich disk/spiral galaxies, then the first early galaxy mergers are "wet". The list of dynamical processes which appear during the mergers stretches from dynamical friction and violent relaxation to stretching, harassment, stripping, squelching and cannibalism. Star formation is either enhanced or quenched depending on the stage that merger is in. The new stellar system left after merger is either spheroidal (major merger) or disk (minor merger).

1.5. Elliptical Galaxies - Early Type

Major mergers of gas-rich disk galaxies followed by the minor mergers with dwarf galaxies are responsible for the formation of elliptical galaxies. As two disk galaxies merge, new star formation is triggered and, as a new galaxy is forming, dynamical processes cause perturbations in orbits, setting stars on random spherical orbits. As the gas cools efficiently, it accumulates at the center with a large density which matches the observations (Hernquist 1992, Hibbard and Mihos 1995, Dubinski et al. 1996, Barnes and Hernquist 1996). Then the galaxy grows in size through a significant number of minor mergers which deposit most of their material in the outer region of an elliptical galaxy. In this manner, the properties of stellar populations do not alter (Khochfar and Burkert 2006, Maller et al. 2006, Hopkins et al. 2009b, Naab et al. 2009, Sommer-Larsen and Toft 2010, Oser et al. 2010). This scenario is still far from being observationally proved since it appears there are not enough satellite galaxies around massive systems. Major mergers (Naab et al. 2007, Nipoti et al. 2003) and puffing up due to AGN feedback (Fan et al. 2008, 2010) and stellar winds (Damjanov et al. 2009) may also contribute to the size increase.

Elliptical galaxies run out of cold gas over time and become dead/red ellipticals with old stars. Hence, mergers of elliptical galaxies are "dry" mergers which lead to the formation of massive elliptical galaxies (cDs) at the centers of galaxy clusters (Toomre and Toomre 1972, Barnes 1992, van Dokkum et al. 1999).

Disks can survive mergers also. They can reform when merging disks contain plenty of gas (Springel and Hernquist 2005, Robertson et al. 2006, Robertson and Bullock 2008, Governato et al. 2009) or if there are gas 'leftovers' after the merger or any kind of cold gas supply (Steinmetz and Navarro 2002).

1.6. Secular Growth of Galaxies

There are two ways that a galaxy can be supplied with cold gas. First is the "hot mode" accretion when hot, virialised gas in halo, cools, loses its pressure support and settles into a disk (Rees and Ostriker 1977, White and Rees 1978, Fall and Efstathiou 1980). Second is the "cold mode" accretion, a rapid inflow of gas through the dense dark matter filaments in the cosmic web (Birnboim and Dekel 2003). About half of the gas cools through the "hot mode" and half through "cold mode" (Keres et al. 2005, Dekel and Birnboim 2006). The cold mode dominates at high redshift and low density environment in low-mass galaxies and halos (Keres et al. 2009), $M_{\rm gal} \leq 2 \times 10^{10}\ M_\odot$ and $M_{\rm h} \leq 2.5 \times 10^{11} M_\odot$. The hot mode dominates in the high density environment and at a low redshift in higher mass objects (galaxy clusters). All of this implies that there is a transitional galaxy mass between the two modes. This critical mass is $\sim 2 \times 10^{10}\ M_\odot$. In a halo with galaxy above this critical mass, gas can not cool in less than the Hubble time and will not contribute to the disk growth (Dekel and Birnboim 2006). On the other hand, while the hot mode has been observed extensively (Crain et al. 2010, Anderson and Bregman 2011), the cold mode has yet to be confirmed by the observations.

2. GALAXIES IN CLUSTERS VERSUS GALAXIES IN FIELD

The critical mass $\sim 2 \times 10^{10}\ M_\odot$ in simulations (the cold mode dominates below this mass and the hot mode dominates above it) is close to the observed characteristic mass for a shift in galaxy properties, $M_{\rm gal} \sim 3 \times 10^{10}\ M_\odot$ (Kauffmann et al. 2004, Kannappan 2004). Galaxies below the critical mass of $M_{\rm gal} \sim 3 \times 10^{10}\ M_\odot$ have larger star formation rate, young/blue stars, large gas amounts, and are mostly disk/spiral galaxies. More massive galaxies have old/red stars, small gas amounts, and are elliptical.

Now let us consider galaxies split into two groups based on their mass compared to critical, and two groups based on belonging to a cluster of galaxies or field. Fraction of massive galaxies in galaxy clusters is much larger than the fraction of small galaxies. Opposite is true for the field galaxies. In field, small galaxies have larger star formation rates than massive galaxies, but in galaxy clusters both small and massive galaxies show large drop in star formation rates (much larger for small galaxies).

It seems that cold versus hot gas accretion and distribution of small versus large galaxies are a simple consequence of the way that structures form. Galaxy clusters are high density regions of shock heated gas (hence, the hot mode accretion dominates) with a large number of galaxies bound to run into each other and merge (galaxy mergers produce elliptical galaxies hence they dominate in number). Field is a low density region of mostly isolated galaxies (they rarely merge so they dominate the field galaxy population). Also, since they are isolated in low density environment, there are no processes which might upset the cold mode accretion so cold mode dominates. If we consider a redshift dependence, the fact that the cold mode accretion dominates at high redshift happens simply because there are no galaxy clusters at high redshift as these structures are becoming virialized only at $z < 2$.

Another class of dead/quiescent galaxies are lenticular (S0) galaxies. At least for those of them found in galaxy clusters, they could be the descendants of spiral galaxies that had their star-formation activity truncated. This process may be related to the environment (Boselli and Gavazzi 2006). If a spiral galaxy becomes a satellite in a large dark matter halo, then it interacts with the intergalactic medium in the halo which might lead to a partial or a total removal of the galactic gas. This might occur as a fast, violent stripping of the entire interstellar medium (Gunn and Gott 1972, Quilis et al. 2000) or as a slow, gradual stripping called "starvation" (Larson et al. 1980, Bekki et al. 2002, Chung et al. 2007, McCarthy et al. 2008). Both processes are known as ram-pressure stripping. Wolf et al. (2009) and Gallazzi et al. (2009) have provided observational evidence for this process. They have found a number of late-type, red galaxies in galaxy clusters with lower star formation rate than the late-type galaxies in the field.

To recapitulate, first galaxies in the early Universe are disk/spiral galaxies. We can consider them all to be field galaxies since clusters have yet to form. Cold mode accretion dominates because of it and they have large star formation rates which is why they appear blue in the color-mass diagram. The position of this population of galaxies in this diagram is called "blue cloud". As galaxies merge, larger structures form, groups then clusters. A newly created starburst galaxy has an even higher star formation rate. Eventually, most of the gas has been used for star formation and as the number of new blue stars starts declining, galaxy begins appearing redder in the color-mass diagram occupying part of the diagram known as "green valley". Galaxy mergers create elliptical galaxies which start overtaking disk/spirals in numbers. Shock heated gas in clusters stops the cold mode in favor of the hot mode as a default mode for gas cooling. There is no more star formation and galaxies appear red ("red sequence" in the color-mass diagram). Disk/spiral galaxies which do not fall into clusters make up a field population where cold accretion still occurs until their halos reach $\sim 10^{12}\,M_\odot$.

3. ORIGIN OF BLACK HOLES IN QUASARS/AGNS

3.1. Black Hole Seeds

In the current picture of SMBH assembly, the black holes begin life as "seeds" at the centers of dark matter halos at high redshift. It's not clear, though, when exactly these BH seeds emerge or what mass they have at birth. They may be a product of the coalescence of many seed black holes within a halo (Begelman and Rees 1978, Islam et al. 2004), or from an IMBH formed, perhaps, by runaway stellar collisions (Portegies Zwart et al. 2004, Miller and Colbert 2004), or they could even be primordial (Mack et al. 2007).

Until recently, the most likely candidates for SMBH seeds were the remnants that form from the first generation of stars sitting deep within dark matter halos (Madau and Rees 2001, Heger et al. 2003, Volonteri et al. 2003, Islam et al. 2003, Wise and Abel 2005) – so called Population III stars. With most probable masses of roughly 100 $M_\odot$, these relic seeds are predicted to lie near the centers of dark matter halos at high redshifts (Bromm et al. 1999, Abel et al. 2000, 2002). However, it seems that Pop III seeds scenario can not explain the formation of $\simeq 2 \times 10^9\,M_\odot$ SMBH which powers a quasar at $z = 7.085$ (Mortlock et al. 2011). Since only ≤ 800 Myr is available for the growth of such a black hole, it is very difficult to explain their origin from $\sim$100 $M_\odot$ Pop III seeds. To make things worse, numerous recent theoretical (Volonteri et al. 2005, Pelupessy et al. 2007, Alvarez et al. 2009, Milosavljevic et al. 2009, Noble et al. 2009, Park and Ricotti 2011, 2012a,b, Jeon et al. 2012) and observational (Elvis et al. 2002, Wang et al. 2006, 2009, Davis and Laor 2011, Bambi et al. 2012, Li et al. 2012) results suggest that radiative feedback in the early Universe suppresses the gas accretion onto the black hole. This suggest that more massive seeds may have a role to play (Tyler et al. 2003, Shapiro 2005, Volonteri and Rees 2006, Tanaka et al. 2012).

Most likely scenario today is the formation of SMBH seeds from the accretion of low angular momentum gas in a dark matter halo (Koushiappas et al. 2004, Bromm and Loeb 2003, 2004). These seeds would form as supermassive stellar remnants, with the initial masses of 10^4–$10^6 M_\odot$ from the direct collapse of $\simeq 10^4$ K primordial gas in DM halos with total masses of $\sim 10^7$–$10^8\,M_\odot$ at $z \geq 10$. There are even some observational evidences that local SMBHs may have been seeded by direct collapse (Greene 2012). This theoretical model seemed to occur rarely and under very specific conditions. Now it appears that these conditions might be satisfied more often in the early Universe than previously assumed (Wise et al. 2008, Regan and Haehnelt 2009, Shang et al. 2010, Bellovary et al. 2011, Wolcott-Green et al. 2011, Agarwal et al. 2012, Inayoshi and Omukai 2012, Johnson et al. 2013, Latif et al. 2013, Petri et al. 2012, Prieto et al. 2013).

3.2. Black Hole Binaries

After halos and their galaxies merge, seed black holes sink to the center of a new halo through dynamical friction and eventually coalesce while accreting gas from the newly created reservoir (Mihos and Hernquist 1994, Di Matteo et al. 2003). This combination of gas accretion and binary black hole coalescence forms the SMBHs we observe today (Soltan 1982, Schneider et al. 2002).

Before two black holes coalesce, they must become bound as a binary (Kazantzidis et al. 2005, Escala et al. 2005). Dynamical friction then continues to shrink the orbit until the binary is hard (i.e, the separation between black holes is such that the system tends to lose energy during stellar encounters) (Heggie et al. 2007). Thereafter, 3-body scattering with the ambient stellar background continues to drain energy from the orbit until the binary becomes so close that the orbit can lose energy via gravitational radiation. In studies of static, spherical potentials, central galactic region runs out of stars as 3-body scattering keeps ejecting them. This usually occurs at the binary separation of ~ 1 pc (last parsec problem). Hence, it may be difficult for stellar encounters alone to cause the binary to transition between the 3-body scattering phase and the gravitational radiation regime (Milosavljevic and Merritt 2003). However, in gas-rich or non-spherical systems, dynamical friction due to the gas leads to the binary hardening and coalescence into one black hole, while emitting copious gravitational radiation in the process (Mayer et al. 2007, Kazantzidis et al. 2005, Berczik et al. 2006, Sigurdsson 2003, Holley-Bockelmann and Sigurdsson 2006).

3.3. Igniting an AGN

The gas accretion onto the SMBH occurs parallel to the star formation which follows galactic merger. In this manner, new SMBH and new galaxy grow together. This was shown in hydrodynamic simulations of cosmological structure formation by Sijacki et al. (2007) and Di Matteo et al. (2008). They followed the growth of high mass SMBHs at the centers of massive elliptical galaxies and clusters of galaxies. Their research was followed by similar semi-analytic work that incorporates a full treatment of dark matter dynamics, radiative gas cooling, star formation and energy feedback processes (Somerville et al. 2008). In this very elegant approach, the SMBH accretes gas through a *quasar mode* – nearly Eddington rate accretion following a galaxy merger (Croton et al. 2006) – and a *radio mode* – Bondi-Hoyle accretion associated with relativistic jets (Somerville et al. 2008). Both modes produce feedback that heats the surrounding gas. In this model, the feedback stops the accretion and locks the growth of the SMBHs to the fundamental plane. At the same time, the feedback also quenches the star formation, which explains the observed shallow metallicity, stellar density and entropy profiles. However, it has recently been suggested that the implementation and importance of AGN feedback may need to be reexamined (Ostriker et al. 2010). Also, radiation fields and winds produced by massive stars may provide the dominant feedback (Hopkins et al. 2010). In fact, it is worth mentioning that AGN feedback is just one of many feedback processes occurring in galaxy centers; supernovae, star formation, and galaxy mergers produce feedback as well (Sinha and Holley-Bockelmann 2010). It is not clear which feedback process contributes the most to the evolution of a given galaxy.

4. SMBH GROWTH: GALAXY MERGERS VERSUS SECULAR EVOLUTION

We have established in previous sections that galaxies grow through mergers and secular gas accretion. This growth depends on many factors including redshift, galaxy mass, environment, etc. As SMBHs reside in the galactic centers, their growth too is a combination of black hole mergers and accretion of gas supplied to the central regions of galaxies. For the last thirty years it was believed that gas accreted onto a black hole is almost always supplied by major mergers of galaxies. However, there are strong recent evidences that secular evolution may be a dominant process controlling SMBH growth. Secular evolution means that internal processes such as bar-driven gas inflow (Kormendy and Kennicutt 2004), and stellar wind (Ciotti and Ostriker 2007) can also supply gas to SMBHs to trigger their activity.

In order for gas to be accreted by a supermassive black hole in a center of a galaxy, it has to be "cooled" first. In other words, angular momentum has to be removed from the gas. This can occur through galaxy mergers (nurture) of through secular evolution (nature). Nurture means that galaxy environment influences the evolution of both galaxies and their supermassive black holes. If the environment is dense (galaxy clusters), it will consist of a large number of galaxies which can potentially merge, cool their gas, and accrete it onto SMBH. Nature means that galaxies manage to evolve from spiral to elliptical in any environment because their evolution depends only on the internal dynamical processes. In the same manner, central SMBHs in galaxies can accrete gas from hot corona regardless on galaxy participation in mergers.

A powerful argument supporting BH mergers as most important mechanism for SMBH growth is the fact that they can build a large reservoirs of gas in a newly created merger remnant. This occurs due to gravitational torques produced by mergers, which efficiently drain angular momentum from the gas. Mergers may also produce a strong starburst in merging galaxies which observationally corresponds to ultra luminous infrared galaxies (ULIRGs). With observational evidence showing post merger features in galaxies hosting AGNs and quasars, a simple, complete model emerged: galaxy merger activates rapid star formation (ULIRGS), followed by the accretion onto SMBH (quasar) (Surace and Sanders 1999, Surace et al. 2000, Canalizo and Stockton 2000, 2001).

There have been a variety of approaches attempting to establish which process is dominant in black hole feeding. Alonso et al. (2007) studied galaxy pairs or pairs of interacting galaxies in SDSS survey. Their criteria for galaxy merger are the existence of distorted morphologies and tidal features and they found 1607 close-pairs based on it. Their results were inconclusive as they found that AGN host are redder regardless whether they were in close pairs or in isolation and that the fraction of AGNs in close pairs was larger by only 10 %. Working on a much larger sample of 11060 SDSS close galaxy pairs, and a control sample of 110600 galaxies without pairs, Ellison et al. (2011) have found that the AGN fraction in close-pairs is 2.5 times larger. They argue that the reason AGN fraction is much larger in their work lies in the fact that previous works have difficulty imaging morphological disturbances. That is why they use entirely different merger criteria. The merger criteria in Ellison et al. (2011) is a simple separation criterion of $d < 80$ kpc and $\Delta v < 200 \ \mathrm{km\,s^{-1}}$. In other words, galaxy pairs in Ellison et al. (2011) are likely to merge because they are close to each other and have small relative velocities. Conclusion is that galaxy mergers are a dominant mechanism for gas accretion onto a black hole. Liu et al. (2012) found that some of the close galaxy pairs are also AGN pairs and the AGN activity increases in pairs with smaller separation. These results mean that if galaxy merger occurs, it is always followed by gas cooling, star formation and AGN activity. However, are the mergers dominant process remains to be seen.

This entire model was challenged recently (Gabor et al. 2009, Darg et al. 2010, Cisternas et al. 2011, Kocevski et al. 2012). Cisternas et al. (2011) analyzed 140 XMM-Newton-selected AGN host galaxies and a matched control sample of 1264 inactive galaxies over redshift range $z \sim 0.3$ - $-$ 1.0 with high-resolution HST/ACS imaging from the COSMOS field. Assuming that post merger features are evidence of galactic merger, they found that 85 % of galaxies with AGNs do not show evidence of a previous merger at $z \leq 1$, which is comparable with the merger fraction of non active galaxies. This suggested that secular evolution is responsible for SMBH growth at least at low redshift. These results have started an avalanche of papers trying to support either merger driven or secular evolution scenarios. There are two battle grounds: how well can we detect merger features and why there are galactic disks around AGNs.

4.1. Hunting for Post-Merger Features

The lack of post merger features may be explained by the time lag between merging and observability of the AGN phase. It is possible that the merging events have happened in distant past, and all post merger features have been wiped out. Mihos (1995) studied elliptical galaxies as merger remnants. He found out, by combining numerical simulation and synthesized Hubble Space Telescope (HST) Wide-Field Planetary Camera 2 (WFPC2) images, that merger remnants appear morphologically indistinguishable from a "typical" elliptical galaxy ≤ 1 Gyr after the galaxies merged, while Combes et al. (1995) estimated from numerical simulations that the time might be even less than 0.5 Gyr. Also, in the early stages of the merger, only modest starbursts are triggered with no major BH accretion, and therefore the galaxies would not be detected as AGN (Di Matteo et al. 2005; Springel and Hernquist 2005). In addition, the AGN may be obscured for ~ 90 % of its lifetime by large column densities, only revealing itself at the end of the merger (Hopkins et al. 2005).

Schawinski et al. (2010) presented a novel approach with convincing results supporting merging scenario. They used a sample called MOSES (Morphologically Selected Early-types from Sloan, Schawinski et al. 2007) of low mass early-type ellipticals which are known to be migrating from blue cloud to red sequence via green valley. For all these galaxies they define an evolutionary sequence assuming that increasingly red optical colors of galaxies along this sequence suggest an evolutionary sequence: 1) blue cloud - early type galaxies which do have star formation reside in the blue cloud on the color-mass diagram; 2) AGN + star formation - early type galaxies whose emission line ratios indicate that the output of ionizing photons from star formation and nuclear activity are roughly comparable and exhibit slightly redder optical colors; 3) green valley - objects dominated by nebular emission from a Seyfert AGN; 4) LINER - objects with weak LINER emission and 5) red sequence - quiescent early type galaxies on the red sequence. Then they looked for merger features in all of these galaxies and counted the number of galaxies with merger features in all 5 classes. If mergers trigger the migration from blue to red, then as galaxies become redder, the merger signs should become less frequent and less obvious and eventually reach the background level seen in passive red sequence galaxies. They found that this is the case and while first two classes of galaxies show ~ 40 % merger fraction, the remaining three classes have merger fraction at the background level of ~ 20 %. In other words, merger fraction drops to the background ~ 500 Myr after starburst and even more importantly, it drops to the background level before AGN phase becomes prominent. Another important point is that MOSES catalog was created by selecting only blue early type galaxies from SDSS. This means that galaxies which are on their way of becoming blue early type are missed which means that the merger fraction should be much larger. This implicates a merger as the trigger for the starburst episode at the beginning of the evolutionary sequence for most, if not all early type galaxies migrating from the blue cloud to the red sequence. Another argument supporting delay in AGN activity with respect to starburst phase was provided by Smirnova et al. (2010). They observed a sample of apparently isolated Seyfert galaxies and found that about 35 % of them show tidal tails, consistent with a gas rich merger in the last $0.5 - 1$ Gyr.

A bigger issue than detection of the merger features is detection of the merger features around AGNs versus around non-active galaxies. Even if most of the AGN hosting galaxies do not have merger features that does not exclude merger driven scenario for the AGN activity. One can always argue that merger features can not be detected for various reasons. However, if fraction of AGNs in galaxies with merger features is comparable to the fraction of non-active galaxies with merger features, then mergers are not responsible for the AGN activity. On the other hand, if SMBH activity is triggered by galaxy mergers, the fraction of galaxies with clear sign of being the results of interactions/mergers should be statistically higher in a sample of AGN host galaxies than in a sample of field galaxies. As mentioned earlier in the text, Cisternas et al. (2011) found former scenario to be the correct one. Since then, there have been major concerns about the possible selection bias in these works. Obscured AGNs can be missed in studies based on optical emission-line ratios, optical spectral classification or even soft X-ray fluxes. In fact, when sample of hard X-ray selected AGNs is used, a strong excess of merging systems with respect to a control sample has been observed (Koss et al. 2010). Cotini et al. (2013) also used hard (> 10 keV) X-ray selected AGN sample and a new morphological criterion for identification of interacting systems, based on a combination of non-parametric structural indexes of concentration, asymmetry, clumpiness, Gini coefficient and second order momentum of light. They found that the fraction of interacting galaxies among the active population exceeds the merger fraction of the control sample by ~ 15 %. Their findings support the scenario in which mergers trigger the nuclear activity of supermassive black holes.

4.2. AGNs Hosted by Disk Galaxies?

Even if the lack of post merger features is not a valid tracer of mergers, there is one more observational evidence which can not be explained by the merger scenario. Cisternas et al. (2011) have found that a significant fraction of AGNs is hosted by disk galaxies. This was later confirmed by Schawinski et al. (2012). As mentioned before, major mergers always lead to formation of spheroidal and bulge dominated galaxies. Even if the disk reforms after the merger (Hopkins et al. 2009a, Bundy et al. 2010), the timescale for such a process can be as much as an order of magnitude larger than the typical quasar lifetime. However, it has recently been shown that SMBH grows at the same time the disk is assembling (Debattista et al. 2013). Debattista et al. (2013) showed that as disk reforms, it compresses the bulge which increases velocity dispersion. In order for a black hole to remain on M - σ relation, it has to grow 50 - 65 %. This means that accretion onto SMBH occurs simultaneously with disk formation and that AGNs which result in galaxy mergers can be observed in disk galaxies.

The question of which processes supply AGN activity will remain in years to come. Perhaps the solution to this problem might be in accepting the possibility of the existence of two different populations of AGNs based on the mass of the host galaxy. Treister et al. (2012) have found that in order to reach the highest AGN luminosities (where the most massive black holes accreted the bulk of their mass) a major merger appears to be required. Most luminous AGNs in most massive galaxies are then connected to major mergers, while less luminous AGNs in low mass systems are driven by secular processes.

5. FIELD GALAXIES

Most of the galaxies in the field are disk/spiral galaxies with bulges or a pseudobulges. They make more than 50 % of field galaxies (Dressler 1980). The rest are S0, elliptical and irregular galaxies, where S0 galaxies outnumber ellipticals 2:1. Field spiral galaxies show properties very similar to spiral galaxies in "loose groups" or Milky Way type galaxies. Few et al. (2012) has performed a set of cosmological simulations of galaxies forming in the field and in the loose groups similar to Local Group. They found that galaxies in both types of environments have similar spheroid-to-disk ratios and metallicity gradients (for the same disk mass). Their properties seem to be more dependent on their growth/merger histories and less on the surrounding density.

In much smaller numbers we can also find elliptical galaxies in the field. Most elliptical galaxies reside in clusters and groups and that is where they are studied the most. Therefore, the detailed properties of field elliptical galaxies have not been extensively studied or very well understood. There are only a few observational studies and the surveys are small. Moreover, the formation mechanisms and evolutionary paths of these "lonely" elliptical galaxies are not yet well understood.

Niemi et al. (2010) have studied formation and evolution of field elliptical galaxies in the Millennium Simulation (Springel et al. 2005) and compared simulated to the observed properties. As mentioned before, elliptical galaxies in the field make a very small percentage of all observed galaxies. Niemi et al. (2010) have found that ≤ 6.4 % of all elliptical galaxies in Millennium Simulation are in the field, but when one counts the central elliptical galaxies only, this percentage increases to 32 %. This increase is expected since only most massive elliptical galaxies are at the centers of galaxy clusters while the rest of them are in their halo.

They also found that most field ellipticals are bright, red galaxies similar to ellipticals in the galaxy clusters. But quarter of all field ellipticals are faint, blue galaxies. This suggests that these could be two separate galaxy populations with different evolutionary paths.

When it comes to dark matter content in the halo around field ellipticals, Niemi et al. (2010) have found that most of them have halos with mass smaller than $7 \times 10^{12}\ M_{\odot}$, and with median mass of $1.2 \times 10^{12}\ M_{\odot}$. There are no field ellipticals in halos above $2 \times 10^{13}\ M_{\odot}$. This is consistent with Memola et al. (2011) who calculated the total masses of field ellipticals NGC 7052 and NGC 7785 (from X-ray observations) to be $\sim 5 \times 10^{12}\ M_{\odot}$ and $1.9 \times 10^{12}\ M_{\odot}$, respectively. The mass of dark matter halos around field ellipticals is important because light halos had poorer merger history and probably no major mergers at all. More massive halos either had rich merger history of minor mergers or just couple of major mergers. Difference in merger history dramatically influences the final properties of galaxies. Evolutionary path of field ellipticals is quite different from ellipticals in clusters. As mentioned above, ellipticals in clusters experience tidal stripping among other dynamical processes in the clusters gravitational potential. As they lose substantial amount of dark matter, the stellar component gets stripped also. This does not occur in field ellipticals. In fact, mass in dark matter and in stars follows almost linear relation. Dark matter halo in the field has more stellar mass than the dark matter of the same mass inside a cluster.

Reda et al. (2005) have observed 36 isolated elliptical galaxies and determined that the mean age of field galaxies is 4.6 ± 1.4 Gyr while Proctor et al. (2005) found age of ~ 4 Gyr for the isolated elliptical galaxy NGC 821. On the other hand, Collobert et al. (2006) found a very broad range 2 - 15 Gyr for the age of 22 observed isolated elliptical galaxies. Simulations of field ellipticals by Niemi et al. (2010) are consistent with these values. After comparing them to the elliptical galaxies in Virgo and Coma clusters, Collobert et al. (2006) conclude that elliptical galaxies in the field are younger or at least a part of this population is much younger than the cluster ellipticals. This large scatter can be explained by very different formation times and evolutionary paths in the field, while elliptical galaxies in clusters have their evolution cut short by the dynamical processes in the cluster.

Niemi et al. (2010) also studied properties of field ellipticals as a function of the number of companion galaxies. How many companion galaxies is found near an elliptical galaxy is one of the criteria of galaxy isolation. Fig. 3 in Niemi et al. (2010) is consistent with the predictions of how the structure forms in the ΛCDM Universe. In a sphere $\sim$ 1Mpc, number of companions in high-mass ($M_{\rm DM} > 10^{12}\ M_\odot$) and low-mass field galaxies ($M_{\rm DM} < 10^{12}\ M_\odot$) is comparable. However, as we count companions inside a sphere of a shrinking radius, their number is becoming larger around high-mass field galaxies. This is a simple consequence of more structure forming in higher density regions. Similar effect is observed when field ellipticals are divided into two groups based on their colors. Red ellipticals have more companions while blue ellipticals are more isolated. In some sense, this result is an extrapolation of color dependence of elliptical galaxies on the density of the environment. Ellipticals in clusters are redder as their star formation ceased due to gravitational interactions in the cluster, while ellipticals in field are bluer due to the ongoing star formation.

The fact that number of red ellipticals decreases in favor of blue ellipticals with the decreasing environment density is also evident in the color-magnitude diagrams of Niemi et al. (2010, Figs. 1 and 2). In these figures, field ellipticals are compared to all ellipticals and it is shown that cluster ellipticals are redder. Cluster ellipticals are dominantly red regardless of the dark matter halo mass, while field ellipticals are red in high-mass halos and blue in low-mass halos. There is a fundamental difference in the nature of these dark matter halos. Cluster ellipticals are almost always subsystems of a large cluster halo under the influence of its gravity, while field ellipticals reside in the main dark matter halo. When this halo is light ($M_{\rm DM} < 10^{12}\ M_\odot$), elliptical galaxy is young and star forming. When main halo is massive ($M_{\rm DM} > 10^{12}\ M_\odot$), elliptical galaxy is red due to larger number of mergers producing large halo.

Luminosity functions for isolated ellipticals and for all ellipticals show interesting differences. There are no isolated ellipticals in simulations of Niemi et al. (2010) brighter than 21.7 mag (in B band). However, there are brighter ellipticals in the clusters. These are central, most massive elliptical galaxies in the clusters. Luminosity functions of the rest of the red ellipticals follow similar distribution in the field and in clusters. When blue ellipticals are added, luminosity function for field ellipticals is bimodal. There is a separate population of blue ellipticals in the field which is almost non existent in the clusters.

Formation and evolution of field and cluster ellipticals is quite different. First, the progenitors of most massive elliptical galaxies form in the early Universe. Structure formation in cold dark matter Universe dictates that structures form in the densest environment first. Hence, galaxy mergers are more likely where the number of galaxies in Mpc^3 is largest. That is where progenitor clusters start forming and later, at $z < 2$, start virializing. At their centers, most massive ellipticals form. On the other hand, field ellipticals form through mergers in low density regions at significantly lower redshift which means they form much later, and so field ellipticals are much younger than central ellipticals in clusters.

Niemi et al. (2010) found that half of the field ellipticals have at least one major merger at some point in their formation history. One third of central cluster ellipticals has major mergers. Surprisingly, there are almost no elliptical galaxies with major mergers in clusters outside of their centers. This means that either elliptical galaxies (at least those in clusters) might form without major mergers, or these galaxies did have major mergers before they became part of the cluster (while they were in the field). In other words, it is possible that elliptical galaxies form in the field through major mergers and later sink into clusters. Note that, either way, there are field ellipticals which had no major mergers at all suggesting that it is quite possible to form an elliptical galaxy without major mergers in the field and in the clusters.

When it comes to accumulation of dark matter and stellar mass from their formation until today, field ellipticals and cluster ellipticals show similarities if they are red. Red ellipticals form their stars early disregarding what kind of environment they are in. Blue ellipticals which are dominantly found in the field accumulate their stellar mass much later. Assembly of dark matter occurs in the similar manner for all ellipticals in all environments.

6. AGNS IN FIELD GALAXIES

As mentioned previously, both nature and nurture appear to be important for galaxy evolution. Is the environment more important than the secular processes is a matter of debate and one of the most important questions in the field.

The most general definition of field galaxies is that these are galaxies outside of clusters. They have subclasses based on the time spent in isolation and environmental density. Truly isolated field galaxies are galaxies which have been isolated for several Gyrs. All other galaxies in the field can be in lose groups, compact groups or isolated.

Miller et al. (2003) have studied field galaxies in SDSS which host AGNs as a function of environment. They found that the AGN fraction is constant over the two orders of magnitude in local galaxy density. 20 % of all galaxies contain an AGN. In other words, there in no difference in AGN fraction between galaxies in cluster cores and galaxies in the field. They only found a small decrease in the AGN fraction in the densest regions, for which they claim that is not statistically significant. They found no AGN density relation for the early and late type galaxies. At that time, this was surprising (and wrong) result since other properties of galaxies (morphology, luminosity, star formation rate etc.) show a strong dependence on local galaxy density. These observations were explained by the hypothesis that the AGN population is tracing only the bulge component of galaxies. This would explain why they saw no dependence on local galaxy density, as most galaxies have a bulge, and why there is no correlation with morphological type, as the disk component is irrelevant to the existence of an AGN. However, a year later, Kauffmann et al. (2004) reported that when AGN sample is limited only to most luminous AGNs, the fraction of field galaxies containing AGN is twice larger than the fraction of AGN hosts in clusters. This was an argument for AGN-density relation similar to the one that already existed for other galaxy properties. Massive galaxies in clusters have their gas supply removed, hence, both star formation and AGN activity decreases dramatically. The increase of AGN fraction from clusters to the field has been confirmed later by Arnold et al. (2009). At higher redshift this increase is even more pronounced. Martini et al. (2009) found an increase by factor of eight at redshift z=1.

Hwang et al. (2012) have studied a sample of almost a million SDSS galaxies in clusters and in the field. They confirm previous findings on AGN-density relation which states that late type galaxies have constant AGN fraction in clusters and in the field, while for early type galaxies they found factor of three larger AGN fraction in the field.

They also found that the activity in galactic nuclei of field galaxies is determined strongly by the nearest neighbor distance and morphology. When the nearest neighbor of a galaxy is an early type, the AGN fraction decreases as the pair separation decreases inside the virial radius of the galaxy in question. If the neighbor is a late type, the AGN fraction is constant outside of the virial radius, increases inside and reaches maximum at 0.2 of the virial radius. A possible interpretation of this result might salvage the merger driven scenario for AGN activity which has been questioned by Cisternas et al. (2011) and numerous other authors in the past three years.

When the nearest neighbor is at the virial radius of a galaxy, galaxies in pair start to interact hydrodynamically (Park et al. 2008). Hydrodynamic interactions together with tidal interactions, trigger nuclear activity. If a galaxy with a SMBH approaches a late type neighbor within the virial radius, the inflow of cold gas from the neighbor into the target galaxy increases and the SMBH starts to accrete the gas and AGN is activated. The crossing time of galaxies across the virial radius is of an order of $\sim 10^9$ yr, which is much shorter than the age of the Universe. The mass transfer between galaxies in pair is usually observed in close pairs with a pair separation of $\sim$ 30 kpc (Kewley et al. 2010, Font et al. 2011). However, recent simulations show that it is quite often the case that after the first pericenter passage below 30 kpc which ignites AGN, the eccentricity of the orbit would drag galaxies apart up to 100 kpc before they finally merge. There are some candidates found in the SDSS images with large pair separations (Park et al. 2008). Moreover, there is a known ultraluminous infrared galaxy with a pair separation of $\sim$ 90 kpc, which shows nuclear activity and large tidal features (IRAS 11223-1244, Kim et al. 2002), which also supports this argument. Even if there is no gas inflow from the neighbor, if the target galaxy is late type, tidal interactions would perturb the gas in the target galaxy. That gas would then be accreted by the SMBH. On the other hand, if an early type galaxy approaches an early type neighbor the SMBH would not be ignited due to the lack of fuel. They do not see this effect inside clusters. The orbital velocities of cluster galaxies are very high. This results in encounters which are too short for the tidal energy deposit. Hence, galaxy properties can not be significantly affected. This will weaken the dependence of galaxy properties on the nearest neighbor galaxies in the cluster region.

7. AGNS IN TRULY ISOLATED GALAXIES

In order to constrain the problem of nature versus nurture better, AMIGA project (Verdes-Montenegro et al. 2005, Analysis of the interstellar Medium in Isolated GAlaxies) focuses on truly isolated field galaxies. It consists of 1050 galaxies compiled using an isolation criterion that the galaxies have been unperturbed for $\sim$ 3 Gyr. This criterion makes AMIGA galaxies more isolated and in less dense environment than most field galaxies. Isolation and lack of mergers is why they host pseudo bulges rather than classical bulges. The main objective of AMIGA is to disentangle the effect of galaxy interactions from the intrinsic evolution in a galaxy by providing a large catalog of isolated galaxies, studying their nuclear activity, counting AGN hosts, and comparing them with galaxies in isolated denser environments. For comparison, Sabater et al. (2012) have used compact groups of galaxies (Hickson Compact Groups - Hickson 1982).

There are $\sim$ 20 % galaxies classified as AGN in the AMIGA sample and $\sim$ 24 % galaxies classified as AGN in the HCG sample. The distribution of AGN hosts is different in the two samples. Galaxies of later types dominate in the AMIGA sample as AGN hosts, in comparison to HCG, and there are more early type hosts in the HCG than in AMIGA. However, if we disregard the type of the host galaxy, and just look at the AGN fractions, they found that both isolated galaxies and compact groups have similar AGN fractions. As expected, the fraction of AGNs increases steeply towards higher luminosities and earlier morphological types. Hernandes-Ibarra et al. (2012) confirms these results by also using photometric catalogs of truly isolated field galaxies. They found that nuclear activity is largest for elliptical and SO galaxies which is also consistent with the results found for "field" galaxies (Heckman 1980, Keel 1983, Kauffmann et al. 2003, Miller et al. 2003). Although a large fraction of isolated galaxies are active, their SMBH has not grown significantly over the last 3

Gyr. This is the result of low luminosity AGNs populating isolated galaxies. Low luminosity means low accretion rates ($< 10^{-3}\ M_{\odot}$ per year) and small radiative efficiency. Even if we assume that AGN can be active for 3 Gyr, and that black hole can accrete at the constant rate for this period (not likely scenario), SMBH should accumulate less than million solar masses. This is consistent with downsizing for SMBH growth. Most massive SMBH in most massive galaxies form rapidly through major mergers. Low mass SMBH in low mass galaxies form slowly through secular evolution. Because of the low accretion rates, SMBH feedback will also be week, and isolated galaxy will not migrate from blue cloud to the red sequence. This is an important part of the puzzle. Notice that there are early type galaxies in isolation. Their existence means that they have formed much earlier through major mergers, and the fact that most of them host AGNs means that they are accreting the remaining gas or they have an external supply of material (minor mergers). Another interesting result is a complete lack of high luminosity AGNs (type 1) in these samples. This result supports the argument that in order to form broad line regions, major merger is required.

8. AGNS IN COMPACT GROUPS

Compact groups are isolated associations of several galaxies within the compact angular configuration. Hickson (1982) has introduced a definition for a compact group. A group of galaxies is considered to be compact if: total number of galaxies within 3 magnitudes of the brightest galaxy in the group is larger than three; angular diameter of the largest circle not containing any additional galaxies is at least three times larger than the angular diameter of a smallest circle containing group's centers and if the mean surface brightness inside this circle is less than 26 mag arcsec^{-2}. There are several compact groups catalogs: Hickson (1982), Lee et al. (2004), McConnachie et al. (2009). There are several studies of nuclear activity in compact group based on these catalogs. Coziol et al. (2000) have studied 193 galaxies in 49 compact groups and found 41 % AGN fraction based on optical spectra. Gallagher et al. (2008) found 54 % AGN fraction based on dust emission in mid-infrared. Martinez et al. (2010) looked into 270 galaxies in 64 compact groups and found AGN fraction to be 42 %. At that point it appeared that compact groups have AGN fractions larger than in the rest of the field galaxies and galaxy clusters. However, as mentioned previously, Sabater et al. (2012) found that AGN fractions are comparable in isolated galaxies and compact groups which underlines the importance of AGN selection criteria.

Sohn et al. (2013) have used McConnachie et al. (2009) catalog but selected the spectroscopic sample only. New sample consists of 58 compact groups with 238 galaxies (64 % early type and 36 % late type). Then, they compared the nuclear activity in these groups to the nuclear activity of 7211 galaxies in 129 clusters (Hwang et al. 2012). They found that the AGN fractions are very sensitive to the way their hosts are identified. AGN fractions are very different if their hosts are classified through week emission lines or through strong emission lines. This fraction varies from 24 % to 42 %. When fractions are compared between early and late type galaxies, they found that depending on host classification method used, early type galaxies have ~ 10 % smaller AGN fraction than late type galaxies. In conclusion, there are more early type galaxies in compact groups but they have lower AGN fraction. When AGN fractions are compared between different environments, they found that AGN fraction in late type galaxies in compact groups are comparable to AGN fraction in the field or in the clusters. Early type galaxies in compact groups show similar trend with the same type in clusters. Only the early type galaxies in compact groups show AGN fractions lower than in the field.

Since compact groups are expected to have large number of galaxy - galaxy interactions, comparable AGN fraction to other environments could be interpreted as an argument against merger driven AGN activity. However, most of the compact group galaxies are early type galaxies. Also, their AGN fraction is smaller than in the late type. This tells us that compact groups went through merger induced AGN phase earlier in their history. That is why early type galaxies dominate in compact groups. Galaxy interactions are still occurring but the gas necessary to induce AGN activity was exhausted earlier. Nuclear activity cannot be triggered in spite of frequent galaxy interactions. This interpretation is also valid for early type cluster galaxies that might have consumed or lost most of their gas.

As mentioned previously AGN fraction in late type galaxies is similar in all of the environments. This suggests that the cold gas of late type galaxies in compact groups or clusters is not stripped or consumed yet. The fact that galaxy is seen as late type means that is has been accreted recently. Otherwise, it would already experience stripping which would transform it into lenticular galaxy.

9. CONCLUSION

Although a great deal is known about mechanisms behind AGN and quasar duty-cycle and processes responsible for gas accretion, the method for supplying gas from large scales to the accretion disk seems to be rather complicated. The classical picture of gas flow toward the SMBH induced by galaxy merger appears to be oversimplified. It still plays an important role, in particular in most massive galaxies where most massive SMBHs grow. However, the recent emergence of new observational evidence for AGNs placed in disk galaxies and a lack of correlation between mergers and AGN activity, suggests that secular processes might also be important. In other words, there are many ways to bring gas to the galactic center without involving galaxy mergers (bar-driven gas inflow, stellar wind, etc.). And these secular processes appear to be more important then ever before. Nevertheless, one should keep in mind that the entire topic is very controversial at the moment. First, because of the question of observability of post merger features, and second, because of the possibility for the existence of galactic disks around AGNs.

On even larger scales, AGNs and quasars are phenomena surrounded by large dark matter halos which have their own growth histories and entirely different set of dynamical processes which control gas cooling from hot halo corona through hot and cold mode accretions. Probably the largest issue is that, in parallel, galactic disk forms through these two modes of gas cooling, gets perturbed secularly so that gas can be channeled toward central SMBH, gets completely destroyed in galaxy mergers, gets blown away by AGN and supernovae feedback, and then it has time to reform. When exactly all of these various processes dominate correlates with redshift, but this correlation is a result of a more fundamental connection between mentioned physical processes and the environmental density in which they are occurring. In dense environment (galaxy clusters), cluster halos are filled with hot gas which can cool only through the hot mode. This hot gas causes ram-pressure induced stripping of most of the galaxies inside the cluster which explains large number of lenticular galaxies while large number of ellipticals is the result of enhanced merger rates in denser environments. If disk galaxies are observed in clusters, that is because they have entered them recently. In low density environment (field), disk galaxies in the cold mode halos dominate. Elliptical galaxies are in lower numbers because of the lower merger rate in low density. From isolated field galaxies to compact galactic groups and galaxy clusters, number of late type galaxies decreases and number of early type galaxies increases. AGNs can be found in all of these galaxies in all environments.

Percentage of AGNs in late type galaxies is the same in the field galaxies, isolated galaxies, compact groups, and in clusters. This is a simple consequence of the fact that almost all late type galaxies observed in clusters have been brought there recently from the field. Percentage of AGNs in early type galaxies decreases from the field (isolated galaxies to compact groups) to clusters as field early type galaxies still have gas to supply their AGNs while all of the gas in cluster early type galaxies has been stripped. All of the field early type AGNs are still accreting but could be a result of a very ancient galaxy merger.

One of the most important recent results is the observed correlation between AGN fraction in field galaxies and nearest neighbor distance and morphology. When the nearest neighbor of a galaxy is an early type, the AGN fraction decreases as the pair separation decreases inside the virial radius of the galaxy in question. If the neighbor is a late type, the AGN fraction is constant outside of the virial radius, increases inside and reaches maximum at 0.2 of the virial radius. This is a strong argument in support of merger driven AGN activity. If two gas rich galaxies (late type) approach to each other, hydrodynamic interactions together with tidal interactions, trigger nuclear activity. If two early type galaxies approach each other, nuclear activity can not be triggered because galaxies do not have gas. Ram-pressure stripping erases this correlation in galaxy clusters.

Acknowledgements – "This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia through project no. 176021, "Visible and Invisible Matter in Nearby Galaxies: Theory and Observations". The author acknowledges the financial support provided by the European Commission through project BELISSIMA (BELgrade Initiative for Space Science, Instrumentation and Modelling in Astrophysics, call FP7-REGPOT-2010-5, contract no. 256772)."

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ГАЛАКСИЈЕ У ПОЉУ И ЊИХОВА АКТИВНА ЈЕЗГРА: ПРИРОДА НАСПРАМ УЗГОЈА

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УДК 524.7–36–42–48–52–54
Прегледни рад по позиву

У овом прегледном раду покушали смо да представимо најновија достигнућа која се односе на веома контраверзно питање који процеси управљају дотоком гаса до центра галаксија где се одигравају акреција и раст супермасивних црних рупа. Такође, стављамо ово питање у контекст утицаја средине (јата галаксија наспрам поља) на ове процесе.