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A Provocative Summary ? Is There Any Unified Model for Triggering Active Galactic Nuclei ?

Yoshiaki Taniguchi[1]

[1]*Research Center for Space and Cosmic Evolution, Ehime University, Japan, Bunkyo-cho 2-5, Matsuyama, Ehime 790-8577, Japan*

Abstract. A provocative summary of the conference on gGalaxy Mergers in an Evolving Universeh is presented. The conference includes the following issues; 1) Mergers at low redshift, 2) Merger dynamics and numerical simulations, 3) Mergers in galaxy evolution, 4) Mergers and active galactic nuclei (AGNs), 5) Mergers at high redshift and submm galaxies, 6) Feedback from starbursts and AGNs, 6) Chemical evolution of galaxies, and 7) Results from new surveys. Although there are many important issues related to galaxy mergers and nuclear activities in galaxies, in this summary, l et us focus on following the question; *Is there any unified model for triggering nuclear activities ?* Given key observational properties of galaxies with AGNs, a possible unified model is discussed as an evolutionary model from starbursts to AGNs based on minor and major mergers between/among galaxies.

1. Introduction

We observe galaxies with an active galactic nucleus (AGN) together with normal and starburst galaxies in the local universe (e.g., Ho et al. 1997). AGNs are considered to be powered by the gas accretion onto a supermassive black hole (SMBH) resided in a nucleus of galaxies (Rees 1984). In this respect, such AGN phenomena are basically different from the ordinary evolution of galaxies that are governed by various star formation history. However, it has been shown that the mass of SMBHs is well correlated with that of the spheroidal component of galaxies (bulges and elliptical galaxies) regardless of the presence of AGN phenomena (e.g., Magorrian et al. 1998). This suggests strongly the co-evolution between SMBHs and galaxies although we have not yet understood what physical processes play a key role.

More importantly, SMBHs are ubiquitously present in the nucleus of galaxies and thus the AGN phenomena should be controlled by some triggering mechanism such as gas fueling onto the SMBH. This means that all AGN phenomena are transient processes during the course of evolution of galaxies. This is also advocated both by the evolution of quasar luminosity function (e.g., Boyle et al. 1992; Ikeda et al. 2011 and references therein) and by the so-called dead quasar problem (Rees 1990).

Another type of activity in nuclear regions of galaxies is starburst phenomena in which more than 10,000 massive stars are formed during a short time interval (Balzano 1983). Since massive stars could provide compact objects such as neutron stars and stellar-sized black holes, it has been also discussed that there may some possible relationships between starburst and AGN phenomena; i.e., starburst-AGN connections (e.g., Taniguchi 2003, 2004). Here we should remind that the starburst activity also needs some triggering mechanisms because a lot of dense gas must be accumulated in the nuclear region of galaxies. In fact, the starburst is intrinsically different from ordinary star formation in galactic disks (Daddi et al. 2010).

In summary, we have to consider various aspects when we investigate the evolution of nuclear activities and chemical and dynamical properties of galaxies as a function of the cosmic age; see Fig. 1. In this article, however, let us focus on the importance of mergers of galaxies toward the understanding of triggering both starbursts and AGNs.

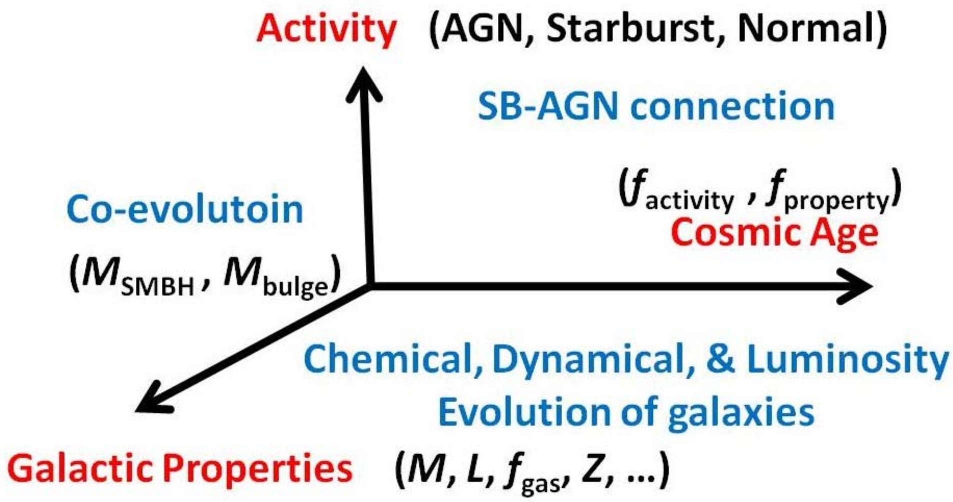

Figure 1. A three-dimensional, schematic summary of evolution of both starbursts and AGNs during the course of galaxy evolution. (1) There are a number of important properties of galaxies such as the mass (M), luminosity (L), gas fraction (f_{gas}), metallicity (Z), and so on. (2) There are two distinct types of nuclear activities, AGNs and starbursts, in addition to the normal phase of nuclei. (3) It is reminded that these two parameters (the nuclear activities and the galaxy properties) that are denoted as $f_{activity}$ and $f_{property}$, respectively, are functions of the cosmic age. If the AGN phenomena are in part related to the growth of SMBHs, the co-evolution between SMBHs and galaxies is expected.

2. Possible Unified Models for Triggering AGNs

In this summary, we are interested in both starbursts and AGNs. However, for simplicity, we first consider what a mechanism can trigger AGN phenomena and then how a physical connection between starbursts and AGNs. Therefore, our questions are summarized as follows.

1. Why do some galaxies show AGN phenomena although almost all galaxies have a SMBH in their nuclear regions ?
2. Do galaxy mergers play an essentially important role for triggering them ?

3 If the answer is yes, how do they work ?

In order to give possible answers for these questions, let us start to adopt the following theorem.

Theorem: There is the unified model for triggering AGNs.

This means the following scenario; If an ordinary (i.e., non-active) galaxy has a certain triggering mechanism, it must *inevitably* evolve to a galaxy with an AGN. Namely, we postulate that there is the only one triggering mechanism of AGNs (see Fig. 2). Therefore, the question is what the only one mechanism is.

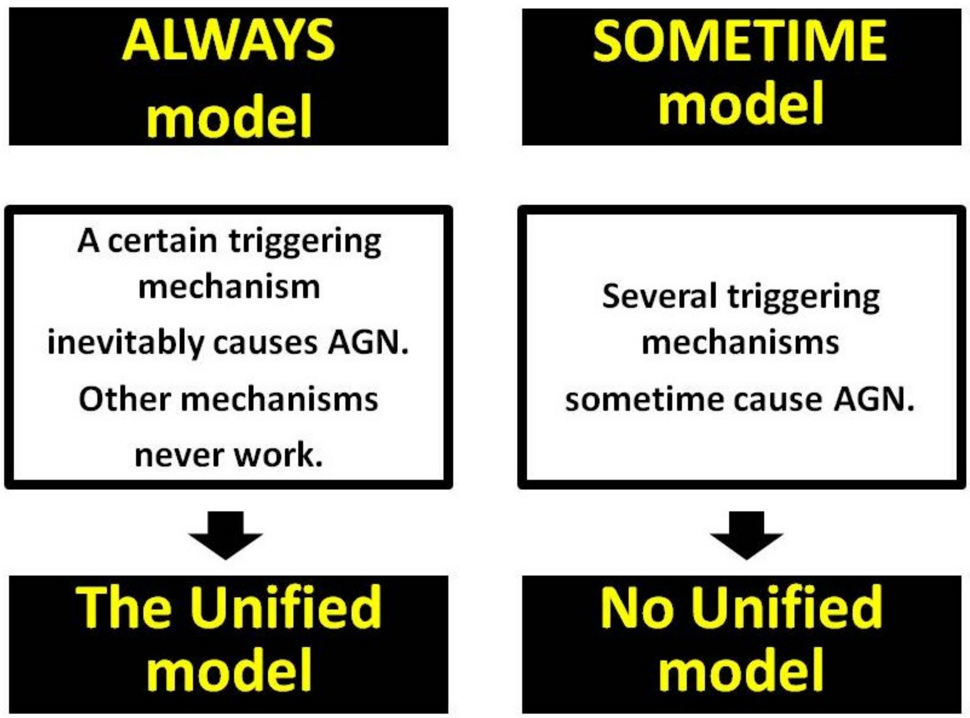

Figure 2. Always model vs. Sometime model. If there is an Always Model, that is the unified model.

As possible triggering mechanisms for starbursts and AGNs, the following items have been discussed intensively (see, for a review, Taniguchi 1999);

1. Secular-evolution fueling in galactic disks
2. Bar-driven fueling
3. Minor-merger-driven fueling

4. Galaxy-interaction-driven fueling
5. Major-merger-driven fueling

2.1. Triggering Seyfert Nuclei

First, let us consider about Seyfert nuclei in the local universe because many observational properties have been investigated to date. At this starting point of discussion, we can omit the major-merger-driven fueling that is considered to play an important role in triggering ultraluminous infrared galaxies (ULIRGs) and quasars (Sanders et al. 1988). We shall come back to this mechanism later.

First, we can exclude the secular-evolution fueling. Since, if this is the case, we cannot specify when and how the Seyfert activity could be triggered, this idea does not fit to any unified triggering mechanism.

As described in Taniguchi (1999), both the bar-driven and interaction-driven fueling mechanisms also do not fit. The fraction of barred spiral galaxies is approximately 70 percent for normal and Seyfert galaxies. In other word, Seyfert galaxies do not show preference of barred spirals. As for the galaxy interaction, only 10 percent of Seyfert galaxies have their companion galaxies.

Accordingly, the minor-merger-driven fueling can remain as a possible unified triggering mechanism for Seyfert activity. Minor mergers have been often considered as a plausible triggering mechanism for nuclear starbursts (e.g., Mihos & Hernquist 1994; Taniguchi & Wada 1996). In particular, minor mergers with a nucleated satellite are expected to surely provide gas fueling very close toward a SMBH in nuclei of galaxies. Since their tidal disturbance is usually weak, it is often difficult to find evidence for minor mergers. However, the observed excess of ringed structures in Seyfert disks, and S0 or amorphous morphology of Seyfert hosts suggest past minor merger events in them. Another line of evidence for minor mergers is advocated by randomly-oriented narrow-line regions with respect to the host disks in Seyfert galaxies. Such properties are naturally explained by an idea that the orbital plane of a dusty torus should be the dynamically preferred plane governed by the orbital motion of a merging satellite galaxy. Although these are not convincing pieces of evidence, the minor-merger-driven fueling can be appreciated as a plausible unified mechanism for triggering AGN (Taniguchi 1999).

2.2. Triggering Quasars

Quasars are the most luminous class of AGNs whose luminosity exceeds $10^{12} L_\odot$. Although their origin has been mysterious for a long time, the discovery of ULIRGs led to the following formation mechanism; major mergers between two gas-rich galaxies could result in the formation of quasars through the phase of ultra luminous starbursts (Sanders et al. 1988). This idea is also reinforced by disturbed morphology of quasar host galaxies (Bahcall et al. 1995). Although some quasar hosts show undisturbed morphology like elliptical galaxies, they can also be interpreted as advanced mergers.

Important physical processes involved in the major-merger scenario are considered to be the growth of SMBHs. The mass of SMBHs in typical disk galaxies may range from 1 million to 10 million $M_\odot$. However, a typical mass of SMBHs in quasar nuclei ranges from 100 million to 1 billion $M_\odot$. Therefore, the growth of SMBHs could be helped by supply of a large number of compact objects as remnants of massive stars formed in ultra luminous starbursts (Taniguchi, Ikeuchi, & Shioya 1999).

Another concern is how many galaxies merged into one to make a quasar. At least, two gas-rich giant galaxies are necessary to possess a lot of cold molecular gas of $\sim 10^{10} M_\odot$ (Sanders et al. 1988). In the local universe, there are a number of compact galaxies whose merging time scale is of order of 1 billion years (Hickson 1982). They are also likely precursors of quasars via ULIRGs (Taniguchi & Shioya 1988).

In summary, one has the following scenario for the formation of quasars;

Step 1. A major merger between or among gas-rich galaxies.

Step 2. The formation of a ULIRG that helps the growth of a SMBH in the merger center.

Step 3. The formation of quasar after the ULIRG phase.

It should be noted that the major merger is the most important triggering mechanism for the quasar formation. In other word, we need any other triggering mechanisms here, providing the unified formation mechanism of quasars.

3. Possible Unified Models for Triggering AGNs: An Evolutionary Unified Model for the Starburst-AGN Connection

We have argued whether possible unified models can be available for the understanding triggering both Seyferts and quasars in the two previous sections. We have found that the minor-merger-driven fueling provides only one mechanism for triggering Seyferts while the major-merger one does that for triggering quasars. In other word, one can postulate that only mergers can trigger the AGN activity regardless of their AGN luminosity.

Here we remind for the case of quasars that the ultra luminous starburst phase comes first and then the quasar activity turns on in the final phase of merger evolution. We interpret this as that such starbursts are necessary to grow up a SMBH in a merger center (Taniguchi, Ikeuchi, & Shioya 1999). If this is also the case in triggering Seyferts, it is suggested that the so-called nuclear starburst phase comes first and then the Seyfert activity turns on. Since it is known that such nuclear starbursts are induced by minor mergers (e.g., Mihos & Hernquist 1994; Taniguchi & Wada 1996), the above suggestion seems to make sense.

Accordingly, one can have a merger-driven, evolutionary unified model from the starburst to the AGN. This model is illustrated in Fig. 3 (see also Taniguchi, Wada, & Murayama 1996).

4. Summary and Future Prospects

Our conclusions are summarized below;

1. Secular-evolution fueling in galactic disks **never works**.

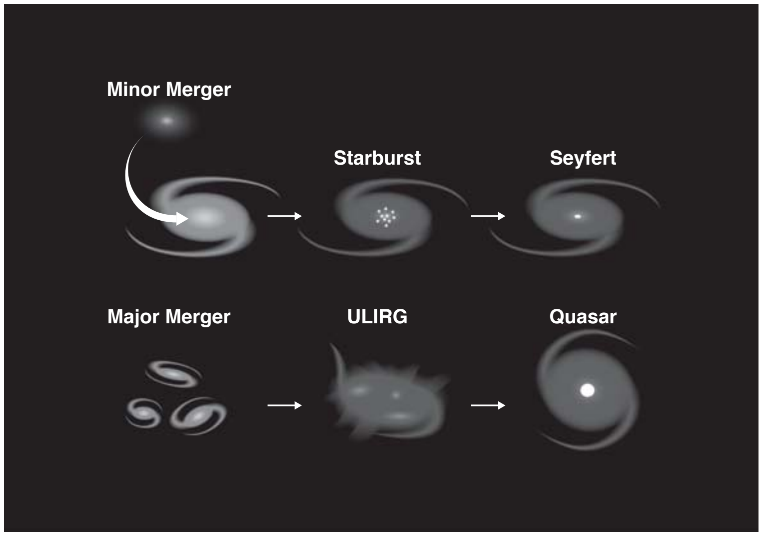

Figure 3. The merger-driven unified model for triggering AGNs. This figure is made by Ryoichi Saito.

2. Bar-driven fueling **never works**.
3. Minor-merger-driven fueling **works** for triggering Seyferts.
4. Galaxy-interaction-driven fueling **never works**.
5. Major-merger-driven fueling **works** for triggering quasars.

One may feel that the above conclusions are somewhat drastic ones. Actually, non-axisymmetric structure such as bars (e.g., Shlosman et al. 1989; Wada & Habe 1995) and non-axisymmetric perturbation such as galaxy interactions (e.g., Noguchi 1988) have been often considered as viable gas fueling mechanisms in AGNs. However, one serious physical difficulty in such fueling mechanisms is that it is generally difficult to reduce the angular momentum of disk gas (~ 1 - 10 kpc scale) toward the inner ~ 0.01 or 0.001 pc around a SMBH (e.g., Peterson 1997). This is the main reason why we discard both the secular-evolution and the bar-driven fueling mechanisms in the proposed unified model.

In order to avoid the angular momentum problem, we would like to note that minor mergers with a nucleated satellite are more preferable because the satellite nucleus surely can reach to the center of the host galaxy (Taniguchi & Wada 1996). Note also that Sanders et al.s scenario for the quasar formation postulates major mergers between tow nucleated galaxies.

In summary, the unified model for triggering both starbursts and AGNs means that any nuclear activities are due not to nature but to nurture. In other words, if a galaxy were isolated during the course of its evolution, it did not have a SMBH and thus never became to an AGN-hosting galaxy. Nuclear starbursts, too. All nuclear activities are driven by second events (minor and major mergers) in terms of the so-called hierarchical clustering model of our universe.

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