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A fresh look at the starburst-AGN connection

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Abstract. There is ever mounting evidence for a connection between the evolution of AGN and starburst-activity, as, for instance, suggested by a relation between the mass of the central black hole and the velocity dispersion of the bulge stars. However, the nature of this connection remains unclear, raising a number of questions, e. g.: Is the AGN triggered by the starburst or is the starburst activity caused by AGN? Which physical processes link starbursts and AGN? Here we will give a short review of crucial observations and theoretical work and describe our plans in that regard.

1. Introduction

Many galaxies show AGN and starburst activity at the same time as, e. g., revealed by the infrared astronomical satellite (IRAS) in 1984. This satellite discovered many luminous infrared galaxies (LIRGs, ULIRGs) whose luminosity is caused by dust-obscured starbursts and AGN driven by strong interacting merger systems as stated in e. g. Sanders et al. [1].

Furthermore, there exists an entire body of observations indicating a correlation, and thus, in all likelihood, a physical connection between these two phenomena. Some theoretical approaches have been undertaken as well, but as yet, however, it is not really clear how starbursts and AGN actually interact with each other, leaving a lot of open questions.

Understanding the starburst-AGN connection will yield a deeper understanding of the origin of starbursts and of AGN, in other words: the evolution of galaxies in general.

2. Observations

Numerous observations indicate a starburst-AGN connection, mostly through correlations between a starburst- and an AGN-related property. Examples are the relation between the black hole mass M_{BH} and the stellar velocity dispersion σ in the bulge, $M_{\text{BH}} \sim \sigma^4$ (e. g., Gebhardt et al. [2]) or a relation between M_{BH} and the bulge mass M_{bulge} (e. g., Kormendy and Richstone [3]).

Wild et al. [4] find a correlation between the time since the onset of a starburst and the accretion rate of the AGN's black hole with the accretion rate steeply rising about 250 Myr after the onset of the starburst. This strongly indicates that the starburst triggers the AGN. Additionally they find that galaxies with strong star formation in their bulges are more likely to host a massive black hole than galaxies with low star-forming activity.

According to Veilleux [5] there is also strong evidence for circumnuclear starbursts in local AGN, and many ULIRGs contain an AGN coexisting with a starburst.

But whether these correlations are based on a connection between starbursts and AGN is difficult to answer, the nature of these correlations remains unknown.

3. Theory

Simulating the starburst-AGN connection has proven to be very challenging, because here very different physical scales are involved. On the one hand, mergers which occur on length scales of about 100 kpc lead to gas inflows which feed starbursts and AGN, on the other hand the accretion of material onto black holes occurs on scales of the Schwarzschild radius. Therefore it is necessary to work with parameterizations. Such a numerical framework for investigating the starburst-AGN connection was developed by Springel et al. [6]. Here, the central black holes are modeled as collisionless sink particles, which grow by accreting gas from their environment. The accretion rate \dot{M}_{BH} of the AGN's central black hole with mass M_{BH} is estimated via a Bondi-Hoyle-Lyttleton parameterization, which is limited by the Eddington rate.

$$\dot{M}_{\text{BH}} = \min \left(\frac{4\pi\alpha G^2 M_{\text{BH}}^2 \rho}{(c_s^2 + v^2)^{3/2}}, \frac{4\pi G M_{\text{BH}} m_p}{\varepsilon_r \sigma_T c} \right)$$

Here ρ is the density and c_s the sound speed of the gas, respectively, v is the velocity of the black hole relative to the gas, m_p the proton mass, σ_T the Thomson cross-section, c the speed of light, ε_r the radiative efficiency, which is usually set to 0.1, and α a numerical parameter of order unity.

A feedback of the AGN is realized via a heating rate $\dot{E} = \varepsilon_f L$ that is proportional to the luminosity $L = \varepsilon_r \dot{M}_{\text{BH}} c^2$ of the AGN and therefore to the central black hole's accretion rate. It couples the accretion process thermodynamically to the surrounding gas. The feedback efficiency ε_f is usually set to 0.05. Star formation and stellar feedback are modeled by using a subresolution multiphase model for star-forming gas, see Springel and Hernquist [7] for details.

With this model Di Matteo et al. [8] simulated galaxy mergers and were able to reproduce the observed $M_{\text{BH}} - \sigma$ relation, here the feedback of the AGN quenches both, star formation and further black hole growth due to unbinding gas from the galaxy, leaving a dead elliptical galaxy and therefore explaining the short quasar lifetime.

Johansson et al. [9] used the same methods but varied mass ratios and used different progenitor morphologies finding that the timescales for star formation termination and for the mass growth of the black hole increase for unequal-mass disk mergers compared to equal-mass disk mergers. Furthermore for original galaxy mass ratios of at least 3:1 star formation is not quenched completely.

DeBuhr et al. [10] use a local viscous estimate to determine the accretion rate onto a black hole, AGN feedback is realized via depositing momentum into the surrounding gas, which is proportional to the luminosity of the AGN. This results in a self-regulated black hole accretion, but different to the results of Di Matteo et al. [8] the AGN feedback does not quench star formation because it shuts down the accretion onto the black hole before unbinding the gas of the interstellar medium.

Likewise in Kim et al. [11] AGN-feedback heats the surrounding interstellar medium and suppresses further star formation resulting in a self-regulated growth of the black hole.

4. Open questions

Some aspects of the starburst-AGN connection have been investigated yet, but many questions remain unanswered or need further investigations:

- Which mechanisms are at all capable of connecting starburst and AGN activities? (e. g. stellar winds, SN ejecta, AGN feedback: jets, heating)
- Do AGN trigger starbursts or vice versa, or are they triggered by external processes? (e. g. tidal interactions, mergers)
- Does this connection show a cosmological evolution?
- Do starbursts and AGN always occur together?
- Can and do they occur as independent processes?
- Are starbursts and AGN well synchronized (with or without a time lag)?
- Can a starburst quench further black hole growth?

5. Future work

To gain a deeper understanding of the starburst-AGN connection and to answer some of the questions raised above we will perform numerical simulations using the TreeSPH code Gadget-2 by Springel [12] with the routines implementing star formation and SN feedback developed by Xiang-Grüß [13].

For treating black hole growth and AGN feedback we will use more specific methods. For instance assuming that the mass flow onto the galaxy's center forms an accretion disk around the black hole we will solve the corresponding hydrodynamic equations with a grid code embedded into Gadget-2 to calculate the mass flow onto the black hole.

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