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Fueling QSOs: the relevance of mergers

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Abstract. To study the relevance of mergers for the fueling of QSOs, we are currently conducting an HST imaging campaign of a sample of QSO host galaxies classified as ellipticals in the literature. Here, we present results from a study of the first five QSO host galaxies imaged with HST/ACS. For the majority of objects, strong signs of interactions such as tidal tails, shells, and other fine structure are revealed. We estimate the nature and age of the merger by comparing the images with numerical simulations. The merger ages range between a few hundred Myr up to a Gyr. These timescales are comparable to starburst ages in the QSO hosts previously inferred from Keck spectroscopy, but longer than theoretical estimates of AGN duty cycles. A possible scenario emerging from our results is that most QSO host galaxies experienced mergers with accompanying starbursts but that the activity is triggered with a delay of several hundreds Myr after the merger. To probe whether there is indeed a causal connection between the merger and the QSO activity, we study a control sample of inactive ellipticals. Our preliminary results do not reveal comparable fine structure.

Key words. galaxies: active – galaxies: interactions — galaxies: evolution — quasars: general

1. Introduction

The ubiquity of supermassive black holes (BHs) in the center of galaxies shows that more than the mere presence of a massive BH is needed to trigger the activity observed in Active Galactic Nuclei (AGNs). Moreover, the steep evolution of activity with redshift indicates that the accretion onto the BH must have been more common in the earlier universe and thus also the triggering mechanism. Mergers have been suggested to induce the sudden inflow of gas to the center needed to feed the

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AGN (e.g. Toomre & Toomre 1972; Stockton 1982; Sanders et al. 1988).

A close connection between mergers and AGN activity has been found for ultra-luminous infra-red galaxies (ULIRGs). Observations of these galaxies are consistent with an evolutionary scheme in which (at least some) ULIRGs form through mergers of gas-rich galaxies and represent the initial dust-enshrouded stage in the evolution of optically selected QSOs (e.g. Sanders et al. 1988; Canalizo & Stockton 2001; Veilleux et al. 2006). Finally, the QSO hosts may end up as inactive elliptical galaxies.

However, a general connection between mergers and AGN activity is still being debated. While there is little doubt that mergers are helpful to provide the gas and remove angular momentum, they are certainly not sufficient, considering the numerous examples of inactive interacting galaxies. Also, mergers may be necessary for QSOs only. For their low-luminosity cousins, Seyfert galaxies, often residing in spiral host galaxies, there is little direct evidence for unusually high rates of interaction (e.g. Malkan, Gorjian, & Raymond 1998). Secular evolution through processes such as bar instabilities may be the dominant effect in the evolution of these galaxies (e.g. Combes 2006). But even for QSOs, the role of mergers for the activity remains unclear. Recent high-resolution imaging studies showed that many QSOs reside in elliptical hosts (e.g. Disney et al. 1995; Bahcall et al. 1997; Floyd et al. 2004). From HST/WFPC2 images of 33 AGNs (radio-loud QSOs, radio-quiet QSOs, and radio galaxies) at a redshift of $z \simeq 0.2$, Dunlop et al. (2003) concluded that "for nuclear luminosities $M_V <$ -23.5, the hosts of both radio-loud *and* radio-quiet AGN are virtually all massive elliptical galaxies with basic properties that are indistinguishable from those of quiescent, evolved, low-redshift ellipticals of comparable mass".

To study the relevance of mergers for the fueling of classical QSOs, we are currently conducting an HST imaging campaign of a sample of QSO host galaxies classified as ellipticals by Dunlop et al. (2003). Here we present results from a pilot study of five QSO host galaxies ($z \simeq 0.2$) using very deep (5 orbits) HST/ACS images (F606W).

2. Results and discussion

For four of the five QSOs, our images reveal dramatic signs of interactions such as tidal tails, shells, and other fine structure in the hosts (Figs. 1,2), suggesting that a large fraction of QSO host galaxies may have experienced a relatively recent merger event (Bennert et al. 2008).

One spectacular example of regular inner shell structure is MC2 1635+119 (Canalizo et al. 2007). In *N*-body simulations, the observed shells can be produced in a minor merger event. Assuming that the outermost shell is at 12.5 kpc (Fig. 2), we estimate a merger age of ~30-400 Myr, depending on the type of profile of the giant elliptical, its effective radius, and the amount of dark matter. Taking into account a larger tidal feature at 65 kpc (Fig. 2) that may be an older shell formed during the same encounter, the merger age can be up to 1.7 Gyr (Canalizo et al. 2007). However, while the inner shell structure can be produced by a radial minor merger, we cannot exclude other scenarios such as a major merger. Indeed, the total light contribution from the shells (~6%) and extended structures are more indicative of a major merger. In this case, the inner shell structure might have been formed by material "raining" back into the central regions of the merger remnant (Canalizo et al. 2007).

For all objects, deep Keck spectroscopy revealed major starburst episodes (~1-2 Gyr; Canalizo et al. 2006, 2007). These timescales are comparable to the merger ages, but significantly longer than theoretical estimates for QSO duty cycles (e.g. Yu & Tremaine 2002). Our results indicate that while most QSO host galaxies experienced mergers with accompanying starburst, there is a time delay of several hundred Myr between the tidal interaction and the actual fueling of the central BH. This is in agreement with recent hydrodynamic simulations (e.g. Springel, Di Matteo & Hernquist 2005; Hopkins et al. 2007).

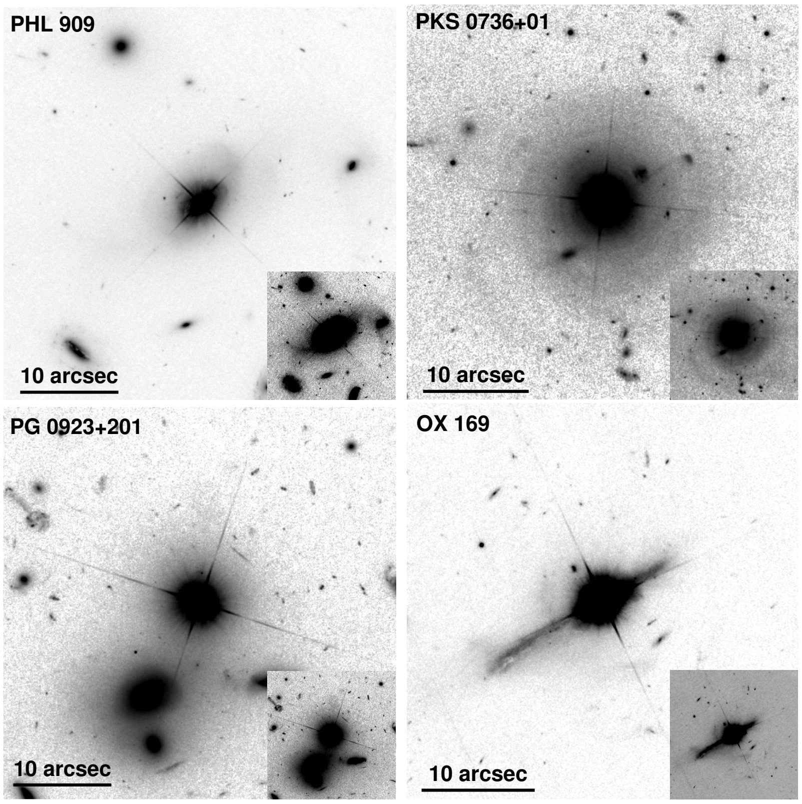

Fig. 1. Deep HST/ACS images of four of the five early-type QSO host galaxies (Bennert et al. 2008). North is up, east is to the left. **PHL 909** (*top left*): A ring-like structure is seen around the QSO nucleus. Diffuse outer material form another ring and tidal tails to both sides of the host. **PKS 0736+01** (*top right*): A large ($r \sim 50$ kpc) but faint spiral-like structure surrounds the QSO. The irregular structure and changes in pitch angle may indicate spatial wrapping of material from a (minor) merger event rather than a spiral disk seen face on. **PG 0923+201** (*bottom left*): No fine structure can be seen in the host galaxy, but it lies in an environment with several interacting companions. **OX 169** (*bottom right*): The extended linear structure is likely a tidal tail seen nearly edge on. Note the extended shell-like features east of the nucleus.

3. Outlook

The question remains whether the QSO host galaxies are truly distinct from inactive ellipticals or whether we can find similar fine structure hinting a recent merger event. To address this question, we selected a control sample of elliptical galaxies from the HST/ACS archive. So far, none of the ellipticals has shown the spectacular fine structure found in the QSO hosts, although some have apparent companions.

Also, we are currently studying 14 more QSO host galaxies imaged with HST/WFPC2. Preliminary results show evidence for mergers in at least some of these QSO hosts as well.

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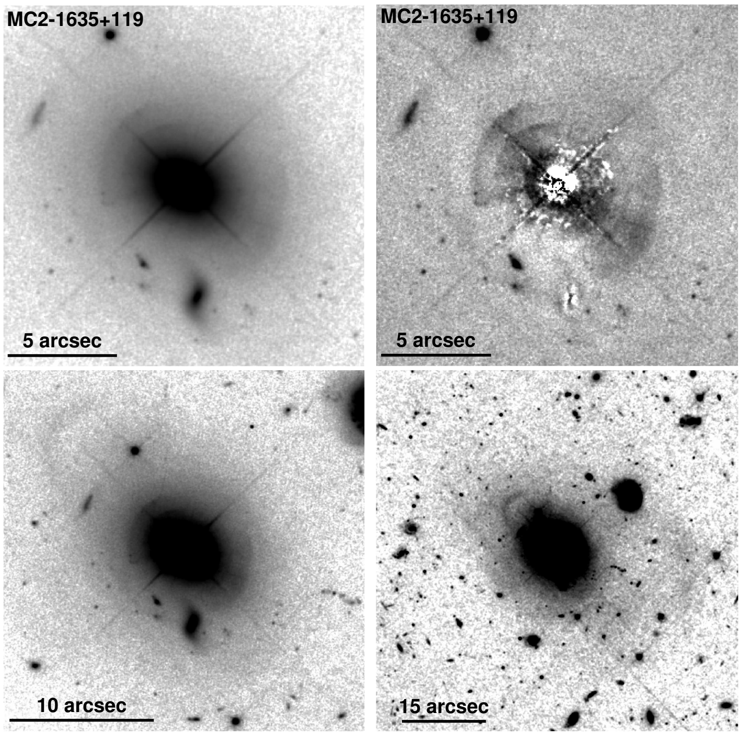

Fig. 2. The same as in Fig. 1 for MC2 1635+119 (Canalizo et al. 2007). Spectacular interleaved shells occur at $r \sim$ 5-12 kpc (*top left*). The shell structure is seen more prominently when subtracting a PSF+host galaxy model as fitted by GALFIT (Peng et al. 2002; *top right*). An arc-like feature extends out to $\sim$ 32 kpc (*bottom left*). An even larger, faint and diffuse structure can be seen $\sim$65 kpc west of the center (*bottom right*).

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