PROCEEDINGS OF SCIENCE

Properties of moderate luminosity mergers

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Interaction and merging are the two most important driving forces of galaxy evolution. In recent years, much research activity has been focused on ULIRGs, which are the result of a disk-disk merger, since they are among the most spectacular objects in the universe. However, ULIRGs are rare objects in the local universe. Thus, a study of a sample of merging galaxies of moderate FIR luminosity ($\sim 10^{10} - 10^{11} L_{\odot}$) may teach us as much as or even more about galaxy formation and evolution than investigations of the most extreme objects. Mergers having a moderate FIR luminosity can also be produced by merging two gas-rich galaxies with unequal mass or a spiral and an elliptical (S+E). Alternatively, they can be a result of a faded major merger. We have obtained multicolour optical and NIR imaging data, optical spectroscopy, HI and CO (i.e. molecular gas) data for a large part of a sample of moderate luminosity merger candidates. A cross section of the results will be presented, and some preliminary conclusions will be drawn. These include an assessment of the crucial question of the extent (and existence) of the starburst resulting from the merger – a dominating young stellar population and significant dust obscuration is indeed suggested for most of the sample galaxies.

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1. Introduction

Galaxy evolution is significantly influenced by interaction and merging. A merger between two large and gas-rich spirals often leads to a brief super starburst accompanied by the enormous far infrared luminosity ($L_{\rm FIR} > 10^{12} L_{\odot}$) of an Ultraluminous Infrared Galaxy (ULIRG). Since ULIRGs are among the most spectacular objects in the universe, much research activity has been focused on them in recent years. However, ULIRGs are rare objects in the local universe, with a space density comparable to quasars. Many mergers have much more moderate FIR luminosities of $L_{\rm FIR} \sim 10^{10} - 10^{11} L_{\odot}$. These objects may represent the overall more important process(es) in galaxy evolution. Despite their importance, such 'moderate luminosity' mergers are still poorly studied and not well understood. In principle, several scenarios could explain the lack of a very high amount of (ongoing) massive star formation in moderate luminosity mergers. The intense starburst phase may have been of brief duration and thus have passed while the optically visually perturbation of the galaxy still persists. Alternatively, there might never have been a strong starburst because the progenitor galaxies were gas-poor and not capable of feeding a strong burst. Indeed, smaller or less gas-rich (elliptical) galaxies dominate the galaxy population. Thus, so-called minor mergers between galaxies of unequal mass or a spiral and an elliptical may well be the origin of many moderate luminosity mergers. Finally, the initial conditions, e.g. the geometry of the collision or the mass distribution within the progenitor galaxies might have been unfavorable, so that the gas never became very centrally concentrated, even though the merger was 'major'.

One of the most essential questions concerning these objects is whether a starburst took place in the past and, if so, what its nature, most importantly its intensity and extent, was. There is very significant disagreement between numerical simulations. A key question is the degree of gas concentration that is reached in the merging process. A ULIRG is characterized by a very compact central gas distribution (a few 100 pc), feeding the super starburst. Weil & Hernquist ([1]) suggest a similarly strong central concentration of the gas in a minor merger, while calculations by Kojima & Noguchi ([2]) indicate a 'scattering' of gas on large scales, possibly not resulting in a starburst at all, since the gas will become too dispersed in the collision. Investigations of the young shell galaxy NGC 4194, which is a moderate lumimosity merger and minor merger candidate, indicate that both scenarios need modification, since a strong and efficient, but extended, burst is found together with evidence of scattering of the molecular gas ([3], [4]).

2. The sample and Observations

Clearly, understanding of the conditions and the development of moderate luminosity mergers requires the systematic multiwavelength 'dissection' of the stellar and gaseous content of a sample of candidate objects in different evolutionary stages. We have embarked on such a project to carry out a systematic analysis of a sample of moderate luminosity merger candidates. The galaxies have been selected from the RC3 catalogue by their classification as early-type objects with peculiar morphology and a radial velocity < 15000 km/s. The resulting candidates were checked with NED and DSS with respect to their environment and morphological appearance. We selected those galaxies where the merger has progressed far enough to show only one obvious nucleus, but an extended tidal structure has survived as an evidence of a merging process significant enough to disrupt the

progenitor galaxies. We excluded peculiar galaxies which are disturbed due to close companions or dense cluster environment, though our target objects are typically members of galaxy groups. Objects with a resolvable double nucleus or known AGNs were al so discarded. Finally, we also chose only galaxies with a FIR luminosity $< 10^{11}\,L_{\odot}$ to exclude ULIRGs which are of a different merger kind. That led to a sample of 16 galaxies.
For our study, we obtained already the main part of the multiwavelegth observation programme. Optical/NIR imaging were done with the NOT (La Palma, Spain), Siding Spring 2.3m (Australia) and Calar Alto 2.2m (Spain), NTT (ESO) and TCS (Tenerife, Spain), optical spectroscopy at Bok (Kitt Peak, USA). Since we are interested in the resolved HI structure, we used interferometers like the WSRT (Netherlands), ATCA (Australia) and the VLA (USA) for our radio observations. Additional CO single dish observations were carried out with the Onsala 20m telescope (Sweden) and IRAM 30m telescope (Spain). Further data from the archives, e.g. FIR observations will complete our multiwavelength study.

3. First results

Here, we present first images of our study. Fig. 1 shows two examples of deep R-band images (integration times $\sim$ 1 hour). Note the prominent tidal features like tails and shells. Although these galaxies looks very similar, spectra of the central regions of these galaxies are very different. Using PEGASE [5], preliminary fits of the star formation history show a young starburst in NGC 4194, whereas NGC 4441 is dominated by an older population, suggesting a burst $\sim$ 1 Gyr ago. This is in agreement with the brighter appearance of the shells in NGC 4441, which are probably more evolved than the shells of NGC 4194. Spectra of other sample galaxies feature differences, but all show signs of a starburst. Disturbations are not only visible in the stellar component, but also in the gaseous one. As an example, we show the large scale HI distribution of NGC 4441 in Fig. 2. Two tails to the north and south are present, following the alignment of the tidal features visible in the Optical. Most of the other galaxies observed in HI show a complex structure. CO is found in some of the observed galaxies, including NCG 4441 and NGC 4194. In fact for those two galaxies we detected an extended CO distribution out to a few kiloparsecs. In summary, we found hints that a similar optical morphology, which would imply occupying the same stage in the sence of a classical merger sequence ([6], [7]), alone is not sufficient enough to classify a merger, but it is neccessary to consider other properties like the gas content and star formation history.

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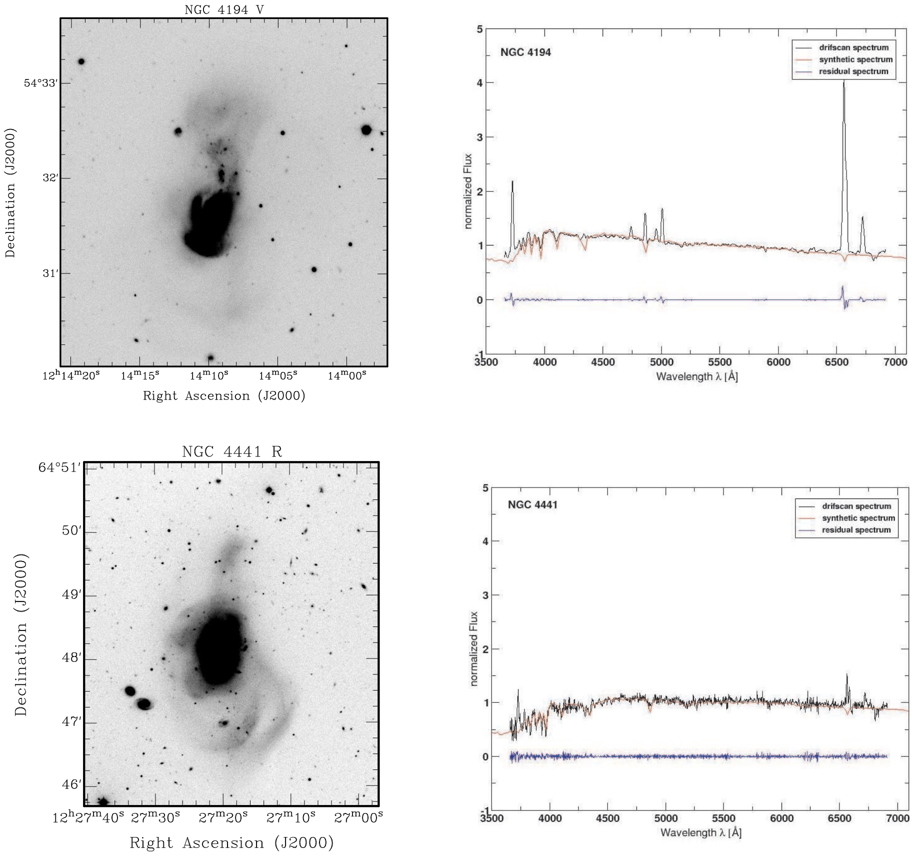

Figure 1: Two sample galaxies: top: NGC 4194, bottom: NGC 4441. Both show similar tidal structures like tails and shells (R-band images taken with the NOT and Calar Alto 2.2m, respectively). The spectra (Bok) however show very different dominating populations in these galaxies. Shown are the measured spectra (black), model spectra (grey) and the residua (dark-grey).

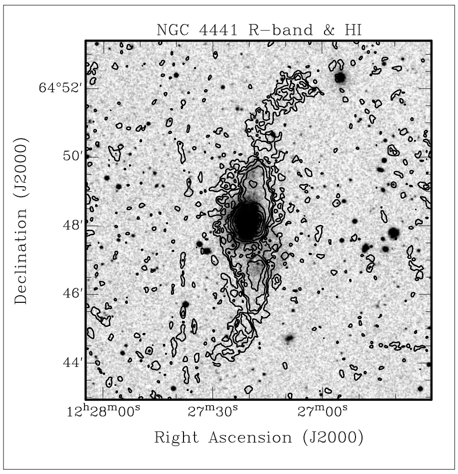

Figure 2: Large scale HI structure of NGC 4441 (WSRT) overlayed on an optical R-band image (Calar Alto 2.2m). The HI distribution follows mainly the optical structure, especially in the north where the HI tail corresponds to the optical tail, but the HI structure is much more extended.