Do mergers make (normal) ellipticals?

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Abstract.

Under the merger hypothesis, elliptical galaxies are built through mergers of gas-rich spirals. However, the relative paucity of HI in most normal ellipticals demands significant processing of atomic gas into other forms if this process is to be viable. Here I present a few qualitative remarks on how the properties of merger-spawned ellipticals might depend on the (evolving) gas content of the progenitor disks, then turn to a more quantitative study of the constraints provided by the nuclear properties of ellipticals and merger remnants.

1. Properties of Merger Remnants - Evolution or Prevolution?

Tests of the merger hypothesis have typically taken the form of a comparison between the properties of merger remnants and normal ellipticals. Such studies have pointed towards two possible discrepancies related to the hydrodynamic evolution (and subsequent aftereffects) of merging galaxies. First, X-ray observations have shown that the hot gas halos surrounding young merger remnants are quite modest – the $L_x/L_B$ ratios for remnants are more typical of those of spiral galaxies than of ellipticals (Read & Ponman 1998; Sansom et al 2000). Second, recent studies of globular cluster populations in mergers hint that young merger-spawned ellipticals may be deficient in globular clusters when compared to elliptical galaxies (Grillmair et al 1999; Brown et al 2000). Subsequent evolution of the remnants will bring these properties more in line with normal ellipticals: the fading of stellar populations will increase the globular cluster specific frequency, while mass loss from evolving stars may subsequently form a hot gaseous halo. However, the evolution must be significant and rapid to make these objects look like normal ellipticals in less than a Hubble time.

Here I argue that in addition to evolution, adding a bit of “prevolution” to the scenario may help explain these apparent discrepancies. Much of our understanding of the detailed evolution of merging galaxies comes from low redshift. Even dynamical simulations have largely focussed on models with merging progenitors similar to those of nearby disk galaxies. When we compare the models to nearby mergers such as the Antennae or NGC 7252, the comparison is well-founded. However, if normal ellipticals were made from mergers at higher redshift, the progenitors may have well been different from galaxies in the local universe. One of the simplest expectations is that mergers at higher redshift may have involved galaxies with a high gas fraction. As an example, in an $\Omega_M = 0.3, \Omega_\Lambda = 0.7$ cosmology, a spiral galaxy formed at $z_f = 3$ with an
exponentially decaying star formation rate with decay timescale $\tau = 5$ Gyr has a gas fraction of $f_g = 0.1$ at $z = 0$ and $f_g = 0.5$ at $z = 1$. The fact that the gas fraction of galaxies is changing with time may lead to systematic differences between the properties of merger-spawned ellipticals of different ages.

Ideally, we would be able to model the complete evolution of the gaseous phase of galaxies to ask how hot halos and young globular clusters form. Such a task has proved exceptionally difficult, due to a combination of physical and computational limitations. Qualitatively, however, it seems that the evolving gas fraction might explain both the low $S_N$ and low $L_x/L_b$ of morphologically young ellipticals. In both cases, if the “processing efficiency” (i.e., the fraction of gas processed into globular clusters or into hot gas through starburst winds or shock heating) is fixed, a falling gas fraction would necessarily result in the formation of low $S_N$, low $L_x/L_b$ over the course of cosmic history. Of course, subsequent evolution likely will move these quantities back towards those of “normal” (i.e., older) ellipticals, but there is no need to demand that they match those older ellipticals. In this sense, rather than being an indictment of the merger hypothesis, discrepancies between the properties of young merger-spawned ellipticals and older normal ellipticals may actually tell us about the effects of galaxy “prevolution” on the merging process.

2. The Central Parameter Relationship for Merger Remnants

Theoretical arguments indicate that it is in the nuclei of remnants where the merger hypothesis may face its most stringent test, as a wide variety of physical processes may act to shape their nuclei. Dynamical heating, gas dissipation and star formation, black holes (and black hole binaries), and low mass accretion can all act to alter the central densities of galaxies in different ways. Yet studies of elliptical galaxy nuclei reveal very well-behaved relationships between their nuclear and global properties. In particular, the so-called “central parameter relationship” shows that elliptical galaxies show a strong anticorrelation between their central densities and their total luminosities (Lauer et al 1995; Faber et al 1997 (F97)). It is a non-trivial question whether or not such a correlation is consistent with a scenario where mergers drive the formation of elliptical galaxies. For example, two of the most discrepant points on the central parameter relationship of F97 are NGC 1316, the central galaxy in the Fornax cluster and a clear merger remnant, and NGC 4486B, a close companion to M87 possessing a double nucleus. If merger remnants in general show marked deviations from the central parameter relationships, the status of the merger hypothesis as a mechanism for forming the majority of normal elliptical galaxies would be in serious doubt. As such, the robustness of the central parameter relationship may provide a strong test of the merger hypothesis.

We (van der Marel et al, in preparation) have used NICMOS to investigate the central parameter relationship in a sample of young ellipticals with significant tidal debris. Our sample is chosen morphologically from the Arp (1966), Vorontsov-Velyaminov (1977), and UV-bright Markarian (Mazzarella & Boroson 1993) catalogs. Our sample is chosen to have galaxies with tidal features indicative of a recent merger – tails, shells, plumes, or otherwise strongly distorted isophotes, and includes the well-known merger remnants NGC 7252 and NGC
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Figure 1. The central parameter relationship for normal elliptical galaxies (open circles; from Faber et al 1997), counter-rotating core galaxies (open triangles; from Carollo et al 1997), and our sample of morphologically peculiar ellipticals (filled circles; van der Marel et al, in preparation). The central luminosity densities for normal and counter-rotating core ellipticals have been converted to the infrared assuming $V - H = 3$, typical for elliptical galaxies (Peletier et al 1990; Silva & Bothun 1998).

3921. The sample is also restricted to $z < 10,000$ km/s, which translates to a spatial resolution of $\lesssim 25$ pc (for $H_0 = 80$) using the NIC1 camera.

Each system was imaged using the NIC2 camera using the F110W, F160W, and F205W filters, and again in F110W using the NIC1 camera for maximum resolution. The images were Lucy deconvolved using the appropriate PSF, after which azimuthal surface brightness profiles were extracted. The surface brightness profiles were then fit by a “nuke law” (Lauer et al 1995) and deprojected to obtain the three dimensional luminosity density. Figure 1 shows the H-band luminosity density at $r = 50$ pc for our sample, plotted as a function of galaxy luminosity. The majority of the objects in our sample lie on the same density-luminosity relationship defined by normal ellipticals. Three of the objects, however, show significantly higher central luminosity densities than would be expected from the normal elliptical density-luminosity relationship: NGC 34, NGC 3921, and NGC 7252. The scatter in central luminosity density in our sample is significantly larger than that seen in normal elliptical samples.

This large scatter is likely the result of a number of effects. First, our sample is morphologically diverse, comprised of galaxies which have suffered a variety of interactions. It is interesting that the three galaxies which show the central luminosity excess have the most prominent tidal debris, suggesting that major mergers are the most likely to affect the central luminosity density of galaxies. However, there is no one-to-one correlation between tidal morphology and nuclear properties: a fourth object in our sample, NGC 7727, also possess a long, prominent tidal tail, yet shows no excess nuclear light. A second effect also likely plays a major role: that of merger age. Their blue nuclear colors suggests that the high luminosity densities observed in NGC 34, 3921 and 7252 are probably a direct consequence of recent star formation triggered by a merger. Stellar populations fade with time, and these galaxies will therefore evolve towards the locus...
of normal elliptical galaxies as time passes. Tidal debris becomes less prominent with age as well, as the tidal tails expand away or fall back and mix into the remnant (Mihos 1995; Hibbard & Mihos 1995). Unfortunately, it is very difficult to disentangle the effects age and encounter type; both effects are almost certainly at work in our morphologically selected sample.

At face value, the large scatter in the nuclear properties of our sample of merge remnants might seem a blow against the merger hypothesis for the formation of ellipticals. However, the morphological selection criteria biases us towards specific types of mergers: major, prograde encounters, which are the most effective at triggering strong nuclear inflows. Mergers in general will sample a wider range of encounter parameters which may not be as efficient at altering the nuclear properties. Furthermore, as noted above, evolution of the stellar populations will likely drive the discrepant objects to lower luminosity and central luminosity density, moving them back towards the mean relationship with time. But this evolution is slow; it will take several Gyr for the starburst population to fade sufficiently. An object like NGC 7727, whose prominent tidal debris argues for a young age, cannot have started with a central luminosity spike as strong as that observed in NGC 3921 and have evolved so quickly onto the central parameter relationship.

Peculiar ellipticals with strong central density spikes may be the natural evolutionary outcome of the ultraluminous IRAS galaxies. These luminous merger induced starbursts possess very strong central concentrations of gas, and if that gas is converted efficiently into stars the resulting central density will be quite high (Hibbard & Yun 1999). Because it can take a Hubble time to evolve back onto the central parameter relationship, our results suggest either that most ellipticals do not go through this ultraluminous central starburst phase, or that the merger ages of most ellipticals must be very large. Our results are inconsistent with the notion that ULIRGs at moderate redshifts formed a significant fraction of the local elliptical galaxy population.

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