The Impact of Stellar Populations on the Dynamics of Merger Remnants

B. Rothberg, J. Fischer

Naval Research Laboratory, Remote Sensing Division, Code 7211, 4555 Overlook Ave SW, Washington D.C. 20375

Abstract. Many studies and simulations suggest gas-rich mergers do not contribute significantly to the overall star-formation rate and total mass function of galaxies. The velocity dispersions ($\sigma$) of Luminous & Ultraluminous Infrared Galaxies measured using the 1.62 or 2.29$\mu$m CO bandheads imply they will form $m < m^*$ ellipticals. Yet, $\sigma$’s obtained with the Calcium II triplet (CaT) at 0.85$\mu$m suggest all types of mergers will form $m > m^*$ ellipticals. Presented here are recent results, based on high-resolution imaging and multi-wavelength spectroscopy, which demonstrate the dominance of a nuclear disk of Red Supergiants (RSG) or Asymptotic Giant Branch (AGB) stars in the near-infrared bands, where dust obscuration does not sufficiently block their signatures. The presence of these stars severely biases the dynamical mass. At $I$-band, where dust can sufficiently block RSG or AGB stars, LIRGs populate the Fundamental Plane over a large dynamic range and are virtually indistinguishable from elliptical galaxies.

1 Introduction

The “Toomre Hypothesis” ([Toomre & Toomre 1972; Toomre 1977]), proposes that the merger of two-gas rich spiral galaxies will form an elliptical galaxy, often with a final stellar mass larger than the sum of the progenitors. In the local universe, Luminous and Ultraluminous Infrared Galaxies are ideal candidates for forming massive elliptical galaxies ([Kormendy & Sanders 1992]). These are objects with $L_{IR} > 10^{11} L_{\odot}$ between 8-1000 $\mu$m ([Sanders & Mirabel 1996]), contain vast quantities of molecular gas, and show strong evidence of recent or ongoing merging activity. Radio recombination line observations of the nearest ULIRG Arp 220 imply a formation rate of $10^3 M_{\odot}$ yr$^{-1}$ ([Anantharamaiah et al 2000]), while CO interferometric data indicate that 0.15-0.46 of the dynamical mass of this system is gaseous ([Downes & Solomon 1998; Greve et al 2009]). The star-formation rates and vast quantities of gas in LIRGs/ULIRGs could add a significant stellar component to the total mass of the merger.

However, a number of studies, all using infrared CO bandheads to measure central velocity dispersions ($\sigma_0$), have shown that LIRGs have masses consistent with low-moderate luminosity elliptical galaxies ($L \sim 0.03-0.15 L^*$) ([Shier & Fischer 1998]) and ULIRGs have masses consistent with $L \leq L^*$ (e.g. [Genzel et al 2001]). These results have raised significant doubts as to whether gas-rich mergers contribute significantly to the formation of elliptical galaxies.

Yet, $\sigma_0$ measured from the Calcium II Triplet absorption lines (CaT), suggest gas-rich mergers, including LIRGs, have masses which span nearly the en-
tire mass range of elliptical galaxies (Lake & Dressler 1986; Rothberg & Joseph 2006) (hereafter RJ06). This difference in \( \sigma \), or \( \sigma \)-mismatch, is counter-intuitive. Namely, that LIRGs/ULIRGs, which are undergoing intense star-formation and possess large quantities of dust, should show smaller \( \sigma \) at longer wavelengths. The use of infrared stellar lines to measure \( \sigma \) was initially motivated by the need to pierce the veil of extinction in starburst galaxies and measure their “true” dynamical masses. However, the results presented here show that IR-luminous mergers are Janus-like, that is, they reveal two different dynamical faces depending on the wavelength observed. The obscuring characteristics of dust in the optical in IR-luminous galaxies behaves in a manner beneficial for determining the true mass of merger remnants.

2 Sample Selection & Observations

The dynamical properties of a sample of 14 advanced (single-nuclei) merger remnants are compared with a sample of 23 elliptical galaxies. The merger remnants are a subsample of the 51 merger remnants discussed in detail in Rothberg & Joseph (2004) (hereafter RJ04). The photometric data for the merger remnants include \( F814W \) (\( \sim \) I-band) imaging from the Wide-Field Planetary Camera 2 (WFPC2) or the Advanced Camera for Surveys Wide-field Camera (ACS/WFC) on HST and K-band imaging from Quick Infrared Camera (QUIRC) on the University of Hawaii 2.2m telescope. The kinematic data for the merger remnants include CaT observations from ESI on Keck-2, and CO observations from either NIRSPEC on Keck-2 or GNIRS on Gemini South (Program GS-2007A-Q-17, P.I. Rothberg). Additional kinematic and photometric data were obtained from the literature for several merger remnants and the comparison sample of ellipticals.

3 The Fundamental Plane and Stellar Populations

A similar \( \sigma \)-mismatch was reported for a sample of 25 nearby early-type (predominantly S0) galaxies by Silge & Gebhardt (2003). They also found that \( \sigma_{\text{optical}} > \sigma_{\text{CO}} \), and suggested that the kinematics of the cold stellar component in S0 galaxies was obscured by dust, and detectable only in the IR while the kinematics of the hot spheroid dominated optical wavelengths. However, it remained unclear whether bona fide ellipticals produced the same discrepancy. As noted in Rothberg (2009), no discernible difference between \( \sigma_{\text{optical}} \) and \( \sigma_{\text{CO}} \) was found for the comparison sample of 23 elliptical galaxies. On the other hand, LIRGs showed a large discrepancy, as first noted in RJ06. The Fundamental Plane (FP) is a two-dimensional plane embedded in the three-dimensional parameter space of \( \sigma \), the half-light (effective) radius (\( R_{\text{eff}} \)), and the surface brightness within the effective radius (\( \mu_{\text{eff}} \)). All elliptical galaxies lie on the Fundamental Plane. The LIRG/ULIRG studies noted earlier found that while these mergers were overly luminous in the infrared, they would eventually evolve onto the FP, but the small \( \sigma_{\text{CO}} \) meant they could not be the progenitors of ellipticals with \( L > L^* \). RJ06, however, found that the observed range of \( \sigma_{\text{CaT}} \) meant that gas-rich mergers could populate nearly all of the mass-range of ellipticals, including \( L > L^* \). Figure 1 is a two panel figure which shows the I-band
The Impact of Stellar Populations on the Dynamics of Merger Remnants

Figure 1. Shown are the $I$-band (left) and $K$-band (right) Fundamental Planes from Scodeggio et al. (1997) and Pahre et al. (1998) respectively. Overplotted in both panels are LIRG merger remnants (open circles), non-LIRG merger remnants (filled circles) and elliptical galaxies (open diamonds). All 6 LIRGs, 20/23 ellipticals, and 3/8 non-LIRG merger remnants are overplotted on the $I$-band FP.

and $K$-band FPs, with LIRG merger remnants (open circles), non-LIRG merger remnants (filled circles) and ellipticals (open diamonds).

As expected, the ellipticals show little difference between the $I$ and $K$-band FPs. The difference in the location of (primarily) the LIRGs in the $I$-band and $K$-band is striking. Figure 1 explains the apparent contradictory results between earlier LIRG/ULIRG studies, which used “pure” $H$ or $K$-band FPs and those from RJ06, which used a “hybrid” FP (CaT $\sigma_0$ and $K$-band photometry). In the $I$-band, the dynamical properties of LIRGs are indistinguishable from ellipticals. Figure 2 shows a comparison between the $M_{\text{dyn}}/L$ and $M_{\text{dyn}}$ in the $I$-band (left) and $K$-band (right) for the merger remnants and elliptical galaxies (same symbols as Figure 1). Overplotted is the evolution of $M/L$ over time for a burst population from Maraston (2005) (hereafter M05). Figure 2 shows that in the $I$-band, the measured dynamical masses and stellar ages of the LIRGs are nearly the same as elliptical galaxies. However, the $K$-band measurements imply LIRGs have smaller $M_{\text{dyn}}$ and young ages.

The $K$-band is dominated by the presence of young stars. Numerical simulations have long predicted that gaseous dissipation in the merging event funnels the gas into the barycenter of the merger (e.g. Barnes & Hernquist (1991); Barnes (2002)). This forms a rotating gaseous disk in the central 1-2 kpc of the merger, which then undergoes a strong starburst, forming a rotating disk of young stars. One observational signature of this starburst is the presence of “excess light” in the surface brightness profiles of mergers (e.g. Mihos & Hernquist (1994)), first detected in the $K$-band by RJ04. The $\sigma$-mismatch detected in IR-luminous galaxies is another observational signature of these rotating central starbursts. Dust associated with these nuclear starbursts blocks most of their
light at $\lambda < 1\mu m$, while allowing the random motions of the nearly virialized older stars to dominate the $\sigma$ measurement at $I$-band. This functions in a similar manner to an occulting mask in a coronograph. At $H$ and $K$-band, the RSG and AGB stars can account for 60-90% of the light (M05), therefore the disk kinematics overpowers the $\sigma_{\text{CO}}$ measurement.

![Figure 2](image_url)  

Figure 2. Two panel figure showing pure $I$-band (left) and pure $K$-band (right) $M/L$ vs. $M_{\text{dyn}}$. The overplotted vector (solid line) in each panel is the evolution of $M/L$ for a single-burst stellar population with solar metallicity and a Salpeter IMF as computed from Maraston (2005). The dotted vertical line in each panel indicates $m^*$.  

References

Anantharamaiah, K. R., Viallefond, F., Mohan, N. R., Goss, W. M., & Zhao, J. H. 2000, ApJ, 537, 613
Barnes, J. E. & Hernquist, L. E. 1991, ApJ, 370, L65
Barnes, J. E. 2002, MNRAS, 333, 481
Downes, D. & Solomon, P. M. 1998, ApJ, 507, 615
Genzel, R., Tacconi, L. J., Rigopoulou, D., Lutz, D., & Tecza, M. 2001, ApJ, 563, 527
Greve, T. R., Papadopoulos, P. P., Gao, Y., & Radford, S. J. E. 2009, ApJ, 692, 1432
Kormendy, J. & Sanders, D. B. 1992, ApJ, 390, L53
Lake, G. & Dressler, A. 1986, ApJ, 310, 605
Maraston, C. 2005, MNRAS, 362, 799 (M05)
Mihos, J. C. & Hernquist, L. 1994, ApJ, 437, L47
Pahre, M. A., Djorgovski, S. G., & de Carvalho, R. R. 1998b, AJ, 116, 1591
Rothberg, B. & Joseph, R. D. 2004, AJ, 128, 2098 (RJ04)
—. 2006, AJ, 131, 185 (RJ06)
Rothberg, B. 2009, in Galaxy Evolution: Emerging Insights and Future Challenges
Sanders, D. B. & Mirabel, I. F. 1996, ARA&A, 34, 749
Scod dei gio, M., Giovanelli, R., & Haynes, M. P. 1997, AJ, 113, 101
Shier, L. M. & Fischer, J. 1998, ApJ, 497, 163
Silge, J. D. & Gebhardt, K. 2003, AJ, 125, 2809
Toomre, A. 1977, in Evolution of Galaxies and Stellar Populations, p. 401
Toomre, A. & Toomre, J. 1972, ApJ, 178, 623