Probing the Physics of Interacting Galaxies

Harriet Cullen and Paul Alexander

Astrophysics Group, Cambridge University, UK

Marcel Clemens

Dipartimento di Astronomia, Universita degli Studi di Padova, Italy

Abstract. The morphological and velocity structures in the gaseous (Hi and CO) and stellar components of two interacting systems are examined. Both Arp 140 and Arp 104 reveal extended tidal tails in the Hi. The Hα and FIR fluxes of Arp 140 yield similar SFR of $\sim 0.8 \, M_\odot \, yr^{-1}$. In contrast the Hα flux of Arp 104 yields a SFR of $\sim 0.05 \, M_\odot \, yr^{-1}$, $\sim 20$ times smaller than that obtained from the FIR flux. Spectra were used to examine the changing velocity of atomic and molecular gas in NGC 5218 (Arp 104). The atomic and molecular gas were found to be dynamically similar with comparable velocities and velocity widths across the galaxy; consistent with the two phases responding similarly to the interaction, or enhanced Hi to CO conversion in the centre of the galaxy.

Keywords: Hi, Interactions, Galaxy Dynamics

1. Introduction

A sample of galaxies consisting of one late and one early-type galaxy is used to examine the effects of galaxy interaction on the ISM. The sample has been selected to represent a range of stages of interaction. Selection of systems in which only one galaxy is gas rich simplifies the modelling and interpretation. A combined observational modelling strategy is used, using morphological and velocity structures observed in gaseous (Hi and CO) and stellar components to constrain the dynamics of these systems. Here we present preliminary results for two systems; Arp 140 (NGC 274/275) and Arp 104 (NGC 5216/5218).

2. Arp 140

Arp 140 consists of two interacting galaxies; NGC 274 (SAB(r)0–pec) and NGC 275 (SB(rs)cd pec). At an assumed distance of 26.9 Mpc, the projected major axis diameter corresponding to $D_{25}$ is 11.7 kpc (1.5′) for both NGC 274 and NGC 275 and the projected separation of their centres is approximately 6.6 kpc (50″).

We detect a large-scale distribution of Hi around Arp 140 (Figure 1a). The total measured Hi flux is 30.5 Jy km s$^{-1}$, corresponding to a
mass of $5.1 \times 10^9 \, M_\odot$. An extended H$_\text{i}$ tail reaches approximately $\sim 4'$ south of the optical galaxies and $\sim 2.5'$ north, inconsistent with a direct collision between the two galaxies. Over the area of optical emission of NGC 275, the line of sight velocity increases relatively uniformly from $\sim 1700 \, \text{km s}^{-1}$ on the south eastern side to $\sim 1875 \, \text{km s}^{-1}$ in the north west, consistent with gas dynamically bound to the galaxy.

? (?) observed an integrated global H$\alpha$ luminosity of $9.54 \times 10^{40} \, \text{erg s}^{-1}$ which corresponds to a SFR of $\sim 0.75 \, M_\odot \, \text{yr}^{-1}$ (SFR(H$\alpha$)/$M_\odot \, \text{yr}^{-1} = 7.9 \times 10^{-42} L_{\text{H}\alpha}/\text{erg s}^{-1}$; ?, ?). At this star formation rate the timescale for consumption of all gas associated with the galaxy is $\sim 7 \, \text{Gyr}$.

A calculation of the star formation rate based on the far-infrared continuum yields a similar value of $\sim 0.8 M_\odot \, \text{yr}^{-1}$, (SFR(FIR)/$M_\odot \, \text{yr}^{-1} = 4.5 \times 10^{-44} L_{\text{FIR}}/\text{erg s}^{-1}$; ?, ?) where the FIR luminosity is given by $L_{\text{FIR}} \sim 1.7 \times L_{60}$ (?).

Figure 1. (a), left, contours of $\Sigma_{\text{H}I}$ VLA C array data ($\theta_{\text{FWHM}} = 23.01'' \times 15.96''$) for Arp 140. Contour levels correspond to (0.03, 0.09, 0.15, 0.21, 0.27, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6) Jy beam$^{-1} \times \text{km s}^{-1}$. (b), right, contours of $\Sigma_{\text{H}I}$ VLA D array data ($\theta_{\text{FWHM}} = 87.79'' \times 82.87''$) for Arp 104. Contour levels correspond to (0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1) Jy beam$^{-1} \times \text{km s}^{-1}$

3. Arp 104

Arp 104 consists of two interacting galaxies; NGC 5216 E0 pec (angular size of NGC 5216 is $2.5' \times 1.5'$), and NGC 5218 SB(s)b? pec (angular size $1.8' \times 1.3'$). At an assumed distance of $44.3 \, \text{Mpc}$, the projected major axis diameter corresponding to $D_{25}$ for NGC 5216 is $32.2 \, \text{kpc}$ ($2.5'$) and $23.2 \, \text{kpc}$ for NGC 5218 ($1.8'$) and the projected separation of their centres is $52.9 \, \text{kpc}$. 
The measured HI flux is $17.1 \, \text{Jy km s}^{-1}$, corresponding to a mass of $7.8 \times 10^9 \, \text{M}_\odot$. The northern spiral galaxy appears disrupted with possible bar formation. It has a tidal plume extending to the north and a bridge to the south. The southern galaxy is an elliptical with a small tail in the south west. These optical features are all reproduced in the low resolution HI map of the Arp 104 system (Figure 1b). A large tidal plume extends to the north east of NGC 5218 approximately 2 arcmin in length (26 kpc). Similarly, a bridge extends from the spiral to elliptical component, with an increase in column density of the HI centred on the small tidal tail extending to the south west of the elliptical.

? (?) have conducted a multicolour photometric study of the tidal features of interacting galaxies which included Arp 104. They found the colours of all the tidal features to be bluer than those of the central regions of either galaxy, but similar to the colours of the outer disk of the spiral component. Given the smooth appearance of the tidal features they propose a scenario in which material is being removed from the disk of NGC 5218.

? (?) observed an H$\alpha$ luminosity of $6.0 \times 10^{39} \, \text{erg s}^{-1}$ giving a SFR of $\sim 0.05 \, \text{M}_\odot \, \text{yr}^{-1}$ (Kennicutt et al 1994) and a timescale for consumption of all gas associated with the galaxy of $\sim 170 \, \text{Gyr}$. However, a calculation of the star formation rate based on the far infrared continuum yields a much larger star formation rate of $\sim 1.2 \, \text{M}_\odot \, \text{yr}^{-1}$ which would reduce the timescale for gas consumption to $\sim 7 \, \text{Gyr}$. The difference in star formation rates can be reconciled if there is $\sim 3.5$ magnitude of extinction towards the star forming regions.

3.1. Velocity Structure of HI and $^{12}\text{CO}(J = 2 \rightarrow 1)$ in Arp 104

HI data from the VLA and $^{12}\text{CO}(J = 2 \rightarrow 1)$ data from the JCMT have been used to determine spectra of the two gas phases at 10 arcsec intervals over a $50'' \times 90''$ area, centred on NGC 5218, the spiral component of the interacting pair. The data are fully sampled with matched spatial and velocity resolution.

We use these data to examine the changing velocity of the atomic and molecular gas through the galaxy: velocities of each component are plotted against radial distance from the galaxy centre in Figure 2. Comparison of the velocity fields is complicated by two factors, (1) there is evidence that the HI becomes optically thick with flat spectra making location of a peak velocity difficult and (2) much of the HI appears in absorption over the region where there is strong CO emission. Considering only those locations in which reliable velocities for both phases are obtained there is good evidence that the atomic
and molecular gas are dynamically similar; the velocities and velocity widths of the two gas phases being comparable across the galaxy. This is consistent with the atomic and molecular gas phases having responded similarly to the interaction, or with an enhanced HI to CO conversion at the centre of the galaxy.

Figure 2. Plot showing the line of site velocity of the atomic and molecular phases of NGC 5218 against the distance in kiloparsecs from the centre of the optical galaxy for two cuts through the galaxy

Acknowledgements

The VLA is operated by the NRAO for AUI. The DPSS was funded by the National Geographic society and produced by the Space Telescope Science Institute from plates taken with the Oschin Schmidt Telescope. This is operated jointly by the California Institute of Technology and the Palomar Observatory. The JCMT is operated by The JAC on behalf of the PPARC on behalf of the UK, the Netherlands Organisation for Scientific Research, and the National Research Council of Canada.