The Environment of X-Ray Binaries in the Dwarf Starburst Galaxy NGC 1569

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Abstract. We use deep, $J$ and $K_s$ observations of NGC 1569 acquired with FLAMINGOS on the KPNO 4-m to search for star cluster counterparts to X-ray binaries identified in archived Chandra images of this dwarf starburst galaxy. Performing near-IR photometry on the star cluster counterparts, we determine their colors, luminosities and masses. Comparing these results to the properties for all clusters in this galaxy, we search for trends in clusters associated with X-ray sources. Combining this study with FISICA, near-IR spectral observations, we further characterize the surroundings to X-ray binaries in NGC 1569. Contrasting this work with findings from a similar study performed on the Antennae galaxies, a large, merging system, we investigate the differences in X-ray binary environments.

1. Introduction

NGC 1569 is a dwarf, starburst galaxy vastly different from the large, merging system of the Antennae. It contains two super star clusters (SSCs) (Arp & Sandage 1985) and 16 X-ray sources, which range in luminosity from $L_X = \sim 5 \times 10^{33} - 3 \times 10^{36}$ erg s$^{-1}$ (Martin, Kobulnicky, & Heckman 2002). At a distance of 2.2 Mpc (Israel 1988), it is closer than the Antennae at 19.3 Mpc (for $H_0=75$ km s$^{-1}$ Mpc$^{-1}$), allowing us to probe star cluster masses down to $\sim 1000$ M$_\odot$.

2. Observations and Data Analysis

On January 17–19, 2005, we acquired IR observations of NGC 1569 using FLAMINGOS on the KPNO 4-meter telescope. FLAMINGOS has a field-of-view (FOV) of $10' \times 10'$ with a plate scale of 0.32". The exposure time was $\sim 2$ hours in $J$ and $\sim 1$ hour in $K_s$, with typical seeing of $\sim 1.2"$ in both filters.

We produced calibrated images using the pipeline, the Florida Astronomy Tool Born Of Yearning for high scientific quality data (FATBOY). FATBOY was developed by C. Warner, A. H. Gonzalez, S.S. Eikenberry, and other members of the FLAMINGOS-2 team. This software calibrates each image using flat fields and dark frames, and corrects for cosmic rays, bad pixels, and image distortion.

Selecting seven sources in common between the IR and Chandra X-ray images (Martin, Kobulnicky, & Heckman 2002), we produced a relative astrometric frame tie with a rms
Figure 1. $K_s$ image of NGC 1569, highlighting IR counterparts to X-ray sources. Red circles are “strong” counterparts and “yellow” circles are possible counterparts. The field-of-view is $\sim 2.5' \times 2.5'$. Ellipse encompasses those sources that are most likely clusters in NGC 1569 and that were selected for the photometric study of IR counterparts.

positional uncertainty of $0.2''$. Confining our counterpart search to the 16 X-ray sources within an elliptical region centered on the galaxy (see Figure 1), we found seven counterparts within $0.6''$ ($3\sigma$) of an IR cluster. An estimate of the IR source density suggests three counterparts are false matches to unrelated objects.

3. Results and Discussion

We restricted photometry to an elliptical region centered on NGC 1569 (see Figure 1), where we are confident most sources are star clusters. We performed $J$- and $K_s$-band aperture photometry on 462 sources within this region using a self-written IDL program. We used a photometric aperture with a 4.4-pixel radius in each band, corresponding to $\sim 3\sigma$ of the Gaussian PSF. We then calibrated our photometry using a bright 2MASS star.

After performing photometry, we produced a $(J - K_s)$ versus $K_s$ color magnitude diagram. Defining a magnitude cutoff using the signal-to-noise ratio (SNR), we selected those sources with SNR >10 to use in further analysis. Comparing star clusters associated with X-rays sources to all clusters reveals a uniform spread in $K_s$ magnitude. Furthermore, there is no significant trend in cluster color. Applying the reddening estimates for NGC 1569 presented in Relaño et al. (2006) to $K_s$ magnitudes, we computed $K_s$ luminosities, $M_{K_s}$, for all IR clusters. We found no trend in $K_s$ luminosity for those clusters associated with X-ray sources compared to the general cluster population. This differs from the Antennae, where we observed that X-ray associated clusters are more luminous (Clark et al. 2007).

We explored the relationship between the number of X-ray sources and cluster mass by defining the following relationship:

$$
\eta(M_c) = \frac{N_X(M_c)}{N_{Cl}(M_c) \cdot M_c},
$$

where $N_X(M_c)$ is the number of detected X-ray sources with an IR cluster counterpart, $N_{Cl}(M_c)$ is the number of detected clusters, and $\eta(M_c)$ is the fraction of X-ray sources per unit mass, all as a function of cluster mass, $M_c$. We first estimated cluster mass using $K_s$
flux. Selecting a bin size of $F_{K_s} = 1.5 \times 10^4$ DN (data numbers), we produced a plot of four $\eta$ values. The plotted points showed no significant slope, indicating no increased number of X-ray sources in more massive clusters. Using Bruzual-Charlot (Bruzual & Charlot 2003) spectral evolutionary models, we converted $\eta$ into units of solar mass. Accounting for the wide range in cluster ages (4 Myr–10 Gyr; Anders et al. 2004), we assumed a uniform distribution in ages and computed 10,000 realizations of $\eta$. We found a mean value of $\eta = 3.3 \times 10^{-6} M_\odot^{-1}$. Cluster evolutionary models presented in Sepinsky et al. (2005) predict $\eta = 9.6 \times 10^{-6} – 11.4 \times 10^{-6} M_\odot^{-1}$, which is within a factor of three of our results.

Figure 2. Reconstructed FISICA image using [He I] (blue), Pa$\beta$ (red), and continuum (green). The diffuse emission surrounding the SSCs is predominantly [He I] emission.

4. FISICA Observations

We supplemented our results using spectral observations taken with the Florida Image Slicer for Infrared Cosmology and Astrophysics (FISICA). This integral field unit (IFU) works in conjunction with FLAMINGOS on the KPNO 4-m telescope. FISICA uses mirrors to slice a 16″×32″ field into 22 strips, arranges the strips in a line and sends this through the FLAMINGOS spectrograph. Using FISICA, we acquired a $JH$ spectrum of the central regions of this galaxy, encompassing the two SSCs. Selecting individual wavelengths, we could recombine the slices using software to produce “narrow-band” images of the FOV. Choosing the prominent emission lines, [He I] (1.083 $\mu$m) and Pa$\beta$ (1.282 $\mu$m), plus continuum, we produced narrow-band images for each. Combining these images, we made a false color image of the central regions of NGC 1569 (see Figure 2). Notice the abundant amount of [He I] emission, a signature of massive stars, in and near the SSCs.

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References