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Internal Kinematics of Disk Galaxies in Cluster CL0024+1654 at $z = 0.4$

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Abstract

We present a determination of the Tully-Fisher relation (TFR) for distant galaxy cluster CL0024+1654 at z=0.4. We have measured internal kinematics of 10 cluster members from rotation curve analysis of spatially resolved emission observed in 2D Keck (LRIS) spectra. Our rotation curve analysis includes modelling for the effects of seeing, slit width and orientation, and instrumental resolution. Relevant structural parameters such as inclination, size, and orientation were made from HST (WFPC2) images. While we do not find evidence fo a change in the zeropoint of the TFR, we do find slight evidence for more scatter in the past. This study is the first step in an ongoing effort to characterize evolutionary signatures in CL0024 disk systems.

1.1 Motivation

Since Butcher and Oemler's (1978, hereafter BO78; 1984) pioneering studies of the color evolution of galaxies in clusters, many physical mechanisms have been proposed as causes for this observed evolution. Viable processes include interactions between the ICM and cluster galaxies (e.g. ram pressure stripping), interactions between galaxies in clusters (e.g. harassment, merging), and tidal interactions between galaxies and the cluster potential well. All of these processes affect galaxy disks and gas, and in particular their mass-to-light ratios. The Tully-Fisher relation between disk galaxy rotation velocities and luminosities is therefore a powerful diagnostic for discerning which evolutionary processes dominate in clusters.

1.2 Target and Dataset

CL0024 is a particularly good candidate for the study of disk galaxies and evolutionary processes. The intermediate redshift of this cluster (z=0.4) places it at an epoch at which color, luminosity, and morphological evolution are expected to have occurred (e.g. BO78, Jorgensen et al. 1999, and Dressler et al. 1997, respectively). As one of the two clusters originally studied by BO78, CL0024 is known to have a high fraction of blue galaxies. Furthermore, studies have shown evidence for mergers (Lavery, Pierce, & McClure 1992) and recent subcluster infall (Czoske et al. 2002).

To study this cluster in greater detail, we have undertaken a Keck (LRIS) spectroscopic survey which has yielded redshifts of 312 galaxies to date, of which 162 are confirmed cluster members. In Table 1 we compare our survey to other recent surveys of the cluster. Strengths of our dataset include high spatial and spectral resolution, necessary for rotation curve analysis. Furthermore, many of our slits were aligned with galaxy major axes. Our kinematic measurements made use of spectra from this survey as well as archival WFPC2 images of the cluster. Structural parameters such as sizes, inclinations, and position angles were derived from the images using GIM2D (Simard et al. 2002).

Table 1.1. *CL0024 spectroscopic survey comparison.*

	Dressler et al. 1999	**Our Survey**	Czoske et al. 2001
Telescope	Palomar	Keck	CFHT
Survey area (sq. ′)	74	63	525
Total # spectra	130	312	687
# cluster members	107	162	295
Depth	r < 22	**R < 24**	V < 23
Range (Å)	3500-9800	4500-9500	4500-8500
Spatial scale (″/pix)	0.4	**0.22**	0.37
Resolution (km/s)	130	**50**	140

1.3 Rotation Curve Analysis

We have measured rotation curves from a sample of 10 galaxies in the CL0024 field. Each is a cluster members and lies within the HST-imaged region of the cluster. All 10 galaxies exhibit emission out to a radius $\geq$ 1 arcsec and have inclinations $\geq$ 30 degrees. Rotation curves were measured from the gollowing emission lines: Hα, [NII], [OIII], Hβ, and in some cases [OII].

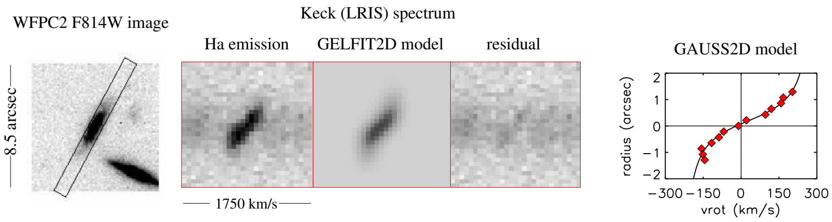

Fig. 1.1. *(Left)*: HST image of a CL0024 member with slit overlaid. *(Middle)*: GELFIT2D example. 2D emission from the object spectrum, a best-fit model emission line, and a residual (data – model) image. *(Right)*: GAUSS2D example. Red points show the velocity curve extracted from Gaussian fits to the emission line; solid line is the best-fit velocity curve extracted from model emission.

Our team has developed two methods for measuring rotation kinematics from emission line fits: GAUSS2D and GELFIT2D. Both methods incorporate comparisons of data to emission line models which assume an arctan velocity distribution and take seeing, instrumental resolution, slit width and position into account. **GAUSS2D** closely resembles the technique used by Vogt et al. (1996, 1997). This method fits Gaussians along each row of an emission line to derive a velocity curve, then derives velocity curves in the same manner from model emission lines to determine the best-fit rotation velocity. GAUSS2D makes no assumptions about the galaxy light distribution and provides the option of concatenating velocity measurements from multiple emission lines (e.g. Hα, [OIII], [OII]) before comparing to models. **GELFIT2D** assumes an exponential light distribution and optimizes velocity measurements by comparing emission line models directly to the full 2D data. Examples of the models are shown in Figure 1.1.

1.4 CL0024 Tully-Fisher Relation

Our preliminary results are shown in Figure 1.2 below, where we show the CL0024 TFR compared to the TFR derived for z=0 cluster galaxies. We find evidence evidence for slightly greater scatter but no chnge in luminosity zero-point when compared to local samples. This result is in agreement with Dale & Uson (2000), who found a 50% higher scatter in the z=0.08 cluster TFR than in the 0.02<z<0.06 relation. Adding corrections for extinction to these data result, however, in the opposite conclusion, i.e., slight luminosity evolution and less evidence for any increase in the scatter. The latter result would corroborate the findings of Milvang-Jensen et al. (2003) who demonstrate evidence for luminosity evolution in a TFR study of distant cluster MS1054-03 at z=0.83.

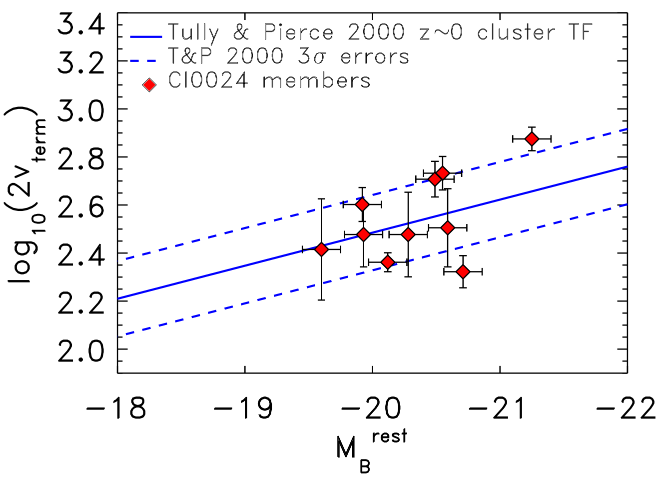

Fig. 1.2. CL0024 Tully-Fisher relation. Red points represent CL0024 cluster members, plotted with one-sigma error bars. The solid blue line is the z=0 TFR determined by Tully & Pierce (2000), plotted with 3-sigma errors (dashed blue lines).

If the larger scatter survives in our final results, a possible explanation is the following: a galaxy with high M/L (scattered high on the TF) in the past may have had its gas stripped due to ram pressure such that its star formation was quenched and it is no longer seen in emission. Galaxies with low M/L in the past may have been experiencing starburst activity which has since dampened.

1.5 Summary and Future Directions

Using high-resolution Keck spectroscopy and HST imaging, we have measured rotation velocities for 10 members of cluster CL0024 at z=0.4, and we have derived one of the first measurements of the Tully-Fisher relation in a distant cluster. We find slight evidence for an increase in scatter in the cluster TFR at z=0.4 as compared to z=0, but see no evidence for a change in luminosity zeropoint.

A comprehensive discrimination between evolutionary processes in clusters requires a comparison of many observables. This Tully-Fisher study is a first step in our ongoing effort to characterize evolutionary signatures in CL0024 disk systems. Analysis of the correlation between Tully-Fisher residuals and other galaxy properties may be particularly enlightening. Kannappan, Fabricant, and Franx (2002) have recently found a correlation between TFR residuals and galaxy colors and star formation rates in a large sample of nearby field galaxies. Tully-Fisher scatter may therefore reflect correlated luminosity and color offsets due to galaxies' star formation histories.

Further analysis is underway and will include structural analysis of CL0024 members from HST imaging, and measurements of emission line diagnostics (such as star formation rates, metallicities, shock ionization) from Keck spectra. Another preliminary kinematic study is shown below.

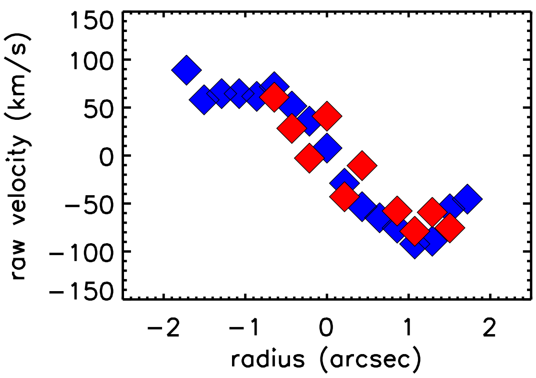

Fig. 1.3. Here we compare rotation from stars and gas in a CL0024 member as measured from Balmer absorption (red points) and [OII] emission (blue points), respectively. We see no evidence for counter-rotation, a signature of mergers, in this galaxy.

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