Photometry and redshifts of galaxies in radio-loud clusters

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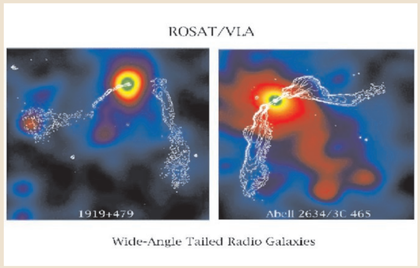
Abstract.

We have produced and refined catalogs of optical galaxy properties in ten, radio-loud clusters of galaxies. The properties, including B, V, and R magnitudes, were measured using the Source Extractor software (Bertin and Arnouts 1996) applied to CCD images taken with the MOSA imager on the Kitt Peak 0.9-m telescope. False sources, like cosmic ray residuals and star diffraction spikes, were removed by manual inspection. The primary science goal is to measure substructure in the clusters. This requires cluster member galaxies to be seperated from foreground and background galaxies and stars. The source extraction software attempts to distinguish galaxies from stars with limited success. We use the color-magnitude relation (CMR) to reveal likely early-type members: ellipticals tend to fall near a line on this plot, and the height of this line depends on the redshift of the cluster. We then explore problems associated with the use of the CMR to identify cluster members. We do this by mining the Sloan Digital Sky Survey for redshifts in our cluster fields. We find many members that would be missed by a CMR-based selection because their colors are too blue.



Radio Loud Clusters

"Radio Loud" Clusters are clusters of galaxies containing radio galaxies. Radio Galaxies produce jets of synchrotron-emitting plasma, often with a bent tail morphology (Left). The jets emerge from the unresolved, active nucleus (AGN) of an elliptical galaxy and extend into the x-ray emitting, intracluster medium (ICM).

White contours: radio emission.

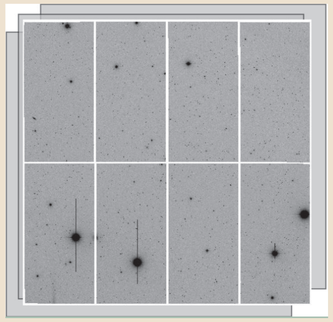
Colors: x-ray emission peaked on galaxy nucleus.

Despite the energy source being a compact, supermassive black hole, radio galaxies seem to tell us something about the state of their parent cluster. First, they are preferentially found in regions of high gas and galaxy density (Burns et al. 1994). Second, their morphology indicates the relative motion of the hot, intracluster medium (ICM) with the radio galaxy, and thus may be a signpost of merger (e.g., Pinkney et al. 1993). If radio clusters have a greater probability of ongoing subcluster mergers, then their galaxy distributions should also be more likely to exhibit 2D substructure. The best way to detect substructure in the galaxies is deep, wide-field imaging. To this end, we have used the MOSA CCD detector on the 0.9-m telescope on Kitt Peak to image 10 clusters containing radio galaxies. Images were taken through B, V, and R filters to allow identification of cluster members.

Imaging with MOSA on the KPNO 0.9-m

The MOSA mosaic imager is an 8-CCD array, which has a diameter of 58.2' on the 0.9-m. This is well-suited to our target clusters which have typical Abell Radii ($2h^{-1}_{75}$ Mpc) of 20'. There are gaps between the CCDs which have a projected size of about 25" on the sky. Hence, either 3 or 4 dithered exposures were combined to allow us to "see around" the gaps.

RIGHT: 300 sec exposure of Abell 695 with gray rectangles indicating three other dithered exposures.



CCD Data Reduction

- Used mscred in IRAF (Image Reduction and Analysis Facility).
- Combined darks, flats, and biases
- Subtracted biases and darks from all frames
- Eliminated crosstalk "ghosts"
- Combined exposures of like filters
- Set world coordinate system: used the USNO-B1 catalogs for reference.

Catalog Building and Cleaning

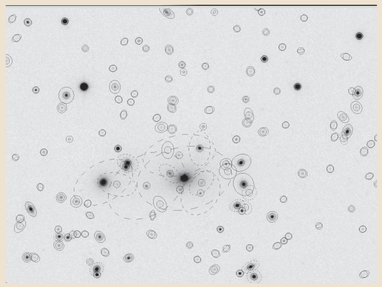
- Used SExtractor (Bertin 1996) to extract sources and properties (See Table Below)
- Determined B and R magnitude zeropoints through comparison with the USNO-B1 catalog. We averaged 2 B and 2 R magnitudes for each comparison object.
- V magnitude zeropoint was calibrated using extended sources (galaxies) and assuming average values of B-V = 0.92 and V-R = 0.60
- Used Fortran program to combine B, V, and R catalogs into one master catalog.
- Cleaned out non-sources and cosmic ray residuals by visual inspection.

	RA(2000)	DEC(2000)	SI1	RAuto	Rerr	RAp	VAp	V-R	PA	ELL	FWHM	MinFlg	Vel	Verr	NavR	NavV	BAp	B-V	B-R
1	11.651498	5.969964	0.49	23.16	0.15	24.04	0.00	0.00	-18.8	0.42	3.5	0	-500.0	0.0	1	0	0.00	0.00	0.00
2	11.651377	5.415136	0.49	22.67	0.17	22.69	0.00	0.00	18.0	0.40	3.2	0	-500.0	0.0	1	0	0.00	0.00	0.00
3	11.651544	6.055838	0.48	21.39	0.07	21.29	0.00	0.00	18.3	0.38	2.7	0	-500.0	0.0	1	0	0.00	0.00	0.00
4	11.651424	5.583415	0.66	22.38	0.12	22.40	0.00	0.00	-37.3	0.37	4.0	0	-500.0	0.0	1	0	0.00	0.00	0.00
5	11.651355	5.319659	0.50	22.75	0.18	21.98	0.00	0.00	-57.6	0.38	2.5	0	-500.0	0.0	1	0	0.00	0.00	0.00
6	11.651416	5.757299	0.01	20.88	0.07	21.09	0.00	0.00	-5.1	0.07	6.0	0	-500.0	0.0	1	0	0.00	0.00	0.00
7	11.651495	5.821290	0.51	23.09	0.21	22.47	0.00	0.00	-69.3	0.42	3.1	0	-500.0	0.0	1	0	0.00	0.00	0.00

Above: Sample catalog

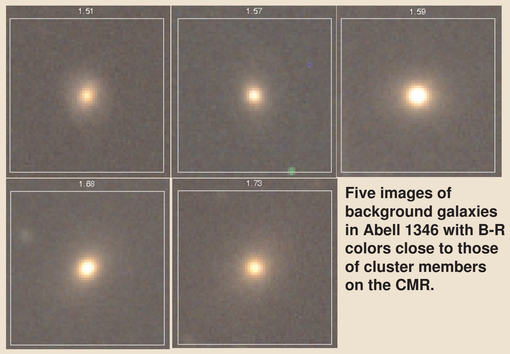
First 6 lines from the master catalog of sources created by SExtractor for Abell 1346. 21828 total sources detected in this image. Some parameters obtained include:

- -position: in RA and DEC
- -stellarity index: larger values mean more stellar (SI1)
- -magnitudes: smaller magnitudes indicate brighter objects (RAuto)
- -colors: in B-R, V-R, B-V
- -FWHM: full width at half maximum



Deblending issues

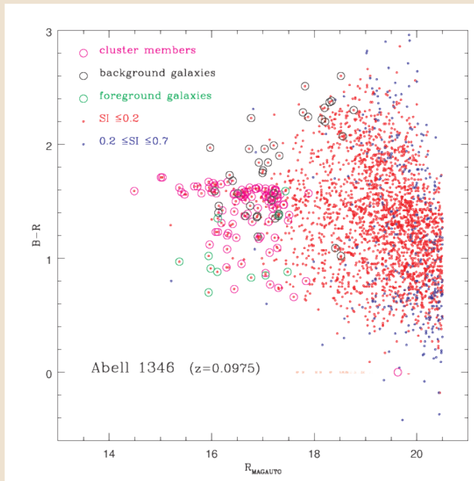
Left: a small part of the R-band "check image" of Abell 1346, created by SExtractor. The large elliptical apertures are used by the "RAuto" magnitude, while small circular apertures were used for "RAp". Notice how some large apertures are centered on small sources because they are not properly deblended from larger neighbors.

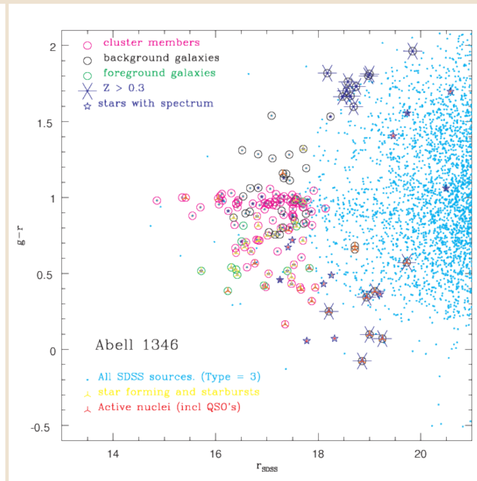


Five images of background galaxies in Abell 1346 with B-R colors close to those of cluster members on the CMR.

Selecting Cluster Members

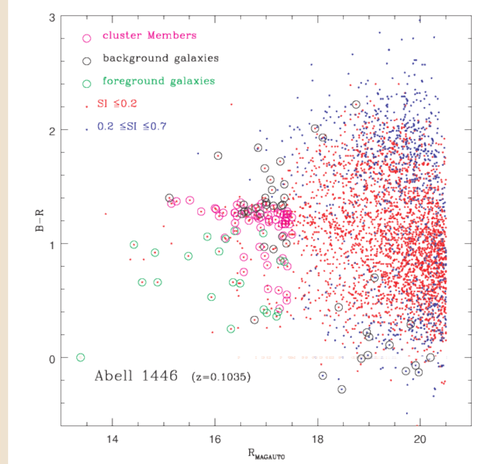
We wish to select samples of galaxies that are members of the cluster using the MOSA photometric information alone. One way to do this is to select the galaxies falling on the "color-magnitude relation" (CMR). This linear locus of points is made up primarily of ellipticals and has a position on the color-magnitude plot that is a function of redshift. In order to check the purity of a sample chosen in this way, we have obtained redshifts for a subsample of objects using the Sloan Digital Sky Survey (SDSS).

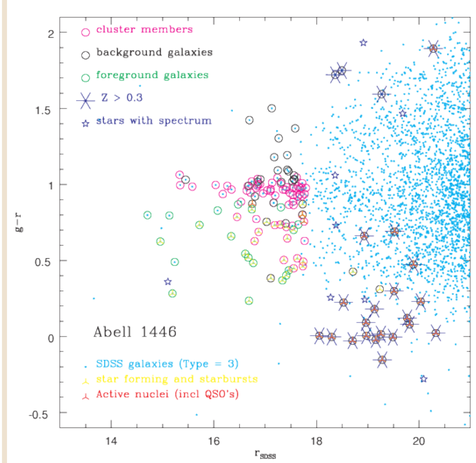




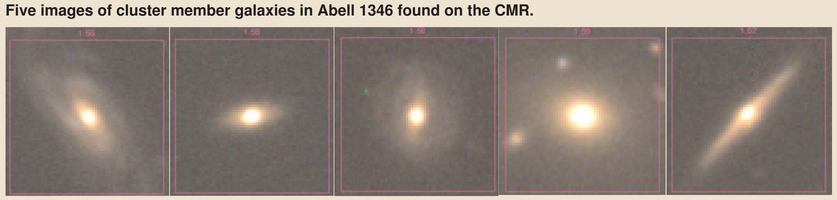
Above Left: B-R color index vs. R magnitude for Abell 1346. Magnitudes come from our MOSA data, while the membership information (circles) comes from the SDSS. Above Right: g-r color index vs r magnitude for Abell 1346. Magnitudes and membership information both come from the SDSS.

Bottom Left: B-R color index vs. R magnitude for Abell 1446. Bottom Right: g-r color index vs r magnitude for Abell 1446.





Five images of cluster member galaxies in Abell 1346 found on the CMR.



Five images of cluster member galaxies in Abell 1346 found below the CMR.

Five images of foreground galaxies in Abell 1346 with B-R colors near or below those of cluster members on the CMR.

RESULTS

Adding redshifts from the SDSS to our catalogs taught us several things about using colors to select galaxy samples:

- The CMR has a much sharper cut-off on the top (red) side than the bottom; this can be used for selecting member galaxies.
- The bottom edge of CMR is smeared out by the presence of starforming galaxies (and AGN to a lesser extent).
- The CMR is about as narrow in our data as the SDSS data, indicating that our magnitudes have fairly small errors. (Deblending problems not too serious.)
- Background galaxies can overlap the cluster's CMR.
- These background galaxies are not distinguishable from the cluster CMR galaxies using morphology alone, so contamination is inevitable in a color-based sample.
- Contamination of the CMR and "green valley" by foreground galaxies is slight.

FUTURE WORK

- Use CMR to select sub-samples and run 2D substructure diagnostics on these sub-samples.
- Finish cleaning all catalogs, and adding velocities to all catalogs.
- Run 3D substructure tests on subsamples with velocities.
- Adjust magnitude zeropoints based on locus of stars in color-color plots.

References

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Acknowledgements

This work benefitted from the use of the NASA Extragalactic Database (NED).