NOAO Observing Proposal *Standard proposal* **Panel:** *For office use.*
Date: August 27, 2007 **Category:** High Z Galaxies

The Luminosity Function of Galaxys in the Virgo Cluster

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)***:**
I propose deep imaging of the Virgo Cluster to construct the luminosity function of Virgo Galaxies. Using the Keck 2m telescope, we can probe the LF down to very faint magnitudes. Along with our existing dataset from the KPNO 4m, this will provide and important constraint on galaxy formation models. We are requesting seven nights of observing to complete this survey.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	Keck-I	CFIM + T2KA	7	darkest	Aug - Oct	Aug - Oct
2						
3						
4						
5						
6						

Scheduling constraints and non-usable dates *(up to four lines).*

I will be attending the Michigan-Notre Dame game on September 12th, and will not be able to observe at that time.

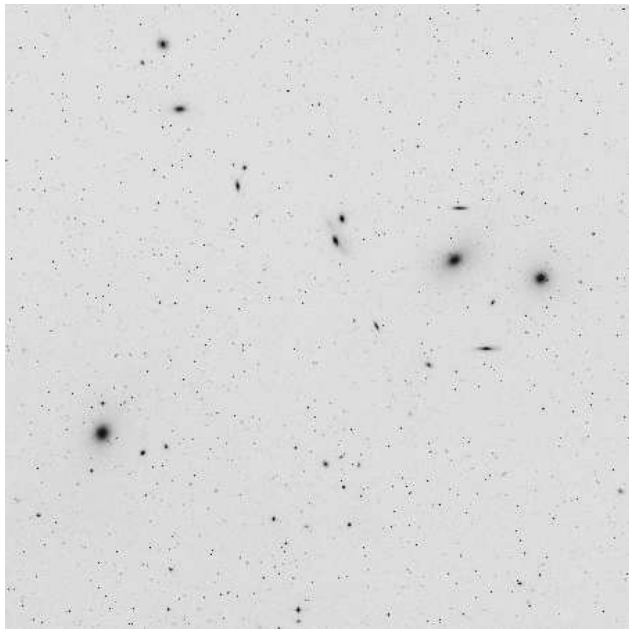

Figure 1: The Virgo Cluster of Galaxies

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

The Virgo cluster is the nearest cluster to us. It has been well-studied at many wavelengths, and provides an unique laboratory for studying galaxy evolution and cluster dynamics. Of foremost interest is the luminosity function of galaxies, still poorly constrained by existing observations. A variety of studies has shown that for the faint end of the luminosity function, $alpha = -1$, at odds with expectation.

Galaxy mergers may explain this discrepancy (Mihos & Hernquist 1994). Over the lifetime of a galaxy, it is expected that it may experience one or more dramatic collisions which can change it's properties. In particular, galaxies may change from spiral to elliptical, or cannibalize smaller galaxies in the process. In the high density regions defined by galaxy clusters, galaxy collisions are thought to be common, which makes galaxy clusters a particularly interesting place to study luminosity functions.

Over the past five years, we have been studying the luminosity function of the Virgo Cluster (Mihos et al, in preparation). Our data has been compiled using the KPNO 4m telescope, and includes imaging in multiple bands, as well as optical spectroscopy. Our dataset is nearly complete, and given one more week of data on Keck, we should be able to finish our survey and acheive our scientific goals.

Luminosity functions can be calculated a variety of ways; one common technique is to use the $1/V_{max}$ statistic, which has significant bias to it. Our solution to this problem is to construct a volume-limited sample of the Virgo cluster down to a limiting magnitude of $M = -16$. It has been shown that volume limited samples provide the best constraints on luminosity functions (Harding, private communication). In particular, variations in μ_{lim} can be minimized through a careful choice of ϵ_{θ}, which we have taken great care to explore.

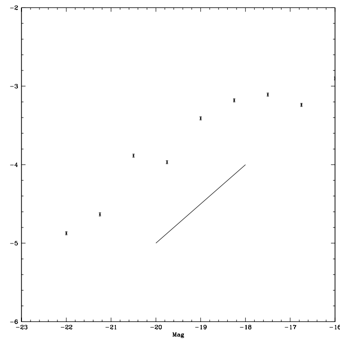

Figure 2: A preliminary luminosity function based on our KPNO 3m data. The additional Keck data we will obtain through this proposal will significantly improve our sample size and the robustness of our results.

Once completed, our survey constraints on the luminosity function will provide important inputs to the HOD formalisms of both SAM and NBDMAX models. These models (Bothun & Gaskell 1987) are the state-of-the-art in terms of their description of galaxy formation in standard CDM. The predicted luminosity functions are extremely sensitive to parameters such as Ω_b and the age of the universe, and comparison to our observed luminosity functions will provide unprecedented insights into the beautiful intracacies of the cosmological evolution of the universe.

References

Blakeslee, J.P. & Metzger, M.R. 1999, *Ap. J.,* **513,** 592

Calcáneo-Roldán, C., Moore, B., Bland-Hawthorn, J., Malin, D., & Sadler, E. M., 2000, *M.N.R.A.S.,* **314,** 324.

Dressler, A. 1984, *Ann. Rev. Astr. Ap.,* **22,** 185

Feldmeier, J.J., Ciardullo R., & Jacoby G.H. 1998, *Ap. J.,* **503,** 109

Feldmeier, J.J., Mihos, J.C., Morrison, H.L., Rodney, S., Harding, P. 2002a, *Ap. J.,* **575,** 779

Feldmeier, J.J., Ciardullo, R., Jacoby, G.H., Durrell, P.R. 2002b, *Ap. J. Suppl.,* submitted

Fort, B. & Mellier, Y. 1994, *A&A Rev.,* **5,** 239

Gregg, M. D. & West, M. J. 1998, *Nature,* **396,** 549.

Herrera, B. & Sanromá 1997, *Astr. Ap.,* **320,** 13

Plionis, M. & Basilakos, S. 2002, *M.N.R.A.S.,* **329,** L47

Richstone, D.O., & Malumuth, E.M. 1983, *Ap. J.,* **268,** 30

Schombert, J.M. & West, M.J. 1990, *Ap. J.,* **363,** 331

Struble, M. & Rood, H.J. 1984, *A. J.,* **89,** 1487

Zwicky, F. 1951, *Pub. A.S.P.,* **63,** 61

Experimental Design *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. (limit text to one page)*

Over the past five years, we have been studying the luminosity function of the Virgo Cluster (Mihos et al, in preparation). Our data has been compiled using the KPNO 4m telescope, and includes imaging in multiple bands, as well as optical spectroscopy. Our dataset is nearly complete, and given one more week of data on Keck, we should be able to finish our survey and acheive our scientific goals.

Our sample of galaxies consists of 165 galaxies in the Virgo cluster which are a mix of SB, Sc, E, and S0. The beauty of Keck lies in its majestic mirror: with seven nights of dark time, we can collect data on many more galaxies and expand our sample. We will be targeting in particular AGN and dSph galaxies, in order to gain a wider census of the galaxy types in Virgo. This is particularly important, as galaxies of different types may have significantly different origins (Johnson et al 2007, Friedrich 2007).

The most important targets are the ones with spectroscopic data already in hand. The spectroscopic data is critical to our sample, and only through the combination of spectroscopy and imaging can we truly tap the scientific potential of the datasets. Our spectroscopic resolution is 1Å, with a S/N per pixel of 10. This type of data is unparalleled over such a large area such as Virgo, and combined with the imaging we can constrain the properties of SAM and HOD models and unlock the secrets of galaxy formation.

Use of Other Facilities *Describe how the proposed observations complement data from non-NOAO facilities. For each of these other facilities, indicate the nature of the observations (yours or those of others), and describe the importance of the observations proposed here in the context of the entire program.*

We have ancillary data from spectroscopic surveys as well. An exciting new features of our dataset is our recently obtained near-infrared imaging from the *Spitzer Space Telescope* as described above. This constrains the AGN lifetimes of the galaxies as well as their star-forming properties.

We also will be proposing for ACS time on the Hubble Space Telescope to get high resolution imaging for our galaxies.

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the PI during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. Please include original proposal semesters and ID numbers when available.*

☆ 5 nights at the KPNO 4-m, Direct Imaging, April 2005. First observations of this survey. Preliminary data reductions look promising.

☆ 5 nights at WIYN, Spectroscopy, May 2005. This represents our spectroscopic data. The observations were all taken under photometric conditions, except for three nights which had passing clouds. Nonetheless, we plan to calibrate the spectrophotometry through a novel new technique pioneered by Morrison (private communication).

☆ 7 nights at the KPNO 4m, Direct Imaging, April 2006. Data reduction will begin soon.

The P.I. has also been involved with studies of the solar corona at different wavelengths, including

☆ SOHO in-flight calibrations of solar data

☆ 6 nights on the McMath solar observatory, June 2004. Data reduced and in press.

Observing Run Details for Run 1: KP-2.1m/CFIM + T2KA

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for WIYN-2hr, WIYN-SYN, YALO, and Gemini runs).*

The constraints provided by the luminosity function measurements are *direct inputs* to the different modeling techniques. A recent conference on galaxy formation (Rio de Janiero, Summer 2006) was devoted to the connection between LF data and SAM models; our data will be revolutionary in this regard. In particular, the exceptionally strong relationship between galaxy type and either α or χ means that even a fraction of the data proposed here will have a strong impact on the field.

Other technical details:

Exposure time

Previous work on the 4m shows that we can acheive S/N=10 in 50 minutes for a galaxy of 21st magnitude. Scaling these exposure times up to the larger primary size of Keck, this implies the exposure times needed will be 8 minutes per galaxy. In seven nights, therefore, we can assemble a much larger sample.

Sky subtraction

Sky subtraction will be performed using standard image reduction techniques (see the IRAF cookbook, for example). It is most important that we

Flat fielding

Flat fielding is important part of the process. To achieve our sensitivity limits ($\mu < 26$), we need to have a flat field accuracy of $< 1\%$ across the entire chip.

Photometric Calibration

We will use the standard spectrophotometric standards available in the Keck observing queue.

Spectral Resolution

We need a spectral resolution of $R = 4000$ to obtain velocity accuracy of better than 10 km/s, a limit which is critical to the accuracy of our kinematic modeling.

Instrument Configuration

Filters: Johnson filters
Grating/grism:
Order:
Cross disperser:

Slit:
Multislit:
λ_{start}:
λ_{end}:

Fiber cable:
Corrector:
Collimator:
Atmos. disp. corr.:

R.A. range of principal targets (hours): 10 14

Dec. range of principal targets (degrees): -12 to 55

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

NOAO observing proposal LaTeX macros v2.7.