Observing Time Request
MDM Observatory

Date: April 10, 2014	*Proposal number:*

TITLE: Uncovering the Origin of Warm Gas in Galaxy Clusters: Identifying Possible Galactic Origins of Cluster Lyman Alpha Absorbers

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Abstract of Scientific Justification: Galaxy clusters are the largest gravitationally bound structures in the Universe, and are host to a variety of gas flow phenomena. We want to be able to map out the warm gas component (T$\sim10^{4-5}$ K) of a galaxy cluster's intracluster medium (ICM), which traces processes such as gas accretion onto the cluster from filaments, and interactions between the ICM and the cluster's galaxies. This has been done recently through Lyα absorption observations in the Virgo cluster with HST's COS. However, being able to discriminate against or determine the possible galactic origins of the warm gas component requires a complete understanding of the velocities of galaxies within a few hundred kpc (in projection) of a given line of sight. In light of upcoming observations of Lyα absorption in the Coma Cluster, we propose to obtain more precise velocity measurements of galaxies around 9 lines of sight in order to better understand the relationship between the observed warm gas and the galaxies within the Coma Cluster.

- *Is this proposal part of a PhD thesis?* N
- *Requesting long-term status? If 'Y', please give # of semesters and nights on the next line.* N

Summary of observing runs requested for this project

Run	Telescope	Instrument, detectors, grisms, gratings, filters, camera optics, etc.
1	2.4	OSMOS, VPH grism
2		
3		

Run	No. nights	Moon age (d)	Optimal dates	Acceptable dates
1	3		March 18-22 ; April 17-20	March 13-22; April 6-20
2				
3				

- *List dates you cannot use for non-astronomical reasons on the next line.*

Scientific Justification *Try to include overall significance to astronomy.*

Lyα absorption seen through the Lyα forest probes the diffuse gas contained within the intergalactic medium (IGM) (Rauch 1998). UV spectrographs aboard the Hubble Space Telescope, most recently the Cosmic Origins Spectrograph (COS), provide a window into Lyα absorption in the nearby Universe. In addition to its usefulness probing baryons in the IGM, Lyα can be used to observe warm gas flows into and out of galaxy clusters. Clusters are hosts to massive dark matter potential wells (10^{14-15} $M_\odot$) that can shock-heat infalling cool gas to the virial temperature of the intracluster medium (T$\sim 10^{7-8}$K). In general, warm gas (T$\sim 10^{4-5}$ K) traces the inflow of gas from pristine filamentary structures, as well as processes unique to cluster environments, shock as the ram-pressure stripping of gas in infalling galaxies, galactic starvation, and galaxy-galaxy interactions. Recently, Yoon et. al. 2012 (hereafter Y12) used COS to systematically probe the warm gas distribution in galaxy clusters through 14 lines of sight to background QSOs through the Virgo cluster. Y12 indicated the presence of an inflowing warm gas component that could have galactic or filamentary origins. Regardless, this compenent traces important dynamical processes associated with galaxy clusters. We propose to conduct observations to discriminate against or determine the possible galactic orgins of this Lyα absorbing gas seen in recent and upcoming lines of sight towards richer and more massive Coma Cluster.

The investigators have secured the necessary time with COS to observe nine lines of sight towards background QSOs through the Coma Cluster. Fig. 1 gives these lines of sight, spread throughout the cluster environment, along with the SDSS galaxies shown in gray. From the results of Y12, we expect a covering fraction of unity for Lyα absorbing gas at N_{HI} above $10^{13.1}$ cm^{-2}. Since we expect a more massive galaxy cluster such as Coma to contain more inflowing warm gas, each of our lines of sight should exhibit some Lyα absorption associated with the Coma Cluster. The circumgalactic medium (CGM) of galaxies in the field show up in Lyα absorption as long as their impact parameter to the line of sight is within a few hundred kpc (Prochaska et. al. 2011). However, cluster environments affect the evolution of galaxies and tend to suppress the CGM; this suppresses the observable galactic Lyα absorption (Yoon & Putman 2013). For this reason, we restrict our target list to galaxies within a few hundred kpc of each line of sight. Yoon & Putman 2013 studied the association of galaxies and Lyα absorbers within the Virgo Cluster, developing a method to pair Lyα absorbers with galaxies. However, this analysis requires a complete understanding of the distribution and velocities of galaxies around each line of sight. Although the Coma Cluster is well studied, and many galaxies already have measured velocities, there are still many near each line of sight with no velocity measurements. We propose to use MDM to obtain velocity measurements of a selection of galaxies near each line of sight in order to extend the analysis of Yoon & Putman 2013 to the Coma Cluster. This is important in order to better understand how a diverse range of cluster environments affect their resident galaxies.

Currently, we are conducting synthetic Lyα observations through a galaxy cluster simulated with the adaptive mesh refinement code Enzo (The Enzo Collaboration et. al. 2013). In this work, we reconstruct the three dimensional distrubution of the observable warm gas within a galaxy cluster in order to determine the origin of the observed absorption features. The synthesis of this computational work, the observations of Lyα absorption in Virgo and Coma, and the observations proposed here will provide a robust test of our theoretical understanding of gas flows in galaxy clusters. The MDM observations are essential, then, towards determining the potentially galactic origin of the observed warm gas, and testing what we predict from cosmological simulations. These observations would provide a better understanding of the relationship between galaxies and their cluster environments, and the evolution of the gaseous baryons within galaxy clusters.

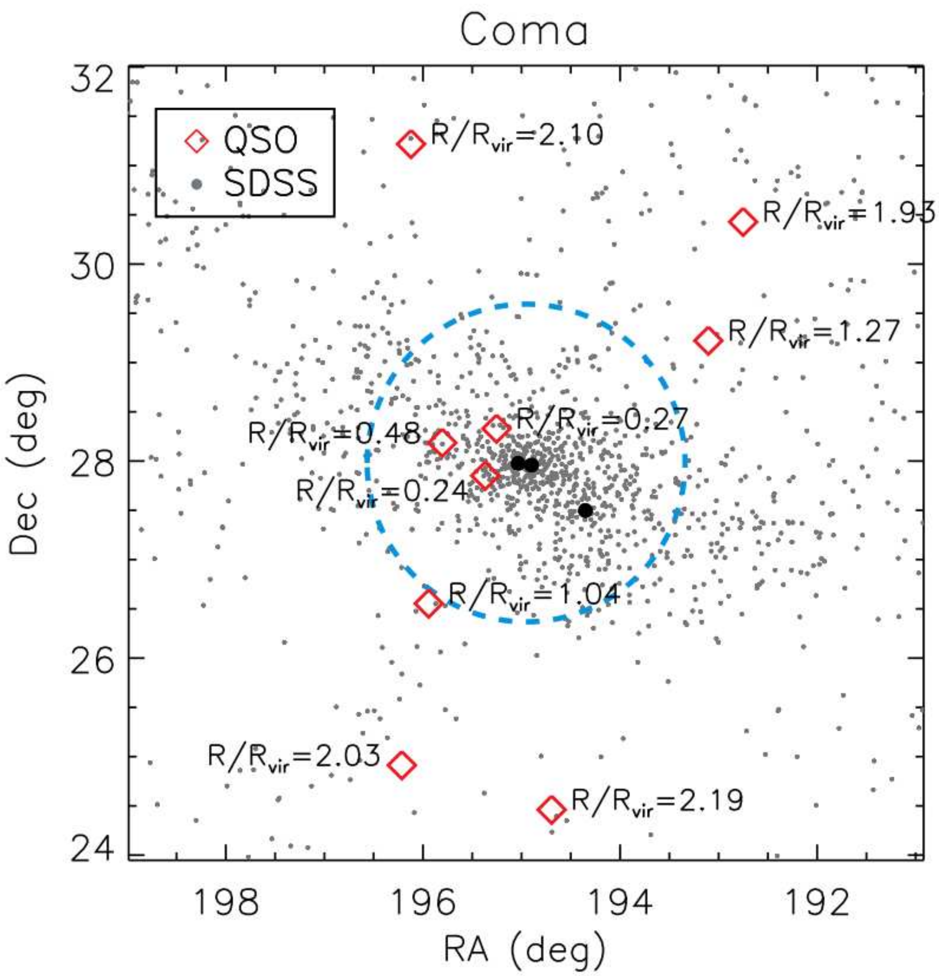

Figure 1: The Coma Cluster with the distrubution of associated galaxies from SDSS (gray dots). The red diamonds give the lines of sight to the QSO's being observed with HST. The dashed circle gives the Coma Cluster virial radius, 2.9 Mpc. The lines of sight as listed in Table 1 are ordered in increasing distance from cluster center.

References

The Enzo Collaboration et. al. 2014, ApJS, 211:19

Prochaska, J. X., Weiner, B., Chen, H.-W., Mulchaey, J., & Cooksey, K., 2011, ApJ, 740, 91

Rauch, M. 1998, ARA&A, 36, 267

Yoon, J. H., Putman, M.E., Thom, C., Checn, H.-W., & Bryan, G. L. 2012 ApJ, 754, 84

Yoon, J. H., Putman, M.E., 2013, ApJ, 722, L29

Yoon, J. H., Schawinski, K., Sheen, Y-K., Ree, C. H., & Yi, S. K., 2008, ApJS, 176, 414

Technical and Scientific Feasibility *List objects, coordinates, and magnitudes (or surface brightness, if appropriate), desired S/N, wavelength coverage and resolution. Justify the number of nights requested as well as the specific telescope, instruments, and lunar phase. Indicate the optimal detector, as well as acceptable alternates. If you've requested long-term status, justify why this is necessary for successful completion of the science.*

We propose to measure the velocity of galaxies given in Table 1. For each galaxy, Table 1 shows its position (RA,DEC), the nearby background QSO, the galaxy's magnitude, and the separation (in arcmin) from the line of sight. At Coma's redshift, z = 0.023, $10'$ corresponds roughly to 250 kpc. Ultimately, there are many galaxies within $10'$ of each line of sight without known velocity measurements. However, we restrict ourselves to the brightest galaxies that are closest to each of the lines of sight. This selection is fairly arbitrary, but restricts our sample to galaxies most likely associated with the Coma Cluster, and galaxies that would most likely be responsible for an observed absorption feature. Some galaxies near the line of sight are likely associated with the Coma Cluster, but only have photometric redshifts available. We restrict ourselves to five galaxies near each sight line shown in Fig. 1, placing precedence on those in Coma with photometric redshifts available.

The velocity of these galaxies can be readily determined using the OSMOS detector on the 2.4m telescope. This instrument was designed specifically for the purpose of studying galaxies in galaxy clusters in the nearby Universe. OSMOS is perfect for observing galaxies within Coma. Given the magntitudes listed in Table 1, we can make our observations within 3 hours of exposure time. Given the possible range of slit dimensions, 0.6-20" long and 0.6-1.2" wide, we will be able to fit all of our galaxies on a single mask (45 slits in all) without collisions between slits.

We will use the VPH grism to conduct observations in two sets, over the wavelength range 310-590nm (peak at 500 nm) and 310-680nm (peak at 640nm). Given the required exposure time per observation, this implies six hours of exposure to make the required measurements. The VPH grism has a peak resolution of R=1600, which would allow velocity measurements accurate to about 180 km/s at Hα. The accuracy of velocity measurements are improved greatly by measuring the Doppler shift for two or three lines. With OSMOS, we will be able to observe Hα (656.28 nm), Hβ (486.13 nm), Hδ (410.17 nm), and the Ca H and K lines (396.85 nm and 393.37 nm). However, Hα and Hβ will likely be the most useful (nearest two to the resolution peaks at 500 nm and 640 nm). For older, elliptical galaxies are not likely to be seen in emission, but rather absorption. For this case, we can use NaD (589.2 nm), Mgb (517.5 nm) and also potentially the Ca H and K lines to measure the velocity.

Why MDM? *If other optical/IR facilities are being used for this project, explain the role that MDM observations will play.*

HST's COS is the only other observational instrument being used for this project. The time on HST has already been obtained, and all observations will be made by the end of summer 2014. The MDM observations are essential for identifying the possible galactic origin of the identified Lyα absorbers in the Coma Cluster. Since the investigators are affiliated with Columbia University, the ease of access to MDM facilities makes it an attractive option for conducting this experiment. More importantly, the availability of the mutli-object spectrograph OSMOS, designed to look at the objects we propose to observe, makes MDM the logical choice.

Object Name	RA	DEC	Sep. (")	Mag.
HB89.1259+281				
SDSS J130129.58+275052.1	195.37329	27.84782	0.400	18.2r
SDSS J130128.71+275134.8	195.36963	27.85968	0.488	19.9r
SDSS J130132.58+275018.0	195.38578	27.83835	1.273	18.6g
ABELL 1656*	195.2308	27.79202	8.081	20.4g
SDSS J130123.95+275316.6*	195.34983	27.88796	2.357	21.0g
HB89.1258+285				
SDSS J130101.38+282011.4	195.25579	28.33652	0.459	19.5r
APD2000 J130104.3+281956	195.26808	28.33228	0.783	18.9R
SDSS J130055.49+281939.7	195.23121	28.32772	1.191	19.4r
GALEXASC J130051.96+281852.4	195.21663	28.31486	2.136	16.9R
SDSS J130056.49+281650.0	195.23539	28.28056	3.068	18.5r
TON0694				
SDSS J130313.13+281114.1	195.80472	28.18726	0.108	20.6g
SDSS J130308.38+281047.7*	195.78494	28.17993	1.075	21.8g
SDSS J130311.68+280832.5	195.79868	28.14238	2.604	19.65
SDSS J130300.41+280945.8	195.75171	28.16275	3.096	19.81
SDSS J130302.68+280852.0	195.76118	28.1478	3.21	19.8g
RX.J1303.7+2633				
SDSS J130346.40+263327.3	195.94334	26.55759	0.239	21.8g
SDSS J130339.80+263329.8	195.91585	26.5583	1.406	18.9g
SDSS J130351.64+263228.9	195.96518	26.54138	1.473	20.8g
SDSS J130340.05+263028.6	195.91692	26.50796	3.06	19.81
SDSS J130359.02+263425.4	195.99593	26.57372	3.149	19.8g
FBQS.J1252+2913				
SDSS J125327.13+291330.0	193.36306	29.22505	0.49	21.7g
SDSS J125320.37+291237.7	193.3346	29.21048	1.24	20.5g
SDSS J125334.07+291232.6	193.39197	29.20907	2.141	19.2g
SDSS J125314.44+291556.2	193.31019	29.26562	3.459	19.5g
SDSS J125314.37+291602.6	193.3099	29.26741	3.55	19.2g
TON0133				
SDSS J125100.27+302637.8	192.75115	30.44385	0.933	19.1g
SDSS J125054.85+302541.9	192.72856	30.42832	1.176	19.9g
SDSS J125105.99+302715.4	192.77499	30.4543	1.984	19.6g
SDSS J125106.96+302743.2	192.779	30.46201	2.48	19.2g
SDSS J125020.07+302310.9	192.58363	30.38638	9.033	18.7g
FBQS.J130451.4+245445				
SDSS J130459.32+245548.0	196.24717	24.93003	2.071	19.3g
SDSS J130445.27+245719.2	196.18866	24.95536	2.91	19.9g
NGP9 F379-0188786	196.194	24.84016	4.492	19.16g
SDSS J130507.51+245517.3 196.2813	24.92148	3.688	19.8g	
SDSS J130512.51+245242.6	196.30213	24.87852	5.207	18.8g
SDSS.J130429.04+311308.2				
SDSS J130428.67+311311.2	196.11947	31.21979	0.092	22.0g
MAPS-NGP O_323_0147666	196.12412	31.27387	3.299	18.35
SDSS J130431.67+311725.5	196.13199	31.29042	4.325	19.72
SDSS J130412.89+311357.4	196.05373	31.23264	3.546	19.9g
GALEXASC J130415.22+311713.9	196.06322	31.28699	5.043	18.5
SDSSJ125846.67+242739.1				
1RXS J125847.1+242740	194.69625	24.46139	0.105	17.8
SDSS J125846.50+242746.5	194.69376	24.46293	0.128	21.5g
SDSS J125845.71+242840.8	194.69048	24.47802	1.05	19.8g
SDSS J125840.10+242821.3	194.66709	24.47259	1.649	19.9g
SDSS J125847.38+243153.8	194.69745	24.53164	4.248	19.2g

Table 1: Given are the positions of proposed galaxies to observe, along with the background QSO each galaxy is near, the separation in arcmin from the line of sight to the QSO, and galaxy magnitude in the designated band. Galaxies marked with * have a photometric redshifts available.

How is it Going? *List your allocations of telescope time at MDM during the past 3 years, together with the current status of the project (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. For ongoing projects, are they achieving their goals?*

AE has not had any previous use of MDM.