An Halpha Survey for Star Formation in Galaxy Groups

Why don't galaxies in dense environments form stars? Galaxies in dense environments (groups at moderate densities and clusters at high densities) have lower average star formation rates (SFRs) and less gas than field galaxies out to at least z~1 (e.g. Balogh et al. 1997, Giovanelli & Haynes 1983, Poggianti et al. 1999, Postman et al. 2005). Several mechanisms, each effective in a different density regime, have been proposed for removing gas from and suppressing star formation in galaxies. *Galaxy-galaxy interactions* exhaust the gas supply through a burst of star formation, and are most effective in groups or cluster outskirts, where densities are elevated but relative velocities are modest. The removal of cold disk gas via *ram pressure stripping* by the intracluster medium (ICM) is effective in cluster cores, where both the ICM density and galaxy velocities peak (e.g. Gunn & Gott 1972). *Starvation* within groups and clusters can remove a galaxy's extended hot gas halo, cutting off the gas supply to the disk and halting star formation (Larson et al. 1980). Past studies have mapped the suppression of star formation in the low redshift universe as a function of galaxy environment to distinguish among these mechanisms. As described below, these studies lack crucial resolved data in moderate-density gropus. Our requested Palomar observations are designed to fill this gap.

Mixed Results from Local Surveys: Studies based on the 2dF and SDSS surveys show that the average galaxy SFR starts to decline at moderate densities (Lewis et al. 2002, Gomez et al. 2003). These results suggest that groups are environments that can suppress star formation in galaxies. Since clusters are formed through the hierarchical merging of groups, then any lack of star formation in clusters could be attributed to "pre-processing" in the group environment. In this scenario, the cluster environment itself plays a minimal role in suppressing star formation. On the other hand, spiral galaxies in the Virgo cluster show evidence of cold gas stripping and truncated star formation (Koopmann & Kenney 2004, Dale et al. 2001, Chung et al. 2007), showing clearly that the cluster environment is actively altering the star formation properties of resident galaxies.

A key difference between these results is that the Virgo studies are based on *resolved* Hα or HI maps while both the 2dF and SDDS studies determine SFRs from fiber spectroscopy and are therefore insensitive to processes that preferentially affect the outer radii of galaxies. This is significant because starvation and ram pressure stripping models generally predict that star formation in the edges of galaxies will be affected more strongly than star formation near galaxy centers (Kawata & Mulchaey 2008, McCarthy et al. 2007). Exiting studies lack the resolved maps that could test the importance of these suppression mechanisms in galaxy groups.

Filling the Gap: We propose to fill the gap in the existing low redshift studies described above by extending resolved studies of star formation to cover a much larger range of environments. We propose to obtain rest-frame Hα and R-band continuum observations of a statistically robust sample of nearby galaxy groups spanning a range of X-ray luminosities (tracing the ICM) and velocity dispersions (tracing relative velocities), and for which we already have HI masses and optical spectroscopy. We are targeting groups for two reasons: (1) to fill the gap between existing field and cluster surveys, and (2) to test the importance of group-based transformation mechanisms such as galaxy-galaxy interactions and starvation. The requested Hα imaging will spatially resolve the star formation in the galaxy at the subkpc level, while the requested deep R-band imaging will trace the stellar disk as well as provide continuum subtraction. We will compare rates and spatial distributions of star formation as derived from the Hα imaging to the HI gas masses and line widths, and to the optical properties. We will identify galaxies with truncated star forming disks and HI deficient galaxies, and we will track their incidence as functions of galaxy mass, group X-ray luminosity, group velocity dispersion, group-centric distance, local galaxy density, and morphological signatures of disruption, to find the parameters that most strongly affect galaxies in groups. We will also compare our group results to those in the field obtained by Lee et al., and to results for more massive clusters (Sakai et al. 2012) to sample the full range of galaxy environments.

Our Sample (also see the Table): We start with the RASSCALS group catalog, which itself was selected from the CfA and Southern Sky redshift surveys and cross-matched with the ROSAT X-ray survey (Mahdavi et al. 2000). We select the subset of RASSCALS groups with X-ray detections that overlap with the ALFALFA HI Survey (Giovanelli et al. 2007) and the SDSS Survey. We then select those groups that can be observed within either the [SII] or 6700 narrow band filter. (None are at low enough redshift to use an Hα filter). We are left with 15 groups that span a range in X-ray luminosity ($42 < \log_{10}[L_X \text{ (erg/s)}] < 43.5$) and group velocity dispersion ($250 < \sigma$ (km/s) < 700). Of these, three have already been observed at Kitt Peak. Based on these observations, we estimate that we can observe 1 group per night at Palomar, and that we can expect to get ~50 Hα detections per group. We request 2 nights to observe 2 groups (100 Hα detections) this semester, and plan to request additional nights to enlarge the group sample (up to 600 galaxies) during future semesters. *A large number of galaxies spanning a range of group properties is needed in order to bin with all of the properties described above, to disentangle which are most important.*

Why Palomar?

The virial radii of these groups extend to about one square degree, requiring a large format camera, such as the aptly named LFC. The three groups for which we have already obtained Hα imaging were observed using the MOSAIC camera on the KPNO WIYN 0.9 meter telescope, and this instrument is no longer available. Although the LFC has a smaller field of view than the MOSAIC camera (24 arcmin diameter as opposed to one square degree), the larger area of the Hale telescope means that observing times are much shorter. We find that we can get to the necessary depths with a night per group, which is a reasonable timescale for acquiring a statistically significant sample.

References:

Balogh et al. 1997. ApJ 488, 75* Chung et al. 2007, ApJ 659, L1 * Dale et al. 2001, ApJ 121, 1886 * Giovanelli & Haynes 1983, AJ 88, 881 * Giovanelli et al. 2007, AJ 133, 2569 * Gomez et al. 2003, ApJ 584, 210 * Gunn & Gott 1972, ApJ 176, 1 * Kawata & Mulchaey 2008, ApJ 672, 103 * Koopmann & Kenney 2004, ApJ 613, 851 * Larson et al. 1980, ApJ 237, 692 * Lewis et al. 2002, MNRAS 334, 673 * Mahdavi et al. 2000, ApJ 534 114 * McCarthy et al. 2008, MNRAS 383, 593 * Poggianti et al. 1999, ApJ 518, 576 * Postman et al. 2005, ApJ 623, 721 * Sakai et al. 2013, ApJS 199, 36.

Estimate of the time required:

<u>We need 18 minutes Per Hα Pointing, and 6 minutes per R-band Pointing:</u> Exposure times were estimated in two ways. First, we used the observed performance of the PTF Hα survey on the 48-inch telescope. (None of the clusters have Hα in either of the two PTF Hα filters, which by design probe near redshift zero (Milky Way) and an immediately adjacent continuum level.) The observed limiting magnitude (18.3 AB in 1 minute, for unresolved objects) was scaled for the larger mirror of the 200-inch, converting the limiting magnitude into an Hα flux and ultimately a SFR. We also used the published noise performance of the LFC, taking into account the mirror size, typical seeing, system throughput, and the shape of the SII filter. We assumed a sky continuum level equivalent to an R-band magnitude of 21 magnitudes per square arcsecond, which is the published value from the Palomar website (R-band encompasses the SII filter). Hα fluxes were derived as a function of SFR using the standard conversion of Kennicutt et al, and we assumed that the galaxy continuum contributed 80% of the total flux in the narrow-band filter. The results roughly agree with the scaling arguments form the 48-inch. The derived 10σ sensitivity in a 18-minute exposure is approximately 0.002 solar masses per year per 1 arcsecond resolution element. Put another way, 18 minutes is sufficient to detect at a similar confidence level approximately 1 solar mass per year of star formation distributed over the galaxy body (at this distance a 10 kpc disk subtends roughly 300 square arcseconds). We will need deep R-band imaging of 6 minutes per pointing for continuum subtraction.

<u>We need 10 Hα and 10 R-band pointings to tile each group:</u> The virial radius of a group at the distances observable with the available Palomar narrow band filters subtends approximately one square degree. The field of view of the LFC is 24 arcmin. We therefore need 9 pointings per filter to cover the virial radius. For each cluster, we will take a 10^{th} pointing at a distance of 3 virial radii, to build up a sample that represents the group outskirts.

<u>We will incur 2.2 hours of overhead per group:</u> To remove cosmic rays and cover detector gaps, we need three exposures per pointing, or 60 exposures per group. The readout is 115 seconds if we do not bin. Therefore, readout accounts for two hours overhead per group.

<u>We will incur 0.5 hours overhead per night:</u>
We will obtain 2—3 spectrophotometric standards and 3 Landolt standard fields per night in each filter on photometric nights, requiring half an hour per night.

*For each group we need (10. * 6. * 3. * 115. / 60.) + (10. * 2. * 3. * 115. / 60.) = 460 min = 7.7 hours, or approximately 1 night with enough time to do standards. We request 2 nights to observe 2 groups. We will choose these from among the entries in the Target List that are labeled "Fall". We show additional Fall and Spring targets as the maximum sample that we would request from Palomar.*

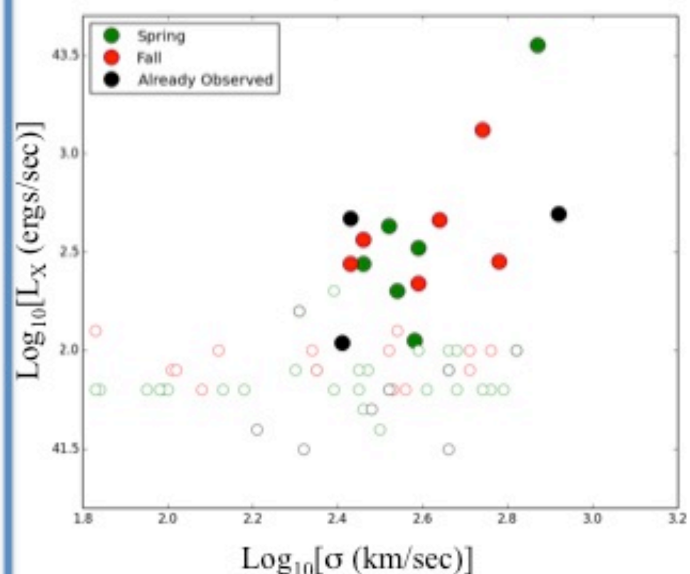

Figure 1. Our group sample spans a range of X-ray luminosities and velocity dispersions (σ). All already have HI imaging and SDSS imaging, and 3 already have Hα imaging from Kitt Peak. With Palomar, we eventually hope to complete the sample of all groups with X-ray detections. (Open circles are X-ray non-detections.) For 2014B, we request 2 nights for 2 of the spring targets.

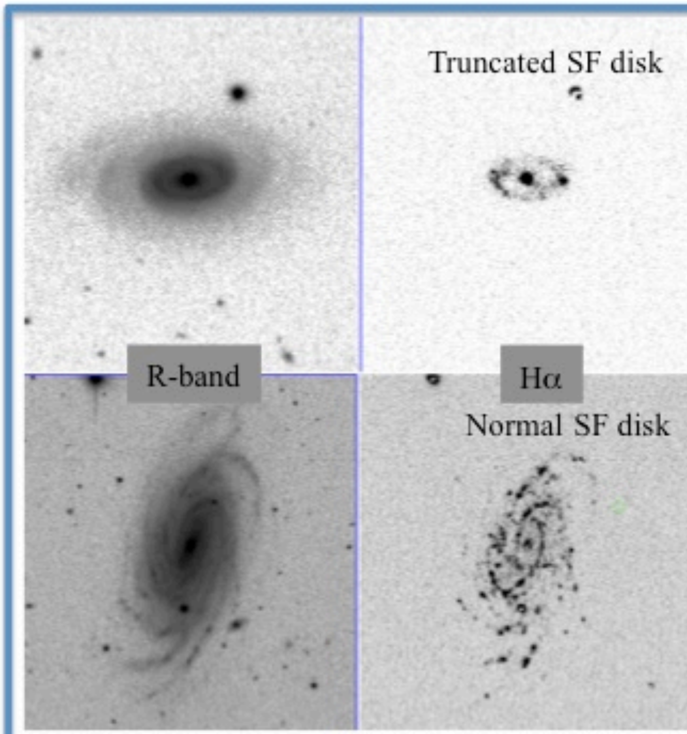

Figure 2. Example of expected depth based on existing imaging. The top row shows a truncated starforming disk. The bottom row shows a "normal" disk.

Group Sample Selection and Characteristics	
RASSCALS **R**OSAT **A**ll-**S**ky **S**urvey **C**enter for **A**strophysics **L**oose **S**ystems	CfA Redshift Survey + Southern Sky redshift Survey→260 groups 61 bright in X-rays (ROSAT) <cz>=7250 km/s <σ> =400 km/s $\langle L(x)\rangle = 3 \times 10^{42} / h_{100}^2$ erg/s
ALFALFA **A**recibo **L**egacy **F**ast **ALFA**	HI masses, redshifts, line widths ~3.5 arcmin resolution; 20 arcsec pointing accuracy $M_{limit}>10^9 M_{sun}$
SDSS	*ugriz* imaging membership for gals with *r*<17.7 Group velocity dispersions (σ) ~1.4 arcsec resolution (0.6—1 kpc)
Palomar Request	R-band continuum observation → stellar structure Rest-frame Hα imaging with [SII] or 6700 nb filter →resolved SFR 5476 < cz (km/s) < 8191 0.44—0.73 km/arcsec ~kpc resolution for ~50 galaxies per cluster

Target List:

RASSCALS Name	RADEC	Recession Velocity (km/s)	$\log_{10}(\sigma)$ (km/s)	$\log_{10}(L_X)$ (ergs/s)	Status
SRGb009	2214480+135017	7812	2.43	42.44	Fall
SRGb013	2250007+114015	7655	2.78	42.45	Fall
SRGb062	0018252+300413	6811	2.64	42.66	Fall
SRGb063	0021384+222420	5665	2.46	42.56	Fall
SRGb145	0231480+011627	6381	2.59	42.34	Fall
SRGb161	0257374+060045	6940	2.74	43.12	Fall
NRGb032	0919480+334532	7473	2.92	42.69	Already Observed
NRGb151	1142094+101630	6265	2.41	42.04	Already Observed
NRGb155	1144446+194159	6706	2.87	43.55	Spring
NRGb177	1204178+201518	7279	2.59	42.52	Spring
NRGb184	1208010+251513	7004	2.54	42.3	Spring
NRGb244	1324108+135847	7245	2.52	42.63	Spring
NRGb247	1329312+114719	7056	2.43	42.67	Already Observed
NRGb251	1334257+344054	7849	2.46	42.44	Spring
NRGb302	1428331+112207	8151	2.58	42.05	Spring

Scheduling Constraints:
We do not require dark time for these observations, but bright moonlight makes it difficult to detect the outermost parts of the galaxies. We therefore request time at least 7 days from full moon.

Previous Palomar Allocations:
The PI has had no previous Palomar Allocations over the last two years.