Science Background: What led to the dramatic decrease in the volume-density of star formation over the last half of the age of the universe to the present time? Many mechanisms have been invoked, from gas strangulation (shutting off the gas supply from inflowing cool filaments), to AGN feedback, mergers and rapid gas depletion. Another process is one involving shocks and turbulence. Our team discovered that galaxies which appear to be transitioning from the blue to red sequence in dense environments often contain large quantities of warm molecular hydrogen heated by shocks (Cluver+13). An extreme example is the intergalactic filament in Stephan's Quintet, which appears to be entirely shock-heated (Cluver+10, Appleton+13), and displays a LINER spectrum in its optical emission line properties (Konstantopolous+14). Alatalo(+14a,+15a) has shown that some of the compact group galaxies contain significant quantities of turbulent molecular gas which seem unable to form stars efficiently, and are moving onto the red sequence without exhausting all their gas. Shocks and turbulence may play a role in halting star formation–at least temporarily. Of course, if the (as yet unknown) source of turbulence is removed, the gas may be able to re-ignite star formation. **We plan to probe the physical conditions of a likely sample of "pure" shocked-dominated galaxies by investigating a rare set of LINER galaxies discovered recently from a large SDSS spectroscopic sample. This is a resubmission because of fog during our 2016A run in May, when most of are targets are visible.**

LINERs are, by definition, the class of galaxies with low-excitation optical emission lines based on commonly observed optical emission line ratios (Heckman 1980, Kewley+06). Fig.1a shows the traditional way of separating galaxies using ratios of strong emission lines. Roughly 7% of all SDSS spectroscopically observed galaxies are LINERS. Unlike traditional AGN, they show low values of [OIII]/Hβ, and enhanced ratios of [NII]/Hα, [SII]/Hα, and [OI]6300/Hα. The nature of LINER emission (Heckman 1980) has always been controversial, with several mechanisms for their excitation being put forward; namely excitation by shock waves (Dopita & Sutherland 1995, Lipari+04), low-luminosity AGN (Ho+97, Kewley+06), or UV excitation by Wolf-Rayet (Shields92) stars or old metal-rich stars (Alonso-Herrero+2000). **Near-IR spectroscopy can help distinguish between photoionization processes and those dominated by shocks.**

Unlike a parallel study going on by our team to sample galaxies with both LINER and post-starburst properties (SPOGS; Shocked Post-starburst Galaxies; Alatalo+14b; Cales+15), this current small project focuses on an population of emission-line galaxies that were discovered when preparing the galaxy sample for the SPOGS project. We discovered an extremely rare class of LINER with high values of -0.6 $<$ [OI]6300/Hα $<$ -0.1 and [OIII]/Hβ $<$ 0.1 (see selection box Fig1a). Their position on the emission-line diagnostic diagram (Fig. 1b) is very similar to that expected from fast, low-density shocks (Fig. 1b; Allen+09, Rich+11), and they share similar properties to regions in the local universe that are known to be heated by large-scale shock waves (Stephan's Quintet; Konstantopoulos+14, or the shocked gas in the interior of the galaxy NGC 1266; Alatalo+15b). Unlike the SPOGs sample, which can be contaminated by Seyfert galaxies, these extreme LINERs lie far from the locus of either star forming galaxies or AGN-dominated galaxies, and are likely to be examples of "pure" shocked galaxies. Out of a sample of 160,000 galaxies from our parent SDSS spectroscopic sample (Oh+11) with high S/N, less than 50 galaxies have been found with these unusually large [OI]/Hα line ratios. These galaxies have the most extreme [OI]6300/Hα ratios of any galaxy in the LINER class of galaxies (see Fig. 1), and have broad (400-500 km/s) line widths similar to that seen in Stephans' Quintet group (See Figure 2a,b).

Science Goals: 1) What is powering the extreme LINERS? Can we rule out galaxies dominated by ultra-low–luminosity AGN with very steep UV power-law continua, or galaxies with many hot stars? If so, they would be unlikely to show evidence of large-scale molecular shocks with kinematically broad lines. Are the galaxies dominated by shock waves?. If so, what is the source of the shock energy? Could they represent a rare form of deeply embedded AGN, in which evidence of the AGN is absent in its usual form (e. g. stong high excitation [OIII]/Hβ emission) but in which the mechanical energy of an AGN-driven outflow appears as shock-like emission lines? (NGC 1266; Alatalo+15b).

2) Resolving Molecular Outflows? With the 115 km s^{-1} resolution of Triple-Spec (R=2600), we will search the galaxies for broad molecular hydrogen, [FeII], or hydrogen recombination lines (Pasα, Br-γ) and compare these line widths with those seen optically in the [OI] line. We would try to distinguish clear outflows from turbulent disk behavior using the spatial information. For shocked galaxies with highly turbulent disks (Ogle+10; Nesvadba+11), we can study how turbulence itself might suppress star formation in the molecular gas.

A key to uncovering the nature of the source of high [OI]/Hα emission is the presence (or absence) of shock waves. Shocks would be apparent through the appearance of both ro-vib H_2 lines (H & K-band) and [FeII]1.64μ lines. The two main excitation routes for ro-vibrational molecular hydrogen emission are UV florescence (from an AGN) and collisions in hot gas in shocks (Shull & Beckwith 1982; Black & Dishoeck 1987), and these can be distinguished by looking at the relative strength of (for example) ro-vibrational line fluxes 2-1S(1)/1-0S(1) (typically 0.1 for T= 2000 K shocks), whereas UV pumping in SF regions leads to much more power in the higher vibrational levels (e. g. 2-1S(1)λ2.25/1-0S(1)λ2.12 $\sim$ 0.5, five time larger than for shocks). Thus these measurements of molecular hydrogen provide an independent way to search for shocked gas. Furthermore, we also expect shocks to be revealed by large [FeII]1.64/Brγemission line ratios (Mouri+1990;2000). Although photoionization and X-rays associated with an AGN could complicate the separation of shocks from SF (XDRs can mimic a wide range of excitation conditions in the H_2), we will use the spatial distribution of the H_2 lines, and line widths along the slit to look for differences in excitation and kinematics away from the nucleus, at least in the brighter objects (Mouri+2000). Most of the galaxies are resolved on the scale of 3-8 arcsecs, and with a long-slit we can see how extended the emission is.

We are in the early stages of understanding how these peculiar galaxies fit into the more general picture of galaxy evolution. Given our ongoing project to study shocked post-starburst galaxies, we will explore whether the current sample is just an extreme tail in the shocked galaxy distribution, or if they are a rare but new class of object. We note that, given the tremendous mapping potential of WFIRST, thousands of these galaxies with similar properties will be potentially discoverable at z = 2 with the WFIRST grism (Appleton 2014 at WFIRST workshop). In the coming revolution of large astronomical data like ZtF, Euclid, SKA etc, locally rare objects may be abundantly studied.

Technical Justification: Based on our experience with TripleSpec in 2015A/B, we can, in 2 hrs of integration, reach deep levels (rms level of $\sim$2 x 10^{-17} ergs s^{-1}cm^{-2} $\AA^{-1}$). We estimated the strength of Pas-α based on the strength of the H-α line seen in the SDSS spectra. The SDSS H-alpha fluxes for our sample are in the range 2-6 x 10^{-18} W m^{-2}. Assuming a canonical extinction of A_V = 1 mag., and case-B recombination, we expect the Pas$\alpha\lambda$1.87 line to be 4x fainter than Hα, so in the range 0.5-1.5 x 10^{-18} W m^{-2}. We make the assumption that the [Fe II] and ro-vibrational lines in H and K band are at least as strong as the hydrogen recombination lines. If longer integration times are needed we will adjust our plans accordingly. Figure 2c shows an example of the detection of several H_2 lines in SPOGS 16183, observed Oct 2-2015B–in 2 hrs, demonstrating feasibility. We should therefore detect our targets at a similar level to the emission seen in SPOGS sample. We will dither along the slit with 300s in an ABBA sequence to maximize S/N. Including overheads, we expect to observe each source (on average) for 2-3hrs, and for 12 targets, we would require three nights of bright time in May 2017 (Table 1). Our successful 2016A proposal (3-nights allocated) was severely affected by fog, and little useful data was obtained. We have two nights scheduled in Oct 2016 (8 targets), but the majority of our sample is centered on LST 12hrs. If successful, this (re-)proposal should provide enough total targets ($\sim$20) for meaningful results to be obtained.

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Previous Palomar runs with T-Spec: were PI'ed by Patrick Ogle (Appleton Co-I) or Pierre Guillard in (3 nights in 2010 and two nights in Oct 2011), (Guillard et al. 2014 and Guilllard et al. 2016). TSPEC time allocated in March 2015A and 2015B have resulted in successful observations of 16 SPOGS in 4.5 clear nights (Fig.2). Our previous successful proposal (2016A) to target these extreme objects was badly affected by severe fog. Only a small number of galaxies were observed in poor conditions. Two nights of 2016B time are pending, but the majority of our high-EW targets are centered around LST 12hrs due to SDSS selection.

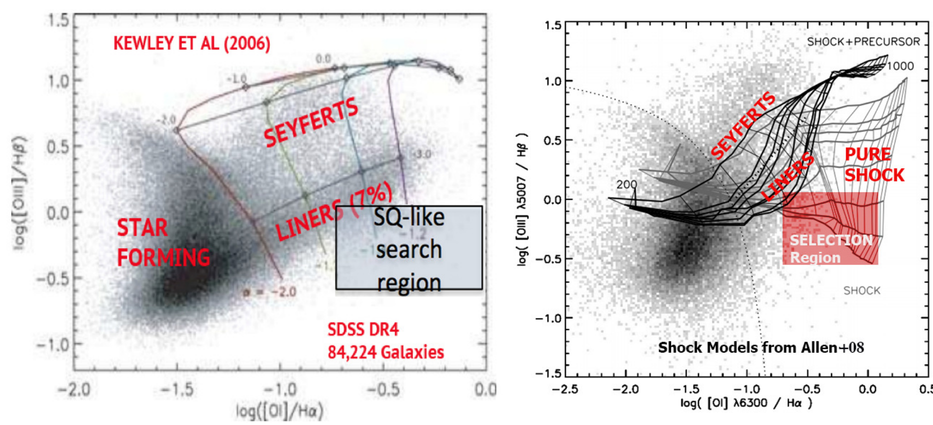

Figure 1: **LEFT: Line diagnostic diagram for galaxies in the SDSS spectroscopic survey (Kewley+2006). We show the region of the LINER galaxies where we found the extreme LINERS proposed in this study. RIGHT: Same diagram showing pure shock, and shock+shock-precursor models from Allen+08). Target galaxies fall in the high-velocity pure shock region.**

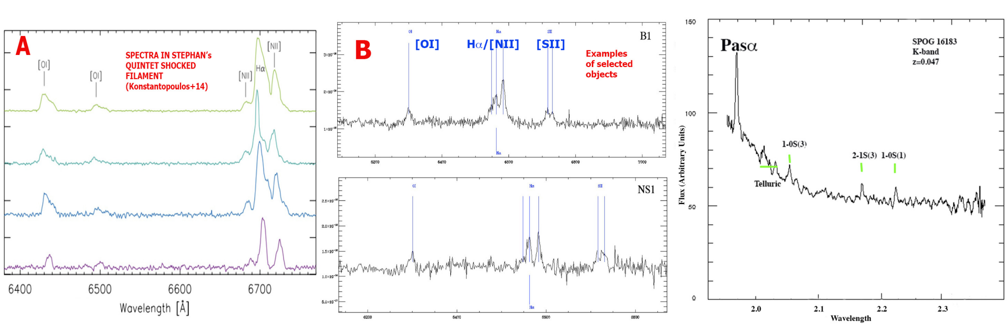

Figure 2: **LEFT: Selected spectra from the shocked gas filament in Stephan's Quintet–very strong [OI] emission and broad lines are detected along the filament. MIDDLE: Sample spectra from our extreme LINER sample showing strong similarities to the intergalactic filament in Stephan's Quintet, despite being entire galaxies at z ∼0.1.RIGHT: Example of 2015B T-Spec observation (K-band) detecting several H_2 lines.**

Target List: Our target list is a subset of ∼50 galaxies galaxies falling in our spectroscopic search area (Figure 1). Most of these targets are visible around 11-14 hrs LST. These galaxies can be feasibly detected on 2-3 hrs (see Figure 2c which had a similar K-band magnitude). Several of the targets have fainter K-band magnitudes yet are very strong H-alpha emitters. These are almost pure line–emitting objects.

BLACKOUT DATES: The PI is out of the country from Dec 02-23 2017

A selection of 12 targets from our larger sample of 50 objects.

Object	**RA (J2000)**	**Dec (J2000)**	redshift	Altname	K_s **(mag)**
SDSSJ122453.69+334424.6	186.22372	33.740185	0.0702552	X11	14.063 *
SDSSJ152548.63+181410.0	231.45264	18.236118	0.12771	X14	14.001
SDSSJ105738.43+371831.6	164.41016	37.308787	0.0422371	X15	13.428
SDSSJ142355.45+262623.2	215.98106	26.43979	0.148236	X17	14.721
SDSSJ162503.91+083432.0	246.26633	8.575565	0.102164	X19	13.787
SDSSJ130738.92+174736.4	196.91218	17.793456	0.031508	X20	14.093
SDSSJ153344.38+131544.7	233.43494	13.26244	0.131864	X22	14.449
SDSSJ111320.50+173541.0	168.33543	17.594743	0.170471	X23	14.668
SDSSJ121427.44+141430.0	183.61437	14.241669	0.15512	X4	14.688
SDSSJ144744.24+422936.8	221.93435	42.493568	0.177449	X6	14.539
SDSSJ161935.41+252021.6	244.89757	25.339349	0.125921	X7	14.699
SDSSJ134414.96+024734.3	206.06235	2.7928848	0.136349	X8	14.562

*Strong emission lines but weak continuum