X-shooter Science Verification Proposal

Caught in the Act: A Rare View of the Formation of Galactic Bulges

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Abstract:

As part of our study of so-called "Lyman break analog galaxies" (LBAs) that were selected to be good local ($z < 0.3$) analogs to young, forming galaxies at high redshift ($z \gtrsim 2$), we have discovered a set of highly peculiar objects not seen before: Some objects consist of an extremely luminous point-like source ("Dominant Compact Object" or DCO) in the middle of a low surface brightness, perturbed disk (Fig. 1). The DCOs are extremely massive ($> 10^9 M_\odot$) and compact (radius $\sim 10^2$ pc), and dominated by star formation and SN feedback (not AGN). The masses, sizes, and densities are similar to the central excess-light seen in cuspy early-type galaxies, but their ages are very young ($\lesssim$50 Myr). We therefore believe that the DCOs represent a rare phase during the dissipative mergers that were common only at high-z and were responsible for the formation of the inner bulges of galaxies. Using the slit mode of XShooter we will be able to observe a wealth of new details, including accurate stellar mass (JHK/NIR), age (H, He absorption lines/VIS), outflows (MgIIλ2800Å/UVB), SN rates ([FeII]$\lambda 1.64\mu$/NIR), SFR (Paα/NIR), WR stars (VIS), velocity dispersions (VIS,NIR), and gas properties (e.g. T_e, N_e, Z/VIS,NIR). Furthermore, XShooter will provide crucial information on the stellar spectral energy distribution from U to K, connecting our FUV spectra (HST/COS) to infrared spectra from Spitzer.

Scientific Case:

Background.– Some of the most remarkable features of high redshift ($z \sim 2 - 6$) galaxies are their small sizes, young ages, and vigorous star formation. Observations of the Lyman-break galaxies (LBGs) with the *Hubble Space Telescope* (HST) indicate that that star formation largely occurs in an extremely "clumpy" mode. These star-forming clumps are reminiscent of star-forming complexes and star clusters in local star-forming galaxies, but their total masses and scale sizes are several orders of magnitudes larger. The formation and evolution of these galaxy "building blocks" are important for understanding the formation of the bulges of spirals and elliptical galaxies and their black holes.

Discovery of local galaxies that resemble high-redshift galaxies.– It would be extremely valuable to study similar processes occurring in nearby galaxies where multi-waveband data with relatively high spatial resolution and sensitivity would allow the relevant physical processes to be probed in much greater detail. Specifically for this purpose, the "Lyman break analogs" (LBA) project was designed in order to search for local starburst galaxies that share typical characteristics of high redshift LBGs (Heckman et al. 2005, Hoopes et al. 2007, Overzier et al. 2008,2009). In brief, the all-sky UV imaging survey performed by the Galaxy Evolution Explorer (GALEX) was used in order to select the most luminous ($L_{FUV} > 10^{10.3}$ $L_\odot$) and most compact ($I_{FUV} > 10^9$ $L_\odot$ kpc^{-2}) star-forming galaxies at $z < 0.3$. The result was a sample of just about 30 galaxies having similarly high SFRs and low extinctions compared to the high redshift LBGs. Even more remarkably, subsequent analysis of their spectra from the Sloan Digital Sky Survey (SDSS) has shown that the **LBAs are similar to high-redshift LBGs in all of their basic physical properties**: e.g., mass, size, metallicity, dust extinction, SFR, gas velocity dispersion and ISM properties. We studied our sample in the UV-optical with HST, finding that also the morphologies of LBAs resemble those of typical high-z galaxies. In particular, **a number of objects was discovered in which the UV images are dominated by an extremely bright, compact star-forming object, surrounded by a disturbed envelope or disk seen in the optical (Fig. 1).** We will use XShooter to explain the remarkable properties of these dominant central objects (DCOs).

Are DCOs rare, forming cusps of early-type galaxies?.– The DCOs are only marginally resolved in the HST images (see Fig. 1), with implied radii of no greater than ∼100 pc. The high masses of $\sim 10^9$ $M_\odot$ we derived for the DCOs combined with the strong constraints on their small effective radii yield very high mass surface densities of $\Sigma_M = M_*/(2\pi R_e^2) \approx 10^{10} - 10^{11}$ $M_\odot$ kpc^{-2}. They thus have masses and sizes that are 1–2 orders of magnitude greater than those of typical nuclear star clusters.

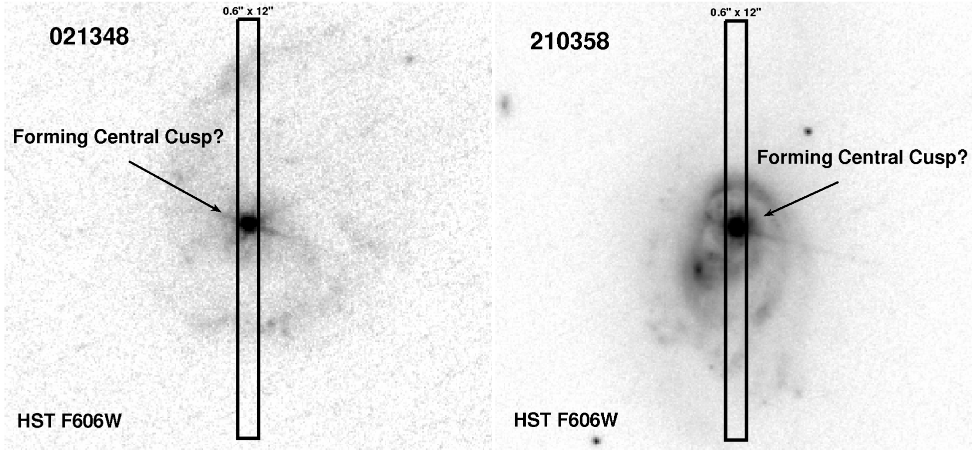

Figure 1: Fig. 1: Puzzling massive ($> 10^9\ M_\odot$, compact ($R_e \sim 100$ pc) star-forming objects found in the cores of two perturbed galaxies. These Dominant Compact Objects (DCOs) are not AGN or star clusters but share the basic characteristics of the massive "cuspy cores" found in low-mass early-type galaxies. Their young ages of 5–50 Myr suggest that they could be a rarely seen, early stage of bulge formation following a dissipative merger and the onset of a starburst. The DCOs are bright and contain numerous stellar and interstellar features in the UV, VIS and NIR making them well-suited for XShooter follow-up.

However, they are very similar to the so-called central "cusps" or "extra light" component seen in local elliptical galaxies (e.g. Kormendy 2009). These cusps have effective radii of $\sim 50 - 500$ pc and are typical for relatively low-mass ($\leq L_*$) ellipticals. It is believed that the extra light/cusp components are very likely the evolved remnant of a massive central starburst in a dissipative ("wet") merger, consistent with the disturbed optical morphologies we see. Our FLAMES Hα spectra further show that the DCOs have large outflows due to the winds from massive stars and SN, consistent with a preliminary estimate for their ages of ∼5–50 Myr determined from their HST colour. We therefore believe that these objects are present-day examples of the massive, feedback-regulated starbursts that must have occurred frequently only at high redshift. We propose to use XShooter to assess numerous specific details.

XShooter study of the DCOs.– Making good use of the entire XShooter bandwidth, we will be able to get immediate constraints on a great number of relevant details. Because the DCOs are so compact (<0.5") we can use the slit and compare galaxy properties "on" and "off" the DCOs. We list some of the immediate objectives below, ordered according to spectral region as probed by XShooter:

UVB ARM

- Starburst-driven outflow speeds from Hα relative to the MgIIλ2800Å interstellar absorption line (see Tremonti et al. 2007).
- Determine the spectral shape from the far-UV (GALEX) to U (relevant for extinction and SFR).

VIS ARM

- Constrain the ages of the DCOs based on the equivalent width of H and He absorption lines (see Gonzàlez Delgado et al. 2005).
- Measure the properties of Wolf-Rayet stars (known to be present in at least 210358).
- Determine the spatial variation in dust and the physical conditions of the ISM.

NIR ARM

- Direct measurement of the supernova rate using the strength of the [FeII]$\lambda 1.64\mu$ feature.
- Unextincted star formation rate based on Paα.
- Measure [SIII]$\lambda\lambda$9069,9536 (sensitive to, e.g., metallicity and the effective temperatures of the hottest stars delivering the radiation field, see Kennicutt et al. 2000).
- Presence of warm molecular gas using H_2 lines.
- Determine the peak stellar emission and the stellar mass of the DCO.

These data will allow a full understanding of these peculiar objects, and will serve as a guide to interpret both their evolved counterparts in the nearby Universe as well as their analogs at high-z that do not allow similarly detailed studies.

Calibration strategy: Telluric and spectrophotometric standards.

Targets and number of visibility measurements

Target	RA	DEC	V mag	Mode (slit/IFU)	Remarks
210358	21:03:58.75	–07:28:02.45	17.8	slit 1.0”	$z = 0.137$; Priority 1 (June–August all night)
021348	02:13:48.54	+12:59:51.46	18.9	slit 1.0”	$z = 0.219$; Priority 2 (August morning)

Time Justification: Our targets have well-known continuum fluxes in all of the UV/VIS/NIR from HST, SDSS and 2MASS. We also have good information on at least the optical continuum and emission line fluxes based on the 40 minute 2.4m SDSS fiber (3” diameter) spectra. The Table below lists the brightness of some prominent features in all of the three arms that we have based our S/N calculation on. For our Priority 1 target (210358) and assuming a total exposure time of ≈ 3×900s=2700s we will reach a $S/N \sim 10$ at the blue end of the UVB arm, $S/N \sim 30-40$ and ~ 100 for, resp., the continuum and the Hα flux of the compact object in the VIS arm, and $S/N \sim 10-100$ in the range J, H, K in the NIR arm. These S/N will be sufficient to look for the absorption and emission line features and continuum components described above. At a $z = 0.137$, some of the most relevant wavelenghts are 3182Å (MgII), 5328Å (WR features), 7462Å (Hα), 1.03/1.08μ ([SIII]), 1.87μ ([FeII]) and 2.13μ (Paα).

Our second target (021348) is fainter but its redshift is slightly higher ($z = 0.219$) making it easier to detect the redshifted MgII feature at 3413Å. This object has a larger fraction of its total continuum and emission line flux inside the unresolved compact core, increasing the efficiency of the observations somewhat despite the fact that it is fainter. We propose 4×900s=3600s of exposure time, pending the outcome of the priority 1 target.

Continuum and Line Fluxes

ID	Redshift	U_{tot} (mag)	V_{DCO} (mag)	Flux Hα (erg s^{-1} cm^2)	J, H, K (mag)
210358	0.137	16.3	17.8	4×10^{-14}	15.0,14.4,13.9
021348	0.219	17.8	18.9	2×10^{-15}	16.7,15.7,15.1

Note: Although we did not yet submit a proposal for Period 84, we are very much interested in working together with the Science Verification Team to study the efficiency and capabilities of the instrument whilst learning new details on our objects. XShooter appears to be the perfect instrument for the follow-up of such bright starburst galaxies.

References: Heckman, T. et al. 2005, 619, L35 • Hoopes, C. et al. 2007, ApJS, 173, 441 • Overzier, R.A. et al. 2008, ApJ, 677, 37 • Overzier et al. 2009, ApJ, To Be Submitted • Kormendy, J. 2009, ASPC Conference Proceeding (arXiv:0812:0806) • Gonzàlez Delgado, R. et al. 2005, MNRAS, 357, 945 • Kennicutt, R. et al. 2000, ApJ, 537, 589 • Tremonti, C. et al. 2000, ApJ, 537, 589