Previous and current research

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Overview

My main line of work is currently in spectroscopic ISM diagnosis of nearby young, star forming galaxies; mainly in the Lyman Alpha Reference Sample (LARS), for which I have written one paper (Rivera-Thorsen et al., 2015) and made contributions to others, in particular Östlin et al. (2014). The work on LARS alone has taken me around analysis of UVB metal absorption lines in HST-COS spectra, HII region diagnostics from Balmer- and forbidden emission lines in optical SDSS spectra, and VLA 21 cm HI interferometry (Pardy et al., 2014). Currently, I am working on a high-detail analysis of Balmer- and forbidden nebular emission in X-Shooter spectra of the (confirmed and suspected, respectively) Lyman-continuum leaking starburst galaxies Haro 11 and ESO 338-IG04.

This work combined has formed a broad and solid knowledge base on star-forming galaxies, Lyman-α radiative transfer, galaxy and galaxy population evolution with redshift, its impact on reionization, etc. This, and my familiarity with HST data, in turn provides an solid basis for working in the BoRG project.

LARS: Gas kinematics and geometry in nearby star-forming galaxies

As part of the Lyman Alpha Reference Sample (LARS, a sample of 14 + 42 star/forming galaxies at $0.03 < z < 0.3$ selected for high star formation, Hayes et al., 2013, 2014; Östlin et al., 2014), I led an analysis of HST-COS spectra of the sample galaxies focusing on the kinematics and geometrical configuration of the neutral ISM. We computed systemic velocities of the sample galaxies from re-measured nebular emission lines in SDSS spectra of the sample galaxies (a number of galaxy properties like metallicity etc. derived from these lines were published in the first LARS paper (Östlin et al., 2014)), and measured bulk in-/outflows of the neutral and hot ISM from, mainly, SiII and SiIV absorption lines.

Furthermore, we applied the Apparent Optical Depth method (e.g. Savage & Sembach, 1991; Pettini et al., 2002; Quider et al., 2009) as implemented by Jones et al. (2013), to disentangle opacity and covering fraction of the neutral gas in metal absorption lines. This method allows a mapping of covering fractions in velocity space, $f_C(v + \delta v)$. Figure 1, lower panel, shows $1 - f_C$ of LARS 1 in red dots, overlaid on the stacked LIS profile. The fact that the combined absorption is almost the same as the covering factor in each bin suggests that gas at any velocity is opaque to the background light, but only covers it partly. However, since gas at different velocities generally does not occupy the same projected area, f_C only provide a lower limit to the total covering fraction. However, a low $f_C^{\max}$ may imply a higher *probability* of finding direct sight lines through the neutral medium. See Rivera-Thorsen et al. (2015) for details. We finally compared the properties found through spectroscopy, to global properties derived from HST-ACS imaging (Hayes et al., 2014) and VLA 21 cm HI radio interferometry (Pardy et al., 2014). Interestingly, we found a strong anticorrelation between f_C^{max} and Hα equivalent width; something we tentatively interpreted as indicating that feedback from strong star formation activity may drive Rayleigh-Taylor instabilities in the outflowing medium, causing it to fragment. This analysis is going to be revisited with new observations from the ongoing extended LARS (eLARS) COS campaign.

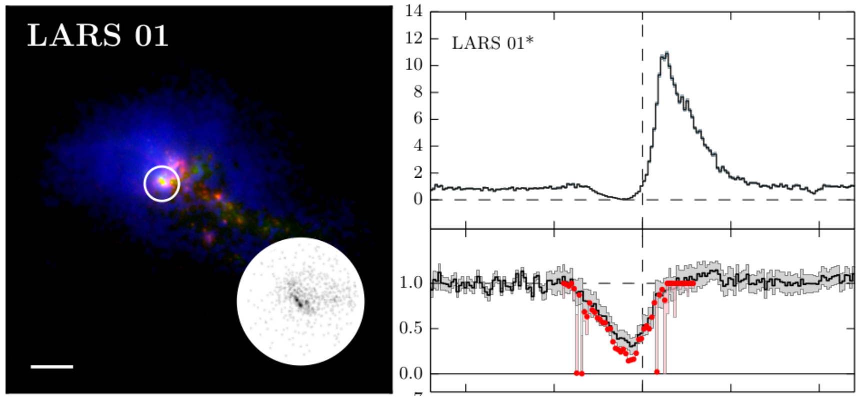

Figure 1: **Left panel:** Color composite of LARS 1 with the COS aperture overlaid. Inset is the COS acquisition image. **Right panel:** Lyα profile (up) and stacked LIS absorption profile (down, in thick black). Red dots mark $1 - f_C$. Both from Rivera-Thorsen et al. (2015).

Besides the LARS galaxies, this analysis has also been applied to the nearby galaxies Haro 11 (see also below) and Tololo 1247-232. Both are classified as Blue Compact Galaxies, and are the only known leakers of Lyman Continuum radiation in the nearby Universe (Bergvall et al., 2006; Leitet et al., 2011, 2013), although Jaskot & Oey (2014) have suggested 2 new candidates for nearby LyC leakers. The inferred kinematic properties and velocity binned covering fractions for Haro 11 and Tololo 1247 have not yet been published, but have been reported by Prof. Göran Östlin at the IAU meeting in Honolulu, Hawaii, August 2015, and the results for Tololo 1247 will be included in an upcoming paper (J. Puschnig et al., in prep.).

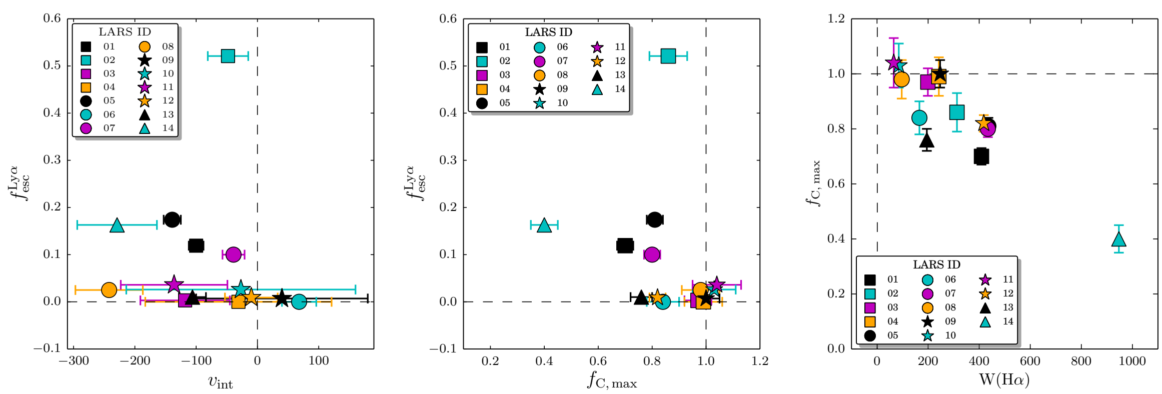

Figure 2: Main findings of Rivera-Thorsen et al. (2015). **Left panel**: Statistically, outflow velocity and Lyα escape fraction are uncorrelated; but only galaxies with a bulk outflow velocity $v \gtrsim 50$ km s^{-1} show any noticeable Lyα escape. **Middle panel**: The picture is similar for the dependence of Lyα escape on f_C: There is only a very weak correlation, but a clear tendency that galaxies with $f_C \gtrsim 90\%$ are opaque to Lyα, although a lower maximum f_C does not guarantee any significant escape. **Right panel**: Rather to our surprise, we found a clear anticorrelation between maximum f_C and *global* Hα equivalent width. The same tendency, albeit weaker, is visible if the in-aperture values of Hα EW found from SDSS spectroscopy is used. We tentatively interpret this as a result of strong stellar feedback creating a clumpy, porous medium.

Spatially resolved nebular emission in long-slit spectra of Haro 11 and ESO 338

Currently, I am in the late stages of an analysis of nebular emission features in a set of VLT/X-Shooter spectra of the galaxies Haro 11 and ESO 338-IG04. Haro 11 is one of only two confirmed Lyman Continuum leaking galaxies in the local Universe (the other being Tololo 1247-232, Leitet et al., 2011), and ESO 338 is suspected to be leaking too, but has too low redshift to have its UV continuum and Ly α accurately studied with current equipment. Interestingly, both galaxies show the kind of strong nebular emission and low metallicity that could probably have them classified as Green Peas if observed at (significantly) greater distance. Observations of these galaxies were performed under very good conditions and have a signal/noise ratio which allows for each pixel row to be extracted separately.

To help with the modeling, I wrote an application tentatively named `grism`; an interactive inspection, exploration and analysis tool designed for this particular project but with future generalization of scope in mind. For each spectrum, each pixel row is extracted as a separate spectrum, and the desired transitions modelled, after which the model is controlled for continuity between neighboring regions in both centroid position, line width and emission strength, and adjusted as necessary. Each component is assigned an ID which can then be used to match components believed to arise from the same physical subsystem. If the data is good enough, this can be used to map line ratios and e.g. metallicity, ionization parameter etc. to each component.

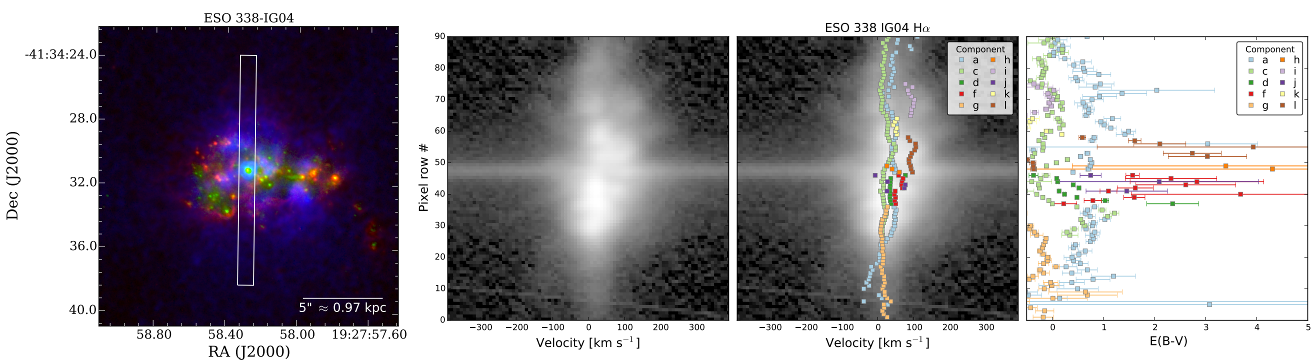

Figure 3: **Far left**: Approximate slit placement for ESO 338. Blue in the color composite image denotes continuum-subtracted Lyα; red Hα, and green FUV continuum. Image data from Hayes et al. (2009); Östlin et al. (2009). **Middle left**: The combined spectrum of ESO 338-IG04 zoomed in on Hα. Colors are scaled logarithmically with cut levels set to enhance detail. **Middle right**: Same, overlaid with centroids of the Gaussian components of the model, with colors being assigned for identification. **Far right**: Dust extinction from $H\alpha/H\beta$ of each component mapped along the slit. While some components are a little hard to interpret, others are clearly separated, probably reflecting depth structure. Figures from Rivera-Thorsen et al. (in prep).

As an example, Hα in ESO 338-IG04 is shown without and with model overlaid in the two middle panels of figure 3. The strong activity of the medium is evident in this plot. Centroid colors are assigned for identification to any group of components which shows reasonable continuity in all of its fit parameters. These labels can then be used to match a component to components believed to arise from the same physical source in e.g. higher-order Balmer lines and other nebular lines. A proof-of-concept of this is shown in figure 3, in which the components shown in fig. 3 above are matched with corresponding components in Hβ to compute color excess for each component, mapping them in depth. Similarly, we are currently in the process of mapping e.g. electron density, temperature and metallicity in the same way. A paper showing this and mapping other properties derived from nebular emission is in preparation.

Other

For my Masters thesis project, I analyzed the absorption features left by a $z = 2.4$ DLA system in a $z = 3$ QSO spectrum observed with the X-Shooter, under supervision of Dr. Johan Fynbo, DARK Cosmology Centre, Copenhagen, Denmark. I have spent a couple of months reducing and cleaning VLA interferometry data for Pardy et al. (2014) in collaboration with Dr. John M. Cannon, and have worked a little on Supernova spectroscopy and imaging data of galaxy fields (the latter for a student project immediately before my Masters thesis project).

Summary & future opportunities

I have a quite solid experience with the properties of star-forming galaxies at low redshifts, including some work with Green Peas and nearby (confirmed or proposed) Lyman Continuum leakers (Haro 11, ESO338-04, Tololo 1247), which seems to be of quite good relevance to both the BoRG, GLASS and RELICS surveys; and with LARS, I have extensive experience with ISM diagnosis regarding Ly-alpha radiative transfer, which is also highly relevant to the question of ionizing radiation escape. I have in LARS benefited from close collaboration with people modeling Ly-alpha radiative transfer, both in idealized and more realistic gas configurations and comparisons with observations (e.g. Dr. Anne Verhamme, Dr. Peter Laursen, Dr. Florent Duval, Dr. Ivana Orlitova); as well as people working on comparisons of these low-redshift galaxies to high-redshift objects in e.g. the Frontier Fields (e.g. Dr. Matthew Hayes, Mr. Andreas Sandberg, Dr. Lucia Guaita). I am not a software-oriented astrophysicist, but do have well above-average programming experience; enough to make the way from idea to implementation short. Not least, I have lately gotten increasingly interested in strongly Ly-alpha and -continuum emitting galaxies, both at high redshift and nearby galaxies.

I think the BoRG project looks like a very interesting opportunity for me. It is new territory, but new territory for which I am well equipped, and I have been curious about moving into high-redshift work for quite some time. Conversely, I believe I have a great deal of experience, creativity and team spirit to contribute to the group, and hope I can be considered for the position.

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