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NEUTRAL ISM, LYMAN-ALPHA AND LYMAN-CONTINUUM IN NEARBY STARBURST HARO 11[1]

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ABSTRACT

Star forming galaxies are believed to be the main source of ionizing radiation responsible for reionizing the early Universe. Direct observations have however been few and with escape fractions far below what would be necessary to account for the ionization history of the Universe. Especially in the local Universe, only a few handfuls of emitters have been observed with typical escape fractions of a few percent. It seems the mechanisms regulating this escape need to be ones that are strongly evolving with redshift, if galaxies are to be held responsible for the reionization. Gas mass, star formation feedback and thus star formation activity are among the main suspects, known to both regulate neutral gas coverage and evolve with cosmic time. In this paper, we present a reanalysis of far-UV HST-COS spectra of the first detected Lyman-continuum leaker in the local Universe, Haro 11, in which we examine the connections between Lyman-continuum leakage and Lyman-α line shape and feedback-influenced neutral ISM properties like kinematics, geometry and column density. In particular, we discuss the two extremes of an optically thin, density bounded ISM and a riddled, optically thick, ionization bounded ISM and how Haro 11 fit into the theoretical predictions made from these models. We find that the most likely ISM model for Haro 11 knot C is one of clumpy neutral medium with a highly ionized interclump medium with a combined covering fraction of near-Unity and a with a residual neutral gas column density of $XXN_{HI} < XX$, high enough to be optically thick to Lyman-α, but low enough to be at least partly transparent to Lyman-continuum.

1. INTRODUCTION AND OBSERVATIONS

1.1. *Background:*

1.2. *About Haro 11:*

Some of the same stuff as in Rivera-Thorsen et al. (in prep.) could be mentioned, with a different emphasis. Star formation rate should be mentioned from Adamo et al. (2010). Population from same and from Micheva et al. (2010). Knots named by Vader et al. (1993), and also mentioned by Kunth et al. (2003). It's an LBA (Hoopes et al. 2007), and an LAE analog (Hayes et al. 2007; Leitet et al. 2011). Knot C a strong Lyα emitter (Hayes et al. 2007), and also a LyC leaker [Bergvall et al. (2006); Leitet2011]. Kinematics, it's a merger (Östlin et al. 1999, 2001, 2015). More weight on the Lyman-α escape thing, and LyC. Mention Lyα escape and the history here, too? References:

This observation is first (?) published in Alexandroff et al. (2015), and also in Verhamme et al. (2015) in which the Lyα profile is dicussed as a .

This observation is part of the sample in Alexandroff et al. (2015), in which details about observation and data reduction are described in depth; we pint the reader there for further information about these. The Lyα profile in this spectrum is discussed in Verhamme et al. (2015). Heckman et al. (2011), Heckman et al. (2015). Jaskot & Oey (2013), Jaskot & Oey (2014). Bouwens et al. (2012).

In this paper, we analyze HST-COS spectra of knot C in Haro 11. The observations were done as part of HST program GO 13017, PI Timothy Heckman. The spectrum has first been published by Alexandroff et al. (2015), a sample paper in which an attempt is made of

2. ANALYSIS

2.1. *Individual lines*

Figure 1 shows the individual profiles of the transitions included in our analysis; the upper panel shows transitions of Si II, lower panel of Si IV. It is plainly visible that the ionization fraction is high, with the Si IV curves being considerably deeper than the low-ionized lines. Looking at the upper panel, Si II $\lambda\lambda1304, 1526$ are somewhat shallower than Si II $\lambda1260$. The former two lines have comparable resonator strengths, both about a factor of 10 lower than that of $\lambda1260$. It is thus clear that we do not find ourselves in the optically thin regime, in

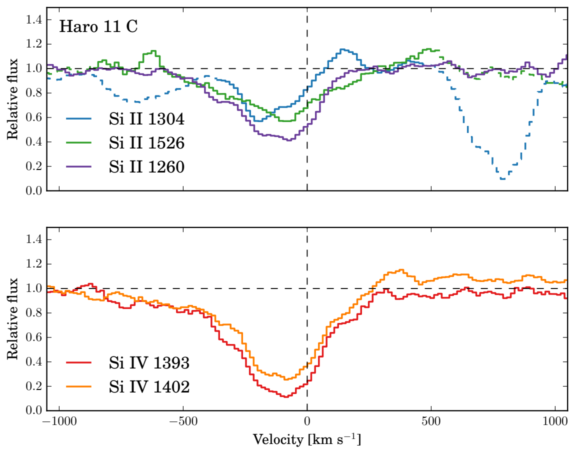

Figure 1. The Si II (**upper**) and Si IV (**lower**) profiles included in this study.

which the latter line should be correspondingly around 10 times stronger; on the other hand, it is possible that the two weak lines are not completely saturated. In the lower panel, the two lines have resonator strengths within a factor of 2 of each other. They are thus at first glance consistent with a medium that is not completely opaque, but not with an optically thin one. The stronger absorption in Si IV reveals a high level of ionization of the medium covering the central cluster.

2.2. N_{Si} *and* f_C

Following the method described in Rivera-Thorsen et al. (2015); we have performed fits for column density and covering factor in each velocity bin, for both the high- and low-ionization state. The results are shown in fig. 2. The upper panels show the pseudo-reduced χ^2 as defined in Rivera-Thorsen et al. (2015) ($= \chi^2/(\mathrm{DOF}+1)$) for each bin, middle panels show the inferred column density in each bin, with surrounding shaded columns showing the confidence intervals. In the lower panels, the mean LIS line profile is shown in black with gray shaded uncertainty intervals. On these are overlaid the best-fit values of f_C as colored dots, with surrounding shaded bars showing the confidence intervals. We again caution that f_C is the covering fraction of HI atoms *within the given velocity bin*, and hence only provides a lower limit for the total, geometric neutral gas covering fraction, since gas at different velocities generally does not occupy the same projected area.

3. DISCUSSION AND CONCLUSIONS

3.1. *Lyman-α and neutral absorption profiles*

Bla bla bla Bla bla bla

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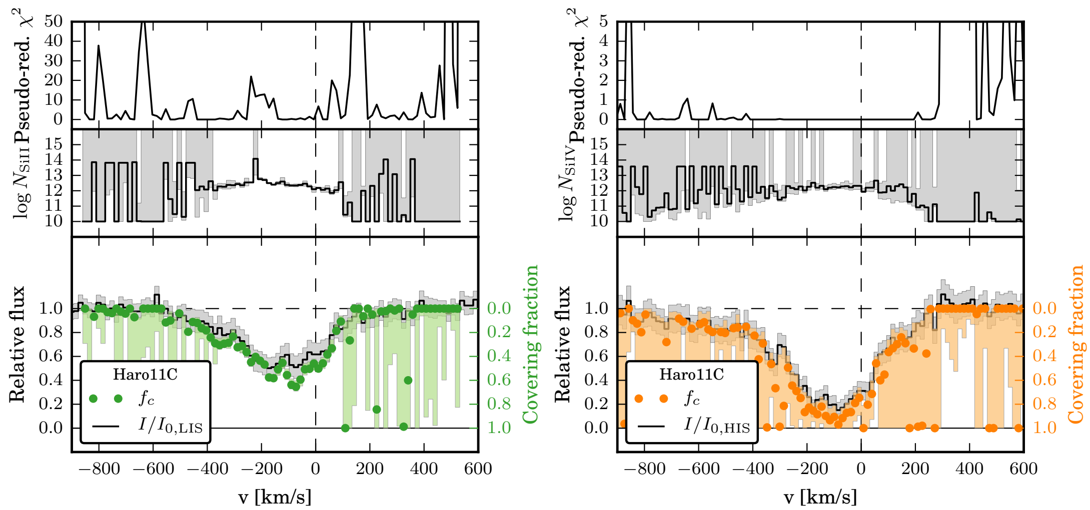

(a) LIS (b) Si IV

Figure 2. **Upper panels**: Pseudo-reduced χ^2 as described in Rivera-Thorsen et al. (2015). **Middle panels**: Best-fit ion column density with confidence intervals in shaded gray. **Lower panels**: Mean LIS/Si IV profile shown as black steps, with inferred f_C shown with yellow dots. Lighter shaded columns show confidence intervals for both.

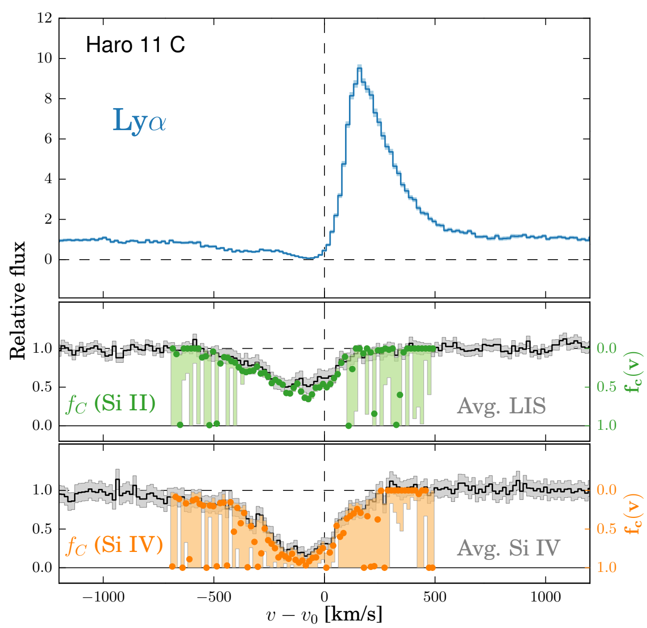

Figure 3. **Upper panel**: Lyα profile of Haro 11 C, in approximate units of the surrounding continuum level. Full line is the measured values smoothed by a 5 px. flat kernel; surrounding shading encloses the $\pm 1\sigma$ error band. **Middle panel**: Black steps show the averaged, LIS line profile, smoothed by a 5px kernel. Surrounding gray shading denotes the $\pm 1\sigma$ confidence band. **Lower panel**: Same as middle panel, but for the Si IV transitions.