# Lyman-alpha Emission from other Galaxies

***Gagandeep Anand***

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## 1 Introduction

The Lyman-alpha (or Ly-$\alpha$) transition occurs when an electron in the *n=2* state of a hydrogen atom drops down to the *n=1* state. This transition results in the emission of an ultraviolet photon with a wavelength of $\lambda\sim$121.6 nm. As hydrogen is by far the most abundant element in the universe at all epochs, one would expect the Ly-$\alpha$ transition to occur frequently in all galaxies. However, not all galaxies are seen to be Ly-$\alpha$ emitters (LAEs), which is defined by a galaxy having an equivalent width of the Ly-$\alpha$ line of at least 20Å. This is a curious result, as clearly all galaxies must emit Ly-$\alpha$ radiation. So, there must be some selective mechanism by which the Ly-$\alpha$ transition is visible to us from some galaxies, but not others. This in itself is important to understand, because this mechanism could come into play in other processes as well. By comparing LAEs to their non Ly-$\alpha$ emitting counterparts, we can gain insight into how galaxies evolve and what physical properties distinguish these two populations. Additionally, LAEs are also important as probes for cosmology. They can be used to probe the epoch of reionization, which is when the majority of the hydrogen present in the universe was reionized. This is an important era in Big Bang cosmology, and is thus crucial to our understanding of the entire theory. LAEs can also be used to examine the evolution of dark energy (Koehler 2009), and thus it is crucial we develop a solid model for their existence and emission.

## 2 Observing the Ly-$\alpha$ Transition in Galaxies

The fundamental Ly-$\alpha$ transition cannot be seen at its rest wavelength from the ground, and thus must be observed with space-based instrumentation. These observations are difficult for a variety of reasons, with the first being a relative paucity of telescope-instrument combinations, especially in the present era. The most prominent of these is *HST*, which is notoriously oversubscribed. In addition to limited observing tools, Ly-$\alpha$ emission is often overshadowed by geocoronal emission, while also being affected by the HI absorption from the Galactic center (Barnes et al. 2014).

For these reasons, Ly-$\alpha$ emitting galaxies are often observed at redshifts where the Ly-$\alpha$ transition is shifted into the optical/near-infrared portion of the electromagnetic spectrum ($2\leq z\leq 7$). Looking at galaxies in this redshift regime allows us to make use of many ground based observatories (Hobby Eberly Telescope, Keck I+II, etc.), as well as additional space-based observatories (e.g. *Spitzer*). It it thus no surprise that the vast majority of Ly-$\alpha$ emitting galaxies have been found in the high-redshift universe ($z\geq 2$). To date, there have been more than 50 surveys to search for Ly-$\alpha$ emitters. Collectively, these surveys have found more than 3300 galaxies that are considered Ly-$\alpha$ emitters (Barnes et al. 2014).

# 3 Ly-$\alpha$ Emission from Galaxies in the High-Redshift Universe

The current number of known LAEs are a fairly small portion of the overall galaxy population in the local universe (~5%). However, this fraction increases out to ~30% at z~6 (Hayes 2015). For this reason, it is important to study them to find out what makes them so uncommon in the local universe, but much more common out at higher redshifts. It is thus no surprise that this field has been increasing in popularity as of late- a simple title search for "Ly-$\alpha$ Emitter" on ADS results in over 4000 refereed publications over just the past five years.

## 3.1 LAEs- Compact star forming galaxies?

One study by Malhotra et al. (2012) compared properties of 343 LAEs (2.25≤z≤6) to a sample of 100 Lyman-break galaxies at similar redshifts. Lyman-break galaxies (commonly referred to as LBS, or sometimes Lyman dropouts) are galaxies that dropout in certain photometric bands. The majority of their emission is upwards of the Lyman limit (912Å)- when the filter is looking at emission that is lower than the rest-frame Lyman limit, the galaxy disappears. The reasons for the large amount of emission at energies lower than the Lyman limit is simply due to the fact that these galaxies are undergoing large amounts of star formation, which means they have large reservoirs of hydrogen gas.

Due to basic atomic physics, this hydrogen gas can only absorb and re-emits photons with energies less than that of the Lyman limit. Now, since these galaxies are actively forming stars, a small portion of them are high mass O&B stars (due to the IMF). These high-mass stars are emitting radiation at wavelengths lower than the Lyman limit, but this radiation is easily absorbed by other neutral gas present in these galaxies. For these reasons, the "dropout" effect is observed when observing these galaxies at wavelengths less than their rest-frame Lyman limit. It is important to note that these are otherwise regular star forming galaxies- it is simply their selection technique that classifies them as Lyman-break galaxies. Since these galaxies are often found through deep ground-based photometric surveys, they are often found in the high-redshift universe (z≥2). This is because if we want to observe the Lyman-break from the ground, it must be redshifted into the optical/near-infrared instead of its rest-frame ultraviolet (similar to Lyman-$\alpha$ emitters).

The goal of this study was to find what differentiates LAEs from LBGs, as well as other populations of galaxies. The team took data from multiple surveys with rest-frame UV coverage. An interesting finding from this study is that LAEs are compact relative to other galaxies at every point in redshift space, at least in the rest-frame UV. This is is certainly a fascinating result. The notion that LAEs are more compact than their regular LBG counterparts indicates that the mechanism for Ly-$\alpha$ escape may very well be tied to the physical size of these galaxies in such a way that it is easier for Ly-$\alpha$ to escape from smaller systems. One can think of this in terms of a simple random-walk process. If we increase the size of the cloud (in this case the galaxy), it will take much longer for the photon in question to escape and thus be detected by an outside observer. Additionally, this increases the likelihood that the photon will simply be absorbed by a dust grain instead of resonantly scattered.

The paper postulates a few additional mechanisms for why LAEs are found to be more compact than other star-forming galaxies. One idea is that the galaxies that are smaller are also ones with lower metallicities, and hence contain less dust that could prevent the escape of Ly-$\alpha$ photons. Another possibility is that since large galaxies are more likely to contain more active starburst regions, which would then cause disturbed gas flows throughout the galaxy. This could in turn lead to less Ly-$\alpha$ photons that escape, which in turn makes it harder to measure the Ly-$\alpha$ emission from larger galaxies.

## 3.2 Recent Studies- Another mechanism for escape?

A more recent study by Hagen et al. (2016) puts into question the results of Malhotra et al. (2012) and others who have made the claim that LAEs are intrinsically smaller galaxies with lower dust abundances. This paper attempts to look at population of LAEs at z$\sim$2, and compare their physical properties to those of optical emission line galaxies (oELGs) at similar redshifts. The team compared the properties of 245 of these oELGs found in the COSMOS, GOODS-N, & GOODS-S surveys to those of 28 LAEs found in the Hobby Eberly Telescope Dark Energy Experiment's (HETDEX) Pilot Survey (HPS) and the Extended Chandra Deep Field-South (ECDF-S).

This paper by Hagen et al. (2016) examined the physical properties of these two populations of galaxies (oELGs and LAEs). They measured characteristics including star formation rates, ellipticity, half-light radius, nearest neighbor distance, stellar mass, and [O III] luminosity. They intriguing finding was that there are no statistically significant differences between the selected samples of oELGS and LAEs, at least in terms of these characteristics. These findings are at least somewhat conflicting to the ones from Malhotra et al. (2012), who found that LAEs are smaller and less dustier than typical galaxies at a large range of redshifts. This paper by Hagen et al. (2016) points to many other recent papers, which have found LAEs with a large range of stellar masses and dust content levels.

The overall result from this team's work is that the idea that LAEs are small, dust-poor galaxies is an antiquated one, and that we need to consider other radiative transfer models for how Ly-$\alpha$ photons escape from LAEs. For instance, one idea presented by Herenz et al. (2015) and argued for by Hagen et al. (2016) is that the the escape of Ly-$\alpha$ photons may be directly tied into how turbulent a galaxy's ISM is- that is, a more turbulent ISM would create more favorable conditions for escape within LAEs. Thus, it may be possible for those who work with simulations to try to replicate the escape of Ly-$\alpha$ photons within galaxies by introducing turbulence into the ISM. A simulation that could replicate these observations could validate this hypothesis. Yet another idea put forth related to Ly-$\alpha$ escape is that it could be related to Ly-$\alpha$ halos that surround certain galaxies (Wisotzki et al. 2016). Whatever the mechanism for Ly-$\alpha$ escape is, the Hagen et al. (2016) team finds that it is not related to the size of these galaxies, as they do not seem to be smaller than their regular star-forming counterparts.

# 4 Conclusion

## 4.1 Future Work

One of the main limitations of both the Malhotra et al. (2012) and the Hagen et al. (2016) studies is the number of galaxies involved in each sample. In fact, this problem isn't just limited to these studies. All studies of LAEs are limited to the sample of the few thousand ones that are known. This however will all change with the upcoming HETDEX experiment. The main goal of HETDEX is to probe the properties and evolution of dark energy as a function redshift. The hope is that this will give us insight into as what dark energy really is, at least from a physical standpoint. During the lifetime of the experiment, it will obtain spectra for ∼800,000 LAEs with $1.9<z<3.5$. This increases the current sample of LAEs by a factor of ∼250, which will allow for much more statistically robust studies of LAEs and their properties when the survey is complete in ∼2019[1].

## 4.2 Summary

Through this review, I have presented the basics of Ly-$\alpha$ emission, especially those from galaxies other than ours. Due to observational constraints, it is easiest to observe LAEs from the ground, which limits the redshift range of observable LAEs to those with $z \geq 1.9$. There have been many surveys carried out to look for these galaxies, and they have found several thousand in total. I have also highlighted a couple key studies that have examined the properties of these LAEs, and compared them to other star-forming galaxies at similar redshifts. The results of these studies differ quite a bit, with some finding that LAEs are more compact and less dusty than their regular star-forming counterparts (Malhotra et al. 2012). These two properties could easily lead to Ly-$\alpha$ escape. Others find that LAEs are not dissimilar from other star-forming galaxies, and that there must be another unique mechanism for Ly-$\alpha$ escape (Hagen et al. 2016). In the near future, HETDEX will find nearly one million LAEs from $1.9<z<3.5$, providing us a more much statistically robust sample for studying the properties of these galaxies. In addition to these studies of galaxies and galaxy evolution, LAEs can also be used to study cosmology as a whole. They can be used to examine the epoch of reionization, as well as probe the evolution of dark energy through cosmic time, which may allow us to find whether it is truly a cosmological constant (see Koehler 2009 for more details).

**References**

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[1] See `hetdex.org` for more details on the HETDEX project.