Damped Ly-α Absorbers and Gravitational Lensing

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Abstract. Gravitational lensing and damped Ly-α (DLA) absorbers may strongly interplay: multiple imaging allows to estimate the DLA transverse size, but single imaging gravitational deflection can lead to over-estimate the separation between a DLA optical counterpart and the QSO line-of-sight; as a consequence of the magnification bias the number density of DLAs and the cosmological density of neutral gas may be significantly be over-estimated in $z < 1$ DLA surveys.

1 Introduction

Three different cases of interplay between gravitational lensing and DLA absorption can be considered:

- a multiply imaged lensed quasar; the DLA absorber is not necessarily related to the lensing agent; two examples are given by the systems HE 1104-1805[7, 4] and Q 1429-008[8, 10], which indicate that the column density profile of a DLA absorber at $z \sim 1.6$ have a typical scale of 20 h^{-1} kpc;
- a lensing foreground galaxy or galaxy cluster located in front of a DLA absorber and a (singly imaged) QSO lead to over-estimate the linear separation between the DLA optical counterpart and the QSO line-of-sight;
- the DLA absorber is the lensing agent; it does possibly, but not necessarily, lead to the formation of multiple images of the background quasar; because of lensing effects, especially the magnification bias, the number density of DLAs and the cosmological density of neutral gas can be over-estimated in $z < 1$ DLA surveys.

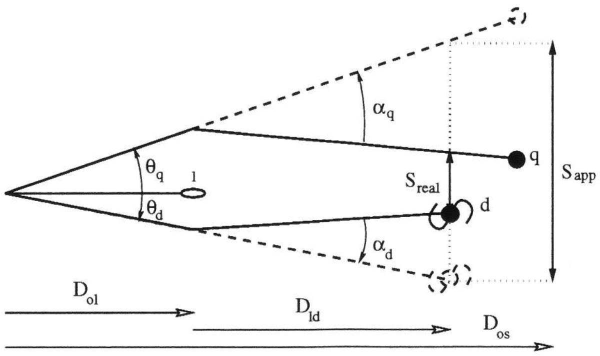

Figure 1: The apparent linear separation $S_{\rm app}$ between a DLA optical counterpart and a QSO line-of-sight may severely over-estimate the real value $S_{\rm real}$ if a galaxy or galaxy cluster is located close to the line-of-sight towards the background QSO. $\alpha_{\rm q}$ and $\alpha_{\rm d}$ are the angular deflection angles for the QSO and the DLA respectively; the $D_{\rm ij}$ are angular diameter distances.

2 Lensing and the impact parameters of DLA optical counterparts

The linear separation between a DLA absorber optical counterpart and a QSO line-of-sight may be significantly over-estimated if they are located behind a lens, as a galaxy or a galaxy cluster, (cf. Fig. 1). Indeed, if $\Delta\theta_{\rm I}$ is the observed angular separation between the QSO and the optical counterpart, the real value of the impact parameter $S_{\rm real}$ is related to the apparent one $S_{\rm app}$ by:

$$\frac{S_{\rm real}}{S_{\rm app}} = 1 - \frac{D_{\rm ld}}{D_{\rm od}} \frac{|\vec{\alpha}^q - \vec{\alpha}^d|}{\Delta\theta_{\rm I}}. \tag{1}$$

For a singular isothermal sphere (SIS), $\sigma = 220$ km s^{-1} L_* lens at $z_{\rm l} = 0.5$ and a $z_{\rm d} = 3$ DLA, the Einstein radius for a source at the DLA redshift is $\theta^{\rm d}_{\rm E} = 0.88''$. Hence, if both $|\theta^q_{\rm S}|$ and $|\theta^d_{\rm S}|$ are larger than this value, no multiple imaging occurs. The projection of the Einstein radius in the lens plane $\simeq 3$ kpc. In the extreme geometry shown in Fig. 1., one thus overestimates the impact parameter of a $z_{\rm d} = 3$ absorber by $\simeq 6$ kpc, which is significant compared to the radius of an HI disk (~ 10 kpc).

The absorber dynamical mass $M_{\rm dyn}$ is [5] $M_{\rm dyn} = (v^2_{\rm rot}\ S_{\rm real})/(G \sin(i))$, where $v_{\rm rot}$ is the rotational velocity of the galaxy – evaluated from the difference in velocity between the DLA line and emission lines arising in the optical counterpart –, and i is its inclination angle. Assuming a face-on disk and a uniform H I distribution, the H I mass is $M_{\rm HI} \sim 10^9\ M_\odot\ (N_{\rm HI}/10^{20}\ {\rm cm}^{-2})\ (S_{\rm real}/20\ {\rm kpc})^2$

[2]. The confusion between $S_{\rm app}$ and $S_{\rm real}$ may thus lead to overestimate the dynamical and H I absorber masses by up to an order of magnitude.

About $\sim 3\%$ of the impact parameters of $z_{\rm d} = 3$ DLAs optical counterparts QSOs are susceptible to be over-estimated by more then 33%. This number does not take into account lensing by groups or clusters of galaxies, and should thus be considered as a lower limit.

3 Gravitational lensing by DLA absorbers

Assuming that DLAs arise in present-day like spiral galaxies which are immersed in SIS dark matter halos, one can estimate the consequences of gravitational lensing on the measured values of the number density ($d\mathcal{N}/dz$), distribution of column density ($f(N)$) and inferred cosmological density of H I ($\Omega_{\rm HI}$) derived from DLA surveys[9]. Two lensing effects were considered: the 'by-pass' (or focusing) effect causes the lines-of-sight (LOSs) towards background QSOs to avoid the central parts of galaxies: this leads to a reduction of the effective cross-section for DLA absorption; the 'amplification bias' leads observers to select QSOs whose LOSs preferentially cross galaxies close to their Einstein radius. Hence, the determination of $d\mathcal{N}/dz$, $f(N)$ and $\Omega_{\rm HI}$ does not only depend on the redshift z and luminosity L of the galaxies responsible for the absorbers but also on the H I column density profile within the galaxies and on the redshift $z_{\rm q}$ and magnitude $b_{\rm q}$ of the background QSO.

For the existing surveys using $b \lesssim 19$ QSOs, the amplification bias dominated the combined effect, resulting in overestimating $d\mathcal{N}/dz$, $f(N)$ and $\Omega_{\rm HI}$. For surveys ideally designed to enhance GL effects, i.e. to search for $z \sim 0.5$ DLAs lines in the spectra of $b_{\rm q} \sim 16$, $z_{\rm q} > 1$ QSOs, $d\mathcal{N}/dz$ may be overestimated by 90%, DLA lines with $N_{\rm HI} > 10^{21}$ cm^{-2} are likely to be up yo 4 times more abundant, so that $\Omega_{\rm HI}$ may be overestimated by a factor of 2.7 (cf. Fig. 2). Our results are significantly different from a parallel study on the same subject[1].

Within the framework of our model, high-z DLA surveys are not significantly affected by lensing; however, $\Omega_{\rm HI}$ may be overestimated by 35% in the $z < 1$ surveys, as the IUE survey[3] or the DLA survey based on MgII selected systems[6]. These calculations were done with the explicit assumption of absence of extinction by dust, which needs to be taken into account consistently with the lensing effects.

On the other hand, one can test if a DLA survey is affected by gravitational lensing by dividing its redshift path in two parts for which the lensing effects are expected to be respectively strong $\mathcal{D}_{\rm strong}$ and weak $\mathcal{D}_{\rm weak}$: if the estimates of $d\mathcal{N}/dz$ and $\Omega_{\rm HI}$ appear significantly larger when derived on data belonging only to $\mathcal{D}_{\rm strong}$ than to $\mathcal{D}_{\rm weak}$, then there is good evidence that lensing is actually taking place. Such an exercise based on the surveys published so far indicate that lensing may be indeed important at $z < 1$, but unfortunately provided too few DLAs to provide a significant test. The large value of $\Omega_{\rm HI}$ at $z < 1$ presented by

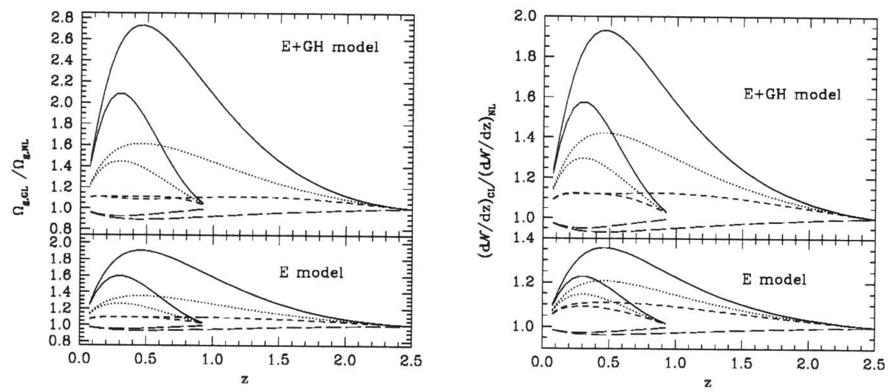

Figure 2: Effect of gravitational lensing on the estimation of the cosmological density of HI. Left (right): ratio of $\Omega_{\rm HI}$ $(d\mathcal{N}/dz)$ when lensing is taken into account $\Omega_{\rm g,GL}$ $((d\mathcal{N}/dz)_{\rm GL})$ to the one derived without any lensing effect $\Omega_{\rm g,NL}$ $((d\mathcal{N}/dz)_{\rm GL})$, for DLAs in front of $z_{\rm q} = 1.0$ and $z_{\rm q} = 2.5$ QSOs. The curves corresponds to $b_{\rm q} = 16$ (solid), $b_{\rm q} = 18$ (dot), $b_{\rm q} = 19$ (short-dash) and $b_{\rm q} = 20$ (long-dash). The E+GH and E models corresponds to two different H I column density profiles within galaxies.

Turnshek (these Proceedings) can possibly be explained by gravitational lensing.

Acknowledgements. AS thanks a grant from the Leids Kerkhoven-Bosscha Fonds and the financial support under grant no. 781-73-058 from the Netherlands Foundation for Research in Astronomy (ASTRON) which receives its funds from the Netherlands Organisation for Scientific Research (NWO).

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