Physical conditions in high-redshift damped Lyman-alpha absorbers

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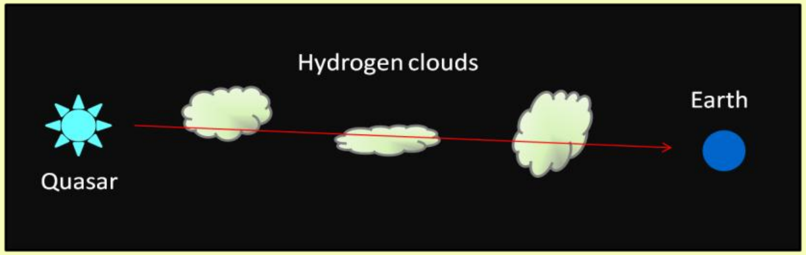
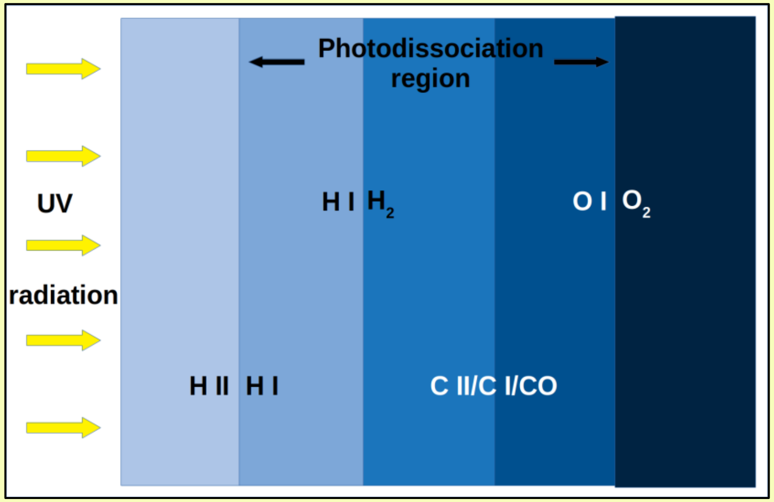
Damped Lyman-alpha absorbers (DLAs)

- Intergalactic reservoirs of neutral hydrogen (H I)
- Relevant to galaxy formation and evolution
- Probed through rest-frame ultraviolet absorption features in the spectrum of a background quasar
- H_2 detected in about 10-15% high-redshift DLAs
- Cool gas likely associated with star formation



Label	Probed quasar sightline	DLA redshift	Molecules detected
DLA 1	LBQS 1232+0815	2.34	H_2, HD
DLA 2	FBQS J0812+3208	2.63	H_2, HD
DLA 3	SDSS J1439+1117	2.42	H_2, HD, CO
DLA 4	QSO J2340-0053	2.05	7 (of 14) components with H_2; HD



Simulating DLA environments

- Plane-parallel geometry of a photodissociation region[1], with constant pressure across the cloud
- Microphysical calculations using the spectral synthesis code CLOUDY[2]
- Gas-phase species, with silicate and graphite dust
- Observed H_2 rotational levels (v, J) and neutral carbon fine structure levels (*C I*, C I**, C I****) act as constraints

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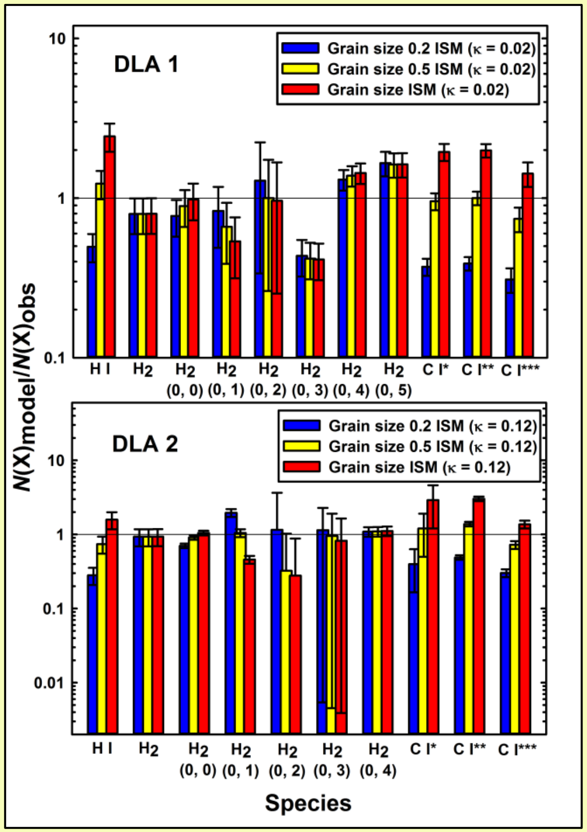
Result 1 – Smaller or porous dust grains

Sub-ISM sized compact grains

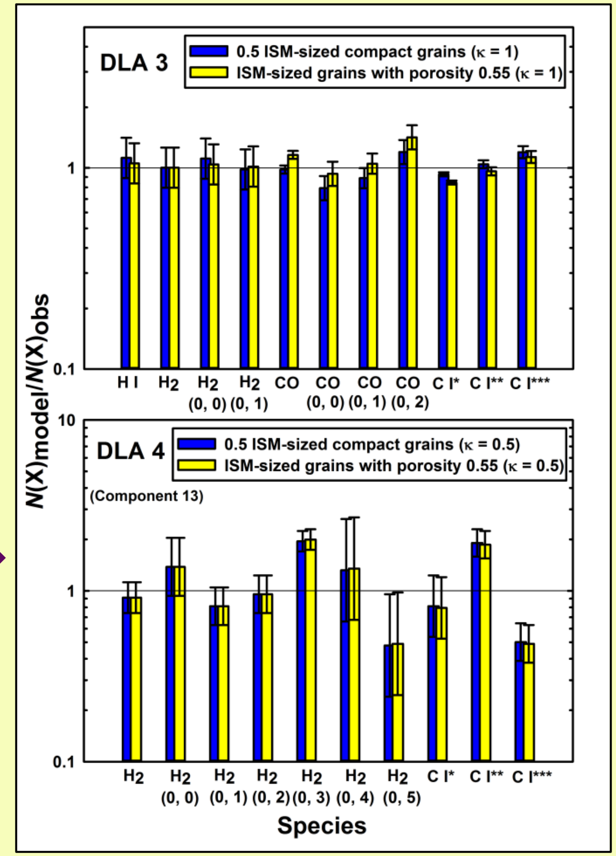
- Power-law grain size distribution[3], $\frac{dn}{da} \propto a^{-3.5}$
- Observed dust abundance (κ) constrains grain sizes to be smaller than in the interstellar medium (ISM)
- Grain radii (a) lie between 0.0025-0.125 µm
- Smaller grains proposed earlier too for DLA 1[4]



Best-fit: 0.5 ISM size

Model vs Observed column density ratios

Alternate model



ISM-sized porous grains

- Porosity is the vacuum fraction in grain volume
- Porosity of 0.55 replicates best-fit results, but with ISM-sized grains
- No robust conclusion, as interstellar grain porosity not tightly constrained yet

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Result 2 – Nature of radiation field

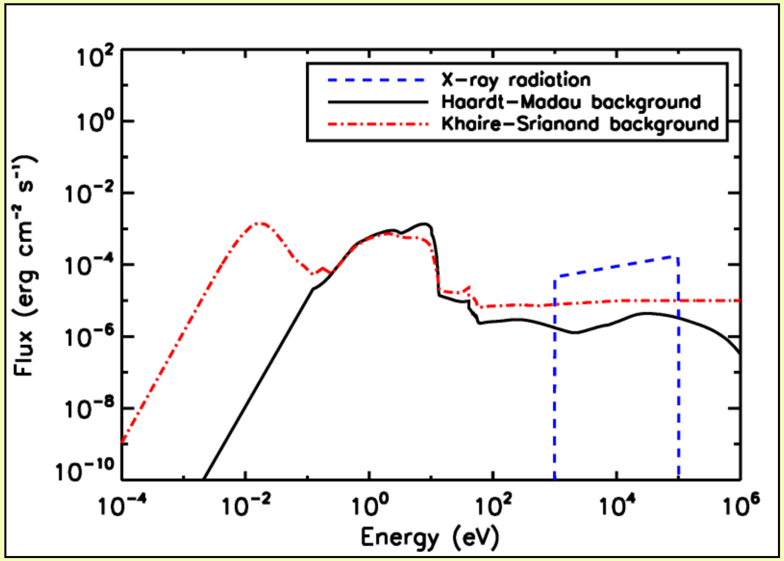
X-ray dominated regions (XDRs)

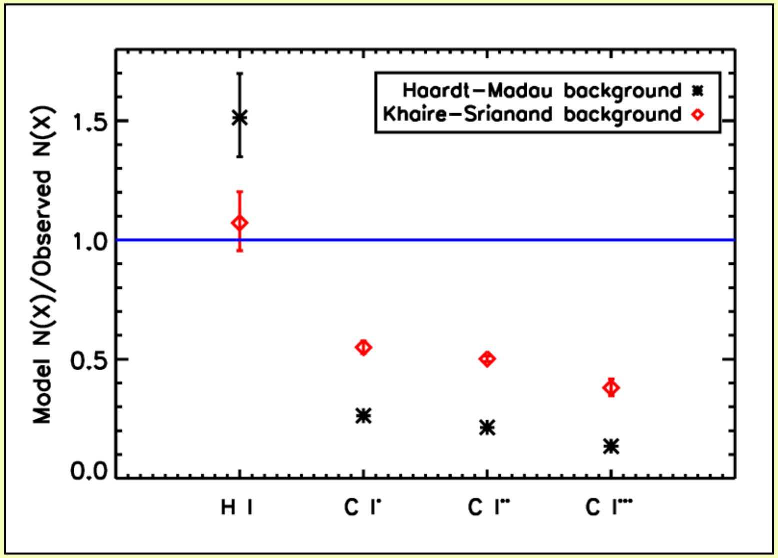
- Metagalactic background radiation from quasars and galaxies incident on all DLAs
- Additional ultraviolet photons from local star formation required in the DLA 2 model
- Power-law X-ray radiation[5] used in case of DLAs 1 and 3 suggests that they are high-redshift XDRs
- Possible sign of the role of hydrodynamical heating

Metagalactic background

- DLA 4 irradiated only by the background photons
- Column densities depend on the background model incorporated in the calculations too
- The Haardt-Madau background[6] over predicts H I and under predicts the C I fine structure levels, as compared to the Khaire-Srianand background[7]
- Need improved understanding of the background

Spectral energy distribution of the background models; Enhanced X-rays for the DLA 1 XDR





Khaire-Srianand background reproduces model column densities closer to the observed values

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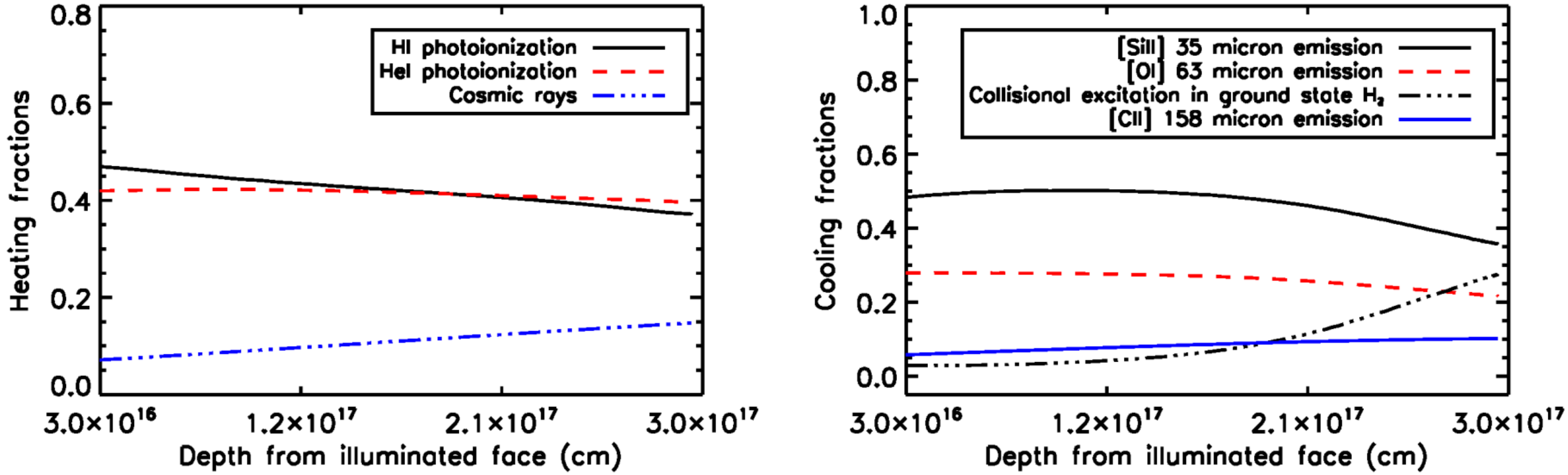
Result 3 – Insight into physical properties and processes

Fractional contribution of various heating and cooling processes within the extent of DLA 4 (component 8)



Physical processes

Physical properties

Property	DLA 1	DLA 2	DLA 3	DLA 4 (7 H_2 components)
Hydrogen density in H_2 region (cm^{-3})	55	63	44	30-120
Gas pressure in H_2 region (cm^{-3} K)	3770	4150	5660	7000-23,000
Gas temperature in H_2 region (K)	59	48	99	140-360
Metallicity (as fraction of solar value)	0.06	1	1	0.15-0.45
Dust abundance (as Milky Way fraction)	0.02	0.12	1	0.35-0.50
Cosmic ray ionization rate (s^{-1})	$10^{-16.20}$	$10^{-16.70}$	$10^{-14.85}$	$10^{-15.70}$ – $10^{-15.10}$

Acknowledgements

Hadi Rahmani, Rajeshwari Dutta, Sajeev Chacko
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