ISM/CGM of galaxies using QALS and CLOUDY

CLOUDY Workshop

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IUCAA

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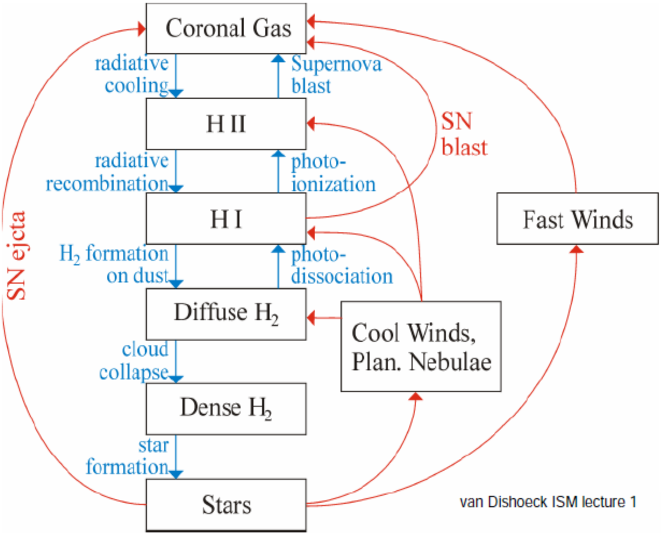
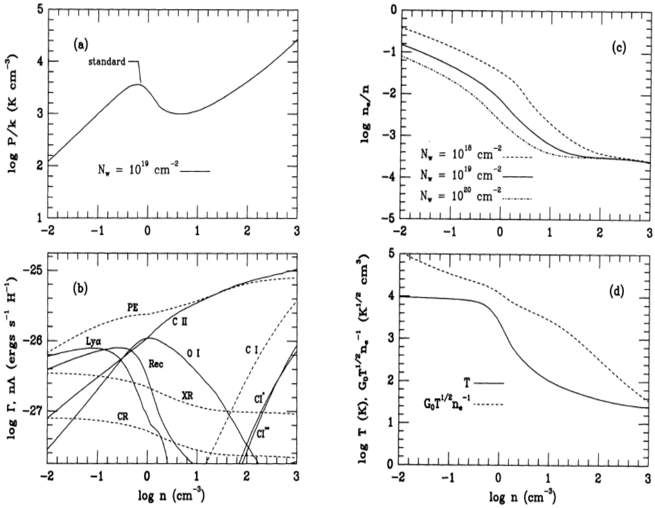
Outline

- ISM/CGM and QALS
- High-z metal-poor DLAs through C II* absorption
- Low-z CGM through H_2 & 21-cm absorption

The interstellar medium

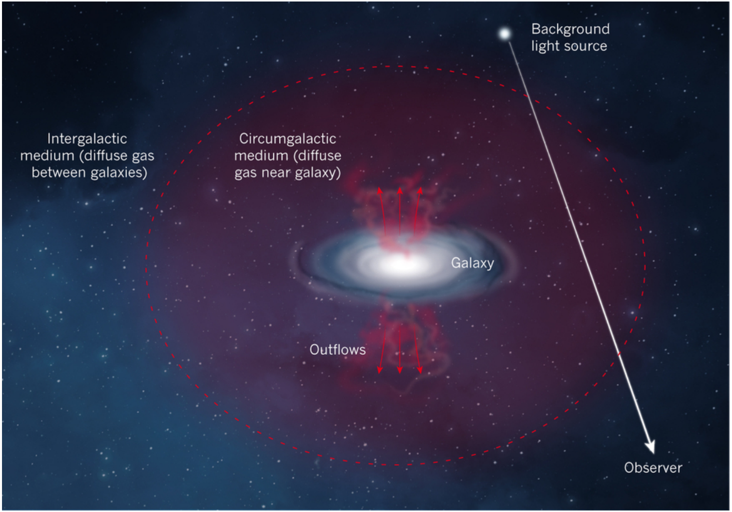


The neutral gas phase



Wolfire et al. 1995

QSO absorption lines as probe of ISM/CGM

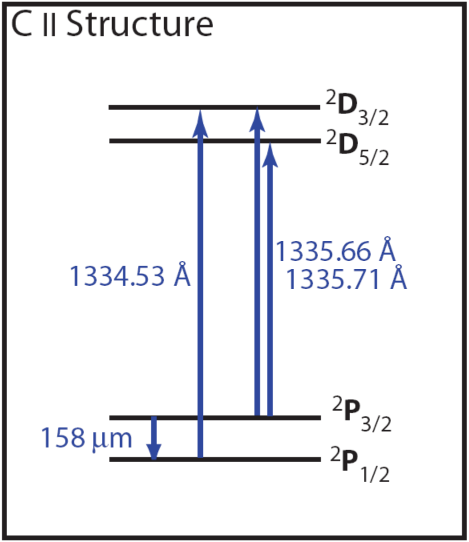


Peeples 2015

Low-metallicity DLAs: Motivation

- Chemical composition and nature of earliest generations of stars (Pop II/III)
- High-z metal-poor DLAs believed to probe gas in or around protogalaxies
- Metal-poor DLAs provide accurate abundance measurements
- Complement studies of metal-poor stars in the Galactic halo

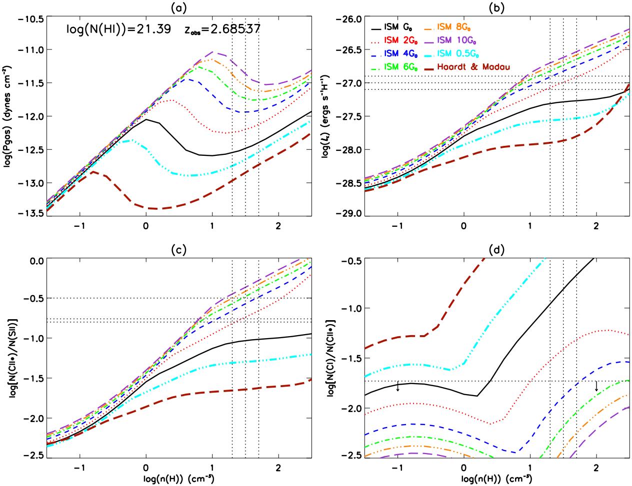
Low-metallicity DLAs: C II* cooling



$$l_c = \frac{N(\mathrm{C\,II^*})h\nu_{ul}A_{ul}}{N(\mathrm{H\,I})}$$

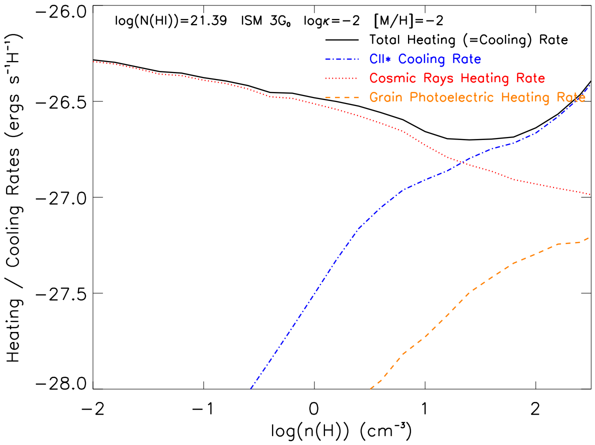
Low-metallicity DLAs: physical conditions

CLOUDY models of low-metallicity DLAs with C II* absorption *(Dutta et al. 2014)*



Low-metallicity DLAs: heating & cooling

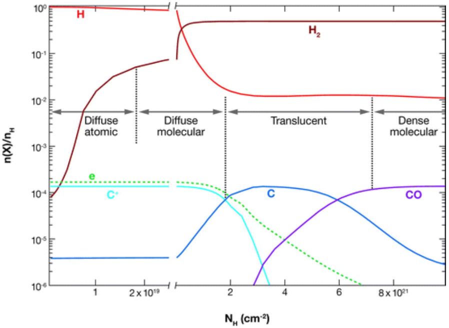
Cosmic ray (CR) heating contribute $\gtrsim 60\%$ to total heating



Low-metallicity DLAs: results

- In-situ star formation required to explain observed C II* cooling rate
- Heating by grains not as effective as in the Galactic ISM
- CRs most probably responsible for observed excitation of C II*

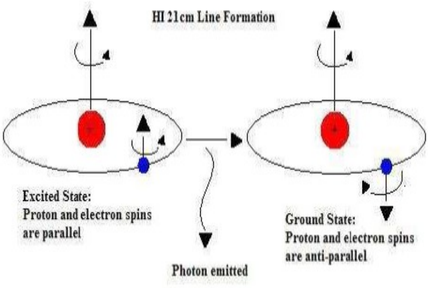
Molecular H_2 absorption: tracer of cold gas



	Diffuse Atomic	Diffuse Molecular	Translucent	Dense Molecular
Defining Characteristic	$f^n{}_{H_2} < 0.1$	$f^n{}_{H_2} > 0.1$ $f^n{}_{C^+} > 0.5$	$f^n{}_{C^+} < 0.5$ $f^n{}_{CO} < 0.9$	$f^n{}_{CO} > 0.9$
A_V (min.)	0	~0.2	~1–2	~5–10
Typ. n_H (cm^{-3})	10–100	100–500	500–5000?	$>10^4$
Typ. T (K)	30–100	30–100	15–50?	10–50
Observational Techniques	UV/Vis H I 21-cm	UV/Vis IR abs mm abs	Vis (UV?) IR abs mm abs/em	IR abs mm em

Snow & McCall 2006

H I 21-cm absorption: tracer of cold gas

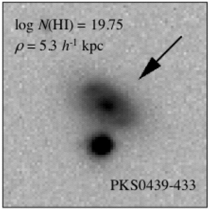


$$N(\mathrm{H\,I}) = 1.8 \times 10^{18}\ T_s/f_c \int \tau dV\ cm^{-2}$$

- Thermal state of H I gas
- Parsec-scale structure of absorbing gas
- Filling factor of cold gas in ISM and CGM

H_2 & 21-cm absorption at low-z

Both H_2 and 21-cm absorption for the first time at $z < 1$
(Dutta+ 2015)



Chen+ 2005

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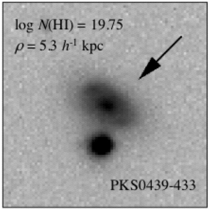
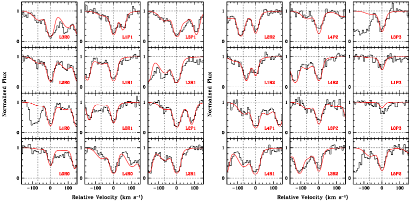
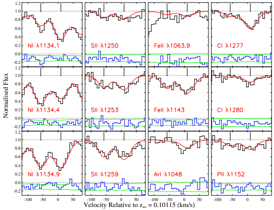
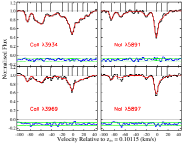


Chen+ 2005

HST/COS spectrum: z=0.10115 sub-DLA, strong H_2 absorption in one component







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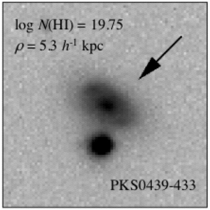

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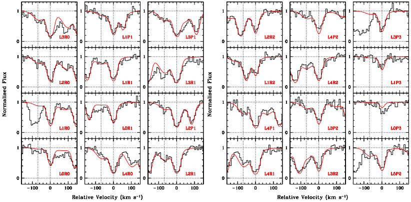
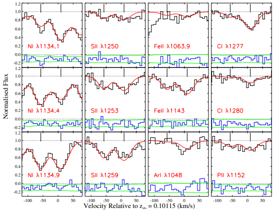
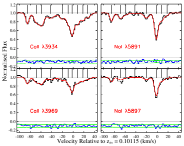
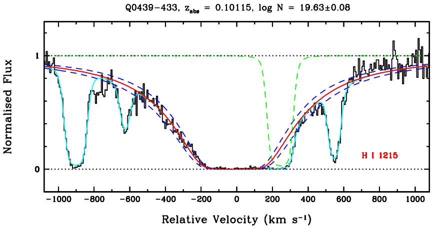






$\log N(H_2) = 16.61 \pm 0.05$ $\qquad \log f_{H_2} = -2.69 \pm 0.09$ $\qquad T_{01} = 133^{+33}_{-22}$ K

H_2 & 21-cm absorption at low-z



Muzahid+ 2015

$$N(\mathrm{H\,I}) = 1.8 \times 10^{18}\ T_s/f_c \int \tau dv\ (cm^{-2})$$

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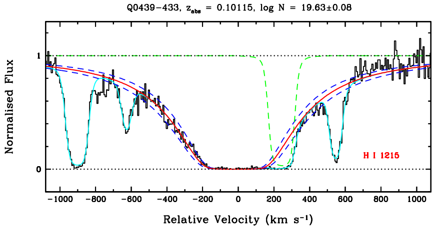

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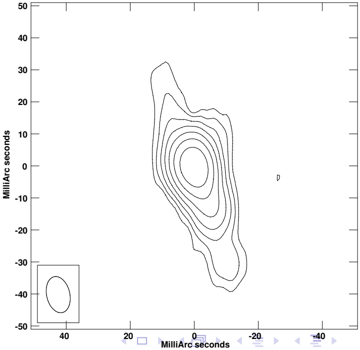
VLBA 1.4 GHz image: 27% of arcsecond scale emission, extent ∼130 pc

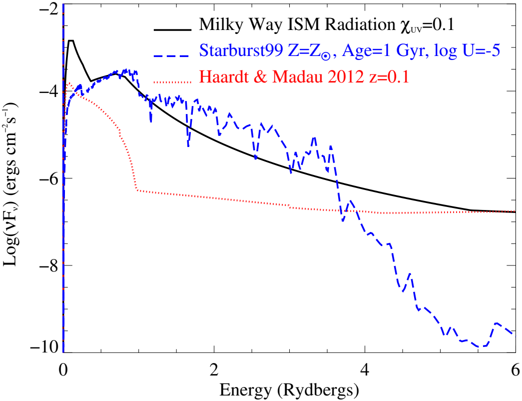


H_2 & 21-cm absorption at low-z

- No 21-cm emission *(Kanekar+ 2001)* $\rightarrow M(\mathrm{H\,I}) \leq 2 \times 10^9\ M_\odot$
- No 21-cm absorption associated with strong H_2 component $\rightarrow$ H I associated with H_2 gas $\leq$ 50% of total or size $\lesssim$ 130 pc
- Weak 21-cm absorption coincident with weaker H_2 component $\rightarrow$ spin temperature $\leq$ 90 K, at odds with weakness of H_2, C I and Na I absorption
- Have now obtained deeper VLA observations

Photoionization models with CLOUDY

Different incident radiation fields



Photoioniztion models with CLOUDY

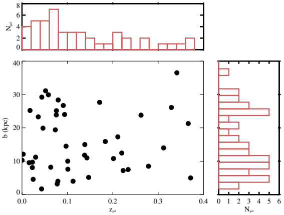
Observational constraints : $N(\text{H I})$, $N(\text{H}_2)$, $N(\text{C I})$, $N(\text{C I*})$, $N(\text{Na I})$, $N(\text{S II})$

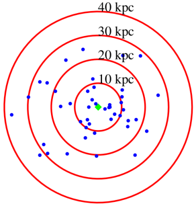
Results from models of the strong H_2 component :

- 30–80% of total $N(\text{H I})$
- density $\sim$ 30–90 cm^{-3}
- size $\sim$ 0.1–1 pc
- radiation field $\sim 0.1 \times$ Galactic mean field
- gas tracing halo rather than stellar disc

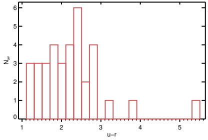
Cold H I 21-cm Absorption Line Survey (CHITALS)

- 46 low-z galaxies ($z \leq 0.4$, median $z = 0.1$) with $b \leq 40$ kpc and median $b = 15$ kpc $\rightarrow$ stellar disks, extended H I disks, extraplanar or intra-group gas



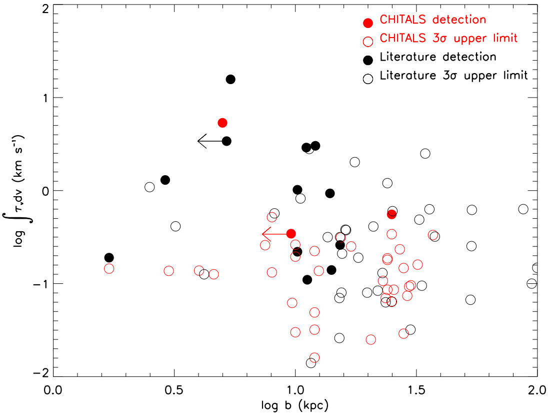


- Wide range of galaxy luminosity and morphology (early- to late-type), with SDSS colour $1.0 \leq u - r \leq 5.0$ and median $u - r = 2$ $\rightarrow$ important resource for understanding high-z galaxy evolution based on absorption line studies



CHITALS – preliminary results

H I 21-cm optical depth around low-z galaxies



THANKS