Chemistry and isotopic ratios in intermediate-redshift molecular absorbers

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Chemical enrichment of the Universe

Star formation → Stars → Mass-loss → Supernovae → Star formation
Molecular absorbers

PKS 1830-211
z=2.5

MA0.89
z=0.89
Molecular absorbers

• Intermediate-redshift galaxies lensing more distant quasars
• Molecular absorption undiluted by distance
  • Line strength proportional to the quasar brightness
  • Study rare isotopologues in distant galaxies
• Probe one or more small regions (=size of quasar image) in the absorbing galaxy
• Absorption depth proportional to line opacity
  • Direct measurement of isotopic ratios (for optically thin lines)
• Only a handful of such systems known, two well studied: MA0.89 and MA0.68
Molecular absorber MA0.89 toward PKS 1830-211
## Molecules in MA0.89

| 1 atom | H\(^{(d)}\), C\(^{(in)}\) |
| 2 atoms | CH\(^{(n)}\), OH\(^{(d)}\), CO\(^{(bcin)}\), 13C\(^{(n)}\), CS\(^{(afn)}\), C\(^{34}\)S\(^{(f)}\), SiO\(^{(jkmn)}\), 29SiO\(^{(km)}\), 30SiO\(^{(m)}\), NS\(^{(k)}\), SO\(^{(kmn)}\), SO\(^{+}\) |
| 3 atoms | NH\(_2\(^{(n)}\), H\(_2\)O\(^{(hn)}\), H\(_2\)\(^{17}\)O\(^{(n)}\), C\(_2\)H\(^{(ekmn)}\), HCN\(^{(aeefkmn)}\), H\(^{13}\)C\(_{N}\)(\(^{(efkmn)}\), HC\(^{15}\)N\(^{(jkmn)}\), HNC\(^{(aeefkmn)}\), HN\(^{13}\)C\(^{(efkmn)}\), H\(^{15}\)NC\(^{(fkmn)}\), N\(_2\)H\(^{(ak)}\), HCO\(^{+}\)(\(^{(aeefkmn)}\), H\(^{13}\)CO\(^{+}\)(\(^{(aeefkmn)}\), HC\(^{18}\)O\(^{(fkmn)}\), HC\(^{17}\)O\(^{+}\)(\(^{(fkmn)}\), HCO\(^{(kmn)}\), HOC\(^{+}\)(\(^{(kmn)}\), H\(_2\)S\(^{(f)}\), H\(^{34}\)S\(^{(f)}\), H\(_2\)Cl\(^{+}\)(\(^{(n)}\), H\(_2\)Cl\(^{37}\)\(^{+}\)(\(^{(n)}\), HCS\(^{+}\)(\(^{(n)}\), C\(_2\)S\(^{(k)}\) |
| 4 atoms | NH\(_3\(^{(ghn)}\), H\(_2\)CO\(^{(cek)}\), I-C\(_3\)H\(^{(k)}\), HNCO\(^{(kmn)}\), HOCO\(^{+}\)(\(^{(km)}\), H\(_2\)CS\(^{(k)}\) |
| 5 atoms | CH\(_2\)NH\(^{(knm)}\), c-C\(_3\)H\(_2\(^{(ekm)}\), I-C\(_3\)H\(_2\(^{(k)}\), H\(_2\)CCN\(^{(k)}\), H\(_2\)CCO\(^{(k)}\), C\(_4\)H\(^{(k)}\), HC\(_3\)N\(^{(ejkm)}\) |
| 6 atoms | CH\(_3\)OH\(^{(klm)}\), CH\(_3\)CN\(^{(km)}\), NH\(_2\)CHO\(^{(m)}\) |
| 7 atoms | CH\(_3\)NH\(_2\(^{(km)}\), CH\(_3\)C\(_2\)H\(^{(km)}\), CH\(_3\)CHO\(^{(k)}\) |

### Toward the SW image

### Toward the NE image

Muller et al. 2014
Molecular absorber MA0.68 toward B 0218+357

MERLIN/VLA 5 GHz (Biggs et al. 2001)  
HST image (York et al. 2005)
Absorption profiles in MA0.68

![Absorption profiles in MA0.68](image-url)
$^{13}\text{C}/^{18}\text{O}$ vs $^{13}\text{C}/^{15}\text{N}$
Isotopic ratios – measured vs chemical evolution models

Model results from Kobayashi et al. 2011
\textbf{\(^{35}\text{Cl}/^{37}\text{Cl} \text{ isotopic ratio}}\)

- \(^{35}\text{Cl} / ^{37}\text{Cl} \text{ ratio in the Sun is 3.13} \)
  - Mainly from supernova nucleosynthesis
- \textbf{MA0.89} SW & NE show ratios \(\sim 3\) in both \(\text{H}_2\text{Cl}^+\) and \(\text{HCl}\)
  - Same ratio in lines of sight at different galactocentric radii (2 vs. 4 kpc), as well as in gas of low and high molecular fraction
  - No significant metallicity gradient or difference in stellar populations; and ISM well mixed
- \textbf{MA0.68} has ratio of \(2.2 \pm 0.3\), the first isotopic ratio to differ between these two galaxies
  - C, N, O, S isotopic ratios the same in both galaxies
  - MA0.68 potentially older (more AGB contribution) or has higher metallicity
Chlorine chemistry

[Chemical network diagram for chlorine chemistry, showing the abundance/reactivity of various chlorine species.]

Neufeld & Wolfire 2009
Chlorine chemistry

• Chlorine has fairly simple chemical network, but we lack constraints on e.g. gas composition along line of sight, metallicity, dust...

• Simple analytical model to explore how chlorine chemistry varies with density, UV radiation field ($G_0$), cosmic ray ionization rate

• Measure $[\text{H}_2\text{Cl}^+]/[\text{HCl}] \sim 1$ in MA0.89 SW and $> 17$ in MA0.89 NE
  • Reflect higher molecular fraction in MA0.89 SW as traced by HCl
  • Need $G_0 > 10$
  • Cosmic ray ionization few times higher than Solar neighborhood
  • May be indicative of a higher star formation rate
Summary

- Intermediate redshift molecular absorbers provide a powerful tool to study the ISM in distant galaxies.
- MA0.89 and MA0.68 mainly show enrichment by massive stars.
  - Only differ in the $^{35}\text{Cl}/^{37}\text{Cl}$ isotopic ratio.
- Chlorine chemistry implies increased UV radiation field and cosmic ray ionization rate in MA0.89.