Chemistry and isotopic ratios in intermediate-redshift molecular absorbers

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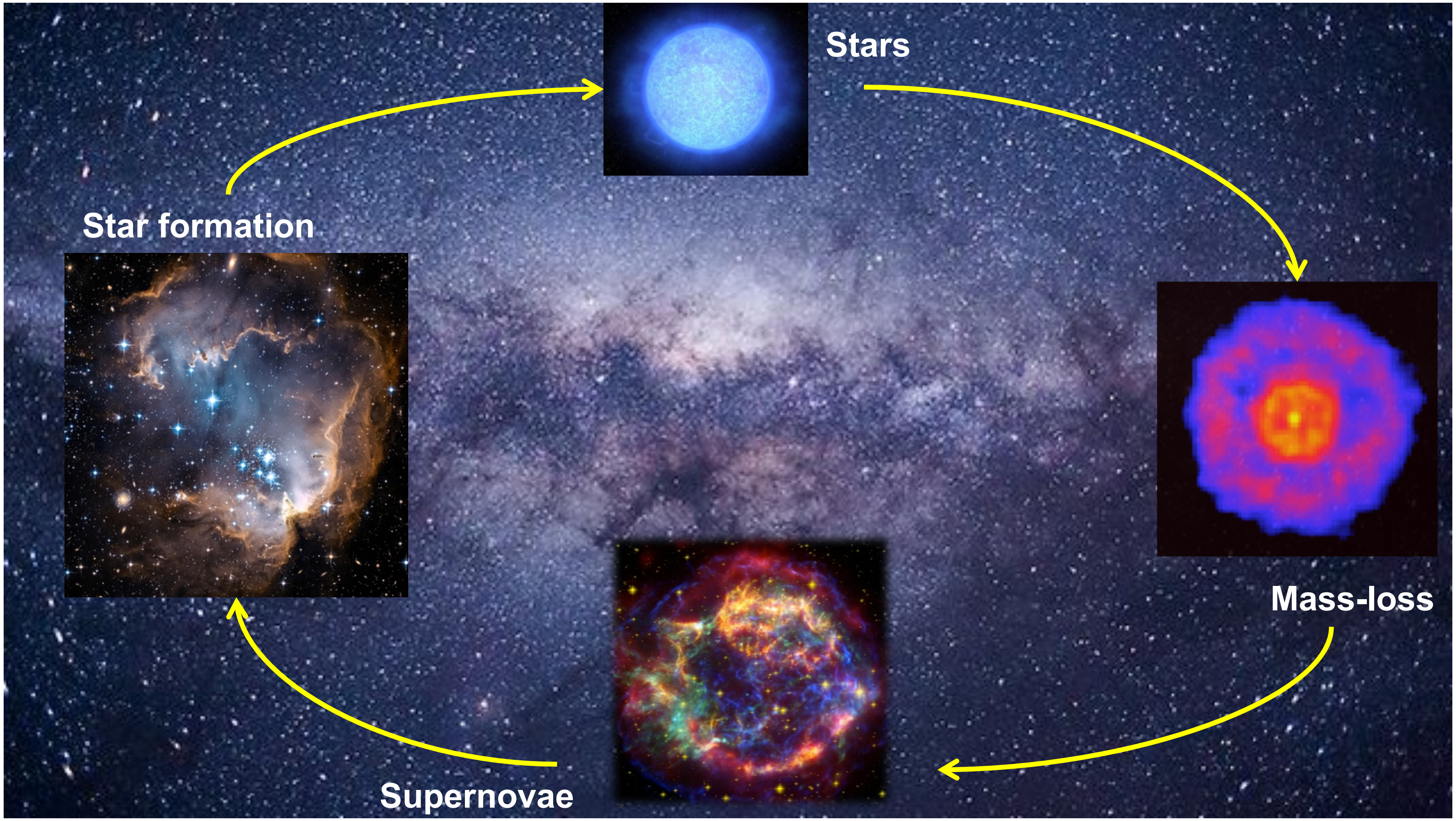
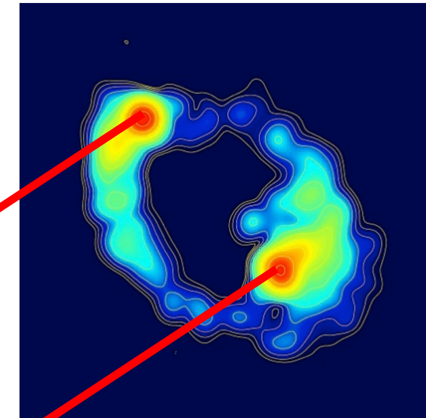
Chemical enrichment of the Universe

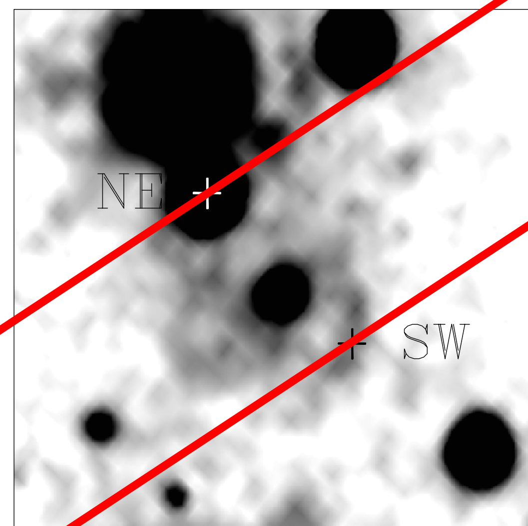


Molecular absorbers

PKS 1830-211
z=2.5



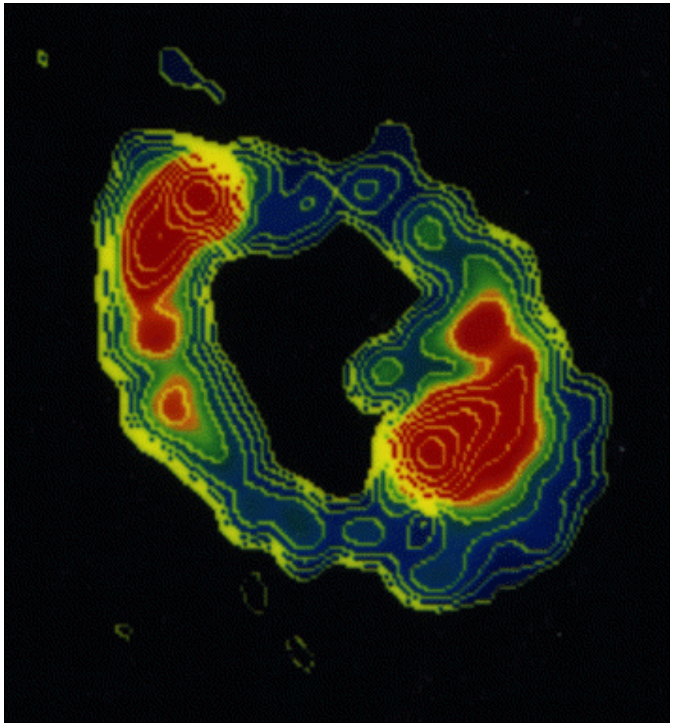
MA0.89
z=0.89



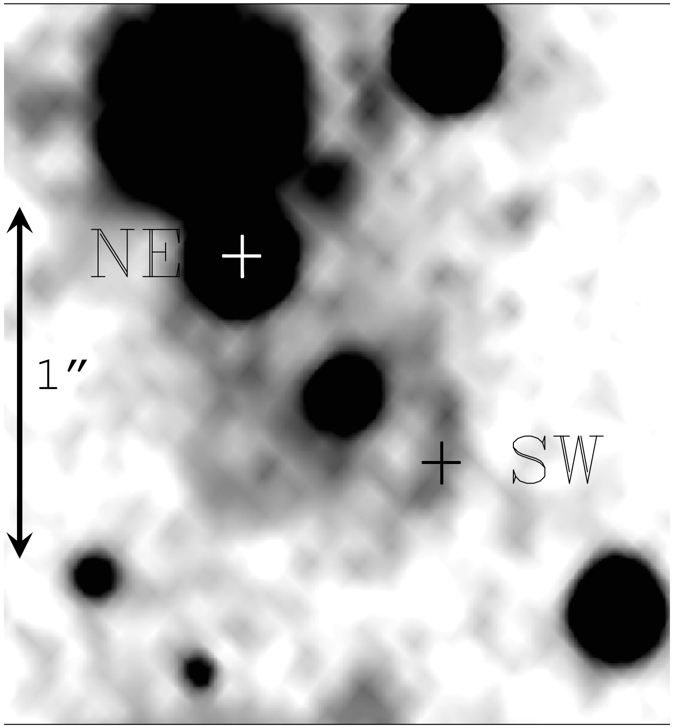
Molecular absorbers

- 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



MERLIN 5 GHz (CSIRO)



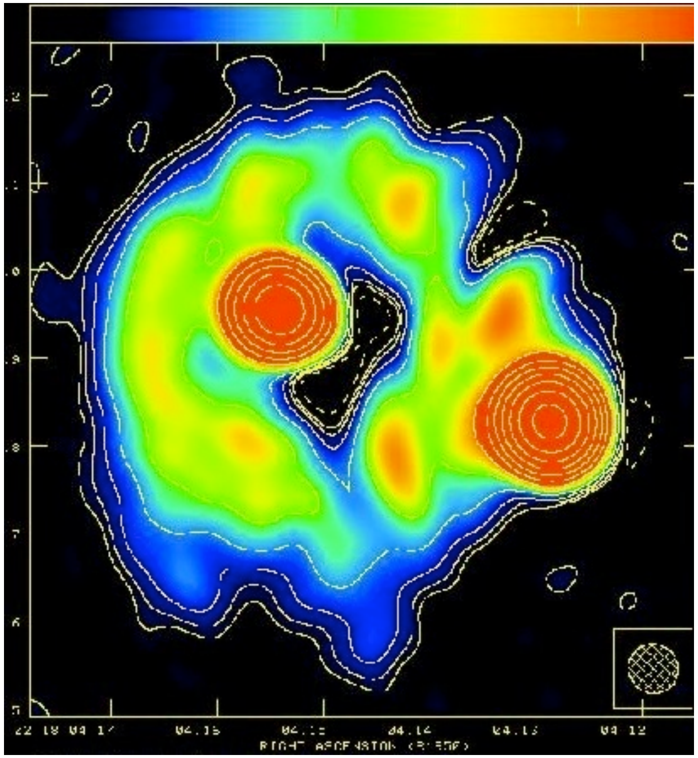
HST image (Muller et al. 2006)

Molecules in MA0.89

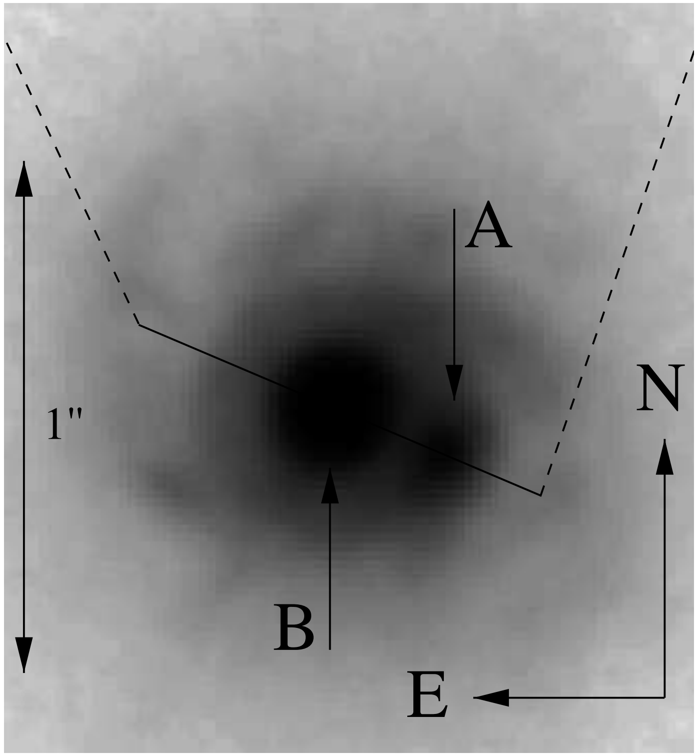
	Toward the SW image
1 atom	H $^{(d)}$, C $^{(in)}$
2 atoms	$\mathbf{CH}$ $^{(n)}$, OH $^{(d)}$, CO $^{(bcin)}$, $^{13}\mathbf{CO}$ $^{(n)}$, CS $^{(afn)}$, $C^{34}S$ $^{(f)}$, SiO $^{(jkmn)}$, ^{29}SiO $^{(km)}$, ^{30}SiO $^{(m)}$, NS $^{(k)}$, SO $^{(kmn)}$, SO^+ $^{(k)}$
3 atoms	$\underline{\mathbf{NH_2}}$ $^{(n)}$, H_2O $^{(hn)}$, $\underline{\mathbf{H_2^{17}O}}$ $^{(n)}$, C_2H $^{(ekmn)}$, HCN $^{(aefkmn)}$, $H^{13}CN$ $^{(efkmn)}$, $HC^{15}N$ $^{(fkmn)}$, HNC $^{(aefkm)}$, $HN^{13}C$ $^{(efkmn)}$, $H^{15}NC$ $^{(fkmn)}$, N_2H^+ $^{(ak)}$, HCO^+ $^{(aefkmn)}$, $H^{13}CO^+$ $^{(aefkmn)}$, $HC^{18}O^+$ $^{(fkm)}$, $HC^{17}O^+$ $^{(fkmn)}$, HCO $^{(kmn)}$, HOC^+ $^{(kmn)}$, H_2S $^{(f)}$, $H_2^{34}S$ $^{(f)}$, $\underline{\mathbf{H_2Cl^+}}$ $^{(n)}$, $\underline{\mathbf{H_2^{37}Cl^+}}$ $^{(n)}$, HCS^+ $^{(m)}$, C_2S $^{(k)}$
4 atoms	NH_3 $^{(ghn)}$, H_2CO $^{(cek)}$, l-C_3H $^{(k)}$, HNCO $^{(km)}$, $HOCO^+$ $^{(m)}$, H_2CS $^{(k)}$
5 atoms	CH_2NH $^{(kmn)}$, c-C_3H_2 $^{(ekm)}$, l-C_3H_2 $^{(k)}$, H_2CCN $^{(k)}$, H_2CCO $^{(k)}$, C_4H $^{(k)}$, HC_3N $^{(ejkm)}$
6 atoms	CH_3OH $^{(kln)}$, CH_3CN $^{(km)}$, NH_2CHO $^{(m)}$
7 atoms	CH_3NH_2 $^{(km)}$, CH_3C_2H $^{(km)}$, CH_3CHO $^{(k)}$
	Toward the NE image
1 atom	H $^{(d)}$, $\mathbf{C}$ $^{(n)}$
2 atoms	$\mathbf{CH}$ $^{(n)}$, OH $^{(d)}$, $\mathbf{CO}$ $^{(n)}$
3 atoms	$\mathbf{H_2O}$ $^{(n)}$, C_2H $^{(kn)}$, HCN $^{(fkmn)}$, HNC $^{(fk)}$, HCO^+ $^{(cfkmn)}$, $\underline{\mathbf{H_2Cl^+}}$ $^{(n)}$
4 atoms	$\mathbf{NH_3}$ $^{(n)}$, H_2CO $^{(k)}$
5 atoms	c-C_3H_2 $^{(k)}$

Muller et al. 2014

Molecular absorber MA0.68 toward B 0218+357

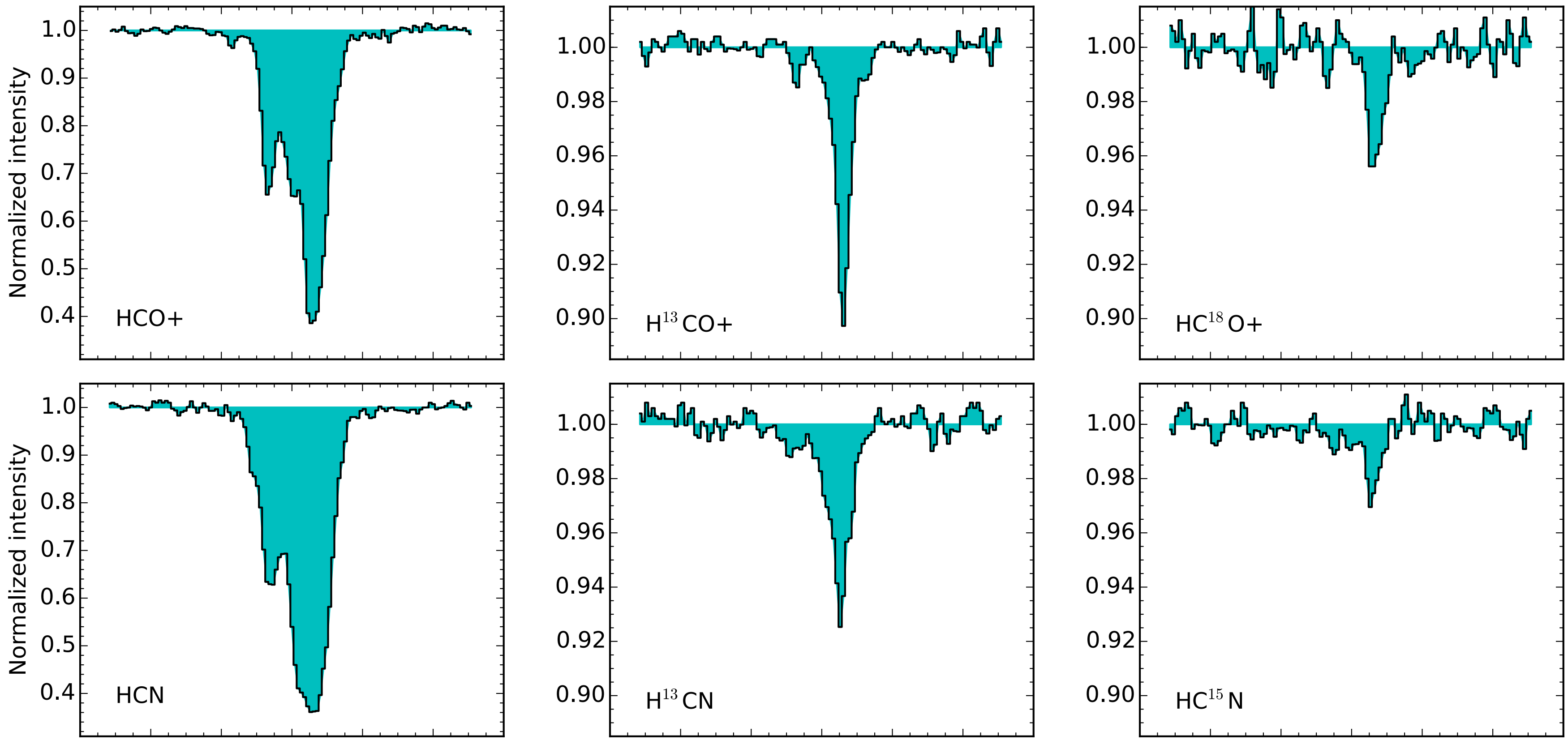


MERLIN/VLA 5 GHz (Biggs et al. 2001)



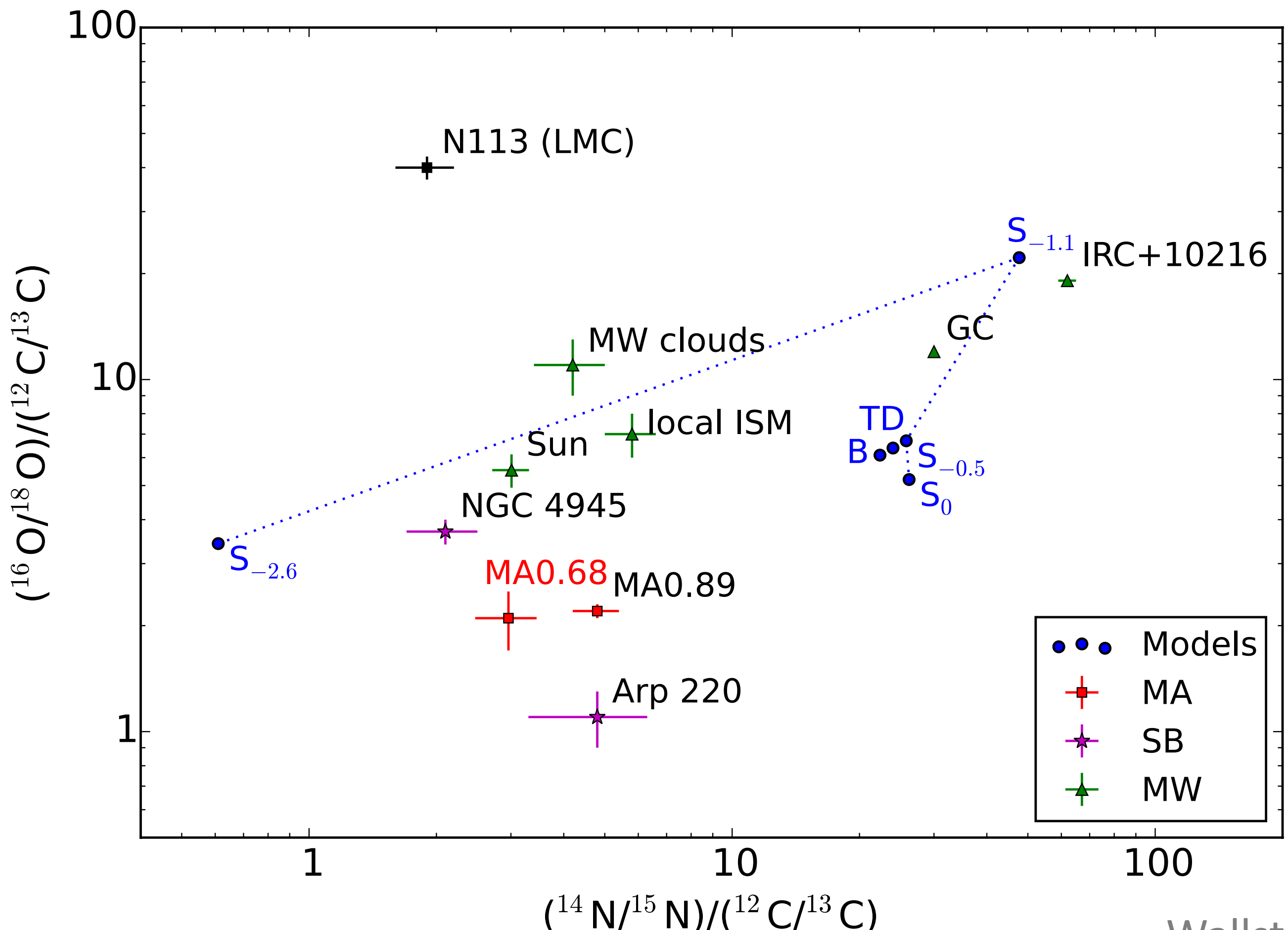
HST image (York et al. 2005)

Absorption profiles in MA0.68



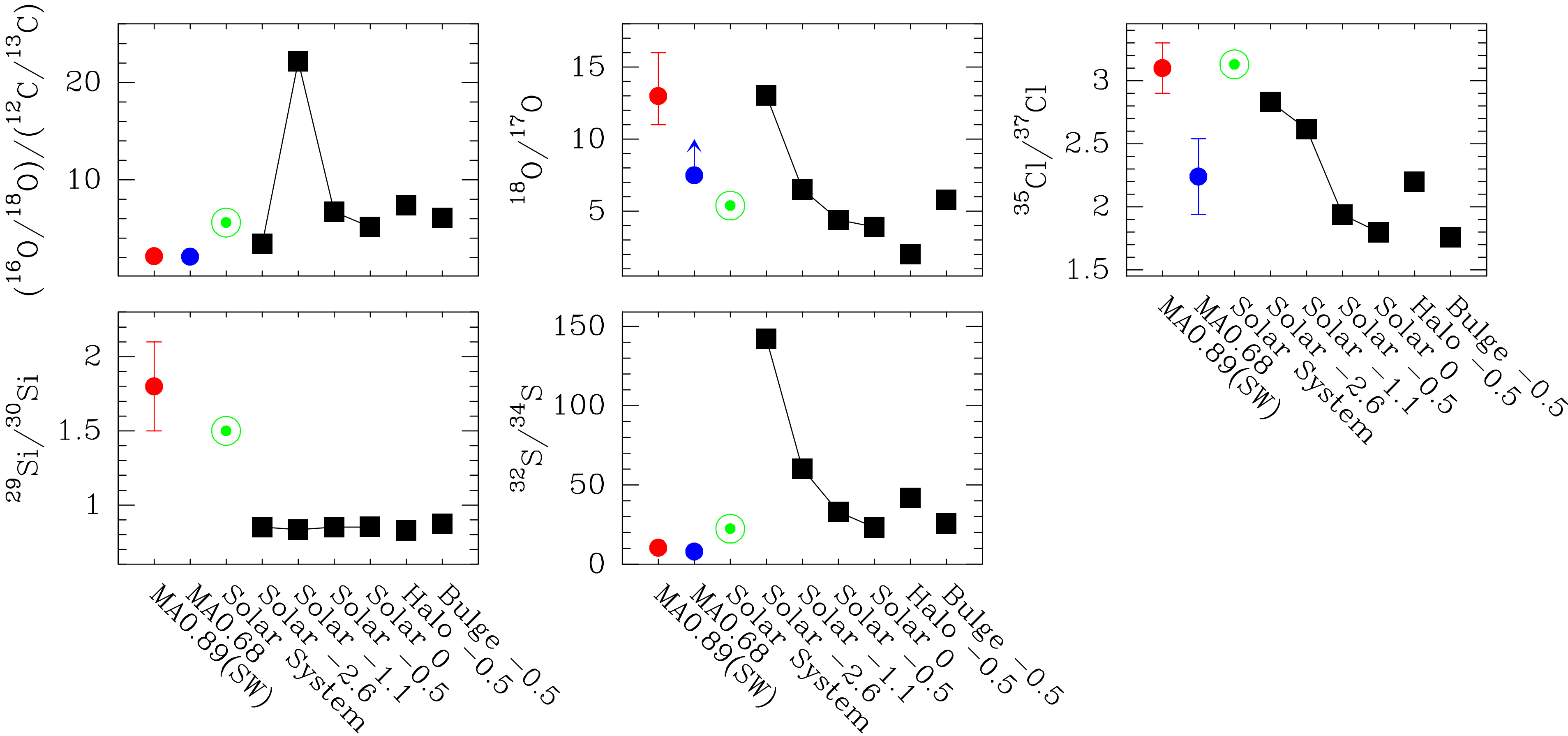
Wallström et al. 2016

$^{13}C/^{18}O$ vs $^{13}C/^{15}N$



Wallström et al. 2016

Isotopic ratios – measured vs chemical evolution models

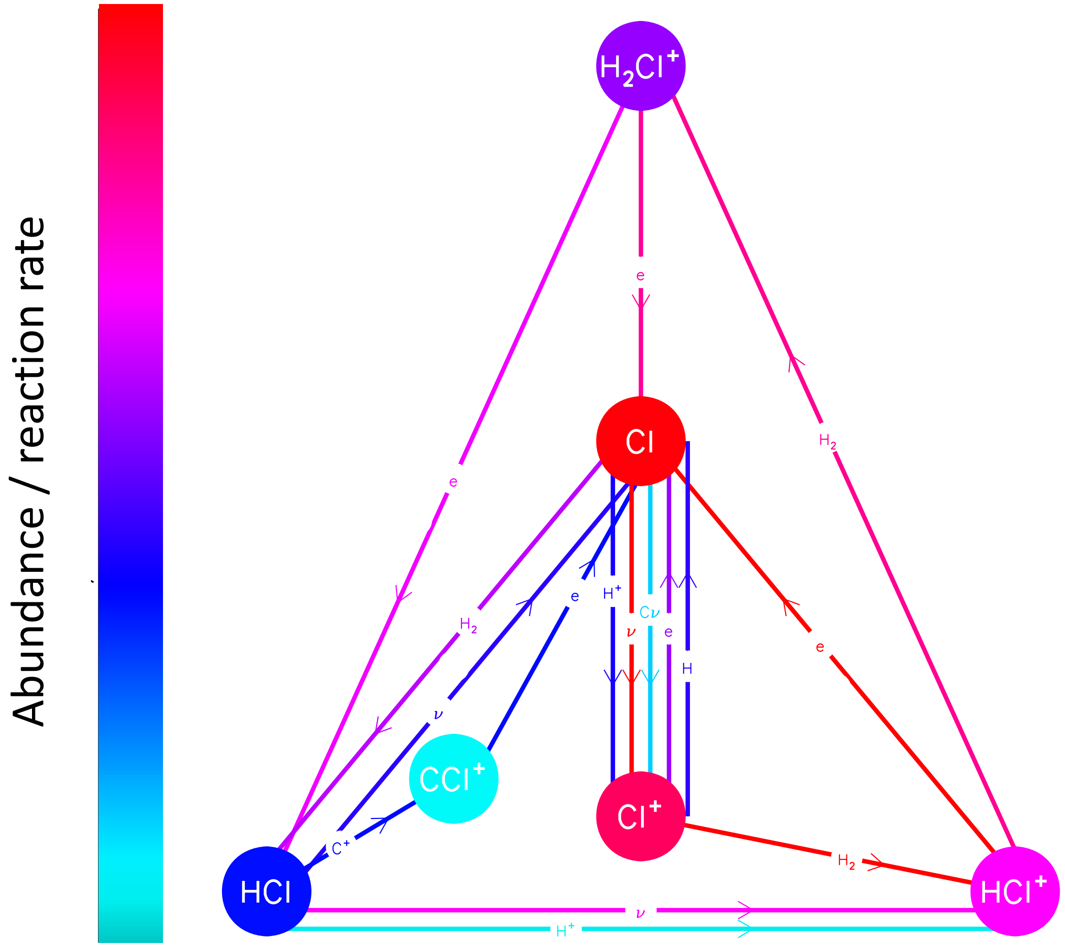


Model results from Kobayashi et al. 2011

$^{35}Cl/^{37}Cl$ isotopic ratio

- ^{35}Cl / ^{37}Cl ratio in the Sun is 3.13
  - Mainly from supernova nucleosynthesis
- MA0.89 SW & NE show ratios ~3 in both H_2Cl^+ and 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
- MA0.68 has ratio of 2.2 ± 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

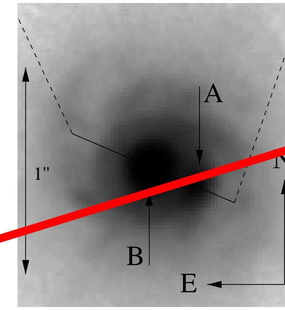


Neufeld & Wolfire 2009

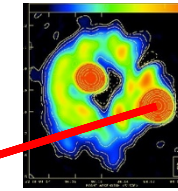
Chlorine chemistry

- 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 chemstry varies with density, UV radiation field (G_0), cosmic ray ionization rate
- Measure $[H_2Cl^+]/[HCl] \sim 1$ 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



MA0.68
z=0.68



B 0218+357
z=0.95

- 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 $^{35}Cl/^{37}Cl$ isotopic ratio
- Chlorine chemistry implies increased UV radiation field and cosmic ray ionization rate in MA0.89