

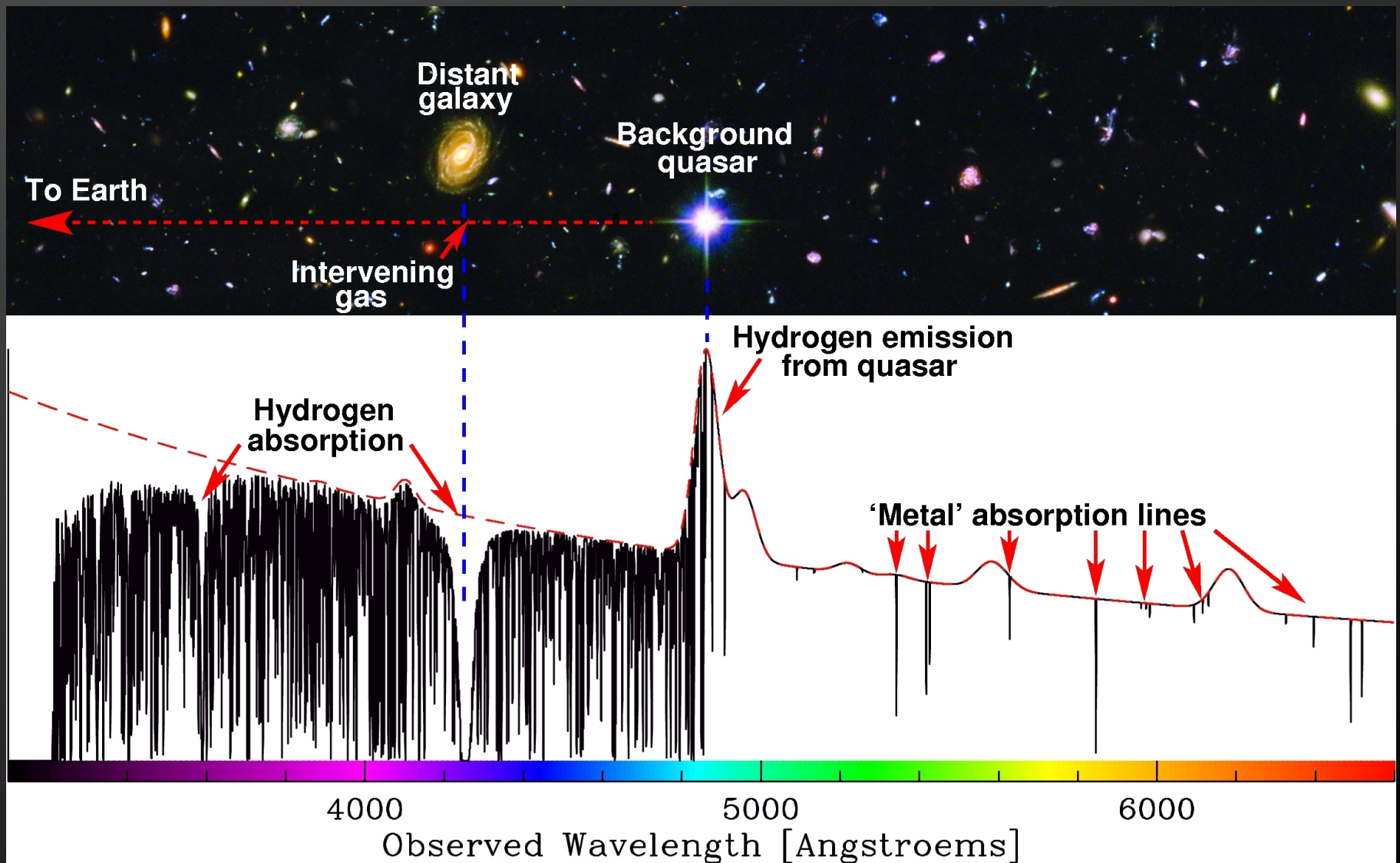
Probing Chemical Evolution with Damped Lyman α Systems

What can DLAs do for you?

Trystyn Berg (Victoria)
trystynb@uvic.ca

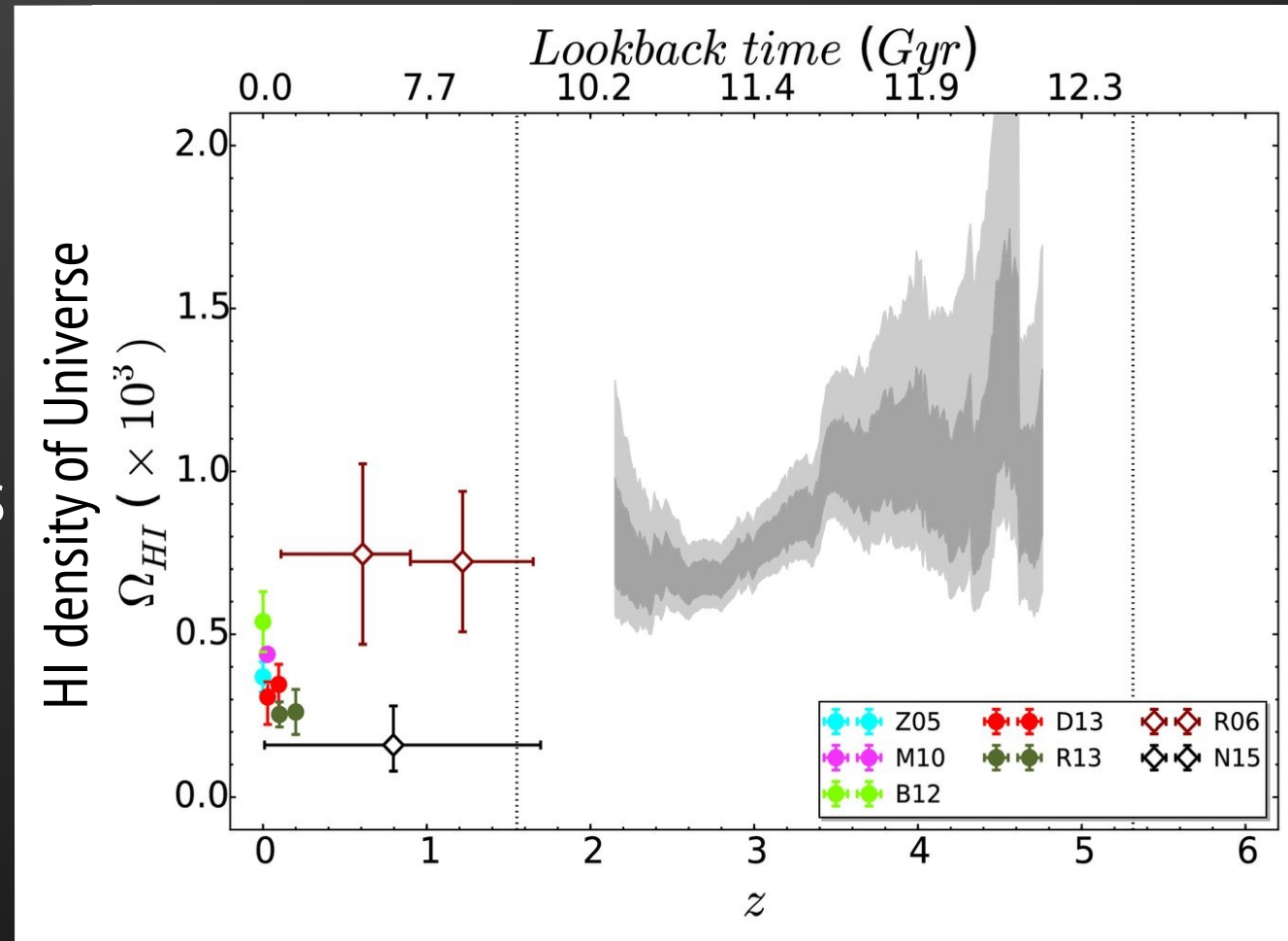
Sara Ellison (Victoria; Supervisor)
J.X. Prochaska (UC Santa Cruz)
Kim Venn (Victoria)

Quasar absorption line systems



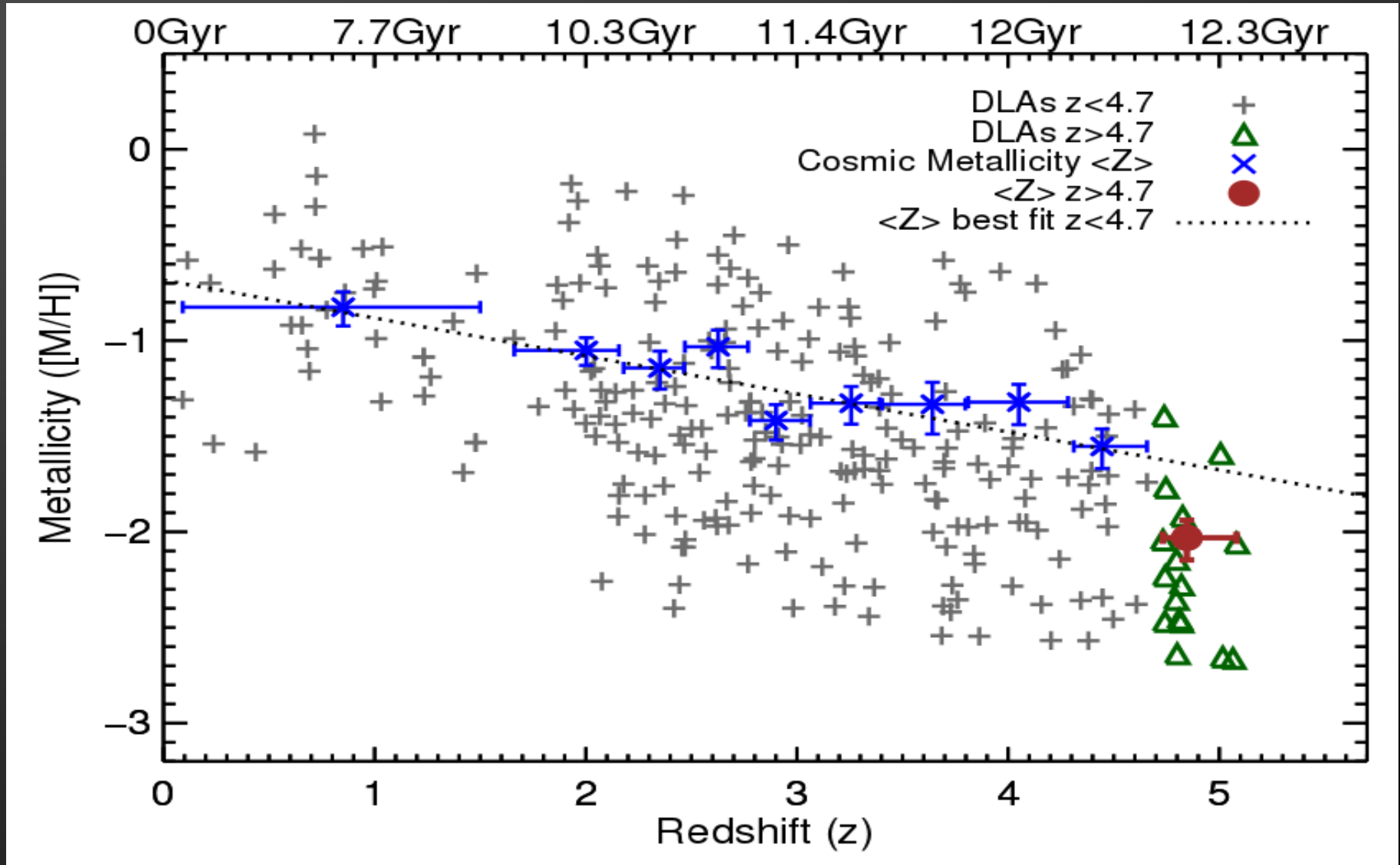
Damped Lyman α Systems (DLAs)

- Large HI column densities; $\log N(\text{HI}) \geq 20.3$
 - Galactic ISM columns
- Dominate HI content of Universe



Sanchez-Ramirez+
2016

Damped Lyman α Systems (DLAs)



Why use DLAs for chemical evolution?

Pros

- Probe evolution all the way back to $z \sim 5$

Cons

Why use DLAs for chemical evolution?

Pros

- Probe evolution all the way back to $z \sim 5$
- Detailed abundances for systems other than Local Group

Cons

Why use DLAs for chemical evolution?

Pros

- Probe evolution all the way back to $z \sim 5$
- Detailed abundances for systems other than Local Group
- **Magnitude and Morphology blind (require gas)**

Cons

Why use DLAs for chemical evolution?

Pros

- Probe evolution all the way back to $z \sim 5$
- Detailed abundances for systems other than Local Group
- Magnitude and Morphology blind (require gas)

Cons

- Lack of galaxy properties without imaging

Why use DLAs for chemical evolution?

Pros

- Probe evolution all the way back to $z \sim 5$
- Detailed abundances for systems other than Local Group
- Magnitude and Morphology blind (require gas)

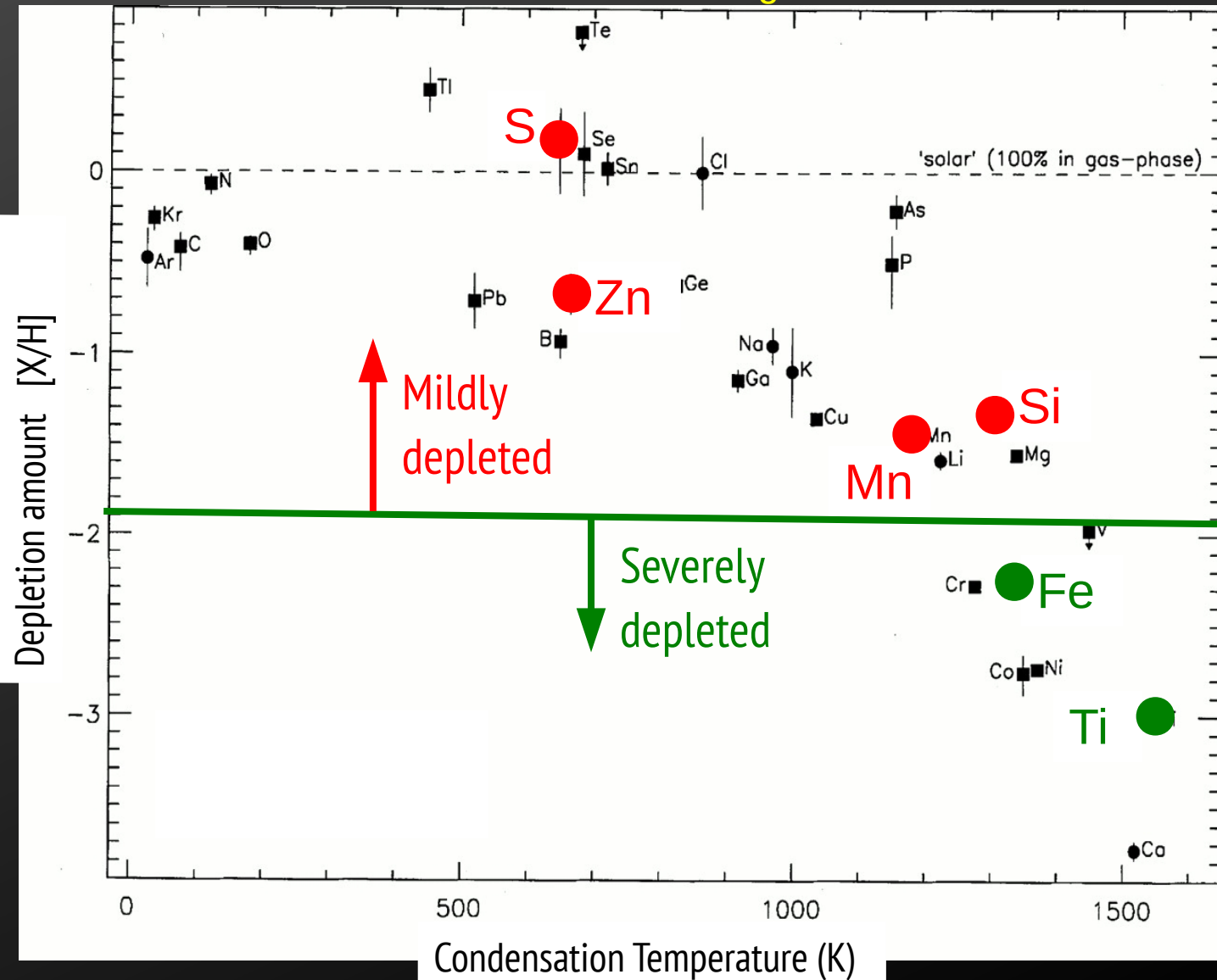
Cons

- Lack of galaxy properties without imaging
- **Gas phase abundances – Dust depletion effects**

The problem with DLAs: Dust depletion

Savage and Sembach 1996

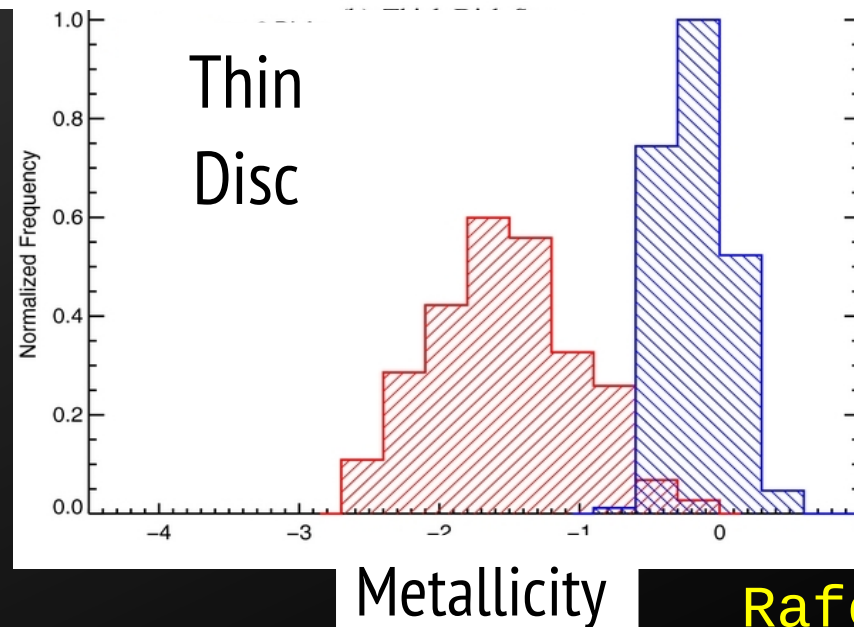
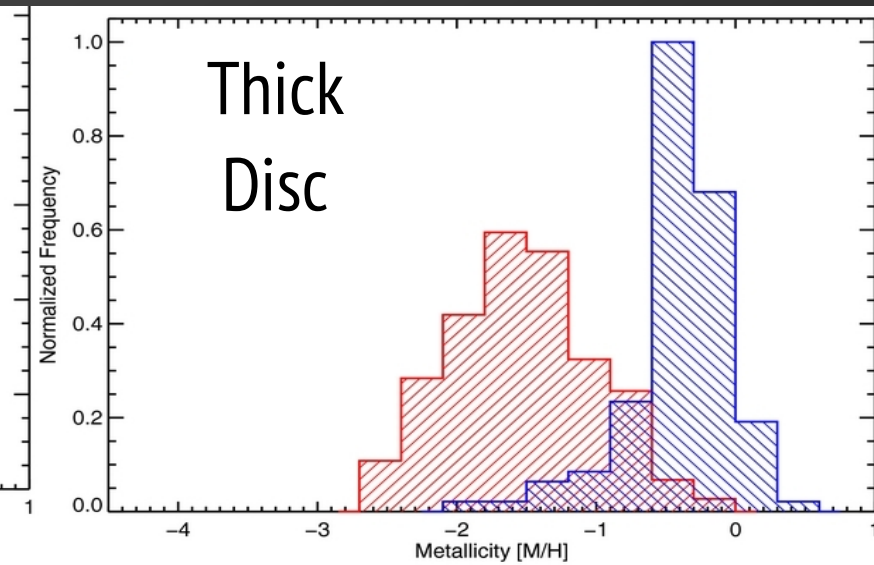
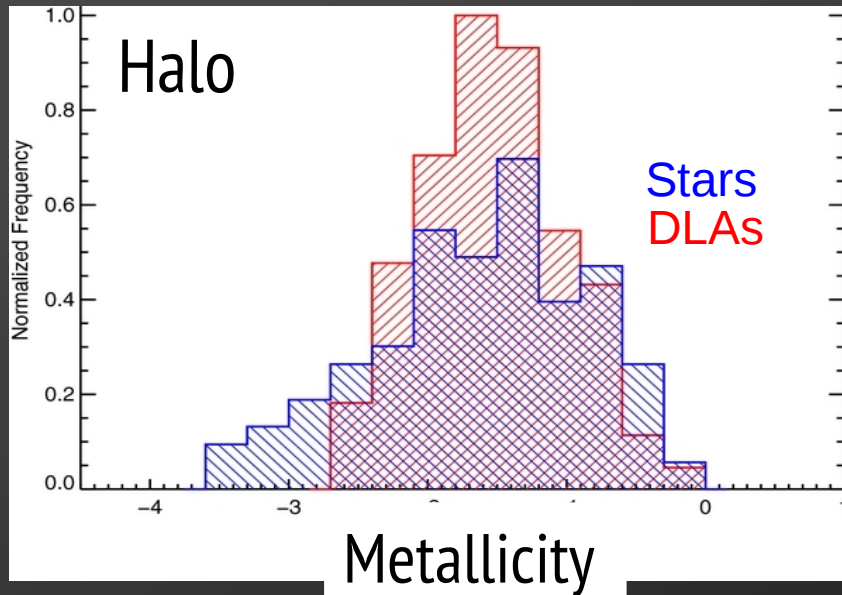
- Condensation onto dust grains
 - Underprediction of total column densities



Goal of using abundances of DLAs

Can we use DLA chemistry to understand what environment DLAs arise whilst correcting for dust depletion?

Environments probed by DLAs



Lack of high-metallicity DLAs to probe thin disc (and dSphs)

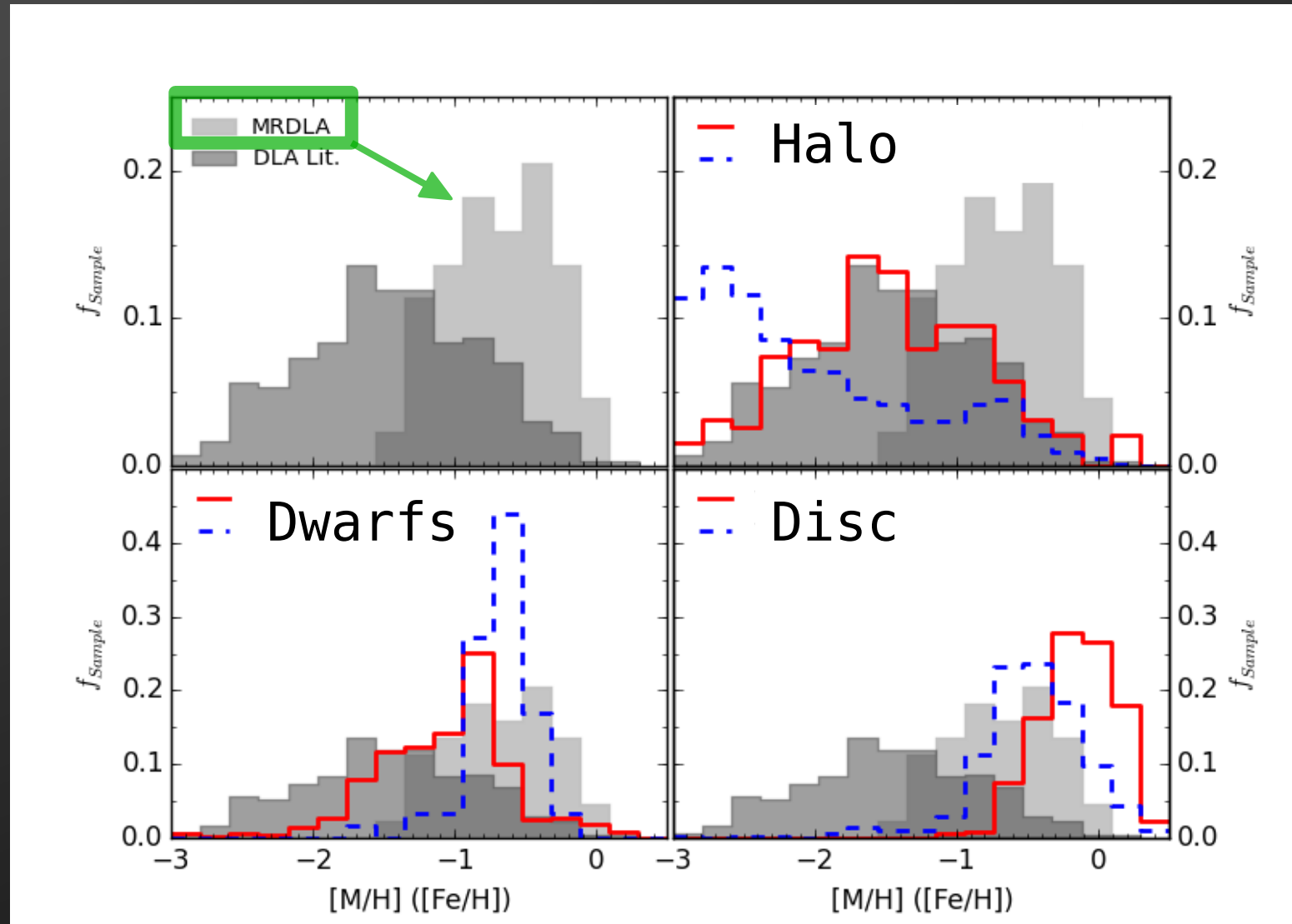
“Metal Rich” DLAs

- Probe galaxies that:
 - Study **thin-disk and dSphs environments at $z \sim 2$ (ISM of stars today?)**
 - May contain **rarely detected elements** (Mn, B, Pb; Prochaska+ 2003)

“Metal Rich” DLAs

- Probe galaxies that:
 - Study thin-disk and dSphs environments at $z \sim 2$ (ISM of stars today?)
 - May contain rarely detected elements (Mn, B, Pb; Prochaska+ 2003)
- 45 metal-rich DLAs with 100+ hours of Keck/HIRES (Berg et al. 2015; Paper I)

Environments probed by DLAs



Detailed Chemistry

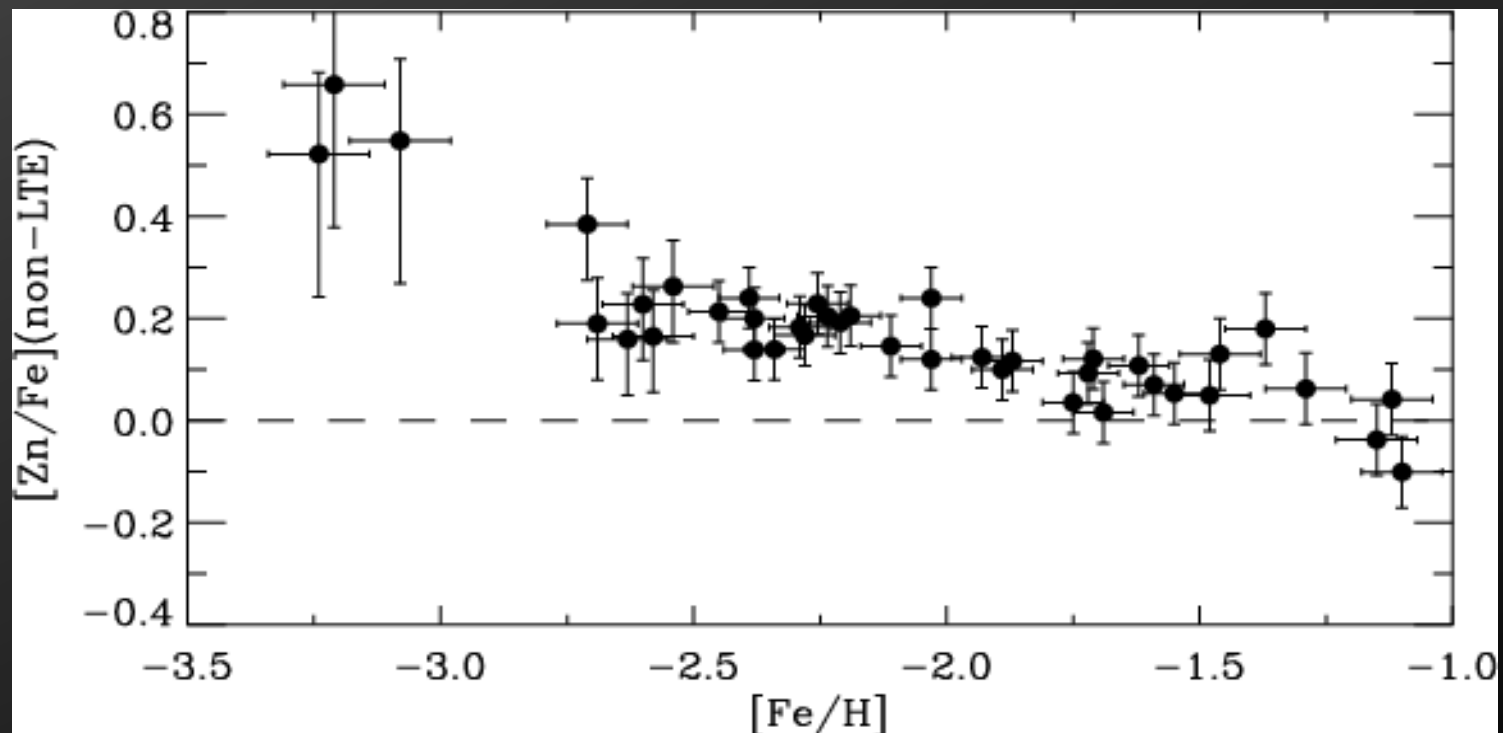
Commonly seen
Rarely detected
My Work

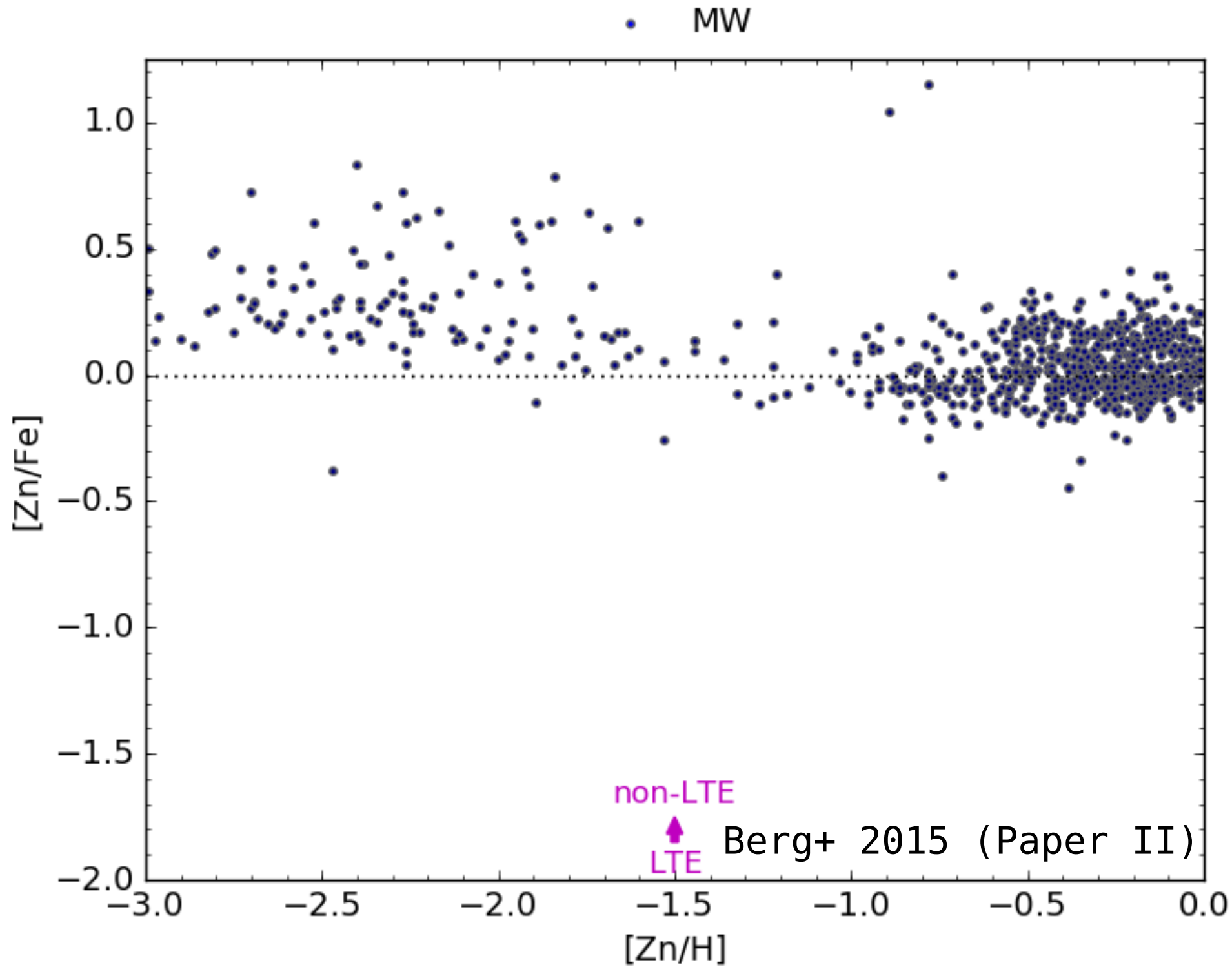
The periodic table below shows elements categorized by their detection frequency. Elements in red boxes are 'Commonly seen', while those in blue boxes are 'Rarely detected'. The text 'My Work' is written in red below the 'Rarely detected' label.

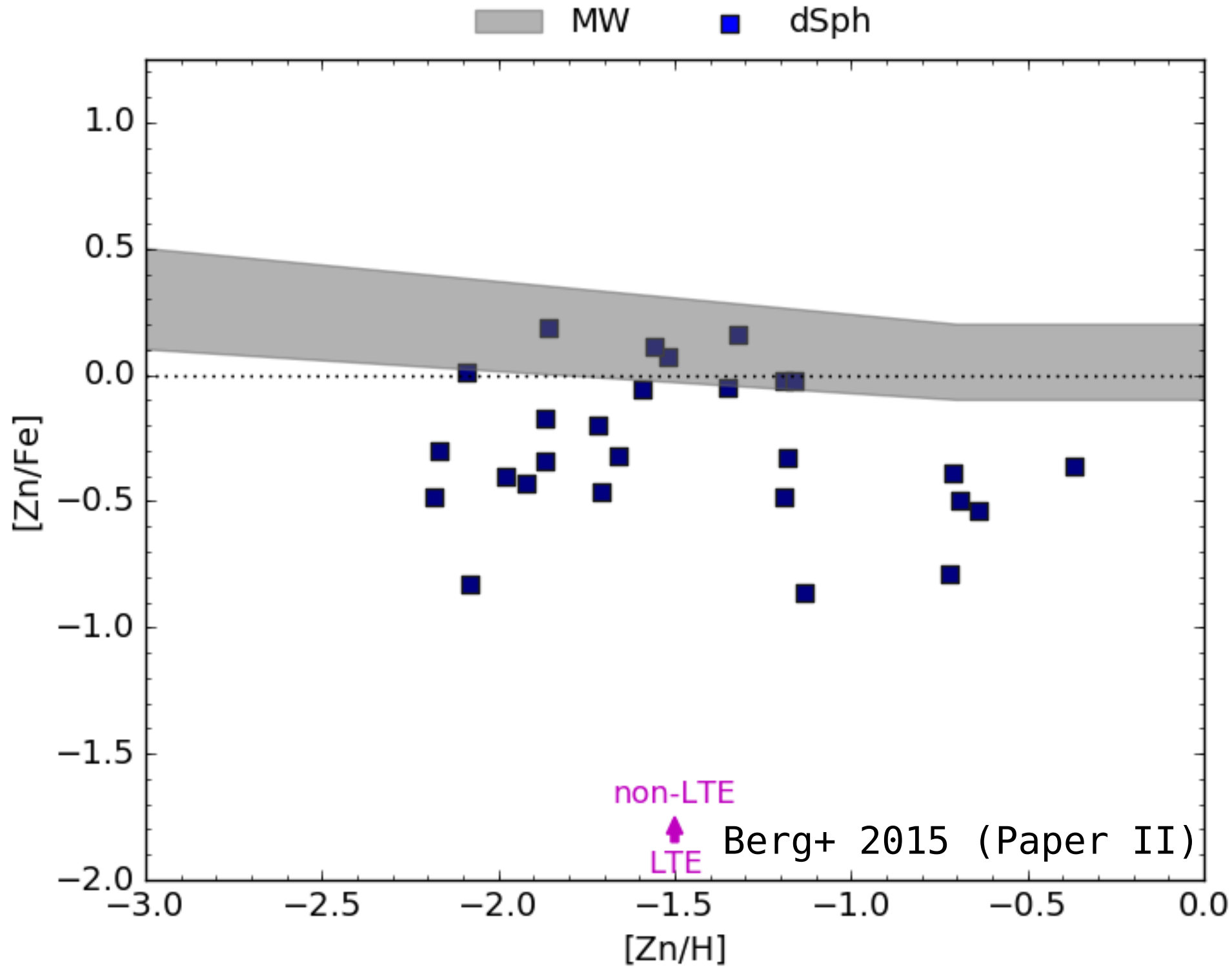
1 H Hydrogen 1.008																	2 He Helium 4.003						
3 Li Lithium 6.941	4 Be Beryllium 9.012																	5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305																	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 84.798						
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294						
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [209]	85 At Astatine [210]	86 Rn Radon [222]						
87 Fr Francium [223]	88 Ra Radium [226]	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium [284]	114 Fl Flerovium [289]	115 Uup Ununpentium [288]	116 Lv Livermorium [293]	117 Uus Ununseptium [294]	118 Uuo Ununoctium [294]						

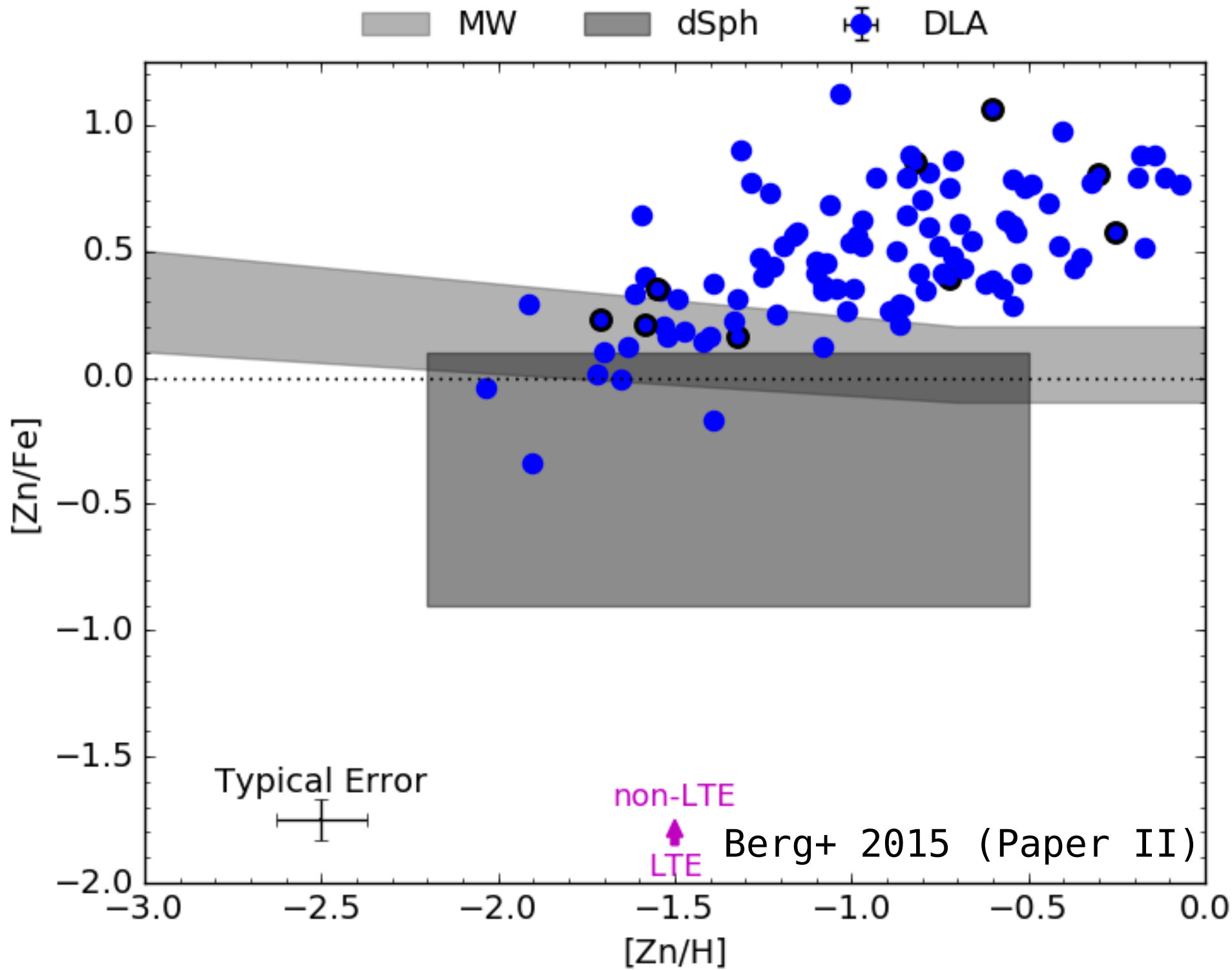
[Zn/Fe] – dust tracer or nucleosynthetic probe?

- Forms in lockstep with Fe at solar metallicities
 - DLA dust tracer (e.g. Pettini+ 1994)?
- Different contribution at low metallicities (hypernovae?)





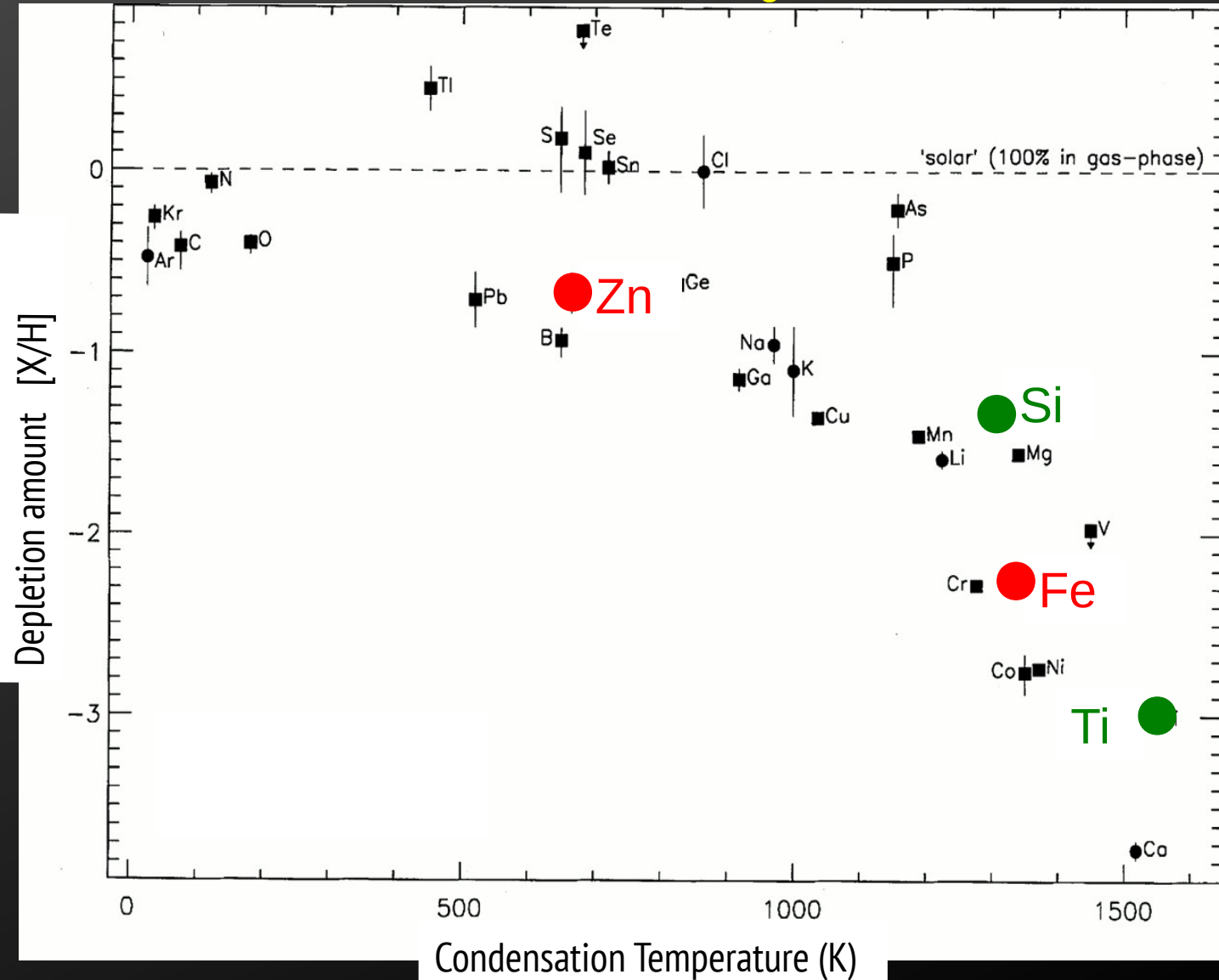




The problem with DLAs: Dust depletion

Savage and Sembach 1996

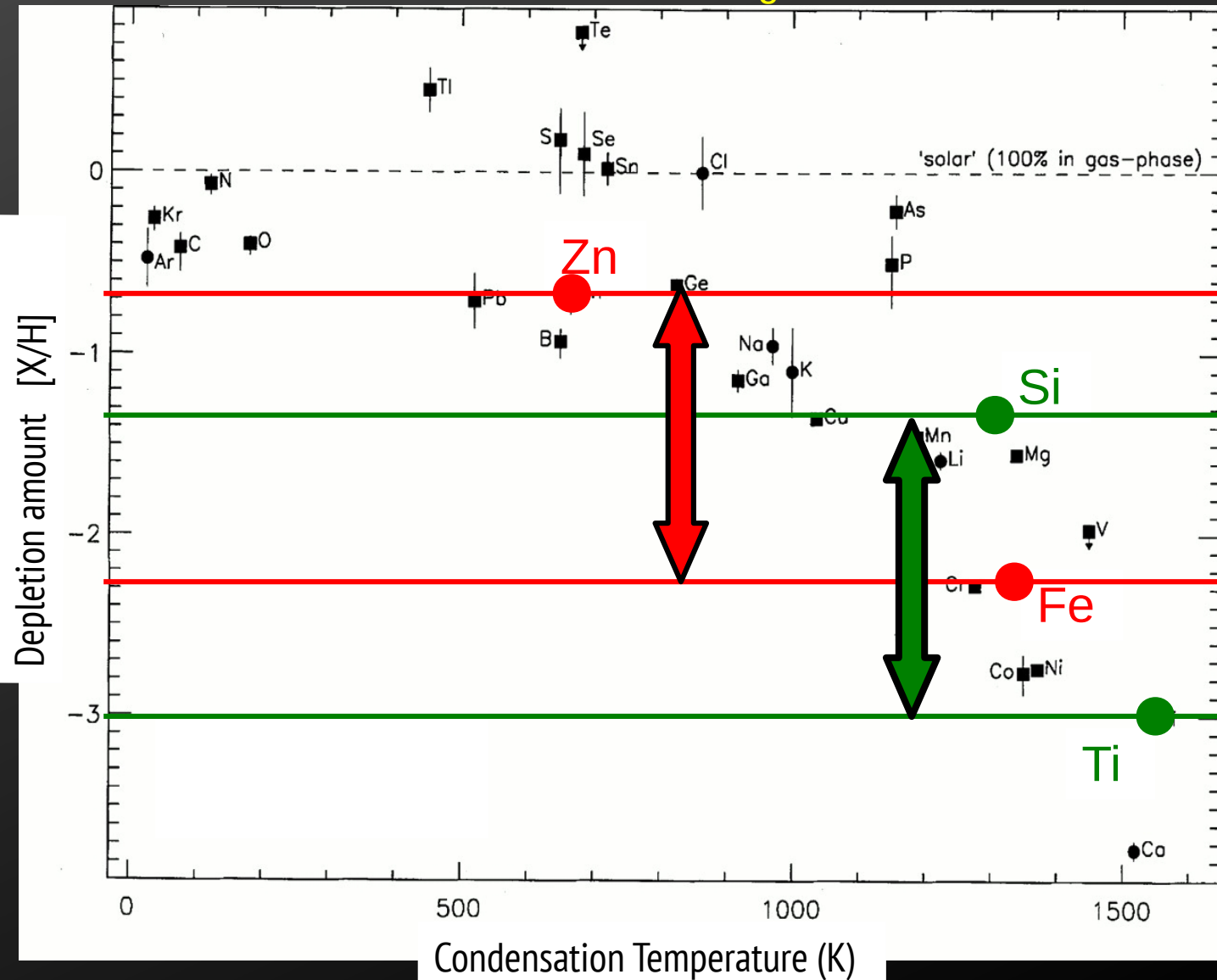
- Relative depletion patterns should scale from galaxy to galaxy
 - Elements with similar nucleosynthetic origin should give dust scaling

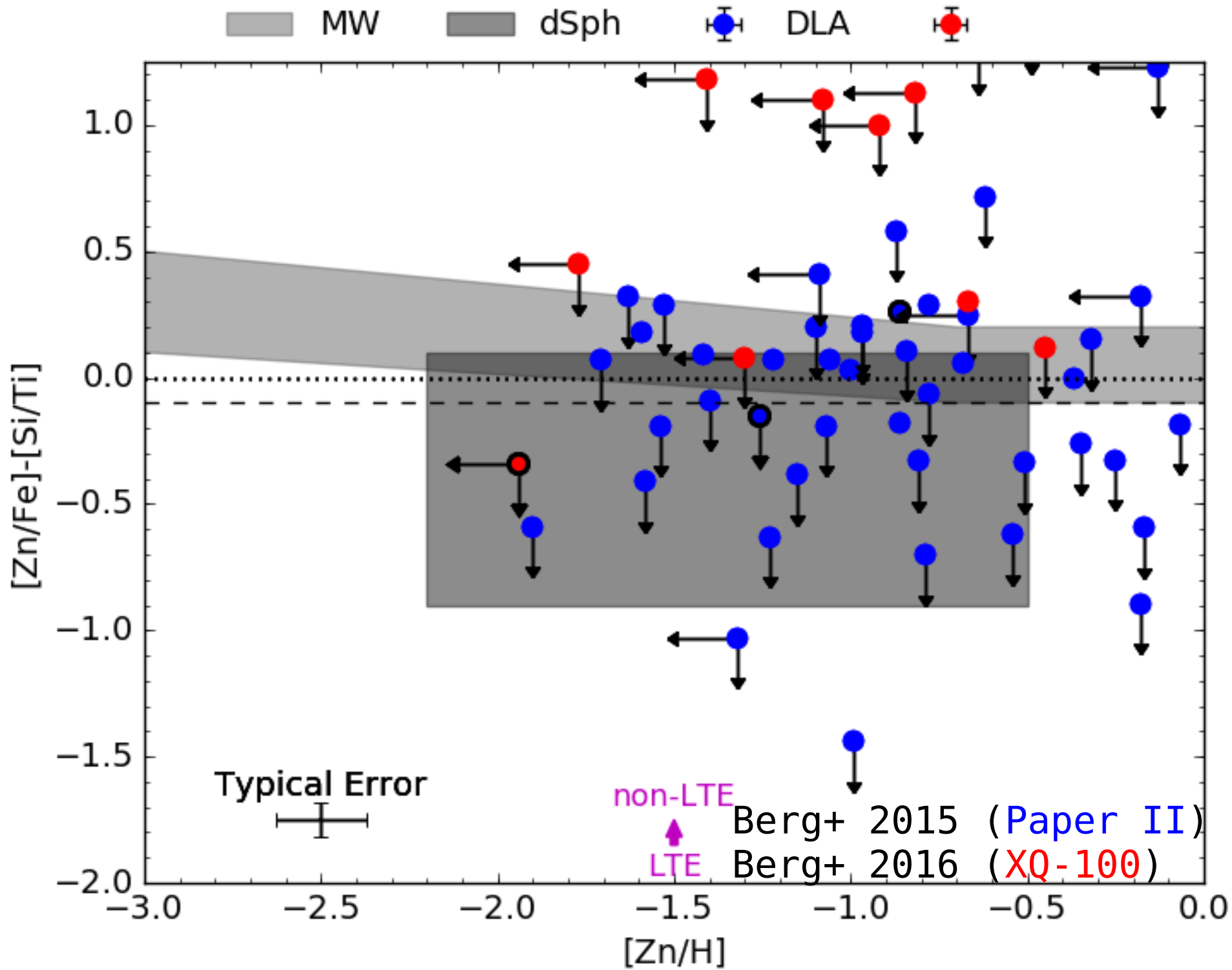


The problem with DLAs: Dust depletion

Savage and Sembach 1996

- Si and Ti both alpha-elements; same relative depletion as Zn-Fe
- $[Zn/Fe] - [Si/Ti]$ will give the nucleosynthetic contribution of $[Zn/Fe]$





Zn an Fe-peak tracer?

- Zn is not an Fe-peak tracer for ALL galaxies
- Some DLAs are similar to dSph [Zn/Fe] values
 - Others are consistent with both MW and dwarfs
- **Need *accurate* Zn abundances in different environments!**

DLA chemistry summary

- DLAs offer probe of observing chemical evolution across cosmic time
- MRDLAs can probe regime where differences in chemistry are seen in Local Group environments
 - [Zn/Fe] – Consistent with MW and dSphs
 - [α /Zn] – Low α in DLAs
 - [Mn/Fe] – Like dSphs (at high metallicities)
- Require handle on odd-Z and Zn in various environments