Abundances and Ionization in the ISM

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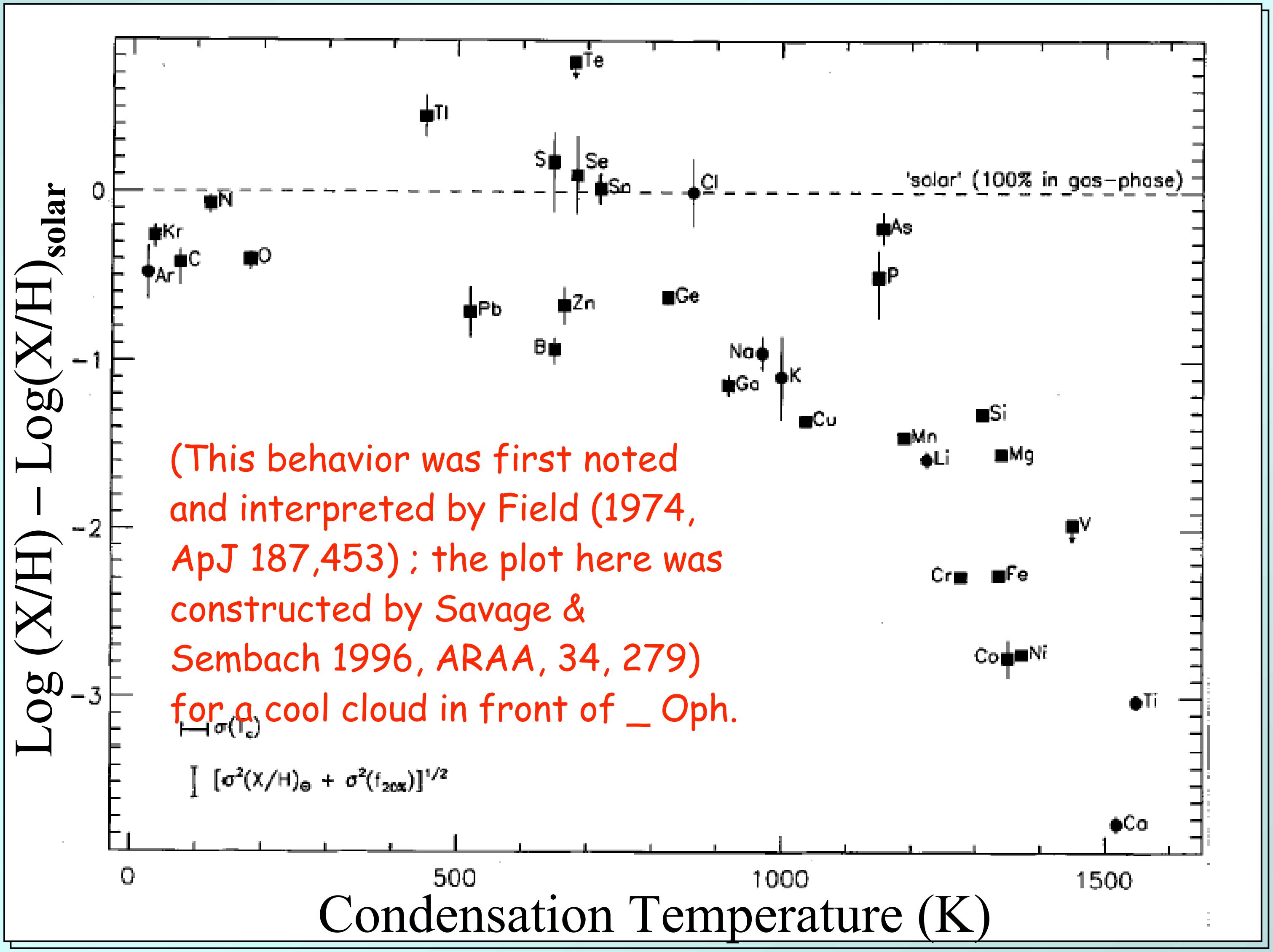
Depletions of Atoms onto Dust Grains

Relationship with the ***condensation temperature*** (the highest temperature at which atoms in a cosmic abundance mixture “freeze out” into chemical compounds in a low density medium, such as the mass-loss wind from a star)

General Rule:

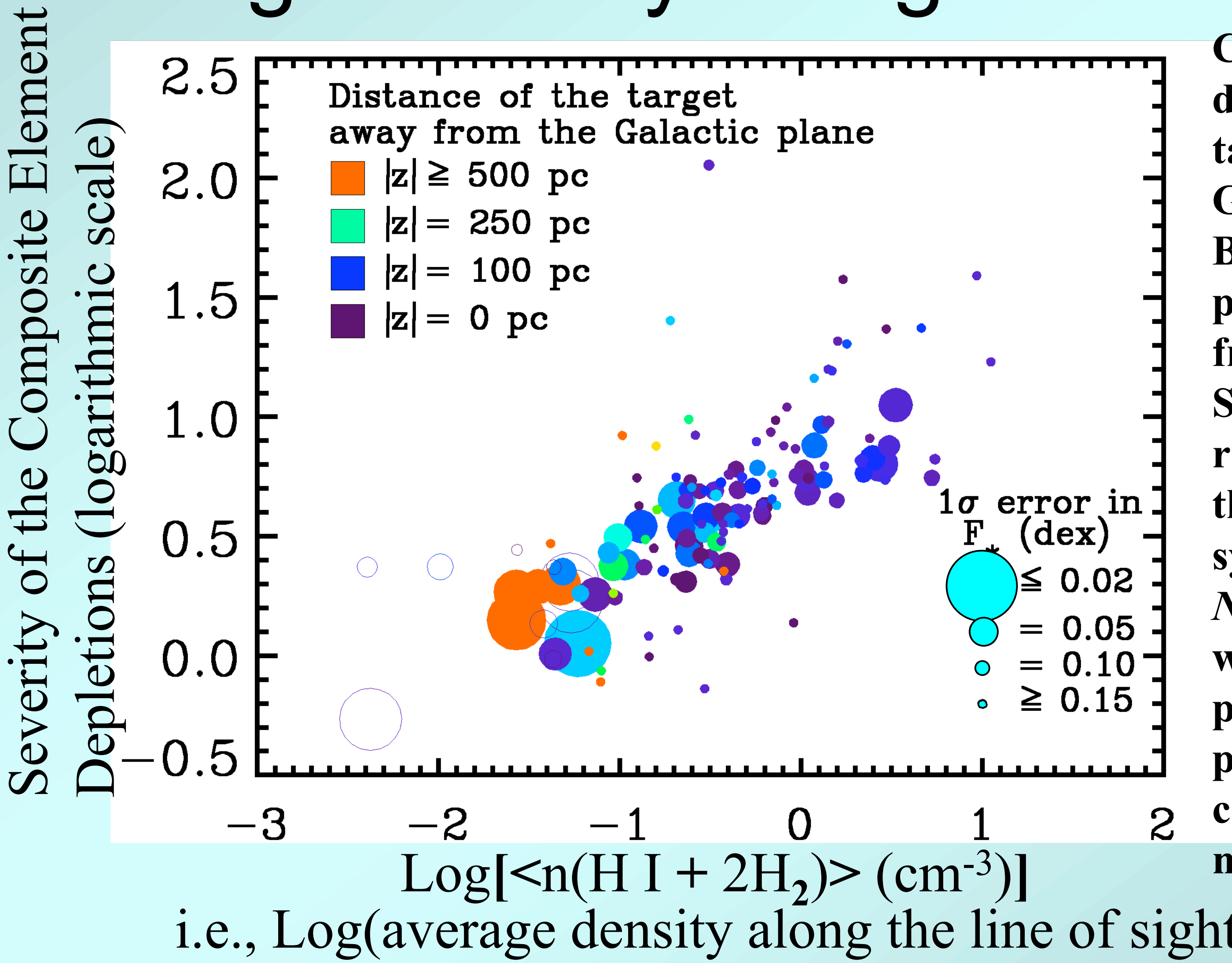
Elements that create refractory compounds show large depletions while volatile elements show little or no depletion

Depletions of Atoms onto Dust Grains



(This behavior was first noted and interpreted by Field (1974, ApJ 187,453) ; the plot here was constructed by Savage & Sembach 1996, ARAA, 34, 279) for a cool cloud in front of _ Oph.

Dependence of the Depletion on the Average Density along a Line of Sight

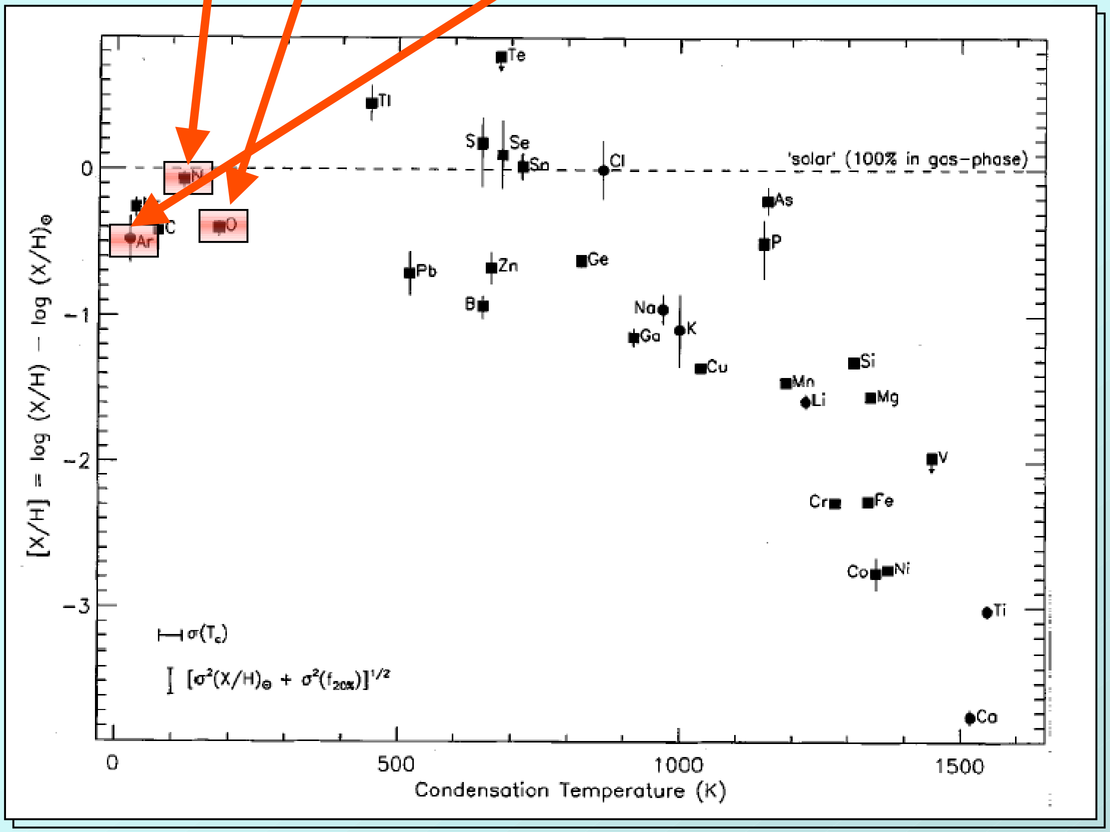


Color signifies the distance of the target star from the Galactic plane: Blue = near the plane, Red = far from the plane. Symbol sizes represent quality of the data. Open symbols denote log *N*(H I) < 19.5, where the effects of partial photoionization could give misleading results.

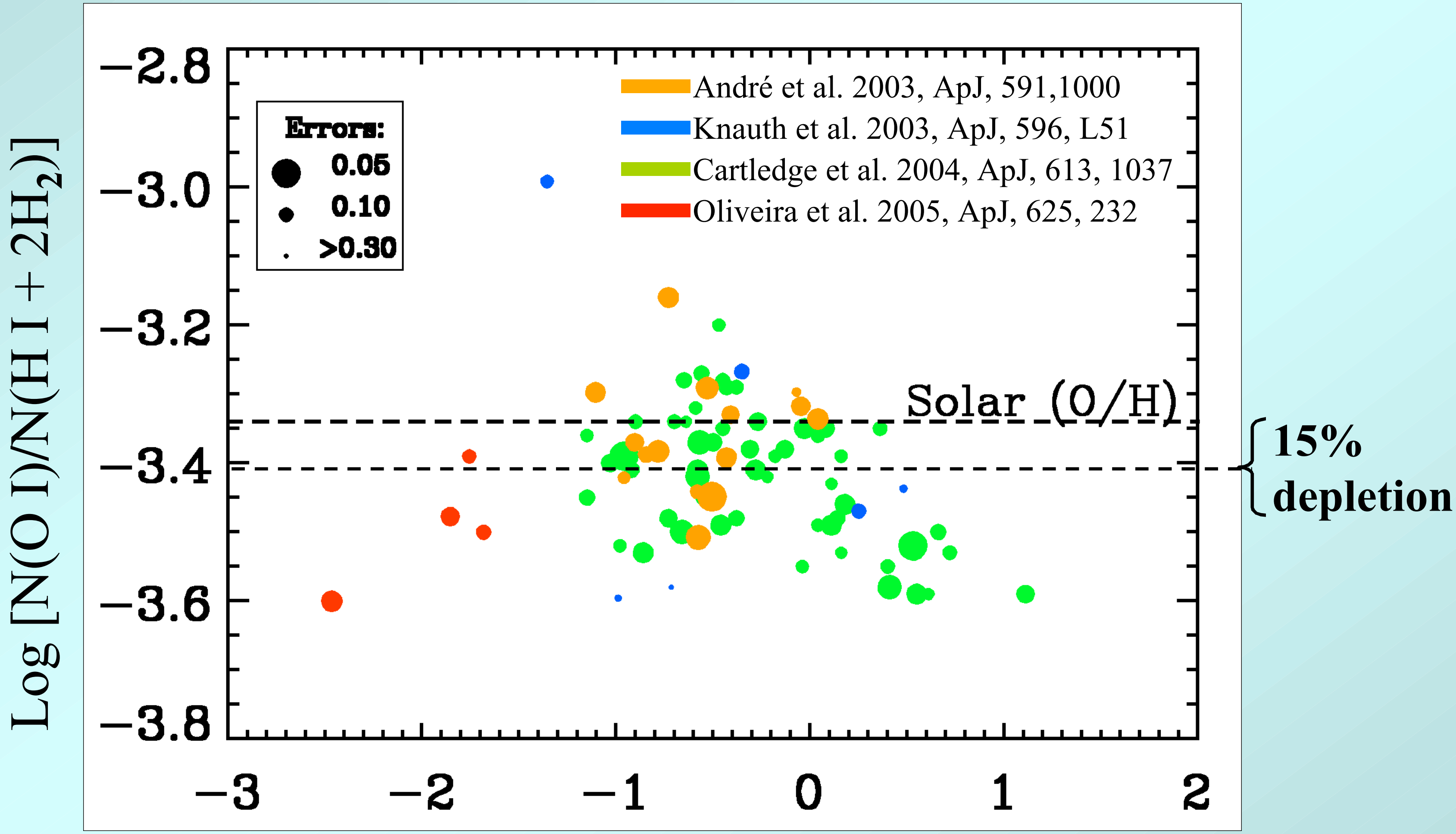
Elements which have Small or Nonexistent Depletions

- Focus of the remainder of this talk will be on the elements N, O and Ar

These three elements are well suited for study by FUSE. What can we learn from their relative abundances?

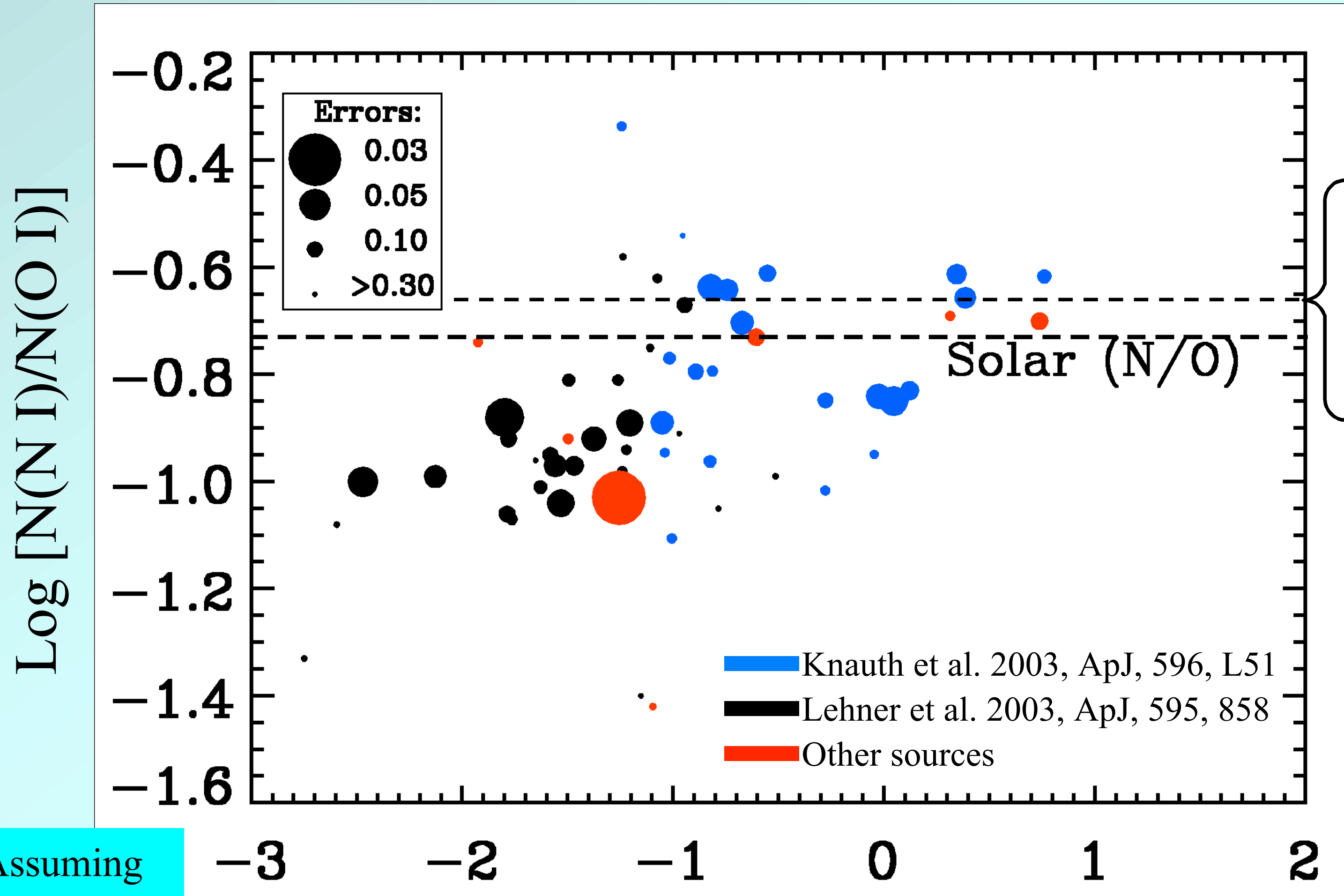


The Abundance of O relative to H



Log[<n(H I + 2H$_2$)> (cm^{-3})]
i.e., Log(average density along the line of sight)

The Abundance of N relative to O



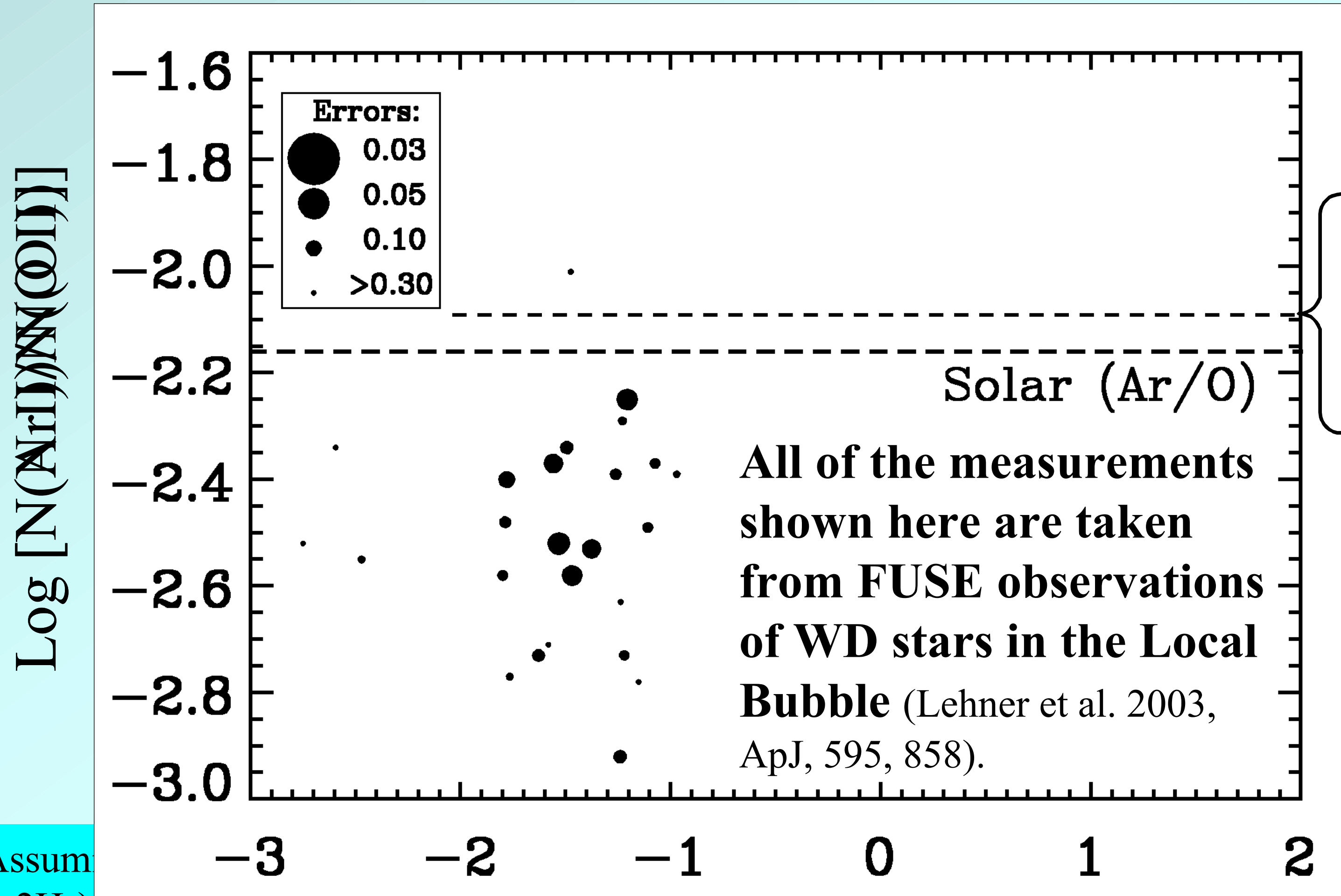
Undepl. N, presuming that O is 15% depl.

Eval. Assuming $n(\mathrm{H\ I} + 2\mathrm{H}_2) = n(\mathrm{O\ I})\_(\mathrm{H/O})_{solar}$

Log[<$n(\mathrm{H\ I} + 2\mathrm{H}_2)$> ($cm^{-3}$)]

i.e., Log(average density along the line of sight)

The Abundance of Ar relative to O



All of the measurements shown here are taken from FUSE observations of WD stars in the Local Bubble (Lehner et al. 2003, ApJ, 595, 858).

Undepl. Ar, presuming that O is 15% depl.

Eval. Assum: $n(H\ I + 2H_2)$ = $n(O\ I)\_(H/O)_{solar}$

Log[<$n(H\ I + 2H_2)$> (cm^{-3})]

i.e., Log(average density along the line of sight)

Interpretation of the Deficiencies of Ar I and N I

- For N, the trend is opposite to the usual correlation of depletion vs. <n(H)>.
- Ar is chemically inert and thus should not be depleted onto dust grains. (Weak physical binding of Ar to dust grain surfaces may occur, but it is probably negated by rapid photodesorption by starlight).
- Our evidence for anomalously low Ar I and N I arises from sight lines mostly within the Local Bubble – a large cavity surrounding the Sun that holds clouds of partly ionized gas (with the fractional ionization of helium being larger than that of hydrogen – still a puzzle!).
- Could some or most of the Ar and N be ionized, and thus be not visible in the form of Ar I and N I? If so, we need to understand why they more strongly ionized than H (or O).

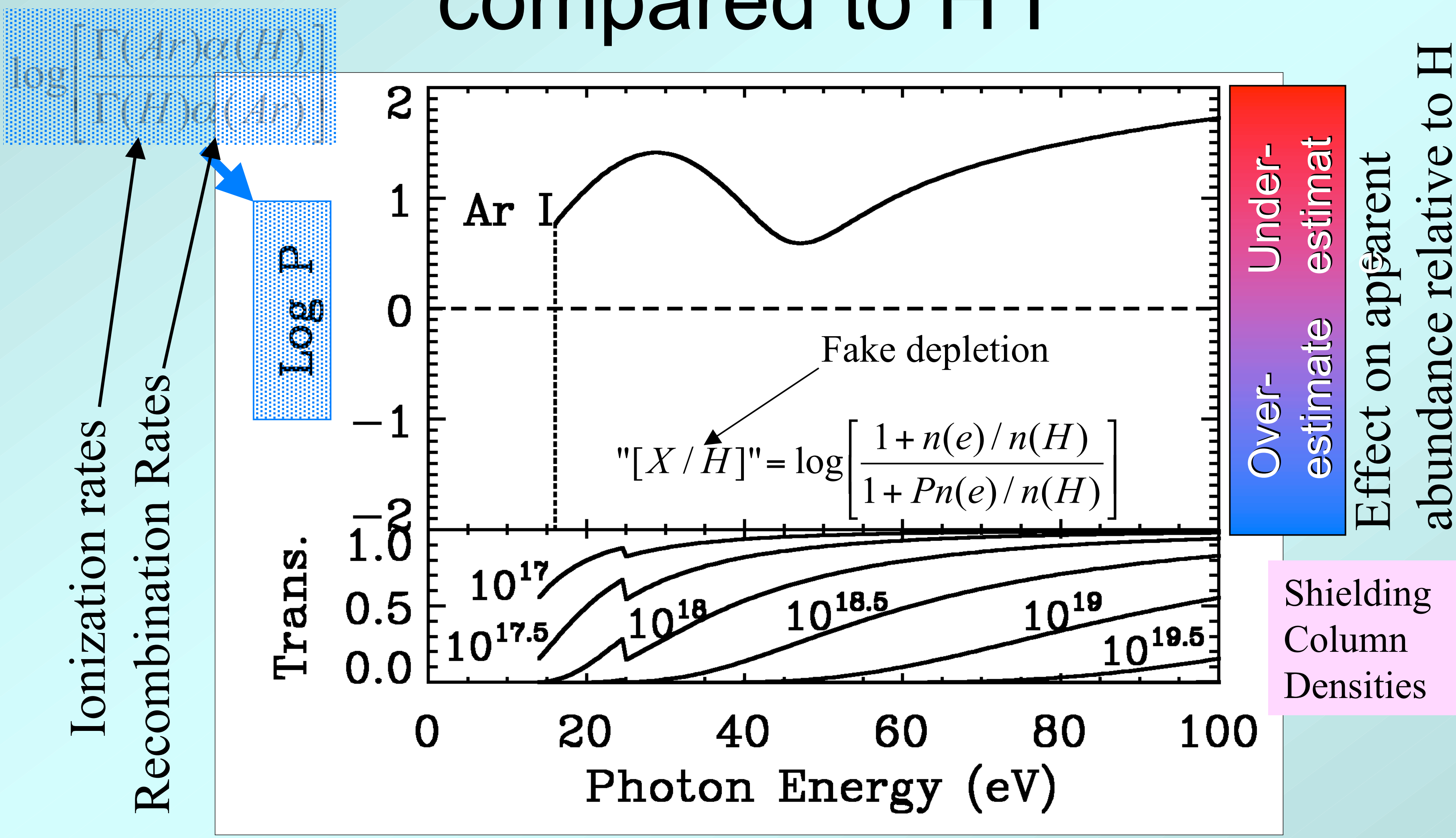
Interpretation of the Deficiencies of Ar I and N I

- Could this ionization be caused by incomplete recombination after some strongly ionizing event in the recent past, such as the passage of a shock from a supernova explosion, as proposed by Lyu & Bruhweiler (1996, ApJ, 459, 216)?
- It’s difficult for this model to explain large differences in ionization –These elements have recombination coefficients that are not very different from each other (or those of H and O).

Interpretation of the Deficiencies of Ar I and N I

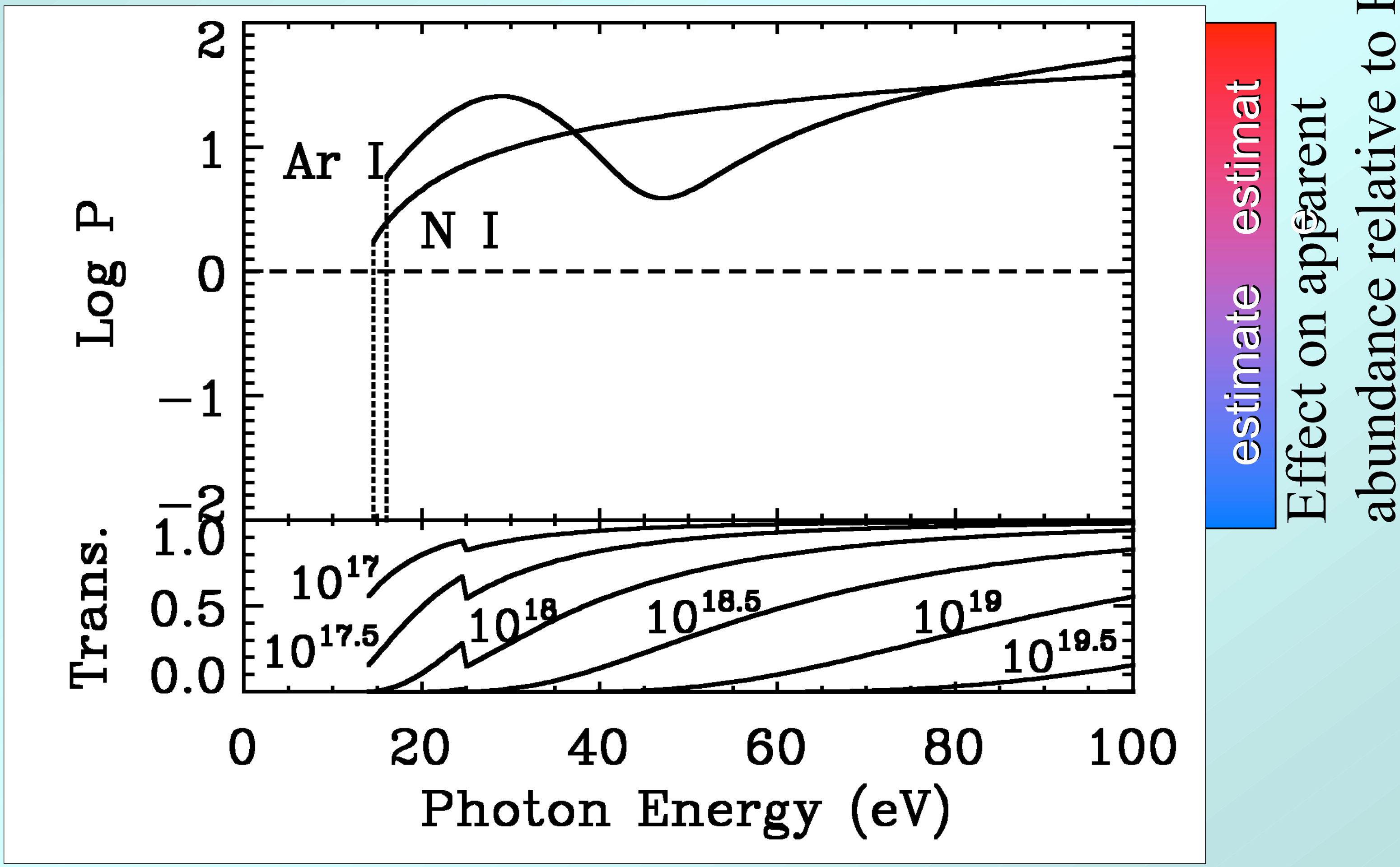
- As an alternative, can we understand the ionization in terms of a steady-state photoionization, caused by EUV stellar radiation and radiation from hot gases in the Local Bubble?
- Perhaps … one interesting property of these atoms is that their photoionization cross sections are vastly different.

Relative Susceptibility to Ionization compared to H I



Adapted from Sofia & Jenkins 1998: ApJ, 499, 951

Relative Susceptibility to Ionization compared to H I



Charge Exchange with H I

- $N^+ + H^0$ _ $N^0 + H^+$
- $O^+ + H^0$ _ $O^0 + H^+$
- Outcome: tends to lock relative ionization to some fixed fraction of that of H I, overcoming the usual equilibrium established by photoionization balanced against recombinations with free electrons.
- The effect is very strong for O, moderately strong for N, and not important for Ar.

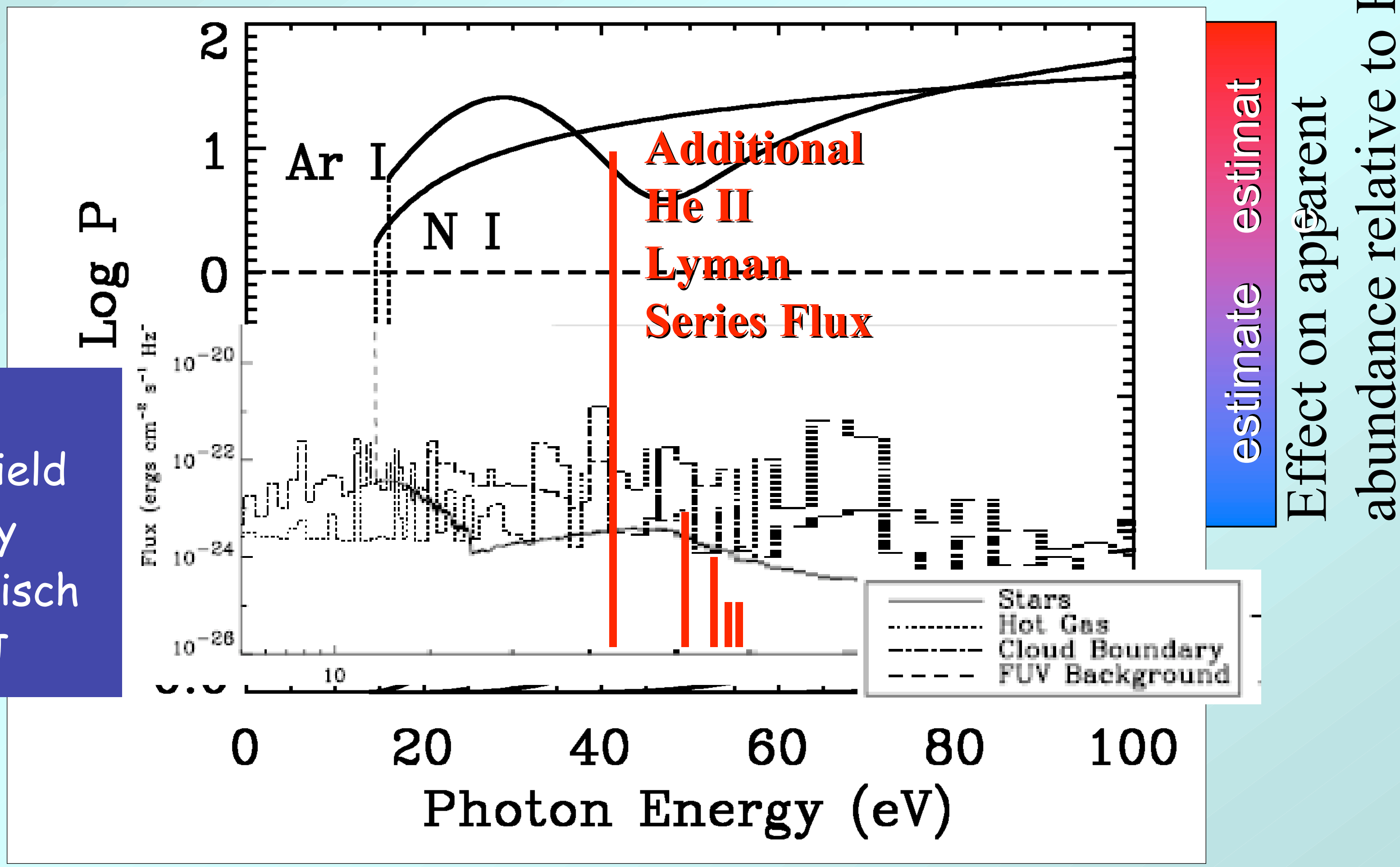
N and Ar Abundances – How do they Compare with Ionization Models?

- Initial model assumptions:
  - EUV radiation from stars taken from *EUVE* observations reported by Vallerga (1998: ApJ, 498, 321), supplemented by radiation from hot gas (bulk hot gas plus interfaces with cold gas) calculated by Slavin & Frish(2002: ApJ, 565, 364)
  - Allow for different amounts of shielding of this radiation within the clouds
  - Explore a range of temperatures from 1000 to 12,000 K, as indicated by observations of clouds in the Local Bubble by Redfield & Linsky (2004: ApJ, 602, 1004).

N and Ar Abundances – How do they Compare with Ionization Models?

- **Outcome for the Model:**
  - Predicted deficiency of Ar I roughly consistent with FUSE observations, but the deficiency of N I should be less than observed.
- How can we modify the model so that we overcome this problem and thus create a means for explaining the deficiency of N I?
- Let’s re-examine the plot of ionization susceptibilities

Relative Susceptibility to Ionization compared to H I



Ambient radiation field estimate by Slavin & Frisch (2002: ApJ ,565, 364)

Conclusions from the FUSE Observations of O I, N I, and Ar I

- In sight lines dominated by dense clouds, N and O are only slightly depleted onto dust grains ($\leq$ 0.2 dex).
- Ar I shows a strong deficiency in the Local Bubble (up to 0.7 dex), probably because it is more strongly photoionized than H (or O).
- Stronger than expected He II Lyman line emission may help to reconcile the expected N I and Ar I abundances with the observations. (This might help to explain why the fraction of singly ionized He is greater than that of H.)