Large metallicity variations in the Galactic interstellar medium

De Cia et al. 2021

https://www.nature.com/articles/s41586-021-03780-0

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2021.12.3 @student seminar

Outline

- Background
- Data
- Methods
- Results
- Summary

Interstellar medium (ISM)

- Three main elements
  - the pristine gas coming from outside our galaxy
  - the metal-rich gas from dying stars
  - the dust created by the condensation of the metals
- Theoretical models assume that the metallicity of the neutral ISM in Galaxy
  - is homogeneously mixed
  - is solar metallicity in the solar vicinity

The Horsehead Nebula (APOD 001229)

Dust depletion

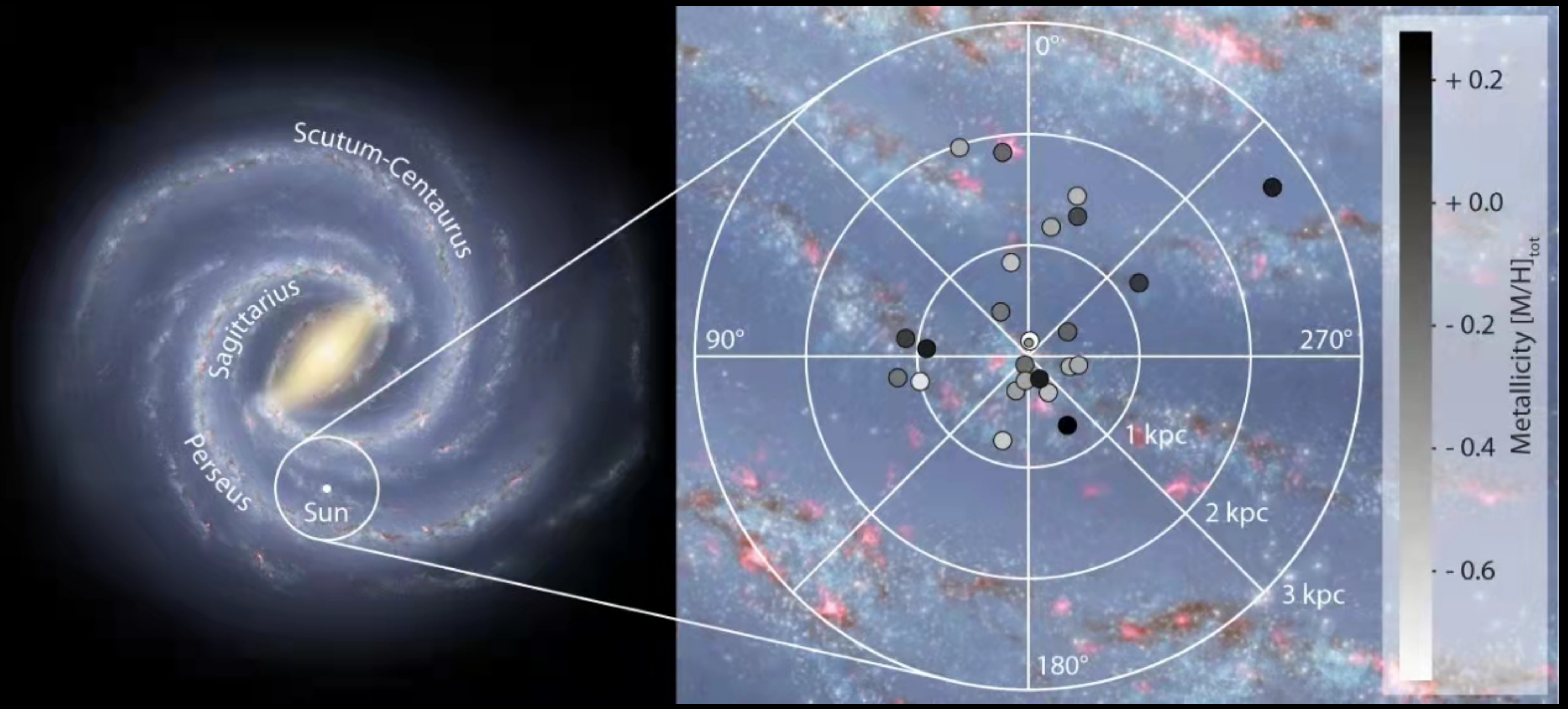
- The phenomenon that metals are missing from the observable gas phase but instead are incorporated into dust grains
- Only the gaseous part of the ISM can be “seen” in ultraviolet/optical spectroscopy; atoms in dust grains don’t leave a spectral fingerprint
- It makes the measurements of the ISM’s metallicity complicated

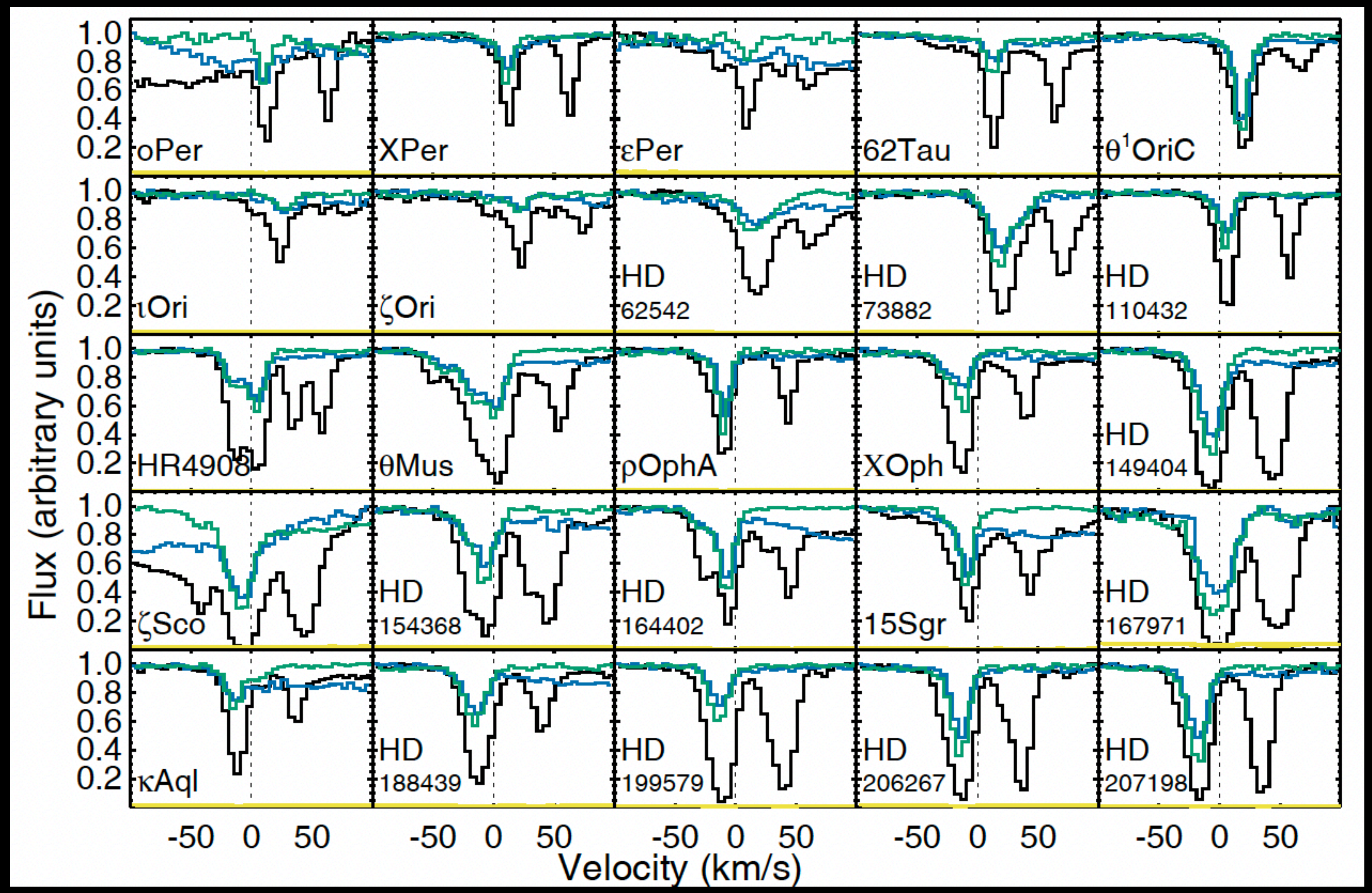
Take-home message

- There are large metallicity variations in the Galactic ISM
- The ISM includes many regions of low metallicity, and the average metallicity is not as high as in the Sun

Data

- 25 bright type-O and type-B stars in the Galaxy
  - HST/STIS near-ultraviolet spectra
  - VLT/UVES high-resolution optical spectra
  - high-enough rotational velocities to disentangle between stellar and ISM features
- Measure column densities from absorption lines in spectra





Methods

- Two methods for dust-correction
  - Relative method
  - F* method
- Dust-corrected abundance: $[X/\mathrm{H}]_{tot} = [X/\mathrm{H}] - \delta_X$
- $$[X/Y] \equiv \log \frac{N(X)}{N(Y)} - \log \frac{N(X)_\odot}{N(Y)_\odot}$$

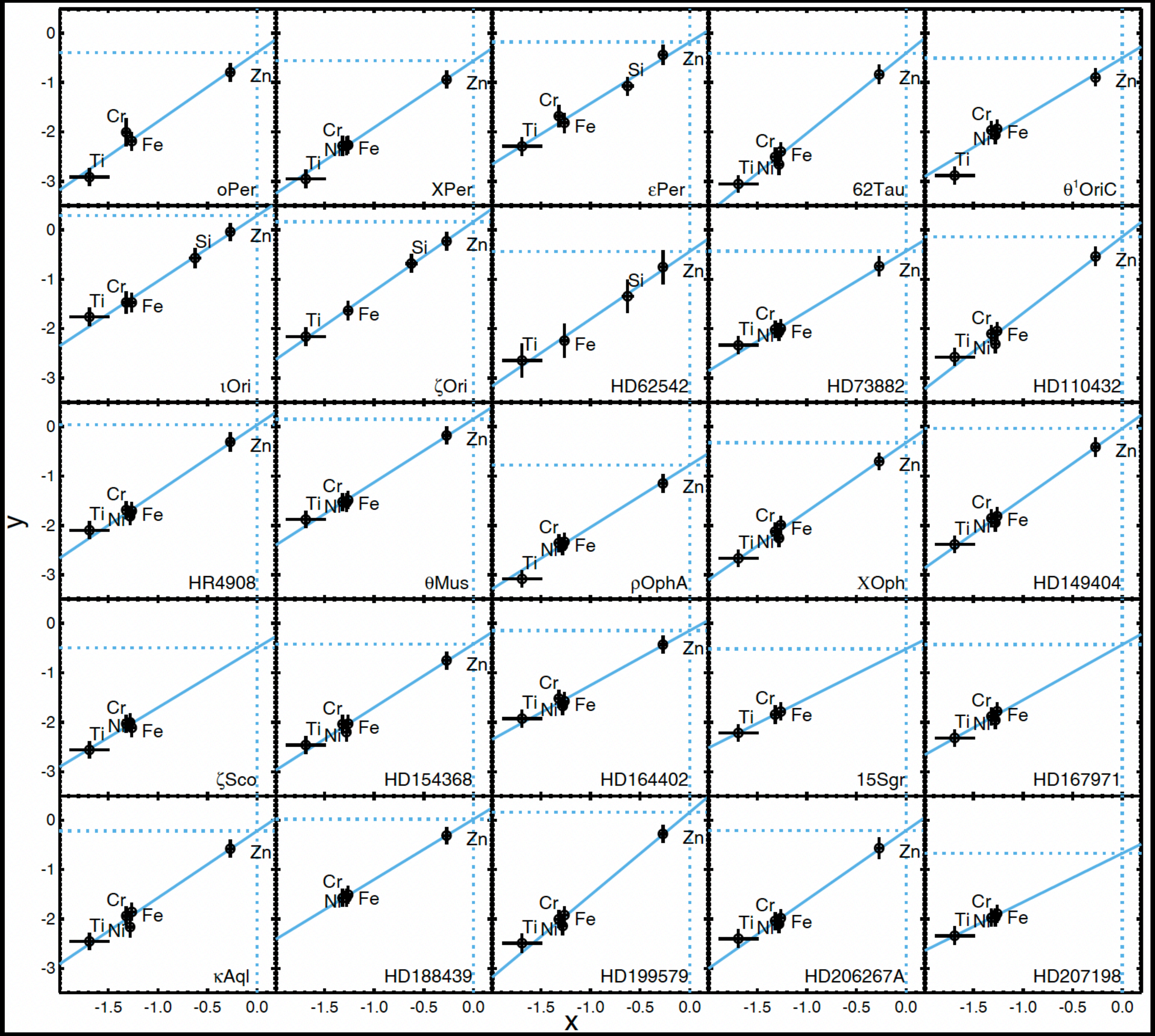
Relative method

- (De Cia et al. 2016, A&A, 596, A97)
- Using any relative abundance [X/Y] where X and Y (here Zn) have very different refractory properties
- [Zn/Fe]: dust tracer
- $\delta_X = A2_X + B2_X \times [\mathrm{Zn/Fe}]$
- Linear fit: $y = a + bx$
  - $a = [M/\mathrm{H}]_{tot}, b = [\mathrm{Zn/Fe}]_{fit}$
  - $x = B2_X, y = \log N(X) - \log N(\mathrm{H}) - \log(X/\mathrm{H})_\odot - A2_X$

F* method

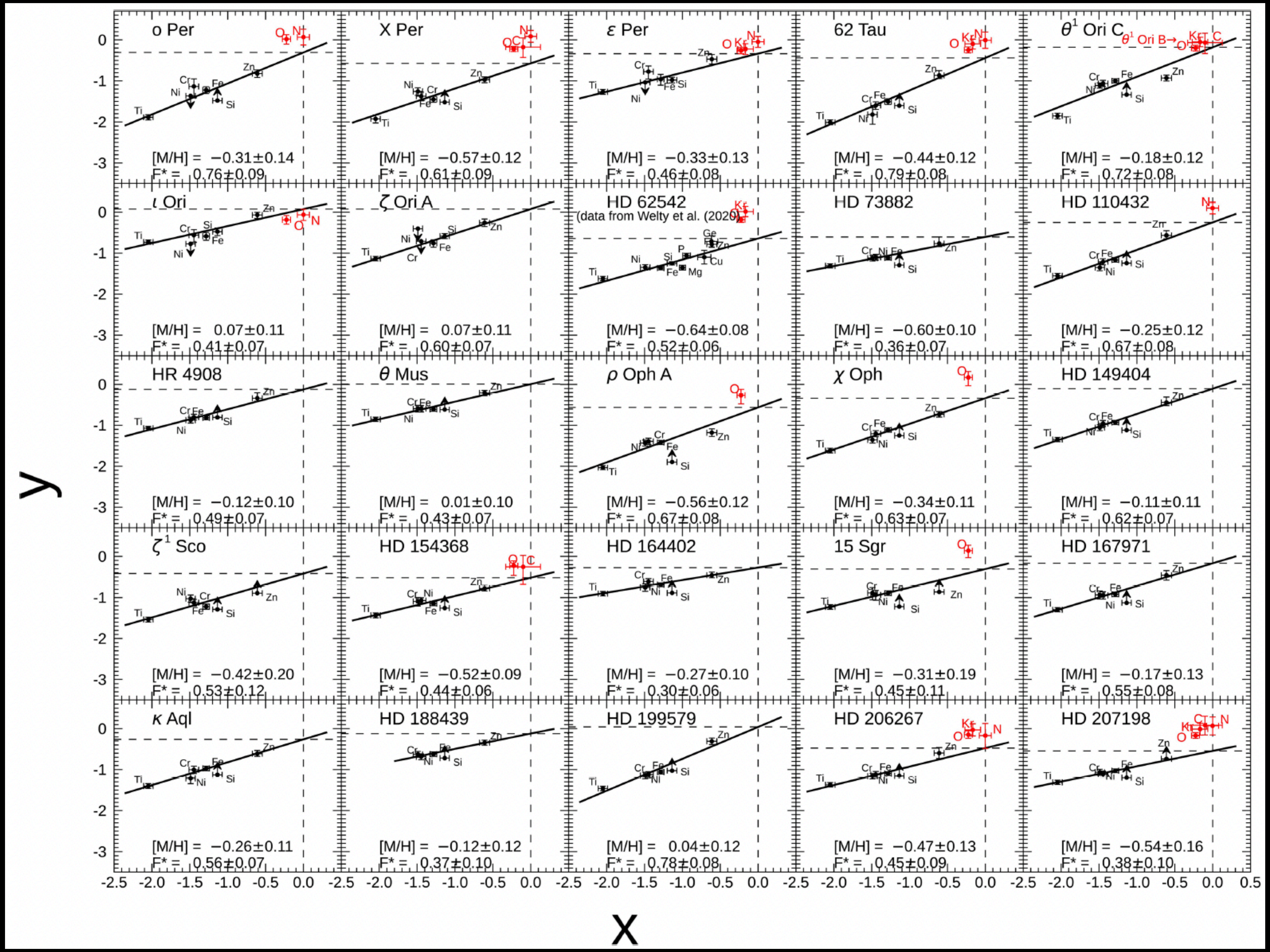
- (Jenkins, E. B. 2009, ApJ, 700, 1299)
- Correlating all the observed abundances and minimizing the residuals with respect to F*
  - F*: a factor representing the overall strength of dust depletion in individual lines of sight
- Linear fit: $y = a + bx$
  - $\delta_X = B_X + A_X(F_* - z_X)$
  - $y = \log N(X) - \log N(\mathrm{H}) - \log(X/\mathrm{H})_\odot - B_X + A_X \times z_X$
  - $x = A_X$, $a = [M/\mathrm{H}]_{tot}$, $b = F*$

Results - relative method



Results - F* method

- Red points: the most volatile elements
- The most volatile elements show disagreement with the mildly depleted elements and the more refractory elements



Results - metallicity

- Total metallicities $[M/\mathrm{H}]_{tot}$ ranging between -0.76 dex and +0.26 dex
- 2/3 of samples show subsolar metallicities
- Average metallicity: -0.26 ± 0.06 dex ($55 \pm 7\%$ solar)
- The maximum variations between lines of sight are more than an order of magnitude, mostly subsolar

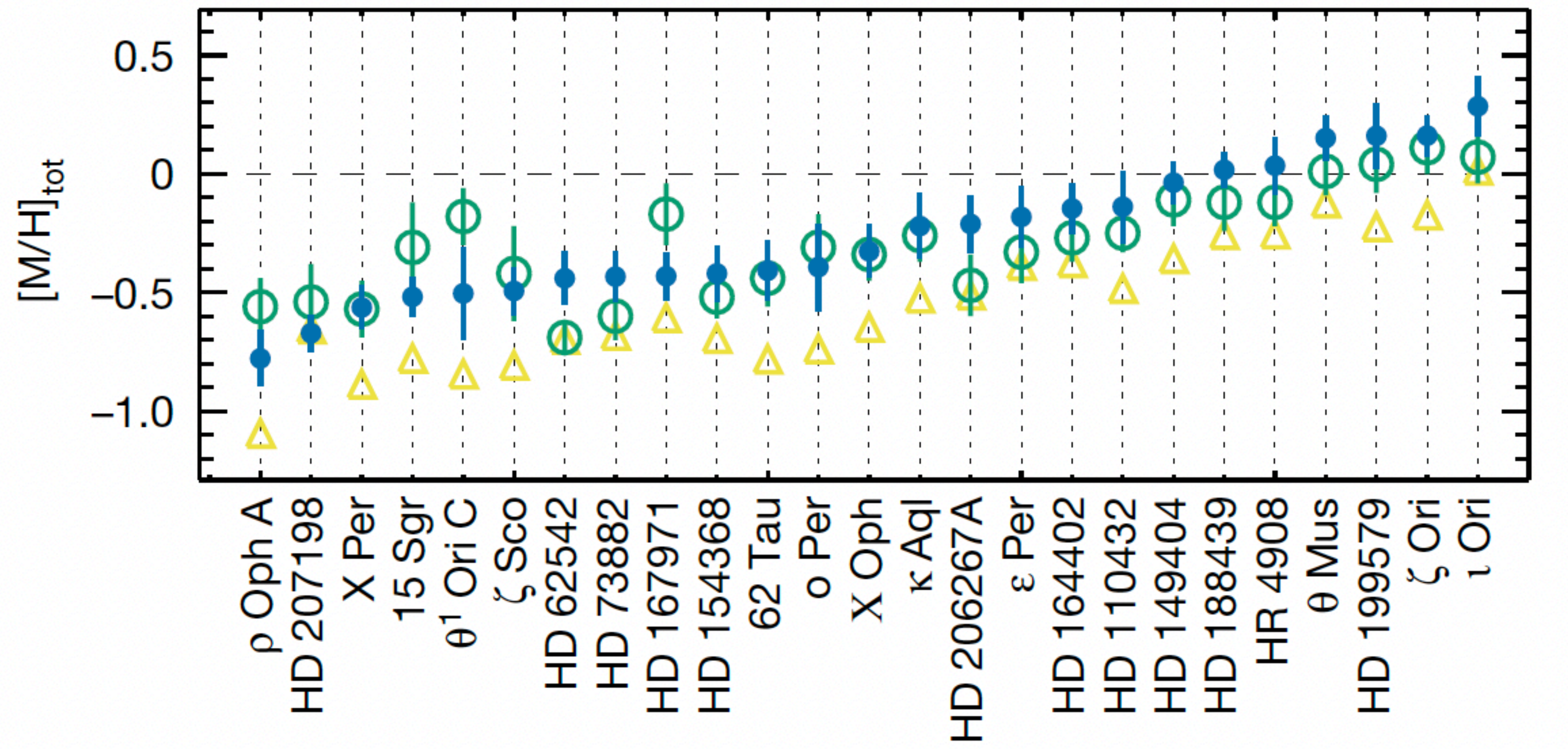


Fig. 3 | Metallicities in the neutral ISM. Dust-corrected metallicities are marked with circles: the filled blue circles are derived with the relative method and the open green circles with the F^* method. The open yellow triangles show the observed [Zn/H], and thus represent a lower limit to the true metallicity. Stars are ordered with increasing metallicity. In our sample, 15 out of 25 lines of sight are more than 3σ away from solar metallicity (horizontal dashed line). The error bars show the 1σ uncertainties.

Possible mechanism

- Pristine gas falling onto the Galactic disk in the form of high-velocity clouds (HVC) can cause the observed inhomogeneities on scales of tens of parsecs.

- Pristine gas does not efficiently mix into the ISM

- The rate of gas accretion on the Galaxy disk ($0.1 - 1.4 M_{\odot} yr^{-1}$) is sufficient to sustain the inhomogeneities

- The inefficiency may be because the different phases involved in the mixing have widely different kinematics and different physical conditions

Comments

- Very surprising results that may have a strong impact on our understanding of the evolution of galaxies

- But the relative and F* methods in the paper are explained too briefly… especially the meaning of some coefficients

Summary

- Large local variations of metallicity in the neutral ISM in Galaxy are measured
- The ISM includes many regions of low metallicity, and the average metallicity is not as high as in the Sun
- The variations may be due to accretion of low-metallicity pristine gas
- The gas mixing is more inefficient than previously thought.

Questions

- Why can [Zn/Fe] be a dust tracer in relative method? Why can it be a parameter rather than a measured value?
- How to get coefficients A_X, B_X and z_X in F* method?
- Why does the y intercept of the linear fitting give $[M/\mathrm{H}]_{tot}$? Does $[M/\mathrm{H}]_{tot}$ equal to $[X/\mathrm{H}]_{tot}$?
- Why can different kinematics and physical conditions lead to inefficiently gas mixing?