Iron Abundance in the Solar Photosphere:

The Role of Ions, Non-LTE, Model Atmospheres, Oscillator Strengths, and Free Parameters

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Background

The photospheric iron abundance is important to understanding solar system formation and evolution.

Methodological designs in the literature have produced significantly different abundance estimates. E.g., oscillator strengths measured by co-authors at Kiel and Hannover resulted in 'low' iron abundances consistent with meteoritic iron. Those by co-authors at Oxford resulted in 'high' abundances (~125% meteoritic).

Grevesse & Sauval (1999) suggest the cumulative effects of different choices for free parameters and oscillator strengths account for the high-low discrepancy.

This raises the general question of what role these and other design choices have played across the entire literature.

Methods

322 original photospheric iron abundances were extracted from 72 primary publications identified through SAO/NASA Astrophysics Data System and Google Scholar, published between 1951 and 2022.
Methodological characteristics corresponding to each abundance estimate were categorised (ion studied, LTE assumption, model atmosphere & dimensions, source of oscillator strengths, and microturbulence velocity).
A linear mixed-effects regression model was implemented to quantify the role these variables play in abundance estimates.

Results

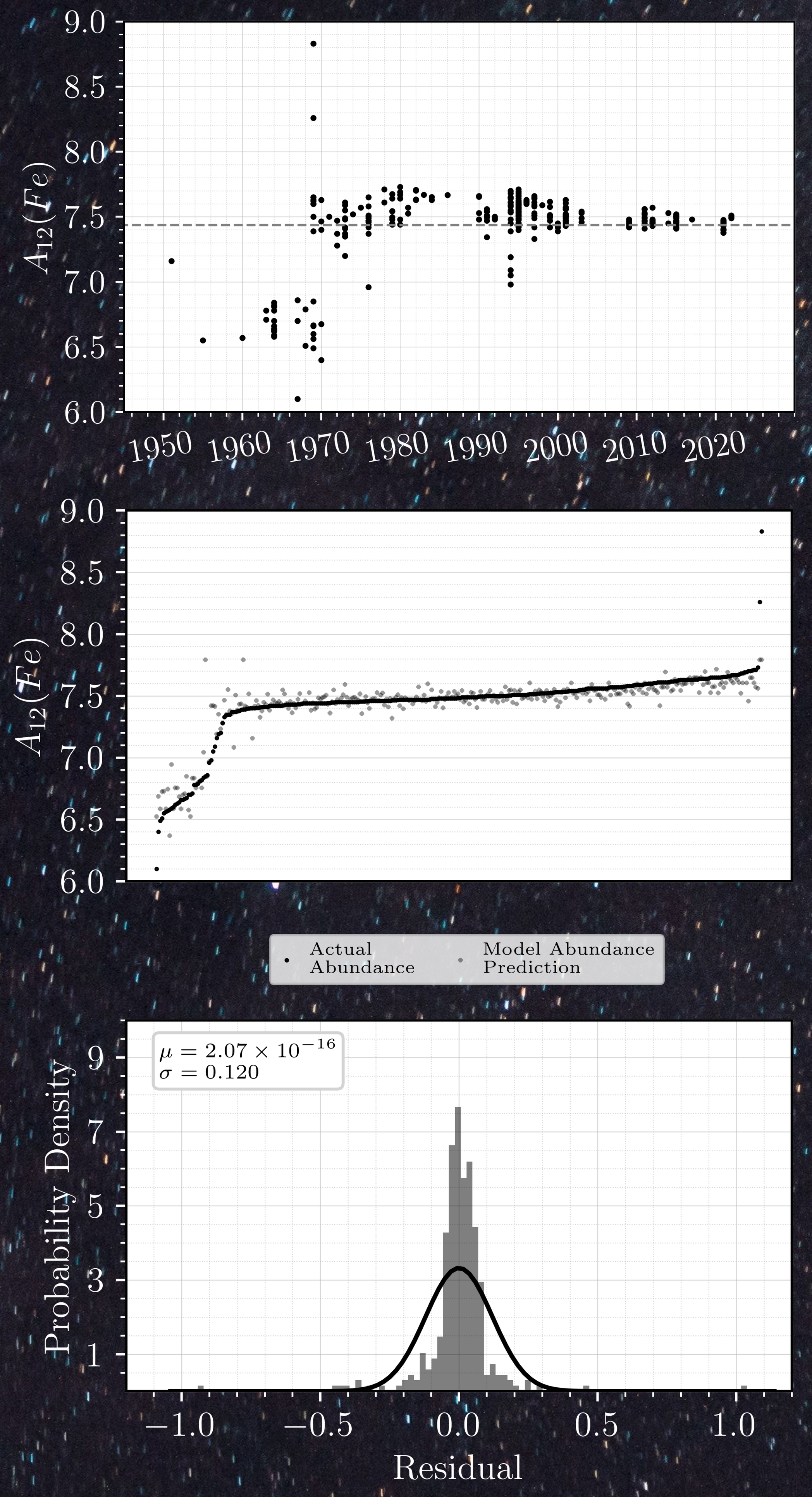

TABLE 1
Model Results

Variable	Regression Coefficient (95% CI)
Constant	7.480 (7.382 – 7.578)**
Ion	
Fe I	0.000 (Referent)
Fe I & II	0.075 (−0.045 – 0.195)
Fe II	0.106 (0.045 – 0.167)**
Thermodynamics	
LTE	0.000 (Referent)
NLTE	0.096 (0.022 – 0.169)*
Ion × Thermodynamics	(See text)*
Model Dimensions	
1D	0.000 (Referent)
2D	−0.003 (−0.175 – 0.169)
3D	0.071 (−0.018 – 0.159)
⟨3D⟩	0.066 (−0.025 – 0.156)
Model Atmosphere	
HM	0.000 (Referent)
ATLAS	−0.055 (−0.141 – 0.030)
HSRA	−0.070 (−0.184 – 0.043)
MAFAGS	−0.052 (−0.190 – 0.087)
MARCS	−0.087 (−0.157 – −0.017)*
Other	−0.122 (−0.185 – −0.059)**
Oscillator Strengths	
Oxford/Kiev	0.000 (Referent)
Kiel/Hannover	−0.066 (−0.178 – 0.046)
Corliss	−0.540 (−0.681 – −0.399)**
Meléndez & Barbuy	−0.087 (−0.217 – 0.043)
Other	−0.071 (−0.160 – 0.018)

* $p < 0.05$, ** $p < 0.001$

This work was not supported by any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Discussion

An attempt was made to quantify the role of various methodological characteristics of iron abundance estimates in the published literature using a statistical model.

The largest differences are accounted for by the ion studied and the LTE assumption. LTE abundance predictions were lower than NLTE predictions for Fe I, but higher than NLTE predictions for Fe II.

In 1D and <3D> models, every 0.1 km s^{-1} increase in the microturbulence velocity parameter results in a 0.04 dex decrease in abundance.

The present study serves as a reminder that careful consideration of study design is required in astrochemical abundance research.

In a recent compilation, Lodders (2019) provides a photospheric iron abundance of 7.48 ± 0.04 dex. More recently, Asplund et al. (2021) give 7.46 ± 0.04, and Magg et al. (2022) give 7.51 ± 0.06. The mean abundance across all sources found in the present study is 7.44 ± 0.02, consistent with these and with the iron abundance in CI-chondrites (7.45 ± 0.02; Lodders 2019).

A preprint of the present study is available at https://doi.org/10.21203/rs.3.rs-1319069/v3

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