UNIVERSITY OF CAMBRIDGE ioa NOIRLab

Probing Exoplanetary Compositions using White Dwarf Stars

Laura Rogers

laura.rogers@noirlab.edu

Collaborators: Siyi Xu, Amy Bonsor, Simon Hodgkin, Markus Kissler-Patig, Patrick Dufour, Beth Klein, Carl Melis, Ben Zuckerman, Andrew Buchan, Alycia Weinberger

Credit: NASA

White dwarfs

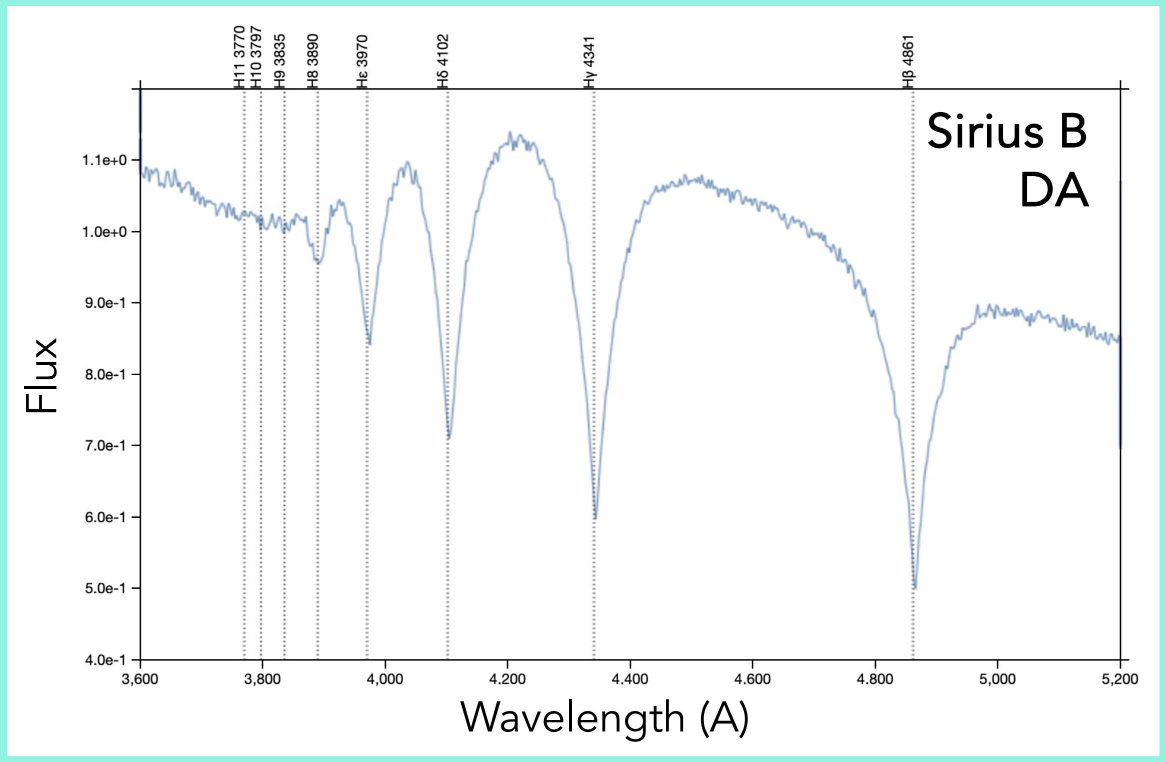
Stellar remnants – core of low mass stars

Very dense - Mass of ~ 0.6 $M_{\odot}$ packed into the radius of the Earth

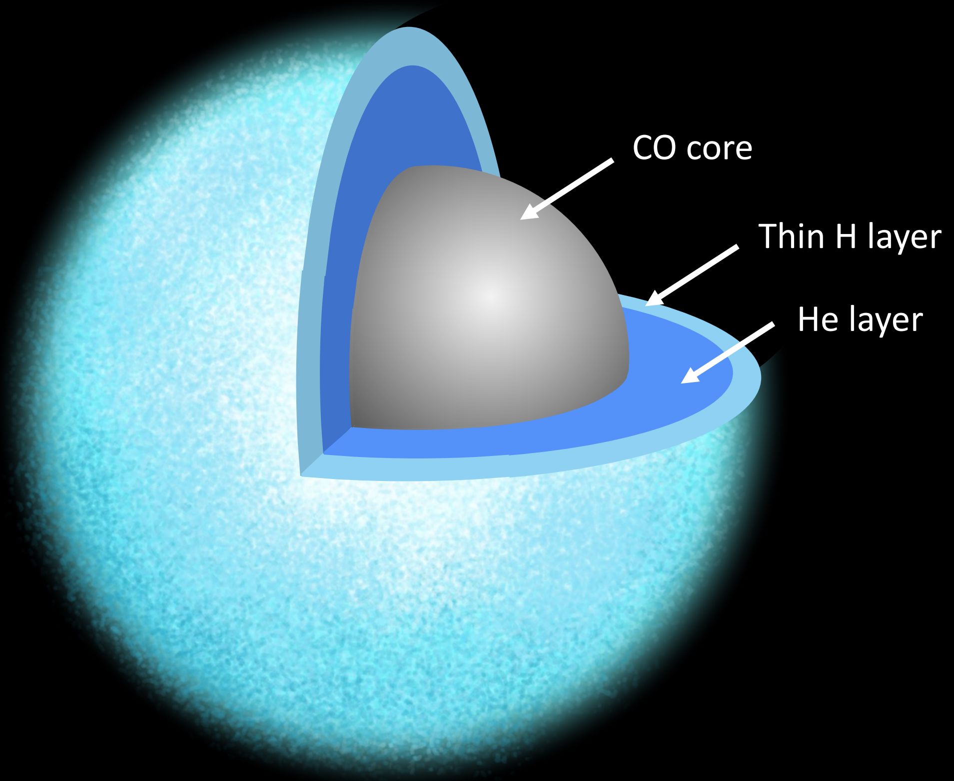
High surface gravities

White dwarfs

White dwarfs should have clean atmospheres (just H or He) due to their high surface gravity



From MWDD

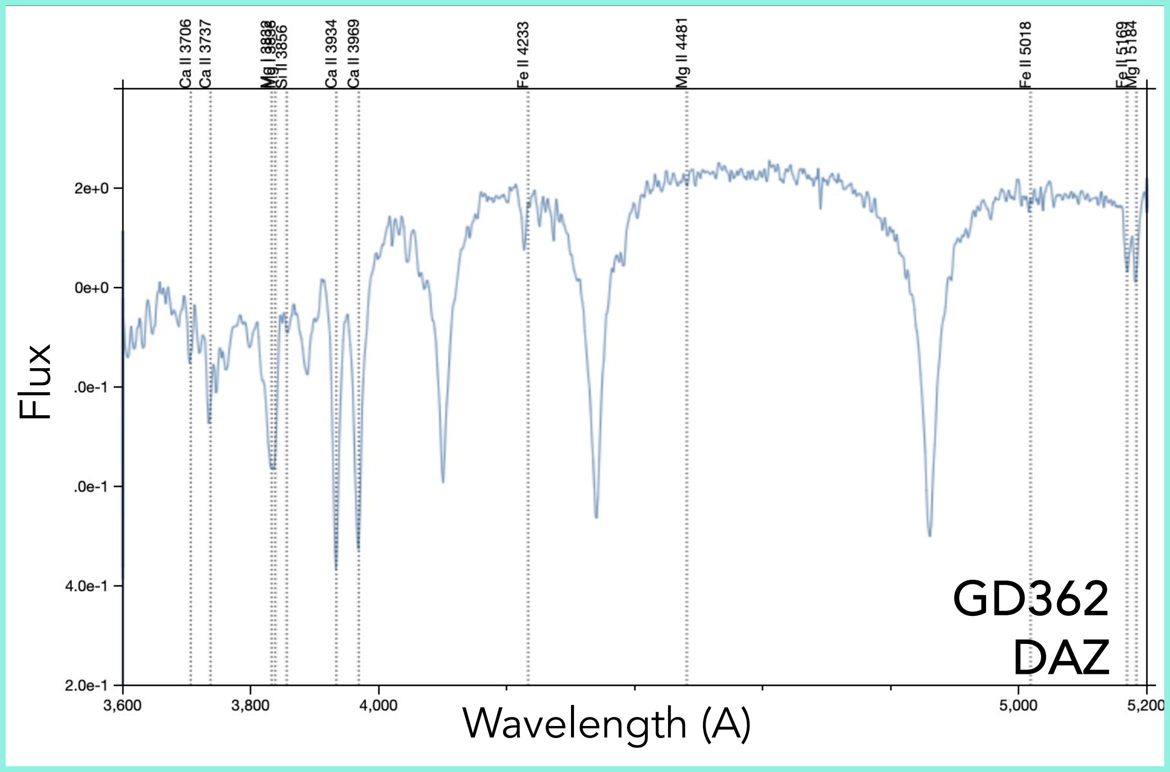


Xu, Rogers, Blouin (2024)

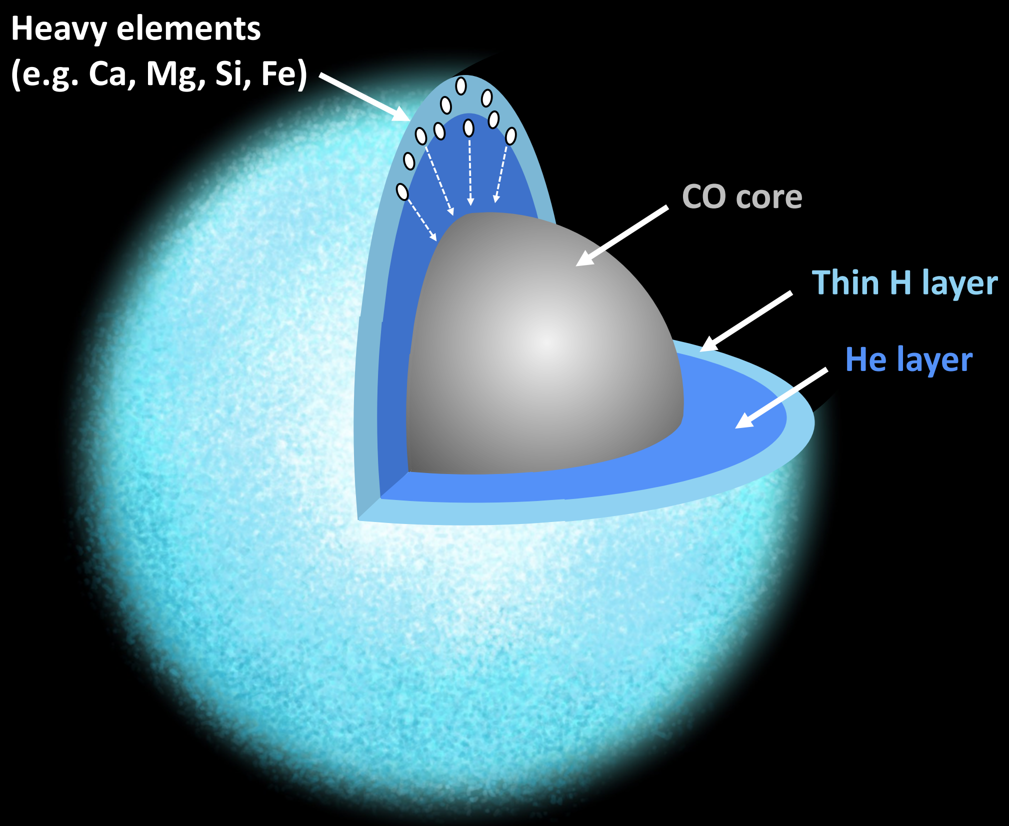
Laura Rogers

White dwarfs

Heavy elements have been observed in the atmospheres of ~30% of white dwarfs -> must be ongoing accretion

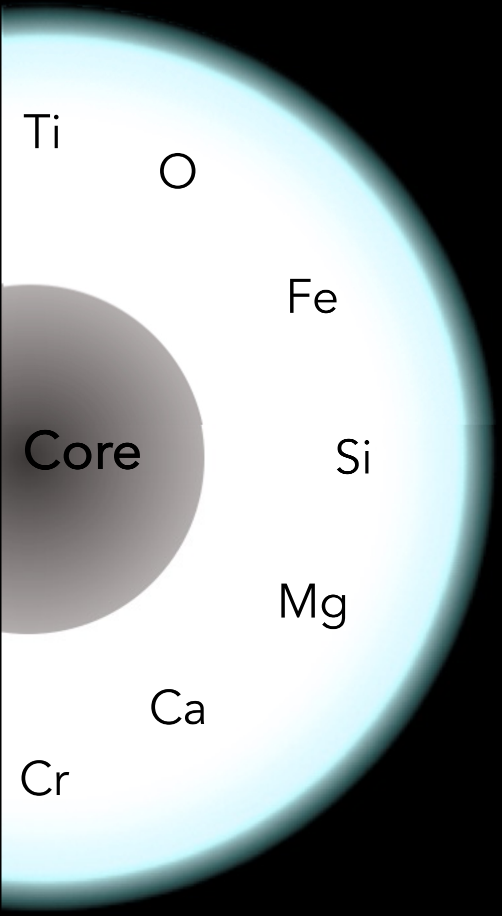


From MWDD



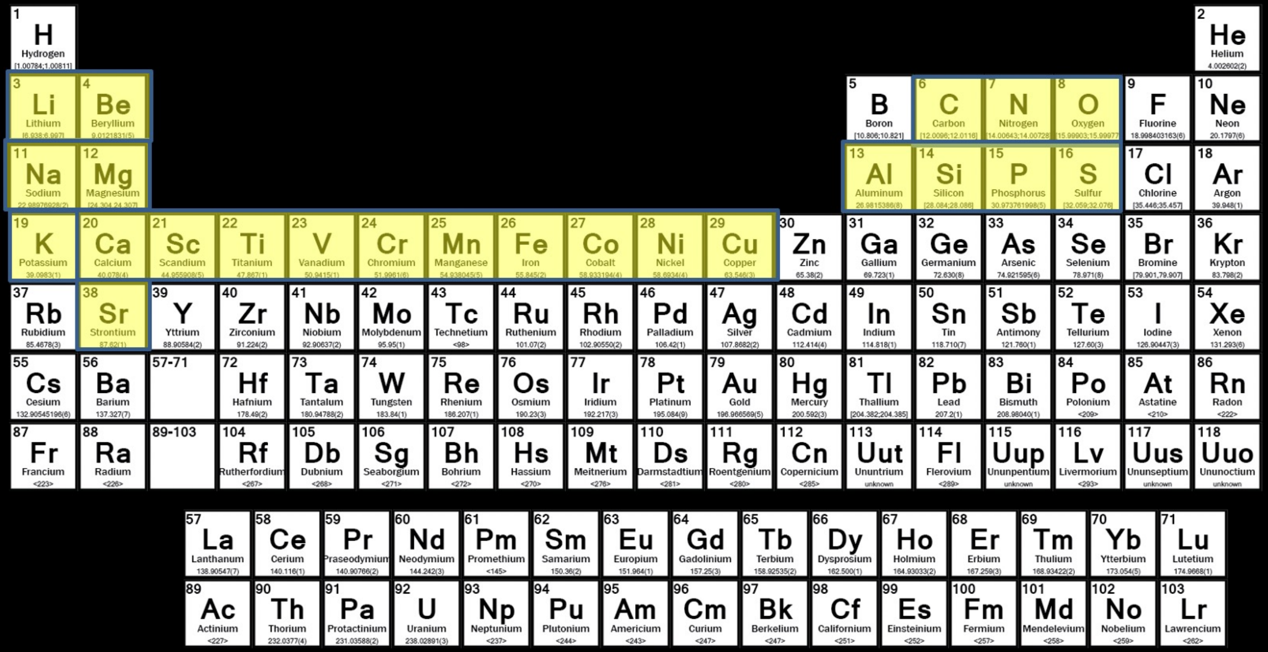
Xu, Rogers, Blouin (2024)

Polluted white dwarf



Infer the **bulk composition** of the accreted material

Most WDs show material that is **dry and rocky**
– bulk Earth like composition



See Klein et al. (2021) for references

Polluted white dwarfs are mass spectrometers for exoplanets

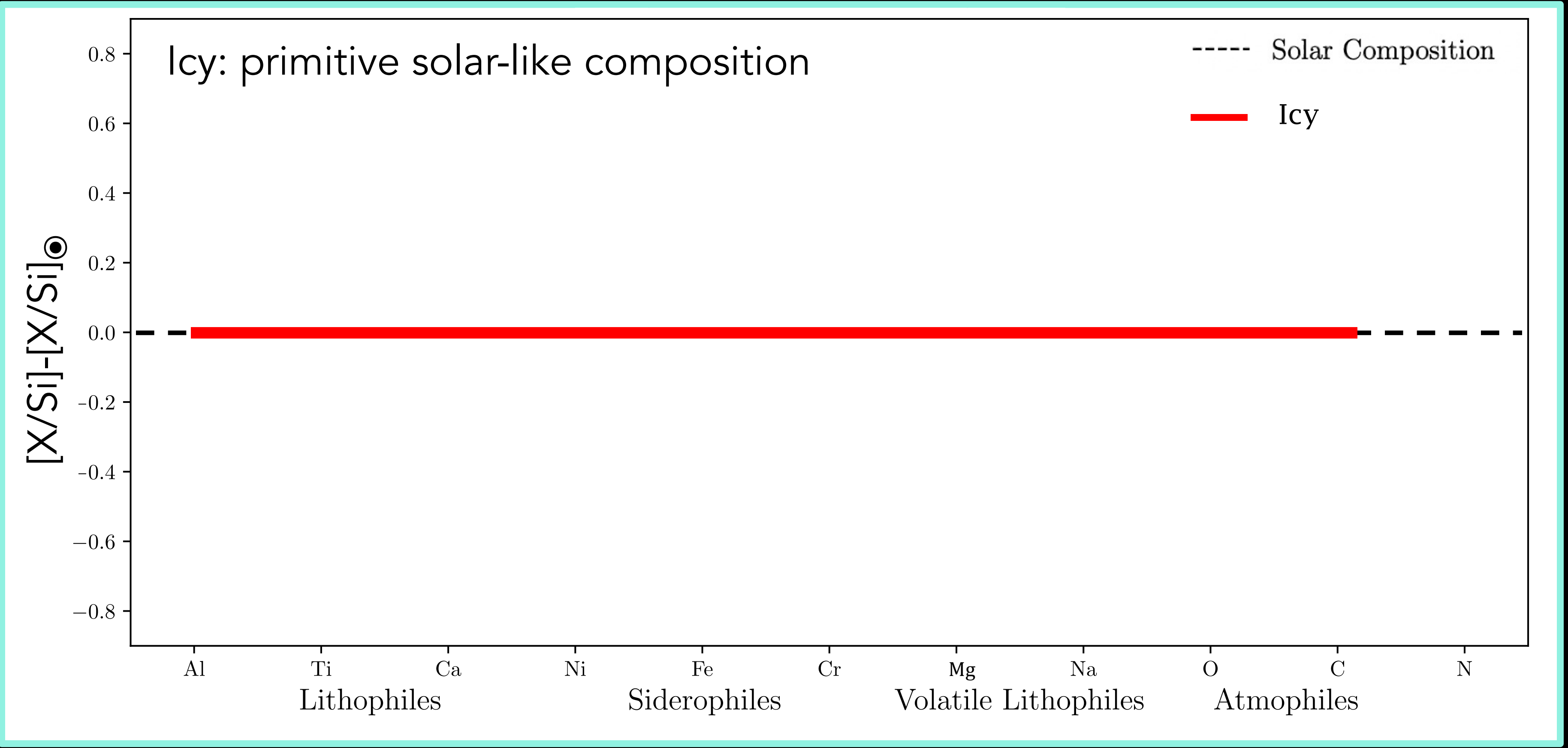
=

Aim: Increase the number of exoplanetary bodies with measured bulk compositions

'Seven white dwarfs with circumstellar gas discs I: White dwarf parameters and pollutant abundances' – Rogers et al. 2024a

'Seven white dwarfs with circumstellar gas discs II: Tracing the composition of exoplanetary building blocks' – Rogers et al. 2024b

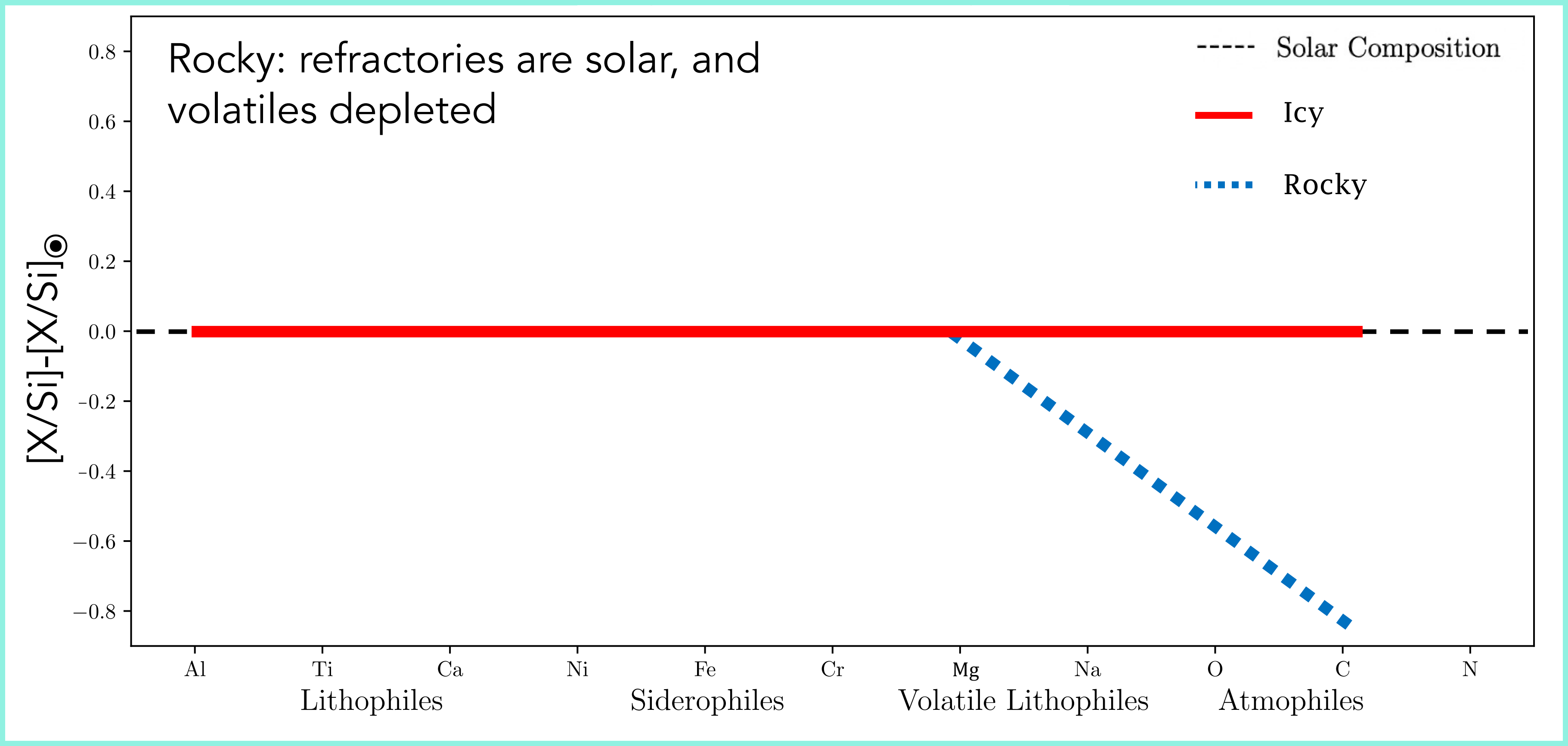
Composition Analysis



See Buchan et al. (2021)

Increasing volatility/decreasing condensation temperature

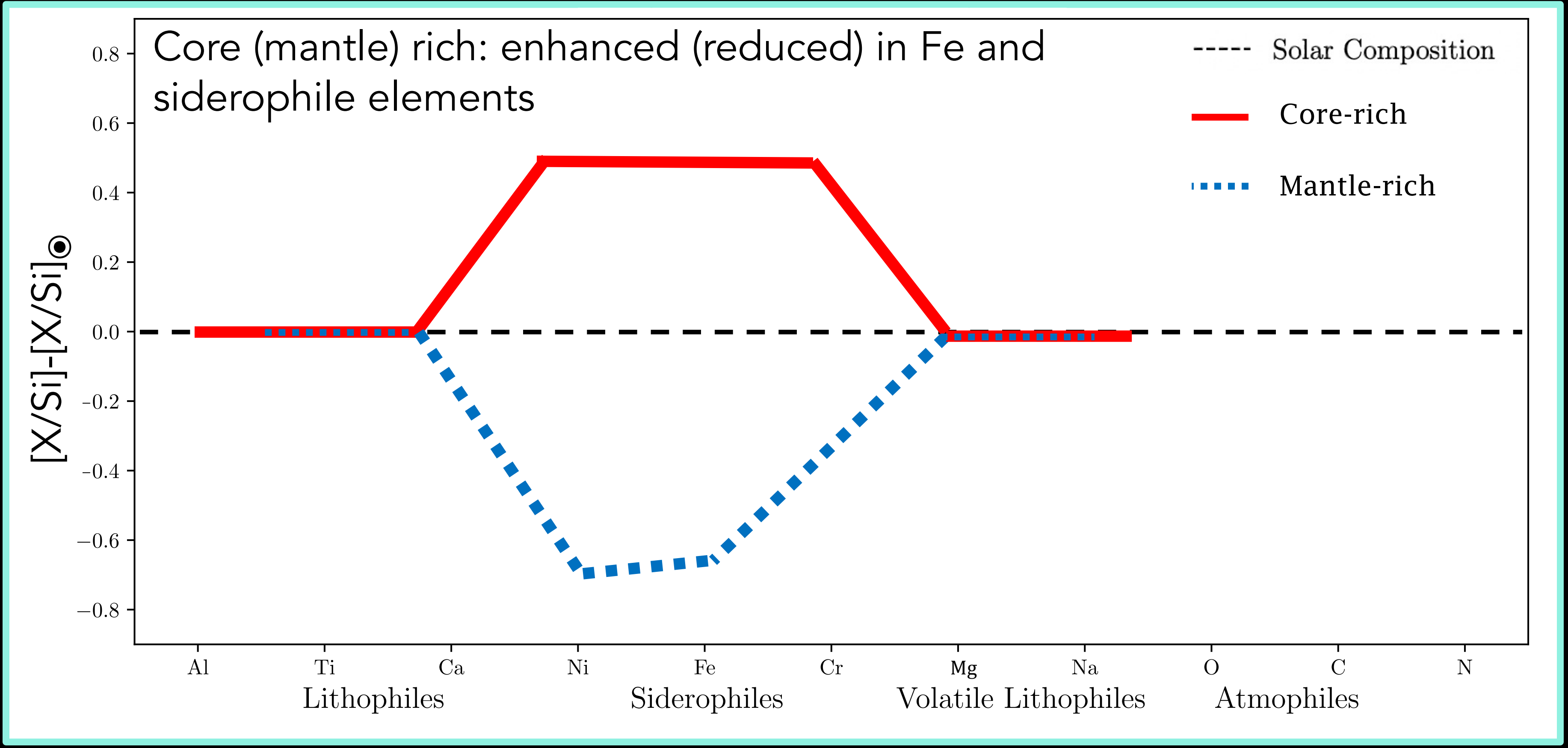
Composition Analysis



Increasing volatility/decreasing condensation temperature

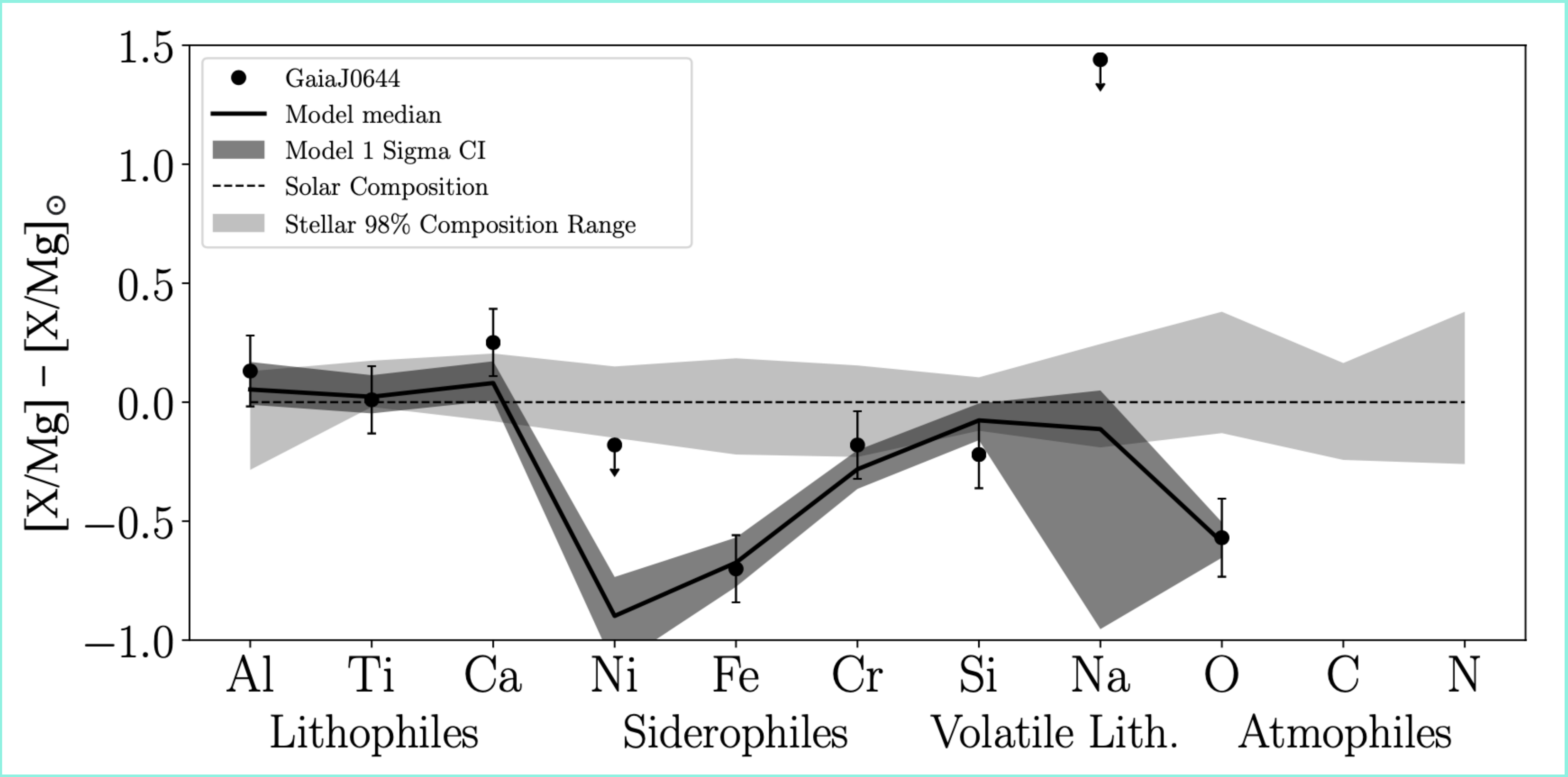
Laura Rogers

Composition Analysis



Increasing volatility/decreasing condensation temperature

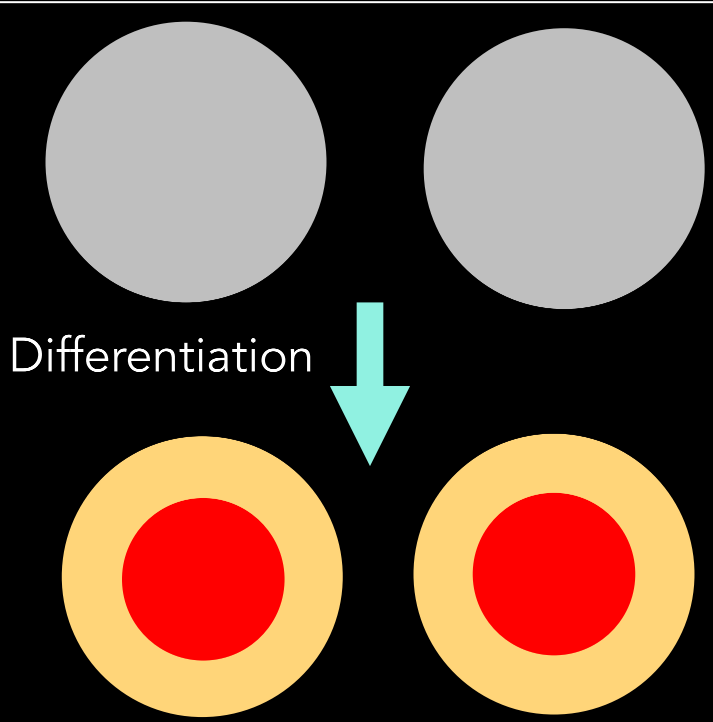
Abundance pattern showing a mantle rich fragment being accreted



Increasing volatility/decreasing condensation temperature

Laura Rogers

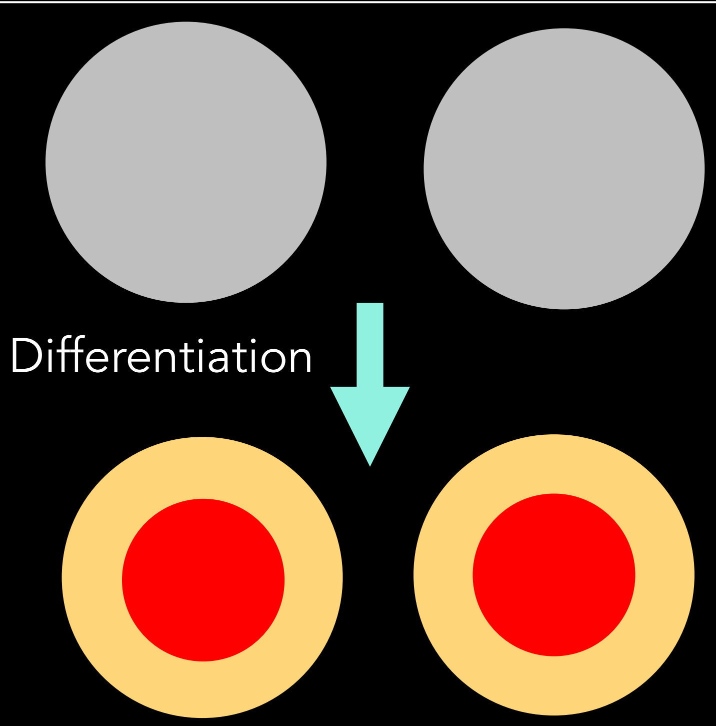
Differentiation and Collisions



Internal heating causes Fe and siderophilic elements to migrate to the core

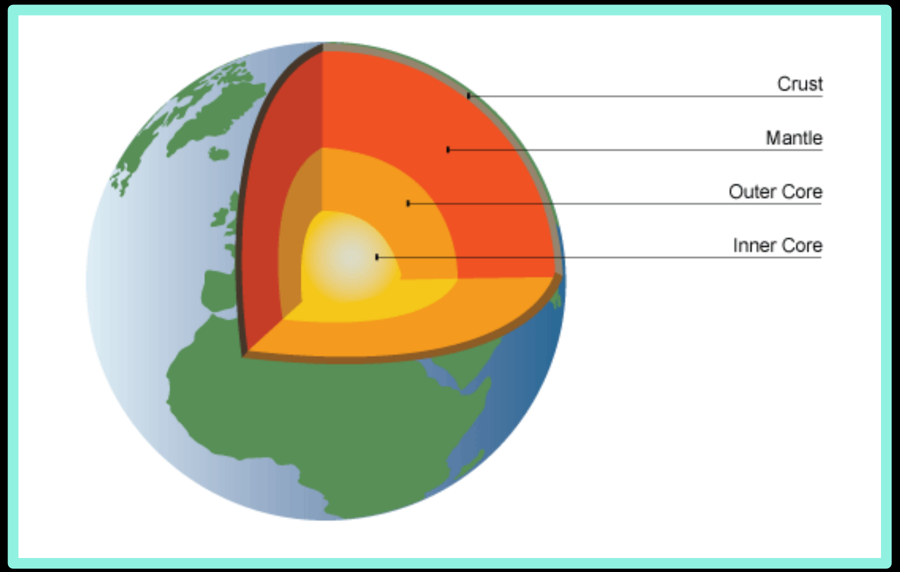
This causes differentiated bodies -> Fe-rich core and Fe-poor mantle

Differentiation and Collisions



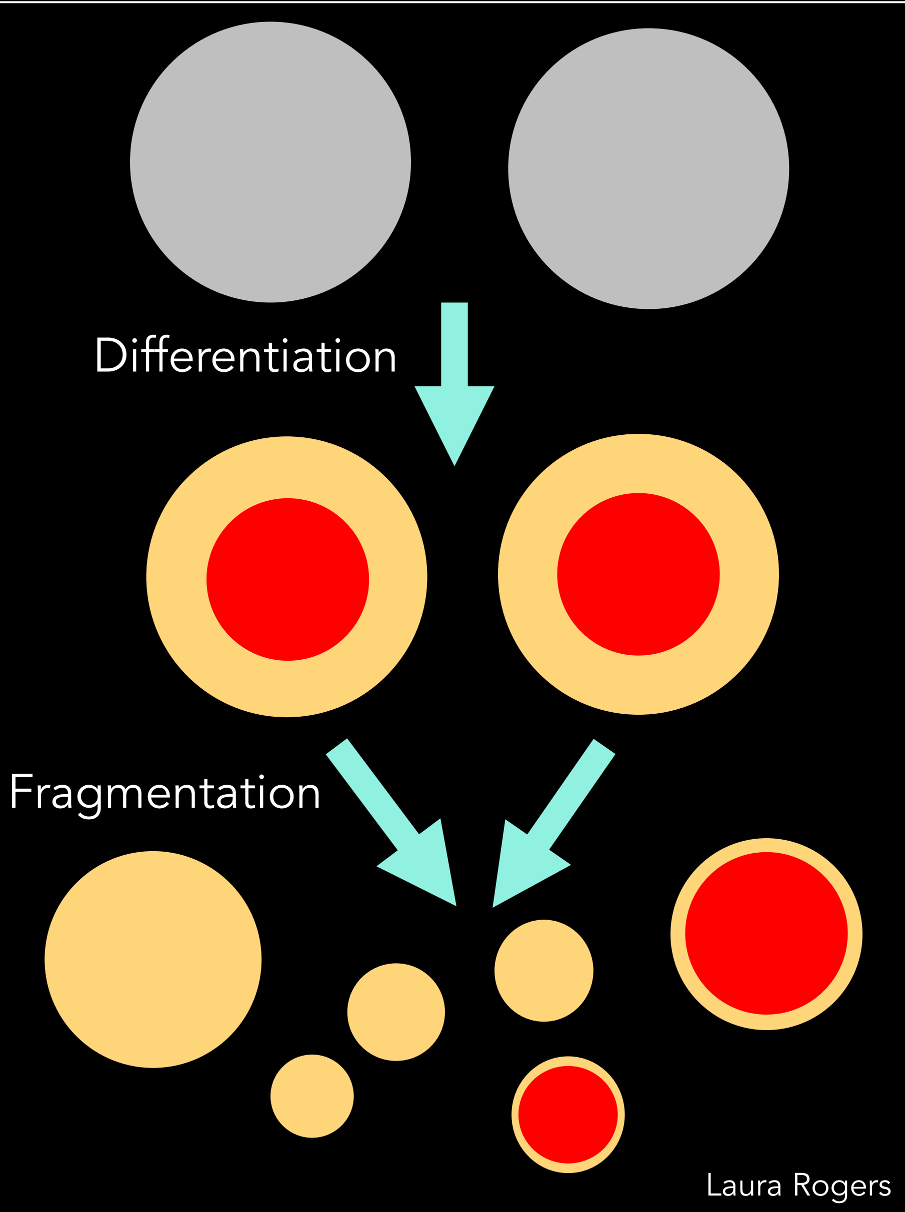
Internal heating causes Fe and siderophilic elements to migrate to the core

This causes differentiated bodies -> Fe-rich core and Fe-poor mantle



Laura Rogers

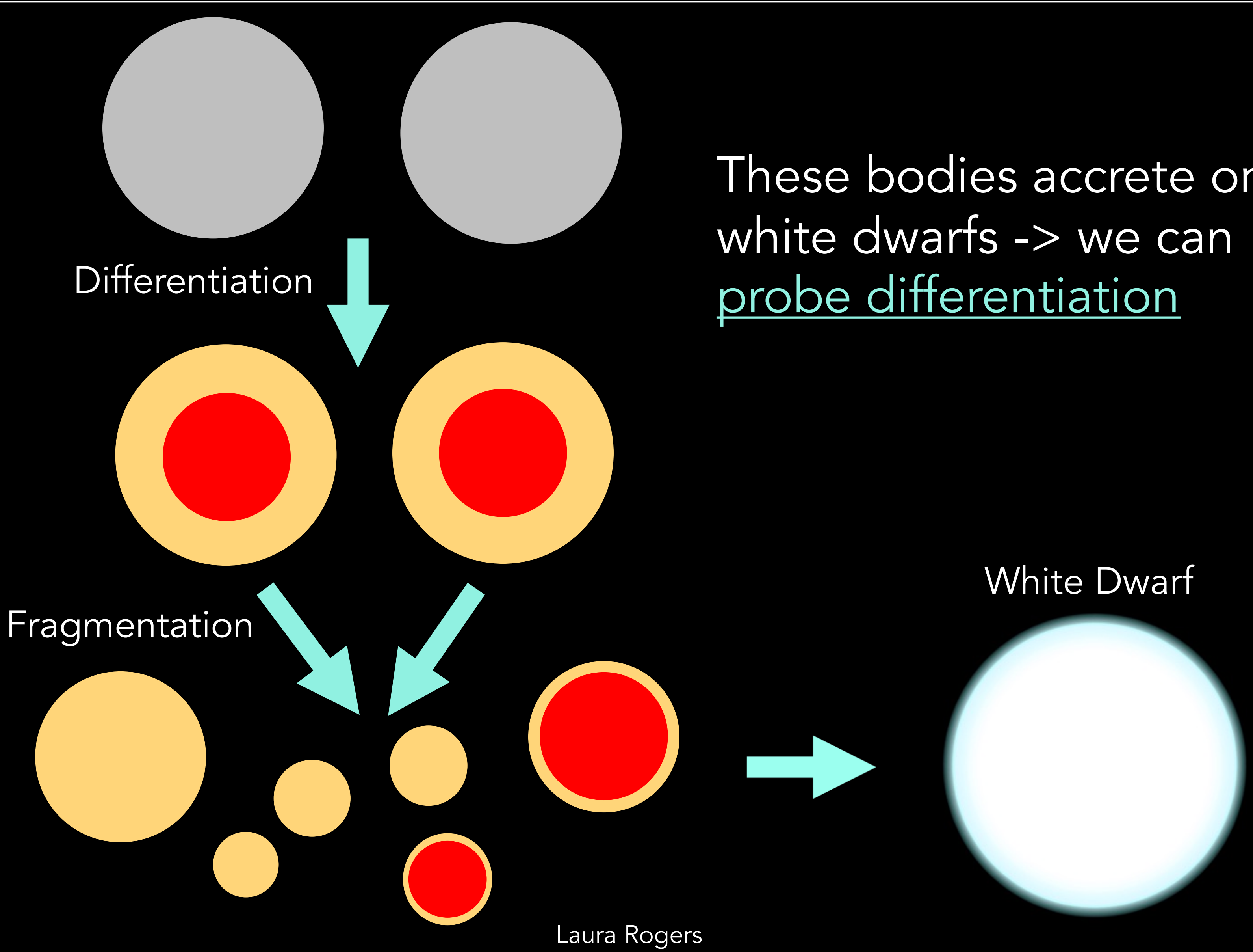
Differentiation and Collisions



Collisions can cause fragmentation which leads to planetesimals that are: core-dominated or mantle-dominated

Note: asynchronous accretion can also lead to core or mantle rich pollutant – Brouwers et al. (2023a)

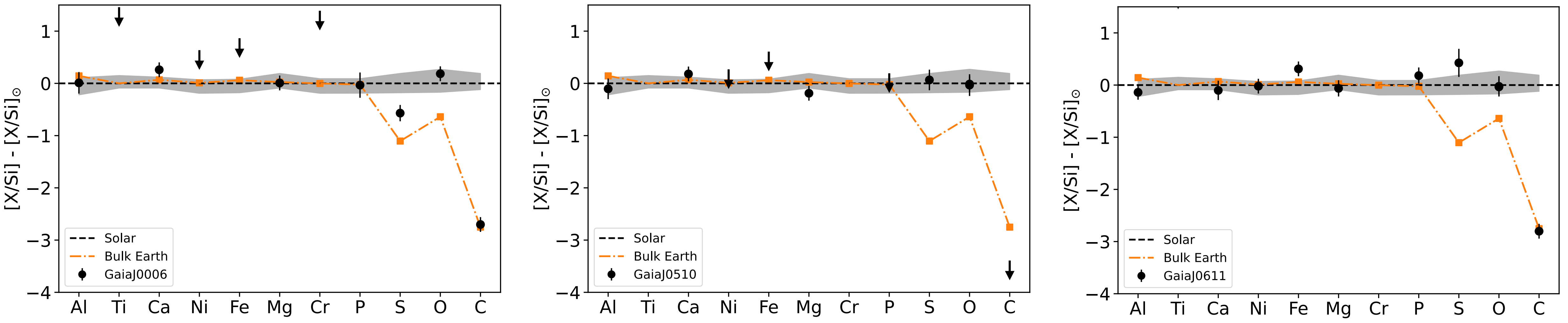
Differentiation and Collisions



These bodies accrete onto white dwarfs -> we can probe differentiation

Abundance Patterns of 3 WDs in the sample

Upper limits denoted with arrows

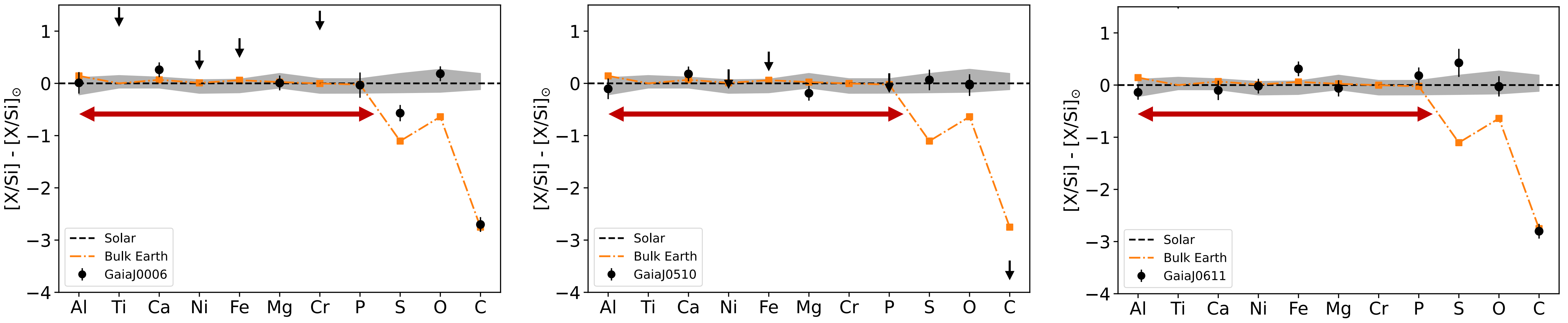


Increasing volatility/decreasing condensation temperature

Rogers et al. (2024a,b)

Abundance Patterns of 3 WDs in the sample

Upper limits denoted with arrows



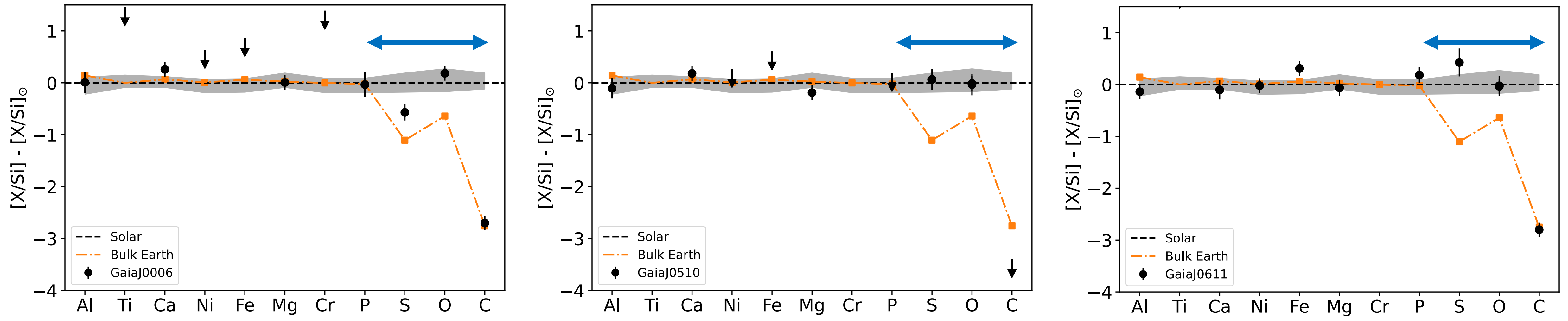
Increasing volatility/decreasing condensation temperature

The more refractory elements roughly match solar/Bulk Earth composition.

Rogers et al. (2024a,b)

Abundance Patterns of 3 WDs in the sample

Upper limits denoted with arrows



Increasing volatility/decreasing condensation temperature

More volatile elements:

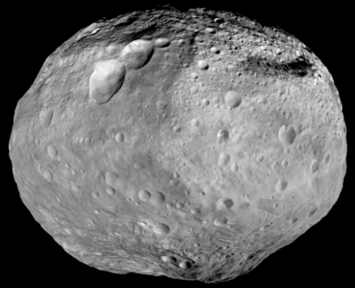
- Oxygen is enhanced **compared to Bulk Earth.**
- Carbon **similar to** Bulk Earth.

Rogers et al. (2024a,b)

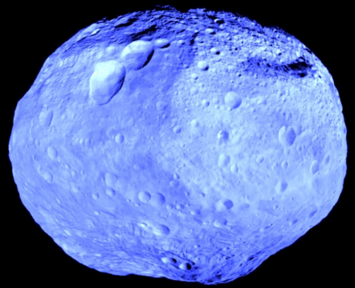
Oxygen Budgeting

Oxygen Abundance [O/H(e)] → Assign to oxides: MgO, SiO_2, Al_2O_3, CaO, and FeO

No excess O: Rocky Body

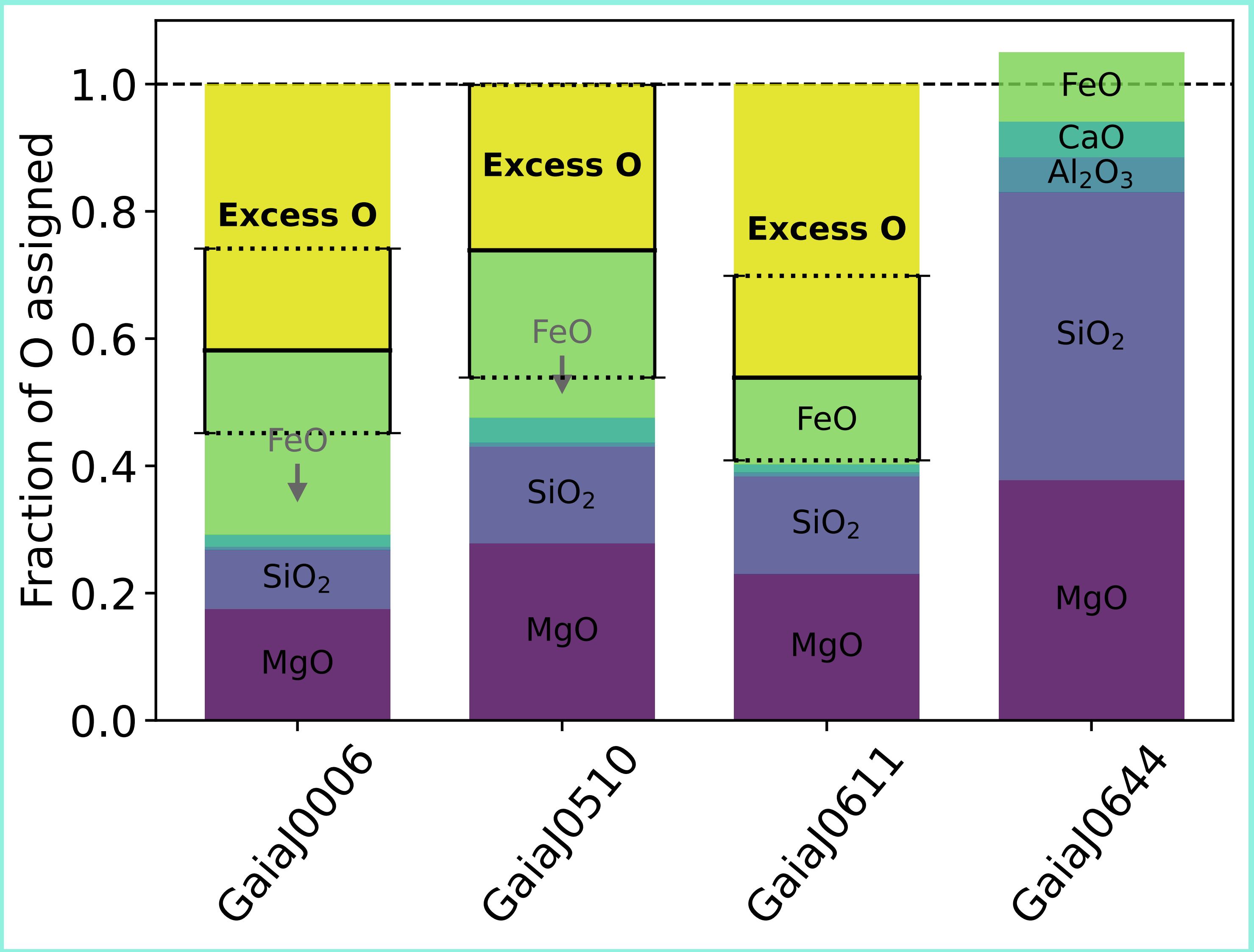


Excess O: Water-rich Body



Method from: Klein + (2010)

Oxygen Excess



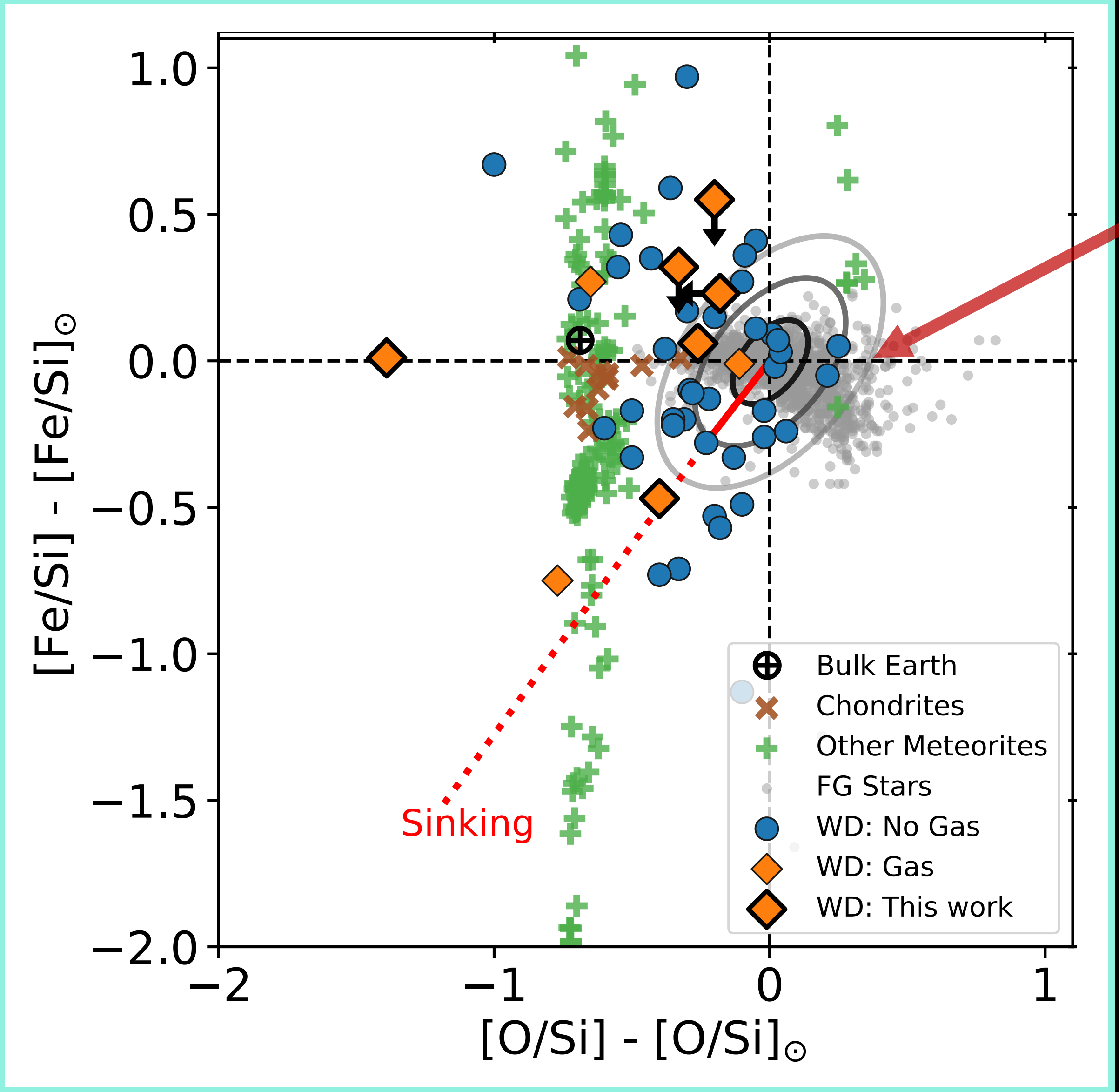
3 with solar/sub-solar O: abundances have excess oxygen

1 where metals in oxide form (mantle rich)

Laura Rogers

Rogers et al. (2024a,b)

Abundances in context

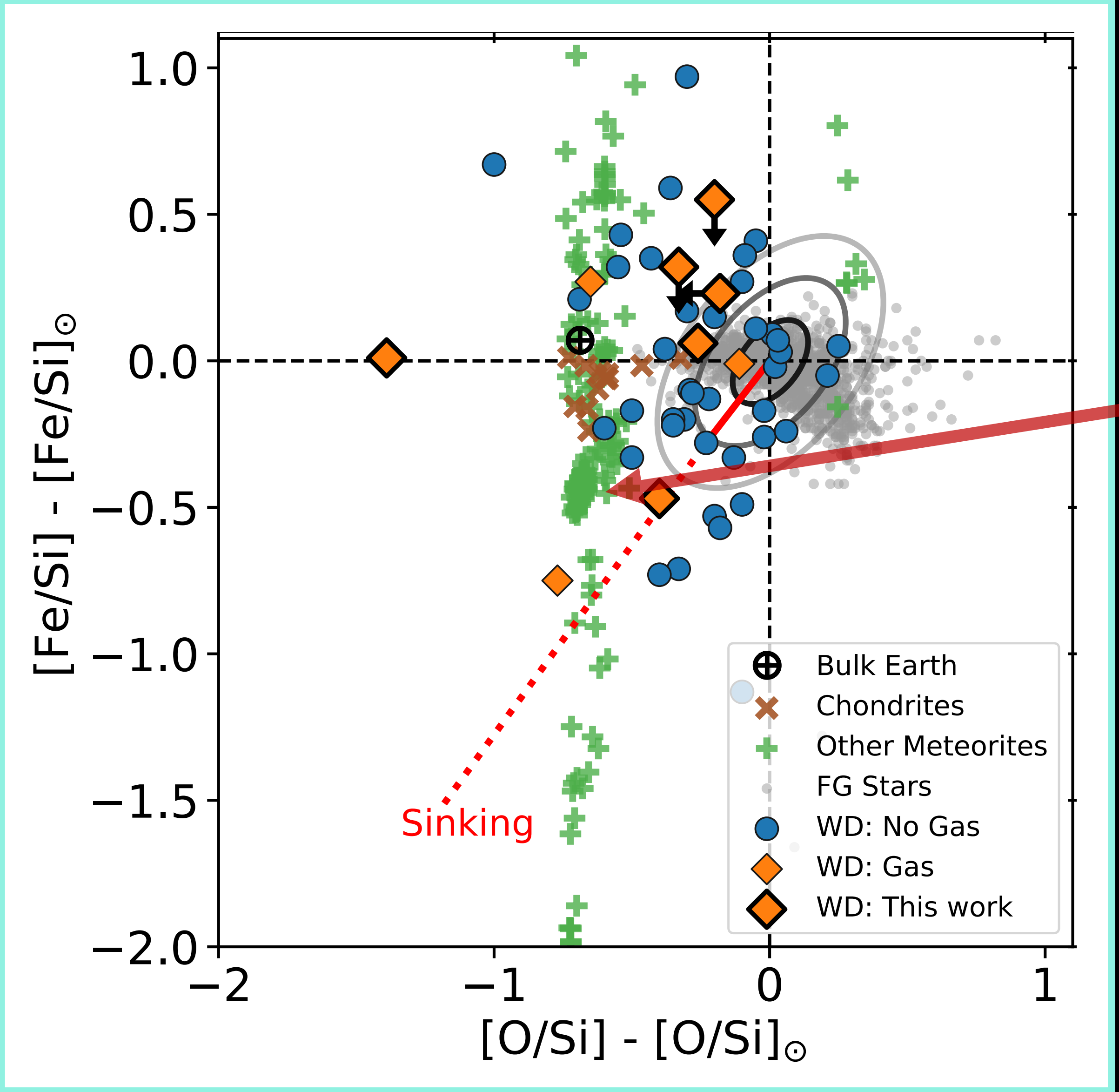


Grey scatter plot: FG stars – range of possible initial compositions

Hinkel et al. (2014)

Rogers et al. (2024b)

Abundances in context

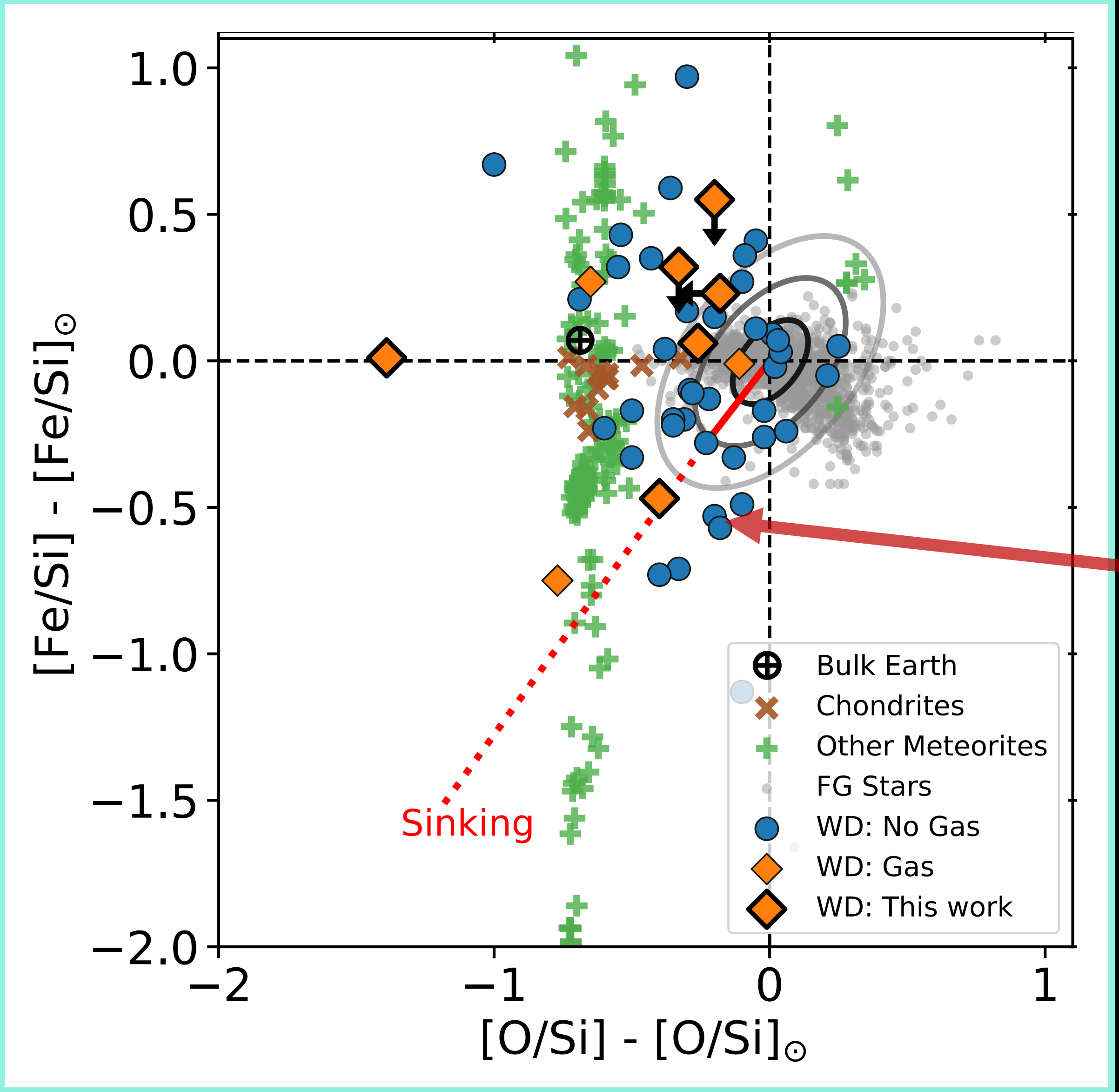


Grey scatter plot: FG stars – range of possible initial compositions
Hinkel et al. (2014)

Green and brown data show abundances of meteorites in the solar system

Rogers et al. (2024b)

Abundances in context



Grey scatter plot: FG stars – range of possible initial compositions

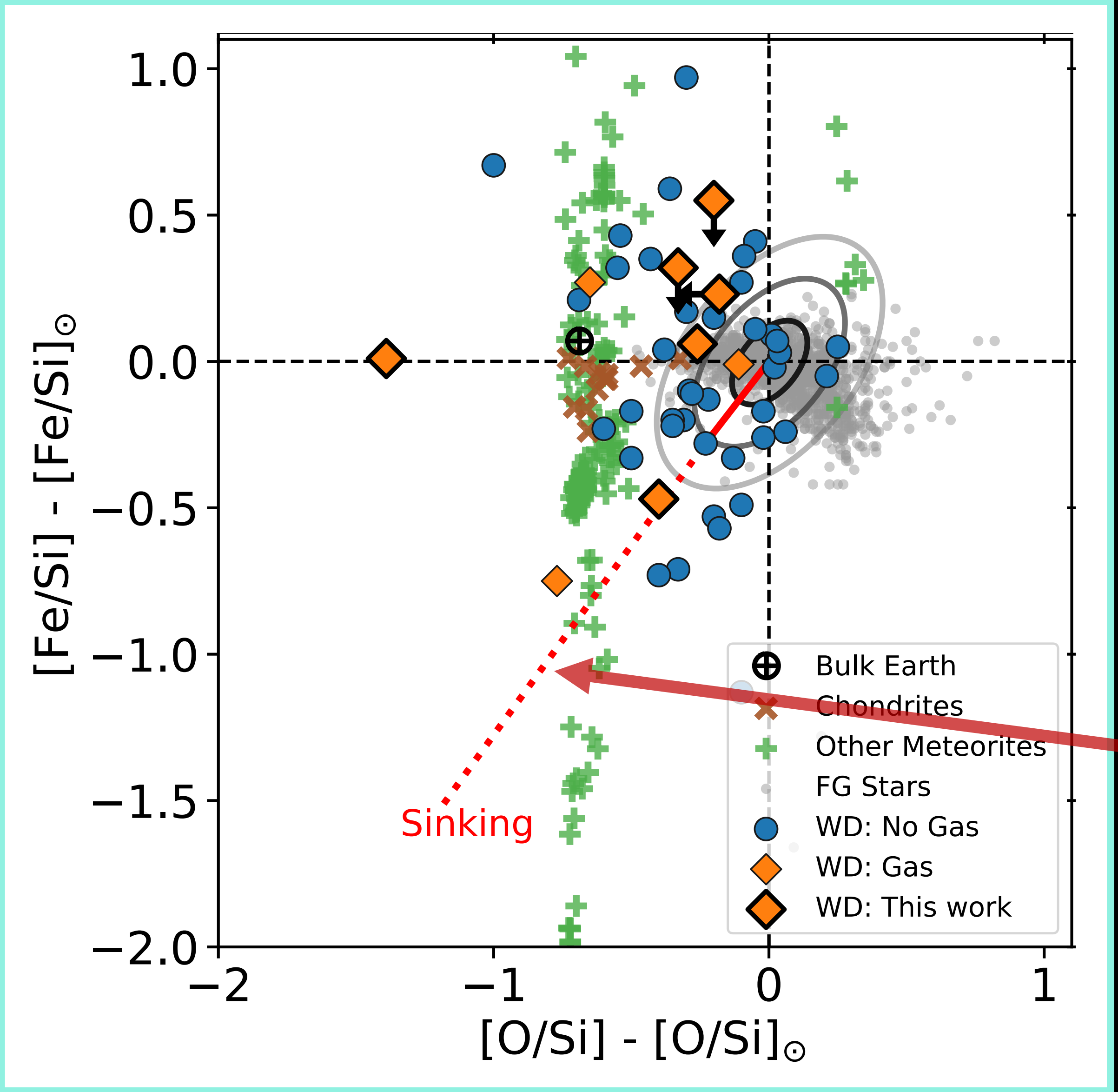
Hinkel et al. (2014)

Green and brown data show abundances of meteorites in the solar system

Orange and blue data are the polluted white dwarf abundances

Rogers et al. (2024b)

Abundances in context



Grey scatter plot: FG stars – range of possible initial compositions
Hinkel et al. (2014)

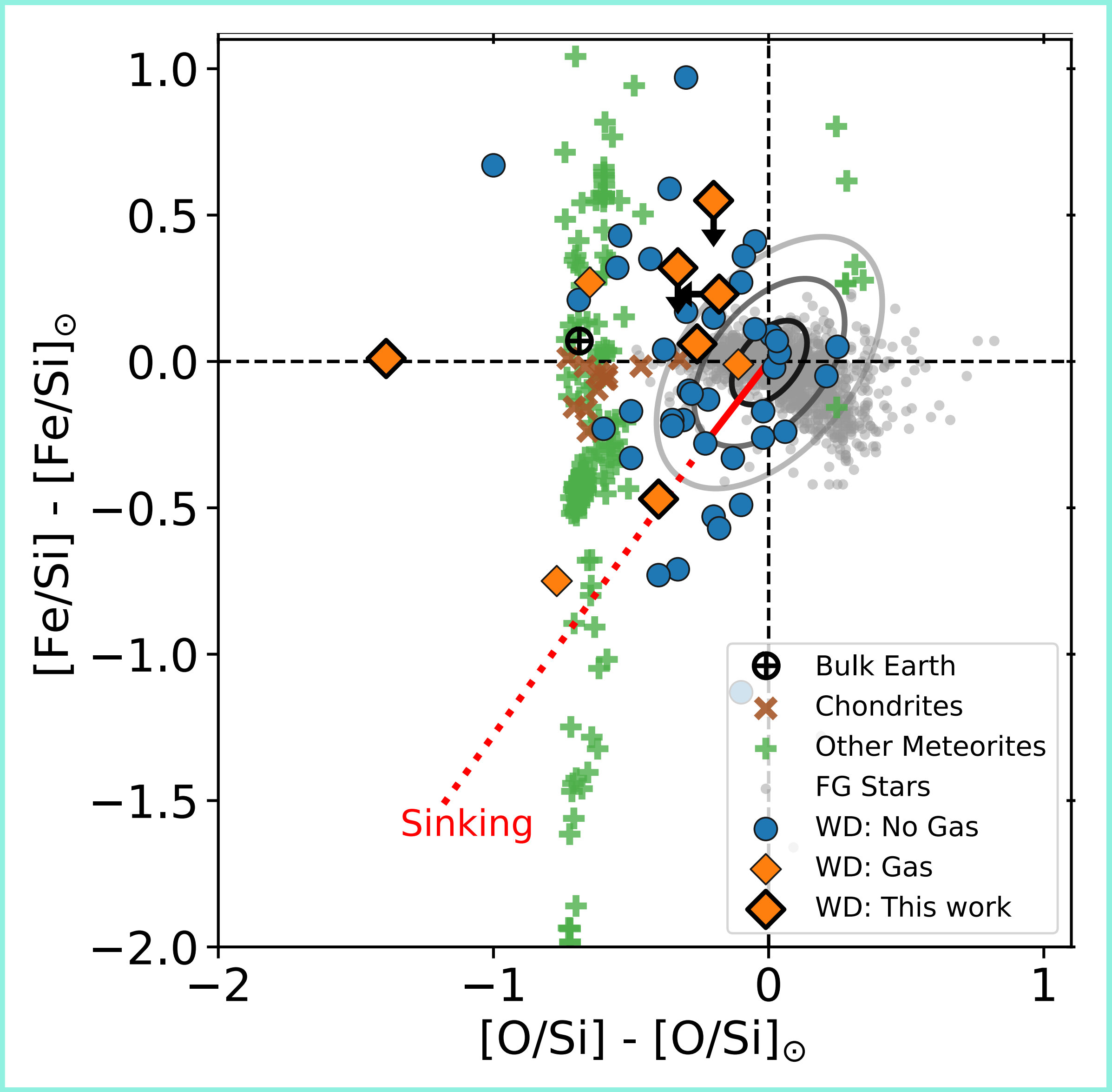
Green and brown data show abundances of meteorites in the solar system

Orange and blue data are the polluted white dwarf abundances

Red lines show how abundances can be affected by sinking in the white dwarf photosphere

Rogers et al. (2024b)

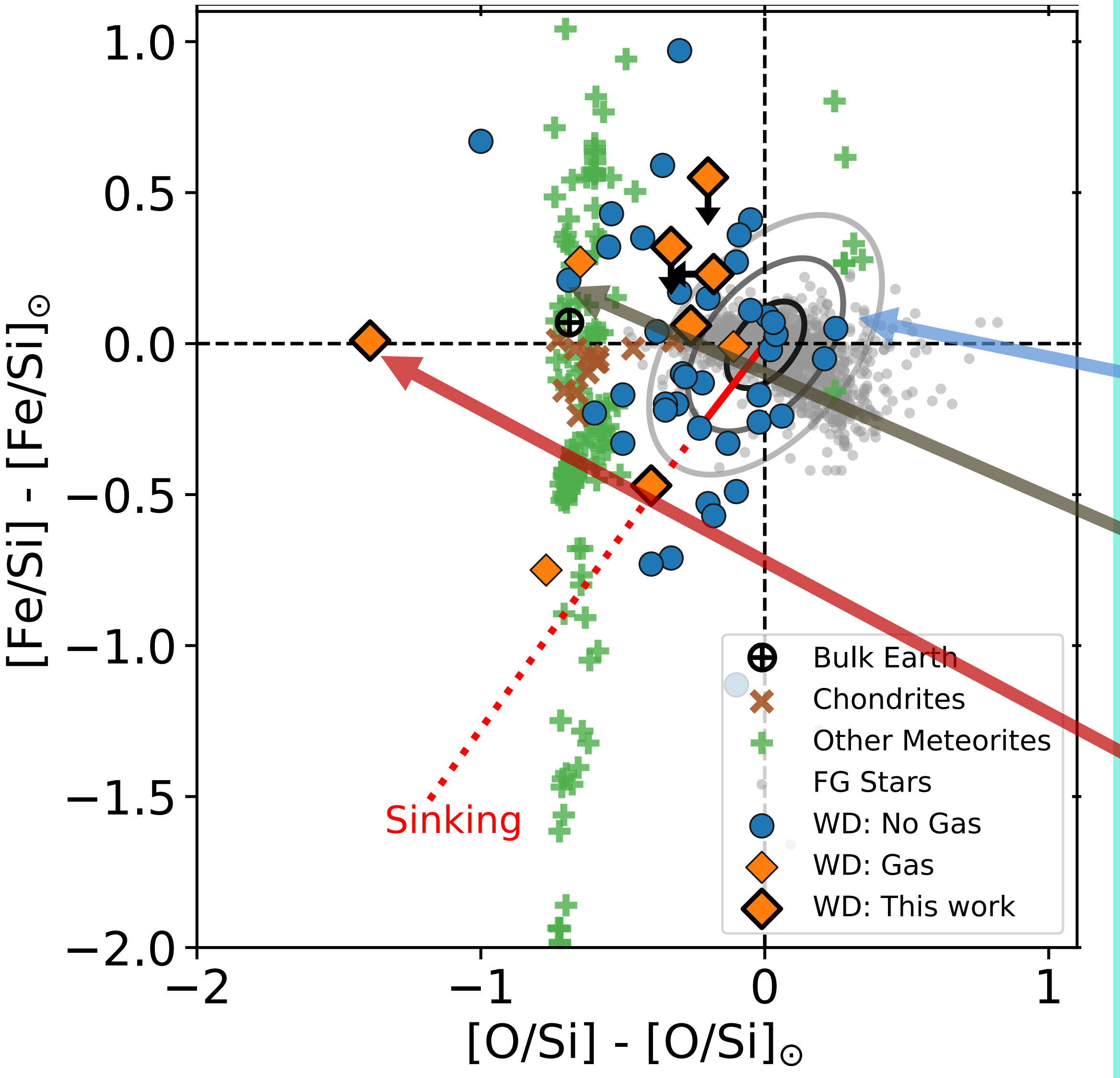
Abundances in context



[O/Si] – assess whether pollutant was oxygen rich – most WDs trace stellar and solar system compositions

Rogers et al. (2024b)

Abundances in context



[O/Si] – assess whether pollutant was oxygen rich – most WDs trace stellar and solar system compositions

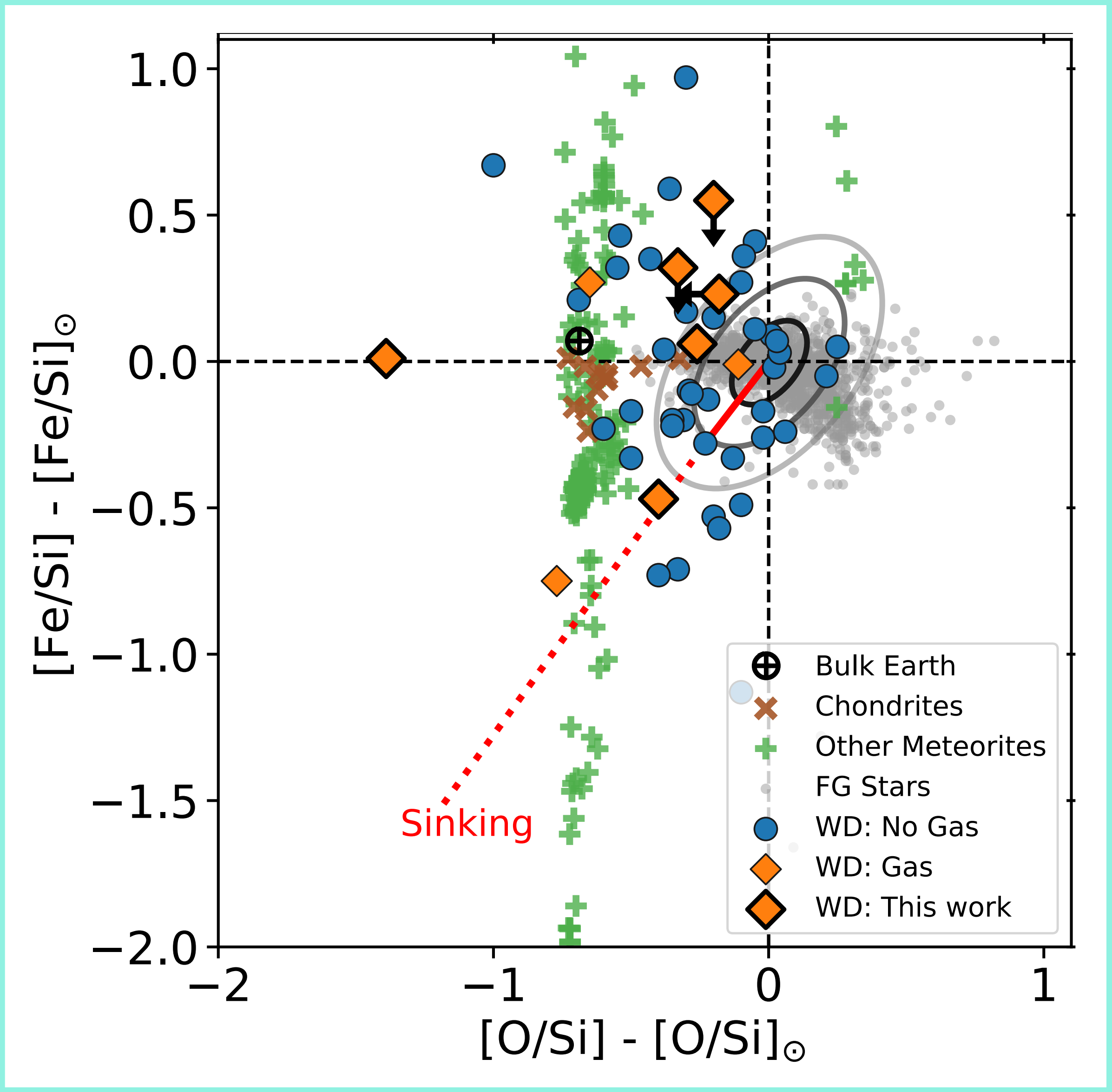
Stellar levels of O

Bulk Earth levels of O

Extreme O depletion

Rogers et al. (2024b)

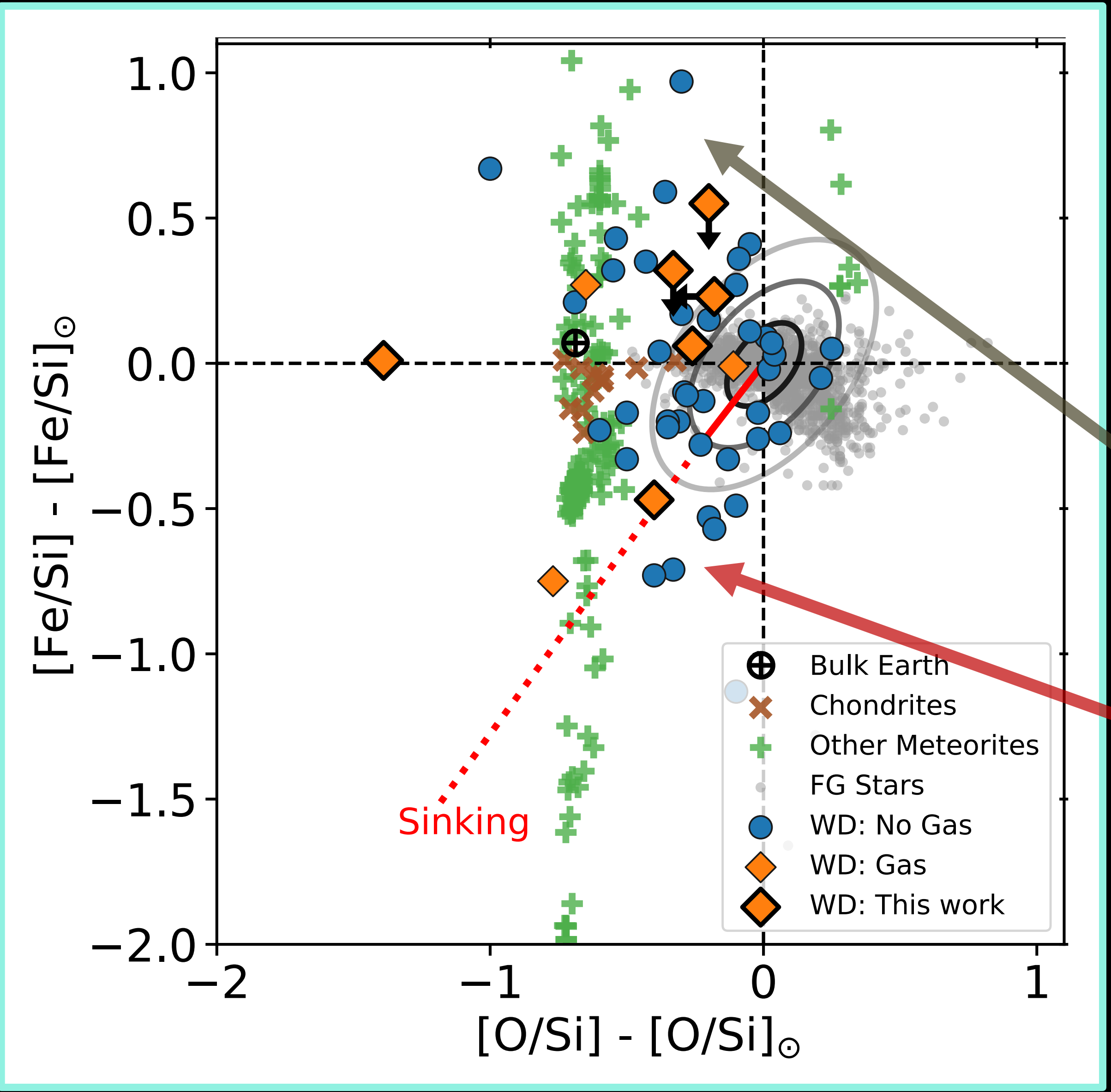
Abundances in context



[Fe/Si] – assess whether pollutant was core-rich or mantle-rich

Rogers et al. (2024b)

Abundances in context



[Fe/Si] – assess whether pollutant was core-rich or mantle-rich

Range of Fe content consistent with meteorites in the SS

Enhanced Fe – core-rich?

Depleted Fe – mantle-rich?

Rogers et al. (2024b)

Summary

Using polluted white dwarfs to probe bulk composition

- Polluted white dwarfs can act as mass spectrometers to infer the bulk composition of exoplanetary material.
- Rogers et al. (2024 a,b):
  - Discovered a new white dwarf accreting mantle like material
  - Discovered 3 new white dwarfs accreting oxygen rich (water rich) material
- At the point where we can start to study large populations of bulk exoplanetary material – find that most resemble the bulk composition of Solar System bodies