Using Stellar Abundances to Determine Planetary Mineralogy and Structure

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Know Thy Star, Know Thy Planet
9-12 Oct, 2017

So You Want to Make a Planet?

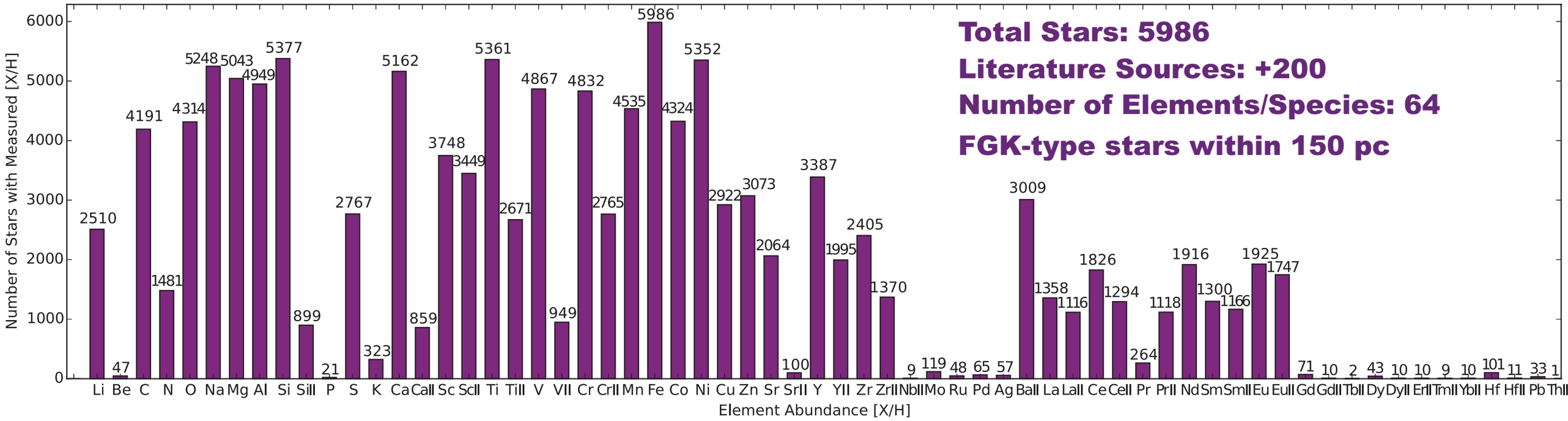
Stars and planets are formed at the same time, meaning they have the similar core compositions.

Right now, we are unable to directly observe the composition of the planet.

Need the mineralogy of a planet to really understand whether a planet is habitable, since it affects melting, geochemical cycling, heat extraction, etc.

Stellar abundances are an underutilized tool for indirect determination of terrestrial planet composition.

The Hypatia Catalog

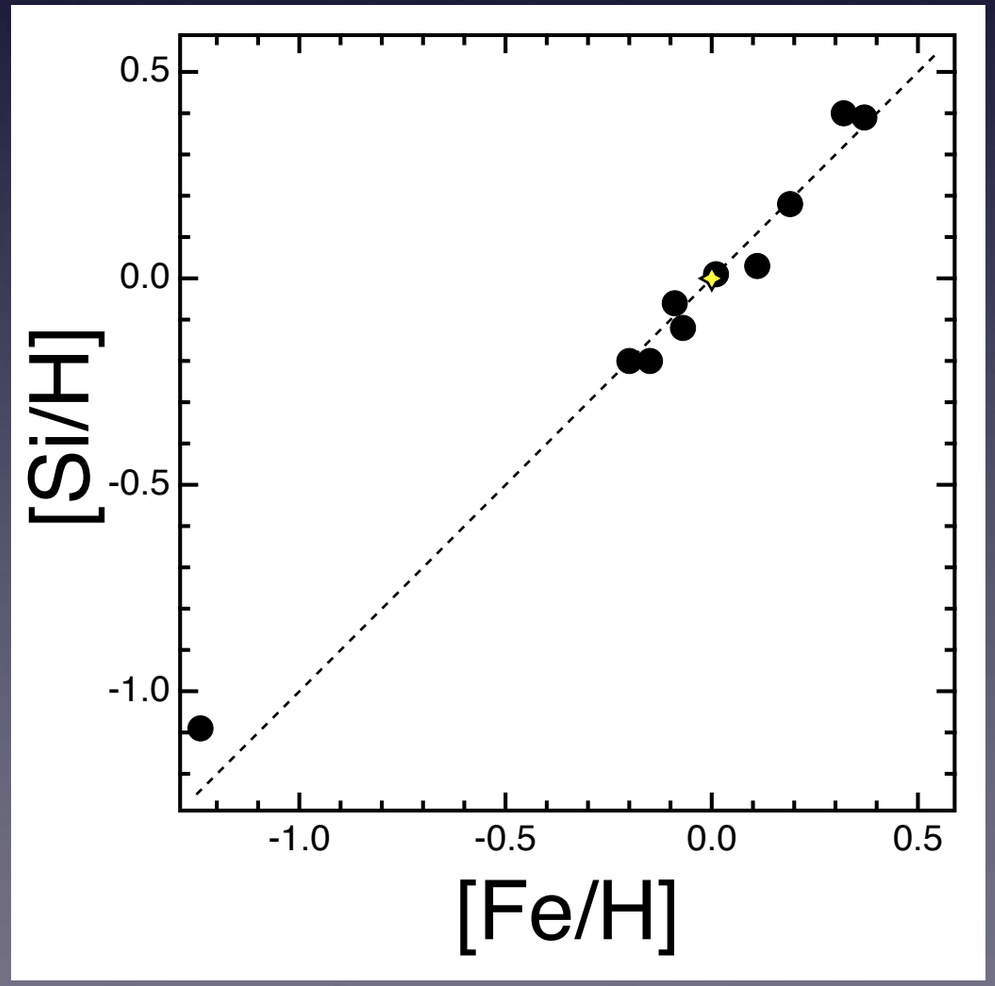


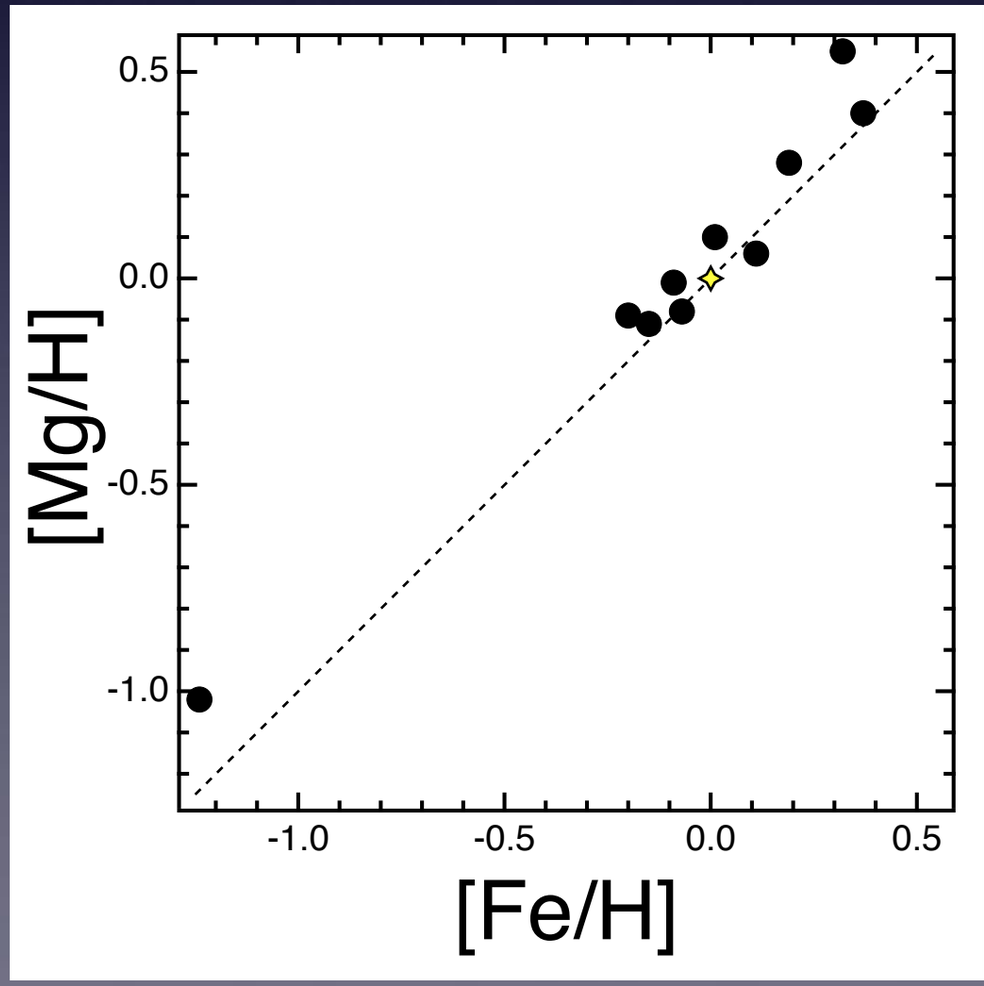
Compiled spectroscopic abundance determinations for stars in the solar neighborhood from published literature sources (Hinkel et al. 2014, 2016, 2017). Variation between groups who measure the same element in the same star = spread in the abundance data.

So You Want to Make a Planet?

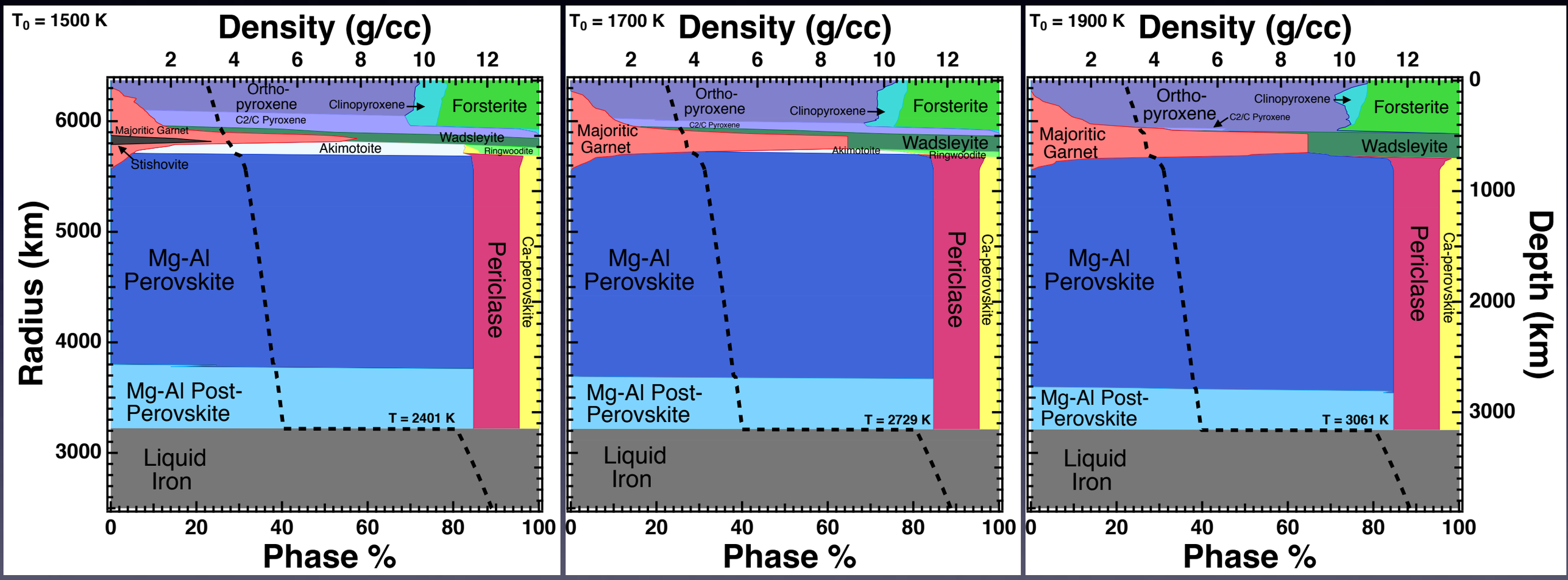
Go from stellar abundances (Mg, Al, Si, Ca, Fe) to element molar fractions.

Examined the 10 nearest stars using elements from the Hypatia Catalog (Hinkel et al. 2014).



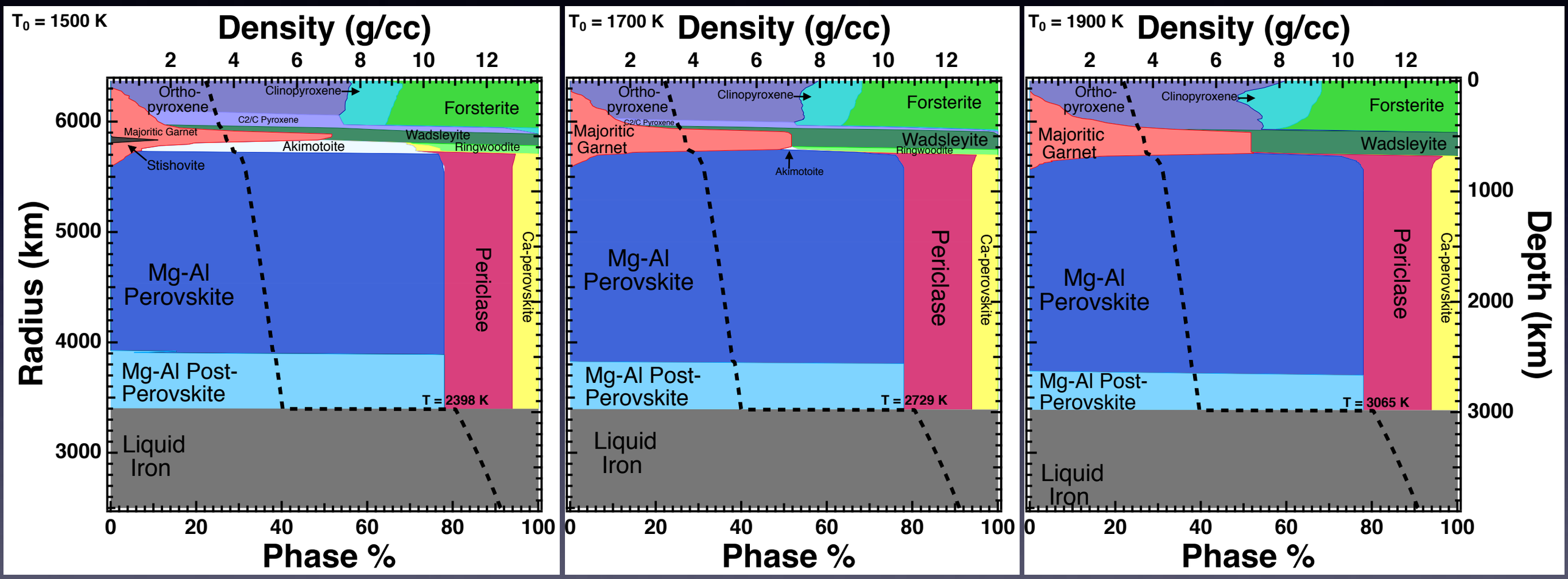


HIP 99240

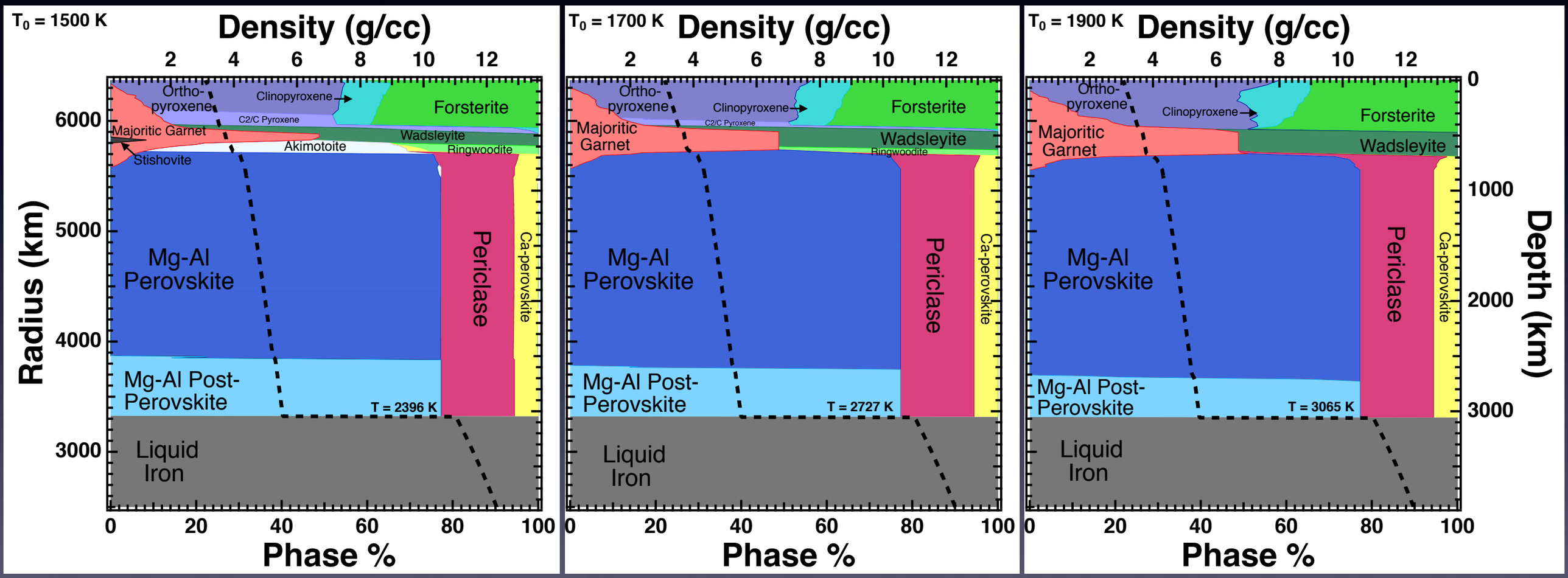


Used the ExoPlex (Unterborn et al. 2017a – talk on Tuesday) mass-radius package, which calculates a planet's interior mantle mineralogy and core mass fraction.

HIP 64394


T0 = 1500 K
Density (g/cc)
2 4 6 8 10 12
Ortho-pyroxene
Clinopyroxene
C2/C Pyroxene
Forsterite
Majoritic Garnet
Wadsleyite
Akimotoite
Ringwoodite
Stishovite
Mg-Al Perovskite
Periclase
Ca-perovskite
Mg-Al Post-Perovskite
T = 2398 K
Liquid Iron
Radius (km)
6000
5000
4000
3000
0 20 40 60 80 100
Phase %
T0 = 1700 K
Density (g/cc)
Majoritic Garnet
T = 2729 K
T0 = 1900 K
Density (g/cc)
T = 3065 K
0
1000
2000
3000
Depth (km)

HIP 108870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Density (g/cc)
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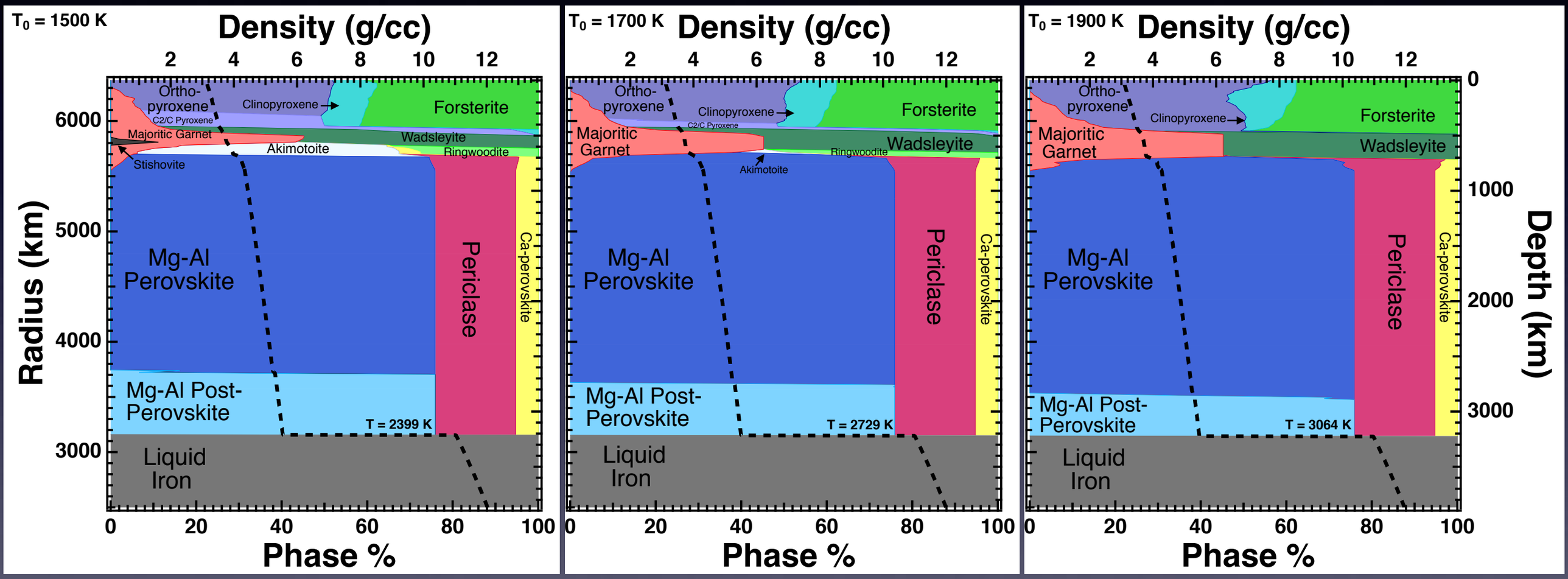
Ortho-pyroxene
Clinopyroxene
C2/C Pyroxene
Forsterite
Majoritic Garnet
Wadsleyite
Akimotoite
Ringwoodite
Stishovite
Mg-Al Perovskite
Periclase
Ca-perovskite
Mg-Al Post-Perovskite
T = 2396 K
Liquid Iron
Radius (km)
6000
5000
4000
3000
0 20 40 60 80 100
Phase %
T0 = 1700 K
Density (g/cc)
T = 2727 K
T0 = 1900 K
Density (g/cc)
T = 3065 K
0
1000
2000
3000
Depth (km)

HIP 2021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Density (g/cc)
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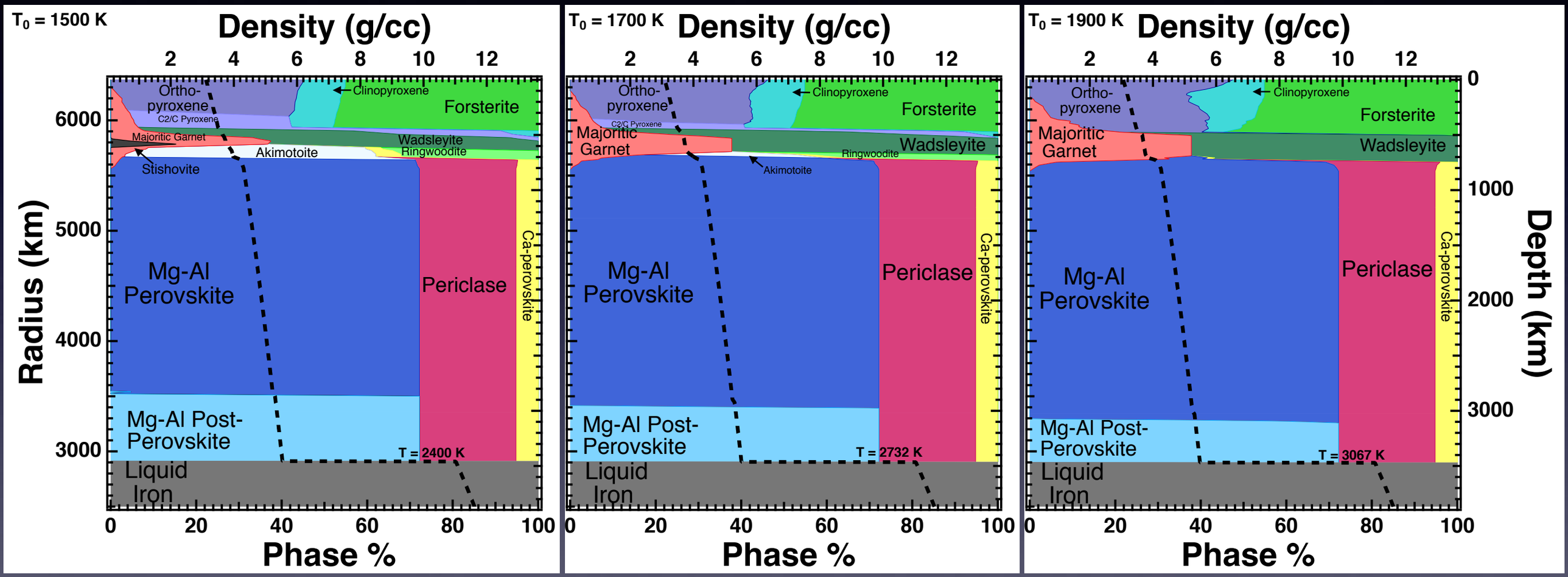
Ortho-pyroxene
Clinopyroxene
C2/C Pyroxene
Forsterite
Majoritic Garnet
Wadsleyite
Akimotoite
Ringwoodite
Stishovite
Mg-Al Perovskite
Periclase
Ca-perovskite
Mg-Al Post-Perovskite
T = 2399 K
Liquid Iron
Radius (km)
6000
5000
4000
3000
0 20 40 60 80 100
Phase %
T0 = 1700 K
Density (g/cc)
T = 2729 K
T0 = 1900 K
Density (g/cc)
T = 3064 K
0
1000
2000
3000
Depth (km)

HIP 57939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Density (g/cc)
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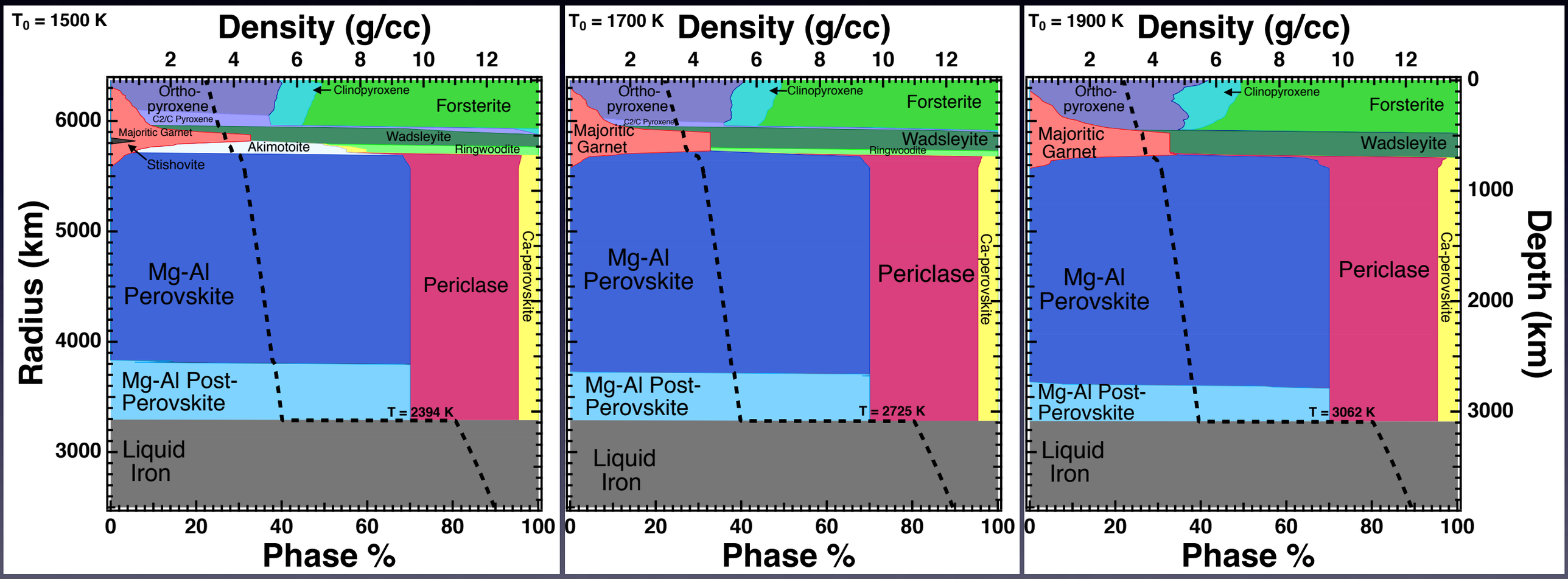
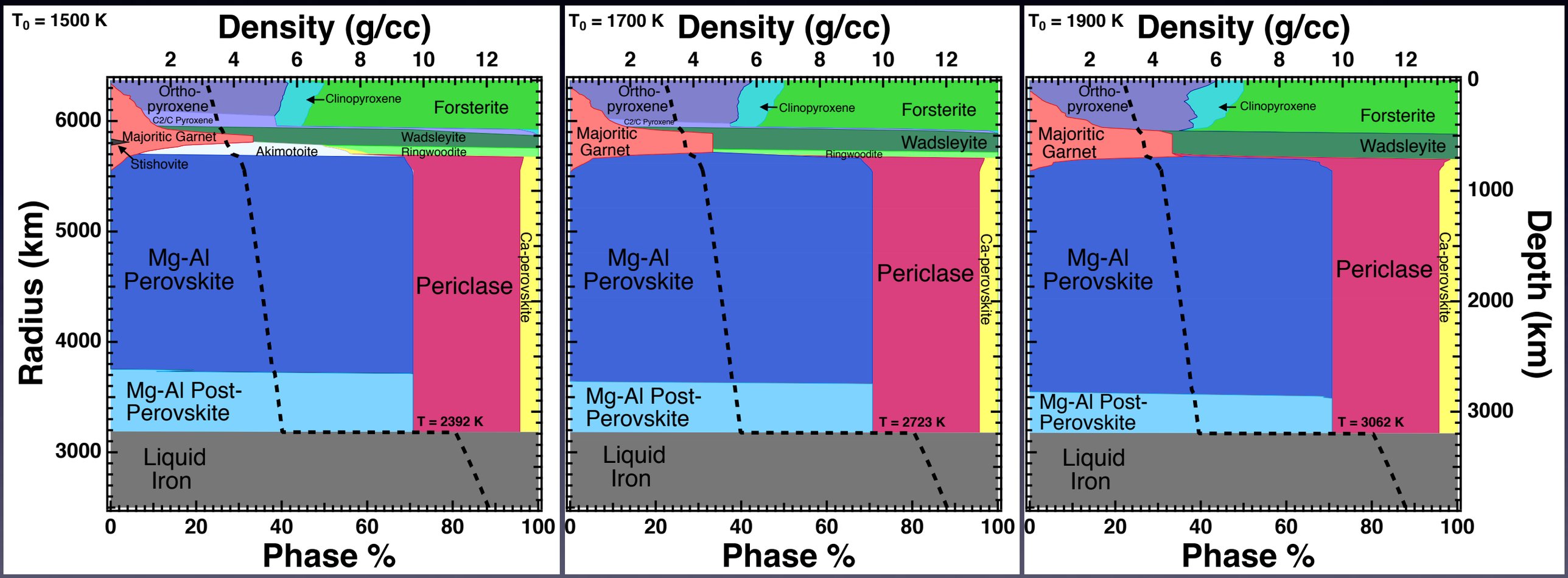
Ortho-pyroxene
C2/C Pyroxene
Clinopyroxene
Forsterite
Majoritic Garnet
Wadsleyite
Ringwoodite
Akimotoite
Stishovite
Mg-Al Perovskite
Periclase
Ca-perovskite
Mg-Al Post-Perovskite
T = 2400 K
Liquid Iron
Radius (km)
6000
5000
4000
3000
0 20 40 60 80 100
Phase %
T0 = 1700 K
Density (g/cc)
T = 2732 K
T0 = 1900 K
Density (g/cc)
T = 3067 K
0
1000
2000
3000
Depth (km)

HIP 96100


T0 = 1500 K
Density (g/cc)
2 4 6 8 10 12
Ortho-pyroxene
C2/C Pyroxene
Clinopyroxene
Forsterite
Majoritic Garnet
Wadsleyite
Akimotoite
Ringwoodite
Stishovite
Mg-Al Perovskite
Periclase
Ca-perovskite
Mg-Al Post-Perovskite
T = 2394 K
Liquid Iron
Radius (km)
6000
5000
4000
3000
0 20 40 60 80 100
Phase %
T0 = 1700 K
Density (g/cc)
T = 2725 K
T0 = 1900 K
Density (g/cc)
T = 3062 K
0
1000
2000
3000
Depth (km)

HIP 7981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Density (g/cc)
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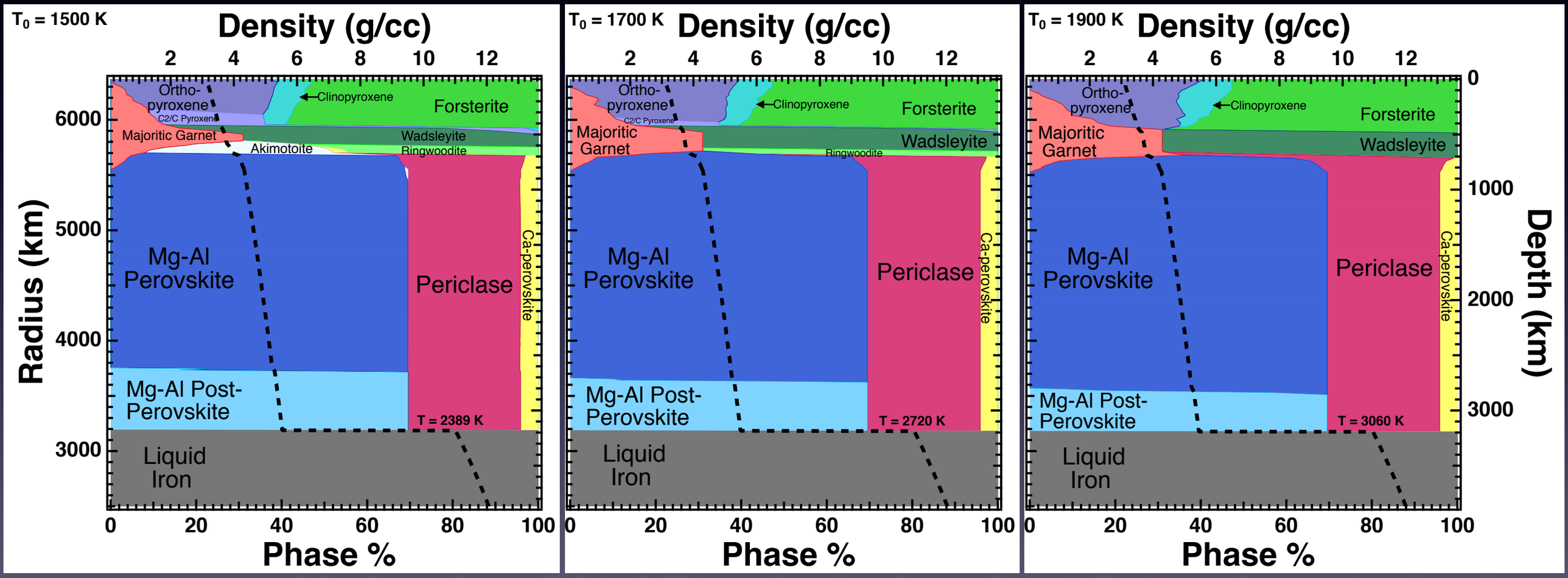
Ortho-pyroxene
C2/C Pyroxene
Clinopyroxene
Forsterite
Majoritic Garnet
Wadsleyite
Akimotoite
Ringwoodite
Stishovite
Mg-Al Perovskite
Periclase
Ca-perovskite
Mg-Al Post-Perovskite
T = 2392 K
Liquid Iron
Radius (km)
6000
5000
4000
3000
0 20 40 60 80 100
Phase %
T0 = 1700 K
Density (g/cc)
T = 2723 K
T0 = 1900 K
Density (g/cc)
T = 3062 K
0
1000
2000
3000
Depth (km)

HIP 17378


T0 = 1500 K
Density (g/cc)
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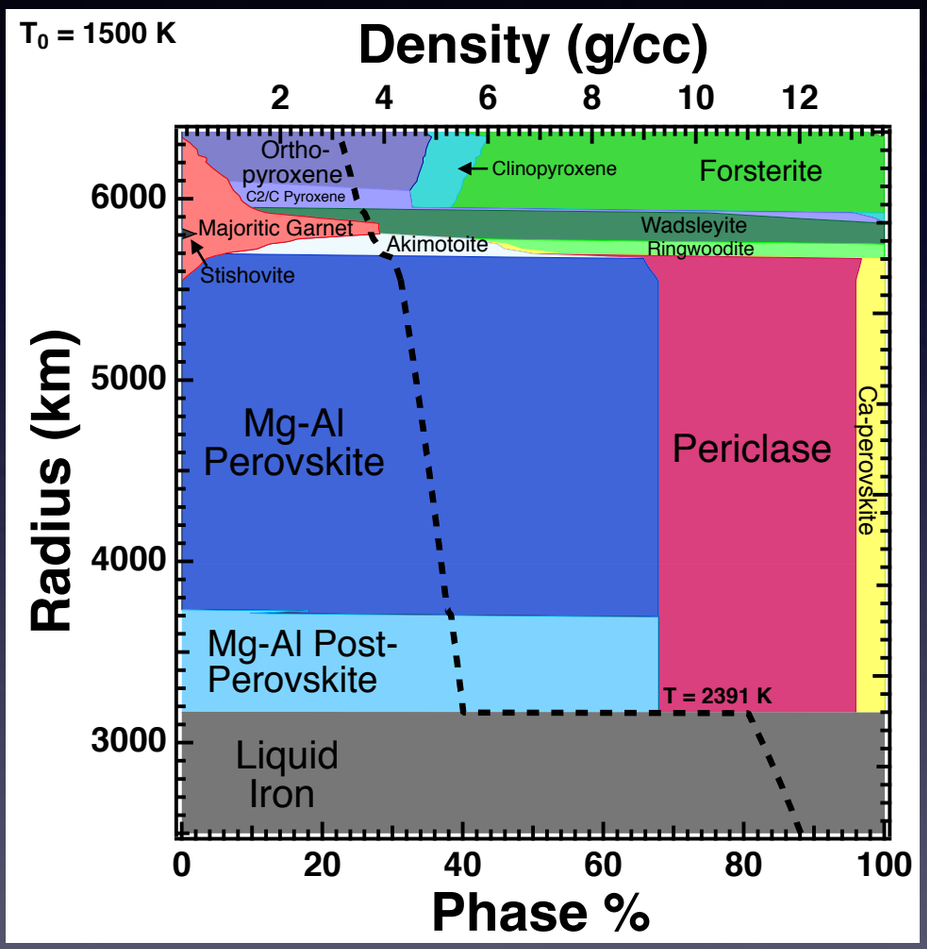
Ortho-pyroxene
C2/C Pyroxene
Clinopyroxene
Forsterite
Majoritic Garnet
Wadsleyite
Akimotoite
Ringwoodite
Mg-Al Perovskite
Periclase
Ca-perovskite
Mg-Al Post-Perovskite
T = 2389 K
Liquid Iron
Radius (km)
6000
5000
4000
3000
0 20 40 60 80 100
Phase %
T0 = 1700 K
Density (g/cc)
T = 2720 K
T0 = 1900 K
Density (g/cc)
T = 3060 K
0
1000
2000
3000
Depth (km)

HIP 3765


T0 = 1500 K
Density (g/cc)
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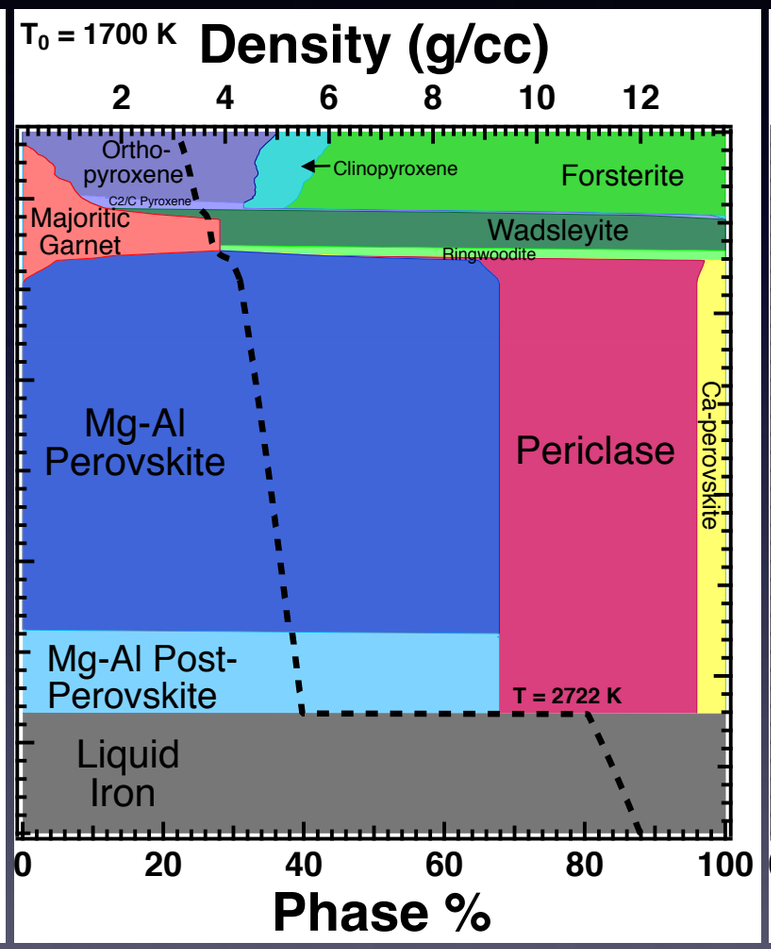
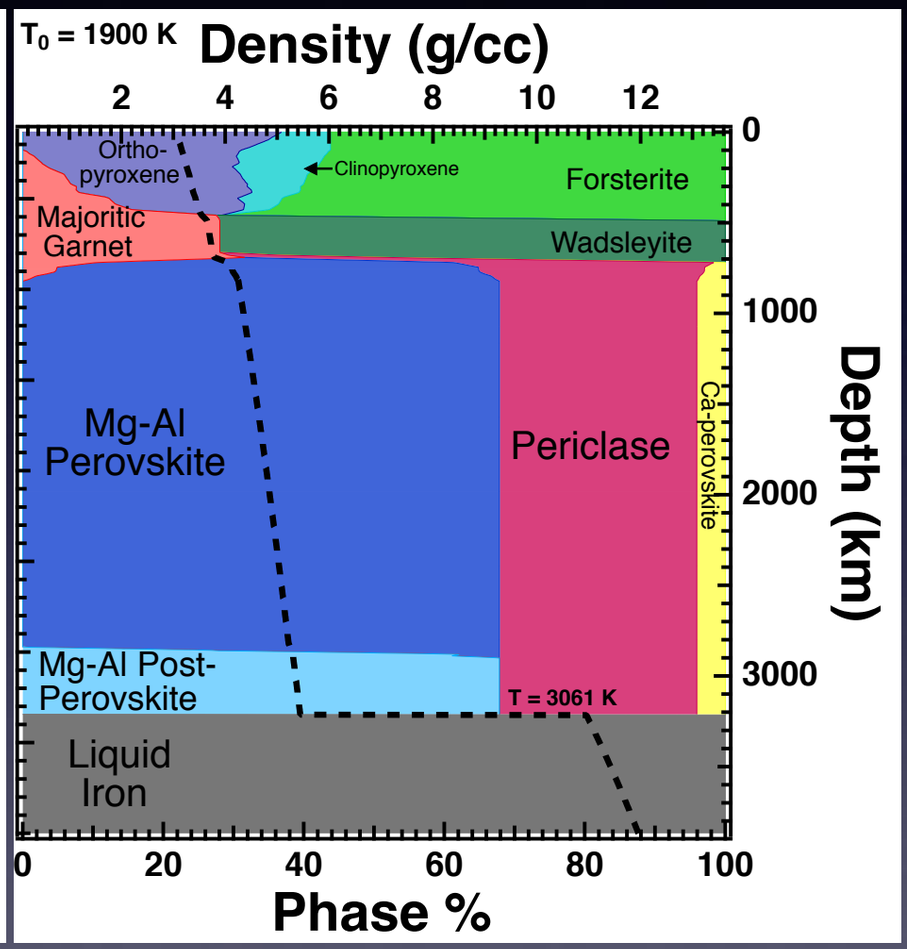
Ortho-pyroxene
C2/C Pyroxene
Clinopyroxene
Forsterite
Majoritic Garnet
Akimotoite
Wadsleyite
Ringwoodite
Stishovite
Mg-Al Perovskite
Periclase
Ca-perovskite
Mg-Al Post-Perovskite
T = 2391 K
Liquid Iron
Radius (km)
6000
5000
4000
3000
0 20 40 60 80 100
Phase %


T0 = 1700 K
Density (g/cc)
2 4 6 8 10 12
Ortho-pyroxene
C2/C Pyroxene
Clinopyroxene
Forsterite
Majoritic Garnet
Wadsleyite
Ringwoodite
Mg-Al Perovskite
Periclase
Ca-perovskite
Mg-Al Post-Perovskite
T = 2722 K
Liquid Iron
0 20 40 60 80 100
Phase %


T0 = 1900 K
Density (g/cc)
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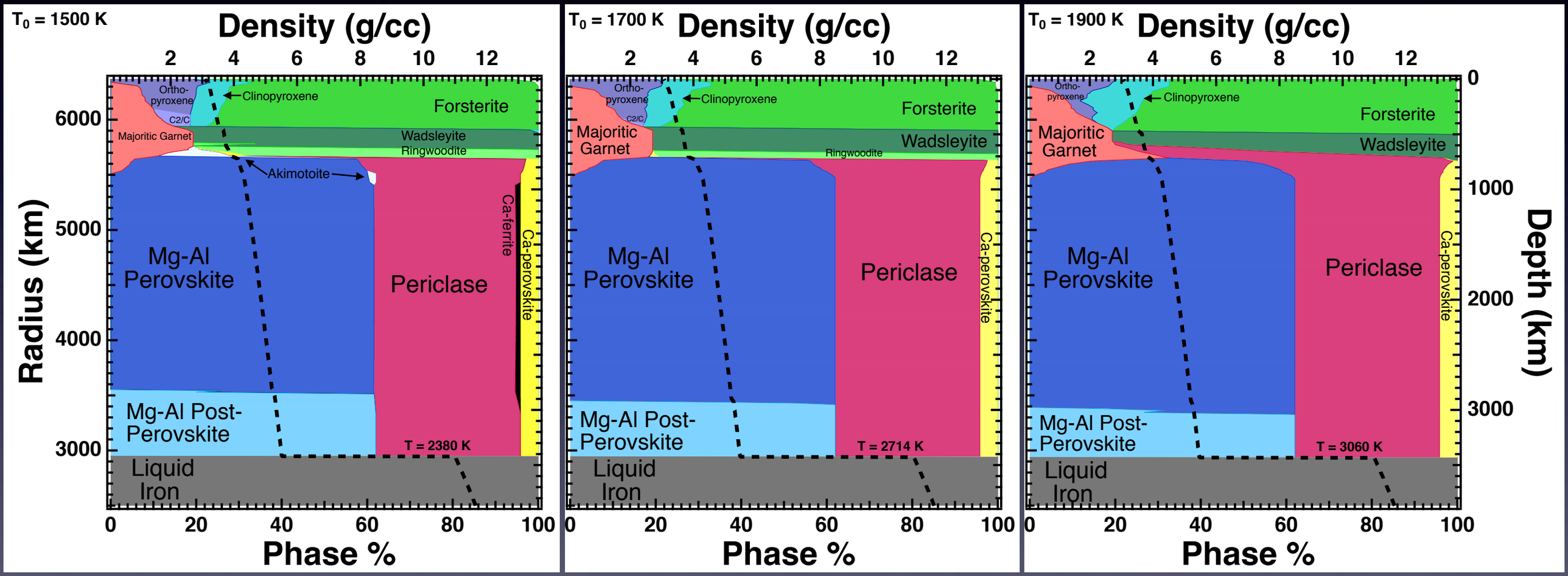
Ortho-pyroxene
Clinopyroxene
Forsterite
Majoritic Garnet
Wadsleyite
Mg-Al Perovskite
Periclase
Ca-perovskite
Mg-Al Post-Perovskite
T = 3061 K
Liquid Iron
0
1000
2000
3000
Depth (km)
0 20 40 60 80 100
Phase %

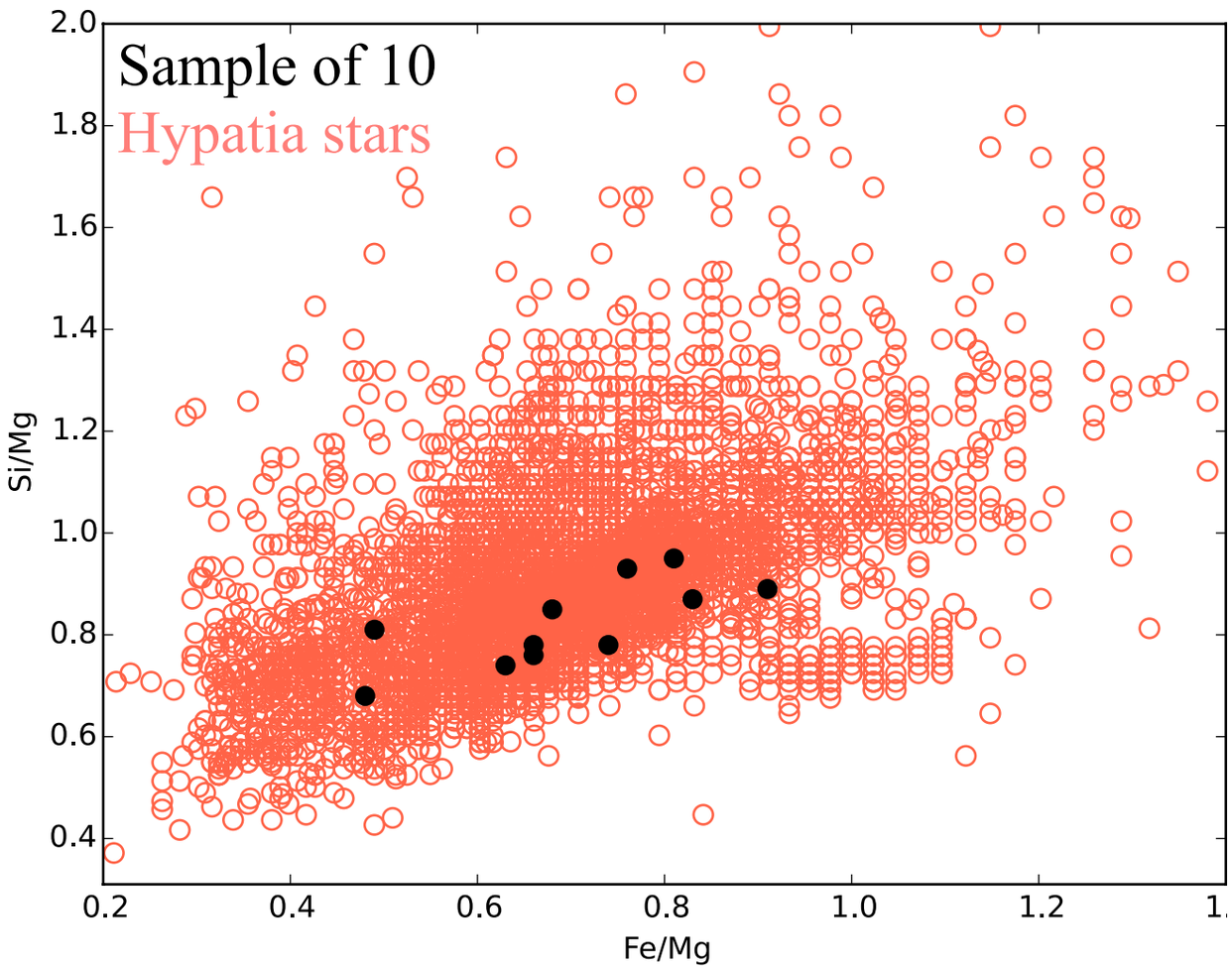
HIP 23311

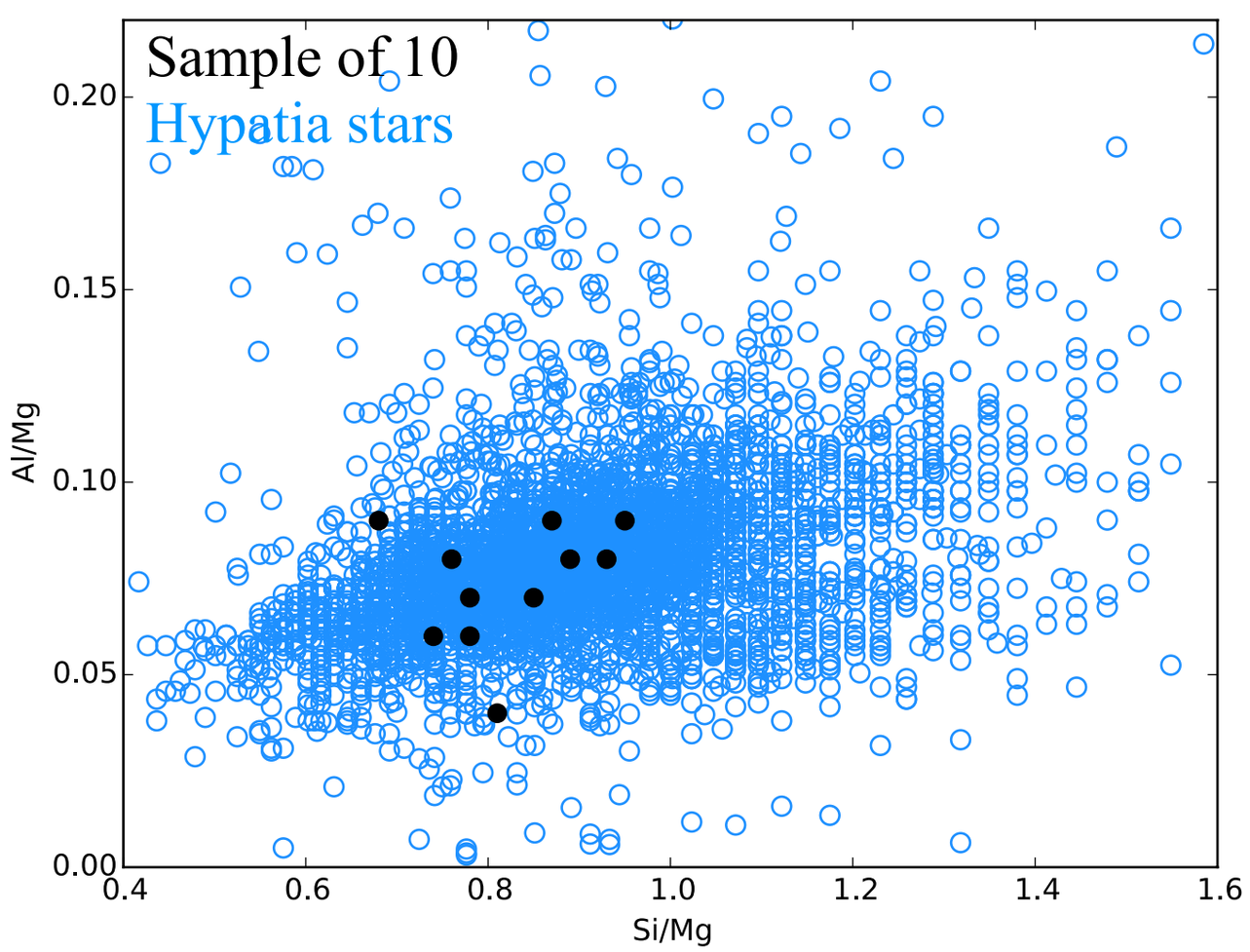

T0 = 1500 K
Density (g/cc)
2 4 6 8 10 12
Ortho-pyroxene
C2/C
Clinopyroxene
Forsterite
Majoritic Garnet
Wadsleyite
Ringwoodite
Akimotoite
Mg-Al Perovskite
Periclase
Ca-ferrite
Ca-perovskite
Mg-Al Post-Perovskite
T = 2380 K
Liquid Iron
Radius (km)
6000
5000
4000
3000
0 20 40 60 80 100
Phase %
T0 = 1700 K
Density (g/cc)
Majoritic Garnet
T = 2714 K
T0 = 1900 K
Density (g/cc)
T = 3060 K
0
1000
2000
3000
Depth (km)

Planet Mineralogy

They look the same!?!

While the stellar abundances differ, the molar fractions are similar.





Planet Mineralogy

They look the same!?!

While the stellar abundances differ, the molar fractions are similar. Additionally! There are large spreads (range between groups) in the stellar abundances.

How do we get them to not look the same?

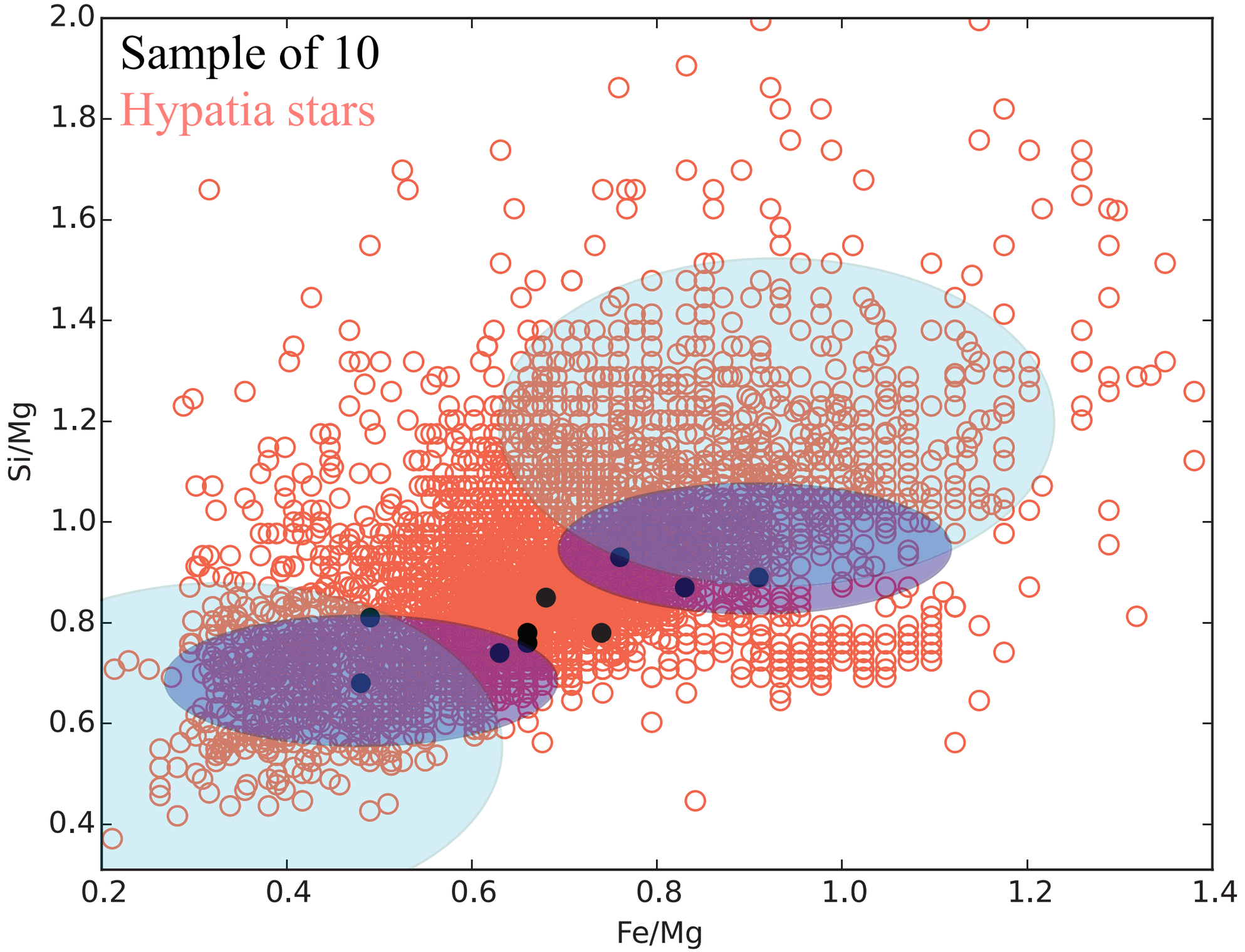
or

What precision do the abundances have to be in order to determine two unique populations?

Mineralogy Algebra

We know how to calculate the error in molar fraction based on the spread/error in the stellar abundances.

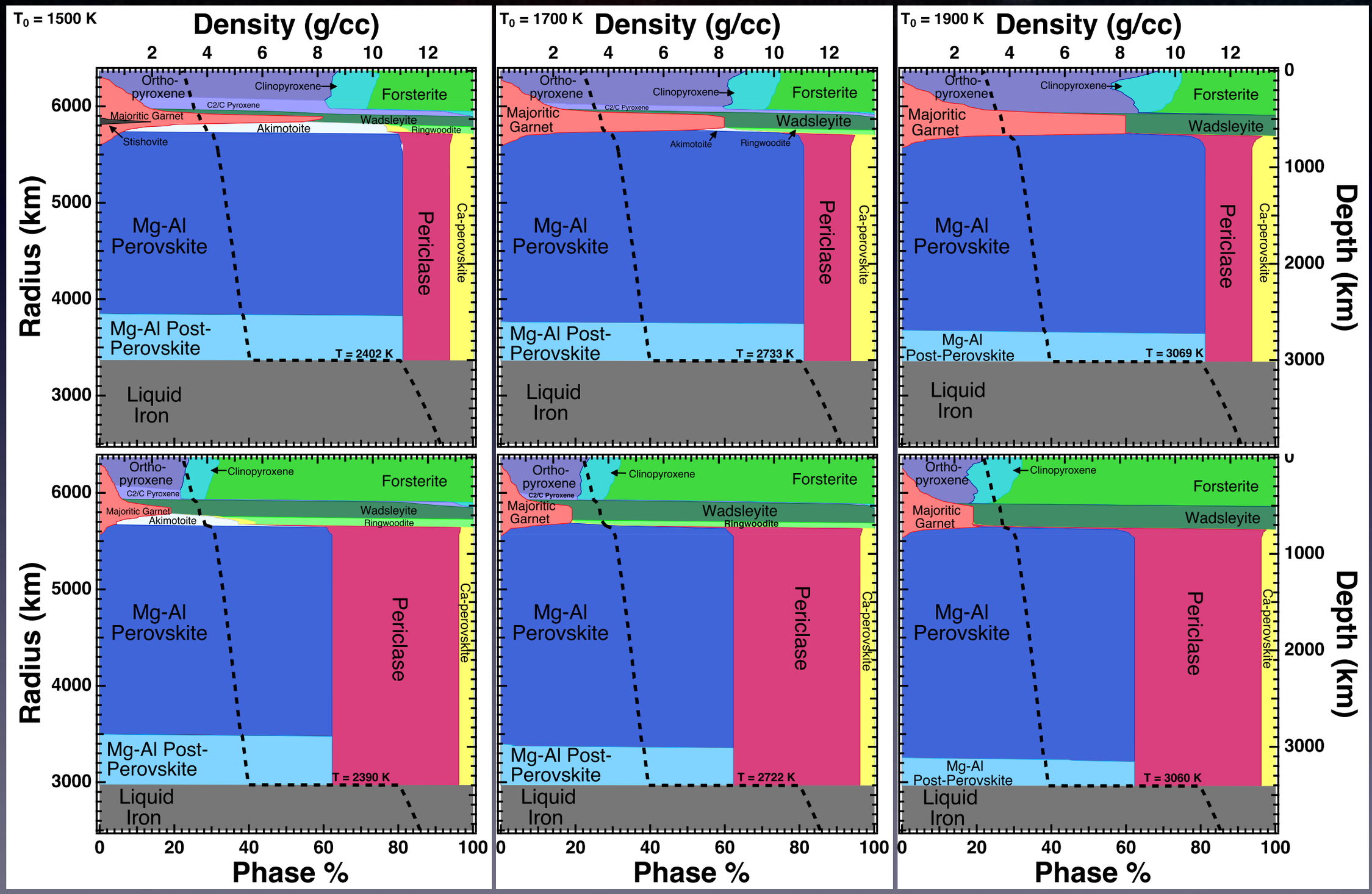
So, looking at the “extremes” in the molar fractions, we split those populations in two and work backwards to determine what precision is needed.


Sample of 10
Hypatia stars
Si/Mg
Fe/Mg
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.4
0.6
0.8
1.0
1.2
1.4

Structures of the 2 Populations

Extreme High

Extreme Low



Can we do it?

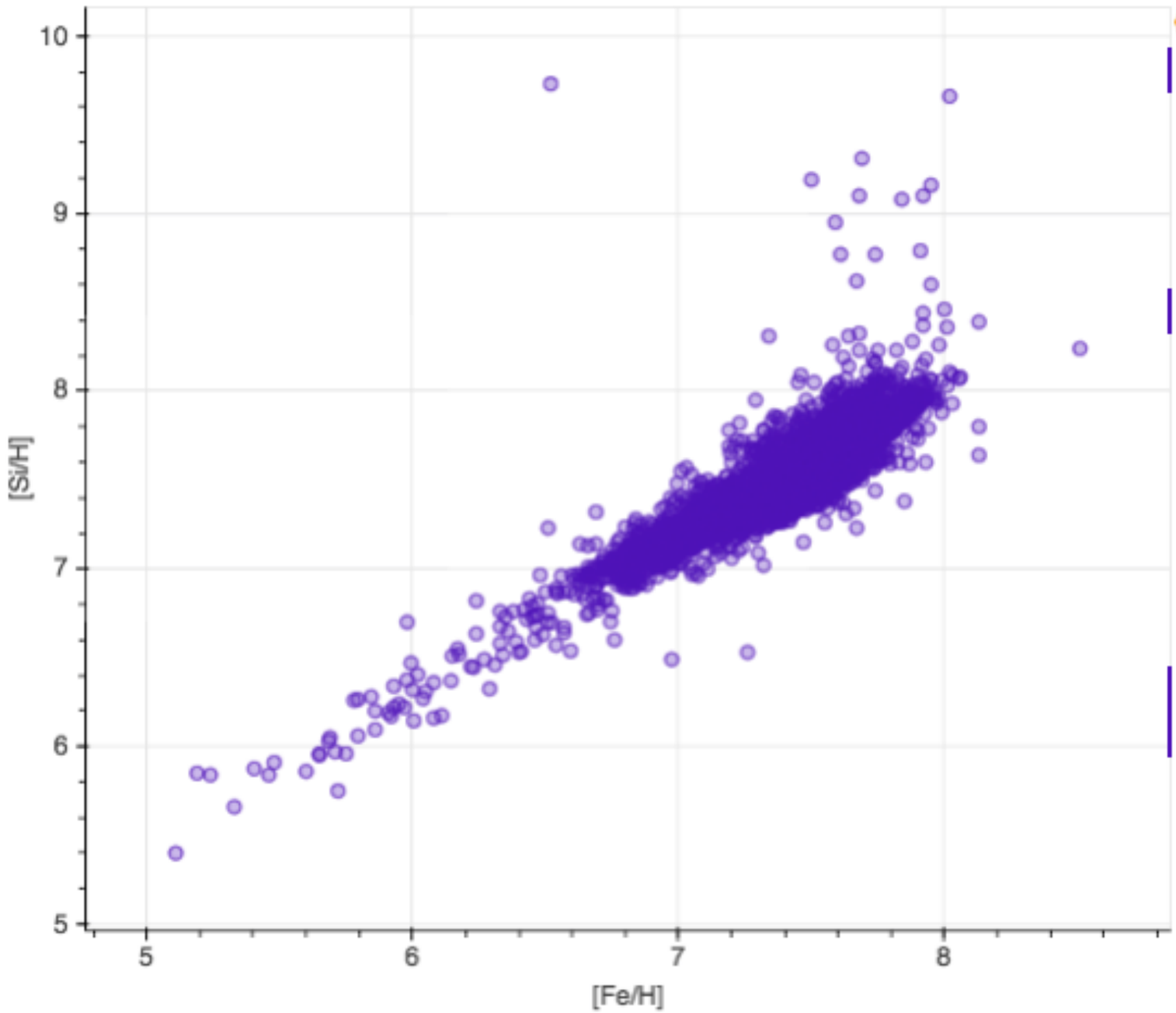
For our sample of 10 stars, the precision in [Fe/H], [Mg/H], [Al/H], [Si/H], [Ca/H] need to be < 0.02 dex!

For the Hypatia sample, or stars within 150pc, we need precision that's < 0.03 dex.

Difficult — but not impossible. There are current high precision abundance techniques that could resolve this difference. With time and effort, additional techniques could also reach this precision.

The Hypatia Catalog Database

Hypatia Catalog | Elements & Properties | Stars With/Without Planets



Filter:

none | minimum | maximum

none | minimum | maximum

none | minimum | maximum

X-axis:

Fe / H log

Y-axis:

Si / H log

Z-axis (color):

none log

Solar Norm:

Absolute

If element ratio is in multiple catalogs:

Use the median

Exclude catalogs:

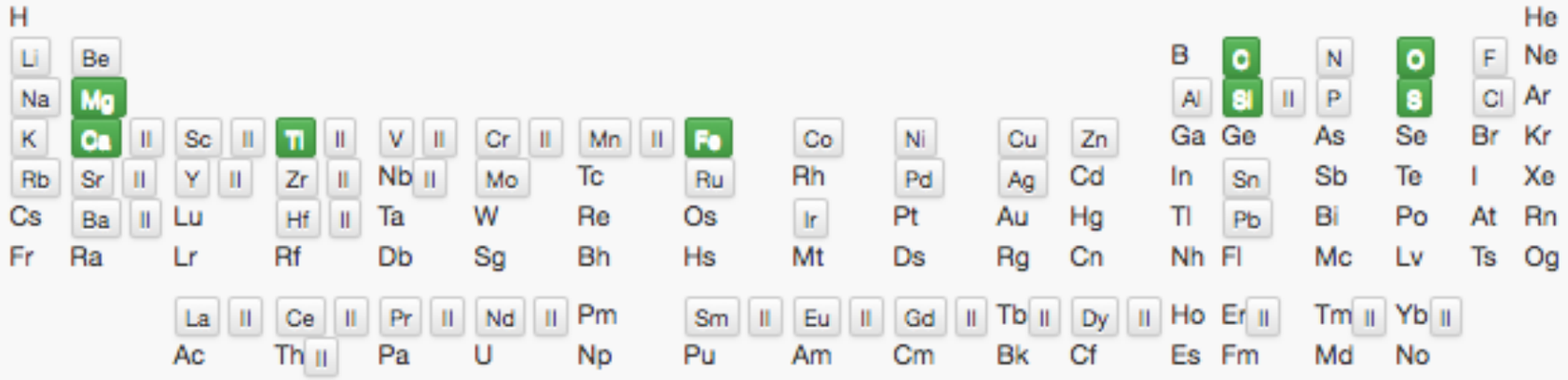
Submit

www.HypatiaCatalog.com

Stellar Data Table 5377 stars selected

Use stars plotted in the graph above

Use stars from a list of HIP identifiers: e.g. 56572,7599,57172



Add Stellar Properties | Add Planet Properties | Add Spread or Error

Submit | Reset | Download Data Table

Fe	err	C	err	O	err	Mg	err
7.72	± 0.13	8.74	± 0.04	8.94	± 0.33	7.87	± 0.06
7.55	± 0.13	8.56	± 0.08	8.75	± 0.16	7.67	± 0.10
7.60	± 0.08	8.57	± 0.19	8.74	± 0.09	7.77	± 0.07
7.77	± 0.13	8.73	± 0.19	8.93	± 0.24	7.89	± 0.16
7.19	± 0.66	8.34	± 0.60	8.59	± 0.38	7.38	± 0.74
7.69	± 0.05	8.69	± 0.09	9.00	± 0.09	7.82	± 0.07

Thank you!

(Find me if you want Hypatia stickers! I'll also have more swag at the Hypatia Catalog Database exhibitor booth at the AAS!)