Tc trends and clues to Galactic evolution

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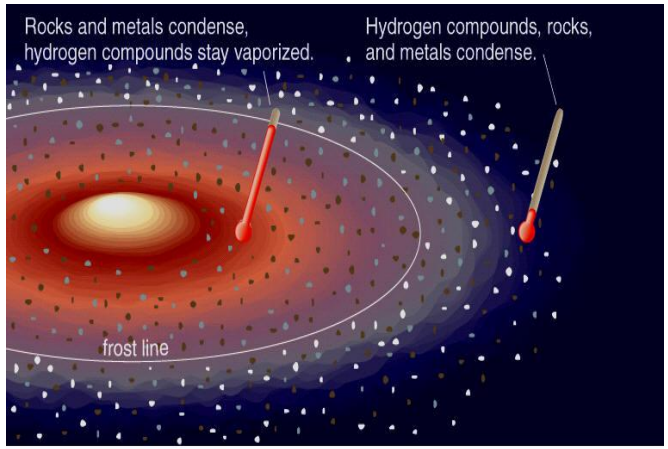
Introduction to Condensation Temperature

When the temperature in the stellar disks drops (with time or with distance from the star), the heaviest compounds (first)began to form solid/liquid droplets, a process called condensation.

The condensation temperature (Tc) for different elements is different and relates with the mass of the particles that become solid.

Low Tc elements - volatiles
High Tc elements - refractories (easily form dust)



Materials in the Solar Nebula

	Metals	Rocks	Hydrogen Compounds	Light Gases
Examples	iron, nickel, aluminum	silicates	water (H_2O) methane (CH_4) ammonia (NH_3)	hydrogen, helium
Typical Condensation Temperature	1,000–1,600 K	500–1,300 K	<150 K	(do not condense in nebula)
Relative Abundance (by mass)	(0.2%)	(0.4%)	(1.4%)	(98%)

[X/Fe] vs. Tc

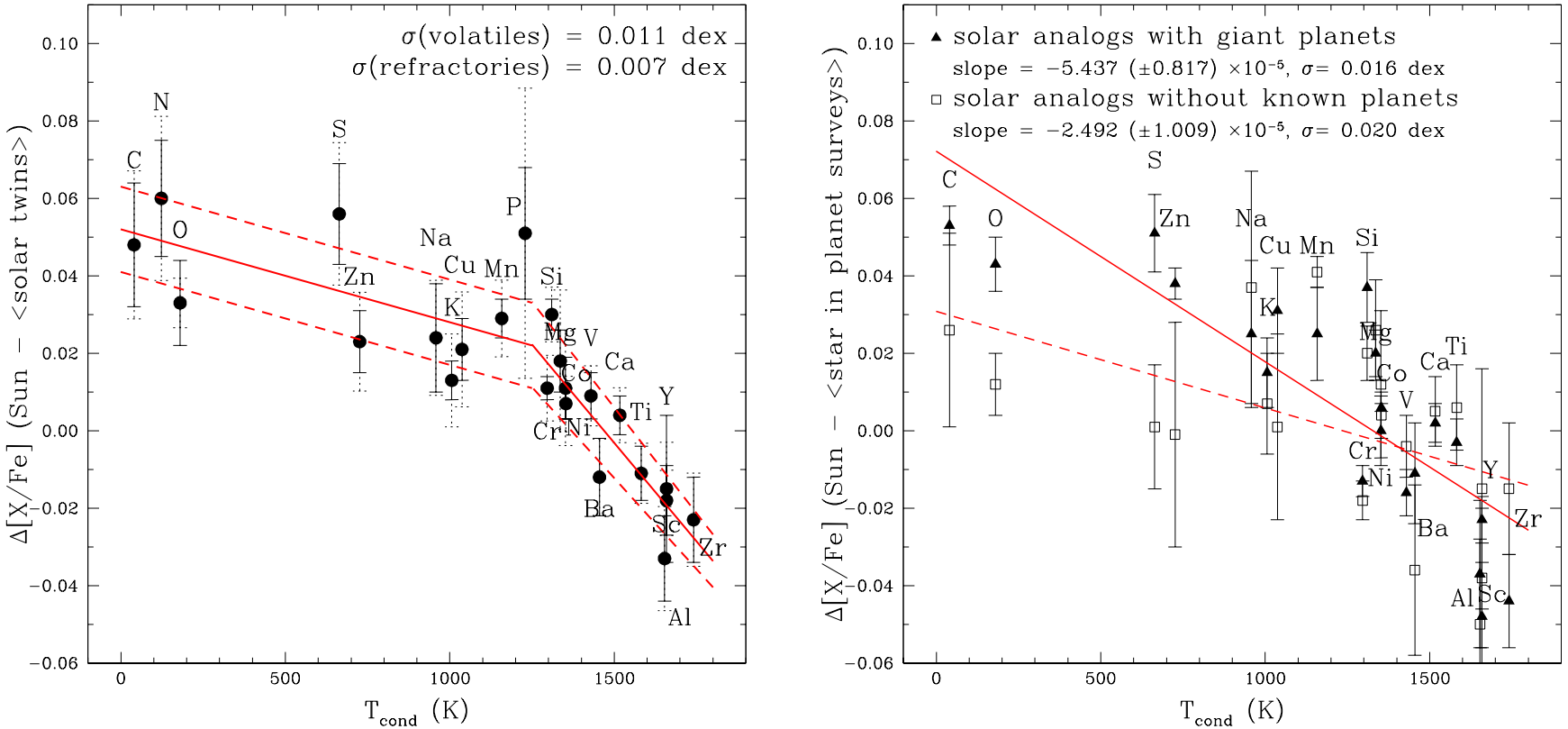
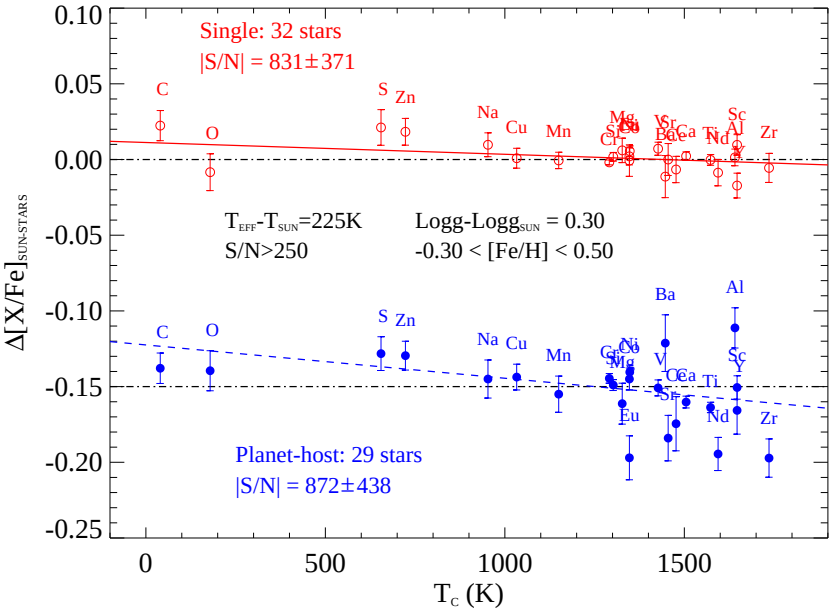


Figure: Melendéz et al. (2009).

Anomalous volatile-to-refractory ratio of the Sun compared to solar twins.

Refractories remained in rocky planets (Ramirez et al. 2009,2010).

[X/Fe] vs. Tc



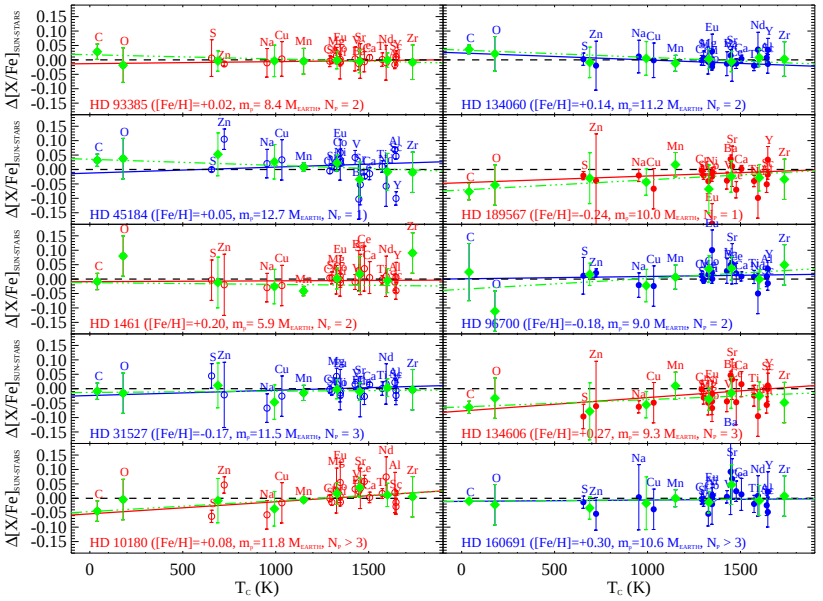


Figure: González Hernández et al. (2013).

No (significant) peculiar abundance ratio

No evidence of relation between volatile-to-refractory abundance ratio and presence of rocky planets (González Hernández et al. 2010,2013).

Contradictory results – need to find the root

What is/are the main factor(s) responsible for the trends with Tc?

Does terrestrial planet formation leave chemical imprints in the atmospheres of their host stars?

The data is from González Hernández et al. (2010,2013)
The ages are from GCS - Casagrande et al. (2011)

Tc slope and stellar age

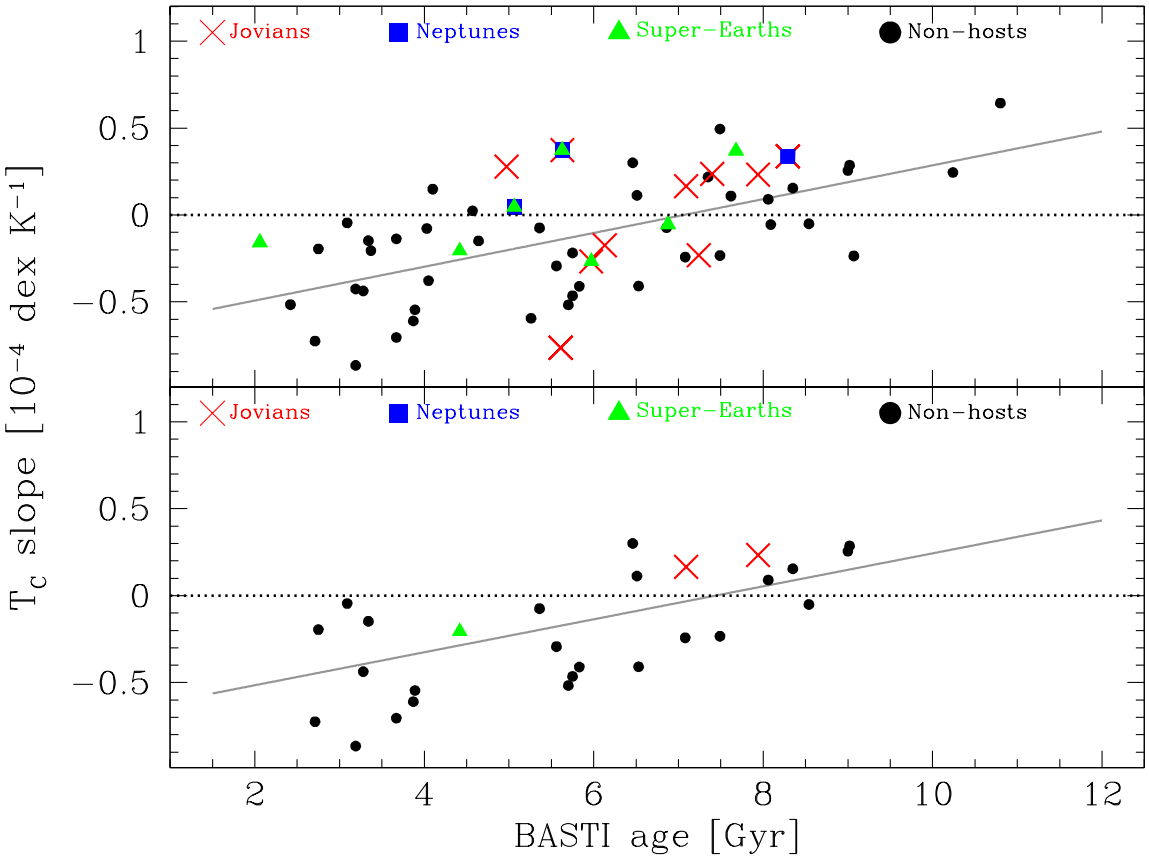


Figure: Adibekyan et al. (2014).

Tc slope strongly correlates with the stellar age

Older stars show lower refractory-to-volatile ratio **independent of the presence of planets**

Tc slope and Galactic Chemical Evolution

For FGK dwarfs stars in the main sequence one does not expect significant changes in their atmospheric chemical abundances with age.
The observed correlation between the Tc slope and age probably reflects the chemical evolution in the Galaxy.

What else relates to Galactic chemical evolution?
The birth place: R_{mean} – mean of the apo- and pericentric distances.

Tc slope and R_{mean}

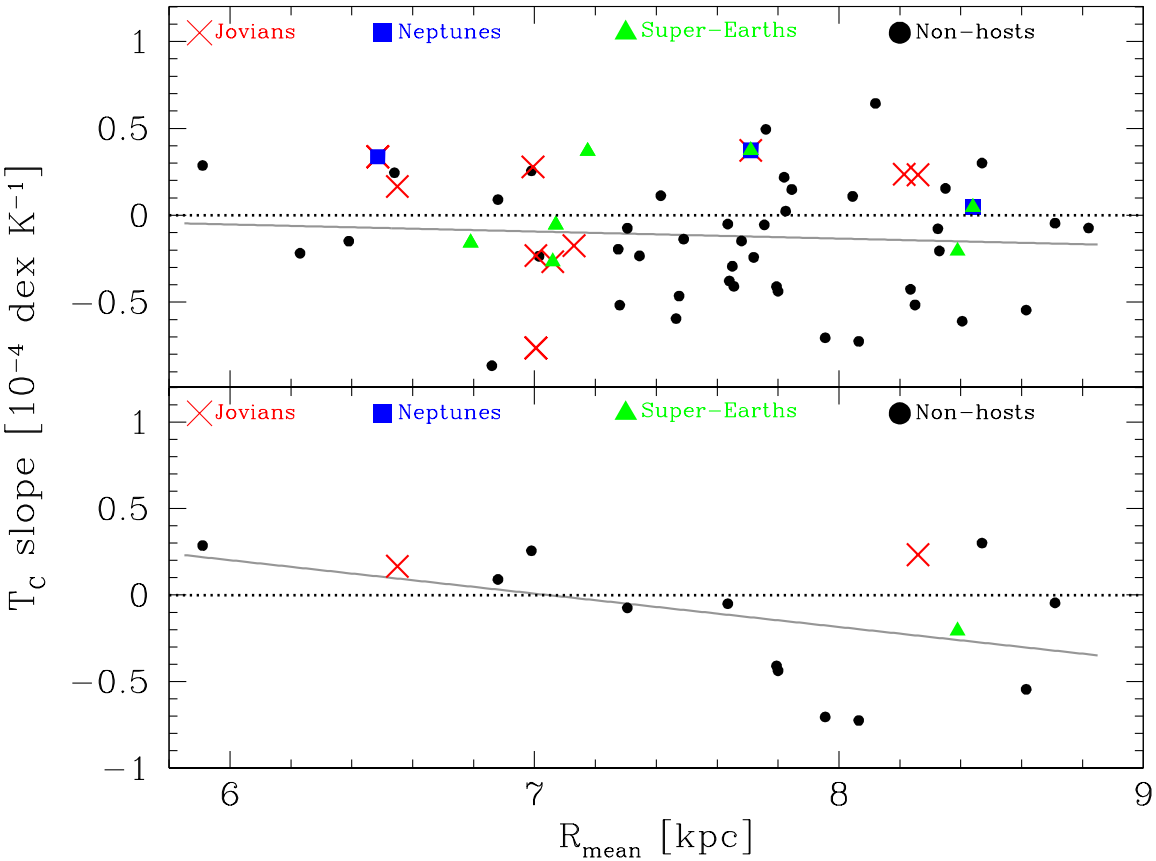


Figure: Adibekyan et al. (2014).

Tc slope correlates with R_{mean}

Stars with smaller R_{mean} show larger Tc slopes.

Tc slope and R_{mean}: Galactic abundance gradients

Tc slope correlates with galactocentric distance?
What the other samples (data) say?

Tc slope and R_{mean}: Galactic abundance gradients

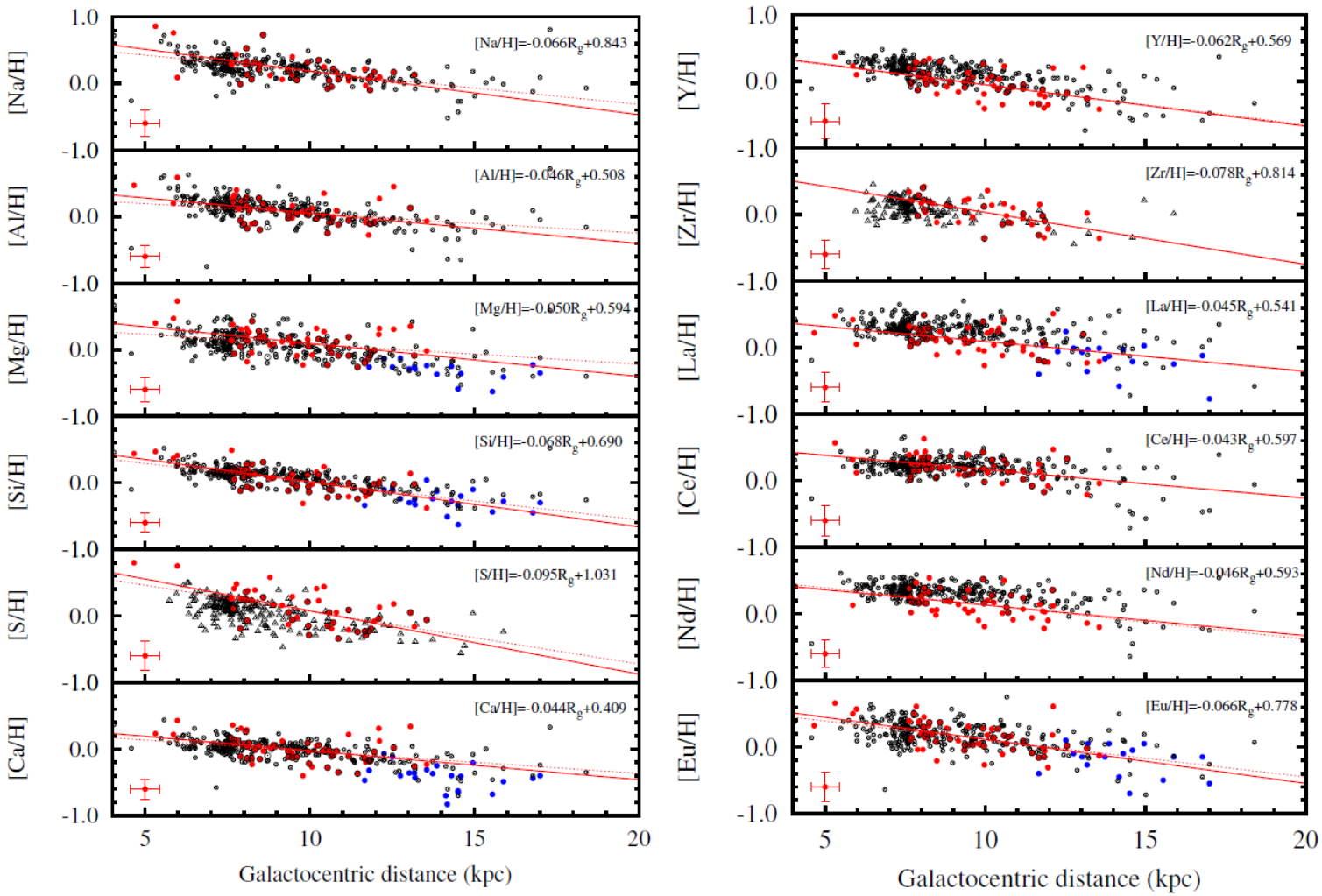


Figure: [X/H] vs. R_{gal}: Lemasle et al. (2008, 2013).

Tc slope and R_{mean}: Galactic abundance gradients

[X/Fe] vs. T_C using the Galactic abundance gradients of Galactic Cepheids from Lemasle et al. (2008, 2013).

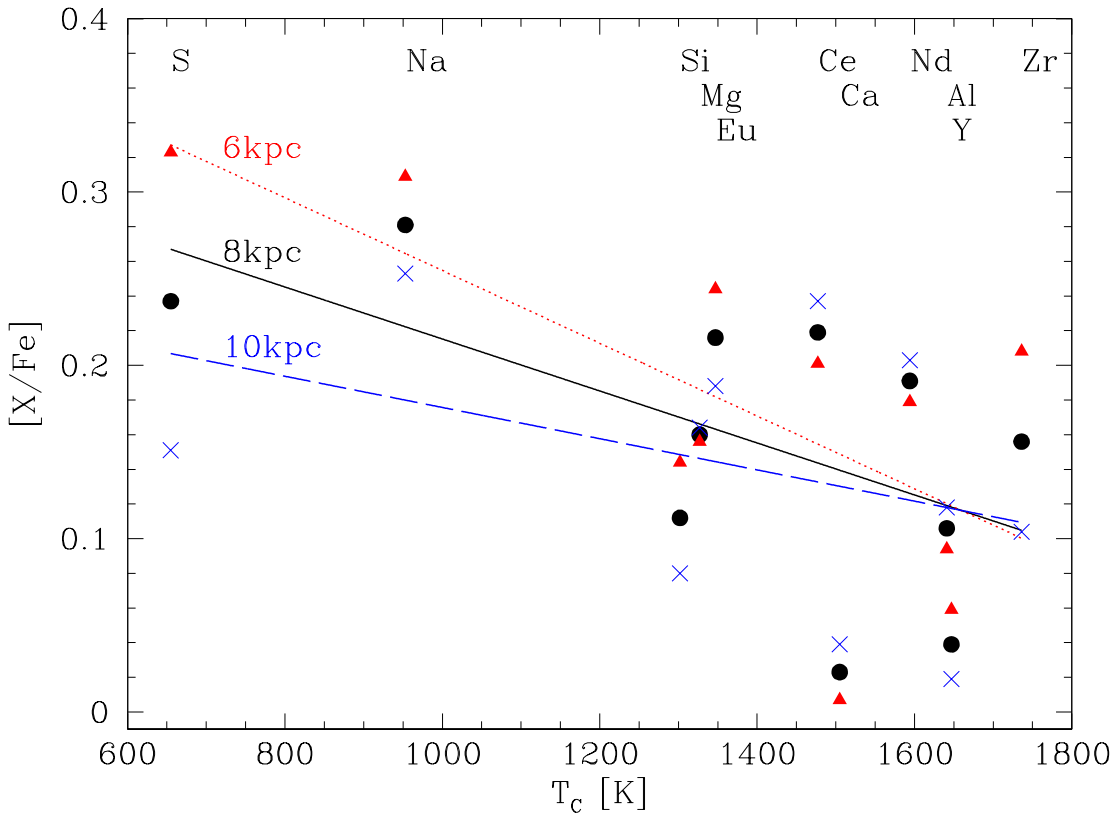


Figure: Lemasle et al. (2008, 2013).

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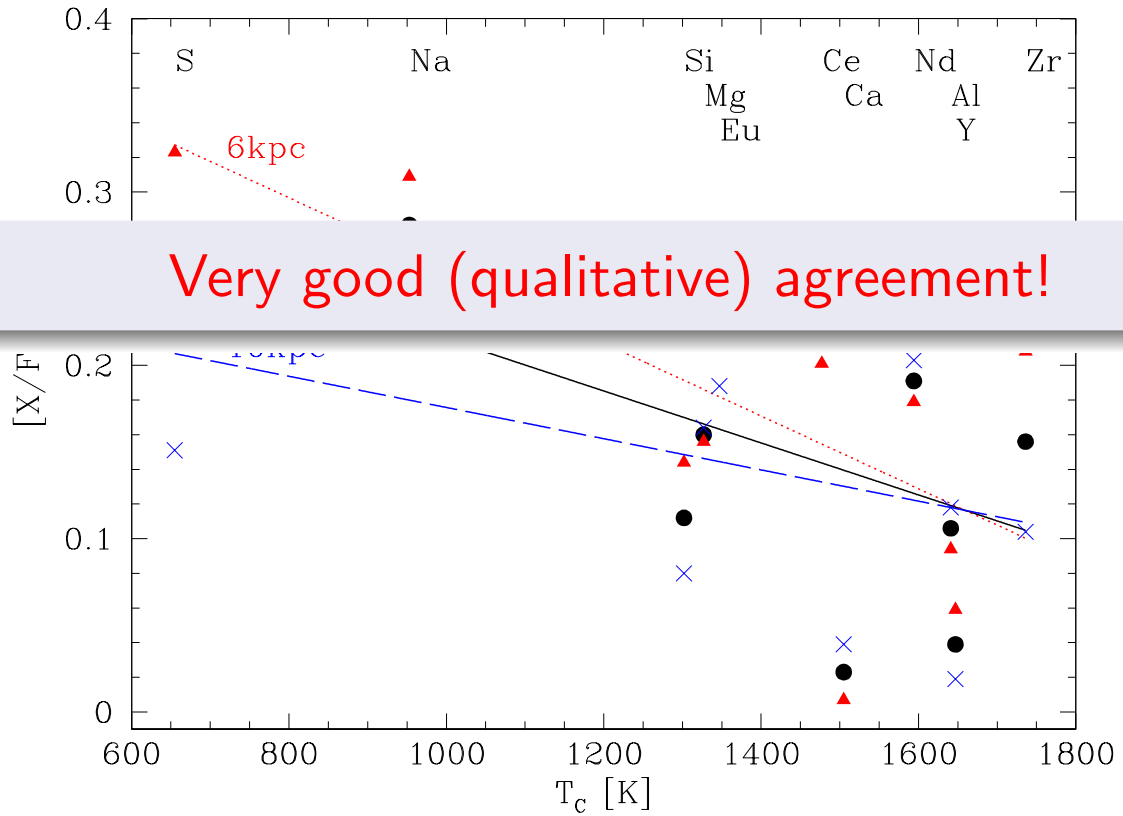

Very good (qualitative) agreement!

Figure: Lemasle et al. (2008, 2013).

Tc slope and planets

Tc slope depends on stellar age and galactic birth place.

What about the planets?

Tc slope and planets

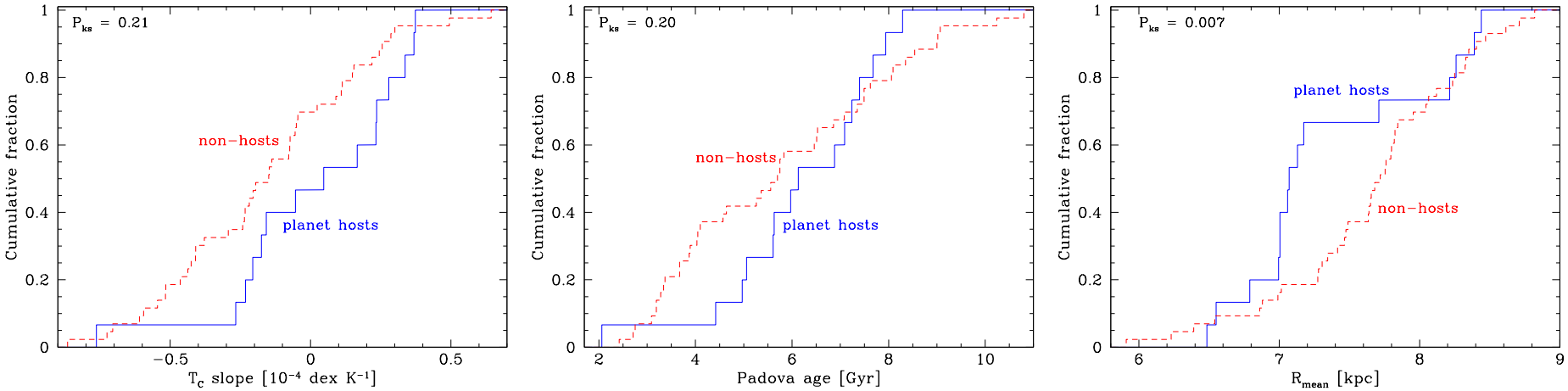

Figure: K-S tests for the Tc slope, age, and R_{mean}: Adibekyan et al. (2014).

No relation to planet formation?

Solar analogues with planets show slightly larger Tc slopes ($P_{KS} = 0.21$). However

- Solar analogues with planets have older age ($P_{KS} = 0.20$)
- Solar analogues with planets show smaller R_{mean} ($P_{KS} = 0.007$)

Tc slope and stellar populations

If the Tc slope relates to birth place and time, can it be used to distinct galactic stellar populations?

Tc slope vs. metallicity: The HARPS data

Red circles - chemically defined thick disk stars

Blue squares - chemically defined thin disk stars

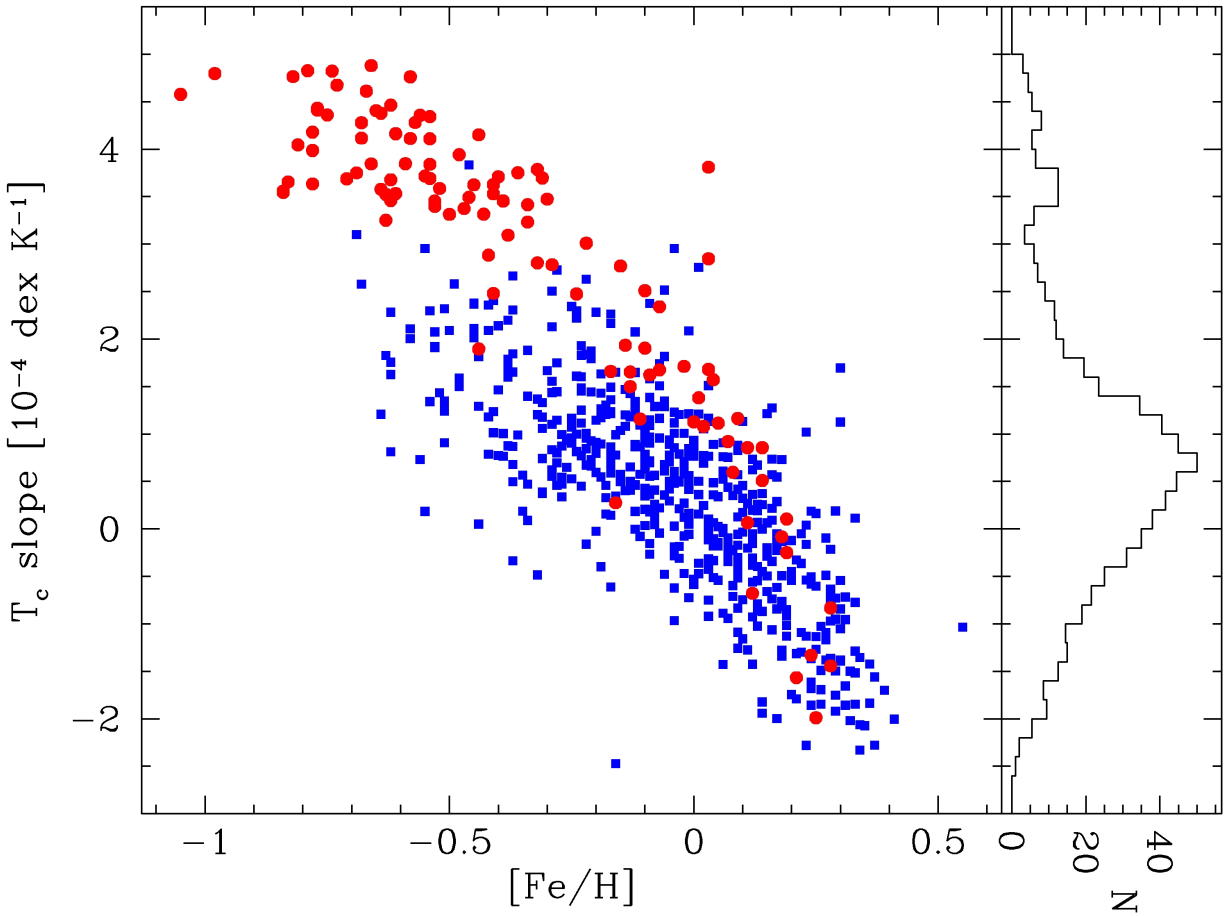

Figure: Tc slope vs. [X/Fe]: Adibekyan et al. (2014) in prep.

Tc slope vs. V_{LSR}: The HARPS data

Red circles - chemically defined thick disk stars

Blue squares - chemically defined thin disk stars

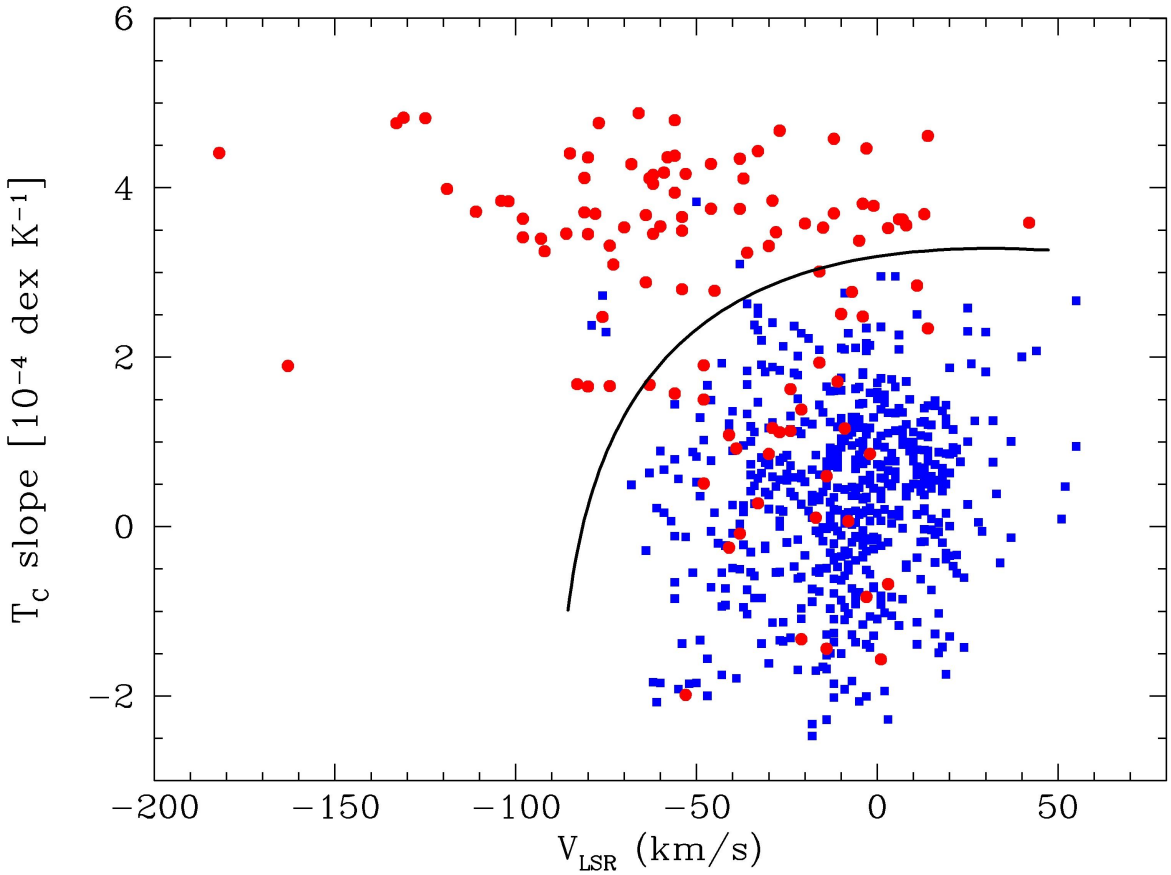

Figure: Tc slope vs. [X/Fe]: Adibekyan et al. (2014) in prep.

Conclusion

Tc slope and Galactic chemo-dynamical evolution

Tc slope relates with the stellar age and R_{mean}.

The age and Galactic birth place are determinant to establish the chemical properties of each star.

Tc slope and planets

Solar analogues with planets mostly come from the inner Galaxy (need to understand why).

Old age and small galactocentric distances are probably the reasons why solar analogues with planets show "peculiar" refractory-to-volatile abundance ratio.

Tc slope and stellar populations

Tc might be a good indicator, but need to be explored better!

Questions?

Thank you!