How Common is Planet Engulfment?

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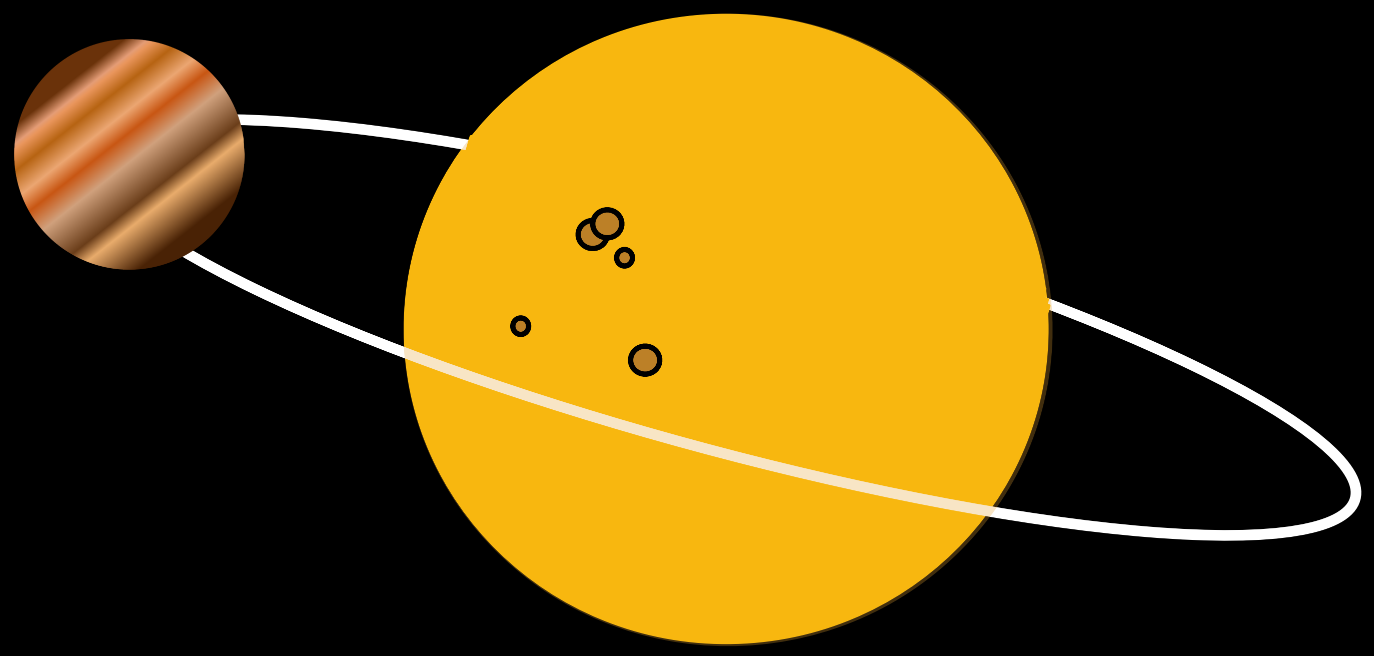
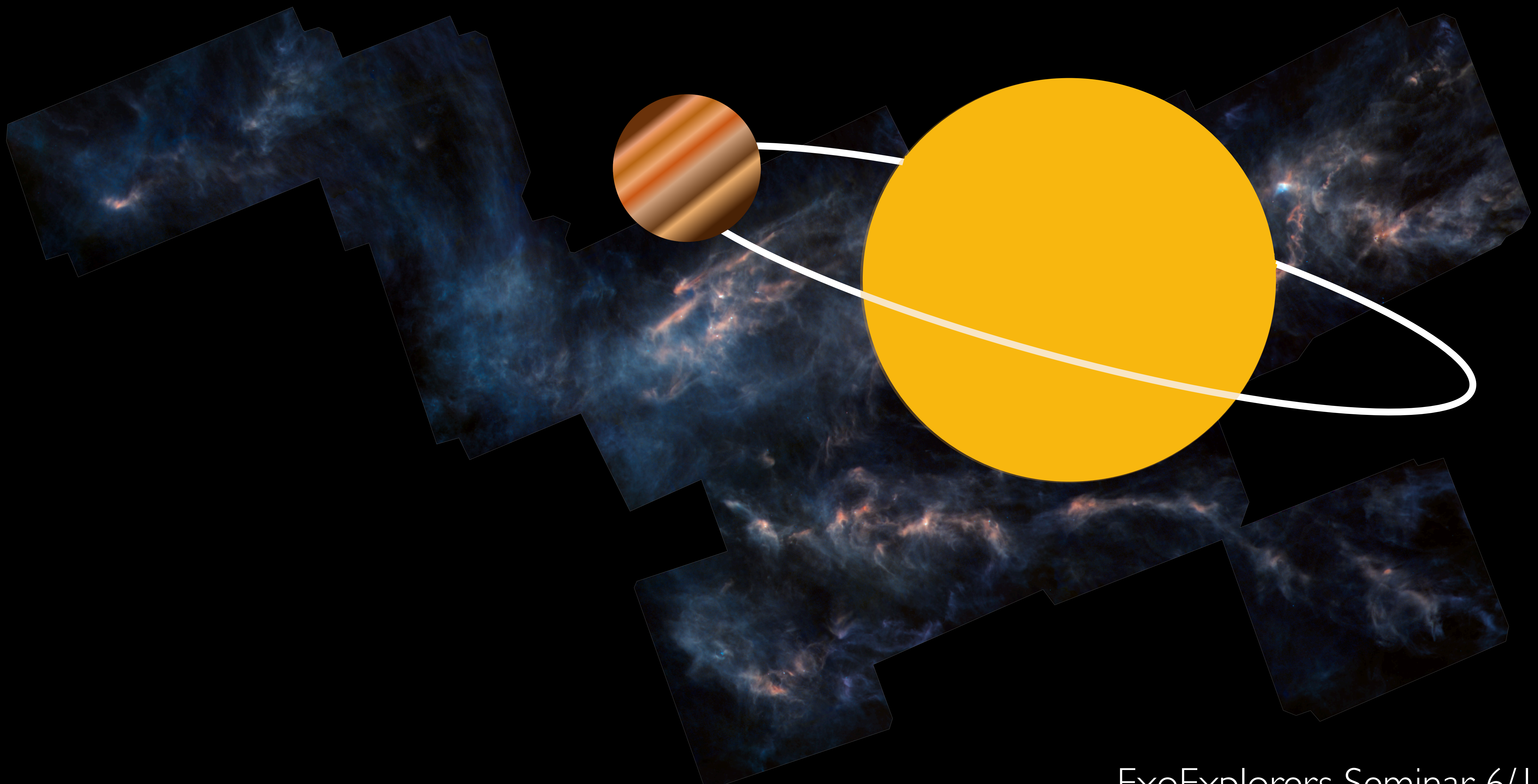
What is planet engulfment?
How do we detect it?



Enhancement in refractory species:

Na, Mg, Al, Si, Ca, Ti, V, Cr, Mn, Fe, Ni, Y, etc.

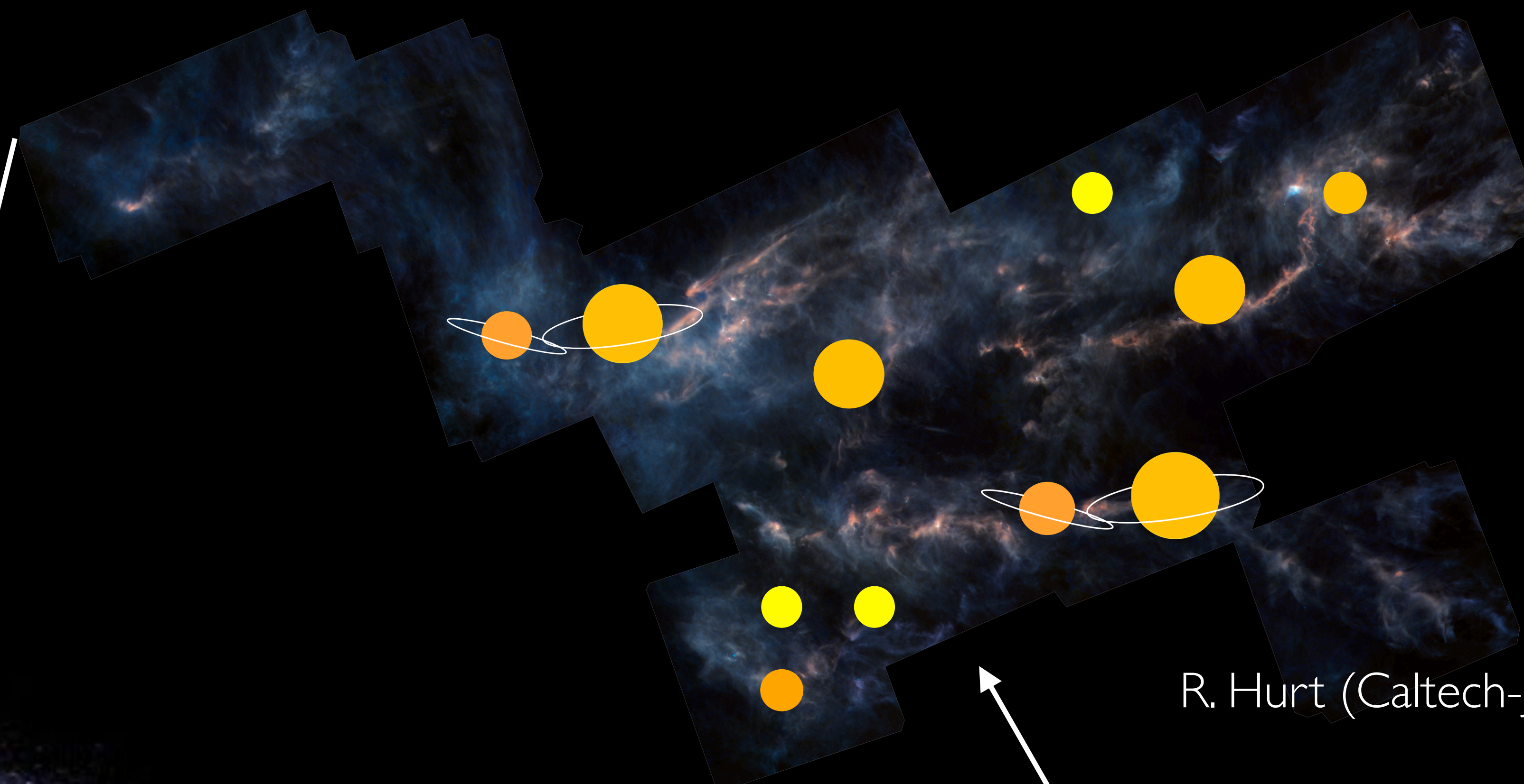
The problem is we don't know the abundances (Na, Mg, Al, Si, Ca, Ti, V, Cr, Mn, Fe, Ni, Y, etc.) a star was born with…



Taurus molecular cloud

stellar nursery

from the same stellar birth cloud…
Made of the same stuff!



R. Hurt (Caltech-JPL)

…and if the stars are obviously bound (like binaries), we know they were born within the same cloud

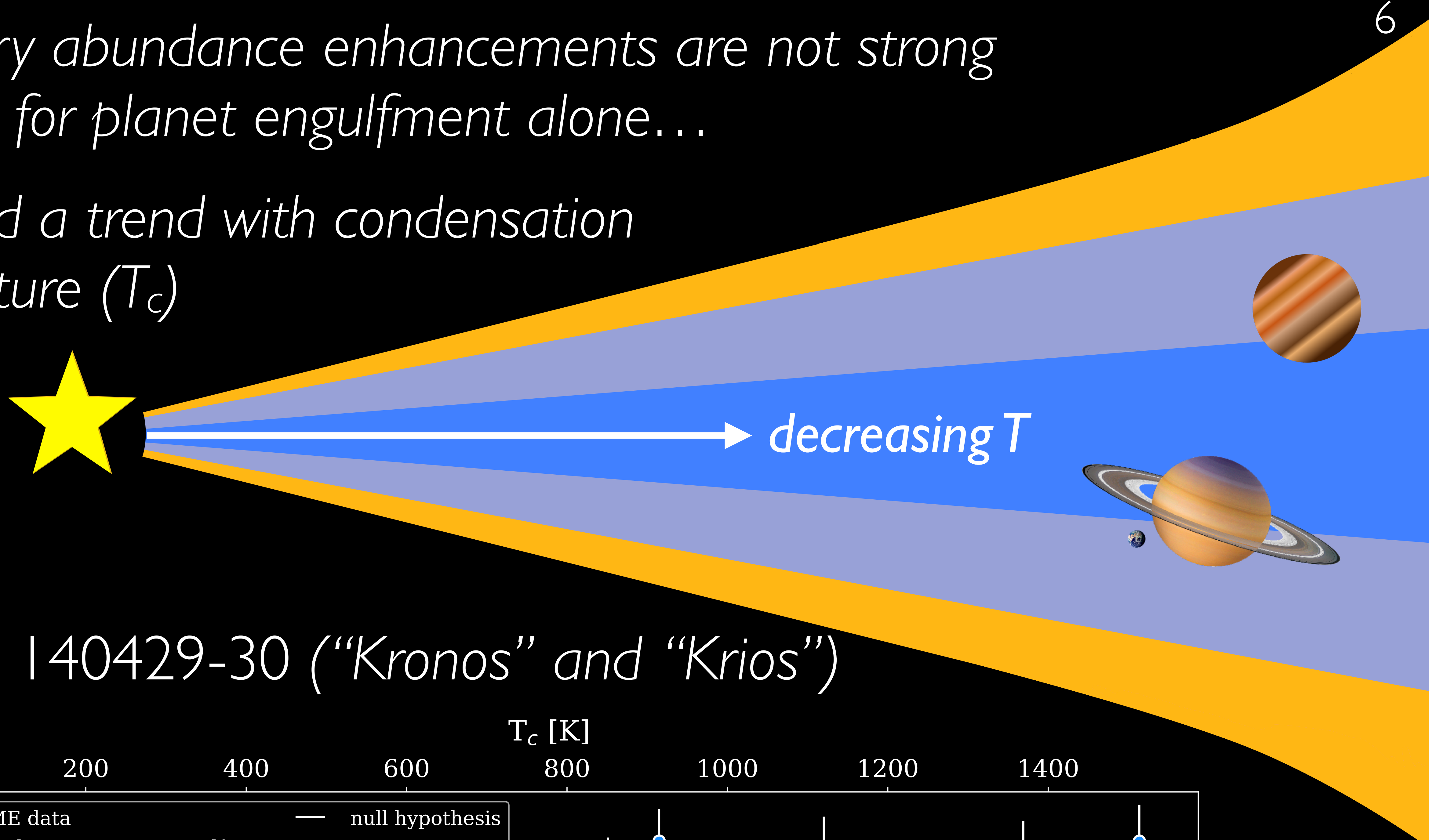
We can look for planet engulfment signatures in multi-star systems

H, He, O, **C**, N, **Si**, … ≠ H, He, O, **C**, N, **Si**, …

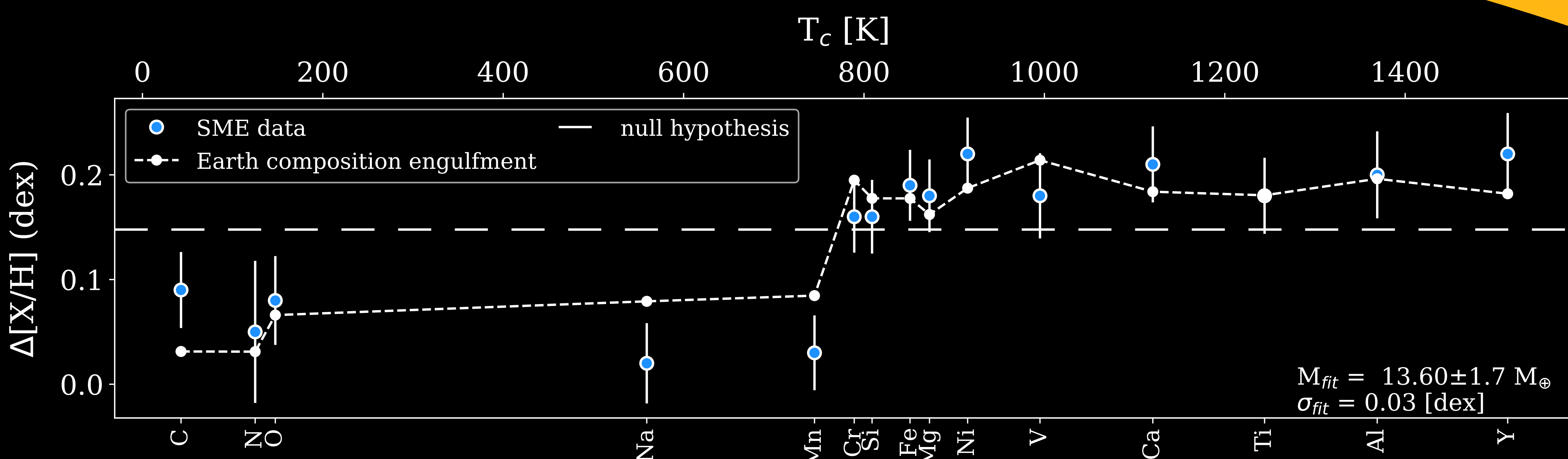
signatures of planet engulfment = rocky material enhancement

Refractory abundance enhancements are not strong evidence for planet engulfment alone…

Also need a trend with condensation temperature (T_c)



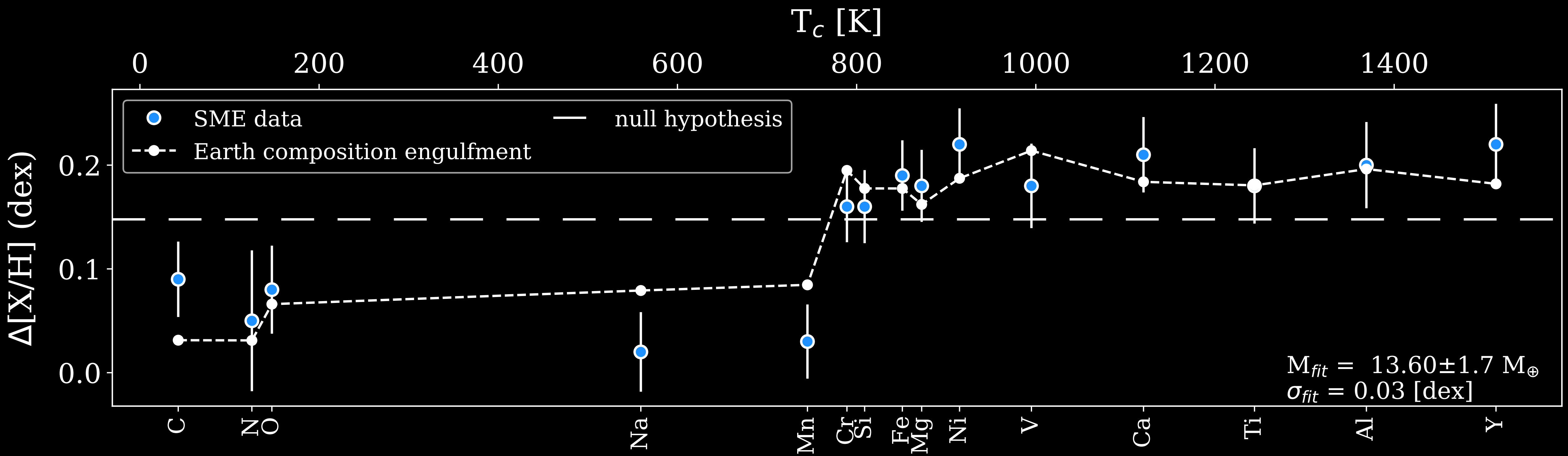
HD 140429-30 (*"Kronos" and "Krios"*)



Behmard et al. (*in prep*)

There are 6 systems with significant refractory differences (>0.05 dex) that trend with T_c reported in the literature

HD 140429-30 (*"Kronos" and "Krios"*)



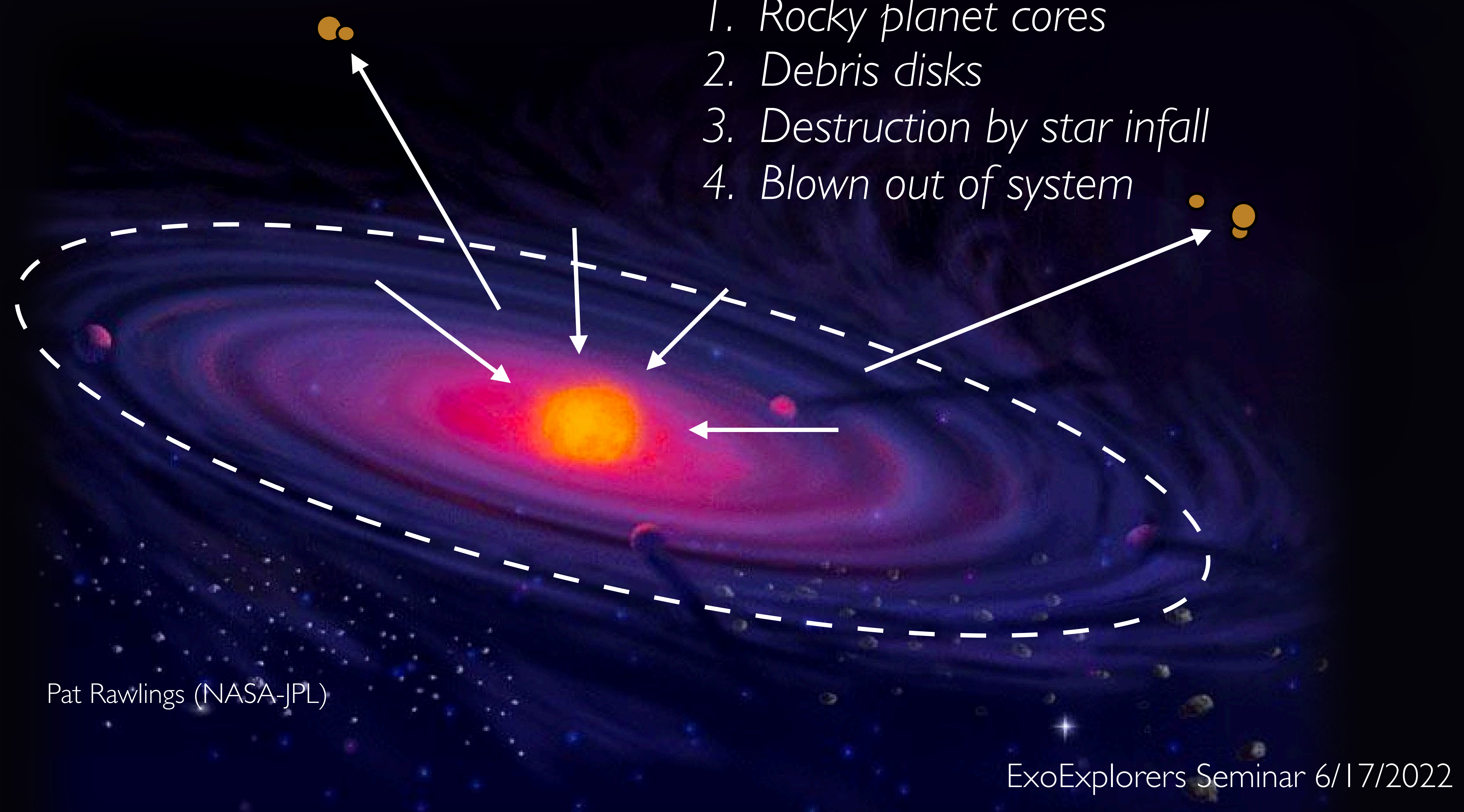
Behmard et al. (*in prep*)

… a lack of dedicated surveys, esp. for planet host systems - no strong observational constraints on engulfment prevalence / role in planetary system evolution

How common is planet engulfment? Why does it matter?

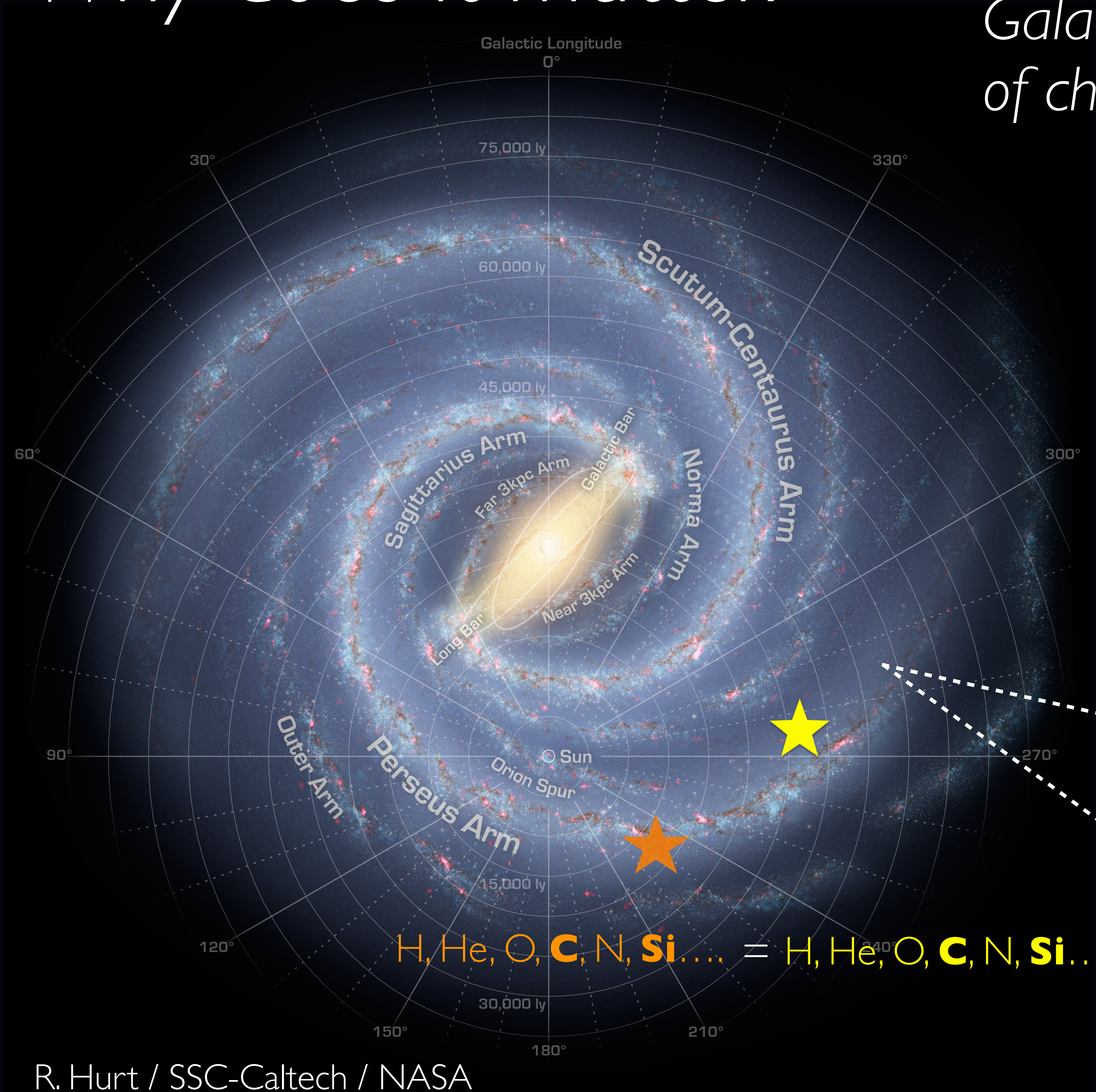
Dust in protoplanetary disks:

1. *Rocky planet cores*
2. *Debris disks*
3. *Destruction by star infall*
4. *Blown out of system*



Pat Rawlings (NASA-JPL)

How common is planet engulfment? Why does it matter?

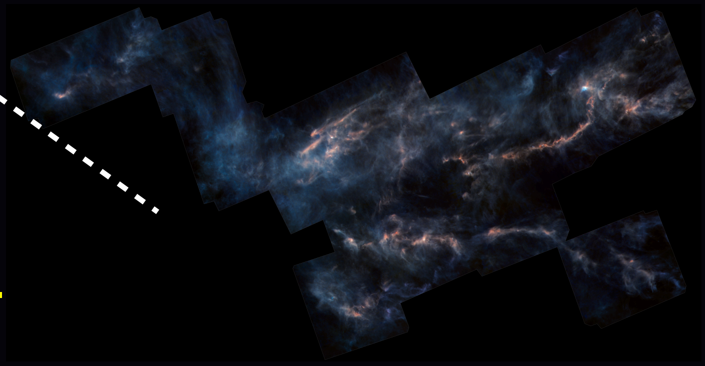


R. Hurt / SSC-Caltech / NASA

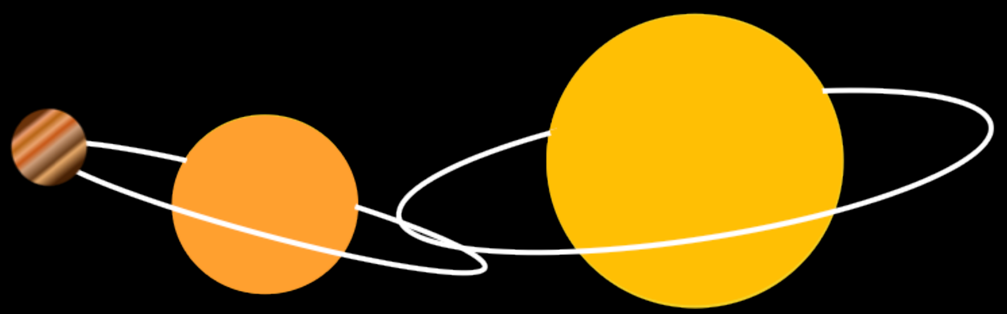
Galactic archaeology / feasibility of chemical tagging!

…only works if we can assume stellar abundances remain unaltered from stellar birth!

Taurus molecular cloud



A dedicated survey of planet engulfment amongst planet-host systems

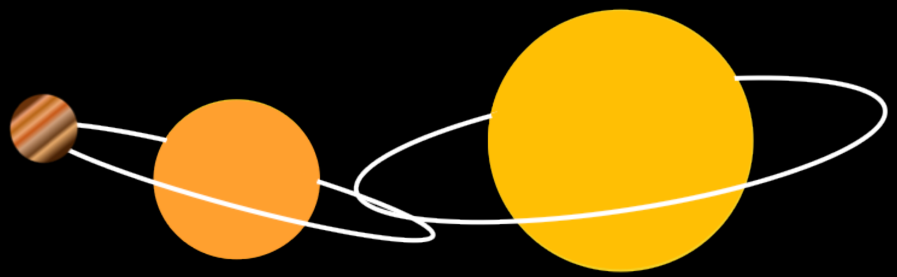


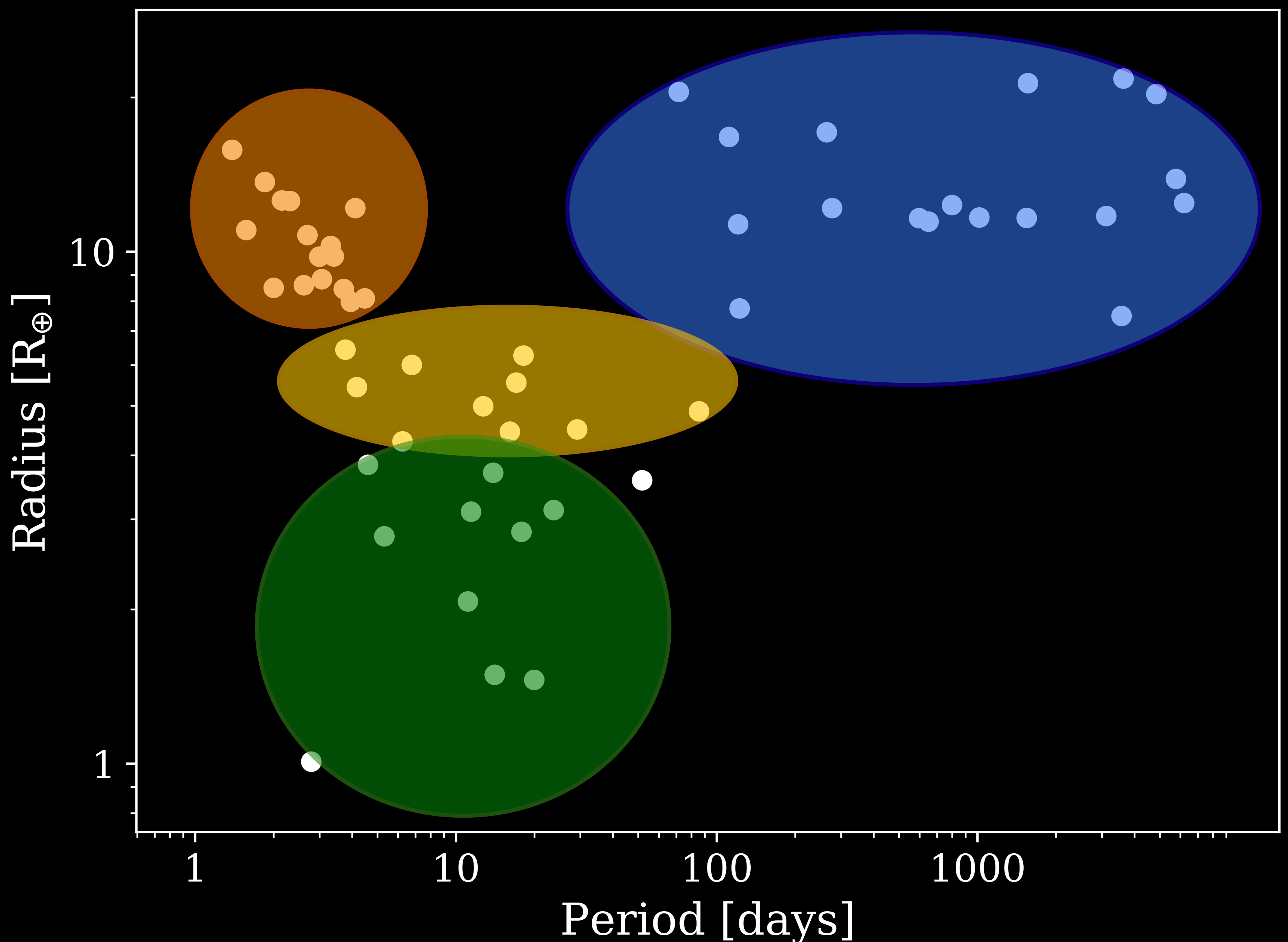
Keck High Resolution Echelle Spectrometer (HIRES):
R ~ 60,000, range of 0.3-1 microns

Mugrauer et al. (2019) - 207 systems + *Exoplanet Archive* (2 additional systems)

<u>After 4700 K < T_{eff} < 6500 K cut:</u>
36 planet host systems that span a wide variety of planet architectures

The sample spans a wide range of planetary architectures





Hot Jupiters

Hot/Warm Saturns

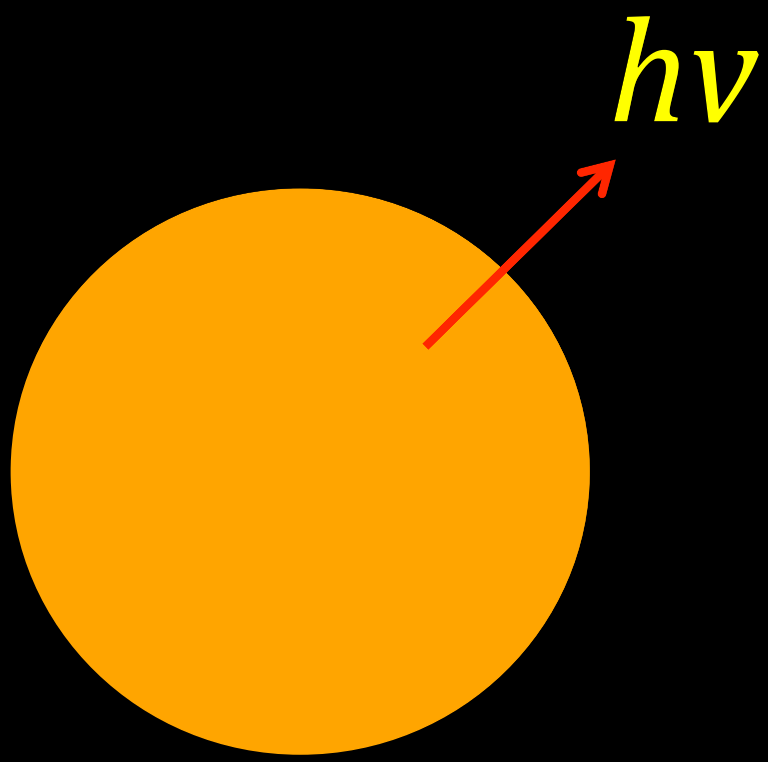
Cold Jupiters

Super-Earths / Sub-Neptunes

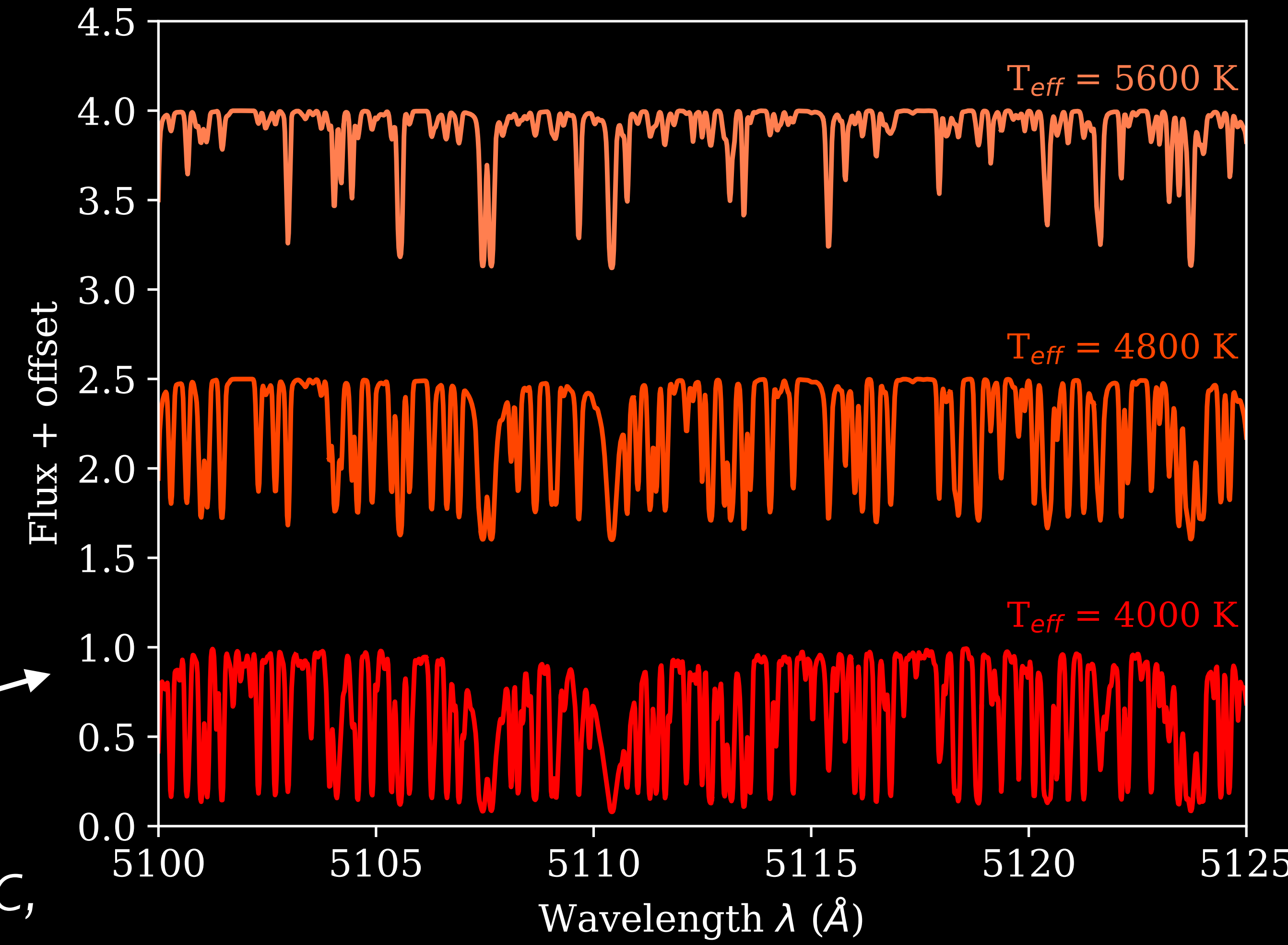
Compact multis

Behmard et al. (*in prep*)

How will we measure stellar abundances?



SpecMatch-Syn (Petigura+2015)



different chemical species (atomic, molecular) will produce different spectral features

Spectroscopy made easy: A new tool for fitting observations with synthetic spectra

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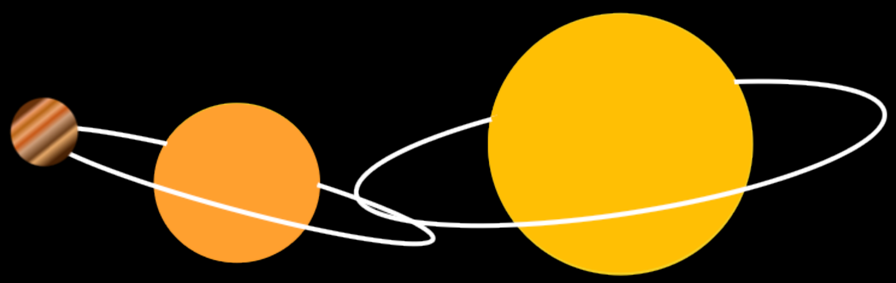
Abstract. — We describe a new software package that may be used to determine stellar and atomic parameters by matching observed spectra with synthetic spectra generated from parameterized atmospheres. A nonlinear least squares algorithm is used to solve for any subset of allowed parameters, which include atomic data (log *gf* and van der Waals damping constants), model atmosphere specifications ($T_{\rm eff}$, log g), elemental abundances, and radial, turbulent, and rotational velocities. LTE synthesis software handles discontiguous spectral intervals and complex atomic blends. As a demonstration, we fit 26 Fe I lines in the NSO Solar Atlas (Kurucz et al. 1984), determining various solar and atomic parameters.

Can fit for:

C, N, O, Na, Mg, Al, Si, Ca, Ti, V, Cr, Mn, Fe, Ni, Y

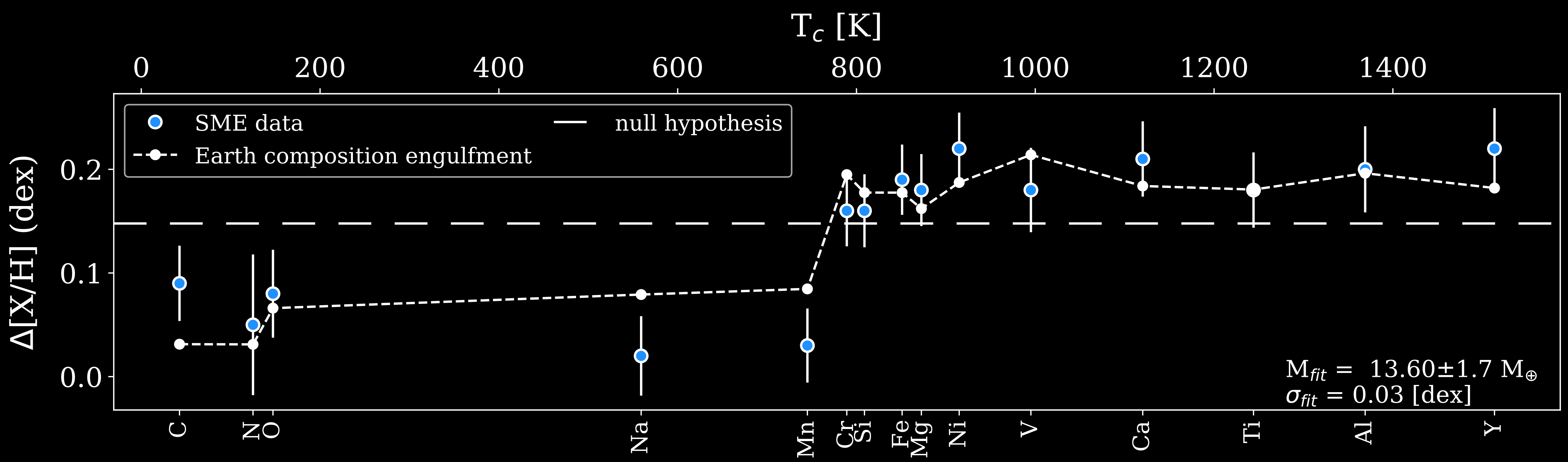
precisions: >0.03 dex

Engulfment model



Estimates mass of bulk Earth composition material engulfed by one star given abundance measurements for a binary pair

Applied to HD 140429-30 (*"Kronos" and "Krios") system*

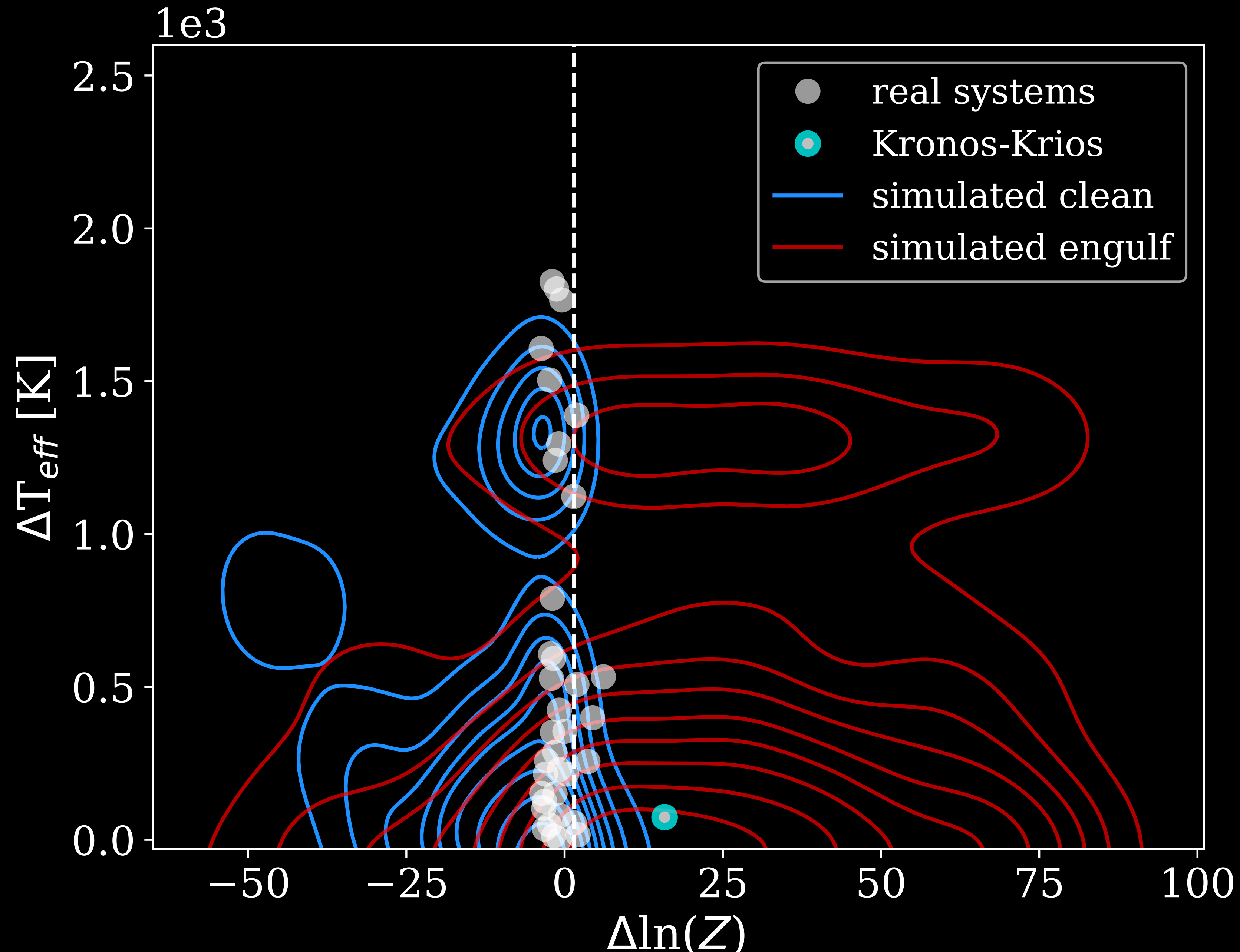


Behmard et al. (*in prep*)

Also outputs Bayesian evidence parameter: $\Delta log(Z) \approx 15.8$

Bayesian evidence criteria

5% FP rate and 95% of simulated engulfment recovered: **Δ***log(Z) ≈ 0.8*



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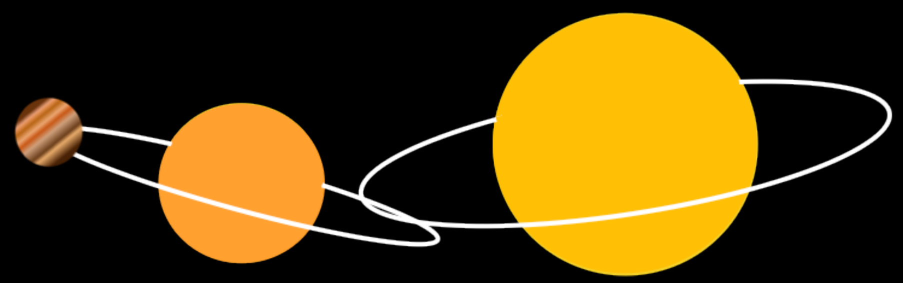
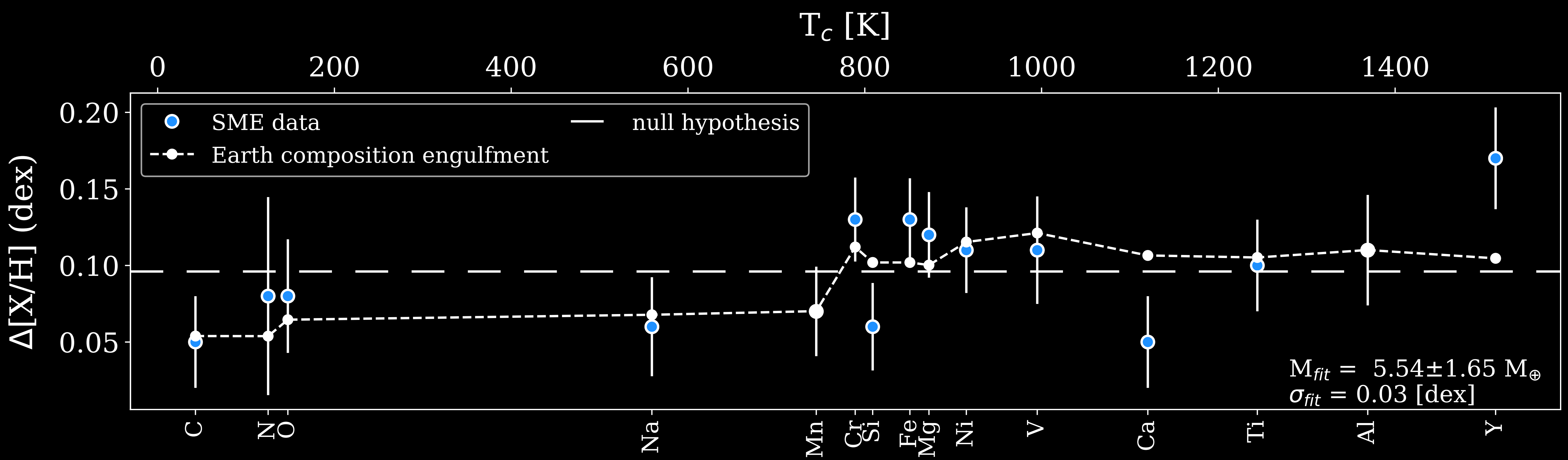
Engulfment criteria



1. *Δlog(Z) of engulfment relative to flat model is >1.5*
2. *Fitted engulfment model shift lies above -0.05 dex*
3. *Passes take-one-out abundance test across all abundances*

Only promising system

***HAT-P-4**: primary known HJ host*

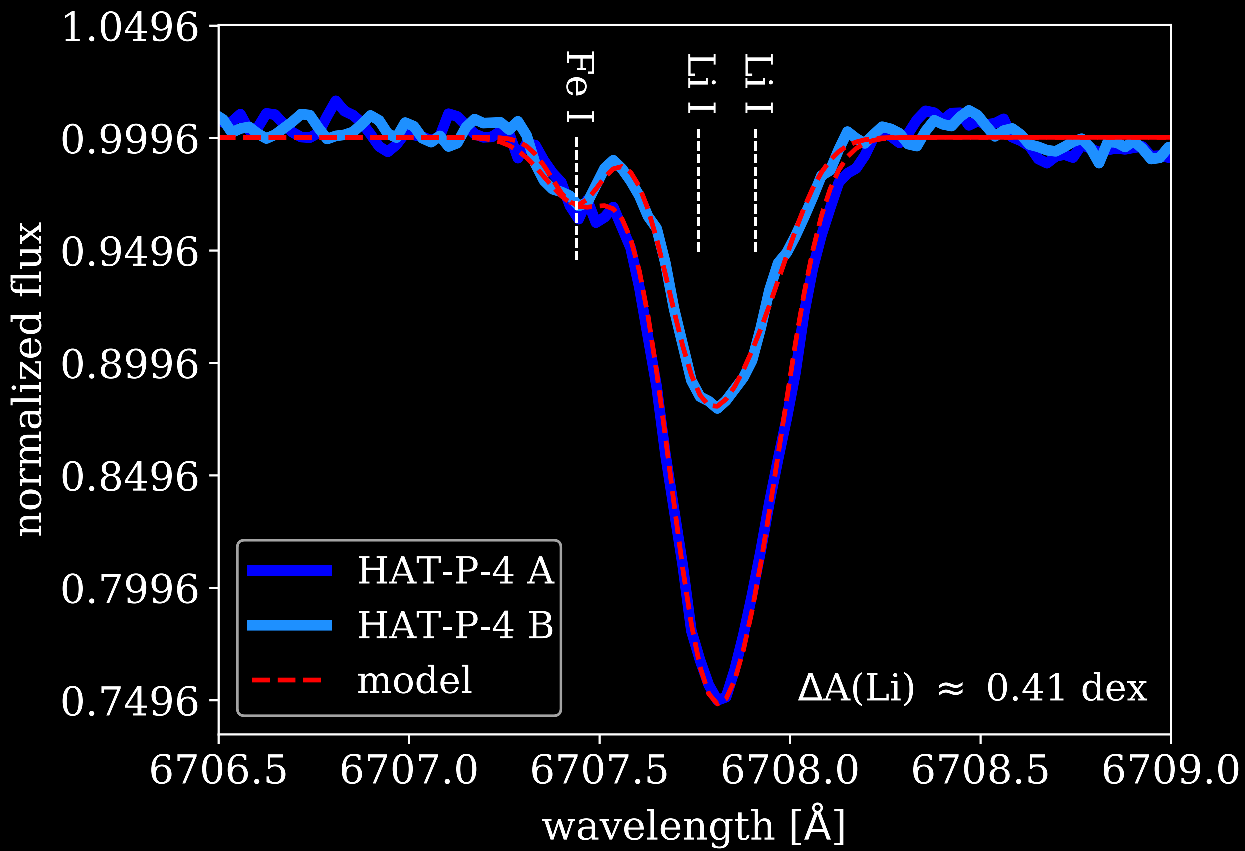


Behmard et al. (*in prep*)

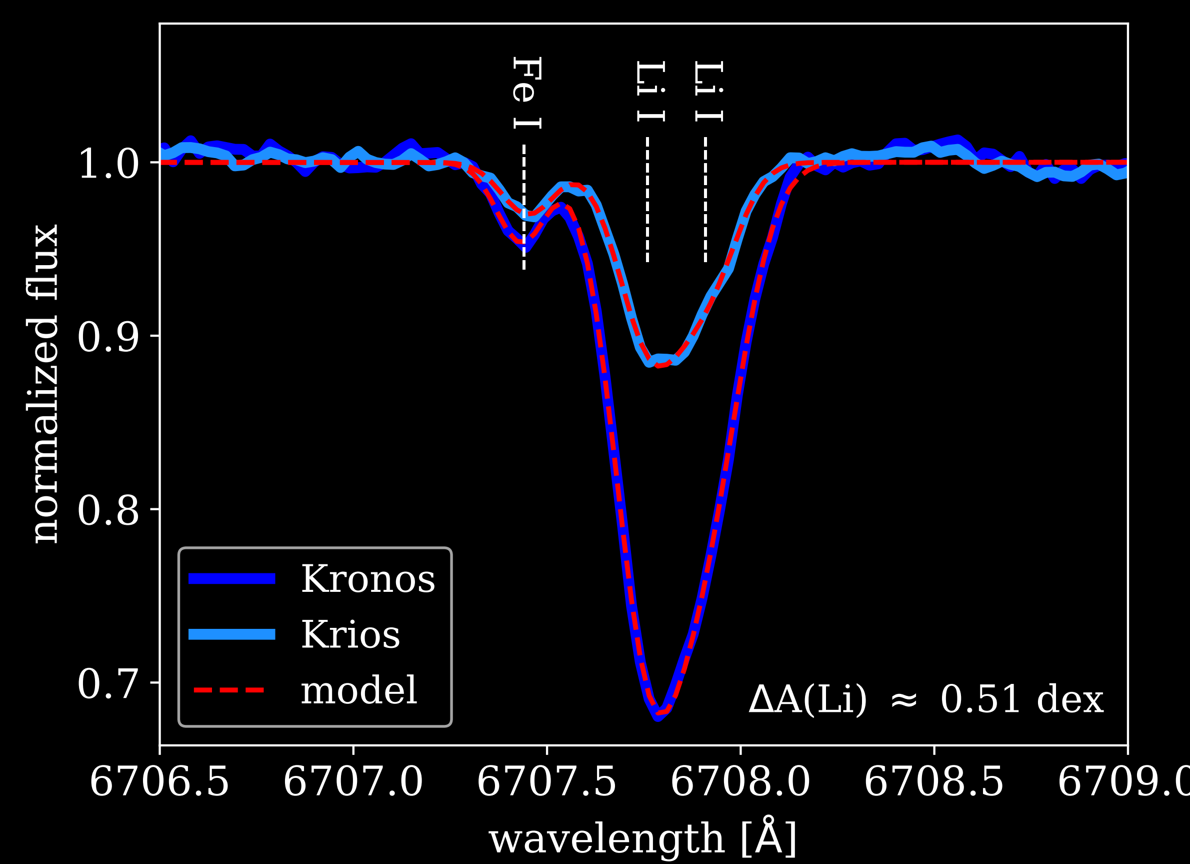
1. *Δlog(Z) ≈ 2.4 (15.8 for Kronos & Krios)*
2. *Stellar twin binary*
3. *Reported as an engulfment system in Saffe et al. (2017) (~10 $M_\oplus$)*

Lithium abundances

HAT-P-4



Kronos-Krios



Behmard et al. (*in prep*)

Li is a short-lived species - further evidence for engulfment

How long will engulfment signatures last?

Matteo Cantiello and Evert Glebbeek (2007)

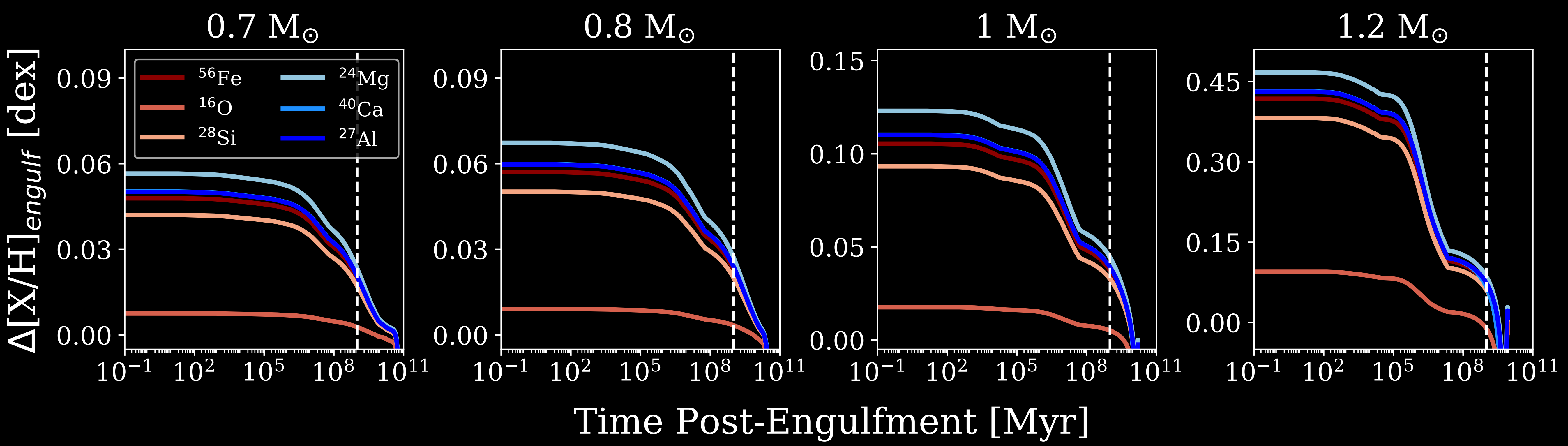
Thermohohaline mixing:

Both mean molecular weight and thermal gradient at play - happens in ocean when saltier water layers lie on top of warmer, less salty layers

Common process in stellar interiors - bleeding of heavier material across the tachocline

Running grid of MESA models (0.5-1.4 $M_{\odot}$):

1. *Evolved stars onto MS*
2. *Accreted bulk Earth composition planetary companions*
3. *Turned on mixing, run models until end of MS lifetime*



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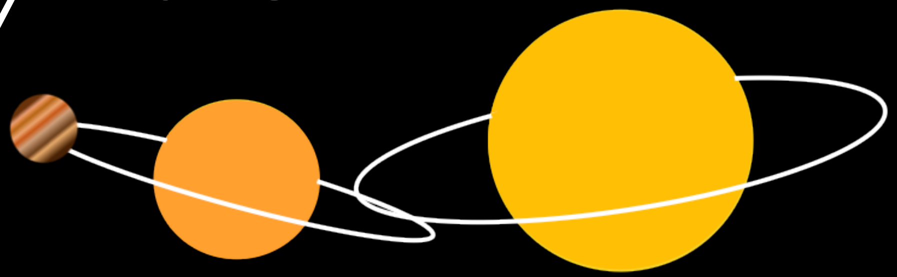
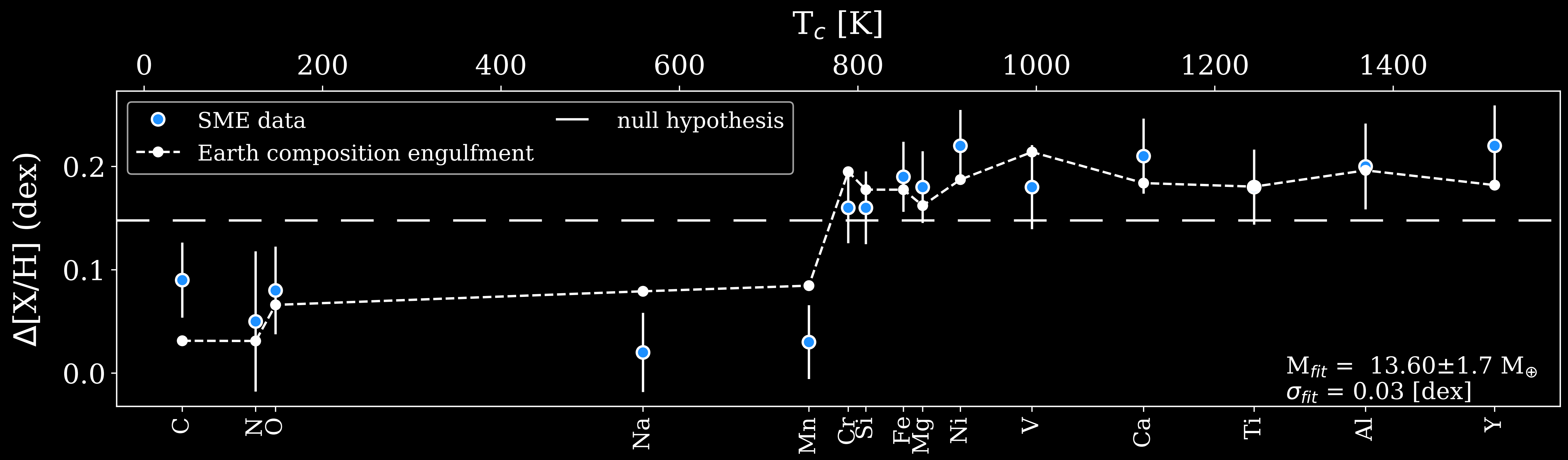
Detectable engulfment signatures (>0.05 dex) will persist for ~1 Gyr in solar-like stars

"Kronos" and "Krios" is ~4 Gyr old!





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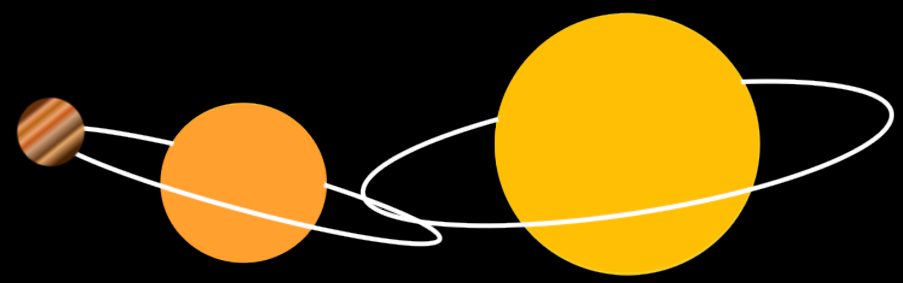
A recent, massive engulfment event?

Summary



1. *HAT-P-4 is the only potential engulfment detection in our sample*
2. *Engulfment signatures may be rare - corroborated by MESA results*

Future directions:

1. *A uniform survey of only stellar twins*
2. *A larger engulfment survey - TESS?*
3. *Survey within young stellar populations?*