

Spectroscopic Follow-up of Young High- α Dwarf Star Candidates: Still Likely Genuinely Young

YUXI(LUCY) LU ^{1,2} CATHERINE MANEA ³ MARYUM SAYEED ³ STEPHANIE T. DOUGLAS ⁴
DOMINICK ROWAN ^{1,2,5} ILYA ILYIN ⁶ ADAM WHEELER ⁷ SVEN BUDER ^{8,9} LOUIS AMARD ¹⁰
MADELEINE MCKENZIE,¹¹ MARC H. PINSONNEAULT ^{1,2} JENNIFER A. JOHNSON,^{1,2} AND OTHERS

¹ *Department of Astronomy, The Ohio State University, Columbus, 140 W 18th Ave, OH 43210, USA*

² *Center for Cosmology and Astroparticle Physics (CCAPP), The Ohio State University, 191 W. Woodruff Ave., Columbus, OH 43210, USA*

³ *Department of Astronomy, Columbia University, 550 West 120th Street, New York, NY, USA*

⁴ *Lafayette College, 730 High St, Easton, PA 18042, USA*

⁵ *Department of Astronomy, University of California Berkeley, Berkeley, CA 94720, USA*

⁶ *Leibniz-Institute for Astrophysics Potsdam (AIP), An der Sternwarte 16, D-14482, Potsdam, Germany*

⁷ *Center for Computational Astrophysics, Flatiron Institute, 162 5th Avenue, New York, NY 10010, USA*

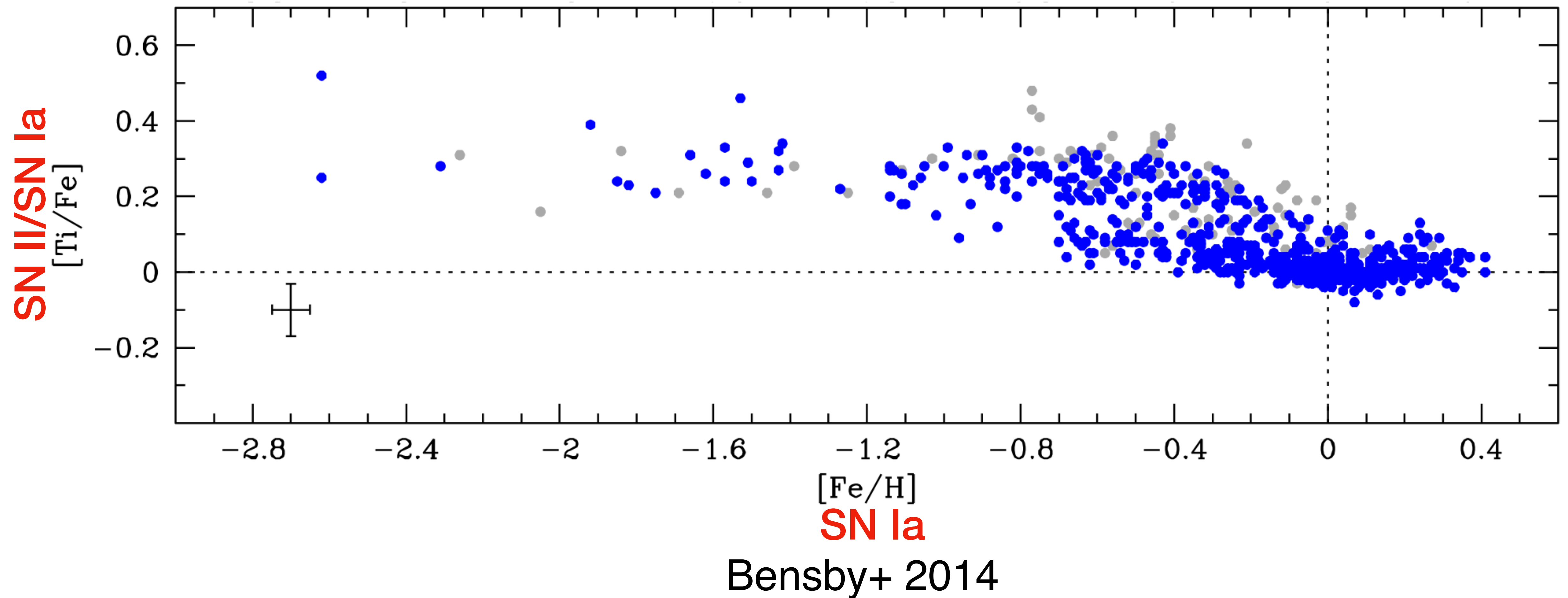
⁸ *Research School of Astronomy & Astrophysics, Australian National University, Canberra ACT 2611, Australia*

⁹ *Center of Excellence for Astrophysics in Three Dimensions (ASTRO-3D), Australia*

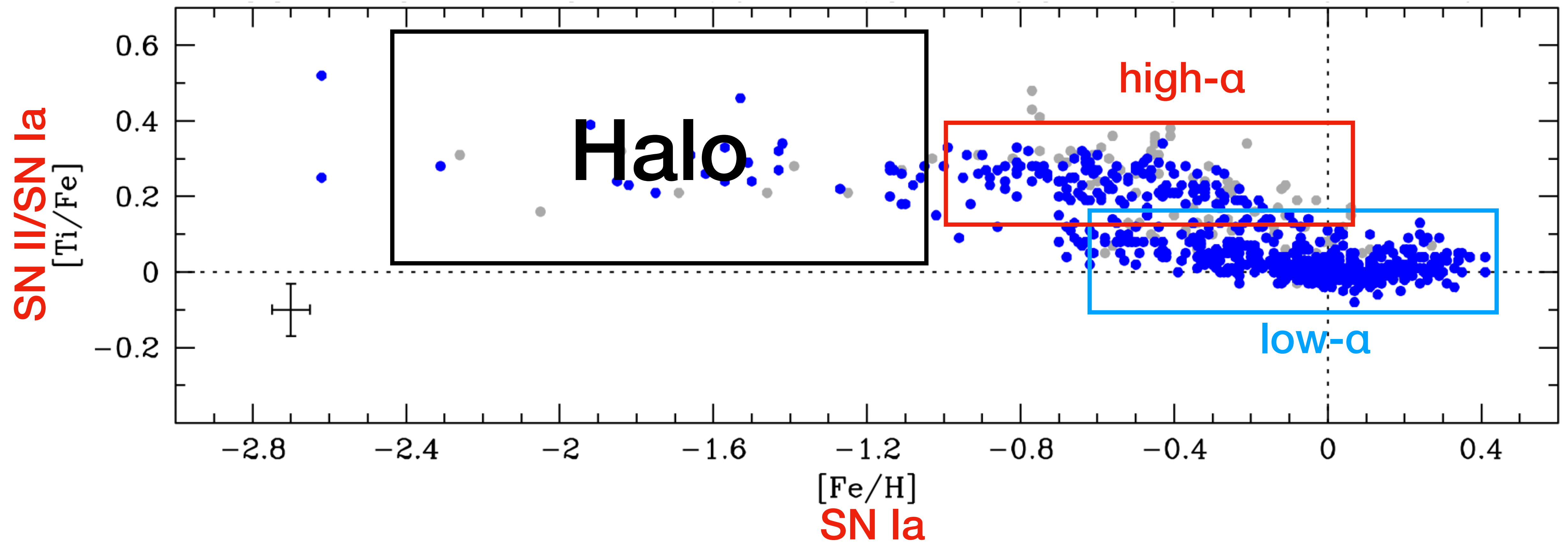
¹⁰ *Departemnt of Astronomy, University of Geneva, Chemin Pegasi 51, CH-1290 Versoix, Switzerland*

¹¹ *Carnegie Observatories, 813 Santa Barbara St, Pasadena, CA, 91101, USA*

Introduction: The bi-modality of the Milky Way disk

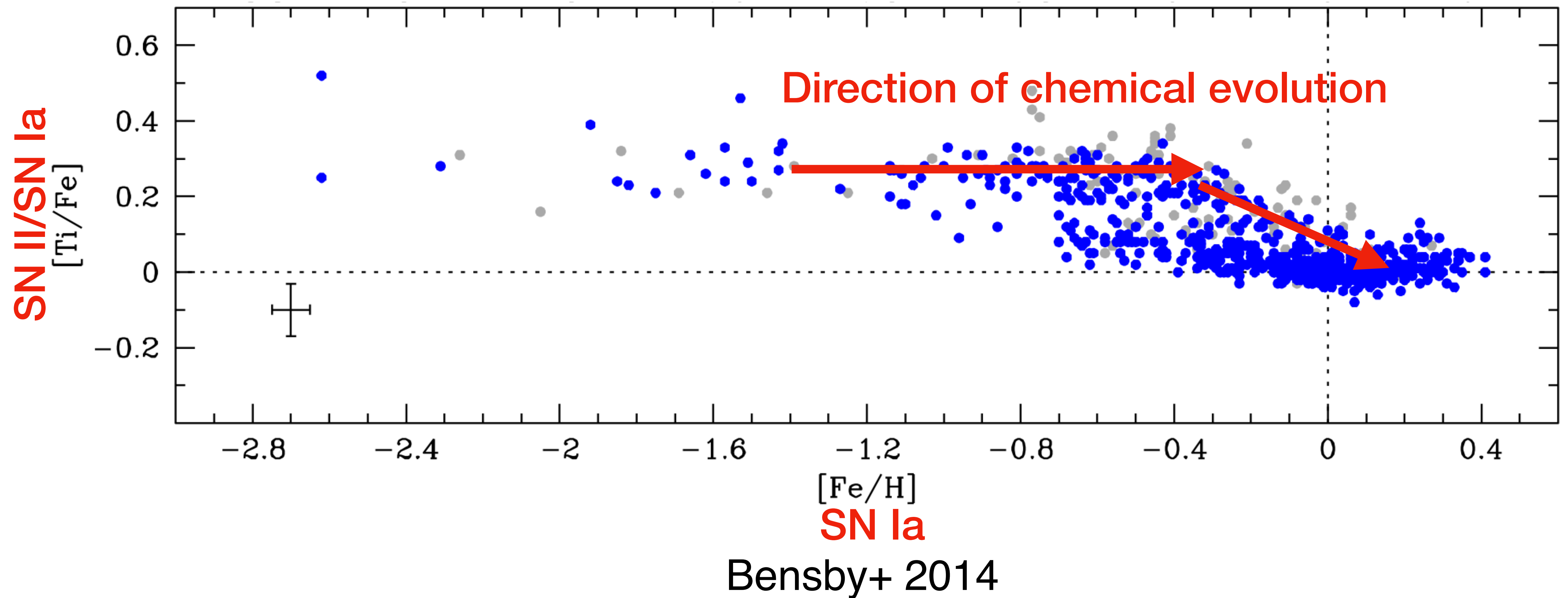


Introduction: The bi-modality of the Milky Way disk

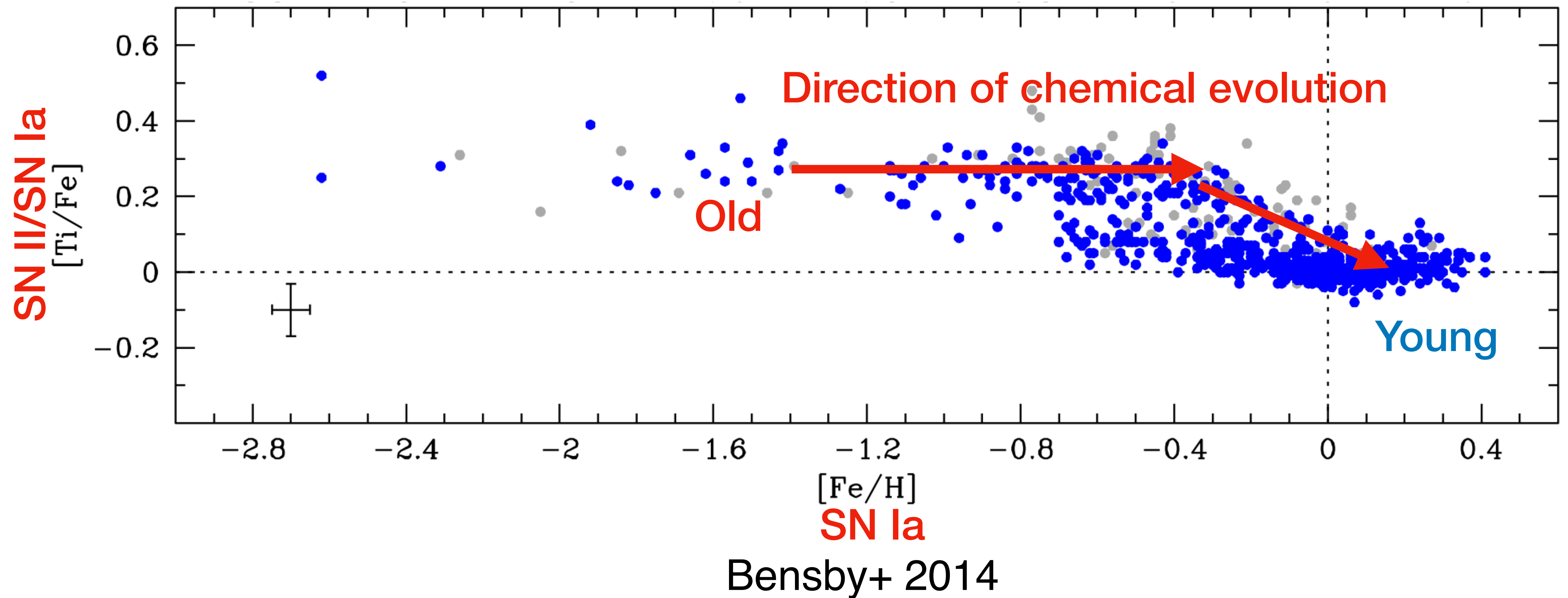


Bensby+ 2014

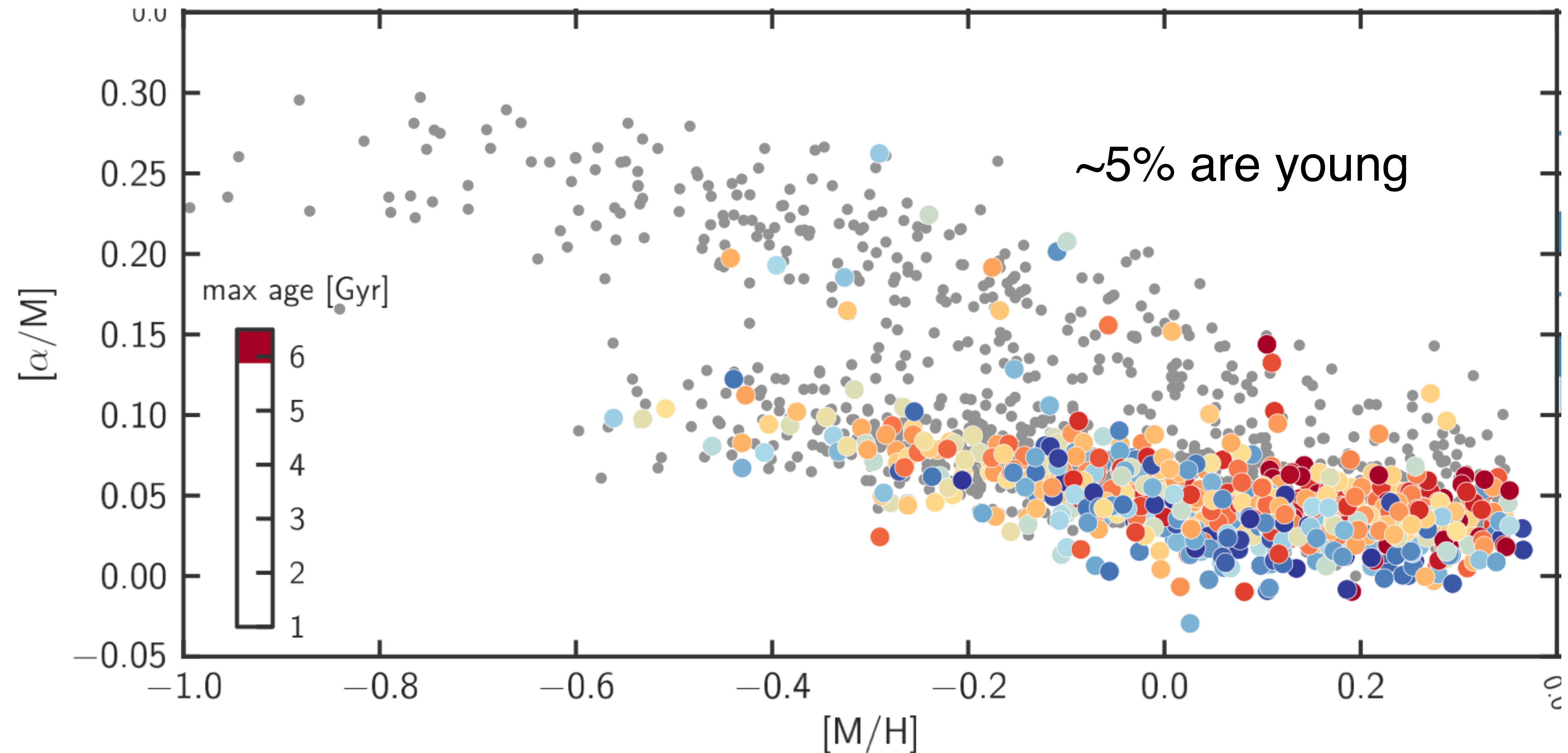
Introduction: The bi-modality of the Milky Way disk



Introduction: The bi-modality of the Milky Way disk

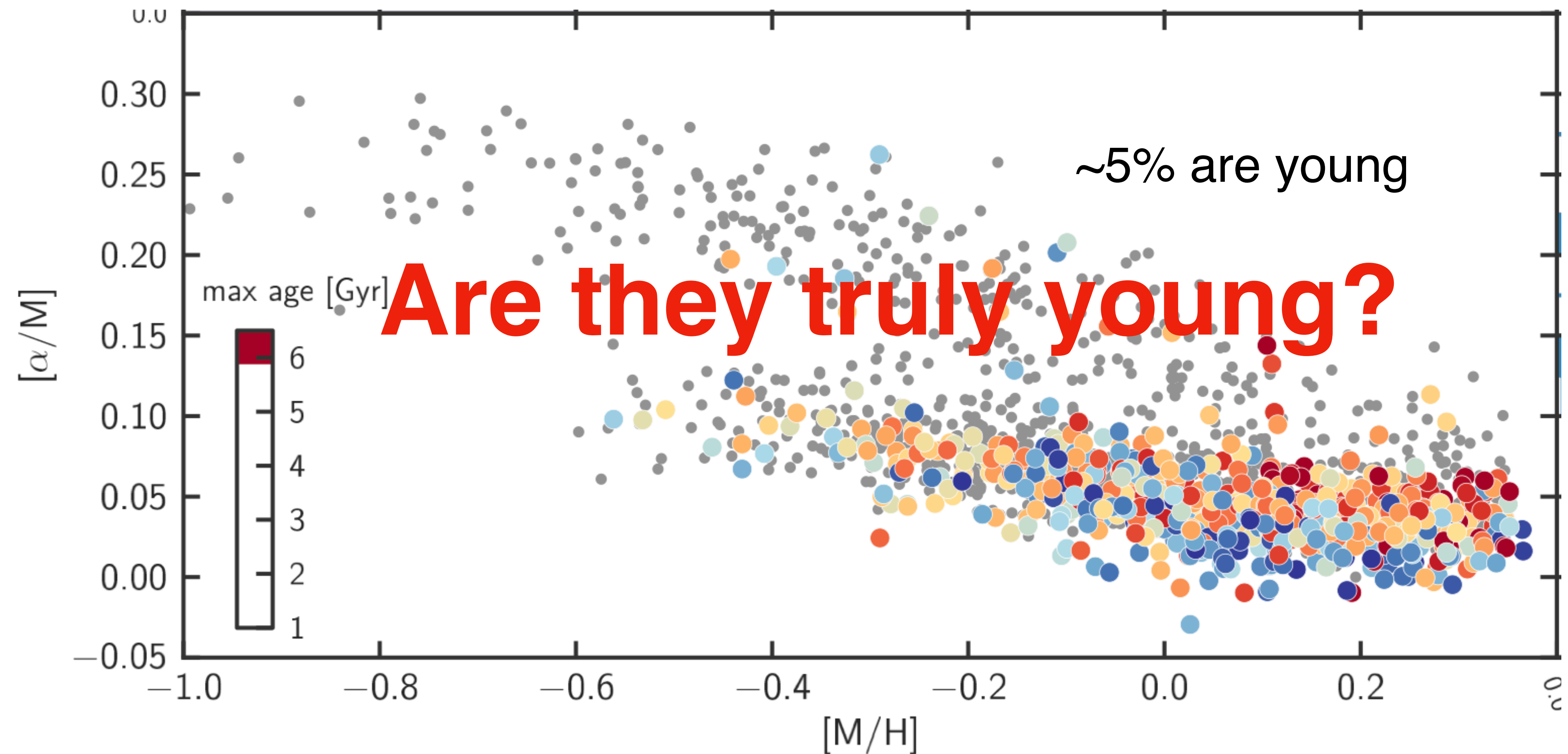


Introduction: The bi-modality of the Milky Way disk



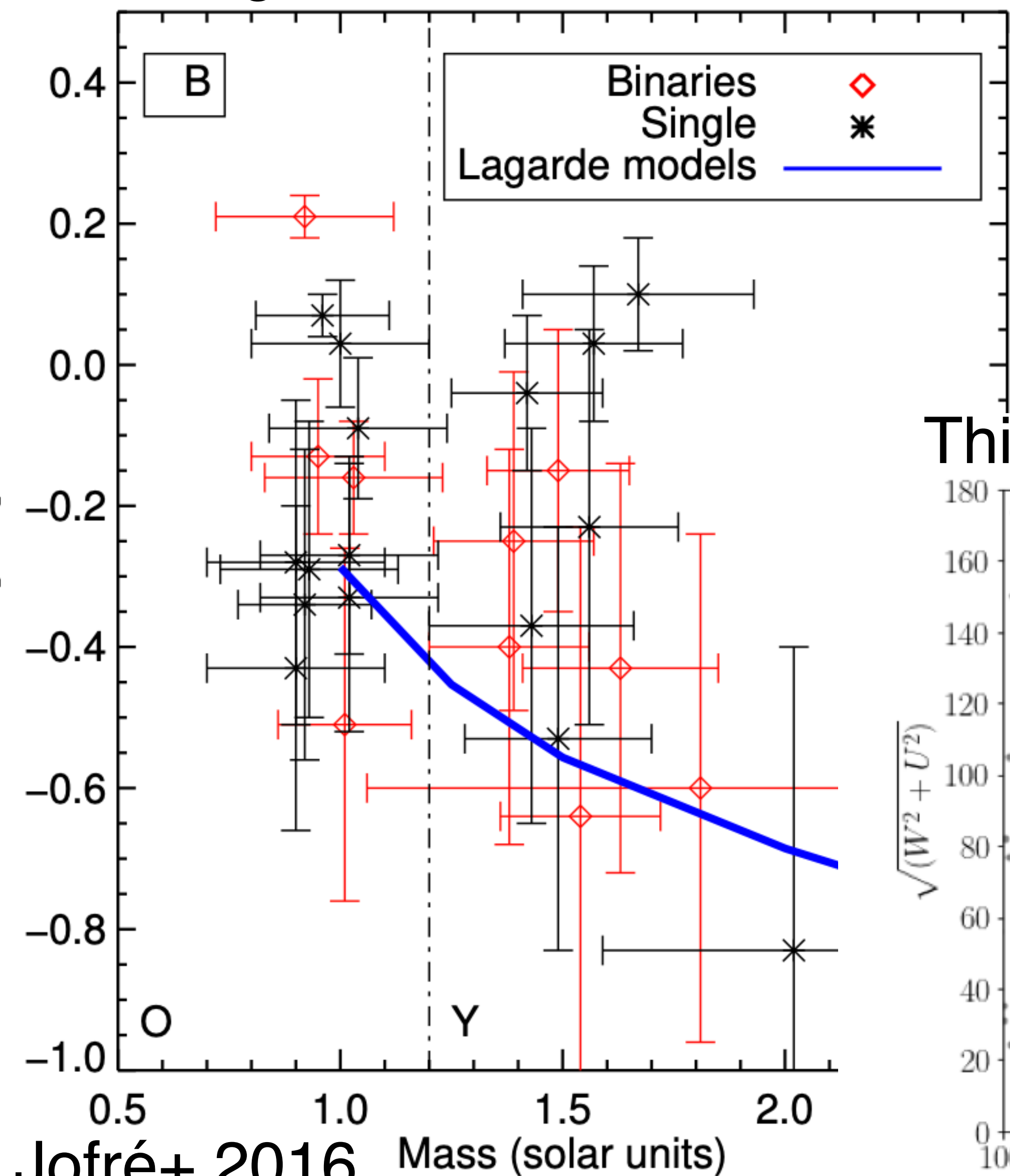
Martig+ 2015, Using APOKASCe ages from Pinsonneault+ 2014

Introduction: The bi-modality of the Milky Way disk



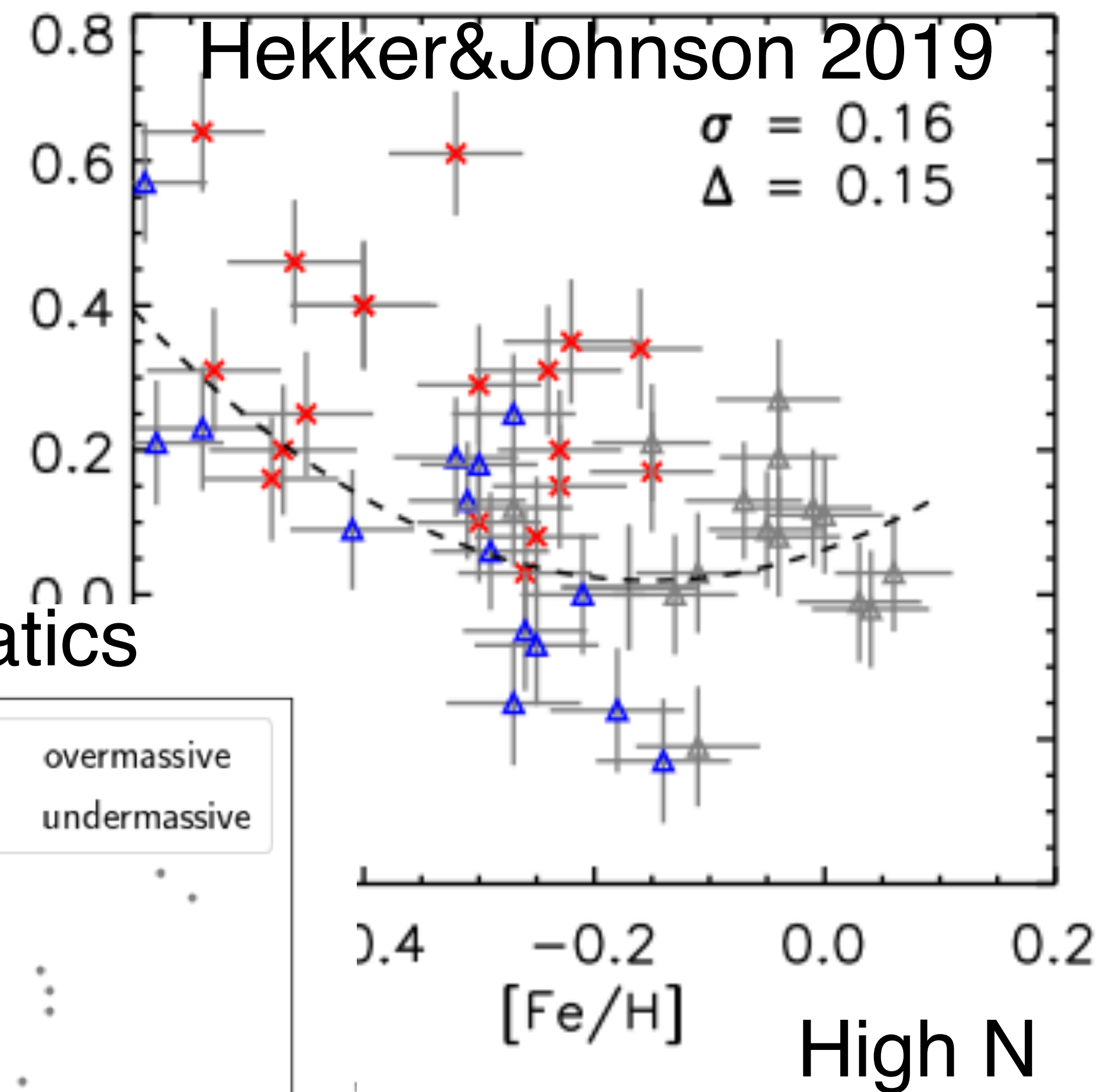
Martig+ 2015, Using APOKASCe ages from Pinsonneault+ 2014

High fraction of binaries



Jofré+ 2016

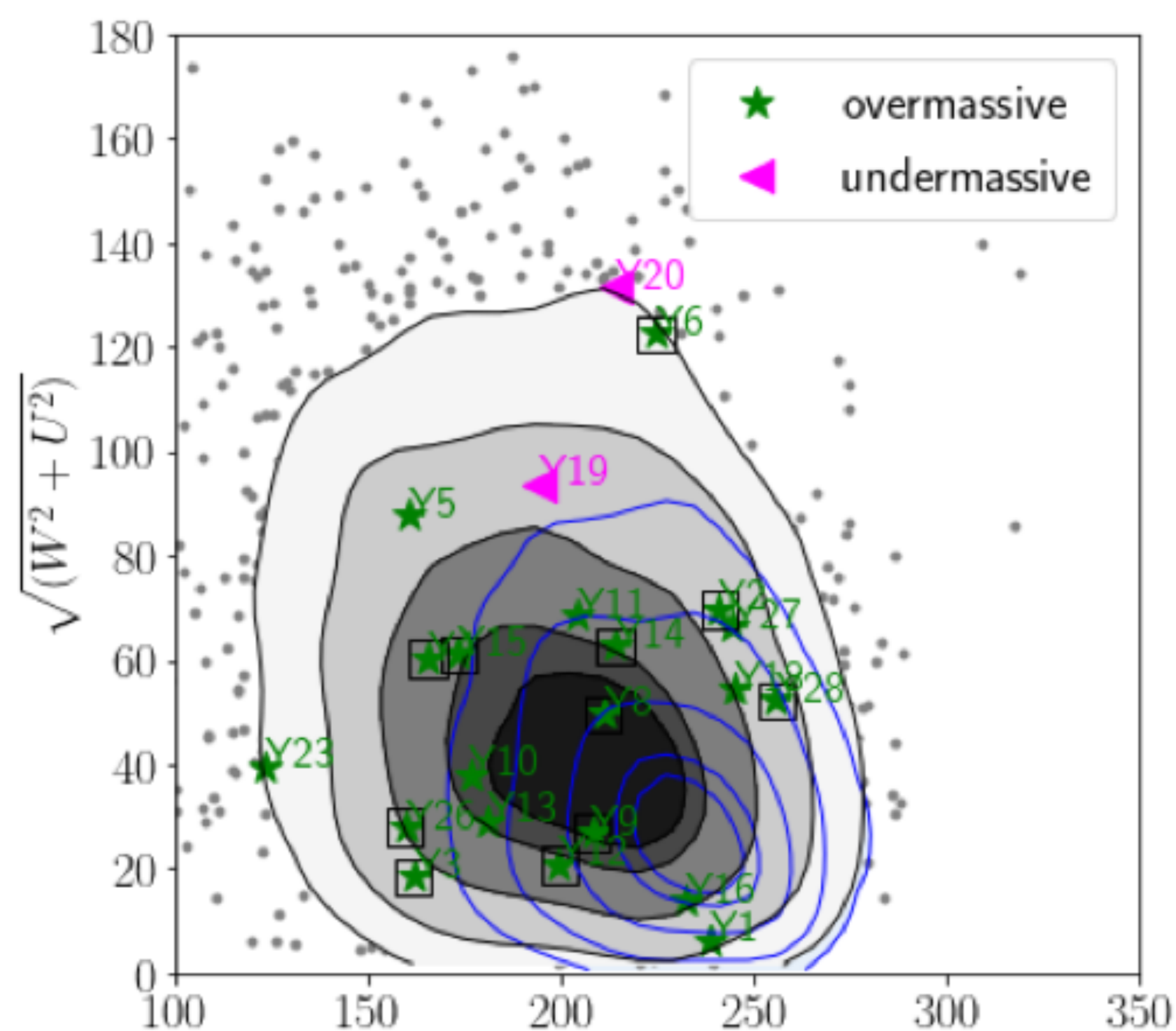
Lucy Lu: lu.3234@osu.edu



Hekker&Johnson 2019

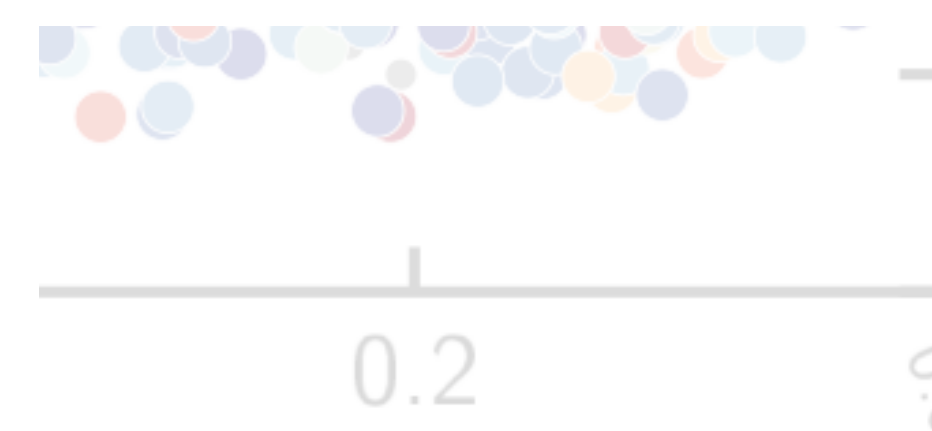
$\sigma = 0.16$
 $\Delta = 0.15$

Thick-disk kinematics

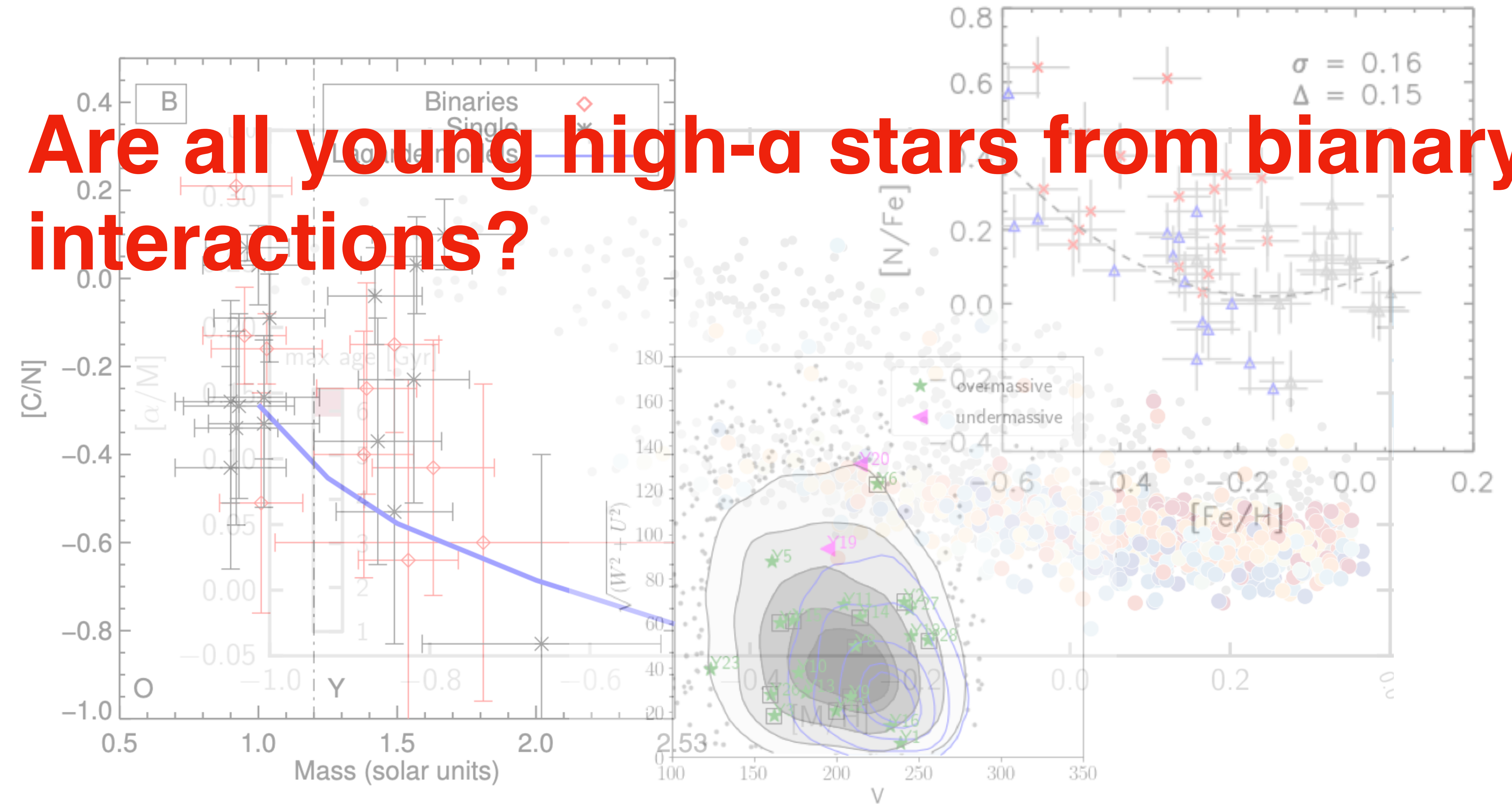


Jofré+ 2023

High N

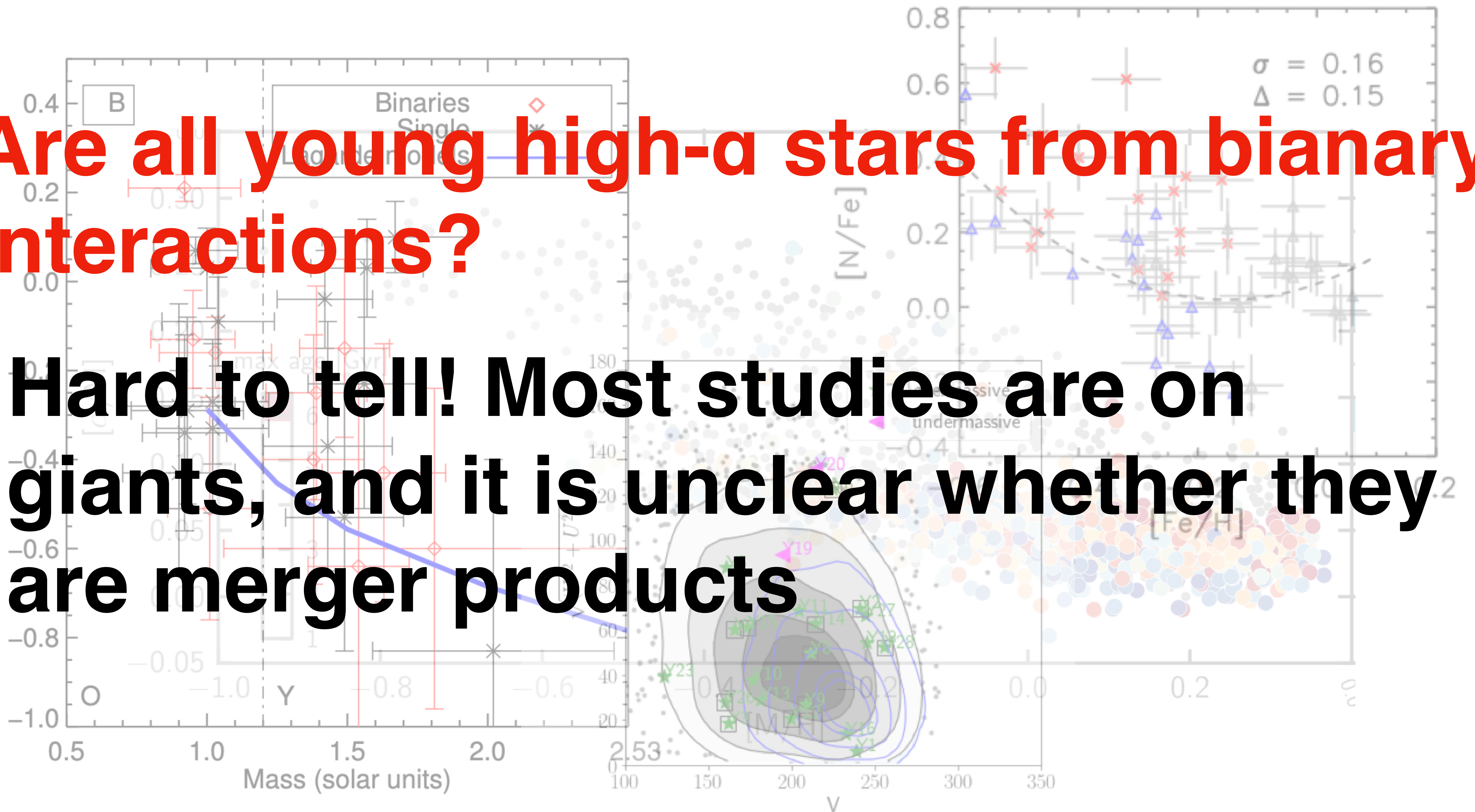


Are all young high- α stars from binary interactions?



Are all young high- α stars from binary interactions?

Hard to tell! Most studies are on giants, and it is unclear whether they are merger products



Introduction: Finding young high- α stars in dwarfs

Indication of youth: Rotation (e.g., Skumanich 1978,
Barnes 2002)

Introduction: Finding young high- α stars in dwarfs

Indication of youth: Rotation (e.g., Skumanich 1978, Barnes 2002)

- **Caveat:** Can be spun-up by binary interactions
 1. **Close-by companion**
 2. **Stellar mergers**
 3. **Planet engulfments**

Introduction: Finding young high- α stars in dwarfs

Indication of youth: Rotation (e.g., Skumanich 1978, Barnes 2002)

- **Caveat:** Can be spun-up by binary interactions
 1. **Close-by companion** — Exclude binaries with RVs
 2. **Stellar mergers** — Lithium (e.g., Ryan+ 2001; Pinsonneault+ 2002; Ryan+ 2002)
 3. **Planet engulfments** — Refractory elements (e.g., Ramirez+ 2009, Teske+ 2016, Melendez+ 2017, Spina+ 2021)

Introduction: Finding young high- α stars in dwarfs

Indication of youth: Rotation (e.g., Skumanich 1978, Barnes 2002)

- **Caveat:** Can be spun-up by binary interactions
 1. **Close-by companion** — Exclude binaries with RVs (**APOGEE**)
 2. **Stellar mergers** — Lithium (**GALAH**)
 3. **Planet engulfments** — Refractory elements (e.g., Ramirez+ 2009, Teske+ 2016, Melendez+ 2017, Spina+ 2021)

Result: PEPSI Spectra Followup



Selected stars:

- High- α stars in APOGEE or GALAH
- With rotation signal from K2 or Kepler

Result: PEPSI Spectra Followup



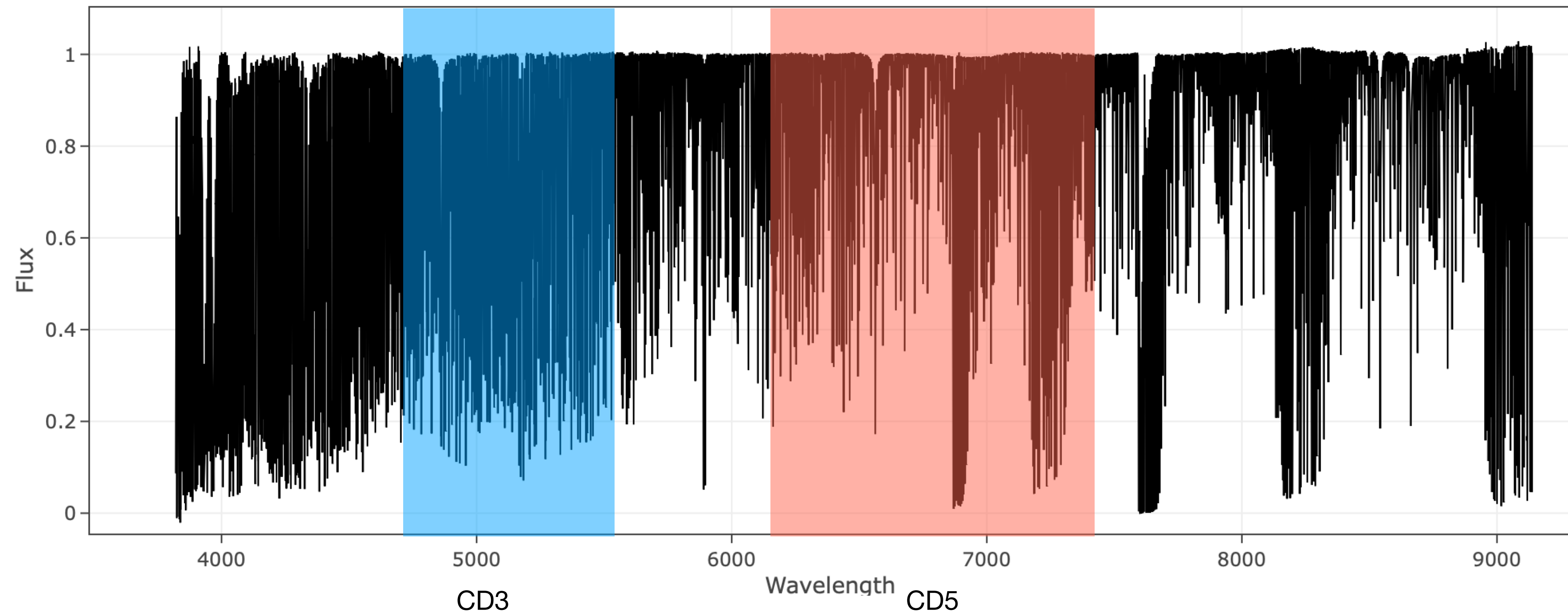
Selected stars:

- High- α stars in APOGEE or GALAH
- With rotation signal from K2 or Kepler
- Bright: V mag < 14 mag
- Visible in 2024 Fall
- Seeing < 1.8 arc

Result: PEPSI Spectra Followup



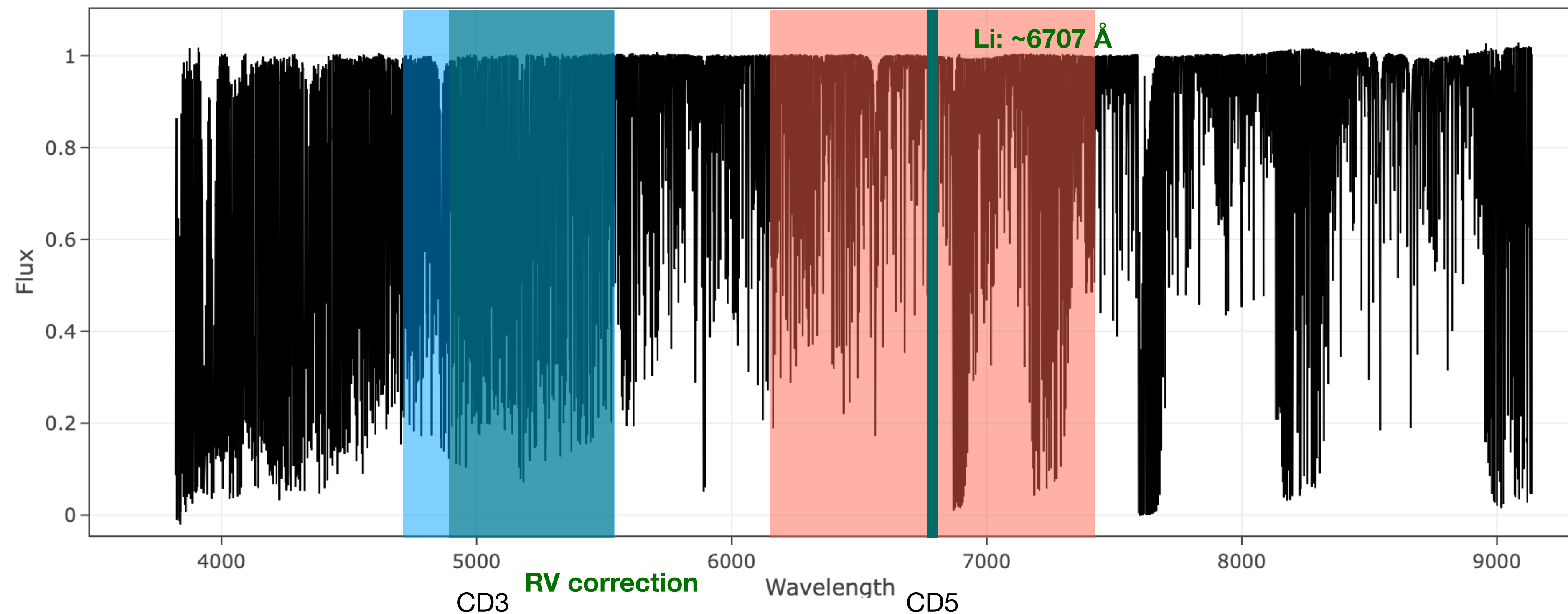
Deep Sun Spectra: Nov 17, 2016



Result: PEPSI Spectra Followup



Deep Sun Spectra: Nov 17, 2016



Result: PEPsi Spectra Followup

Sample	2MASS ID	Gaia DR3 ID	V mag	N Obs.	Comb. SNR	Obs. Date	Exp. Time [s]
A-K2	03413908+2359163	68164639977312384	13.9	2	103	Oct. 25, 2024	1440
...	...	...	...	...	...	Nov. 1, 2024	1440
G-K2	03435417+1719250	44497171153467008	11	7	132	Sep. 20, 2024	240
...	...	...	...	...	...	Oct. 8, 2024	160
...	...	...	...	...	...	Oct. 8, 2024	160
...	...	...	...	...	...	Oct. 23, 2024	120
...	...	...	...	...	...	Oct. 31, 2024	120
...	...	...	...	...	...	Oct. 31, 2024	120
...	...	...	...	...	...	Nov. 1, 2024	240
G-K2	01084954-0030464	2533196969884293888	13.6	3	82	Oct. 21, 2024	1200
...	...	...	...	...	...	Oct. 31, 2024	1200
...	...	...	...	...	...	Nov. 24, 2024	600
A-K	18432994+4356589	2117326900207932288	14.2	1	47	Sep. 20, 2024	1800
G-K2	01064189-0027182	2533233700444556800	13.8	5	111	Sep. 22, 2024	1320
...	...	...	...	...	...	Oct. 10, 2024	1780
...	...	...	...	...	...	Oct. 10, 2024	1780
...	...	...	...	...	...	Oct. 23, 2024	1320
...	...	...	...	...	...	Oct. 31, 2024	1320
G-K2	08280198+1913343	662897729347117312	13.0	4	85	Oct. 8, 2024	800
...	...	...	...	...	...	Oct. 8, 2024	800
...	...	...	...	...	...	Oct. 25, 2024	600
...	...	...	...	...	...	Nov. 1, 2024	600
A-K2	01231989+0031088	2534334689540935040	13.5	1	71	Oct. 25, 2024	1200
A-K2	01244193+0124528	2559177811173201920	12.9	5	92	Oct. 8, 2024	780
...	...	...	...	...	...	Oct. 8, 2024	780
...	...	...	...	...	...	Oct. 21, 2024	600
...	...	...	...	...	...	Oct. 31, 2024	600
...	...	...	...	...	...	Oct. 31, 2024	600
A-K2	04314519+2502357	150907970912262016	13.7	1	117	Sep. 20, 2024	1320
A-K2	08443258+1116500	601835320304886400	13.7	1	50	Nov. 24, 2024	1020
A-K	19101724+4944353	2132794829787857792	10.3	1	35	Sep. 19, 2024	30
A-K	19380704+4708008	2128545109969957888	12.3	1	27	Oct. 25, 2024	1200
A-K	19580796+4052023	2075066724134857344	14.3	1	35	Sep. 20, 2024	2100

Observed stars:

- 9 APOGEE stars for Li measurements
- 4 GALAH stars for multiple RV measurements

Result: PEPsi Spectra Followup

Sample	2MASS ID	Gaia DR3 ID	V mag	N Obs.	Comb. SNR	Obs. Date	Exp. Time [s]
A-K2	03413908+2359163	68164639977312384	13.9	2	103	Oct. 25, 2024	1440
...	...	...	...	...	...	Nov. 1, 2024	1440
G-K2	03435417+1719250	44497171153467008	11	7	132	Sep. 20, 2024	240
...	...	...	...	...	...	Oct. 8, 2024	160
...	...	...	...	...	...	Oct. 8, 2024	160
...	...	...	...	...	...	Oct. 23, 2024	120
...	...	...	...	...	...	Oct. 31, 2024	120
...	...	...	...	...	...	Oct. 31, 2024	120
...	...	...	...	...	...	Nov. 1, 2024	240
G-K2	01084954-0030464	2533196969884293888	13.6	3	82	Oct. 21, 2024	1200
...	...	...	...	...	...	Oct. 31, 2024	1200
...	...	...	...	...	...	Nov. 24, 2024	600
A-K	18432994+4356589	2117326900207932288	14.2	1	47	Sep. 20, 2024	1800
G-K2	01064189-0027182	2533233700444556800	13.8	5	111	Sep. 22, 2024	1320
...	...	...	...	...	...	Oct. 10, 2024	1780
...	...	...	...	...	...	Oct. 10, 2024	1780
...	...	...	...	...	...	Oct. 23, 2024	1320
...	...	...	...	...	...	Oct. 31, 2024	1320
G-K2	08280198+1913343	662897729347117312	13.0	4	85	Oct. 8, 2024	800
...	...	...	...	...	...	Oct. 8, 2024	800
...	...	...	...	...	...	Oct. 25, 2024	600
...	...	...	...	...	...	Nov. 1, 2024	600
A-K2	01231989+0031088	2534334689540935040	13.5	1	71	Oct. 25, 2024	1200
A-K2	01244193+0124528	2559177811173201920	12.9	5	92	Oct. 8, 2024	780
...	...	...	...	...	...	Oct. 8, 2024	780
...	...	...	...	...	...	Oct. 21, 2024	600
...	...	...	...	...	...	Oct. 31, 2024	600
...	...	...	...	...	...	Oct. 31, 2024	600
A-K2	04314519+2502357	150907970912262016	13.7	1	117	Sep. 20, 2024	1320
A-K2	08443258+1116500	601835320304886400	13.7	1	50	Nov. 24, 2024	1020
A-K	19101724+4944353	2132794829787857792	10.3	1	35	Sep. 19, 2024	30
A-K	19380704+4708008	2128545109969957888	12.3	1	27	Oct. 25, 2024	1200
A-K	19580796+4052023	2075066724134857344	14.3	1	35	Sep. 20, 2024	2100

Observed stars:

- 9 APOGEE stars for Li measurements
- 4 GALAH stars for multiple RV measurements

Found 3 stars with:

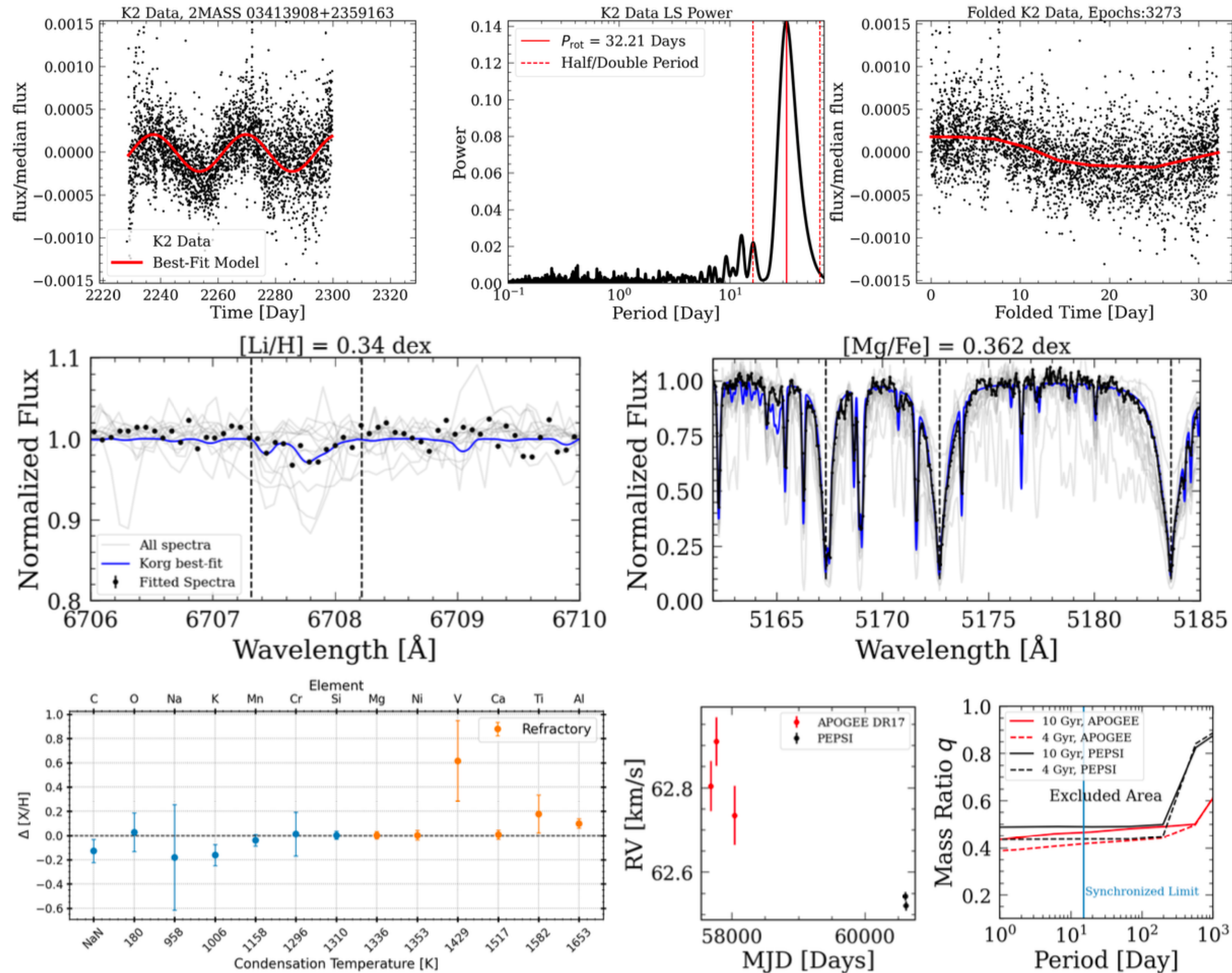
- Confirmed high [Mg/Fe] ([α /Fe])
- Multiple RV suggesting against stellar binary
- Significant Li measurements
- No signature of planet engulfments

Result: PEPsi Spectra Followup

Sample	2MASS ID	Gaia DR3 ID	V mag	N Obs.	Comb. SNR	Obs. Date	Exp. Time [s]
A-K2	03413908+2359163	68164639977312384	13.9	2	103	Oct. 25, 2024	1440
...	...	...	...	...	...	Nov. 1, 2024	1440
G-K2	03435417+1719250	44497171153467008	11	7	132	Sep. 20, 2024	240
...	...	...	...	...	...	Oct. 8, 2024	160
...	...	...	...	...	...	Oct. 8, 2024	160
...	...	...	...	...	...	Oct. 23, 2024	120
...	...	...	...	...	...	Oct. 31, 2024	120
...	...	...	...	...	...	Oct. 31, 2024	120
...	...	...	...	...	...	Nov. 1, 2024	240
G-K2	01084954-0030464	2533196969884293888	13.6	3	82	Oct. 21, 2024	1200
...	...	...	...	...	...	Oct. 31, 2024	1200
...	...	...	...	...	...	Nov. 24, 2024	600
A-K	18432994+4356589	2117326900207932288	14.2	1	47	Sep. 20, 2024	1800
G-K2	01064189-0027182	2533233700444556800	13.8	5	111	Sep. 22, 2024	1320
...	...	...	...	...	...	Oct. 10, 2024	1780
...	...	...	...	...	...	Oct. 10, 2024	1780
...	...	...	...	...	...	Oct. 23, 2024	1320
...	...	...	...	...	...	Oct. 31, 2024	1320
G-K2	08280198+1913343	662897729347117312	13.0	4	85	Oct. 8, 2024	800
...	...	...	...	...	...	Oct. 8, 2024	800
...	...	...	...	...	...	Oct. 25, 2024	600
...	...	...	...	...	...	Nov. 1, 2024	600
A-K2	01231989+0031088	2534334689540935040	13.5	1	71	Oct. 25, 2024	1200
A-K2	01244193+0124528	2559177811173201920	12.9	5	92	Oct. 8, 2024	780
...	...	...	...	...	...	Oct. 8, 2024	780
...	...	...	...	...	...	Oct. 21, 2024	600
...	...	...	...	...	...	Oct. 31, 2024	600
...	...	...	...	...	...	Oct. 31, 2024	600
A-K2	04314519+2502357	150907970912262016	13.7	1	117	Sep. 20, 2024	1320
A-K2	08443258+1116500	601835320304886400	13.7	1	50	Nov. 24, 2024	1020
A-K	19101724+4944353	2132794829787857792	10.3	1	35	Sep. 19, 2024	30
A-K	19380704+4708008	2128545109969957888	12.3	1	27	Oct. 25, 2024	1200
A-K	19580796+4052023	2075066724134857344	14.3	1	35	Sep. 20, 2024	2100

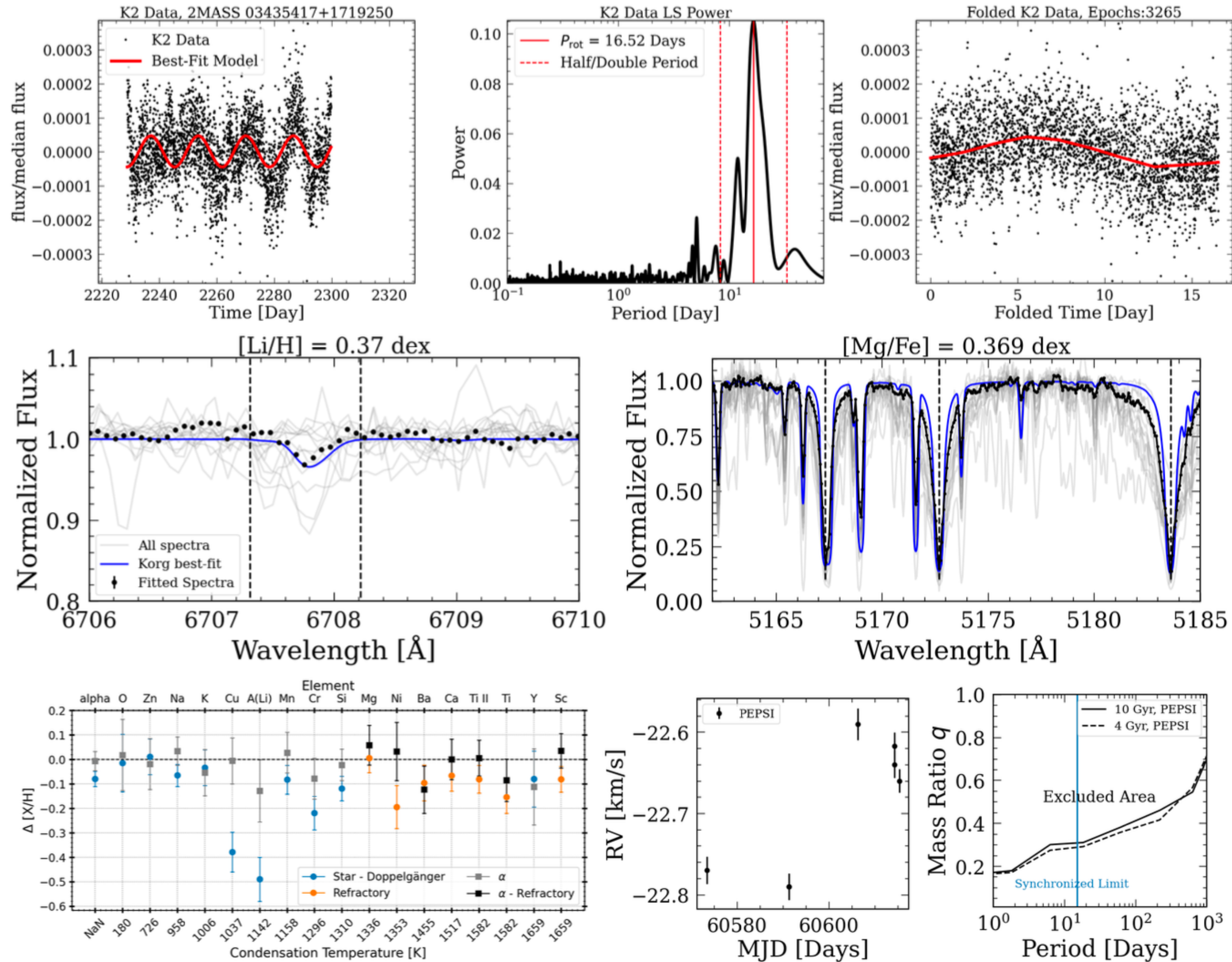
- Observed stars:
- 9 APOGEE stars for Li measurements
 - 4 GALAH stars for multiple RV measurements
- Found 3 stars with:
- Confirmed high [Mg/Fe] ([α /Fe])
 - Multiple RV suggesting against stellar binary — Binary isn't the reason these stars are spinning fast
 - Significant Li measurements — Haven't gone through binary mass transfer
 - No signature of planet engulfments — likely have not engulfed a planet

Result: Star 1 — 2MASS 03413908+2359163



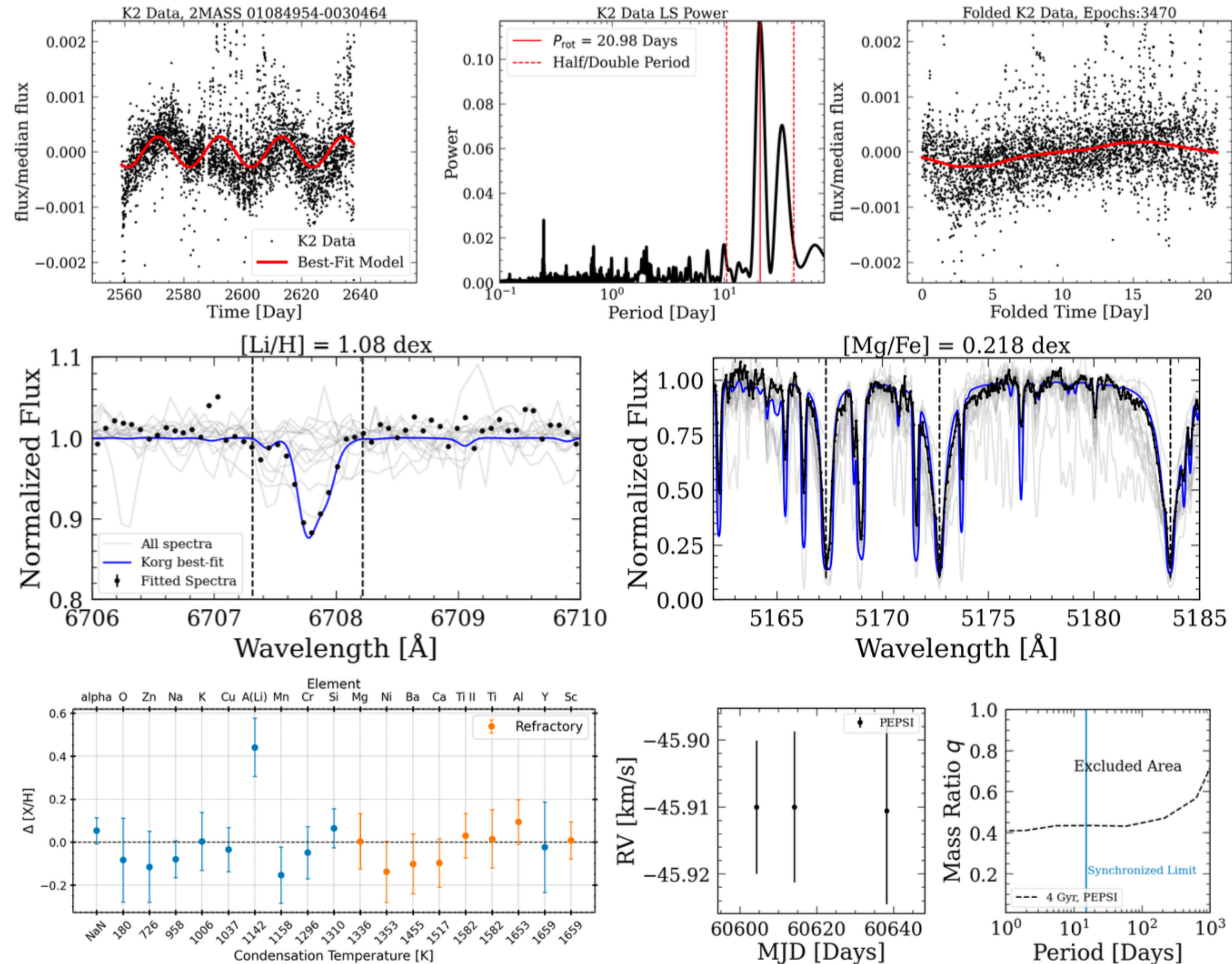
Lu+ in prep.

Result: Star 2 — 2MASS 03435417+179250



Lu+ in prep.

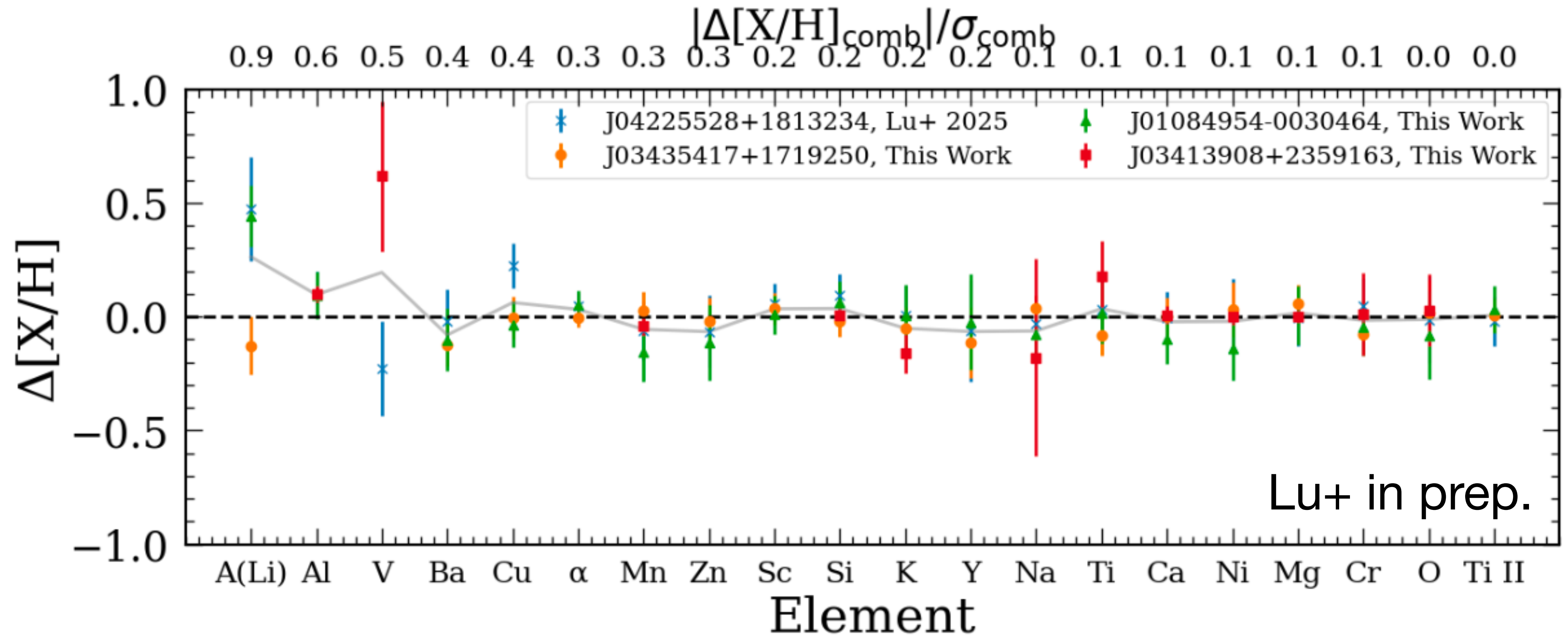
Result: Star 3 — 2MASS 01084954+0030464



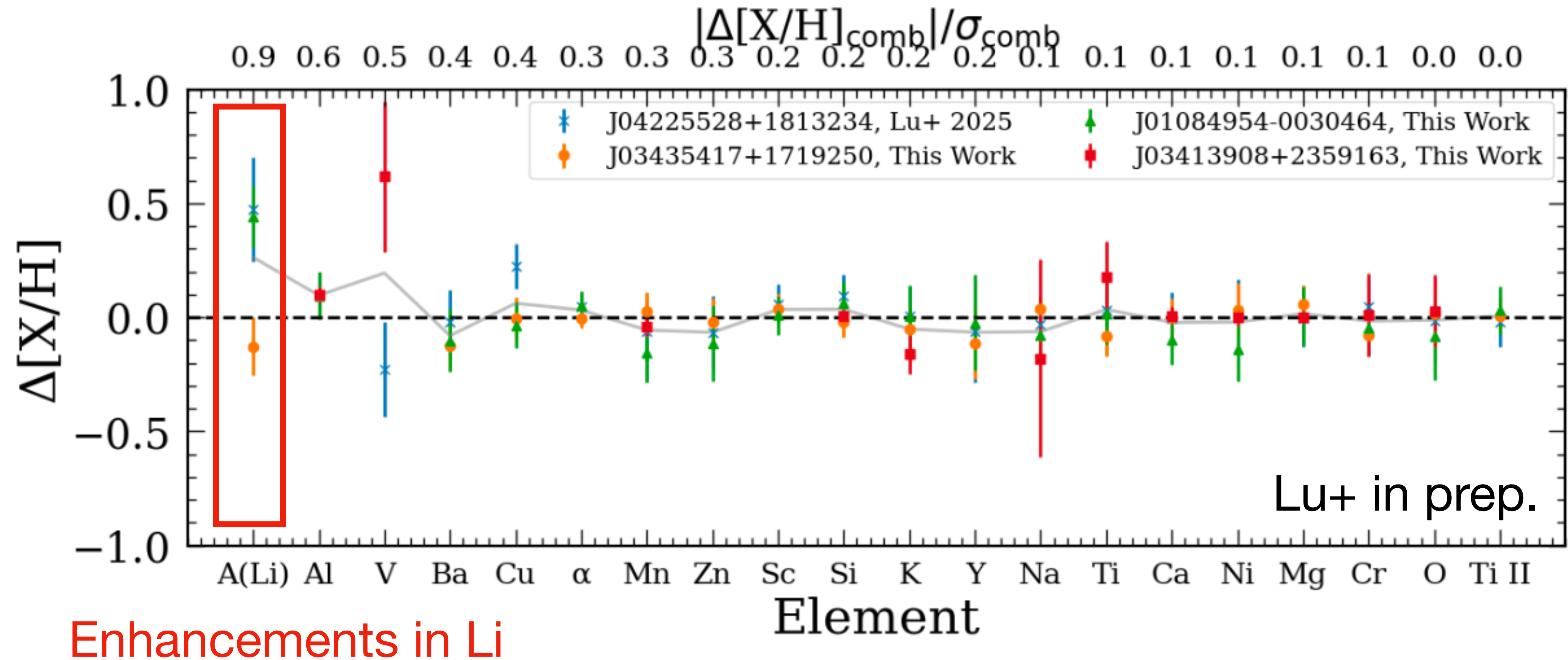
Lu+ in prep.

Truly young High- α stars exist, how are they made?

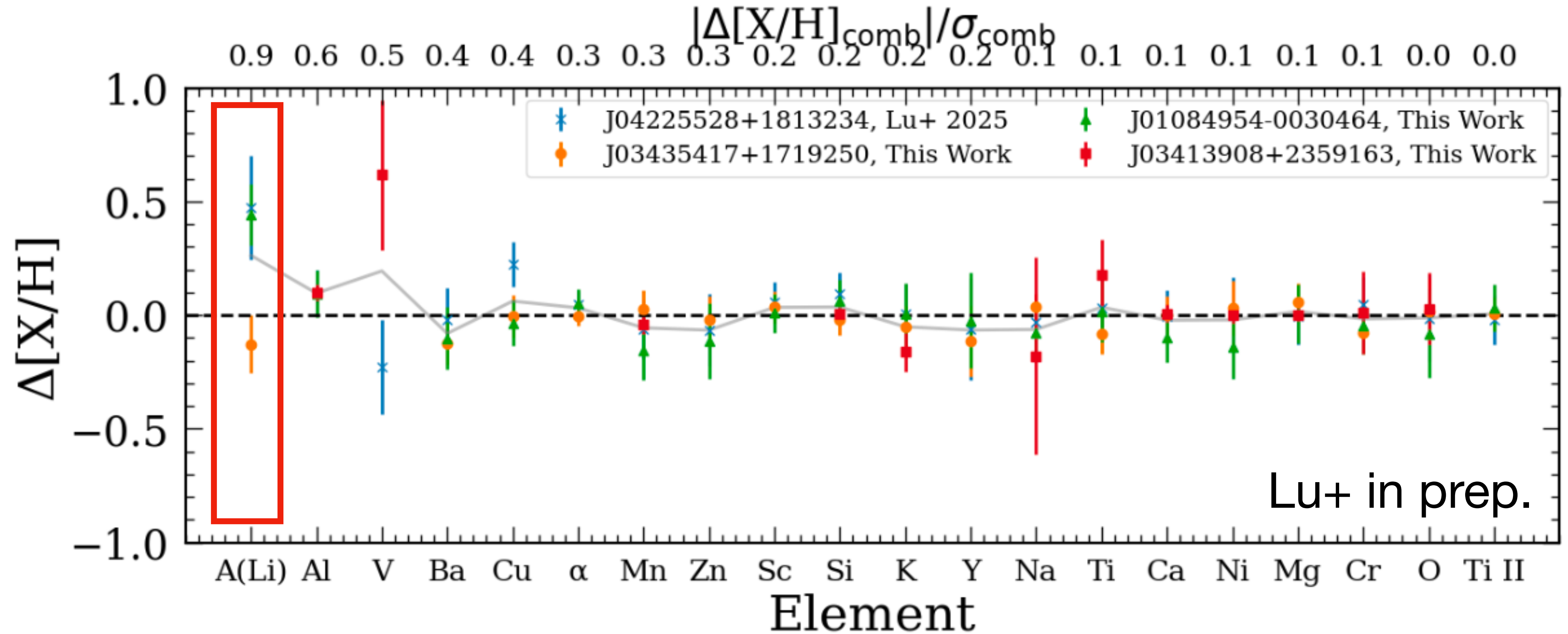
Result: Formation pathway



Result: Formation pathway

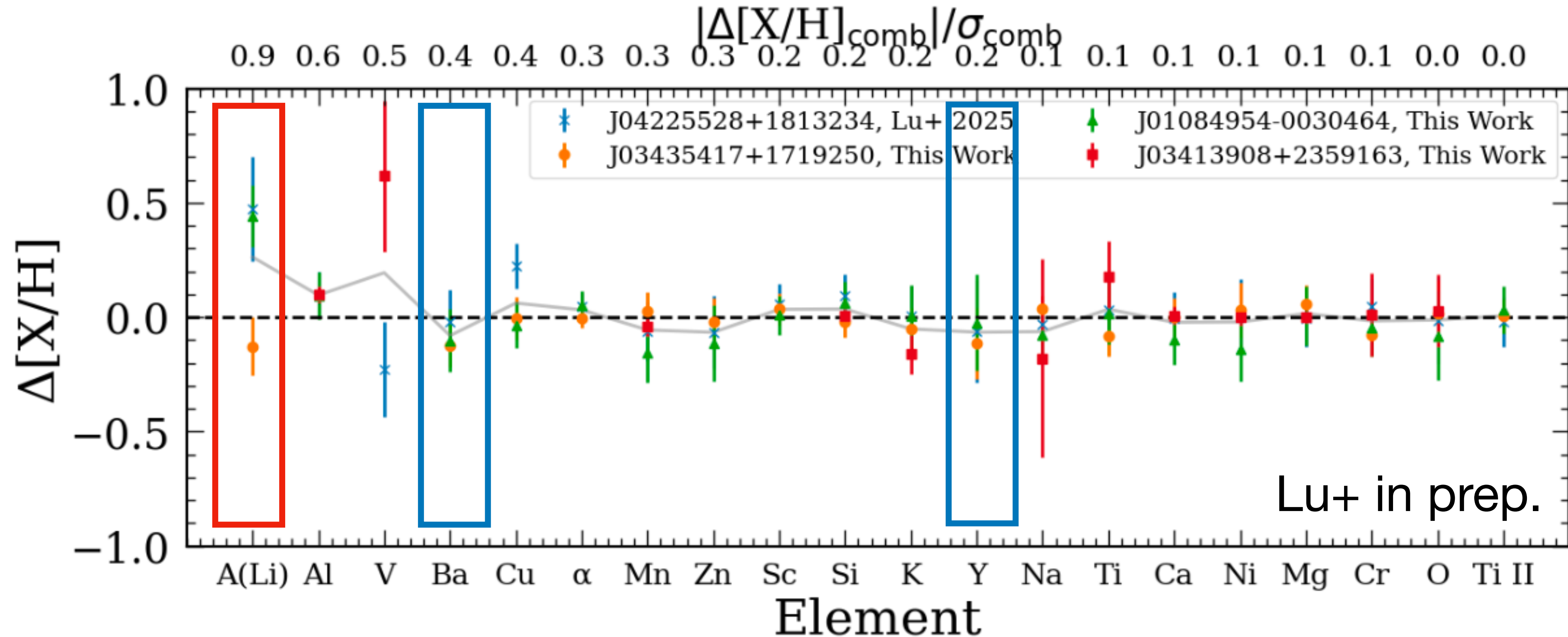


Result: Formation pathway



AGB mass transfer?

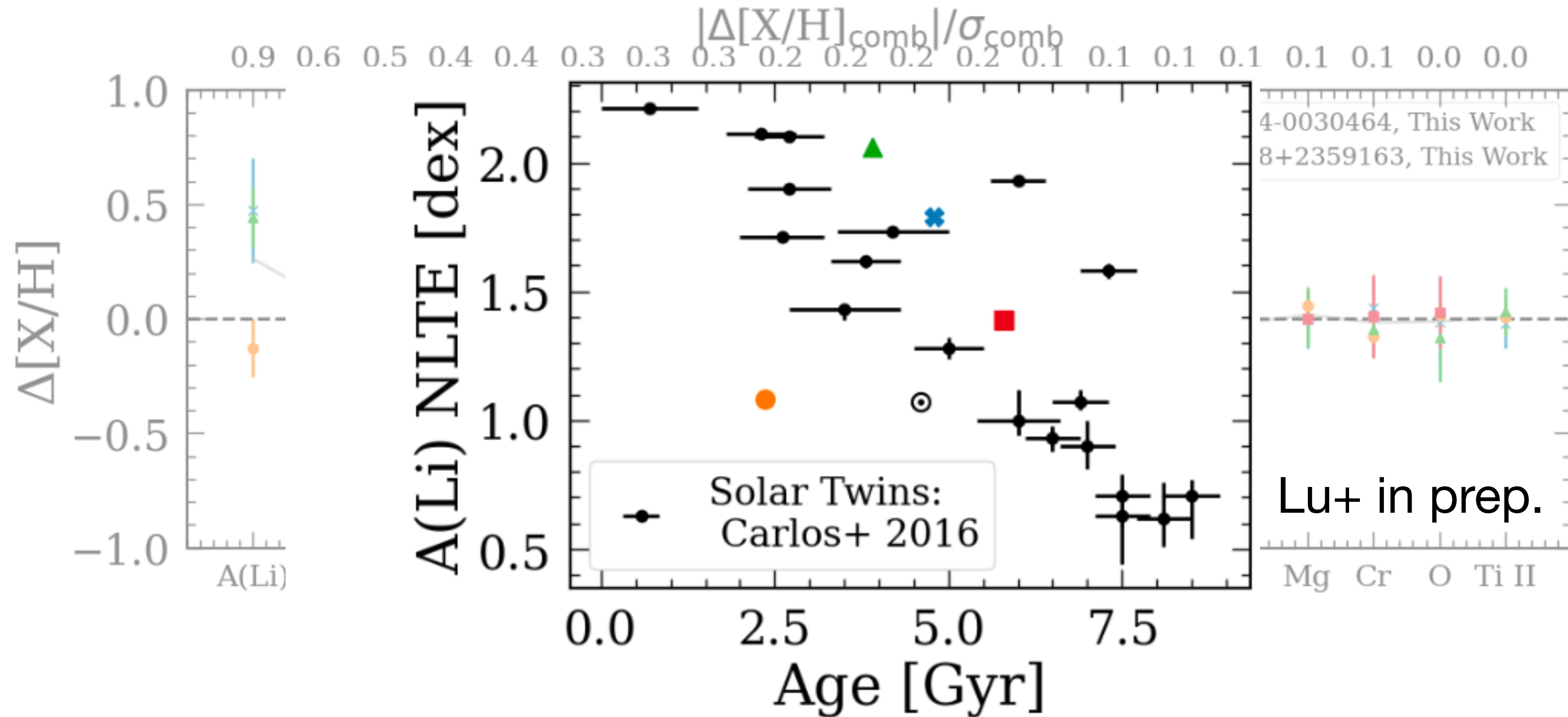
Result: Formation pathway



AGB mass transfer?

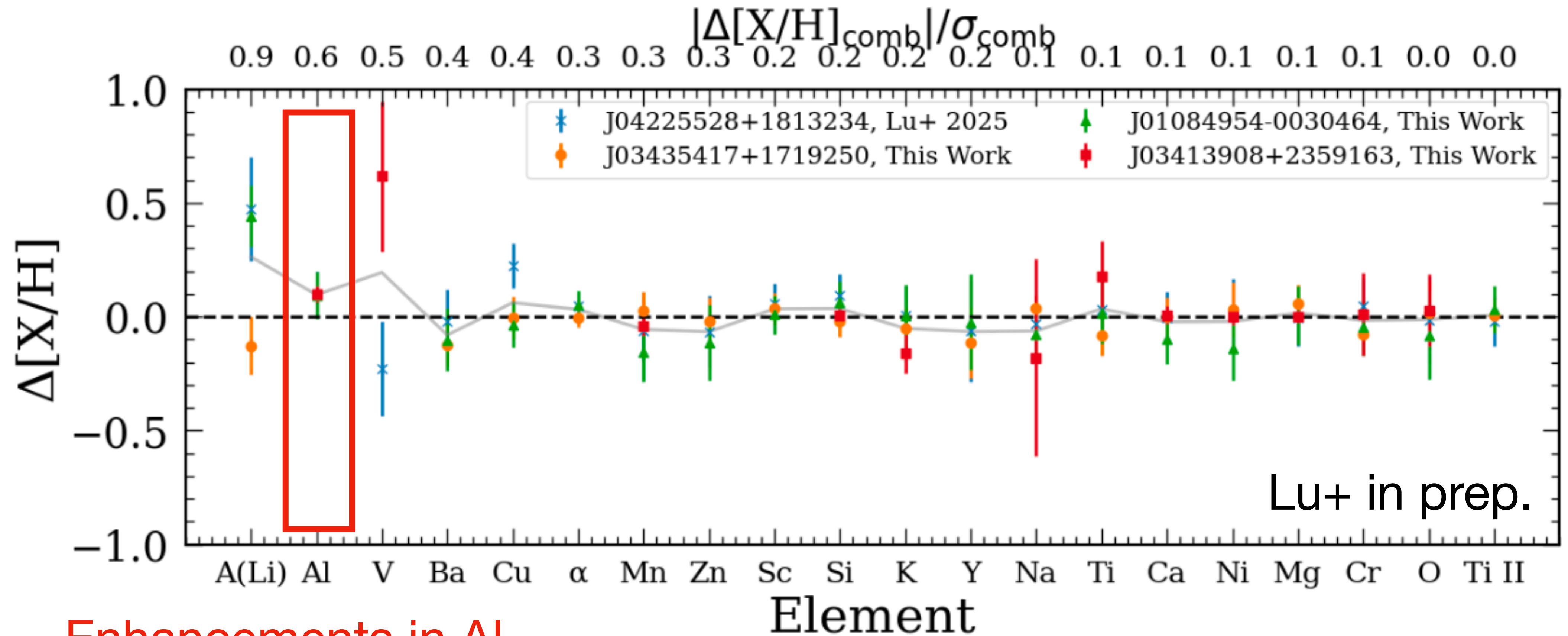
Probably not, no enhancements in s-process elements

Result: Formation pathway

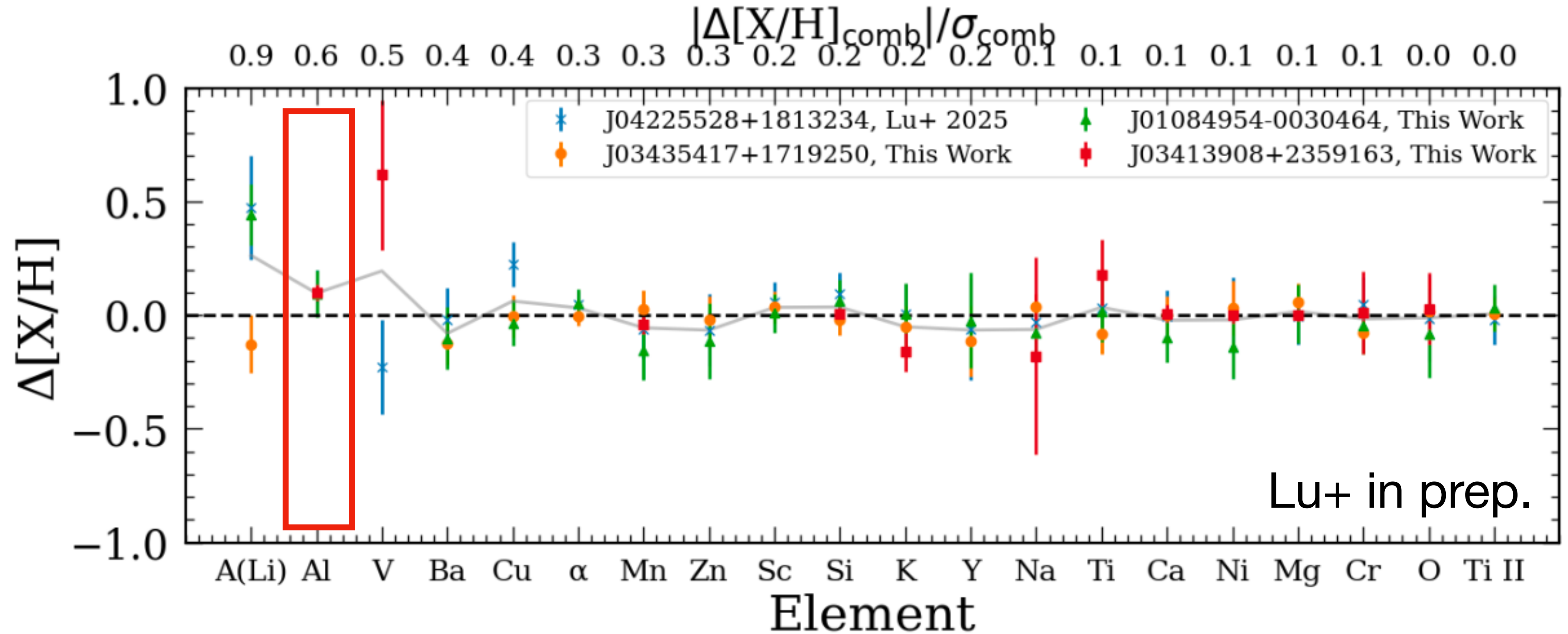


Matches with the typical solar twin Li-age trend, likely did not get Li from engulfing planets

Result: Formation pathway

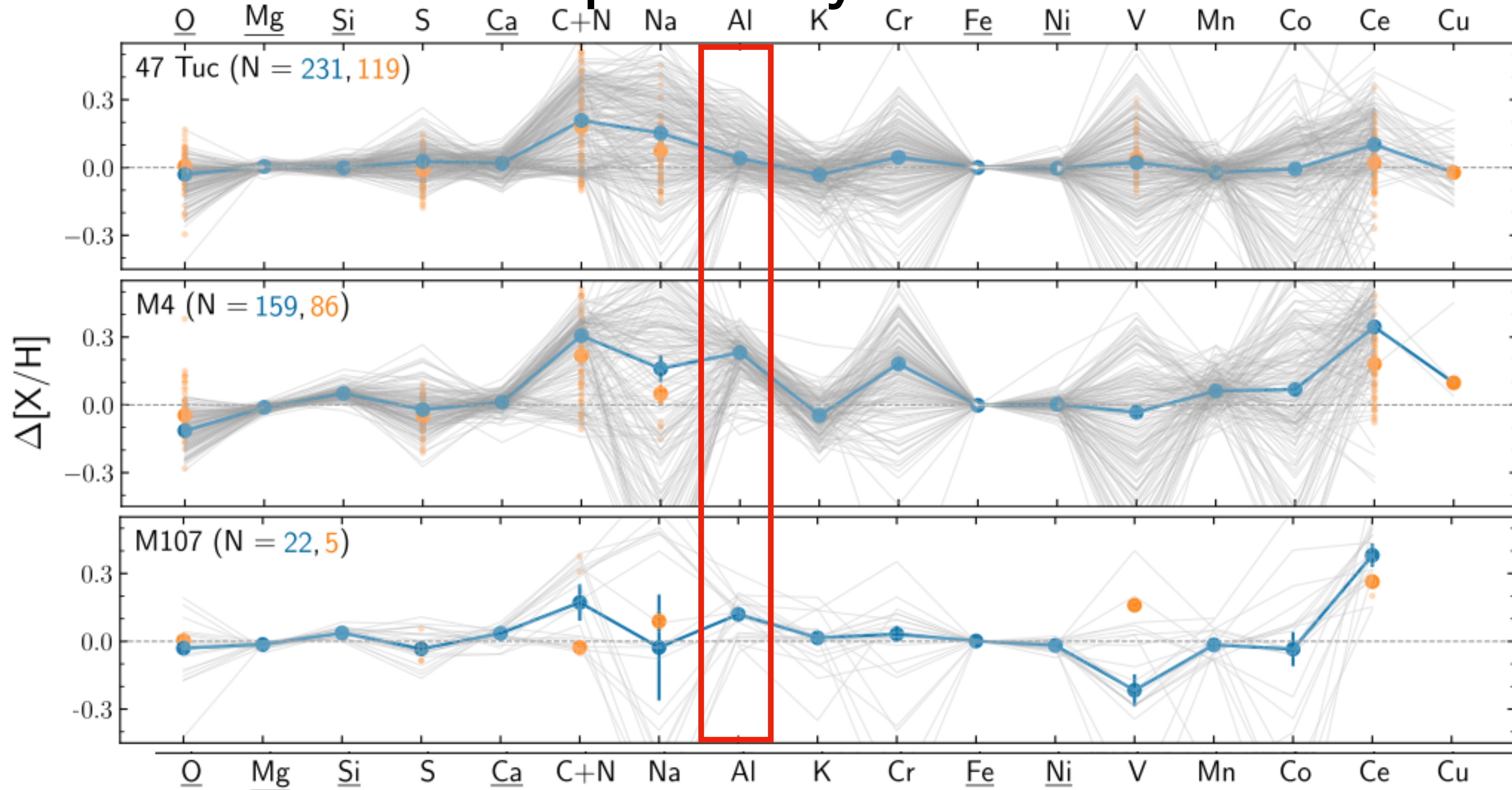


Result: Formation pathway



Similar process in Globular clusters?

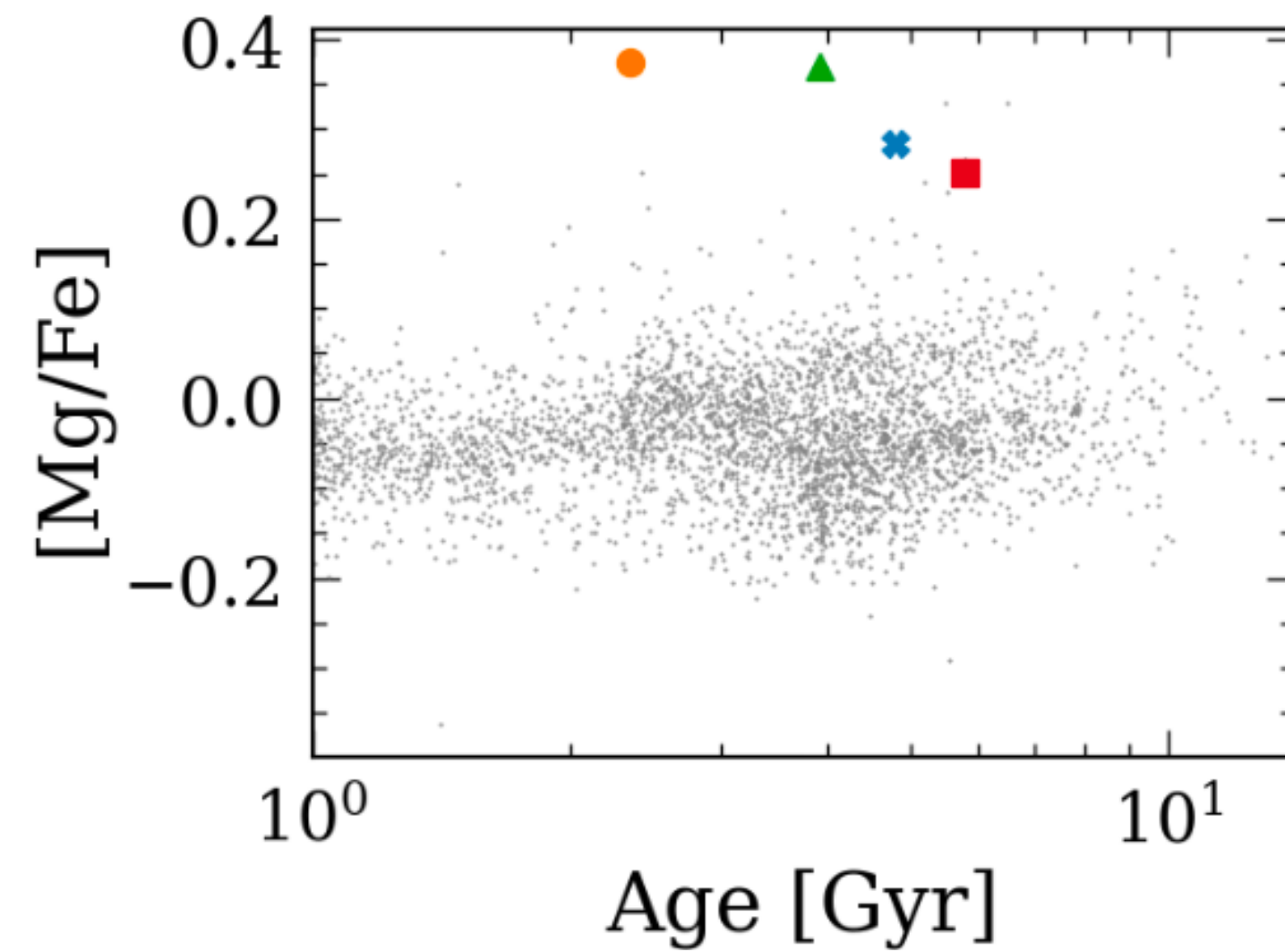
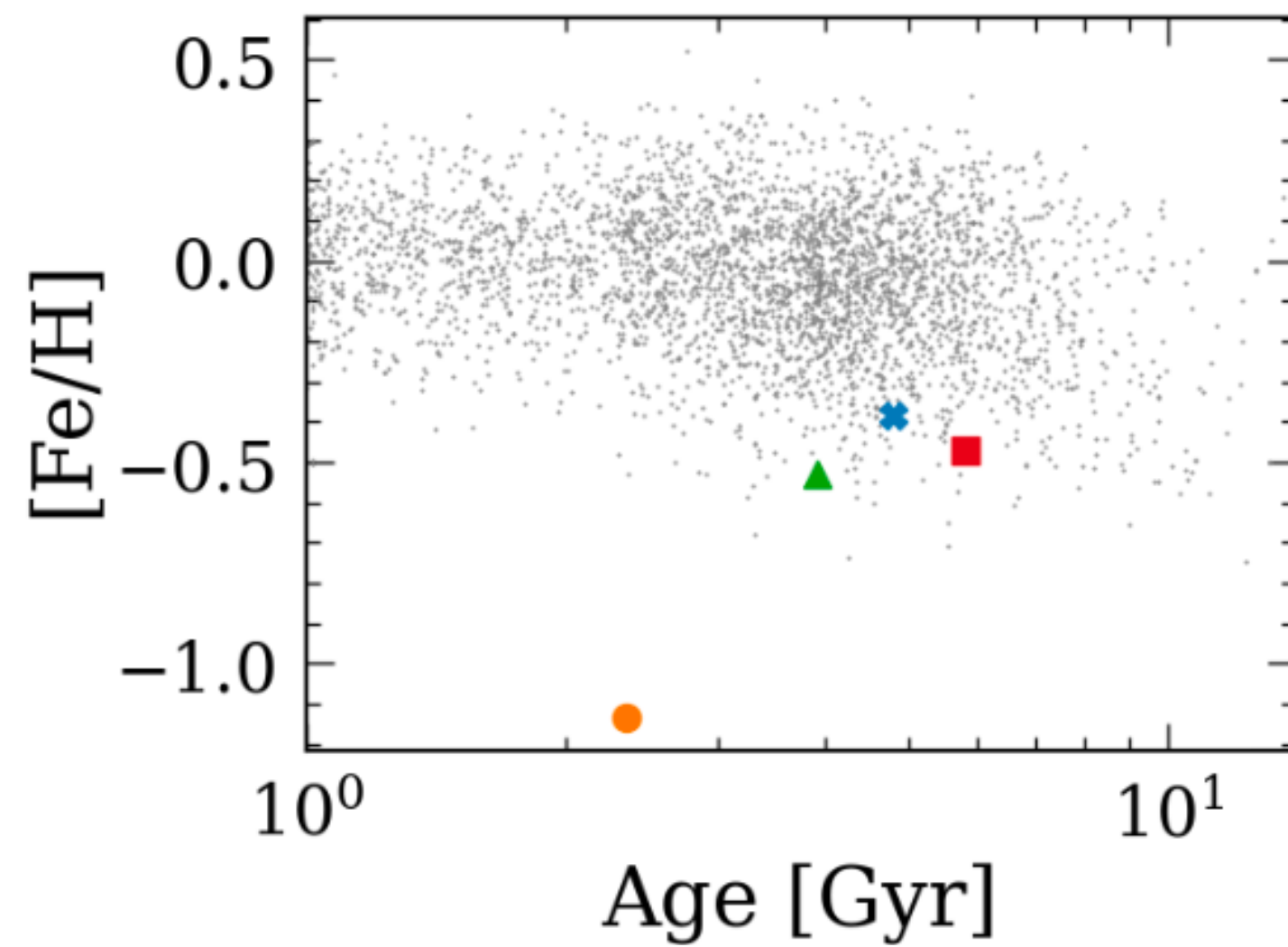
Result: Formation pathway



Sit+ 2024

Result: Formation pathway

Lu+ in prep.



Johnson+ 2021

