Identifying Mass Transfer Stars from Age Abundance Outliers

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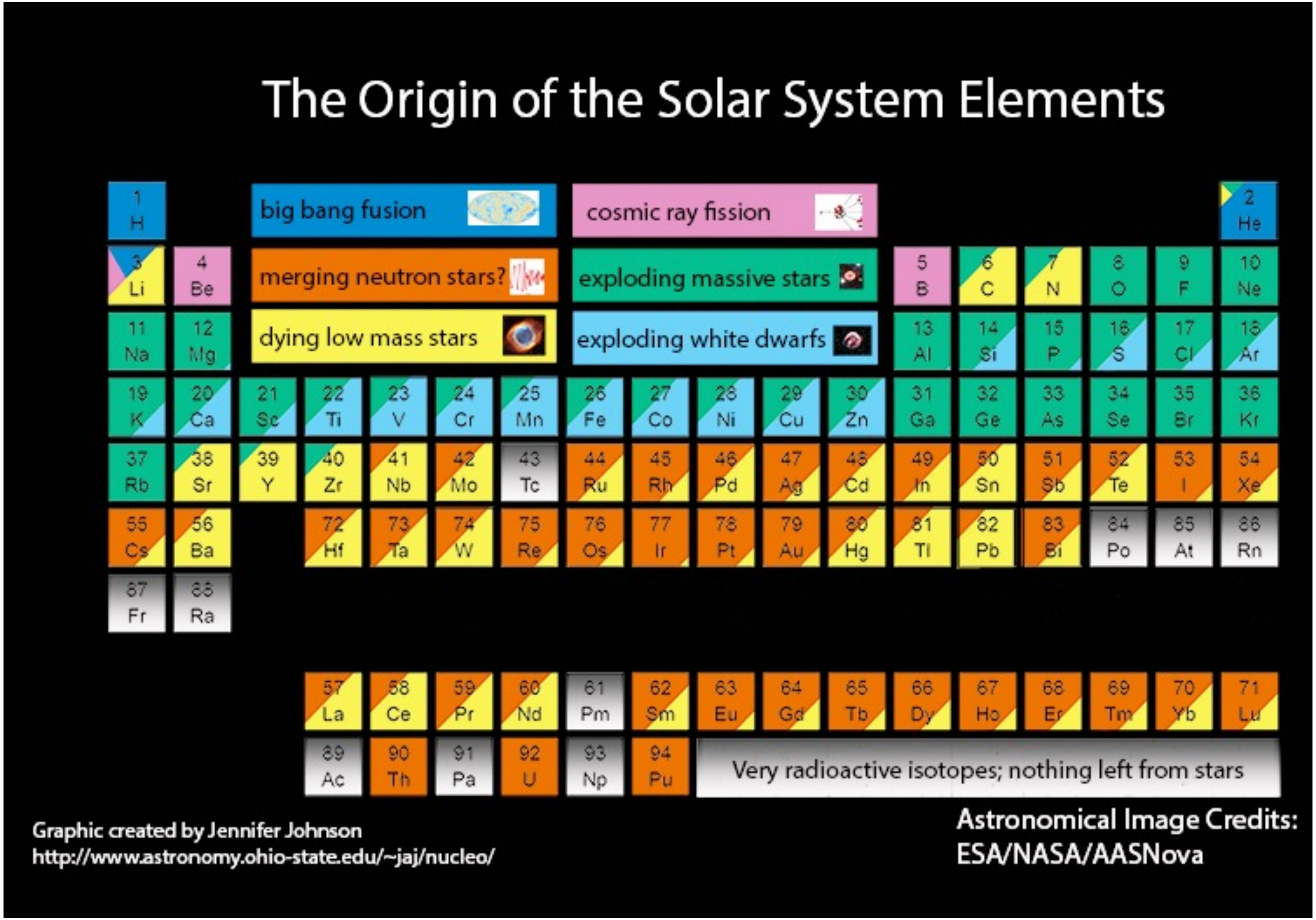

The Origin of the Solar System Elements
big bang fusion
cosmic ray fission
merging neutron stars?
exploding massive stars
dying low mass stars
exploding white dwarfs
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
57 La
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
89 Ac
90 Th
91 Pa
92 U
93 Np
94 Pu
Very radioactive isotopes; nothing left from stars
Graphic created by Jennifer Johnson
http://www.astronomy.ohio-state.edu/~jaj/nucleo/
Astronomical Image Credits:
ESA/NASA/AASNova

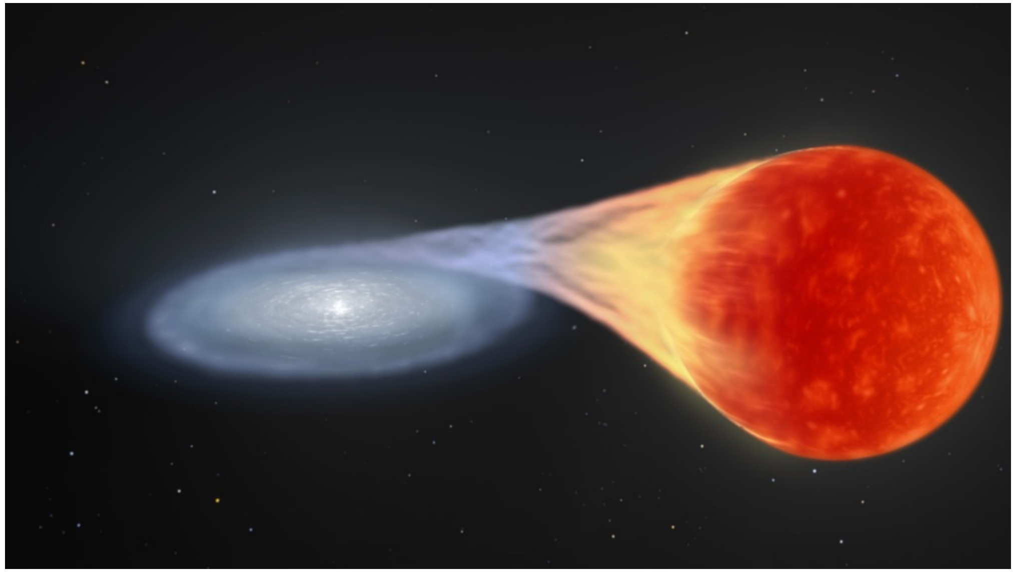
Exploding massive stars - type II core collapse supernovae

- Enriched early universe
- Supermassive stars undergo nuclear fusion creating heavy elements (like iron) in core
- When fusion stops, the core collapses
- Alpha elements (like magnesium) outside core disperse across universe

https://ccapp.osu.edu/events/core-collapse-supernovae-neutrino-driven-1d-explosions-light-curves-and-spectra

Exploding white dwarfs - type Ia supernovae

- Enriched later universe
- White dwarf in binary system accretes mass and increases in temperature, allowing carbon / oxygen fusion into heavier elements
- Energy released during this process causes star to explode



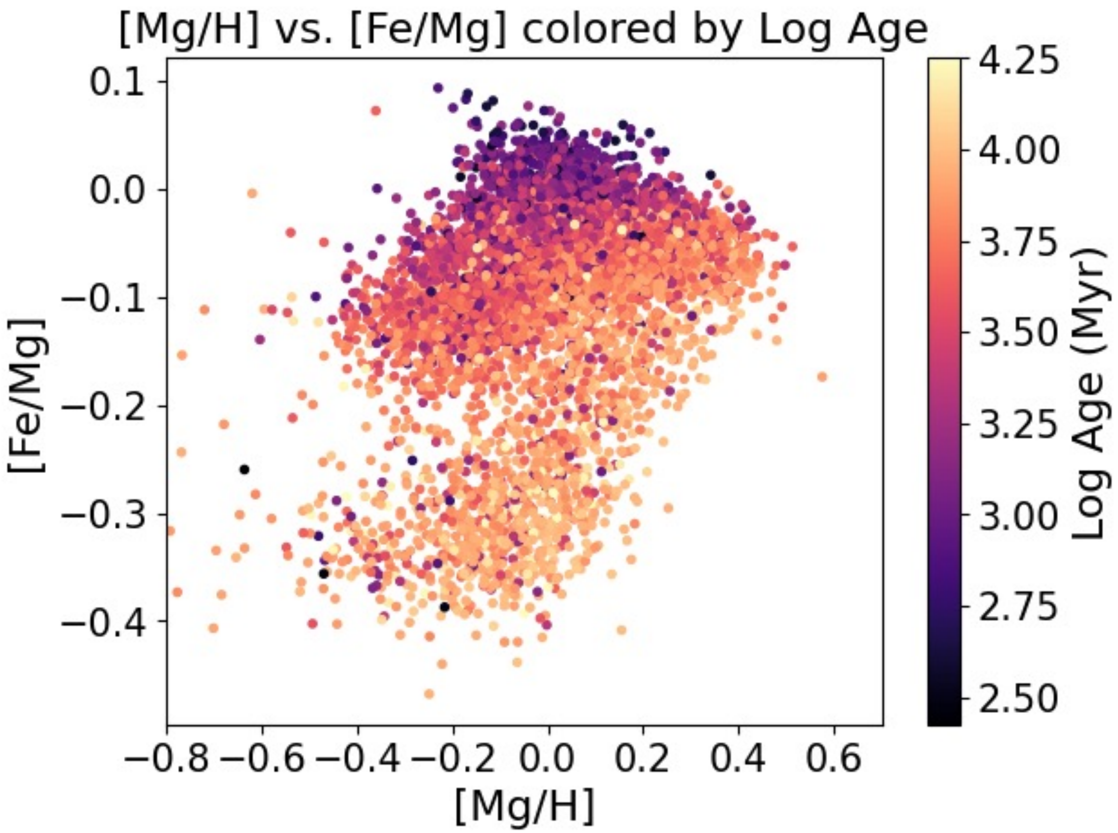
https://svs.gsfc.nasa.gov/20344

APOGEE Stellar Abundances

- Data from APOGEE ASPCAP DR 17 (Abdurro'uf et al. 2022)
- Telescopes collect light and produce spectra, absorption lines are matched with wavelengths that correspond to specific elements
- This measures the stars' outer layer abundances from a previous generation of supernovae
- "Fingerprint" of past generations

Abundance / Age Correlation

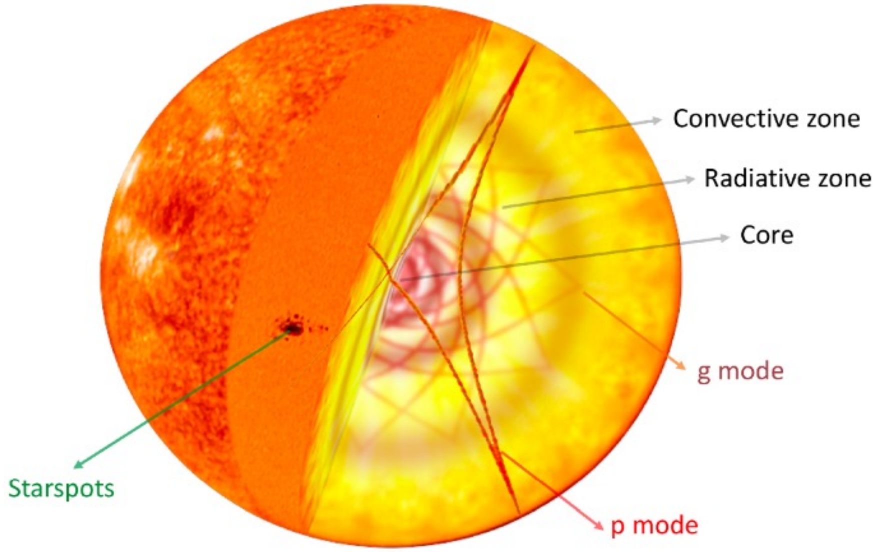
- Different processes enrich on different timescales
- New stars born from elements dispersed by supernovae; enriched by metals made from previous generation of stars



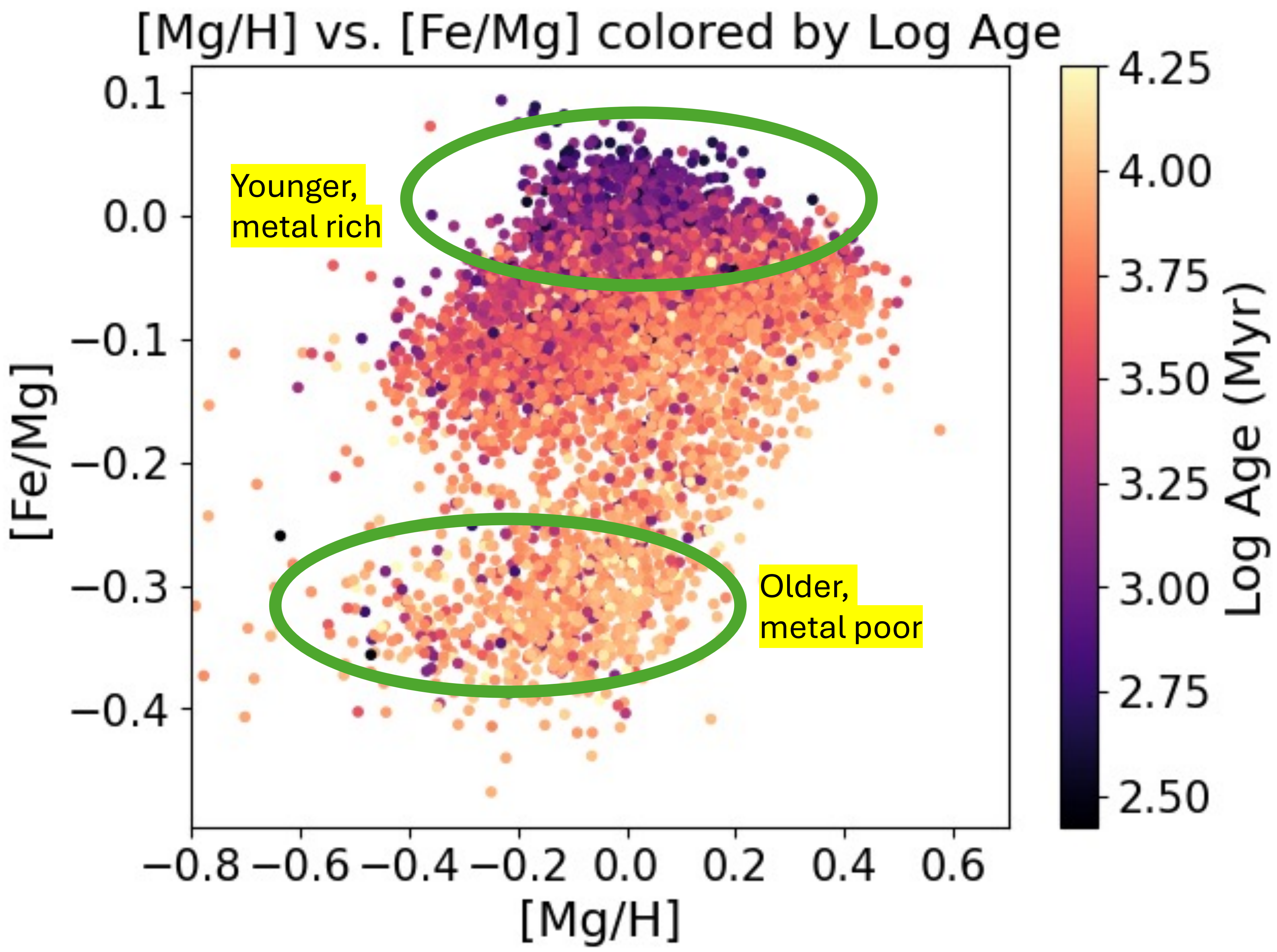
Determining asteroseismic ages

- Sound waves in the star cause oscillations that we observe
  - Determine mean density → infer mass
  - Determine surface gravity → infer radius
- Compare these values to theoretical stellar evolution models, predict age

Asteroseismic ages come from mass!

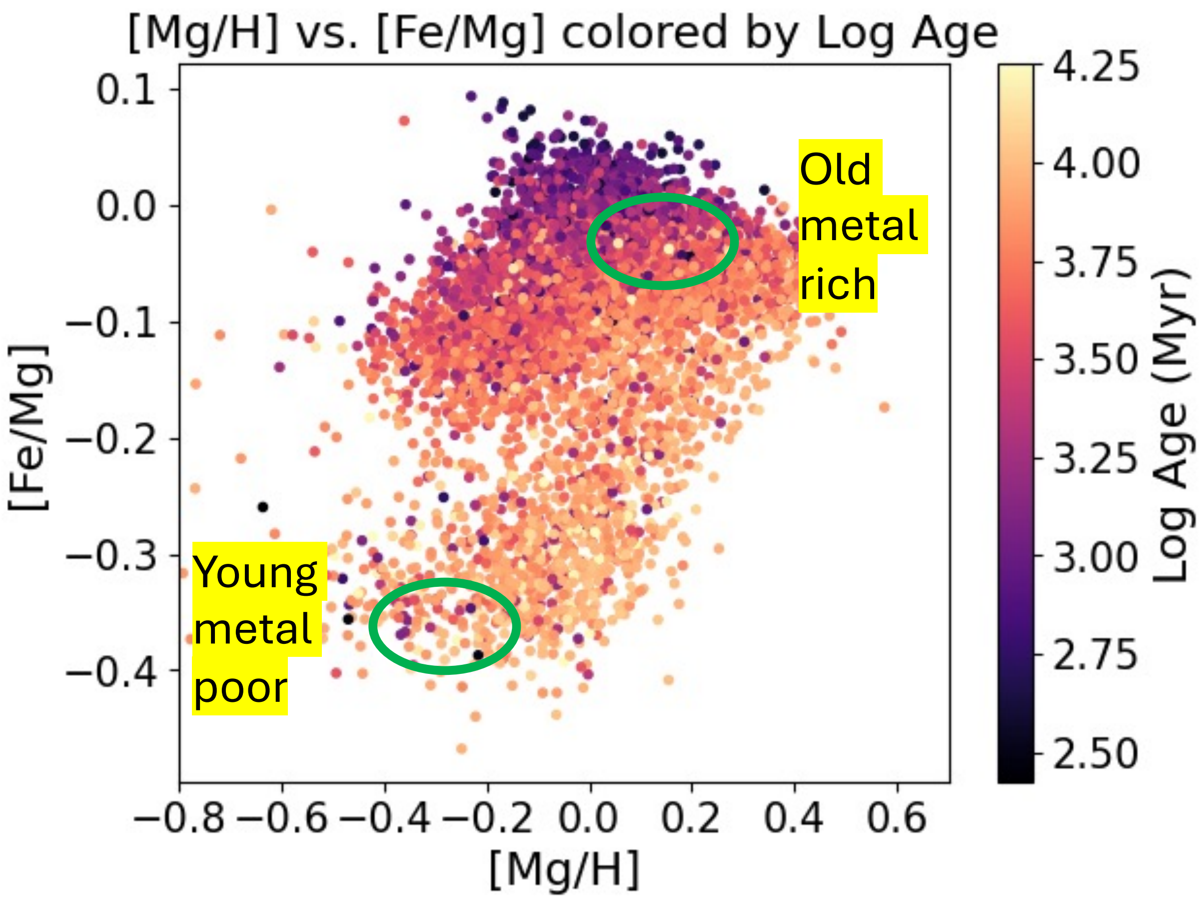


https://doi.org/10.1007/s41116-019-0020-1


[Mg/H] vs. [Fe/Mg] colored by Log Age
Younger, metal rich
Older, metal poor
[Fe/Mg]
[Mg/H]
Log Age (Myr)
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.8
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
4.25
4.00
3.75
3.50
3.25
3.00
2.75
2.50

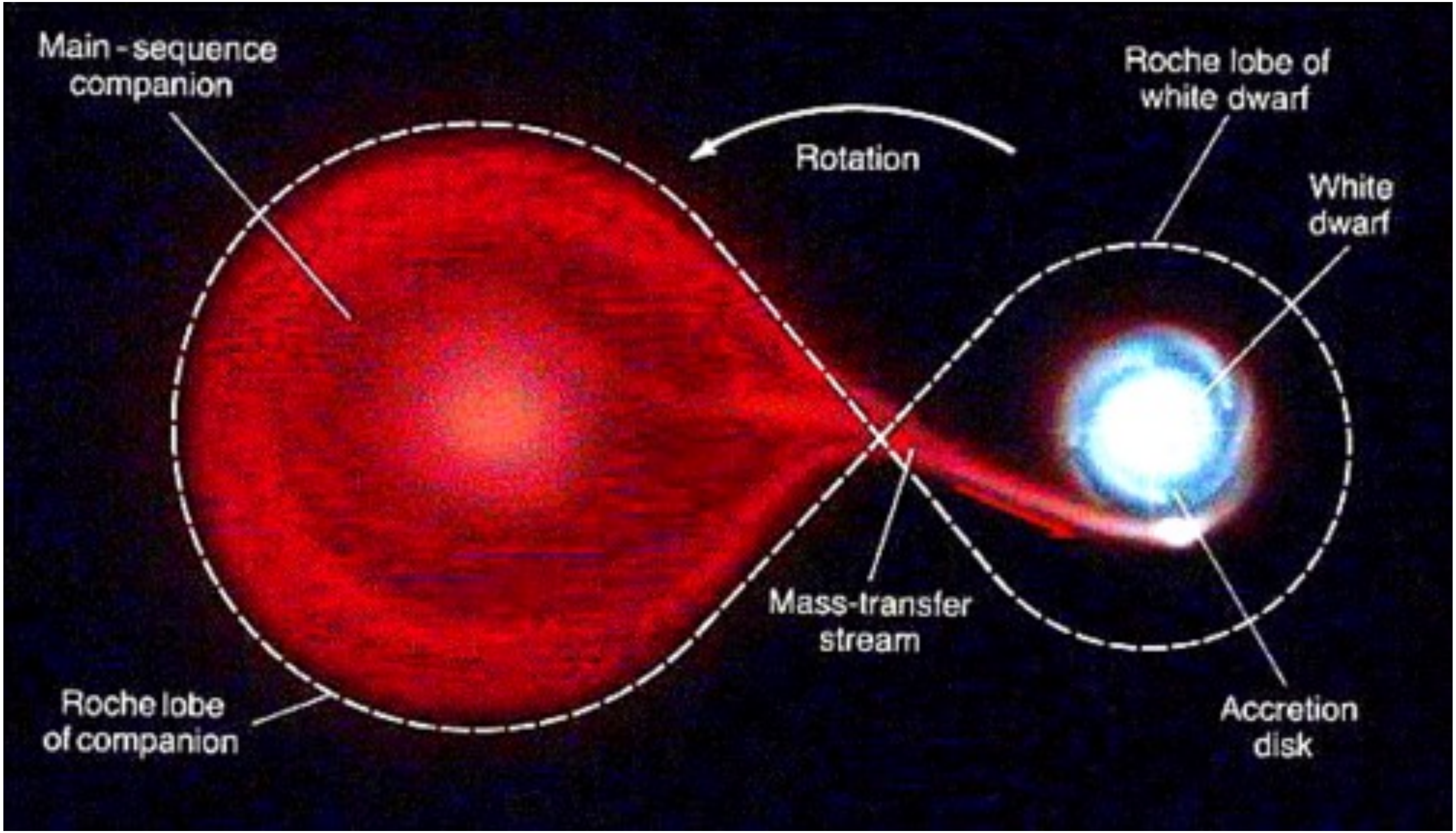
Outliers in age abundance correlation

- Some ages do not match surface abundance
- Outlier? Mass transfer?
- Mass transfer stars will have altered masses, and therefore altered asteroseismic ages



Motivation in studying these outliers

- Past works have studied outliers like these, making cuts in abundance or mass: Chiappini et al. 2015, Martig et al. 2015, Jofre et al. 2016, Jofre et al. 2023, Zhang et al. 2021 and Hekker et al. 2019
- Focus on age outliers
    - Might be remnants of mass transfer
- Select a broader group of outliers based on comparing them to a control group through a data driven process
- Potential limit to asteroseismic ages



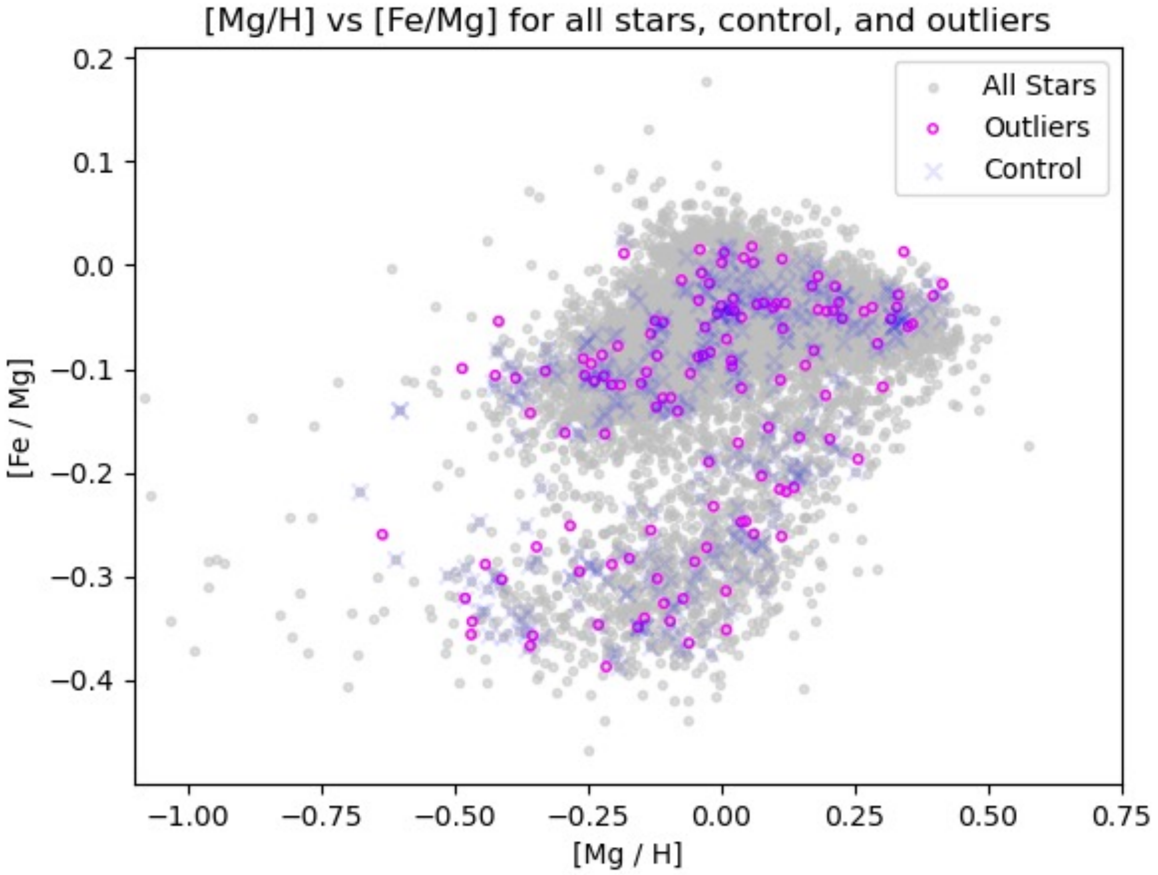
https://cosmosatyourdoorstep.com/2021/01/18/what-about-binary-systems/

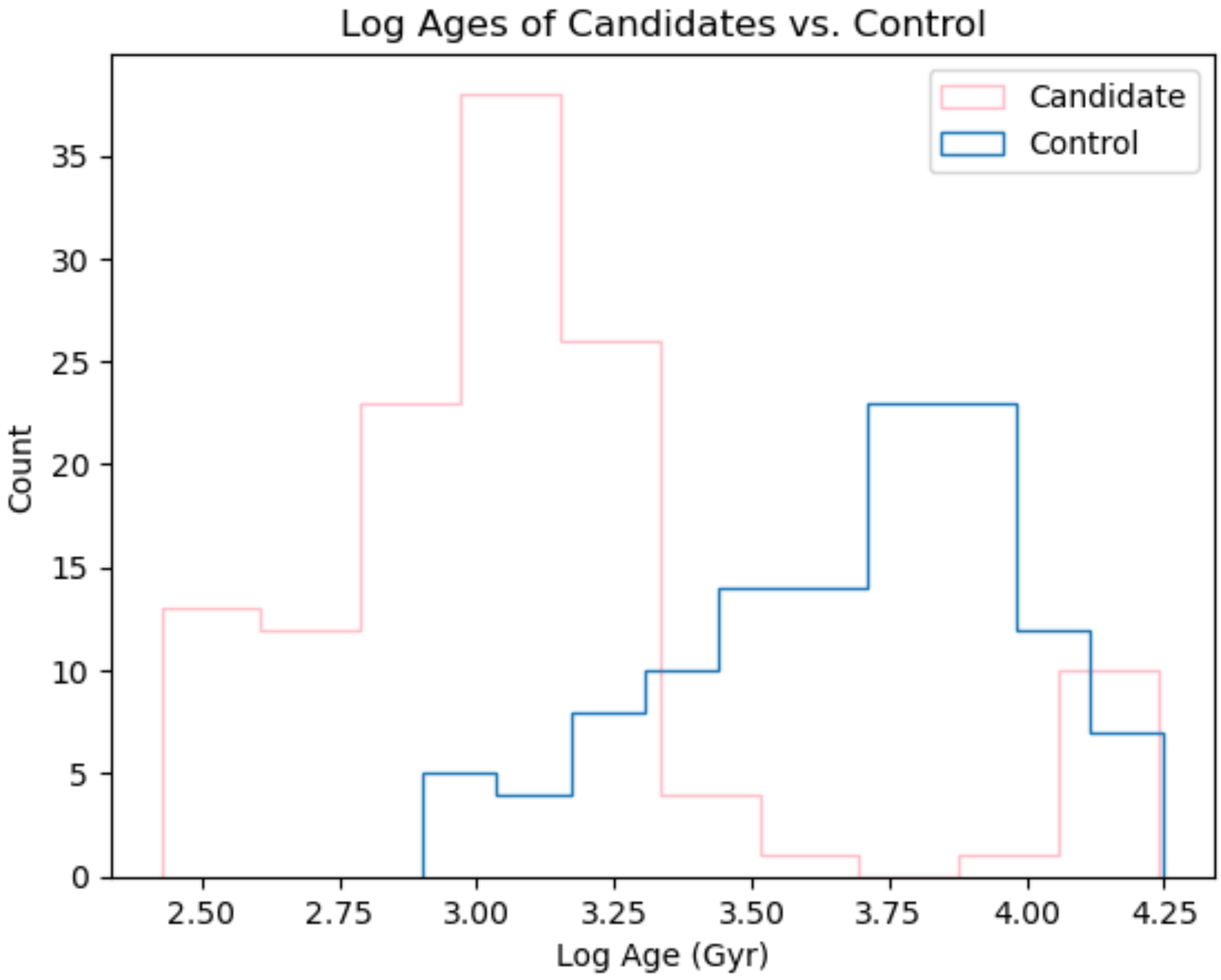
Data

- 6613 stars from APOKASC 2
- [Mg/H] and [Fe/Mg] abundance ratios and other stellar parameters from APOGEE DR 17
- Asteroseismic ages from APOKASC 2

Our selection

- For each star, found neighbor with most similar elemental abundances
- Predicted age of each star = median age of its neighbors
- Outliers: difference between predicted age and asteroseismic age exceeded 0.6 Myr
- Identified 128 outliers

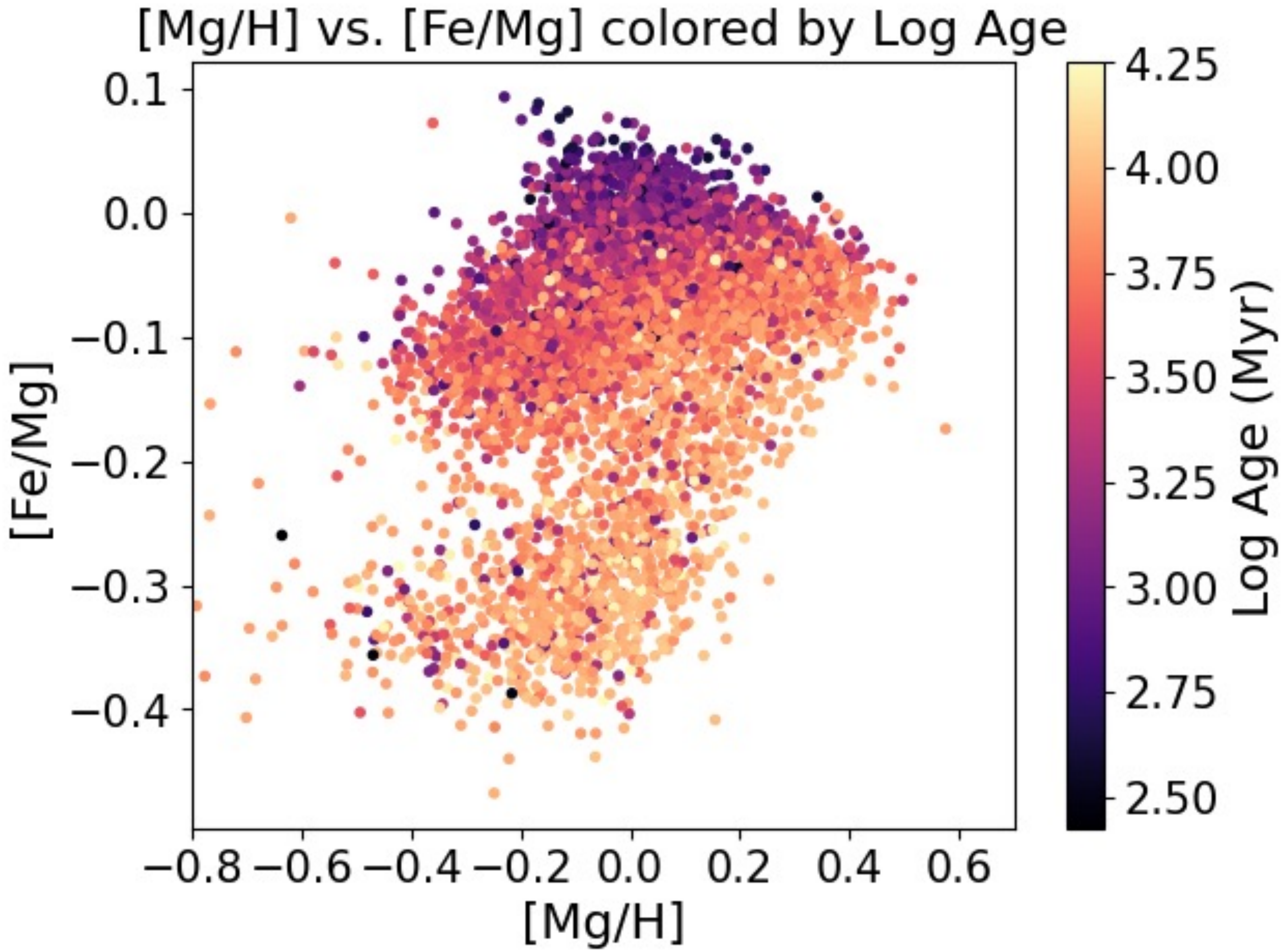




Log Ages of Candidates vs. Control
Candidate
Control
Count
Log Age (Gyr)
0
5
10
15
20
25
30
35
2.50
2.75
3.00
3.25
3.50
3.75
4.00
4.25

Other expected characteristics of a mass transfer

- High VSCATTER - binary interaction would cause the star's motion to differ from that of a single star
- UV excess - binary star systems that actively undergo mass transfer will be hotter and glow in the UV more
- Other unusual abundance ratios
- Fast stellar rotation / high vsini



Summary

- Identified 128 outliers/mass transfer candidates by predicting ages based on neighbors (control sample)
- Found stars for which abundances did not well predict ages