Abundances in Metal-Poor Stars

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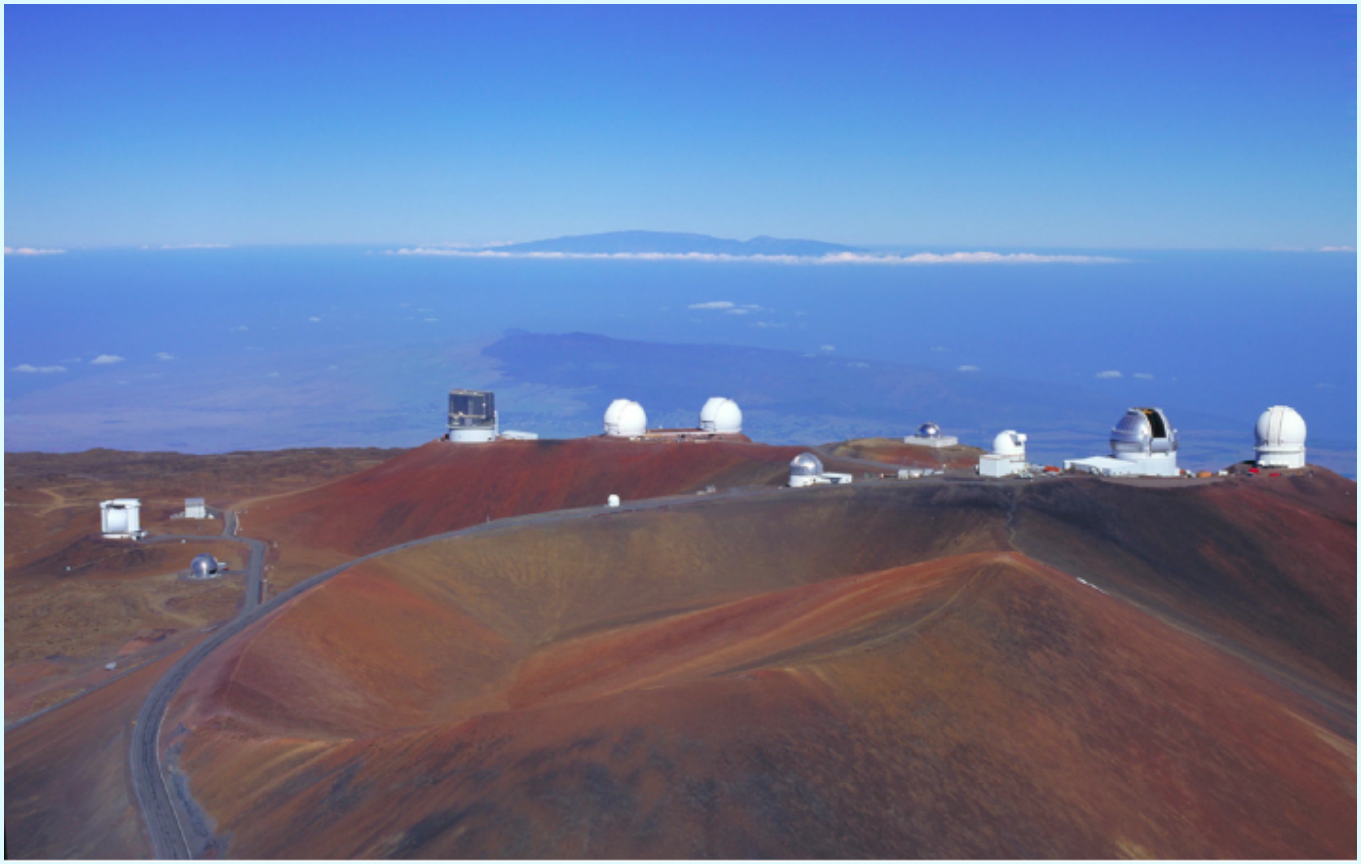


Photo by Richard Wainscoat

Formation and Chemical Evolution of the Galaxy

Tracers: light element - Be

abundant element - O

alkali element - Na

alpha-elements - Mg and Ti

Fe-peak element - Fe

OBSERVATIONS - Field Stars

103 stars: [Fe/H] between -0.5 and -3.5

Keck I + upgraded HIRES

3 CCDs, 15 μ pixels

3000 - 6000 Å

High-resolution: ~42,000

High signal-to-noise: median 106 per pix in uv

higher on the green and red chips

17 Keck nights - 15 clear

OBSERVATIONS - Cluster Stars

3-5 turnoff stars in M 71, M 13, M 92

Keck I + (old) HIRES

1 CCD, 24 μ pixels

4430 - 6880 Å

High-resolution: ~45,000

Medium signal-to-noise: 30 - 60 per pix

M 92 - King et al. 1998

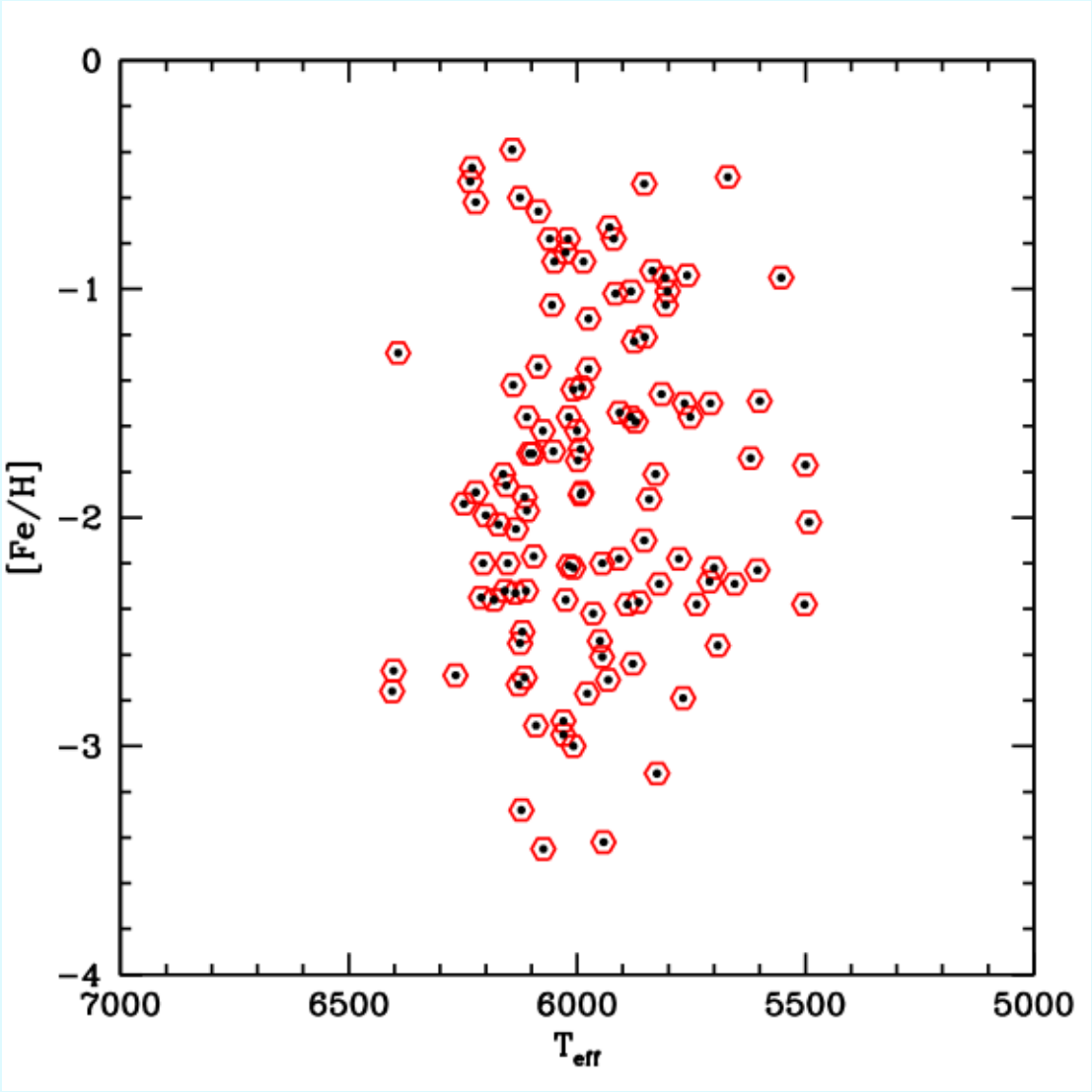
M 71 - Boesgaard et al. 2005

M 13 - Boesgaard et al. in preparation

Field Stars

[Fe/H]
-0.5 to -3.5

T_{eff} (K)
5500 - 6500



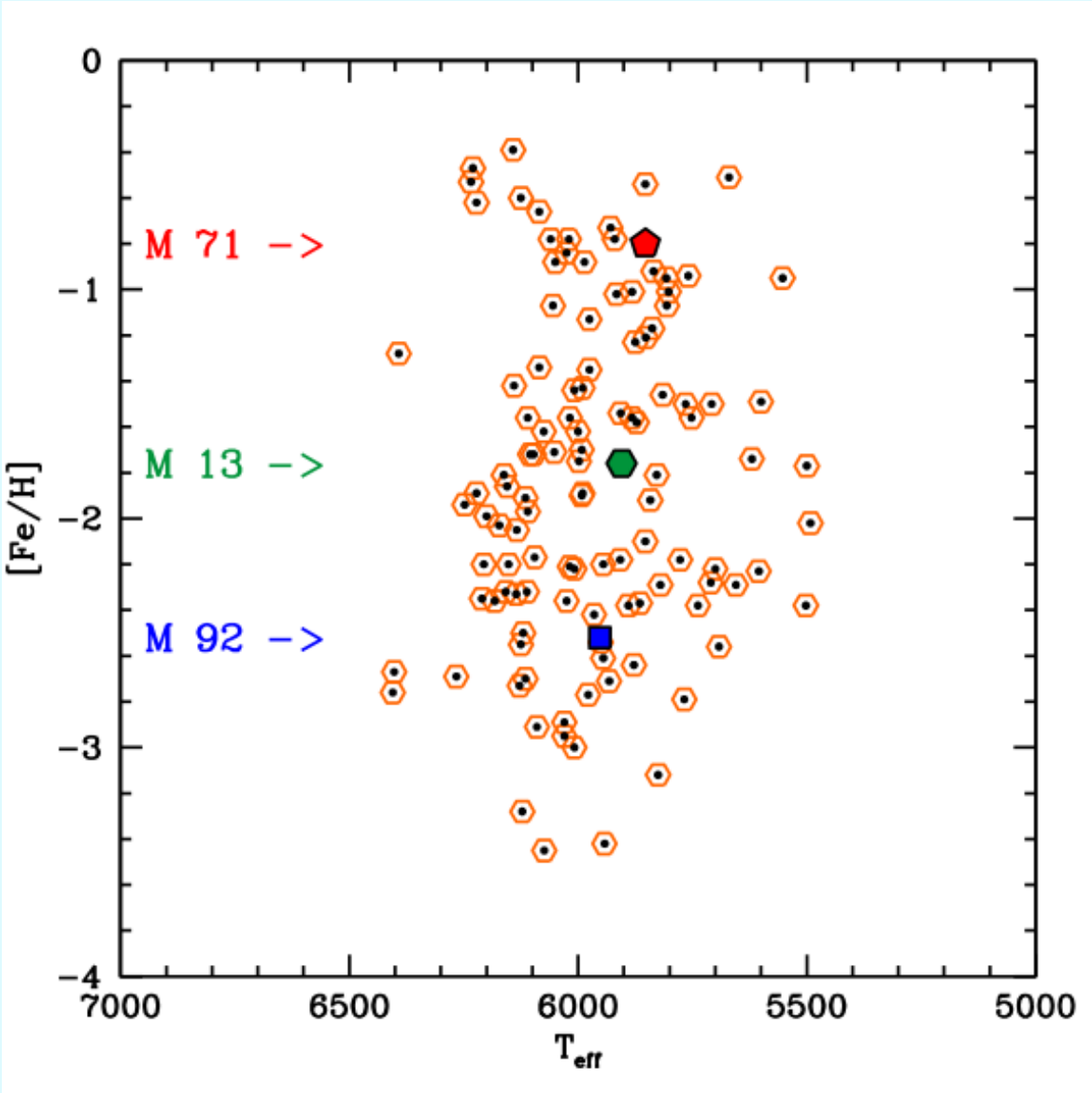
Globular Cluster Stars

[Fe/H]

M 71 -0.80

M 13 -1.76

M 92 -2.52



Analysis of Field Stars

Parameters were determined for 103 stars spectroscopically by iteration:

T_{eff} (K), log g, [Fe/H], ξ

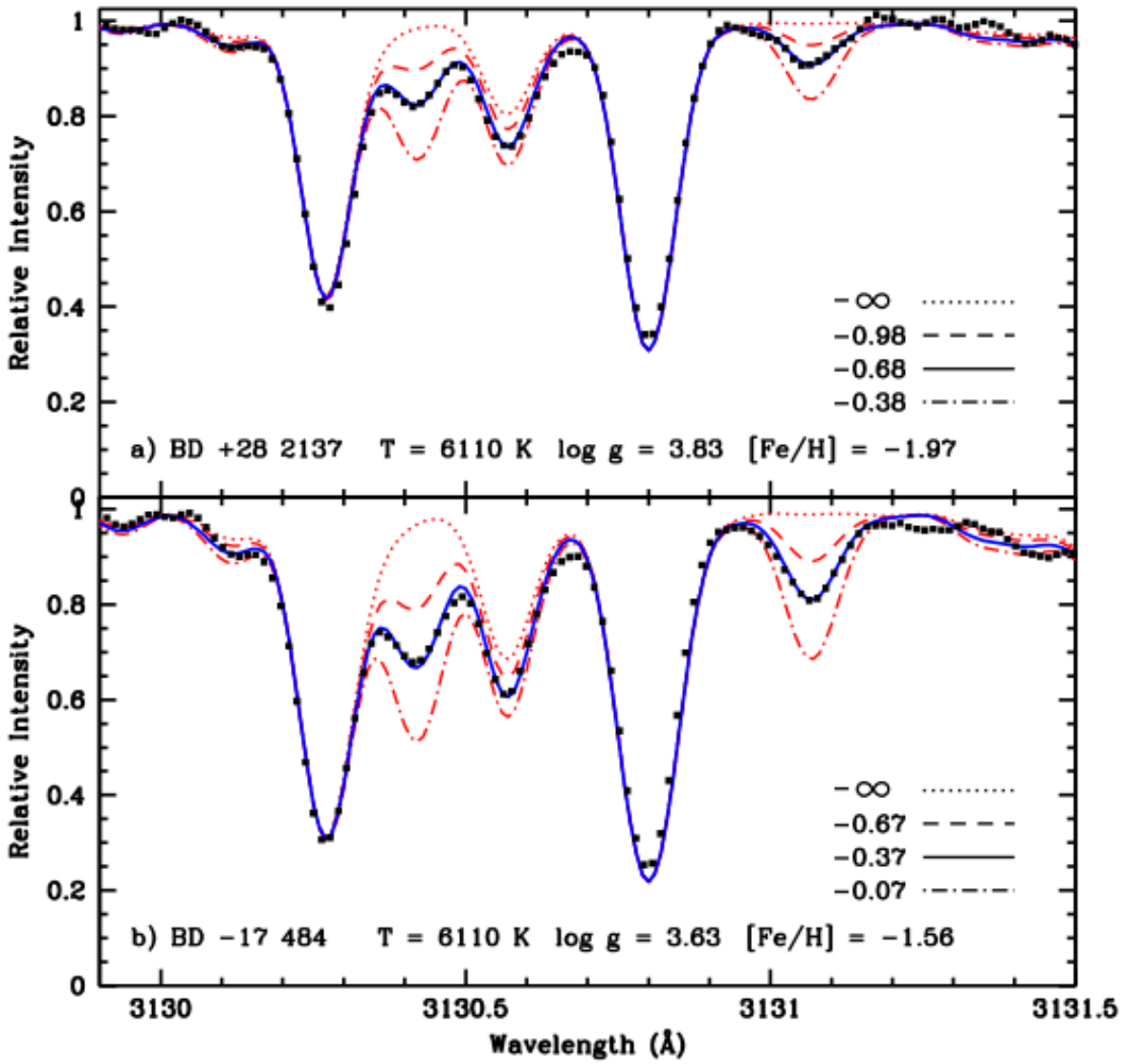
Kurucz model atmospheres

Abundances of Fe, Be, O, Na, Mg, Ti

Synthesis method for Be and O

Line lists for Fe I, II, Na I, Mg I, Ti I, II

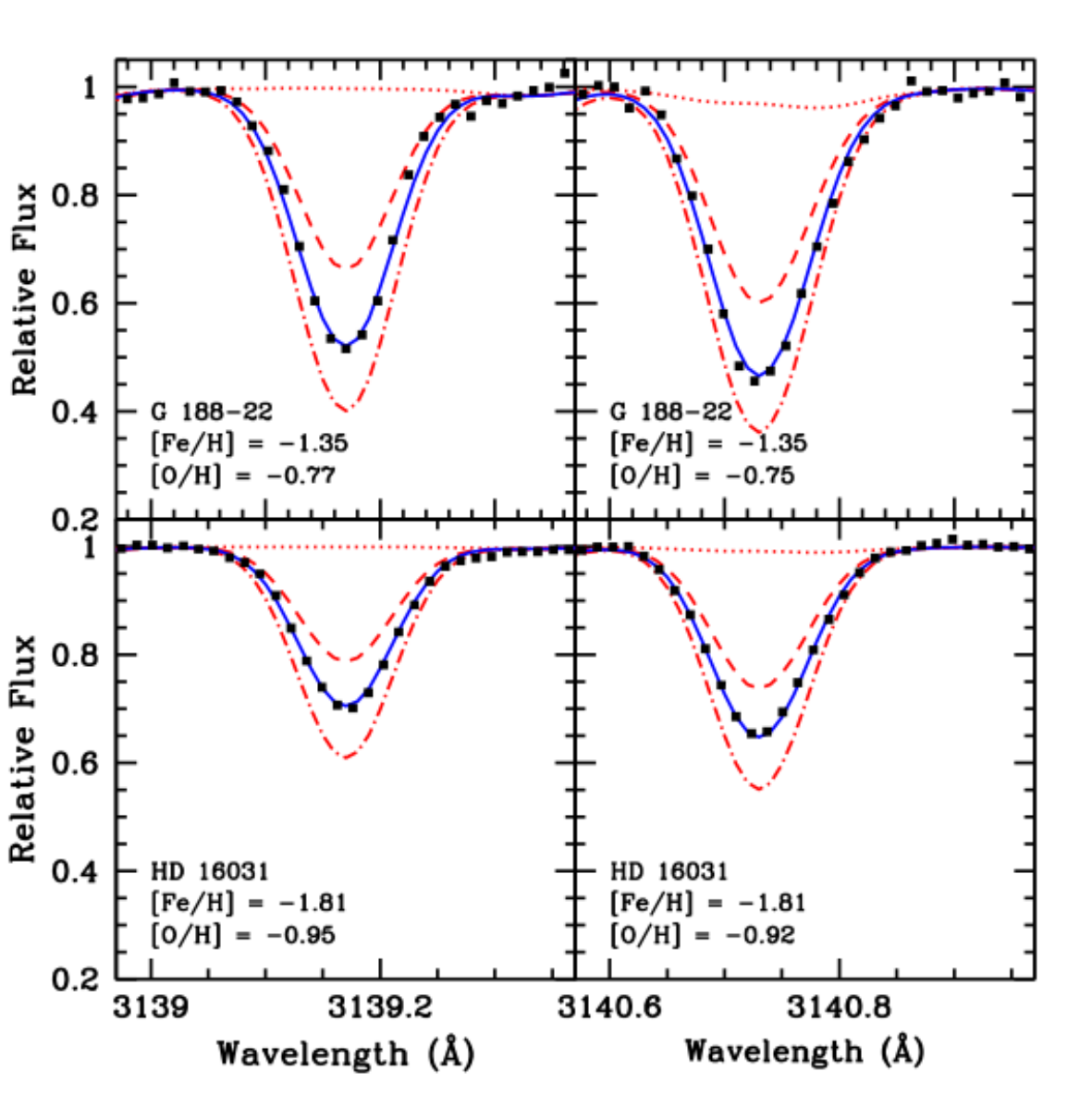
Synthesis of Be II lines



BD +26 2137
[Fe/H] = -1.97
A(Be) = -0.68

BD -17 484
[Fe/H = -1.56
A(Be) = -0.37

Synthesis of OH lines in the UV

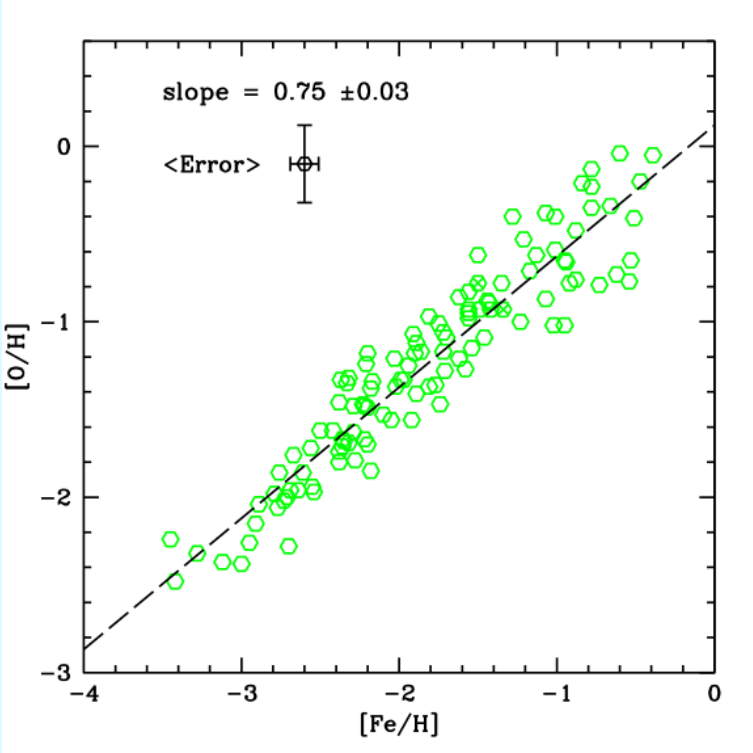


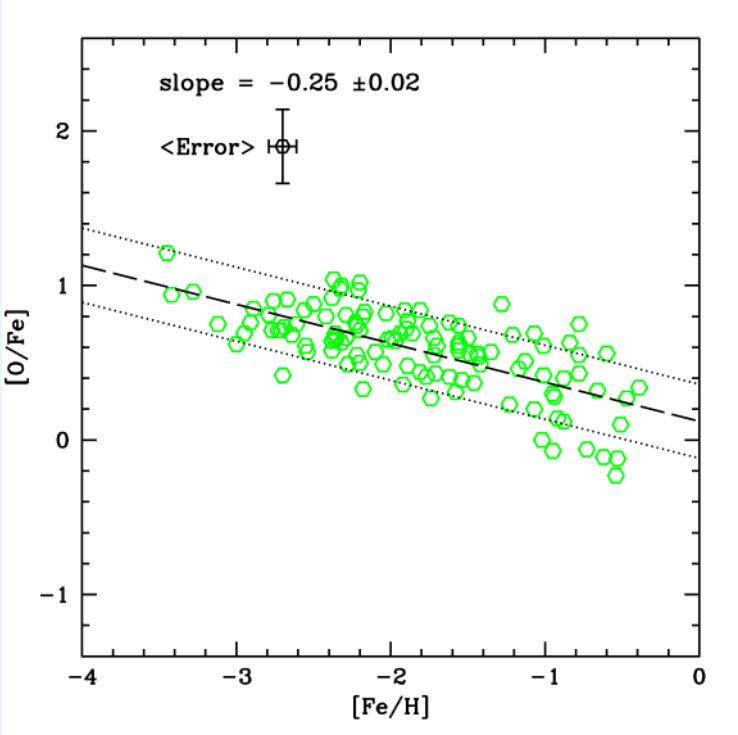
3 OH features;
3130, 3139, 3140

G 186-12
[Fe/H] = -1.35
[O/H] = -0.76

HD 16031
[Fe/H] = -1.81
[O/H] = -0.94

Fe and O



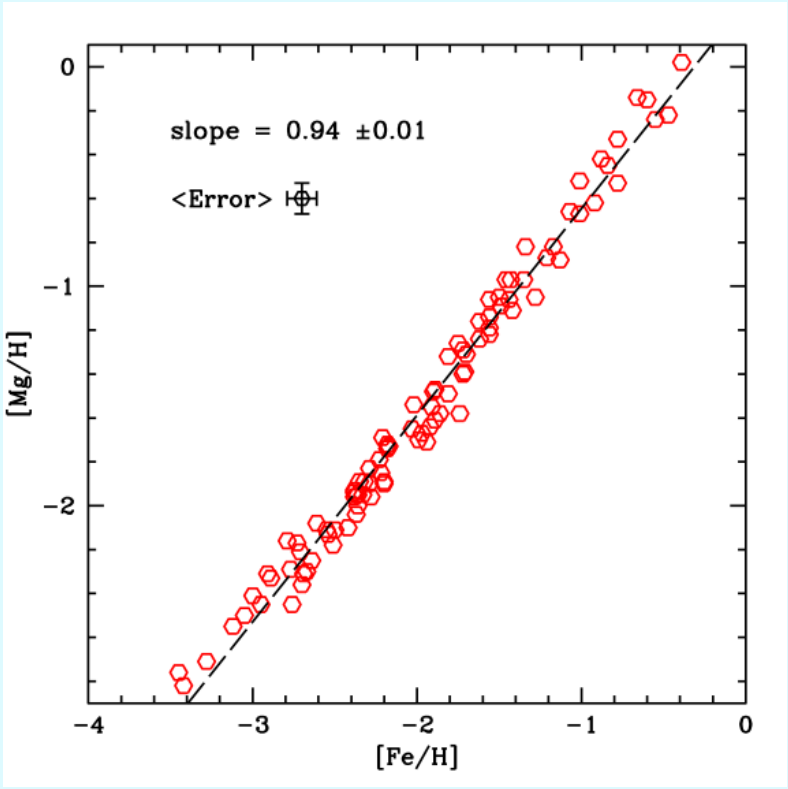


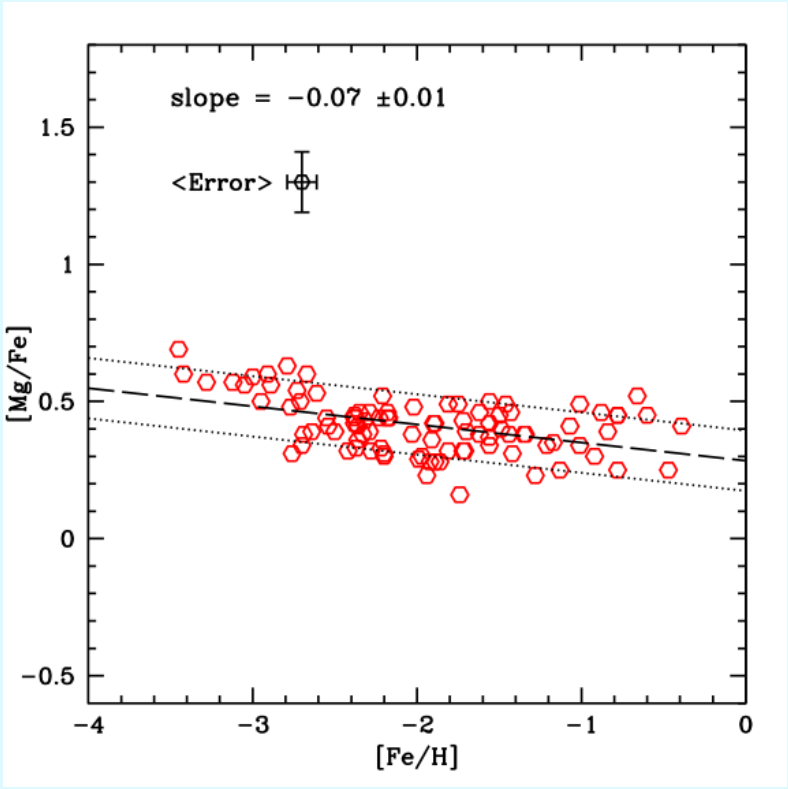
Tight relationship between Fe and O from the UV lines of OH.

[O/Fe] shows a smooth decline from [Fe/H] of -3.5 to -0.5.

Larger spread in O at higher [Fe/H].

Fe and Mg

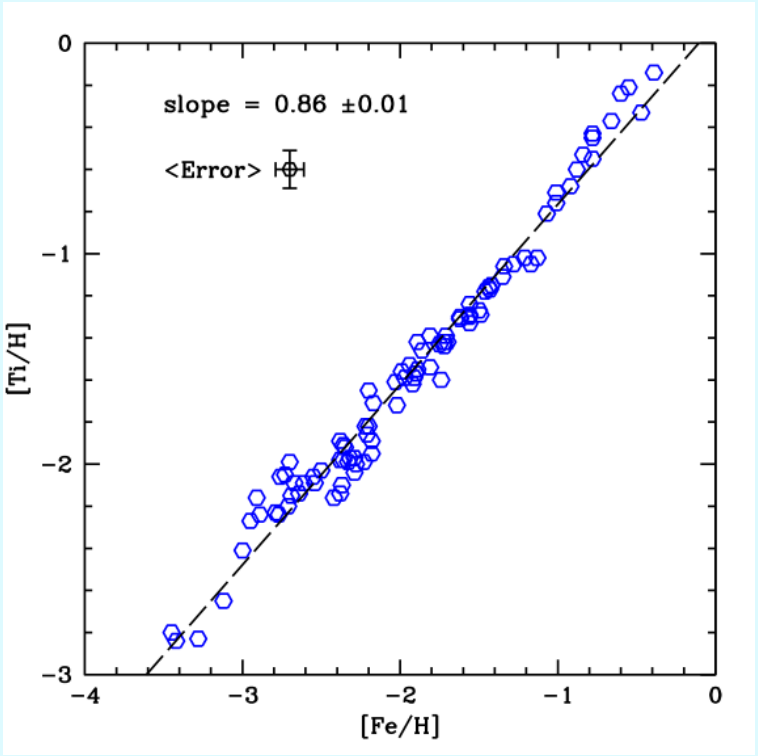


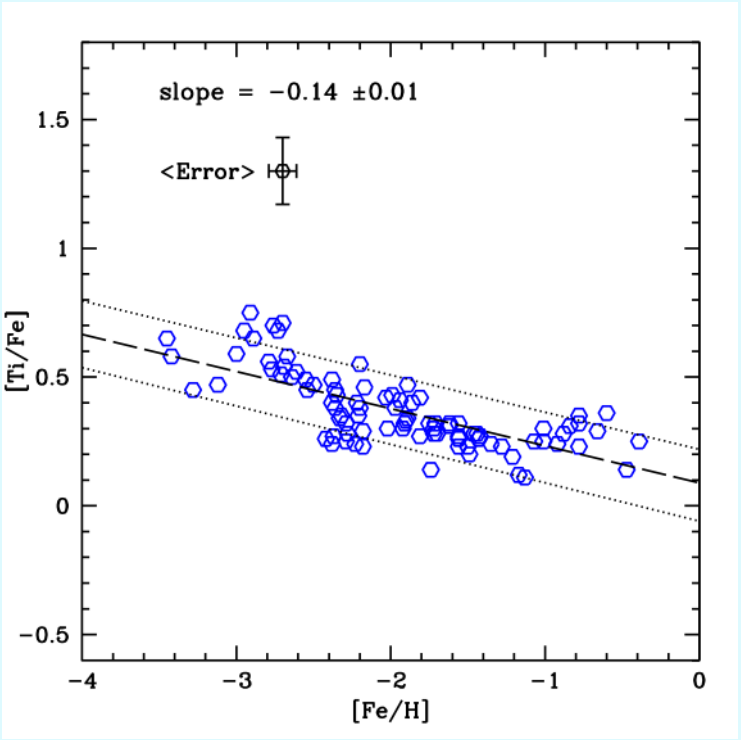


[Mg/H] and [Fe/H] are remarkably well correlated

Shallow slope between [Mg/Fe] and [Fe/H]

Fe and Ti





[Ti/H] and [Fe/H] are remarkably well correlated

Steeper slope between [Ti/Fe] and [Fe/H]

The Role of Supernovae

Supernovae SNe Ia contribute

~57 % of Fe

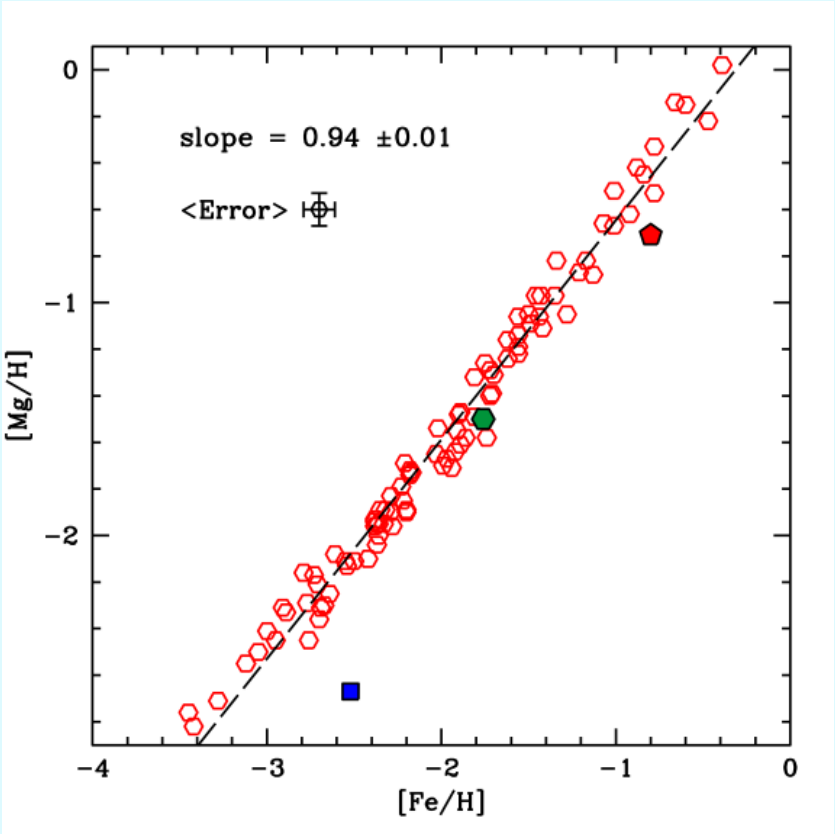
~1 % of Mg

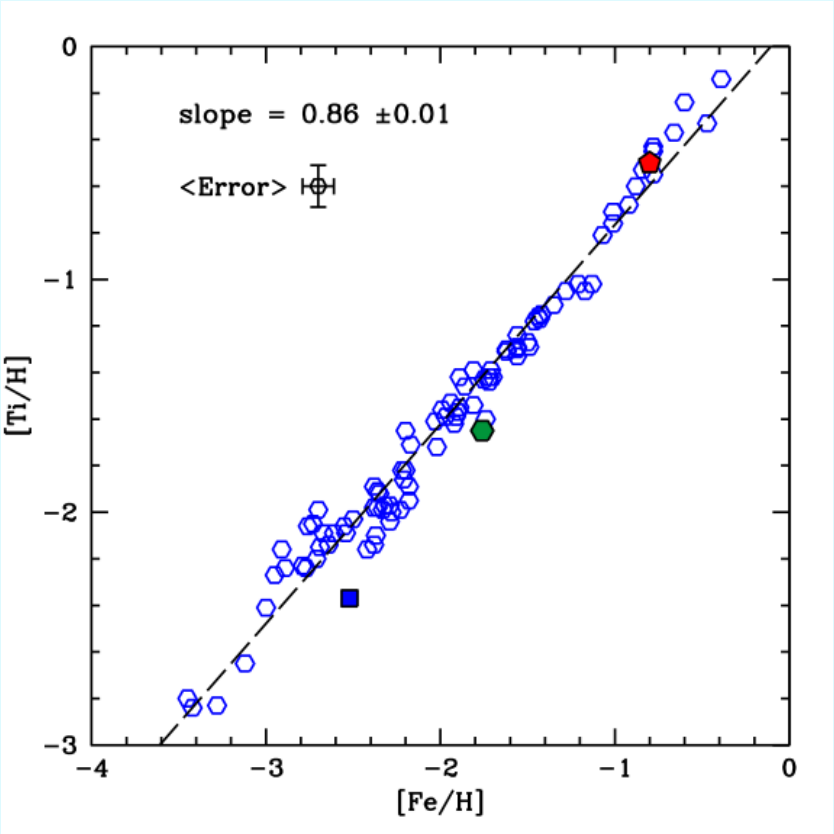
~6 % of Ti

to the solar abundances (Tsujimoto et al 1995)

Mg is almost all from SN II

Fe, Mg, Ti in Globular Clusters

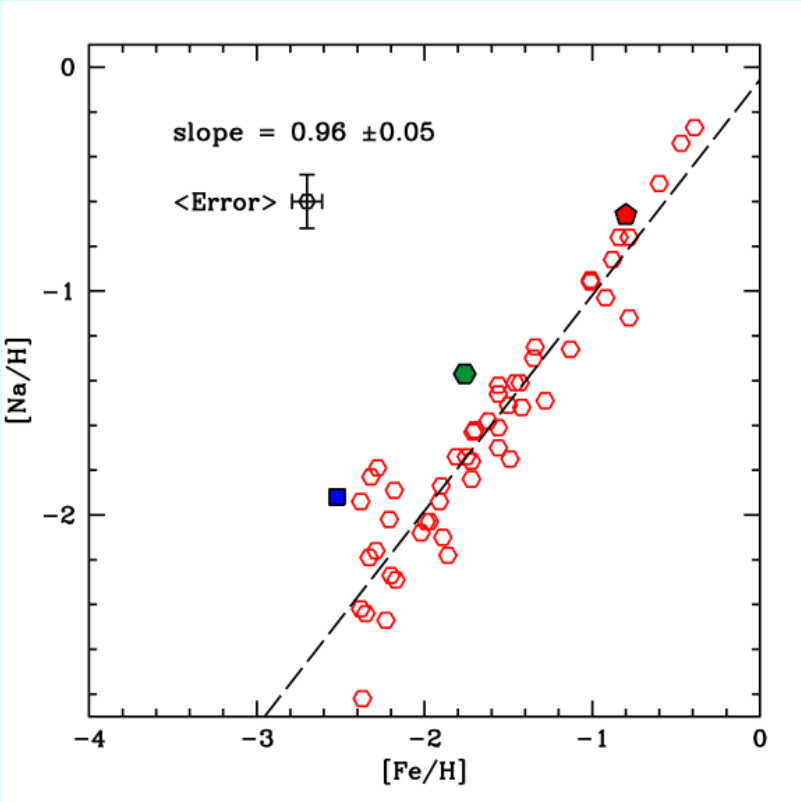


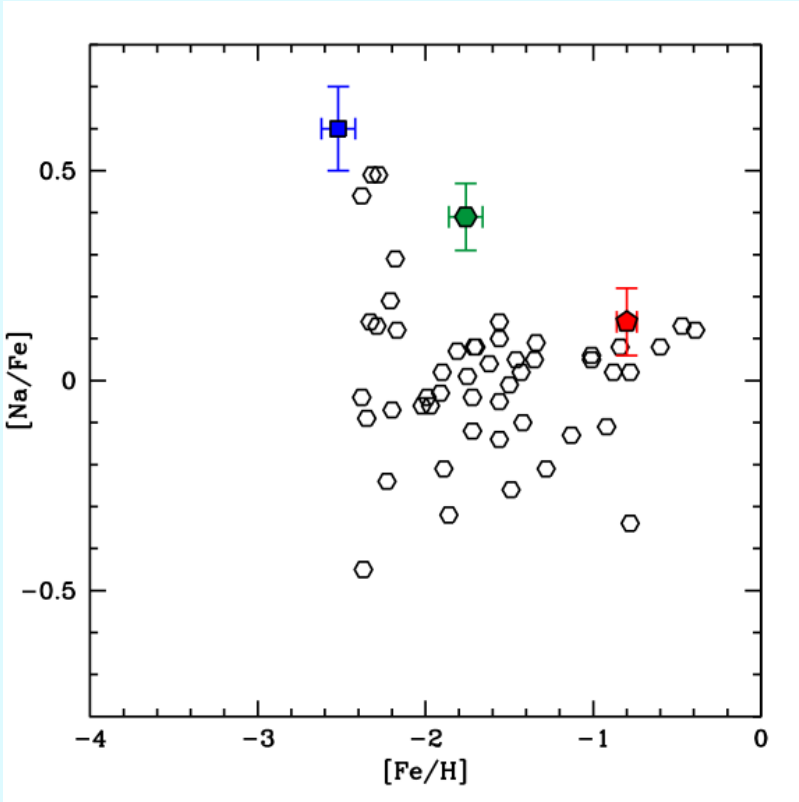


[Mg/H] is lower than the field stars in M 92

M 13 and M 71 match the field stars

Fe and Na



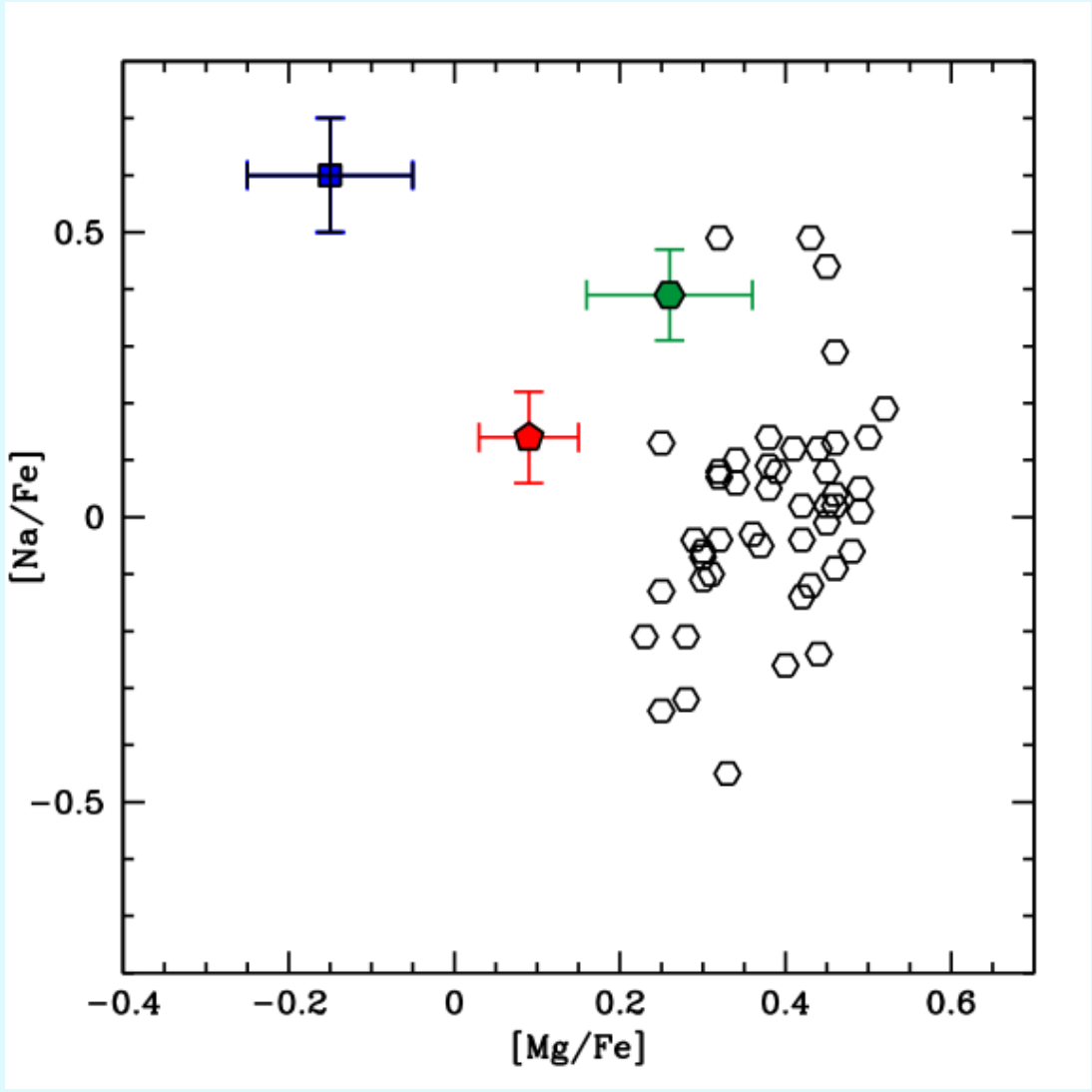


M 71 OK

M 13 Na maybe higher

M 92 Na higher than field star relationship

Na and Mg



M 92

Na enhanced

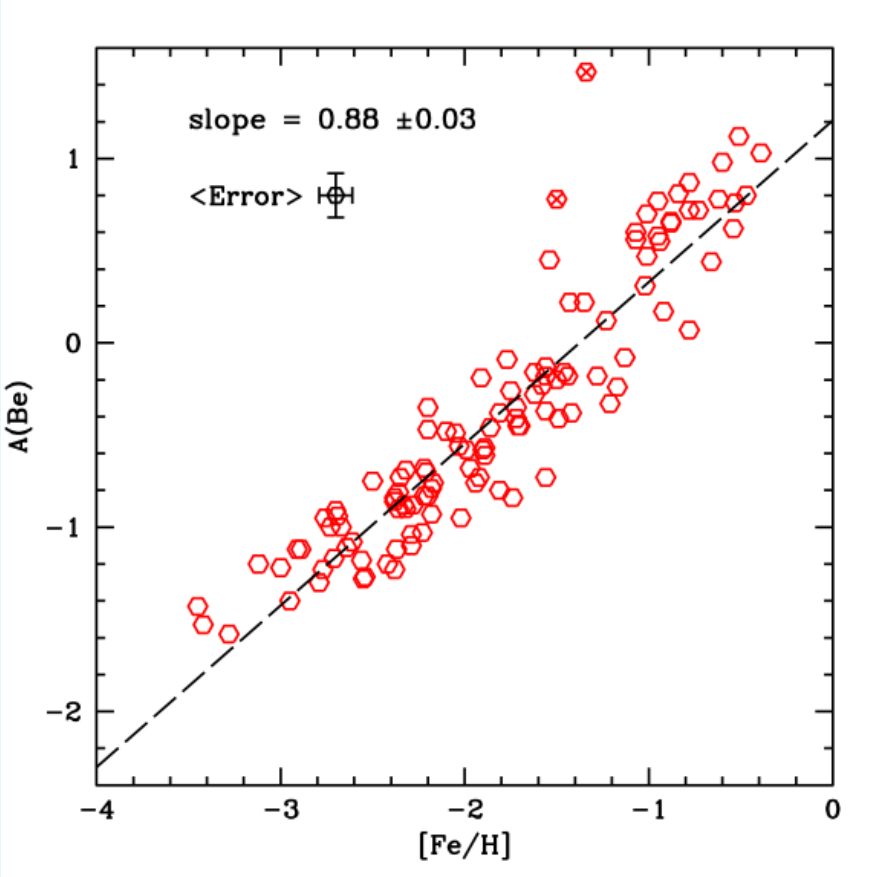
Mg depleted

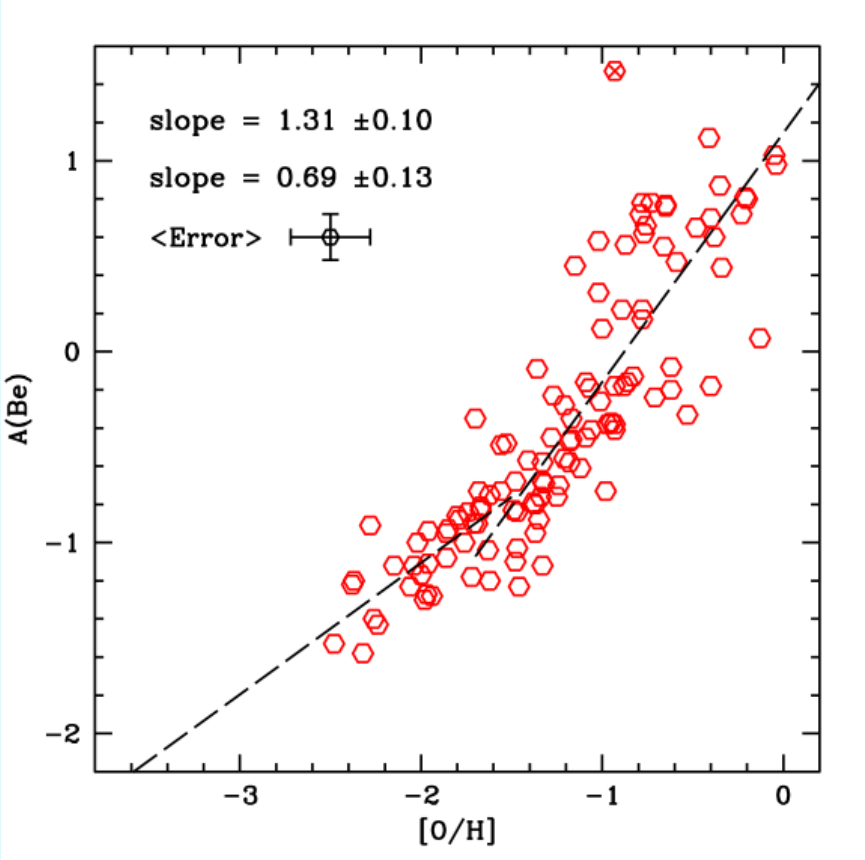
Ne → Na cycling

Mg → Al cycling

King et al. 1998

Beryllium Results





Be is enriched at early eras relative to Fe and O.

Be is made then in the vicinity of supernova.

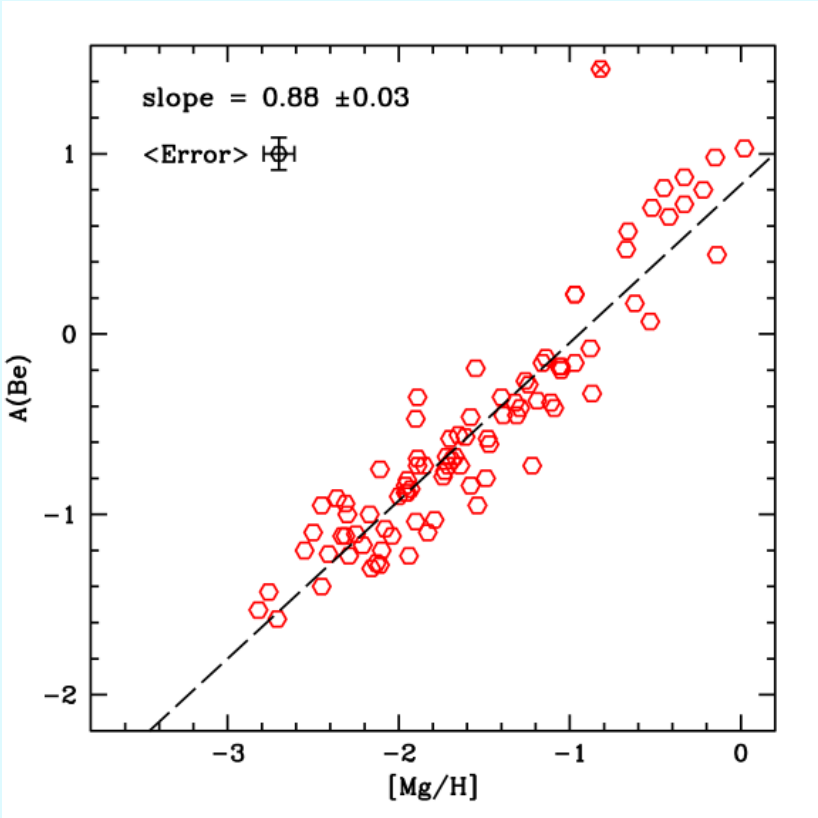
Be Formation Mechanisms

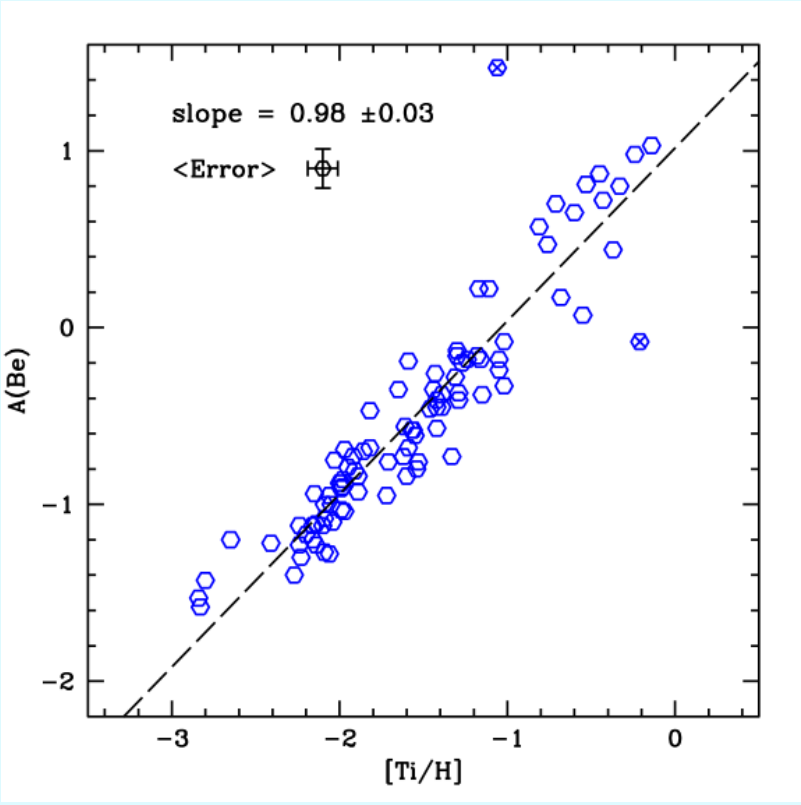
1. In the vicinity of supernova: CNO nuclei are accelerated into surrounding gas and are broken up into smaller pieces, e.g. Li, Be, B. CNO as "bullets." Dominates in oldest stars. Be-O slope ≤ 1.

2. Standard Galactic Cosmic Ray (GCR) spallation reactions. Energetic cosmic rays (>150 Mev) bombard CNO in the ISM producing Li, Be, B etc. CNO as "targets."

   steeper slope: Be-O slope ≤ 2.

Be and Mg Be and Ti





Mg and Ti as surrogates for O

Be and Mg

slope = 0.88 ± 0.03

Be and Ti

slope = 0.98 ± 0.03

Kinematics and Beryllium

Dissipative stars:

Galactic rotation larger than 40 km/s

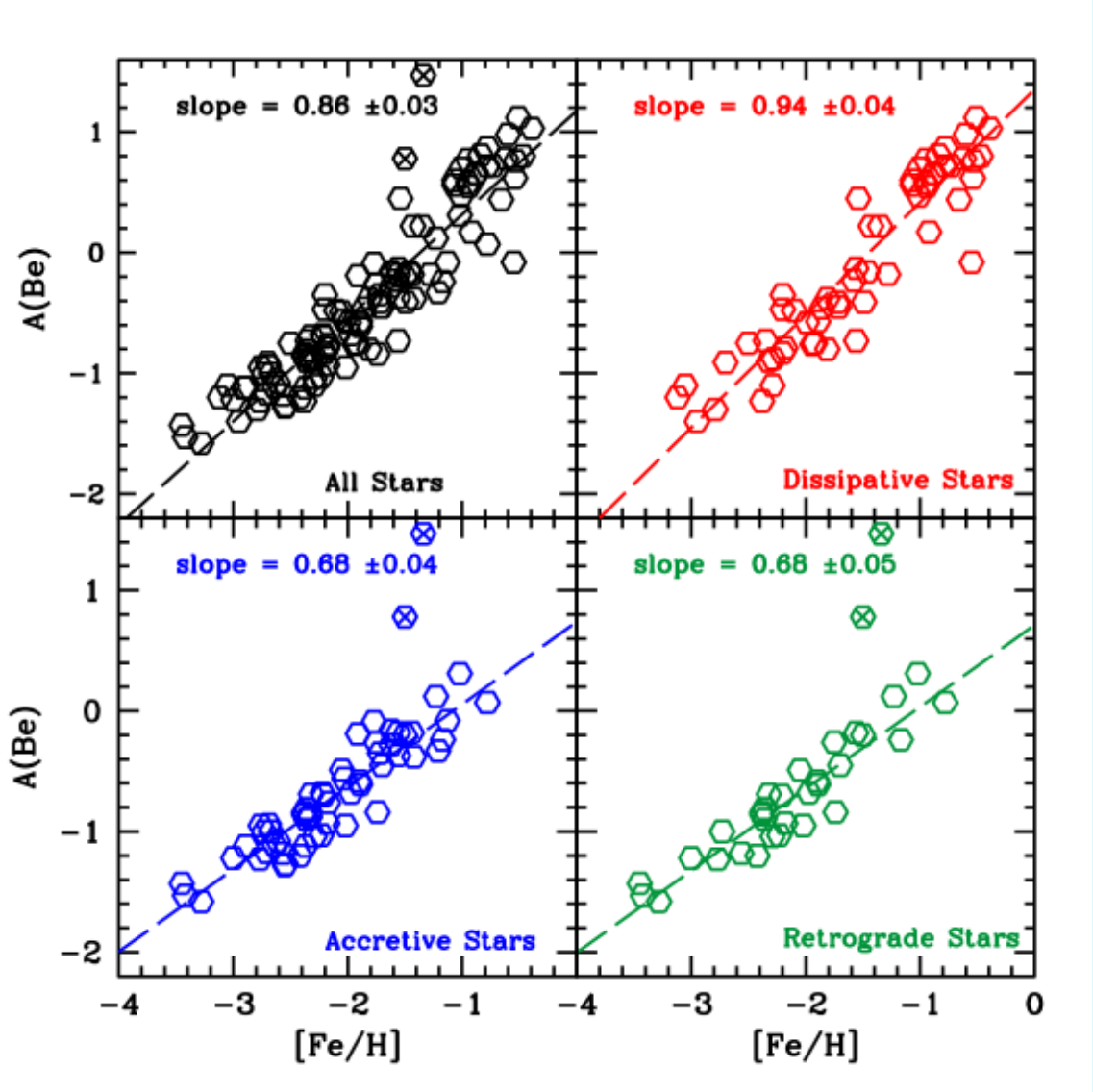
Apogalactic distance less than 15 kpc

Accretive Stars: all others

Retrograde Stars: V below -220 km/s

Gratton et al. 2003

Different relationships of Be and Fe



Dissipative

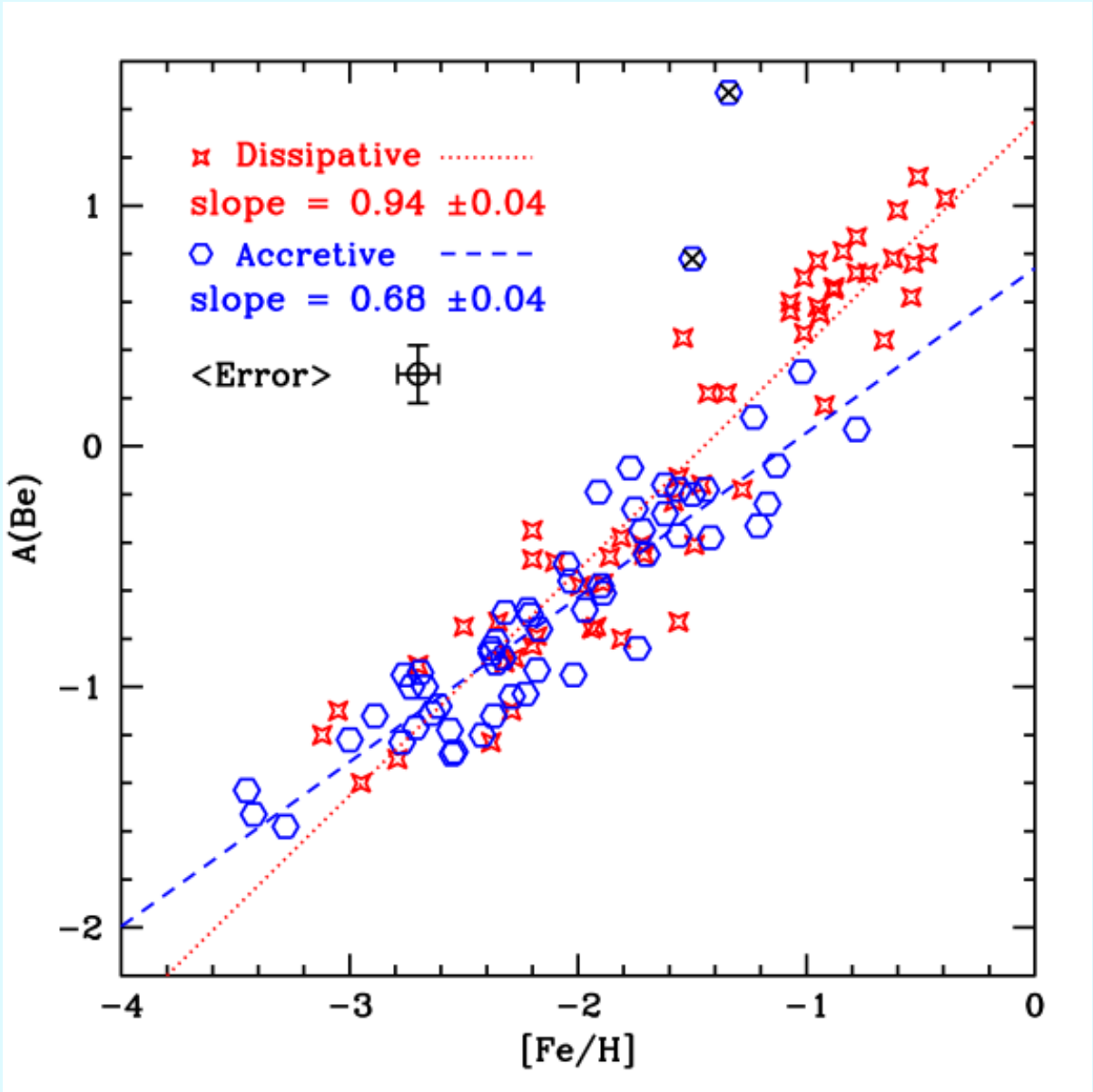
slope = 0.94±0.04

Accretive

slope = 0.68±0.04

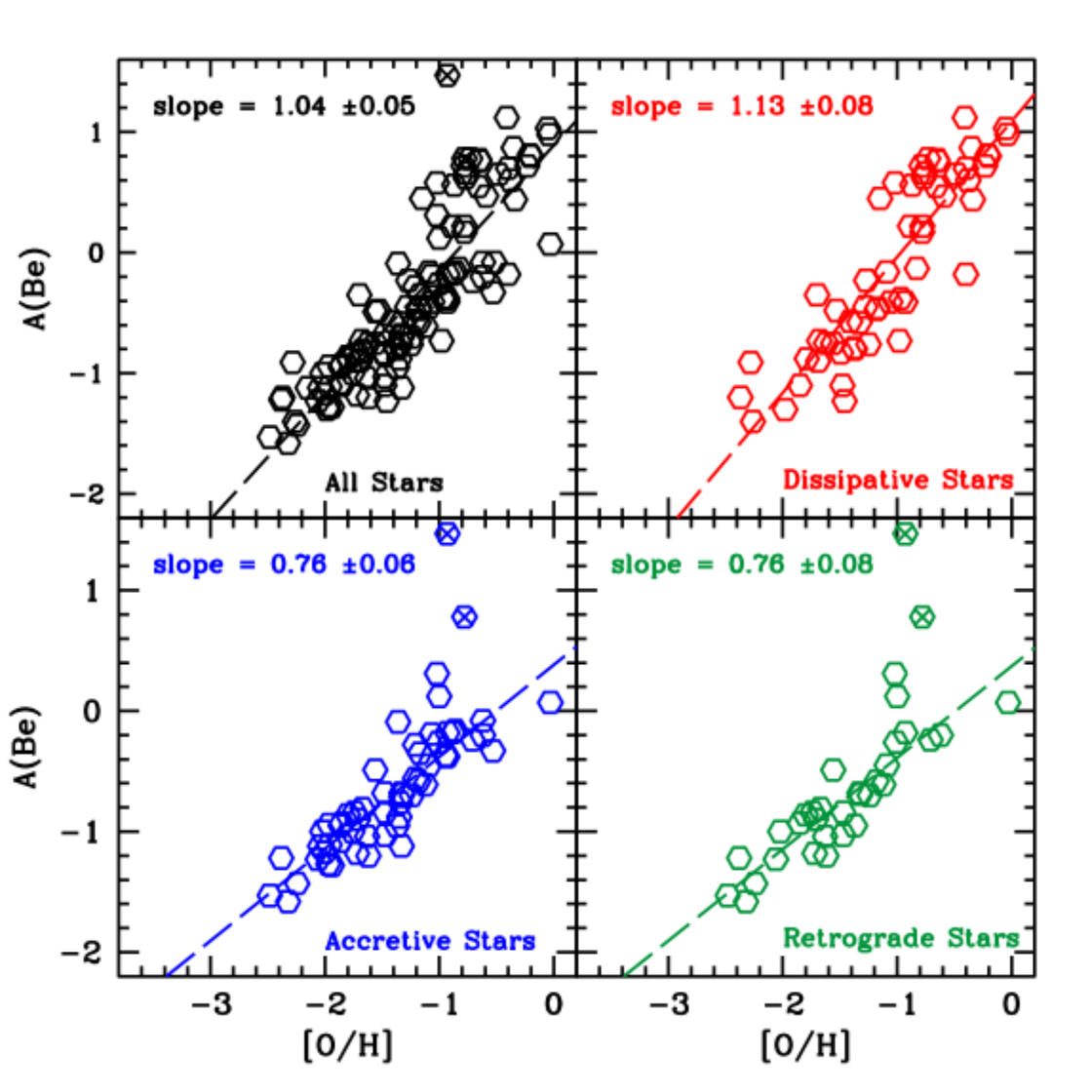
Retrograde

slope = 0.68±0.05



The different groups have different Be histories and formation mechanisms

Different relationships of Be and O



Dissipative

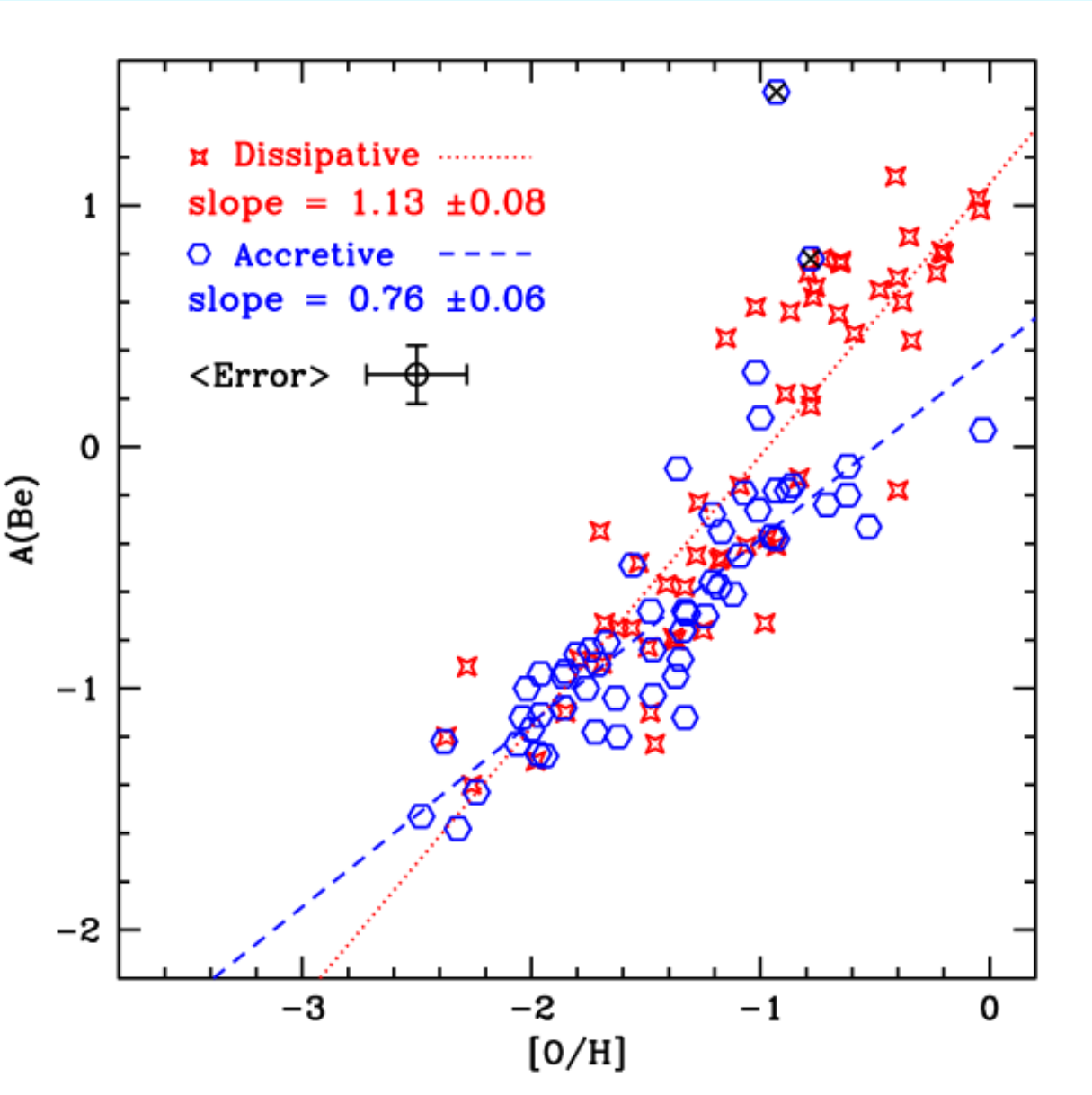
slope = 1.13±0.08

Accretive

slope = 0.76±0.06

Retrograde

slope = 0.76±0.08



Different populations →

Different Be formation mode

Dissipative - primarily GCR

Accretive - primarily near SN II

Summary/Conclusions

Excellent data set - high S/N, high resolution

Uniform analysis, 103 unevolved stars

[Fe/H] from -0.5 to -3.5

Abundances of Be, O, Na, Mg, Ti, Fe

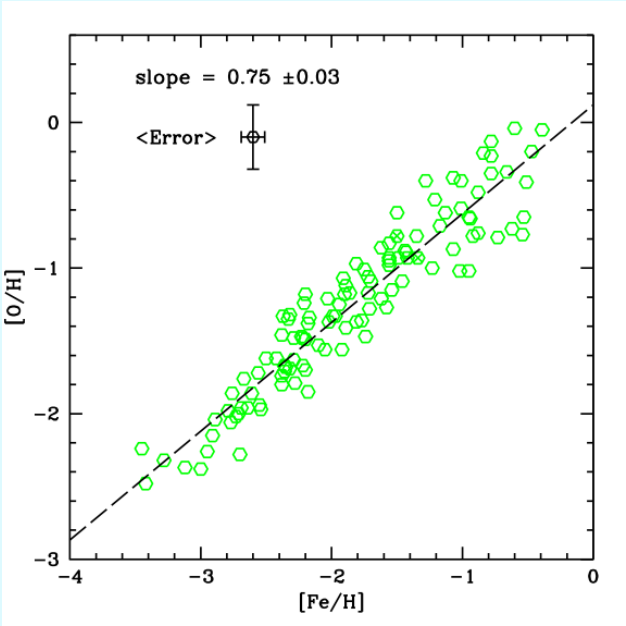
Kinematics known for all except 2

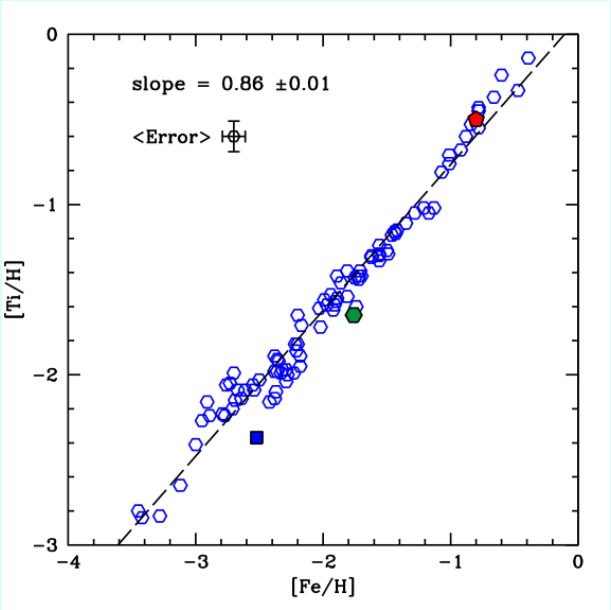
Plus 3-5 turn-off stars in 3 globular clusters

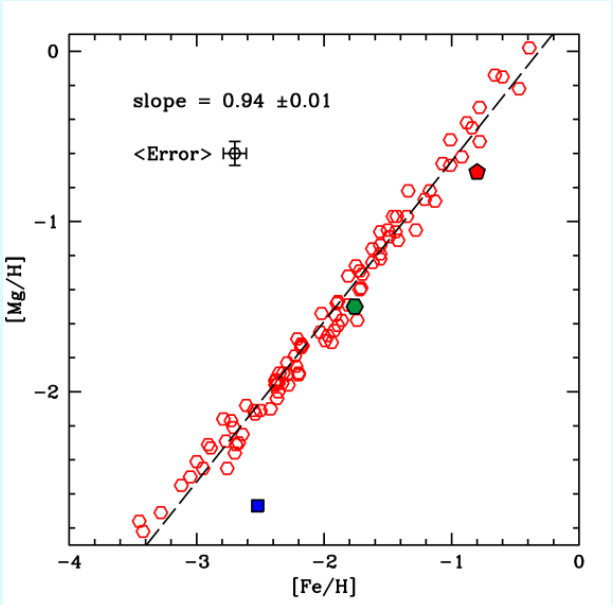
[Fe/H] vs [O/H] **slope = 0.76 ± 0.03**

[Fe/H] vs [Mg/H] **slope = 0.94 ± 0.01**

[Fe/H] vs [Ti/H] **slope = 0.86 ± 0.01**





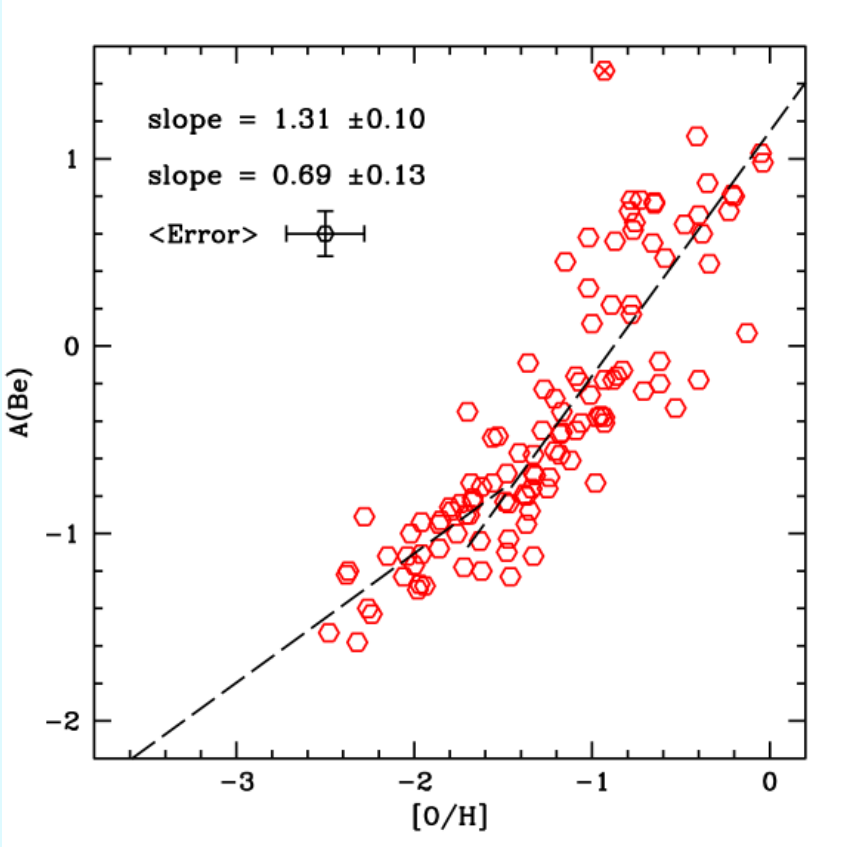


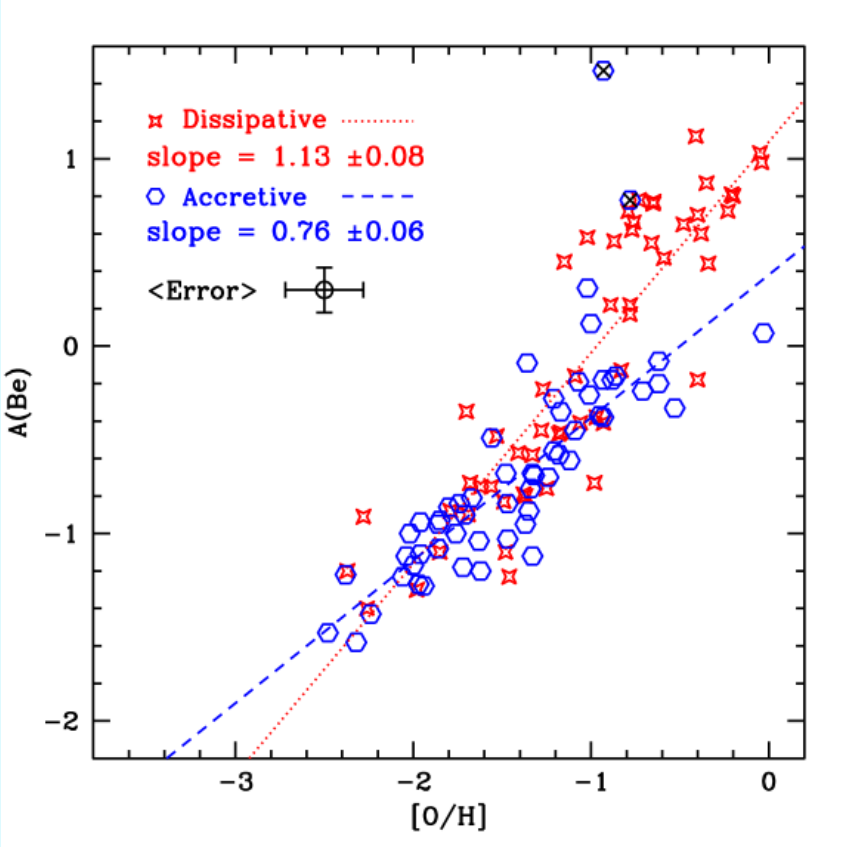
Tight correlations between Fe and O

Fe and Ti

Fe and Mg

Beryllium and Oxygen

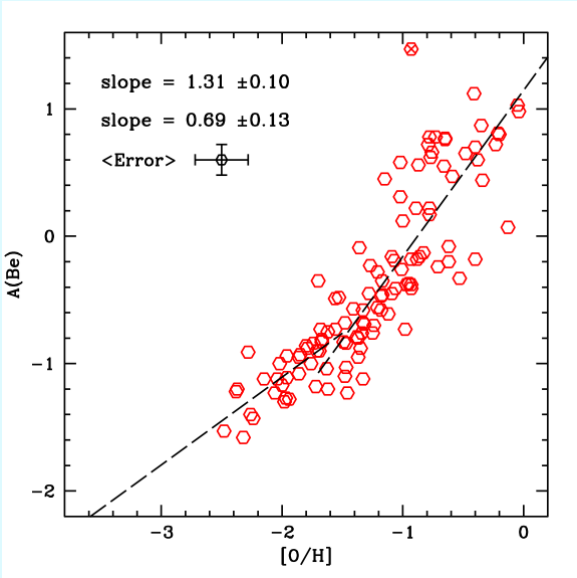


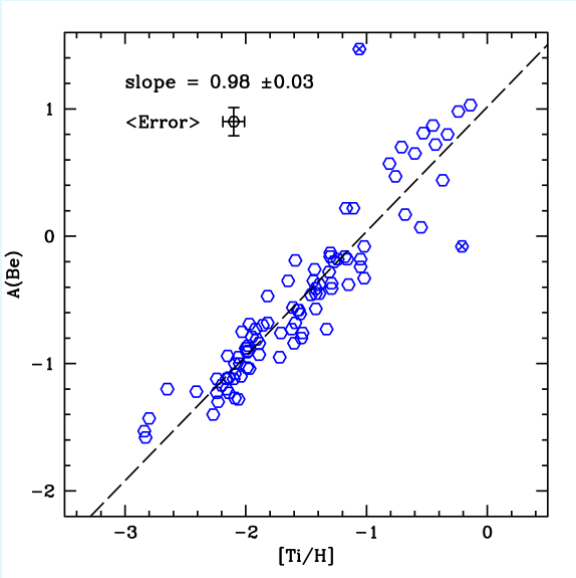


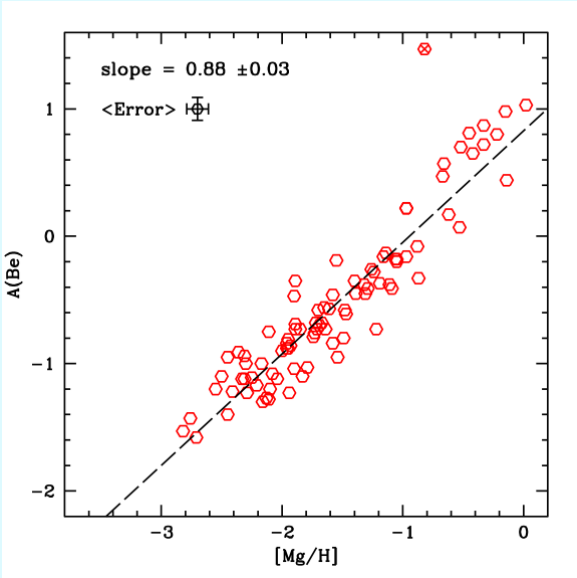
Supernovae vs GCR production of Be

CNO “bullets” CNO “targets”

Be with O, Ti, Mg







A(Be) vs [O/H]: low O 0.69 ±0.13

high O 1.31 ±0.10

A(Be) vs [Ti/H]: 0.88 ±0.03

A(Be) vs [Mg/H]: 0.98 ±0.03