Carbon in Milky Way Dwarf Spheroidal Galaxies

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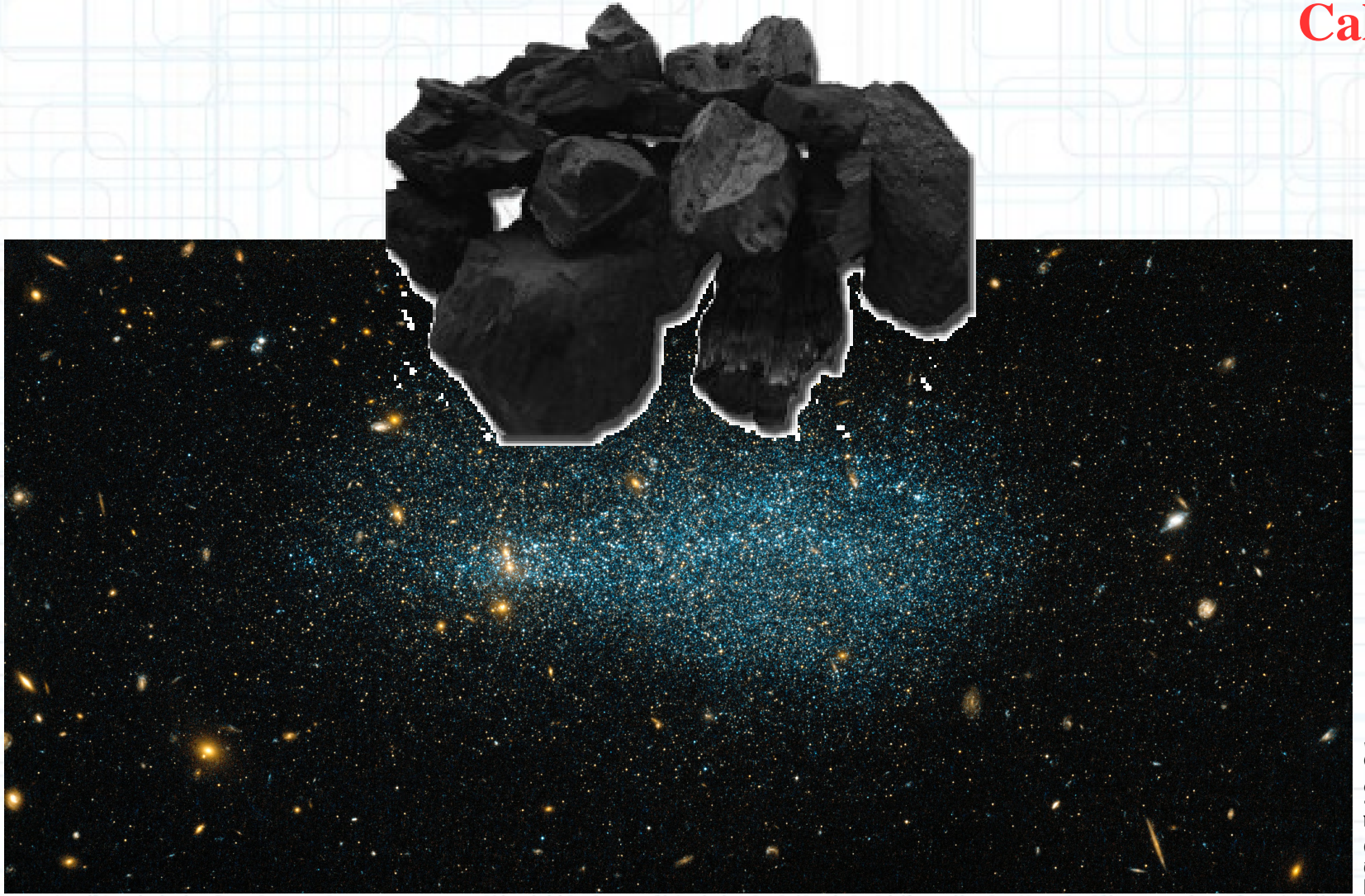
Caltech



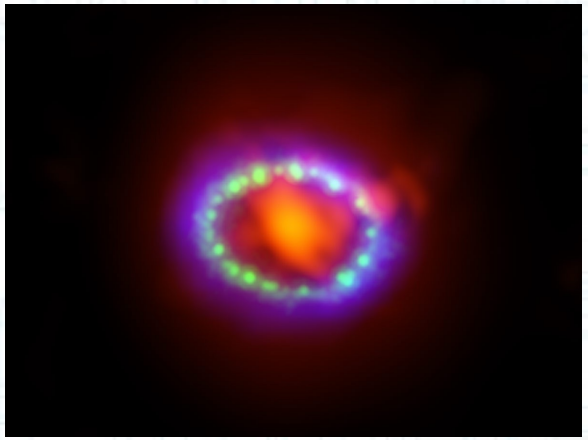
ESO 540-31
credit: ESA/Hubble & NASA

Kirby, Guo, Zhang, Deng, Cohen, Guhathakurta, Shetrone, Lee, & Rizzi, ApJ, in press, arXiv:1501.06908

Carbon has sources and a sink.

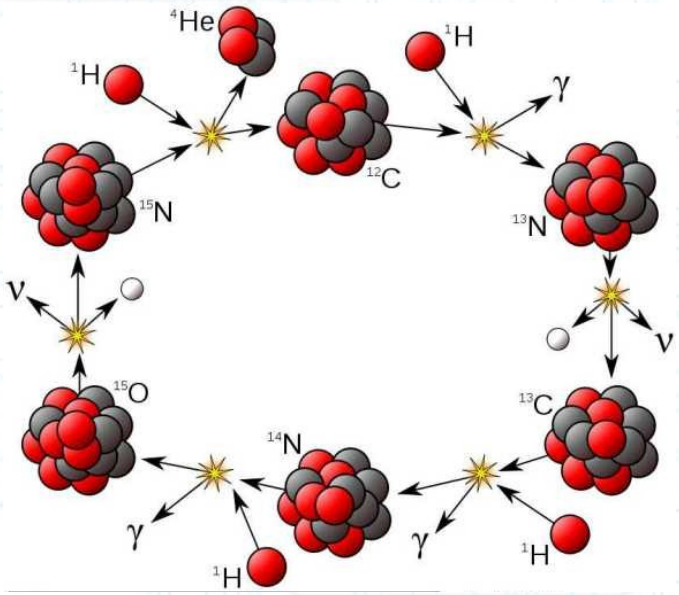
Sources:

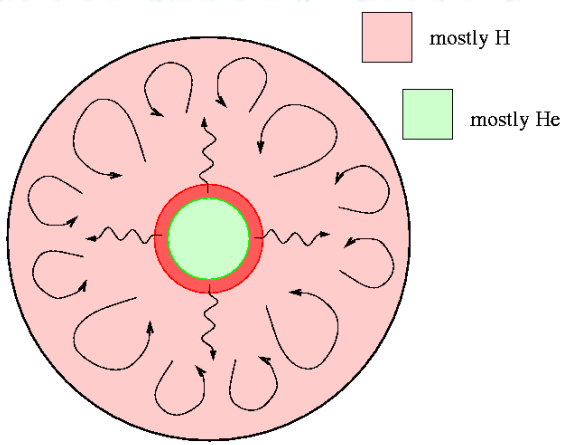
AGB winds



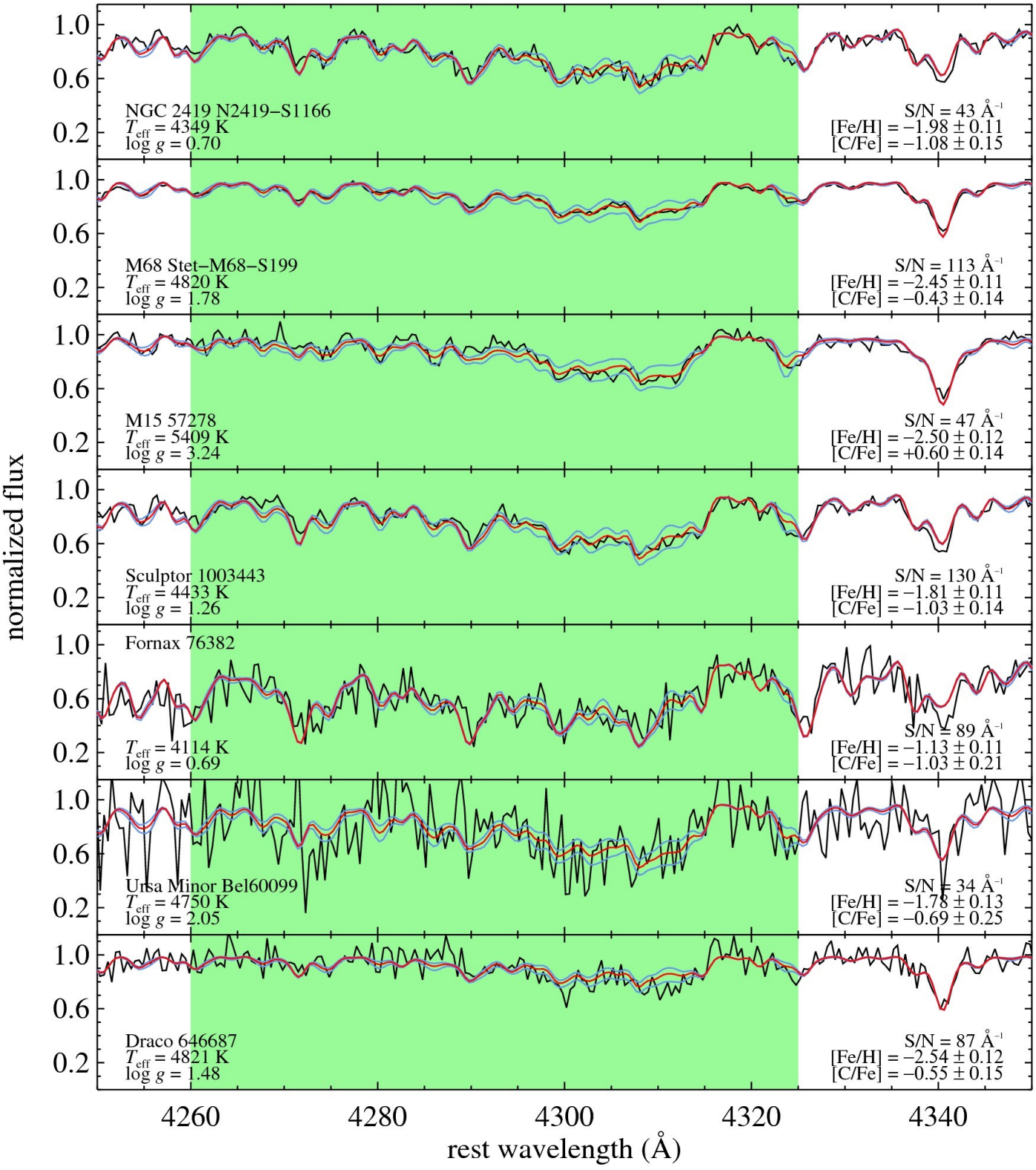
supernovae

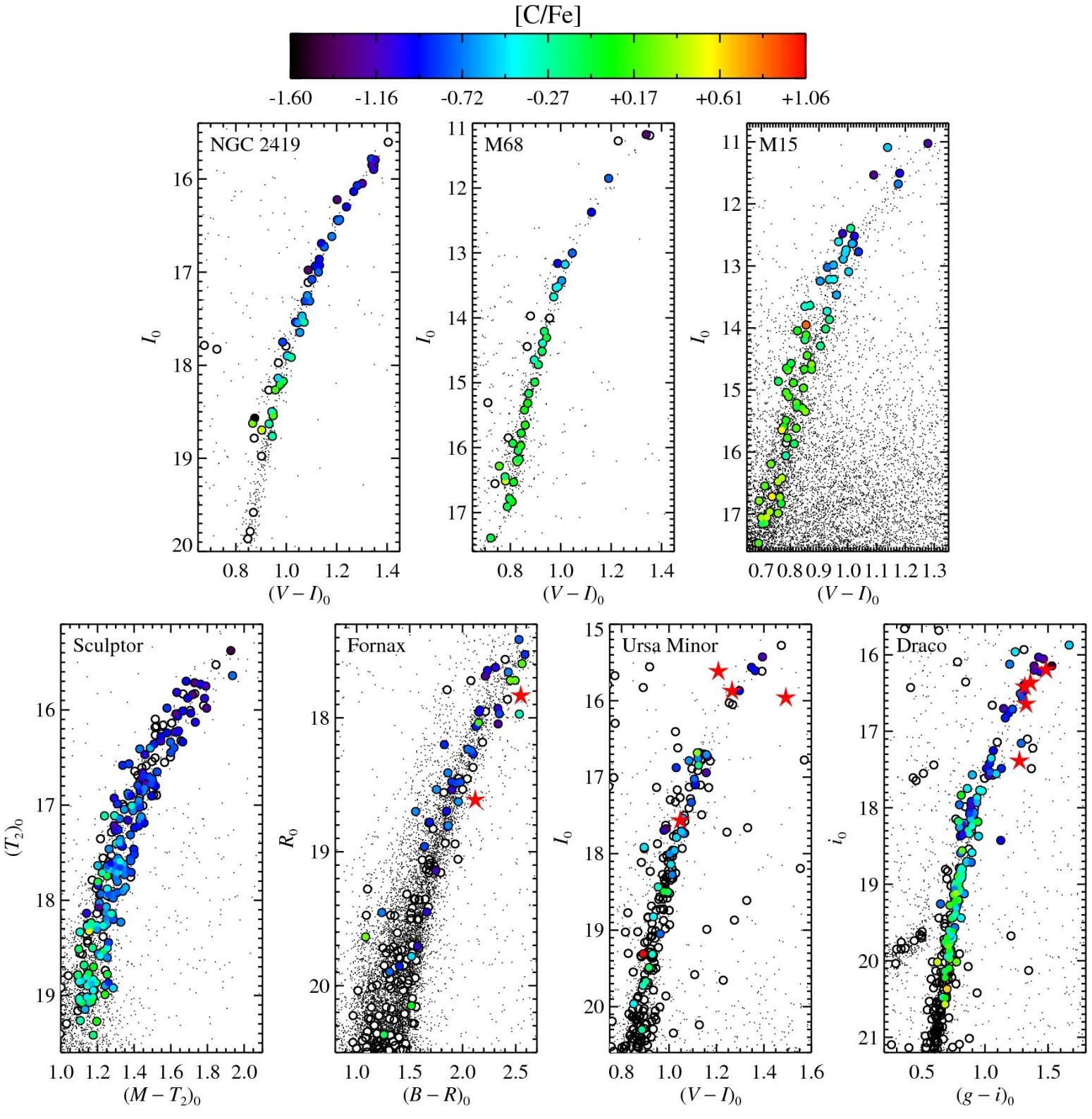
Sink:



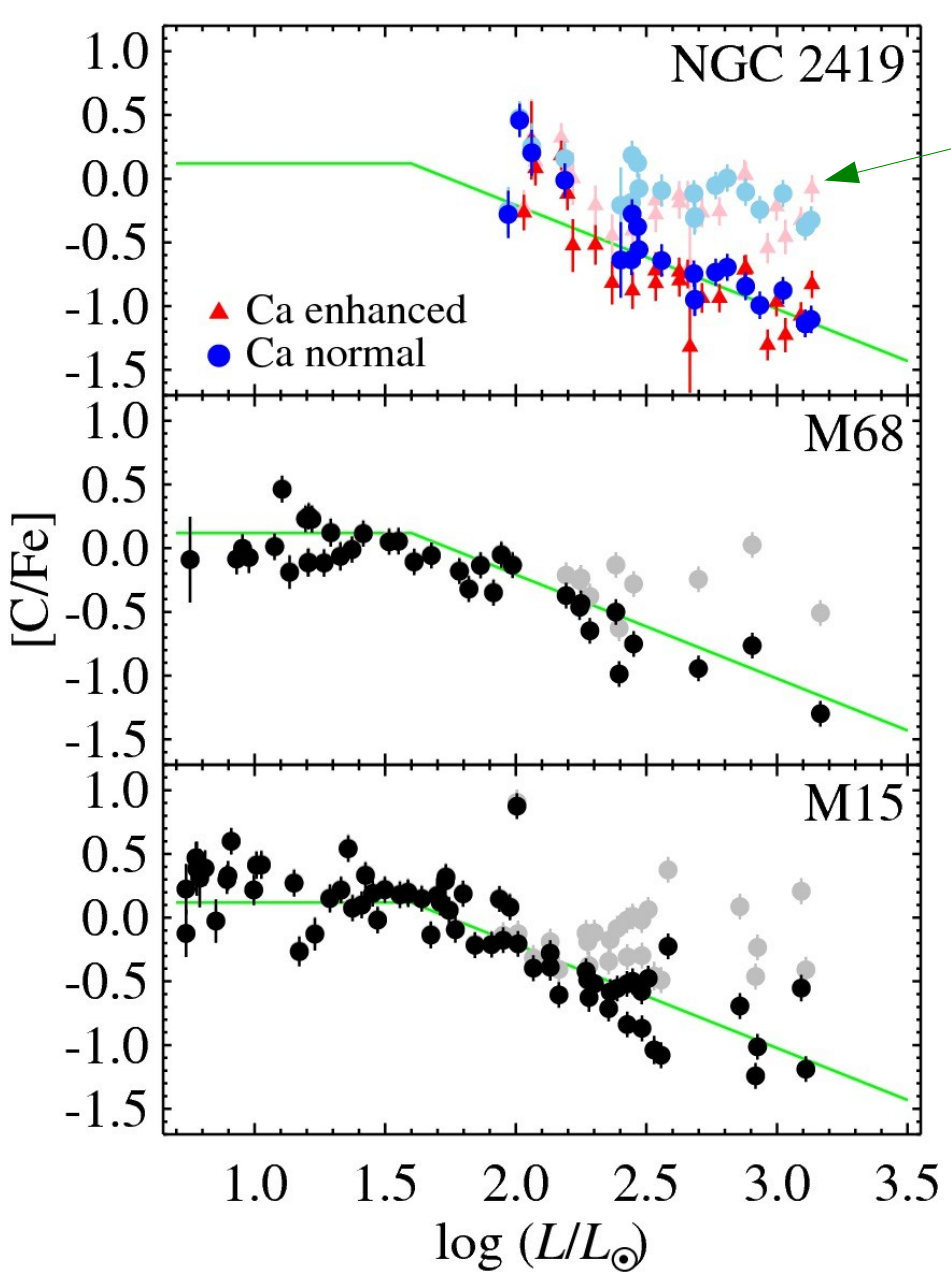


CNO cycle in red giants


normalized flux
rest wavelength (Å)
4260
4280
4300
4320
4340
1.0
0.6
0.2
NGC 2419 N2419−S1166
$T_{\rm eff}$ = 4349 K
log g = 0.70
S/N = 43 Å^{-1}
[Fe/H] = −1.98 ± 0.11
[C/Fe] = −1.08 ± 0.15
M68 Stet−M68−S199
$T_{\rm eff}$ = 4820 K
log g = 1.78
S/N = 113 Å^{-1}
[Fe/H] = −2.45 ± 0.11
[C/Fe] = −0.43 ± 0.14
M15 57278
$T_{\rm eff}$ = 5409 K
log g = 3.24
S/N = 47 Å^{-1}
[Fe/H] = −2.50 ± 0.12
[C/Fe] = +0.60 ± 0.14
Sculptor 1003443
$T_{\rm eff}$ = 4433 K
log g = 1.26
S/N = 130 Å^{-1}
[Fe/H] = −1.81 ± 0.11
[C/Fe] = −1.03 ± 0.14
Fornax 76382
$T_{\rm eff}$ = 4114 K
log g = 0.69
S/N = 89 Å^{-1}
[Fe/H] = −1.13 ± 0.11
[C/Fe] = −1.03 ± 0.21
Ursa Minor Bel60099
$T_{\rm eff}$ = 4750 K
log g = 2.05
S/N = 34 Å^{-1}
[Fe/H] = −1.78 ± 0.13
[C/Fe] = −0.69 ± 0.25
Draco 646687
$T_{\rm eff}$ = 4821 K
log g = 1.48
S/N = 87 Å^{-1}
[Fe/H] = −2.54 ± 0.12
[C/Fe] = −0.55 ± 0.15

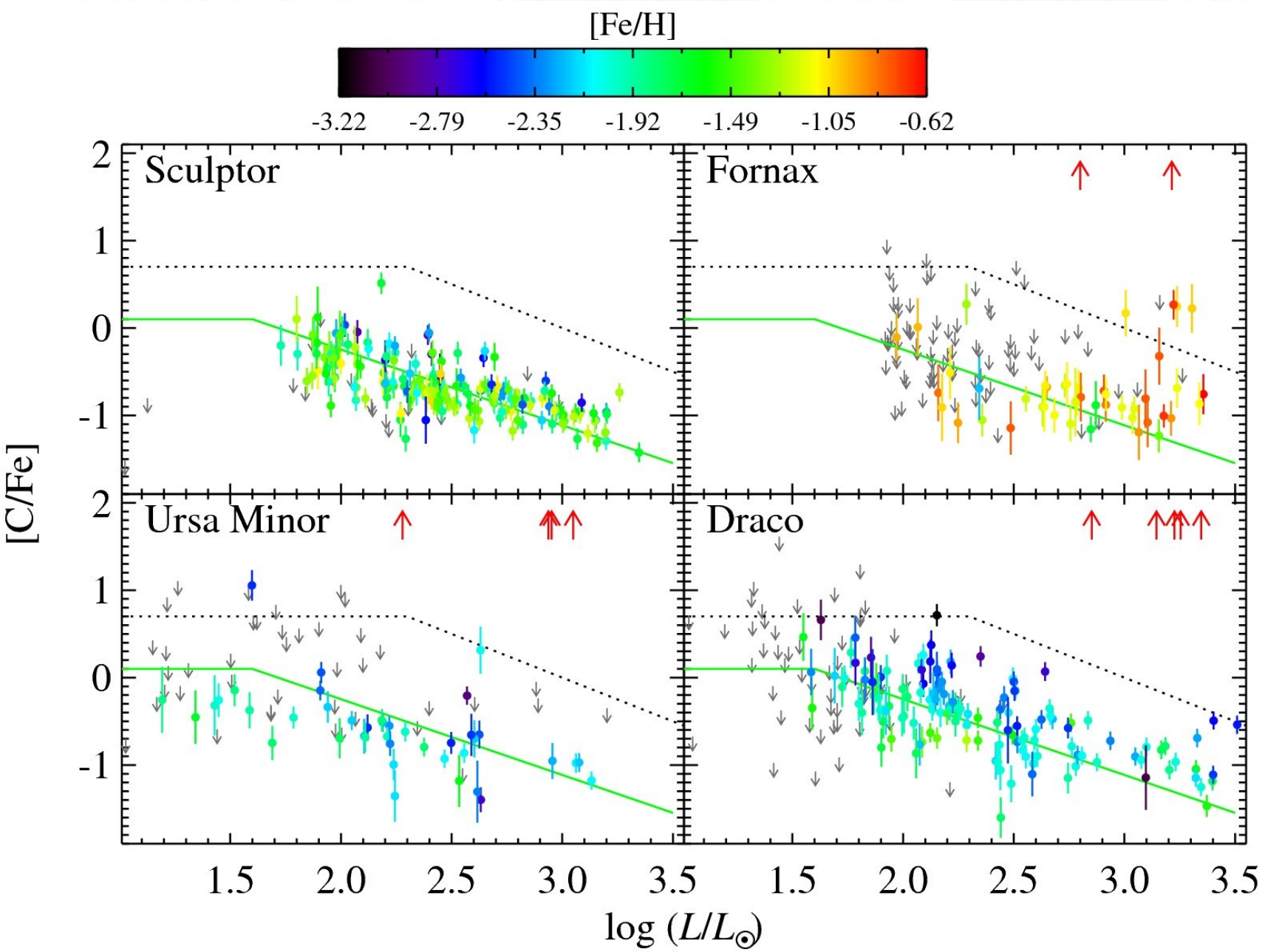

[C/Fe]
-1.60
-1.16
-0.72
-0.27
+0.17
+0.61
+1.06
NGC 2419
M68
M15
Sculptor
Fornax
Ursa Minor
Draco
I_0
$(V-I)_0$
$(T_2)_0$
$(M-T_2)_0$
R_0
$(B-R)_0$
i_0
$(g-i)_0$

Red giants eat carbon.

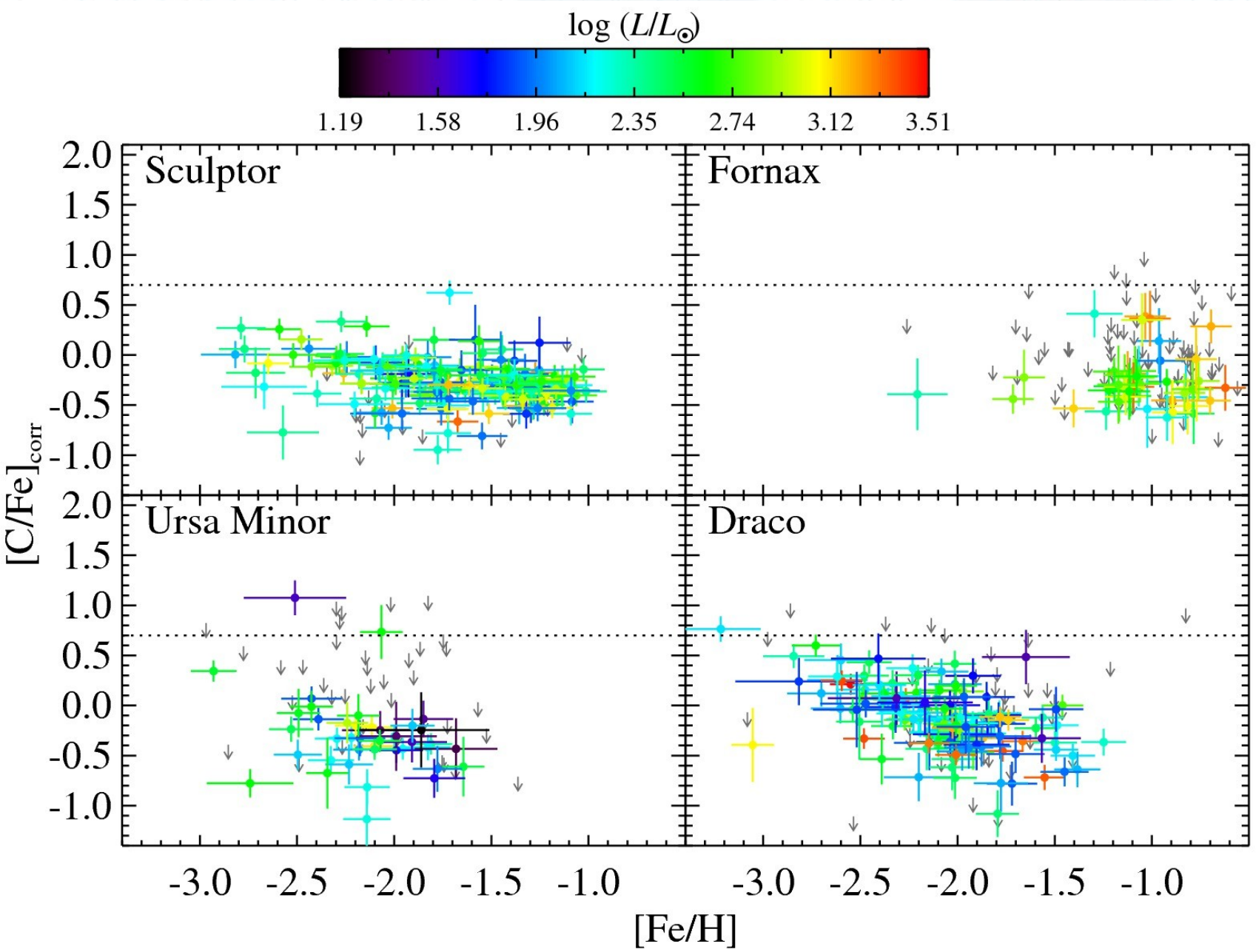


Corrected for astration
(Placco et al. 2014)

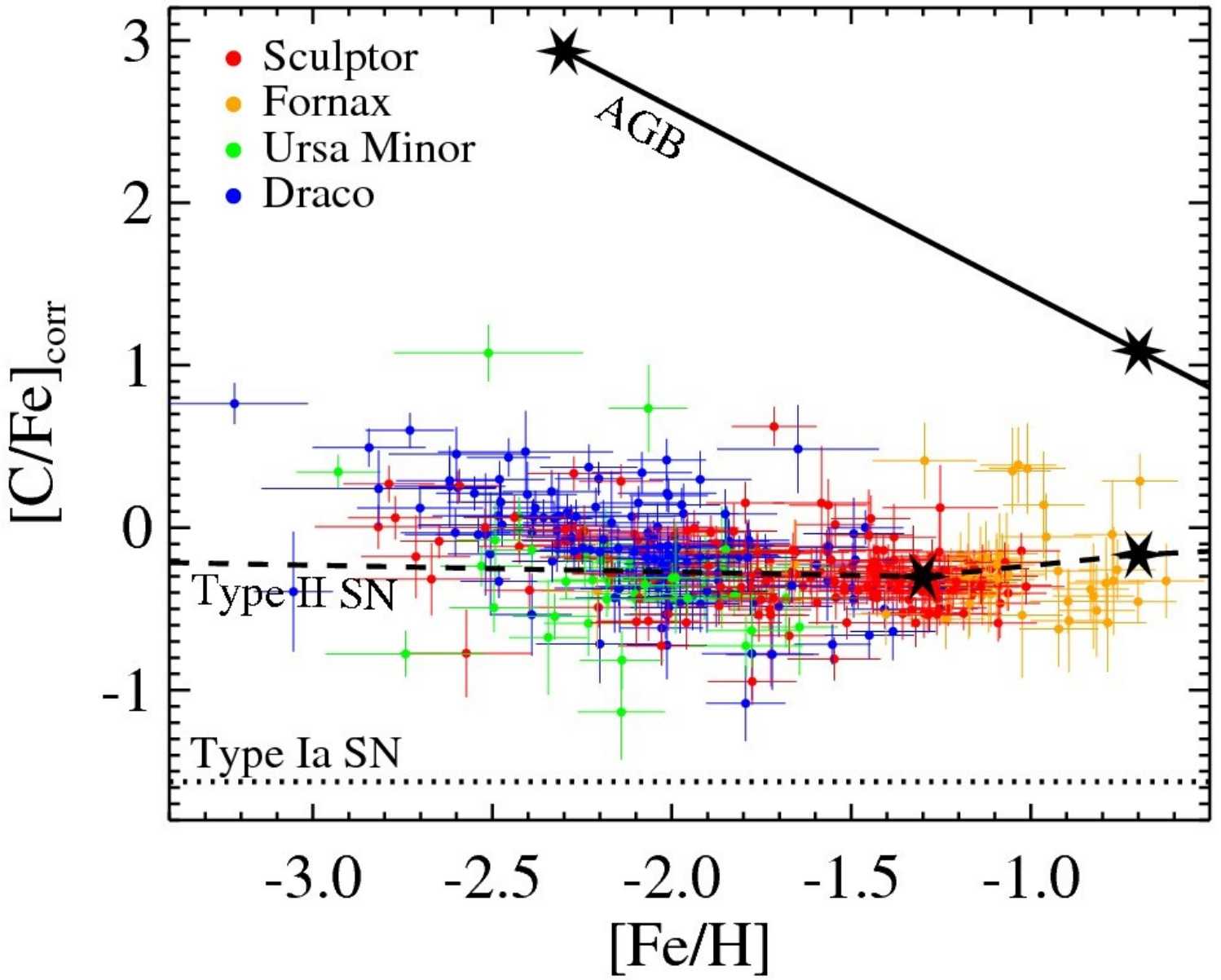
Red giants eat carbon in dSphs, too.



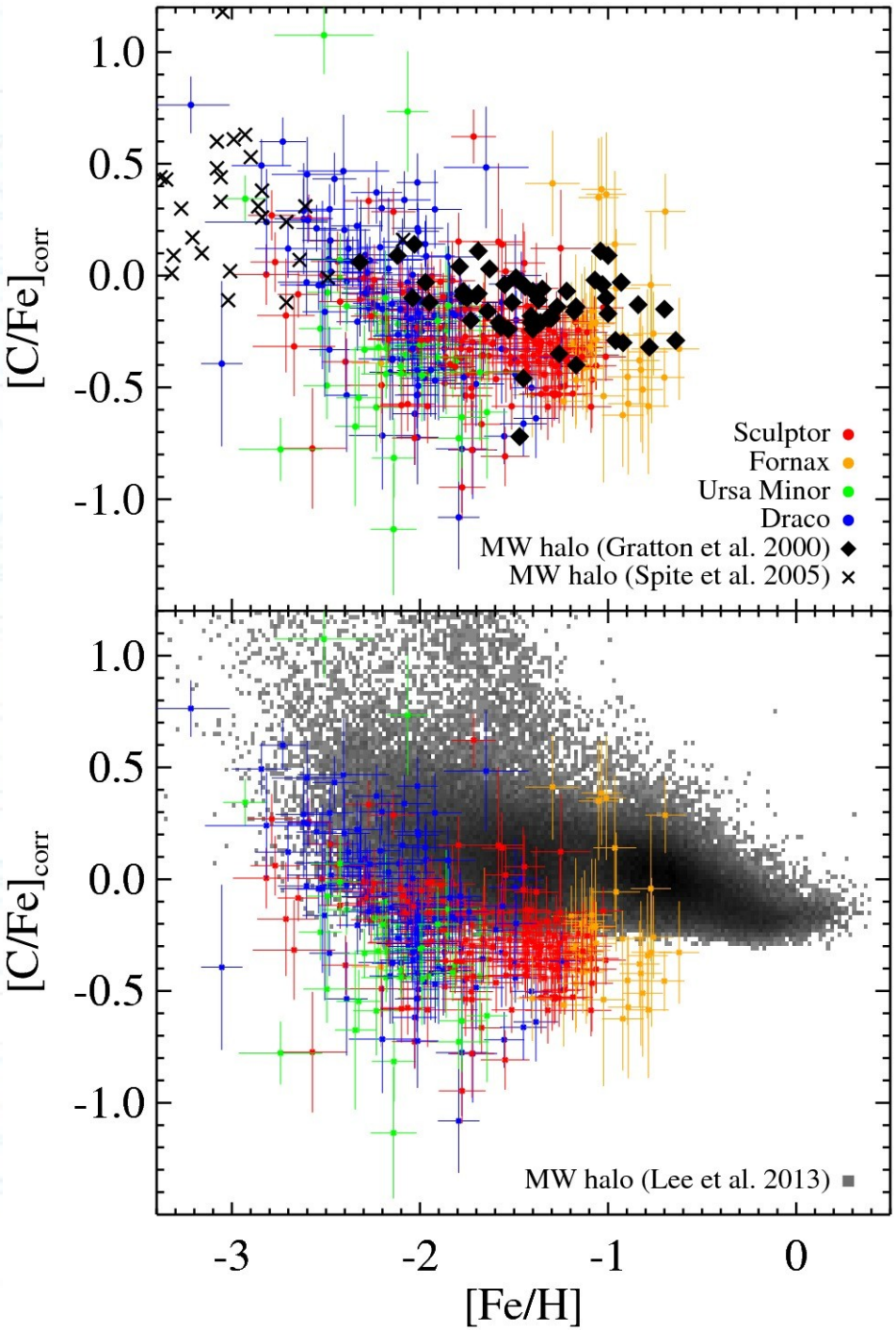
[C/Fe] depends on [Fe/H].



Carbon has at least three nucleosynthetic sources.



Carbon evolves differently in dSphs and the halo.

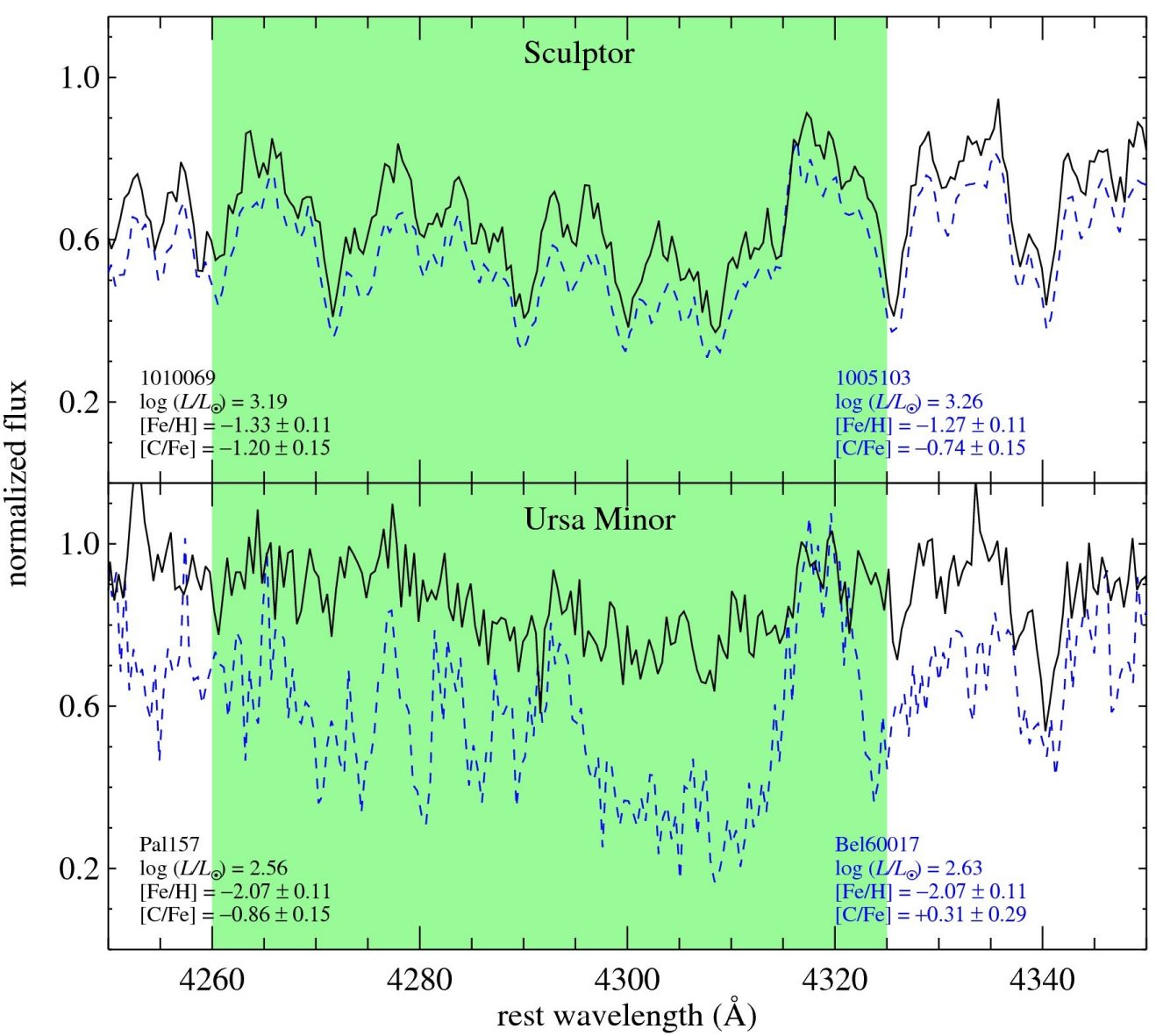


Summary

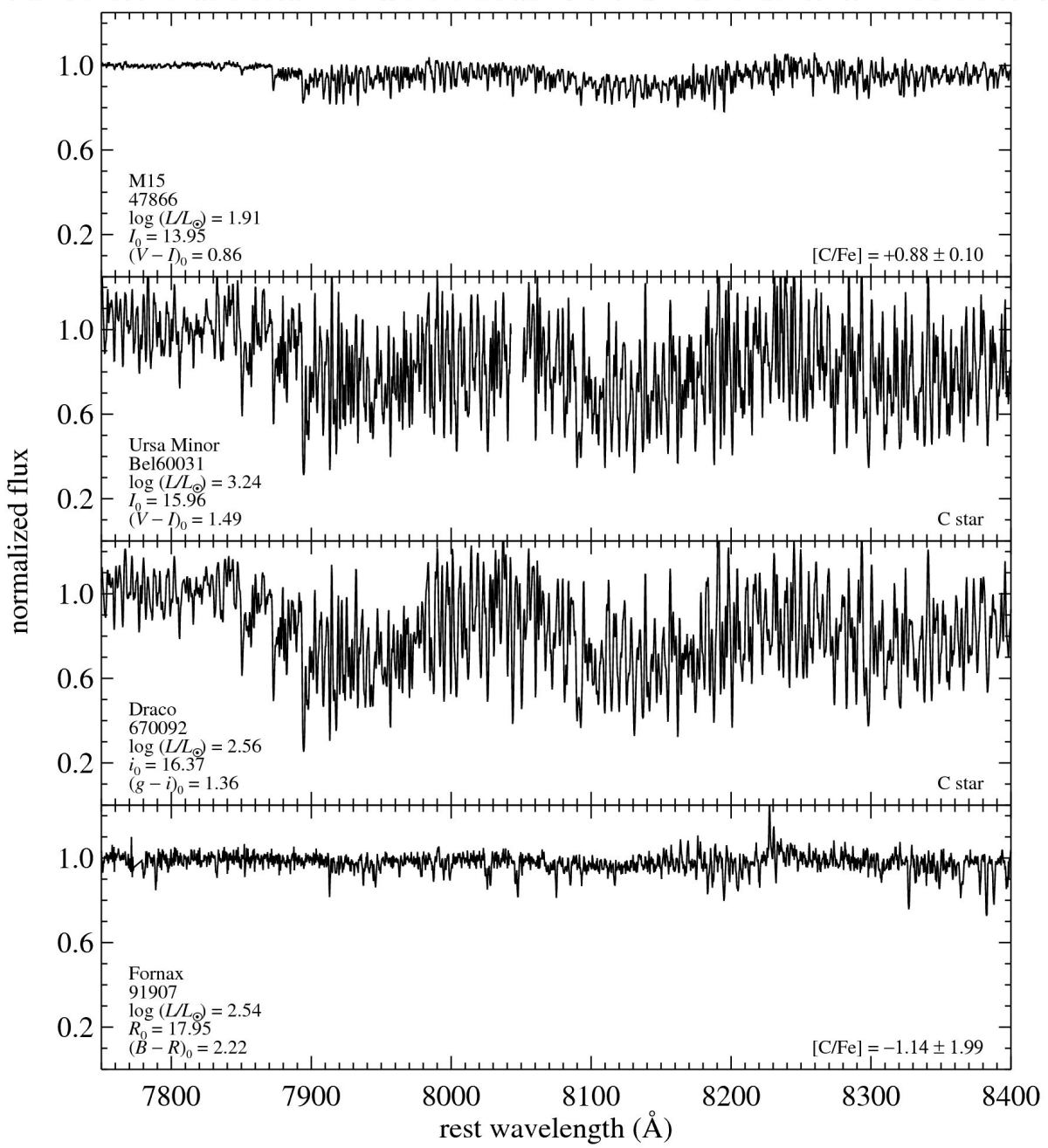
- Carbon has a complex evolution.
  - sources: AGB stars, Type II supernovae
  - sink: CNO cycle in red giants
- The decline of [C/Fe] in dSphs can be attributed to the rise of Type Ia supernovae and the metallicity dependence of AGB yields.
- The Milky Way halo has higher [C/Fe] than dSphs because it had more vigorous star formation.

Kirby, Guo, Zhang, Deng, Cohen, Guhathakurta, Shetrone, Lee, & Rizzi, ApJ, in press, arXiv:1501.06908

You can see the carbon variations with your eyes.



dSphs have some C stars.

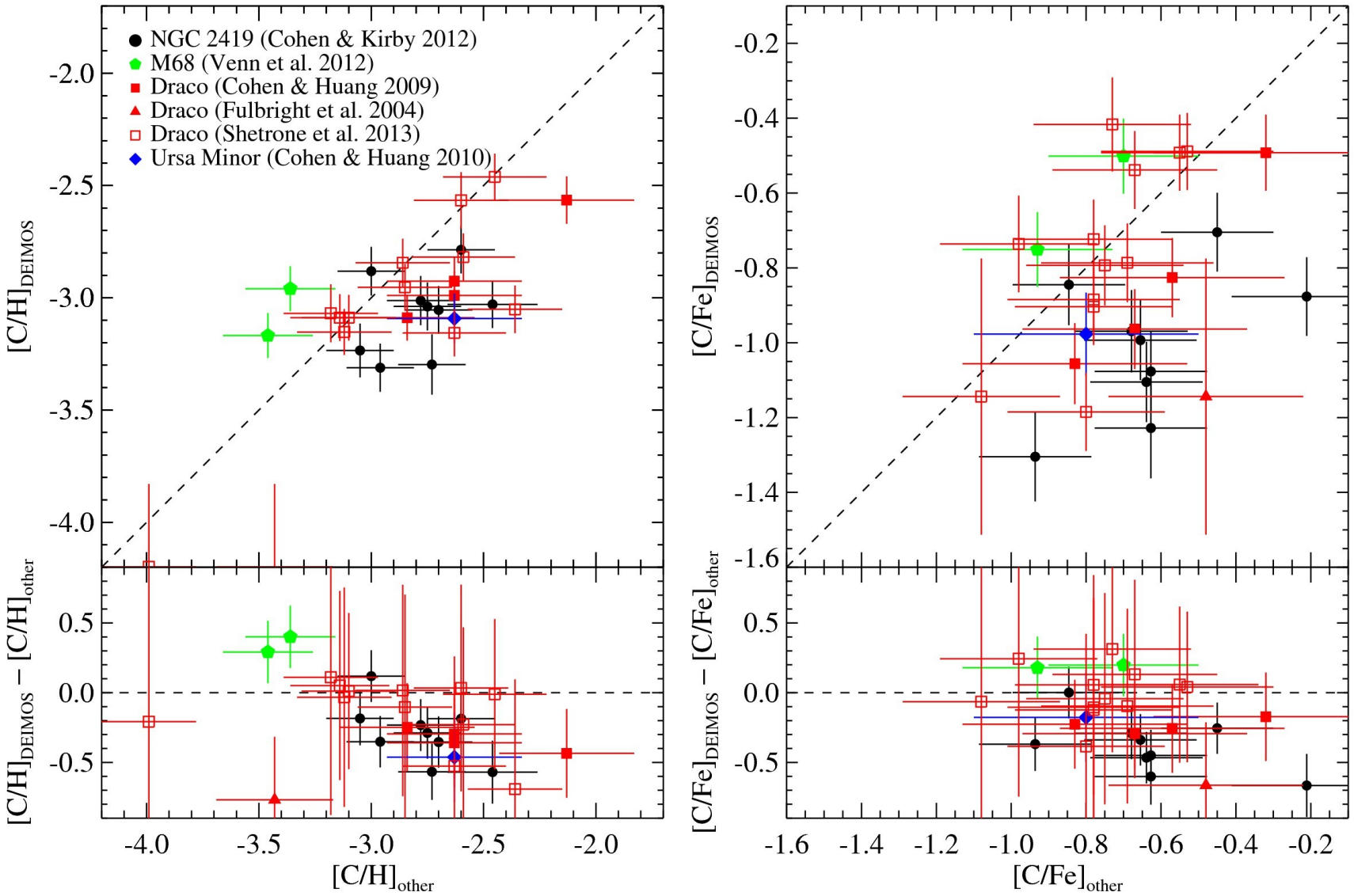


dSphs have some C stars.

Carbon Stars

DSph	Name	Reference	Reference ID
Fornax	50465	this paper	...
Fornax	98788	this paper	...
Ursa Minor	Bel60031	Aaronson et al. (1983)	34227
		Armandroff et al. (1995)	VA335
Ursa Minor	Bel60230	this paper	...
Ursa Minor	Bel80022	Shetrone et al. (2001)	UM 1545
Ursa Minor	Bel10023	Canterna & Schommer (1978)	COS215
		Zinn (1981)	K
		Aaronson et al. (1983)	K
		Armandroff et al. (1995)	K
		Shetrone et al. (2001)	K
		Winnick (2003)	COS215
Draco	670092	Armandroff et al. (1995)	461
Draco	569394	Aaronson et al. (1982)	3203
		Armandroff et al. (1995)	C1
Draco	607050	Aaronson et al. (1982)	J
		Armandroff et al. (1995)	C2
Draco	571725	Aaronson et al. (1982)	3237
		Armandroff et al. (1995)	C3
Draco	682522	Azzopardi et al. (1986)	578
		Armandroff et al. (1995)	C4

Comparison to high-resolution spectroscopy



[C/Fe] dependence on [α/Fe]