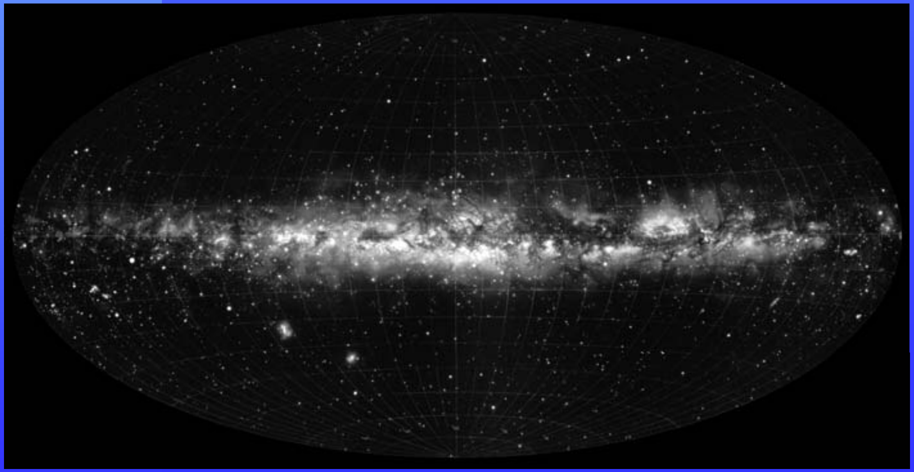
Galactic Stellar Populations and what they tell us

Rosemary Wyse



JOHNS HOPKINS
UNIVERSITY

The Fossil Record: Galactic Archaeology

- Studying low-mass old stars nearby allows us to do Cosmology locally.
- There are copious numbers of stars nearby that have ages > 10 Gyr : formed at redshifts $\gtrsim 2$
  - Complementary approach to direct study of galaxies at high redshift.
- Derive metallicity distributions, kinematics to dynamics, age distributions….separately
  - Stellar IMF
  - Merging history
  - Gas flows

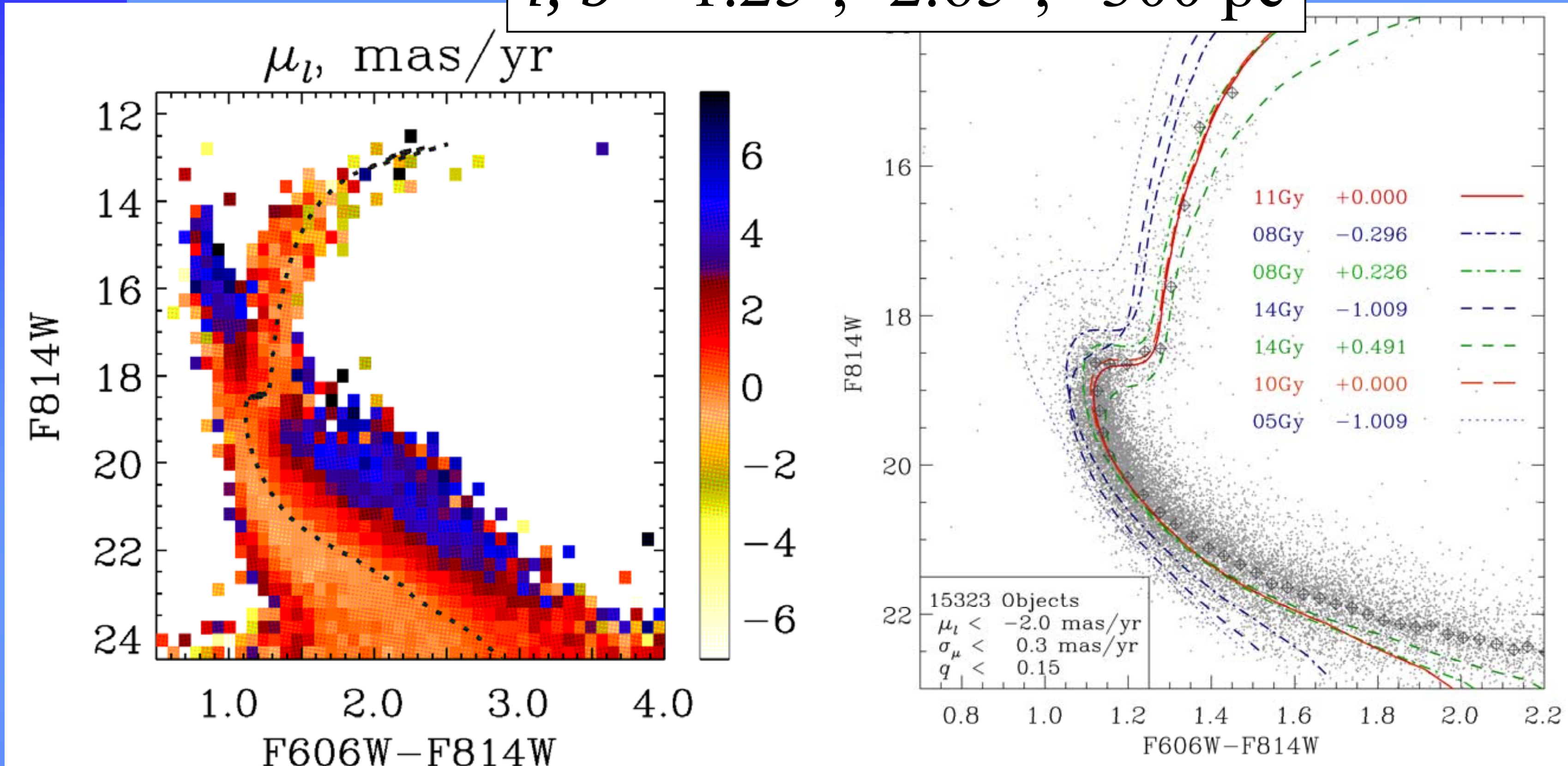
    → break degeneracies of integrated light

    → constrain 'feedback' prescriptions

Stellar Components: Bulge, Halo, Satellites…

- Central Bulge: $M_* \sim 2 \times 10^{10} M_\odot$, mildly triaxial, 1 : 0.4 : 0.3 (Bissantz & Gerhard 2002), oblate rotator, (exponential) scale-height ~300pc
  - expected to be the location of a significant population of 'early' stars – plus later star formation
  - inner (robust) parts of relatively massive satellites could also contribute if accreted
  - gas flows induced by mergers could fuel star formation
  - stars from disk could also be added, either by mergers or by disk-bar-instabilities

→Age and elemental abundances key discriminants *l*, *b* = 1.25°, -2.65°; ~300 pc



Sgr low-extinction window:

Clarkson, Sahu et al. 2008

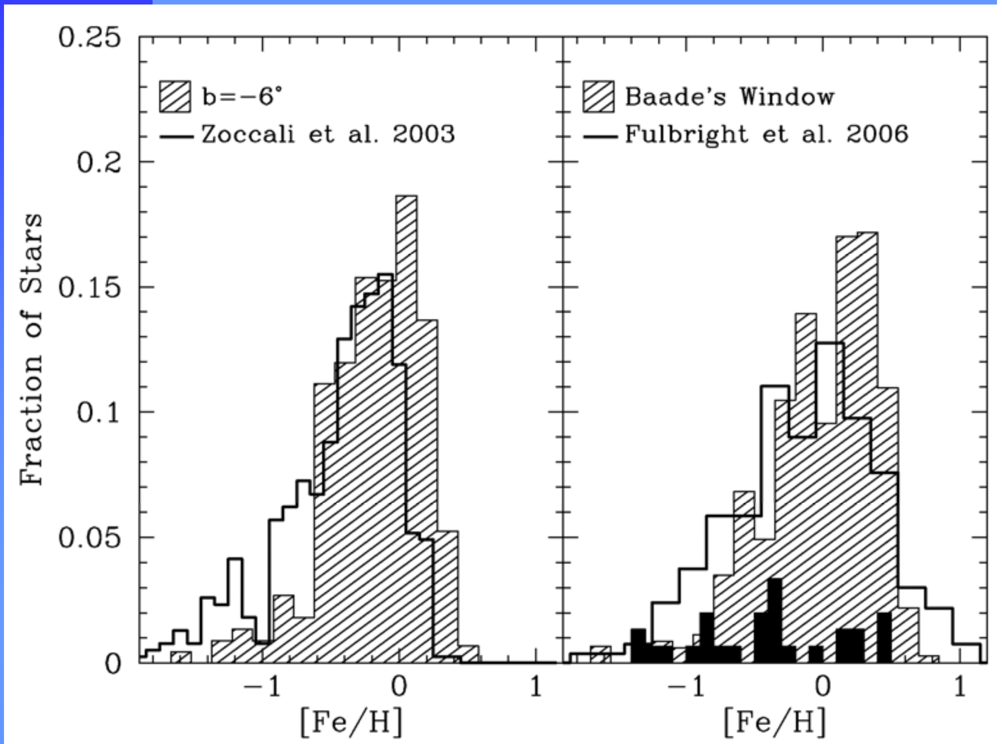
Bulge/disk decomposition by proper motions:

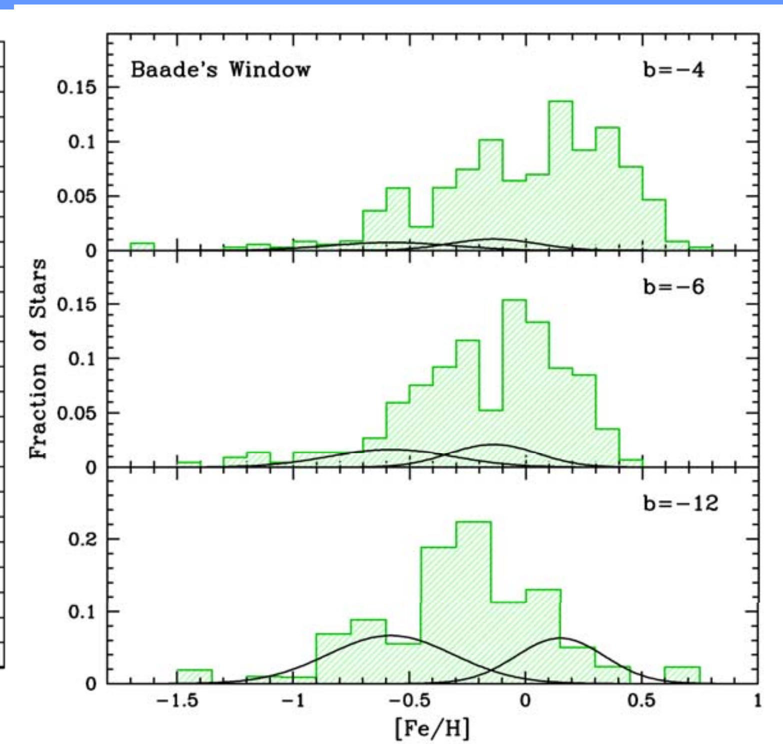
bulge is OLD, $\gtrsim$ 10 Gyr (plus some blue stragglers)

(agrees with Feltzing & Gilmore 00; Zoccali et al 03; van Loon et al 03)

Limits late accretion of gas and stars → limits mergers

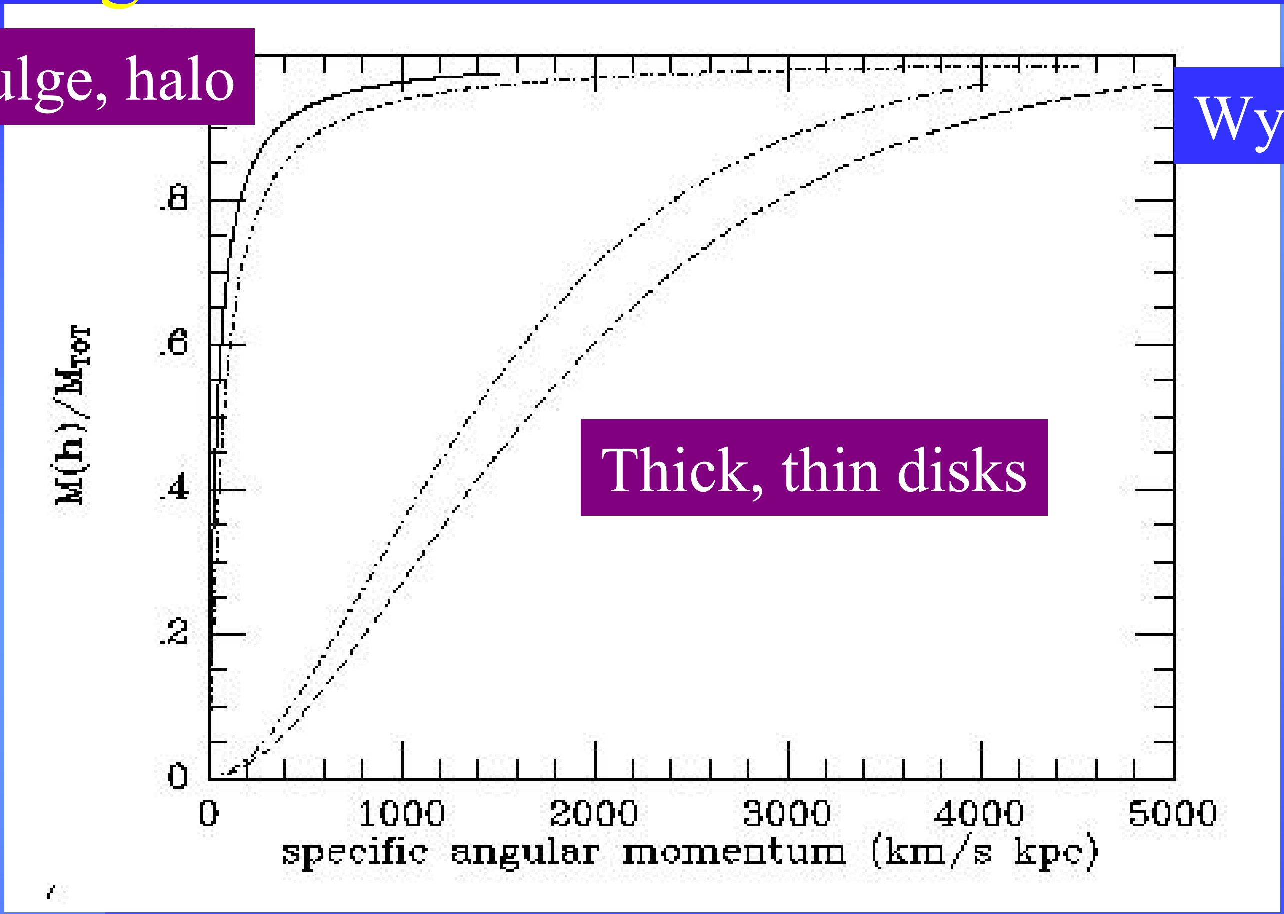
Zoccali et al 2008 – at least a hundred (giant) stars each field





- Iron abundance peaks ~ solar value, suggests stars formed in a deep potential well, *in situ*?
- Few stars below -1 dex: 'G-dwarf problem' analog? Note RR Lyrae stars exist so certainly old, metal-poor stars
- Vertical gradient (cf. Minniti et al 1995):
  → dissipation, gas flows – at early times, rapid formation (cf. Ferreras, Wyse & Silk 2003)

Bulge—Stellar halo connection?



Bulk of halo mildly prograde rotation

Bulge angular momentum distribution consistent with dissipational collapse of gaseous ejecta from stellar halo star-forming regions -- mass ratios (10:1) also agree with low metallicity of stellar halo cf Hartwick 1979

- Elemental abundances in typical bulge stars show signatures of enrichment by only Type II SNe (core-collapse, massive star progenitors): enhanced levels of alpha-elements to iron.
    - Decline in O,Si,Ca,Ti above solar iron due to metallicity-dependent yields from Type II (McWilliam, Matteucci et al 2008)

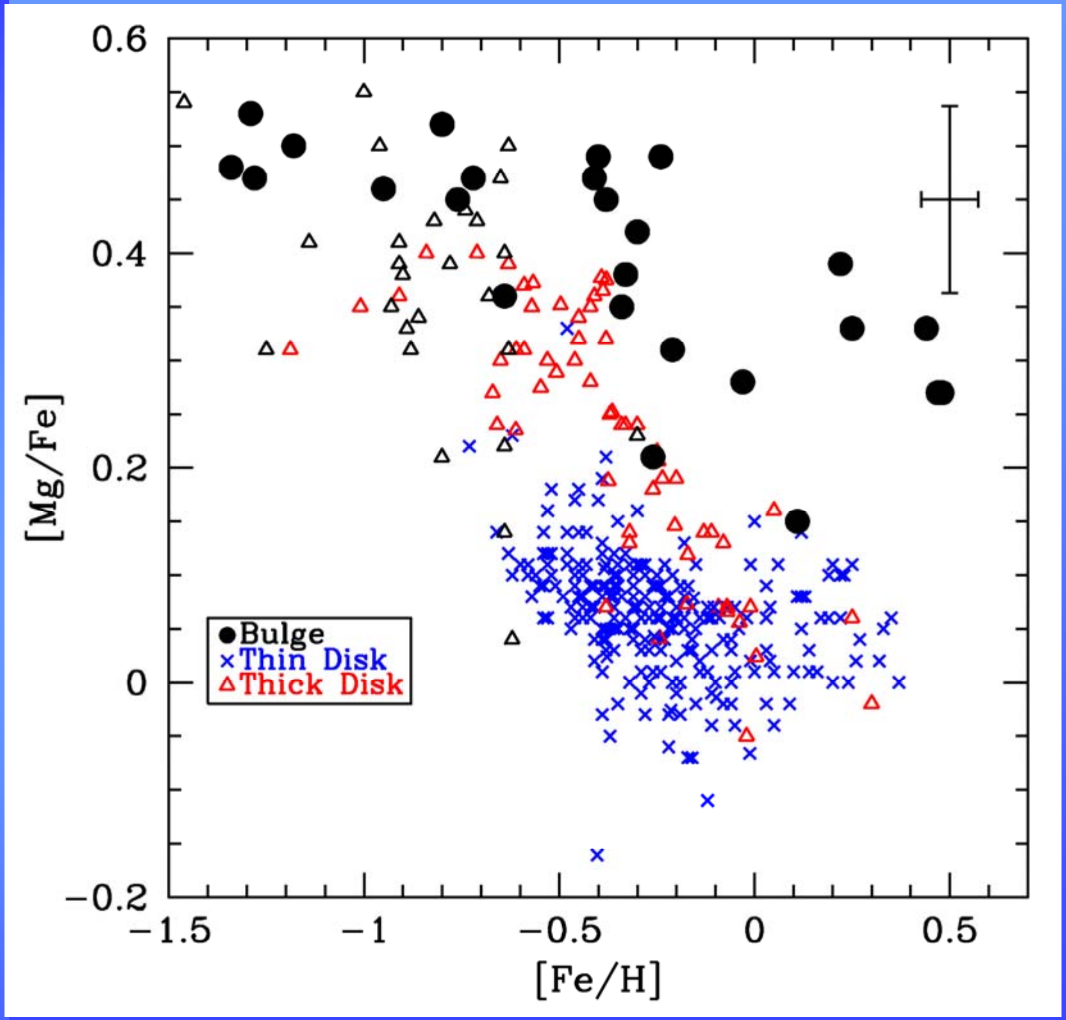
→ Short duration of star formation

- Perhaps higher enhancement than disk stars, indicative of flatter massive-star IMF? (Ballero et al 2007)

→Where do the lens-magnified dwarf stars fit in?

Metal-rich (above solar), low values of [α/Fe] and intermediate-age (e.g. Cohen et al. 08; Johnson et al 07 – see Johnson et al poster this conference)

Elemental abundances in K-giants in Baade's Window

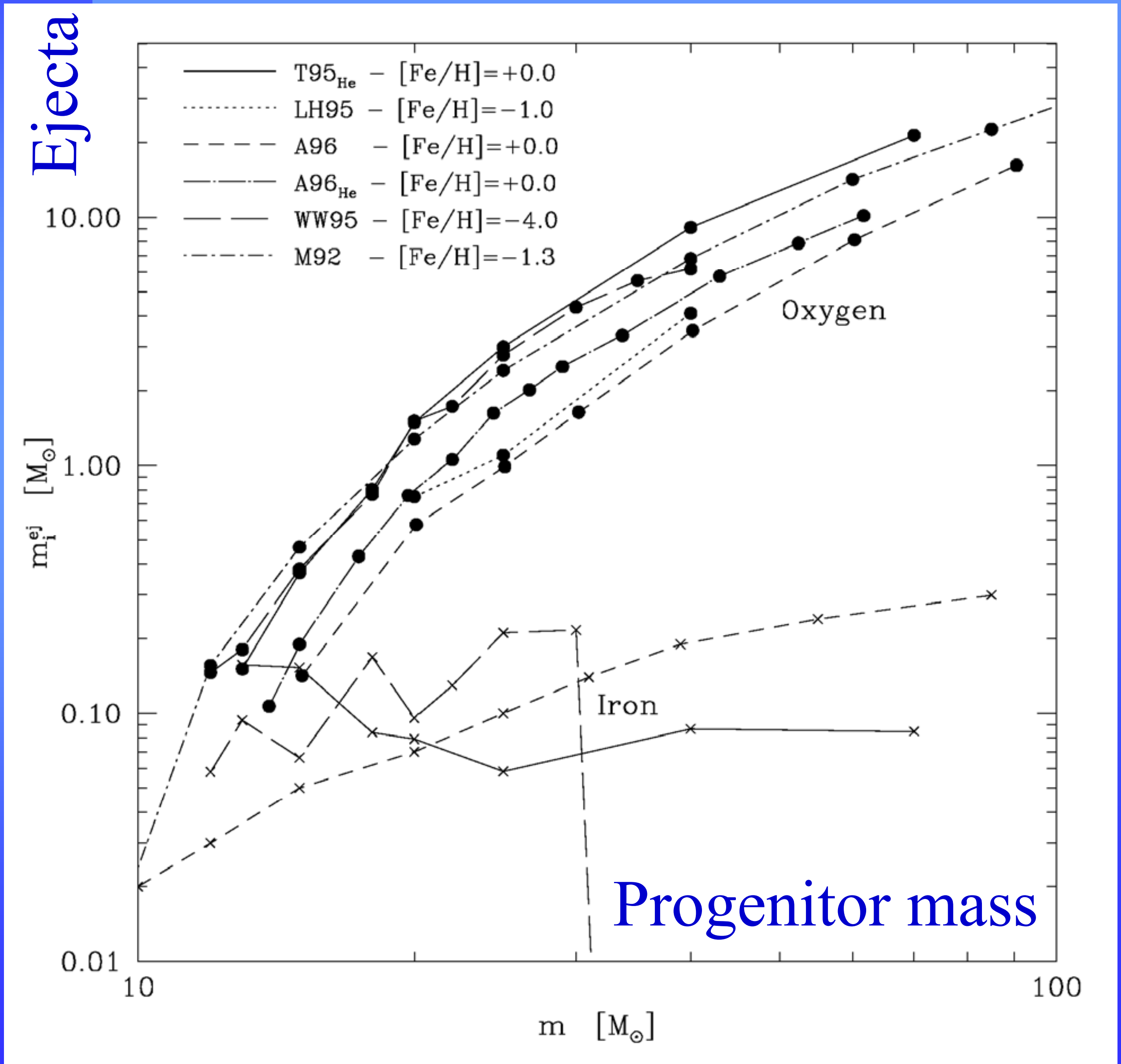


l,*b* = 1°,–4°

Scatter consistent with error; very low intrinsic scatter

Fulbright, McWilliam & Rich 2007; see also Lecureur et al 2007

IMF dependence due to different nucleosythesis of progenitors of different masses

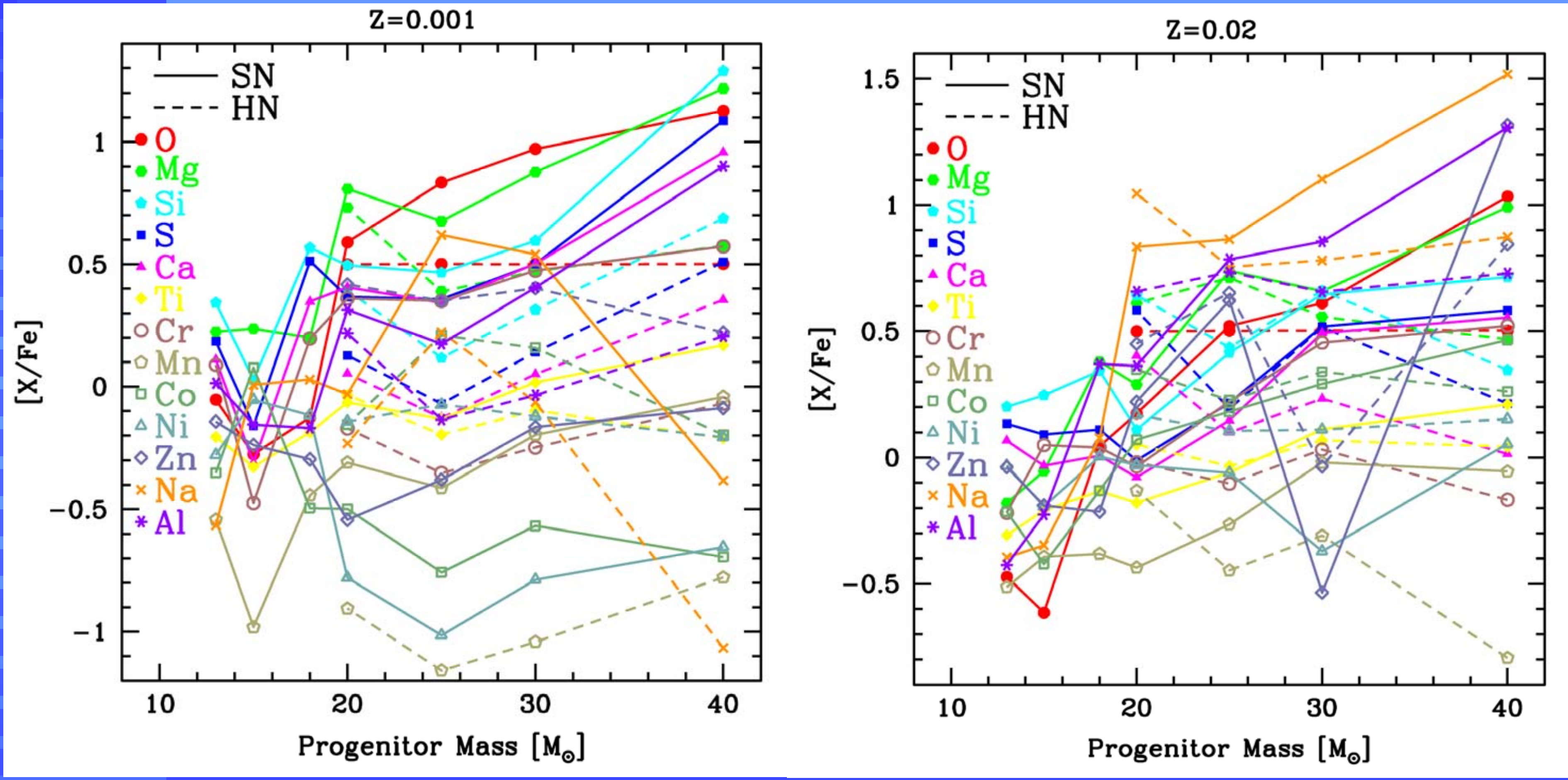


Type II Supernova yields

Salpeter IMF (all progenitor masses) gives [α/Fe] ~ 0.4

Gibson 1998

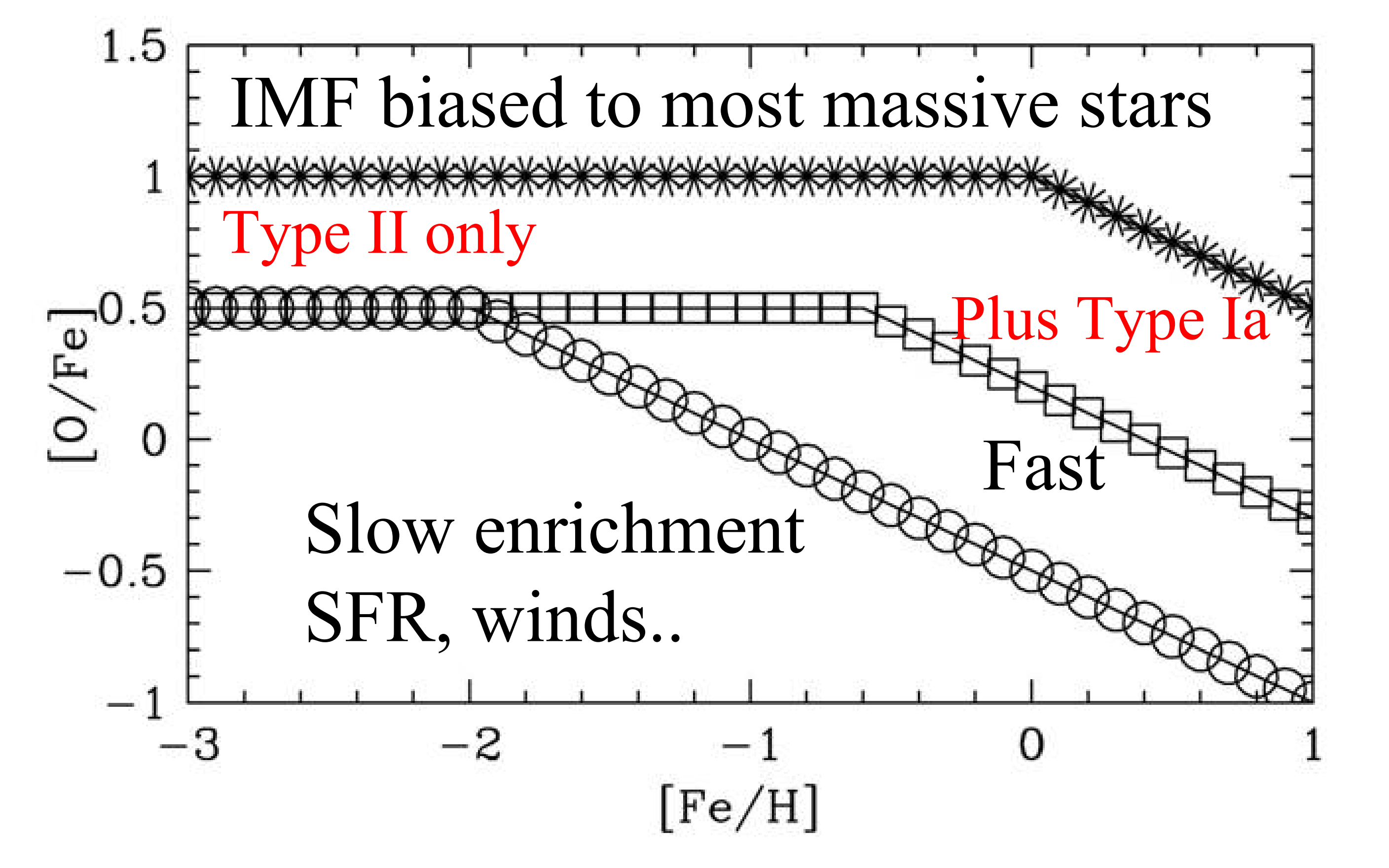
Kobayashi et al 2006



Same trend of increasing [α/Fe] with increasing Type II progenitor mass (SN)

Schematic [O/Fe] vs [Fe/H]

Wyse & Gilmore 1993



Self-enriched star forming region.
Assume good mixing so IMF-average yields

Wyse & Gilmore 1992

TABLE 1. Woosley data: Dependence of the elemental yields and [O/Fe] on the slope of the IMF.

Main Sequence Mass ($M_\odot$)	10	12	15	20	25	35	50	100
Oxygen Produced ($M_\odot$)	0.1	0.5	0.5	1.5	3	6.5	12	30
Iron Produced ($M_\odot$)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
IMF Slope	−2.3		−1.5		−1.5		−1.1	
Δ[O/Fe]		0.2				0.1		
				0.3				

TABLE 2. Thielemann *et al.* data: Dependence of the elemental yields and [O/Fe] on the slope of the IMF.

Main Sequence Mass ($M_\odot$)	13	15	20	25	40	100
Oxygen Produced ($M_\odot$)	0.22	0.43	1.5	3	20	20
Iron Produced ($M_\odot$)	0.24	0.15	0.075	0.05	0.05	0.05
IMF Slope	−2.3		−1.5	−1.5		−1.1
Δ[O/Fe]		0.3			0.15	
			0.45			

Salpeter IMF slope: -1.35;

Scalo: -1.5

Matteucci & Brocato for Bulge: -1.1;

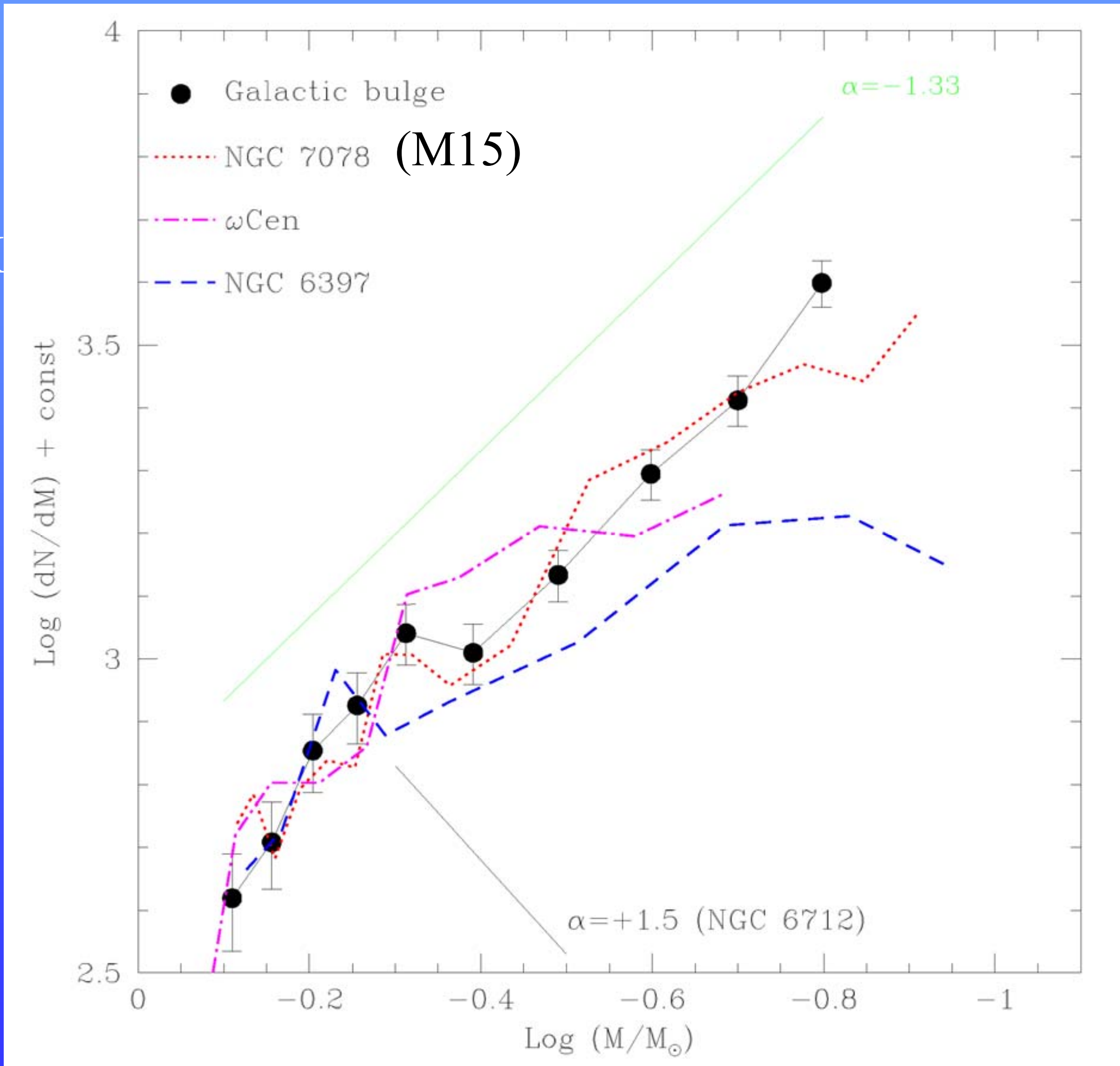
Ballero et al: -0.95

Low-Mass MF in Bulge:

Zoccali et al 2000

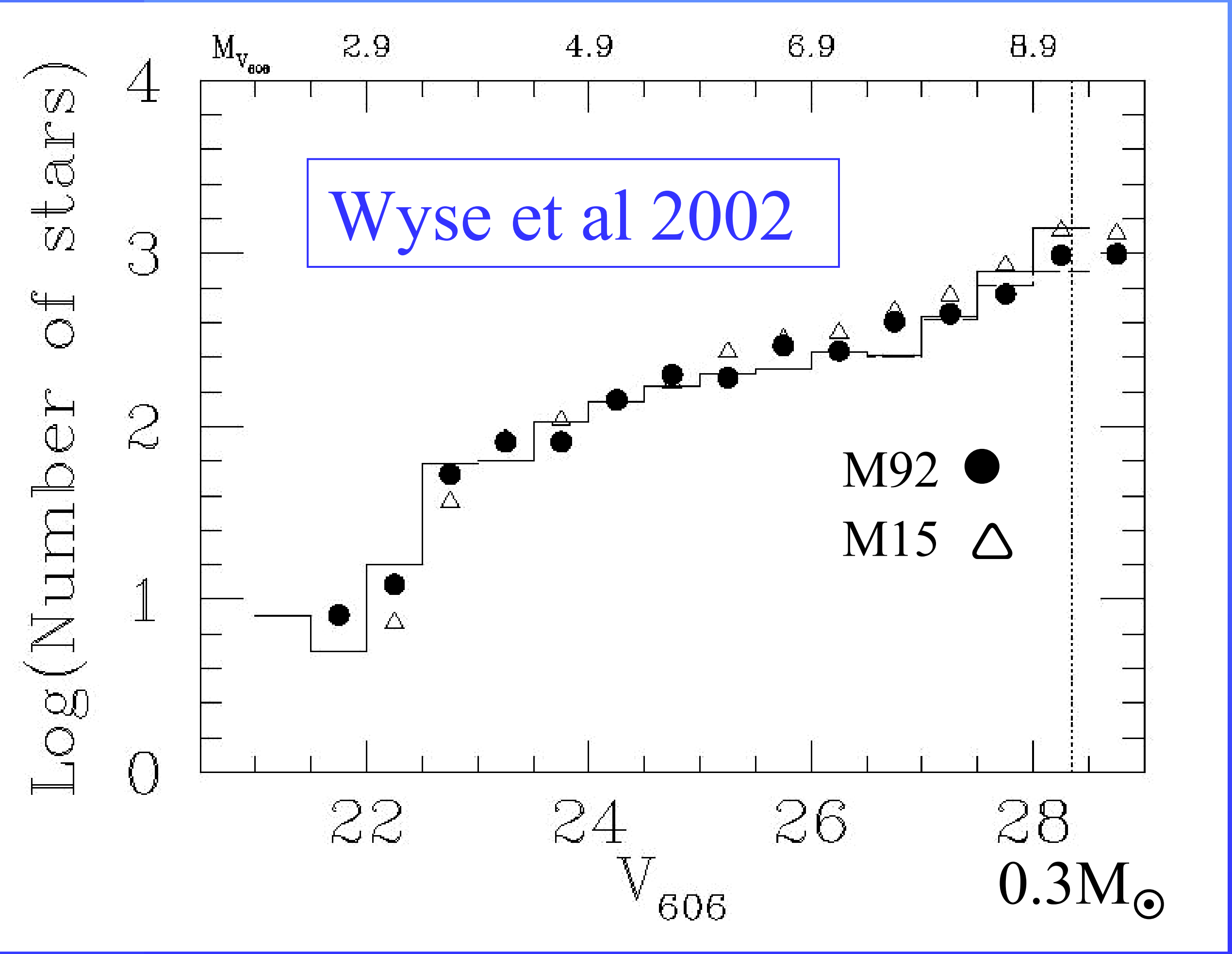
Matches local disk (Kroupa 2000) And M15 – which matches the UMi dSph:

Low-mass IMF Invariant wrt metallicity, time..



Main sequence luminosity functions of UMi dSph and of globular clusters are indistinguishable.

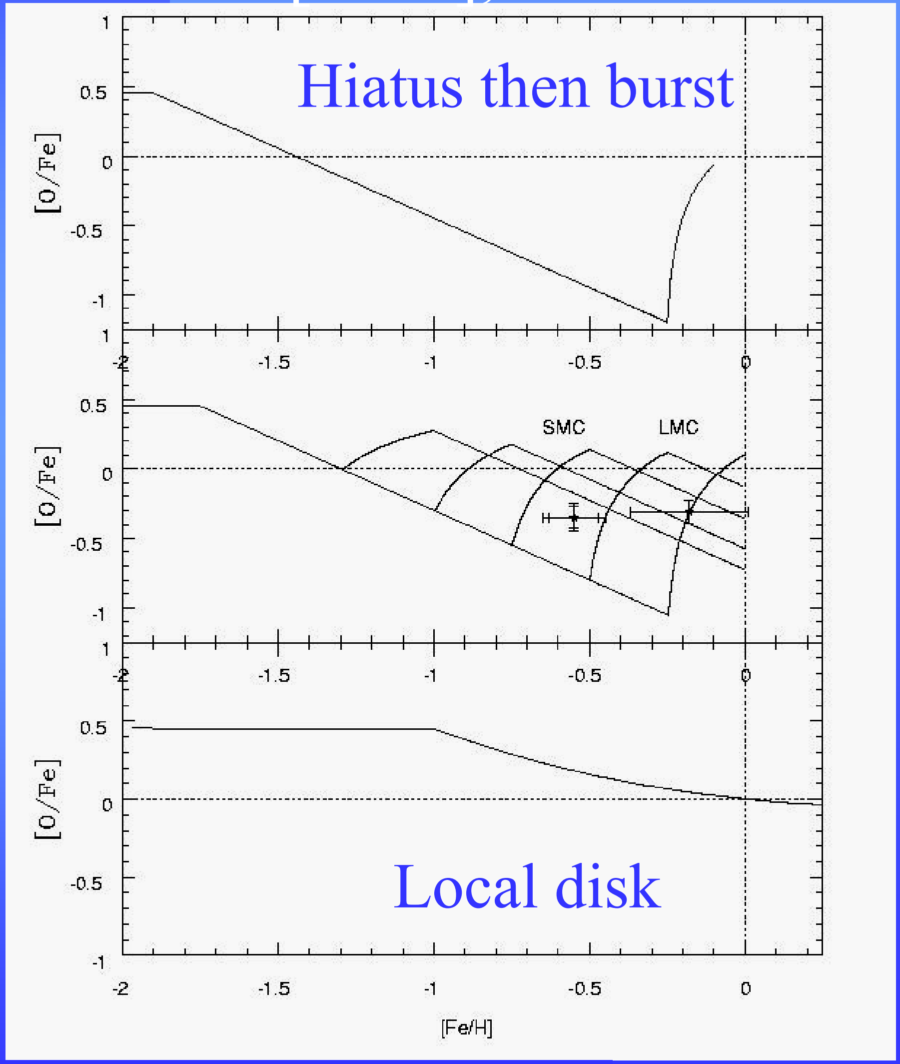
→ normal stellar M/L



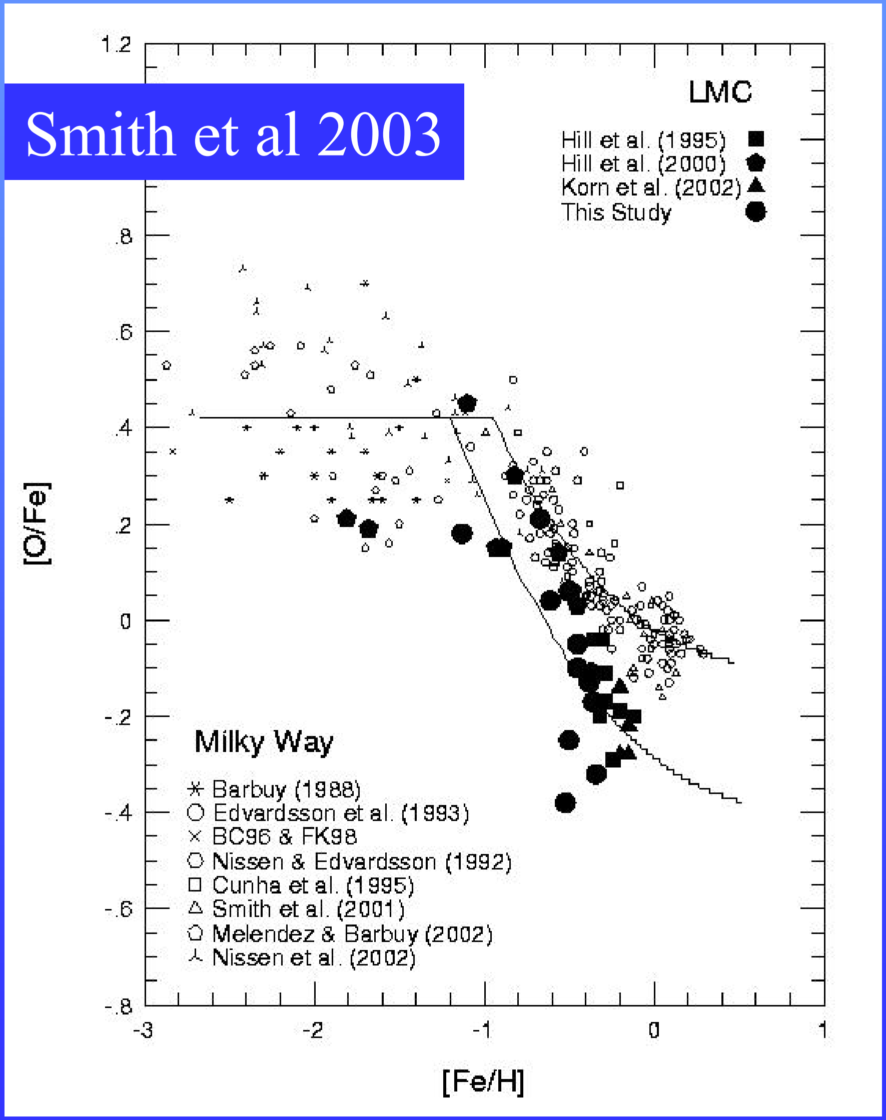
HST star counts

Massive-star IMF constrained by elemental abundances – also normal IMF

Extended, low-rate star formation and slow enrichment with gas retention, leads to expectation of ~solar (or below) ratios of [α/Fe], such as in LMC stars

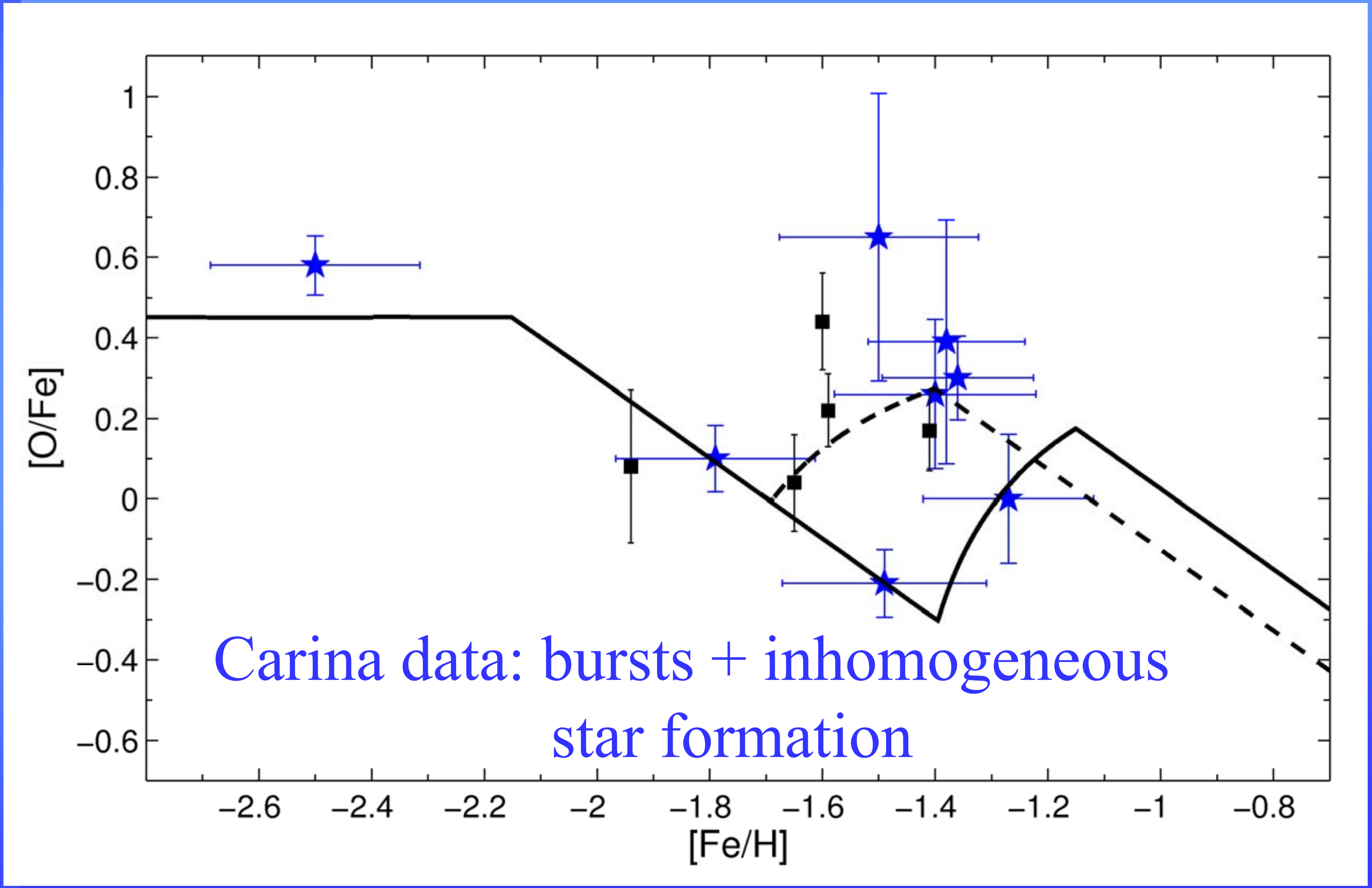


Gilmore & Wyse 1991



Elemental abundances with bursts of star formation

Gilmore & Wyse 1991



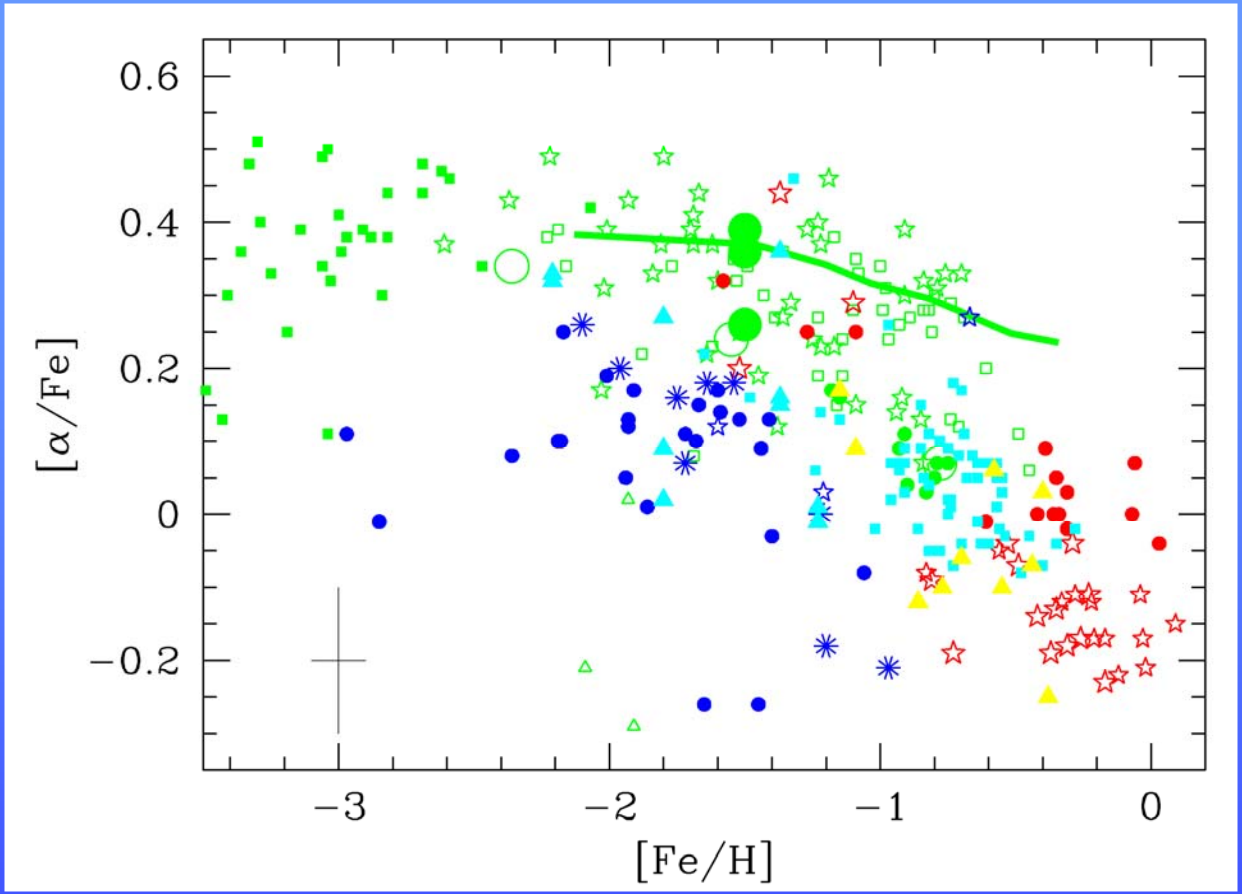
Massive star IMF invariant

Koch et al 2007

Geisler et al 2007 cf Venn et al 03

MW halo: green

dSph and LMC: others

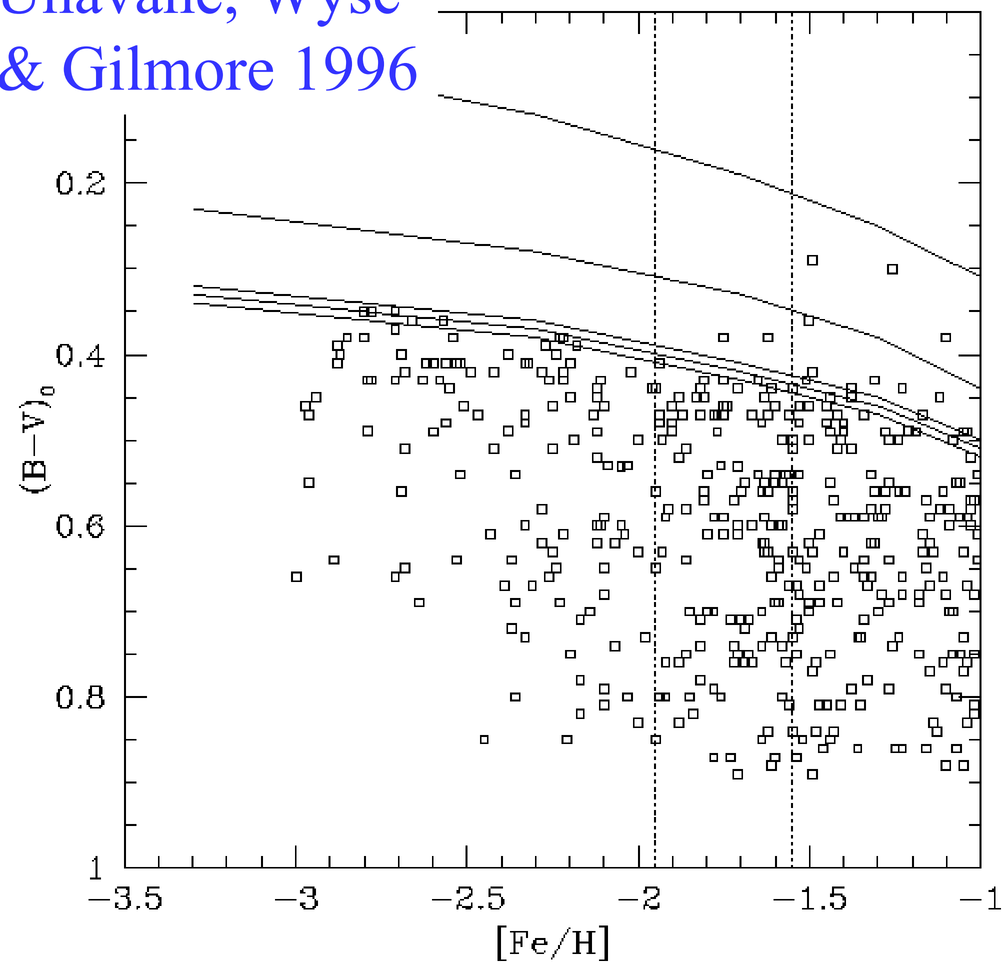


Elemental ratios in dwarf galaxies reflect extended star-formation histories and slow inefficient enrichment. Lie below stellar halo, bulge and disks at same [Fe/H]: Did not contribute many stars to these components!

Bulk of stellar halo is OLD, as is bulge:
Did not form from typical satellites, with extended star formation, if disrupted later than a redshift of ~2.

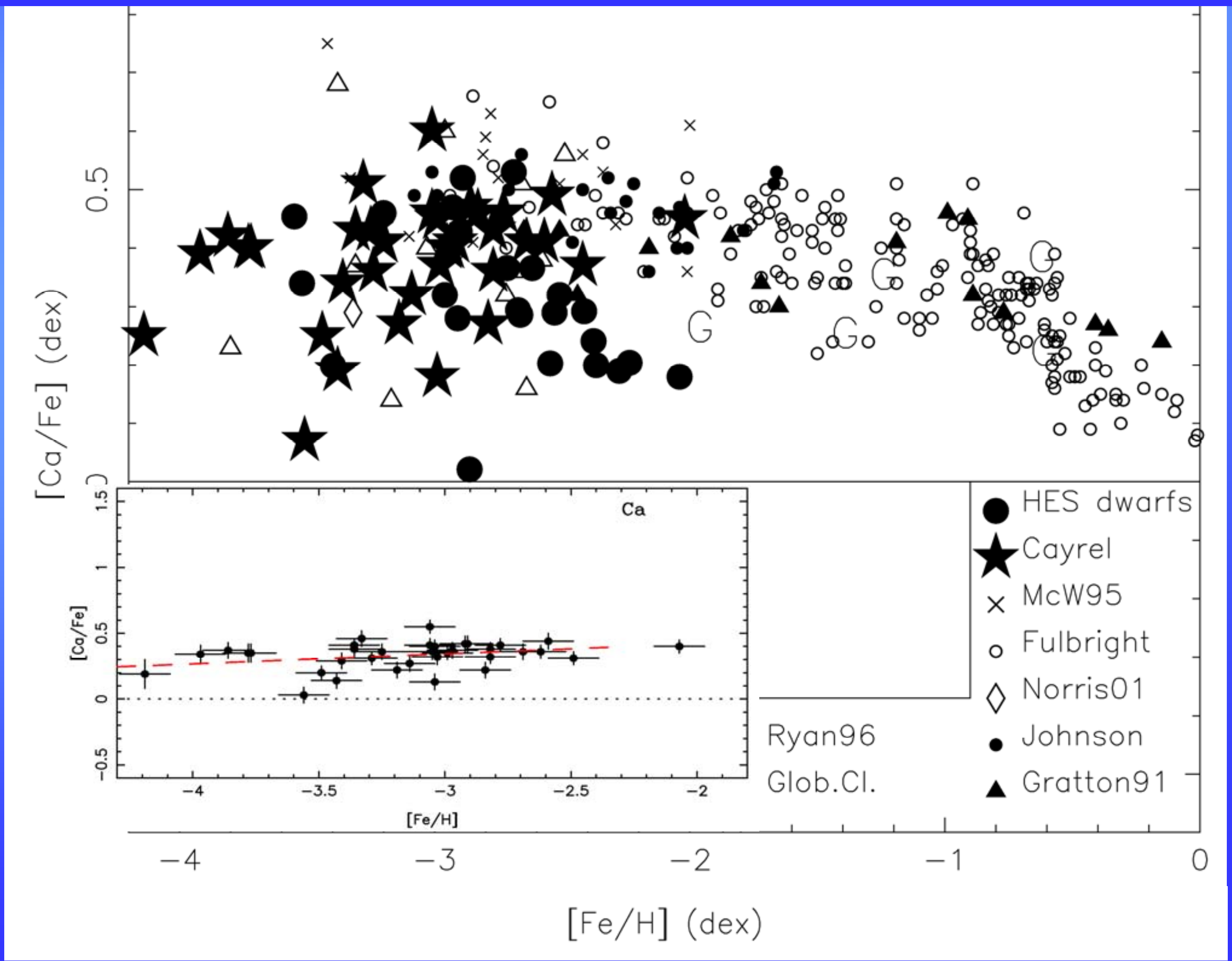
Similar conclusions from metallicity distbs and elemental ratios Venn, Helmi

Unavane, Wyse & Gilmore 1996



Scatter plot of [Fe/H] vs B-V for local high-velocity halo stars (Carney): few stars bluer (younger) than old turnoffs (5,10,15Gyr Yale)

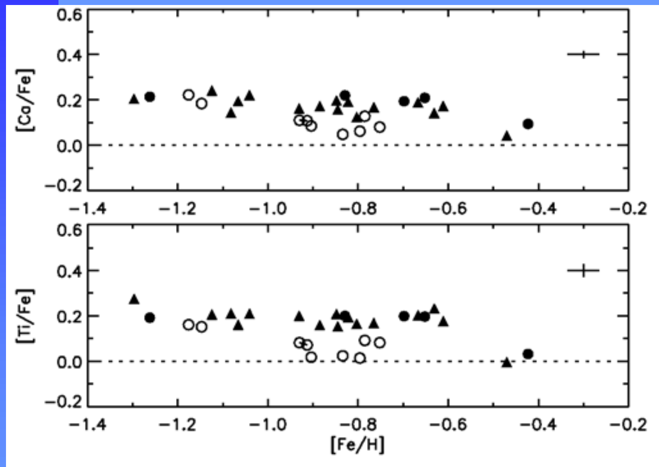
Detailed elemental abundances for halo stars show very low intrinsic scatter down to -4 dex, same IMF and good mixing of SNe ejecta, Type II enrichment only: short duration of star formation

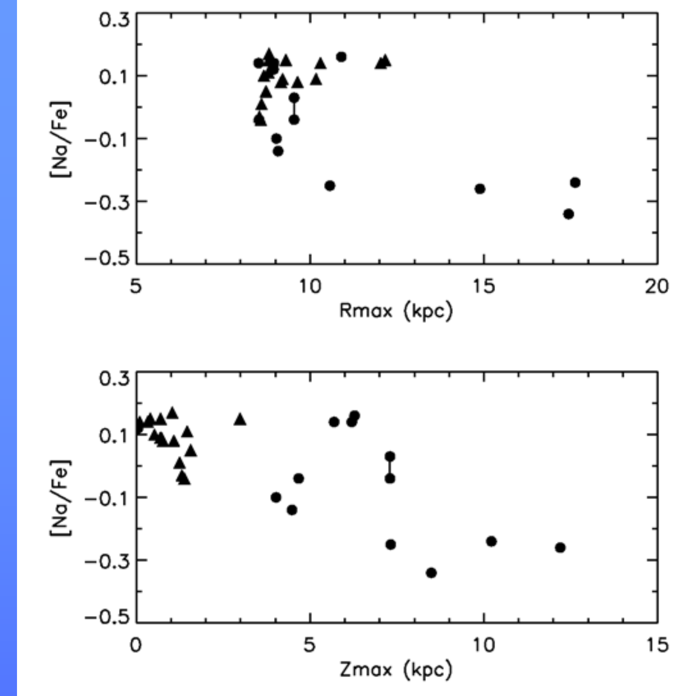


Cohen et al 02

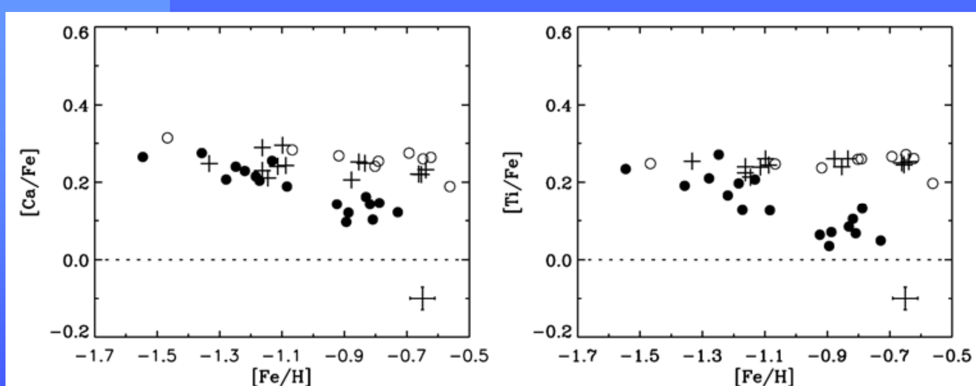
Cayrel et al 02

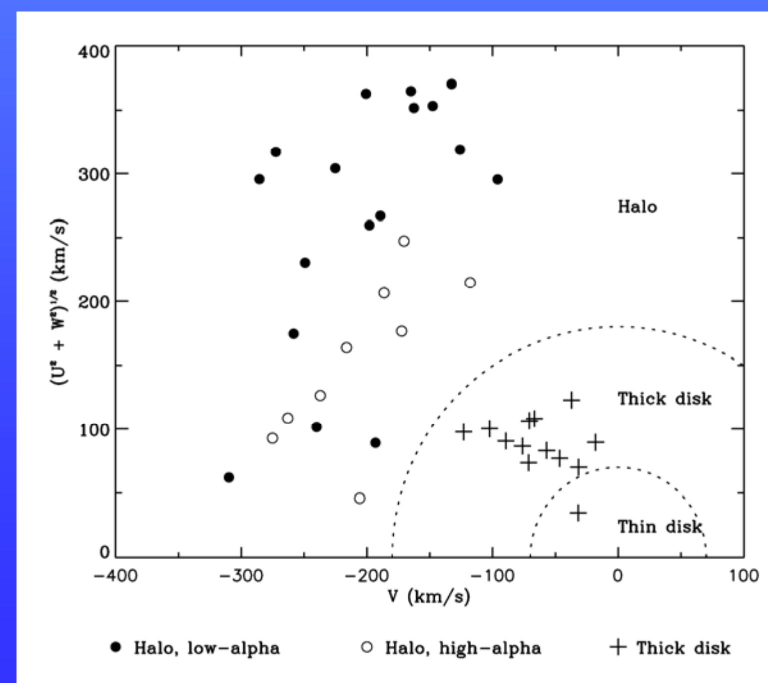
- Stellar halo, mass ~ 2 x $10^9 M_\odot$, most inside solar circle, mostly old, enhanced [α/Fe], low metallicity, same IMF as rest of the Galaxy, little evidence for substructure $R_{GC} < 20$ kpc
  - Mix together systems, each with inefficient truncated chemical enrichment (gas removal) and short duration of star formation
- Outer stellar halo shows significant substructure in coordinate and phase space, but most due to 'a few very well-defined structures at large radii' (e.g. Sgr dSph) (Bell et al 07).
- Different mean kinematics (retrograde) of very outer halo (cf Carollo et al 07): formed from recent satellite accretion?
  - 'Low-alpha' halo stars tend to be on energetic radial orbits – late accretion if satellite debris?





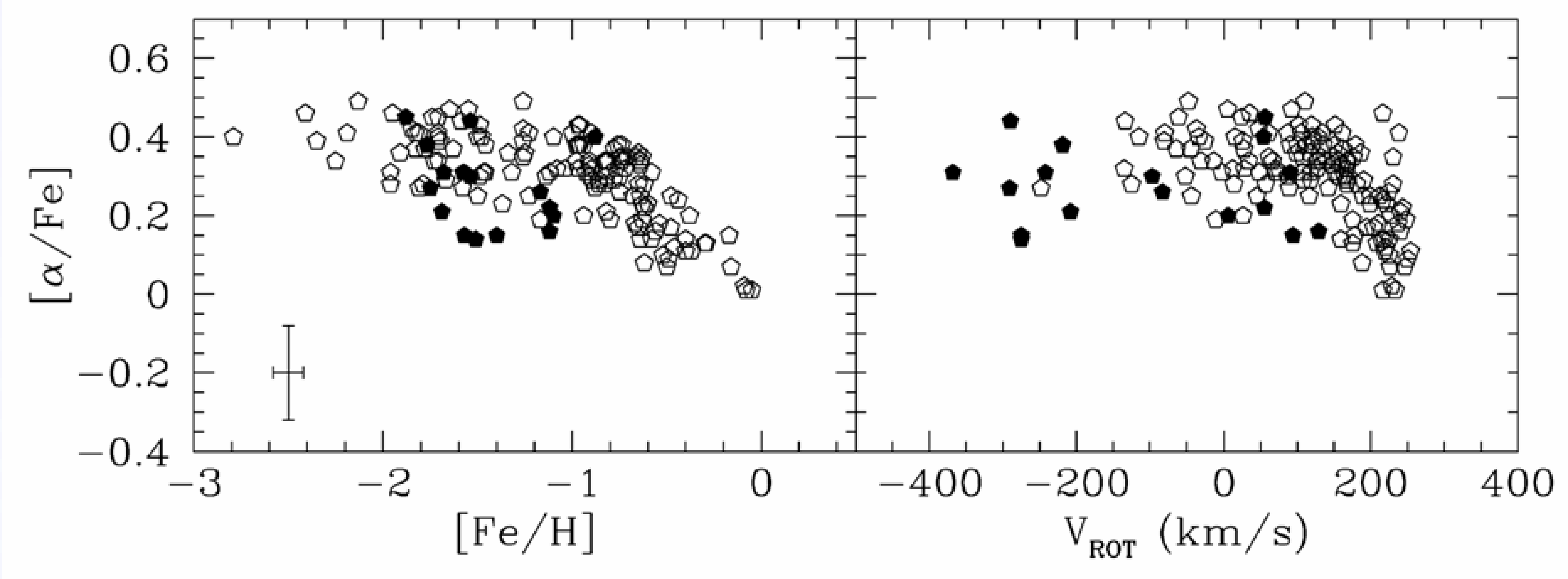
Above, Nissen & Schuster 97
Below, Nissen & Schuster 08





Eccentric orbits, low R_{PERI} → accretion?

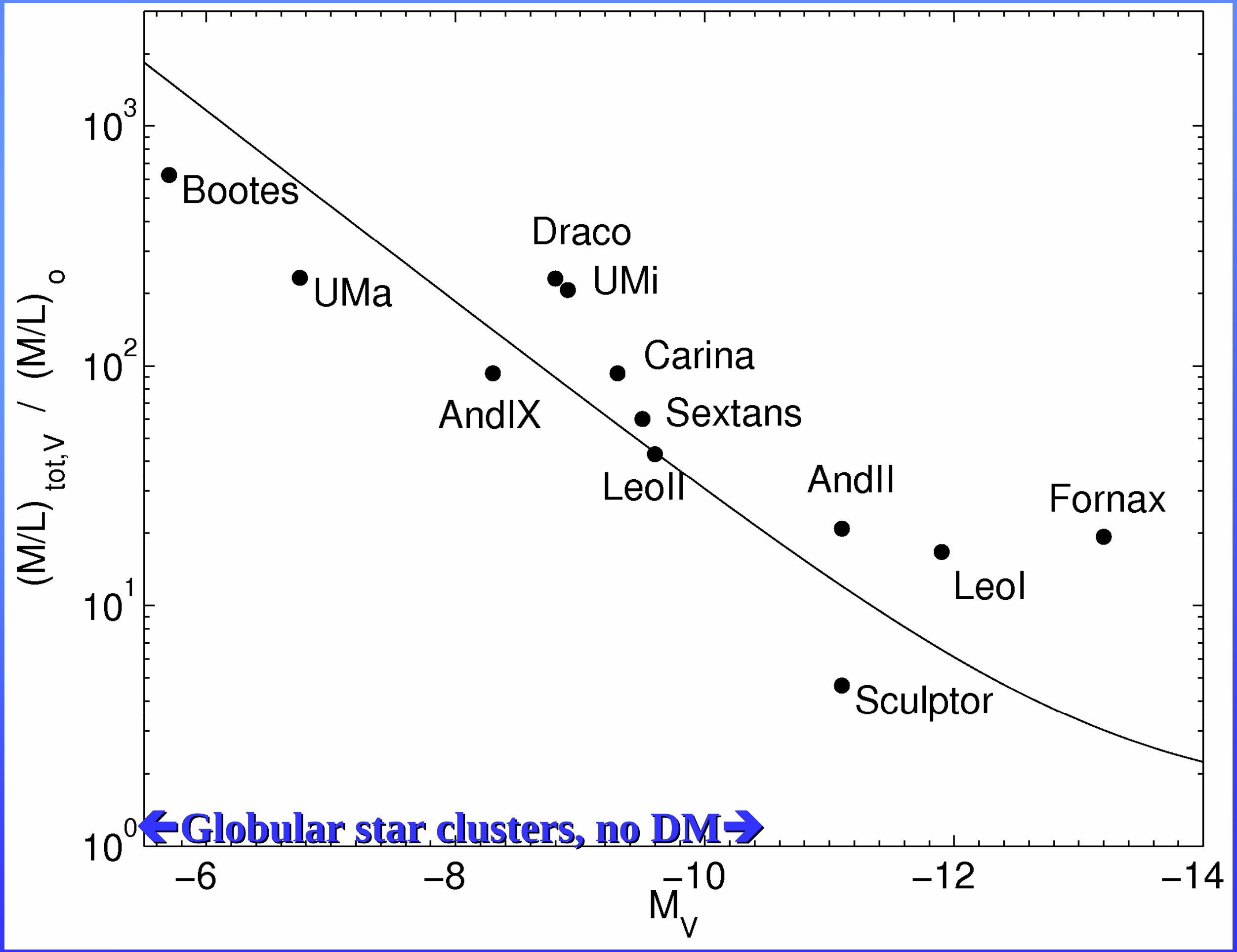
A different dataset..



Data from Fulbright (2000, 2002)

Filled symbols: stars on orbits with R_{MAX} > 20kpc
-- mean V_{ROT} retrograde, and mildly lower [α/Fe]
→ More data needed!! (WFMOS on Subaru/Gemini)

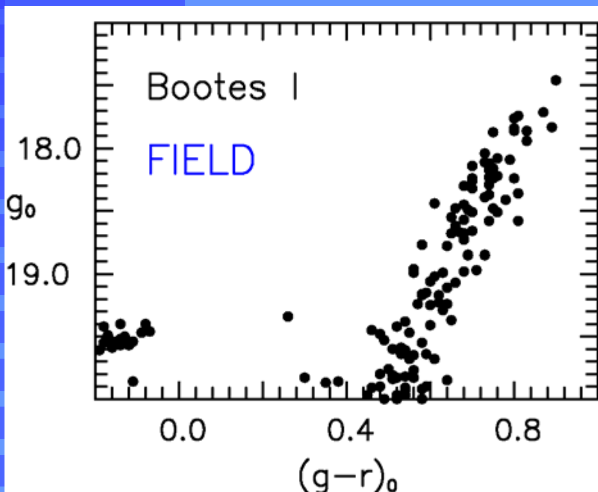
What are stellar populations in the low-luminosity dwarfs? Expect early stars here too (z_{form} ~ 15 from central density fits). Allow 'clean' study of dark halo, minimal baryonic component: very similar dark matter potentials, cored profiles; M/L increases, mass enclosed within stellar extent ~ 4 x $10^7 M_\odot$

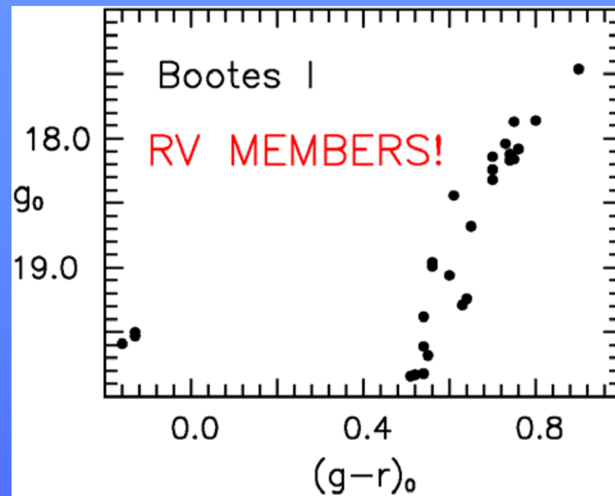


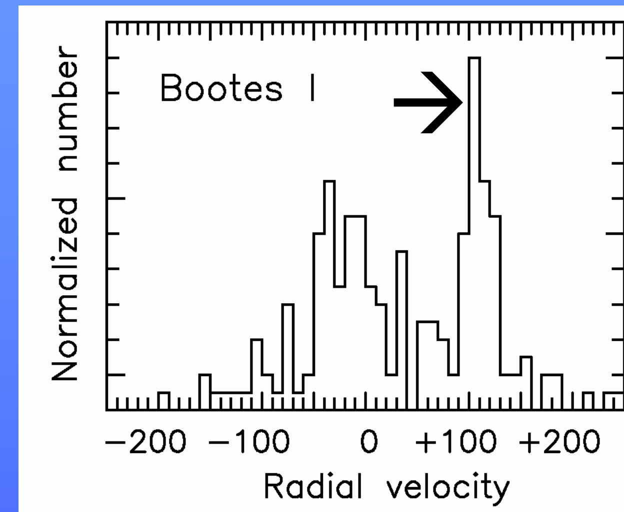
Gilmore et al 07

Or $10^7 M_\odot$ within 300pc
Strigari et al 08

Bootes I, $M_* \sim 4 \times 10^4\ M_\odot$ (Belukorov et al 06)

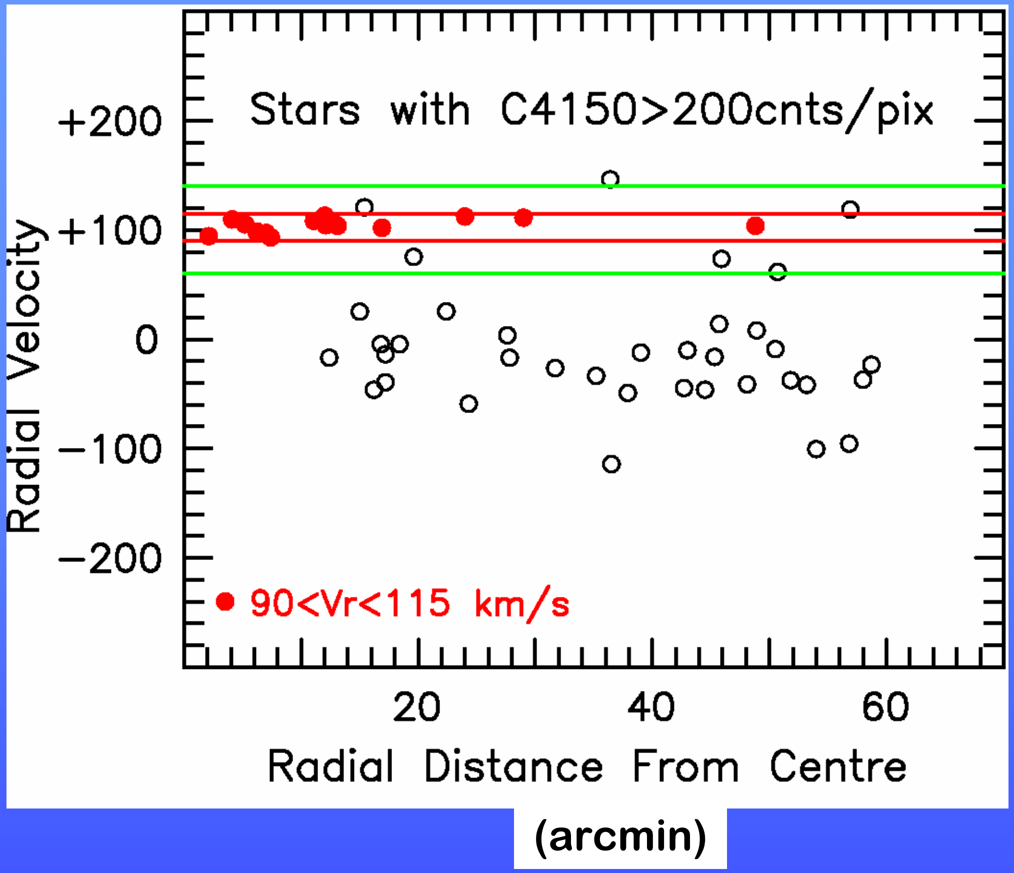






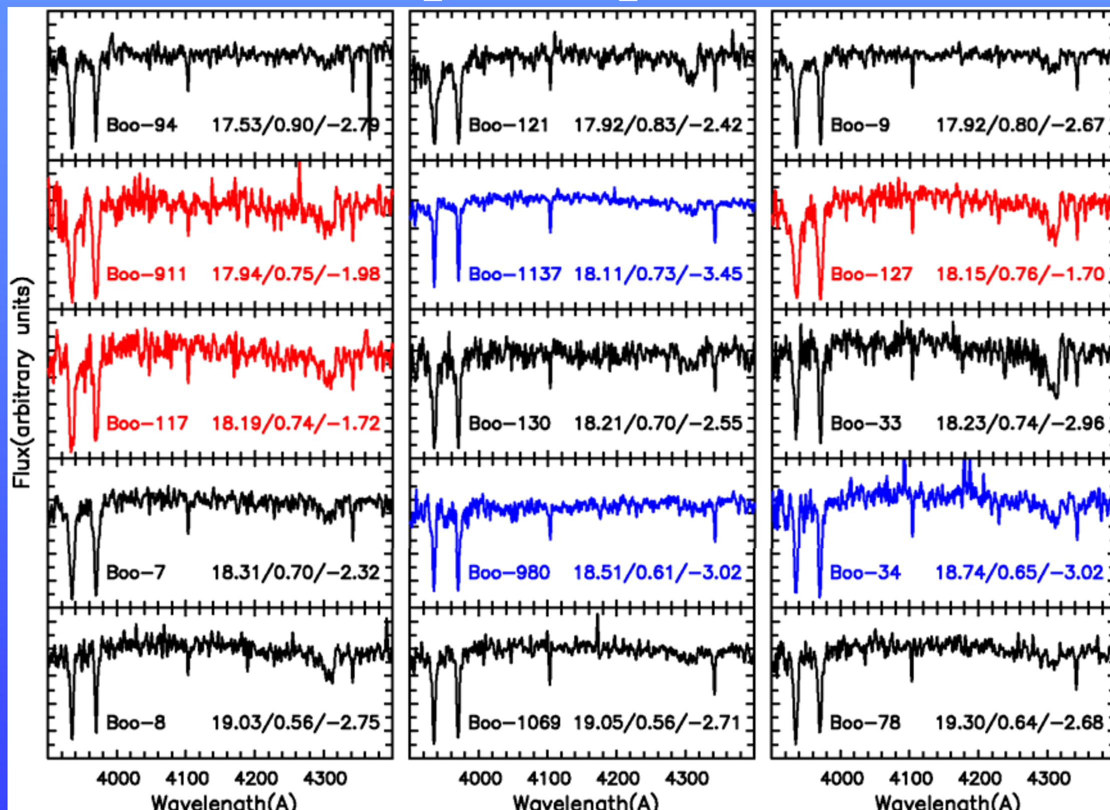
Data from AAOmega MOS on the AAT, velocities good to better than 10 km/s (dispersion of 6 repeats with Martin et al 07).

Metallicity distribution: Norris, Gilmore, RW et al 08



Derive metallicities for 16 candidate members with sufficient S/N : method uses Ca II K-line (3933 Å).

We obtain a mean [Fe/H] of -2.5 dex, with a broad range of metallicities, down to below -3dex in [Fe/H].



$g_0/(g-r)_0$/[Fe/H]

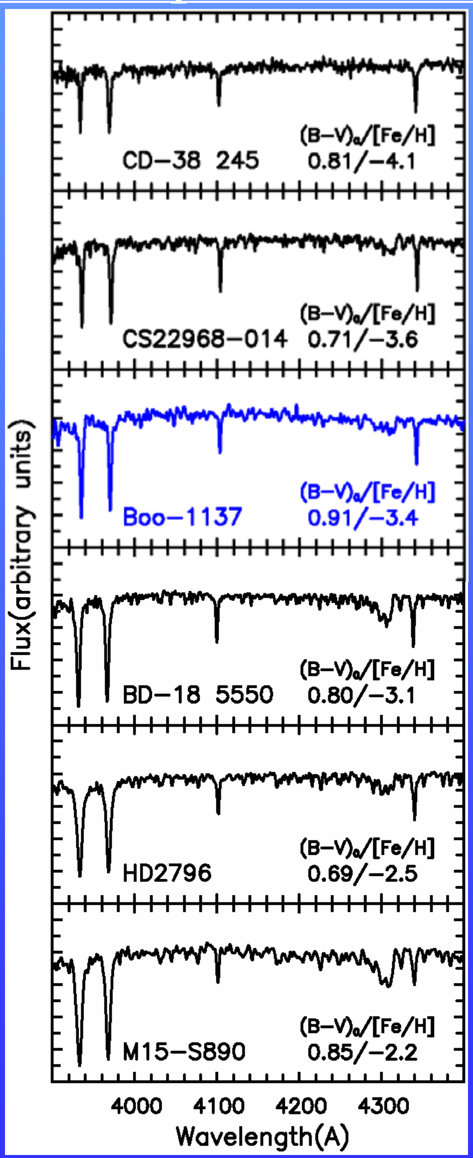
Internal error: σ([Fe/H])= 0.35

W(CaIIK), B-V ⇨ Beers et al 1999 calibration ⇨ [Fe/H]

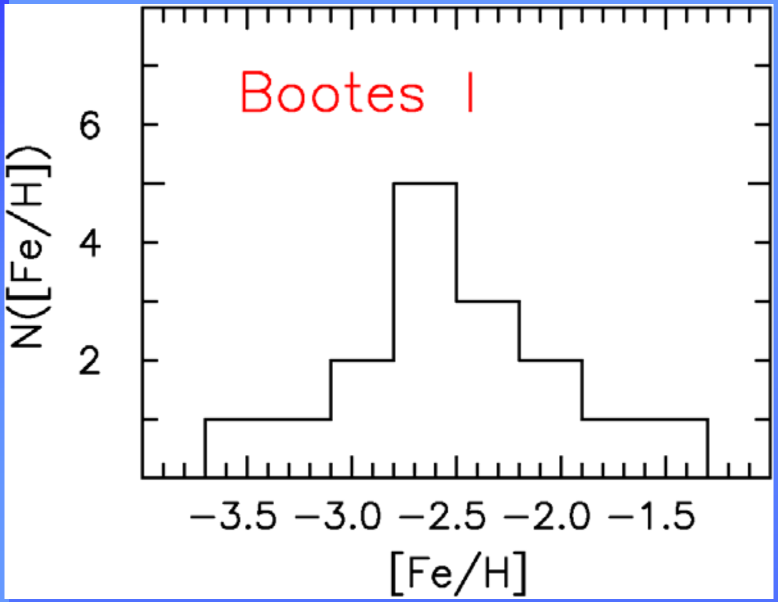
Candidates with [Fe/H] < -3 likely members, despite being beyond 2 half-light radii, given the rareness of field stars with [Fe/H] < -3.0.

From the HK survey for metal-poor stars Beers et al (1992) and from the HES, Christlieb (2008, priv. comm.) we estimate one should expect only ~0.02 field halo giants having [Fe/H] < -3.0 within the central 30 arcmin of Bootes I.

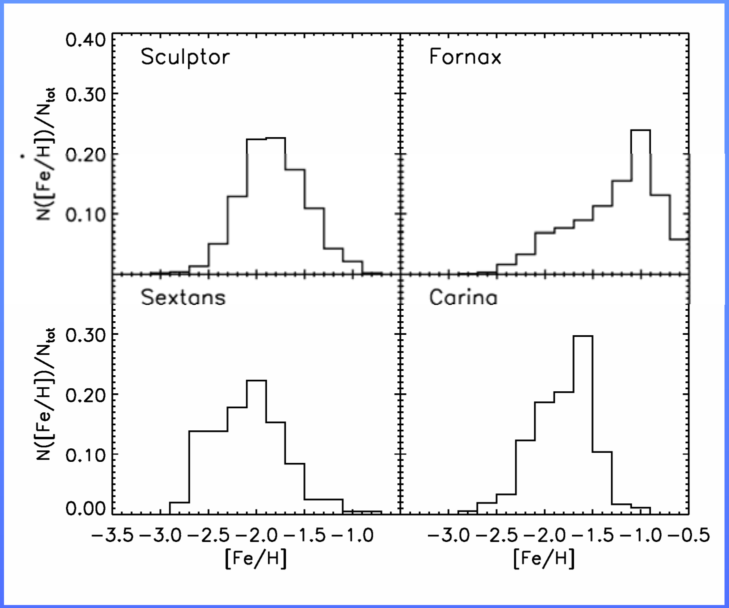
Boo-1137 versus extremely metal-poor stars



Norris et al 08



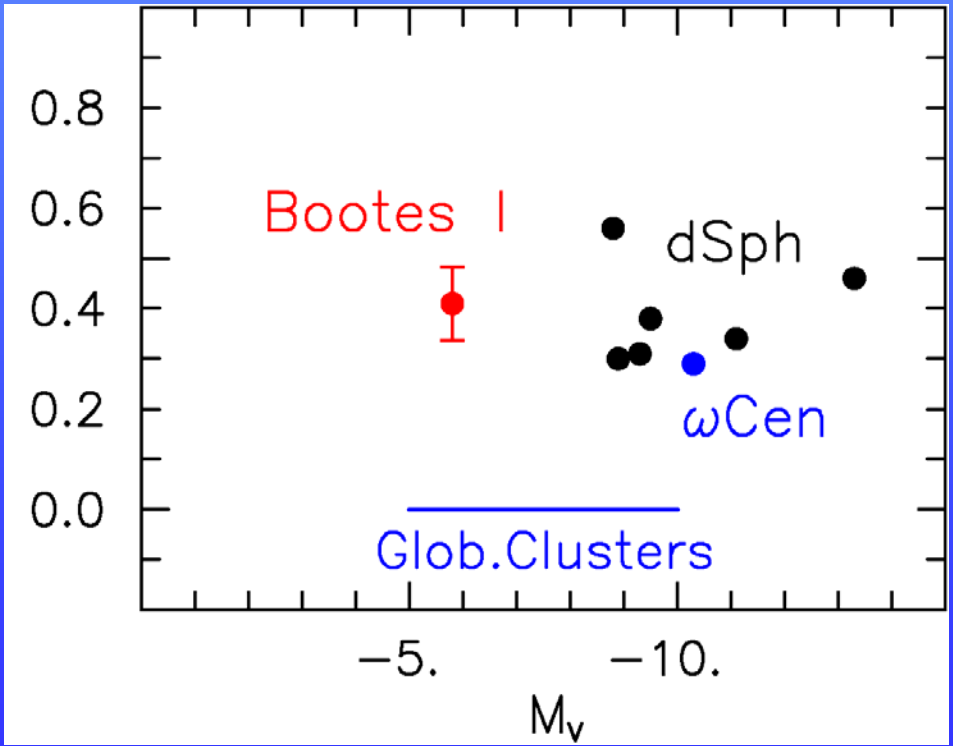
Helmi et al 2006



We do not find a lack of stars below -3 dex, as proposed for more luminous dSph by Helmi et al 06. Kirby et al 08 similarly find very metal-poor stars in 8 other extremely low-luminosity dwarfs, using a different technique.

- Even at very low luminosities, find evidence fo significant self-enrichment
  → dark matter halo
- 'Feedback' limits chemical enrichment?
- Small star-forming regions, inhomogeneities?

Metallicity dispersion (dex)



Concluding Remarks

- The bulk of the stellar mass in the central bulge appears to have formed *in situ* in a short-lived star-formation phase, SFR ~ $10M_{\odot}$/yr
  - Addition of stars from satellite galaxies and/or later gas inflow must be small
  - Significant mergers only occur at early times, 12Gyr ago -- either gas-rich systems, or drive existing thin disk gas to central regions
  - Similar constraints on merger history from uniform old age of thick disk stars, 10-12Gyr
    - Same last merger?
- Most halo stars also formed in systems of short star formation duration; well-mixed now
- Little evidence for variable IMF at both high and low ends, across wide range of metallicity, time, environment
- Low surface-brightness systems allow 'clean' study of dark halo, minimal baryonic component to potential well: very similar dark matter potentials, cored profiles, self-enriched to produce variety of stellar populations.