Globular Cluster Systems and Galaxy Halo Masses

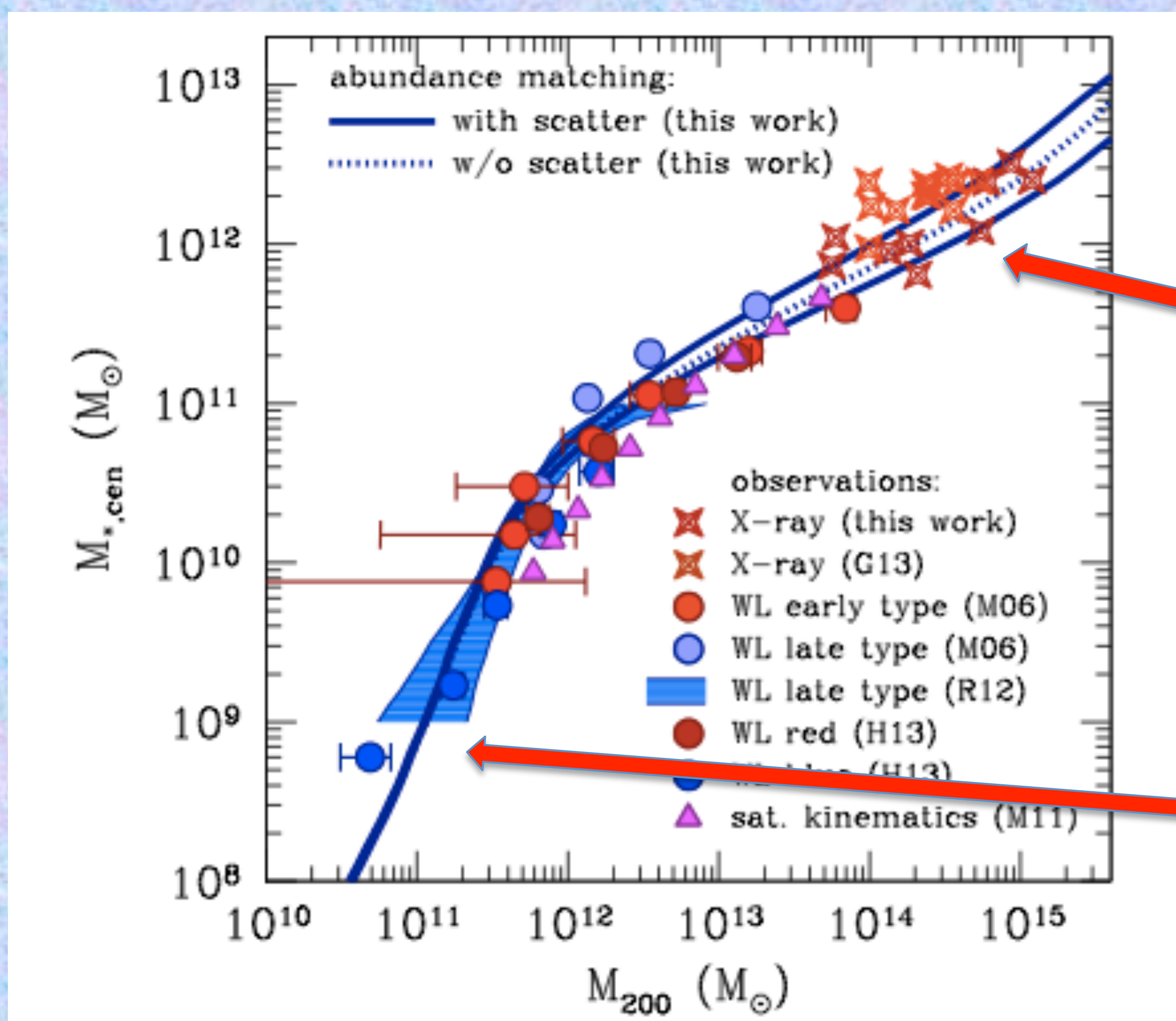
Does Dark Matter Control GC Populations?

How do we gauge the net effect of feedback during galaxy formation?

Bill Harris

RASPUTIN (Oct 2014)

M(stellar) strongly nonlinear function of M(halo)
Dominance of dark matter highest for either dwarfs or supergiants



Strong differences in types and level of feedback

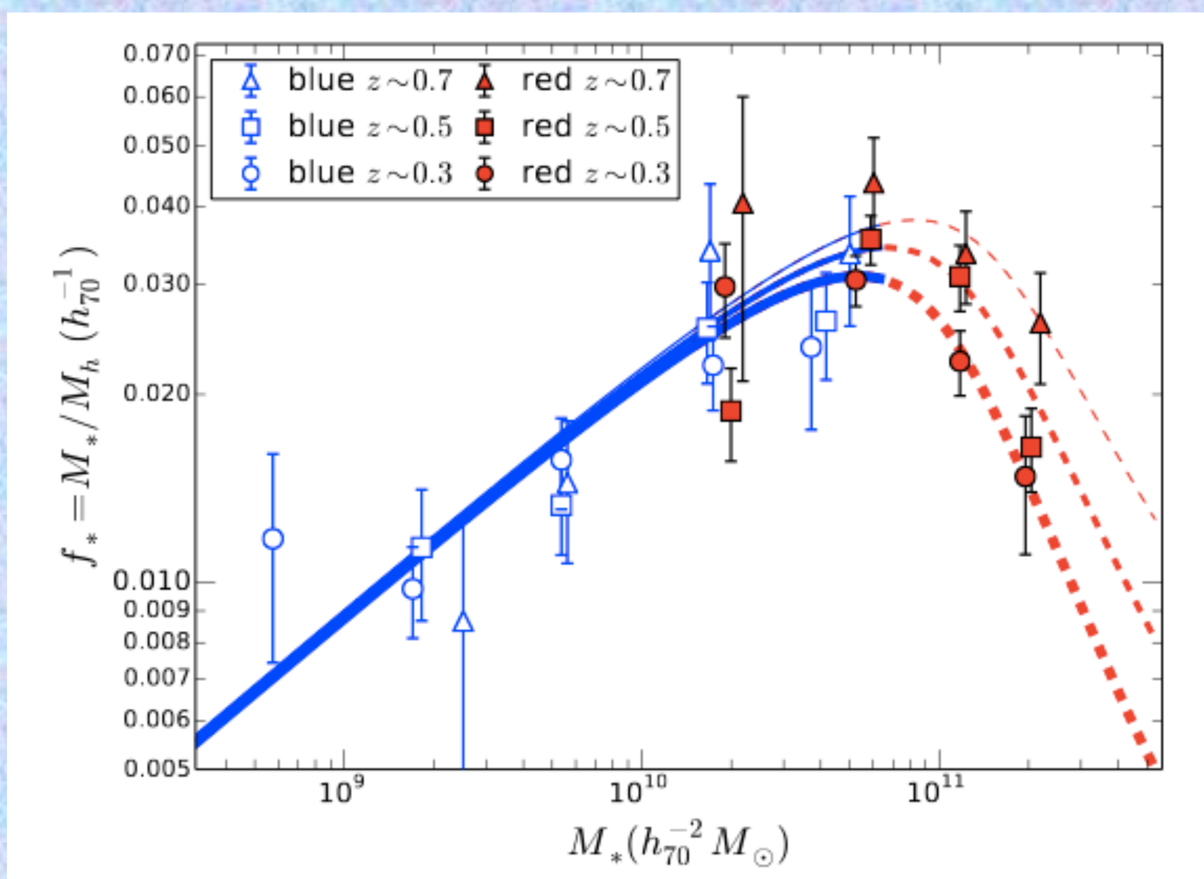
AGN heating,
infall heating

Stellar winds,
SNII heating,
reionization ??

Kravtsov et al. 2014 (1401.7329)

Hudson et al. 2014 (1310.6784)

SHMR curve: (M_*/M_h) versus M_* ("absolute" star formation efficiency)



- M(halo): weak lensing measurements from CFHT Legacy Survey fields
- 2 x 10^6 lenses over redshift range $0.2 < z < 0.8$, $i'_{AB} < 23$

Lenses stacked and $<M_h>$ derived in 13 M_r bins and 3 redshift bins

- M(stellar): $M_* = L_K \cdot (M/L)_K$

General question: *is there any stellar population that forms in direct proportion to halo mass?*

Globular cluster formation epochs are z = 2 – 8 (ages 10-13 Gyr), perhaps before much feedback reduces SFE

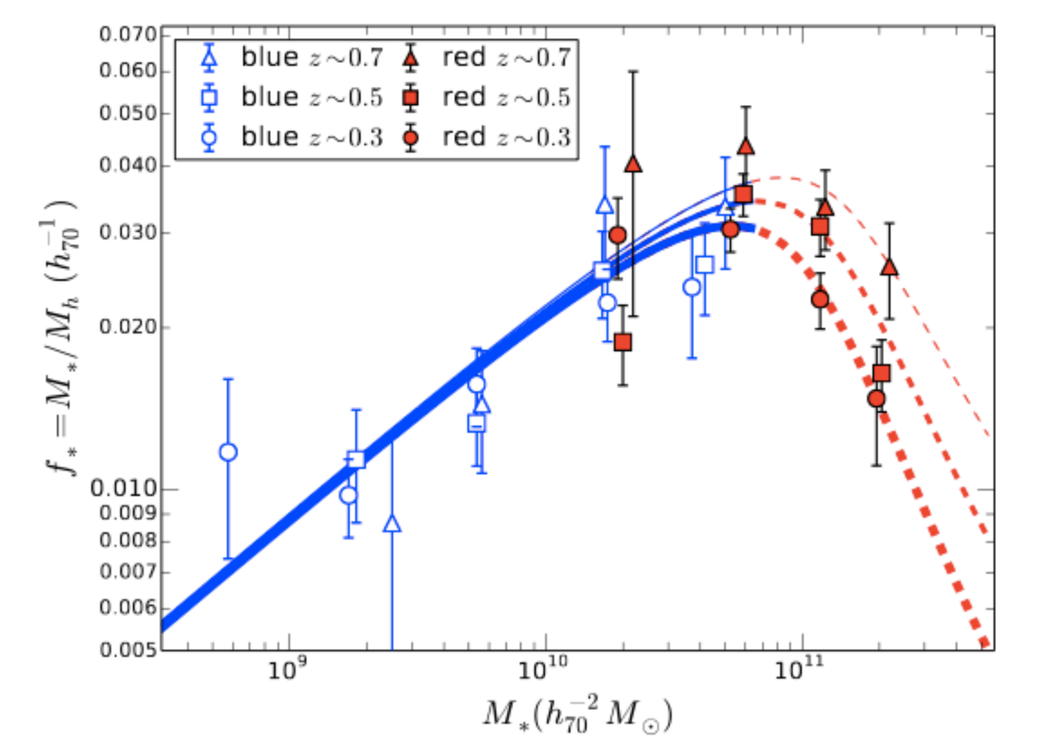
NGC 3311, central cD in A1060 (Wehner & Harris, Gemini-S GMOS)

Instead of (M_*/M_{halo}), try the different ratio (M_{GCS}/M_{halo}); is it more nearly a constant?

Observationally based arguments	Blakeslee, Tonry, & Metzger 1997, AJ 114, 482 Blakeslee 1997, ApJL 481, L59 McLaughlin 1999, AJ 117, 2398 Blakeslee 1999, AJ 188, 1506 Kavelaars 1999, in Galaxy Dynamics, ASP Conf Ser 182, p.437 Spitler et al. 2008, MNRAS 385, 361 Peng et al. 2008, ApJ 681, 197 Spitler & Forbes 2009, MNRAS 392, L1 Georgiev et al. 2010, MNRAS 406, 1967 Harris, Harris, & Alessi 2013, ApJ 772, 82 Hudson, Harris, & Harris 2014, ApJ 787, L5
Theory	Kravtsov & Gnedin 2005, ApJ 623, 650 Moore et al. 2006, MNRAS 368, 563

Assembling the data: (1) Galaxy halo masses

From Hudson et al. 2014 calibration, based entirely on weak lensing



Yang et al. 2003 parametrization with
β= 0.68, γ = 0.8

$$f_* = \frac{M_*}{M_h} = 2f_1\left[\left(\frac{M_h}{M_1}\right)^{-\beta} + \left(\frac{M_h}{M_1}\right)^{\gamma}\right]^{-1}$$

Predict M_h from M_* for each catalog galaxy (with extrapolation to zero redshift)

Assembling the data: (2) GC system total mass

New catalog of globular cluster systems in 419 galaxies (Harris, Harris & Alessi 2013). Covers entire luminosity range except very smallest Sloan-type dwarfs

- 245 E, 93 S0, 81 S/Irr

Sum over GCLF, including known trend of "turnover" magnitude and LF dispersion with galaxy size (giant galaxies have broader, brighter GCLFs)

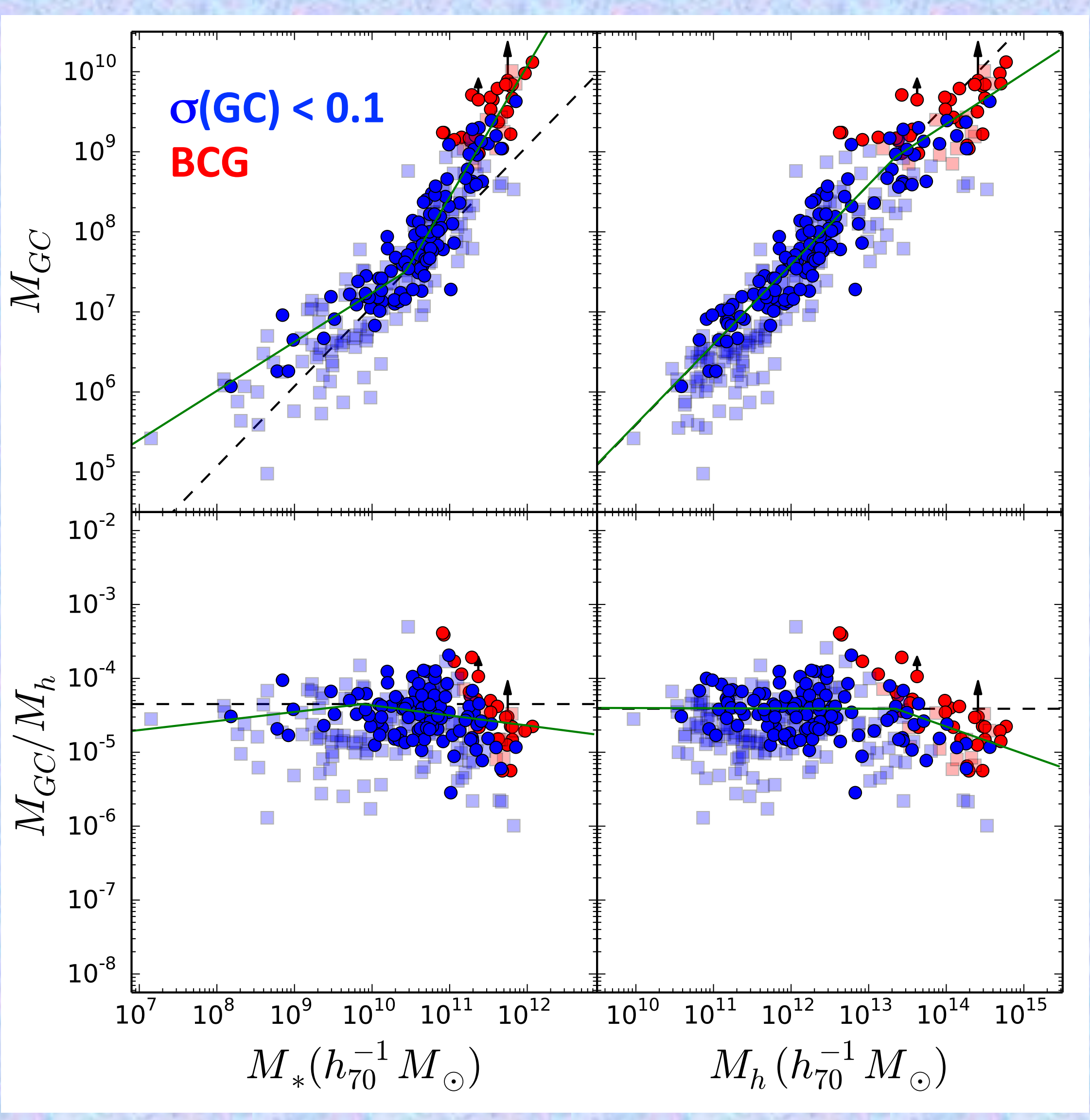
$$M_{GC} = \left(\frac{M}{L}\right)_V \int L \cdot n(L)\,dL$$

$(M/L)_V = 2$

Define $\eta = M_{GC}/M_h$

M_{GC} = total mass in globular clusters, M_h = halo mass

Hudson, Harris, & Harris 2014, ApJ 787, L5



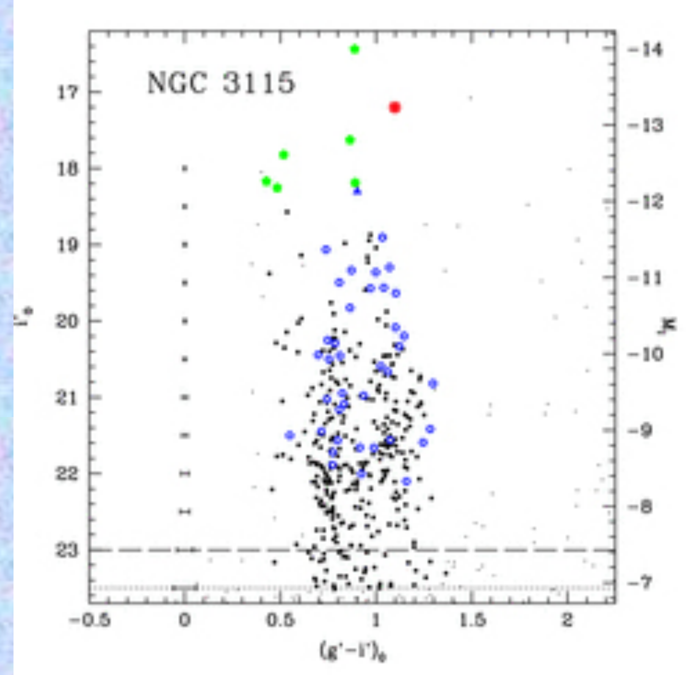
M_{GC} vs. M_* and M_h

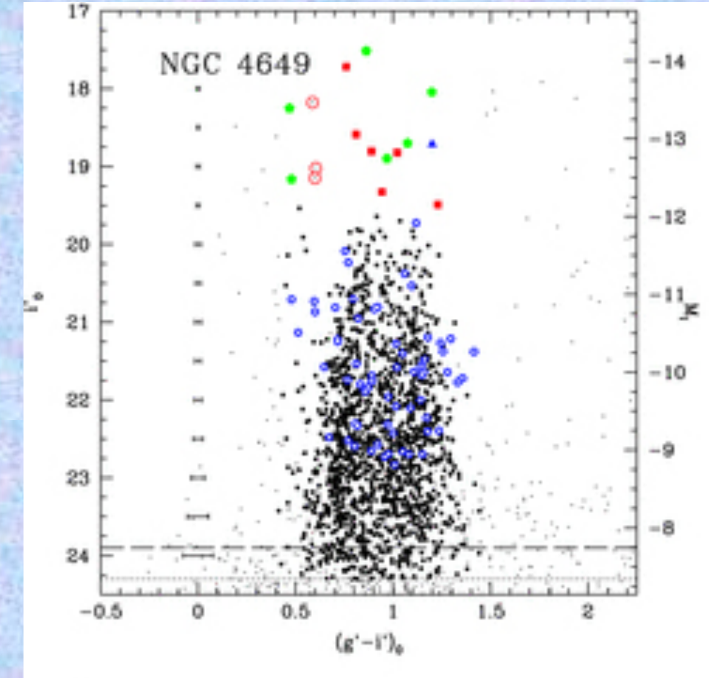
Nearly linear behavior over 10e5 in mass!

(M_{GC}/M_h) vs. M_* and M_h

$\eta = M_{GC}/M_h = 4 \times 10^{-5}$

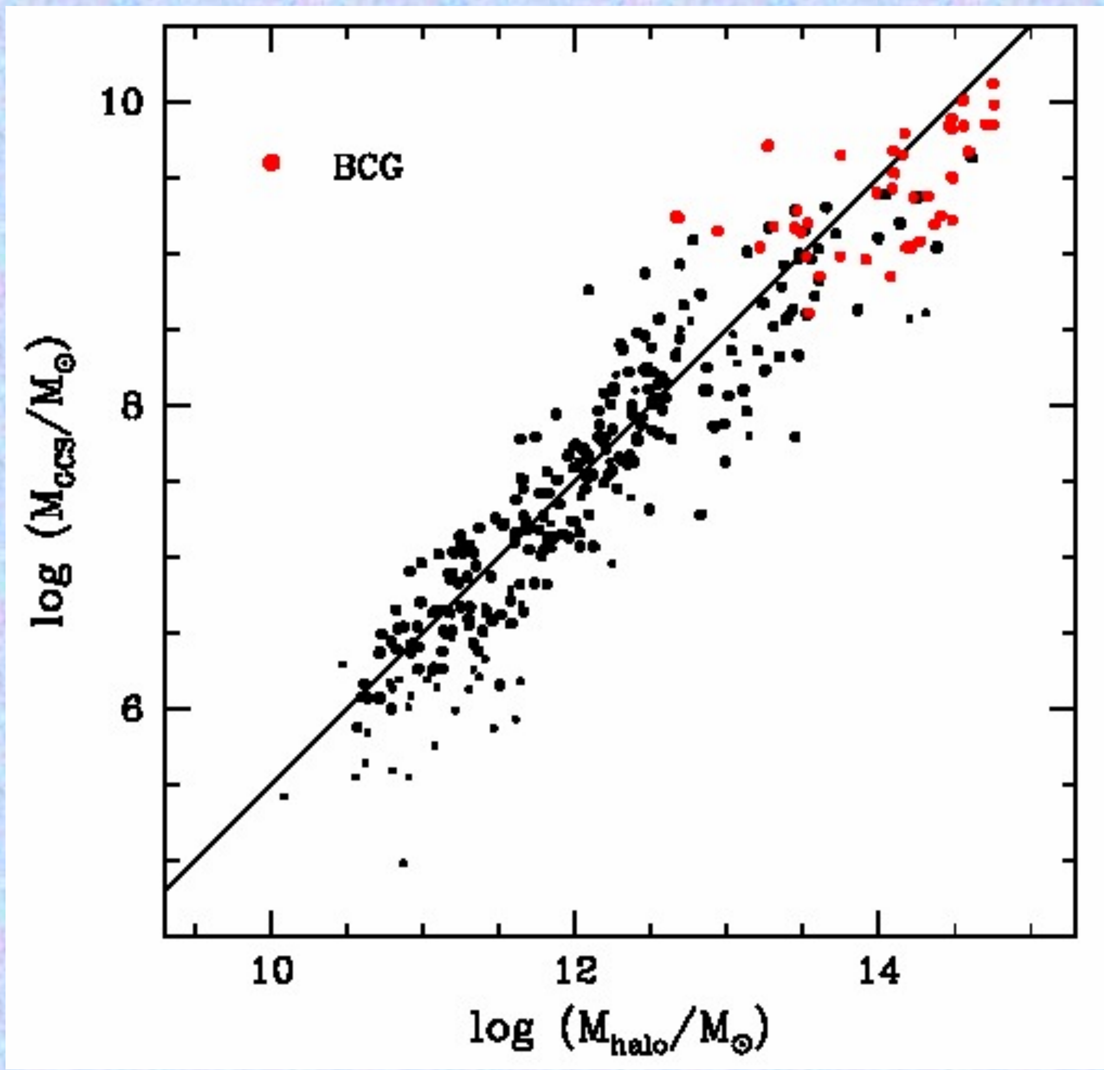
The bimodality question: “red” and “blue” GC subpopulations. Is one correlated better with M(halo)?





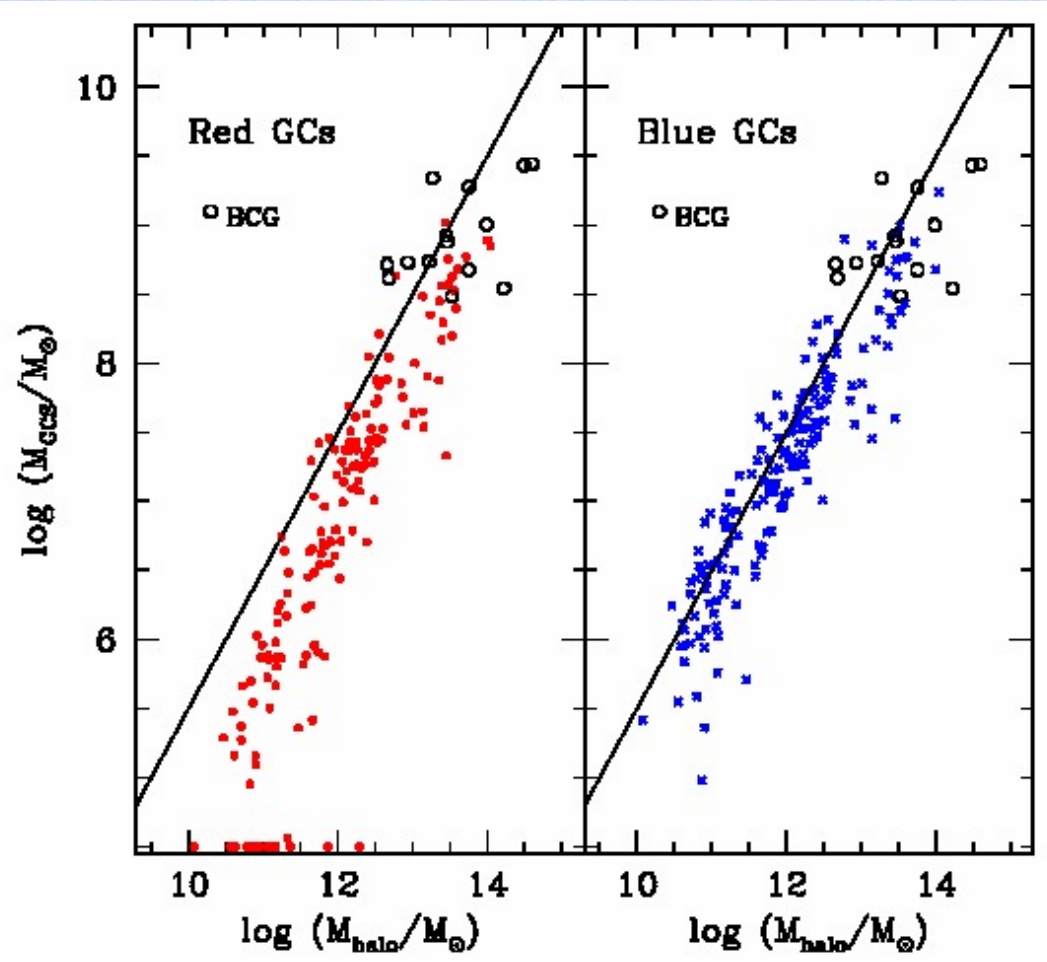
Faifer et al. 2011, MNRAS 416, 155

- Calibrations in nearby galaxies indicate “blue” GCs are older (by 2-3 Gy) and more metal-poor; also more spatially extended in the halo
- “Red” GCs progressively more prominent in bigger galaxies with longer, more complex star formation histories

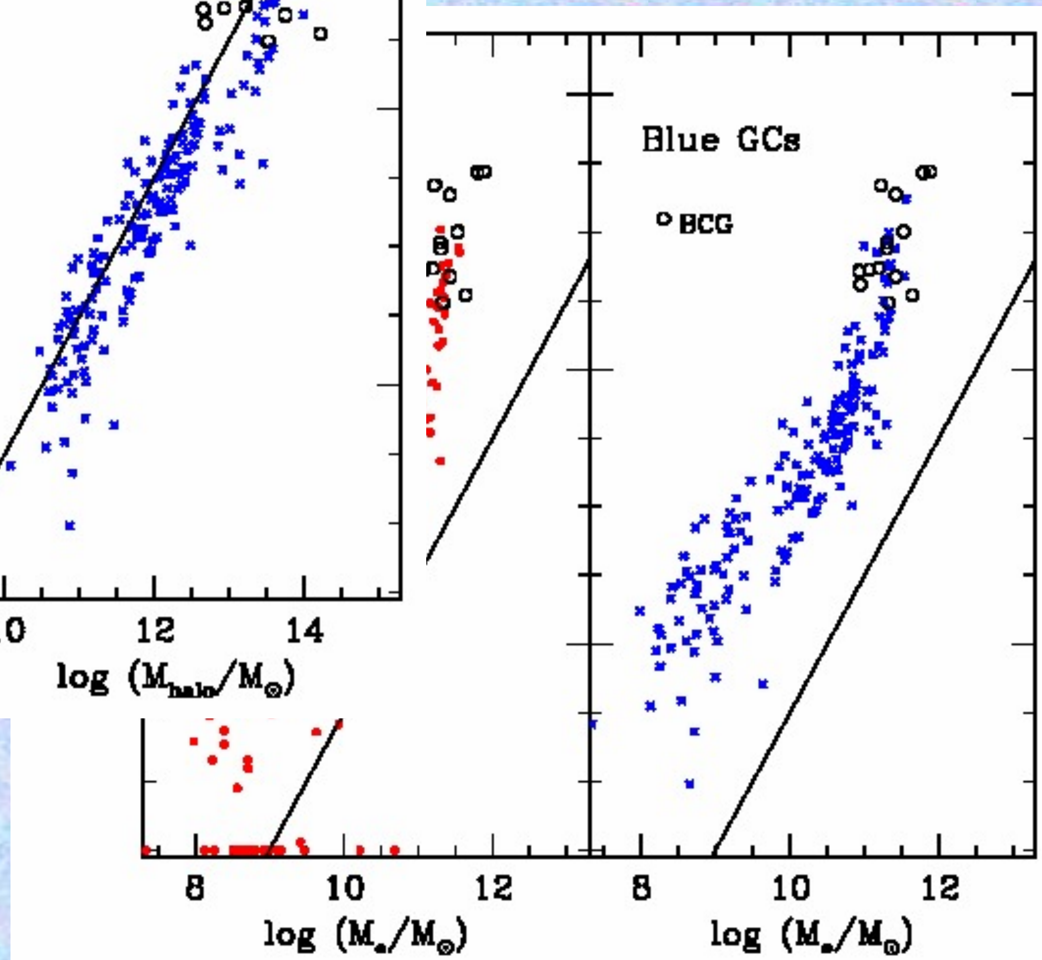


Correlation of M_{GCS} with M_{halo} for all GCs (red +blue)

(NB: BCG totals likely underestimated)



Halo mass



Stellar mass

$M_{GC} \sim$ const. M_h suggests 3 conditions needed:

- *Initial* gas mass present in pregalactic potential well is proportional to halo mass

- GC formation rate is proportional to available gas mass

- GCs formed earliest, before feedback effects dominate

***** The GC population best represents the star formation efficiency as it would have been without feedback *****

Back-of-envelope scaling:

$$\eta \sim \left(\frac{M_{bary}}{M_h}\right) \times \left(\frac{M_{GMC}}{M_{bary}}\right) \times \left(\frac{M_{PGC}}{M_{GMC}}\right) \times \left(\frac{M_{GC}}{M_{PGC}}\right)$$

$$\sim 0.15 \times 0.25 \times 0.01 \times 0.1 \sim 4\cdot 10^{-5}$$

GMCs large enough to build GCs

Massive dense proto-GCs

Infant mortality and long-term dynamical evolution

Estimating galaxy masses from their globular cluster populations
(e.g. Spitler & Forbes 2009):

How well does it do for the Milky Way?

M (10^{12} M_{sun})	Source	Method
1.2 +- 0.5	Hudson && 2014	GCS mass
0.9 +- 0.3	Watkins && 2010	halo satellite tracers (isotropic)
0.4	Deason && 2013	(R < 50 kpc) halo BHB stars
1.2 +- 0.6	Battaglia && 2005	halo satellite velocity dispersion
1.6 +- 0.6	Boylan-Kolchin && 2013	Leo I motion + simulations
3.1 +- 1.4	Sohn && 2013	Leo I timing
(>0.8)	Li & White 2008	calibrated timing argument
4.2 +- 3	Gonzalez && 2014	entire Local Group
1.6 +- 0.2	Eadie && 2014	satellite motions + Bayesian/MCMC

See poster here

The simulated night sky 2.5 pc (one half-mass radius) from the center of a massive globular cluster (Harris & Webb, *Astronomy,* July 2014)