Spectroscopy of M81 Globular Clusters

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Galaxy Formation and Globular Clusters

- Questions: How did galaxies get to be different? Did all galaxies of similar mass and Hubble type form the same way? To what extent are earliest formation processes and present galaxy properties related?
- Old globular clusters (GCs) date back to earliest eras of galaxy formation and have simple age and metallicity structure, allowing them to serve as "fossils" of early galaxy formation
- GCs are bright enough to study in most nearby galaxies (out to tens of Mpc and more), and provide much greater spatial detail than high-redshift galaxy studies

Why study GCs in M81?

- GC systems (GCSs) of spiral galaxies in general (except for MW & M31) not yet well-studied
- Similar in mass, Hubble type to MW & M31; helps us understand if MW & M31 are typical of early-type massive spirals
- Interactions with M82 have affected recent star formation history; may have also affected GC system
- Very nearby (~3.5 Mpc), so GCs are bright, easy to observe spectroscopically, easy to resolve with HST or adaptive optics
- Only 46 of expected 200+ GCs were spectroscopically confirmed (before this research)

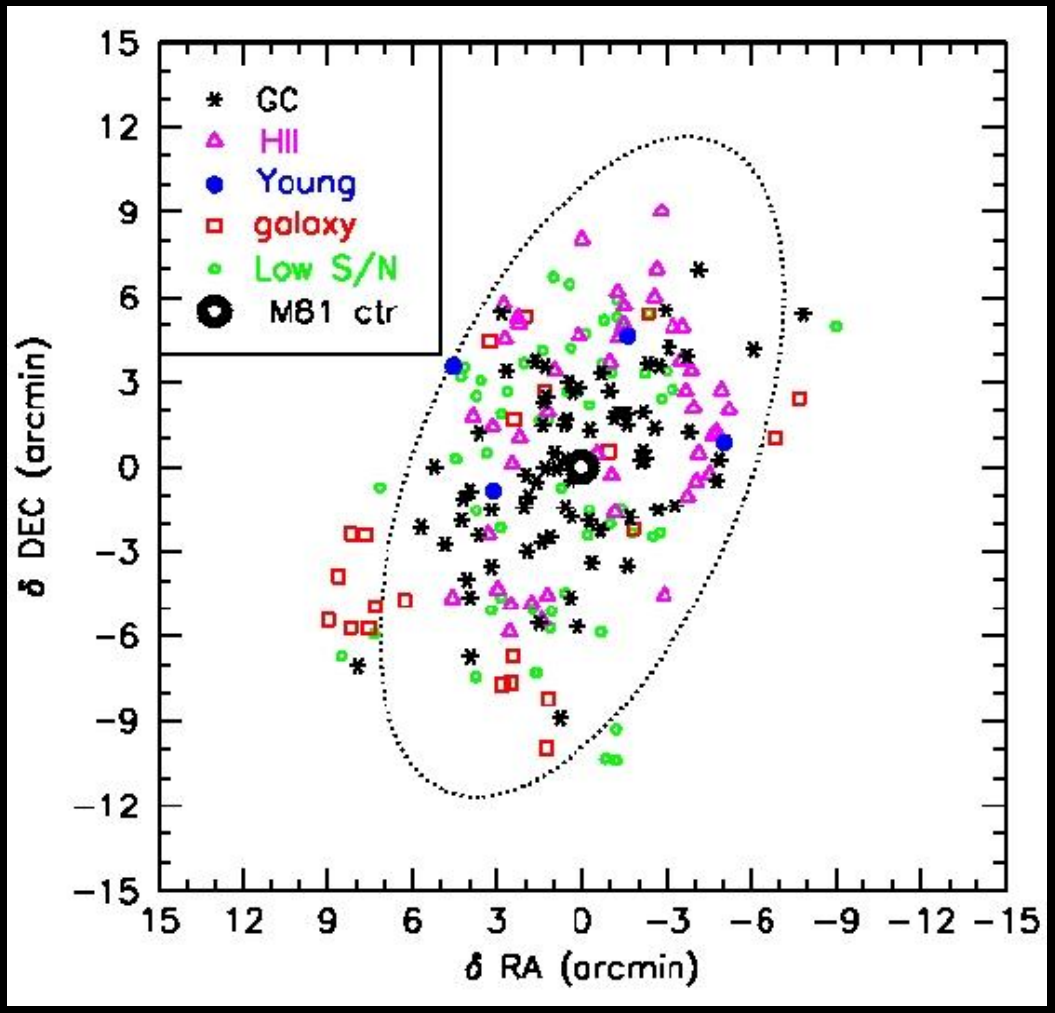
Data and Analysis

- Candidates identified in HST I-band survey, selected to be extended so as to weed out foreground stars
- Spectra taken with MMT (Mt. Hopkins) Hectospec
- Wavelength coverage 3700-9150Å, resolution ~5Å
- Exposure times 60-160 minutes
- 151 useful spectra of GCs, galaxies, HIIs, and young clusters (207 spectra total)
- 74 GCs identified, 62 never previously spectroscopically confirmed, more than doubling number of confirmed GCs
- Metallicities determined via updated Brodie & Huchra (1990) method, described below

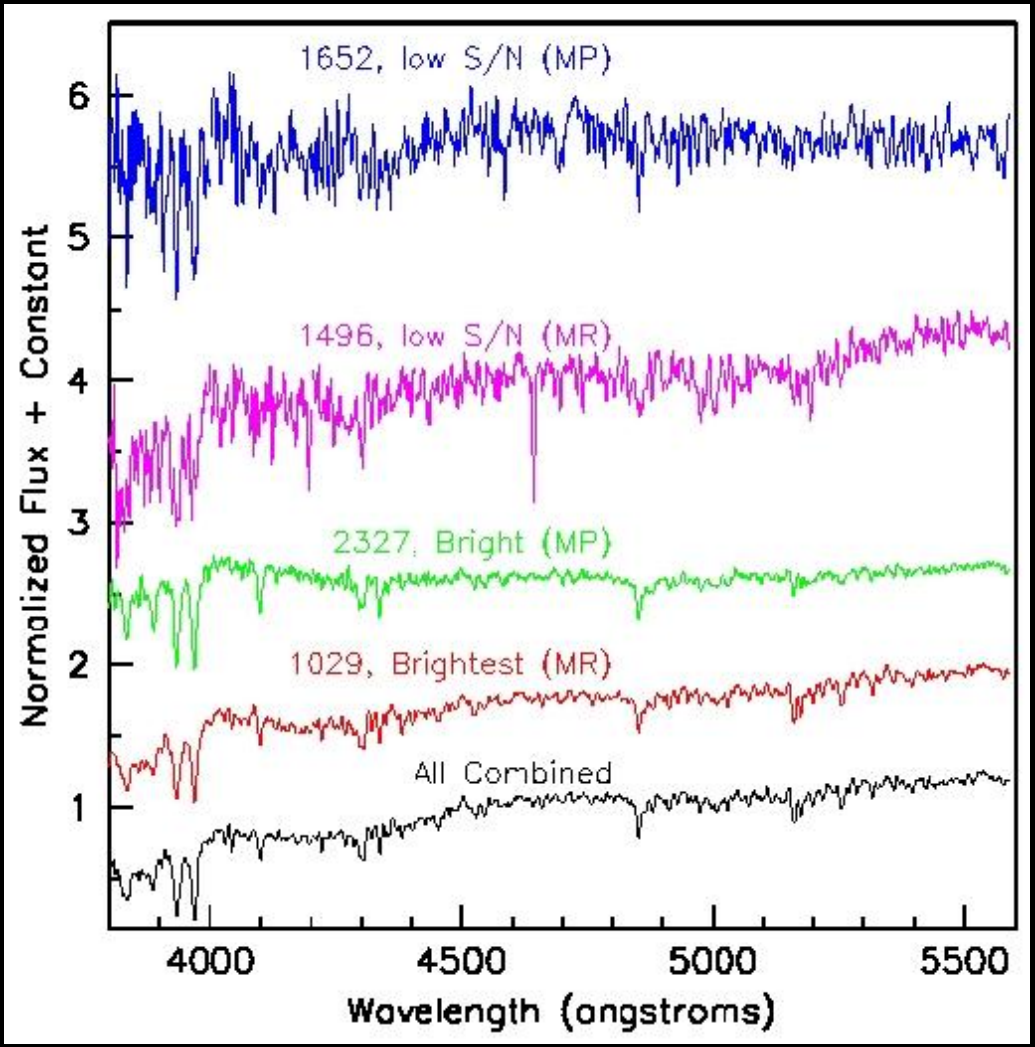
Metallicity Analysis Methodology

- Update of Brodie & Huchra (1990) spectral index-metallicity calibrations using Schiavon et al. (2005) GC spectra and Harris (1996) metallicities
- Schiavon et al. spectra degraded to match resolution of our spectra
- 25 indices calibrated: the 12 Brodie & Huchra (1990) indices (8 of which have equivalents in Lick/IDS) plus 13 indices with Lick/IDS (Trager 1998) wavelength definitions
- 9 indices chosen based on combination of high S/N in our data and high correlation with metallicity: MgH, Mg2, Mgb, Fe52, Fe53, Fe54, G43, δ (4000 Å break), & CNR

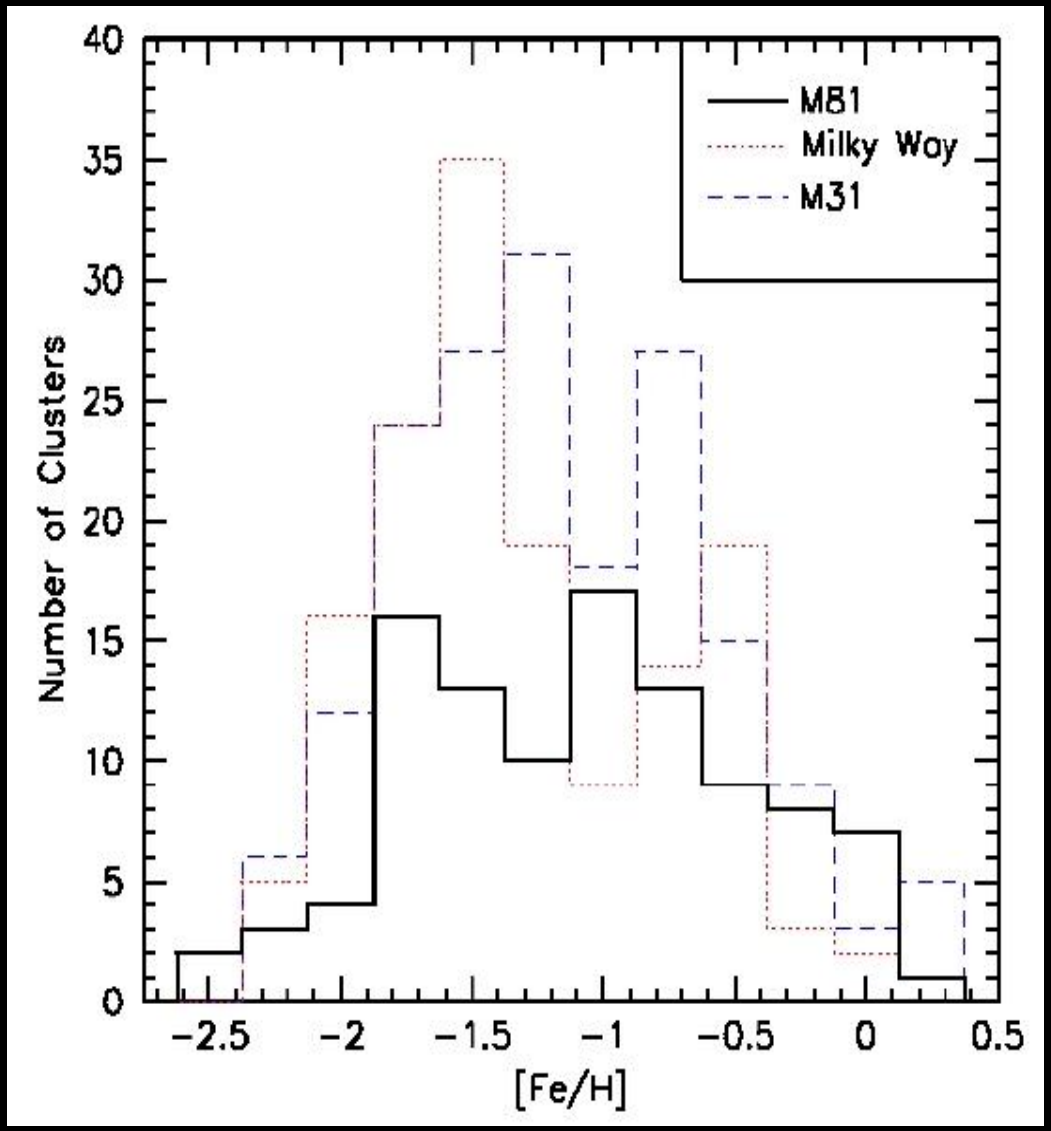
M81 Spectra - Spatial Distribution



M81 GC Sample Spectra



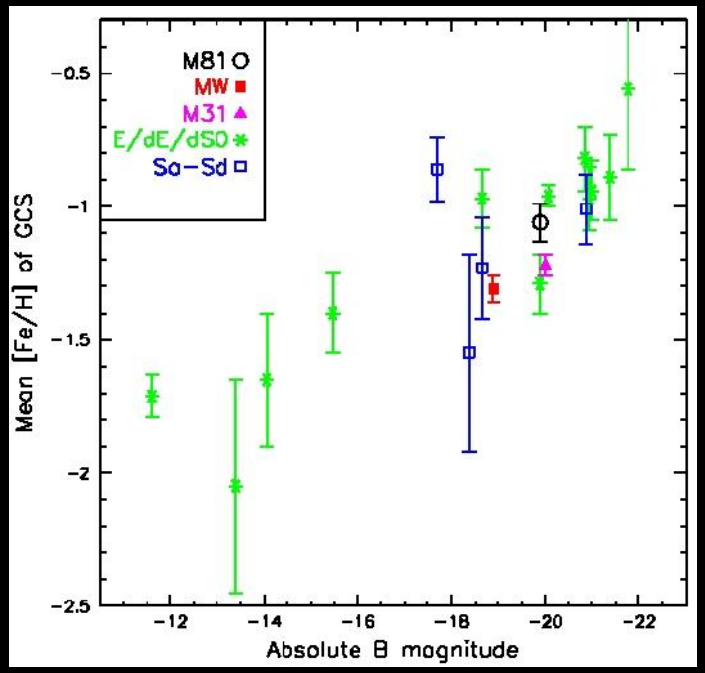
M81 Spectroscopy - Metallicity Histogram



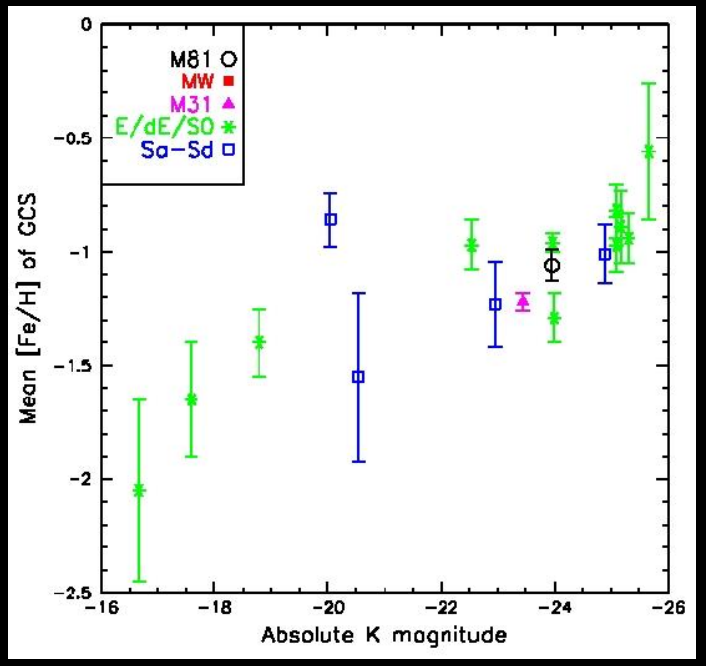
- Mean [Fe/H] = -1.06 $\pm$ 0.07
- Marginal evidence of bimodality: KMM peaks -1.55 and -0.61 with P = 0.14
- Nearly even MR/MP split

M81 Spectroscopy: GC Metallicity - Galaxy Luminosity Relation

B-band



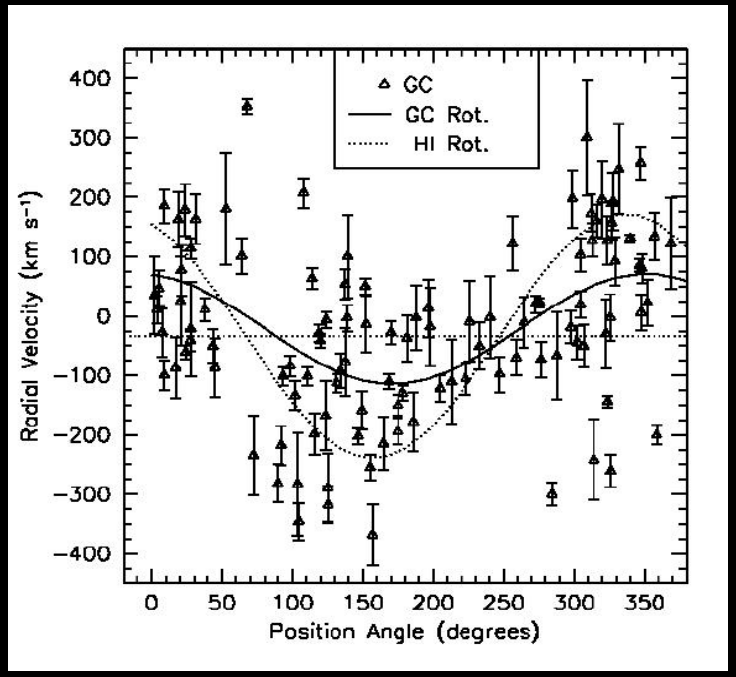
K-band



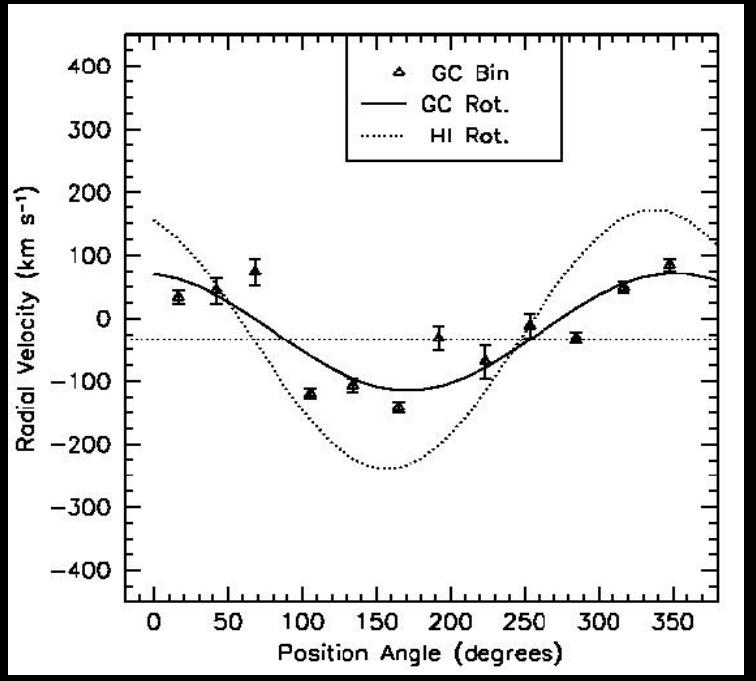
- M81 consistent with GC metallicity - galaxy luminosity relation

M81 Spectroscopy - GC Rotation Curves

All Objects Individually



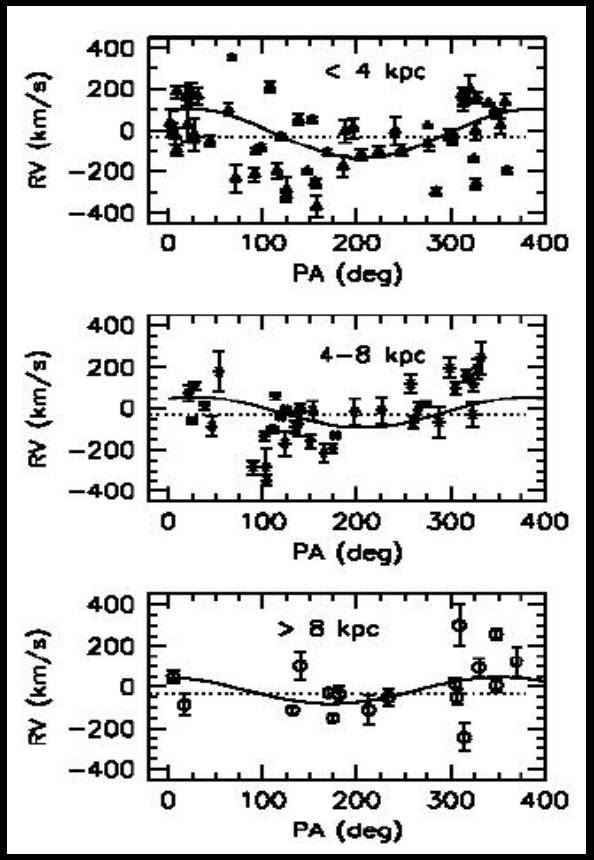
30 Degree Bins



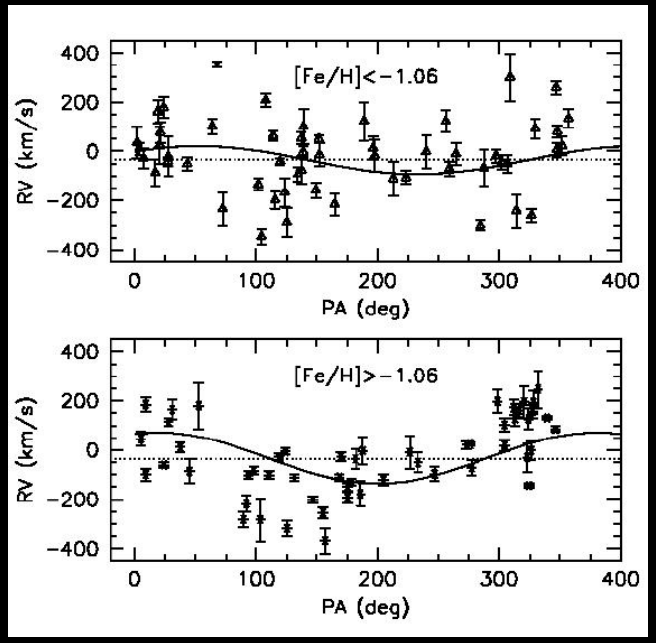
- V_r (deprojected) = 108 ± 22 km/s; 45% of peak HI rotation amplitude (240 km/s)
- Velocity Dispersion = 145 km/s ($V/\sigma = 0.74$)
- Rotation-corrected σ = 128 km/s

M81 Spectroscopy - GC Subpop. Rotation Curves

Projected Radius



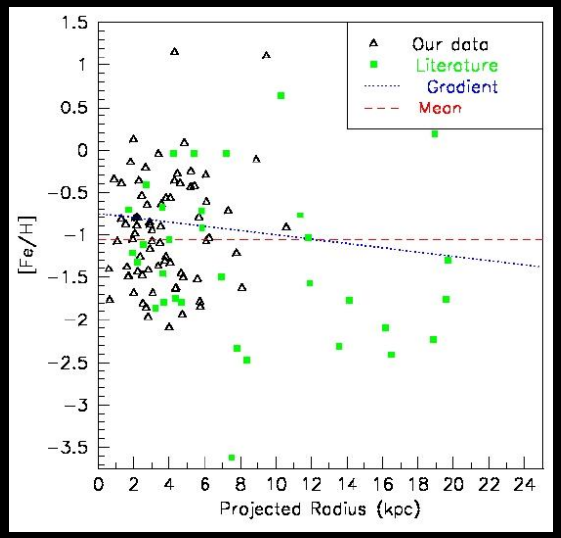
Metallicity



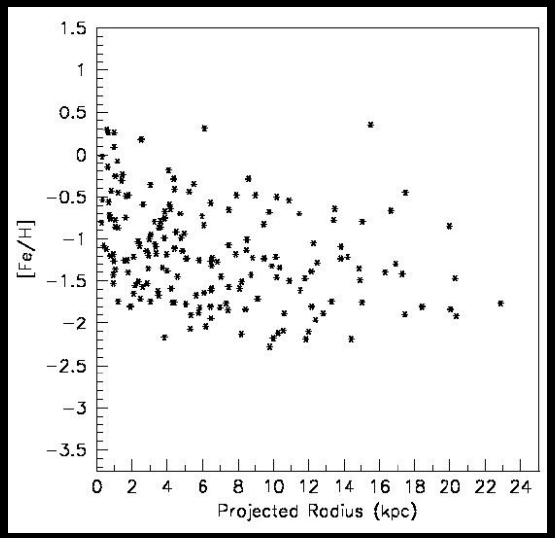
- Metal-rich (122 ± 18 km/s) and inner (133 ± 40 km/s) clusters rotate strongly
- Metal-poor clusters show marginal signs of rotation (67 ± 38 km/s)

M81 GC Metallicity Gradient

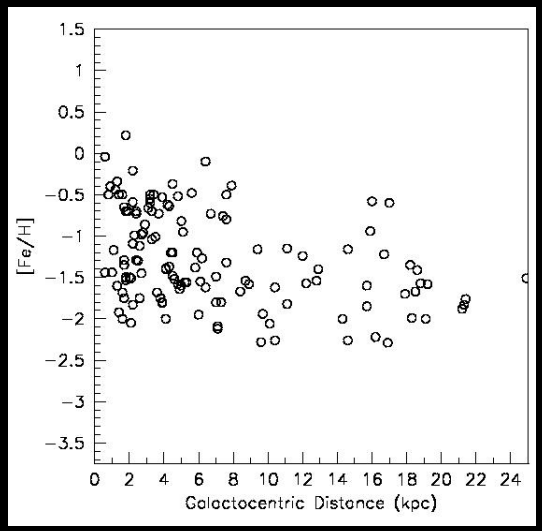
M81



M31



Milky Way



- Hint of metallicity gradient in overall GC system: -0.025 ± 0.020 dex/kpc
- Stronger metallicity gradient among MP clusters alone: -0.031 ± 0.012 dex/kpc

Spiral Galaxy GC Comparisons: Metallicity

- M31 and MW have clearly bimodal GC distributions; M81 probably bimodal as well
- M31, MW, & M81 metallicity peaks similar, and all consistent with GC metallicity-galaxy luminosity relations for MR and MP peaks
- M31, MW, & M81 all show signs of metallicity gradients as a function of galactocentric distance

Spiral Galaxy GC Comparisons: Kinematics

- Kinematic subpopulations exist in MW, M31, M81, possibly even M33 (Chandar et al. 2002), but no evidence of them in M104 (Bridges et al. 2007)
- In MW, MR clusters rotate significantly, MP clusters rotate little; in M31, both rotate (but with lower V/σ for MP)
- In M81, rotation pattern similar to, but slightly stronger than, MW

Summary of Results

- 62 new M81 GCs spectroscopically confirmed, more than doubling known M81 GC sample
- Marginal evidence for bimodal [Fe/H] distribution in M81, with peaks similar to MW & M31
- M81 consistent with GC metallicity vs. galaxy luminosity relation
- M81 GCs in general, and especially MR & inner ones, show evidence of rotation
- Evidence for Metallicity Gradient among MP M81 GCs
- Metallicity-luminosity relations & MP metallicity gradient suggest link between early GC formation processes & gravitational potential well of eventual host galaxy

Acknowledgments

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