What we have learned from Extragalactic Globular Cluster Systems about Globular Cluster and Galaxy Formation (and vice versa)

i.e., The Globular Cluster–Galaxy Connection

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Some observations...

1. Young GCs in ongoing starbursts/mergers → GCs form in such environments. Major star-forming events in galaxies accompanied by significant GC formation.

2. Lack of mass-radius relation in young and old GCs, open clusters. **+ HIGH PRESSURE**

3. Two (or more) populations of GCs in old ellipticals; “red” more centrally concentrated than “blue”. Also kinematic differences. (?)

4. Two populations of GCs in spirals; halo and disk/bulge.

5. Intermediate-aged GCs in a few youngish ellipticals.
GLOBULAR CLUSTER SYSTEMS

USEFUL PROBES OF GALAXY FORMATION & EVOLUTION

AND

GALAXIES/COSMOLOGICAL PARAMETERS USEFUL PROBES OF GLOBULAR CLUSTER SYSTEM FORMATION & EVOLUTION
SPECIFICALLY... GCS FORMATION MODELS SHOULD BE CONSISTENT WITH ESTABLISHED IDEAS CONCERNING:

1. COSMOLOGICAL STRUCTURE FORMATION

2. GALAXY FORMATION

Normal Es: GCS formation scenarios


Pros: predicted metallicity bimodality, red GCS more concentrated than blue GCS; “known” model of E formation; major mergers expected in, e.g., ΛCDM cosmologies.

Cons: 1992 version underpredicts number of blue GCs in Es.

Solution: additional blue GCs contributed by accretion of high-$S_N$ dwarfs.

* AZ92: FORM IN "SEARLE-ZINN" FRAGMENTS, I.E. PRE-/PROTO-GALACTIC ORIGIN
2. Dissipationless merging (Côté et al. 1998, 2002). Metal-poor clusters from accreted dwarfs, metal-rich clusters form around largest “seed” galaxy.

Pros: explains correlation between metallicity of red GCs and galaxy mass.

Cons: requires mechanism to prevent seed “spinning up,” forming disk.

Solution: Angular momentum transfer?
3. Two-phase collapse (Forbes et al. 1997). Metal-poor and metal-rich clusters both form \textit{in situ} around E; GC formation “switched off” between bursts.

Pros: explains correlations between GCS properties and host galaxy properties.

Cons: Currently lacking physical basis. \textsl{(HANDWAVY)}

\textbf{LARGE METALlicity GRADIENTS IN METAL-RICH GCs?}
\textbf{SPIN UP \rightarrow MORE ROTATION THAN OBSERVED}


Pros: GCs form in mergers; assumed high gas fraction \rightarrow no efficiency worries?

Cons: why are some galaxies Es, others Ss?

\textbf{+ BEASLEY ET AL (2002)}
Distinguishing models I: theory

1. Simulations of galaxy formation (E and S)

2. Detailed investigation of GCS properties (e.g., Monte Carlo sims, SAMs).

✓ (i) Age distributions

(ii) Metallicity distributions + GRADIENTS

? (iii) Spatial distributions

✓ (iv) Kinematics

? (v) Total and relative numbers of clusters

Distinguishing models II: observation

Observe ages, metallicities, spatial distributions, kinematics, numbers.
Back to GC formation

Globular clusters *can* form in major mergers, but metal-poor GCs do not. Are critical physical conditions the same, or is there more than one way to form a GC?

Bursts of star formation *could* raise ISM pressures in dwarfish things, but only for limited timescales.

“Pseudo-cosmological” formation possible? (Bromm and Clarke 2002).
PREGALACTIC FORMATION OF METAL-POOR GLOBULAR CLUSTERS PROBLEMATIC:

TOM ABEL: RESULTING
GCS TOO SPATIALLY CONCENTRATED

MIKE FALL: RESULTING
GCS TOO SPATIALLY EXTENDED

#@$?

SUMMARY

GLOBULAR CLUSTER SYSTEMS OF ELLIPTICALS
COLOR BIMODALITY ⇒
2 (OR MORE) BURSTS OF GC FORMATION
OCCURS IN ΛCDM PARADIGM
WITH MAJOR MERGER FORMING RED CLUSTERS
TWO-PHASE COLLAPSE MODEL VIVABLE?
DIAGNOSTICS: AGES, KINEMATICS