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...

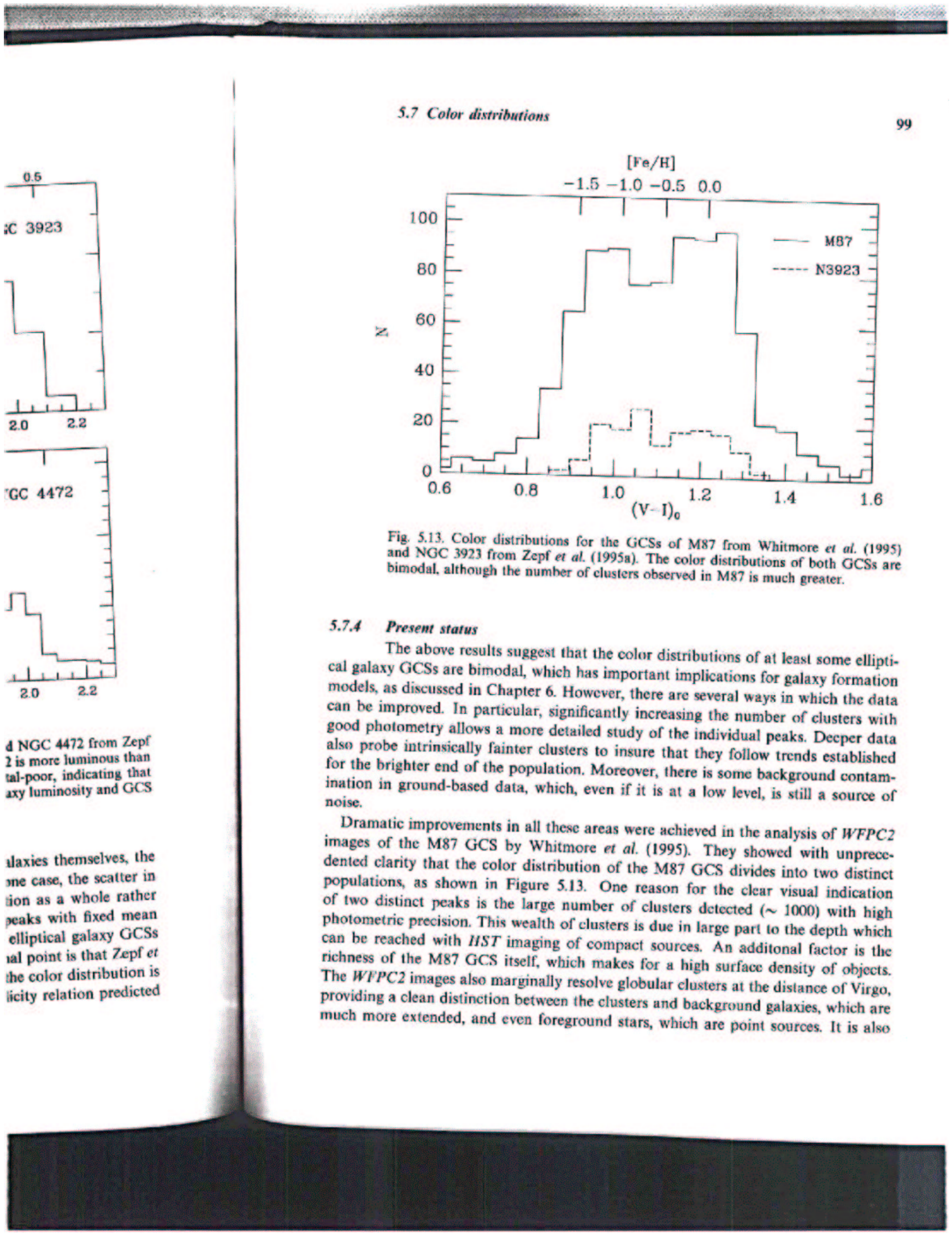
1. Young GCs in ongoing starbursts/mergers → GCs form in such environments. Major star-forming events in galaxies accompanied by significant GC formation.

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.



d NGC 4472 from Zepf
2 is more luminous than
tal-poor, indicating that
axy luminosity and GCS

laxies themselves, the
one case, the scatter in
ion as a whole rather
peaks with fixed mean
elliptical galaxy GCSs
ial point is that Zepf et
the color distribution is
licity relation predicted

5.7 *Color distributions* 99

Fig. 5.13. Color distributions for the GCSs of M87 from Whitmore *et al.* (1995) and NGC 3923 from Zepf *et al.* (1995a). The color distributions of both GCSs are bimodal, although the number of clusters observed in M87 is much greater.

5.7.4 *Present status*

The above results suggest that the color distributions of at least some elliptical galaxy GCSs are bimodal, which has important implications for galaxy formation models, as discussed in Chapter 6. However, there are several ways in which the data can be improved. In particular, significantly increasing the number of clusters with good photometry allows a more detailed study of the individual peaks. Deeper data also probe intrinsically fainter clusters to insure that they follow trends established for the brighter end of the population. Moreover, there is some background contamination in ground-based data, which, even if it is at a low level, is still a source of noise.

Dramatic improvements in all these areas were achieved in the analysis of *WFPC2* images of the M87 GCS by Whitmore *et al.* (1995). They showed with unprecedented clarity that the color distribution of the M87 GCS divides into two distinct populations, as shown in Figure 5.13. One reason for the clear visual indication of two distinct peaks is the large number of clusters detected (~ 1000) with high photometric precision. This wealth of clusters is due in large part to the depth which can be reached with *HST* imaging of compact sources. An additonal factor is the richness of the M87 GCS itself, which makes for a high surface density of objects. The *WFPC2* images also marginally resolve globular clusters at the distance of Virgo, providing a clean distinction between the clusters and background galaxies, which are much more extended, and even foreground stars, which are point sources. It is also

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

1. Major mergers (Ashman & Zepf 1992). S+S → E. Metal-poor clusters* from spiral halos, metal-rich clusters form in merger.

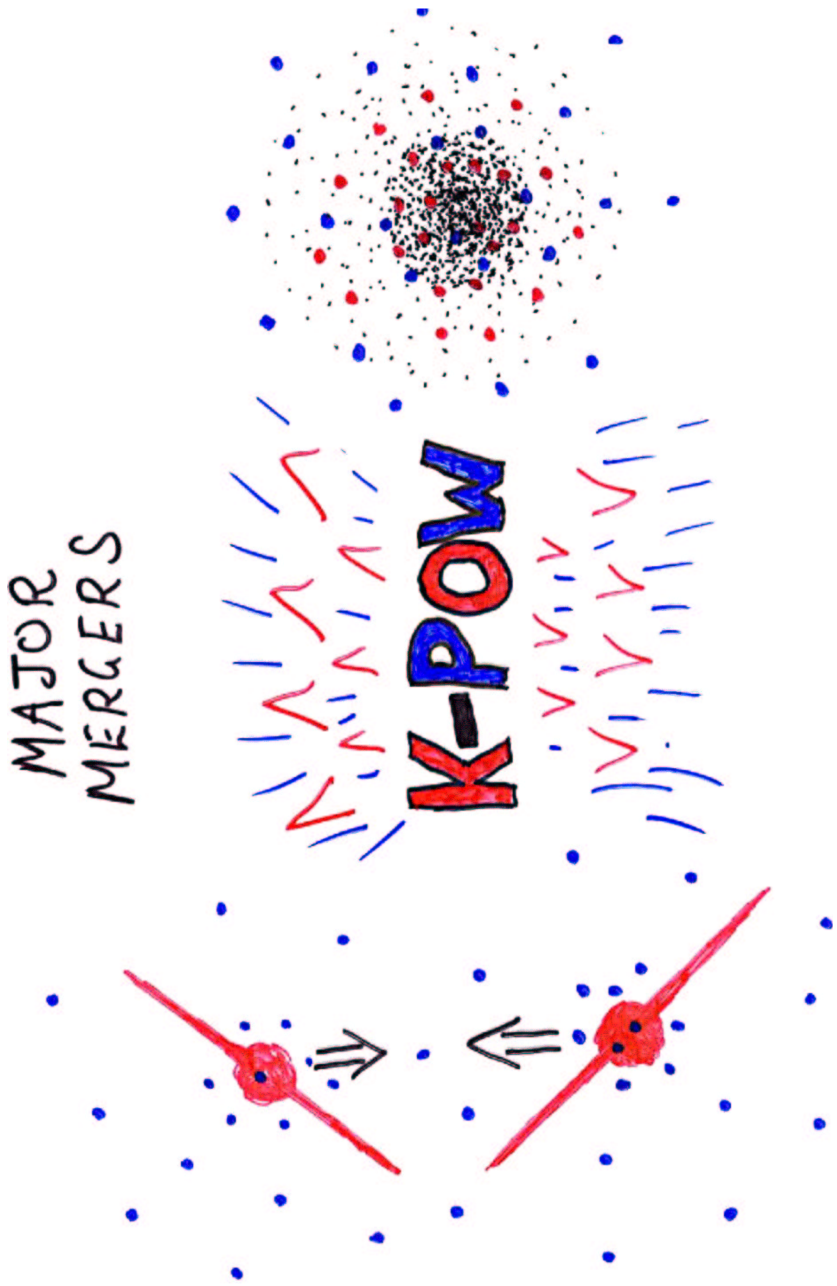
Pros: predicted metallicity bimodality, red GCS more concentrated than blue GCS; "known" model of E formation; major mergers expected in, e.g., ΛCDM cosmologies.

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



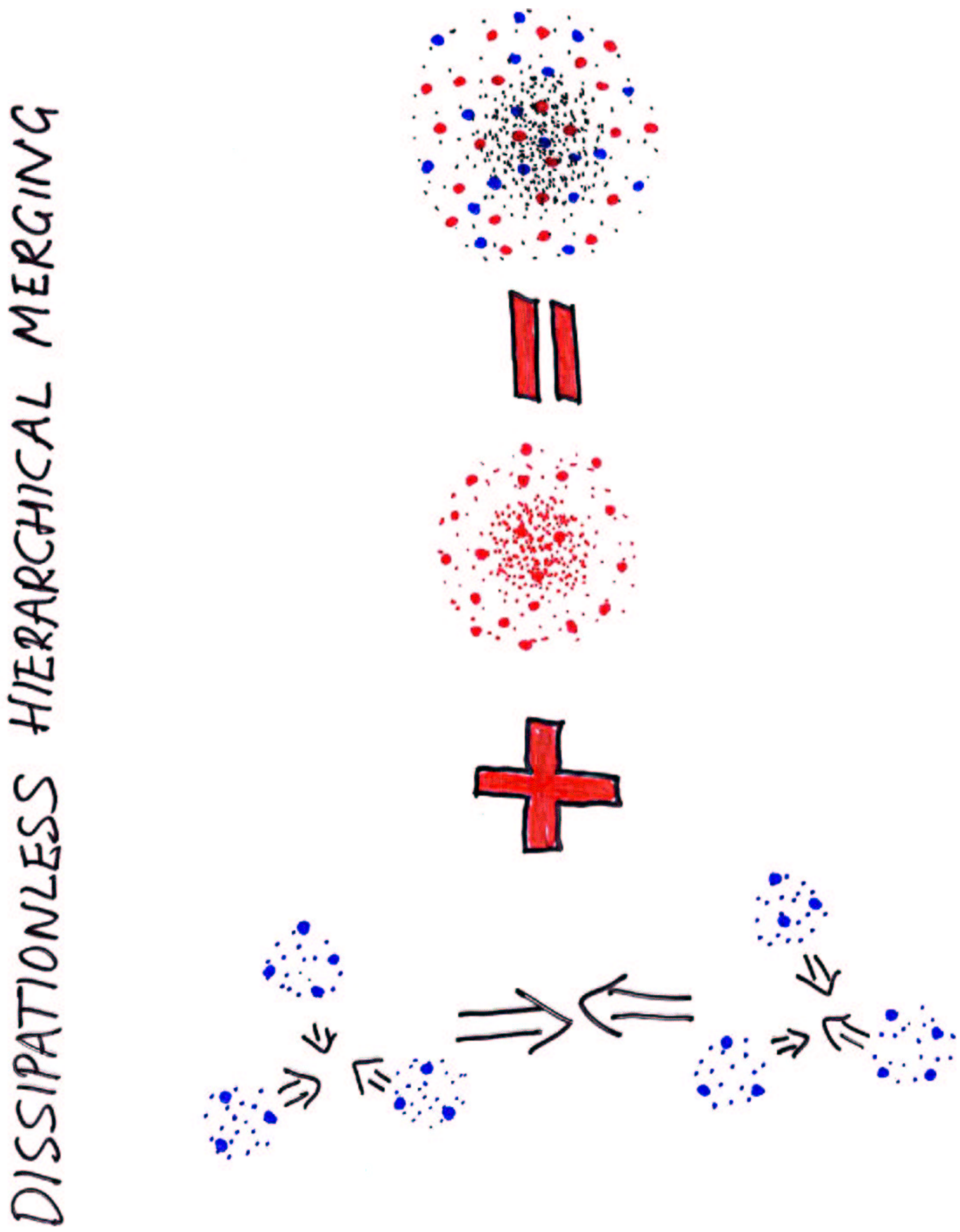
2. Dissipationless merging (Côté et al. 1998, 2002). Metal-poor clusters from accreted dwarfs, metal-rich clusters form around largest "seed" galaxy.

?

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 *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. (HANDWAVY)
LARGE METALLICITY GRADIENTS IN METAL-RICH GCS?
SPIN UP ⇒ MORE ROTATION THAN OBSERVED

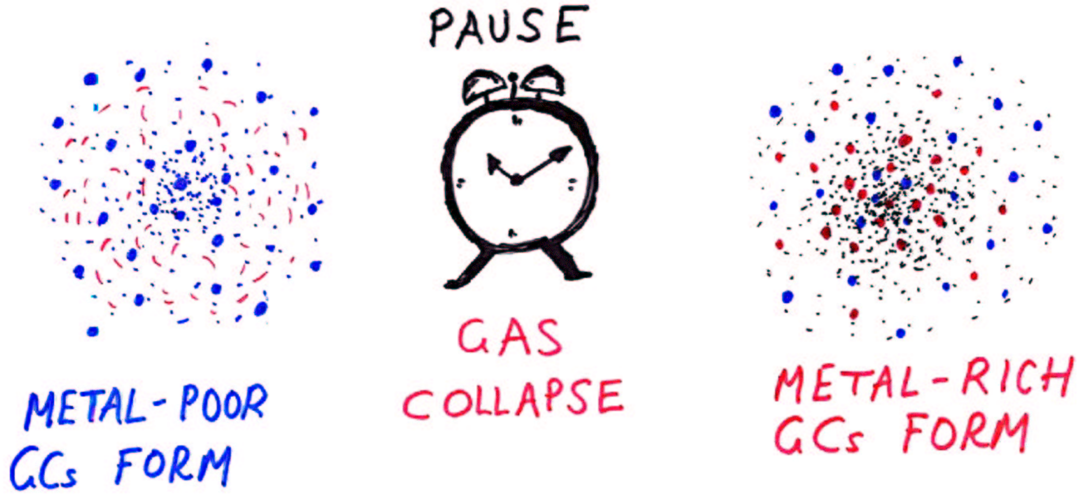
4. Multiple mini gassy mergers? (W. Harris, Forbes?). Metal-poor clusters "first generation," metal-rich form in mini-mergers.

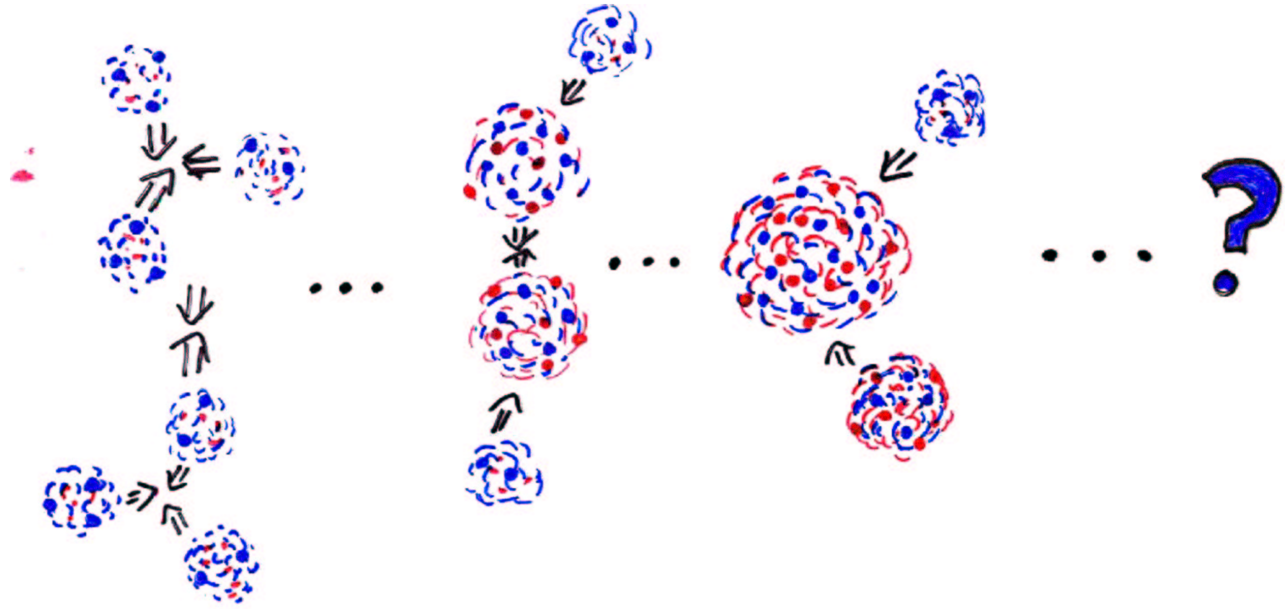
Pros: GCs form in mergers; assumed high gas fraction → no efficiency worries?

Cons: why are some galaxies Es, others Ss?

+ BEASLEY ET AL (2002)

TWO-PHASE COLLAPSE





MULTIPLE MINI GASSY MERGERS

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 + <u>GRADIENTS</u>

? (iii) Spatial distributions

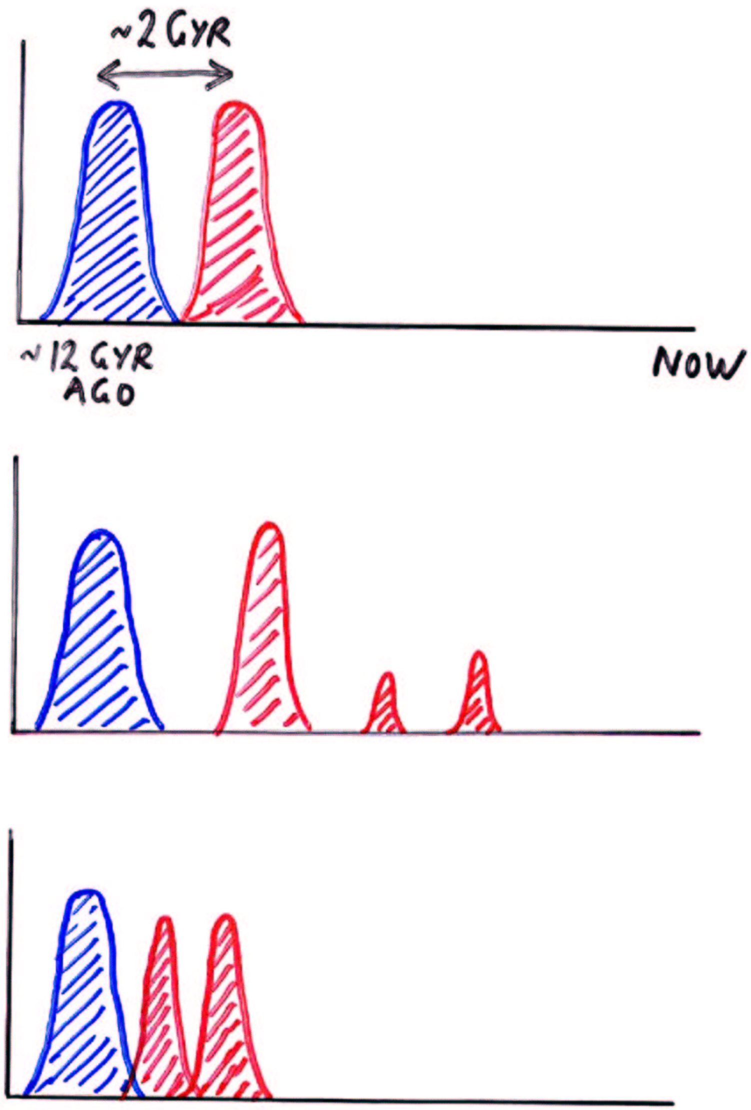
✓ (iv) Kinematics

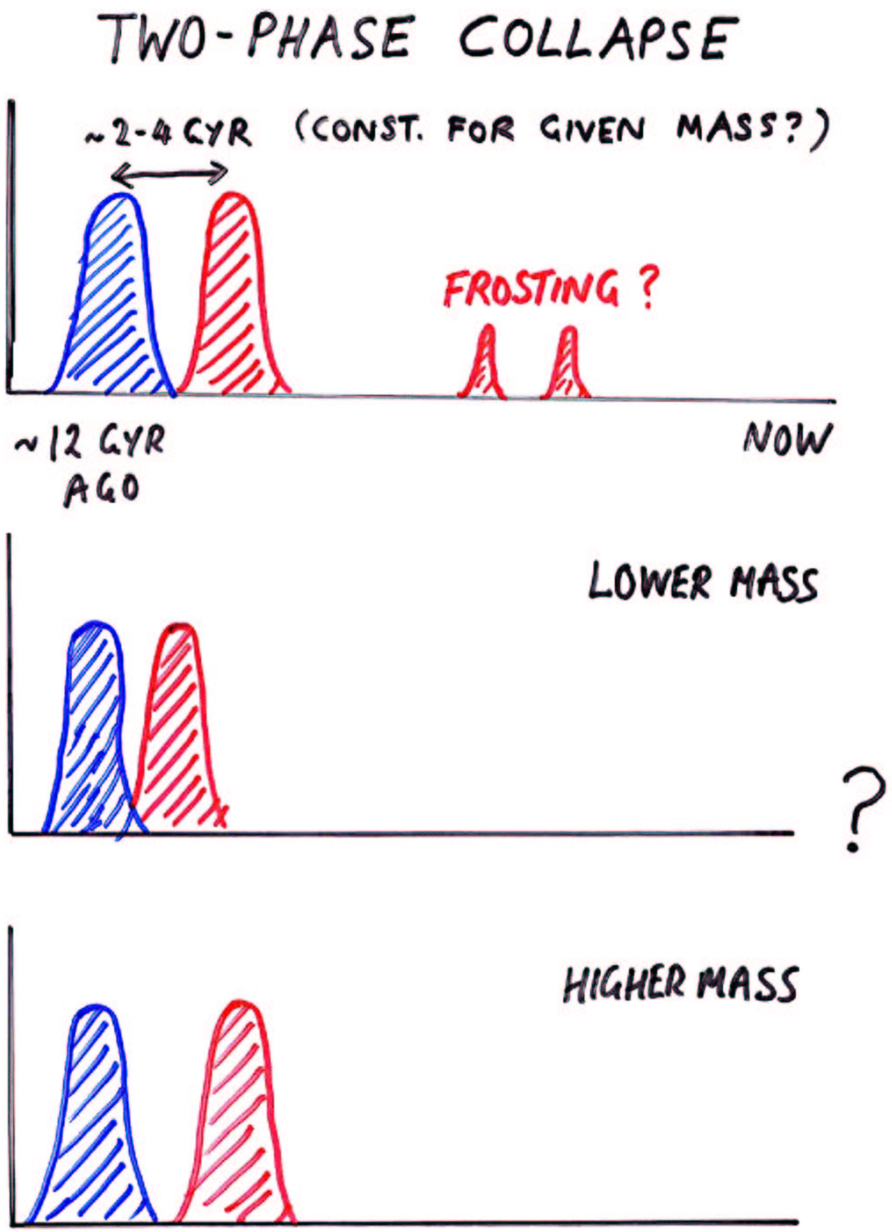
? (v) Total and relative numbers of clusters

Distinguishing models II: observation

Observe ages, metallicities, spatial distributions, kinematics, numbers.

MERGER MODEL





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 VIABLE ?

DIAGNOSTICS: AGES, KINEMATICS