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FORMATION AND DISRUPTION OF GLOBULAR STAR CLUSTERS

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and
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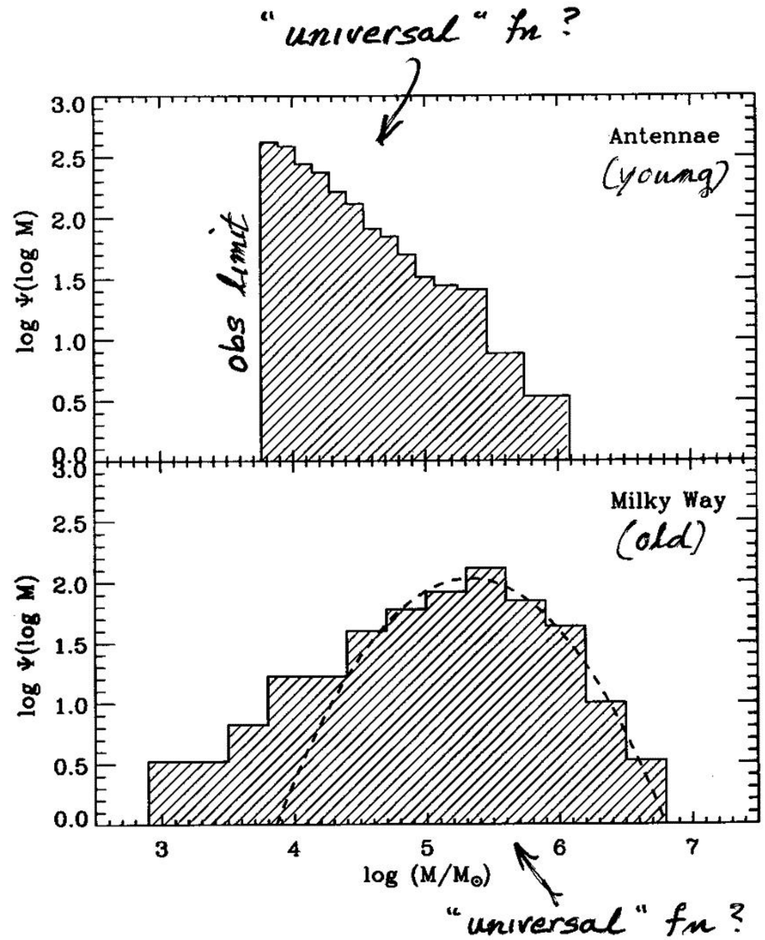

Qing Zhang & SMF (1999)

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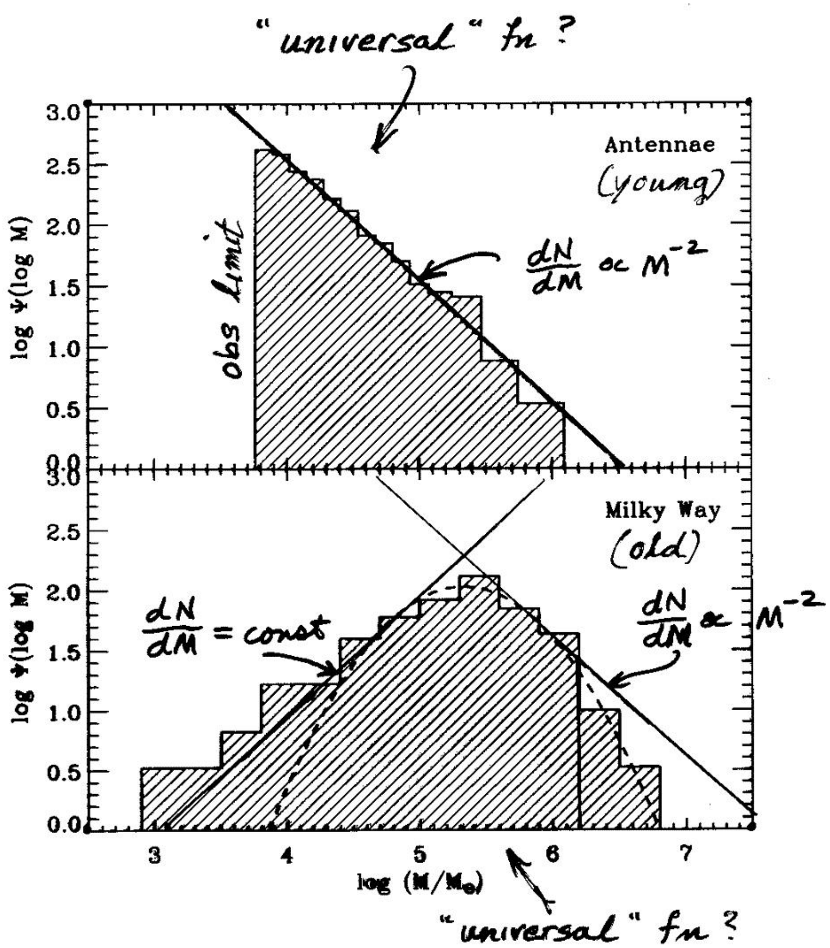

Qing Zhang & SMF (1999)

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EMPIRICAL MASS FUNCTION
YOUNG CLUSTERS – ANTENNAE GALAXIES

Typical ages ~ few × 10^7 yr
Wide spread, $\Delta t/t \sim 1$
⇒ mass fn ≠ lum fn

Use colors to estimate ages, reddening, hence masses from luminosities

Results: approx power law

$\psi(M) \propto dN/dM \propto M^{-2}$

for $10^4 \lesssim M \lesssim 10^6\ M_\odot$

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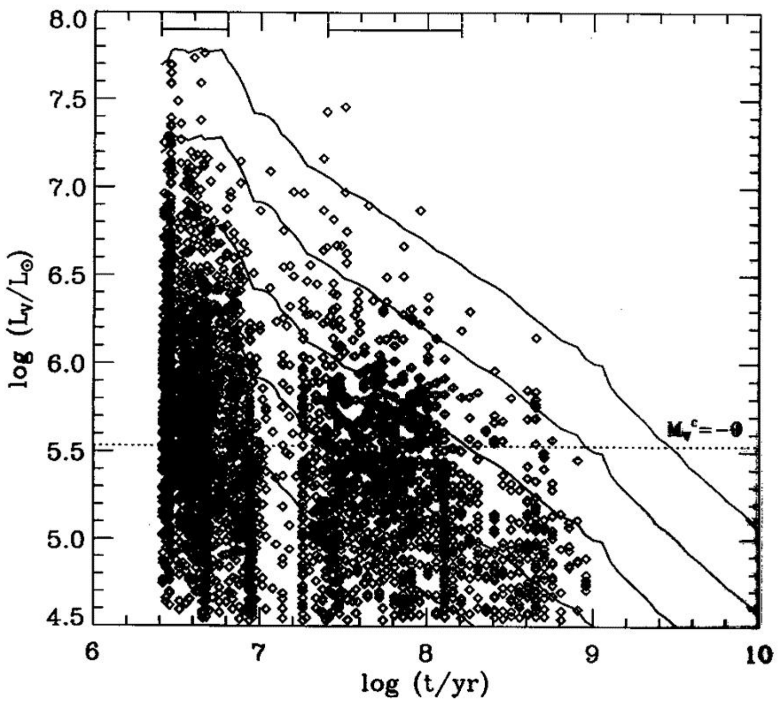

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EMPIRICAL MASS FUNCTION
OLD GLOBULARS – MILKY WAY

Typical ages ≈ 12 Gyr
Narrow spread, $\Delta t/t \lesssim 20\%$
⇒ clusters have similar $M/L_V (\approx 3)$
mass fn ≈ lum fn

Results:

Peak at $M \approx 2 \times 10^5 M_\odot$
similar for $R < 5$ kpc and $R > 5$ kpc

Low-mass end

$\psi(M) \propto dN/dM \approx$ const
(Not lognormal)

High-mass end

drops below M^{-2} extrapolation
at 2–3σ statistical significance

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LUMINOSITY AND MASS FUNCTIONS

General

$$\phi(L) = \int dM \int d\tau \; \dot{n}(M(L,\tau),\tau)$$

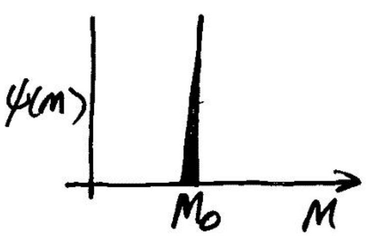
$\dot{n}(M,\tau)$ is the birth rate in the past of clusters of mass M and current age τ

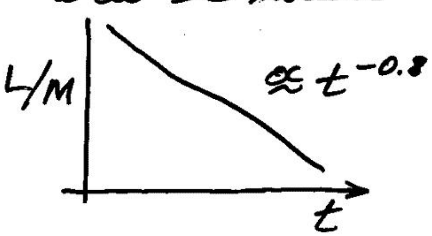
$M(L,\tau)$ is the mass of a cluster of current luminosity L and age τ

Example:

$$\dot{n}(M,\tau) = \text{const} \times \delta(M - M_0)$$

$L/M \propto t^{-\alpha}$ with $\alpha \approx 0.8$ fading à la BC models





$\Rightarrow \phi(L) \propto L^{-2.2} \approx$ obs lum fn!

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FORMATION

Molecular clouds in the Milky Way

$$\frac{dN}{dM} \propto M^{-1.8}$$

Similar to mass fn of young star clusters in the Antennae

Power-law mass fn related to fractal structure of the ISM (Elmegreen & assoc)

But what physical processes determine the fractal dimension of the ISM hence index of the cluster mass fn, i.e.

why M^{-2} rather than M^{-1} or M^{-3}?

Is this independent of energy injection rate, pressure, vorticity, metallicity, dust content, etc. Why?

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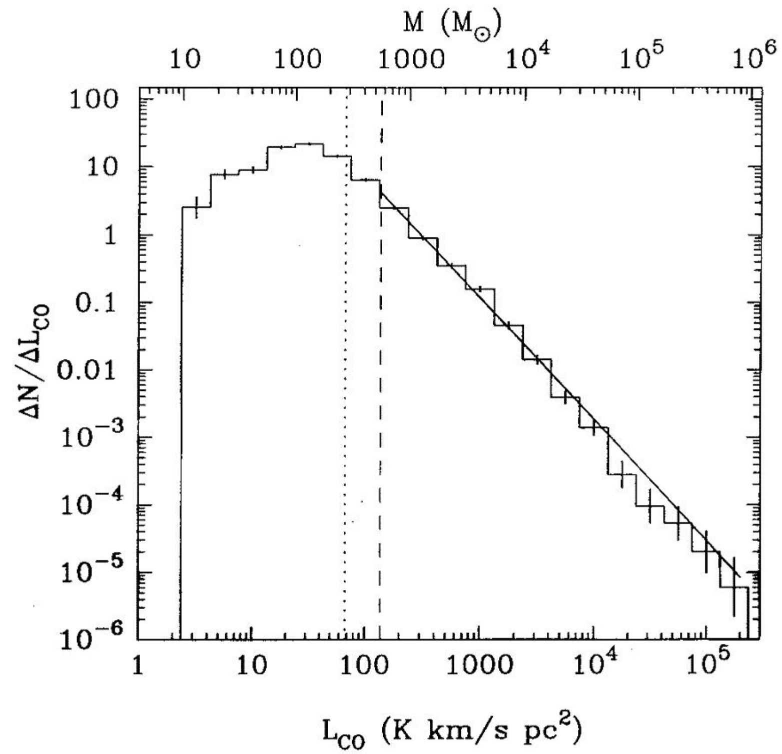

Fig. 3.— The CO luminosity function, $\Delta N/\Delta L_{CO}$ for 3901 identified objects. The top x coordinate shows the corresponding mass scales assuming a constant CO to H_2 conversion factor. The vertical dotted line denotes the detection limit of L_{CO} and the vertical dashed line marks the completeness limit of L_{CO} at a distance of 10 kpc. The power law fit to bins above the completion limit (solid line) is $\Delta N/\Delta L_{CO} \propto L_{CO}^{-1.80\pm0.03}$.

Heyer et al. (2001)

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DISRUPTION: NEW ANALYSIS

SMF & Qing Zhang (2001)

Calculate evolution of $\psi(M, t)$ caused by

- Stellar mass loss (winds & SN)
- Two-body relaxation
- Gravitational shocks
- Tidal limitation

$\bar{\rho} = M/(\frac{4}{3}\pi r_t^3)$ set by galactic tidal field at pericenter of orbit

Try different initial mass fns $\psi_0(M)$ and initial position-velocity distn fns $f_0(\mathbf{r}, \mathbf{v})$

Galactic ptl (steady)

singular isothermal sphere

$$\phi(R) = V_c^2 \ln R + \text{const}$$

with $V_c = 220\ \text{km s}^{-1}$

Initial DFs

(a) Eddington

$$f_0(E,J) \propto \exp(-E/\sigma^2)\exp[-\tfrac{1}{2}(J/R_A\sigma)^2]$$

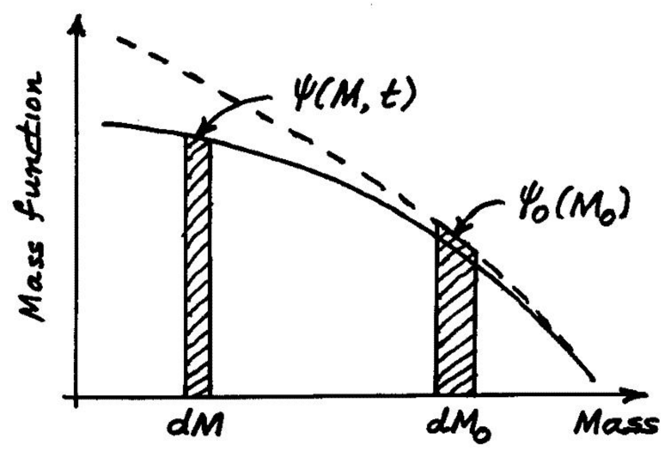
radial anisotropy increases w/ R

(b) Self-similar

$$f_0(E,J) \propto \exp(-E/\sigma^2)\, J^{-2\beta}$$

radial anisotropy constant w/ R

The anisotropy parameter (R_A or β) is varied; the other parameters are fixed by obs.



Continuity eqn

$$\Psi(M,t)\,dM = \Psi_0(M_0)\,dM_0$$

Disruption eqn

$$\dot{M}/M = -\nu_{ev} - \nu_{sh} - \nu_{se}$$

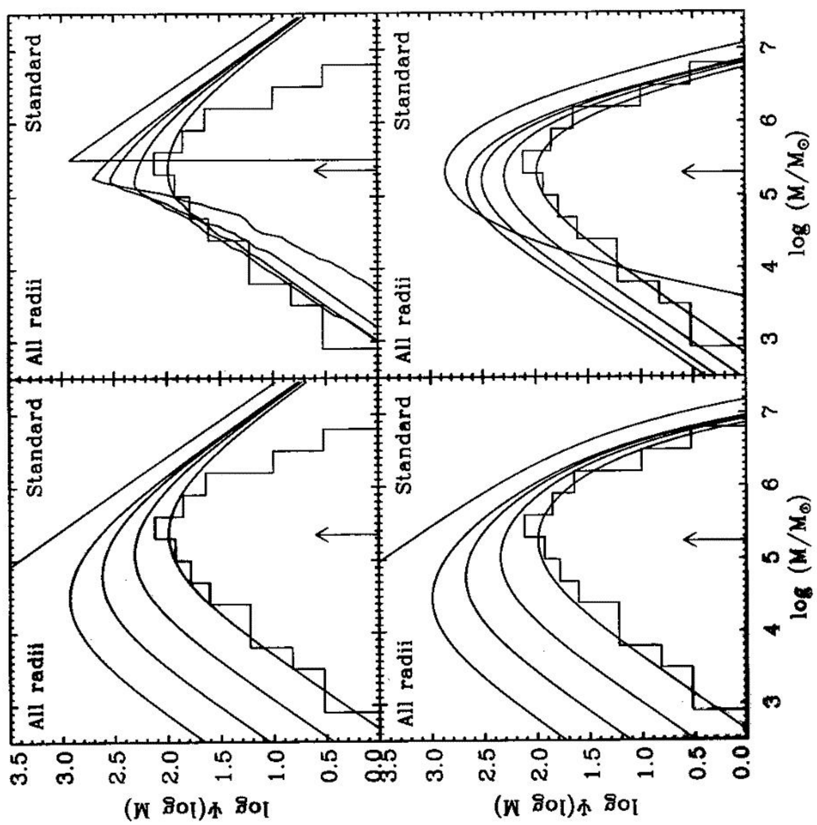
with

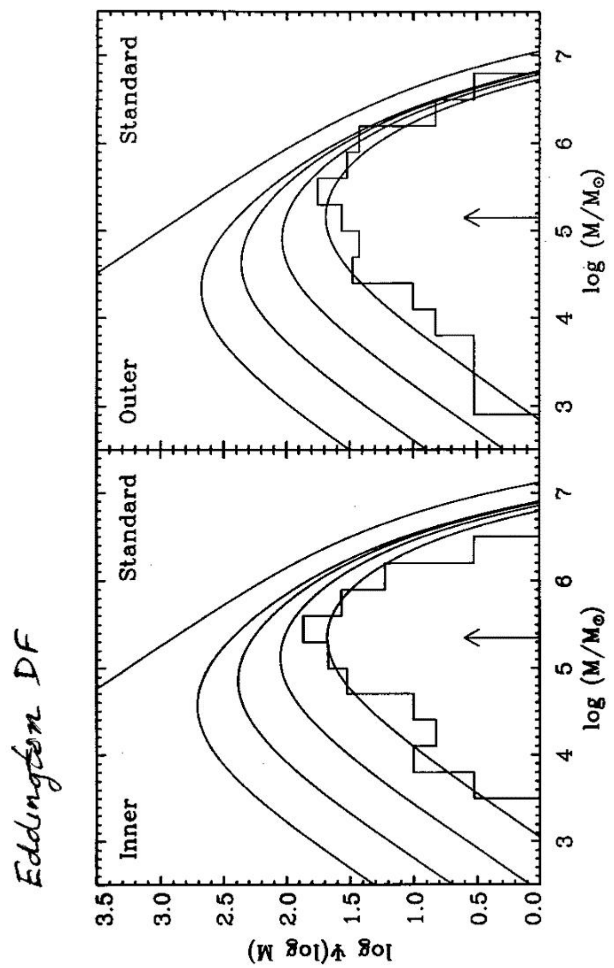
$\nu_{ev} \propto 1/t_{rh} \propto (\bar{\rho})^{1/2} M^{-1} \propto M^{-1}$

$\nu_{sh} \propto 1/t_{sh} \propto (\bar{\rho})^{-1} \propto \text{const}$

ν_{se} = known function of t

Solve for $M(t)$; hence $M_0(M,t)$


All radii
Standard
All radii
Standard
All radii
Standard
All radii
Standard
log ψ(log M)
log ψ(log M)
log (M/M⊙)
log (M/M⊙)


Eddington DF
Inner
Standard
Outer
Standard
log ψ(log M)
log (M/M⊙)
log (M/M⊙)

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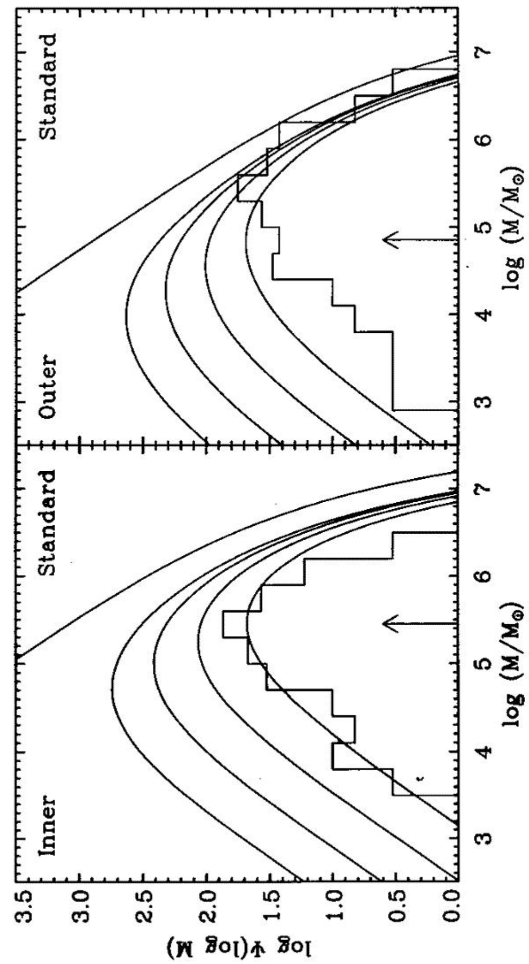
Self-sim DF



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GC MASS – GALAXY SCALING RELN

Baryonic TF reln

$M_{gal} \propto V_c^{\,k}$

$\Rightarrow \bar{\rho}_{gal} \propto V_c^{\,6-2k}$ ← Virial thm

$k = 3-4$ "Obs"

GC peak mass

Two-body evaporation

$\Rightarrow M_p \propto t_{rh}^{-1} \propto (\bar{\rho}_{clus})^{1/2}$

$\propto (\bar{\rho}_{gal})^{1/2} \propto V_c^{\,3-k}$ ← tidal limitation

$\Rightarrow M_p = \text{const}$ for $k = 3$

$M_p \propto V_c^{-1}$ for $k = 4$

∴ Weak or no dependence of peak GC mass on properties of host galaxy

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RESULTS

1. Peak and low-mass shape of mass fn agree with observations for almost any $\psi_0(M)$ & $f_0(E, J)$ (no free parameters).

2. Radial variation of mass fn depends on initial position–velocity DF:

   a) Agreement with obs requires radial anisotropy to increase outward, e.g. Eddington DF.

   b) Some initial DFs do not work, e.g. circular-orbit, isotropic, scale-free DFs.

But weaker variations are expected in galaxies with non-spherical and/or time-dependent potentials

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3. Weak or no dependence of GC mass fn on mass (circ vel) of host galaxy (for reasonable slopes of the "baryonic" Tully-Fisher reln)

SOME IMPLICATIONS

1. Peak mass increases with age
2. Peak mass decreases with galactocentric radius
3. Many field spheroid stars could be debris of disrupted clusters (exact fraction depends on slope and lower cutoff of initial mass fn)
4. Any features in the initial mass fn below the peak (i.e., $M \lesssim 2 \times 10^5 M_\odot$), e.g. a Jeans-type cutoff, would have been erased
5. Characteristic mass scale of cluster populations of any age set by disruption time ~ age

Remaining Issue:

Rarity of clusters with masses $\gtrsim$ few $\times 10^6 M_\odot$; ie shape of high-mass part of mass function. Related to dwarf-satellite problem in CDM?

Future: NGST