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A Binary Origin For Blue Stragglers in Globular Clusters

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What is the dominant channel for blue straggler production in globular clusters?

(Assuming there is one…)

- The two simplest distinct formation channels are
  - Single-single physical collisions
  - Binary evolution (mass transfer and/or coalescence)
- There are also potentially important "hybrid" channels
  - Physical collisions during 3- or 4-body interactions (Fregeau et al. 2004)
  - Evolution of dynamically-formed or dynamically-altered binaries

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Can formation channels be inferred from observations?

- Very difficult for individual blue stragglers
  - Possible tracers include rotation and abundances, but…
  - No firm theoretical predictions: what signature is expected for each channel?

- Mostly have to rely on statistical approaches, e.g.
  - The number of collisional BSs may be expected to scale with collision rate
  - The number of binary BSs may be expected to scale with total stellar mass

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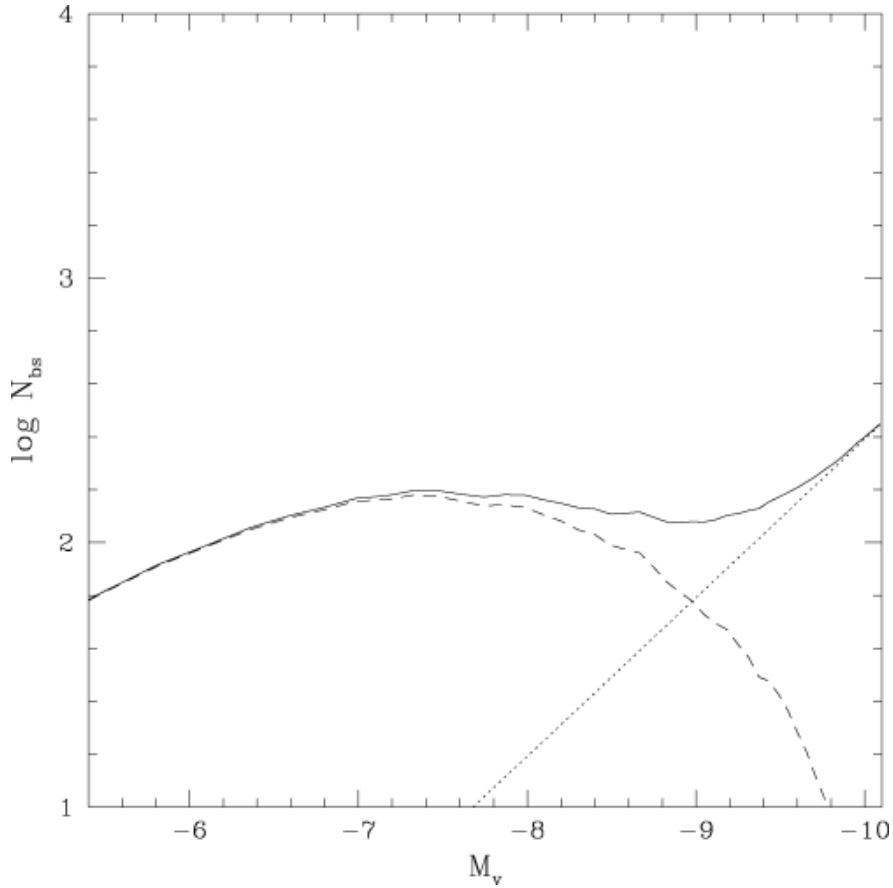
How do these expectations compare to observations?

- Total (core + halo) BSs *numbers* seem "largely independent of both total mass and stellar collision rate" (Piotto et al. 2004; Davies et al. 2004)
- Do collisions and binaries both contribute and conspire to produce roughly flat distributions?
- Overall, the situation seems confusing
  - It is still not clear which channel dominates in which parts of what clusters!

Davies et al. 2004



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Our Approach

- Focus on cluster cores, using Leigh et al. (2008) catalogue (c.f. Moretti et al. 2008)
  - If collisions/dynamics dominates anywhere, it will be in the dense cores
- Analyse only BSS numbers, rather than specific frequencies (i.e. counts normalized to other populations)
  - Easier to interpret
    - Theoretical predictions are for numbers, not frequencies
  - Cleaner
    - Correlations with cluster parameters are guaranteed to be due to BSS rather than the normalizing populations
- Search for correlations with physically motivated cluster parameters
  - Collision rate: $\Gamma_{coll} \propto \rho_c^2 r_c^3 \sigma_c^{-1}$
  - Core mass: $M_c \approx (4\pi/3) r_c^3 \rho_c$
  - Generalized models: $r_c^\alpha \rho_c^\beta \sigma_c^\gamma$

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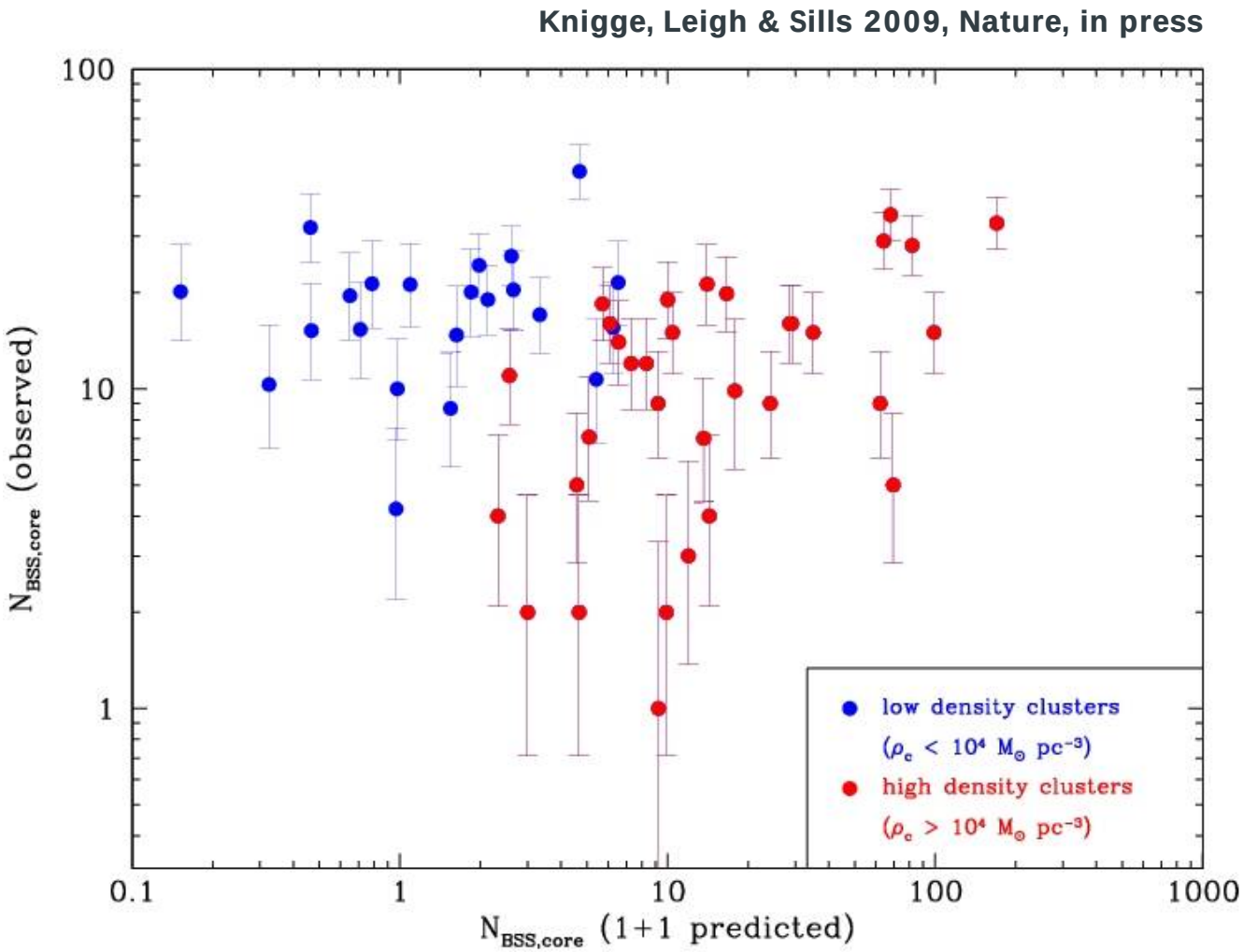
Core BS Numbers vs Collision Rate



- Globally, core BS numbers do **not** correlate with collision rate

  (c.f. Leigh et al. 2008; Moretti et al. 2008)

- For dense clusters, a positive, but weak, correlation is present

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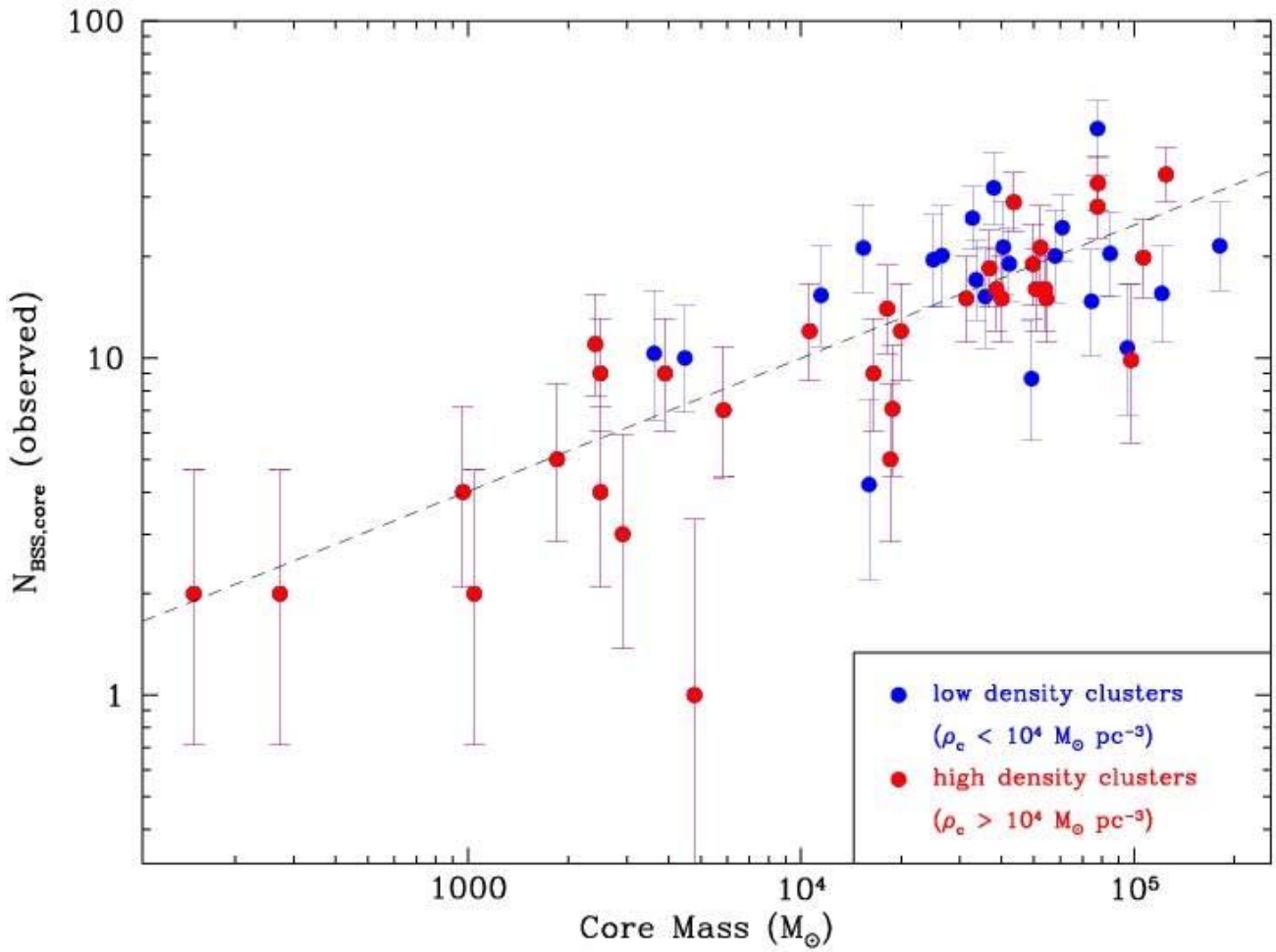
Core BS Numbers vs Core Mass

Knigge, Leigh & Sills 2009, Nature, in press



- **There is a strong correlation between core BS numbers and core mass across the entire GC sample**
- The relationship between N_{BSS} and M_{core} is clearly sub-linear: $N_{BSS} \sim M_{core}^{0.4}$
- Simplest interpretation:

Even in the core, binaries, rather than collisions dominate BS formation

A Generalized Model Fit to BS Numbers

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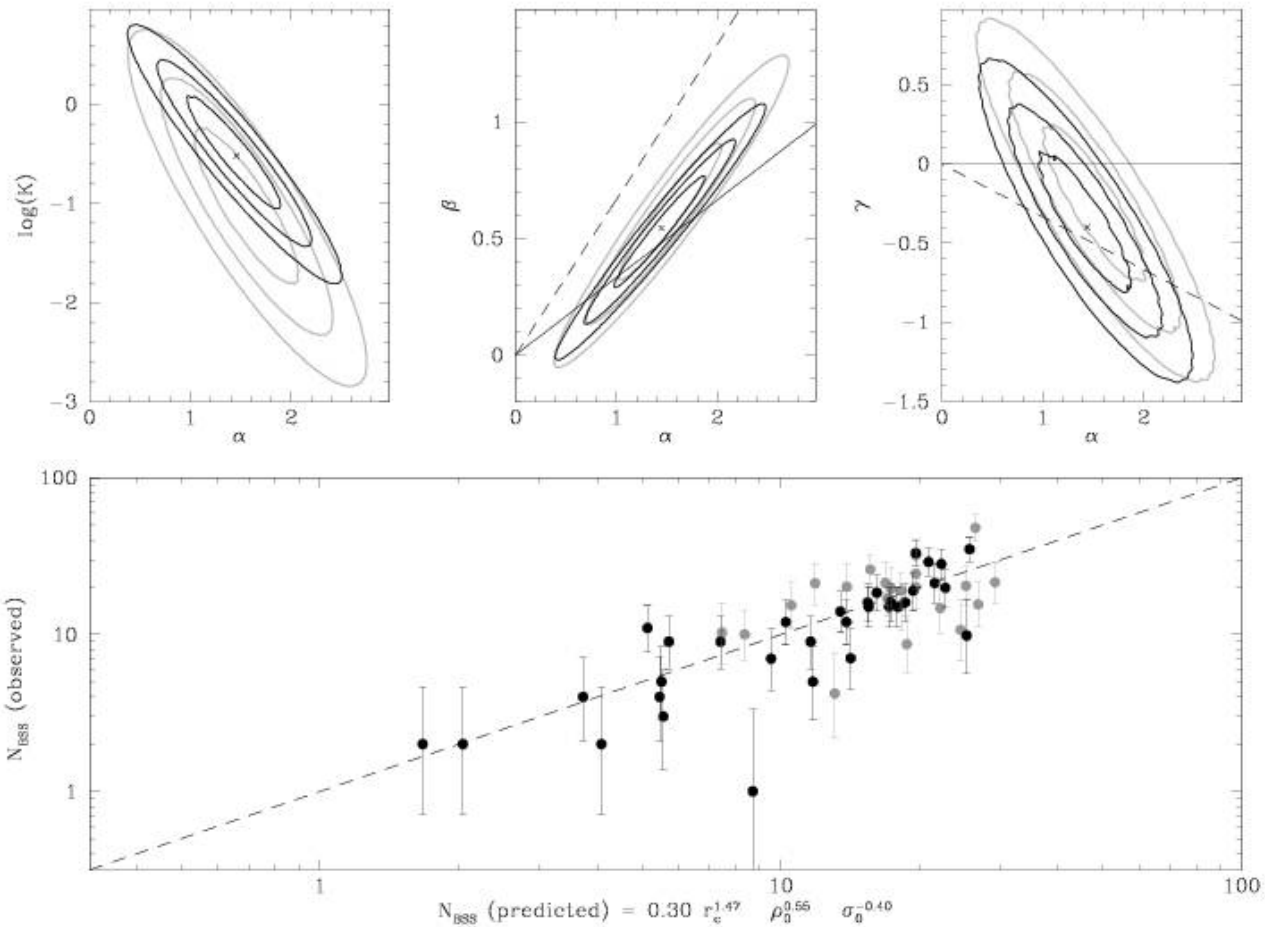
Knigge, Leigh & Sills 2009, Nature, in press



- Generalized power law: $N_{BSS} = Kr_c^{\alpha}\rho_c^{\beta}\sigma_c^{\gamma}$
- Power law dependence on N_{coll}: $\alpha = 1.5\beta = -3\gamma$
- Power law dependence on M_{core}: $\alpha = 3\beta \quad \wedge \quad \gamma = 0$
- Fit is consistent with $M_{core}^{0.5}$ dependence (but not a power law in N_{coll})
- No need for a dependence on σ

Why is the N_{BSS} vs M_{core} correlation sub-linear?

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- If core BSS descend from binaries

  $N_{BSS} \sim f_{bin} M_{core}$

- Observationally, we find

  $N_{BSS} \sim M_{core}^{0.4\text{-}0.5}$

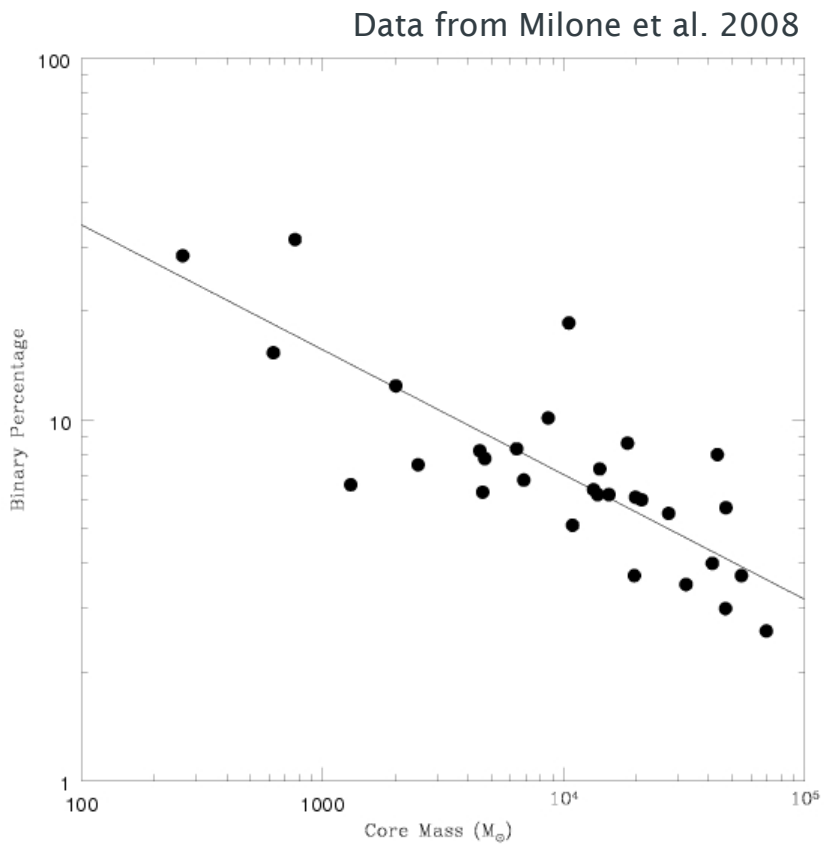
- The two can be reconciled trivially if

  $f_{bin} \sim M_{core}^{-(0.5\text{-}0.6)}$

- Analysing two recent compilations of binary fractions in GC cores (Sollima et al. 2008; Milone et al. 2008)

  $f_{bin} \sim M_{core}^{-0.35}$

- This is promisingly close, albeit not perfect



Skeletons in the closet?

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- Selection effects and completeness
  - We obtain essentially identical results if we use the Moretti et al. BSS sample
  - RGB and HB stars are comparably bright and their numbers scale roughly linearly with core mass, as expected
- Mass segregation
  - Should be less than a factor of ~2 effect if collisions dominate (Leonard 1989)
  - Splitting the sample by half-mass relaxation time does not provide evidence for collisional dominance obscured by mass segregation
- Hybrid Models (Binary Interactions)
  - Collision rates become
    - 2+1: $\Gamma_{2+1} \propto f_{bin} \rho_c^2 r_c^3 \sigma_c^{-1}$
    - 2+2: $\Gamma_{2+1} \propto f_{bin}^2 \rho_c^2 r_c^3 \sigma_c^{-1}$
  - Neither improves the match to observations
  - Fundamental problem is that all collision scenarios predict too strong a density dependence
  - Nevertheless too early to rule out hybrid models

Additional evidence pointing towards binaries

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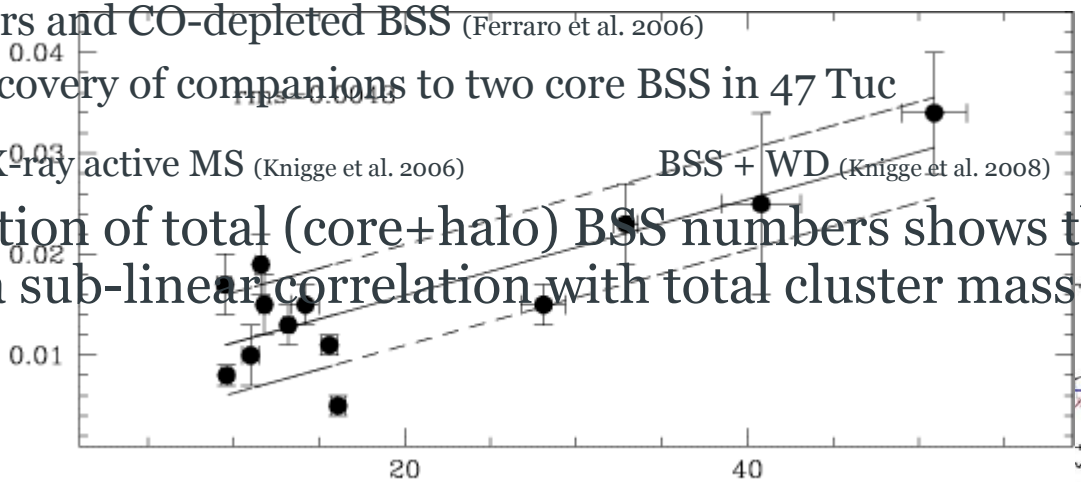
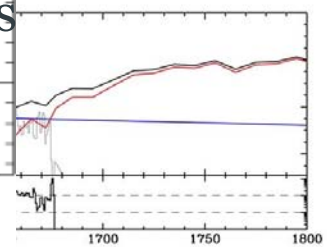
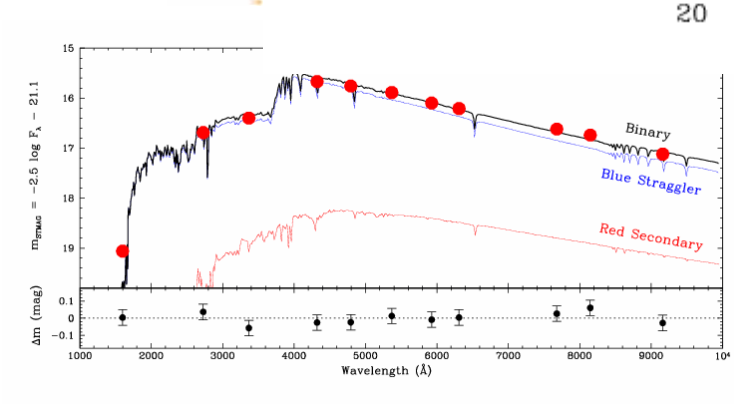
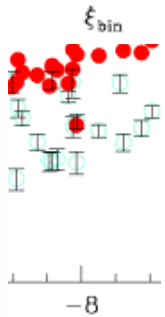
- Correlation between core binary fraction and BSS frequency in a sample of clusters
- Direct detections of binary BSS
  - W UMa stars and CO-depleted BSS (Ferraro et al. 2006)
  - Recent discovery of companions to two core BSS in 47 Tuc
    - BSS + X-ray active MS (Knigge et al. 2006)
    - BSS + WD (Knigge et al. 2008)
- Close inspection of total (core+halo) BSS numbers shows that there probably is a sub-linear correlation with total cluster mass

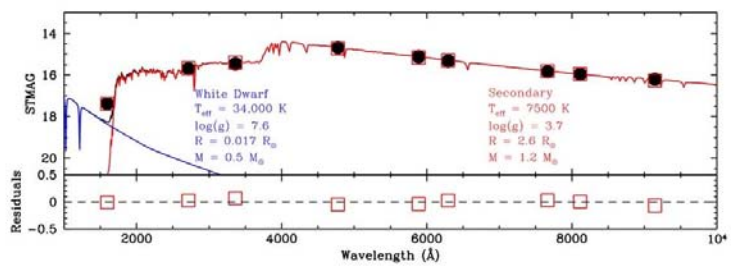
Sollima et al. 2008











Davies et al. 2004

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Summary

- There is no global correlation between core BSS numbers and collision rate
- There is, however, a strong, sub-linear correlation between the number of blue stragglers found in GC cores and total core mass
  - $N_{BSS} \sim M_{core}^{0.4\text{-}0.5}$
- There is also an anti-correlation between core binary frequency and core mass
  - $f_{bin} \sim M_{core}^{-0.35}$
- Together, the two *almost* agree with the simplest possible binary formation idea
  - $N_{BSS} \sim f_{bin} M_{core}$
- **This (and other evidence) strongly suggests that most BSS descend from binaries**
  - **even in GC cores, single-single collisions do not dominate BSS numbers**
- It remains to be seen if hydrid models (involving both binaries and dynamics) can work
  - Expected 2+1 and 2+2 collision rates still scale too strongly with density compared with observations