Delayed mergers:

The contribution of ellipticals, globular clusters, and protoclusters to the LIGO detection rate

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LIGO-G050446-00-Z

Outine

- Prompt mergers and blue light
- Delayed mergers in ellipticals
  - Elliptical galaxies
  - Delayed mergers in ellipticals
  - LIGO rate

References:
Regimbau et al, gr-qc/0506058

- Delayed mergers from globular clusters
  - Globular clusters
  - Model: Mass segregation and mergers
  - LIGO rate

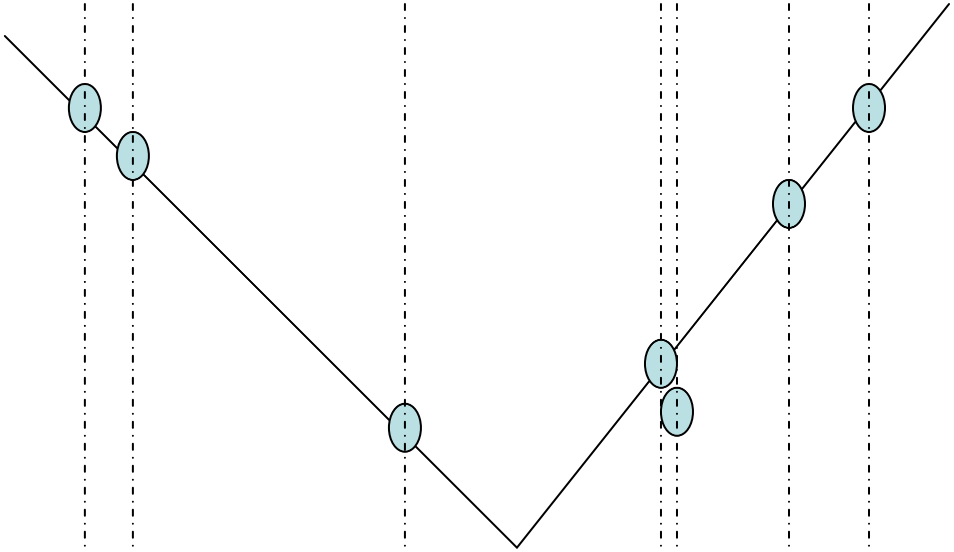
References:
Portegeis Zwart and McMillan 1998
O'Leary et al 2005, astro-ph/0508224

- Delayed mergers from protoclusters
  - Cluster formation & stripping/disruption
  - GC initial and present mass function
  - LIGO rate

LIGO merger rate from spirals

- **Blue luminosity**:
  - assume mergers are fast
  - Compact objects: from short-lived massive (blue) stars

… blue light traces merger rate



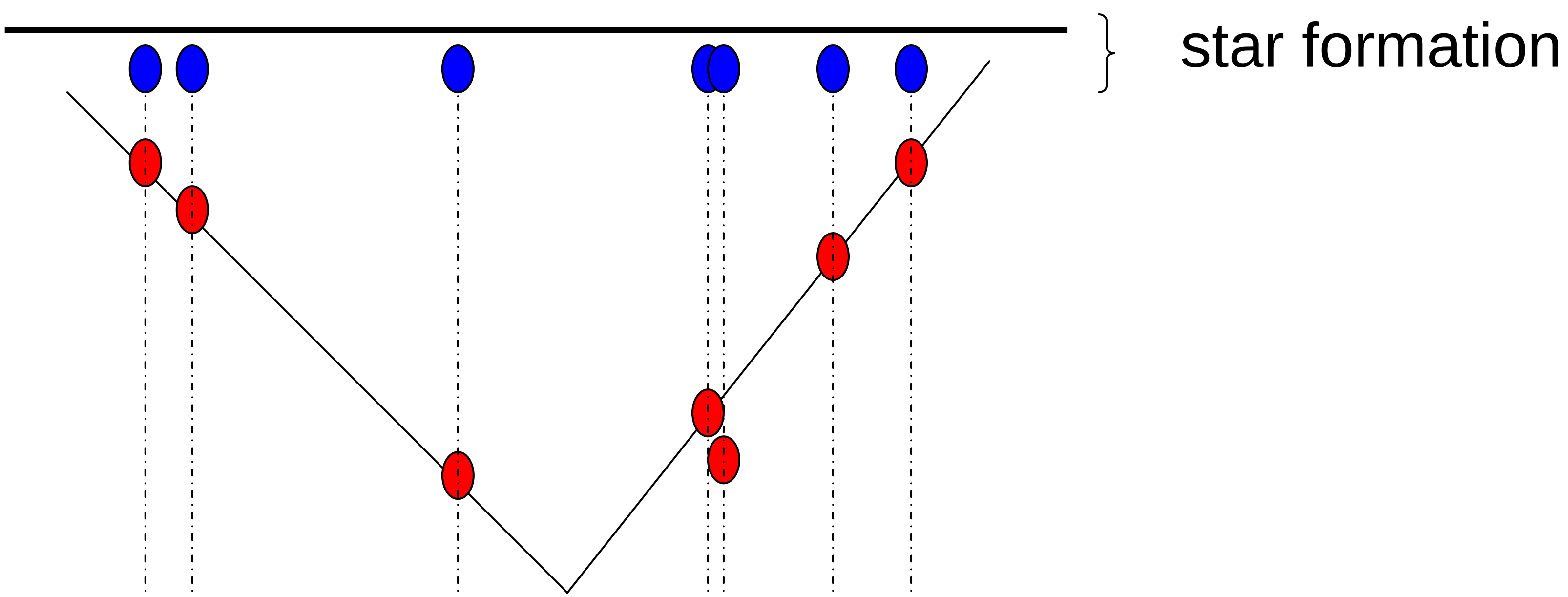
Spirals

- continuous star formation
- most common
- dominate blue light

Delayed mergers

- Some mergers can take Gyr
- Blue light **not** reflective of merger rate?
  - spirals: **already** accounted for
  - everything else:

    …**any** other star formation must be included



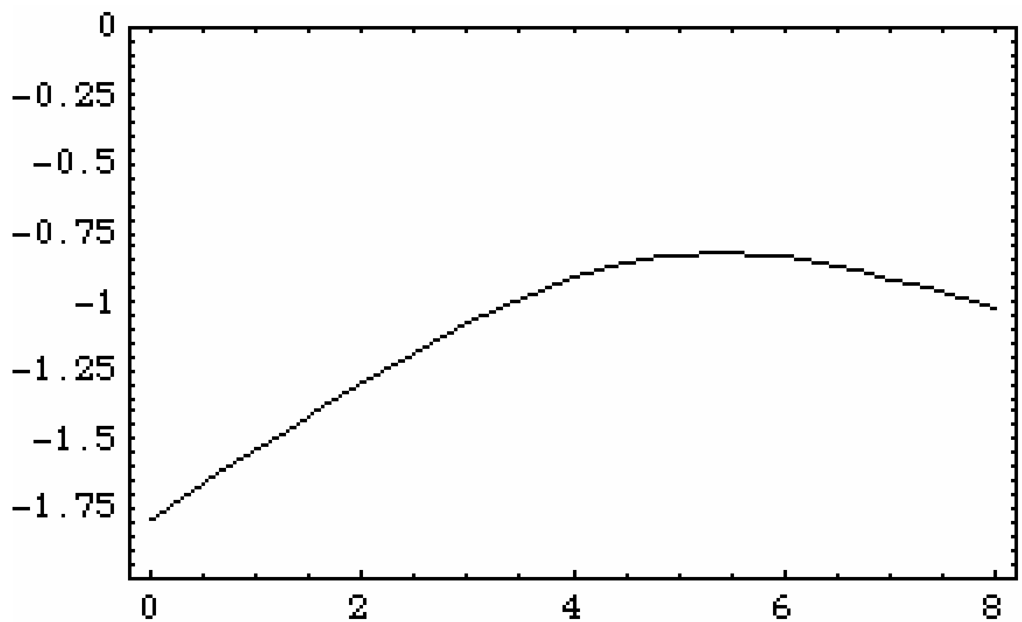
Star formation history

…and most stars form long ago

Experiment

QuickTime™ and a
None decompressor
are needed to see this picture.

Theory



Schneider et al, MNRAS 324 797
Pei, Fall, Hauser ApJ 522 604
Madau astro-ph/9907268

Hernquist and Springel, MNRAS 341 1253

Mergers from Ellipticals

- Elliptical galaxies
  - **Big**:

    $M_{elliptical} \sim 2 \quad x\ 10^{11}\ M_O$ [some get very large]

    $M_{spiral} \sim 0.9\ x\ 10^{11}\ M_O$

  - **Old**:
    - Most stars form early on
    - Less blue light now (per unit mass)
  - **Uncommon**:

    $\rho_{elliptical} \sim 0.0025\ /\ Mpc^3$

    $\rho_{spiral} \sim 0.01\ /\ Mpc^3$

Heyl et al MNRAS 285 613

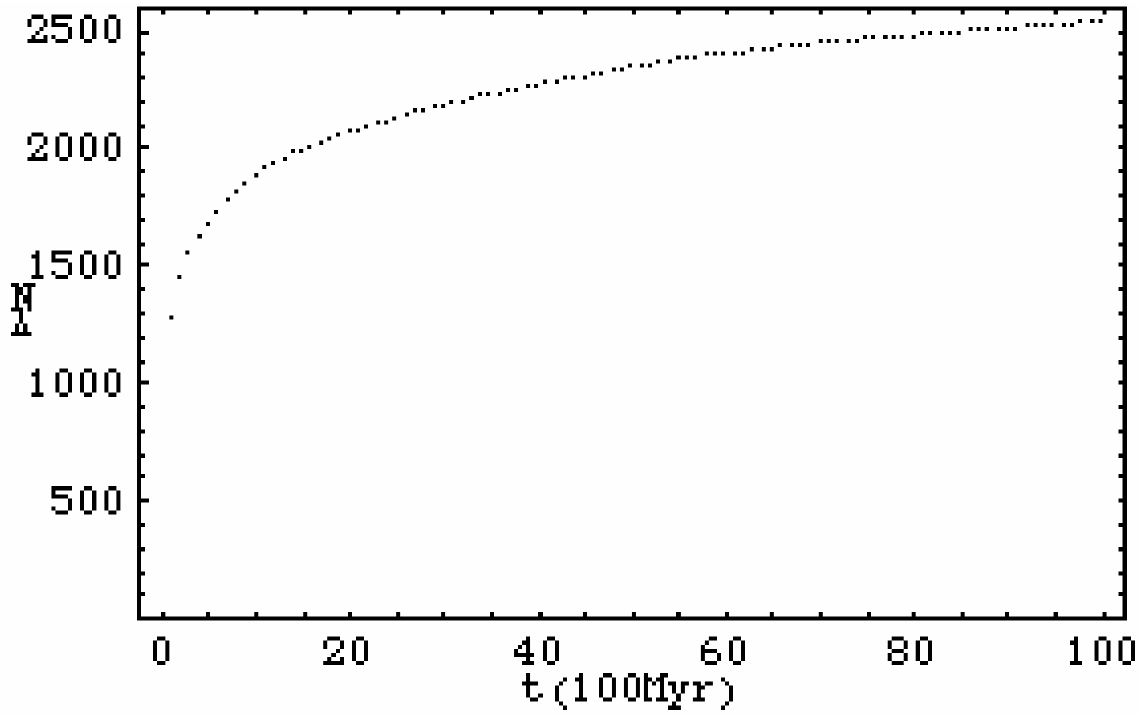
Portegeis Zwart & McMillan ApJ 528 L17

Mergers from Ellipticals

- Merger distribution from quick burst
  - Predict via standard pop-synth (**same code** as for spirals)

Result:

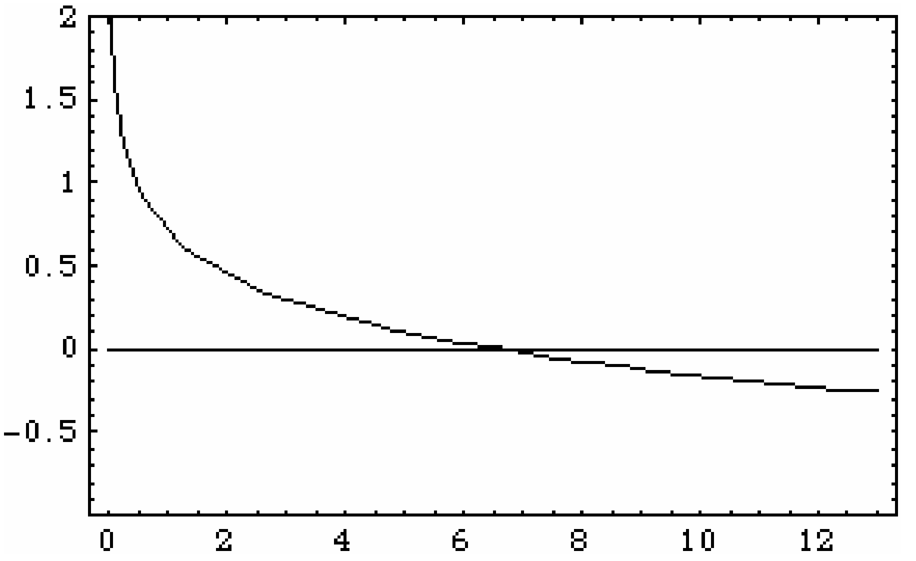
- Many happen quite late..



Mergers from Ellipticals

- NS-NS merger rate
  - per canonical elliptical
  - **scaled** to merger rate for MW
    (works w/ any popsyn assumptions)

$\log_{10}(R/R_{MW})$



t (Gyr)

Mergers from Ellipticals

- Alternate approach:

  Regimbau et al (gr-qc/0506058)

+ Better elliptical model

  (flatter IMF; fit to observed)

+ Ad-hoc popsyn

+ **Fixed** popsyn model

R(1/yr)

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

…. details scarce in paper

t (Gyr)

Mergers from Ellipticals

- NS-NS merger rate
  - **Possibly** significant: O(20%-2x) correction

    ellipticals ~ 5x less common than spirals

    disagreement over population synthesis results

      (galaxy-by-galaxy basis)

- …similarly for BH-BH, BH-NS

Ellipticals <u>could</u> matter

Mergers from Globular Clusters

- Globular clusters
  - **Old**

    ~ same age as galaxy [O(10 Gyr)]

    [though some “young” GCs are seen]

  - **Small**

    $M \sim 2 \times 10^5 M_O * 10^{\pm 1}$

  - **Common** [density]

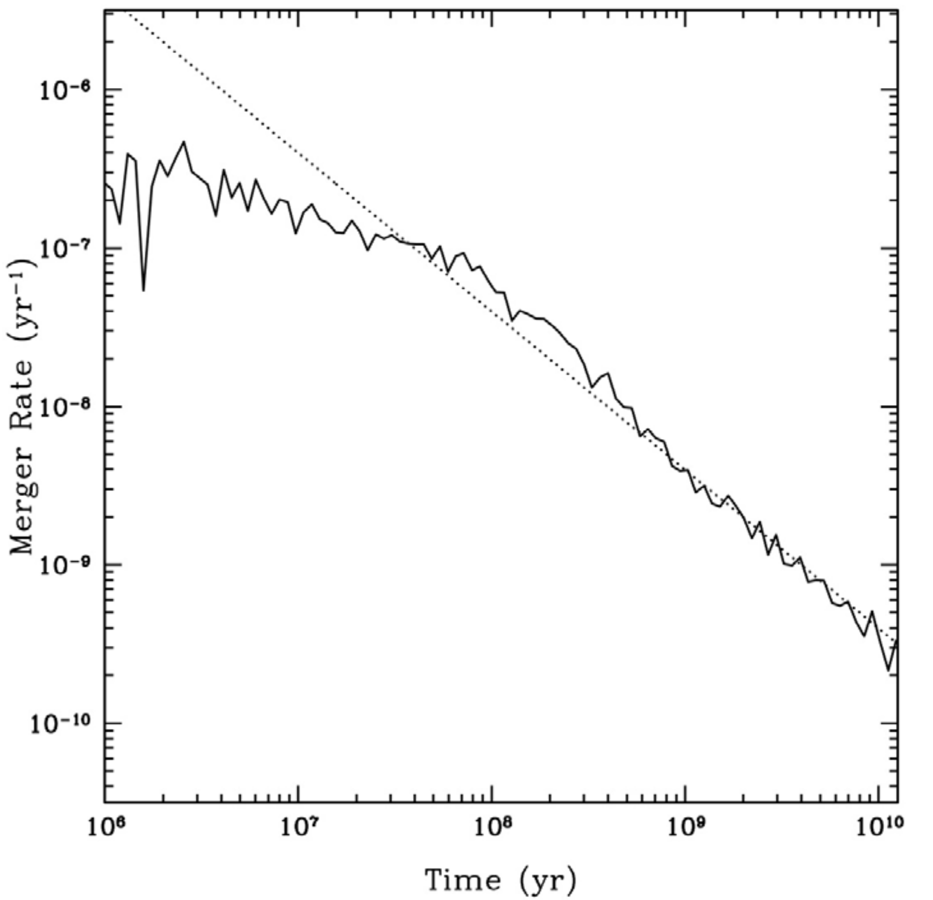
    $\rho \sim 3 / Mpc^3$

  - **Dense (interacting** !)
    - relaxation time ~ 10^2 - 10^3 Myr
    - **mass segregation** $t \sim t_{relax} * <m>/m_{BH} \sim$ 10-100 Myr

Mergers from Globular Clusters

- Decoupled BH subcluster
  - Subcluster forms
    [relaxation time]
  - Fast evolution and interactions
    [BH relaxation time!]
    - **Form** and **eject** binaries
      (3-body interactions, Kozai, etc)
    - Many **late** mergers
      (~ 1/2 of all mergers)
  - Ejected binaries <u>eventually</u> merge
    … rate ~ **1/t**
    … **10^{-4} mergers/M_O**
    [=rate ~ cluster mass]

<u>Plot</u>:
rate for $5x10^6 M_O$ cluster
512 BH initially…. $5x10^3 M_O$ in BHs



Mergers from Globular Clusters

- LIGO-II rate : **simplified** calculation
  - Short range:
    - **Merger rate** [~1/t] is ~ constant ~ $\mathbf{3*10^{-10}/yr}$
    - **LIGO range:**

$$D = 191 \text{ Mpc } (M_c/1.2\ M_O)^{5/6}$$

  - BH masses:
    - assume M ~ 14+14 Msun (conservative!)

Result: $R_{GC} \sim 3/yr$

(~ prediction from spirals)

Comments

- Compare with Portegeis-Zwart & McMillan:
  …similar; they miss **1/t**

- Limitations?:
  - Large clusters only: minimum mass for process
  - Competing effect (runaway collisions) ?
  - Cluster modelling (velocity dispersion)
  - Need **birth** masses of **GC** [using present masses]

- Higher chirp masses (vs from spirals):
  - Flatter IMF ("primordial"/salpeter)
  - **All** BHs formed contribute
  - Binary formation biased to high mass

  } [..M=14 is conservative]

- Birth time effect:
  - Weak
  - More recent formation (z~1) increases by only ~ x2

Comments

Details….

O’Leary et al, astro-ph/0508224

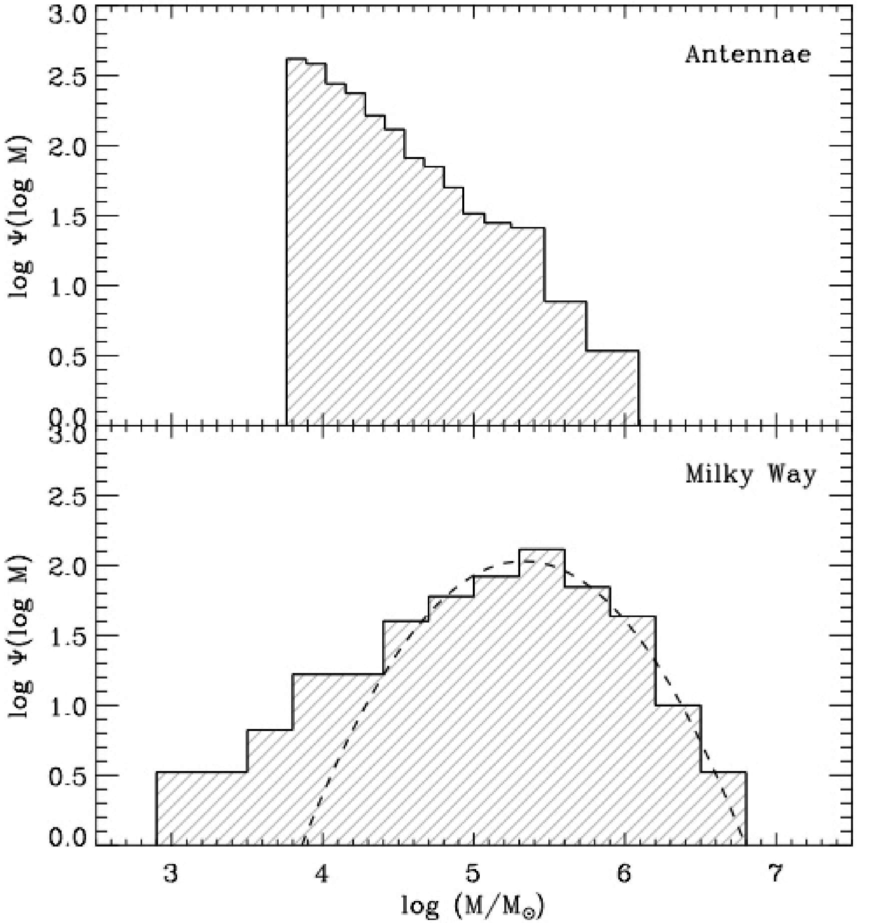
Delayed mergers from young clusters

- Clusters disrupt (!)
  - Birth distribution is **not** preserved

Young clusters

-> **suggest** $p(M)\, dM \sim M^{-2}$

Old clusters (Milky way)



Fall and Zhang, ApJ 561, 751

Delayed mergers from young clusters

- Evolving mass distribution:
  - Birth distribution **consistent** with

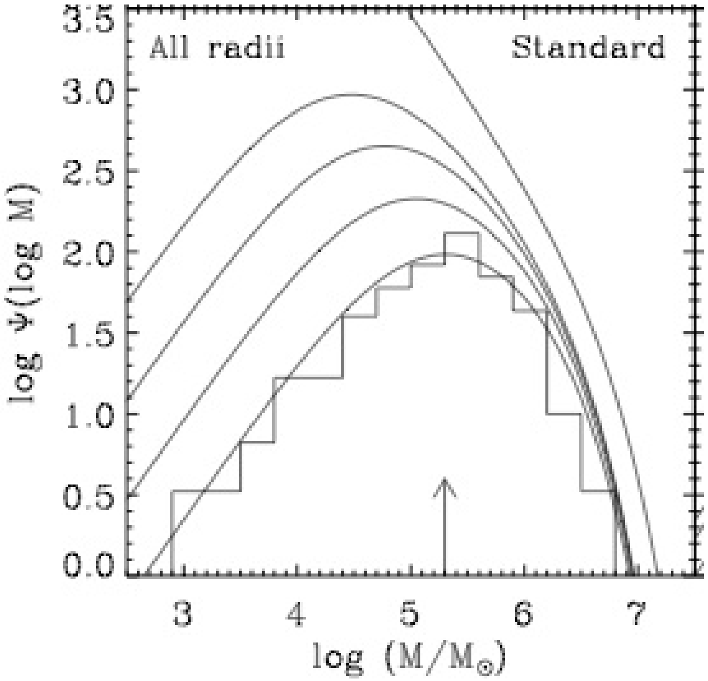
$$p_b(M)dM \propto \frac{dM}{M^2} e^{-M/M_*}$$

$M_* = 5 \times 10^6 M_{\odot}$

  - Present distribution **roughly**

$$p_b(M)dM \propto M dM e^{-M/M_*}$$

$M_* = 0.6 \times 10^6 M_{\odot}$

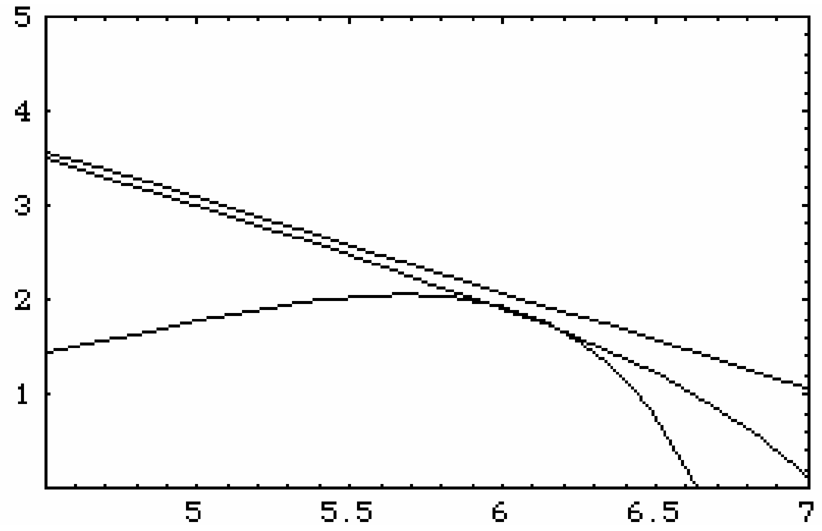


Fall and Zhang, ApJ 561, 751

Delayed mergers from young clusters

- <u>Scaling up</u>:
  - Process **requires** $M>10^5$
  - Rate ~ mass
  - For clusters $M>10^5$
    - M_{now} :Total mass in **all** clusters $M>10^5$
    - M_{birth} :Total mass in **all** clusters $M>10^5$

$M_{birth}/M_{now} \sim 3$



$\log_{10}(M/M_O)$

- <u>LIGO-II rate</u>:

$R_{GC} \sim 10/yr$

(conservatively)

Delayed mergers from young clusters

- Optimistic model
  - 10% of baryons form stars
  - **30%** stars form in clusters early
  - ~ 50% of cluster mass in clusters > $10^5 M_O$

  … with 20+20 M_O (ignoring redshifting & band issues)

2×10^8 M_O/Mpc^3

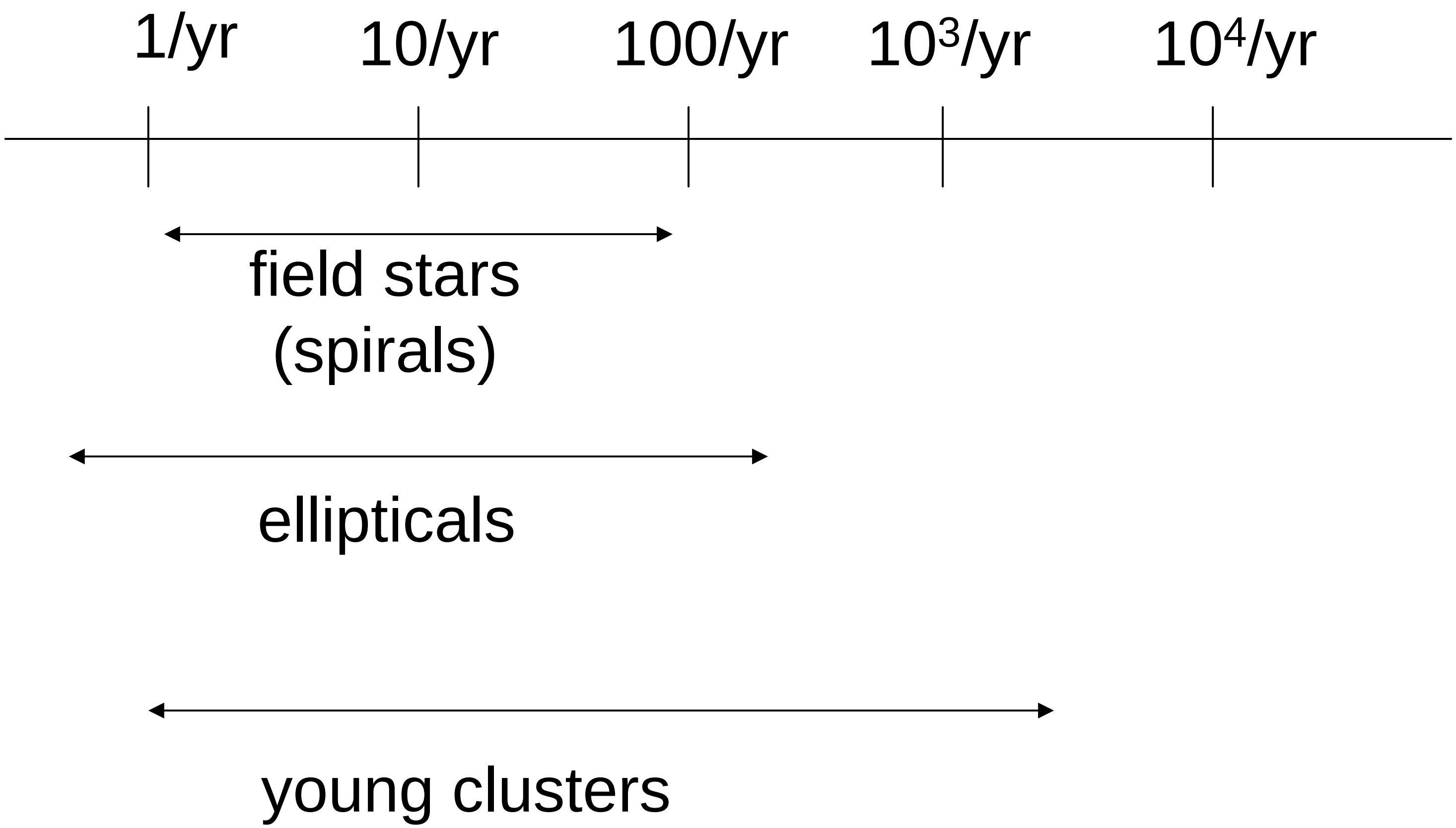
R ~ 10^3/yr [possibly slightly more]

- Consistency?
  - **Problem**…consistency w/ GC distribution?

    … but GC birth mass uncertain (stripping)

Delayed mergers from young clusters

- <u>BH-BH detection rate:</u>
  - Range of possibilities…



What does this mean to you?

- Multiple population models

  Field stars and clusters produce different binaries

  …different injections?

- Push **low** frequency sensitivity hard!