# Compact object merger rates

## Predictions

## Constraints

(including short GRBs)

**work in progress!**

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LSC, March 21, 2006

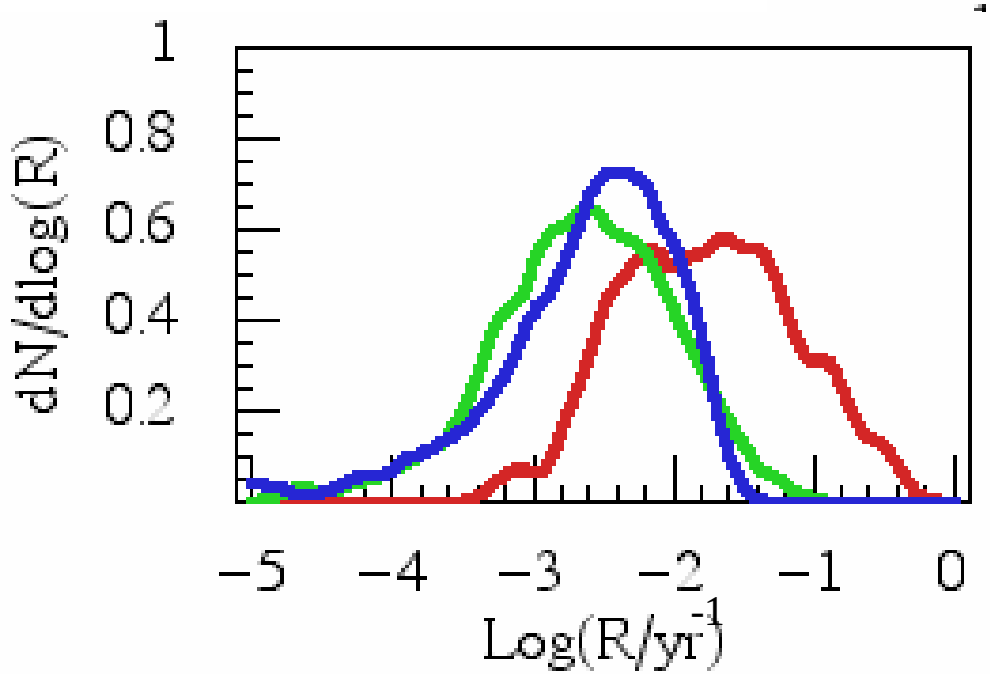
LIGO-G060157-00-Z

# Results (2005)

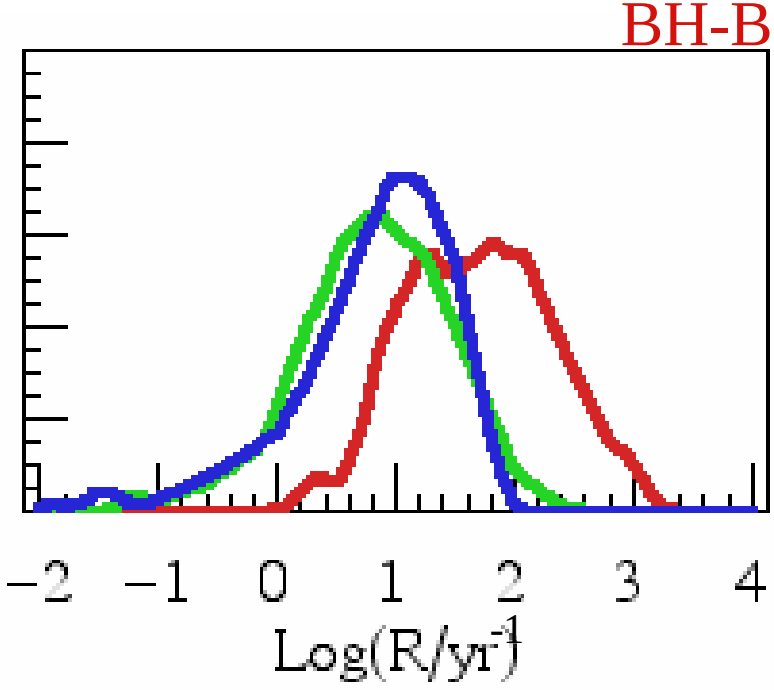
- LIGO rates:

**Key:**
NS-NS
BH-NS
BH-BH

INITIAL




ADVANCED



# Details (2005) [H]

- LIGO rates:

  + spiral density

$$\rho_{gal} = 0.01 / Mpc^3$$

  + euclidean universe (no cosmology)

  + LIGO single-IFO range

$$d_{init} = 14\,Mpc\,(M_c / 1.2\,M_O)^{5/6}$$

$$d_{adv} = 191\,Mpc\,(M_c / 1.2\,M_O)^{5/6}$$

  + Chirp mass distrib (estimate):

$< M_c^{15/6} >$ = 111 $M_O^{15/6}$ BH-BH (i.e. $M_{BH} < 10$)

= 5.8 $M_O^{15/6}$ BH-NS

= 2 $M_O^{15/6}$ NS-NS (i.e. $M_{NS} > 1.4$)

$$R_{init} = 0.7 \times 10^2 R_{MW} < (M_c / M_O)^{15/6} >$$

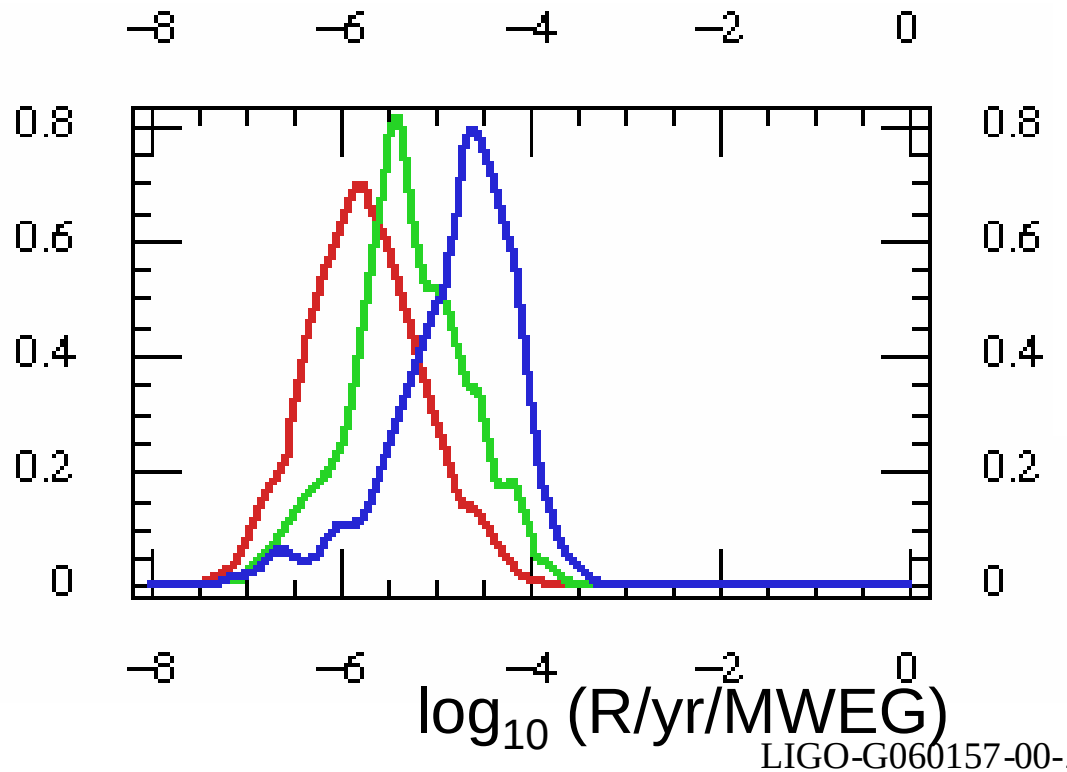
$$R_{adv} = 2 \times 10^5 R_{MW} < (M_c / M_O)^{15/6} >$$

# Method (2005)

- **Based on Milky Way** (well understood: history, population, …)

__ + **density of spirals** $\rho_{gal} = 0.01/Mpc^3$

- Rates/MW (now):




**Key**:

NS-NS

BH-NS

BH-BH

Uncertainties

Monte carlo over plausible astrophysical assumptions

# Method (2005)

- Other contributions?:
  - Prompt mergers ( << 1400 Myr ~ universe age)

| PSR name | $P_s$ (ms) | $P_b$ (hr) | e | $\tau_{life}$ (Myr) |
|---|---|---|---|---|
| B1913+16 | 59.03 | 7.752 | 0.617 | **365** |
| B1534+12 | 37.90 | 10.1 | 0.274 | **2700** |
| J0737-3039A | 22.70 | 2.45 | 0.088 | **185** |
| J1756-2251 | 28.46 | 7.67 | 0.181 | **2.0** |

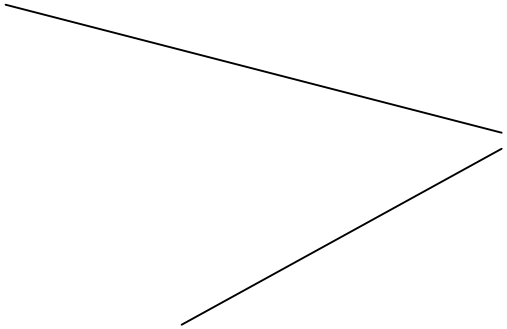
C. Kim (talk 2005
ROS et al (2005)

  - Spirals dominate local SFR / blue light

**Reason** why $N_G$ used
(in inspiral analysis interpretation)

# Key assumptions (2005)

- Steady star formation
- Prompt mergers dominate
- Spiral-like birth conditions (IMF)



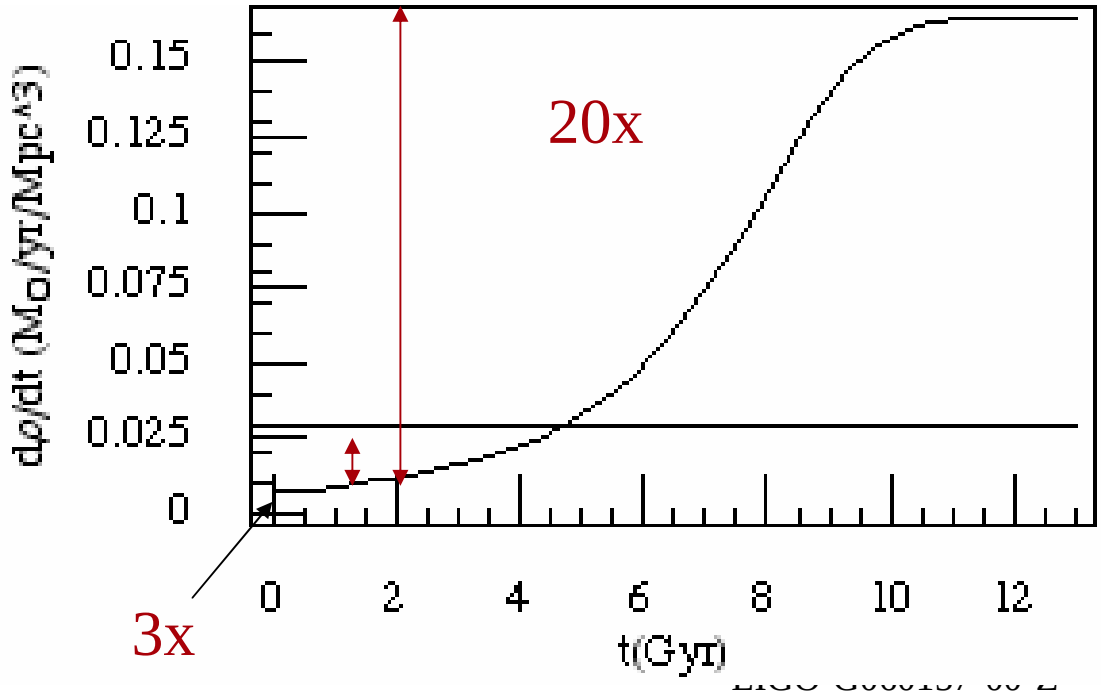
Extrapolation
Universe **all** like
Milky Way

# Refinements

Star formation history:

- Previous estimate: $\rho_{gal} = 0.01/Mpc^3 \quad SFR_{mw} = 3M_O yr^{-1}$

- Observed history:




- Estimate 3x too high (locally)
- Past ~ 20x present

**…are mergers "prompt enough?"**

# Refinements

Delay time distribution :

- Delay time = merger time - birth time

*Sample distribution*

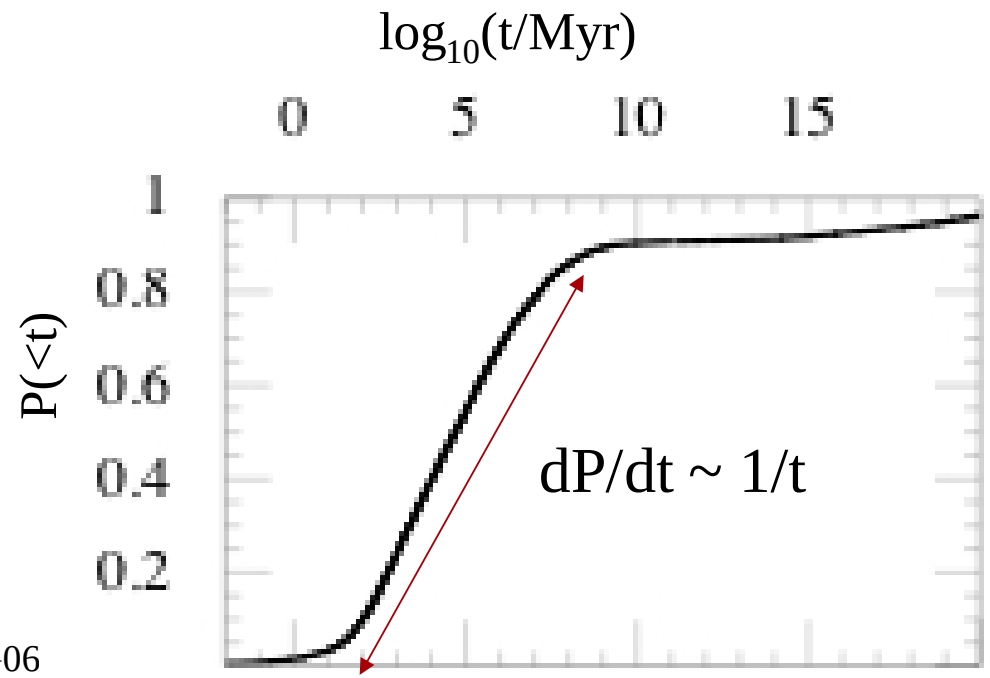
(model-dependent)

+ **1/t** works well

[long times]

… over a **specific range**

+ some prompt/instant



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Recent vs ancient contribution?

$$dRate \sim (d\rho/dt)\ dt/t$$

$$\frac{dRate(1Gyr)}{dRate(10Gyr)} \sim \frac{\rho(1Gyr)}{\rho(10Gyr)} 10 \sim 1$$

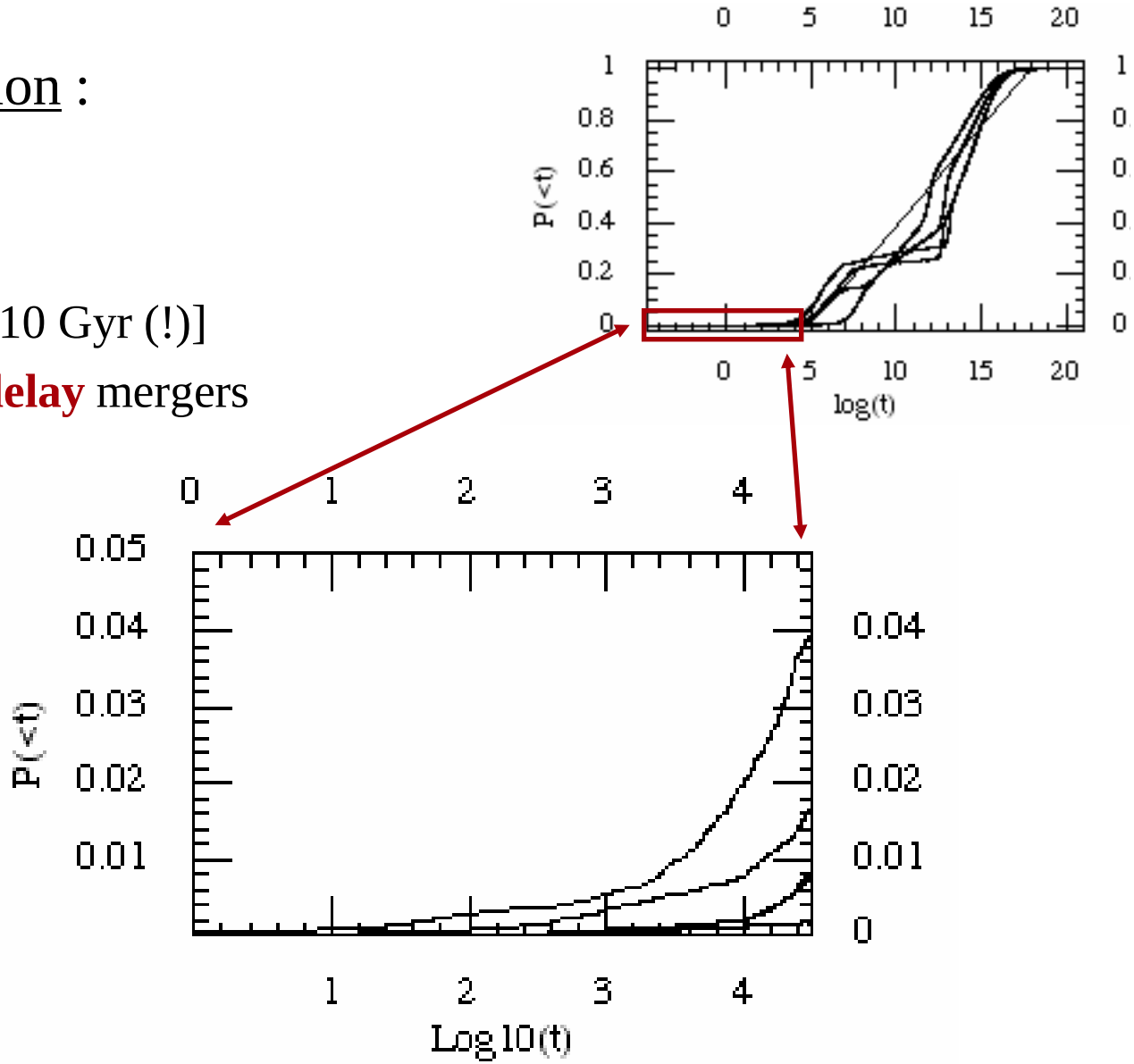
**ancient star formation important…**

# What's changed? [H]

Delay time distribution :

**…..except**

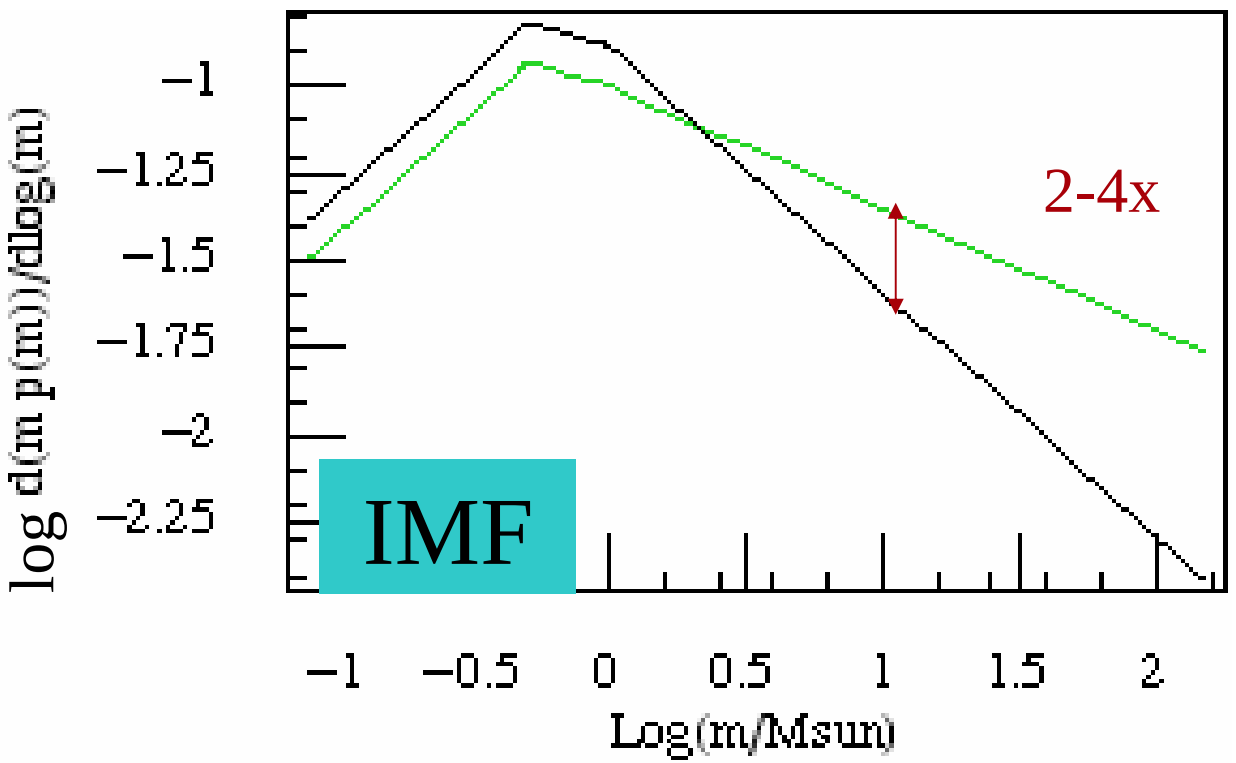
- BH-BH :
  - **1/t fails: [**tmin ~ 10 Gyr (!)]
  - ~ requires **long-delay** mergers



# Refinements

Heterogeneity

- Spirals
  - Young
  - Hard to make high M stars
- Ellipticals
  - Old
  - Easier to make high M stars




Ellipticals: **at least 2-4x** more high-mass progenitors

# What's changed? [H] (*)

Heterogeneity: Details

- Elliptical/spiral census (now, evolving)
  Census info
  Panter et al 2004, Read & Trentham 2005
  Fukugita, Hogan, Peebles 1998, 2004
  Bundy et al 2004 [low-z]

- Elliptical conditions (=old stars)
  Smith et al 2005,
  De Lucia et al 2006

- Star formation histories
  Heavens 2004, s De Lucia et al 2006

# Ingredient:
# Galaxy heterogeneity I [H]

## Heterogeneity details: Census

$$\Omega_{\text{spheroid stars}} = \left(0.00180\,^{+0.00121}_{-0.00085}\right) h^{-1},$$

$$\Omega_{\text{disk stars}} = \left(0.00060\,^{+0.00030}_{-0.00024}\right) h^{-1},$$

$$\Omega_{\text{stars in Irr}} = \left(0.000048\,^{+0.00033}_{-0.00026}\right) h^{-1},$$

Census info

Fukugita, Hogan, Peebles 1998, 2004

Census info

Read & Trentham 2005

| | $\Omega_b$ | $\Omega_*$ |
|---|---|---|
| E | 0.00064 | 0.00064 |
| S0 | 0.00073 | 0.00068 |
| Sa+Sab | 0.00036 | 0.00032 |
| Sb+Sbc | 0.00056 | 0.00040 |
| Sc+Scd | 0.00072 | 0.00047 |
| Sd+Sdm+Sm | 0.00037 | 0.00021 |
| Irr+dIrr | 0.00013 | 0.00007 |
| dE | 0.00002 | 0.00002 |
| total | 0.0035 | 0.0028 |

# What's changed? [H](*)

Heterogeneity + SFR : Model A:

Key features:

– More formation long ago

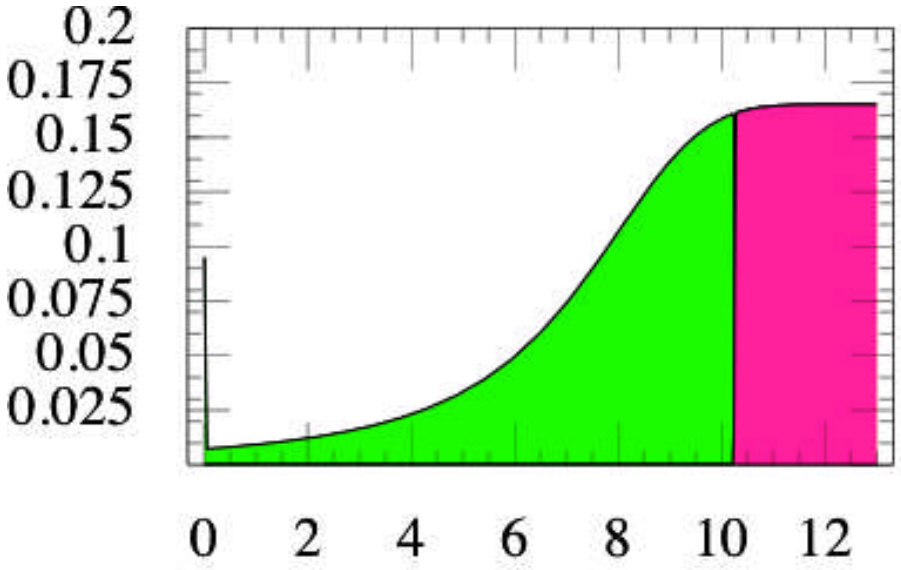
– Recently (z<2) ~ ok;

early = ??

– Ellipticals all old

…**but**

lots of early spirals



# Refinements

Summary (usually)

- Steady star formation
  - **Wrong**….early dominates
- Prompt mergers dominate
  - **Wrong**…long delays dominate
- Spiral-like birth conditions (IMF)
  - **Wrong**…ellipticals dominate

Scorecard: **old** vs **young**

IMF : up x 3

SFR : up x 10

Delay: down x 10

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Net : up x ~ 3

# Revised results?

Merger rates (/volume) versus redshift:

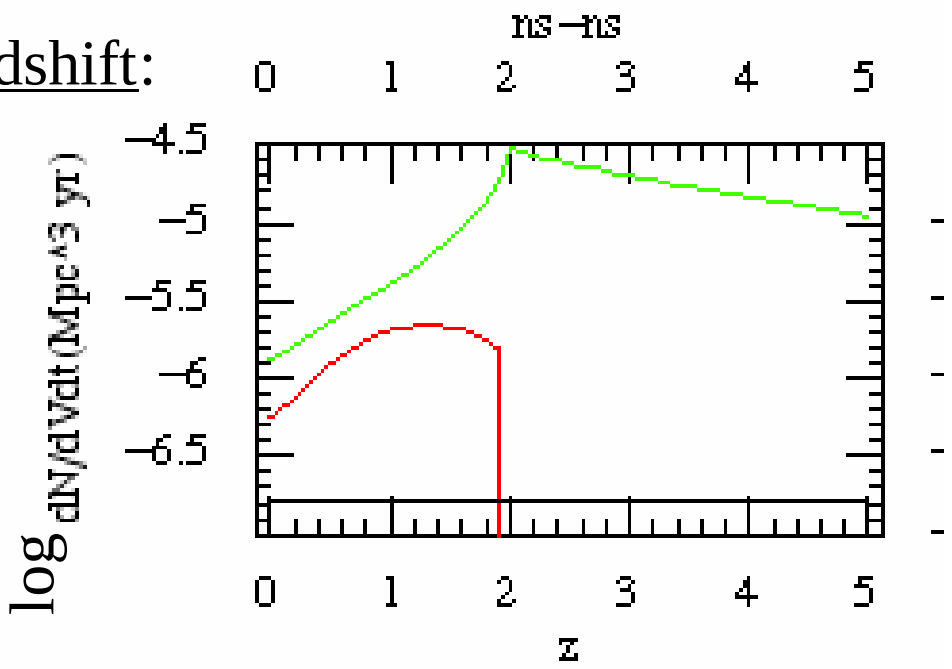
*…sample result*

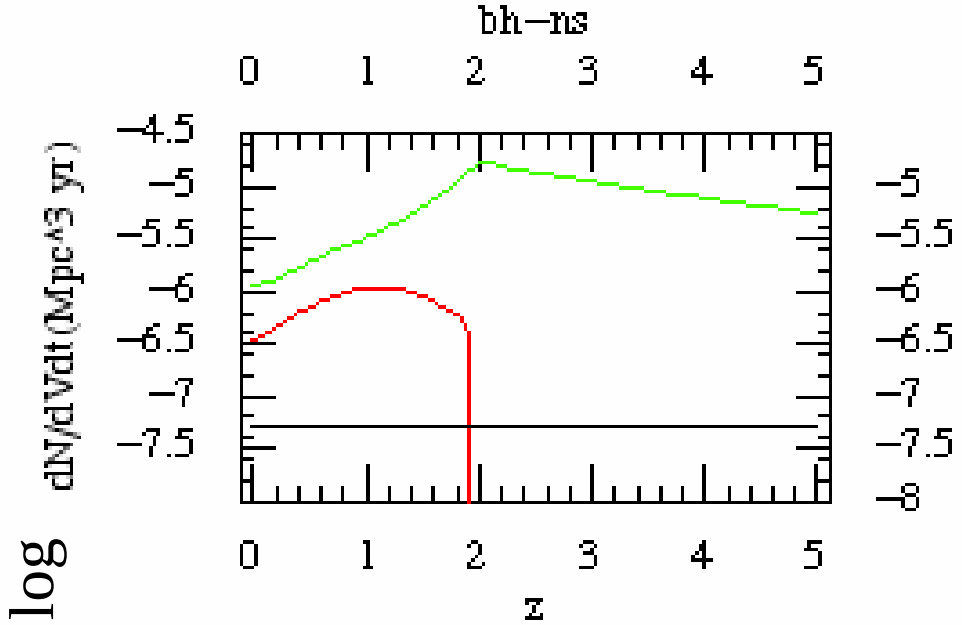
**Key**

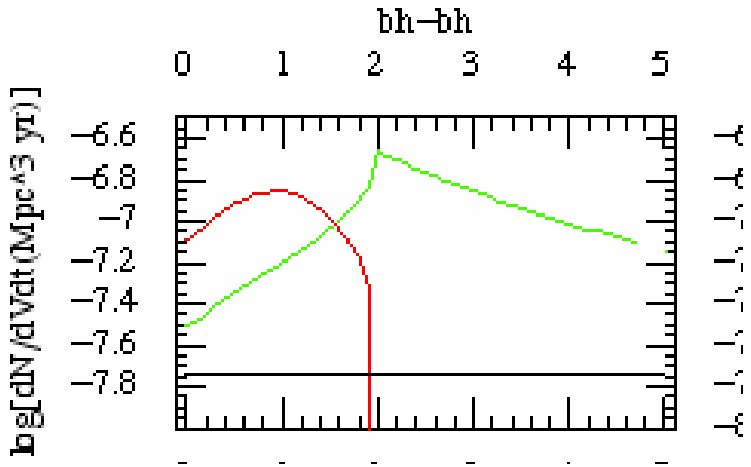
‘Reference’

Spirals

Ellipticals



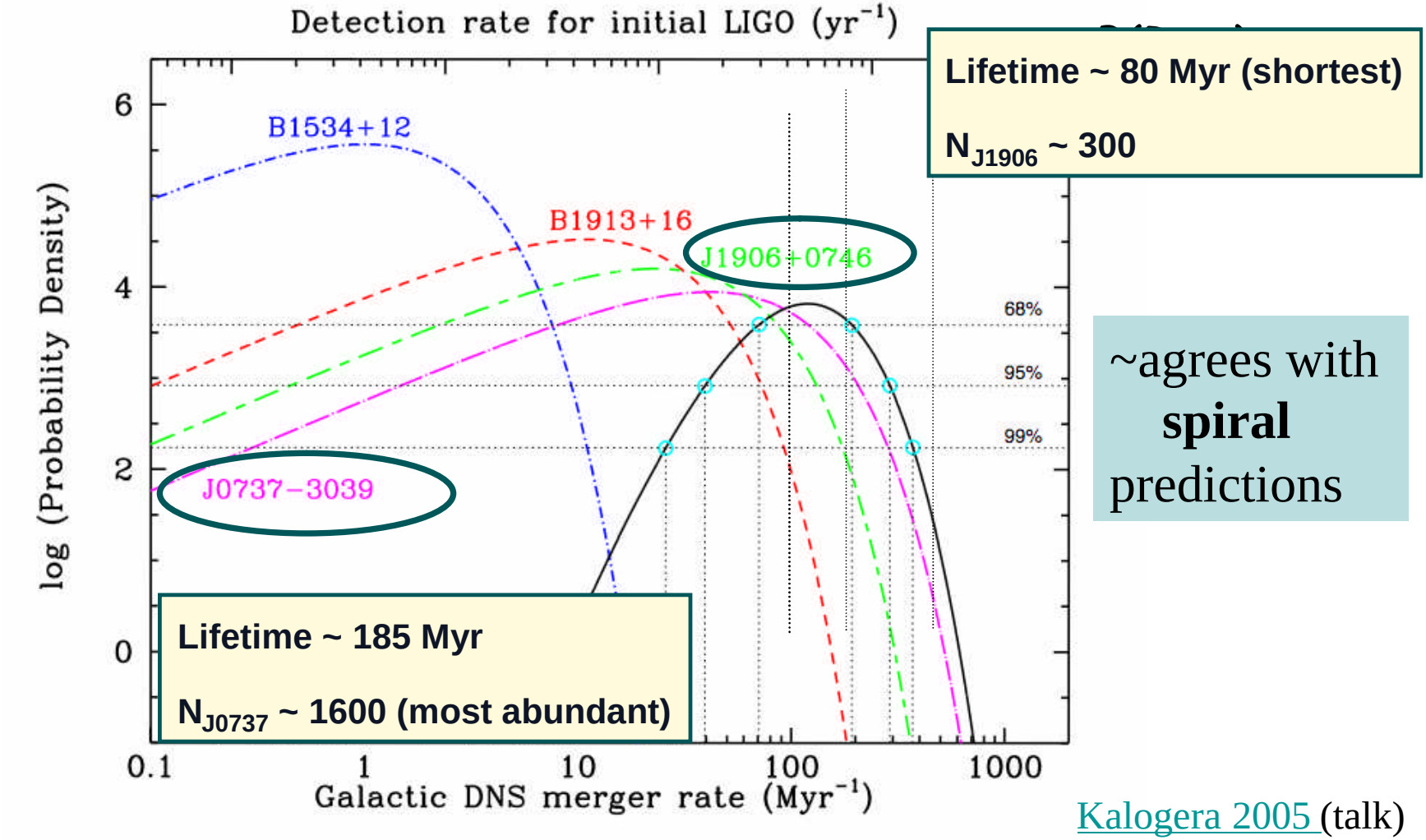

-00-Z

# Matching observations? [H]

- Relative galaxy populations/histories (check)
- Milky way
  - Overall pulsar-like sources [check, mod beaming]
  - Overall active binaries [selection effects unknown?]
  - Distribution of NS-NS?
    - Merger rates [w/ tuning, mod beaming]
    - Ratio young:old [check]
  - Distribution of WD-NS ? [w/ tuning]
- Local universe
  - Supernova rates **[spiral-dominated]** [check]
- Distant universe
  - Short GRBs [~check; broad range]

# Observations: MW NS-NS [H]

- **Observed** (MW) **NS-NS population -> MW merger rate**




~agrees with **spiral** predictions

Kalogera 2005 (talk)

# Observations: MW NS-NS [H]

- **Observed** (MW) **population -> merger rate**

Method =

SELECTION EFFECTS (understood)

+ POPULATION MODEL

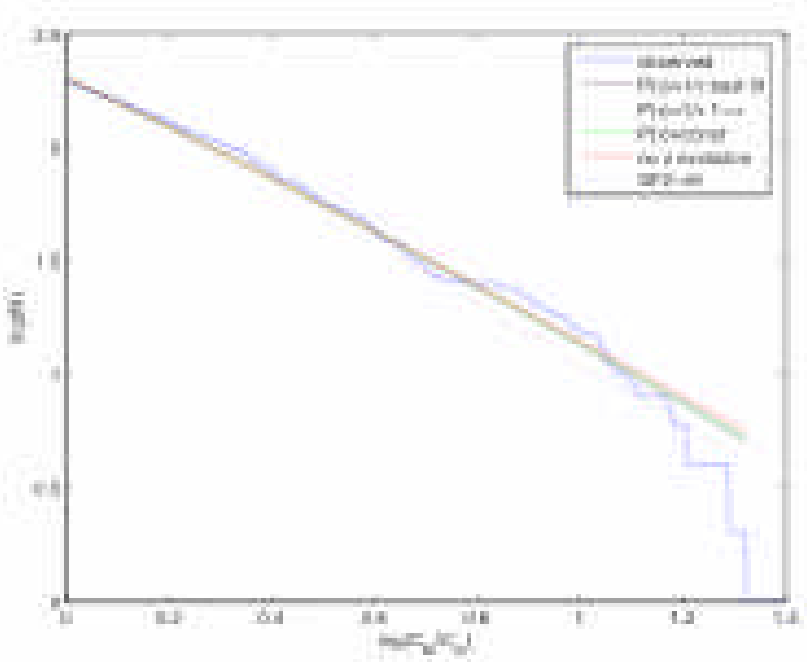
…including

- **Luminosity** function [allow for *faint unseen* sources]
  …understood from **single** pulsars
- **Beaming correction**

# Observations: Short GRBs

Review

- Many seen (gamma-ray)
  [detection rate 1/(2-3 months)]
  … many **missed** (too faint)



- Afterglows & assocations
  - **Variety**, includes **OLD**
  - Offsets (!)
  - Weak afterglows [low-density]
    …not SN
  - Beaming?

Merger model
(BH-NS, NS-NS)
**consistent**

# Observations: Short GRBs [H]

## Details: Known systems

| Short GRB | Host galaxy | Redshift | Energy |
|---|---|---|---|
| 050509b | Very old (E) | 0.22 (~900 Mpc) | $4.5 \times 10^{48}$ |
| 050709 | Young (Sb/Sc) | 0.16 (~660 Mpc) | $6.9 \times 10^{49}$ |
| 050724 | Old (E) | 0.26 (~1 Gpc) | $4 \times 10^{50}$ |
| 050813 | Very old (cluster) | 1.8 / 0.72[?] | |
| 051221 | young | 0.547 | $9 \times 10^{50}$ |

E. Berger (review article)
Gehrels (KITP talk) **[link]**
Nakar (LIGO talk) **[link]**

…**suggests** rate ~ 1/(2 month)$(\text{Gpc})^3$

# Observations: Short GRBs [H]

Details: Opening angles

…still **very sketchy/tentative** measurements

- Jet opening angles

  $\theta \sim 10\text{-}20^{o}$

…**suggests** rate ~ 50x higher

~ 50/ $(\text{Gpc})^3$/year

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

# Observations: Short GRBs

- 'Experimental' rates:
  - Conservative : (~what is **seen**)

    $R_{GRB,low} \sim 3x10^{-8}/Mpc^3/yr$

    $= \sim$ expected [spirals alone]

  - Optimistic?: (correct for **faint** and **off-axis**)

    $R_{GRB,high} \sim R_{GRB,low} (L_{cut}/L_{min}) f_b$

    $\sim R_{GRB,low} (\sim 100) \times (\sim 3)$

    $\sim 1x\ 10^{-5} / Mpc^3/yr$

would be **almost** visible by initial LIGO
…runs into problems (run out of SN)

# Applying experimental constraints I: N(<P) [H]

- Matching:

  **SFR history**

  + (homogeneous)

  + **delay time distribution**

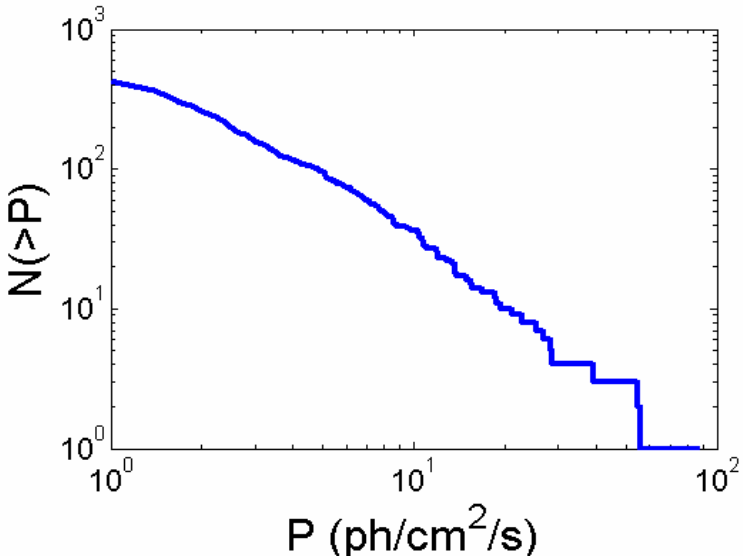
    (try a few)

  + **intrinsic LF**

    (try a few)

  **= guess**

  **FIT TO OBSERVED**




Results:
rate ~ O(0.1-10 / Gpc$^3$/yr)
[depends on model]

Guetta and Piran 2005/6
Ando 2004

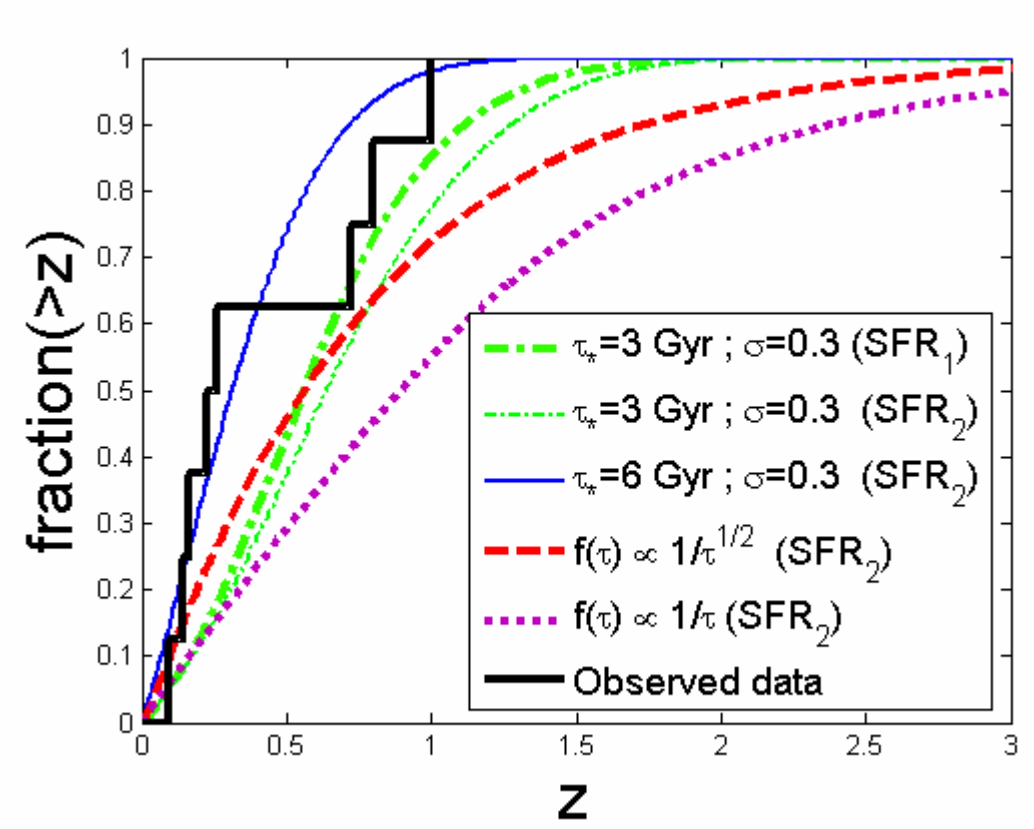
# Applying experimental constraints III: N(<P) + observed 'z'

- Method:
  - Previous
  - + match z distrib
  - + limit faint end

    [Tanvir et al 2005]

- **Odd claims**:
  - 1/t excluded (!?)

    [what is tmin?]
  - 6 Gyr lifetime preferred?




**Results**

(i) No beaming: 10/Gpc$^3$/yr

(ii) Beaming, faint: $10^5$/Gpc$^3$/yr (~x30) (~ $3 \times 10^3$)

Nakar et al 2005