Binary models for short GRBs

Richard O'Shaughnessy
V. Kalogera, K. Belczynski
Northwestern University
2005-12-11

Goals of talk

- Why a merger model?

  [=Lamb's plenary talk Friday]

- Does a merger model work?
  - Do we make enough mergers?
  - Are the right galaxies hosts?
  - Do the binaries last long enough to escape?

    [=Chris Belczynski's talk today]
  - Are the redshifts consistent with expectations?

Earlier work

- For long GRBs:
  - Bromm and Loeb (2002), …
- For short GRBs:
  - Voss and Tauris (2003); Bloom et al (2003)
  - Ando (2004), Guetta and Piran (2005)
    Nakar, Gal-Yan, Fox (2005), …

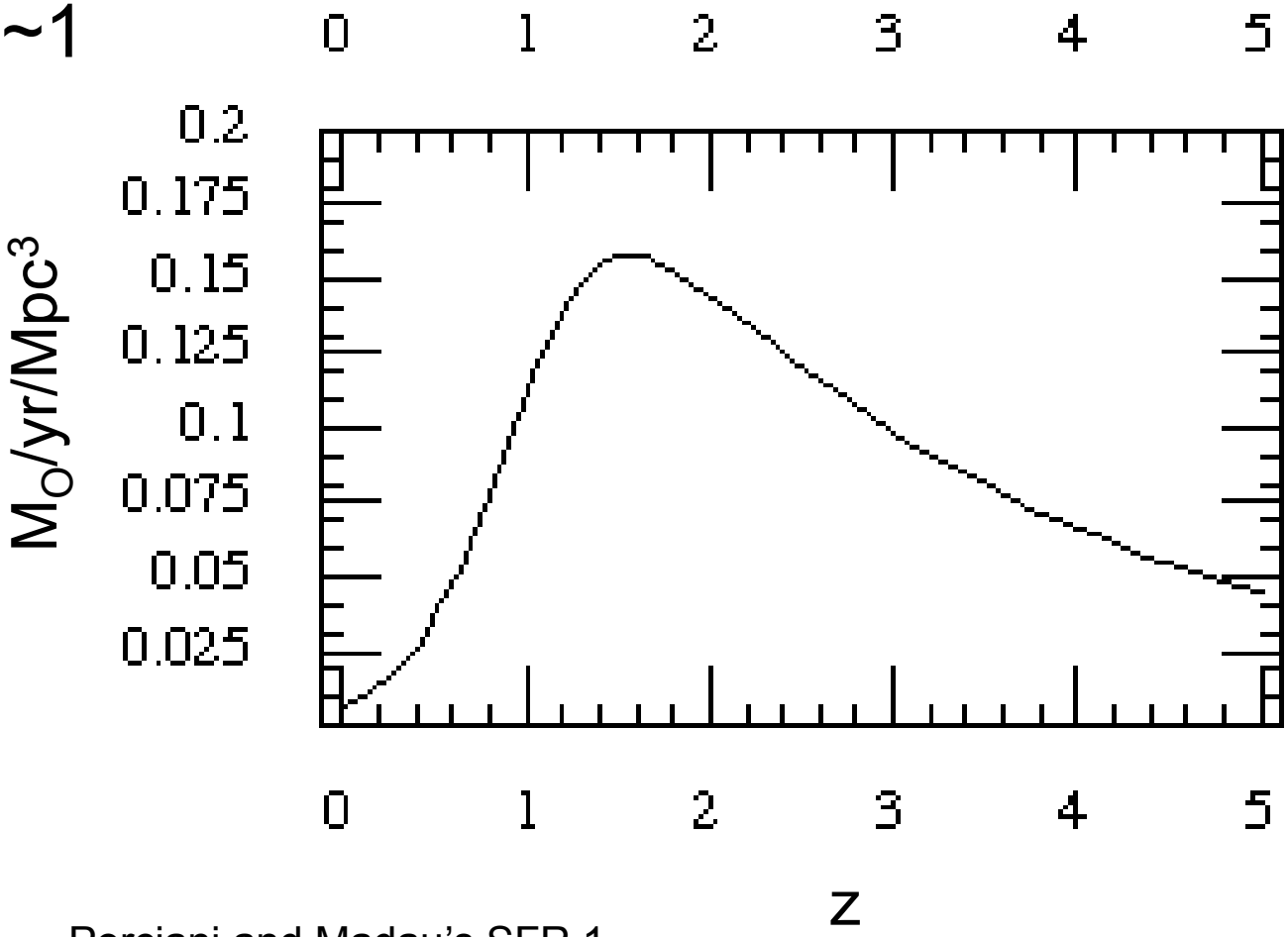
Outline

- Population synthesis for the universe
  - Star formation history
  - Heterogeneity: Ellipticals and spirals
  - NS-NS and BH-NS population synthesis
    - Mass efficiencies
    - Merger times
- Implications for mergers and GRBs
  - Long-lived progenitors
  - Merger rates
  - Relative frequency in ellipticals/spirals
  - Redshift distribution

    [intractable w/o luminosity function]

Star formation history

- Peaks near z~1



Porciani and Madau's SFR 1
[cf. Heavens; XXX]

Heterogeneity

- **Idealized model**:

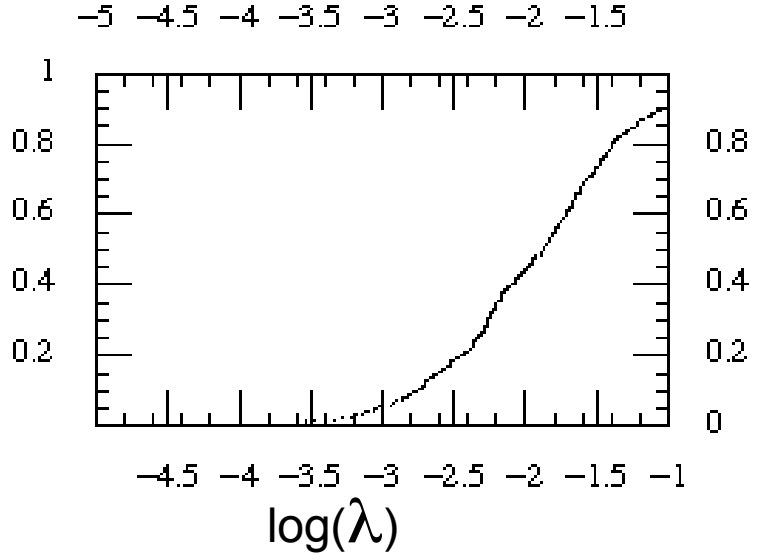
	Fraction	Z	IMF
Spirals	80%	$Z_O = 0.02$	Kroupa
Ellipticals	20%	0.5-2x Z_O	~Salpeter

Population synthesis

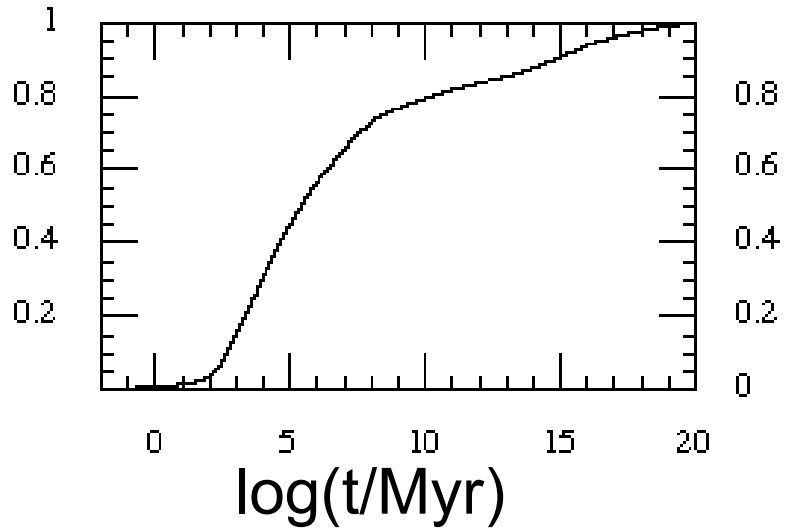
- BH-NS (elliptical conditions)

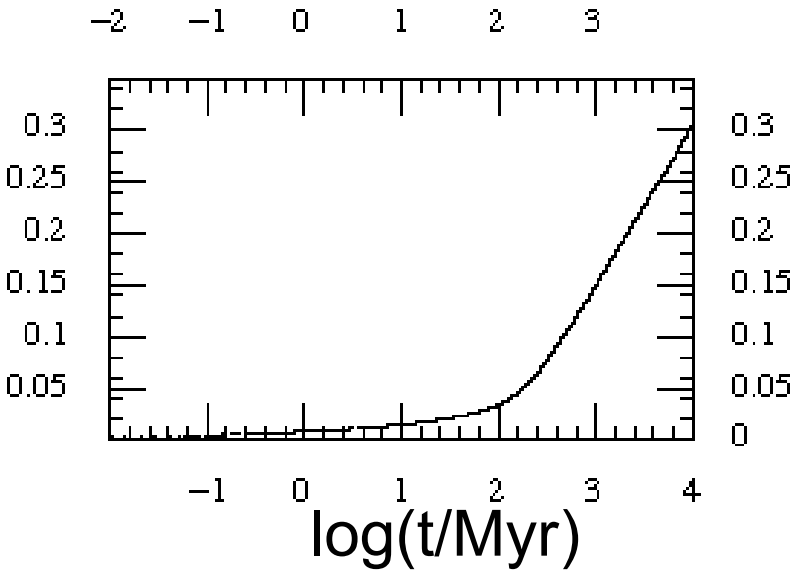
Mass efficiency

$\lambda_{e,BH\text{-}NS} \sim 1.3 \times 10^{-2}/M_O$



Merger time distribution



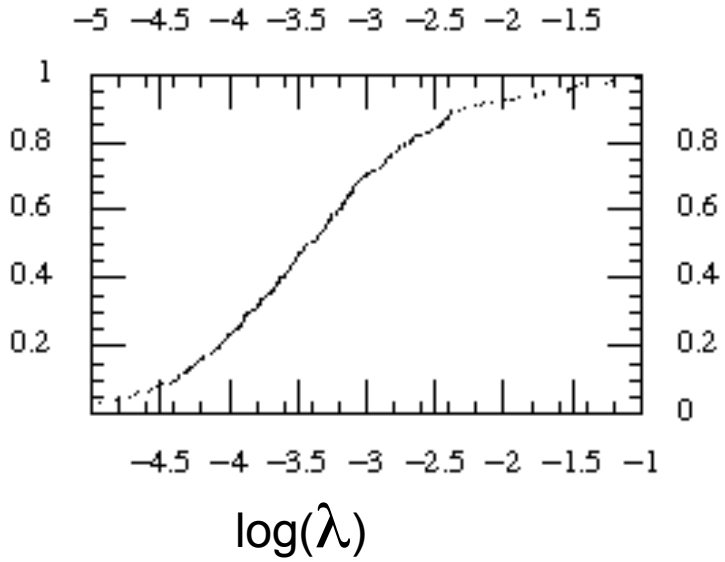


Population synthesis

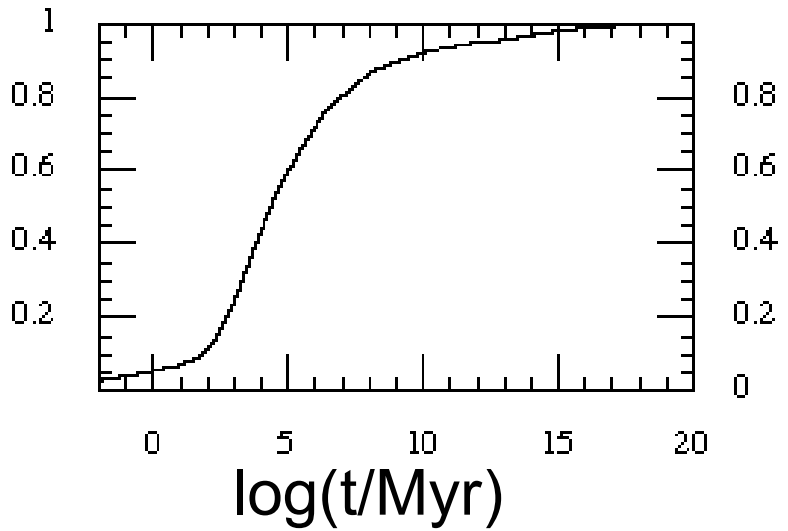
- BH-NS (spiral conditions)

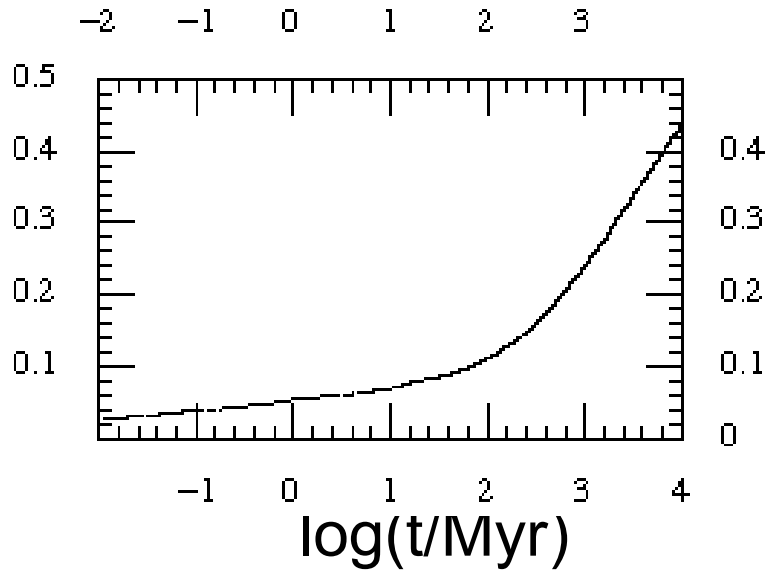
Mass efficiency

$\lambda_{s,BH\text{-}NS} \sim 3.7 \times 10^{-4}/M_O$



Merger time distribution



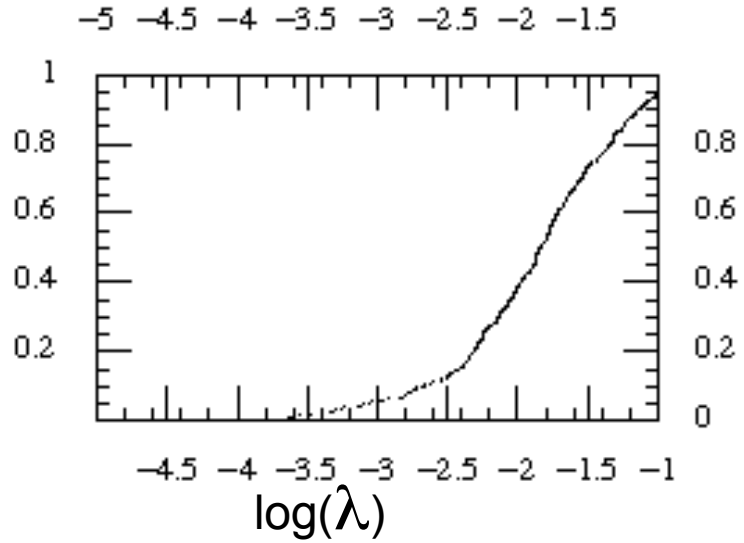


Population synthesis

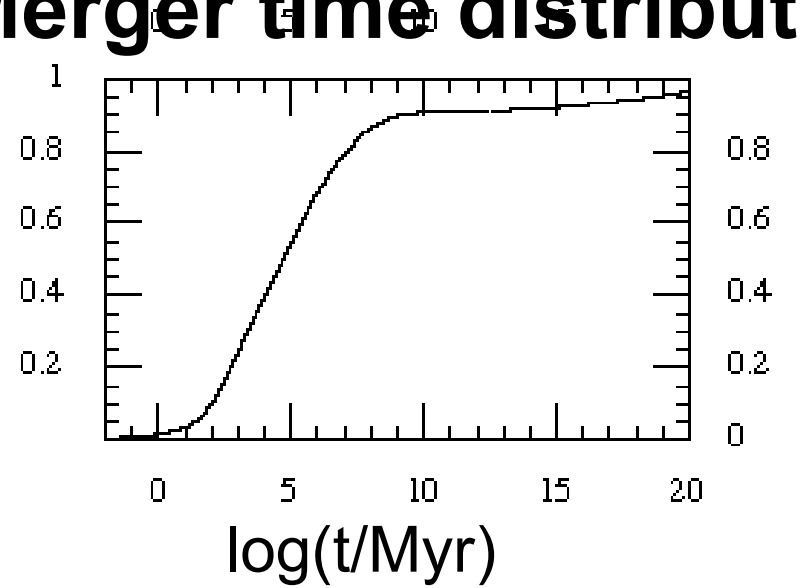
- NS-NS (elliptical conditions)

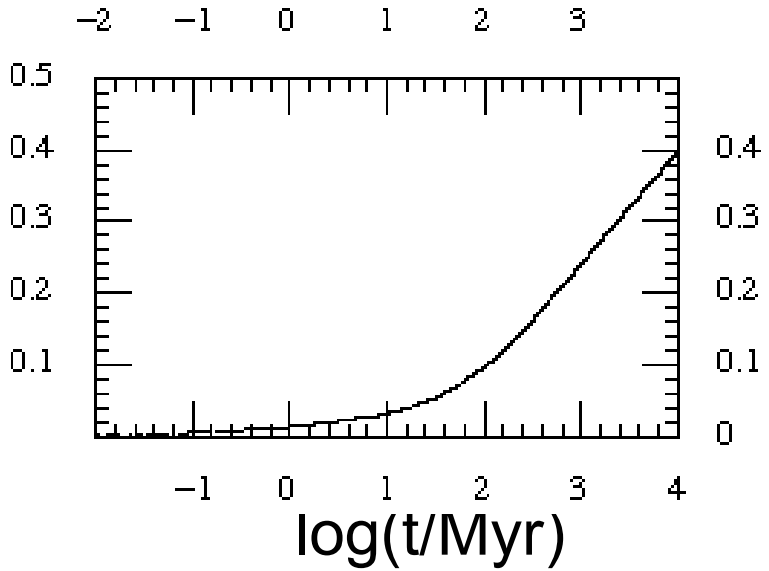
Mass efficiency

$\lambda_{e,NS\text{-}NS} \sim 1.5 \times 10^{-2}/M_O$



Merger time distribution



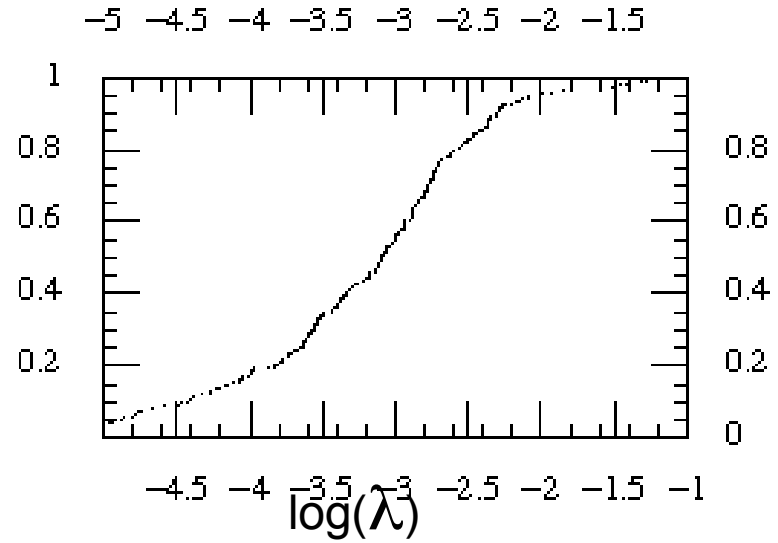


Population synthesis

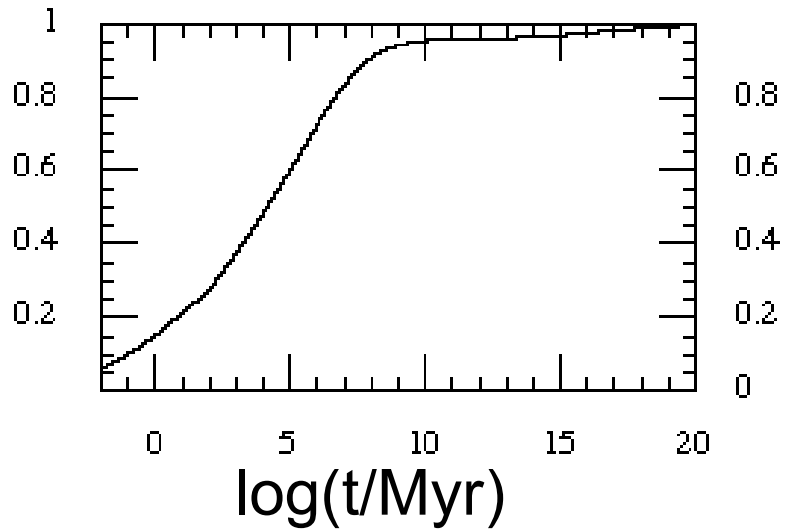
- NS-NS (spiral conditions)

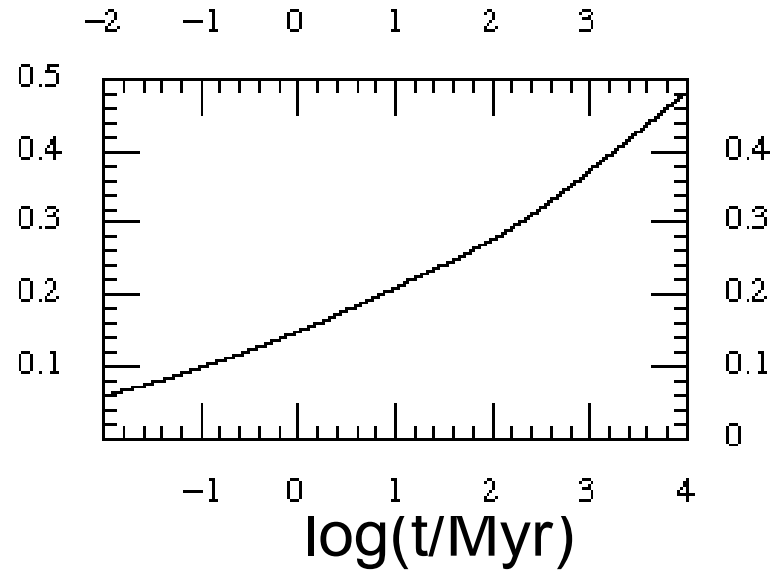
Mass efficiency

$\lambda_{s,\ NS\text{-}NS} \sim 10^{-3}/M_O$



Merger time distribution





Population synthesis

- Key points:
  - Elliptical conditions =

    flatter IMF =

    higher mass efficiency (10x - 50 x)

  - Many progenitors **long-lived**

    Fraction of merging systems with t_{mgr}>100 Myr dominates

    Fairly independent of popsyn assumptions

    ….except NS-NS (under spiral conditions)

Implications:
Long-lived progenitors?

- **Many** long-lived progenitors

1-P(0.1 Gyr)/P(10 Gyr)

	elliptical	spiral
NS-NS	75%	**43%**
BH-NS	89%	75%

- **Useful** for explaining…
  - Distance from host galaxy
  - Presence in host galaxy with old stellar population

Implications:
Merger & intrinsic GRB rates at present?

- **Model 0**: Reference model (estimate)
  - Method
    - ~ 35% merge
    - Sprials only:
      - density n_s=0.01/Mpc^{-3}
      - SFR : dM/dt/galaxy = 3.5 M_O/yr
  - Result:

    ~ confirmed by more detailed calculations

    [O'Shaughnessy et al ApJ 633 1076]

Method 0

Mpc^{--3} yr^{--1}

NS-NS	4x 10^{-7} -- 4x 10^{-4}
BH-NS	4x 10^{-7} -- 4x 10^{-4}

  - Problems:
    - Spirals only ("blue light" normalization)
    - Ignores time dependent SFR & merger delays

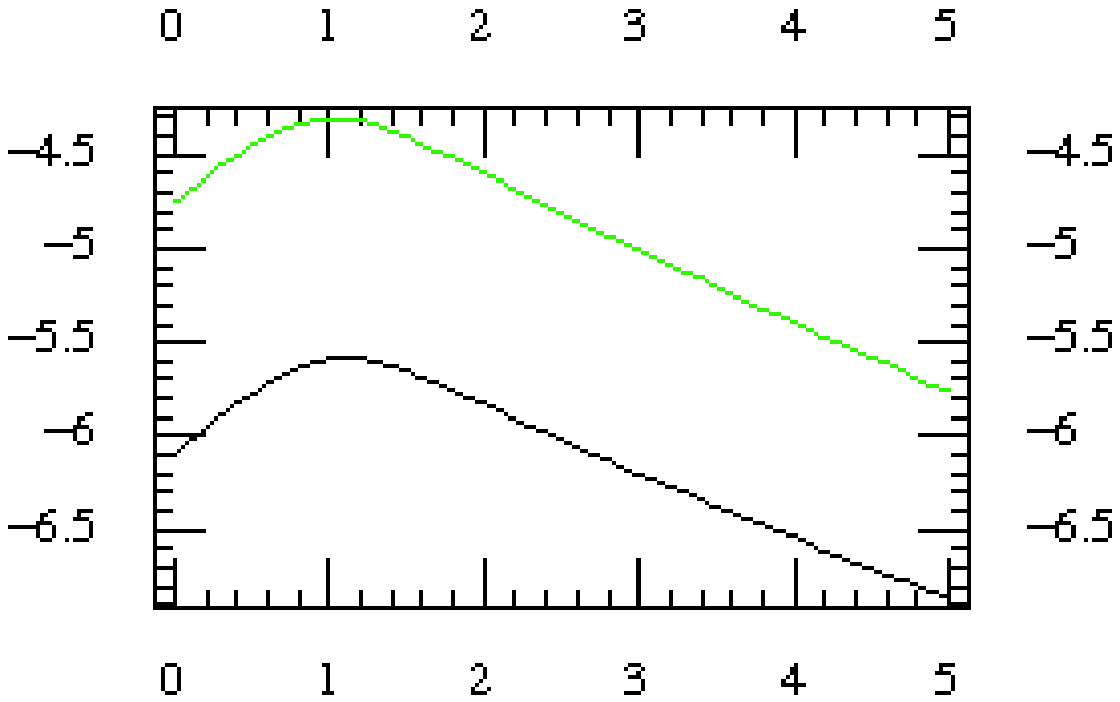
Implications:
Merger & intrinsic GRB rates at present?

- **Model 1**: Use SFR of universe
  - Method
    - Fix elliptical:spiral ratio
    - Convolve each with SFR
  - Result:
    …slightly higher
  - Problems:
    - Dominated by recent ‘elliptical’ star formation
    - Needs continuous elliptical SF at present

	Method 1 $Mpc^{-3}\ yr^{-1}$	Method 0 $Mpc^{-3}\ yr^{-1}$
NS-NS	$10^{-5.5}$-$10^{-2.5}$	$10^{-6.5}$-$10^{-3.5}$
BH-NS	10^{-6}-10^{-3}	$10^{-6.5}$-$10^{-3.5}$

Implications:
Merger & intrinsic GRB rates at present?

- **Model 1**: Use SFR of universe
  - Elliptical, spiral merger rate history: (BH-NS)



Implications:
Merger & intrinsic GRB rates at present?

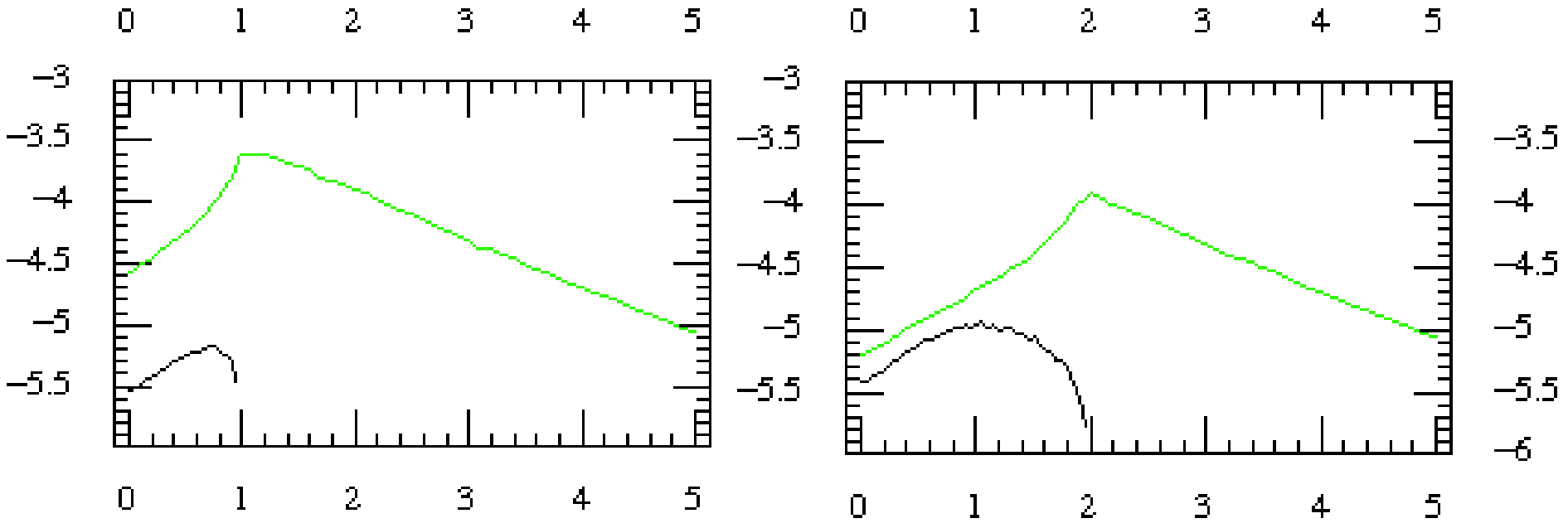
- **Model 2**: Ellipticals only form *early*
  - Method
    - Ellipticals for z>1, spirals for z<1
    - Convolve each with SFR
  - Result:

	Method 2 $Mpc^{-3}\ yr^{-1}$	Method 0 $Mpc^{-3}\ yr^{-1}$
NS-NS	$10^{-6.5}$-$10^{-3.5}$	$10^{-6.5}$-$10^{-3.5}$
BH-NS	$10^{-6.5}$-$10^{-3.5}$	$10^{-6.5}$-$10^{-3.5}$

…ends up same as by naïve approach

Implications:
Merger & intrinsic GRB rates at present?

- **Model 2**: Use SFR of universe
  - Elliptical, spiral merger rate history: (BH-NS)



Transition at z=1

Transition at z=2

Implications:
Relative frequency of hosts?

- Competing factors
  - Ellipticals form more massive stars
  - Spirals form stars now; + more spirals

$R_{spiral}/R_{elliptical}$	Estimate $\frac{\lambda_{sp} f_{sp}}{\lambda_{el} f_{el}}$	Calculation (Method 2)
NS-NS	0.2	0.05
BH-NS	0.1	0.1

Implications:
GRB detection rate and Redshift distribution?

- Tricky!
  - Need good detection model
    (i.e. luminosity function)
  - Received flux depends on
    - Viewing geometry (beaming)
    - BH spin (BH-NS cases)

    →**no** a priori method

    →not enough data from experiment

    [cf. Nakar et al astro-ph/0511254 , Ando (2004), Guetta and Piran (2005)]

Summary

- Bias towards early-type galaxies **can** be explained
  - Higher mass efficiency via IMF
  - Long progenitor lifetimes permissible
- Predictive? Not yet…
  - IMFs and elliptical:spiral ratio critical!
  - LF needed!
- Questions:
  - Where are non-escaping mergers?
  - Stellar interactions?