BBH coalescence rates for ET

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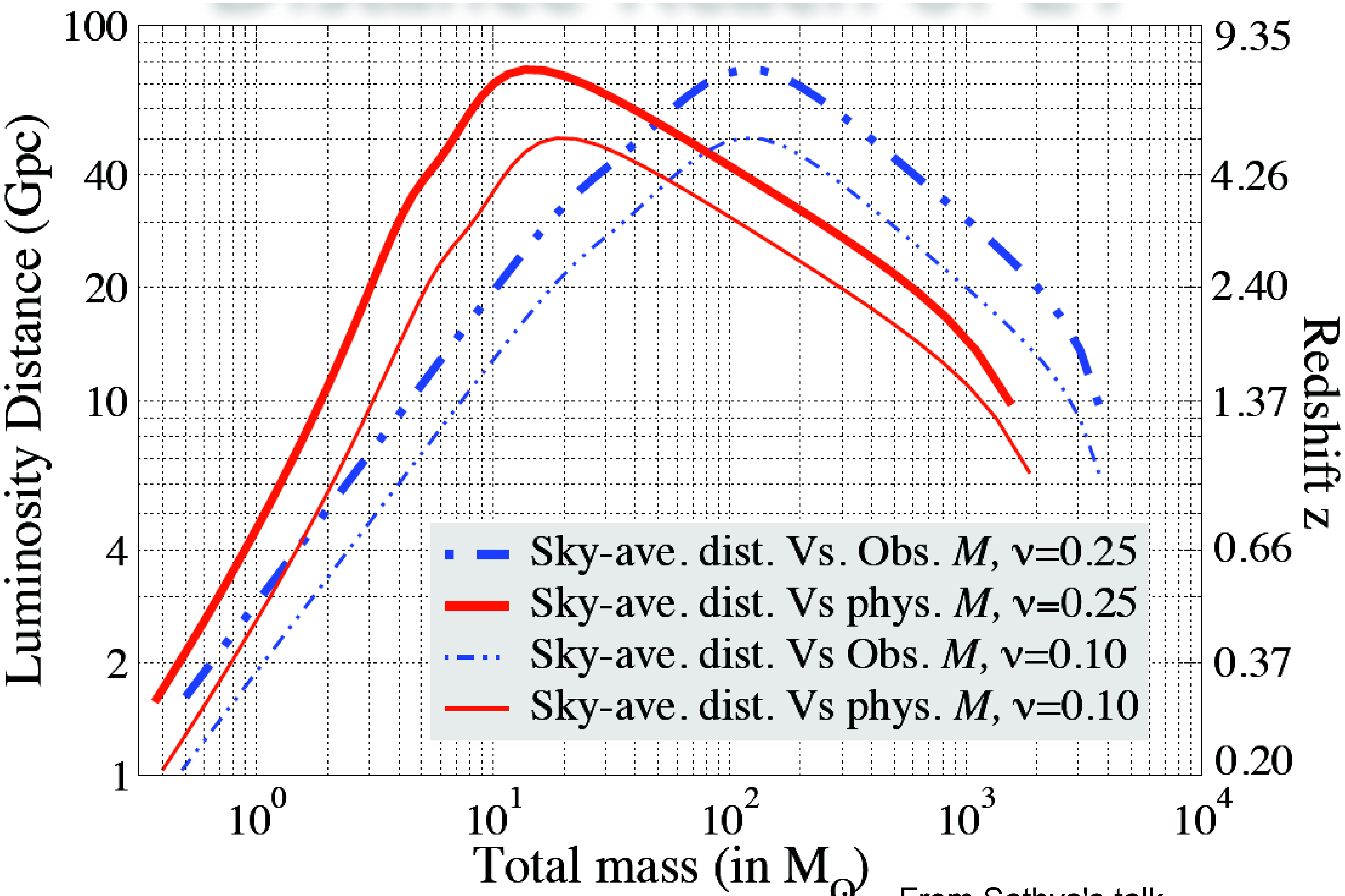
Range



From Sathya's talk

Stellar mass binary black holes

- Total masses 10 to perhaps 100 solar mass
- Detectable up to z=8
- Nice, clean systems from the GR point of view
- But...
- None seen yet
- Do they exist? If so, how many? And where?

Formation of binary BHs

Start from two stars at ZAMS

Want to make them tight so that the merger time is below the Hubble time

But the stars themselves become large in the course of evolution

Need to shrink the orbit → common envelope!

The common envelope phase

Mass transfer from a more massive donor to less massive companion

Mass transfer unstable

Rapid shrinking of the orbit

Expelling the envelope of the donor at the expense of orbital energy

Will end if the donor has a well established core-envelope structure

The principal CE phase: a solution but also a bottleneck....

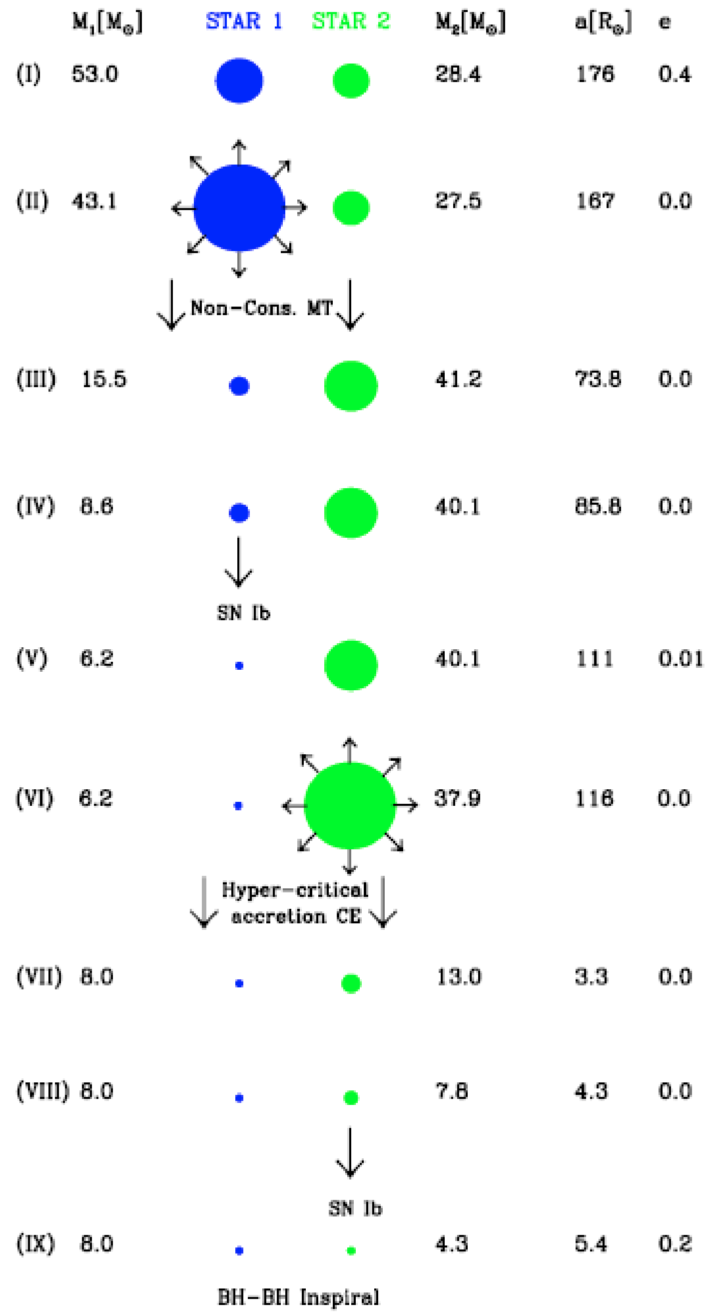


Fig. 1. An example evolutionary scenario leading to formation of a double black hole binary. For details see the text.

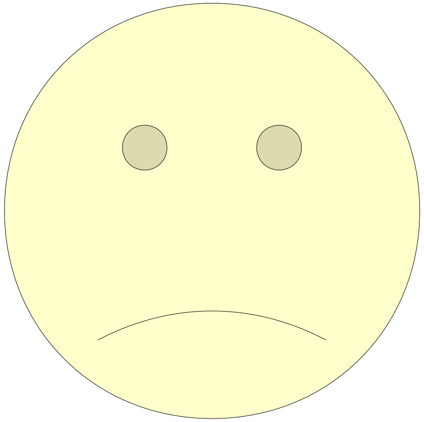
Solar metallicity

Large mass ratio at the onset of CE

Donor has no well established core - envelope structure

CE leads to a merger and formation of a TŻ-object

No BBH formed



Stellar evolution for low metallicities

Metallicity affects opacities

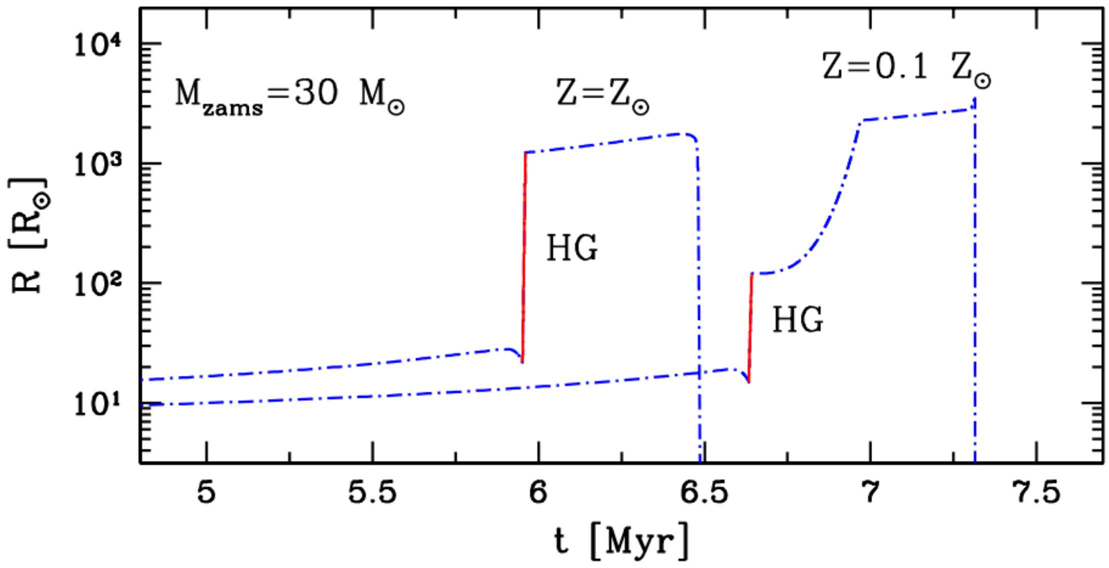
Opacities affect winds

Opacities affect radiation pressure

Thus

- Larger BH masses
- Smaller sizes at the giant stage

Stellar radius



Stars at low metallicity make smaller giants.
Thus they will enter the CE phase after the HG phase, and may produce BBH rather than merge with formation of TŻ objects .

BH masses

Smaller metallicity stars make more massive BHs

The mass ratio at the onset of CE closer to unity

May stabilize the mass transfer

Survival of the CE phase more likely

Expected local merger rate

Assuming half and half composition of solar and 0.1 solar metallicity we obtain

$$R \approx 10^{2}\, Gpc^{-3}\, yr^{-1}$$

Belczynski, Dominik, B., 2010

Observational evidence

Observations of massive binaries in nearby galaxies

IC10 X-1: a BH with the mass at least 23 Msun with a WR companion of at least 17 Msun

NGC300 X-1: a BH of ~20 Msun with WR companion of 15 Msun

X-ray binaries- stable mass transfer!

Future evolution of IC10 X-1 ad NGC300 X-1

Stable mass transfer

WR star looses mass by wind and through Roche lobe

WR star explodes as a SN

Formation of BH or NS

SN kicks probably do not affect the survival of the system (orbital velocity is large)

Formation of a merging BBH binary

Formation rate

Formation rate:

$$R \sim \sum V^{-1} t^{-1}$$

V- observed volume

t - X-ray active time

Merger rate

If merger time less than Hubble time and assume constant star formation then

merger rate = formation rate

Merger rate

$$R \approx 1.5 \times 10^{3}\, Gpc^{-3}\, yr^{-1}$$

What to think of this estimate

Relies on observations of systems that are pre BBH binaries

Based on two objects but dominated by the contribution of one object (IC10 X-1)

Quite uncertain but conservative in my opinion

Similar to the population synthesis estimates

As good (or as bad) as observational estimates of BNS merger rates

ET BHBH rates

Assume maximum redshift for coalescences =2

- Optimistic (obs. based): $\sim 5\times10^{6}\,yr^{-1}$
- Good (pop. synth based): $\sim 3\times10^{5}\,yr^{-1}$
- Low (pessimistic): 10-100 yr^{-1}

  Local rates will be known with Advanced LIGO/VIRGO.

ET stellar BHBH science

Probing the star formation of massive star to z=8

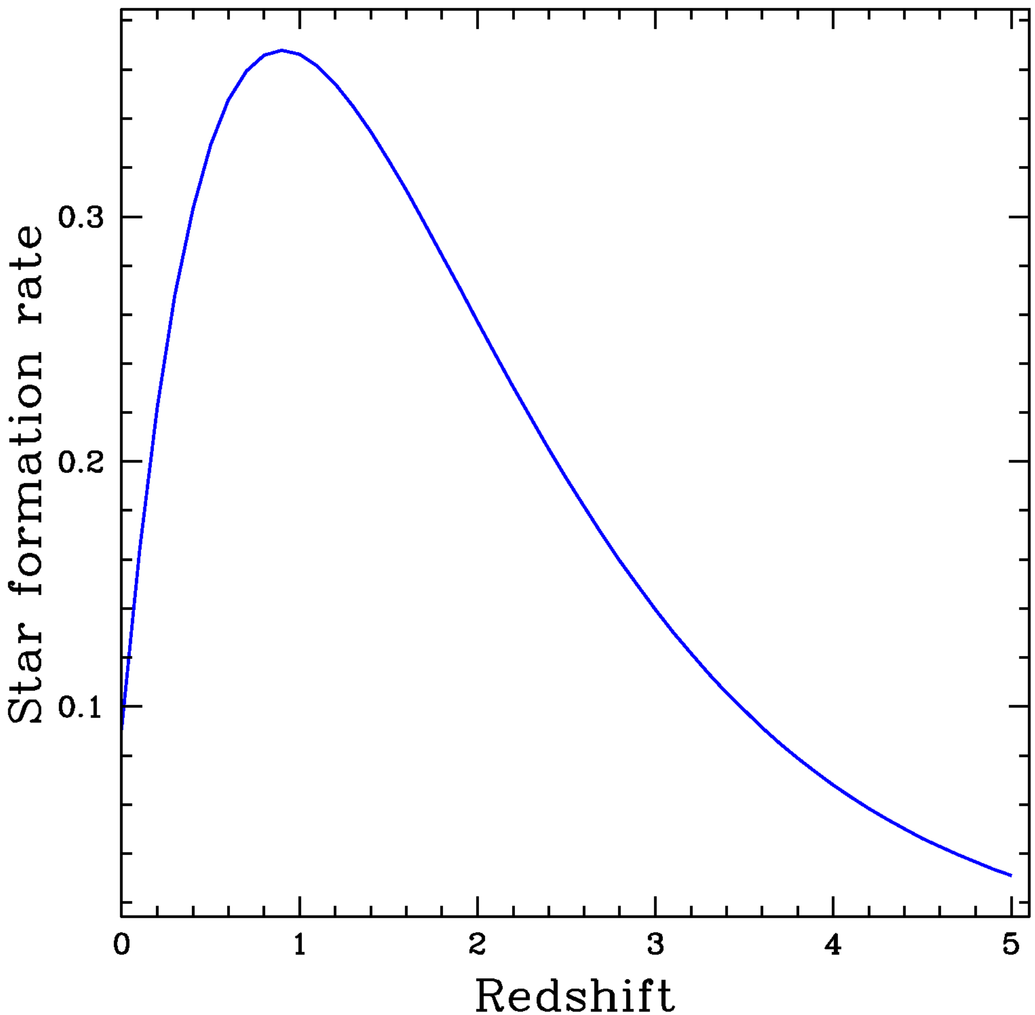
Tracing the evolution of BH masses

Rate carries little information: it is like Drake equation

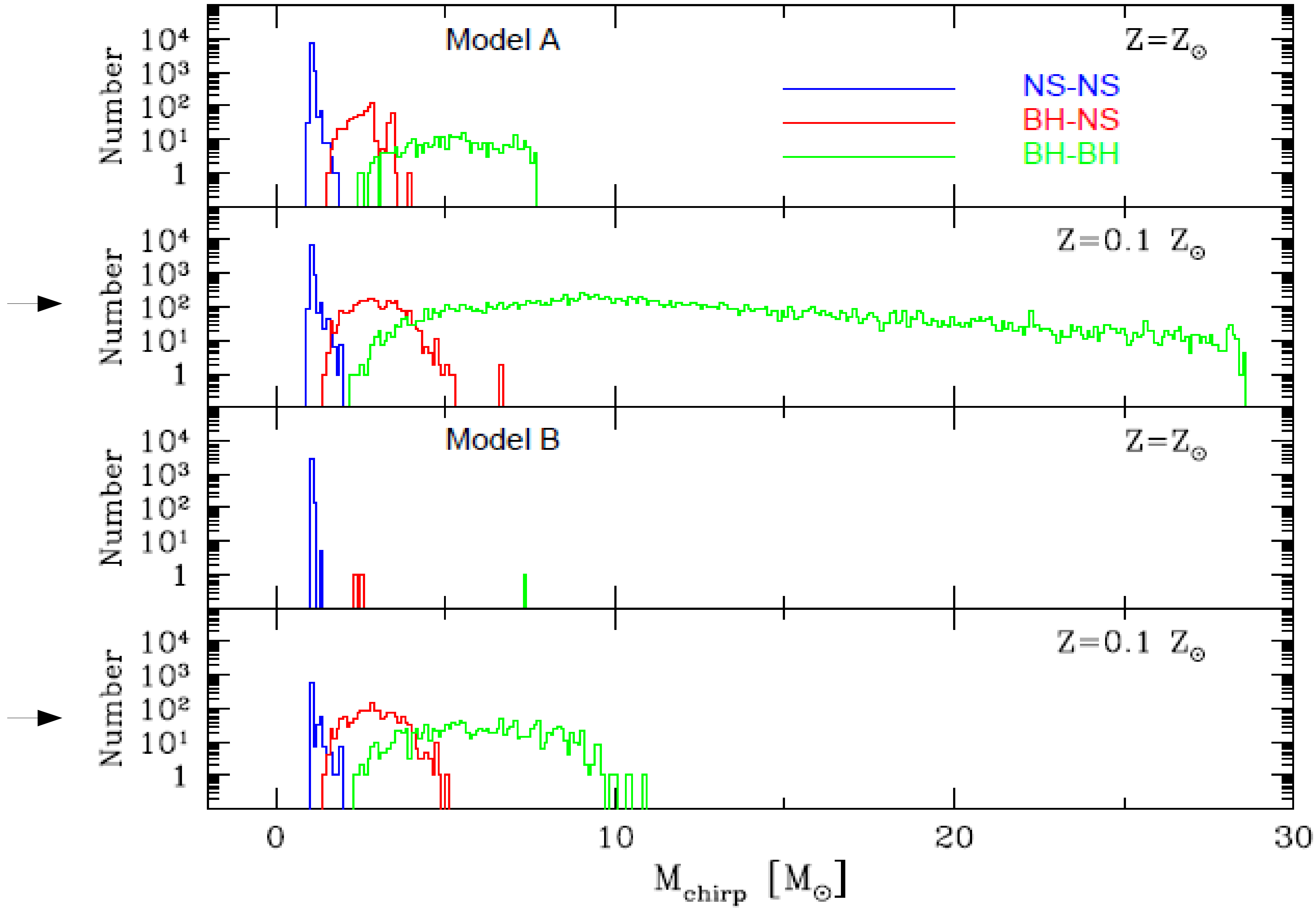
Distributions of masses and distances allows to study high mass stellar evolution in the very early Universe

A toy model

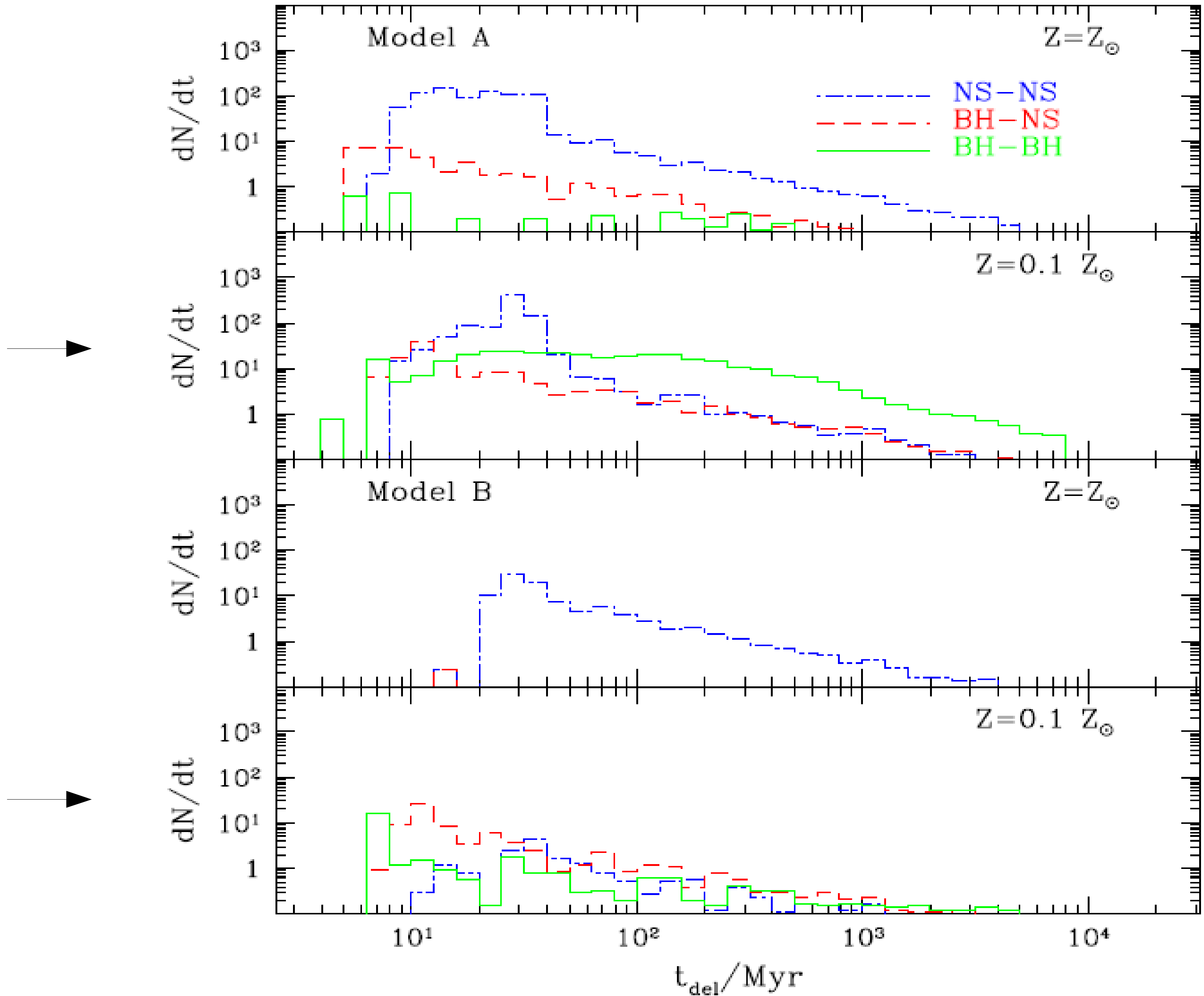
- Metallicity 0.1 solar, two cases: (not) surviving the crucial CE phase
- SFR model
- Delays from population synth.
- Model of ET



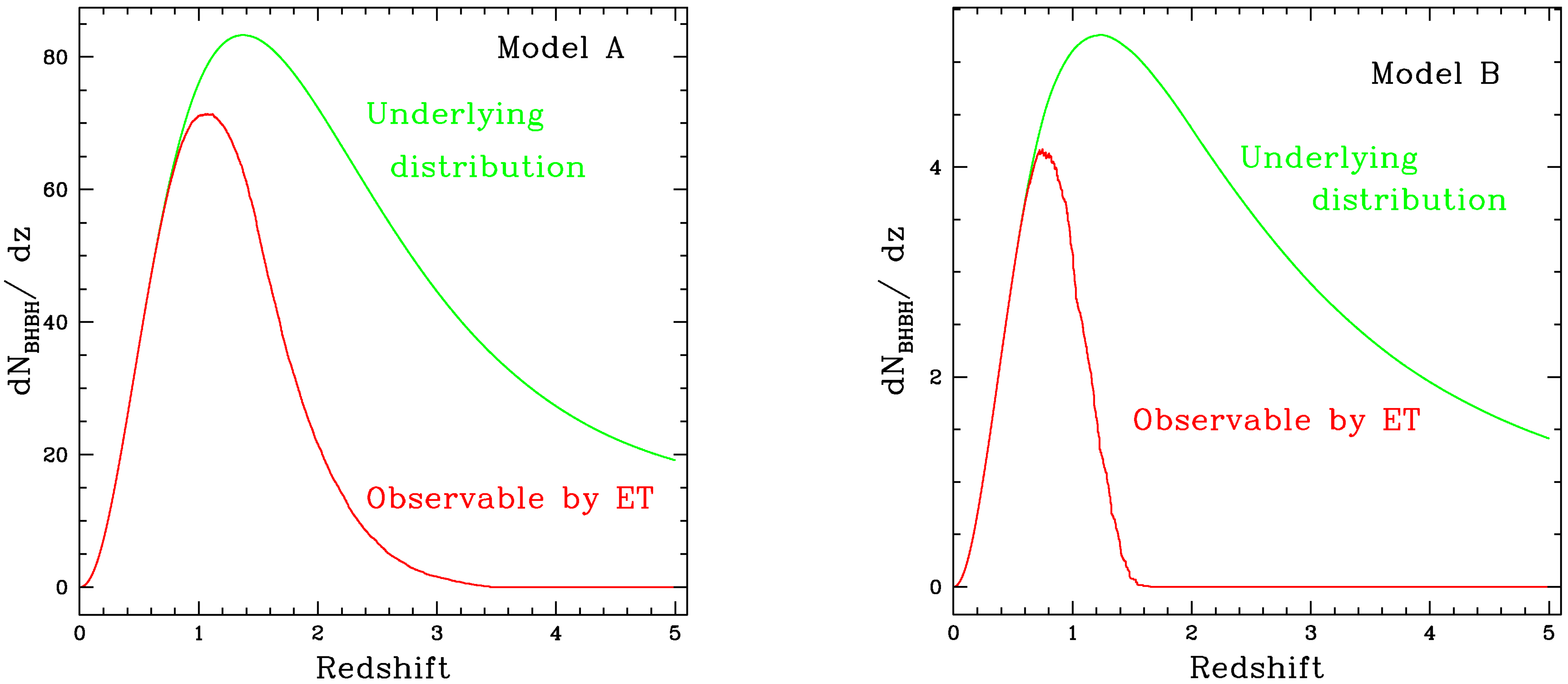
Chirp mass distribution



Delay distribution



BBH rates as function of z

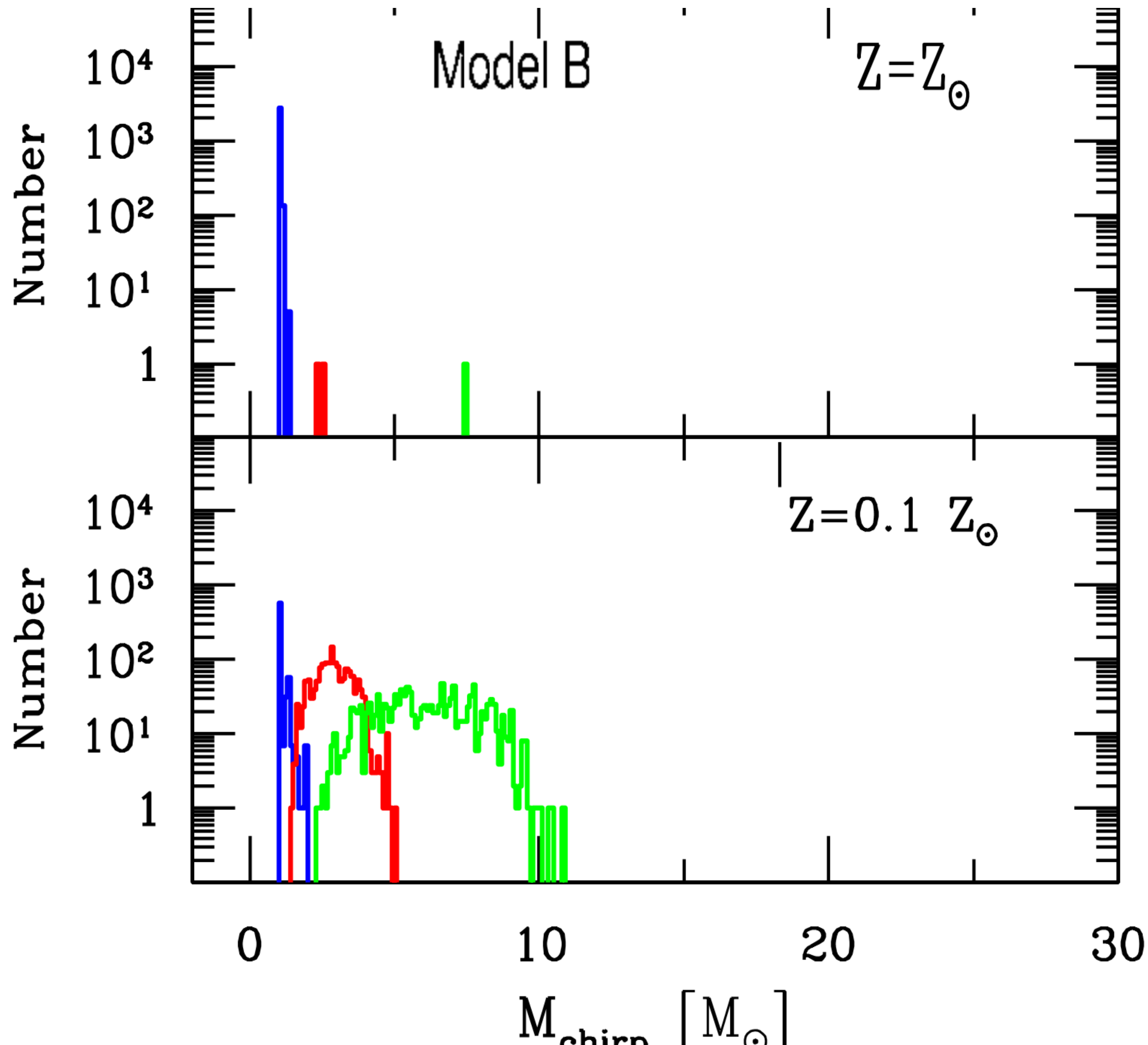


Summary

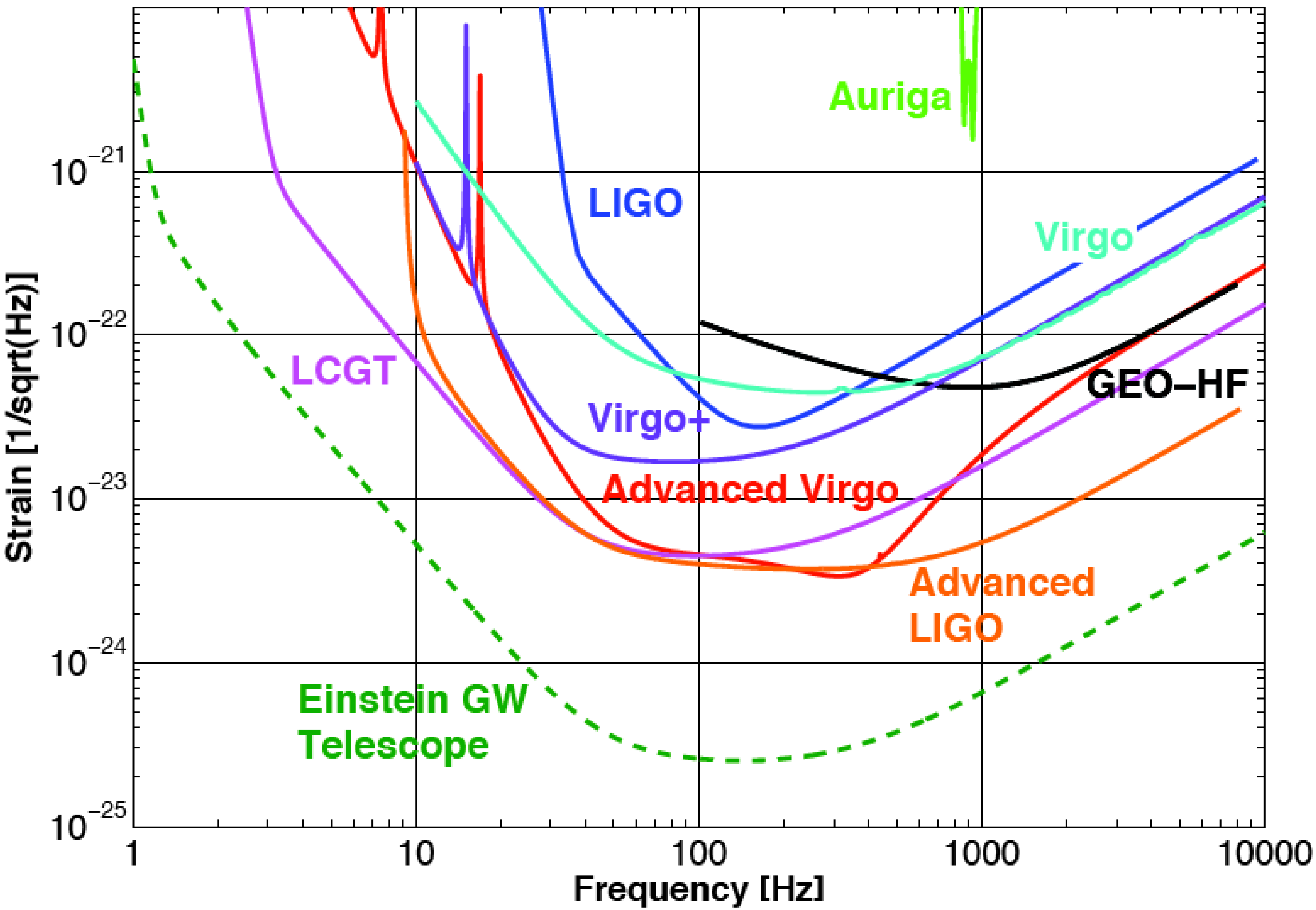
- Stellar BBH are very likely to exist - based on population synthesis and observations
- Rates may be quite high, and LIGO/VIRGO results will guide us
- ET will provide a tool to systematically probe the massive star evolution to high redshifts
- I have not touched the Population III binaries

To be continued...

Expected chirp mass distribution



Sensitivity



From Sathya's talk

ET coalescence rate calculation

- Star formation rate: peaks at z=1-2,
- Metallicity evolution: it is not z single valued function, but a distribution evolving in time
- What we need is combined star formation and metallicity evolution as function of redshift
- Evolution of delay times between formation and coalescence.
- What is the maximum radius where coalescences occur?