Probing Light Seeds of Massive Black Holes with Gravitational Waves

Ilya Mandel (Northwestern)
Jonathan Gair (Cambridge), Alberto Sesana (PSU), Alberto Vecchio (U. B'ham)

Sesana, Gair, IM, Vecchio: ApJL 698 129 (2009), arXiv:0903.4177
+ Gair, IM, Sesana, Vecchio - in print

Marcel Grossman 12, Paris, 15/07/2009

Seeds of massive black holes

- Galactic black holes grow via two mechanisms: 1) accretion, 2) BH mergers following halo / galaxy mergers.
- First generation of black holes probably created by collapse of very massive, zero metallicity “population III” stars.
- There are various freedoms in galaxy merger models
  - Seed black hole masses
  - Seed black hole abundance
  - Seed black hole formation mechanism
  - Massive black hole accretion prescription
- Different models predict very similar event rates for massive BH mergers detected by LISA. If seeds are light, a detector in the 1-50Hz range could detect first epoch of mergers.

Computing Merger Rates

- Construct semi-analytic merger trees by following mergers of dark matter halos (e.g., Volonteri, Haardt & Madau 2003).

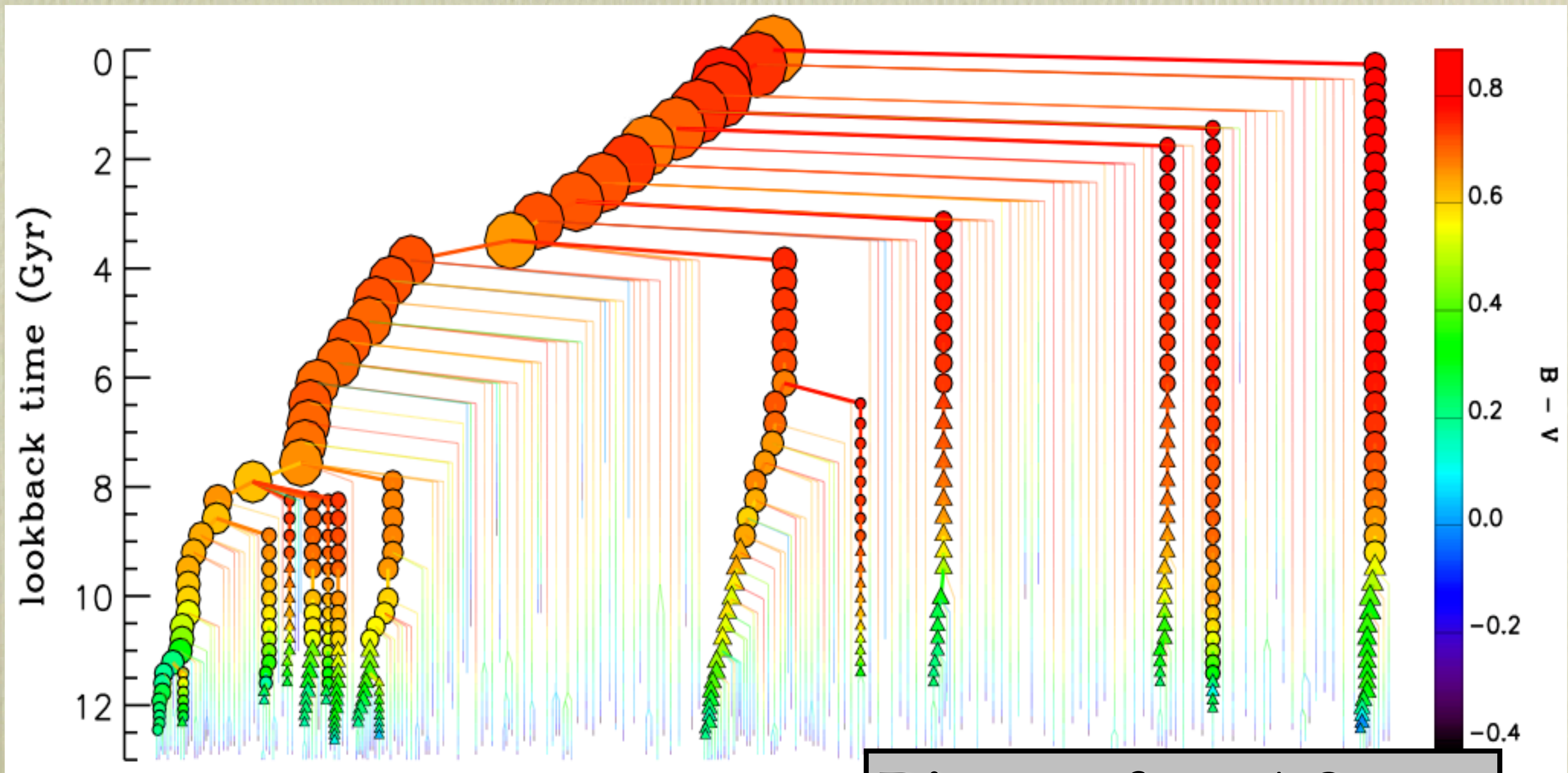
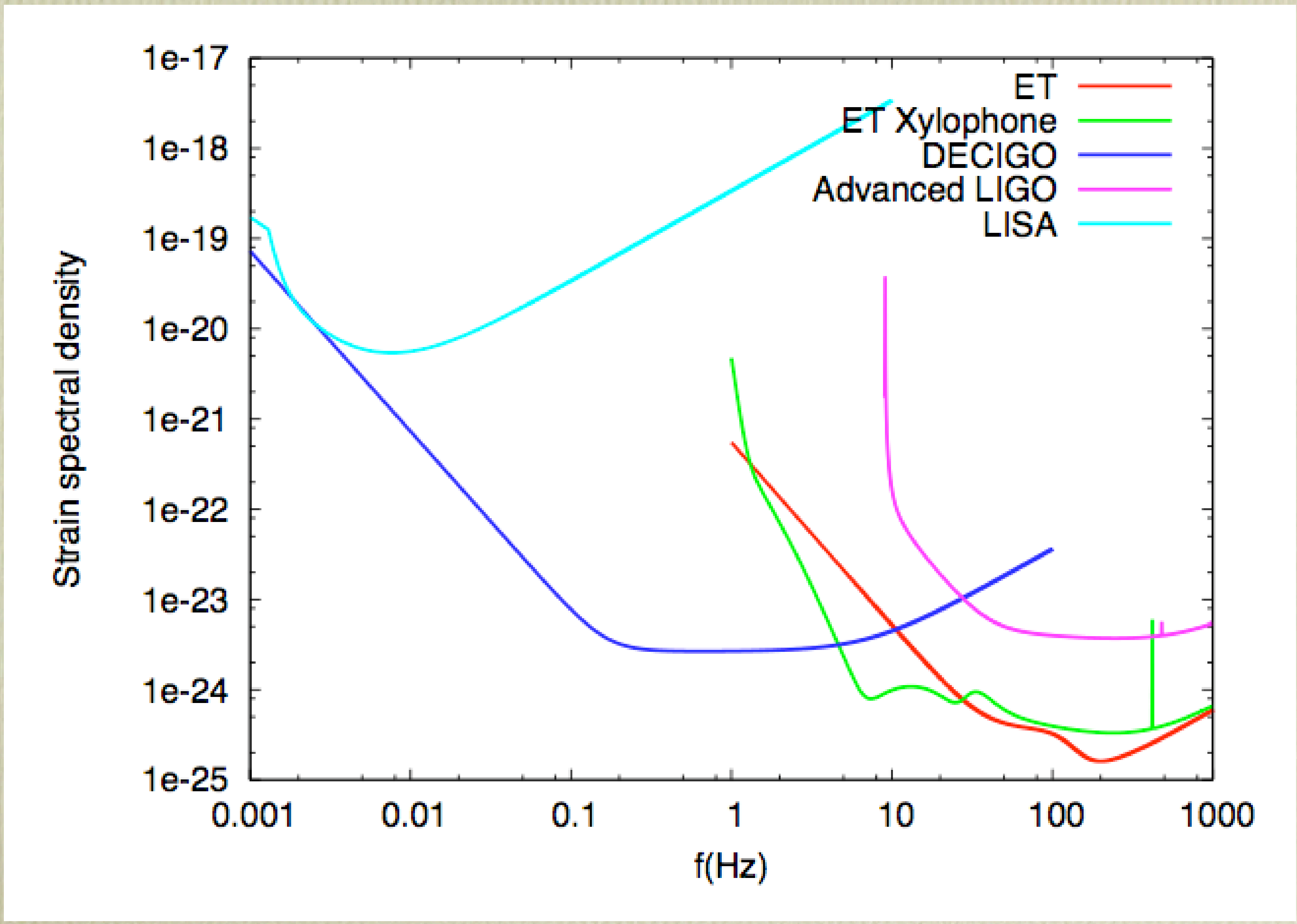


Diagram from A Sesana

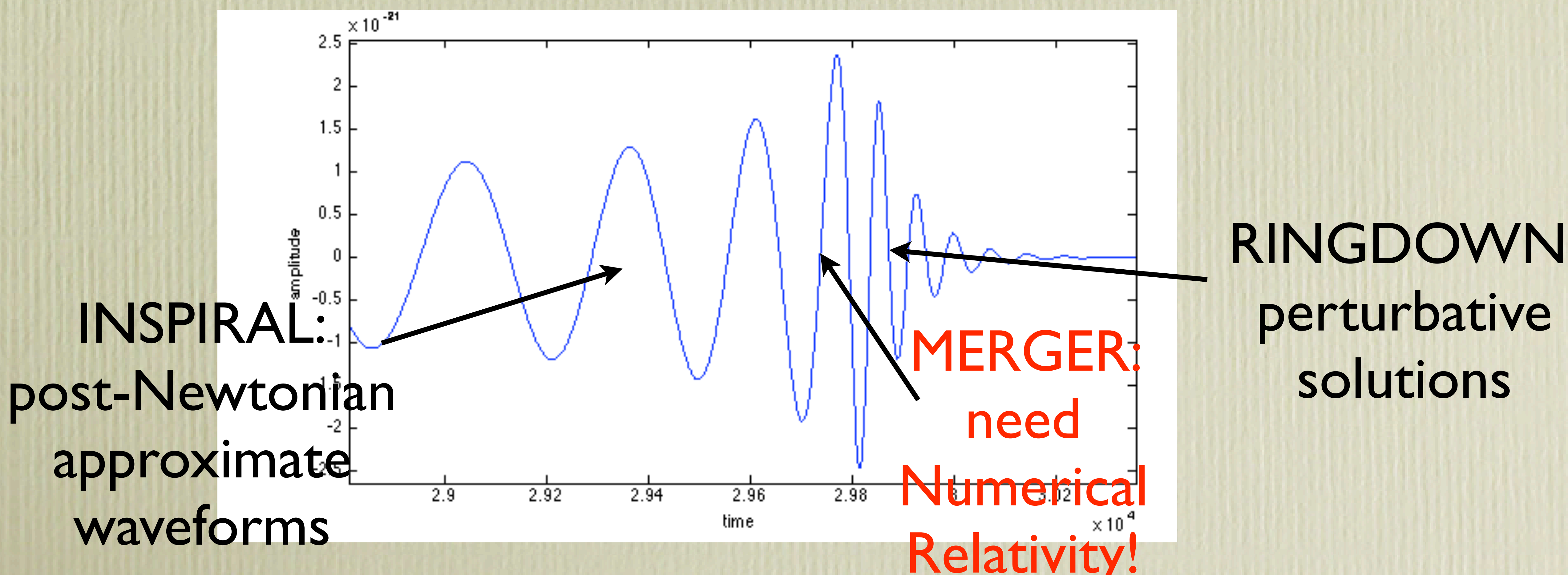
Proposed Detector Sensitivity



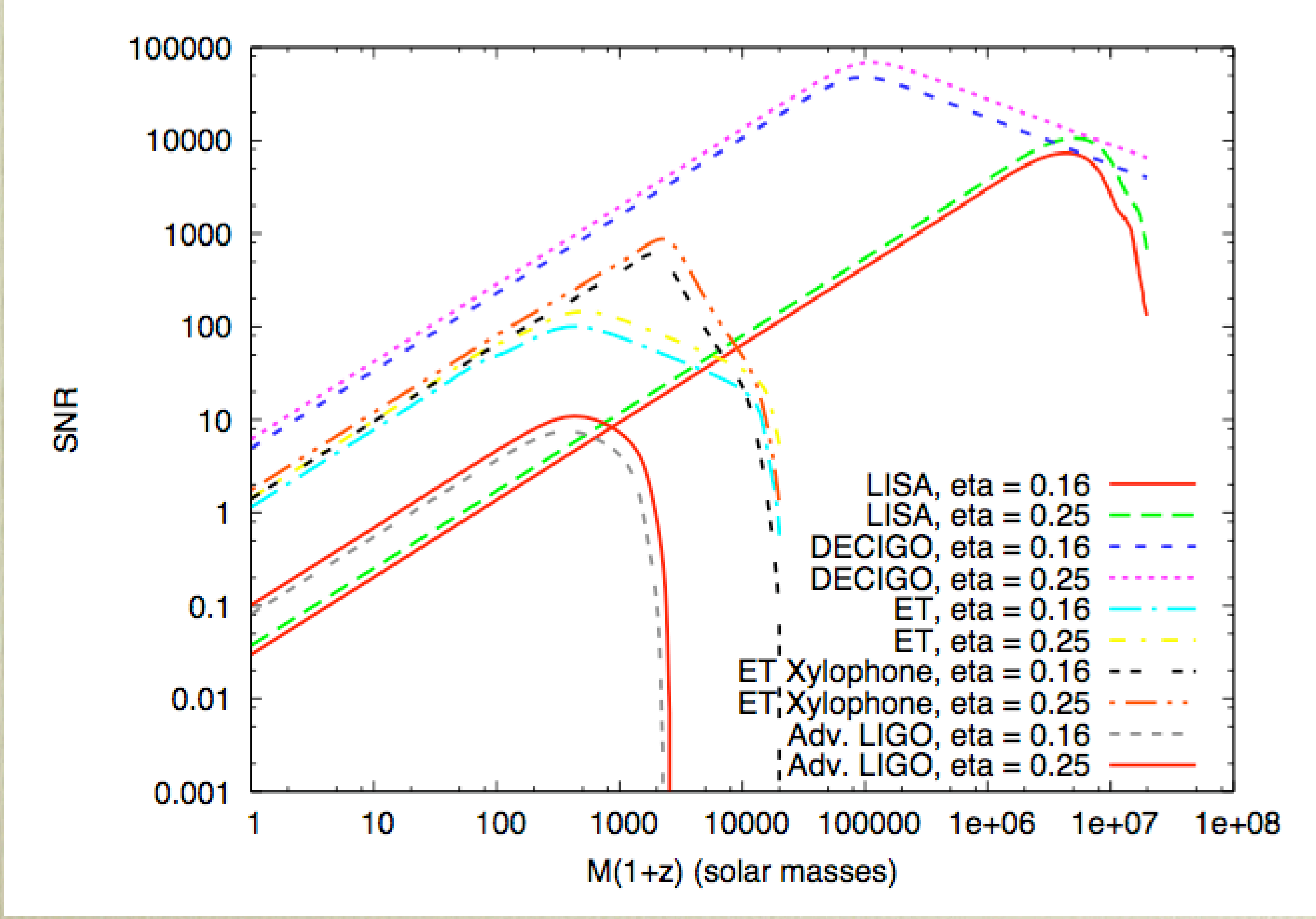
Event Rate Calculation

- Estimate event rates using galaxy merger trees. Assume BH seeds form in 3.5σ density peaks at z=20. Use four different models for mass distribution and accretion history.

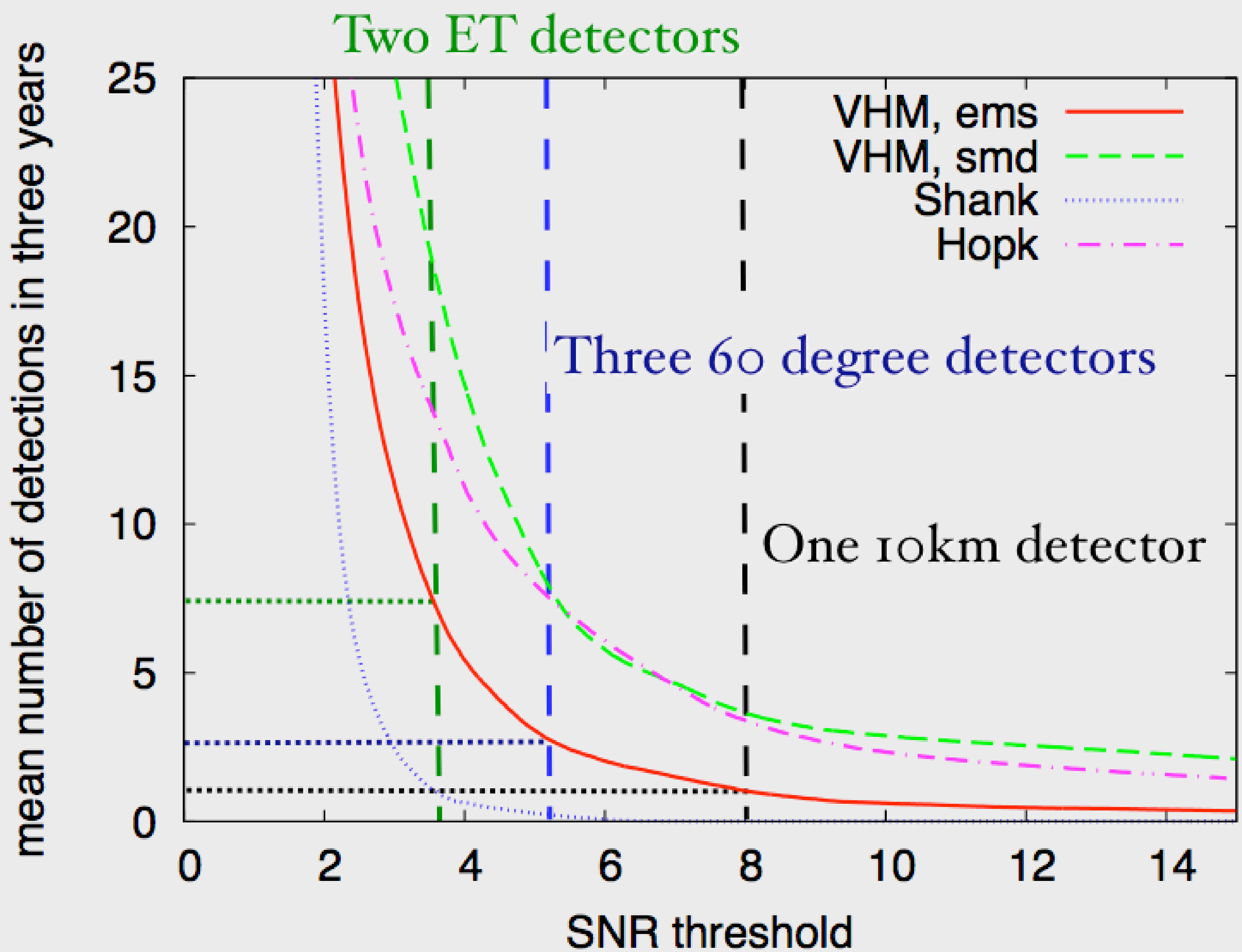
- Compute SNRs using the inspiral/merger/ringdown waveform model of Ajith et al. (2008). Average over positions and orientations. Assume threshold network SNR of 8 for detection.



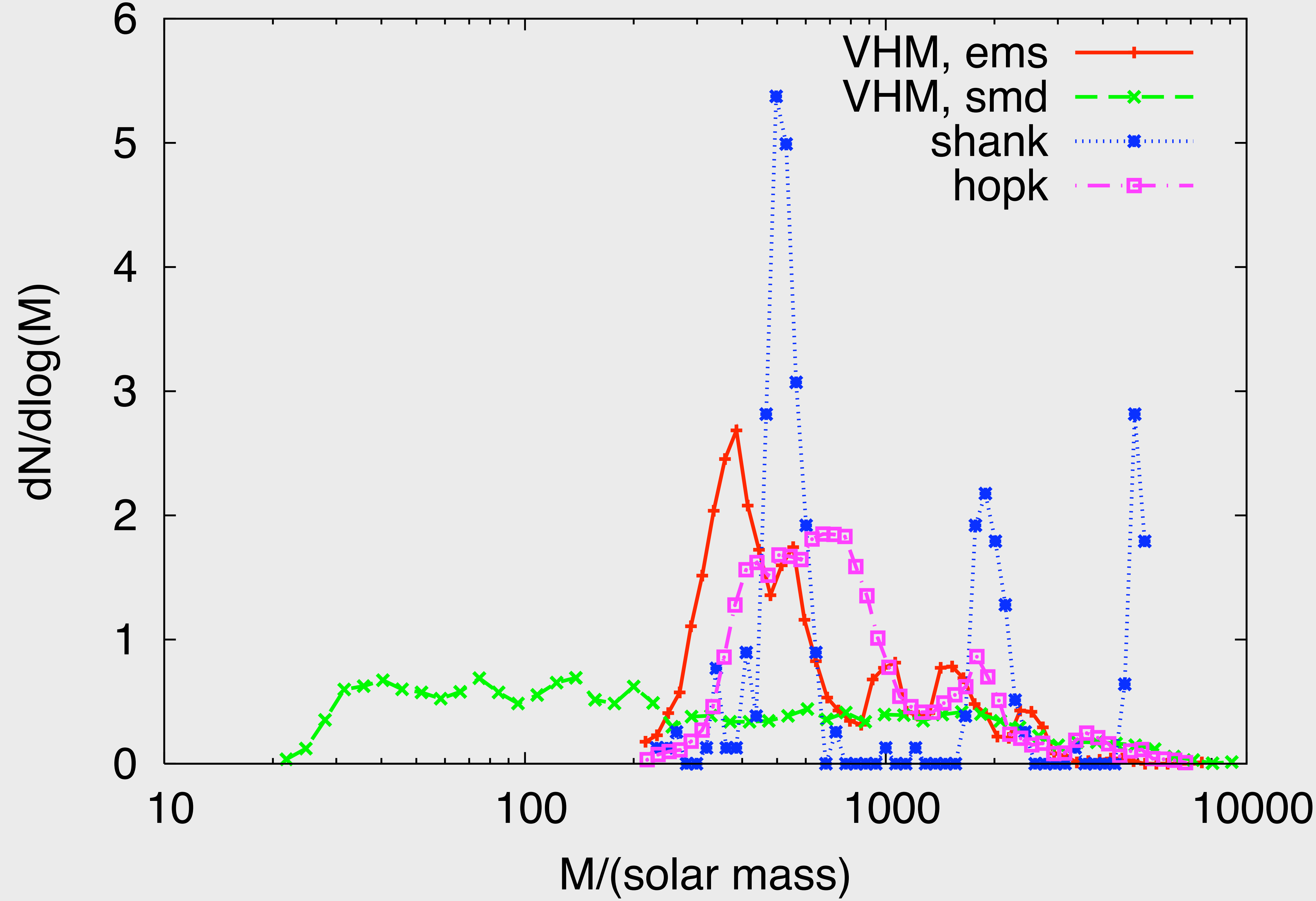
Signal-to-noise Ratios



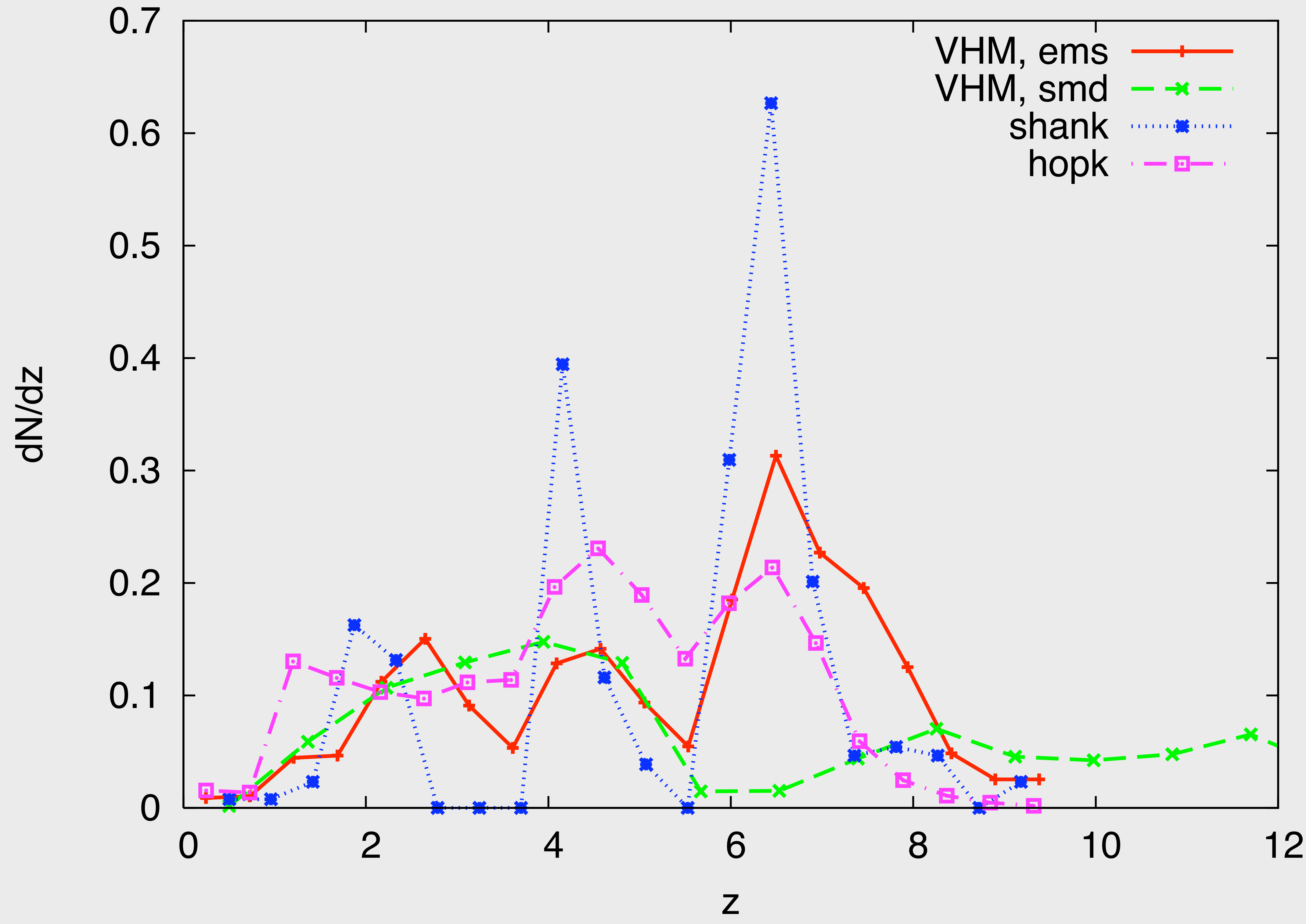
ET event rate



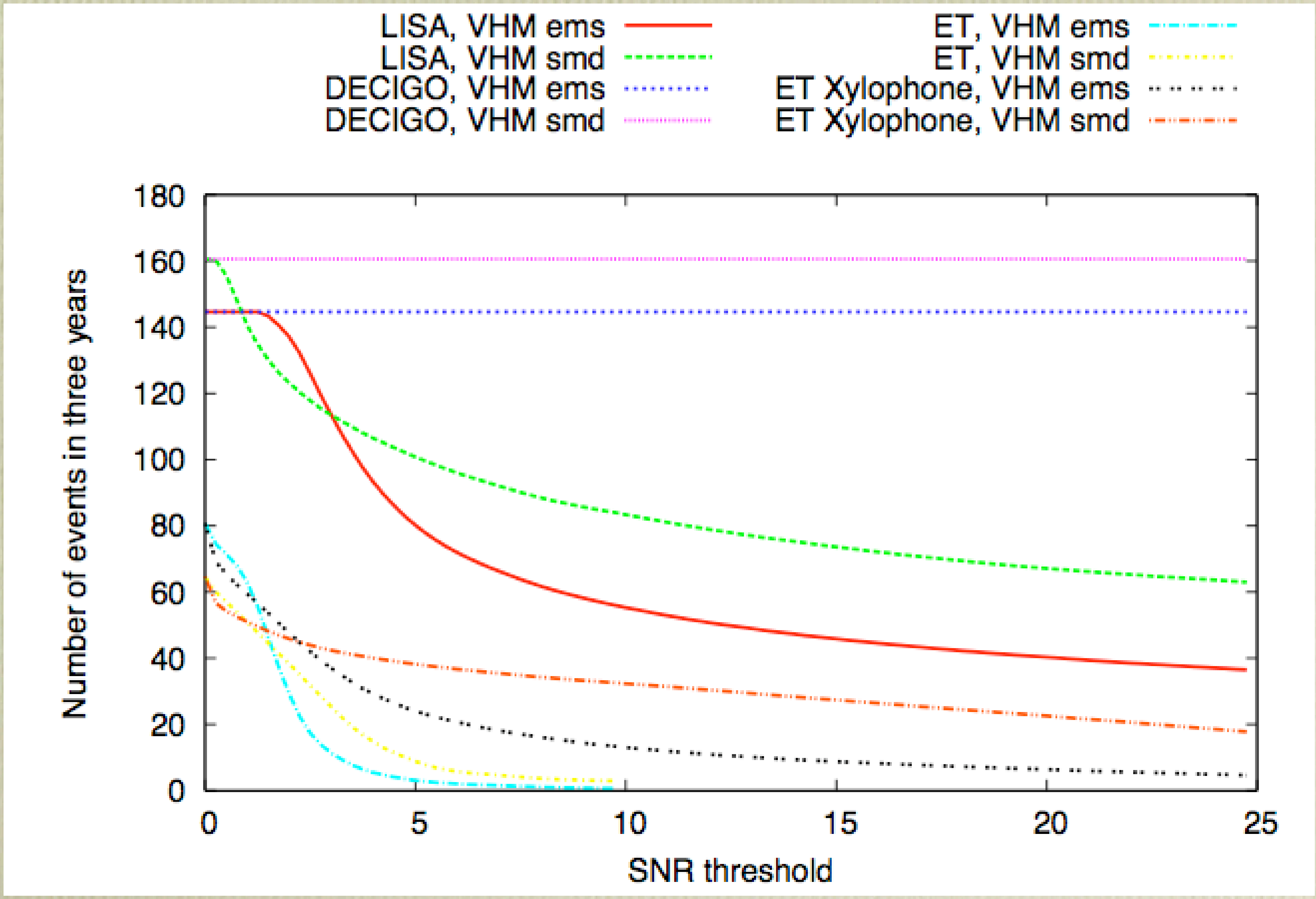
ET event mass distribution



ET event redshift distribution



Event rate comparisons



Parameter estimation accuracy

- Can compute parameter estimation accuracy using Fisher Matrix formalism.

$$\Gamma_{ij} = \langle \frac{\partial \mathbf{h}}{\partial \lambda_i} | \frac{\partial \mathbf{h}}{\partial \lambda_j} \rangle$$

- Waveform depends also on several extrinsic parameters - distance, sky position and source orientation $D_L, \theta_S, \phi_S, \theta_L, \phi_L$, plus initial phase ϕ_0 .

- Have at most two independent coplanar and colocated detectors - four measurements for six parameters. One detector cannot provide enough information to measure distance.

- Assume another detector exists and estimate ability of network to measure parameters.

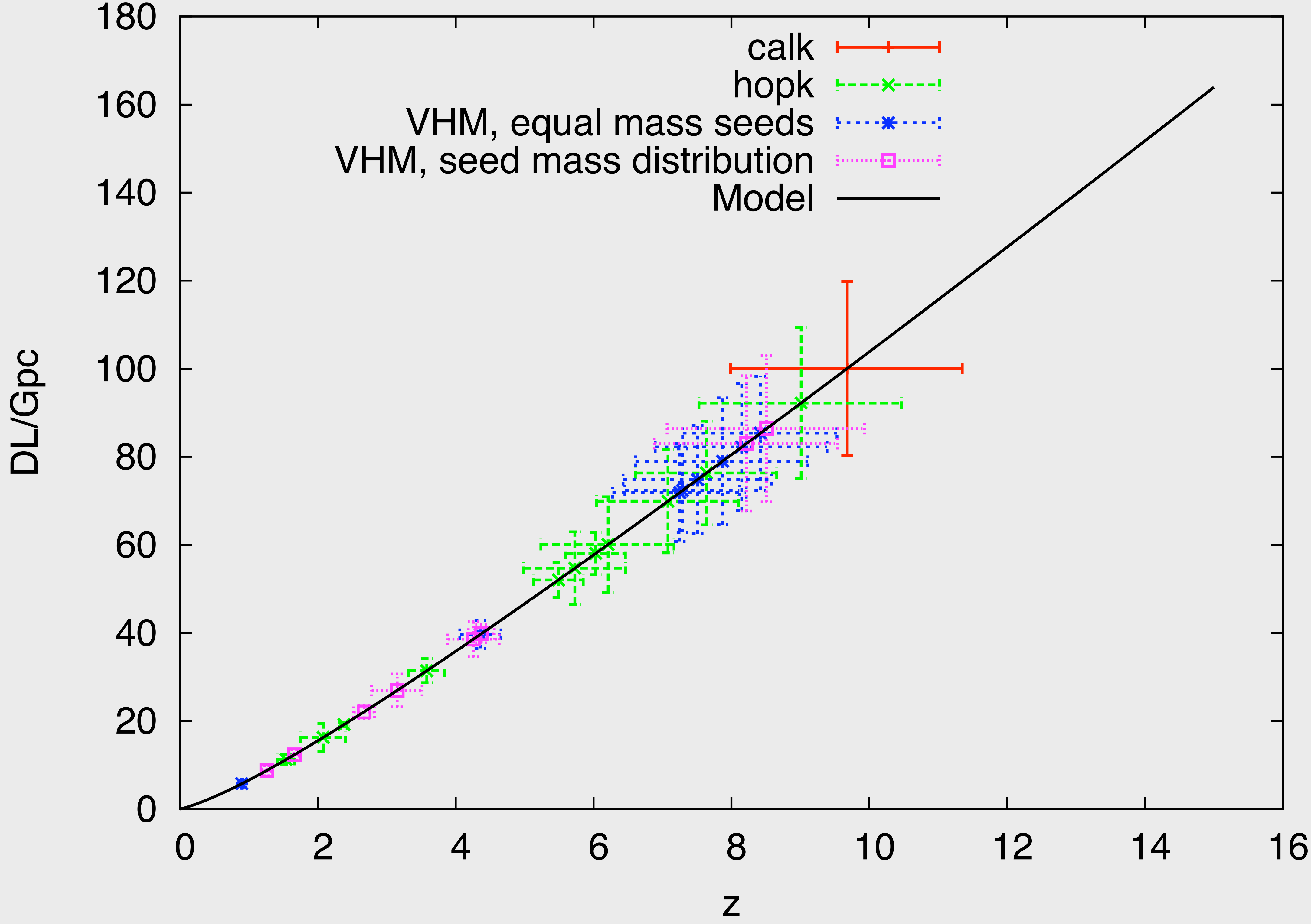
ET Network Parameter Errors

- Assuming two ETs at geographic locations of VIRGO and LIGO Hanford, the network returns typical errors:

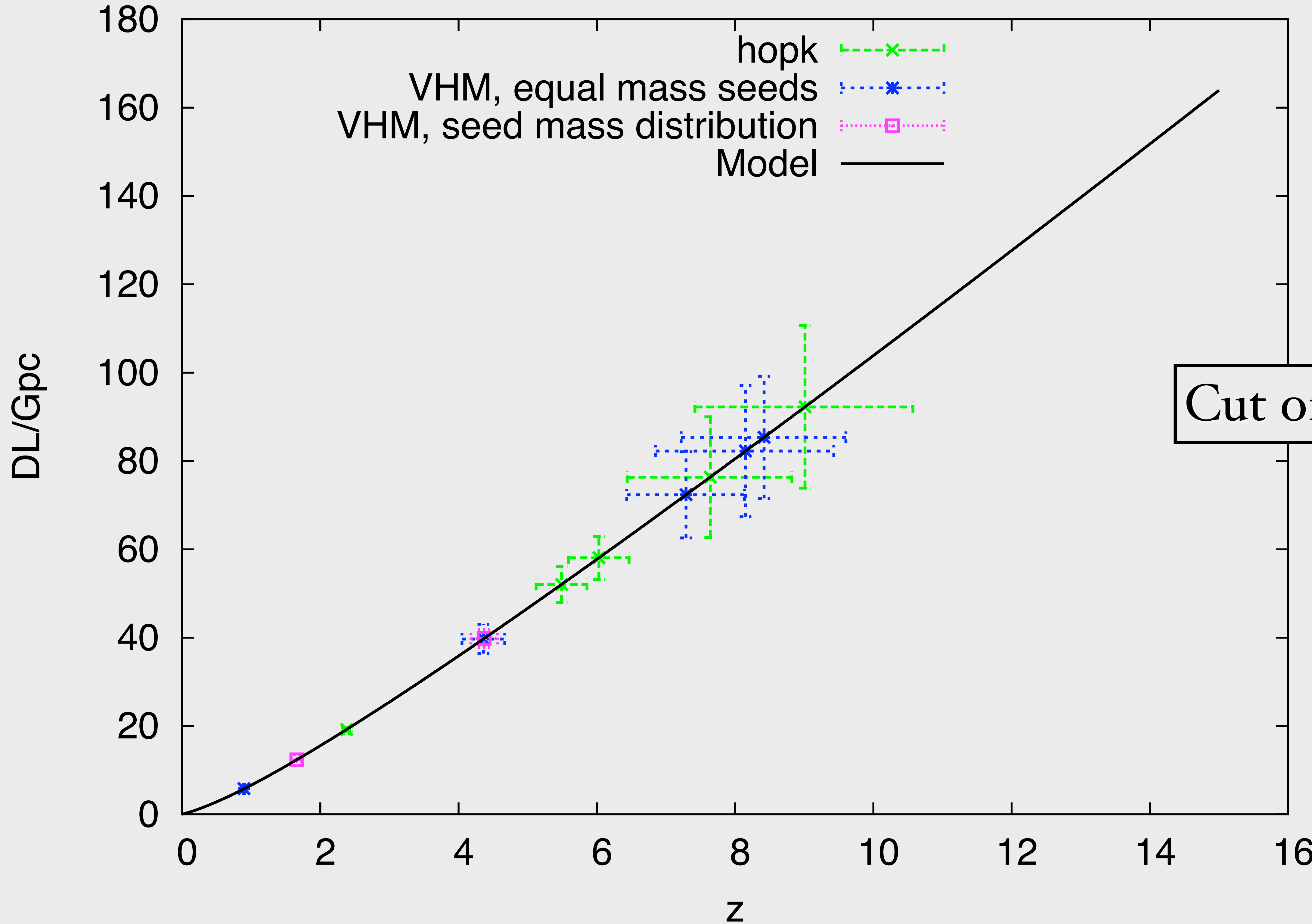
$(1+z)M_{\rm tot}$	η	$\Delta(\ln M_z)$	$\Delta(\ln \eta)$	$\Delta(\ln D_L)$
100	0.25	0.2%	0.06%	15-30%
100	0.15	0.1%	0.05%	15-30%
500	0.25	0.1%	0.1%	15-30%
500	0.15	0.8%	0.4%	15-50%
1000	0.25	0.3%	0.1%	15-50%
1000	0.15	2%	1%	15-50%

- First column is the redshifted mass, and all events have been renormalised to a network SNR of 8. With three ET detectors, errors are roughly the same for the same network SNR.

ET event error bars



ET events - effect of low-f cutoff



Cut off at 5Hz

ET discovery space

- If seed BHs do not come from pop III stars, or the initial accretion epoch is very rapid, ET may not see any light progenitors of massive BHs (but LISA will see the massive BHs regardless). ET probes this seed population directly.
- **Number of events**: we only probe the tip of the population. However, a lot (10-20) of events at $z>10$ will tell us BH formation is much more efficient than most models assume.
- **Masses**: tell us about seed mass distribution (currently unknown), and early accretion history of pop III black holes.
- **Redshift distribution** is very important. Events at $z > 7$-8 must be pop III remnants. Events at $z < 5$ may come from IMBHs formed in globular clusters (**IM**, Brown, Gair & Miller ApJ **681** 1431 (2008)). Excess of events at low redshift may probe cluster mergers.