LISA to NGO - consequences for EMRI rates and science

Jonathan Gair (IoA, Cambridge)

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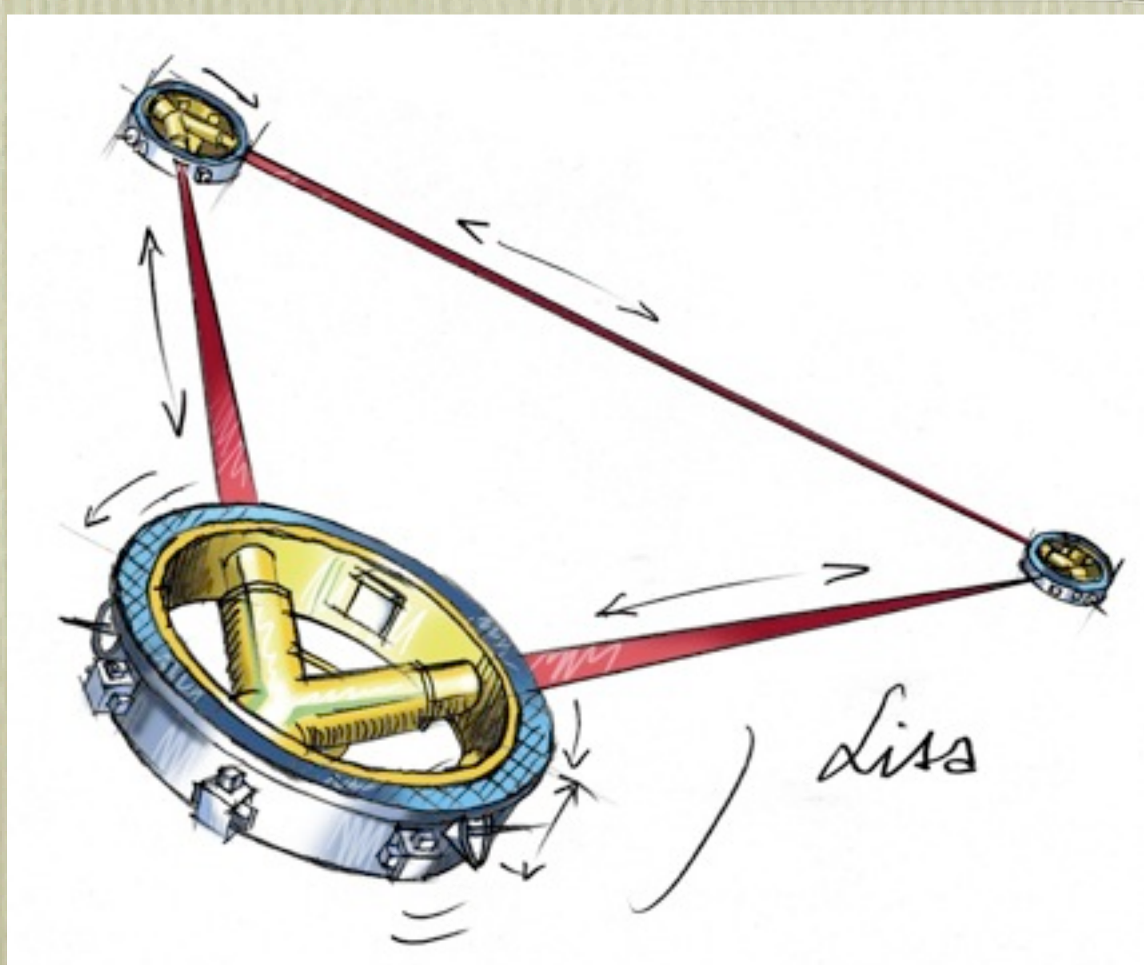

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NASA funding crisis

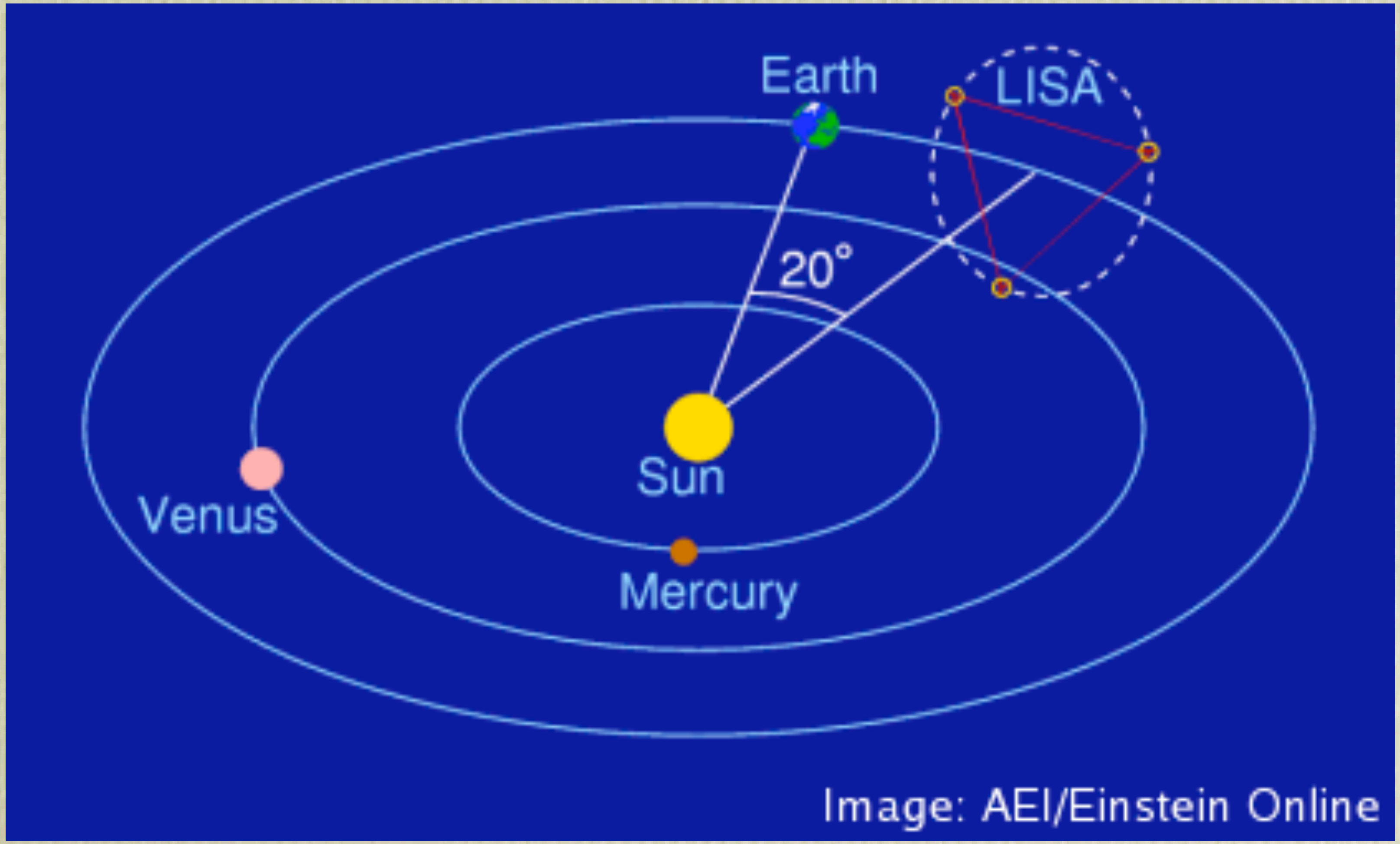
- In April 2011, due to funding shortages and cost overruns of JWST, NASA announced that it would no longer be able to contribute to the joint L-class mission with ESA scheduled for the end of this decade (~2018).
- Three missions in competition for this slot
  - **LISA** - space-based gravitational wave observatory.
  - **IXO** - X-ray mission (formerly Zeus and Constellation X).
  - **Laplace** - planetary mission to Jupiter; two probes, one that would visit Europa and one Ganymede.
- ESA's response was to withdraw from its commitment to a joint mission, and pursue ESA-only mission concepts for each project.

ESA L-class Competition

- Goal: fly a large space observatory by 2012.
- Budget: 850 million Euros + contributions from nation agencies.
- Gravitational mission concept given the working title **New Gravitational Observatory (NGO)**, no official name yet.
- Classic LISA design would have cost ~1.3 billion Euros. Need to propose a new design within the tighter budget cap.
- Various components to a mission where costs can be reduced
  - **Launcher** - use (several) Soyuz, rather than an Ariane.
  - **Propellant** - closer orbit, shorter mission lifetime.
  - **Spacecraft/Payload** - reduce size and weight of the satellites.

NGO Design Study

- The design study has explored various elements of the LISA/NGO design in order to develop the proposal.
- **Orbits**
  - **LISA-like** - heliocentric, Earth-trailing at 10-20 degrees. Different armlengths.



NGO Design Study

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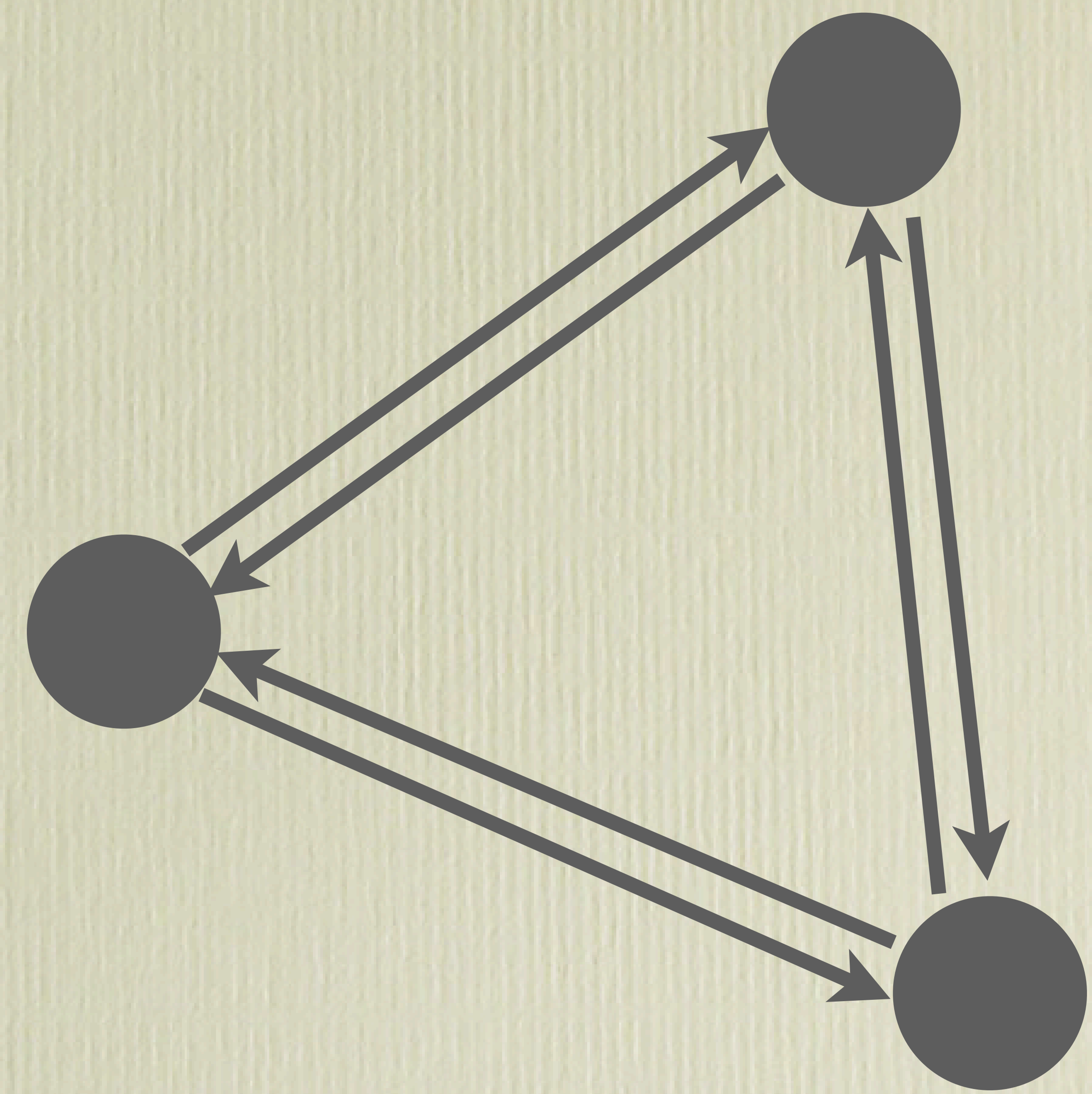
- **Orbits**
  - **LISA-like** - heliocentric, Earth-trailing at 10-20 degrees. Different armlengths.
  - **Halo** - now rejected as not long-term stable.
- **Laser power** - reduced power reduces weight, increases noise.
- **Telescope diameter** - smaller telescope reduces size/weight.
- **Inertial system** - LISA design target (DRS) or LISA Pathfinder model (LPF) - already space-qualified.
- Different elements not independent. Low laser power/smaller telescope requires shorter arms.

4-link versus 6-link

- Baseline LISA proposal called for **three** identical spacecraft, linked with **six** laser links, **two** along each arm. Response equivalent to **two** independent right-angle Michelson interferometers.



4-link versus 6-link

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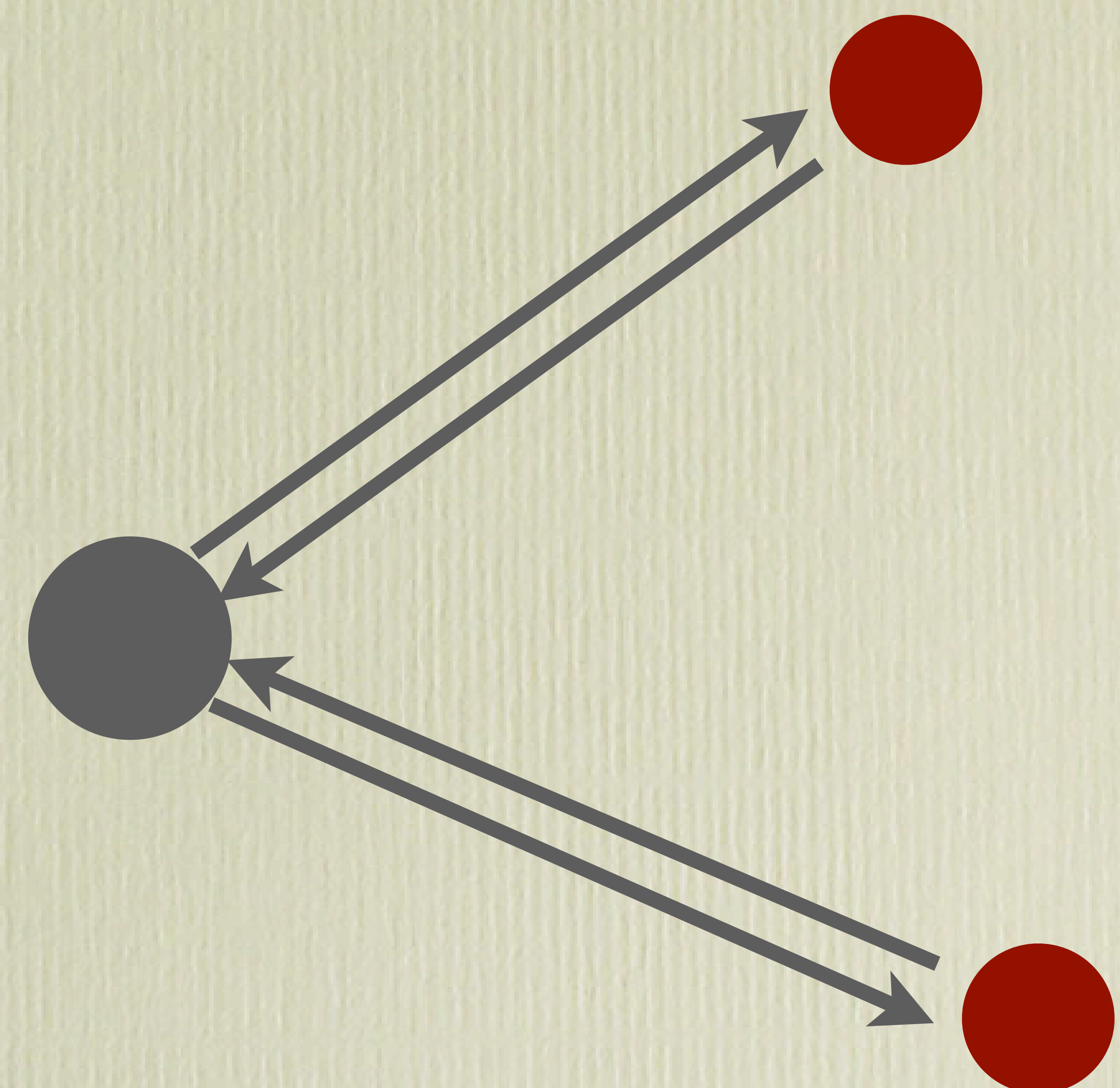
- Also consider a **mother-daughter** configuration, with only **four** laser links and equivalent response to **one** Michelson.

- Possible launch configuration: two Soyuz launchers - one with mother, one with daughters.

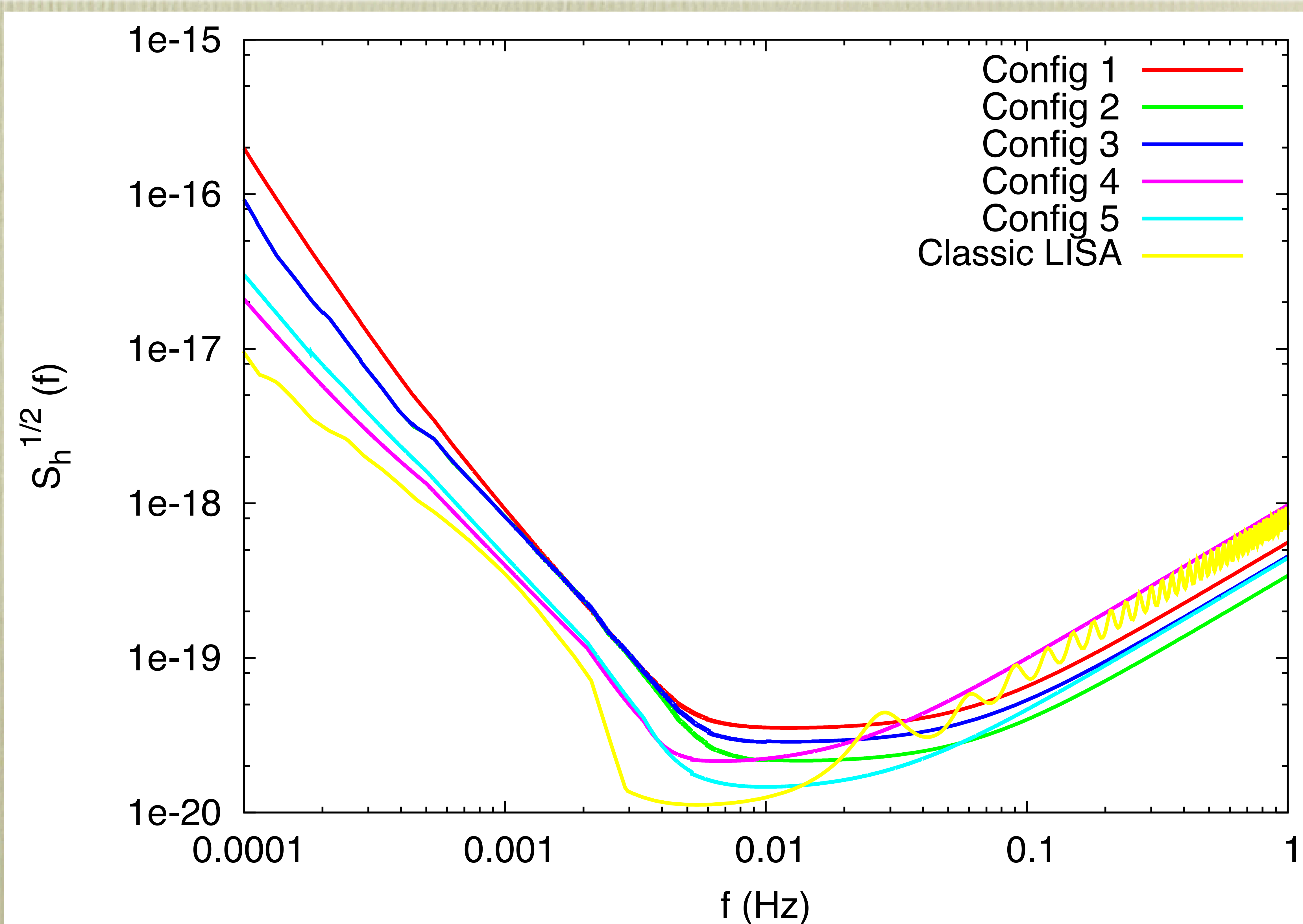


NGO Configurations

	Most Pessimistic		New Baseline		Most Optimistic
	C1	C2	C3	C4	C5
Orbits	LISA, 9°	LISA, 10°	LISA, 10°	LISA, 10°	LISA, 10°
Laser	0.05W	2W	0.7W	0.7W	2W
Telescope	0.4m	0.4m	0.25m	0.25m	0.28m
Inertial Sys	LPF	DRS	DRS	DRS	DRS
Armlength	1×10^9m	1×10^9m	1×10^9m	3×10^9m	2×10^9m

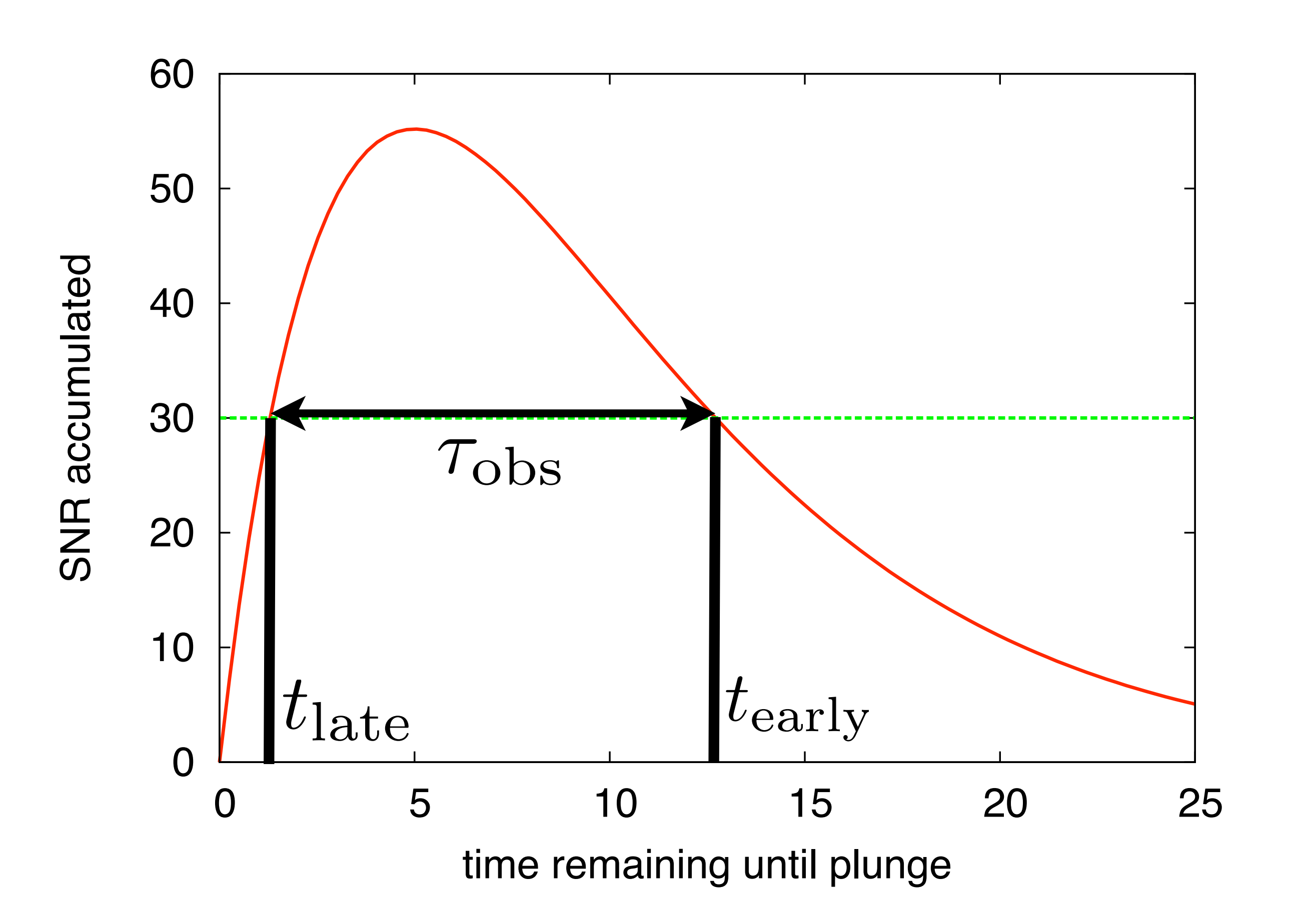
- Consider 6-link and 4-link configurations in each case.

NGO Sensitivity Curves



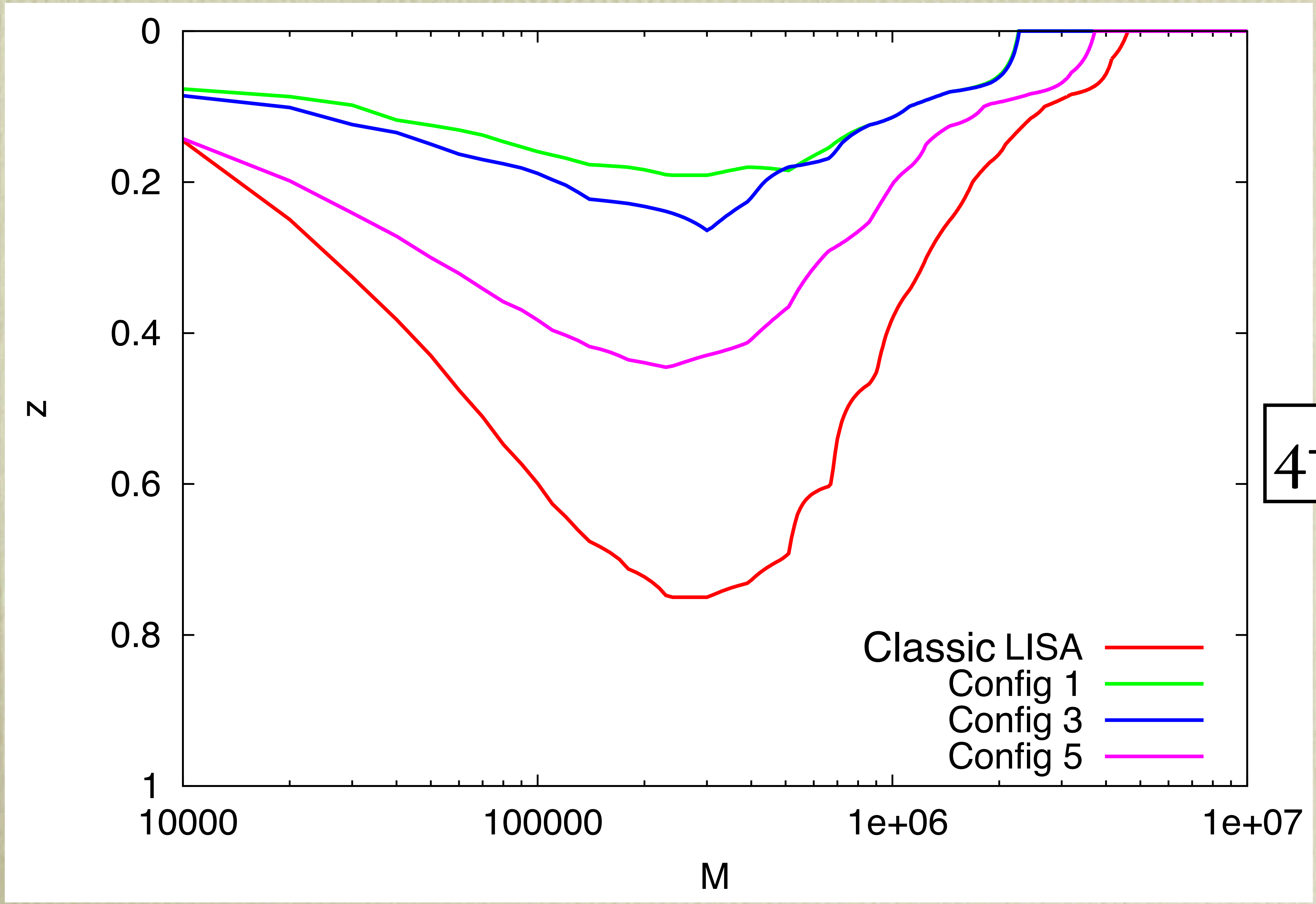
EMRIs - SNRs

- Characterise EMRI detectability in terms of the **observable lifetime**, t_{obs} - the length of time during which LISA could start taking data and event be observed with sufficient SNR.
- Rate of observed events is then t_{obs}/T, where T is the average time between plunges.
- Compute observable lifetimes for EMRIs in the LISA/NGO configurations using circular, equatorial Teukolsky fluxes. Take SNR detection threshold of 20.



EMRIs - SNRs

- Contours of constant observable lifetime, for 1 year, assuming all black holes are non-spinning.



4-link

EMRIs - SNRs

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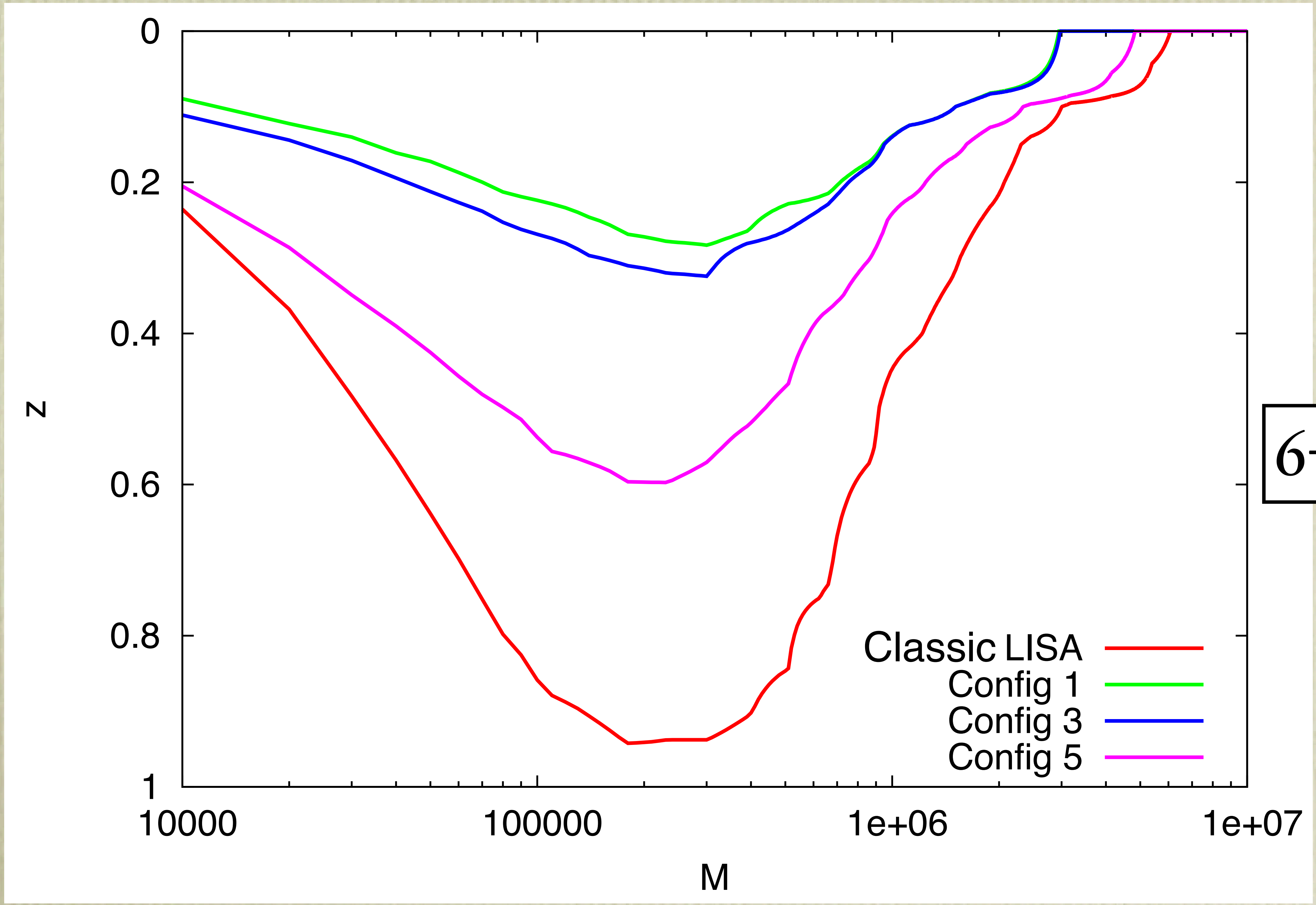
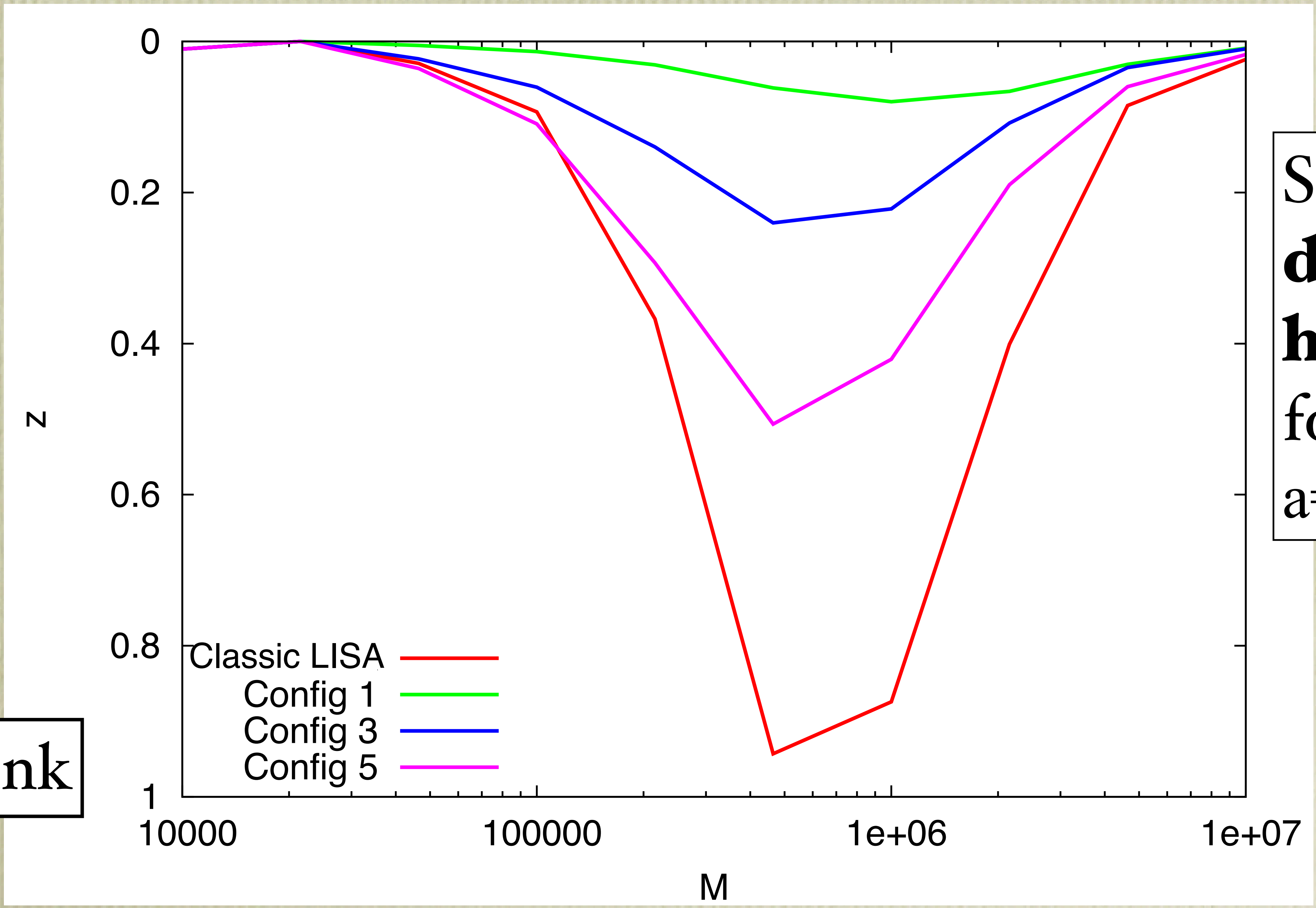


6-link

EMRIs - SNRs

- Compute SNRs using analytic kludge waveforms to include eccentricity and as a cross-check.



Showing **detection horizon** for e_p=0.25, a=0

4-link

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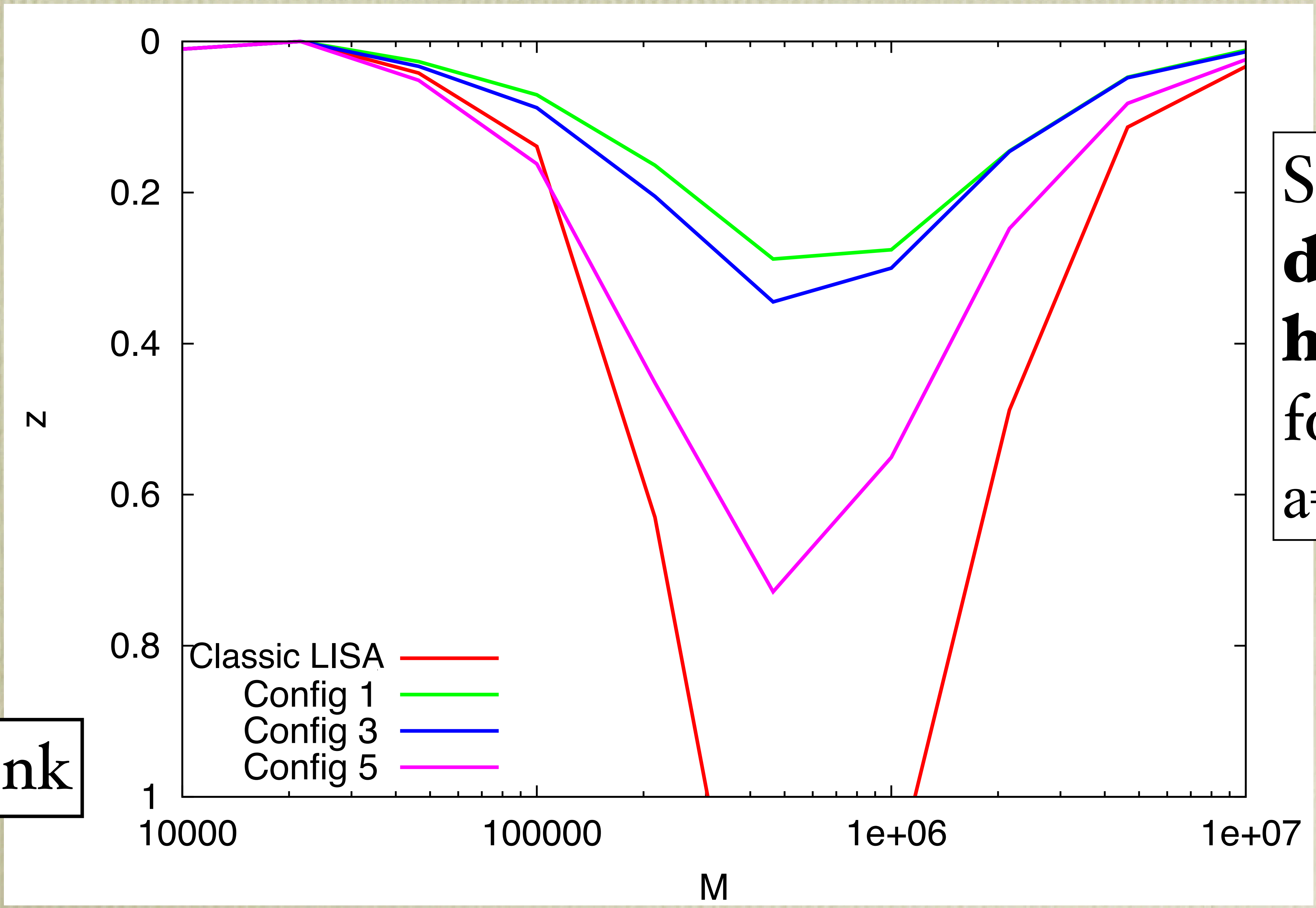


Showing **detection horizon** for e_p=0.25, a=0

6-link

EMRIs - Event Rates

- Estimate number and properties of LISA events by assuming
  - **Mass function of black holes** is flat in logarithm in the LISA range.

$$\frac{\mathrm{d}N}{\mathrm{d}\ln M} = 0.002\mathrm{Gpc}^{-3}$$

  - **EMRI rate per galaxy** has a simple power-law scaling with the mass of the central black hole.

$$\rho = 400\mathrm{Gyr}^{-1}\left(\frac{M}{3\times 10^{6} M_{\odot}}\right)^{-0.15}$$

  - **EMRI orbits are circular and equatorial**, so we can use the Teukolsky results. Assume all black holes have the same spin, a = 0, 0.5, 0.9.

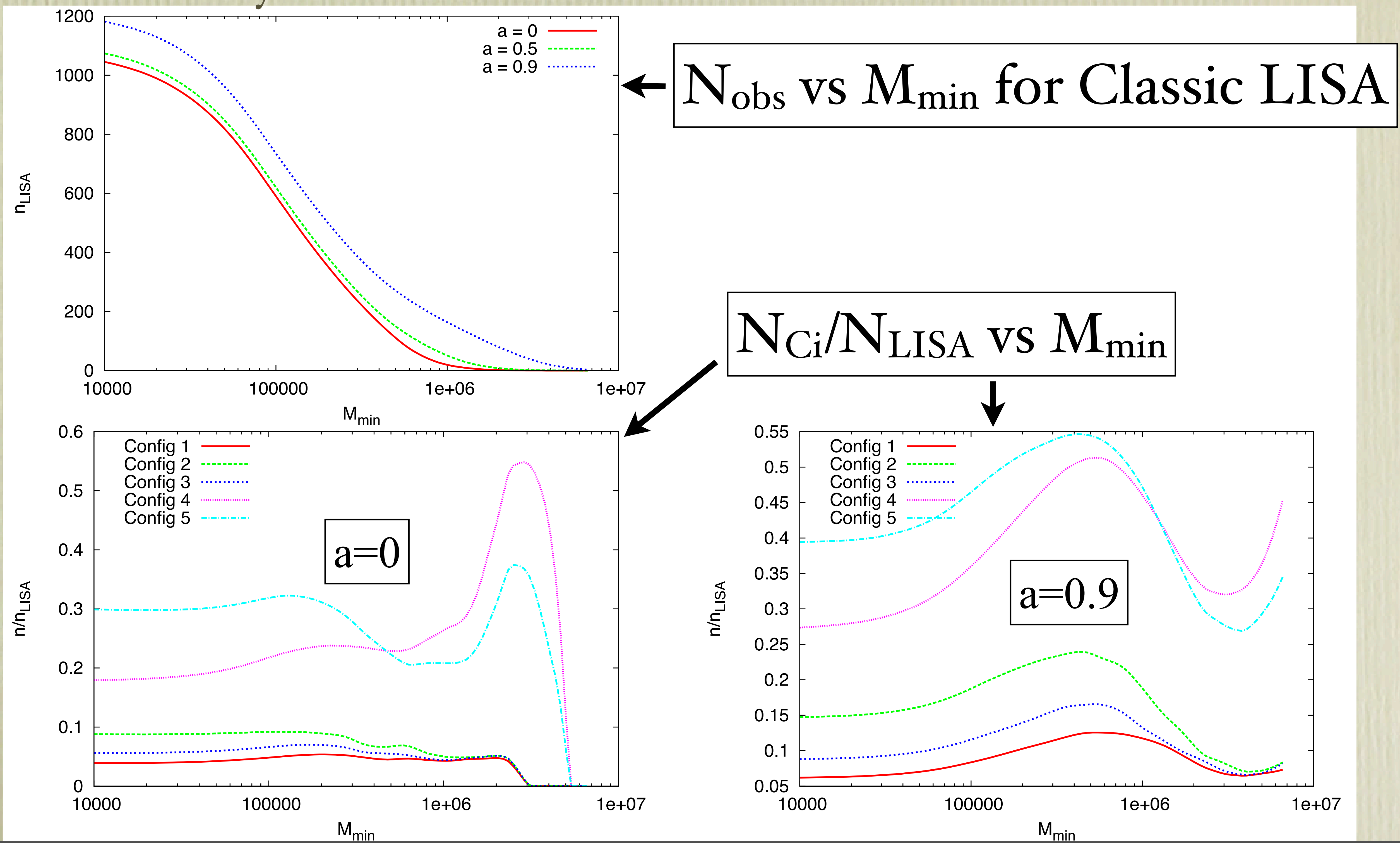
EMRIs - Event Rates

Config	4-link			6-link		
	Black hole spin			Black hole spin		
	0	0.5	0.9	0	0.5	0.9
C1	15	20	30	40	45	75
C2	45	50	90	90	110	175
C3	25	30	50	60	65	105
C4	80	90	145	185	210	320
C5	140	155	235	310	335	465

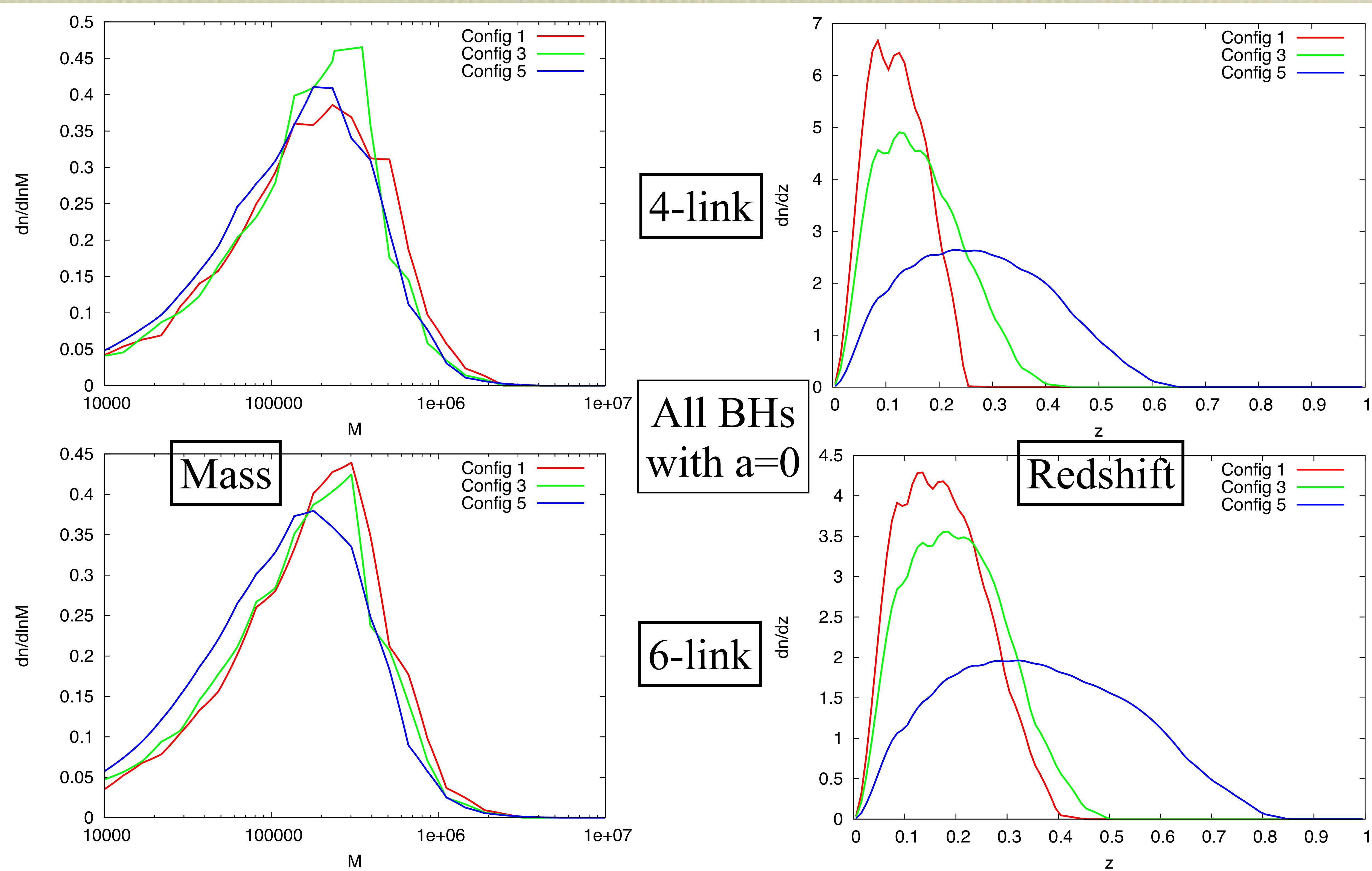
- Note intrinsic rate uncertainties are an order of magnitude or more.

EMRIs - Event Rates

- Low mass end of mass function poorly constrained. Event rate is lower if very low mass massive black holes do not exist.



EMRIs - Event Properties



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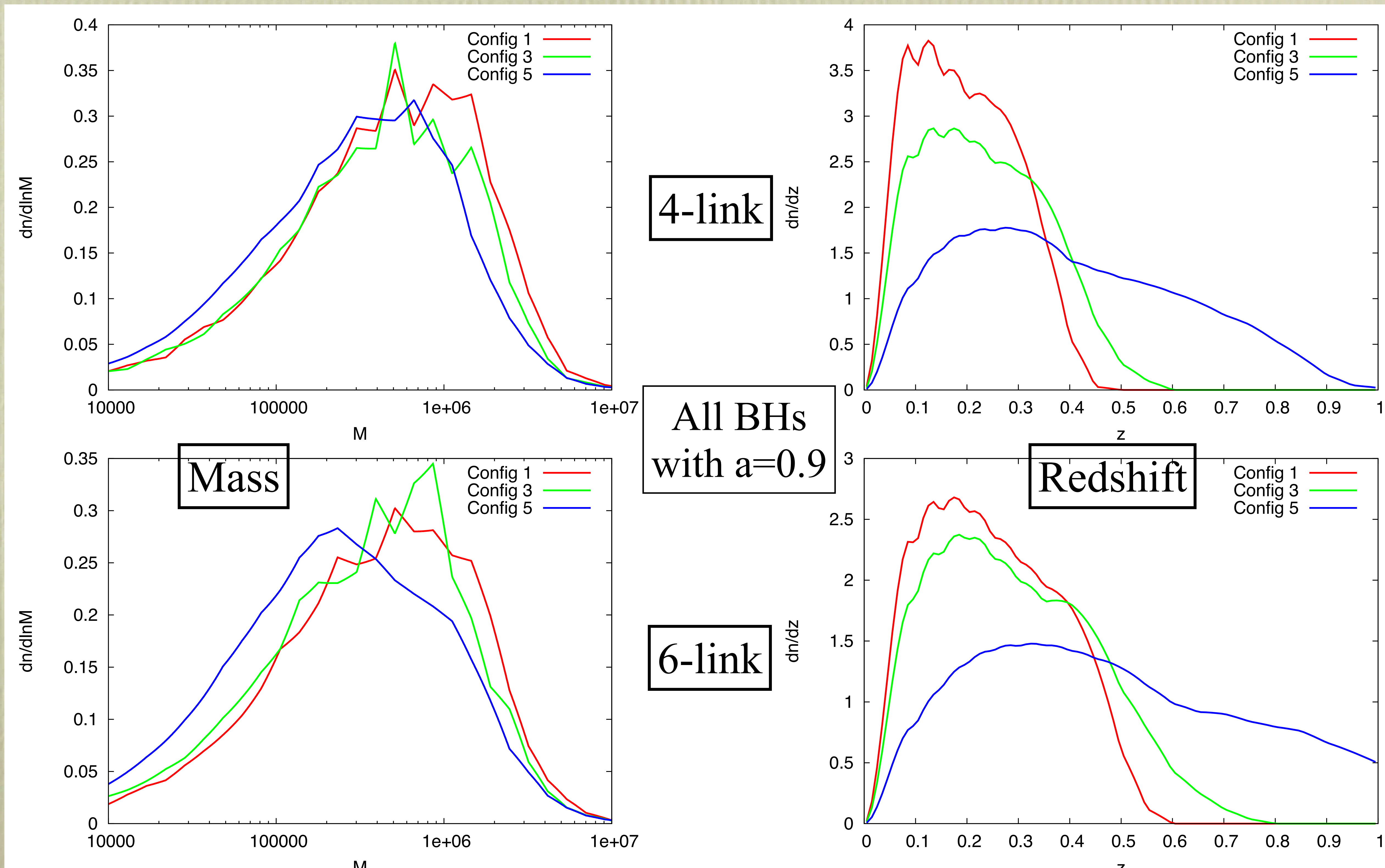


EMRIs - Parameter Estimation

- Compare precision of parameter estimation for sources observed at a fixed SNR of 30.

	4-link				6-link			
Parameter	**C1**	**C3**	**C5**	**Classic LISA**	**C1**	**C3**	**C5**	**Classic LISA**
ln(M)	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
ln(m)	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}
a	3×10^{-4}	3×10^{-4}	3×10^{-4}	3×10^{-4}	3×10^{-4}	3×10^{-4}	3×10^{-4}	3×10^{-4}
Sky Pos.	2^o	2^o	2^o	2^o	1^o	1^o	1^o	1^o
ln(D)	0.125	0.125	0.125	0.125	0.1	0.1	0.1	0.1

EMRIs - Science

- **Fundamental physics** - testing "no-hair" property of black holes; test theory of relativity; probe possible exotic central objects. Relies on observing large number of cycles. Any event detected with SNR > 20 suitable.
- **Astrophysics** - accurate parameter estimation for all detected sources. Measure slope of black hole mass function with N_{obs} events to precision $\Delta\alpha \approx 0.3\sqrt{10/N_{\rm obs}}$ (JG et al. 2010). Current limit is ~0.3 - beaten by all configurations.
- **Cosmology** - measure Hubble constant to 1% precision with ~20 EMRI events at z<0.5 (McLeod & Hogan 2008). Possible in all configurations with these reference EMRI rates.
- Science potential for EMRIs is as strong as classic LISA, although will have fewer events, and SNR of a particular event will be lower than it would have been for classic LISA.

White-dwarf Binaries

	C3 - 4 links new baseline	C3 - 6 links new baseline	C1 - 4 links pessimistic	C5 - 6 links optimistic
# SNR > 7	3350	5750	900	6200
# df/dt < 20%	1150	1500	300	1650
# d^2f/dt^2 < 10%	1	2	0	3

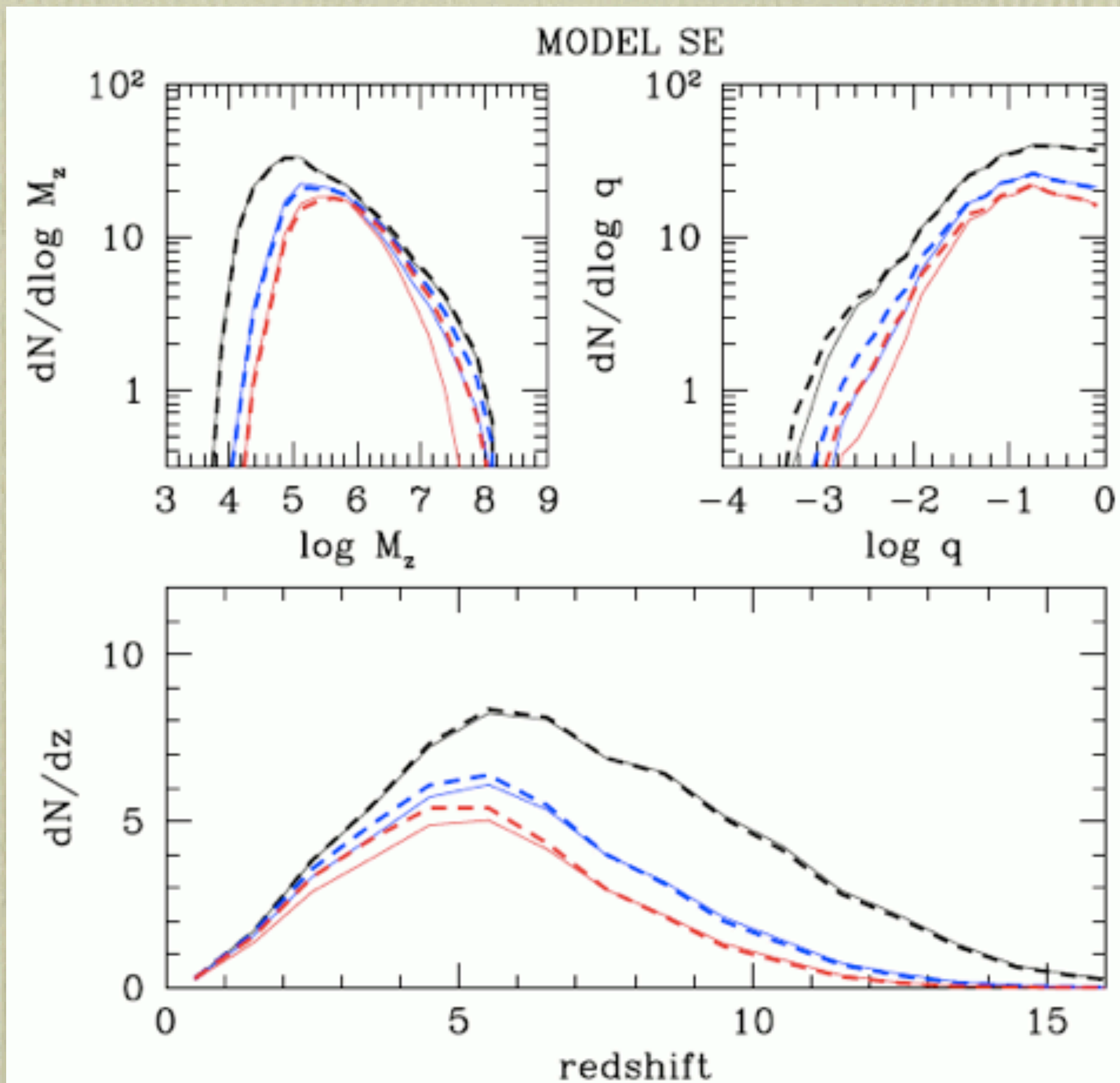
- All configurations will see ~2-4 **verification binaries**, i.e., binary systems with electromagnetically measured periods etc.

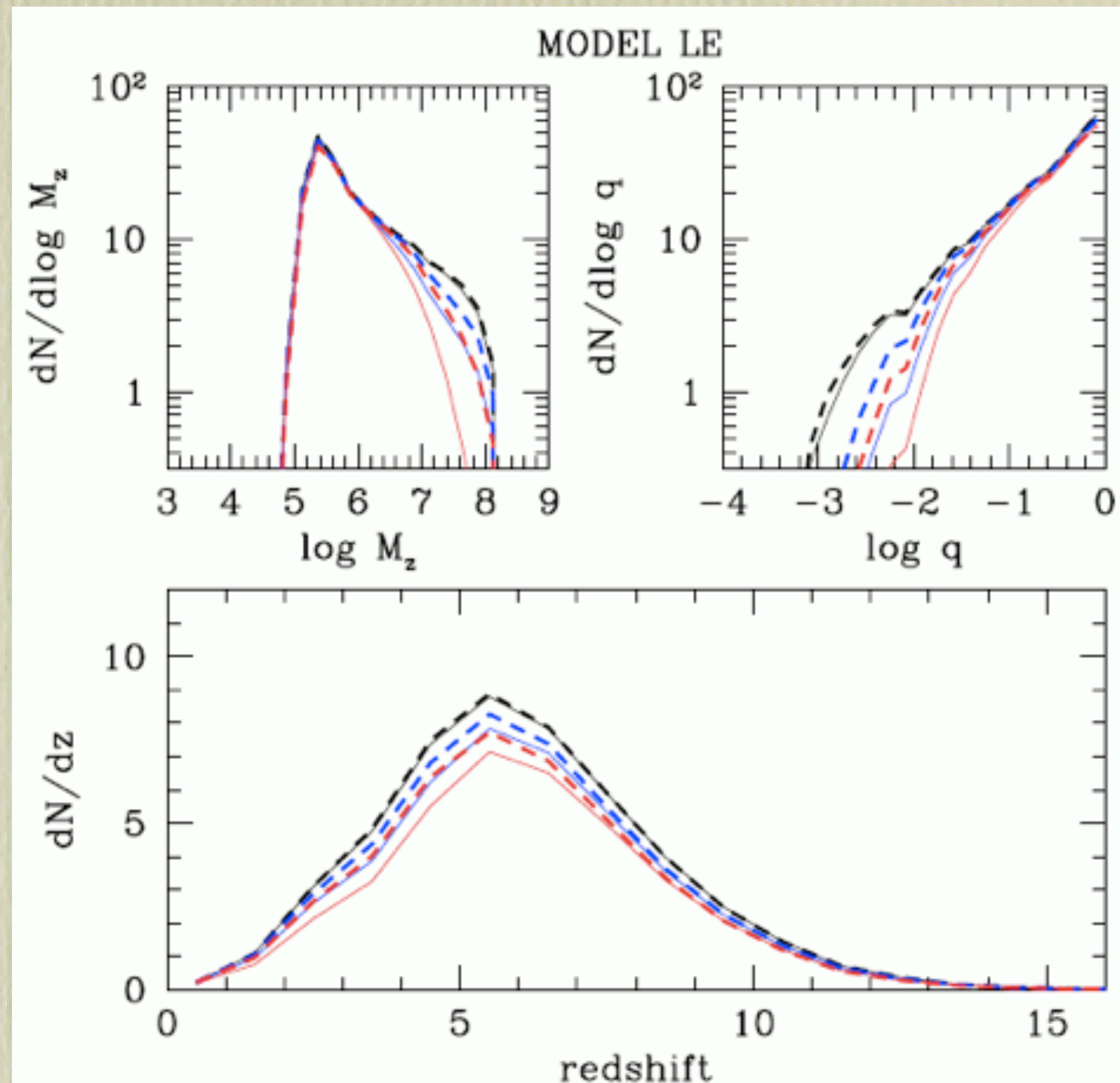
Massive Black Hole Mergers

- Estimate number of observed events under "light" (S) and "heavy" (L) seed scenarios and with "efficient" (E) or "chaotic" (C) accretion.

Model	Detector	4-link		6-link	
		SNR > 8	SNR > 20	SNR > 8	SNR > 20
SE	LISA	65	41	80	50
	C5	40	23	50	30
	C1	32	18	41	24
SC	LISA	71	47	85	56
	C5	46	27	56	35
	C1	38	21	46	28
LE	LISA	49	46	49	49
	C5	45	35	48	42
	C1	42	28	46	36
LC	LISA	43	40	43	42
	C5	39	30	41	36
	C1	35	25	39	31

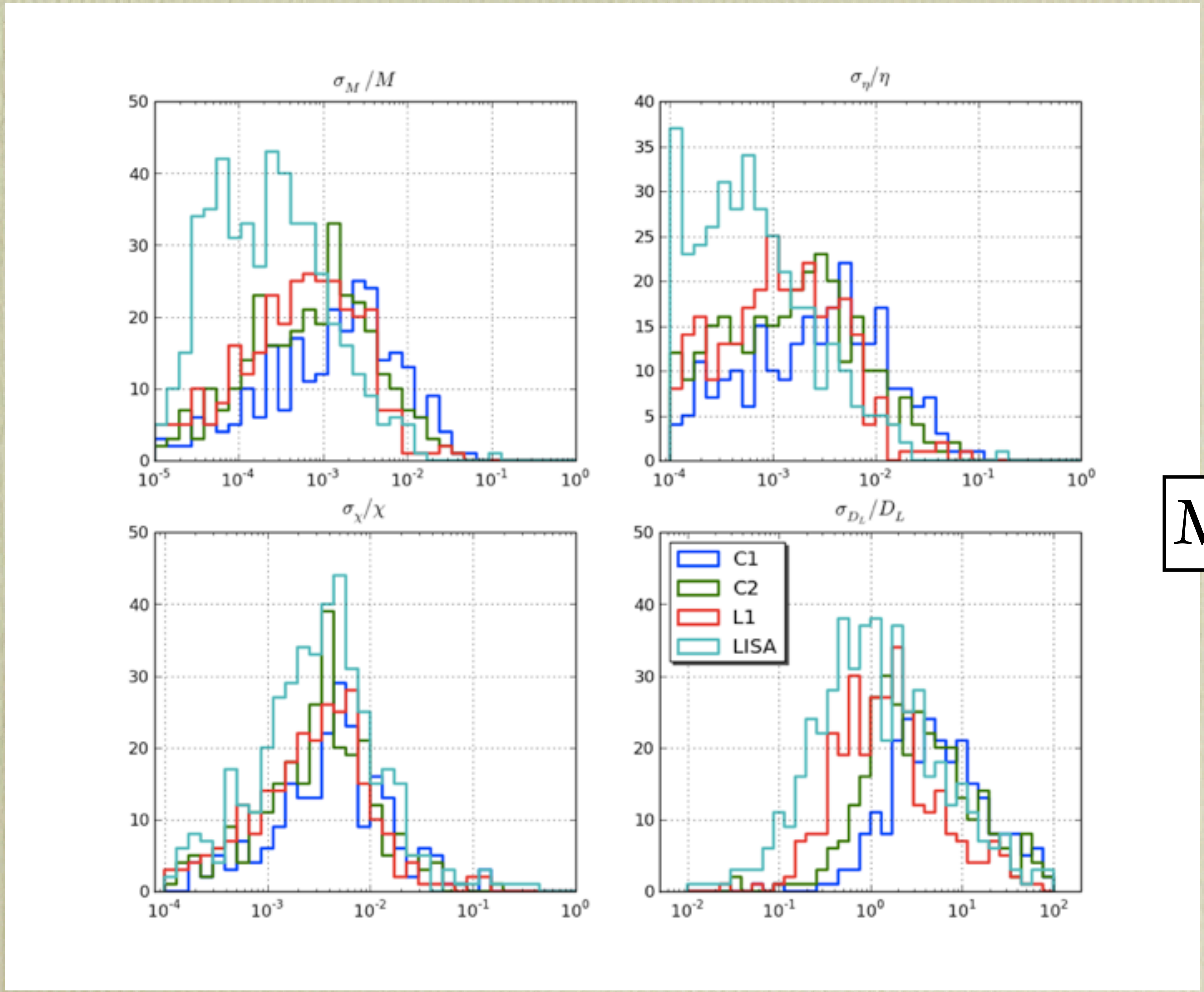
Massive Black Hole Mergers





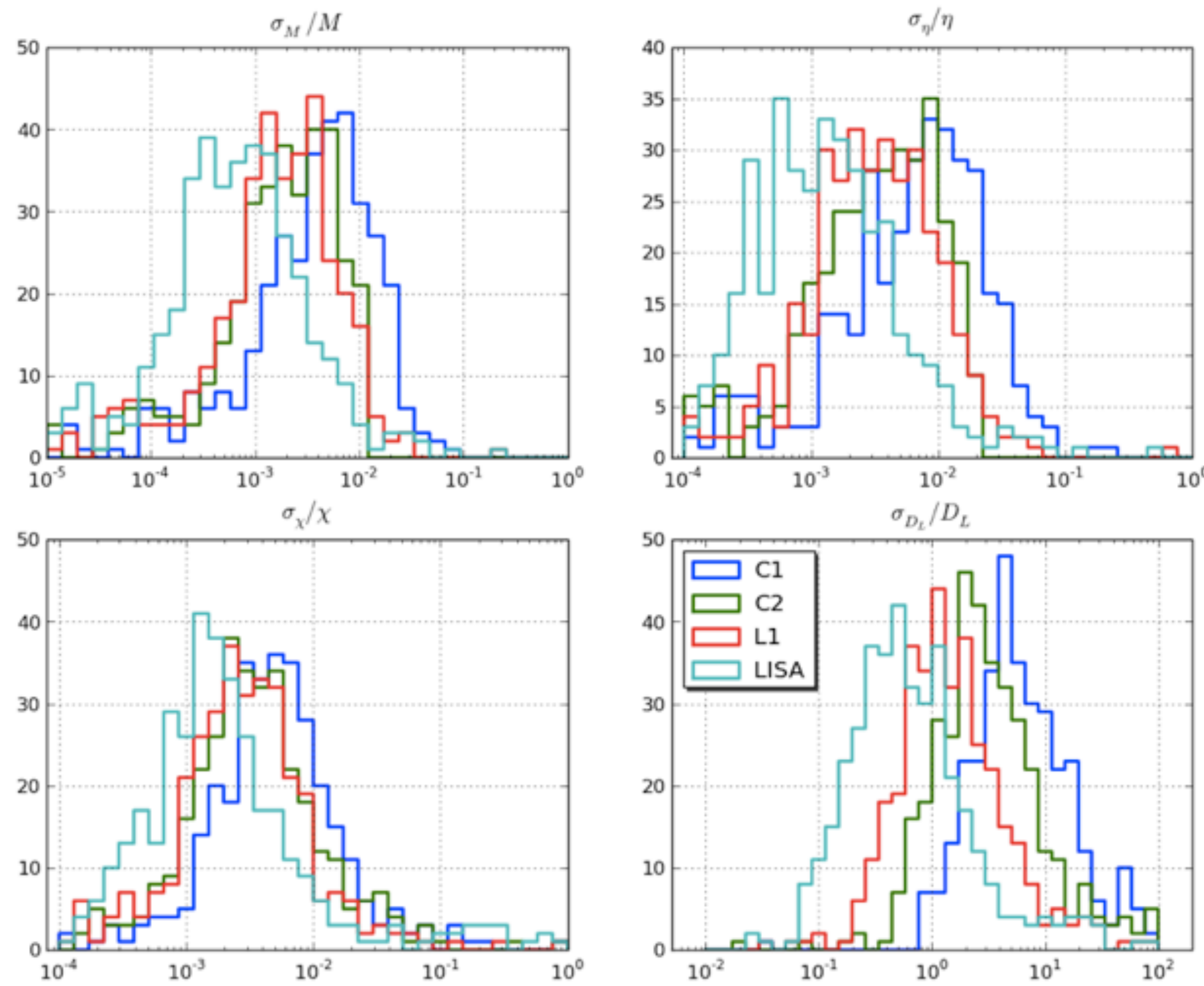
- Sources at z > 10 not observable with descope designs.
- Do not see lower mass binary sources, but high mass events are visible in all configurations.

MBH Mergers - Parameter Est.



Model SE

MBH Mergers - Parameter Est.

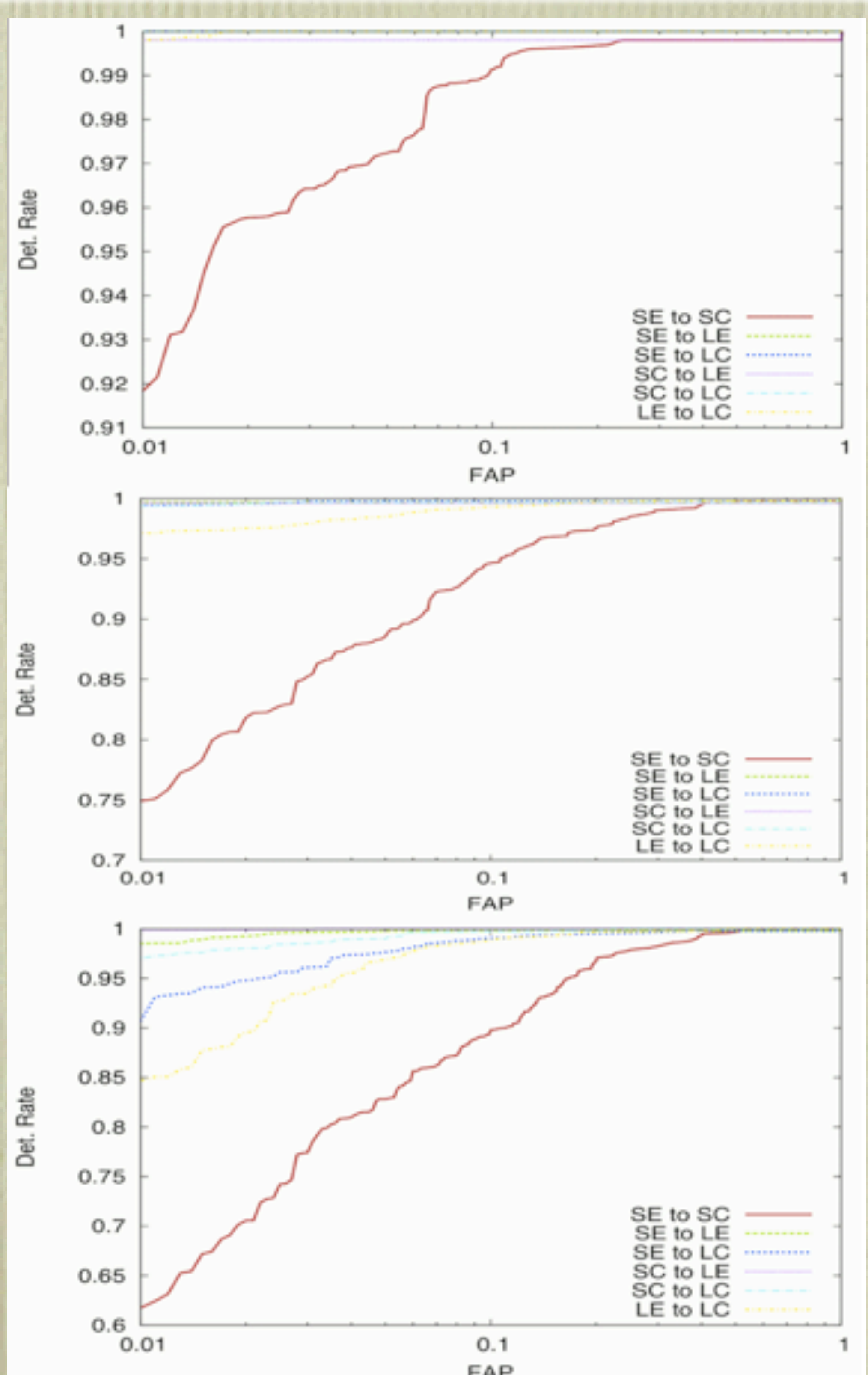


Model LE

MBH Mergers - Parameter Est.

- Overall expect to have parameter precisions
  - **Redshifted Mass** - better than 10^{-3}.
  - **Mass Ratio** - better than 10^{-2}.
  - **Spin** - better than 10^{-2}.
  - **Sky Position** - 10 square degrees or worse.
  - **Luminosity Distance** - errors of O(1) or worse.
- These are based on **non-spinning** or **aligned spin** waveforms, without higher harmonics. Precessing spins and harmonics are known to break distance and sky position degeneracies, to improve estimates by factors of 10-30.

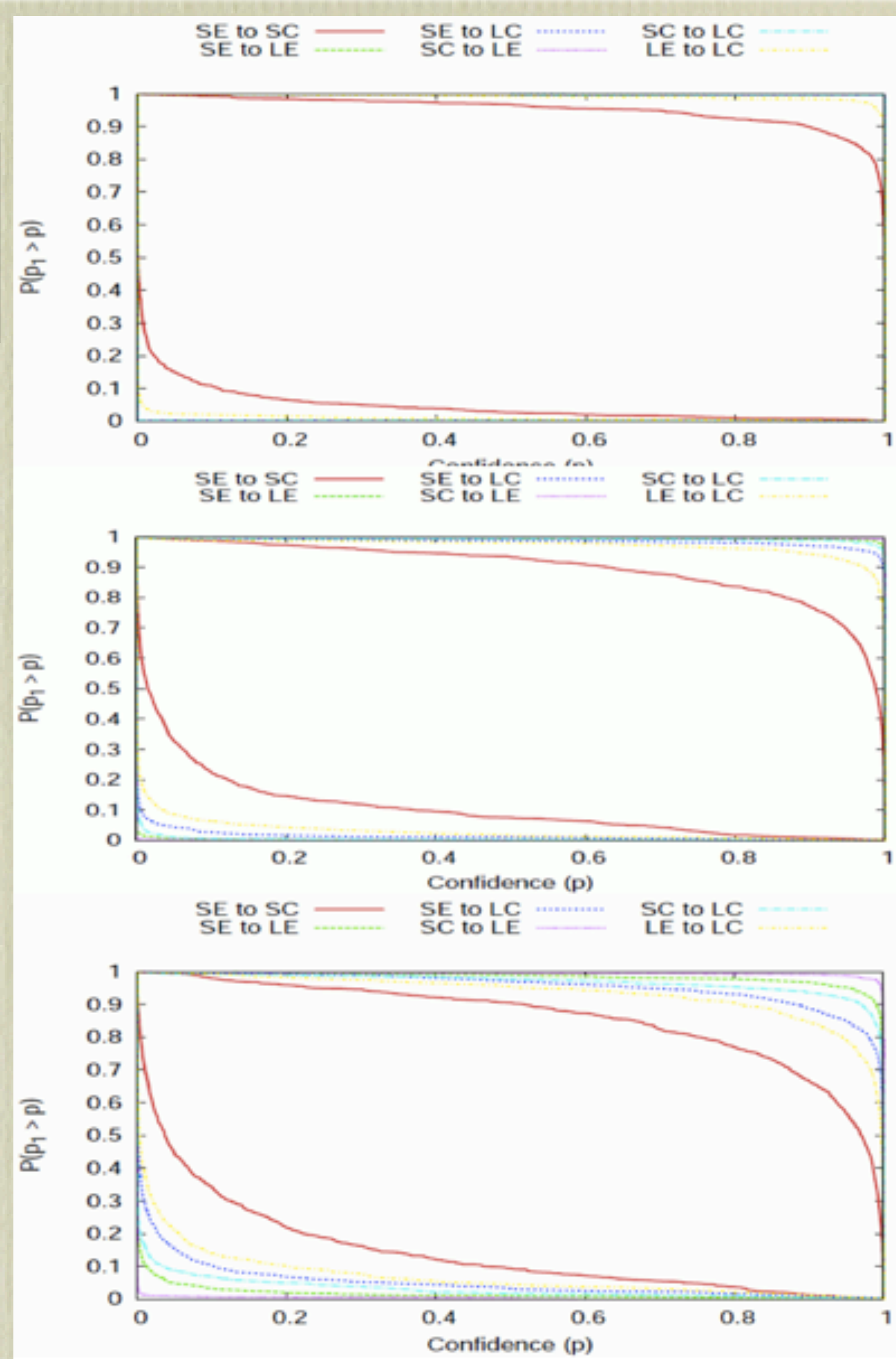
MBH Mergers - Model Selection



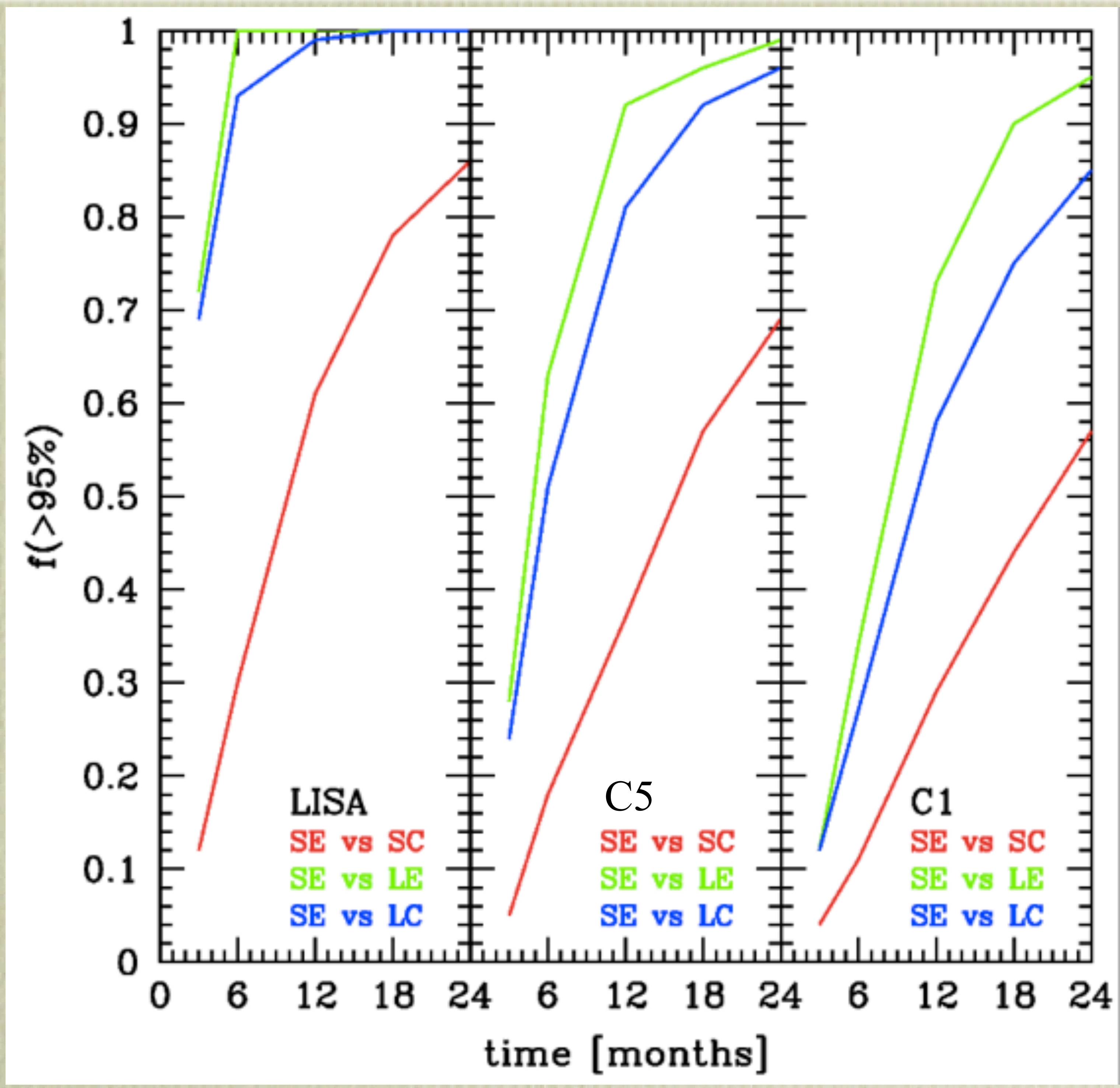
Classic LISA

C5

C1



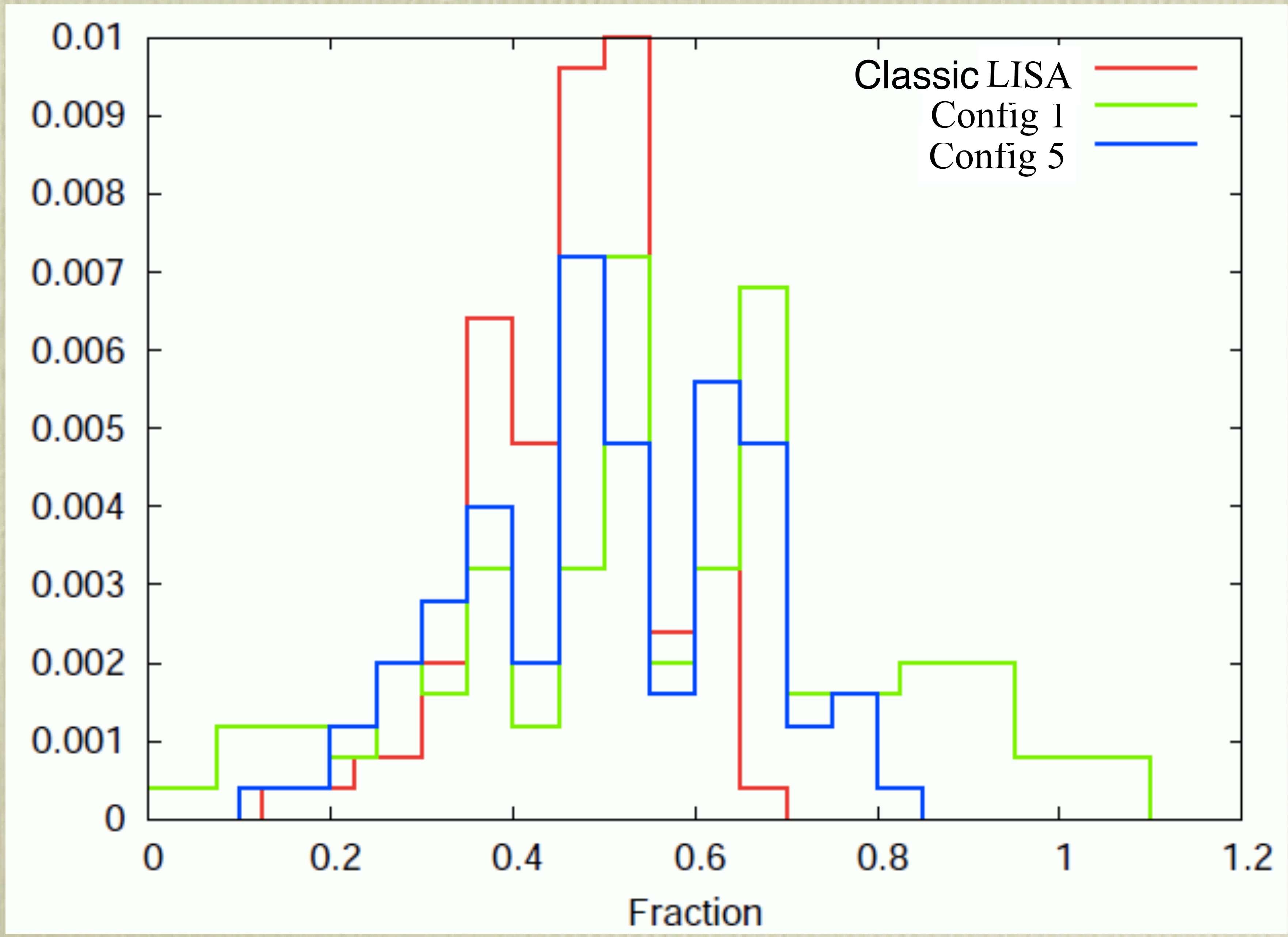
MBH Mergers - Model Selection



- Impact of mission duration. Note that we ignore spins. If they were included, SE and SC would always be distinguishable.

MBH Mergers - Model Selection

- Can also consider **model mixing**. Can measure mixing parameters with descoped configurations, albeit less precisely than would have been possible with Classic LISA.



ESA Timeline

- **July 2011:** CDF study, define detector configuration.
- **November 2011:** science case Yellow Book.
- **February 2012:** ESA proposal approval.
- **Summer 2012:** down-selection from three to two candidates.
- **Summer 2014:** final selection.
- **Early 2020's:** launch.

Summary

- Descope exercise being carried out within ESA at the moment. New concept for a low-frequency gravitational wave detector in space will be finalised by february 2012.
- Prospects for detection of EMRIs are good - expect ~100 events at redshift $z < 0.5$ for new baseline mission.
- EMRI parameter estimation precisions comparable to estimates for classic LISA **for sources at a given SNR**.
- Strong potential for EMRI science - fundamental physics, astrophysics and cosmology. Relative to classic LISA we will see fewer events, and lower SNRs for sources with given parameters. However, large rate uncertainties arise from astrophysics.
- Strong prospects for WD binaries and SMBH mergers as well. Have fewer events than classic LISA. (Possibly) poor luminosity distance precision for SMBH mergers.