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Black Hole Mergers as Probes of Structure Formation

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Background and Motivation

- Hierarchical Structure Formation
- Little observational data of $z \sim 5$ - 20 era
- Gravitational waves to the rescue!
  - Massive BH mergers trace mergers of halos/galaxies
  - Observable for redshifts where there is currently little observational data
- Problem: Estimates of merger rates span 5 - 6 orders of magnitude

Goals

- Develop semi-analytical, phenomenological model of MBH mergers, with several representative parameters.
- Use statistical methods to generate synthetic LISA observable data (total BH mass, redshifts, merger event rates).
- Blindly analyze data to evaluate confidence regions of parameters.

Method

- Assume halo number densities at redshift $z+dz$ given by Sheth & Tormen (1999) modification of Press-Schechter (1974) algorithm.
- Probability of merger by redshift z given by Extended Press-Schechter (Lacey & Cole 1993).
  - Note that this is single-step only; we do not construct a full merger tree!
- Generation of synthetic data (masses, redshifts, merger rates).
- MCMC to constrain model parameters given the data; confidence regions.

Tests and Results

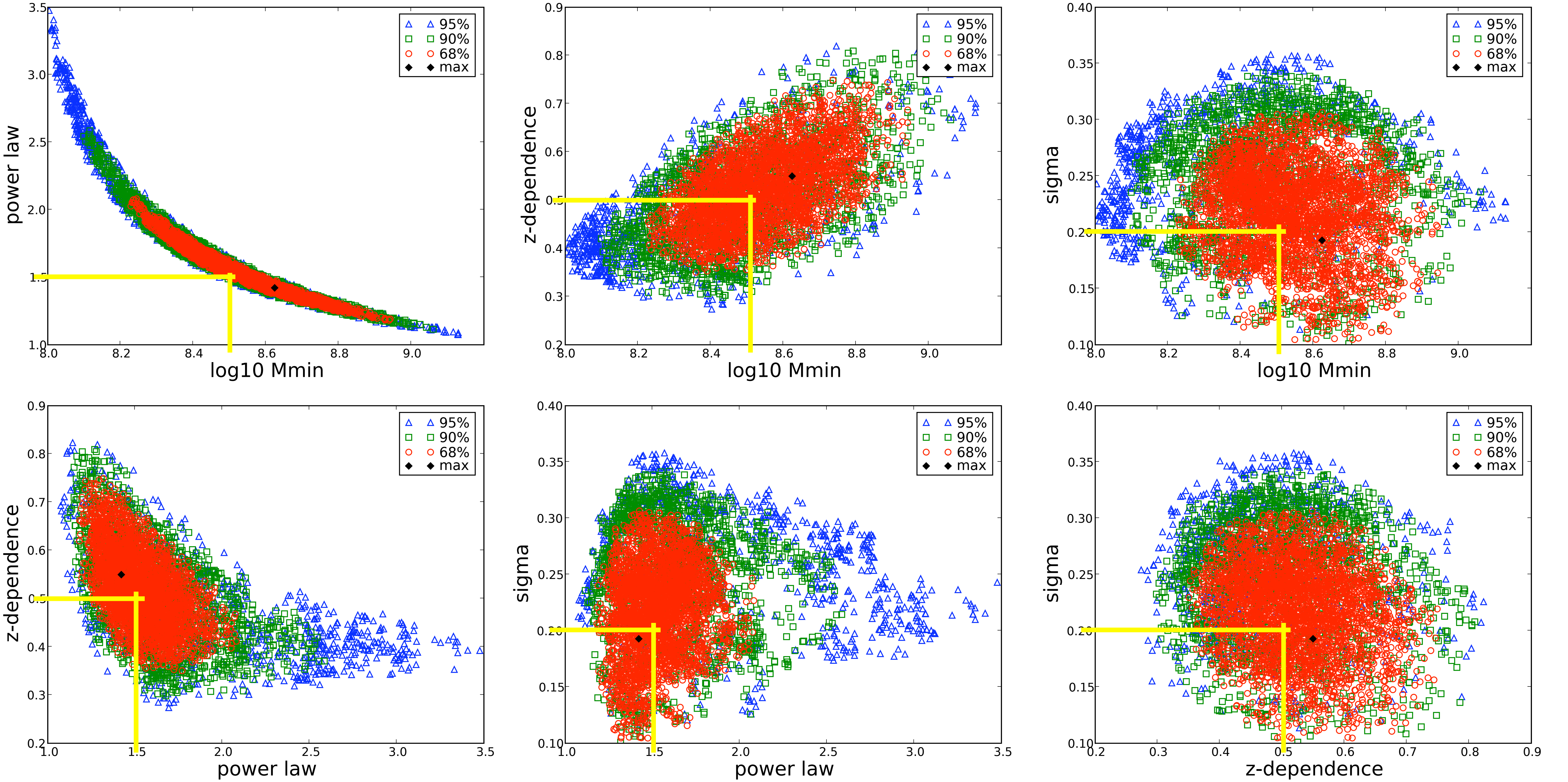
- Four model parameters:
  - min halo mass:
  - power law:

$$P_{\rm occ}(M, z=20) = \begin{cases} 1, M > M_{\rm min} \\ \left(\frac{M}{M_{\rm min}}\right)^p, M < M_{\rm min} \end{cases}$$

  - z-dependence: $M_{\rm BH,0} = \left[M_{\rm BH}(M_{\rm halo})\right](1+z)^n$
  - sigma: $P(\log(M_{\rm BH})) \propto e^{(\log(M_{\rm BH}) - \log(M_{\rm BH,0}))^2/2\sigma^2}$

- Calculate the likelihood of the data given the model parameters, thus establishing confidence regions.

Tests and Results



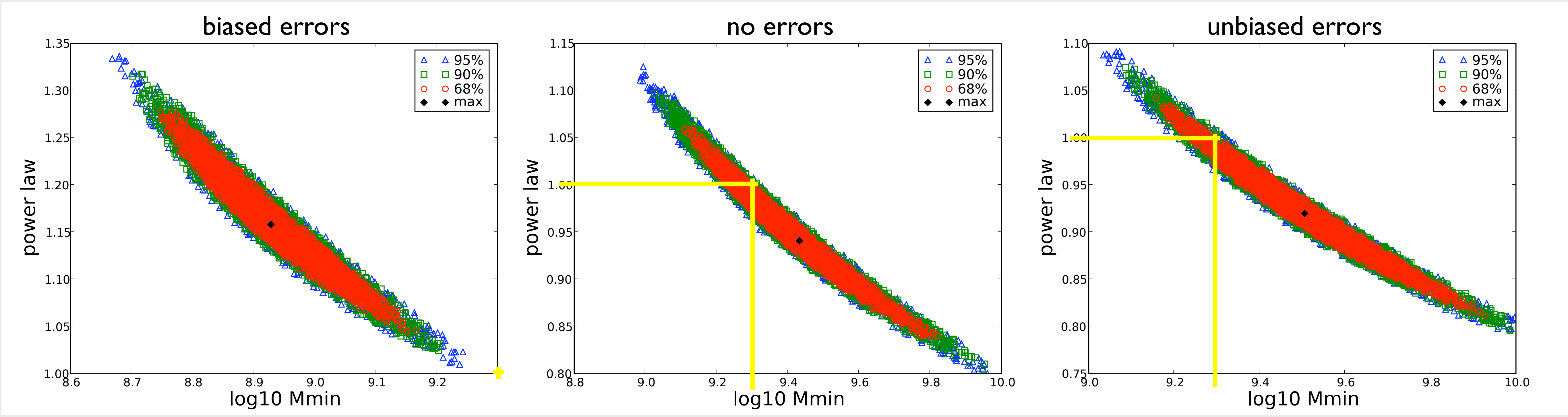
169 merger events (3 yrs observation)

Actual values: $\log_{10}(M_{min}) = 8.5$ power law = 1.5
z-dependence = 0.5 sigma = 0.2

Tests and Results

- But what if measurements aren't perfect?
- We simulated the effects of observational uncertainty by adding errors to the synthetic data.
  - Biased errors - uniformly distributed between 0% and 40%
  - Unbiased errors - uniformly distributed between -20% and +20%
- Results show that observational uncertainty does not significantly affect our method's ability to constrain merger parameters.

Tests and Results

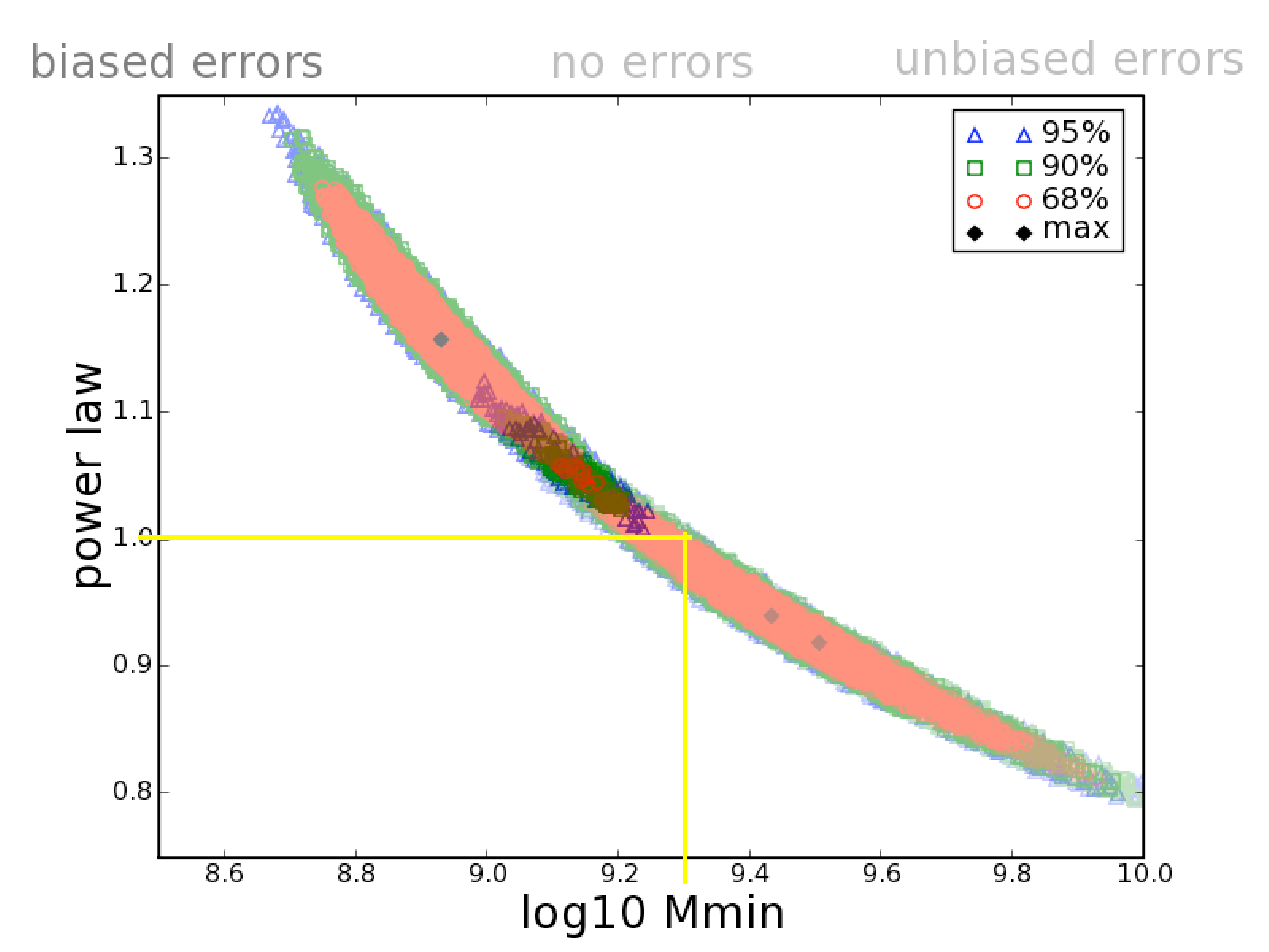


245 merger events (3 yrs observation)

Actual values: $\log_{10}(M_{min}) = 9.3$

power law = 1.0

Tests and Results



Conclusions

- Results show that our proof of principle works.
    - Note that the method works for other kinds of observational data, not just gravitational waves.
- Many aspects of our analysis are robust against observational errors.
- To do: include more physically-driven parameters.