Resolving Features in LIGO/Virgo's Binary Black Hole Mass Spectrum

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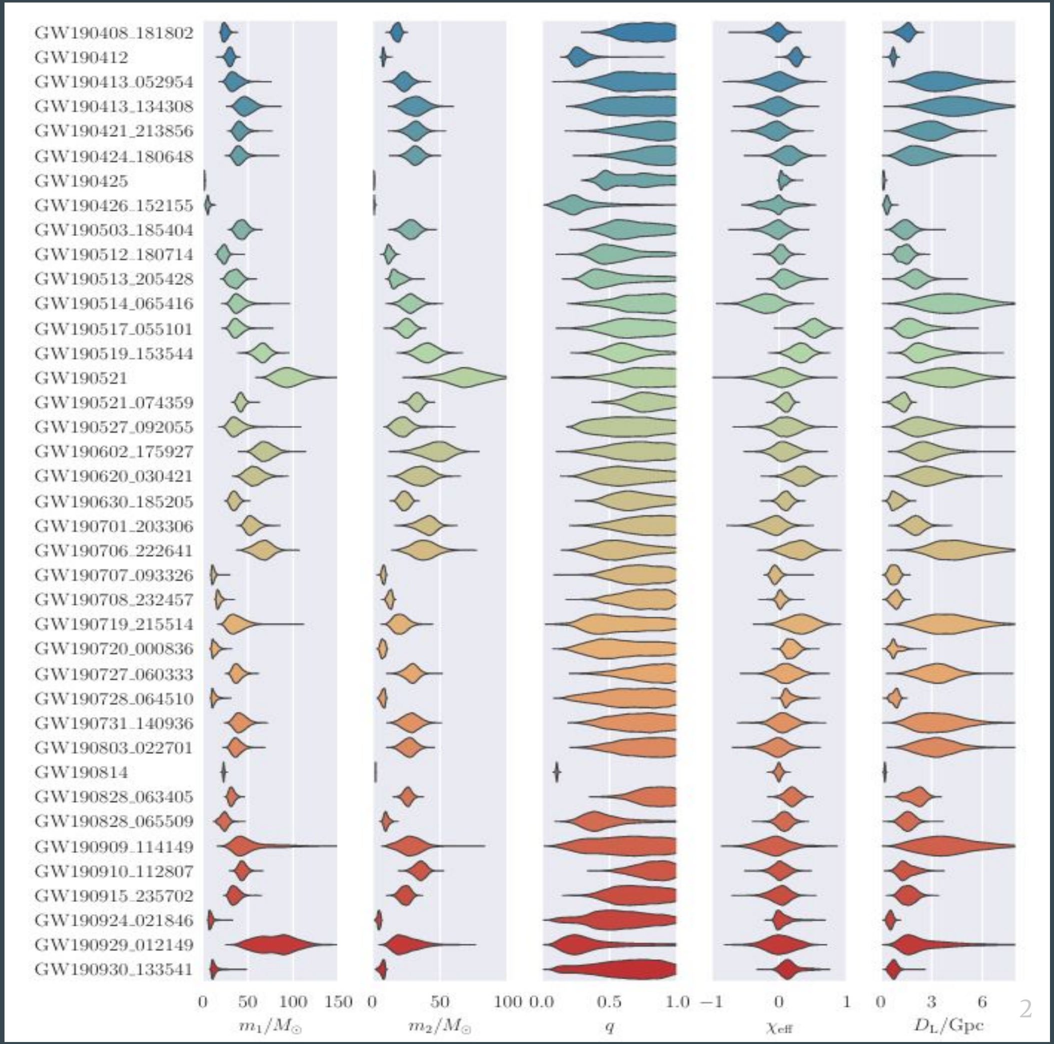
LSC LIGO

BBHs in GWTC-2

- GWTC-2 included 46 BBH mergers
- Asymmetric mass ratio BBH (GW190412)
- Most Massive BBH to date (GW190521)
- Possible Lightest BH or heaviest NS (GW190814)

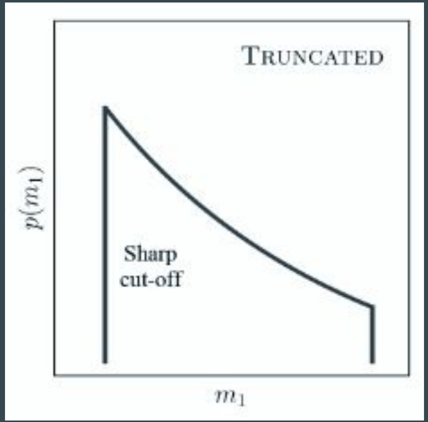


LVK: O3a Catalog (2010.14527)

Hierarchical Bayesian Modeling

- How many BBH mergers are there in the Universe?
- How often do they merge?
- How are their event properties distributed?

$$p(\theta|d) = \frac{\mathcal{L}(d|\theta)p(\theta)}{\mathcal{Z}(d)}$$



$$p(\theta|\Lambda)$$

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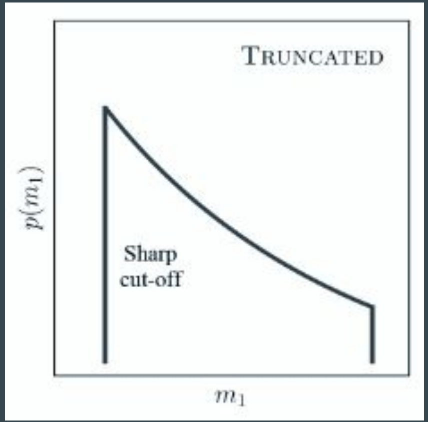

$$p(\theta|d) = \frac{\mathcal{L}(d|\theta)p(\theta)}{\mathcal{Z}(d)}$$

$$p(\theta|\Lambda)$$

$$p(\Lambda|d) = \frac{p(\Lambda)\int d\theta \mathcal{L}(d|\theta)p(\theta|\Lambda)}{\mathcal{Z}(d)}$$

Hierarchical Bayesian Modeling

- How many BBH mergers are there in the Universe?
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Selection Effects: Avg. Sensitive Time-Volume given hyper-parameters

$$p(\Lambda, \mathcal{R}_0 | \{d_i\}) \propto p(\Lambda) p(\mathcal{R}_0) \prod_{i}^{N_{\rm obs}} \left(\frac{1}{K_i} \sum_{j}^{K_i} \frac{p(\theta_i^j | \Lambda)}{p_{\varnothing}(\theta_i^j)} \right) \mathcal{R}_0^{N_{\rm obs}} e^{-\mathcal{R}_0 \xi(\Lambda)}$$

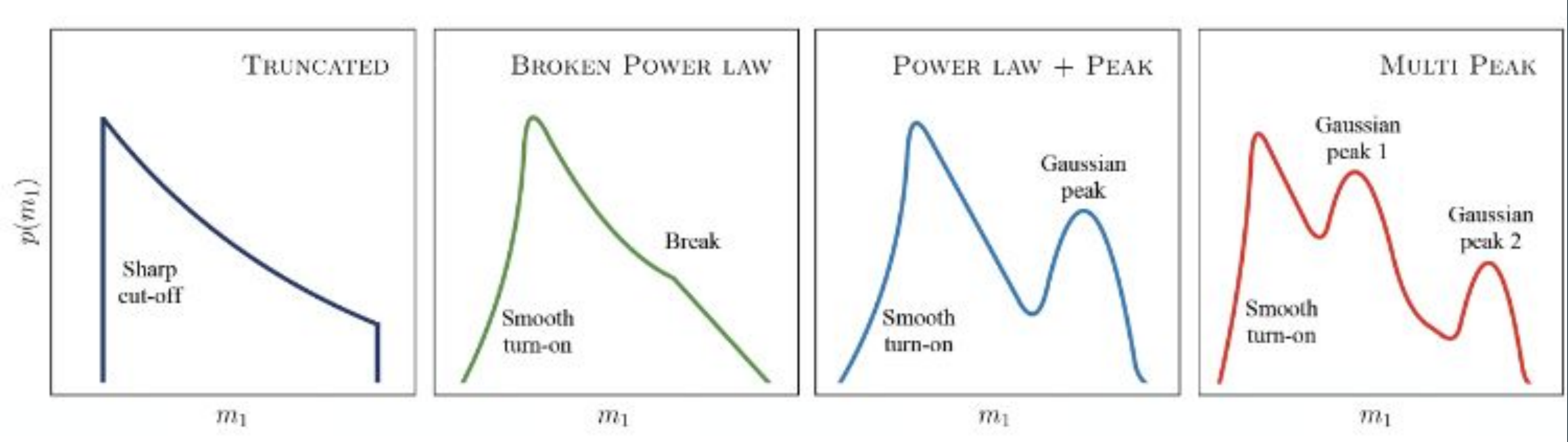
Priors on hyper-parameters

Multiply Each events Likelihood

Importance sampled integral marginalizing event likelihoods over event properties

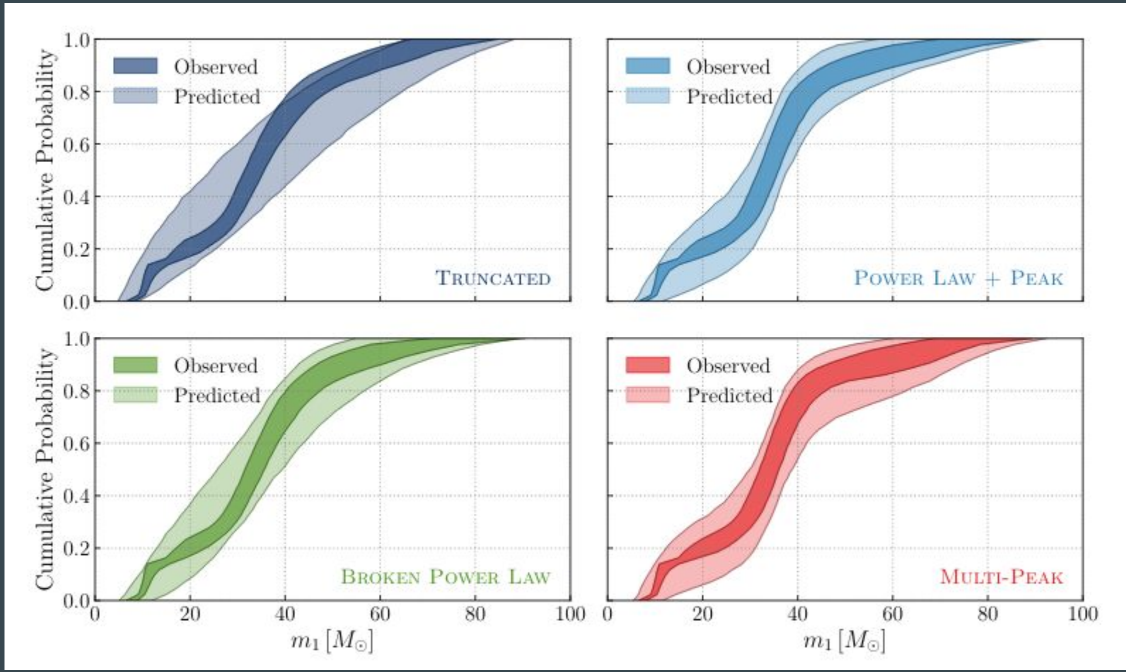
Hyper-posterior

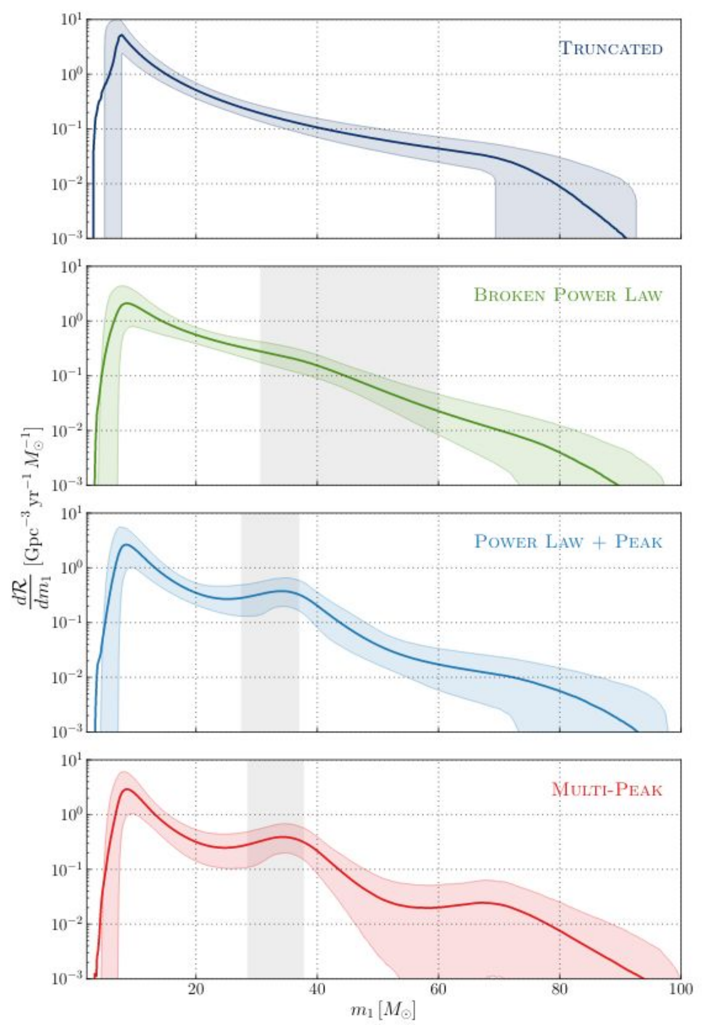
BBH Population after O3a



LVK: O3a Catalog (2010.14527)

BBH Population after O3a





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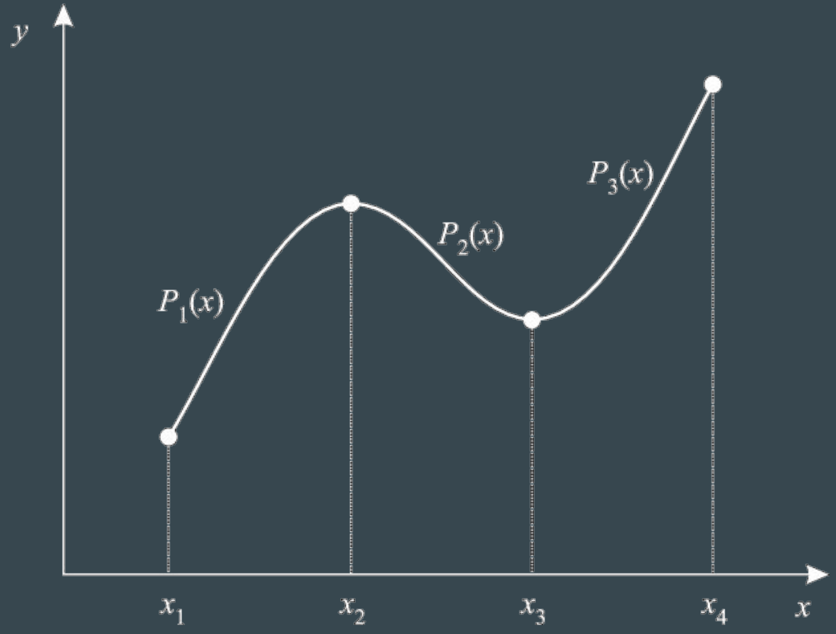
Non-Parametric Perturbation Model

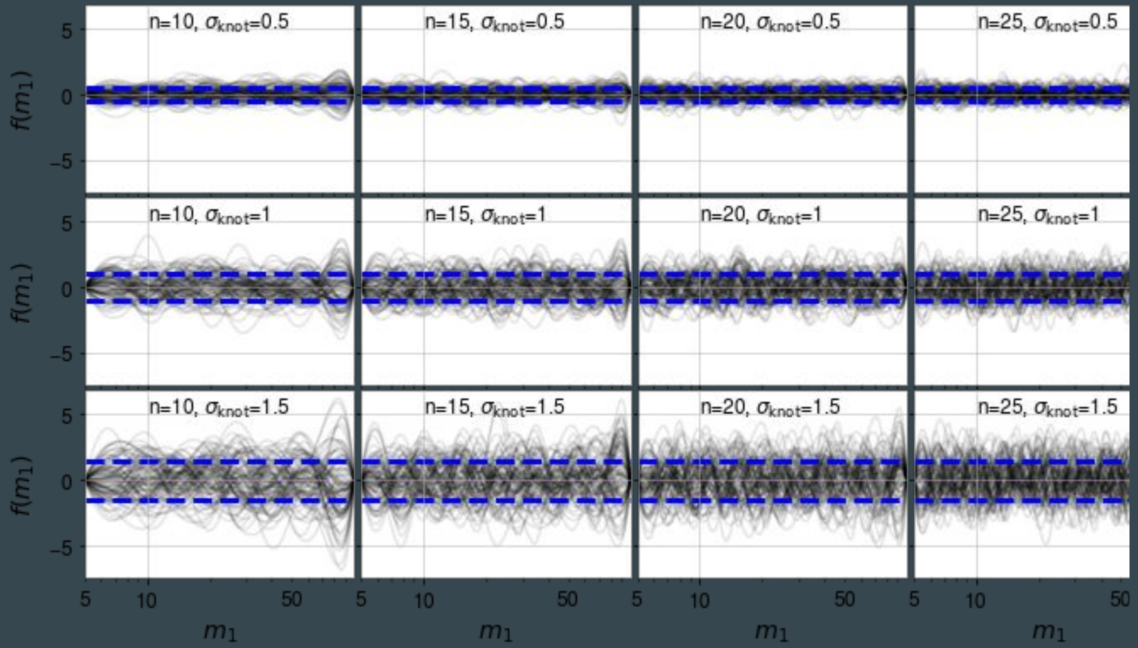
- fitting very flexible models with arbitrarily large number of parameters, with few assumptions on the shape
- KDEs, Gaussian Processes, splines, etc
- Introduce a perturbation factor to a *simple* primary mass distribution
- We choose to model f with a cubic spline function



$$p_{\rm spline}(m_1|\Lambda, \{f_i\}) \propto p(m_1|\Lambda)\exp(f(m_1|\{f_i\}))$$
$$f(m_1) = \mathcal{I}_3(m_1; \{m_n, f_n\})$$

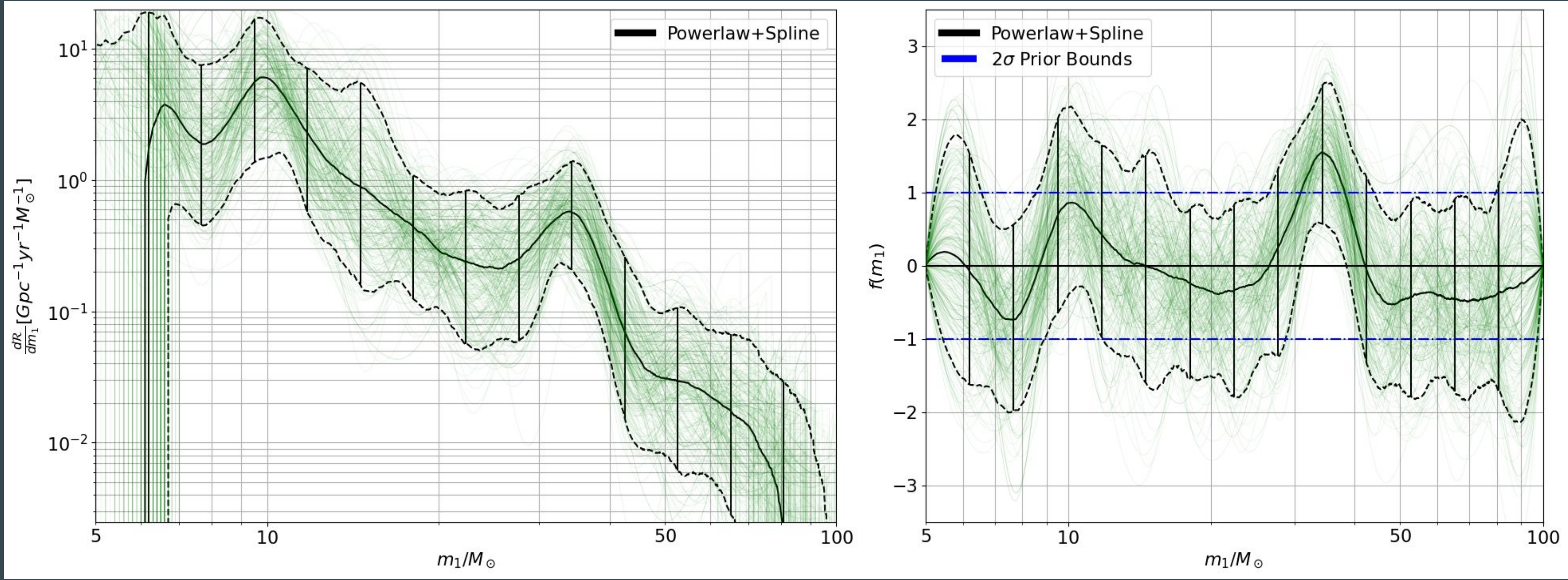
Non-Parametric Perturbation Model

- We place N knots linearly spaced in log-m1 space, which adds N parameters to our inference that describe our perturbations
- Gaussian Priors on knot heights centered on zero
- Two knobs to control size of perturbation (sigma_knot) and resolution (number of knots, n)



$$p(\{f_i\}) = \mathcal{N}(\mu = 0, \sigma = \sigma_{\text{knot}})$$

Spline Results on GWTC-2's 46 BBHs



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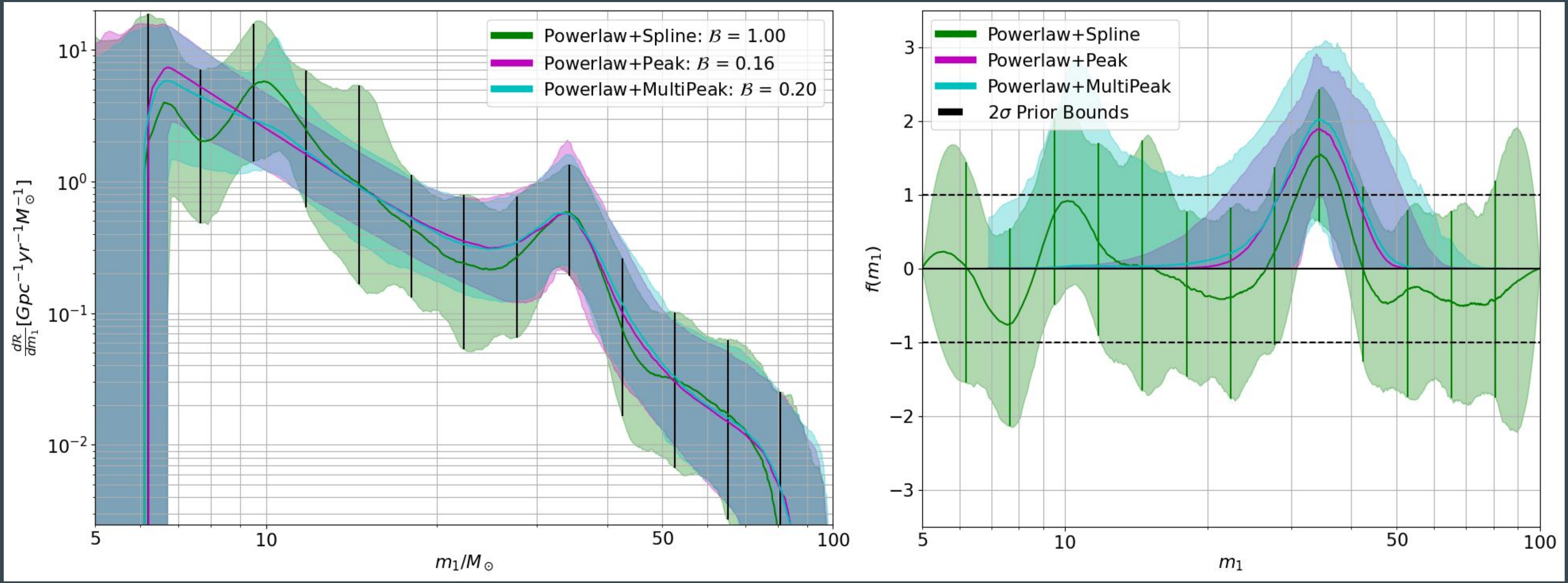
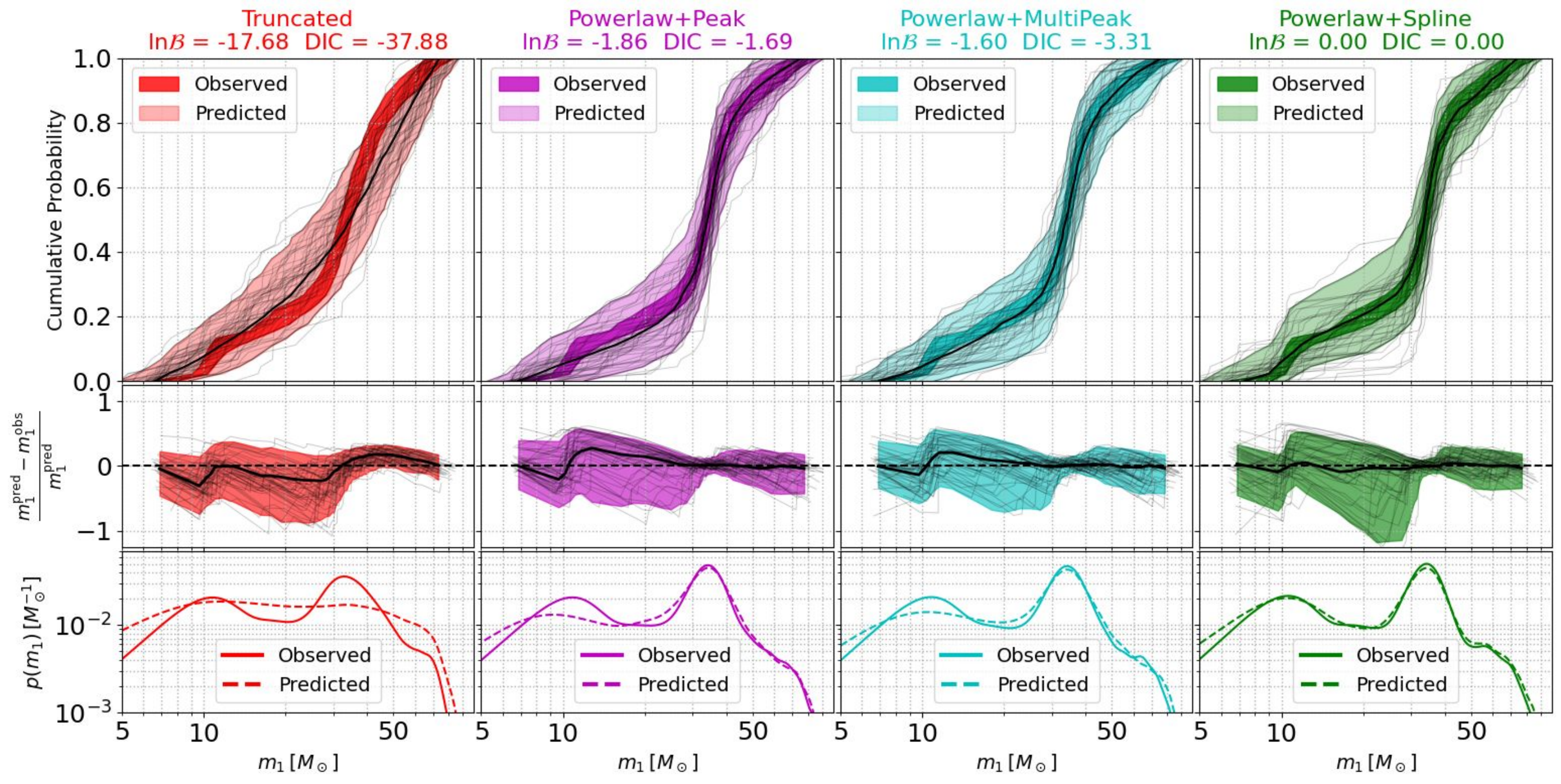


Posterior Predictive Checks



Conclusions and Next Steps

- Spline Model finds/fits 35Msun peak similarly to PL+Peak
- Spline Model seems to find an under-density of events at ~8Msun and over-density at ~10Msun
- Posterior Predictive Checks agree best with spline model

- Model is being used for LVC O3b Astrophysical distribution paper
- Add perturbation to other parameters population model (spins, mass ratio, etc.)
- Fit Joint mass spectrum of GW sources (lower-mass gap?)
- Adaptive-resolution spline

Thank You!

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