Gravitational-wave Paleontology

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ESRF

COMPAS

The inverse problem of gravitational-wave astrophysics: how to go from a population of observed sources to understanding key uncertainties about binary evolution?

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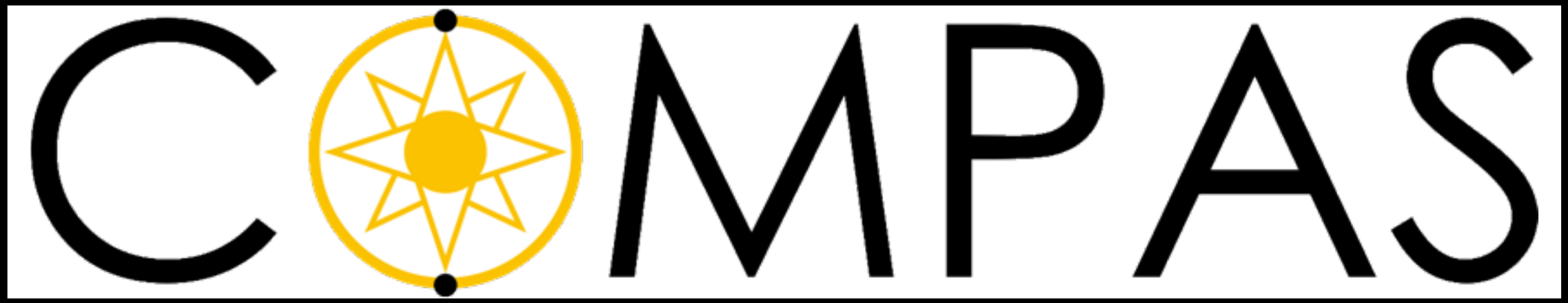
Alejandro Vigna Gómez

Simon Stevenson

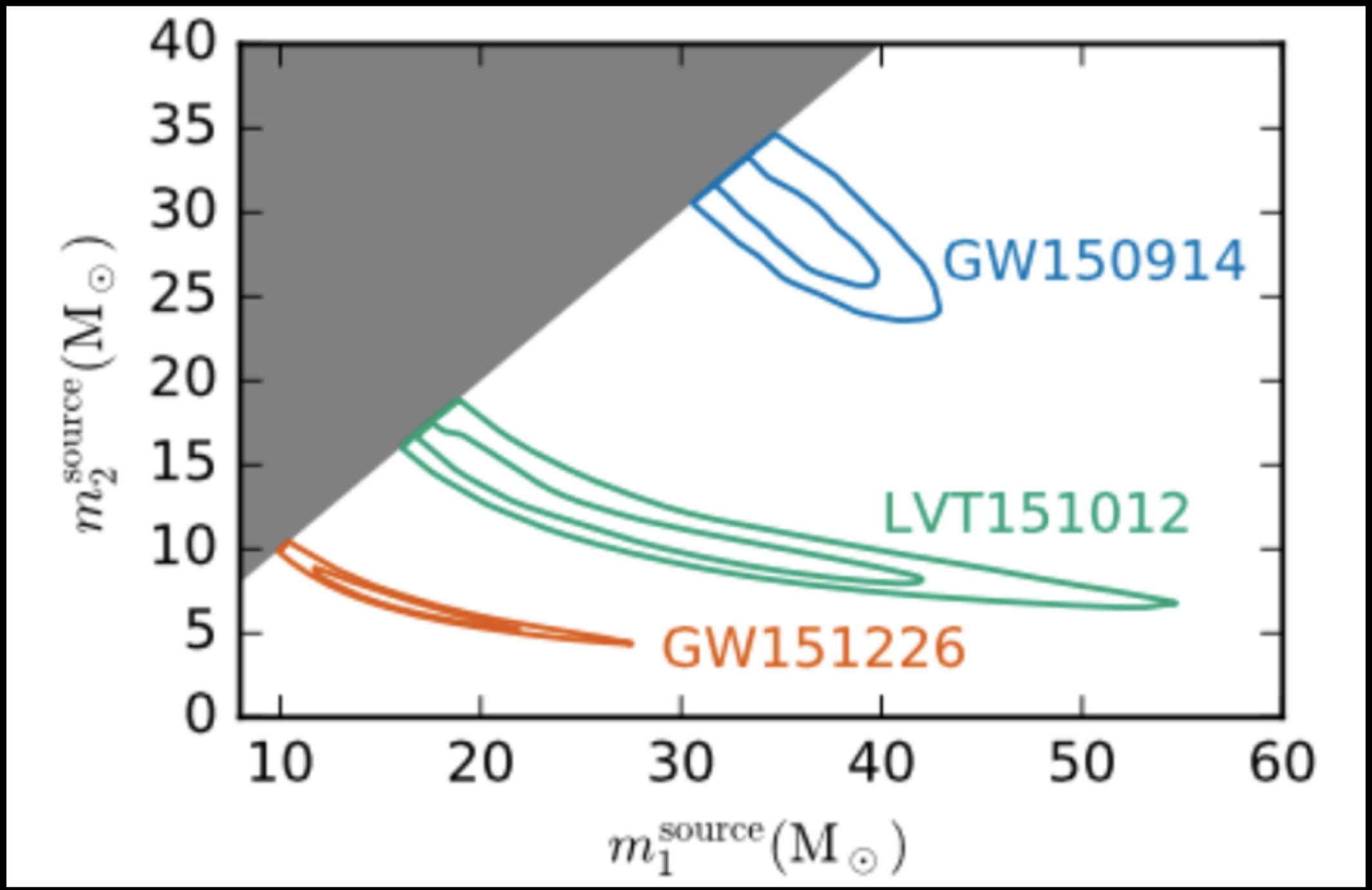
Jim Barrett

Key collaborators / advisors: Christopher Berry, Will Farr, Selma de Mink, Natasha Ivanova, Vicky Kalogera, Chris Belczynski, Gijs Nelemans, Philipp Podsiadlowski… **YOUR NAME COULD BE HERE!**



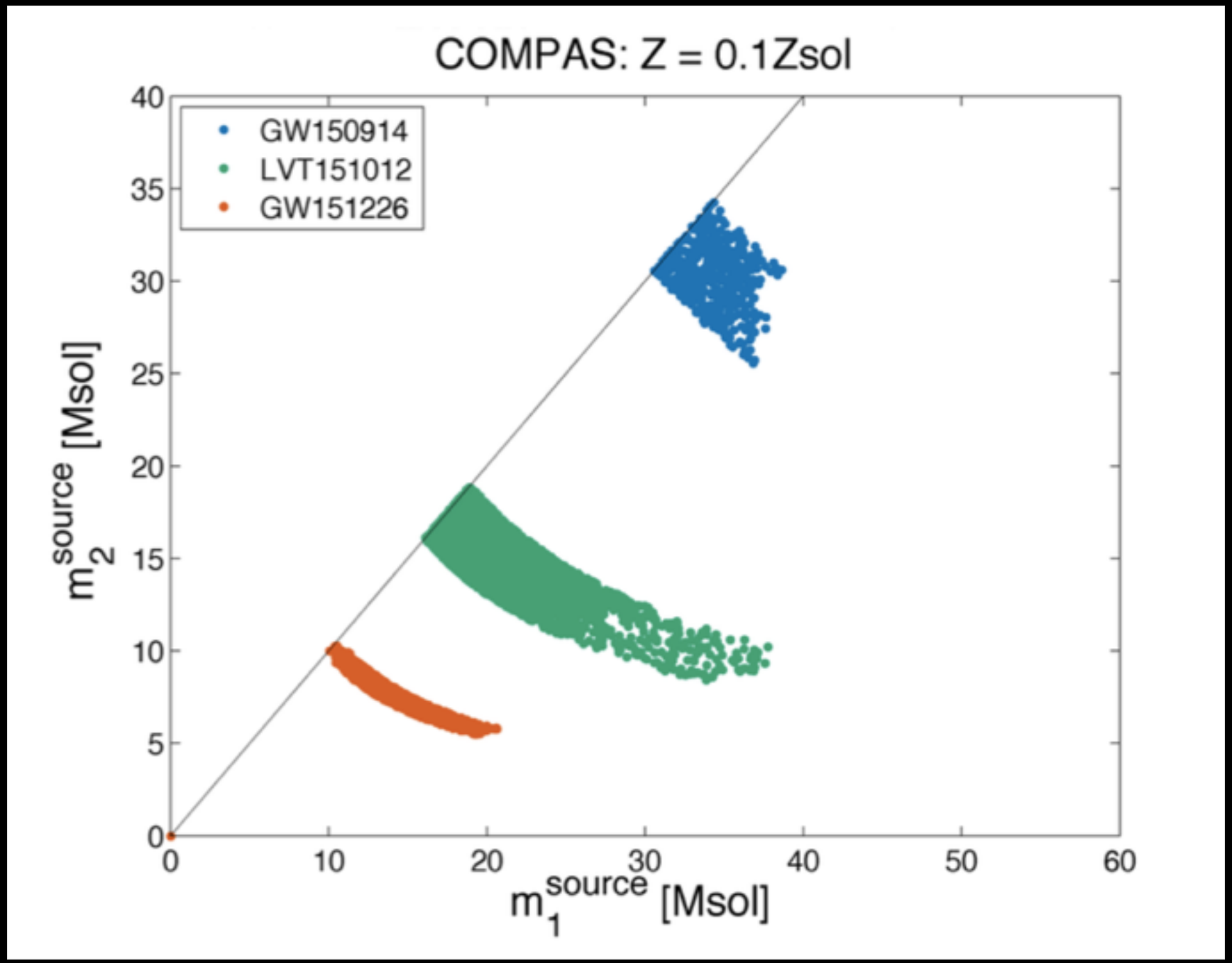
- Key questions:
  - What are the robust predictions we can use to test the theory?
  - What combinations of hyper-parameters are measurable from observations?
  - How many observations do we need to make progress?
- Key tools:
  - Plug and play population synthesis code developed with astrostatistics in mind
  - Interpolation tools
  - Population reconstruction and inference tools
  - Clustering tools

Population Synthesis



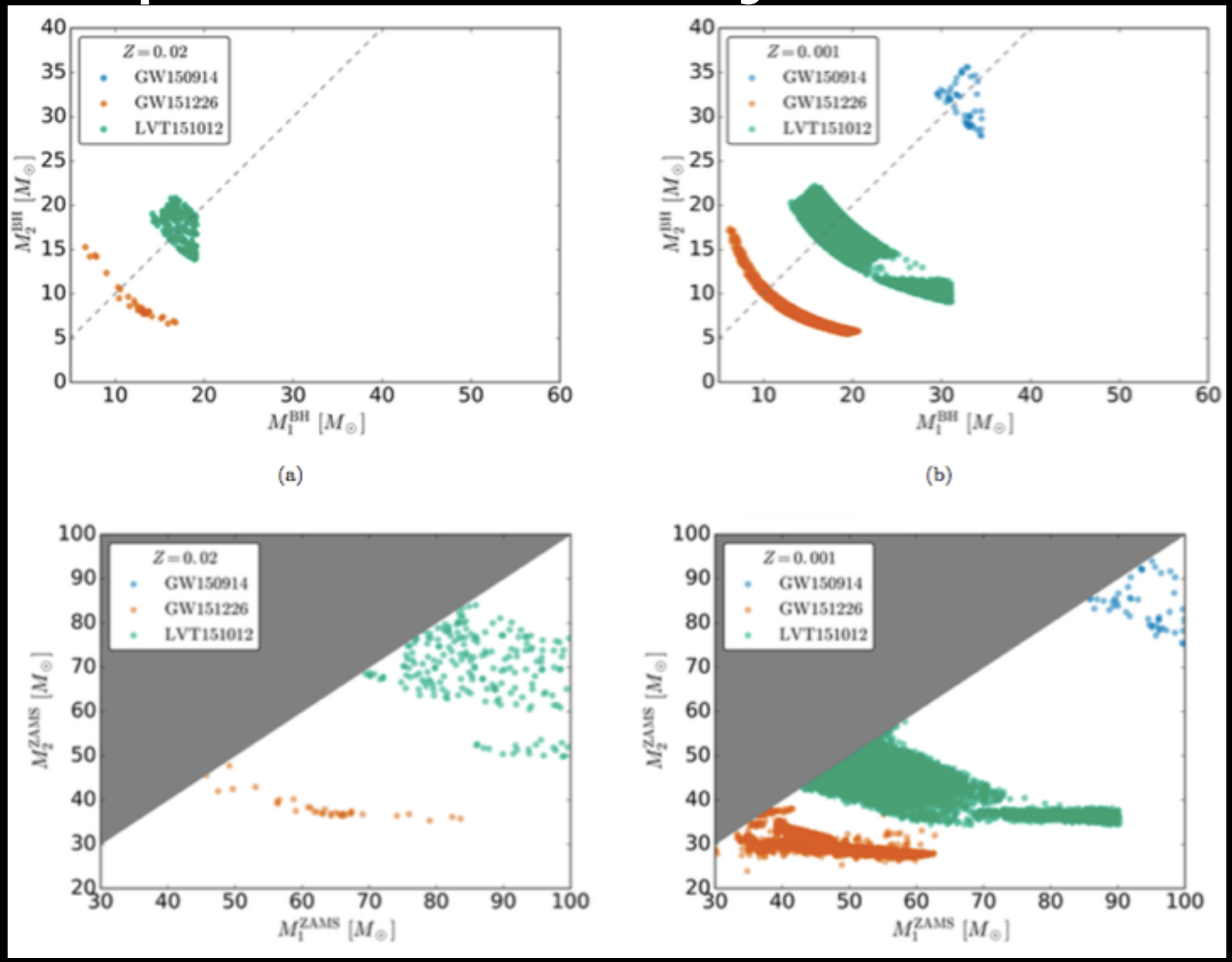
Abbott+ (LVC), 2016

Population Synthesis



Stevenson, Vigna Gomez, Mandel, Perkins, Barrett, de Mink, 2016

Population Synthesis



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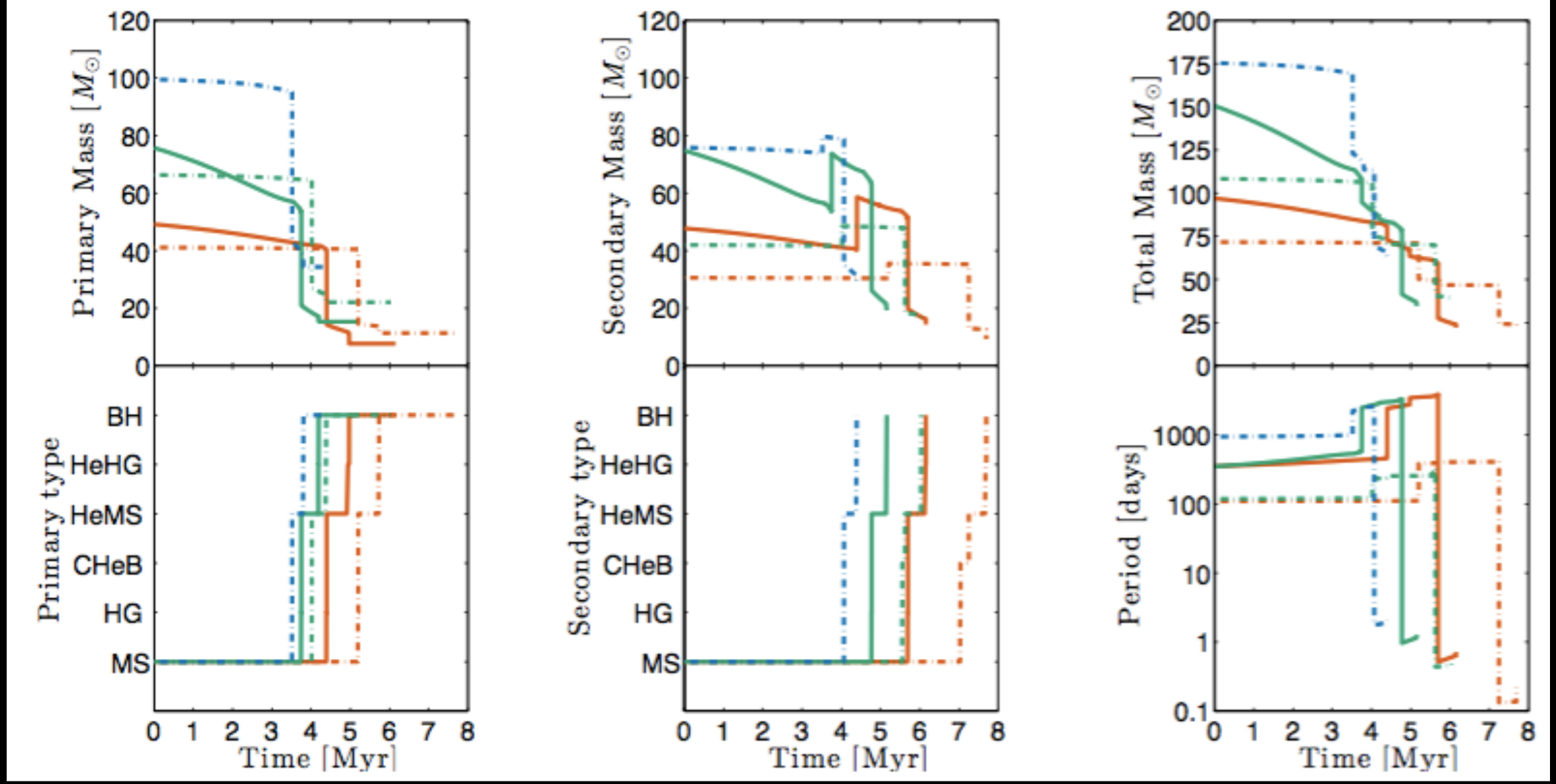
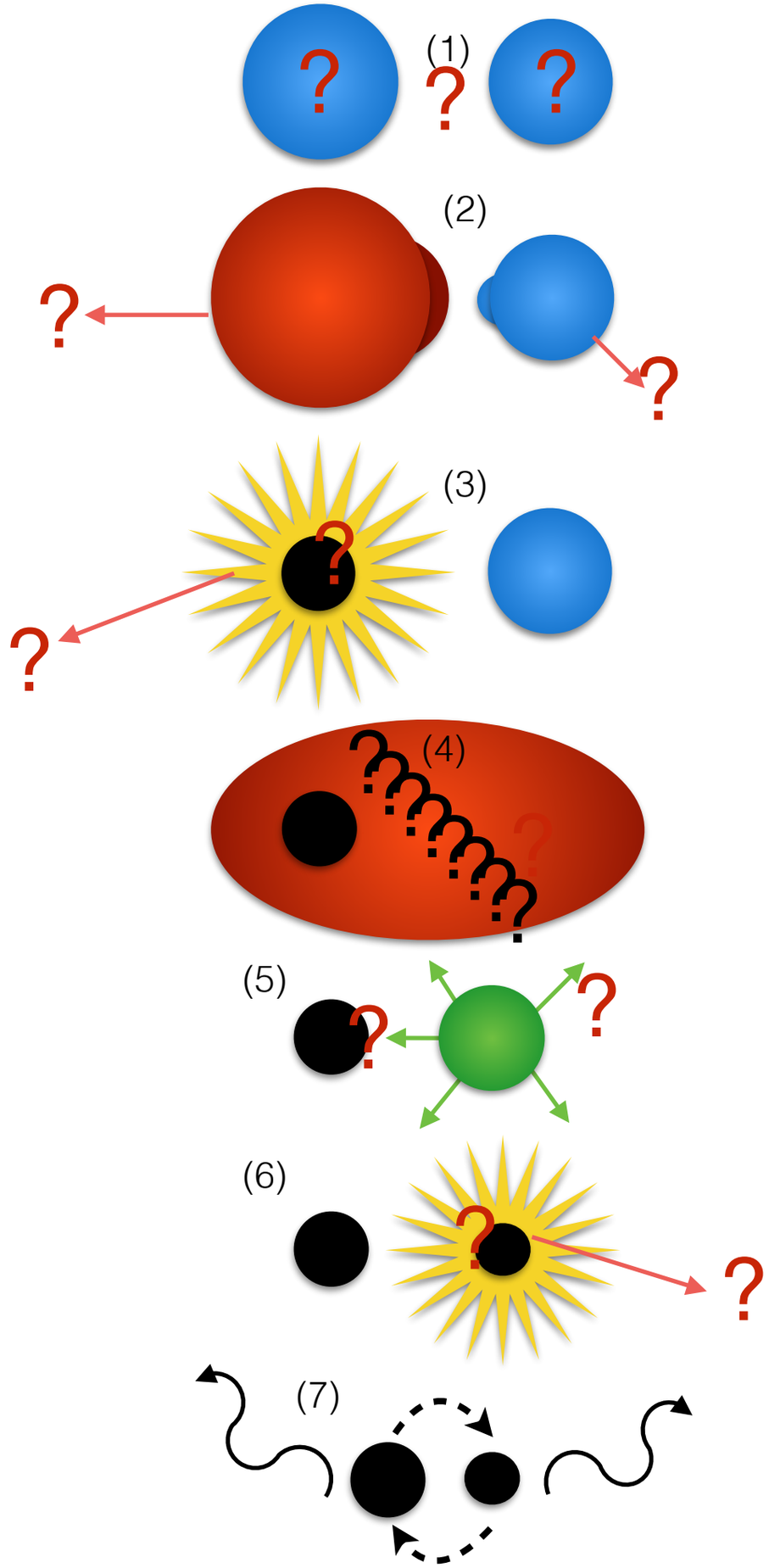


Stevenson, Vigna Gomez, Mandel, Perkins, Barrett, de Mink, 2016

Interpolation

Stevenson, Vigna Gomez, Mandel, Perkins, Barrett, de Mink, 2016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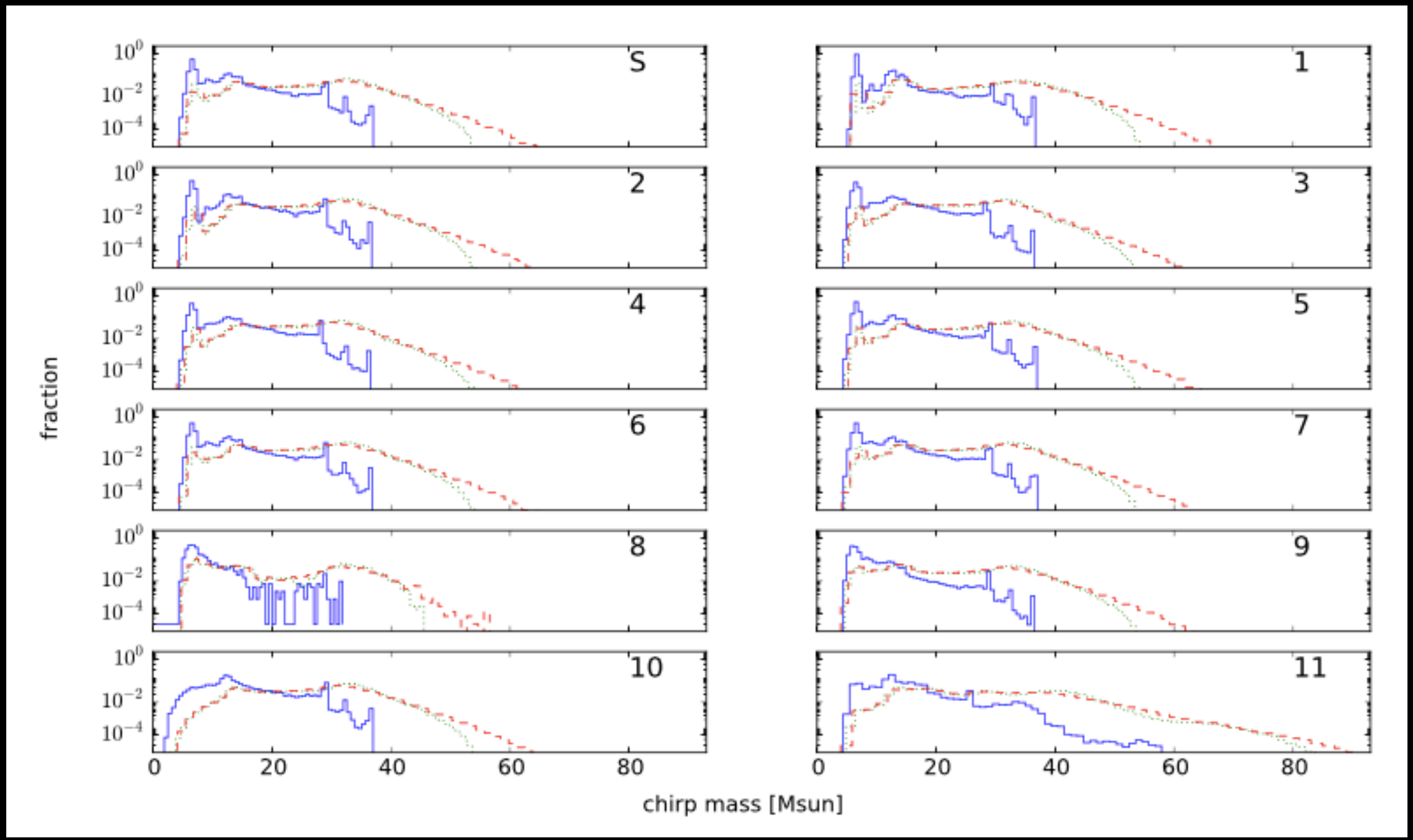
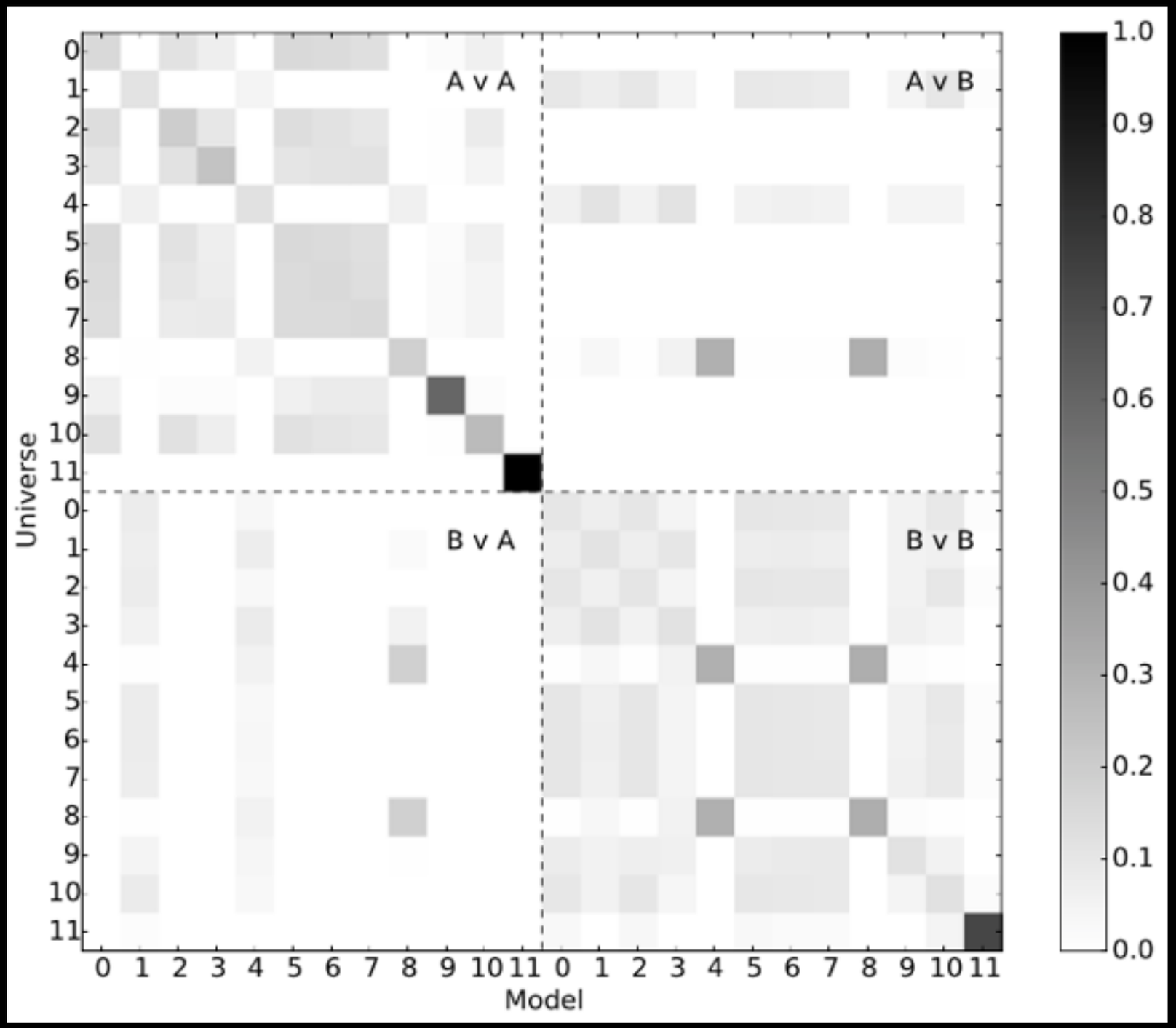
Interpolation



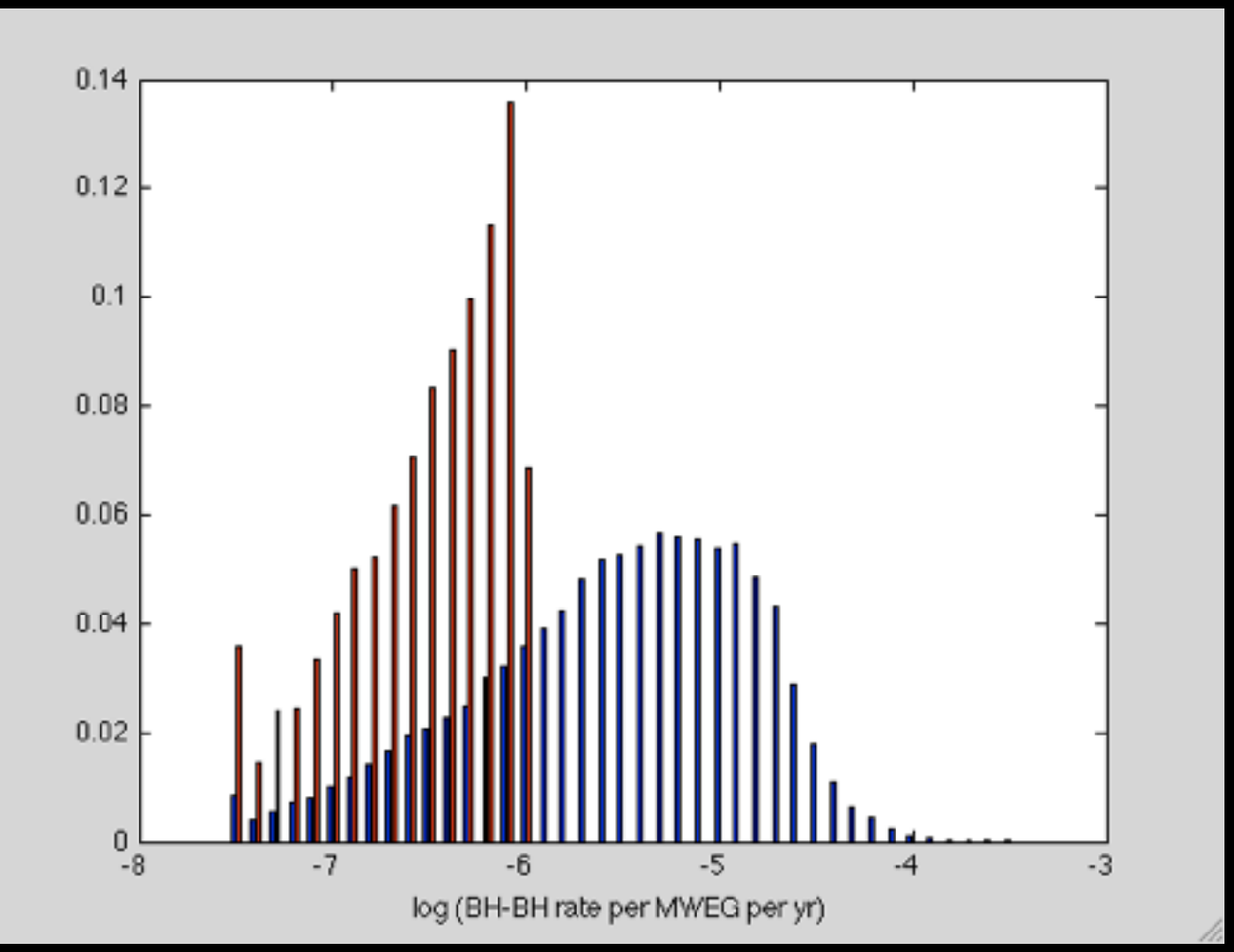
Stevenson+ 2015, from Dominik+ 2012

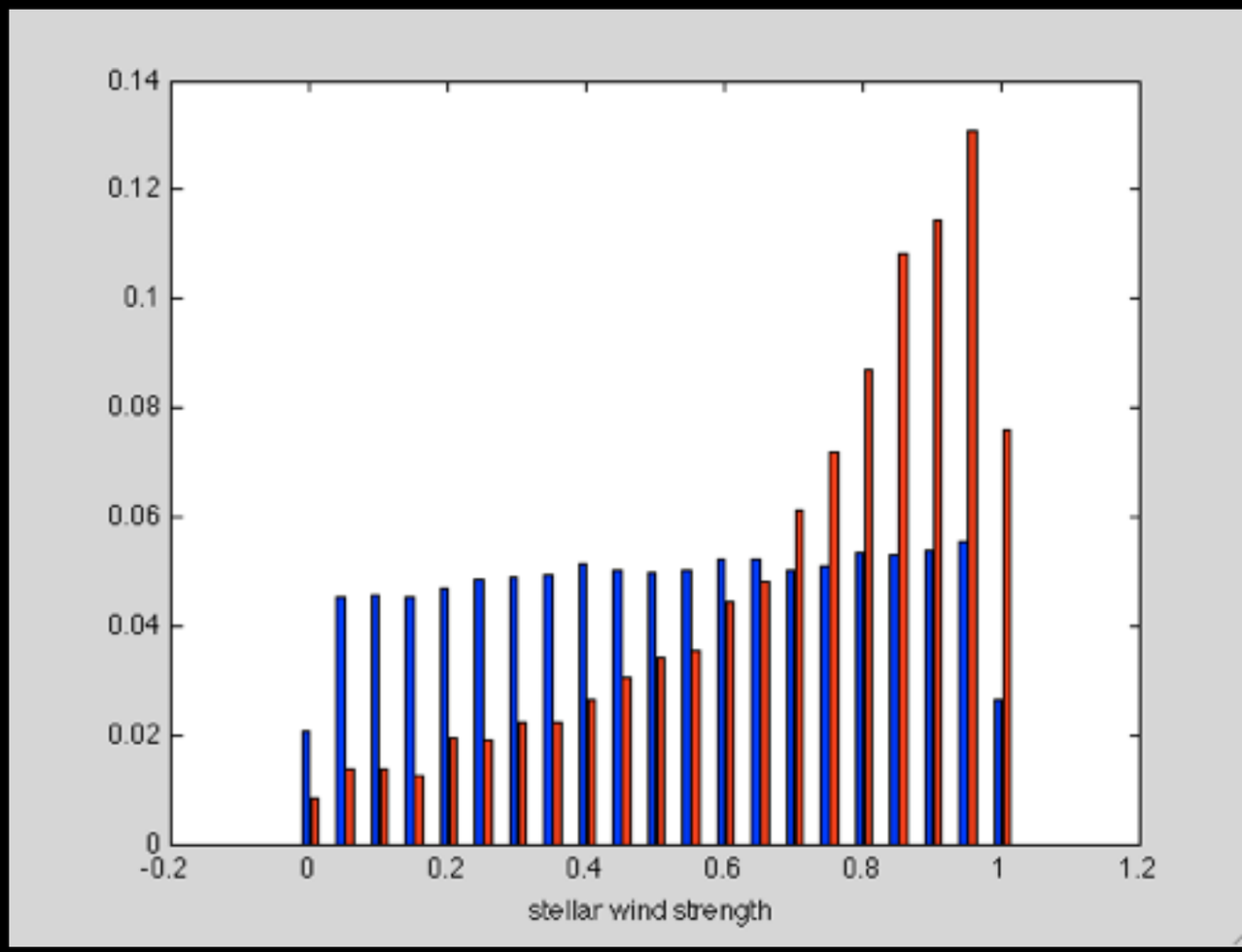
Interpolation



Stevenson+ 2015

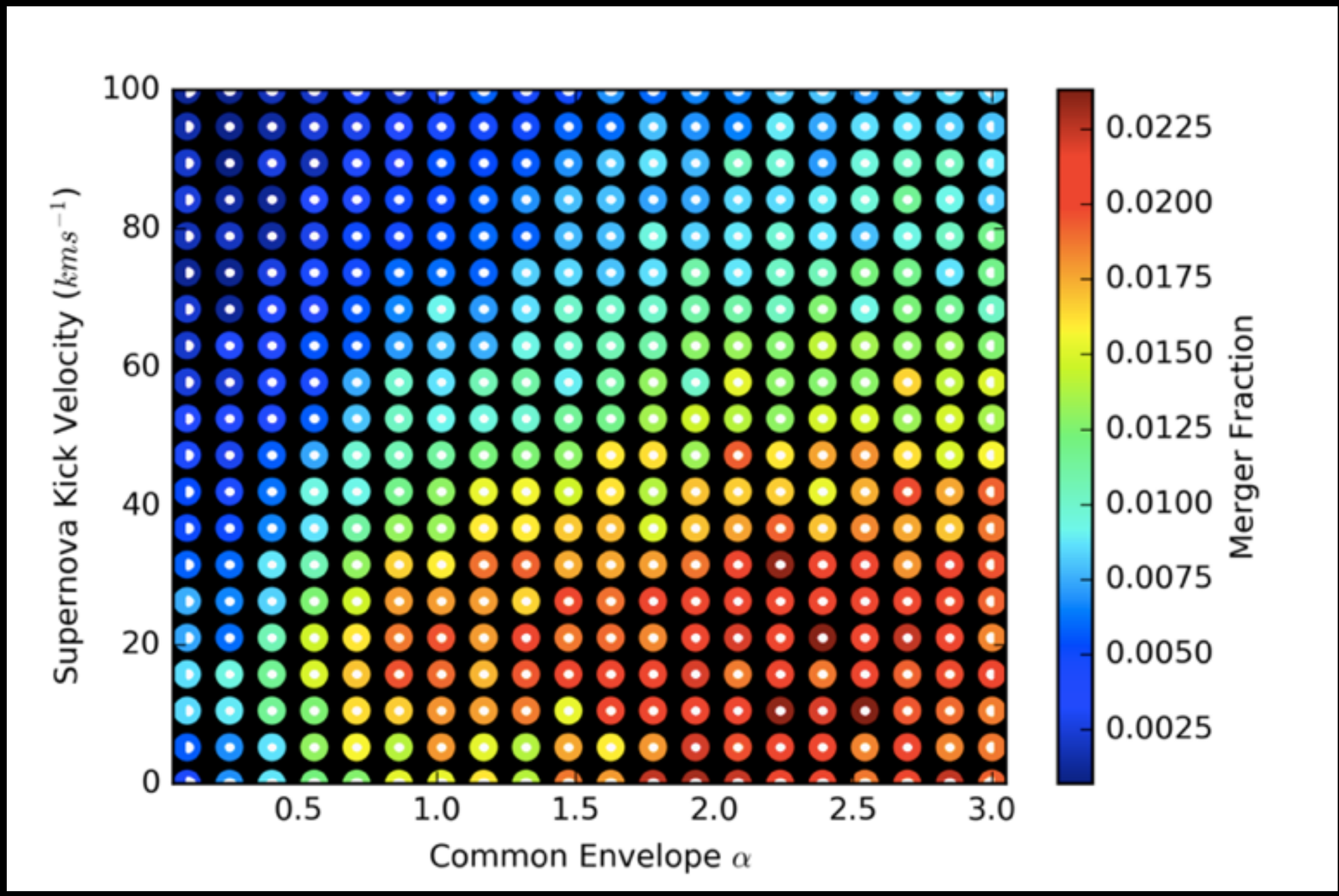
Interpolation





Mandel & O'Shaughnessy, 2010

Interpolation



Barrett et al., in prep.

Population Reconstruction

- Selection effects and measurement uncertainty

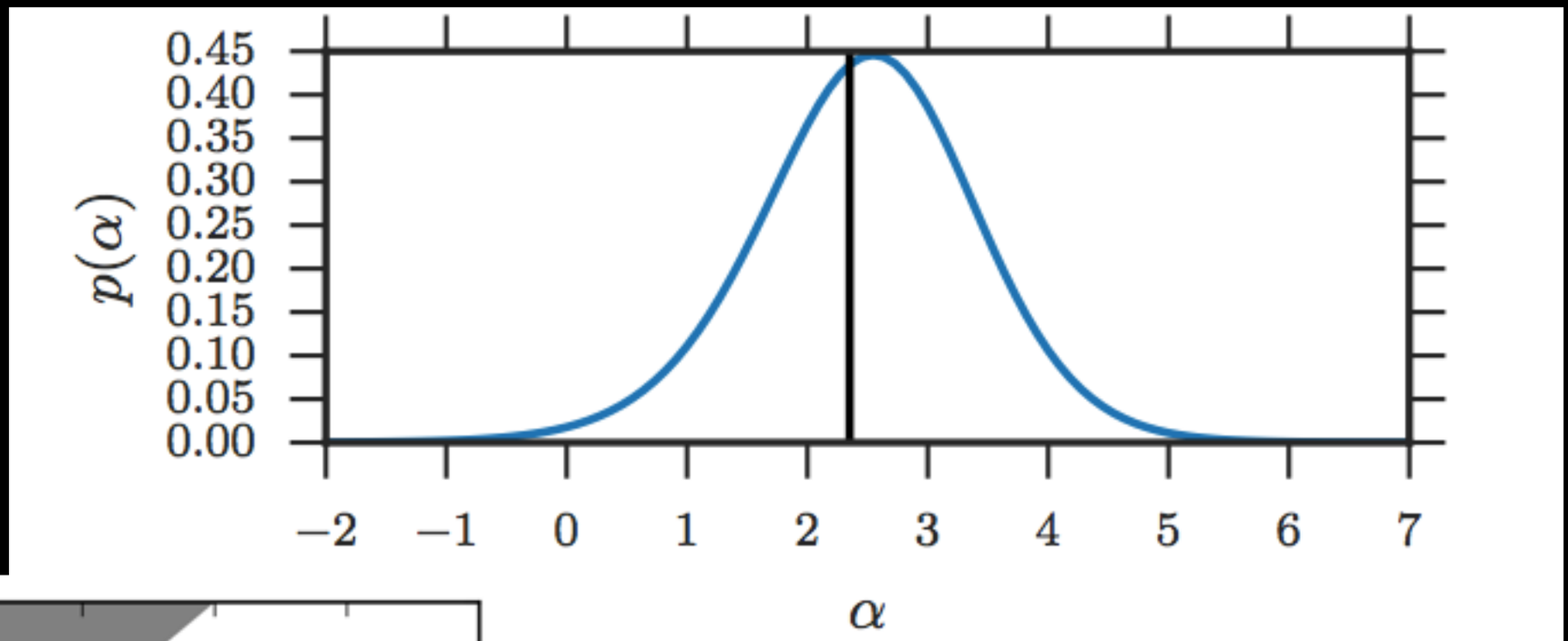
$$p(\{\vec{d}^{(i)}\}|\vec{\lambda}) = \prod_{i=1}^{k} \frac{\int d\vec{\theta} p(\vec{d}^{(i)}|\vec{\theta}) p_{\rm pop}(\vec{\theta}|\vec{\lambda})}{\int d\vec{\theta} p_{\rm det}(\theta) p_{\rm pop}(\vec{\theta}|\vec{\lambda})}$$

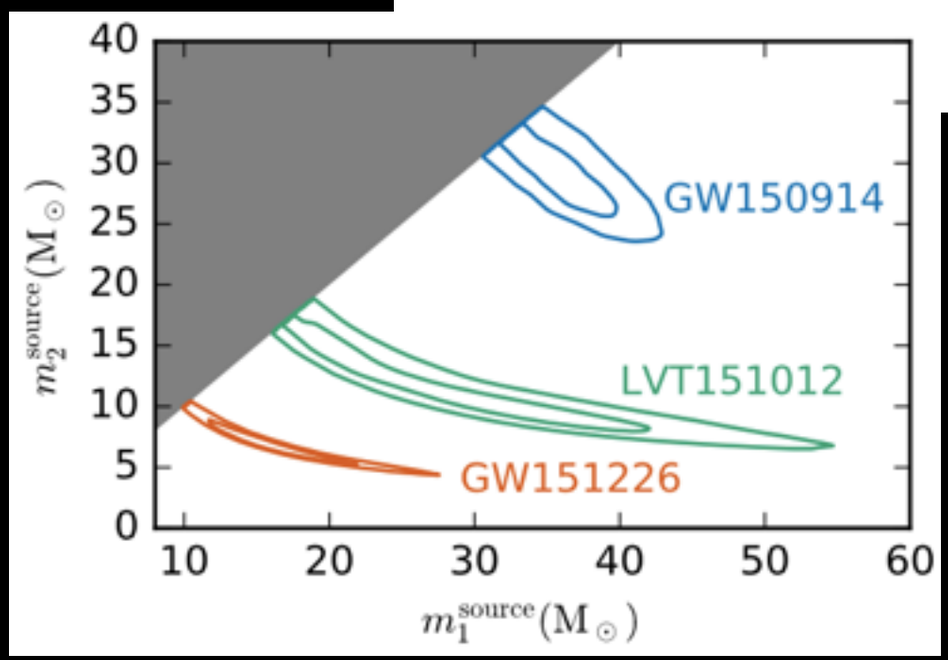
Mandel, Farr, Gair, in prep.

- [Counting and confusion — Farr, Gair, Mandel, Cutler, 2015]

Population Reconstruction

$p(m_1) \propto m_1^{-\alpha}$ flat q

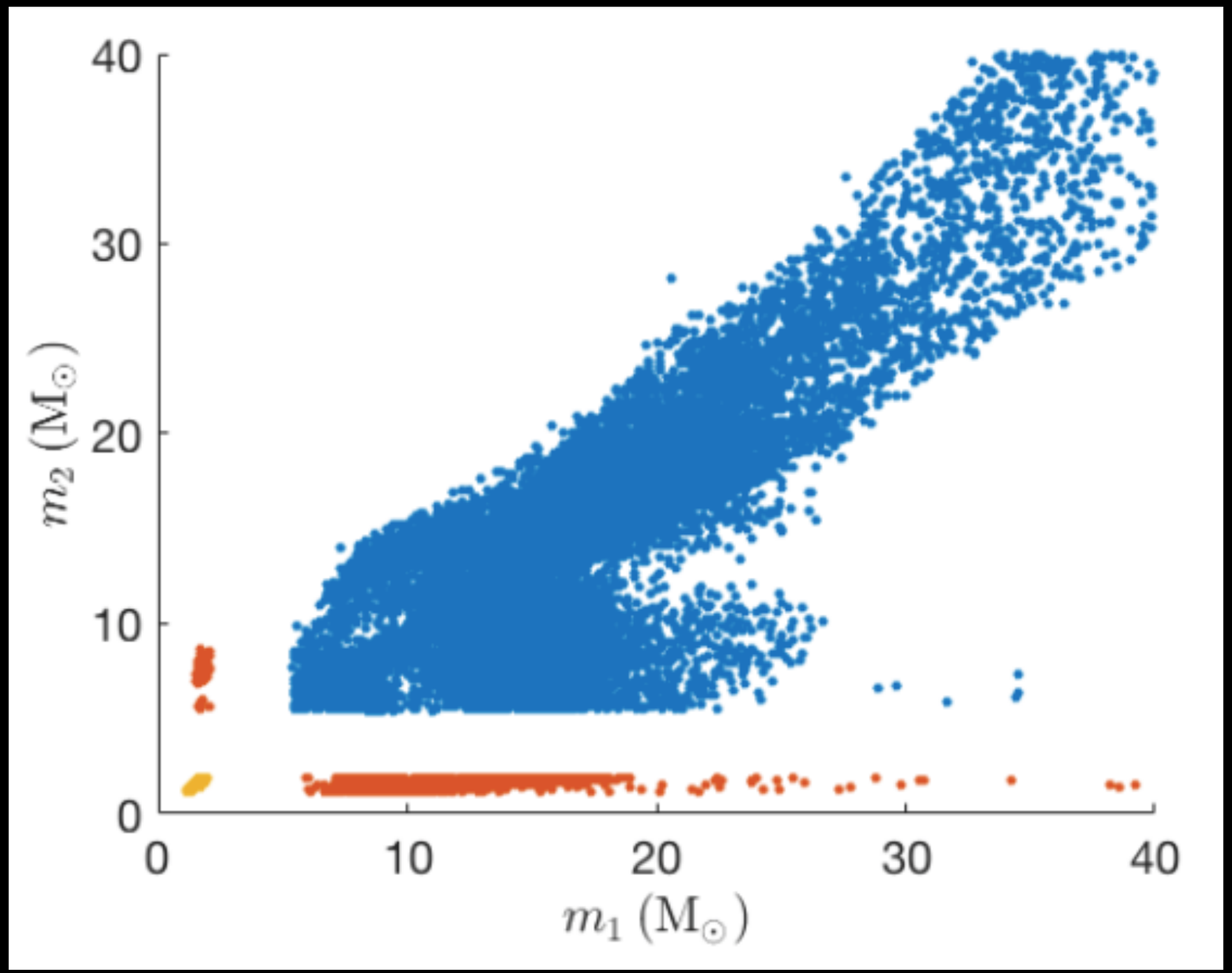




Abbott+ (LVC), 2016

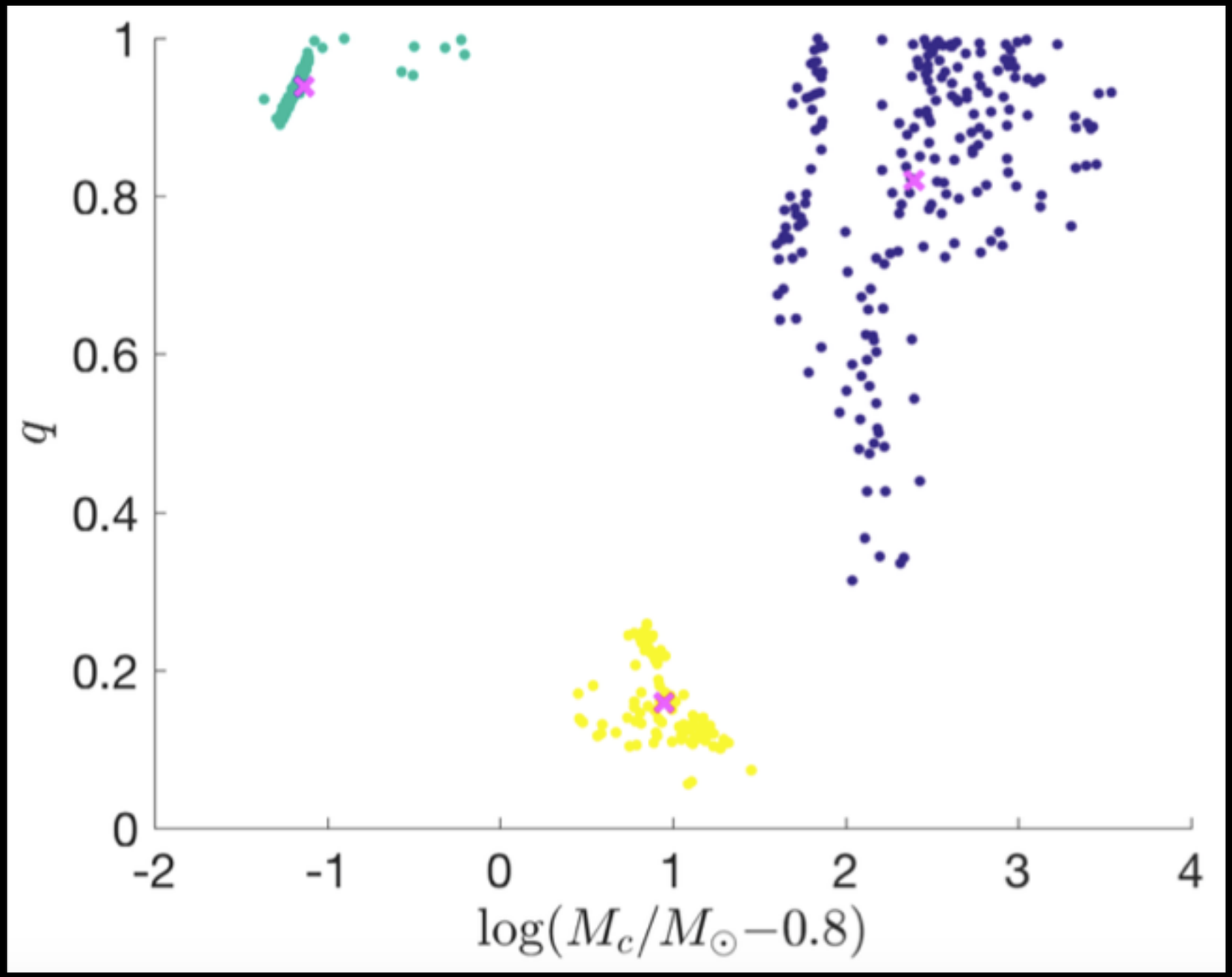
$h(f) \sim M^{5/6} \Rightarrow V \sim M^{2.5}$

Unmodeled Inference: Binary population clustering



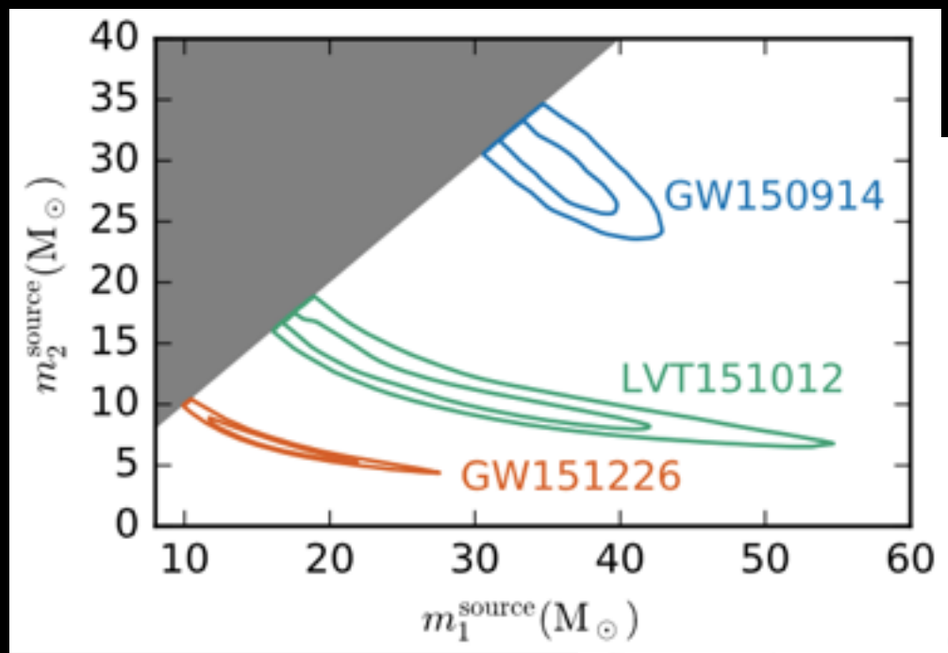
[Mandel et al., 2015; Dominik et al., 2015; Stevenson et al., 2016]

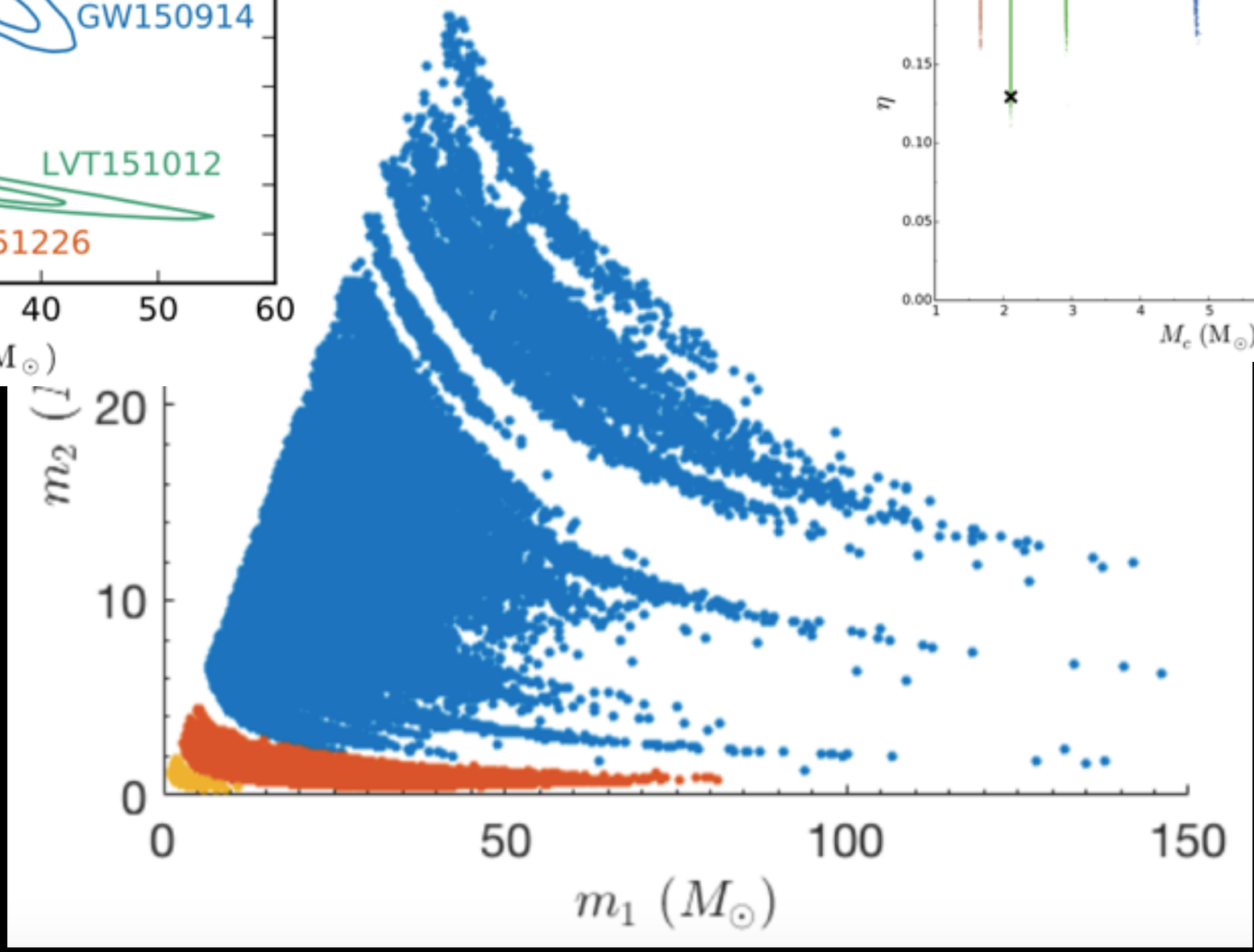
K-means clustering on perfect measurements

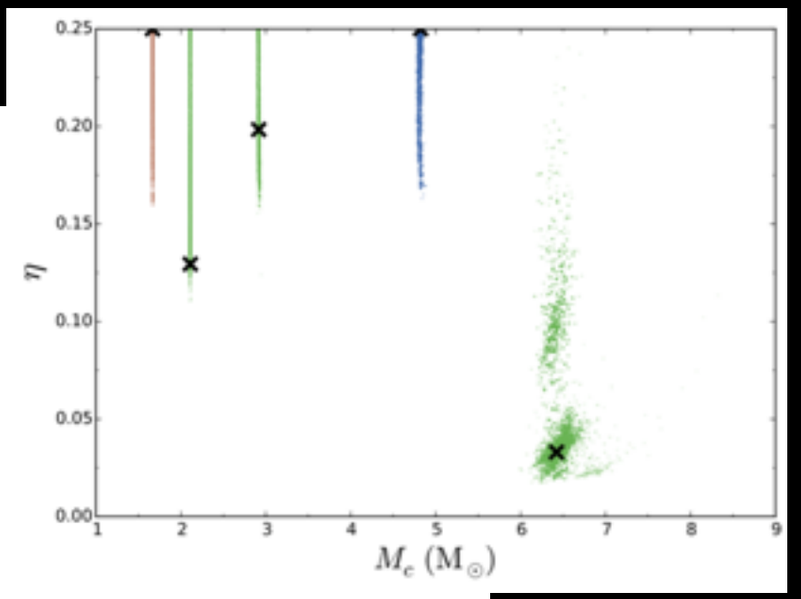


Mandel et al., 2016

Measurement uncertainty



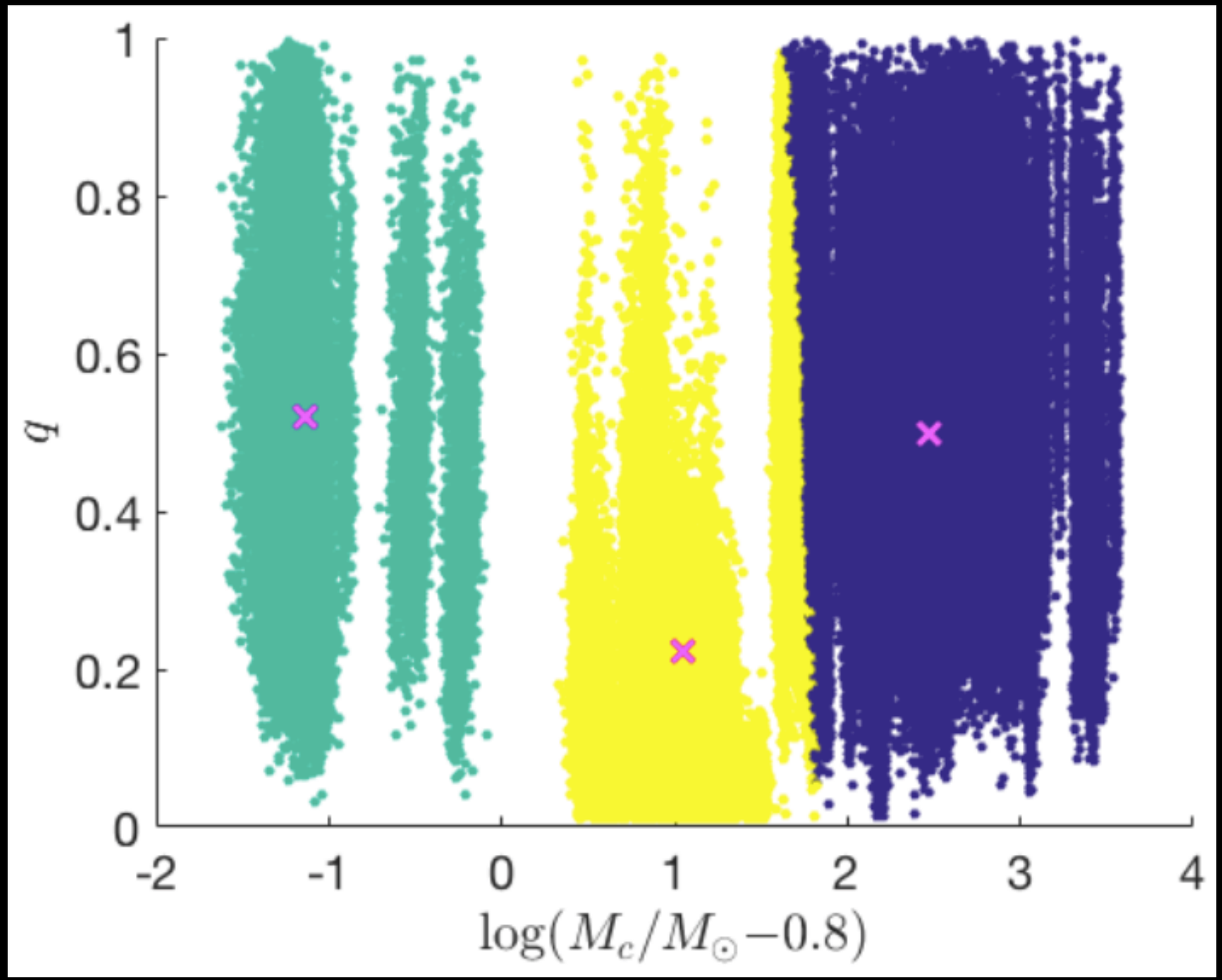




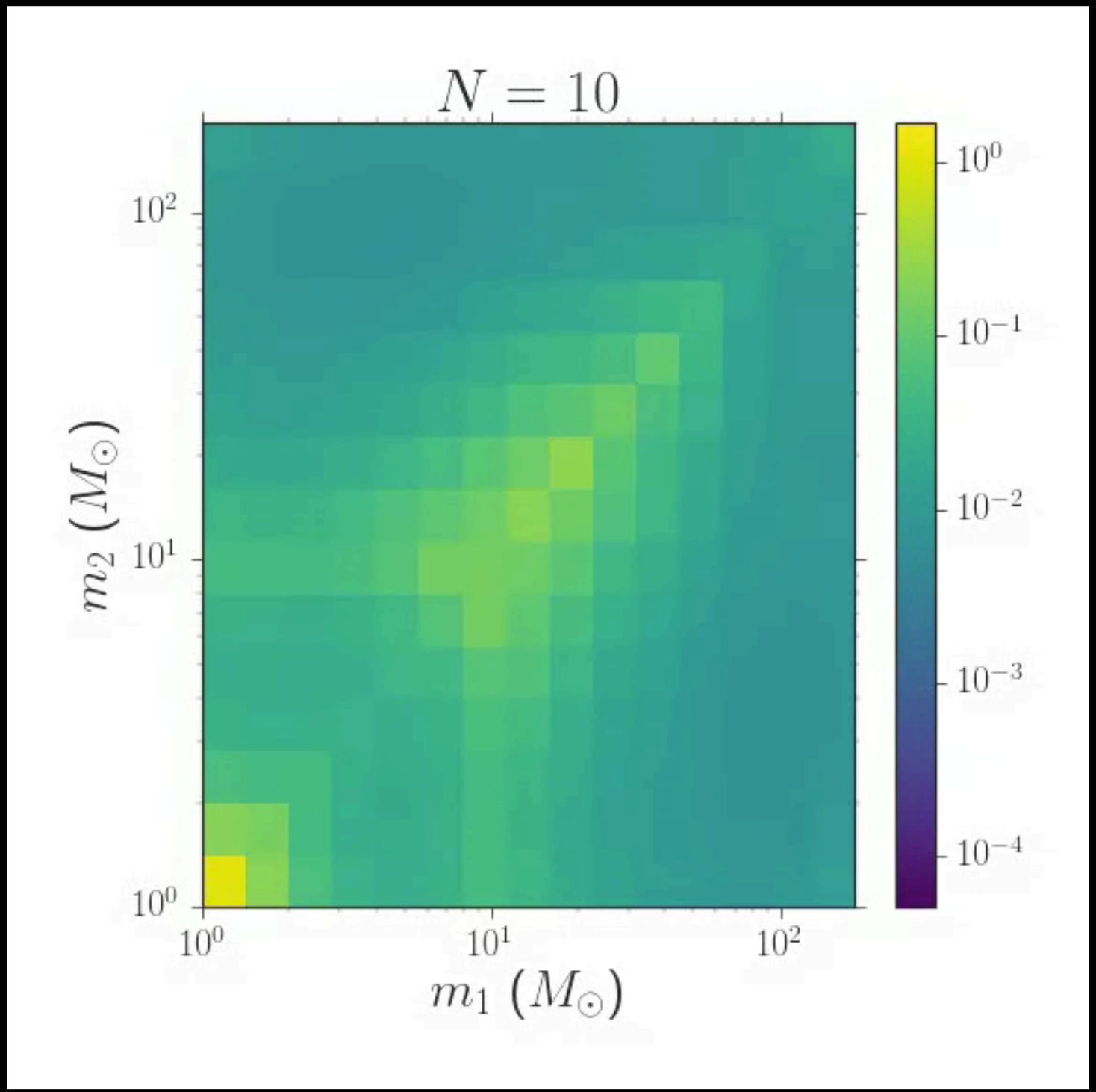
[Abbott et al., 2016; Mandel et al., 2015; see also Littenberg et al., 2015]

Unmodeled Inference

Clustering on opened bags of posterior samples



Mean inferred bin density



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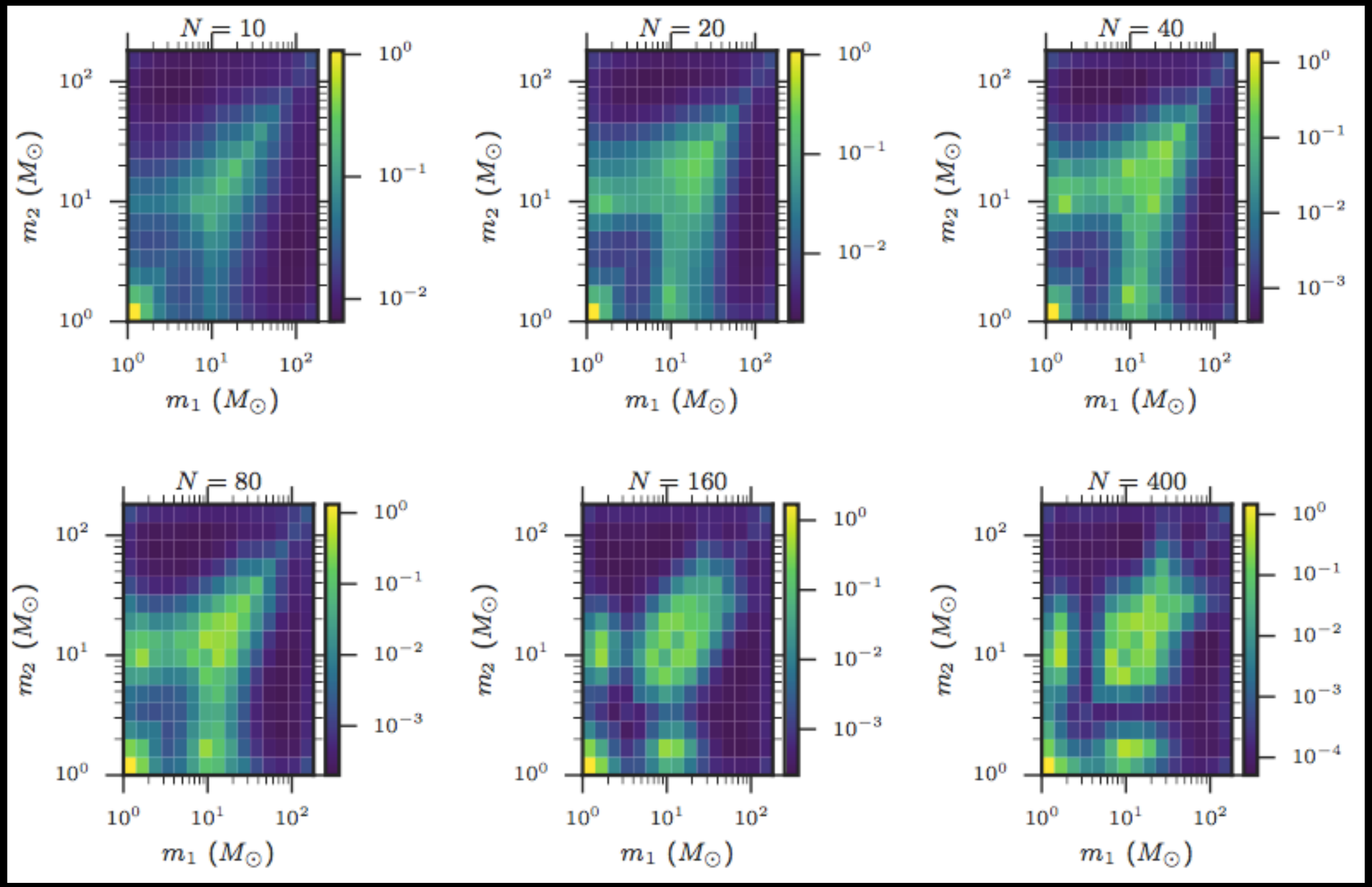
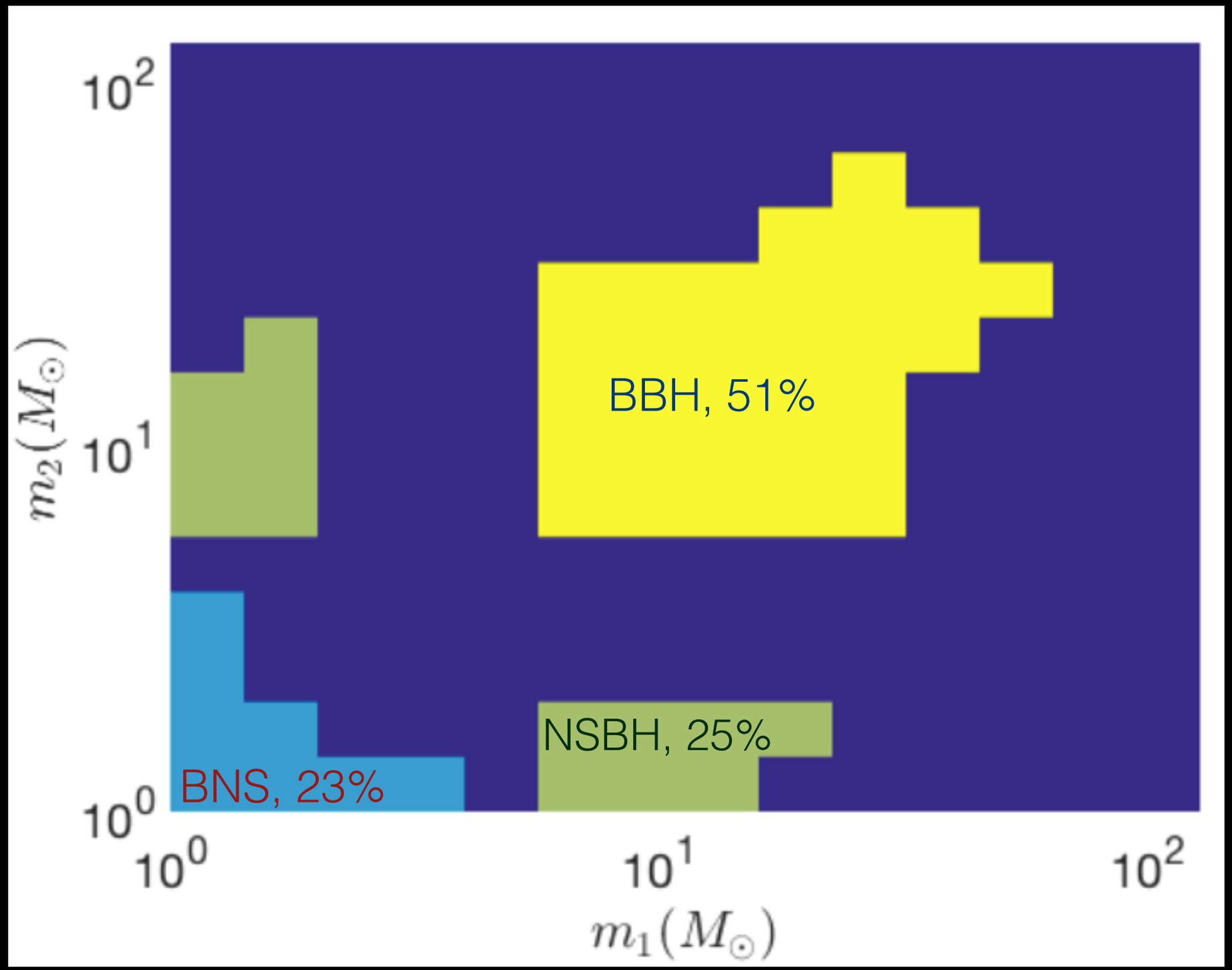
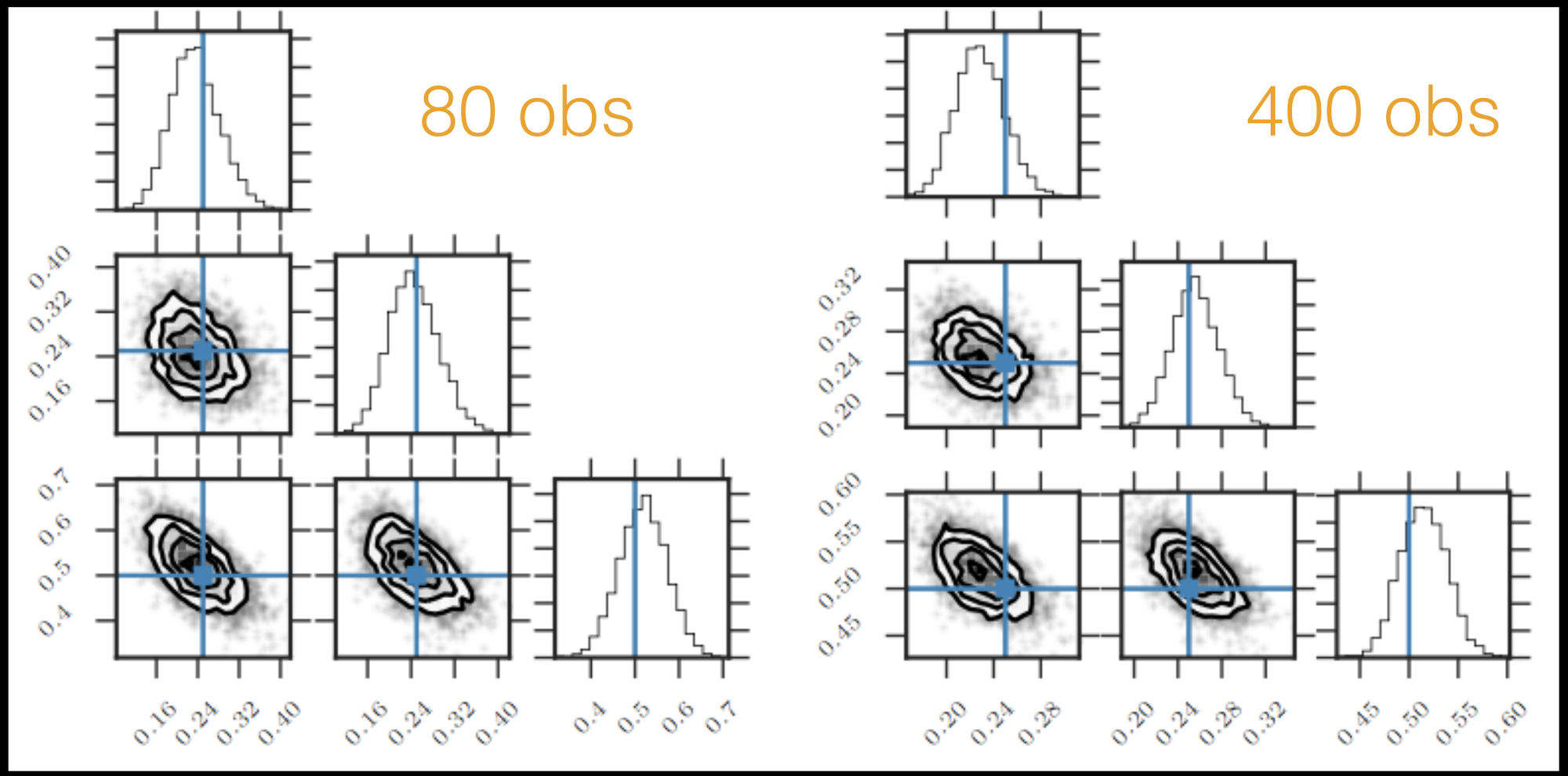


Water filling on mean density



Unmodeled Inference



Future

- Bring together modelling and astrostatistics
- Figure out what questions we can realistically answer… and answer them!
- Use full observation set — concordance binary evolution?