NORTHWESTERN UNIVERSITY

CIERA

Informing Astrophysics With Gravitational-wave Astronomy

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Open Questions

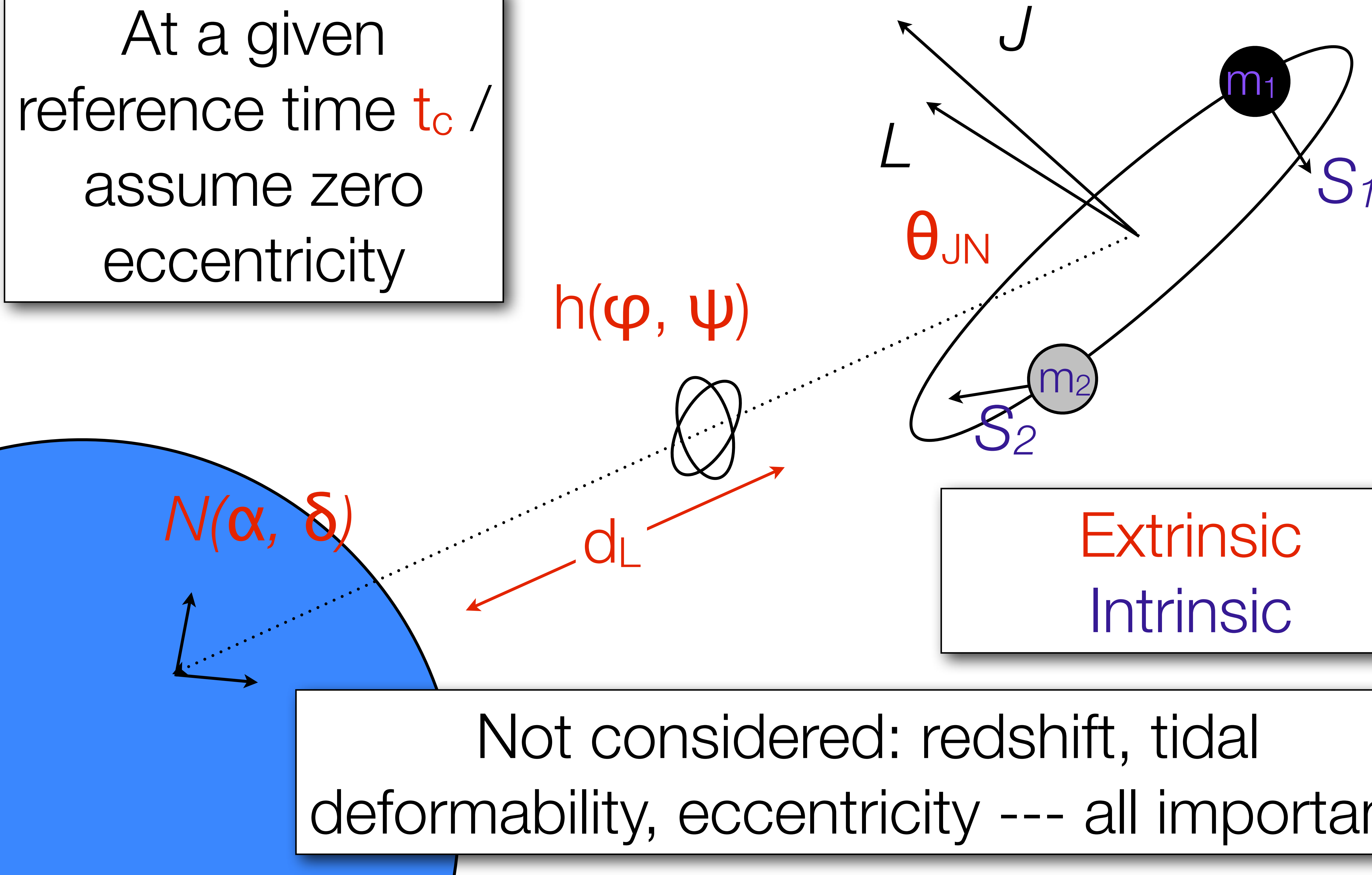
- Can population statements of BBH allow us to identify their origin and evolution channels?
- Can gravitational-wave observations **quickly** and **accurately** estimate parameters?
    - ...do biases need to be taken into account when reporting sky positions?
- Can gravitational-wave observation make definitive statements about the “mass gap”? Is the presence of a neutron star extricable from the measurement?
- Can electromagnetic observations, in turn, increase the precision with which we measure the physical properties of binaries?

Parameter Estimation and Correlation

- Measuring the properties (mass, spin, orientation) of the binaries is a complicated process: model space is wide, waveform models are often incomplete in at least one way, noise spectrum is not flat
    - Markovian, stochastic sampling has produced the most robust way of providing parameter estimates
- Even given its wide success, there are inherent biases because of correlations between parameters that arise from the covariant properties of the system in general relativity convolved with limited sensitivity
    - e.g. inability to resolve component masses in favor of chirp mass
- Focus on understanding and mitigation of these correlations in service of making population and astrophysically relevant measurements

System Parameterization

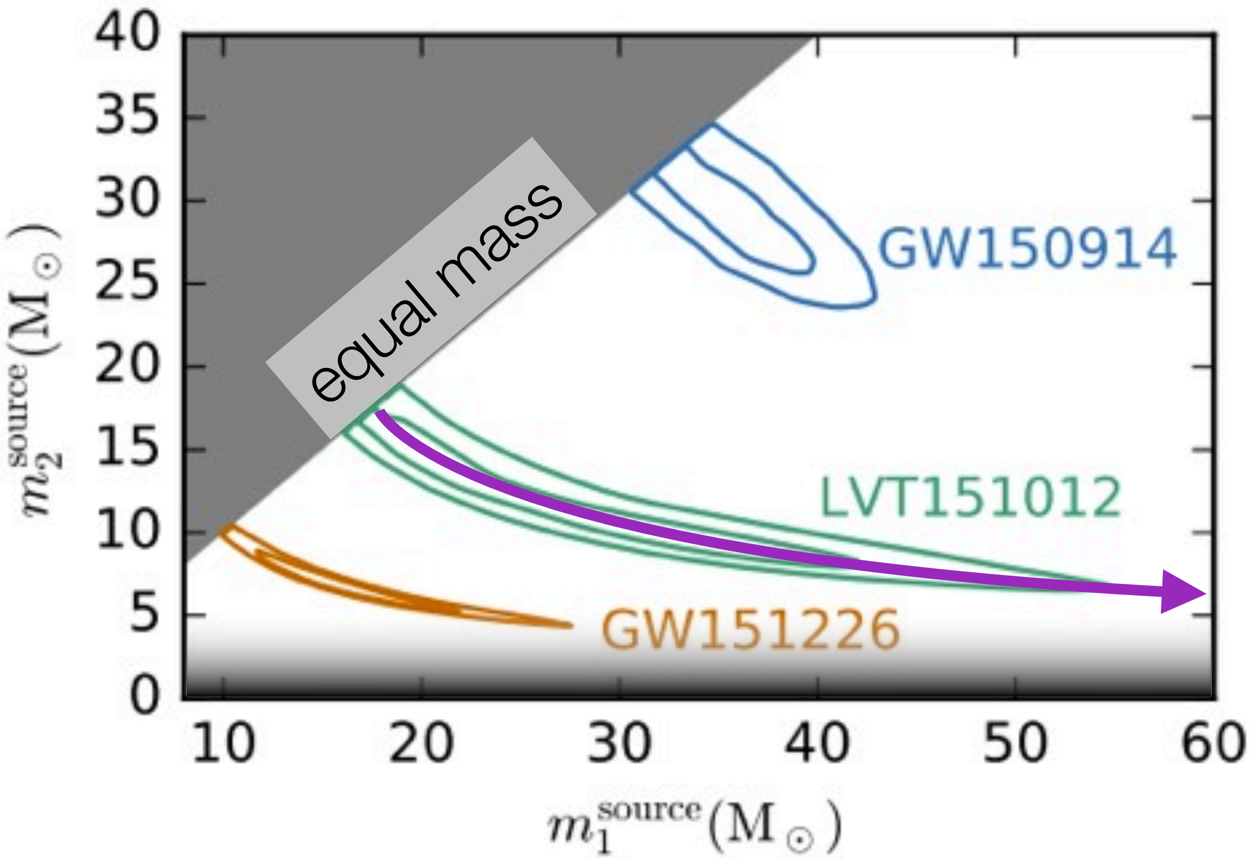
At a given reference time t_c / assume zero eccentricity



Extrinsic
Intrinsic

Not considered: redshift, tidal deformability, eccentricity --- all important!

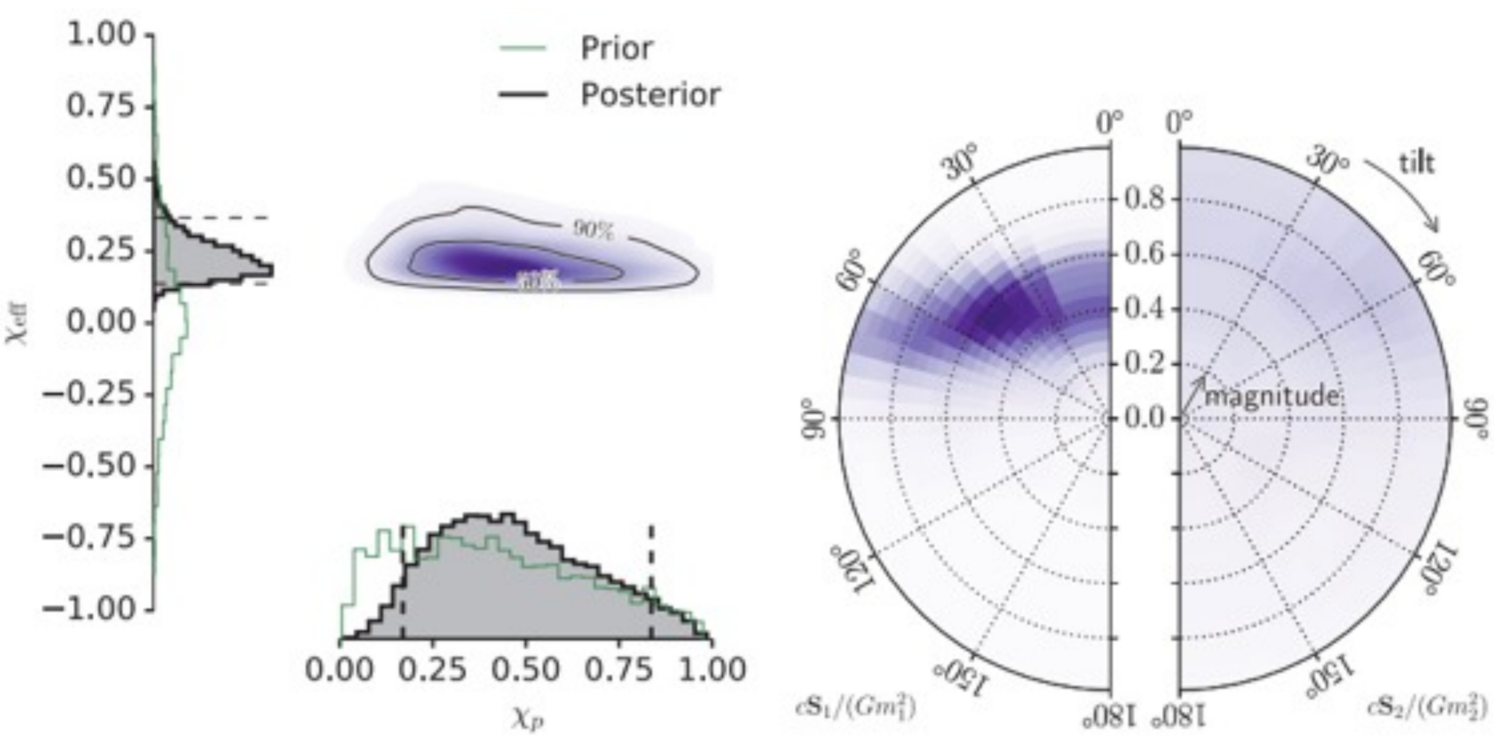
MCMC Param. Correlations: Masses and Spins



Parameter Degeneracies:
Primarily sensitive to the *chirp mass* — leaves **large degeneracies** along contours of chirp mass (**GW151226** approaching $m_2 < 3$ region)

$$\mathcal{M}_c = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

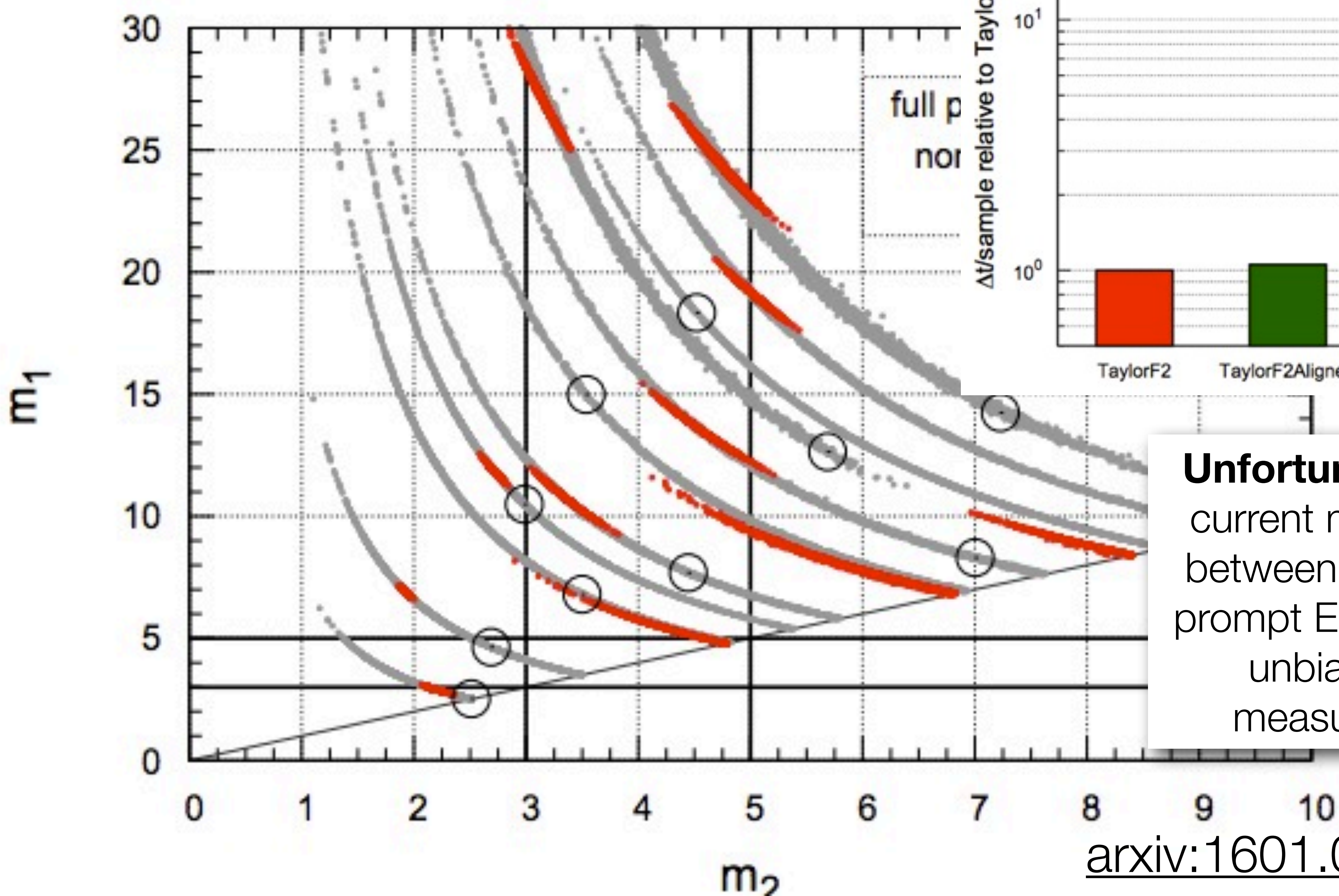
$$\chi_{\mathrm{eff}} = \frac{m_1 s_{1,z} + m_2 s_{2,z}}{m_1 + m_2}$$

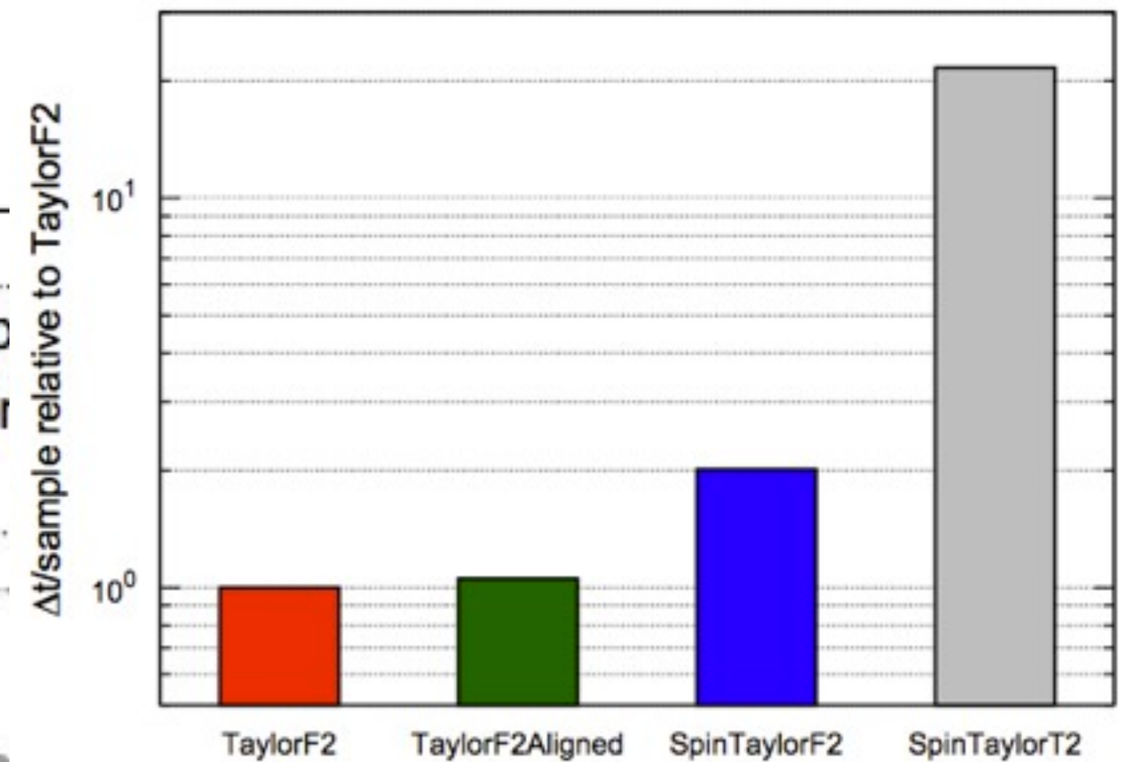


Frequency content (and thus “length in band” affected by both *effective spin* and *mass ratio* at same order in expansion of radiation amplitude/phase

Phys. Rev. Lett. 116/241103

Spin-Biases from Incomplete Models





Unfortunate Choice: With current models, the choice between speed (and hence prompt EM observation) and unbiased mass/spin measurement is tricky

arxiv:1601.02661

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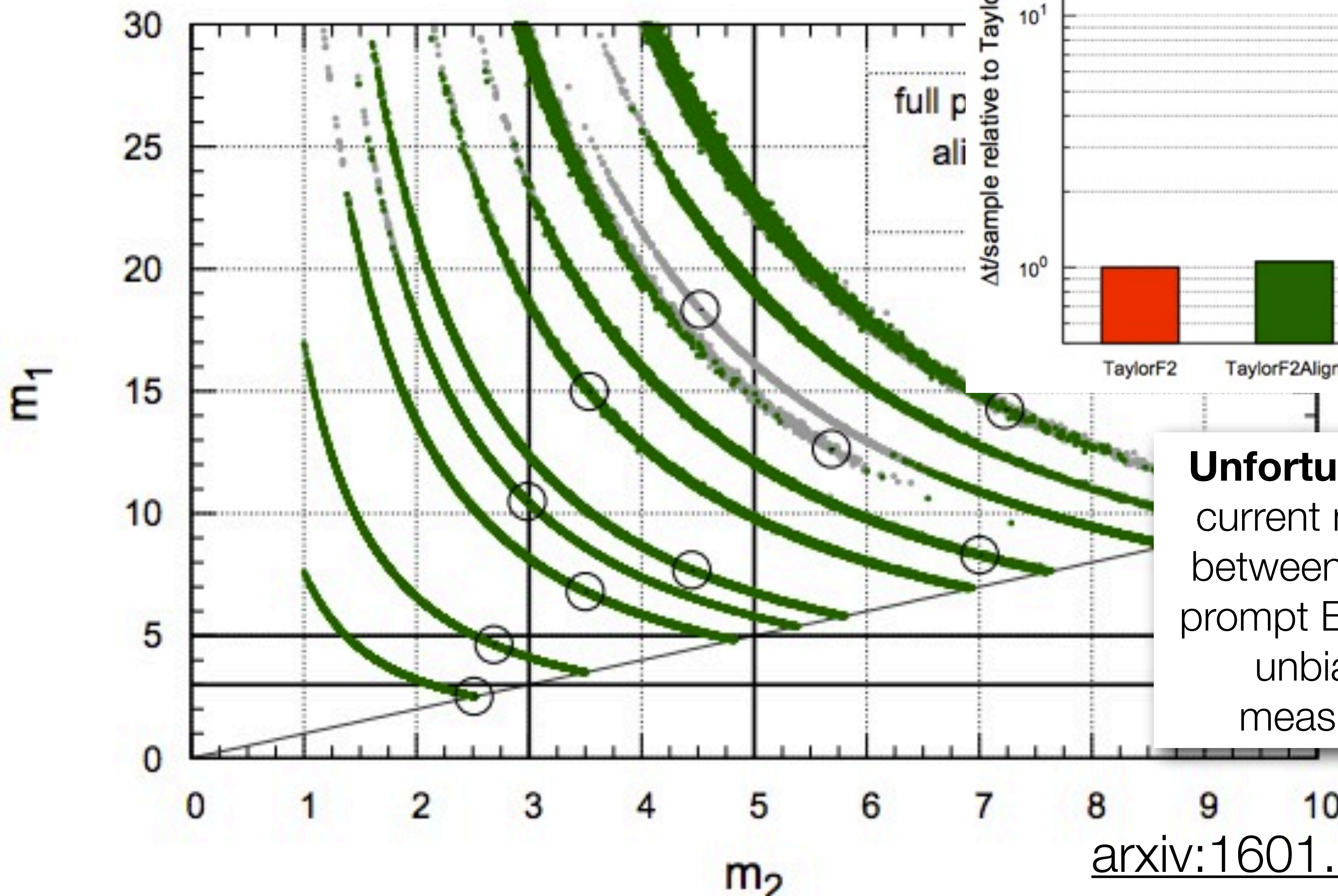

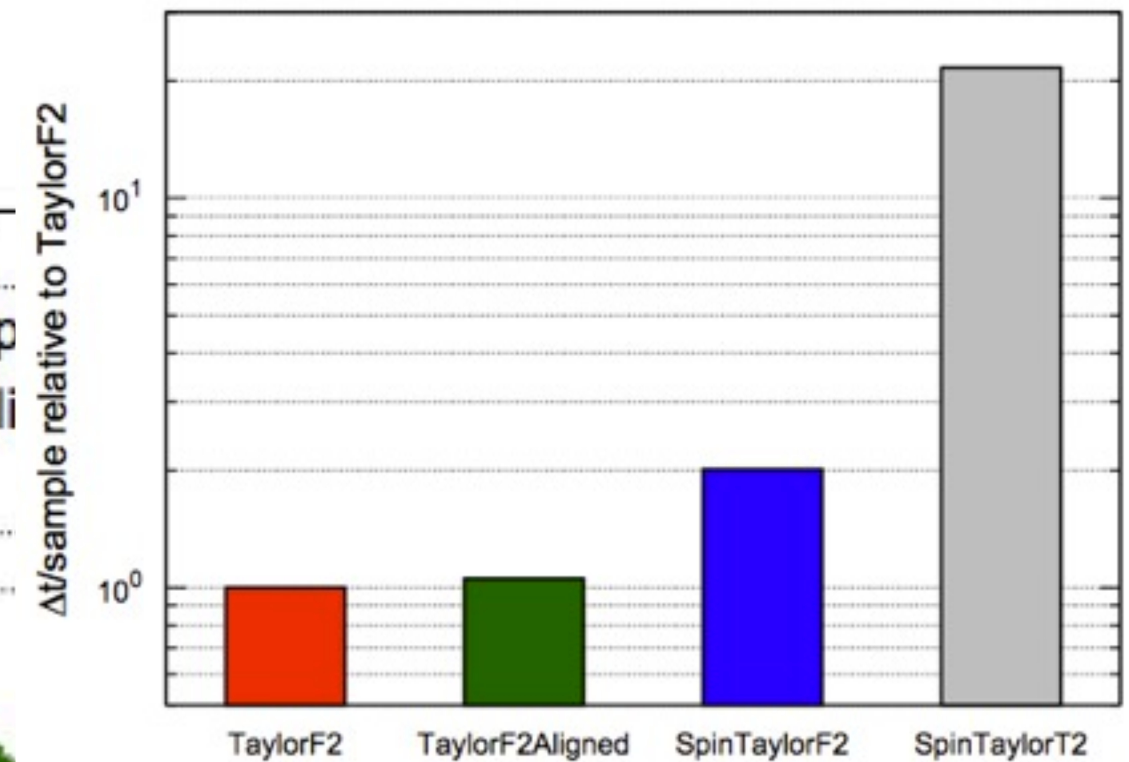

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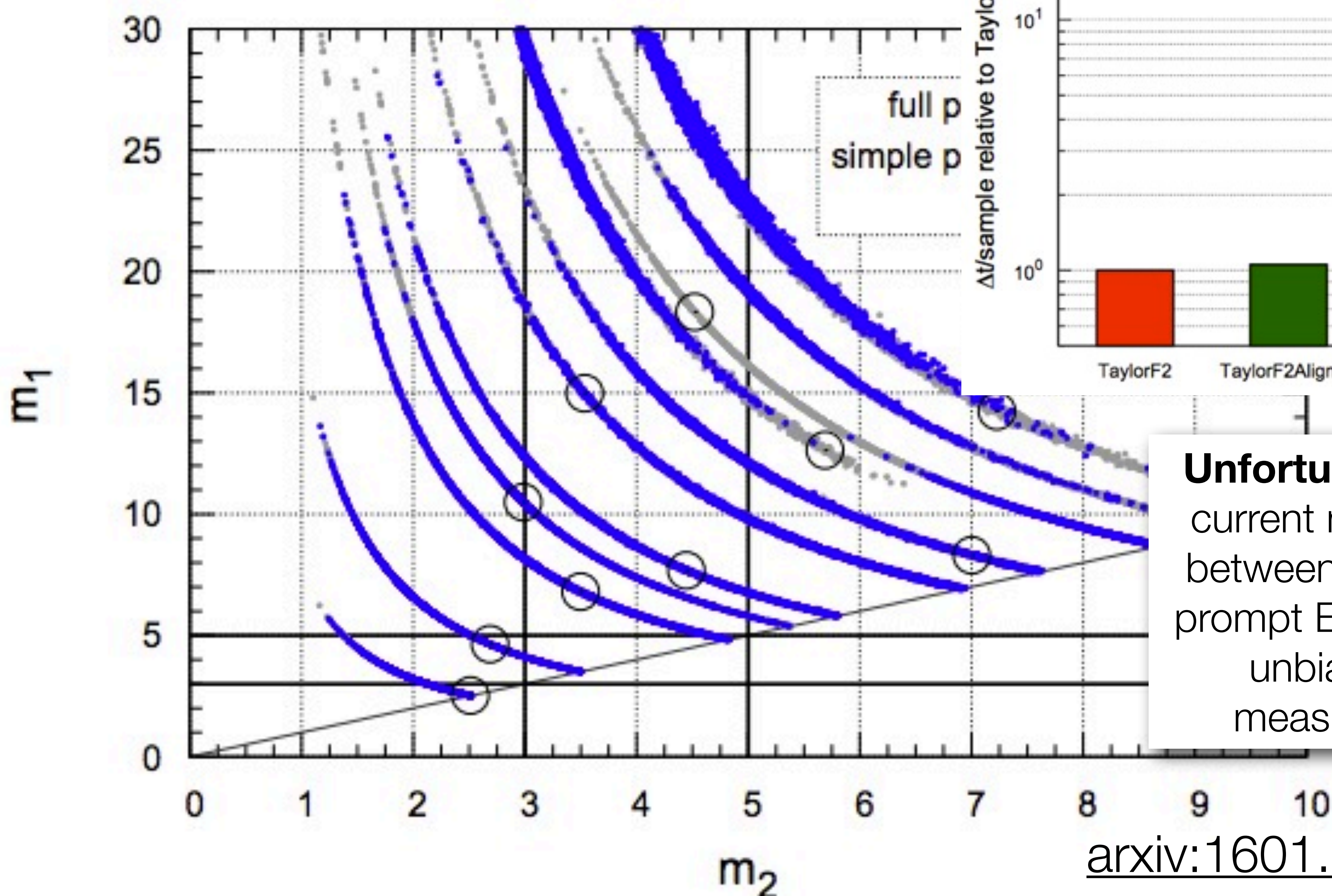

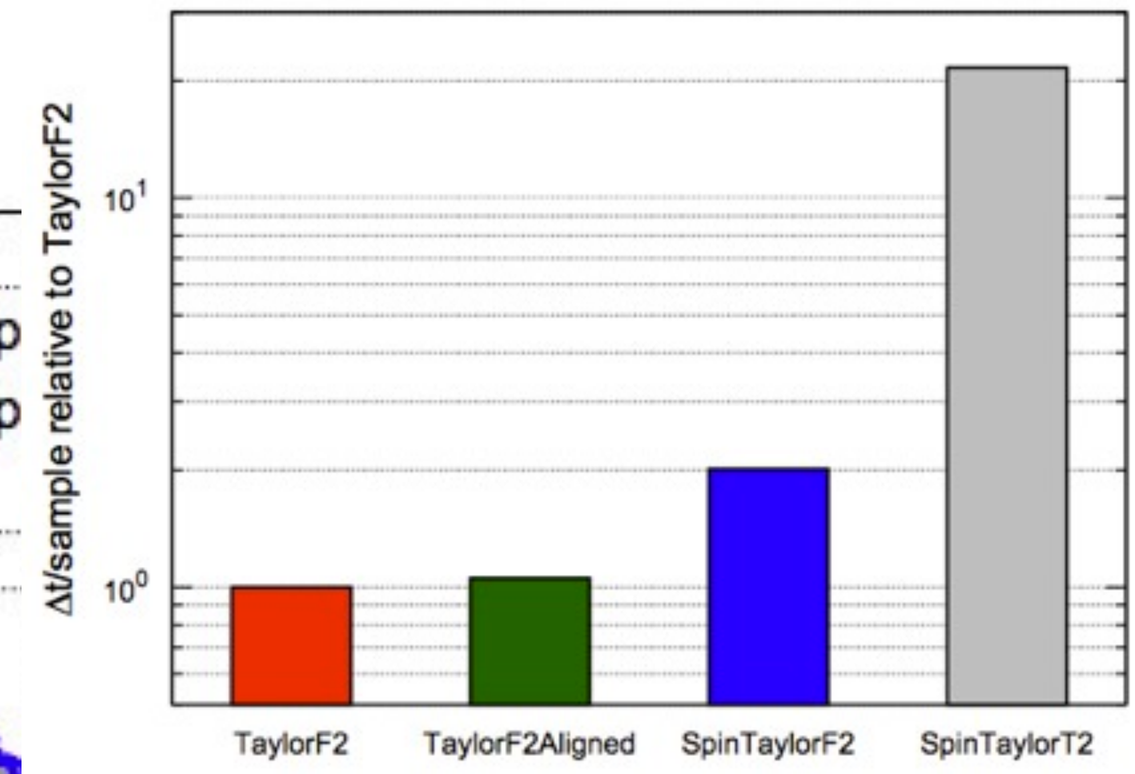

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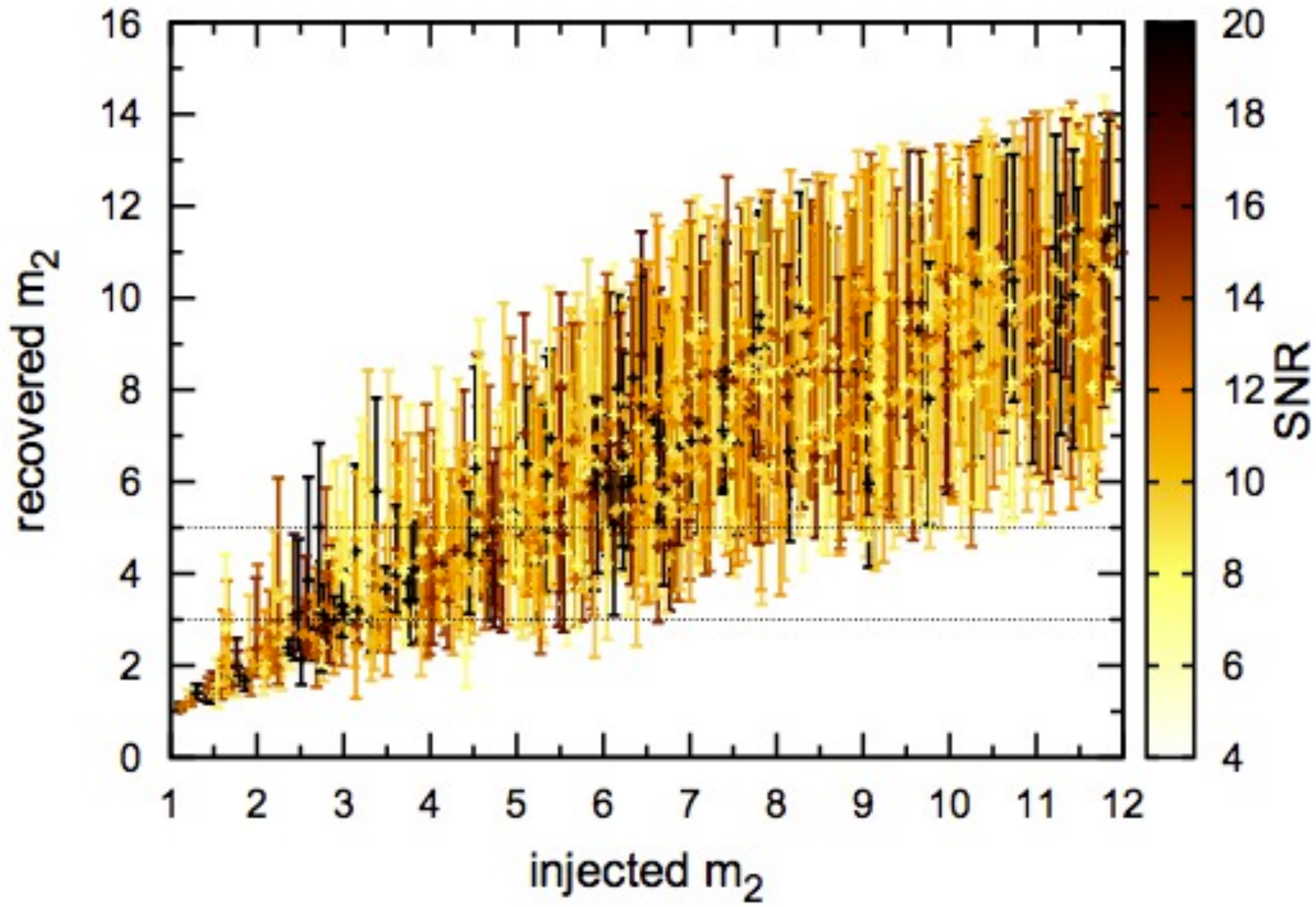
Probing the Mass Gap / Neutron Star Determination

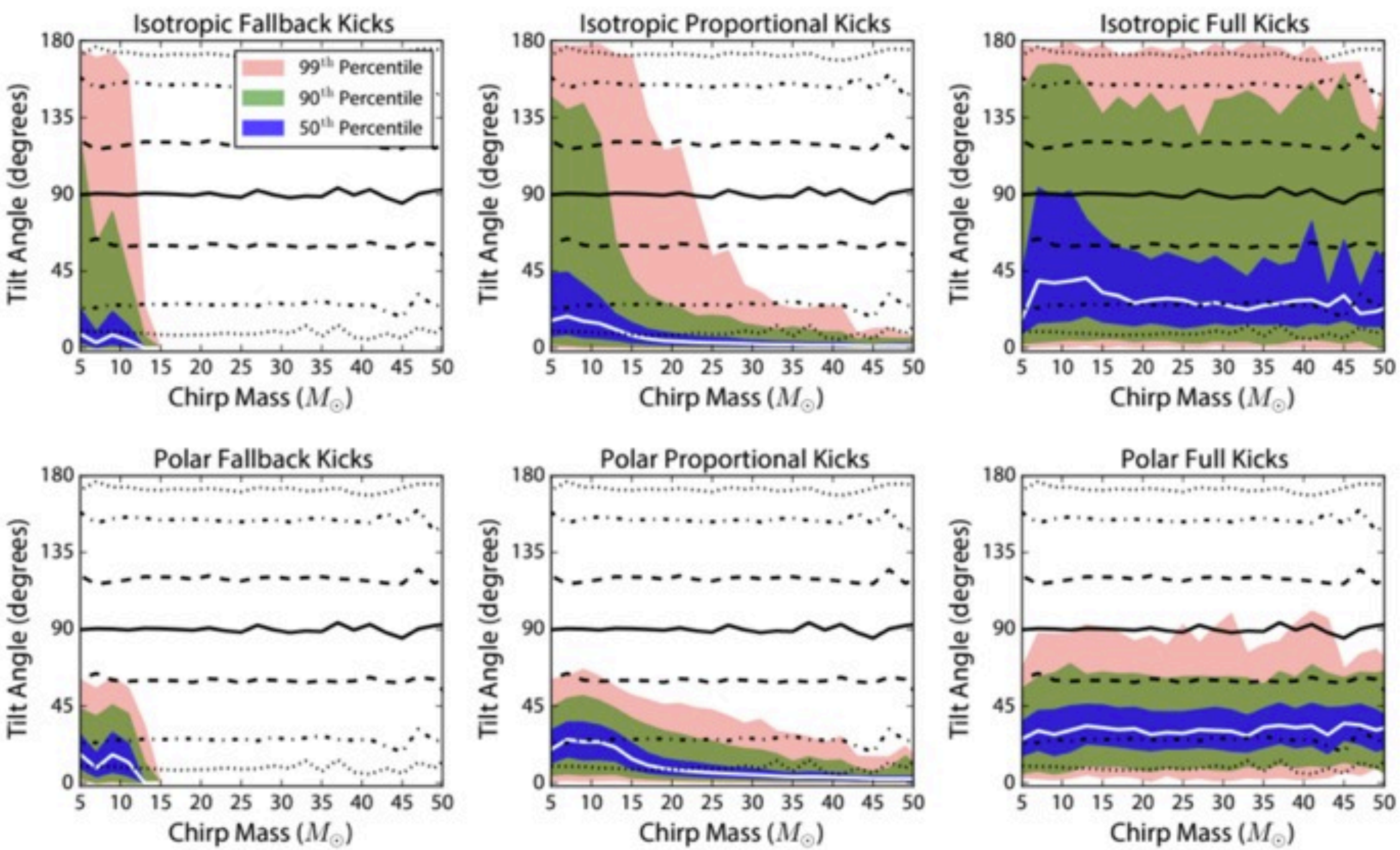


Spanning the "Mass Gap":
Uncertainties from posterior determination with compact binaries often span the entire mass gap and lead to posterior weight for neutron stars when the system is a BBH

arxiv:1503.03179

Black Hole Spin Orientation and Origin Classification

Upshot: Field binaries strongly prefer aligned spins especially for heavy GW150914



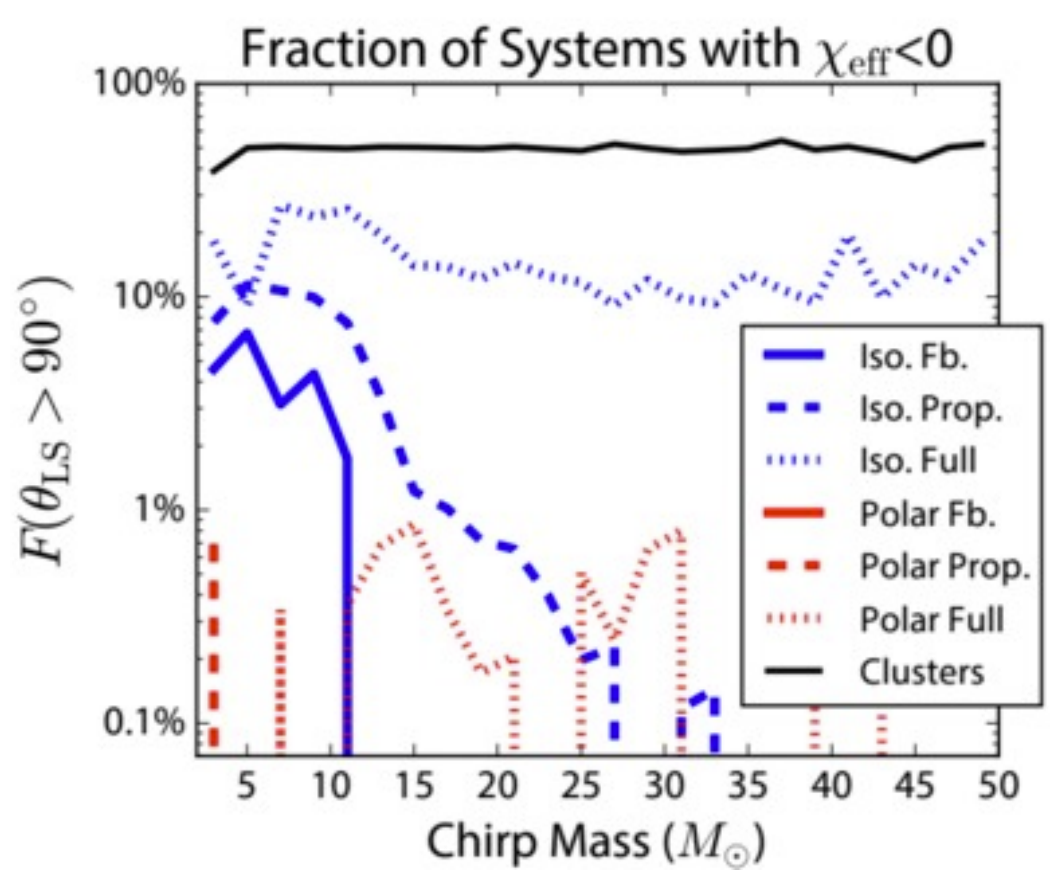
Model selection for spin alignment likely could distinguish formation channel

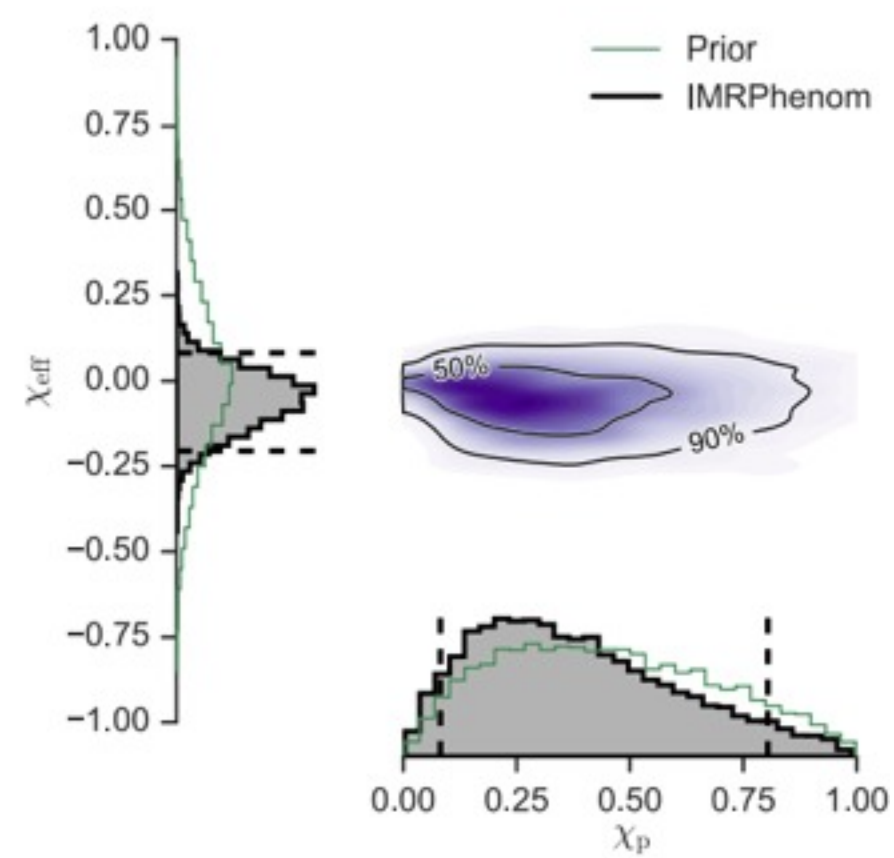
These are the **most conservative** distributions!

Discussion / Consequences

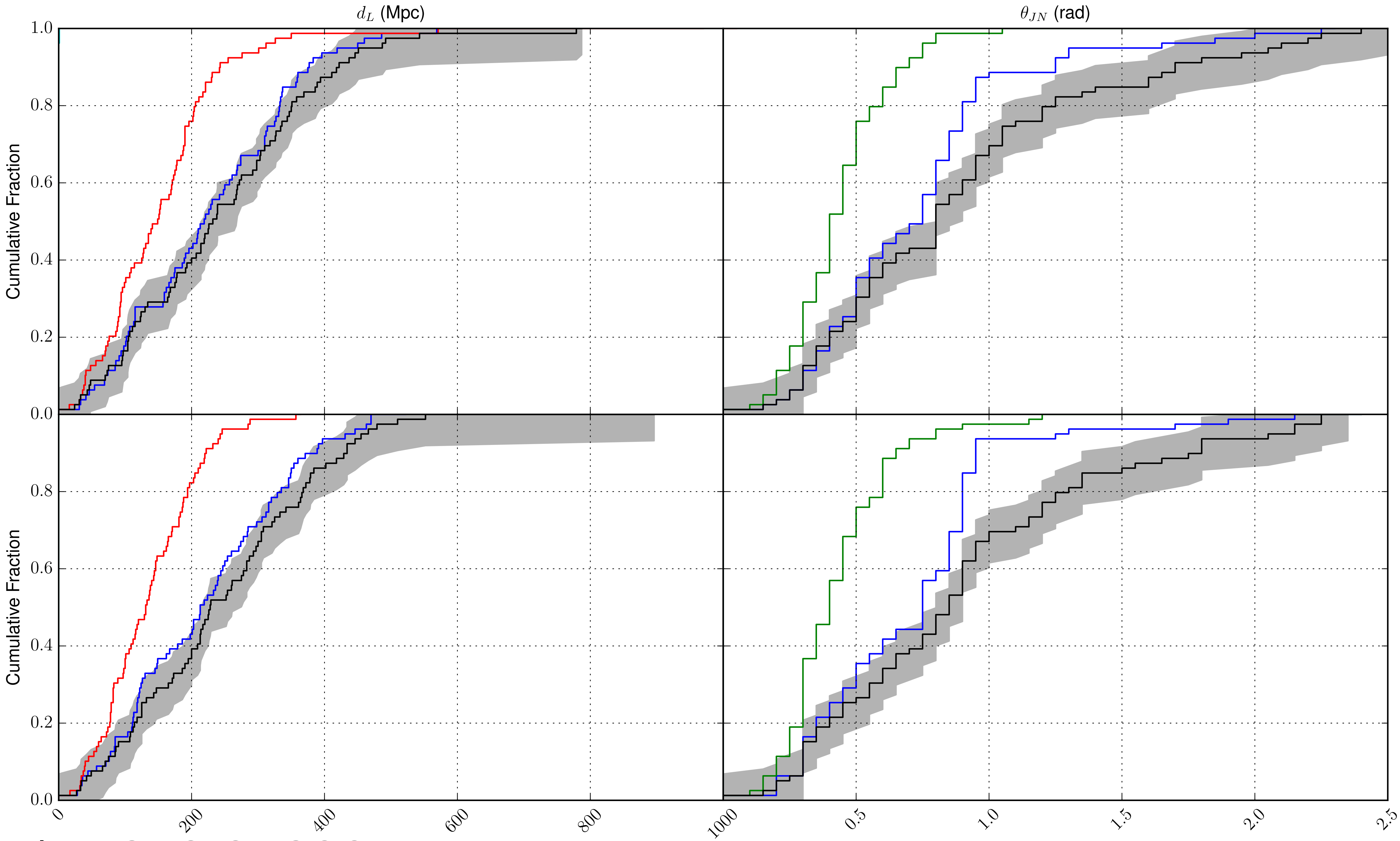
Measuring $\chi_{eff} < 0$, under mild assumptions about evolution would give high odds towards cluster based formation

Reminder: GW150914 has $\chi_{eff} < 0$ at ≳ 75% probability





Astrophysical Prior Information and GW Inference



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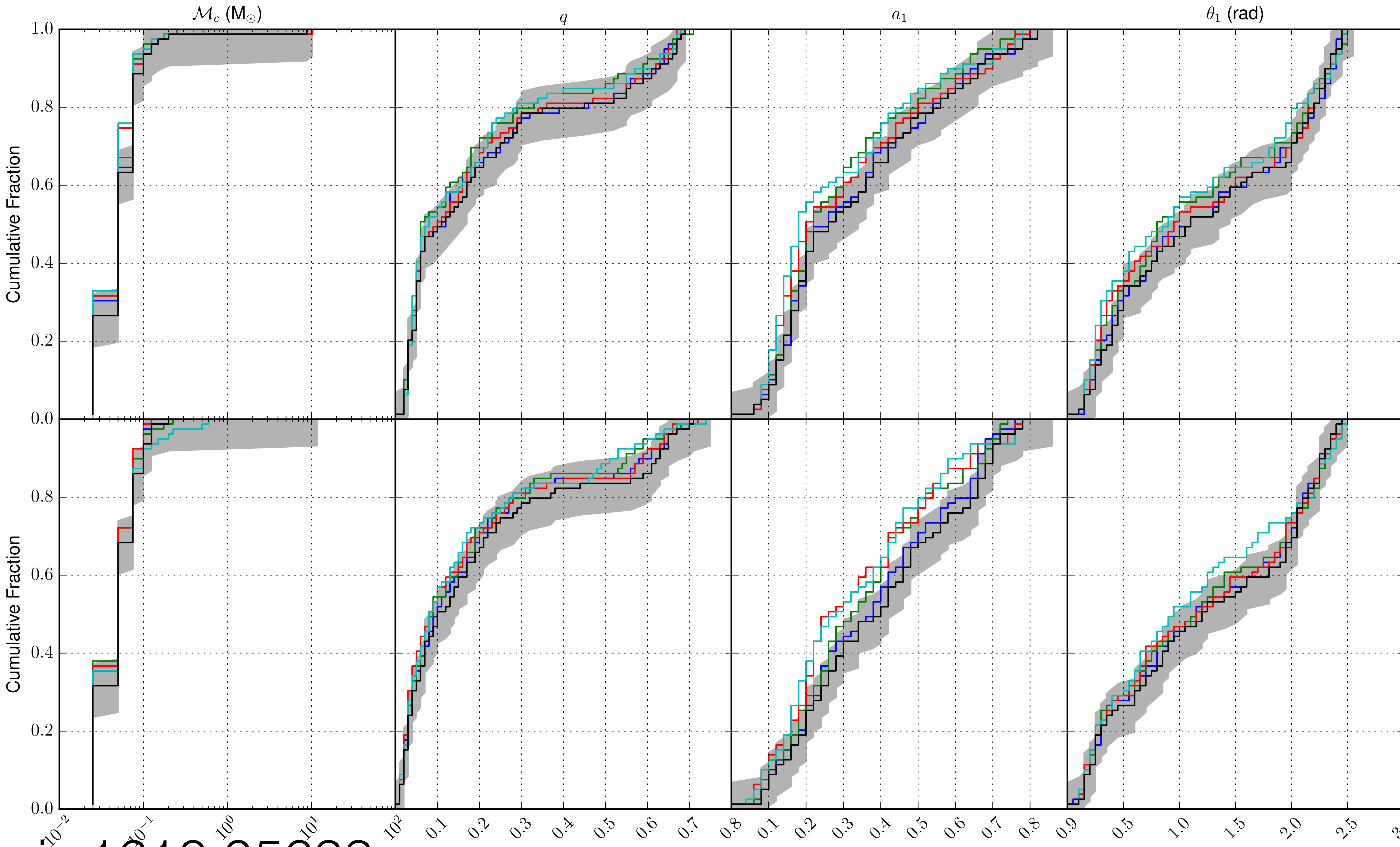

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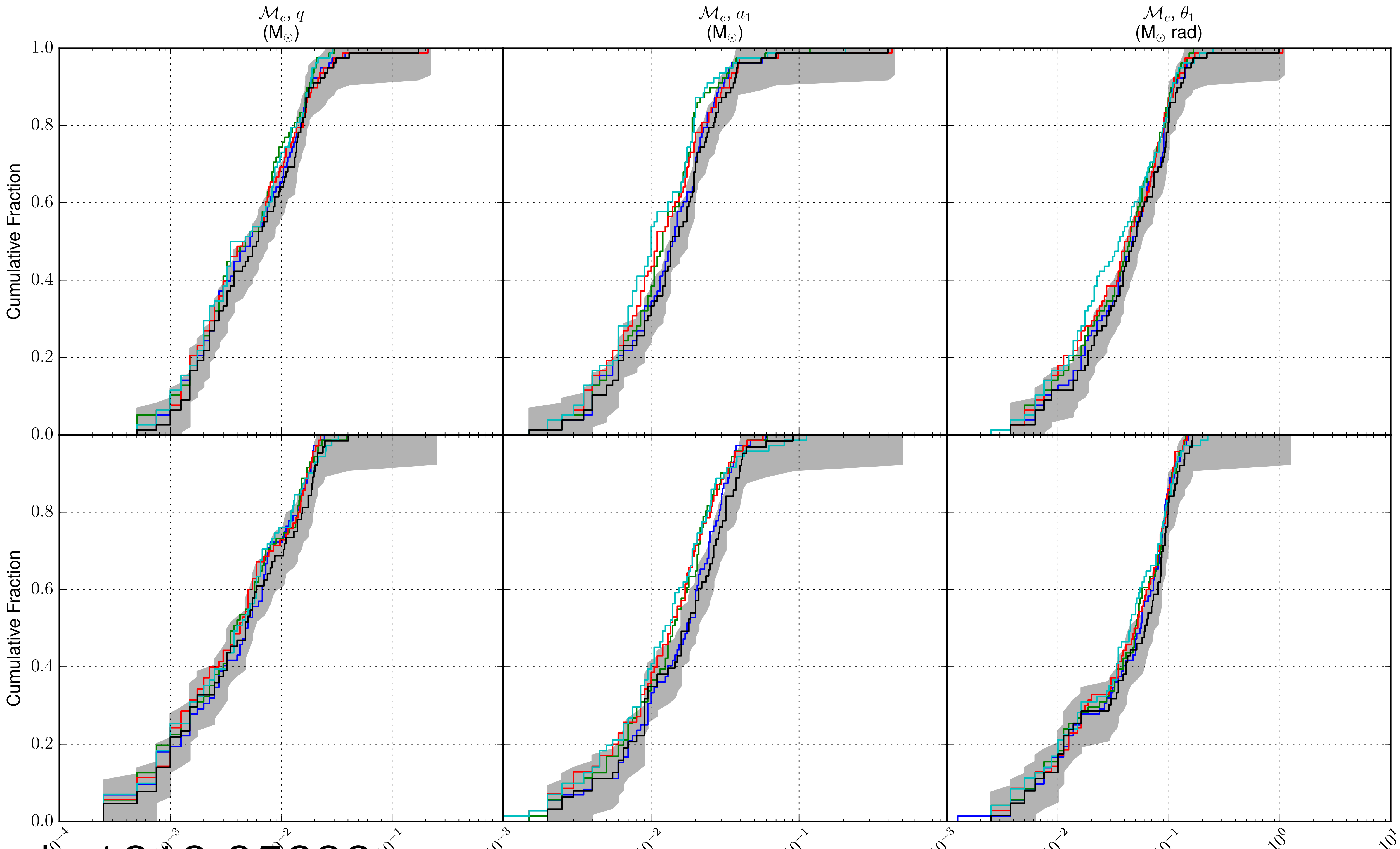

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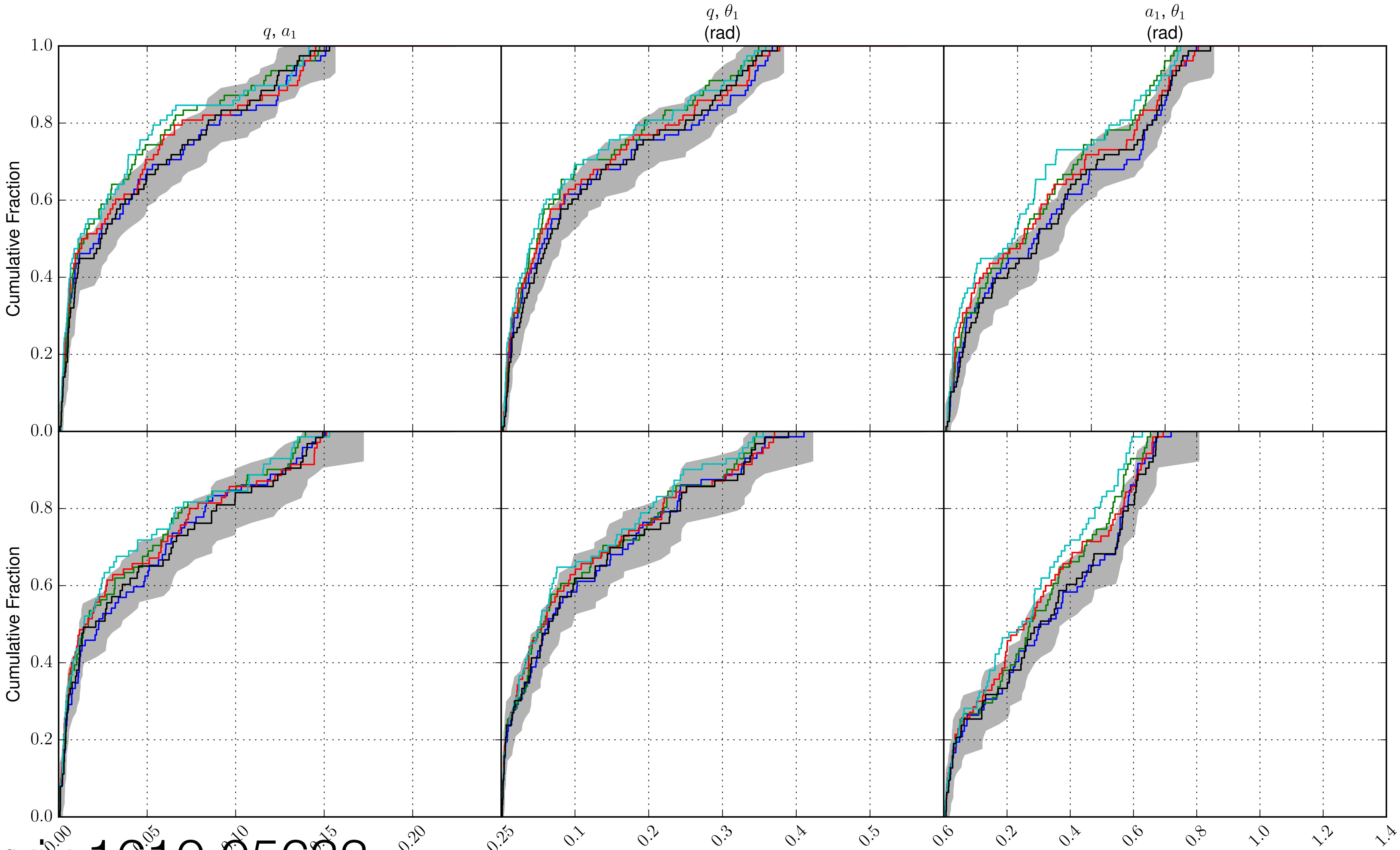

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