Institute of
Gravitational Wave Astronomy

UNIVERSITY OF
BIRMINGHAM

Constraints on the gravitational wave background with pulsar timing arrays

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Chen, Middleton, et al. doi.org/10.1093/mnras/stx475
Middleton, Chen, et al. arXiv:1707.00623

Overview

- Pulsar timing searches for gravitational wave background
- No detection yet, but upper limits reaching astrophysically interesting sensitivities
- Recent doubt cast on binary assembly theories
  $\rightarrow$ are mergers stalling / accelerated??
- Bayesian analysis with astrophysical prior
- Are prediction consistent with upper limits?
  $\rightarrow$ yes so far!

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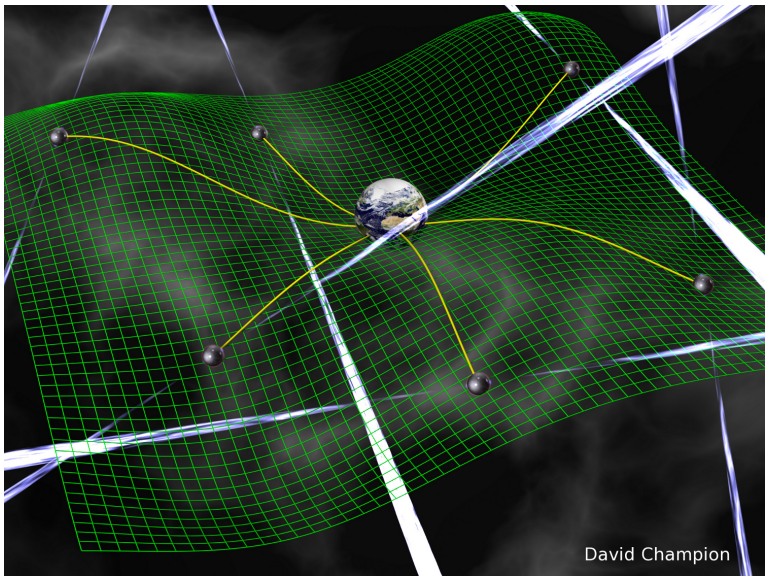
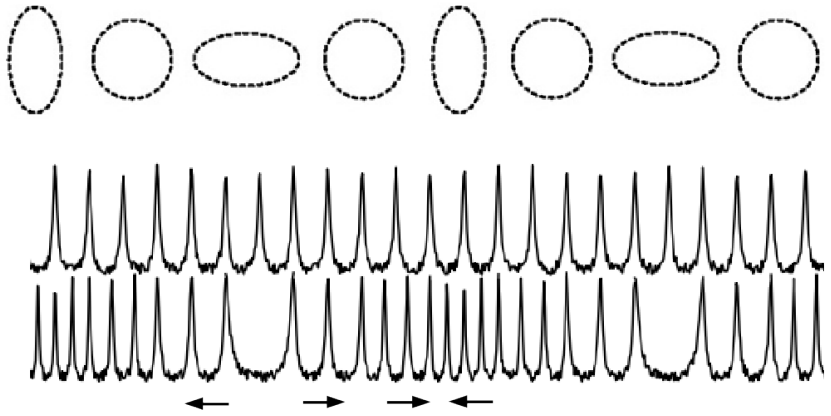
Pulsar timing arrays



Pulsar timing array

- Gravitational wave background from many mergers
- At nHz frequencies
- Search for deviations in pulse time of arrivals



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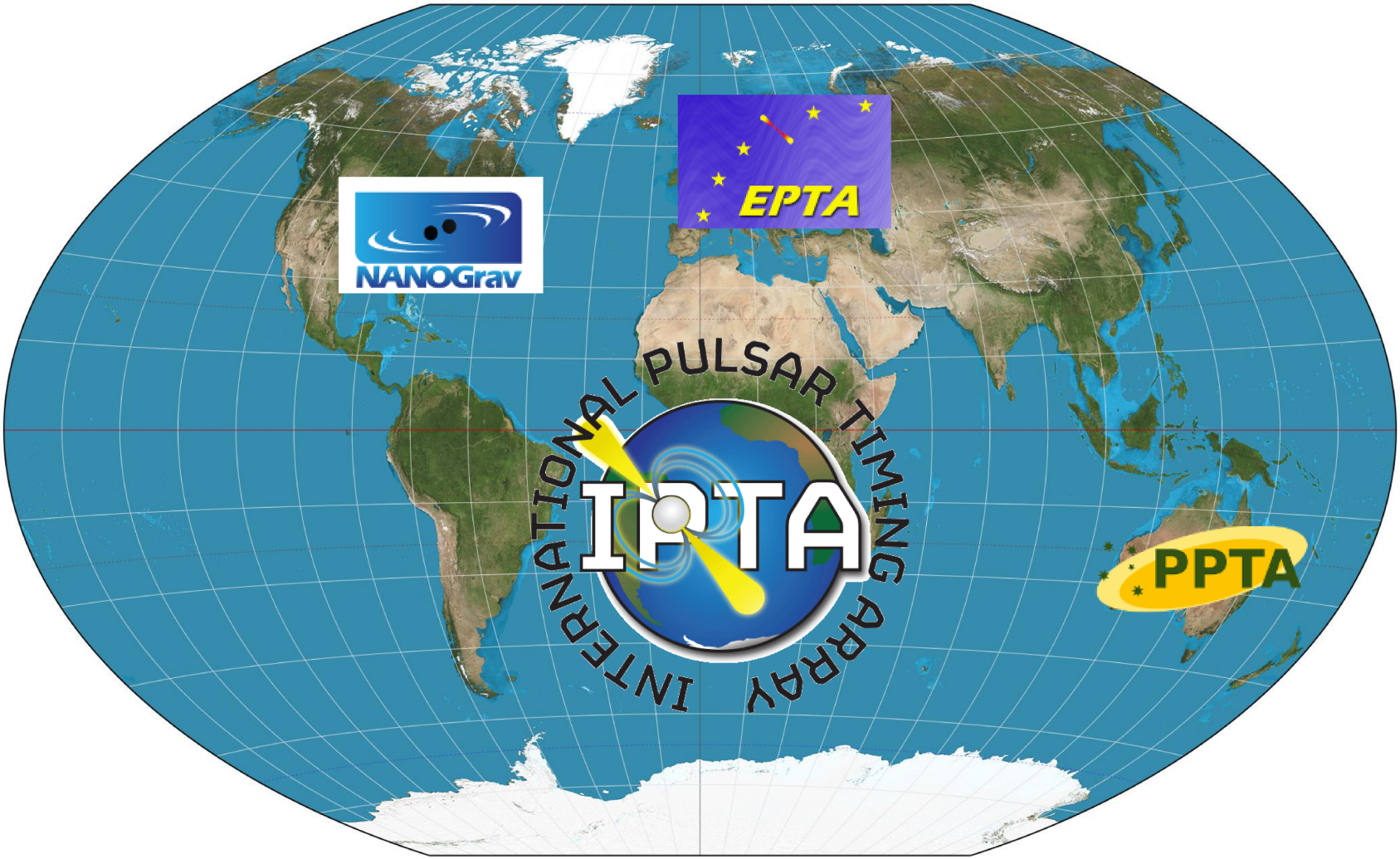
Searching for the background



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Recent results – data

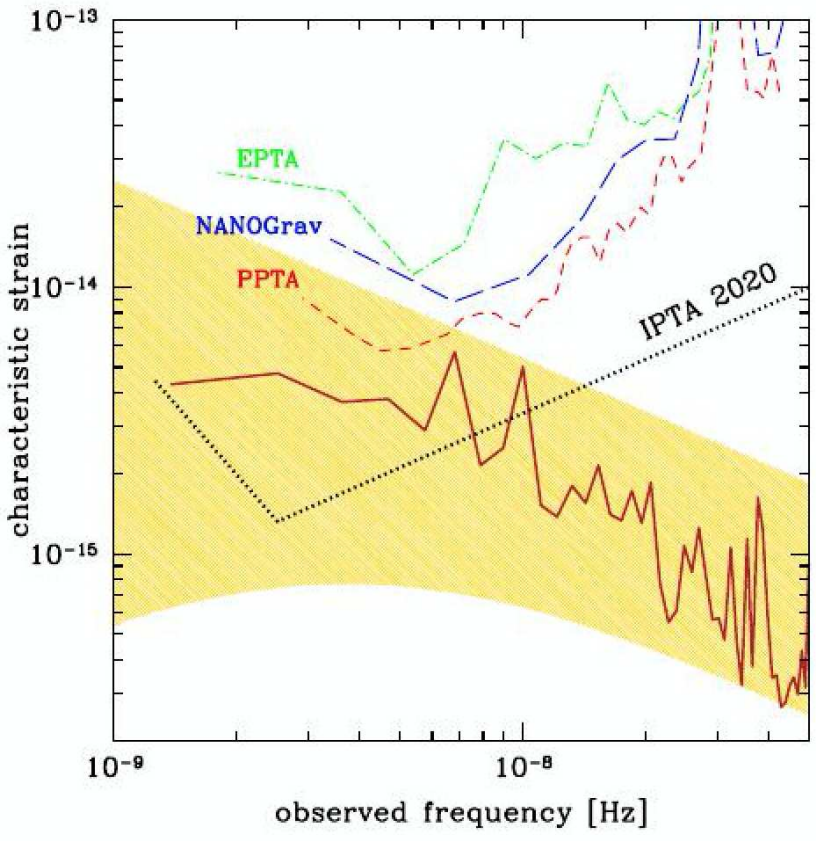

Image: A. Sesana

(reproduced from Hobbs & Dai 2017)

- Most stringent upper limit from Parkes Pulsar Timing array (Shannon et al 2015)
- $h_{ul} < 1 \times 10^{-15}$ at 95% confidence ($f = 1/1\mathrm{yr}$)
- Are predictions in trouble?
  - Eccentricity?
  - Stalling?

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Can we place any constraints on the population?

- Bayesian analysis with astrophysical prior
- Can we make any statements on our current predictions for the gravitational wave background
- Our model:
  - merger rate density
  - chirp mass distribution ($\mathcal{M} = (m_1 m_2)^{3/5}/(m_1 + m_2)^{1/5}$)
  - redshift distribution
  - eccentricity at decoupling from the environment

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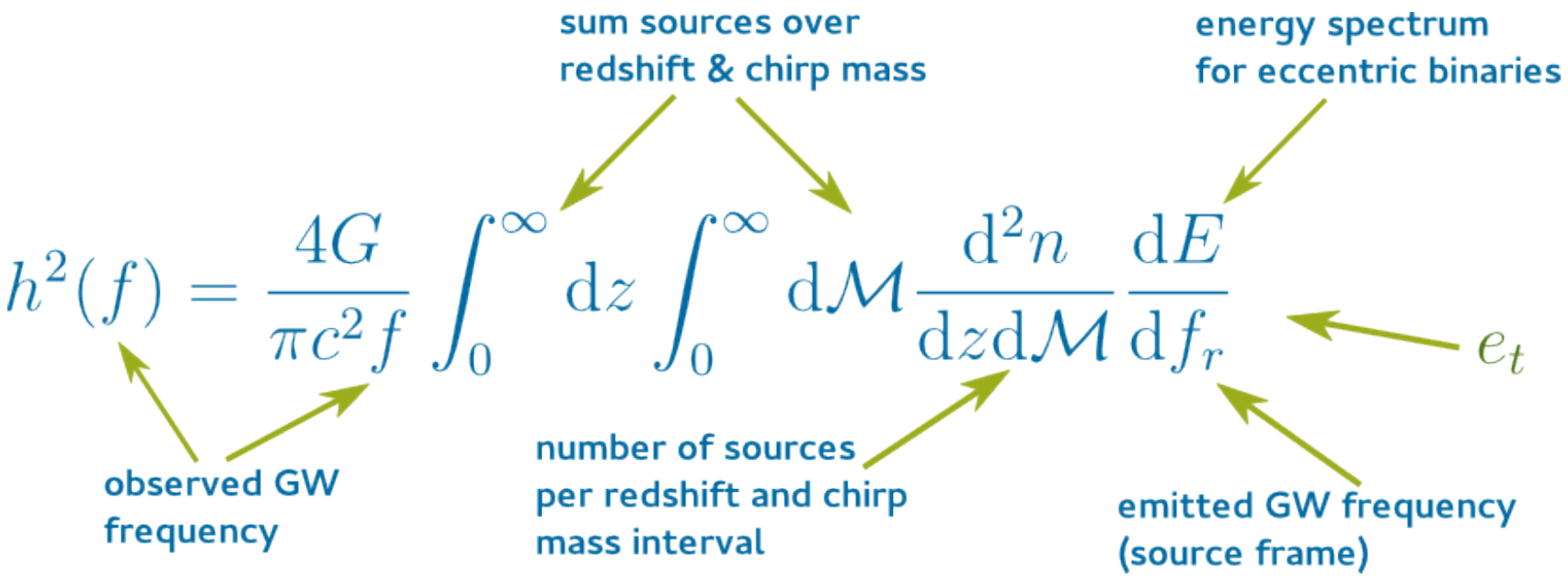
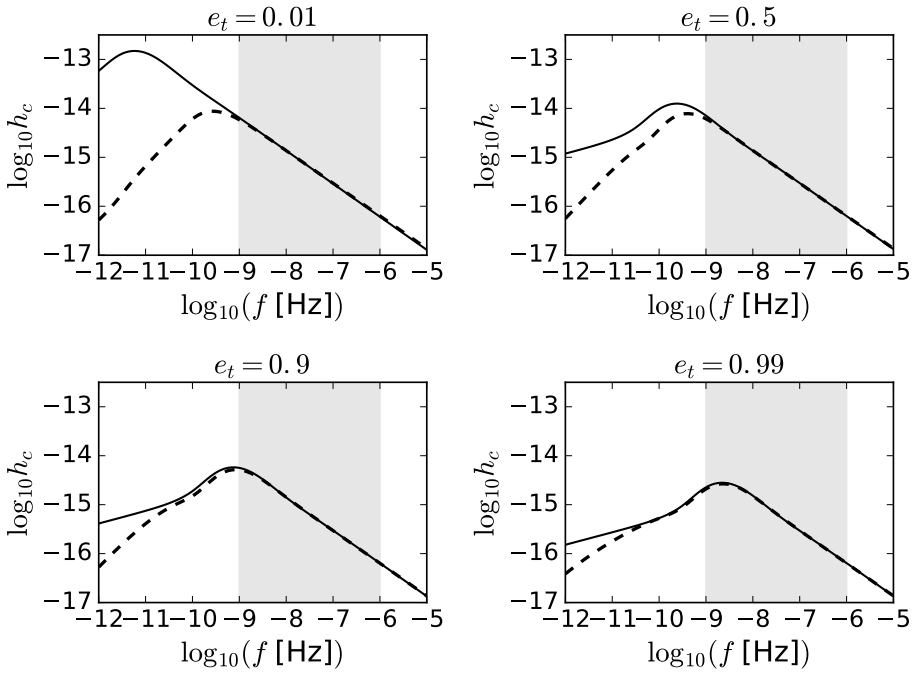
Model



Chen, Sesana & Del Pozzo 2017 (10.1093/mnras/stx1093)

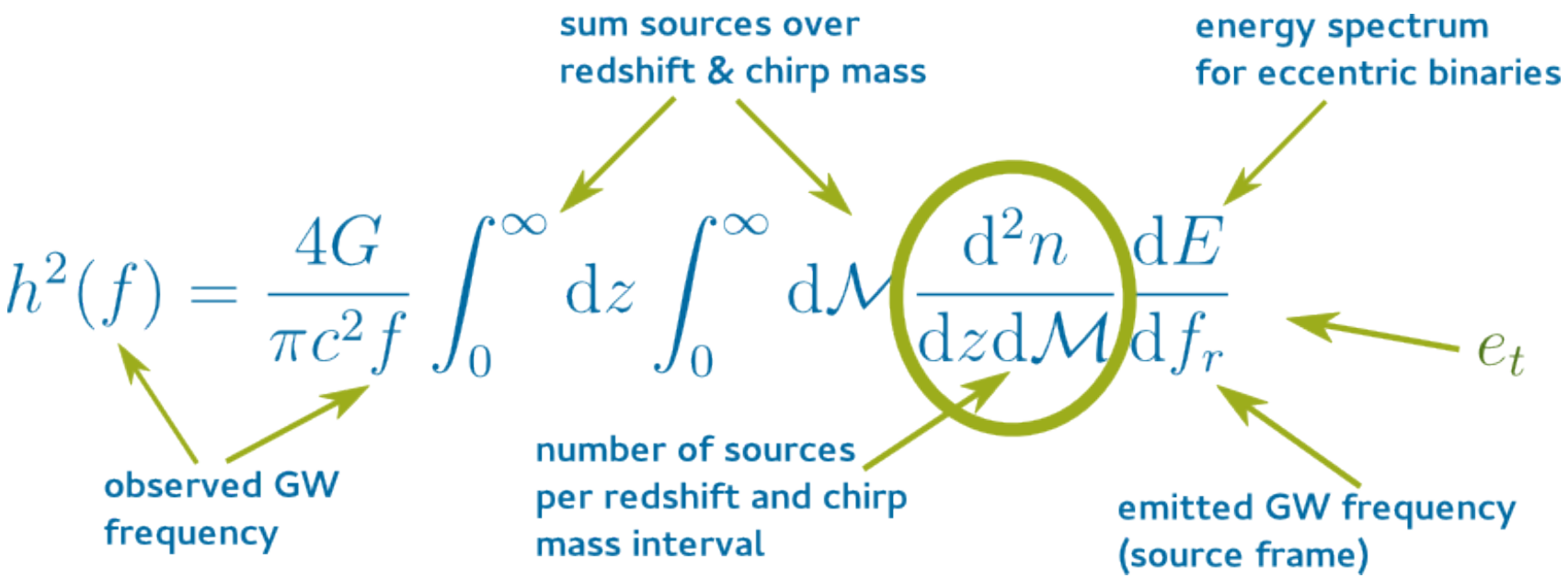
Eccentricity



- Some eccentricity at decoupling
- Population of eccentric gravitational wave driven binaries
- Environmental influence affects lower than PTA band
- Depletes sources at low frequency
- This is the **same** for all binaries

Chen, Sesana & Del Pozzo 2017 (10.1093/mnras/stx1093)

Model



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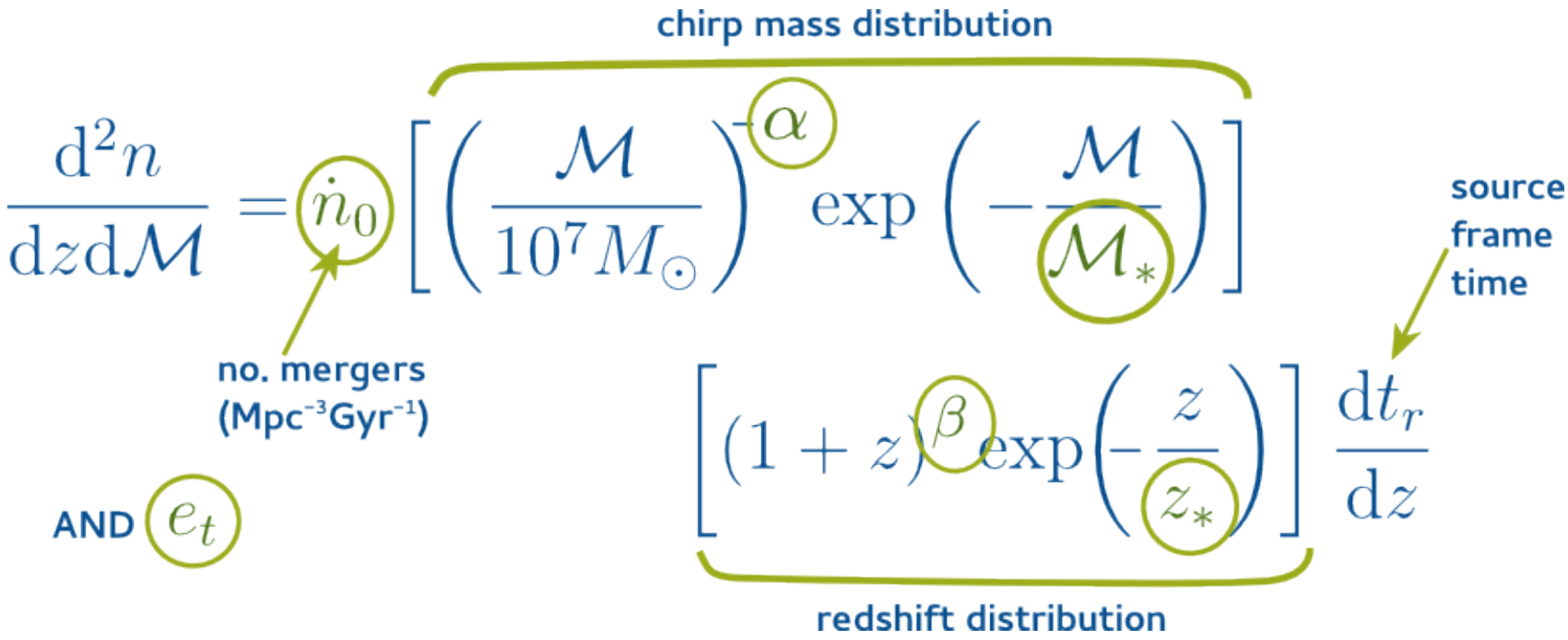

6 parameters model:

- $\dot{n}_0$ (merger rate density)
- α, $\mathcal{M}_*$ (chirp mass distribution)
- β, z_* (redshift distribution)
- e_t (decoupling eccentricity)

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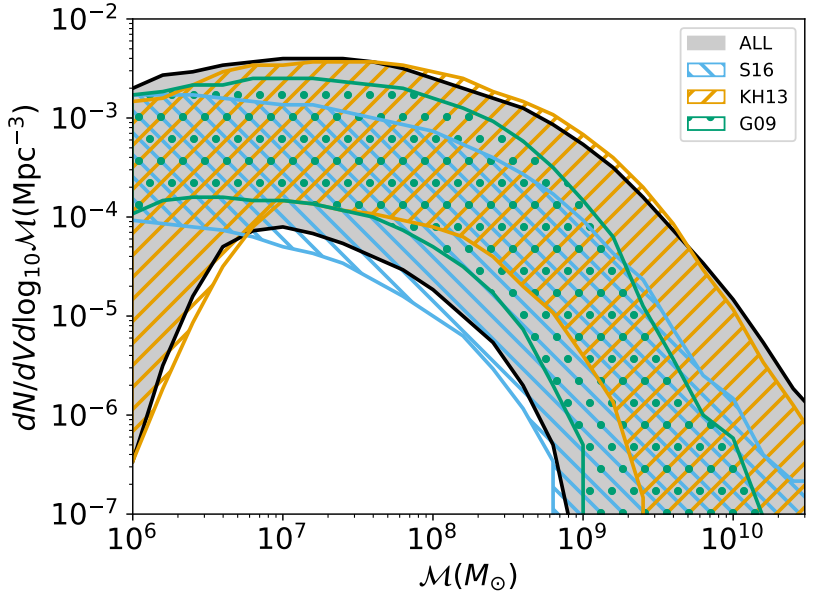
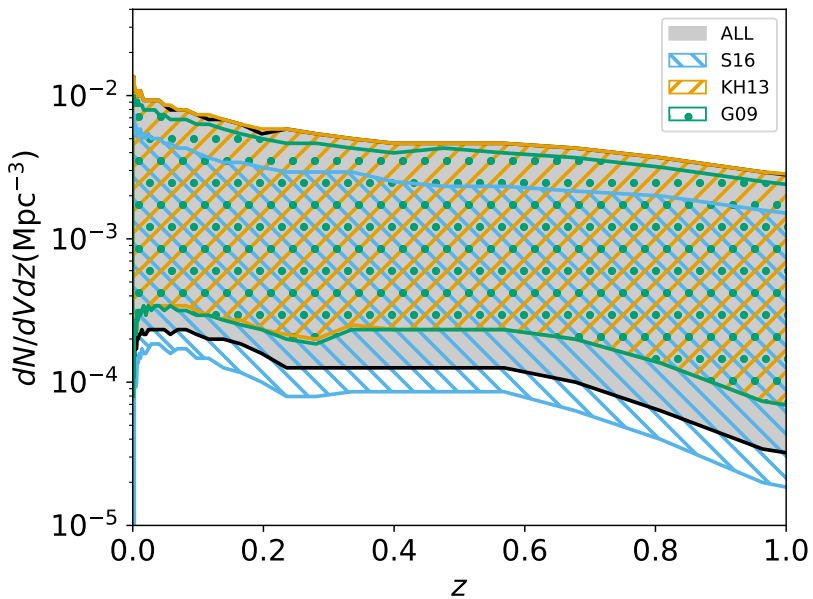
Astrophysical Prior

Model	median strain at $f = 1/1\mathrm{yr}$
Pessimistic $\approx$	4×10^{-16}
Middling $\approx$	7×10^{-16}
Optimistic $\approx$	1.5×10^{-15}
All+ $\approx$	8×10^{-16}

(Shankar+ 16, Gültekin+ 09, Kormendy Ho 13)





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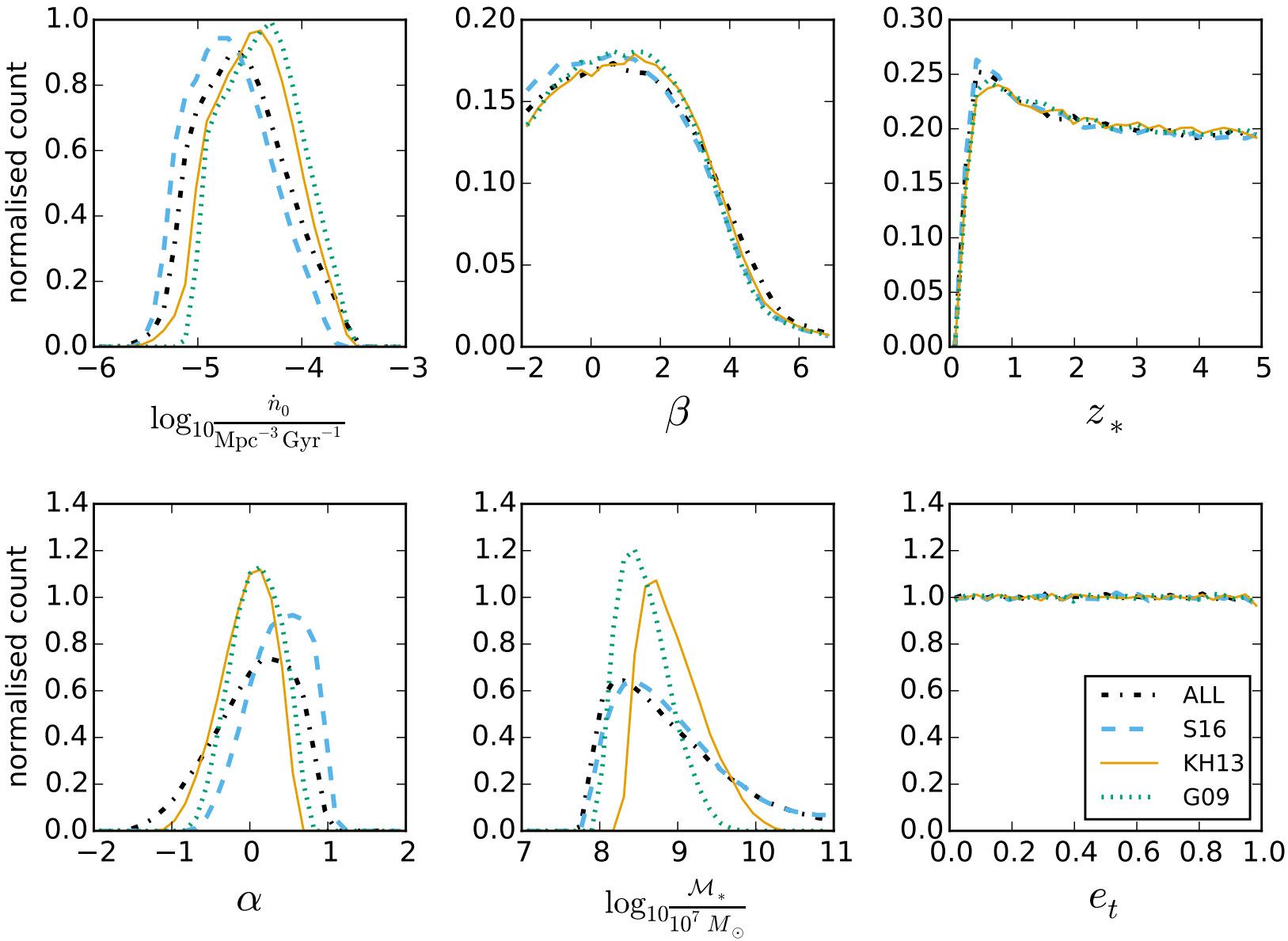

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Method Overview

$$p(\theta|dM) = \frac{p(\theta|M)p(d|M,\theta)}{p(d|M)}$$

Method Overview

PRIOR
for 6 parameters

$$p(\theta|dM) = \frac{p(\theta|M)p(d|M,\theta)}{p(d|M)}$$

Method Overview

PRIOR
for 6 parameters

LIKELIHOOD:
upper limit or
detection?

$$p(\theta|dM) = \frac{p(\theta|M)p(d|M,\theta)}{p(d|M)}$$

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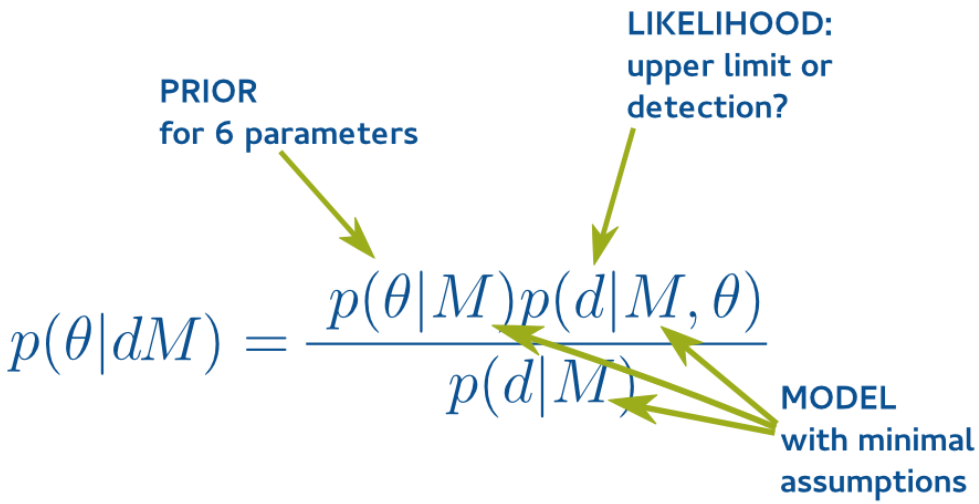

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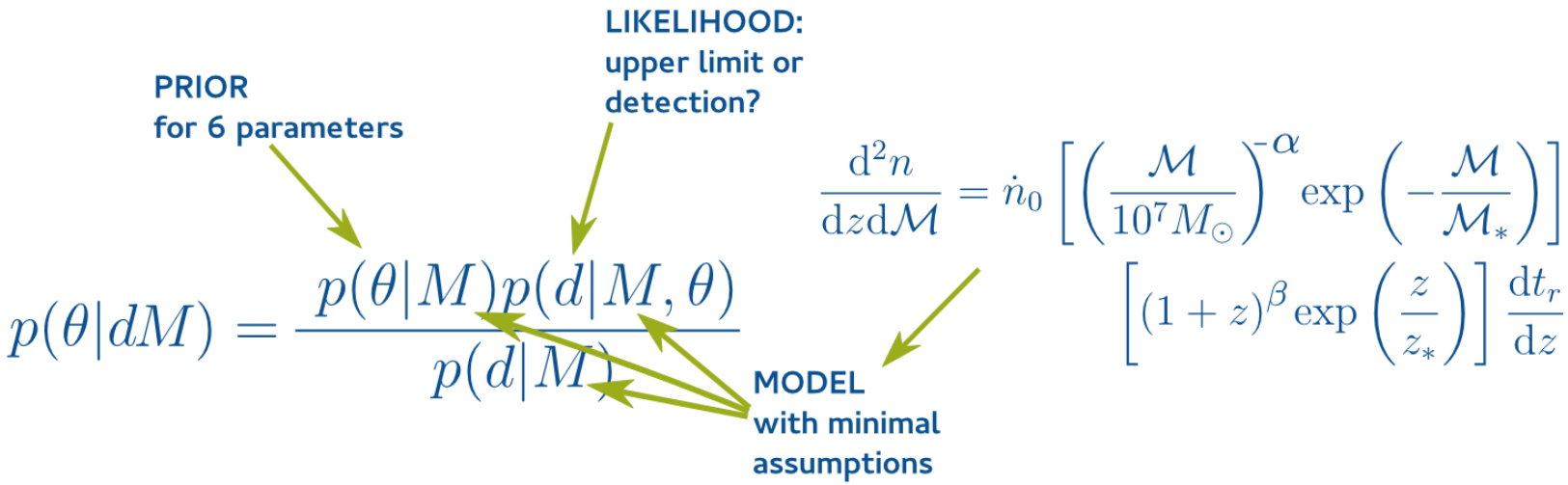

$$p(\theta|dM) = \frac{p(\theta|M)p(d|M,\theta)}{p(d|M)}$$

$$\frac{\mathrm{d}^2 n}{\mathrm{d}z\mathrm{d}\mathcal{M}} = \dot{n}_0 \left[\left(\frac{\mathcal{M}}{10^7 M_\odot}\right)^{-\alpha} \exp\left(-\frac{\mathcal{M}}{\mathcal{M}_*}\right)\right] \left[(1+z)^\beta \exp\left(\frac{z}{z_*}\right)\right] \frac{\mathrm{d}t_r}{\mathrm{d}z}$$

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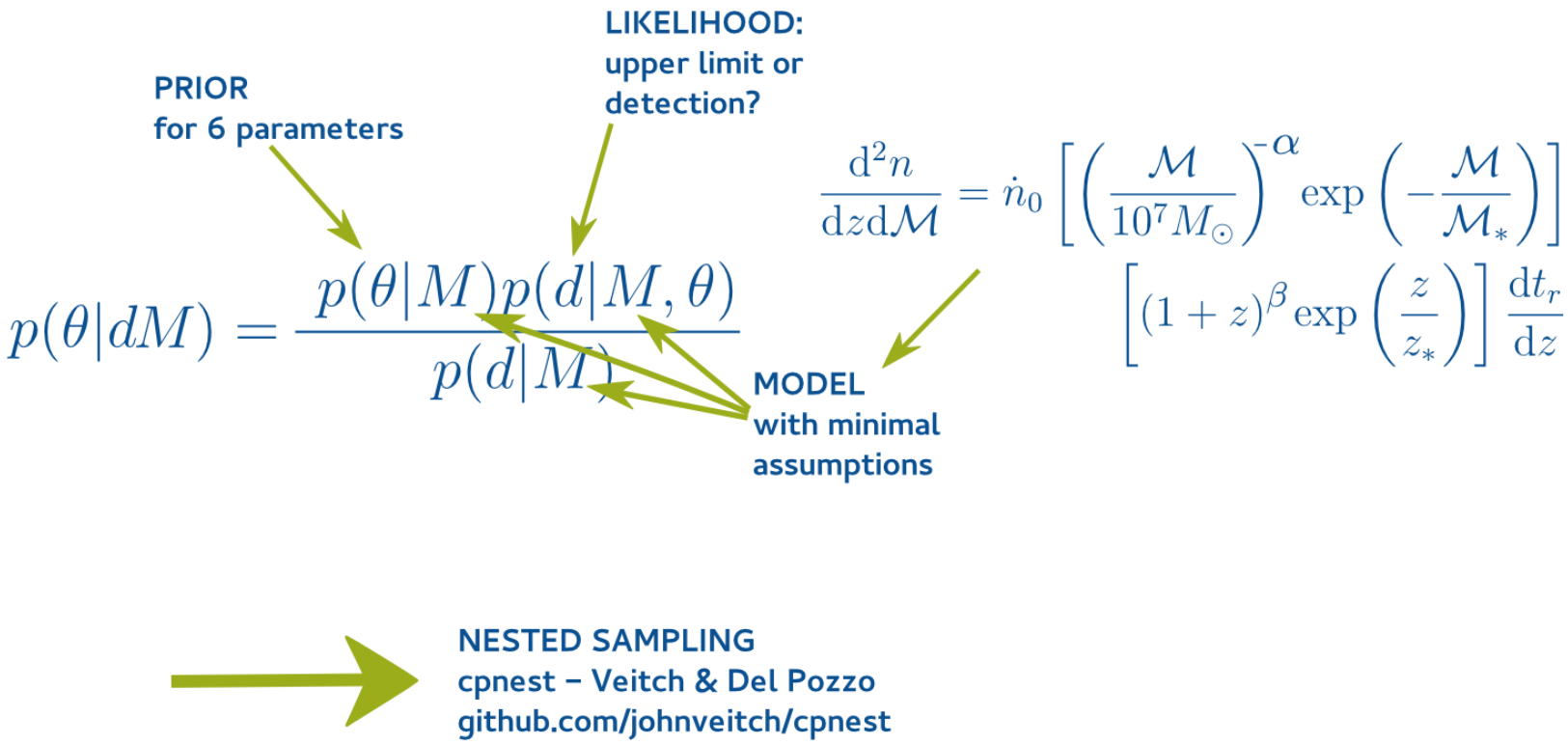

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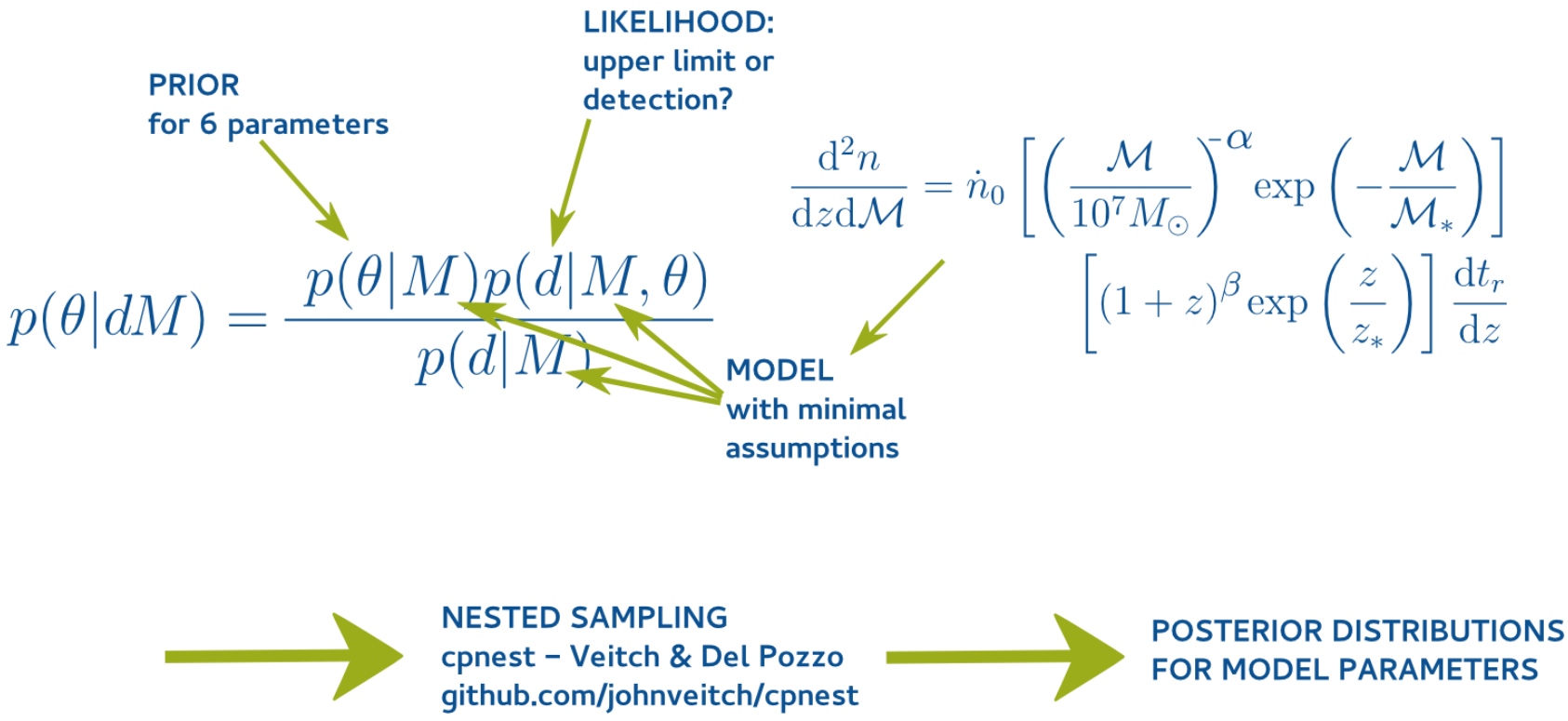

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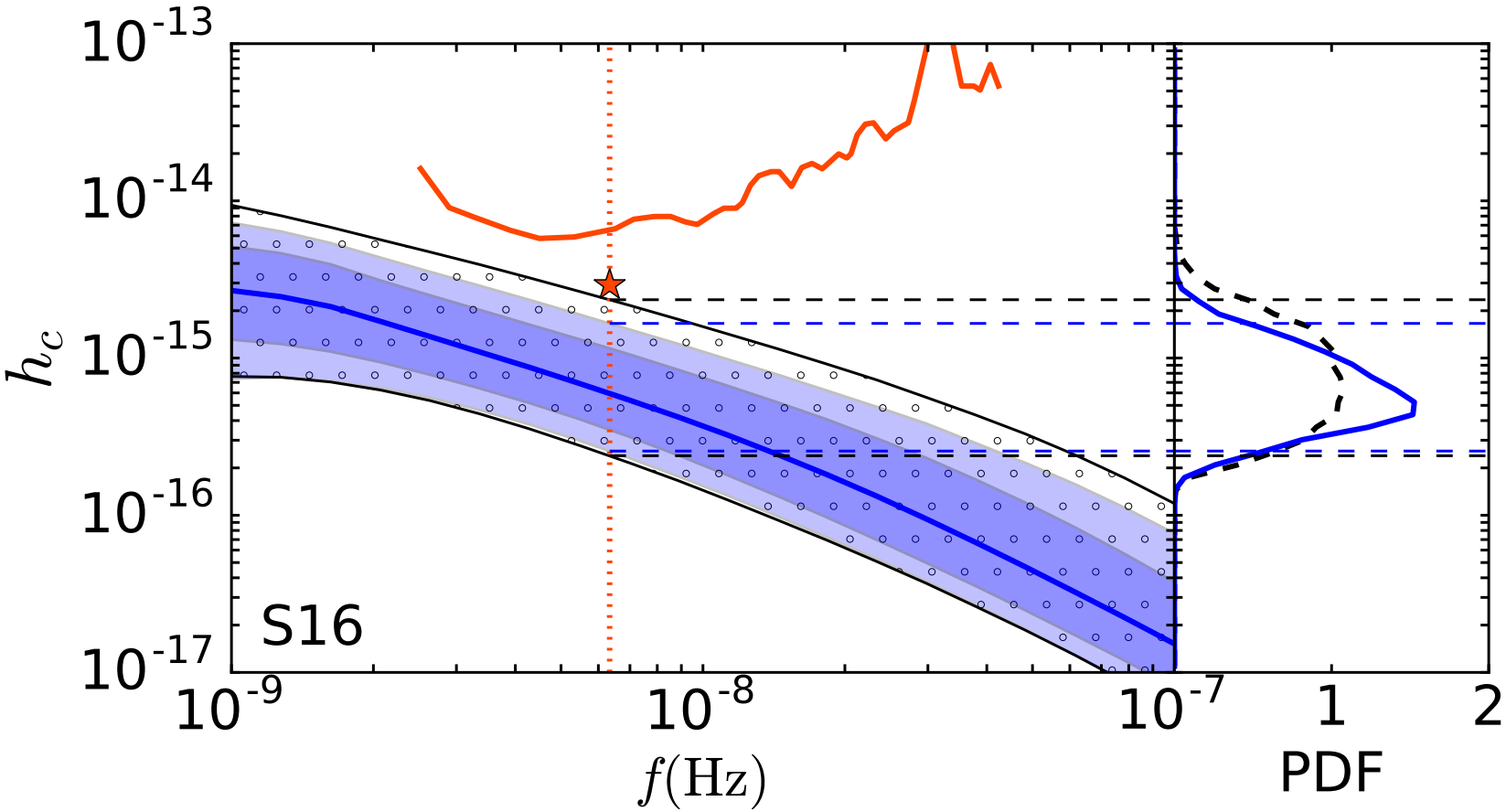
Results

pessimistic



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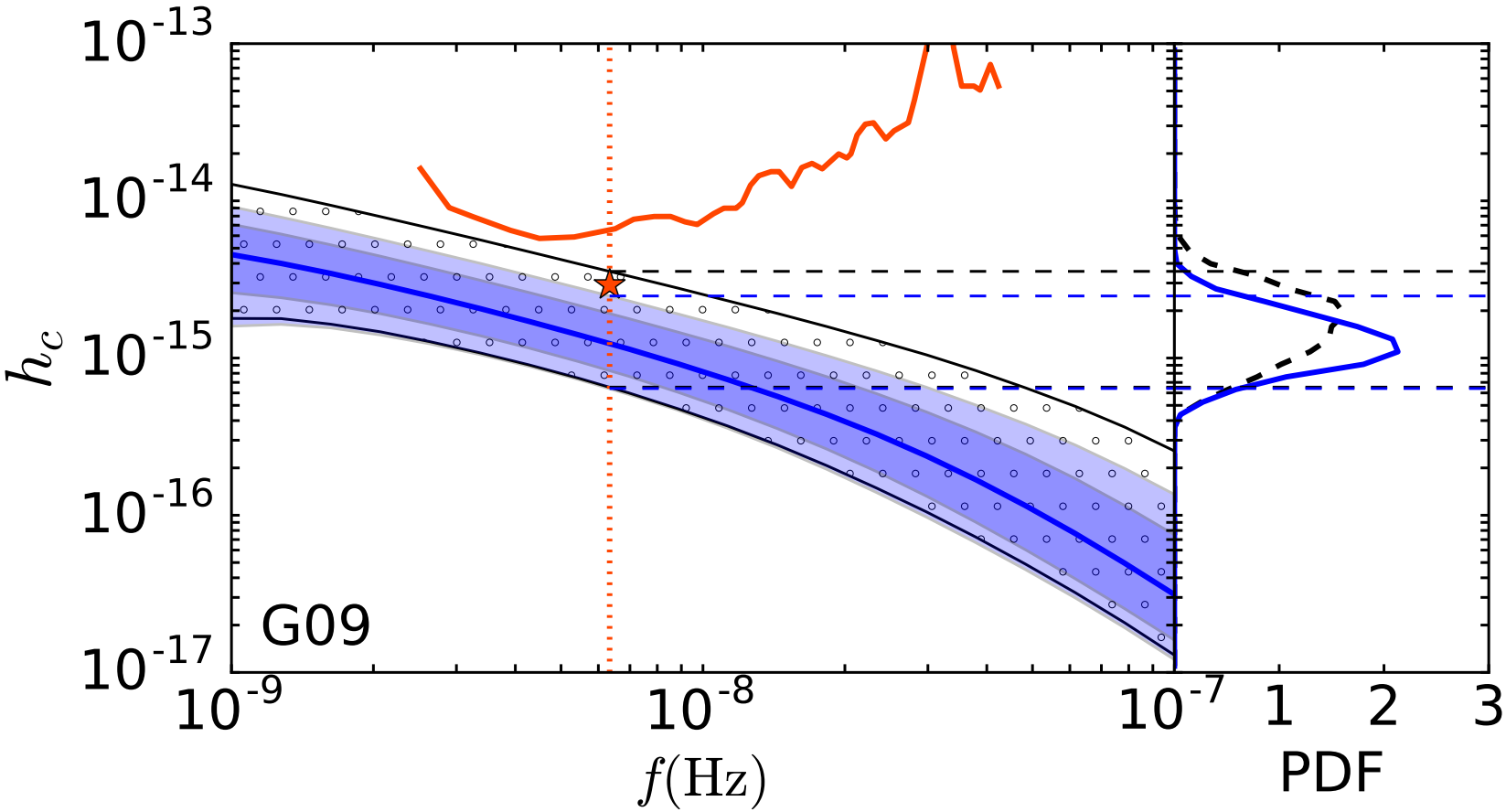
Results

middling



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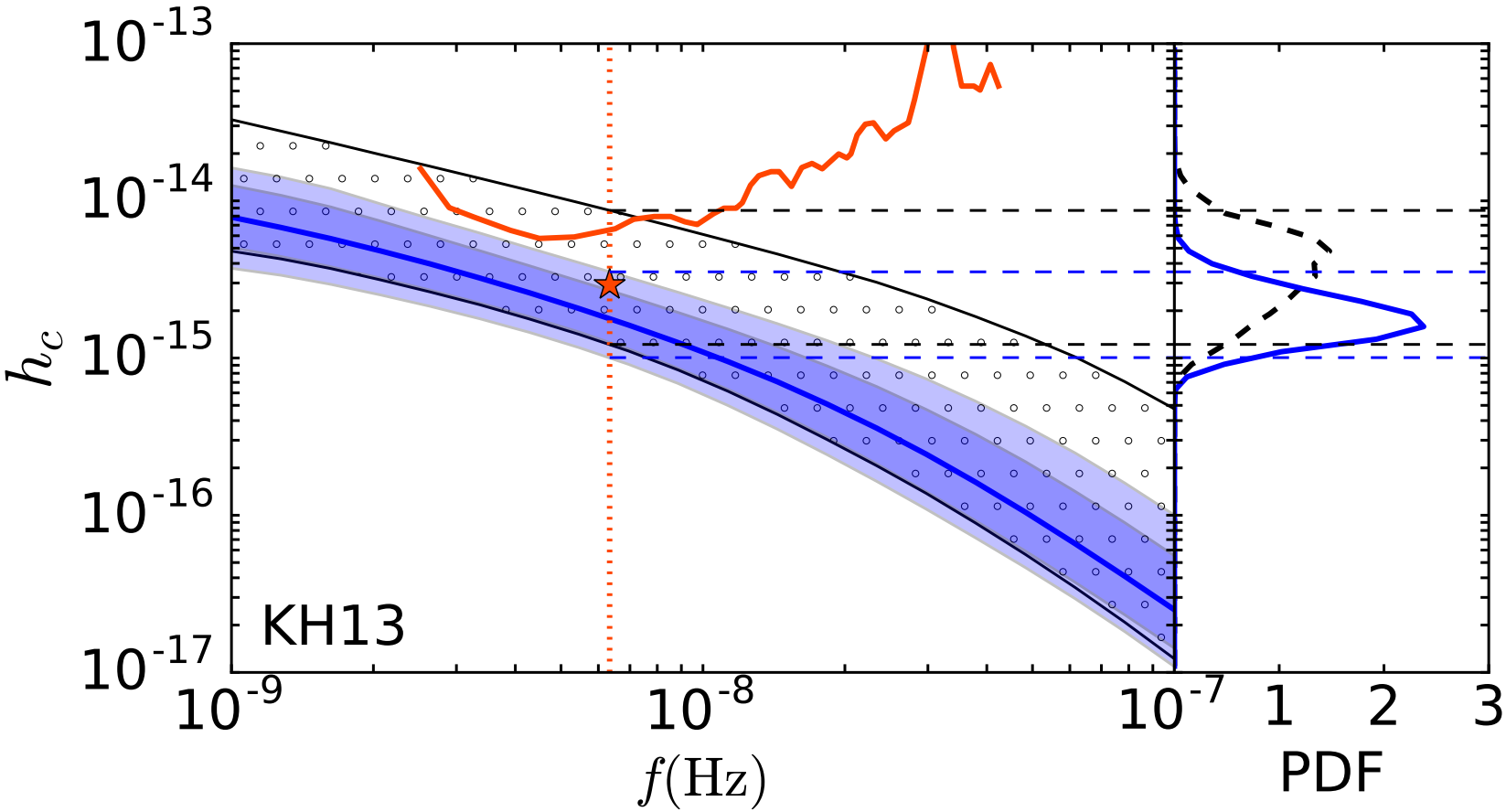
Results

optimistic



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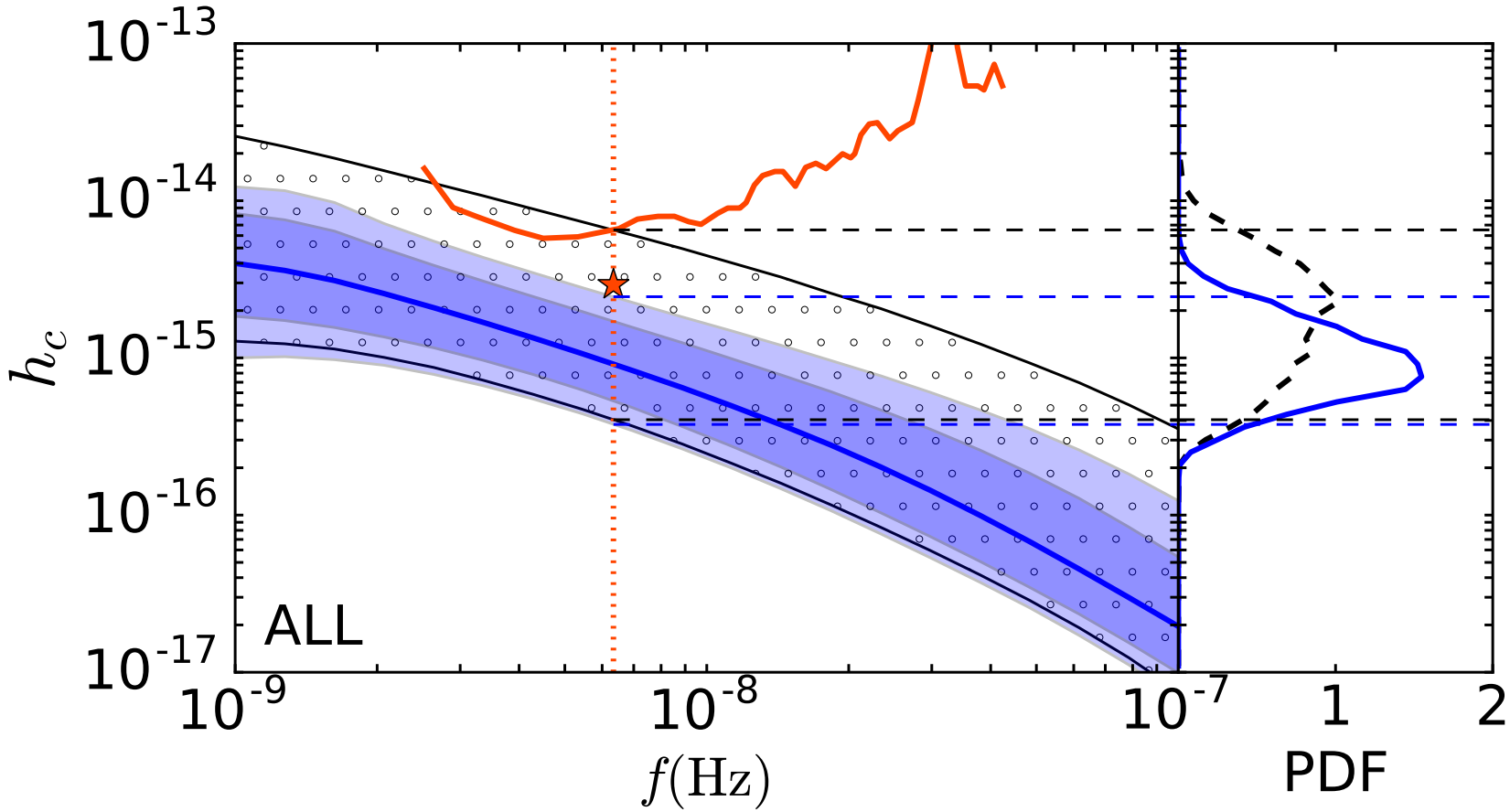
Results

all+



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Summary

- Upper limits are eating into predicted values
- But **models are still consistent with observation**
- Little constraint on the model parameters – eccentricity not essential
- No need to rethink predictions yet
- Order of magnitude improvement in sensitivity would put optimistic predictions in more trouble

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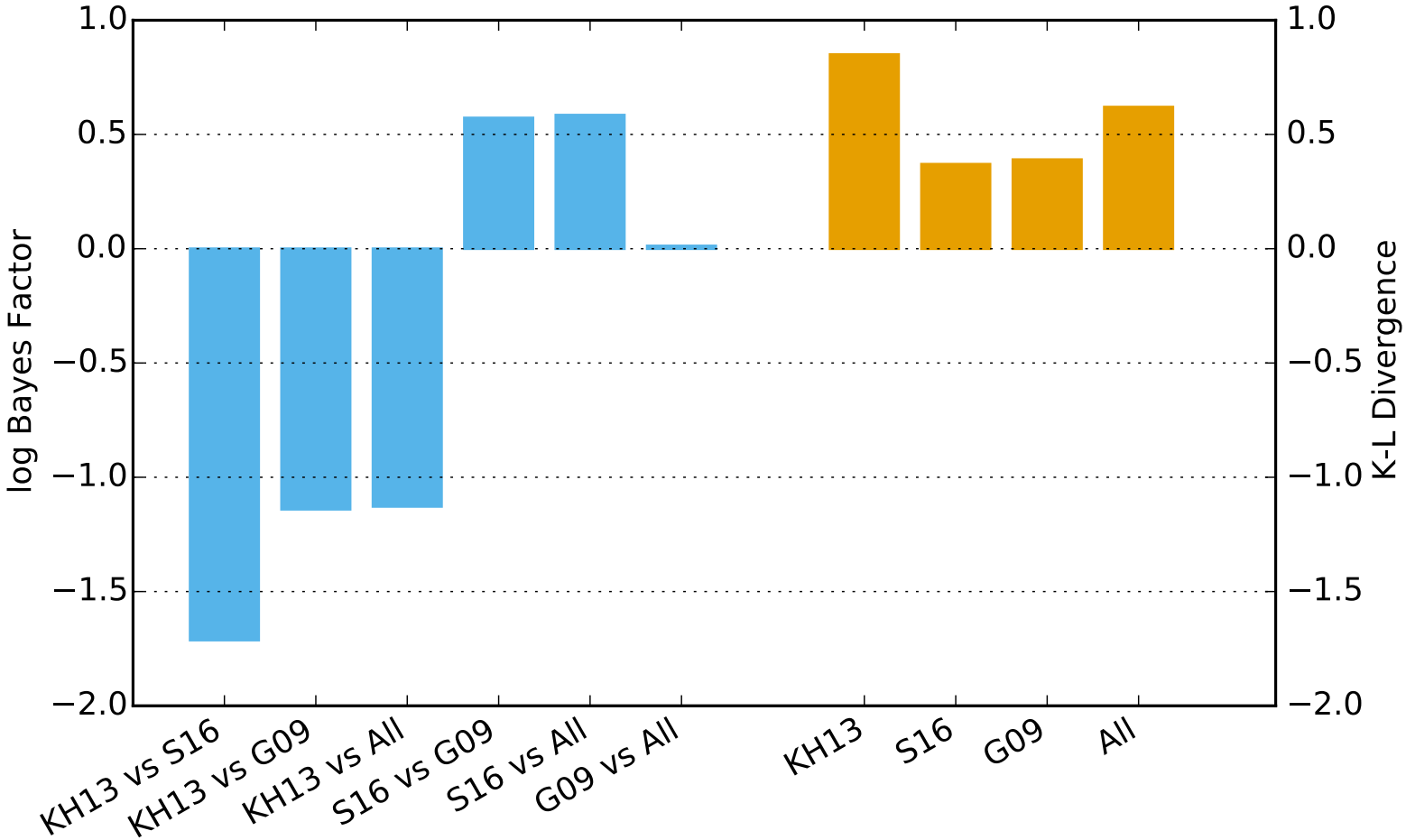
Bonus slides! Quantitative Results



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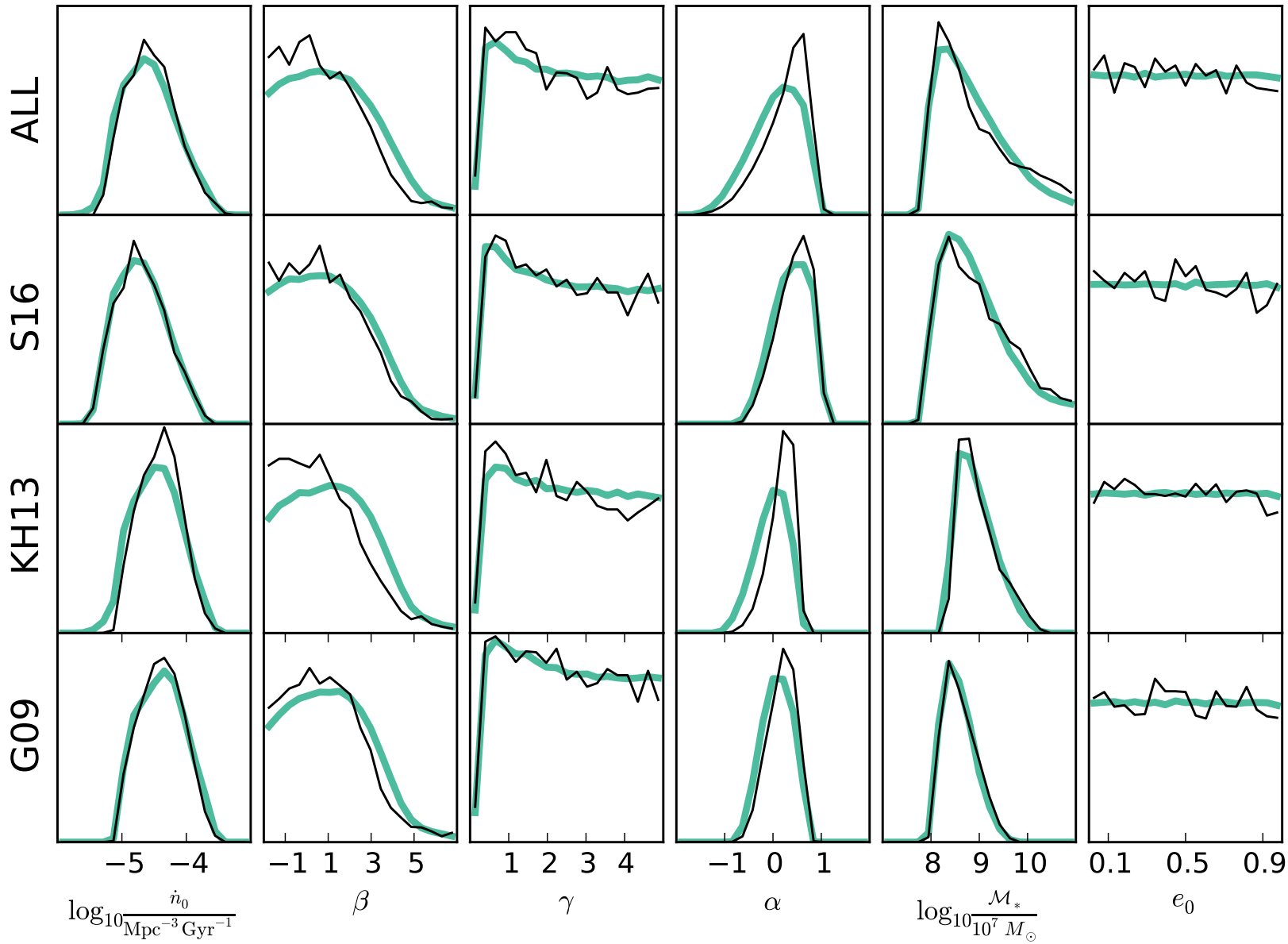
Bonus slides! Parameters



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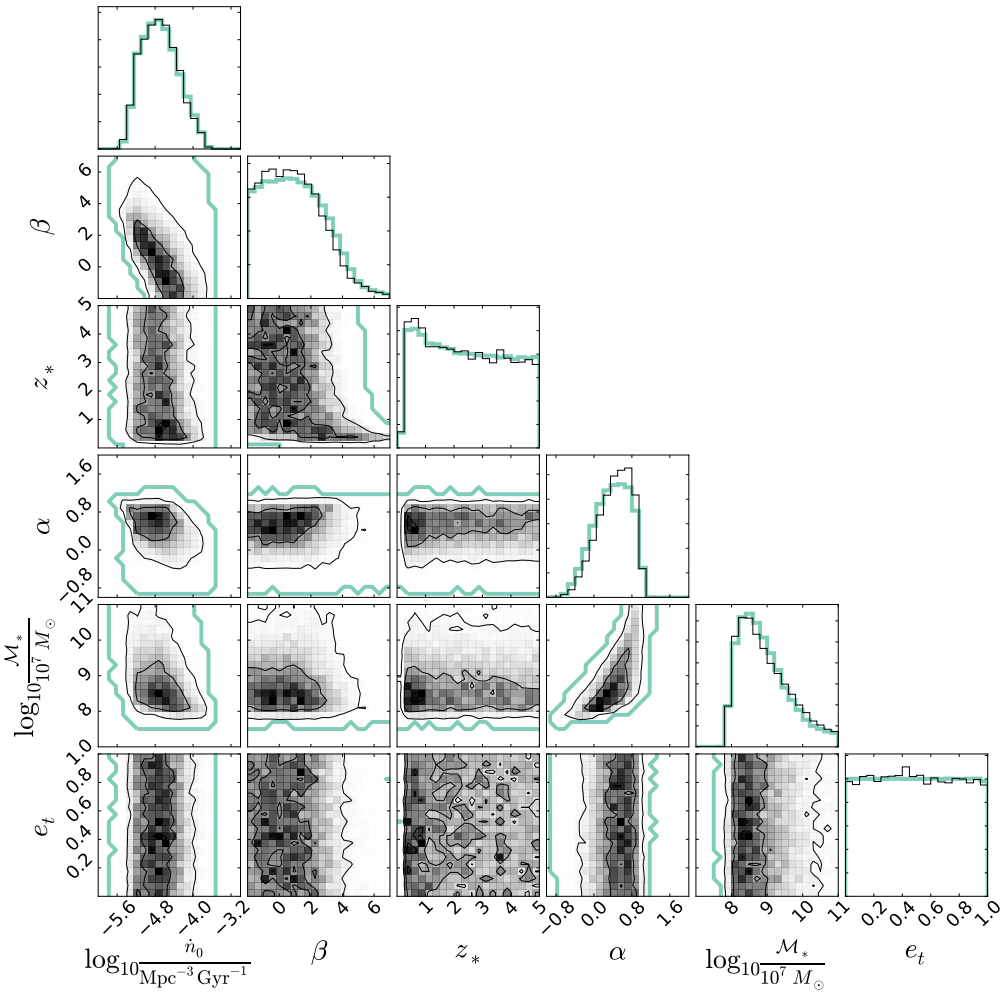

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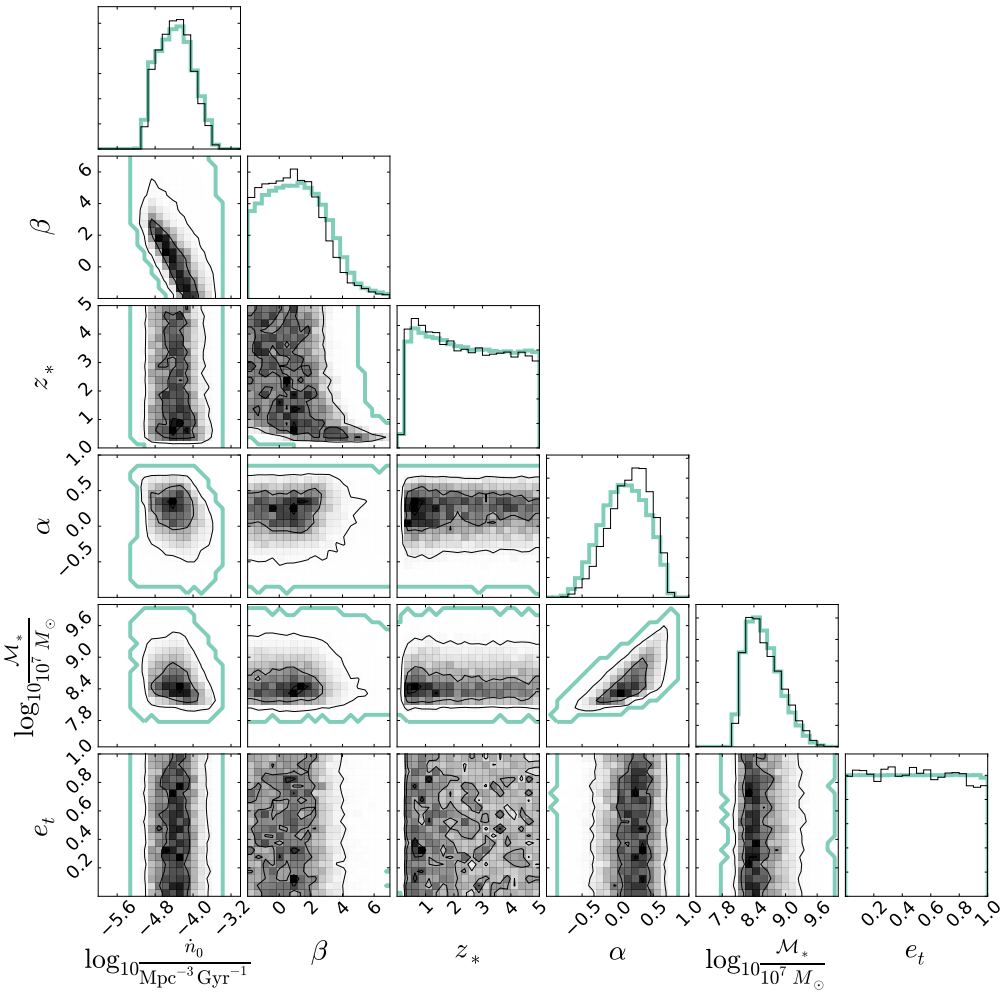
Bonus slides! Parameters

middling



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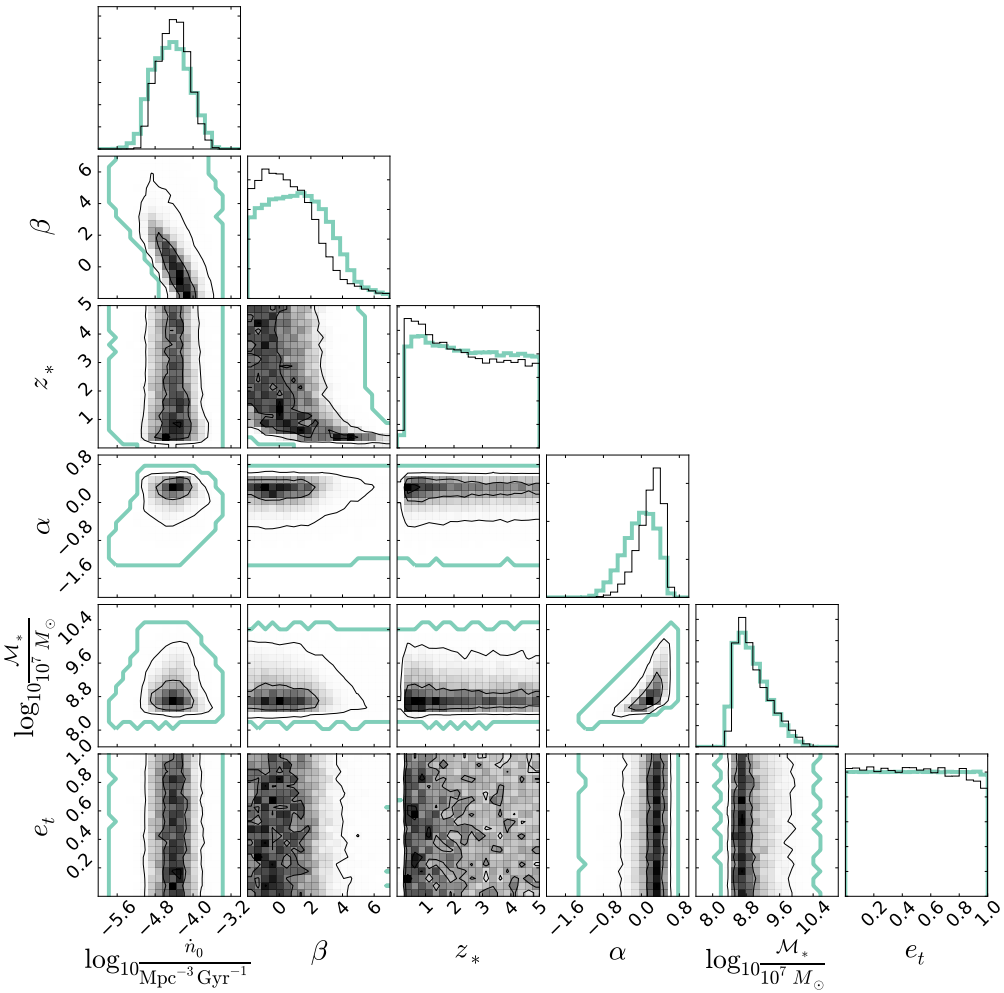
optimistic



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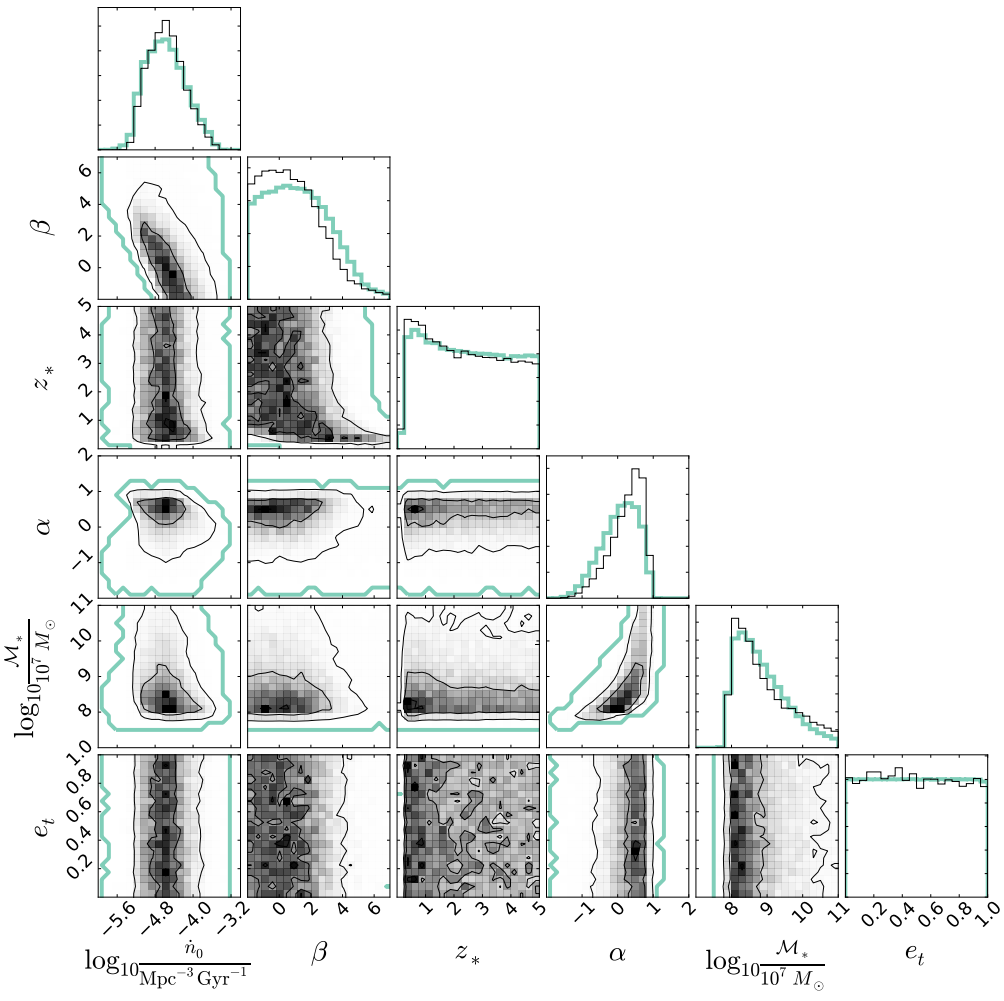

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