MONASH University

OzGrav

ARC Centre of Excellence for Gravitational Wave Discovery

GAMMA RAY BURST AFTERGLOWS AND GRAVITATIONAL WAVES

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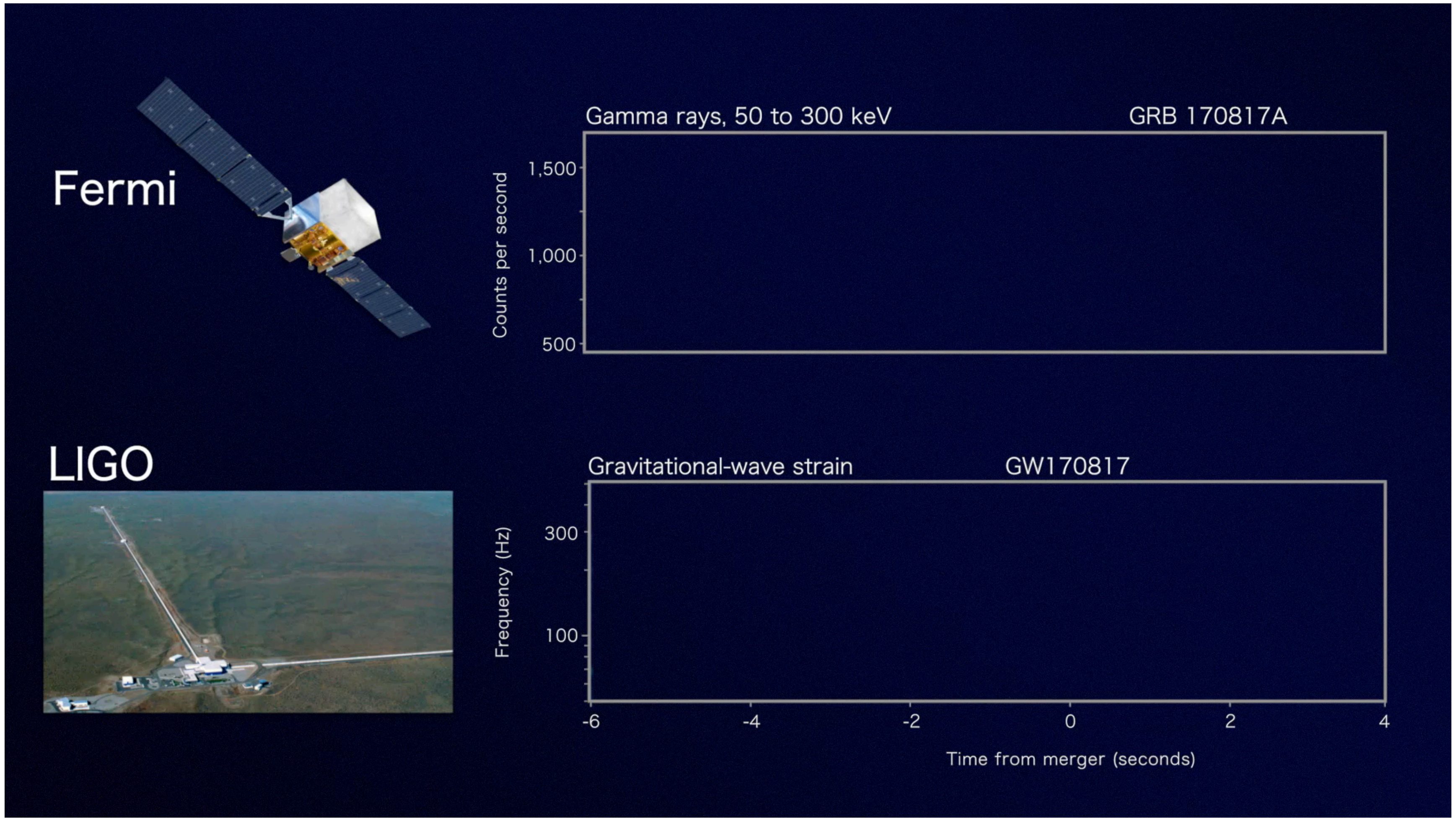
GREG ASHTON

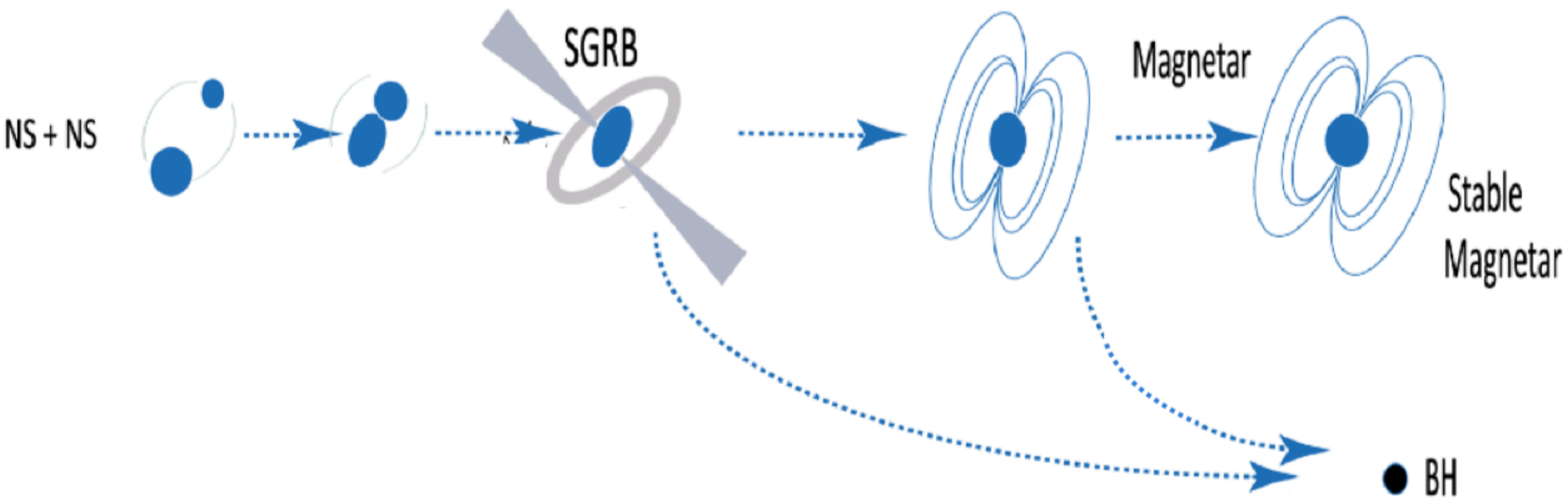
GW170817

- The first binary neutron star merger detected by aLIGO.
- Coincident with a short gamma-ray burst, GRB170817



Graphic by
Jonah B. Kanner
(Caltech)

NEUTRON STAR MERGERS



Adapted from Chu et al. (2016)

POST MERGER REMNANT

- We do not know the equation of state. We do not know the nature of the remnant.
- Millisecond magnetars are one of the proposed post-merger remnants.
- Millisecond magnetars spin down due to radiation.

SPIN DOWN

- One can derive a model for the energy lost through radiation.

$$L(t) = L_0 \left(1 + \frac{t}{\tau}\right)^{\frac{1+n}{1-n}}.$$

- We can relate L(t) to $f_{gw}(t)$

$$f_{gw}(t) = f_{gw,0}\left(1 + \frac{t}{\tau}\right)^{\frac{1}{1-n}}$$

$$\Omega = f_{gw}\pi$$

$$\dot{E} = I\Omega\dot{\Omega}$$

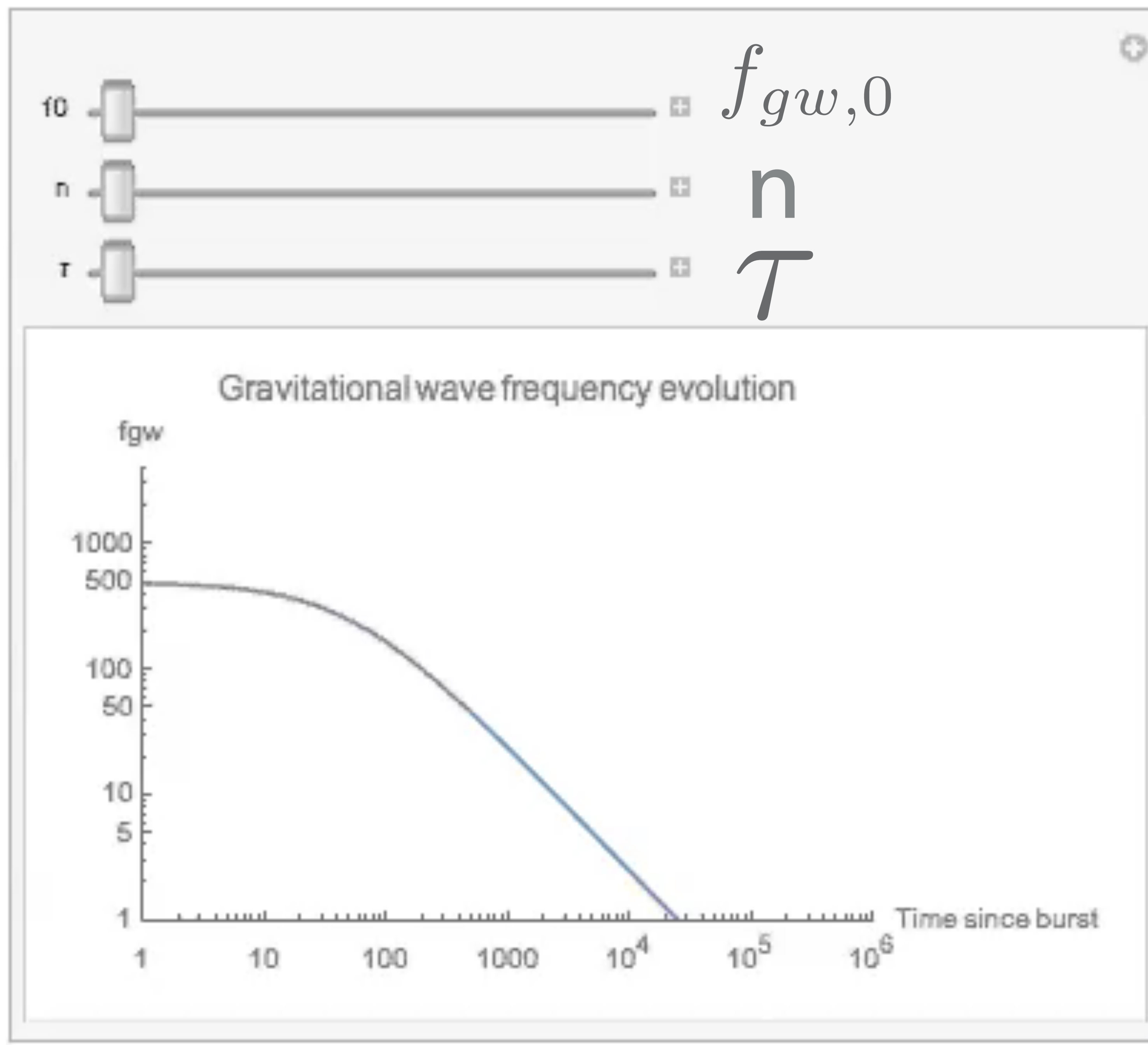
$$L = \eta\dot{E}$$

Lasky, Sarin & Sammut
(LIGO Document T1700408)
Abbott et al. (2017)
Search for post-merger gravitational waves from the remnant of the binary neutron star merger GW170817

GRAVITATIONAL WAVE FREQUENCY EVOLUTION

$$f_{gw}(t) = f_{gw,0}\left(1 + \frac{t}{\tau}\right)^{\frac{1}{1-n}}$$

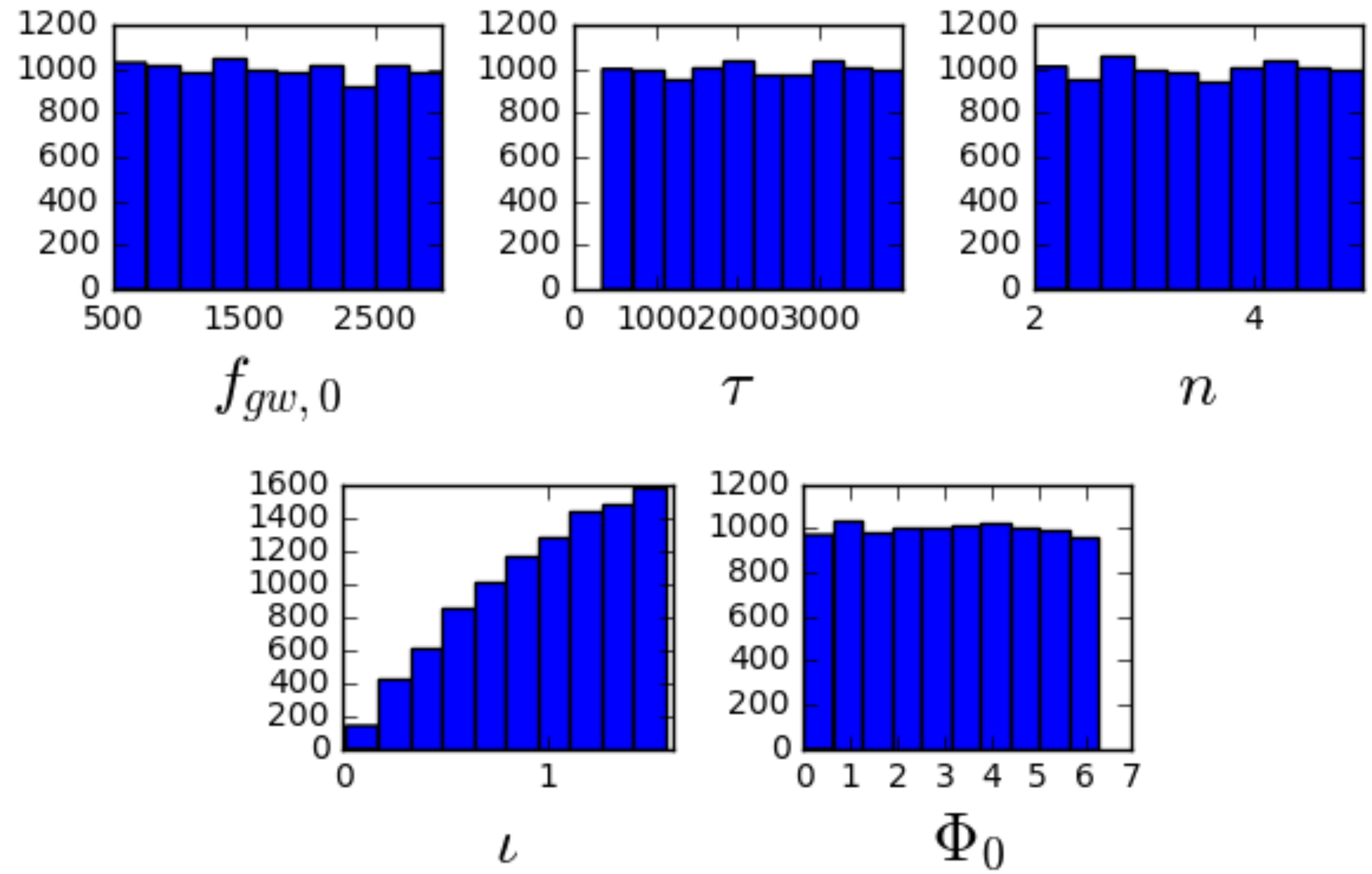
- n is referred to as the braking index.
- $f_{gw,0}$ is the initial gravitational wave frequency.
- τ is the spin down timescale.



WAVEFORM PARAMETERS

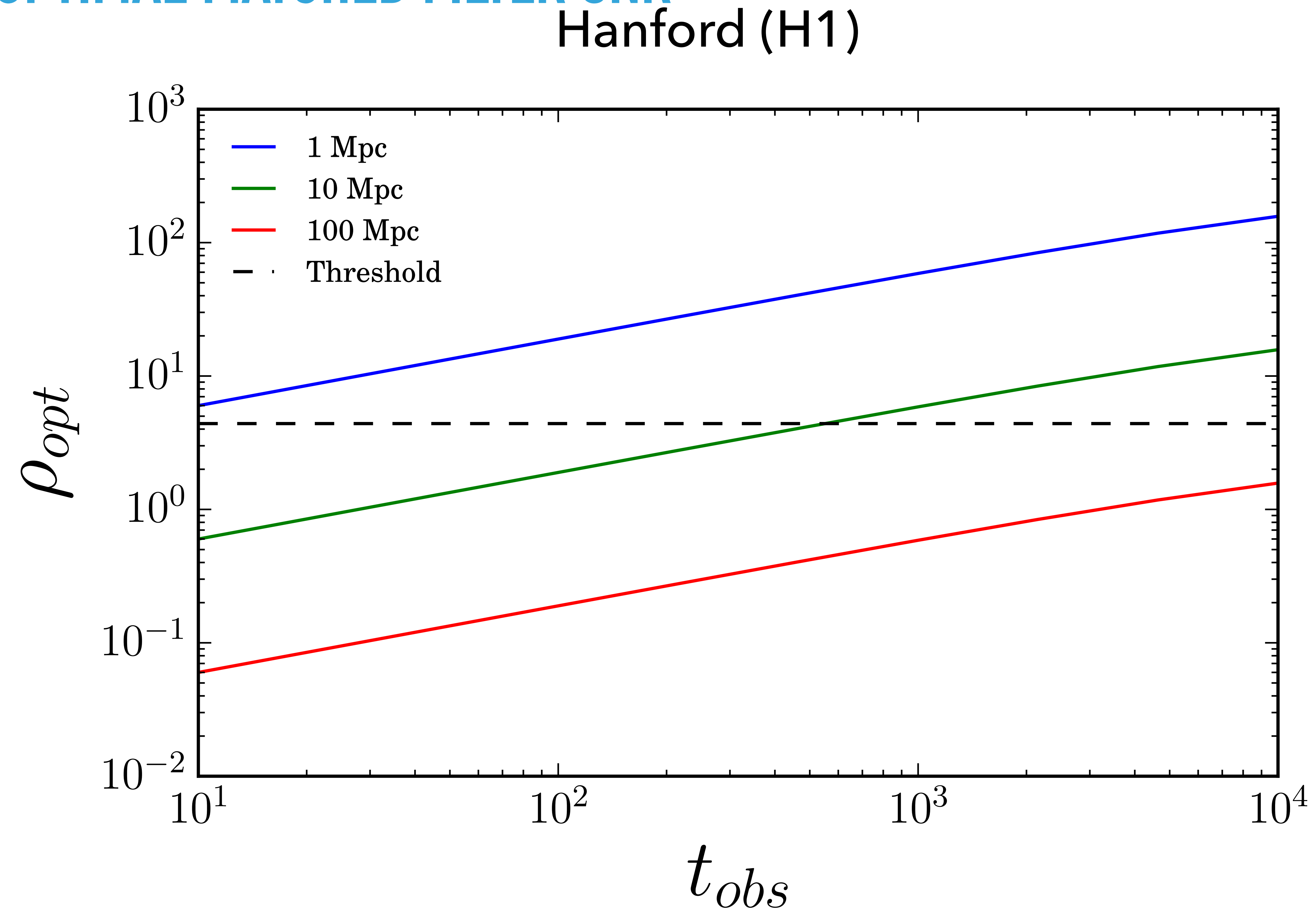
$$f_{gw,0},\ \tau,\ n,\ \Phi_0\ \&\ \iota$$

- We can make uniform distribution for our waveform parameters for plausible values.
- This distribution serves as priors for our waveforms.

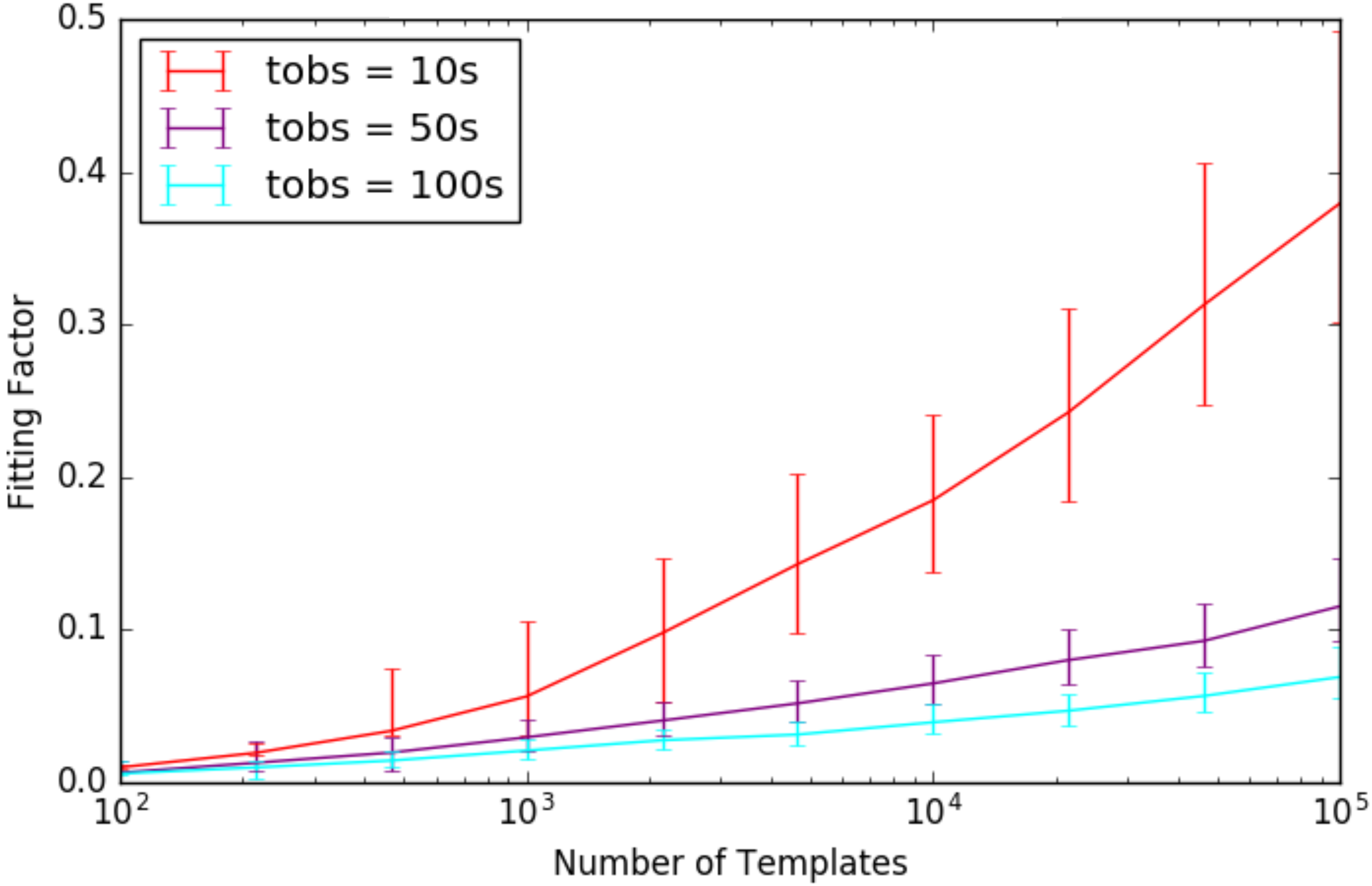


Uniform Priors

OPTIMAL MATCHED FILTER SNR



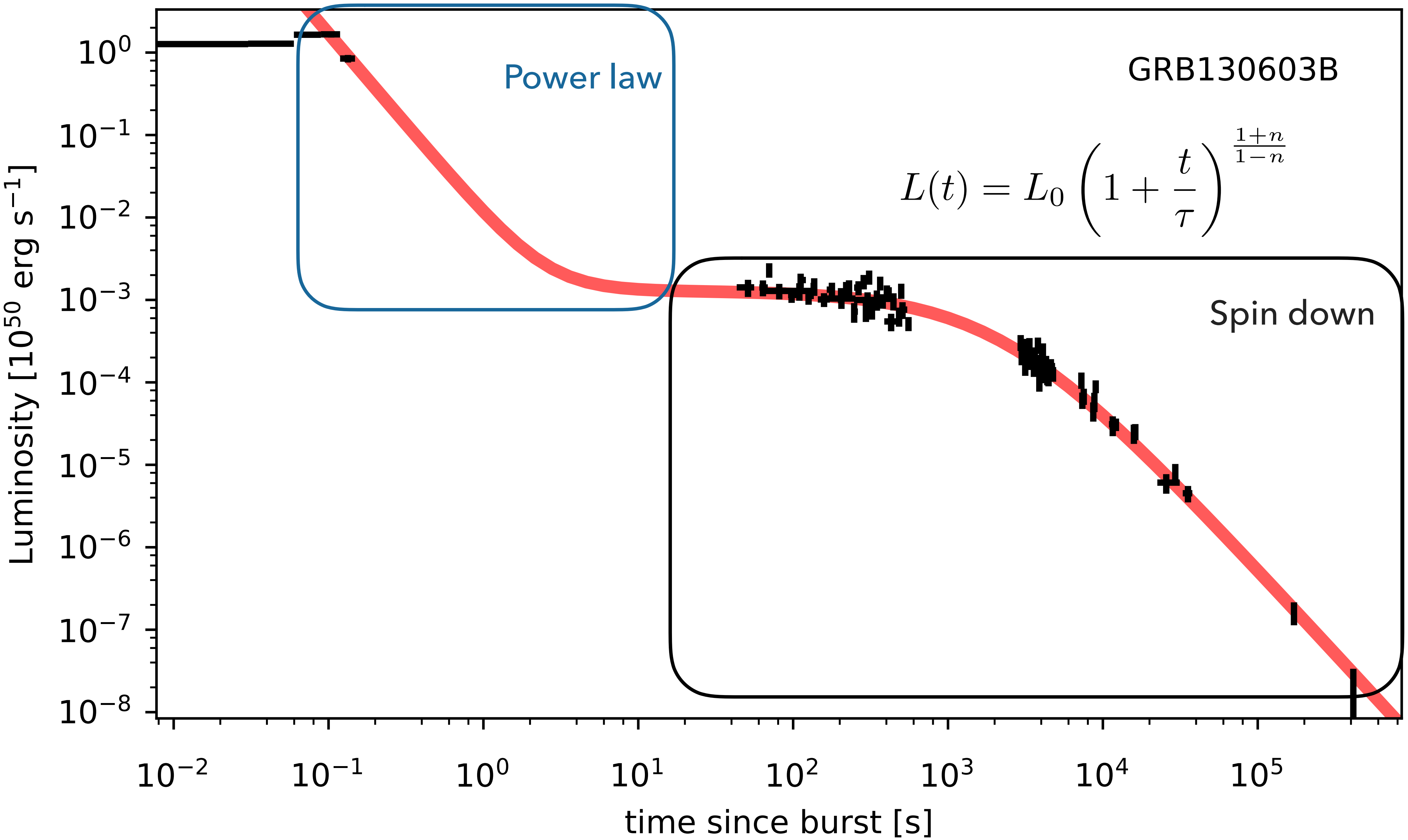
TEMPLATE BANK - UNCONSTRAINED



$$\mathbf{max}(\rho_{\text{templates}}) = \rho_{FF}\rho_{\text{opt}}$$

WE CAN DO BETTER

- Neutron star mergers are progenitors of short gamma-ray bursts.
- Some short gamma-ray bursts have an extended lower energy emission known as x-ray afterglows.



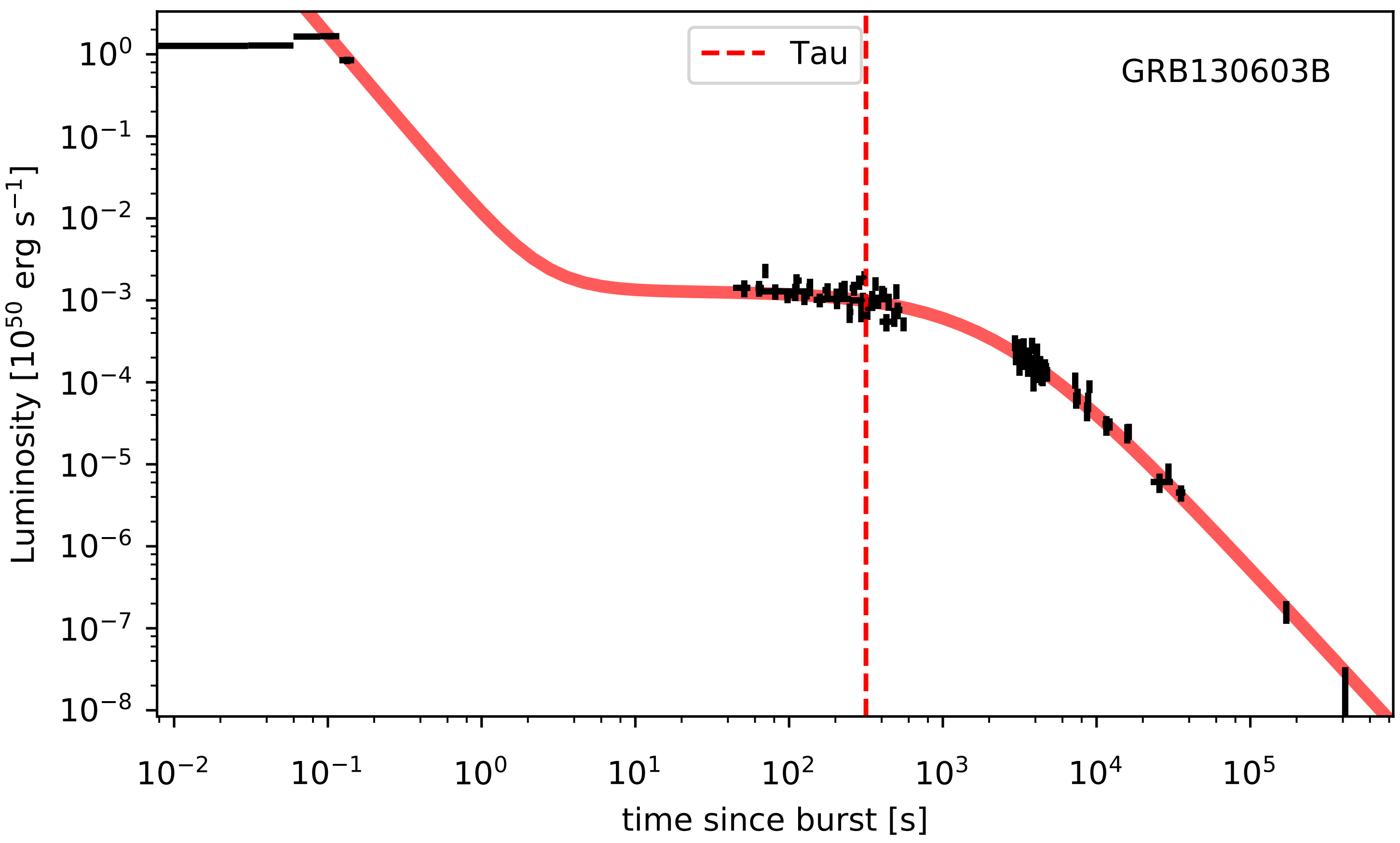
- Rowlinson et al. (2013) fit a similar model only including magnetic dipole radiation

CONSTRAINING THE DATA

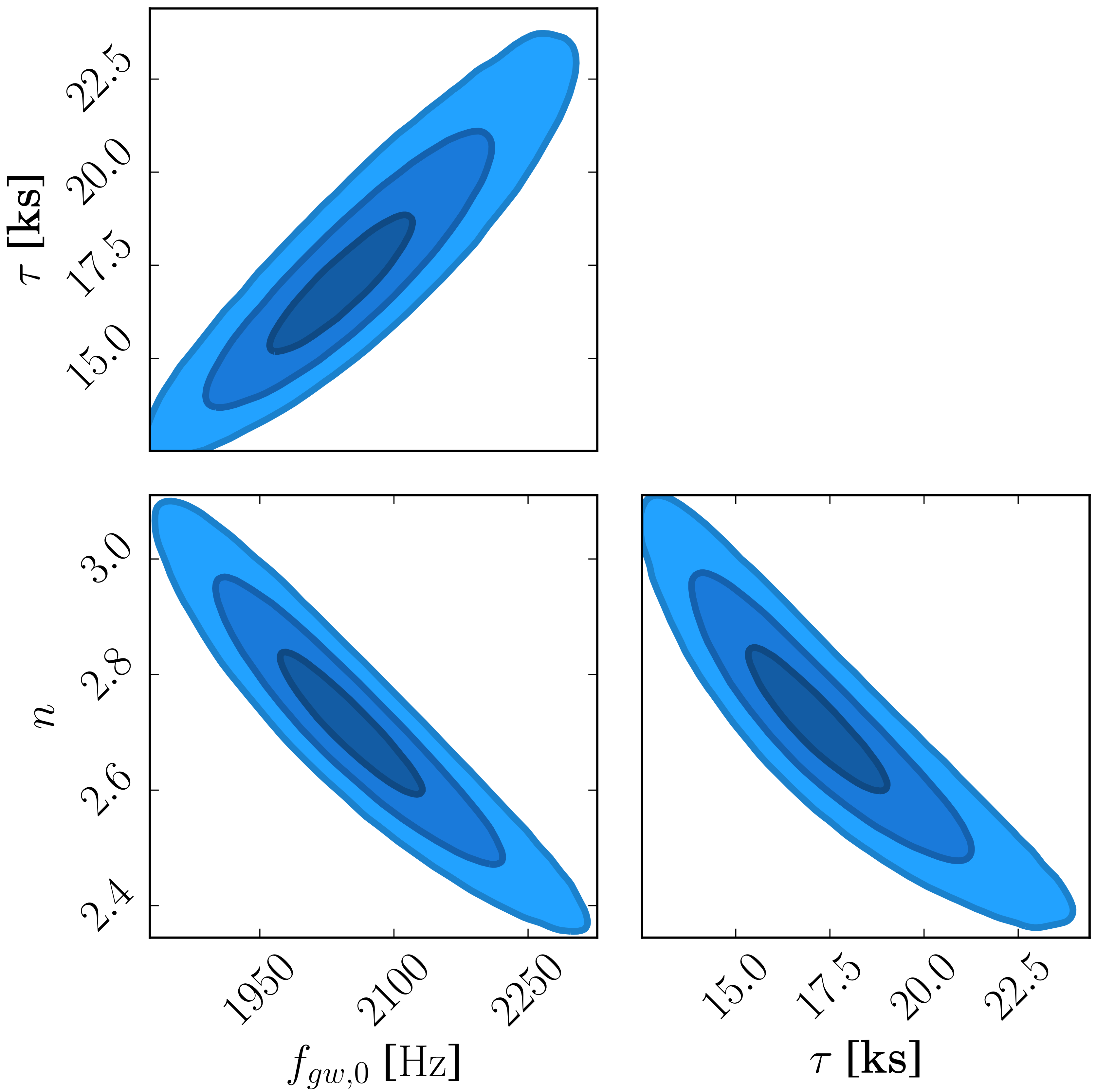
$$f_{gw}(t) = f_{gw,0}\left(1 + \frac{t}{\tau}\right)^{\frac{1}{1-n}}$$

- Can use the x-ray observations to fit our model to the data.

- We fit our model to the data using a Markov-Chain Monte Carlo (MCMC) method.



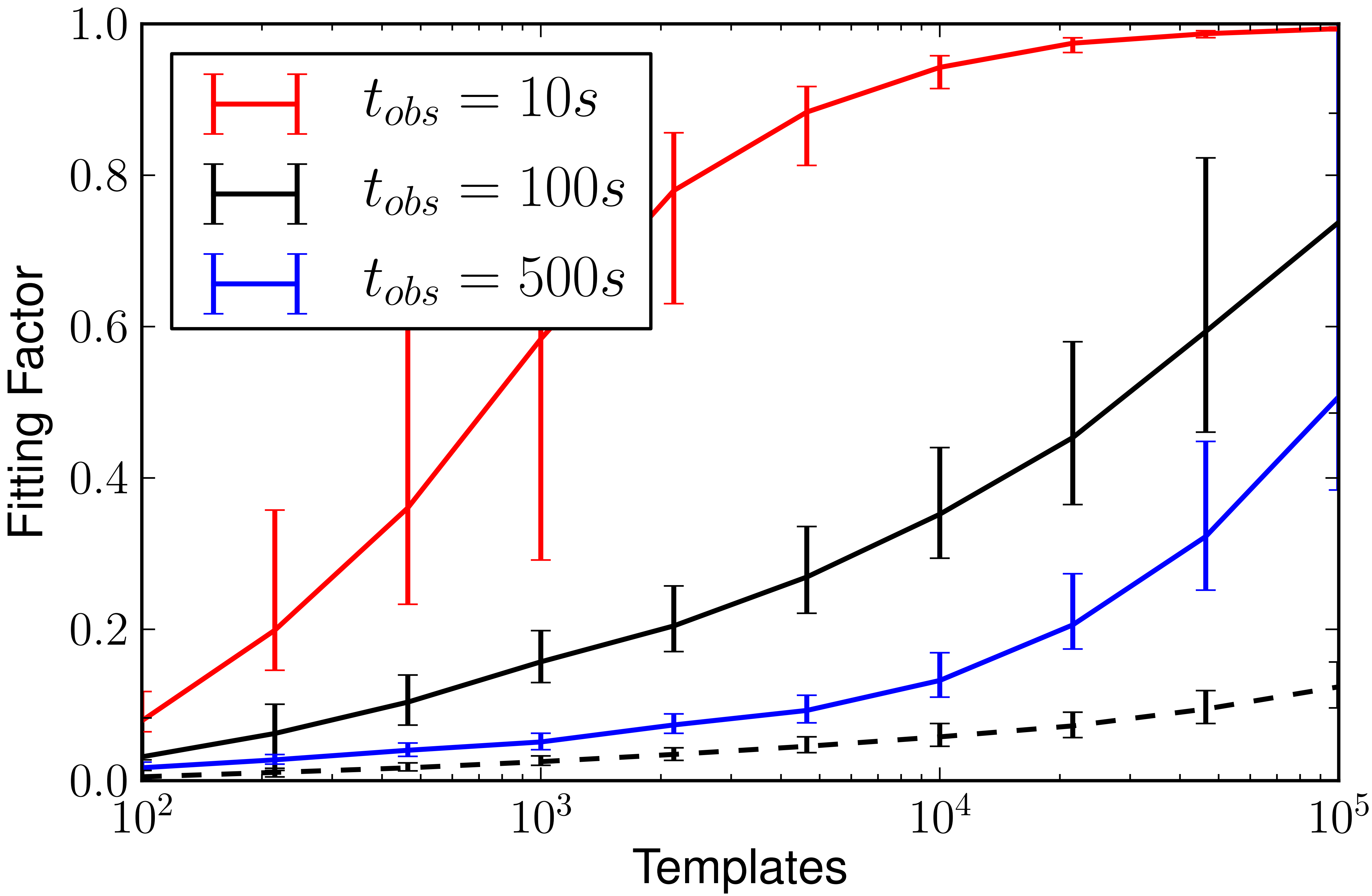
POSTERIORS



22.5
20.0
17.5
15.0
τ [ks]
3.0
2.8
2.6
2.4
n
1950
2100
2250
$f_{gw,0}$ [Hz]
15.0
17.5
20.0
22.5
τ [ks]

MATCHED-FILTER SEARCH

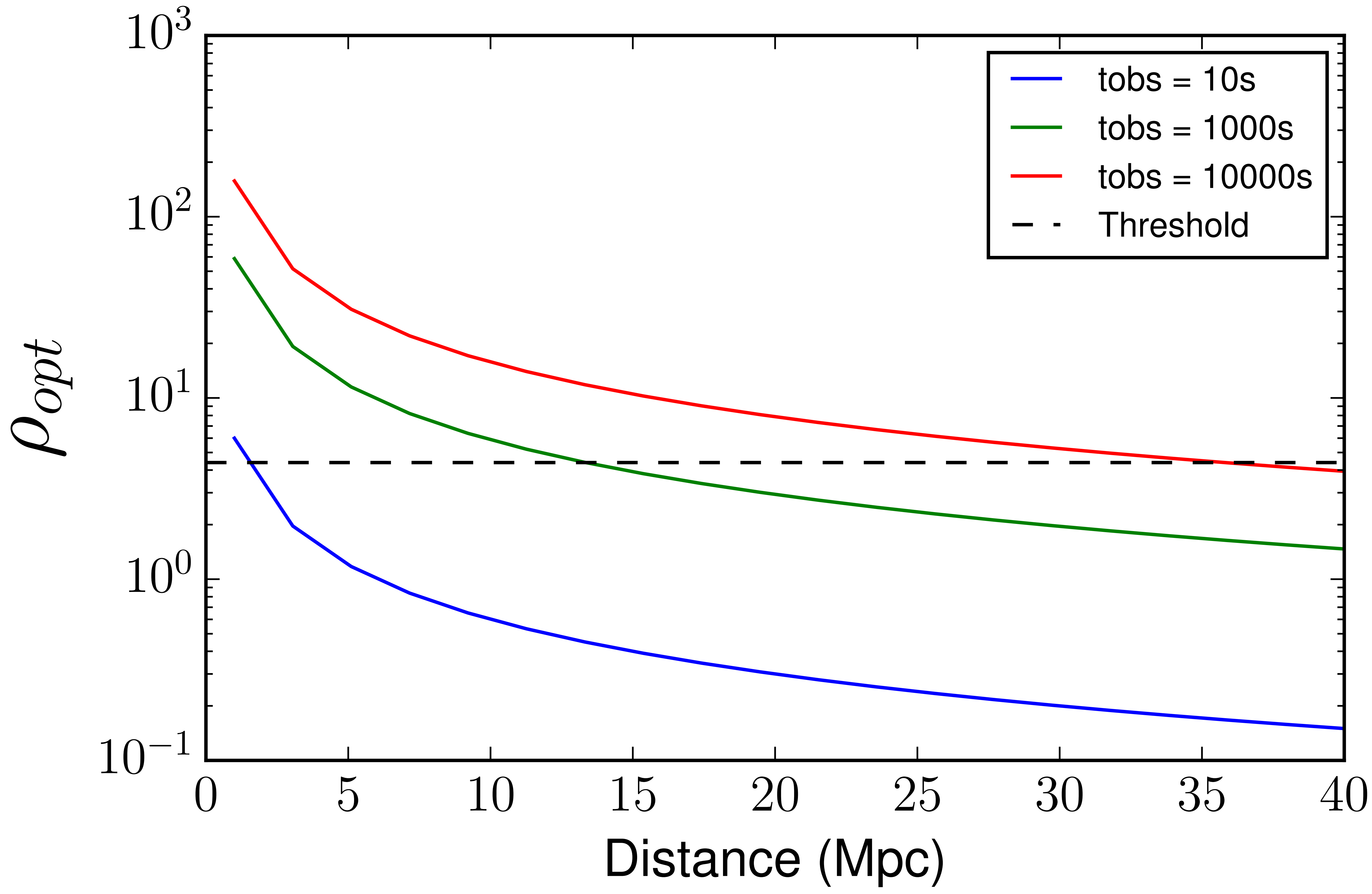
- Use constrained parameters for a targeted search for a post-merger remnant following any short gamma-ray burst with x-ray afterglow observations.
- By using informed priors, a targeted matched-filter search becomes feasible.



$$\mathbf{max}(\rho_{\text{templates}}) = \rho_{FF}\rho_{\text{opt}}$$

CONCLUSIONS

- Neutron star mergers could produce a magnetar remnant that spins down through gravitational-wave emission.
- A matched-filter search for these gravitational waves is unfeasible with uninformed priors but we can inform priors using short gamma-ray burst x-ray afterglows.
- Preliminary horizon distances are around 30 - 35 Mpc with aLIGO at design sensitivity.



10^3
10^2
10^1
10^0
10^{-1}
ρ_{opt}
0
5
10
15
20
25
30
35
40
Distance (Mpc)
tobs = 10s
tobs = 1000s
tobs = 10000s
Threshold

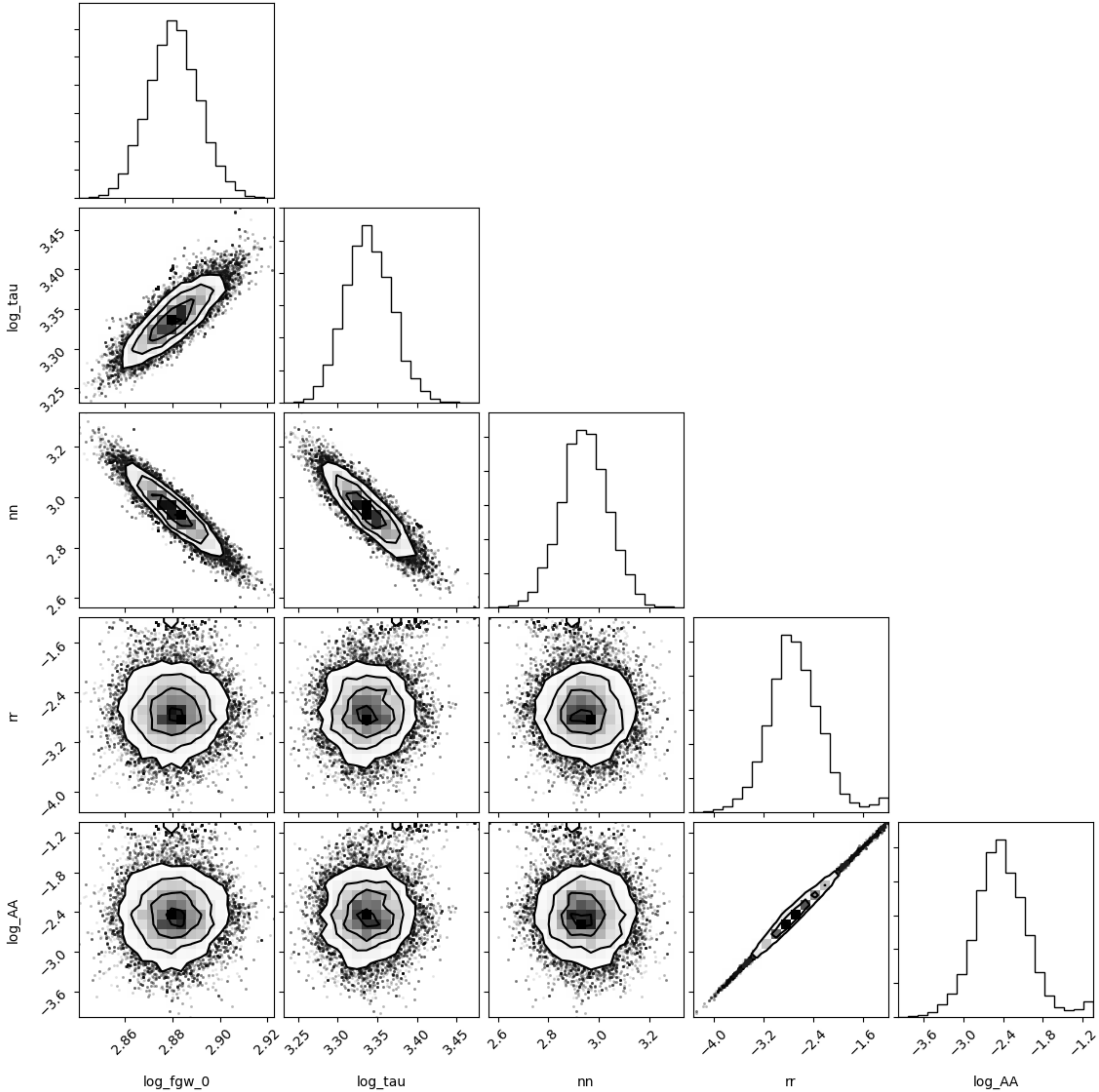
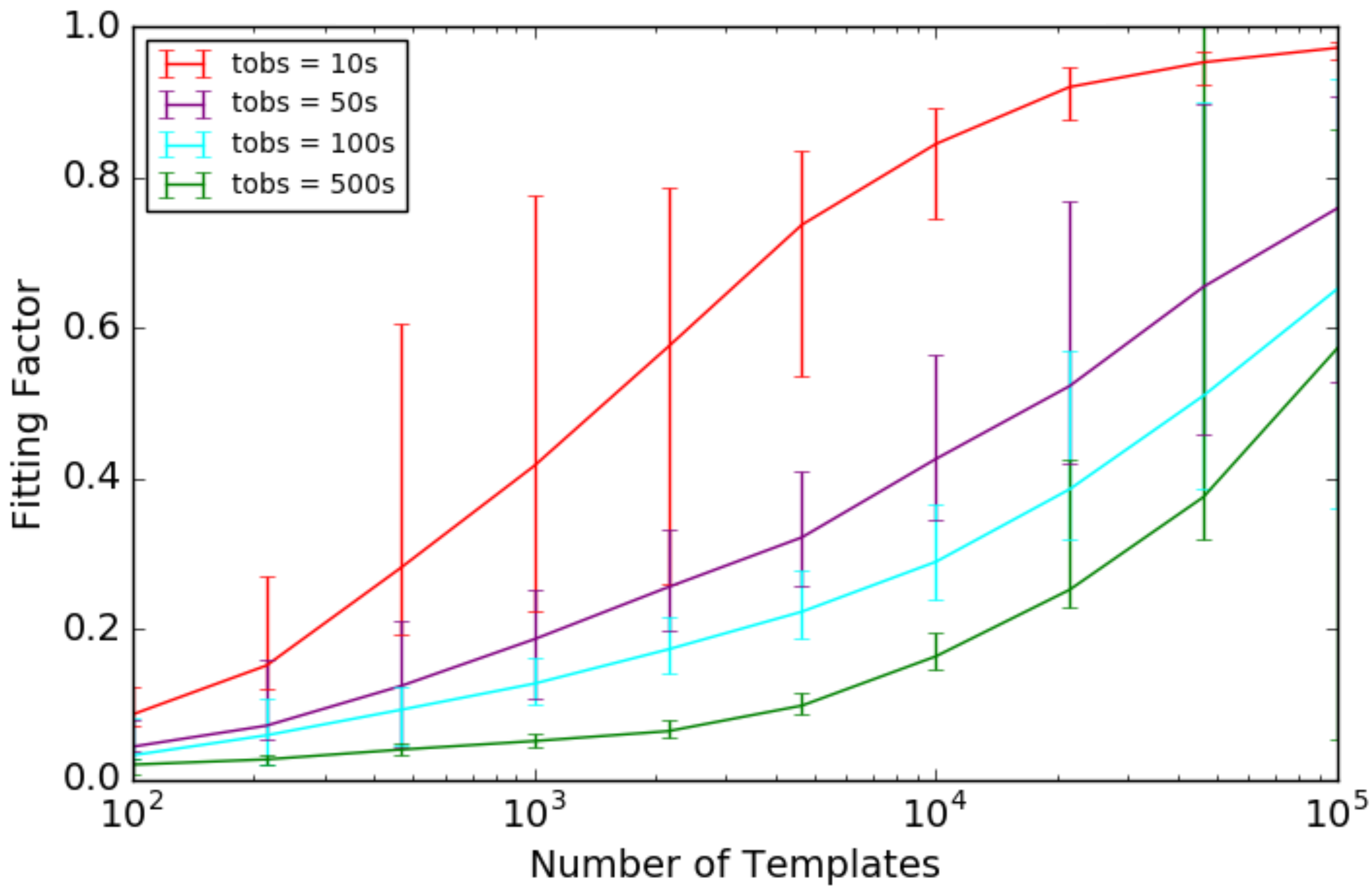
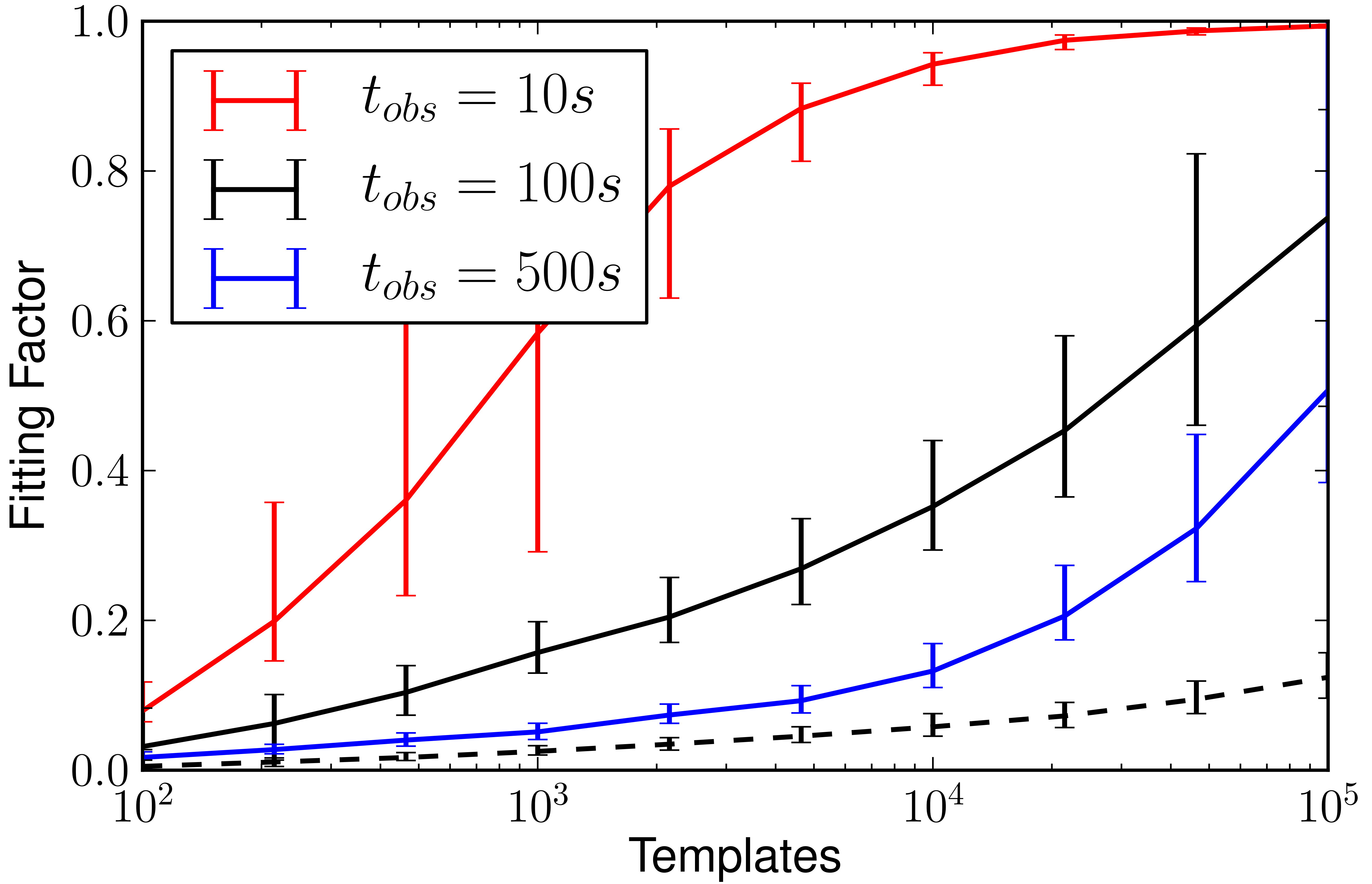


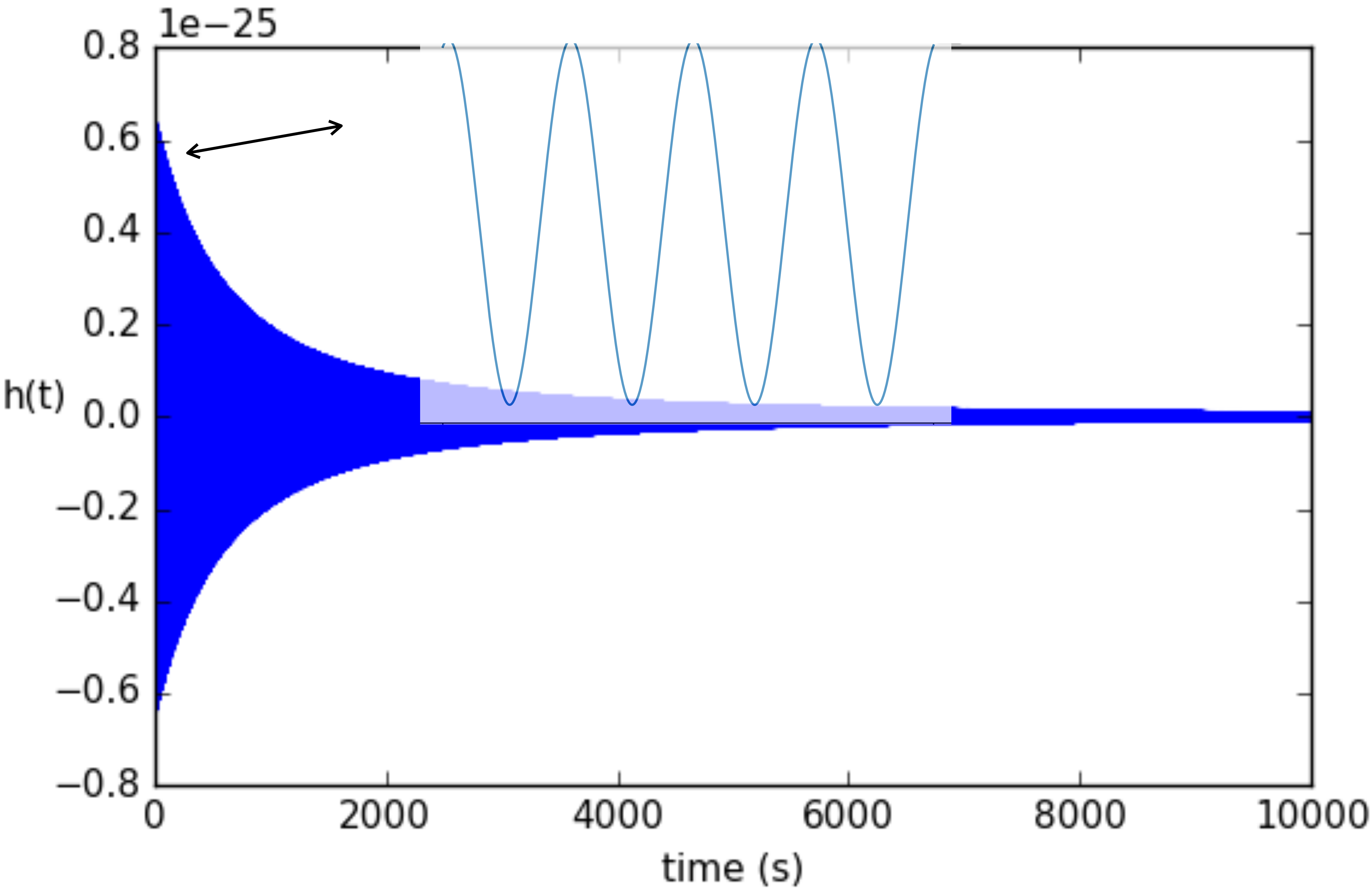
Figure B: GRB130603B Corner Plot

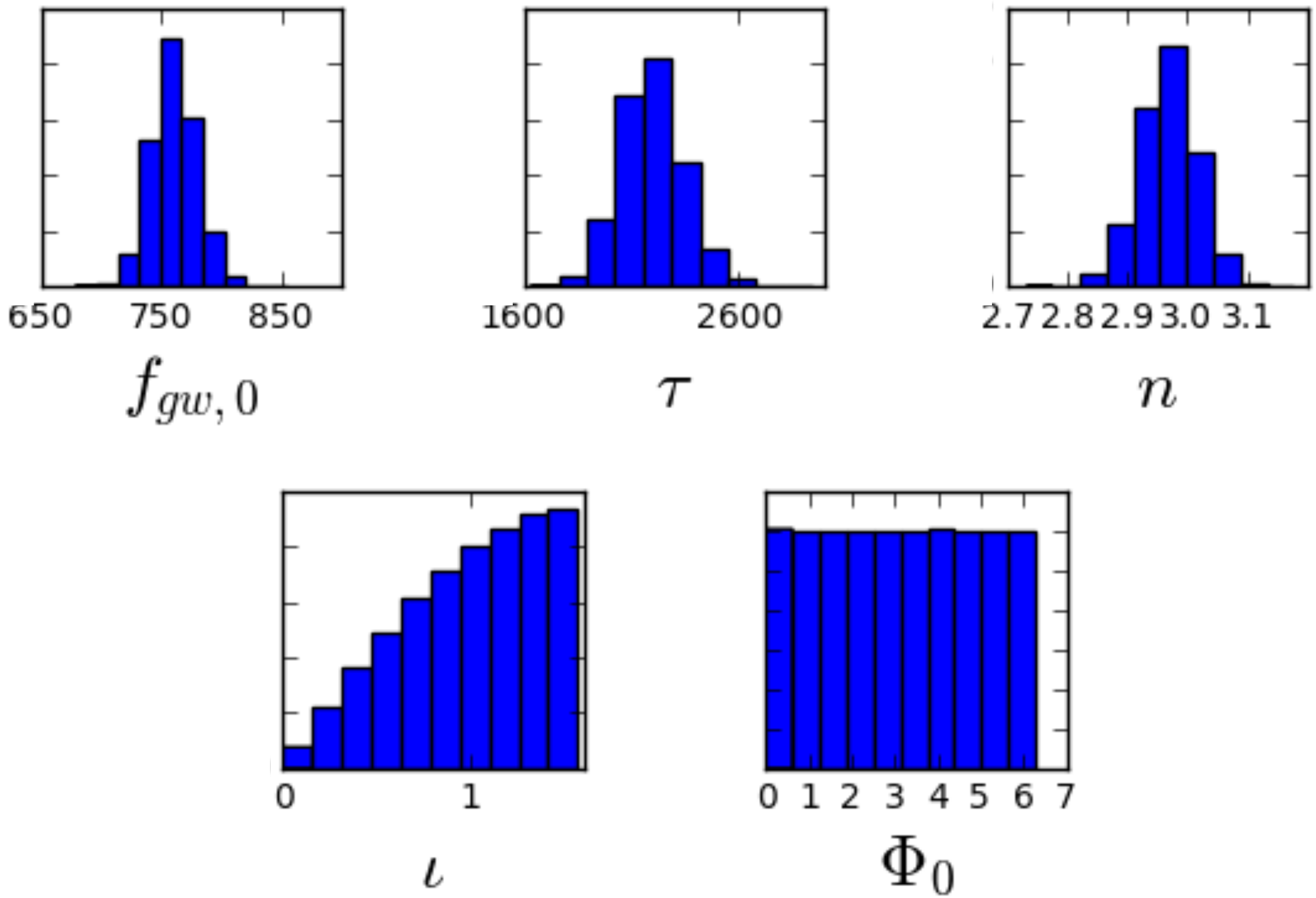


$$\mathbf{max}(\rho_{\text{templates}}) = \rho_{FF}\rho_{\text{opt}}$$



$t_{obs} = 10s$
$t_{obs} = 100s$
$t_{obs} = 500s$
Fitting Factor
Templates
1.0
0.8
0.6
0.4
0.2
0.0
10^2
10^3
10^4
10^5


1e−25
0.8
0.6
0.4
0.2
h(t)
0.0
−0.2
−0.4
−0.6
−0.8
0
2000
4000
6000
8000
10000
time (s)



650
750
850
$f_{gw,0}$
1600
2600
τ
2.7
2.8
2.9
3.0
3.1
n
0
1
ι
0
1
2
3
4
5
6
7
Φ_0

X-RAY AFTERGLOWS

- Remnant neutron star will spin-down over time as it loses energy through radiation.
- Spin down enough and it will collapse to a black hole.

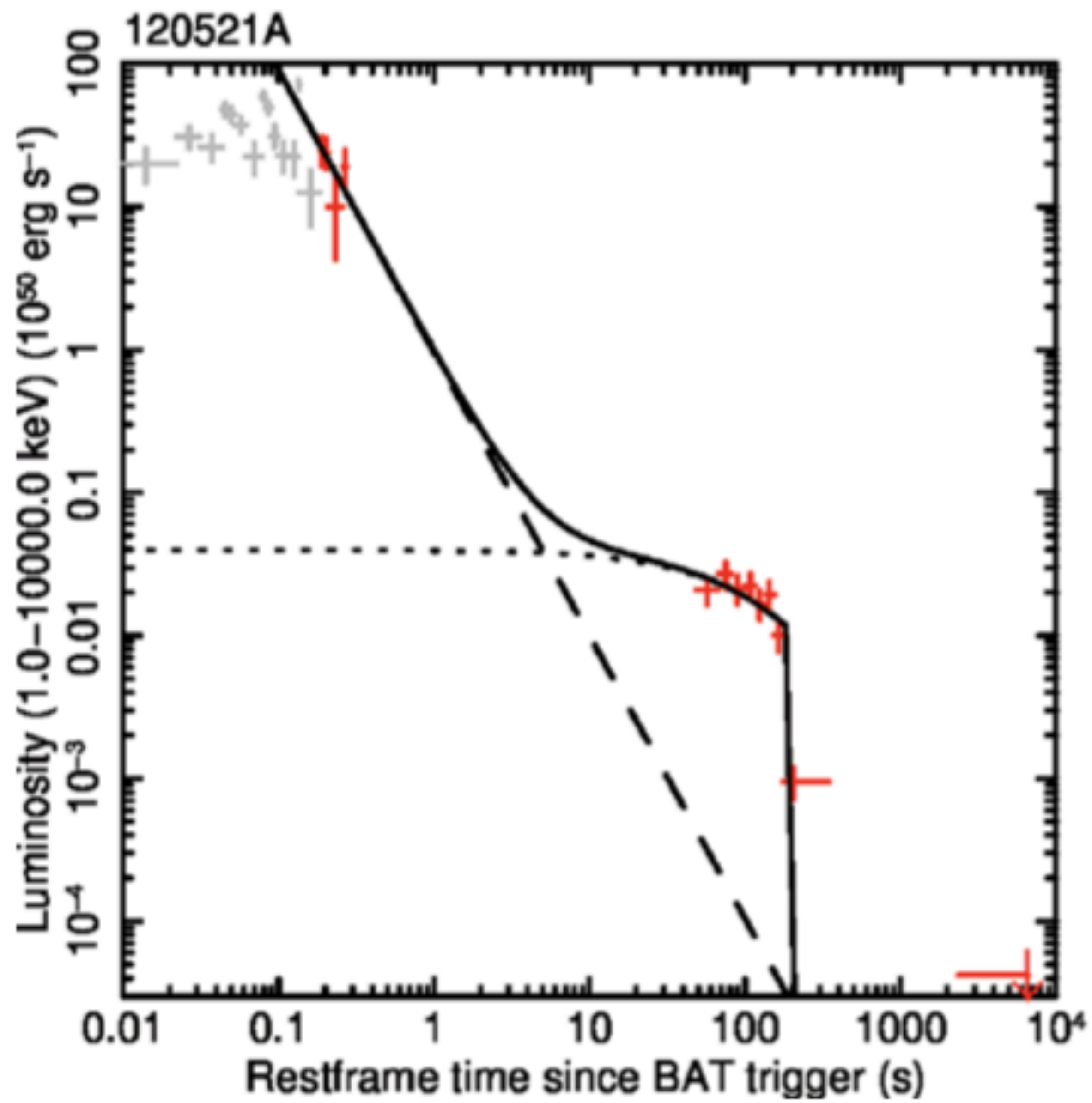


Figure: X-ray afterglow of a merger remnant that collapses to a black hole Rowlinson et al.(2013)