Recovering Higher Order Modes in the Ringdown of BBH Coalescences

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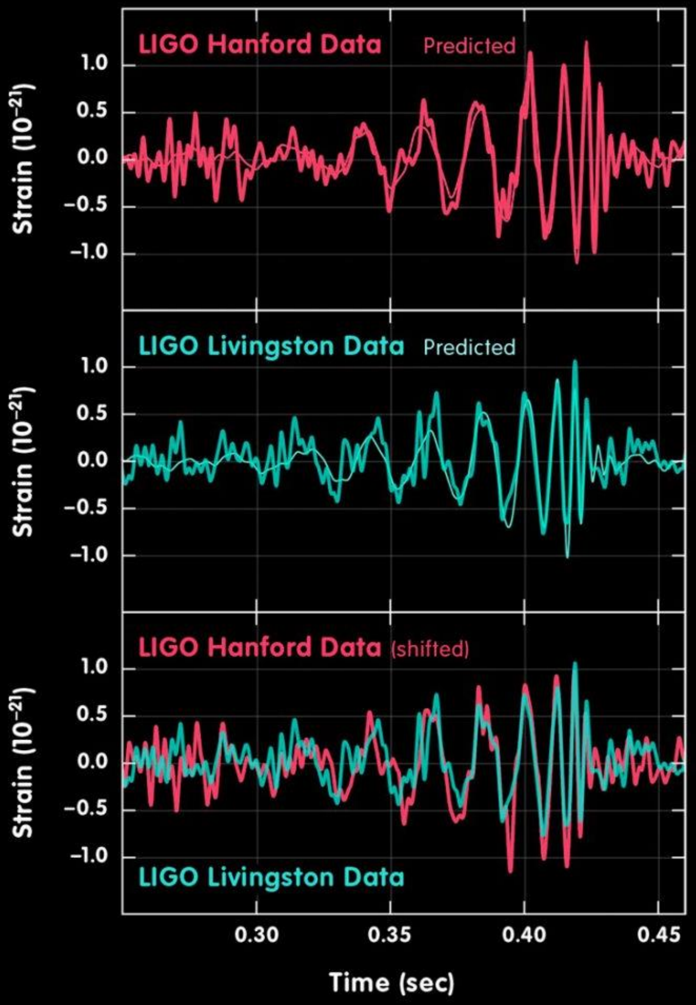
Overview

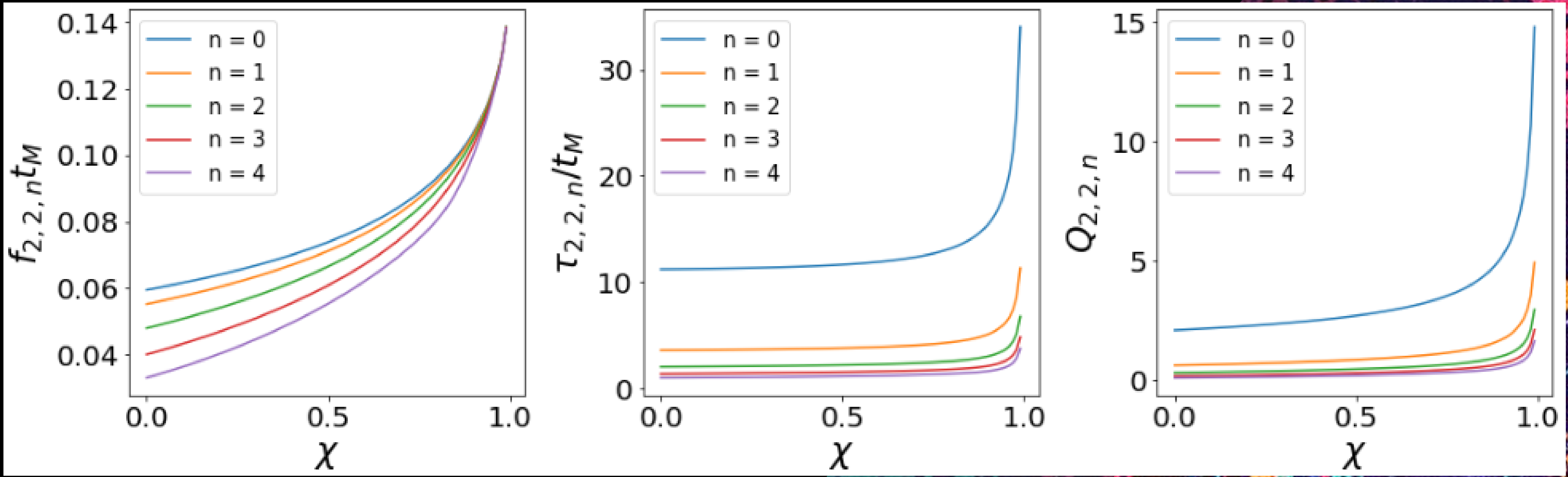


- BBH mergers
- Time domain ringdown analysis
- Quasinormal Modes (QNMs)
- Higher Order Modes (HOMs)
- No Hair Theorem (NHT)

$$t_M = \frac{GM}{c^3}$$

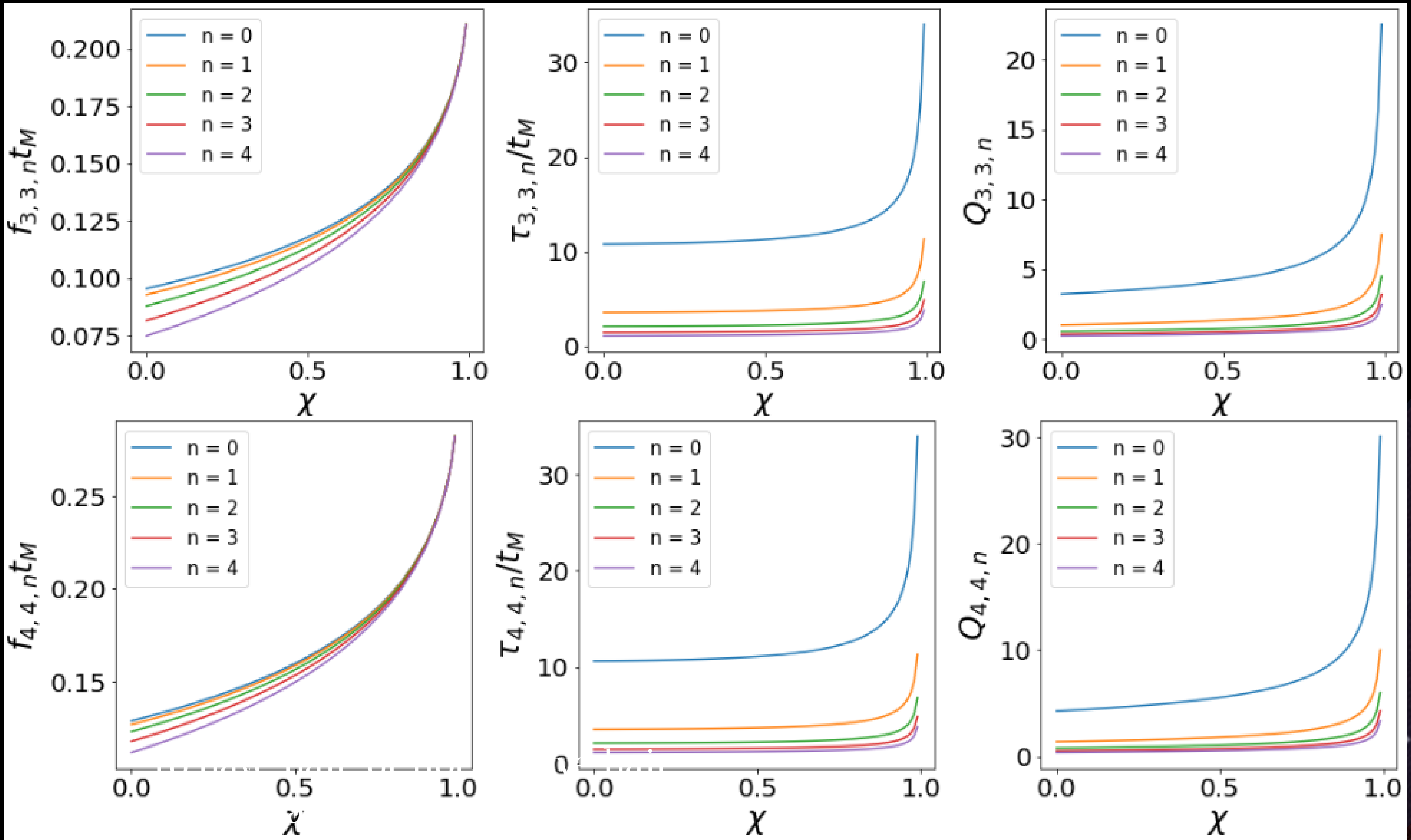
$$Q = \pi f \tau$$

Quasinormal Modes (QNMs)



$Q = \pi f \tau$

$$t_M = \frac{GM}{c^3}$$



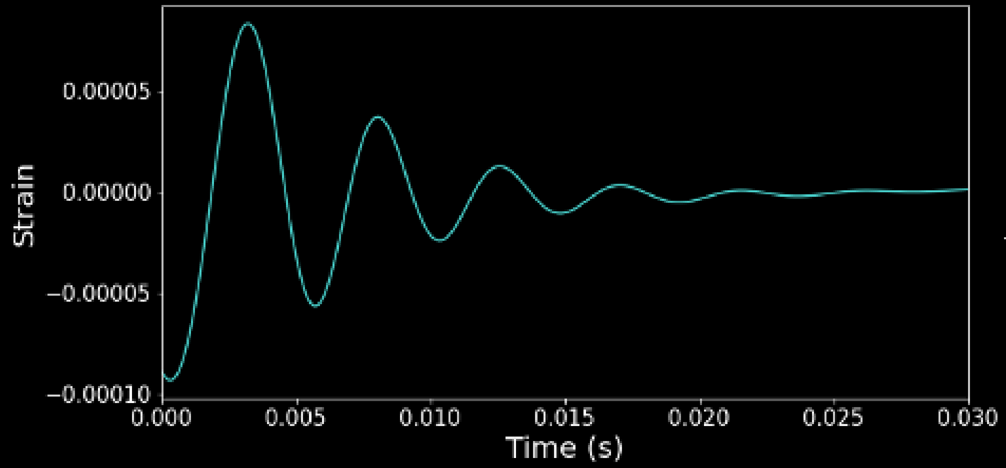
IMRPhenomXP(HM)

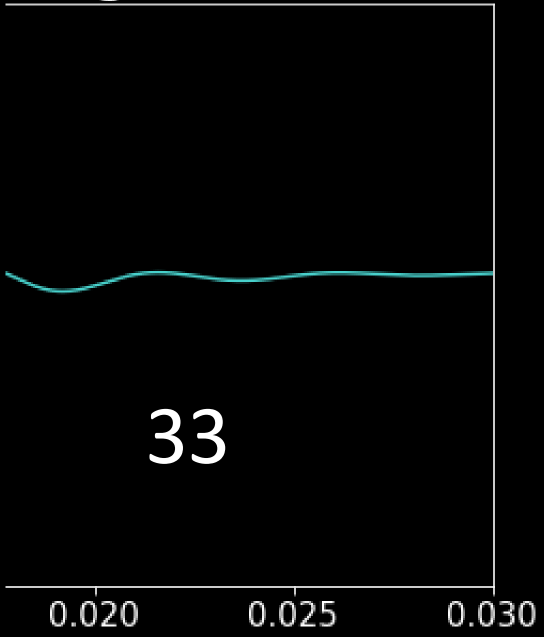
- Approximant
  - Combines inspiral, merger, ringdown
  - Phenomenological model
  - Precessing BBHs
- QNM configuration
  - 21 (XPHM)
  - 22 (XP)
  - 32 (XPHM)
  - 33 (XPHM)
  - 44 (XPHM)

  } $n = (0, 1, 2)$

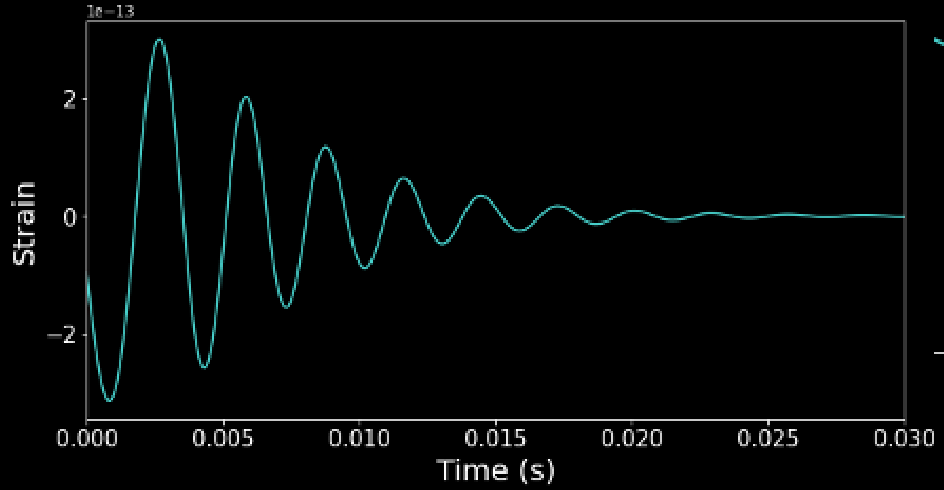
Ringdown

22

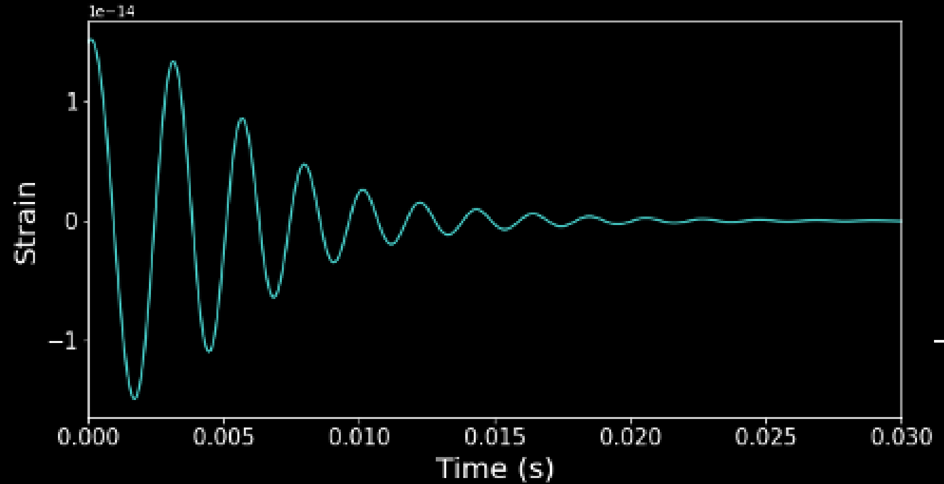




33



44



Recovery Method ....does it do a good job?

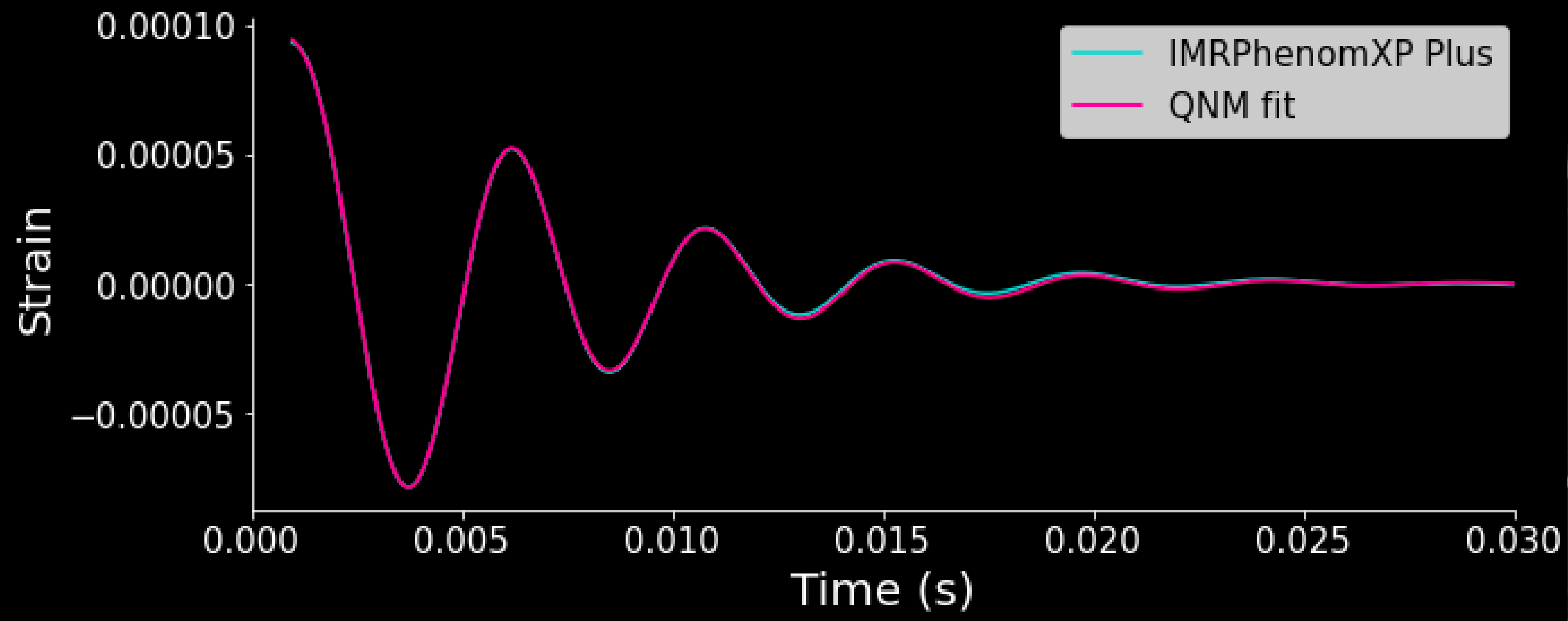
scipy.optimize.curve_fi
t

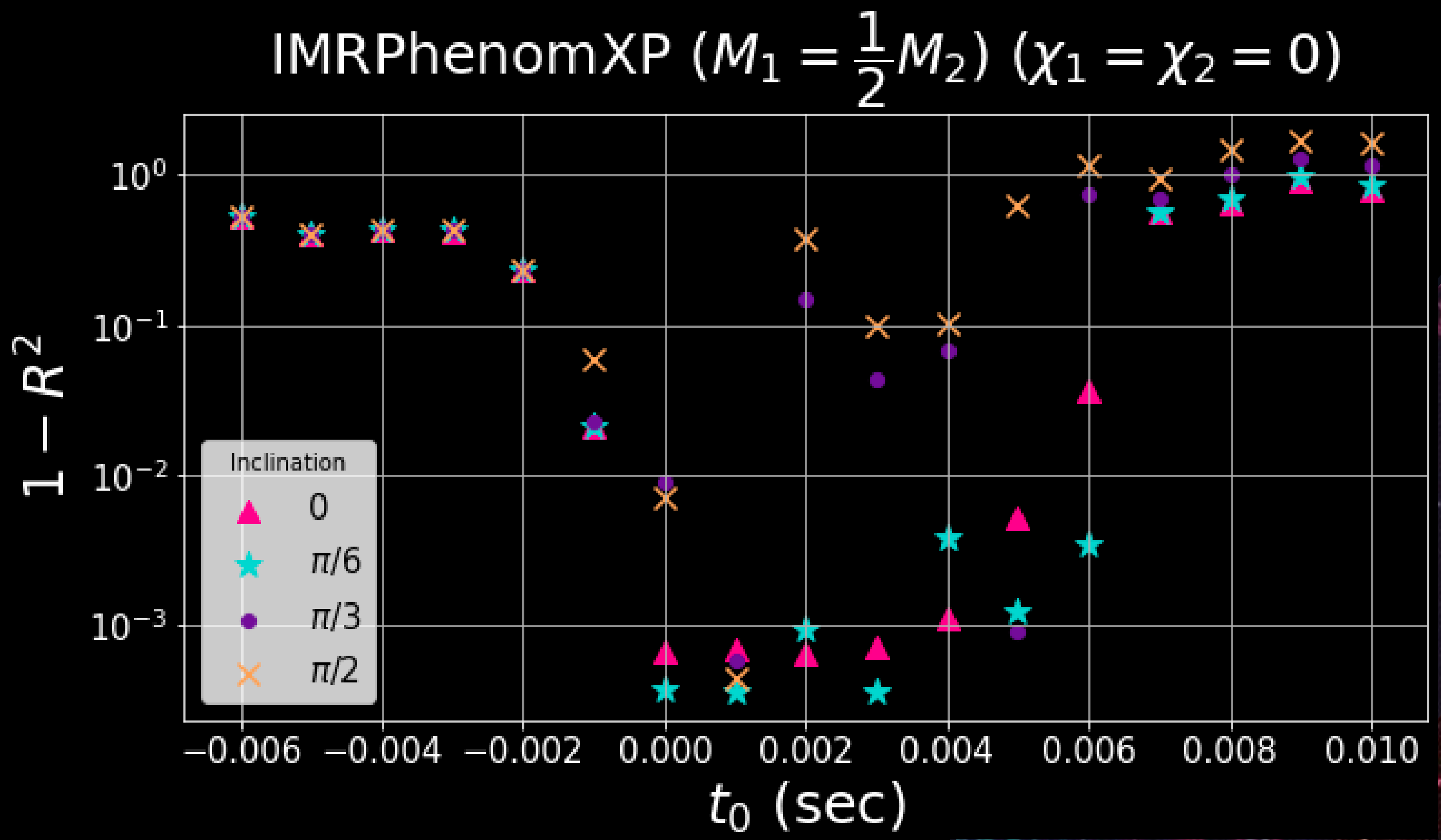
```
scipy.optimize.curve_fit(f, xdata, ydata, p0=None, sigma=None,
absolute_sigma=False, check_finite=True, bounds=(- inf, inf), method=None,
jac=None, **kwargs)
```

$$h \sim \sum_{lmn} A_{lmn} \sin(2\pi f_{lmn} t) e^{-t/\tau_{lmn}}$$

$$1 - R^2 = \frac{RSS}{TSS}$$

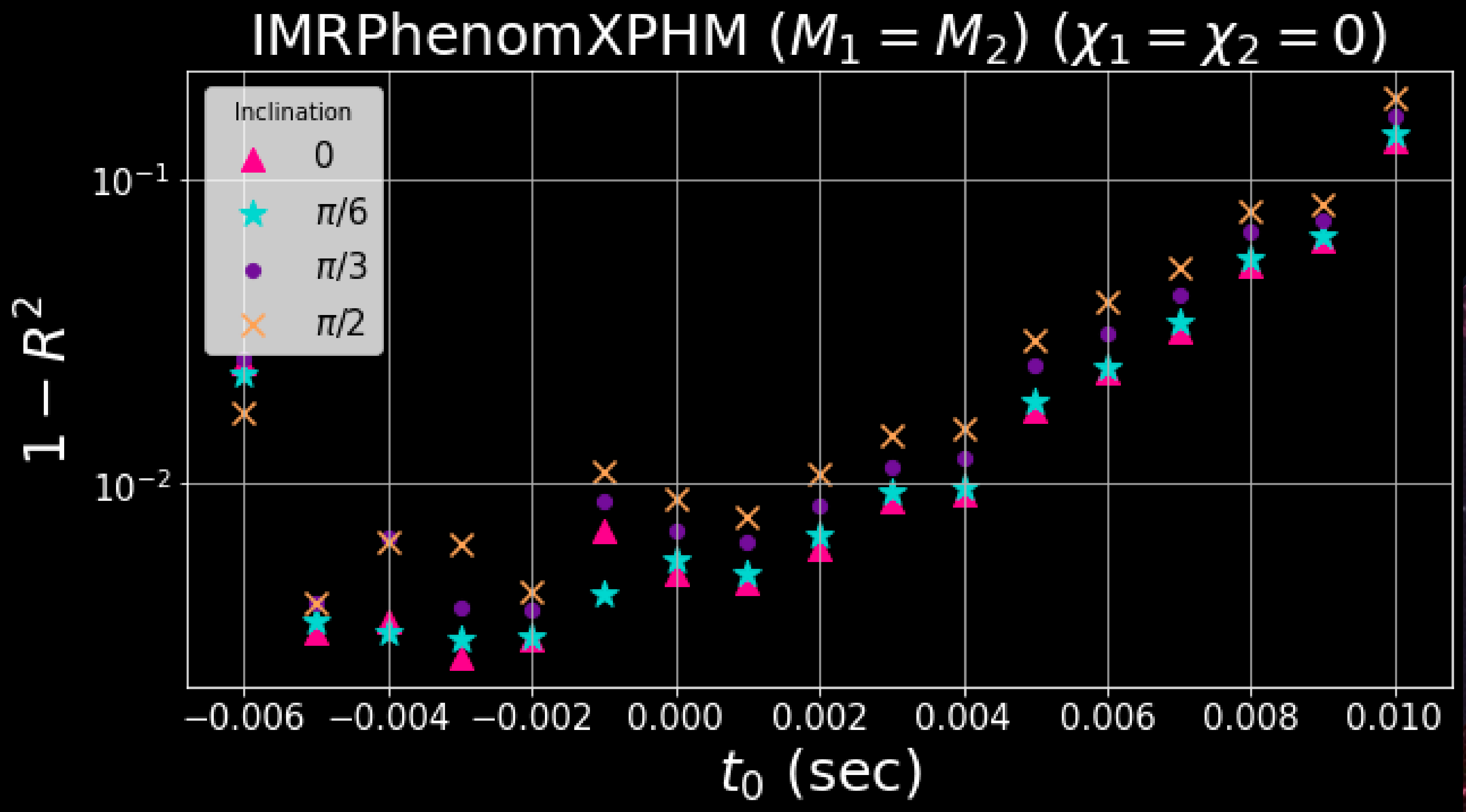
IMRPhenomXP [22]



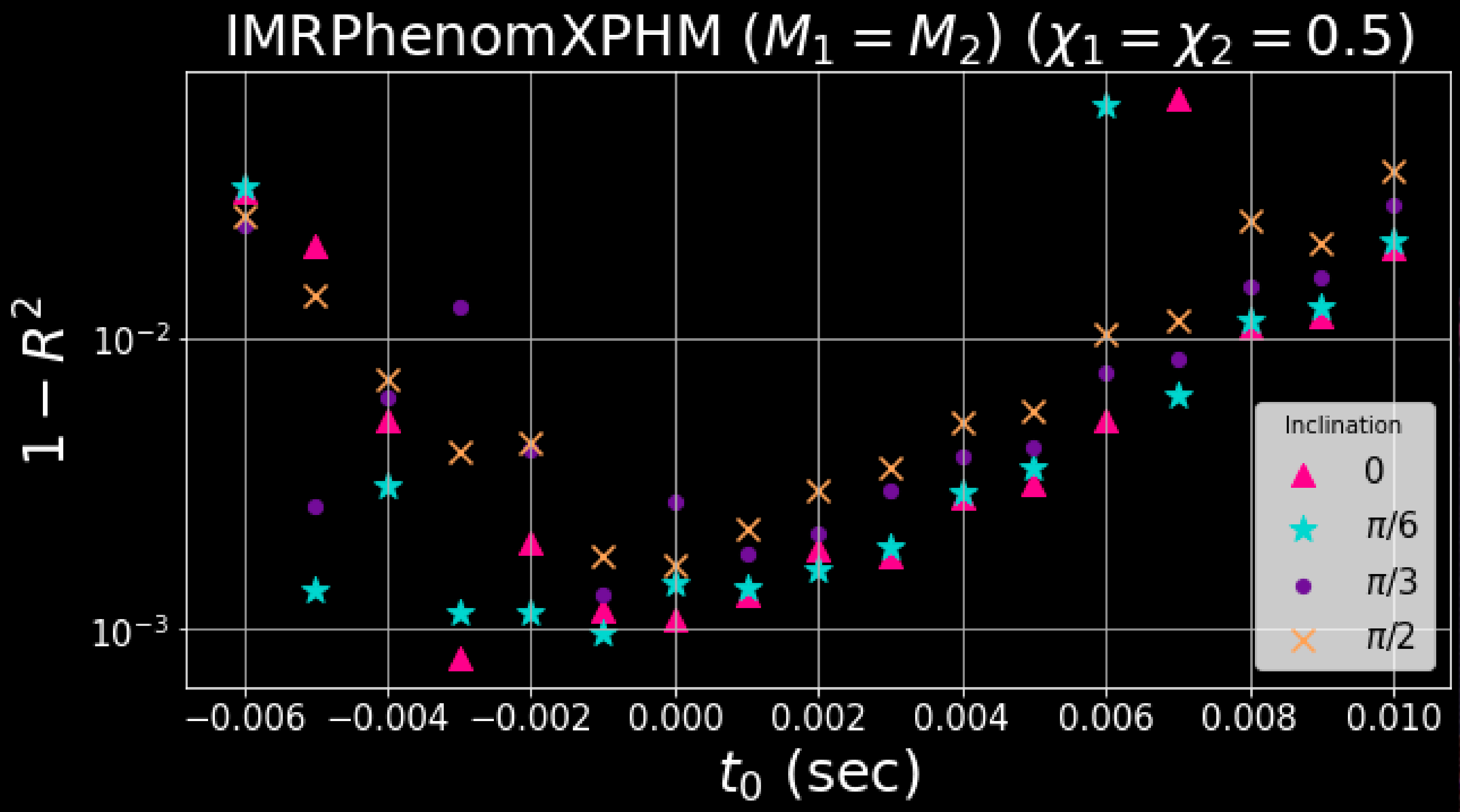


IMRPhenomXP Modes: [22]

Note: t_0 can be in units of t_M using $t_M = \frac{GM}{c^3}$



*IMRPhenomXPHM Modes: [21,22,32,33,44]



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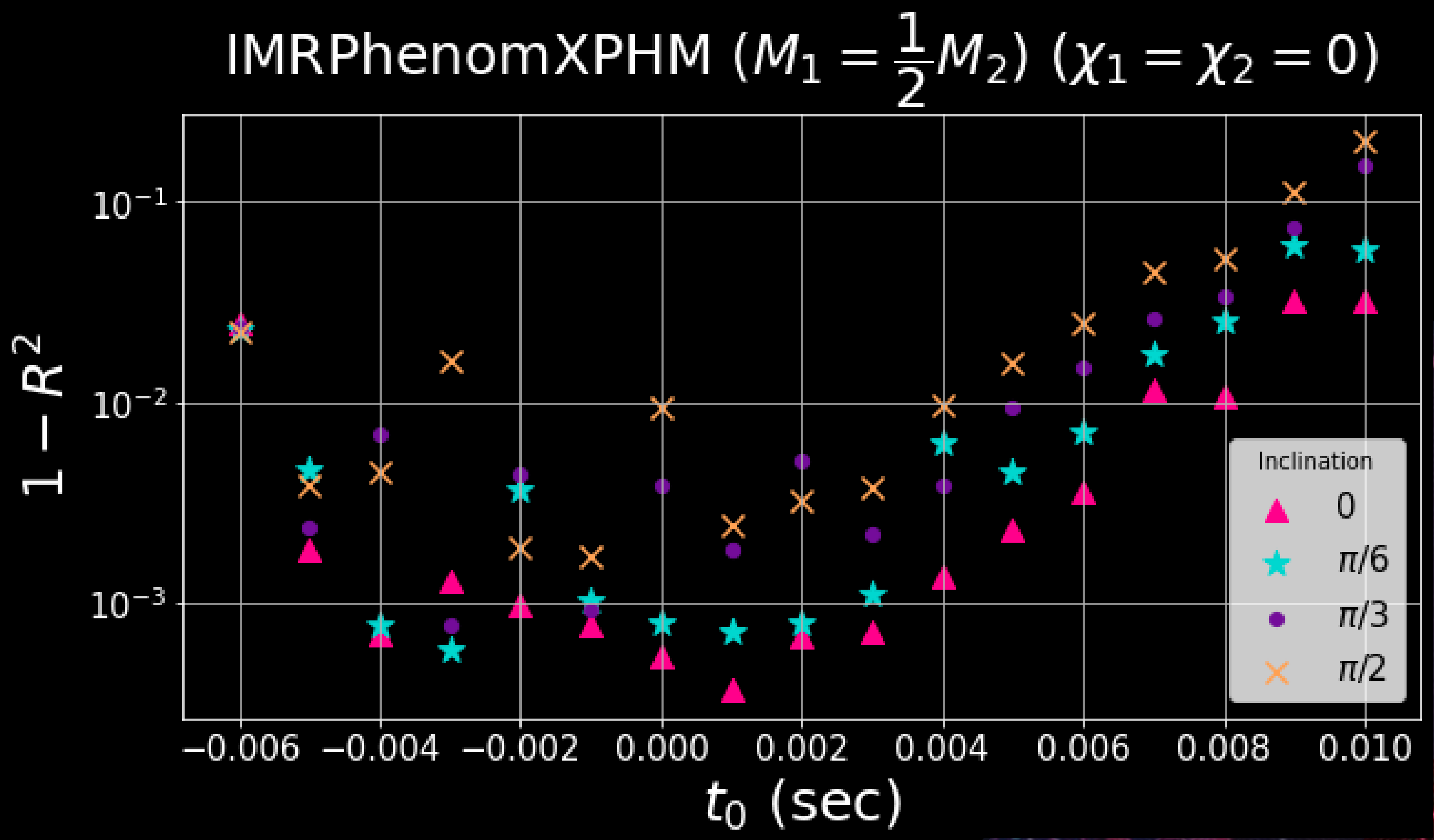

*IMRPhenomXPHM Modes: [21,22,32,33,44]

Remnant BH Parameter Recovery

XPHM [21,22,32,33,44]

- SurfinBH
  - returns … nd spin
  - 1-sigma

mass	chi
78.639717	0.870000
78.452861	0.870000
71.000252	0.793228
76.845981	0.860198
78.999563	0.840552
78.675252	0.860175
78.200119	0.853722
76.917871	0.845052

```
chi = 0.831245957632349
mass = 74.61579536670621
```

To Summarize:

- IMRPhenomXP(HM)
  - Amplitude & phase
  - Remnant mass & spin
- Recovery is highly dependent on t_0 and inclination
- No violations of NHT

What's Next?

- Short-term
  - Compare ringdown analyses
    - Parameter estimation
- Long-term
  - Better understand waveform models
  - Real data analyses
  - Test NHT

References

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