Gravitational-wave spin memory effect for compact binaries

David A. Nichols

Dept. of Astrophysics / IMAPP

Radboud University

Gravity at Malta Conference, 2018

23 January 2018

Based on arXiv:1702.03300 / PRD 95 084048 (2017)

Gravitational-wave memory effect: Overview

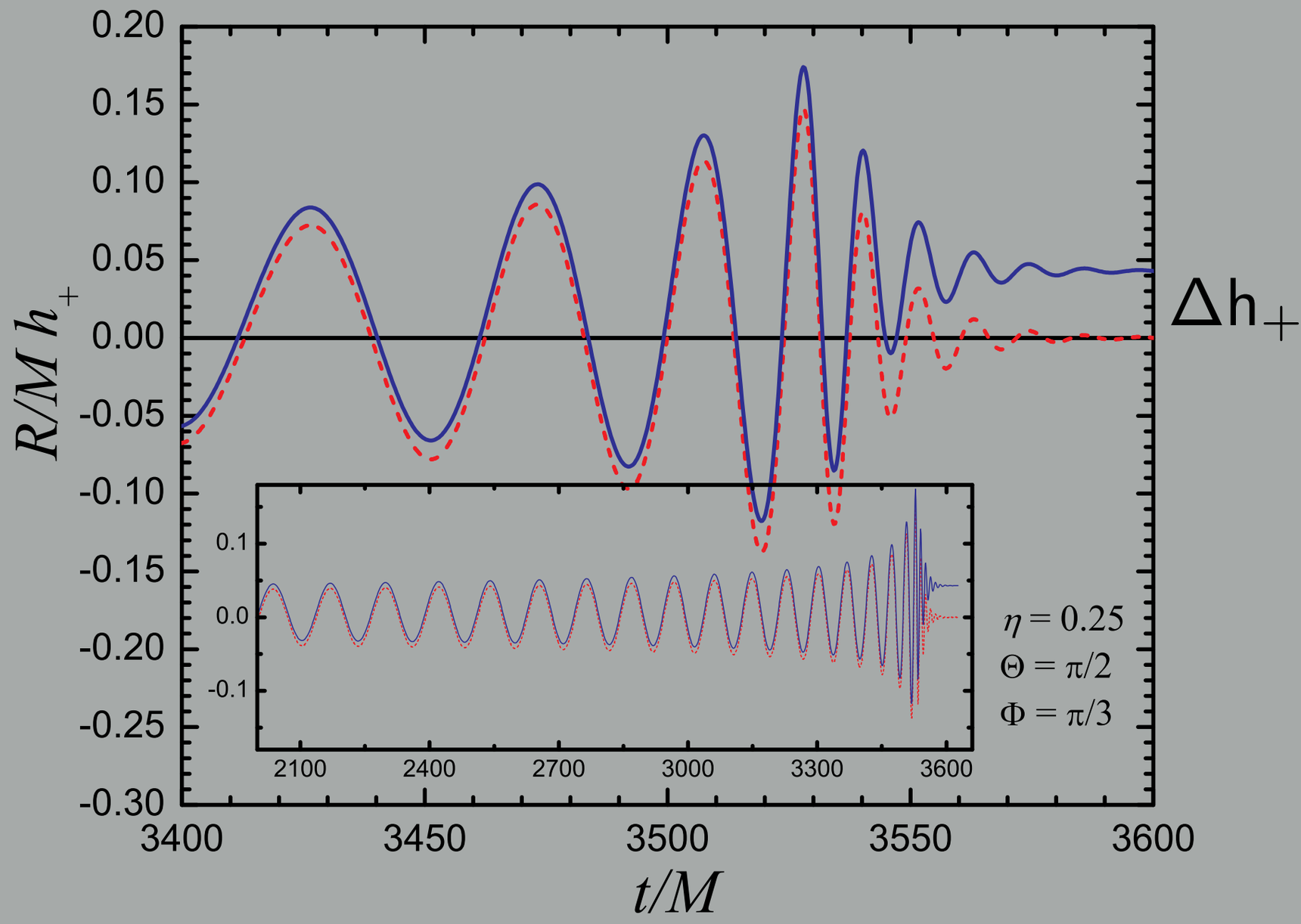


Figure from M. Favata, arXiv:0811.3451

Gravitational-wave memory effect: Overview

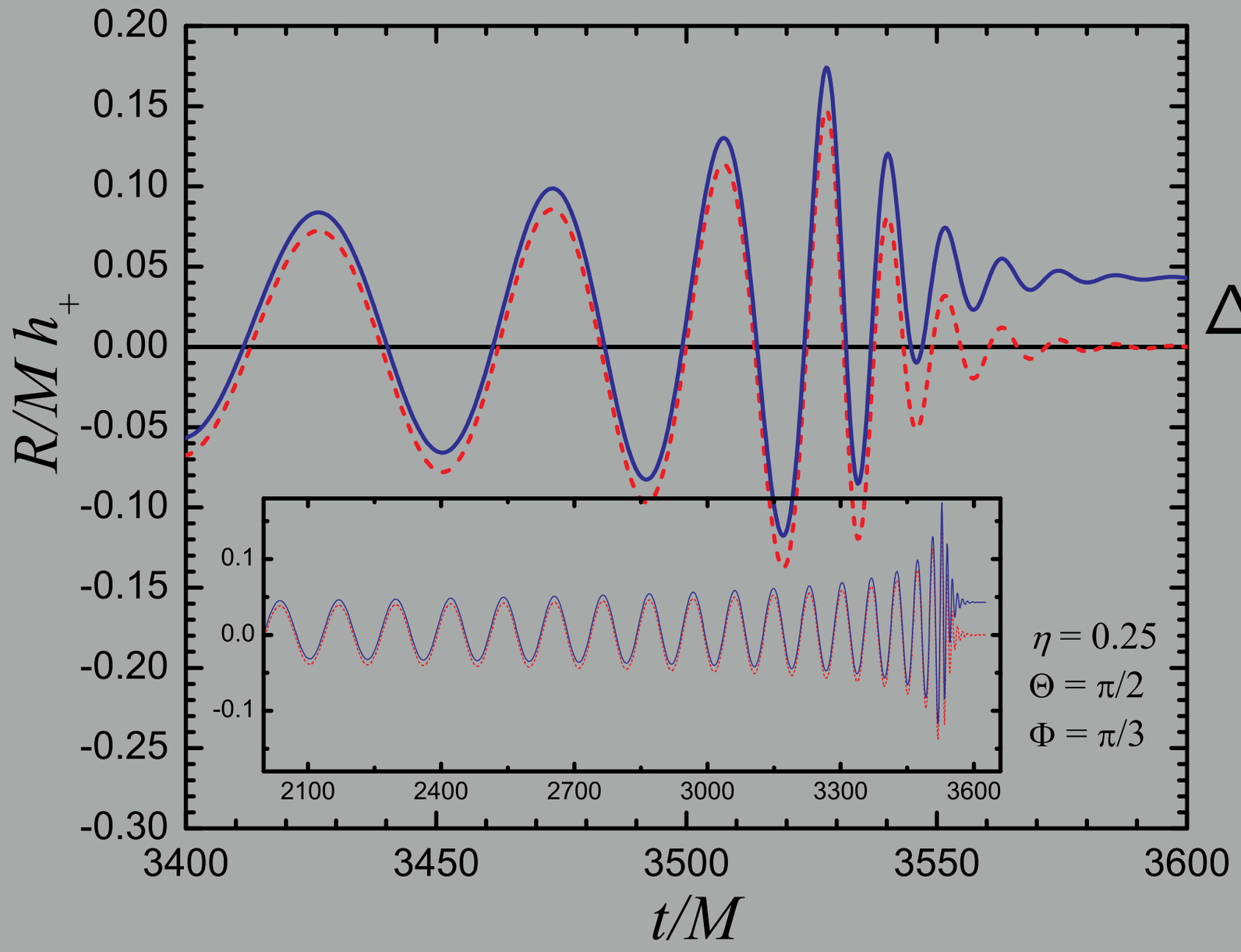
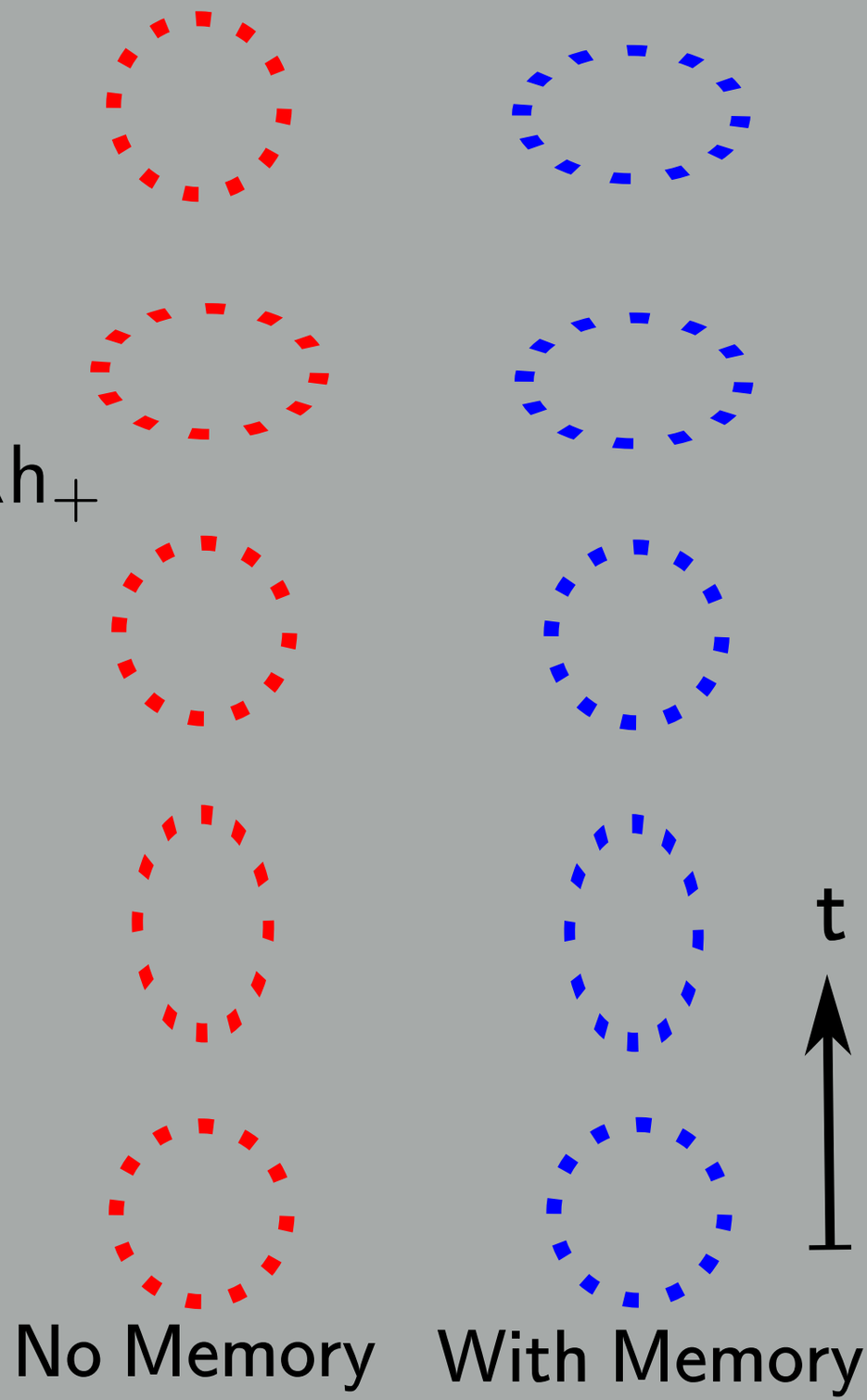


Figure from M. Favata, arXiv:0811.3451

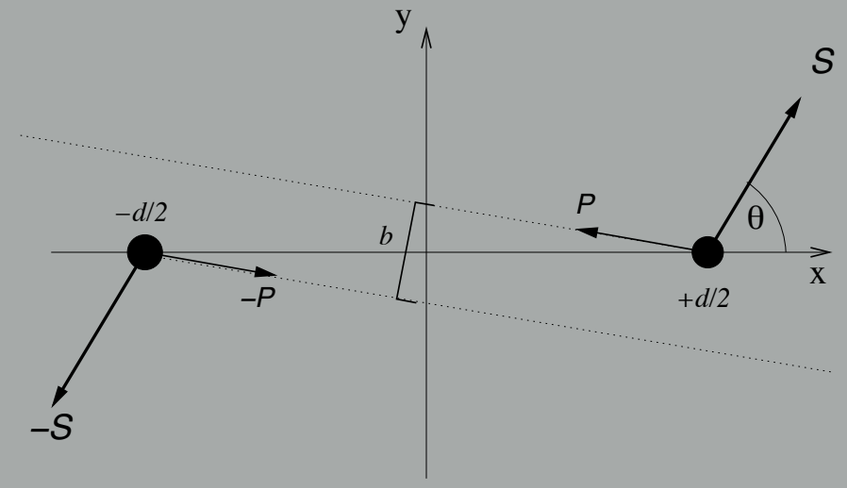


Sources of GW memory

$$\text{“}\Delta h_+\text{”} \sim \underbrace{\overbrace{\Delta m}^{\text{Ordinary}}}_{\text{Linear}} + \overbrace{r^2 \int du \underbrace{\left(T_{uu} + \mathcal{T}^{GW}_{uu} \right)}_{\text{Nonlinear}}}^{\text{Null}}$$

Sources of GW memory

$$\text{“}\Delta h_+\text{”} \sim \overbrace{\Delta m}^{\text{Ordinary}} + \overbrace{r^2 \int du \underbrace{\left(T_{uu} + \underbrace{\mathcal{T}_{uu}^{GW}}_{\text{Nonlinear}} \right)}_{\text{Linear}}}^{\text{Null}}$$

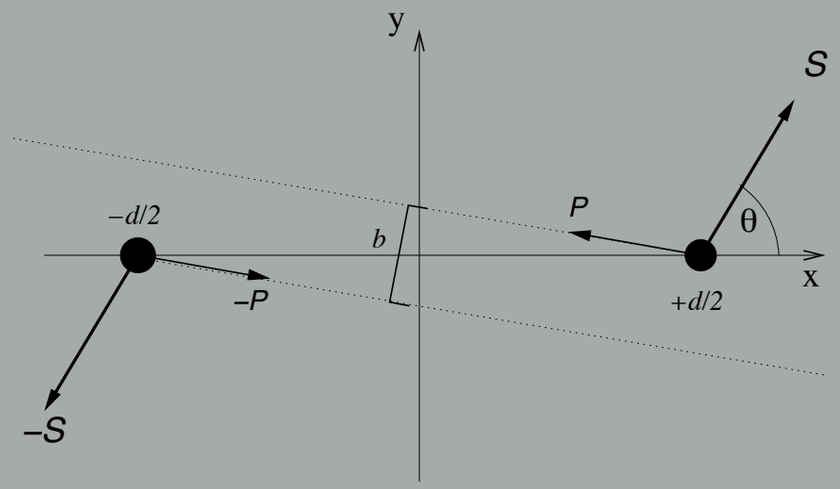


Ex. Hyperbolic Scattering

Zel'dovich & Polnarev, 1974

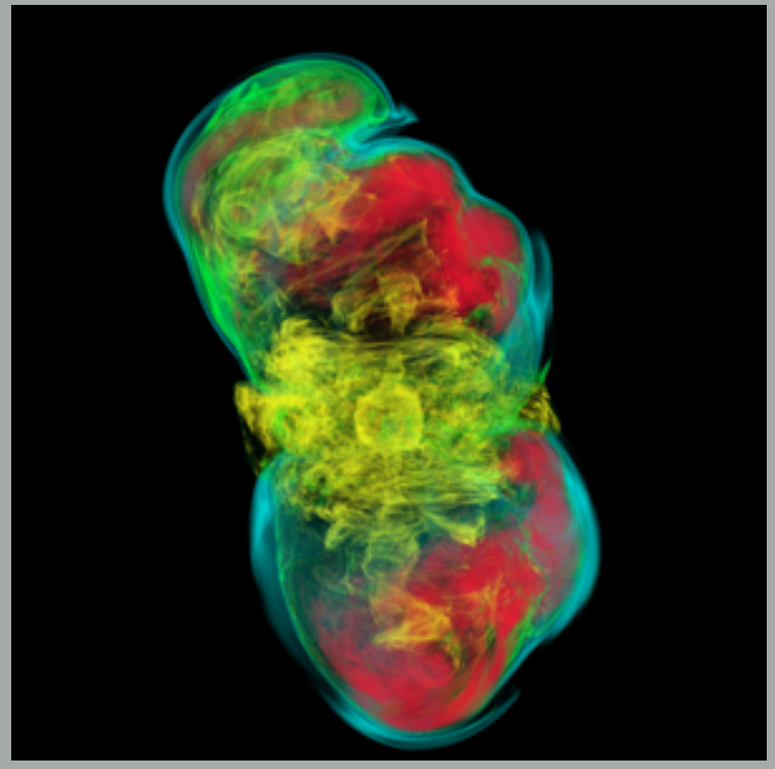
Sources of GW memory

$$\text{“}\Delta h_+\text{”} \sim \overbrace{\Delta m}^{\text{Ordinary}} + \overbrace{r^2 \int du \underbrace{\left(T_{uu} + \underbrace{\mathcal{T}_{uu}^{GW}}_{\text{Nonlinear}} \right)}_{\text{Linear}}}^{\text{Null}}$$



Ex. Hyperbolic Scattering

Zel'dovich & Polnarev, 1974



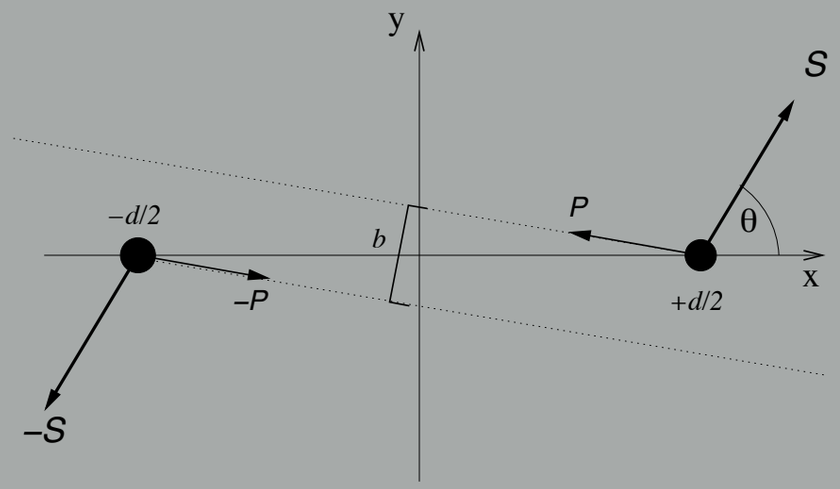
Ex. SNe neutrinos

Turner, 1978

Sources of GW memory

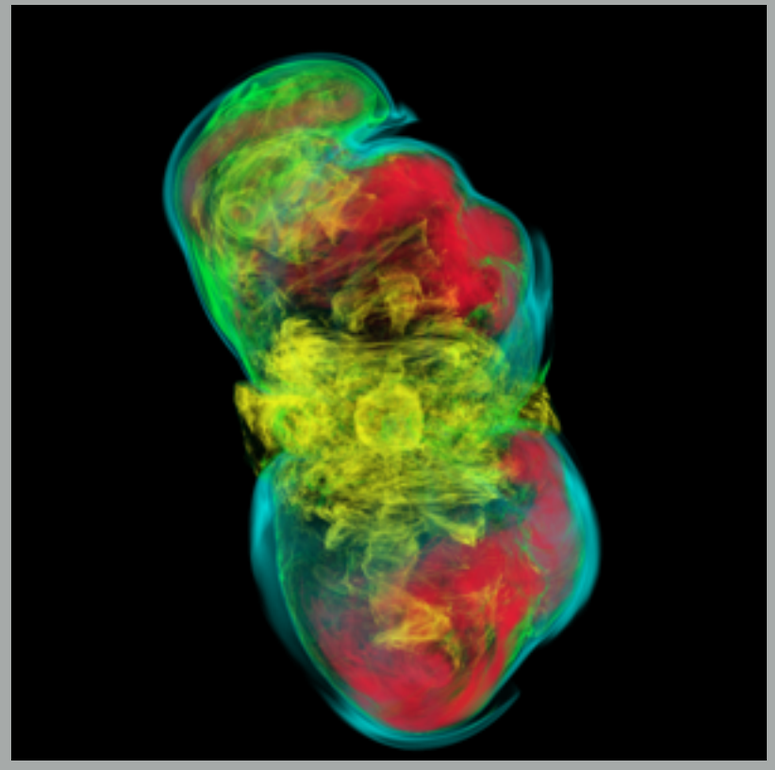
$$\text{“}\Delta h_{+}\text{”} \sim \underbrace{\overbrace{\Delta m}^{\text{Ordinary}}}_{\text{Linear}} + \underbrace{r^2 \int du \left(T_{uu} + \mathcal{T}^{GW}_{uu} \right)}_{\text{Nonlinear}}$$

Null



Ex. Hyperbolic Scattering

Zel'dovich & Polnarev, 1974



Ex. SNe neutrinos

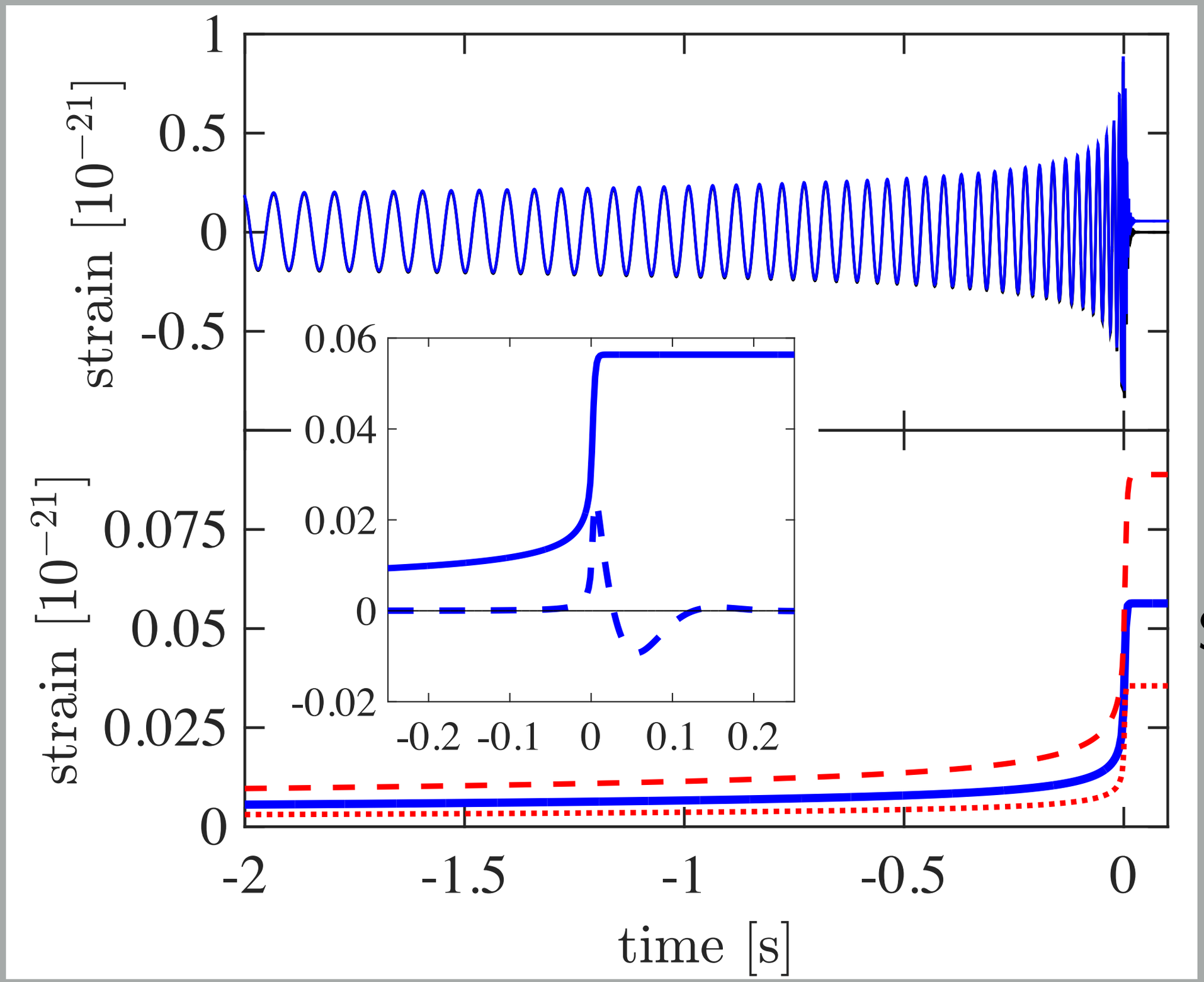
Turner, 1978

Ex: BBH mergers

Christodoulou 1992,

Blanchet & Damour, 1992

Detecting displacement memory with LIGO



GW150914-like event

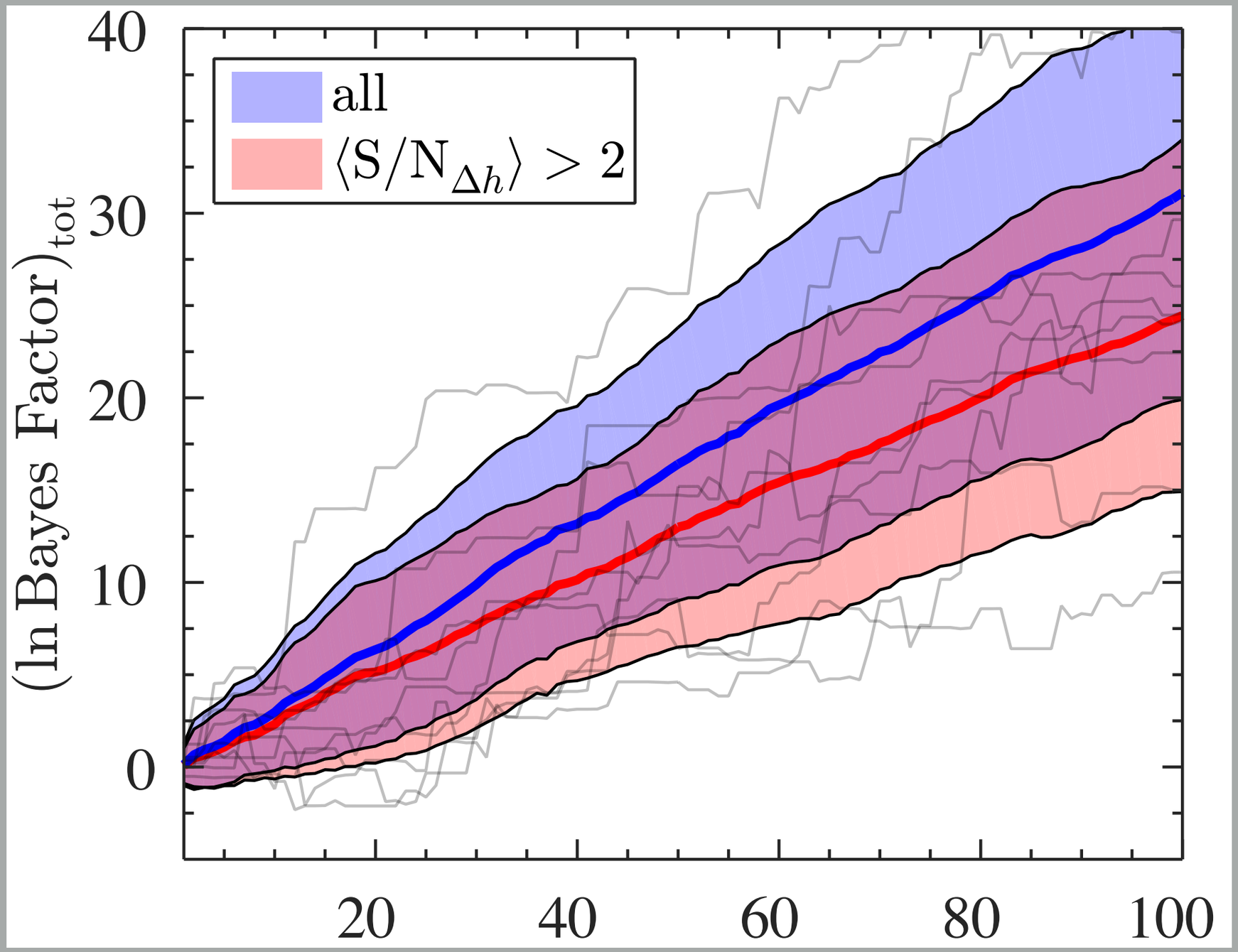
SNR for h $\sim$ 24

SNR, $\Delta h_+ \sim 0.5$

Lasky et al., PRL 117, 061102 (2016)

Stacking memory signals to detect with LIGO

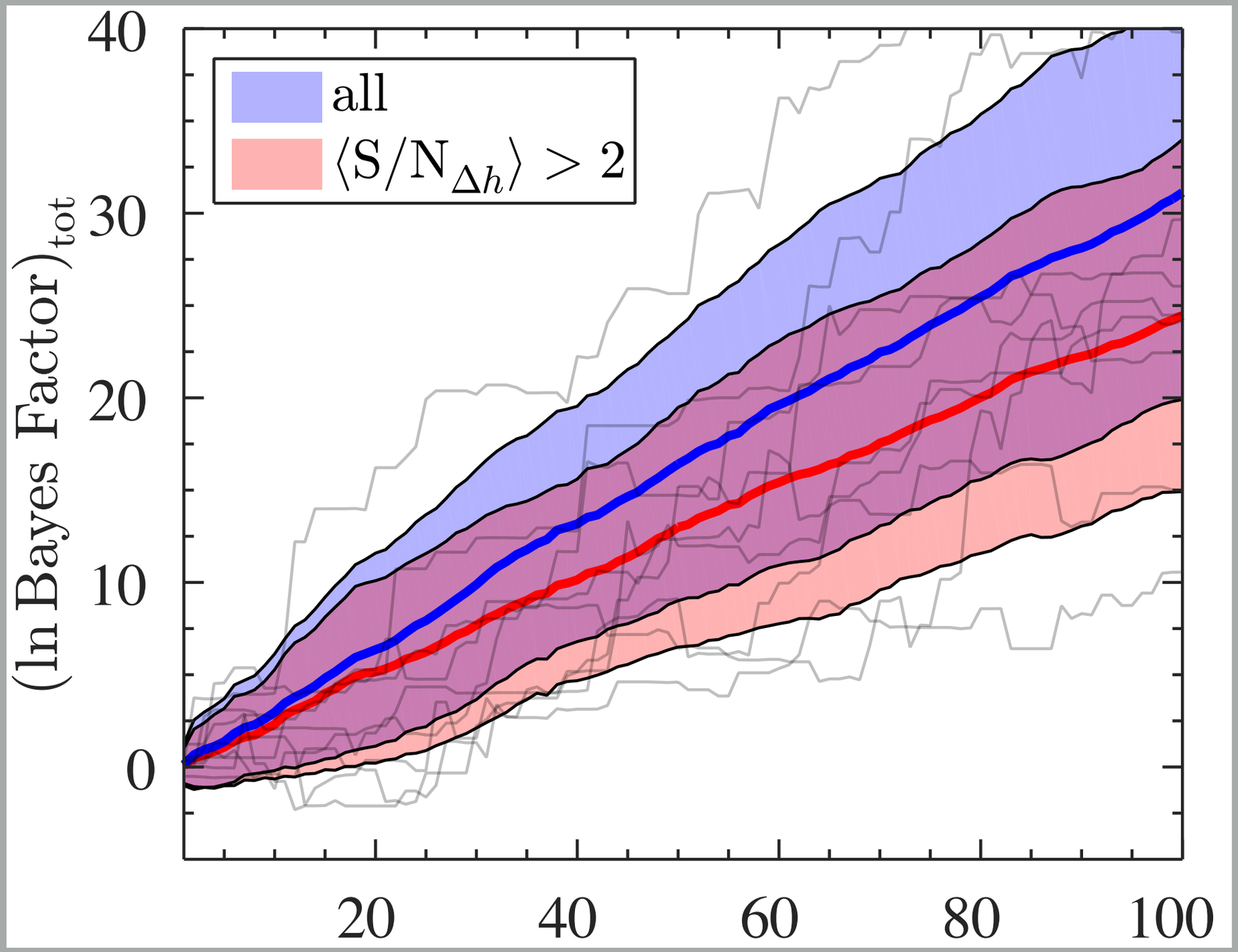
Must measure higher multipoles to get polarization and coherently add



Lasky et al., PRL 117, 061102 (2016)

Stacking memory signals to detect with LIGO

Must measure higher multipoles to get polarization and coherently add



Lasky et al., PRL 117, 061102 (2016)

Observing memory would confirm supertranslation symmetry

New memory: Spin memory effect

Barnich & Troessaert, 2009: New symmetries—super-rotations

Pasterski et al. 2015: New related “spin memory” effect

New memory: Spin memory effect

Barnich & Troessaert, 2009: New symmetries—super-rotations

Pasterski et al. 2015: New related "spin memory" effect

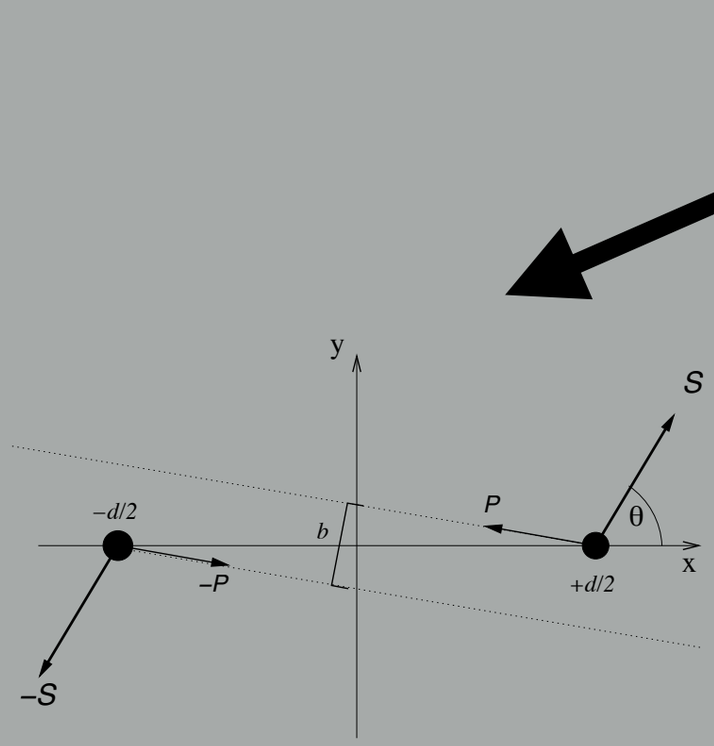
$$\Delta\Sigma \sim \text{“}\int \mathrm{du}\, \mathrm{h}_{\times}{}'' \sim \epsilon^{\mathrm{AB}} \mathrm{D}_{\mathrm{B}} \left[\Delta \hat{\mathrm{N}}_{\mathrm{A}} + \int \mathrm{du} (\hat{\mathrm{T}}_{\mathrm{uA}} + \mathcal{T}^{\mathrm{GW}}_{\mathrm{uA}})\right]$$

New memory: Spin memory effect

Barnich & Troessaert, 2009: New symmetries—super-rotations

Pasterski et al. 2015: New related "spin memory" effect

$$\Delta\Sigma \sim \text{“}\int \mathrm{du}\, \mathrm{h}_{\times}{}'' \sim \epsilon^{\mathrm{AB}}\mathrm{D}_{\mathrm{B}}\left[\Delta\hat{\mathrm{N}}_{\mathrm{A}} + \int \mathrm{du}(\hat{\mathrm{T}}_{\mathrm{uA}} + \mathcal{T}^{\mathrm{GW}}_{\mathrm{uA}})\right]$$



Ex. Hyperbolic Scattering

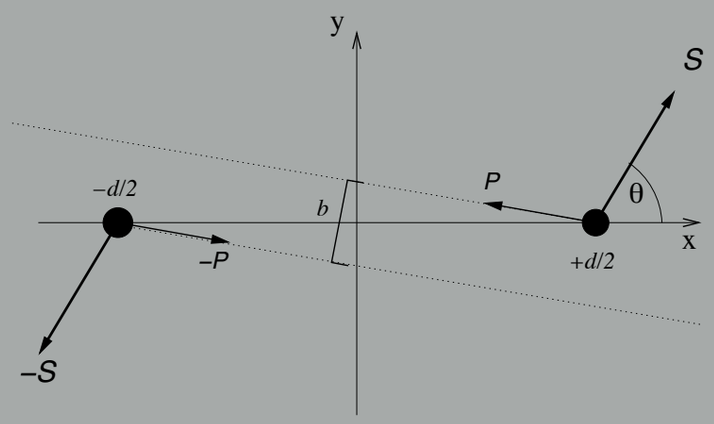
Pasterski et al., 2015

New memory: Spin memory effect

Barnich & Troessaert, 2009: New symmetries—super-rotations

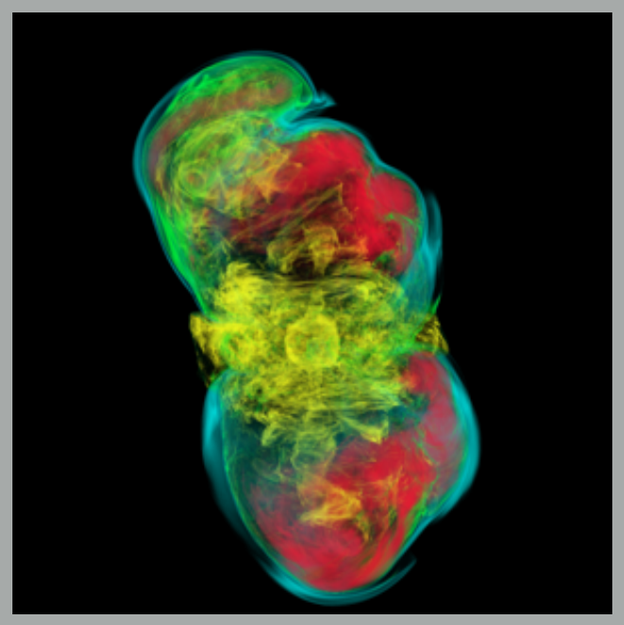
Pasterski et al. 2015: New related "spin memory" effect

$$\Delta\Sigma \sim \text{“}\int \mathrm{du}\, h_{\times}{}'' \sim \epsilon^{AB} D_B \left[\Delta \hat{N}_A + \int \mathrm{du}(\hat{T}_{uA} + \mathcal{T}^{GW}_{uA})\right]$$



Ex. Hyperbolic Scattering

Pasterski et al., 2015



Ex. SNe neutrinos

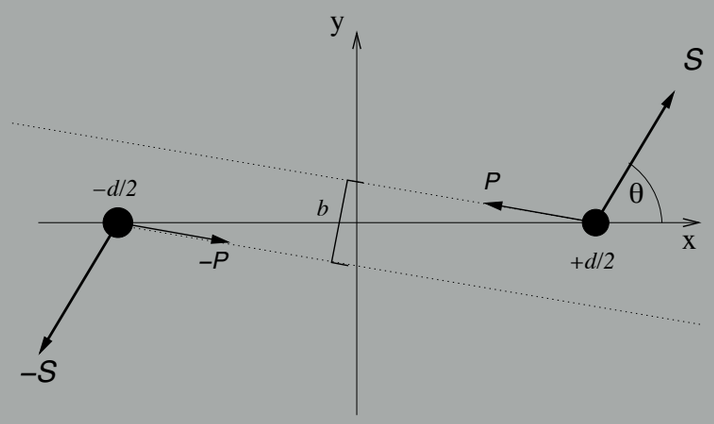
Presumably, but contrived

New memory: Spin memory effect

Barnich & Troessaert, 2009: New symmetries—super-rotations

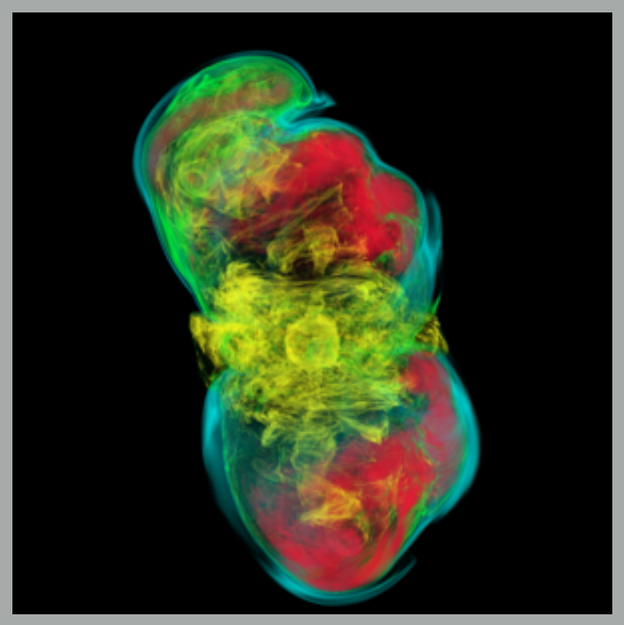
Pasterski et al. 2015: New related "spin memory" effect

$$\Delta\Sigma \sim \text{“}\int \mathrm{du}\, h_{\times}{}'' \sim \epsilon^{AB} D_B \left[\Delta \hat{N}_A + \int \mathrm{du}(\hat{T}_{uA} + \mathcal{T}^{GW}_{uA})\right]$$



Ex. Hyperbolic Scattering

Pasterski et al., 2015



Ex. SNe neutrinos

Presumably, but contrived

Ex: BBH mergers

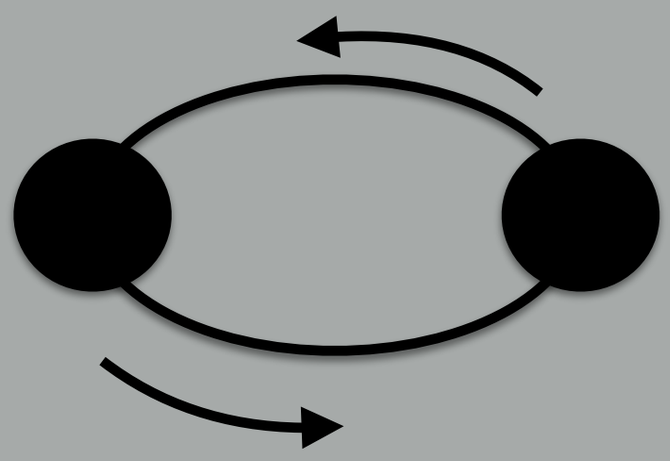
D.A.N., 2017

Spin memory effect: Post-Newtonian binaries

Non-spinning compact binaries, spin memory in (L,m)=(3,0) mode

$$\Delta\Sigma = \int \mathrm{du}\, \mathrm{h}^{\mathrm{smm}}_{\times} = \frac{3}{64\pi \mathrm{r}} \int \mathrm{du} \Im[\bar{\mathrm{U}}_{2,2}\dot{\mathrm{U}}_{2,2}] \sin^2\theta\cos\theta + \ldots$$

Expand for quasi-circular binaries in terms of $\mathrm{x} = (\mathrm{M}\omega)^{2/3}$



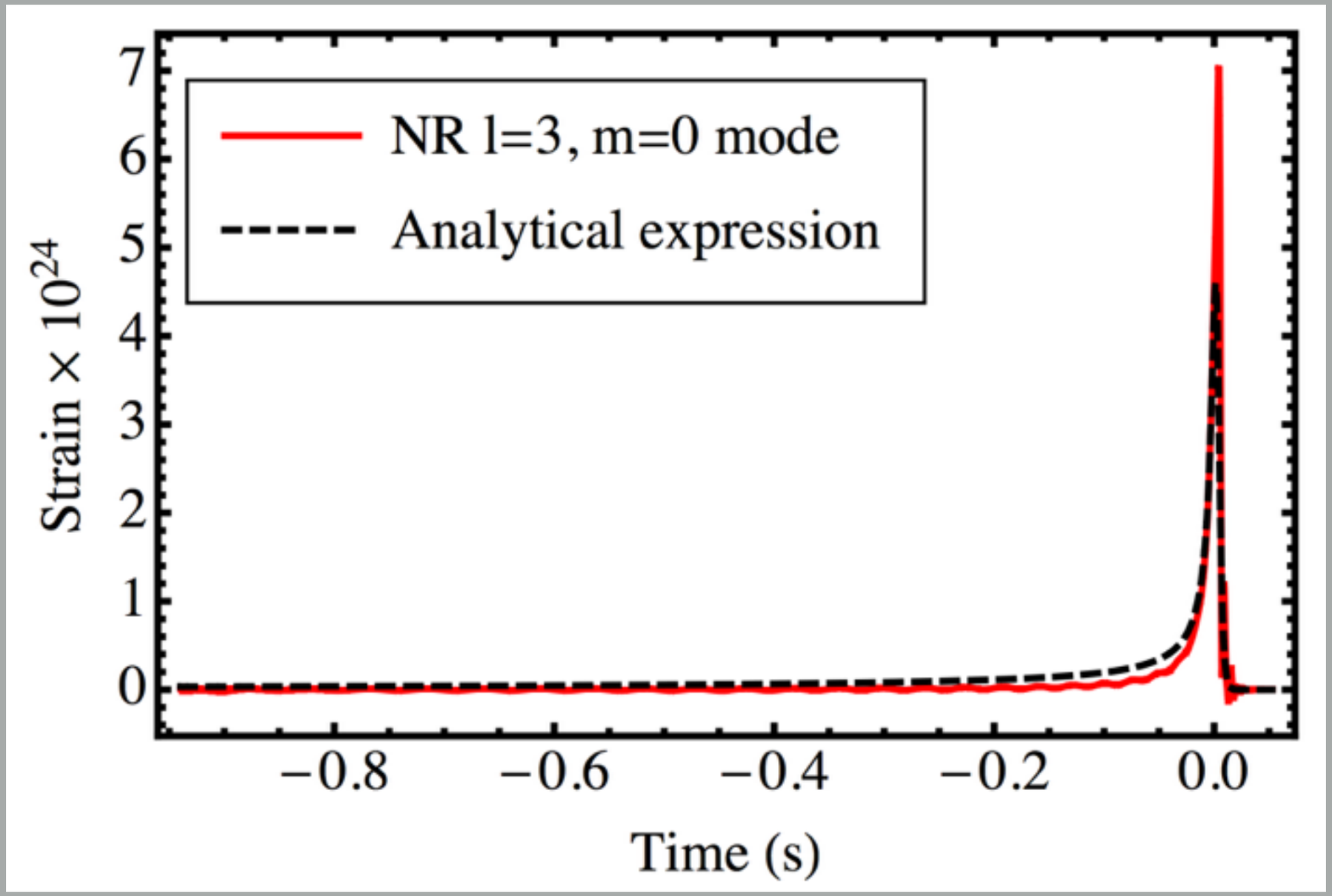
$$\Delta\Sigma = \frac{3\mathrm{M}\eta^2}{8\mathrm{r}} \mathrm{x}^{-1/2}\Big|_{\mathrm{x}=\mathrm{x}_0}^{\mathrm{x}=\mathrm{x}_\mathrm{f}} \sin^2\theta\cos\theta$$

$$\mathrm{h}^{\mathrm{smm}}_{\times} = \frac{3}{64\pi \mathrm{r}} \Im[\bar{\mathrm{U}}_{2,2}\dot{\mathrm{U}}_{2,2}] \sin^2\theta\cos\theta + \ldots$$

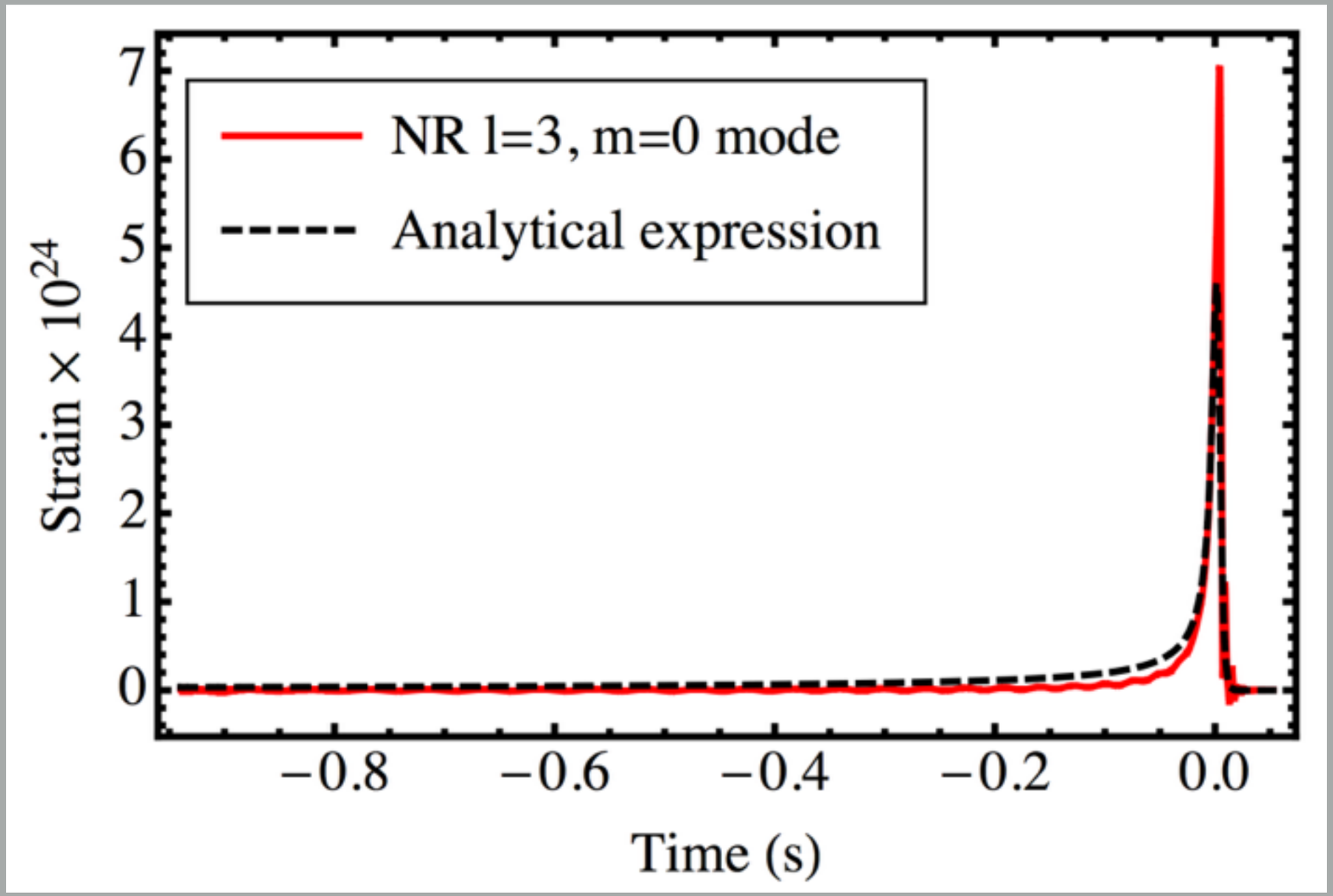
$$= -\frac{12\mathrm{M}\eta^2}{5\mathrm{r}} \mathrm{x}^{7/2} \sin^2\theta\cos\theta + \ldots$$

Cannot measure $\Delta\Sigma$ with LIGO, but can measure $\mathrm{h}_{\times}$

Spin memory effect for compact binaries



Spin memory effect for compact binaries



Mode	SNR in LIGO	SNR in ET
Quadrupole	$\sim 1 \times 10^2$	$\sim 5 \times 10^3$
Displacement Memory	~ 1	~ 30
Spin Memory	~ 0.03	~ 1

Conclusions

GW memory effect

- A prediction of GR in nonlinear and dynamical regime and an observational consequence of symmetry/asymptotic flatness

- Detectable LIGO by stacking ~100 GWs from BBH mergers

Conclusions

GW memory effect

- A prediction of GR in nonlinear and dynamical regime and an observational consequence of symmetry/asymptotic flatness
- Detectable LIGO by stacking ~100 GWs from BBH mergers

Spin memory effect

- Prediction of GR related to extended symmetries
- Requires stacking and next generation detectors to observe