

# GW memory effects: Testing GR by measuring non-oscillatory gravitational waves from BBHs

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Testing GR 1: General

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# GW memory effect: Overview

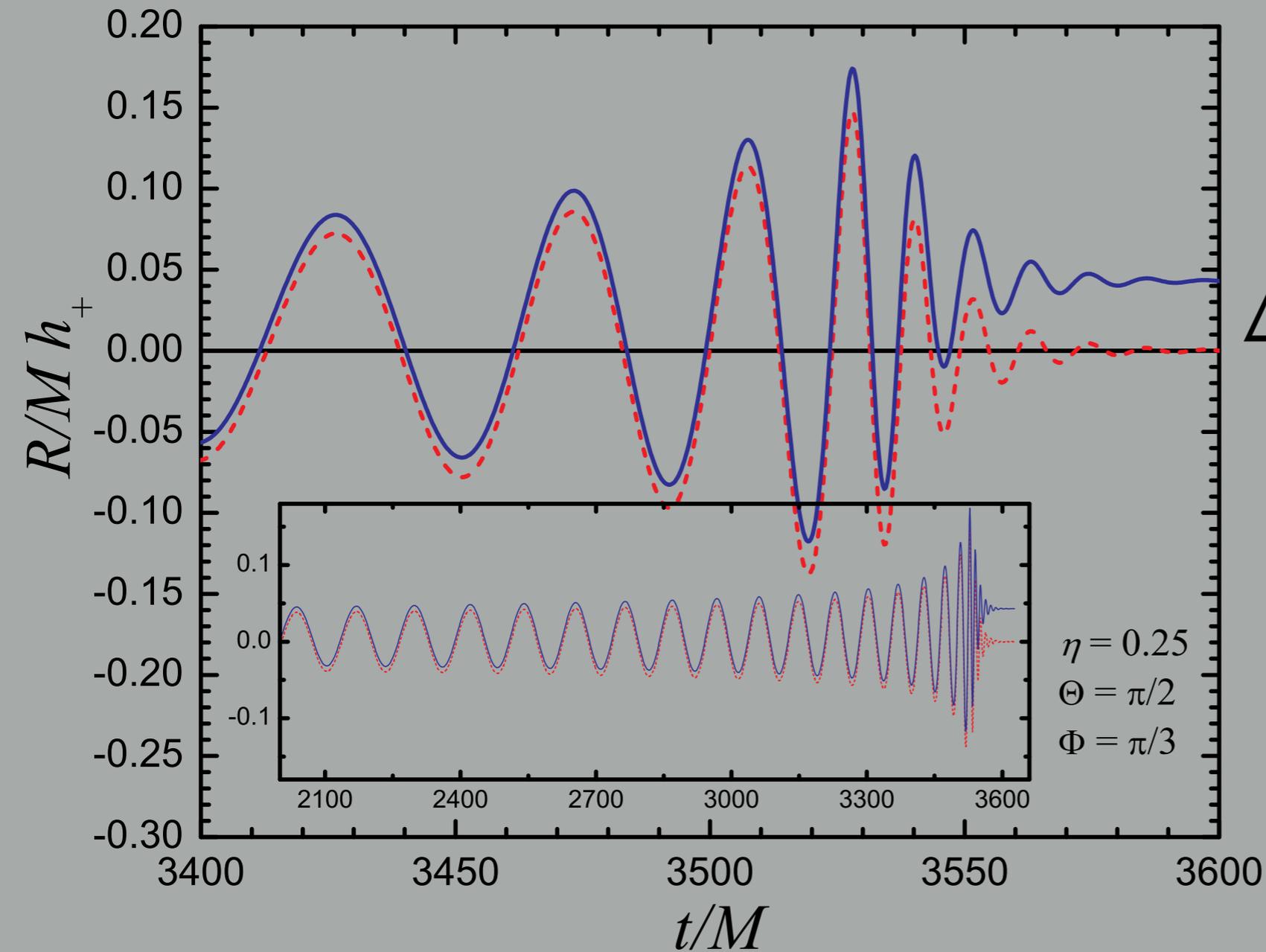
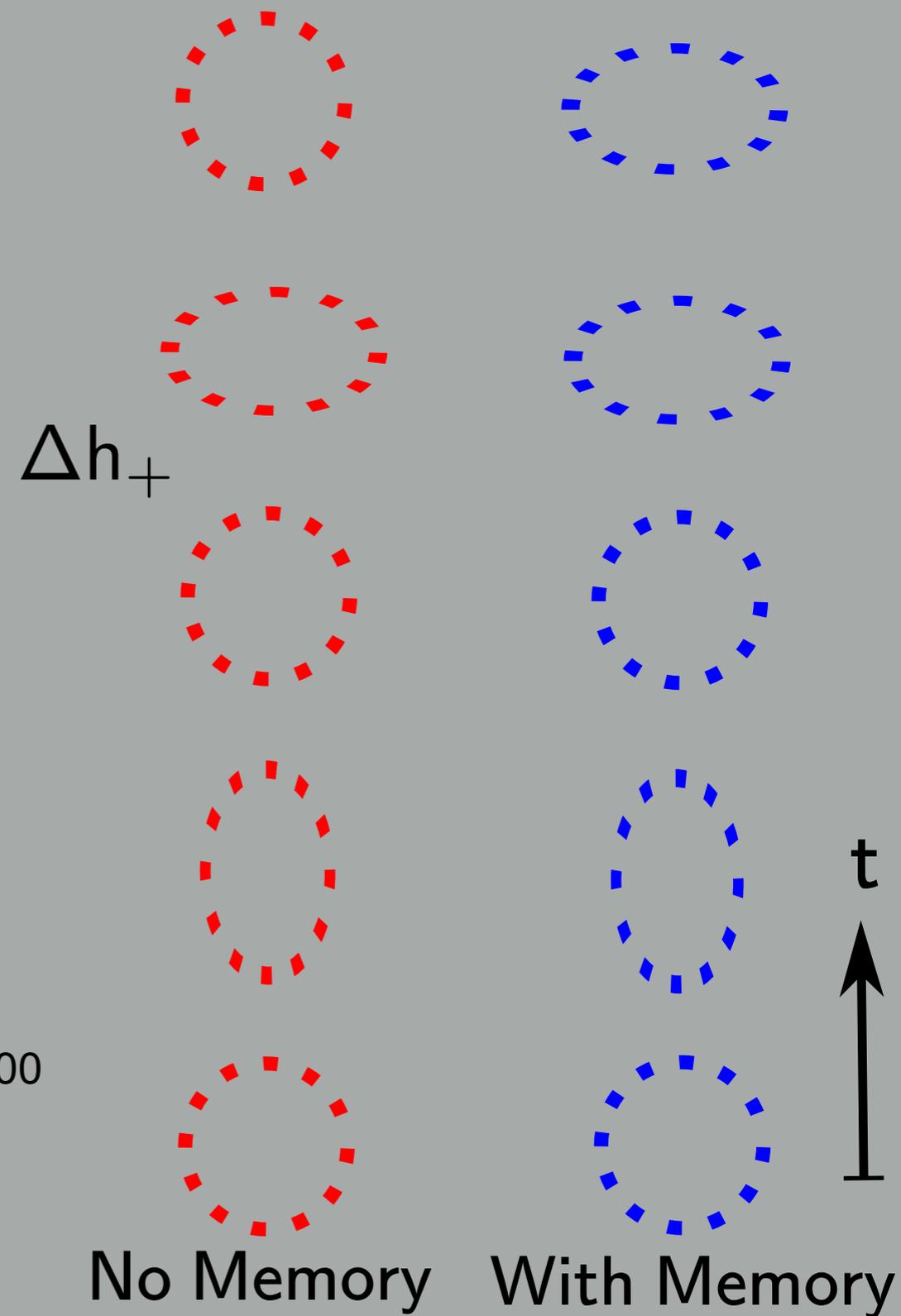
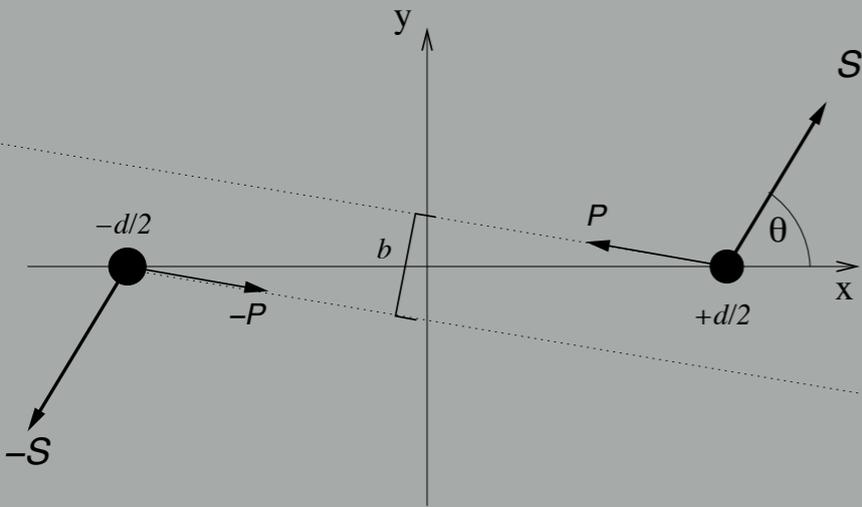
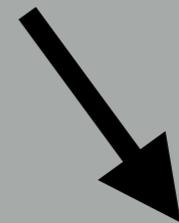
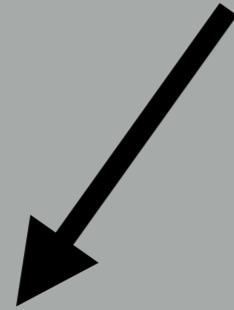


Figure from M. Favata, arXiv:0811.3451



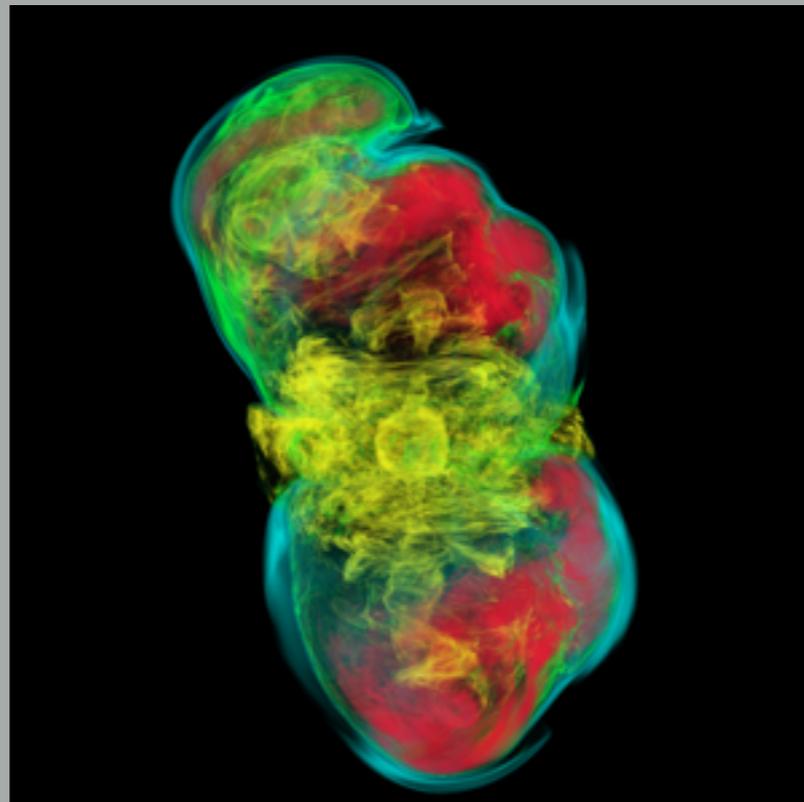
# Sources of GW memory

$$\text{“}\Delta h_+\text{”} \sim \underbrace{\overbrace{\Delta m}^{\text{Ordinary}} + r^2 \int du \left( T_{uu} + \underbrace{\mathcal{T}_{uu}^{\text{GW}}}_{\text{Nonlinear}} \right)}_{\text{Linear}} \underbrace{\hspace{10em}}_{\text{Null}}$$



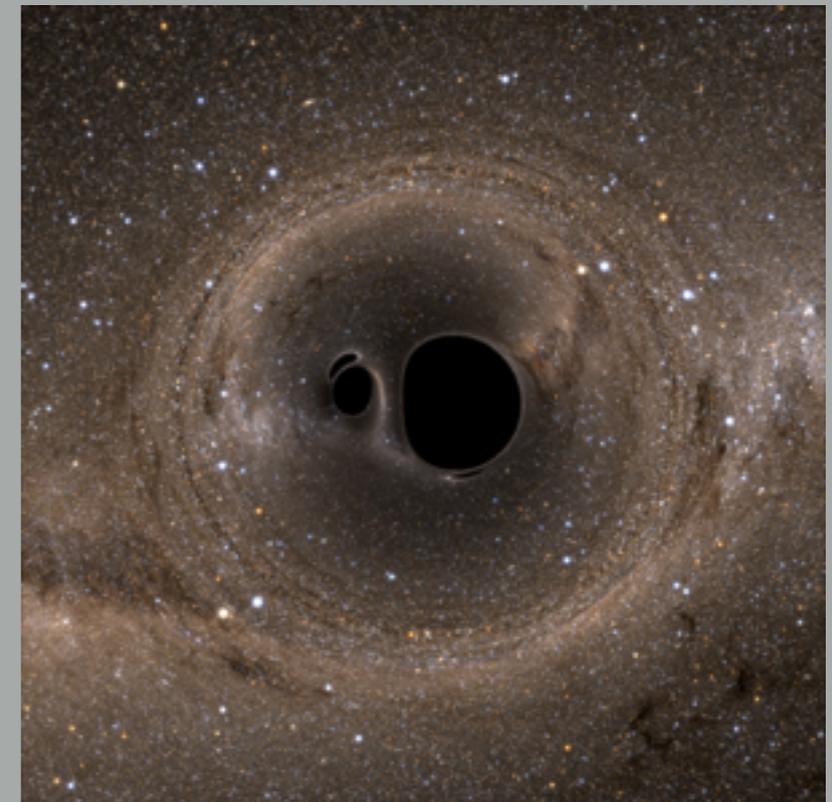
Ex. Stars/BHs  
Scattering

Zel'dovich & Polnarev, 1974



Ex. SNe neutrinos

Turner, 1978

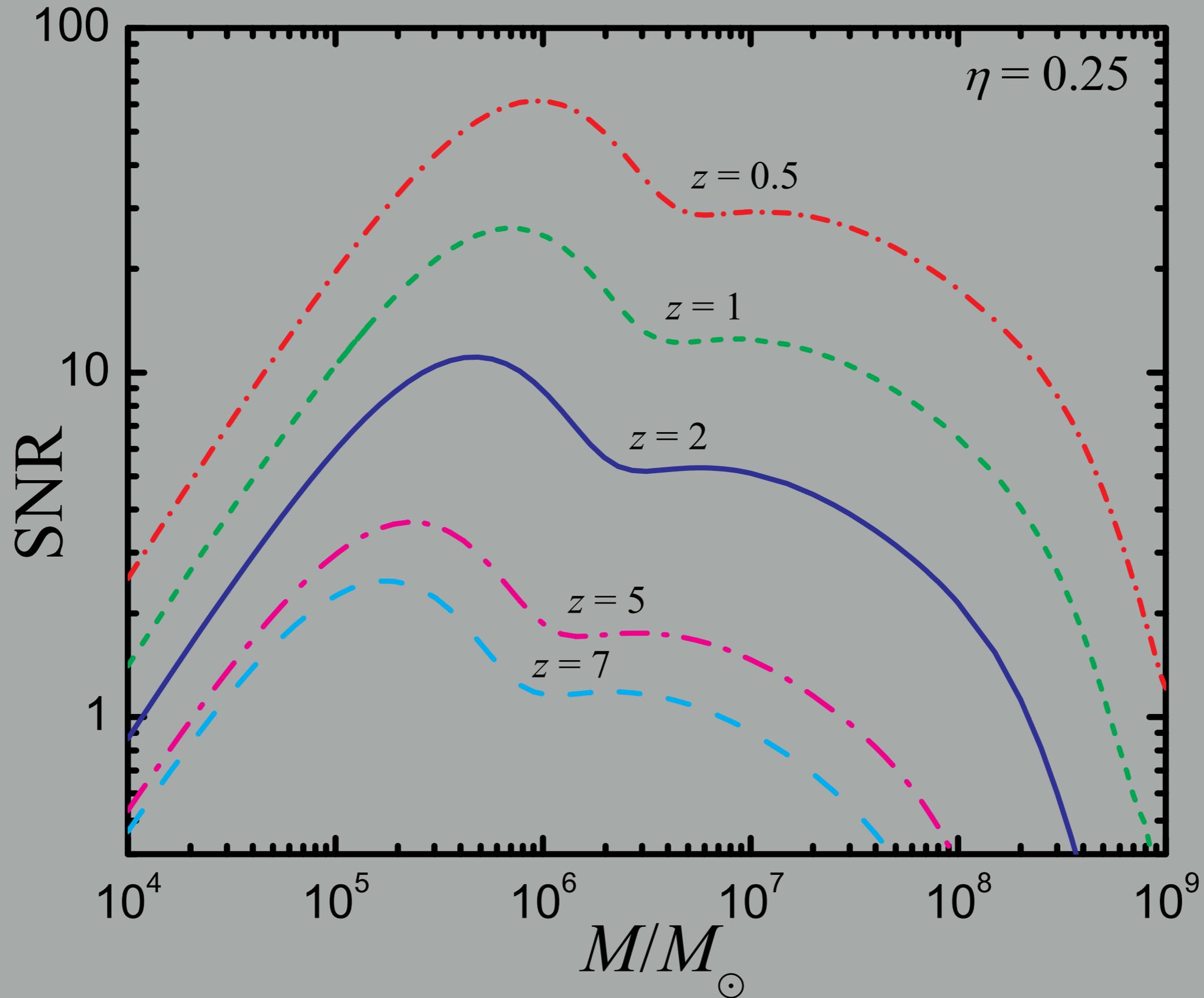


Ex: BBH mergers

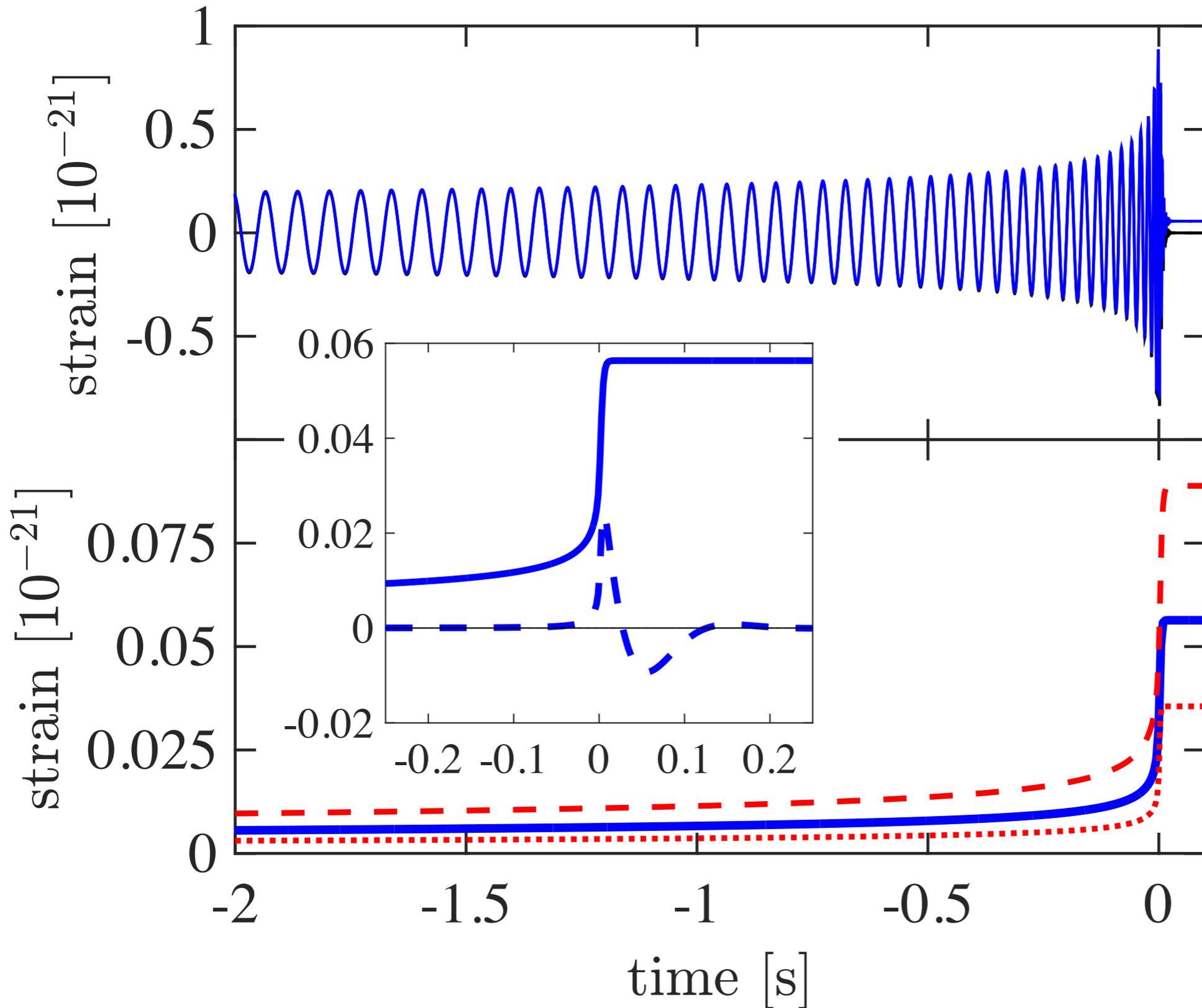
Christodoulou 1992,  
Blanchet & Damour, 1992



# Detecting memory with LISA from SMBHBs



# Detecting displacement memory with LIGO

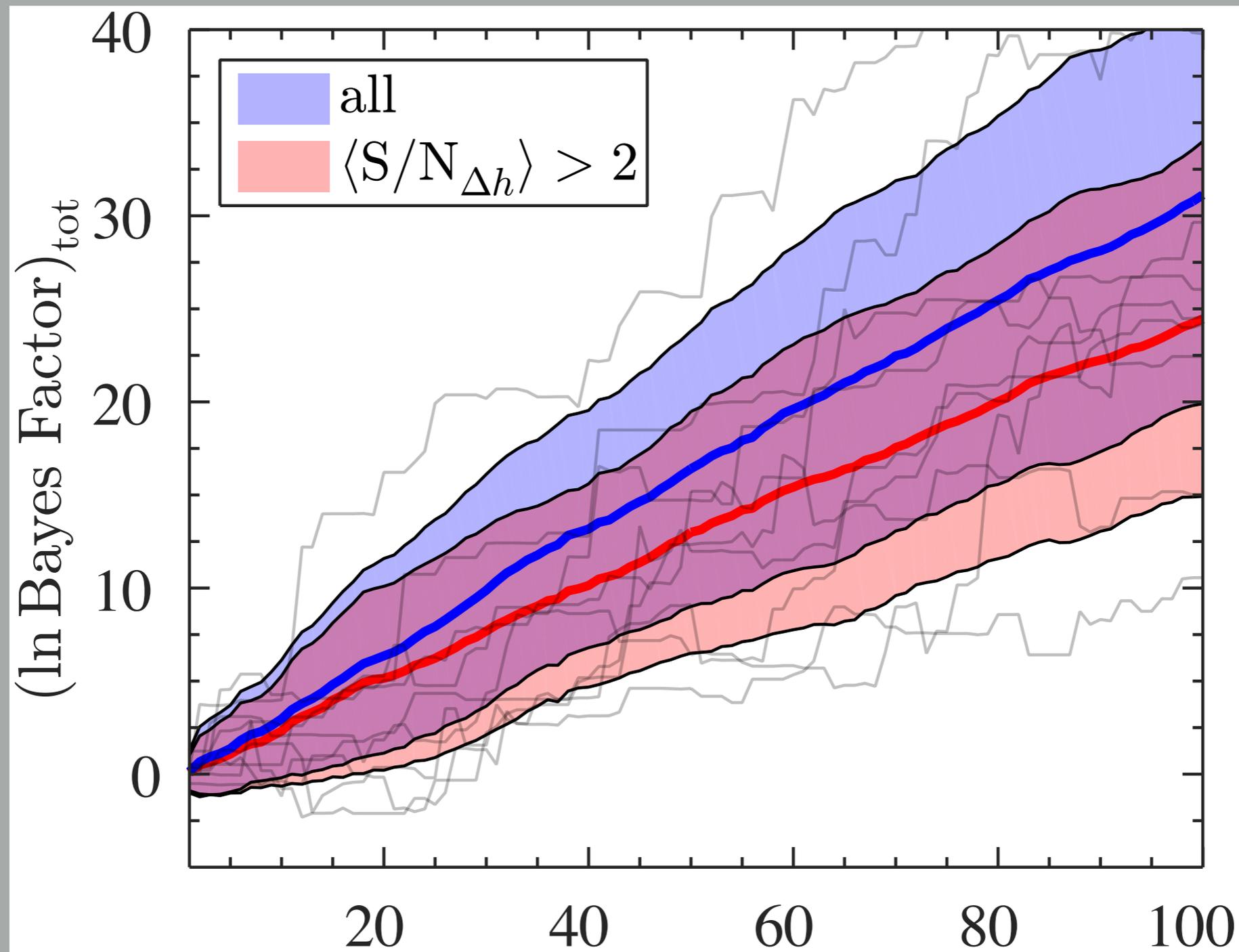


GW150914-like  
event

SNR for  $h \sim 24$

SNR,  $\Delta h_+ \sim 0.5$

# Stacking memory signals to detect with LIGO



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

$$h_{\text{mem}} = F_{+}(\theta, \phi, \psi) \Delta h_{+}, \text{ where } \Delta h_{+} \geq 0$$

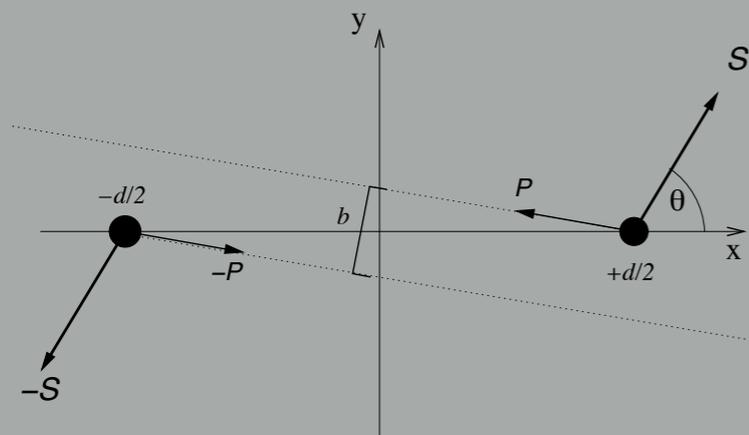
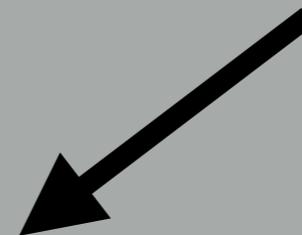
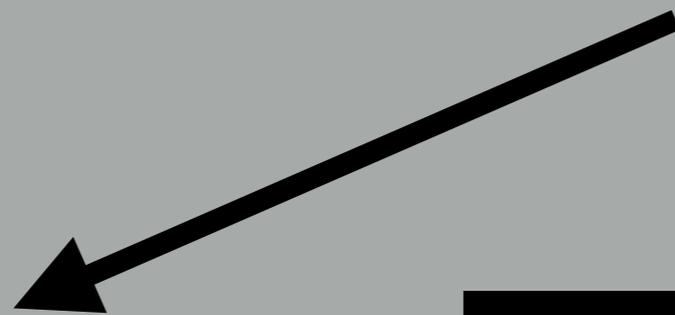
To stack, must know sign of  $F_{+}(\theta, \phi, \psi)$ ; possible with higher modes

# New memory: Spin memory effect

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

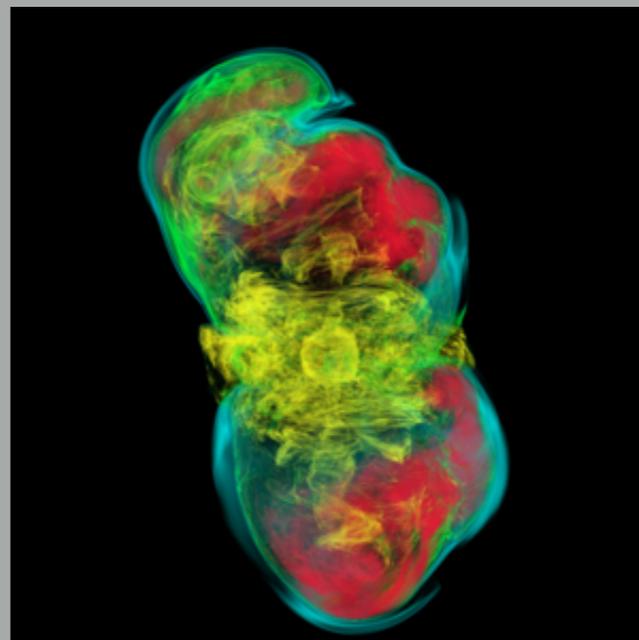
Pasterski et al. 2015: New related “spin memory” effect

$$\Delta\Sigma \sim \left\langle \int du h_x \right\rangle \sim \epsilon^{AB} D_B \left[ \Delta\hat{N}_A + \int du (\hat{T}_{uA} + \mathcal{T}_{uA}^{GW}) \right]$$



Ex. Hyperbolic  
Scattering

Pasterski et al., 2015



Ex. SNe neutrinos

Presumably, but contrived

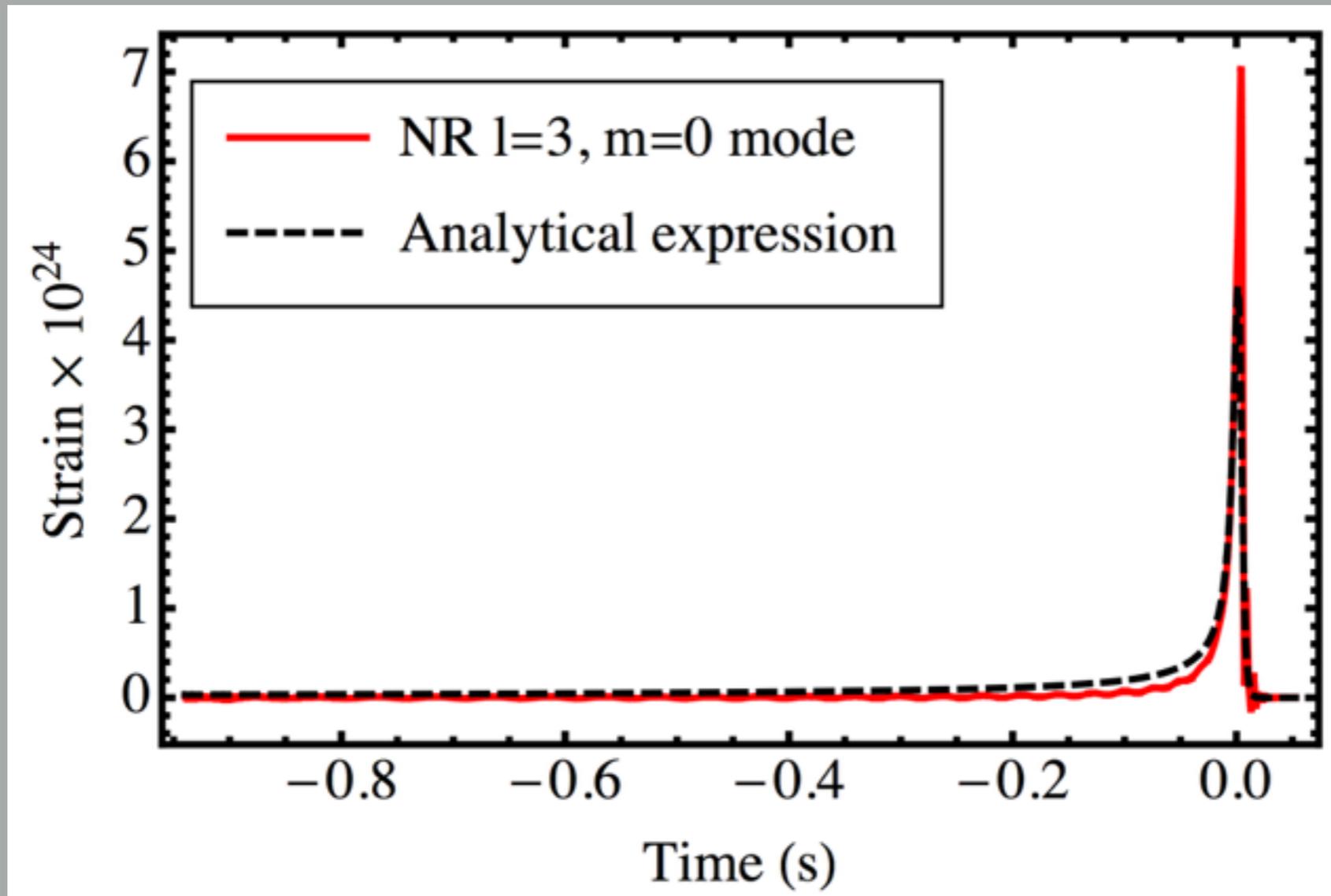


Ex: BBH mergers

D.A.N., 2017

# Spin memory effect for compact binaries

Cannot measure  $\Delta\Sigma$  with LIGO, but can measure  $h_{\times}$



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

# Summary of Memory/Points for discussion

Memory is *not* just a curiosity; it is also

- A prediction of GR based on the boundary conditions of asymptotic flatness that should be tested
- A direct observational consequence of BMS symmetry

Challenges for detecting the memory

- Patience: Waiting for LISA or CE/ET and a loud event
- 2G detectors: Low SNR requires stacking  $\sim 100$  detections & stacking requires accurate polarization, sky localization
- More accurate memory waveforms from NR using CCE