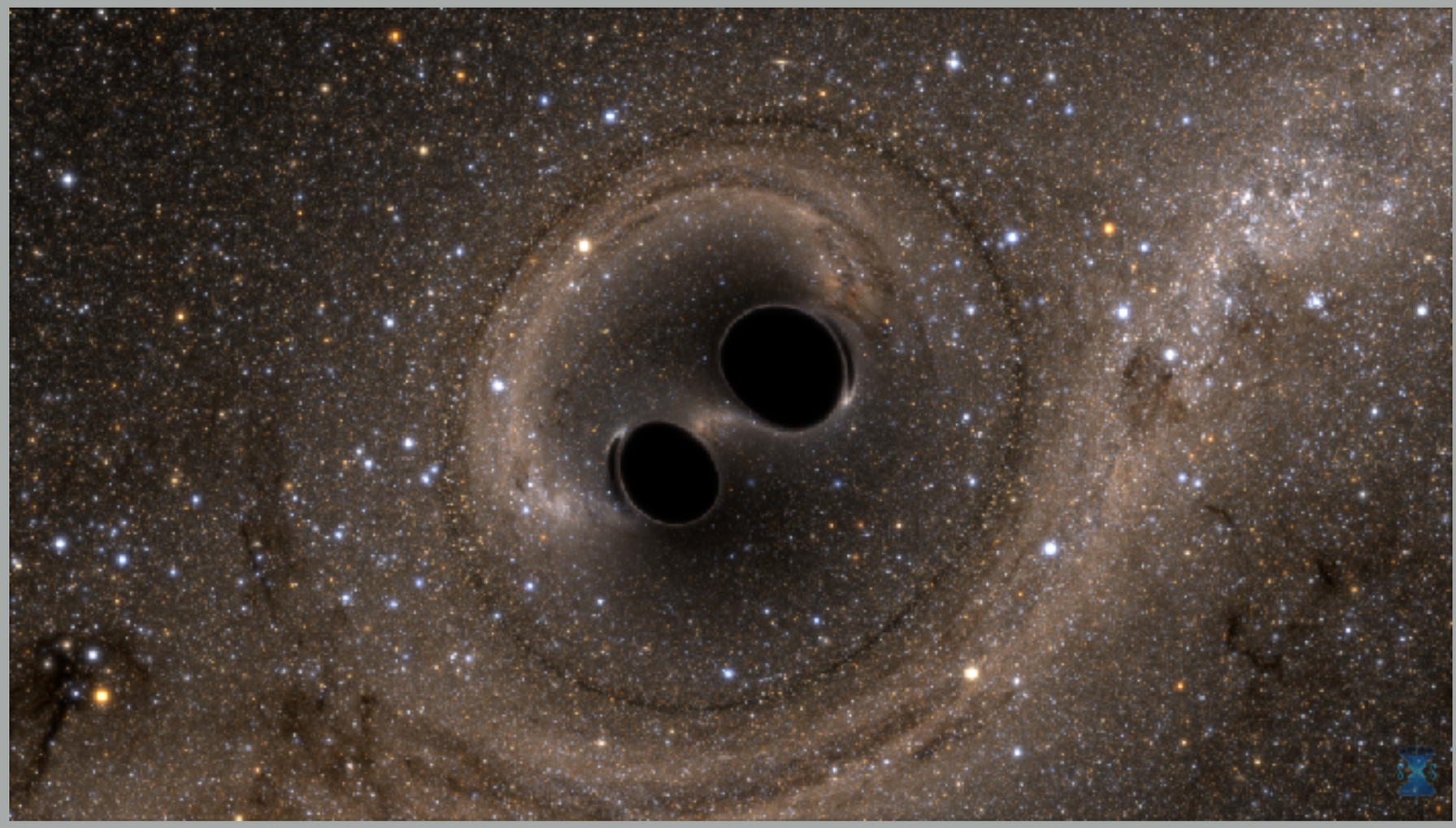
Observing gravitational-wave memory effects and the infrared triangle



David A. Nichols, University of Virginia, Dept. of Physics

Celestial Amplitudes Workshop

Corfu Summer Institute (via Zoom)

September 2, 2021

Motivation

Theoretical

Infrared properties of gauge and gravity theories are characterized by "infrared triangles" relating asymptotic symmetries, soft theorems and memory effects

Observational

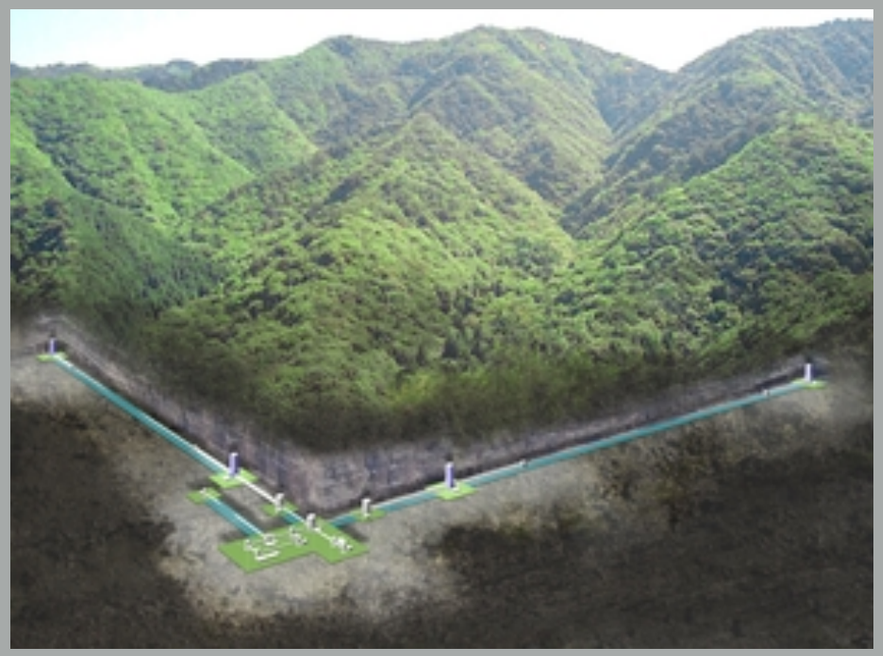
Gravitational-wave memory effects have a good chance of being detected in this decade, and being studied precisely in the next decade

LIGO, Virgo, and KAGRA detectors

LIGO Hanford

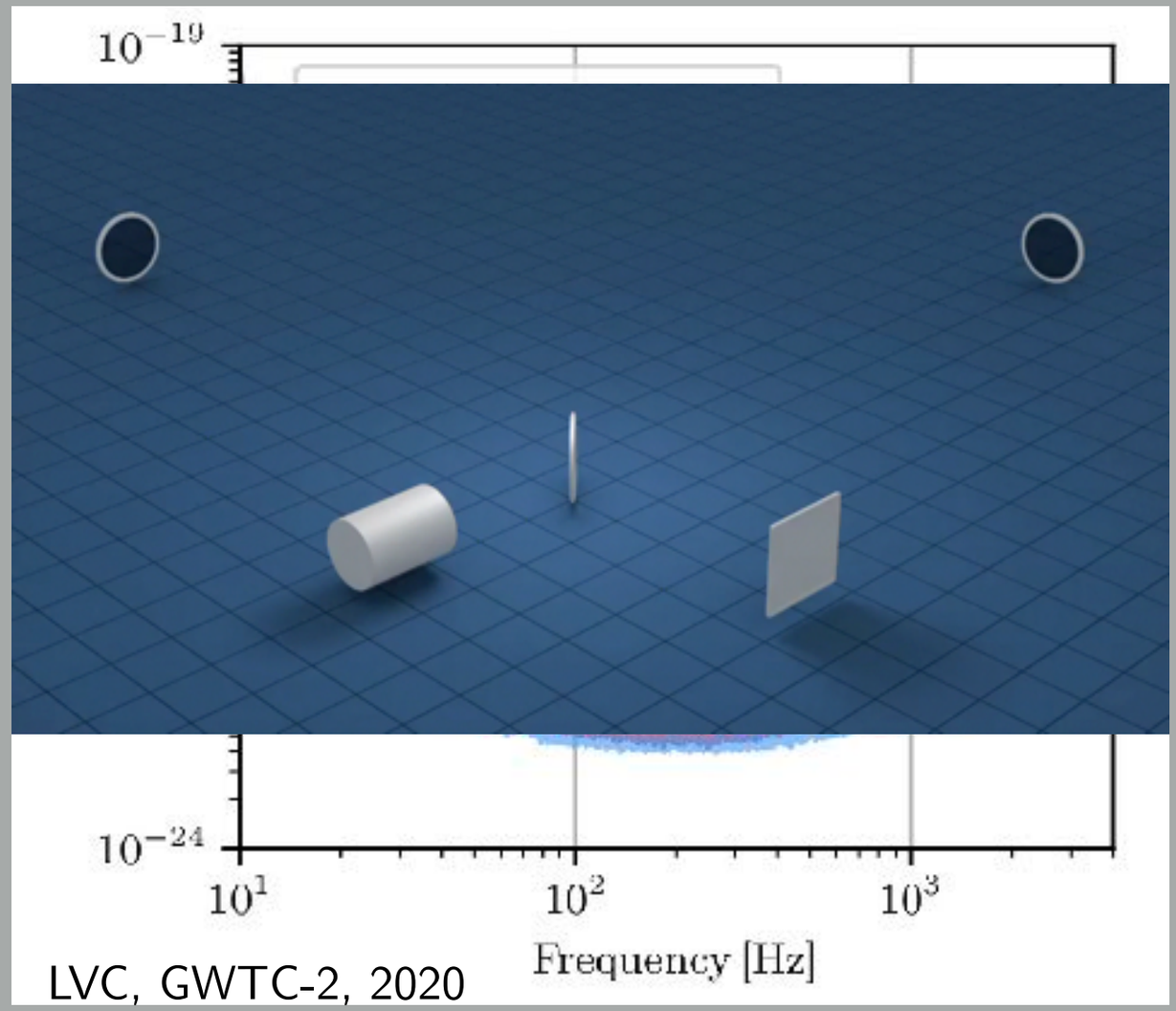
LIGO Livingston

Virgo



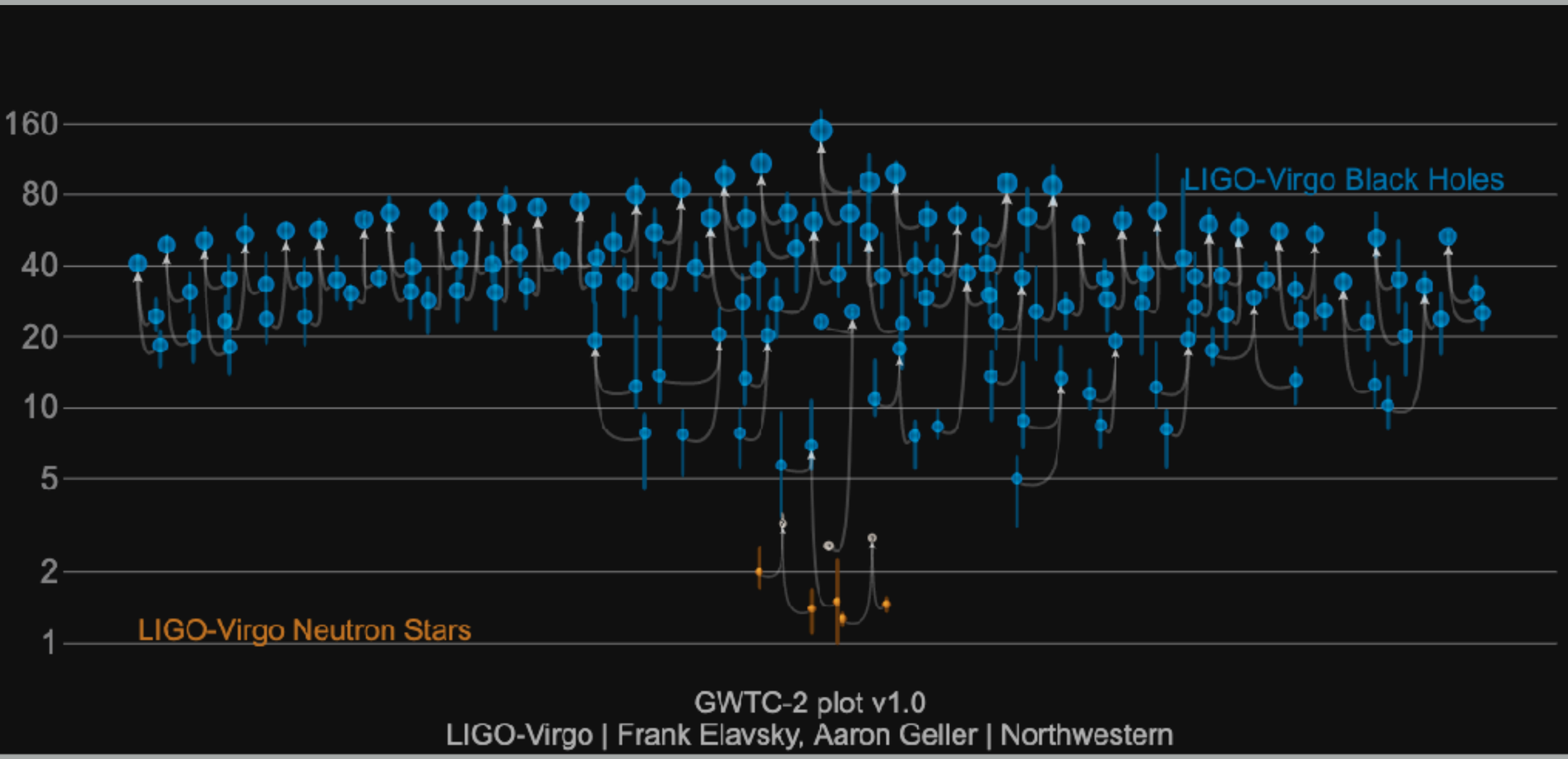
KAGRA

Image Credits: LIGO/Virgo/KAGRA



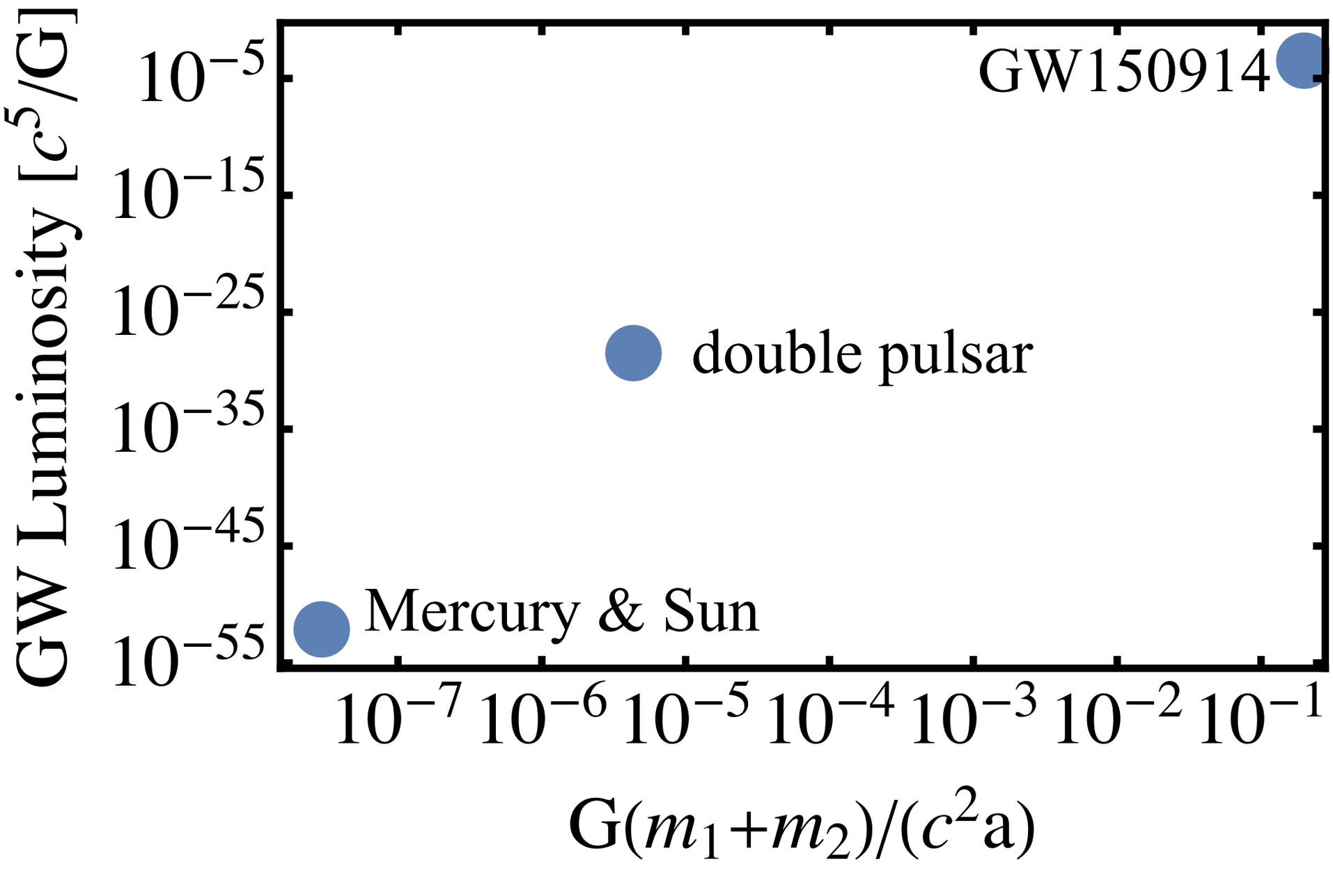
LVC, GWTC-2, 2020

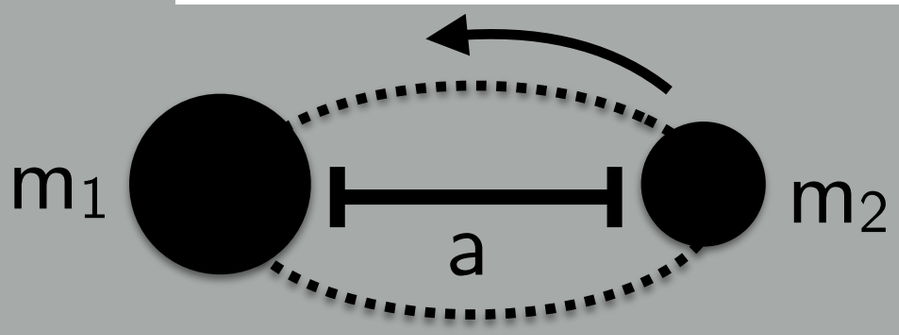
LIGO and Virgo Detections



- First observing run (O1): 3 binary black holes (BBH) in 3 mo.
- Second (O2): 7 BBH in 9 months
- First half of third (O3a): 36 BBH in 6 months!

Strong gravity and high luminosities

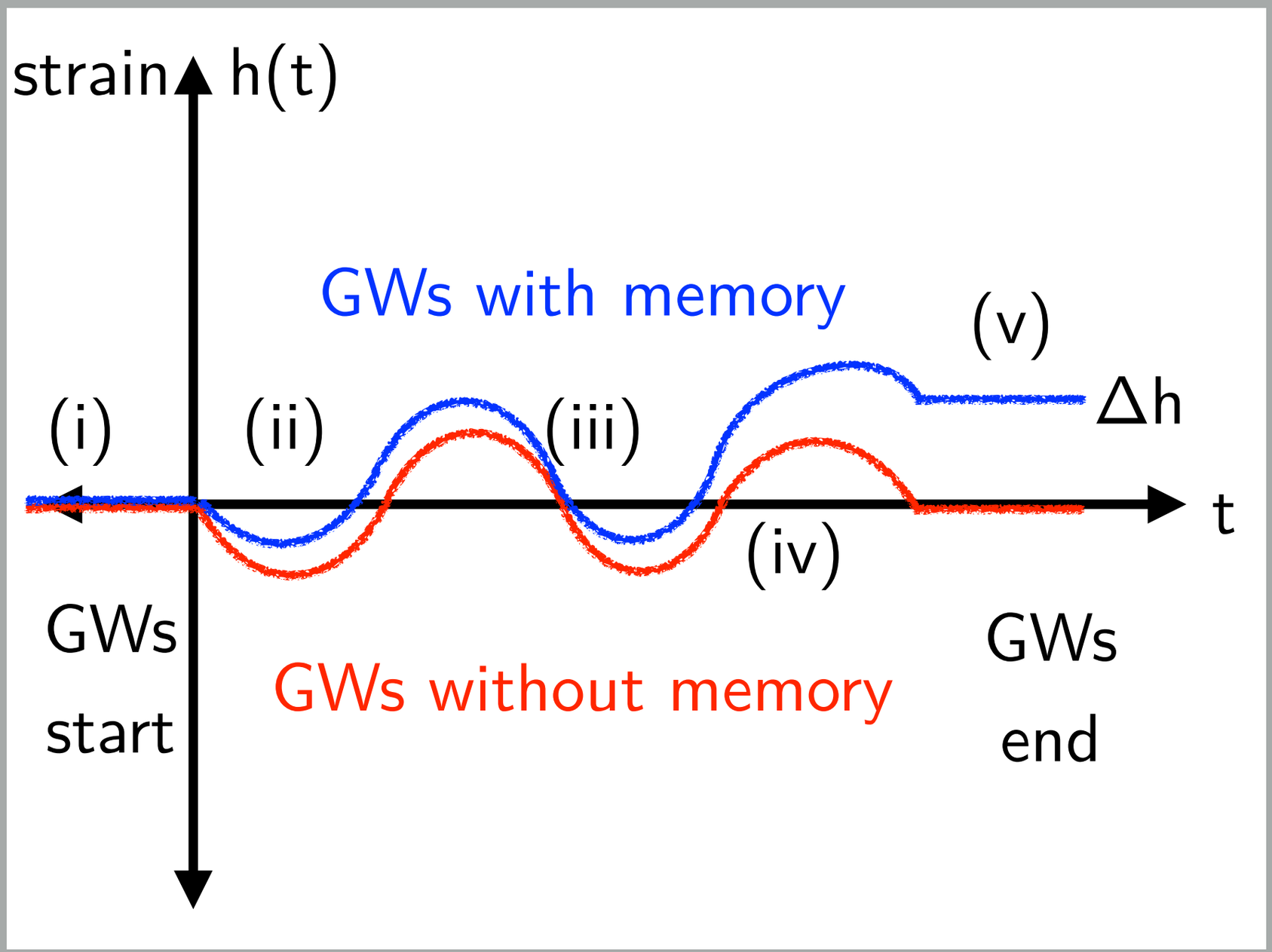


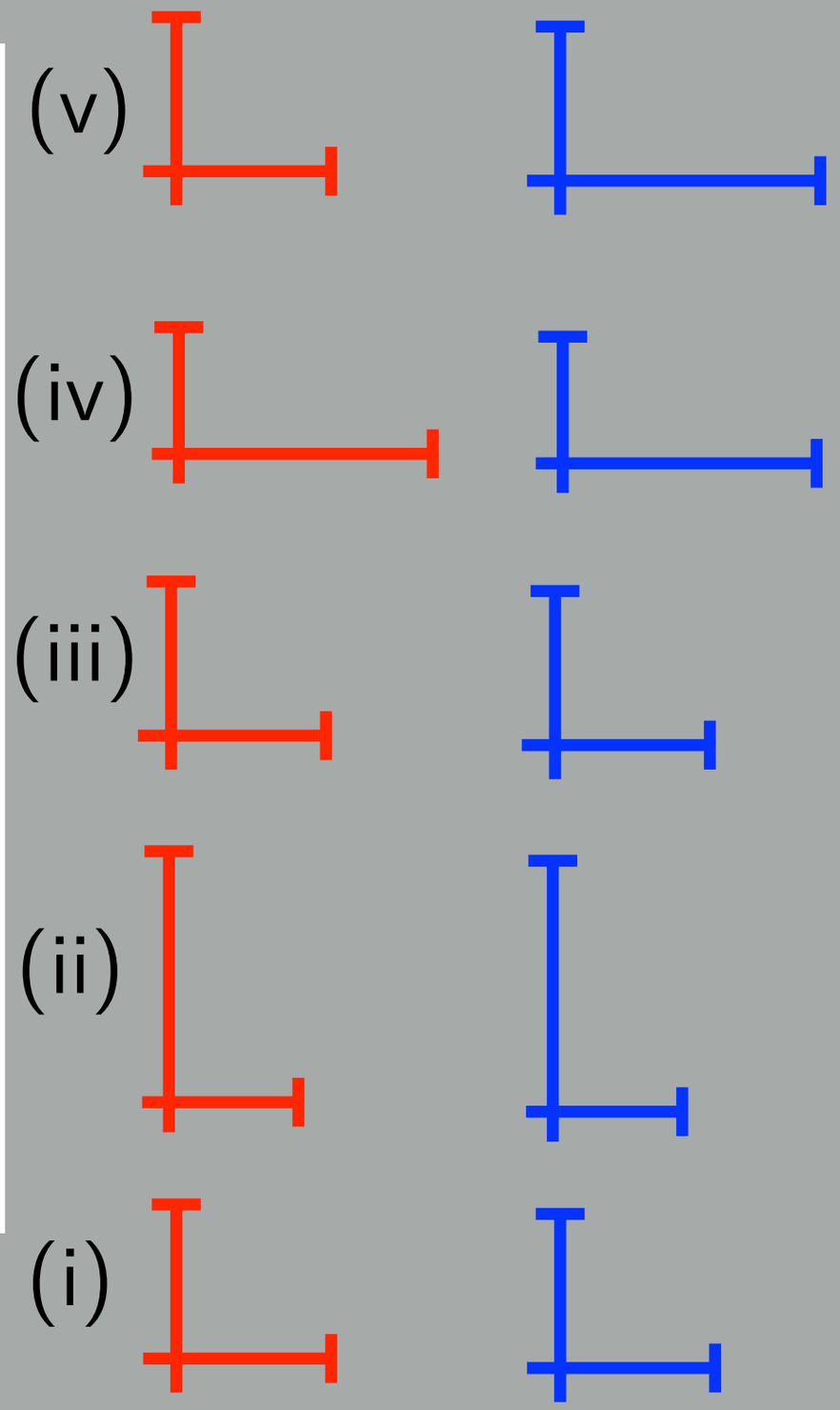


"Planck luminosity"

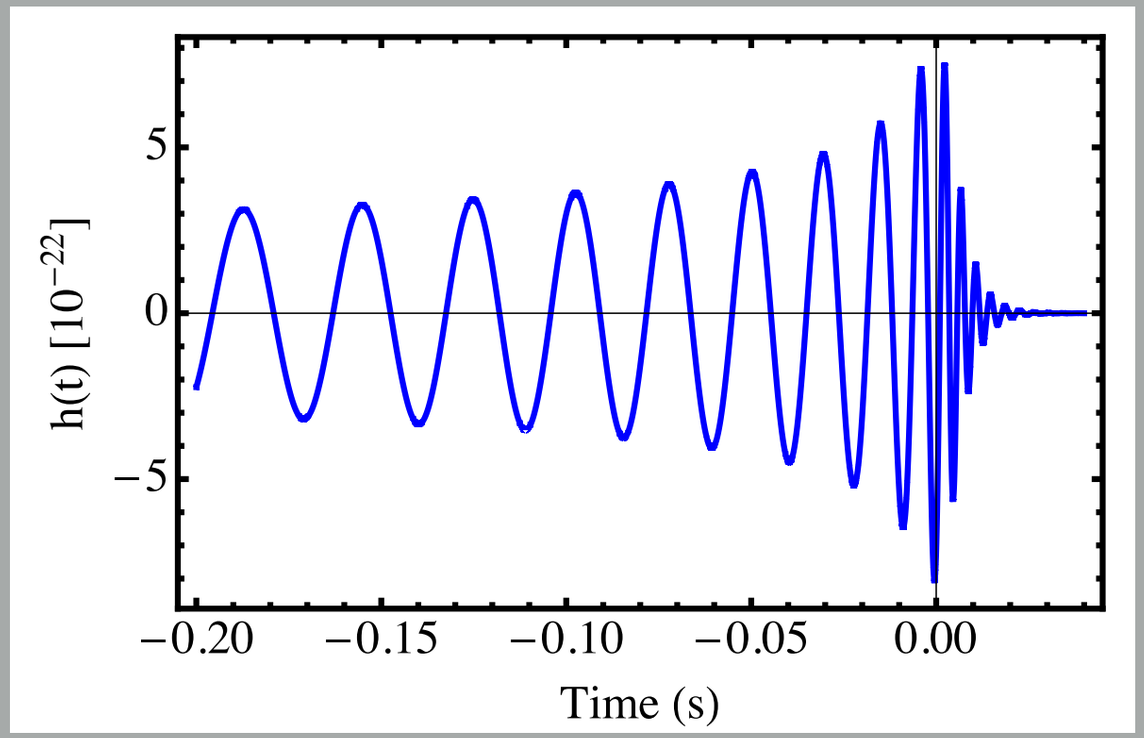
$$\frac{c^5}{G} \approx 3.6 \times 10^{52} \mathrm{W}$$

Gravitational-wave (GW) memory effect

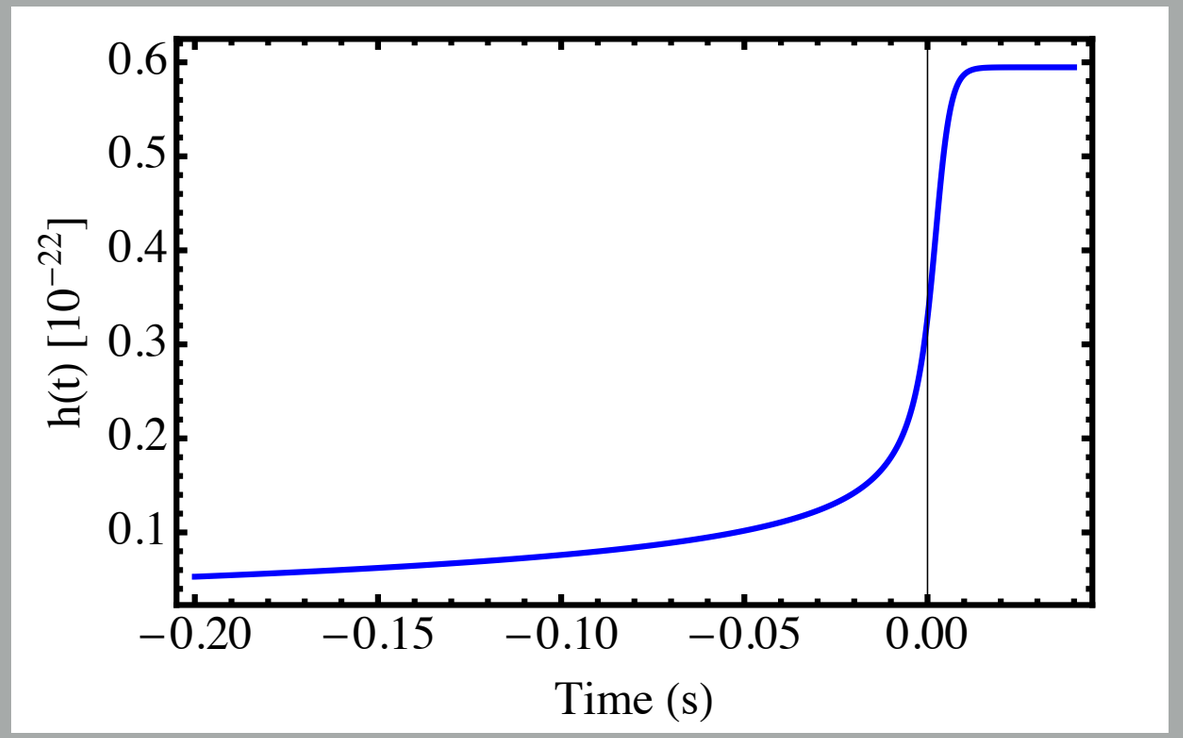




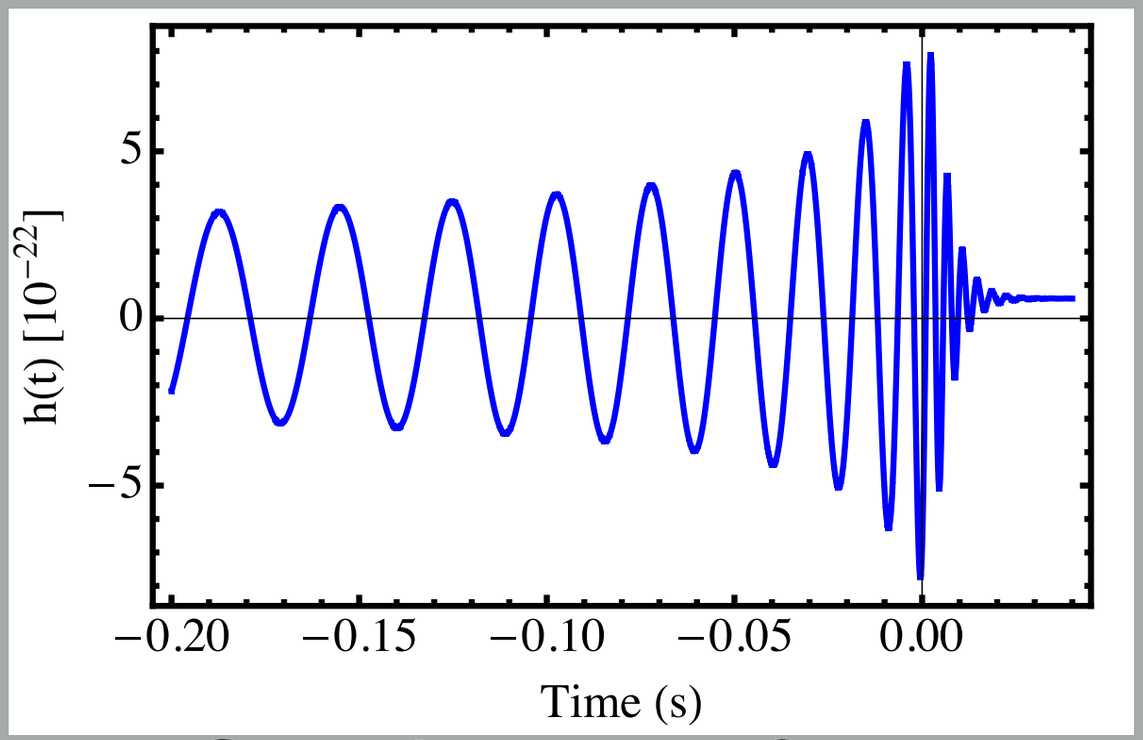
Detecting GW memory (GW150914)



Waveform, no memory



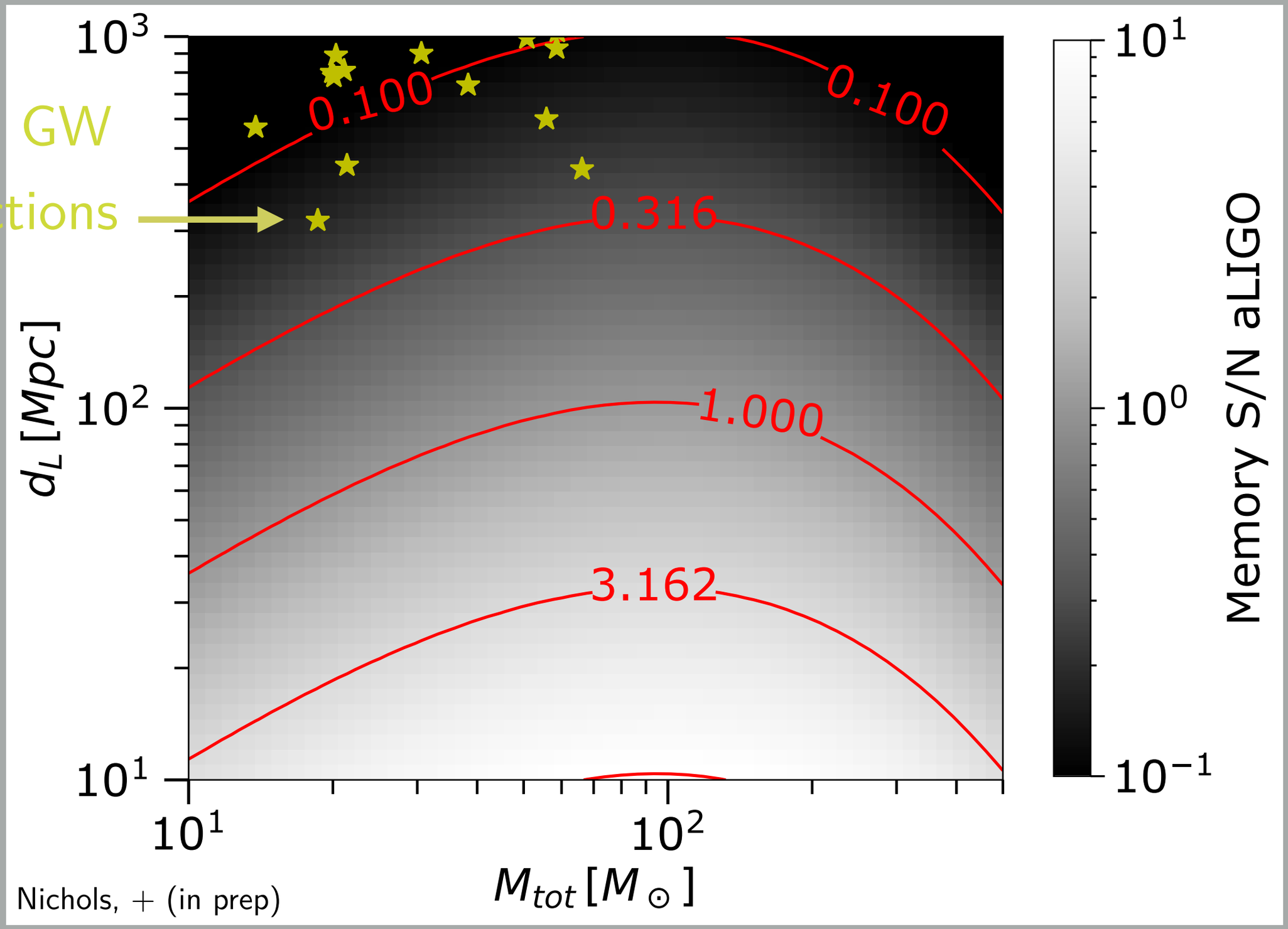
GW memory waveform



Complete waveform

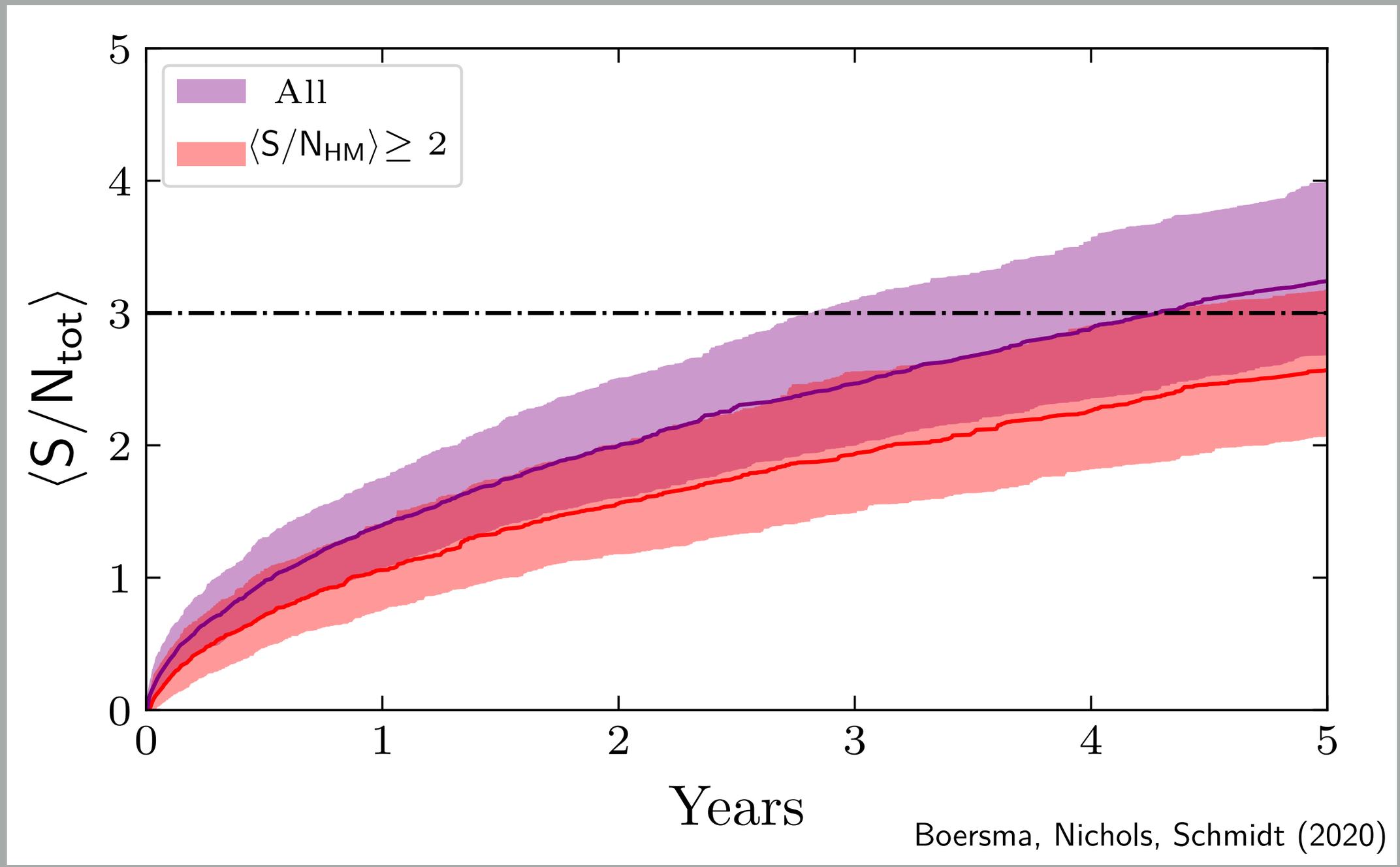
- Want to determine if waveform w/ vs. w/o memory is preferred by the data
- Will use additional signal-to-noise (S/N) in memory waveform to assess

Prospects for measuring GW memory



- S/N is roughly the significance of the detection in σ

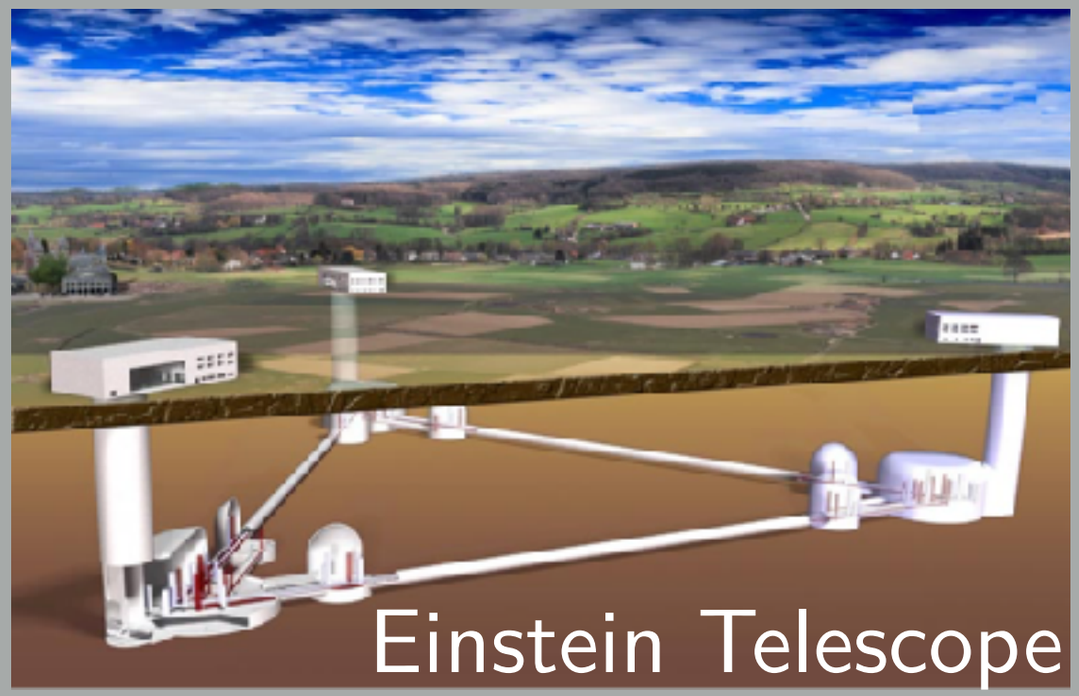
Populations and time to memory detection

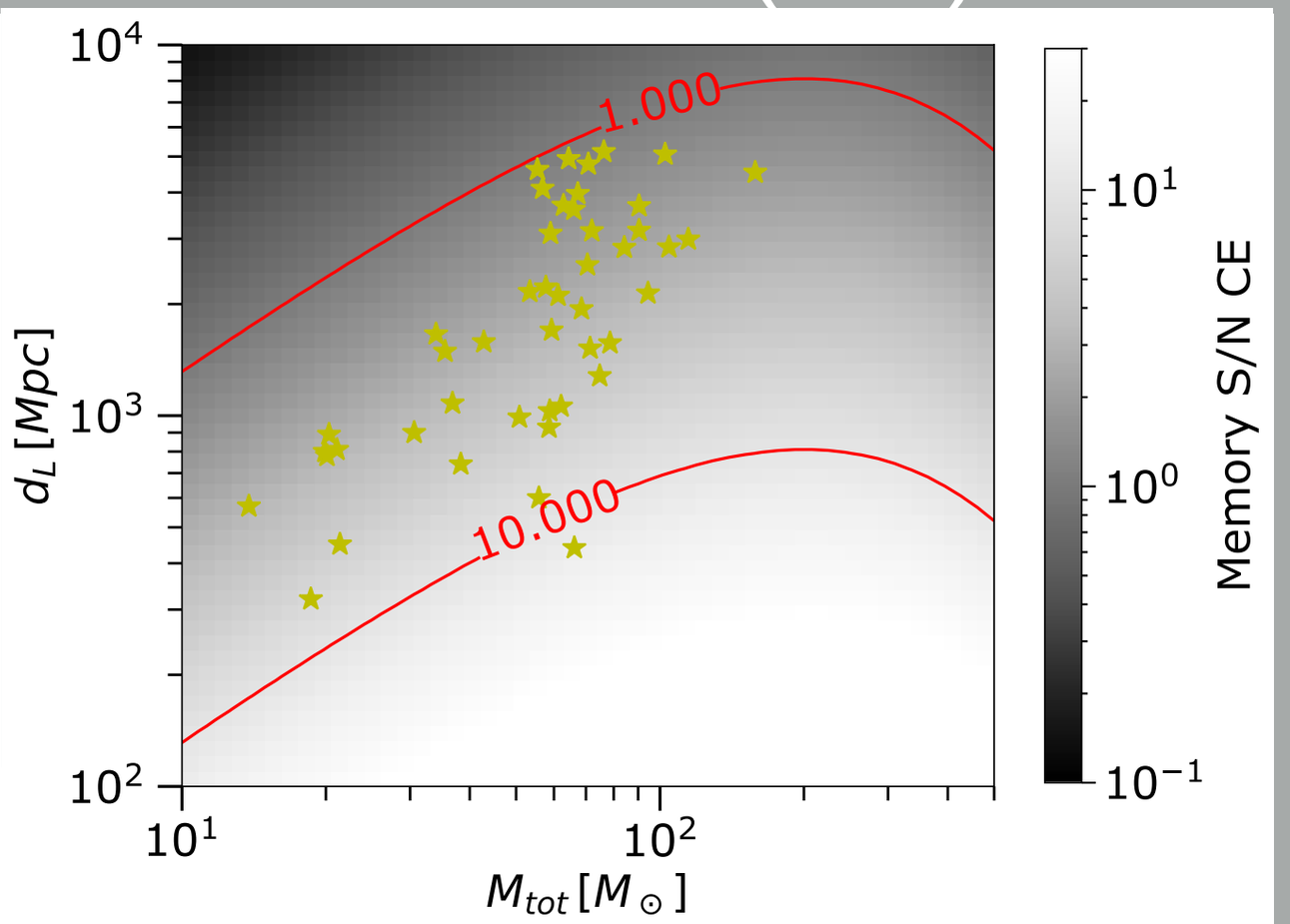


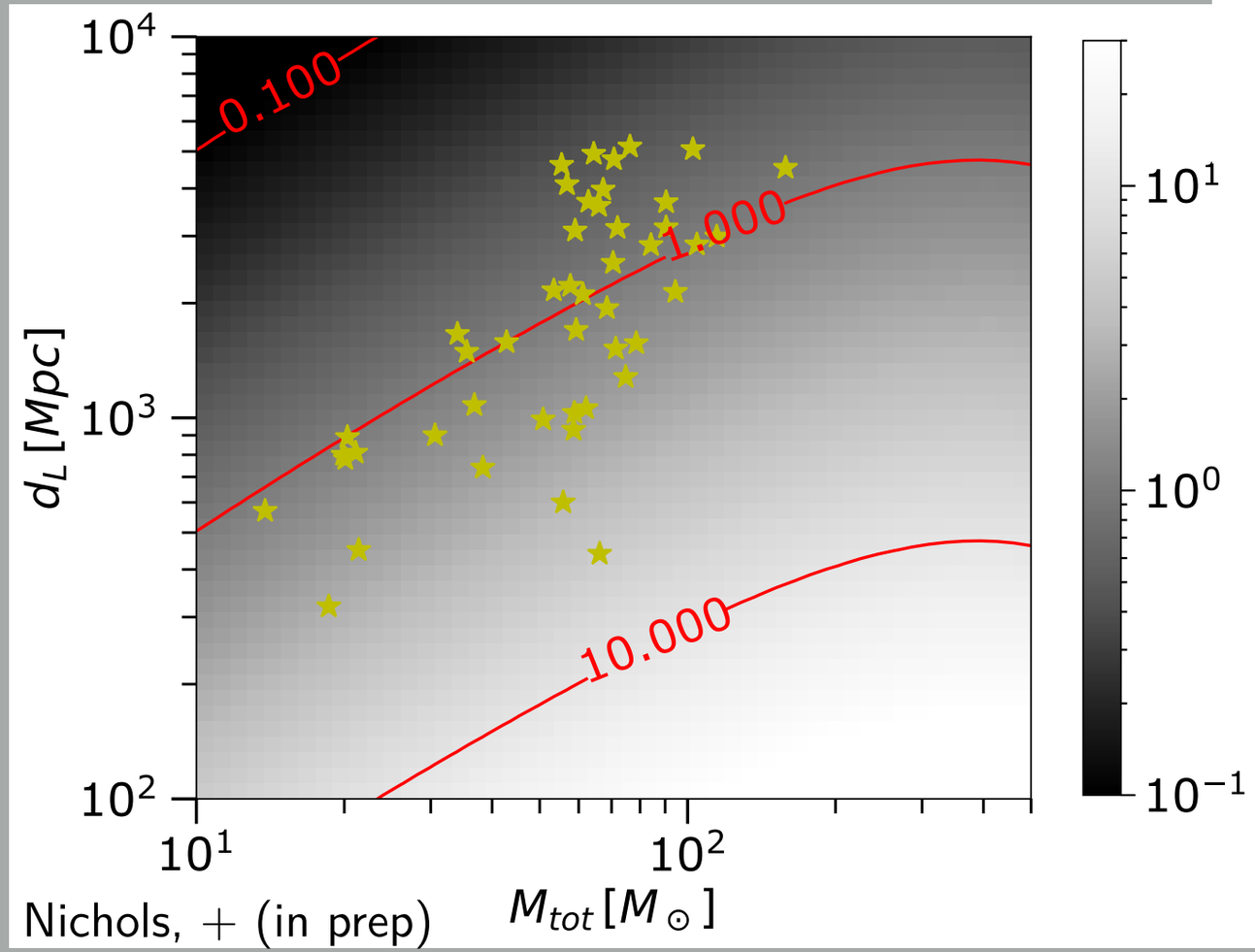
Boersma, Nichols, Schmidt (2020)

- Make many realizations of a BBH population consistent with O1 & O2; take median and 1-sigma error over populations
- aLIGO and AdVirgo design sensitivity; with 50% duty cycle

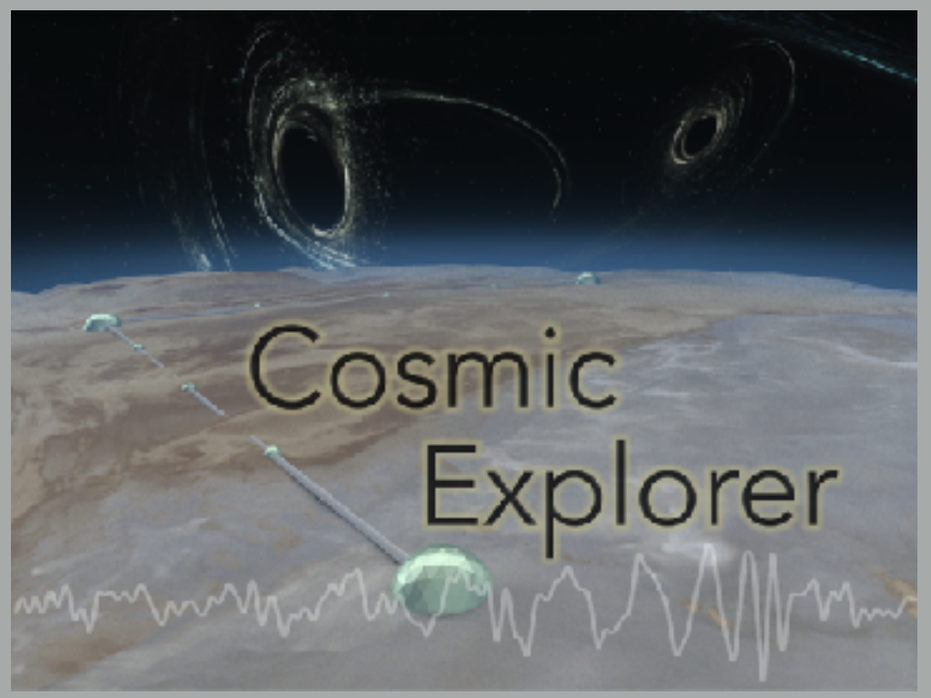
Planned GW detectors on Earth (3G)







Nichols, + (in prep)



Summary

- GW memory will most likely be detected statistically at the end of this decade with LIGO A+/aVirgo+
- Future GW detectors (CE/ET) will study it more precisely
- Measuring it will give observational access to one vertex of the infrared triangle

Did not discuss

- Two types of memory effects related to extended BMS conservation laws: spin memory and center-of-mass memory
- Spin memory possibly measurable by ET/CE with stacking
- CM memory is most likely too weak even for 3G detectors
- Subleading triangle more challenging to observe