Credit: Karan Jani/Georgia Tech

Bridging the gap between year-long signals and second-long signals: long-transient gravitational waves

L. Sun for the LIGO Scientific Collaboration and Virgo Collaboration, PASCOS 2018

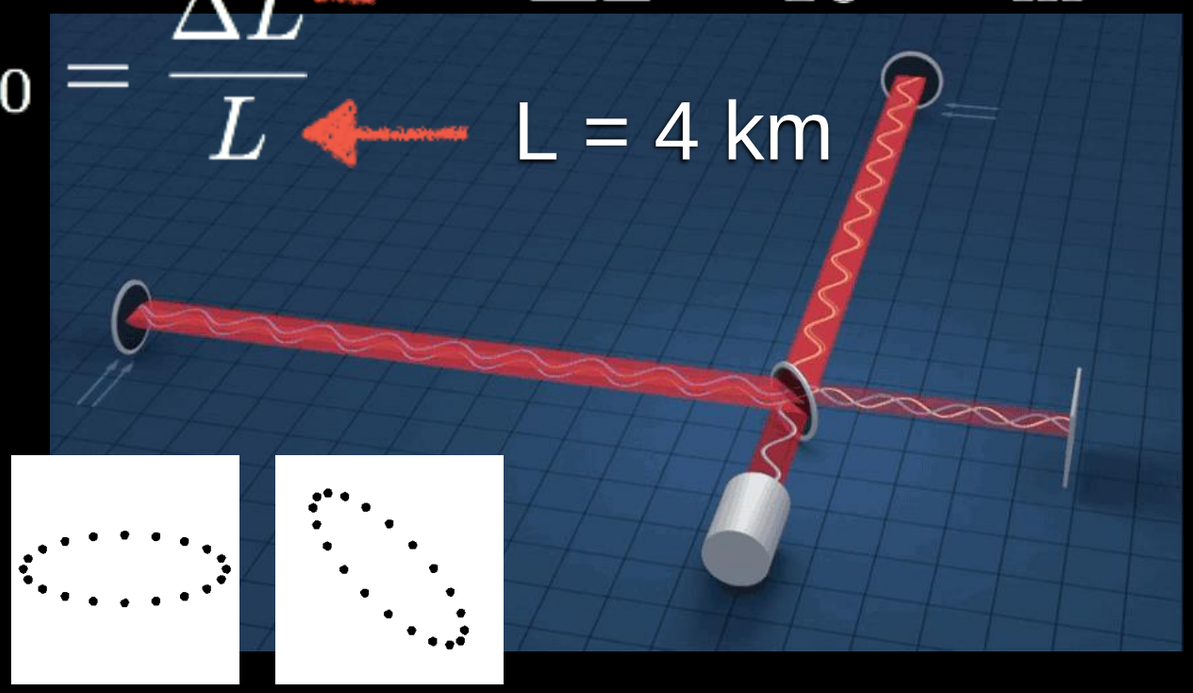
Laser Interferometer Gravitational-Wave Observatory and Gravitational wave detections

1/10,000 of a proton!

$$\Delta L \sim 10^{-19}\,\mathrm{m}$$

$$h_0 = \frac{\Delta L}{L}$$

L = 4 km

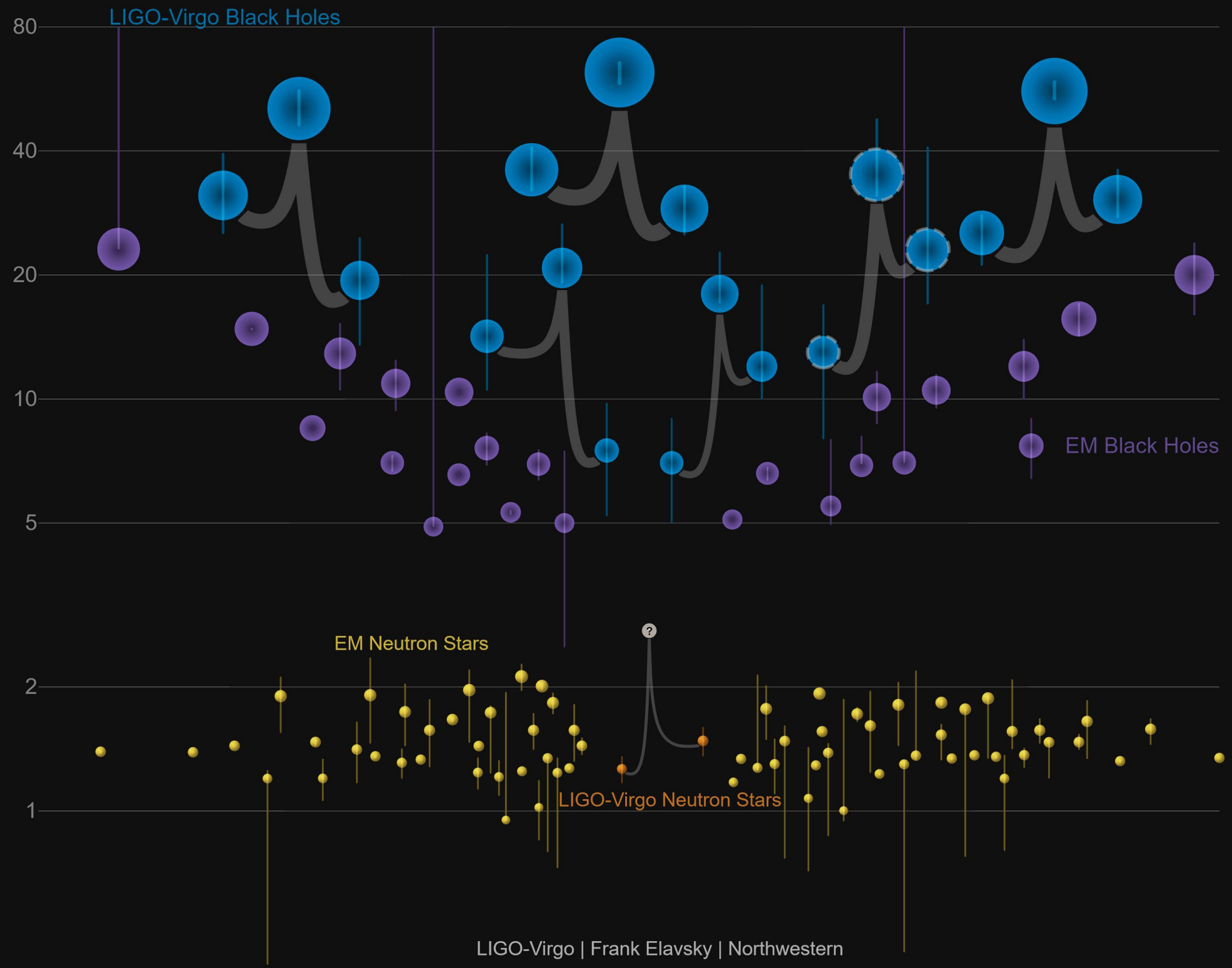


Credit: LIGO/Virgo

Credit: NASA/Dana Berry, Sky Works Digital

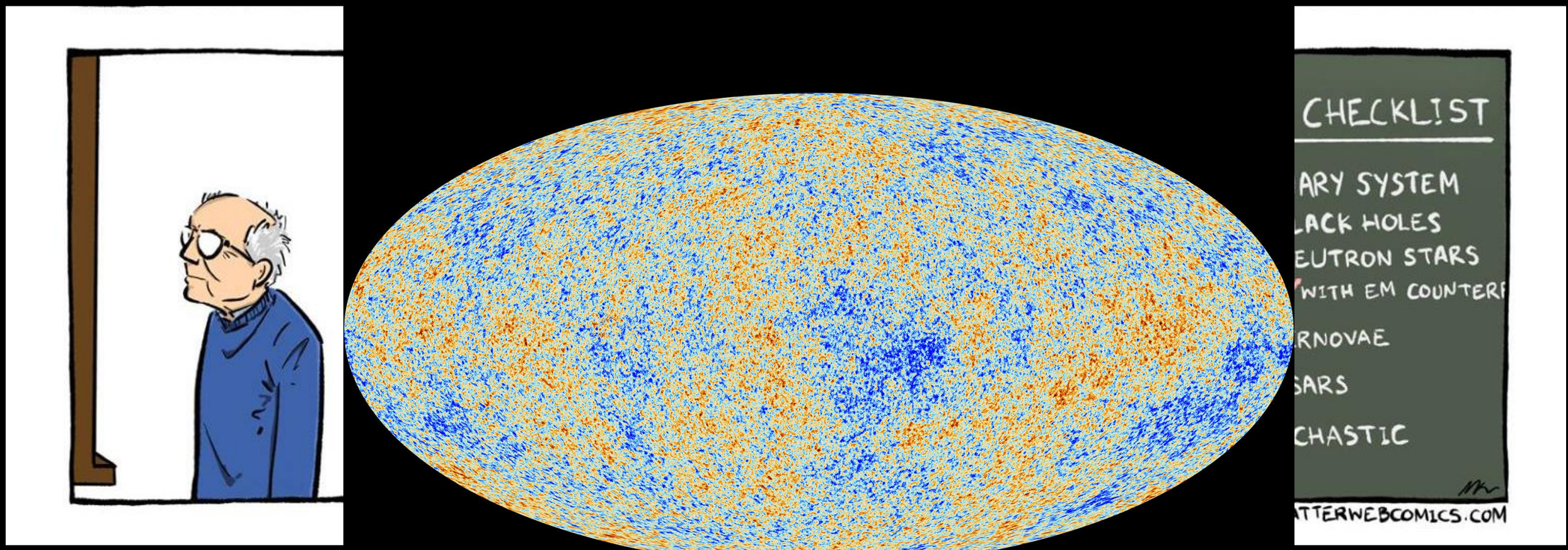
Masses in the Stellar Graveyard

in Solar Masses



LIGO-Virgo | Frank Elavsky | Northwestern

What else?

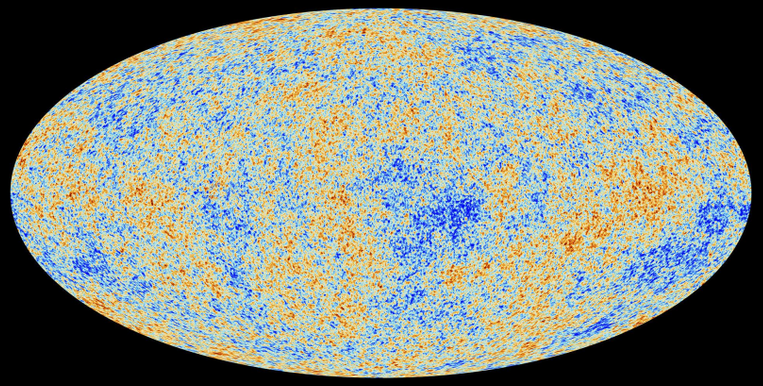


Credit: ESA and the Planck Collaboration

What's in between?

Compact Binary Coalescence

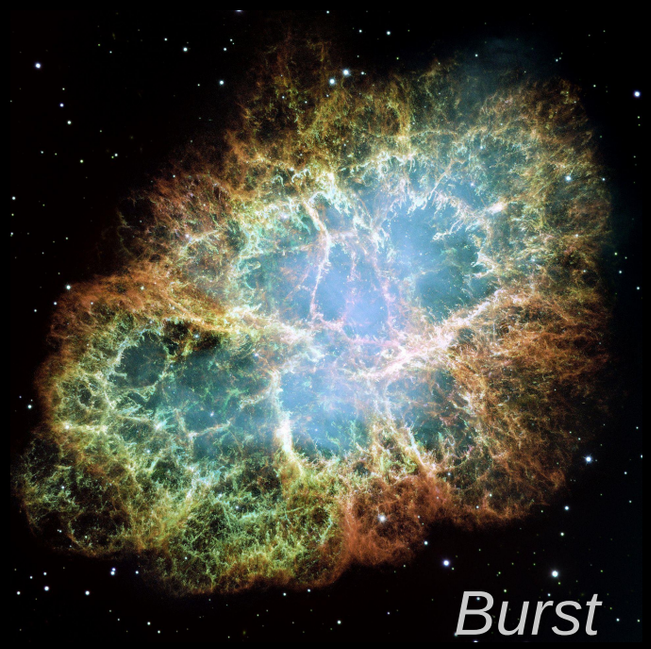
Stochastic Background



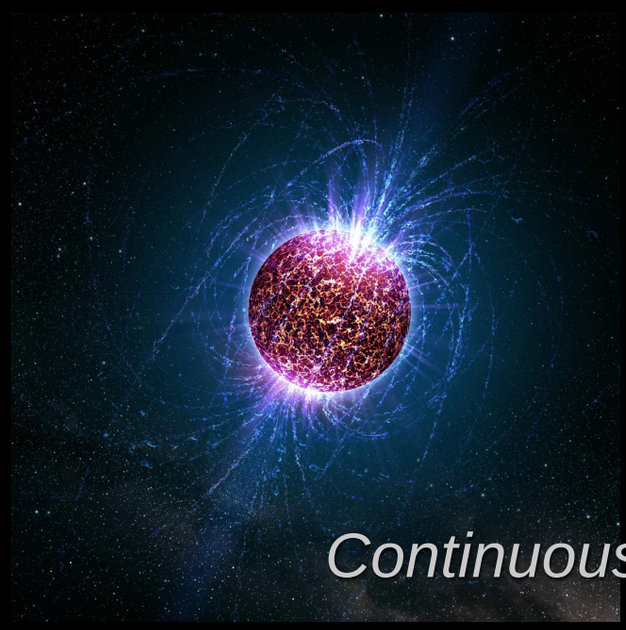
? ? ?

seconds

years

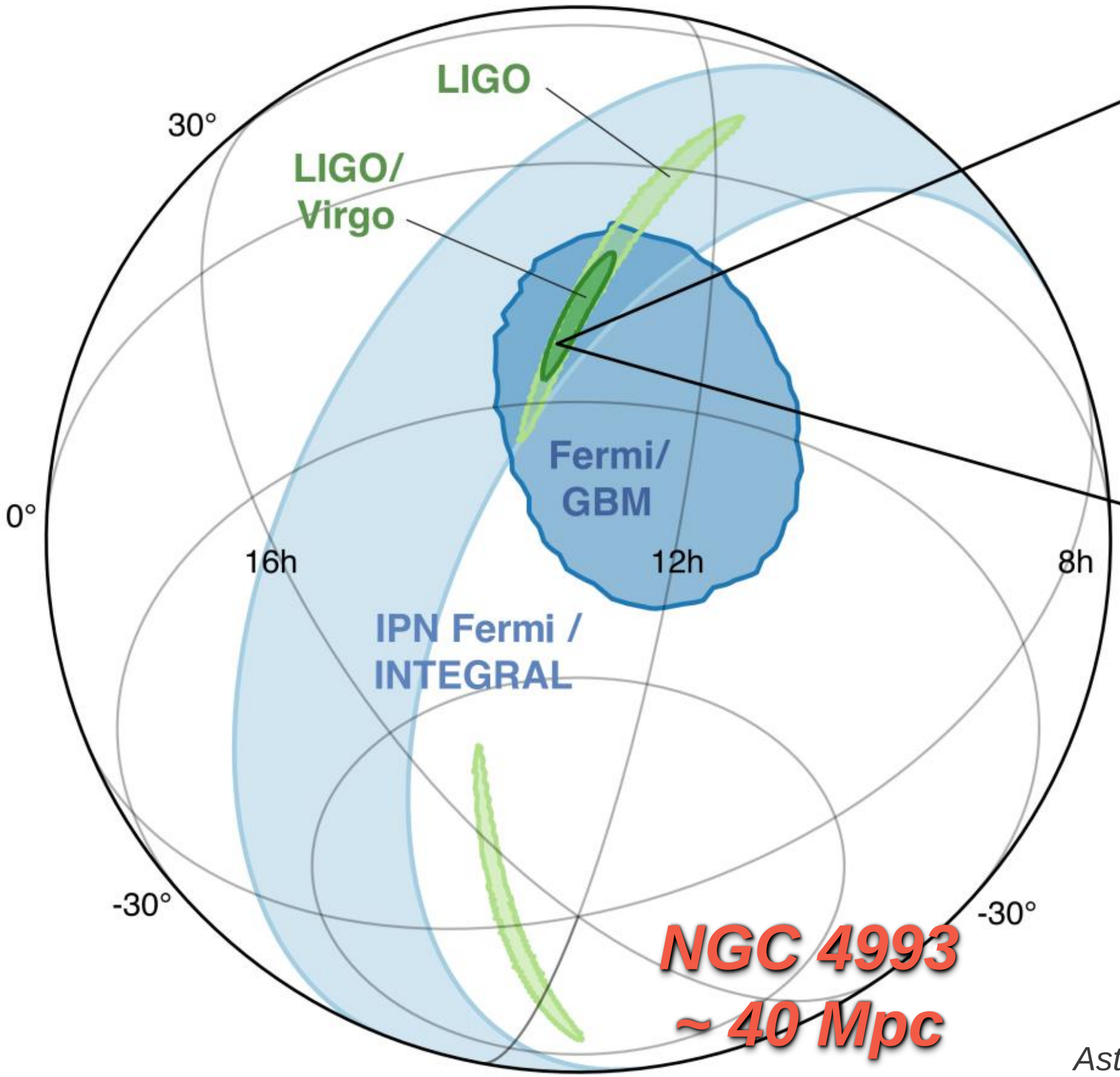


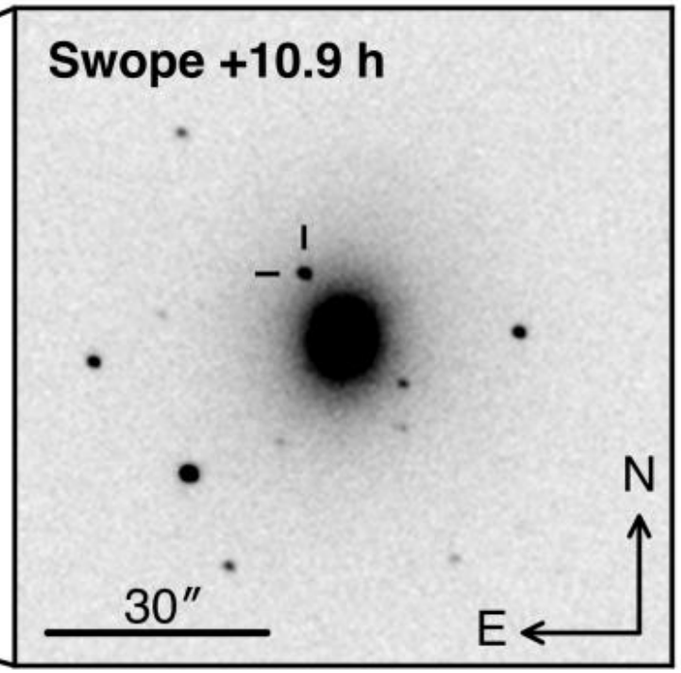
Burst

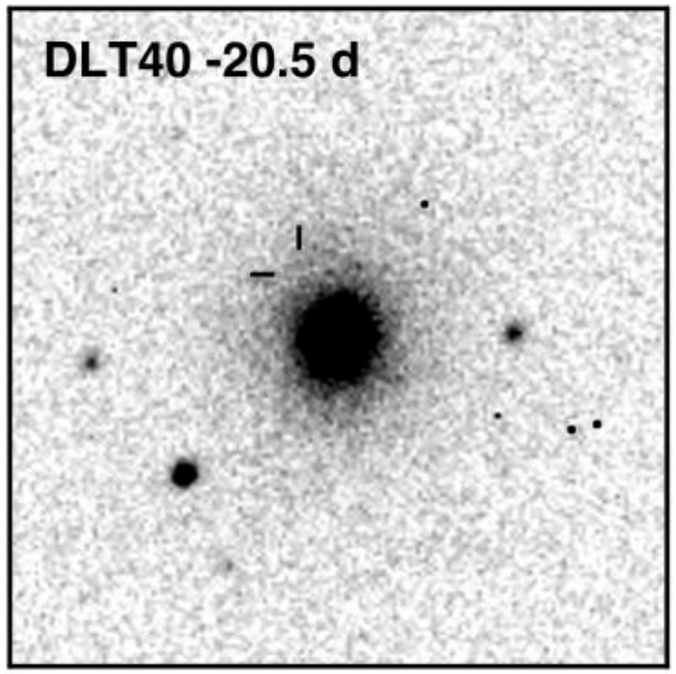


Continuous Waves

Binary neutron star coalescence - GW170817







NGC 4993
~ 40 Mpc

Astrophys. J. Lett. 848, L12 (2017)

What is left over after GW170817?

- *Prompt formation of a BH*
- *Hypermassive NS that collapses to a BH in ~ < 1s*
- *Supramassive NS that collapses to a BH in ~10 − 10^4 s*

GW170817

$$M = 2.74^{+0.04}_{-0.01} M_\odot$$

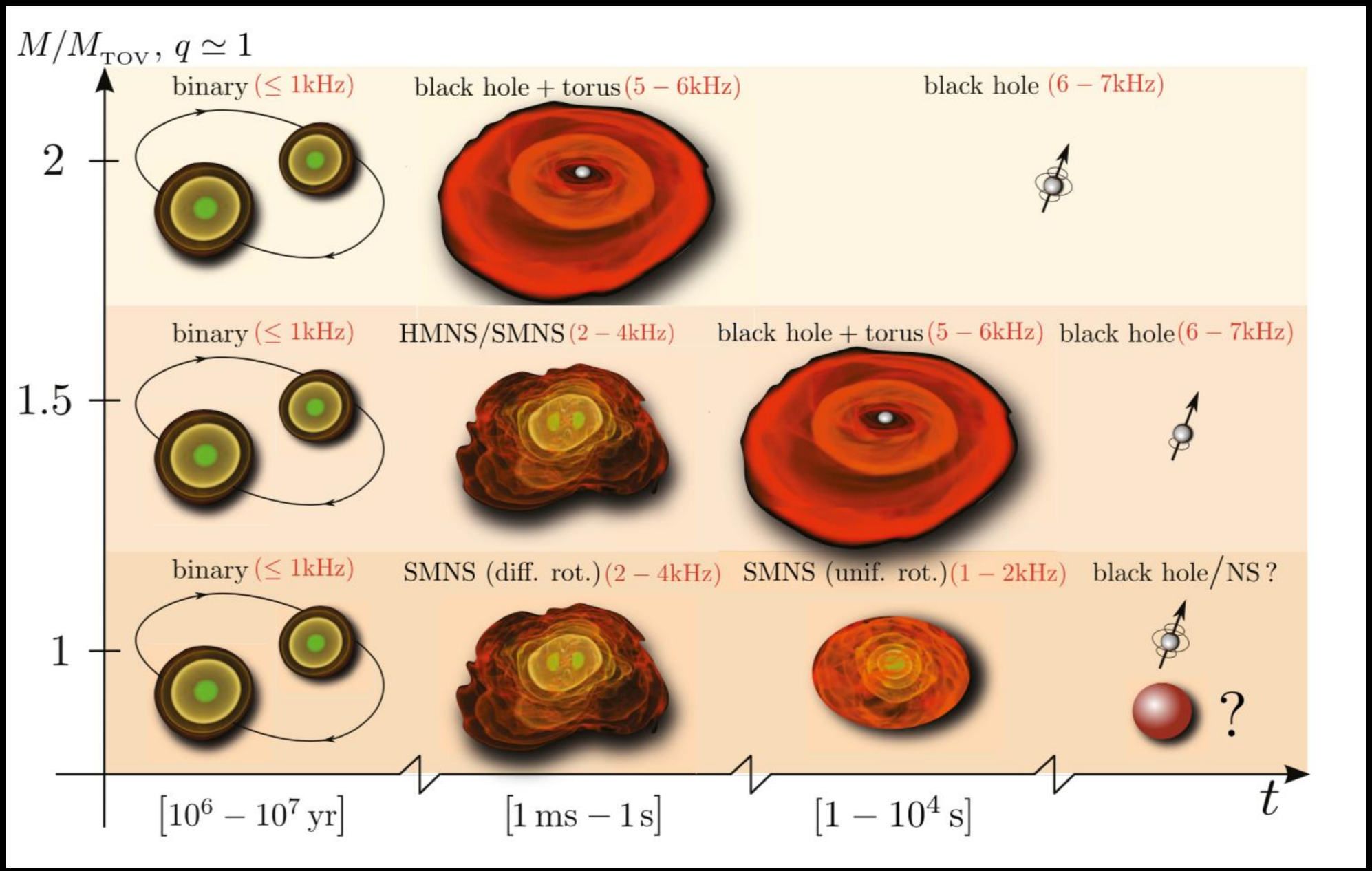
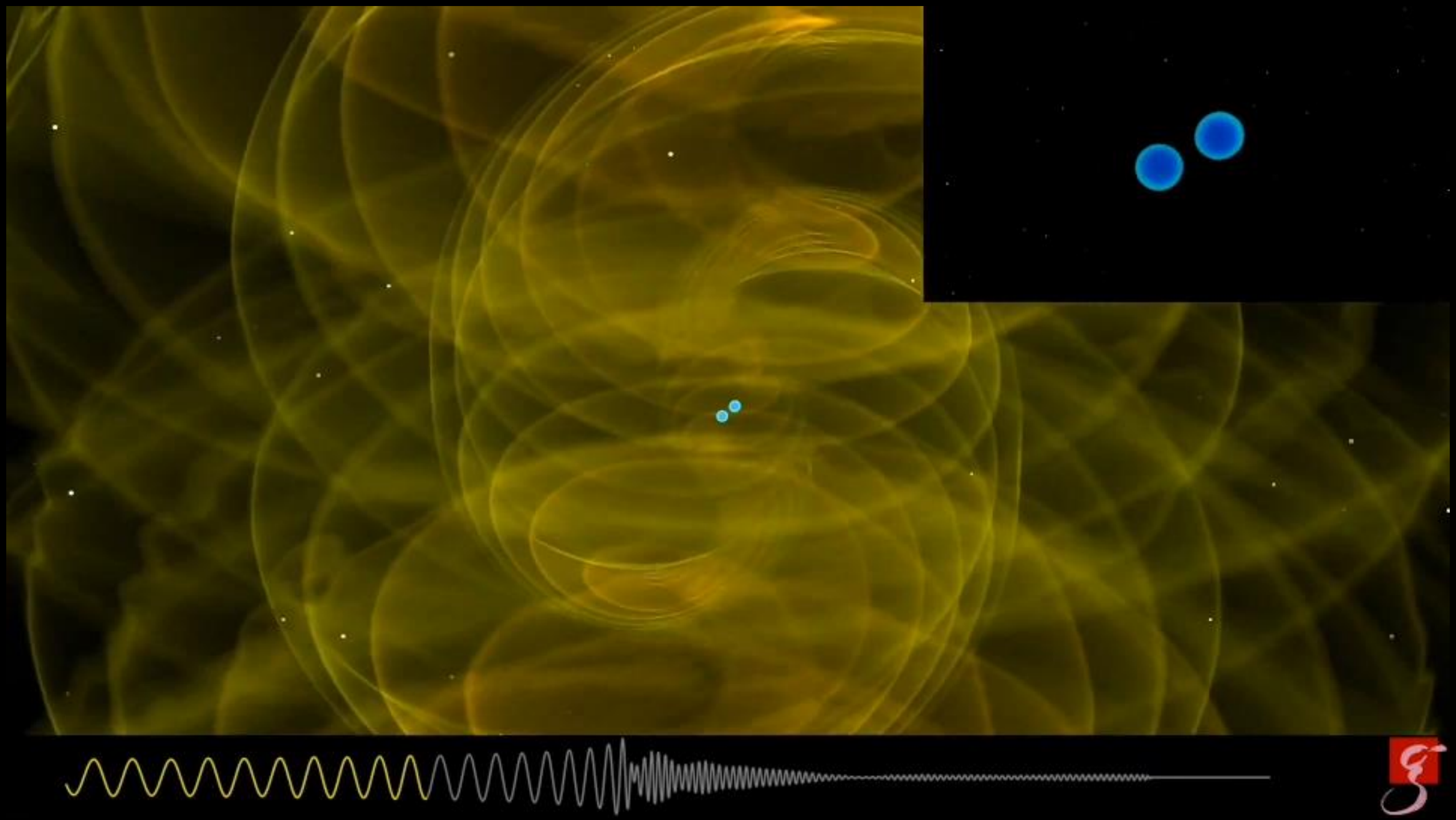


Image: Baiotti & Rezzolla (2017)

Search for postmerger remnant GW signals
Motivations?



Credit: T. Dietrich, S. Ossokine, H. Pfeiffer, A. Buonanno/Max Planck Institute for Gravitational Physics/BAM collaboration

Postmerger remnant models

- *Formation of a millisecond magnetar (e.g. Giacomazzo+ 2013, 2014; Dall'Osso+ 2012; Lü+ 2015; Rowlinson+ 2013; Gompertz+ 2013, 2014)*

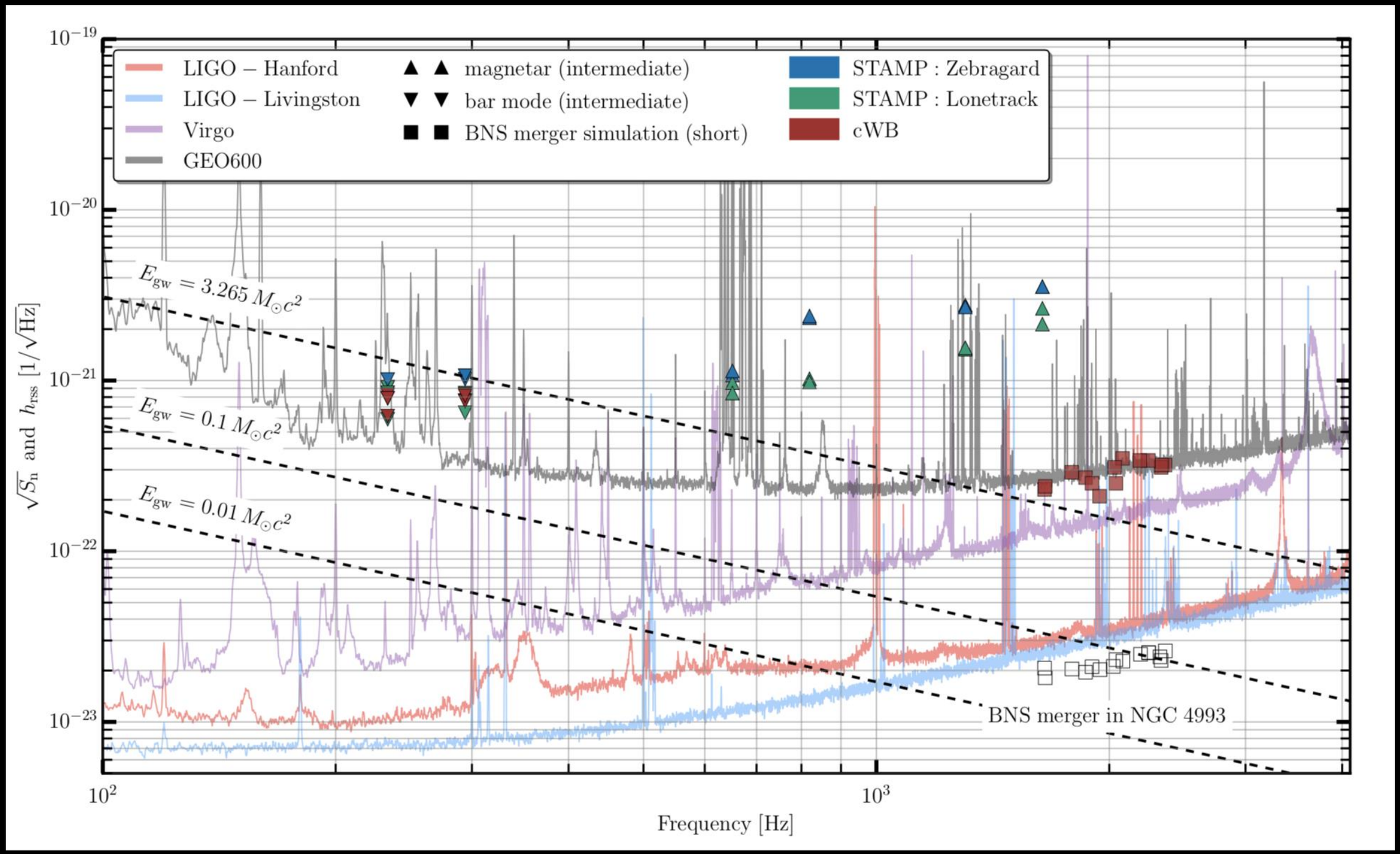
- *Development of dynamical or secular instabilities, like r-modes or bar-modes (e.g. Andersson 1998; Lindblom 1998; Corsi+ 2009; Passamonti+ 2013; Doneva+ 2015)*

- *Other scenarios…*

First short-duration remnant search (unmodeled)

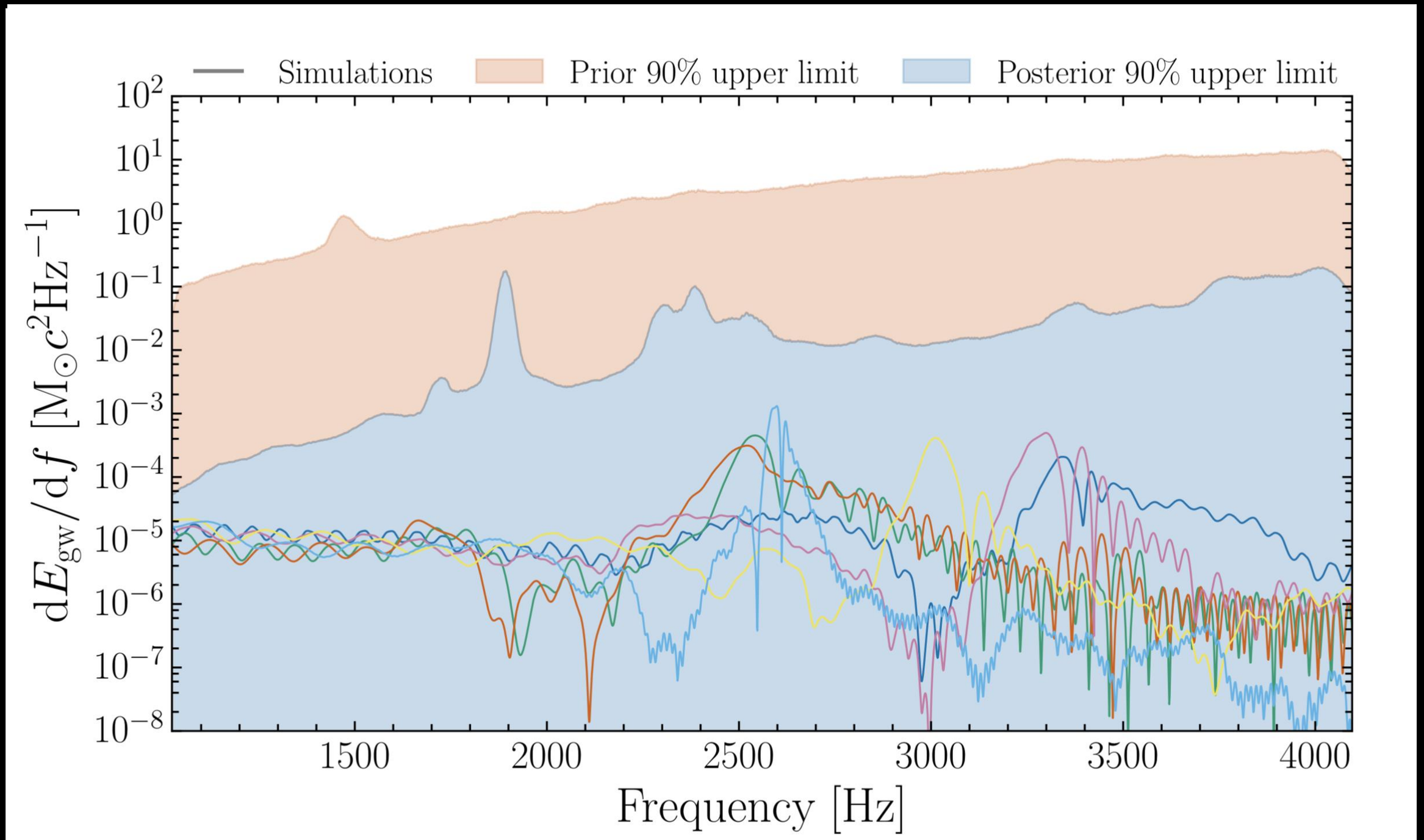
- *cWB analysis - $\lesssim$1s, 1k-4k Hz, HL, and $\lesssim$1000s, 24-2048 Hz, HLV*
- *STAMP analysis - 500s, 24-4000 Hz, HL*

No detection



Abbott et al. ApJL, 851, L16, 2017

Short-duration remnant Bayesian analysis (< 1s; unmodeled)



Abbott et al. 2018

Long-duration remnant searches

- *Analyze the data on time-scale ~10^2—10^5s*
- *Unmodeled analyses:*
  - *STAMP-VLT (Stochastic Transient Analysis Multi-detector Pipeline @ Minnesota)*
  - *Hidden Markov model tracking (CW search @ Melbourne)*
- *Modeled analyses: (millisecond magnetar model, Lasky+ 2017)*
  - *FrequencyHough (CW search @ Rome)*
  - *Digitized Power Law Tracker (CW search @ Mallorca)*

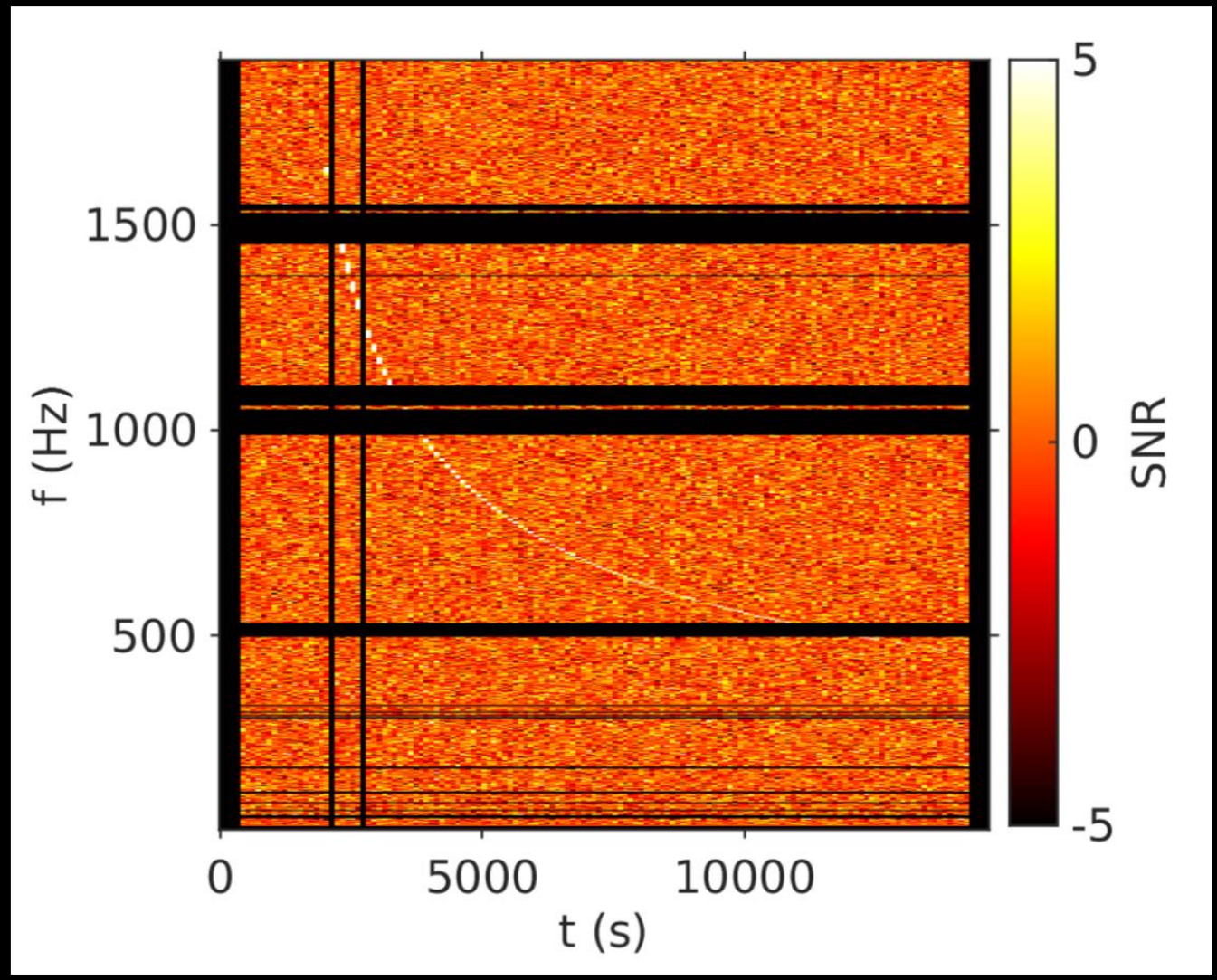
$$f_{\rm gw}(t) = f_{\rm gw,0}\left(1+\frac{t}{\tau}\right)^{\frac{1}{1-n}}$$

STAMP seedless clustering (unmodeled)

$$\Gamma = \begin{bmatrix} f(\tau) \\ t(\tau) \end{bmatrix} = (1-\tau)^2 N_0 + 2(1-\tau)\tau N_1 + \tau^2 N_2$$

$$\mathrm{SNR}_\Gamma = \frac{1}{\mathcal{N}} \sum_\Gamma w(t;f)\rho(t;f,\hat{n})$$

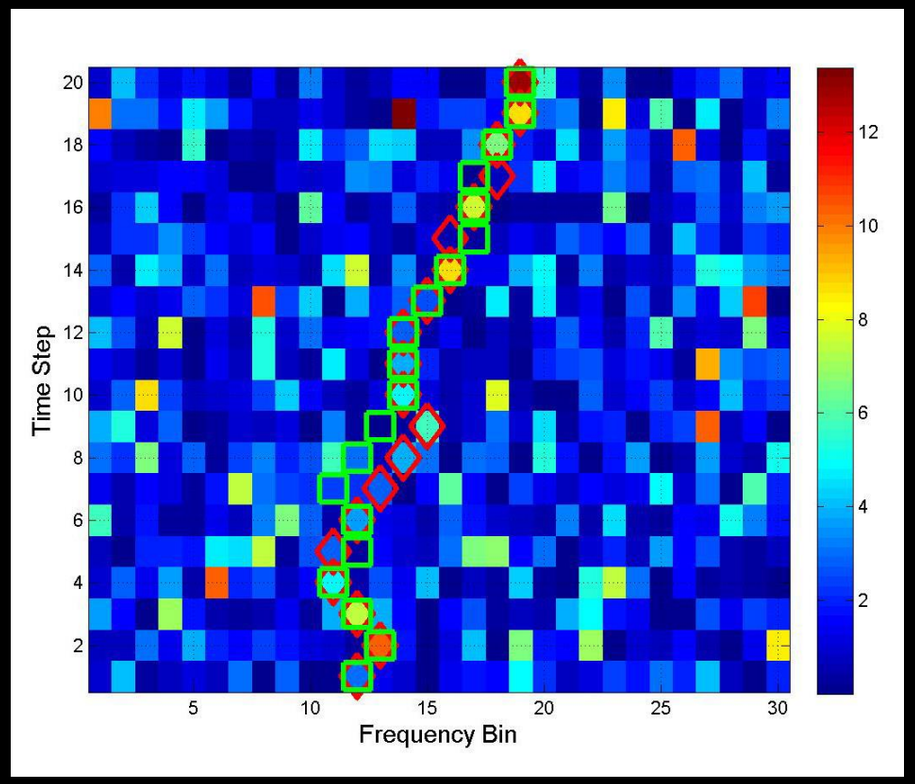
- *Three points are picked randomly and monotonically on the ft-map and fit using quadratic Bezier curves.*
- *Sum over weighted and normalized pixel SNRs on the track*
- *Thrane+ 2011; Thrane & Coughlin 2013,2014*



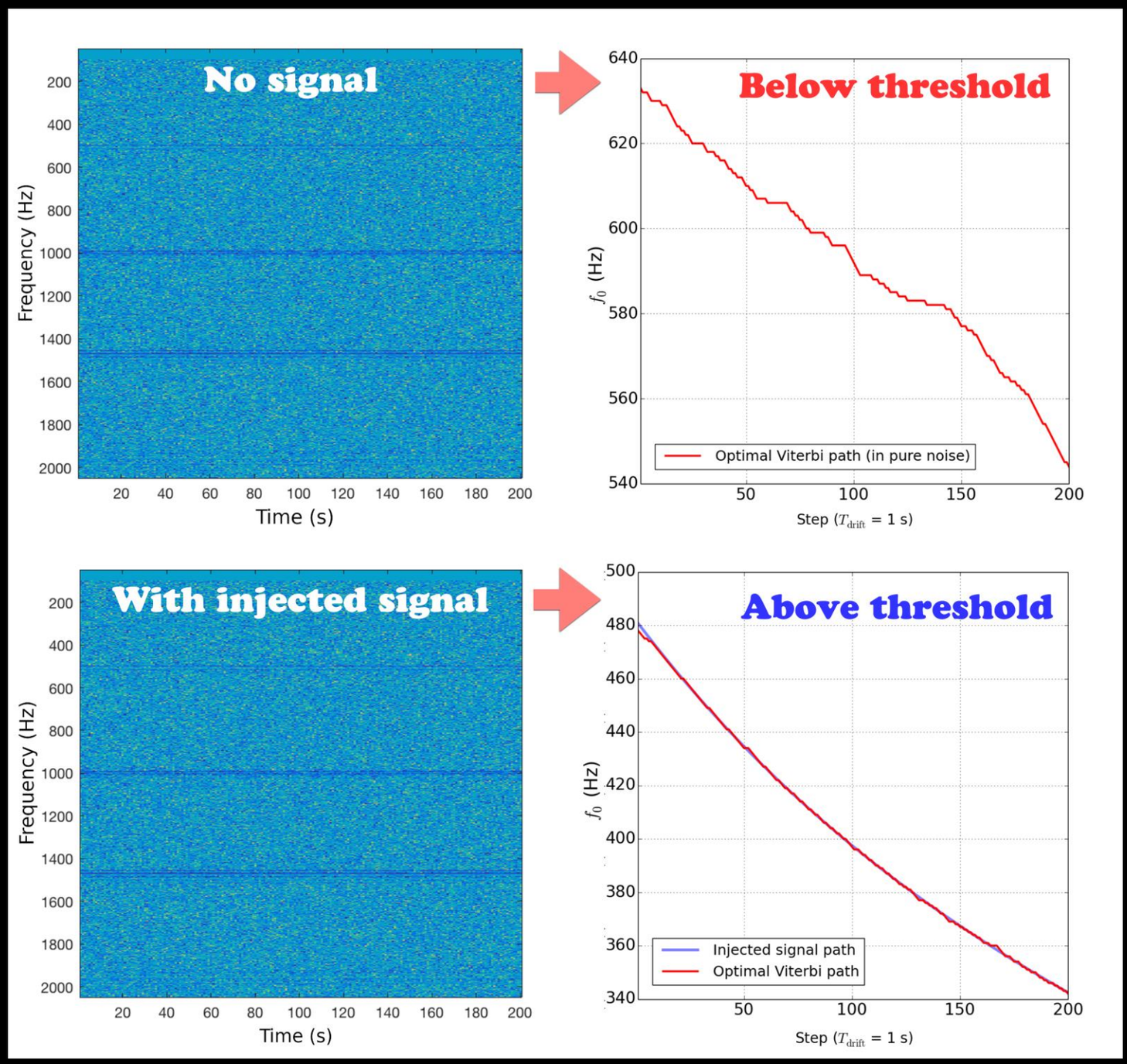
Hidden Markov Model Tracking (unmodeled)

$$\Pr[q(t_k) = q_i | q(t_{k-1}) = q_j; O^{(k)}] =$$

$$L_{o(t_k)q_i} A_{q_i q_j} \max_{q_m} \Pr[q(t_{k-1}) = q_j | q(t_{k-2}) = q_m; O^{(k-1)}]$$



- *Tracking rapidly evolving signal frequency using HMM.*
- *Suvorova+ 2016; Abbott+ 2017; Sun+ 2018*

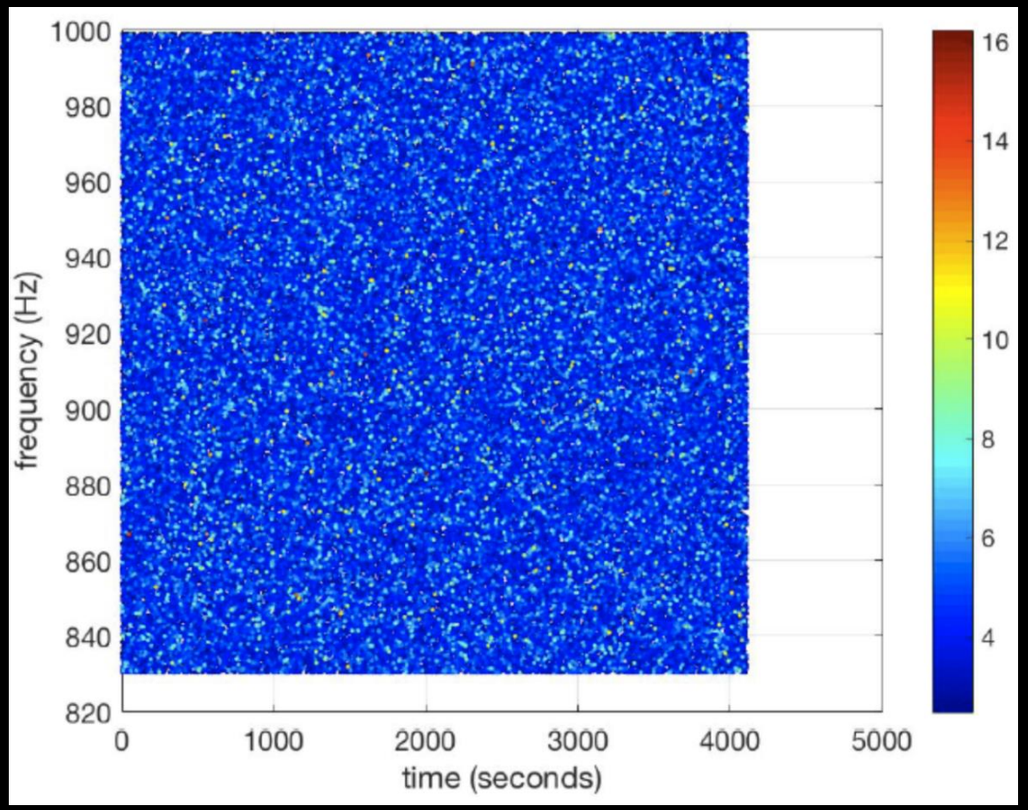


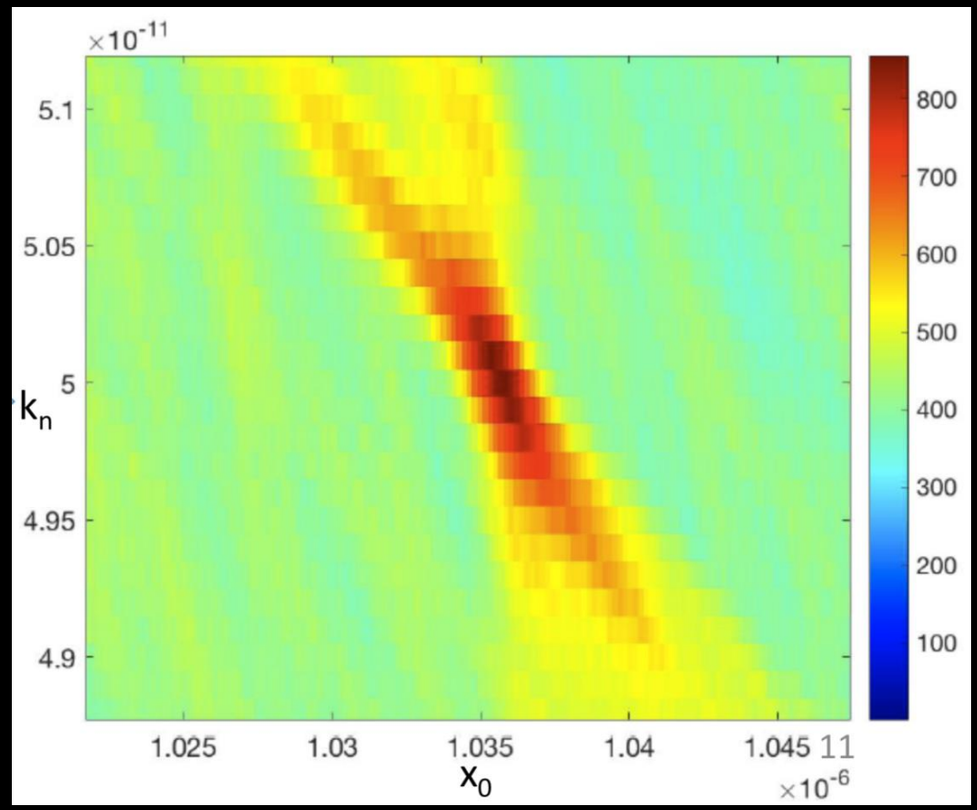
Hough Transform (modeled): FrequencyHough & Digitized Power Law Tracker

- *Krishnan+ 2004; Palomba+ 2005*
- *Example with generalized FrequencyHough: Peaks in frequency-time plane are mapped to straight lines in x_0-k_n plane*

$$k_n = -\frac{\dot{f}}{f^n}, x_0 = f_0^{1-n}$$

$$f(t) = f_0 \left[1 + (n-1)(t-t_0)k_n f_0^{n-1}\right]^{\frac{1}{1-n}}$$



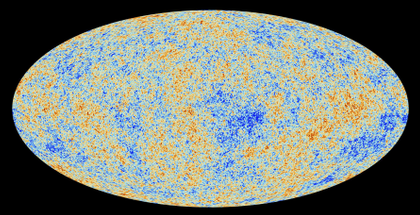


Other long-transient signals

- *BNS postmerger remnants*
- *Newly born supernova remnants*
- *Glitching pulsars*
- *Accreting objects*
- *… etc.*

Compact Binary Coalescence

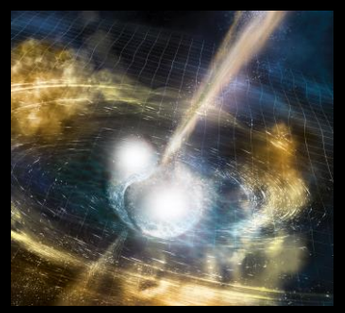
Stochastic Background

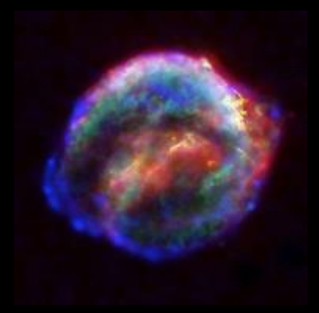


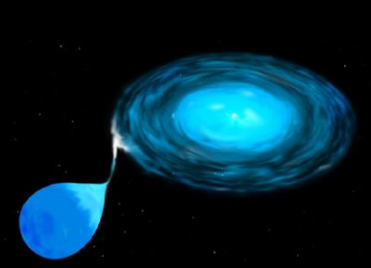
long-transient GW

seconds — *years*

Burst







Continuous Waves

- *Unmodelled long-transient all-sky search already carried out (e.g., Thrane+ 2015, Abbott+ 2018)*
- *More long-transient searches under development (e.g., Prix+ 2011, Keitel 2016, Keitel & Ashton 2018, Sarin+ 2018)*

Summary & Conclusion

- *Detection of GW signals from the post-merger remnant could provide important information of the NS structure and nuclear EoS.*

- *It is unlikely that post-merger signals can be detected from event GW170817 at distance ~40 Mpc (at least 10x beyond current sensitivity). Upper limits can be placed on signal properties.*

- *Searches will benefit from improved detector sensitivity at high-frequencies and third-generation interferometers in near future.*

- *Searches for other types of long-transient signals are also being carried out.*

Credit: Karan Jani/Georgia Tech

Thanks!
Questions?