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Searches for long-duration gravitational-wave transients with Advanced Virgo and Advanced LIGO

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Status of GW astronomy in 2022

- 3 observing runs by Advanced LIGO - Advanced Virgo since 2015
- Compact binary coalescences (NS and stellar-mass / intermediate BH)
  - Detected by Advanced LIGO and Advanced Virgo since 2015
  - Only sources detected so far (~80 detections)
- **What about other types of sources / signals?**
  - Continuous waves
  - Stochastic GW background(s)
  - **“Bursts”**

GW “bursts”

Operational definition: all transient GW signals that do not fall in the CBC category

Example: core-collapse supernovae, NS excitations, cosmic string cusps…

Long-duration bursts: transient GW signals with typical duration ~ minutes to hours (days?)

- BNS post-merger
- Millisecond magnetars
- Accretion disk instabilities
- “Exotic” CBCs (e.g highly eccentric, high mass ratio)
- Magnetar flares

Common point: no precise model of waveform for these signals

Search for long-duration GW transients

Challenges:

- No precise waveforms
  - Need for signal-agnostic search algorithm
- Transients with duration ~ 10 - 1000 s
  - Signal diluted over time and faint
- All-sky / all-time:
  - Large amount of data to analyze
  - Large parameter space

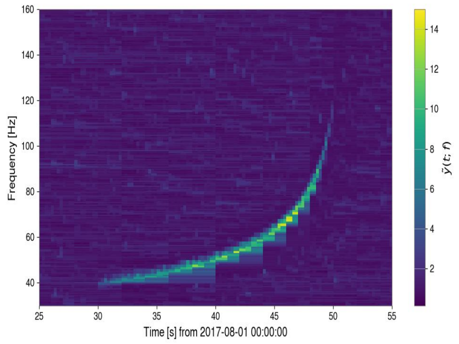
Goal: develop a full-scale data analysis pipeline to search for those signals

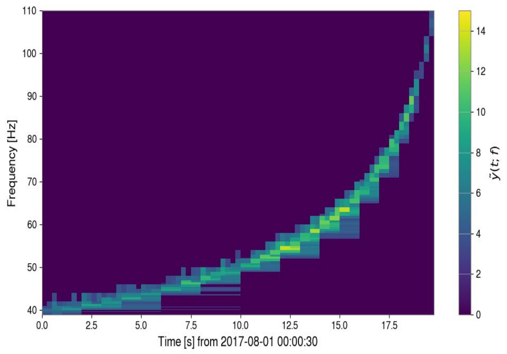
➔ Computationally efficient
➔ Sensitive to a wide diversity of signals
➔ Able to analyze year-long datasets

Principle of the search

Search for excess power in the data (STAMP, Thrane et al., PrD, 2011)

- Use time-frequency representation
- Search for “clusters” of excess-power
- Cross-correlate different detectors to discriminate signal from noise

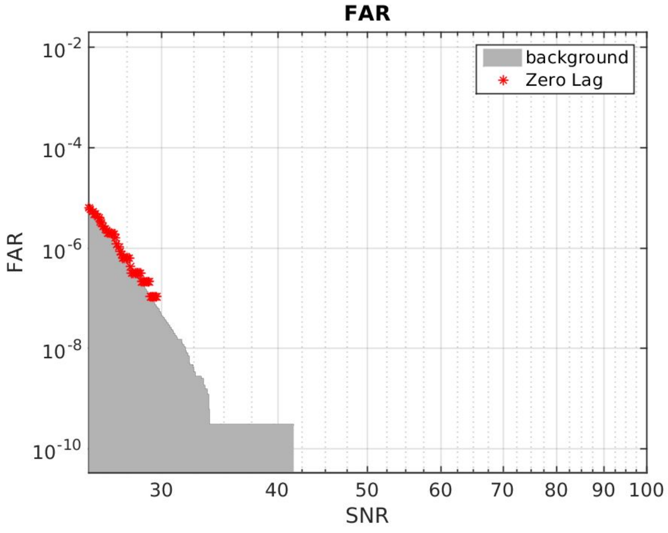




Workflow of the PySTAMPAS pipeline

Macquet et al., PRD, 2021

1. Split the dataset into windows with duration ~500s
2. Build time-frequency maps for each window
3. Run a pattern recognition (“clustering”) algorithm
4. Cross-correlate each cluster with other detector’s data
    a. Noise: no correlation
    b. GW signal: correlated
5. Assign a coherent detection statistic to each cluster
    a. Detection statistics reflects the probability of the cluster being a true GW signal



Time shift data sets from 2 detectors to analyze background distribution: get false-alarm probability vs detection statistic.

Performances

- Able to detect signals with various duration, frequency range, spectral morphology
- Low computing time (~10 times faster than other long-duration pipelines)

Comparison with optimal matched filtering:

- Unmodelled search is ~ 5-10 times less sensitive than optimal matched filtering
- Matched filtering is not feasible for this search
- Close that sensitivity gap
  - Add more information on the signal
  - Tweak clustering algorithm

Search for long-duration GW around magnetar giant flares

Motivation:

- Magnetars have a large reservoir of magnetic energy (B~10^{14} G)
- Giant flares release 10^{44}-10^{47} ergs of energy in gamma-rays
  - 3 observed so far in the galaxy
  - Extra-galactic MGFs -> new class of short gamma-ray bursts (GRBs) ?
- 4 short GRBs from close galaxies associated with potential MGF origin (Burns et al., ApJL, 2021)

➔ Large energy released at short distance
➔ High volumetric rate
➔ Potential for GW emission

GW emission from MGFs

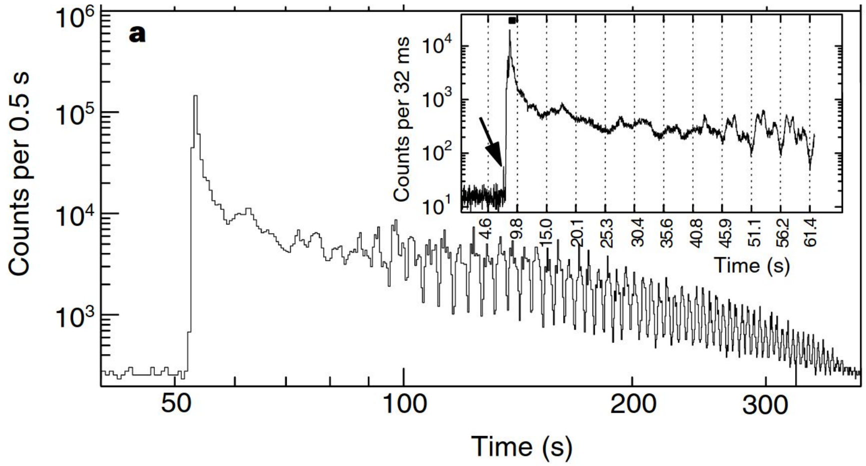


Fig. from Hurley et al., Nature, 1999

- Short peak
- Pulsating tails lasting ~ 10^2 s at frequencies 20-600 Hz
  - Non-radial oscillations ?
  - Potential GW emission in the LIGO/Virgo sensitive band

No precise waveform + long lived pulsating tails → suited for PySTAMPAS

Events targeted

3 short GRBs from 2005 and 2007

- Data from initial LIGO (>10 times less sensitive than today)
- GRB 051103 - M81 (3.6 Mpc)
- GRB 070201 - M31 (0.8 Mpc)
- GRB 070222 - M83 (4.6 Mpc)
- *GRB 200415a - NGC 253 (3.3 Mpc) -* ***No LIGO/Virgo data***

➔ Use PySTAMPAS to search for GW candidates in a [-500s +500s] window around each event

➔ Derive upper limits by injecting damped sine waveforms

Results and prospects

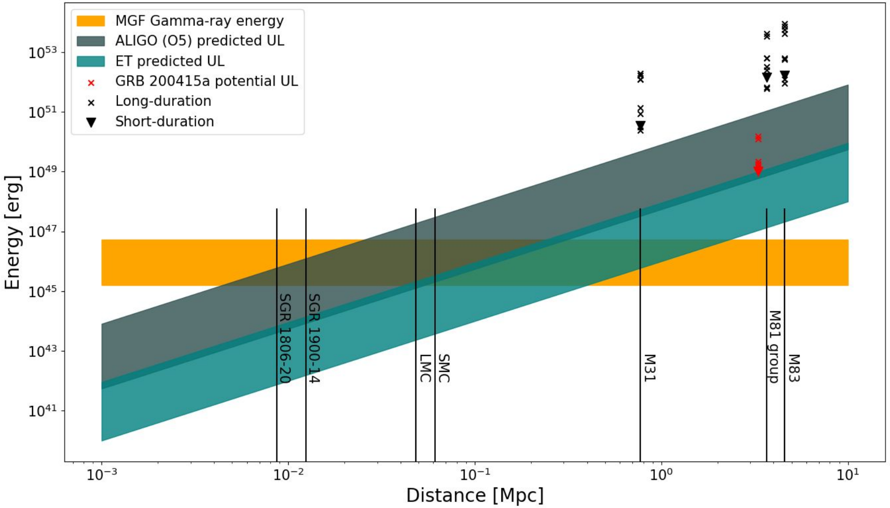


Fig. from Macquet et al., ApJ, 2021

Assume GW energy released ~ fraction of EM energy:

- Upper limits not constraining for 2005/2007 events
- Adv LIGO sensitive to galactic MGFs
- ET sensitive up to 1Mpc
- Less energetic flare also a potential target
- Stochastic background from MGFs?

Conclusion

- Provide a tool to search for weakly modelled GW signals with intermediate to long duration
    - All-sky, “agnostic” searches
    - Targeted searches around specific events
    - Computationally efficient
- Potential candidates in the near future (O4/O5):
    - Long-lived remnant of core-collapse SN (ms magnetar, fallback accretion….)
    - Post-merger signal from close BNS (type of GW170817)
    - Magnetar Giant Flare in the galaxy (3 in 40 years)

Caveats

- Dephasing between detectors due to delay of arrival
  - Unknown sky position and polarization: need to test ~100 values and maximize the total SNR
- Non-Gaussian detector noise
  - Transient noise events ("glitches") and Instrumental lines
  - Define and combine several discriminant variables to differentiate non-Gaussian noise events to real GW signals