QC for gravitational waves

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- GW signals are – typically - deeply embedded in detector noise
- This is true, in particular, for Continuous Waves: still not detected persistent signals emitted e.g. by spinning neutron stars
- Matched filtering, based on the cross-correlation among the data and signal templates, is not computationally feasible for wide parameter searches
- Less sensitive semi-coherent searches have been developed for wide parameter exploration. The analyses are still computationally bound for classical computing. E.g.: Hough and Radon Transforms

❖ The number of waveform templates, needed to cover the searched parameter space (sky, frequency, frequency derivatives), can be estimated as:

$$N_{\rm tot} = 10^{-8}\pi \frac{T_{\rm obs}^8}{\Delta t^5 \tau_{\rm min}^3} = 1.33 \times 10^{29} \left(\frac{T_{\rm obs}}{4\ \text{months}}\right)^8 \left(\frac{0.001\text{s}}{\Delta t}\right)^5 \left(\frac{10^4\ \text{years}}{\tau_{\rm min}}\right)^3$$

total observation time

sampling time

minimum spin-down decay time

(for full coherent searches, i.e. matched filtering)

* Waveform made of O(10^6-10^7) samples

$$N_{\rm tot} \approx 5.6\pi \times 10^{-9} K_f K_{\rm sky} \left(\frac{T_{\rm FFT}}{\delta t}\right)^{3+j_{\rm max}} \prod_{j \le j_{\rm max}} \left(\frac{T_{\rm obs}}{\tau_{\rm min}}\right)^j \approx 10^{21}$$

for T_{FFT} =1 day (and the other parameters as in the previous case)

(for a semi-coherent search based on the Hough Transform)

* Image of O(1000 x 1000) pixels

❖ Different frequency ranges can be explored independently (and for semi-coherent searches also different time intervals)

- Quantum Radon (Hough?) Transform
  - Interpolation-based Discretization Radon Transform for line detection (Ma+, arXiv: 2107.05524)
  - Polynomial speed-up w.r.t. classical version
  - Preliminary contacts with the QC theory group in Pavia (Profs. Perinotti, Maccone,…)

- Quantum Matched filter
  - Grover's algorithm (quantum counting) + QFT (Gao+, arXiv: 2109.01535)
  - Speed-up roughly sqrt(N_{sky})
  - Templates can be computed from models: no need for qRAM

- Quantum Machine Learning
  - Classical ML promising for some kinds of GW searches
  - QML promising in the context of NISQ devices

- Quantum Computing could be a game-changer for GW Data Analysis in third generation detectors (namely, Einstein Telescope)

- We expect an increasing interest of the GW experimental community in the next years (in Virgo initial trigger by Prof. Rapagnani)

- We are beginners in the field, and warmly welcome collaborations with more expert people