Science with 3G detectors: “Extreme gravity and fundamental physics/waveform modeling’

On behalf of the working group

https://github.com/gwic-3g/3g-science-case/blob/master/work-space/xg/XG-WM-report-v1.pdf

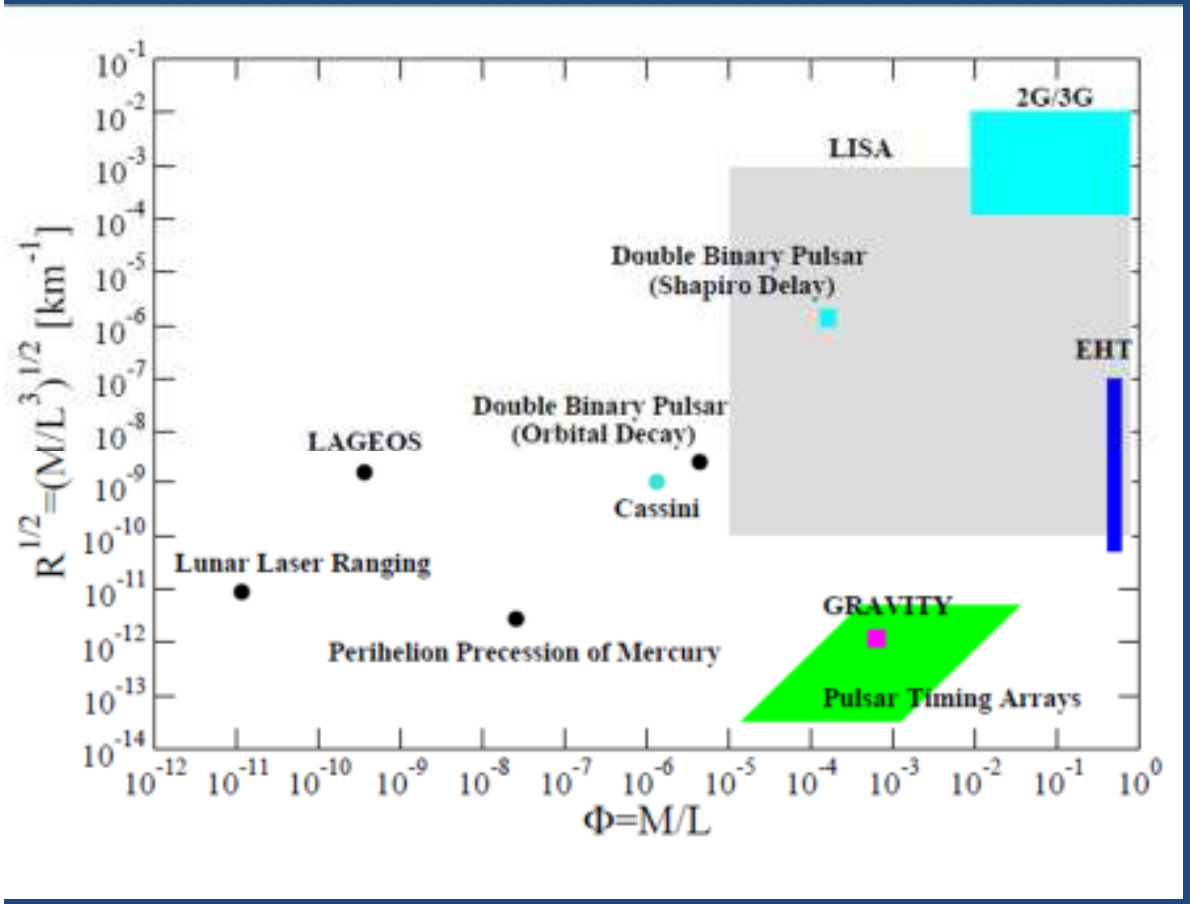
Organization/process

- 4 subgroups with contact persons:
  - Fundamental questions in gravity & particle physics (Chatziioannou & Sotiriou)
  - Extreme matter (Vitale & Yunes)
  - Exotic objects and phenomena (Archisman & Pani)
  - Waveform modeling and data analysis challenges (Ajith & Purrer)
- Preliminary draft by late june
- Co-chairs Buonnano,Lehner & Van den Broeck worked on preliminary draft, reported end of september
- Contributions from further several people, including: Arun, Barausse, Baryakhtar, Brito, Dietrich, East, Gerosa, Harry, Hinderer, Maselli, Pfeiffer, Pratten, Shao, Tamanini, van de Meent, Varma, Vines, Zumalacarregui, Yang, ...

Overarching qns driving the report

- *The nature of gravity*: "Is Einstein (still) right?" [beyond the standards in gravity theory]
- *The nature of dark matter*: aiding in the quest to understand DM through grav waves
- *The nature of compact objects*: [beyond the standards in compact objects]

‘anchor plot’

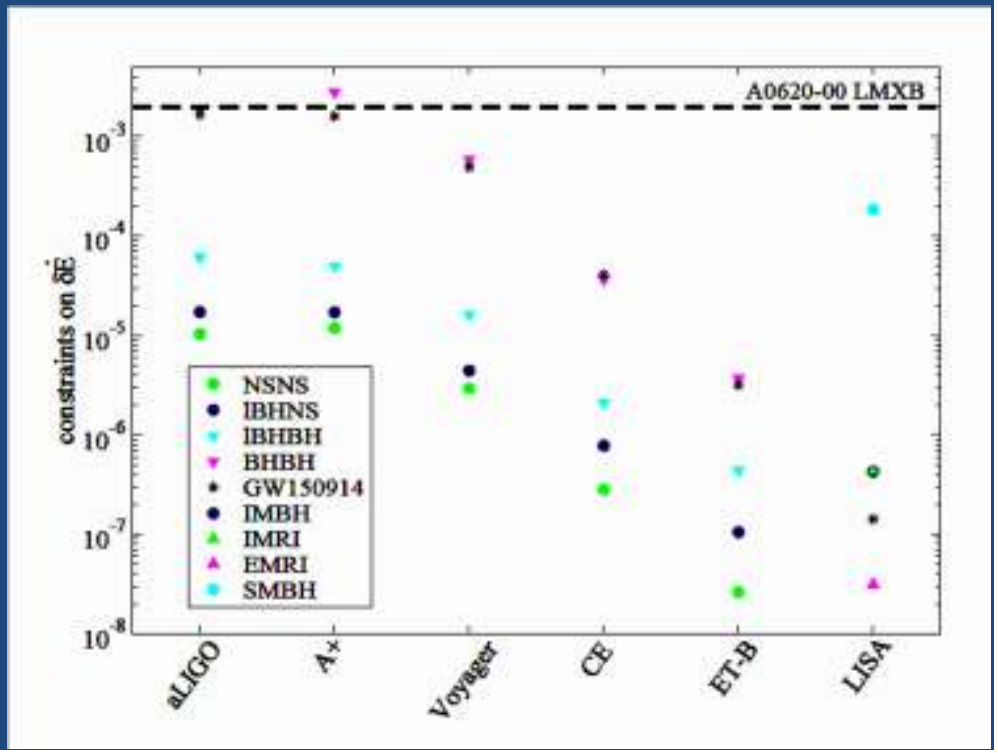


- From a ‘curvature/potential’ point of view 2G/3G detectors arguably probe the strongest limits
- *Barring surprises from nature* these are the ‘shortest scales/highest energies’ we can access precision measurement --as opposed to ‘next scale’ probes-- is what is required to go after new physics

New physics: gravity road

- Beyond null tests/phenom deviation searches, guidance from theory can significantly enhance prospects & interpretation
- Lovelock theorem: departures from GR requires extra degrees of freedom or giving up basic principles.
  - Extra fields
    - additional polarizations

    violation of strong equiv. principle through possible non-minimal couplings of matter & gravity



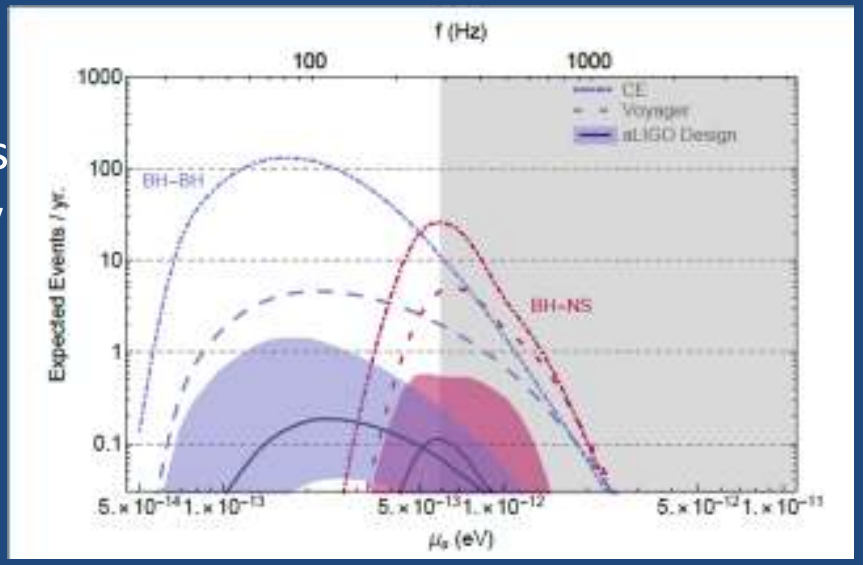
- *Graviton mass*: LIGO/VIRGO bounds can be improved by 2 orders of magnitude thanks to distance reach.

- *Lorentz violations*: 'superluminal propagation' possible and further polarizations.

- *Parity violations*: scalar dipole –> modifies source's quadrupole; birefringence (helicity dependence: one circularly polarized mode is slightly enhanced/other reduced). Expected bounds in 3G slightly stronger than from binary pulsar bounds)

- *Time dependent G, local position invariance*: possible dependence with redshift. 3G ability to go to large redshifts crucial. Estimates of 8th orders of improvements wrt 2G!

- *Extra particles*: particles/fields with suitable Compton wavelengths (e.g. axions) can extract rotational energy from BHs. Up to ~ 10% of 'mass' can be in a cloud around BHs.
  - The cloud can 'decay' emitting rather monochromatic CWS. [few to hundreds events/yr for bosons with 10^{-13}-10^{-12} ev
  - BHs spins driven to smallish values
  - Inspiraling BHs could go through decay thus strongly modifying tidal effects

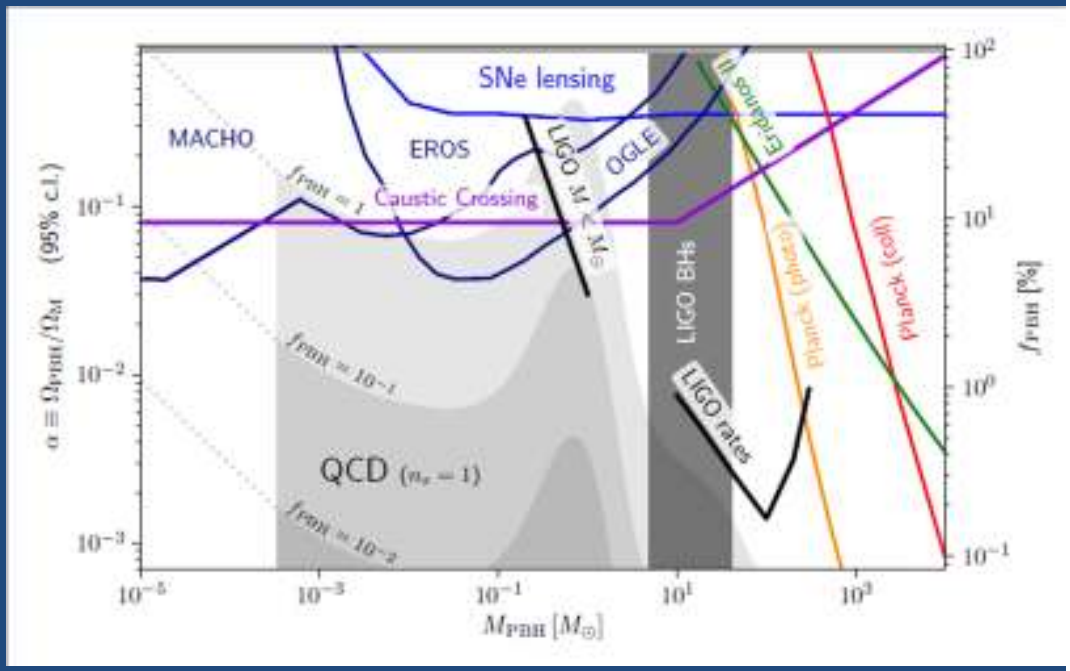


Some challenges identified

- 'simple' extensions: Scalar-Tensor theories explored to some degrees and steps to turn info into templates ongoing
- Other theories largely unexplored
  - In some, BH solutions identified but only a smaller subset QNMs know [e.g. are BHs stable?, QNM spectra?]
  - Most theories are 'sick' from a mathematical point of view, incipient efforts to identify strategies to move forward towards understanding nonlinear regimes
  - … a long way from templates/inform phenomenological modifications of known templates. Which theories and why?

Nature of dark matter

- Current knowledge of dark matter from igravitational effects. GW observations complement laboratory efforts



- DM is PBHs?
  - Even if just a small fraction of DM, distribution would provide clues to behavior of primordial density fluctuations, QCD phase transitions. 3G's ability to see BHs to large redshifts is crucial

- Detecting DM with GWs?
  - DM described by particles/fields in the right mass range can yield GWs/affect inspiral dynamics.
  - binaries evolving in a DM-rich environment will suffer a ‘gravitational drag’ as they accrete DM. The effect is small, but its detection would be possible, at least, in binaries observed both in LISA and 3G
  - DM can be captured in the core of stars and lead to their collapse. In turn, a mechanism to create light BHs in regions of high DM densities

Questions

- What else / anything missing?
- Overlaps?