Stage M2

Contribution to the GW detectors calibration

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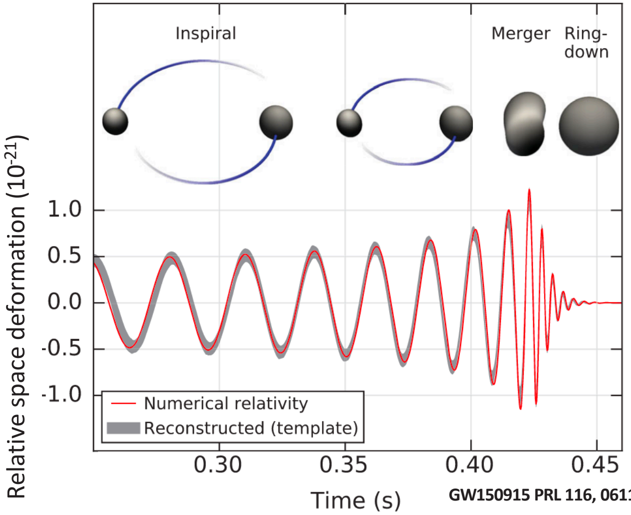
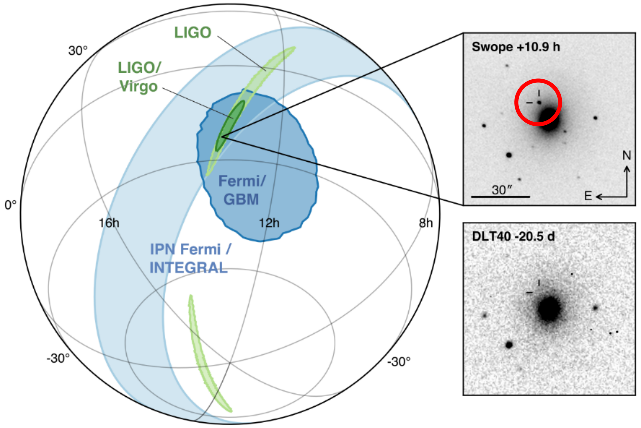
Gravitational Waves (GW): A Blooming Field

The First Signal



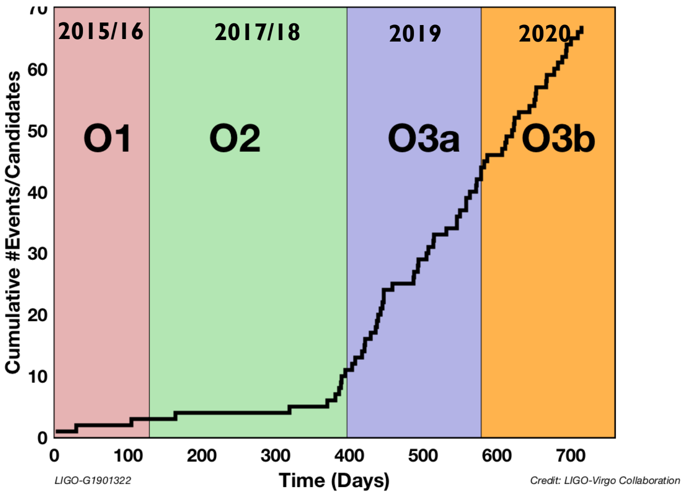
GW150915 PRL 116, 061102 (2016)

The Dawn of Multi-Messenger Physics



GW170817 + GRB170817A + AT 2017gfo

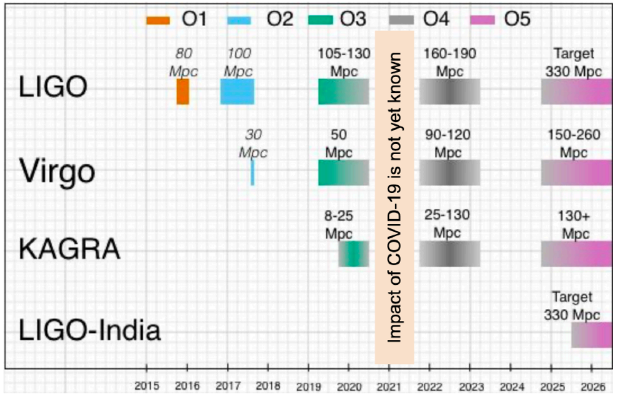
Cumulative Counts of Events

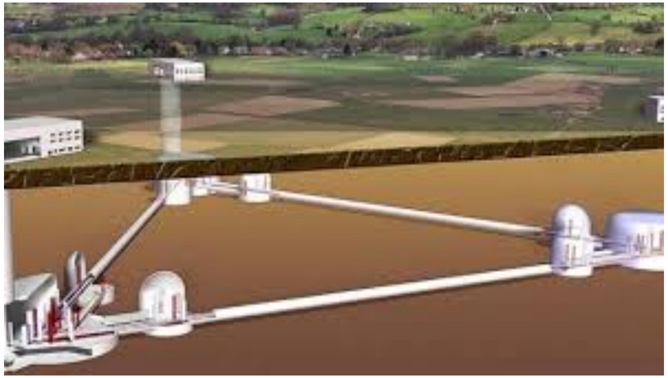


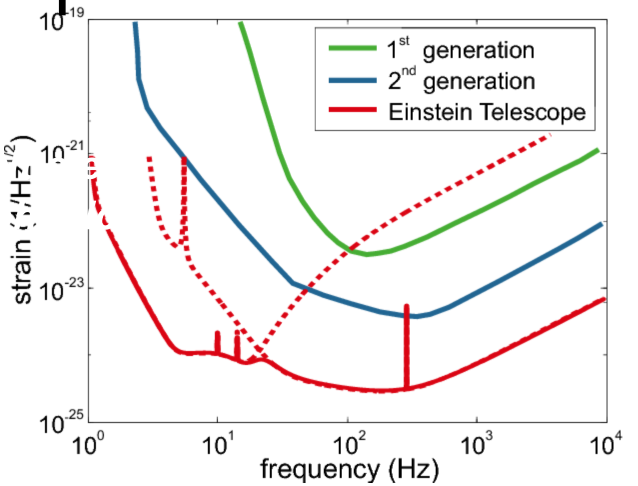
- **2015: First observation of GW: collision of two black holes (BH)**
- **2017: First observation of GW from two Neutron Stars + electromagnetic counterparts**

  2017: Nobel prize for the observation of GW
- **2018: First LIGO-Virgo catalogue: 11 events (O1+O2)**
- **2019-2020: LIGO-Virgo O3 data taking: 56 new candidates released online**

Coming up: AdV+ and then the Einstein Telescope



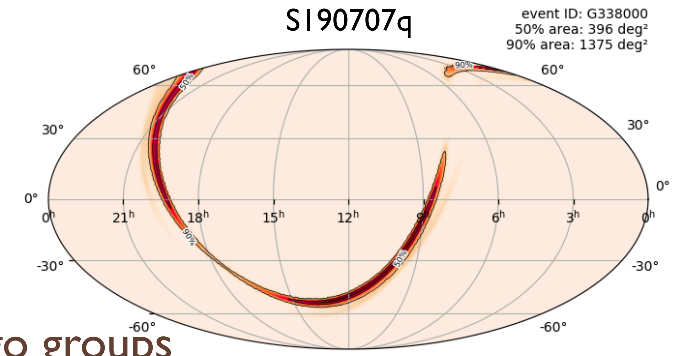




- 2022+: New data takings of Advanced Virgo+ and aLigo 'A+':
  - Volume of space searched increases by up to a factor 50
- 2030+: 3rd Generation: the Einstein Telescope: A new larger facility in Europe
  - Volume of space searched: x1000 → enable a large science program, like:
    - Sense all stellar-mass BH mergers in the visible Universe: the seed for massive BH at center of galaxies?
    - Precision tests of General Relativity in extreme condition (BH): is GR right or do we need new physics?
    - Insight into how the Universe is expanding and evolving: is dark energy just a cosmological constant?
    - Explore the ultra dense matter: how neutron stars tear each other apart before smashing together?

IPHC astroparticules team: Virgo specific activities

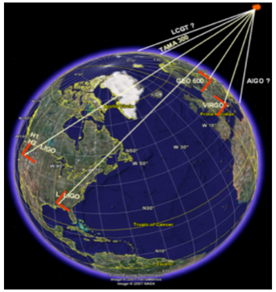
- Search for Compact Binary Coalescence
  - Online search to produce low latency alerts
  - Offline analysis to produce catalogue of event
  - People involved:
    - One Phd student + "half" a postdoc + B.M. + other Virgo groups

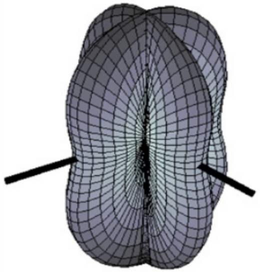


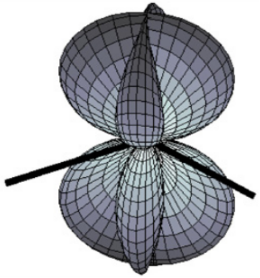
- Calibration: Newtonian calibrator
  - For an accurate detector calibration
  - People involved:
    - "half" a postdoc + T.P., B.M. and technical staff

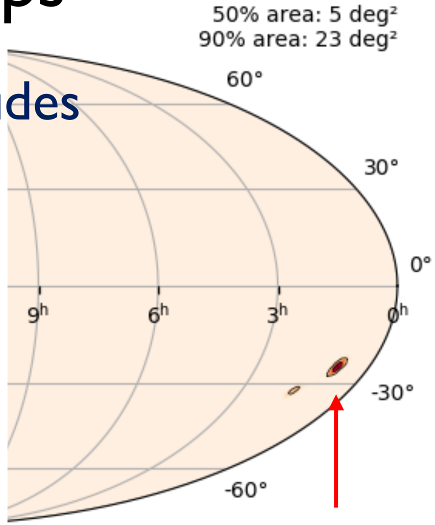
Why an accurate calibration for GW? Sky maps

- Sky maps built using times of flight and relative amplitudes









GW190814: 23+2.6 M

- Need a reconstructed h(t) accurately calibrated in:
  - Time/phase over the full frequency spectrum
    - → Need to target less than 10 us (i.e. 0.3 mrad @ 50 Hz)
  - Amplitude
    - Current SNR up to 20-30
    - Could expect SNR close to 100 within few years and much more with ET
    - → Require sub-percent accuracy
  - + Cross calibration between detectors
- A better calibration will be needed to find weak optical counterparts

Why an accurate GW calibration? Hubble constant

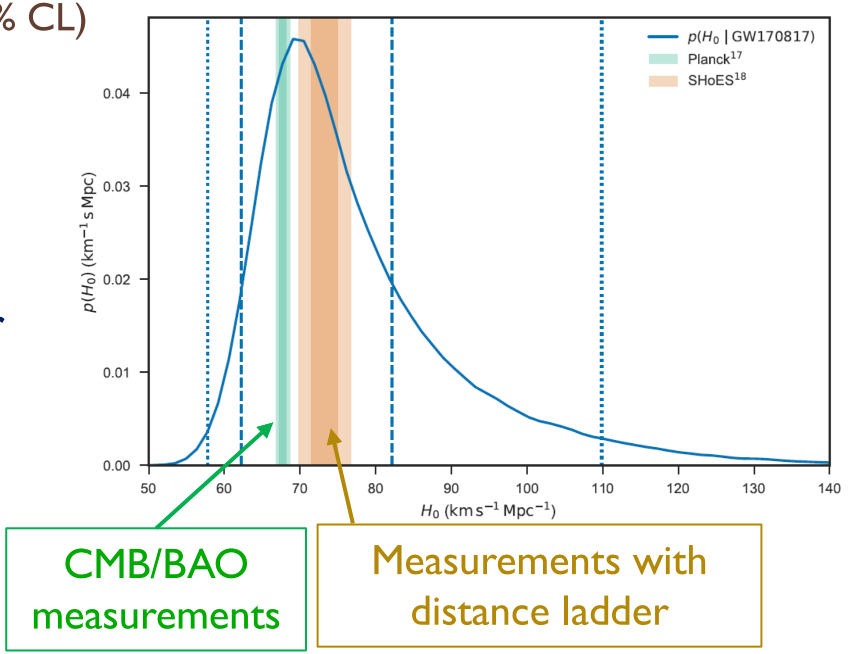
$$v_H = H_0 d$$

Hubble flow velocity from host galaxy NGC4993

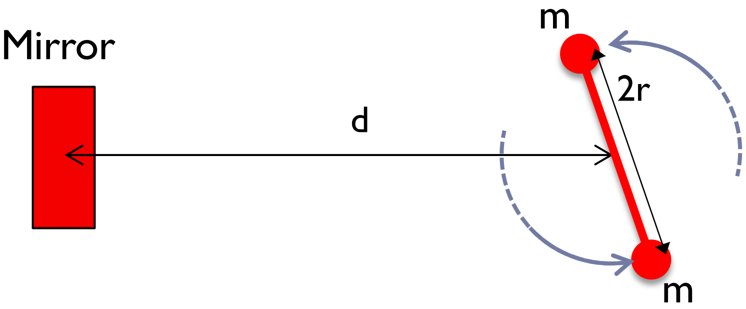
Distance from GW

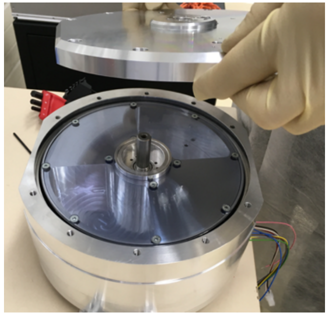
- Measuring the Hubble Constant with GW:
  - GW170817 – AT2017gfo
    - GW only; d $=40^{+8}_{-14}$ Mpc (90% CL)
    - Using sky position of AT2017gfo: d = $43.8^{+2.9}_{-6.9}$ (68% CL)
    - → H_O = 70.0 +12.0 -8.0 km/s/Mpc
    - Could be improved with radio counterpart info:
      - H_O = 72.4 +7.9 -7.3 km/s/Mpc
  - Statistical measurement with BBH possible

- Error on h(t) calibration translate to H_0 error
  - Will become dominant with the coming up runs
    - More events, at larger distances
    - → Systematic take over statistical errors
    - Need to target sub-percent accuracy



Virgo Newtonian Calibrator (NCal)





- Principle: inject a know mirror displacement and validate/correct h(t).
- Basic NCal model: rotor made of two masses
  - The non linear Newtonian force creates the signal; signal at twice the rotor frequency; $1/d^4$ effect
- Expected benefits
  - Signal depends mostly on the rotor geometry and position
  - No aging effect of the signal
  - Simple interface with the interferometer: could be moved to LIGO or KAGRA
- Challenges
  - Well known geometry and mass
  - Able to rotate at few hundred Hz (10k-20k RPM), for years "Without" extra noise

The internship: Contribution to the GW detectors calibration

- Proposed work for this internship
  - Study the effect of the NCal metrology on the detector calibration
    - What's the impact of position and NCal geometry errors?
    - How could we measure the NCal positions?
      - (will depend on the technical progress made)
  - Relative calibration of LIGO Virgo using Binary Black Hole events
    - Either already observed and with the upcoming observation
- A good start to continue with a PhD

GW190412