GWADW2019 summary

with contests and prizes

Livia Conti

INFN Padova
International Advisory Committee

F. Fidecaro (Pisa), Co-chair
S. Meshkov (Caltech), Co-chair
R. Adhikari (Caltech)
M. Ando (Tokyo)
S. Ballmer (Syracuse)
M. Barsuglia (APC)
G. Cagnoli (LMA)
D. Coyne (Caltech)
M. Evans (MIT)
S. Fairhurst (Cardiff)
A. Freise (Birmingham)
G. Hammond (Glasgow)
J. Harms (GSSI)
S. Hild (Glasgow)
S. Kawamura (Nagoya)
K. Kokeyama (Tokyo)
A. Lazzarini (Caltech)
H. Lueck (AEI)
E. Majorana (INFN - Roma)
D. McClelland (ANU)
C. Miller (Maryland)
M. Punturo (Perugia)
D. Reitze (Caltech)
B. Sathyaprakash (Penn State)
R. Schnabel (Hamburg)
J. Van den Brand (NIKHEF)
S. Vitale (MIT)
R. Ward (ANU)
B. Willke (AEI)

28 males, 1 female
Disclaimer

- The following reflects only my personal views of the conference.
- Talks were all interesting
- For each talk\(^{(1)}\) I selected the slide which I found most significant or representative.
- For parallel sessions I could only attend some of the talks

\(^{(1)}\) only talks which slides were uploaded in the indico page in time
Mo AM 1: Science for 3G Multi-messenger
Convener: Marica Branchesi (GSSI)
Take-home message

- multimessenger aspects play a key role in the present and future of GW astronomy should be given full consideration in planning 3G detectors

3G era - multimessenger perspective

- **NSNS/NSBH** - from single event investigation to large statistical analysis compact binary population, SGRBs, nucleosynthesis, ..

- great opportunities for yet undetected sources
  - increased potential to fully understand GW emission from **galactic SNe** (but not increased event rates)
  - much better prospects to detect continuous GW signals from **isolated and accreting NSs** and GW transients from **bursting/glitching NSs**
The contribution of EM searches

- We are very confident that we do not miss any SN event within 10-20 Mpc
- BUT: SN event timing becomes crucial
- A reverse approach: the EM transient triggers an a-posteriori, targeted search for the GW signal in the interferometric data.
- The ET era will greatly enhance this business.
- That is the area where we (meaning EW people) should work.
- Requires a higher coordination level: not yet there.
- LSST era: see talk by A. Palmese
Mo. AM1
Gravitational wave cosmology with large galaxy surveys
Speaker: Antonella Palmese (Fermilab)
Mo AM 2: Science for 3G
Conveners: Katerina Chatziioannou (Flatiron), Salvo Vitale (LIGO MIT), Yuri Levin (Flatiron)
Mo.AM2
Low frequency and populations
Speaker: Salvo Vitale (LIGO MIT)
The 3G Landscape

- Seed Black Holes
- Compact Binaries
- Multi-Messenger Observations
- Extreme Gravity
- Neutron Stars
- Cosmology
- Supernovae
- Waveform Models
- Detector Networks

Inspired by Vicky and Sathy
Low vs high frequencies


Mo.AM2
Fundamental physics with 3G detectors
Speaker: Thomas Sotiriou (University of Nottingham)
Mo PM 3:
Upgrades to present facilities
Convener: Stefan Ballmer
(Syracuse University)
AdV+ project is divided into 2 phases

- Phase I
  - 40-50W input power
  - signal recycling mirror
  - Newtonian noise cancellation
  - frequency depend squeezing
  - preparatory work for phase II

- Phase II
  - large mirrors implementation

---

Mo.PM3
AdV+
Speaker: Jerome Degallaix (Laboratoire des Matériaux Avancés - CNRS)
A+ Enhancements

- Improved Coatings
- Frequency Dependent Squeezing
- Boosted Optical Efficiency for Deeper Squeezing
  - High-efficiency Faraday isolators
  - Adaptive Wavefront Control (US/Australia)
- Balanced Homodyne Readout (UK)
  - Several improvements, SRC control, backscatter (see G1800459)
- Enlarged Beamsplitter and Suspension (UK)
- Improved Suspension Fibers (UK)
  - see G1900942
Sensitivity

- No plans for competitive sensitivities
- In 2015, we decided to NOT pursue this route ->
  - or any other major sensitivity upgrades
- Pursuing technologies applicable to high frequency sensitivity
Four upgrades examples

1. Low frequency
2. High frequency
3. 40kg test masses
4. Freq. dependent squeezing

---

Figure 48: Sensitivity curves for bKAGRA and upgrade candidates. Sensitivity curves for Advanced LIGO (aLIGO), A+ and bKAGRA are shown for comparison [464].
Mo PM 4: Newtonian Noise
Convener: Jenne Driggers (Caltech)
Newtonian Noise

Mo.PM4
NN cancellation in underground GW detectors
Speaker: Francesca Badaracco (GSSI)

Infrasound NN cancellation
Speaker: Donatella Fiorucci (CNRS)

Seismic metamaterials and their applications to reducing Newtonian Noise
Speaker: Dr Brittany Kamai (Caltech)

ET seismic NN estimation
Speaker: Jan Harms (GSGC)
Water flow and waves are both too slow for (1) – (3) to matter (exponential cut-off at very low frequencies), even if the water flows closely to the test mass.

Perturbation produced by vortices and other structures included in (4) – (6) in the NN band are supported by small water volumes and associated NN is very likely insignificant, but one should look at this more carefully.
Tu AM 1:
Thermal Noise
Conveners: Bram Slagmolen (The Australian National University), Stuart Reid (University of the West of Scotland)
Summary

- Building blocks + staffing established over first 18 months
  - deposition tools
    CSU, UCB, UH, Strathclyde, Sannio, Montreal, LL
  - characterization tools
    high throughput RT mechanical loss: Caltech, Syracuse
    additional cryo loss tools: SU, U Glasgow
  - computational tools: SU, UF
    scattering data -> structures
    structure-property relations
  - fabrication concepts
    high-T deposition
    doping suppression of crystallization
    nano-layer suppression of crystallization
- Further connections emerging between theory and exp’t
- Design concepts tested
  - multi-material coatings
- Using theory to direct experimental choices
The **Urbach energy** is a parameter which quantifies the homogeneity of the structure by absorption investigation, probing a multi-range structural organization. **Annealing and doping** modify the structure leading to a more organized/homogeneous atomic dispositions, reducing the mechanical loss angle.

![Graph](image-url)

Amato et al 2019
arXiv:1903.06094
1. KAGRA+ thermal noise
   Thermal noise itself in white paper does not matter.
   Kazuhiro’s comment: Smaller absorption mirror or higher thermal conductivity sapphire fibers are necessary to simplify assembly.

2. Thermo-optic noise
   Thermal noise interferometers can give constrain on $\alpha$ and $\beta$ of coating, which are important parameters to evaluate thermo-optic noise.
   At room (cryogenic) temperature, thermo-optic noise could be an issue in near future (is not problem at all).
Tu.AM1
Thermal noise in 3G instruments

Speaker: Harald Lueck (AEI Hannover (MPI f. gravitational Physics / Inst. f. Grav.physics Leibniz Uni Hannover))
Tu AM 2:
Upgrades to Current Facilities
Convener: Stefan Ballmer
(Syracuse University)
Current squeezing performance

- About 4.5 dB of squeezing (and 15 dB of anti-squeezing) down to ~30 kHz
The UK-India collaborative efforts - the Newton Bhabha project

Speaker: Mariela Masso Reid

Work packages

Five research themes and one management theme have been identified this time.

PI of Project: Hammond (UK) / Raychaudhury (India)

- WP1: Project management (Hammond, Raychaudhury + representatives from all Institutes)
- WP2: Data analysis and Modelling (Heng, Andersson, Sutton, Raychaudhury)
- WP3: Low thermal noise coatings and suspensions (Reid, Hammond, Rajalakshmi, Prabhakar, Raman)
- WP4: Interferometer modelling & simulation (Daw, Rapol)
- WP5: Entrepreneurial Activities (Gibson, Raychaudhury, Indian Trade Embassy representatives)
- WP6: Outreach Activities (Vecchio, Souradeep)

Objectives delivered through research exchanges, industrial engagement, educational initiatives and outreach activities.
Science goals

- Low phase noise interferometry with cryogenic silicon mirrors of up to ~100kg
- Providing a flexible testbed to explore various combinations of cryogenic temperatures and laser wavelength
- Investigating the interplay of thermal noise, quantum noise and control noises in the sub 10Hz region
- Various tests of cryogenic issues (liquids vs cryo-coolers; stable control of mirror temperature; contamination handling of mirror surfaces; low power actuators ...)
- Testbed for new control techniques and sensors
- Seismic Attenuation System (AEI-SAS)
  - Suspension platform interferometer (SPI)
  - Optical levers
- Pre-Stabilised Laser
  - Power stabilisation (aLIGO style PD array)
  - Frequency stabilisation (10 m suspended reference cavity)
- Single Arm Test
  - 100 g pilot optics (wire suspension)
- Control and Data System (CDS)
Tu PM 3: Space technology for the future
Convener: Seiji Kawamura (Nagoya University)
From LPF to LISA

- In LISA all the TMs will be drag-free along their x-axis.
- Force gradients and Tilt-To-Length (TTL) need to be calibrated.
- Inertial forces in LISA could enter the signal through actuation crosstalk.
- Force glitches need to be understood both as instrumental origin that for discrimination techniques.
- TDI mixes many signals and introduces correlations that makes even instrument noise characterization non trivial.

Tu.PM3
From LISA Pathfinder to LISA, a gravitational waves space-based observatory
Speaker: Daniele Vetrugno (Istituto Nazionale di Fisica Nucleare)
Study Office Near-term Goals

- Develop “menu” of possible NASA contributions
  - Payload systems and subelements (req. tech development)
  - Spacecraft components
  - Ground segment contributions
  - Operations contributions
  - Science support
  - ...

- Assess each contribution
  - Compatibility with partners/ease of interface
  - US interest
  - NASA capabilities
  - Cost

- Work with NASA HQ, ESA, Consortium to consolidate final roles and responsibilities

John W. Conklin, GWADW, Elba, ITALY, 20 April 2019
The Japanese space gravitational wave detector DECIGO/B-DECIGO
Speaker: Mitsuru Musha (Institute for Laser Science, University of Electro-communications)
Conclusions

A robust method of charge management using photoelectrons with the following advantages:

- Infrequent or no charge measurement
- Precise timing of UV illumination not required
- Power stability of UV source not critical
- No need for the accurate determination of the UV illuminated surface properties  
  - Quantum efficiency
  - Angle dependence of photoemission
  - Reflectivity
- No precise processing or maintenance of the UV illuminated surfaces required
- Simple in-flight fine-tuning of system for unforeseen changes

The PCM method relies upon the:

- Stability of the surface properties of materials (after aging)
- Straightforward biasing by either dc bias sleeves/plates or AC modulation of the UV-LEDs
We AM 1,2 A: Thermal Noise and Coatings
Convener1: Riccardo Bassiri (Stanford University)
Convener2: Gianpietro Cagnoli (University of Lyon)
Conclusions and Open Questions

- Are low TLS in ultrastable a-Si (and IMC) the “exception that proves the rule” of universal low T glass properties? Or, is there a new rule – “universal glass properties” at low T are perhaps due to the universal nature of liquid quenching and domain growth/correlation length growth/boundaries?
- Is low TLS related to growth near $T_K$? (If (and only if) surface mobility during growth is high). Fragile glasses have $T_K$ near $T_g$, where mobility is high, so low TLS would be correlated with fragility.
- Or is low TLS related to nature of bonding: overconstrained (tetrahedral Si) versus underconstrained e.g. Si-O-Si bonds in a-SiO$_2$ and TLS in a-Si due to nanovoids.
- Silica, alumina show increased density and reduced loss at low T with increased $T_{growth}$; not as much as a-Si, but not yet at $T_{growth} = 0.8 T_g$.
- Tantalum shows reduced losses at low T with increased growth $T$; not as much as a-Si, and likely at $T_{growth} = 0.8 T_g$; annealing big effects, $T_{growth}$ not stabilizing structure.
- Low losses at room temperature in all are not well correlated with low losses at low T.
- Route to low room T losses is to find a material like a-SiO$_2$ with strong well formed bonds in liquid state (i.e. strong glass) and moderately high $T_g$.
- Route to low low T losses is fragile glass with moderate $T_g$ and suppress crystallization.

We.AM1a
Two Level Systems and Ultrastable Glasses
Speaker: Frances Hellman (UC Berkeley)
We.AM1a
Mechanical Loss Calculations
Speaker: Francesco Puosi (University of Pisa and INFN Pisa)

Molecular Dynamics – Mechanical Spectroscopy (MD-MS)

Unilateral tensile oscillatory deformation

Apply a sinusoidal strain $\gamma(t)$ with selected frequency along one direction

Strain amplitude in the linear elastic regime

Storage and loss moduli

\[ E' = \frac{\omega}{N\pi} \int_0^{N2\pi/\omega} \sin(\omega t) \frac{\Sigma(t)}{\gamma_0} \, dt \]

\[ E'' = \frac{\omega}{N\pi} \int_0^{N2\pi/\omega} \cos(\omega t) \frac{\Sigma(t)}{\gamma_0} \, dt \]

Dissipation

\[ Q^{-1} = \tan \delta = \frac{E''}{E'} \]
### Crystalline Coatings

**Speaker:** Stuart Reid (SUPA, University of Strathclyde)

#### MBE

<table>
<thead>
<tr>
<th>Material</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlGaAs</td>
<td>Developed technology ✓, Optical performance ✓, Grown on GaAs wafers X, Requires transfer X</td>
</tr>
<tr>
<td>AlGaP</td>
<td>Mechanical loss ✓, Lattice matched to silicon ✓, Not well-developed X, Optical properties X, Growing on 200kg scale optics X</td>
</tr>
<tr>
<td>Others?!?!</td>
<td>AlGaN Growth on Al2O3, GaN or AlN.</td>
</tr>
</tbody>
</table>

**Issues of quality of films on Al2O3:**

#### Common challenges:

- electro-optic and piezoelectric effects (initial discussion Abernathy T1400726)
- scaling (Cole estimated ~$40M for GaAs substrate + MBE + bonding tool)
- Mechanical loss at RT on crystalline substrates
- Scatter and absorption evaluation, effect of defect, large area
- Who is doing the work? (how much will industry drive, how much do we need to do)?


---

L. Conti - GWADW2019
We.AM2a
Alloys, nanolayers and multi-material coatings
Speaker: Slawek Gras (MIT)
We PM 3 B:
kHz detection
Convener: Denis Martynov
(University of Birmingham)
Finding the state-space rep for transfer func.

1. Identify desired transfer function (freq. domain)
2. Find a state-space representation (time domain)
3. Find the physically realizable one

Example: tuned cavity
\[ G(i\omega) = \frac{i\omega - \gamma}{i\omega + \gamma} \]
\[ \dot{x} = A\bar{x} + B\bar{u} \]
\[ \bar{y} = C\bar{x} + D\bar{u} \]

No unique mapping from \( G \) to \( (A, B, C, D) \)!

Need to ensure that
\[ d[x_i, x_j] = 0 \text{ Constrains (A, B, C, D)} \]
Th AM 1:
Squeezing, Topology, Quantum Information
Convener: Haixing Miao (University of Birmingham)
Th.AM1
Squeezing status from LIGO & VIRGO
Speakers: Fiodor Sorrentino (GE), Haocun Yu

- Red trace: BLRMS strain noise in 2.6+3.1 kHz: 3.25 dB squeezing dB anti-squeezing
- Blue trace: BLRMS strain noise in 20÷30 Hz: evidence of RPN?
- Need to keep injected squeezing at moderate level in O3

L. Conti - GWADW2019
Th.AM1
Einstein-Podolsky-Rosen (EPR) squeezing experiments from ANU & Hamburg
Speakers: Jan Gniesmer (University of Hamburg), Min Jet Yap (Australian National University)
Optomechanical (ponderomotive) squeezing at room temperature
Thomas Corbitt (LSU)
GWADW 2019
N. Aggarwal, T. Cullen, J. Cripe, G. D. Cole, R. Lanza, A. Libson, D. Follman, P. Heu,

Image: Elsa Hahne, LSU.

Th.AM1
Optomechanical squeezing experiment at LSU
Speaker: Thomas Corbitt (LSU)
Current status

- Chip design being finalised
- Ongoing study on coupled cavity control (modelling+experiment)
- First aLIGO CDS standalone rack built in Birmingham
- Practising optomechanics with the existing chip
- Design of the experimental layout ongoing
Th AM 2: 3G Light Sources and Optics
Convener: Benno Willke (Albert Einstein Institute Hannover)
Th.AM2
Fiber amplifiers for 3G GWDs
Speaker: Michael Steinke
Diode-pumped MO: 50mW, compact

- Pump using 450mW 1.55μm single-mode fiber-coupled diode laser
- Single longitudinal mode, linewidth < 100 kHz
- Output power 70mW max, limited by pump power
- Pump-power dependent frequency tuning of 620 kHz/mA (bandwidth?)

---

Th.AM2
Tm: Fiber lasers and optical absorption at 2um
Speaker: Peter Veitch (University of Adelaide)
Squeezing results

- Typical squeezer experiment ~10 mrad RMS phase noise
- Currently, < 50 mrad RMS


OzGrav

Th.AM2
Squeezed light at 2 um
Speaker: Vaishali Adya (Australian National University)
First Results: OPO Wavelength Tuning

- measured OPO output spectra for different temperatures of the nonlinear crystal
- degeneracy reached at around 70°C (higher than expected, needed some redesign of our OPO to reach those temperatures)

Bruker Equinox 55 FT-IR Spectrometer (picture from UWLAX, ours looks similar)
Th PM 3: Commissioning 2G
Convener: Viviana Fafone (ROMA2)
Livingston Noise Budget

Bravo!

Th.PM3
LIGO
Speaker: Jenne Driggers (Caltech)
Conclusions

• Commissioning (sensitivity) progresses happen in jumps;
• Efficiency is made of several ingredients (non exhaustive list):
  • Person power – not necessarily on site;
  • Ahead planning – that will be updated in time;
  • Flexibility – issues or new needs must be considered on the fly.
• Collaborations are incredibly rich reservoirs of knowledge!
• One last point:
  • Commissioning teams should meet more often;
  • Last workshop was in 2017 in KAGRA;
  • What about a workshop at every LVC meeting?

In the end, everything will be fine,
If not, it means it is not the end yet.
Our current focus: Commissioning of both arms is now on-going (feedback to test mass)

- All of the main mirrors installed
- 3 TMs are now ~ 20K

X arm comm. - 2019 Jan
Th PM 4:
Backscatter Modeling/Interferometer Simulation
Convener: Andreas Freise
(University of Birmingham)
Comparing to LISO

- LISO files in Zero can be compared to LISO automatically
  - `zero liso my-circuit.fil --compare`
  - Runs LISO directly and overlays results to Zero
- Automatic tests against hundreds of LISO files identical within $10^{-5}$ relative/absolute tolerance
Conclusion

- Stray-light is an old enemy of GW interferometric antennas
  - It comes from a diversity of possible defects
  - It can probe seismically excited mechanical structures and recombine with the ITF main beam burying GW signals
  - It is difficult to simulate
  - It is inherently non-linear

- Despite huge efforts, it threatens the achievement of design sensitivity, in particular at low frequency
- Further advances in prediction, mitigation and monitoring are needed
- New materials with lower BRDF are to be explored for 3rd gen, and possibly chose a site that is...

Th.PM4
Scattered light in Virgo
Speaker: Francesco Fidecaro (PI)
Conclusions

- Still useful to use analytic calculation to search parameter spaces, find solutions
- Useful to check all cases of chosen realization through simulation
  - Need tools to help here
- Diffuse scatter more a geometric problem, but plucks into optical sensitivities (determinable through incoherent simulation)
  - Is diffuse modeling fully separable?
  - Backscatter not separable, but also less geometric.
  - Specular scatter geometric, is it separably modellable
- (squeezed) shotnoise-limited field sensitivity sufficient for output backscatter calculations
  - Radiation Pressure effect “ignorable” (must use worst case)
  - (but does not relax reqs. W.R.T. SN.)
- Unmodelled sensing noise isn’t necessarily a scatter problem, but (more total) controls modeling may prevent design flaws.
  - Want to drive this point for future ASC design
Better Baffles: Helical

- Reflections on a helical baffle send light in an infinite helical path along the beam pipe, which is always hidden from the mirrors.
- Light is effectively totally absorbed without a chance of scattering towards the mirrors.
- This removes the requirement that the pipe surfaces are dark.
- Spiral baffles also do not need to be dark.
- Shiny hydrophobic surfaces can be implemented
  - To reduce surface scattering on the baffles themselves
  - To reduce the vacuum water load in the pipe, the bake-out requirements and its costs.
Fr AM 1: Errors Not To Be Made Again
Convener: Harald Lueck (AEI Hannover (MPI f. gravitational Physics / Inst. f. Grav.physic Leibniz Uni Hannover))

L. Conti - GWADW2019
The beauty of hindsight: a discussion of Mis-steps in KAGRA

Speaker: Tomotada Akutsu (National Astronomical Observatory of Japan)

The tunnel

- The tunnel has a dead-end at the end of the X-arm; not escappable.
- The number of portable air tanks (respirators) are limited.
- The volume of the tank would not be sufficient for 3-km running; usable for only 10-min walking, 5-min running. (ref: I take 12 mins by E-assisted bike + walk.)
Fr.AM1
The beauty of hindsight: a discussion of Mis-steps in LIGO
Speaker: David Shoemaker (MIT LIGO)
Fr AM 2: Future Detectors and New Infrastructures
Convener: Stefan Hild (University of Glasgow)
ET: challenging project roadmap

• 2018-2019 Form the ET collaboration
• 2019-2020 ESFRI roadmap
  • Light TDR to be realised, refine CDR cost evaluation, key options to be selected, ESFRI proposal
• 2022 Site Selection
  • Technical/political activity
  • Requirements need to be compared with the site characteristics through an intense experimental activity in the next 3 years
• 2023 Full Technical Design Report
  • Cost definition
• 2025 Infrastructure realization start (excavation, ....)
• 2030 -2031 end of infrastructure construction, beginning of installation
• 2032+: installation / commissioning / operation
Current Plans – A CE Centric View

**Cosmic Explorer Stage 1**
- Facility engineering design & Detector design
- Construction & Commissioning

**Cosmic Explorer Stage 2**
- Observations & Operations
- Installation & Commissioning
- Observations & Operations

**Stage 1 R&D**
- seismic isolation improvements
- larger test masses & suspensions
- squeezing improvements

**Stage 2 R&D**
- coatings for new wavelength
- interferometer prototype testing
- cryogenics
- large silicon test masses & coatings
- high-power laser
- high-efficiency photodetectors

- 2020
- 2022
- 2024
- 2026
- 2028
- 2030
- 2032
- 2034
- 2036
- 2038
- 2040
- 2042
- 2044
- 2046

Fr.AM2
Cosmic Explorer
Speaker: Matthew Evans (MIT)
Fr PM 3:
Beyond GW IFO
Conveners: Fiodor Sorrentino (GE), Matteo Barsuglia (APC-CNRS)
Fr.PM3
The search for gravitational-waves from white dwarf binaries in gravimetric and seismic data using Earth’s normal modes resonance response in the mHz frequency band
Speaker: Josipa Majstorovic
Fr.PM3
Status of TORPEDO torsion bar
Speaker: Bram Slagmolen (The Australian National University)
Readout Scheme

Coupled-cavity wave front sensor (new idea)

Compensate Gouy phase by auxiliary cavity
- HG10 mode resonates as well as HG00
- Induced HG10 is enhanced
- Higher sensitivity than normal WFS
  \[ 5 \times 10^{-16} \text{ rad/\sqrt{Hz}} @ 0.1 \text{ Hz} \]

Optical configuration →
AND THE WINNER IS...