Ground-based Gravitational-wave Detectors: Prospects for the Future

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For the LIGO Scientific Collaboration and Virgo Collaboration

Image Credit: Aurore Simmonet, Sonoma State
The Next Hour

- Primer on Gravitational-wave Detectors
- Advanced LIGO: Current Status
- Advanced LIGO: Near Term Prospects
- Beyond Advanced LIGO: The ‘A+’ Upgrade
- Probing the Horizons of the Gravitational-wave Universe: Voyager & Cosmic Explorer
The Advanced LIGO Interferometer

- Advanced LIGO uses enhanced Michelson interferometry
  - suspended (‘freely falling’) mirrors

- Passing GWs stretch and compress the distance between the end test mass and the beamsplitter

- The interferometer acts as a transducer, turning GWs into photocurrent
  - A coherent detector

\[ h(f) = \frac{\Delta L}{L}(f) \]

LIGO Layout and Nomenclature

**IMC** – Input mode Cleaner
**PRM** – Power Recycling Mirror
**PRC** – Power Recycling Cavity
**BS** – Beam Splitter
**MIC** – Michelson Interferometer formed by BS and ITMs
**FI** – Faraday Isolator

**DARM** = $L_x - L_y$
**CARM** = $L_x + L_y$
**MICH** = $l_x - l_y$
**PRCL** = $l_p + (l_x + l_y)/2$
**SRCL** = $l_s + (l_x + l_y)/2$

**ETM** – End Test Mass
**ITM** – Input Test Mass
**ERM** – End Reaction Mass
**CP** – Compensation Plate
**SRM** – Signal Recycling Mirror
**SRC** – Signal Recycling Cavity

**HWS** – Hartmann Wavefront Sensor
**OMC** – Output Mode Cleaner
**DARM** – Difference between Arm Length: $L_x - L_y$
**LIGO Layout and Nomenclature**

**IMC** – Input mode Cleaner  
**PRM** – Power Recycling Mirror  
**PRC** – Power Recycling Cavity  
**BS** – Beam Splitter  
**MIC**H – Michelson Interferometer  
formed by BS and ITMs  
**FI** – Faraday Isolator

**HWS** – Hartmann Wavefront Sensor  
**OMC** – Output Mode Cleaner

**DARM** – Difference between Arm Length: Lx-Ly

**ETM** – End Test Mass  
**ITM** – Input Test Mass  
**ERM** – End Reaction Mass  
**SRM** – Signal Recycling Mirror  
**SRC** – Signal Recycling Cavity

**DARM** = Lx - Ly  
**CAHM** = Lx + Ly  
**MIC**H = lx - ly  
**PRCL** = lp + (lx + ly)/2  
**SRCL** = ls + (lx + ly)/2
Advanced LIGO ‘Test Mass’ Mirrors

- **Truly the ‘crown jewels’ of the detector**
- **Physical specifications:**
  - Ultra-pure, ultra-homogeneous fused silica
  - 340 mm diameter, 200 mm thick, 40 kg mass
- **Surface figure:** super-polish followed by ion beam ‘spot’ polish
  - < 0.15 nm RMS deviation from sphere
- **Coatings:** TiO$_2$-doped Ta$_2$O$_5$/SiO$_2$
  - Reflectivity depends upon type of mirror
  - Ultralow absorption (< 0.5 ppm)
Advanced LIGO Suspensions: A Tour-de-Force in Engineering

Concept:

\[ m \ddot{x} = -k(x - X) - \gamma (\dot{x} - \dot{X}) \]
\[ \left( \omega_0^2 + \frac{i \gamma \omega}{m} - \omega^2 \right) \ddot{x} = \left( \omega_0^2 + \frac{i \gamma \omega}{m} \right) \dot{X} \]
\[ \ddot{x} = \frac{\omega_0^2}{\omega_0^2 + \frac{i \gamma \omega}{m} - \omega^2} \dot{X} \]

Implementation:

Upper ‘ear’  Lower ‘ear’
Advanced LIGO: Current Status
H1, L1 Uptime Dashboard

Hanford H1 operating mode overview
[1164556817-1187733618, state: Observ. open]
- Observing [64.6%]
- Locking [8.4%]
- Environmental [2.9%]
- Commissioning [2.5%]
- Maintenance [5.4%]
- Planned engineering [16.0%]
- Unknown [0.0%]
- Undefined [0.0%]

Livingston L1 operating mode overview
[1164556817-1187733618, state: Observ. open]
- Observing [56.8%]
- Locking [12.4%]
- Environmental [11.9%]
- Commissioning [4.7%]
- Maintenance [6.5%]
- Planned engineering [7.4%]
- Unknown [0.2%]
- Undefined [0.0%]
LIGO Network Duty Factor

LIGO network duty factor
- Double interferometer [43.2%]
- Single interferometer [30.2%]
- No interferometer [26.6%]
Comparison of Strain Sensitivity: O1 vs. O2

- L1 detector is 30 – 40% more sensitive than in O1
  - 25 W laser power into the interferometer
  - Limited by high power amplifier stage failure at LLO prior to O1
- H1 is slightly ~ 5 – 10% less sensitive
  - 30 W laser power; noise penalty at higher power related to input beam jitter
Binary Neutron Star Inspiral Range

- Goal for O2: > 80 MPc BNS range for H1 and L1
Binary Neutron Star Inspiral Range

- Goal for O2: > 80 MPc BNS range for H1 and L1
Nonetheless, LIGO is an Observatory!

NEW RESULT!
The Newest Black Hole Merger

Black Holes of Known Mass

Solar Masses

GW150914
LVT151012
GW151226
GW170104

X-Ray Studies

LIGO

Reported June 1, 2017

Credit: Robert Hurt/Caltech, Aurore Simmonet, SSU
ADVANCED VIRGO

6 EU countries
20 labs, ~250 authors

APC Paris
ARTEMIS Nice
EGO Cascina
INFN Firenze-Urbino
INFN Genova
INFN Napoli
INFN Perugia
INFN Pisa
INFN Roma La
Sapienza
INFN Roma Tor
Vergata
INFN Trento-Padova
LAL Orsay – ESPCI
Paris
LAPP Annecy
LKB Paris
LMA Lyon
NIKHEF Amsterdam
POLGRAW (Poland)
RADBOUD Uni.
Nijmegen
RMKI Budapest
University of Valencia
Path to join O2 includes:

- Improve power recycling cavity (PRC) stability with thermal compensation (TCS)
- Suspend the detection bench (includes output photodiodes)
- Employ low noise actuation
- Make use of noise subtraction techniques
- Initiate weekend engineering/science runs
- Increase interferometer input power from 13W to 25W
- Noise hunting!
Advanced LIGO: Near Term Prospects
Roadmap to

Design Sensitivity for Advanced LIGO

- Roadmap developed in 2013 by the LIGO Scientific Collaboration
  - Based on collective knowledge of LIGO’s Detector Science and Engineering Team at that time

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Fig. 1
Regions of aLIGO (top left), AdV (top right) and KAGRA (bottom) target strain sensitivities as a function of frequency. The binary neutron star (BNS) range, the average distance to which these signals could be detected, is given in megaparsec. Current notions of the progression of sensitivity are given for early, mid and late commissioning phases, as well as the final design sensitivity target and the BNS-optimized sensitivity. While both dates and sensitivity curves are subject to change, the overall progression represents our best current estimates.
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```
runs of many months. O2 began 30 November 2016, transitioning from the preceding engineering run which began at the end of October, and is anticipated to continue until 25 August 2017. To date in O2, H1 has not operated above 80 Mpc and L1 has also sometimes operated below 80 Mpc; we therefore expect that the achieved sensitivity across the run will probably be in the range 60 – 100 Mpc[19]. Assuming that no unexpected obstacles are encountered, the aLIGO detectors are expected to achieve a 190 Mpc BNS range by 2019. After the first observing runs, circa 2020, it might be desirable to optimize the detector sensitivity for a specific class of astrophysical signals, such as BNSs. The BNS range may then become 210 Mpc. The sensitivity for each of these stages is shown in Figure 1.

The H2 detector will be installed in India once the LIGO-India Observatory is completed, and will be configured to be identical to the H1 and L1 detectors. Operation at the same level as the H1 and L1 detectors is anticipated for no earlier than 2024.
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L1 Noise Budget

- DARM 24W (29 May 2017)
- Seismic
- Laser Noise
- Suspension thermal
- Coating Brownian (G1700820)
- Dark
- Quantum
- MICH
- SRCL
- Angular controls
- PUM actuator
- Input jitter
- Output jitter
- OMC length
- Wenzel AM + PM
- Residual Gas
- SRM holder
- Quantum+Gas+SRM
- Total sum

Displacement [m/√Hz]
Frequency [Hz]

SRM peak
Gas damping
LIGO

L1 Noise Budget

![Graph showing noise budget](image)

- **SRM peak**
- **Gas damping**
- **Displacement [m/√Hz]**
- **Frequency [Hz]**

**Slide Credit:** Valera Frolov
LIGO

L1 Noise Budget

Frequency [Hz]

Displacement [m/\sqrt{Hz}]

- DARM 24W (29 May 2017)
- Seismic
- Laser Noise
- Suspension thermal
- Coating Brownian (G1700820)
- Dark
- Quantum

- MICH
- SRCL
- Angular controls
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- Input jitter
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- OMC length

- Wenzel AM + PM
- Residual Gas
- SRM holder
- Quantum + Gas + SRM
- Total sum

SRM peak

Gas damping

Coating Thermal Noise

Slide Credit: Valera Frolov
‘Rogues Gallery’ of Possible Noises

- Bi-Linear coupling of length control system auxiliary loops to DARM
- Bi-Linear coupling of angular sensing and control system noise (> 10 Hz)
- Radiation pressure anomaly?
- Laser frequency noise (~bilinear)
- Laser amplitude noise (~bilinear)
- Audio RAM from electro-optic modulators
- Gas damping (between ERM and ETM)
- Penultimate mass coil driver electronics
- Correlated noise in output mode cleaner photodiodes
- Magnetic fields (~RF and baseband)
- Electric fields in main vacuum chambers
- Audio band vacuum chamber motion
- Downconversion of $f > 100$ kHz laser noise
- ‘Crackling’ mechanical noise in the blades of the test mass suspensions
- Excess thermal noise in the suspension monolithic stage (ears/fibers)
- Auxiliary optics coating noise
- Scattering from auxiliary vacuum chambers
- Backscatter from the arm beamtubes
- PUM coil driver electronics
- Backscatter from the end stations
- Upconversion of low frequency seismic motion
- Pointing/Intensity noise of TCS lasers
‘Rogues Gallery’ of Possible Noises

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Major H1, L1
Work Planned for post-O2

- Replace H1’s ITMX (excess absorption)
- Squeezed Light injection at LLO
  - Target is 3 dB of effective squeezing: equivalent to doubling the laser power
  - LHO will get the hardware as well; install & commissioning TBD
- Scattered Light Control improvements & additions
- 70 W laser amplifier stage
  - LLO: allows doubling of O2 laser power
  - LHO: plan to move from the HPO to a 70 W amplifier as well
- Replace End Reaction Masses w/ Annular versions
  - Squeezed film damping; possibly electro-static charge
  - May also replace End Test Masses
- Monolithic Signal Recycling Mirrors
  - Remove several kHz peak in DARM; lower frequency impact?
The Road to O3 ‘Late aLIGO’

LLO
- 70 W amp
- Corner volume: scattered light baffles, new SRM, etc
- Commissioning with higher power & squeezed light
- Gate valve repair
- ERM & ETM replacement

Commissioning to O3
- 4 – 7 months

O2 end
- Squeezed light upgrade
- September 2017
- 0 – 1 months

LHO
- Squeezed light upgrade: in-air table; electronics; vacuum OPO
- 70 W amp
- Cryo-pump decommissioning

Commissioning to start of O3
- 5 – 8 months
Problems with High Laser Power: Parametric Instability

Theory: V. B. Braginsky, S. E. Strigin, and S. P. Vyatchanin, Phys. Lett. A 305, 111 (2002)
Experiment: C. Zhao, L. Ju, J. Degallaix, S. Gras, and D. G. Blair,
Passive Damping of Parametric Instabilities

Thermal tuning of the Test Mass Radii of Curvature

**LLO**: ring heaters tuned to ‘sweet spot’ (low PI mode density)
Active Damping of Parametric Instabilities

End Reaction Mass (X, Y arms)

Active Electrostatic Damping of PI modes

Passive Thermal Tuning of the Mirror Radii of curvature via Ring Heater

In O2, 4 modes are actively damped (130 kW in the arm cavities)
At 50 W, 10 modes are actively damped (200 kW in the arm cavities)
Challenge: Going beyond 200 kW will require new methods (passive acoustic mass dampers)
**H1’s ITM-X: Excess Absorption**

March 2017: discovered small absorber on H1’s ITM-X high reflecting surface

- 60 nm distortion over 20 mm

**Hartman wavefront sensor image**

- Small absorber, ~ 15 mW absorbed (out of 130 kW arm power)

**Results in phase front distortion negatively impacting:**
- RF sideband build-up
- Alignment sensing
- Noise couplings
- Higher-order mode jitter

Vented in May 2017 to **inspect and clean**

Absorber remained, so ITMX replacement is being planned for post-O2
Quantum Engineering
‘Squeezed’ Light for O3

- Electromagnetic fields are quantized:
  \[ \hat{E} = \hat{X}_1 \cos \omega t + i \hat{X}_2 \sin \omega t \]

- Quantum fluctuations exist in the vacuum state:
  \[ \langle (\Delta \hat{X}_1)^2 \rangle \langle (\Delta \hat{X}_2)^2 \rangle \geq 1 \]

Wu, Kimble, Hall, Wu, PRL (1986)
Electromagnetic fields are quantized:
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Quantum fluctuations exist in the vacuum state:
\[ \langle (\Delta \hat{X}_1)^2 \rangle \langle (\Delta \hat{X}_2)^2 \rangle \geq 1 \]
Squeezed Light Sensitivity Improvement

Projections for L1 strain noise

- L1 25W O2: BNS 95 Mpc, BBH (20/20 Msol) 1175 Mpc
- L1 50W: BNS 107 Mpc, BBH (20/20 Msol) 1331 Mpc
- L1 50W + 3dB SQZ: BNS 120 Mpc, BBH (20/20 Msol) 1481 Mpc

Preliminary

x2 Higher power or 3 dB squeezing

x2 Higher power + squeezing

No further reduction of low frequency noise assumed in this plot.
Annular End Reaction Masses

- The current end reaction masses are solid cylinders
  - Gap spaced 5 mm from the end test mass
- ‘Squeezed film’ gas damping is non-negligible
  - Will be a limit assuming existing tank pressure; but could be a limiting noise source now

Annular ERM

Same electro-static force as current ERM
Beyond Advanced LIGO: The A+ Upgrade 2020-2025
Near term: ‘A+’, a mid-scale upgrade of Advanced LIGO
  » Improvements across all bands

Projected time scale for A+ operation: 2023 - 2025
Why A+?

- An incremental upgrade to aLIGO that can happen in the next 5-7 years
- A+ leverages existing technology and infrastructure, with minimal new investment, and moderate risk
- Target improvement: factor of 1.7* increase in range over aLIGO
  
  ≫ About a factor of 5 greater CBC event rate

- Stepping stone to 3G detector technology
- Can be observing within 5 years (possibly late 2022)
- “Scientific breakeven” within 1/2 year of operation
- Incremental cost: a small increment of the aLIGO cost

*BBH 20/20 $M_\odot$: 1.64x
*BNS 1.4/1.4 $M_\odot$: 1.85x
Summary of Major A+ Upgrades

Key A+ parameters:

- Frequency-dependent squeezing
  - Phase squeezing at high frequencies; amplitude squeezing at low frequencies
- 12dB injected squeezing
  - 15% readout loss
- 100 m filter cavity
  - 20 ppm round trip filter cavity loss
- Coating thermal noise half of aLIGO

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Summary of Major A+ Upgrades

Key A+ parameters:

- Frequency-dependent squeezing
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- 12dB injected squeezing
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  - 20 ppm round trip filter cavity loss
- Coating thermal noise half of aLIGO

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What can be improved?

aLIGO limiting noise at full power

**aLIGO Noise Curve:** $P_{\text{in}} = 125.0 \text{ W}$

- **Quantum**
- **Seismic**
- **Newtonian**
- **Suspension Thermal**
- **Coating Brownian**
- **Coating Thermo-optic**
- **Substrate Brownian**
- **Excess Gas**
- **Total noise**

**ALIGO Parameters:**
- Laser Power: 125.00 Watt
- SRM Detuning: 0.00 degree
- SRM transmission: 0.3500
- ITM transmission: 0.0140
- PRM transmission: 0.0300
- Finesse: 446.41
- Power Recycling Factor: 40.54
- Arm power: 710.81 kW
- Power on beam splitter: 5.07 kW
- Thermal load on ITM: 0.385 W
- Thermal load on BS: 0.051 W

**ALIGO Astrophysics:**
- BNS range: 191.04 Mpc (comoving)
- BNS horizon: 436.32 Mpc (comoving)
- BNS reach: 272.08 Mpc (comoving)
- BBH range: 1.37 Gpc (comoving, $z = 0.3$)
- BBH horizon: 3.24 Gpc (comoving, $z = 0.9$)
- BBH reach: 2.12 Gpc (comoving, $z = 0.5$)
- Stochastic Omega: 2.42e-09

Slide Credit: Mike Zucker
..plus squeezing with
~100m scale filter cavity

**A+ Parameters with Squeezing:**
- Laser Power: 125.00 Watt
- SRM Detuning: 0.00 degree
- SRM transmission: 0.3500
- ITM transmission: 0.0140
- PRM transmission: 0.0300
- Finesse: 446.41
- Power Recycling Factor: 40.54
- Arm power: 710.81 kW
- Power on beam splitter: 5.07 kW
- Thermal load on ITM: 0.385 W
- Thermal load on BS: 0.051 W

**A+ Astrophysics with Squeezing:**
- BNS range: 258.72 Mpc (comoving)
- BNS horizon: 592.49 Mpc (comoving)
- BNS reach: 370.29 Mpc (comoving)
- BBH range: 1.74 Gpc (comoving, z = 0.4)
- BBH horizon: 4.14 Gpc (comoving, z = 1.3)
- BBH reach: 2.77 Gpc (comoving, z = 0.5)
- Stochastic Omega: 9.32e-10

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**aLIGO Noise Curve:** $P_{in} = 125.0$ W

**Slide Credit:** Mike Zucker
..plus coating thermal noise reduction

**A+ Parameters with Squeezing/CTN:**
- Laser Power: 125.00 Watt
- SRM Detuning: 0.00 degree
- SRM transmission: 0.3500
- ITM transmission: 0.0140
- PRM transmission: 0.0300
- Finesse: 446.41
- Power Recycling Factor: 40.54
- Arm power: 710.81 kW
- Power on beam splitter: 5.07 kW
- Thermal load on ITM: 0.385 W
- Thermal load on BS: 0.051 W

**A+ Astrophysics with Squeezing/CTN:**
- BNS range: 354.06 Mpc (comoving)
- BNS horizon: 814.04 Mpc (comoving)
- BNS reach: 510.28 Mpc (comoving)
- BBH range: 2.24 Gpc (comoving, z = 0.6)
- BBH horizon: 4.14 Gpc (comoving, z = 2.1)
- BBH reach: 2.77 Gpc (comoving, z = 1.1)
- Stochastic Omega: 6.78e-10
**Challenge: Thermal Noise in Optical Coatings**

- Simple picture: $kT$ of energy per mechanical mode, viscous damping
- For coating dominated noise and structural damping:

$$S_x(f, T) \approx \frac{2k_B T}{\pi^2 f} \frac{d}{w^2 Y} \phi \left( \frac{Y'}{Y} + \frac{Y}{Y'} \right)$$

Where:
- $k_B$ is the Boltzmann constant
- $T$ is the temperature
- $d$ is the coating thickness
- $w$ is the beam radius
- $Y$ is the coating elastic loss

**Comparative Values**

- For TiO$_2$:Ta$_2$O$_5$: $\phi = 2 \times 10^{-4}$
- For SiO$_2$: $\phi = 4 \times 10^{-5}$

Compare: Bulk Silica $\phi \sim 10^{-6}$ to $10^{-8}$

Probing the Horizons of the Gravitational-wave Universe: Voyager & Cosmic Explorer 2025 - 2035+
**LIGO Voyager:**
*Fully Exploiting the Current LIGO Facilities*

Si optics, > 100 kg
Si or AlGaAs coatings
(Mildly) Cryogenic
$\lambda \sim 2 \mu m$, 300 W

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Voyager Noise Curve: $P_{in} = 300.0$ W

- Quantum
- Seismic
- Newtonian
- Suspension Thermal
- Coating Brownian
- Coating Thermo-optic
- Substrate Brownian
- Excess Gas
- Total noise

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BNS $R < 800$ Mpc
BBH $z < 5$ (@10 $M_\odot$)
~$100M\$
Einstein Telescope, Cosmic Explorer: New Observatories

Horizon and 10, 50 and 75 % confidence levels

Cost \sim \text{G\$}/\text{G\€}

First Stars Formed

High SNR Signals!

Redshift \( [z] \)

Total mass \( [M_\odot] \)

BNS, NSBH, BBH, POP3?

ET

T1600140; T1500491; P1400147; ET-0106C-10
How to Get From Here to There?

GWIC (Gravitational Wave International Committee)

Body formed in 1997 to facilitate international collaboration and cooperation in the construction, operation and use of the major gravitational wave detection facilities world-wide

- Affiliated with the International Union of Pure and Applied Physics
  - From 1999 until 2011, GWIC was recognized as a subpanel of PaNAGIC (IUPAP WG.4).
  - In 2011, GWIC was accepted by IUPAP as a separate Working Group (WG.11).

Links to the:
  - International Astronomical Union (IAU)
  - International Society for General Relativity and Gravitation (ISGRG)
Who is GWIC?

The membership of GWIC represents all of the world’s active gravitational wave projects*, as well as other relevant communities, covering gravitational wave frequencies from nanohertz to kilohertz. Each project has either one or two members on GWIC depending on size.

ACIGA    Bram Slagmolen
AURIGA   Massimo Cerdonio
Einstein Telescope Michele Punturo
European Pulsar Timing Array Michael Kramer
GEO 600   Karsten Danzmann, Sheila Rowan (Chair)
IndIGO    Bala Iyer
KAGRA     Yoshio Saito, Takaaki Kajita
LIGO      Dave Reitze, David Shoemaker
LISA      Neil Cornish, Bernard Schutz, Ira Thorpe, Stefano Vitale,

NANOGrav  Xavier Siemens
NAUTILUS  Eugenio Coccia
Parkes Pulsar Timing Array George Hobbs
Spherical Acoustic detectors Odylio Aguiar
Theory Community Clifford Will
Virgo Fulvio Ricci, Jean-Yves Vinet
IUPAP AC2 (ISGRG) Beverly Berger
IAU D1 Vacant
Executive secretary: David Shoemaker
Co- secretary: Stan Whitcomb

*no CMB community membership
GWIC’s role in coordinating 3G detector development

GWIC Subcommittee on Third Generation Ground-based Detectors

GWIC subcommittee purpose and charge:
With the recent first detections of gravitational waves by LIGO and Virgo, it is both timely and appropriate to begin seriously planning for a network of future gravitational-wave observatories, capable of extending the reach of detections well beyond that currently achievable with second generation instruments.

The GWIC Subcommittee on Third Generation Ground-based Detectors is tasked with examining the path to a future network of observatories/facilities.
Membership

Co-Chairs: Michele Punturo – ET/David Reitze - LIGO

Federico Ferrini – European Gravitational Observatory
Takaaki Kajita - KAGRA
Vicky Kalogera – Northwestern (co-opted)
Harald Lueck, AEI (co-opted)
Jay Marx, LIGO (co-opted)
David McClelland, ACIGA (co-opted)
Sheila Rowan - GWIC Chair
Bangalore Sathyaprakash – Penn State (co-opted)
David Shoemaker – Executive Secretary
Goals

1) **Science Drivers for 3G detectors:** (Kalogera, Sathyaprakash + subcommittee) commission a study of ground-based gravitational wave science from the global scientific community, investigating potential science vs architecture vs. network configuration vs. cost trade-offs, recognizing and taking into account existing studies for 3G projects (such as ET) as well as science overlap with the larger gravitational-wave spectrum.

2) **Coordination of the Ground-based GW Community:** (Lueck, McClelland + subcommittee)

develop and facilitate coordination mechanisms among the current and future planned and anticipated ground-based GW projects, including identification of common technologies and R&D activities as well as comparison of the specific technical approaches to 3G detectors. Possible support for coordination of 2G observing and 3G construction schedules.

3) **Networking among Ground-based GW Community:** (Punturo, Reitze)

organize and facilitate links between planned global 3G projects and other relevant scientific communities, including organizing:
- town hall meetings to survey the community
- dedicated sessions in scientific conferences dedicated to GW physics and astronomy
- focused topical workshops within the relevant communities
4) **Agency interfacing and advocacy:** (Rowan)

identify and establish a communication channel with funding agencies who currently or may in the future support ground-based GW detectors; communicate as needed to those agencies officially through GWIC on the scientific needs, desires, and constraints from the communities and 3G projects (collected via 1) – 3) above) structured in a coherent framework; serve as an advocacy group for the communities and 3G projects with the funding agencies.

5) **Investigate governance schemes:** (Ferrini, Marx + subcommittee)

by applying knowledge of the diverse structures of the global GW community, propose a sustainable governance model for the management of detector construction and joint working, to support planning of 3rd generation observatories.

*The subcommittee should provide a preliminary report and set of proposed actions recommendations to GWIC no later than the 2017 GWIC meeting. Subsequent reports should be delivered future GWIC meetings.*
Upcoming Near Term Meetings of Interest

6-7 July, 2017  
Syracuse, NY  
What’s Next for Gravitational Wave Astronomy?  
Marriott Syracuse Downtown, 100 E Onondaga St, Syracuse, NY 13202

9-14 July, 2017  
Pasadena, CA  
12th Edoardo Amaldi Conference on Gravitational Waves  
Hilton Pasadena, 168 S Los Robles Ave, Pasadena, CA 91101

28 Aug-1 Sep, 2017  
Geneva, Switzerland  
LIGO-Virgo Collaboration Meeting  
CERN, Geneva, Switzerland

The committee will need your input and help to develop the proper path forward!

gwic-3g@sympa.ligo.org
LIGO’s second observing run O2 is underway!

- Began November 30, 2016, slated to end on August 25, 2017
- L1 detector is more sensitive than in O1; H1 is slightly less sensitive
- *One more confirmed black hole merger: GW170104!*

12-15 month break planned for Fall 2017

- Sensitivity goal for O3: H1, L1 > 120 Mpc binary neutron star inspiral range
- Substantial work planned at both Hanford and Livingston

Planning and R&D underway to upgrade Advanced LIGO detectors

The next few years will be very interesting ones for the field of gravitational-wave science!

Stay Tuned...
LIGO Scientific Collaboration
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