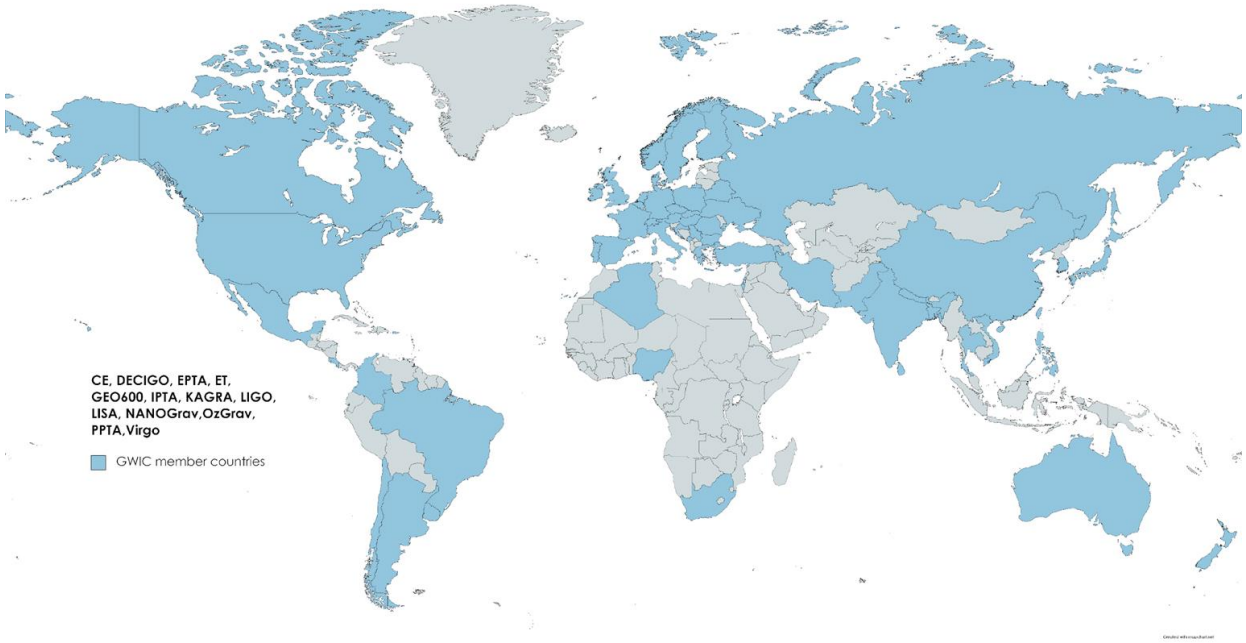
Gravitational Wave International Committee report

Jo van den Brand for GWIC

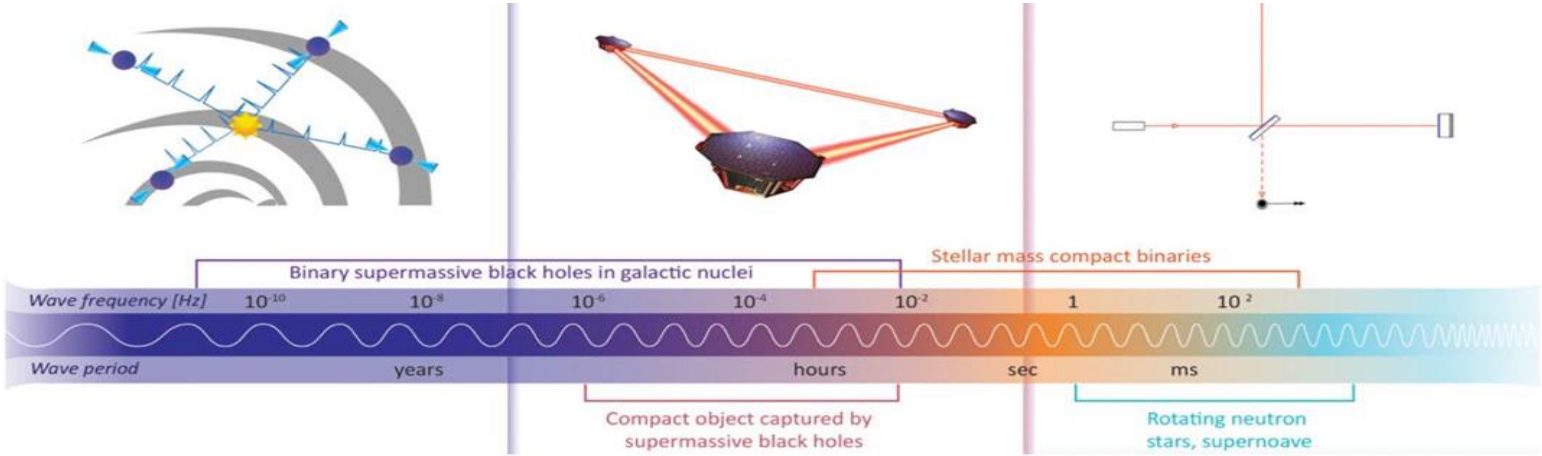
Presentation to APPEC
June 28, 2023; jo@nikhef.nl



Overview

Topics for today

1. Introduction: what is GWIC? GWIC member projects and collaborations
2. Scientific highlights
3. Overview of GWIC projects
4. Discussion points



Introduction

GWIC mission: facilitate international collaboration and cooperation in the construction, operation and use of the major gravitational wave detection facilities world-wide. See https://gwic.ligo.org

GWIC member projects and collaborations

Project	Focus	Project	Focus
Cosmic Explorer	Ground-based (nextgen)	LIGO-India	Ground-based
DECIGO	Space-based	LISA community	Space-based
Einstein Telescope	Ground-based (nextgen)	NANOGrav	Pulsar timing
European Pulsar Timing Array EPTA	Pulsar timing	OzGrav/PPTA	Ground-based/Pulsar timing
GEO 600	Ground-based	Virgo	Ground-based
KAGRA	Ground-based	GW Theory Community	All
LIGO	Ground-based		

Statistics about GWIC member projects

- LISA about 1,550 members from 60 countries, IPTA about 200 members
- LIGO SC, Virgo and KAGRA about 2,800 members
- Cosmic Explorer and ET about 1,500 members

Slides represent the opinion of GWIC members

Affiliated members

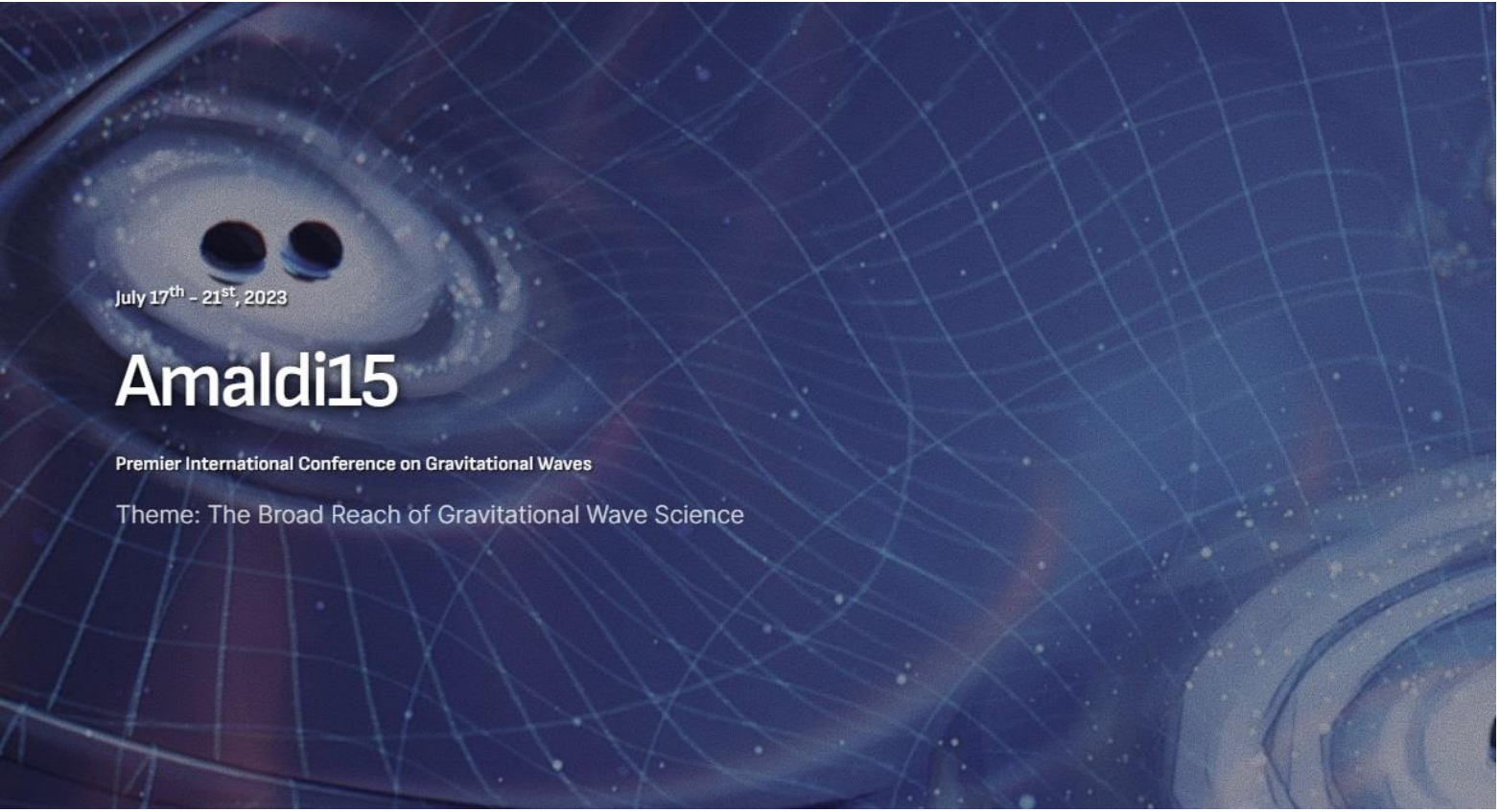
- GWIC is Working Group 11 of IUPAP
- International Society of General Gravitation – ISGRG is an Affiliated Commission (AC2) of
- IAU Commission D1

IAU – International Astronomical Union

Commission D1:Gravitational Wave Astrophysics has members from over 30 countries

Amaldi 2023

Premier biannual international conference on gravitational wave science and gravitational wave detection
Virtual world-wide conference using Zoom from July 17th to 21st, 2023

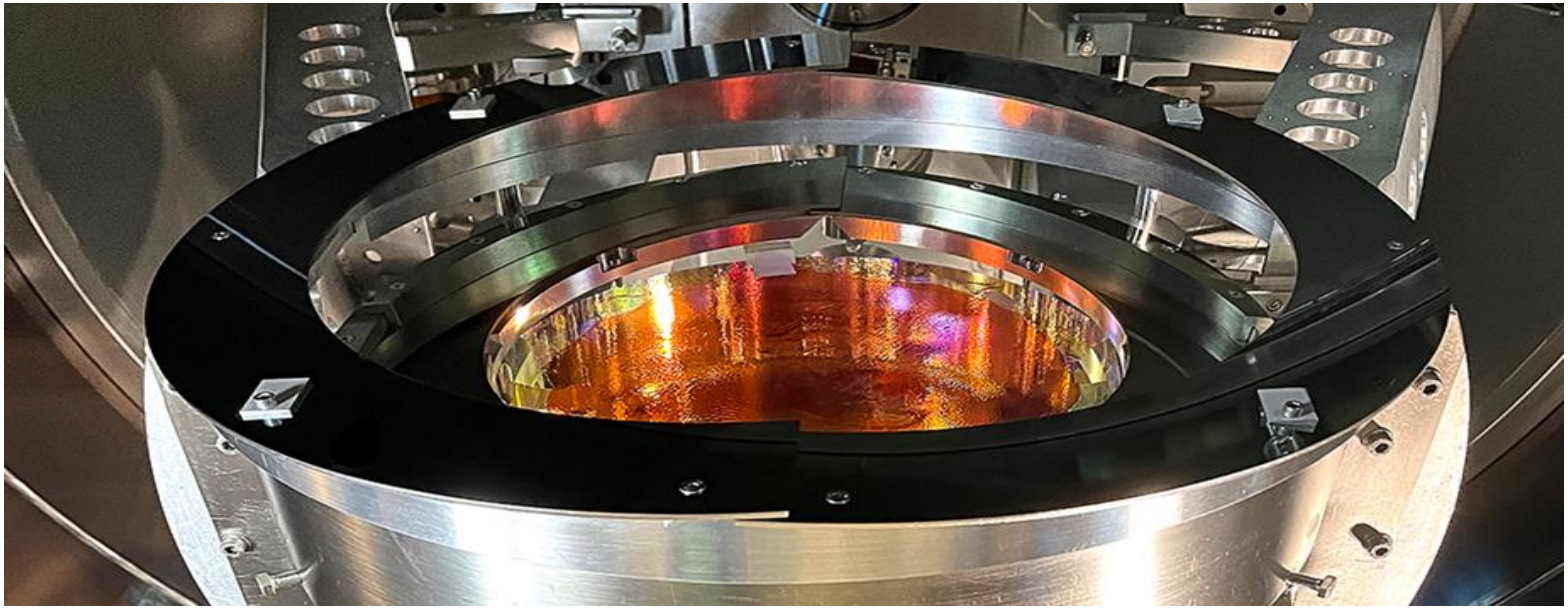


LIGO-Virgo-KAGRA collaboration started run O4

After three years of work to improve the performance of the detectors, Observing Run 4 started on May 24th, 2023

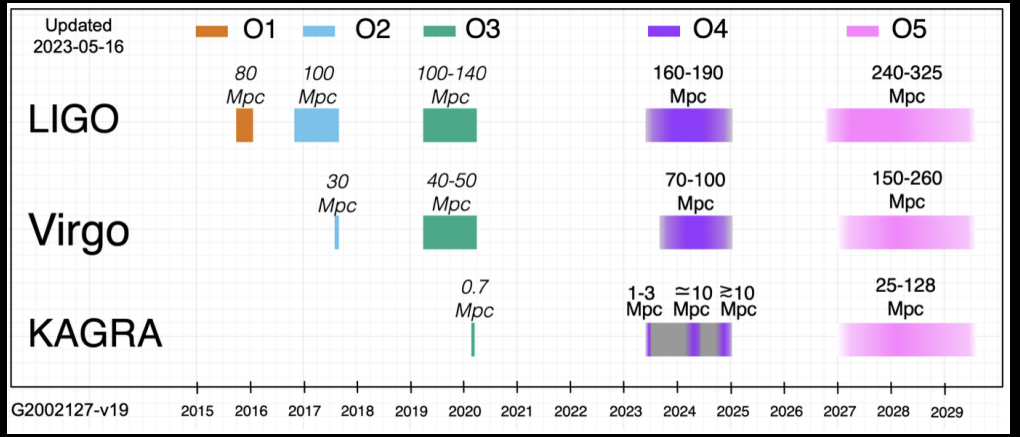
The LIGO detectors have moved from commissioning and running in engineering mode to observing run O4. O4 is expected to last 20 months (including a 2-month commissioning break)

The Virgo Collaboration and KAGRA have decided to postpone the entry in the next observing run (O4), in order to continue the detector commissioning activities and further increase their sensitivity



Virgo current status

Adv+ phase 1

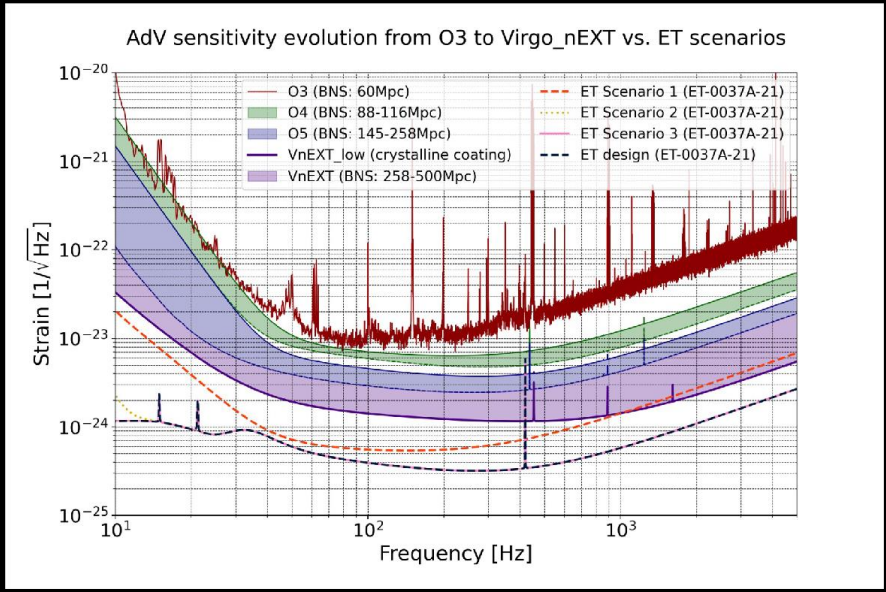


- Virgo is working on preparing for O4 (AdV+ Phase 1)
- Sensitivity is currently limited by excess thermal noise from two interferometer mirrors
- This requires a complicated intervention inside the vacuum system, which will take a few weeks to complete
- After the end of the intervention and the recovery of the interferometer, estimated to be completed by the end of June, we will reassess the situation and will be able to provide updated information
- Virgo will not join O4 observations on May 24 but will join a few months later

Virgo future developments

Adv+ phase 2 and Virgo_next

- Preparatory activities for O5 already started (AdV+ Phase 2), but the overall plan needs to be revised based on the experience gathered during the commissioning for O4
- We released a concept study for a post-O5 upgrade (Virgo_nEXT), which was well received by our funding agencies
- The Virgo_nEXT concept also needs to be revised in light of new information
- These revisions will start immediately



Lot of synergies between Virgo and third generation observatories for the development of crucial technologies (high power laser, adaptive optics, parametric instabilities, frequency dependent squeezing, large optics, suspensions, innovative coatings, control noise mitigation)

Overall, Virgo is working to improve its sensitivity and continue making important contributions to the field of gravitational wave astronomy

LIGO Laboratory/ Observatory Status

- Completed upgrades planned for O4; NSF+STFC/ARC funding
  - Frequency dependent squeezing a major undertaking
  - Close to goal of 160 Mpc BNS range – commissioning is hard
  - Engineering run underway
  - Event rate ~1.5-2X over O3 → one event every two to three days; NSBH alert 18 May
- LIGO LLO-LHO started O4 Observing on 24 May, 15:00 UTC - yesterday!
  - 20 month run planned, ~2 months of break for commissioning foreseen
- Phase 2 of the A+ upgrade will be implemented for the O5 run (~2027 start)
  - 3 years planned, 240-330 Mpc goal sensitivity
- Plans firming for ‘the last 4km upgrade’ – A# -- in early 2030’s; another 2x reach
- The LIGO Hanford Observatory inaugurated the LIGO Exploration Center (LExC), a new educational outreach facility, complementing LLO facility

LIGO Scientific Collaboration (LSC)

- 1525 members
  - 82 groups; ~950 authors; ~704 FTEs.
  - ~3 new groups per year.
  - 50% US-based; 50% non-US.
- LIGO Magazine

- Observational science in O4
  - Gravitational-wave candidate alerts will be distributed publicly. Expect a few detections per week. See OpenLVKEM [1] for more information.
  - Pipelines capable of early-warning detection of binary-neutron star mergers are being commissioned.
  - 43 papers are planned to report on compact binary science, searches for unmodeled bursts, stochastic backgrounds, and continuous signals.
  - Preparations for detecting new source types are under way. 16 standby papers in the event of exceptional discoveries

[1] https://wiki.gw-astronomy.org/OpenLVEM.

KAGRA

Large-scale Cryogenic Gravitational wave Telescope underground in Kamioka, Hida-city, Gifu, Japan

http://gwcenter.icrr.u-tokyo.ac.jp/en/

The first 2.5th generation GW detector in the world
- located deep underground
- using cryogenic mirrors

Host Institutions

* ICRR (Institute for Cosmic Ray Research, U. Tokyo)
* NAOJ (National Astronomical Observatory of Japan)
* KEK (High Energy Accelerator Research Organization)

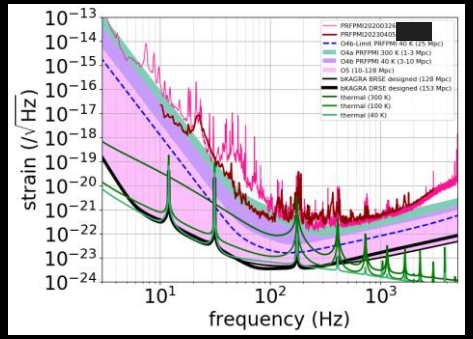
Funded by:

MEXT(Ministry of Education, Culture, Sports, Science and Technology, Japan) , also supported by JSPS; NRF, KISTI, KASI, MIST in Korea; and AS, NSTC in Taiwan.

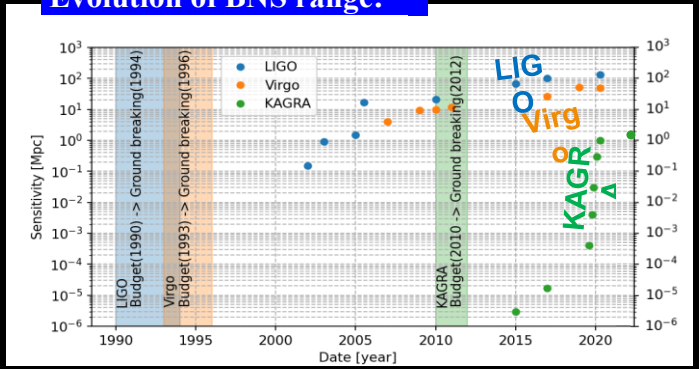
International Collaboration:

489 members in 15countries and regions
155 authorship holders, 112 research groups
(as of April 2023)

Sensitivity:



Evolution of BNS range:



Brief history and plan for O4:

KAGRA got funded in 2010, 20 years after LIGO and 17 years after Virgo, and started its construction in 2012. We performed test operation at room temperature in 2016 and at cryogenic temperature in 2018. In 2019, we signed a joint research MoA with LIGO and Virgo, constituting the LVK collaboration since then. In March 2020 we joined O3 performing a joint observation with GEO600(O3GK) with a nominal sensitivity around 0.7Mpc with 1Mpc at the maximum in the BNS range under the outbreak of Covid-19. After that, we had been conducting a number of improvement work, opening all the vacuum tanks to fix the suspension and install more sensors and baffles as well as a high-power laser. Now the entire system is much more stable than before with a sensitivity higher than 1Mpc as of April, 2023. KAGRA will join O4a on May 24, 2023 for one month, then resume commissioning toward about 10Mpc in the BNS range by spring, 2024 when we will perform observation for three months or so with fully cryogenic operation. We will further improve the sensitivity toward the end of O4. As the first gravitational-wave detector in 2.5th generation in the world, our technologies can be a reference to the third-generation detectors such as the Einstein Telescope.

GEO 600

- British-German 600m interferometric gravitational wave detector located near Hannover Germany

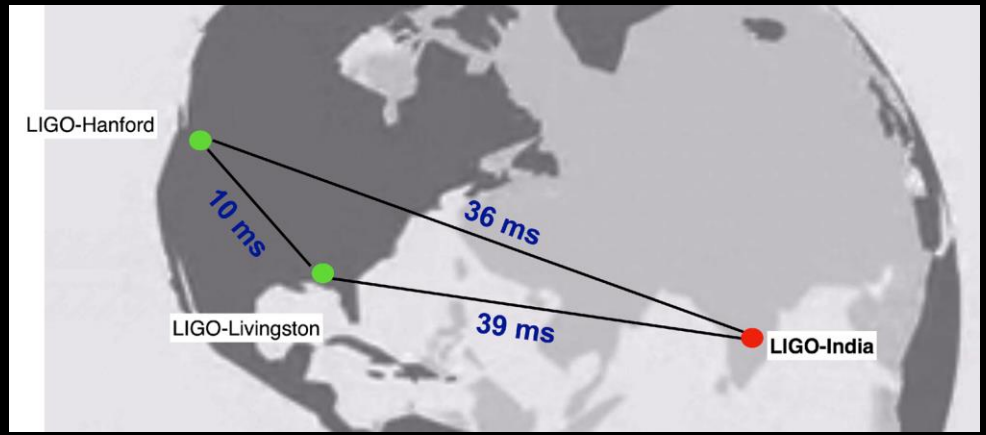
- Technology pioneer
  - Built with 2nd generation “advanced” technologies, beginning in 1998
  - Added quantum noise mitigation technology in 2010 - success at GEO led to early adoption at LIGO and VIRGO.
  - Continuing to research and develop new technologies around quantum noise mitigation and interferometer controls to include machine learning techniques on an active full-scale detector
- Astrowatch detector
  - Taking gravitational wave data quasi-continuously over night and on weekends and when the detector isn’t being used for instrument science.
  - Providing coverage during downtimes of other detectors undergoing upgrades and maintenance.

LIGO-India Project

(Conceptual arial view of LIGO India Observatory)

- A project under the Mega-Science Consortium of Department of Atomic Energy and Department of Science and Technology of India
- **Recently funded for construction of 4km Observatory in India**
- Uses NSF-funded 3rd LIGO detector
- The LIGO-India Observatory will be set up under an international collaboration with LIGO Laboratory, Caltech & MIT

The LIGO-India Observatory will join the other two LIGO detectors at LIGO Hanford, and the LIGO Livingston, by the end of this decade to workas a single Global Network of LIGO Gravitational Wave Detectors



International Gravitational-Wave Observatory Network (IGWN)

- Create an organization that facilitates management and operations of the global terrestrial detector network by delivering shared services and infrastructure necessary to maximize the science.

Benefits should include:

- Formally sharing the costs of the development and operations of common infrastructure and services.
- Reducing the overhead associated with decision-making and management of common activities.
- Facilitation of coordinated upgrades and synchronized observations to maximize gravitational-wave and multi-messenger science.

The LIGO-Virgo-KAGRA Collaboration is taking the lead to define and initiate the formation of IGWN:

- A draft charter has been under discussion since summer 2022
- A joint LVK committee will begin work next month on clarifying the purpose, structure, and roles of IGWN while renegotiating the LIGO-Virgo-KAGRA memorandum of agreement.
- Anticipate engaging other terrestrial detector collaborations.

OzGrav GWAC Report , 2023

Bailes, McClelland

OzGrav R&D

- On 2G++ and 3G detectors, Pulsar Timing Arrays, data analysis and astrophysics
- *ARC funding awarded for a NEW $35M 7 year Centre of Excellence commencing April 2024*

  - Director M. Bailes - expanded from 6 nodes to 8 nodes with broader astronomy engagement (cosmology & radio)
- lobbying for gravitational wave detectors to be included under the Australian National Collaborative Research Infrastructure

  - seeking funds to develop industry engagement
- New supercomputer (12,000 cores) and seeking GW Data Centre funding renewal
- continuing development of the 'NEMO' kHz band detector concept

Advanced LIGO

- Australian Research Council (ARC) Funding for Australian Partnership in Advanced LIGO+ renewed for a further 4 years: mid-2021 to mid-2025 - Australian hardware contributions and commissioning personnel; plus remote commissioning facilities established in Australian institutions to enable offsite activities in Australian daylight hours!
- contract for A+ beamsplitter coating

3G Activities

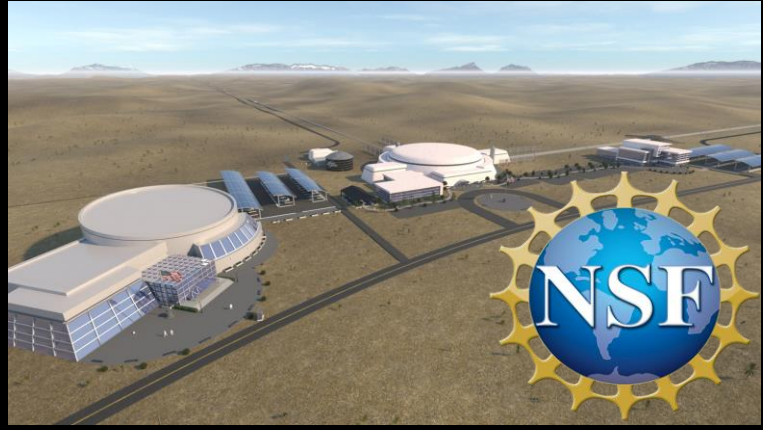
- Cosmic Explorer Project has OzGrav member participants: technical design and Project Advisory Committee
- some collaboration with ET participation

Pulsar Timing Gravitational Wave Detection

Deeply engaged in the Australian Parkes Pulsar Timing Array and South Africa's MeerKAT Pulsar Timing Array

Cosmic Explorer

The US Vision for Gravitational-Wave Astrophysics



- Next-Generation Gravitational-Wave Observatory
  - 40 km and 20 km L-shaped surface observatories
  - 10x sensitivity of today's observatories
  - Use Advanced LIGO Technology → Low Risk
  - Stellar to intermediate mass mergers throughout Cosmic Time
  - Plan for a Global network together with European Einstein Telescope
    - Growing common effort; CERN-ET-CE joint effort for 'value engineering' of vacuum system
    - International partners currently actively contributing – Australia, UK, Germany, Canada
- Project Status
  - Proposed Project Development via 7 proposals to NSF; hope to hear of funding very soon
    - Coordinated effort on observational science, detector and infrastructure technology
  - NSF "Next-Generation Gravitational Wave Observatory Subcommittee" established to form recommendations on a roadmap for the US
  - CE, LIGO Lab preparing White Papers with CE Consortium support
    - Network studies including current/future detectors
  - **With sustained funding, believe mid-2030's could be a possible completion of Project phase**

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Einstein Telescope

Next-Generation GW detector in Europe

- Underground Observatory,
  Wide-band high-sensitivity detectors
- What, when, and where for ET in study; Configuration study completed, with Risk Assessment and Work Breakdown structure being actively pursued
- ET Collaboration: 1360 members, 23 countries
- Project structure of a Proto-Council,
  Project Directorate, Collaboration Board, and structured activities
- Vacuum Pipe Studies undertaken with CERN; recent meeting, good progress
- Serious Engagements by Italy and Netherlands for sites and funding; Site selection process well structured
- Timeline in evolution, but with target of Observing mid-2030's
- **Great momentum in the science, technology, and funding**

DECIGO

Deci-hertz Interferometer Gravitational Wave Observatory

DECIGO:

Design parameters: under optimization for detection of primordial GWs

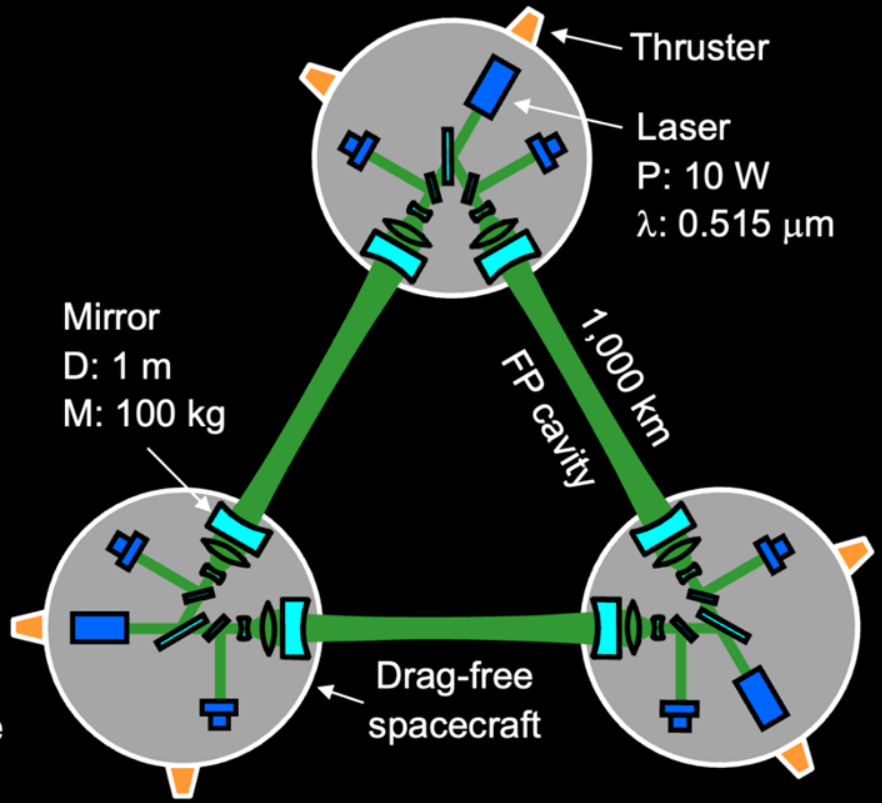
B-DECIGO:

Pathfinder science mission for DECIGO

SILVIA:

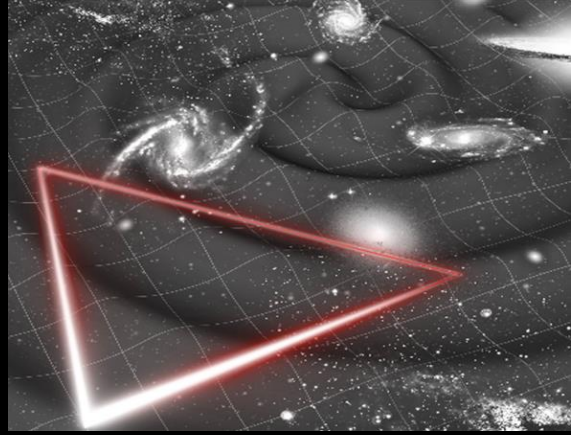
Mission for demonstrating formation flying and drag-free technologies

Approved to proceed to mission definition phase
Study for mission definition underway



Preconceptual design of DECIGO

Laser Interferometer Space Antenna (LISA)



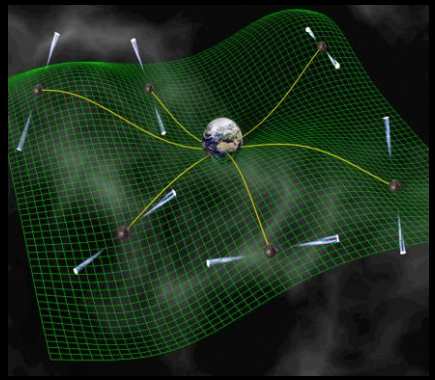
- Configuration and Science Goals
  - Sun-sized constellation of three spacecraft connected via laser links
  - Observe GWs in the millihertz band from distant massive black holes, compact binaries in the Milky Way, and other sources
  - Broad range of astrophysics and fundamental physics applications
  - ESA-led large class mission; Substantial hardware and science analysis contributions from ESA Member States and NASA
- Status
  - Approaching end of Definition phase
  - Technology development substantially complete
  - Formal international agreements in development
  - Discussions on data release plans, community organization
  - Next major milestone: ESA Mission Adoption (early 2024)
  - Launch in mid-2030’s planned

The International Pulsar Timing Array (IPTA)

http://ipta4gw.org/

Current Pulsar Timing Arrays (PTAs)

- Seek to detect nanohertz-frequency GWs by timing ~100 millisecond pulsars with large radio telescopes; sources 10^7 - 10^{10} solar-mass black holes
- Data shared through global International Pulsar Timing Array (IPTA) collaboration
- Search for spatially correlated noise yielding GW detection
- Detection of background will soon be followed by individual sources and persistent multi-messenger astrophysics.



IPTA Countries and constituent PTAs:

- USA, Canada - NANOGrav (70 Pulsars)
- Germany, France, UK, Italy, Netherlands - EPTA (45 Pulsars)
- Australia - PPTA (25 Pulsars)
- India+Japan - InPTA (30 Pulsars)

Emerging PTAs

- South Africa/Australia (89 Pulsars) MeerKAT, MeerTime
- China (40 Pulsars) FAST/ China PTA
- SKA & DSA 2000 (later this decade)

Global PTAs and Telescopes

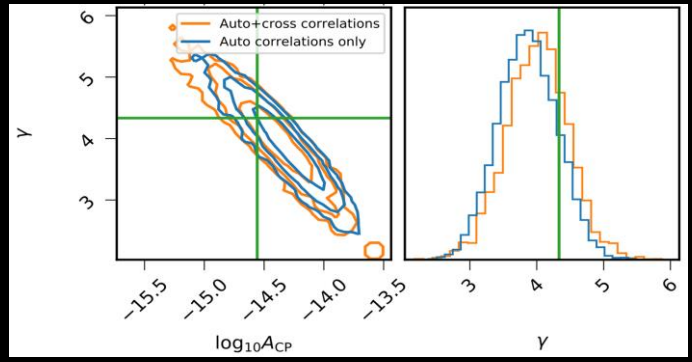
Progress

- IPTA “DR2” result published Jan 2022. Common process detected, consistent with expectations of supermassive black hole binary background. Spatial correlations not yet detected

Upcoming

- **Four PTAs (EPTA+InPTA,PPTA,NANOGrav,CPTA) see interesting (and similar amplitude) potential GW backgrounds, with some evidence for spatial correlations**
- Coordinating publication of four new independent GW papers using recently completed data releases
- The results are submitted for publication and the press-release is expected on 29th June
- Combined dataset analysis and release (IPTA-DR3) is also in progress

Significant IPTA funding eg (NSF’s AccelNet)



Discussion points

Einstein Telescope and Cosmic Explorer

Close interaction between various stakeholders is needed

- Facilitating exchange visits of scientists involved in ET and CE
  - Enormous potential to increase productivity, grow careers, and reduce the ‘reinvention of the wheel’

Proposal to Gravitational Wave Agencies Correspondents (GWAC)

- See https://www.nsf.gov/mps/phy/gwac.jsp
- Facilitate a global workshop/conference having the aim to coordinate the actions of the future 3G observatories
- Funding opportunities for coordinating specific 3G actions, like R&D on specific items of global interest (vacuum, infrastructures, …)

The road from 2G to 3G observatories

Issues of importance

LIGO-Virgo-KAGRA-LIGOIndia

- Community faces challenges in meeting requirements for future observation runs: O4, …
- A# and Virgo Next: when are proposals expected?
- Impact and opportunities: 2G versus 3G
- What is the timeline (final configuration) for LIGO-India?

Cosmic Explorer and Einstein Telescope

- Timeline for funding CE?
- Status of configuration study of ET?
- What is status of OzGrav's NEMO?

Gravitational-wave research is growing rapidly

- Upgrades of 2G facilities and preparation for 3G observatories
- Fast increase in event rate expected
- Missing FTEs in computing domain: LVK should develop a coherent plan

Resources and priority should also grow to allow our community to handle these challenges effectively and to serve a broad community

Multi-messenger Astronomy

Involve relevant communities

Ensure timely development of instruments for EM follow-up

- Astro 2020 Decadal
  - Exploring the cosmos in the multi-messenger and time domains is a key scientific priority for the coming decade, with new capabilities for discovery on the horizon with the Rubin Observatory, Roman, LIGO, Virgo, and KAGRA, and IceCube
- APPEC
  - Update of Roadmap
- Astronet Roadmap 2022 - 2035
  - Improvements in neutrino and cosmic-ray capabilities will greatly enhance possibilities in multi-messenger Astronomy
- NASA – NSF meeting
  - TDAMM meeting in the fall. Both the present and future GW observatories will profit from a robust program of space and ground photon and particle observatories
- Voyage 2050
  - Long-term planning of the ESA science programme
  - See https://www.cosmos.esa.int/documents/1866264/1866292/Voyage2050-Senior-Committee-report-public.pdf/e2b2631e-5348-5d2d-60c1-437225981b6b?t=1623427287109
  - Recommendation: ESA should develop a Large mission capable of deploying new instrumental techniques such as [illegible] wave detectors or precision microwave spectrometers to explore the early Universe (say $z > 8$)

Reference material

What is GWIC (Gravitational Wave International Committee)?

Organization formed in 1997 to facilitate international collaboration and cooperation in the construction, operation and use of the major gravitational wave detection facilities worldwide

GWIC

Affiliated with the International Union of Pure and Applied Physics (Working Group WG.11). Through this, GWIC is connected with the International Society on General Relativity and Gravitation (IUPAP's Affiliated Commission AC.2), its Commission C19 (Astrophysics), and another Working Group, the AstroParticle Physics International Committee (APPIC)

Current Chair: Jo van den Brand
Executive Secretary: David Shoemaker

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

- **Pulsar timing arrays, covering low-frequency nanohertz GW sources**
- **Space based detectors, covering the micro – mHz band**
- **Ground-based detectors, covering the Hz – kHz band**

*no Cosmic Microwave Background Community membership

Complementary approaches **essential to maximizing the scientific potential of the field**

Full membership and more information at: https://gwic.ligo.org/

GWIC Goals and Missions

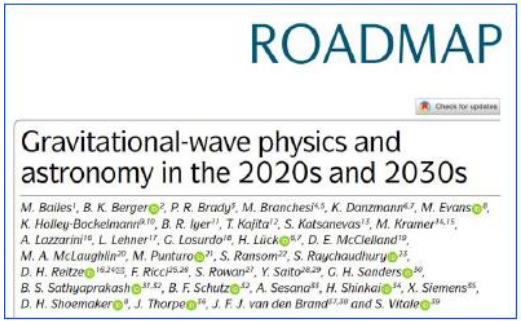
Organization formed in 1997 to facilitate international collaboration and cooperation in the construction, operation and use of the major gravitational wave detection facilities worldwide

- Promote international cooperation in all phases of construction and scientific exploitation of gravitational-wave detectors → **GWIC 3G Subcommittee**
- Coordinate and support long-range planning for new instrument proposals, or proposals for instrument upgrades → **GWIC 3G Subcommittee**
- Promote the development of gravitational-wave detection as an astronomical tool, exploiting especially the potential for multi-messenger astrophysics → Updated GWIC Roadmap
- Organize regular, world-inclusive meetings and workshops for the study of problems related to the development and exploitation of new or enhanced gravitational-wave detectors, and foster research and development of new technology → **Amaldi Meeting**
- Represent the gravitational-wave detection community internationally, acting as its advocate → **GWAC**
- Provide a forum for project leaders to regularly meet, discuss, and jointly plan the operations and direction of their detectors and experimental gravitational-wave physics generally → **Annual GWIC Meeting**

More at https://gwic.ligo.org/

GWIC Goals and Missions

GWIC Roadmap "Gravitational-wave physics and astronomy in the 2020s and 2030s" was published in Nature Reviews Physics 3, 344-366 (2021)


ROADMAP

Gravitational-wave physics and astronomy in the 2020s and 2030s

M. Bailes[1], B. K. Berger[2], P. R. Brady[3], M. Branchesi[4,5], K. Danzmann[6,7], M. Evans[8], K. Holley-Bockelmann[9,10], B. R. Iyer[11], T. Kajita[12], S. Katsanevas[13], M. Kramer[14,15], A. Lazzarini[16], L. Lehner[17], G. Losurdo[18], H. Lück[6,7], D. E. McClelland[19], M. A. McLaughlin[20], M. Punturo[21], S. Ransom[22], S. Raychaudhury[23], D. H. Reitze[16,24,25], F. Ricci[25,26], S. Rowan[27], Y. Saito[28,29], G. H. Sanders[30], B. S. Sathyaprakash[31,32], B. F. Schutz[33], A. Sesana[34], H. Shinkai[35], X. Siemens[36], D. H. Shoemaker[8], J. Thorpe[36], J. F. J. van den Brand[37,38] and S. Vitale[39]

GWIC Ground-based Third Generation Subcommittee Reports https://gwic.ligo.org/3Gsubcomm/