Worldwide Coordination of Ground-based Gravitational Wave Antennae

ASPERA Roadmap Workshop

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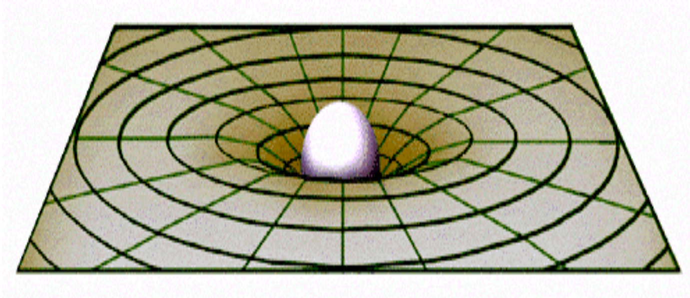
Why worldwide coordination?

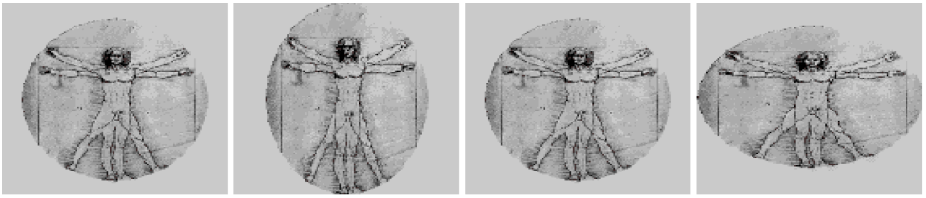
- Driven by the science and nature of GWs
  - Need multiple instruments observing the same gravitational wave in coincidence to extract full astrophysical information content

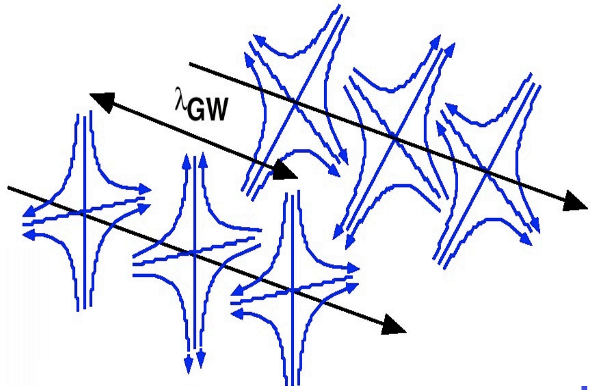
- Field is moving rapidly towards global coordination, and coherent analysis of data from multiple detectors

Nature of Gravitational waves



- Ripples of space-time curvature
  that propagate at the speed of light
- Emitted by accelerating aspherical mass distributions
- Transverse, quadrupole waves with 2 polarizations that stretch and squeeze space transverse to direction of propagation

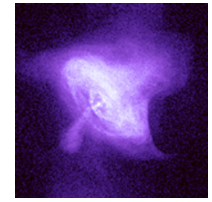




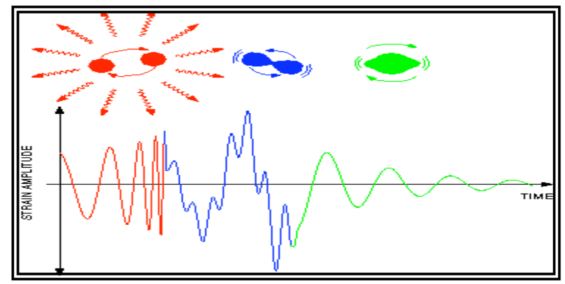
- Matter is essentially transparent to gravitational waves-- waves travel essentially unimpeded to us from their source
- Information about source is encoded on the GW wave

Some detectable astrophysical sources of GWs

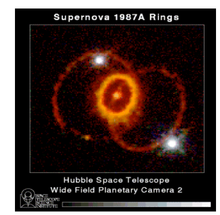
- Periodic sources in our galaxy
  - e.g. pulsars--spinning neutron stars



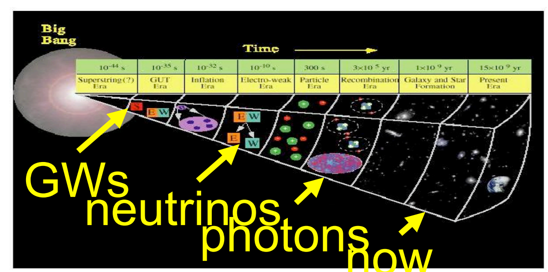
- Coalescing compact binaries
  - e.g NS-NS, BH-BH, NS-BH



- Burst events
  - e.g. GRBs, supernovae with asymmetric collapse



- Stochastic background
  - Primordial Big Bang (t ~ 10^{-22} sec)



- The Unexpected

Why characteristics of GW drive need for global array?

Multiple detectors observing the same wave are needed for-

- **Reliable detection**
  - Need incredibly sensitive detectors; S/N will not be large
  - Want coincidences between widely separated detectors so not fooled by local noise.
- **Angular resolution of source**
  - Source location in sky found by triangulation using relative time-of-arrival of signal at different detectors
  - Angular resolution ~projected area of triangle as seen by source
    - For good full sky resolution need a tetrahedron of detectors with intercontinental baseline
- **Extraction of signal polarization**
  - Requires multiple detectors oriented differently to project out the two polarizations
- Also get higher on-air duty cycle with multiple detector array

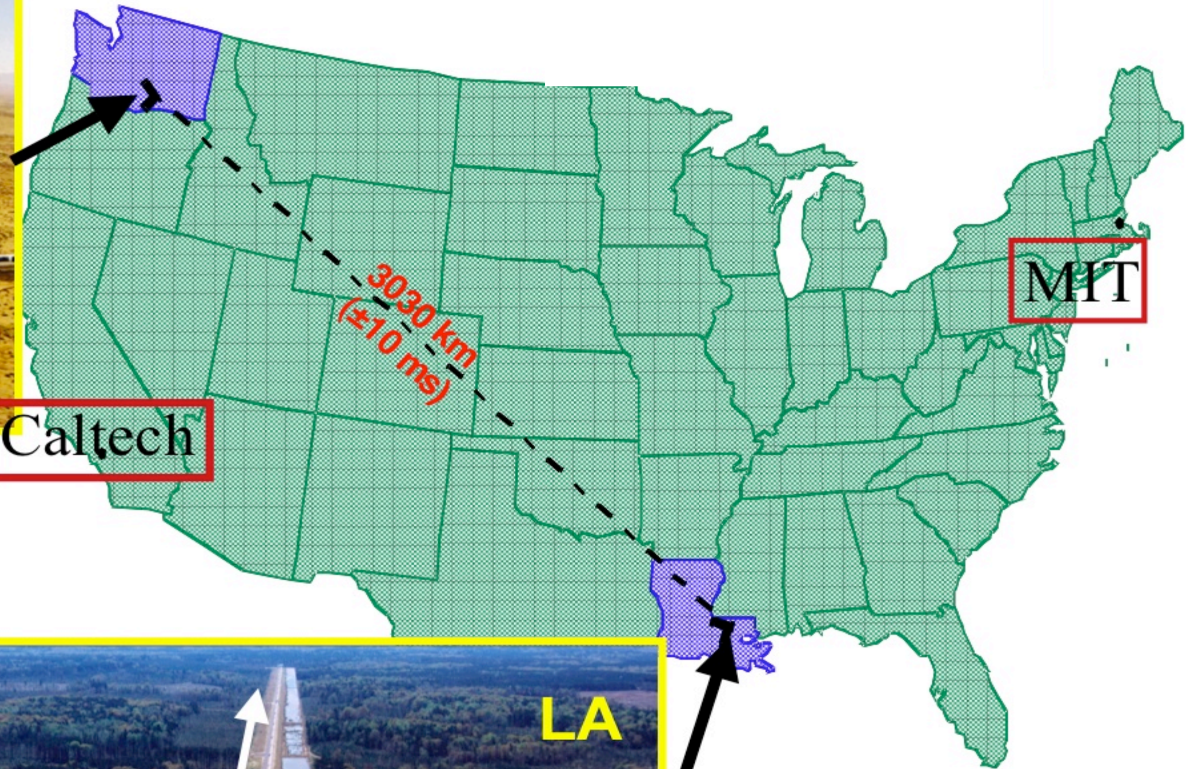
The global array of ground-based GW detectors

Now and in the future

Note--

- Not considering space-based instruments; e.g. LISA, DESIGO in this talk
- Their observation band will be complementary to ground-based detectors

LIGO Laser Interferometer Gravitational-wave Observatory



- Managed and operated by Caltech & MIT with funding from NSF
- LIGO Scientific collaboration- ~500 members & 45 institutions, world-wide

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GEO-600

600 meter arm length

- Hannover, Germany
- GEO collaboration-UK, Germany
- Part of LIGO Scientific Collaboration
- Funded by STFC, MPG, Niedersachsen, VW, BMBF

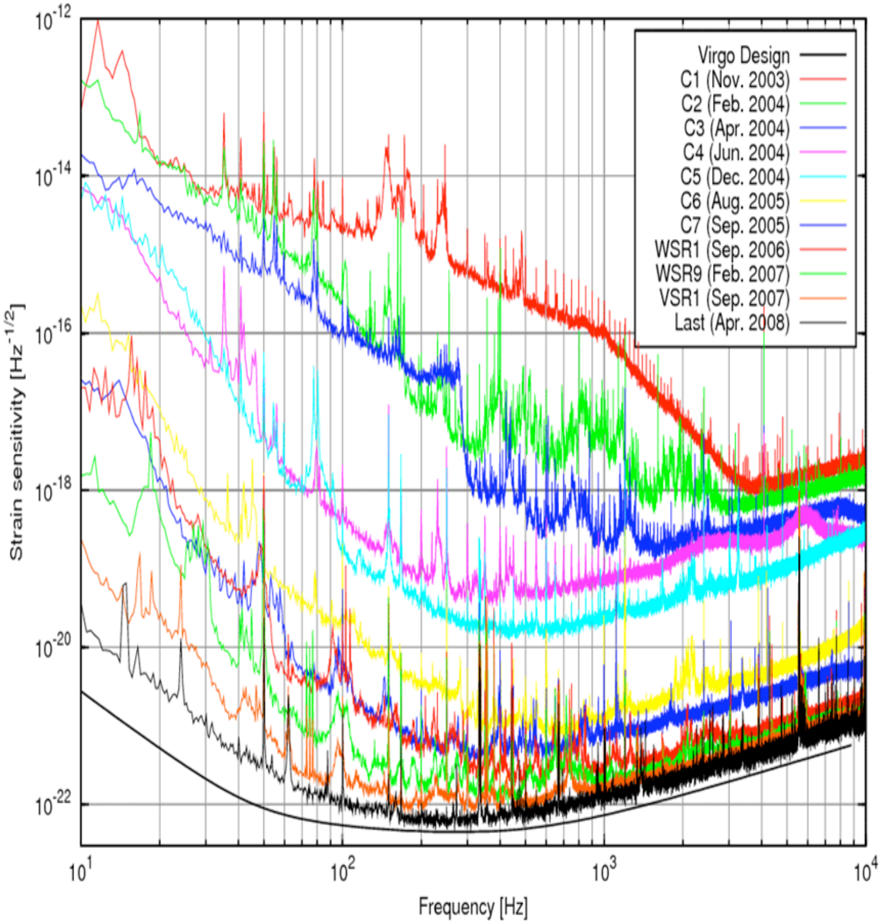
Virgo

3 km arm length

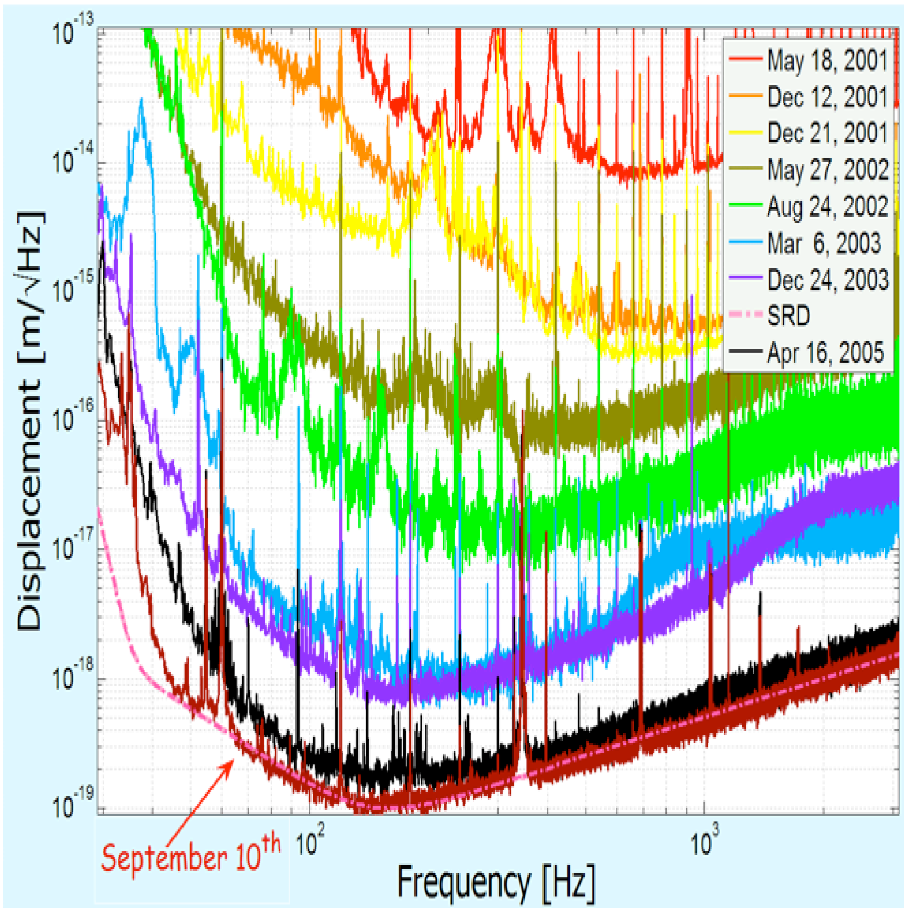
- Cascina, near Pisa Italy
- Italy, France, Netherlands, Poland collaboration
- funded by INFN & CNRS
- Operated by the European Gravitational Wave Observatory (EGO)

Orders of magnitude improvement in the sensitivity of GW interferometers in past years

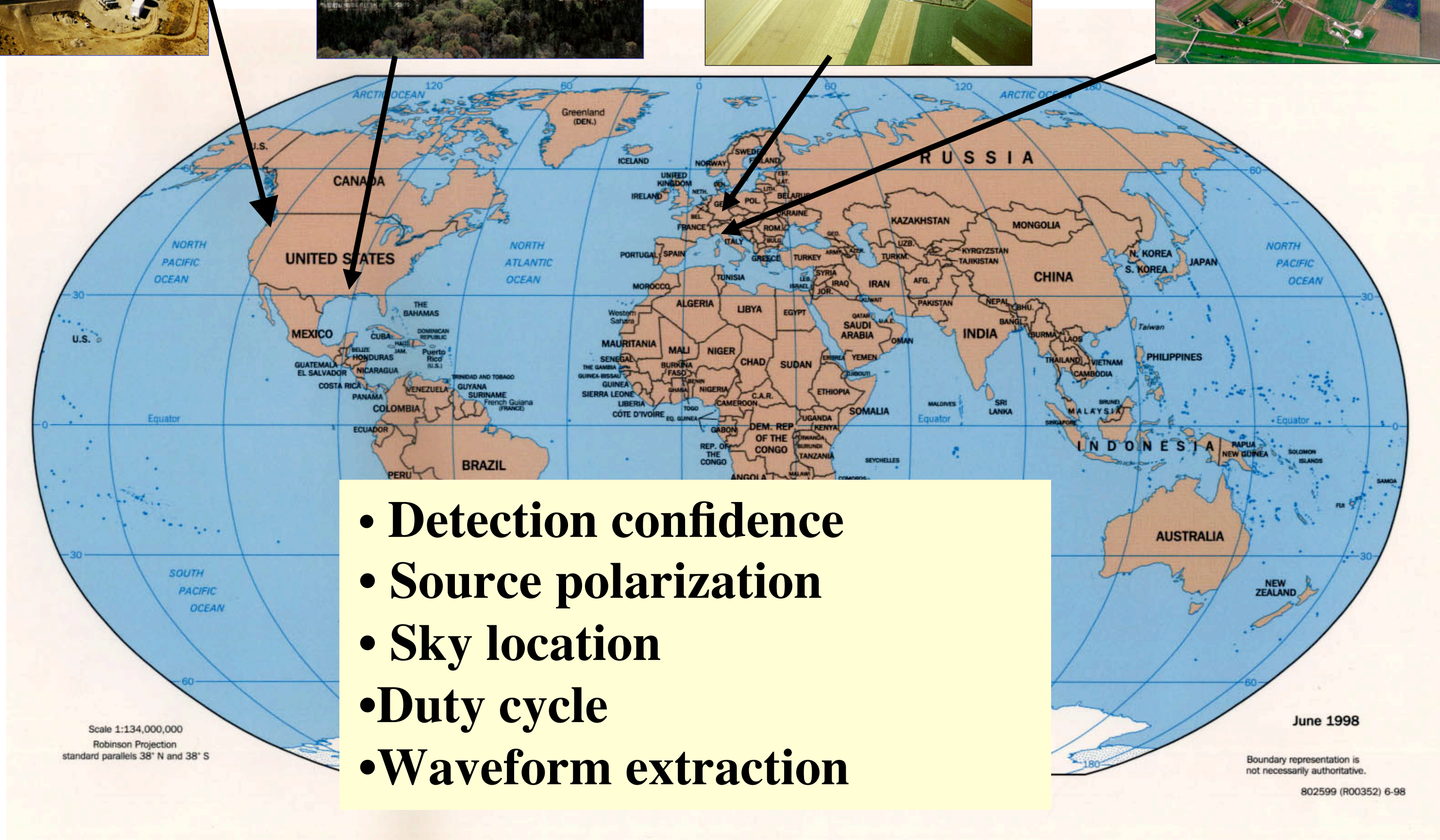
Virgo



LIGO



2008-Global network of 5 interferometers



- **Detection confidence**
- **Source polarization**
- **Sky location**
- **Duty cycle**
- **Waveform extraction**

Other GW facilities

• R&D facilities to develop advanced techniques and as basis for future large-scale facilities

Japan--

• TAMA- 300m arm length at National Astronomical Observatory near Tokyo
• CLIO-- 100m cryogenic interferometer in Kamioka mine

⟶ **LCGT**-- Large Cryogenic Gravitational Wave Telescope
proposed 3 km cryogenic interferometer in Kamioka mine

Australia--

• AIGO R&D- 80m R&D facility at Gingin Australia

⟶ **AIGO**-- Australian International Gravitational Wave Observatory
planned 4 km interferometer at Gingin

Network of advanced detectors coming online-- ~2015-2020

Advanced LIGO- 3x4 km with10x improved sensitivity over initial LIGO

- construction began April 1, 2008; completion in 2014
- funded by US NSF with in-kind contributions from UK and Germany

Advanced Virgo- sensitivity comparable to Advanced LIGO

- expect construction start in 2009 funded by INFN & CNRS

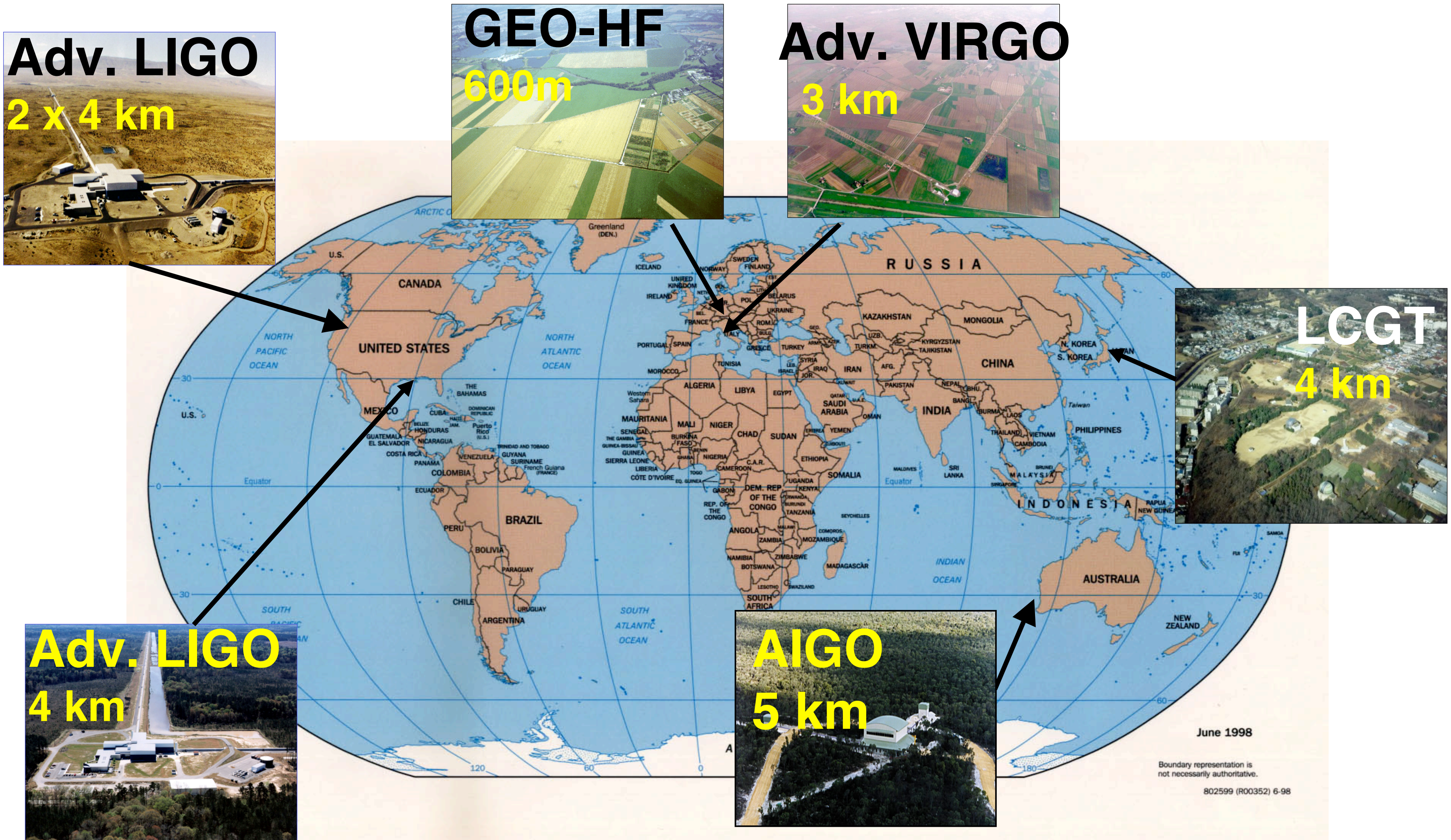
GEO-HF- New technical developments at GEO-600 will give improved sensitivity at high frequency (~1kHz)

LCGT- proposed 3 km cryogenic detector in Kamioka mine (Japan)

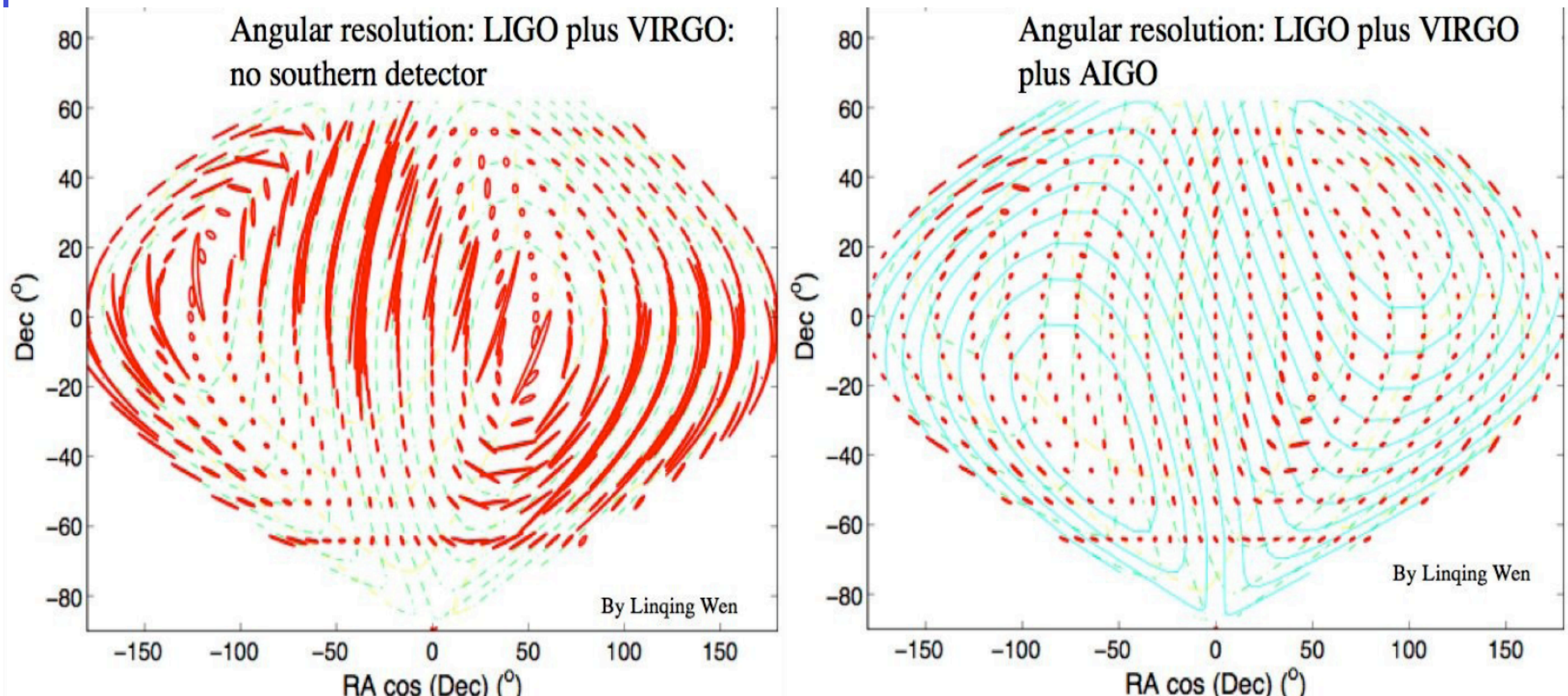
AIGO- to be proposed 4 km detector at Gingin (Australia)

~2015-2025- *Global network of interferometers*

including Asia and Southern hemisphere

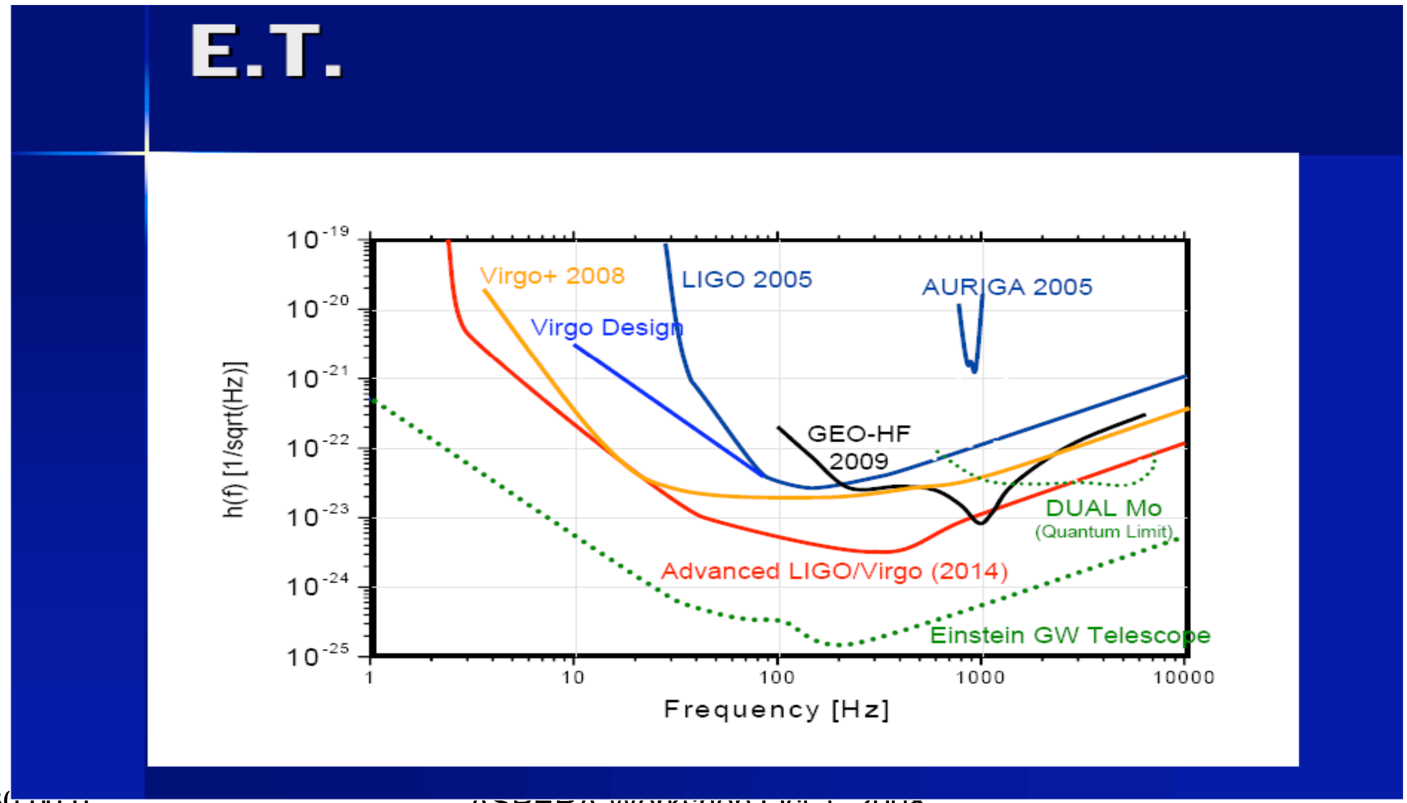


Example-A detector in Australia (or Japan) comparable to LIGO and Virgo would significantly improve network's angular sensitivity



~2025--the Einstein Gravitational Wave Telescope

- ET is a European initiative for next-generation underground GW telescope-
  - ~ 10x more sensitive than Advanced LIGO
  - Sensitive from ~1 Hz to ~10^4 Hz



How coordination between operating detectors is handled now

--the details--

Focus on LIGO, GEO, Virgo

Status of the global coordination

- GEO and LIGO have been carrying out all observing and data analysis as one team, the LIGO Scientific Collaboration (LSC).
- Many years ago in anticipation of future joint analyses, LIGO and Virgo agreed on a common data format

Status of the global coordination

- In early 2007 LIGO (incl. GEO) and Virgo signed an MOU
  - MOU is supported by funding agencies- NSF, INFN, CNRS, STFC, MPG

- Agreed to begin joint data analysis and joint run planning.

- ***To further development of the global network, LIGO-Virgo MOU explicitly states that this collaboration is open to other interferometers when they reach the appropriate sensitivity levels.***

LIGO-Virgo collaborative arrangement-- a working model-- Governance highlights

- Collaborations keep their identities, independent governance and independent funding
- All data analysis activities are open to all members of the LSC and Virgo Collaborations
- Joint committees have been set up to coordinate data analysis, review results, run planning, and computing.
  - The makeup of these committees decided by mutual agreement between the projects.
- Joint publication of observational data whether data from Virgo, or LIGO (GEO) or both
  - Organization of joint data analysis described in detailed attachment to MOU

LIGO-Virgo collaborative arrangement-- a working model-- Governance highlights

- Author lists are separately established according to the rules of each collaboration, and maintained by them.
  - When papers are published, the author lists will be combined in a manner established by mutual agreement between the collaborations."
- Joint collaboration meetings 4 times/year alternating between Europe and US
- Bi-weekly meeting of LIGO and Virgo leadership
- After 1 1/2 years the LIGO/GEO-Virgo collaboration is working extremely well

The Gravitational Wave International Committee (GWIC) roadmap

GWIC-Another component of the international GW community

- GWIC, the Gravitational Wave International Committee, was formed in 1997
- It is affiliated with the International Union of Pure and Applied Physics as a sub-committee of IUPAP's "Particle and Nuclear Astrophysics and Gravitation International Committee".
- An international organization to facilitate international collaboration and cooperation in the construction, operation and use of the major gravitational wave detection facilities world-wide.
- Members include the leaders of all projects world-wide: ground-based & space based, as well as theory, numerical relativity, pulsar timing

GWIC Roadmap for the GW field

In July 2007, GWIC charged a committee with developing a 30-year roadmap for the field

- Roadmap is a platform for global planning for the development of the field and for cooperation and collaboration across the globe
- GWIC Roadmap process is still in progress
  - Report will be presented to full GWIC in a few months
- Ground-based part of roadmap focuses on the path to a true global network of instruments for GW astrophysics/astronomy

GWIC Roadmap committee --membership

- **Representing**
  - Space and ground-based community
  - Major projects, world-wide
  - Japan, Europe, US, Australia
  - Astrophysics, instrument science
  - Theory, experiment

- **Committee members**
  - Karsten Danzmann (Europe)
  - Jim Hough (GWIC chair) (Europe)
  - Kazuaki Kuroda (Japan)
  - Jay Marx (chair) (US)
  - David McClelland (Australia)
  - Benoit Mours (Europe)
  - Sterl Phinney (US)
  - Sheila Rowan (Europe)
  - Flavio Vetrano (Europe)
  - Stefano Vitale (Europe)
  - Stan Whitcomb (US)
  - Cliff Will (US)

GWIC
Gravitational Wave International Committee

Topics for Roadmap

- The long-term scientific value of the field and how it fits into the larger scientific landscape
- Anticipated **scientific opportunities** utilizing gravitational waves in the 10, 20, 30 year horizon and the facilities and capabilities **on earth and in space** needed to reach these opportunities
- The scientific value of existing and planned facilities ***in the perspective of a global network***
- **Theory and numerical relativity** —anticipated developments and impact on the science capabilities of the field
- Impact of **technologies**
  - Projected new technologies that will improve capabilities.
  - Impact of technologies developed in our field on other fields of science

Summary

- Evolving global network of GW detectors is driven by science and nature of GWs
- Currently LIGO (incl. GEO) and Virgo are fully linked--coherent data analysis and joint planning
  - A working model for governance of collaborating collaborations
  - Open to other collaborations as other high sensitivity instruments come on-line
- Expect network to evolve to include LCGT (Japan), AIGO (Australia) and future underground 3rd generation detectors (e.g. ET)
- GWIC furthers international collaboration
  - GWIC roadmap for field being prepared- expected completion in a few months