Gravitational Waves and LIGO (India)

Jayanti Prasad

Inter-University Centre for Astronomy & Astrophysics (IUCAA)
PUNE - 411007

OSG All Hands Meeting 2017
San Diego Supercomputer Center (SDSC) at UC San Diego
March 06 - 09, 2017

Why to study gravitational waves ?

- Direct confirmation of the existence of black holes, including a test of the fundamental “no-hair” theorem
- Tests of general relativity under extreme strong-field conditions
- Measurement of the propagation speed of the graviton
- Detailed information on the properties of neutron stars, including the equation of state
- Insights into the earliest stages of the evolution of the universe through the measurement of primordial gravitational waves
- Studies of galactic merging through the observation of coalescing massive black holes at their centers

[Camp J.B and Cornish N. J. (2004), Annu. Rev. Nucl. Part. Science **54**, 525]

How Gravitational are detected ?

3.2 Physical Properties of Gravitational Waves | 39

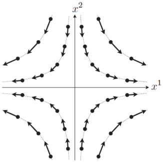


Figure 3.1 Lines-of-force diagram in the transverse plane of a purely plus-polarized gravitational wave. The name "plus" arises from the shape of these lines of force.

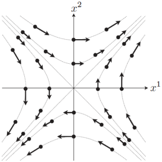


Figure 3.2 Lines-of-force diagram in the transverse plane of a purely cross-polarized gravitational wave. The name "cross" arises from the shape of these lines of force, cf. Figure 3.1.

[Jolien D. E. Creighton, Warren G. Anderson (2011)]

Gravitational Wave detectors

60 | *3 Gravitational Waves*

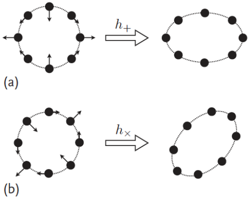
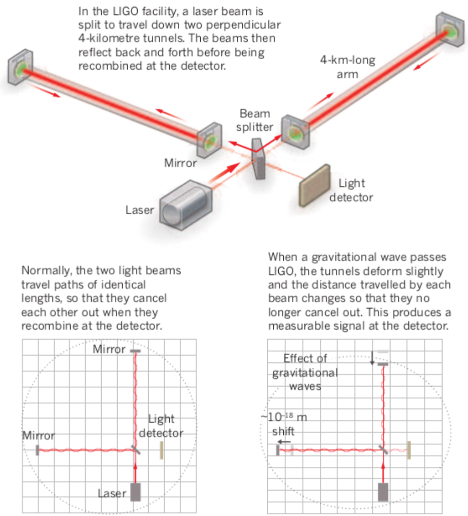


Figure 3.3 The distortion of a hoop of particles lying in the transverse plane of a passing gravitational wave; (a) the effect of a purely plus-polarized gravitational wave and (b) the effect of a purely cross-polarized gravitational wave.

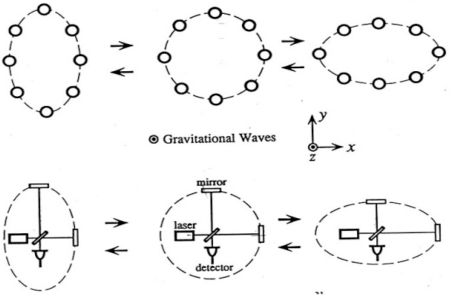
[Jolien D. E. Creighton, Warren G. Anderson (2011)]

How LIGO works ?



[Alexandra Witze, Nature (2014) **511**, 16 July 2014]

How LIGO works ?



The effect of a passing gravitational wave on a set of masses arranged in a circle and the detection scheme using a Michelson interferometer.

LIGO Observatories

LIGO

Laser Interferometer Gravitational-Wave Observatory

Binary mergers are the main source of GW

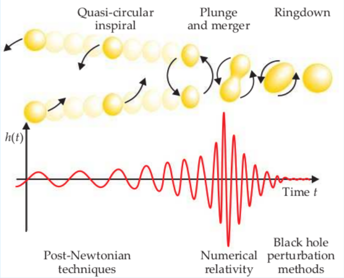
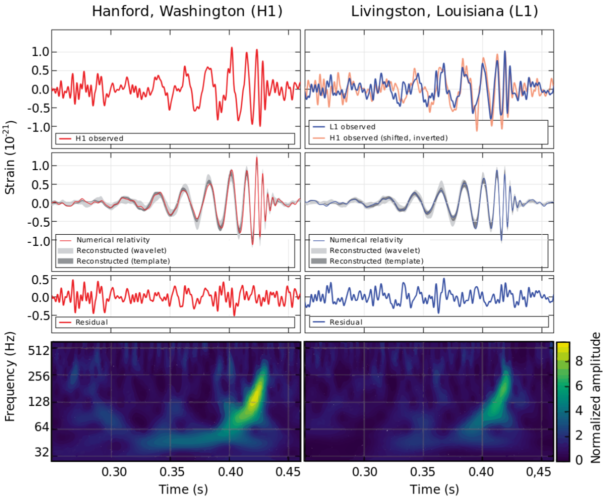


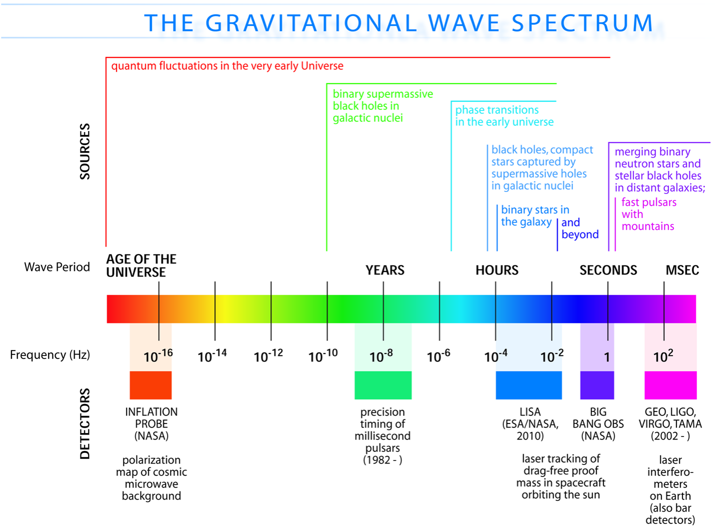
Figure 1. Coalescence of a compact binary. The loss of energy and angular momentum via the emission of gravitational radiation drives compact-binary coalescence, which proceeds in three different phases. The strongest gravitational-wave signal, illustrated here as the gravitational-wave amplitude *h*, accompanies the late inspiral phase and the plunge and merger phase; for that part of the coalescence, post-Newtonian and perturbation methods break down, and numerical simulations must be employed. (Adapted from ref. 3.)

[Thomas W. Baumgarte and Stuart L. Shapiro, Physics Today October 2011]

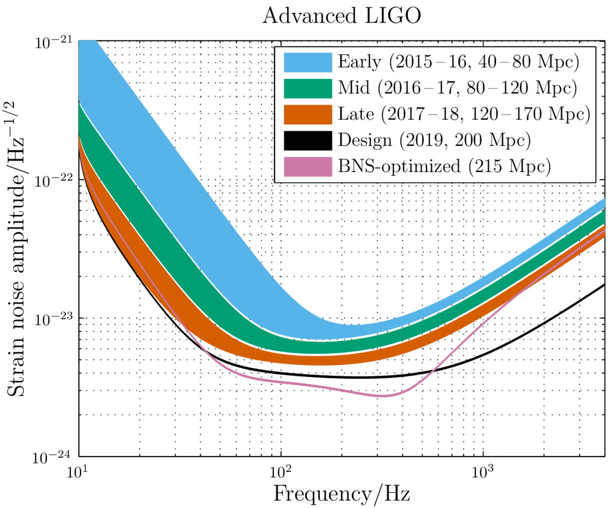
GW 150914 !



[Abbott et. al.,Phys. Rev. Lett. 116, 061102 (2016)]



[http://www.ligo.org/science/faq.php]



[http://www.ligo.org/]

Why LIGO-India ?

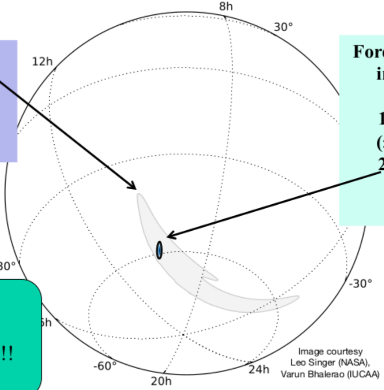
- A network of ground based gravitational wave detectors, strategically located at different geographical location, has many advantages.
- Hanford-Livingston pair of LIGO detectors in USA can localize a source of gravitational waves only within few hundred square degrees.
- Adding an extra LIGO detector in India will give significant improvement in the sky localization of the gravitational wave source.

The LIGO-India Advantage

LIGO INDIA

LIGO-US observatories have detected a GW signal
(announced publicly on Feb 11, 2016)

Current:
Two US detectors sky-localization (620 square degree 2500 full moons)

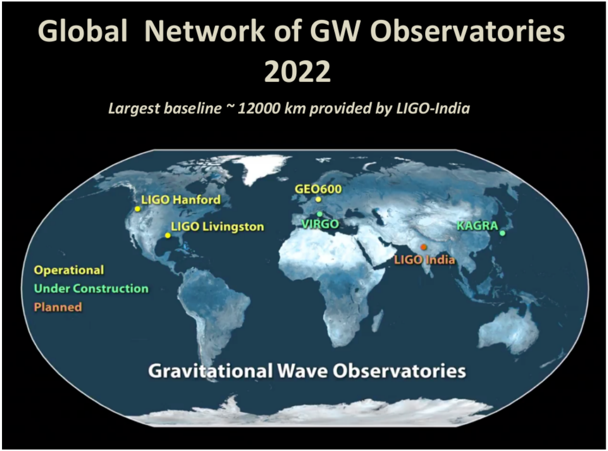


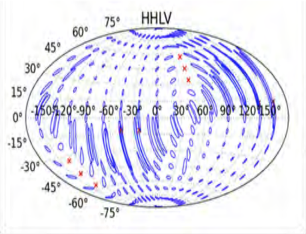
Forecast : LIGO-India in joint operation sky-localization 100 time smaller (5 square degrees 20 full moons) !!!

LIGO-India will make a BIG difference !!!!

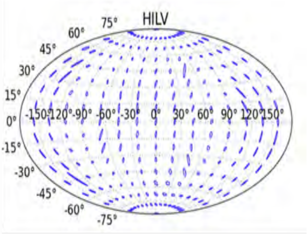
6

[Tarun Souradeep (2016), Beyond Gravitational wave discoveries with LIGO-India]


Global Network of GW Observatories
2022
Largest baseline ~ 12000 km provided by LIGO-India
LIGO Hanford
LIGO Livingston
GEO600
VIRGO
KAGRA
LIGO India
Operational
Under Construction
Planned
Gravitational Wave Observatories

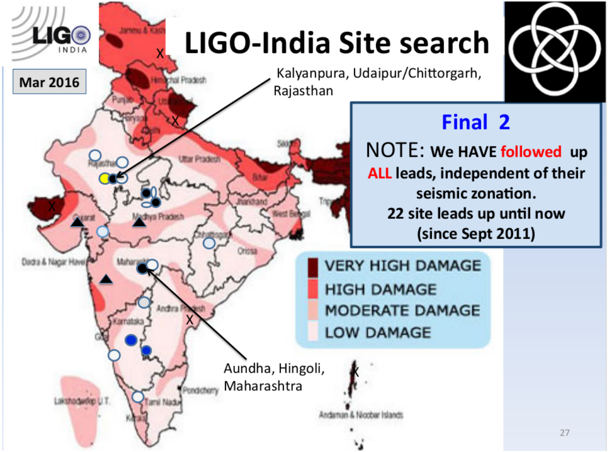


Original plan
2 +1 LIGO USA+ Virgo



LIGO-India plan
1+1 LIGO USA+ Virgo+ LIGO India

Maps of the sky comparing how accurately the positions of compact binary coalescence sources can be located without (left) and with LIGO-India (right).



[Tarun Souradeep (2016), Beyond Gravitational wave discoveries with LIGO-India]

LIGO-India Project
An Indo-US Collaboration

Funding agencies: NSF (USA) and jointly **DAE**(India) & **DST**(India)

Institutions: LIGO Laboratories, **Caltech** & **MIT** (USA), **IPR**, **IUCAA** & **RRCAT** (India

Proposed Indian commitment

- **Construction and Operation of an Advanced LIGO Gravitiational-wave observatory on Indian soil in collaboration with the LIGO Laboratory**
- Infrastructure including 8 km of UHV system (10 million litres) with controls, installation of detector, as well as, the build up the team to build and operate the observatory.

Proposed US commitment

- **The entire hardware components of an advanced LIGO detector** along with facility designs and software provided by LIGO-USA.
- Close collaboration, technology transfer.

8

[Tarun Souradeep (2016), Beyond Gravitational wave discoveries with LIGO-India]

LIGO-India: Proposed Project Work Breakdown

To be executed by three lead institutes under a central project management team:

1. **Inter-University for Centre for Astronomy & Astrophysics (IUCAA)**
2. **Institute for Plasma Research (IPR)**
3. **Raja Ramanna Centre for Advanced Technology (RRCAT)**

The Project Work is sub-divided into broad activity-wise categories

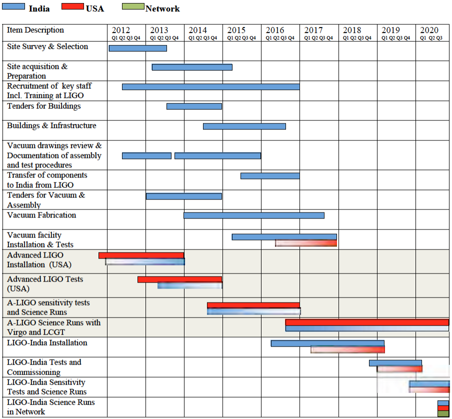
These activities will be carried out as per the MOU among them.

IUCAA	IPR	RRCAT
Site selection and survey	Civil Infrastructure and facilities	Detector Hardware Documentation & Pre-installation
Data analysis & Computing facility	Vacuum System & Mechanical Engineering	Optics & 3rd generation R&D
Science & Human Resource Development	Implementation of CDS system	Detector integration, installation and commissioning

8

[Tarun Souradeep (2016), Beyond Gravitational wave discoveries with LIGO-India]

LIGO-India schedule



Note: The installation and commissioning of the LIGO-USA detector will be complete by about 2016 and some LIGO scientists and engineers who are experienced on the assembly and tests of the detector (post-doctoral associates and engineers) will be able to join the LIGO-India effort for short durations from few months to a year or two. This will accelerate the LIGO-India schedule, as indicated in this table. The red stripes along with the blue one indicate some LIGO-USA involvement, with cost management from LIGO-India.

[LIGO-India Project report (outdated)]

What IUCAA is doing for LIGO data ?

GW Data Centre @ IUCAA

Towards Future Tier-1 with LIGO-India operations

- **Earlier IUCAA data center:** (oper. Jan 2013) 30Tf , 600 Tb [10Tf for GW]
- **New GWDA center:** ~100Tf, 2520 cores [~1.2M$USD, 80 M Ind Rupee]
  - The cluster is now ready to be opened for LVC collaboration
  - 50% resources will be devoted to LVC (beta mode in first two weeks)
  - will be integrated to LDG accounting system
  - information on how to access the cluster will be circulated shortly
- **TATA Trust grant for GW science center [~1.2M$USD - 3yrs]**
  - A system administrator (Dr. Jayanti Prasad) and an assistant has been hired
  - Discussions with CDAC are under progress for long term partnership
- LSC system administrators (especially Satya Mohapatra) have provided crucial support & IUCAA system administrators are also putting significant amount of time

All infrastructure for future expansion to ~500 Tf in place

➢ *Planned LIGO Tier-3 Computing Cluster at ICTS-TIFR*

- **Budget: 1 cr INR (.17 M$) 500 Cores, ~20 Tf, 100 TB storage**
- **Installation of compute nodes completed Feb 2016**
- **Plan to upgrade to Tier-2 by 2018**

17

GW Data Centre @ IUCAA

- **Current IUCAA data centre:** (oper. Jan 2013) 30Tf , 600 Tb [10Tf for GW]
- **GWDA centre:** ~100Tf, 2400 cores (LSC Tier2 level) [Jan 2016]:
  Hardware arrived, installation to begin
- **Future Tier-1 LIGO data centre post LIGO-India operations**
- **All** infrastructure for future expansion to ~500 Tf in place



3.3. Tier 2 Centers

The LDG Tier 2 centers are LSC members institutions who provide collaboration-wide computing resources to authorized users through LIGO Data Grid funding and/or institutional funds. Designation as a Tier 2 center must be approved by the LSC Computing Committee. Tier 2 centers are **required** to provide:

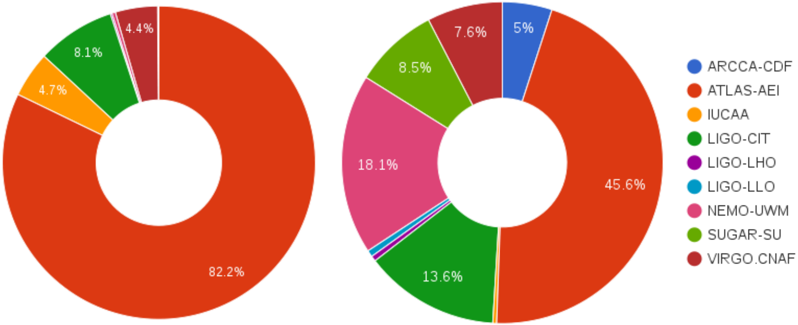
- LIGO Data for distribution to other compute centers
- compute resources to authorized users for data analysis
- user support for the same
- access to LIGO Data to all authorized users
- a web server for user pages authenticated with the LIGO IdM infrastructure.

Tier 2 centers are **authorized** to provide:

- LIGO IdM protected collaboration tools for the LSC such as wiki pages, mailing lists, etc.
- a Kerberos KDC to support LIGO IdM authentication
- an authorization infrastructure for access control
- distribution of the LIGO data to authorized compute resources outside the LDG
- low-latency data replication services

Reference : LIGO-M0900325-v13

Sarathi as part of Ligo Data Grid



Software and Hardware Resources

- Scientific Linux 7.2
- Globus Toolkit (6.0)
- Condor (8.6.1)
- pegasus (4.7.4)
- LIGO Data Grid: 5.2.4
- LSCSOFT

Login node1	ldas-grid.gw.iucaa.in	2 Intel Xeon E5-2680-v3 (24 C), 256 GB RAM
Login node2	ldas-pcdev1.gw.iucaa.in	2 Intel Xeon E5-2680 -v3(24 C), 256 GB RAM
Compue nodes	cn001-cn100	2 Intel Xeon E5-2680-v3 (24 C), 256 GB RAM (20 nodes), 128 GB (80 nodes)
GPU nodes	gpu001-gpu001	2 Intel Xeon E5-2680-v3 (24 C), 256 GB RAM, 2 Nvidia Tesla K40m
Storage	All nodes	240 TB (NAS), Each node with 200 GB SSD + 600 GB Spinning disk
Network	Cluster internal	1G , 10 G

Services

- LDAP
- NFS
- grid-mapfile (lgmm)
- gsissh
- gridFTP
- condor
- ganglia
- Shibboleth authenticated (web) services
- LDG accounting
- Wikis
- mailing lists
- bug-tracking (redmine)
- Documentation
- CMU

Acknowledgements

Members of Sarathi team at IUCAA

- Sanjit Mitra
- Jayanti Prasad
- Malathi Deenadaylan
- Ajay Vibhute
- Sarah Ponrathnam

Thank You !