LIGO-India:
An Indian mega-science (ad)venture

FGWA 2019
ICTS-TIFR, Bengaluru
Aug 22, 2019

LIGO-India Project

An Indo-US Collaboration

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

Institutions: LIGO Laboratories, **Caltech** & **MIT** (USA),
LIGO-India: IPR, **IUCAA, RRCAT, DCSEM** (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 key hardware components of an advanced LIGO detector** (80M USD) + facility design, open technology provided by LIGO-USA.
- Close technology collaboration.

The LIGO-India Advantage

First GW detection by Advanced LIGO-US observatories

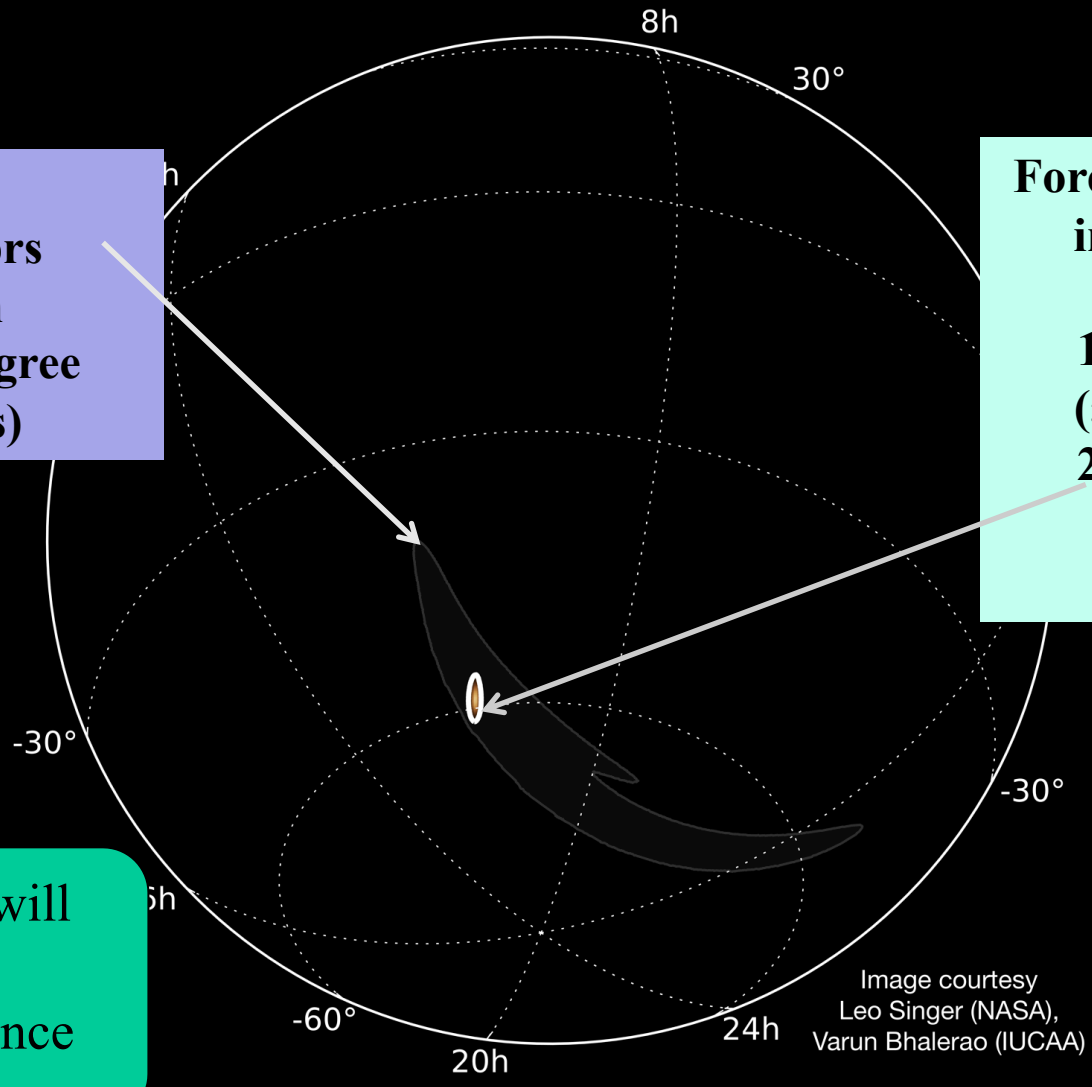


Image courtesy
Leo Singer (NASA),
Varun Bhalerao (IUCAA)

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 !!!!

B. P. ABBOTT *et al.* PHYS. REV. X **6**, 041015 (2016)

LIGO-India: unique opportunity

Setup, commission & operate by India

By lead institutes: IUCAA (UGC), IPR (DAE), RRCAT(DAE)

IUCAA is the key science stakeholder

- **LIGO-India: Allow full exploitation of *Gravitational-wave observations as integral part of Multi-messenger astronomy***

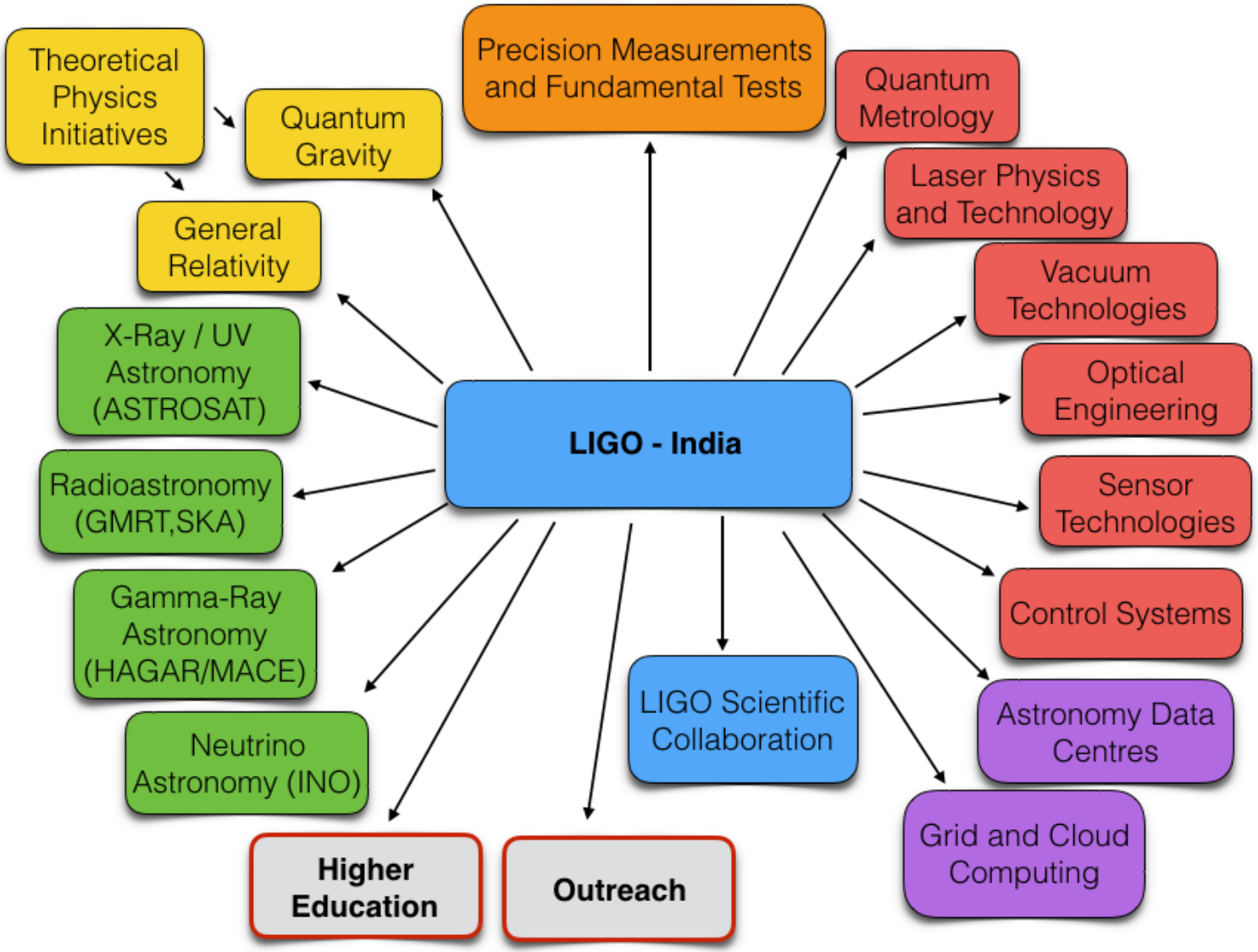
- **High end frontier Technology**
  Transformational for Indian hi-tech capabilities
  in photonics, lasers, controls systems & vacuum

- Strategic Indian Geographical & Demographic advantage
  Implies Global cooperation, not competition

- Research opportunity at home for UG & PG students of S&T
  Implies possibility for extensive HRD and training in frontier areas

LIGO INDIA

Highly Multi-disciplinary Astro^{++}



IndIGO Consortium – a brief history

- **Dec. 2007 : ICGC2007 @IUCAA: Rana Adhikari's visit & discussions**

- 2009:
  - Australia-India S&T collaboration (Iyer & Blair)

  Establishing Australia-India collaboration in GW Astronomy

- **IndIGO Consortium: IUCAA Reunion meeting (Aug 9, 2009)**

- 2009-2011:
  - Meeting with Intl committee at Kochi, Pune, **Shanghai**, Perth, Delhi
  - July 2011: IndIGO admitted to GWIC in : Intl. recognition of the growing GW activity & community in India.
  - IndIGO accepted into the LIGO Science Collab. (LSC) : pan-Indian 7 institutes: 15 members

- March 2011: IndIGO-I Proposal: Participation in LIGO-Australia ~10-15%

- **May 2011+: LIGO-India..**

Early steps towards LIGO-India

- April 2011: First informal queries about LI possibility
- October 2011: LIGO-India included in the list of Mega Projects under consideration by the Planning commission
- Nov 2011: IndIGO submitted Project Proposal to DAE-DST Consortium proposing the consideration of LIGO-India as a Mega-Science Project in the XIIth five-year plan
- April 2012 – LIGO-India discussed at Atomic Energy Commission (AEC) meeting and approved
- August 2012 National Science Board go ahead for LIGO plans for relocating third detector to India

LIGO-India: Key Milestones

- Feb 2016: LIGO-India granted 'in principle' approval by Union cabinet
- Mar 31, 2016 : Indo-US MoU signed between NSF (USA) and DAE + DST (India)
- Jul 2016: LIGO-India site selection committee report recommends primary site.
- Aug 2016 : DAE & DST form LI Apex comm., Project & Scientific Mgt. Boards
- Aug. 2016: LI Site acquisition team constituted.
- Jul 2017: pre-project funds committed (~150 Cr INR = 23M USD) sanctioned.
- Aug 5, 2017: First land acquisition- State Govt. (5.94 ha) to LIGO-India.
- Aug 11, 2017: DAE Office Memo on Standard Operating procedures for finances

Cont'd...

LIGO-India: Key Milestones

- Jul 2018: DAE sets in place the necessary project appraisal committee for DPR
- Aug 2018: First LIGO-India Apex Committee meeting with DAE-DST top brass
- Sept 24, 2018: Clearance “Forest” land diversion by Forest Advisory Committee.
- Jan 9, 2019: Environmental and Pollution Board Clearance from State (SEAC).
- Jan 31, 2019: Crucial meeting of Niti Ayog & Principal Scientific Advisor (PSA).
- Feb 16, 2019: LIGO-India DPR approved by Atomic Energy Commission (AEC)
- Mar 2019: 99% land acquisition completed (172 of 174 hectares)
- Jun, 2019: Cabinet note submitted to PMO. Awaiting Union cabinet approval

LIGO-India: Executive structure

- ✓ **LIGO-India Apex Committee**

  Chair: Jointly DAE and DAE Secretary

- ✓ **LIGO-India Project Management Board**

  Chair: Director RRCAT , [members includes other LI Lead insitute Directors]

  Member Sec.: Dr. Sendhil Raja

- ✓ **LIGO-India Scientific Management Board**

  Chair: Director IUCAA , [members includes other LI Lead insitute Directors]

  Member Sec.: Dr. Tarun Souradeep

(All lead institute coordinators co-opted to the Boards.)

LI Project Coordinator: Chair LI-PMB (Director RRCAT)

Oversees LI-Coordinators at LI lead institutions [iPR, IUCAA, RRCAT, DCSEM]

Teams at lead institutions under Activitiy leaders

(Total number of members in LI Observatory: 37

+ More personnel not listed in in LIO.)

LIO : Site acquisition & Prep.

- **Land Acquisition: 100% complete !!!**
  [The most major existential risk to project retired]

- **Formally in construction phase (since Jan.) :** Tenders for Construction of Site Office (Future Estate office) issued, bids under review for selection (two rounds).

- **Environmental Clearance** of the Project received from State SEIAA.

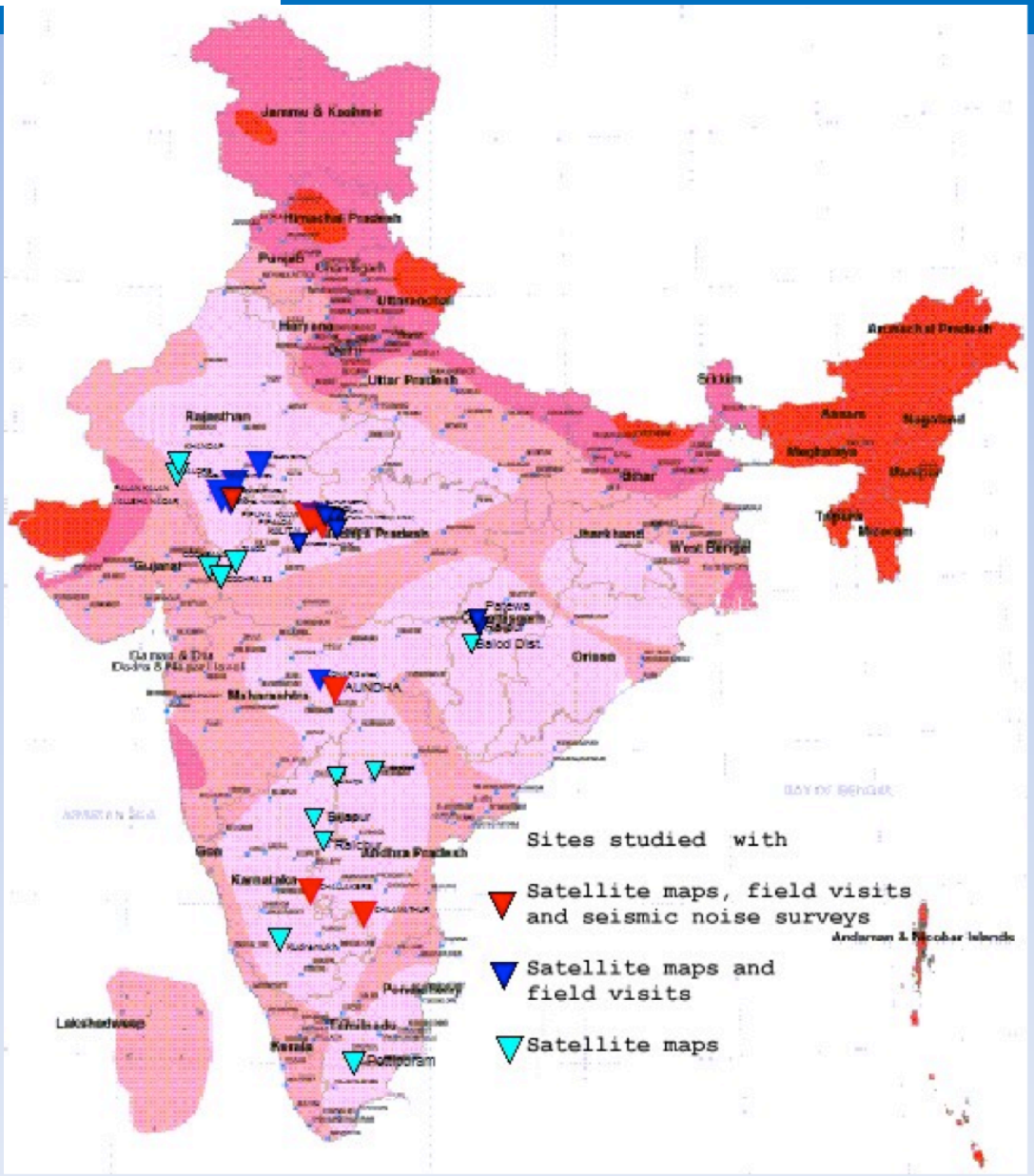
- **Geo-technical & Geo-physical survey** has been completed early 2019.

- **Seismological survey** with 5 stations over 1 year: MOU with Natl. Geophys. Res. Inst. (NGRI) is underway.

- Demand note for **Power (5MW) & water** supply cost from district agencies.

- Advanced stage of **campus land** acquisitions in neighboring town and city.

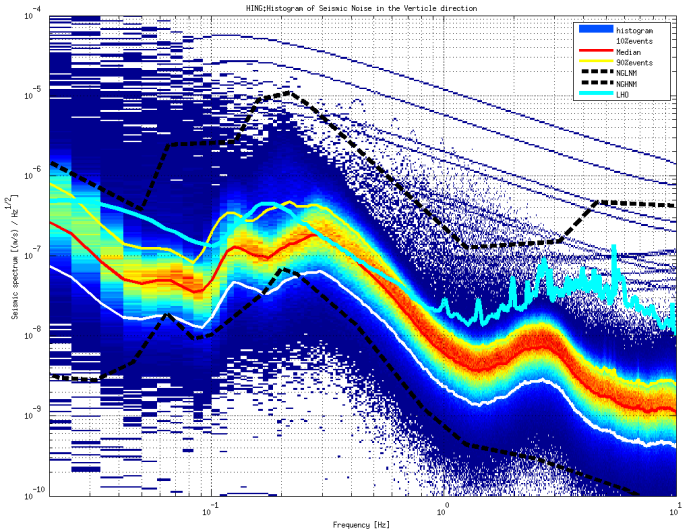
LIGO-India Site search

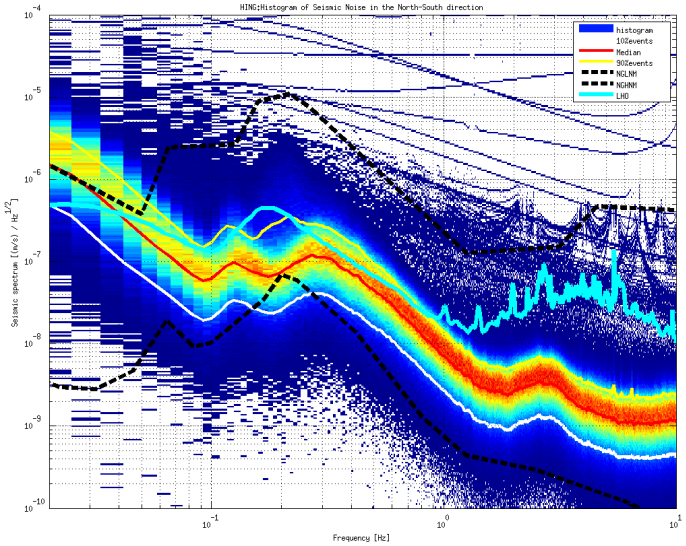


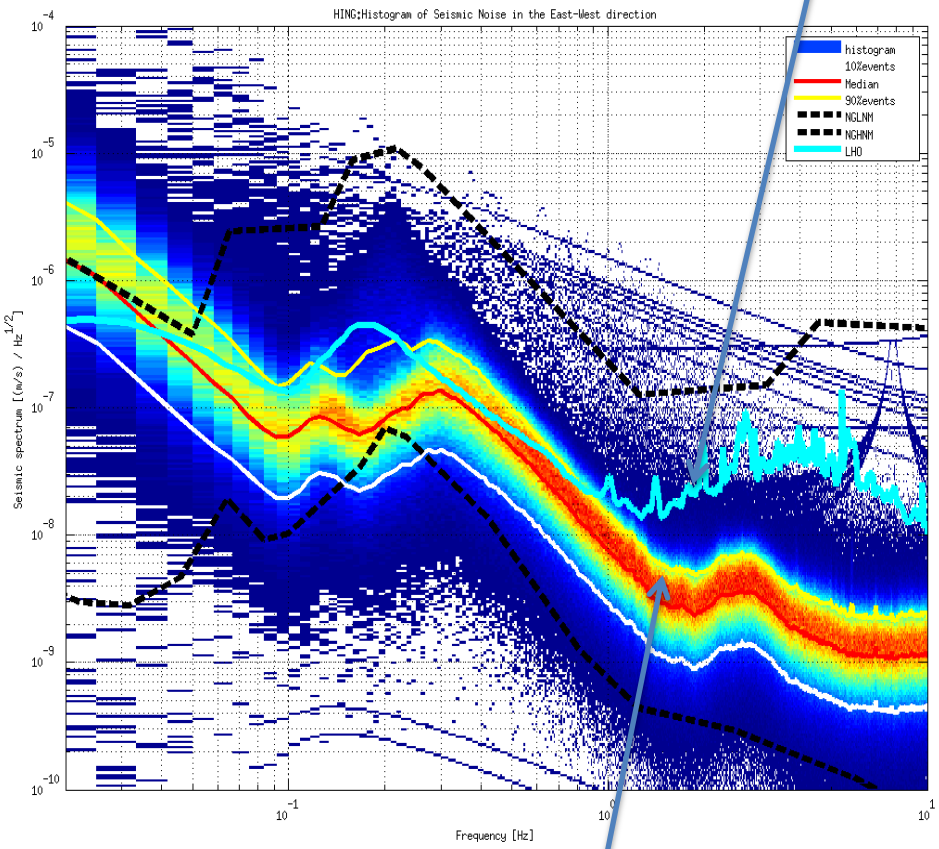
LIGO-India selection
(Sept 2011 – Sept 2016)
39 site leads followed up
Recommendation for primary and backup site Sep 2016

Prelim. Seismic study

Aundha site, Hingoli District, Maharashtra (near Nanded)
[Sep 29-Oct 15, 2013]





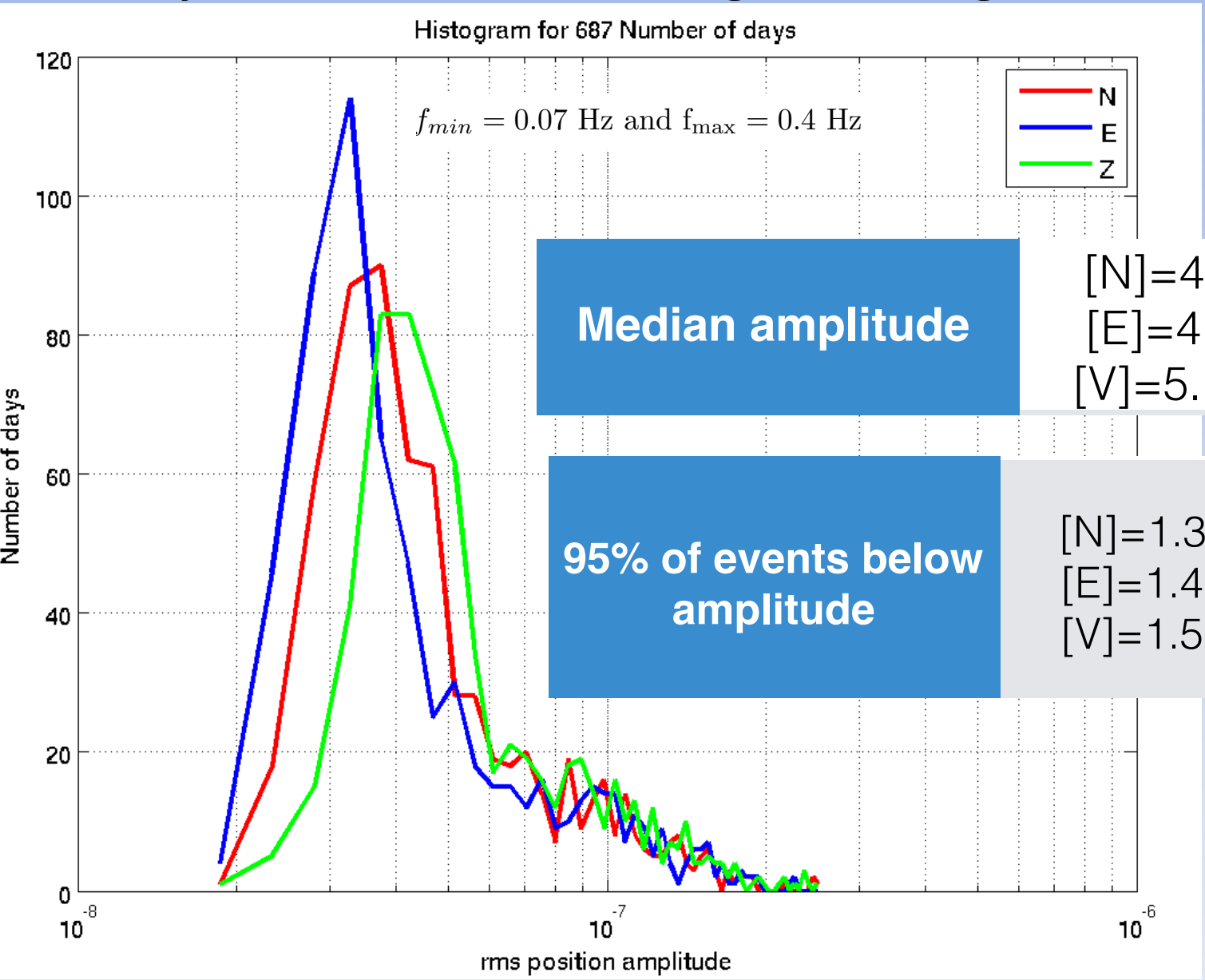


Noise level at US detector site (cyan)

Noise level at our site (red)

Prelim. Micro-Seismic study

2 year data at Nanded College seismological observatory



(2010-2011)

Median amplitude

[N]=4.587x10^{-8} M
[E]=4.083x10^{-8} M
[V]=5.1301x10^{-8} M

95% of events below amplitude

[N]=1.362x10^{-7} M
[E]=1.456x10^{-7} M
[V]=1.503x10^{-7} M

LIGO-India site

LIGO-India site

LIGO-India

Architectural design of LIGO-India at the site (courtesy: DCSEM)

LIO: Civil & Vacuum Infrastructure

Civil:

- Complete Detailed building report for civil infrastructure ready. Reviewed by LI team and a joint discussion with LIGO labs
- Site leveling plan underway.
- Equipment layout confirmed with vacuum and detector. Electrical and mechanical layout drawings.

Vacuum:

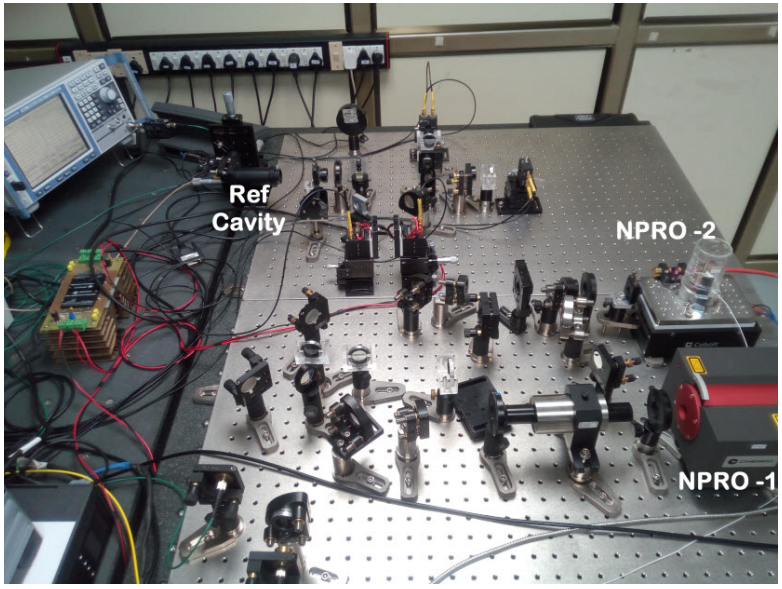
- Conceptual Vacuum drawings, System Requirement document ready and reviewed. Project execution plan for vacuum section under preparation
- Vacuum requirement for prototype HAM, BSC and 40m prototype Beam tube being finalized
- Design of outgassing measurement chamber dedicated for measurement of LIGO steel coupons being finalized.

LIO: Tech. Dev. & Capacity Building

Development of suspended Fabry-Perot Cavity:

A suspended mirror Fabry-Perot Cavity as a test setup for the Controls Team. The suspended mirror Fabry-Perot Cavity designed to achieve a finesse of 400 or higher to match the final requirements for the Control system in LIGO.

Development of Narrow-line width laser



Drawing suspension silica fibers

LIGO-India Science buildup

LIGO-India: The Road Ahead

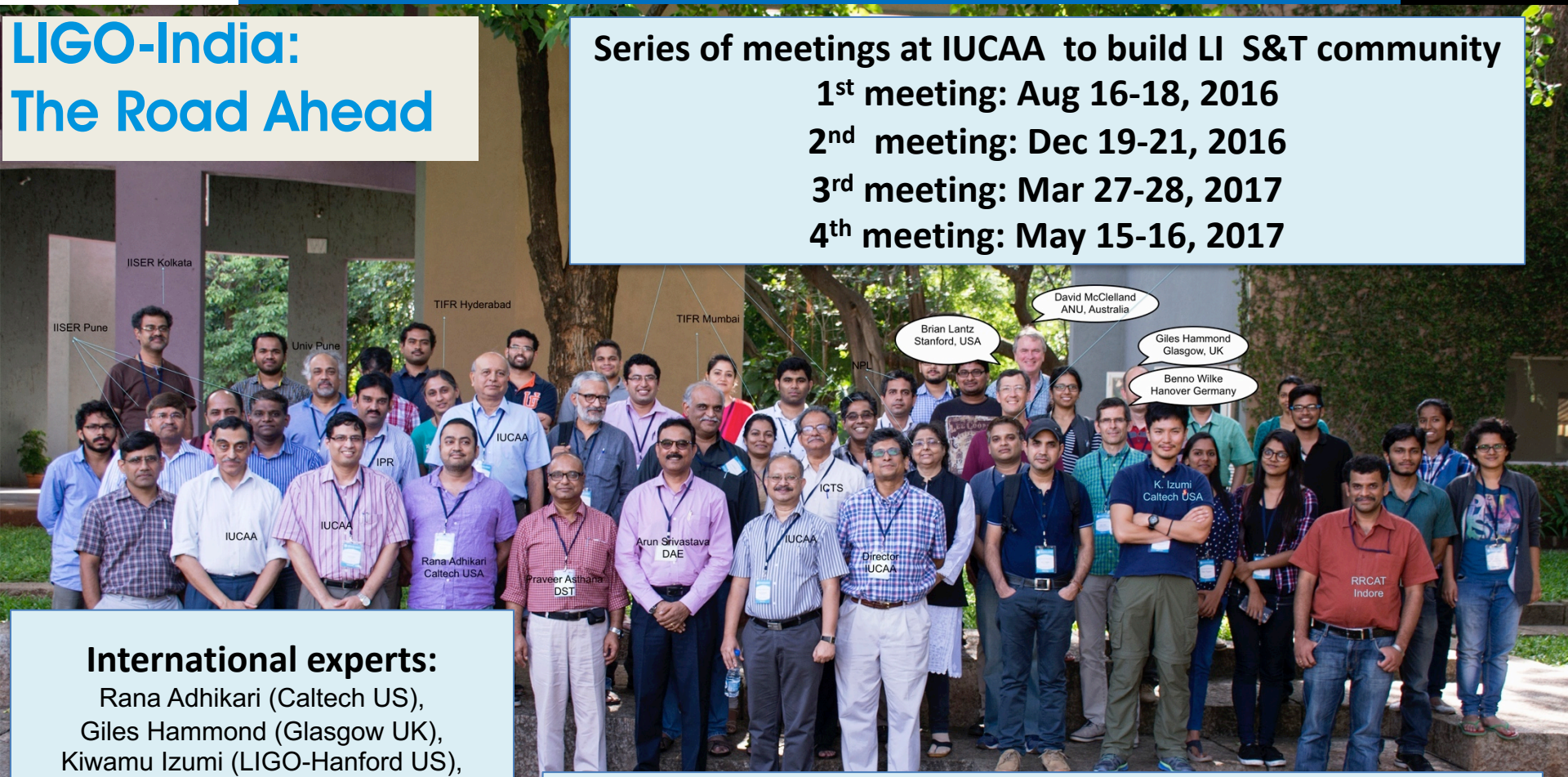
Series of meetings at IUCAA to build LI S&T community

1st meeting: Aug 16-18, 2016

2nd meeting: Dec 19-21, 2016

3rd meeting: Mar 27-28, 2017

4th meeting: May 15-16, 2017



International experts:

Rana Adhikari (Caltech US),
Giles Hammond (Glasgow UK),
Kiwamu Izumi (LIGO-Hanford US),
Brian Lantz (Stanford U, US),
David McClelland (ANU, Aus.),
Benno Willke (AEI-Hannover, Germany)
Brett Shapiro (Stanford U., US)
Andreas Friese (U. Birmingham, UK)
Peter Saulson (Syracuse Univ.)
B.S. Stathyprakash (Penn State U.)
L. Singer (NASA Goddard)

Indian Institutions: IUCAA, IPR, RRCAT, IIT Madras, IIT Delhi, IIT Kanpur, IISER Pune, IISER Tvm, IISER Kolkata, TIFR Mumbai, TIFR Hyderabad, ICTS-TIFR, Physical Research Lab., National Physical Laboratory, Univ. of Pune & Nanded, SINP Kolkata, …

LI-TRD (Training, Research & Development)

Ongoing LI-R&D projects under TDCB grant

- Squeezed light technology
- Improved Mirror coating
- Advanced Optics & Laser technology
- Mitigation Newtonian Gravity noise
- Wind loading noise on LIGO-India building structure

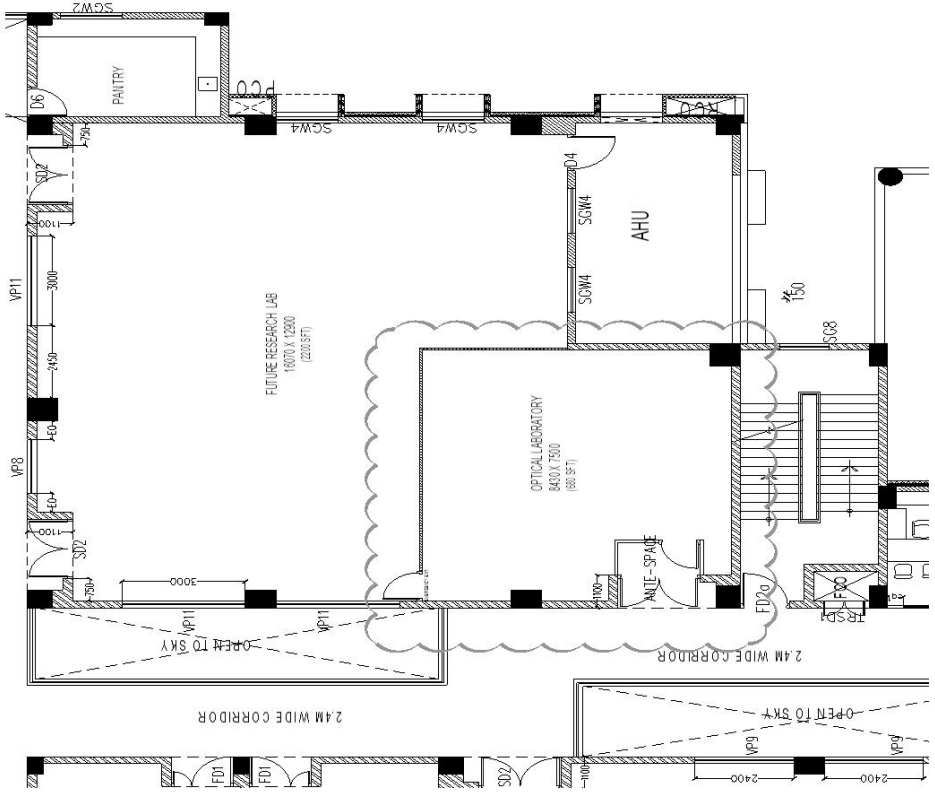
LI-TRD: Training, Research & Development

IISER-IUCAA joint CGPA

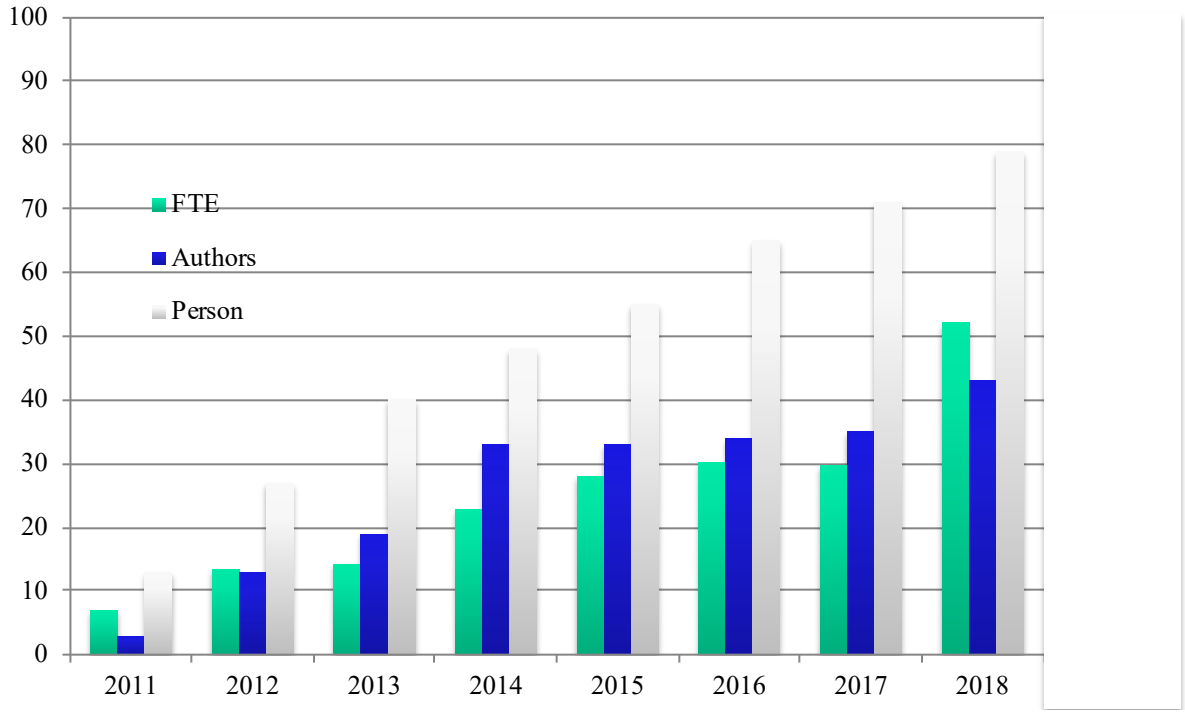
The primary goals of the Centre:

- Create a collaborative research and teaching activity that includes researchers from both institutes,
- Expose talented young researchers to exciting scientific challenges in the area of Gravitational Physics and Astronomy
- Development of human resources for research in the relevant areas.

Laboratory space ~600 SFT: 90% construction complete



LISC: LIGO-India Scientific Collaboration



A single group at IUCAA 2000-10 has grown currently to a 15 institutions

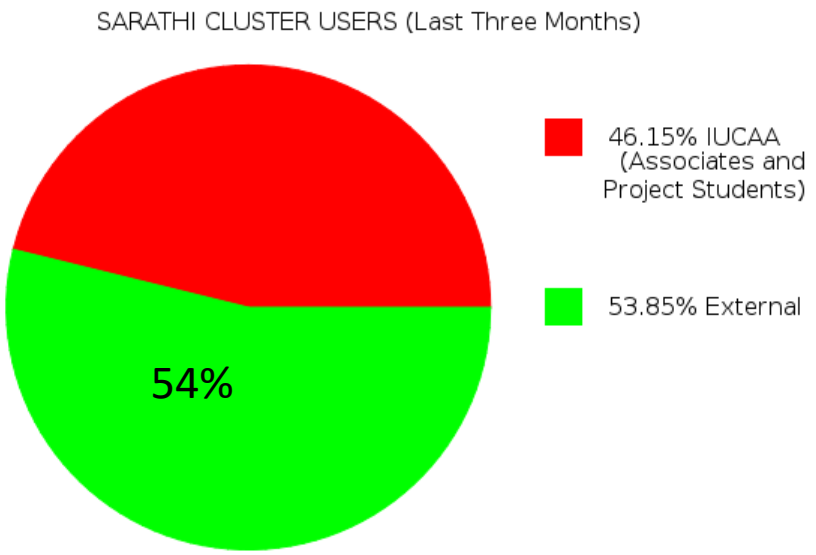
(IPR, IUCAA, RRCAT, DCSEM TIFR, ICTS-TIFR, CMI, IAR, IIT-Gn, IIT-Hyd, IIT-M, IIT-B, IISER-Kolkata, IISER-Pune)

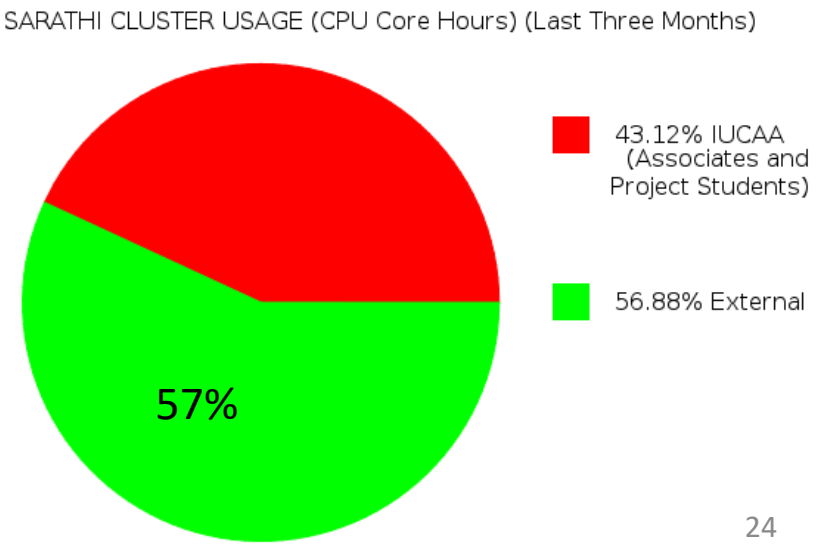
Pan-Indian group currently with 93 members [FTE:54.8, Authors:60]

GW Data Centre @ IUCAA

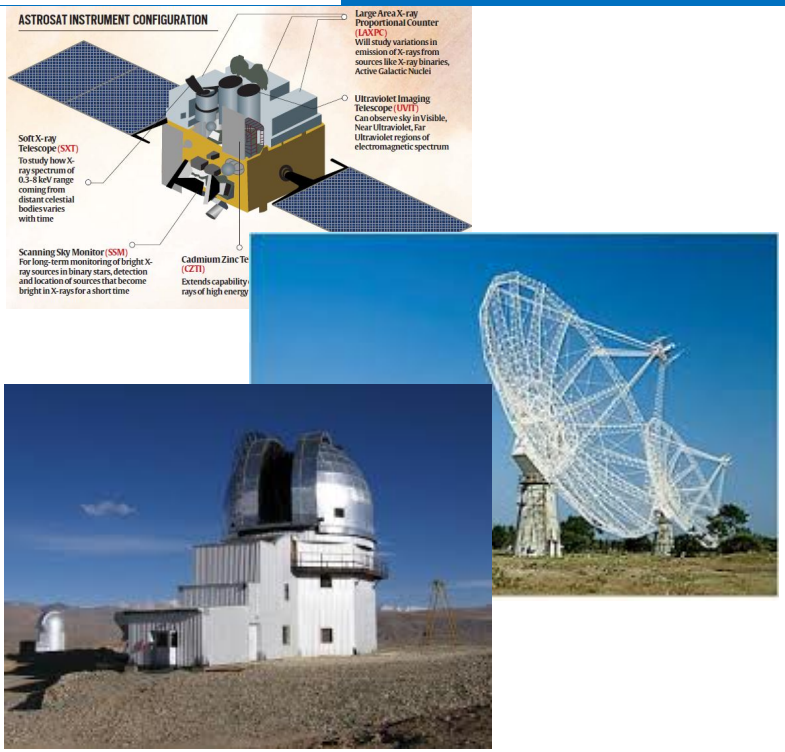
- **Progressing well towards Future Tier-1 with LIGO-India operations**
  - **detailed study performed for technical configuration and budget for the DPR**

- **GW Data Center: ~225Tf, 4040 cores [~2M$USD, 100M INR]**
  - **More than 300Tf computing power (> 3500 cores) is being added**
  - **2PB storage is being added with LIGO-India fund**
- **Significant usage by LVC members outside IUCAA**
  - external usage is increasing steadily
- All infrastructure for future expansion to 1 Pf in place at IUCAA





EM follow up from India



Recent Binary Neutron Star merger (GW170817) : Indian Astro response

- **10 Indian faculty from 9 different Astro groups/institutions (+ students) are on the major papers on EM follow up of GW170817**
- Installation of dedicated ~70cm optical telescope underway at Hanle for follow up of transients, in particular, GW event triggers. Expect operations before O3.
- Daksha mission for X-ray Gamma ray follow up given seed funds by ISRO

GROWTH
Global Relay of Observatories Watching Transients Happen

PALOMAR TRANSIENT FACTORY

LI EPO

- **EPO activities with dedicated stuff**
  - **massive boost in social media activities**
  - more people will be involved this year
- **LIGO exhibit and activities for the Vigyan Samagam – year long National Mega-science Exhibition (4 metros, 8 weeks each)**
- **Several activities were performed in the areas near the site**
  - activities include popular talks at schools & colleges, coordination between amateur astronomers
  - **good coordinated coverage in the local newspapers**
- Popularisation drive at the Astronomical Society of India (**ASI**) meeting

IUCAA

LI Site region

LVC Colleagues

RRCAT

LI EPO

LI-EPO Interview series at LIMMA20

LI Multi-Mess. Astro. Meeting at Khandala
Jan 15-18, 2018

LI Status

- **Continued top level for LIGO-India**

- **LIGO-India site acquisition 99% complete.**
- Civil and vacuum facility plans high readiness

- LIGO-India offsite facility at RRCAT

- Technology Development and Capacity building efforts for the high end technology

- Scientific HRD thru pan-Indian training, R&D (LI-TRD) program

- **Enormous challenges ahead !!!**

LI: Challenges Ahead

- Management structure for efficient execution of LI construction (project phase)

- Smooth transition from project phase to Operations.
  - Operations: Expectation that an academic sector entity with adequate Gravitational Physics & Astronomy and allied technology strength.
  - Scope and scale of the entity (known). Under ..?, Admin. Structure?

- Training & HRD
  - Short term for LI construction, installation, commissioning
  - (Project phase)
  - long term for LI Operations
  - National level healthy, sustainable, allied S&T ecosystem spread over multiple institutions (i.e., appropriate dividend for India commensurate with its investment.)

Global Network of GW Observatories 2024

Largest baseline ~ 12000 km provided by LIGO-India

Come, join us

!!! Thank you !!!

LIGO-India Panel Discussion : A few points from Sreekumar

Human resource generation :

Most serious concern

Ph.D student involvement : define 50% experimental Ph.D thesis work linked to LIGO-India programs

Use of engineering Ph.D students through programs like the IIA MTech/Ph.D program – establish special MOU with such institutes.

5 to 10 core group of users/scientists of LIGO-India to be identified to get deeply exposed to LIGO-India instrumentation, testing and commissioning activities – starting immediately.

Day-to-day management of this complex project involving institutions with very different management and work cultures – **need to identify a single Program Director with adequate decision making powers** – model of ITCC (for TMT) maybe adopted.

Periodic in-depth technical reviews to be put in place by an independent set of engineers and scientists (have different sub-committees for vacuum systems, optics-related areas, etc) – these could be different from PMB reviews for overall progress monitoring. Time scheduling – adopt an integrated (across all work centers), realistic schedule where all activities are linked using tools like MS-Project.

An independent group to look into progress monitoring of A+ developments in India.

Greater considerations to be given to contingency planning ; “Plan B” may not be in place in some areas

Further optimise the process, frequency and working level interactions with LIGO labs for maximum information exchange and technical assistance.

LIO: Project Milestones

Milestone/Task Completion	Date
Site Acquisition Complete	Feb 2019
Start Site development	Apr 2019
Review of Design based report of Civil infrastructure	Apr 2019
Design based report finalised	June 2018
Facilities Final Design Report Complete	Dec 2019
Site development Complete	Jun 2020

Phase-1

Phase-2

Begin Corner Station Construction	Jan 2020
Prototype Vacuum Chambers Acceptance	Mar 2020
Beam-Tube Prototype Test Complete	Dec 2020
RRCAT LIGO-India 10-m Prototype Complete	Mar 2020
Storage & Staging Bldg Hand-over	Sep 2021
Detector Components Received at Site	Nov 2021
Corner-Station Hand-over	Dec 2021
End-Station Hand-over	Jun 2022

Phase-3

Begin Detector Installation	Sep 2022
Beam-Tube Installation Complete	Dec 2022
Beam-Tube Bake-out Complete	Mar 2024
Detector Installation Complete	Nov 2024
First Full lock of the interferometer	Mar 2025
2-Hr Lock Achieved, Engineering run complete	Dec 2025
Start Science run	Jan 2026
Completion of Project, transition to O&M	Mar 2026

LIGO-India 'in principle' Approval
By Indian Union cabinet on Feb 17, 2016

Press Information Bureau
Government of India
Cabinet

17-February-2016 14:55 IST

Cabinet grants 'in-principle' approval to the LIGO-India mega science proposal

The Union Cabinet chaired by the Prime Minister Shri Narendra Modi has given its 'in principle' approval to the LIGO-India mega science proposal for research on gravitational waves. The proposal, known as LIGO-India project (Laser Interferometer Gravitational-wave Observatory in India) is piloted by Department of Atomic Energy and Department of Science and Technology (DST). The approval coincides with the historic detection of gravitational waves a few days ago that opened up of a new window on the universe to unravel some of its greatest mysteries.

The LIGO-India project will establish a state-of-the-art gravitational wave observatory in India in collaboration with the LIGO Laboratory in the U.S. run by Caltech and MIT.

The project will bring unprecedented opportunities for scientists and engineers to dig deeper into the realm of gravitational wave and take global leadership in this new astronomical frontier.

LIGO-India will also bring considerable opportunities in cutting edge technology for the Indian industry which will be engaged in the construction of eight kilometre long beam tube at ultra-high vacuum on a levelled terrain.

The project will motivate Indian students and young scientists to explore newer frontiers of knowledge, and will add further impetus to scientific research in the country.

... on a positive note with a BIG BANG !!!!

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LIGO-India: Indo-US MoU signed

Indo-US MOU between
Department of Atomic Energy &
Department of Science &Tech., India
and
National Science Foundation, USA
signed on March 31, 2016
at Washington DC
in the personal presence of
Hon. Prime Minister of India

LIGO-India

Continued attention at top-level and recognized nationwide

PM applauds GW community

Mar. 16, 2018: PM at Indian Science Congress

PMO India @PMOIndia · 4h

Our Government has already given the go-ahead to establish 3rd LIGO detector in the country. It will expand our knowledge in basic sciences in the areas of lasers, light waves & computing. I am told that our scientists are tirelessly working towards making this a reality: PM

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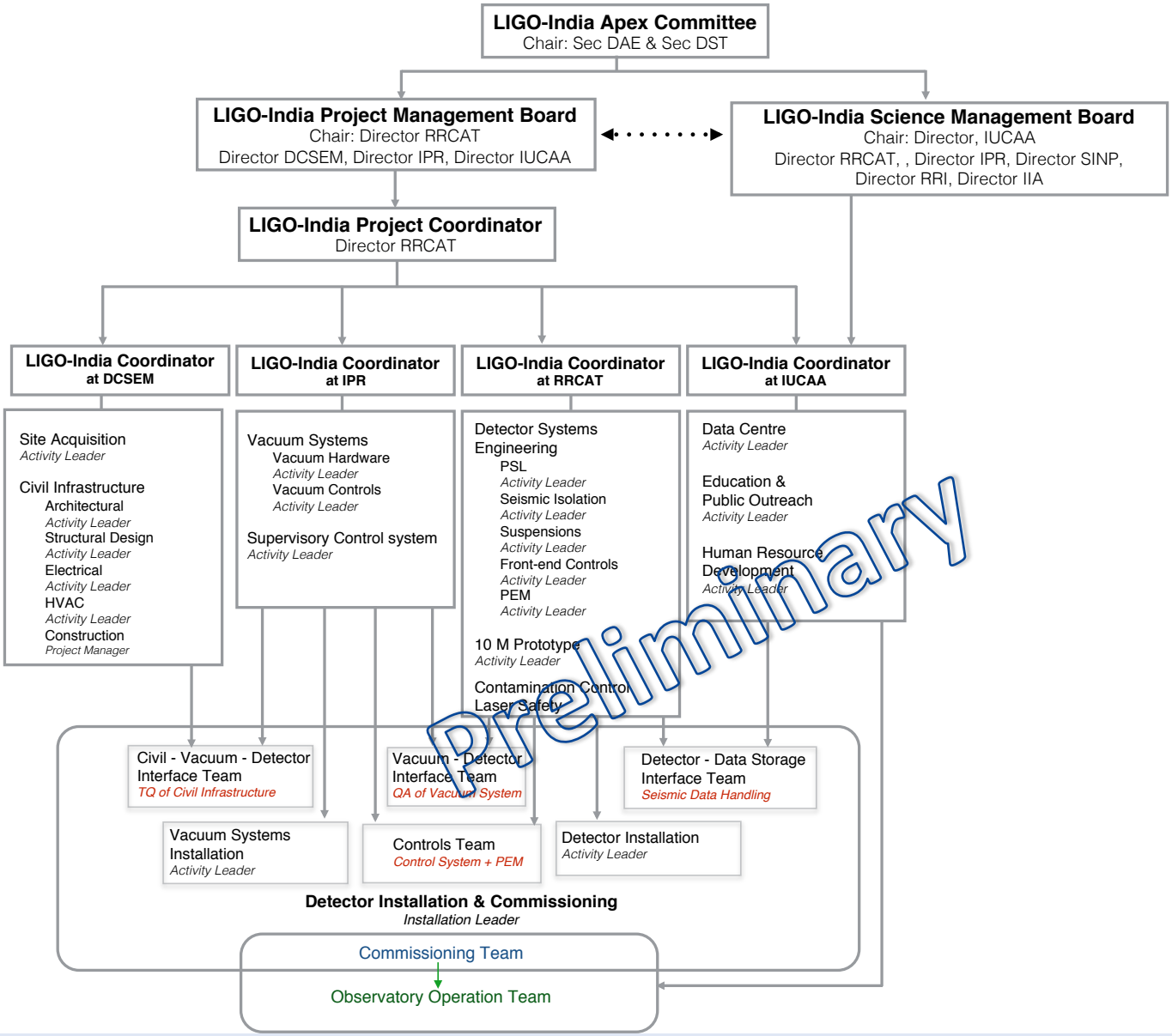
LIGO-India: Executive structure



Near the LIO site

- Temporary LIGO-India Office and Guest House

LI Training, Research & Development

Development of training tools for:

- Michelson interferometry with fixed and suspended mirrors in atmosphere
- Michelson interferometry with Suspended mirrors in Atmosphere
- Replication of the above in high vacuum
- Stabilisation principles of lasers
- Optical resonator physics
- Stabilisation of lasers and optical resonators
- Electronic control systems-design for lasers' and resonator stabilisation
- Noise analysis
- Vacuum technology
- And many more adjacent areas. . .

Interferometer Modeling and simulations

Ongoing India-UK project through Newton-Bhabha Funds from the British Council

Deliverables:

1. Working prototype of a training kit of concepts in optical interferometry
2. Demonstration and training in using simulations tools (Finesse for e.g)
3. Mechanical Q measurement system

Indian Institutions:

1. TIFR – Hyderabad center (Rajalakhshmi, Karthik)
2. IIT- Madras (Anil Prabhakar)
3. IISER – Pune (Umakant Rapol)
4. IUCAA – Pune (Sukanta Bose, Tarun Souradeep, Sanjit Mitra, Suresh Doravari, Manasadevi T. Shivraj K.)

UK Institutions:

1. Sheffield University (Ed Daw)
2. University of Birmingham (Andreas Freise)
3. Giles Hammond (Glasgow)
4. Stuart Reid (Strathclyde)