LIGO-India

A critical element of the International Network of Gravitational Wave detectors

Bala Iyer

ICTS-TIFR, Bangalore, India
Chair, IndIGO Consortium Council

IndIGO

Indian **I**nitiative in **G**ravitational-wave **O**bservations

Feb 13 2016

indigo

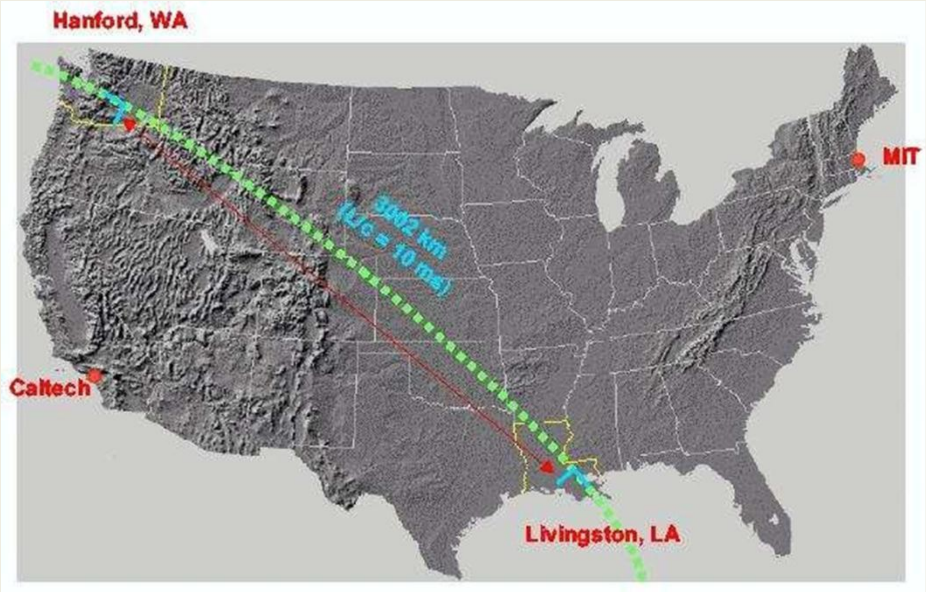
International Centre for Theoretical Sciences
Tata Institute of Fundamental Research

LIGO India

GWIC 2010
The Future of Gravitational Wave Astronomy
A Global Plan

- 2010 - Gravitational Wave International Committee (GWIC) prepared a global roadmap for future of GW detection and astrophysics with a 30 year horizon.
- "A true global array of gravitational wave antennae separated by **inter-continental distances** is needed to pinpoint the sources on the sky and to extract all the information about each source's behavior encoded in the gravitational wave signal ......"
- "First priority for ground-based gravitational wave detector development is to expand the network, adding further detectors with appropriately chosen **intercontinental baselines** and orientations to maximize the ability to extract source information"

The Global Network of Large GW Detectors 2010

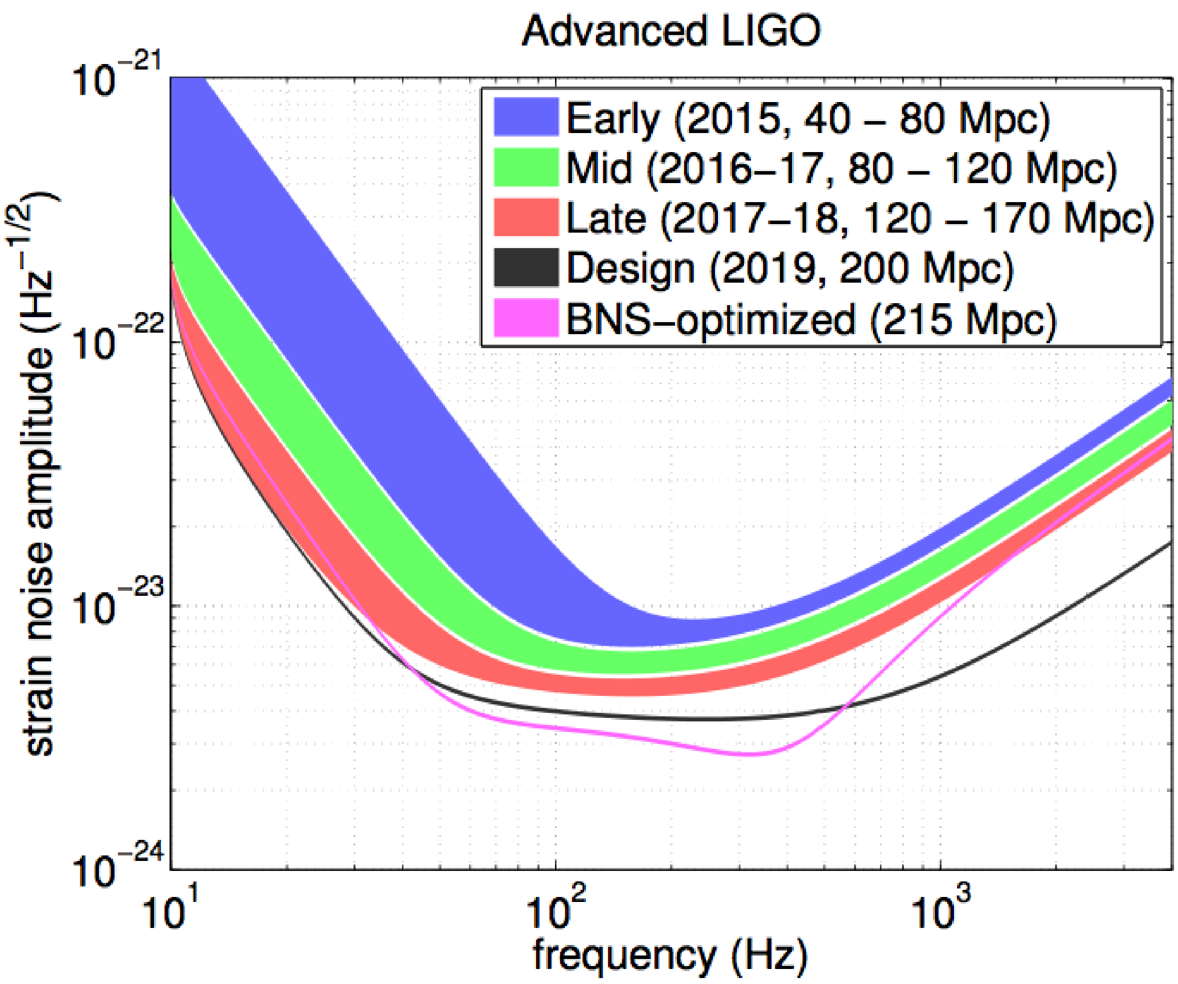


Two IFO's in the same Beam tube

Indian GW legacy to IndIGO

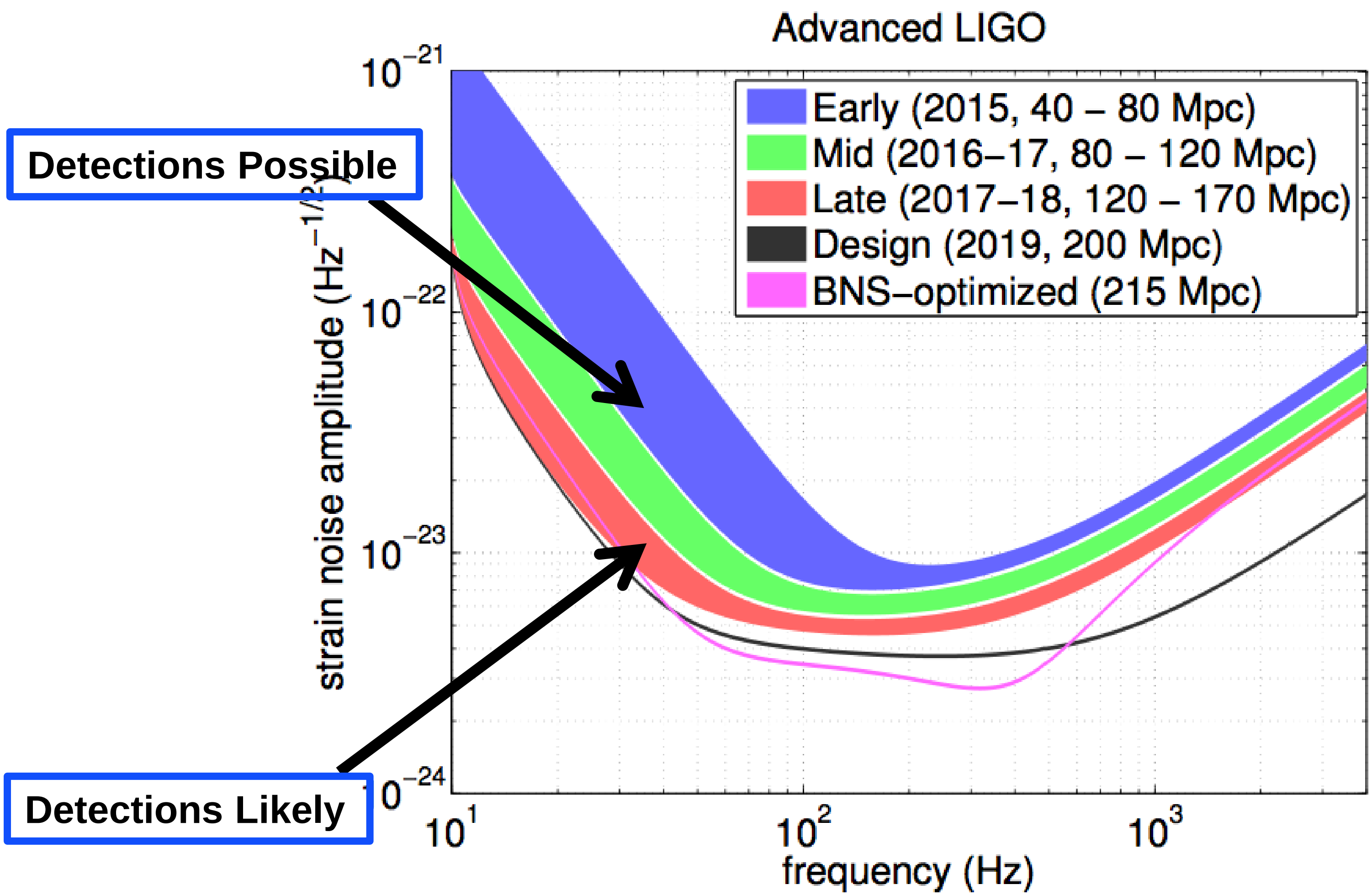
- 1990-2010: Indian contribution to the global effort for detecting GW during was on two significant fronts. Source Modelling at RRI in Group around BI & GW Data Analysis at IUCAA in Grp around Dhurandhar.
- Unfortunately, Proposals on GW Detector Development & UHV for AIGO 500 (IUCAA, RRCAT) though attempted did not get funded
- Fortunately, Students and post-docs from groups at IUCAA and RRI, after post-doc stints in leading GW groups abroad are back in faculty positions at different institutions in India currently
- With the 1G detectors achieving design sensitivity, it was opportune to jump start Indian participation in GW Experiment
- 2007 - ICGC meeting in IUCAA: Rana Adhikari suggested we think about a GW detector in India: IndIGO
- 2008 : Project "Indo-Australian collaboration on GW Astronomy" Funded (AISRF Project - BI et al , D. Blair et al)
- **2009 - Formation of the IndIGO Consortium**
- Participation in AIGO → LIGO-Australia
- Interacted with GWIC to explore possible ways to extend the International Advanced GW Network

A look at the near future of Observations



Courtesy Shoemaker

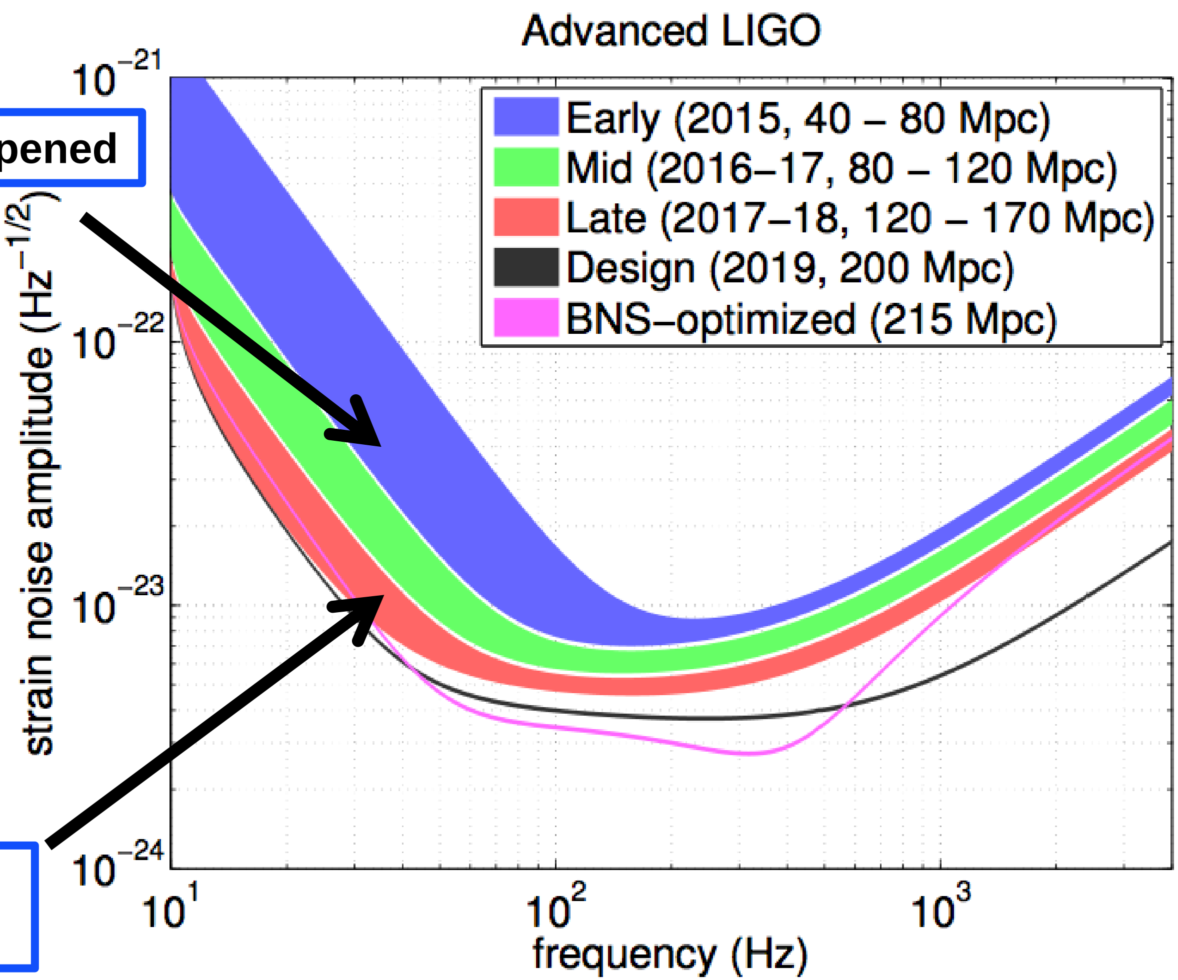
When do we think we can see something?



Courtesy Shoemaker

How often will we see events? What else will we see?

Detection Happened



How often,
What else?

Courtesy Shoemaker

Beyond detection of GW

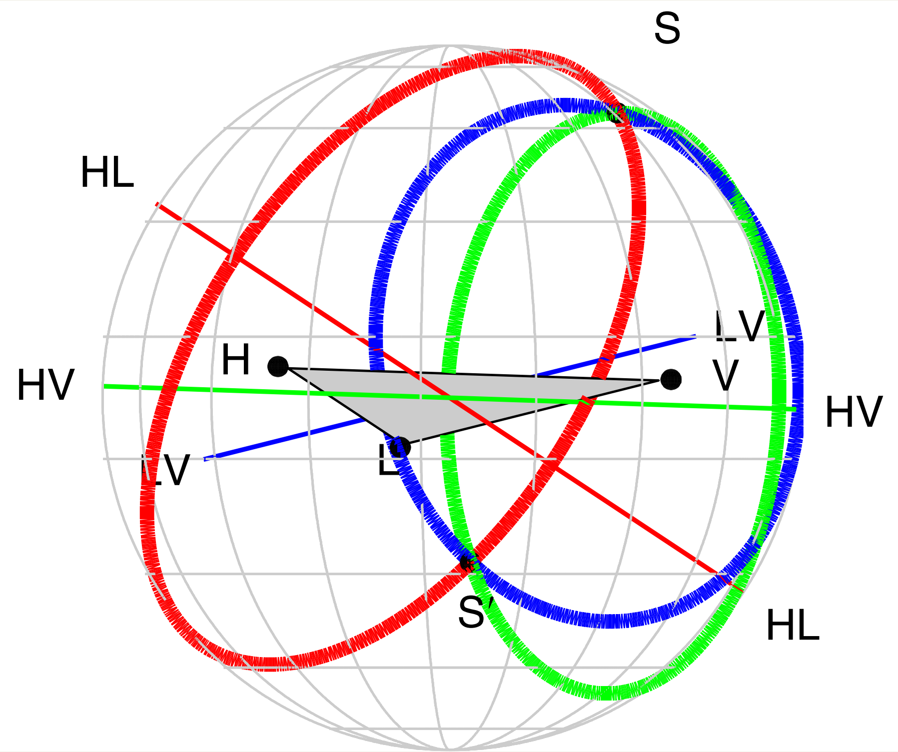
- ✓ **Direct detection of GW - 1st mandate of Laser Interferometric GW detectors**

- ➢ **Promise and Real Excitement -**
  - ➢ **New Observational Window into the Dark Universe;**
  - ➢ **Tool for Astrophysics and Cosmology;**
  - ➢ **Experimental Probe for Basic Physics**
  - ✓ GW signals propagate un-attenuated
  - ✓ GW observations privy to aspects not accessible to the EM astronomy and thus uncover NEW aspects of the physics
  - ✓ Direct detection probes strong field regime of gravitation
  - ✓ GW must occur in any relativistic theory of Gravity but properties of the GW in different theories can be different..

Multi-messenger Astronomy including GW

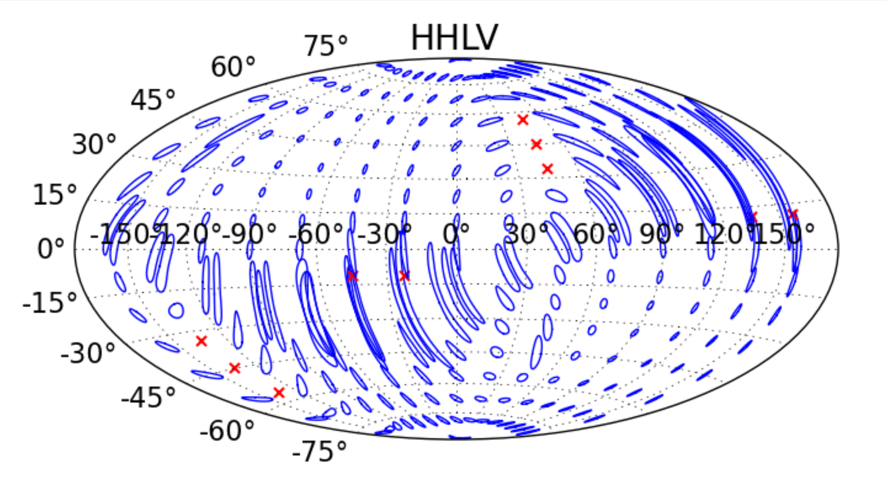
- Observation of GW coincident with short Gamma Ray Burst (sGRB) will test the sGRB-GW connection and aid determination of sGRB progenitor.
- Measurement of Time delay between GW and EM from sGRB can help determine the speed of GW
- GW and EM observations of binary coalescence will provide independent measures of distance and red-shift→ precision tests of cosmology.
- Multi-messenger observations triggered by accurately and rapidly localizing object by GW observations and then using EM (Optical, X-ray, radio) observations to follow up the event. Ambitious Project to follow up GW candidates in host of EM telescopes. - Palomar Transient factory, Pan Starrs, Sky Mapper, LOFAR. Typical Field of view 10 sq.deg → Need Localization of GW sources on similar angular scales with latency of few minutes

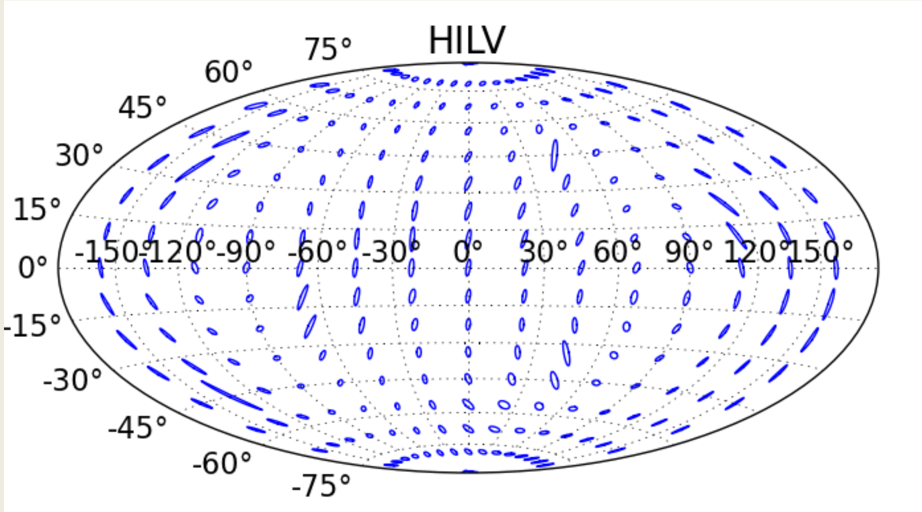
LOCALIZATION

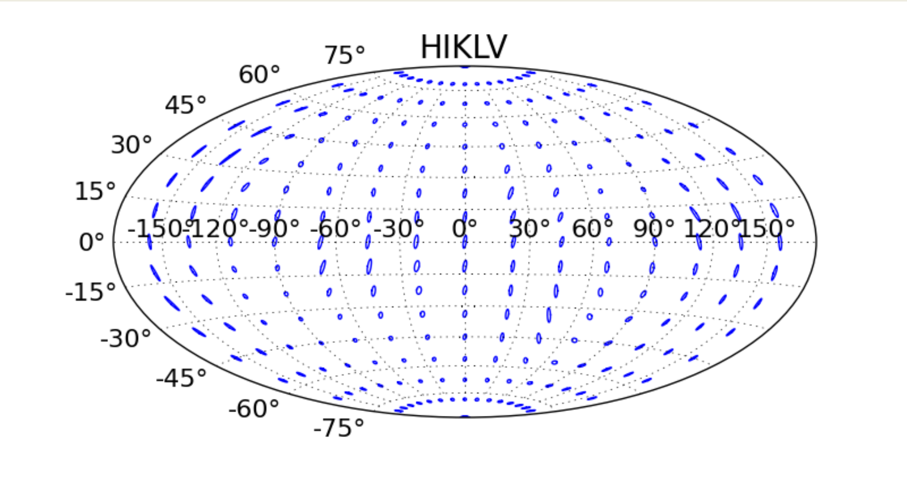


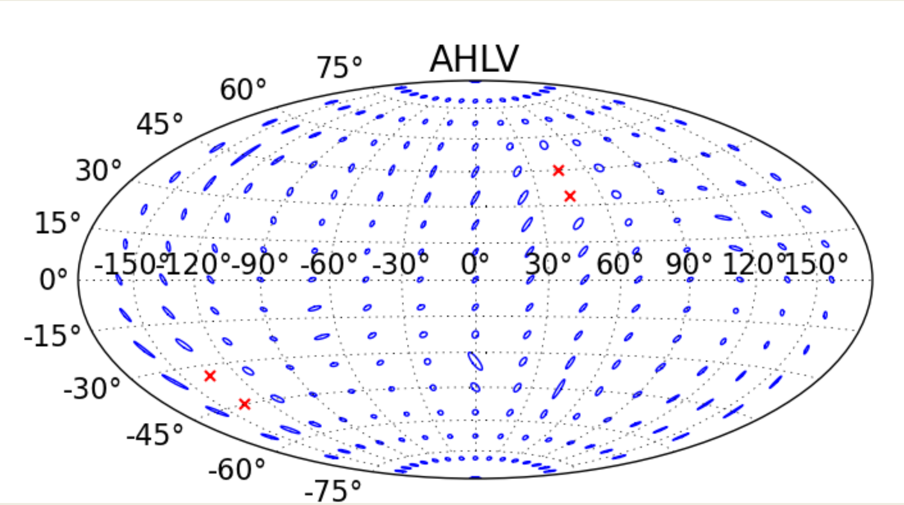
Courtesy: LIGO-G1200972-v3

- ✓ Good leading order estimate of localization provided by Triangulation using measured time delays between different sites
- ✓ Timing accuracy determines sky localization scale
- ✓ 2 sites – 1 time delay **Annulus on the Sky**
- ✓ 3 Sites – 2 Time delays – **Mirror images in Detector Plane**
- ❑ Localization poor for sources in and close to plane









Source localization error – Courtesy Steve Fairhurst

Similar results: Sathyaprakash; Klimenko & Vedovato

LI – 39 ms LA – 42 ms

LIGO-India: Why is it important?

- **Geographical relocation of the second Hanford detector is strategic for GW astronomy**

A fourth site not in the plane formed by the two US LIGO sites and Virgo & far from them greatly improves source localization ability.

- *Increased event rates (x2-4) by **coherent analysis***
- *Improved duty cycle*
- *Improved Detection confidence*
- *Improved Sky Coverage*
- *Improved Determination of the two GW polarizations*
  - **Improved Source Location required for multi-messenger astronomy**

Inclusion of LIGO-India would improve angular resolution on an average by four times and in some directions by a factor of 10-20

LIGO-India

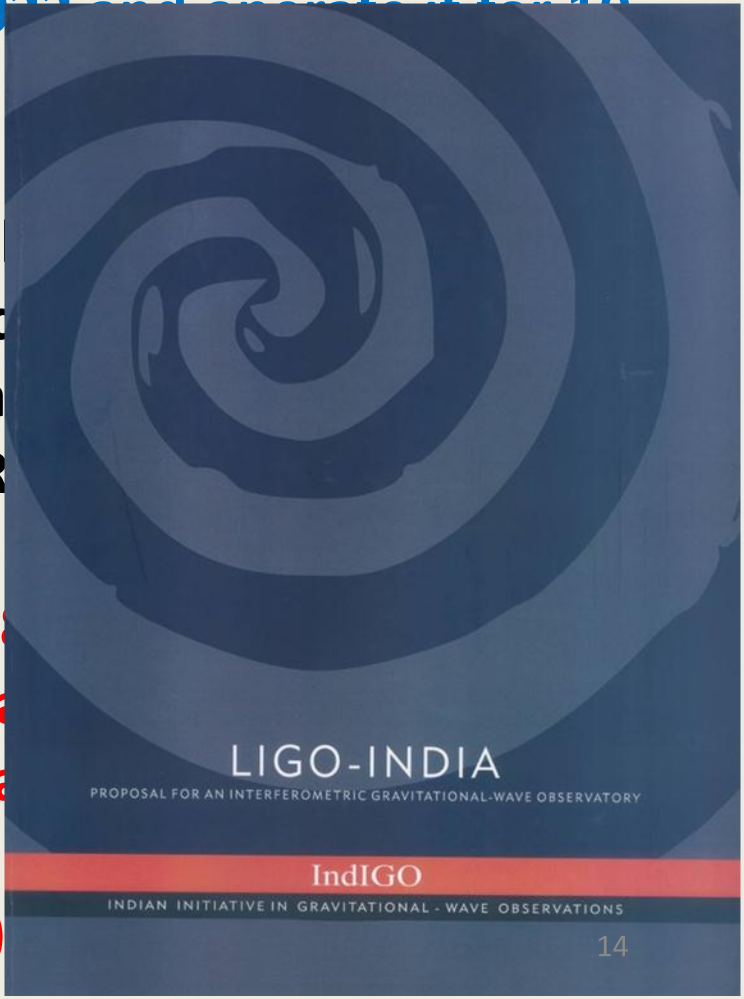
- **June 2011: Preliminary discussions for relocating H2 Advanced LIGO interferometer in India – LIGO-India**
- **Oct 2011 - Formal offer by LIGO-Lab on LIGO-India.**
- **Nov 2011 – Proposal submitted in India to Dept of Atomic Energy (DAE) & Dept of Science & Technology (DST) and presented at meeting on Mega Projects**
- **After Four LIGO-Lab visits to Indian Institutions in 2011-2012 and Three NSF Revs in Oct 2011, Apr, June 2012**
- **April 2012 – LIGO-India included in Atomic Energy Commission (AEC) meeting as a DAE Mega Project**
- **August 2012 National Science Board, USA, approves the proposed Advanced LIGO Project change in scope, enabling plans for the relocation of an advanced detector to India.**
- **Dec 2012 – LIGO-India included and figures in the list of Mega-Projects in the report of National Development Council to approve the Twelfth Five year Plan**

LIGO-India Project

❖Construction and Operation of a Advanced LIGO Detector (*Displacement Sensitivity: 4x10⁻²⁰ m/√Hz*) in India in collaboration with the LIGO Lab. Set up the Indian node of the three node global Advanced LIGO detector network by 20
years.

➢The entire hardware components of t
with designs and software to be provic
UK, German and Australia
($120 M including R

✓The entire infrastructure including the
and End stations, Related Labs and clea
team to build and operate the Observa
responsibility
($250 M, 15 yrs)



LIGO-India:

Indo-US collaboration project

Funding agencies:

NSF (USA) and jointly DAE(India) & DST(India)

Institutions:

(USA)

LIGO Laboratories, Caltech & MIT

(India)

1. Inter-University for Centre for Astronomy & Astrophysics (IUCAA), Pune
2. Institute of Plasma Research (IPR), Bhat
3. Raja Ramana Centre for Advanced Technology (RRCAT), Indore

Role of LIGO-Lab in LIGO-India

- Share and Provide Detailed designs and documentation of all aspects of the LIGO detector: site infrastructure, vacuum system, controls, lasers and optics, suspensions,….
- Assist by appointing points of contact for various sub-systems for regular consultation and to visit when needed.
- Host members of the LIGO-India team during aLIGO commissioning for training recruited manpower in optics and lasers and other subsystems.
- Assist during Installation, commissioning and noise limited operation at LIGO-India site.

LIGO-India:
Proposed Project Work Breakdown

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

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

Activities under an MOU among the lead institutes

Scientific participation in LSC via IndIGO-LSC

Managed jointly by IUCAA-IndIGO under a MoU

Team Building, Training..

- Visits of LIGO Scientists about once in 3-4 months
- Visits of LIGO-India scientists to LIGO, GEO, Virgo, KAGRA
- Fortnightly LIGO-India telecons of core team with LIGO-Lab
- Weekly IndIGO-LSC telecons., Biannual F2F meetings.
- Post docs in LIGO and Virgo
- Graduate students in LIGO and GEO
- Summer students in SURF at Caltech
- IUCAA+ICTS involved in
- Introductory workshops for UG students;

  3 Advanced Workshops on GW Experiment aspects;

  Advanced school on NR and DA;

  International meeting GWPAW;

  Astronomy & Physics with LIGO-India and Meeting on Transients..

IUCAA – GW Group

IUCAA - LIGO-India Site Search

Requirements:

✓Low 'seismicity' (ground noise PSD)

✓Low human generated noise

✓Air connectivity, road connectivity, data connectivity,…

✓ Proximity to Academic institutions, labs, industry preferred, …

Approach :

❖Identify potential sites not too far from existing facilities

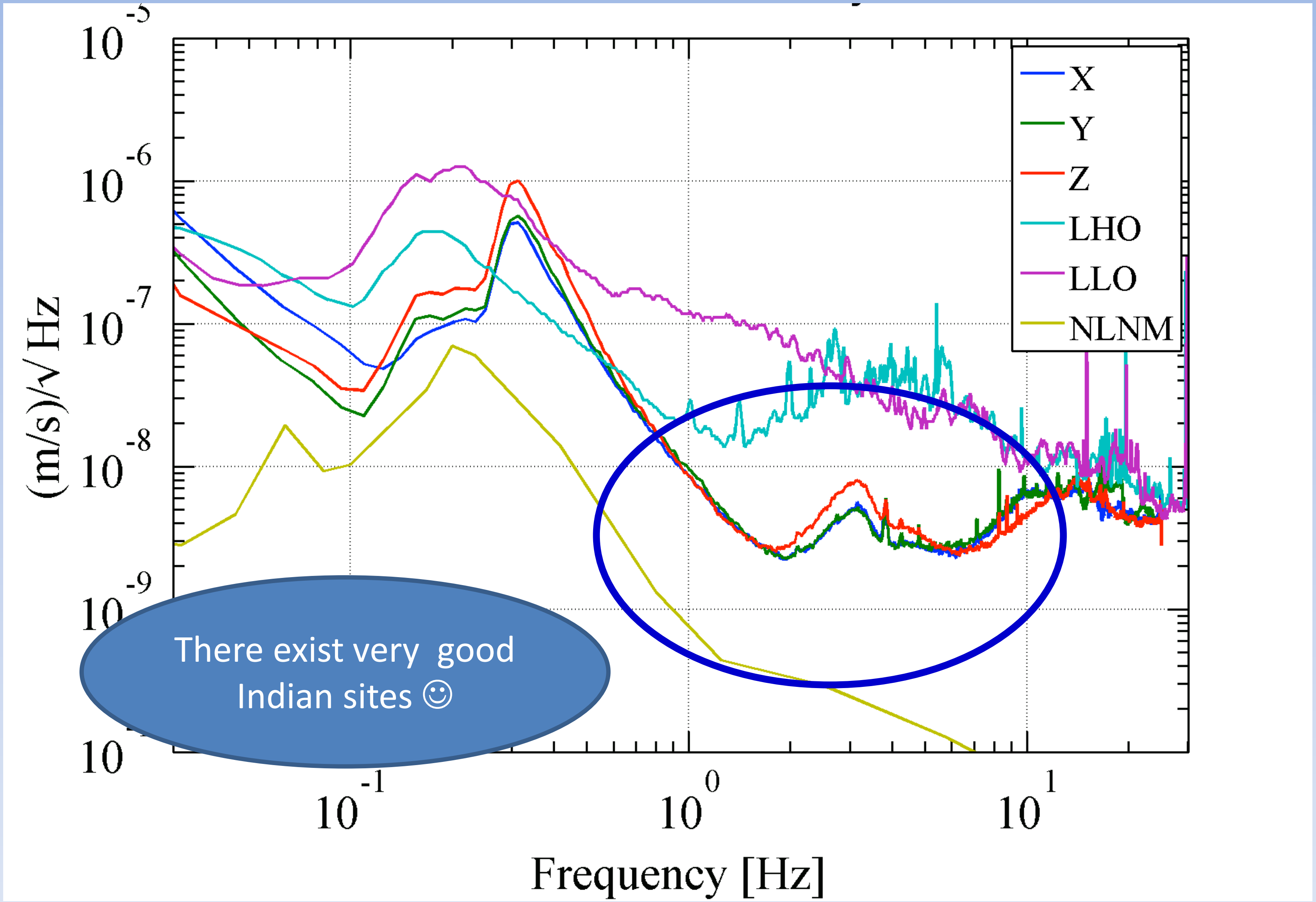
❖Establish contact with local & high level state officials

❖Desktop survey of sites, Followed by team visit

❖2-3 week seismic survey : ground noise PSD at 0.1-100 Hz range

❖ Interesting possibilities emerged

Preliminary Seismic Survey



IUCAA, RRCAT + Supriyo Mitra, Rajesh Nayak (IISER Kolkata)

Site Search & Selection Update

- **Sites narrowed down from ~ 20 leads to a shortlist of 2**
  - ✓ Finalization of site selection requires two professional studies
    - **Land acquisition cost and time estimate for each shortlisted site**
    - **Constructability at site: Engg. feasibility, cost and time assessment**

(Remote Sensing data from SAC, ISRO made especially available)

- **TCE : engineering feasibility study at shortlisted sites.**
  (study funded by IUCAA). Completed July 2015
- **Report from Land acquisition expert**

land acquisition procedures, estimate of time at various steps, Land records available, Regional development plans,

- Reports presented & discussed at LIGO-India Site committee meeting on Oct 27, 2015.

- Visit by LIGO-US expert Fred Asiri to LI site Nov 16-20. Report from LIGO-USA as input to TCE report revision.

- **Revised TCE report circulated to site committee members on Dec 6, 2015.**

Coordinated Indian Follow-up of (GW) Transients (IUCAA)

- **Increased awareness among Indian astronomers of efforts for following up GW triggers in search for EM/ particle counterparts: (Varun Bhalerao, IUCAA)**
  - **Encouraging Indian institutes / observatories to submit MOUs for following-up GW triggers from LIGO and Virgo detectors.**
  - **Progress toward drawing up MoU for ToO protocols among some Indian observatories**
  - **IUCAA Girawali Observatory (IGO) and ASTROSAT CZTI-IUCAA (x-Ray) already have MoUs for follow up.**
  - **Plans for a future observatories dedicated to transient / time-domain astronomy.**

IUCAA Data Centre

LIGO Data Centres IUCAA, ICTS

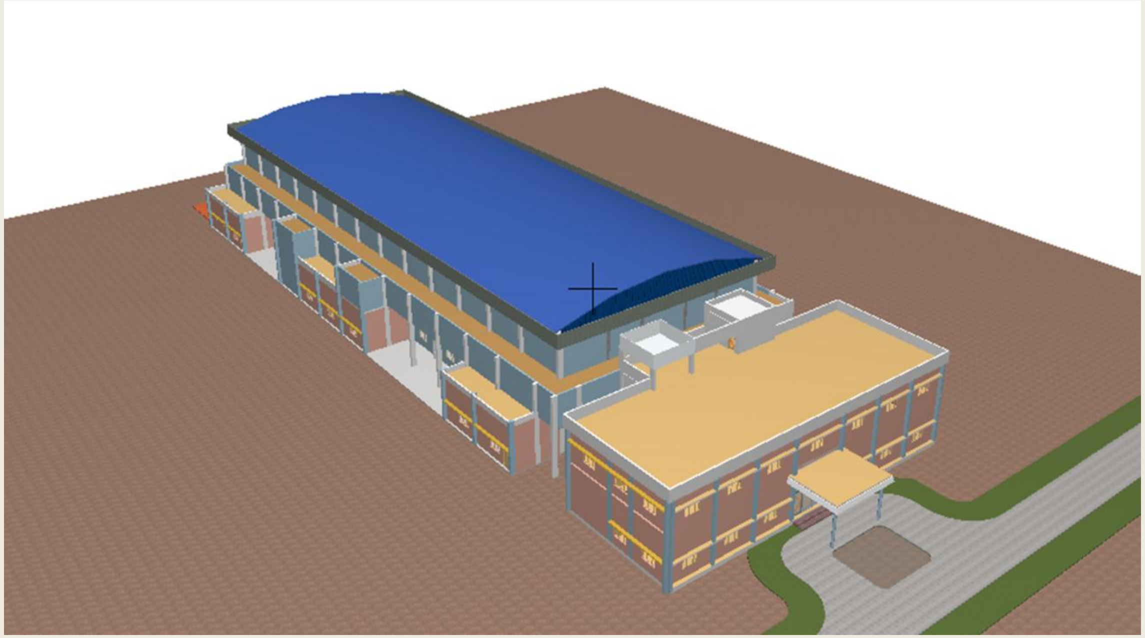
- **Current IUCAA-LDAS Prototype**
  - 10TF , Memory 128GB/node; 150TB shared storage; .8 Gbps to Caltech
  - **Enough floor space to host an upgrade to ~300TF data centre**
  - **25% of current resource open to all LSC (modalities to be finalised)**

- Planned **upgrade (operational Mar 2016):**
  - **Budget ~1M $; 2520 computing cores:, 16 TB Total RAM, : RAM per core ≥ 5GB, 250 TB Total storage:, In addition, 200GB solid state drive in every node, 10 NVIDIA Tesla K40 GPU cards**

- **Planned LIGO Tier-3 Computing Cluster at ICTS-TIFR**
  - **Budget: 1 cr INR (.17 M$)**
  - **Installation of compute nodes completed this week!!**
  - **500 Cores, ~20 Tfl peak performance, 100 TB storage**
  - **Plan to upgrade to Tier-2 by 2018**

RRCAT activities

- In anticipation of the Cabinet note approval, the Pre-project Proposal for the initial phase of funding and the draft DPR for the complete LIGO-India Project have been prepared.
- The detailing and architectural drawing of the off-site laboratory facility being setup at RRCAT has been completed. The engineering drawings for preparation of tender has also been prepared.



RRCAT Activities in 2015

- PSL Related work done at AEI and RRCAT
- Suspension Fiber Drawing related
- Wave-front sensing related

Laser Instrumentation Laboratory (LIL), RRCAT

Sendhil Raja S [Group Leader], Jogy George, Siddhesh Pai, Brijesh C P,

Rajan C, Ishant Dave, Rohan Bhandare

Work at RRCAT

Development of 100 mW monolithic DPSS Laser at 1064 nm

We developed monolithic 100 mW CW Laser with the following objectives:

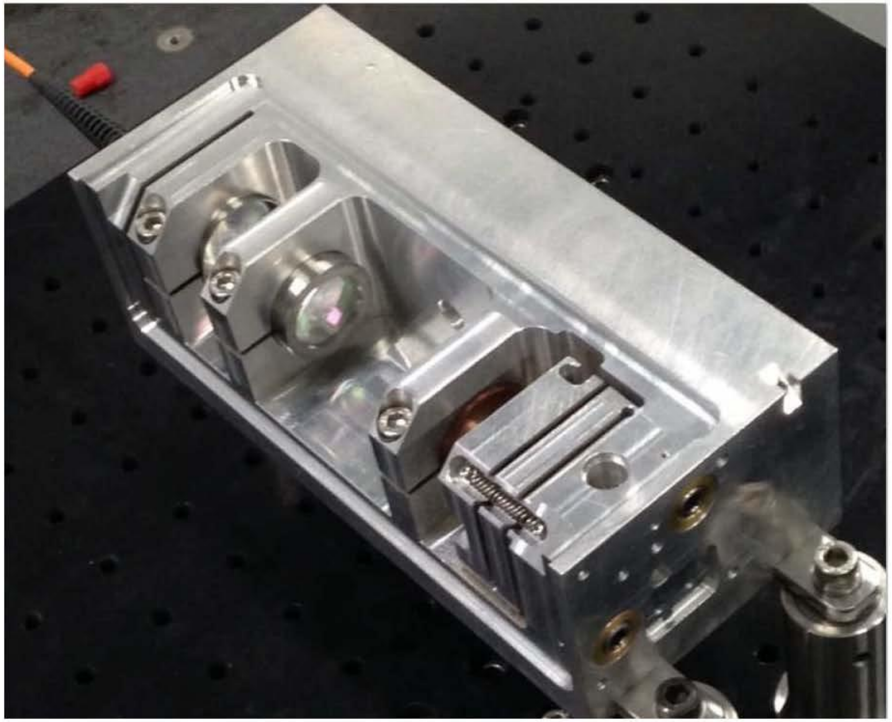
1. Excellent mechanical stability that offer < 5% stability over >10 hrs
2. Crystal holder should provide stable reference for HR mirror, and allow for axial expansion of the crystal during end pumping
3. Output coupler must be field replaceable.
4. Output power must have 100 % de-rating to allow long term performance

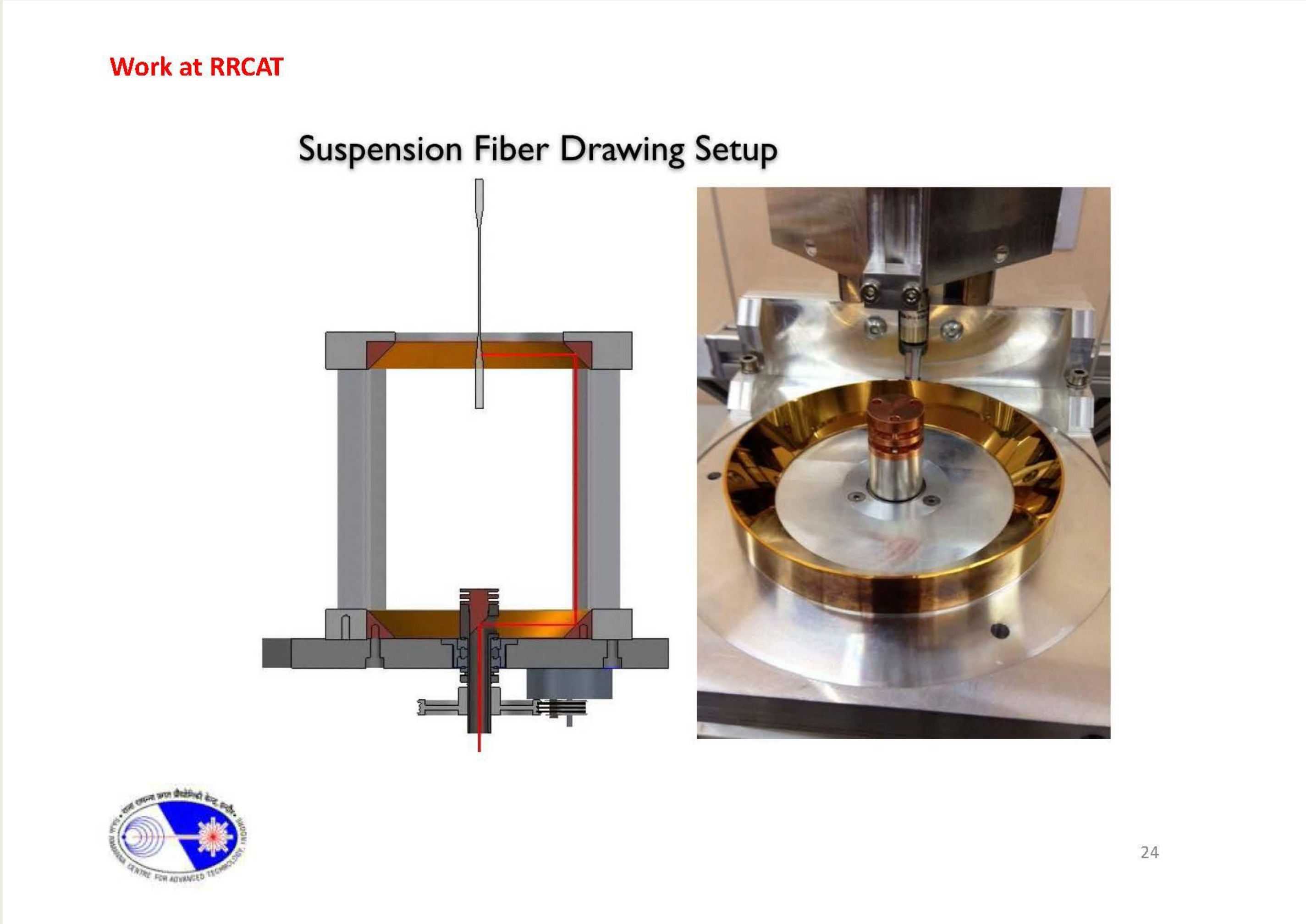
Laser Specifications

Max Output Power	: 250 mW
Long term Power Stab (16 hrs)	: 2.5%
RIN (0-500 kHz)	: < 67 dB
Laser Resonator Mount Design	: Flexure based

Work at RRCAT

100 mW monolithic DPSS Laser at 1064 nm

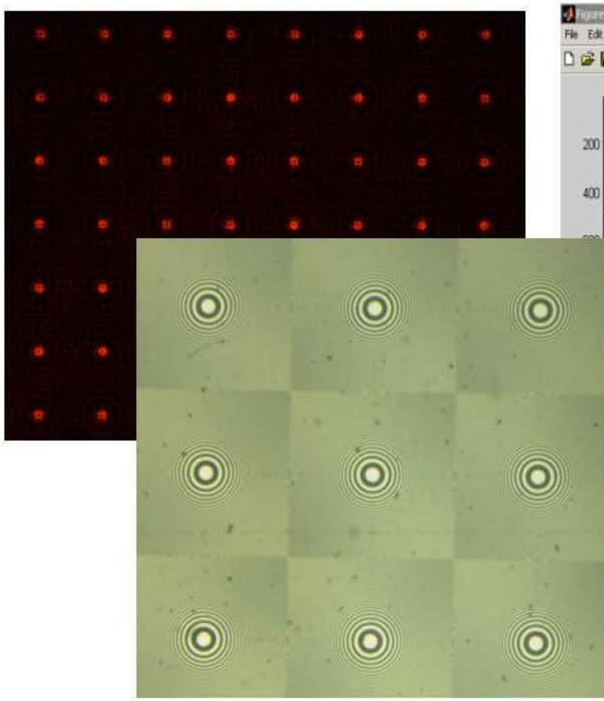


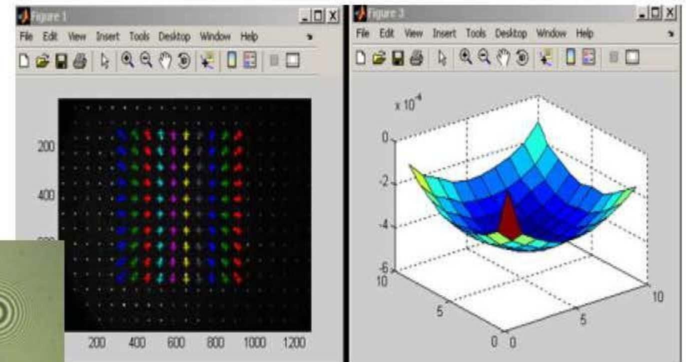


The components for a suspension fiber drawing setup and ear tab welding system have been fabricated. Assembly and integration of the two systems are in progress.

Work at RRCAT

Micro-lenslet for Shack-Hartmann





Microlenslet array was fabricated using the laser micro-machining.

The micro-machined lenslets have a (600 x 600 microns) and a focal length of 2.7mm at the design wavelength of 632nm.

Using this lenslet array and a digital CCD camera (1064 X 1500 pixels) a Shack-Hartmann wave-front sensor has been developed for use at 632nm.

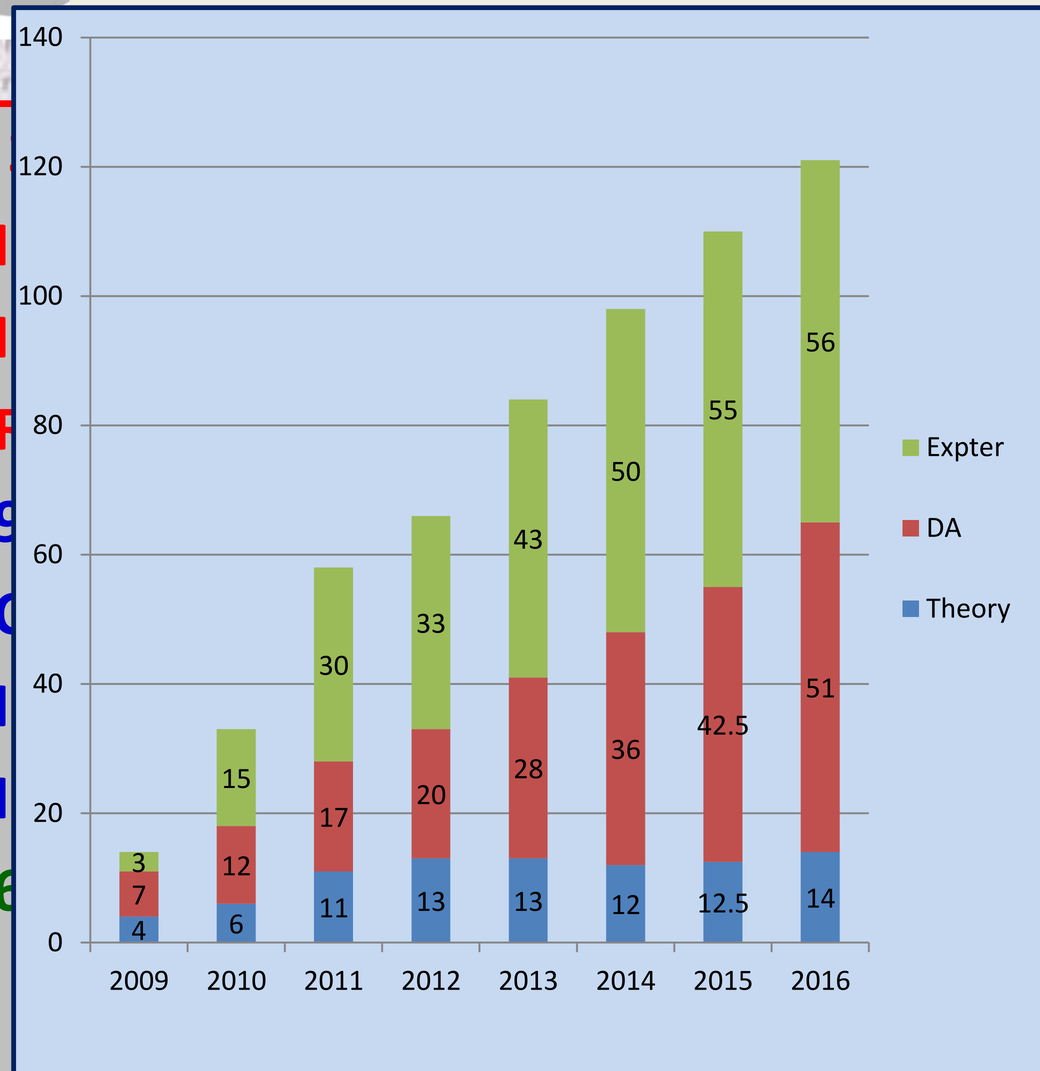
IPR activities

- System Requirement Document for civil infrastructure discussed with LIGO-USA and inputs incorporated. Conceptual design of Civil infrastructure has been completed.
- Conceptual drawing of vacuum system has been completed and under discussion with LIGO-USA for dimension verification.
- Meeting with Infrastructure companies, UHV & Steel manufacturing industries..
- Out-gassing measurement of SS sample is under progress as per LIGO-USA design report.
- Z.Khan and M.K. Gupta visited KAGRA (Nov 2014) during the beam tube installation and Hanford and Livingston (April 2015)

IPR LIGO-India Group

S Sunil, Rakesh Kumar, Manoj Kumar Gupta, Ziauddin Khan, Amit Kumar Srivastava, Arnab Das Gupta, Karmesh Mehta

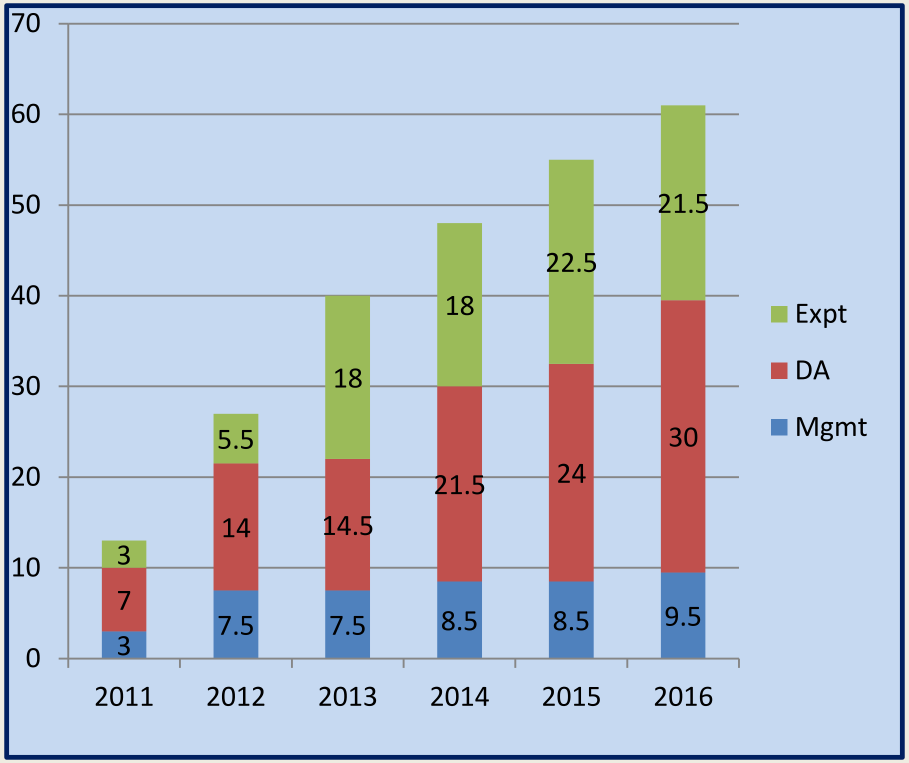
Multi-Institutional, Multi-disciplinary Consortium



Currently 121 (14, 51, 56)

IndIGO-LSC

Indian presence in LIGO Scientific Collaboration

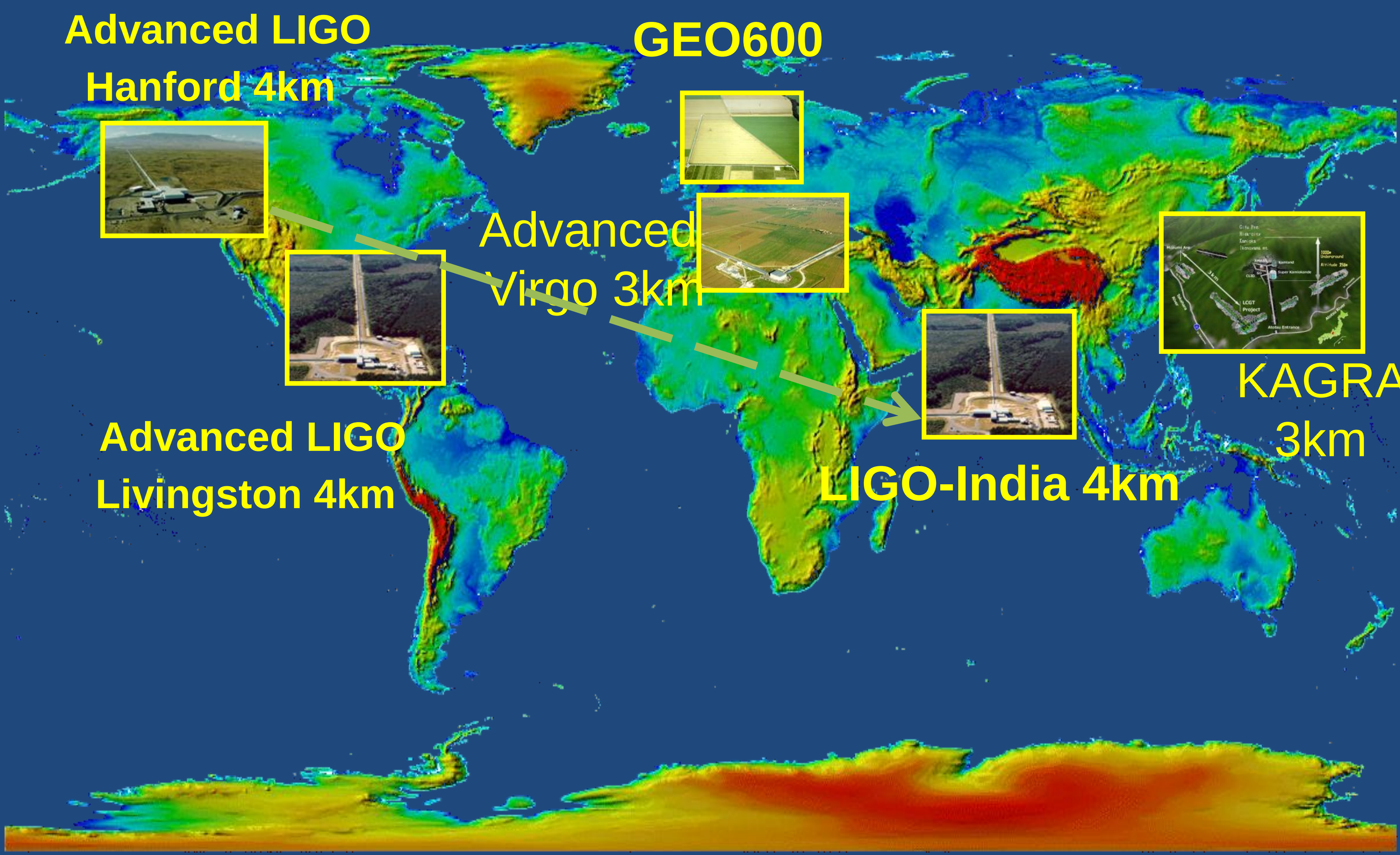


A single group at IUCAA 2000-10 has grown currently to a 9 institution

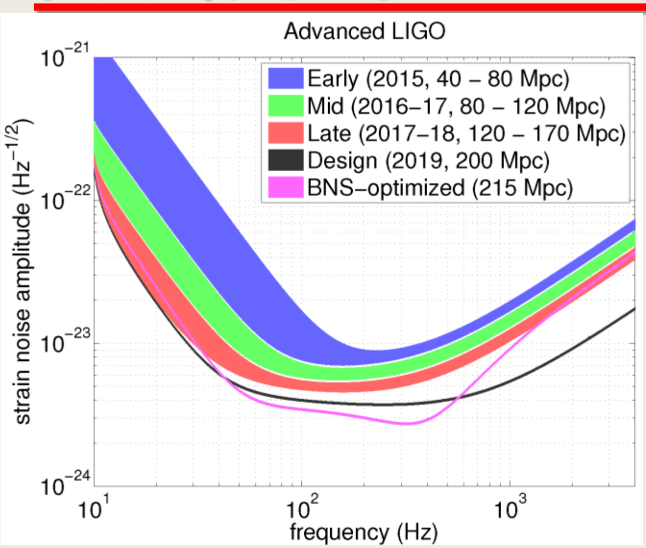
(IPR, IUCAA, RRCAT, TIFR, ICTS-TIFR, CMI, IIT-Gn, IISER-Kolkata, IISER-Tvm)

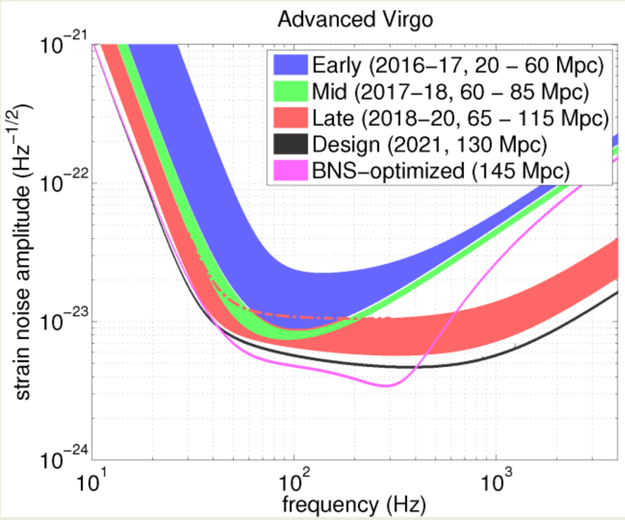
pan-Indian group with 61 members

The GW Detector Network ~ 2022



From GW detections to GW Astronomy





Aasi et al 2013 arXiv 1304. 0670

Epoch	Run Duration	BNS Range (Mpc) LIGO	BNS Range (Mpc) Virgo	Number of BNS Detections	Median Area Sq.Deg	% BNS Localized in 5 Sq. deg	%BNS Localized in 20 Sq.deg
2015	3 months	40 - 80	-	.0004 – 3	2000	-	-
2016-17	6 months	80 - 120	20 – 40	.006 - 20	70	2	5 - 12
2017-18	9 months	120 -170	40 - 50	.04 - 100	84	1 - 2	10 - 12
2019+	Per year	200	40 -80	0.2 - 200	31	3 - 8	8 - 28
2022+ **LIGO-India**	Per year	200	80	0.4 - 400	11	**17**	**48**

As the Global GW Network Expands to include LIGO-India, successful operation of Advanced Detectors will transform the field from GW Detection to GW Astronomy

Current Status of LIGO-India Project

Final Decision
on the in principle Approval
of Cabinet Awaited …..

Highly Multi-disciplinary

+++astro

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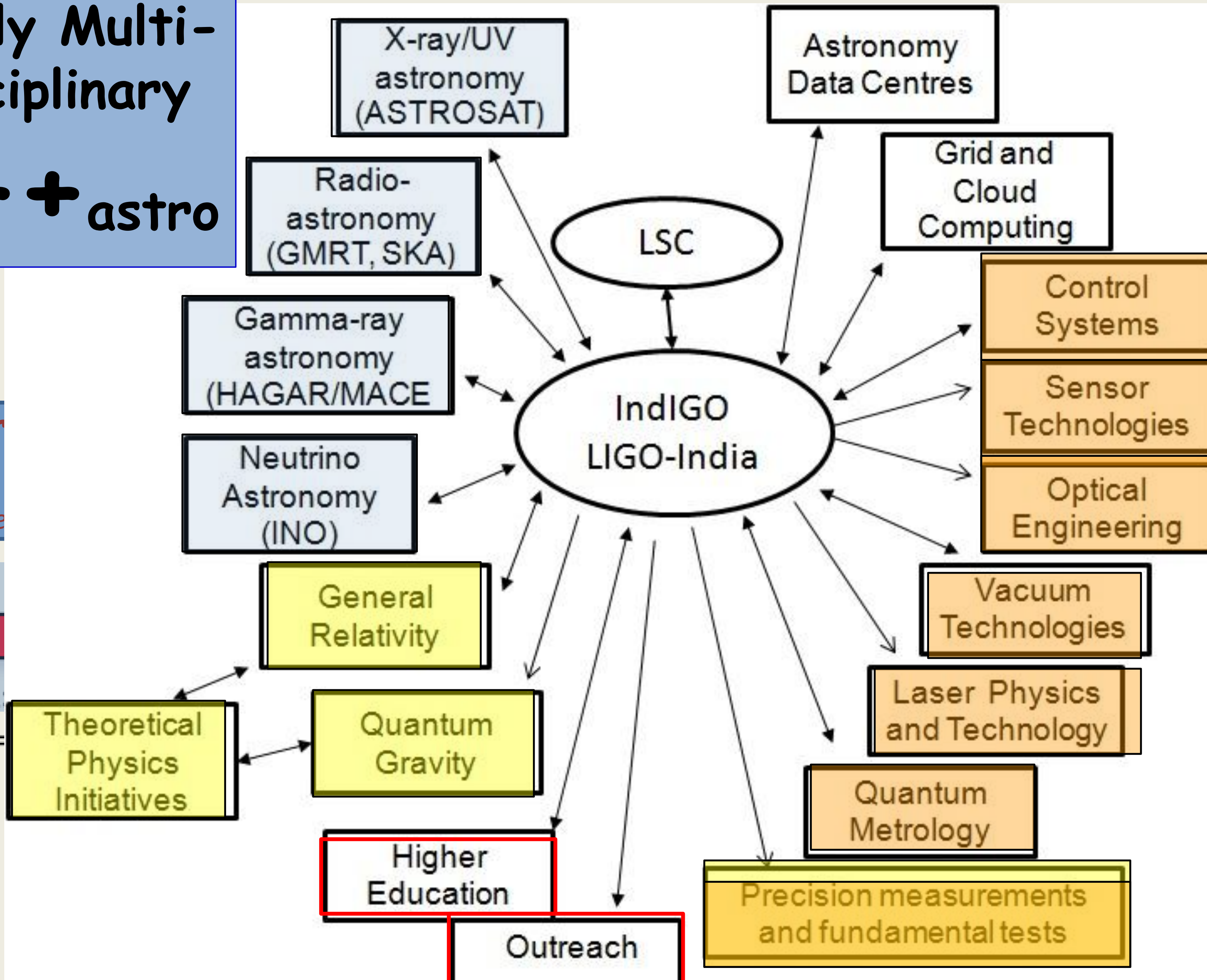
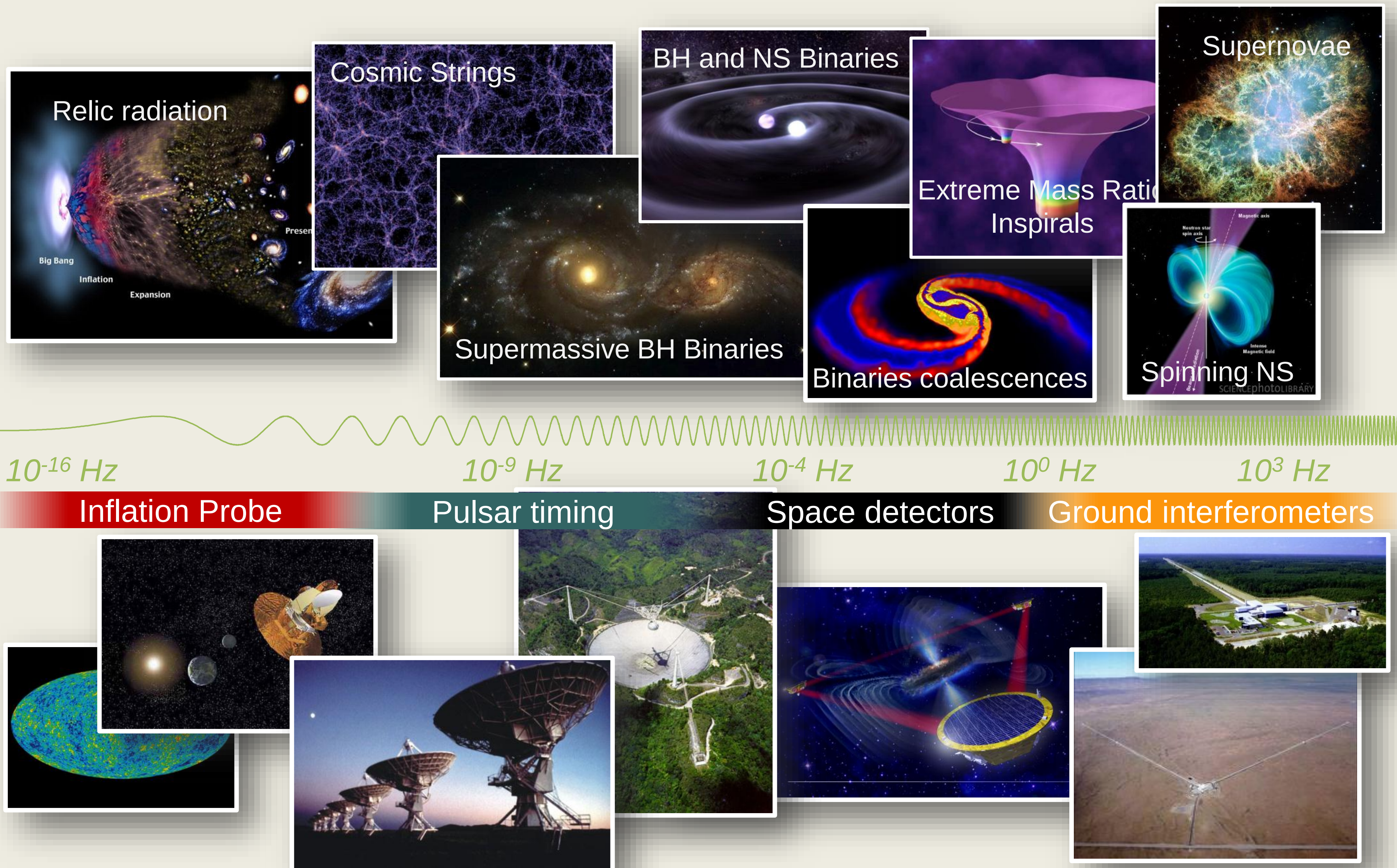


The GW Spectrum



To conclude…

- Four centuries after Galileo's Telescope launched Optical Astronomy and a century after Einstein's inspired discovery of general relativity, a MAJOR revolution in astronomy is round the corner with a facility in India having the opportunity to play a key role. LIGO-India will be a critical element of the Global GW Detector network for GW Astronomy
- Though most of the Universe is EM dark, we can reconstruct it better from the footfalls of Einstein's messengers that will be heard in our GW detectors in the near future when LIGO-India joins the global GW network
- Today, Though **Einstein** seems to be **right,**
- The question remains: Is he **100% Right??**
- Many **Enigmatic** Aspects of Gravity still remain,
- **Decoding** Gravitation is the holy grail and the *Odyssey* encompasses the whole universe most of it dark with its symphony in GW from the chirps and wails of dying stars and black holes and eventually the murmurs of the big bang ..

Last words..

Change is possible only if you dare to dream, are not afraid to fail and have the humility to collaborate..

The Gravitational Wave community was built on these ideals and

I hope IndIGO will emulate it and go beyond to get there in time..

THANK YOU FOR YOUR ATTENTION