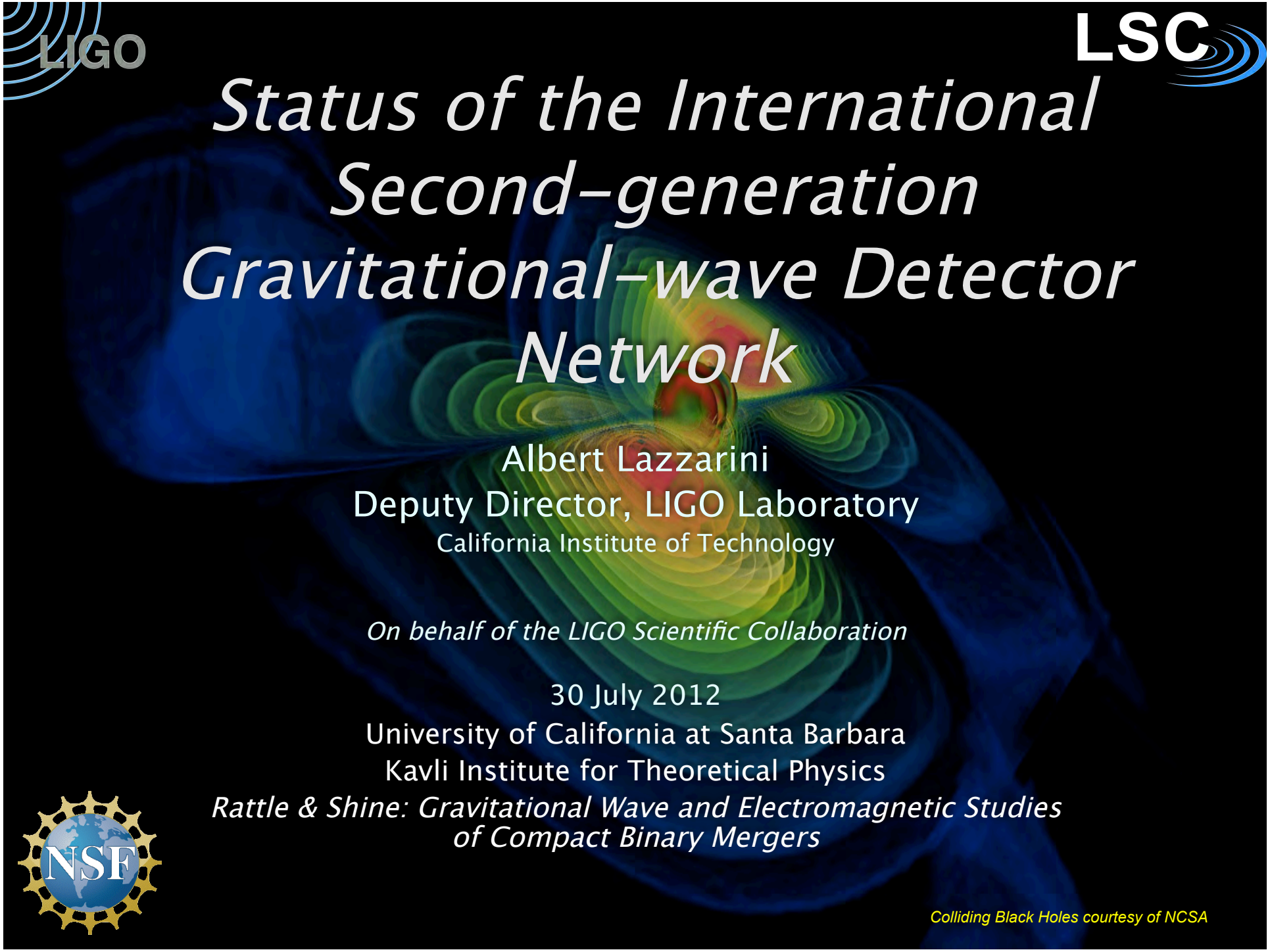


Status of the International Second-generation Gravitational-wave Detector Network

Albert Lazzarini
Deputy Director, LIGO Laboratory
California Institute of Technology

On behalf of the LIGO Scientific Collaboration

30 July 2012
University of California at Santa Barbara
Kavli Institute for Theoretical Physics
Rattle & Shine: Gravitational Wave and Electromagnetic Studies of Compact Binary Mergers

Colliding Black Holes courtesy of NCSA

Outline

- End of an era – the first generation
- Advanced detectors – status
  - Advanced LIGO
  - Virgo (EU)
  - KAGRA (Japan)
  - GEO600 (Germany/UK – LSC)
  - LIGO-India (Proposed by LIGO, India)
- Towards a global network

LIGO Science Run 6 (S6) & Virgo Science Runs 2/3 (VSR2/3) Last Science Run of Initial Detector Era

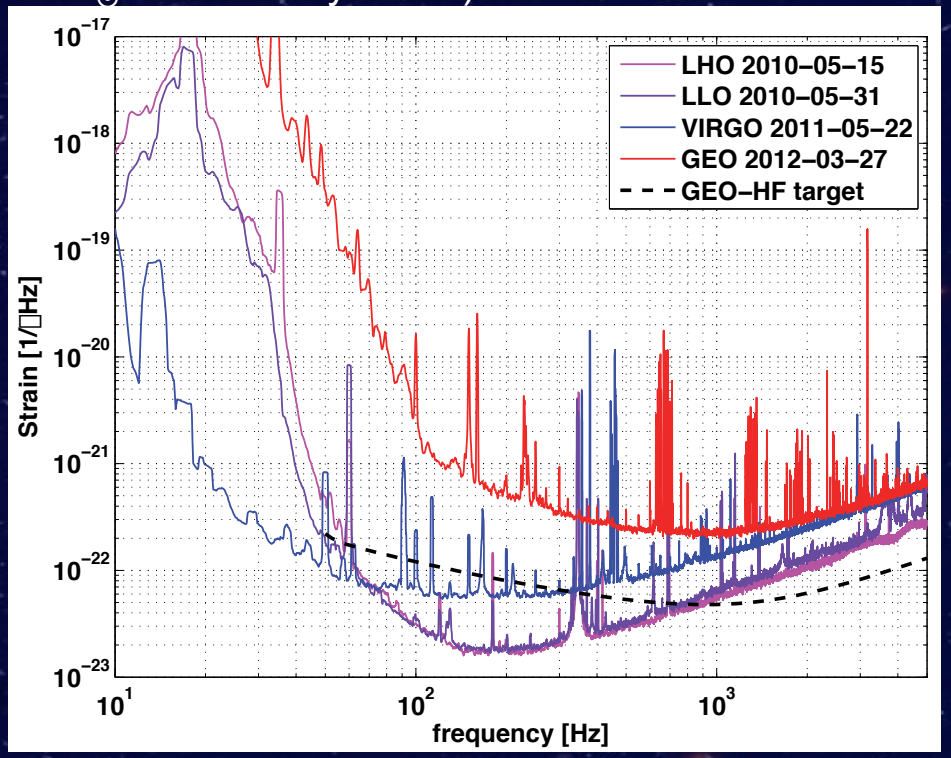
Run was a success:

- LIGO: Best strain data ever recorded
- Virgo: Best sensitivity below 60 Hz
- Both H1 and L1 ran consistently in the 18–20 Mpc range for NS+NS binaries during quiet times (SNR = 8 for $1.4M_{\odot}+1.4M_{\odot}$ NS/NS systems)
- Maximum range observed ~21 Mpc

- Range defined as a sky & source-orientation averaged *effective* distance

- Maximum distance to which a source may be detected: Horizon distance -- for an optimally located & oriented source is ~ 2.3X greater (> 45 Mpc)

- First public release of LIGO data associated with a paper (search on Google) http://www.ligo.org/science/GRB051103/GRB051103_trigvals.php



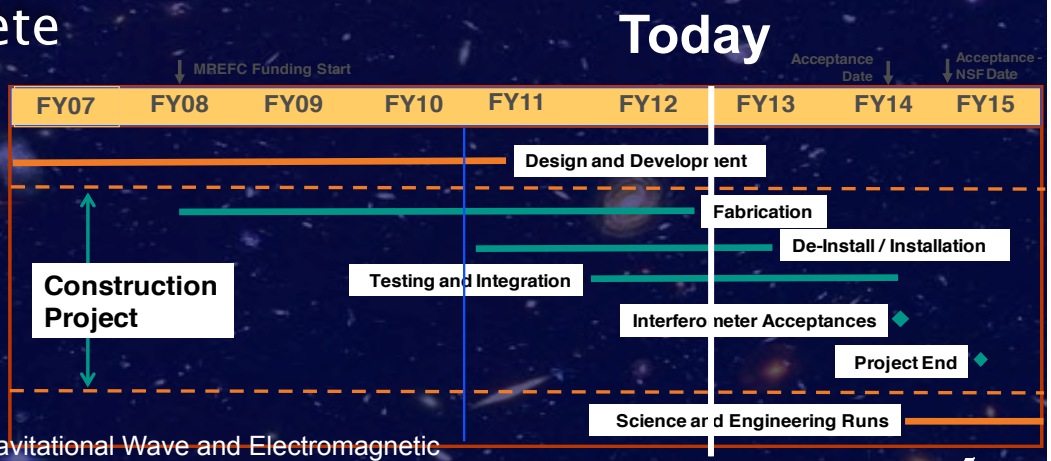
Graphic courtesy of H. Grote, GEO

GW Astrophysics during the Initial Detector Era

- First generation observations:
  - Science runs S1 – S6 (LIGO), VSR1–3(Virgo)
  - Spanned the epoch 2002 – 2010
- Nascent global network – LIGO + Virgo + GEO
  - Different sensitivities, duty factors, ….
- 63 publications to date
  - 7 pending publication or in various stages of internal review
- No detections reported
  - Not unexpected with the sensitivities of the first generation detectors
  - Papers present progressively better upper limits, sophistications in analyses methods
  - A few papers preclude the certain types of sources for (nearby) GRB events

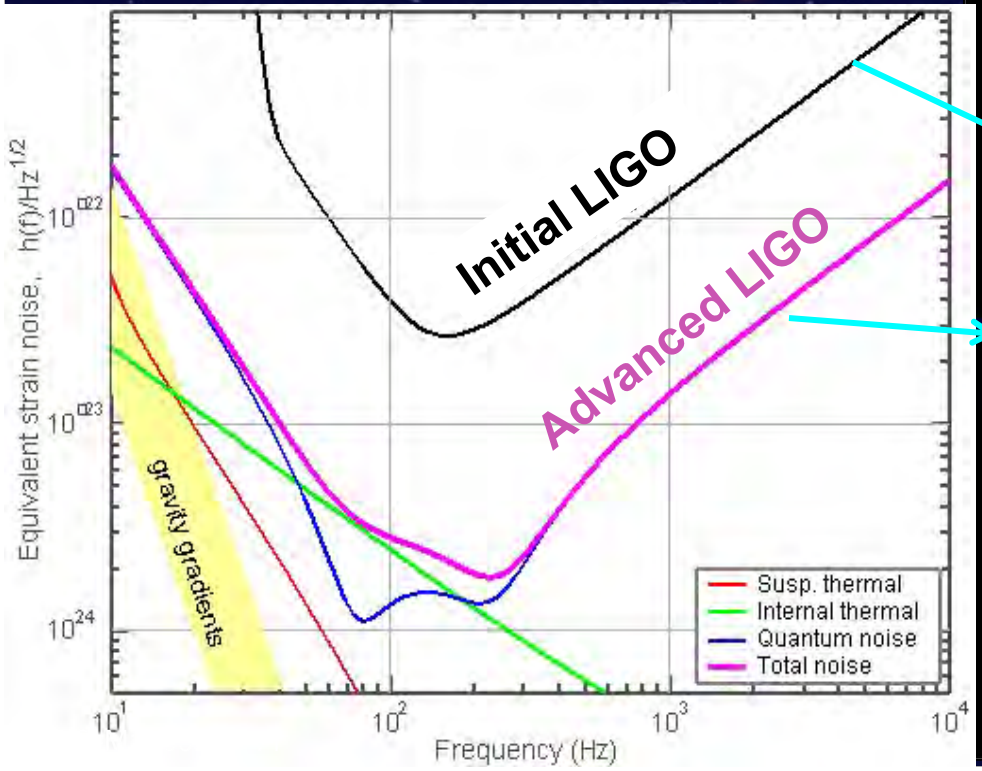
Advanced LIGO – the plan

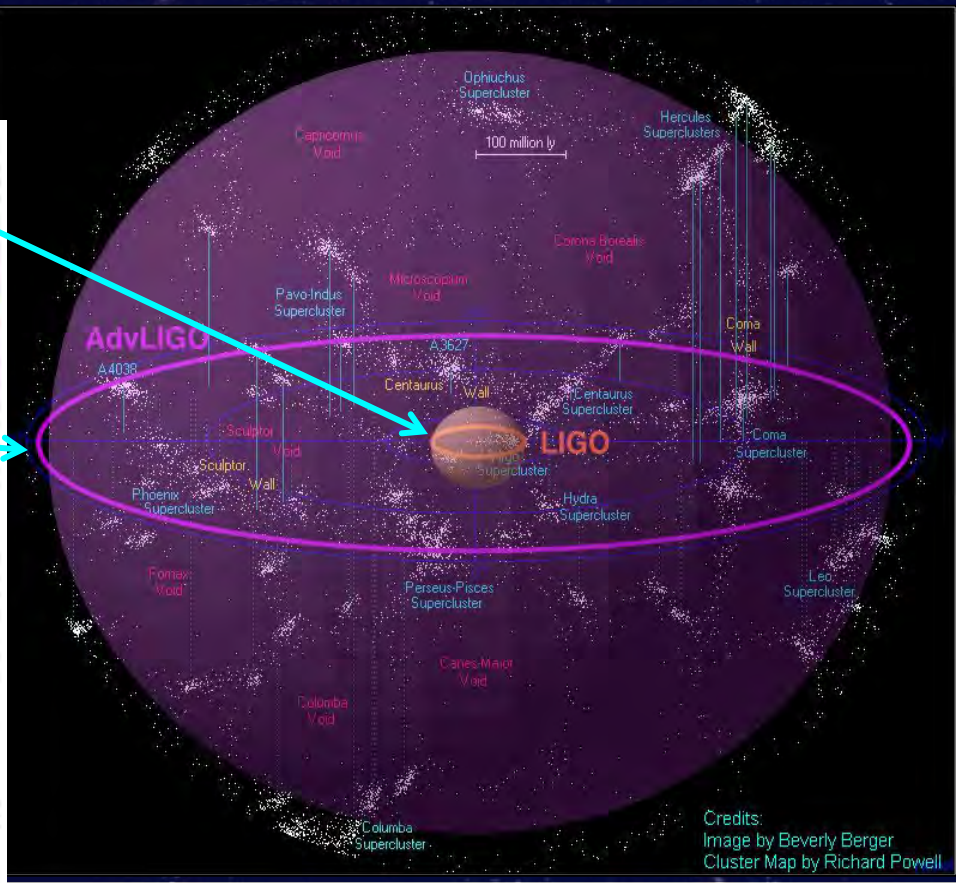
- Complete upgrade of all LIGO interferometers to 2nd generation designs
- Take advantage of new technologies and R&D during the past decade to build a 2nd generation detector:
  - Active anti-seismic system operating to lower frequencies
  - Lower thermal noise suspensions and optics
  - ~8X higher laser power
  - More sensitive and more flexible optical configuration
- $205M construction project, funded by the U.S. National Science Foundation
  - Additional 12% in-kind contribution from GEO (UK+Germany)
- Project is currently 75% complete
  - Construction began in April 2008
  - Installation began in October 2010
  - Commissioning started Spring 2012
  - Expect first lock in 2014



Advanced LIGO:
A 2nd generation detector

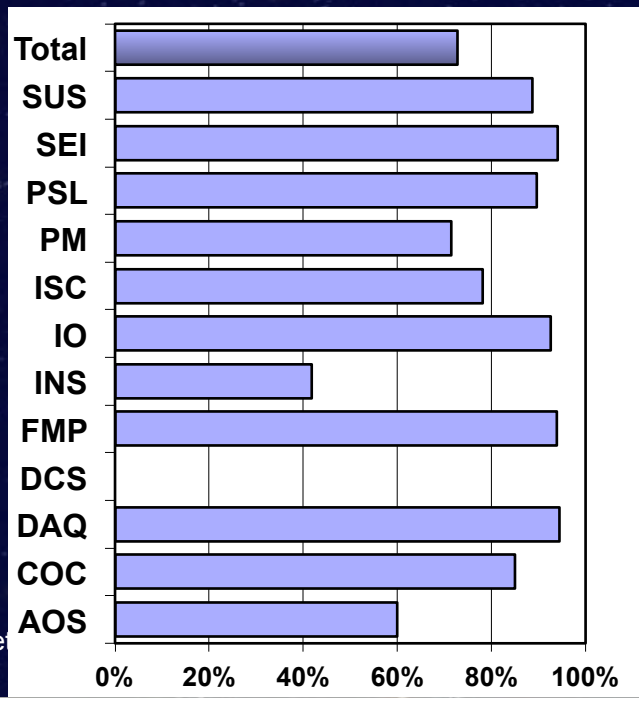
- 10X better amplitude sensitivity
  - Event rate ∝ (reach)^3 ~ 1000X greater
    - 1 day of observation with Advanced LIGO ≫ 1 year with Initial LIGO!





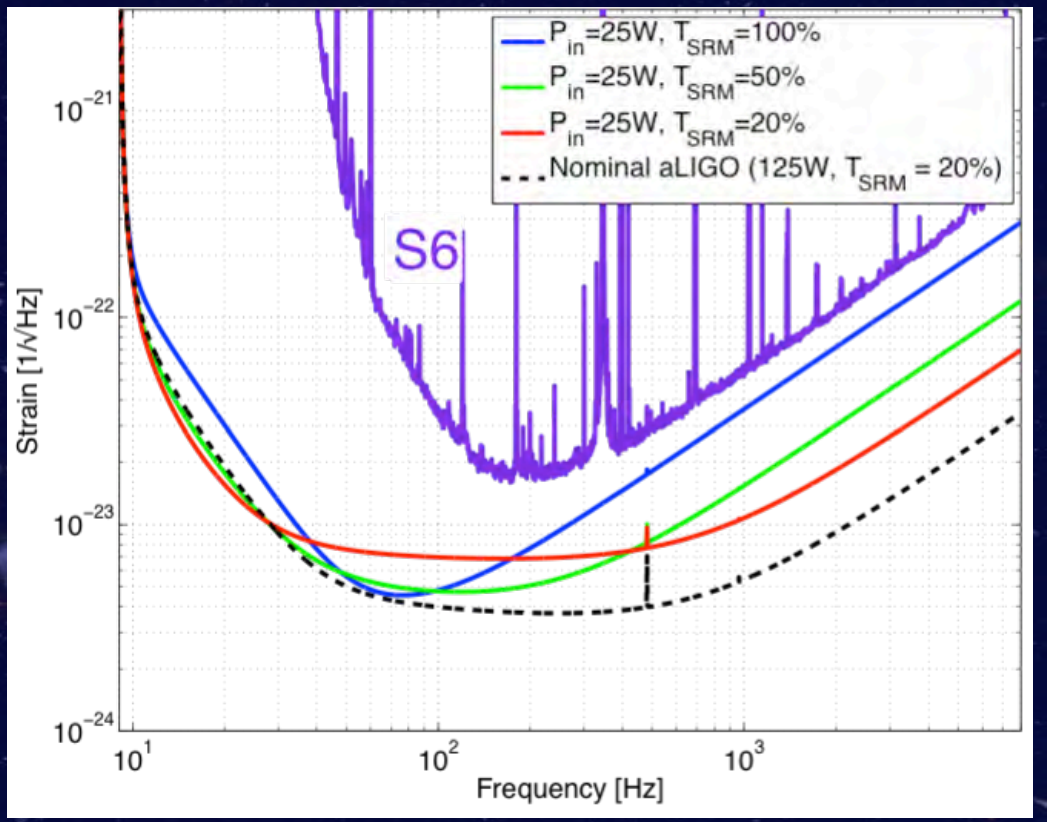
Where are we?

- All designs are complete, all major items procured
- ~85% of the subsystem work is completed
- The installation phase is well underway, with at least one example of each part installed ….and they all fit and work together, happily
- The 'integrated testing' of many components together is getting started
  - Tests of isolation, suspension, optics, and the pre-lock system; not a complete interferometer…but still a big step forward!
  - First 4km aLIGO cavity locked at Hanford last month!
  - First light in suspended mode cleaner at Livingston!

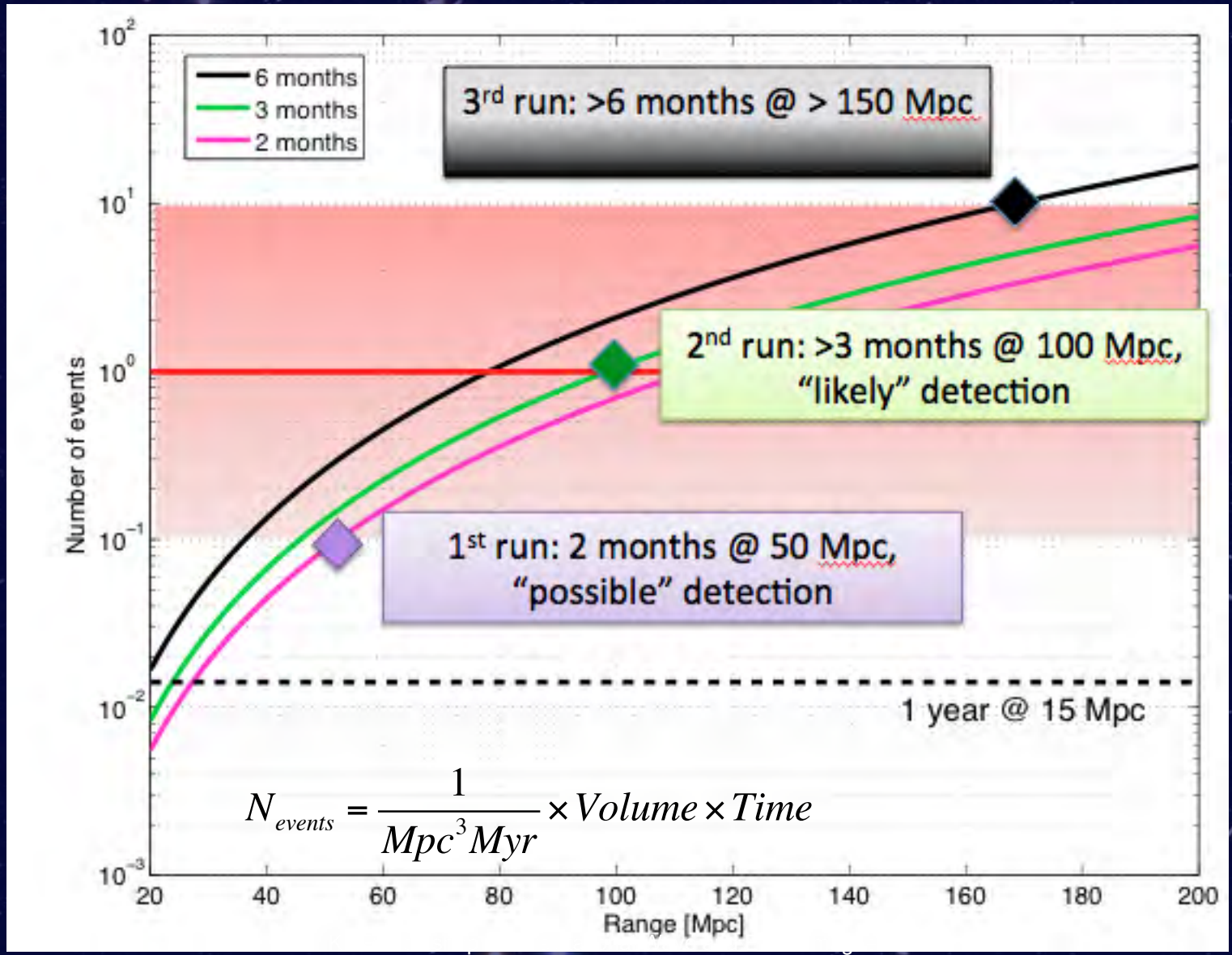


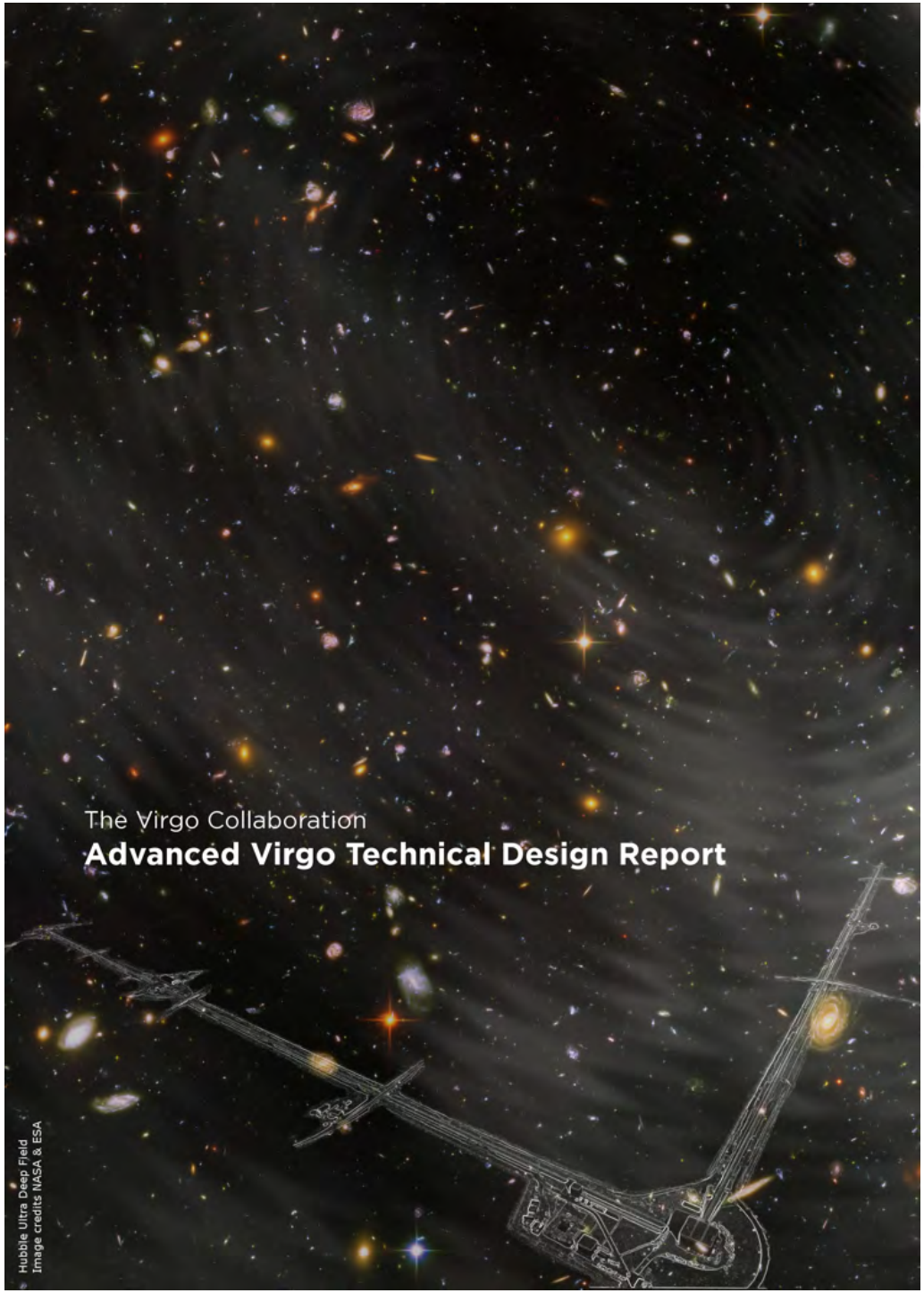
After the Construction: Tuning for Astrophysics, and Observation

- Work hard to begin observations by 2015/2016
- Transition from Project back to Lab/collaboration performance tuning after two-hour lock
  - Planned for 2014
- First operation with low laser power
  - No heating problems
  - No optically-driven torques
  - Focus on low frequencies
  - Probably no signal recycling
- Provides for first astrophysics as well
  - Focus on low-f operations
  - Standard candles are binary neutron stars
    - Most SNR in the 20-200 Hz region
- Focus later on high power, high frequency range



A plausible scenario for LIGO sensitivity evolution, observation





Advanced Virgo Technical Design Report

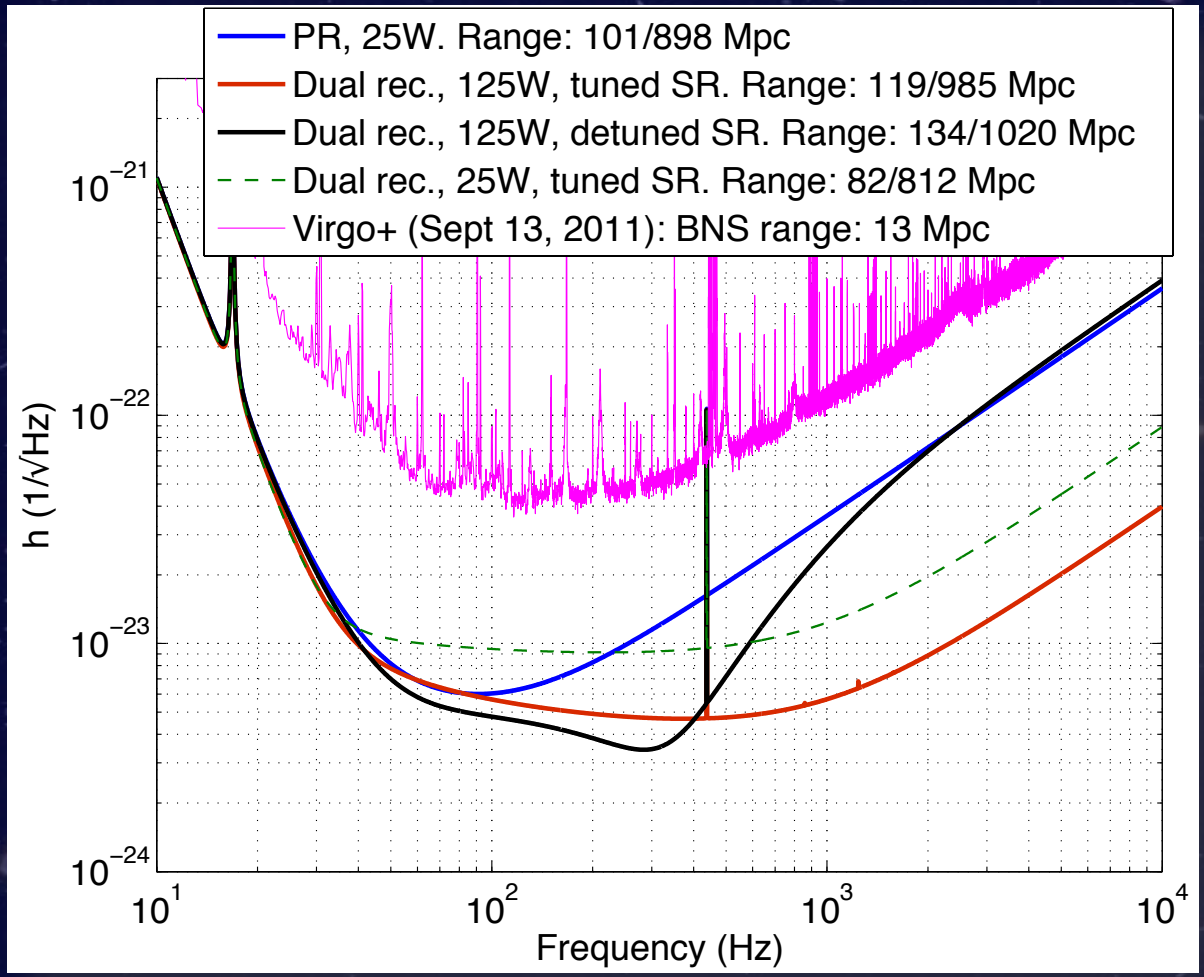
The Virgo Collaboration

VIR–0128A–12

April 13, 2012

Slide courtesy of G. Losurdo, Adv. Virgo Project Leader

Advanced Virgo Sensitivity Goals



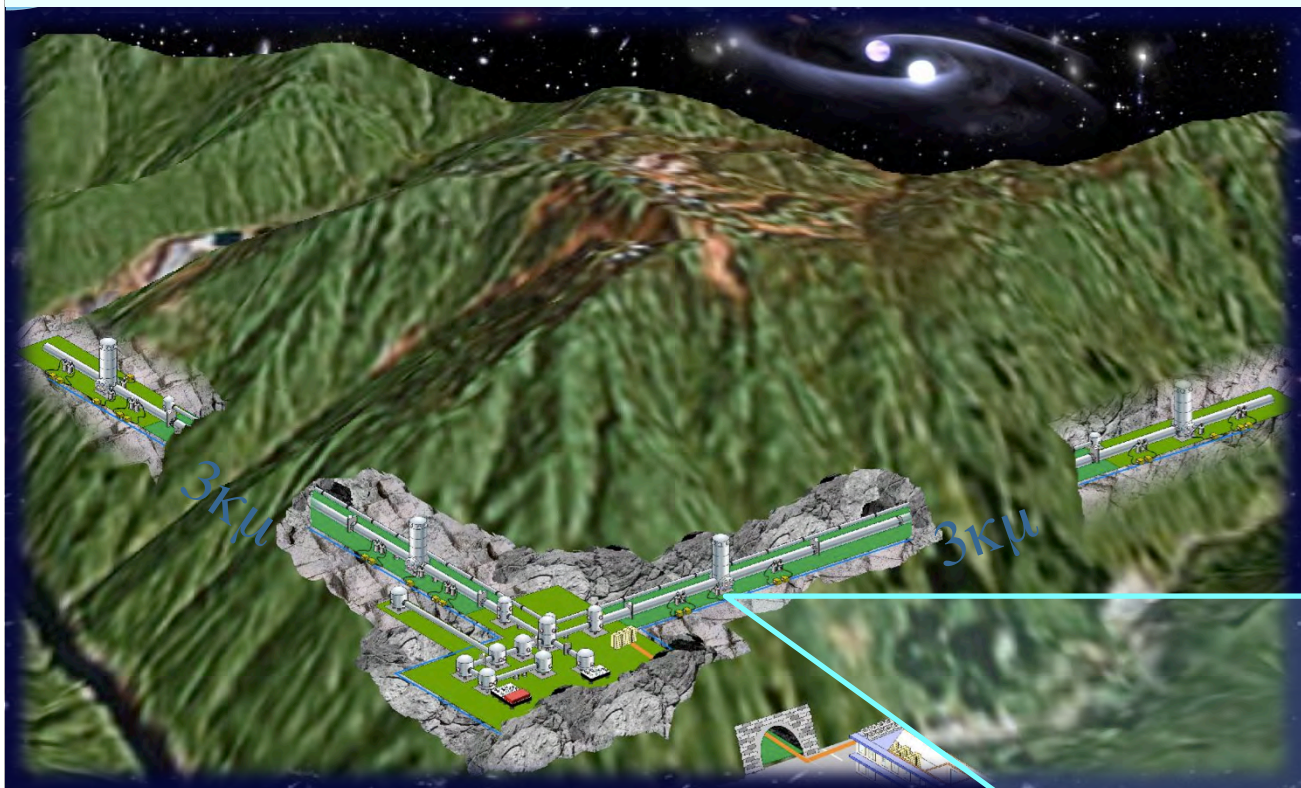
Slide courtesy of G. Losurdo, Adv. Virgo Project Leader

LIGO Advanced Virgo Timeline Scenario

- A scenario on the possible evolution of the sensitivity has been drafted (to go along a similar exercise by LIGO and respond to the pressure of the DA community. In fact, not much discussion/ study behind it…)
  - 2015: commissioning ongoing. 0-20 Mpc. maybe able to join a science run at the end of the year
  - 2016-17: commissioning ramp-up: 20-80 Mpc
  - 2017-18: SR introduced in 2017. 60-110 Mpc
  - 2019+: 110-135 Mpc
- However, the experience with the commissioning of the initial detectors warns that such a kind of predictions are difficult
- Our duty is to do the best to anticipate problems and work to speed up the commissioning time

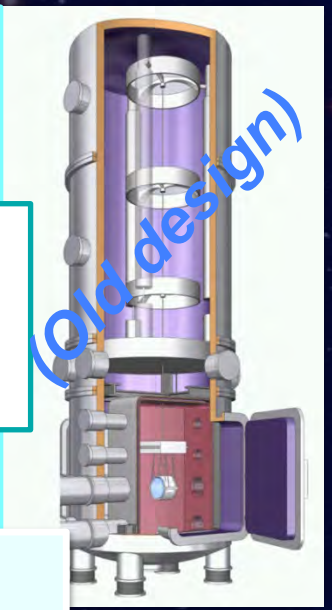
Slide courtesy of G. Losurdo, Adv. Virgo Project Leader

KAGRA: Key features



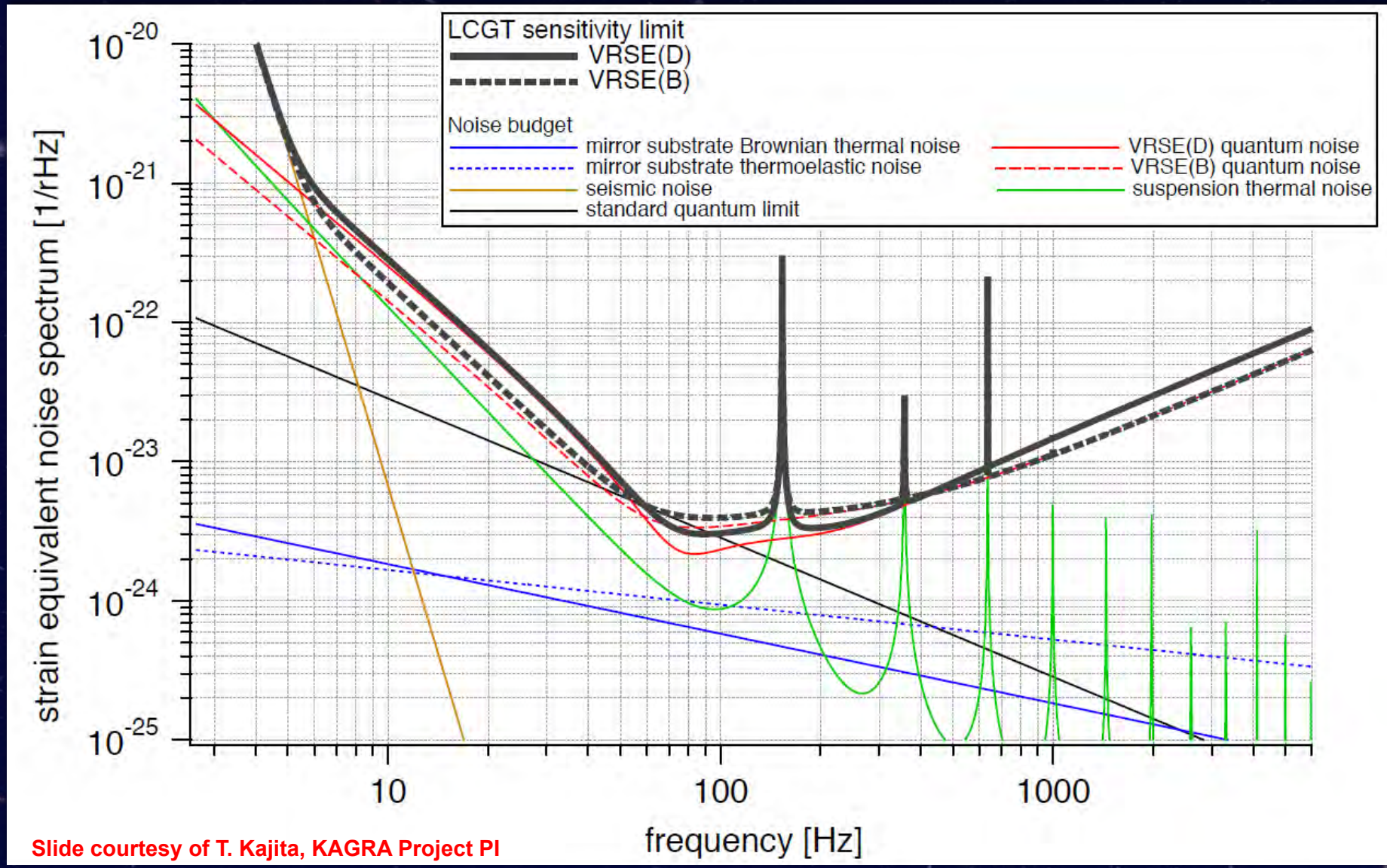
The detector will be constructed underground Kamioka.
➔ Reduction of seismic noise (by approximately 1/100).

Cryogenic mirrors will be used to reduce the thermal noise (in the 2nd phase).



➡ NS-NS merger within >200Mpc to be observed.

KAGRA: Calculated sensitivity



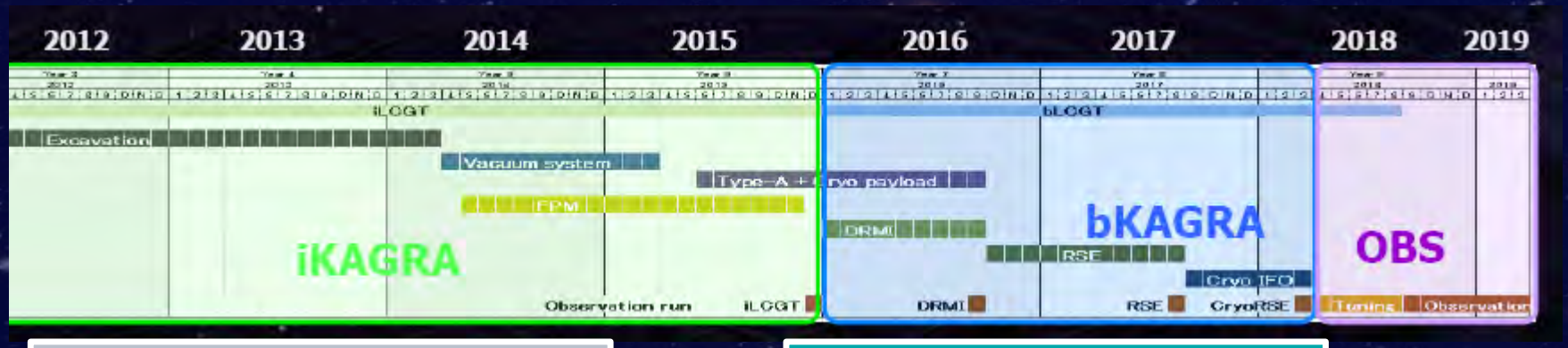
Slide courtesy of T. Kajita, KAGRA Project PI

KAGRA: Key features and timeline

Key features of KAGRA:

- The detector will be constructed underground Kamioka. ➔ Reduction of seismic noise (by approximately 1/100).
- The construction will be in 2 phases (iKAGRA and bKAGRA).
- Cryogenic mirrors will be used to reduce the thermal noise in the 2nd phase (bKAGRA).

Timeline



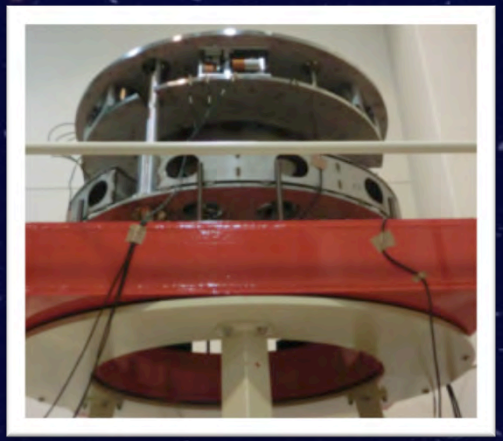
iKAGRA (2010 – 2015)
3km FPM interferometer
(Room temperature operation)

bKAGRA (2016 – 2018)
Operation with full config.
(Cryogenic operation at the end of this period)

Observation (2018 –)
Tuning and long-term obs.

KAGRA: Status

Tunnel excavation near one of the end mirrors. The excavation started in May 2012.



Testing the vibration isolation system.

Tunnel excavation (main entrance to the experimental area)

Production of the cryostat.

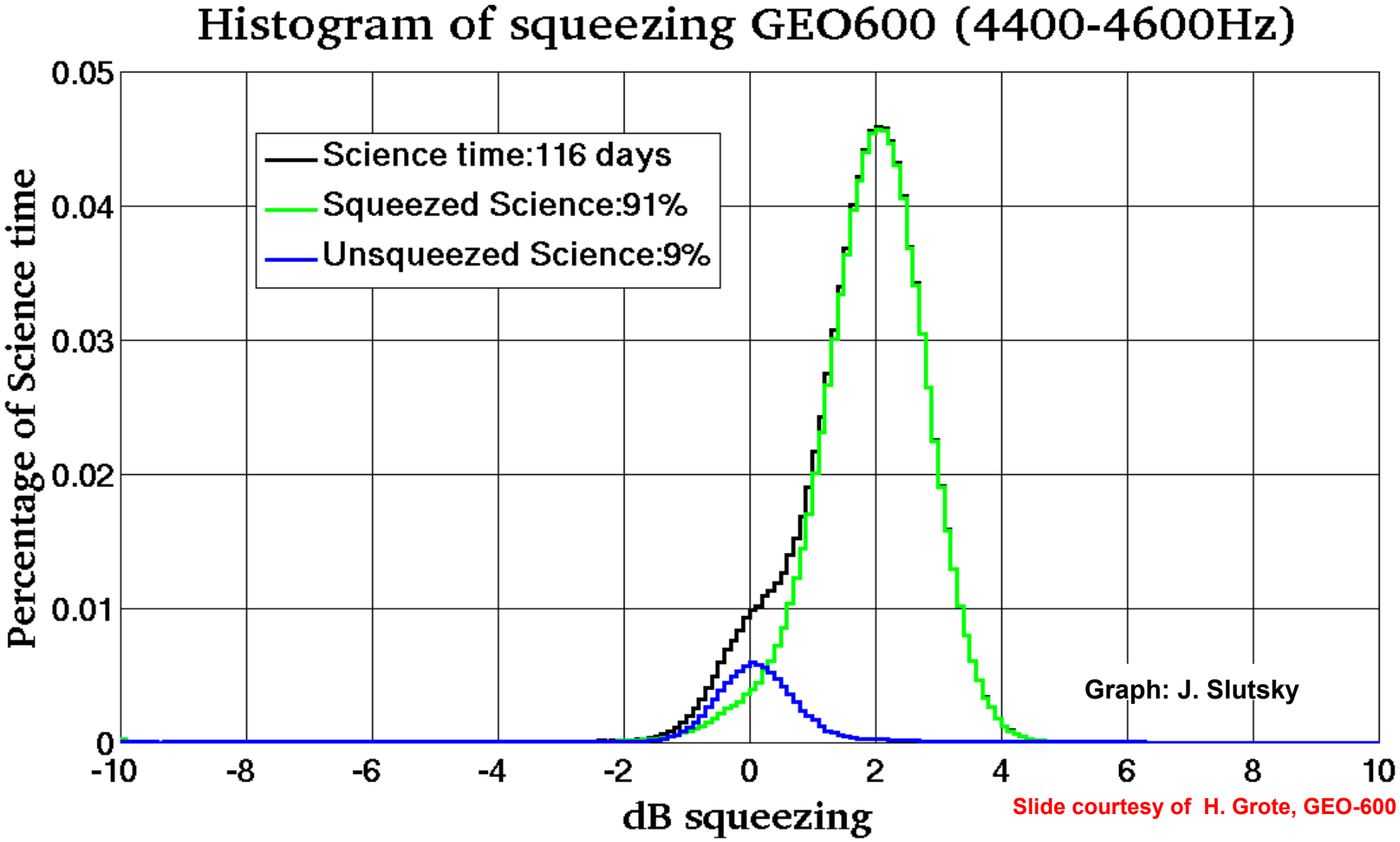
Transportation of the vacuum pipes to Kamioka.

The construction is in progress almost as scheduled.

GEO600 High-frequency (HF)

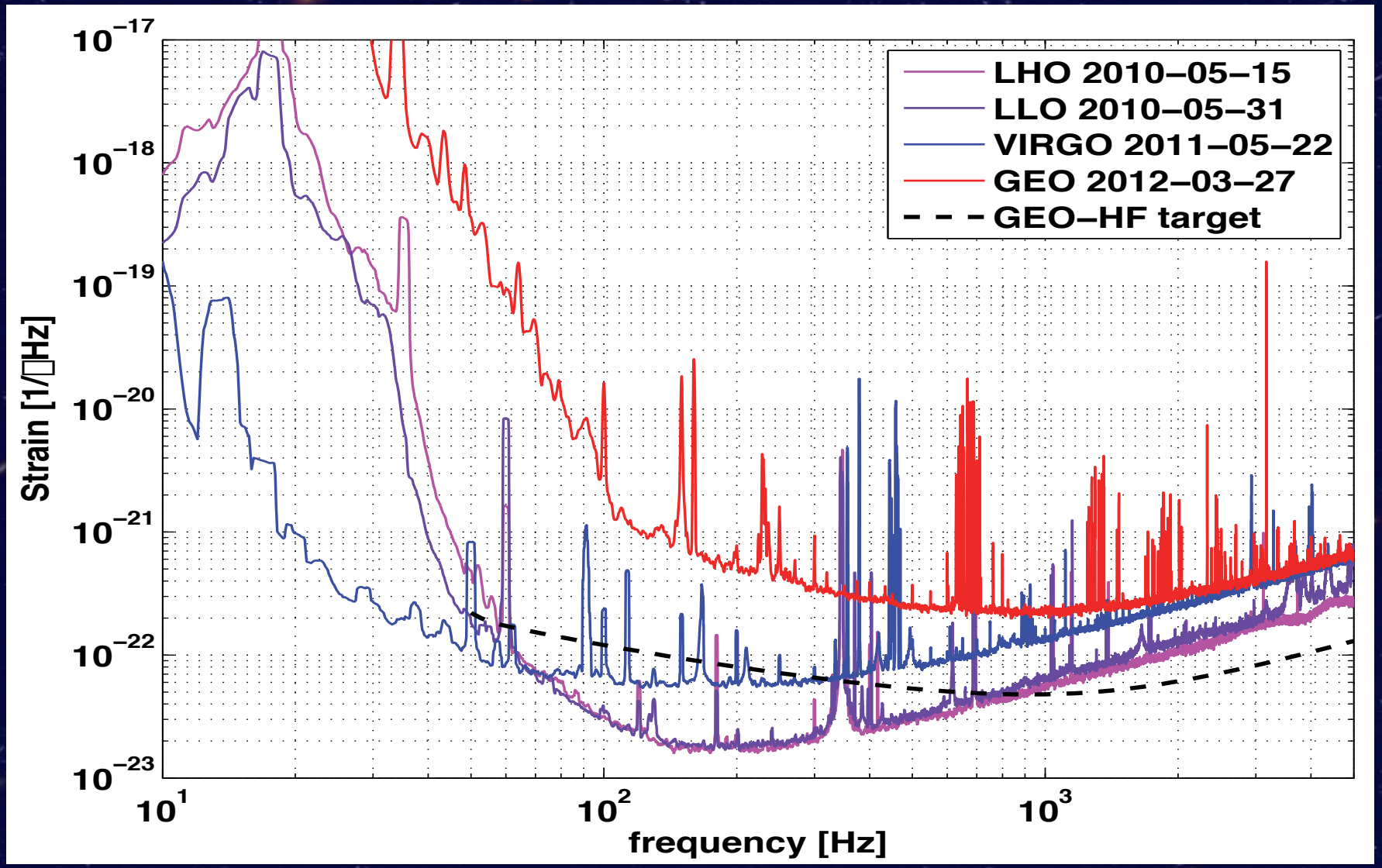
Slide courtesy of H. Grote, GEO-600

GEO pioneered squeezed light interferometry for GW detectors



Slide courtesy of H. Grote, GEO-600

GEO HF Sensitivity



Graphic courtesy of H. Grote, GEO

Slide courtesy of H. Grote, GEO-600

GEO-HF plans for the next years

- Interferometer input power increase to 20W
- Achieve 6dB of Squeezing
- Research on squeezing and output mode cleaner (OMC) readout techniques with GEO
  - Help with Adv. Detector development
- 'Astrowatch' data taking (until first detections)
- Possibly contribute to some detections in Adv. Detector era (at high frequencies)

Slide courtesy of H. Grote, GEO-600

LIGO-India

- LIGO Laboratory and the IndIGO consortium pursuing a proposal to locate an Advanced LIGO interferometer in India
- Additional long baseline provides greatly improved sky localization of gravitational-wave events
- LIGO Laboratory provides components for one Advanced LIGO interferometer from the Advanced LIGO project
  (leaves two in the US – WA, and LA)
- India provides the site, roads, building, vacuum system, and the team to make it happen
- Working its way through the Indian government funding system, and the NSF
- NSF has given approval for LIGO to stop work on 2nd interferometer at LHO in anticipation of shipping it to India.
  - For now, 3rd interferometer components going into storage

Candidate sites in green, blue

Status of LIGO-India

- Excellent progress in moving forward on the Indian and US sides!
- India
  - LIGO-India identified as a 'Mega-Science Project' in the XIIth Plan Commission Report
    - Referred to Cabinet of the Government of India for funding
  - Inter-University Centre for Astronomy and Astrophysics (IUCAA), Raja Ramanna Centre for Advanced Technology (RRCAT), and Institute for Plasma Research (IPR) taking on leading roles in India
  - Site selection/characterization has begun
- USA
  - LIGO Laboratory has ceased installation of second Advanced LIGO interferometer at Hanford for use in India
    - Development of plans for packaging, shipping
  - Strongly positive reviews of LIGO-India National Science Foundation; process for final approval by the National Science Board has begun
  - LIGO-India featured as one of three major cooperative large scale science project at the US State Department Second Indo-US Joint Commission Meeting on Science and Technology Cooperation
  - NSF planning to bring proposal to its governing board, NSB, later this year
- Expect formal project approval on both sides later this year
- LIGO-India will be operating early in the next decade

Growing International Network of GW Interferometers

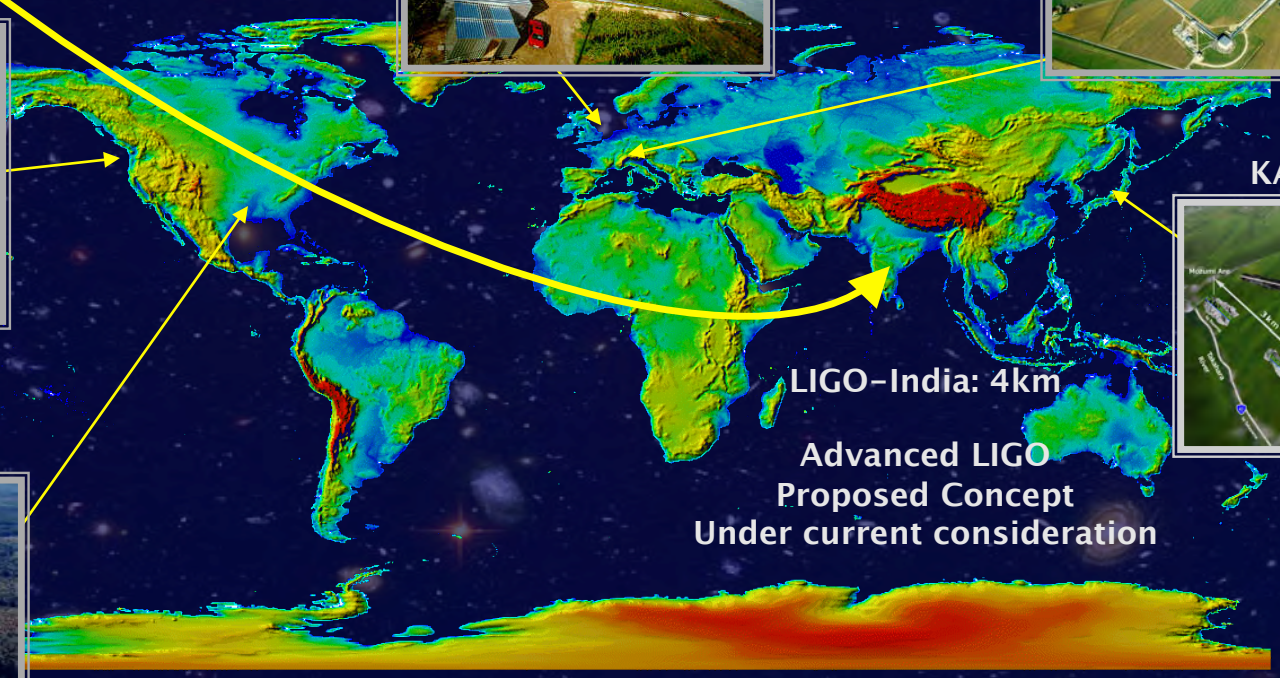
Operated as a phased array – aperture synthesis GW astronomy:

- ***Enhance detection confidence***
- ***Localize sources by exploiting time-of-arrival differences over intercontinental baselines***
- ***Decompose the polarization of gravitational waves***

GEO-HF: 0.6km
On-line

VIRGO: 3km
Advanced Virgo

LIGO-LHO: 4km + 4km
Advanced LIGO



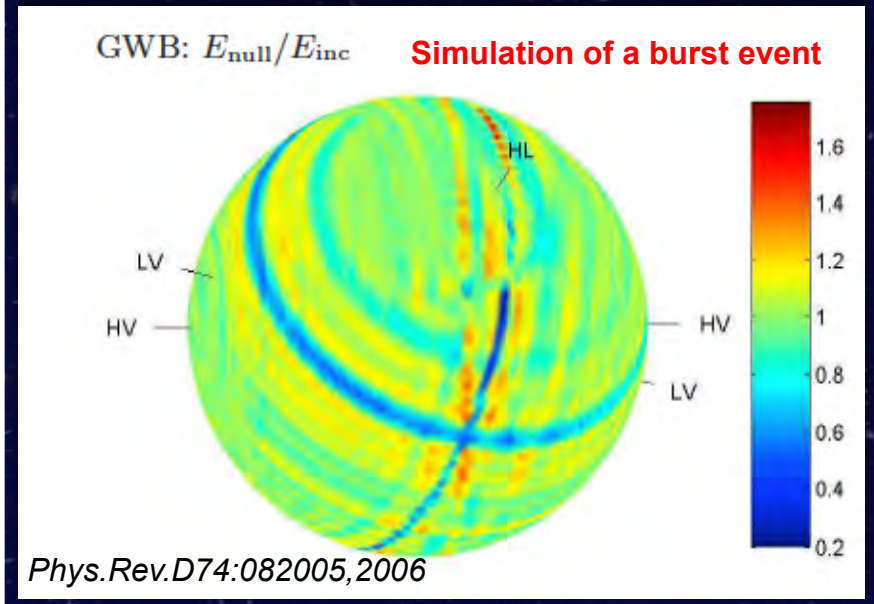
KAGRA: 3km

LIGO-India: 4km

Advanced LIGO
Proposed Concept
Under current consideration

LIGO-LLO: 4km
Advanced LIGO

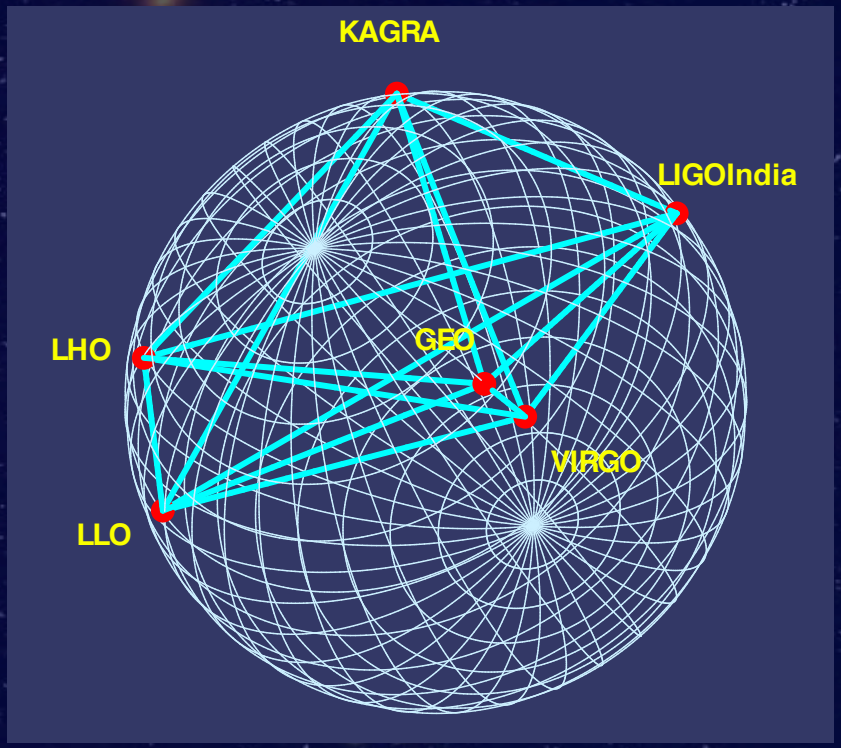
Localization: International Array of GW Interferometers

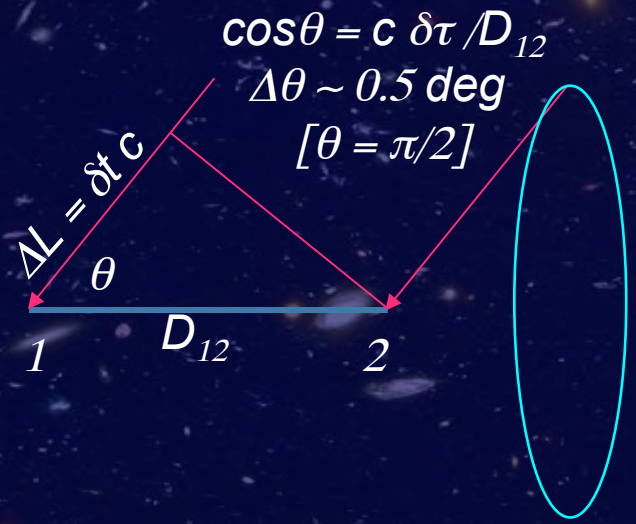


- Exploit time-of-arrival differences, δt_{ij}, to triangulate source direction

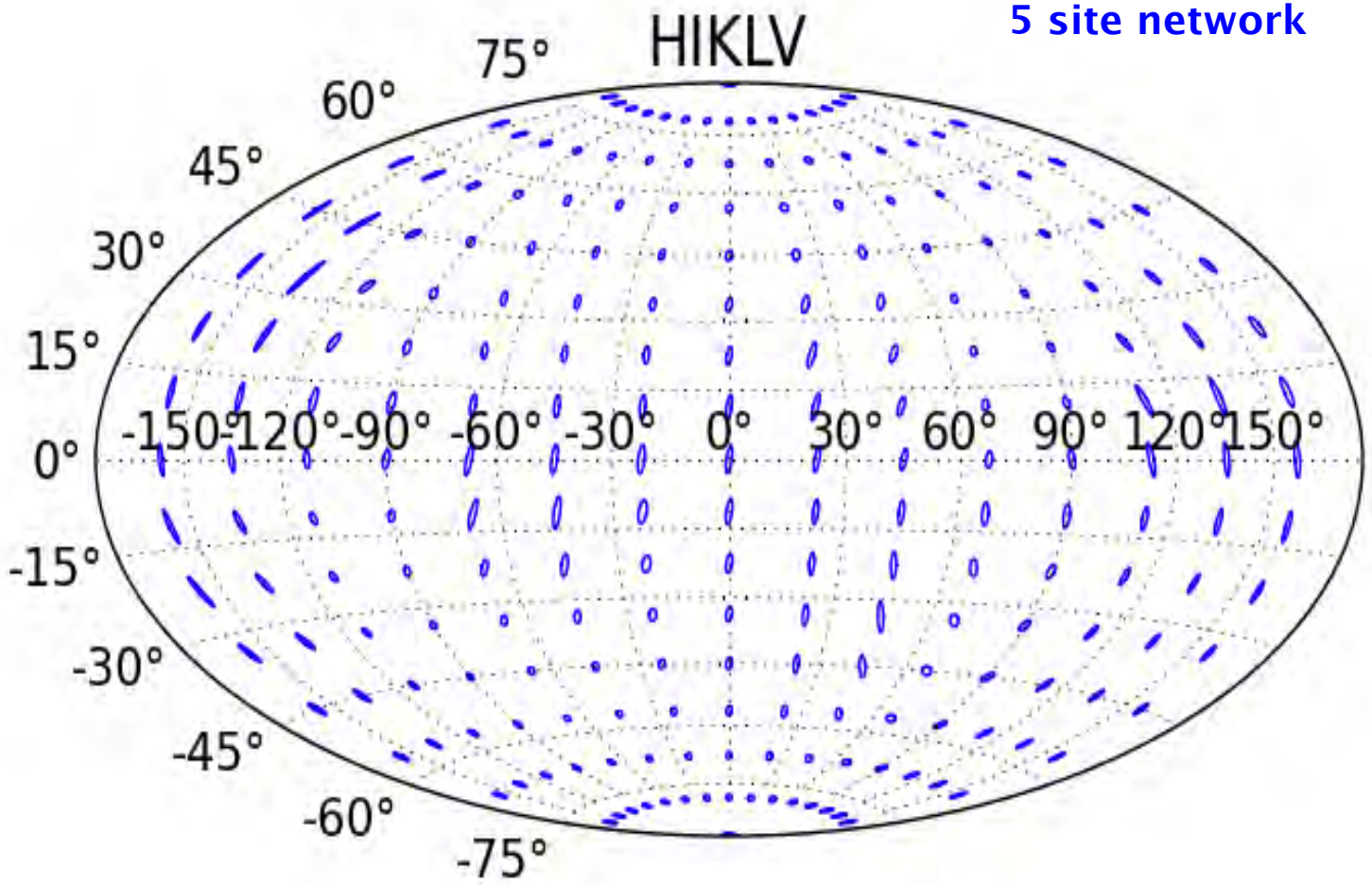
Ref: S. Fairhurst's talk

Global array of interferometric GW detectors





Binary Neutron Star Merger Localization

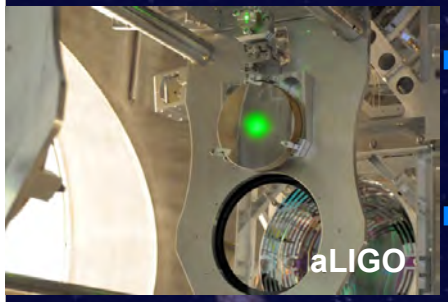


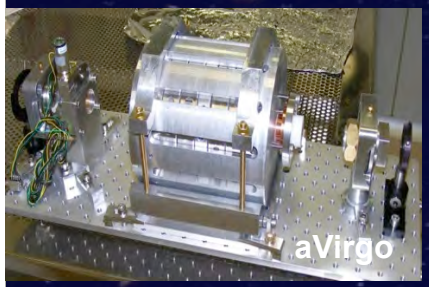
5 site network

Hanford-Livingston-Virgo-India-KAGRA

Ref: S. Fairhurst, "*Improved source localization with LIGO India*", arXiv:1205.6611v1

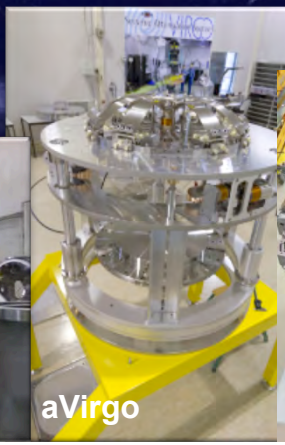
Summary

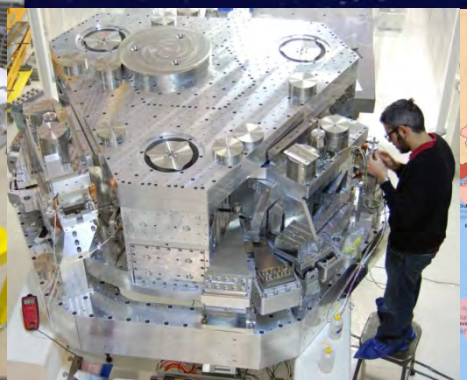




- The next generation of gravitational-wave detectors will have the sensitivity to make frequent detections
- The Advanced LIGO detectors are coming along well, planned to complete in 2014
- Virgo, KAGRA also under construction
- GEO HF (w/squeezing) performing astrowatch duty now, will be online during Advanced Detector Era for HF operation at comparable sensitivity
- The world-wide community is growing, and is working together toward the goal of gravitational-wave astronomy

Planning on a first observation 'run' as early as 2015





LIGO-M1200269-v1


LIGO
FINIS