Gravitational Wave Detection from the Ground Up

Peter Shawhan
(University of Maryland)
for the LIGO Scientific Collaboration

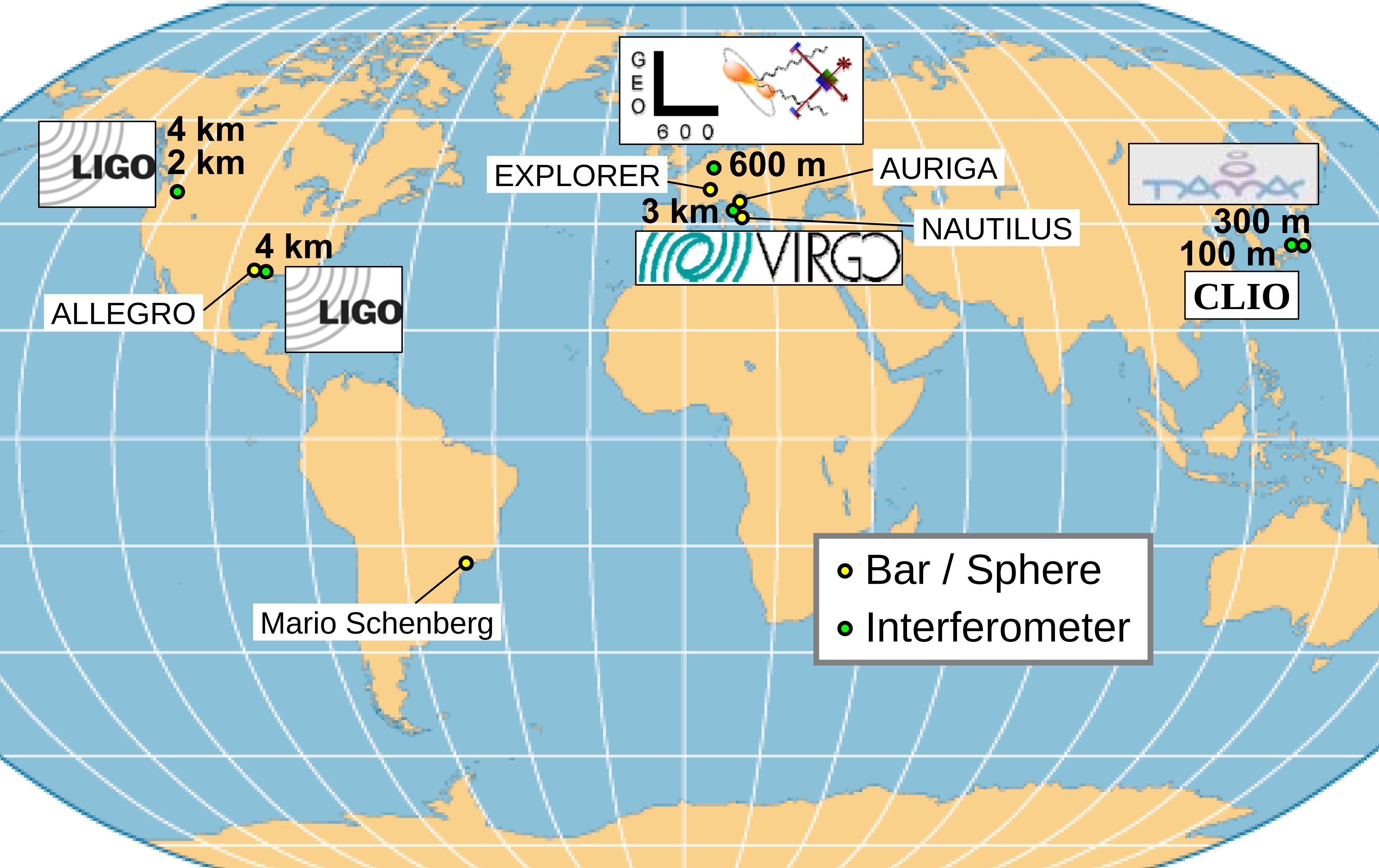
LIGO-G080393-00-Z

From Simple Beginnings…

Joe Weber
circa 1969

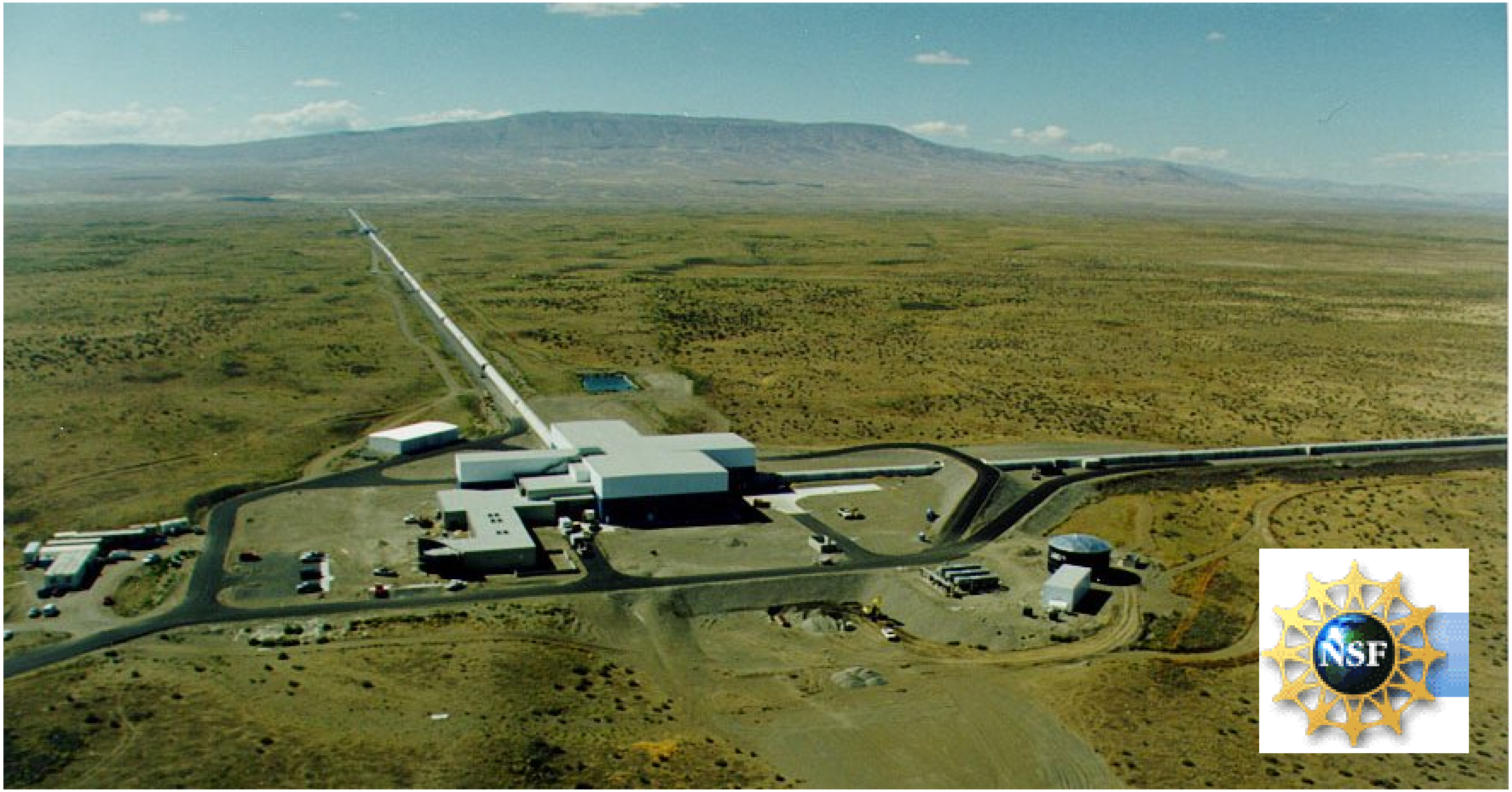
AIP Emilio Segre Visual Archives

… to a Worldwide Network



LIGO Hanford Observatory

Located on DOE Hanford Site north of Richland, Washington



Two separate interferometers (4 km and 2 km arms) coexist in the beam tubes

LIGO Livingston Observatory

Located in a rural area of Livingston Parish east of Baton Rouge, Louisiana

One interferometer with 4 km arms

GEO 600

British-German project, located among fields near Hannover, Germany

Virgo

French-Italian project, located near Pisa, Italy

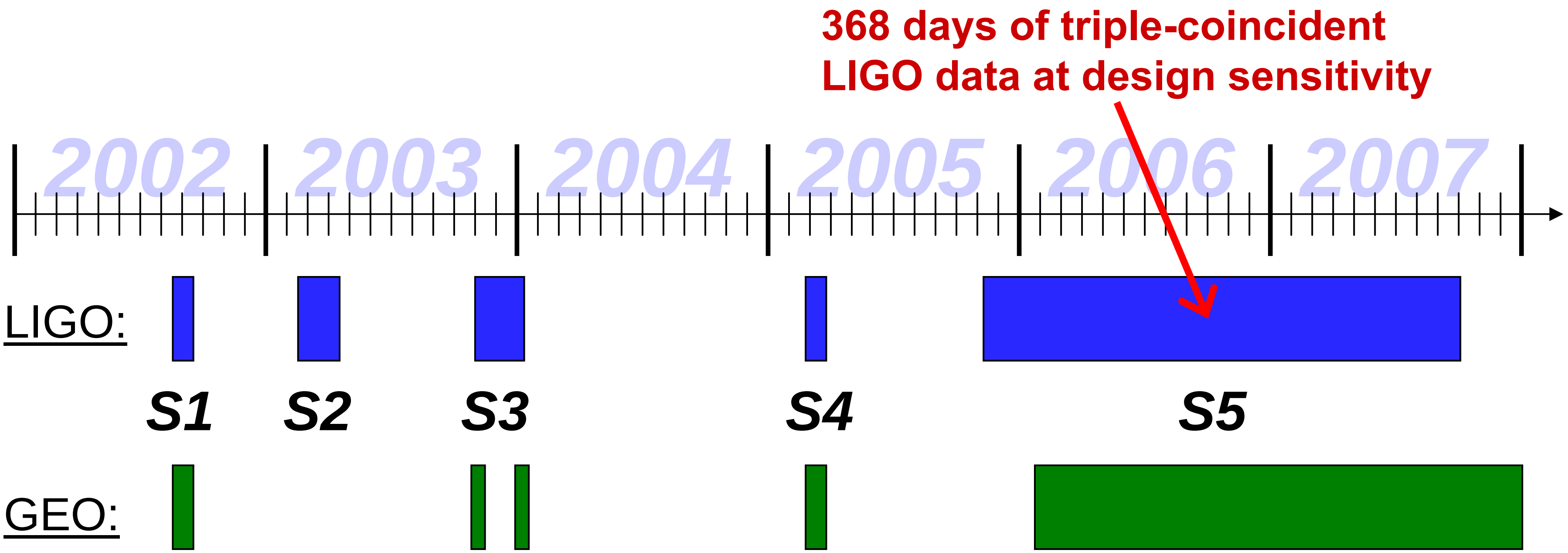
3 km arms

Main Challenges
for Ground-Based GW Detectors

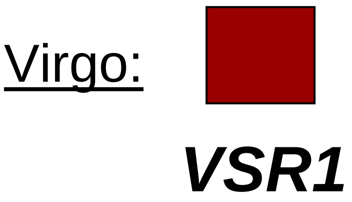
Address with:

Seismic noise	Passive and active vibration isolation
Thermal noise	Mirror substrates, coatings, suspensions, beam size, cooling?
Photon quantum noise	Laser power, mirror mass
Shot noise, radiation pressure	
Technical noise sources	Laser stability, arm length locking, servo gains, charge management
Signal detection	
Templates	Post-Newtonian theory, numerical relativity
Arbitrary signals	Robust methods, consistency tests
Non-stationary noise	Detector characterization, environmental monitoring, vetoes

Science Runs So Far

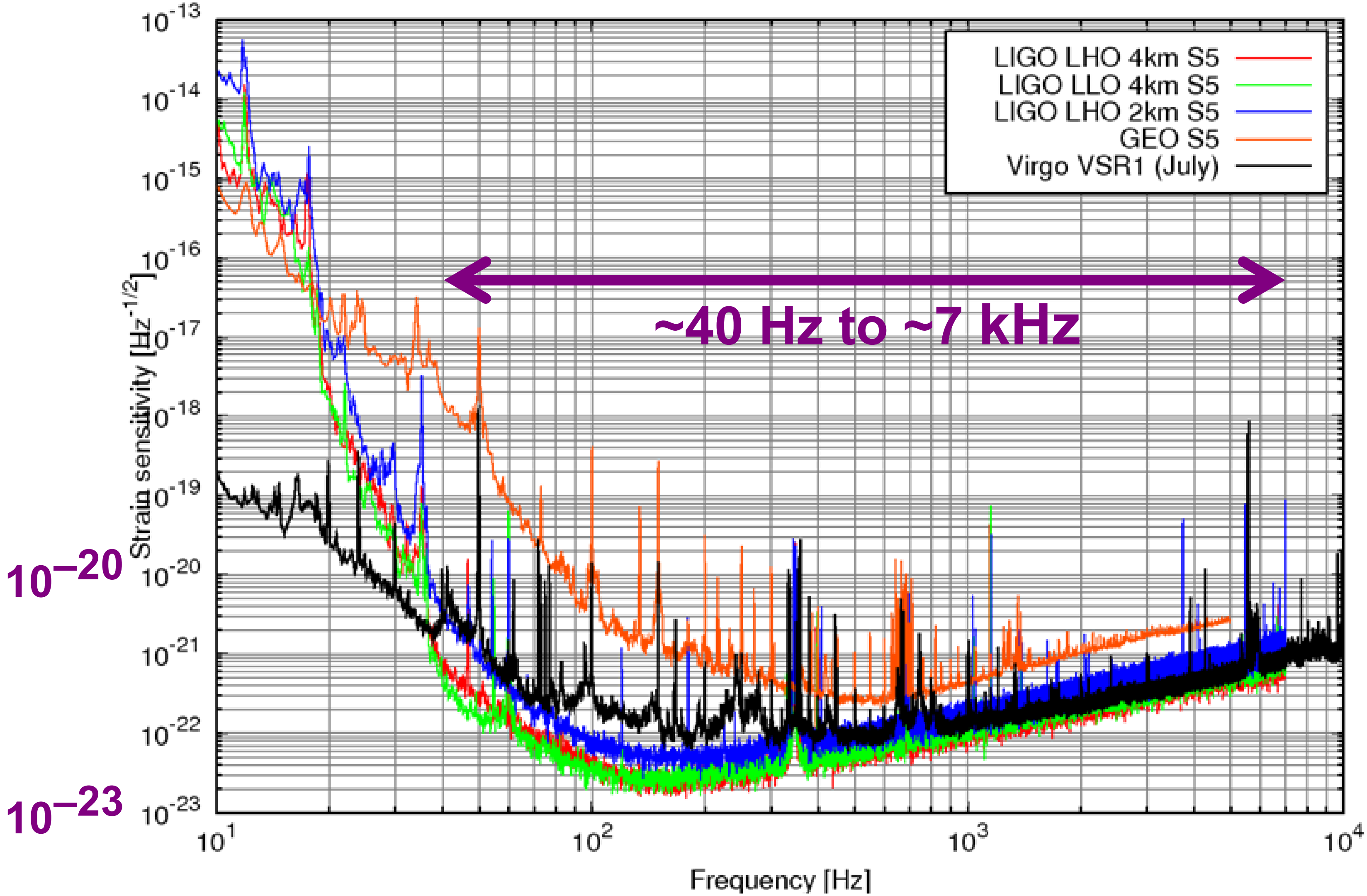


LIGO Scientific Collaboration (LSC) = LIGO + GEO

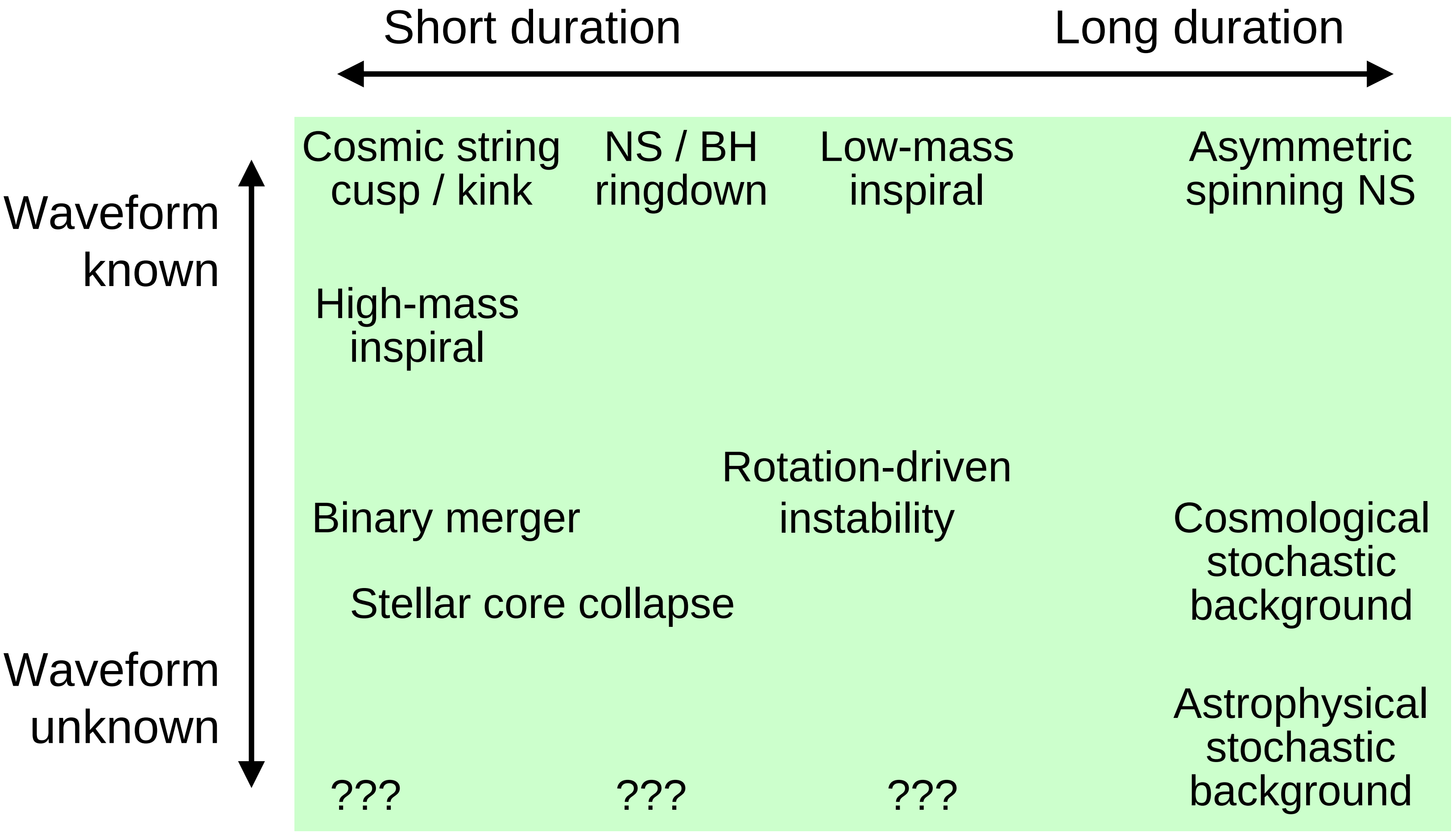


LSC and Virgo are analyzing S5/VSR1 data together

Summer 2007 Performance of the Large Interferometers



The GW Signal Tableau
for Ground-Based Detectors



Science Goals
for Ground-Based Detectors

First direct detections of GW signals

Test GW properties (e.g. polarization components)

Study strong-field gravity – system dynamics, GW emission

Survey source populations

So far, only setting upper limits on GW emission…

GRB 070201

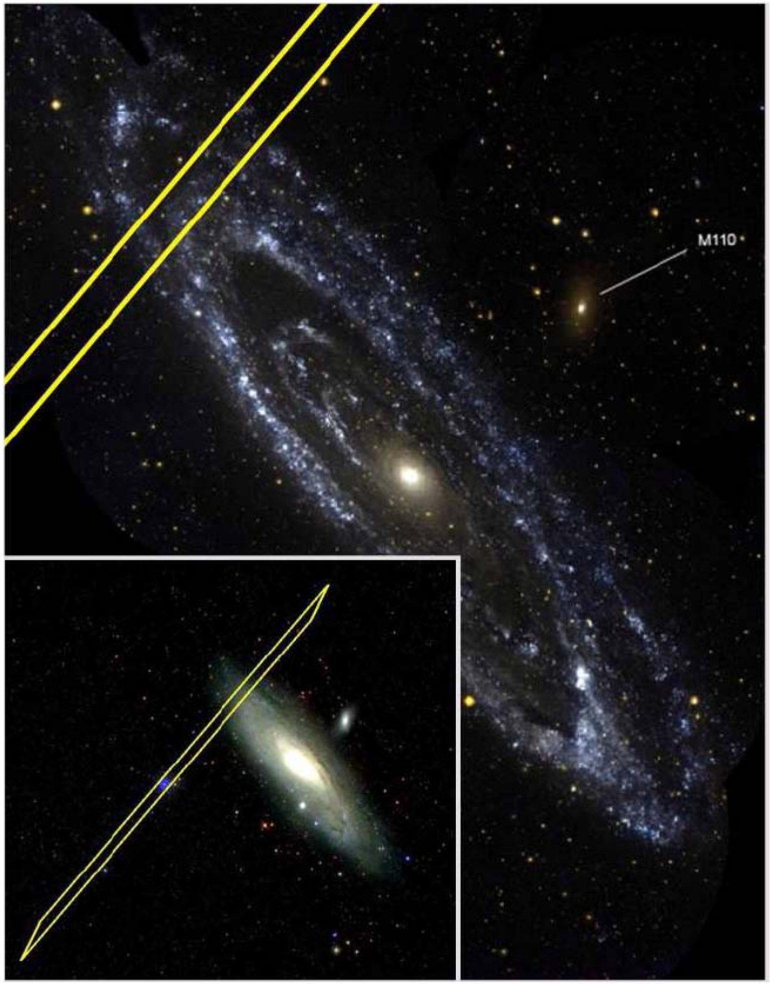


FIG. 1.— The IPN3 (IPN3 2007) (γ-ray) error box overlaps with the spiral arms of the Andromeda galaxy (M31). The inset image shows the full error box superimposed on an SDSS (SDSS 2007) image of M31. The main figure shows the overlap of the error box and the spiral arms of M31 in UV light (Thilker et al. 2005).

Short, hard gamma-ray burst

A leading model for short GRBs: binary merger involving a neutron star

Position (from IPN) consistent with being in M31

LIGO H1 and H2 were operating

Result from LIGO data analysis:
No plausible GW signal found; therefore very unlikely to be from a binary merger in M31

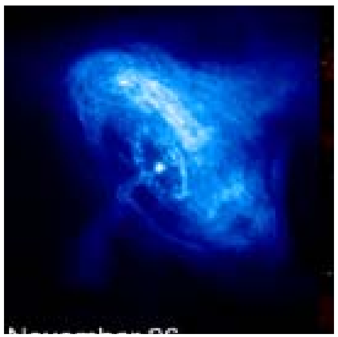
[Preprint arXiv:0711.1163 ; ApJ in press]

Crab Pulsar

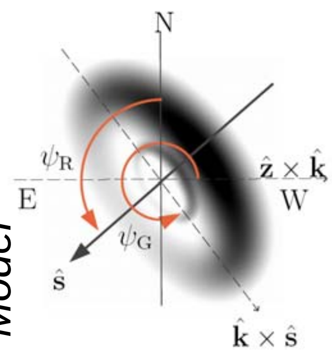
Search for continuous-wave signal

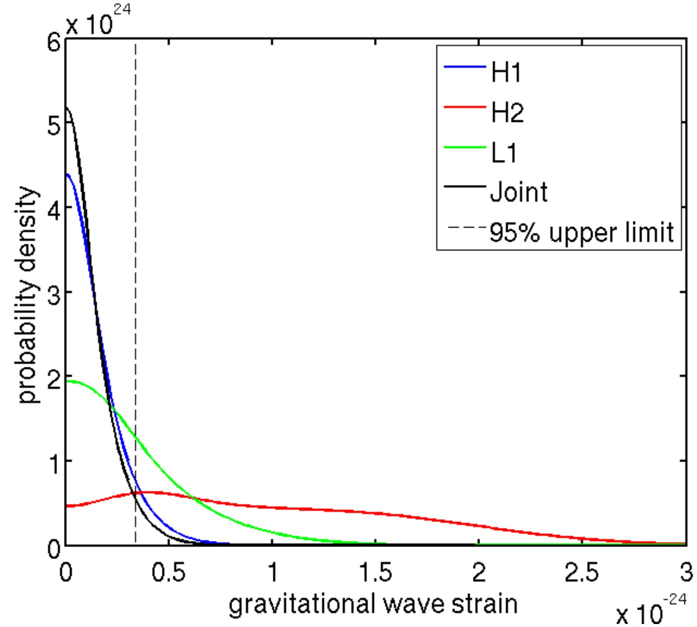
Result from first 9 months of S5:
Consistent with Gaussian noise →

Chandra image



Model





Upper limits on GW strain amplitude h_0

- Single-template, uniform prior: **3.4×10^{-25}**
- Single-template, restricted prior: **2.7×10^{-25}** ←
- Multi-template, uniform prior: **1.7×10^{-24}**
- Multi-template, restricted prior: **1.3×10^{-24}**

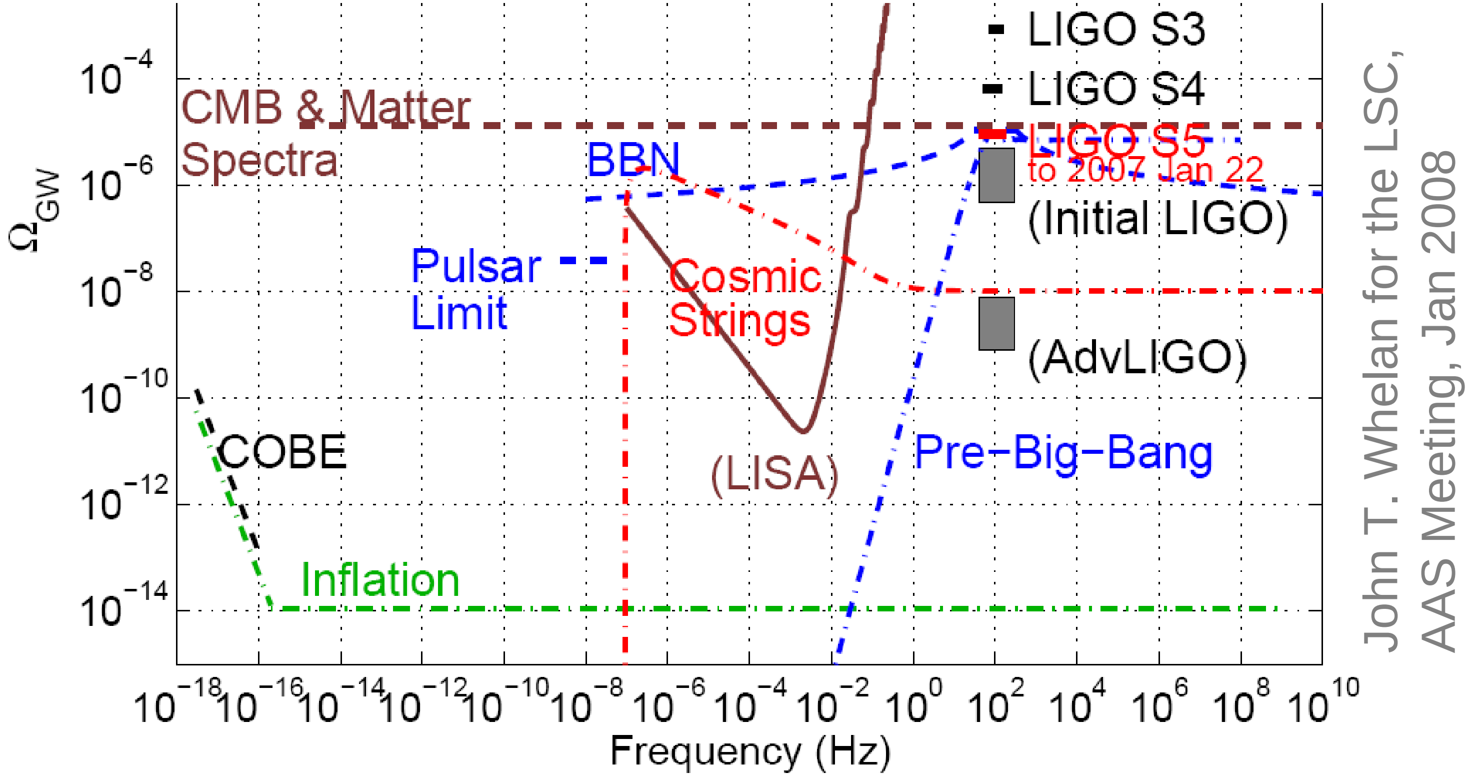
Implies that GW emission accounts for ≤ 4% of total spin-down power

[arXiv:0805.4758 ; ApJL in press]

Search for a Stochastic GW Background

Cross-correlated LIGO data streams to estimate energy density in isotropic stochastic GW, assuming a power law

Partial, preliminary **result from S5 is comparable to constraint from Big Bang nucleosynthesis**



Upgrades Currently In Progress

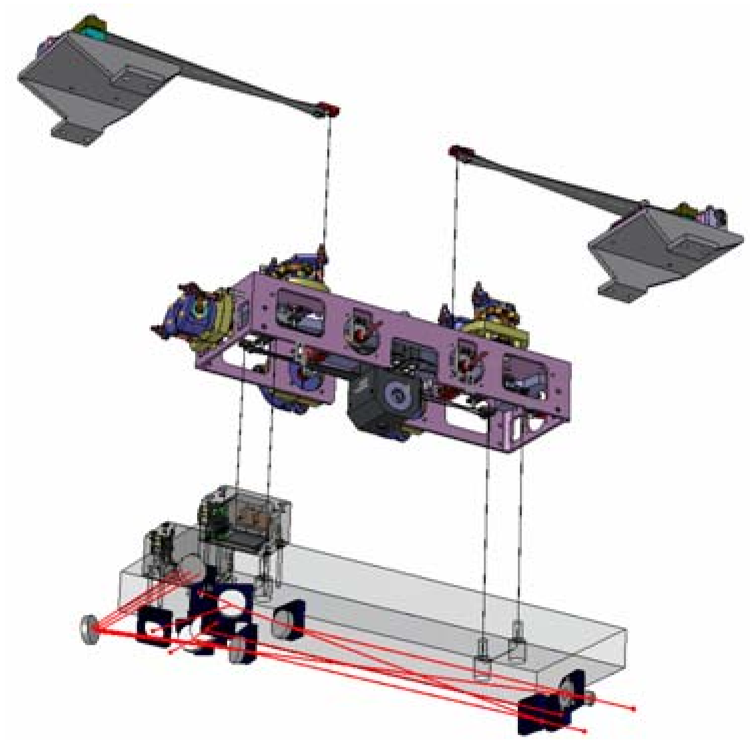
LIGO 4-km interferometers being "enhanced"

Increase laser power to 35 W

DC readout scheme

Photodetector in vacuum, suspended

Output mode cleaner



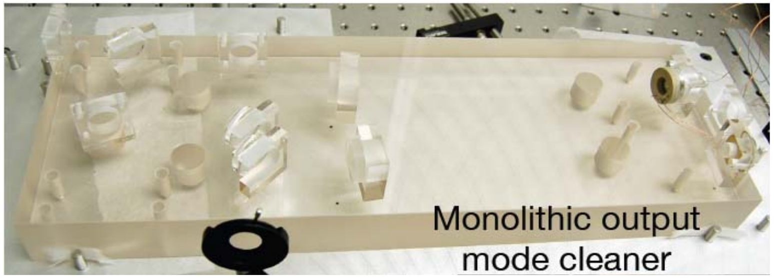
Aiming for a factor of ~2 sensitivity improvement

S6 run planned to begin Spring 2009, run through end of 2010

Virgo improvements and joint running (VSR2) planned on same time scale

Meanwhile, LIGO Hanford 2-km and GEO are running in "AstroWatch" mode

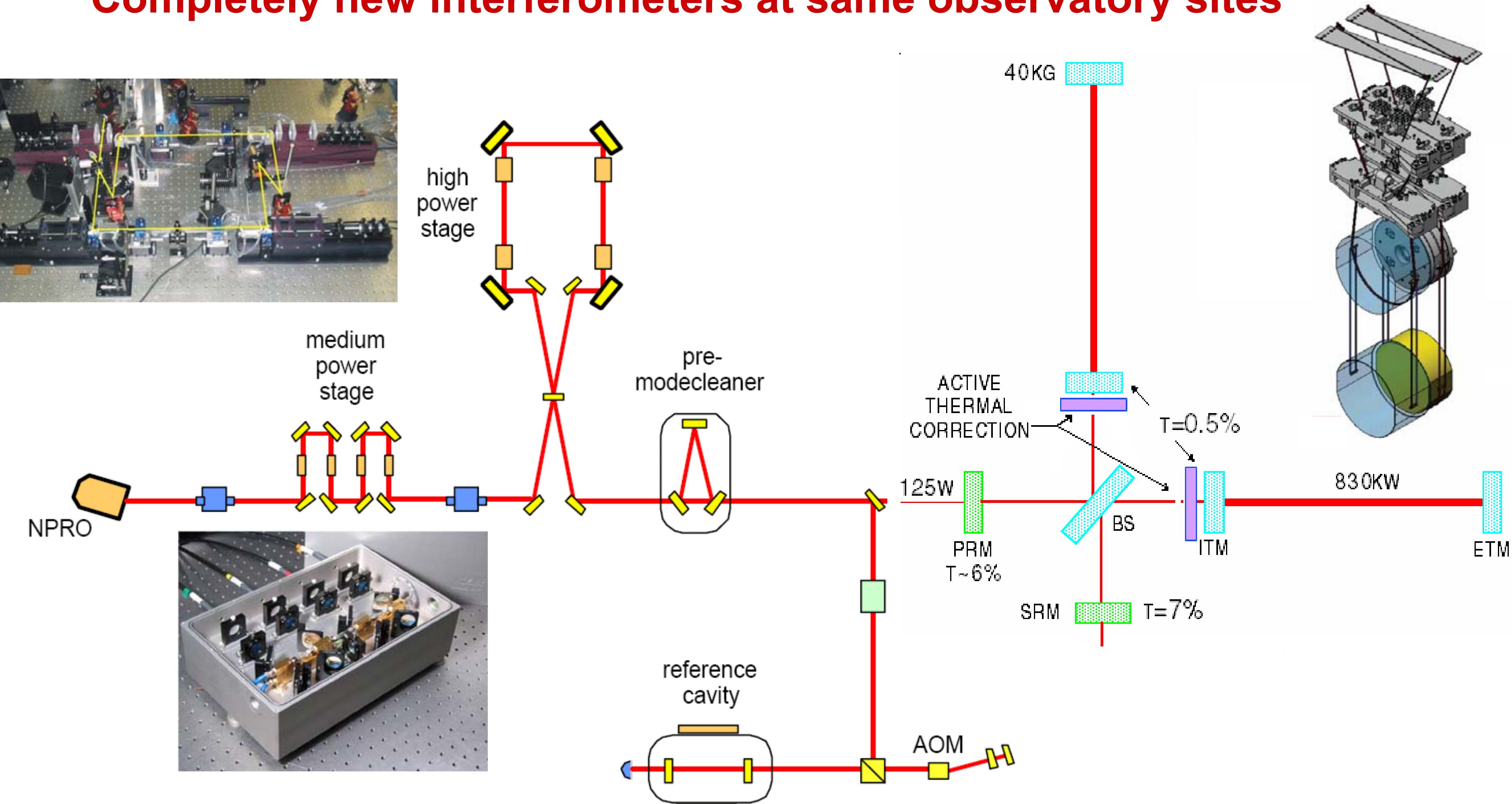
"GEO HF" upgrade next year



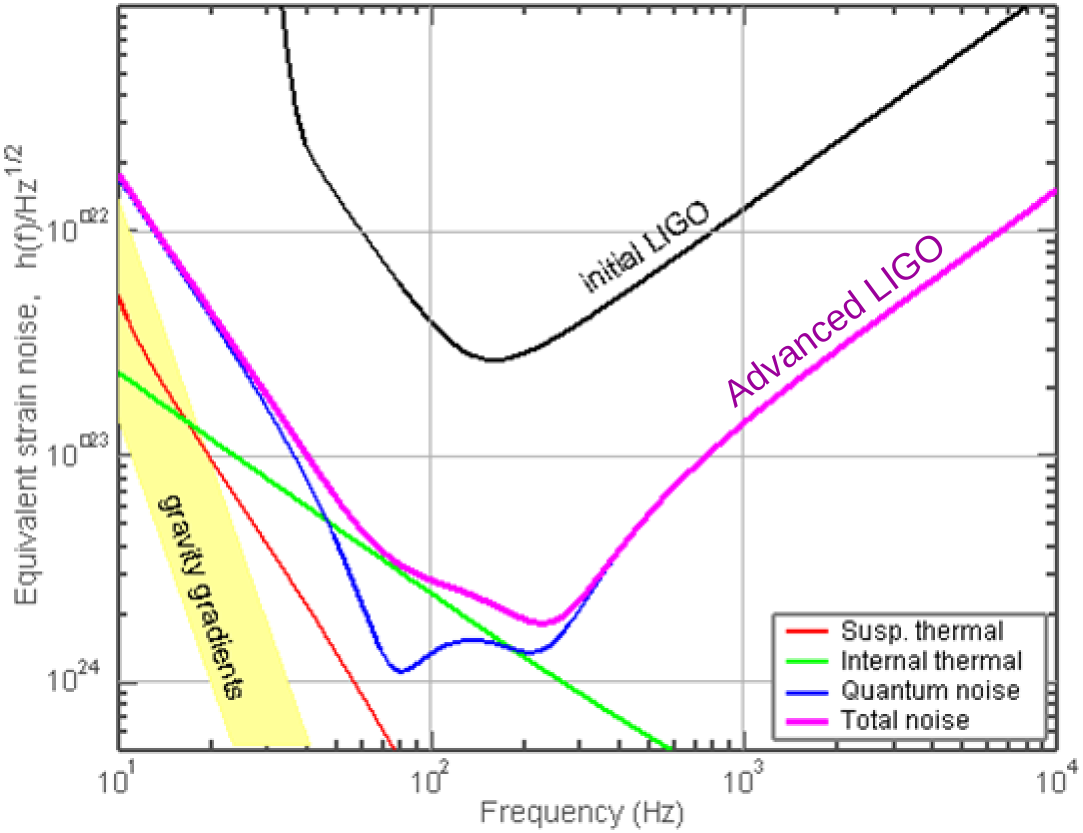
Monolithic output mode cleaner

In the Works: Advanced LIGO

Completely new interferometers at same observatory sites



Advanced LIGO Sensitivity



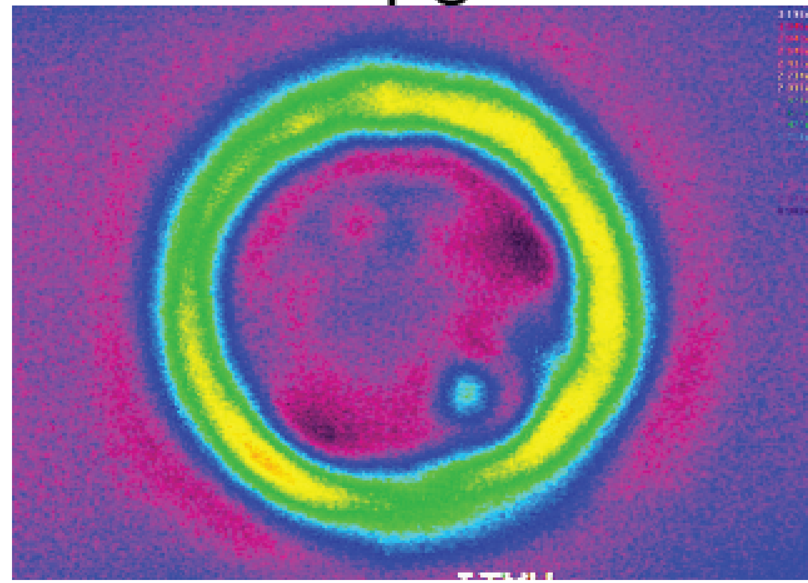
Factor of ~10 better than initial LIGO ⇒ factor of ~1000 in volume

Expect routine detection of GW signals !

Approved, funded, construction project has officially begun

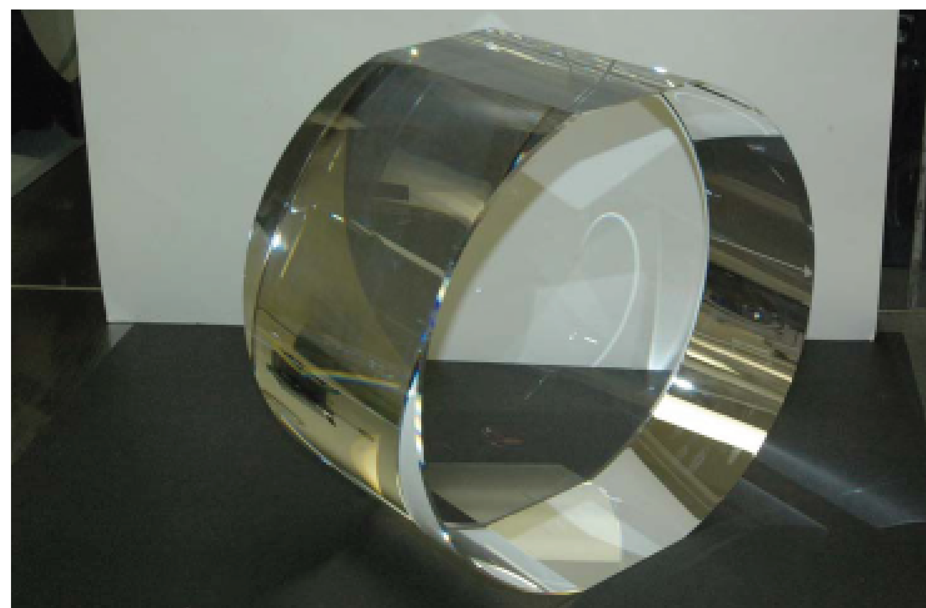
Advanced Virgo* *upgrade planned on same schedule

TCS upgrades



Quad
at
LASTI

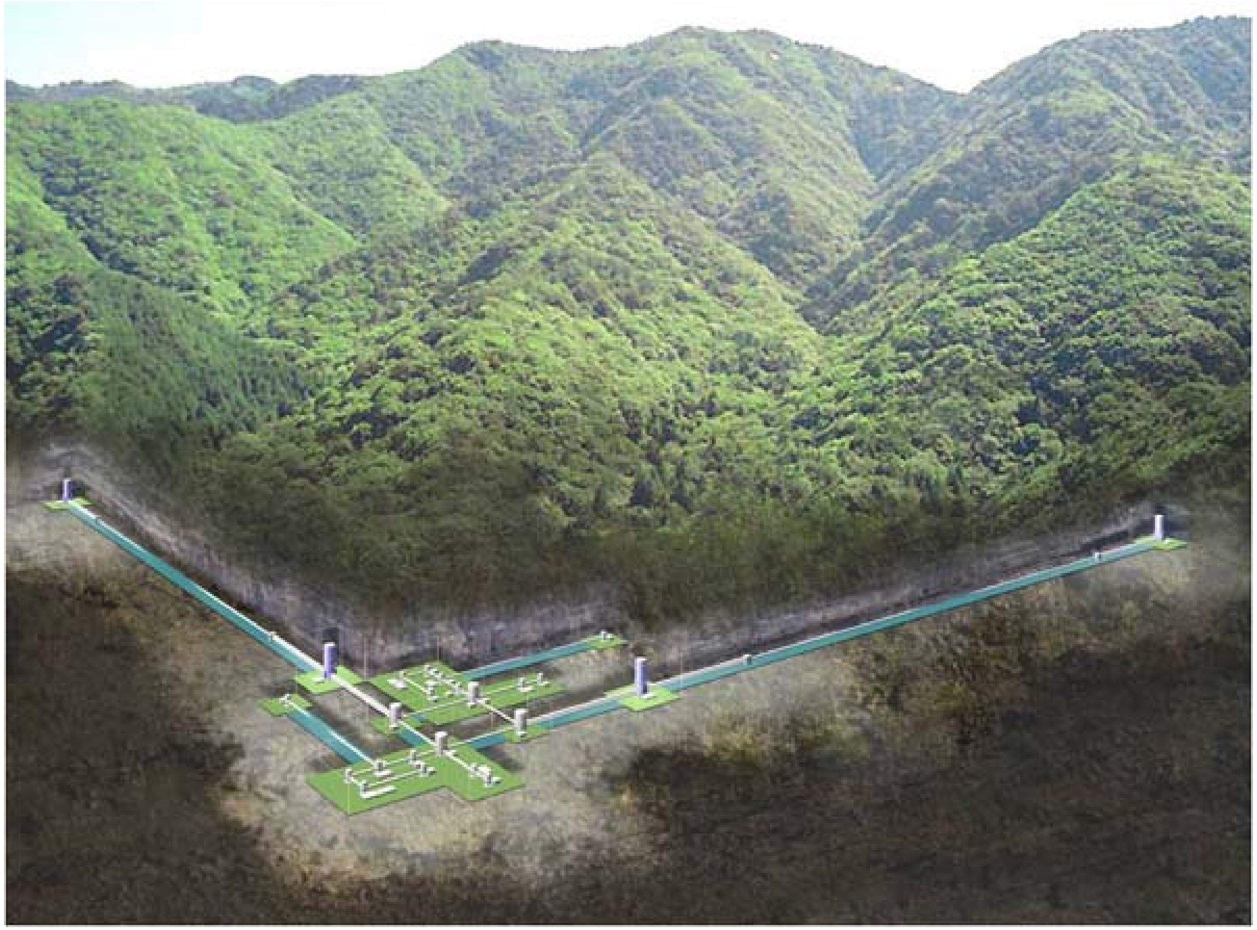
RFQ's for blanks
"out on the street"



Proposed New Detector: LCGT (Large Cryogenic GW Telescope)

Planned to be constructed inside Kamioka mine

Funding being requested from Japanese government



Proposed New Detector: AIGO (Australian International Gravitational Obs.)

Proposed extension of Gingin research facility

Southern hemisphere location benefits the network greatly

Road map, funding proposal being prepared

How Far Can We Push Ground-Based GW Detection?

What are the science goals?

e.g. favor low vs. high frequency, wideband vs. narrowband

What techniques can we gain the most from?

Arm length

Cryogenics

High laser power

Squeezed light

Non-Gaussian beams

Underground site

More sophisticated vibration isolation

Different interferometer configurations and technologies

…

Part of the GWIC (Gravitational Wave International Committee) Roadmap project

"Einstein Telescope" Concept

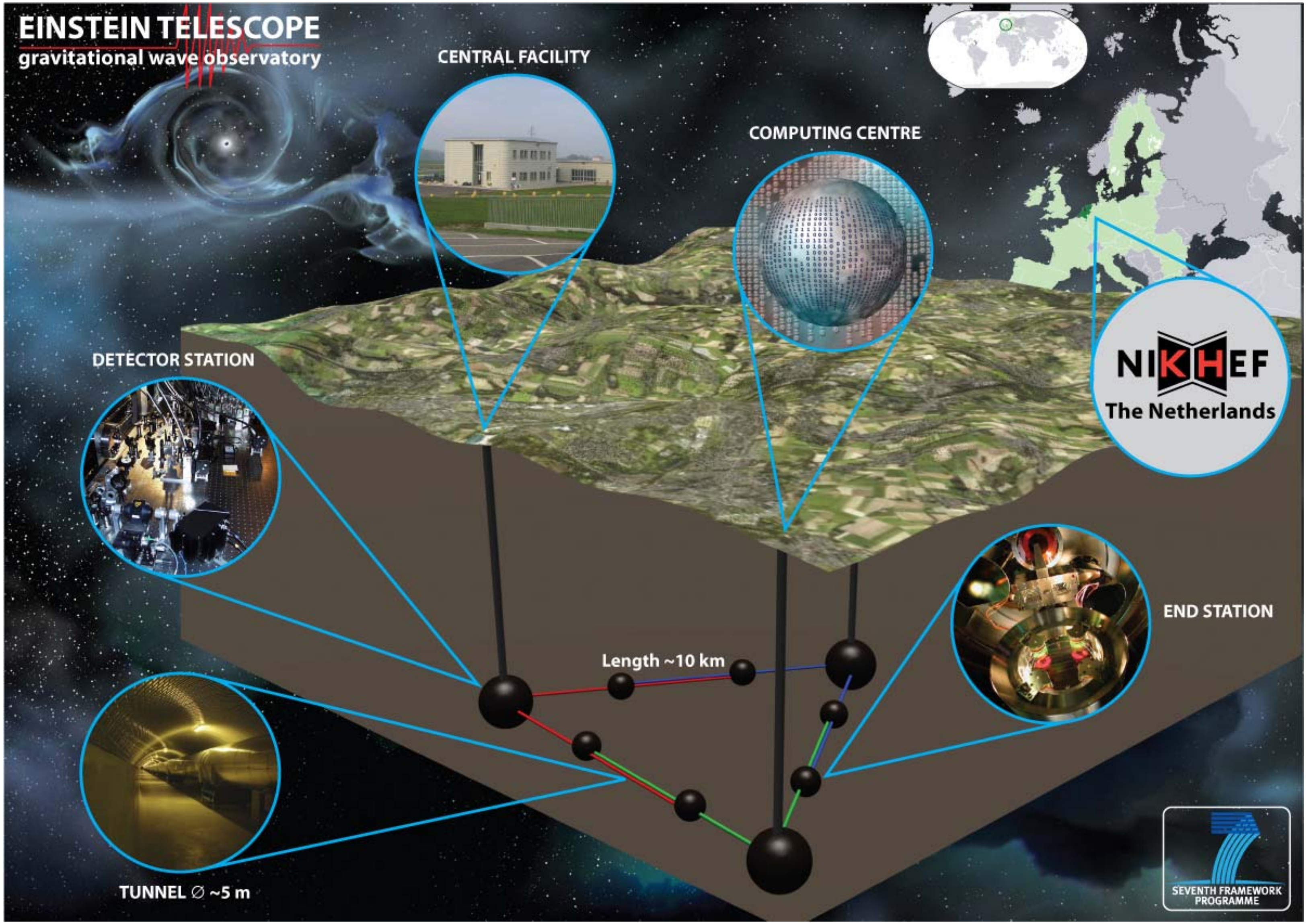
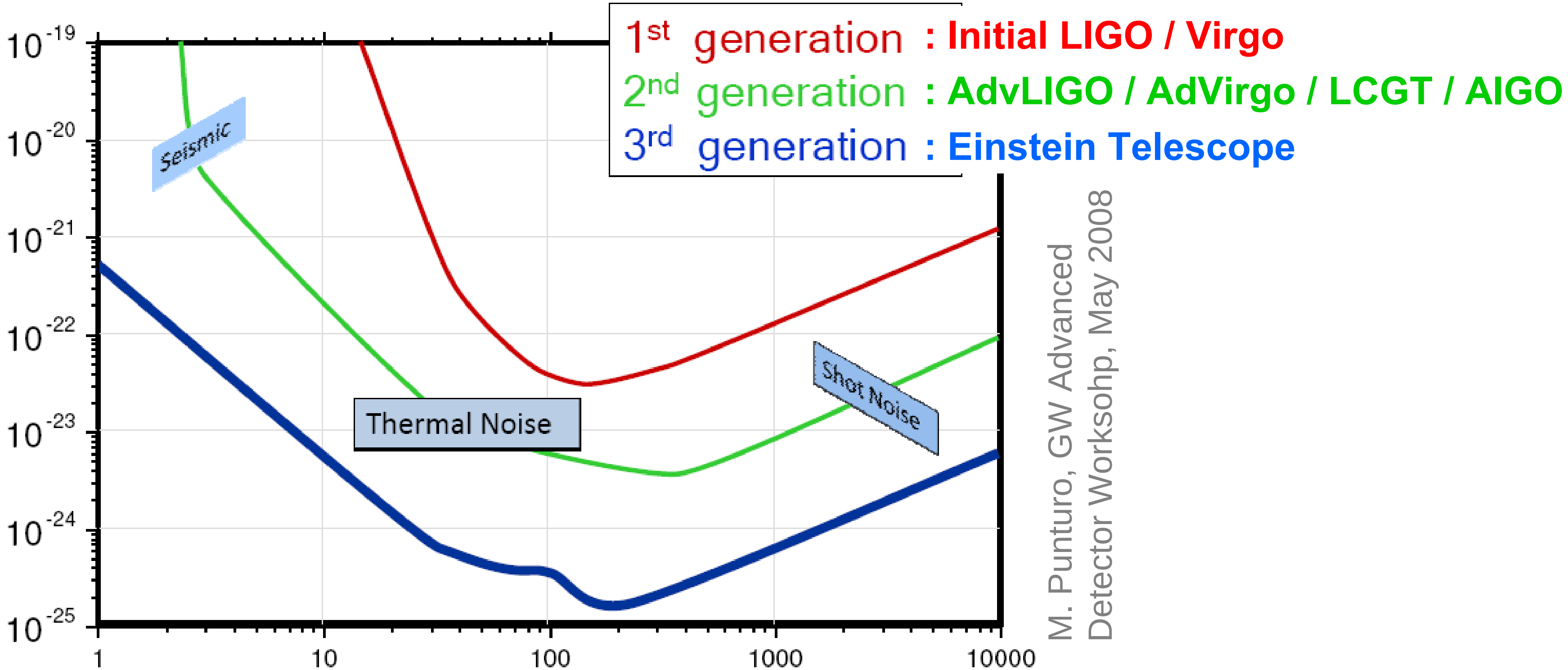


Image: J. van den Brand / K. Huyser / NIKHEF

Einstein Telescope Prospects

EU-funded design study is underway

Aim for another factor-of-10 sensitivity improvement



Time scale: operational ~15 years from now?

Summary

GW detectors work!

- Initial LIGO detectors reached sensitivity goal
- Currently enhancing sensitivity, working toward expanding network

Ground-based GW detection will make good on its promise

- Routine signal detections by ~2014-2015
- First detection *might* come sooner

Will tell us a lot about GW signals above a few Hz

- For lower frequencies, have to go into space