LIGO Commissioning Experience and Engineering Runs

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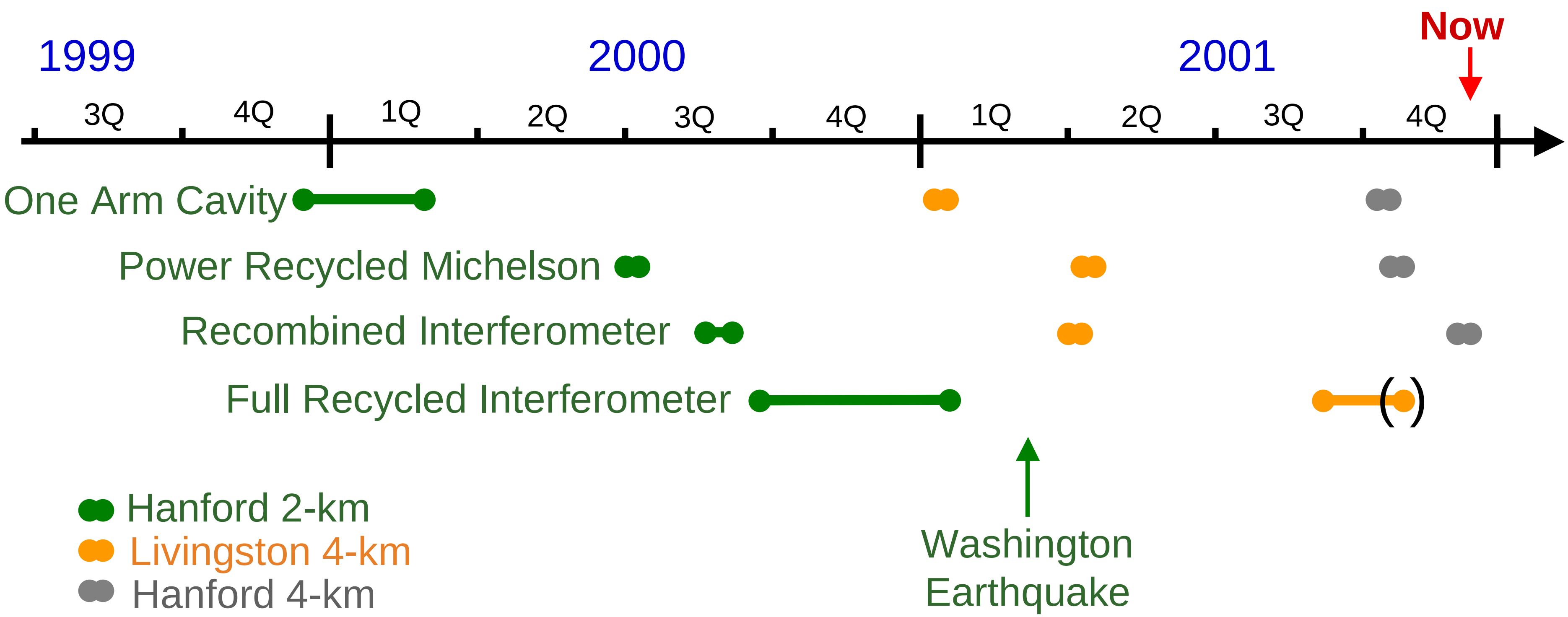
Commissioning Strategy

Installation and commissioning have proceeded serially, to make best use of personnel

- Hanford 2-km
  - The “pathfinder”
  - Certain problems encountered and diagnosed, but not immediately fixed, *e.g.* scattered laser light in local position sensors
- Livingston 4-km
  - Took advantage of lessons learned from Hanford 2-km
  - Approached more systematically
- Hanford 4-km
  - Trying to do things right the first time

Revisit H2k and L4k as time & manpower permit

Commissioning Milestones



Length of bar represents (roughly) the time from first trying a configuration to achieving a long-lived lock

Current Configuration of Hanford 2-km Interferometer

Operating in final optical configuration

Recycled Michelson interferometer with Fabry-Perot arms

Input laser power: 1 Watt

Digital length-control servo

Feedback to end test masses, input test masses, beamsplitter

Lock acquisition uses software to continuously evaluate interferometer state and adjust the sensing matrix accordingly

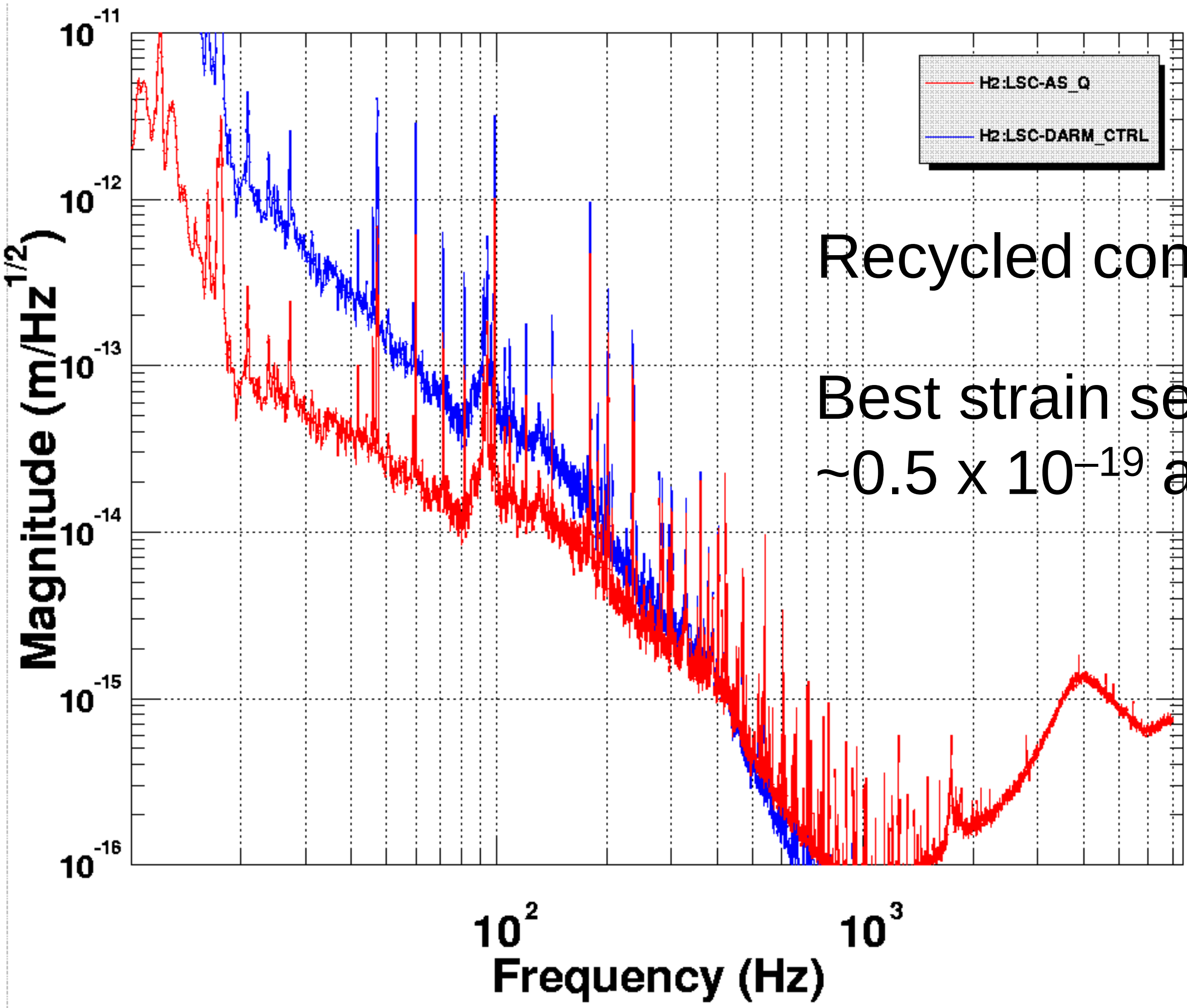
Alignment servo

Partially implemented; uses one wavefront sensor for large mirrors

Earth-tide compensation

Common-mode correction is made by gradually adjusting laser frequency to follow Earth-tide model; differential correction not yet implemented

Best-Yet Noise Performance of Hanford 2-km Interferometer



Recycled configuration

Best strain sensitivity $\sim 0.5 \times 10^{-19}$ at ~1 kHz

H2k Current Issues

Office building construction prevents work during the day

Lock acquisition is touchy

- Seems to be very sensitive to alignment
- Violin modes are sometimes excited to large amplitudes
- Parameters used by lock-acquisition servo may not yet be optimal

Can't always achieve robust lock in recycled configuration

Working on identifying and fixing specific noise sources

Duration of lock is limited by differential Earth-tide

Current Configuration of Livingston 4-km Interferometer

Have had some success with full recycled configuration, but difficult to reproduce

For now, focusing on "recombined" configuration

- Michelson with Fabry-Perot arm cavities, but no recycling

Input laser power: 1 Watt

Digital length control servo – like H2k

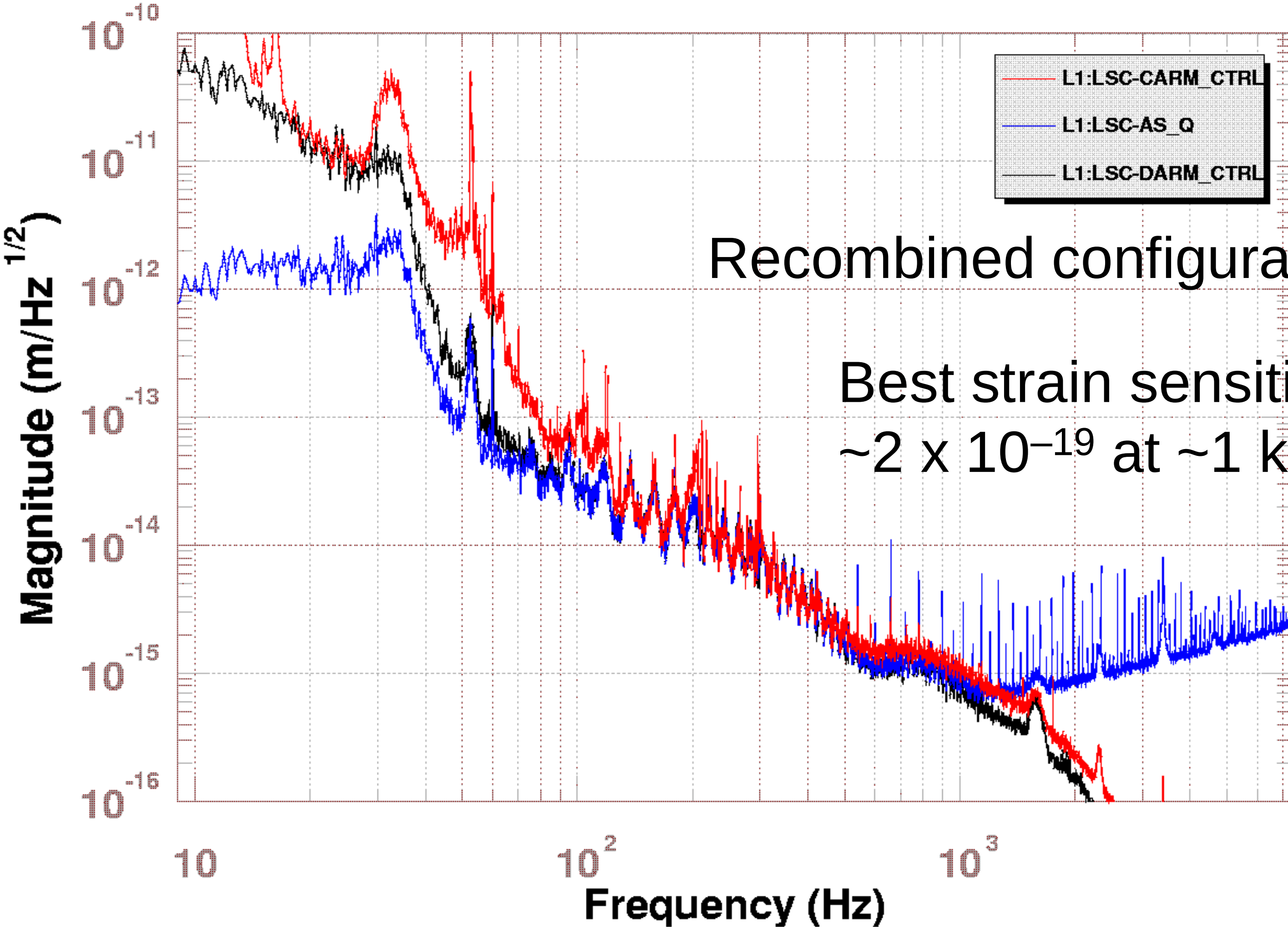
Alignment servo – like H2k

Earth-tide compensation – like H2k

Microseismic feed-forward system, using piezo actuators

- Compensates for ground motion below 0.25 Hz
- Significantly reduces total RMS motion of mirrors

Best-Yet Noise Performance of Livingston Interferometer



Recombined configuration

Best strain sensitivity
~2 x 10^{-19} at ~1 kHz

The Big Issue at Livingston: “Seismic” Noise from Human Activity

Evident in seismometers in 1-3 Hz band
(where seismic isolation system provides no isolation !)

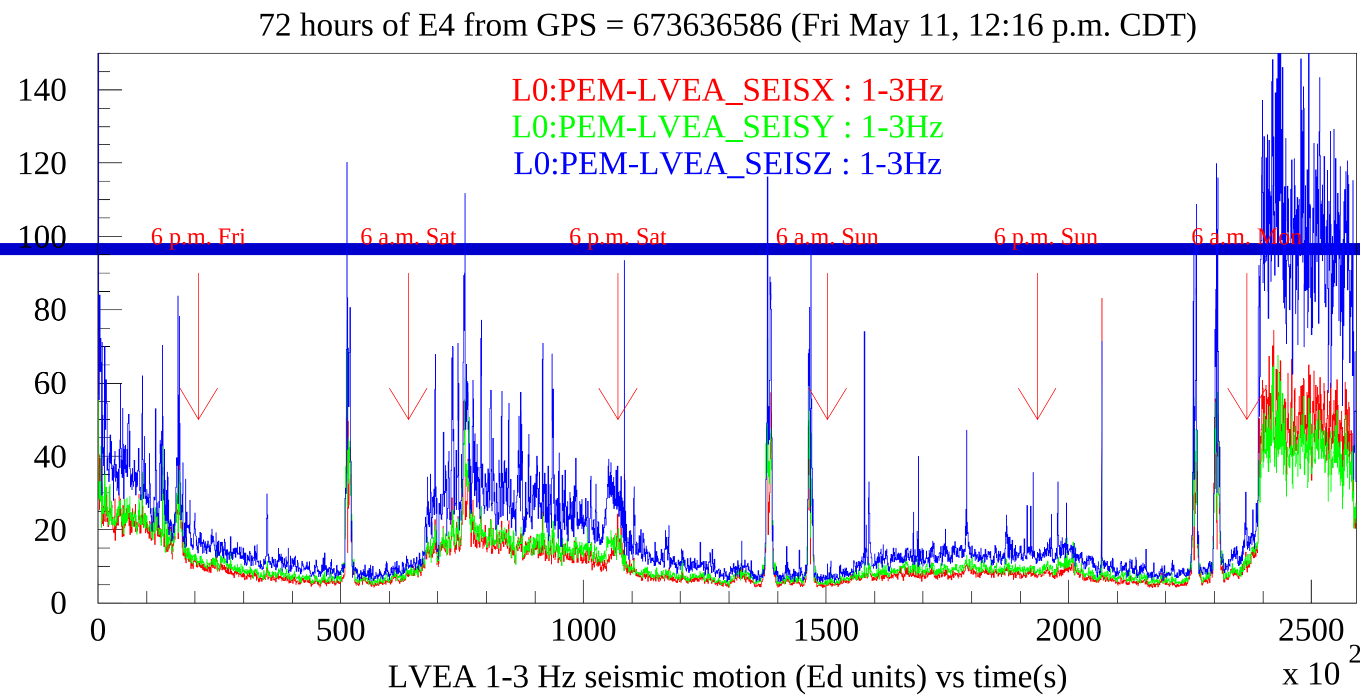
Associated with traffic, nearby industry and logging operations, trains, …

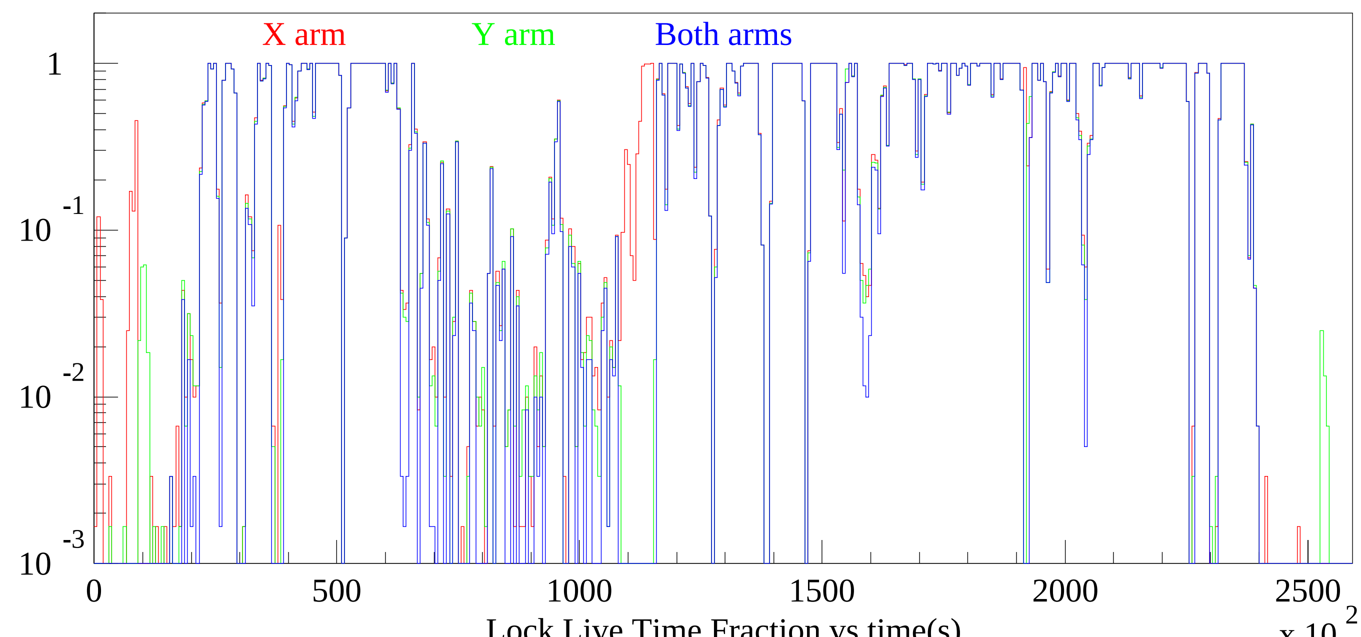
Induces angular motion of mirrors

Prevents locking even the “recombined” interferometer during weekdays

Overall duty cycle is limited to ~60%

Seismic Noise & Locking Over a Weekend





Plans to Address the Severe Seismic Noise at Livingston

Short term: higher-current coil drivers

Being used now

Requires protection circuit to avoid burning out coils

Amplifies effect of thermal noise in coil-driver circuit
⇒ Cannot reach LIGO “design” noise curve with these coil drivers

Longer term: active compensation

Accelerate work on part of the system designed for Advanced LIGO

Feed-forward from external seismometers to hydraulic actuators

Want to have this ready by late next year

Other Activities at Livingston

Working on identifying and fixing specific noise sources

e.g. noise from various parts of the servo electronics

Recently enabled intensity stabilization servo, reducing noise in 100 Hz – 1 kHz region

Want to enable common-mode length servo

Final servo loop to stabilize the laser frequency

Considering how to instrument an additional "pick-off" optical signal

To use as a diagnostic, and possibly also for lock acquisition

Status of Hanford 4-km Interferometer

Have been chasing down hardware problems and setting basic operating parameters

First LIGO interferometer to use digital suspension controllers

- Allows more flexible filtering, and a frequency-dependent control matrix
- Currently being shaken down

News flash: successfully locked in recombined configuration for the first time on December 10 !

Still many things to tune up

No noise curve measured yet

Why Interrupt Commissioning with an Engineering Run?

Run in a fixed configuration for a while

Accumulate a body of knowledge about a well-defined system

Gain experience in continuous operation

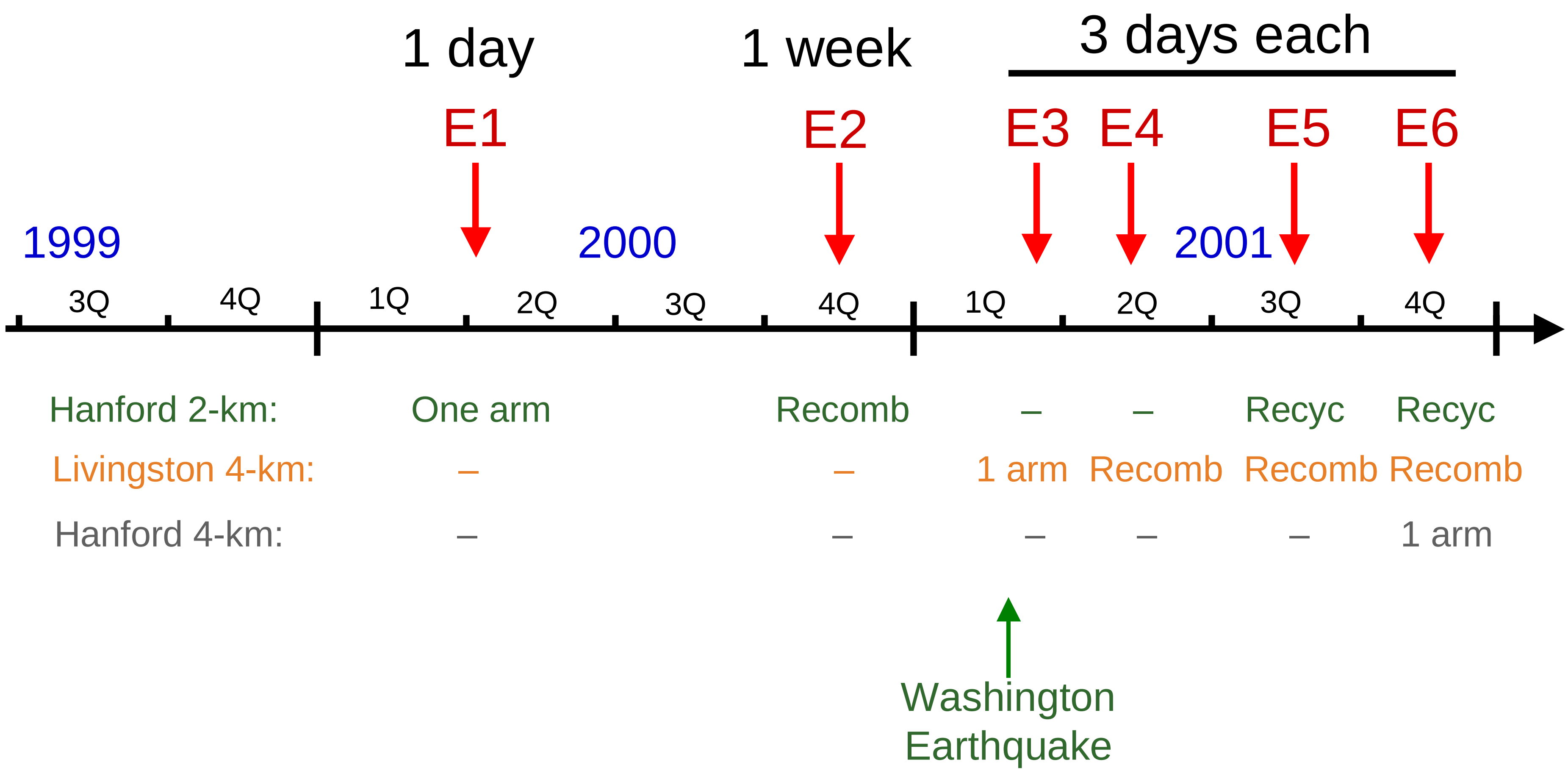
Procedures, 24-hour shifts (operators and scientists)

Give more people a chance to spend time working with the interferometers

See if things continue to work when the detector experts take a break!

Record some data to analyze later

Engineering Runs So Far



Focus of Engineering Runs So Far

Emphasis so far has been on "detector characterization"

With a pre-arranged set of studies performed by members of the LSC Detector Characterization Working Group

Detector characterization is an important part of analysis

Determine information needed for gravitational-wave signal analysis, *e.g.* lock history, calibrated detector response, noise spectrum

Identify veto conditions, *e.g.* transients seen in environmental channels

Evaluate systematic uncertainties, *e.g.* from correlated noise sources

Provide feedback to operators to tune interferometer

Some studies can be done using "online" tools

Real-time viewers: Data Viewer, Diagnostic Test Tools (DTT)

Data Monitoring Tool (DMT) – Background data processing to generate triggers, trend information, histograms, web-page summaries, etc.

Detector Characterization Studies During E6 Run

Calibrate response of detectors to gravitational waves

Identify and catalog environmental disturbances

Investigate sources of lock losses, and measure overall livetime

Investigate angular fluctuations

Quantify correlations between gravitational-wave channel and other channels

Quantify strength and stability of line noise in the gravitational-wave channel

Quantify correlated ambient noise between sites (*e.g.* 60 Hz and harmonics)

Quantify correlated environmental transients between sites

Check servo control signal drift against prediction of Earth-tide model

Test simulated astrophysical signal injection

Quantify timing precision (intra- and inter-site)

Check data integrity end-to-end

Check offline data access and data merging

Data Collection and Data Access

Full data stream

- Total data volume for all three interferometers: over 800 GB per day
- Write to “temporary” disk (E1-E5: ~1 day capacity. E6: whole run)
  - LDAS can access data on disk
- Copy to tape, send tapes to Caltech, copy into robotic tape archive
  - “getFrames” utility retrieves selected channels / time intervals from the archive

Reduced Data Set (RDS) – selected channels

- Write to disk on special “sandbox” data analysis machines at observatories
- Direct access for programs running on these machines (DTT, DMT, etc.)
- Also available remotely using “getFrames”
- RDS data must eventually be deleted to make room for newer data

Astrophysics Analysis of Engineering Run Data

Very limited experience so far

- Inspiral search code has been run on 16 minutes of data from E5 run
- “tfclusters” burst search code was run on E6 data as it was collected, using a script to automatically submit LDAS jobs as data became available

Important to do this early, because real data is imperfect

- Non-gaussian, non-stationary
- Locked stretches have limited duration
- Do these things negatively affect the search algorithms being used?

Need to put together all the pieces to do complete analysis

- Search algorithm (develop and implement)
- Mechanics of data processing
- Choices of how to extract a result (*e.g.* veto criteria)

Plan for the E7 Run

28 December 2001 – 14 January 2002   (17 days)

Operate interferometers in robust configurations

- H2k: recycled
- L4k and H4k: recombined

Idea is to treat this as a trial science run, performing complete astrophysics analyses (as much as possible)

(See talk by Erik Katsavounidis)

Lessons Learned / Issues

It's not clear what to do while on 'scientific monitoring' shift

- Operators take care of most tasks requiring human intervention
- There's a risk of becoming complacent

DMT and its outputs are not being used to full potential

- It's hard to decide what channels are important to process & look at
- Need "high-level" analysis of lists of transient events, etc.
- Currently no reasonable way to retrieve and display DMT "trend" outputs
- Should feed back to how the interferometers are operated
- Need more evaluation of monitor algorithms and parameters

Lessons Learned / Issues (2)

Data volume makes it inconvenient to analyze data offline

- Have developed tools to get data from tape archive, but they are slow and cannot be accessed automatically by LDAS at this time
- Will need to streamline this

Ultimately, would like feedback from astrophysics analyses to optimize detector operation parameters

- Currently, we just take whatever we get

Summary

LIGO has made real progress

Three working gravitational-wave detectors !

… But there is much more to be done

Robustness problems

~4 orders of magnitude in noise performance

"Engineering" runs will soon give way to science runs

Now the challenge is to make good use of the data !