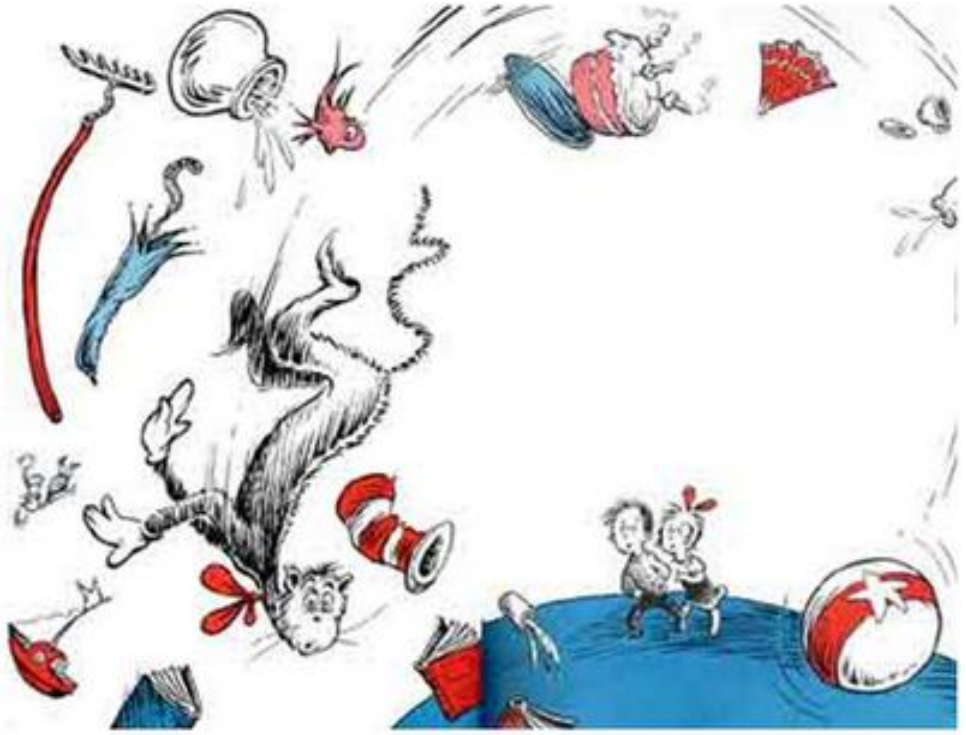
GWADW

Summary of Controls Sessions

we make it look easy, but …



General Comments

- Controls is a new topical session for the GWADW this year
- Based on the number of participants in the controls session, we should include controls as a topical session in future GWADWs

Controls Sessions

A	System identification and modern Control
B	Optimal feedback
C	Noise feedforward and subtraction
D	Lock acquisition problems and improvements
E	Interferometer stability (Keeping the IFO Lock)
F	Next Generation Control System Architecture

- *Good sessions, good discussions, useful, but …*
- *Perhaps too much scope – not focused enough, not enough "homework" in preparation in advance?*
- *A few too many prepared talks*
- *In future GWADWs, address next generation systems (V+, A+, Voyager, Longo,…)*

Summary D: Lock Acquisition Problems & Improvements Acquisition overview/problems & discussions

- aLIGO (Shiela Dwyer, Keita Kawabe (LHO); Anamaria Effler (LLO))
  - Lock acquisition is deterministic for the arms (ALS) but stochastic for DRMI
  - Works most of the time; acquires in 15-30 min
  - Reasons for lock difficulty:
    - Poor initial alignment (drift)
    - Mode hopping
    - Bounce & roll modes not adequately damped sometimes (plant drifts)
    - CARM depends on RC gain
    - High winds (LHO)
      - causes DRMI lock to take more time
      - with high ETM green transmission, ALS arm lock problems
  - Simulation:
    - Optickle (and derivatives), E2E

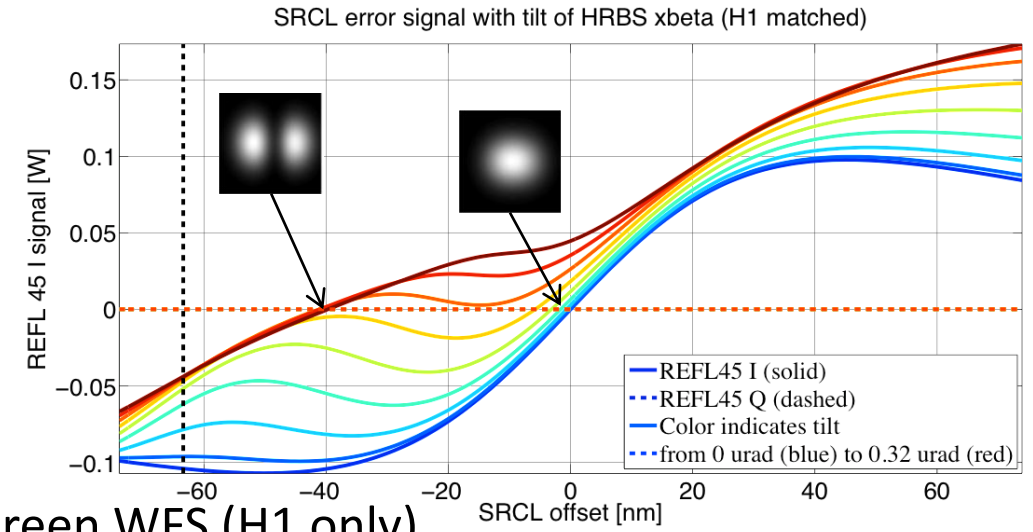
Summary D: Lock Acquisition Problems & Improvements Acquisition overview/problems & discussions (continued)

- Virgo (Gabriele Vajente, Bas Swinkels)
  - iVirgo Thermal transients in ITM at full lock caused drift
    - solution was to wait ~10 minutes
    - Lower absorption for aVirgo
  - Planning to use same variable finesse locking technique, but don't yet have a solution for SRC
  - Added high frequency RF sidebands (132 MHz) for use in lock acquisition – less sensitive to aberrations (thermal et. al.)
  - Plan to use guided lock acquisition (ala TAMA) if needed
    - aVirgo arm cavity finesse is 450 (was 150 for iVirgo)
    - Simulation indicates that guided lock acquisition may not always be needed
  - Digital demodulation
  - Simulation:
    - E2E, Optickle, Finesse (for thermal)

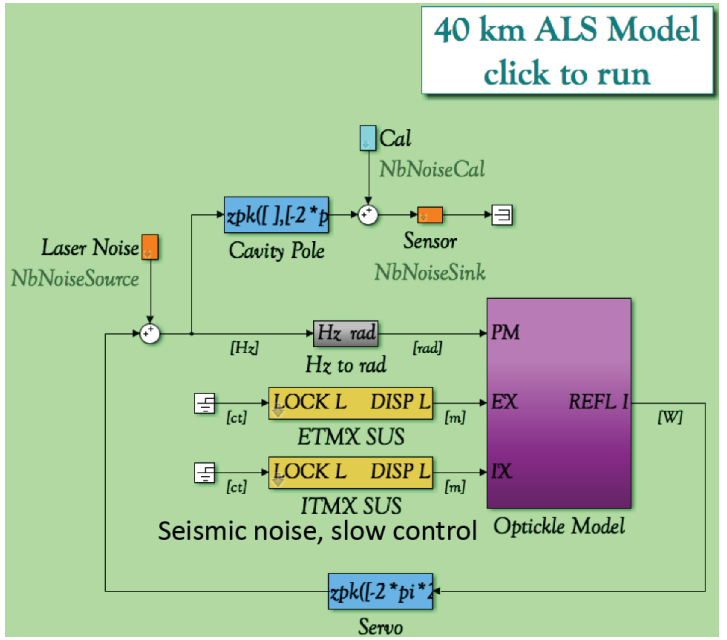
Summary D: Lock Acquisition Problems & Improvements Acquisition overview/problems & discussions (continued)

- Geo (Emil Schreiber, [Hartmut Grote])
  - “only” 3 DOFs, but PR factor is higher
  - Automated, guided, stochastic locking for each DOF in sequence
    - PRC → Michelson (with 2kHz detuned SRC via heterodyne) → SRC
    - Then OMC beacon lock acq.; switch on slow controls (alignment, power ramp up, …)
    - ~3 – 5 min total for lock sequence
  - No (significant) lock acquisition problems
- KAGRA (Yuta Michimura)
  - Same basic approach as for aLIGO, with 2 differences:
    - Inject green ALS beam through PR2/SR2 (rather than fiber to ETMs)
    - Non-resonant SB for DRMI instead of 3f (AM, not PM)

Summary D: Lock Acquisition Problems & Improvements



- Mode Hopping Problems (Paul Fulda)
  - ALS
    - Causes: Low finesse; alignment
    - Solutions: improved SEI performance (tuning); ALS green WFS (H1 only)
    - Will replace ETMs with proper green transmission
  - H1 DRMI (but not L1)
    - Causes: Alignment; mode matching; Gouy phase; Cross-coupling
    - Solutions: improve alignment, increase HOM separation
    - Would be good to measure RC optics with better ROC accuracy
- Simulation for Commissioning/Controls (Chris Wipf)
  - SimulinkNB – noise budget tool
  - Example application: ALS for 40 km long arm (FSR @3kHz)
  - Tool for designers and commissioners



Summary D: Lock Acquisition Problems & Improvements

- Bayesian approach for locking high finesse cavities (Manuel Marchiò, Giancarlo Cella)
  - Apply force outside of resonance (to slow down the optic) based on a dynamics model
  - State space (position, velocity) Guassian distribution + linear dynamics → Kalman filter estimator
  - Use transmitted power to know that you are passing a TEM00 resonance
  - Plan to include PDH off-resonance signal with particle filter (sum of Gaussians) method
  - Could this approach work for DRMI, for a more deterministic lock?

D: Lock Acquisition Problems & Improvements: *goals/questions*

- From each interferometer, gather a compendium of
  - lock acquisition problems
  - Locking metrics & statistics
- Discuss approaches to address each lock acquisition problem and their relative merits and success to date
- Are the pre-lock auxiliary systems (OptLev, ALS, TCS, …) adequate, or are improvements necessary?
- Shouldn't future interferometers be designed to observe and control all DOF (bounce, roll, violin modes)?
- Would we benefit from embedding independent sensing/actuation into the interferometers for routine diagnostic measurements & characterization?
- Which lock acquisition problems can & should be pursued on small scale research interferometers?
- SIMULATION TOOLS
- STOCHASTIC LOCKING NOT GOOD

Summary E: Interferometer Stability
Lock Loss Causes

- aLIGO (Keita Kawabe, Shiela Dwyer (LHO); Anamaria Effler (LLO))
  - We can automatically detect lock loss, but not the cause (yet)
  - Detchar has a tool for auto plotting signals of typical interest just preceding a lock loss event
    - Will make auto & publish
  - Clear need for better local sensing of poorly controlled (damped) modes: roll, bounce, violin modes
  - Not yet clear if the limited actuation authority for these modes is stable/reliable or not (i.e. do we also need better actuation?)
    - Depends on alignment & beam position
    - Bounce & roll don't change at LLO; stable with good alignment
    - Find good alignment based on RC gains (automated procedure)
  - Inspiral range creeps down (sometimes) – thermal?
  - Leading lock loss causes at LLO:
    - Parametric Instability
    - EQs every 2-3 days
  - Saturation
    - Detchar is working on ODC checks on saturation
    - DAQ system has automatic saturation detection code

Summary E: Interferometer Stability
Lock Loss Causes (continued)

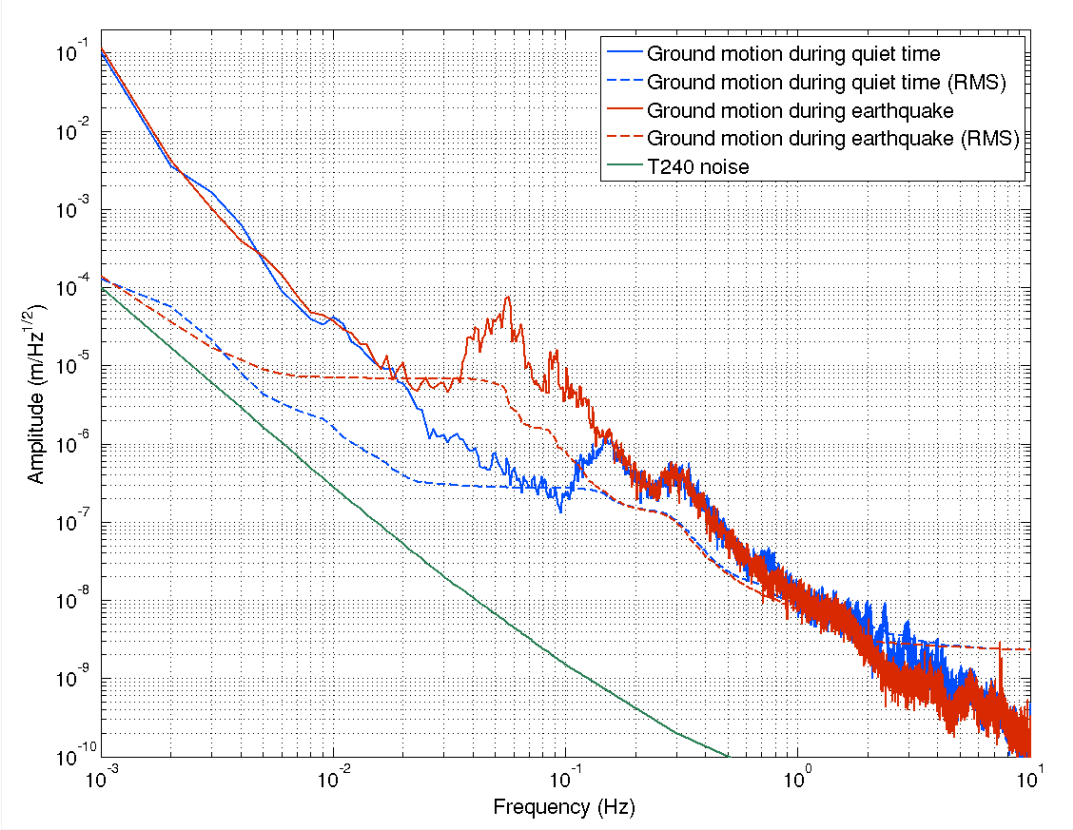
- Virgo (Bas Swinkels)
  - Reviewed VSR1 – 3 lock/unlock statistics
  - Improved caused lock loss events from 1-2/week (mag 6, Indonesia) to 1 per 2-3 weeks (mag 7, Indonesia)
  - VSR3: 90% locked, 80% science, 143 hr longest lock
  - Maintenance period (typ 4 hr/week) was largest contributor
  - Instrument/hardware reliability comparable to maintenace
- Geo (Emil Schreiber)
  - Auto lock loss detection (& plotting) and re-acquire

Summary E: Interferometer Stability

- Ground Tilt (Krishna Venkateswara)
  - Wind induced gnd tilt is significant for LHO (> 20 mph, 15% time)
  - Optic yaw response in high wind
    - Might be bilinear coupling with mis-centered beam?
    - Could be mis-balanced coil drivers
    - Investigate ISI to SUS cross-coupling, esp. yaw
    - Suggestion to simulate wind (high amplitude motion in ISI) to discover coupling path
    - LIGO pursuing a 2nd Beam Rotation Sensor (BRS) for LHO testing
- TCS (Alastair Heptonstall)
  - Plan to maintain ITM/CP thermal lens with CO2 laser when main beam losses lock – Operator sets thermal lens power with Guardian
  - Need to separately tune SRC & PRC (Virgo does this already for PRC) – LIGO considering the addition of a “ring heater” (or similar) to SR3 & PR3

Summary E: Interferometer Stability

- Earthquakes (Sebastien Biscans, et. al.)
  - LIGO has a few unlocks per week
    - (maybe same order of magnitude for Virgo)
  - Tilt is not well known for EQs
  - Displacement ASD high < 0.1 Hz
  - LIGO ISI platform (apparently) tilts a lot in response
  - ISI platform trips on S-wave or surface waves , approx. 30 min typ from EQ p-wave → time to prepare
    - With USGS network at least a few min warning for “all” EQs
    - EQ Monitor (Jan Harms, Michael Coughlin) can predict to amplitude factor of 4 & 1-2 sec arrival
    - Reduce digital gain & increase analog gain
    - What to do to prepare & ride-out a mild EQ, e.g. higher blend freq.
    - Each EQ is different; requires testing. LASTI?



E: Interferometer stability (maintaining lock) *goals/questions*

- Gather a compendium of lock loss event causes
  - Do we have detchar infrastructure for automatic detection, logging, and calculation of statistical metrics?
- Discuss approaches to address each lock loss cause and their relative merits and success to date
- Are the lock loss prevention auxiliary systems adequate, or are improvements necessary?
- Would we benefit from embedding independent sensing/actuation into the interferometers for environment sensing?
- Which lock loss problems can & should be pursued on small scale research interferometers?

Summary F: Next Generation Control System Architecture

- How can we improve controls infrastructures to facilitate development of "modern" or "advanced" controls?
- Rolf Bork and Bas Swinkels gave brief overviews of the current aLIGO and aVirgo controls infrastructure

- Leverage commercial off-the shelf
  (LIGO: server-class computers, PCIe I/O, Beckhoff, RT linux patch, EPICs, etc.)

vs

- flexibility and control of custom
  (Virgo: DSPs, TOLM, ALP, etc.)
  - Both can work.
  - Virgo hopes to move from ALP to Tango. Should LIGO move from EPICs to Tango to leverage the entire LVC community?
  - No group conclusions; not really all the right people/expertise

Summary F: Next Generation Control System Architecture

- We then heard from people working on controls technology about what they would like to see:
  - Increase availability to modern/advanced algorithms that are ready to move beyond R&D (e.g. drop in "RCG part"):
    - State Space/LQR
    - Kalman filters
    - LQG adaptive algorithms (prototyped at 40m Lab)
  - Adaptation rate < loop rate
    - Leverage multiple processors to offload adaptive calculations from front-ends, or
    - multi-rate front-end calculations
  - Increase accessibility, e.g. reduce hardware requirements, to facilitate development of prototypes, simulations, etc.
  - Modularity and flexibility in the infrastructure is the key to facilitating future controls development
  - Build a set of canonical problems (e.g. SUS angular control) and matching algorithms (e.g. Kalman filter) to develop a super-set of control system requirements
  - Couple the control system design tool (RCG for LIGO) directly to a simulation (e.g. SimPlant prototype at 40m Lab)

Final Comments

- How can we as a community share and sustain a growing expertise in the application of advanced/modern controls to GW interferometer systems?
  - LVC wiki pages for Controls
    - Get a critical mass
    - Share examples, code, experiences
  - Regular LVC (virtual) meetings on Controls
    - Perhaps an “official” LVC working group on controls?
  - Detchar “gold star” vetted tools wiki page
- In future GWADWs:
  - Address next generation systems (V+, A+, Voyager, Longo, …)
  - Consider truly advanced techniques, with adequate prep (NN, deep learning, …)