Next Generation Low Frequency Control Systems

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Current 2G Low Frequency Problems

Should consider two types of low frequency problems:
One important for Volume the other for Time.

Excess Low-Frequency Motion Causing In-Band Noise

- Scattered Light
- Angular Control
- Glitches / Non-Stationarity

Low-Frequency/Environmental Impacts on Duty Cycle

- Intra-cavity Thermal Mode Evolution
- Environmental Thermal Control
- Tilt Confusion Noise
- Earthquakes

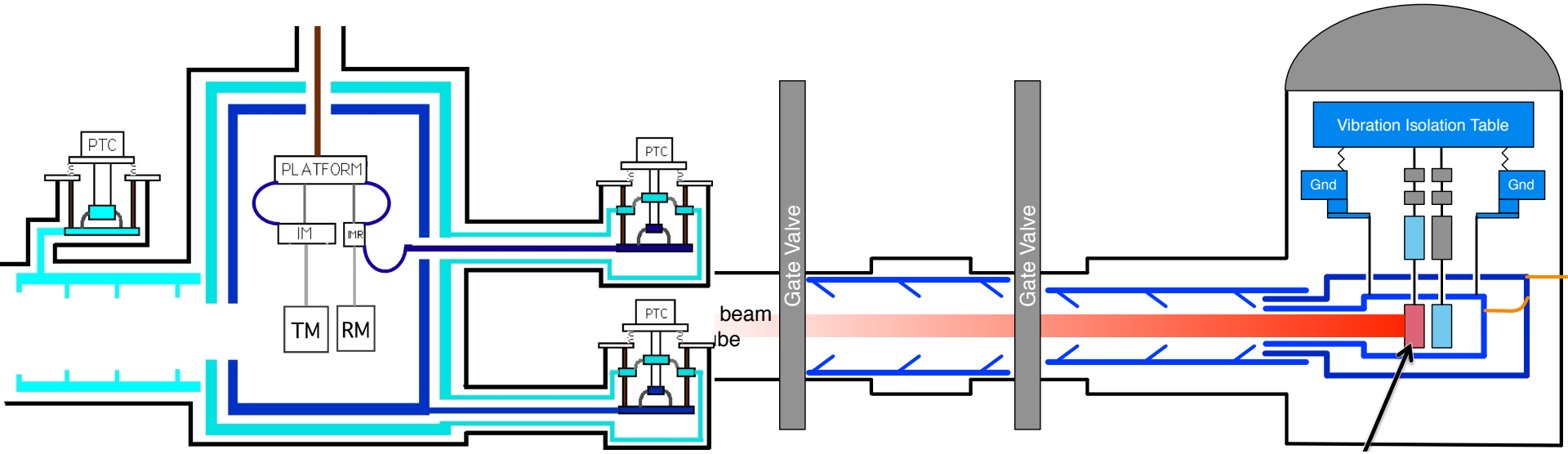
Excess Motion: Scattered Light

- As optical configurations get more sophisticated and beams get bigger – there will lot more scattering surfaces in and around the core resonant cavities
  - May need more sophisticated math/physics too – see G1700320
- aLIGO has learned that one must pay much attention to baffles and dumps early and often in the design
  - but somehow without occulting too many views of those optics (optical levers, cameras, photon calibrators, auxiliary interferometers)
- **2G Examples**: Parasitic IFOs and Scattering Ports are everywhere, not just in Arm Cavities

  Input Optics Baffle LHO aLOG 35735

  PCAL Periscope LLO aLOG 33015

- **Implications for 2G+ / 3G IFOs**: Many suspended / sensed / controlled Baffles



Excess Motion: Angular Control

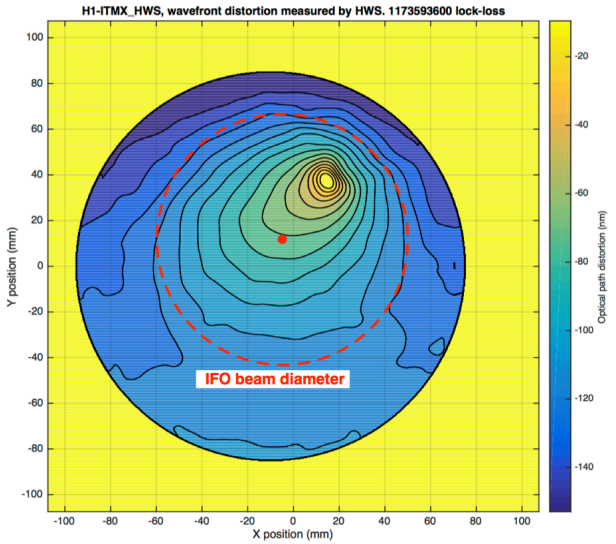
- **2G Examples:** You just heard M. Kasprzack's Talk…

- Early commissioning phases are the most challenging for any generation
- If shot noise limited, light pickoffs for ASC error signals are a balance of
  - how much current can sensors handle
  - how much optical loss you are willing to tolerate
- If electronics noise limited -- are there areas for electronics noise improvements?
  - Rich Abbott says "Not that I know of, if there were I would used them!"
- Must be able to account for changes in plant with IFO power (especially during lock acquisition)
- **Implications for 2G+ / 3G detectors**: Elastic Waistband, Belt *and* Suspenders:
  - *Reduce the input:* We should continue to pay attention to Low-Frequency Seismic control in *all* degrees of freedom
  - *Increase Observability and Control*: Must have excellent noise, stable, local angular sensors to complement global sensors
    - Connect seismic platforms with **Seismic Platform IFOs** LIGO-P1300043
    - In-vacuum EUCLIDs? LIGO-P1300051, LIGO-C1600066
    - A 3G worthy optical lever?

Excess Noise: Intra-Cavity Thermal Control

- Optic thermal modal distortions evolve on the time-scales of 1-4 hours impacting (with **2G Examples**):
  - Interferometric Sensing and Control Signals (LLO aLOG 17792),
  - Noise couplings (LHO aLOG 26264),
  - Parametric Instabilities (LLO aLOG 17016),
  - Response to Gravitational Waves (LHO aLOG 35041)
- Spend time with your Optical Mode Sensor Array!
  - Sensors for optical mode matching like HWS and bullseye

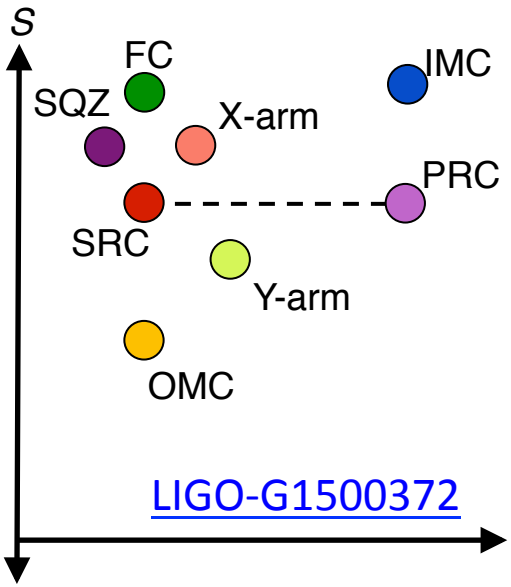
    WFS should *not* be an after thought



LHO aLOG 34900

- 2G+ / 3G optical layouts hope to push the limits of matching 5- 10 cavities:

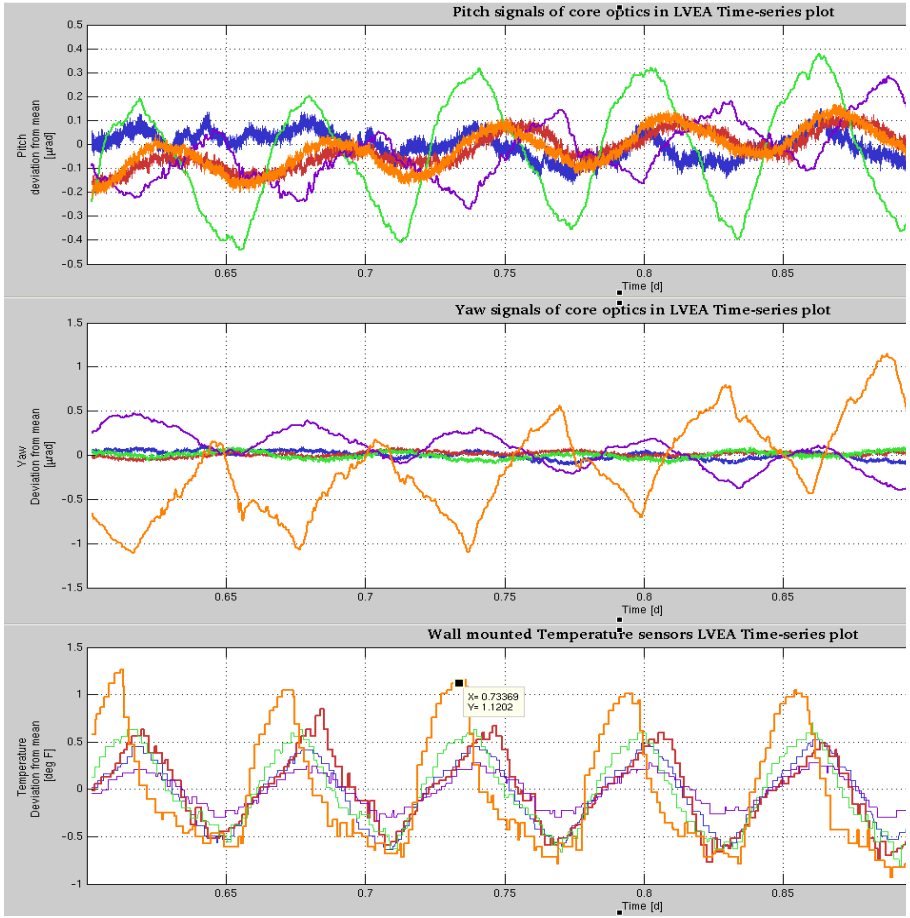
  PMC JAC IMC (IMC2?) PRC XARM YARM
  SRC SQZ FC1 (FC2?) OMC (OMC2?)



LIGO-G1500372

- **Implications for 2G+ / 3G IFOs:** Active wave-front sensing and control essential
  - See talks in Day 5 Plenary Session

Duty Cycle: Environmental Thermal Control

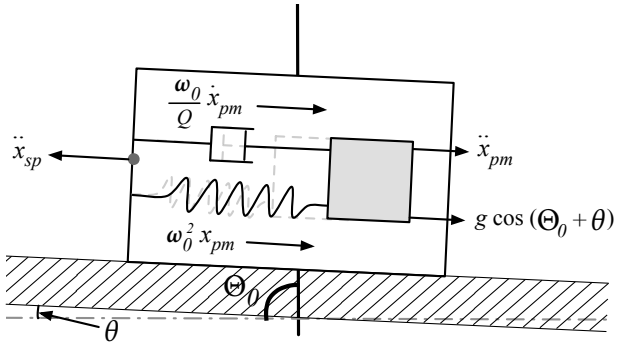


LIGO-G1500590

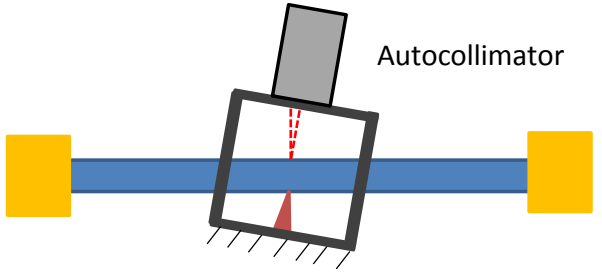
- Vacuum Enclosure Area Temperatures evolve on 12 to 24 hour time-scales
- **2G Examples**:
  - large changes in DC alignment LHO aLOG 32757
  - suspensions sagging and rubbing LHO aLOG 32746
  - laser polarizations swing around LHO aLOG 31471
- **2G+ / 3G Implications:** Suspensions are going to be long with low resonance frequencies
  - Low-noise in-vacuum temperature sensing
  - Excellent thermal control of Vacuum Enclosure Areas

Duty Cycle: Tilt Confusion Noise & EQs

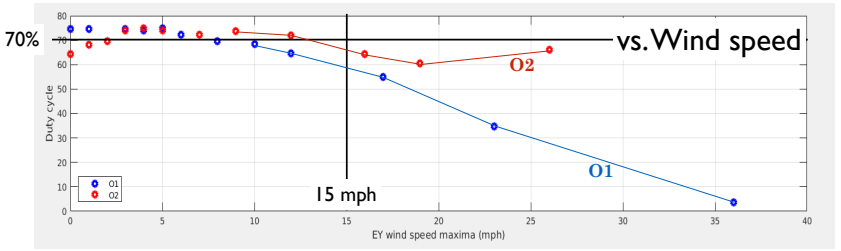
- **2G Examples:** An array of ground rotation sensors – Demonstrable Improvements to IFO Duty Cycle at LHO
  - Venkateswara, K., et al. *RSI* 85.1 (2014): 015005.
  - Venkateswara, K., et al. *BSSA* 107.2 (2017): 709-717.
  - LIGO-G1700331, LIGO-G1700346, LIGO-G1700246

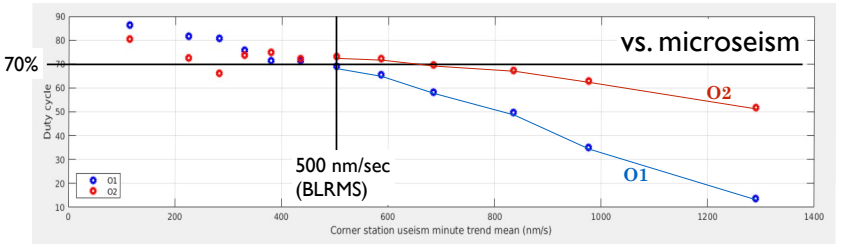


- You just heard Conor's Talk…



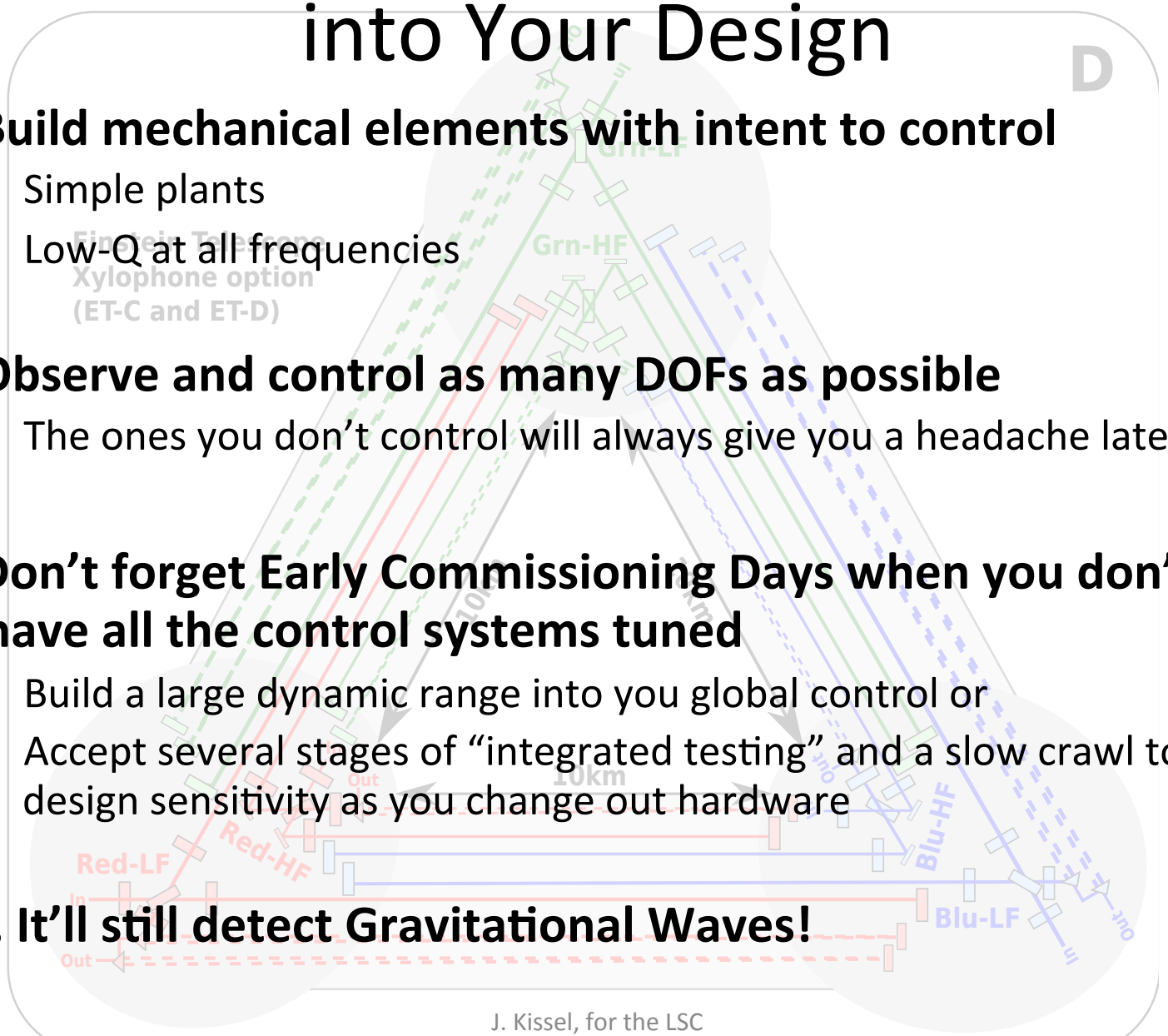
- **2G+ / 3G Implications**:
  You better have
  - Rotation Sensors -- someone convince Krishna to commercialize!
  - Seismic Platform Interferometers LIGO-P1300043, arxiv:1201.4718, LIGO-G1401221
- Adaptable local / global control for Eqs
  - LIGO-G1700328





Conclusion: Build the Control System into Your Design

1. **Build mechanical elements with intent to control**
   - Simple plants
   - Low-Q at all frequencies
2. **Observe and control as many DOFs as possible**
   - The ones you don't control will always give you a headache later!
3. **Don't forget Early Commissioning Days when you don't have all the control systems tuned**
   - Build a large dynamic range into you global control or
   - Accept several stages of "integrated testing" and a slow crawl to design sensitivity as you change out hardware
4. **… It'll still detect Gravitational Waves!**




Thank You :: Let’s Discuss!