Rana Adhikari
for the
LSC's AIC WG
and the
Caltech ph237
class

GWADW 2010

Rana Adhikari

Enhancing the 2nd generation interferometers

G1000524-v1

LIGO 2.5 Strawman Design

Hiro Yamamoto / LIGO Lab

- January 9~11, 2012 @ Caltech, 40 attendees
  - » https://nodus.ligo.caltech.edu:30889/wiki/doku.php?id=strawman
- Why : To work toward adopting a baseline for the next generation LIGO detector. Our goal will be to have a baseline and then a backup to this baseline. We will fallback to the backup if future calculations or experiments demand it. Our subsidiary goal will be to understand better how much R&D will need to be done for each of the options explored and to prepare the groundwork for a followup meeting in the spring where we may change everything.

Attendees

Koji Arai, Jan Harms, Jim Hough, Rai Weiss, Zach Korth

Matt Evans, Iain Martin, John Miller, Stefan Hild, Yanbei Chen, Patrick Kwee, Lisa Barsotti, Sheila Rowan, Haixing Miao, Valera Frolov, Rana Adhikari, David Ottaway, Andreas Freise, Eric Gustafson, Stefan Ballmer, Hiro Yamamoto, Giles Hammond, Warren Johnson, Peter Fritschel, Norna Robertson, David McClelland, Ludovico Carbone, Alastair Heptonstall, Jenne Driggers, Jamie Rollins, Alan Weinstein, Aidan Brooks, Eric Quintero, Frank Seifert, GariLynn Billingsley, Mindy Jacobson, Tara Chalermsongsak, Bill Kells, Stan Whitcomb, Christian Ott

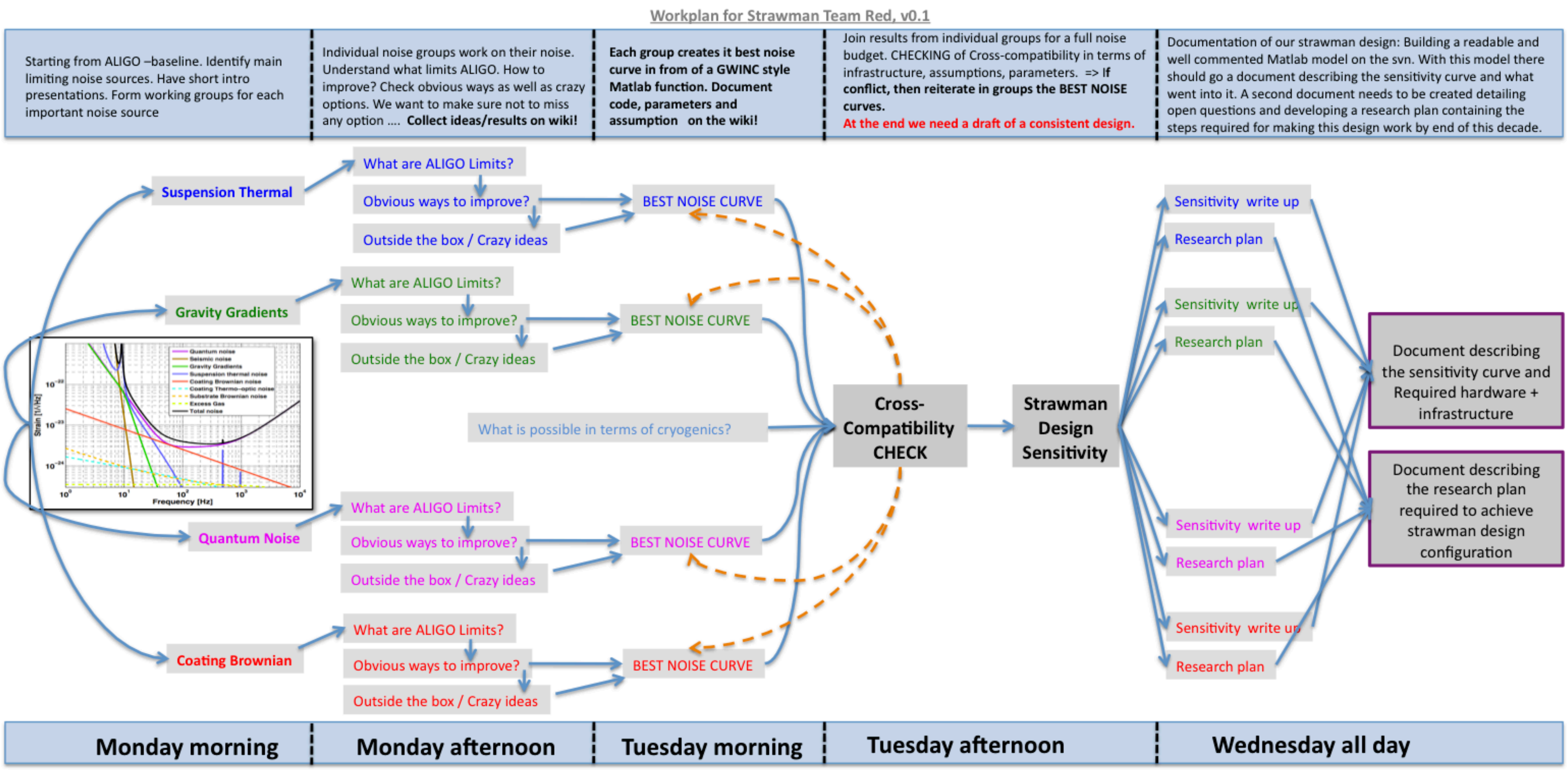
Basic vision

- Is this 2.5 generation or 3, no consensus!!!
- After GW signals are detected by some IFOs
  - » 2020-2022
- Use existing LIGO facilities with minimal upgrade
  - » Modify BSC for cryogenic operation
- ~ a few hundred million $s
- Final design will accommodate the detected GW signal
- Start now because histories indicate that it takes ~10 years from the first discussion to the start of the actual funding and construction.

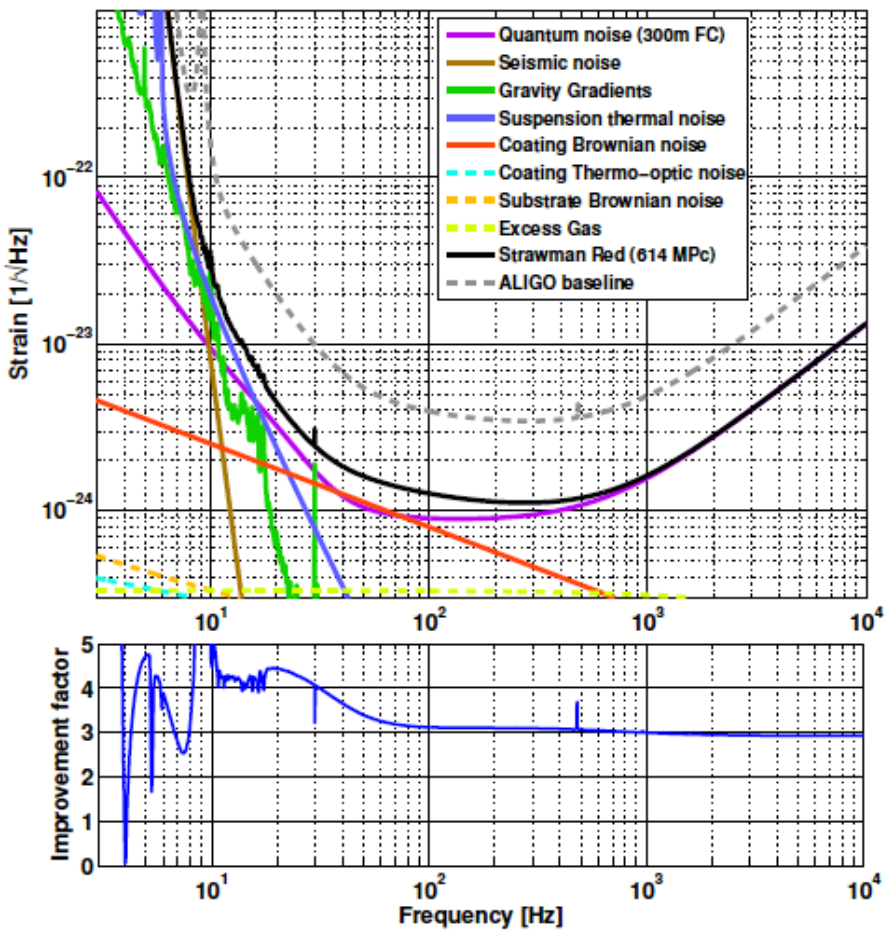
Three Commandos

- Red Team (Stefan Hild)
- Green Team (Stefan Ballmer)
- Blue Team (Rana Adhikari)
- Do whatever you like with a few common assumptions
  - Optical Properties of Silicon
  - Temperature Dependence of the Young's Modulus of Silicon
  - Building blocks for future detectors: Silicon test masses and 1550 nm laser light
  - The quest for inexpensive, compact, low phase noise laser sources for fiber optic sensing applications Phase noise performance comparison of COTS, specifically Nd:YAG lasers, Er-doped fiber lasers, external cavity semiconductor lasers, and semiconductor DFB lasers (for 1550nm).
  - Temperature Dependence of the Thermal Conductivity of Silicon
  - Temperature Dependence of the Thermo-Optic Coefficient of Silicon

RED team (Stefan Hild)



Red team Overview



Strawman Red Design Overview		
Subsystem and Parameters	**Advanced LIGO Baseline Design**	**Strawman Red Design**
Sensitivity		
Binary Neutron Star Inspiral Range	200 Mpc	614 Mpc
Anticipated Strain Sensitivity	$3.5 \cdot 10^{-24}/\sqrt{\text{Hz}}$ @ 300 Hz	$1.2 \cdot 10^{-24}/\sqrt{\text{Hz}}$ @ 250 Hz
Instrument Topology		
Interferometer	Dual-recycled Michelson with Armcavities	Dual-recycled Michelson with Armcavities
Quantum Noise Reduction	n.a	Frequency-dependent input squeezing
Laser and Optical Parameters		
Laser Wavelength	1064 nm	1064 nm
Optical Power at Test Masses	730 kW	730 kW
Arm Cavity Finesse	450	450
Signal Recycling	$T = 20\,\%$, tuned	$T = 20\,\%$, tuned
Squeezing Factor	n.a.	20 dB
Filtercavity (FC) length	n.a.	300 m
FC Detuning	n.a.	-16.8 Hz
FC Input Mirror Transmittance	n.a.	425 ppm
Squeezing Losses	n.a.	9 % + 30 ppm roundtrip in FC
Test Masses and Suspensions		
Mirror Material	Fused Silica	Fused Silica
Main Test Mass Diameter	35 cm	55 cm
Main Test Mass Weight	42 kg	160 kg
Masses in Main Quad (from top)	22 kg/22 kg/40 kg/40 kg	44 kg/66 kg/120 kg/160 kg
Masses in Reaction Chain (from top)	22 kg/22 kg/40 kg/40 kg	22 kg/22 kg/40 kg/40 kg
Total Mass of a Main Suspension	250 kg	520 kg
Length of Final Suspension Stage	0.6 m	1.2 m
Fused Silica Fibre Diameter	400 μm	566 μm
Fibre Diameter at Bending Point	800 μm	1624 μm
Coating Noise Reduction		
Improvement Factors	n.a.	factor 1.6 from increased beam size **PLUS** factor 2 from either (i) better coatings, **OR** (ii) Khalili cavities, **OR** (iii) waveguides
Operation Temperature	290 K	290 K
IM/EM ROC	1934/2245 m	1849/2173 m
IM/EM spotsize	5.31/6.21 cm	8.46/9.95 cm
Khalili cavity length	n.a.	50 m
Gravity Gradient Noise		
Assumed Seismic Level	???	LLO ETMX, 90th percentile
Assumed subtraction factor	n.a.	5

GREEN team (Stefan Ballmer)

General considerations

- Thermal noise is the gorilla in the room
- We looked at
  – Low risk options if we have no TN
  – Required research for TN improvement
- No full ready design
  – But many ideas

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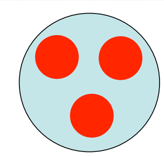
Stefan Ballmer*, Koji Arai, Haixing Miao, David Ottaway,
Rich Mittleman, Jim Lough, Antonio Perreca, Gregg Harry,
Jeff Kissel, Giacomo Ciani, Riccardo DeSalvo, Sam Waldman,
Guido Mueller, Vuk Mandic, Zach Korth, Rich Abbott, Keita Kawabe

Explored so far

Green team

- 1) LG feasibility
- 2) Coating options
- 3) GWINC design for
  - NO thermal noise improvements
  - 2.5x thermal noise improvements
- 4) Squeezing integration
- 5) Seismic improvements / implications
- 6) Cryogenics

General Ideas on improving Thermal noise

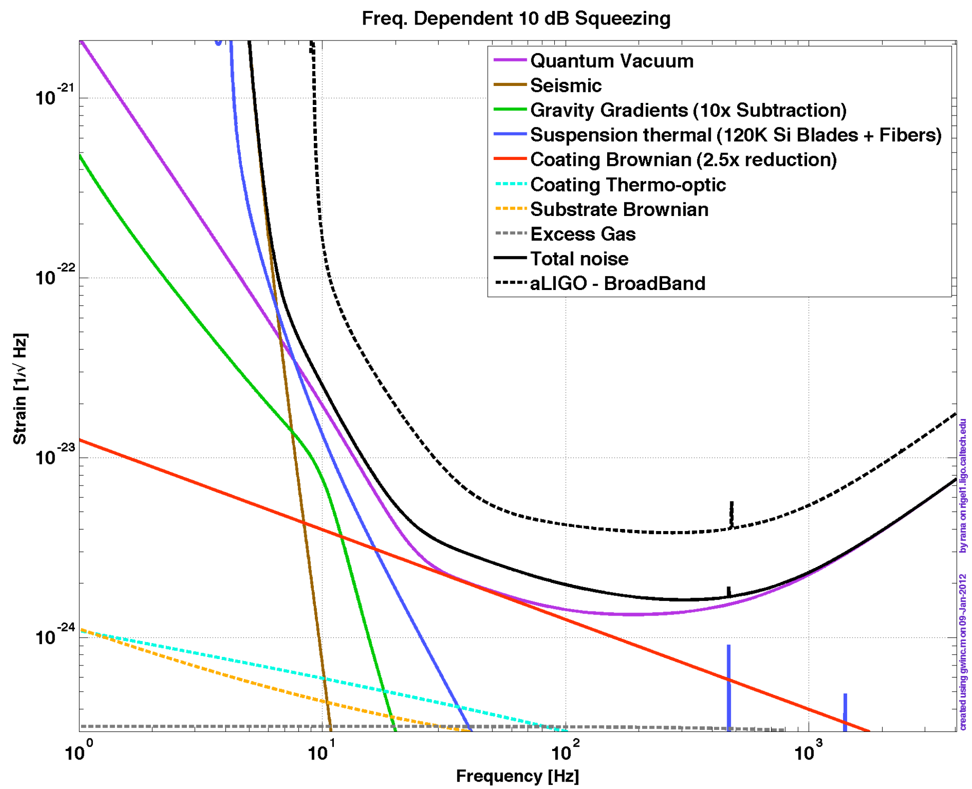


- Improve the beam area more!
  - Three beams? 3x in Area! (another x1.7 in TN)
  - Polish 3 spherical dents on one large optic
  - Effectively 3 IFOs… … but optical combining possible (cheaper)
  - ASC for free!
- Of course there is also the delay line…

BLUE Team (Rana Adhkari)

- Blue One) Core Optics (Billingsley, Brooks, Gustafson, Kells, Miller, Route, Torrie, Yamamoto)
- Blue Two) Coatings (a-Si, GaAs, GaP) (Adhikari, Chen) & 1550 laser operation (Frolov, Miller, Slagmolen) & ALS (Gustafson, Slagmolen, Miller)
- Blue Three) Seismic / Newtonian Noise estimate for LLO/ LHO (Coughlin, Schofield, Evans, Lantz, Driggers)
- Blue Four) Input Squeezing Filter Cavity (Miao, Evans, Kokeyama)
- Blue Five) Suspension Options (1 = 300K silica, 2a = 120K Si, 2b = 18K Si) (Robertson, Torrie, Smith, Heptonstall, Johnson)

Blue team



- 150 kg Silicon Mirrors
- AlAs / GaAs coatings
- Laser wavelength → 1560 nm
- ~~Laser power increase to get 3 MW arm power~~.
- Silicon fibers
- Silicon blades on the PUM
- 10 dB Squeezing injection
- 100 m filter cavity for frequency dep. squeeze angle rotation
- 10x Newtonian noise subtraction (5-20 Hz) using an array of ~20 vertical geophones per test mass
- SEI improvements: lower noise inertial sensors on stage 2, chamber/ pier stiffening, increase feedback BW on stage2, FF from stage0 to stage1, etc.
- ALS w/ 1310 nm phase locked to 1560 via ???

Workshop Conclusion Baseline

- **Optical Topology**
  - Dual - recycled FPMI
  - Squeezing injection (> 10 dB) with filter cavity
  - cryogenic silicon mirrors may allow up to several MW in arms
- **Optic**
  - 120-150 kg Si Mirror (@120 K)
  - Coatings (Epitaxial, Amorphous Si, etc.)
  - Larger beams (~1.5-2x in radius)
- **Suspension**
  - New Quad suspension (to accommodate large mirror mass)
  - keep existing HEPI / ISI
  - 2 hot stages
  - 2 lower stages are cold (120K) (fiber + test mass)
  - making single plot with comparison of all schemes
- **Newtonian**
  - ~20-30 sensors per building
  - combination of online FF and offline subtraction
- **Lasers**
  - 1550 nm lasers (fiber for the high power stage) LZH
  - 200 (existing) - 1000 (future) W lasers ?
  - 1550 looks harder than 1064 so far
- **Facility Changes**
  - NN array requires many vaults/domes
  - ~100 m beam tube for filter cavity
  - Possible modify BSC (4 per IFO) to allow 120K operation