GWADW2016 - Impact of Recent Discoveries on Future Detector Design

SUMMARY NOTES

Albert Lazzarini
27 May 2016
Isola d'Elba, Italy

SXS Image: of Merger of GW150914

LIGO

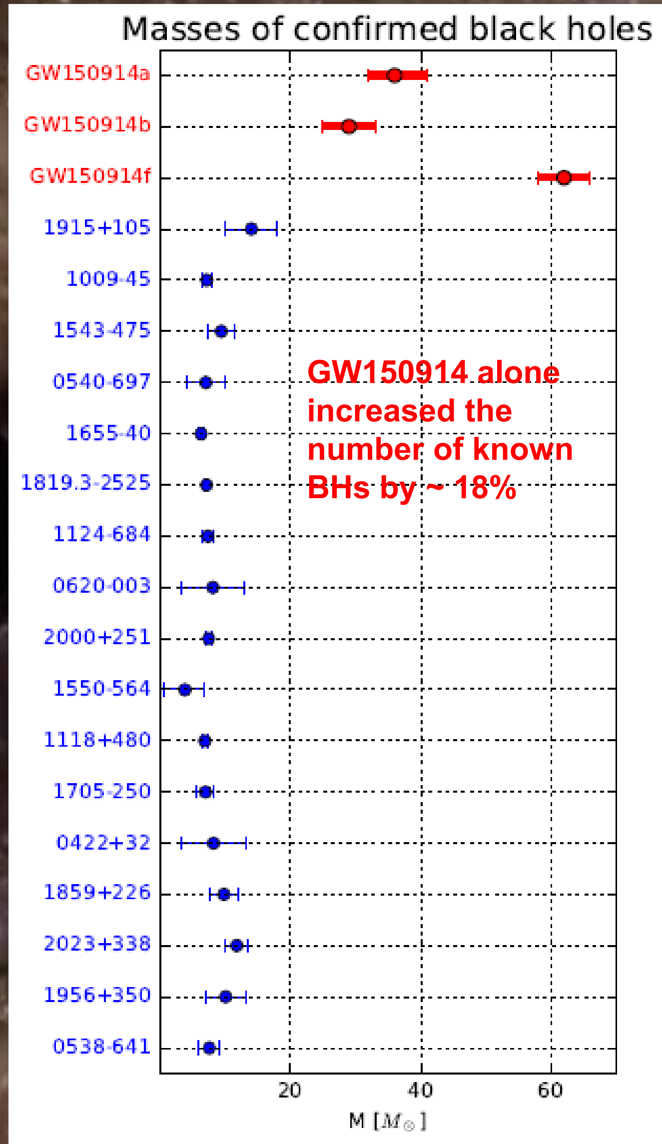
What did we learn this week?

- Effects of detection on near term plans
- Science case for 3G Detectors
- Cryogenics implementation plans
- Space detectors – status and plans
- Interferometer enhancements within ~ 12 years
- (Global) Coordination of future development of 3G detectors
- Requirements for 3G detectors
- Interferometer configurations

(Workshop summaries have already been presented)

Effects of detection on near term plans (S. Vitale , L. Barsotti, S. Fairhurst)

- GW150914 has raised many questions that must await additional discoveries



The final message: what we can/can not do with a 2G network

	Sky Localization	Spin Estimation	Mass Estimation	Distances	Cosmology	Merger Physics
BNS	2GNet	2G	2G	2GNet	>2G	>2G
NS-BH	2GNet	2G	2G	2GNet	>2G	>2G
Light BBH	2GNet	2G	2G	2GNet	>2G	>2G
Heavy BBH	2GNet	>2G	2G	2GNet	2G	2G?

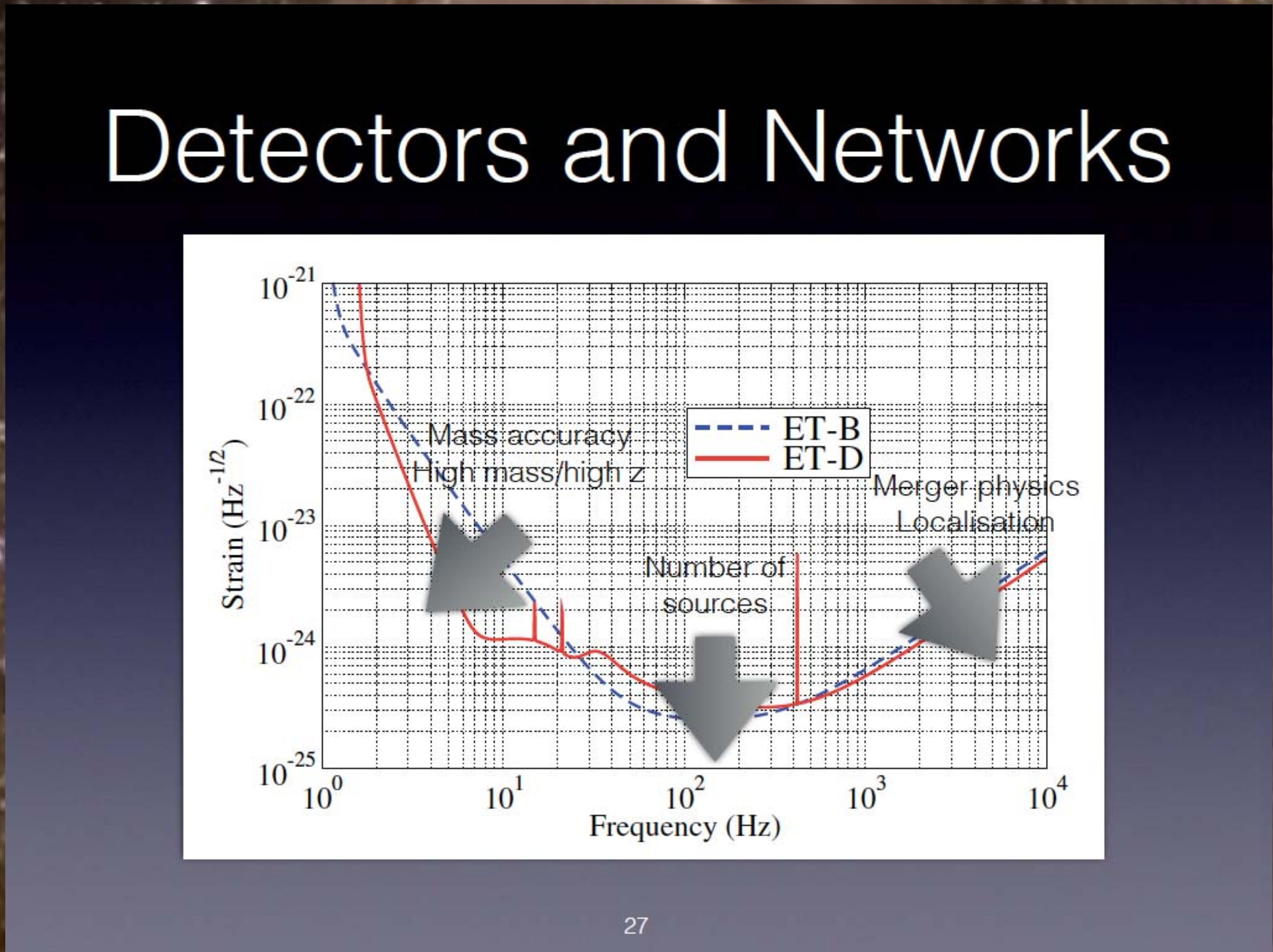
Science case for 3G Detectors
(S. Fairhurst, B. Sathyaprakash)

3G SCIENCE CASE

- *extremes of physics*
- *black holes through cosmic history*
- *explosive phenomena*

38

Science case for 3G Detectors (S. Fairhurst, B. Sathyaprakash)



Cryogenics
(K. Somiya, G. Hammond, K. Yamamoto, C. Wipf)

University of Glasgow

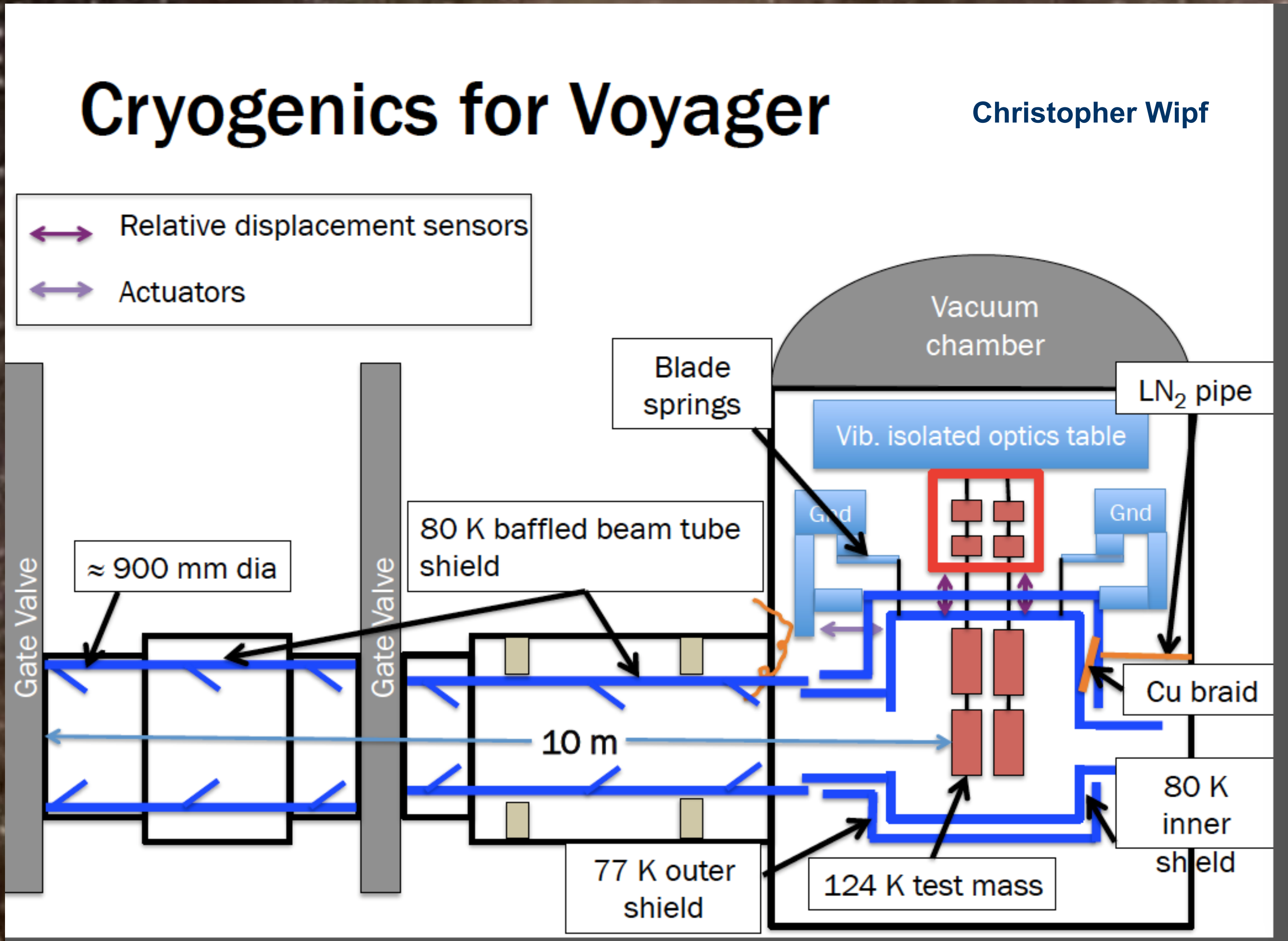
Summary

Giles Hammond

- Hybrid suspensions:
  - no significant performance gain
  - challenges with thermal gradients, jointing
- Silicon suspensions
  - Above 105K, radiative cooling ensures high powers can be supported
  - Best performance at 20K
  - At 120K, surface loss limits the performance
  - Vertical bounce mode and violin modes are close together (40Hz and 140Hz)
- Sapphire suspensions:
  - Above 118K, radiative cooling ensures high powers can be supported
  - Good performance at 20K/120K, not quite as good as silicon
  - Vertical bounce mode and violin modes are close together (75Hz and 105Hz)
  - Sapphire fibres are easier to fabricate

10

Cryogenics
(K. Somiya, G. Hammond, K. Yamamoto, C. Wipf)



Cryogenic Considerations for LIGO Voyager

Summary

Christopher Wipf

- 123 K silicon offers a broadband sensitivity enhancement within today's facilities
- Very low absorption is available in large silicon crystals
- Thermal noise/scatter from cryo system should be tolerably small
- Monolithic suspension, or "hybrid"?

Cryogenics
(K. Somiya, G. Hammond, K. Yamamoto, C. Wipf)

KAGARA – Overview of the 20K configuration

4. Summary Kazuhiro Yamamoto

Operation below 20K

(1)How much is the noise below 20K ?
All kinds of thermal noise is smaller than goal sensitivity of 2nd generation.

2)However, cooling below 20K is challenge.
Heat path is an issue. We need "thick" heat path.
It implies low violin modes and large external vibration effect.

Solution
- Larger mirror with smaller absorption
- Vibration isolation
- Thermal switch

34

Space Detectors
(J. Conklin, S. Vitale, K. Danzmann)

- Stefano & Karsten

DID NOT TELL US HOW WELL LPF WORKS

lisa pathfinder

esa plain tex press re

ESA

Back to Index

French | German

Nº 19–2016: CALL FOR MEDIA: FI PATHFINDER MISSION

24 May 2016

Media representatives are invited to a brief Pathfinder mission, a technology demonstr from space.

The media briefing is being organised by th Space Astronomy Centre (ESAC) in Villanue June, 11:30–13:00 CEST. Doors open at 11

esa Elba 24/05/2015 S. Vitale

From the horse's mouth…

lisa pathfinder

nature International weekly journal of science

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Archive > Volume 531 > Issue 7592 > News > Article

NATURE | NEWS

Successful test drive for space-based gravitational-wave detector

Mission paves the way for planned €1-billion space observatory.

Elizabeth Gibney

25 February 2016

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Scientists have long dreamed of launching a constellation of detectors into space to observe gravitational waves — the ripples in space-time predicted by Albert Einstein and observed for the first time earlier this month.

That dream is now a step closer to reality. Researchers working on a €400-million (US$440-million) mission to try out the necessary technology in space for the first time — involving firing lasers between metal cubes in free fall — have told *Nature* that the initial test drive is performing just as well as they had hoped.

Nature Special: Gravitational Waves

"I think we can now say that the principle has worked," says Paul McNamara, project scientist for the LISA Pathfinder mission, which launched last December. "We believe that we now are in a good shape to look to the future and look to the next generation."

"Everything works as we designed it. It's sort of magical, and you rarely see that in your career as an experimentalist," says Stefano Vitale, a physicist at the University of Trento in Italy, and a principal investigator for the Pathfinder mission.

PRECISION LAB IN SPACE

LISA Pathfinder has shown that an intricate experiment consisting of two metal cubes in freefall, isolated from all forces except gravity, can operate in space.

At the heart of Pathfinder are two free-falling metal cubes, shielded from all forces except gravity by their housing.

Any disturbance to the relative motion of the cubes affects

"I think we can now say that the principle has worked" Paul McNamara, LPF project scientist

"*Everything works as we designed it. It's sort of magical, and you rarely see that in your career as an experimentalist,*" Stefano Vitale, principal investigator for the Pathfinder mission.

"*Woo-hoo!*" Cesar Garcia, LPF Project Manager

Paper accepted on PRL. On-line publication: June 7, 12:00 CET

http://www.nature.com/news/successful-test-drive-for-space-based-gravitational-wave-detector-1.19452

Space Detectors
(K. Danzmann, S. Vitale, J. Conklin)

Meanwhile in the U.S.…

- Astronomy mid-decadal review (National Academy) will have recommendations on NASA (re)engagement on LISA
- NASA L3 Study Team appointed with this in mind
  - Survey/analyze candidate NASA/U.S. contributions…
- R&D plans (& hopes?) on a number of fronts:
  - Lasers (GSFC)
  - Telescopes (GSFC)
  - Phasemeter(JPL)
  - Thrusters(JPL/Busek)

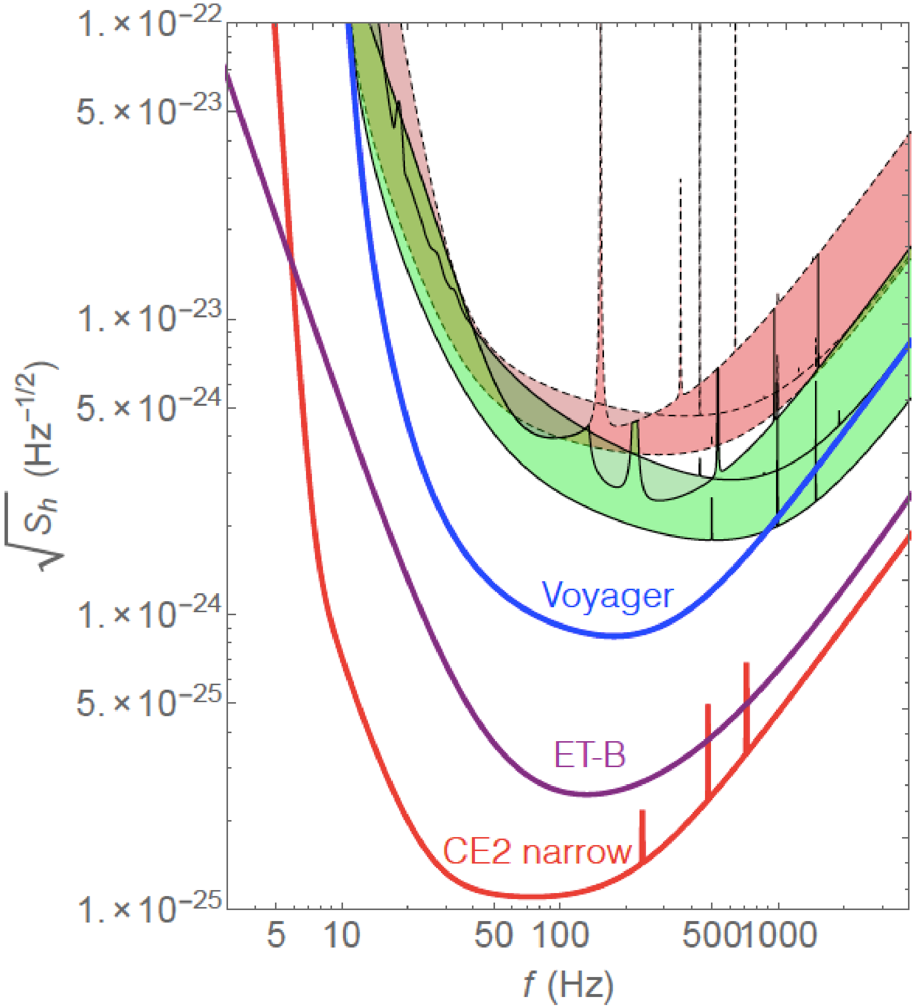
  And maybe…
  - Photoreceivers(GSFC)
  - Optical bench design/fabrication (U.Fl.)
  - UV LED-based charge control & metrology (U. Fl.)

Enhanced Interferometers (within 12 yrs)

(Y. Chen, L. Barsotti, G. Cagnoli, E. Capocasa. S. Steinlechner)

Scenarios of Upgrade

Yanbei Chen



2020 -2025	A+ (LIGO-H & LIGO-L) VIRGO+++ KaGRA+ 3x @ high frequencies
2025 - 2030	3 Voyagers (L, H & I) 3- 4x overall VIRGO+++ KaGRA+
2030	Adding ET 10 x overall, 10 Hz *how many ETs, where?* *roles of 4km ifos?*
2035-	Adding CE 30x overall, 10 Hz *how many CEs, where?* *roles of 4km ifos & ET?*

VIRGO+++: Eleonora Capocasa
KaGRA+: Kentaro Somiya

Enhanced Interferometers (within 12 yrs)

(Y. Chen, L. Barsotti, G. Cagnoli, E. Capocasa. S. Steinlechner)

Conclusions

Lisa Barsotti

(aLIGO upgrades)

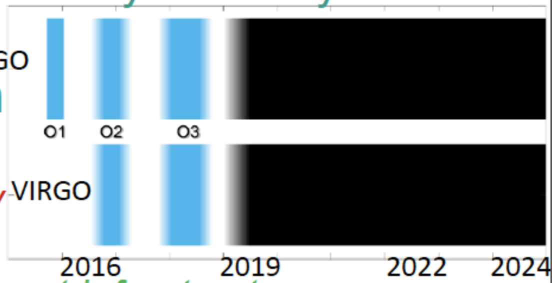
- Post-detection era will see a sequence of observing runs and incremental upgrades
- A+ targets quantum noise and coating thermal noise reduction, up to a factor of 2 improvements over aLIGO design
  - "Flow" of improvements, following noise hunting and power increase progress
  - incorporate lessons learned from aLIGO

GWADW Elba, May 25, 2016 LIGO: the A+ upgrade 12

Enhanced Interferometers (within 12 yrs)

(Y. Chen, L. Barsotti, G. Cagnoli, E. Capocasa. S. Steinlechner)

- Securing the AdV target sensitivity and duty cycle
- 3 phases of implementation
  - PHASE 1 (2017-2021): *achieve the design sensitivity*
  - PHASE 2 (2021-2025): *the best we can do in the current infrastructure*
  - PHASE 3 (>2025) *possible implementation of 3G technology*



Gianpietro Cagnoli

	Milestones	Budget	Infrastructure	Implementation
Signal Recycling	- Demonstration - Coatings depos.	Available	No impact	After O2
HP Laser	- Choice (2016/06) - Long term test	Available	No impact	After O2
FI Squeezing	- Demonstration - 2 benches suspension	1.2 M€	No impact	After O2
R&D coatings	- Technology selection	0.6 M€+ 3 M€	No impact	Now (R&D) After O3 (Imple.)
NN site characterization	- Sensor development	0.1 M€	No impact	After O2
NN detection	- Deployment new sens.	0.3 M€	No impact	After O3
FD Squeezing	- Demonstration - Installation of vacuum	> 1.7 M€	Housing the filter cavities	After O3

Enhanced Interferometers (within 12 yrs)

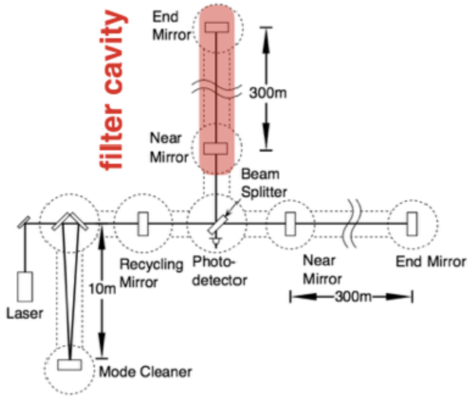
(Y. Chen, L. Barsotti, G. Cagnoli, E. Capocasa. S. Steinlechner)

Eleonora Capocasa

Ongoing activities

Virgo + KAGRA Collaboration

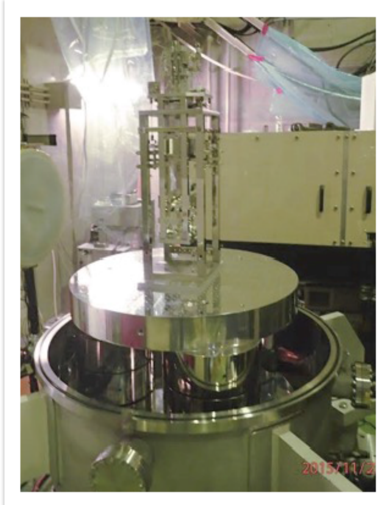
- 300 m filter cavity prototype is being installed at NAOJ in TAMA infrastructure



PHYSICAL REVIEW D 93, 082004 (2016)

Estimation of losses in a 300 m filter cavity and quantum noise reduction in the KAGRA gravitational-wave detector

Eleonora Capocasa,[1,2,*] Matteo Barsuglia,[1] Jérôme Degallaix,[3] Laurent Pinard,[3] Nicolas Straniero,[3] Roman Schnabel,[4] Kentaro Somiya,[5] Yoichi Aso,[2] Daisuke Tatsumi,[2] and Raffaele Flaminio[2]



11

- End 2016 filter cavity characterization and losses measurements
- 2017 frequency independent squeezing production
- 2018 frequency dependent squeezing measurement

Enhanced Interferometers (within 12 yrs)

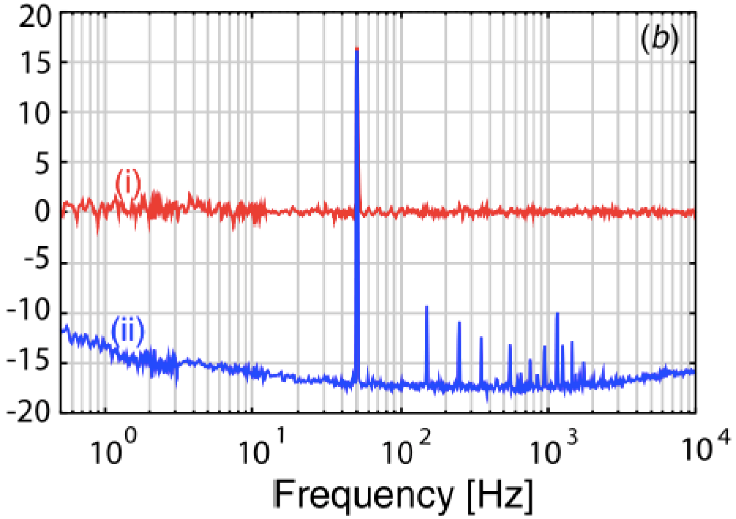
(Y. Chen, L. Barsotti, G. Cagnoli, E. Capocasa. S. Steinlechner)

Balanced Homodyne Detection

Sebastian Steinlechner

Why?

- Background: look into details of (imperfect) BHD for the Glasgow Speed Meter. Knowledge can be transferred to big instruments?
- Technical reasons
  - want to reduce stray light at OMC, can get rid of dark-fringe offset
  - want to have lots of dark-noise clearance without huge DC levels
    - see e.g. Fritschel *et al.*, Optics Express 22, 4224 (2014)
    - but also Grote *et al.*, LIGO-P1500203
  - reduced coupling of laser noise & higher-order modes (?)
- Conceptual reasons
  - advanced interferometry concepts almost universally assume BHD
    - speed meters (▸ talk on Friday)
    - variational readout
    - quantum-dense metrology (▸ talk on Friday)
  - want quantum-noise limited readout of arbitrary light-field quadrature



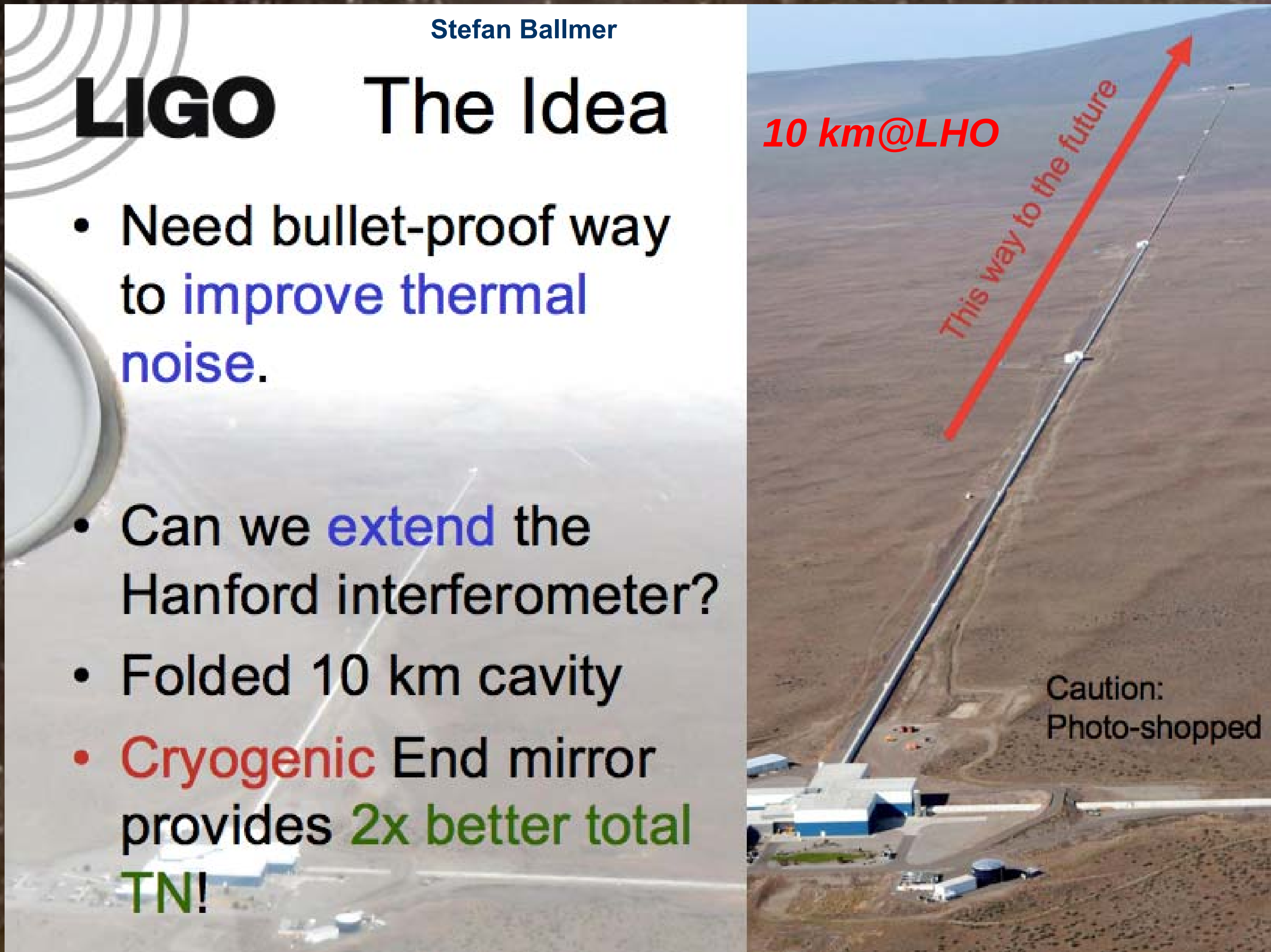
Enhanced Interferometers (within 12 yrs)
(R. Bassiri, S. Ballmer, A. Freise, R. Adhikari)

Coatings: what's possible

Riccardo Bassiri

- Goals:
  - A better idea on whether loss can be reduced by:
    - changes in deposition rate
    - ion-assisted deposition
  - Structure to thermal noise understanding converging
    - Mechanical loss modelling will work with experimental characterization
- Now:
  - Change in e.g. titania doping to increase refractive index
  - Multi-material a-Si for ETMs: @1064 ~ 20% TN reduction
  - By Dec 2016, we will likely know whether loss can be reduced by elevated temperature deposition on IBS tantala
- In 1 – 3 years:
  - Elevated temperature deposition (production)
  - Higher temperature annealing before crystallization reduces loss
    - Nano-layer Titania-Tantala coating
    - Zr:Ta_2O_5
- In 3 - 5+ years (if the right MBE and 2 people are available)
  - AlGaA
  - AlGaP – proven low loss – other parameters need further study

Enhanced Interferometers (within 12 yrs)
(R. Bassiri, S. Ballmer, A. Freise, R. Adhikari)



Enhanced Interferometers (within 12 yrs)
(R. Bassiri, S. Ballmer, A. Freise, R. Adhikari)

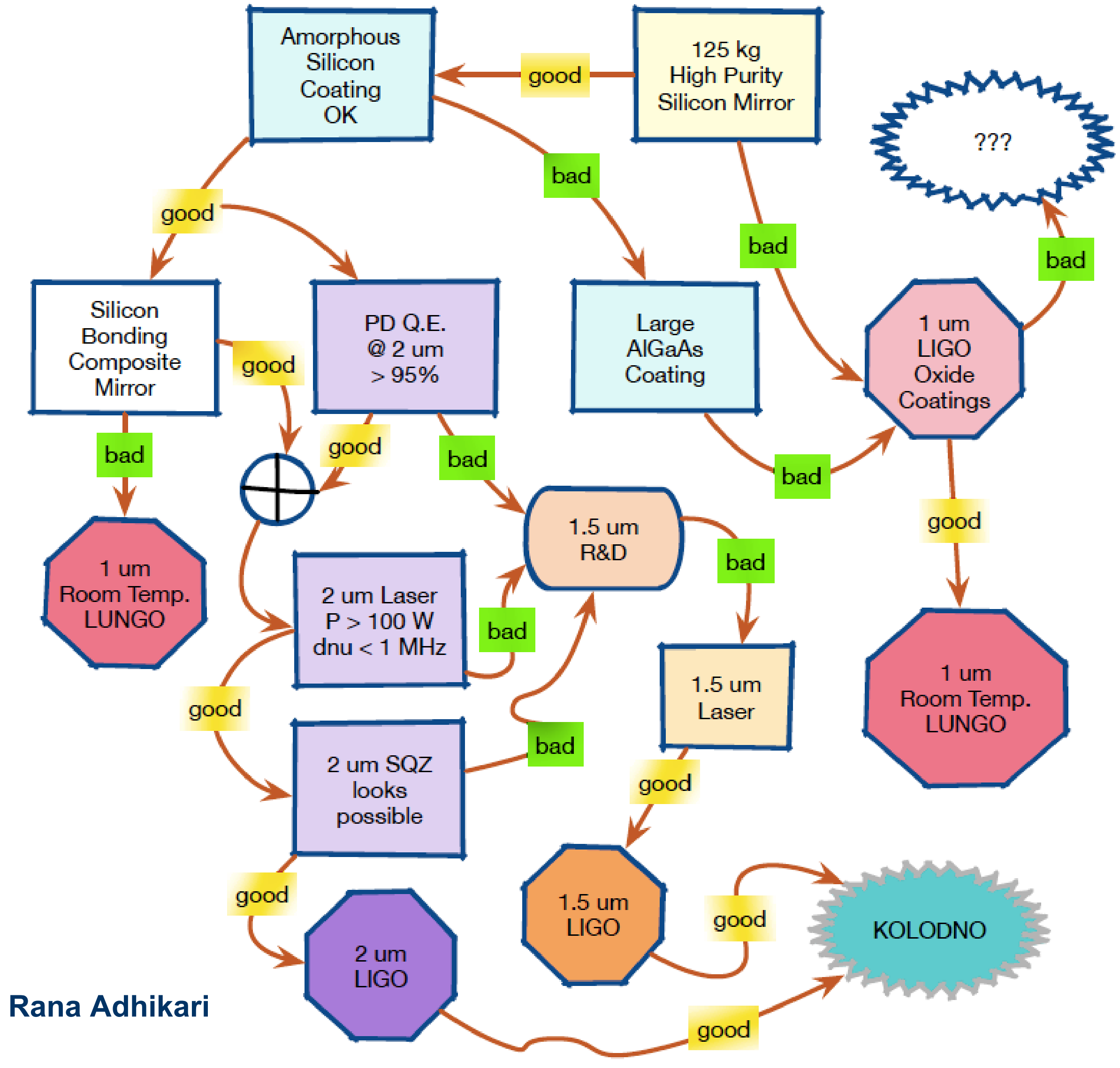
UNIVERSITY OF BIRMINGHAM

- Laguerre-Gauss modes : 1.7 TN reduction, good body of work for preliminary investigations, currently not actively continued
- Large beam and mirror sizes: 1.7 or 2.5, an 'engineering problem' for the suspension, challenge for coating uniformity, and need some better approach for alignment control

Not all of this sounds like fun, but is any of this really more difficult than cryogenics (or any other advanced technique)?

12 Andreas Freise, GWADW 25.05.2016

Enhanced Interferometers (within 12 yrs)
(R. Bassiri, S. Ballmer, A. Freise, R. Adhikari)



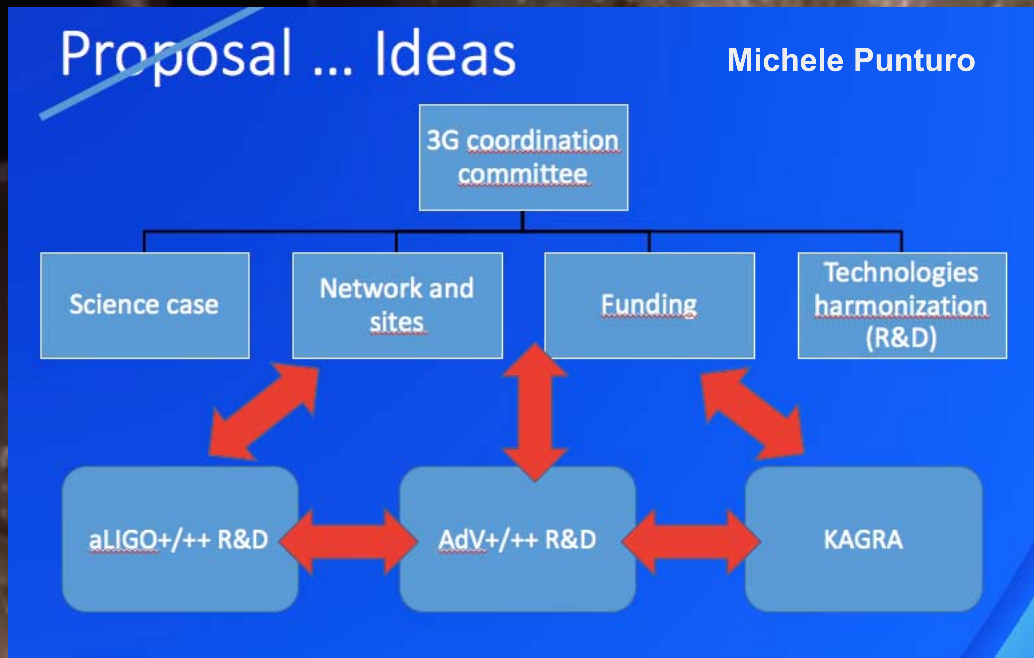
Sheila Rowan

❑ Possible models for GWIC's role

- Assess the current GWIC roadmap, update it.
- Constitute a subcommittee focused on aiding international planning of future facilities

(Directly?) interact with funding agencies?

From the ILC home page:
"In order to begin developing international funding mechanisms for the ILC, a high-level international group comprised of representatives from funding agencies around the world called Funding Agencies for Large Colliders (FALC) been put in place."



The case for proposing upgrades to existing facilities and new facilities housing 3G detectors is both strong and urgent! BUT …

- *Essential* Advanced LIGO must reach its design sensitivity
  - #1 -- because it provides proof that we understand and can tame the noises in 2G interferometers
  - #2 -- it will demonstrate to funding agencies that we can deliver on our design goals
- *Essential* The science case for 3G detectors must be extremely well developed given what we know at the time of the proposal
- *Essential* The community will have to prepare their respective funding agencies that big projects are being planned
  - It can take 5 years to get a project 'queued up' into the NSF Major Research Equipment and Facilities Construction budget
- *Essential (for Cosmic Explorer)* An external evaluation must be conducted by a panel of experts
  - Is the science case sufficiently strong for a 3G detector?
  - Is the technology development mature?
  - Is their preliminary costing and project planning, or is there a path to those?
- **Essential** ~~*Nice to Have*~~ International planning and coordination
  - May be essential for CE-class project
- **Essential** ~~*Nice to Have*~~ Support and advocacy from an outside community
  - They support GW science because it adds to their science
  - For the GW community, it's the astronomers, perhaps nuclear physicists

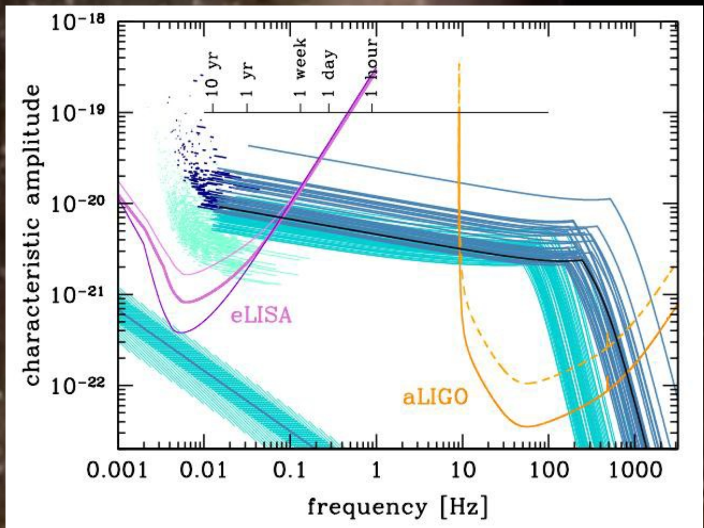
Dave Reitze

Future detectors requirements, goals, possibilities (S. Vitale, J. Harms, S. Ballmer)

Salvatore Vitale

- NF will be online, at earliest, in the 2030s.
- Which among the interesting astrophysical questions *today* will still be relevant *then*?
- When to decommission previous generation instruments?
- Instruments a factor of 2/3 behind the leading IFOs will probably not be very useful
  - Could help for sky localization of nearby events

- Sesana (1602.0695) pointed out that heavy BBH such as GW150914, and louder would be visible in eLISA band weeks to years before they coalesce in the band of ground based detectors



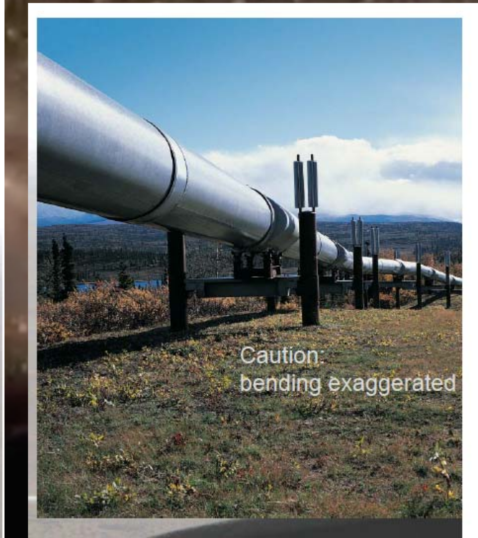
Future detectors requirements, goals, possibilities (S. Vitale, J. Harms, S. Ballmer)

Assessment

Stefan Ballmer

Deflect the cavity beam to follow Earth curvature

- Used sparsely, lenses/wedges could be a good tool
- Good option once you go really long:
  - Brownian noise less important to start with, more limited by quantum noise
  - $$$ savings from small arm direction changes
- Suspend lenses like test masses



Constraints on Observatory Designs

Jan Harms

Surface

Wind noise – Few meters underground or aerodynamically shaped buildings?

Strong seismic noise from local sources – Improve design of laboratory infrastructure?

How much digging required for 40km arms?

Stick the ends into mountains

Strong mitigation of atmospheric NN

Detrimental effects on seismic NN cancellation (necessarily complex topography)

Underground

Detector infrastructure – How to avoid elevated underground seismic noise?

Future detectors requirements, goals, possibilities (M. Evans, A. Freise, G. Hammond, D. Sigg)

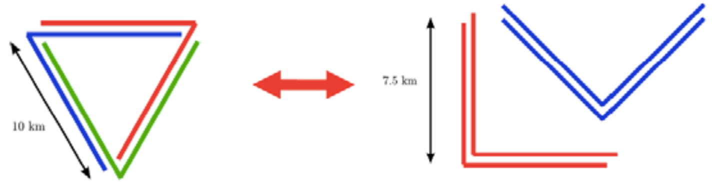
Simple Equations

Andreas Freise

UNIVERSITY OF BIRMINGHAM

Co-aligned, and both polarisation:

$$\mathrm{SNR}_{2L,7.5\,\mathrm{km}} = \frac{2}{\sqrt{2}}\frac{7.5}{10}\mathrm{SNR}_{L,10\,\mathrm{km}} \approx 1.06\ \mathrm{SNR}_{L,10\,\mathrm{km}}$$



Detector Networks

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- Network of three L-shaped detectors:
  - locate them at large distances
  - mis-align them for detection of both polarisations
- 3G detector in a heterogenous network:
  - Longer L or shorter △?
  - Science case still evolving

Lanky et al: `Detecting gravitational-wave memory with LIGO: implications of GW150914', https://arxiv.org/abs/1605.01415

14 Andreas Freise, GWADW 26

The Message

Matt Evans

- We should start going beyond GWINC
- Non-fundamental noises can drive design choices (e.g., need large mirrors also to increase moment of inertial to avoid alignment instability)
- Full length and alignment control schemes will be needed before we can be sure our designs make sense, so expect design iteration

5/26/16 M. Evans at GWADW 2016 12

Future detectors requirements, goals, possibilities (M. Evans, A. Freise, G. Hammond, D. Sigg)

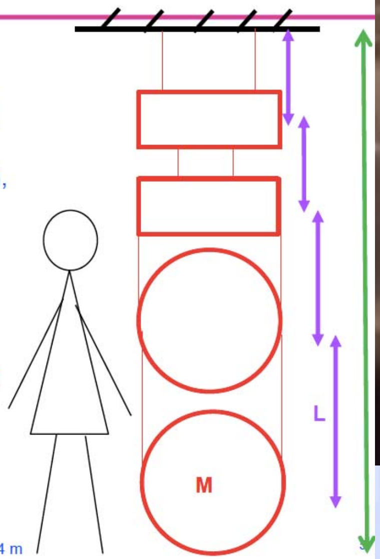
Possible Suspension Design

- New test mass 400 kg:
  - » 730 mm diam. (D) x 430 mm thick
- PUM = test mass (M), upper masses each 0.5 M
- **Overall mass (main chain) = 3M = 1200 kg**
- Final stage length, L >= D+0.1 = 0.83 m minimum, up to (say) 1.2 m
- Upper lengths; 0.5 L, 0.5 L, 0.75 L
- **Overall length to bottom of optic**
  = 2.75 L + D/2 = 2.4 m up to ~ 3.6 m

Compare to aLIGO design: final length 0.602 m, total mass 124 kg and total length 1.8 m

Total load on ISI for new design ~3 tonnes

(assume reaction chain mass is ~½ main chain mass, add support structure, telescope)



G1601071-v3

Approx. to scale for 2.4 m

Hammond/Robertson

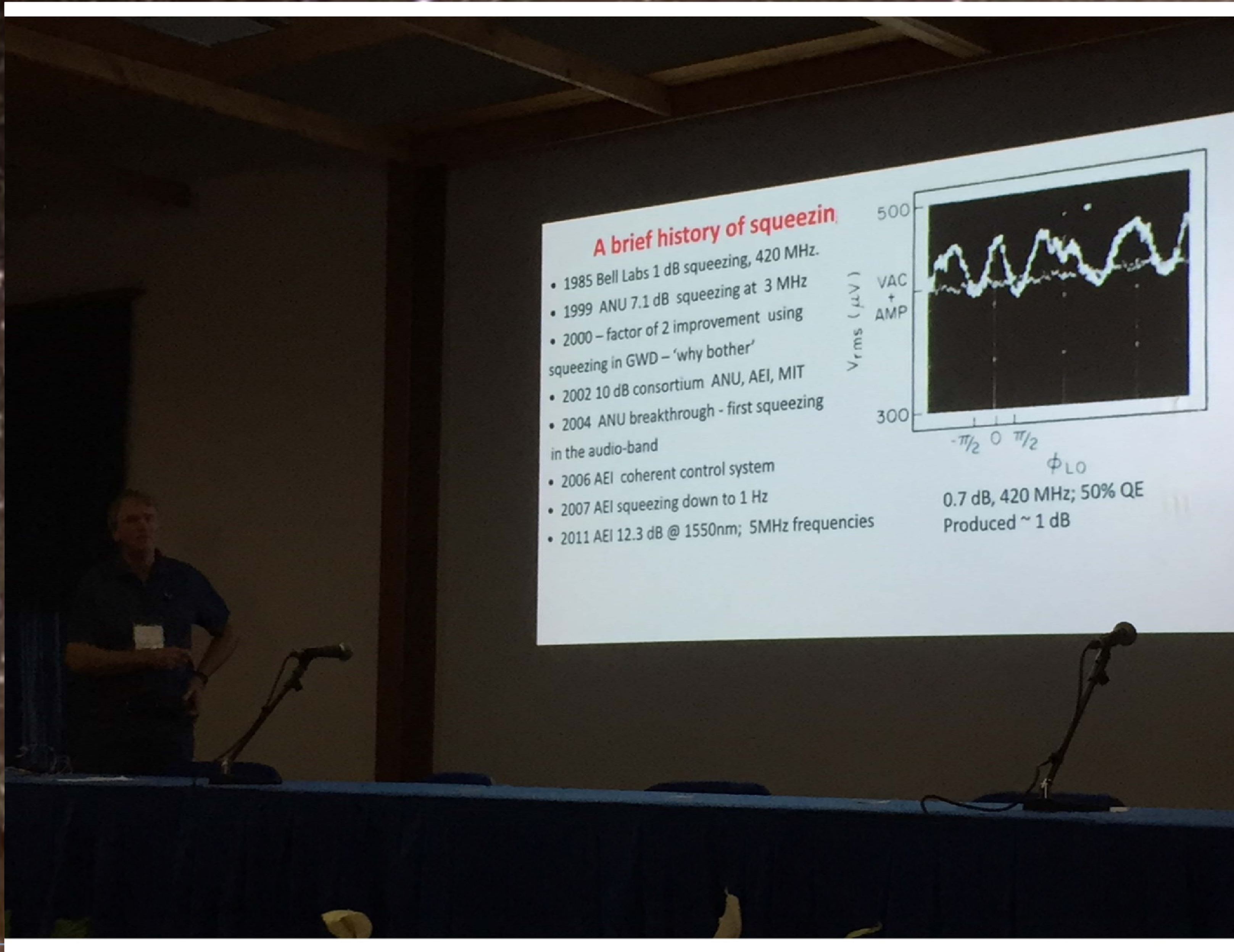
- General Conclusion: Larger and Longer Suspensions are Feasible
- −Engineering Considerations are Important.

Heterogeneous Networks

Daniel Sigg

- 1-2 3G detector facilities + advanced detectors
- Cut on high SNR events in 3G detector
- Solid angle reduction (SNR 3G/AD ~ 10)
  - Add one 3G facility: ~2
  - Add two 3G facilities: ~10
  - Three 3G facilities: ~70 (due to reduced bandwidth)
- Will allow for distance measurements
- Two 3G facilities on their own?

IFO configurations & squeezing
(D. McClelland, H. Vahlbruch, A. Schoenbeck, Y. Chen, K. Somiya)



IFO configurations & squeezing
(D. McClelland, H. Vahlbruch, A. Schoenbeck, Y. Chen, K. Somiya)

Summary / Outlook

Leibniz Universität Hannover

Henning Vahlbruch

- 15dB vacuum squeezing demonstrated in a doubly resonant linear OPA cavity design
- Operated in air with only 1.7mrad phase noise
- 10dB squeezing with only 11dB anti-squeezing with low pump power
- Calibration of PD quantum efficiency to 99.5 +/-0.5%
- Doubly resonant linear OPA design transferable to the GEO-Squeezer layout

GEO 600

Summary / Outlook

Leibniz Universität Hannover

Summary

Axel Schönbeck

- Different wavelengths for gravitational wave detectors are suggested
- Squeezing at 532 nm, 1064 nm and 1550 nm has been demonstrated
- Higher wavelengths are difficult to obtain because of the limited quantum efficiency of photo detectors

IFO configurations & squeezing
(D. McClelland, H. Vahlbruch, A. Schoenbeck, Y. Chen, K. Somiya)

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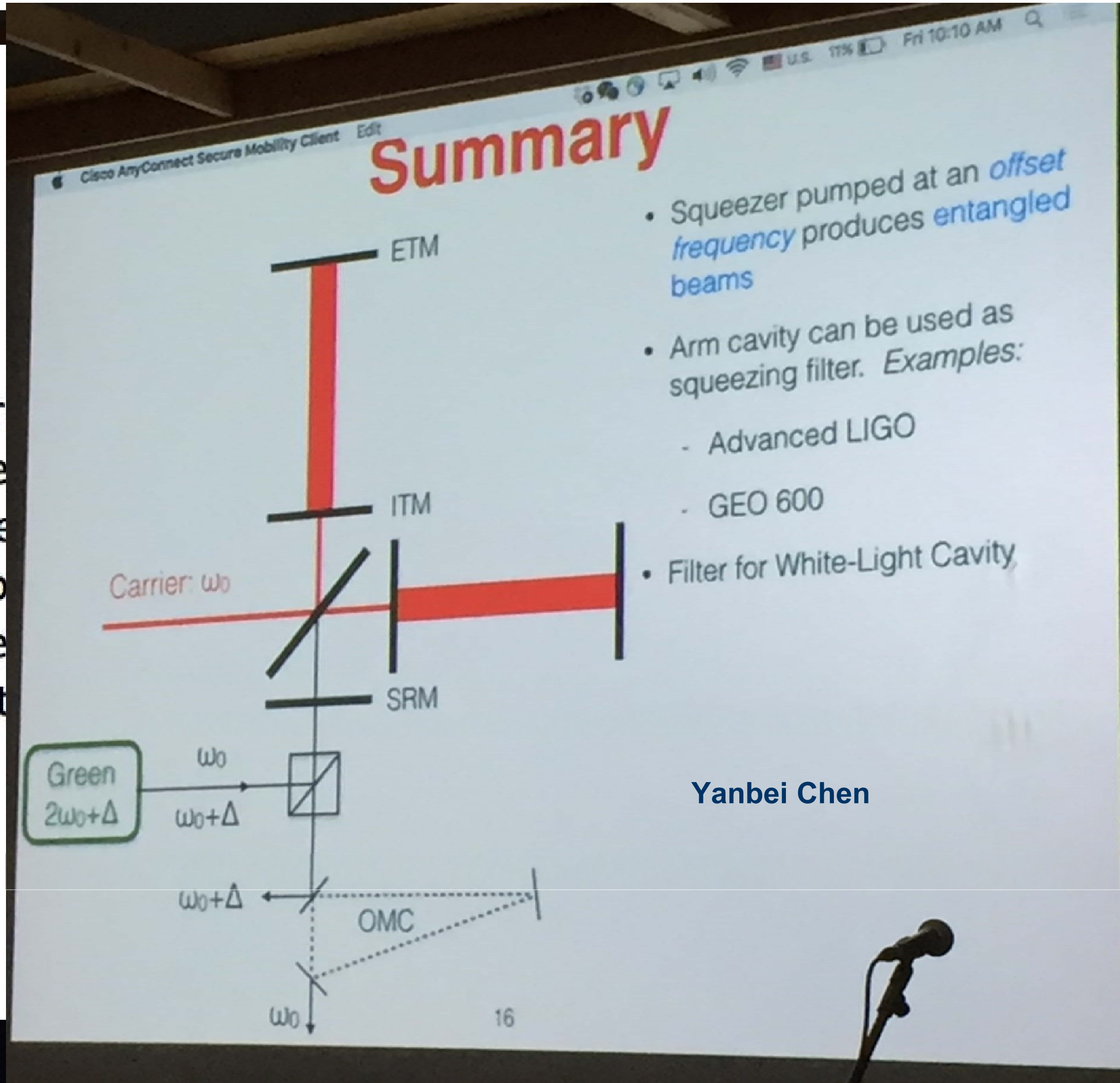

Yanbei Chen

IFO configurations & squeezing
(D. McClelland, H. Vahlbruch, A. Schoenbeck, Y. Chen, K. Somiya)

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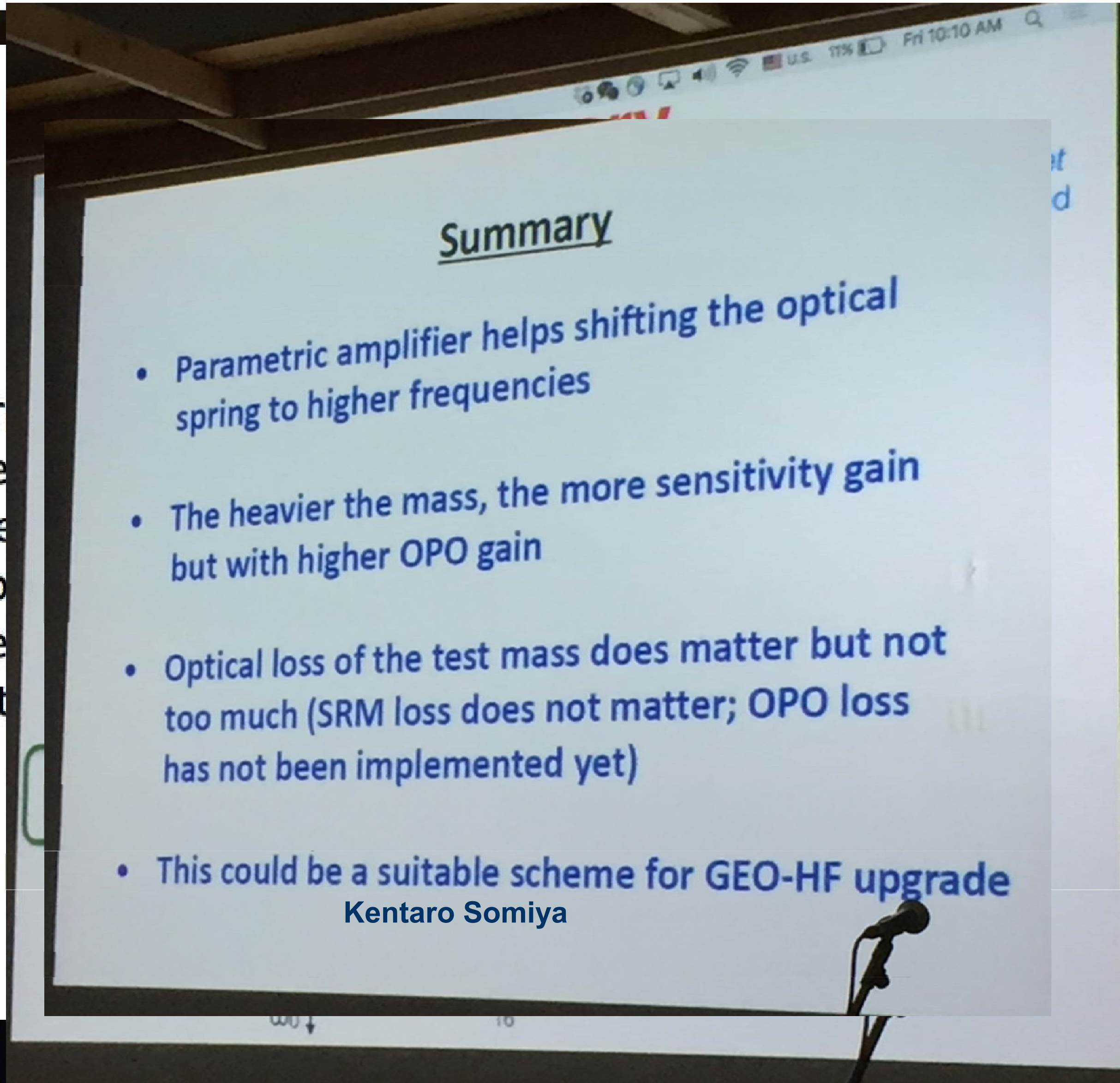
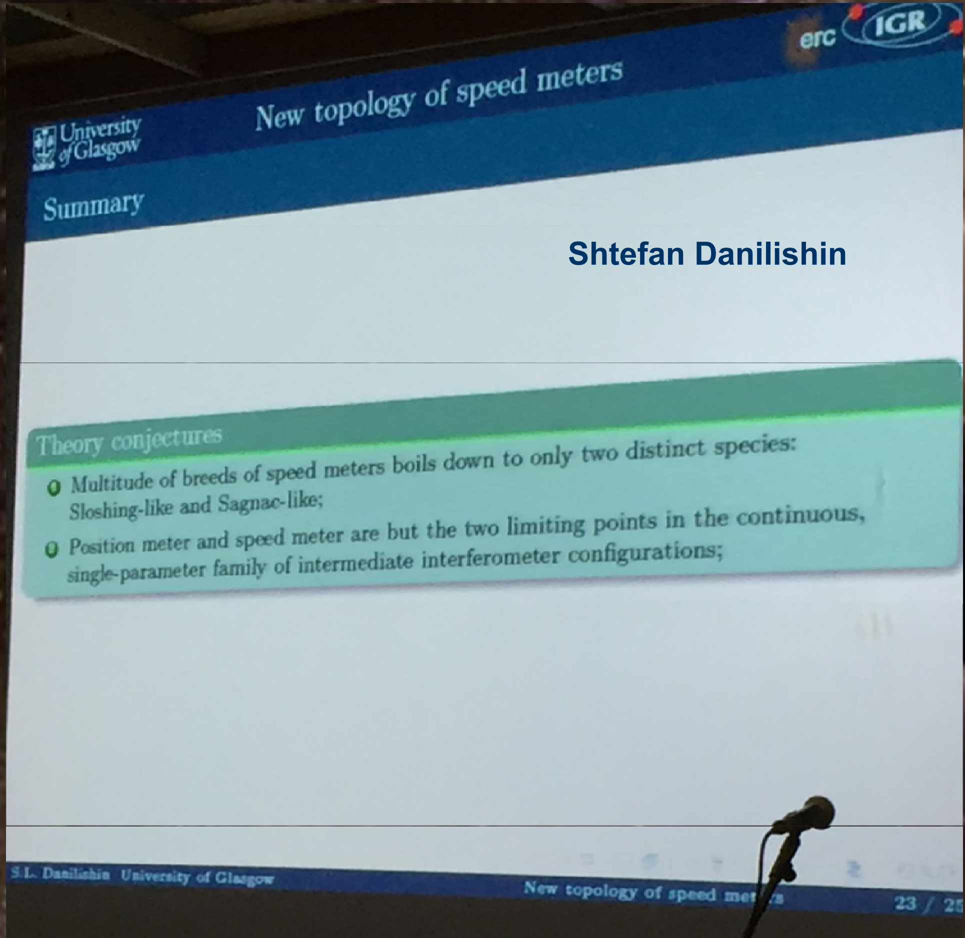
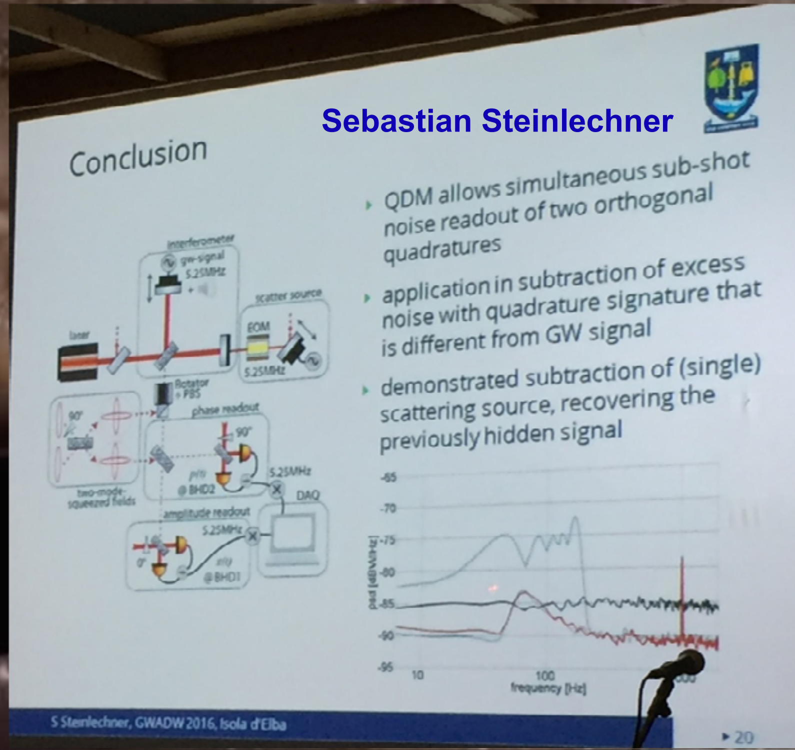


Kentaro Somiya

IFO configurations & squeezing
(S. Steinlechner, S. Danilishin, P. Bouyer)





Philippe Bouyer _ MIGA Project

- **Underground laboratory for atom interferometry ~ 300m scale atom interferometer**
- **Local environmental characterization radar/superconducting gravimeters/seismometer network/tiltmeters/pressure meters to understand ambient motions**
- **Goal: strain < 10^{-20} /Sqrt[Hz] @ 0.1 Hz**
- **Eventually deploy atom internferometers on longer baseline to suppress local gravity gradient noise ($\lambda_{GW} >> \lambda_{NN}$)**