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Advances and Challenges in Thermal Noise

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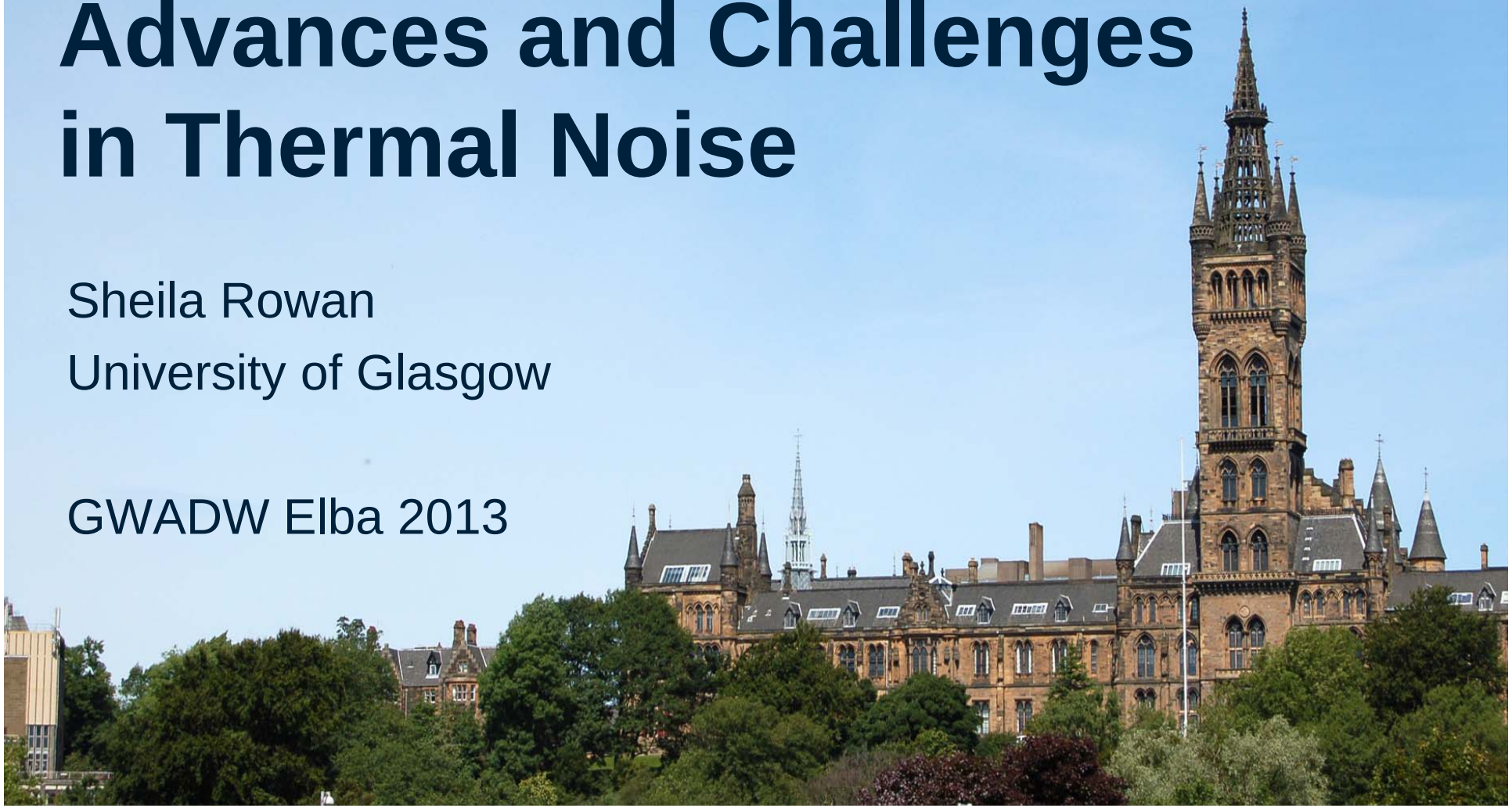
GWADW Elba 2013



Beyond Advanced detectors – what are the top level challenges?

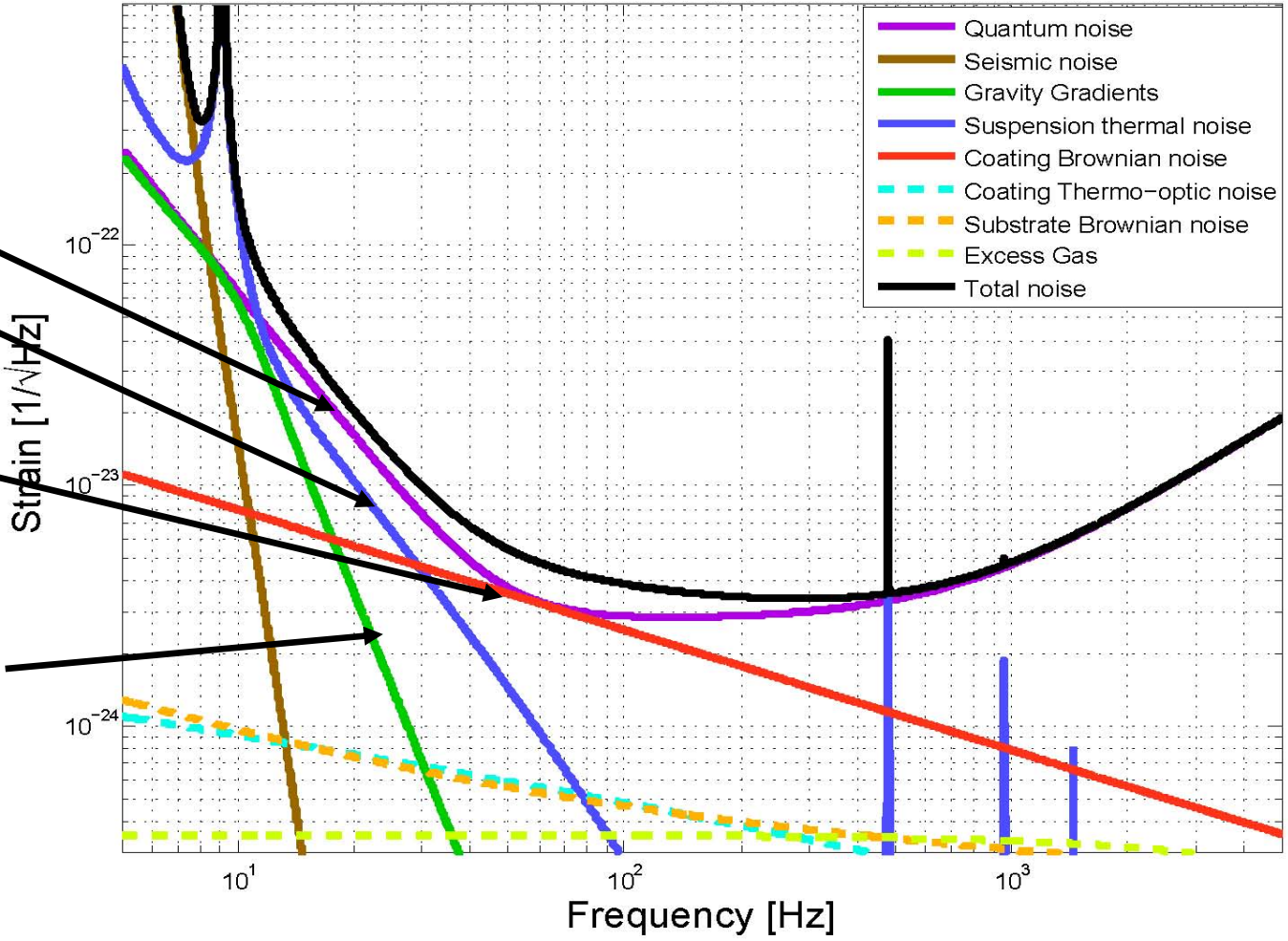
Pretty clear:

Quantum noise

Suspension thermal noise

Coating thermal noise (bulk thermal noise)

Gravity gradient noise



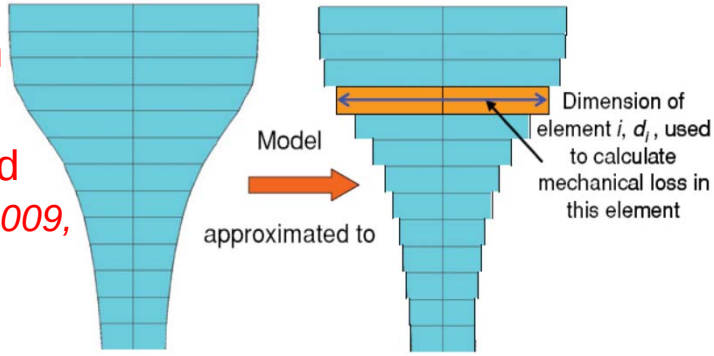
To get to that point what were the challenges..?

Fused silica quasi-monolithic suspensions

1. **Conceptual use based on empirical meas. of low loss/ 'small scale' demonstrations** ✓
   - *(Weiss (way back)...Braginsky 1994,1996, .. Rowan PLA1997a, PLA1997b, etc....Cagnoli PRL2000, Gretarsson PLA2000, Penn RSI2001, Willems PLA2002, Amico2002, Numata2002.. and many many more....)*

~2.8kg mass on 2 fibres

2. **Understanding the physics (There were 'unknown unknowns'...)** ✓
   - thermal noise from spatially inhomogeneous loss (*Levin PRD 1998*)
   - cancellation of thermo-elastic suspension noise in loaded fibres *(Cagnoli PRB2002*)
   - correct calculation of dilution *(Willems PLA2002*) and expected thermal noise with FEA, (*Cumming CQG2009, Cumming CQG2012,...)*



Proper design of the Advanced detector suspensions would not have been possible without these....

To get to that point what are/were the challenges..?

Silica quasi-monolithic suspensions

3. Construction challenges ✓

- **reliably making low loss/high strength silica-silica joints** (*Rowan PLA1998, Smith CQG2003, Sneddon CQG2003, Cunningham CQG2010 etc*)
- **fabricating silica fibres to the specifications required** *(Heptonstall 2011*, *Cumming 2012 etc etc*)
- **qualification of the resulting suspensions** (*Cumming 2012, Bell in prep,)*

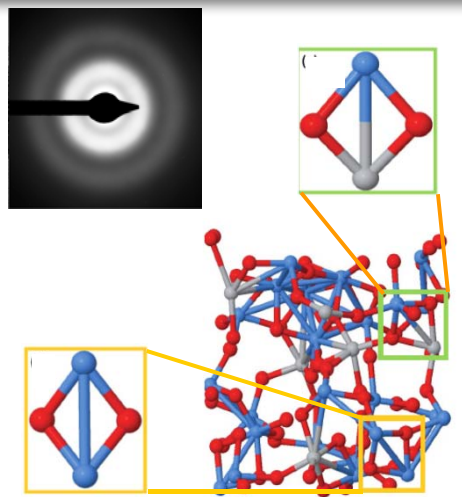
talk at this meeting by P. Puppo)

What are/were the challenges..?

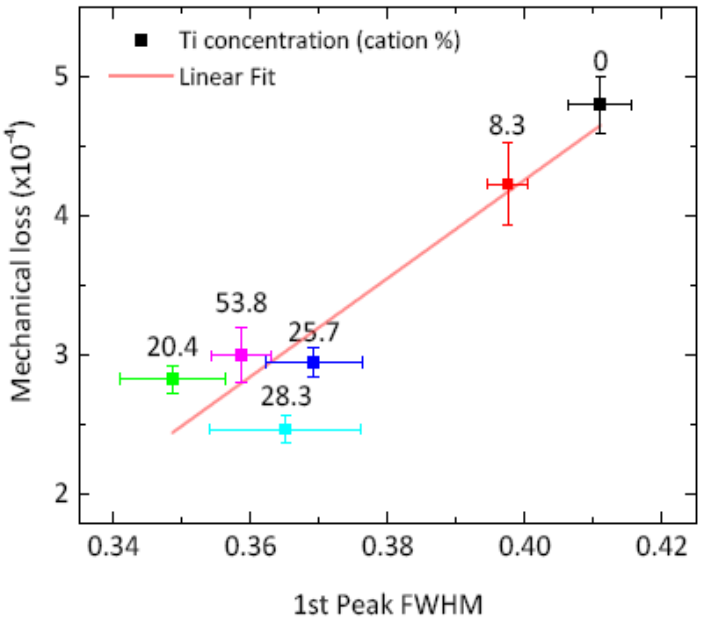
Coating thermal noise

1. Empirical measurements of magnitude of coating loss ✓
   - *Crooks/Harry/Penn/Martin/Yamamoto/Jena/LMA and others...*
2. Understanding the physics X
   - What causes the loss.... ? (*Bassiri, Hai Ping-Cheng, LMA et al,* ...)
   - What are the other relevant coating properties?, *Abernathy (in prep), Gretarsson (in prep)....*
   - Modelling of coating thermal noise *(Levin, Nakagawa, Harry, Evans, others..)*
   - *Still ongoing....*
3. Construction challenges..... ?
   - Ongoing in collaboration with LMA – Advanced detector coatings

Advances: See talk by R. Flaminio,



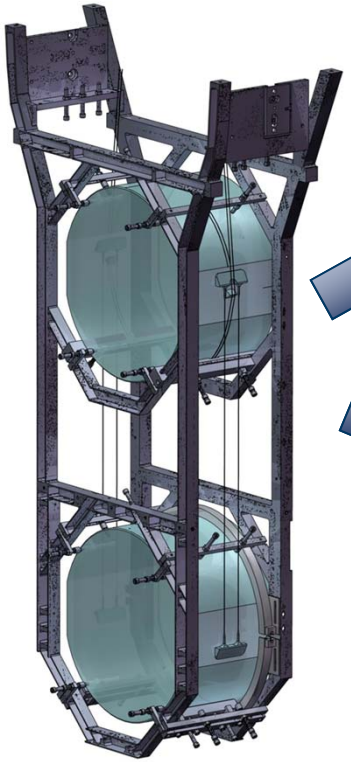
(See poster M. Hart)



Challenges for the next stage – and Advances?

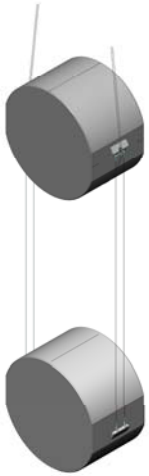
Silicon/sapphire

1. Conceptual use..... based on empirical measurements of mechanical loss/ demonstrations
2. Understanding the physics
3. Construction challenges



- Room T. upgrades to the Advanced detectors (160kg fused silica test masses)

- Cryogenic upgrades to advanced detectors/KAGRA/ ET

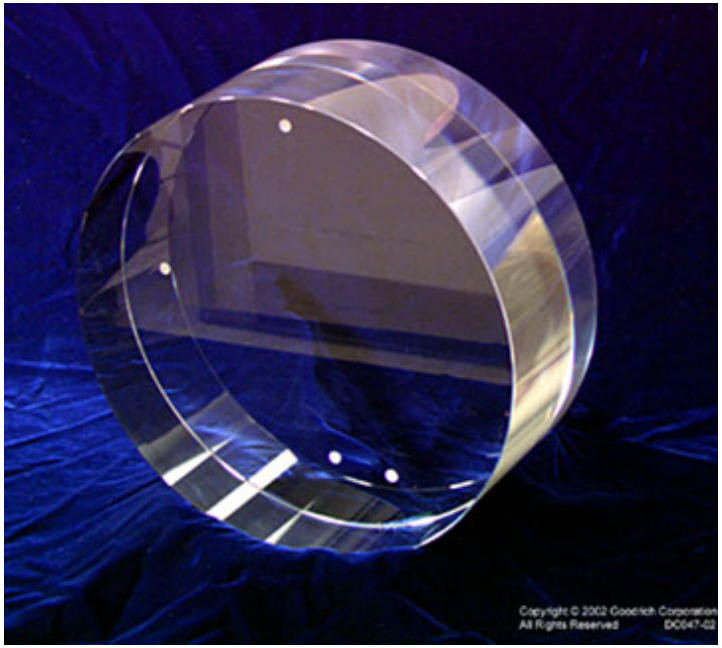


Challenges for the next stage – and Advances?

Sapphire

1. Conceptual use..... based on empirical measurements of mechanical loss/demonstrations
   - **Historical demonstrations of low loss by Braginsky et al**
   - **Many years of research in Japan (Eg: Uchiyama1998,1999 etc)**
   - **(Lot of R&D on the optical properties done at time of mirror materials downselect for aLIGO)**

   - **Challenge – ramp up to full size sapphire optics and engineered suspensions on the KAGRA timescale**
   - **Advances: KAGRA design: See talk by K. Yamamoto**



Sapphire piece used in the spot polishing compensation demonstration; 25cm diameter sample (photo courtesy Goodrich)

- **Work still needed - even on empirical loss measurements**

Challenges for the next stage – and Advances?

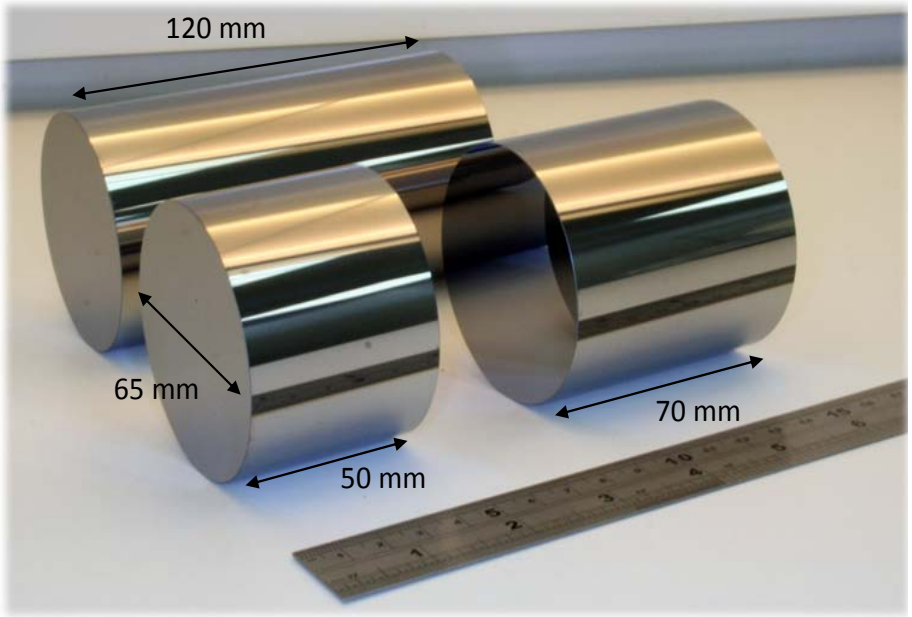
Silicon

We are about where we were for silica suspensions in 1994/8...

Challenge #1 – do it all faster this time !

1. Conceptual use..... based on empirical measurements of mechanical loss/demonstrations *(McGuigan, Winkler1991, Rowan2000, Rowan2003, Amico2004, Reid2006, Nawrodt2013, the ET design study, Red/Blue/Green team designs etc etc)*

- What kind of silicon do we need for the mirrors?..and suspension elements? (Czochralski???/Float zone –more pure but size limited..?)
- Why do different types of silicon have the loss they do ? crystal cut? impurities? combination of both..?
  - Work ongoing in Jena/Glasgow
  - **Advances: talk by G. Hoffman**



- **Work still needed - even on empirical loss measurements**

Challenges for the next stage – and Advances?

2. Understanding the physics...silicon/sapphire
   - Silicon: right now – at the stage of interacting with the basic loss measurements – making sure we can quantify and identify loss (effect of surfaces, doping, cut etc)
   - Moving to a new regime for both silicon and sapphire .....
     - **Challenges**: what about non-equilibrium thermal noise effects..?
     - **Advances : see talk from Claudia Lazzaro**

Challenges – what about Donald Rumsfeld??????
(...the unknown-unknowns...)?

Challenges for the next stage?

- Silicon /sapphire

  3. Construction challenges

  – Fibre shape – strength/thermal noise (cooling?) – what is the ‘right’ design in silicon/sapphire? (extra challenges over silica)
    - **Advances:** Silicon - **(see poster - G. Hammond)**
    - **Advances:** Sapphire - LOTS of work over last year under ‘Elites’ award linking ET/KAGRA research
    - **See talk by K. Yamamoto / poster G. Hoffman**

  – Fabricating suspension elements (can’t just weld.... – can etch, grow..?)
    - **Advances – sapphire – commercial ‘growers’**

    - **Challenges – quality? Strength? Reproducibility?**
    - **Challenges – silicon - how to make it**...?

Challenges for the next stage?

Silicon /sapphire

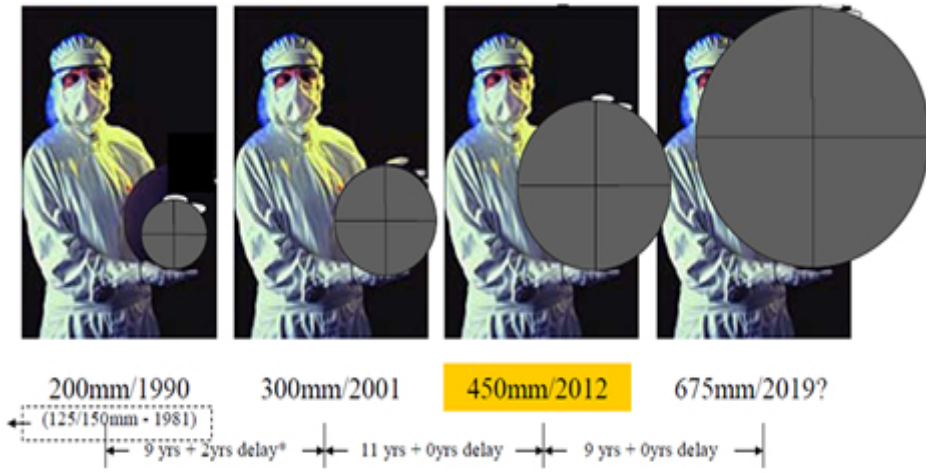
3. Construction challenges – more!

– Can we get big enough bits of the -right kind- of silicon/sapphire..?

- **Challenges -** Can we piggy back on commercial developments or not?

– Jointing crystalline materials

- **Challenges** - can't weld...can bond - Previous bonding results Dari 2010 - <10Mpa (room T)
- **Advances:** Silicon:(Beveridge 2013) – tailored jointing treatment – reliable at 77K
- **Advances: Sapphire: new cryogenic sapphire bonding results – poster R. Douglas**
- **Challenges – what will the loss and thermal noise be?**



Sapphire bonded samples which broke across the bond surface, but with damage to the bulk sapphire. Strengths 60-80MPa at 77K

Challenges for the next stage?

Coatings

1. Conceptual use..... based on empirical measurements of mechanical loss and ‘small scale’ demonstrations

- Amorphous coatings:
  - LOTS of ongoing cryogenic studies
  - **Challenge** – get good optical AND mechanical loss.....
- Crystalline coatings:
  - **Advances:** x3 improvement in thermal noise using AlGaAs?

  talk by G. Cole
  - **Advances**: equivalent improvement from AlGaP?

  talk by A. Lin
- Waveguide reflectors:
  - **Advances**: new formalism to better estimate expected thermal noise - also looks good for structured silicon.....

  talk by S. Kroker

Challenges for the next stage?

Coatings

2. Understanding the physics....

- Amorphous coatings – see earlier – work in progress
- Crystalline coatings
  - **Challenges: all experience suggests that small scale tests don't tell you everything you need.....**
  - **See talk by M. Abernathy** for the known unknowns, what about the **unknown unknowns**.....?
- Waveguides
  - **Challenges:** experimental demonstration of improved thermal noise performance .....
- Modelling – can we find a topology that is less sensitive to coating thermal noise? **Advances – talk S. Ballmer**

3. Construction challenges

- Amorphous – see advanced detectors + **challenge of new materials**...
- Crystalline coatings: **Challenge:** need reliably coated optics in large sizes (so far nothing has scaled up –exactly- the way we expected.....)
- Waveguides – **manufacturing challenges:** (what will drive the improvements we want in this ? (so far nothing has scaled up –exactly- the way we expected.....)

Challenges for the next stage?

- Two possible outcomes from this talk

Or