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LSC

Reducing coating thermal noise through atomic structure investigations

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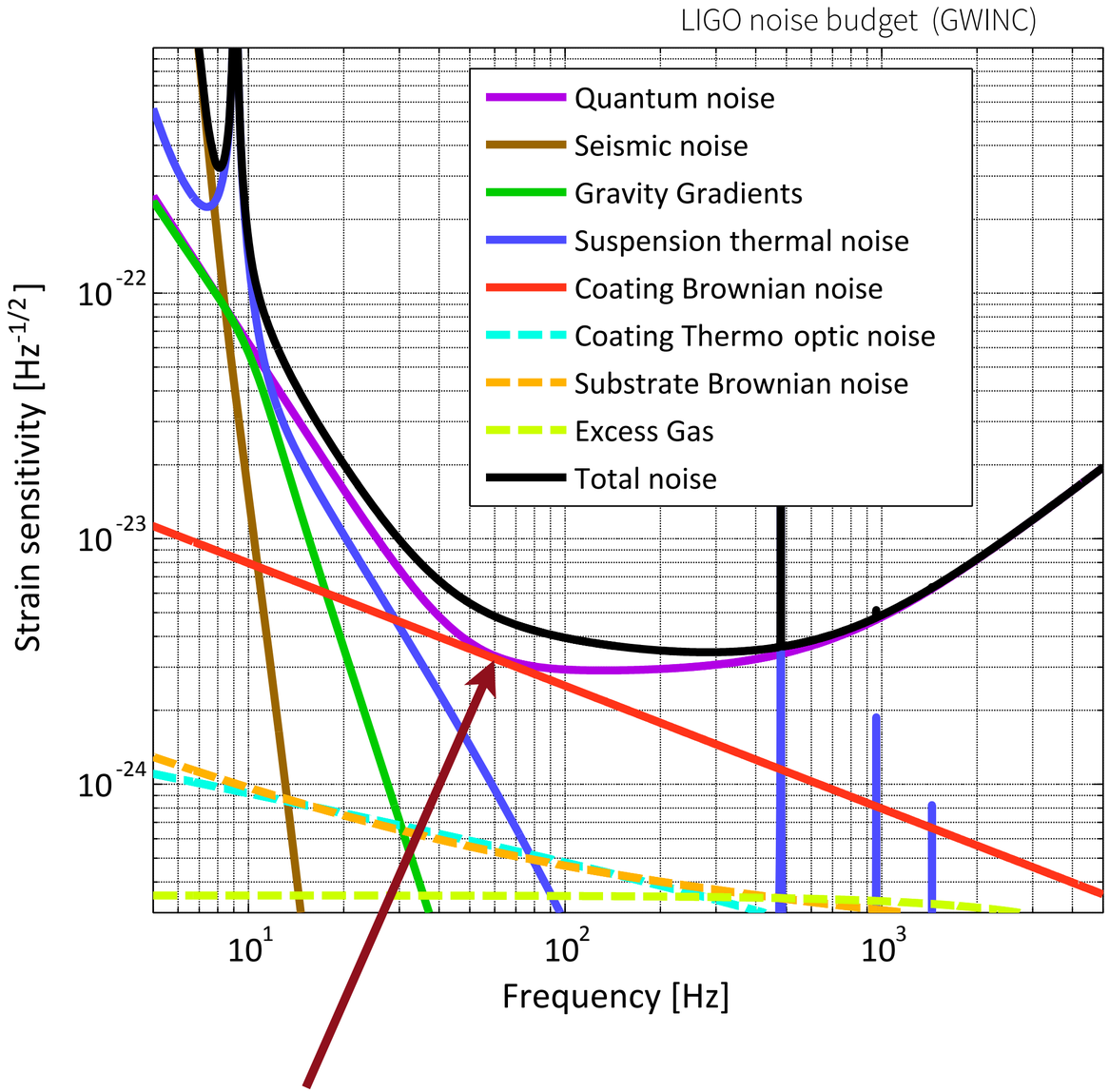
Introduction

- Enable gravitational wave astronomy
  - Mitigate noise sources that limit sensitivity
- Ensure and enhance the success of Advanced LIGO (aLIGO)
- Develop technologies for future generation detectors



Reduce coating Brownian thermal noise

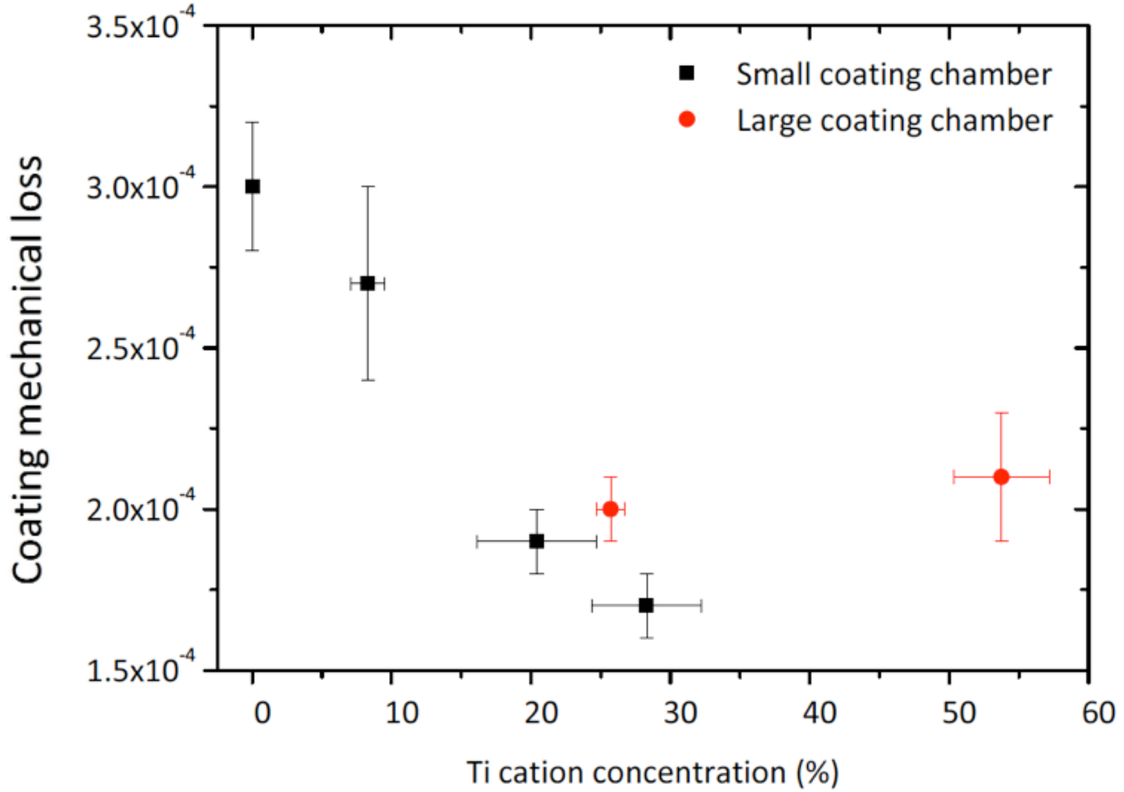
Introduction

- aLIGO mirrors are dielectric stacks of ion beam sputtered (IBS) silica and titania doped tantala
- Thermal noise related to mechanical loss through:

temperature coating thickness

$$S_x(f,T) \approx \frac{2k_BT}{\pi^2 f}\frac{d}{w^2 Y}\phi\left(\frac{Y'}{Y}+\frac{Y}{Y'}\right)$$

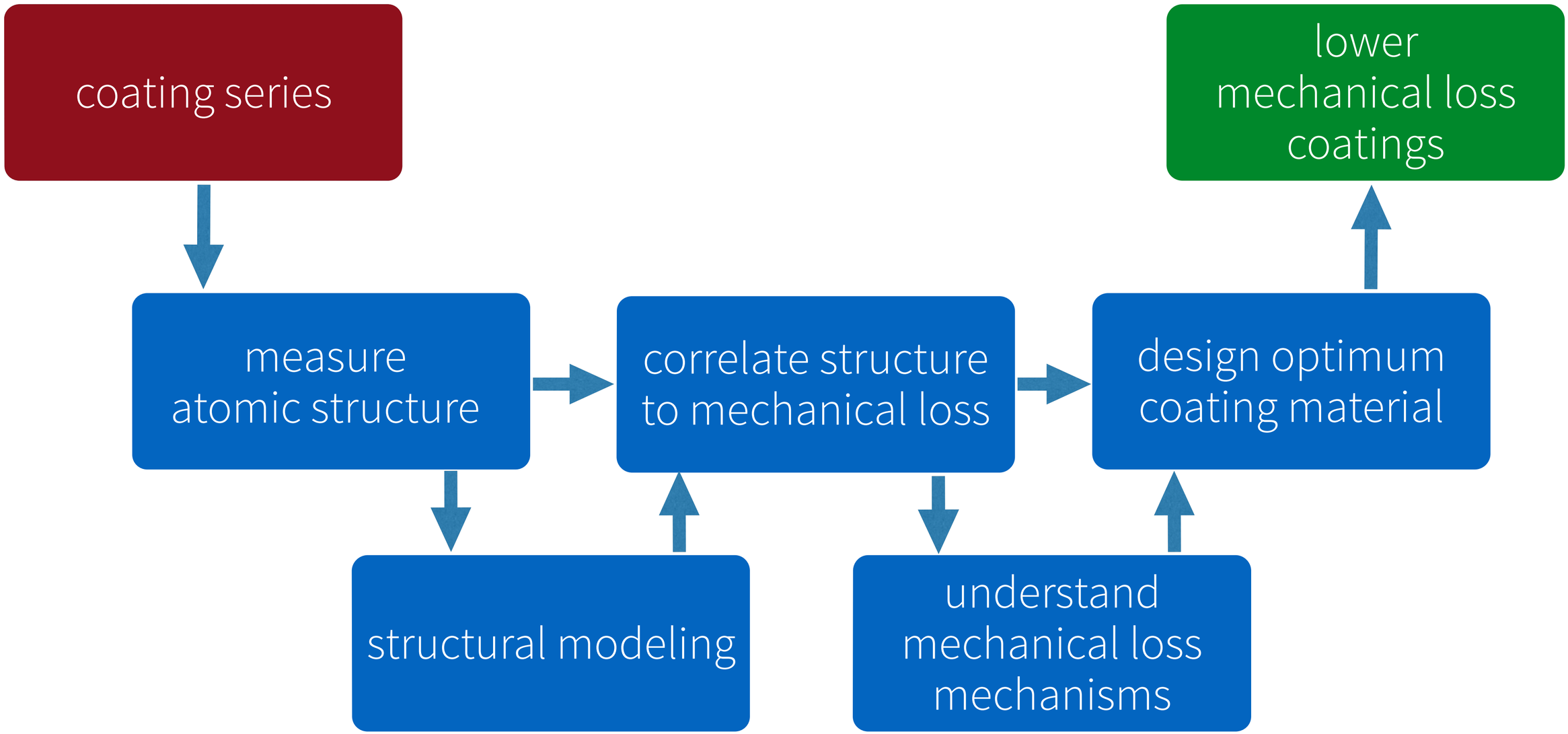
laser beam radius coating mechanical loss



[G M Harry et al, Class. Quant. Grav. **24** 405, 2007]

- Tantala is the highest source of mechanical loss
  - Reduced by 40% through titania doping
- **Changes in mechanical loss are the result of changes in atomic structure**

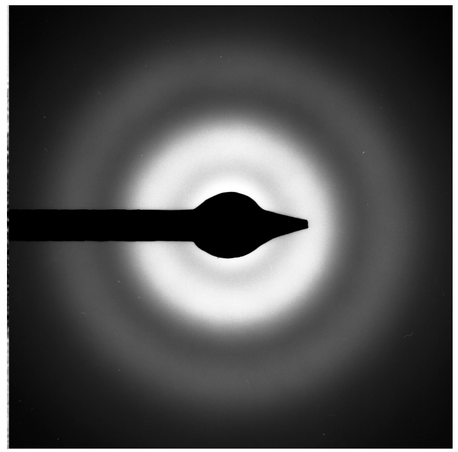
Research Approach

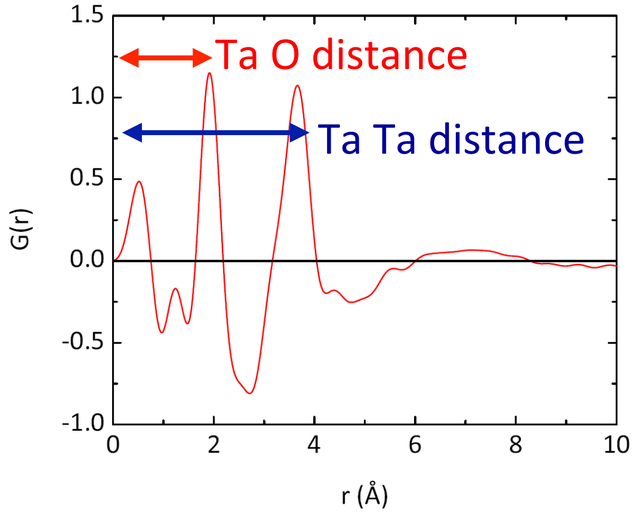


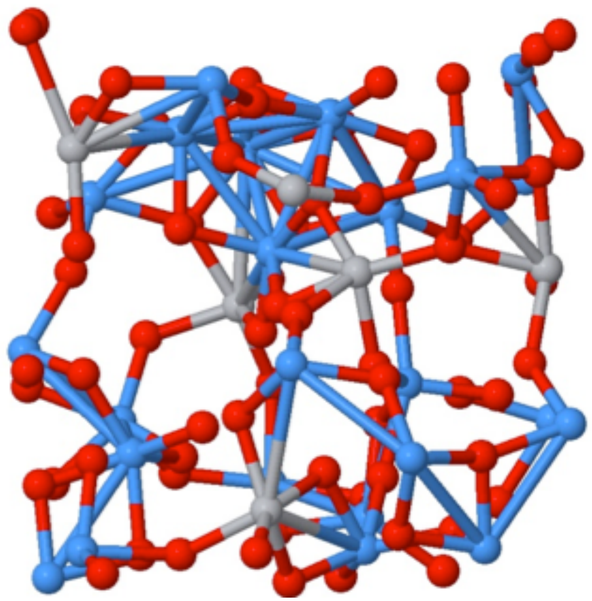
R. Bassiri et.al, Appl. Phys. Lett. **98**, 031904 (2011)
R Bassiri et al, Acta Mat. **61**, 1070–1077 (2013)

Atomic structure

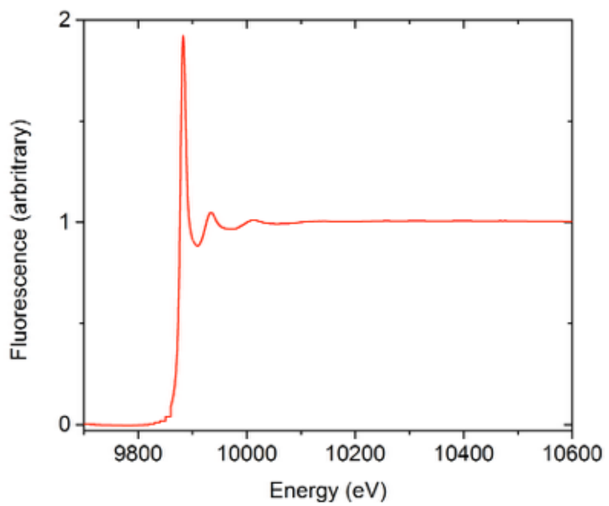
- Main experimental tools for measuring the atomic structure:
  - Pair Distribution Function (PDF), G(r), electron or X-ray diffraction

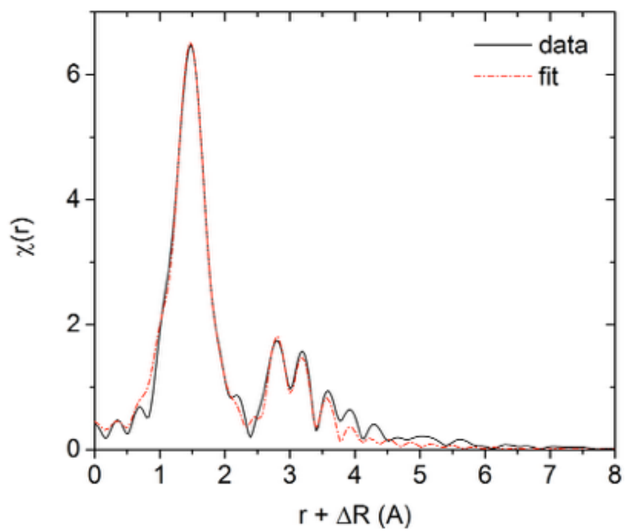






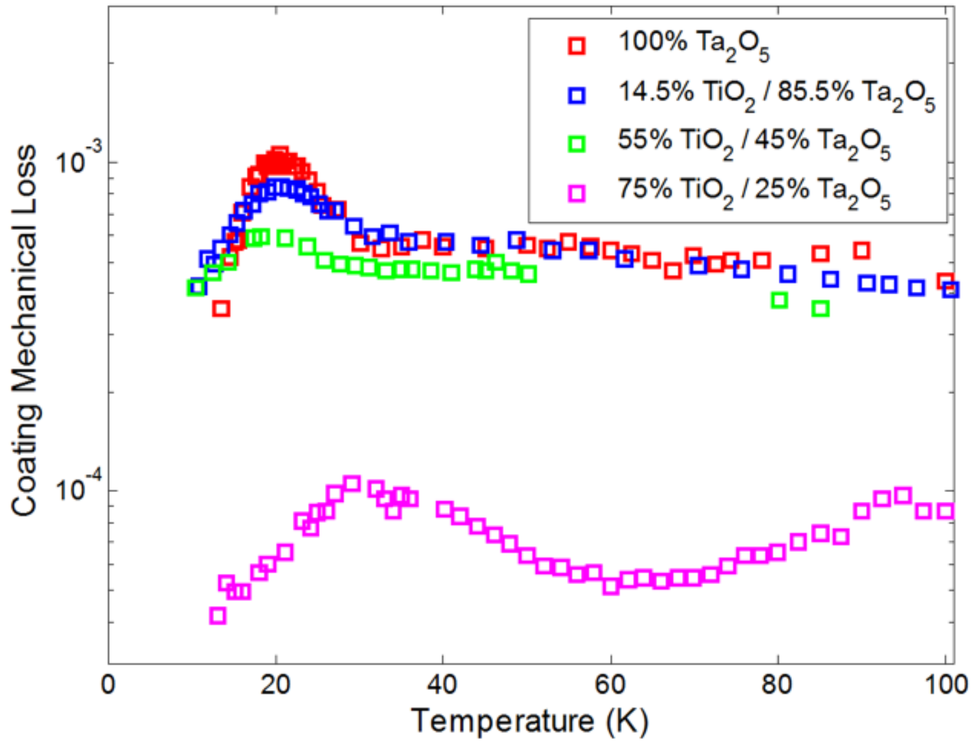
  - Extended X-ray Absorption Fine Structure (EXAFS), Ta L_{III} edge



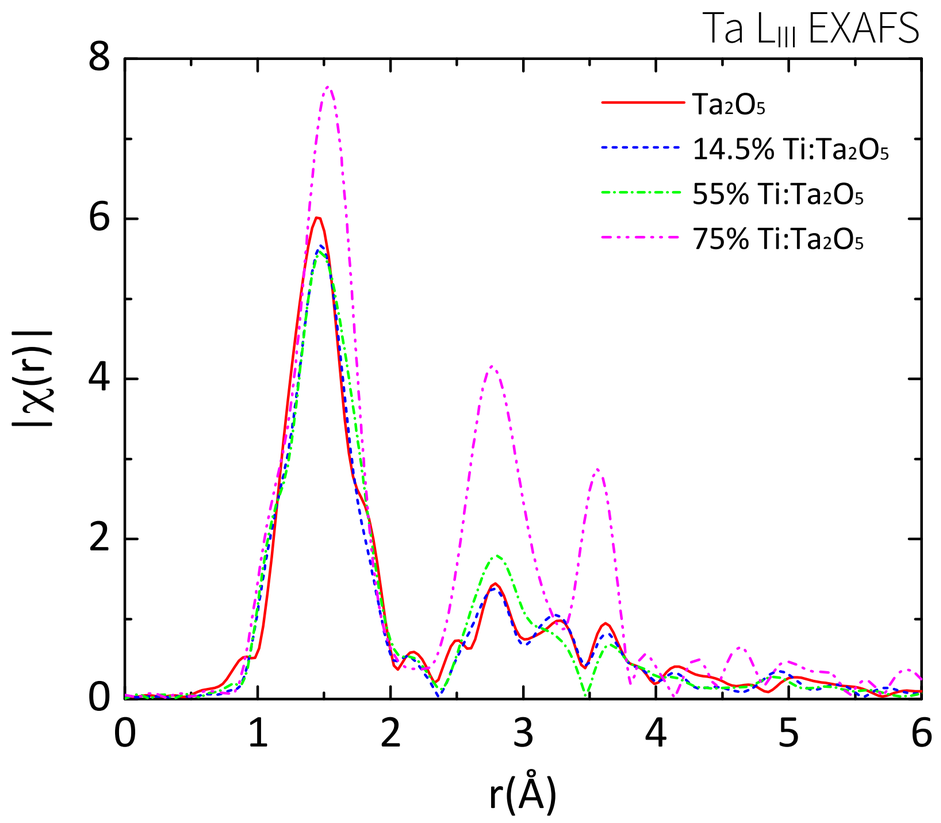


Atomic structure

- Titania doped tantala



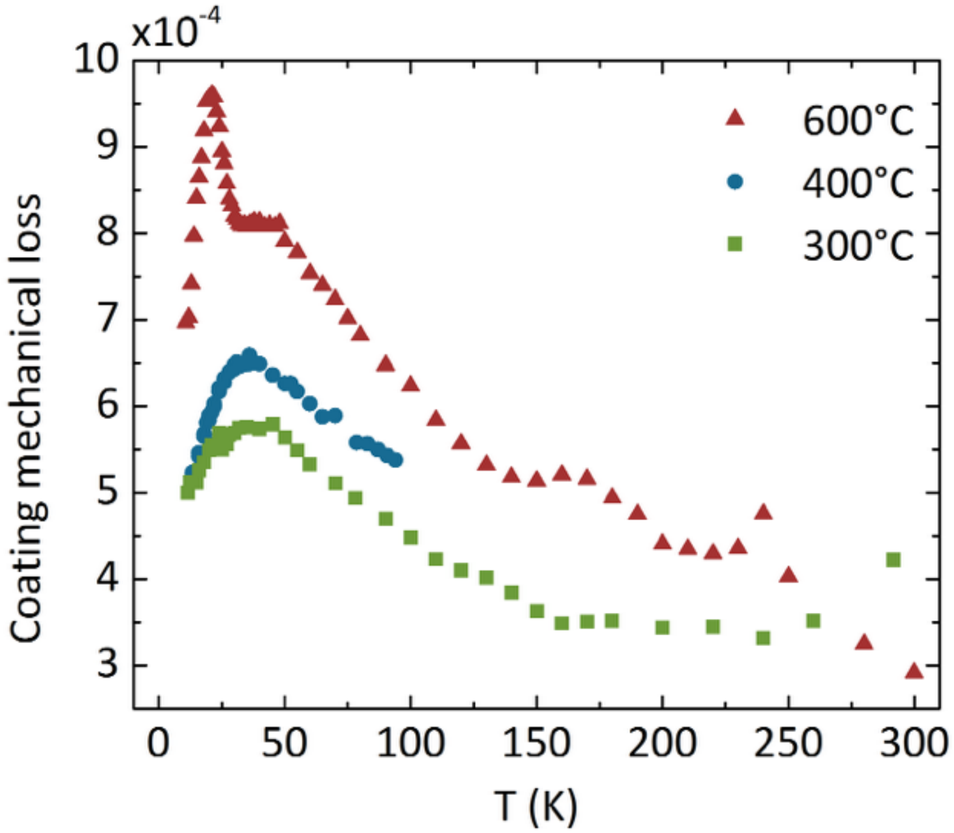
[P. Murray et al, Glasgow]

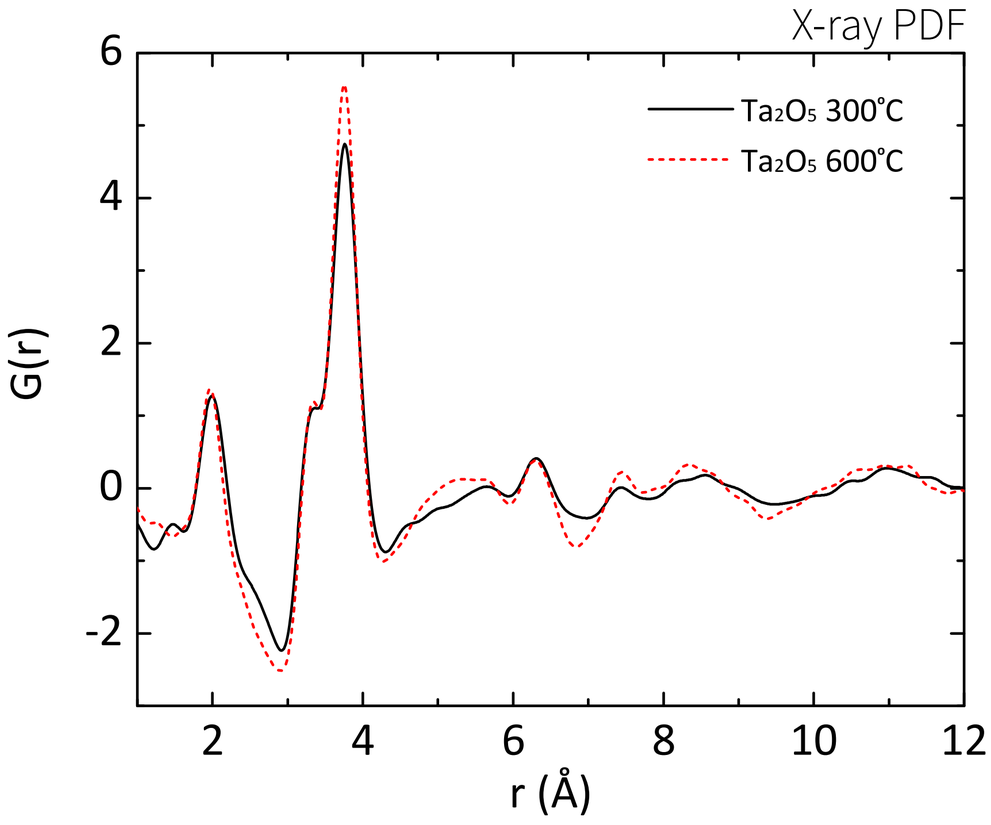


- Increasing Ti-doping suppresses the low temperature loss peak
  - 75% Ti-doping shows large reduction of loss
- Large differences in structure occur above 2 Å
  - Metal-metal and metal-oxygen distance suppression with higher doping

Atomic structure

- Heat-treated tantala

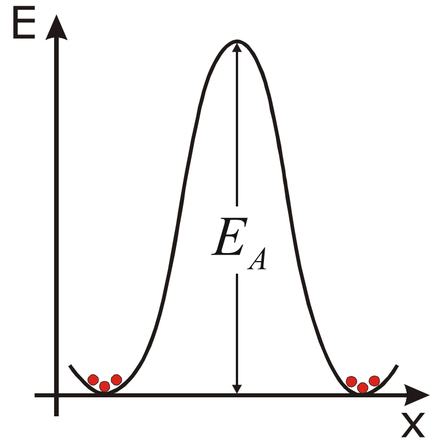




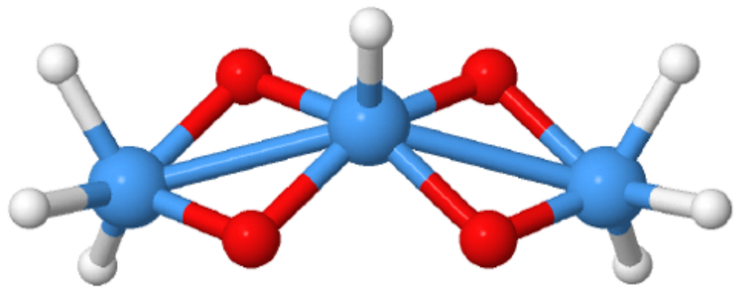
- Heat-treatment results in low temperature loss peaks [I W Martin et al, Class. Quant. Grav. 27 225020, 2010]
- Main differences in structure occur above 2 Å
  - First X-ray PDF measurements show changes in structure in short and medium range

Atomic structure

- Mechanical loss mechanism
  - Double-well potential
    - Activation energy gives a range of possible movements
    - Changes with heat-treatment and doping
  - Bad actors acting as loss centers
    - Nano-crystalline structures in the medium range
    - Defects over a longer range
    - Ordering of metal-metal and > 2 Å metal-oxygen distances may be key to identifying further correlations with loss



- What can change/improve IBS coatings?
  - Heat-treatment, doping
  - Oxygen partial pressure
  - Heat-treatment environments
  - Multi component systems

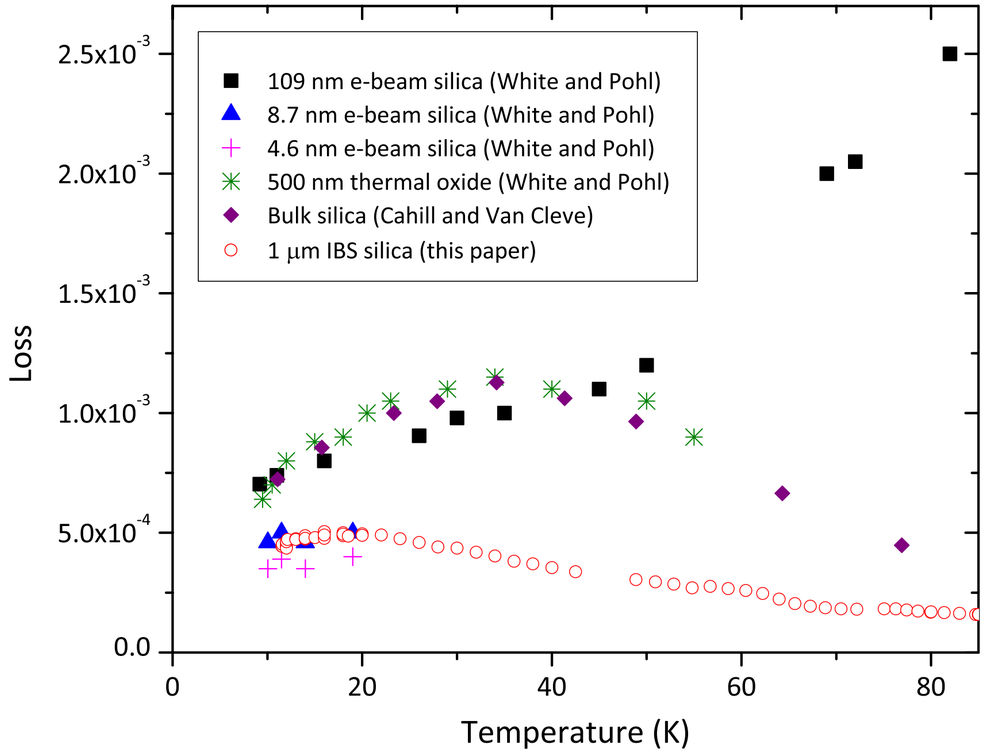


Future work

- Continuing atomic structure investigations
  - Atomic modeling based on X-ray, TEM data
  - Focus on mechanical loss correlations

- Depth dependent measurements
  - Depth dependent structure on coatings
  - Include studies of silica - understand silica coating vs. surface vs. bulk

- Development of materials-by-design approach
  - Model effect of different dopants on structure, correlate with loss based on Ti-doping model



[I W Martin et al, Class. Quant. Grav. **31** 035019, 2014]

Conclusions

- Targeted approach: coating atomic structure vs. mechanical loss

- Tantala coating atomic structure
  - Both heat-treatment and Ti-doping show larger differences in the atomic structure beyond the first nearest neighbor
  - Possible further correlation to mechanical loss

- Results will target studies to probe mechanical loss mechanisms

- Atomic structure investigations provide:
  - Capability for materials-by-design approach
  - **Key route to understanding and mitigating mechanical loss, to lower coating thermal noise**

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