Update on sapphire growth in Lyon

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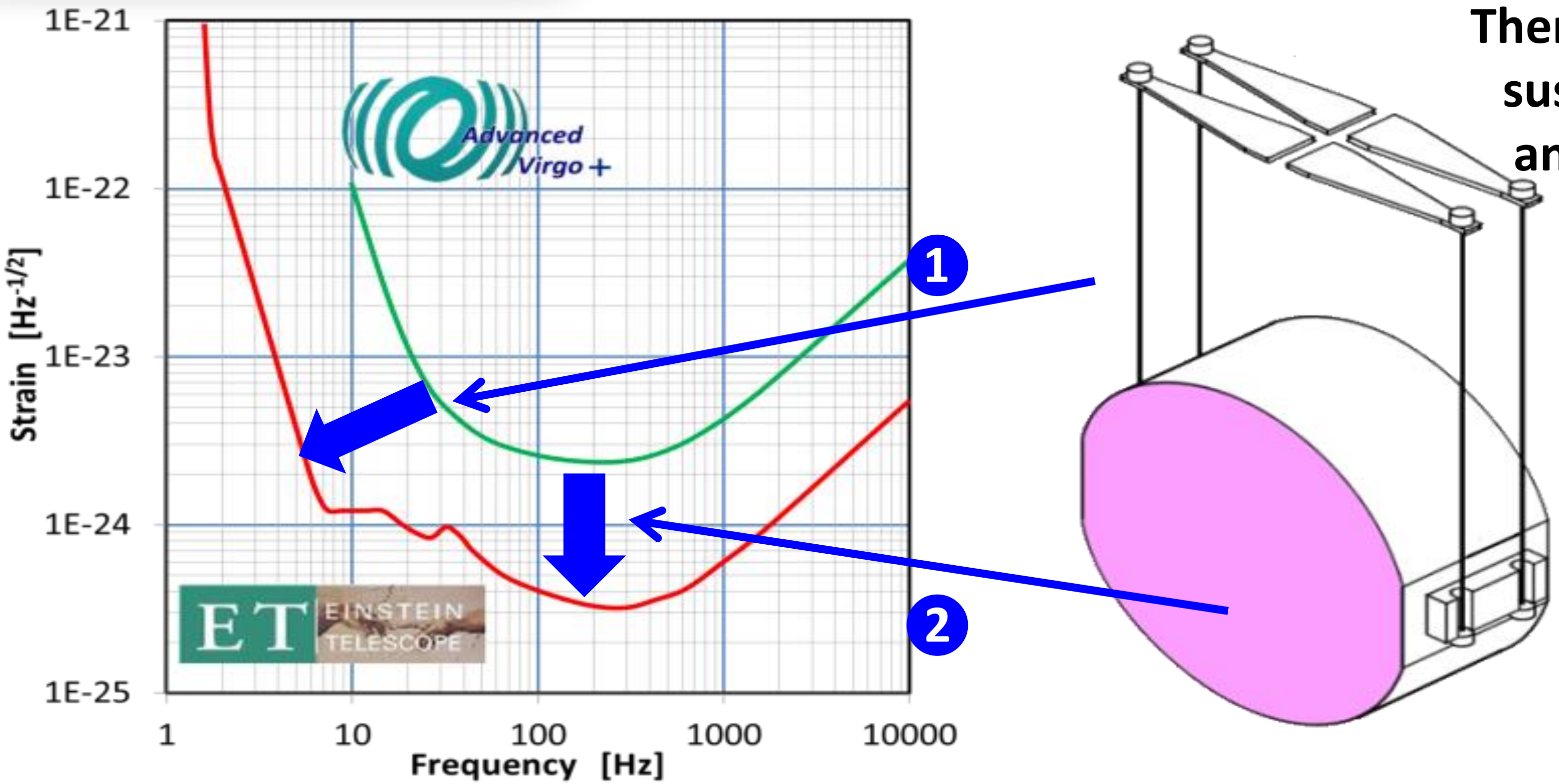
Presentation Outline

- Mirror substrates for ET-LF
- Sappire and silicon comparison
- Sapphire crystal samples
- 1064 nm absorption coefficient measurements
- Birefringence measurements
- OSAG
- Conclusion

Mirror substrates for ET-LF



Thermal noise on suspensions ① and mirrors ② limits the detection of GW

To reduce thermal noise and increase sensitivity, ET-LF will run at cryogenic temperatures. As Silica is not a possible candidate at these temperatures, we need to find other substrates.

Mirror substrates for ET-LF

Suitable candidates must present a number of properties at cryogenic temperatures :

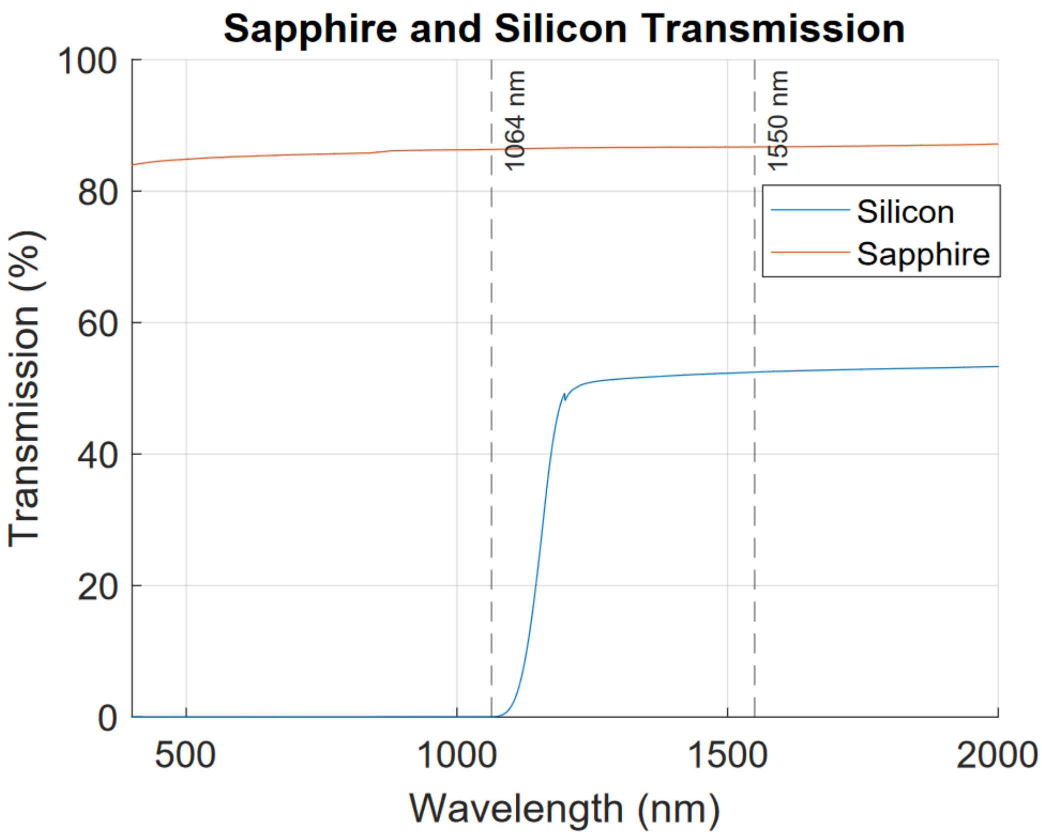
- Good mechanical quality
- High thermal conductivity
- Low thermal expansion
- Very low absorption at the laser wavelength
- The ability to manufacture and produce large samples (200kg for ET)

Two possible candidates are investigated:

- Sapphire (α-Al_2O_3)
- Crystalline silicon

Transparency window

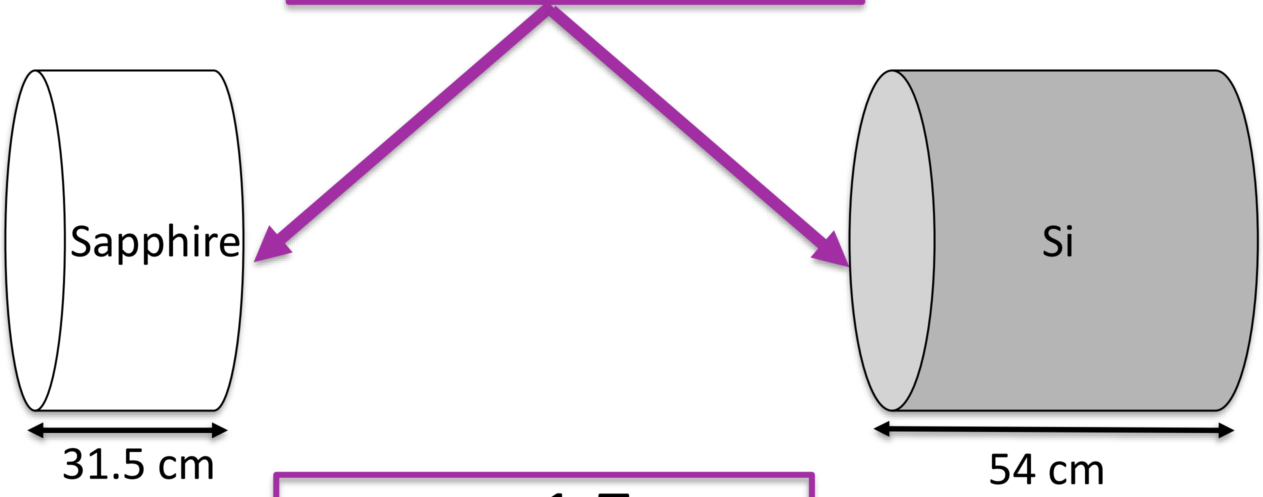
- Sapphire is transparent at 1064, 1550 and 2000 nm
- Silicon isn't transparent at 1064 nm → must develop new laser and detector technologies



Optical Absorption

Mirror substrate dimensions :

Mass of 200 kg
Diameter of 45 cm



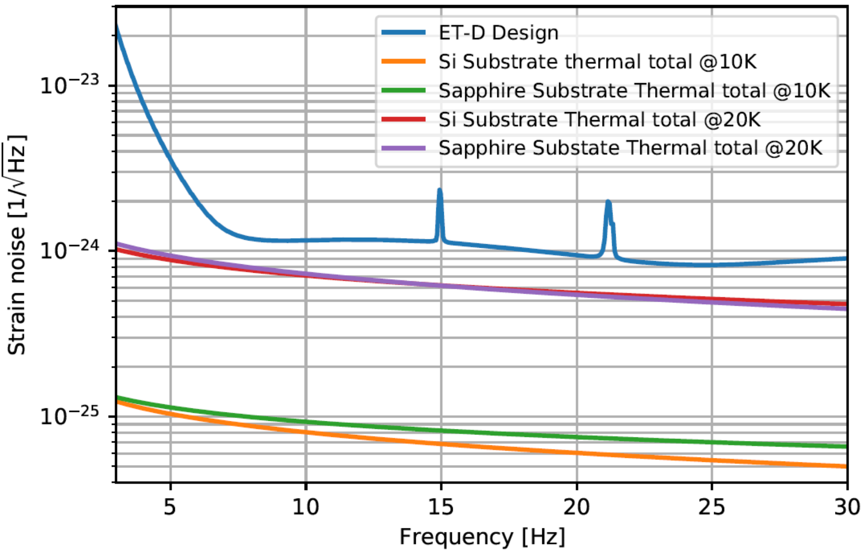
$$\alpha_{saph} = 1.7\alpha_{Si}$$

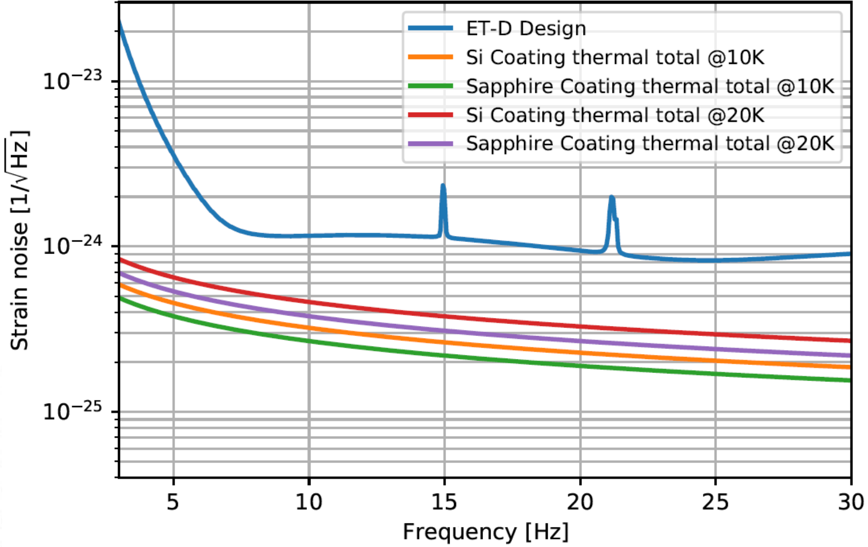
For a heat absorption of 0.1 W :

$\alpha_{Si} = 29.4$ ppm/cm

$\alpha_{saph} = 50.5$ ppm/cm

Thermal strain noise simulations


Substrate thermal noise


Coating thermal noise

Simulations using the ET noise budget package with a 1550 nm laser

Substrate thermal noise contributions :

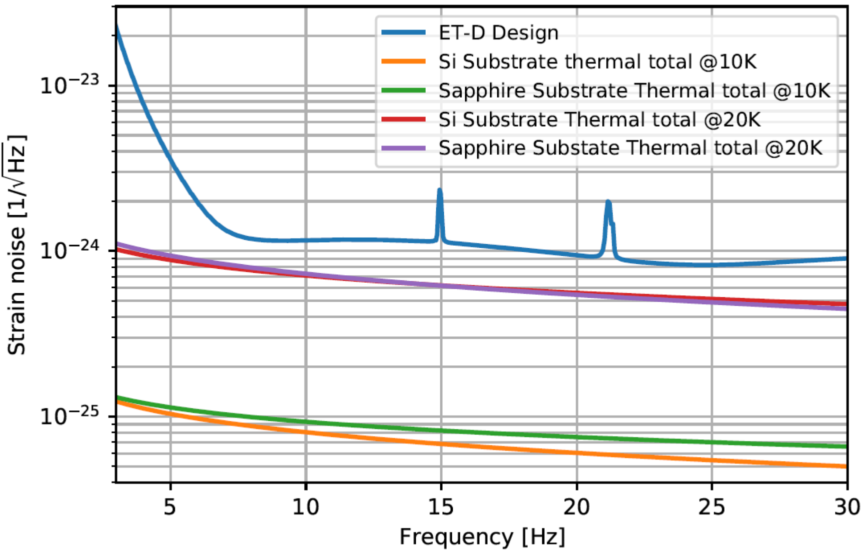
- Substrate brownian
- Substrate thermo-elastic
- Substrate thermo-refractive

Coating thermal noise contributions :

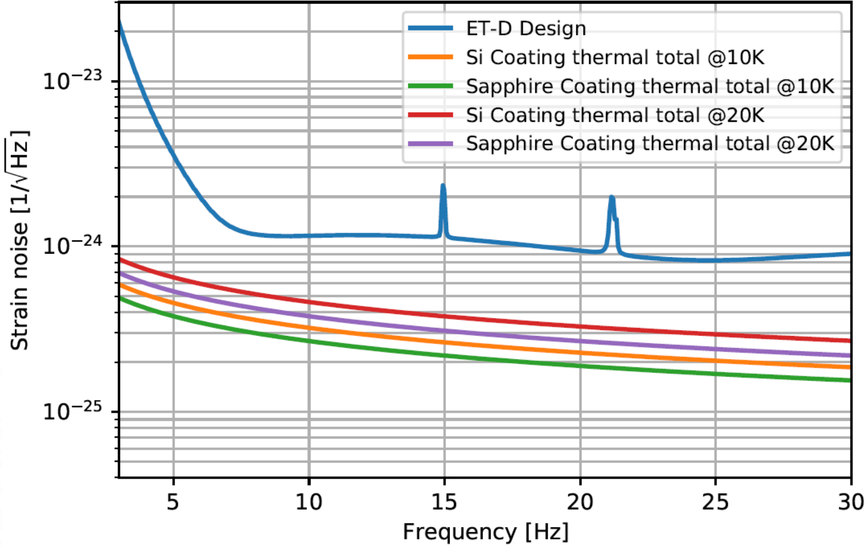
- Coating brownian
- Coating thermo-optic

Thermal strain noise simulations

Substrate thermal noise

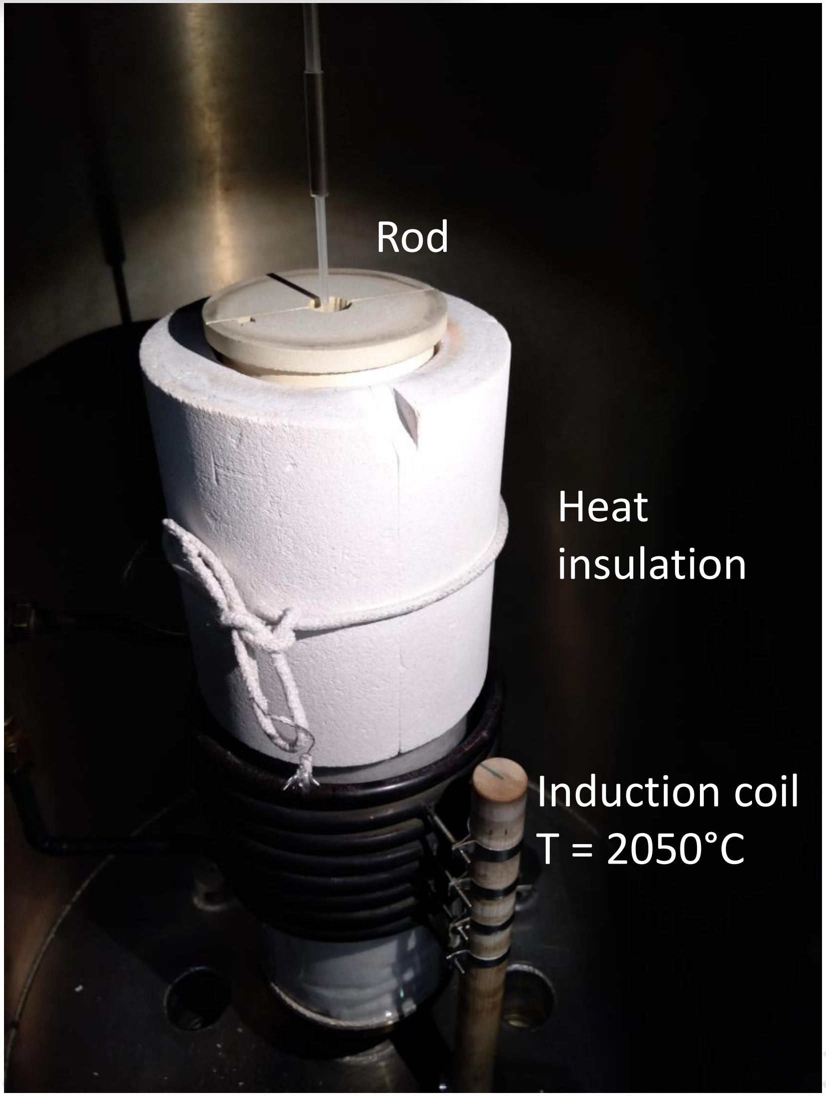


Coating thermal noise



- Running at 10 K will lead to much lower thermal noise levels
- Coating thermal noise is dependent on the substrate material (and inversely proportional to the Young's modulus)
- Substrate thermal noise is dominant at 20 K
- Coating thermal noise is dominant at 10 K
- Sapphire substrates display a lower noise total noise at both temperatures

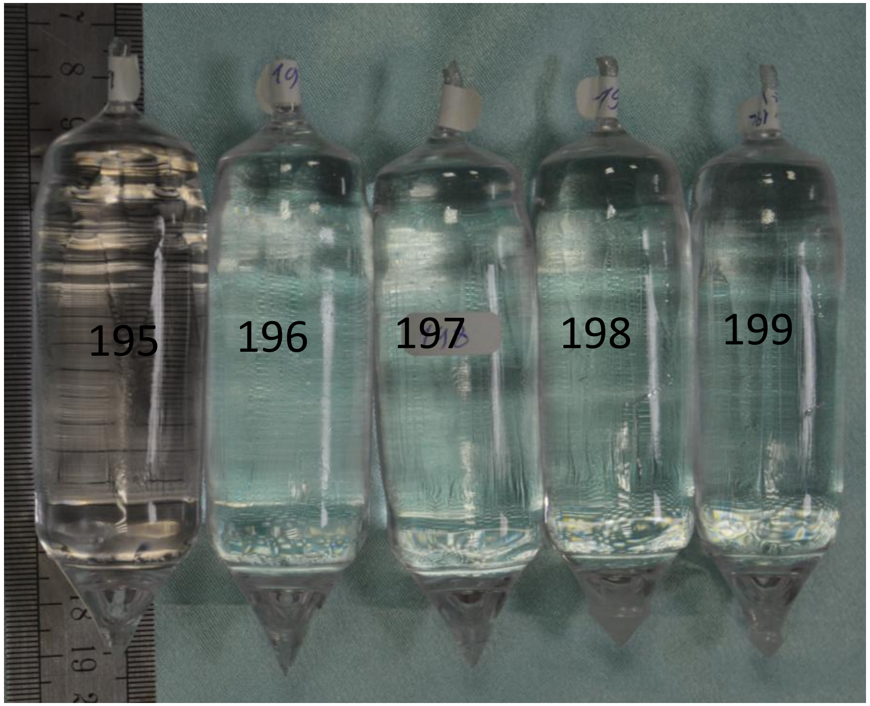
Sapphire Czochrlaski Growth



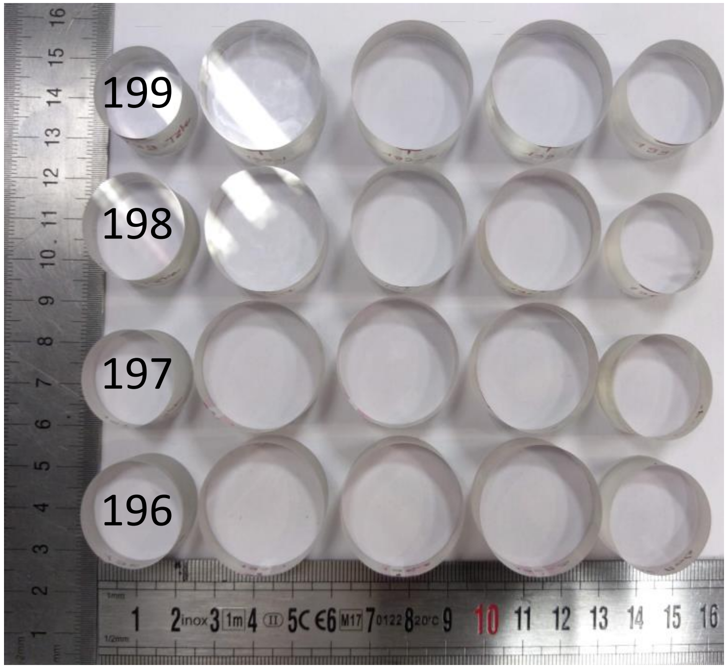
Sapphire Czochrlaski Growth

The crystals are cut into 15 mm thick samples and polished on both sides.

Four growth parameters were varied : v_{rot}, v_{pull}, $v_{crucible}$ and seed orientation



Sapphire crystals as-grown



15 mm thick samples cut and polished

1064 nm absorption coefficient measurement

PDS – Photothermal deflection spectroscopy and detection

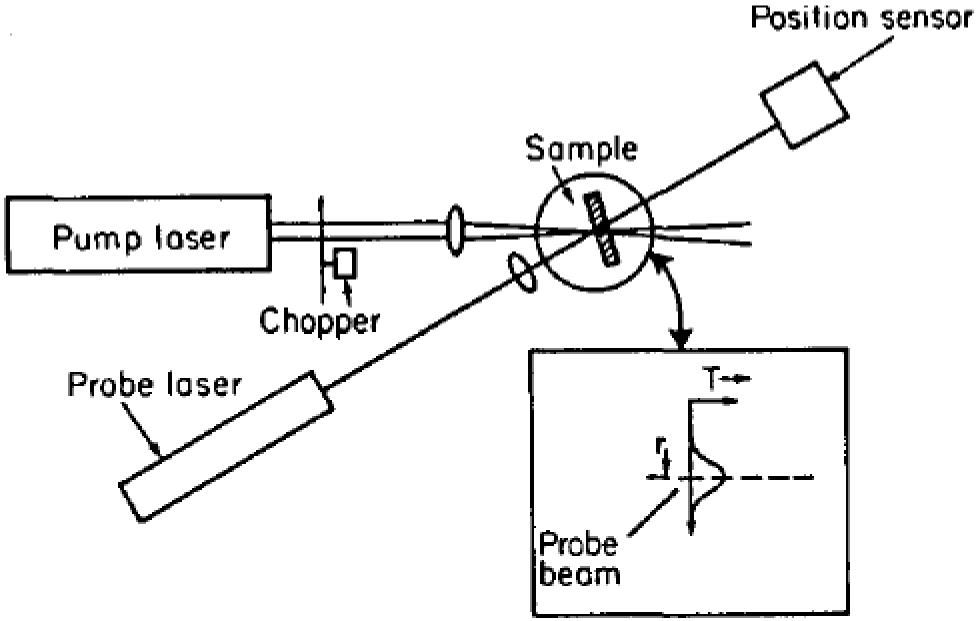
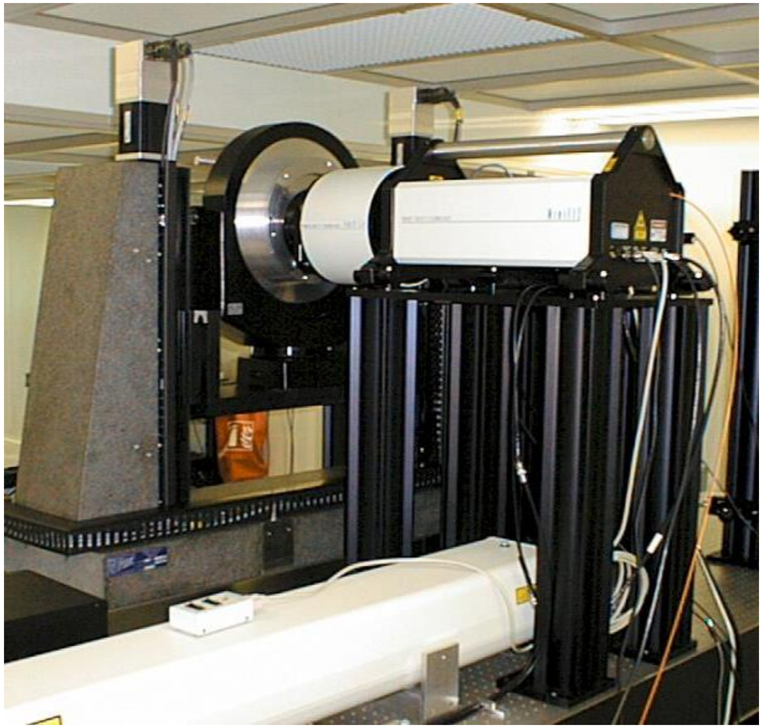


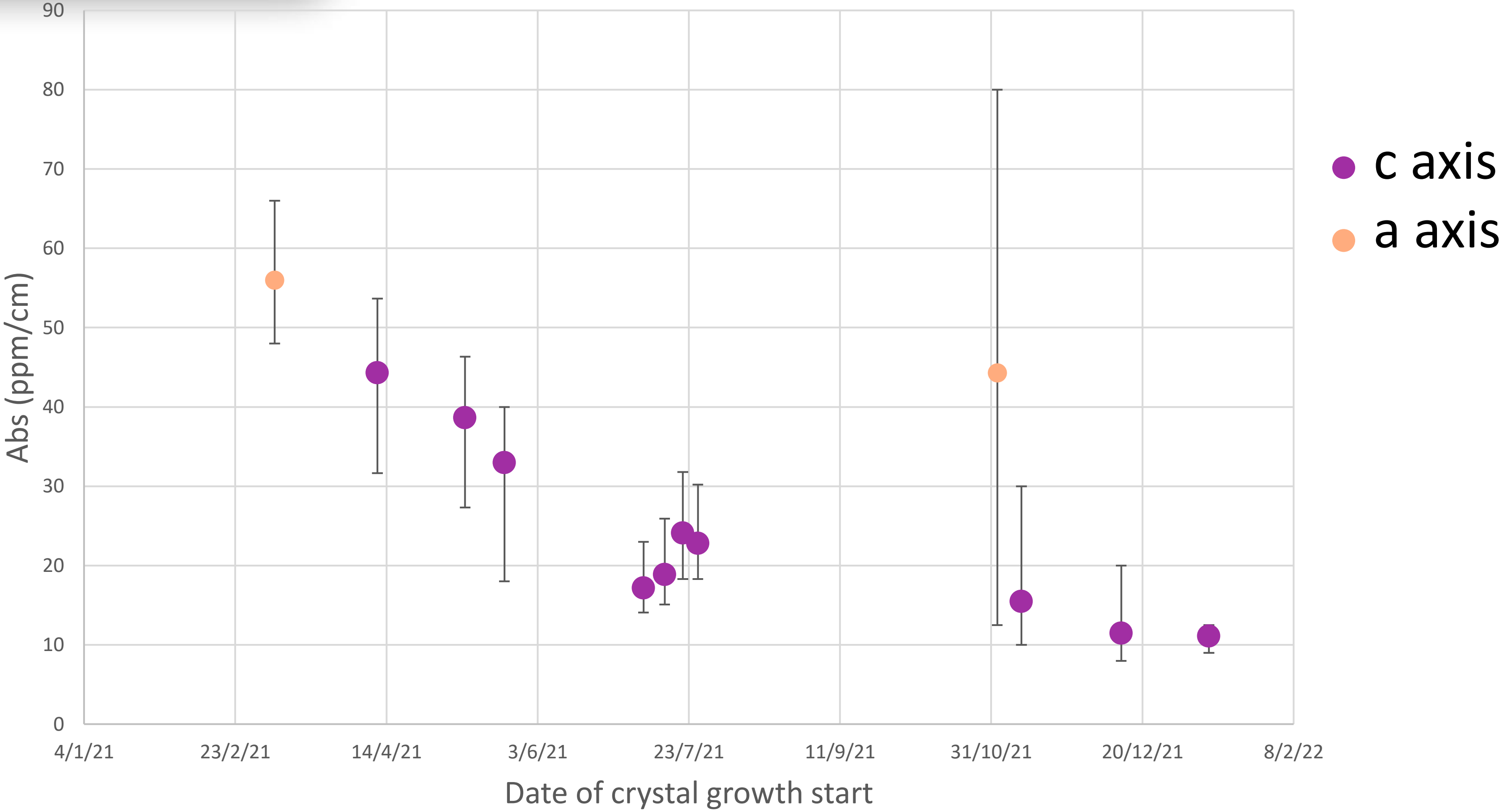
Diagram of a collinear PDS experimental apparatus



Absorption Bench at 1064 nm (LMA)

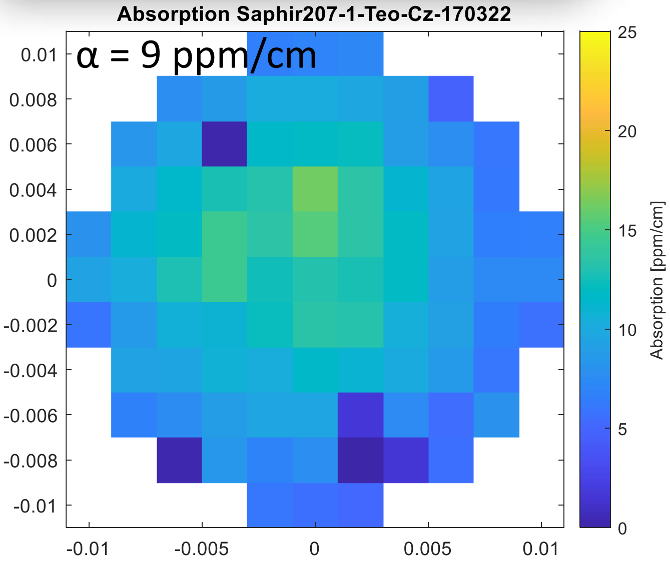
Jackson, W. B., Amer, N. M., Boccara, A. C. & Fournier, D. Photothermal deflection spectroscopy and detection. Applied Optics 20;8 (1981).

1064 nm absorption coefficient measurement

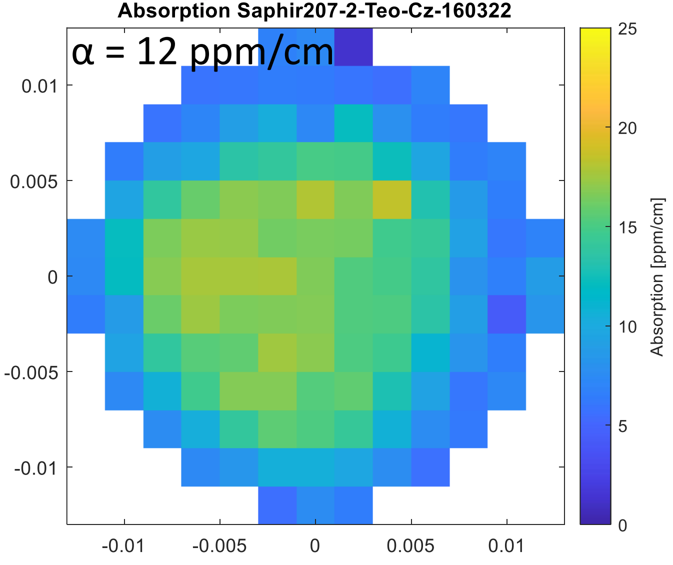


Timeline of the crystal growths and their mean absorption coefficient. The error bars indicate the max and min absorption coefficients of the different samples from the same crystal

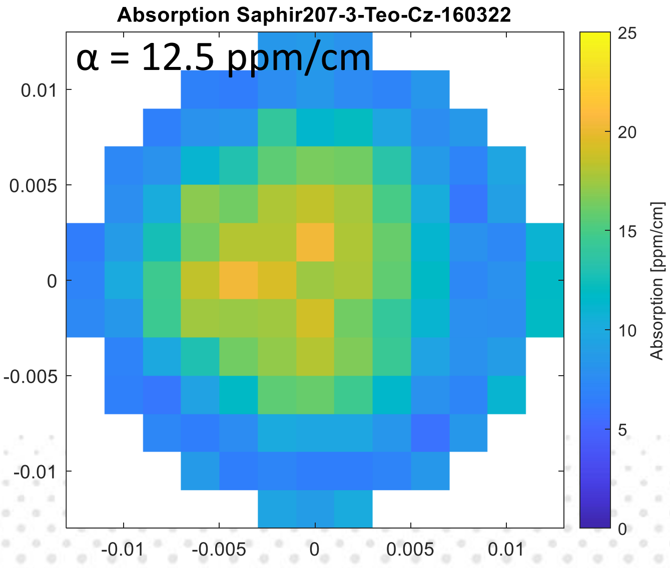
1064 nm absorption coefficient mappings



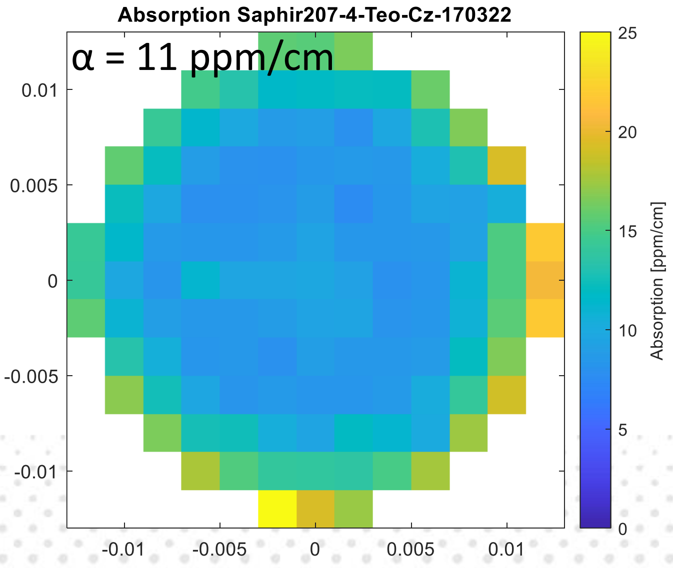
Absorption Saphir207-1-Teo-Cz-170322



Absorption Saphir207-2-Teo-Cz-160322



Absorption Saphir207-3-Teo-Cz-160322



Absorption Saphir207-4-Teo-Cz-170322

Absorption maps of 4 samples from crystal 207

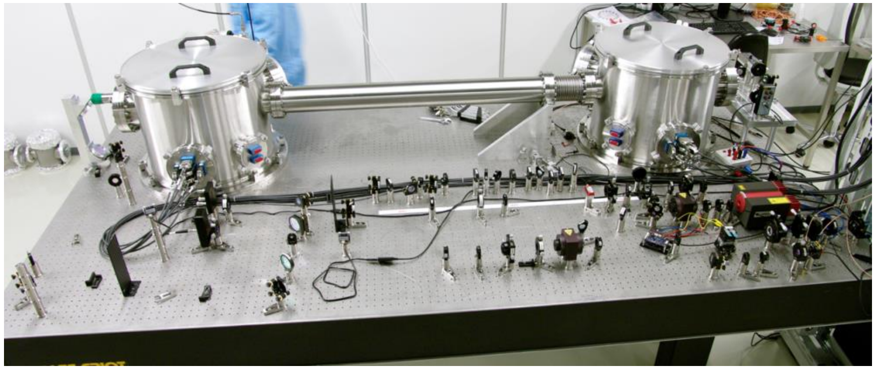
The colour scale is the same for all maps and goes from 0 ppm/cm in blue to 25 ppm/cm in yellow.

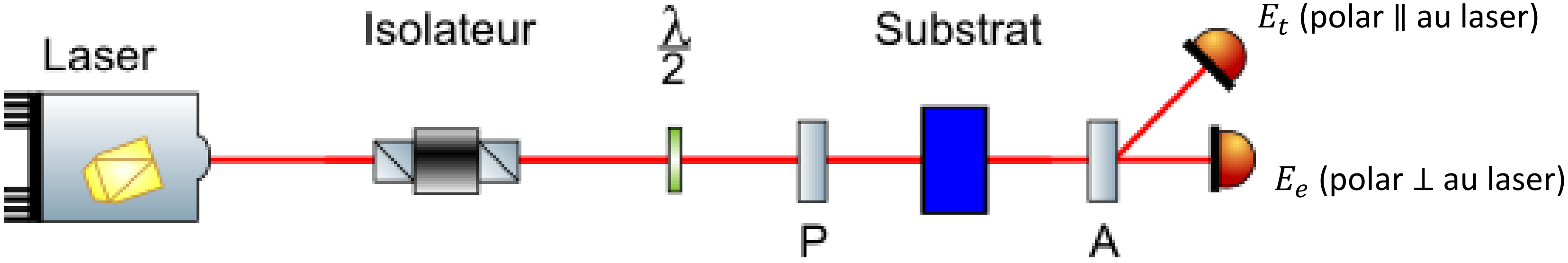
The value at the top is the mean absorption coefficient of each map.

Birefringence measurements

Principle of detection :

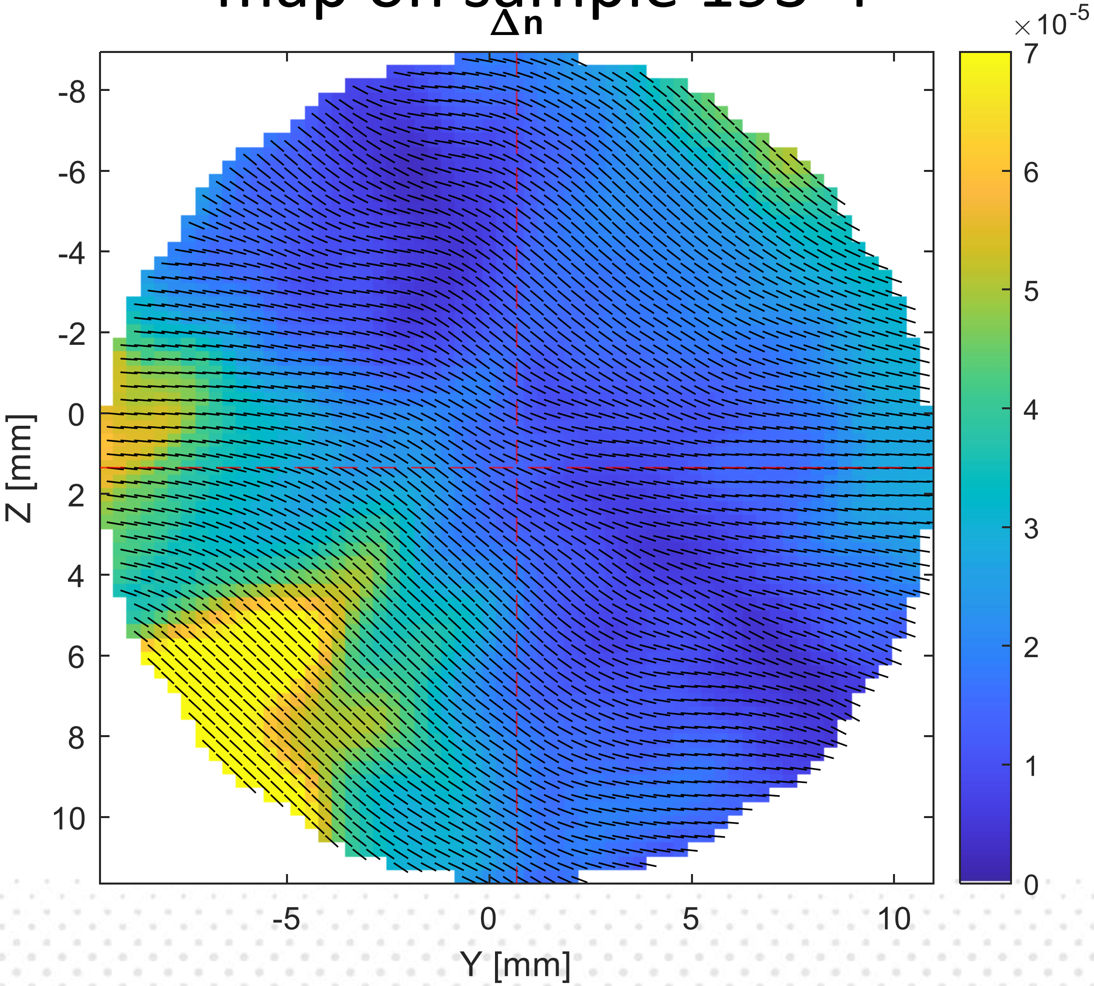
- A monochramatic linearly polarized light is sent through the substrate
- Transmitted light is decomposed into its parallel and perpendicular composants
- Light intensity is then analysed to calculate the substrate birefringence





Birefringence measurements

Example of a birefringence map on sample 193-4



Measurements yields an optical index variation value and a birefringence direction

Current problems :
Taking into account the parasite cavity effects during measurements to make sure we only measure effects from the sample

OSAG

OSAG (Optiques en Saphir pour l’Astronomie Gravitationnelle) project with IDEX Lyon.

Goal : growth of sapphire single cristals with a diameter of 450 mm and a mass of 500 kg with outstanding optical properties.
(absorption target : < 50 ppm/cm)

Largest crystals grown now has a 300 mm diameter using doped sapphire for other applications.

Conclusion

- Sapphire is the most promising candidate with regards to the thermal noise and is less strict on the optical absorption
- Low 1064 nm absorption (< 50 ppm/cm) has been obtained in a repeated fashion thanks to the control of the growth parameters and a high quality raw material.
- Even in crystals with very low absorption coefficient gradients along the growth and the radial directions have been observed on nearly all samples.
- Birefringence measurements have started at LMA
- 1550 nm absorption bench is being built at LMA
- Sample studied are smaller than the requirements for KAGRA but the technology learned here will be applied to the OSAG project.