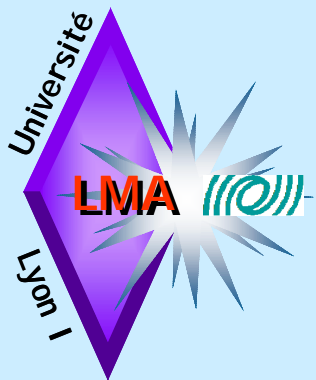


December 2003 – January 2004



Large sapphire substrate absorption measurements for LIGO

- \emptyset 250 mm sapphire mass from the University of Glasgow
- \emptyset 314 mm « pink » sapphire mass from the Caltech

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Large sapphire substrate absorption measurements for LIGO

• Orientation of the substrates

Two sapphire substrates were measured.

The first one, the « Ø 250 mm sapphire mass from the University of Glasgow » has a green reference mark on the edge (slide # 3).

The second one, the « Ø 314 mm pink sapphire mass from the Caltech » has a black reference mark on the edge, showing the c axis (slide # 9).

For all measurements, the substrate is set so that the reference mark is on the front and at the bottom of the substrate.

• Accuracy of the absorption measurements

The absorption measurement is based on a photothermal deflection technique. The pump laser is a 30 W CW laser at 1064 nm. The angle between the pump and the probe beams is 3.5°. The elementary volume measured has the following dimensions: 0.1 mm in the X and Y directions and 3 mm in the Z direction. These dimensions correspond to the highest resolution that can be reached.

The absolute value of the sapphire absorption is calculated thanks to the measurement of the absorption of a silica standard, the density and the specific heat capacity of sapphire and silica. The modulation frequency used for the measurement is high : 3000 Hz.

The absorption of the silica reference is calculated thanks to the measurement of the absorption of ultra pure water (0.13 cm⁻¹), the density and the specific heat capacity of silica and water. A cross calibration was made with the Laboratoire d'Optique at ESPCI Paris. The agreement is in the percent range. The uncertainty on the absolute value of the absorption measurement is about 20 %.

The absorption of the two sapphire substrates was recorded during 1 hour in the center part, in order to check the stability of the measurement.

- For the « Ø 250 mm sapphire mass from the University of Glasgow », the measurement gave : 9.6 +/- 0.2 ppm.cm⁻¹ (slide # 3).

- For the « Ø 314 mm pink sapphire mass from the Caltech », the measurement gave : 6.9 +/- 0.1 ppm.cm⁻¹ (slide # 9).

• Absorption maps

For each substrate, 3 absorption maps were recorded at 3 different depths: One at ¼ of the depth, one at ½ of the depth, and one at ¾ of the depth. The diameter of the maps is 200 mm and the step between the points is 2.5 mm.

- For the « Ø 250 mm sapphire mass from the University of Glasgow » (slide # 4), the absorption varies from ≈7 to ≈26 ppm.cm⁻¹ with a mean value between 12 and 13.5 ppm.cm⁻¹ for each map. (slides # 5-7). A zoom on one of the previous maps shows variations of absorption at the 0.1 mm scale. (slide # 6).

- The « Ø 314 mm pink sapphire mass from the Caltech » (slide # 10), is less absorbing: The absorption varies from ≈3 to ≈13 ppm.cm⁻¹ with a mean value between 7.2 and 7.6 ppm.cm⁻¹ for each map. (slides # 11-13). A zoom on one of the previous maps shows variations of absorption at the 0.1 mm scale. (slide # 12).

• Absorption vs depth

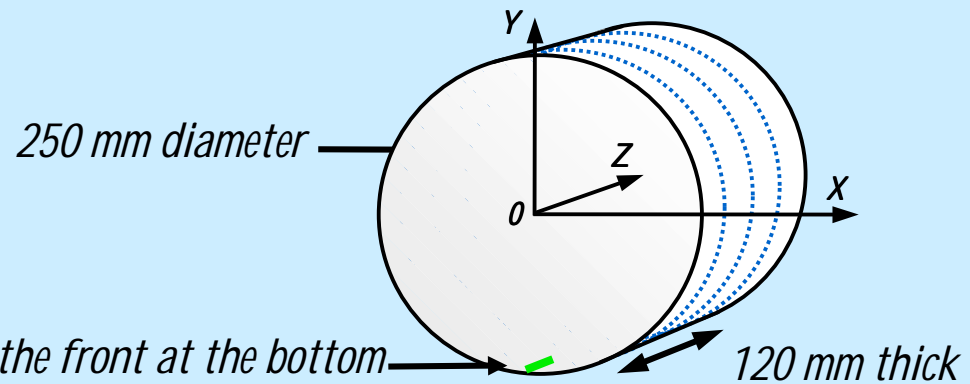
The absorption versus the depth (Z) was scanned at 3 different (X,Y) positions: (-50 mm ; -50 mm) , (0 mm ; 0 mm) and (50 mm ; 50 mm) , for each substrate.

- For the « Ø 250 mm sapphire mass from the University of Glasgow », the range of absorption variation for each (X,Y) position is respectively: [10 - 21] , [9 - 24] and [7 - 15] ppm.cm⁻¹ (slide # 8).

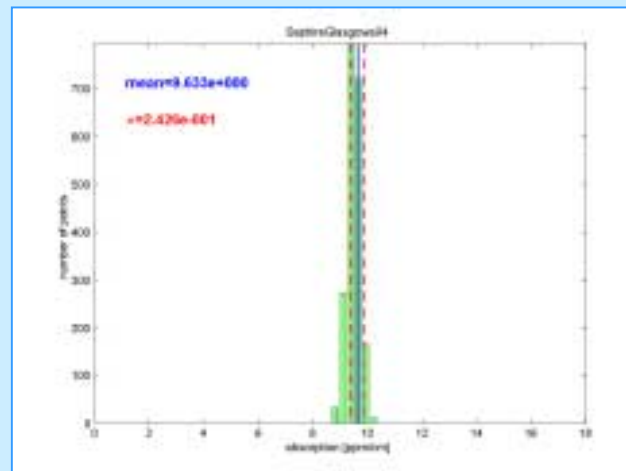
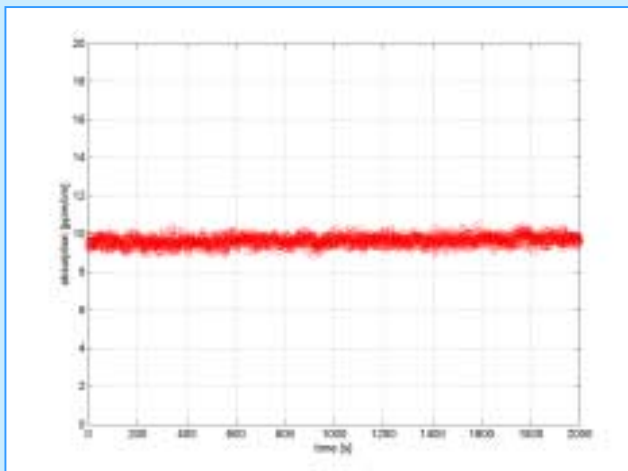
- For the « Ø 314 mm pink sapphire mass from the Caltech », the range of absorption variation for each (X,Y) position is slightly smaller. It is respectively [5.8 - 8.9] , [5.6 - 8.8] and [5.6 - 9.2] ppm.cm⁻¹. (slide # 14) Nevertheless, unlike the Glasgow mass, at each (X,Y) position, the absorption increases at the edges of the substrate, up to 45 , 90 and 48 ppm.cm⁻¹ respectively. The surfaces had been cleaned at SMA-VIRGO. The absorption increase at the edges may be due to the polishing. It must be mentioned that this absorption increase does not only occur at the surface but also inside the bulk in a region, near the surface, whose depth can reach 20 mm.

■ \varnothing 250 mm sapphire mass from the University of Glasgow

- Orientation of the substrate



- Accuracy of the absorption measurements : $\pm 0.2 \text{ ppm.cm}^{-1}$

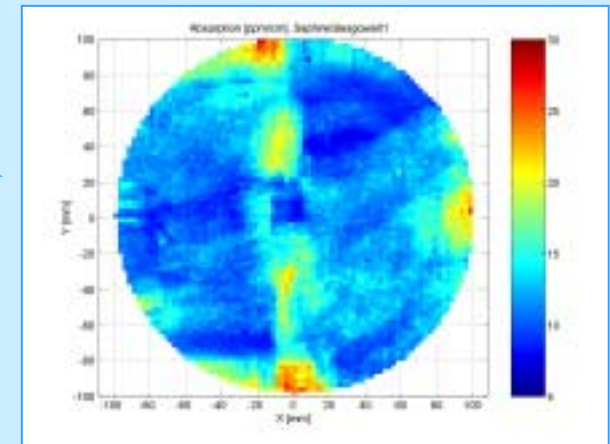
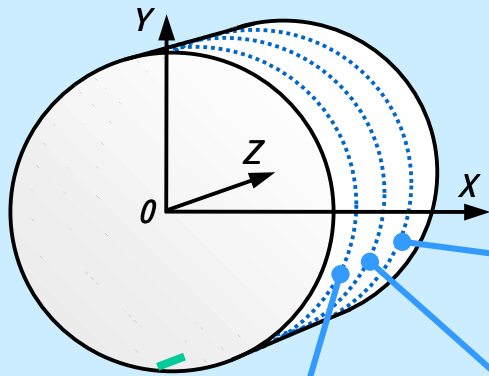


Absorption recorded at

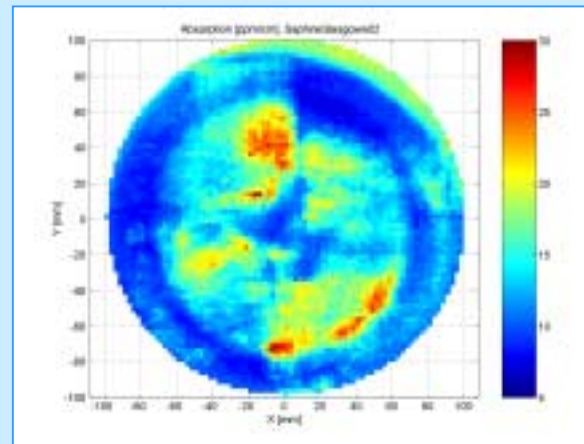
$X = 0 \text{ mm}$
 $Y = 0 \text{ mm}$
 $Z = 60 \text{ mm}$

during 1 hour :

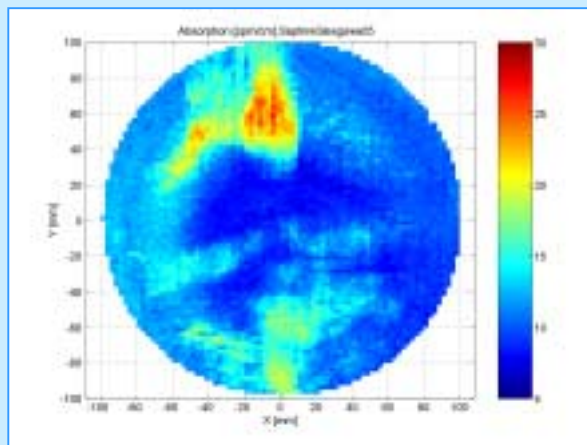
$9.6 \pm 0.2 \text{ ppm.cm}^{-1}$



$Z = 90$ mm

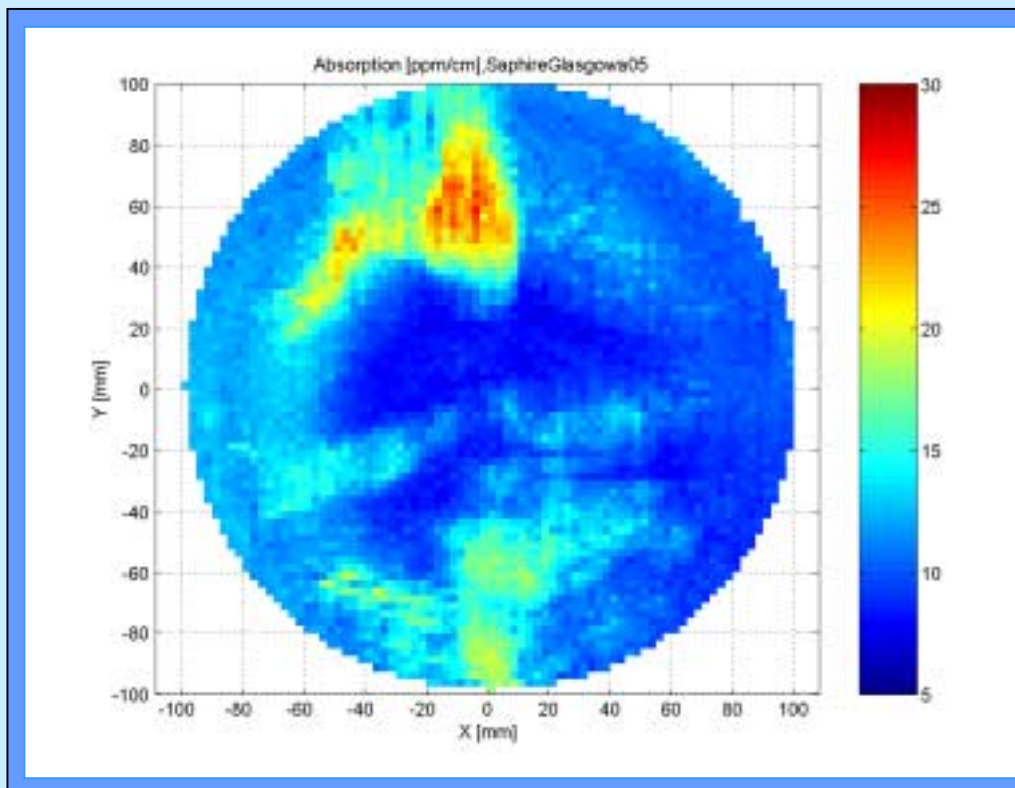


$Z = 60$ mm

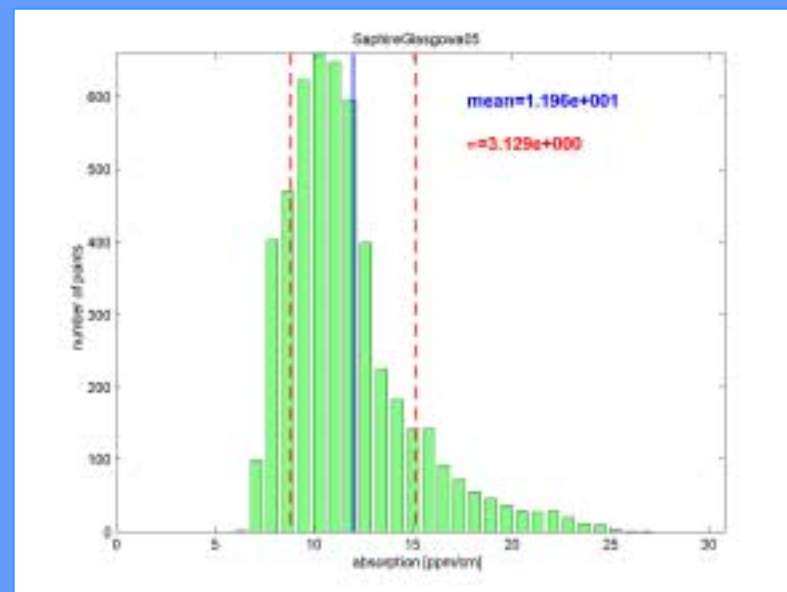


$Z = 30$ mm

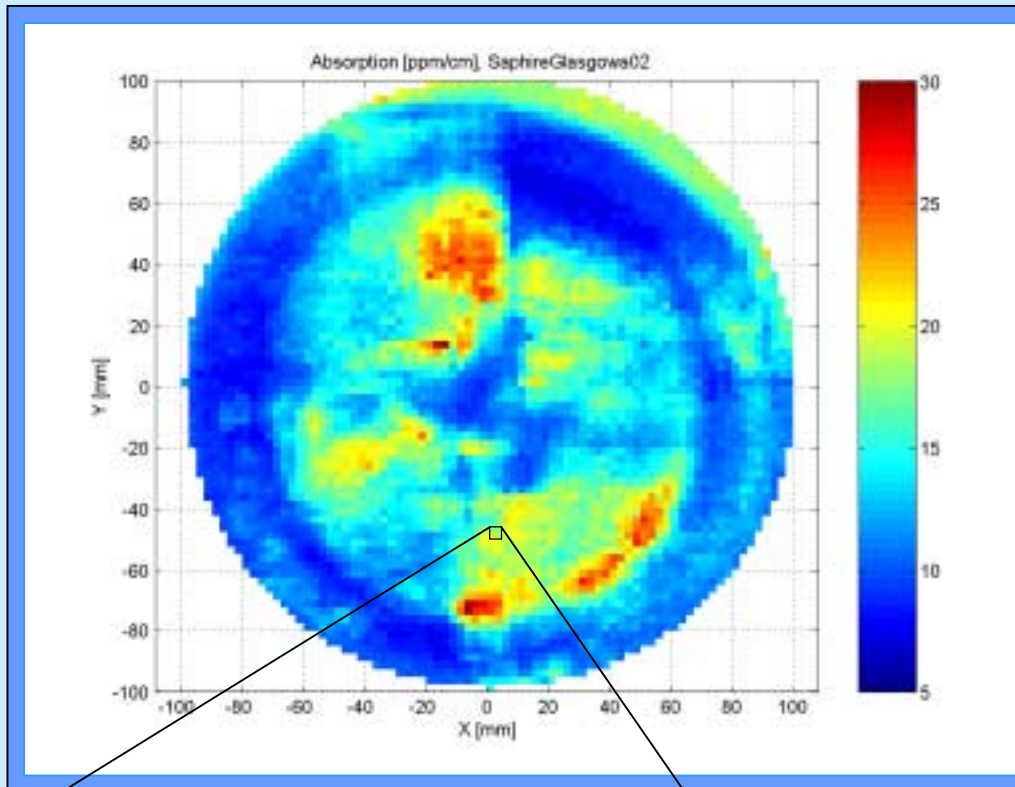
- Absorption maps at 3 different depths



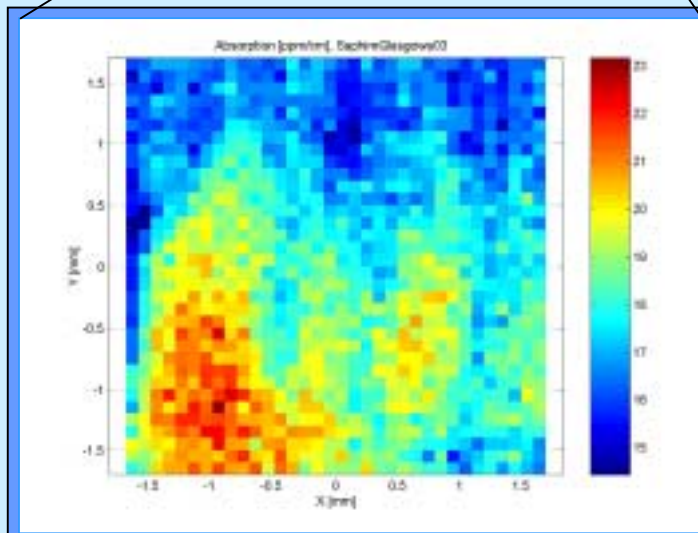
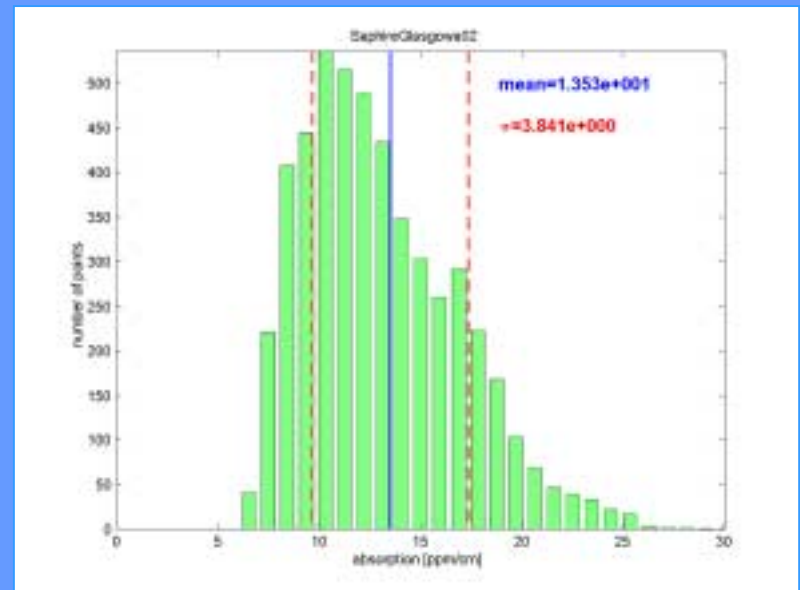
*Mean absorption: 12.0 ppm.cm⁻¹
 ϕ 200 mm scan, 2.5 mm steps*



- *Absorption map at
 $Z = 30$ mm*

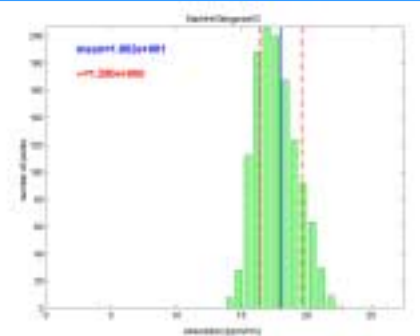


*Mean absorption: 13.5 ppm.cm⁻¹
 ϕ 200 mm scan, 2.5 mm steps*

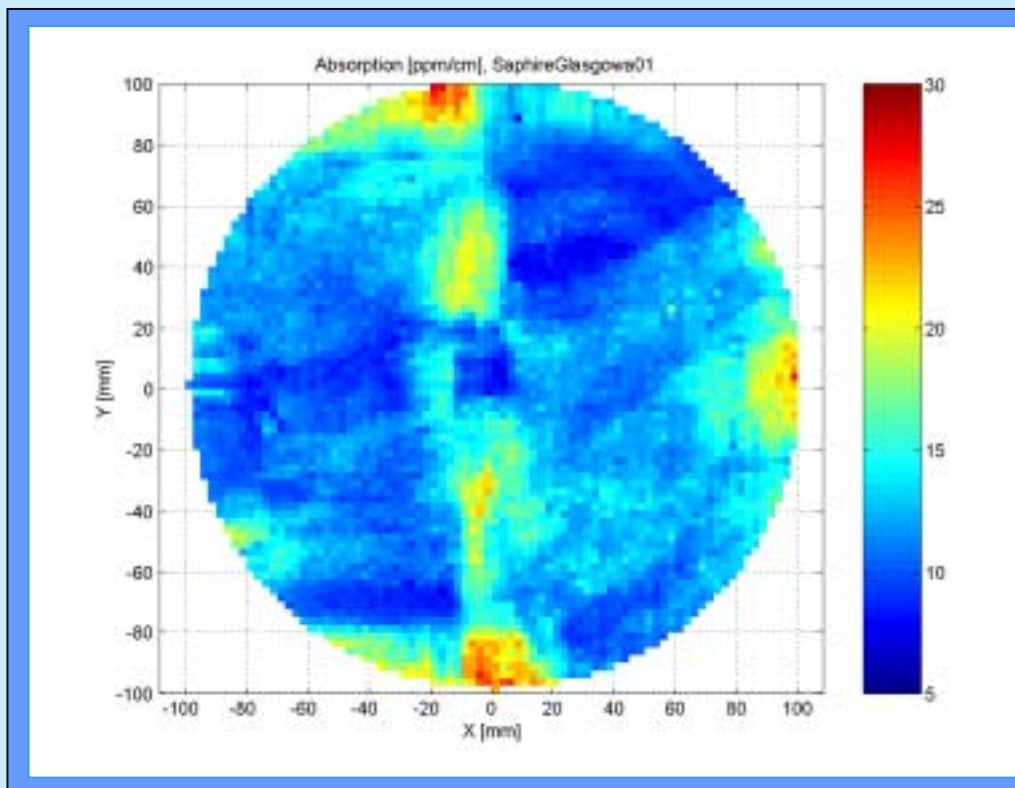


zoom

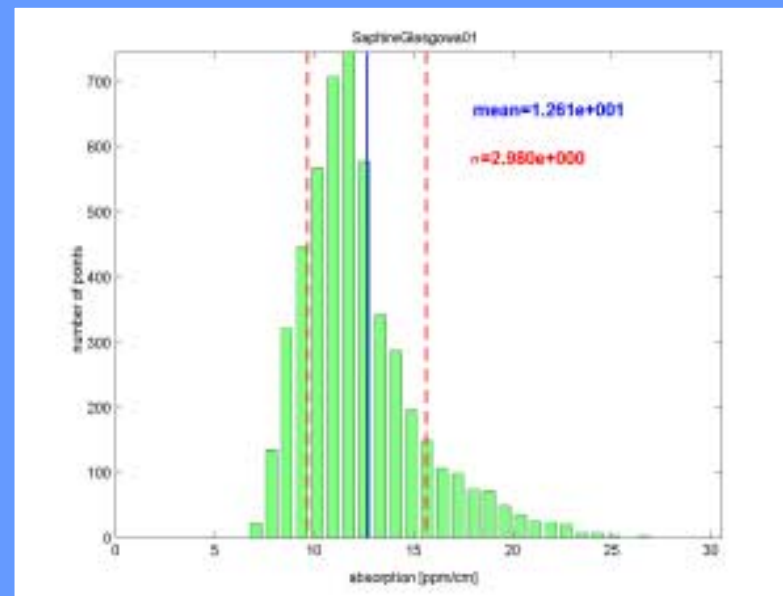
*Mean absorption: 18 ppm.cm⁻¹
 3.5 x 3.5 mm², 0.1 mm steps*



- *Absorption map at
 $Z = 60$ mm*

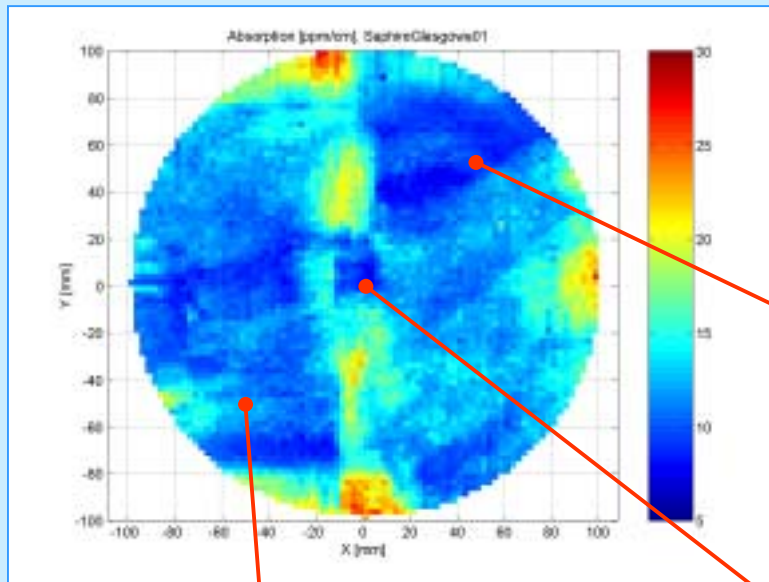


Mean absorption: 12.6 ppm.cm⁻¹
ϕ 200 mm scan 2.5 mm steps

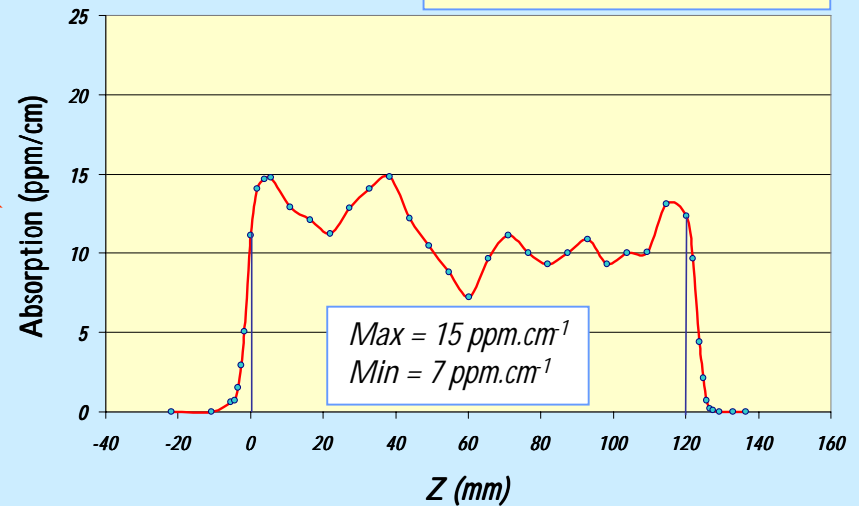


- *Absorption map at
Z = 90 mm*

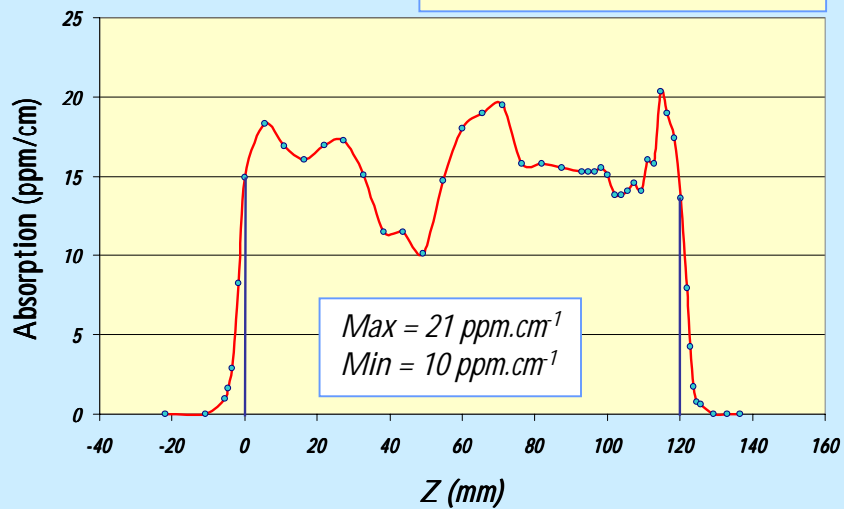
- Absorption versus depth*



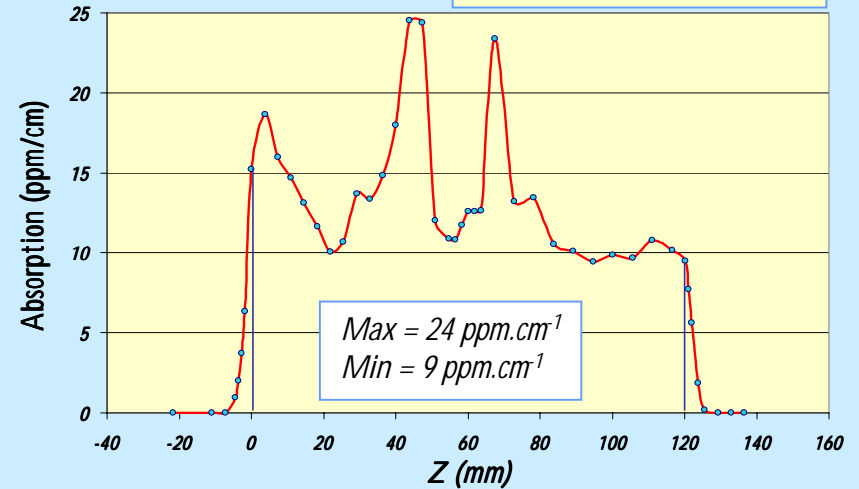
$(X; Y) = (50 \text{ mm} ; 50 \text{ mm})$



$(X; Y) = (-50 \text{ mm} ; -50 \text{ mm})$



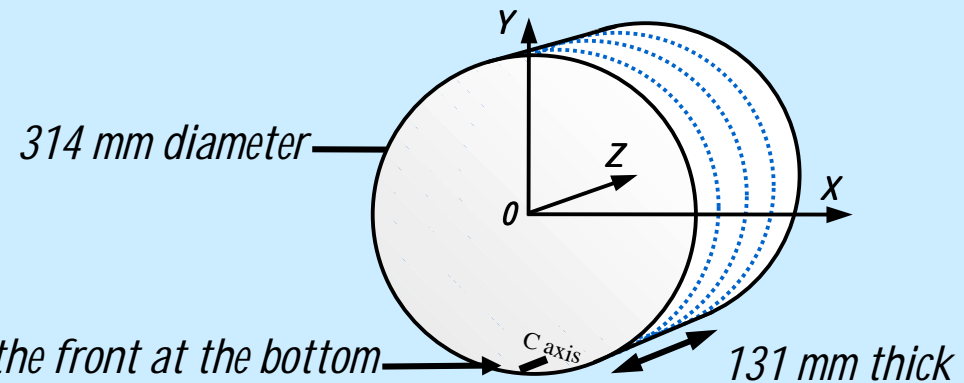
$(X ; Y) = (0 \text{ mm} ; 0 \text{ mm})$



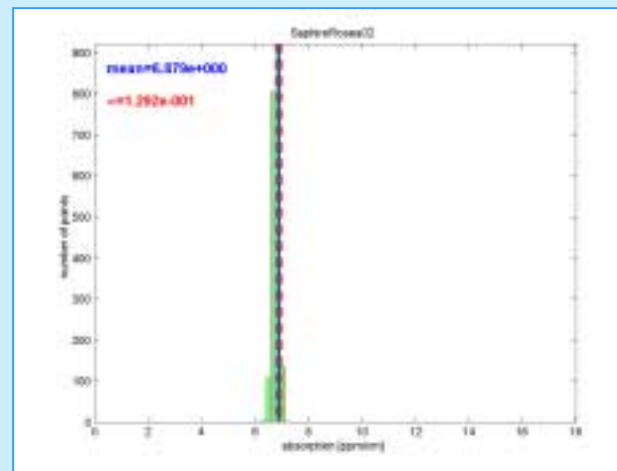
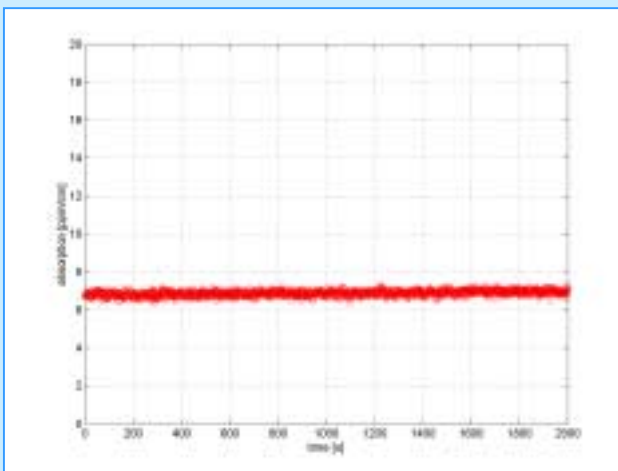
Ø 250 mm sapphire mass from the University of Glasgow

■ \varnothing 314 mm « pink » sapphire mass from the Caltech

- Orientation of the substrate



- Accuracy of the absorption measurements : $\pm 0.1 \text{ ppm.cm}^{-1}$

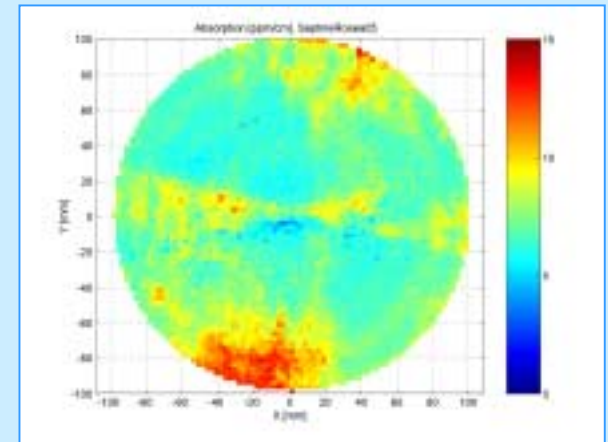
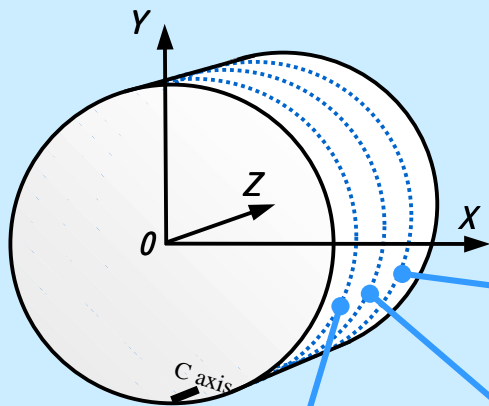


Absorption recorded at

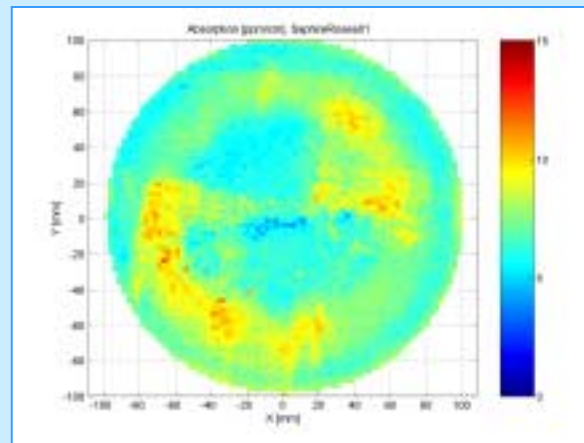
$X = 0 \text{ mm}$
 $Y = 0 \text{ mm}$
 $Z = 65.5 \text{ mm}$

during 1 hour :

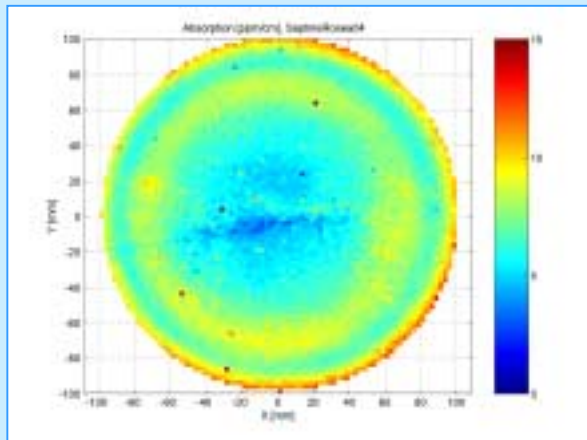
$6.9 \pm 0.1 \text{ ppm.cm}^{-1}$



$Z = 98.25 \text{ mm}$

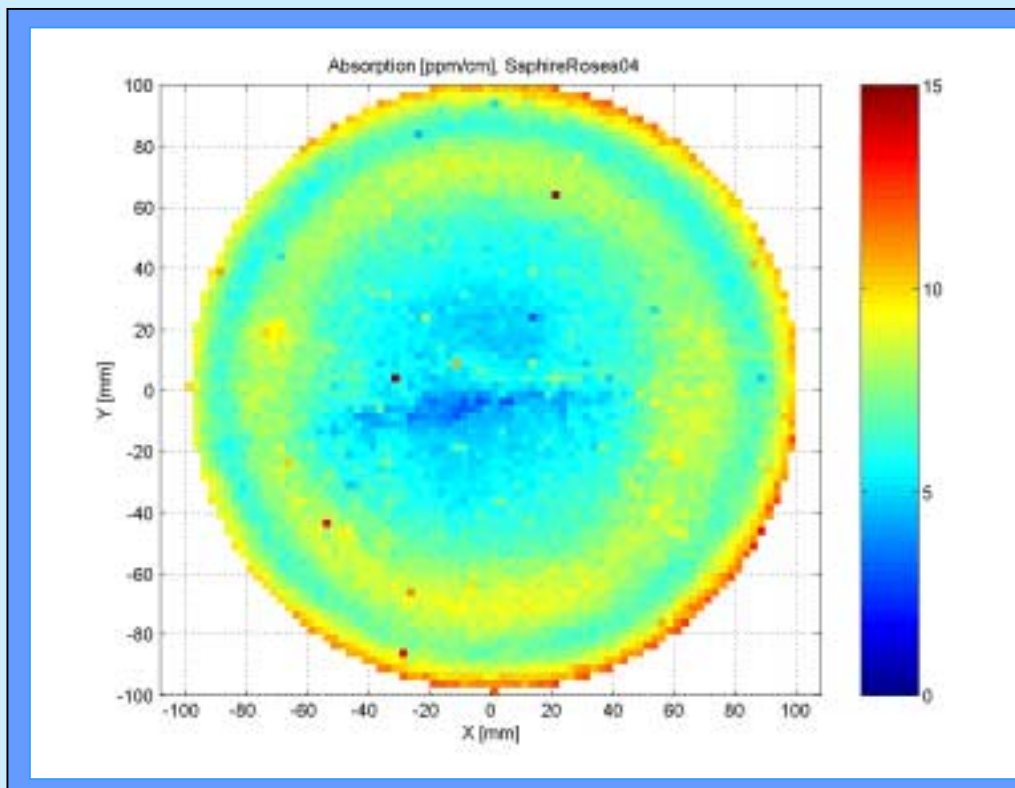


$Z = 65.5 \text{ mm}$

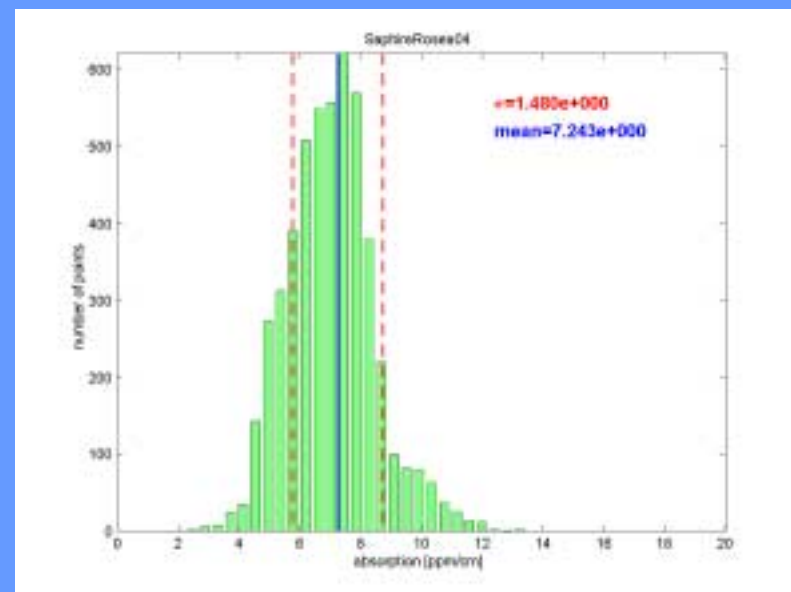


$Z = 32.75 \text{ mm}$

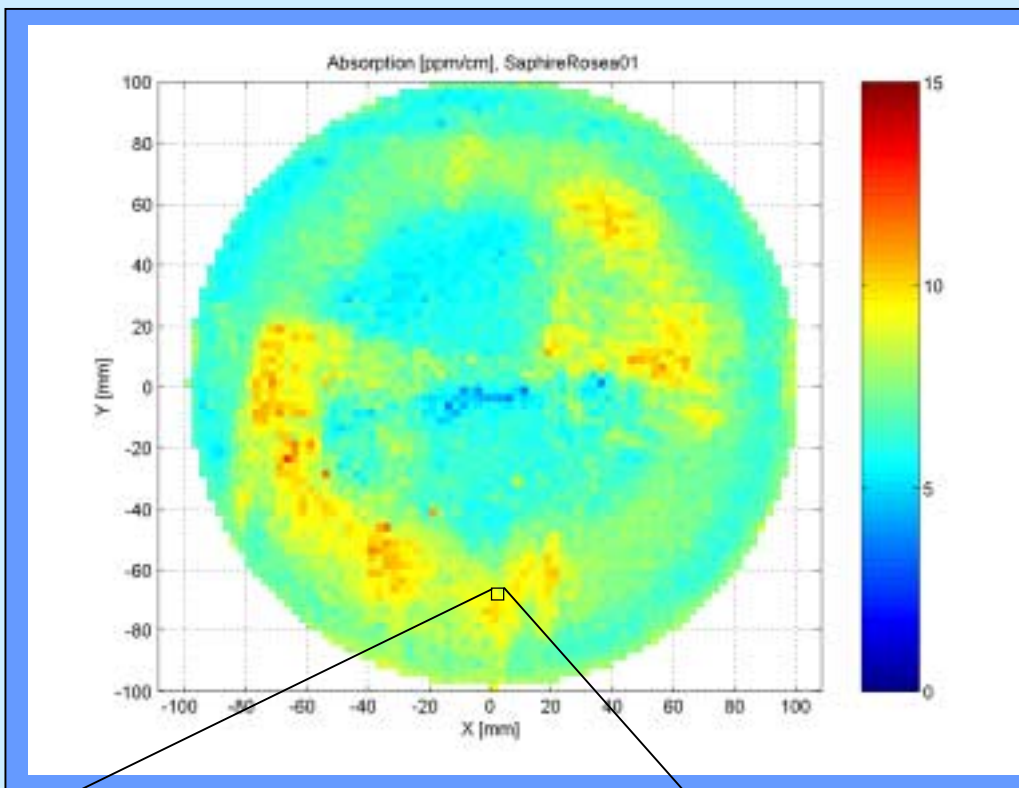
- Absorption maps at 3 different depths



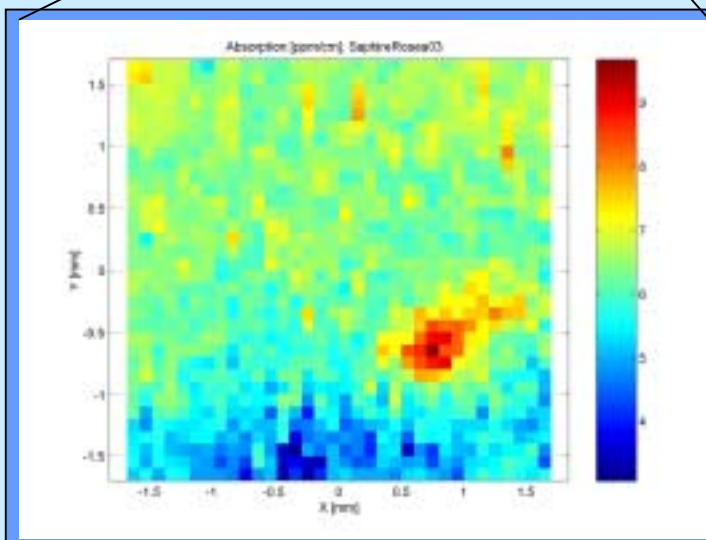
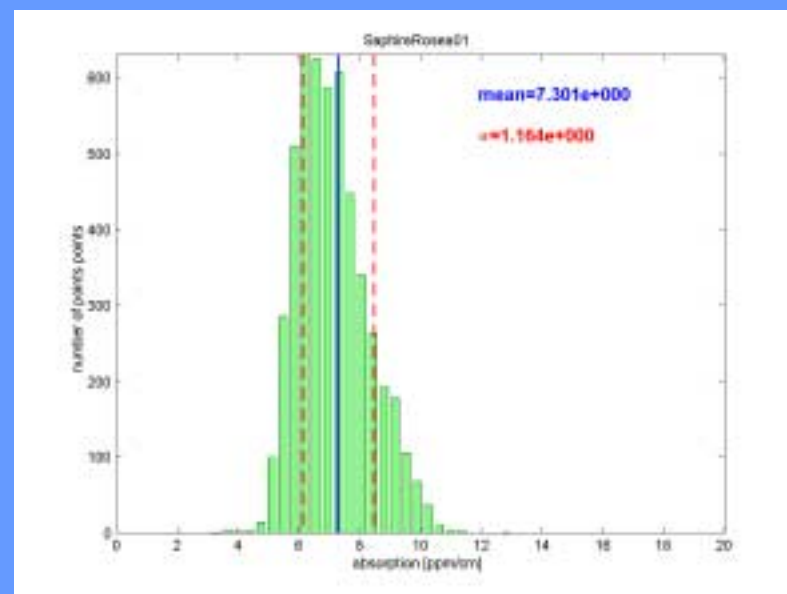
*Mean absorption: $7.2 \text{ ppm}\cdot\text{cm}^{-1}$
 ϕ 200 mm scan, 2.5 mm steps*



- *Absorption map at
 $Z = 32.75 \text{ mm}$*

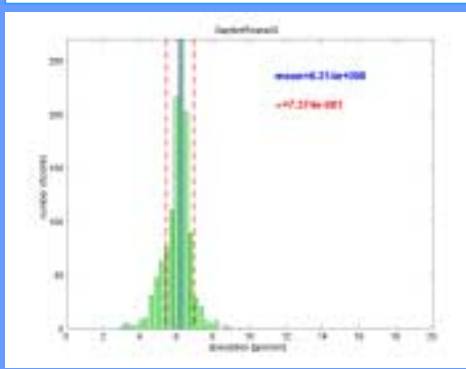


Mean absorption: $7.3 \text{ ppm}\cdot\text{cm}^{-1}$
 ϕ 200 mm scan, 2.5 mm steps

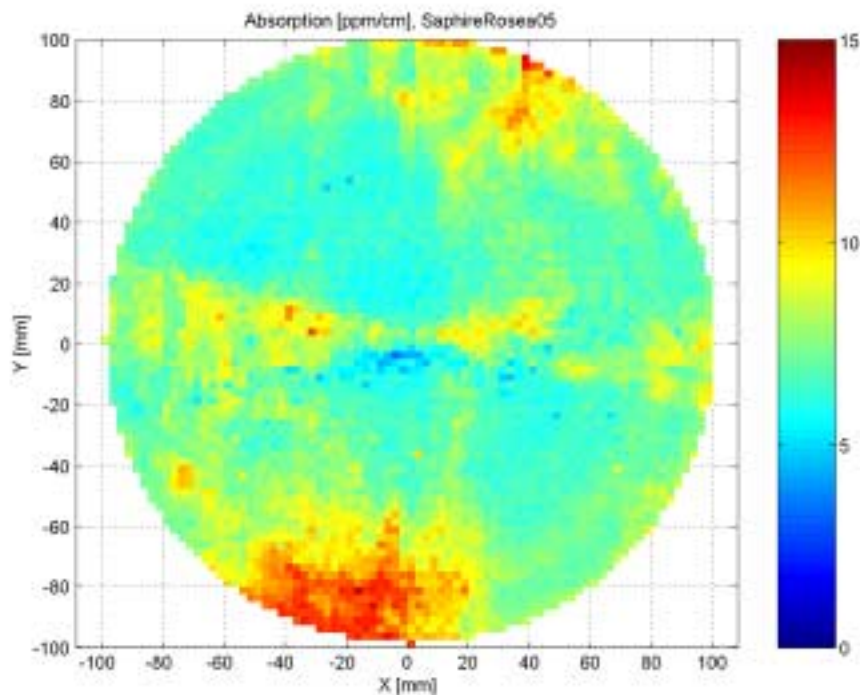


zoom

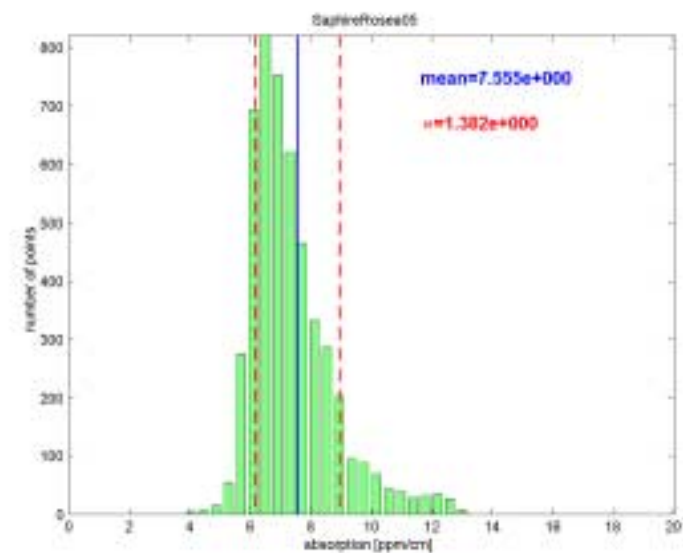
Mean absorption: $6.2 \text{ ppm}\cdot\text{cm}^{-1}$
 $3.5 \times 3.5 \text{ mm}^2$, 0.1 mm steps



- Absorption map at
 $Z = 65.5 \text{ mm}$

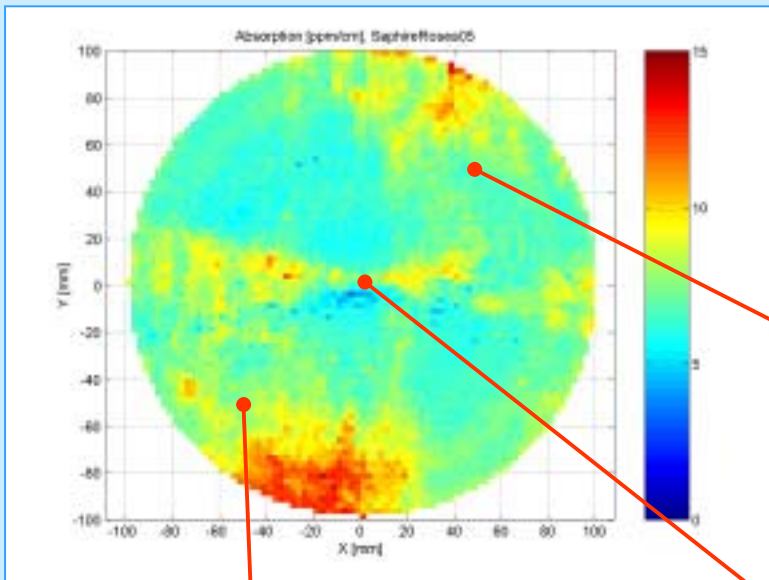


*Mean absorption: $7.6 \text{ ppm}\cdot\text{cm}^{-1}$
 ϕ 200 mm scan 2.5 mm steps*



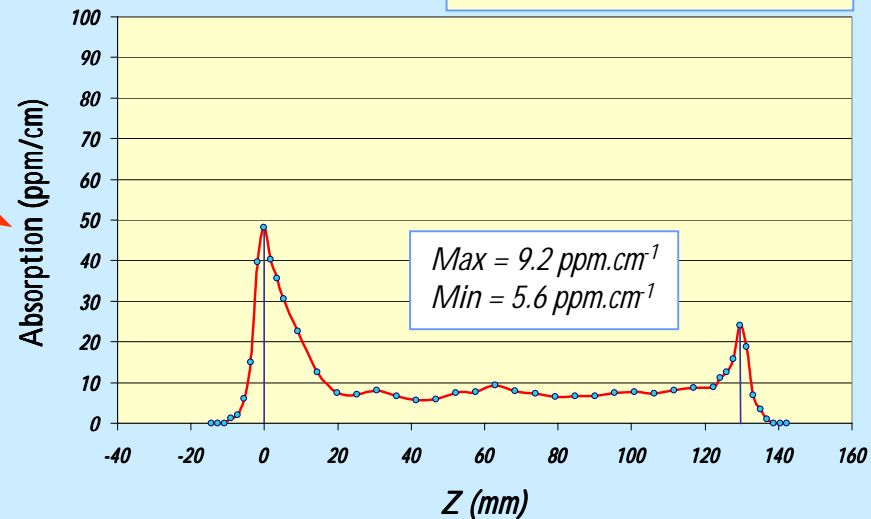
- *Absorption map at
 $Z = 98.25 \text{ mm}$*

• Absorption versus depth

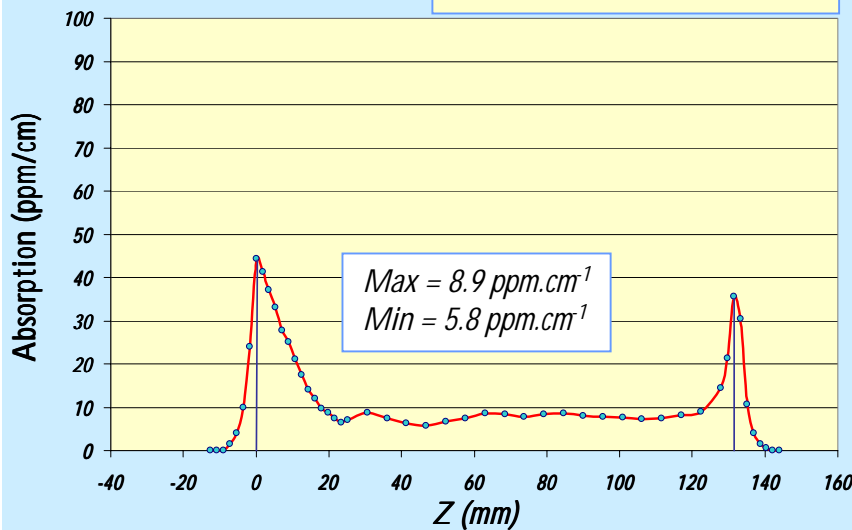


Z = 98.25 mm

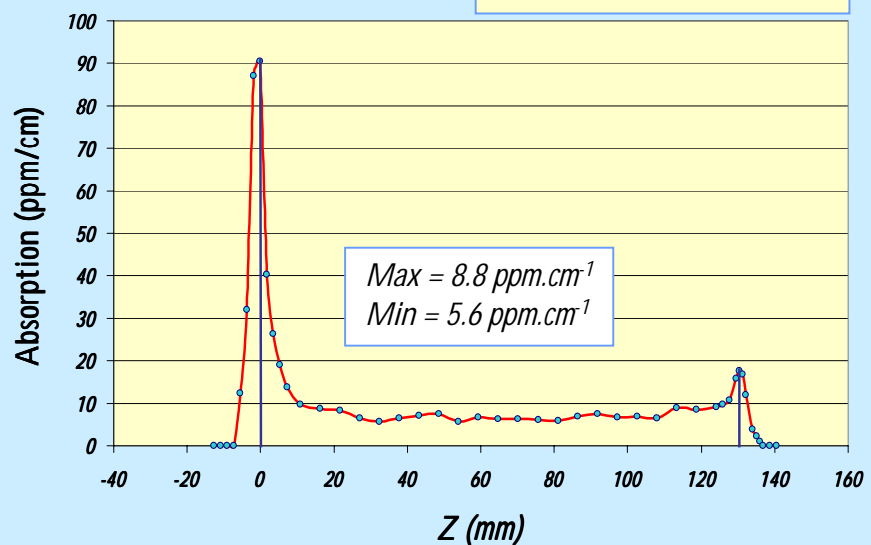
(X;Y) = (50 mm ;50 mm)



(X;Y) = (-50 mm ; -50 mm)



(X ; Y) = (0 mm ; 0 mm)



Ø 314 mm « pink » sapphire mass from the Caltech