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# Nonlinear acoustic characterization of Carrara marble degradation under thermo-hygric cycles

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Carrara marble is a widely used type of marble, in buildings and in sculptures, in ancient and in recent works. Yet, Carrara marble exposed to environmental conditions can develop deteriorations over time, such as bowing, cracks, expansion, reduction of mechanical strength. Previous studies [1] have shown that these degradations can result from exposure to temperature variations. Moreover, these deteriorations can be enhanced by the combination of variations of temperature and relative humidity [2].

The aim of the study is to understand and to characterize the effects of cyclic variations of temperature and relative humidity with a non-destructive method, suitable for the study of cultural heritage.

The Nonlinear Resonant Ultrasound Spectroscopy (NRUS) is chosen as it has proven to be highly sensitive to damage and to microstructural evolutions in rocks [3] and in concrete [4].

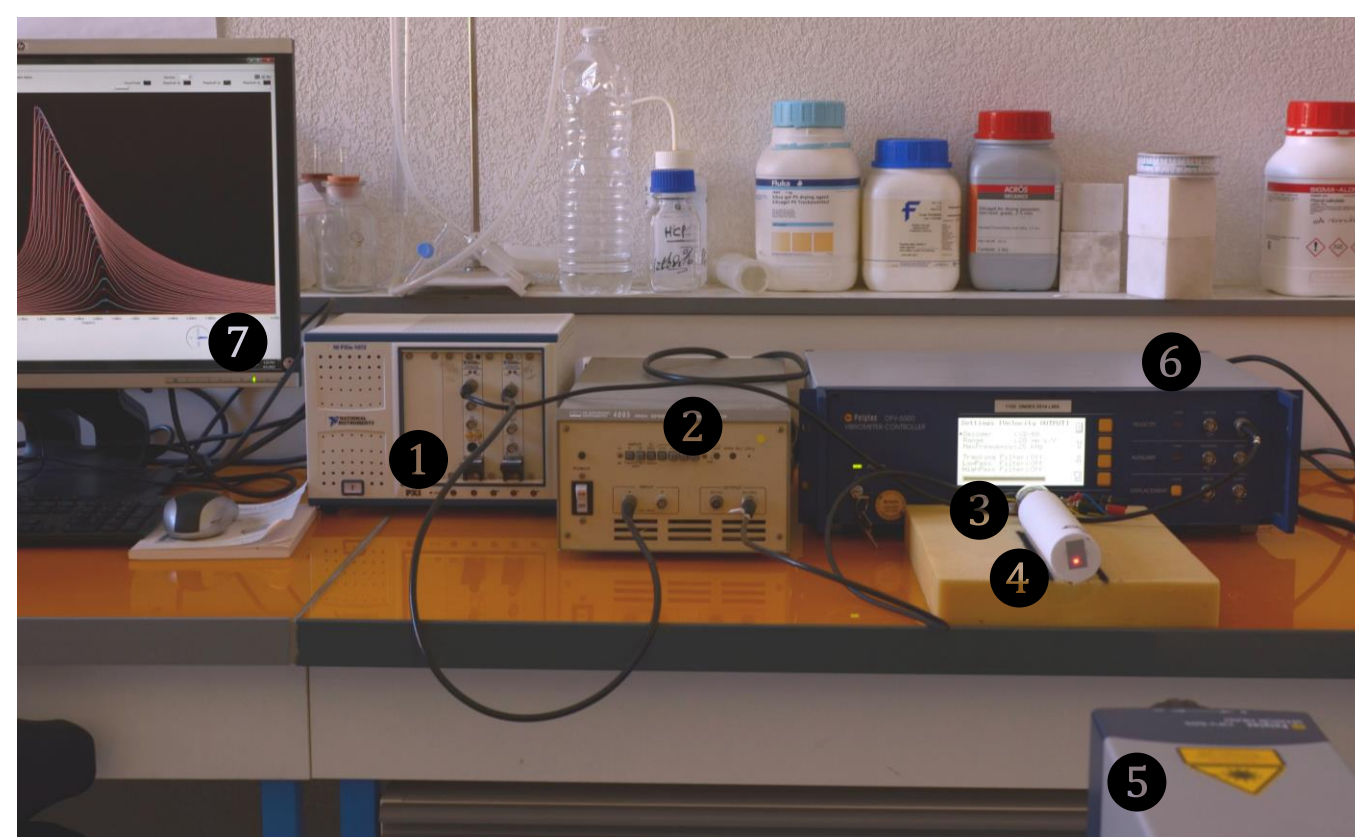


War memorial of Aubagne (P. Bromblet)

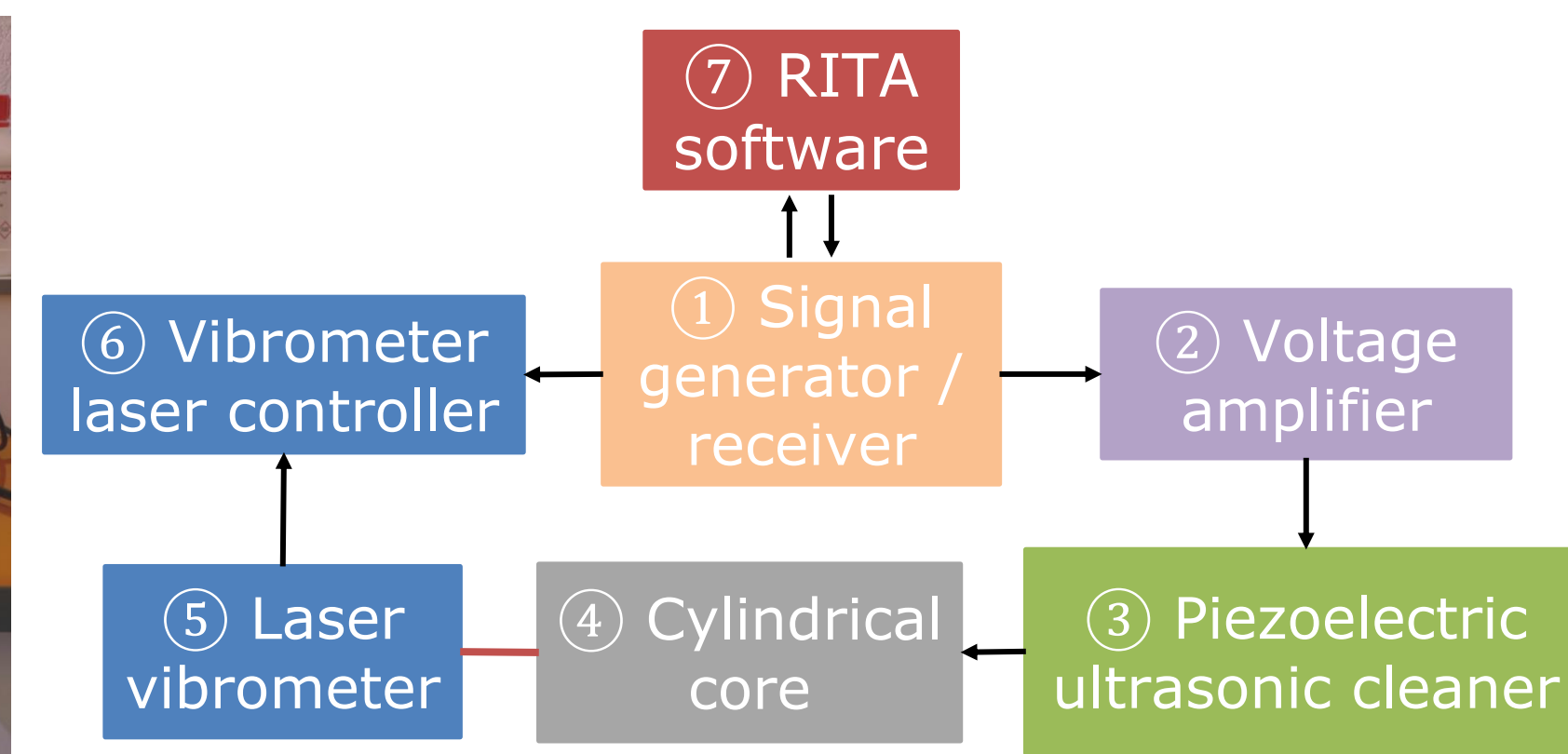
## Methodology

Nonlinear Resonant Ultrasound Spectroscopy (NRUS)

- non-destructive
- contactless wave reception

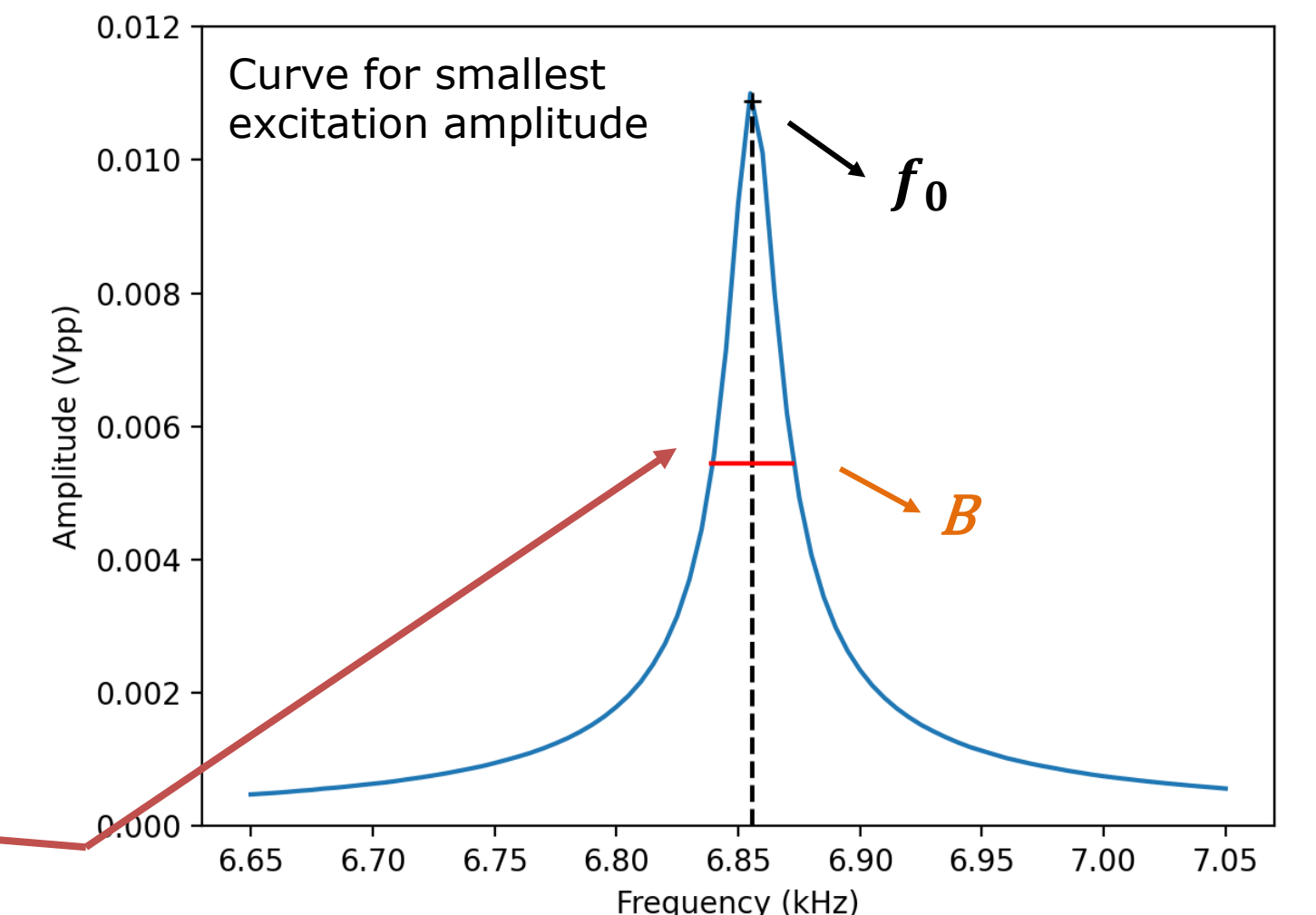
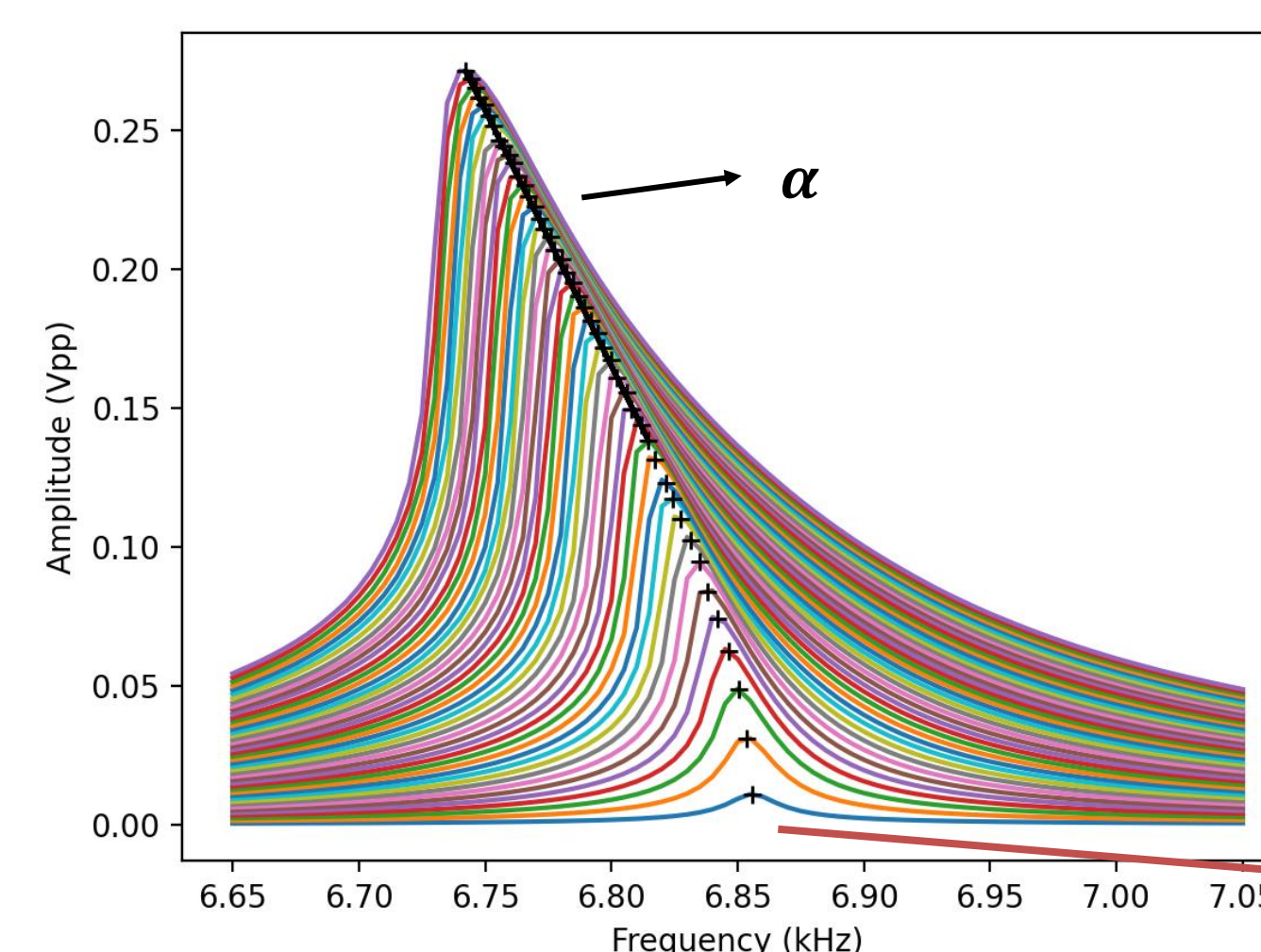


Experimental set-up for NRUS tests



Study of 3 parameters

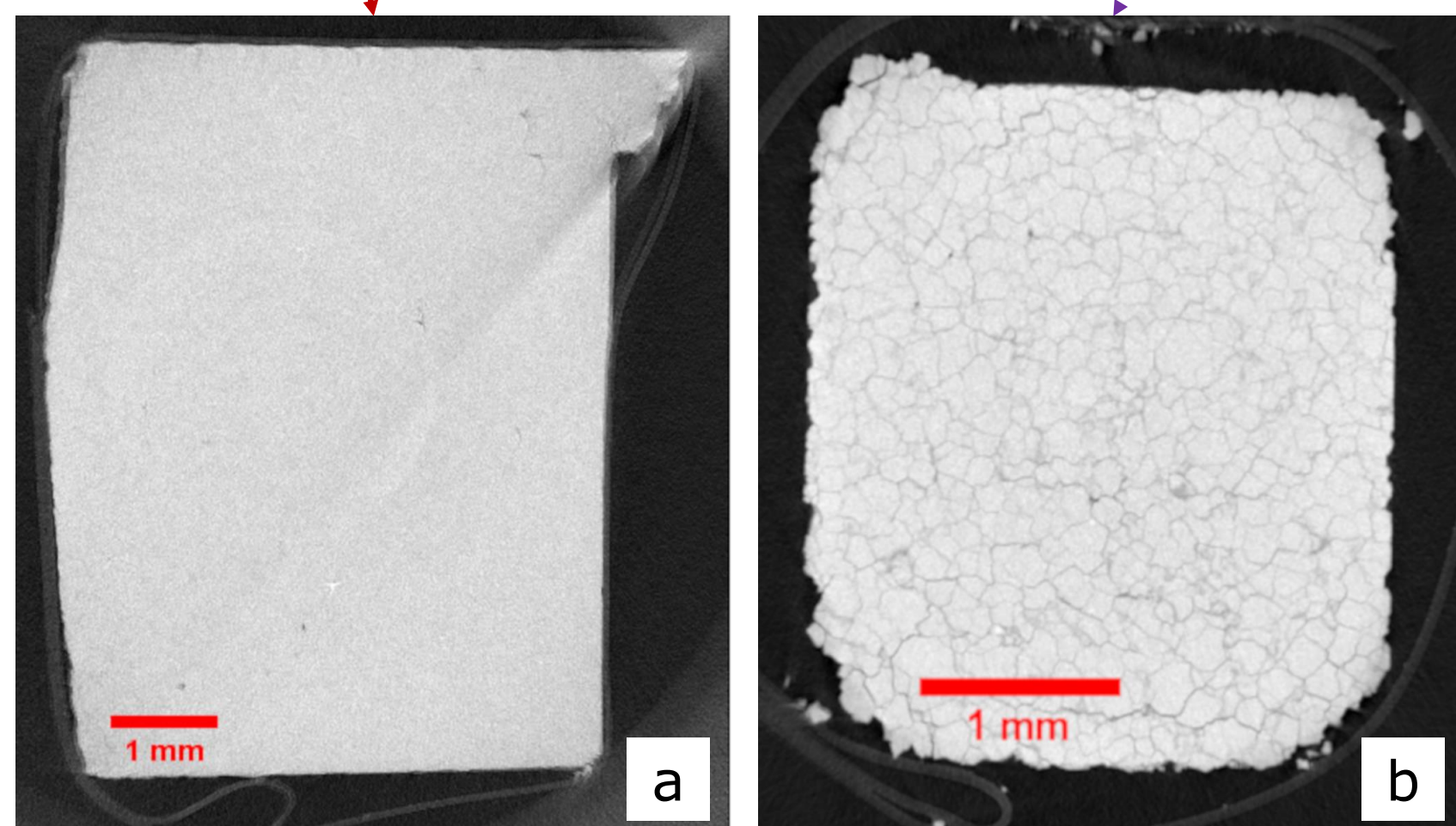
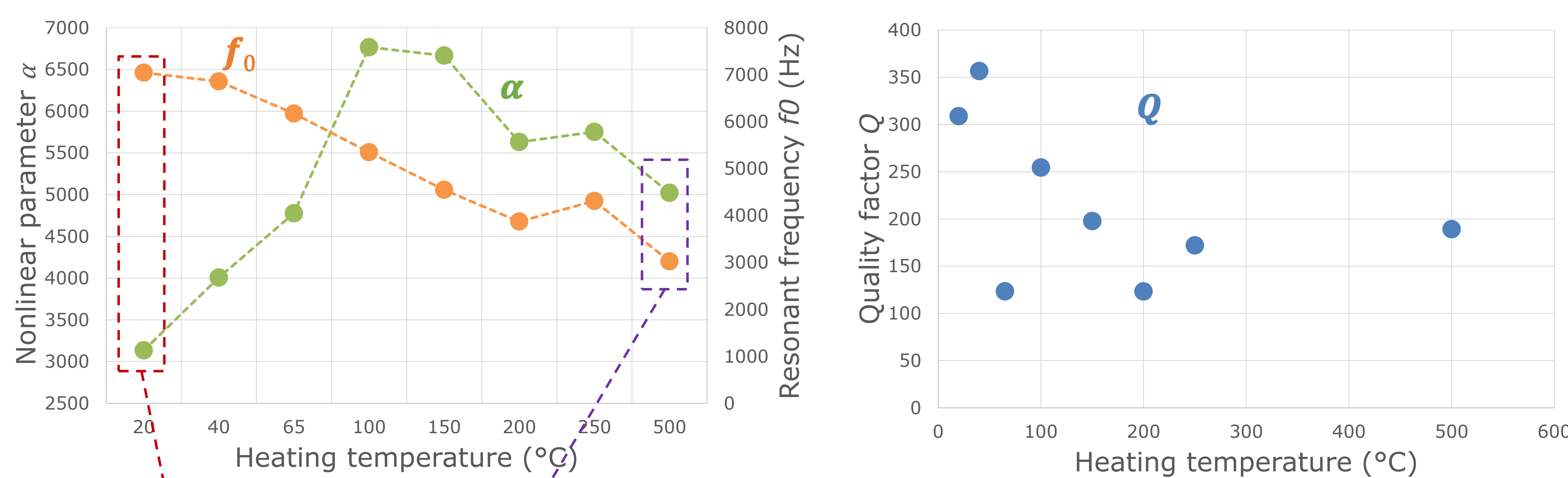
- resonant frequency  $f_0$
- quality factor  $Q = f_0/B$
- nonlinear parameter  $\alpha : \Delta f/f_0 = \alpha \Delta \epsilon$



NRUS curves for marble heated at 40°C

## Preliminary results

### Temperature variations

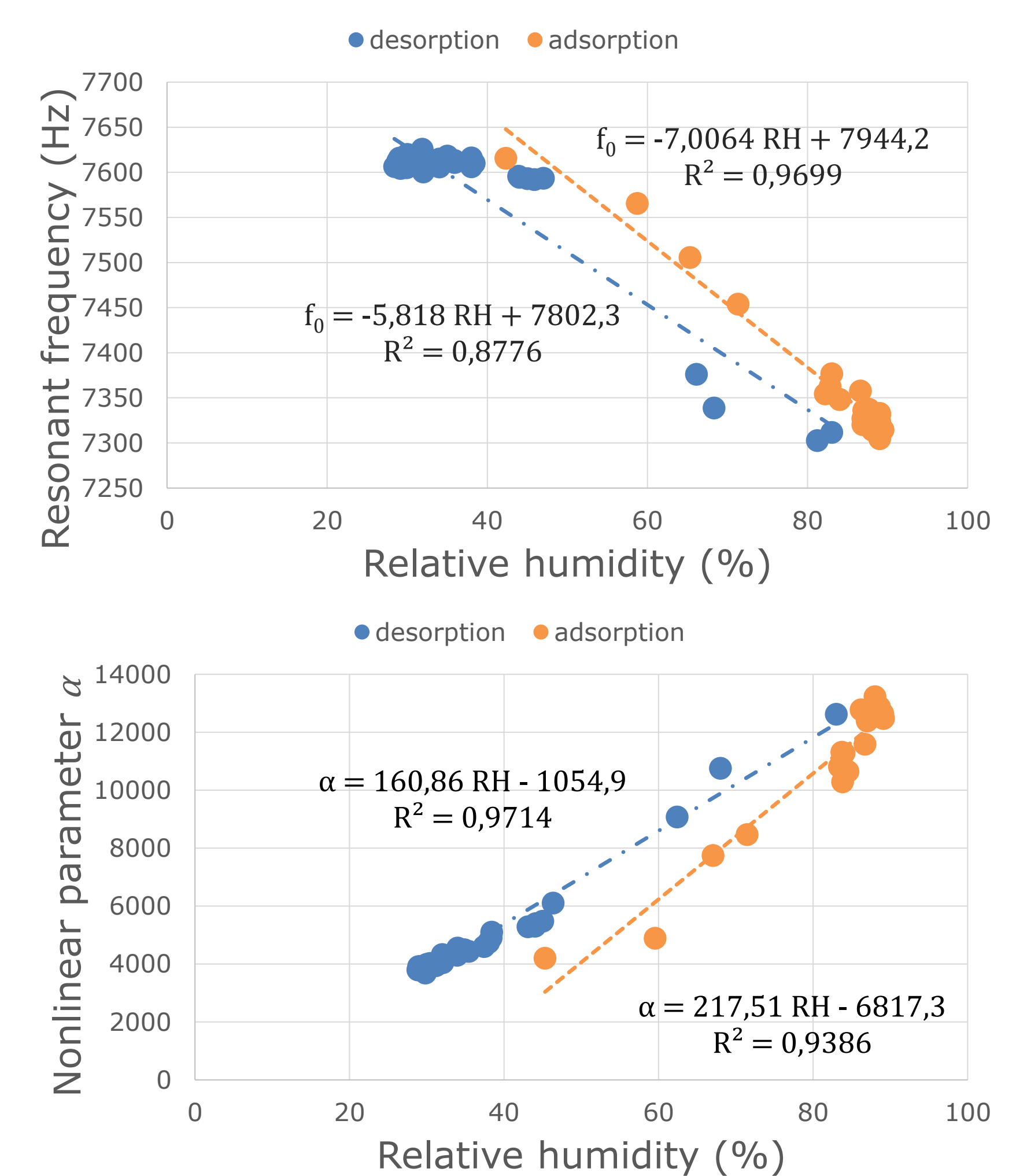


X-ray micro-CT scans for (a) undamaged marble and (b) marble heated at 500°C. Acquisition and reconstruction by L. Sabatier (LMA)

- Loss of stiffness and increasing attenuation with increasing heating temperature
- Loss of stiffness and increasing damage with increasing relative humidity

### Relative humidity variations

Marble heated at 65°C



## Conclusions

- NRUS method sensitive to the effects of variations of temperature and of relative humidity
- Degradation detectable even at low temperatures
- Links between the NRUS results and observations on the microstructure

## Perspectives

- Study of more temperatures between 40 and 100°C
- Study of the effects of cyclic variations at low temperatures
- Development of a scanning method suitable for art works and for the study of their degradation

## References

- [1] Schouenborg *et al.*, Journal of ASTM International, 2007
- [2] Koch *et al.*, Environmental Geology, 2004
- [3] Van Den Abeele *et al.*, J. of Geophysical Research, 2002
- [4] Payan *et al.*, J. of the Acoustical Society of America, 2007