Extension of age limits by fitting TL/OSL dose response curves using analytical expressions from physical models

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Introduction

Nowadays, both Thermoluminescence (TL) and Optically Stimulated Luminescence (OSL) are widely used in archaeometry, especially for the age determination of different samples and materials. The lower and upper age limits of TL and OSL are set by the TL and OSL response to natural dose. In routine dating applications, it is highly desirable that the dependence of TL and OSL on the dose is linear. On the other hand, there are several cases of non-linear such response. The possibility to use the entire TL/OSL dose response curve and not only the linear part, is expected to result in a significant extension of the age that can is calculated. However, for this to be applicable, exact analytical equations describing the TL/OSL as a function of dose are required.

Recently, Pagonis et al., (2020) suggested a new analytical equation for the TL versus dose; the use of this equation enabled the fitting of the whole TL dose response behavior. In this study, the analytical TL dose response of Pagonis et al., (2020) is extensively investigated in several experimental TL/OSL curves of both synthetic and natural materials. The results showed that the newly proposed equations fit excellently experimental TL/OSL dose response curves, allowing thus to estimate much larger, than usual, equivalent doses and significantly extending the upper limits of TL and OSL dating techniques.

In the aforementioned study, there are two models describing the phenomena: a) the simplest model, namely One Trap One Recombination (OTOR) and b) the more complex one, named Two Traps One Recombination (TTOR). The new analytical equations for the dose response of dosimetric materials were created with the use of the well-known Lambert W function. We managed to recreate these expressions in an Excel spreadsheet, for a more practical use. Also, using the same Lambert W function, two other spreadsheets were constructed, describing the continuous wave optically stimulated luminescence (CW-OSL), as well as the standard TL deconvolution model.

Results and Discussion

Model	Equation	Clarifications	Free parameters
OTOR	$\frac{n}{N} = 1 + \frac{W\left[(R-1)\exp\left(R-1-\frac{D}{D_c}\right)\right]}{1-R}$	$\frac{n}{N} = \frac{I}{I_0}$	I_0, D_c, R
TTOR	$\frac{n_2}{N_2} = 1 - (\frac{1}{B} W\left(B \exp(B) \exp\left(-\frac{D}{D_c}\right)\right)^{\frac{A_2}{A_1}}$	$\frac{n_2}{N_2} = \frac{I}{I_0}$	$I_0, D_c, B, \frac{A_2}{A_1}$

***Table 1**: Dose response equations based on the lambert W function*

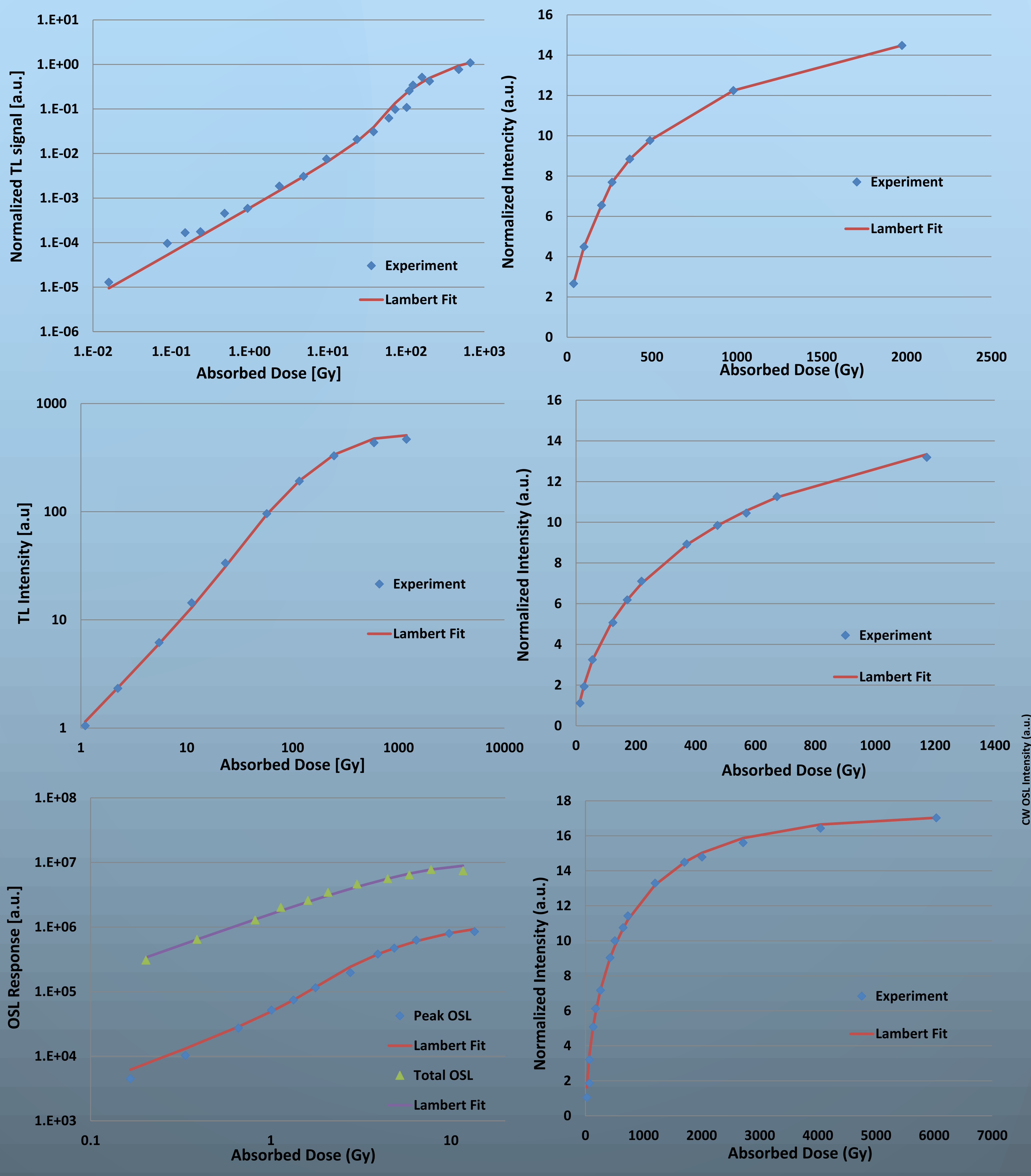

Figure 1: *Deconvolution of different samples based on absorbed dose.* ***Left)*** *TTOR model* ***Right)*** *OTOR model.*

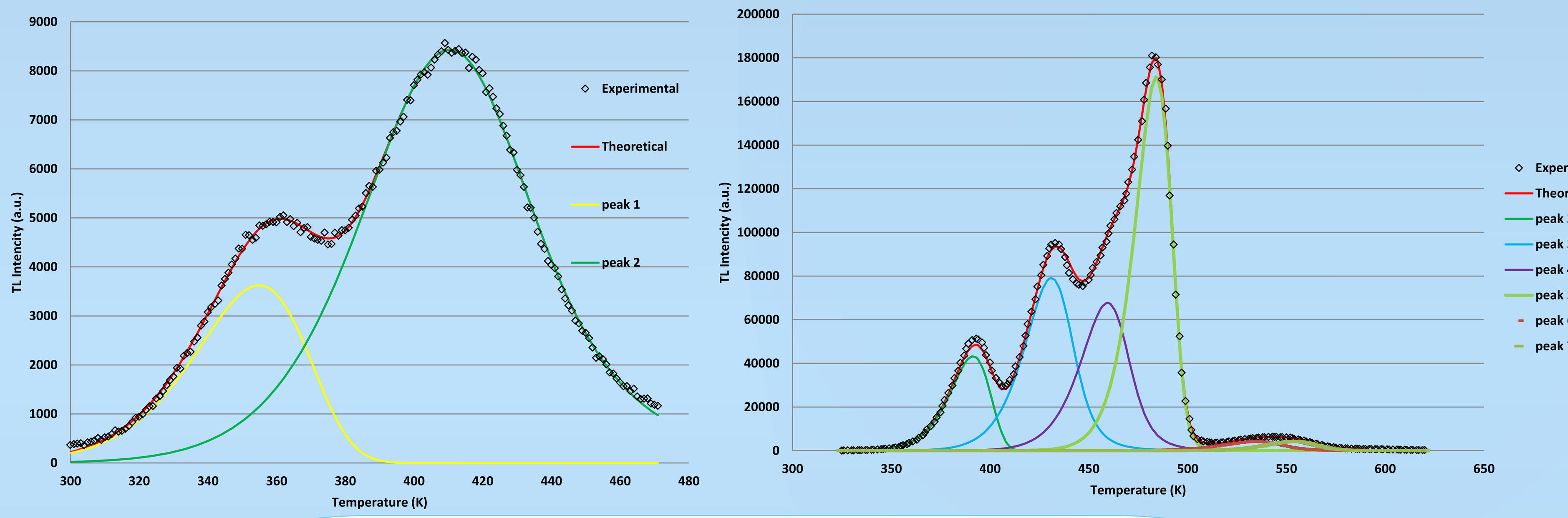

Figure 2: *Deconvolution of two samples using the TL equation.* ***Left)*** *BeO sample* ***Right)*** *LiF sample.*

Model	Equation	Clarifications	Free parameters
CW-OSL	$I = \frac{I_0\lambda}{W[e^{z_1}] + W[e^{z_1}]^2}$	$z_1(t) = \frac{R}{1-R} - ln\left(\frac{1-R}{R}\right) + \lambda\frac{t}{1-R}$	I_0, λ, R
TL	$I = I_m \exp\left(\frac{E(T-T_m)}{kTT_m)}\right)\frac{W[e^{z_{1m}}] + W[e^{z_1 m}]^2}{W[e^{z_1}] + W[e^{z_1}]^2}$	$z_1 = \frac{R}{1-R} - ln\left(\frac{1-R}{R}\right) + \frac{Ee^{\frac{E}{kT_m}}}{kT_m^2}\frac{F(T,E)}{1-1.05R^{1.26}}$ $F(T,E) = \frac{kT^2}{E}E^{-\frac{E}{kT}}\left(1-2\frac{kT}{E}\right)$	I_m, T_m, E, R

***Table 2**: TL and CW-OSL equations based on the lambert W function*

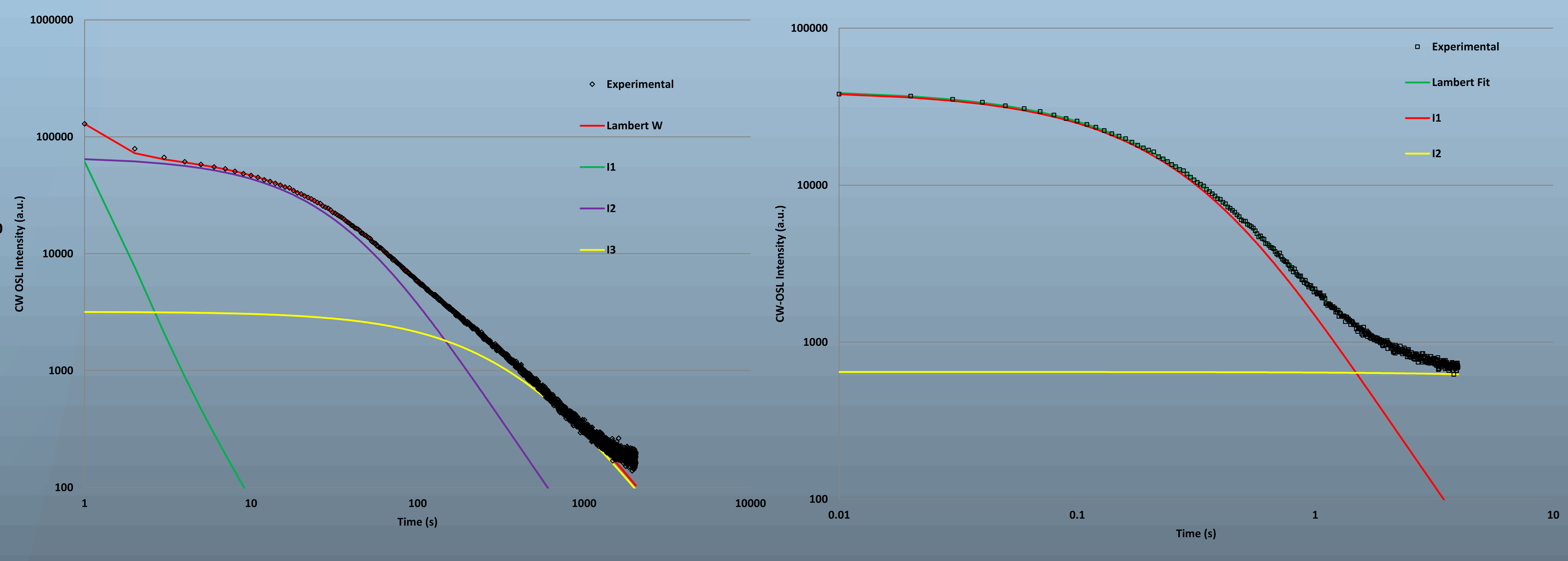

Figure 3: *Deconvolution of two BeO samples using the CW-OSL equation.*

Conclusions - Implications

- The fact that all equations have a solid fit is confirmed once more.
- Up to today, the equations that have been traditionally applied for the dose responses, have not relations with TL and OSL and have included mainly the saturation exponential area. Unfortunately, these latter fittings could not be used for dosimetry and age assessment when the signal shows non-linear behavior and finally approaches saturation. The analysis of the present study implies that the new analytical equations can take full advantage of the entire dose response region, including, in addition to linear, the non-linear response and the early saturation part of it. This allows accurate calibration, through the additive dose technique for evaluation of the equivalent dose, in dose regions well above the linear one and up to part of the saturation region. As a result, this study will provide the possibility of measuring the higher values of equivalent dose and therefore of the upper luminescence age limits beyond 1 Ma.

References

[1] Pagonis, V., Kitis, G., Chen, R., 2020. A new analytical equation for the dose response of dosimetric materials, based on the Lambert W function, Journal of Luminescence, 225, 117333, 2-3.

[2] Kitis, G., Polymeris, G.S., Pagonis, V., 2019. Stimulated luminescence emission: From phenomenological models to master analytical equations, Applied Radiation and Isotopes, 153, 108797.