Supplementary Information (SI) for Journal of Materials Chemistry C.

Supporting Information

Structural Phase Transition and Cooperative Luminescence in $K_3Yb(PO_4)_2:Eu^{3+}$ for Multimodal Down-shifting and Up-converting Luminescence Thermometry

Anam Javaid[1], Maja Szymczak[1], Damian Szymanski[1], Lukasz Marciniak[1*]

[1] Institute of Low Temperature and Structure Research, Polish Academy of Sciences,

Okólna 2, 50-422 Wrocław, Poland

*corresponding author: l.marciniak@intibs.pl

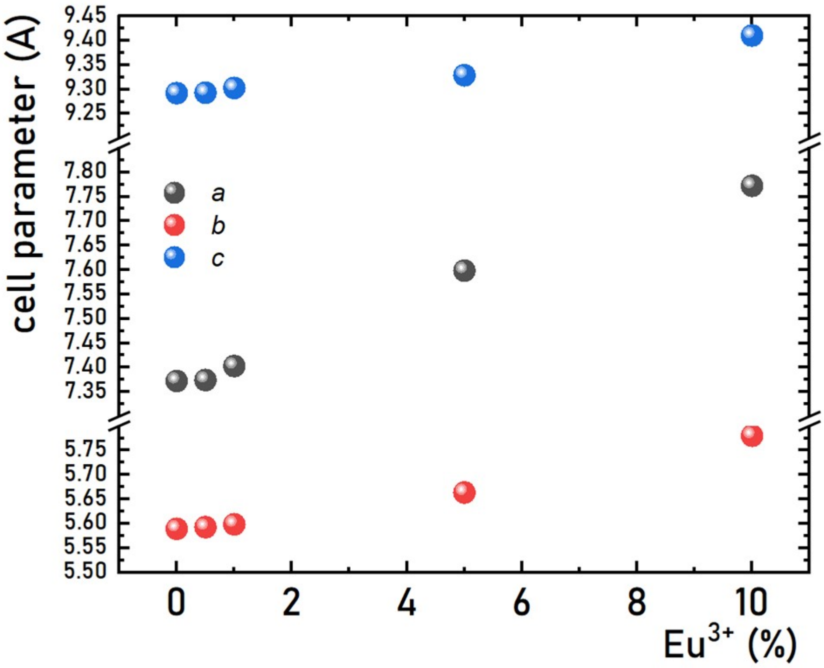

Figure S1. The influence of Eu^{3+} ions concentration on the unit cell parameters for $K_3Yb(PO_4)_2:Eu^{3+}$.

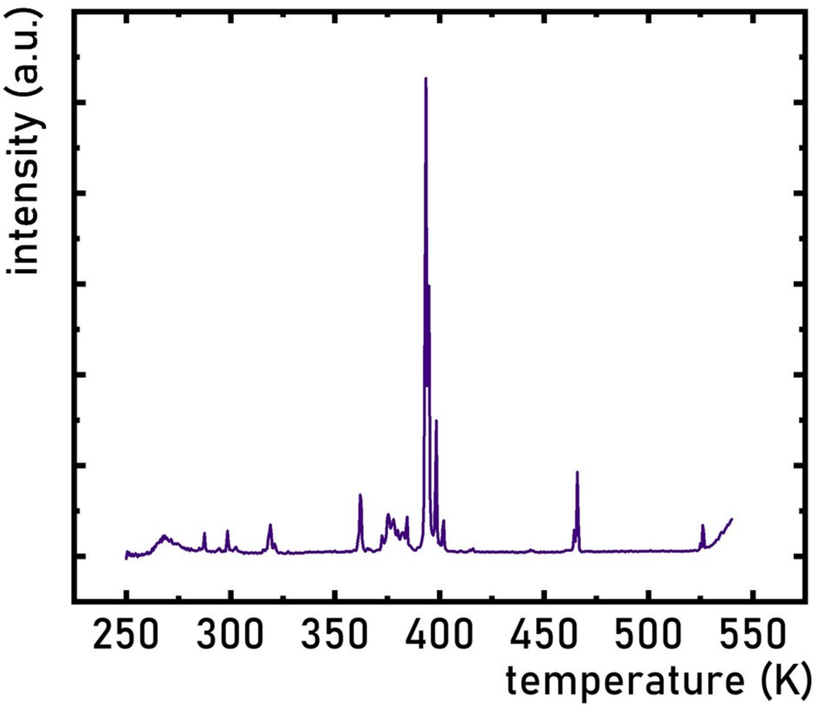

Figure S2. Excitation spectra of Eu^{3+} ions in $K_3Yb(PO_4)_2$:0.5%Eu^{3+} measured at 93 K.

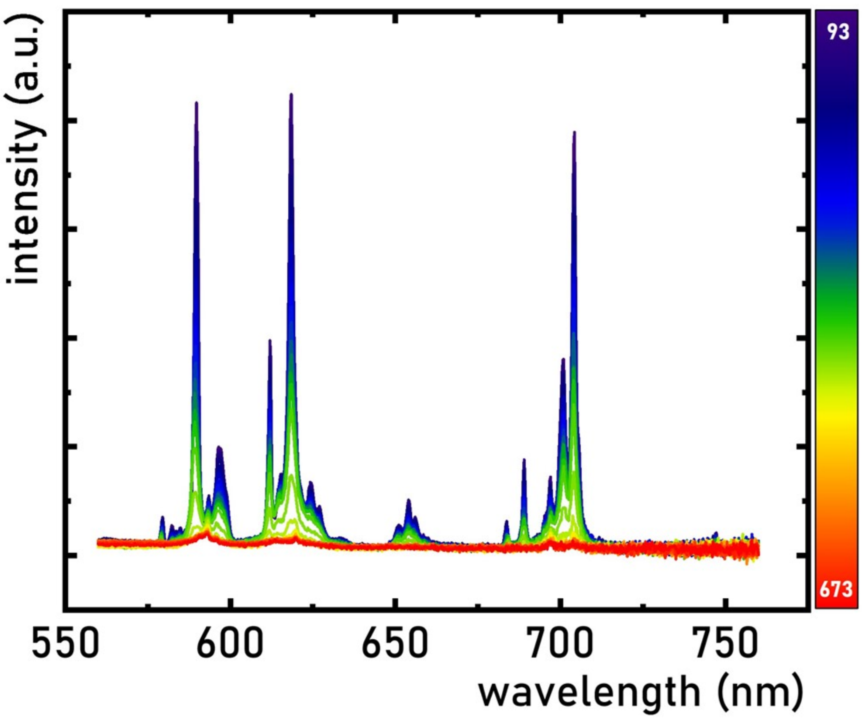

Figure S3. Emission spectra of Eu^{3+} ions in $K_3Yb(PO_4)_2$:0.5%Eu^{3+} measured as a function of temperature.

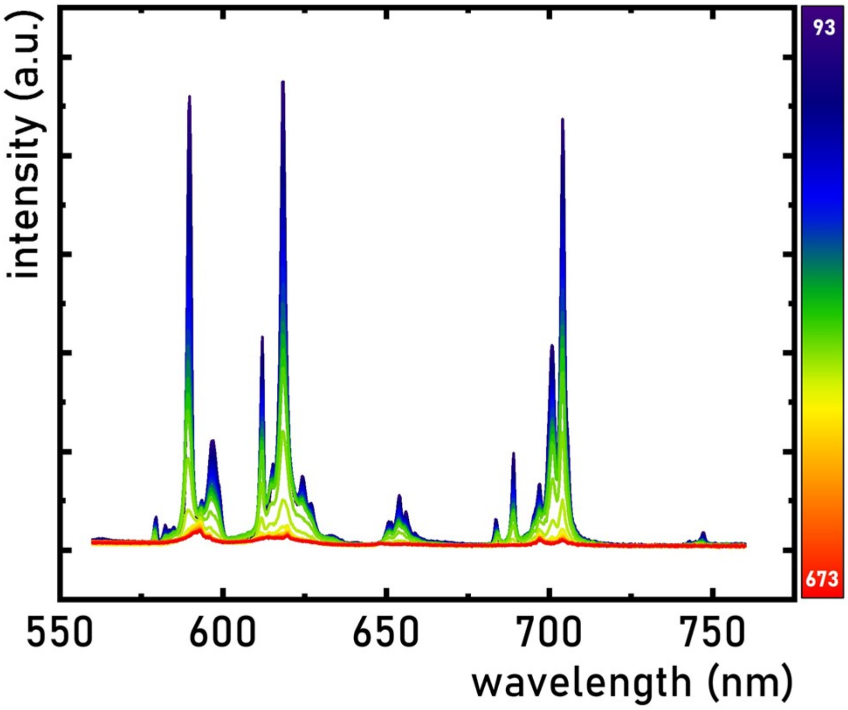

Figure S4. Emission spectra of Eu^{3+} ions in $K_3Yb(PO_4)_2$:1%Eu^{3+} measured as a function of temperature.

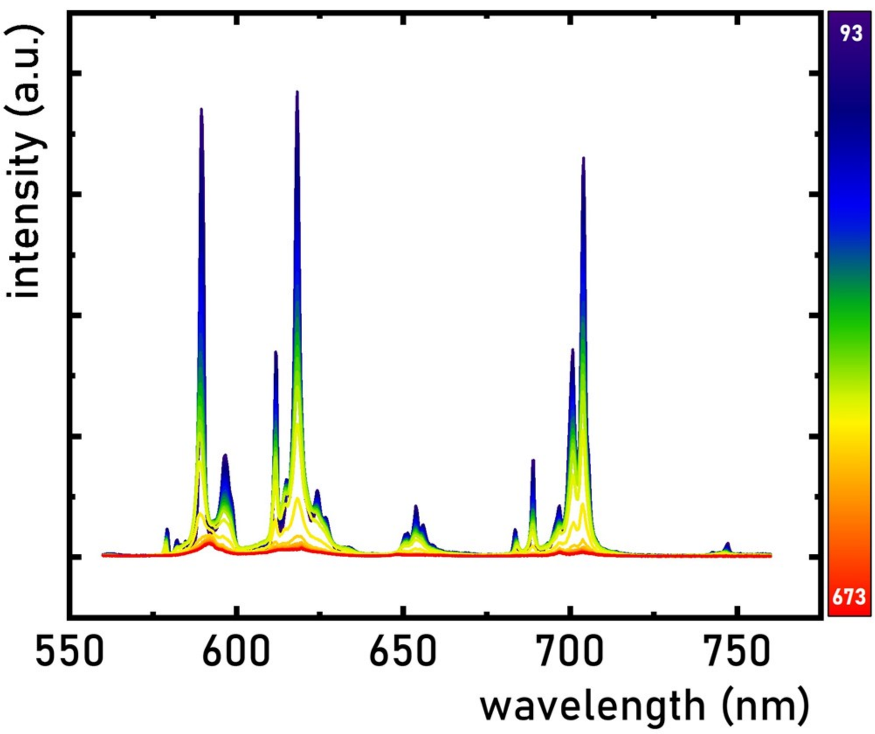

Figure S5. Emission spectra of Eu^{3+} ions in $K_3Yb(PO_4)_2$:5%Eu^{3+} measured as a function of temperature.

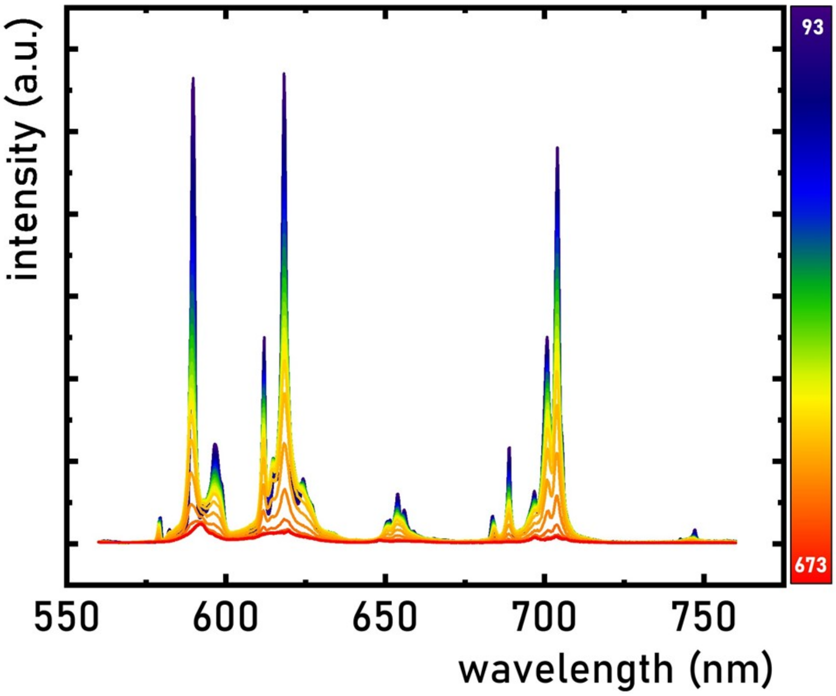

Figure S6. Emission spectra of Eu^{3+} ions in $K_3Yb(PO_4)_2$:10%Eu^{3+} measured as a function of temperature.

Temperature determination uncertainty (δT) can be estimated from the relative sensitivity and the signal to noise ratio using the equation given below:

$$\delta T = \frac{1}{S_R}\frac{\delta LIR}{LIR} \tag{S1}$$

where δLIR/LIR represents the uncertainty in the LIR determination, primarily influenced by the signal-to-noise ratio:

$$\frac{\delta LIR}{LIR} = \sqrt{\left(\frac{\delta I_{LT}}{I_{LT}}\right)^2 + \left(\frac{\delta I_{HT}}{I_{HT}}\right)^2} \tag{S2}$$

where the δI is the uncertainty of the emission intensity determination and I_{LT}, I_{HT} represents the emission intensity of LT and HT phases of $K_3Yb(PO_4)_2$:Eu^{3+}, respectively.

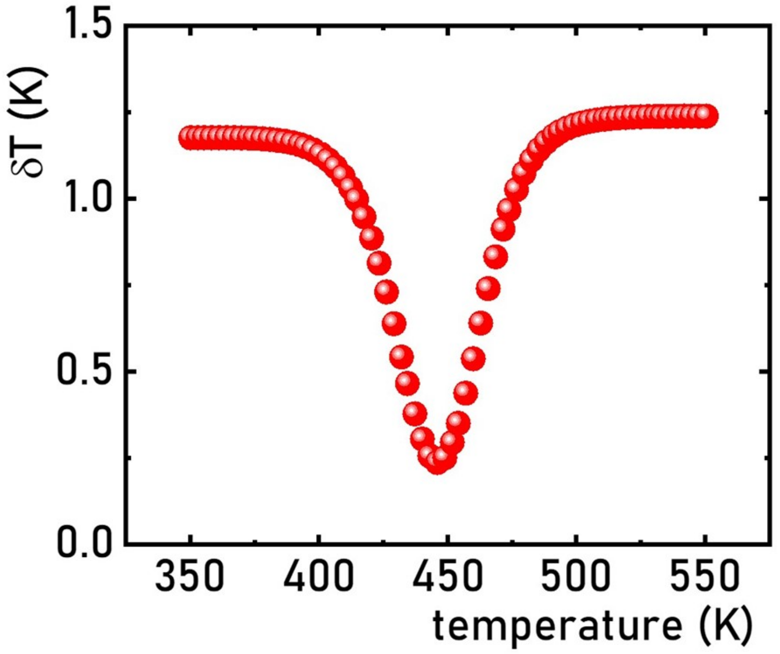

Figure S7. Temperature determination uncertainty δT determined for LIR_2 of $K_3Yb(PO_4)_2$:0.5%Eu^{3+} based on the methodology described above.

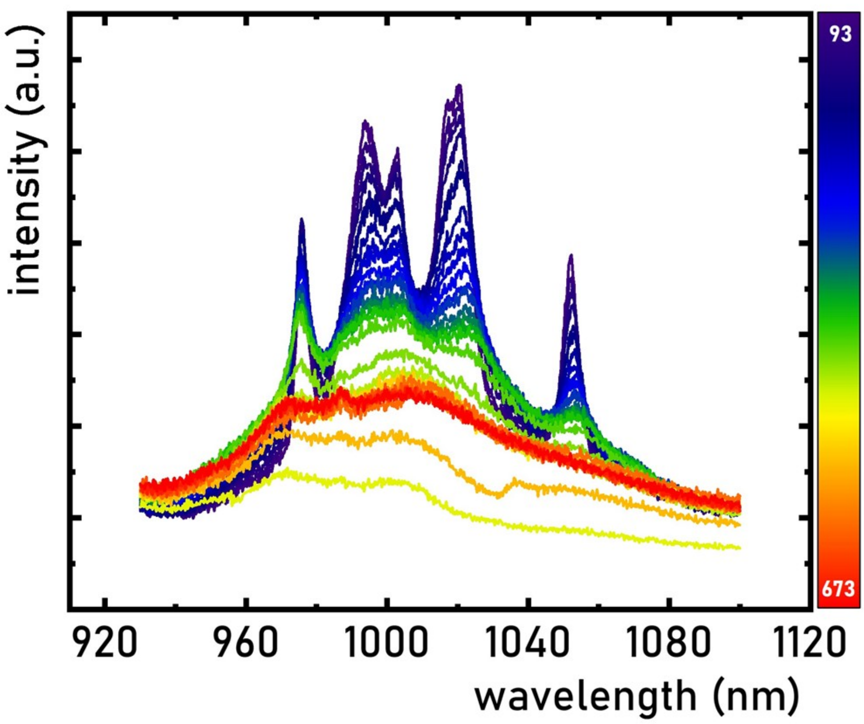

Figure S8. Emission spectra of Yb^{3+} ions in $K_3Yb(PO_4)_2$:0.5%Eu^{3+} measured as a function of temperature.

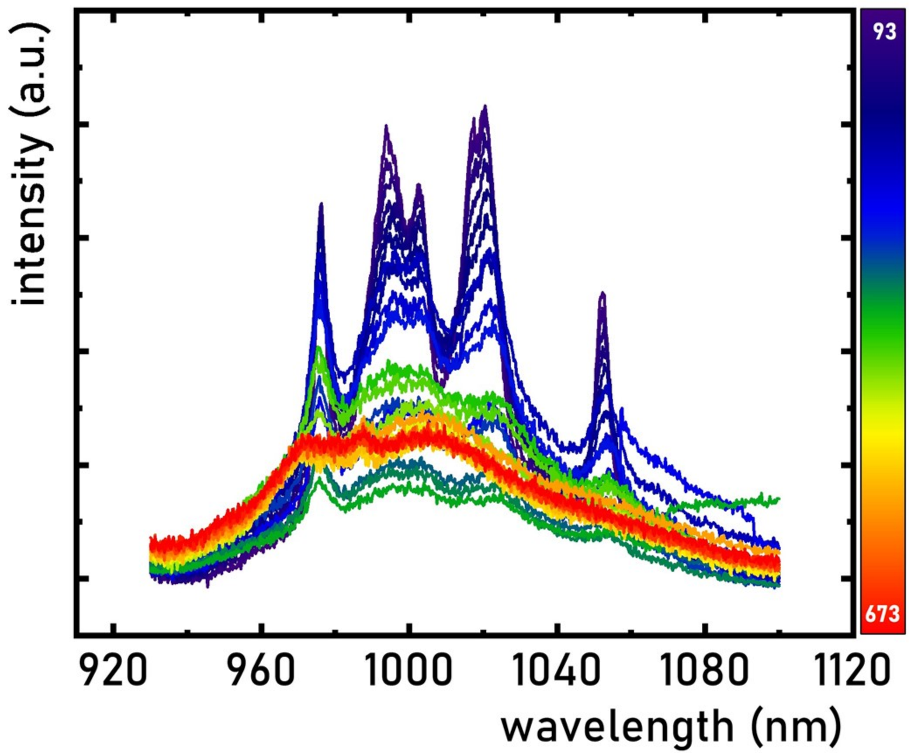

Figure S9. Emission spectra of Yb^{3+} ions in $K_3Yb(PO_4)_2$:1%Eu^{3+} measured as a function of temperature.

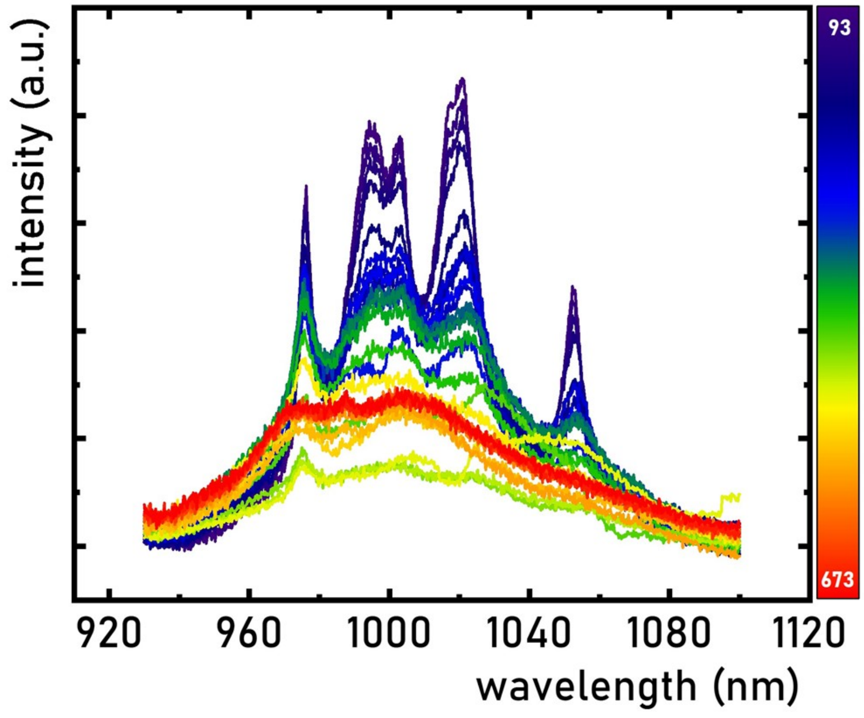

Figure S10. Emission spectra of Yb^{3+} ions in $K_3Yb(PO_4)_2$:5%Eu^{3+} measured as a function of temperature.

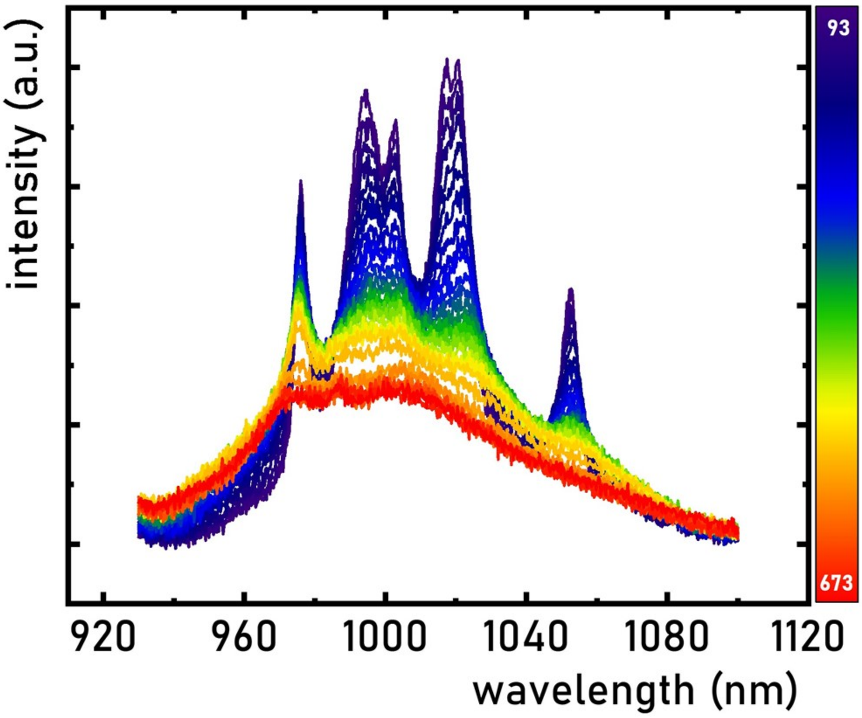

Figure S11. Emission spectra of Yb^{3+} ions in $K_3Yb(PO_4)_2$:10%Eu^{3+} measured as a function of temperature.

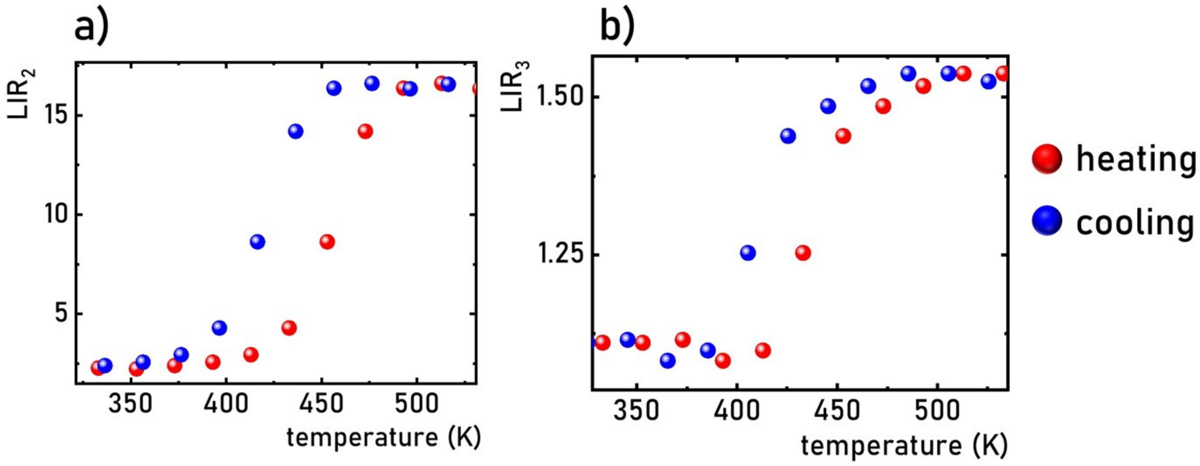

Figure S12. Thermal dependence of LIR_2 – a) and LIR_3 -b) for $K_3Yb(PO_4)_2$:0.5%Eu^{3+} within heating and cooling cycle.

The temperature determination uncertainty associated with the hysteresis (δT_H) effect can be calculated as follows:

$$\delta T_H = T(LIR_{2H}) - T(LIR_{2C}) \quad \text{(S3)}$$

The average LIR_{2avr} can be calculated based on the thermal dependence of LIR_2 during heating (LIR_{2H}) and cooling cycles (LIR_{2C}) as follows:

$$\mathrm{LIR}_{2\mathrm{avr}}(T) = \frac{\mathrm{LIR}_{2\mathrm{H}}(T) + \mathrm{LIR}_{2\mathrm{C}}(T)}{2} \tag{S4}$$

Temperature determination uncertainty associated with the presence of the hysteresis loop can be reduced using the LIR_{2avr}:

$$\delta T_H = T(LIR_{2avr}) - T(LIR_{2C}) \tag{S5}$$

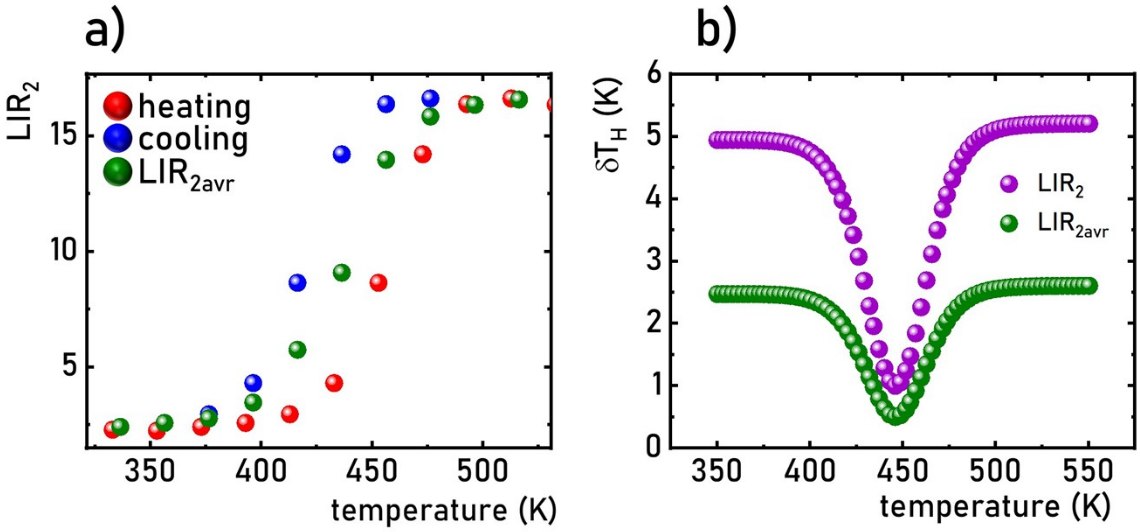

Figure S13. thermal dependence of LIR_2 for $K_3Yb(PO_4)_2$:Eu^{3+}:0.5%Eu^{3+} withing heating and cooling cycle with the LIR_{2avr} – a); temperature determination uncertainty for this luminescence thermometer resultant from the hysteresis effect determined using LIR_2 and LIR_{2avr} – b).

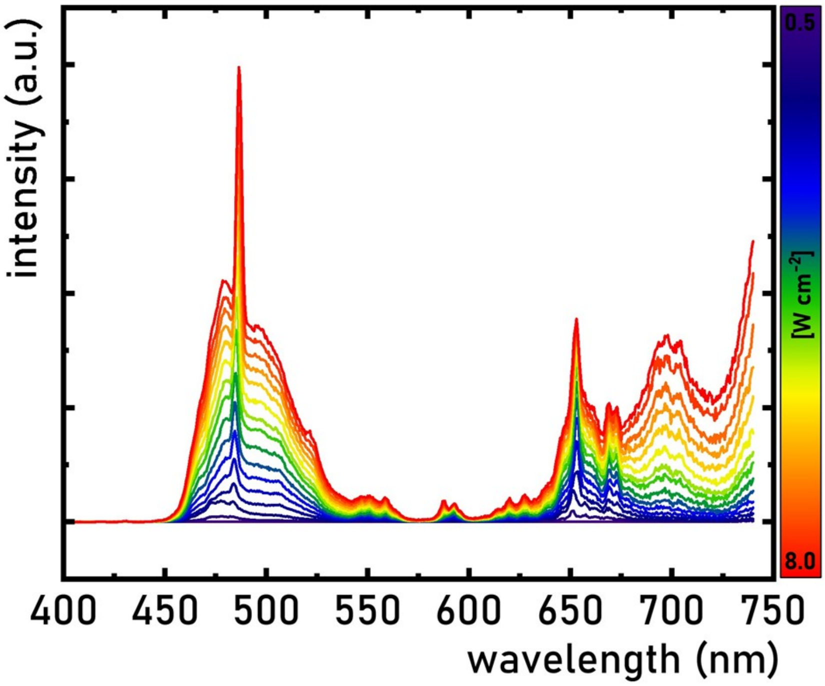

Figure S14. Up-conversion emission spectra of $K_3Yb(PO_4)_2$:0.5%Eu^{3+} measured as a function of excitation density.

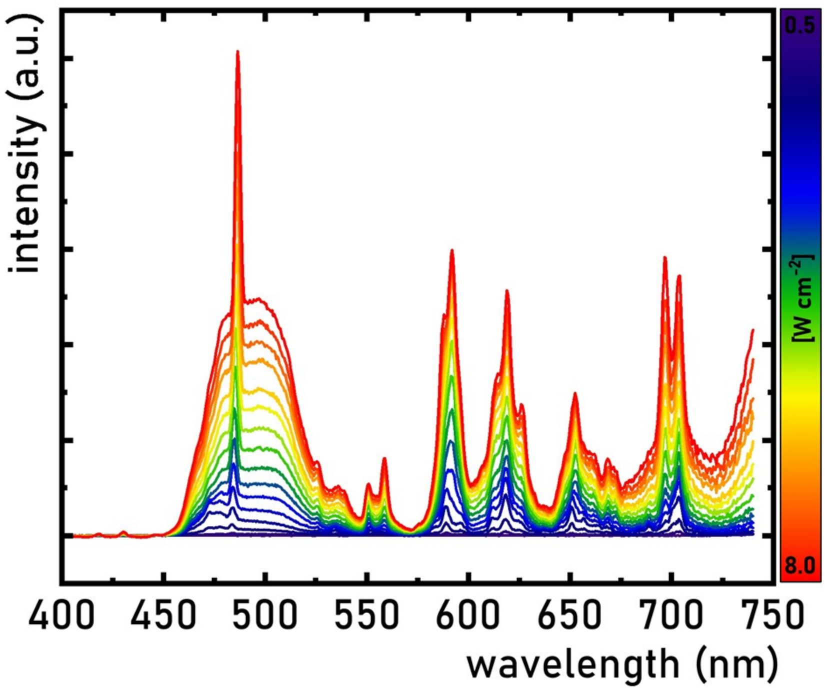

Figure S15. Up-conversion emission spectra of $K_3Yb(PO_4)_2$:10%Eu^{3+} measured as a function of excitation density.

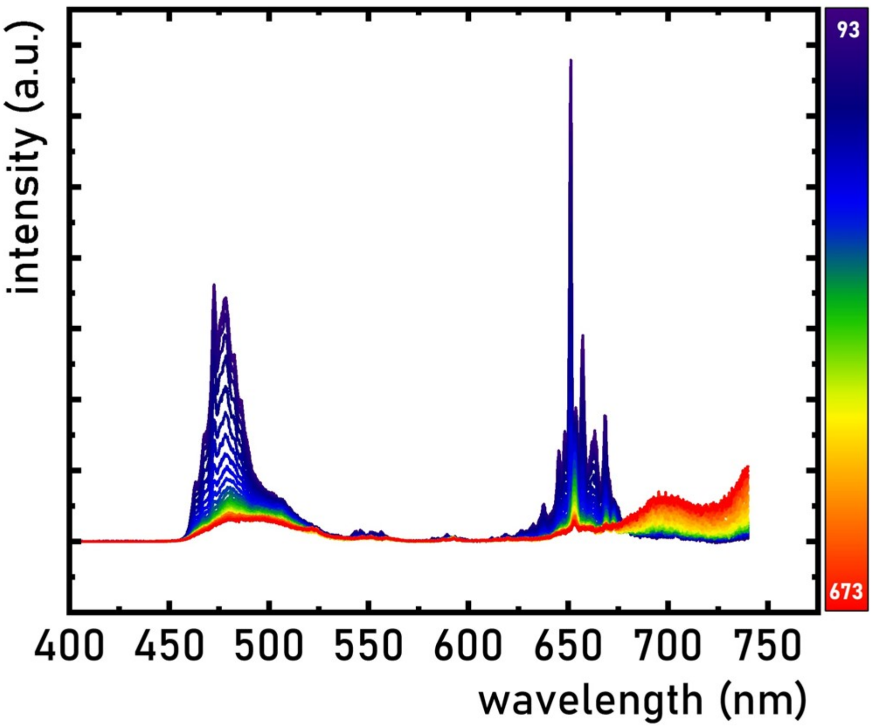

Figure S16. Up-conversion emission spectra of $K_3Yb(PO_4)_2$:0.5%Eu^{3+} measured as a function of temperature.

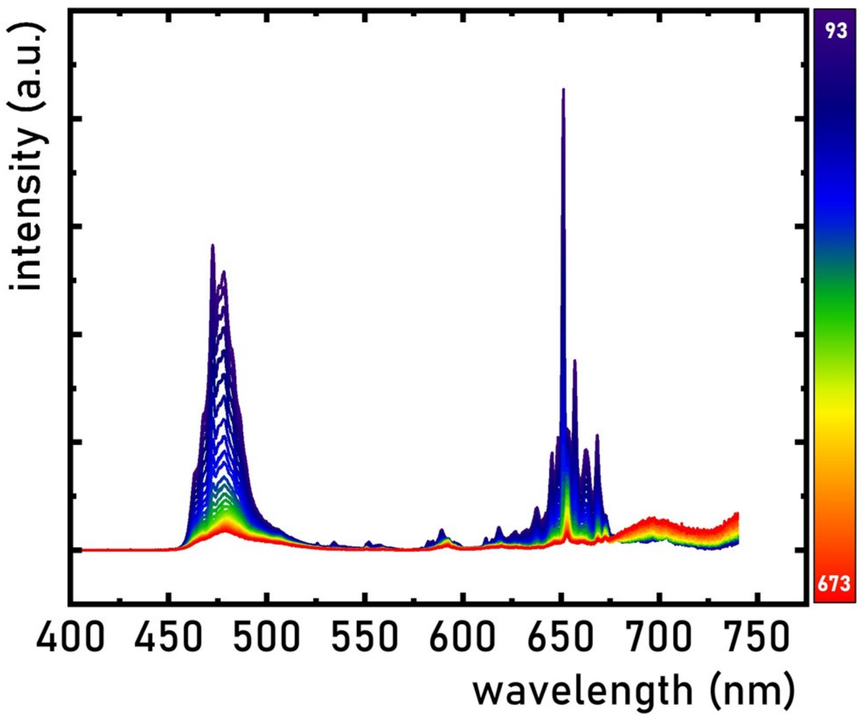

Figure S17. Up-conversion emission spectra of $K_3Yb(PO_4)_2$:1%Eu^{3+} measured as a function of temperature.

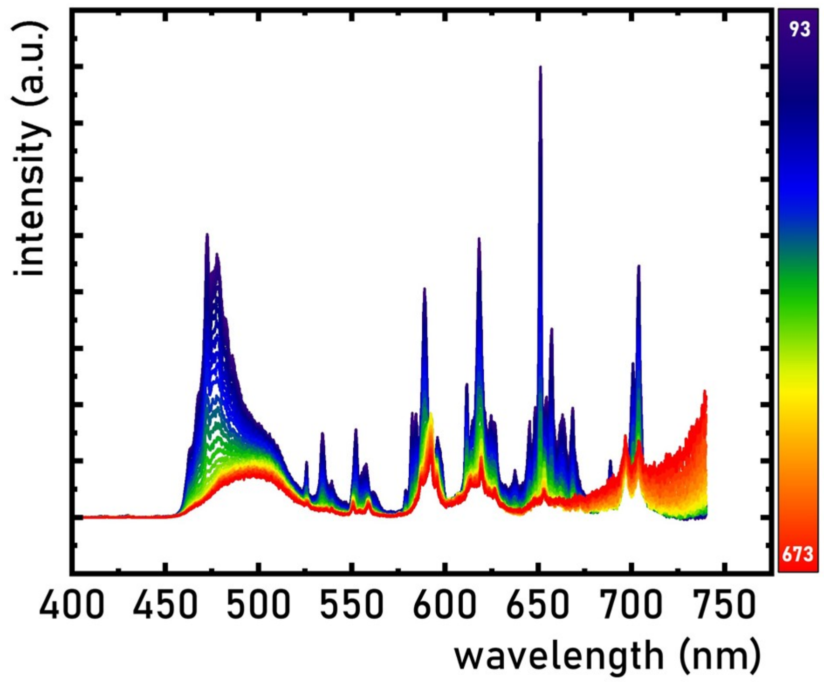

Figure S18. Up-conversion emission spectra of $K_3Yb(PO_4)_2$:10%Eu^{3+} measured as a function of temperature.