Saturated Kerr-type nonlinear properties of thiol-capped CdTe QDs

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Abstract: In this work we report an experimental investigation of the nonlinear optical properties of thiol-capped CdTe QDs in strong confinement regime and near resonance. Using a cw laser excitation in a Z-Scan experimental setup, we show the presence of saturated Kerr-type nonlinear optical properties of CdTe QDs, at low intensity levels. The huge optical nonlinearity and the control of the linear and nonlinear optical properties with the QDs size is of special interest for applications in integrated nanophotonic devices.

1. Linear properties of CdTe QDs colloidal samples

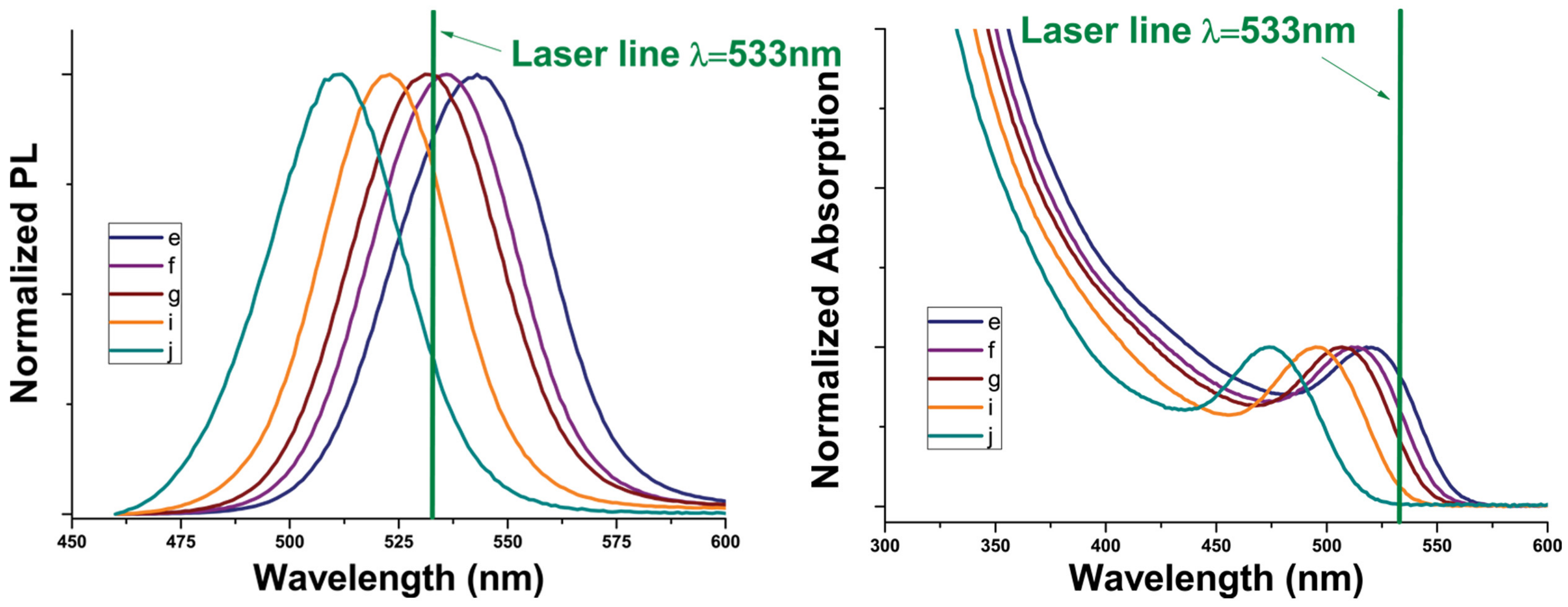
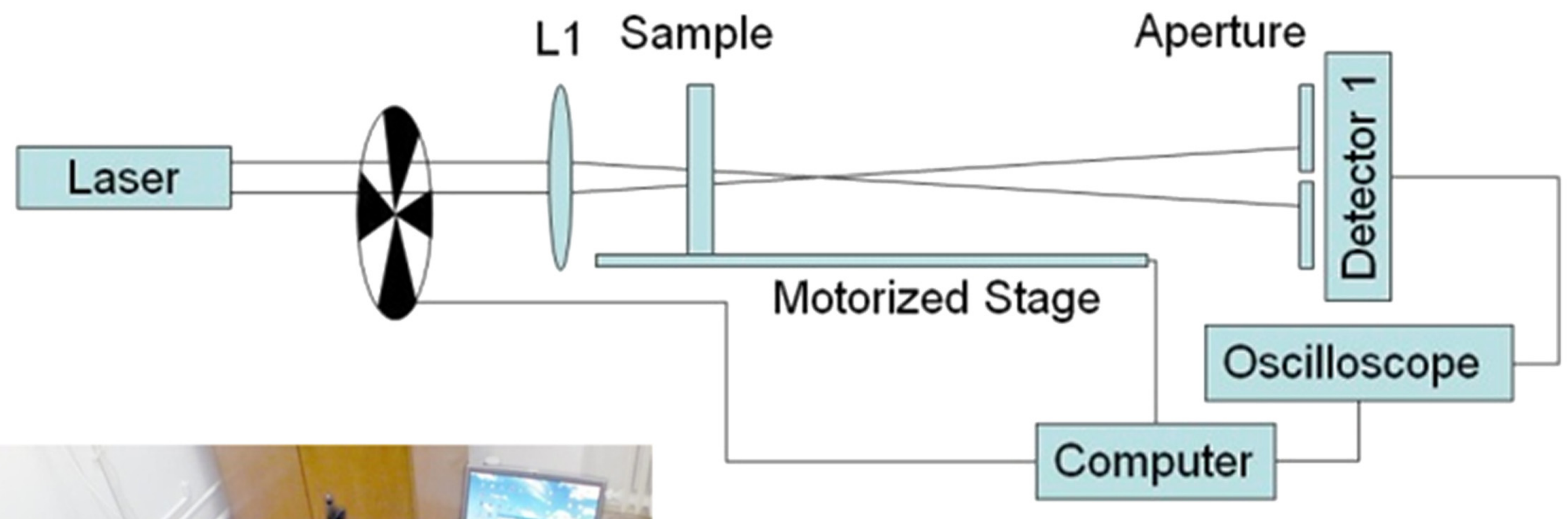


Fig.1. We have specially designed our CdTe QDs to have their resonances near the excitation wavelength of the laser used in the nonlinear experiments (λ=532nm)

2. Z-Scan experiments on CdTe QDs



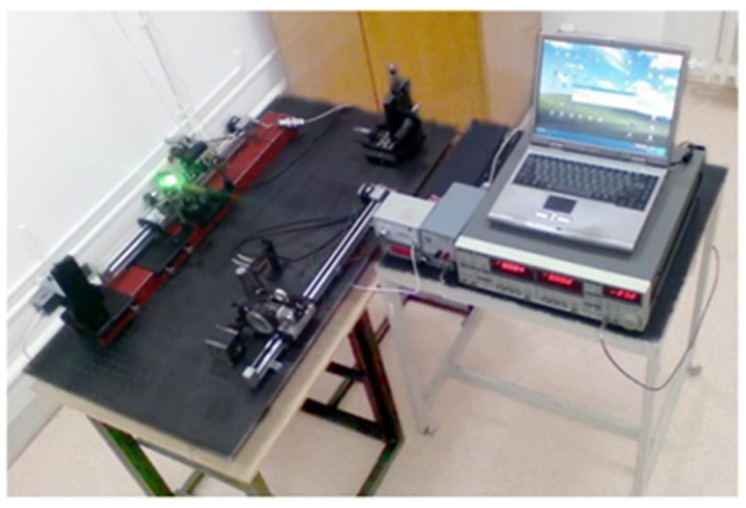


Fig.2. Z-Scan experimental setup

Laser	cw SHG Nd:YAG (λ=532nm)
L1	f=3.5 cm
Sample	Colloidal CdTe QDs in water in a 0.2 mm spectroscopic cell
Detector	Si detector

3. Nonlinear properties of Cd-Te QDs samples set

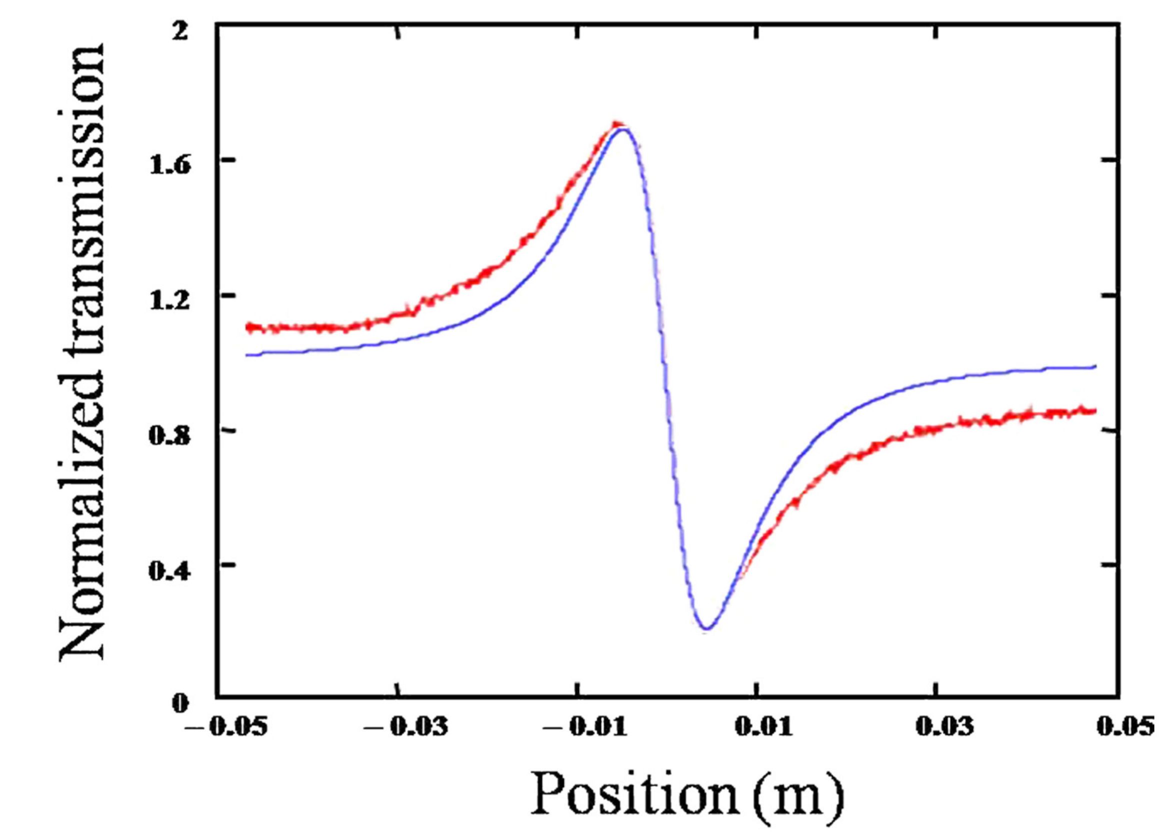


Fig. 3. Typical Z-Scan experimental curve (red) for CdTe QDs fitted with eq. 1 (blue), for obtaining the nonlinear refractive index change (Δn)

The theoretical function for finding the nonlinear refractive index change from the Z-Scan experimental data is:

$$T_{\beta=0}(x,\Delta\phi_0) \cong 1 + \frac{4\Delta\phi_0 x}{(x^2+1)(x^2+9)} \qquad (1)$$

where $x = z/z_0$, is the normalized distance, z_0 - the Rayleigh distance, $\Delta\phi_0 = k\Delta n L_{eff}$, Δn is the nonlinear induced refractive index change, $L_{eff} = (1-e^{-\alpha L})/\alpha$ is the effective length of the medium, α - the linear absorption and L the thickness of the medium.

We consider the case of saturated Kerr type nonlinear refractive index change, and we can write it as:

$$\Delta n(I_0) = \frac{n_2 I_0}{1+\frac{I_0}{I_{sat}}} \qquad (2)$$

Using this equation we obtain the values for the nonlinear refractive index, n_2, and for the saturation intensity, I_{sat}, presented in Table 1, Fig. 5 and Fig. 6

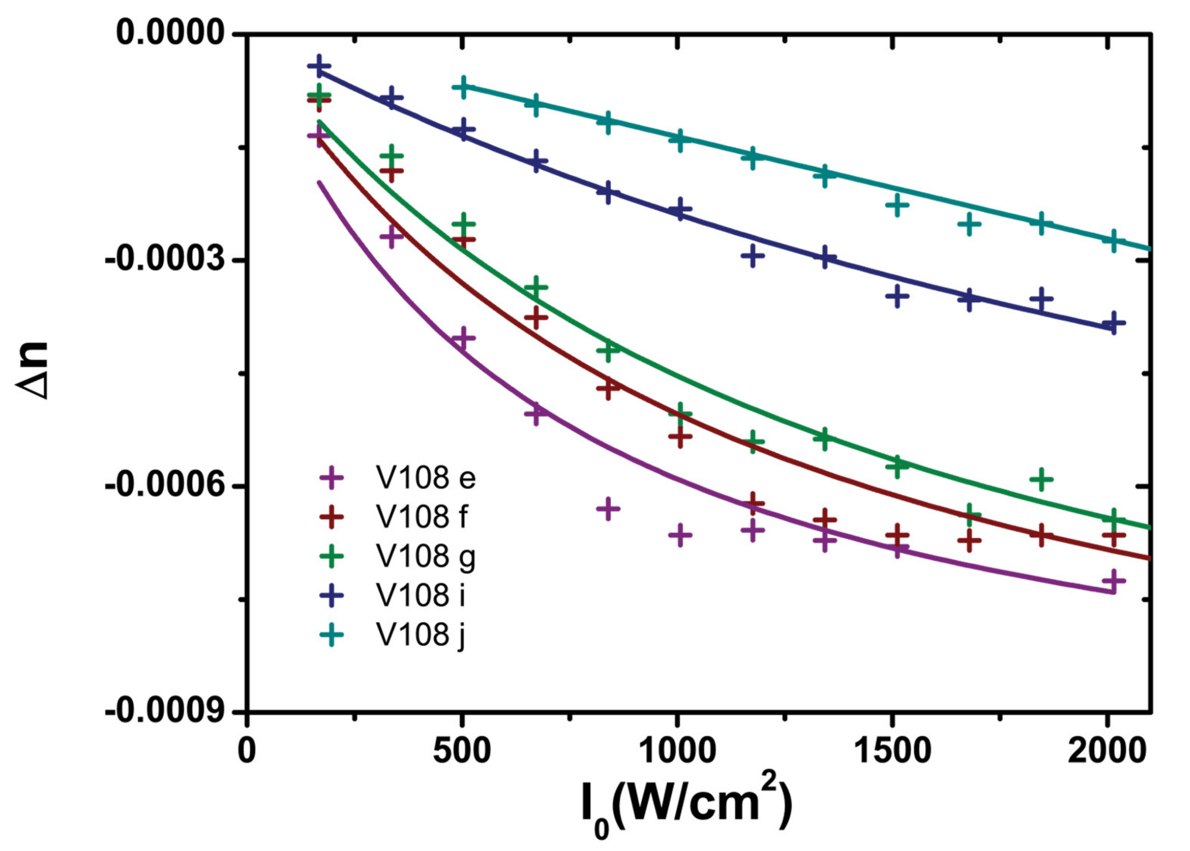


Fig. 4. Experimental values for nonlinear refractive index change (Δn) for different CdTe QD's sizes function of the incident intensities fitted with the equation for saturated Kerr effect (eq. 2)

Table 1. CdTe QDs sample properties

Name	*1s-1s Pos (nm)*	*PL max (nm)*	*size (nm)*	*n_2 (10^{-7}cm²/W)*	*I_{sat} (W/cm²)*
v108j	*474*	*510.4*	*1.8*	*-1.36*	*-*
v108i	*495*	*522.4*	*2.0*	*-3.09*	*3409.9*
v108g	*507*	*531.3*	*2.1*	*-7.72*	*1424.4*
v108f	*511*	*535.4*	*2.2*	*-9.57*	*1111.7*
v108e	*518*	*542.1*	*2.2*	*-14.65*	*674.5*

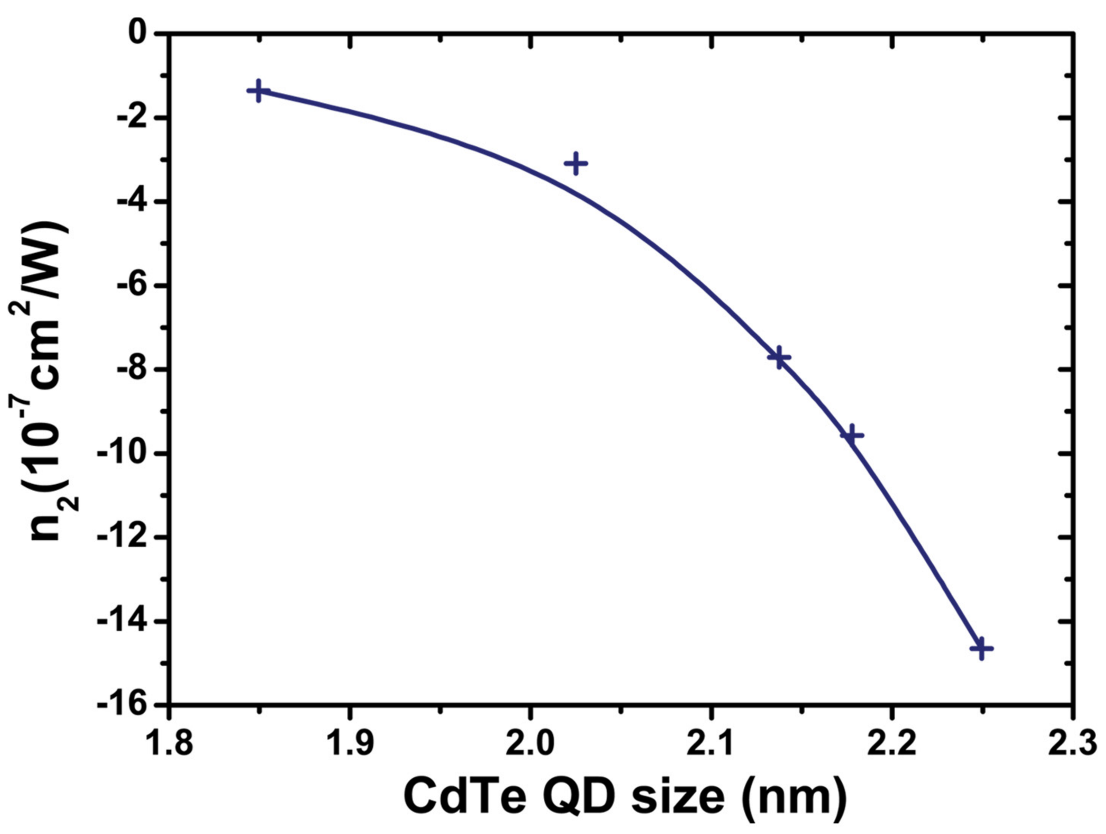


Fig. 5. Nonlinear refractive index, n_2, function of the QDs size

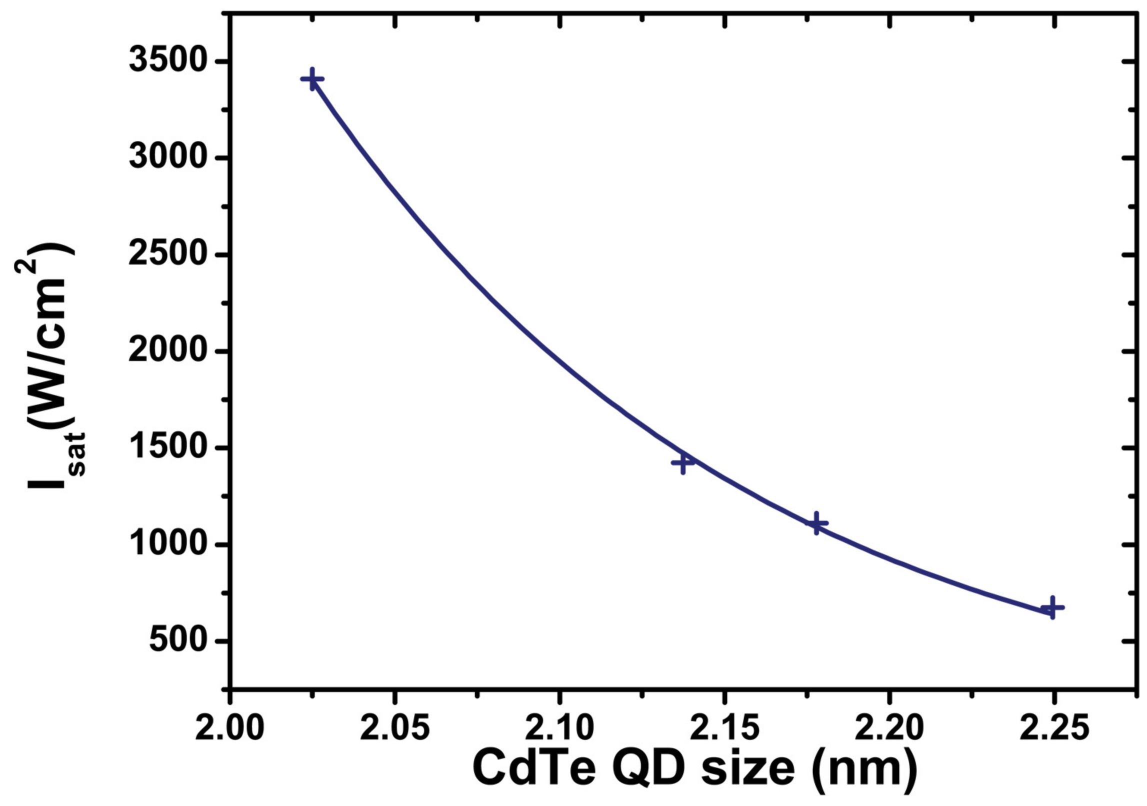


Fig. 6. Saturation intensity function of the QDs size

The saturated Kerr type is a process that is described by a single nonlinear refractive index in the formula 2 and can easily explain the saturation of the nonlinear refractive index change with excitation intensity. If we calculate the numbers of atoms in the volume of excitation, taking into account the concentration of the nanocrystals / litre and the number of atoms in one nanocrystal we arrive to the conclusion that we have ~5 nanocrystals in the volume of excitation, far from focus, which leads to a maximum number of ~950 atoms. If we go to the focus of the excitation beam the number of atoms will dramatically decrease resulting in an easily saturation of colloid excitation.

4. Conclusions

In conclusion, in this paper we show, for the first time, huge and size controllable nonlinear optical effects in CdTe colloidal nanocrystals, which reach saturation at low intensity levels (order of 10^3W/cm²). These types of nonlinear properties are of special interest for application in integrated nano-photonic devices.

Acknowledgement

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