
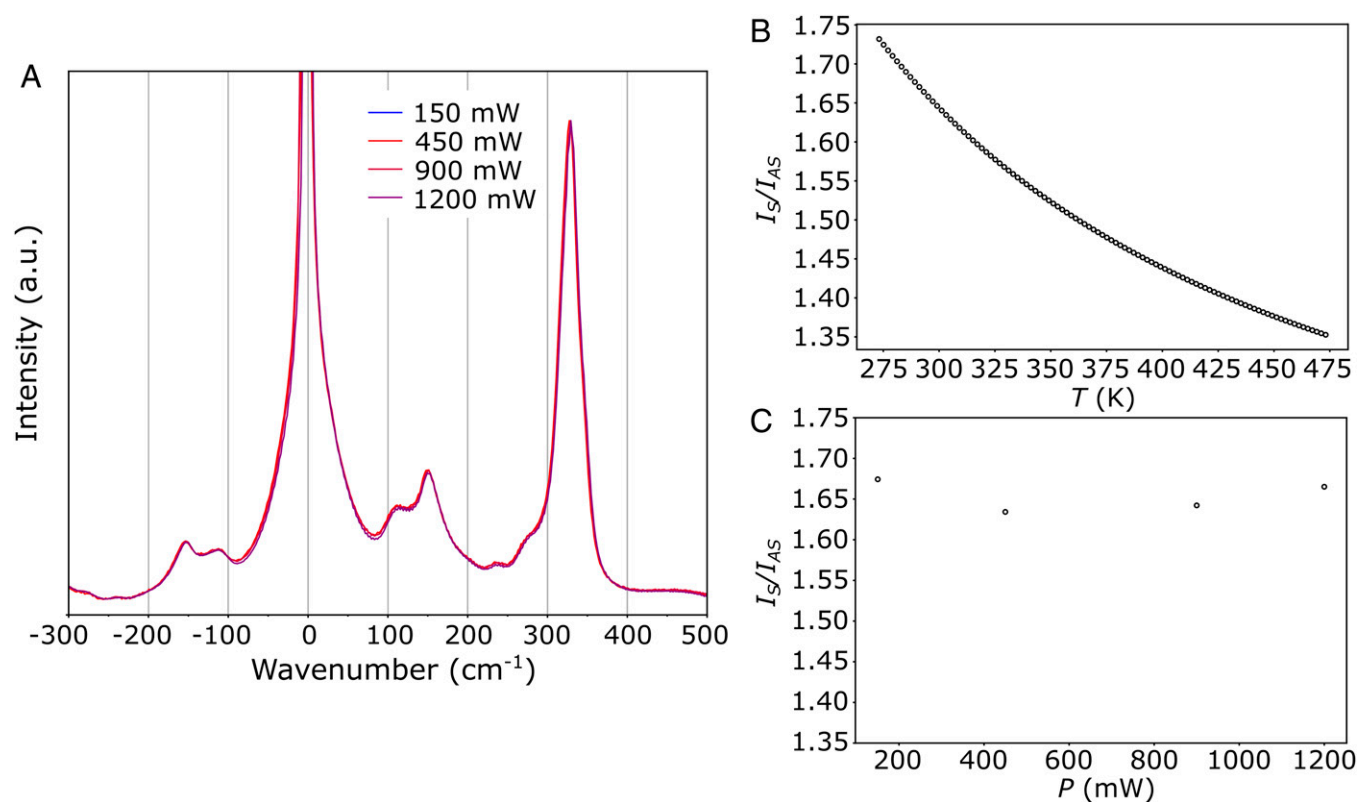


# Reply to Liao and Wynne: The size of crystal nucleus remains an open question

Takuji B. M. Adachi<sup>a,1</sup> , Johanna Brazard<sup>a</sup>, and Oscar Urquidi<sup>a</sup>



**Fig. 1.** (A) Low-frequency Raman spectra measured on the setup described in Urquidi et al. (2). The detection part was modified using SureBlock XLF Notch filters (Coherent) to be able to measure the low-frequency region of Raman spectrum. The sample is SnCl<sub>2</sub> dissolved in water (1 mol·L<sup>-1</sup>). This sample is suited for this purpose because it has well-defined peaks at the region where we can measure both Stokes and anti-Stokes Raman spectrum. No change of the spectra was observed from 150 mW up to 1.2 W. If the temperature were elevated by the 532-nm laser, the relative peak intensity of Stokes Raman ( $I_S$ ) to anti-Stokes Raman ( $I_{AS}$ ) would have decreased. (B) The expected ratio of  $I_S$  to  $I_{AS}$  at 111 cm<sup>-1</sup> peak as a function of temperature calculated using the model in ref. 5. As expected, the  $I_S/I_{AS}$  decreases as temperature increases. (C) The  $I_S/I_{AS}$  calculated from the data shown in A. The ratio remains constant around room temperature even at 1.2-W laser power.

The letter by Liao and Wynne (1) criticizes the established knowledge in the field of optical trapping prior to our work. In this reply, we highlight some key literature along with the experiments we performed to reconfirm the pre-established facts.

We estimated the temperature increase as 20 mK (2) based on Ito et al. (3). Mao et al. (4) presented a model to calculate the temperature increase by laser and experimentally verified it. Their model (ref. 4, equation 4a) predicts a 70-mK increase, at most, in our experiments. Two different methods estimate a similarly small temperature increase.

The letter by Liao and Wynne (1) lacks a description of key parameters used in their “back-of-the-envelope calculation.” It is hard to comment whether they simply made an error in calculation or the model may not be suited for this case (e.g., dimensionality of the heat equation) to obtain a 163-K increase. Liao and Wynne used Raman thermometry to support their claim and estimated an even higher temperature increase (400 K). Neither raw

Raman spectra nor the wavenumber used for calculating temperature are shown, which makes it hard to point out what they did wrong. Raman thermometry requires careful measurement and analysis (5). Also, as a basic principle, one should avoid extrapolating data for 1.2 W using data from 10 to 50 mW.

Fig. 1 shows Raman spectra of SnCl<sub>2</sub> aqueous solution measured on our setup. The laser power was varied up to

Author affiliations: <sup>a</sup>Department of Physical Chemistry, Sciences II, University of Geneva, 1211 Geneva, Switzerland

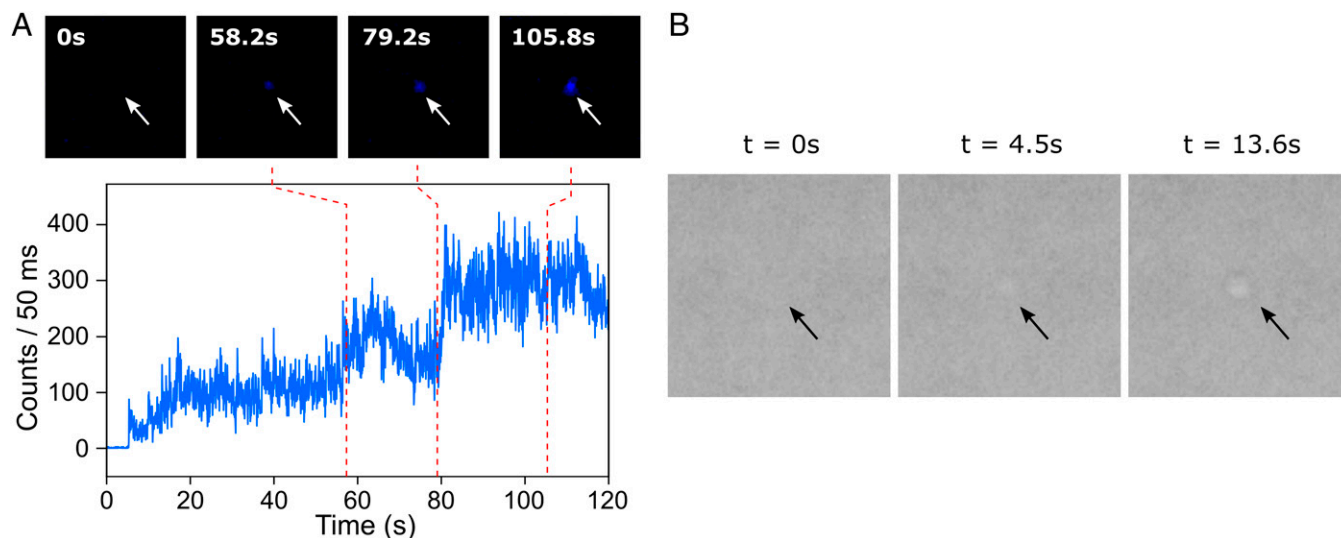
Author contributions: T.B.M.A., J.B., and O.U. wrote the paper; and T.B.M.A., J.B., and O.U. performed the experiments and analysis shown in this letter.

The authors declare no competing interest.

Copyright © 2022 the Author(s). Published by PNAS. This article is distributed under Creative Commons Attribution-NonCommercial-NoDerivatives License 4.0 (CC BY-NC-ND).

<sup>1</sup>To whom correspondence may be addressed. Email: Takuji.Adachi@unige.ch.

Published July 25, 2022.



**Fig. 2.** Demonstration of optical trapping of nanoparticles. (A) Fluorescence time trace of 120-nm polystyrene nanoparticles doped by fluorescent label (Spherotech Inc., light yellow) under 785-nm continuous-wave (CW) laser irradiation. The 785-nm laser works as an optical trapping beam and two-photon excitation beam. The number of trapped nanoparticles increases, and fluorescence intensity increases. Fluorescence microscope images also confirm that the laser spot becomes brighter due to the increased number of trapped nanoparticles. (Scale:  $10 \times 10 \mu\text{m}$ .) The arrows indicate the focused laser spot. Similar experiments were originally reported in ref. 8. (B) Bright-field microscope images of 60-nm polystyrene nanoparticles (Spherotech Inc.) under optical trapping by a 532-nm CW laser. (Scale:  $10 \times 10 \mu\text{m}$ .) The arrows indicate the laser spot. The size of particles is smaller than the diffraction limit of optical microscope; therefore, images appear blurry. The blurry objects at the center, however, gradually become more evident over the course of trapping as the number of trapped nanoparticles increases. Similar experiments were originally reported in ref. 9.

1.2 W. This sample shows distinct peaks and is better suited than the glycine/D<sub>2</sub>O solution used by Liao and Wynne. No temperature increase was observed. Moreover, movie S1 in ref. 2 shows no boiling.

The optical trapping model in the Rayleigh regime (6, 7) predicts that nanoscale objects can be stably trapped. There are many papers showing this. We reproduced the results reported in refs. 8 and 9 (Fig. 2) to reconfirm this fact. Liao and Wynne cite ref. 10 to claim that particles of  $<1 \mu\text{m}$  cannot be trapped. However, this reference discusses the trapping of nanomaterials. In Urquidi et al. (2), the glycine solution was filtered (200-nm pore) to avoid microscale dust particles, and no microscale particle is seen in movie S1 in ref. 2.

The title of the letter by Liao and Wynne (1) indicates that they wrongly interpreted our paper. We have never

mentioned that oligomers are the cause of nucleation. We specifically wrote a sentence stating that, “in this work, we could not estimate the size of aggregates prior to nucleation.” Our contribution is proposing that the structure of glycine prenucleation aggregates may be hydrogen-bonded linear networks, which goes beyond the general description of prenucleation aggregates as “amorphous.” The size of the nucleus remains an open question. Our results show, however, that it is at least smaller than the diffraction limit of optical microscopy.

Liao and Wynne recently showed that laser can transform microparticles into crystals (11). It is, however, an overstatement to claim that all the other works in the field of laser-induced crystallization occur through the same path. Liao and Wynne (11) present no evidence to impose such a strong conclusion on the previous works from other experts.

1. Z. Liao, K. Wynne, Mesoscopic amorphous particles rather than oligomeric molecular aggregates are the cause of laser induced crystal nucleation. *Proc. Natl. Acad. Sci. U.S.A.*, 10.1073/pnas.2207173119 (2022)
2. O. Urquidi, J. Brazard, N. LeMessurier, L. Simine, T. B. M. Adachi, In situ optical spectroscopy of crystallization: One crystal nucleation at a time. *Proc. Natl. Acad. Sci. U.S.A.* **119**, e2122990119 (2022).
3. S. Ito, T. Sugiyama, N. Toitani, G. Katayama, H. Miyasaka, Application of fluorescence correlation spectroscopy to the measurement of local temperature in solutions under optical trapping condition. *J. Phys. Chem. B* **111**, 2365–2371 (2007).
4. H. Mao, J. R. Arias-Gonzalez, S. B. Smith, I. Tinoco Jr., C. Bustamante, Temperature control methods in a laser tweezers system. *Biophys. J.* **89**, 1308–1316 (2005).
5. D. Tuschel, Raman thermometry: Understanding the mathematics to better design Raman measurements. *Spectroscopy (Springf.)* **34**, 8–13 (2019).
6. A. Ashkin, J. M. Dziedzic, J. E. Bjorkholm, S. Chu, Observation of a single-beam gradient force optical trap for dielectric particles. *Opt. Lett.* **11**, 288 (1986).
7. Y. Harada, T. Asakura, Radiation forces on a dielectric sphere in the Rayleigh scattering regime. *Opt. Commun.* **124**, 529–541 (1996).
8. C. Hosokawa, H. Yoshikawa, H. Masuhara, Optical assembling dynamics of individual polymer nanospheres investigated by single-particle fluorescence detection. *Phys. Rev. E Stat. Nonlin. Soft Matter Phys.* **70**, 061410 (2004).
9. R. Gillibert et al., Raman tweezers for small microplastics and nanoplastics identification in seawater. *Environ. Sci. Technol.* **53**, 9003–9013 (2019).
10. S. E. S. Spesytseva, K. Dholakia, Trapping in a material world. *ACS Photonics* **3**, 719–736 (2016).
11. Z. Liao, K. Wynne, A metastable amorphous intermediate is responsible for laser-induced nucleation of glycine. *J. Am. Chem. Soc.* **144**, 6727–6733 (2022).