Electronic Supplementary Material (ESI) for Journal of Materials Chemistry C.

Electronic supplementary information

White light emission from gold nanoclusters embedded bacteria

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Experimental Section

Chemicals and growth Media

Tetrachloroauric acid (17 wt. % solution of $HAuCl_4$ in dilute HCl; 99.99%) and 3-mercaptopropionic acid were purchased from Sigma-Aldrich Chemicals, U.S.A. Growth media for different bacteria i.e. nutrient broth (NB) for *Bacillus cereus* MTCC 1305, brain–heart infusion (BHI) for *Enterococcus faecalis* MTCC 439 and Luria-Bertani broth (LB) for GFP and *Escherichia coli* MTCC 433 were procured from Hi Media, Mumbai, India. Milli-Q grade water (>18 MΩ cm−1, Millipore) water was used for all the experiments.

Bacterial Strains

The generation of white light has been achieved with two Gram negative and two Gram positive bacteria. Gram negative bacteria *Escherichia coli* MTCC 433 and GFP expressing *Escherichia coli* were grown in Luria-Bertani broth (LB) under ambient condition (37°C at 220 rpm for 12 h). Whereas Gram positive *Bacillus cereus* MTCC 1305 and *Enterococcus faecalis* MTCC 439 bacteria were grown in nutrient broth (NB) and brain heart infusion Broth (BHI) media respectively under similar conditions.

Synthesis of Au NCs on Bacteria

The dispersion containing bacteria (grown overnight) were centrifuged at 10,000 rpm for 2 min. The so obtained pellet was washed with de-ionized water and redispersed in water. The dispersed bacteria were serially diluted to obtain bacterial concentrations of 2×10^6, 10^6,10^5 and 10^4. In order to synthesise Au NCs on bacterial template, 18µL $HAuCl_4$ (10 mM)

and 6µL of 0.11M MPA were added to a dispersion containing bacteria. The pH of the dispersion was maintained at ~7. Following thorough mixing, the dispersion was kept at 37 °C for 5 min and was cooled thereafter. The dispersion obtained herein was luminescent upon excitation at 320 nm. The luminescent dispersion was centrifuged at a speed of 10,000 rpm for 2 min. The pellet following repeated washing, was thereafter redispersed in water and was used for further experiments.

UV-Vis and luminescence measurements:

UV−visible spectrophotometer (PerkinElmer Lamda 25) was used for recording the UV-Vis absorbance spectra. Photoluminescence measurements were performed using Fluromax – 4 spectrofluorimeter (Horiba Jobin Yvon).

Transmission Electron Microscopy (TEM) analysis:

TEM analysis was performed using Jeol JEM 2100 operating at an accelerating voltage of 200 KV. TEM samples were prepared by drop casting the sample onto a carbon coated copper TEM grid.

X- Ray Photoelectron Spectroscopy (XPS) analysis:

To confirm the electronic state of Au NCs synthesized on the surface of bacteria X- ray photoelectron spectroscopy (XPS) analysis was carried out in PHI 5000 Versa Probe II, FEI Inc. scanning XPS microprobe.

Field-Emission Scanning Electron Microscopy (FESEM):

JEOL JSM-7610F was used for FESEM analysis of the samples. The dispersion was drop cast onto an aluminium foil and was dried in a desiccator. Prior to analysis, the samples were

coated with platinum using platinum coating sputter coater (JEC-3000FC auto fine coater) JEOL.

Atomic Force Microscopy (AFM):

The prepared samples were drop cast on an aluminium foil and observed under atomic force microscope (Agilent, Model 5500 series).

Confocal Microscopy:

White light generation from bacteria was confirmed by detailed confocal studies using Zeiss LSM 880 microscope. The as synthesized Au NCs on bacteria were drop cast on a glass slide and was covered with a coverslip which was further sealed on both sides by using nail paint. The prepared samples were observed under different emission range e.g. blue, green and red (upon excitation at 405nm). Samples containing control GFP expressing bacteria were excited using a laser source of 488 nm.

CIE chromaticity coordinates

The "go cie" software was used to calculate the CIE chromaticity coordinates.

Calculation of quantum yield:

The quantum yield of white luminescent bacteria was calculated with reference to quinine sulphate in 0.1 M H_2SO_4. The following equation has been employed to calculate the quantum yield of white luminescent GFP expressing bacteria:

$$Q_{Bac} = Q_{Ref} \times (I_{bac}/I_{Ref}) \times (A_{Ref}/A_{Bac}) \times (\eta^2_{Bac}/\eta^2_{Ref})$$

Here, Q_{Bac}= Quantum yield of Au NCs synthesised on GFP expressing bacteria;

Q_{Ref} = Quantum yield of quinine sulphate. It has been reported as 0.54

I_{Bac}= Area under photoluminescence curve of Au NCs synthesised on GFP expressing bacteria;

I_{Ref} = Area under photoluminescence curve of quinine sulphate;

A_{Ref} = Absorbance of quinine sulphate;

A_{Bac}= Absorbance of Au NCs synthesised on GFP expressing bacteria;

η = Refractive Index of Au NCs synthesised on GFP expressing bacteria and quinine sulphate respectively;

The optical density of all the samples was maintained below 0.1. The quantum yield has been calculated to be **2.5 ± 0.7%.**

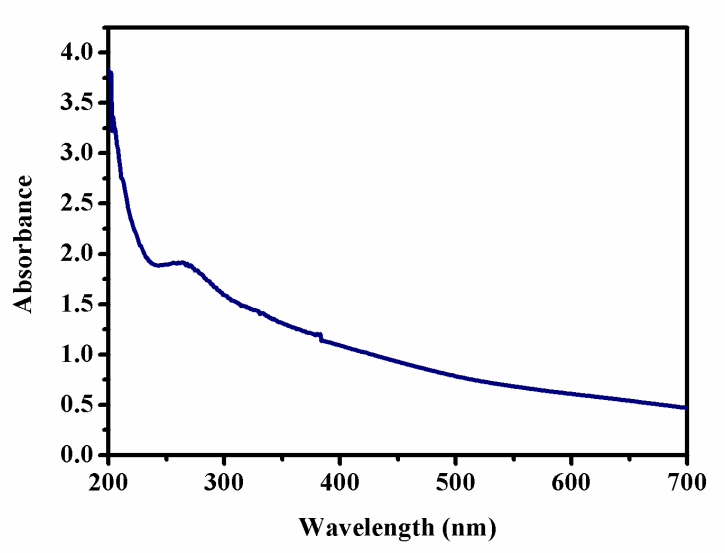

Fig. S1: UV-Vis absorbance spectrum of GFP expressing bacteria.

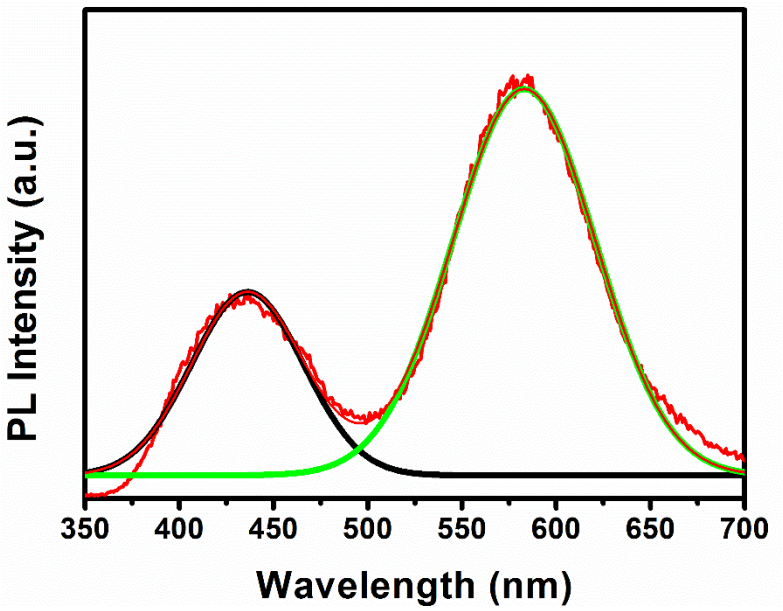

Fig. S2: Deconvoluted emission spectrum of GFP expressing bacteria following synthesis of Au nanoclusters.

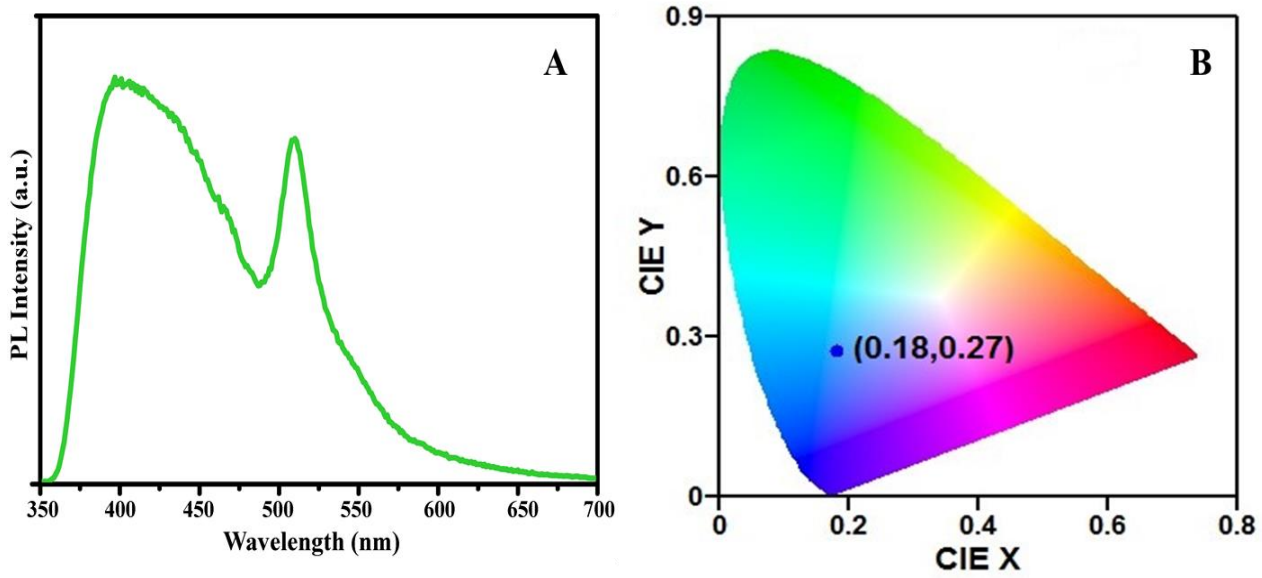

Fig. S3: (A) Photoluminescence spectrum of green fluorescent protein expressing bacteria and **(B)** Corresponding CIE chromaticity diagram showing chromaticity index of 0.18 and 0.27.

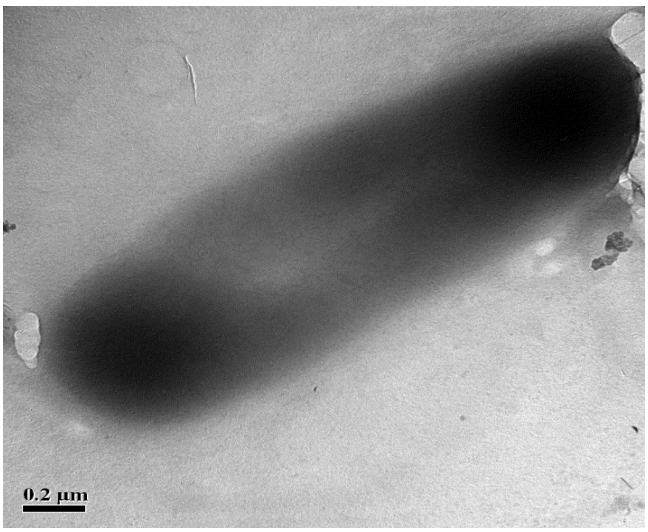

Fig. S4: Transmission electron microscopic image of GFP expressing bacteria**.**

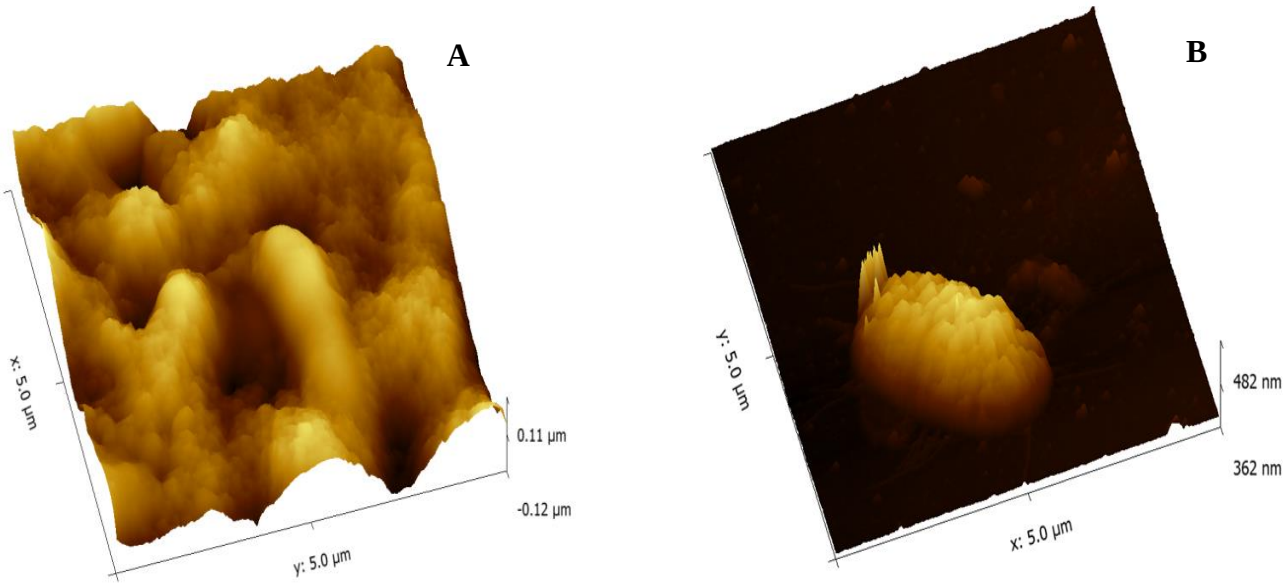

Fig. S5: Atomic force microscopic (AFM) image of **(A)** green fluorescent protein (GFP) expressing bacteria following synthesis of Au NCs and **(B)** control GFP bacteria.

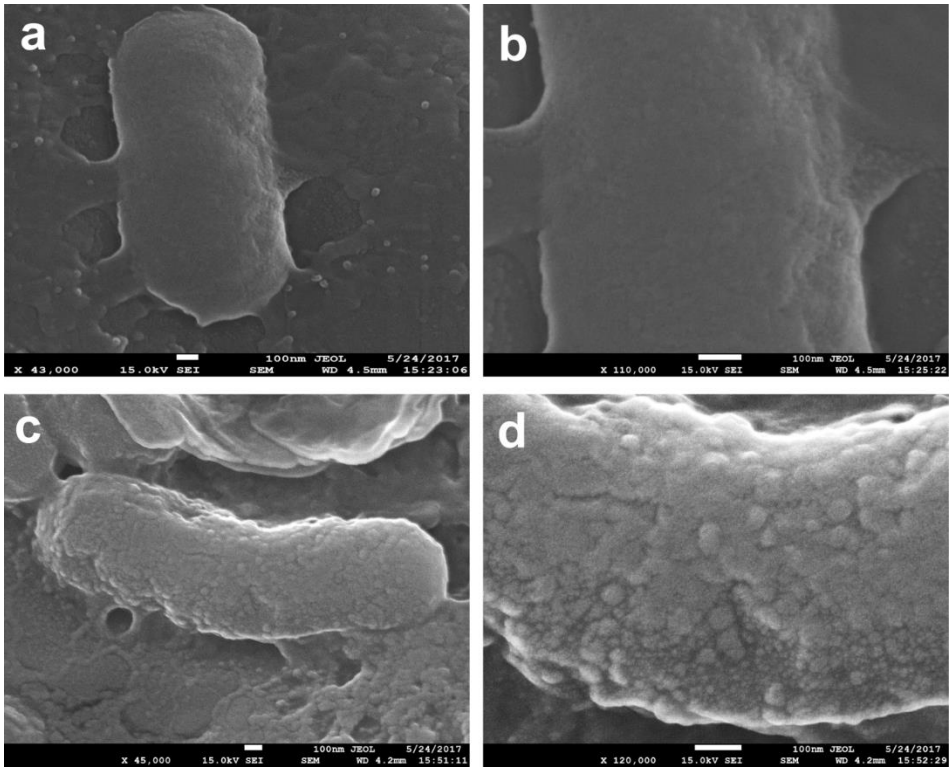

Fig. S6: Field emission scanning electron microscopic (FESEM) image of (A) control GFP expressing bacteria, (B) High magnification image of (A). FESEM image of (C) GFP expressing bacteria following synthesis of Au NCs and (D) High magnification image of (C).

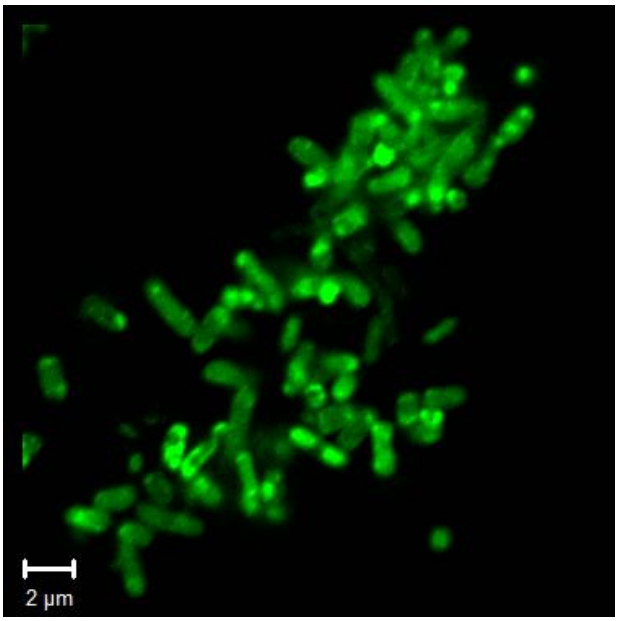

Fig. S 7: Confocal laser scanning microscopic (CLSM) image of GFP expressing bacteria.

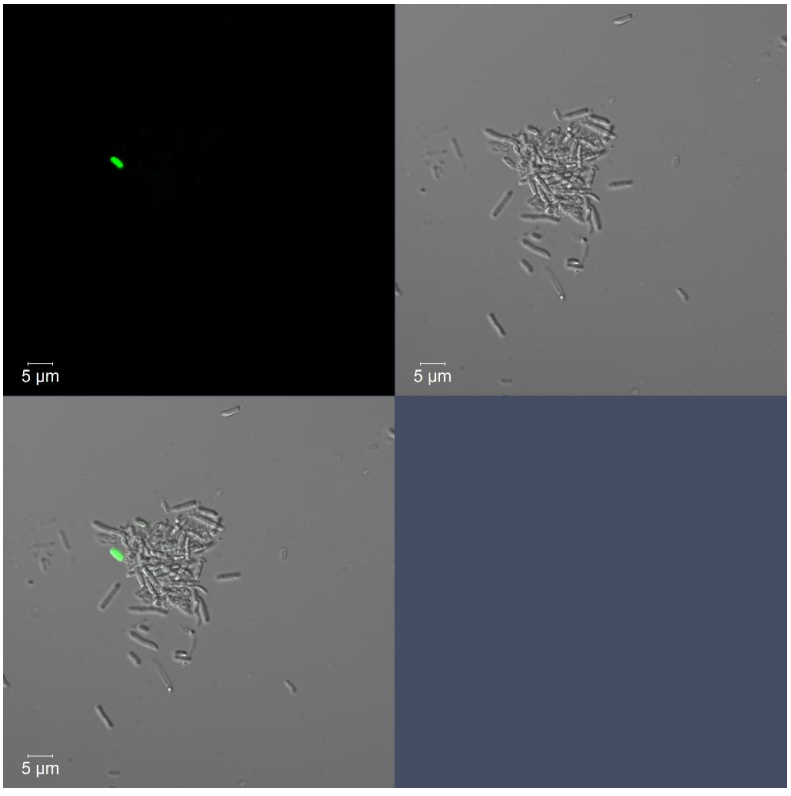

Fig. S8: Confocal laser scanning microscopic (CLSM) image of a mixture of control GFP expressing bacteria and Au NCs synthesised on the former at a laser excitation of 488 nm.

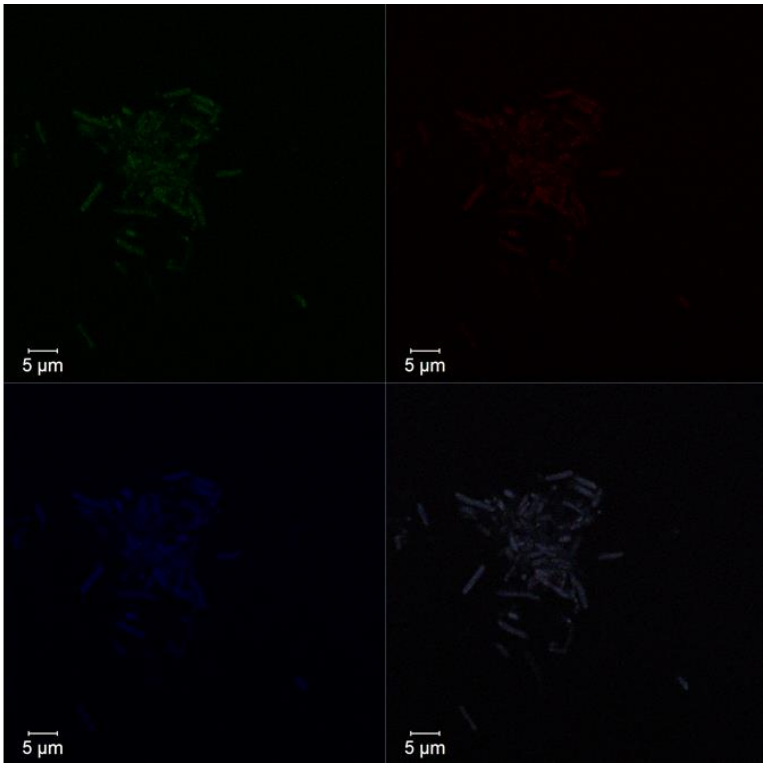

Fig. S9: Confocal laser scanning microscopic (CLSM) image of a mixture of control GFP expressing bacteria and Au NCs synthesised on the former at a laser excitation of 405 nm.

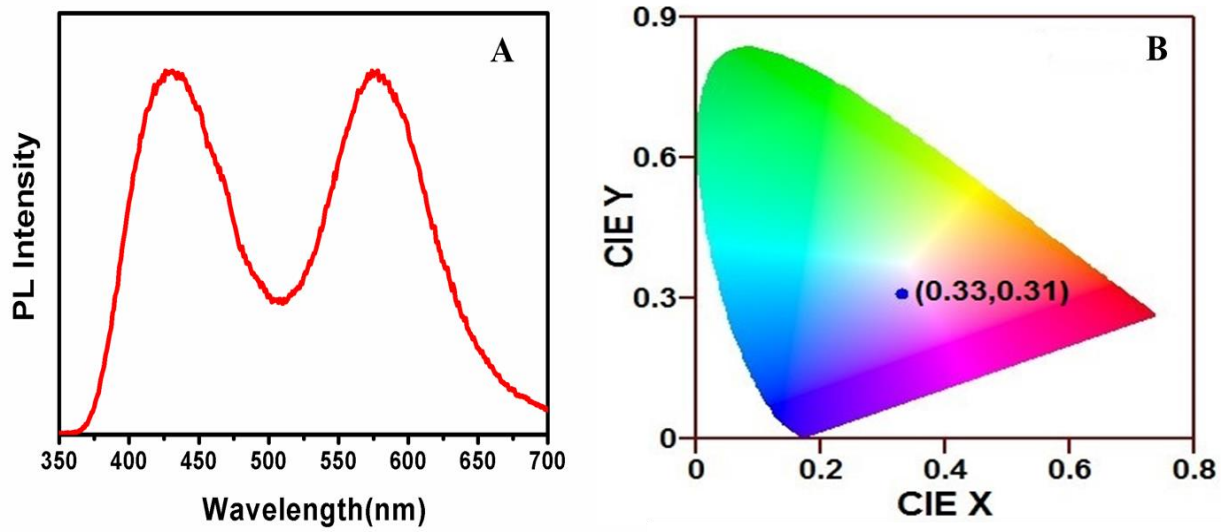

Fig. S10: (A) Photoluminescence spectrum of *Escherichia coli* MTCC 433 following synthesis of Au NCs, **(B)** Corresponding CIE chromaticity diagram showing chromaticity index of 0.33, 0.31.

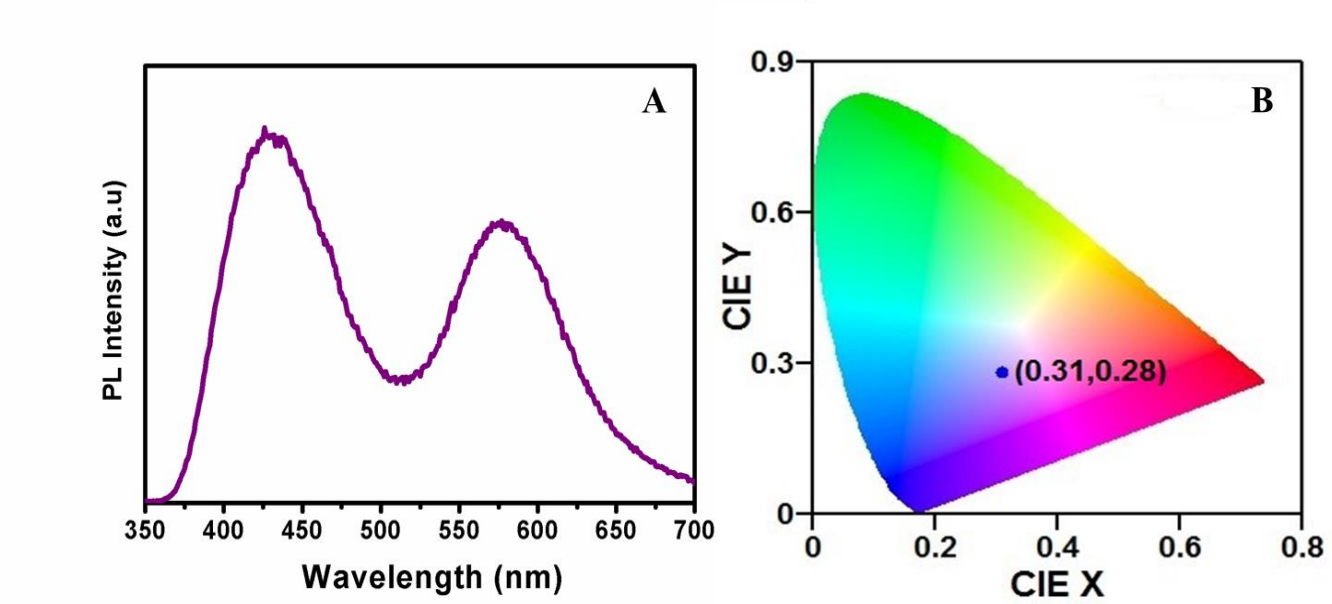

Fig. S11: (A) Photoluminescence spectrum of *Bacillus cereus* MTCC 1305 bacterial strain following synthesis of Au NCs, **(B)** Corresponding CIE chromaticity diagram showing chromaticity index of 0.31, 0.28.

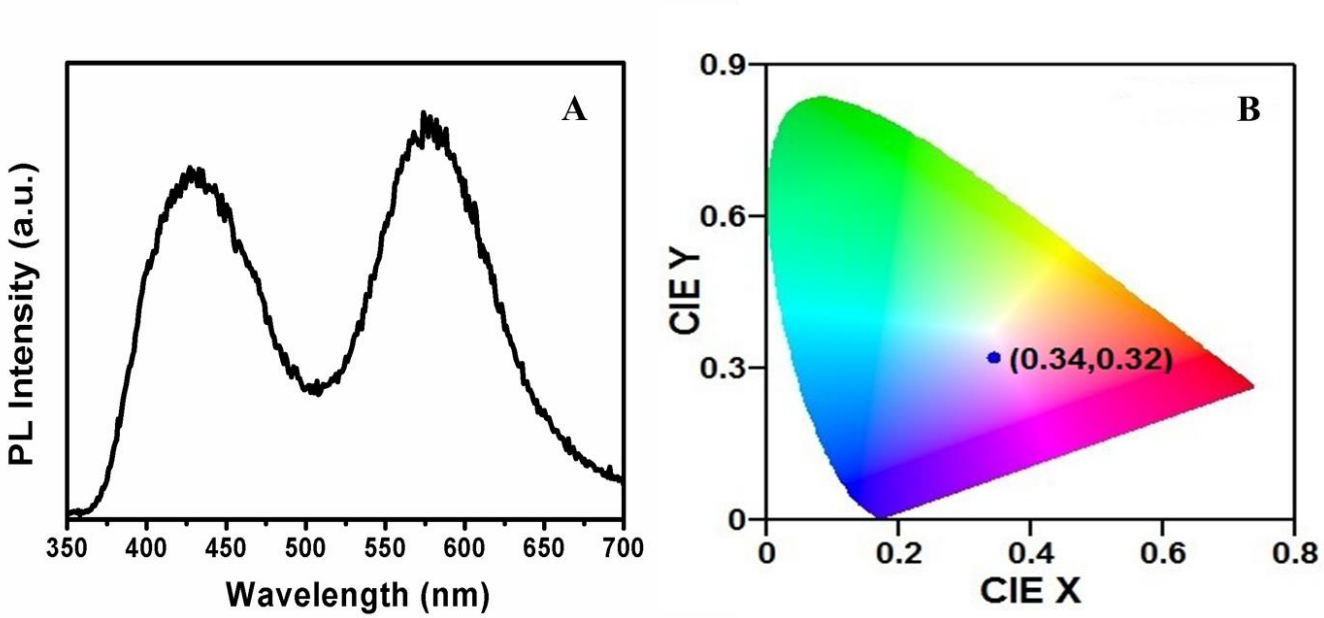

Fig. S12: (A) Photoluminescence spectrum of *Enterococcus faecalis* MTCC 439 *bacterial strain* following synthesis of Au NCs, **(B)** Corresponding CIE chromaticity diagram showing chromaticity index of 0.34, 0.32.

Table S1: Correlated color temperature (CCT) and Colour rendering index (CRI) calculated on various strains of bacteria emitting white light.

Bacterial strain	CCT	CRI
Bacillus Cereus **MTCC 1305**	**7329**	**81**
Escherichia Coli **MTCC 433**	**5589**	**74**
Enterococcus Faecalis **MTCC 439**	**4936**	**72**

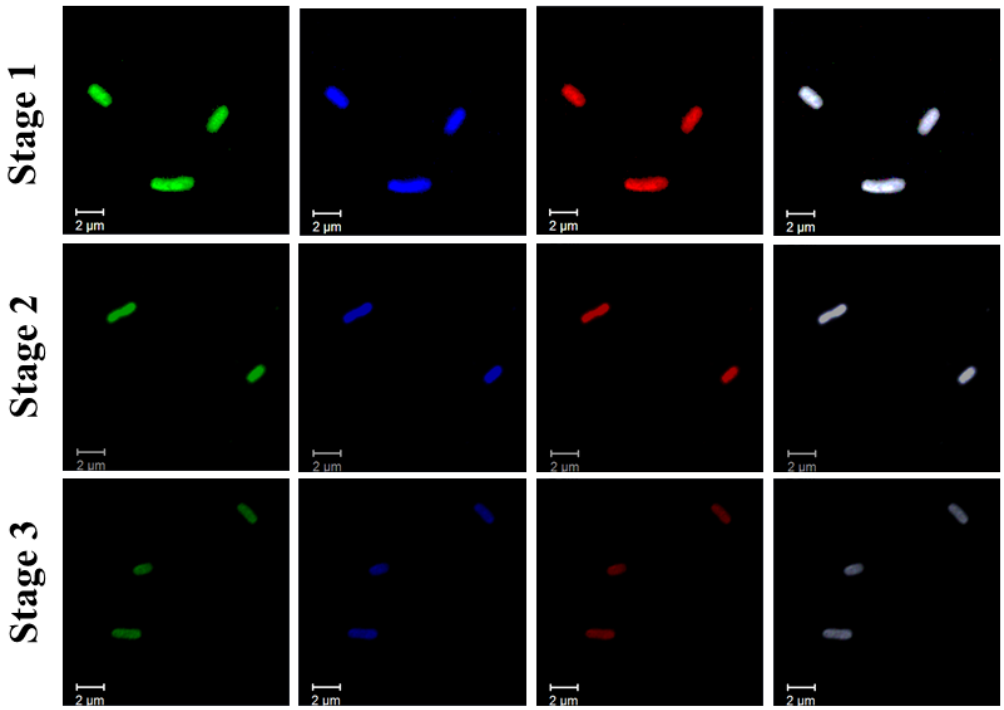

Fig. S13: CLSM images of GFP expressing bacteria following synthesis of Au nanoclusters acquired at various thermal conditions. Stage 1: 30 ˚C, Stage 2: heated at 50 ˚C followed by cooling at room temperature, Stage 3: Again heated at 50 ˚C followed by cooling at room temperature.

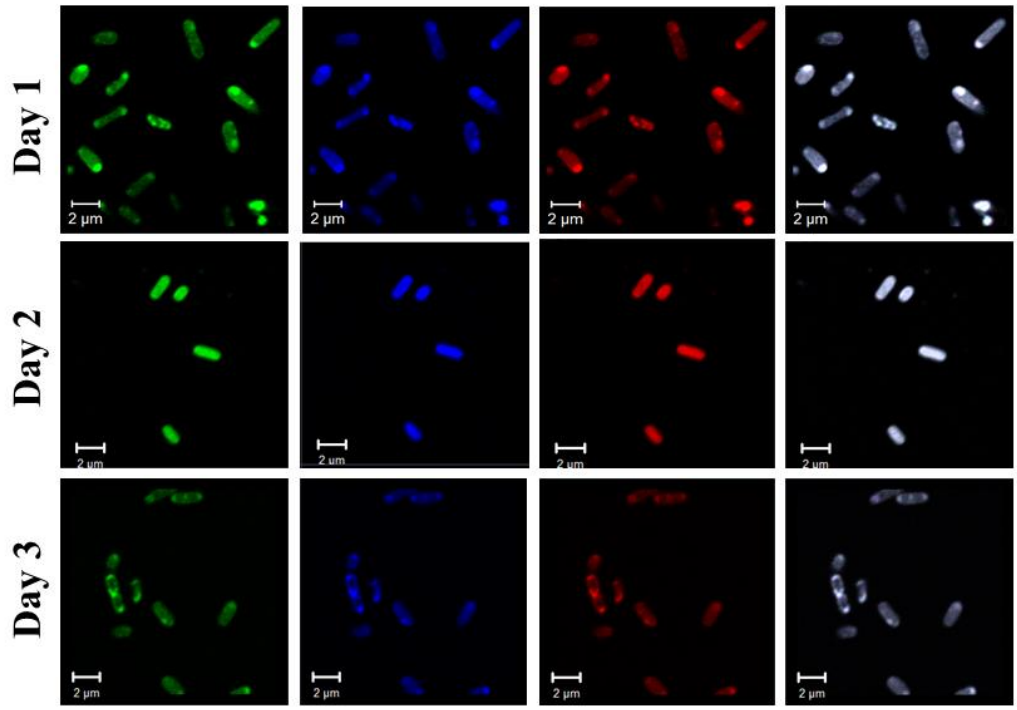

Fig. S14: CLSM images of GFP expressing bacteria following synthesis of Au nanoclusters acquired at various time intervals.

Additional figures:

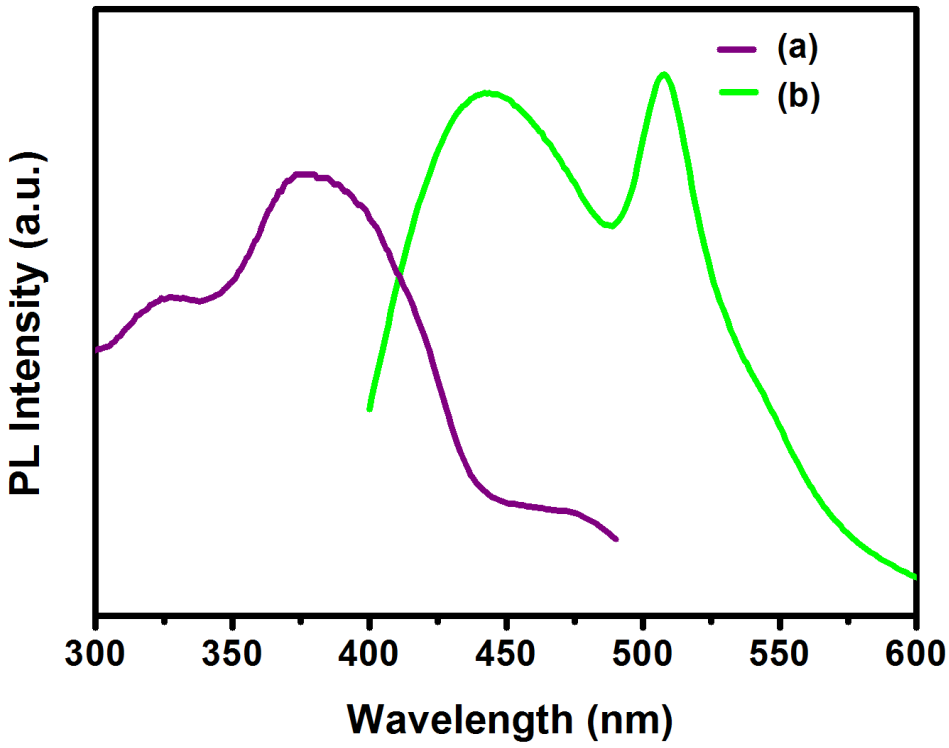

Fig. S 15: (a) Excitation and **(b)** emission spectra of GFP expressing bacteria.

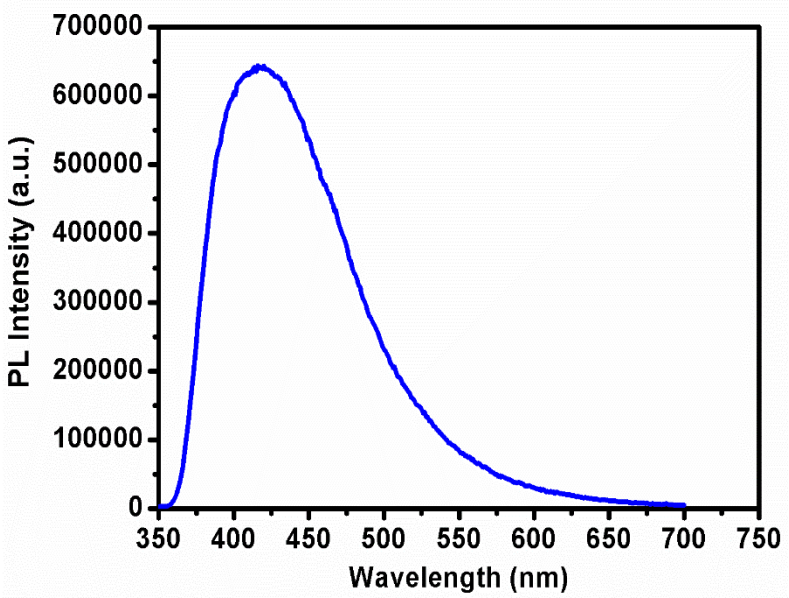

Fig. S16: Emission spectrum of *Bacillus cereus* MTCC 1305.

Additional representative confocal laser scanning microscopic (CLSM) images of white light emitting bacteria

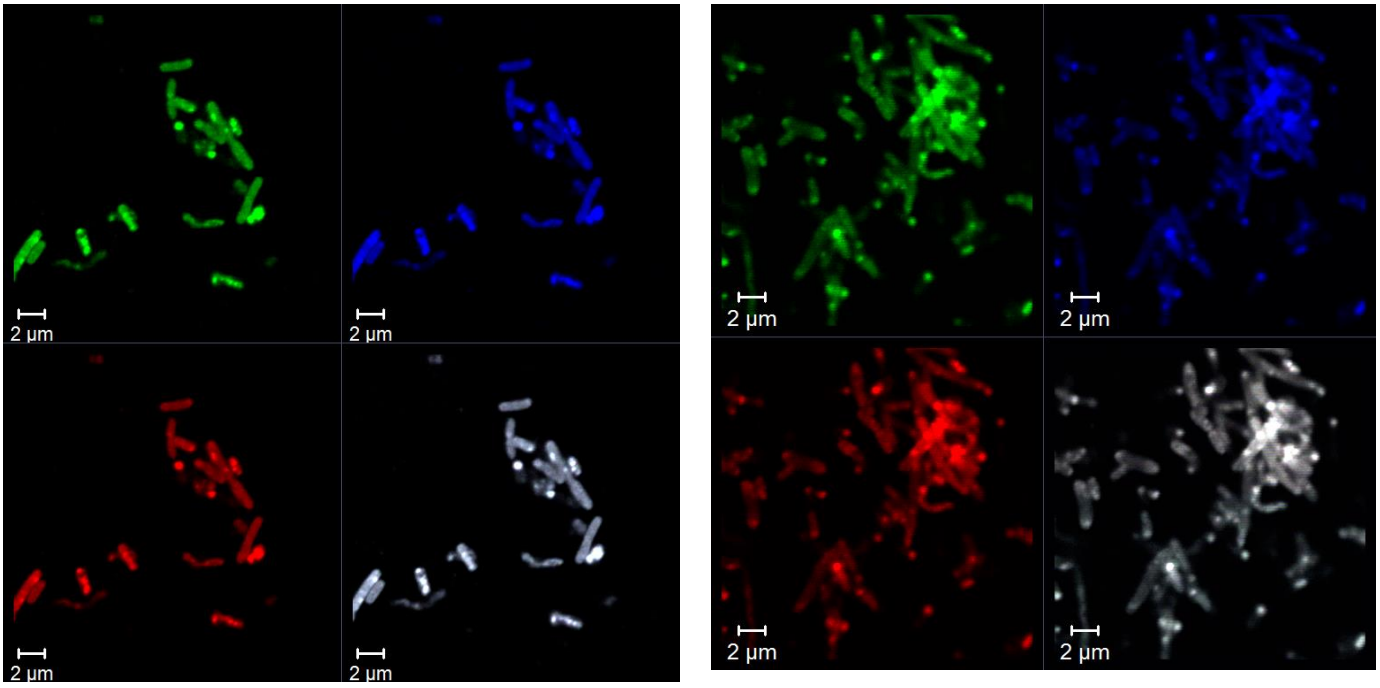

Fig. S 17: CLSM images of GFP expressing bacteria following synthesis of Au NCs upon laser excitation of 405 nm. The images highlight the presence of white light emitting bacteria.

Additional CLSM image of Au NCs embedded GFP expressing bacteria. Here, higher number of bacteria (than required for white light emission) have been employed to synthesise Au NCs. Hence the luminescent bacteria appear bluish white.

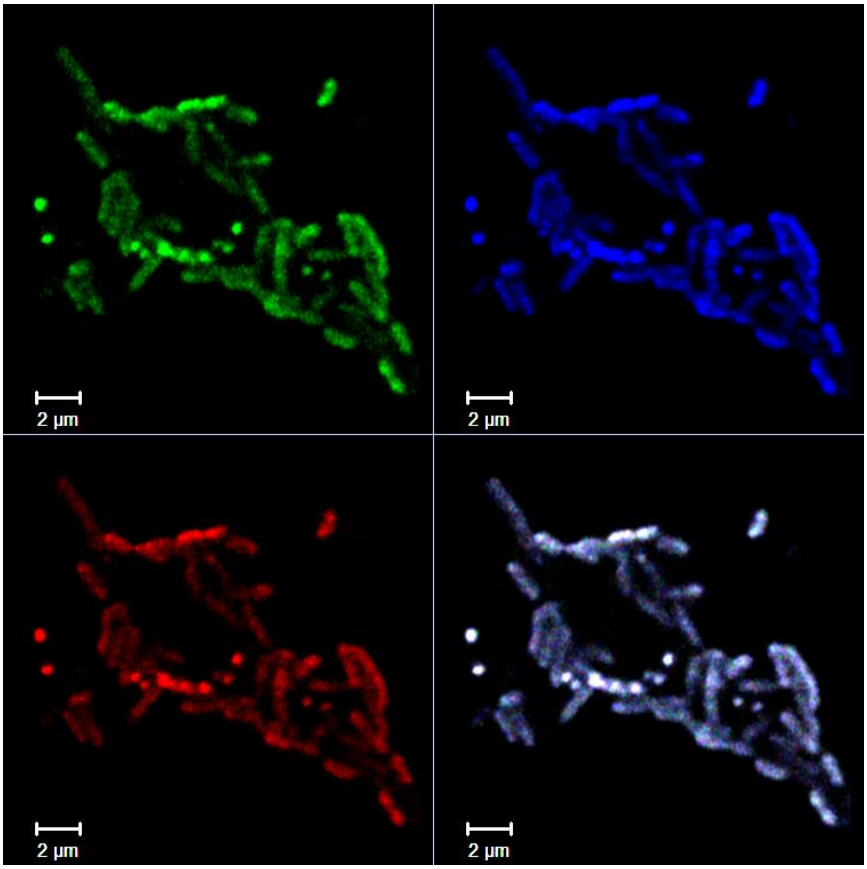

Fig. S18: CLSM image of Au NCs synthesised on GFP expressing bacteria showing bluish white emission. The excitation wavelength was set at 405 nm.