Luminescence Nanothermometry in Living Cells

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Londra 2012 -32 SAMSUNG PARTNER UFFICIALE

Tutto il rosa della vita

L'ITALIA CHE VINCE
E ANDIAMO!
Germania a noi due

EURO2012
Dominata l'Inghilterra, colpiti due pali e ai rigori arriva la vittoria (4-2) Giovedì semifinale coi tedeschi

DA PAGINA 2 A PAGINA 19

l'Editoriale

LA NAZIONALE PIU' BELLA

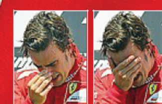
di **ANDREA MONTI**

La più bella Nazionale dai tempi del Mondiale di Germania conquista la semifinale di Euro 2012 ai calci di rigore. Avrebbe strameritato di chiuderla prima ma la sofferenza rende ancor più bella la notizia di questa straordinaria domenica. C'è un'Italia che vince. Vince col cuore, con classe, con grinta.

L'ARTICOLO A PAGINA 23

L'abbraccio fra Alessandro Diamanti, 29 anni, e Gigi Buffon, 34 anni, al termine della partita con l'Inghilterra INSIDE

F.1 GP D'EUROPA CHE IMPRESA



Fernando Alonso, emozionato sul podio

Capolavoro ALONSO

Da 11° a primo: trionfo Ferrari a Valencia. E adesso è in fuga Mondiale

ORA SI PUÒ SOGNARE

DI **UMBERTO ZAPELLONI**

Le lacrime di Alonso sono dolci come quelle che ti porta una gioia inattesa, una vittoria neppure sognata. Sono la cornice di un'impresa che produce solo superlativi per Fernando e la sua Ferrari. La gara dipinta sulla pista di Valencia resterà nella storia del suo sport.

L'ARTICOLO A PAGINA 34
ALLIEVI, CREMONESI, PERNA, CORTINOVIS DA PAGINA 34 A PAGINA 39

L'UOMO PARTITA IL COLPO MAGICO
Pirlo e il cucchiaio decisivo «Ha ridato forza a tutti»
GRAZIANO A PAGINA 10

L'ALLENATORE IL C.T. «GRANDE PARTITA»
Prandelli: «Lo meritavamo Poteva andare solo così»
ELEFANTE A PAGINA 8

IL PRESIDENTE A PETRUCCI E ABETE
Il messaggio di Napolitano «Rivedo Berlino 2006»
CECCHINI A PAGINA 9

IL ROMPI PALLONE
DI **GENE GNOCCHI**
Massa si giustifica: «Ho accumulato ritardo perché al rifornimento ho anche fatto compilare la carta carburante».

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Tutto il rosa della vita

GERMANIA ANCORA BATTUTA (2-1) E ORA LA SPAGNA

DI TESTA Balotelli insacca il cross di Cassano al 20' p.t. IPP

DI FORZA Balotelli scaraventa in rete il 2-0 al 36' p.t. RAMELLA

IN GRUPPO Gli azzurri festeggiano con SuperMario INFOPHOTO

IN PIAZZA L'entusiasmo dei tifosi davanti ai maxischermi REUTERS

SIAMO NOI!!!
Super Balotelli: tutta l'Italia è in festa

È EUROFINALE
Cassano e Montolivo lo ispirano e lui segna due gol da campione. Al 92' il rigore tedesco

l'Editoriale

E' NATA UNA STELLA

di **ANDREA MONTI**

Finalmente è nata una stella. Eccolo lì piantato in mezzo al campo, strafottente come un bronzo di Riace da playstation, il simbolo della nuova Italia: SuperMario Balotelli, il ragazzo dei sogni.
Il limite è il cielo, avevamo scritto dopo la prova con l'Inghilterra. Non era retorica, era un giudizio. Ieri la Nazionale lo ha toccato davvero e lo ha dipinto col suo colore: solo azzurro nella notte magica di Varsavia.

L'ARTICOLO A PAGINA 23

L'eroe della magica azzurra: Mario Balotelli, 21 anni. Eccolo dopo il secondo gol mentre mette in mostra tutta la sua forza e grinta REUTERS

GARLANDO, ARCHETTI, CECCHINI, CENITI, ELEFANTE, GRAZIANO, LICARI, RICCI, VELLUZZI, VERNAZZA, ANGIONI, CITO, DEGL'INNOCENTI, FROSIO, MANCINI, SCHIANCHI, BAZZONI PAG. 2-23

GIOIA MARIO
«E' stata la serata più bella della mia vita»
A PAGINA 6

PRANDELLI
«Troveremo le forze anche per gli spagnoli»

Il c.t. Cesare Prandelli, 54 anni
ALLE PAGINE 8-9

IL ROMPI PALLONE
DI **GENE GNOCCHI**
Berlusconi su Thiago Silva: «Ha chiesto un incredibile aumento di stipendio, se divento tesoriere della Margherita lo accontento».


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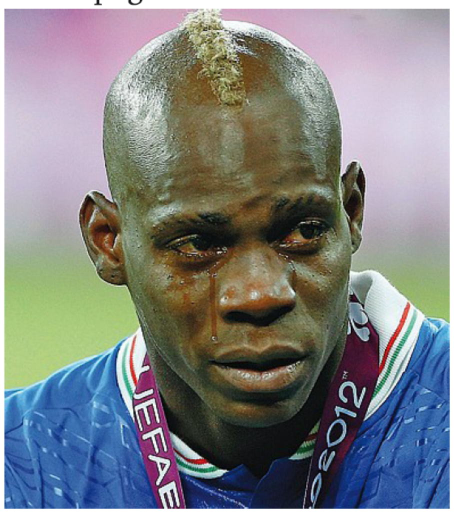
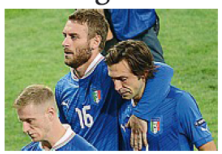
Tutto il rosa della vita

VINCE LA SPAGNA 4-0: E' CAMPIONE D'EUROPA
SERATACCIA: GLI AZZURRI ESCONO IN LACRIME

COSÌ FA MALE...

Partita chiusa già nel primo tempo: dal 61' siamo rimasti in dieci
Gli spagnoli dominano e mettono a segno uno storico Triplete





INCONSOLABILI
Mario Balotelli in lacrime, come il resto dei compagni di squadra. Delusione pure tra i tantissimi tifosi che hanno seguito la partita davanti ai maxischermi nelle piazze d'Italia

ARCHETTI, BAZZONI, BIANCHI, BIANCHIN, BOVOLENTA, CENITI, CITO, DE CALO', DI FEO, GRAZIANO, LICARI, MANCINI, RICCI, SCHIANCHI, VELLUZZI, VERNAZZA DA PAG 2 A PAG. 35

l' Editoriale

GRAZIE LO STESSO

di **ANDREA MONTI**

Semplicemente, come si canta allo stadio: grazie ragazzi. Grazie lo stesso. Certo, la lezione è stata severissima. E la valle di lacrime a fine partita lo testimonia. In una finale europea o mondiale non si ricordavano 4 gol di scarto, ma non parliamo di umiliazione. Caronte ieri sera ci ha traghettato all'inferno, esausti, malconci, tormentati dai mostruosi diavoli spagnoli che sanno sempre cosa fare col pallone e come punire i peccati altrui.

L'ARTICOLO A PAGINA 35

il Commento

SENZA BATTERIA

di **LUIGI GARLANDO**

Avevano ancora una tacca di batteria, speravamo di riuscire a fare l'ultima chiamata. E invece nulla. Crollati esausti ai piedi della Spagna, che resta sul trono, splendida regina d'Europa e del mondo. Il 4-0 suona umiliante, ma non deve rimpicciolire l'orgoglio per il grande torneo giocato dagli azzurri. Anche perché ieri non c'era in campo la vera Italia che, senza la piena salute agonistica, non esiste.

L'ARTICOLO ALLE PAGINE 2-3

IL TECNICO «ERAVAMO TROPPO STANCHI»

Prandelli: «Grande torneo E il progetto va avanti»

CECCHINI, ELEFANTE A PAGINA 10

CICLISMO LO SVIZZERO RESTA LEADER

Sagan mette sotto Cancellara Il Tour trova un protagonista

PASTONESI, SCOGNAMIGLIO ALLE PAGINE 46-47

TENNIS OGGI TRE ITALIANE IN CAMPO

Giorgi, sorpresa di Wimbledon «Adesso non mi pongo limiti»

MARTUCCI, BERTOLUCCI A PAGINA 55

SUPERBIKE NEL GP DI ARAGONA

Biaggi-Melandri: finisce pari Tra scintille e pace sul web

GOZZI A PAGINA 44

IL ROMPI PALLONE

DI **GENE GNOCCHI**

Dopo la deludente prestazione contro la Spagna rivista la quotazione di Balotelli. Moody's l'ha declassato a Forlan.

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LA ROJA SE EXHIBE COMO EL MEJOR EQUIPO DE TODOS LOS TIEMPOS

ESPAÑA Y NADIE MÁS

4-0

La selección tritura a Italia con un fútbol primoroso, gana su tercera Eurocopa y consigue la Triple Corona que nadie logró jamás

1-0 Silva, de cabeza a centro de Cesc, abre el marcador

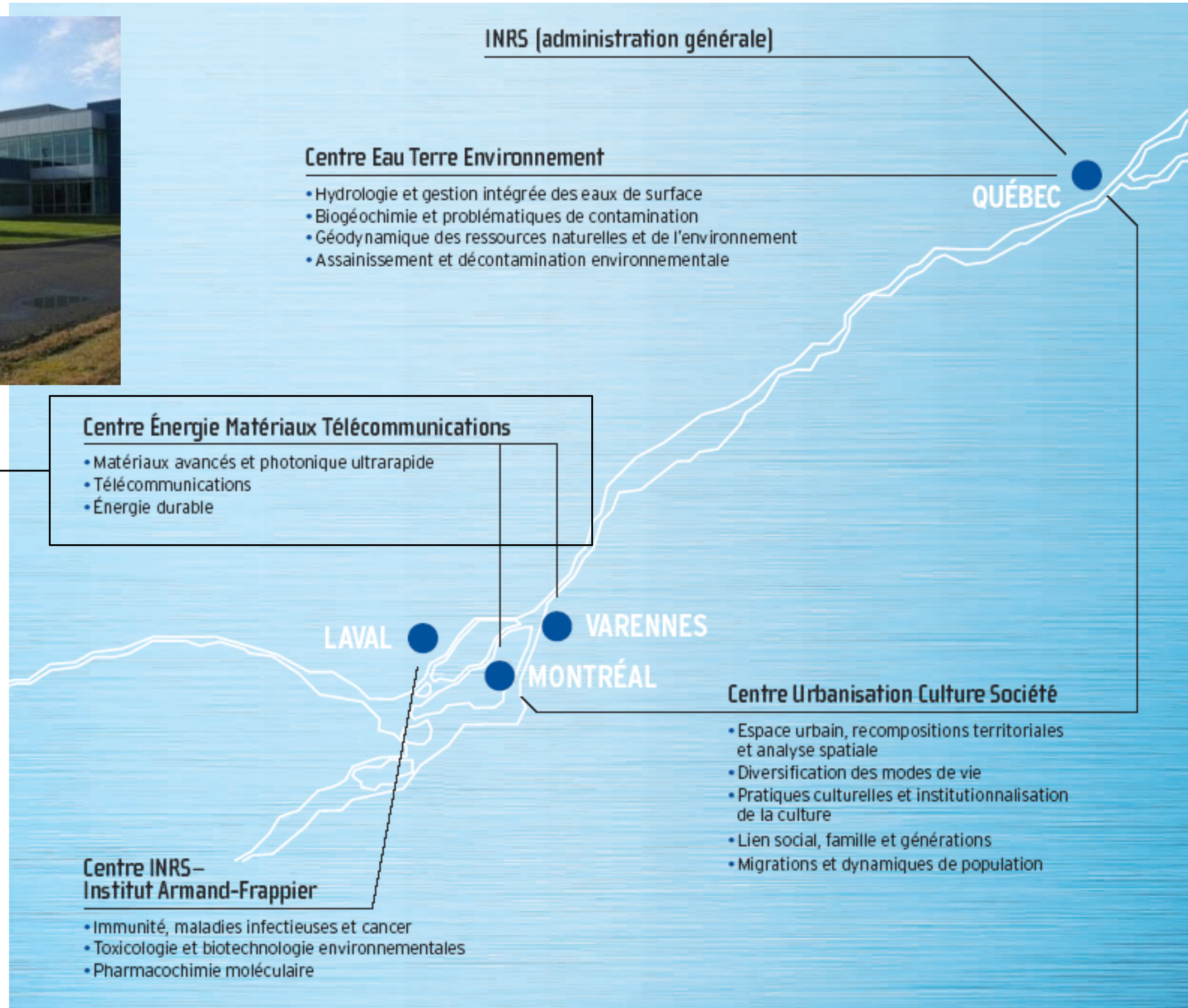
2-0 Alba galopa por la banda y marca a pase de Xavi

3-0 Xavi deja a Torres solo para batir a Buffon

4-0 Torres asiste a Mata, que anota a placer

Torres, Pichichi de la Euro e Iniesta, MVP de la final

El manchego, máximo favorito para ser Balón de Oro de la Euro
• 'El Niño': dos finales, dos goles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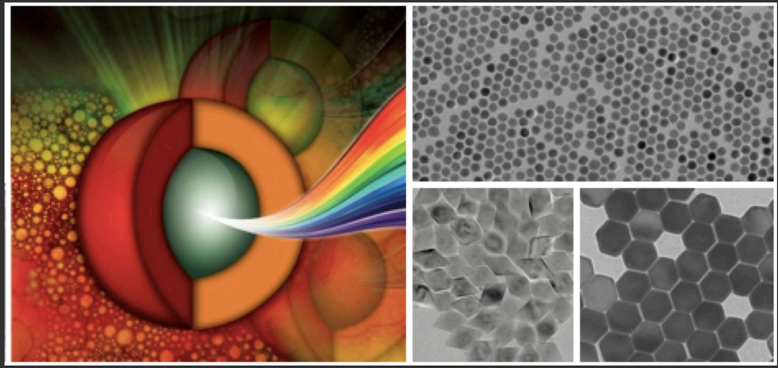
• Toxicologie et biotechnologie environnementales
• Pharmacochimie moléculaire

Synthesis

- Novel multiphoton excited nanoparticles
- Novel NIR emitting nanoparticles

Multifunctional Nanovehicles

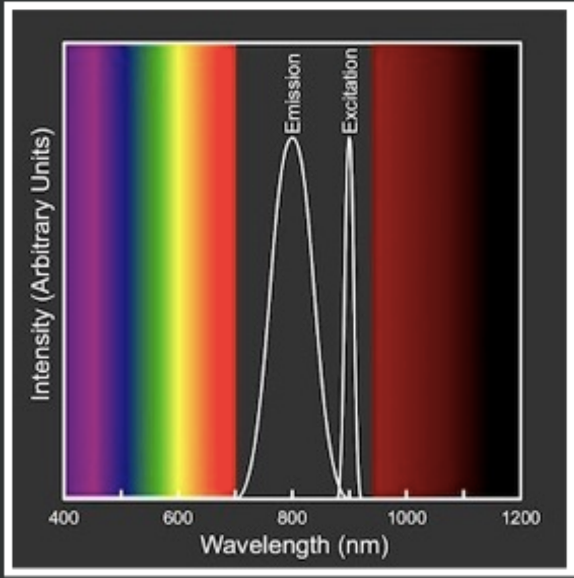
- Light sensitized targeted release of bone growth factors (bone regeneration, bone cancer)



Biosensing

- Optical barcode sensor arrays
- Ir-Metal NP-Multiphoton Excited NP-DNA complexes

Nanothermometry



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REVIEW

Luminescence nanothermometry†

Daniel Jaque*[a] and Fiorenzo Vetrone*[b]

ed 30th March 2012, Accepted 14th May 2012
0.1039/c2nr30764b

rrent status of luminescence nanothermometry is reviewed in detail. Based on the main
eters of luminescence including intensity, bandwidth, bandshape, polarization, spectral shift and
e, we initially describe and compare the different classes of luminescence nanothermometry.
uently, the various luminescent materials used in each case are discussed and the mechanisms at
t of the luminescence thermal sensitivity are described. The most important results obtained in
ise are summarized and the advantages and disadvantages of these approaches are discussed.

Minireviews

Upconverting Nanoparticles

Upconverting Nanoparticles for Nanoscale Thermometry

*Lorenz H. Fischer, Gregory S. Harms, and Otto S. Wolfbeis**

Angew. Chem., **50**; 4546 (2011)

Thermometry at the Nanoscale

Carlos D. S. Brites,[a] Patricia P. Lima,[a] Nuno J. O. Silva,[a] Angel Millán,[b] Vitor S. Amaral,[a]
Fernando Palacio,*[b] and Luís D. Carlos,*[a]

DOI: 10.1039/C2NR30663H

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- Dr. Haiguang Zhao
- Fuqiang Ren
- Yue Huang

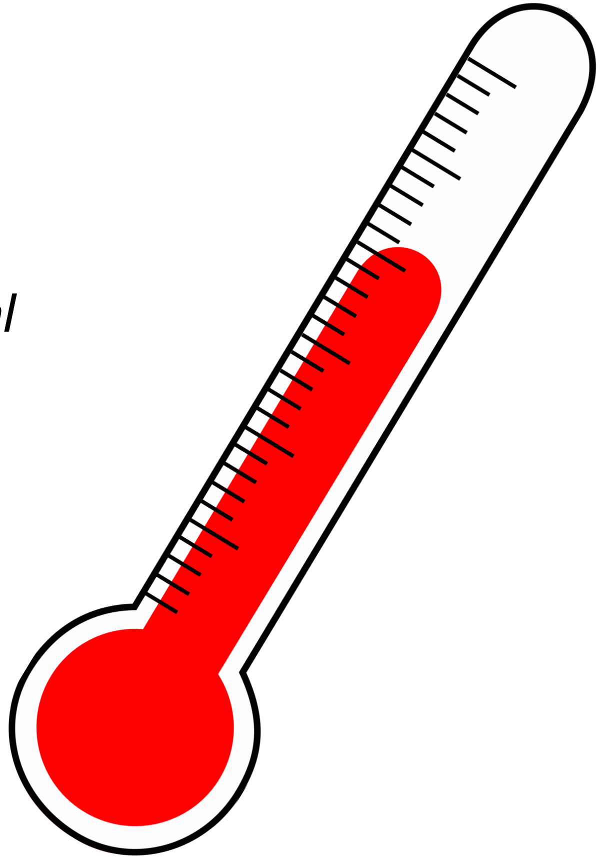
Nanothermometry

- What is Nanothermometry?

  Nanothermometry aims to extract knowledge of the local temperature of a given system with sub-micrometric spatial resolution

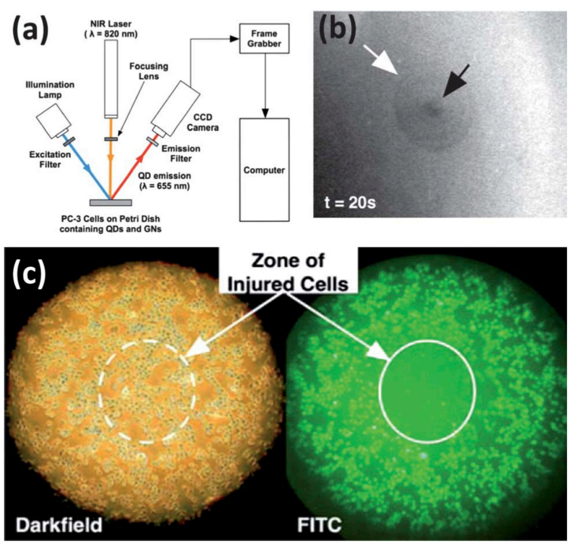
- Why is it Important?

  Such knowledge is required for the complete understanding of micrometric and nanostructured systems whose dynamics and performance are strongly determined by temperature



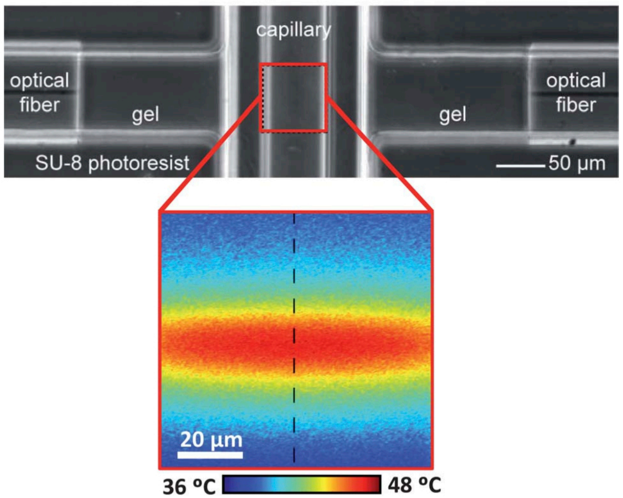
Uses of Nanothermometry

- Micro/Nano-Electronics
- Integrated Photonic Devices
- Biomedicine



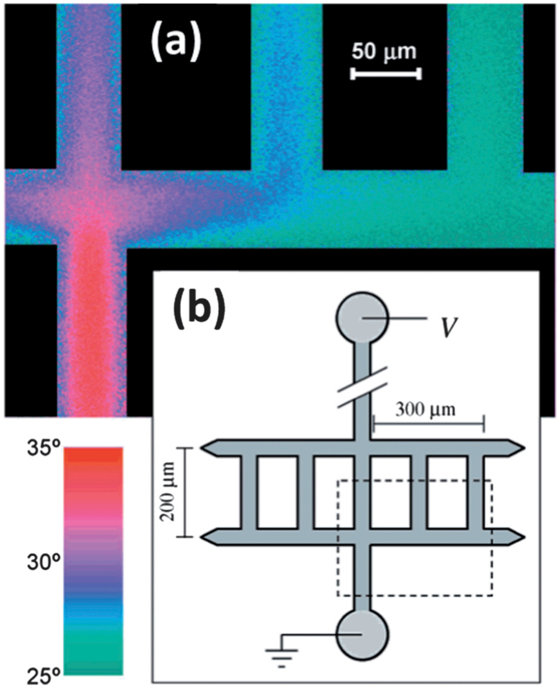
Cell culture during gold nanoparticle mediated heating by an NIR laser beam

B. Han, W. L. Hanson, K. Bensalah, A. Tuncel, J. M. Stern and J. A. Cadeddu, *Ann. Biomed. Eng.*, 2009, **37**, 1230-1239



Thermal image of an opto-fluidic device using fluorescent dyes

N. Ishiwada, S. Fujioka, T. Ueda and T. Yokomori, *Opt. Lett.*, 2011, **36**, 760-762.



Color coded thermal image of a multi-branched microfluidic circuit

D. Ross, M. Gaitan and L. E. Locascio, *Anal. Chem.*, 2001, **73**, 4117-4123

Nanothermometry in Biomedicine

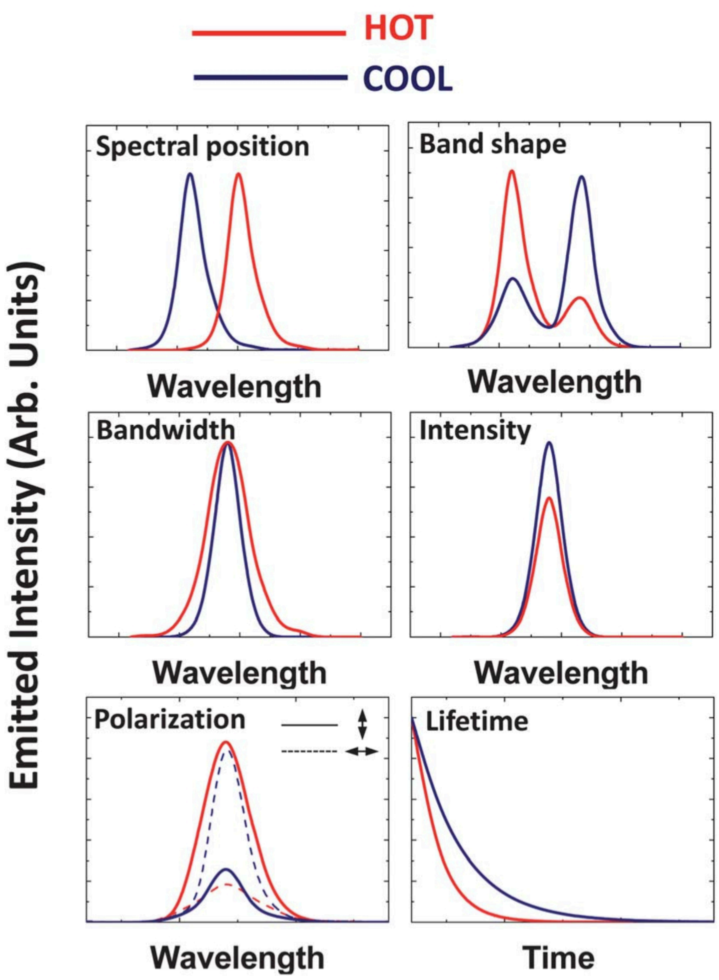
- Fundamental Interest: Temperature plays a **crucial** role in most biosystems determining their dynamics and properties
  - Cell division rates (i.e. determines rate of tissue growth)
  - Drastically affects mechanical, structural and optical properties (i.e. leads to denaturation in proteins)
- Disease Detection: Vital for the early detection and treatment of many diseases
  - First signatures of any given illness is the appearance of thermal singularities.
  - In cancer, thermal singularity associated with incipient tumors becomes detectable when they reach a size consisting of thousands of cancer cells (i.e. when the tumor size is well below 1 mm)

Types of Nanothermometers

- Electrical Nanothermometry
- Mechanical Nanothermometry
- Optical Nanothermometry
  - Interferometry
  - Reflection
  - Raman
  - Pyrometric
  - Infrared
  - Fluorescence/Luminescence

Different Classes of Luminescence Nanothermometers

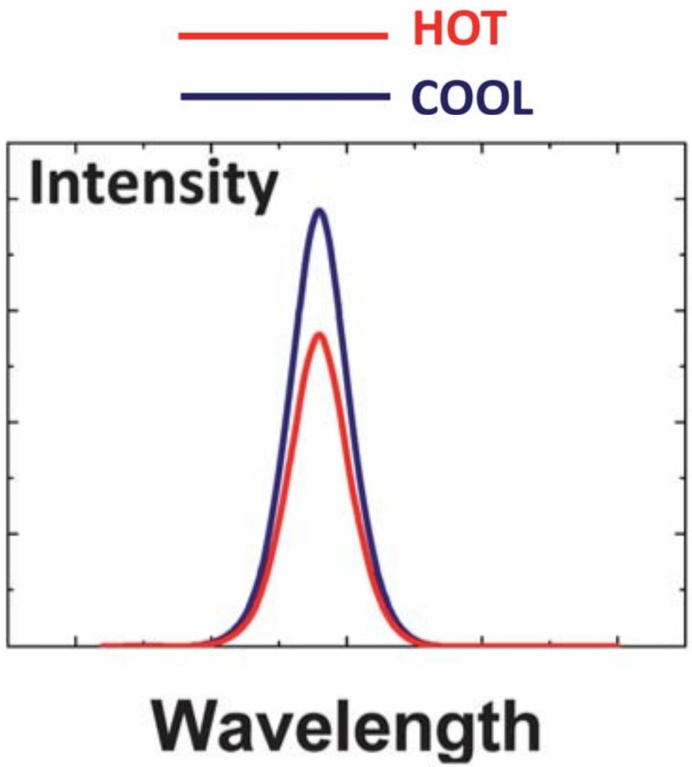
- Intensity Luminescence Nanothermometry
- Band-Shape Luminescence Nanothermometry
- Spectral Luminescence Nanothermometry
- Polarization Luminescence Nanothermometry
- Bandwidth Luminescence Nanothermometry
- Lifetime Luminescence Nanothermometry



D. Jaque and F. Vetrone, *Nanoscale*, 2012, **4**, 4301-4326

Intensity Luminescence Nanothermometry

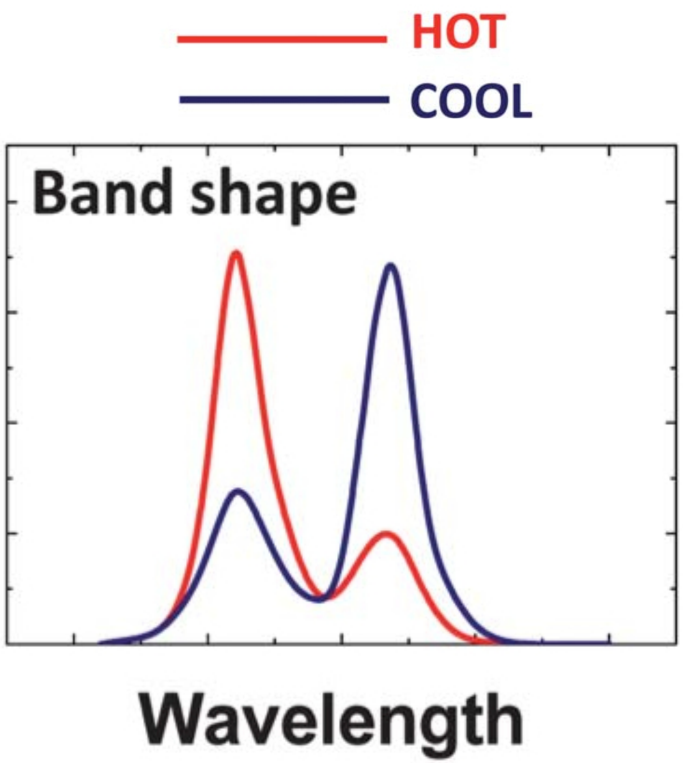
- Thermal sensing is achieved through the analysis of the luminescence intensity
- When temperature changes, there is an overall change in the number of emitted photons per second such that the emission spectrum becomes less (or more) intense
- Generally caused by the thermal activation of luminescence quenching mechanisms and/or increases in the non-radiative decay probabilities



D. Jaque and F. Vetrone, *Nanoscale*, 2012, **4**, 4301-4326

Band-Shape Luminescence Nanothermometry

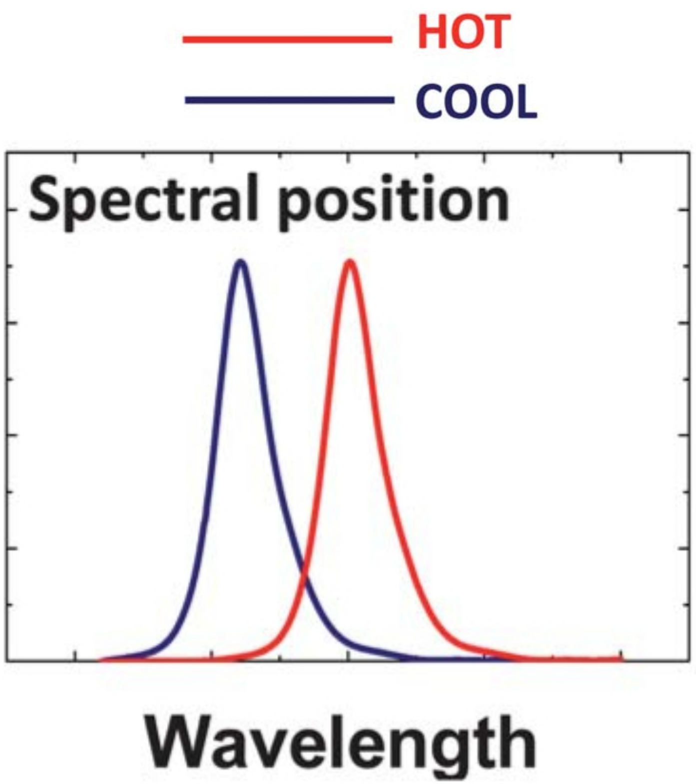
- Refers to the relative intensity between the different spectral lines that make up the luminescence spectrum
- Thermally induced variations in the band-shape usually take place when the electronic states from which emission is generated are very close in energy such that they are thermally coupled
- Often referred to as **ratiometric** sensing
- Can be also present in mixed systems, *i.e.* systems containing more than one class of emitting centers



D. Jaque and F. Vetrone, *Nanoscale*, 2012, **4**, 4301-4326

Spectral Luminescence Nanothermometry

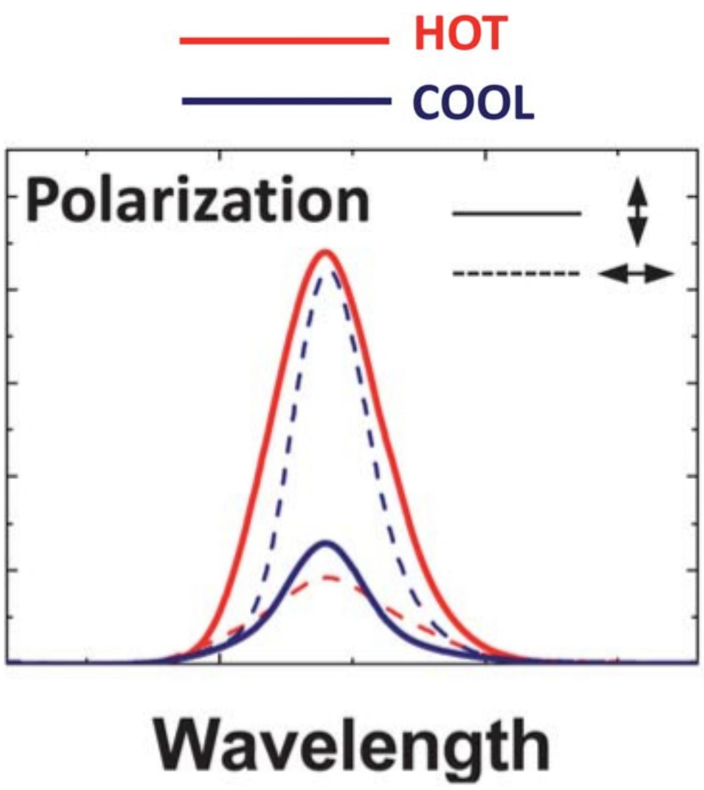
- Based on the analysis of the spectral positions of the emission lines, which are unequivocally determined by the energy separation between the two electronic levels involved in the emission
- This depends on a large variety of temperature dependent parameters of the emitting material including:
  - Refractive index
  - Inter-atomic distances (density)



D. Jaque and F. Vetrone, *Nanoscale*, 2012, **4**, 4301-4326

Polarization Luminescence Nanothermometry

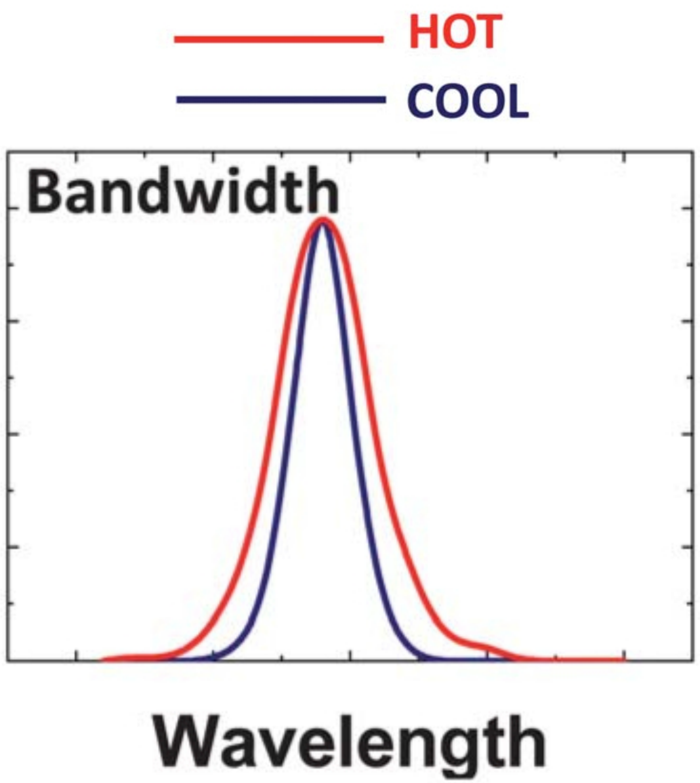
- In anisotropic media, the emitted radiation is generally non-isotropically polarized
- Consequently, the shape and intensity of the emitted radiation are strongly dependent on its polarization
- Exploits the ratio between the luminescence intensities emitted at two orthogonal polarization states



D. Jaque and F. Vetrone, *Nanoscale*, 2012, **4**, 4301-4326

Bandwidth Luminescence Nanothermometry

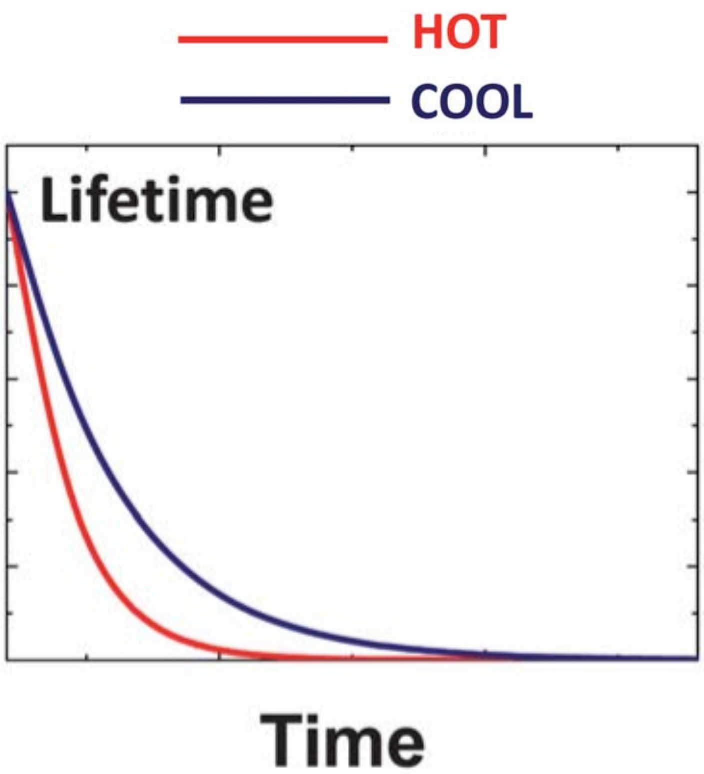
- The width of the various emission lines that make up any luminescence spectrum is determined by the properties of the material:
  - Degree of disorder
  - Temperature
- As the temperature of a luminescent material is increased, a corresponding increase in the density of phonons occurs resulting from the spectral contribution of homogeneous line broadening
- Near RT, homogeneous line broadening leads to a linear relationship between bandwidth and temperature



D. Jaque and F. Vetrone, *Nanoscale*, 2012, **4**, 4301-4326

Lifetime Luminescence Nanothermometry

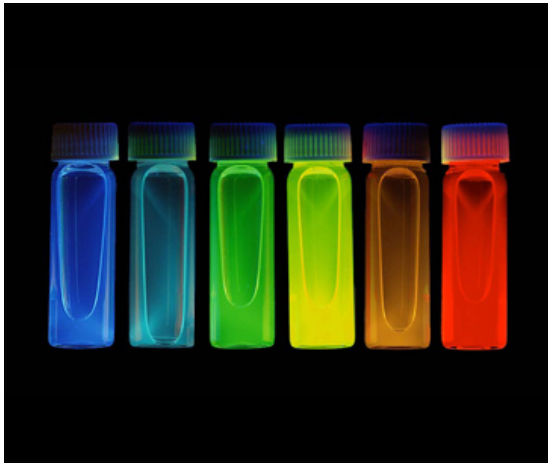
- Luminescence lifetime, τ_f, is defined as the time that the emitted luminescence intensity decays down to 1/*e* of its initial value after a pulsed excitation
- Indication of the total decay probability of the emitted intensity (this probability is defined as the inverse of the luminescence lifetime)
- Decay probabilities from electronic levels depend on many factors and many of them are related to temperature
  - Phonon assisted energy transfer processes
  - Multiphonon decays



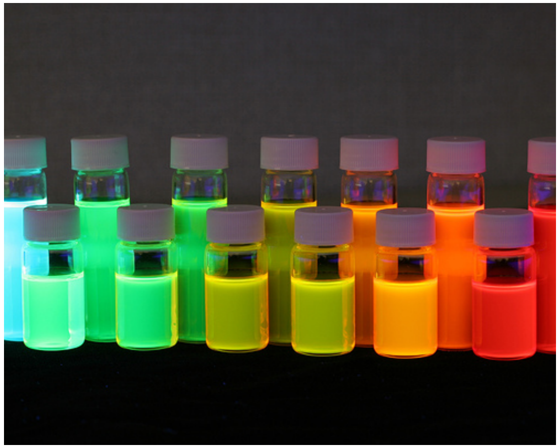
D. Jaque and F. Vetrone, *Nanoscale*, 2012, **4**, 4301-4326

Luminescent Nanoparticles

- Nanoparticles have demonstrated their significant potential in applications related to both diagnostics and therapeutics.
- Semiconductor quantum dots (QDs) are widely used in many fields
- Most nanoparticles are excited with UV light, which has several limitations
  - Low penetration depths
  - High autofluorescence
  - Potential damage to specimens under study



http://nanoe.ece.drexel.edu/wiki/index.php/Quantum_Dot_Challenge

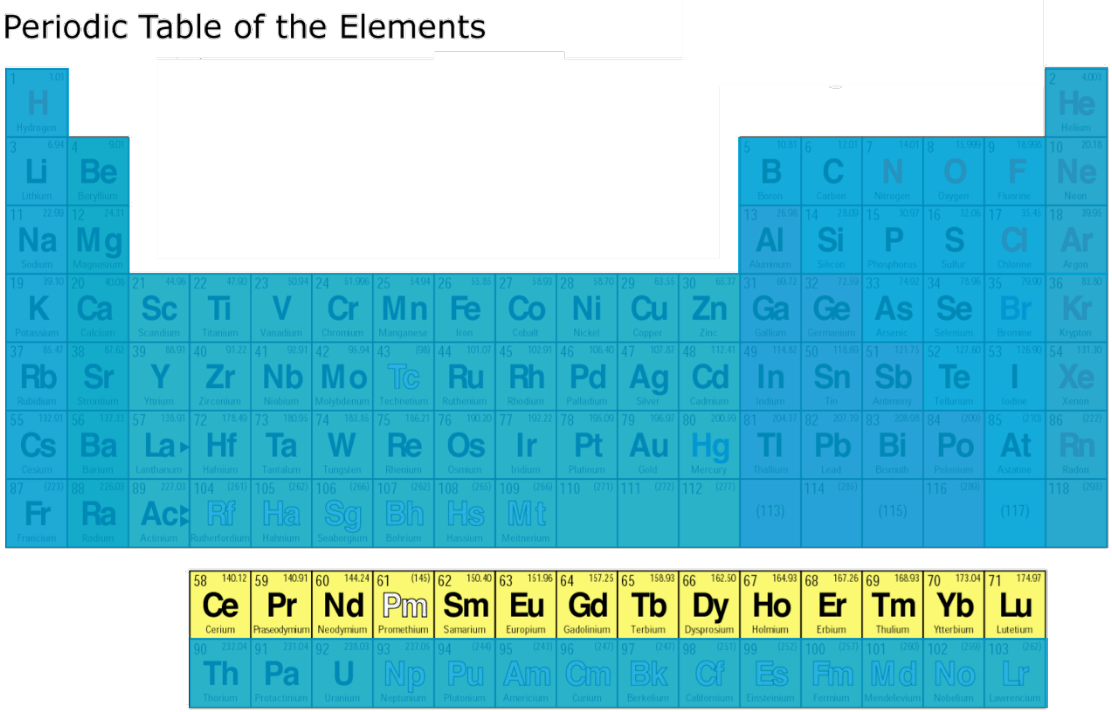


http://www.immunology.utoronto.ca/FlowCytometry/FlowIntro.htm

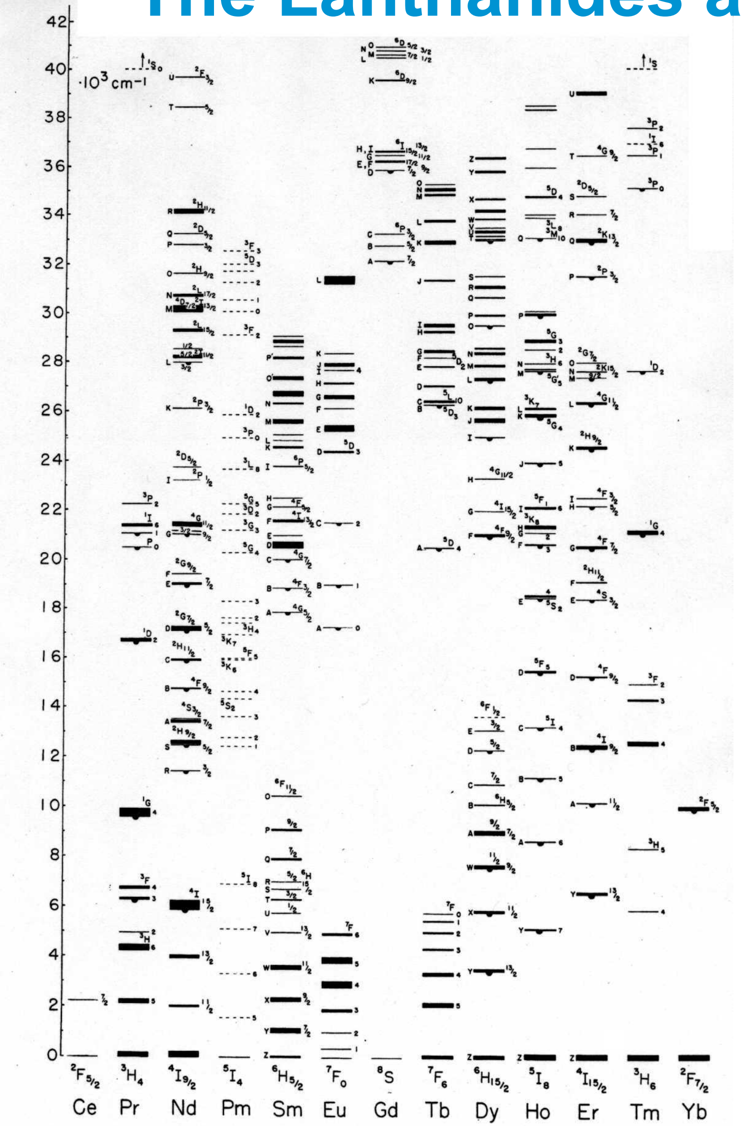
Multi-Photon Excited Luminescent Nanoparticles

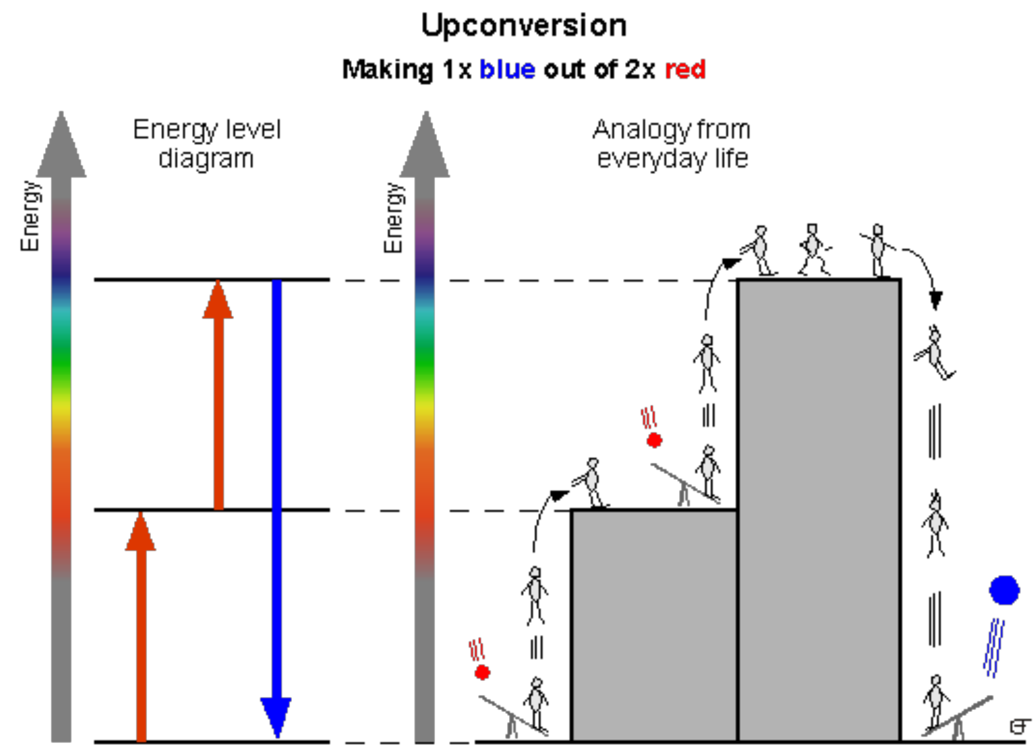
- Multi-photon excited luminescent nanoparticles are finding widespread use in nanomedicine
- Semiconductor quantum dots (QDs), gold nanorods (GNRs) are being used in two-photon imaging applications
- Excitation with NIR light (800-1000 nm):
  - Increases tissue penetration depths
  - Minimizes autofluorescence
  - Does not have negative effects on biological specimens

The Lanthanides



The Lanthanides and Upconversion



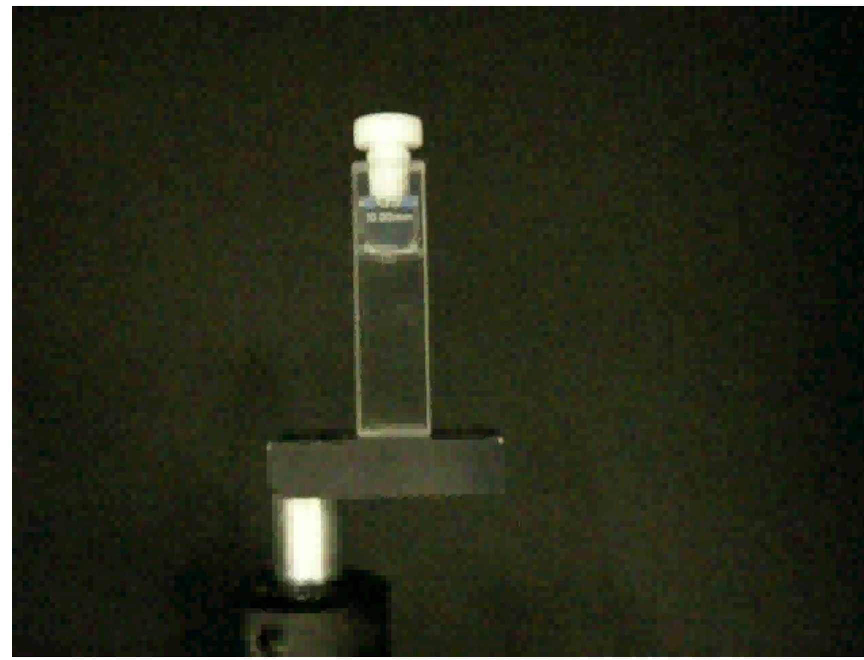


http://www.dcb-server.unibe.ch/groups/guedel/research/hug_upc_movie.htm

Upconverting Lanthanide-Doped Luminescent Nanoparticles

- Goal:
  - *Synthesis of new luminescent Ln^{3+}-doped nanoparticles and investigate their application to biology, specifically in nanothermometry*
- Requirements:
  - Small size with narrow particle size distribution
  - Monodispersed
  - Water dispersible and/or dispersible in aqueous media
  - Biocompatible
  - Appropriate surface functionalization

Upconversion of Lanthanide-Doped Nanoparticles



$NaYF_4$ nanoparticles co-doped with Er^{3+} (or Tm^{3+}) and Yb^{3+} ions

J. C. Boyer, F. Vetrone, L. A. Cuccia, J. A. Capobianco, *J. Am. Chem. Soc.*, **128;** 7444 (2006)

The Fluorides, Why $MLnF_4$ (M = Na, Li and Ln = Y, Gd)?

- Fluorides possess highest upconversion efficiencies among bulk materials

- Upconversion reported from colloidal dispersion of various fluoride nanoparticles

- $NaYF_4$
- $NaGdF_4$
- $LiYF_4$
- $BaYF_5$
- KY_3F_{10}
- CaF_2
- GdF_3
- $KGdF_4$

Synthesis of Fluoride-Based Upconverting Ln^{3+}-Doped Nanoparticles

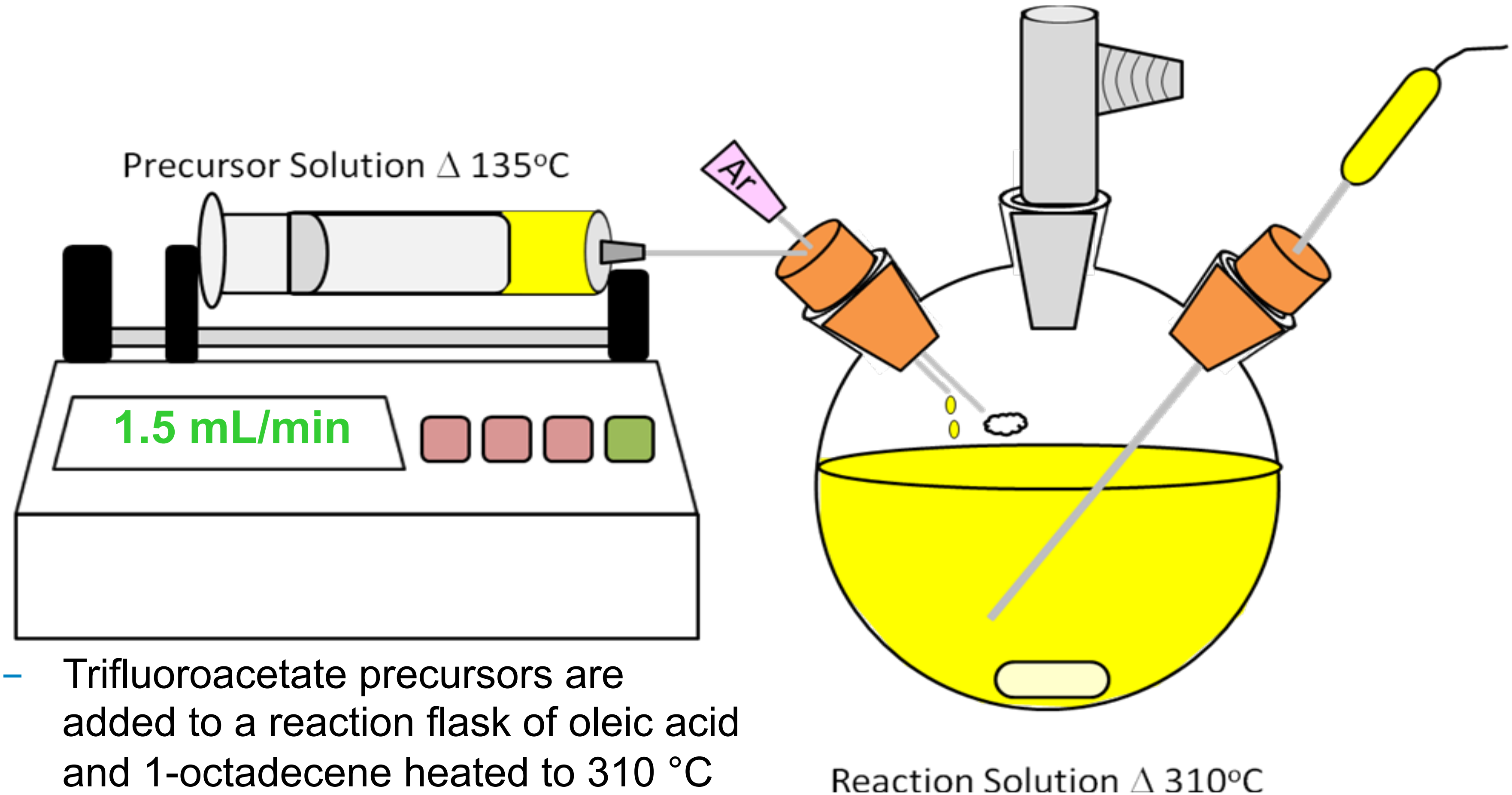
- Three main synthesis strategies:

1. Prepare hydrophobic nanoparticles *via* **thermal decomposition synthesis**
   - Modify the surface for water dispersibility

2. Directly prepare hydrophilic nanoparticles *via* **solvothermal synthesis**

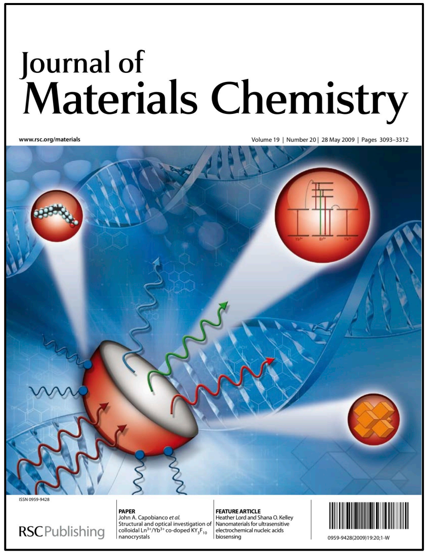
3. Rapidly prepare upconverting nanoparticles *via* **microwave-assisted synthesis**

Thermal Decomposition



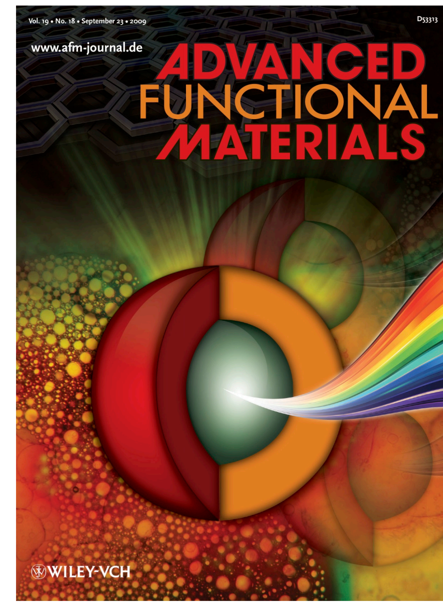
- Trifluoroacetate precursors are added to a reaction flask of oleic acid and 1-octadecene heated to 310 °C

R. Naccache, F. Vetrone, V. Mahalingam, L. A. Cuccia, J. A. Capobianco, *Chem. Mater.*, **21**; 717 (2009)



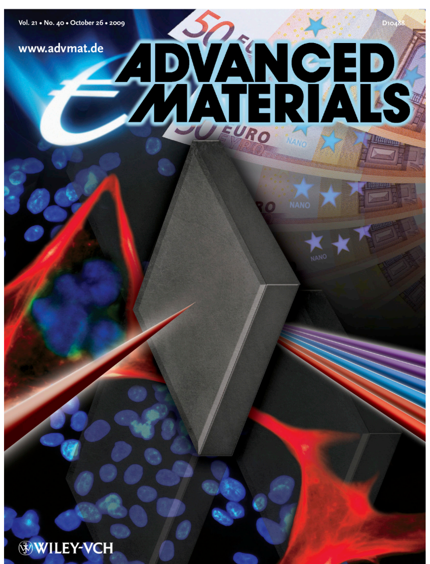
$KY_3F_{10}:Er^{3+}, Yb^{3+}$

V. Mahalingam, F. Vetrone, R. Naccache, A. Speghini, J. A. Capobianco, *J. Mater. Chem*, **19**; 3149 (2009)



$NaGdF_4:Er^{3+}, Yb^{3+}$ core / $NaGdF_4:Yb^{3+}$ shell

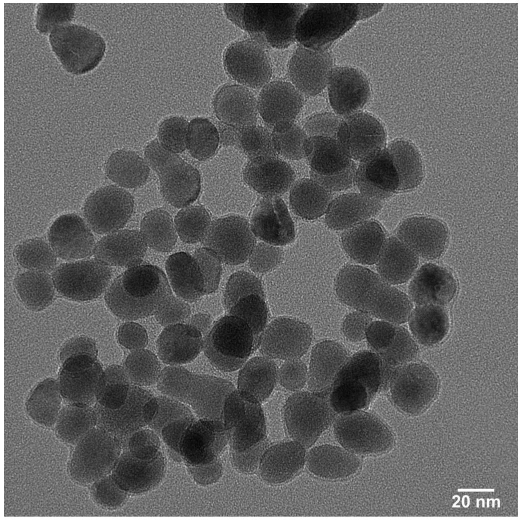
F. Vetrone, R. Naccache, V. Mahalingam, Christopher G. Morgan, J. A. Capobianco, *Adv.Funct.Mater.*,**19**; 2924 (2009)



$LiYF_4:Tm^{3+}, Yb^{3+}$

V. Mahalingam, F. Vetrone, R. Naccache, A. Speghini, J. A. Capobianco, *Adv.Mater.*,**21**; 4025 (2009)
UV to NIR luminescence, **Nature Photonics, Research Highlights**, Volume 3, Page 606, November 2009

Solvothermal Synthesis



- Synthesize upconverting nanoparticles that can be dispersed directly in water
- No additional step required
- Prepared starting from the metal chlorides and NH_4F and a capping ligand in ethylene glycol
- Ligands (e.g.)

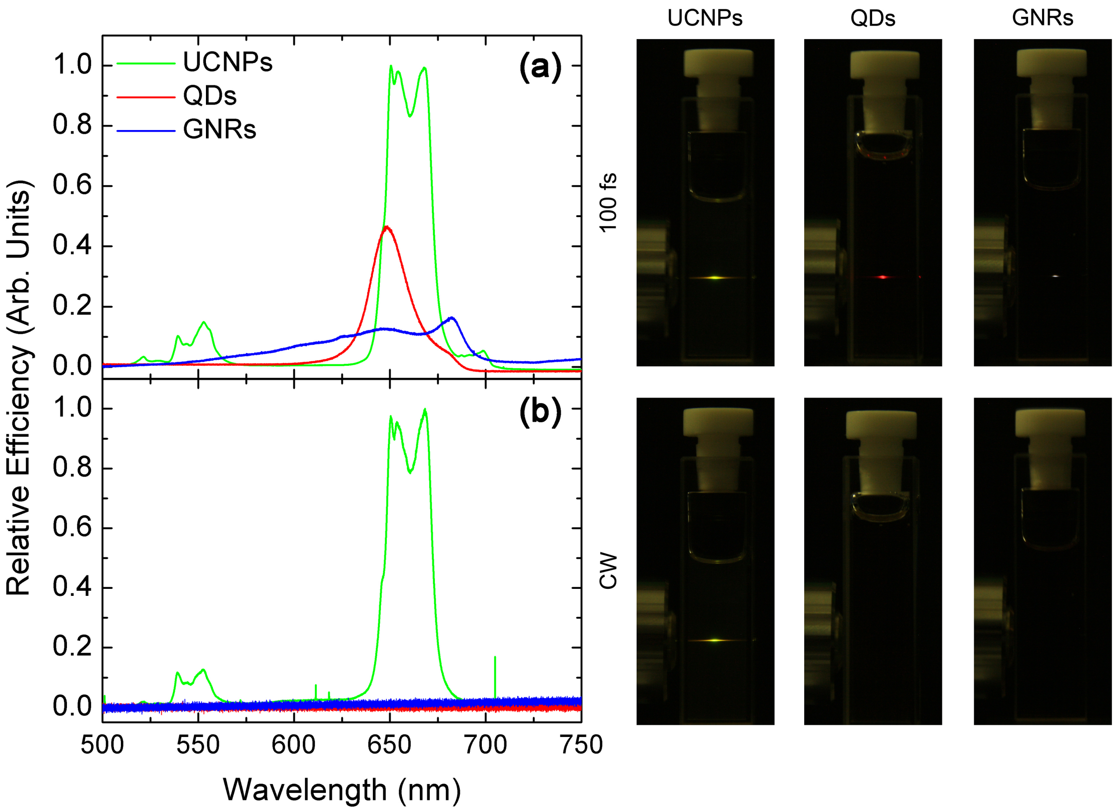
  Polyethylenimine (PEI) – NH_2 Groups

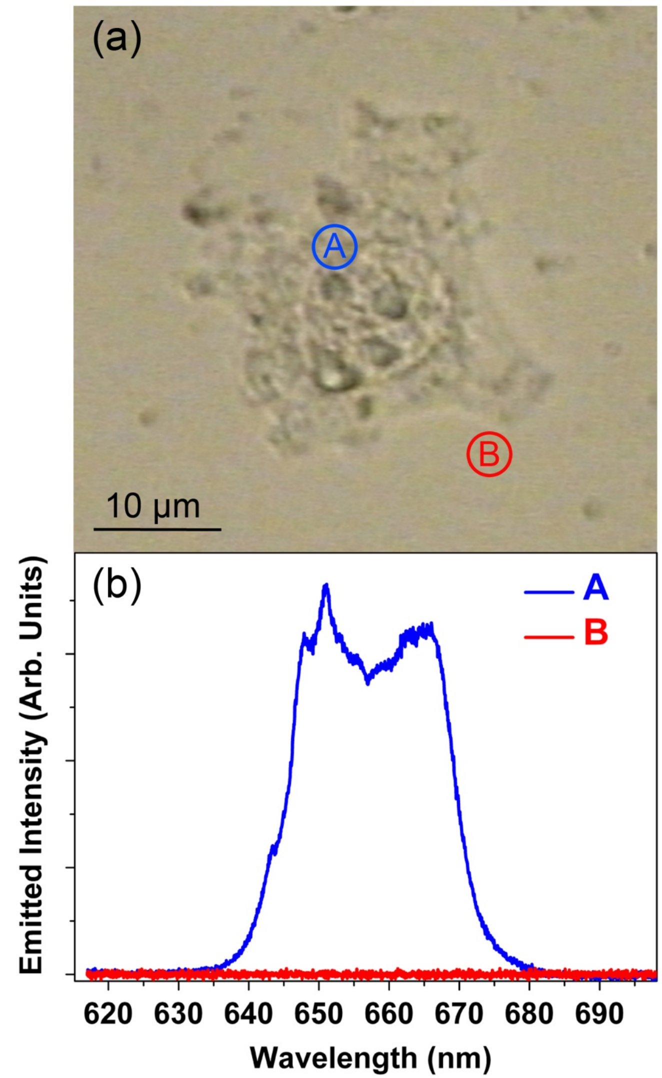
  Poly(sodium 4-styrenesulfonate) – SH Groups

  Polyacrylic acid – COOH Groups

F. Vetrone, R. Naccache, A. Juarranz de roFuente, F. Sanz-Rodríguez, A. Blazquez-Castro, E. Martin Rodriguez, D. Jaque, J. García Solé, J. A. Capobianco, *Nanoscale*, **2**; 495 (2010)

Two-Photon Optical Imaging

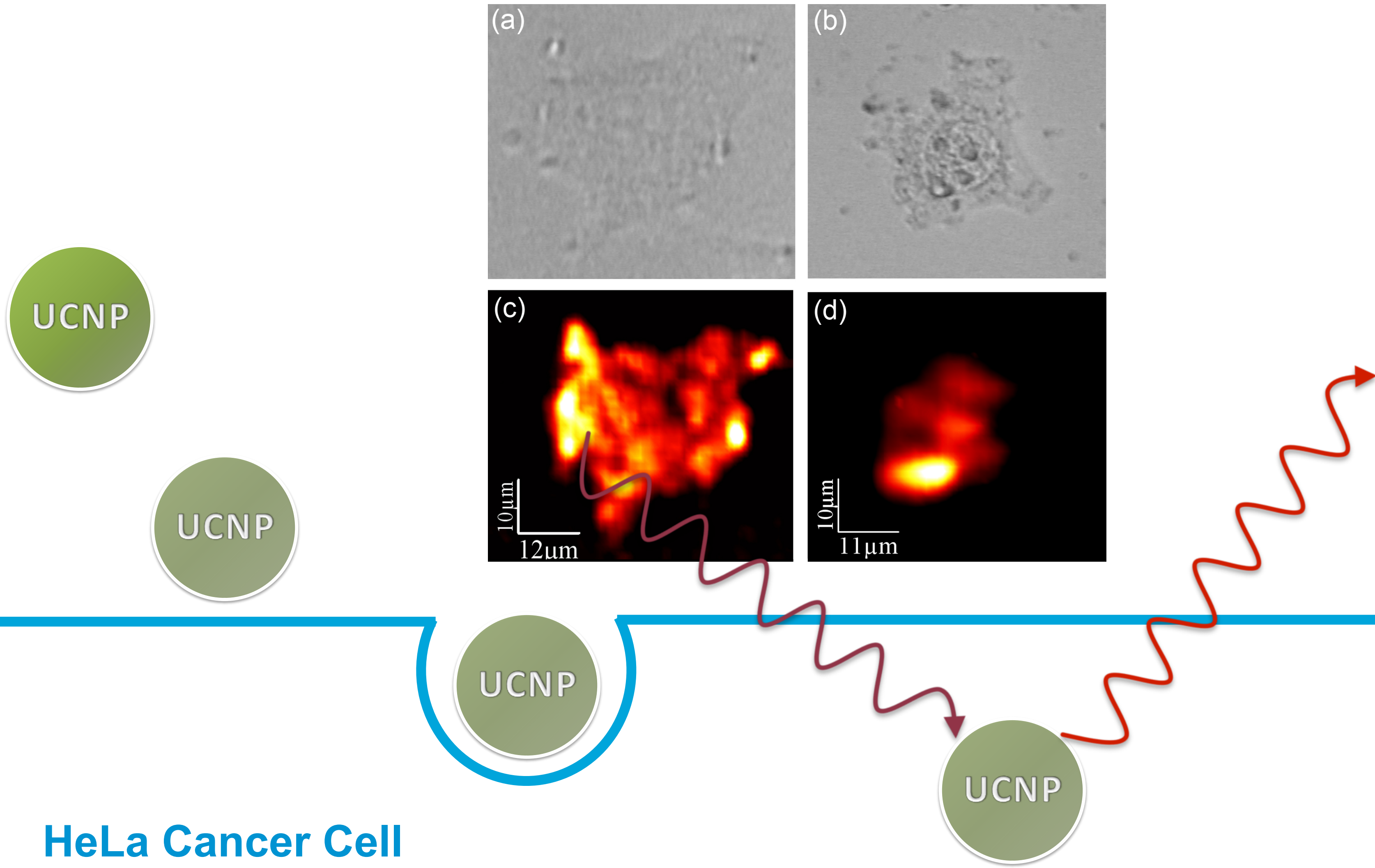




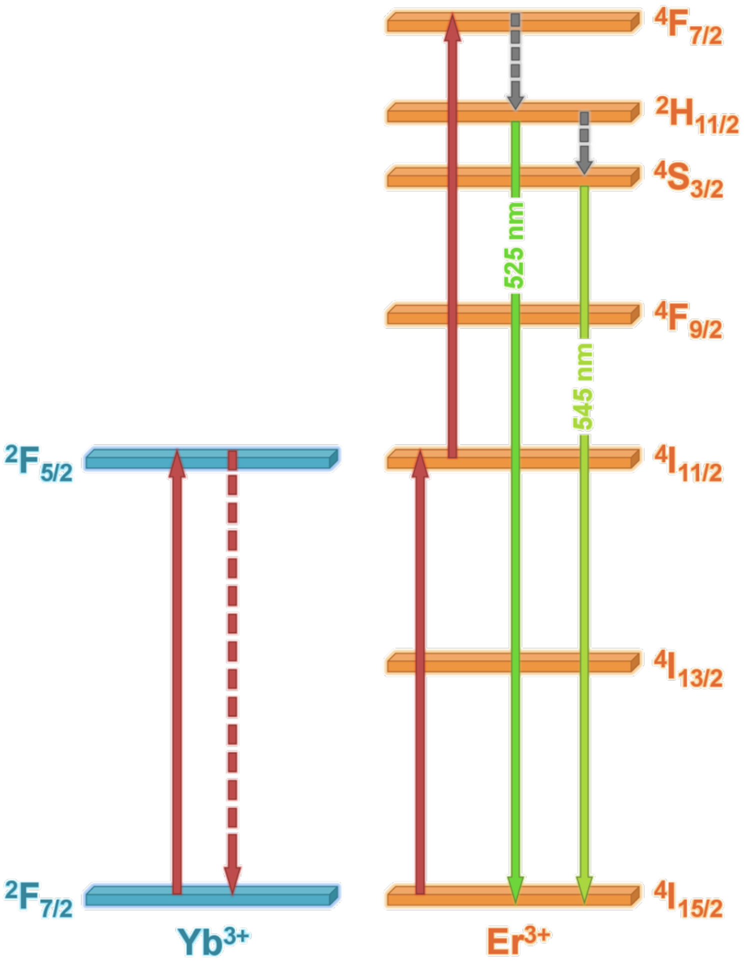
L. Martinez Maestro, E. Martín Rodriguez, F. Vetrone, R. Naccache, H. L. Ramirez, D. Jaque, J. A. Capobianco and J. García Solé, *Opt. Express*, **18**; 23544 (2010)

F. Vetrone, R. Naccache, A. Juarranz de la Fuente, F. Sanz-Rodríguez, A. Blazquez-Castro, E. Martin Rodriguez, D. Jaque, J. García Solé, J. A. Capobianco, *Nanoscale*, **2**; 495 (2010)

Two-Photon Optical Imaging

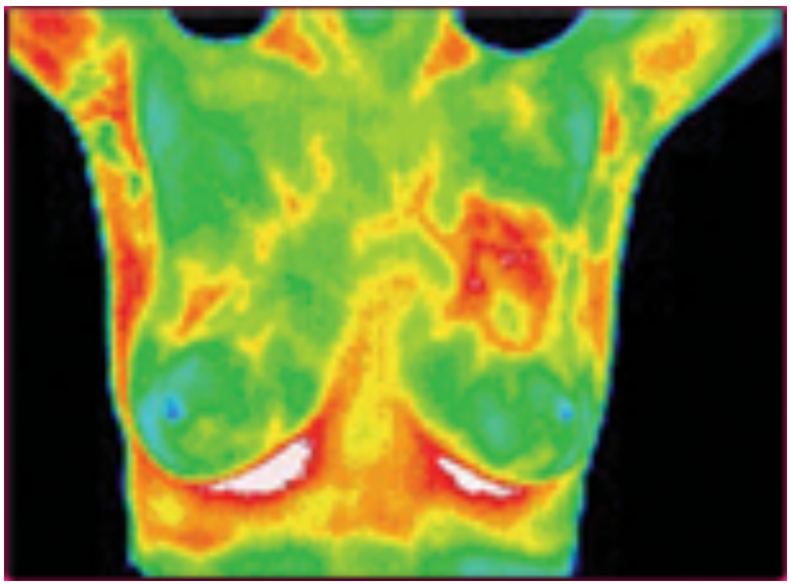


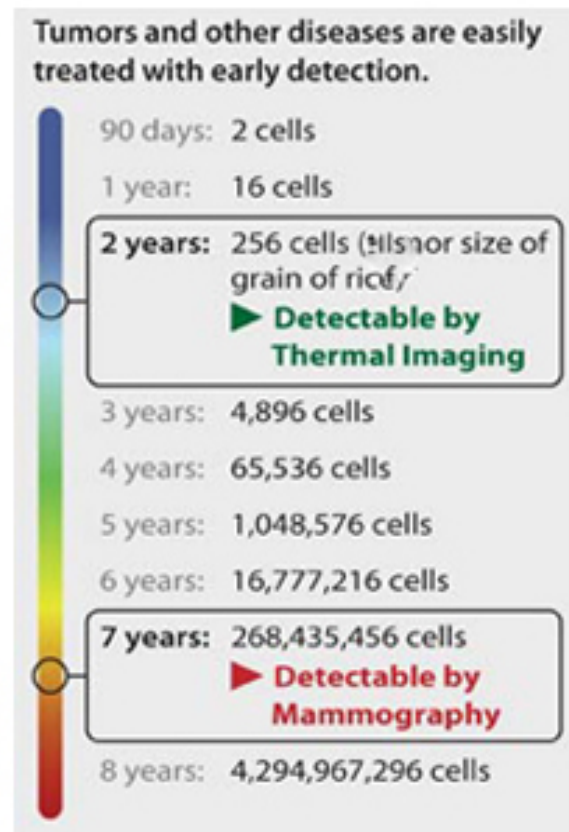
Er^{3+}/Yb^{3+} Co-Doped Nanparticles



Nanothermometry → Thermal Imaging – Why?

- Tumors are "warmer" because their larger metabolic activity and also because the more intense blood circulation in its surroundings

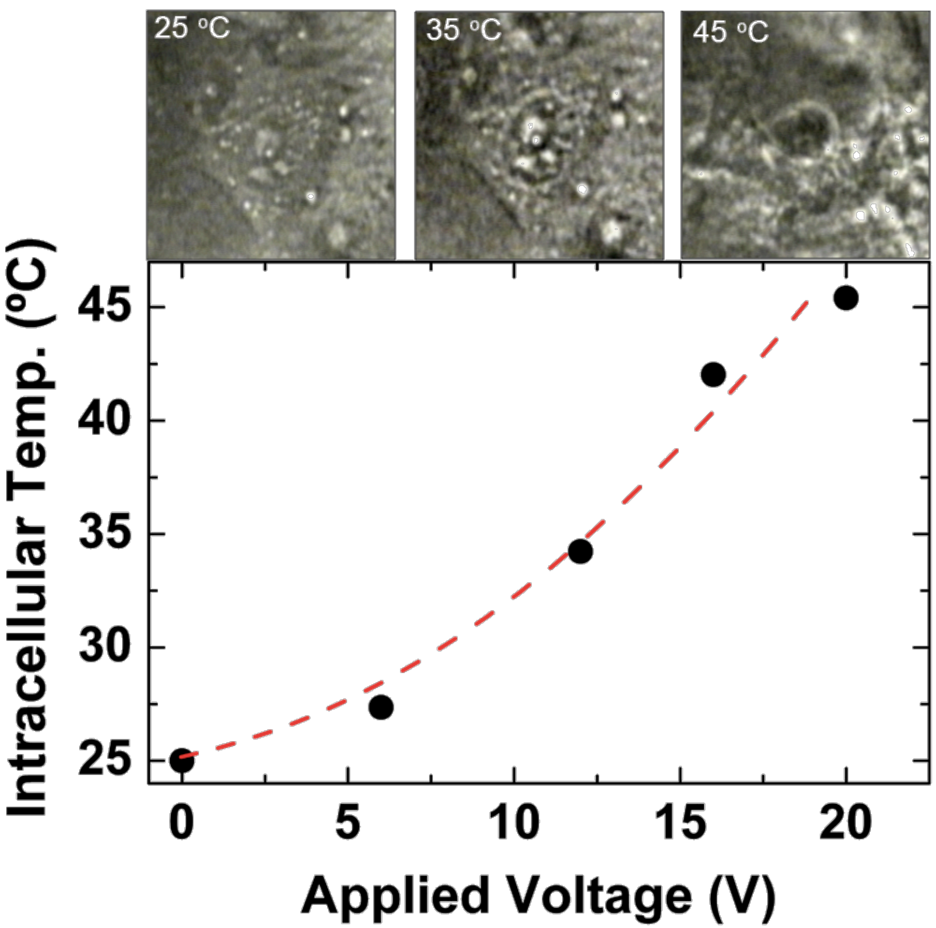


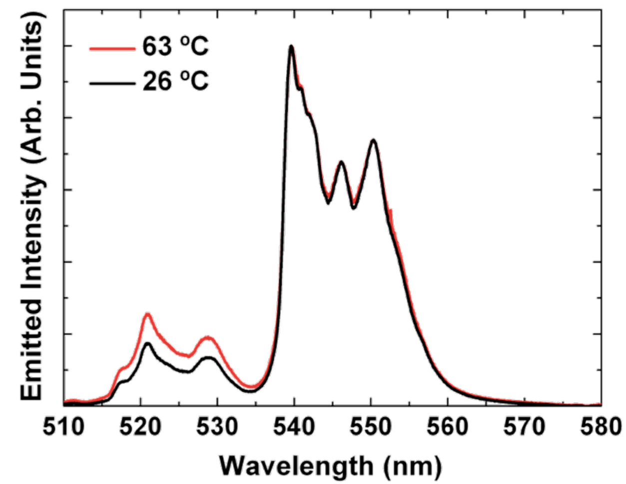


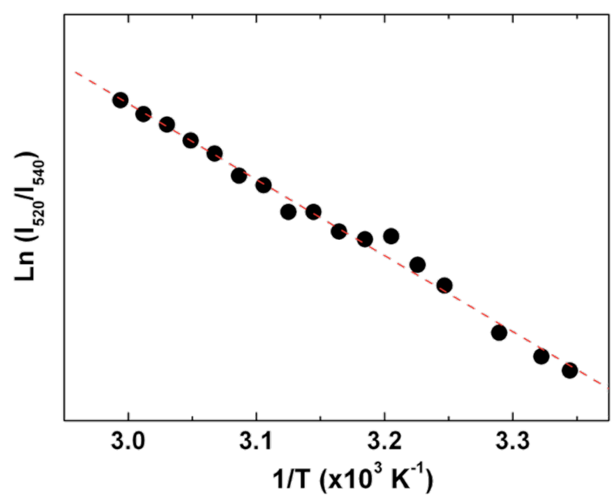
- Early detection of disease
- Several years before a mammogram

http://www.breastthermography.com/breast_thermography_mf.htm

Nanothermometer







F. Vetrone, R. Naccache, A. Zamarrón, A. Juarranz de la Fuente, F. Sanz-Rodríguez, L. Martinez Maestro, E. Martín Rodriguez, D. Jaque, J. García Solé, J. A. Capobianco, *ACS Nano*, **4**; 3254 (2010)

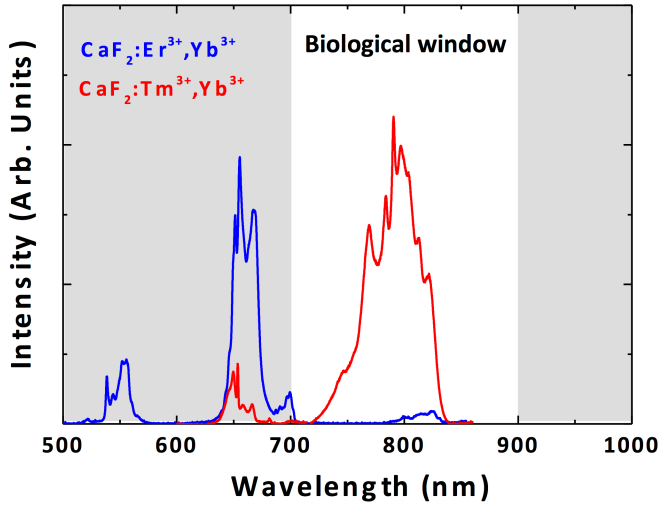
NIR-NIR Multi-Photon Imaging

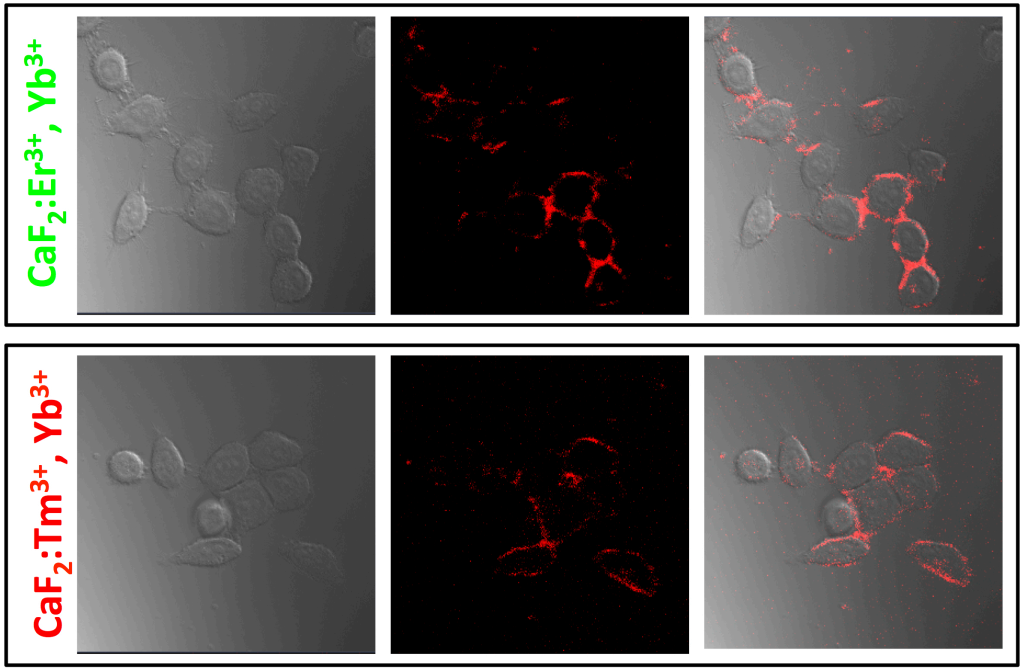
- The advantages of NIR excitation light has been previously discussed

- However, an optimal system with **both** excitation and emission wavelengths that lie within the optimal window for tissue penetration would be a powerful tool for future *in vivo* imaging and nanothermometry

- The Tm^{3+} ion has a strong emission at 800 nm

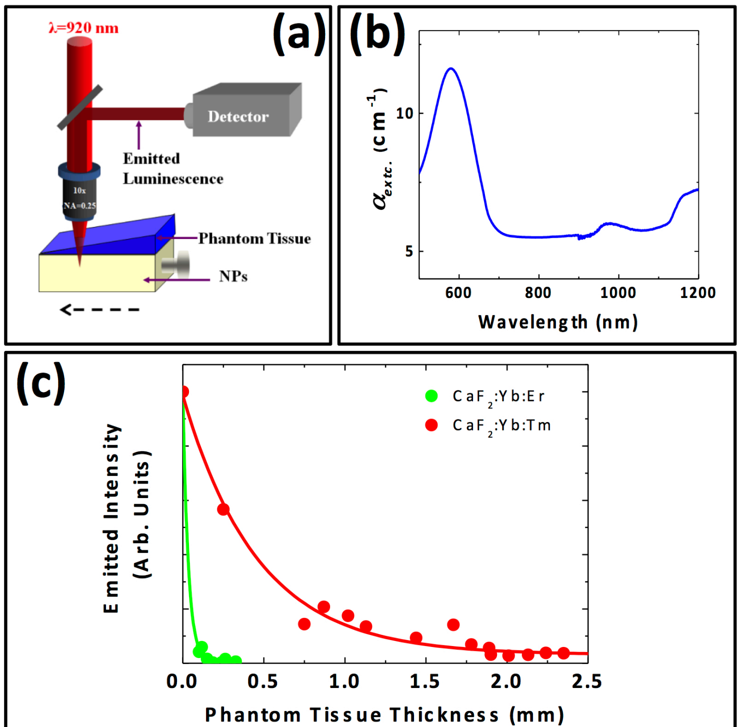
NIR-to-NIR Multi-Photon Imaging with $CaF_2:Tm^{3+}$, Yb^{3+} Upconverting Nanoparticles

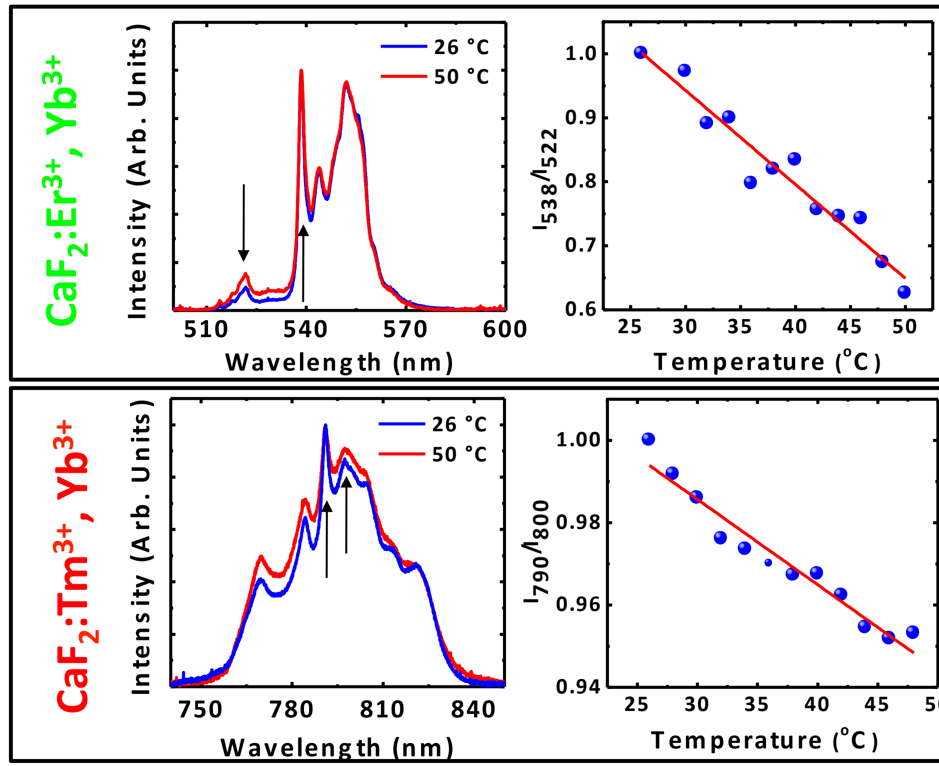




N.-N. Dong, M. Pedroni *et al.*, *ACS Nano*, **5**; 8665 (2011)

$CaF_2:Tm^{3+}$, Yb^{3+} Upconverting Nanoparticles: Towards Multi-Modality





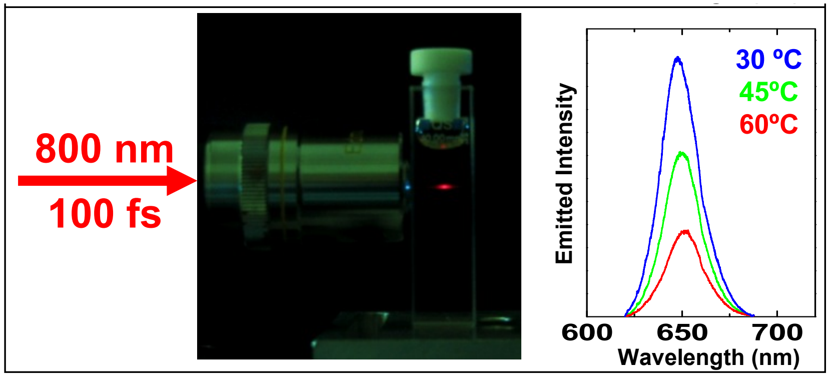
N.-N. Dong, M. Pedroni *et al.*, *ACS Nano*, **5**; 8665 (2011)

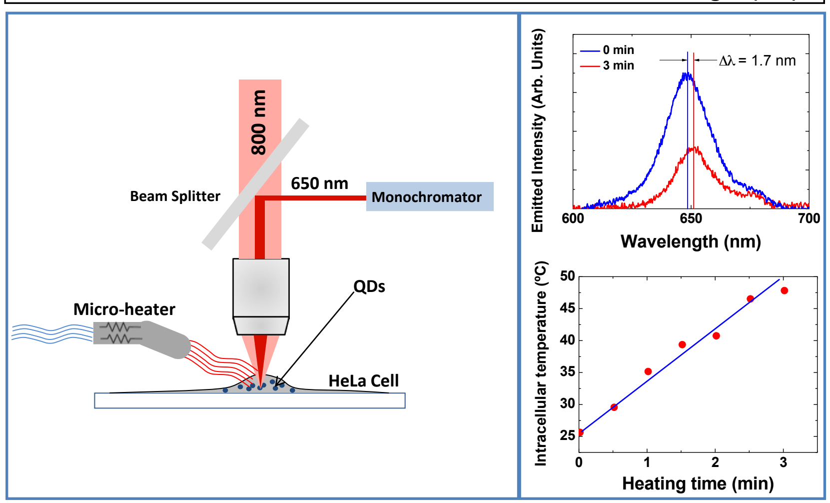
Quantum Dots as Nanothermometers

- CdSe/CdS or CdTe
- PbS/PbSe (Chalcolgenides)
- Core/Shell (PbS core/CdS shell)

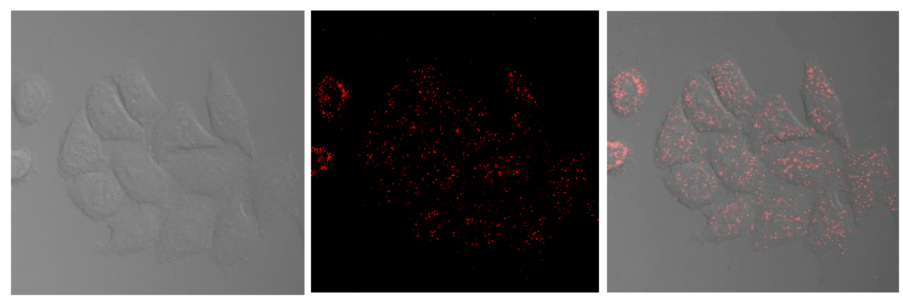
N.-N. Dong *et al., ACS Nano*, **(In Press)**

QD Nanothermometers (CdSe)



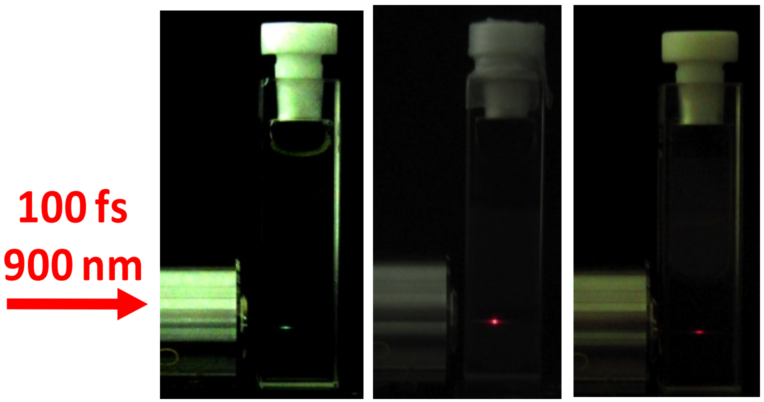


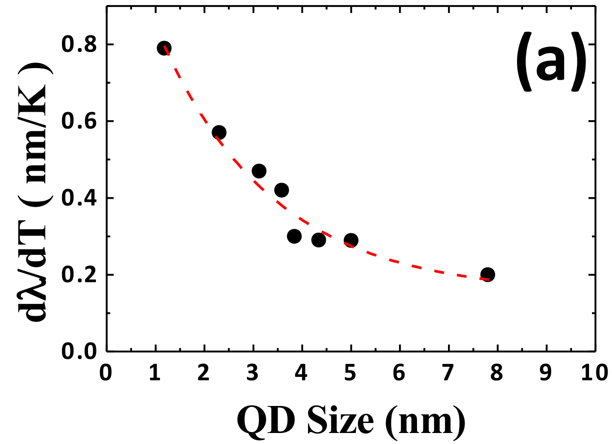
- The two-photon excited emission of CdSe QDs show a double dependence of temperature
  - Red shift of the emission
  - Decrease in intensity

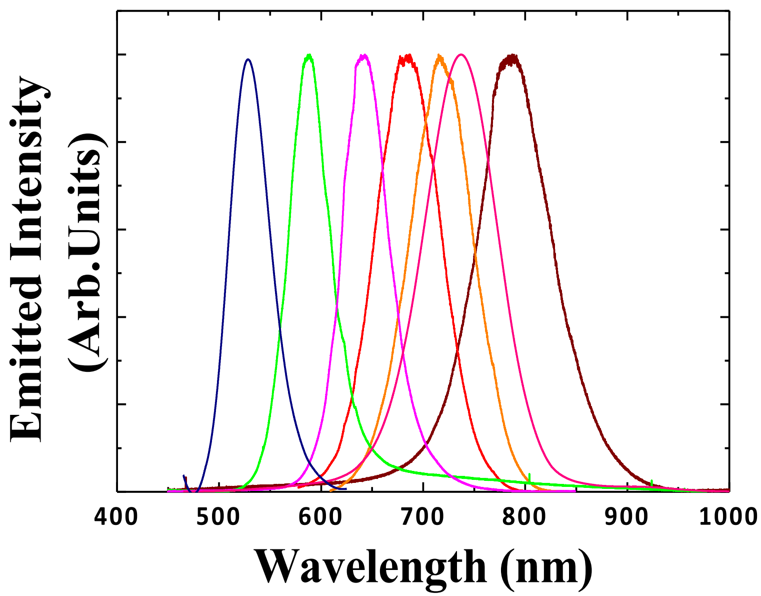


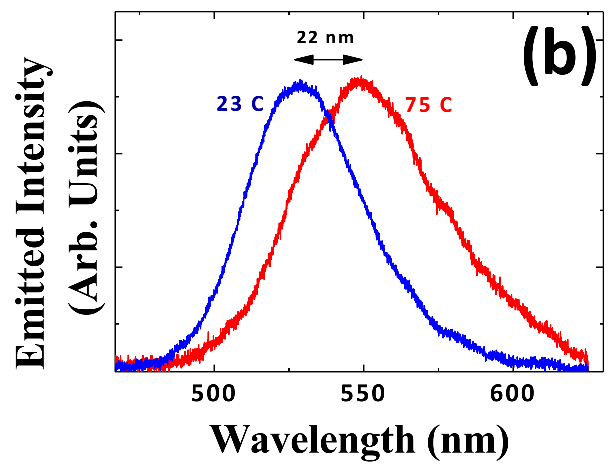
L. Martinez Maestro, E. Martín Rodriguez, F. Sanz Rodríguez, M. C. Iglesias-de la Cruz, A. Juarranz, R. Naccache, F. Vetrone, D. Jaque, J. A. Capobianco and J. García Solé, *Nano Letters*, **10**; 5109-5115 (2010)

QD Nanothermometers (CdTe)



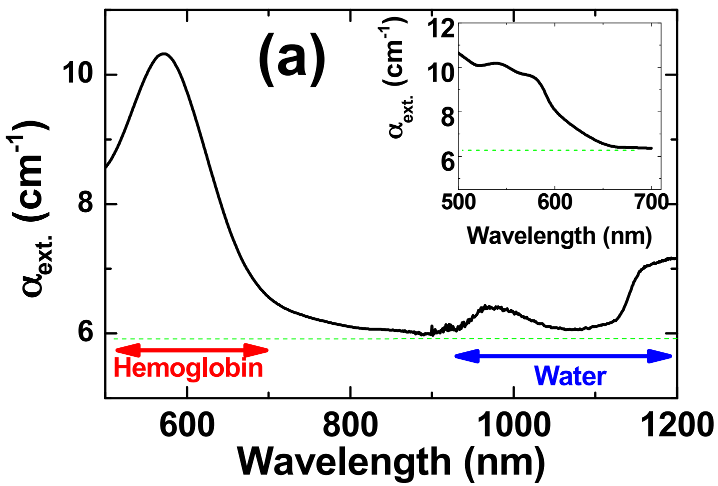


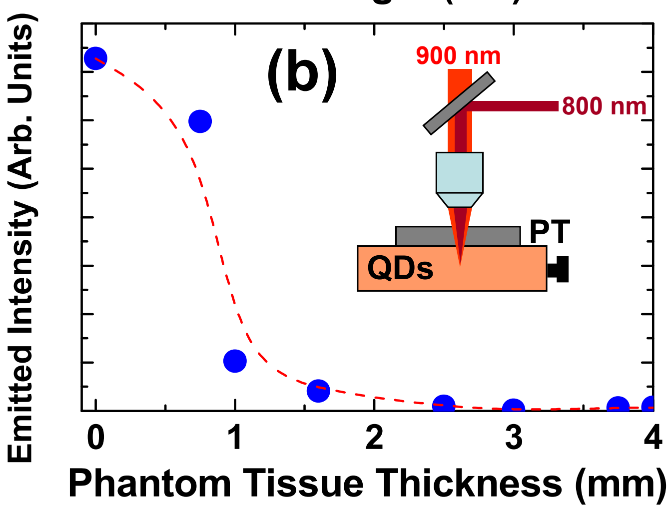


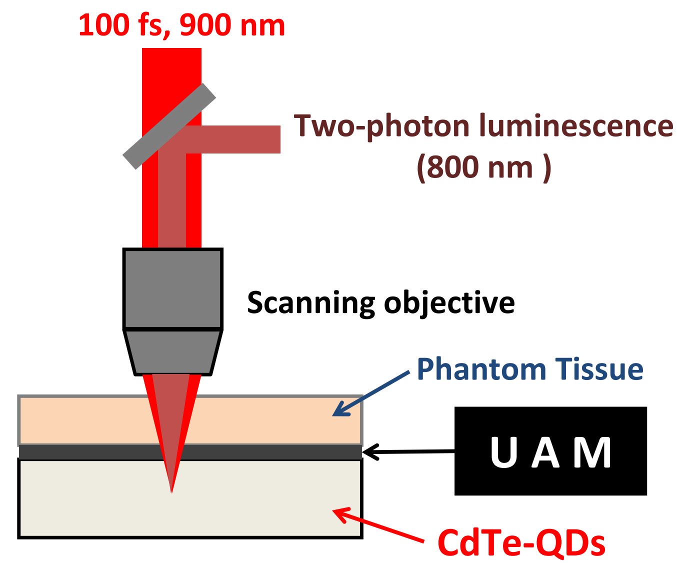


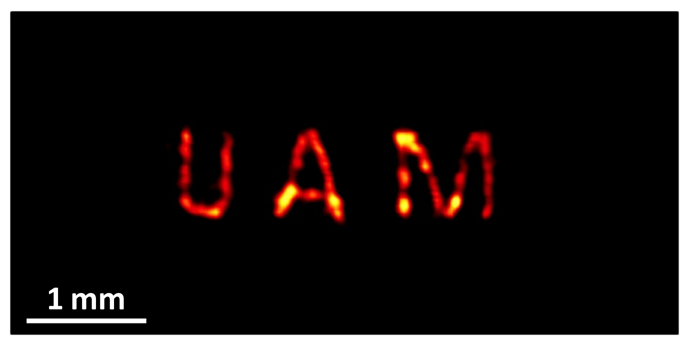
L. M. Maestro, C. Jacinto, U. S. Rocha, F. Vetrone, J. A. Capobianco, D. Jaque and J. García Solé, *Small*, **7**; 1774-1778 (2011)

NIR-to-NIR Multi-Photon Imaging with CdTe QDs









L. M. Maestro, J. E. Ramírez-Hernández, N. Bogdan, J. A. Capobianco, F. Vetrone, J. García Solé and D. Jaque, *Nanoscale*, **(In Press)**

Conclusions

- Multiphoton excited nanoparticles, (i) lanthanide-doped nanoparticles and (ii) semiconductor quantum dots are capable of (up)converting near-infrared light to higher energies.
- Can be synthesized by various techniques
  - Thermal decomposition (requires subsequent surface modification)
  - One-step solvothermal synthesis
  - Microwave-assisted synthesis
- Can be used in various biological applications
  - Biosensing
  - Two-photon optical imaging
  - Nanothermometry

Acknowledgments

ICIP
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Canadian Institute for
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NSERC
CRSNG

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