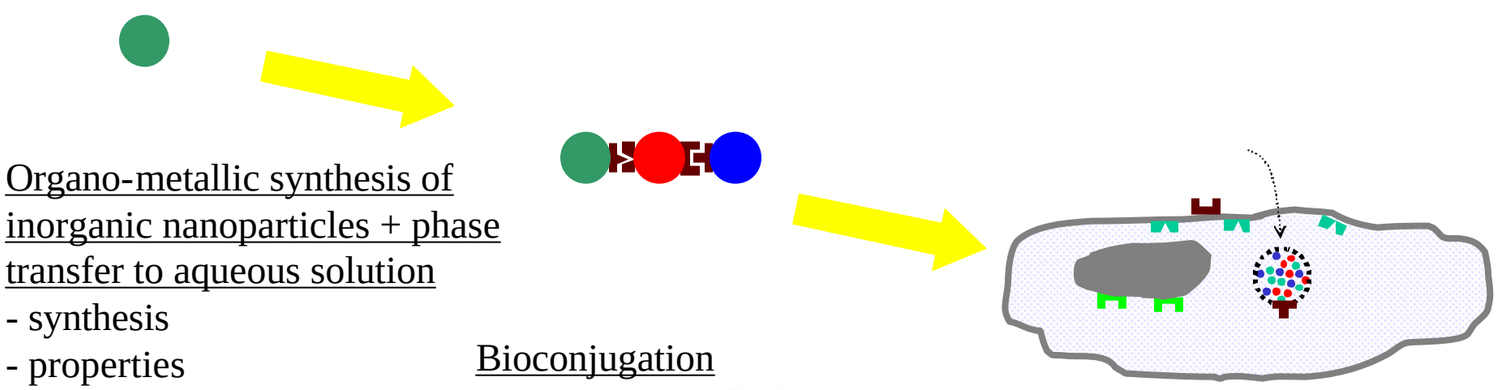
W. J. Parak

Inorganic Nanoparticles -From Synthesis to Biological Applications

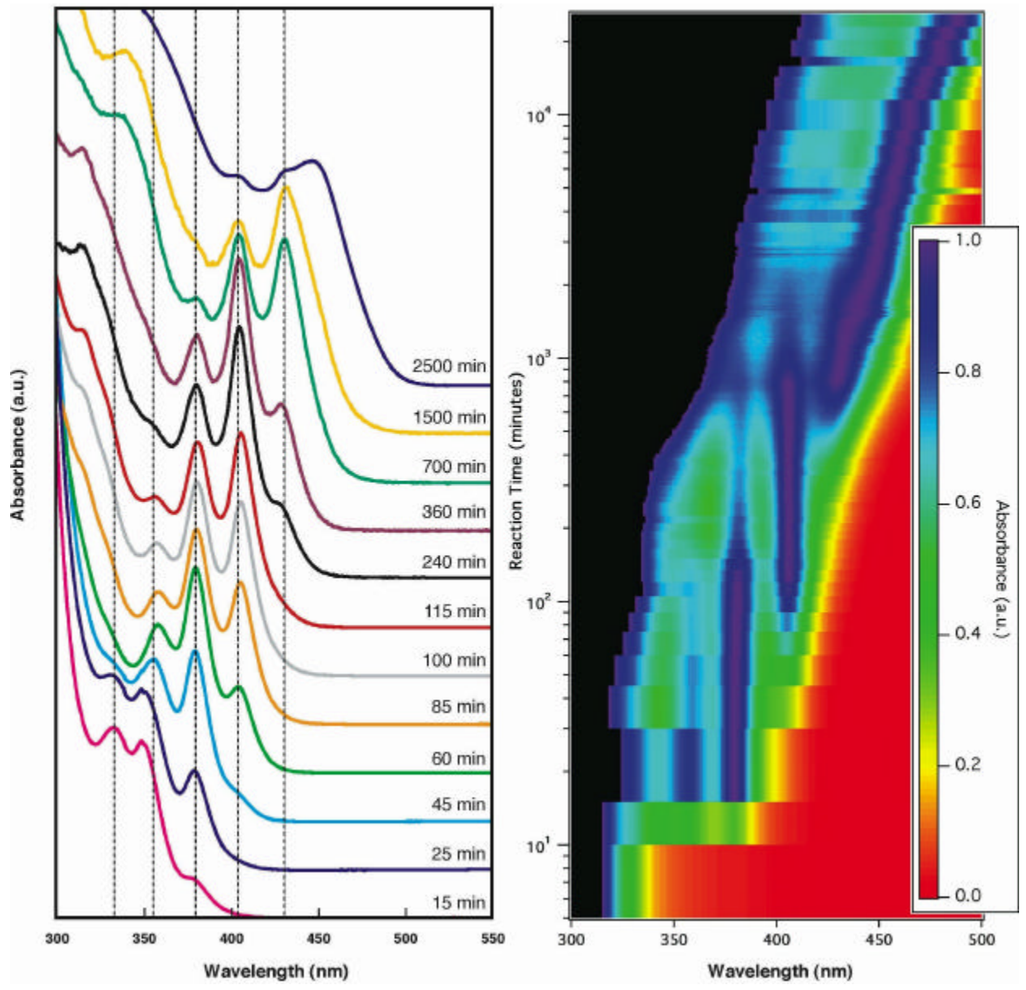


Organo-metallic synthesis of inorganic nanoparticles + phase transfer to aqueous solution
- synthesis
- properties
- hybrid materials
- phase transfer

Bioconjugation
- model-system DNA-Au
- particles with single molecules
- particles saturated with molecules
- introduction of functional groups
- transfer to other particles / molecules
- polymer capsules

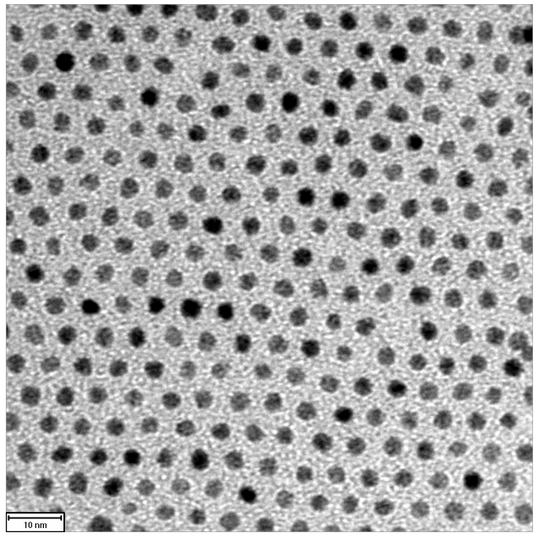
(biological) Applications
- Light-addressable electrodes
- Phagokinetic tracks (motility assay)
- Drug delivery
- Smart Sensors

CdSe magic-size nanocrystals



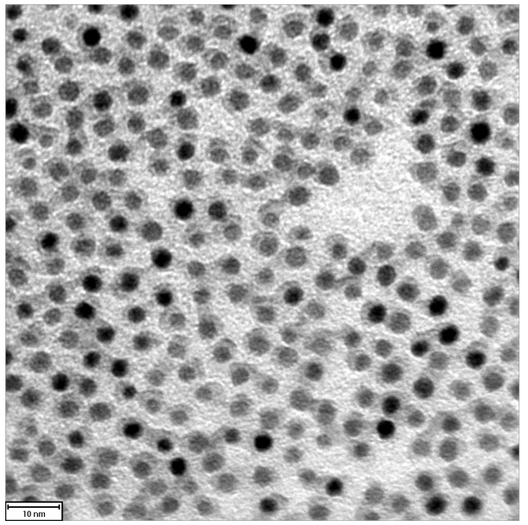
S. Kudera, M. Zanella, C. Giannini, A. Rizzo, Y. Li, G. Gigli, R. Cingolani, G. Ciccarella, W. Spahl, W. J. Parak, L. Manna, "Sequential growth of magic-size CdSe nanocrystals", *Advanced Materials* **19**, 548-552 (2007).

Hybrid materials: two functionalities within one particle



FePt

(adopted from the synthesis protocol of H. Gu et al., JACS, 2004)



FePt@CdS

one material grown on top of another ? potentially two functionalities within of particle (e.g. fluorescent + magnetic)

many material combinations are possible: FePt@(CdS, ZnS, PbS, CdSe, ZnSe, PbSe) ? very general synthesis route

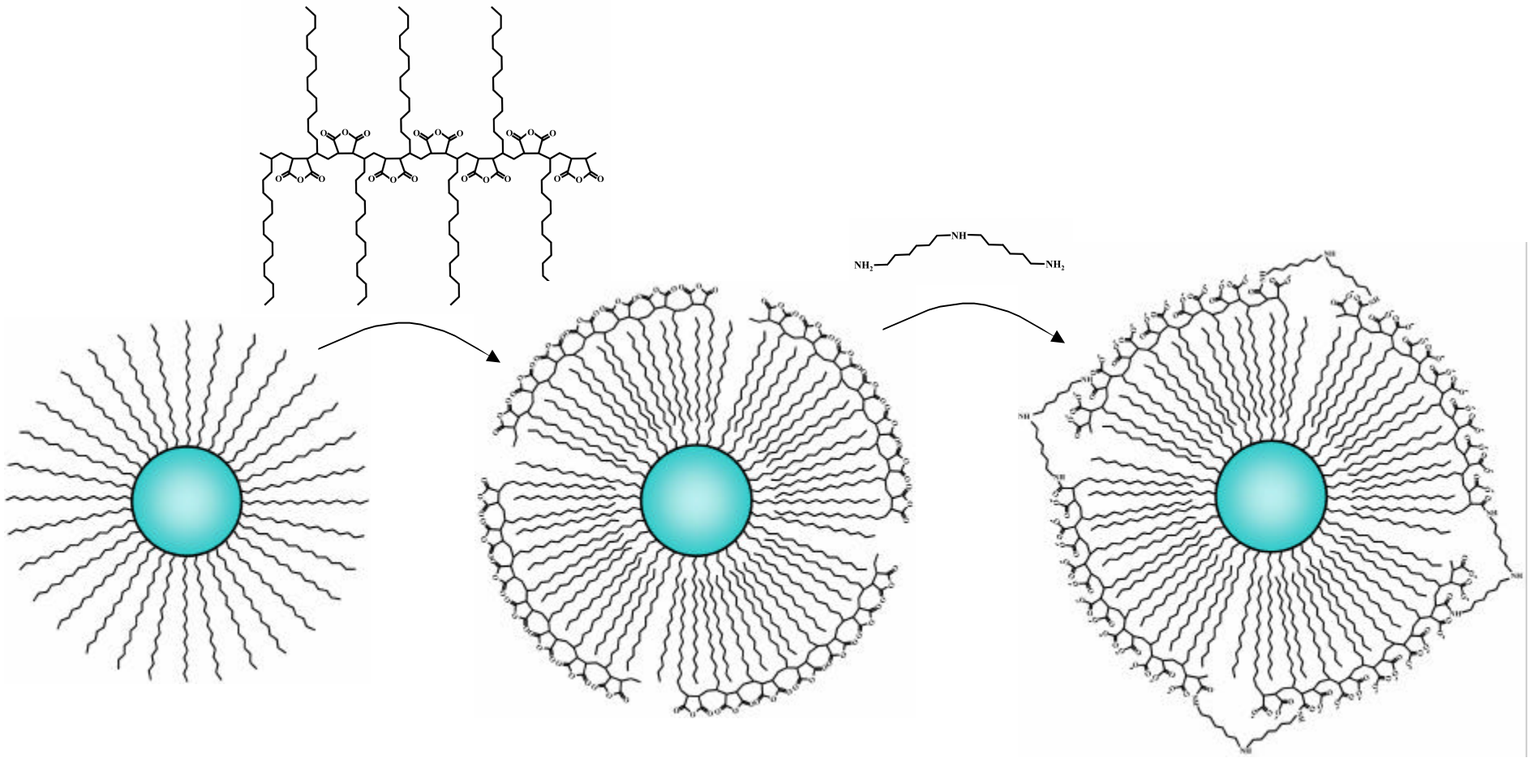
but: are properties of the original materials retained?
? to our experience: slightly reduced magnetic moment + strongly quenched fluorescence

problems with this concept for hybrid particles: hydrophobic, decreased performance of functionality ? surface modification

M. Zanella, A. Falqui, S. Kudera, L. Manna, W. Parak, in preparation

Transfer to aqueous solution: Polymer coating procedure

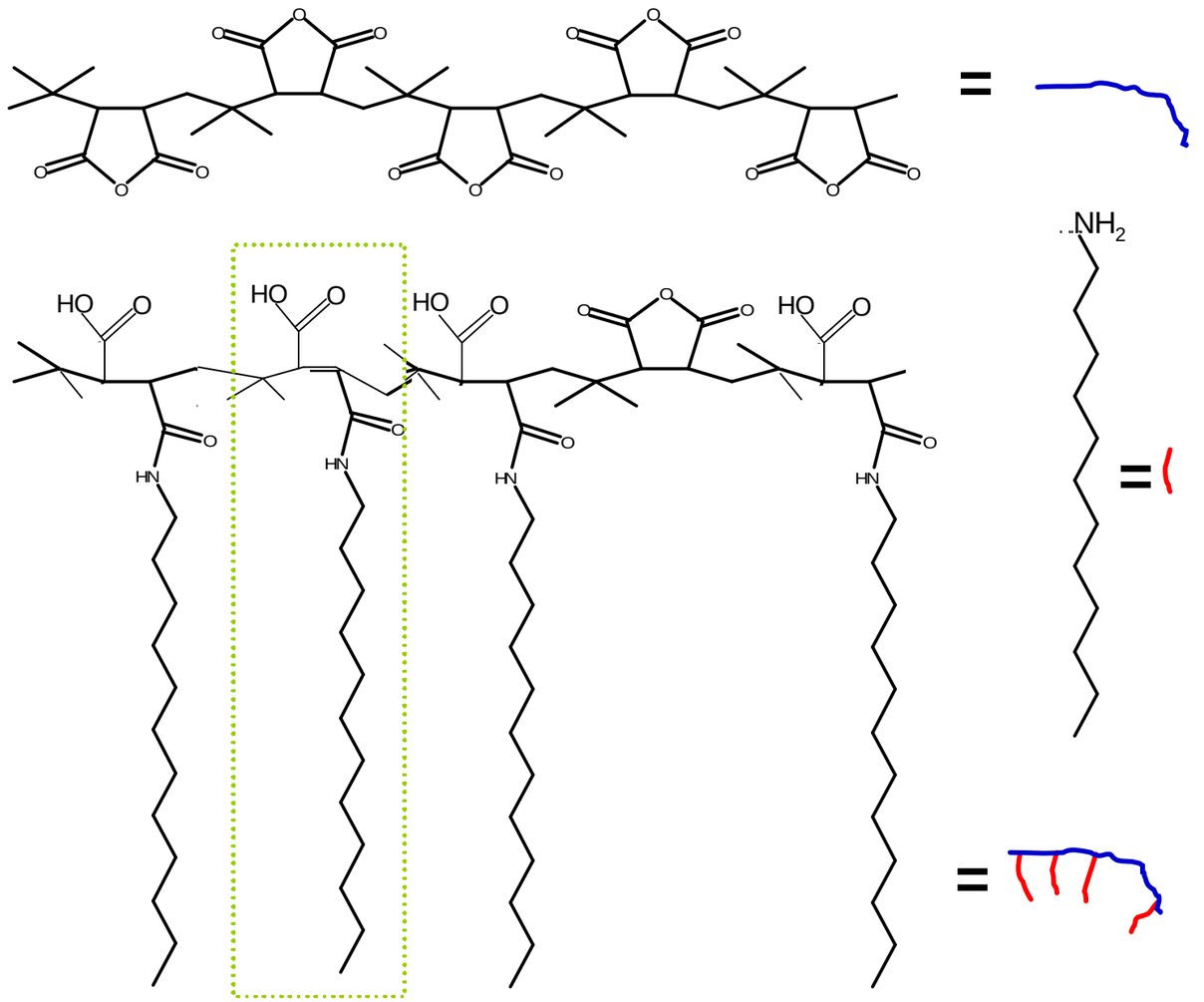
wrap particles in an amphiphilic polymer shell



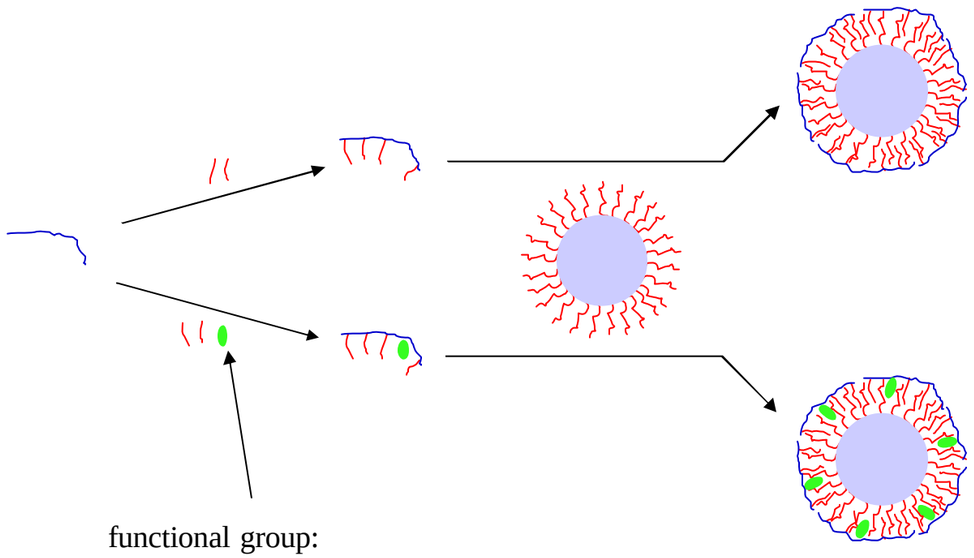
works for all particles with hydrophobic stabilizer chains

T. Pellegrino, L. Manna, S. Kudera, D. Koktysh, A. Rogach, S. Keller, J.Rädler, G. Natile, W. J. Parak, Nanoletters 4, 703-707 (2004)

Synthesis of the amphiphilic polymer



Direct embedding of functional groups in the polymer shell

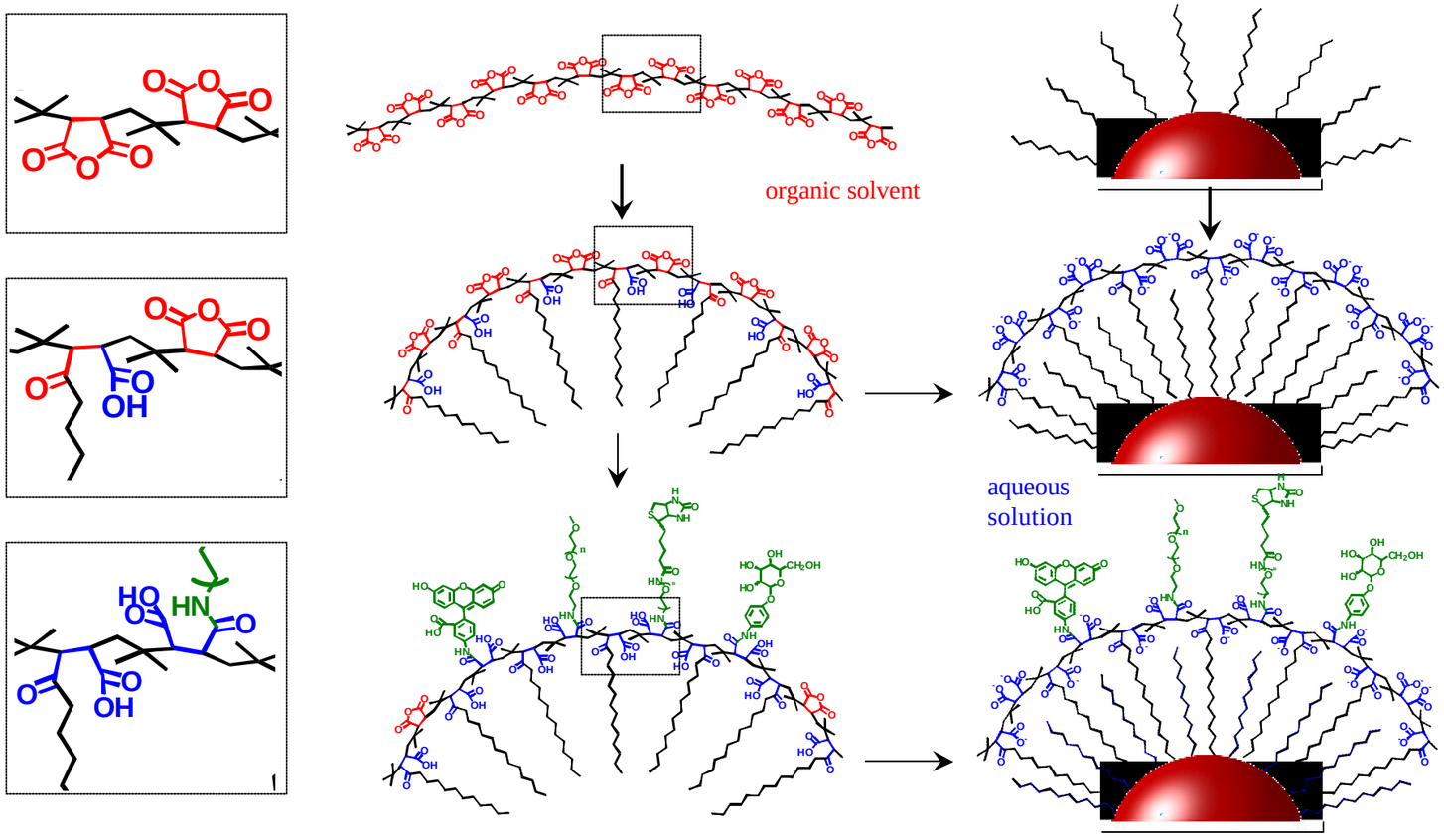


functional group:
- PEG
- organic fluorophore
- sugar
- biotin
- ....

we can directly incorporate functional groups into the polymer shell without the need for post bioconjugated chemistry

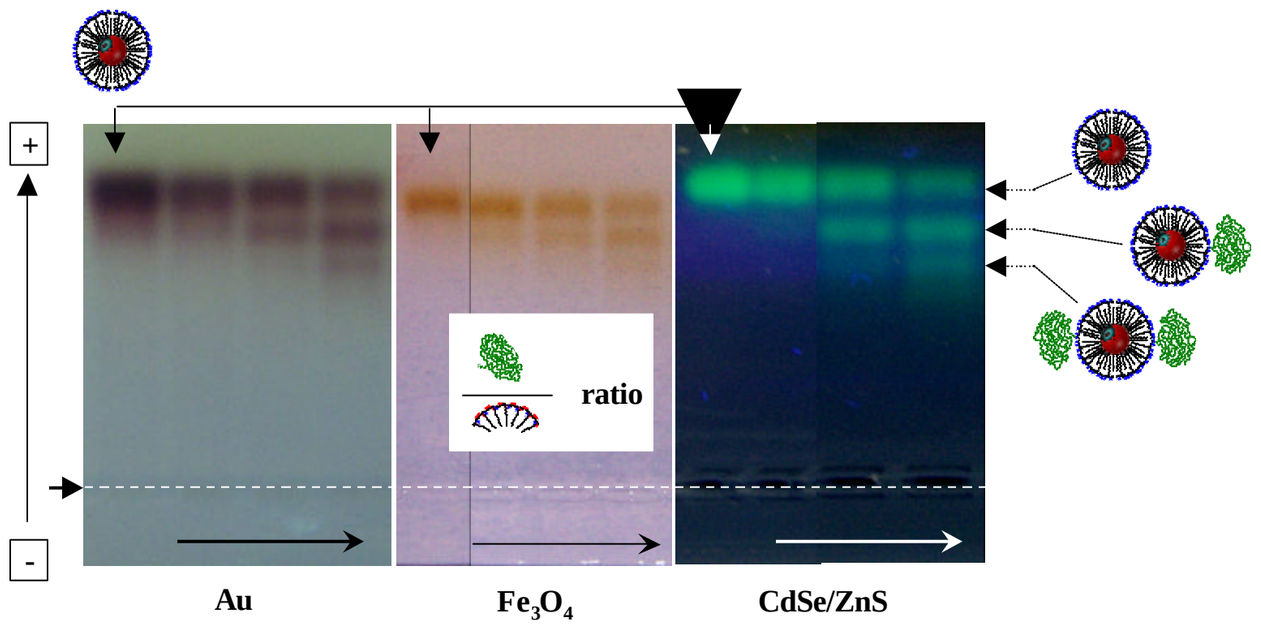
Cheng-An J. Lina, Ralph A. Sperling, Jimmy K. Li, Ting-Ya Yang, Pei-Yun Li, Marco Zanella, Walter H. Chang, Wolfgang J. Parak , submitted to SMALL

Direct embedding of functional groups in the polymer shell



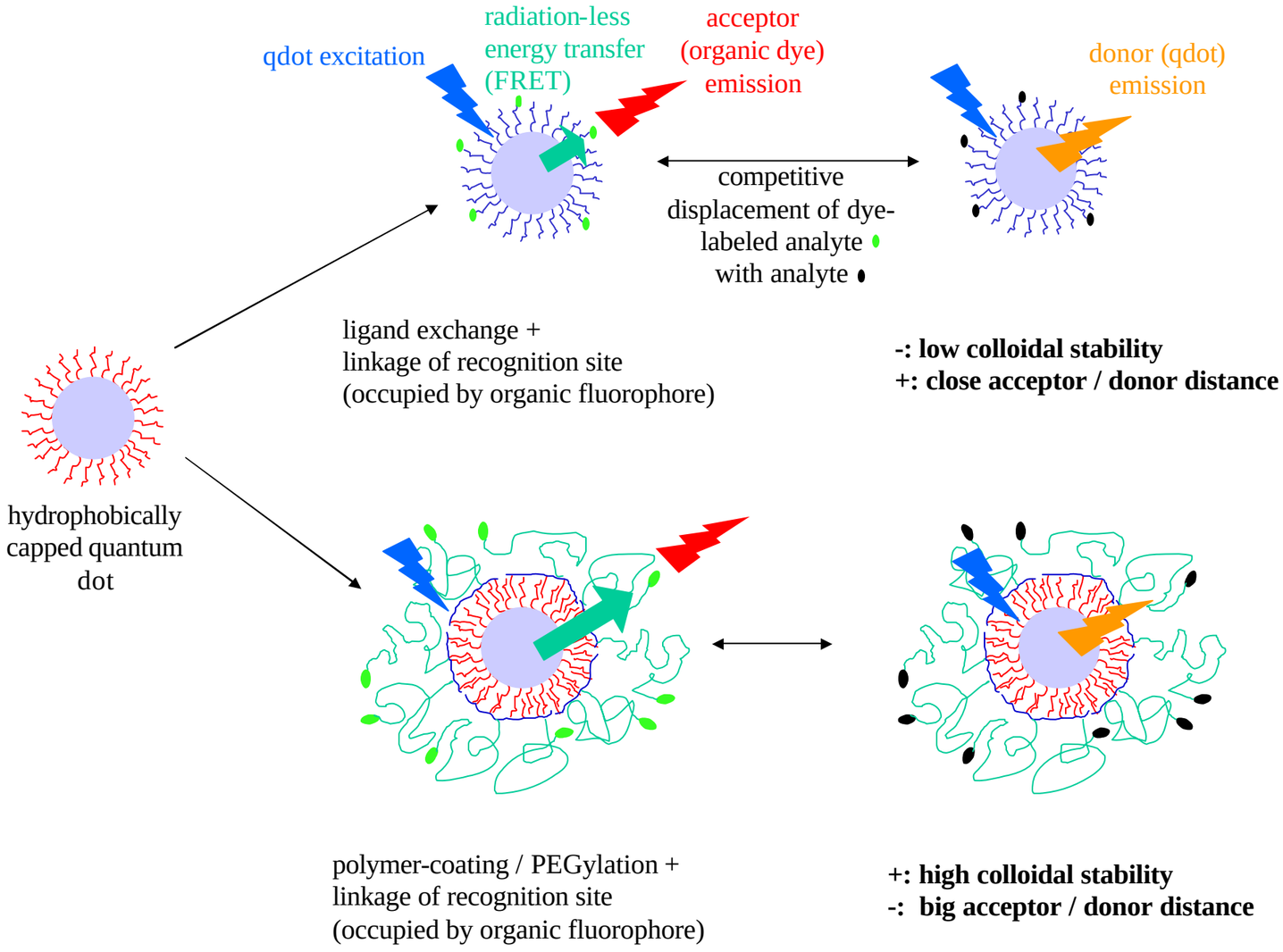
Cheng-An J. Lina, Ralph A. Sperling, Jimmy K. Li, Ting-Ya Yang, Pei-Yun Li, Marco Zanella, Walter H. Chang, Wolfgang J. Parak ,
submitted to SMALL

General bioconjugation (with controlled number of single molecules)



R. A. Sperling, T. Pellegrino, J. K. Li, W. H. Chang, W. J. Parak, *Advanced Functional Materials*, **16**, 943-948 (2006).
Cheng-An J. Lina, Ralph A. Sperling, Jimmy K. Li, Ting-Ya Yang, Pei-Yun Li, Marco Zanella, Walter H. Chang, Wolfgang J. Parak , submitted to *SMALL*

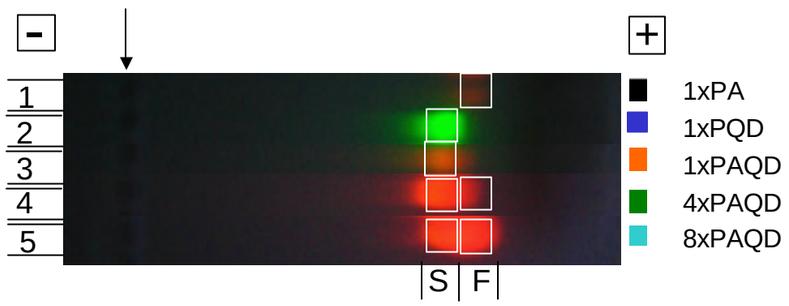
Commonly used quantum-dot based FRET assemblies

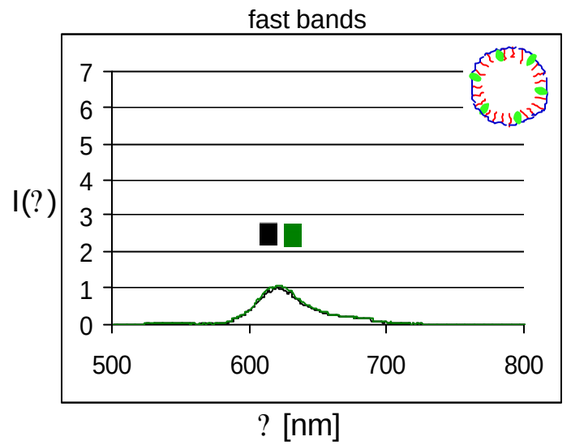


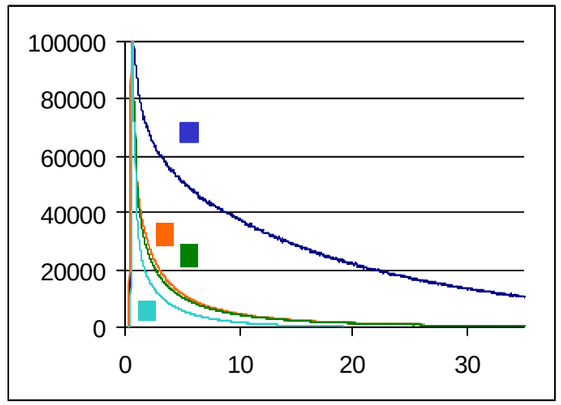
Polymer with embedded organic fluorophores
Sample purification with gel electrophoresis

Polymer coating yields next to polymer-coated particles also some empty micells!

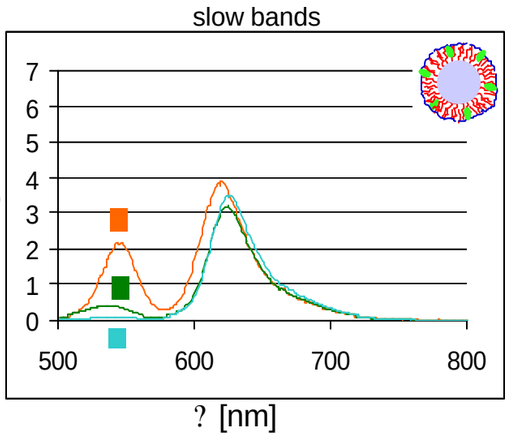
FRET of acceptor embedded in polymer around donor







sample	? [ns]
1xPQD	10
1xPAQD	2.5
4xPAQD	2.1
8xPAQD	1.7

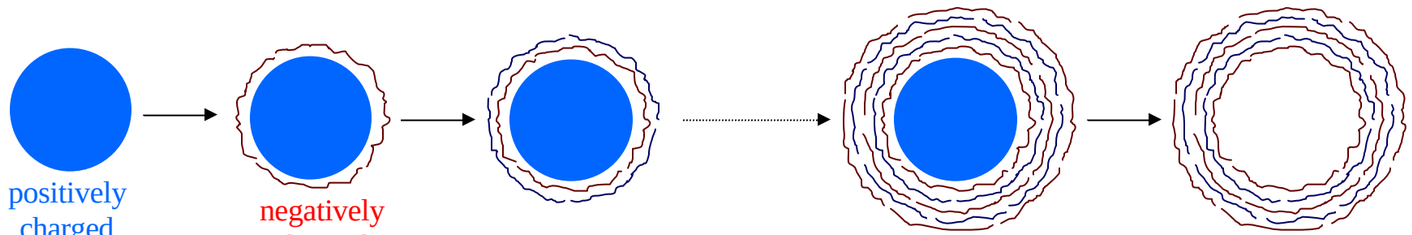


María Theresa Fernández-Argüelles, Aleksey Yakovlev, Camilla Luccardini, Ralph Sperling, Stéphane Gaillard, James Lin, Alfredo Sanz Medel, Walther Chang, Jean-Maurice Mallet, Jean-Marie Brochon, Anne Feltz, Martin Oheim, Wolfgang Parak, NanoLetters, in press.

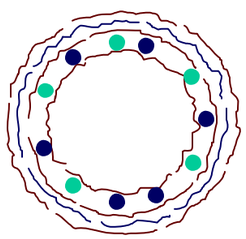
Polymer capsules as multifunctional containers

form polyelectrolyte onion-shells (PSS/PAH) around template + dissolve template
load with fluorescent (+ magnetic + metallic) nanocrystals + biological molecules

= loading of a "container" with particles of different functionality (see work of G. Decher, H. Möhwald)

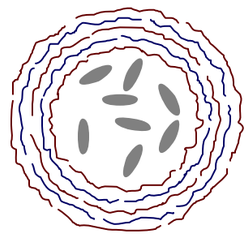


functional nanoparticles can be embedded into wall of capsules by electrostatic attraction
? **functionality**



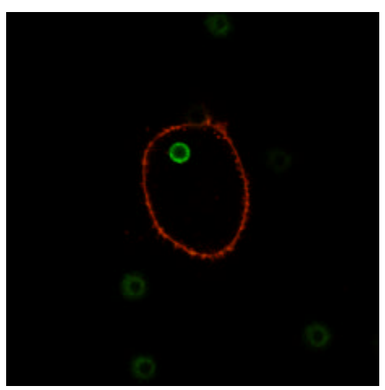
size of capsule: ? m
size of nanoparticles: nm

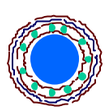
load can be embedded into interior of capsules by
- impregnation of the template core
-swelling + shrinking of the mesh of the walls at different pH
? **transport container**



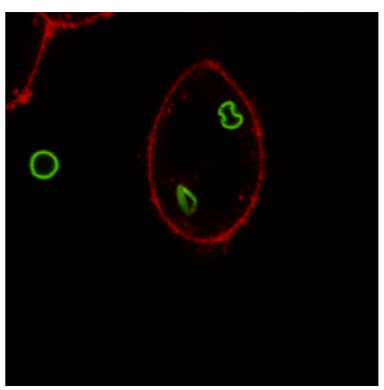
capsule preparation by group of G. Sukhorukov

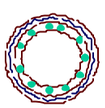
Targeted local delivery and release
Capsule uptake by living cells



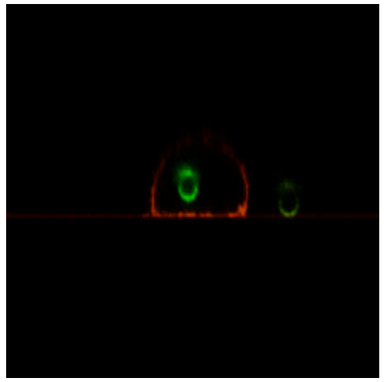


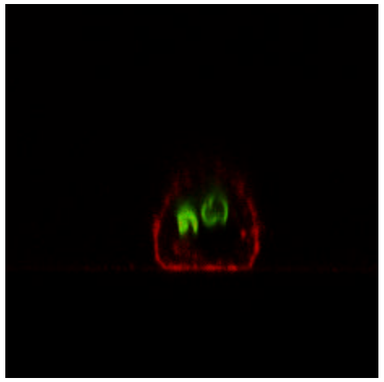
„hard“ capsules
(template core not removed)
walls labeled with dye





„soft“ capsules
(template core removed)
walls labeled with dye





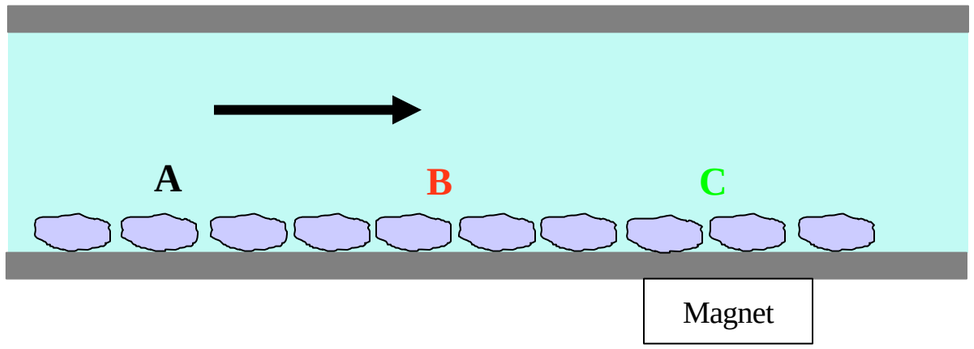
"hard" and "soft" capsules are ingested by the cells; the "soft" capsules are deformed

MCF-7 cells

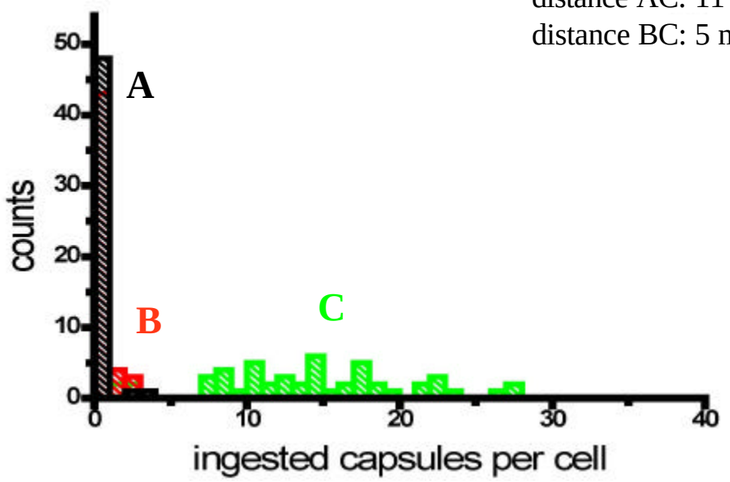
confocal microscopy: Maximilian Semmling

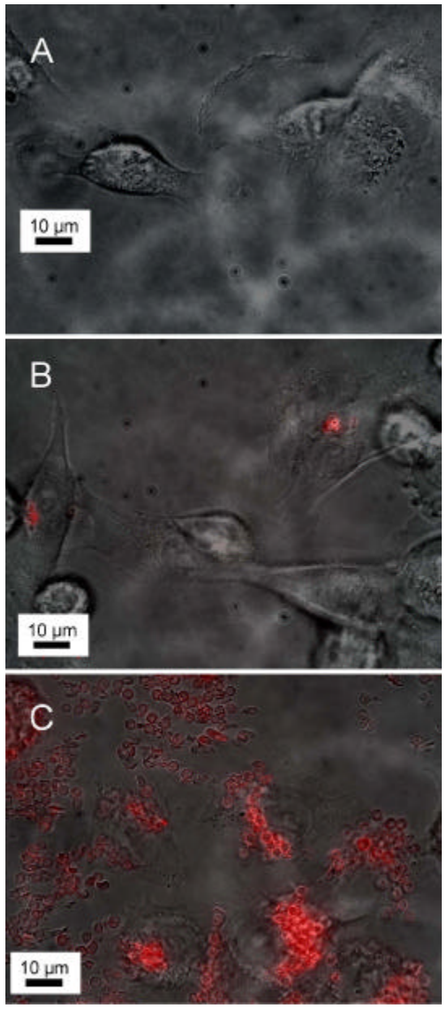
A. Muñoz_Javier, S. Kempter, O. Kreft, M. Semmling, A. Skirtach, O. Bruns, J. Rädler, J. Käs, G. Sukhorukov, C. Plank, W. Parak, in preparation

Targeted local delivery and release - Magnetic direction of capsules



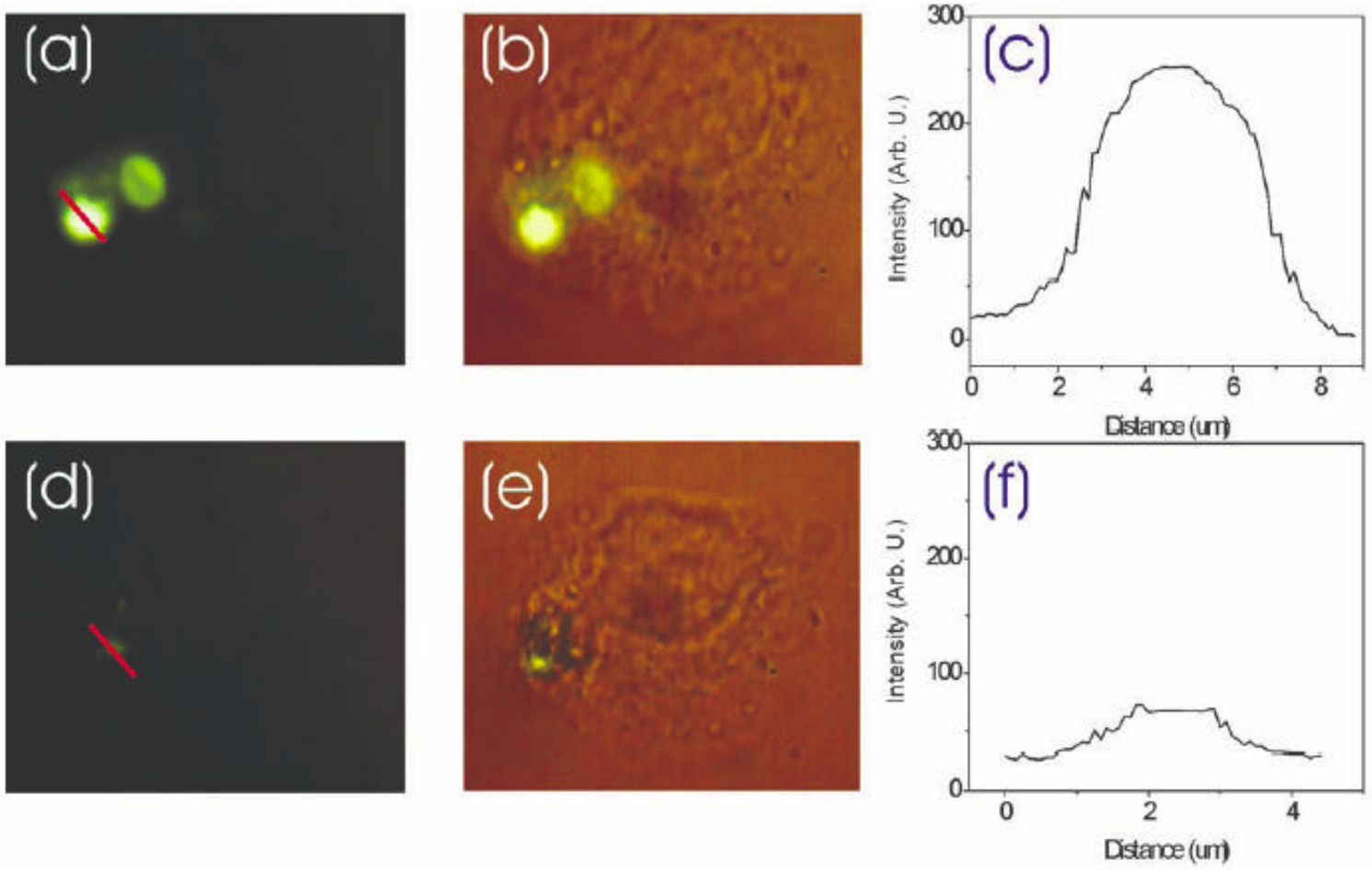
distance AC: 11 mm
distance BC: 5 mm





B. Zebli, A. S. Susha, G. B. Sukhorukov, A. L. Rogach, W. J. Parak, *Langmuir* **21**, 4262-4265 (2005).

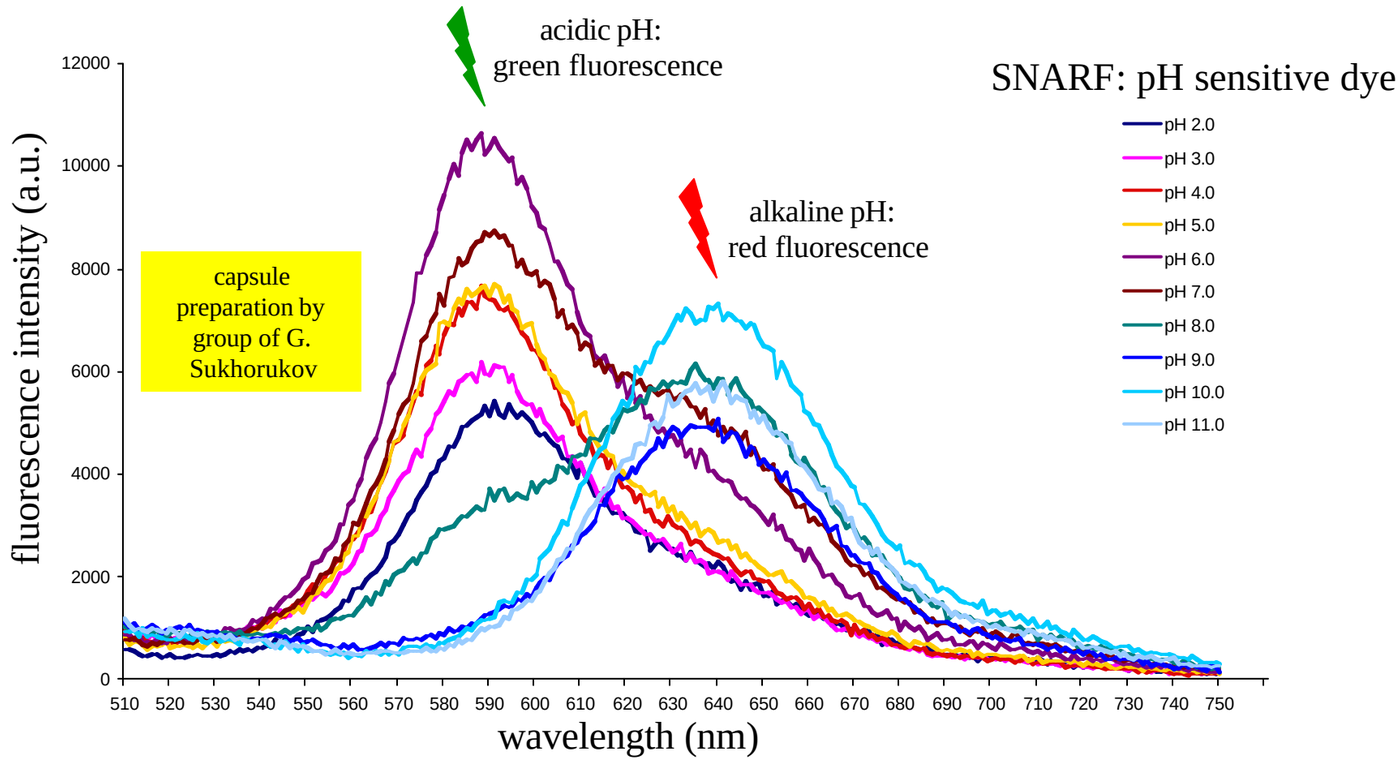
Targeted local delivery and release
Capsule opening with a light pointer



A. Skirtach, A. Munoz Javier, O. Kreft, K. Köhler, A. Piera Alberola, H. Möhwald, W. J. Parak , G. Sukhorukov, *Angewandte Chemie*, 2006

Capsules as intracellular sensors: pH-sensitive capsules

embed sensitive dyes (e.g. pH sensitive, Ca sensitive) in polymer capsules ?
- dye is protected against degradation, cell is protected from free dye ? long term measurements
- many dye molecules are embedded in one capsule ? sensitivity
- dye is confined to capsules ? localization

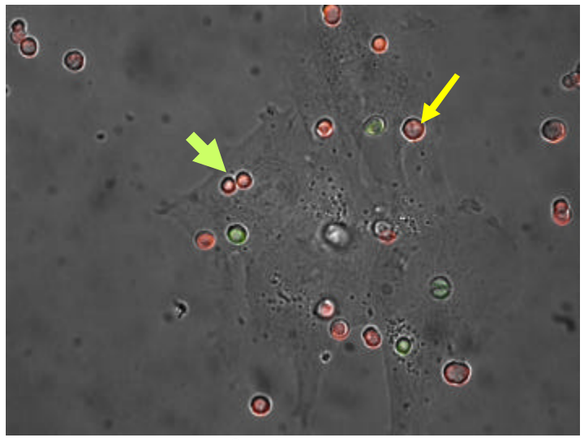


O. Kreft, A. Munoz Javier, G. Sukhorukov, W. J. Parak, Journal of Materials Chemistry, in press

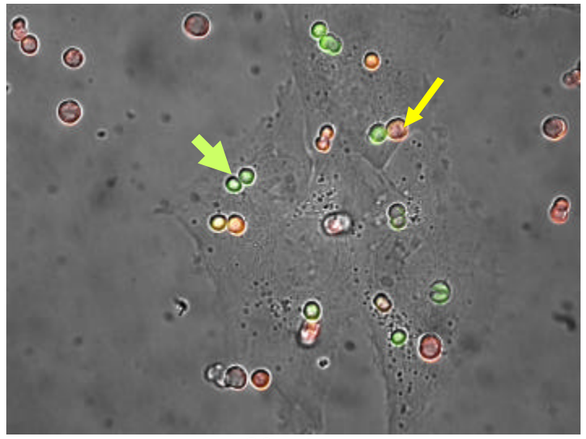
Capsules as intracellular sensors: pH-sensitive capsules

acidic pH:
green fluorescence

alkaline pH:
red fluorescence



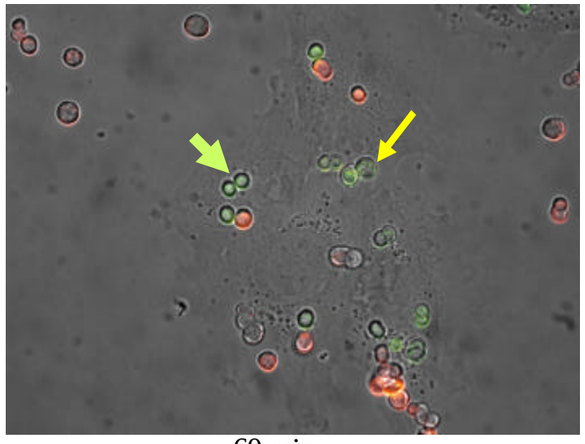
0 min



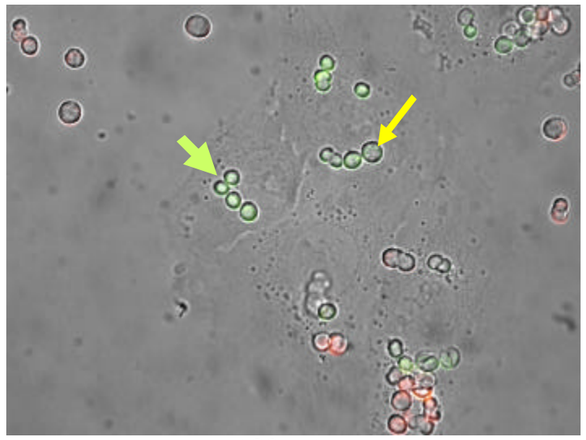
30 min

capsules in
extracellular medium:
alkaline environment

capsules ingested by
cells in endosomes:
acidic environment



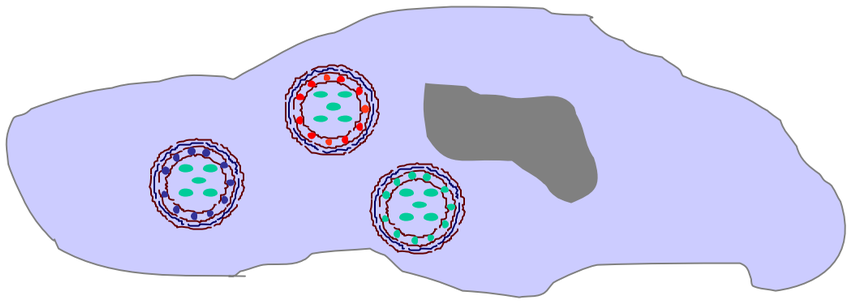
60 min



180 min

O. Kreft, A. Munoz Javier, G. Sukhorukov, W. J. Parak, Journal of Materials Chemistry, in press

Capsules as intracellular sensors: multiplexed measurements?

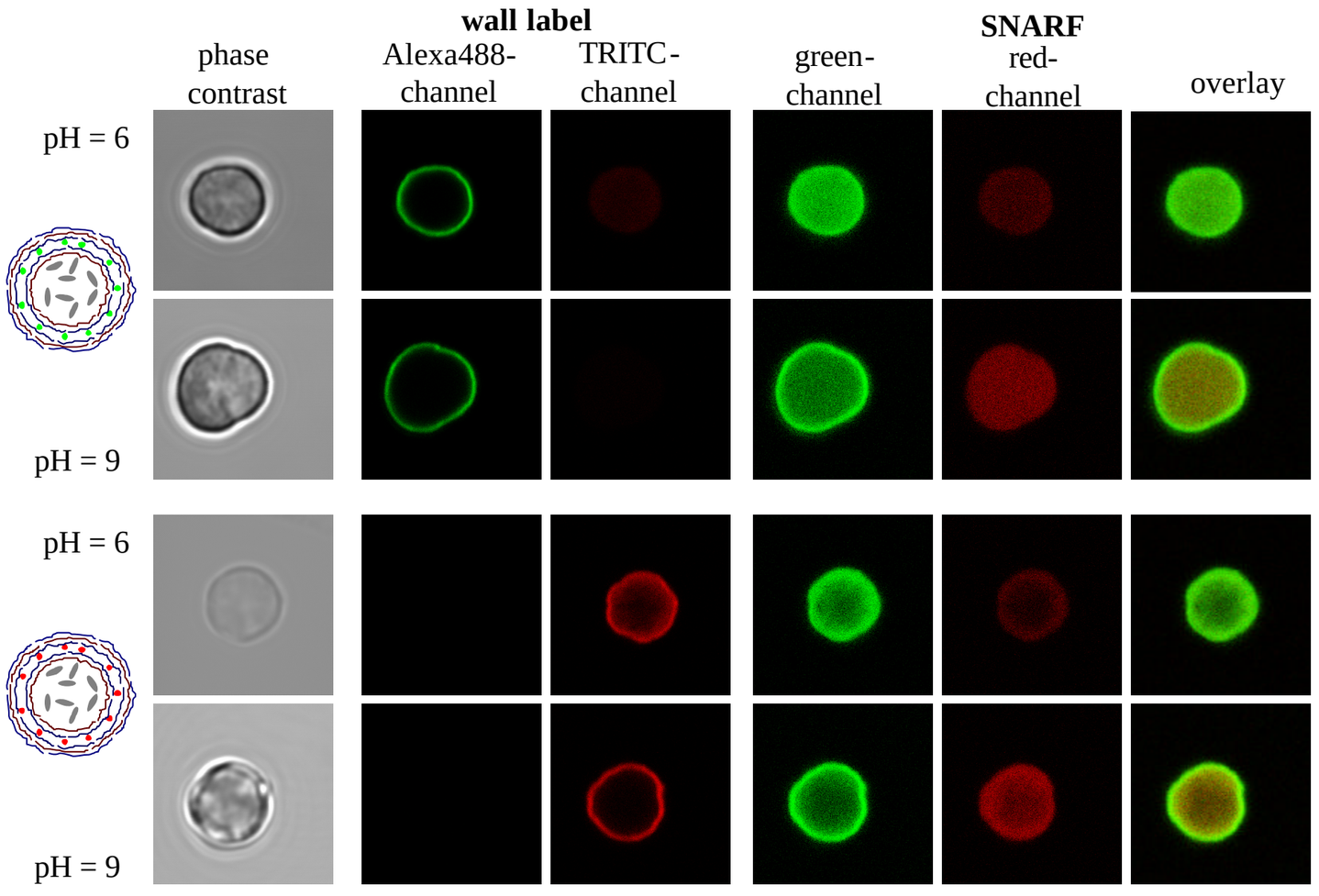


capsules can carry fluorescence molecules at two disctinct positions:

cavity ? ion sensitive dye
wall ? spectral barcode ? quantum dots

problem: release of capsules for endosome to cytoplasm

Capsules as intracellular sensors: multiplexed measurements?



O. Kreft, A. Munoz Javier, G. Sukhorukov, W. J. Parak, Journal of Materials Chemistry, in press

Acknowledgement

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Hermann Gaub

Teresa Pellegrino
Liberato Manna

A. Paul Alivisatos
Carolyn A. Larabell

Josef Käs

Aleksey Yakovlev
Camilla Luccardini
Stéphane Gaillard
Jean-Maurice Mallet
Jean-Claude Brochon
Anne Feltz
Martin Oheim

Eric Dulkeith
Moritz Ringler
Thomas Klar
Andrei Susha
Andrey Rogach
Jochen Feldmann

Oliver Bruns

Alicia Piera
Susi Kempter
Joachim Rädler

Jimmy Li
James Lin
Walter Chang

Alfredo Sanz Medel

Christian Stoll
Fred Lisdat

Oliver Kreft
Andrei Skirtach
Mathieu Bedard
Gleb Sukhorukov

Birgit Bußmann
Tobias Schrader
Stephan Malkmus
Markus Braun