Scottish Government gov.scot

Hydro Nation Scholars Programme

1st year summary

Nanomaterials and photonic solutions. Novel ‘at source’ approaches to stop hospital derived pharmaceuticals reaching the sewer network

Manuel-Thomas Valdivia

NHS Highland

Scottish Water

SEPA Scottish Environment Protection Agency

HIE Highlands and Islands Enterprise Iomairt na Gàidhealtachd ’s nan Eilean

POLYCAT UK

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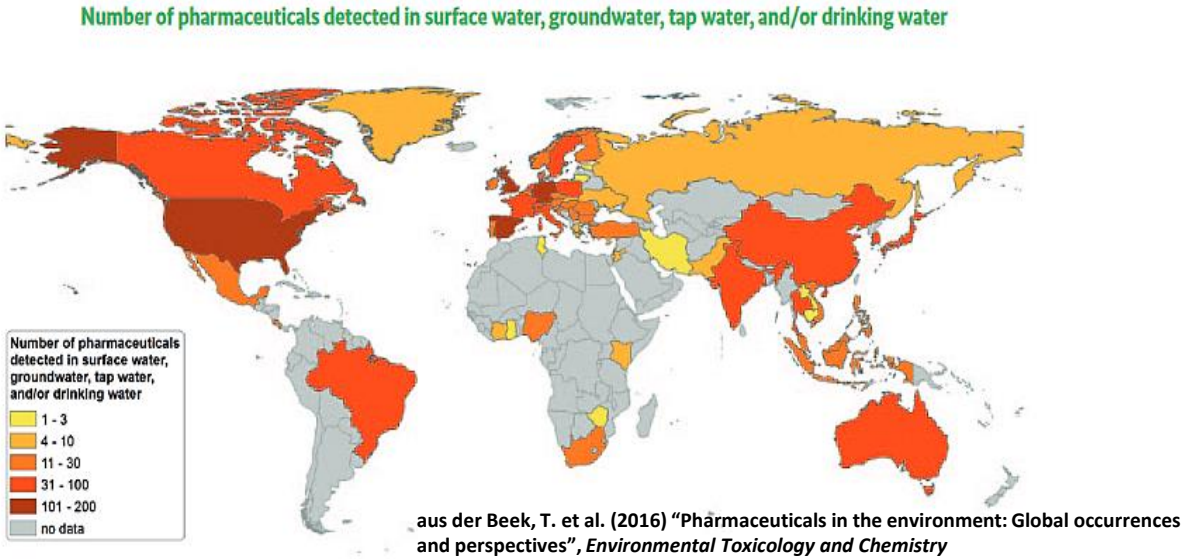
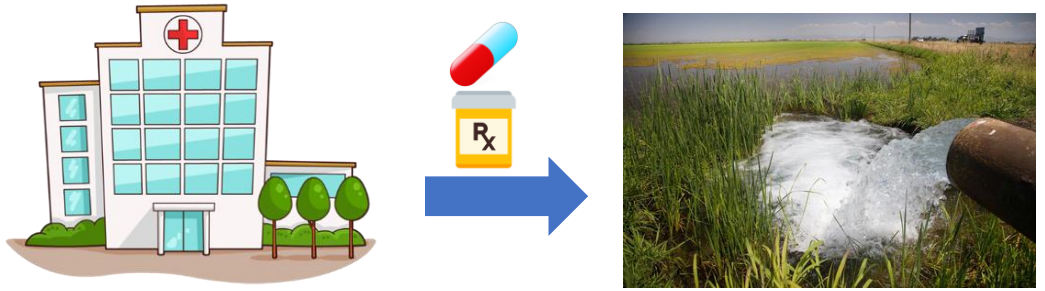
Why this project ?



aus der Beek, T. et al. (2016) "Pharmaceuticals in the environment: Global occurrences and perspectives", *Environmental Toxicology and Chemistry*



Point source

630 different pharmaceuticals in 71 countries

Effects hospital-specific drugs:

- Statins: Disruption of cholesterol synthesis in fish
- Cytostatics: Chronic toxicity on aquatic species

Accumulation in WWTP or food chains
-> Resistances in bacteria (Antibiotics: AMR)
-> Impact on humans?

- Antibiotics
- Analgesics
- Cytostatics
- Sex hormones
- Beta blockers
- H2-blockers
- Antiepileptics
- Benzodiazepines
- Lipid-lowering drugs
- Beta agonists
- Contrast agents
- Calcium channel blockers
- ACE-Inhibitors

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Why this project ?

Conventional biological treatment

Minute API concentrations:
1ng/L – ug/L

Advanced Oxidation Processes

O_3
UV/H_2O_2

Persistent APIs

Toxic by-products
Expensive

Efficient?, sustainable, less toxic solution:

Photocatalysis

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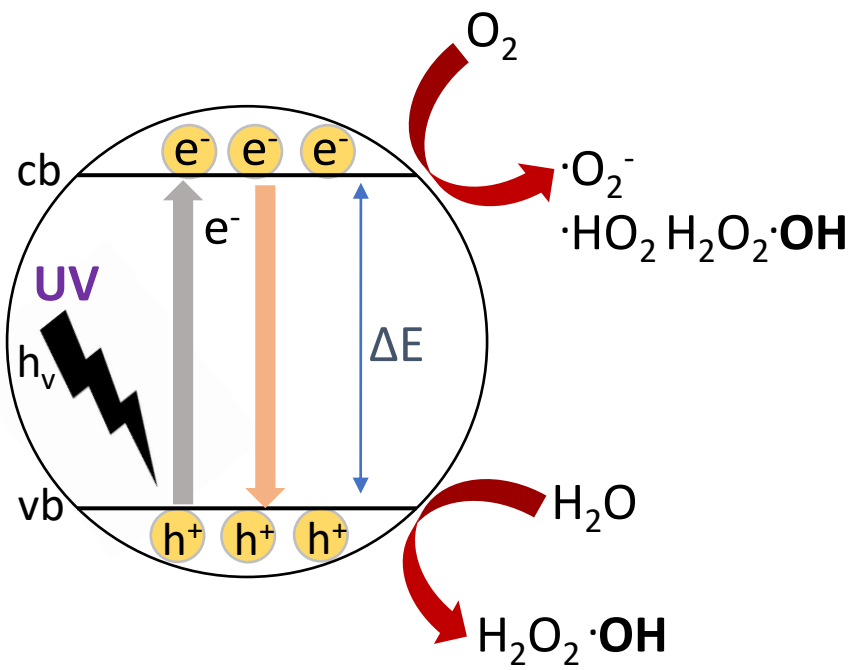
Photocatalysis – Advantages and current limitations

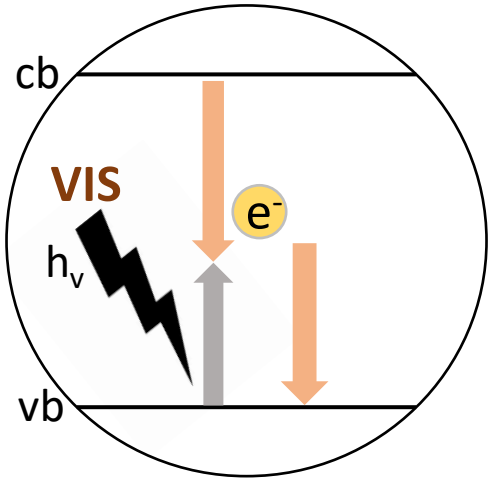
- ΔE : Required photon energy to excite electrons from the vb onto the cb

- Reusable, wide band-gap (ΔE ≥ 3.1 eV) photocatalysts

ZnO (ΔE = 3.37 eV -> λ ~370nm)
TiO_2 (ΔE = 3.20 eV -> λ ~390nm)



Problem
Recombination



UV-A 4-6%
VIS 43%

TiO_2 Solar Disinfection
min. 5 hours of sun-light required

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Project plan

Aim: **Demonstrate proof-of-principle that photocatalytic approaches can eliminate (oxidise) persistent pharmaceuticals**

1. Literature review ✓
2. Select target pharmaceuticals ✓
3. Develop analytical techniques to quantify pharmaceuticals at low ng/L concentrations first results
4. Develop set-up for photocatalysis experiments ✓
5. Quantify photocatalytic oxygen centred radical release current work
6. Conduct immobilisation experiments of photocatalysts and/or drugs on support materials
7. Identify photocatalytic transformation products via HPLC-MS
8. Determine toxicity of drugs + transformation products after photocatalysis
9. Modify metal oxides to enhance photocatalytic performance

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Literature review

1st review article

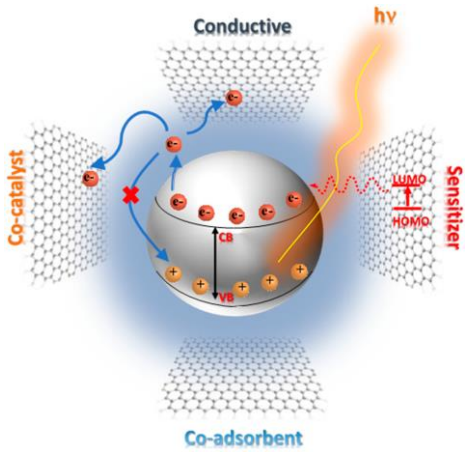
Significance of hospitals as point-sources for the release of active pharmaceutical ingredients into the water cycle: A global comparative overview and implications for human health

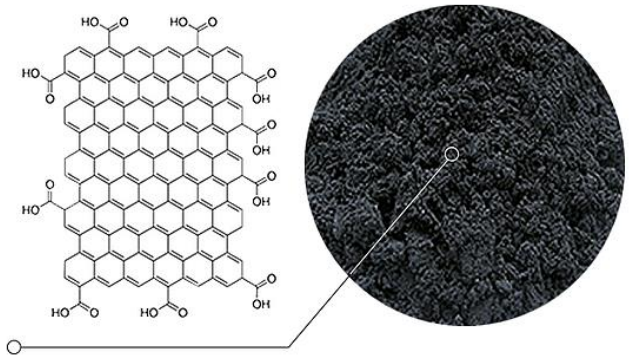
Thesis Introduction

2nd review article

Photocatalytic metallic nanomaterials immobilised onto porous structures for at-source pharmaceutical removal from hospital wastewater: Potential benefits over existing technologies

Identification of “market gap”





Immobilisation of photocatalysts onto (carbonaceous) surfaces or trapping of drugs prior to photocatalysis

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Compound selection

Environmental Risk (RQ)

↓

Persistence in wastewater (physico-chemical properties)

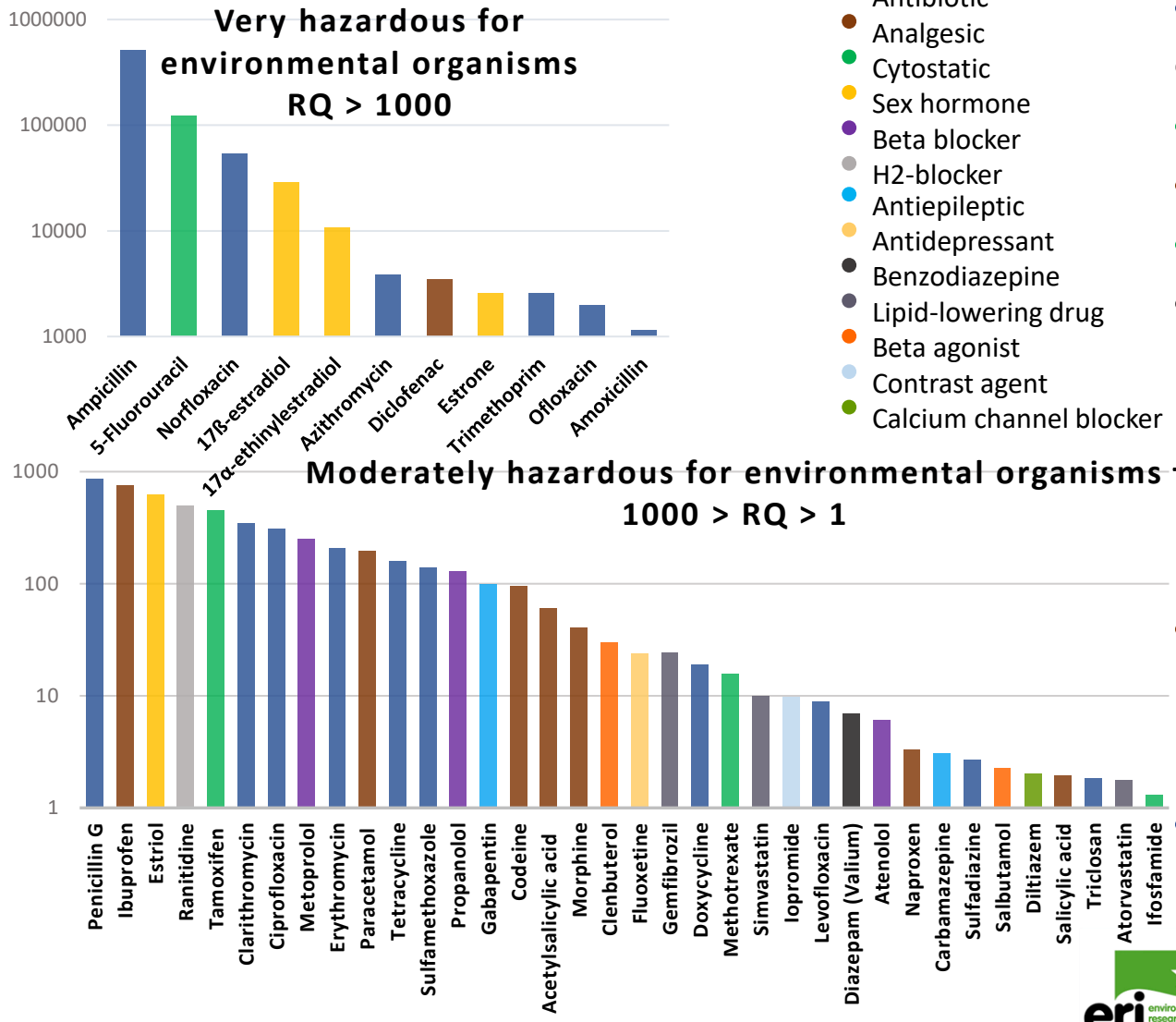
↓

Literature: Pharmacokinetics excretion rates + WWTP removal

↓

Prescribing volumes primary care (ISD, HMUD)

High ecotoxicity → Moderate ecotoxicity



Parent compounds:

- Amoxicillin
- Ranitidine
- Tamoxifen
- Paracetamol
- Methotrexate
- Simvastatin

Metabolites/ Transformation Products:

- N-acetyl-p -benzoquinone imine (NAPQI)
- AMX-S-oxide

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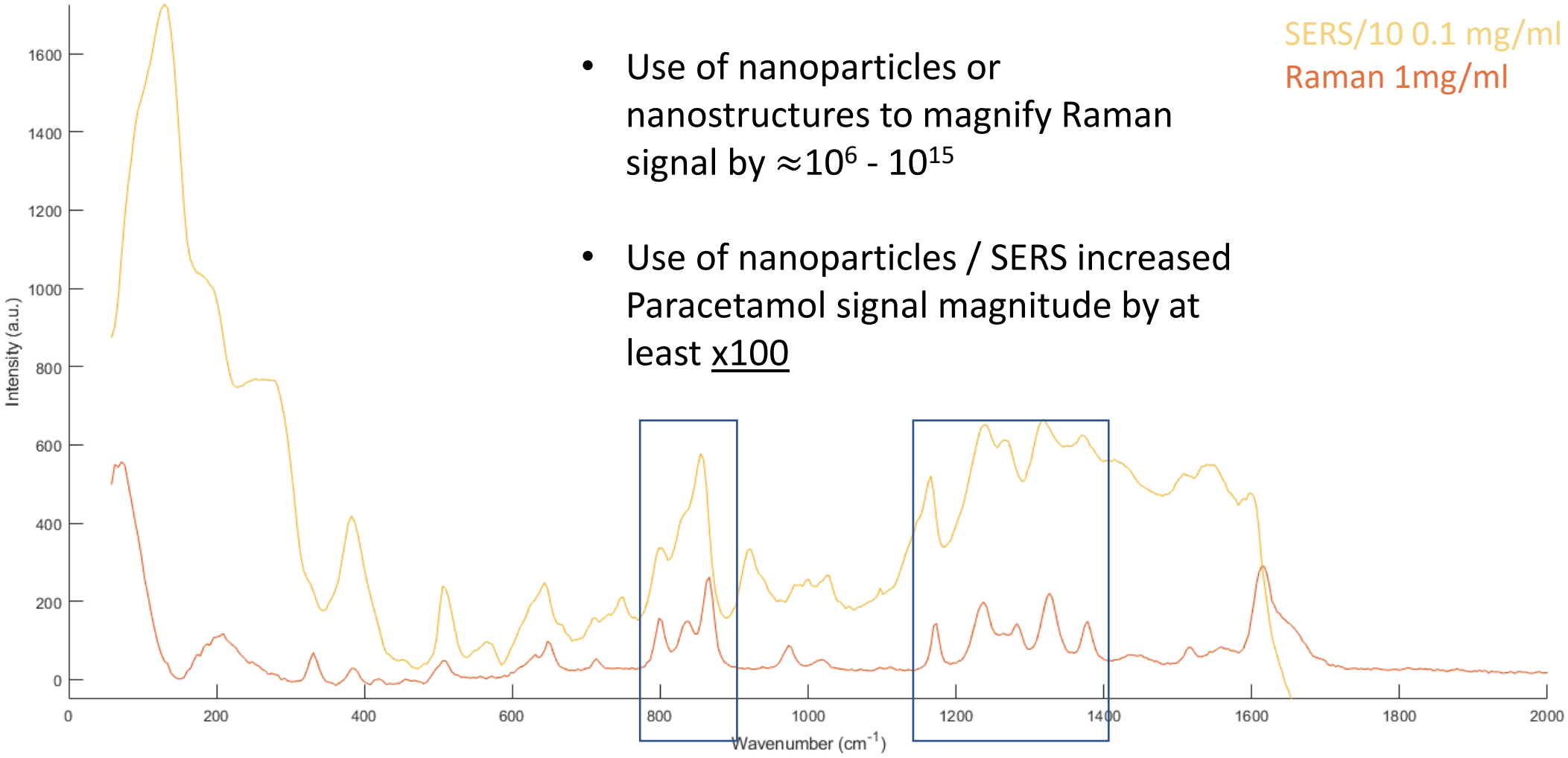
Quantification of pharmaceuticals
Regular Raman vs SERS with 1 g/L paracetamol



- Use of nanoparticles or nanostructures to magnify Raman signal by $\approx 10^6$ - 10^{15}
- Use of nanoparticles / SERS increased Paracetamol signal magnitude by at least <u>x100</u>

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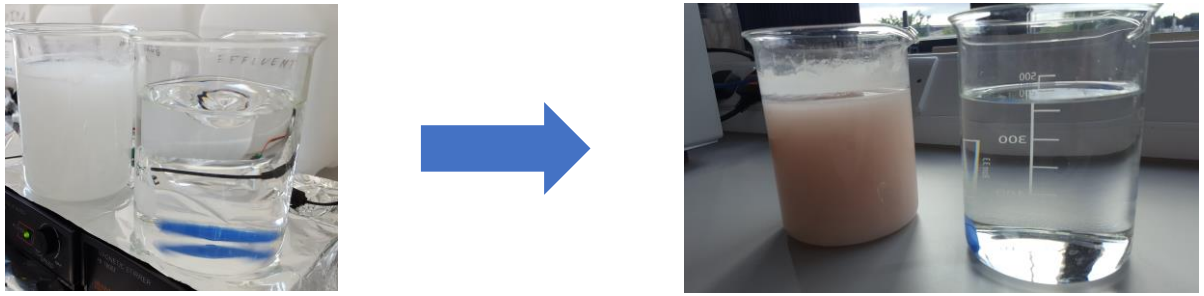
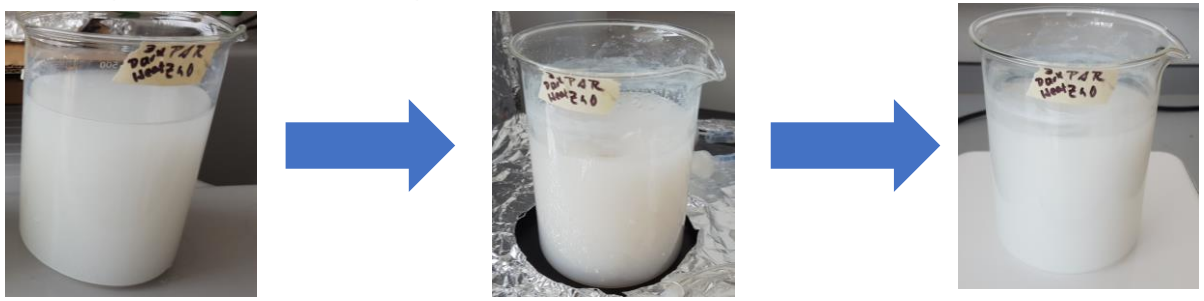
Photocatalytic pilot - paracetamol

Initial problem: Confounder colour interference

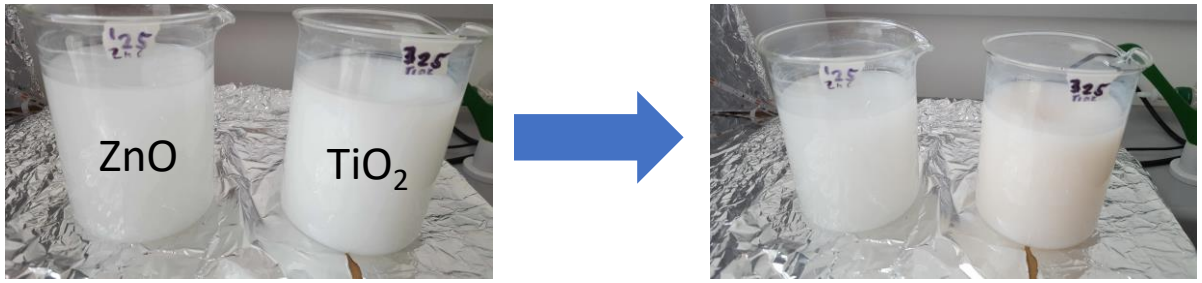
1. 1 g/L ZnO, 100 mg/L Paracetamol



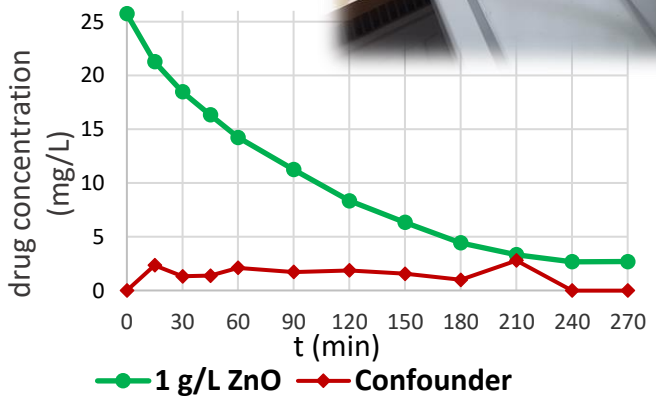
2. 1 g/L ZnO, 25 mg/L Paracetamol + T°C const

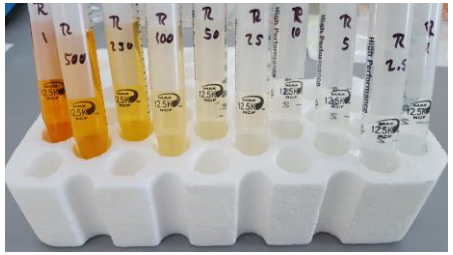


3. 1 g/L metal oxide



Tap water pH 7, metal oxides ZnO TiO_2, $paracetamol_{aq}$, UV-light exposure t=300min





Colorimetric detection at 430nm
LOD: ~1mg/L

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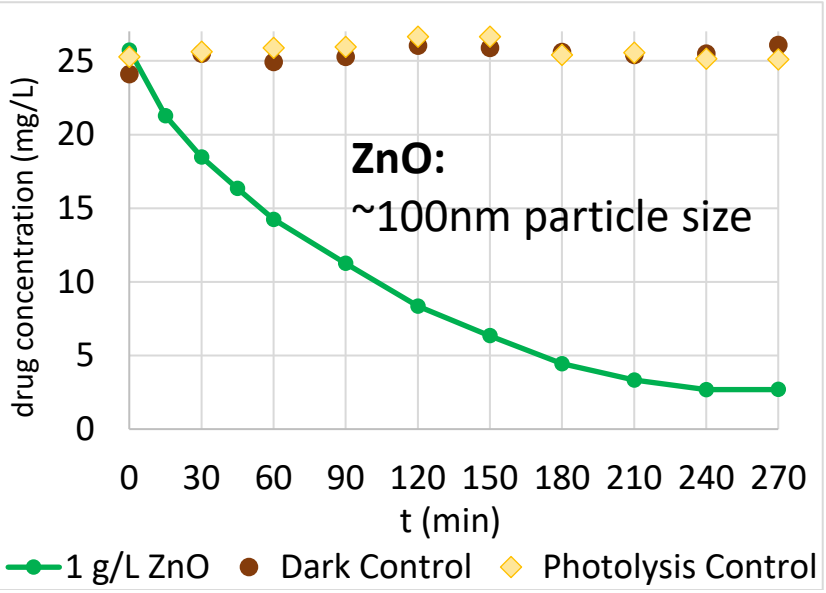
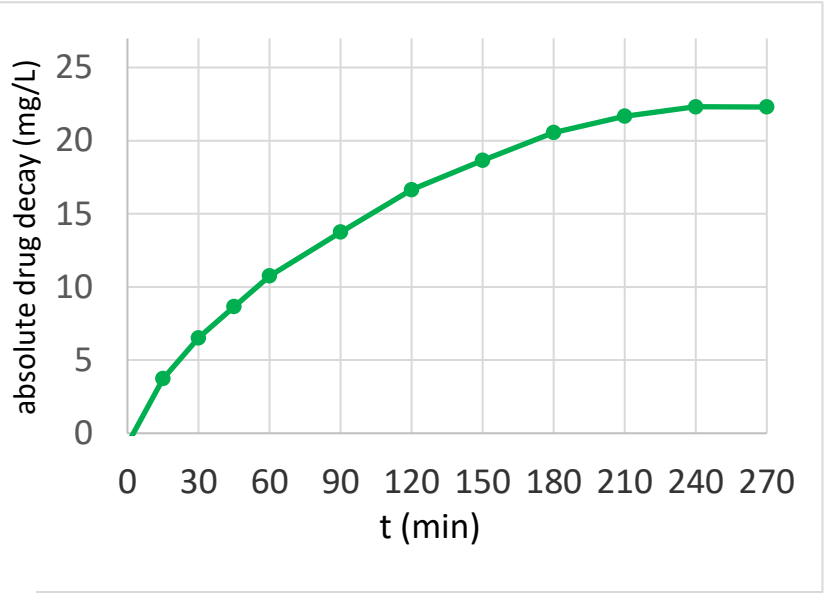
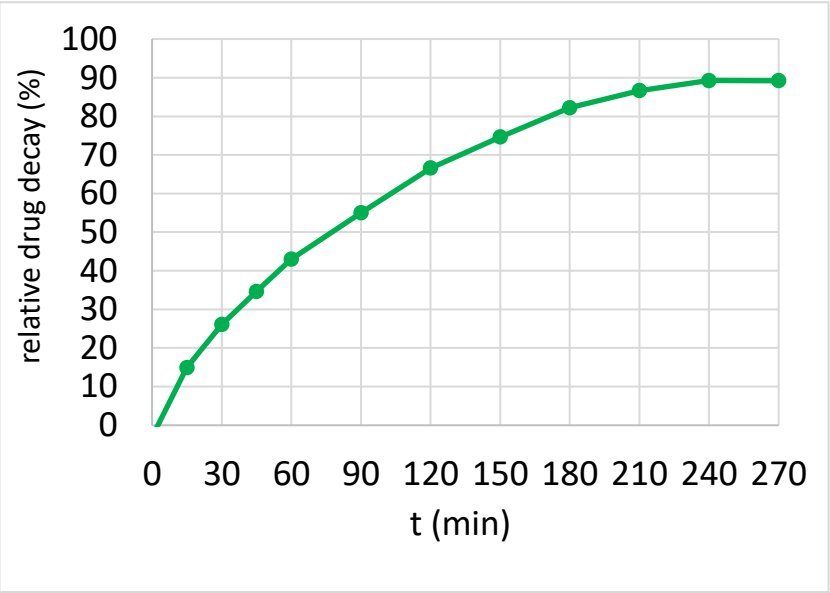
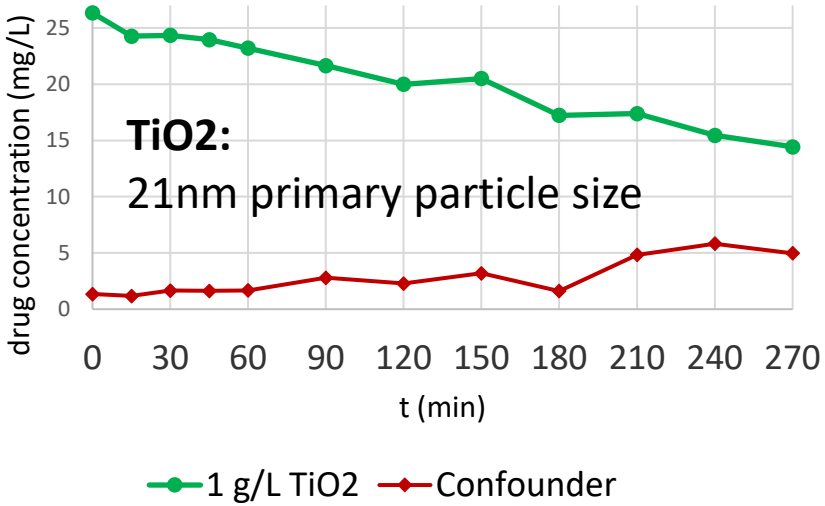
Photocatalytic pilot - paracetamol

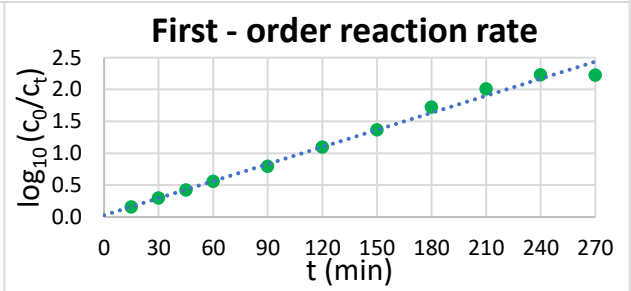
~90 % elimination of paracetamol after 4 h UV-light exposure











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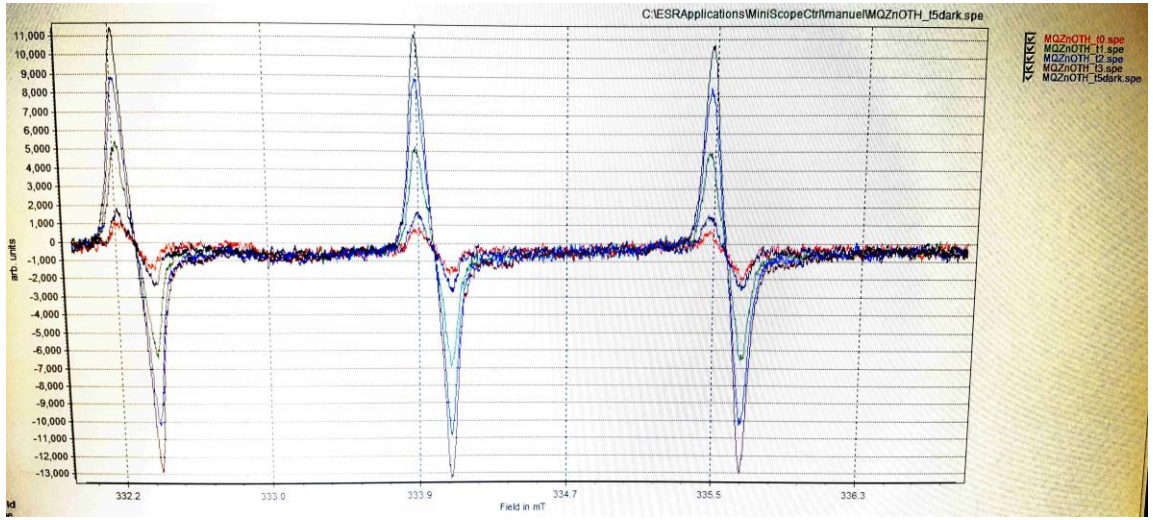
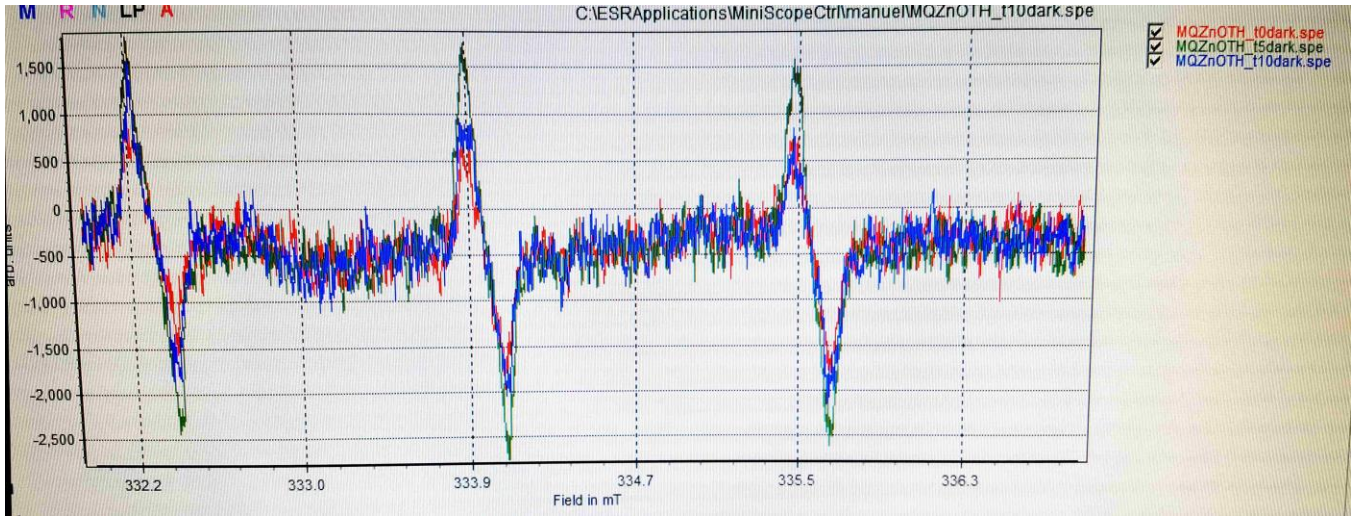
Photocatalytic oxygen-centred radical release of ZnO

Spin-Trap: Tempone-H (characteristic 3-peaks)



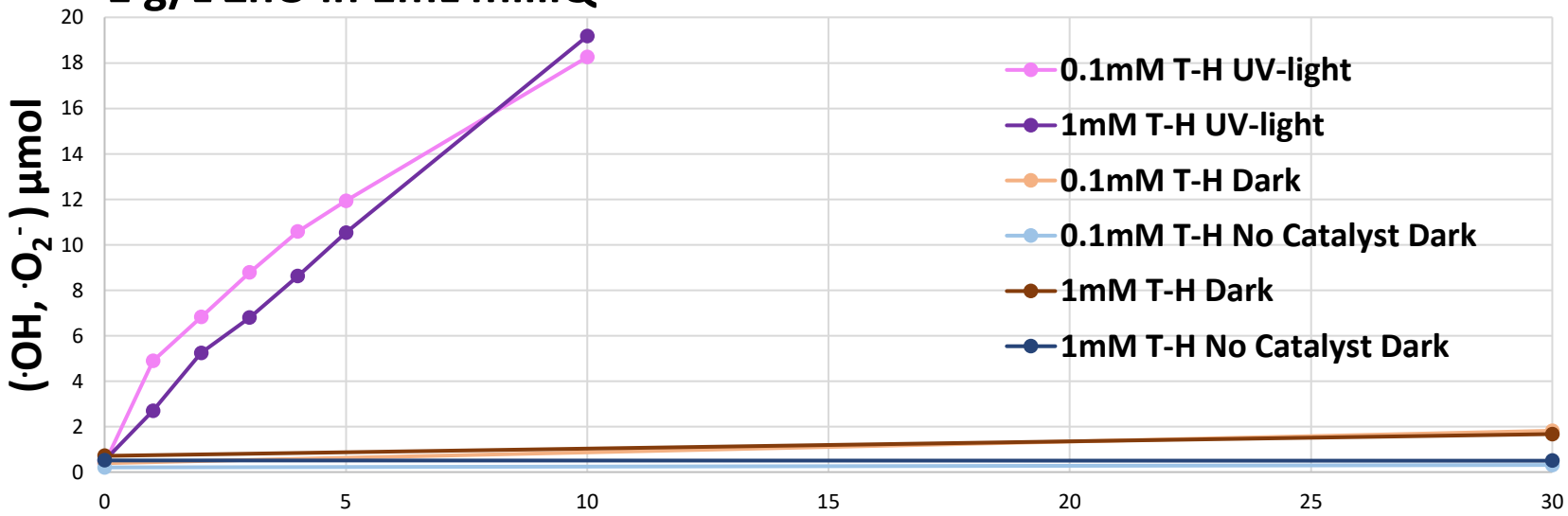
UV-light exposure
0-3 minutes



Dark Control
0-10 minutes

Electron Spin Resonance spectroscopy

1 g/L ZnO in 1mL milliQ



Photocatalytic $\cdot O_2^-$ generation:
~2-3µmol radical/min

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Future

Identification of photocatalytic transformation products via HPLC-MS

- Many “unknowns” – challenging identification (maybe no reference standards available)
- Database use such as METLIN (parent-/fragment-ion RT, masses, spectra)

Determination of drug + TP toxicity after photocatalysis

- Combination of approaches (environment/human health):

1. Human endothelial cell line EA.hy 926
   + MTT-assay (cell metabolism, proliferation -> cell death)
2. Indicator organisms (Daphnia Magna, microalgae)
3. Microtox
4. Lactuca sativa (lettuce seeds) *WaterToxNetwork*

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Supervisory Team: Prof Ian Megson, Prof Alistair Kean, Dr Mark Taggart, Dr Szabolcs Pap

Dr Susanna Challinger (Medical Nanotechnology)

Thank you

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