QUANTERA

ERA-NET Cofund in Quantum Technologies

Mid-term QUANTERA meeting

Granada, November the 13th 2019

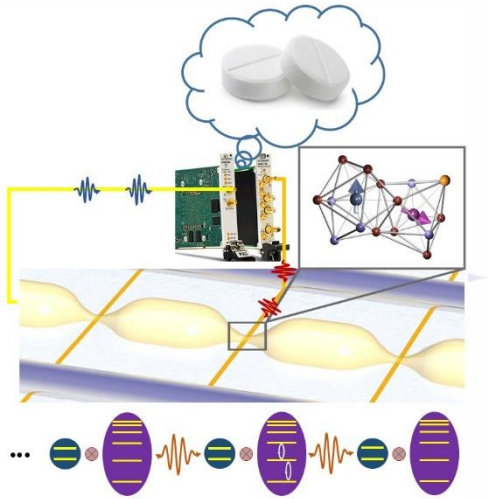
Scaling Up quantum computation with MOlecular spins (SUMO)

Fernando LUIS
(ICMA-CSIC)

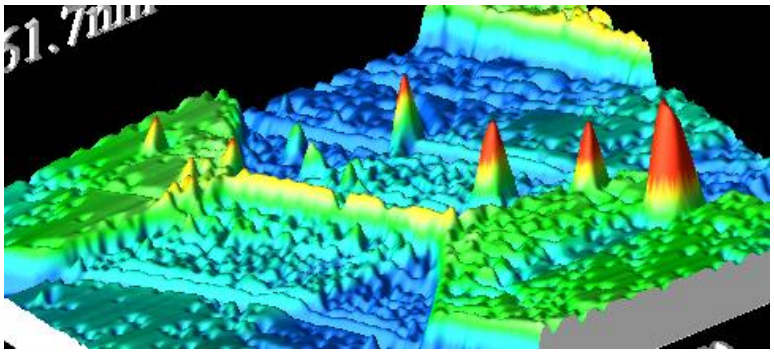
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731473.

Outline

1. Introduction: What we aim for?



2. Results: What has been achieved?



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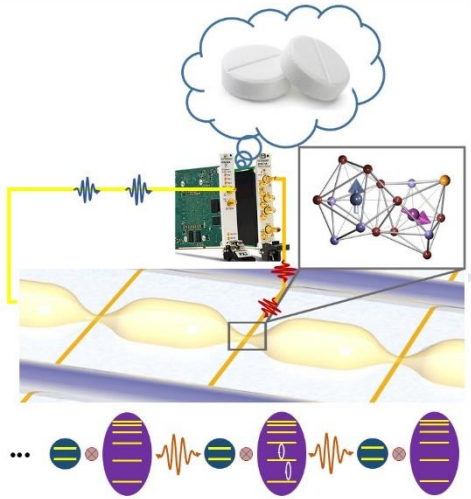
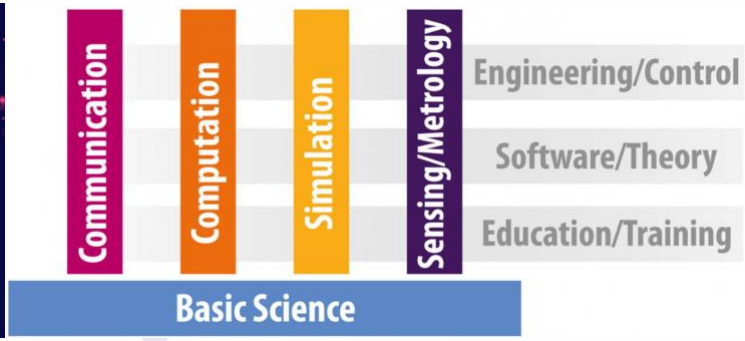


2. Results: What has been achieved?

Quantum Technologies Roadmap

M. F. Riedel et al, Europhysics News **49**, 5-6 (2018)



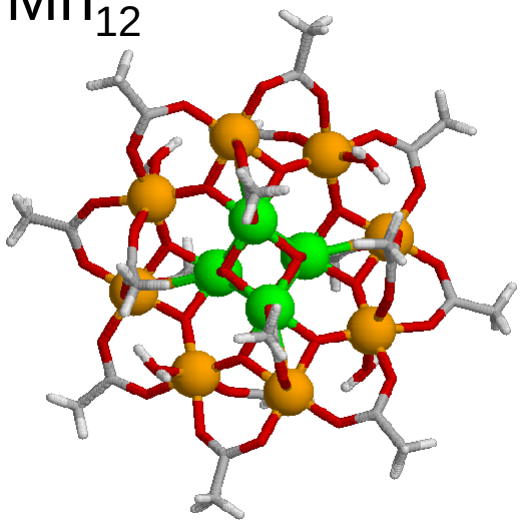
Quantum Sensors | Simulators | Q-internet | Q-computing

2015 — 2035

1 qubit | > 50 qubits | 10^8 qubits

Molecular nanomagnets

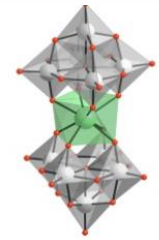
Mn_{12}

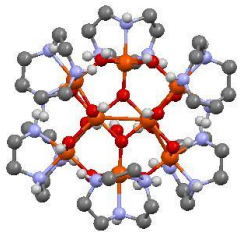


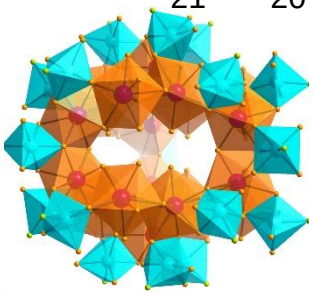
Mn^{3+}

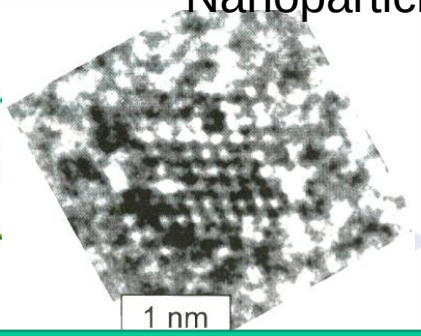
Mn^{4+}

ErW_{10} Fe_8 $Ni_{21}Gd_{20}$ Nanoparticle Magnet









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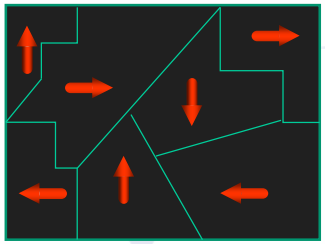
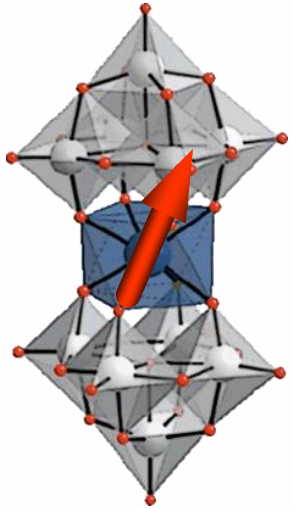


0.1 nm 1 nm 10 nm > 50-100 nm

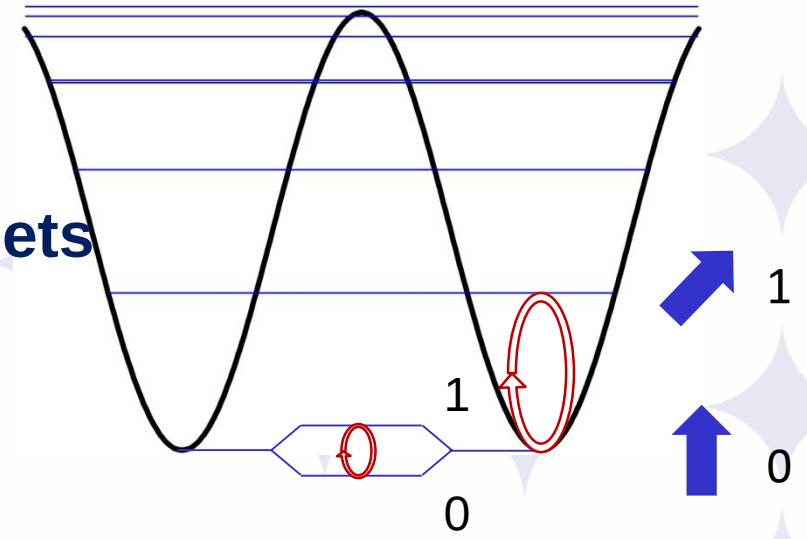
Molecular Magnets: Physics and Applications, edited by J. Bartolomé, F. Luis & J. F. Fernández, Springer Verlag (Berlín, Heidelberg, 2014); W.-P. Chen et al, *Nature Commun.* **9**, 2107 (2018)

Molecular spin qubits

A. Gaita-Ariño et al, *Nature Chem.* **11**, 301–309 (2019);
M. Atzori & R. Sessoli, *JACS* **141**, 11339 (2019)



Single ion magnets



Some appealing properties

- Simples (1 magnetic ion)
- Weak spin-spin interactions
- Magnetically soluble
- Tunable

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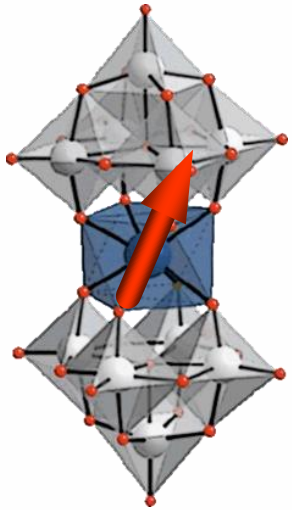

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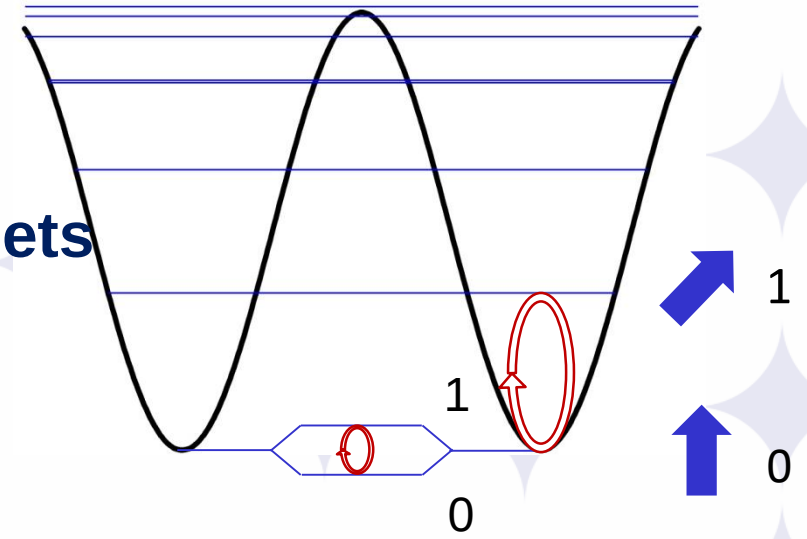

Some appealing properties

- Simples (1 magnetic ion)
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SUMO

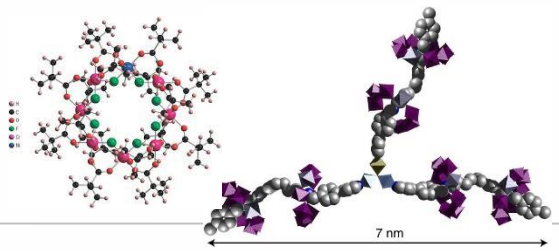
Scalable architecture to wire up qubits

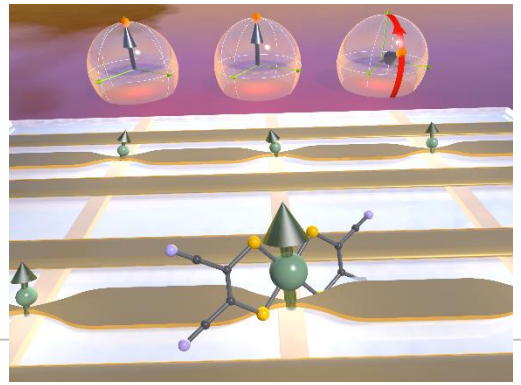
SUMO

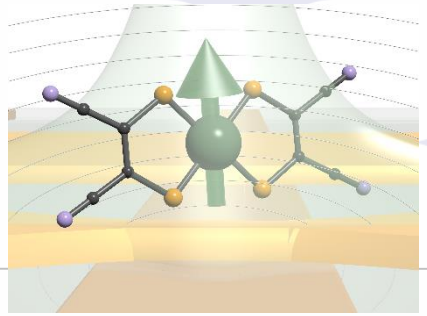
Scaling up within each molecule

Wiring up different molecules

WG1 Synthesis	WG2 Spin coherence	WG3 Quantum gates	WG4 SC nano-resonators	WG5 Molecular integration	WG6 Circuit QED







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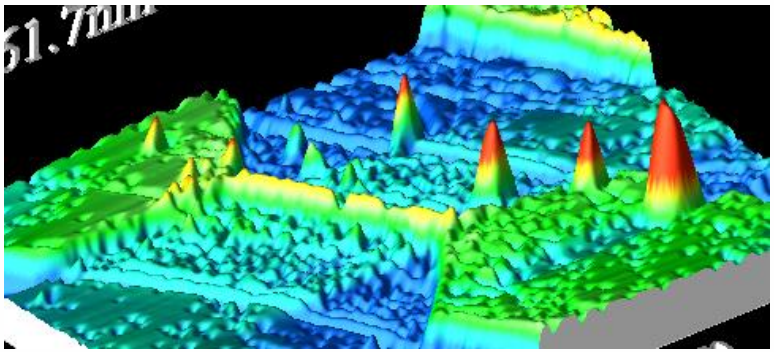
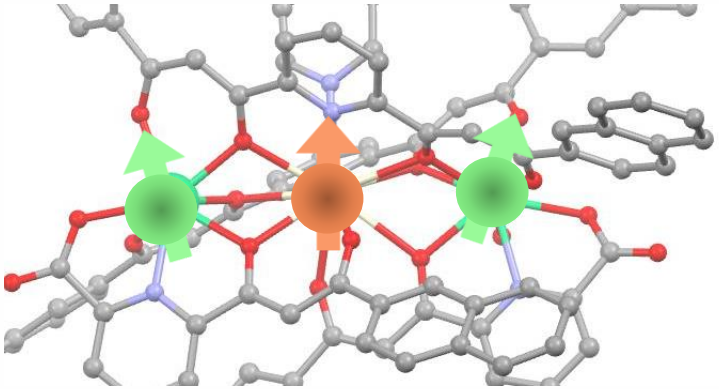
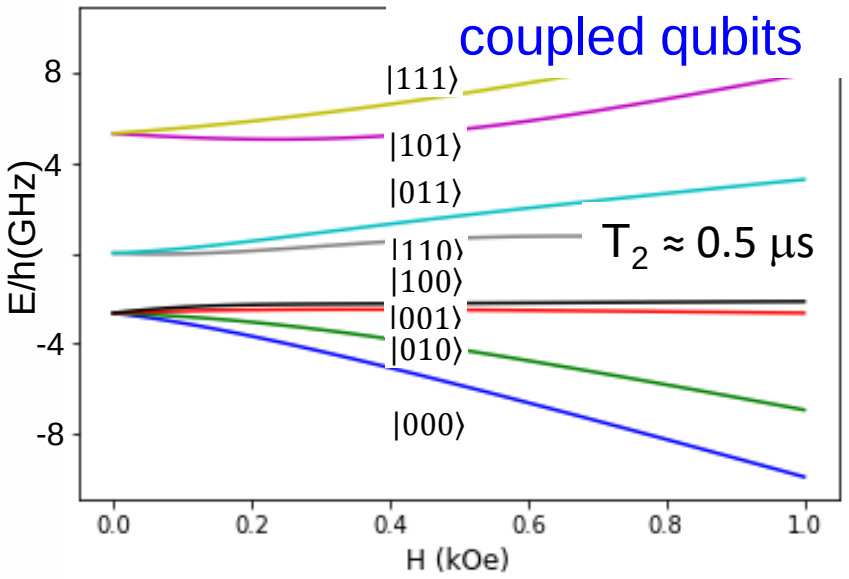


Molecular logical qubits

[ErCeEr]



Three different & coupled qubits



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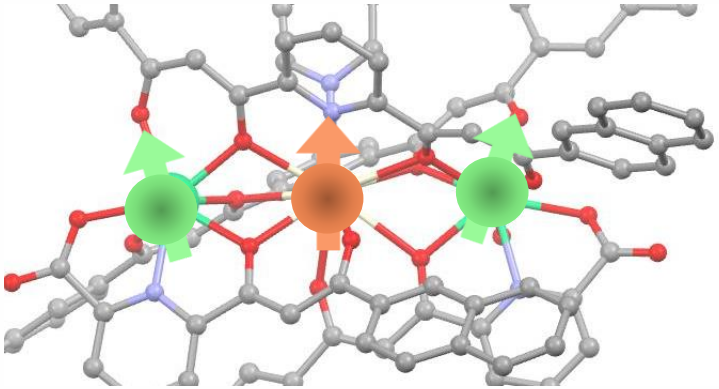

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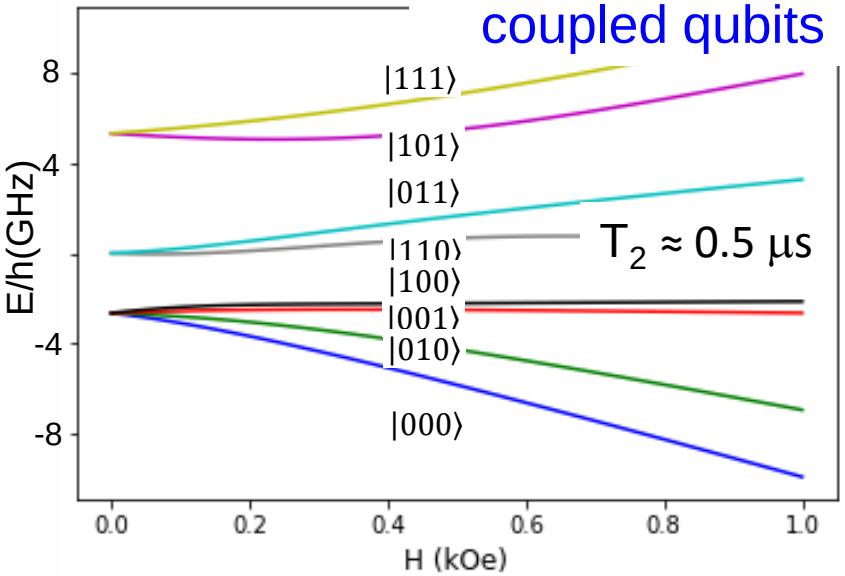
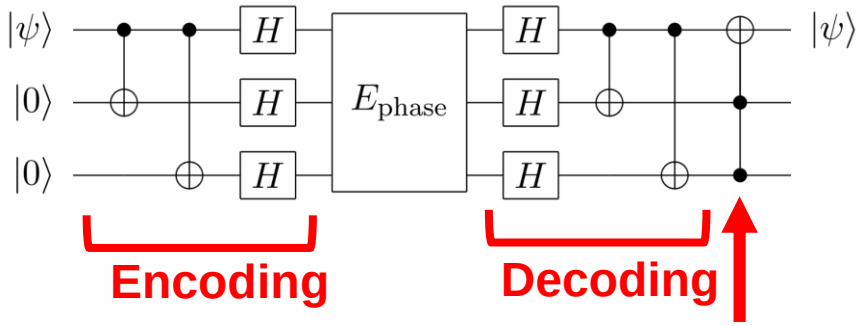
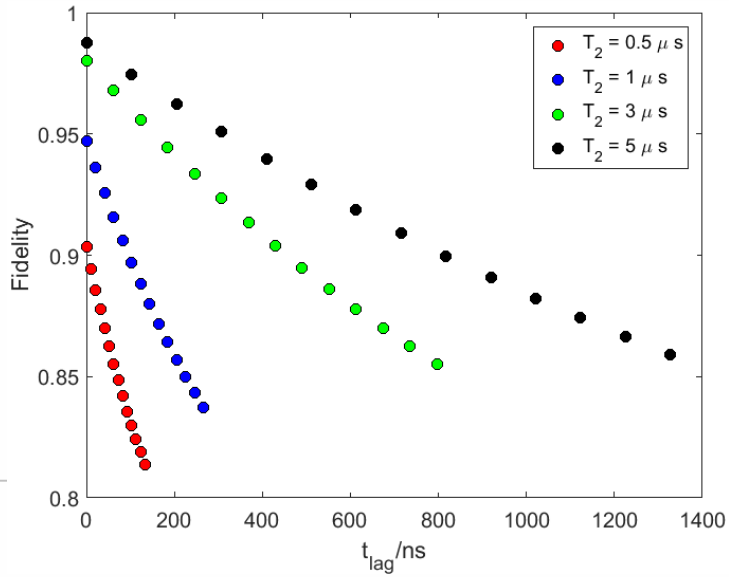


Three-qubit repetition code

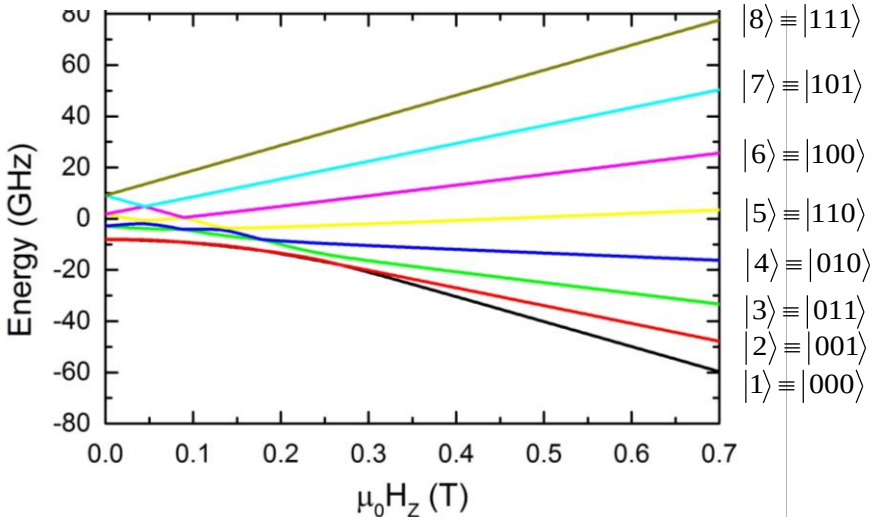


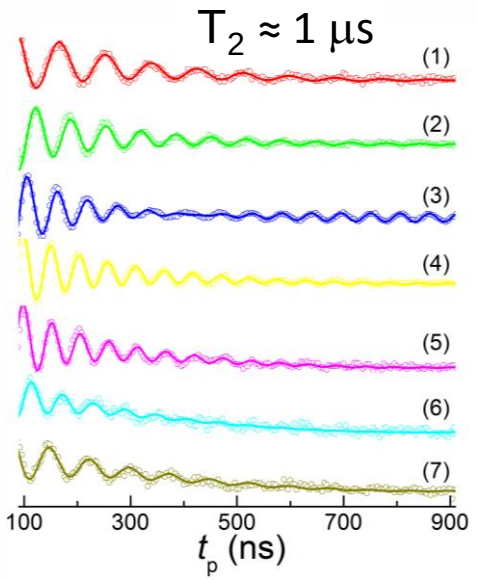
Error correction

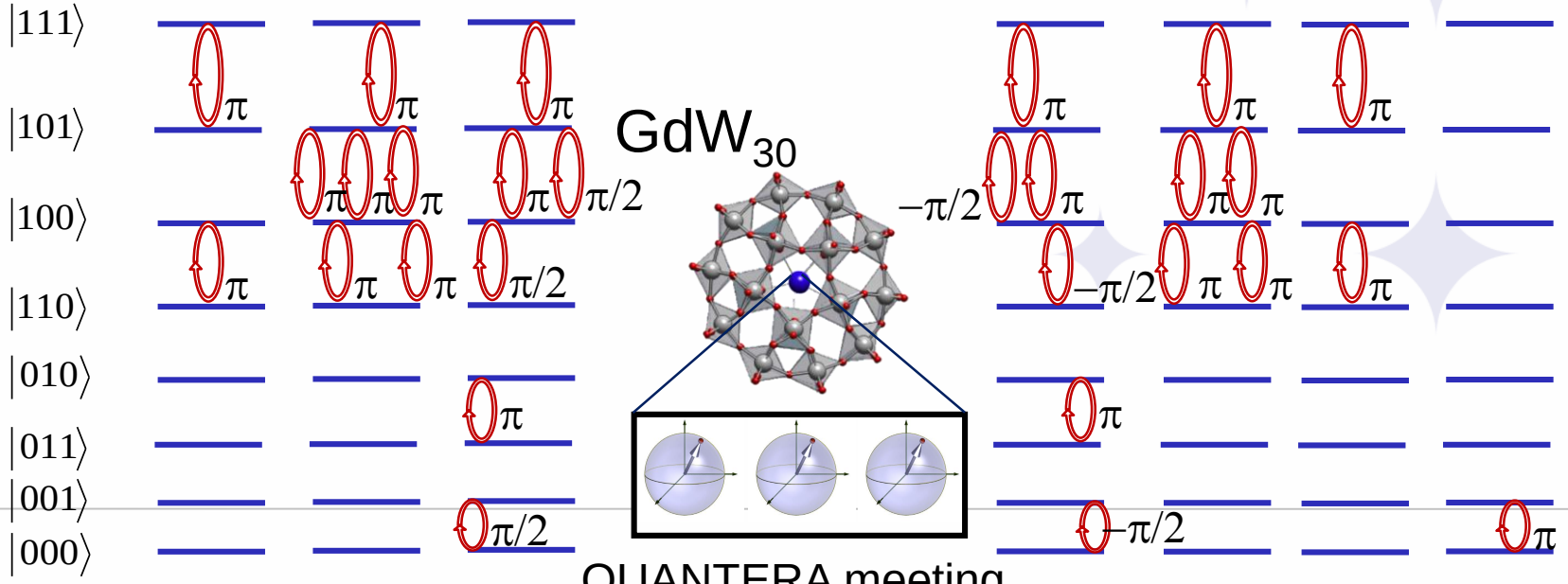


From qubits to qudits

M. D. Jenkins et al, Phys. Rev. B **95**, 064423 (2017)

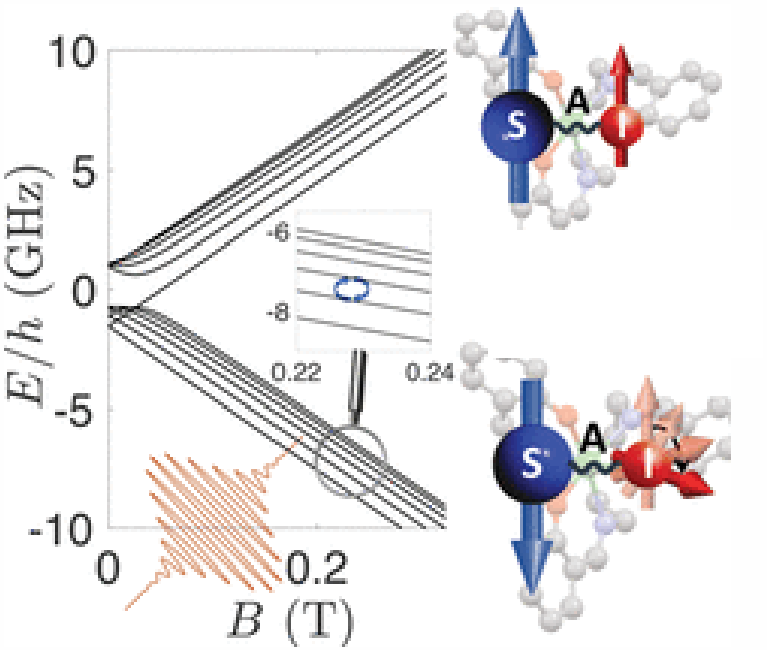


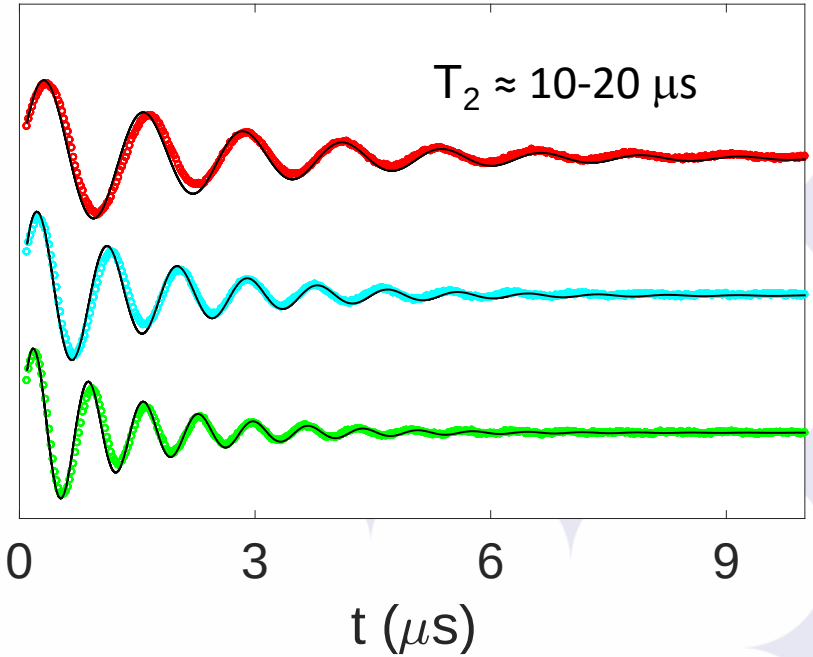




Alternative QECCs

Yb-trensal





R. Hussain et al, J. Am. Chem. Soc. **140**, 9814–9818 (2018)

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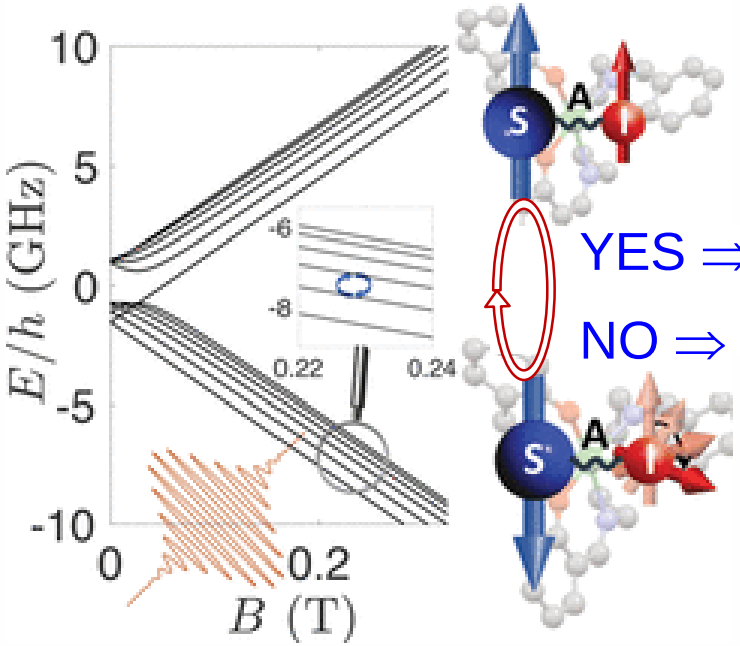
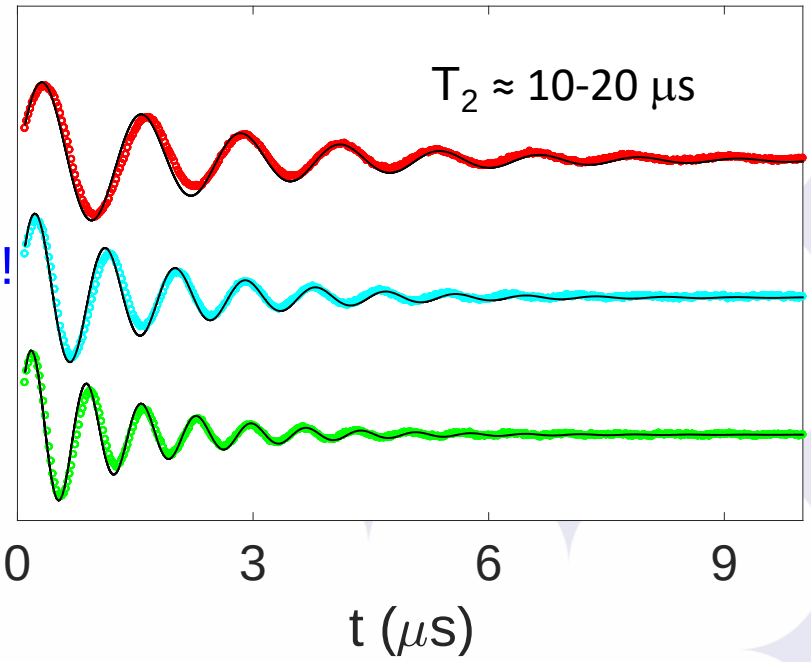
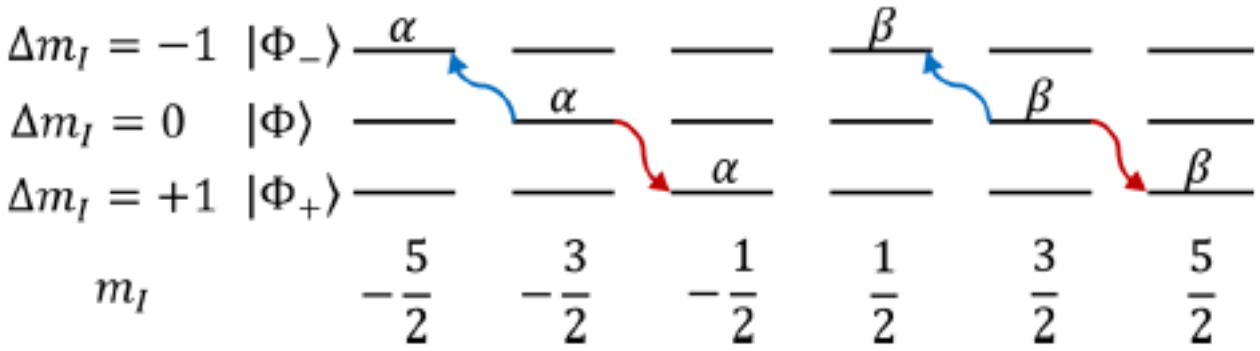


YES ⇒ ERROR!!

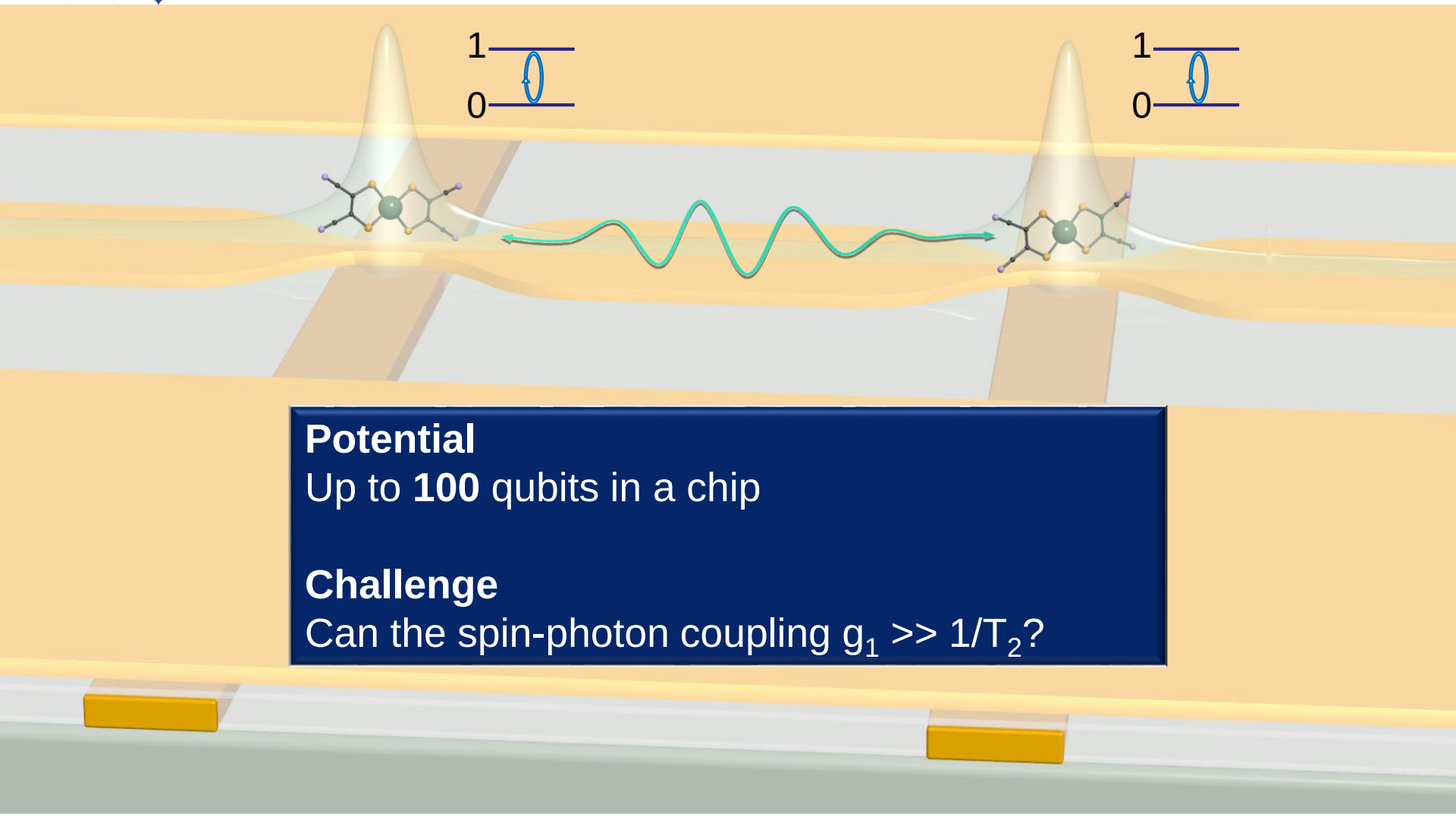
NO ⇒ OK!!





R. Hussain et al, J. Am. Chem. Soc. **140**, 9814–9818 (2018)

Wiring-up different molecules

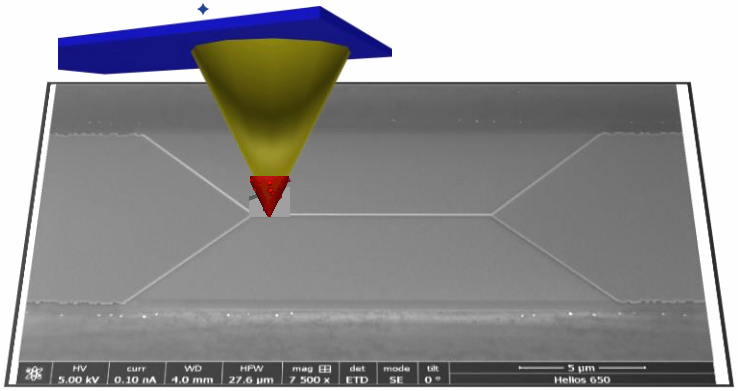


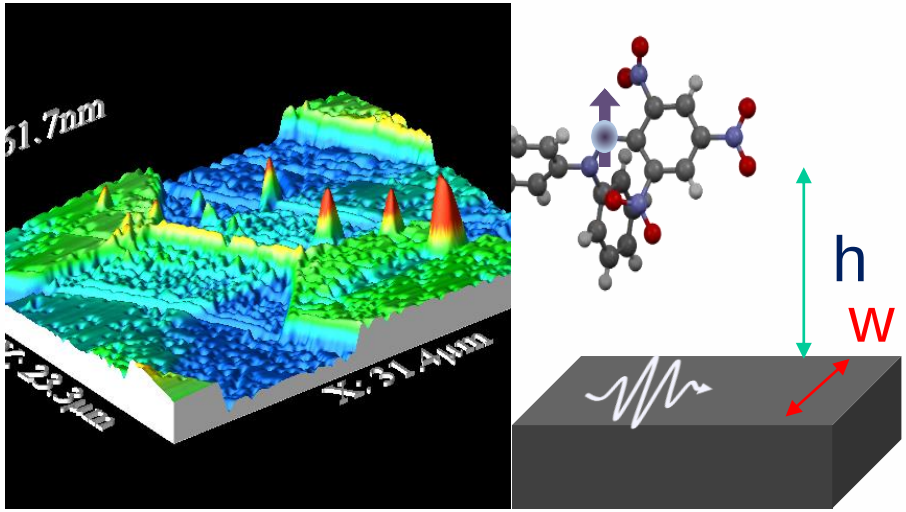
Potential
Up to **100** qubits in a chip

Challenge
Can the spin-photon coupling $g_1 >> 1/T_2$?

M. Jenkins et al., Dalton Transactions **45**, 16682 (2016)

SC nanoresonators





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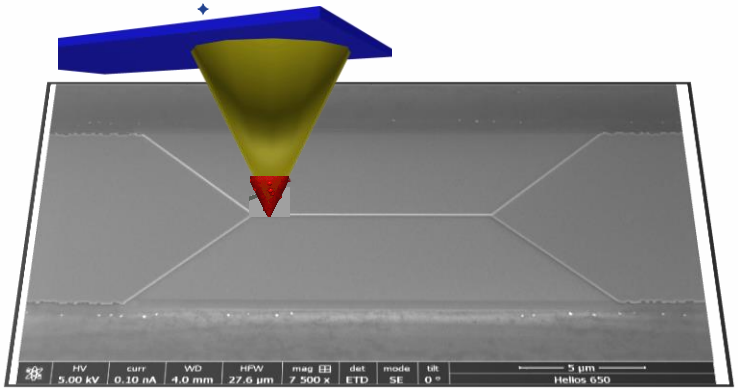
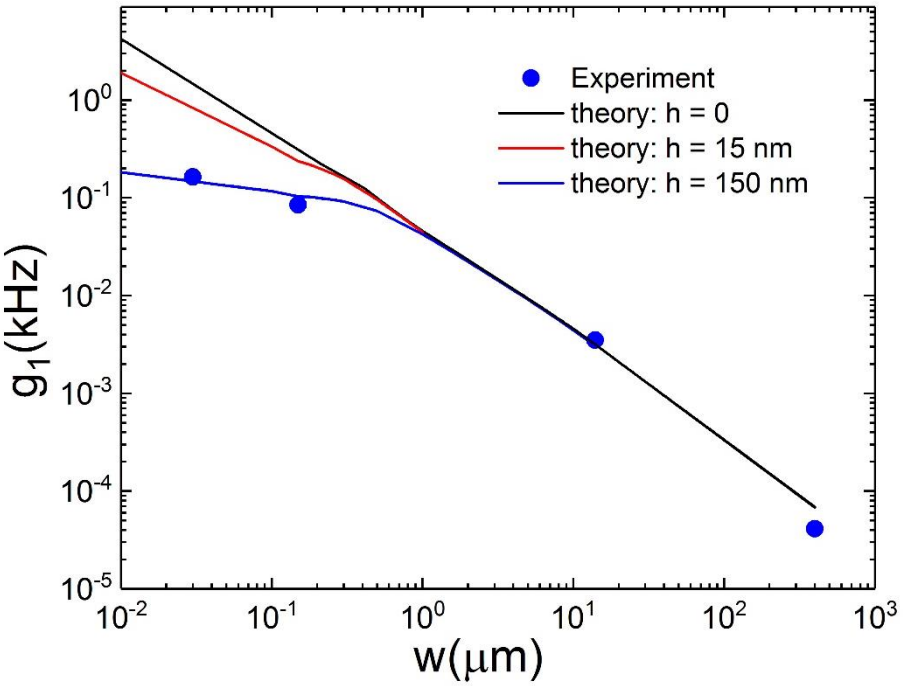
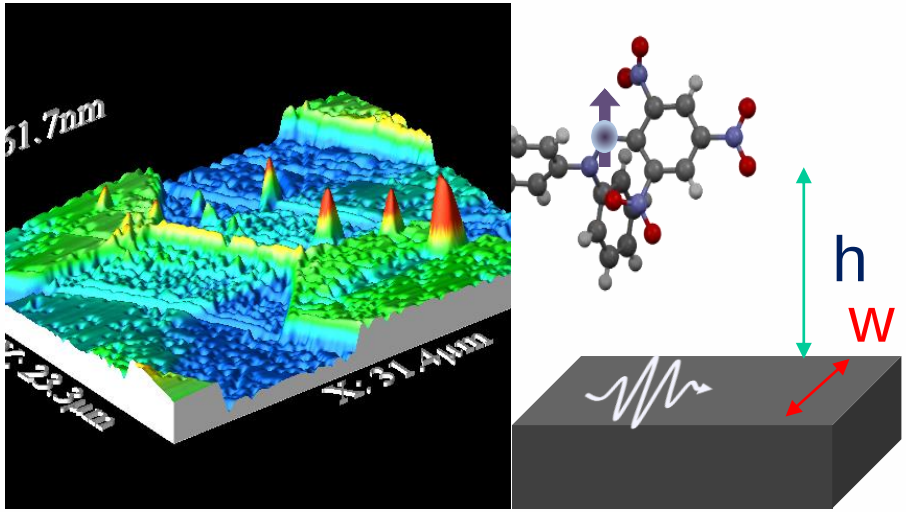




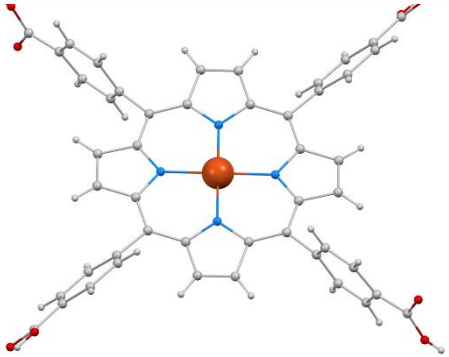


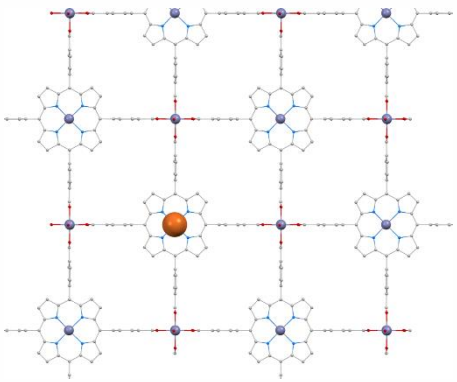
10^3 enhanced coupling near nanoconstrictions

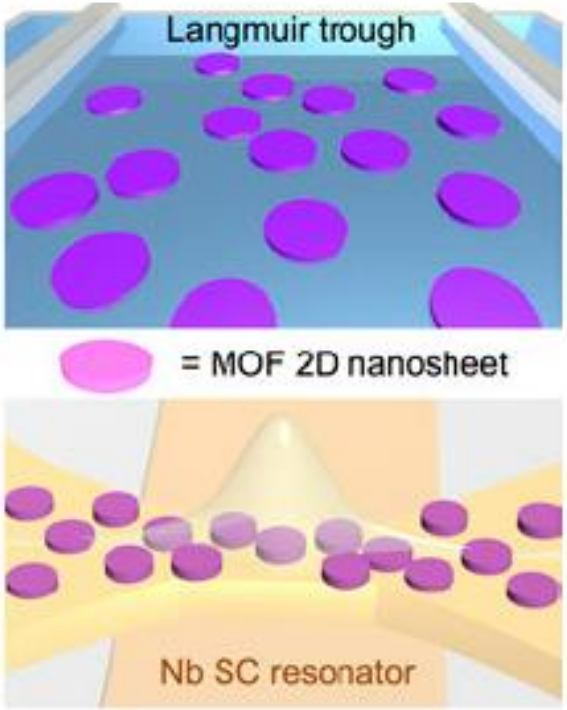
g_1T_2 ~ 0.01-0.1

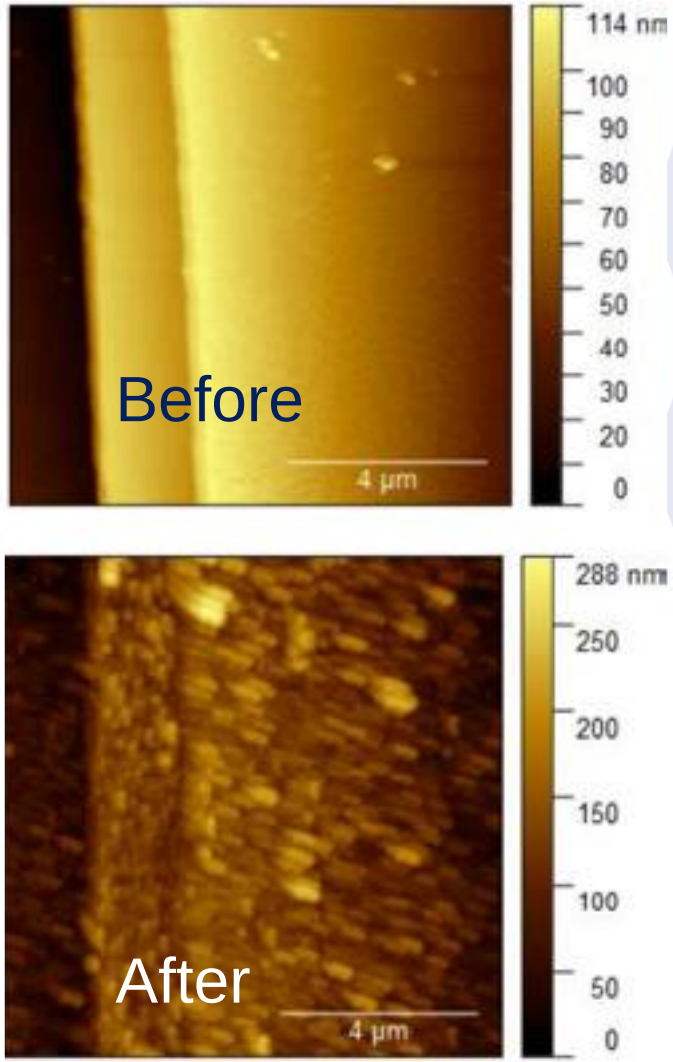
Optimal qubit integration

In-situ chemical synthesis of qubit networks: VO-porfirin







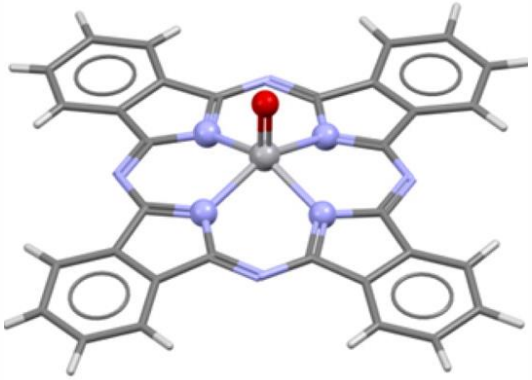


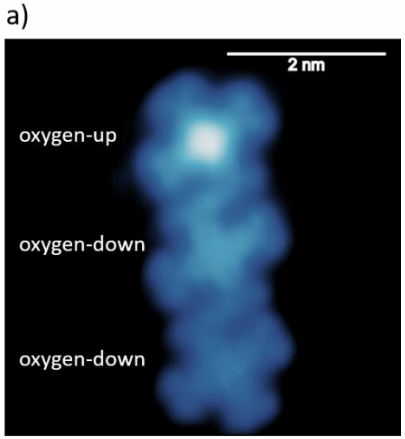
Further 50× enhancement of g_1

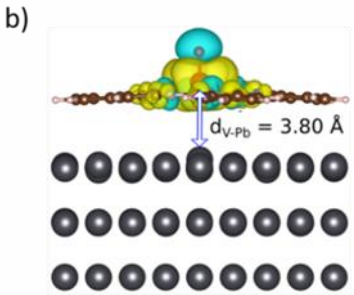
A. Urtizberea et al, Materials Horizons (2019), accepted

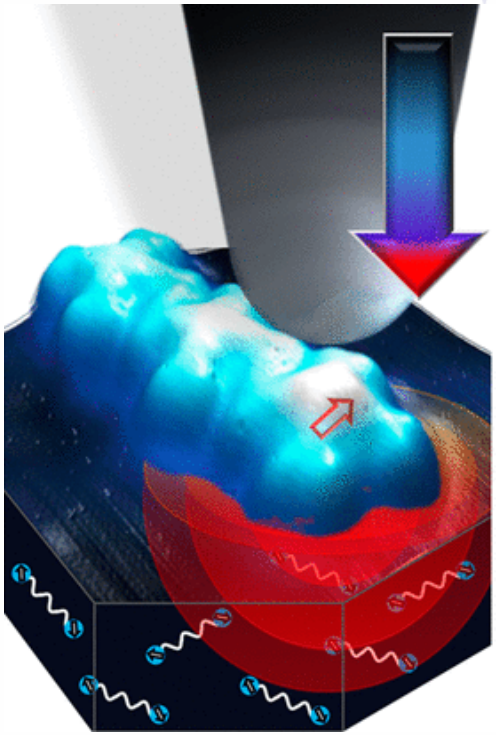
Single-molecule characterization

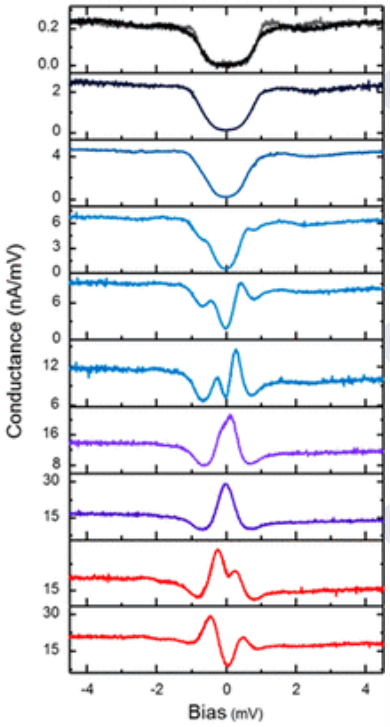
VO-porfirin @ Pb









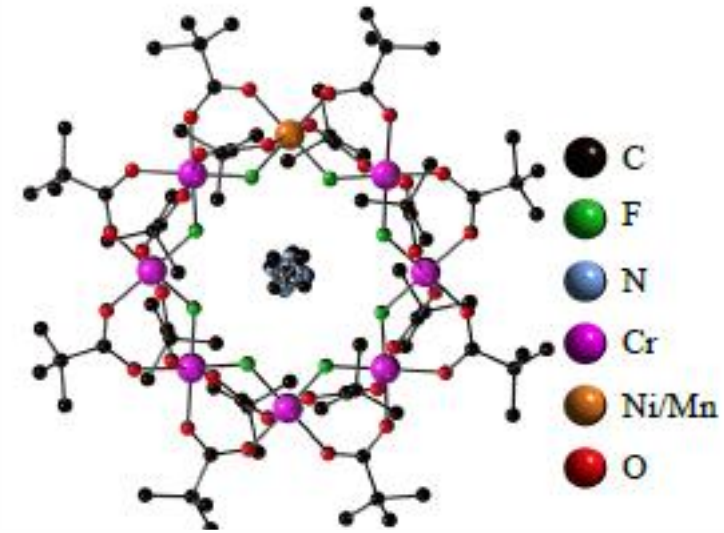


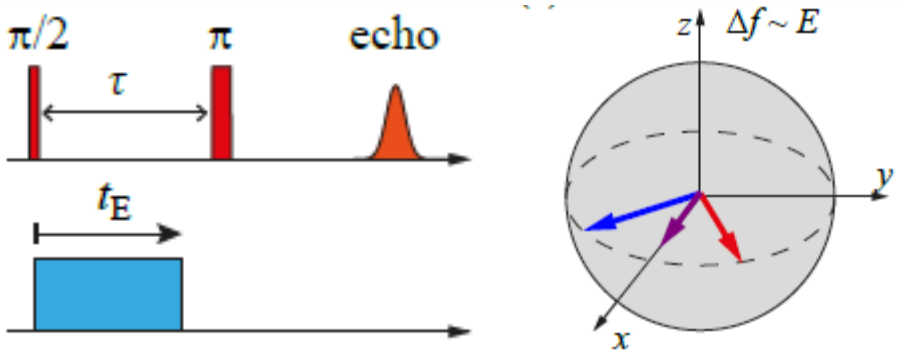
Robust and tuneable spin states at SC surfaces

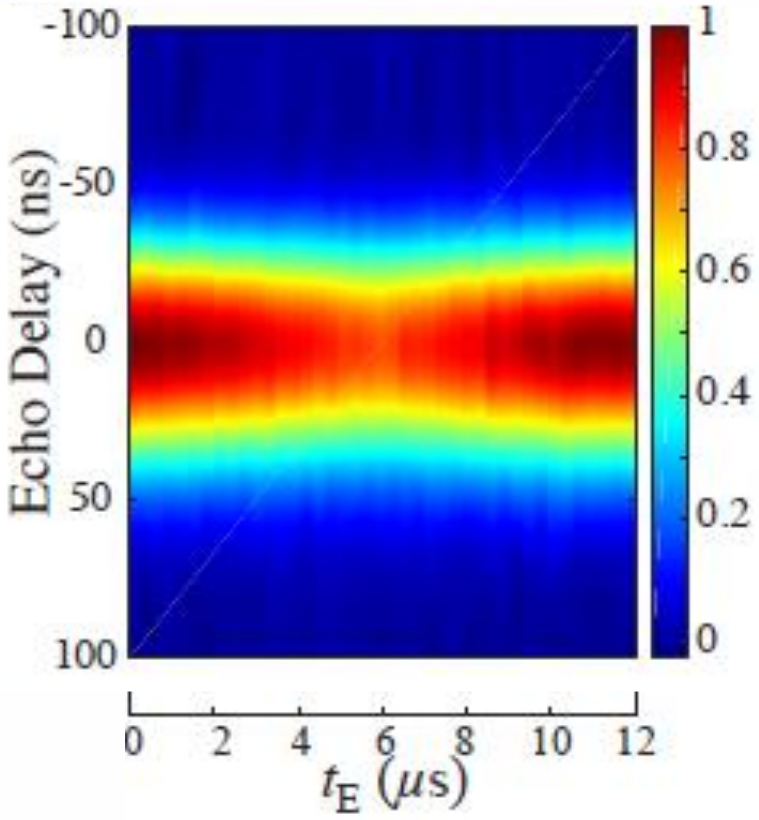
L. Malavolti et al, Nano Letters **18**, 7955 (2018)

Electric-field control

Cr_7Mn in a 3D cavity





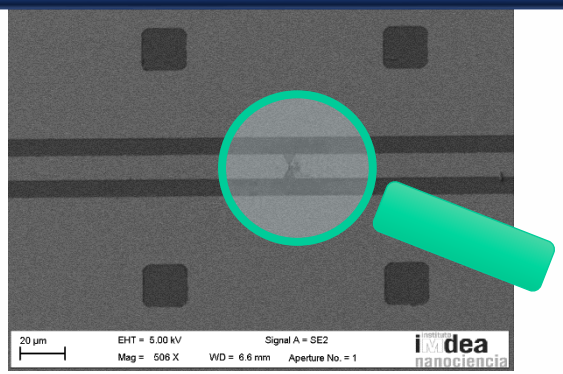


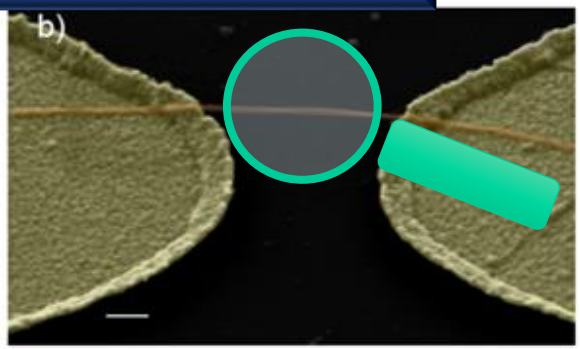
Coherent control over the spin quantum dynamics

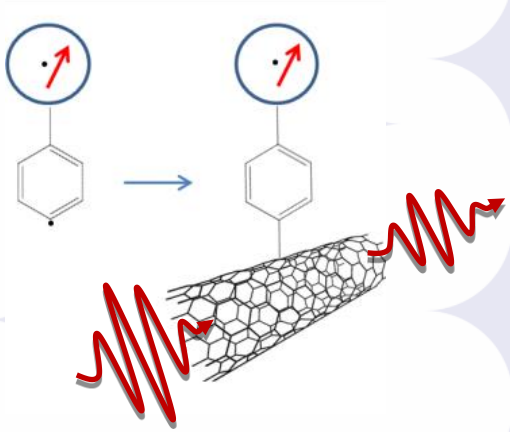
J. Liu, et al, Phys. Rev. Lett. **122**, 037202 (2019)

Next steps (SUMO and beyond)

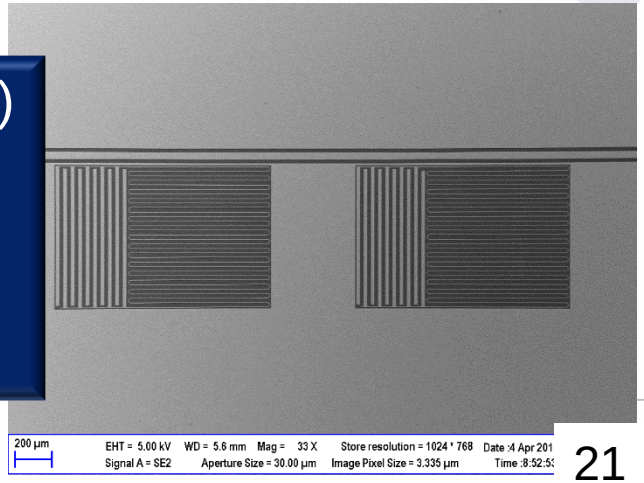
- “Circuit QED” + molecular electronics
- C nanotubes or 2D SC materials (NbSe2)







- LC resonators (KIDS)
- Multiple frequencies
- Scalability



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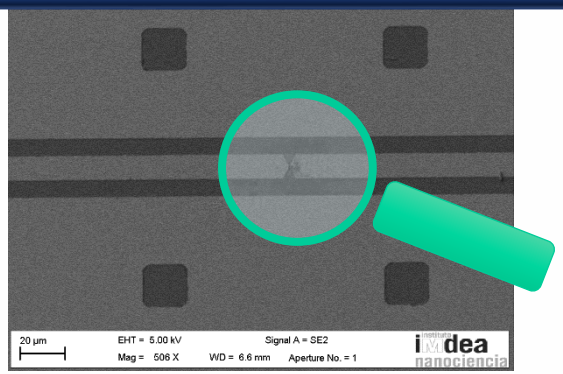
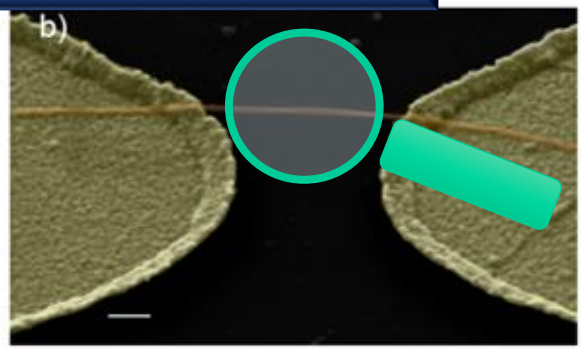
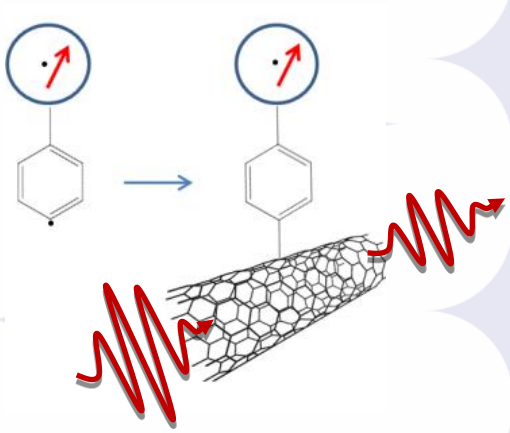
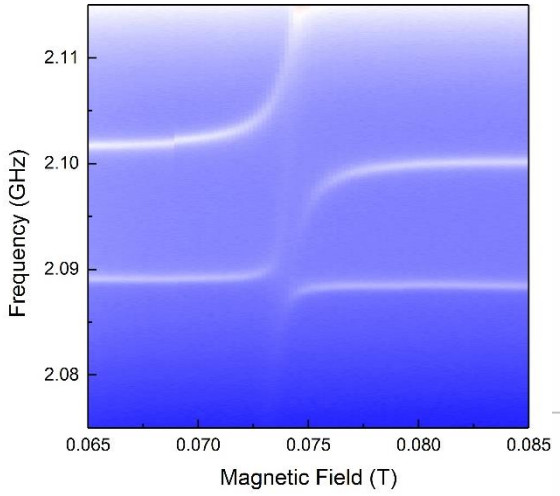
- "Circuit QED" + molecular electronics
- C nanotubes or 2D SC materials (NbSe2)

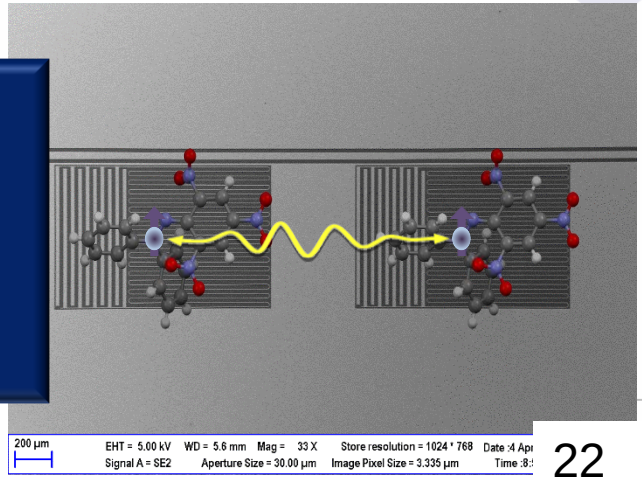




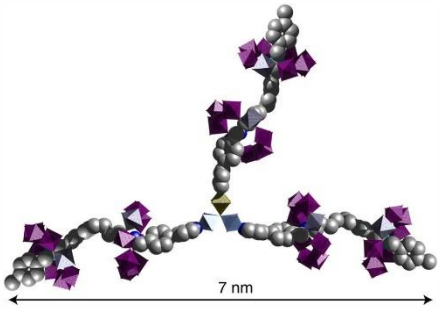


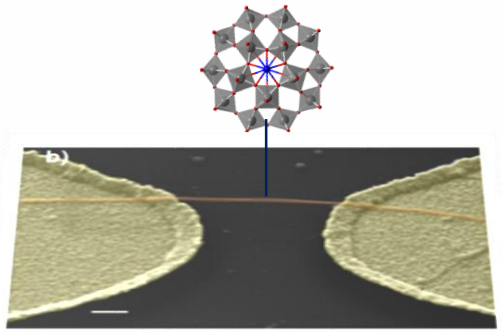


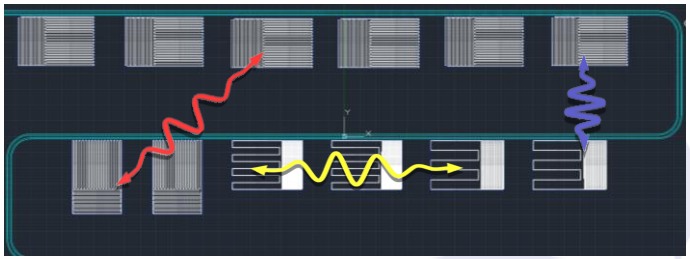
- LC resonators (KIDS)
- Multiple frequencies
- Scalability



Our roadmap







Molecular processors (1-6 qubits)

Strong coupling 1 photon 1 molecule

Multiple resonators

QECC in each molecular unit

Up to 100 molecules per resonator

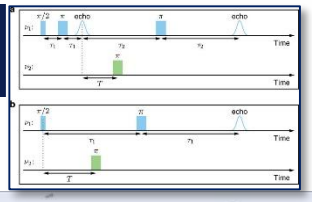
Large scale simulation and computation

2019 — 2021 — 2030

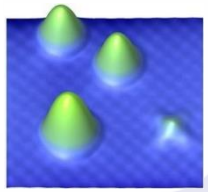
SUMO

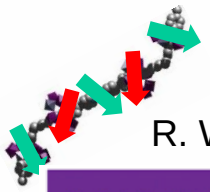
Thanks

A. Ardavan

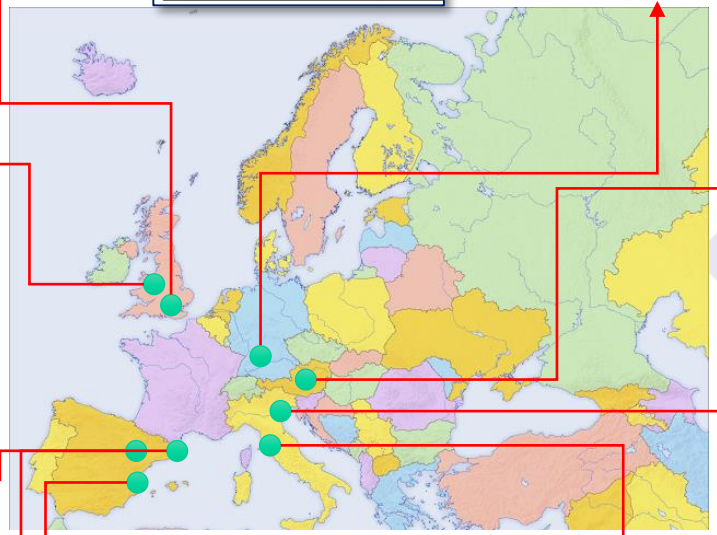


S. Loth

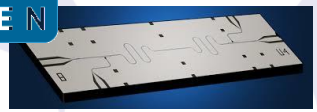


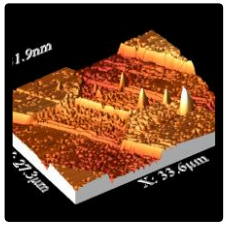


R. Winpenny



J. Majer

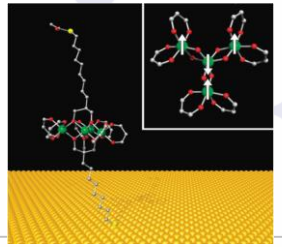




F. Luis

E. Coronado

S. Carretta



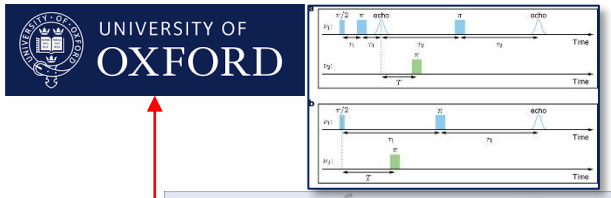
G. Aromí

R. Sessoli

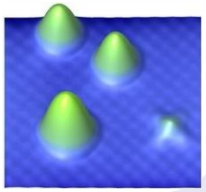
Thanks

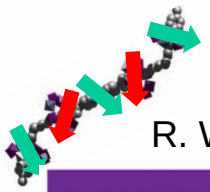
FET-OPEN

A. Ardavan

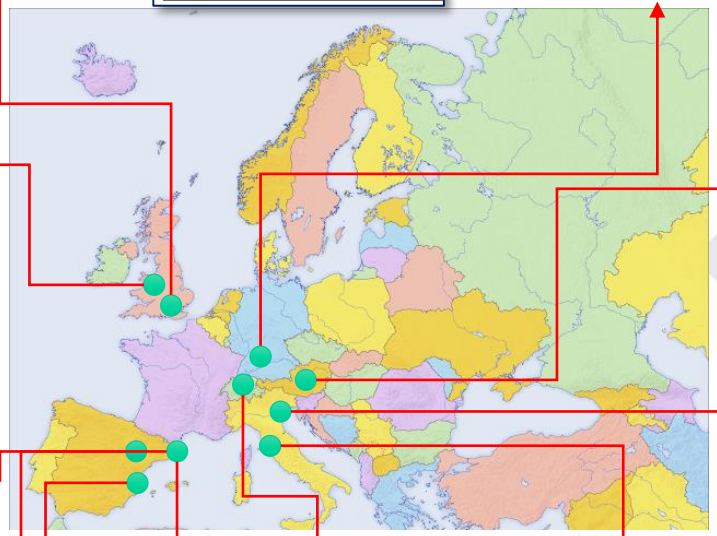


S. Loth

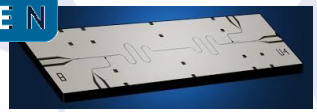


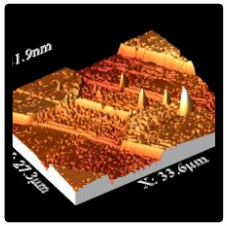


R. Winpenny



J. Majer

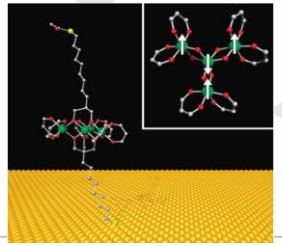




F. Luis

E. Coronado

S. Carretta



I. Tavernelli

G. Aromí

M. Almendros

R. Sessoli