QUANTERA

ERA-NET Cofund in Quantum Technologies

# QuantERA Mid-term Strategic Conference

**Granada, Spain, 13-14 November 2019**

# QUANtum Technologies with 2D-OXides
# QUANTOX

M. Salluzzo CNR-SPIN Italy

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

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QUANTOX project is committed to the realization and study of an innovative technological platform, based on ***2D-oxides*** for the realization of ***topological quantum systems***

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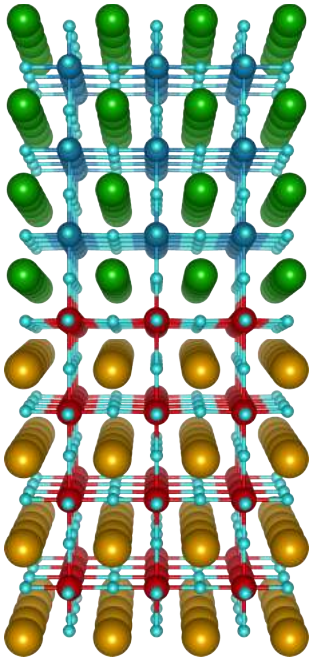


$LaAlO_3$

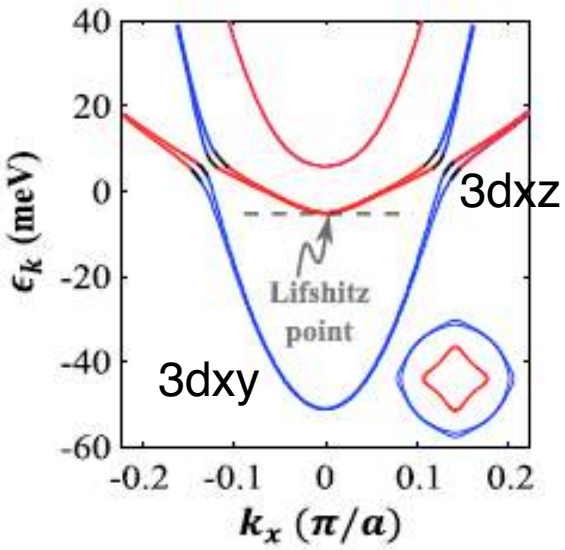
$SrTiO_3$

Multi-band transport from Titanium 3d bands

2D superconductor
- t=10nm
- ξ=70nm
- Tc≈250mK

Large SO coupling (tunable)
- Δso≈8mV

S-I transition via electric field effect



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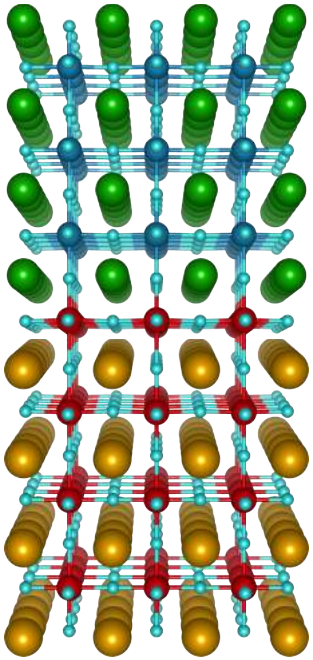

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Multi-band transport from Titanium 3d bands

2D superconductor
- t=10nm
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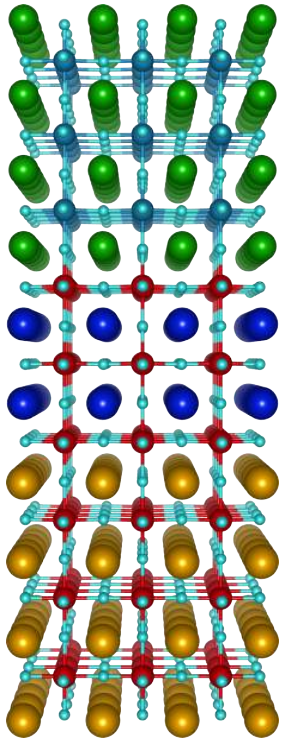
S-I transition via electric field effect

ferromagnetism

Atomic Engineering



$LaAlO_3$

$EuTiO_3$

$SrTiO_3$

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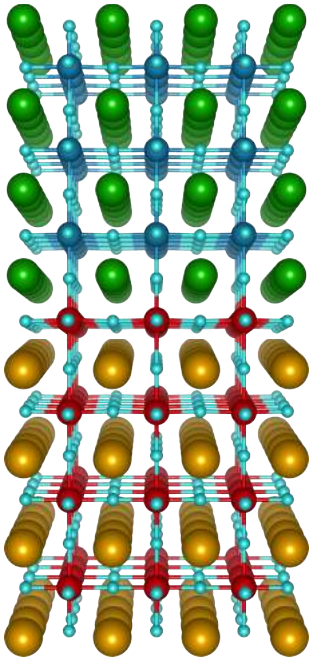
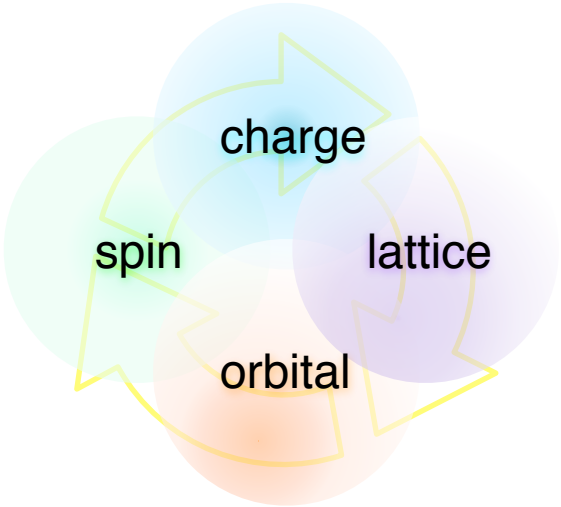
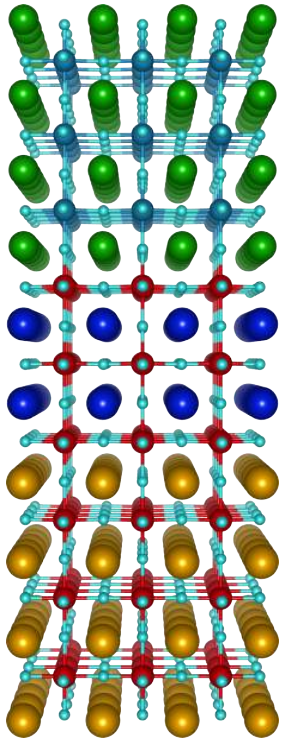


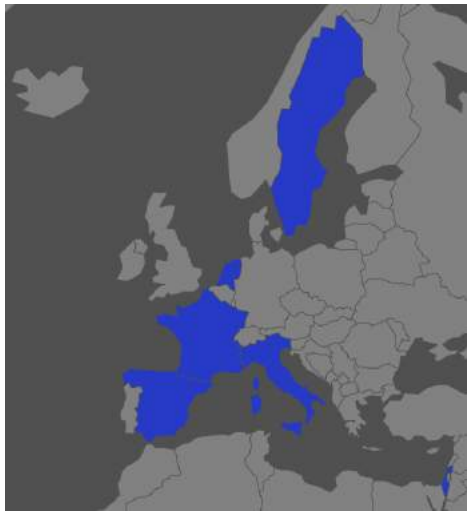


Our idea is to exploit the unique combination of ***Rashba SOC, 2D-magnetism*** *and* ***superconductivity*** to realize topological superconductors and topological qubits whose properties can be locally *tuned using* ***electric field effect***

# the team

| *country* | *institution* | *principal investigator* |
|---|---|---|
| Italy | CNR-SPIN | Marco Salluzzo |
| Netherland | TU-Delft | Andrea D. Caviglia |
| Sweden | MC2-Chalmers | Alexei Kalaboukhov |
| France | CNRS-Thales | Manuel Bibes |
| Spain | UCM | Jacobo Santamaría |
| France | ESPCI | Nicolas Bergeal |
| Israel | BIU | Beena Kalisky |



kick-off meting

| *consortium meetings* | |
|---|---|
| 22/05/2018 | Capri (Italy) |
| 23-24/01/2019 | Paris (France) |
| 18-19/09/2019 | Delft (Netherland) |

# WPs - activities started

R. Citro- CNR

Optimization of oxide heterostructures by combining advanced methods of characterization and deposition

Characterization of basic physical properties of oxide 2DEGs

Work Package 1

Theoretical modeling of oxide 2DEG nano-channels and quantum gates

Theoretical modeling of the topological superconductivity in oxide 2DEG using the realistic band structure and physical parameters as obtained from the experiments

Work Package 2

Optimization and orbital control of SC and Rashba SOC in oxide 2DEGs

A. Kalaboukhov
Chalmers

Work Package 3

Quantum gates based on MZMs

A. Caviglia
DELFT

Optimization of the nano-patterning technique and characterization of the nanochannels.

Milestone 1

Optimization of SC oxide 2DEG with full orbital control

Milestone 2

Topological edge states in 2D oxides

Milestone 3

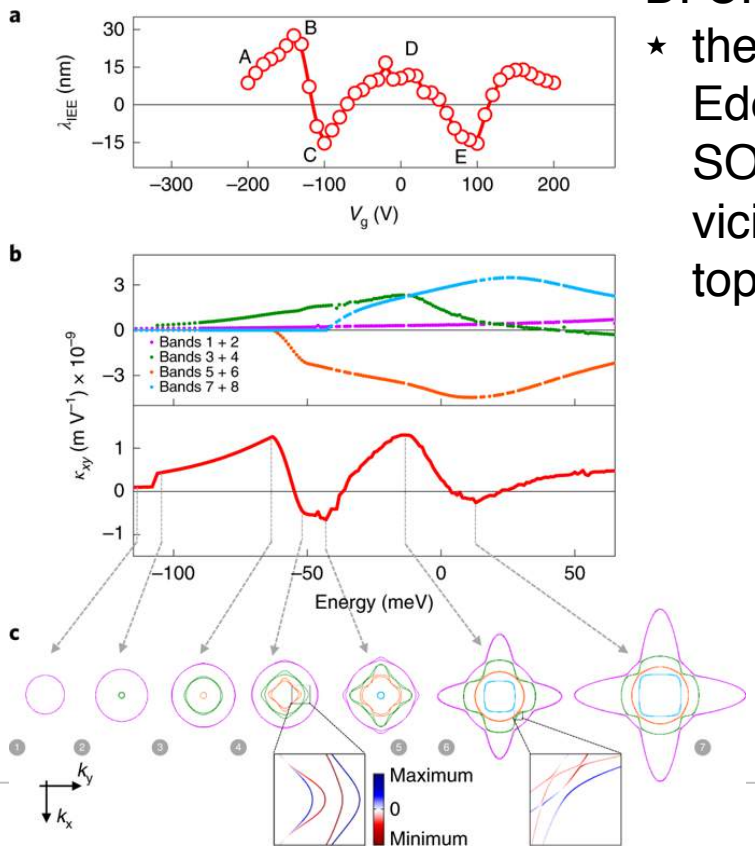
Demonstration of MZMs in 2D oxides

Milestone 4

Manipulation of TS and MZMs in 2D oxides

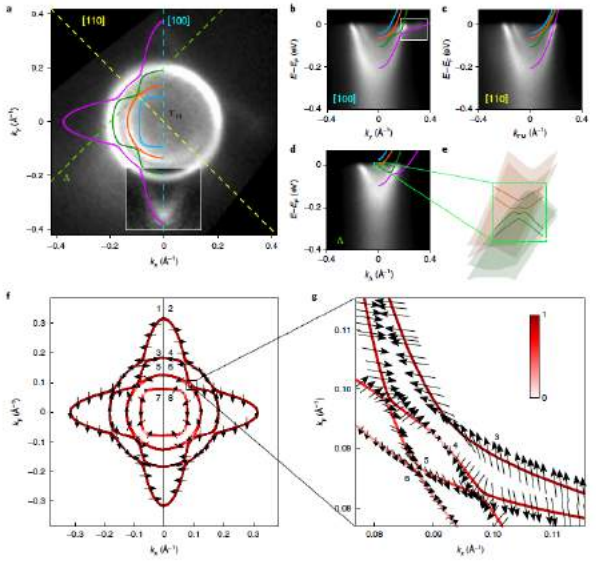
Scanning Squid Microscopy for the characterization of individual devices and local detection of edge currents

# Selected results - Giant spin-charge conversion and topological states in oxides

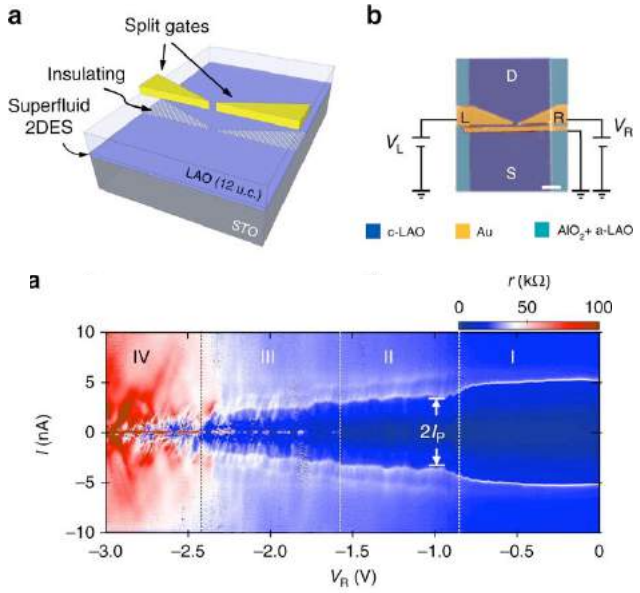



D. C. Vaz et al., *Nature Materials* 39, 78 (2019)

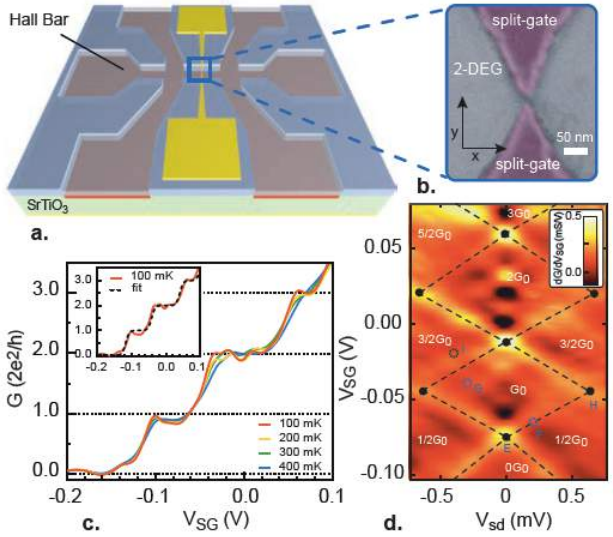
⋆ the conversion process, due to the inverse Edelstein effect, is amplified by enhanced SOC splitting due to orbital mixing and in the vicinity of avoided band crossings with topologically non-trivial order.



# Selected results - Split gate nanodevices




H.Thierschmann, et al., *Nature Communications* 9, 2276 (2018)

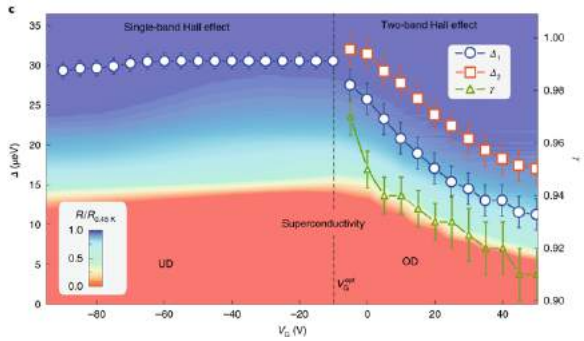



A. Jouan, et al., Nature electronics *under review*

LAO/STO based split-gate quantum point contacts

- ⋆ fully tunable
- ⋆ spectrometer for the detection of Majorana states

# Selected results - non trivial superconductivity

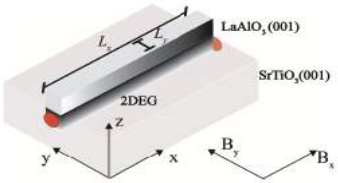


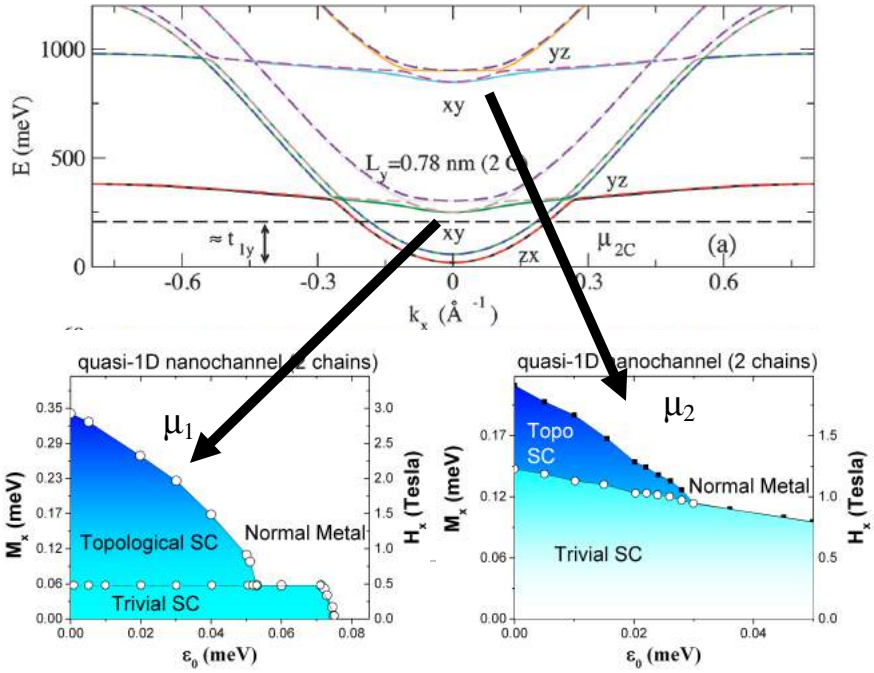

G. Singh et al., *Nature Materials* 18, 948 (2019)

- ⋆ microwave transport is used to extract the superfluid stiffness of the (110)-oriented LAO/STO
- ⋆ evidence of a transition from single-condensate to two-condensate superconductivity

Trivial/topologial phase diagram in quasi 2D nanochannels in magnetic field (Theory)
Phys. Rev. B 100, 094526 (2019)

**Evolution of topological superconductivity by orbital-selective confinement in oxide nanowires**



# other results

- Theoretical modeling of the topological superconductivity in oxide 2DEG
  Phys. Rev. B 100, 094526 (2019)

- Trigonal crystal field and trigonal distortion in (111) STO-based oxide 2DEGs
  Physical Review B 99, 201102 (2019)
  Physical Review B 99, 205421 (2019)
  Physical Review B 98, 115143 (2018)

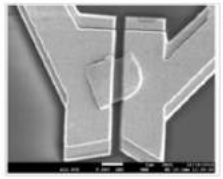
- Magnetism and WAL in LAO/ETO/STO
  Physical Review B 98 75409, (2018)

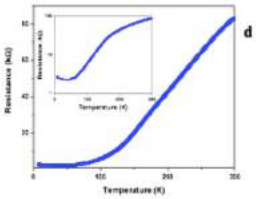
- Advanced scanning SQUID techniques for 2D superconductors
  Nature Physics 14, 1205 (2018)
  Review of Scientific Instruments 90 53702 (2019)

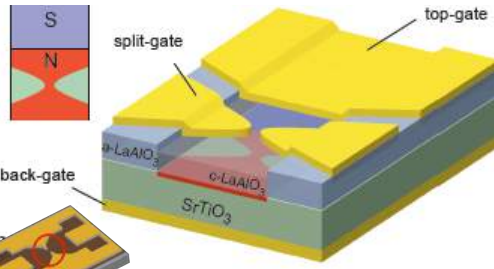
# Key challenge and future activities

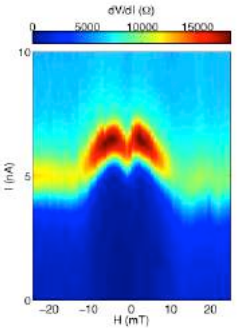
Focus on unconventional/topological superconductivity in LAO/STO and LAO/ETO/STO

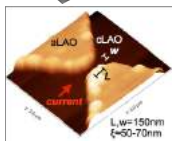
- using new fabrication techniques for oxide 2DEGs nanodevices and Josephson junctions including freestanding LAO/STO 2DEGs membranes and FIB nanojunctions





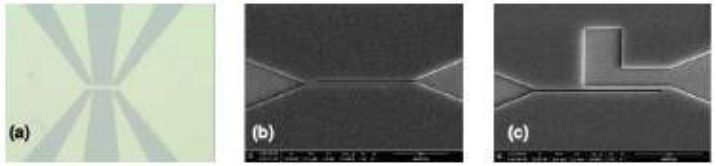




Experiment to search for MZM

- quantum point contact (and noise) spectroscopy
- realization of locally tunable SN junctions using the side/top gate layout
- anomalous Josephson effect (including transport and scanning squid experiments)



# QUANTOX

20 papers published, among which:

- 2 Nature Materials
- 2 Nature Physics
- 1 Nature Communications
- 2 Physical Review Letters

>30 talks to international conferences

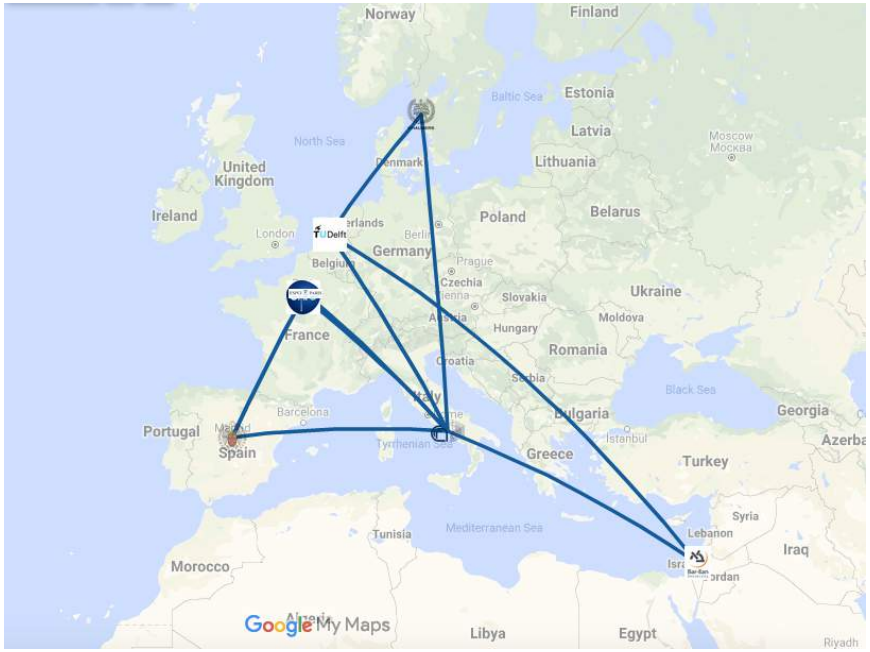
3 meetings organized

the project partecipated to the organization of three phd schools(France, Italy)

partnership with the new PhD program in Quantum Technologies at the University of Naples

dissemination activities (Researchers night, Futuro Remoto…)

ongoing collaborations




Ph.D. |Qu>ANTUM |T>ECHNOLOGIES

# acknowledgements

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R. Citro

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