TMR-based high sensitivity sensor for space application

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CONTENT

- Magnetic measurements in space
- Ultra-sensitive sensor using Symmetric Response MTJ
- Free Layer Stabilization
- Comparison of two stabilization technics
- Integration of Flux Concentrators

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- **Magnetic measurements in space**
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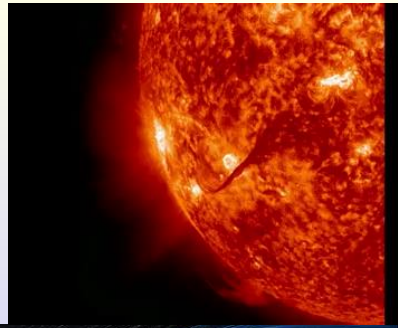
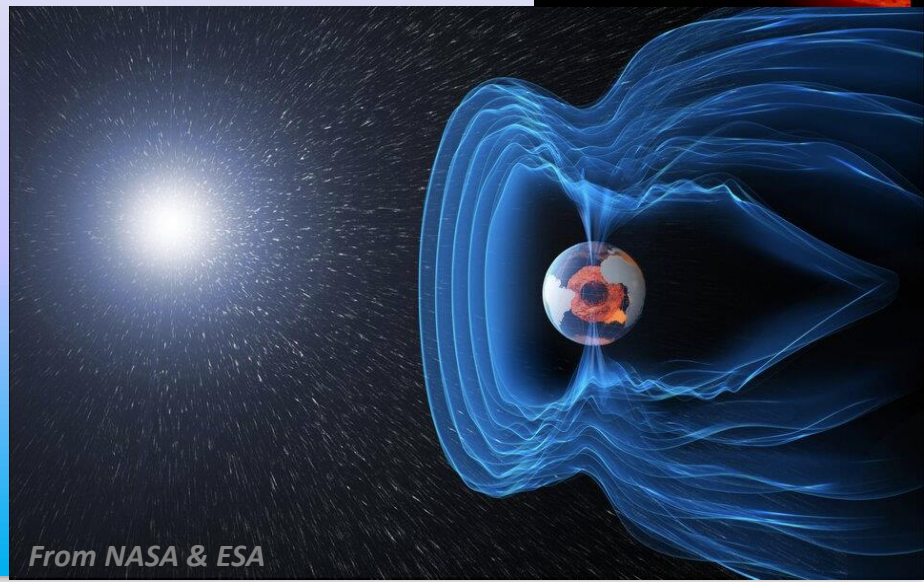
Why measuring magnetic field in space ?

- **Geomagnetism → Study of earth's inner core 3000 km deep**
  - Acceleration of the North pole drift towards Siberia: 50-60 km/year
  - South Atlantic anomaly : decreased by 10% in 20 years



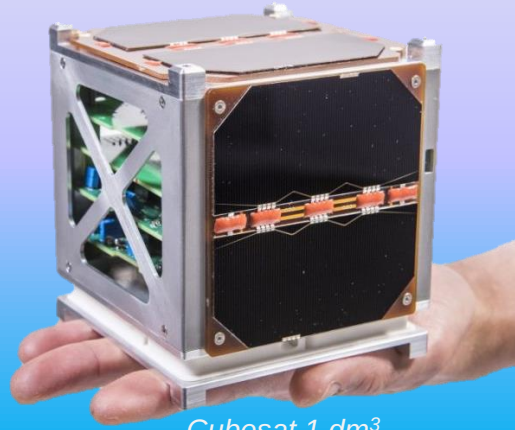
- **Earth –sun interactions**
  - Space weather due to solar eruptions
- **Space exploration**
  - Local characterizations



Space magnetometers

➢ **Need to develop new instrumentation for space exploration**

- **Small satellites**



- **Bulky instrumentation**

Search Coil

- 515 g
- 1000 cm³
- 5 fT/$\sqrt{Hz}$ à 1000 Hz
- 10 pT/$\sqrt{Hz}$ à 10 Hz

+ Fluxgate

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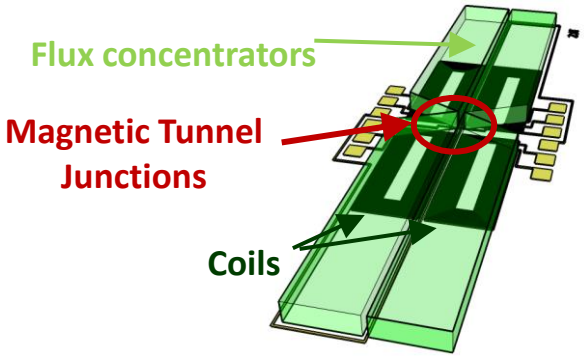
Design of a high Sensitivity Magnetometer

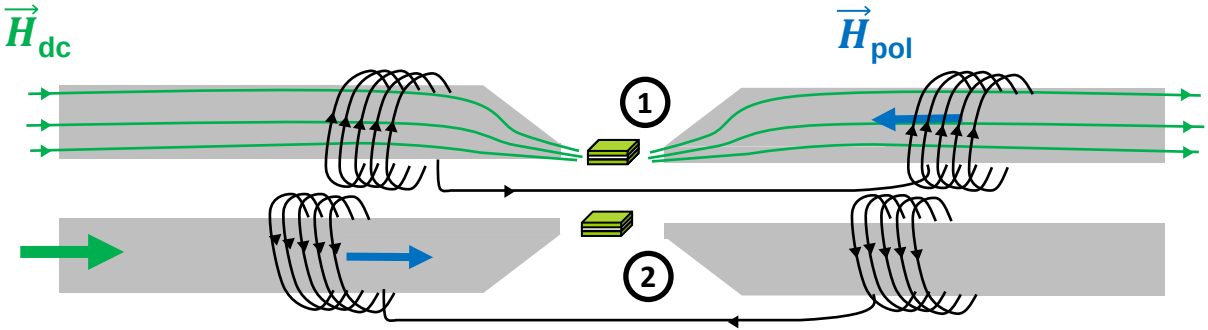
Project objective

- Use of MTJ
- Bring measurement at high frequency ➢ 1/f noise ↘
- Negative feedback ➢ Large dynamic range ([1 pT-50 µT])
  ➢ Thermal drift compensation

Sensor design



Schematic of the sensor architecture

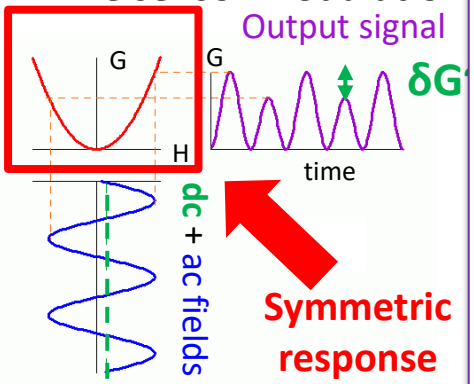


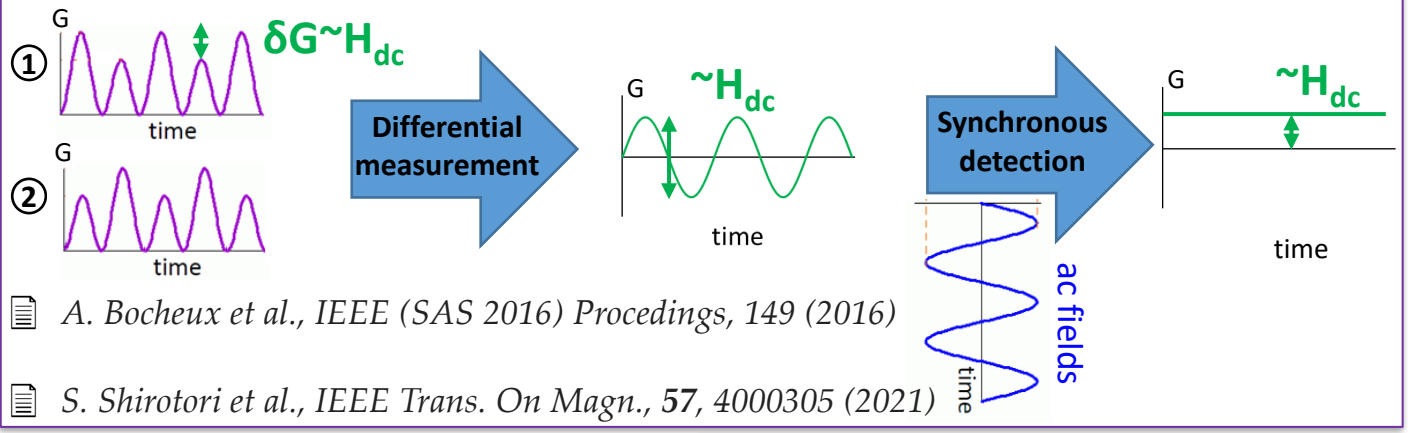
Combination of 4 elements:

- **Magnetic Tunnel Junctions**
  ➢ Sensitive element
- **Flux concentrators**
  ➢ Focus the field on the MTJ
- **Coils**
  ➢ Magnetic modulation (100 kHz) + Negative feedback
- **Electronics**

Design of a high Sensitivity Magnetometer

The sensor modulation

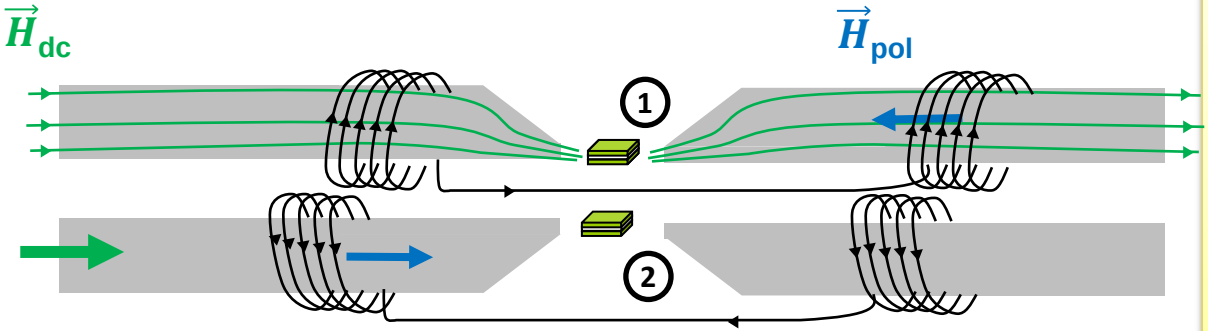




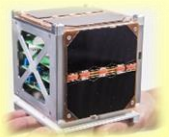
A. Bocheux et al., IEEE (SAS 2016) Procedings, 149 (2016)

S. Shirotori et al., IEEE Trans. On Magn., **57**, 4000305 (2021)

Schematic of the sensor architecture

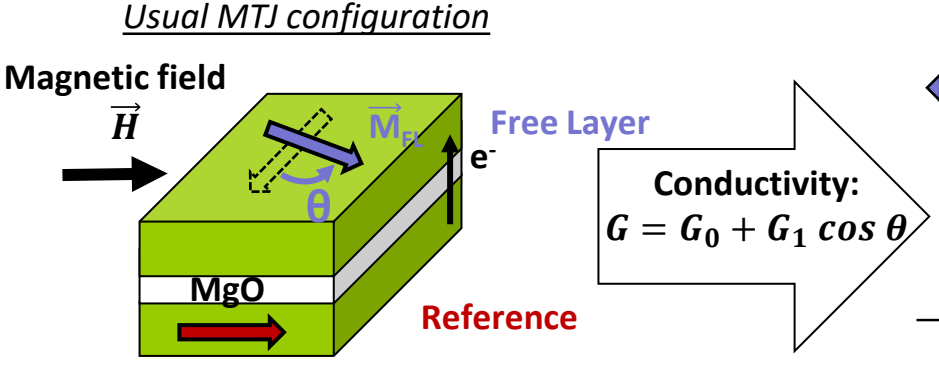


- **Good detectivity:**
  1 pT/$\sqrt{Hz}$ at [1 Hz - 10 kHz]
- **Small sensor:**
  ~ cm³

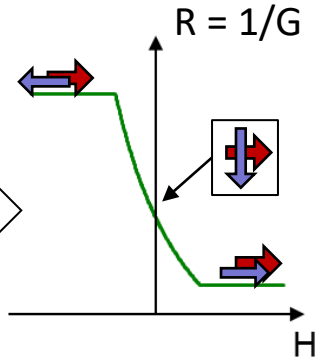


SR-MTJ configuration

Usual MTJ configuration



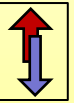
Conductivity:
$G = G_0 + G_1 \cos\theta$



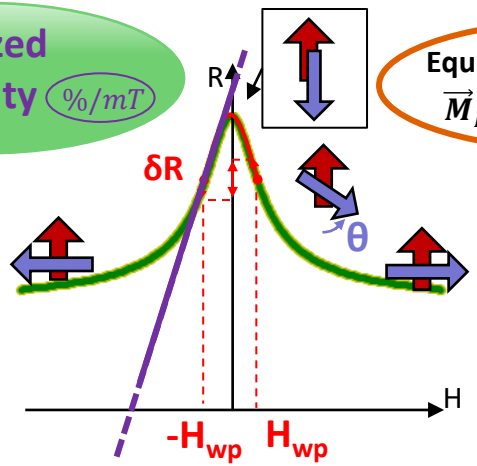
$$\text{Detectivity} = \frac{\text{Noise}\ (V/\sqrt{Hz})}{\text{Sensitivity}\ (V/T)}\ \ (T/\sqrt{Hz})$$

Objectives:

- Symmetric Response MTJ
  - Sensitive
  - Low working point (H_{wp})

Free Layer stabilization → 

Normalized Sensitivity (%/mT)



Equilibrium configuration:
$\vec{M}_{FL} \uparrow\downarrow \vec{M}_{ref}$ (AP state)

Saturation:
$\vec{M}_{FL} \perp \vec{M}_{ref}$

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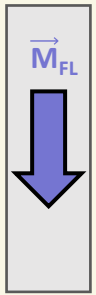
Optimum stabilization

- 3 stabilization methods

Use of additional Transversal Field

H_{trans}

Rectangle 4x25 µm²



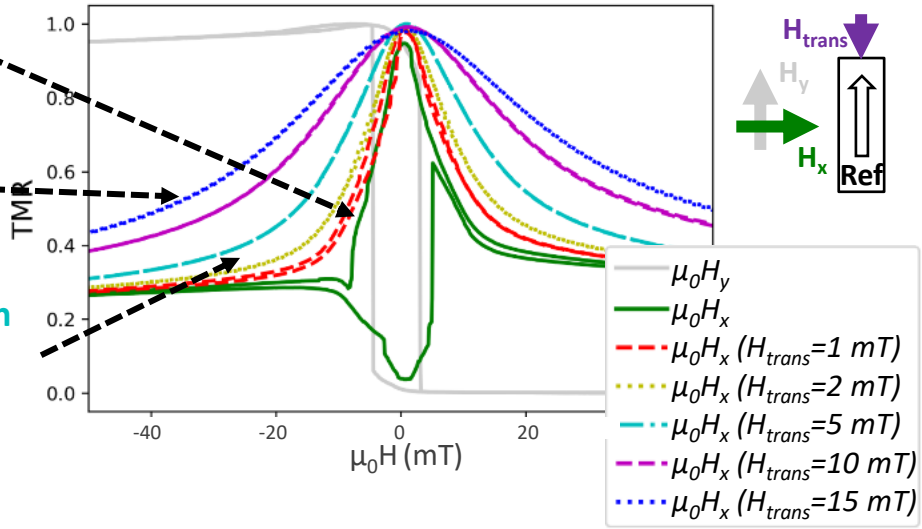
*J. Moulin et al., APL **115**, 122406 (2019)*

Variation of the stabilization value by using a transversal field

Shape anisotropy only = 1.8 mT

High stabilization
$\mu_0 H_{trans}$ = 15 mT
(+1.8 mT)

Minimum stabilization
$\mu_0 H_{trans}$ = 5 mT
(+1.8 mT)



With minimum stabilization:
→ Normalized sensitivity = 3.7 %/mT

→ Coherent rotation

→ High sensitivity

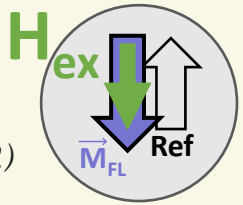
Soft pinning stabilization

- **3 stabilization methods**

Soft Pinning

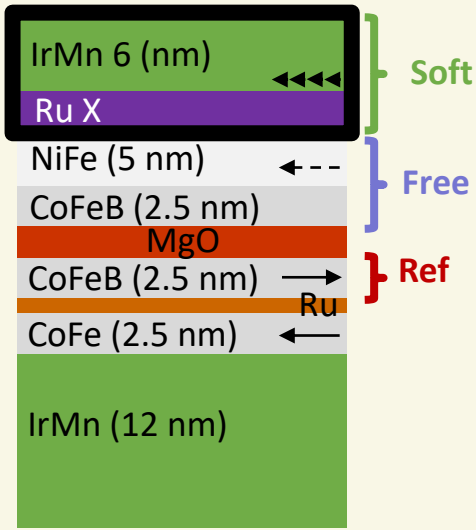
- H_{ex} set with Anti-Ferromagnet + annealing
- Tuning of the soft pinning with Ru spacer

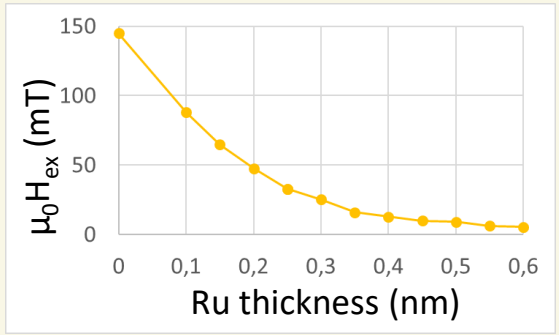
R. Ferreira et al., IEEE vol. 48, no. 11, 3719 (2012)



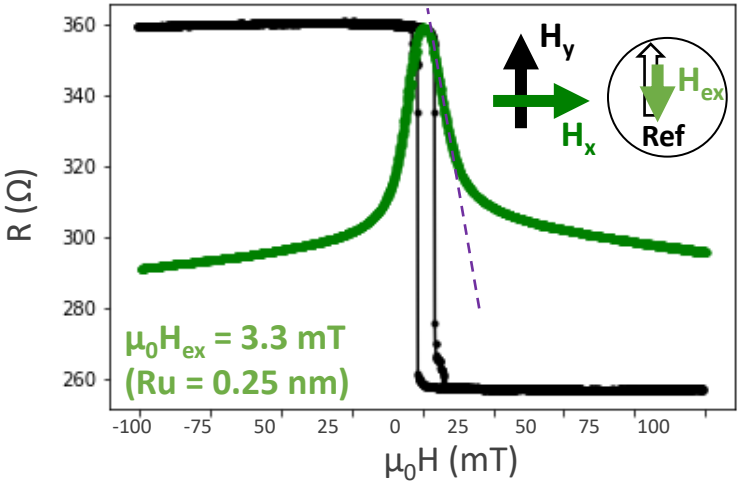
Circle
4 µm wide

Magnetic stack:





Coherent rotation with soft-pinning layer



→ **Normalized sensitivity: 4.7 %/mT**

→ **Coherent rotation**

→ **High sensitivity**

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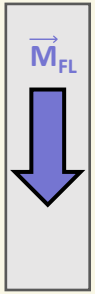
Comparison of stabilization methods

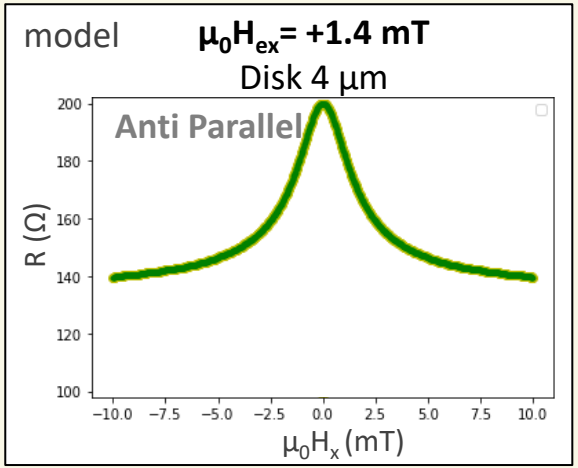
Exchange



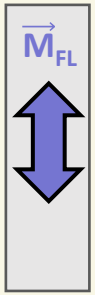
$H_{ex} > 0$

- Soft Pinning
- additional Transversal Field

Computation of R-H responses by using Stoner & Wohlfarth model



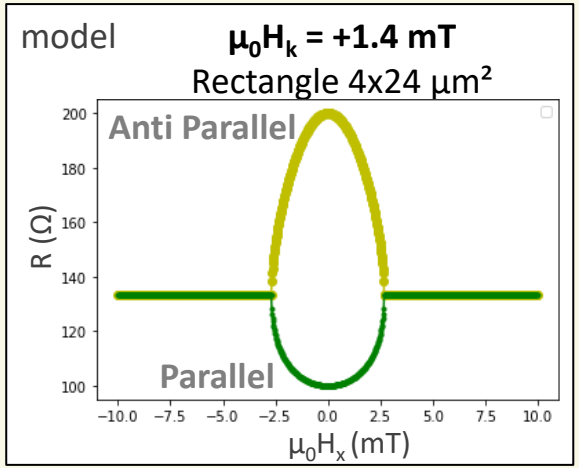
Anisotropy



Ref → $H_k > 0$

Ref → $H_k < 0$

- Shape Anisotropy



WP: at highest sensitivity

Sensitivity ↗
H_{wp} ↘

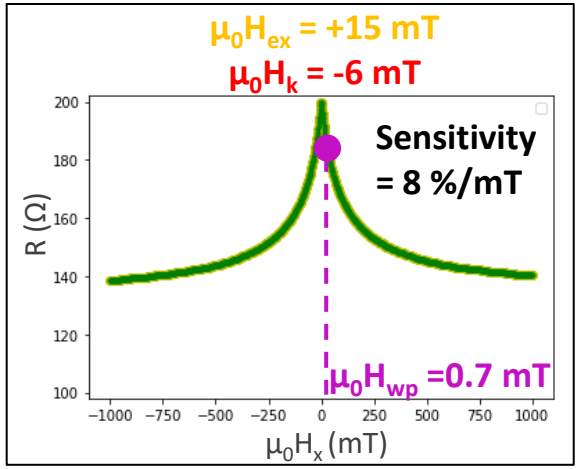
⇦ **Stabilization** ⇨ **Coherent rotation**

Tuning of the working point computed

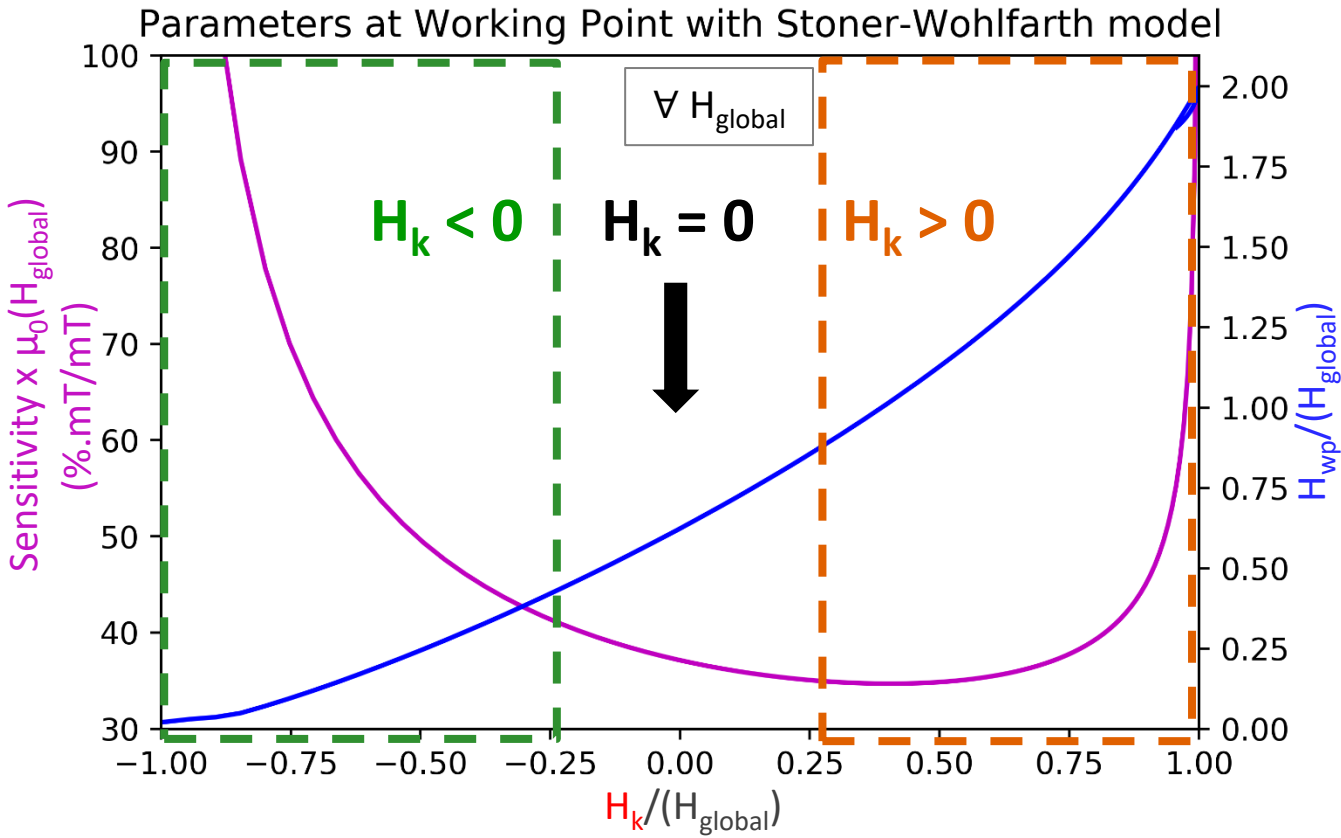
Stabilization:

$H_{global} = H_{ex} + H_k$

$(H_{global} > 0)$



→ Low H_{wp}



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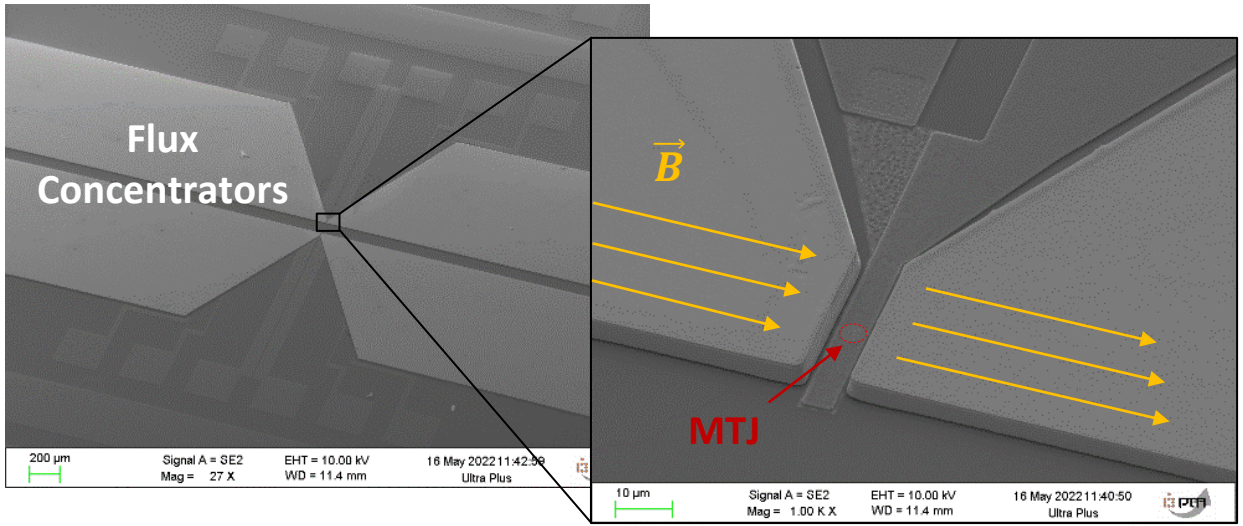
Flux concentrator integration

Objective:

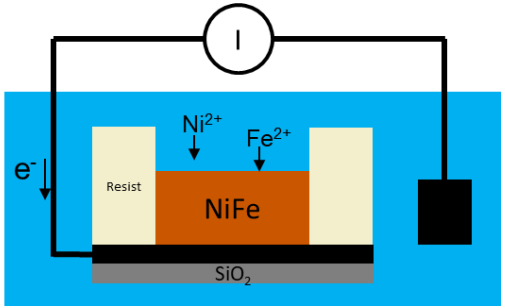
- **Focus $\vec{B}$ on MTJ**
- **Increase the sensitivity**

→ Permalloy

→ Design:
- 5-7 µm thick
- 5 mm long
- 10 µm air-gap



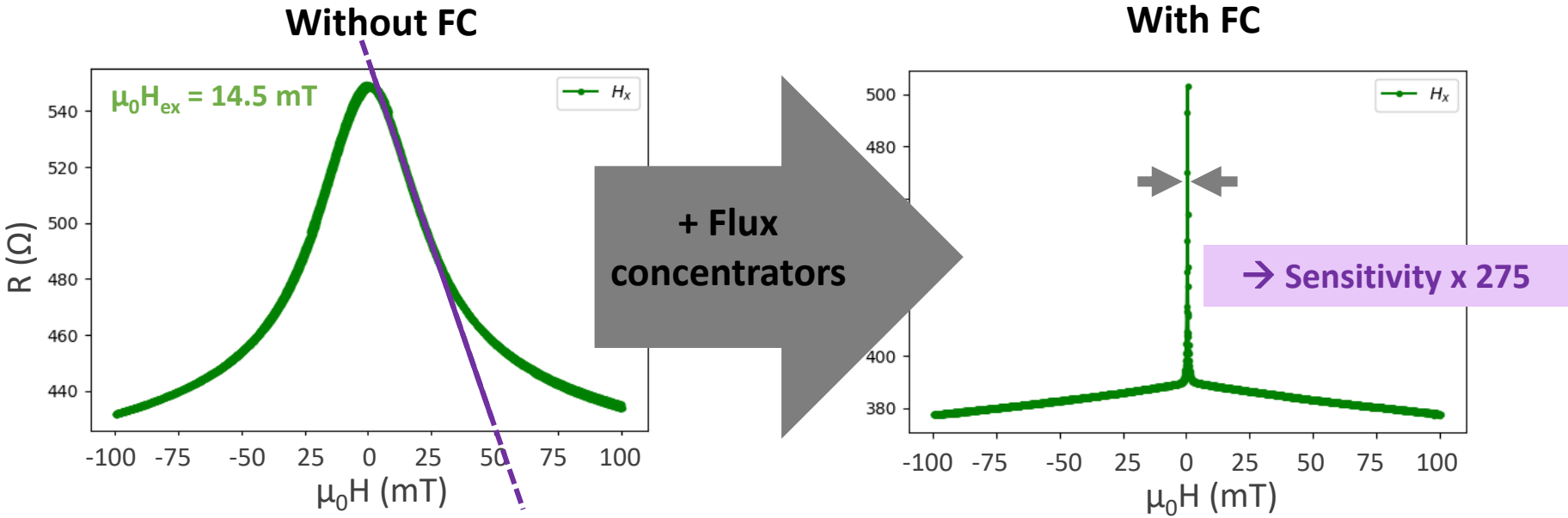
- **Growth by electrodeposition**



Current density -10 mA/cm² → $Ni_{80}Fe_{20}$

High gain flux concentrator

- **Field amplification measured with MTJ**



Usual gain : 10^1

S. Cardoso et al., Microsyst Technol no. 20, 793 (2014)

→ Gain = 275

in linear range of 2 mT

CONCLUSION

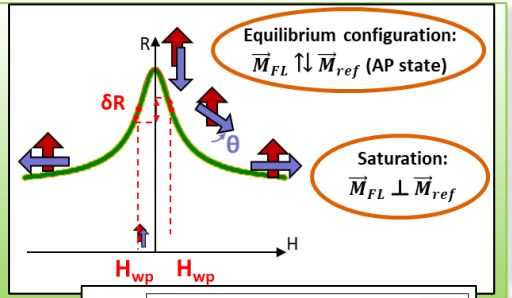
Symmetric Response MTJ

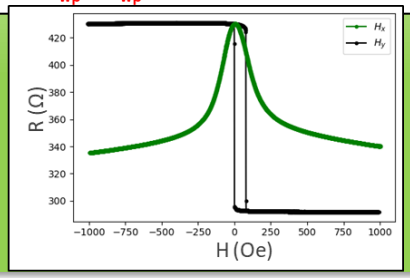
3 stabilizations technics:

- Shape Anisotropy
- additional Transversal Field
- Soft Pinning

Good symmetry

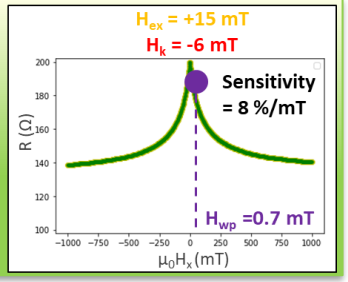
Sensitive response





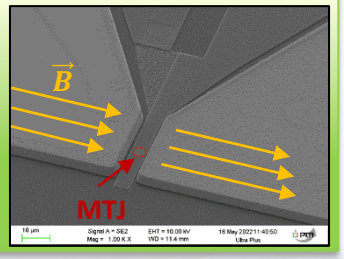
Combination H_{ex}+H_k

Low Working Point



Flux concentrators

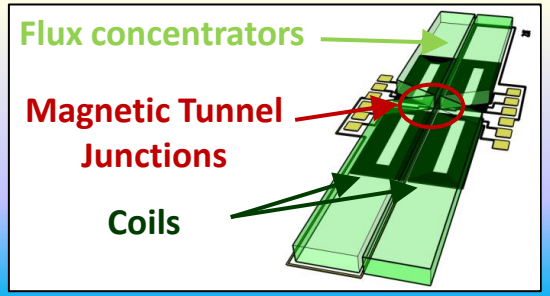
Sensitivity x275



Perspectives:

Addition of modulation

➢ **Sensor for space exploration**



Thank you for your attention !

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