Electron irradiation with SIRIUS Facility

The SIRIUS installation | Laboratoire des Solides Irradiés (polytechnique.edu)

Antonino Alessi

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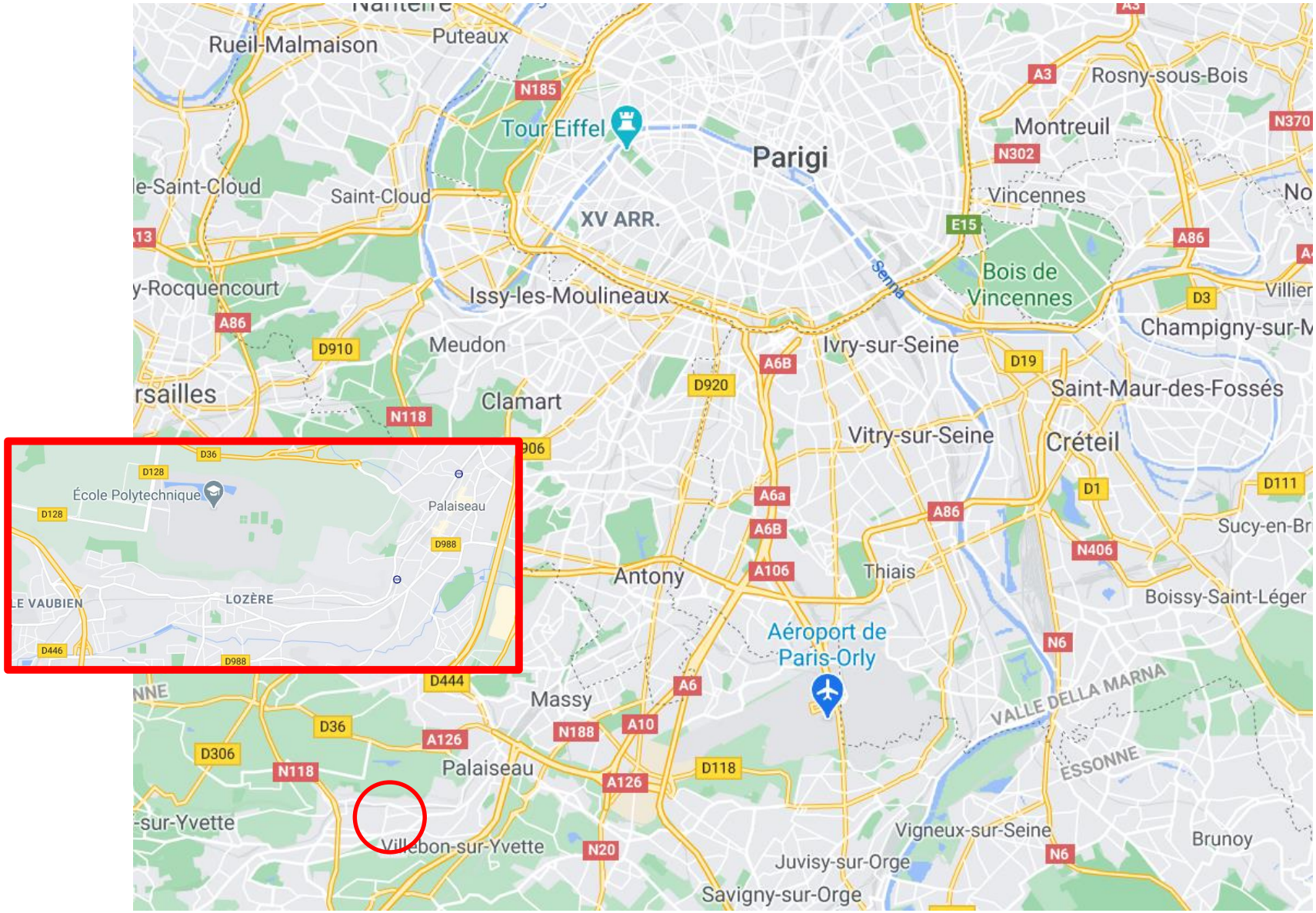
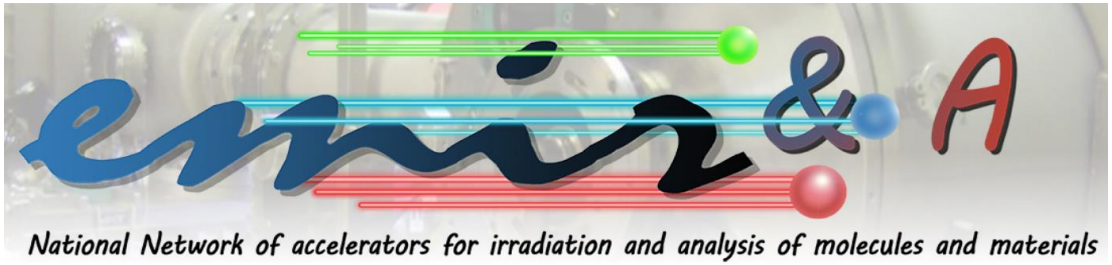
SIRIUS Facility



SIRIUS Facility

[L'installation SIRIUS | Laboratoire des Solides Irradiés (polytechnique.edu)]

Beamline Manager: Antonino Alessi
Technical Manager: Olivier Cavani
Beamline Scientist : Romain Grasset
Support Developments: Audrey Courpron



emir.in2p3.fr

ACCELERATOR

The important particularity of SIRIUS :

- The NEC Pelletron accelerator
- Adjustable energy (150 keV - 2.5 MeV) and current (10 nA - 50 µA).
- The accelerator is equipped with several irradiation set-ups.
- Two beamlines.

Application fields :

Glasses
Polymers
Semiconductors
Ceramics
Metal
Superconductors
Nuclear fuel
Solid state physics
Solar cell
Cements
others

Dose

Interaction with the atom as a whole **Soft collisions b>>a**

Exciting the atom or ionizing it by ejecting a valence electron, the atom receives a small amount of energy

The *most probable* type of interactions; accounts for about half of energy transferred to the medium

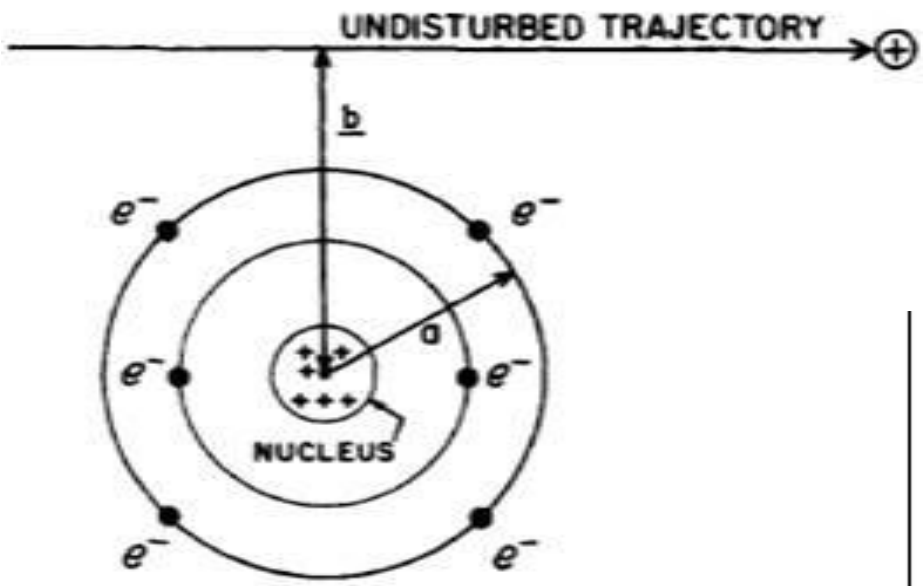
Interaction with a single atomic electron **Hard collisions b~a**

Ejected electron with high kinetic energy

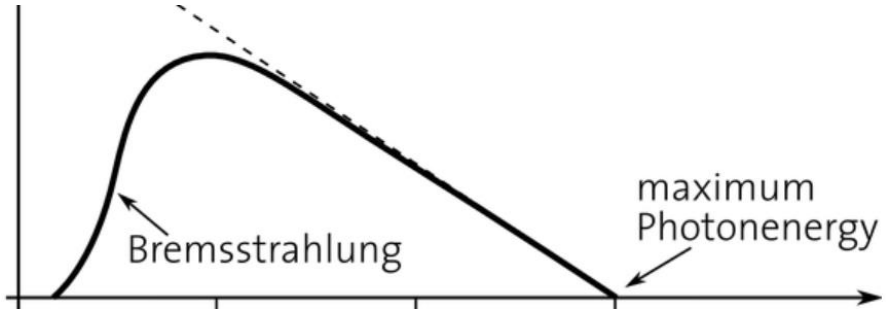
Less probable but the fraction of primary particle´s energy that is spent by this process is comparable to the soft one.

Coulomb interactions with nuclear field a>>b

In 2-3% of cases electron loses almost all of its energy through inelastic radiative (**Bremsstrahlung**) interaction

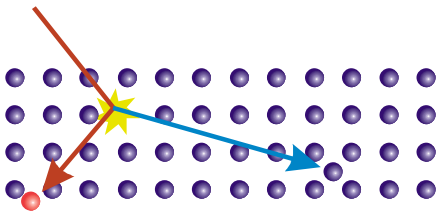


Bremsstrahlung (X, γ)
Generated by sample holder or other materials
Different from the sample



Displacement damage

Displacement damage



Ballistic collision

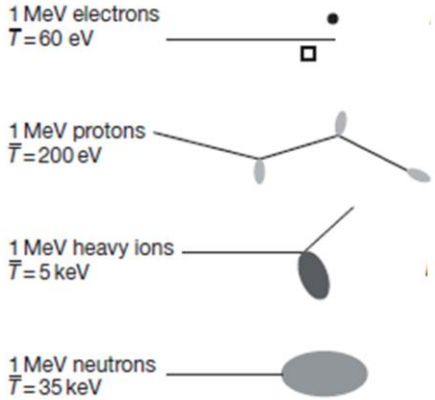


Figure 5 Difference in damage morphology, displacement efficiency, and average recoil energy for 1 MeV particles of different types incident on nickel. Reproduced from Was, G. S.; Allen, T. R. *Mater. Char.* **1994**, *32*, 239.

Isolated defects

Electrons produce low energy PKAs

The defect density in **cluster or cascade subcluster or subcascade** will be much higher than that of 1 MeV electron irradiation.

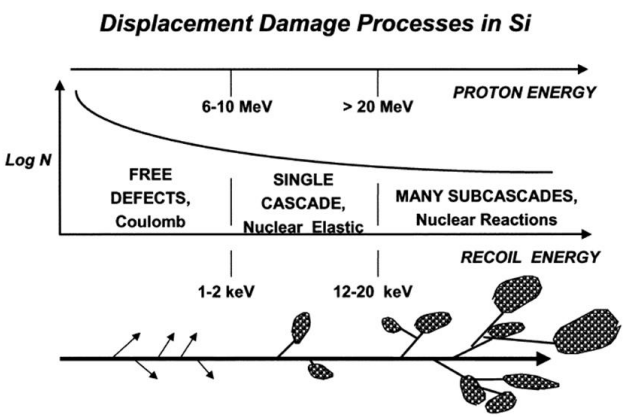


Fig. 5. Pictorial relating the initial defect configuration to the primary knock-on atom energy in Si material. Note from the plot of the number of interactions (N) versus incident proton energy that most interactions are Coulomb events producing isolated defects. For recoil energies above ~2 keV, the overall damage structure is relatively unchanged due to the formation of cascades and subcascades (after [140]).

In subclusters, the defect density is much greater than the impurity concentration, so the nonimpurity-related defects dominate recombination

In the isolated defect case, the radiation-induced defect density and the impurity concentration can be comparable. Importance of impurity-defect

Beam distribution

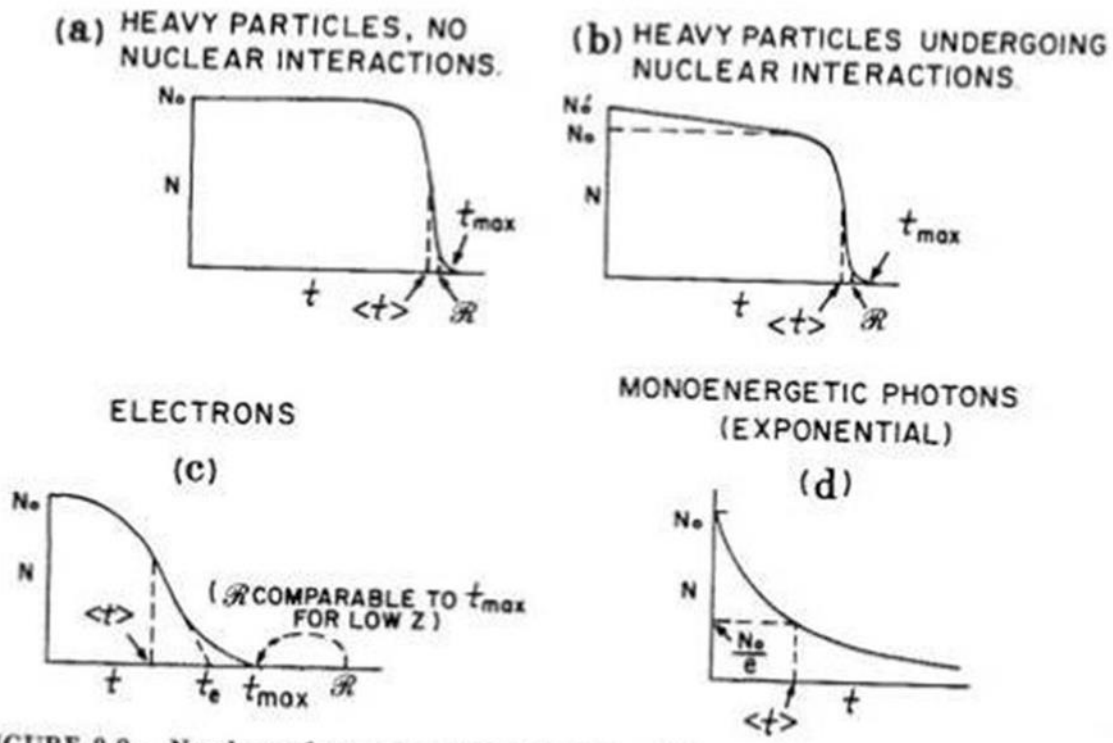
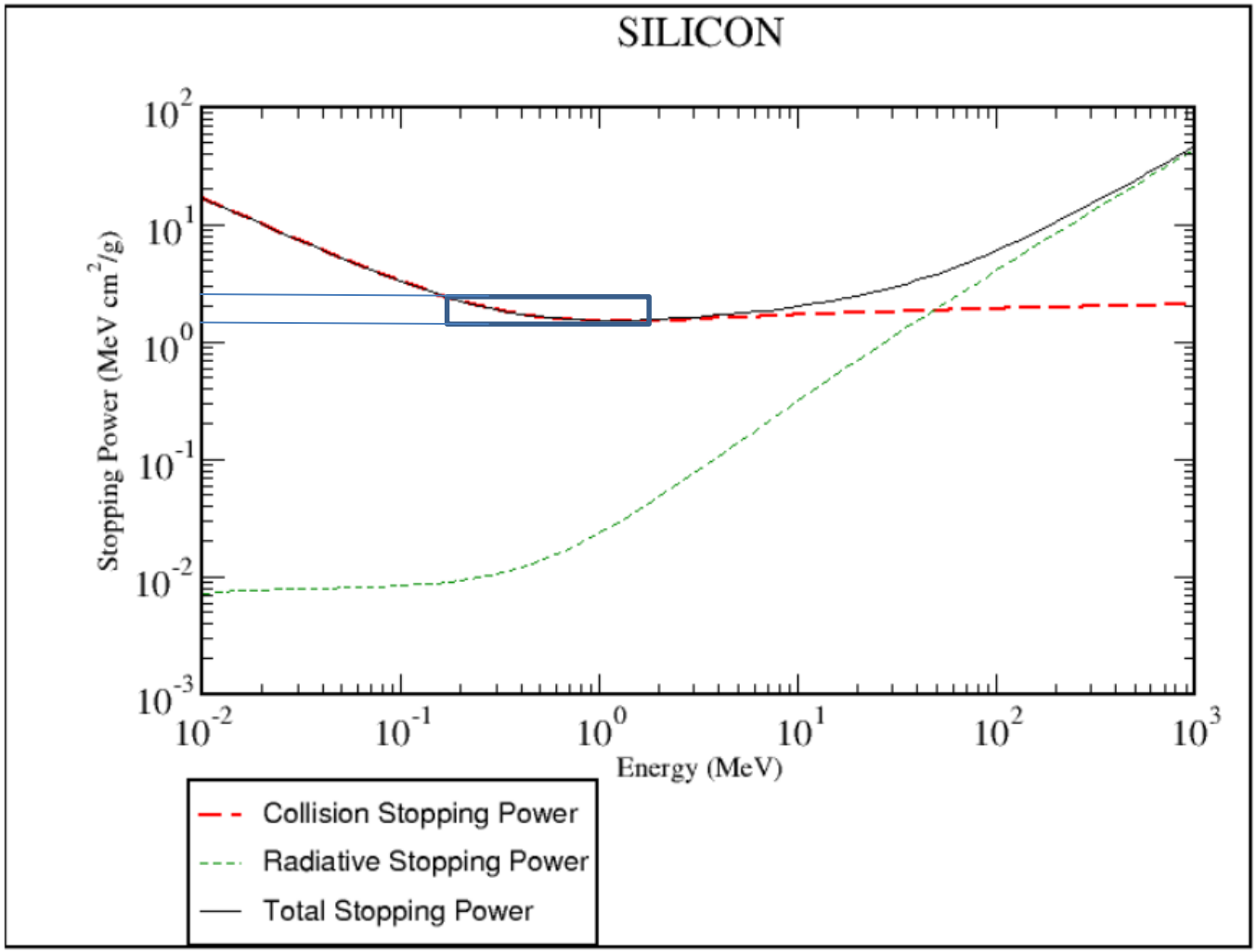


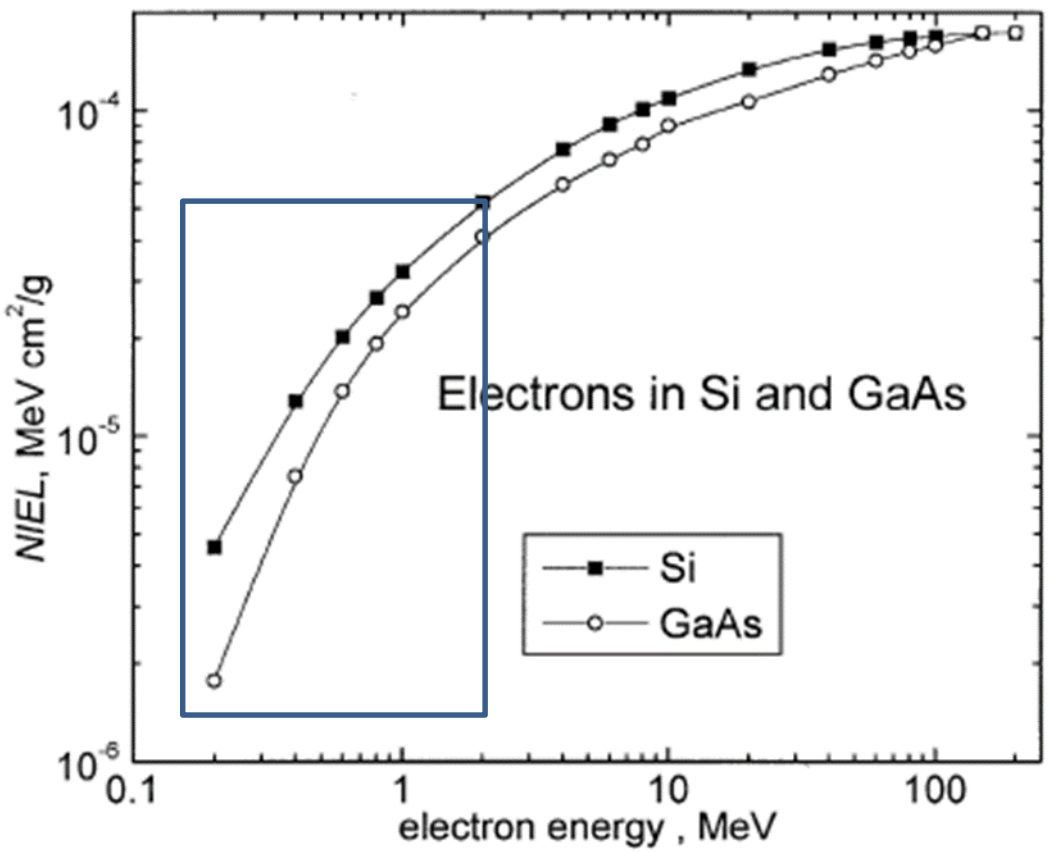
FIGURE 8.9. Numbers of monoenergetic charged particles or photons penetrating through a slab thickness t of absorbing medium. Scattered photons are assumed to be ignored in d. $\langle t \rangle$ is the projected range, t_e is the extrapolated penetration depth, t_{max} is the maximum penetration depth, and R is the range ($\cong R_{CSDA}$).

SIRIUS Facility: Stopping power

ESTAR : Stopping Power and Range Tables for Electrons



SIRIUS Facility: NIEL



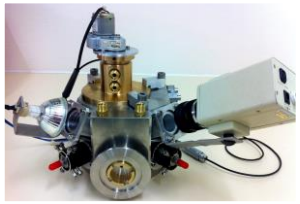
SIRIUS Facility: Cells

CIRANO

IRRAPLAST

GRANDE SURFACE

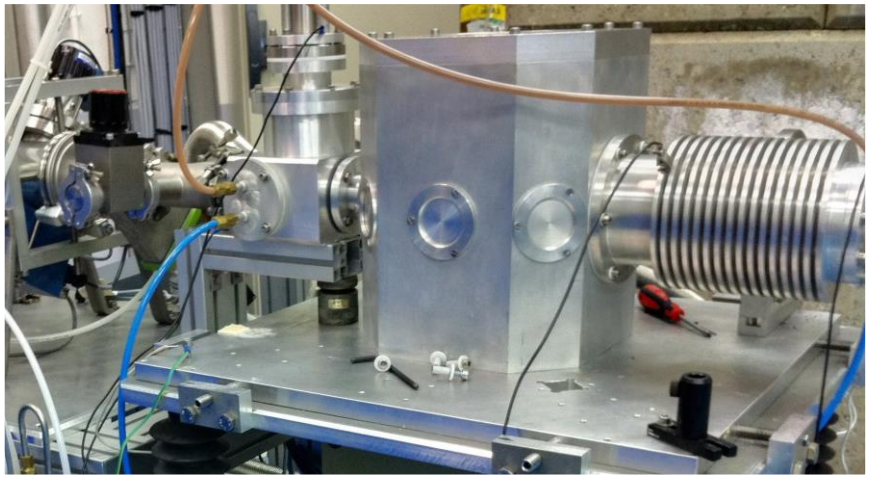
IN SITU SPECTROSCOPY



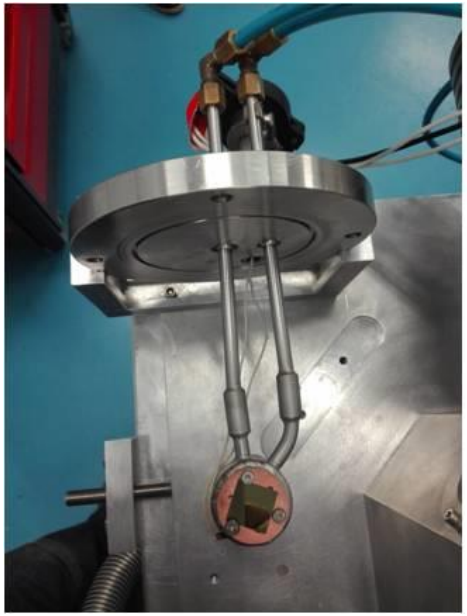
CRYO 1

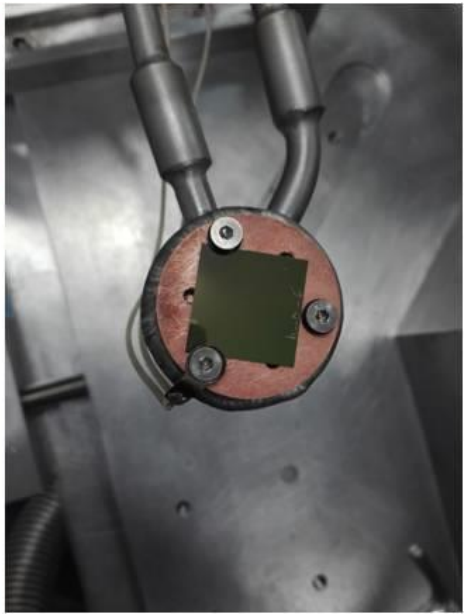
CRYO 2

CIRANO

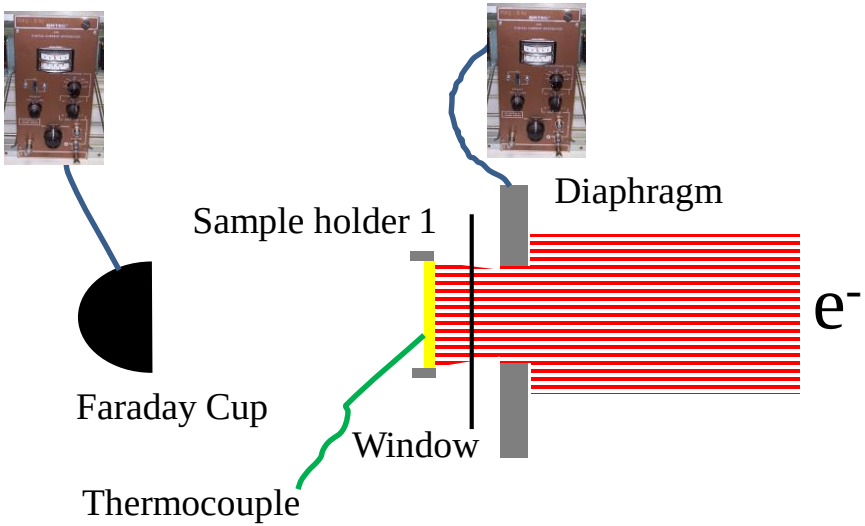


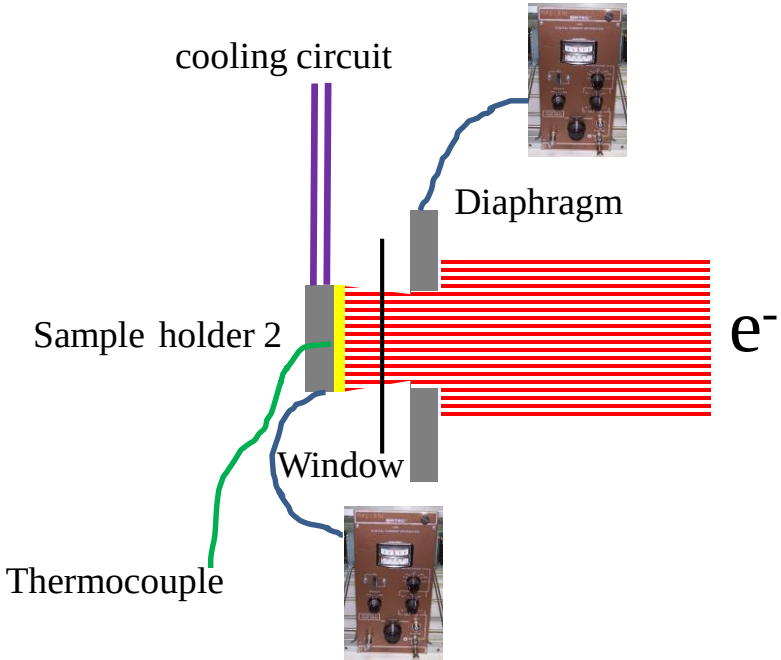
Parameter	Values
Current beam	< 40 µA
Temperature	300 K < T < 600 K
Standard sample	Ø 28 (or 19) mm
Atmosphere	(vacuum, air, hélium, argon)
Optical aperture	for in situ UV-VIS absorption





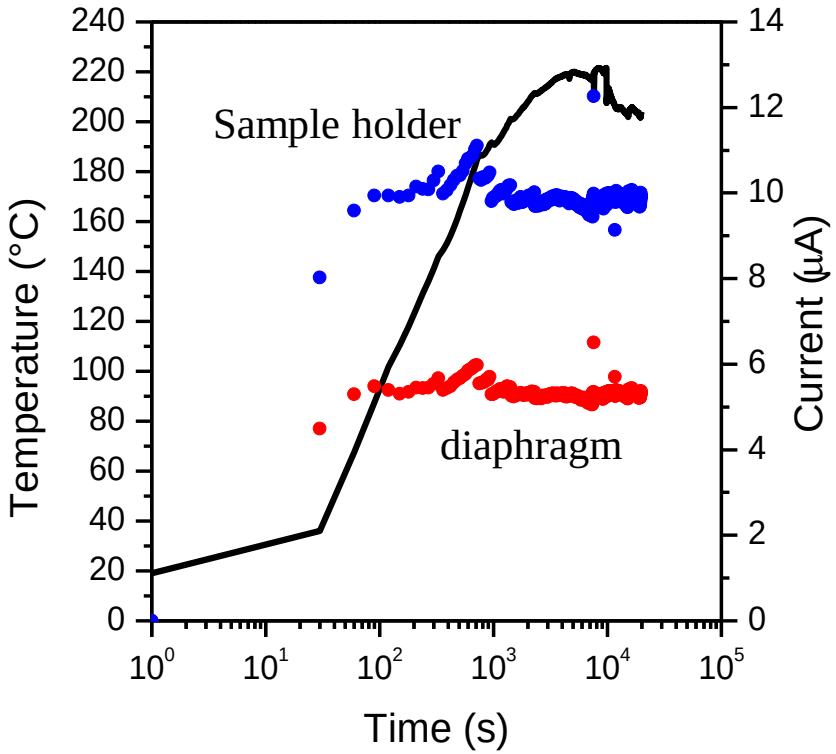
CIRANO

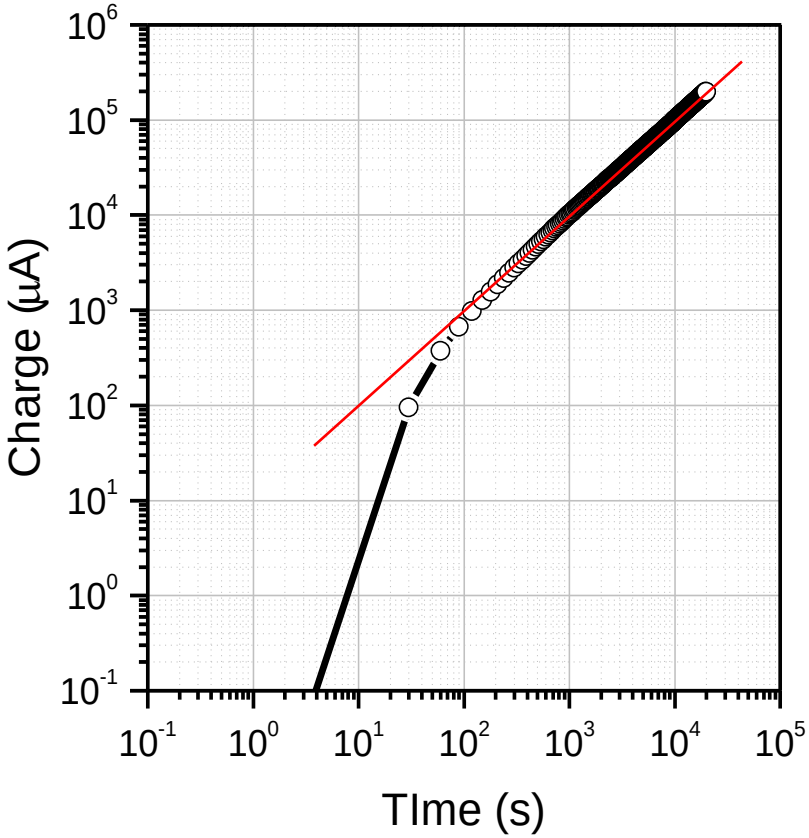

Diaphragm
Sample holder 1
e-
Faraday Cup
Window
Thermocouple


cooling circuit
Diaphragm
Sample holder 2
e-
Window
Thermocouple

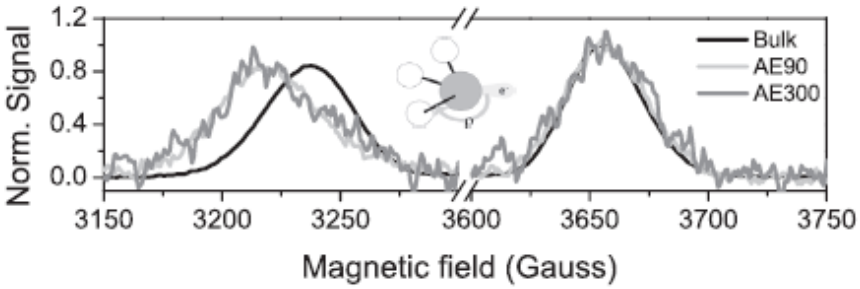
CIRANO

Low He atmosphere to allow the sample to heat up.
66% of the current on the sample and 33% on the diaphragm.
2.5 MeV
Samples not thick enough to stop electrons.





After irradiation



A. Alessi et al. JNCS 423–424 (2015) 41–44

The samples can be irradiated by varying the beam energy to reconstruct the NIEL curve.

Study the generation processes of the various defects.

Study the processes of precipitation or aggregation of different elements in different materials.

B. Radiguet et al, Nuclear Instruments and Methods in Physics Research B 267 (2009) 1496–1499

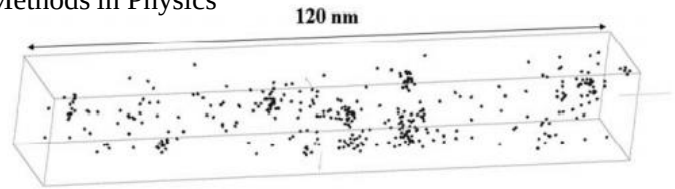
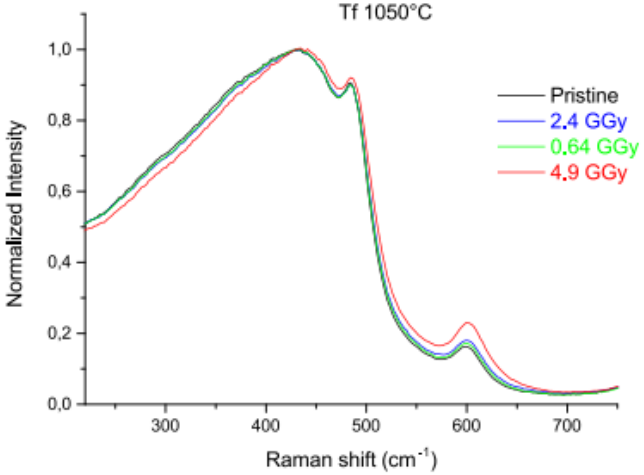


Fig. 1. 3D distribution of phosphorous atoms in FeCuMnNiP model alloy, irradiated with electrons at 300 °C up to 10^{-3} dpa. A high number density of P clusters is visible.

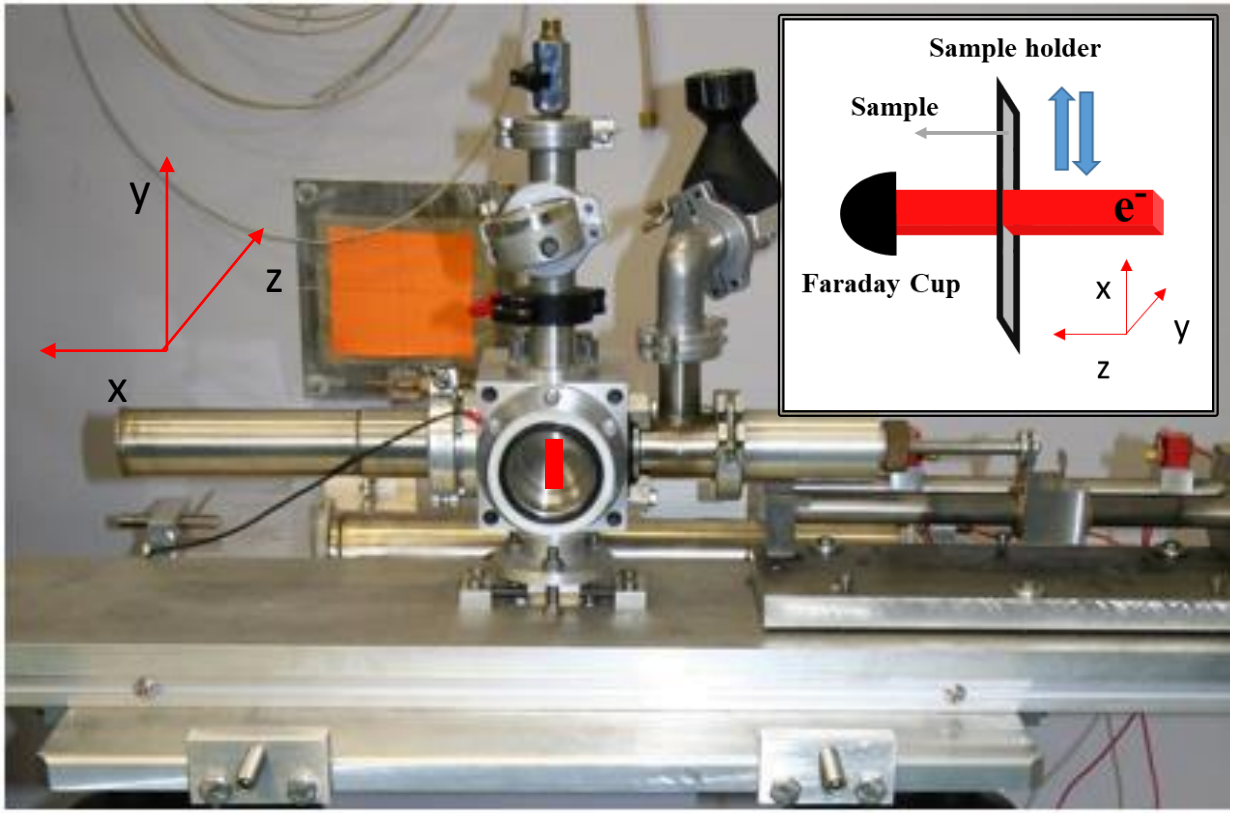


N. Ollier et al. Scientific Reports 9, 1227, 2019

Compare theoretical to experimental threshold energies.

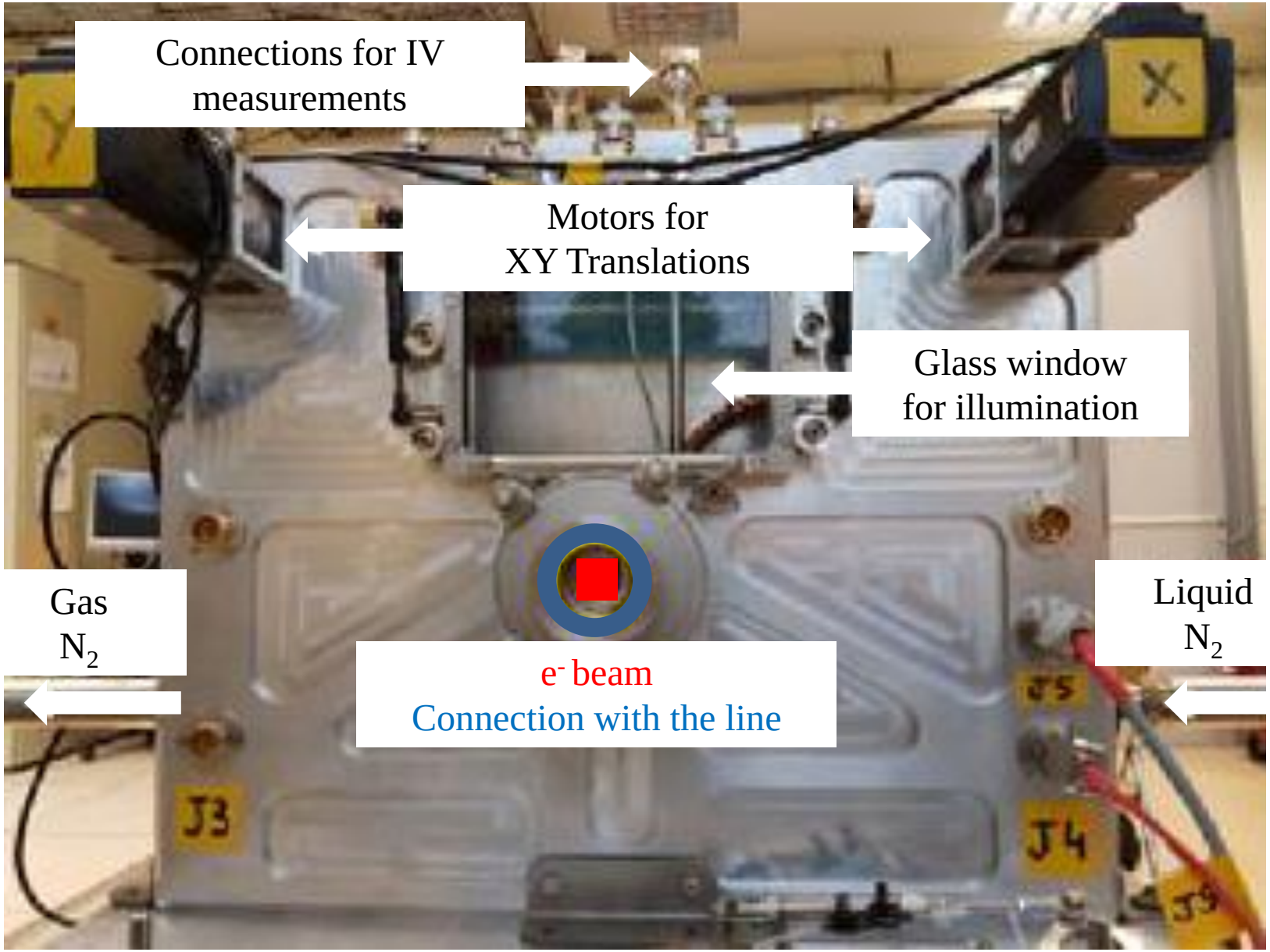
Use irradiation to improve the properties of a material. Studies as a function of flux, fluence, beam energy, temperature.

IRRAPLAST



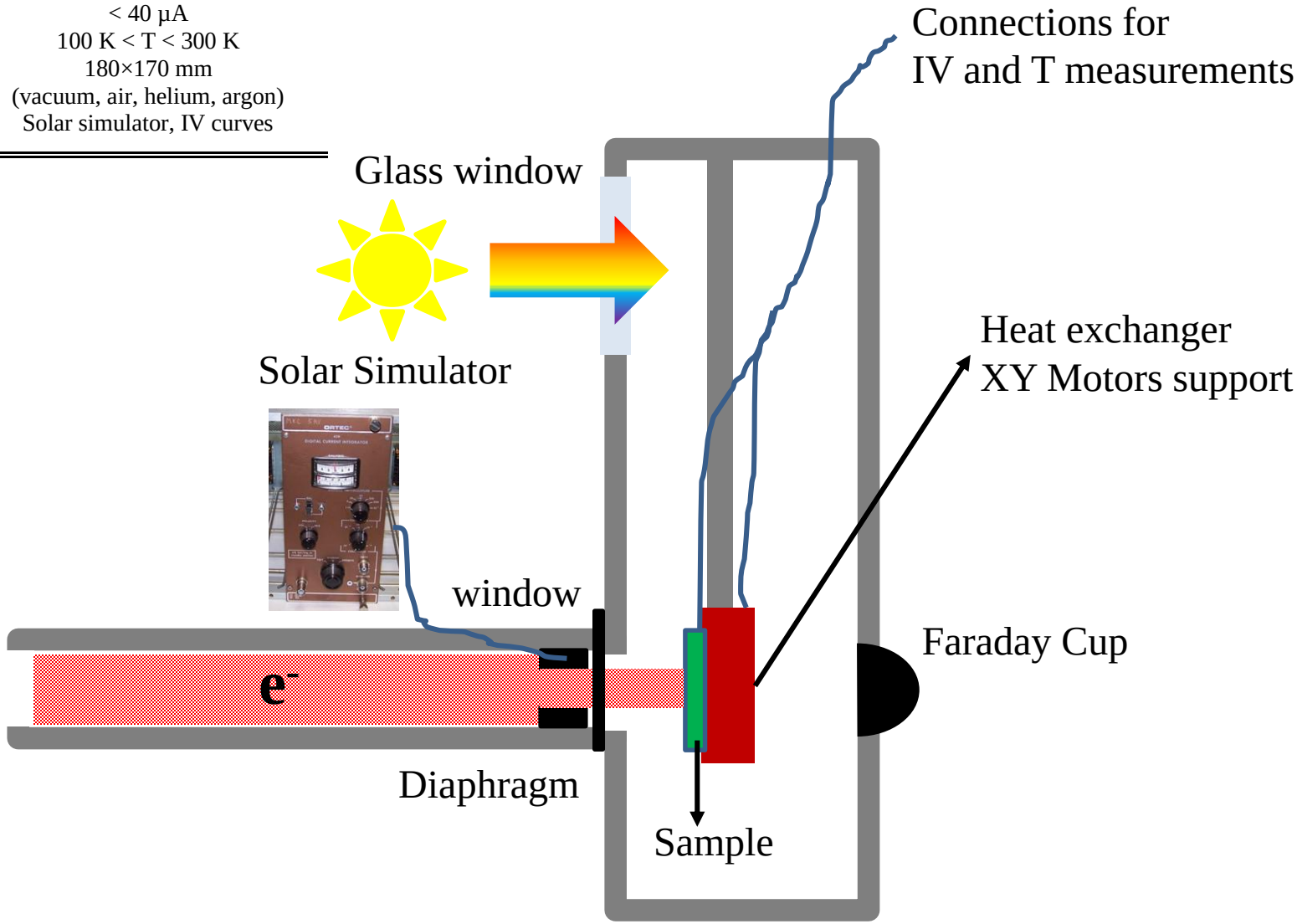
Parameter	Values
Current beam	< few µA
Temperature	300 K
Standard sample	20×120 mm
Atmosphere	(vacuum, air, hélium, argon)

GRANDE SURFACE

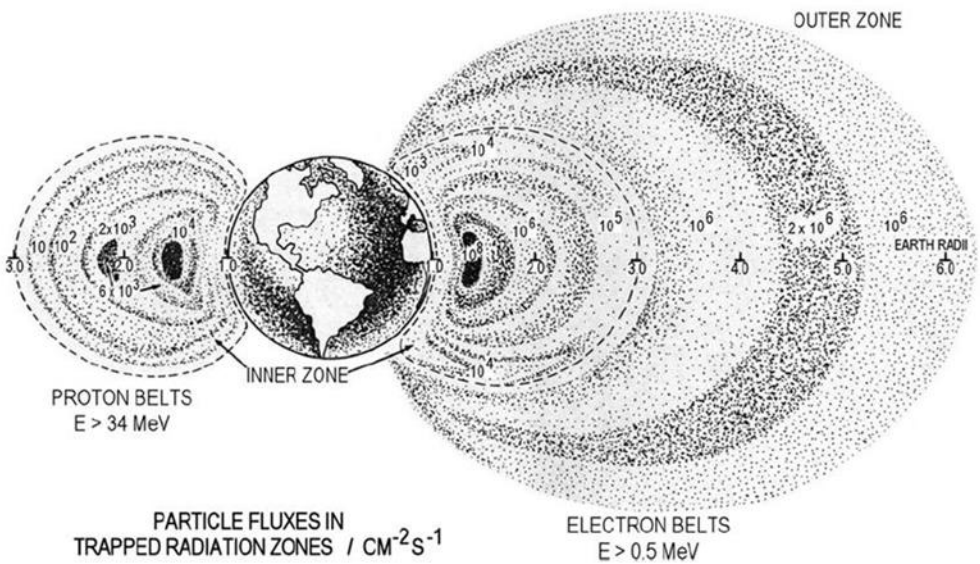


GRANDE SURFACE

Parameter	Values
Current beam	< 40 µA
Temperature	100 K < T < 300 K
Standard sample	180×170 mm
Atmosphere	(vacuum, air, helium, argon)
Optical window	Solar simulator, IV curves

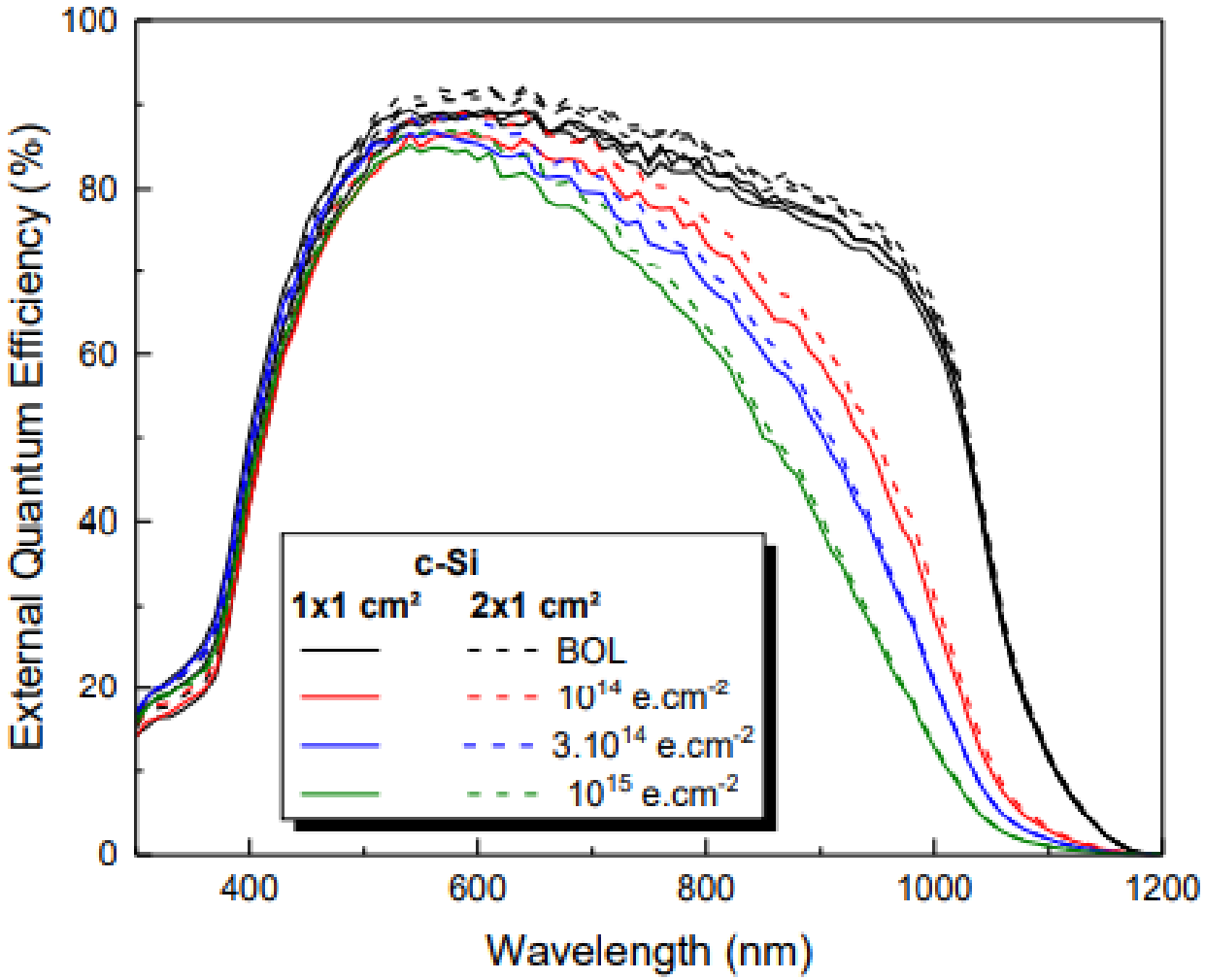


GRANDE SURFACE



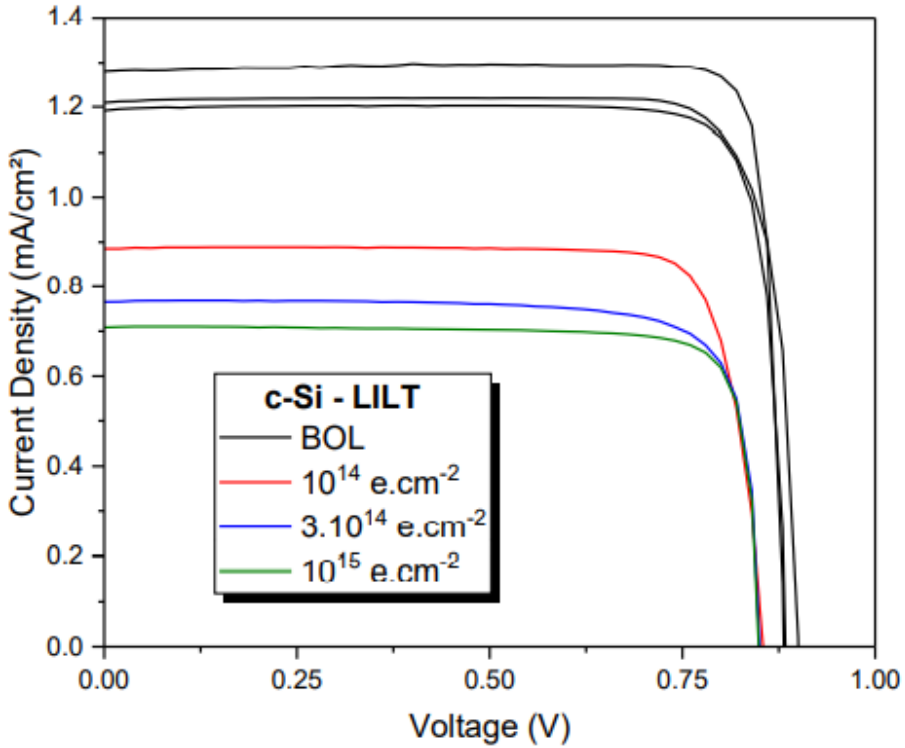
Different irradiation and lighting conditions depending on the mission. the mission to Jupiter provides for 3.5% illumination that to Mars 10%.

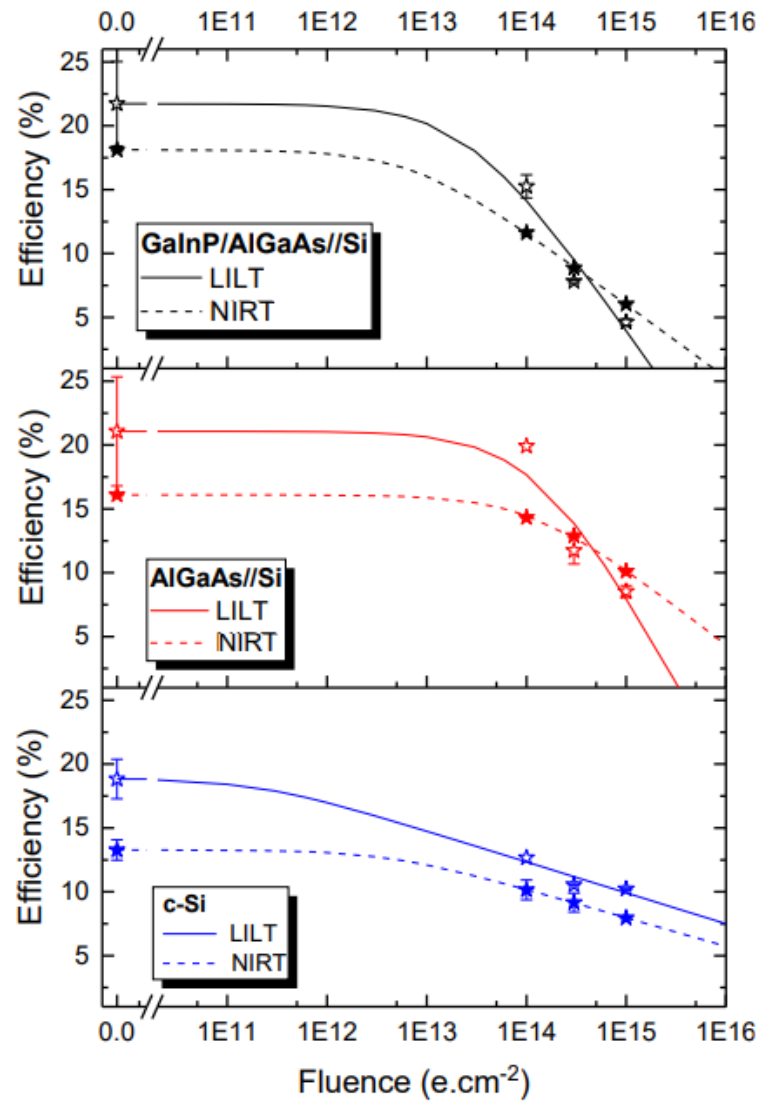
GRANDE SURFACE



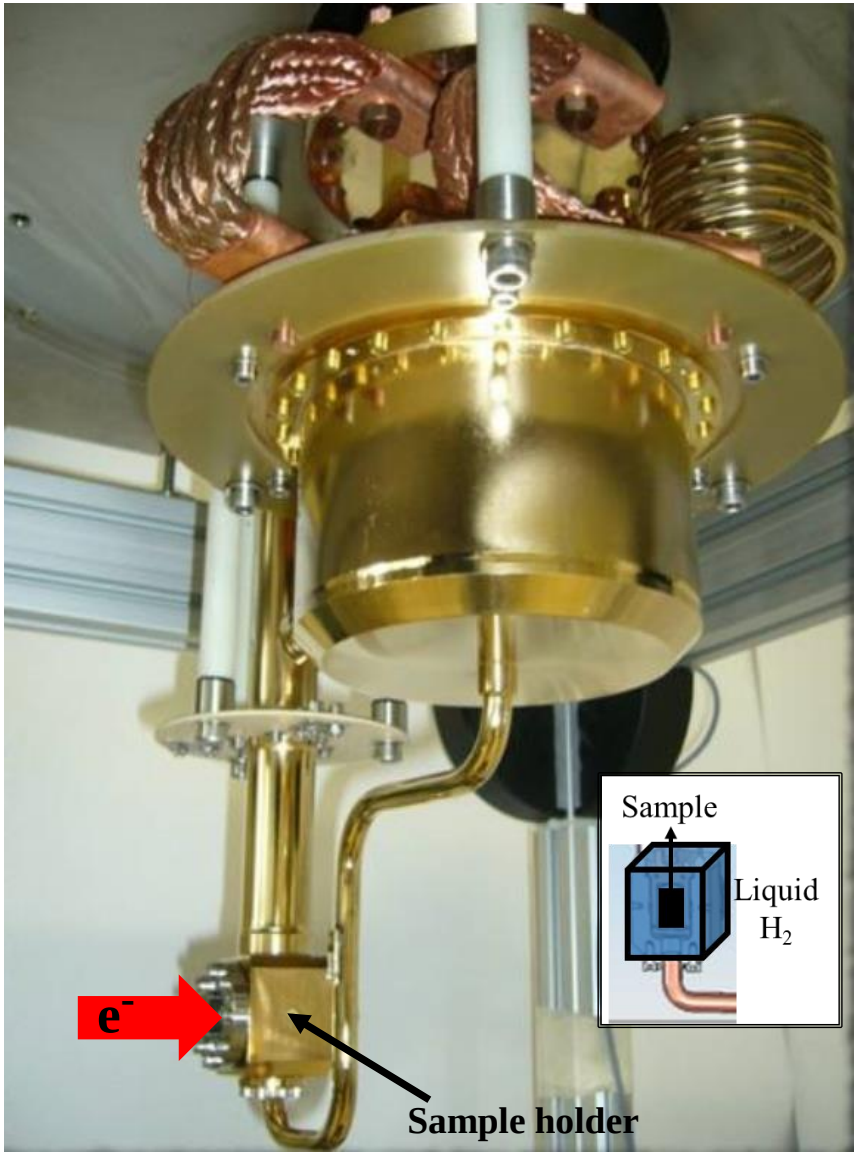
GRANDE SURFACE

Dark IV curve can depend on irradiation

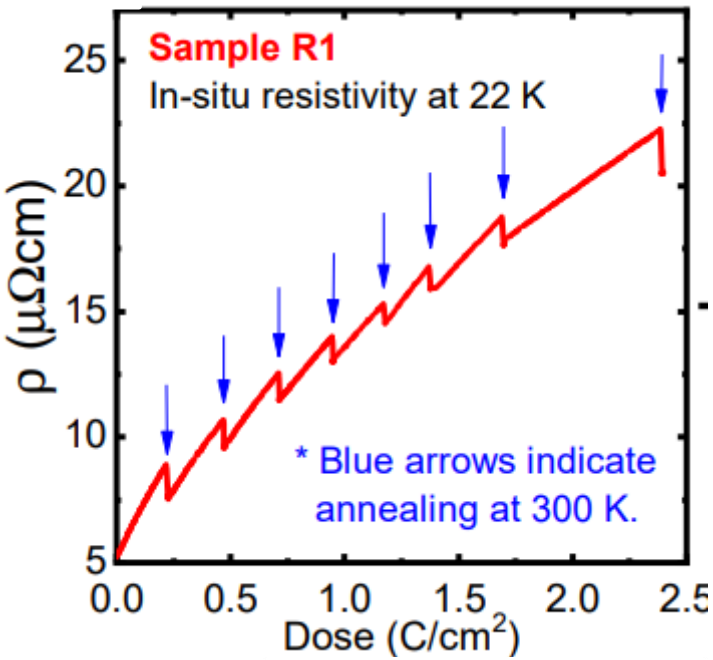




CRYO 1



Parameter	Values
Current beam	< 5 µA (optional up to10 µA)
Temperature	22 K
Standard sample	5 mm
Atmosphere	Sample immersed in liquid H_2
Electrical	Resistivity



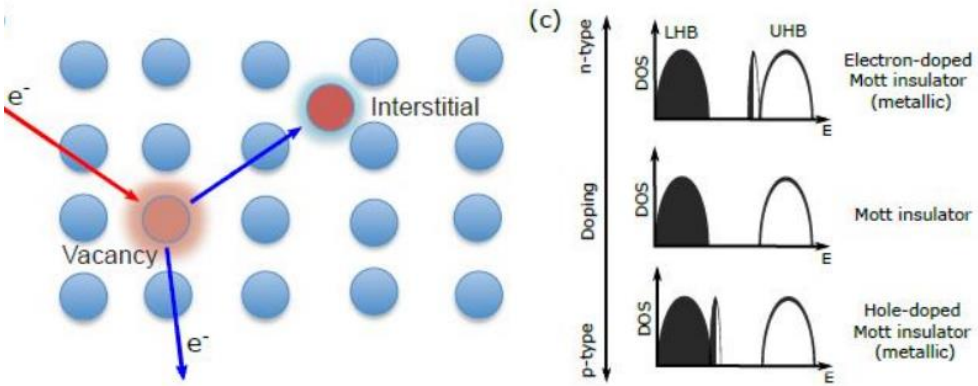
K. Cho et. Using controlled disorder to probe the interplay between charge order and superconductivity in NbSe2 Nature Communications 9, 2796, 2018.

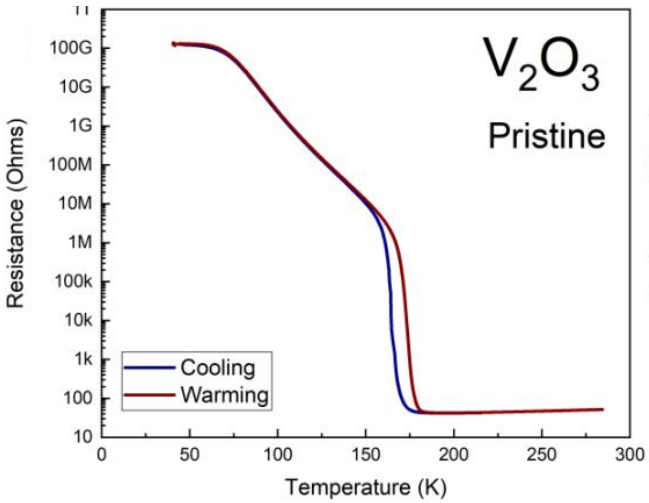
CRYO 1

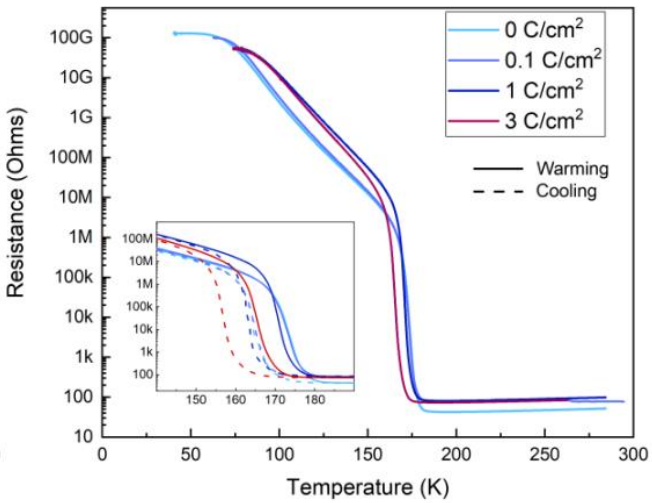
The Mott transition is a quantum phase in which electron-electron (e-e) interactions in a solid lead to an insulating phase whereas band theory predicts a metallic phase. In Mott insulators external excitation (thermal, electrical, optical, mechanical, etc...) can switch the system back to a metallic phase.

changing the fluence
tune the amount of doping

beam energy
nature of the doping (p or n-type)







SIRIUS Facility

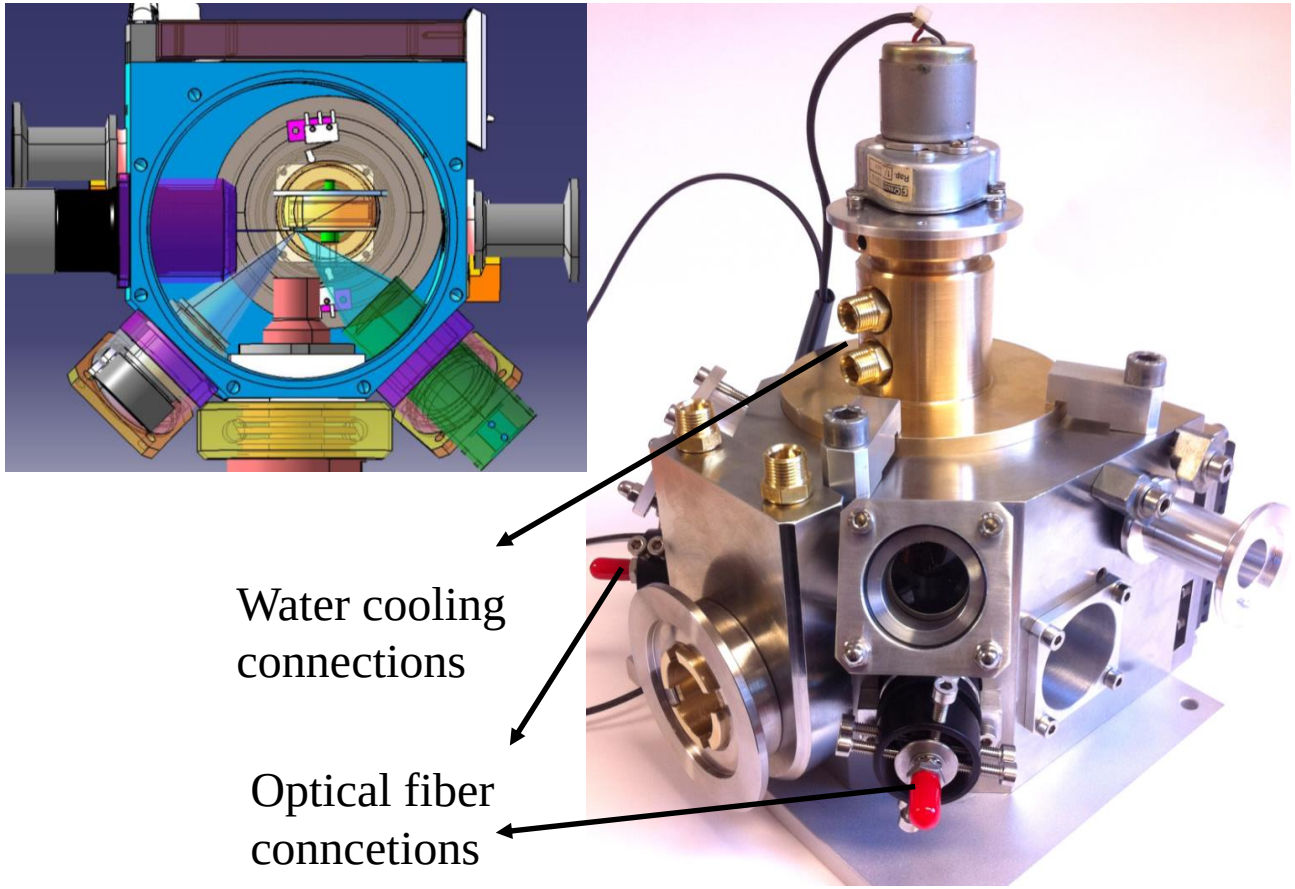
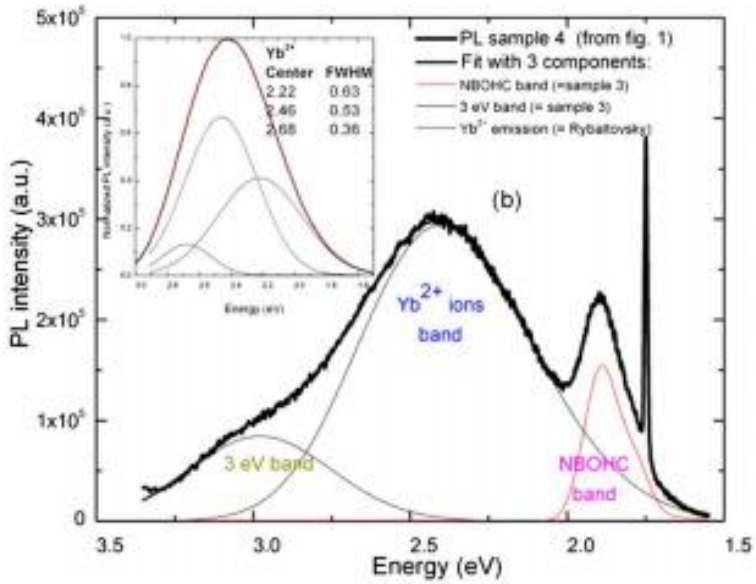


Photo- and Chato-luminescence

IN SITU SPECTROSCOPY



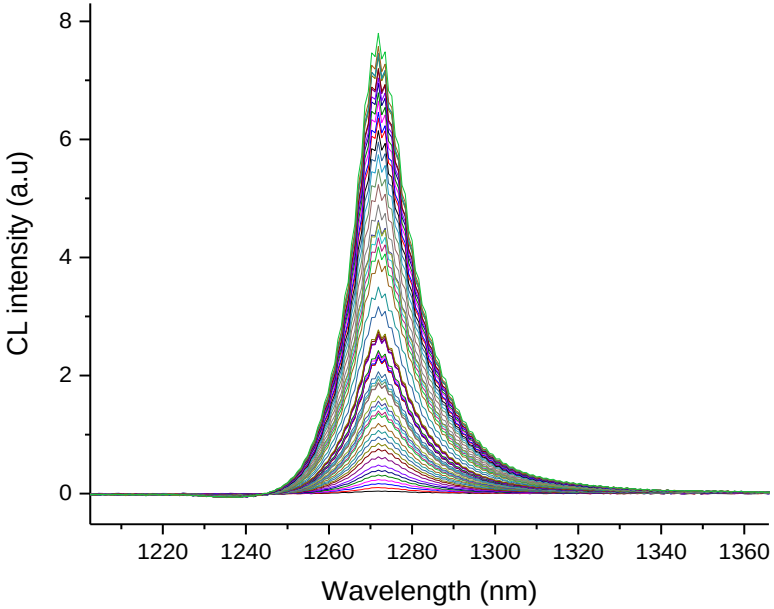
N.Ollier, Opt. Let. 2016, 41, 2025

T = 300 K
Water-cooled sample holder
Photoluminescence
Time-resolved photoluminecence
Cathodoluminescence

Standard sample : Ø ~10 mm

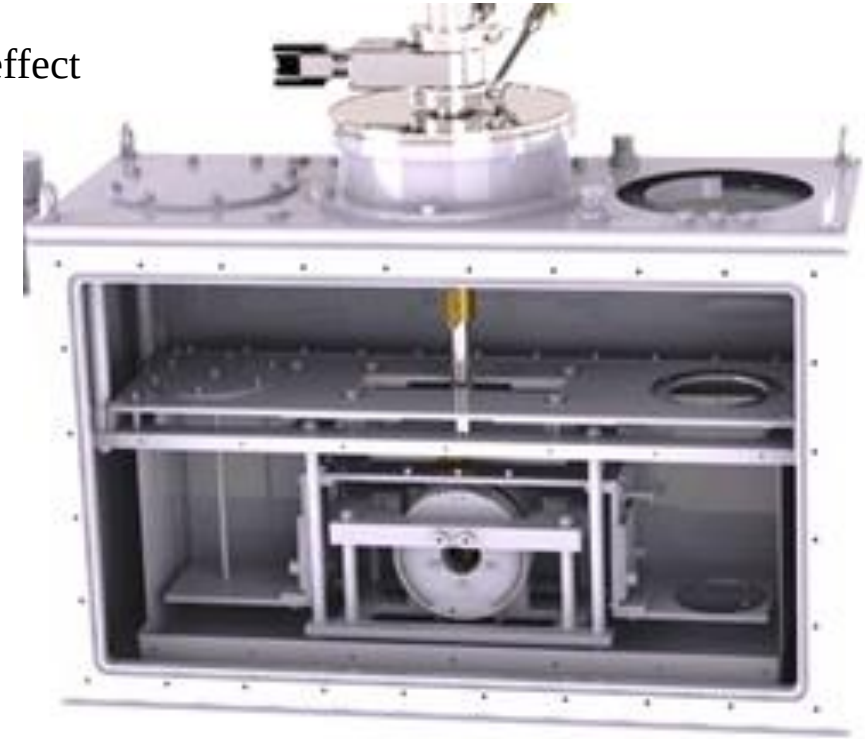
ICCD and InGaAs camera: 250 nm -1.7 µm

Data provided by N. Ollier

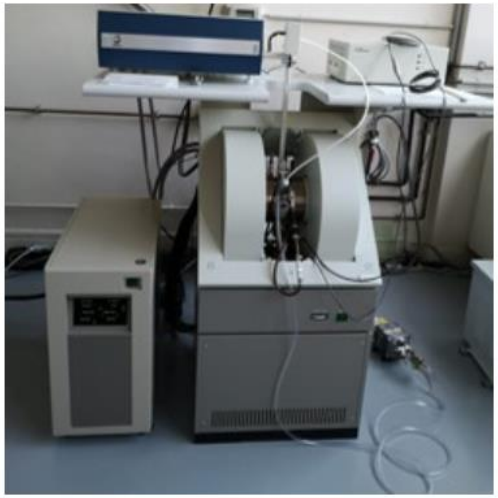


CRYO 2

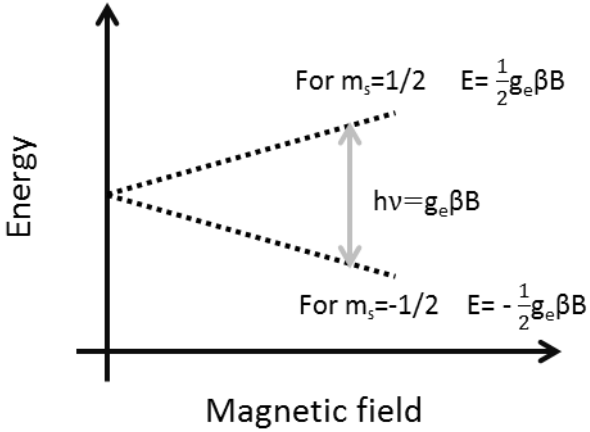
< 5 µA
4 K < T < 300 K
Vacuum
sample : Ø 5 mm
Possible in situ resistivity and Hall effect
On-line EPR under development



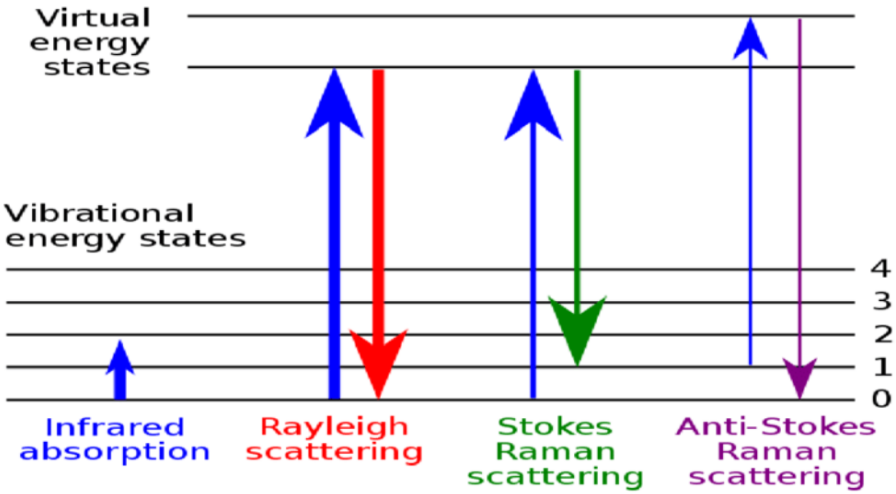
Other SPECTROSCOPY

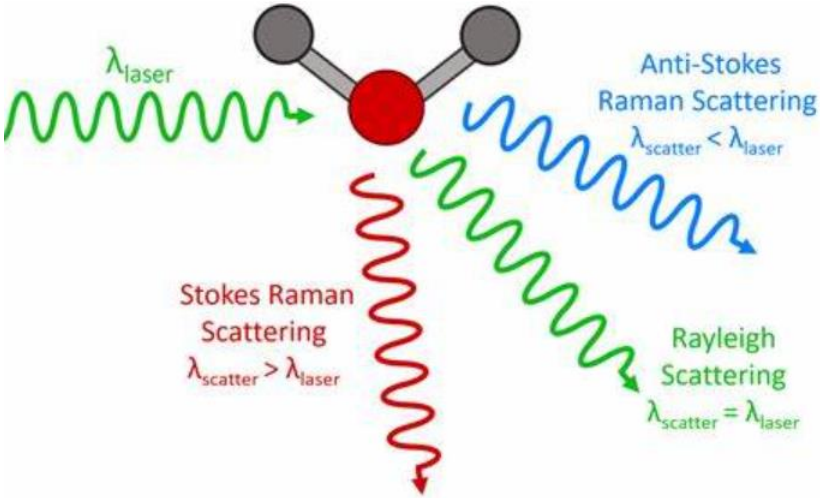


EPR spectrometer: JEOL JES-X310
Microwave frequency: 8.75-9.65 GHz (X-Band)
Microwave power : 100nW - 200mW
Maximum Magnetic field : 650 mT
Modulation frequency : 25 KHz, 50 KHz and 100 KHz
Measurement Temperature : From ~110 to ~ 450 K



Renishaw 488 nm Raman instrument coupled with an Andor sr-303i spectrometer and an Andor DU420-OE CCD camera to investigate structural modifications.





THANKS

MERCI

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