
# Joint Meeting between CNRS GdR MEETICC and Physique Quantique Mésoscopique

**Organizers :** D. Carpentier, P. Delplace, P. Foury, M. Goerbig, E. Janod, B. Plaçais

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**Support :** CNRS GdR MEETICC and Physique Quantique Mésoscopique, Laboratoire Pierre Aigrain, Laboratoire de Physique (ENS de Lyon), ENS de Lyon

# PROGRAM

## Lundi 03/10

09:30 - 10:00 : Accueil Café

09:55 - 10:00 : welcoming address

## Isolants topologiques

10:00 - 11:00 : Jérôme Cayssol (LOMA, Bordeaux)
*Short introduction to topological insulators*

11:00 - 11:30 : Erwan Bocquillon (LPS, Paris)
*Gapless Andreev bound states in a topological junction on the Quantum Spin Hall insulator HgTe*

11:30 - 12:00 : Candice Thomas (Inst. Néel, Grenoble)
*Revealing Dirac fermions in strained HgTe topological insulators via Quantum Hall spectroscopy*

12:00 - 12:30 : Andreas Inhofer (LPA, Paris)
*Critical Field for Screening by the Topological Surface States of Strained HgTe*

12:30 - 13:00 : Marcin Konczykowski (Laboratoire des Solides Irradiés, Palaiseau)
*Irradiation induced doping of topological insulators, route to surface controlled electronic transport*

13:00 - 14:30 : Déjeuner CROUS

14:30 - 15:00 : Hélène Bouchiat (LPS, Orsay)
*Ballistic edge states in Bismuth nanowires revealed by SQUID interferometry*

15:00 - 15:30 : Marino Marsi (LPS, Orsay)
*Ultrafast study of out-of-equilibrium Dirac fermions in topological insulators*

15:30 - 16:00 : Pause Café

## Semi-métaux Topologiques

16:00 - 17:00 : Jens Bardarson (MPI, Dresden)
*Weyl semimetals — from chiral anomaly to fractional chiral metal*

17:00 - 17:30 : Milan Orlita (LNCMI, Grenoble)
*Magneto-optical signature of massless Kane electrons in Cd3As2*

17:30 - 18:00 : Sergueï Tchoumakov (LPS, Orsay)
*Unveiling relativistic properties of Weyl quasiparticles*

19:30 : Dîner sur Péniche

## Mardi 04/10

### Topologie, interactions, supraconductivité et magnétisme

09:00 - 09:30 : Tristan Cren (INSP, Paris)
*Two-dimensional topological superconductivity in Pb/Co/Si(111)*

09:30 - 10:00 : Julia Meyer (INAC, Grenoble)
*Multi-terminal Josephson junctions as topological matter*

10:00 - 10:30 : Pause Café

10:30 - 11:00 : Pierre Pujol (IRSAMC, Toulouse)
*Topological states in quantum antiferromagnets*

11:00 - 11:30 : Cécile Repellin (MPI, Dresde)
*Topological order in materials with strong spin-orbit coupling*

11:30 - 13:30 : Déjeuner CROUS

### Matériaux Topologiques

13:30 - 14:30 : Claudia Felser (MPI, Dresden)
*Topology – from the materials perspective*

14:30 - 15:00 : Philippe Ballet (LETI, Grenoble)
*MBE-growth of HgTe/CdTe topological insulator structures*

15:00 - 15:30 : Benjamin Sacépé (Inst. Néel, Grenoble)
*Signature of topological superconductivity at the surface of* $Bi_2Se_3$

15:30 - 16:00 : Sergey Krishtopenko (L2C, Montpellier)
*Phase transitions in two tunnel-coupled HgTe quantum wells: Bilayer graphene analogy and beyond*

# LIST OF ABSTRACTS

## Isolants topologiques

### Short introduction to topological insulators

J. Cayssol

Université de Bordeaux

In this introductive talk, i will first talk about the basic concepts of topological insulators using graphene as a guideline. Topological insulators are band insulators with robust gapless edge or surface states. Following the historical way, the Haldane model and the Kane-Mele model will be presented with an emphasis on their topologically protected edge states. 3D generalizations of the Kane-Mele insulator will also be discussed.

In the second part, i will turn to real materials, both 2D and 3D, where topologically protected metallic edge and surface states have been predicted and successfully observed. Due to the large spin-orbit coupling and a particular band inversion, these edge/surface states have unique spin-momentum locking properties.

Finally, if time allows, i will discuss the connexion between the bulk topological invariants and the edge/surface states.

**Gapless Andreev bound states in a topological junction on the Quantum Spin Hall insulator HgTe**

E. Bocquillon[1], R.S. Deacon[2,3], J. Wiedenmann[1], T.M. Klapwijk[4], P. Leubner[1], C. Brüne[1], S. Tarucha[3,5], K. Ishibashi[2,3], H. Buhmann[1], and L.W. Molenkamp[1]

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Two dimensional topological insulators coupled to superconducting and ferromagnetic electrodes are a candidate system for the realization of Majorana fermions. Majorana physics has recently attracted considerable attention in both theoretical and experimental studies due to the prospects for new physics stemming from non-Abelian exchange statistics and the associated applications to topological quantum computation. However, experimental studies unveiling the interplay between superconductivity and topological electronic transport remain scarce.
Here we report the observations of signatures of topological superconductivity induced in a HgTe quantum well, a system that exhibits the quantum spin Hall effect. Namely, we observe the fractional Josephson effect, in two different manners. When an rf excitation is applied, a doubling of the Shapiro steps is observed [1]. Besides, a clear emission line can be detected at half the Josephson frequency under dc voltage bias conditions [2]. Both features appear more clearly when the sample is gated towards the quantum spin Hall regime, in a regime where the current flows mostly along the edges of the device. These signatures thus strongly point towards induced topological superconductivity in the quantum spin Hall edge states.

*[1] E. Bocquillon et al., Nature Nanotechnology 10.1038/nnano.2016.159*
*[2] R.S. Deacon et al., arXiv 1603.09611*
*Revealing Dirac fermions in strained HgTe topological insulators via Quantum Hall spectroscopy.*

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**Revealing Dirac fermions in strained HgTe topological insulators via Quantum Hall spectroscopy**

Candice Thomas
Institut Néel, Grenoble

Quantum Hall regime with well-defined Hall resistance plateaus and vanishing longitudinal resistances is evidenced in our thin HgTe topological insulator structures. Temperature dependent analysis of the Quantum Hall effect enables direct demonstration of Dirac fermions in these structures. We also demonstrate that the coupling between the top and bottom topological surface states leads to a degeneracy lifting of the Landau levels through a mechanism specific to these Dirac surface states. Our study demonstrates the relevance of such thin topological insulators in the design of quantum circuits based on novel Dirac states.

**Critical Field for Screening by the Topological Surface States of Strained HgTe**

A. Inhofer[1], B.A. Assaf[2], G. Fève[1], J.M. Berroir[1], and B. Plaçais[1], S. Tchoumakov[3], M. Goerbig[3], D. Carpentier[4], K. Bendias[5], D. Mahler[5], E. Bocquillon[1,5], R. Schlereth[5], C. Brüne[5], H. Buhmann[5], L.W. Molenkamp[5]

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From an electronic transport perspective, strained mercury telluride (HgTe) is one of the most promising platforms for fundamental research of topological insulators (TIs). In HgTe, low bulk doping allows for a gate-tuneable surface state density over a large range of chemical potential. Surprisingly, almost pure surface state electronic response has been reported over an energy range extending well beyond the bulk band gap, a phenomenon called “Dirac screening”. We investigate the equilibrium and transport (electric) field-effect response of topological surface states in strained HgTe using a radiofrequency metal-oxide-TI (MOTI)-capacitor. By virtue of the gate electrode, we are able to control the surface chemical potential over a bipolar energy range (±400meV) and at the same time the electric field over a broad range (±0.6V/nm). Measurements at higher frequencies (up to the GHz range) allow us to probe the conductivity and the surface compressibility of the sample. We will present a comparative study of these electronic properties between uncapped samples, exhibiting lithography-induced doping, and capped almost dopant-free samples. We present several experimental results supporting a) Dirac screening, b) a change of the TSS’ Fermi velocity at high E-fields, c) the population of massive (i.e. non-topological) surface states (MSS) at high electric fields, d) inter-band-scattering between these MSS and the TSS. All these effects can be described semi-quantitatively by a simple model based on the existence of excited MSS, which will also be presented.

**Irradiation induced doping of topological insulators, route to surface controlled electronic transport.**

M. Konczykowski
Laboratoire des Solides Irradiés, CNRS & CEA, Ecole Polytechnique, 91128 Palaiseau, France

Native defects retained in the crystal during the growth process of topological insulators (TI) provide free carrier and large bulk conductivity masking surface related electronic transport. Attempts to reduce the contribution of bulk carriers, involving nanostructured synthesis/growth, chemical doping or compositional tuning, did not give satisfactory results. We introduced alternative method using irradiation with energetic particles to drive topological insulator to charge neutrality point (CNP) in the bulk [1]. We apply this method to two classes of TI's: time reversal symmetry protected (Bi2Te3 and Bi2Se3) and crystal symmetry protected Pb1-xSnxSe. We focused on the low temperature (20K), 2.5 MeV electron irradiation producing mainly vacancies on Bi or Pb sites acting as donors in Bi2Te3 and Bi2Se3 and as acceptors in Pb1-xSnxSe. Thus, starting from p-type in the first case or with n-type in the second we can drive system to metal insulator transition followed by conductivity type inversion. To obtain stable condition close to CNP we proceed in two steps, irradiation far above type inversion followed by partial annealing.
Electronic transport measurements and ARPES spectroscopy were performed on irradiation modified Bi2Te3 and Bi2Se3 samples.

- Dirac cones of surface states were not altered by irradiation-induced disorder, ARPES reveals only shift of the Fermi energy, reversible after annealing.
- Evolution of Shubnikov-de Hass oscillations reflects shrinking/expansion of the Fermi sphere with irradiation dose. Close to the CNP contribution of the surface states appears via Berry phase.
- Semiconducting temperature dependence of resistivity, exhibiting various regimes from thermally activated to variable range hopping is observed in samples close to CNP.
- Weak antilocalization type magnetoresistance was observed close to CNP, it fits perfectly Hikami-Larkin-Nagaoka formula with prefactor corresponding to two conduction channels.

Ref. [1] L. Zhao, M.K et al, Nature Comm. 7, 10957 (2016)

This work was realized in collaboration with Lukas Zhao, Haiming Deng, Inna Korzhovska, Milan Begliarbekov, Zhiyi Chen, Lia Krusin-Elbaum (CUNY, New York)
Evangelos Papalazarou, Marino Marsi (LPS, Orsay)
Luca Perfetti, (LSI, Palaiseau)
Andrzej Hruban, Agnieszka Wołos (Institute of Physics, Warsaw)

## Ballistic edge states in Bismuth nanowires revealed by SQUID interferometry

Anil Murani[1], Alik Kasumov[1], Shamashis Sengupta[1], F. Brisset[2], Raphaëlle Delagrange[1], Alexei Chepelianskii[1], Richard Deblock[1], Sophie Guéron and Hélène Bouchiat[1]

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Spin-orbit interactions are known to have drastic effects on the band structure of heavy-element-based materials. Celebrated examples are the recently identified 3D and 2D topological insulators. In those systems transport takes place at surfaces or along edges, and spin-momentum locking provides protection against (non-magnetic) impurity scattering, favoring spin-polarized ballistic transport. We have used the measurement of the current phase relation of a micrometer-long single crystal bismuth nanowire connected to superconducting electrodes, to demonstrate that transport occurs ballistically along two edges of this high spin-orbit material. In addition, we show that a magnetic field can induce to 0-pi transitions and phi0-junction behaviour, thanks to the extraordinarily high g-factor and spin orbit coupling in this system, providing a way to manipulate the phase of the supercurrent carrying edge states.

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## Ultrafast study of out-of-equilibrium Dirac fermions in topological insulators

M. Marsi
Laboratoire de Physique des Solides, CNRS, Univ. Paris Sud, Université Paris-Saclay, Orsay, France

The surface states in three-dimensional topological insulators constitute a Dirac cone with a chiral texture in the electron spin distribution, and hold the promise for many novel technological applications thanks to their unique transport properties.

One of the most exciting opportunities disclosed by their discovery is the photoexcitation of topological insulators with femtosecond lasers to explore the ultrafast dynamics of Dirac fermions. Time-resolved ARPES is a particularly well adapted experimental technique to study these effects. Selected exemples will be presented and discussed to illustrate the unique properties of out-of-equilibrium Dirac fermions in topological matter, like for instance the possibility of creating a transient metallic state with a surprisingly long lifetime.

**"Weyl semimetals — from chiral anomaly to fractional chiral metal"**

Jens Bardarson
MPI, Dresden

Quantum anomalies is the phenomena that a symmetry classically present is broken in the quantum theory. The chiral anomaly, in particular, refers to the non-conservation of chiral charge or current, and has been discussed for example in the context of the electroweak interactions and neutral superfluid helium. In the solid state, it has recently been realized that Weyl and Dirac semimetals, in which the conduction and valence points touch in a set of non-degenerate Weyl nodes, have a chiral anomaly. In this context electrons with different chirality belong to a different Weyl node, and the chiral anomaly is a mechanism by which parallel electric and magnetic field pump charge between different Weyl nodes. Due to disorder scattering a characteristic non-equilibrium steady state is obtained. In this talk I will discuss how this state is obtained, what are its defining features, and how they can be experimentally observed. I will also discuss recent experiments [1] on negative magnetoresistance in Weyl semimetals and their relation to the chiral anomaly. Finally, I will briefly talk about an interacting generalization of the Weyl semimetal, the fractional chiral metal, whose electromagnetic response is characterized by a fractional chiral anomaly [2].

*[1] F. Arnold et al., Nature Communications 7, 11615 (2016)*
*[2] T. Meng, A. G. Grushin, K. Shtengel, J. H. Bardarson, arXiv:1602.08856*

**Magneto-optical signature of massless Kane electrons in $Cd_3As_2$**

M. Orlita

Laboratoire National des Champs Magnétiques Intenses, CNRS-UGA-UPS-INSA
Grenoble, France

Cadmium arsenide ($Cd_3As_2$) has recently been identified [1-4] as the premier 3D topological Dirac semimetal stable under ambient conditions, thus inspiring a renewed interest in the electronic properties of this widely investigated compound. The current consensus is that the electronic bands of $Cd_3As_2$ comprise a single pair of symmetry-protected 3D Dirac nodes located in the vicinity of the  point of the Brillouin zone. Nevertheless, the exact location, size, anisotropy and tilt of these conical bands still remain a puzzle. Most strikingly, ARPES studies imply cones extending over a few hundred meV [2,3] or even eV [1]. In contrast, the band inversion estimated in STM/STS experiments [4], in line with recent and past theoretical modeling [5,6], invokes Dirac cones which extend over an order-of-magnitude smaller energy range.

Using our recent high-field magneto-optical experiments [7], we clarify this controversy. We argue that the band structure may in fact include two types of conical features, one spread over the large, and the second on the small energy scale. The widely extended conical band results from the standard Kane model [8,9] applied to a semiconductor with a nearly vanishing band gap. This cone is not symmetry-protected and hosts carriers that are referred to as massless Kane electrons [10]. The symmetry-protected Dirac cones, if present in $Cd_3As_2$ at all, may only appear on a much smaller energy scale (a few ten meV at most), in contrast to conclusions of ARPES studies [1-3], but in line with the STM/STS data [4].

*[1] Z. Liu et al., Nat. Mater. **13**, 677 (2014).*
*[2] M. Neupane et al., Nat. Commun. **5**, 3786 (2014).*
*[3] S. Borisenko et al., Phys. Rev. Lett. **113**, 027603 (2014).*
*[4] S. Jeon et al., Nat. Mater. **13**, 851 (2014).*
*[5] J. Bodnar, in Proc. III Conf. Narrow-Gap Semiconductors, Warsaw, edited by J. Raułuszkiewicz, M. Górska, and E. Kaczmarek (Elsevier, New York, 1977), p. 311.*
*[6] Z. Wang, H. Weng, Q. Wu, X. Dai, and Z. Fang, Phys. Rev. B **88**, 125427 (2013).*
*[7] A. Akrap, M. Hakl, S. Tchoumakov, I. Crassee, J. Kuba, M. O. Goerbig, C. C. Homes, O. Caha, J. Novák, F. Teppe, S. Koohpayeh, Liang Wu, N. P. Armitage, A. Nateprov, E. Arushanov, Q. D. Gibson, R. J. Cava, D. van der Marel, C. Faugeras, G. Martinez, M. Potemski, and M. Orlita, Physical Review Letters, to be published, arXiv:1604.00038 (2016).*
*[8] E. O. Kane, J. Phys. Chem. Solids 1, 249 (1957).*
*[9] P. Kacman and W. Zawadzki, Phys. Stat. Solidi B **47**, 629 (1971).*
*[10] M. Orlita et al., Nat. Phys. **10**, 233 (2014).*

Acknowledgements: ERC MOMB (No. 320590), TWINFUSYON (No. 692034) and Lia TeraMIR.

## Unveiling relativistic properties of Weyl quasiparticles

S. Tchoumakov, M. Civelli and M.O. Goerbig
LPS, Orsay

In condensed matter, massless Dirac quasiparticles are described by a conical shaped band dispersion that may show asymmetries in the group velocity for opposite directions. This asymmetry is the consequence of a tilt in the band dispersion and shows two critical behaviors, the type-I and type-II Weyl semimetals. Whereas the tilt is moderate in the case of a type-I Weyl semimetal, the tilt is so strong in a type-II Weyl semimetal that it is characterized by open Fermi surfaces.
In this talk we explain how such tilted quasiparticles behave under an external magnetic field and that there exist strong analogies with special relativity. In particular we will explore how the magneto-optical selection rules are influenced by such a tilt and how it allows one to distinguish between the two types of Weyl semimetals.

Ref: Phys. Rev. Lett. 117, 086402 (2016)

**Two-dimensional topological superconductivity in Pb/Co/Si(111)**

Tristan Cren[1], G. C. Ménard[1], S. Guissart[2], C. Brun[1], M. Trif[2], F. Debontridder[1], R. T. Leriche[1], D. Demaille[1], D. Roditchev[1], P. Simon[2]

[1]Institut des NanoSciences de Paris, CNRS & Sorbonne University
[2]Laboratoire de Physique des Solides,CNRS & Saclay University

Majorana fermions are very peculiar quasiparticles that are their own antiparticle. They obey non-abelian statistics: upon exchange, they behave differently from fermions (antisymmetric) and bosons (symmetric). Their unique properties could be used to develop new kind of quantum computing schemes. Majorana states are predicted to appear as edge states of topological superconductors, in a similar way as Dirac surface states appears at the edge of topological insulators. Spectroscopic signatures of Majorana bound states were first observed in one-dimensional (1D) InAs nanowires proximity-coupled to a bulk superconductor. Then Nadj-Perge et al. [1] have realized a chain of Fe adatoms on a Pb(110) that induce locally a 1D topological p-wave superconductivity as demonstrated by the appearance of Majorana bound states at the extremity of the Fe chain. The Majorana states are strongly localized; they appear only on a few atoms at the end of the magnetic chains which inhibits their manipulation.

We have recently decided to follow a different strategy using sizeable magnetic disks made of Cobalt buried under a superconducting monolayer of Pb/Si(111). We have observed that dispersive edge states crossing the gap appears around the magnetic domains [2]. We have interpreted these spectroscopic features as signatures of a locally induced topological superconductivity in 2D Pb/Co/Si(111). Indeed, we expect to get some propagative Majorana edge states around 2D topological domains since the edges have a 1D character. This is at odds with the Fe chains whose edge states are intrinsically 0D and are thus characterized by non-propagative bound states. The edge states in 2D topological superconductors are analogous to the edge states in Quantum Spin Hall systems. However, there is a very fundamental difference here as the superconducting topological edge states we observe have the specificity of being Majorana excitations. In addition, we found that superconducting vortices generated in the topological domains support localized MBS in their core. Such MBS in the vortex cores have been the focus of numerous theoretical proposals for quantum computing schemes due to non-Abelian anyonic nature of the MBS. The manipulation of vortices in such 2D architecture may be thus be an efficient way to do braiding experiments with Majorana bound states.

*[1] S. Nadj-Perge, I. K. Drozdov, J. Li, H. Chen, S. Jeon,J. Seo, A. H. MacDonald, B. A. Bernevig, and A. Yazdani, Science 346, 602 (2014)*
*[2] G. C. Ménard, S. Guissart, C. Brun, M. Trif, F. Debontridder, R. T. Leriche, D. Demaille, D. Roditchev, P. Simon, T. Cren, arXiv:1607.06353 (2016)*

### Multi-terminal Josephson junctions as topological matter

Julia Meyer
CEA, Grenoble

We show that $n$-terminal Josephson junctions with conventional superconductors may provide a straightforward realization of tunable topological materials in $n$–1 dimensions, the independent superconducting phases playing the role of quasi-momenta. In particular, we find zero-energy Weyl points in the Andreev bound state spectrum of 4-terminal junctions. The topological properties of the junction may be probed experimentally by measuring the transconductance between two voltage-biased leads, which we predict to be quantized

### Topological states in quantum antiferromagnets

Pierre Pujol
LPT, Université Paul Sabatier, Toulouse

We shortly review some examples of exotic phases found in quantum magnetism, some of which have particularly interesting topological properties. Among them, mostly are phases with gapped magnetic excitations, or magnetic plateaux phases. We discuss a method to understand the physics of these plateau states and how one can realize phases which can be seen as the magnetic analog of quantum Hall states.

### Topological order in materials with strong spin-orbit coupling

Cécile Repellin
MPI, Dresden

The prediction and experimental realization of the quantum spin Hall effect in HgTe/CdTe quantum wells in 2006 have opened the possibility to realize topological phases in the absence of a magnetic field. In these materials, the spin-orbit coupling is the essential ingredient that leads to a non-trivial band structure characterized by a topological invariant. The interplay of topology and strong interactions could lead to even more interesting phases akin to the fractional quantum Hall effect and supporting fractionalized excitations. I will review some of the mechanisms that can lead to such phases and show how they can be probed numerically. I will discuss the stability of time-reversal symmetric fractional topological insulators in the presence of perturbations such as a Rashba spin-orbit coupling. Finally, I will consider a case where the topology emerges not from spin-orbit coupling, but from the interactions themselves, by taking the example of a frustrated magnet supporting a spin-liquid phase.

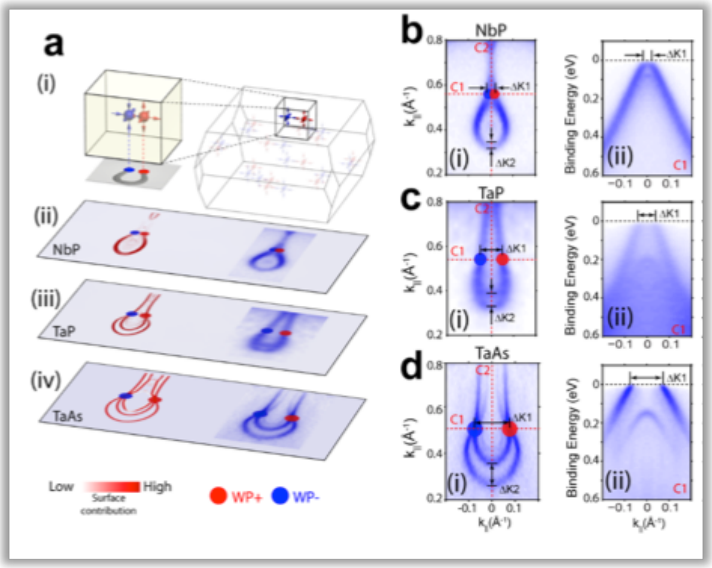
## Topology – from the materials perspective

Claudia FELSER, Binghai YAN, Chandra SHEKHAR

Max Planck Institute of Chemical Physics for Solids, Dresden, 01187, Germany

Topological insulators (TIs), Weyl and Dirac Semimetals are a new quantum state of matter, which have attracted interest of condensed matter science. Heusler compounds are a remarkable class of materials with more than 1,000 members and a wide range of extraordinary multifunctionalities [1] including tunable topological insulators (TI) [2]. Many of these ternary zero-gap semiconductors in Heusler compounds (LnAuPb, LnPdBi, LnPtSb and LnPtBi) contain the rare-earth element Ln, which can realize additional properties ranging from superconductivity (for example LaPtBi) to magnetism (for example GdPtBi) and heavy fermion behavior (for example YbPtBi). These properties can open new research directions in realizing the quantized anomalous Hall Effect and topological superconductors. C1b Heusler compounds have been grown as single crystals and as thin films. The control of the defects, the charge carriers and mobilities can be optimized. The band inversion is proven by ARPES [3]. Dirac cones and Weyl points can occur at the critical points in the phase diagrams of TI, first Heusler compounds were identified.

Weyl points, a new class of topological phases was also predicted in NbP, NbAs and TaP. The magneto-transport properties of NbP show a large magnetoresistance of 850,000% at 1.85 K (250% at room temperature) in a magnetic field of up to 9 T, without any signs of saturation, and an ultrahigh carrier mobility of $5 \times 10^6$ cm$^2$ V$^{-1}$ s$^{-1}$ that accompanied by strong Shubnikov–de Haas (SdH) oscillations. We found also ultrahigh magneto resistance, mobilities and Fermi arcs in NbP, TaAs and TaP [4,5]. More emerging quantum properties and potential applications will be discussed




Weyl Semimetals NbP TaP and TaAs and the Fermi arc, calculation vs. Angle Resolved Photoemission (ARPES)

1. *Tanja Graf, Stuart S. P. Parkin, and Claudia Felser, Progress in Solid State Chemistry 39 (2011) 1*
2. *S. Chadov, X. Qi, J. Kübler, G. H. Fecher, C. Felser, S.-C. Zhang, Nature Mater. 2010, 9, 541*
3. *Z. K. Liu, et al., Nature Communication in press*
4. *C. Shekhar, et al., Nature Physics 11 (2015) 645*
5. *Z. K. Liu, et al., Nature Materials 15 (2016) 27*

**MBE-growth of HgTe/CdTe topological insulator structures**

Ph. Ballet
LETI, CEA, Grenoble

In this introduction to HgTe material and epitaxy we will describe the general aspects of Hg-based MBE and what are the requirements to realize high quality topological insulator structures in this peculiar material system. More specifically we will discuss the surface and interface control where electronic surface state transport is expected to occur. Finally we will briefly discuss some of the remaining issues and future developments in the MBE growth of HgTe/CdTe structures.

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**Signature of topological superconductivity at the surface of Bi2Se3**

Benjamin Sacépé
Institut Néel, CNRS Grenoble

The surface of a 3D topological insulator exhibit unique electronic properties given by the existence of topologically protected surface state. Coupled to superconducting electrodes, the spin-momentum locking of these surface states induces an unconventional spinless p-wave superconductivity that carries gapless, 4-peridoc Andreev bound states. In this talk, after reviewing our efforts on crystal growth of Bi2Se3 and related compounds, I will present measurements of the ac Josephson effect on junctions on Bi2Se3, which show anomalies in the Shapiro step sequence. I will discuss these results in light of the available theories on the fractional ac Josephson effect in topological Josephson junctions.

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**Phase transitions in two tunnel-coupled HgTe quantum wells: Bilayer graphene analogy and beyond**

Sergey Krishtopenko
Laboratoire Charles Coulomb, Montpellier

HgTe quantum wells possess remarkable physical properties as the quantum spin Hall insulator state and the “single-valley” analog of graphene, depending on their layer thicknesses and barrier composition. However, double HgTe quantum wells yet contain more fascinating and still unrevealed features. In this talk we report on the quantum phase transitions in tunnel-coupled HgTe layers separated by CdTe barrier. This system is the most suitable to study effects of inter-layer coupling on the modification of the bulk and edge states. We demonstrate that such system has a 3/2 pseudo spin degree of freedom and features a number of particular properties related with the spin-dependent coupling. We discover a specific metal phase, arising in wide range of HgTe and CdTe layer thicknesses, in which a gapless bulk and a pair of helical edge states coexist. This phase has the band structure and shares some properties of bilayer graphene such as unconventional quantum Hall effect and electrically-tunable band gap. In this “bilayer graphene” phase, electric field opens the band gap and drives the system into the quantum spin Hall insulator state. Furthermore, we discover a new type of quantum phase transition arising from a mutual inversion between second electron-like E2 and H2 hole-like subbands. The picture of edge states in different phases will be presented in the talk. Our work paves the way towards physics of new multi-layered systems based on tunnel-coupled topological insulator materials.

# LIST OF POSTERS

### The saturation effects of circular dichroism on doped Bi2Se3

M. Hakl, L. Ohnoutek, M. Veis, B. Piota, C. Faugeraza, G. Martineza, M. Yakusheve, R. Martine, Č. Drašarc, A. Maternad, G. Strzeleckad, A. Hruband, M. Potemskia and M. Orlitaa

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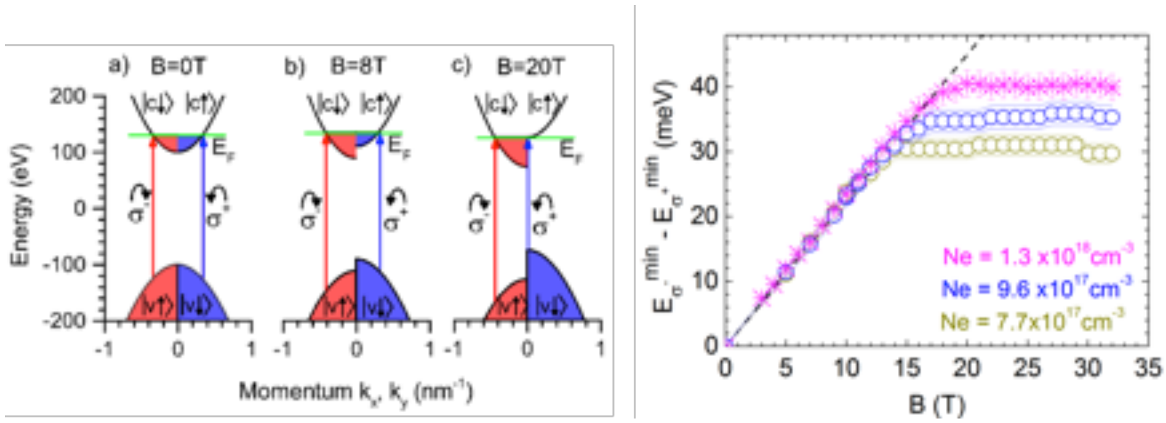
Bi2Se3 belongs to a class 3D topological insulator with a bulk narrow gap of 200 meV and conductive surface states. The current research effort is aimed to separate the contribution of the semiconductor-like bulk band structure from the E(k) dispersion of Dirac cone residing at crystal facets in the optical and transport response [1]. Here, we try to trace the signature of topologically non-trivial band inversion on bulk magnetic circular dichroism. In a classical regime of the low magnetic field, electron gas in bulk crystal becomes spin polarized affecting the occupancy of the conduction band (CB). As one branch of CB populates, the second depletes until the full polarization state of the system is reached. The carrier redistribution governs lowest possible transitions of circularly polarized light (Fig. 1L). In transmission the optical response is perceived as a gradual splitting of the absorption edge with a consecutive saturation (Fig. 1R). Electron-hole mass symmetry and p-like nature of both bands make the g-factors of conduction and valence bands equal [2]. Thus, the Pauli-blocking becomes the major driving mechanism of the circular dichroism in the vicinity of the gap. The absorption is related to the refractive index through Krammers-Kronig transform. The dichroism brings phase retardation between σ+, σ- components for excitations below the energy gap that stems for the strong Faraday rotation [3] with a clear crossover from the Verdet's law [4] in concordance to the behavior of the absorption edge splitting.

Keywords: Magnetic dichroism; Faraday rotation; Inverted band structure

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## Topological Kondo Insulators :Local Electronic Structure around a Single Impurity in an Anderson Lattice Model

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Shortly after the discovery of topological band insulators, the topological Kondo insulators (TKIs) have also been theoretically predicted. The latter has ignited revival interest in the properties of Kondo insulators. Currently, the feasibility of topological nature in SmB6 has been intensively analyzed by several complementary probes. Here by starting with a minimal-orbital Anderson lattice model, we explore the local electronic structure in a Kondo insulator. We show for the first time that the two strong topological regimes sandwiching the weak topological regime give rise to a single Dirac cone, which is located near the center or corner of the surface Brillouin zone. We further find that, when a single impurity is placed on the surface, low-energy resonance states are induced in the weak scattering limit for the strong TKI regimes and the resonance level moves monotonically across the hybridization gap with the strength of impurity scattering potential; while low energy states can only be induced in the unitary scattering limit for the weak TKI regime, where the resonance level moves universally toward the center of the hybridization gap. These impurity induced low-energy quasipar-ticles will lead to characteristic signatures in scanning tunneling microscopy/spectroscopy, which has recently found success in probing into exotic properties in heavy fermion systems.

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## Spin polarisation of Shiba states as a probe of the properties of the host superconductors

Vardan Kaladzhyan
IPhT Saclay

We propose to use the spin-polarised spectroscopy of magnetic impurities to analyse various properties of the host superconductors, both singlet and triplet.

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## Generating a Chiral Superfluid quantum phase transition using Floquet engineered lattices

Kirill Plekhanov.
LPTMS, Orsay

# Low energy magnetic excitations and spin-charge separation in the one-dimensional quantum spin liquids $SrCuO_2$ and $Sr_2CuO_3$

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Within the last decades, one dimensional systems have attracted much attention for their exotic physics [1-3]. Among those systems, the spin chains cuprates $SrCuO_2$ and $Sr_2CuO_3$ are found to be the best experimental realizations of one-dimensionality. Both the compounds satisfy the uniform antiferromagnetic half integer spin chains Heisenberg model. Besides, they belong to the family of strongly correlated electrons systems which makes them Mott insulators. Furthermore, these materials exhibit highly anisotropic and ballistic heat transport by spin current along the spin chains direction giving rise to: spinons-phonons and spinons-defects scattering mechanisms [4].

In order to probe the broken chain effect on the thermal conduction properties of these systems and understand the underlying mechanisms involved during heat transport, we study the effect of substitution, on the copper site, with magnetic or non-magnetic impurities, or on the strontium site, by non-isovalent elements, on the physical properties of these materials. High quality single crystals of the pristine (x=0) and doped $Sr_{(1-x)}La_xCuO_2$, or $SrCu_{(1-x)}M_xO_2$ (with M= Zn or Mg and x=0.01) and $Sr_2Cu_{(1-x)}M_xO_3$ (with M=Ni and x=0.01 or 0.02) have been grown by the travelling solvent floating zone method.

Inelastic neutrons scattering measurements have been carried out on the pristine and doped $SrCuO_2$ and highlight the opening of a spin pseudo-gap upon doping, inferred to the segmentation of the chains into a distribution of finite size chains, just as it has been reported upon Ni-doping in the same compound [5]. On the other hand, these oxides behave as Tomonaga-Luttinger spin liquids. Indeed, the separation of the collective modes of charge and spin (holons and spinons) have been reported in both materials [2]. Angle Resolved Photoemission Spectroscopy allowed us to follow the spinons branch evolution, in terms of binding energy, upon doping. Here, we present the results obtained for the pristine and Ni-doped $Sr_2CuO_3$.

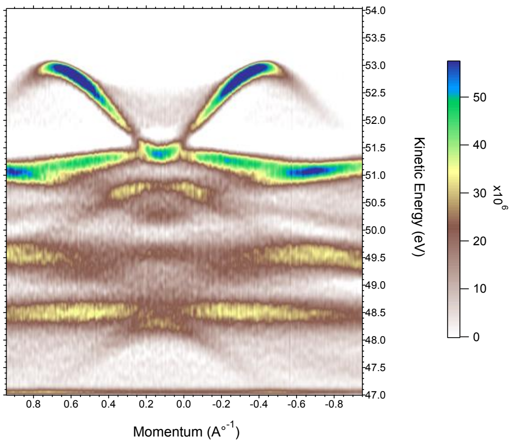


**Figure:** Spin-charge separation in $Sr_2CuO_3$ probed by Angle Resolved Photoemission Spectroscopy. The figure shows the distinct holon dispersion branches and, more discrete, spinon branch that lies between the two V-shaped holon branches.

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**Spectroscopy of topological and hybrid Andreev States in Multi-terminal and closely-spaced junctions**

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In a Josephson junction, the supercurrent is carried by Andreev Bound States (ABS) localized in the weak link between two superconductors. Their energy depends on the phase difference between electrodes and the properties of the weak link.
It has been recently shown [1] that if junctions has more than two terminals, one can engineer ABS that behaves as topologically protected Weyl singularities. In our work, we develop an experimental scheme to probe these topological states using a tunnel Josephson junction as a microwave spectrometer. Measuring absorption spectra as a function of phase, one should be able to detect signature of Weyl singularities by observing crossings at zero energy.
Another way to control the behavior of ABS consists of bringing two junctions closer than the superconducting coherence length. In that case, ABS of the two junctions hybridize and form entangled pairs of Cooper pairs, also called quartets [2]. In contrast with Weyl fermions, their spectral signatures are avoided crossings between ABS inside the superconducting gap. Based on a microscopic model, we show that we could detect these signatures with a Josephson junction based spectrometer and in the non-local current-phase relation of the device.

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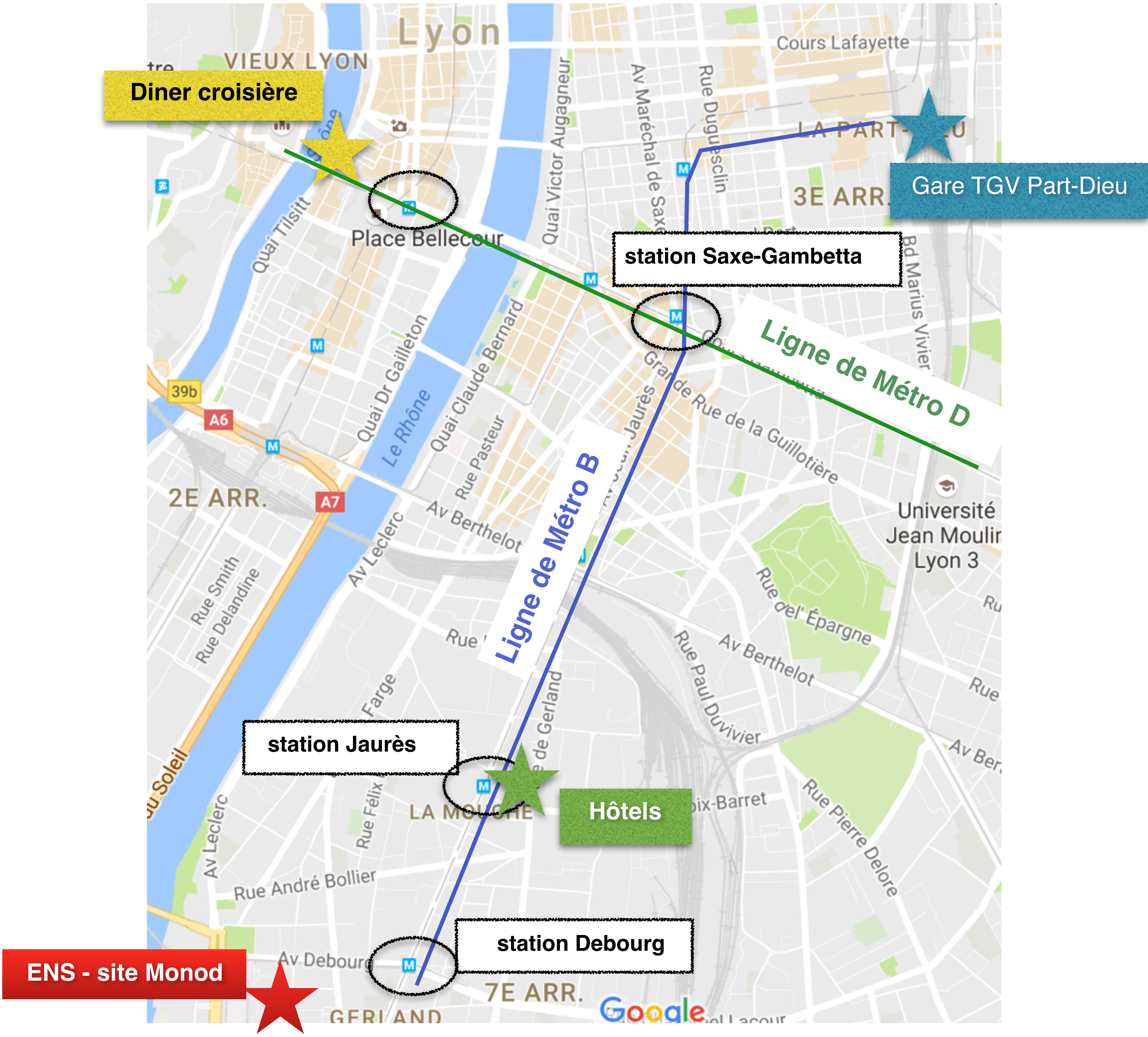
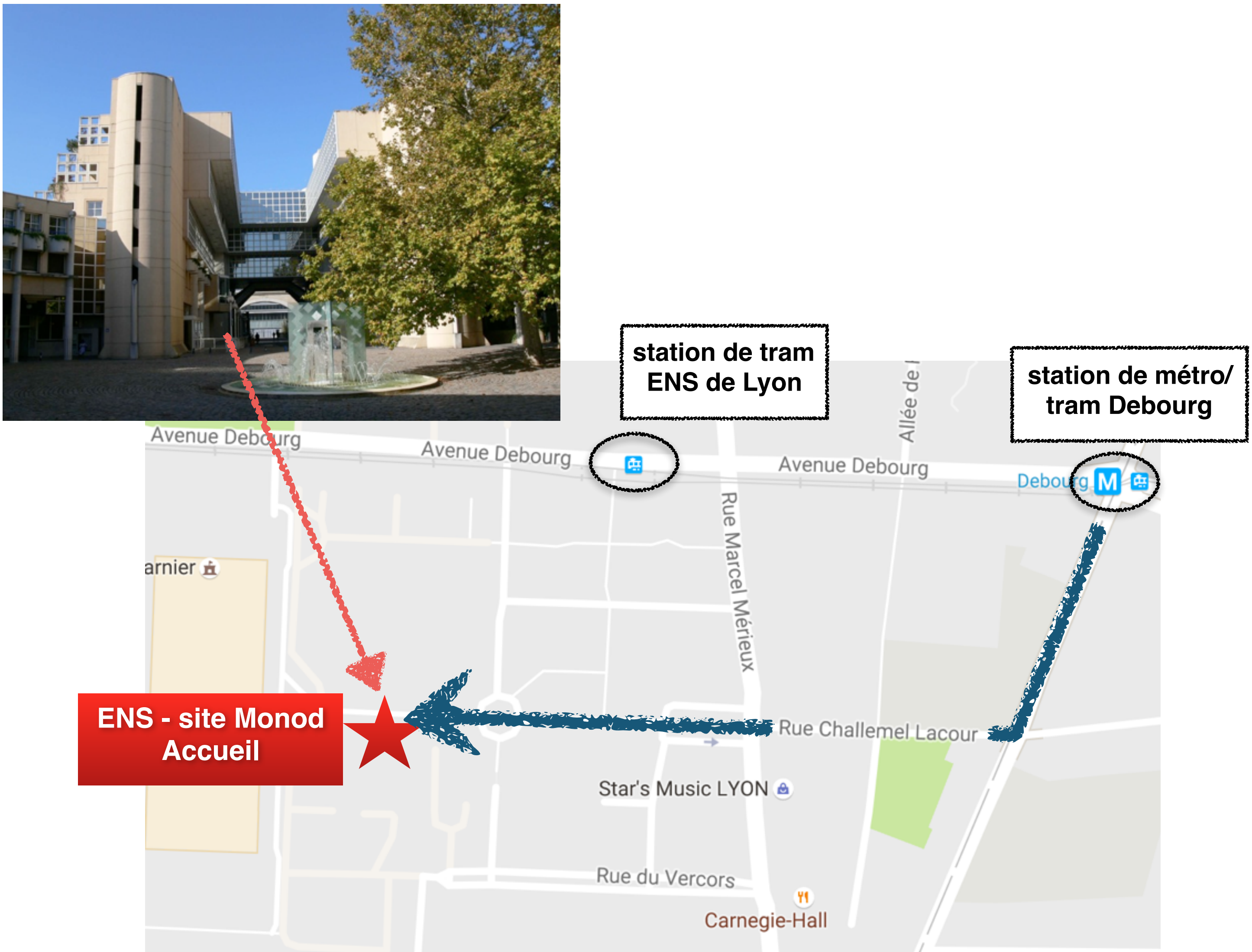
# MAPS / Transports



# ENS de Lyon - Site Monod

**L'accueil des participants s'effectue dans le Hall du bâtiment de gauche sur la photo, au 46 allée d'Italie.**
**Il y a environ 650m entre l'arrêt de métro Debourg et le bâtiment d'accueil.**

**Le workshop (ou atelier en français), a lieu au centre Blaise Pascal, dans l'enceinte du site Monod de l'ENS Lyon.**



# Dîner Croisière

**L’embarquement et le débarquement pour le diner croisière s’effectuent au: 2, quai des Célestin.**