A twist connecting magnetism and electronic-band topology

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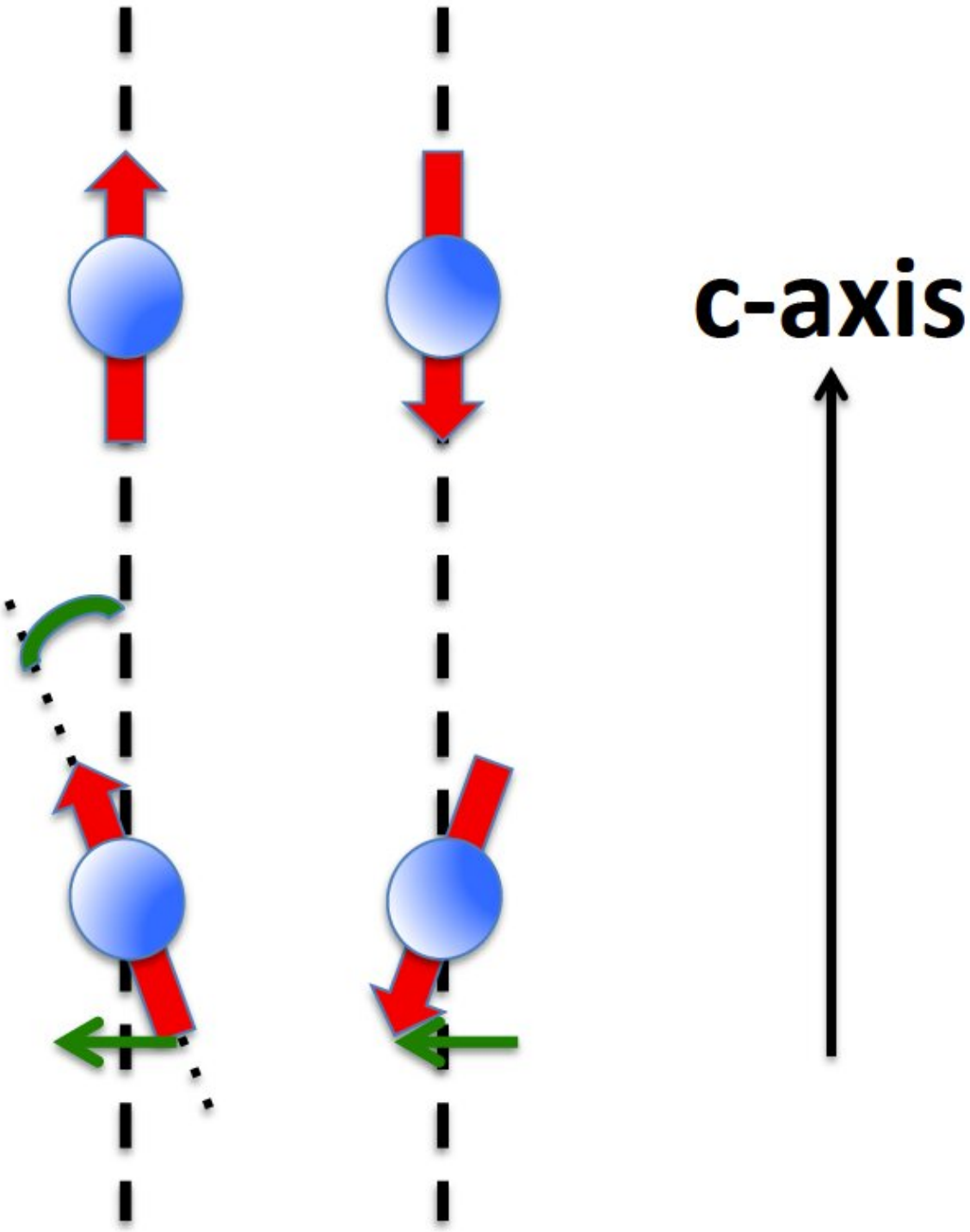

Antiferromagnetic (top) and canted-antiferromagnetic order (bottom). In the latter case the spins are canted relative to the easy c-axis, leading to a

ferromagnetic contribution in the plane orthogonal to that axis (represented by green arrows). Credit: ETH Zurich/D-PHYS

Materials that combine topological electronic properties and quantum magnetism are of high interest for the quantum many-body physics they exhibit and for possible applications in electronic components. ETH physicists have now established the microscopic mechanism linking magnetism and electronic-band topology for one such material.

Dirac matter is an intriguing class of materials with interesting properties: Electrons in these materials behave as if they have no mass. The most prominent Dirac material is graphene, but others have been discovered over the past 15 years. Each serves as a rich playground for exploring exotic electronic behaviors, some of which could enable novel components for electronics.

However, there are only very few examples where the topology of the electronic bands is connected in a well-defined manner to the magnetic properties of the materials. One material in which such interplay between topological electronic states and magnetism has been observed is $CaMnBi_2$, but the mechanism connecting the two remained unclear. Writing in *Physical Review Letters*, postdoc Run Yang and Ph.D. student Matteo Corasaniti from the Optical Spectroscopy group of Prof. Leonardo Degiorgi at the Laboratory for Solid State Physics of ETH Zurich, working with colleagues at Brookhaven National Laboratory (US) and the Chinese Academy of Sciences in Beijing, now report a comprehensive study providing clear evidence that a slight nudge on the magnetic moments, known as spin canting, provokes substantial changes in the electronic band structure.

$CaMnBi_2$ and the related compound $SrMnBi_2$ display quantum

magnetism—the manganese ions are antiferromagnetically ordered at around room temperature and below—and at the same time, they host Dirac electrons. That there is interplay between the two properties has been suspected, as at ~50 K, there appears an unexpected 'bump' in the conduction properties in these materials. But the precise nature of this anomaly was poorly understood until now.

In earlier work studying optical properties, Corasaniti, Yang and co-workers had already established a link to the electronic properties of the material. They exploited the fact that the bump-like anomaly in the transport properties can be shifted in temperature by replacing some of the calcium atoms with sodium. To determine the microscopic origins of the observed behavior, they studied samples with different sodium dopings by torque magnetometry. In this technique, the torque on a magnetic sample is measured when it is exposed to a suitably strong field, analogous to a compass needle aligning with the Earth's magnetic field. This approach pointed the team to the origins of the anomaly.

A firm link between magnetic and electronic properties

In their magnetic torque experiments, the researchers found that at temperatures where no anomaly is observed in the electronic transport measurements, the magnetic behavior is resembles an antiferromagnet. However, at temperatures at which the anomaly manifests, a ferromagnetic component appeared, which can be explained by a projection of magnetic moments onto the plane orthogonal to the easy spin c-axis of the original antiferromagnetic order (see figure). This phenomenon is known as spin canting, induced by a so-called super-exchange mechanism.

These two sets of experiments—the optical and torque

measurements—were supported by dedicated first-principles calculations. In particular, for the case where spin canting was included in the calculations, a peculiar hybridization between the manganese and bismuth atoms was found to mediate the interlayer magnetic coupling and to govern the electronic properties in the material. Taken together, the study establishes a direct link between the magnetic properties and changes to the electronic band structure, reflected in the bump anomaly of the transport properties.

These findings open the door to exploring the electronic properties of $CaMnBi_2$ and related compounds, as well as the possibilities arising from the connection between magnetic properties and topological states in these intriguing forms of matter.

More information: R. Yang et al, Spin-Canting-Induced Band Reconstruction in the Dirac Material $Ca_{1-x}Na_xMnBi_2$, *Physical Review Letters* (2020). DOI: 10.1103/PhysRevLett.124.137201

M. Corasaniti et al. Fermi surface gapping in the Dirac material Ca1−xNaxMnBi$_2$, *Physical Review B* (2019). DOI: 10.1103/PhysRevB.100.041107

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