Bethe strings experimentally observed

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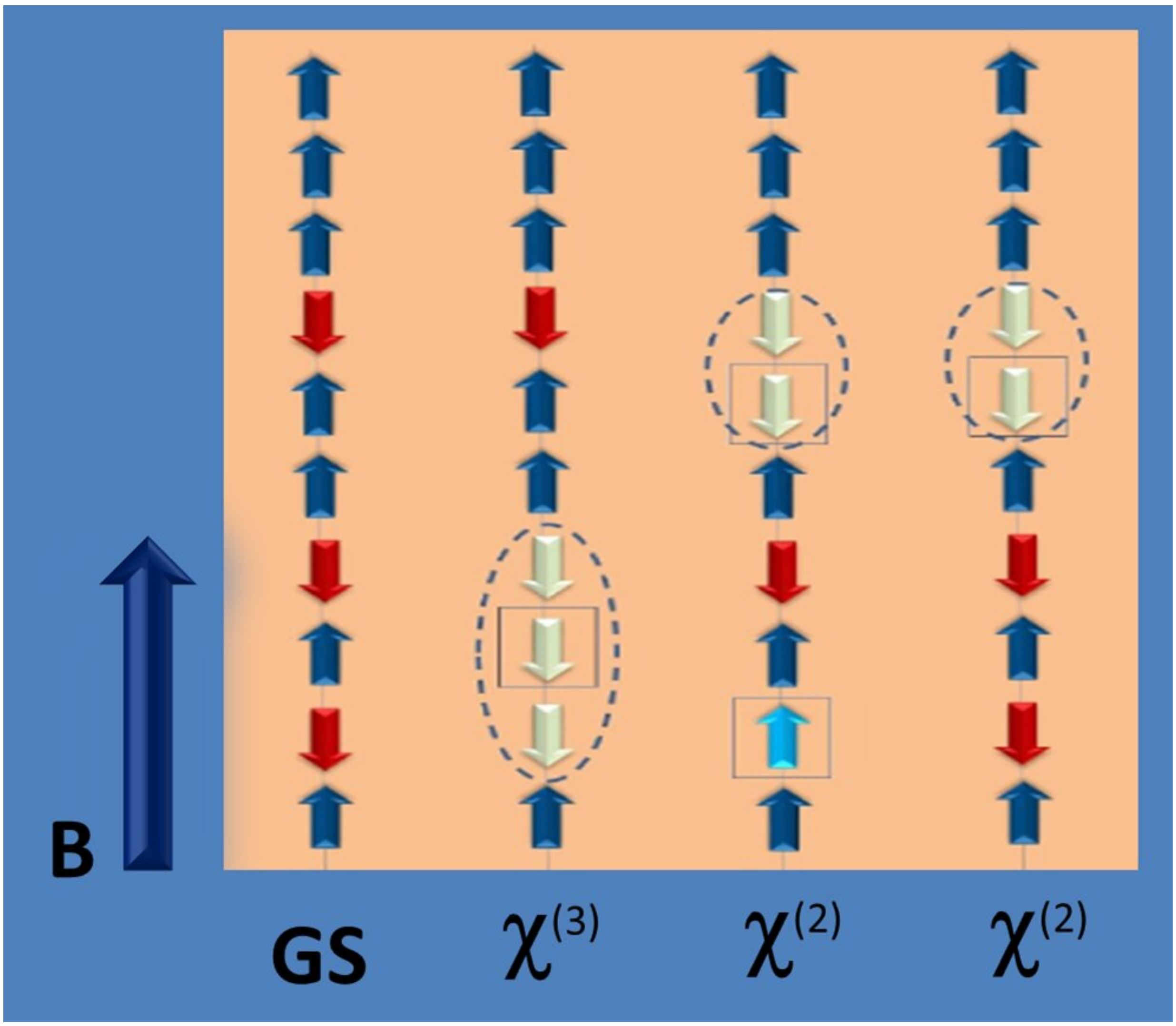

In the ground state the magnetic moments are either upward or downward, the spins antiparallel to the external magnetic field (red) are never together (right). By excitation, further spins can align antiparallel and Bethe chains are formed (white spins, left). Credit: HZB

Ninety years ago, the physicist Hans Bethe postulated that unusual patterns, so-called Bethe strings, appear in certain magnetic solids. Now, an international team has succeeded in experimentally detecting such Bethe strings for the first time. They used neutron scattering experiments at various neutron facilities, including the unique high-field magnet of BER II at HZB. The experimental data are in excellent agreement with the theoretical prediction of Bethe, and prove once again the power of quantum physics.

The regular arrangement of atoms in a crystal allows complex interactions that can lead to new states of matter. Some crystals have magnetic interactions in only one dimension, i.e., they are magnetically one-dimensional. If, in addition, successive magnetic moments are pointing in opposite directions, the crystal comprises a one-dimensional antiferromagnet. Hans Bethe first described this system theoretically in 1931, also predicting the presence of excitations of strings of two or more consecutive moments pointing in one direction, so called Bethe strings.

However, those string states could not be observed under normal experimental conditions because they are unstable and obscured by the other features of the system. The trick used in this paper is to isolate the strings by applying a magnetic field.

Now, an international cooperation around the HZB physicist Bella Lake and her colleague Anup Bera was able to experimentally identify and characterize Bethe strings in a real solid for the first time. The team made crystals of $SrCo_2V_2O_8$, which is a model system one-dimensional antiferromagnet. Only the cobalt atoms have magnetic moments, they all are aligned along one direction and adjacent moments cancel each other out.

At the Berlin neutron source BER II, it was possible to investigate the sample with neutrons under extremely high magnetic fields up to 25.9 Tesla. From the data, the physicists obtained a phase diagram of the sample as a function of the magnetic field, and also further information about the internal magnetic patterns, which could be compared with the idea of Bethe that were quantified by a theoretical group led by Jianda Wu.

"The experimental data are in excellent agreement with the theory," says Prof. Bella Lake. "We were able to clearly identify two and even three chains of Bethe strings and determine their energy dependence. These results show us once again how fantastically well quantum physics works."

More information: Anup Kumar Bera et al. Dispersions of many-body Bethe strings, *Nature Physics* (2020). DOI: 10.1038/s41567-020-0835-7

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