VISUALIZING MAGNETIC FIELDS AT MICROMETER SCALE: THE QUANTUM DIAMOND MICROSCOPE

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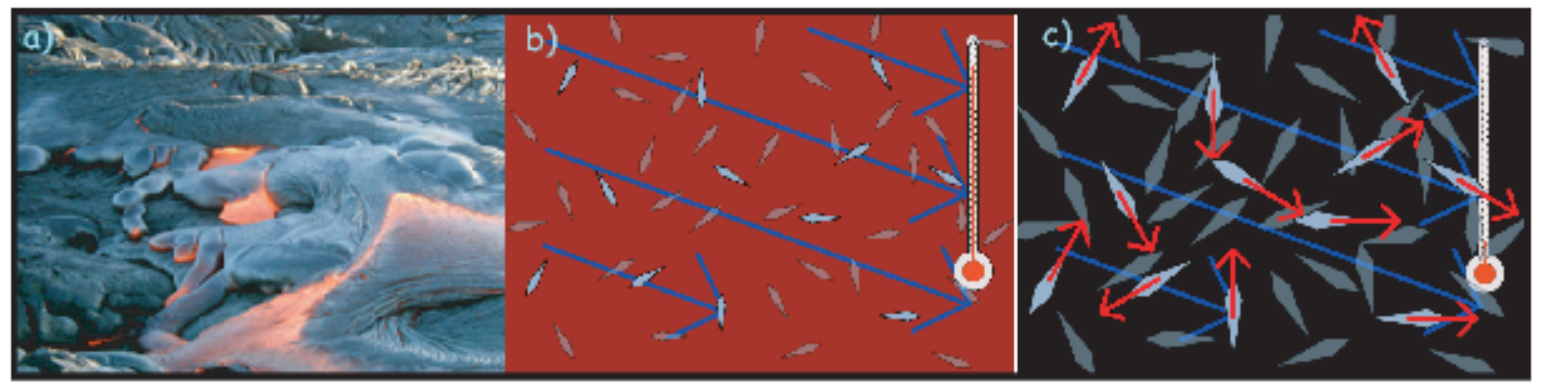
How rocks get magnetised

The study of past magnetic fields of the Earth and other planetary bodies relies on the accurate measurement of a sample's magnetisation. Most rocks contain ferro-magnetic minerals particles or inclusions, which may have recorded the past magnetic field.

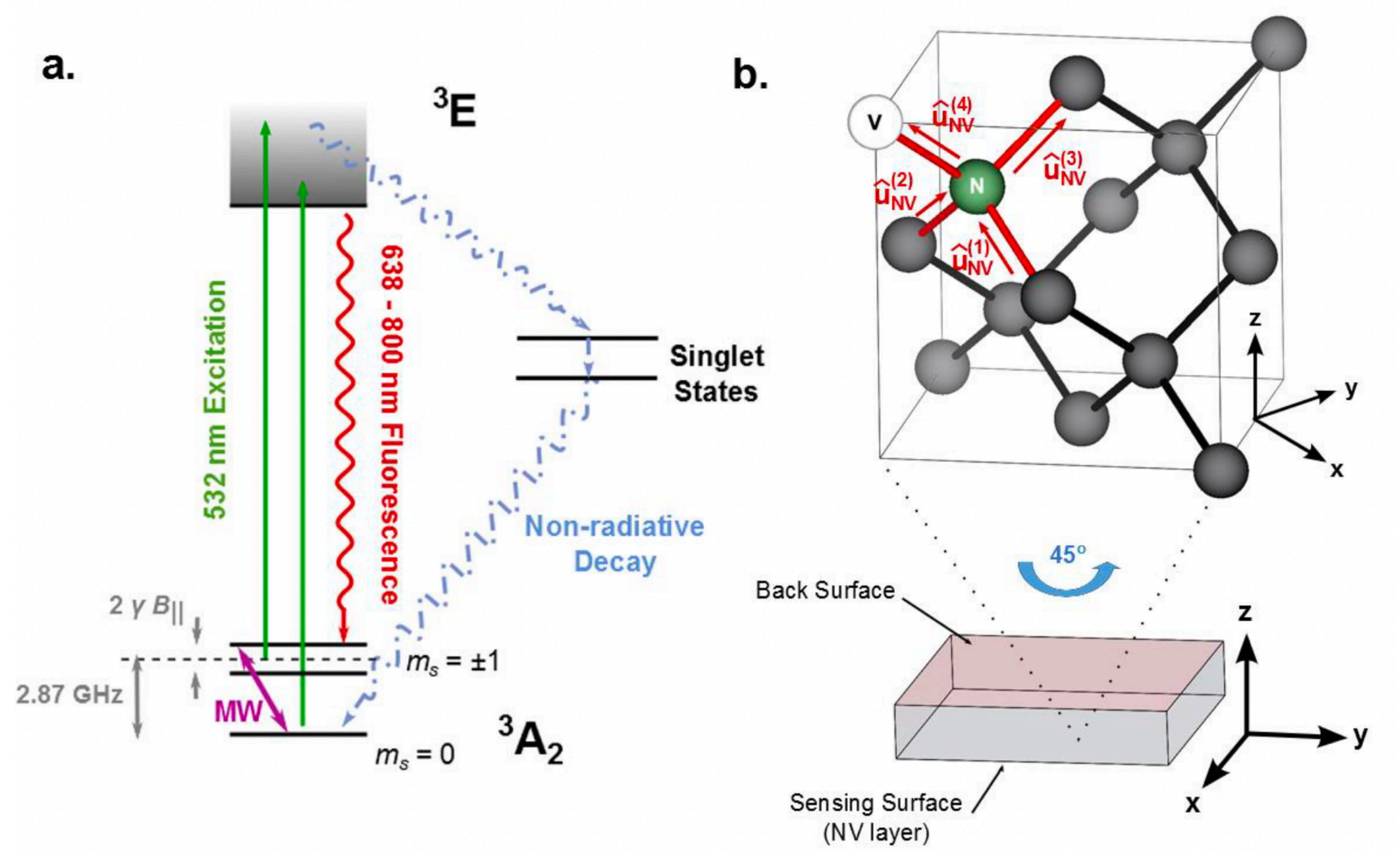


A magnetic grain in a rock is magnetised, when it cools in a magnetic field. It thereby records the direction (i.e. N/S and up/down) and intensity of the magnetic field at that time, often 100s of millions of years ago.

Small changes in temperature can change the magnetic information, so that detailed measurements of these grains inside a rock hold the key for understanding many Earth processes, such as plate tectonics, geomagnetic reversals and possibly earthquakes.

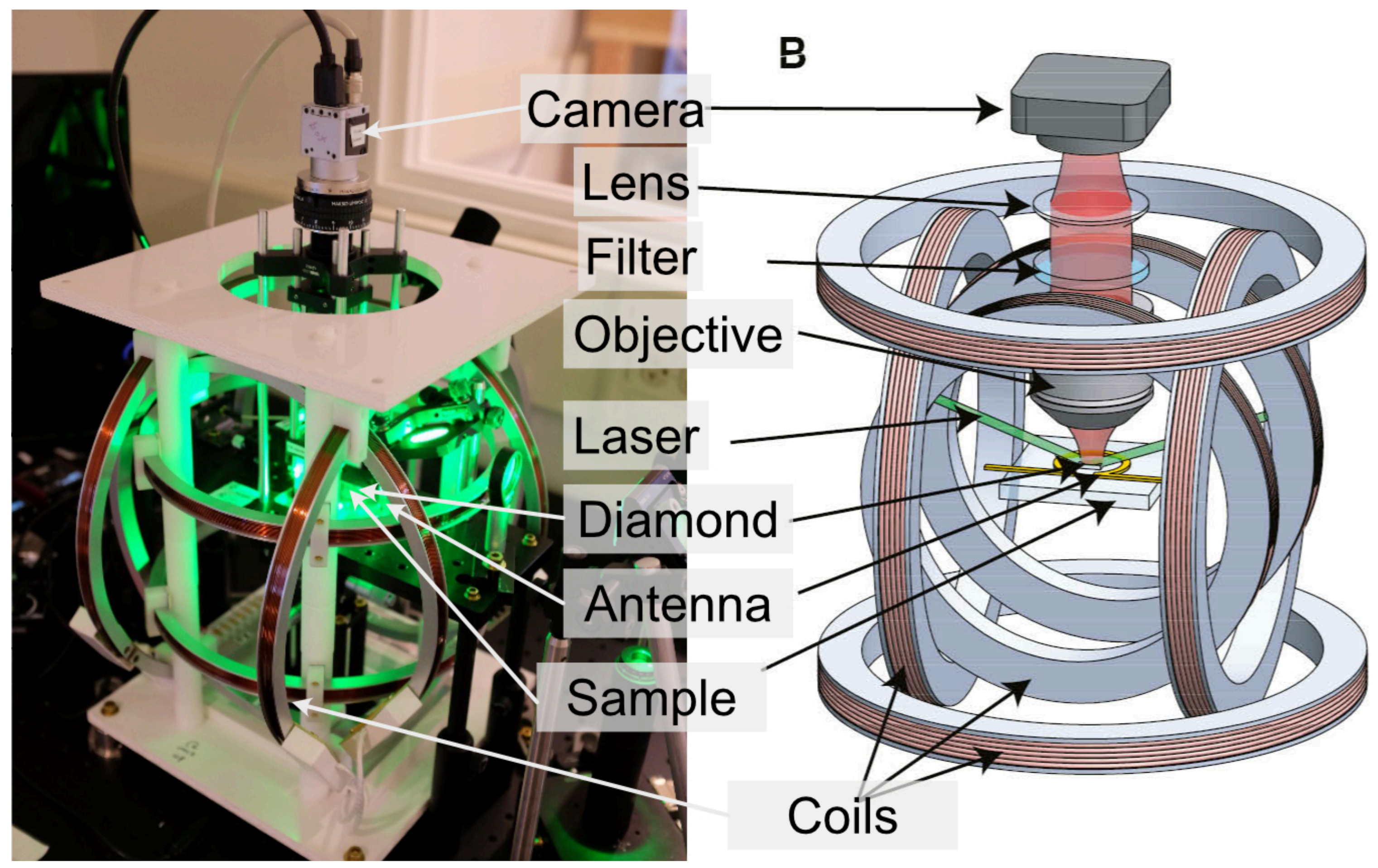
The quantum Diamond Microscope

Diamond is a fascinating material. If one of the carbon atoms is replaced by a Nitrogen atom and a neighbouring **C** is removed, a Nitrogen-vacancy (NV) centre is created. Through quantum-mechanical effects, these NV centres enable sensitive imaging of static magnetic fields in micrometer spatial resolution. The quantum diamond microscope (QDM) is a simple and robust implementation of NV magnetic imaging.



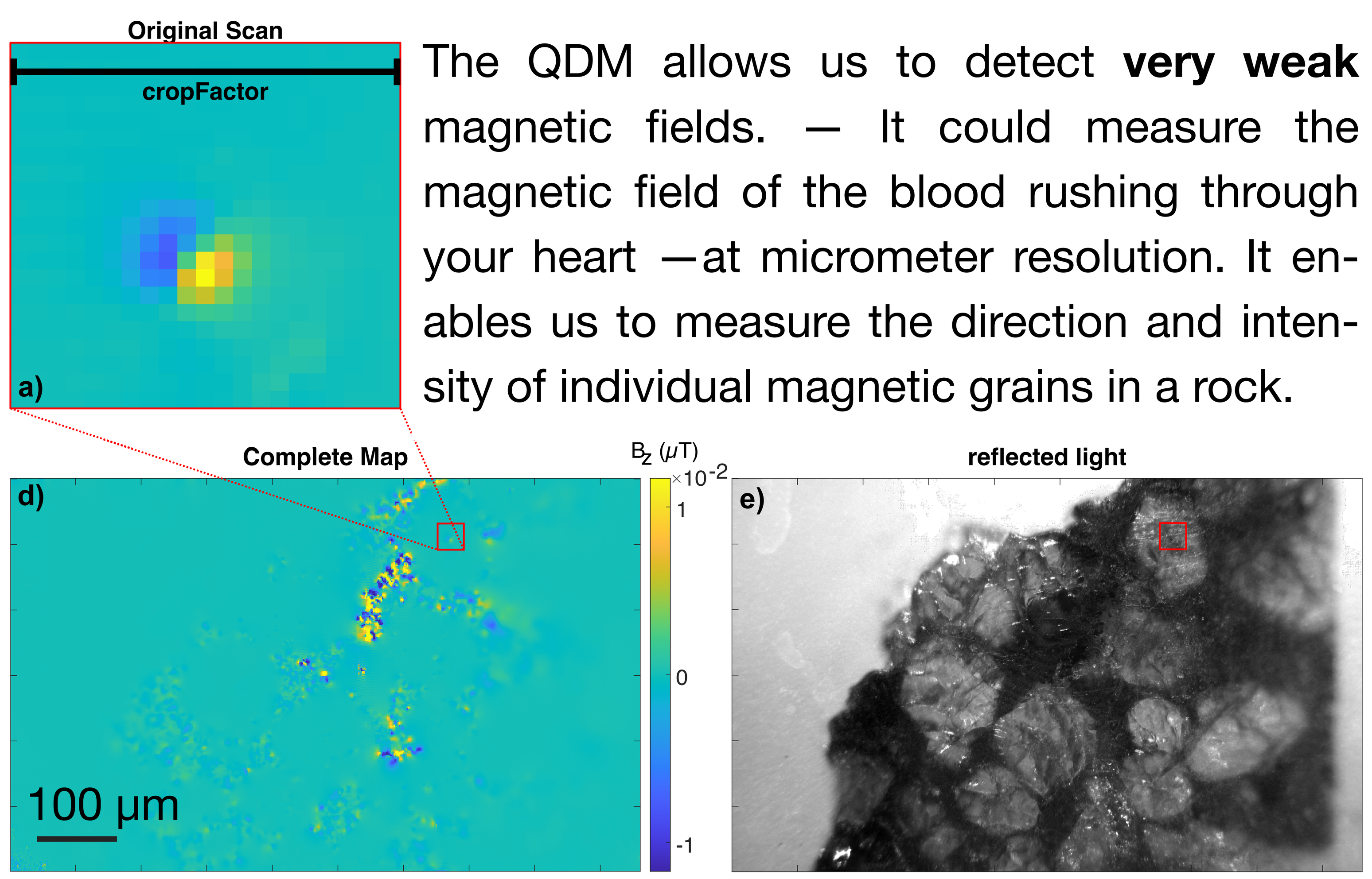
Anatomy of the QDM

- 532nm (green) laser
- NV-diamond pressed against the sample surface
- Camera to detect the fluorescence
- Objective to focus onto the sample region at 1µm resolution
- Microwave loop to find resonance
- Helmholtz coils to separate individual NV axis



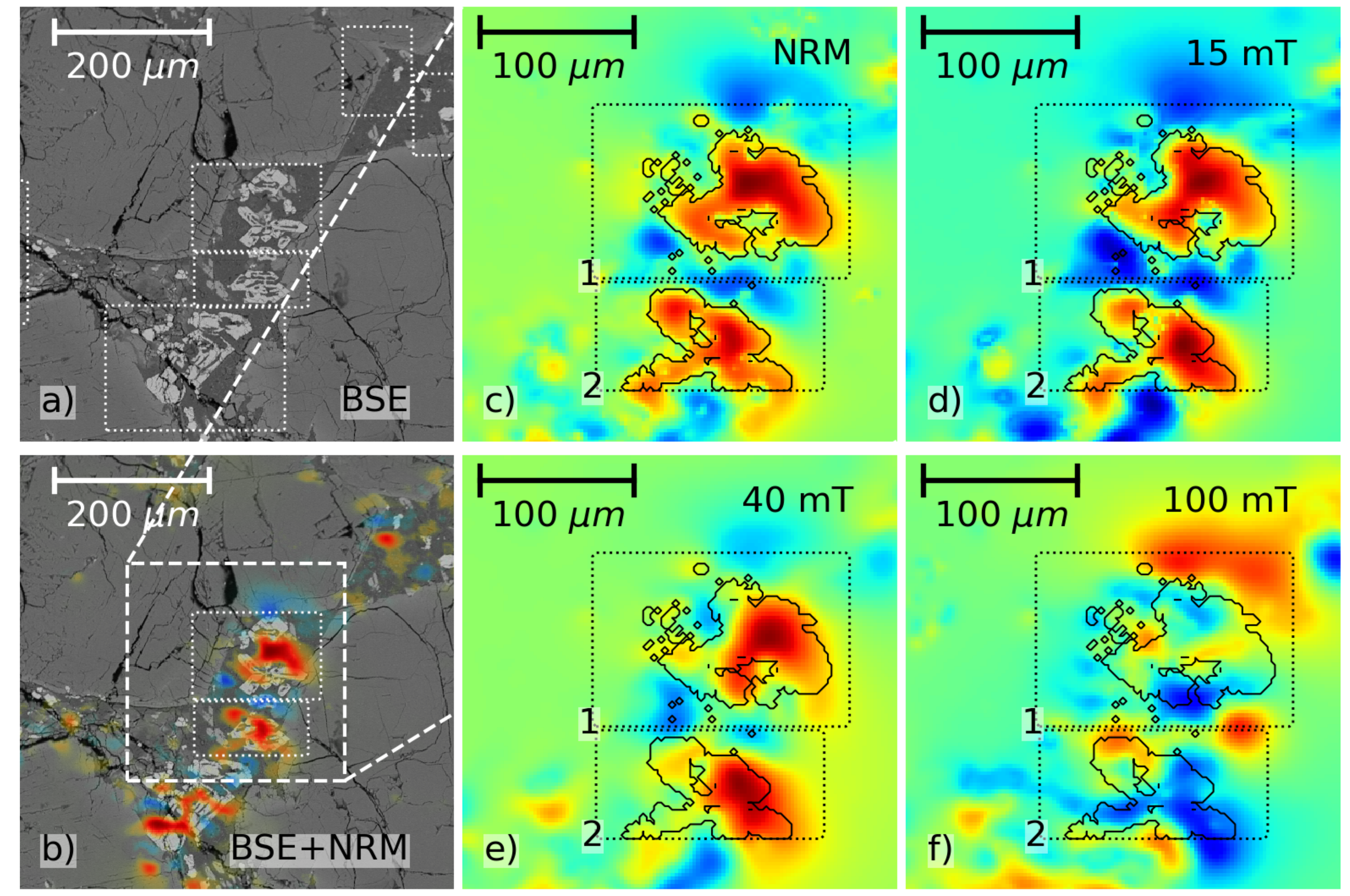
What does the QDM show?

The QDM allows us to detect **very weak** magnetic fields. — It could measure the magnetic field of the blood rushing through your heart —at micrometer resolution. It enables us to measure the direction and intensity of individual magnetic grains in a rock.



This is a the QDM measurement of a thin slice of a martian meteorite where we were able to extract the direction of the martian magnetic field from a single magnetic grain.

Even more importantly, the QDM, combined with other paleomagnetic techniques, can determine how the magnetisation changes with temperature. For example, earthquake slip generates heat which raises the temperature, weakens the faults and partially demagnetises the magnetic minerals.



Is this slice of a martian meteorite you can see small 100µm long magnetite grains. These grains are demagnetised using alternating magnetic fields. The magnetisation of the grains remains unchanged until fields of 40 mT or more are applied.

By successively demagnetising a rock and measuring the same section on the QDM we can determine how the magnetisation of individual grains changes with temperature. This gives us a lot of information not only on the magnetic grains themselves but also the conditions these grains were magnetised / remagnetised in.

The QDM and DeepNL

Temperature plays a key role in how ruptures in the Earth's crust happen and earthquakes are generated. Accurate Models of earthquakes on faults in the Groningen gas reservoir, thus, require knowledge on the temperature profiles of past slip-zones —plaeotemperatures.

The incredible spatial resolution of the QDM allows us to map changes in magnetisation in the immediate vicinity of slip zones. Thereby, constraining the evolution of friction and temperature within fault rocks fault rocks analogous to those presently active in the Groningen reservoir.