Exploring the last white spot on Earth: ESRF inaugurates unique new X-ray facility

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This computer-generated image shows the different layers of the Earth: The outer solid crust, the viscous upper and lower mantle, the liquid outer core, and the solid inner core. Credit: ESRF

Scientists will soon be exploring matter at temperatures and pressures so extreme it can only be produced for microseconds using powerful pulsed lasers. Matter in such states is present in the Earth's liquid iron core, 2500 kilometres beneath the surface, and also in elusive "warm dense matter" inside large planets like Jupiter. A new X-ray beamline ID24 at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France, allows a new quality of exploration of the last white spot on our globe: the centre of the Earth.

We know surprisingly little about the interior of the Earth. The pressure at the centre can be calculated accurately from the propagation of Earthquake waves, and it is about three and a half million times atmospheric pressure. The temperature at the centre of the Earth, however, is unknown, but it is thought to be roughly as hot as the surface of the sun.

ID24, which was inaugurated today, opens new fields of science, being able to observe like in a time-lapse film sequence many rapid processes, whether laser-heating of iron to 10.000 degrees, charge reactions in new batteries or catalysts cleaning pollutants. It is the first of eight new beamlines built within the ESRF Upgrade Programme, a 180 million Euros investment over eight years to maintain the world-leading role of the ESRF. ID24 extends the existing capabilities at the ESRF in X-ray absorption spectroscopy to sample volumes twenty times smaller and time resolutions one thousand times better than in the past.

This image shows the heating of a catalyst sample in an "in situ" cell at actual operating conditions. The catalyst is studied using time-resolved X-ray absorption spectroscopy. At ID24, the time resolution can be as short as a few microseconds. Credit: ESRF

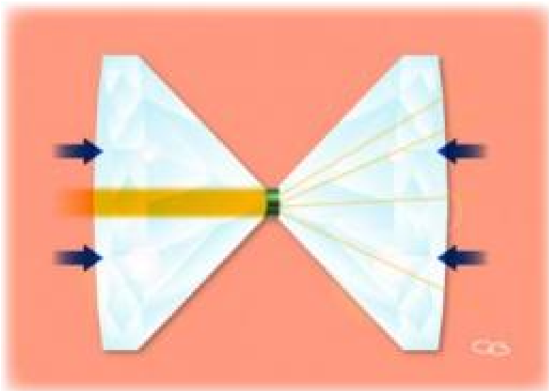
"Scientists can use several other synchrotrons notably in Japan and the

U.S for fast X-ray absorption spectroscopy, but it is the microsecond time resolution for single shot acquisition (or experiments) coupled to the micron sized spot that makes ID24 unique worldwide," says Sakura Pascarelli, beamline responsible scientist for ID24. "The rebuilt ID24 sets the ESRF apart, and even before the first users have arrived, I am asked to share our technology."

The Earth's interior is literally inaccessible and today it is easier to reach Mars than to visit even the base of the Earth's thin crust. Scientists can however reproduce the extreme pressure and temperature of a planet's interior in the laboratory, using diamond anvil cells to squeeze a material and once under pressure, heat it with short, intense laser pulses. However, these samples are not bigger than the size of a speck of dust and remain stable under high temperatures only for very short time, measured in microseconds.

Thanks to new technologies employed at ID24, scientists can now study what happens at extreme conditions, for example when materials undergo a fast chemical reaction or at what temperature a mineral will melt in the interior of a planet. Germanium micro strip detectors enable measurements to be made sequentially and very rapidly (a million in one second) in order not to miss any detail. A stable, microscopic X-ray beam means they can also be made in two dimensions by scanning across a sample to obtain a map instead of a measurement only at a single point. A powerful infrared spectrometer complements the X-ray detectors for the study of chemical reactions under industrial processing conditions.

Today, geologists want to know whether a chemical reaction exists between the Earth's mostly liquid core and the rocky mantle surrounding it. They would like to know the melting temperature of materials other than iron that might be present in the Earth's core in order to make better models for how the core -- which produces the Earth's magnetic field -- works and to understand why the magnetic field changes over time and periodically in Earth's history, has disappeared and reversed.



This illustration depicts a diamond anvil cell which allows to compress microscopic pieces of material to pressures of 3 Mbar and more. Laser pulses (black arrows) then heat the sample and an X-ray beam (orange) passes through the cell to probe the states of matter at these extreme conditions. Credit: ESRF/Format Editions

We know even less about warm dense matter believed to exist in the core of larger planets, for example Jupiter, which should be even hotter and denser. It can be produced in the laboratory using extremely powerful laser shock pulses compressing and heating a sample. The dream of revealing the secrets of the electronic and local structure in this state of matter with X-rays is now becoming reality, as ID24 allows to look at sample volumes 10000 times smaller than those at the high power laser facilities, making these experiments possible at the synchrotron using table top lasers.

The ID24 beamline works like an active probe rather than a passive detector, firing an intense beam of X-rays at a sample. It uses a technique called X-ray absorption spectroscopy where the way how atoms of a given chemical element absorb X-rays is studied in fine detail. From this data not only the abundance of an element can be deducted but also its chemical states and which other atoms, or elements, are in their immediate neighborhood, and how distant they are. In short, a complete picture at the atomic scale of the sample studied is obtained.

In the past weeks, ID24 has been tested with X-ray beams, and it will be open for users from across the world as of May 2012, after the ESRF winter shutdown 2011/12. The date for its inauguration was chosen to coincide with the autumn meeting of the ESRF's Science Advisory Committee of external experts who played a key role in selecting the science case for ID24 and the other Upgrade Beamlines.

"ID24 opens unchartered territories of scientific exploration, as will the seven other beamlines of the ESRF Upgrade Programme. The economic crisis has hit our budgets hard, and it is not obvious to deliver new opportunities for research and industrial innovation under these circumstances", says Harald Reichert, ESRF Director of Research. "I wish to congratulate the project team for extraordinary achievements, and I look forward to seeing some extraordinary new science."

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