SOLEIL SYNCHROTRON AND SCIENCE OF THE UNIVERSE

SCIENCE OF THE UNIVERSE...THE EXPRESSION EVOKES AN INFINITE FIELD OF INVESTIGATION EXTENDING FROM THE PLANET EARTH TO THE MOST REMOTE STARS. SCIENTISTS IN THIS FIELD MAKE OBSERVATIONS, DEVELOP THEORIES, COMPARE THEM, AND ADVANCE THEM... FOR THE PAST FIFTEEN YEARS, THEIR RESEARCH HAS BENEFITED FROM A REMARKABLE TOOL: SYNCHROTRON RADIATION. RESEARCH IN GEOPHYSICS, ASTROPHYSICS, AND ASTROBIOLOGY USING THIS LIGHT TENDS TO ADDRESS THE FUNDAMENTAL QUESTIONS:

WHAT ARE THE ORIGINS OF LIFE?

WHAT IS INSIDE THE EARTH?

The Huygens probe dives into Titan's atmosphere. Artist's conception. Credit: ESA.

TITAN: A GOOD CANDIDATE FOR THE SEARCH FOR THE ORIGINS OF LIFE?

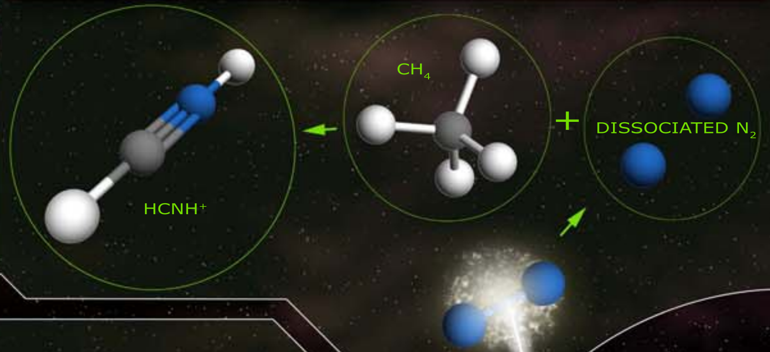
THE CASSINI-HUYGENS MISSION

Cassini-Huygens is the first space mission devoted to the exploration of Saturn and its largest satellite, Titan. The vessel began orbiting Saturn on 1st July 2004 after a seven-year voyage covering 3.5 thousand million km. On 14th January 2005, the Huygens probe plunged into Titan's atmosphere and landed on its surface. One of the objectives of the mission is to increase our knowledge of the chemical mechanisms that can lead to the creation of life.

IN THE LABORATORY

Because it is continuous and tunable, synchrotron radiation simulates the ionising activity of the Sun.

The operator subjects a mixture of nitrogen (N_2) and methane (CH_4), the two main components of Titan's atmosphere, to ultraviolet synchrotron radiation. By selecting a precise energy, the scientist breaks the complex chemical processes occurring there into elementary reactions and observes how the species produced are formed. An interesting result: in a certain excited state of nitrogen, after its dissociation by the ultraviolet rays, a significant quantity of $HCNH^+$ is formed. This ion is said to be responsible for the formation of amino acids.



THE HOMOCHIRALITY OF LIFE

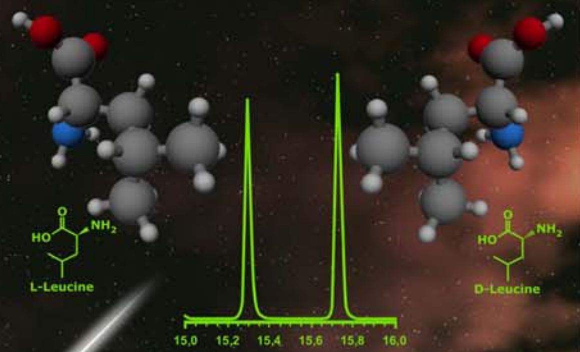
CHIRALITY AND POLARISATION: TWO DIFFERENT EXPRESSIONS OF ASYMMETRY.

The vast majority of biological molecules come in two versions which are optically the reverse of each other: these are chiral molecules. When chemists synthesize them in a laboratory, they generally obtain equal numbers of right- and left-hand forms. In living organisms, however, certain fundamental molecules are present in one form only. Thus amino acids, the constituents of proteins, are all left-handed, whilst DNA sugars are right-handed. The same applies to hormones, enzymes, and all the chemical equipment by which living things operate and reproduce. The homochirality of life is often heard of, but where does it come from? Was it started in interstellar space by a light which was also asymmetric, i.e. polarised?

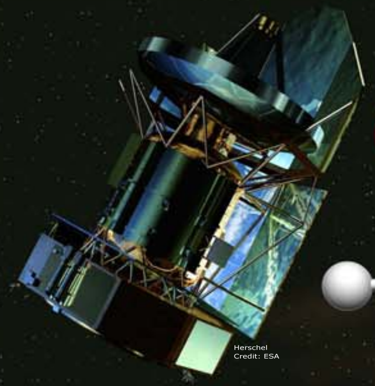
IN THE LABORATORY

Because its polarisation is adjustable, synchrotron radiation can be used to study molecular symmetry.

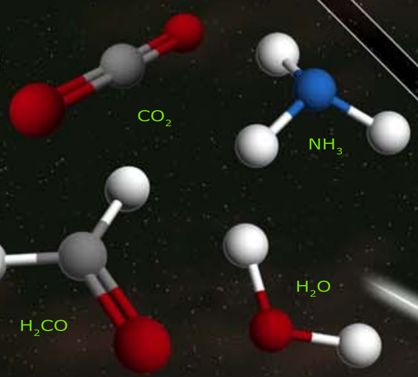
A sample of leucine (an amino acid that has a strong presence in the human body) is irradiated under laboratory conditions with left- and right- circularly polarised synchrotron radiation. Initially, the sample has as many right-hand forms (R) as left-hand forms (L). After 20 hours of irradiation, there is a 2.6% excess of the right-hand form. This result suggests that the homochirality of amino acids appeared in interstellar space. These asymmetric amino acids could later have been transported to Earth, for example by meteorites, where they could eventually have triggered the creation of life...

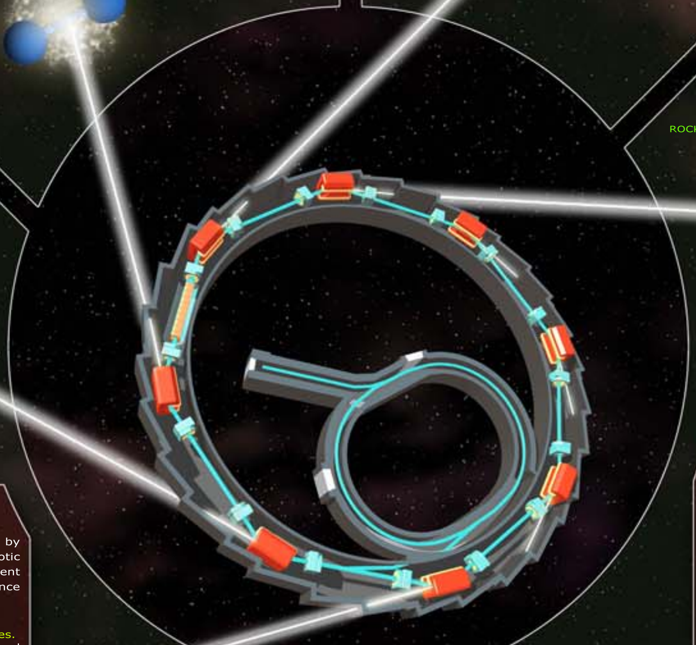


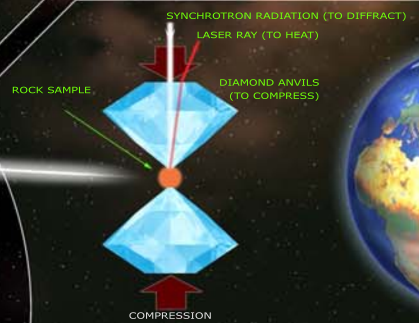
Strongly polarised radiation was discovered in a molecular cloud of the Orion nebula. Identical light must have existed in the nebula that gave birth to our solar system...

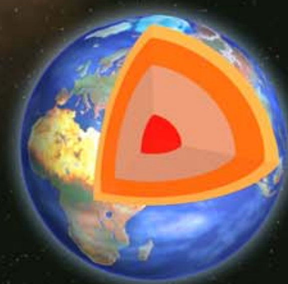


Herschel Credit: ESA









THE INTERSTELLAR ENVIRONMENT: A VACUUM... FULL OF ORGANIC MOLECULES

THE HERSCHEL MISSION

The Herschel satellite, whose launch is scheduled for 2008, will perform an inventory of the molecules in interstellar space by recording their spectrum in the infrared domain (more than a hundred of them are already known, including some prebiotic molecules). Molecules will not be identified immediately, however, because the spectra obtained depend on the ambient temperature and pressure conditions in space. Preparations for the mission must therefore include constituting a spectral reference library.

IN THE LABORATORY

Brilliant, stable, with very little divergence, synchrotron radiation can be used to record the infrared spectrum of very dilute molecules.

Scientists perform laboratory synthesis of molecules liable to be present in the interstellar environment and record their infrared spectra by varying the temperature and pressure in 'spatial' conditions. To identify the absorption lines of very dilute molecules, the infrared beam must perform many return trips to and from the analysis cell. Synchrotron radiation allows these long optical paths to be travelled with little divergence.

SOLEIL, A CALIBRATION STANDARD SOURCE

SOLEIL can operate as a calibration source in the UV and X range, to become the national reference for these types of photonic radiation.

THE DEPTHS OF THE EARTH: EXTREME CONDITIONS

INSIDE THE EARTH

To study the internal structure of the Earth, geophysicists combine two 'indirect' investigation methods: the study of meteorites and the study of seismic waves. Meteorites give information about the chemical composition of the layers, and seismic waves provide data about the density of materials and the discontinuities between layers. They cross-reference these data and establish models which are then validated experimentally.

IN THE LABORATORY

Because it is highly focused, synchrotron radiation is used to determine the crystallographic structure of very small samples of material (a few tens of microns).

A micro-sample of perovskite $MgSiO_3$ is subjected to the extreme conditions that prevail in the Earth's lower mantle (e.g., 140 GPa, 2500 K). It is compressed between two diamond anvils and heated by infrared laser. Synchrotron radiation provides an intense, focused beam of X photons, which diffracts on the sample. The diffraction figure obtained allows geophysicists to study the properties of the compound $MgSiO_3$ (density and elasticity) for each pressure–temperature pair.

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