An instrument open to the scientific community through the lasers and plasmas institute (ILP)

An essential instrument for the Simulation Program run by CEA's Military Applications Division, the Megajoule Laser (LMJ) and its prototype, the Laser Integration Line (LIL), will also be opened up to the scientific community for experiments on high-energy lasers and plasmas, stellar plasmas in particular.

The great scientific instrument formed by the Megajoule Laser (LMJ: Laser Mégajoule), together with its **laser** chain of several **petawatts**, is to be opened up to academic research. CEA, the French CNRS (National Scientific Research Council), the École Polytechnique and Bordeaux-I University signed, on 3 March 2003, the framework convention setting up the Lasers and Plasmas Institute (ILP: Institut lasers et plasmas). The institute's remit, on a national scale, will be to coordinate and develop, on the one hand, the science and technology areas involved in high-energy lasers and their applications, and, on the other hand, the physics of laser-driven dense, hot **plasmas**. (1) The institute includes a research federation (ILP–Recherche), presently bringing together over twenty laboratories, spread over five regions. ILP's remit is also to foster the bringing to market and commercialization of technologies, and technology transfers, arising from construction of high-energy lasers, and to play a part in the European research drive centering on large laser facilities. The institute will further act as project leader in the setting up and operation of new research tools, such as the Multi-Petawatt Laser, associated with the Laser Integration Line (LIL).

The ILP–Research federation carries through a threefold remit for research, training, and acting as an access service to large laser facilities. Its scientific program centers on **inertial-confinement fusion** (ICF), with a view to power generation, and is extensively involved in the advancement of the sciences concerned with matter in extreme conditions. The main themes supported may, essentially, be summed up as follows:

- the physics of inertial-confinement fusion, leading on to a number of fundamental and applied research areas;
- fusion-plasma diagnostics, with an emphasis on the complementarity between **X-radiation** sources and particle sources (**proton** radiography, **neutron** imaging);
- optics and lasers; in this key area for the future of inertial-confinement fusion, research projects are concerned, in particular, with identifying and overcoming processes limiting laser performance, and with enhancing repeat rate. Finally, in the field of very-high-intensity lasers, ILP is seeking, in conjunction with the Aquitaine Region (south-western France) and CEA/CESTA, to pave the way leading from petawatt (10^{15} watts) to exawatt (10^{18} watts).

A few examples from the realm of astrophysics will serve to illustrate, in the context of the present issue, devoted as it is to our **star**, the range and extent of the research fields related to inertial-confinement fusion. The experimental devices used to achieve mastery of inertial confinement of plasmas are, by their very operating principle, powerful means for the investigation of the physics of matter in extreme conditions. Further, the very close coupling between laser experiments and intensive numerical simulation is an effective factor making for the rise in the **modeling** of astrophysical objects.

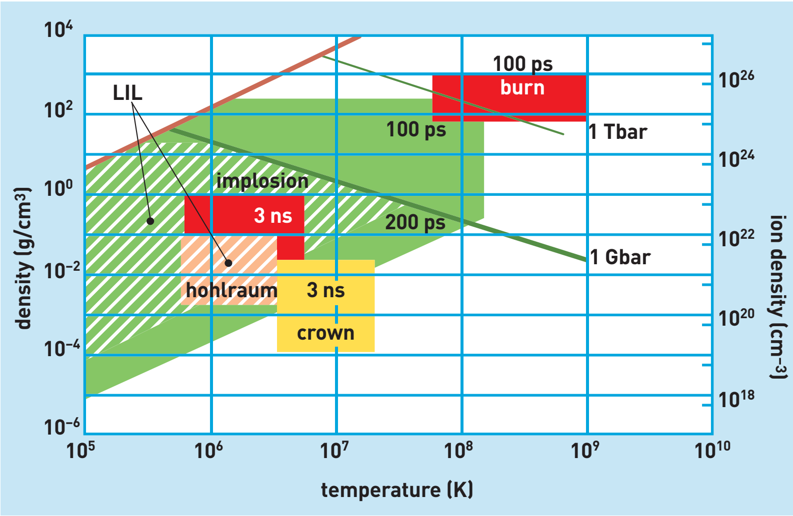

Figure.
Representation of the temperature domain (expressed in kelvins) and density domain (expressed in number of ions per cubic centimeter) covered in an experiment involving implosion of a DT capsule, leading to **ignition** and burn, in the indirect-drive regime. Once the ultraviolet laser beams' energy enters inside the hohlraum, where it is converted into X-radiation characteristic of a temperature of several million degrees, several types of plasma, of varying characteristics, are generated. Ablation of the hohlraum gold yields the "**hohlraum** plasma," whereas that of the DT target's shell yields less dense plasma, propelled by a violent explosion. Naturally, it is inside the imploding capsule itself that the densest, hottest plasmas are generated. Ignition of thermonuclear reactions finally brings the fusion plasma to a temperature of about a billion degrees. The hatched regions correspond to the domain that will be open to investigation with the Laser Integration Line, the prototype of the Megajoule Laser. The order of magnitude is also shown, on this figure, for plasma life spans in each characteristic domain, and two equal-pressure lines (isobars) serve to delimit the pressure domain lying between 10 **gigabars** and 1 **terabar**. The red diagonal line represents the characteristics of plasmas found in the Sun, from the surface (photosphere) down to the core. It should be noted that inertial-confinement fusion plasmas are slightly denser than the Sun's core, and also much hotter.

Simulating the violent Universe

The nonstationary character of laser experiments is put to advantage in order to simulate a large number of violent processes occurring in the Universe: shock-waves, **supernova** explosions… This aspect is specific to laser-driven plasmas, where the great flexibility available as regards the nature of the targets allows shocks

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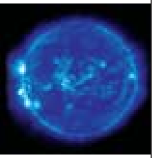

of various kinds to be generated, travelling at over a hundred kilometers per second, through homogeneous or heterogeneous media. The relevance, in astrophysical terms, of such experiments relies in part on the existence of scale-transformation laws, making it possible to refer back to a laboratory experiment the investigation of a process for which the characteristic times and distances involve astronomical scales.

Towards the physics of the extreme

The plasmas found in planetary and stellar interiors cover a very wide thermodynamic domain, which only the new generation of power lasers makes it possible to investigate. They open the way to experimental determination of such fundamental physical data as the radiative properties of dense, hot plasmas, relevant to a number of astrophysical objects (stellar interiors, **accretion disks** in the vicinity of **black holes**…), or the **equation of state** of colder plasmas, brought to very high pressures (greater than 1 **megabar**), and thus dominated by Coulomb interactions between particles.

At the core of planets...

The experimental investigation of the thermodynamic properties of dense, hot matter is an instance of transverse activity, being related as it is equally to the design of energy-gain targets (properties of D_2, CHBr or BeCu) and the understanding of the internal structure of planets. For over twenty years, the description, by way of at times contradictory models, of the behavior of fluids in the conditions prevailing in planetary interiors has presented an intractable problem in atomic physics. The properties, under very high pressure, of iron, in the Earth's core, of **hydrogen** inside Jupiter or Saturn, or of water inside Neptune and Uranus are far from being well understood. In these environments, pressures prevail of several hundred **gigapascals**, together with relatively modest temperatures, of a few thousand degrees. Very-high-power lasers allow this singular domain to be investigated: the goal is indeed the creation – for a few **nanoseconds** – of minuscule "planetary cores," in order to investigate their thermodynamic properties. The fusion curves of a variety of materials, their equations of state and solid–liquid–plasma transitions may be investigated by varying laser-beam intensities.

... as of stars

The flow of radiation inside stars and stellar atmospheres determines their structure, their evolution and their lifespan. It is controlled by processes of **photon** scattering, absorption and emission by **electrons**, which dictate the rate of the X-radiation's slow progress, from the star's interior to the surface, where the energy is finally radiated out into space. It is in the spectral range 0.1–1 **keV** (12.4–124 **nanometers**) that interaction between photons and (partly **ionized**) matter is at its most intense, but equally hardest to compute! For some years now, experiments on the absorption of radiation in plasmas have contributed to advances in modeling their **opacity** to X-radiation. Such breakthroughs in atomic physics, fundamental as they are for the mastery of the physics of ICF, have also enabled greater mastery in modeling pulsating stars such as the Cepheids, providing as they do a yardstick for the scale of distances in the Universe. They further contribute to closer agreement between models of the Sun's internal structure and data originating in **helioseismological** observations, yielding precise evidence as to the physical conditions prevailing inside our star.

Thus, the Laser Integration Line, along with its successor, the Megajoule Laser, by allowing conditions to be accessed that are ever closer to astrophysical plasmas, should mark a major stage in the progress of that oldest of sciences, astronomy.

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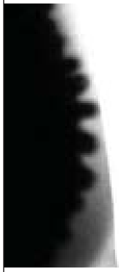
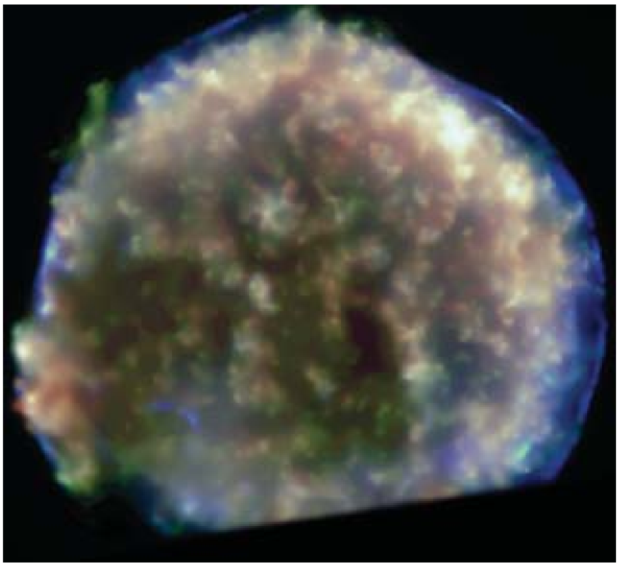


CEA-DAM



NASA/CXC/SAO

Image, acquired by the Chandra X-ray observation satellite in the 300 eV–7 keV spectral band, of the remnants of the type-Ia supernova whose explosion was observed by Tycho Brahe in 1572. This remnant is circumscribed by a shockwave (emitting photons covering the 2.56–7 keV band, coded in blue), propagating into the interstellar medium. This is generated by the rapid, albeit decelerated, expansion of the supernova's own materials (the so-called ejecta), of which the scalloped outer surface may be seen, observed in the 0.3–2.65 keV band. This deceleration may induce development of instabilities of the Rayleigh–Taylor type, this being responsible for the "sponge-like" appearance of the ejecta–interstellar medium interface. The same kind of instability (at left) has been experimentally reproduced and analyzed (Astrolabe I experiment) after the passing of a strong shock, at the interface between a heavy material and a light material, brought by shock conditions to the plasma state. The energy used to generate in the heavy material (left) the shockwave passing into the light material was delivered by one of the Phébus laser's two beams (CEA/DAM). The second beam was used to yield, by lateral X-radiography, the image shown here, of the interface destabilized by deceleration of the heavy material, induced by the light material. This type of experiment makes use of the ability of power lasers to propel dense, hot plasmas to very high velocities, greater than 100 km/s.