Design of Zeeman spectroscopy experiment with magnetized silicon plasma generated in the laboratory

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Compressing a strong seed magnetic field by laser driven implosion makes it possible to generate a strong magnetic field of more than 10 kT on the Earth. 10 kT is close to a strength on the surface of a compact star like a white dwarf. Magnetic field strength is one of the most important parameters for understanding the structure of the compact stars. Zeeman effect is frequently used as a measure of the magnetic field in the astronomical observation. The Zeeman effect is splitting of a spectral line into several components in the presence of a magnetic field. High power laser is a novel tool to generate simultaneously both strong magnetic field and high temperature plasma enough to simulate the astronomical Zeeman effect in the laboratory under controlled conditions.

We are designing an experiment to measure the Zeeman splitting in the soft X-ray spectrum emitted from a magnetized silicon plasma generated by laser. Silicon is one of the abundant materials in the universe. We will use a capacitor coil target to generate a kT level seed field and compress the seed field by laser driven implosion. According to hydrodynamic calculations, the peak field strength of 10 kT is achievable on GEKKO-XII. At the peak compression timing, plasma dynamic pressure (10^3 Mbar) is much larger than the 10-kT magnetic field pressure (10^2 Mbar).

Two coils will be used in order to generate a spatially uniform magnetic field. A cylindrical plastic shell filled with a low density SiO_2 foam (5 mg/cm^3) will be placed in the magnetic field and the cylinder surface will be irradiated by high power laser. The seed magnetic field is compressed by the plasma shell converging to the center of the shell, SiO_2 becomes a plasma having 10^{20} cm^{-3} of electron density and 80 eV of electron temperature at the peak compression timing. The magnetized SiO_2 plasma emits soft X-rays and the soft X-rays will be measured with a grazing incident soft-x-ray spectrometer from the direction along the cylinder axis. The Zeeman splitting width of a Si line (50 nm) is calculated to be 0.7 nm in 10 kT of the magnetic field strength. This splitting is measurable with the spectrometer ($\Delta\lambda/\lambda > 1/100$). Compressed magnetic field strength will be measured by using an independent proton radiography technique. Laboratory experiments on the Zeeman effect under such a strong magnetic field will give astrophysicists valuable information to deepen the understanding of the universe.