Lightweight carbon fiber reinforced plastic structures for astronomical instruments

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Using carbon fiber reinforced plastic (CFRP) in the basic structure of astronomical instruments can improve their sensitivity and resolution. A CFRP structure for the X-Shooter spectrograph on the ESO VLT telescope offers distinct advantages over the present aluminum design.

Discovering the first generation of stars and galaxies is one of the highest-priority areas in modern astrophysics, creating a strong demand for greater sensitivity and resolution (spatial and spectral) in new astronomical telescopes. Consequently, there is a need for increasing the size of the collecting area of the telescopes (implying larger and larger mirrors) and for improving the performance of the instruments detecting the collected photons.

Limitations on how much mass the telescopes can carry puts a severe constraint on the very-complex new generation of astronomical instruments. Traditionally, aluminum or steel have been used for their basic support structure. However, CFRP offers a great range of attractive possibilities for designing a basic material with desired mechanical properties. A CFRP laminate can be designed to have a very low coefficient of thermal expansion (CTE) and a very high stiffness, which combined with a very low density, results in smaller deformations and higher eigenfrequencies than equivalent aluminum or steel structures.

CFRP in plate structures already has good properties, but lattice structures offer the possibility of optimizing materials for specific purposes. Since these structures carry loads in just one direction, the laminate properties need only be optimized in the axial direction. The properties are determined by the type of fibers and resin, the fiber volume content, the lay up angle distributions, and the layer thicknesses. By choosing these parameters properly, it is possible to design a laminate with better stiffness than steel, or a CTE close to zero with one-fifth the density of steel. Even negative CTE is obtainable, making it possible to compensate for other components of the structure with a positive CTE.

To illustrate how much can be gained by changing to a CFRP structure, we examined the design of the X-Shooter on the ESO VLT telescope. X-Shooter is a Cassegrain instrument covering simultaneously, for a single target, the electromagnetic spectrum from the UV to the near infrared in three spectrographs.

The main purpose of the X-shooter aluminum backbone structure is to keep the three spectrograph slits aligned independent of where it is pointing. Figure 1 presents a CFRP lattice structure. The flange interfaces directly with the inner steel ring of the telescope rotator bearing. Since no thermal deformations are allowed in the interface, the flange also is made out of steel. The rest of the structure is made out of CFRP struts with Invar connection points. The struts have been designed to give an optimal stiffness. In the center there is a CFRP plate providing the optical bench for the imaging optics.

Deformations with the aluminum and the CFRP structure have been simulated using finite-element analysis (FEA) with the telescope pointing 30° above the horizon and the rotator turning 360°. First, the strut dimension was optimized to give the same deformation as the aluminum design (see Figure 2). Then,
the dimension of the struts was increased to decrease the deformations. The CFRP design can give a gain of roughly a factor of three in the deformations.

For the chosen CFRP design, the thermal expansion within the operational temperature range of -20°C–+30°C is only about 7% of the expansion of the aluminum design. If the CFRP is optimized to give a low CTE, this value can be decreased further.

Conclusion
For astronomical instrumentation CFRP has important advantages compared to aluminum and steel, providing significantly smaller deformations and lighter structure, higher specific stiffness, much lower CTE, and the possibility for designing lattice structures optimized for a specific mechanical property.

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Niels Jessen graduated in 1982 as a mechanical engineer, with subsequent experience in the design of mechanics for space and ground-based telescopes and instruments for astronomy, material research, nanotechnology, wind, and nuclear energy.

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References