The Spatial Heterodyne Spectrometer: A New Tool for Atmospheric Science

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Instrument Basics

The basic Spatial Heterodyne Spectrometer (SHS) layout (figure 1) is similar to a Michelson Interferometer, with the mirrors in each arm replaced by reflection diffraction gratings tilted at an angle (Θ) with respect to the optical axis[1].

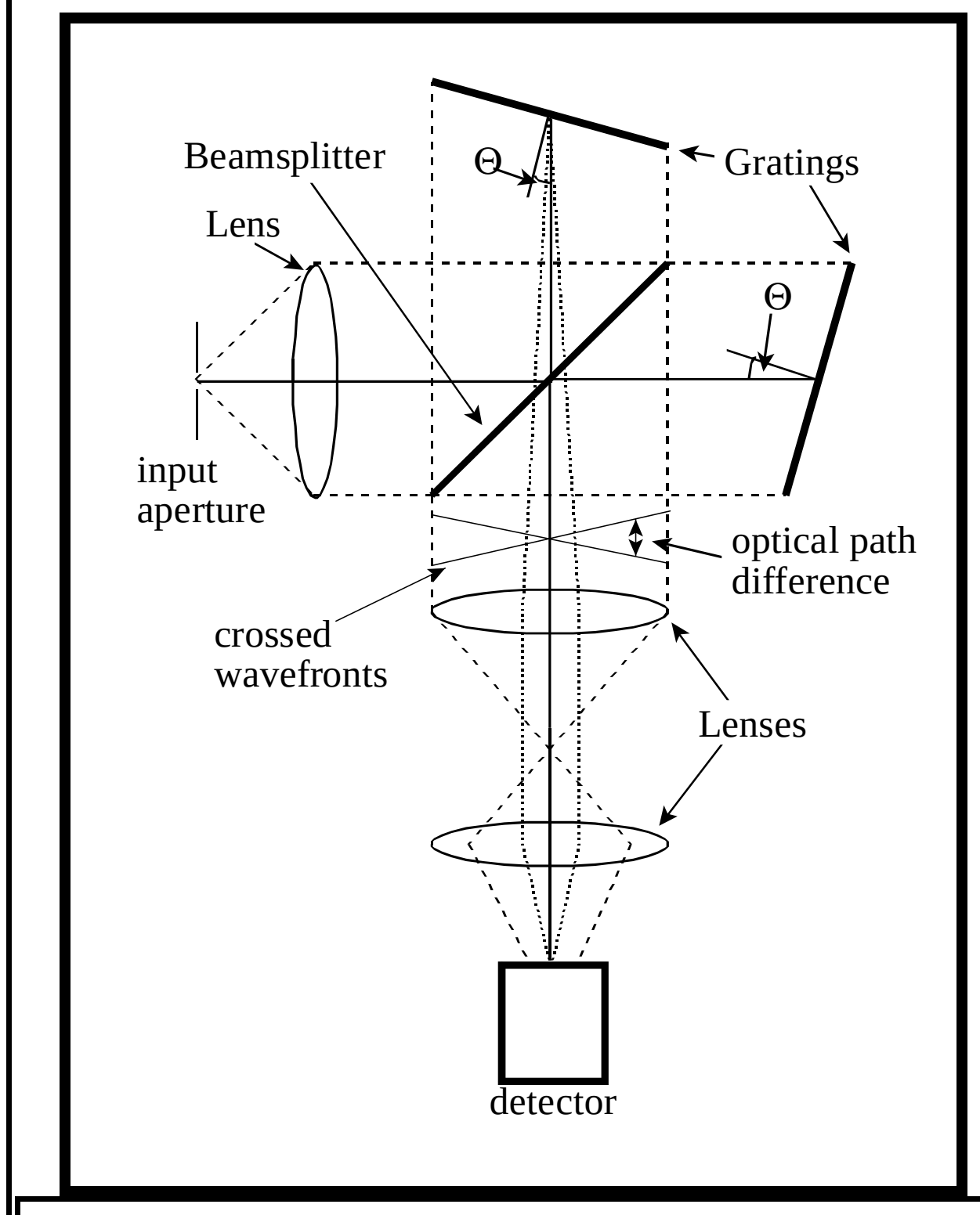


Figure 1. Schematic of basic SHS

Light collimated into the system emerges as crossed wavefronts, which interfere to create a Fizeau fringe pattern (figure 2). The spatial frequency of the fringe pattern, in the grating dispersion direction, is a heterodyned combination (difference frequency) of the input wavenumber(s) and the *Littrow wavenumber*. Littrow is the wavenumber for which light striking the gratings on-axis has its first-order diffraction come out on-axis. At that wavenumber, the wavefronts are co-linear, resulting in one bright fringe across the interferogram. This fringe pattern is imaged onto a two-dimensional detector.

The intensity function of this inteferogram is effectively a *cosine Fourier transform* of the input spectrum, centered on the Littrow wavelength.

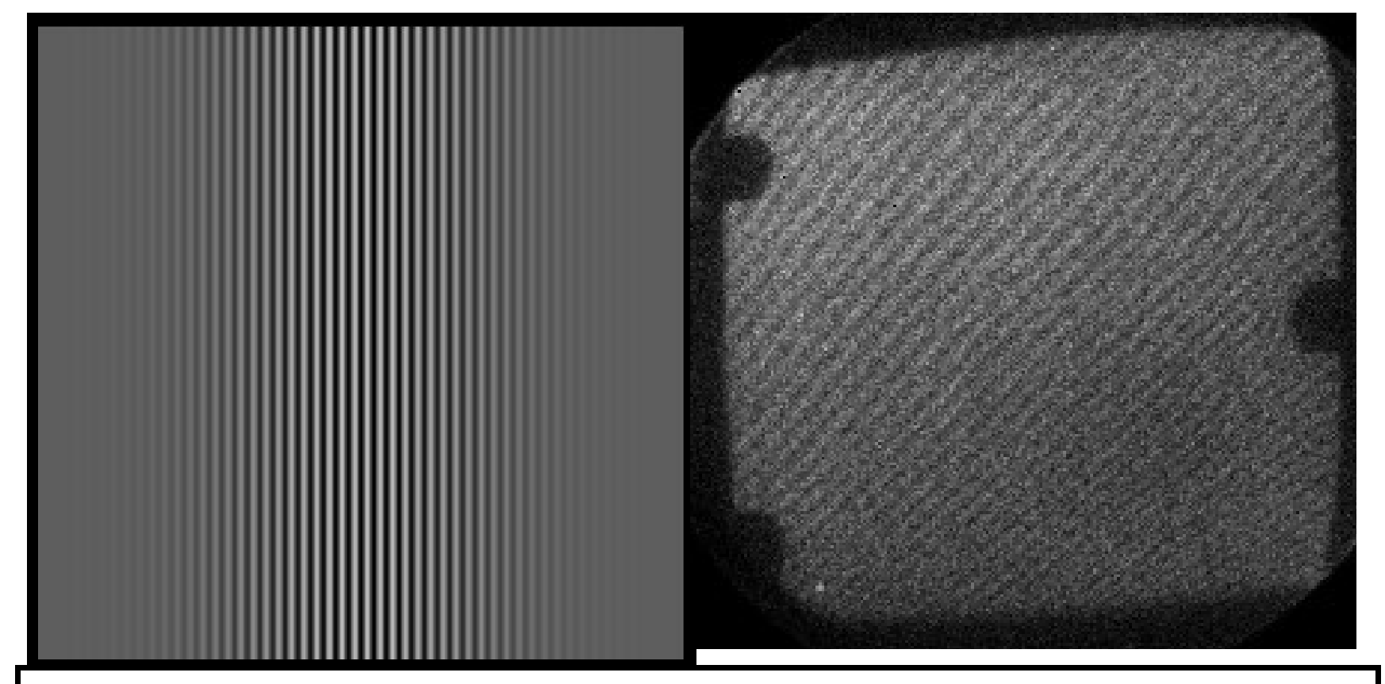


Figure 2. (*Left*) An idealized SHS interferogram, a Fizeau fringe pattern. (*Right*) A real SHS interferogram, from the instrument shown in figure 3.

Field Widening

Like a Michelson interferometer, the SHS can be field-widened by inserting prisms into each arm. The prisms in this case are wedged, so that, when the gratings behind them are viewed from the output, they appear rotated so as to be co-linear. Field-widening can increase the SHS etendue by a couple orders of magnitude over the basic configuration, making it very useful for diffuse-source observations.

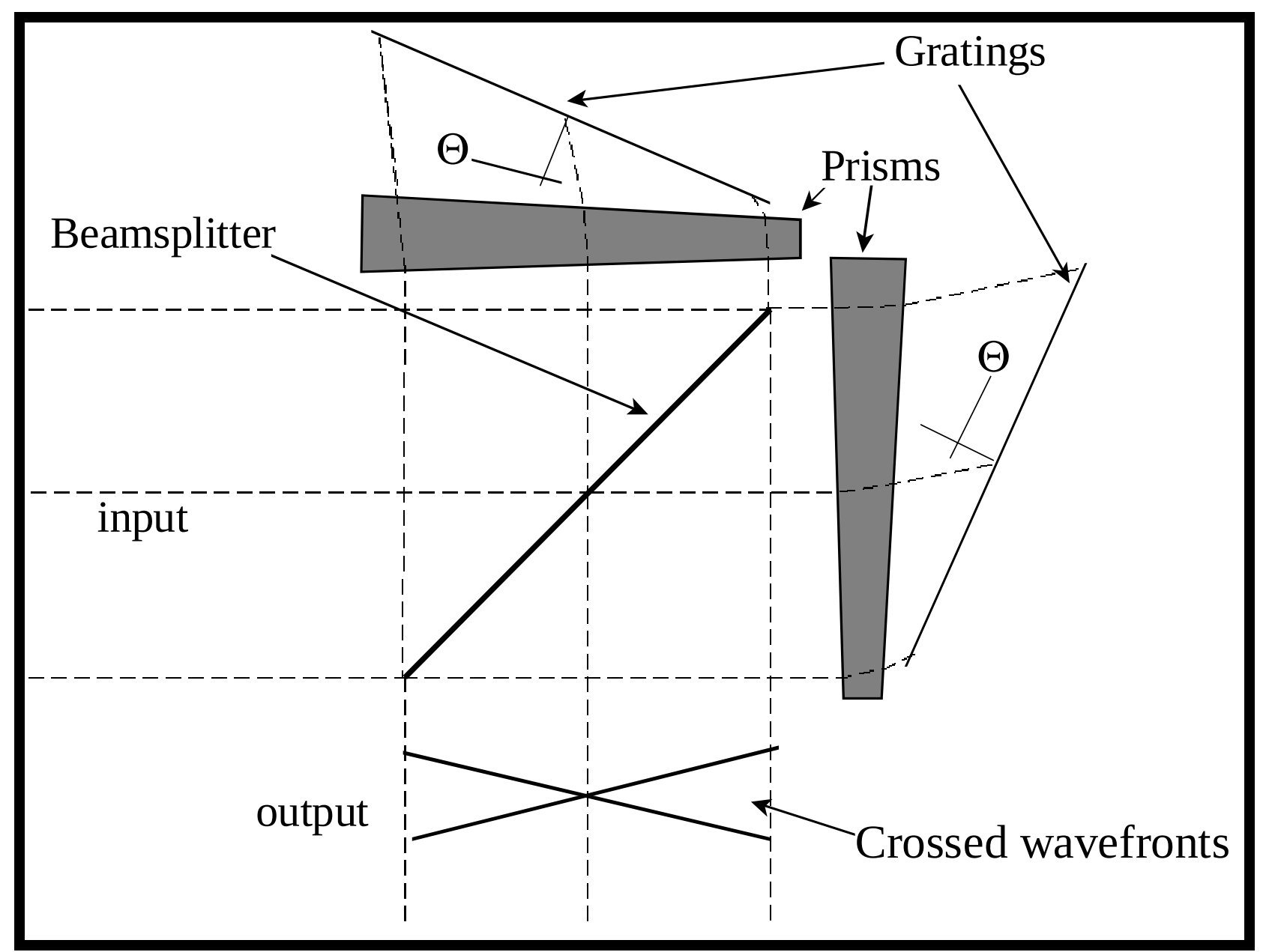


Figure 6. Gratings, beamsplitter, and prisms for the field-widened SHS

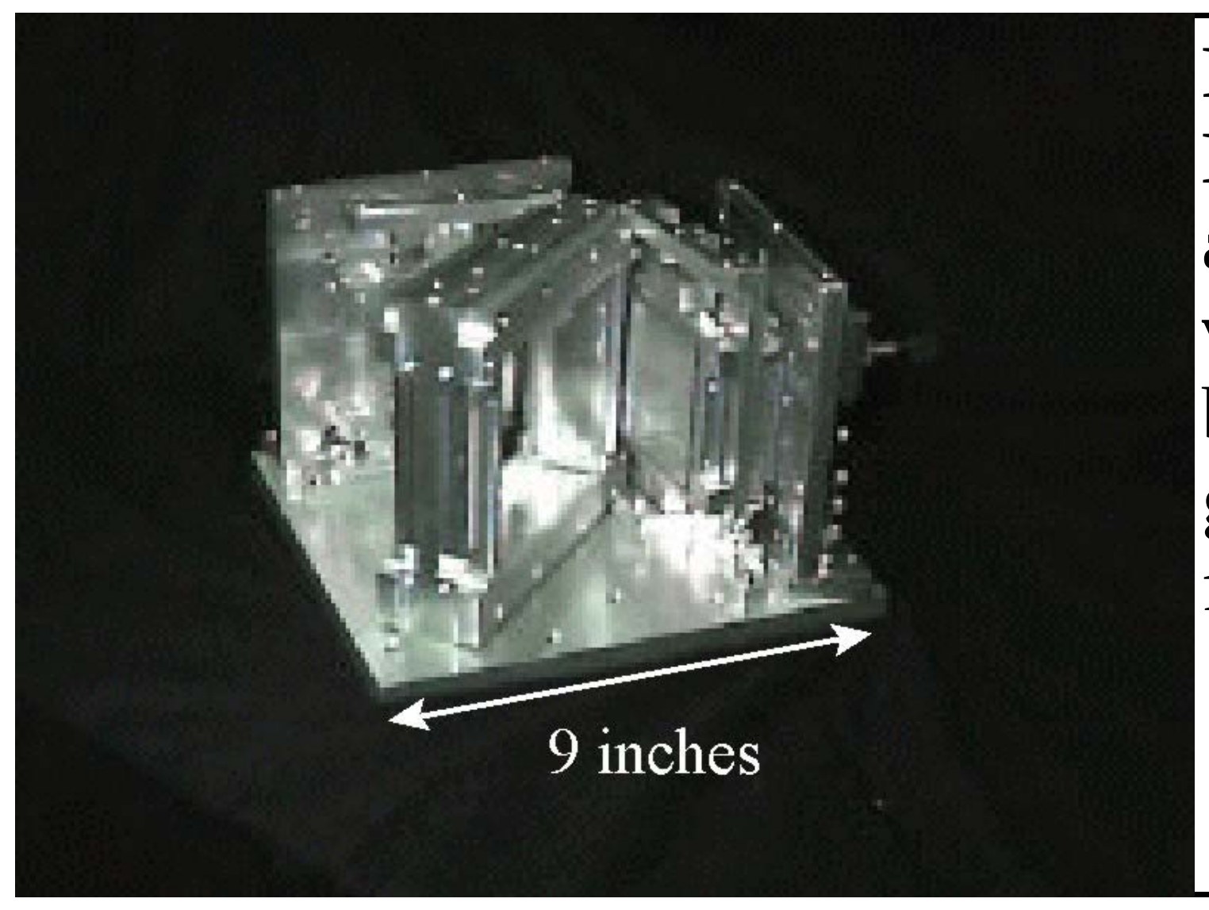
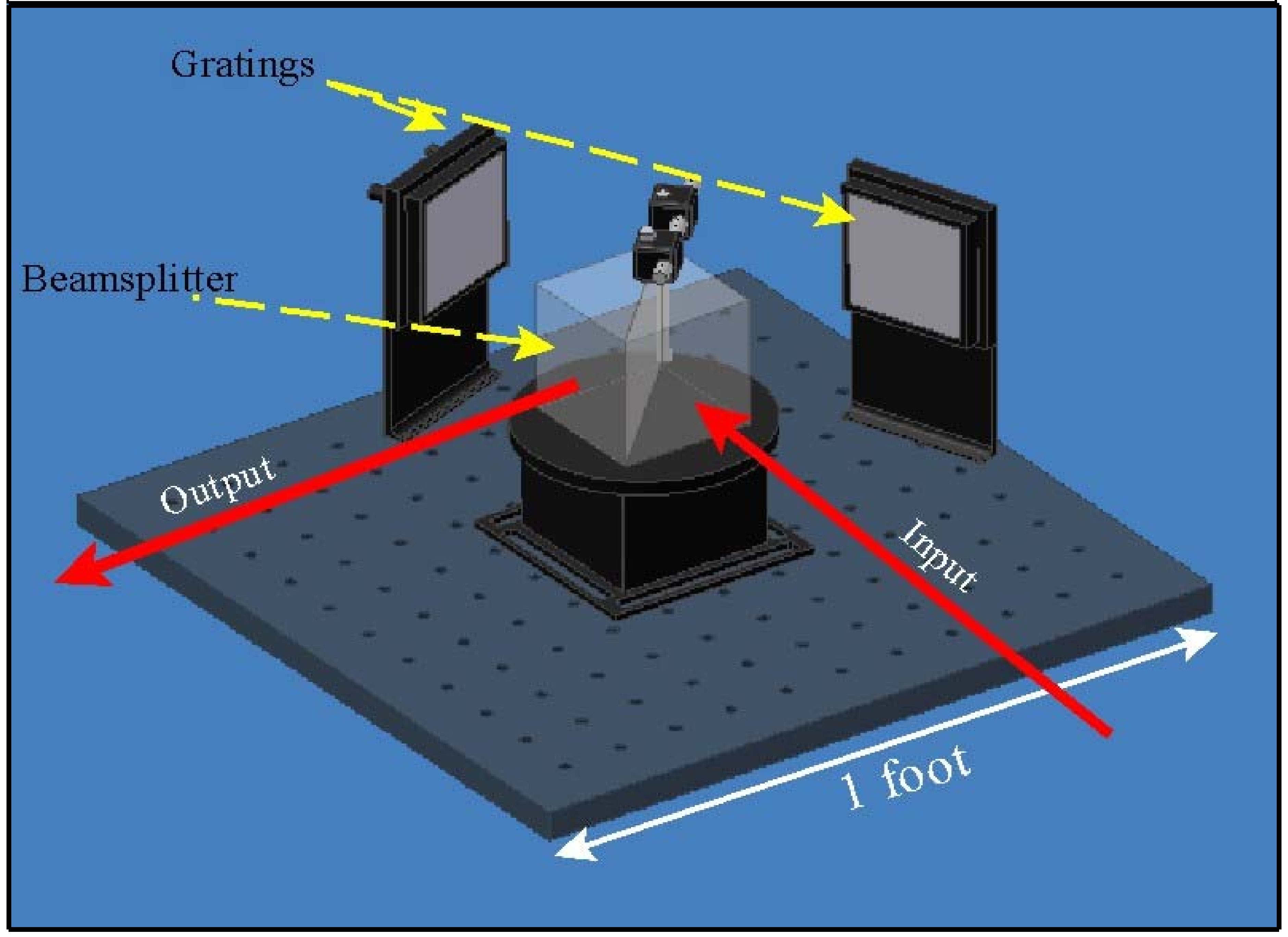


Figure 3. Cutaway view of a Spatial Heterodyne Spectrometer built for VUV astronomical observations at the University of Wisconsin—Madison[3]. The beamsplitter, field-widening prisms, and gratings were sandwiched between plates for stability.

Figure 4. Tabletop Layout for Spatial Heterodyne Spectrometer Proposed to CEDAR 2004 for Airglow Observations



Monolithic SHS

The monolithic SHS is a recent development which takes the greatest advantage to date of the compactness and stability advantages the SHS has over other interferometers.

First developed at the Naval Research Laboratory[2], the monolithic SHS fuses all the instrument's critical optics into a single block. Depending on the required resolving power and field of view, this block can be made quite small (figure 5). Such a design is especially advantageous for cases where space is at a premium (such as computer-card-based spectroscopy), and for airborne and space-based observations.

Further modifications to this design include the possibility of etching the gratings directly onto the arms of the interferometer; and, for work in the infrared, using solid blocks in the arms rather than hollowed-out spacers.

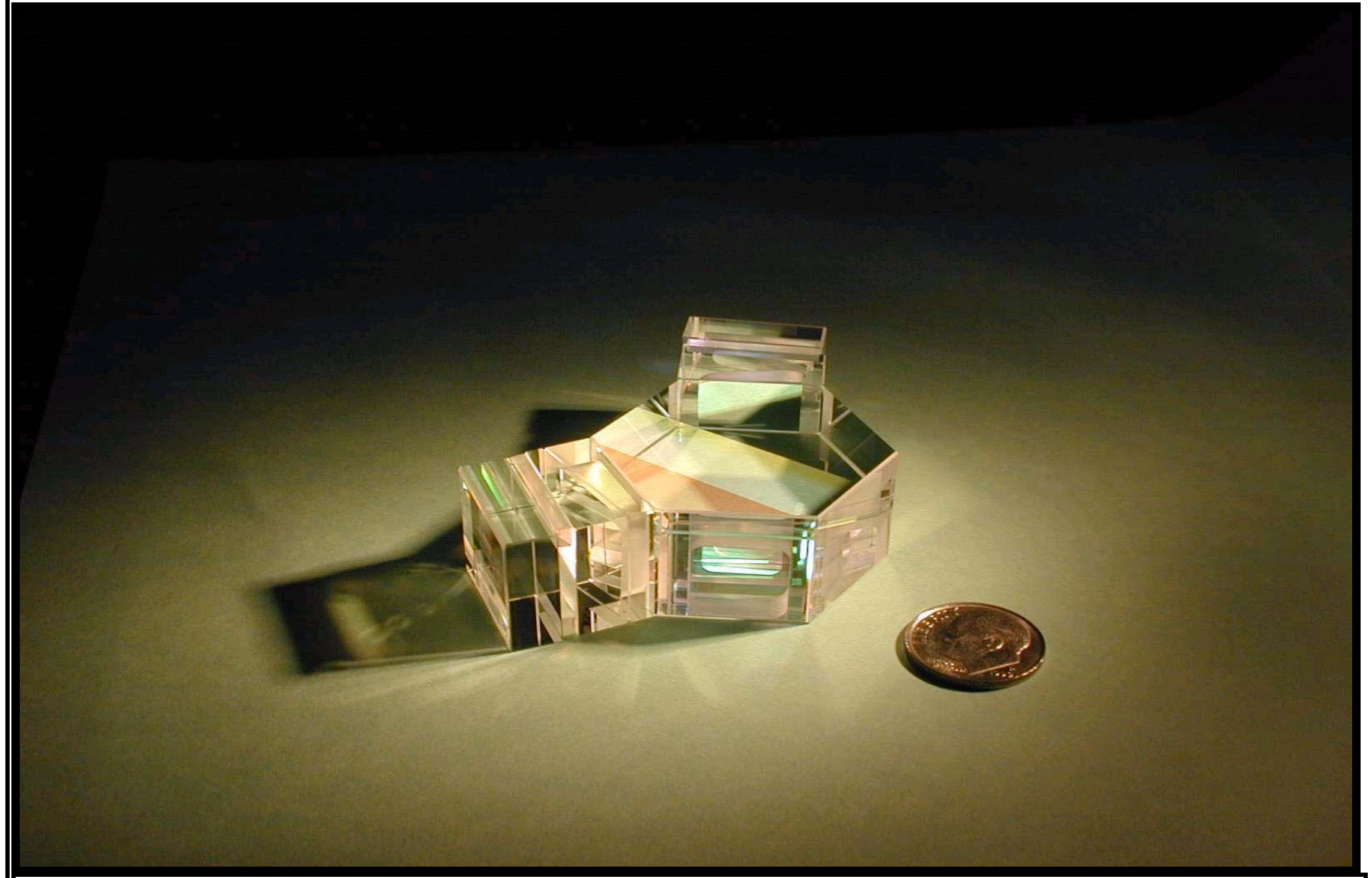


Figure 5. The monolithic SHS constructed at the Naval Research Laboratory in 2002.

Applications

Airglow Observations: Because of its observational flexibility, a single Spatial Heterodyne Spectrometer on a tabletop is very well-suited to study a host of airglow lines, including Bowen fluorescence (λ 8446), O II emissions (λλ 7320, 7330), and O I emissions (λ 6300). These all have important consequences for the energetics and dynamics of the middle atmosphere, as outlined in the CEDAR Phase III Report.

Planetary Atmospheres: Being particularly useful for space missions (its robustness and light weight are great advantages for launch), the SHS has a bright future in the exploration of the Solar System. Already, a monolithic SHS has been designed for space-based Earth observations[2], and such an instrument would be an extremely good fit for missions to study the atmosphere of Mars.

Advantages over Other Spectrometers

Slit Spectrometers

Compared to slit spectrometers at the same resolving power, the Spatial Heterodyne Spectrometer has distinct advantages in etendue and compactness.

Etendue: The resolving power of the SHS equals the theoretical maximum resolving power of its gratings. This would be the resolving power the gratings would have in a grating spectrometer with vanishingly small slits. Such small slits would lead to an impractically low etendue, while the SHS operates at the same resolving power normally.

Compactness: The SHS is also more compact at a given resolving power than slit spectrometers. Figure 6 shows a Rowland Spectrograph payload designed for VUV astronomical observations[4]. On the same scale, a comparable SHS payload would be about one-third the size (shown on the right in figure 6).

Conventional Interferometers

Conventional intereferometers — such as the Michelson and Fabry-Perot — share the SHS's advantages over slit spectrometers. However, unlike these other instruments, the SHS is *unscanned*. The range of path differences creating the interference is contained completely within the crossed wavefronts, requiring no movement of components or change in pressure or applied voltage to scan through (even in field-widened mode). This leads to advantages in robustness and flexibility.

Robustness: The optical pieces in the SHS module can be built into rigid structure (figures 3 and 5), with no delicate scanning mechanisms required. This makes SHS particularly suitable for harsh environments and space-based studies.

Flexibility: The SHS can also be assembled as separate pieces on a tabletop for ground-based observations. In this mode, the SHS can be designed to look, with similar resolution, at several lines hundreds of nanometers apart. If component efficiency is roughly constant over this range, the only necessary adjustment is to rotate the gratings to bring each spectral line, in turn, near Littrow.

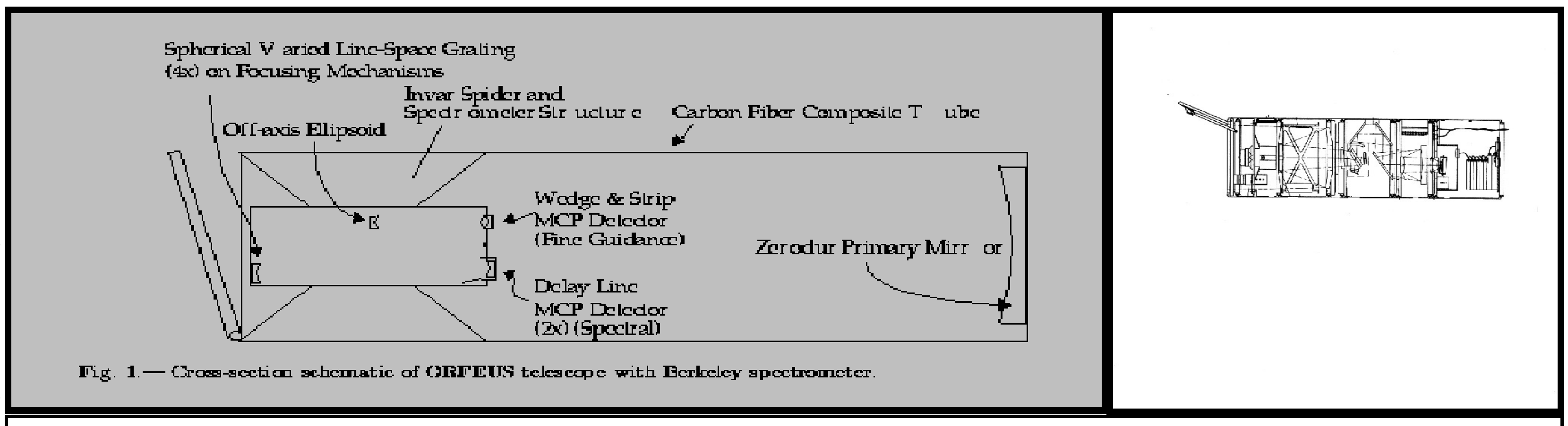


Figure 6. (*Left*) A Rowland Spectrograph payload for VUV astronomical observations. (*Right*) A comparable SHS payload, on the same scale.

References

1. Harlander, J., R. J. Reynolds, F. L. Roesler, Spatial Heterodyne Spectroscopy for the exploration of diffuse interstellar emission lines at far-ultraviolet wavelengths, *ApJ*, **396**, 730, 1992.

2. Harlander, John M., Fred L. Roesler, Christoph R. Englert, Joel G. Cardon, Robert R. Conway, Charles M. Brown, Jeff Wimperis, A robust monolithic UV interferometer for the SHIMMER instrument on STPSat-1, *App. Opt.*, **42**, 2829, 2003.

3. Watchorn, S. F. L. Roesler, J. Harlander, K. P. Jaehnig, R. J. Reynolds, W. T. Sanders, Development of the Spatial Heterodyne Spectrometer for VUV remote sensing of the interstellar medium, UV/EUV and Visible Space Instrumentation, *SPIE Proceedings*, **4498**, 2001.

4. http://albert.ssl.berkeley.edu/orfeus/orfeus-revised.html