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Recent auroral measurements using a field-widened interferometer spectrometer

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Utah State University and Air Force Geophysics Laboratory have been developing field-widened interferometer systems since the late 1960's. These instruments have been developed primarily to remotely sense spectral emissions from the night sky in the near infrared. However, the systems also have application for making measurements of any dim extended source.

The three generations of field-widened instruments developed have demonstrated increased throughput gains, and have been used to make excellent atmospheric emission measurements. The first FWI instrument was for visible and near ir application. It employed a large granite V-groove slide and a worm-gear drive. Results with this instrument were reported by Despain, et.al.[1,2] The need for a faster drive system became obvious for auroral work. Consequently, a second generation instrument using a gas-lubricated bearing was developed in 1973. This instrument has provided excellent results and is still making state-of-the-art measurements. Instrument description and measurement results using this instrument are summarized by Steed[3], Haycock[4], and Baker[5]. The current field operating configuration of this second generation system is described in this paper and recent auroral results are presented. A third generation rocketborne version of this instrument has been developed by Haycock, et.al.[6] Atmospheric measurements have been made using this instrument (Huppi[7]).

There are a number of possible configurations for field compensating an interferometer (Baker[8]). The methods used in all of the USU versions was first suggested by Connes[9] and is illustrated in Fig. 1. The plane mirrors of a standard Michelson are replaced by optical wedges which are mirrored on the back side and retardation is achieved by driving one of the wedges along its image plane. Second order spherical aberrations are essentially eliminated if compensated properly; the compensated set of theoretical limiting aberrations becomes those illustrated in Fig. 2. This figure shows a comparison of the field-widened field-of-view (FOV) limits imposed by chromatic aberrations, 4th order spherical aberrations, and astigmatism as a function of resolving power. A plot of $\Omega_M = 2\pi/R$, the limit for a conventional Michelson interferometer, is included in this figure for

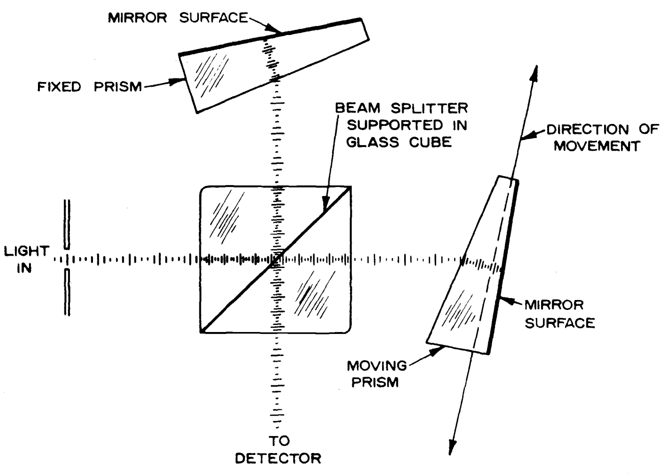

Fig. 1. Field compensation method used by Bouchariene and Connes.

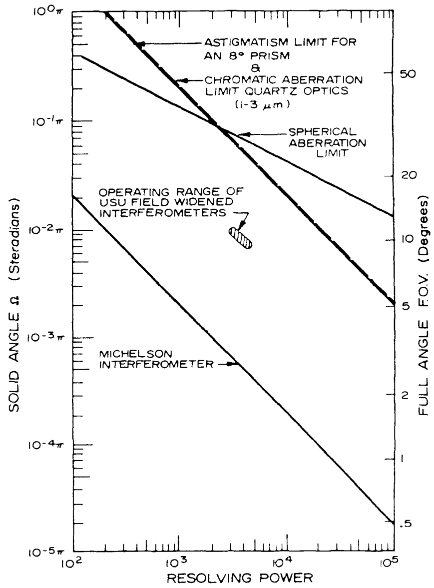

Fig. 2. Field compensated theoretical aberration limits compared with conventional Michelson system.

reference. The aberration limits for the field-widened case are: $\Omega = \Omega_M[n(n^2-1)/\Delta n]$ (chromatic), $\Omega = \Omega_M n(2R)^{1/2}$ (spherical), and $\Omega = 2\Omega_M/\tan^2\alpha$ (astigmatism), where Ω_M = max solid angle FOV for a standard Michelson interferometer, n = index of refraction of optical material, α = wedge angle, and R = resolving power.

It is noted that astigmatism varies with wedge angle; only the plot of an 8° wedge with n = 1.5 is shown in the figure. USU/AFGL instruments have utilized 8° wedges fabricated from quartz and CaF_2.

Experience has shown that theoretical FOV limits for the field-widened case are difficult to achieve since vignetting occurs before the limits can be achieved. The systems described achieve full angle fields-of-view in the 9-12° range depending on detector and wavelength region. If large throughput is to be achieved, large detectors and fast collector optics are needed to collect the radiation and this can be the FOV limiting factor.

The gains that have been achieved by field widening can also be seen from Fig. 2 where the actual operating region of the systems are indicated. It can be seen that Ω gains of more than an order of magnitude have been realized which translates to measurement time gains of more than a factor of 100. System specifications are contained in previous reports (Steed[3]).

Photographs of the field interferometer system are given in Figs. 3 and 4. The system is housed in two sections, an optical section shown in its cryogenic enclosure and the electronics and support equipment which are housed in a portable shipping container. The shipping container also serves as the field operating platform.

Fig. 3. FWI optical head in field operational environmental enclosure.

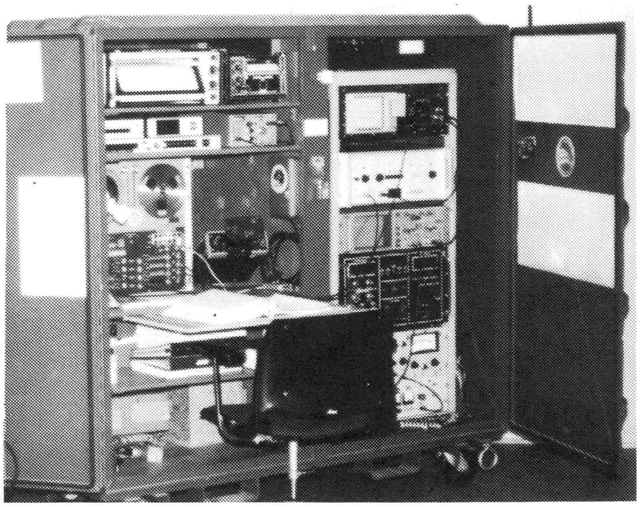

Fig. 4. FWI field support electronics including FFT unit and recording system.

The basic components in the electronic section are the drive control electronics for the interferometer, the time-code generator, and an FFT processing system which performs a 16,384 point transform and displays the results in less than a second at the end of each interferogram scan. The spectral results of each scan are continually updated on the display giving immediate feedback to the system operators on the status of the measurement. The FFT unit can also be set to co-add a number of scans if desired. Interesting spectral displays from the FFT unit can be permanently recorded on an XY plotter for future examination. The shipping rack also contains instrumentation for supporting experiments (radiometer, photometer, and weather information).

The interferograms are recorded on a Hewlett Packard 3968A analog FM instrumentation recorder mounted on the left side of the rack. Since near ir emissions from the night sky exhibit a line profile instead of a continuum, the interferogram dynamic range is not large. The dynamic range of the FM recorder is sufficient to handle the signal-to-noise ratio resulting from the sky source and little or no signal degradation has been observed as a result of the recording system. When performing blackbody calibrations, it is required to co-add a number of scans since the needed dynamic range is large for the broad spectral features of the internal calibration sources. During field operations the FFT unit receives its input from the playback amplifiers of the tape recorder so that the continually displayed spectrum demonstrates that the entire system is operating properly and data are properly recorded.

The FFT unit is a Unigon Model 4516 Real Time Spectrum Analyzer and is used as a field check on the system operation only. Data reduction is performed at the end of the field trip with a home-based special purpose computer which offers greater flexibility.

The interferometer enclosure is fabricated so that the instrument can be cooled to liquid nitrogen temperatures when desired. The enclosure contains a vacuum shell around the instrument and a 30-liter nitrogen holding tank to facilitate this cooling. When operated cryogenically, the cold boil-off gas from the liquid nitrogen is used to support the gas-lubricated bearing and then the dry nitrogen gas is exhausted around the window interface between the interferometer and the stack to prevent frost from building up on the interface window.

Fig. 5 shows one 40 second spectral scan of an auroral arc taken with this system in Andoya, Norway, on November 11, 1980. The FWI instrument was pointed at the zenith, and a separate dual channel radiometer (shown also in Fig. 3) was co-aligned with the interferometer to provide long-term OH and $O_2{}^1\Delta$ emission levels as well as help verify the interferometer calibration. The instrument was operating at a resolution of 2.5 cm^{-1} in the 0.85 to 1.7 μm spectral range. During the arc presence, a co-aligned photometer registered 30 kR of 3914 Å auroral emission in the FOV. The arc was fairly stable during the measurement period.

In addition to the N_2^+ Meinel, N_2^+1P, NI, and OI enhancements, the He 10830 Å line was observed to be enhanced during the arc and remained at an elevated level after the arc decreased. Detailed analysis of the data will be forthcoming in future publications. With the instrument throughput it is possible to obtain excellent signal-to-noise results in a single scan. Transient events such as aurora and twilight transitions can for the first time be analyzed at this spectral and temporal resolution.

Preliminary measurements with a very recently acquired Ge detector from Applied Detector Corporation indicates that an instrument sensitivity of better than 5×10^{-15} w/cm^2srcm^{-1} can be achieved with this system at 1.4 μm in a 20 second scan. When this detector is properly interfaced with the instrument, the FWI should be five times more sensitive than when the measurements reported herein were taken. This work has been sponsored by the Air Force Geophysics Laboratory and the Air Force Office of Scientific Research.

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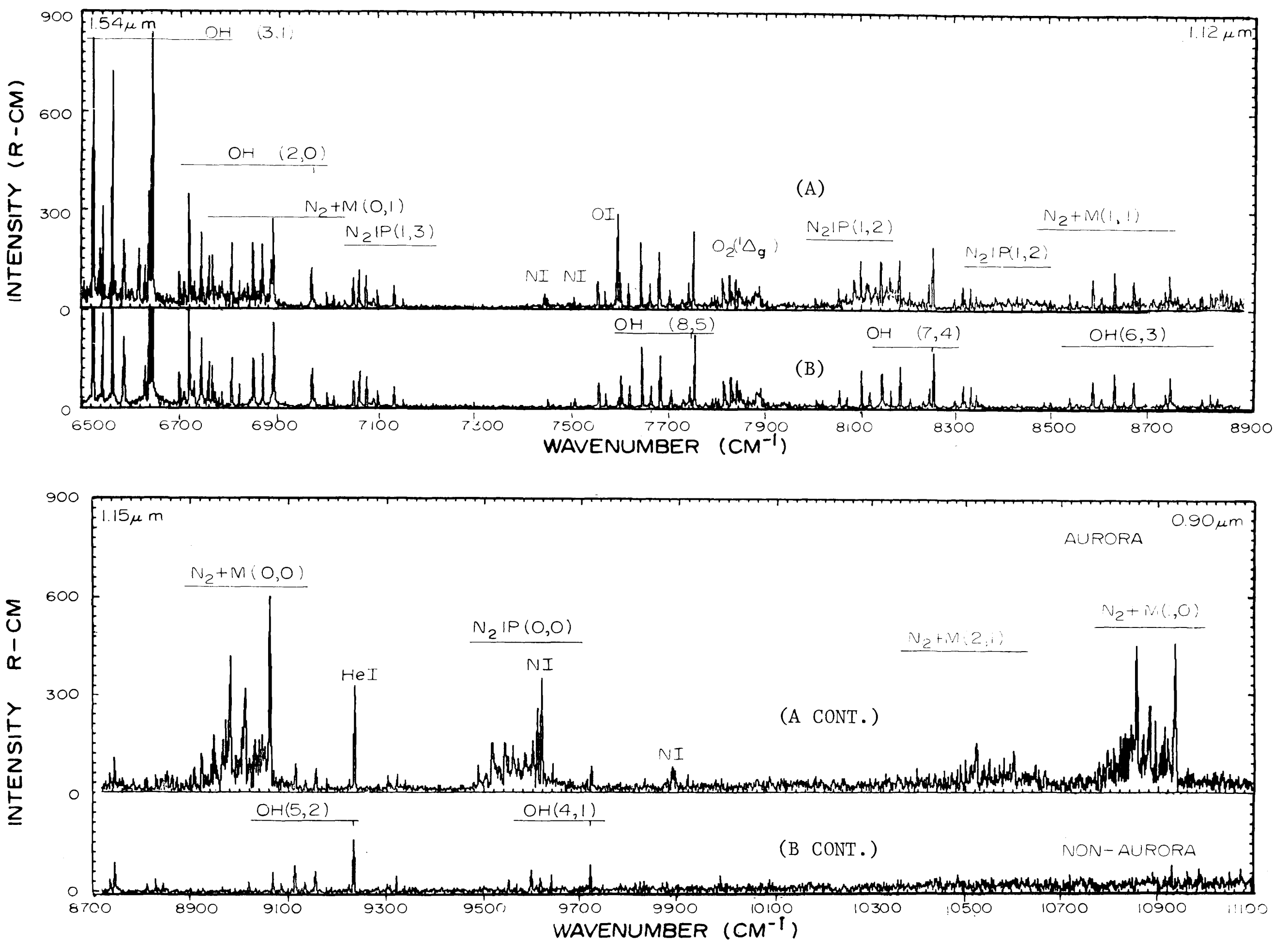

Fig. 5. Plot of spectral emission from auroral arc (A) compared with no aurora airglow emission (B). Spectra A was taken approximately 3 minutes later than spectra B after the arc formed. Both were taken looking at the Zenith on November 11, 1980, from Andoya, Norway. Measurement time was 40 seconds for each scan.