N92-12840

Ground-Based Observations of Comets, the Jupiter Plasma Torus, and Io

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Strategy

We have been investigating aspects of cometary and magnetospheric physics by means of ground-based astronomical spectroscopy. We have used high-throughput, dual-etalon Fabry-Perot spectrometers (usually at the McMath solar telescope on Kitt Peak) to obtain very high resolution spectra of atomic, molecular, and ionic emission lines from the diffuse gases and plasmas associated with comets and the Jupiter plasma torus. The Fabry-Perot spectrometers were also used with a CCD camera to obtain images of these extended emission sources in individual spectral lines at high spectral resolution.

We also recently began a new program using the McMath solar-stellar spectrograph to observe emission lines from Io. The McMath spectrograph has a high-resolution mode ($\lambda/\Delta\lambda \gtrsim 10^5$) which allows the detection of narrow, relatively faint emission lines superposed on Io's reflected solar spectrum.

Progress and Accomplishments

1) Ground-based observations of cometary ions can be used to help constrain models of the solar wind-cometary plasma interaction and photochemical models of ion reactions in the inner coma. Our goal in Fabry-Perot observations of cometary H_2O^+ emissions is to determine the outflow velocities of plasma in the coma and tail directly by measuring the Doppler shifts of the emission lines. Displacements of features in cometary plasma tails, obtained from photographs and CCD images, have been used to infer plasma motions with tailward velocities in the range of 20 to 250 km s^{-1} (Celnik and Schmidt-Kaler 1987, Jockers 1981, 1985). The question of whether these apparent motions represent propagating disturbances such as MHD waves moving down the tail or actual mass motions of the cometary ions or a combination of both can be resolved with Doppler measurements of H_2O^+.

High-resolution spectra of Comet Halley H_2O^+ emissions, primarily the 6158.64, 6158.85 Å spin doublet, were obtained in 1985 and 1986 using a 150 mm Fabry-Perot scanning spectrometer at the McMath west auxiliary solar telescope on Kitt Peak. On each night of observations, spectra were obtained at several distances in the range of 0 to 2×10^6 km from the comet head along the anti-Sunward direction. The outflow velocities of the cometary plasma were determined from the Doppler shifts of the emissions. The results usually but not always were consistent with constant acceleration of the plasma along the anti-Sunward direction, but the acceleration varied from night to night over a range of about 30-300 cm sec^{-2} (Scherb et al. 1990).

These accelerations do not seem to be consistent with the smaller values obtained by Celnik and Schmidt-Kaler (1987), using time-lapse photography of the plasma tail. This apparent discrepancy deserves further study, but for now we note that our 150 mm Fabry-Perot spectrometers are 10-25 times more sensitive to spatially diffuse emission than photographic techniques. Thus, one possibility is that the bright condensations recorded photographically were relatively massive, which could account for their smaller accelerations.

2) For our Comet Halley observations, the Fabry-Perot spectrometer provided effective isolation of cometary [OI]6300 emission from nearby cometary NH_2 lines, as well as terrestrial OH and [OI]6300 emissions. Our high resolution spectra of the 6300 Å region showed conclusively that there was no other cometary emission line of measurable strength within 0.5 Å of the cometary [OI]6300 emission line. Since the cometary [OI]6300 line was free of contamination, we were able to obtain values of the production rate of $O(^1D)$ atoms by measuring the total amount of [OI]6300 emission within the field of view and correcting for the amount of emission outside the field of view. These production rates are nearly model-independent when the field of view is large enough to include most of the [OI]6300 flux. This condition can usually be met over a large range of cometary heliocentric distances with the large field of view of a Fabry-Perot spectrometer. The $O(^1D)$ production rates were then used to obtain production rates for H_2O, using an appropriate model for the photodissociation of H_2O (Magee-Sauer et al. 1990).

3) Comet Austin (1989cl) presented a new opportunity for our group to carry out important studies of the comet and its interaction with the solar wind in interplanetary space. We observed Comet Austin in April and May 1990 with the Fabry-Perot spectrometer at the West Auxiliary of the McMath Solar Telescope. The spectrometer had two modes of operation: (1) a high spectral resolution mode with a Doppler velocity resolution of 1.2 km s^{-1} and (2) a mode with medium spectral resolution of 10 km s^{-1}. Spectral line profile data were obtained by photon counting with a photomultiplier as the Fabry-Perot scanned over an emission feature, and imaging data were obtained with a Photometrics CCD camera using a TK516 Ford chip. The field of view on the sky was 10'.5; the CCD images had a spatial resolution of 7".6.

The program included observations of both ions and neutral species in the cometary atmosphere and tail. Although Comet Austin was about one hundred times fainter in April and May than predicted in January 1990, the techniques we used were still able to obtain data of good quality (Schultz, et al. 1990).

The cometary [OI]6300 and NH_2 6298.6 emission lines were observed, both in high and medium resolution modes. Since the high resolution mode was able to resolve the emission profiles the observed widths of the lines provide information on outflow velocities of the comet's atmosphere. The medium resolution [OI]6300 observations provide production rates for $O(^1D)$. These production rates can then be used to obtain production rates for H_2O, with the same basic procedure as was used to obtain H_2O production rates for Comet Halley.

The H_2O^+ emission doublets at 6159 Å and 6147 Å were observed with medium spectral resolution scans and images. Velocity resolved sequences of images (data cubes) were obtained on nine nights. Each data cube consisted of a sequence of four to eight images, with the central wavelength of the spectrometer stepped 0.2 Å (10 km s^{-1}) between each image in the sequence. Each image took from five to fifteen minutes to acquire.

4) On the basis of a proposal we submitted to the National Solar Observatory (NSO), in February 1990 the staff of NSO used the McMath solar telescope high-resolution echelle stellar spectrograph to search for "auroral" [OI]6300 emission from Io's atmosphere. Six spectra of Io and two spectra of Europa were obtained at a spectral resolving power of about 120,000, with excellent signal/noise. An examination of the observations indicates that [OI]6300 emission from Io was detected, and the emission was not present in the Europa spectra. The [OI]6300 emission, which was superposed on Io's bright, reflected solar spectrum, had an intensity of about 30 kiloRayleighs, assuming that it was produced in a thin atmospheric layer near Io.

Since the [OI]6300 emission is probably time variable, the NSO staff carried out a new set of observations of Io and Europa in February 1991, and a third set of observations is planned for May 1991.

This type of observation appears to open up a new method of studying the Jupiter plasma torus/Io system.

Projected Accomplishments

1) Interesting variations in the structure of the Comet Austin (1989c1) ion tail were seen at different wavelengths in all the Fabry-Perot H_2O^+ data cubes. A major effort in data analysis will involve treating the time variability of the comet plasma, since the morphology of the H_2O^+ emission changed significantly from the first to the last image of each data cube. The Joint Observatory for Cometary Research (JOCR) obtained interference filter H_2O^+ images of the comet on four nights when data cubes were obtained by the Wisconsin group. The JOCR images, which were taken about every ten minutes, can be used to monitor temporal changes in the morphology of the H_2O^+ emission, thus allowing us to treat the time variability separately from velocity structure within the H_2O^+ emission. We plan to carry out an extensive analysis of the Wisconsin data cubes and JOCR images in order to investigate the dynamics of the solar wind-cometary plasma interaction.

2) The new data from the February 1991 observing program at the McMath telescope to search for [OI]6300 emission from Io will be analyzed as soon as it is received from NSO. If further data is obtained in May 1991, we will promptly analyze it, also. It may be possible to obtain some information on the spatial distribution of the emission around Io, using the

McMath stellar spectrograph image slicer, but seeing/guiding problems may preclude this possibility.

3) The analysis of our 1988 Jupiter plasma torus observations will be completed and the results will be submitted for publication. We will also compare these results with our earlier work on the torus in 1981, 1982, 1984, and 1987.

Publications

Magee-Sauer, K., F. Scherb, F.L. Roesler, and J. Harlander 1990. Comet Halley O(^{1}D) and H_2O production rates. Icarus 84, 154-165.

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