LETTER

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Letter to the Editor

HST mid-ultraviolet spectroscopy of comet 46P/Wirtanen during its approach to perihelion in 1996–1997

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Abstract. We have used the Hubble Space Telescope Faint Object Spectrograph to observe the mid-UV spectrum of the *ROSETTA* mission target comet, 46P/Wirtanen, on three dates during the comet's apparition in 1996 and early 1997. During this time the comet moved inward from a heliocentric distance near 2.7 AU to 1.3 AU. The first measurement (22.7 July 1996) detected only reflected solar continuum; based on these measurements, we set an upper limit on the nuclear radius of 1.45 km. A second measurement (25.9 Aug 1996) detected this reflected continuum, as well as weak OH (0-0) emission; the third measurement (15.2 Jan 1997) detected three OH bands at high signal-to-noise (the 0-0, the 1-0, and the 1-1), along with emission features from the CS radical and the CO_2^+ ion; upper limits on their emission brightness and production rate of C_2 was set. Our key findings are as follows: The data indicate that $Q(H_2O)$ varies like $R^{-4.9\pm0.25}$ inside 2.5 AU, and that the CS_2/H_2O production ratio at 1.3 AU is close to 3×10^{-4}. We also found that the 2600–3200 Å mid-UV coma color slope is more neutral (∼25%/1000 Å) than typical comets (∼40–70%/1000 Å, but is steeper than Wirtanen's own visible-wavelength color slope. Wirtanen's CS_2/H_2O production ratio is near the low end of the range observed to date. $Af\rho$ was estimated from the data as a measure of dust production; we found $Af\rho$ (2950 Å) values of 15, 18, and 15 cm, respectively, for the three FOS datasets, after correction for the estimated flux contribution of the nucleus. Interestingly, we found that production of dust, to which the UV is sensitive, did not appear to vary by more than a factor of about two with heliocentric distance over the 2.7 to 1.3 AU range, despite a factor of 50 variation in the production of H_2O. Wirtanen appears to be a small, but relatively normal comet. However, Wirtanen's ratio of dust (i.e., $Af\rho$) to H_2O production is smaller than in > 90% of the 85 comets in A'Hearn et al.'s (1995) large sample.

Key words: comets: general – comets: individual: Wirtanen – ultraviolet: solar system

1. Introduction

Although comet 46P/Wirtanen is set to be the focus of intense scrutiny by the *ESA/ROSETTA* mission, little is known about its properties or behavior. For example, although ultraviolet spectroscopy is a rich source of information about comets, no ultraviolet observations of comet Wirtanen were made during the comet's previous apparitions (cf., Schulz & Schwehm 1996). We therefore requested and received Hubble Space Telescope (HST) Director's Discretionary observing time to obtain mid-UV spectroscopy of 46P/Wirtanen. This HST investigation of Wirtanen was initiated as part of our instrument design activity for the *ROSETTA*/ALICE Ultraviolet Spectrometer (cf., Stern et al. 1996).

Our main objectives were (i) to study the reflectance spectra of the comet, and (ii) to characterize Wirtanen's water and minor species production rates during its approach to perihelion from ∼2.7 to 1.3 AU. This span of heliocentric distance covers much of the heliocentric range through which the *ROSETTA* mission will scrutinize Wirtanen two orbits hence. It was expected that the comet's H_2O sublimation rate would go from essentially zero to a significant level during our observation time frame. In the following sections, we discuss the details of these HST observations, and the results that these spectra have yielded.

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Table 1. Wirtanen HST/FOS observation summary

Date (UT)	Integration Time	Heliocentric Distance (R)	Helio Radial Velocity ($\dot{R}$)	Geocentric Distance (Δ)	Aperture Scale (3.66x1.29"^{2})	Phase Angle
1996 July 22.7	1190 s	2.722 AU	−12.43 km/s	1.783 AU	4791x1668 km	10.1°
1996 Aug 25.9	1280 s	2.469 AU	−13.27 km/s	1.514 AU	4032x1417 km	09.8°
1997 Jan 15.2	1430 s	1.308 AU	−12.50 km/s	1.690 AU	4501x1581 km	35.3°

2. Observations

We obtained three observations of 46P/Wirtanen between 22 July 1996 and 15 January 1997. All these observations were obtained using the HST Faint Object Spectrograph (FOS).[1] Data were collected using the largest (i.e., A-1) aperture aboard the FOS in order to maximize sensitivity to faint emissions; this aperture has an effective size of 3.66×1.29 arcsec^2. Each of the three FOS observations of Wirtanen was allocated 1 orbit of spacecraft time. The spacecraft sequence for the observations was to maneuver to the comet, conduct an acquisition of Wirtanen in the FOS aperture, and then obtain the data spectrum.

To accomplish the acquisition and centering of the comet's center of brightness in the aperture, HST acquired Wirtanen using a blind maneuver to its calculated apparent position as seen from the spacecraft, obtained a fine acquisition image using the flat mirror, and then conducted an FOS peak up using A-1/BIN mode. This complete, the flat mirror was replaced in the FOS optical train by grating G270H, and an exposure of approximately 1300 s across the spectral region 2222–3277 Å was then obtained.

Our analysis of the FOS acquisition images taken for each observation indicate that the pointing residuals relative to the comet's center of brightness were small (≈ 0.7" or less), and most likely did not introduce photometric errors > 20–30% in determining either the continuum flux and molecular production rates. Table 1 summarizes the observational circumstances for the three observation epochs on which we obtained data.[2]

3. The FOS spectra

Fig. 1 shows the three FOS flux spectra we obtained, binned at 8 Å intervals[3] and their associated 1σ error bars; for comparison, we also show a reference solar spectrum in the lowermost panel. Light from Wirtanen was detected at all three observation epochs; the spectral range containing significant signal extended progressively toward shorter wavelengths as the comet approached the Sun and brightened. Second, strong coma OH emission (e.g., the 0-0 band at 3080 Å; see also Fig. 3), was detected in the January 1997 spectrum; far weaker OH emission was detected in the August 1996 spectrum; no OH emission was detected in the July 1996 spectrum.

An interesting parameter these data allow us to calculate is an upper limit on the comet's nuclear cross section, and hence an upper limit on the characteristic radius of Wirtanen's nucleus. Using the geometrical circumstances of the observations (cf., Table 1) and the HST-measured UV fluxes of the July 1996 and August 1996 observations,[4] we find that the apparent nuclear cross-sectional area must be $< 5.7(0.04/p_{\rm uv})$ km^2 and $< 6.6\ (0.04/p_{\rm uv})$ km^2, respectively, for these observation dates, where $p_{\rm uv}$ is the actual average UV geometric albedo of the nucleus in the 2600–3200 Å bandpass. Assuming a circular nuclear cross section implies equivalent presented radii for Wirtanen of < 1.35 and < 1.45 km, respectively, during the July and August observations. This result is consistent with, but less constraining than the most recent and direct evaluation of the radius (0.60$\pm$0.02 km) by Lamy et al. (1998).

The size constraints we just derived are upper limits because they assume all of the light in the UV continuum spectra of Wirtanen came from the nucleus. Both indirect nuclear radius estimates for Wirtanen (Böhnhardt et al. 1997; Rickman & Jorda 1998), and more direct estimates (Lamy et al. 1998), allow us to make the additional, though not very surprising conclusion: that our measurements were strongly contaminated by coma.[5] More quantitatively, adopting the 0.6 km radius of Lamy et al., we find that a $p_{\rm uv} = 0.04$ nucleus can be contributing no more than 17–20% of the observed UV flux, and therefore that $\gtrsim 80$% of the July 1996 spectrum was due to reflection off the coma.[6]

4. Continuum reflectance

Fig. 2 shows the three Wirtanen spectra we obtained, after dividing by the Cycle 22 mean solar minimum solar spectrum, as measured by the SOLSTICE UV solar irradiance instrument aboard the Upper Atmospheric Research Satellite (UARS; Woods et al. 1996), and converting these spectra to $Af\rho$ units. We have not converted the flux spectra to albedo because of the uncertainty in the fraction of light coming from the coma, and

[1] As a historical note, we point out that the January 1997 observation of Wirtanen was the final cometary observation by the FOS prior to its extraction from HST in February, 1997.

[2] An observation conducted on 25 October 1996 at 1.98 AU heliocentric range and now in the HST archives failed, owing to an HST ephemeris error.

[3] For comparison, the A-1 aperture gives a resolution near 23 Å for a filled slit.

[4] And neglecting phase function effects.

[5] This is confirmed by inspection of the FOS acquisition images of Wirtanen.

[6] One can also say that for a 0.6 km nuclear radius, the UV surface albedo could be up to 0.21$\pm$0.02; of course, because the total reflective cross section in the FOS aperture also contains the coma grain contributions, this nuclear albedo constraint must be viewed as a rather uninteresting upper limit.

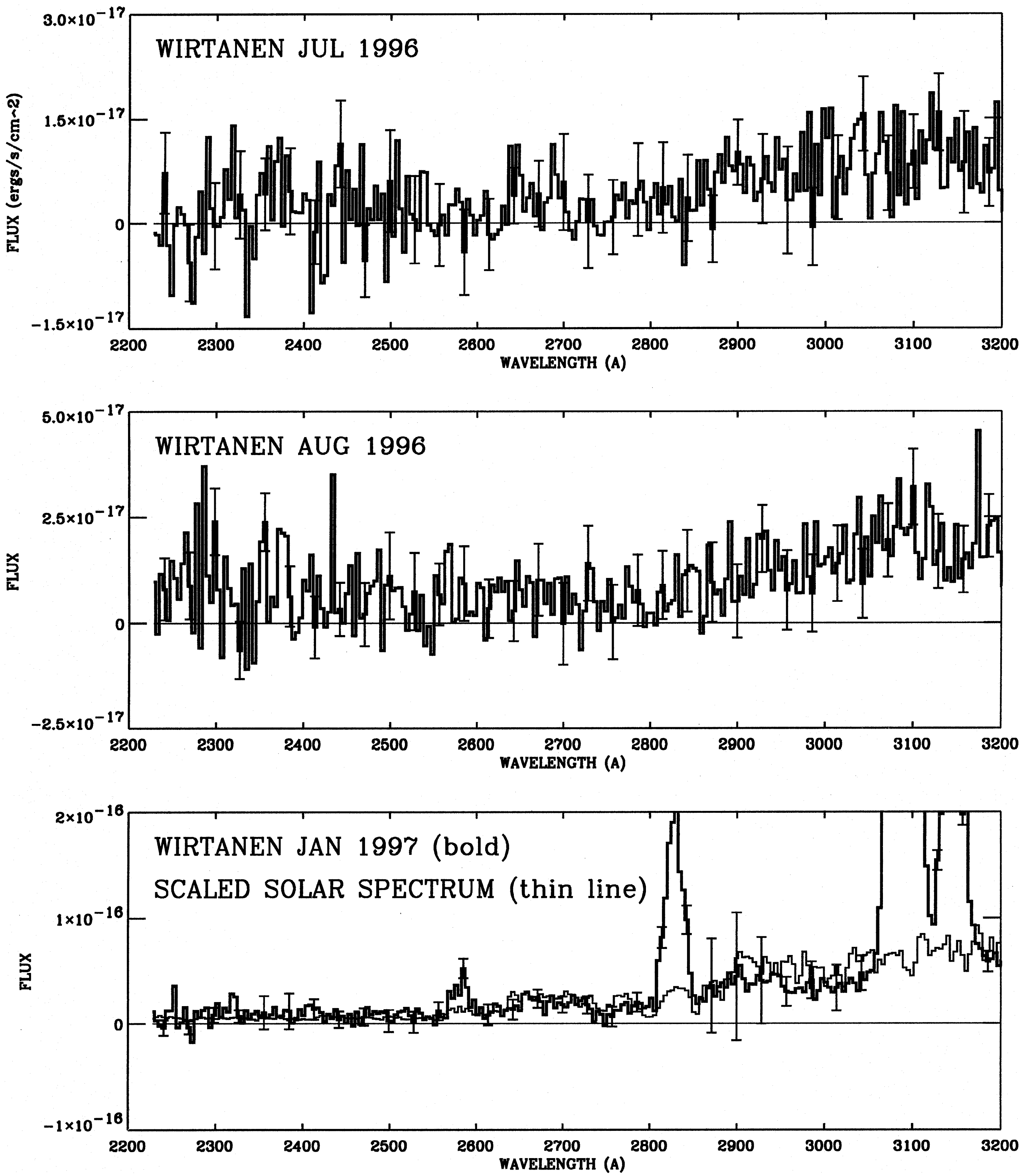

Fig. 1. The three panels in this figure show the HST/FOS G270H flux spectra obtained on the three dates shown in Table 1; the flat, thin line in each panel is the zero flux level, for reference. The flux spectra (in units of ergs cm^{-2} s^{-1}) are binned to 8 Å resolution; the error bars shown are the calibrated FOS flux vectors. A rescaled solar spectrum (Woods et al. 1996) is also plotted as a thin line in the lowermost panel for comparison.

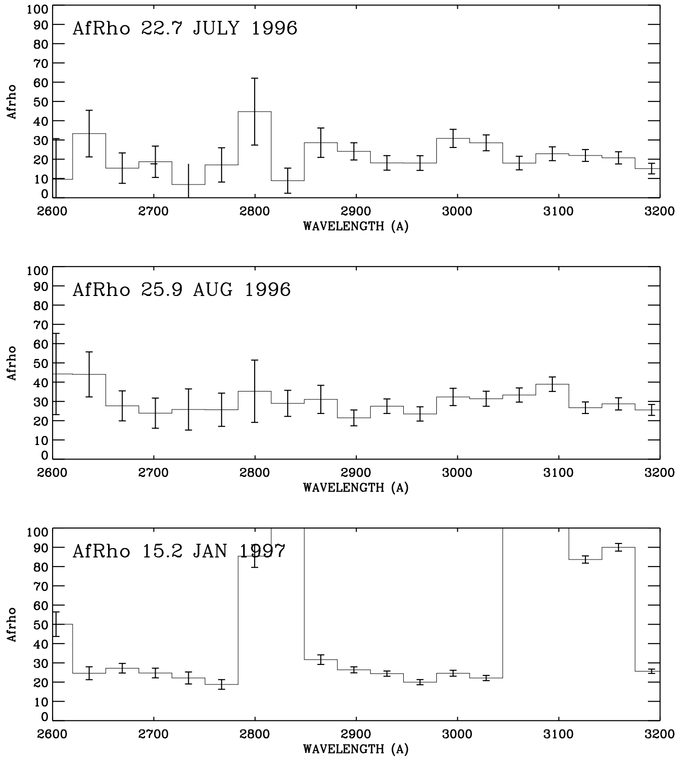

Fig. 2. Upper panel: Wirtanen's $Af\rho$ spectrum for the three FOS observation dates at a binned resolution of 32 Å; molecular emissions have not been removed from these spectra, but should be ignored for the pupose of $Af\rho$ analysis.

the fact that the cross section of Wirtanen is uncertain (and probably time variable, owing to rotational and seasonal effects).

We turn now to the slope of Wirtanen's coma reflectance. We have calculated error-weighted least squares fits to each of our three coma spectra over the wavelength range 2600 Å to 3200 Å after smoothing and division by the solar spectrum (we omitted spectral regions with emission features in obtaining these fits). We find formal average slope solutions of 22%/1000 Å, 30%/1000 Å, and 25%/1000 Å, for the July '96, August '96, and January '97 observations, respectively. The differences between these results are likely not significant, given the uncertainties in our exact pointing in the inner coma and statistical noise in the data. The measured slopes are flatter than the typical 40–70%/1000 Å slopes found in other comets whose continuum spectrum has been measured in the same UV wavelength range (e.g., Feldman & A'Hearn 1985; Feldman et al. 1987; Roettger et al. 1989).

Wirtanen's UV color slope slope is significantly steeper than the 6%/1000 Å B-V and 8%/1000 Å V-R color slopes observed on 17–18 Aug 1996 by Meech et al. (1997), and the 10%/1000 Å V-R slope measured on 28 Aug 1996 by Lamy et al. (1998). This leads one to infer that either the coma particle-size distribution, or the average coma particle albedo, must significantly change between the mid-UV and visible wavelengths. It also indicates that the *slope* of the coma reflectance must decline somewhere between our 2600–3200 Å mid-UV slope measurement bandpass and the optical.

Comparison of Wirtanen's optical continuum color slope to the measured 0–20%/1000 Å reflectances of other cometary comae (Jewitt & Meech 1986) shows that the optical color slopes of 46P/Wirtanen measured in the July–August 1996 time frame are not unusual.

5. Dust production as measured by the $Af\rho$ Proxy

We now turn to the subject of Wirtanen's dust production, using the $Af\rho$ formulation as a measure (cf., A'Hearn et al. 1984). We calculated $Af\rho$ assuming that (i) the flux in the FOS's rectangular aperture is equivalent to that in a circular aperture of the same area and (ii) that all of the measured flux comes from the coma. The spectra shown in Fig. 2 are uncorrected for the fact, discussed above, that up to 20% of the total UV flux measured by the FOS came from Wirtanen's nucleus. In Table 2 we give averaged $Af\rho$ values in the 2930–2990 Å bandpass, which *have* been corrected downward by 20% to remove the first-order contribution of Wirtanen's nucleus and therefore better estimate its coma $Af\rho$.

Our $Af\rho$ results (see Table 2) can be compared to Lamy et al.'s (1998) value of $Af\rho$ (6700 Å) = 23 cm, obtained when Wirtanen was at $R = 2.45$ AU in late August of 1996. Taking our August 1996 measurement at 2950 Å, and applying the 8–10%/1000 Å visible-wavelength coma color slope (measured by Meech et al., and Lamy et al.), one predicts that at 6700 Å one would expect to observe $Af\rho = 23 \pm 4$ cm. This is in excellent agreement with Lamy et al.'s 6700 Å measurement of $Af\rho = 23$ cm, and indicates that the coma's red color slope must indeed flatten somewhere relatively close to our 3200 Å cutoff.

Next, we turn to the fact that Wirtanen's UV $Af\rho$ did not significantly vary during the six month interval from July 1996 to January 1997 in which our measurements were obtained. Similarly, Wirtanen's $Af\rho$ measured in the visible (Schulz et al., 1998), remainded about constant near ∼20 cm between 2.8 and 1.8 AU; interestingly, however, near 1.6 AU the visible $Af\rho$ increased to ≈ 76 cm in what may have been an outburst. To the extent that $Af\rho$ is a valid measure of dust production, our HST measurements indicate that the production of small dust particles (to which the UV continuum we measured is sensitive), did not significantly vary with heliocentric distance.[7] As we show in the next section, this is in stark contrast to the factor of > 50 increase in H_2O production observed during this same timeframe, and indicates a significant decrease in dust/gas ratio as the comet approached the Sun. Such a situation, though

[7] Owing to uncertainties in the appropriate UV phase function for the coma dust and the nucleus of comet Wirtanen, we chose not to correct for phase angle effects. Because the phase angle in January 1997 was substantially larger than for the earlier observations, we therefore may have underestimated the increase in production of dust as the comet approached the Sun. Reasonable scattering functions suggest that the resulting possible increase in dust production could not be more than a factor of two.

Table 2. Wirtanen HST/FOS coma results

Feature[a]	Date	Brightness[b]	Column Density	Parent Production Rate[b]
$Af\rho$ (2950 Å)	22.7 July '96	N/A	N/A	15±4 cm
$Af\rho$ (2950 Å)	25.9 Aug '96	N/A	N/A	18±3 cm
$Af\rho$ (2950 Å)	15.2 Jan '97	N/A	N/A	15±3 cm
OH (3085 Å)	22.7 July '96	<2.7 R	$<4.6\times10^{10}$ cm^{-2}	$<1.2\times10^{26}$ s^{-1}
OH (3085 Å)	25.9 Aug '96	8±1.4 R	$1.2\pm0.2\times10^{11}$ cm^{-2}	$2.6\pm0.5\times10^{26}$ s^{-1}
OH (3085 Å)	15.2 Jan '97	1180±8 R	$4.5\pm0.03\times10^{12}$ cm^{-2}	$5.1\pm0.03\times10^{27}$ s^{-1}
CS (2576 Å)	22.7 July '96	<1.7 R	$<2.5\times10^{10}$ cm^{-2}	$<8.8\times10^{23}$ s^{-1}
CS (2576 Å)	25.9 Aug '96	<2.5 R	$<3.0\times10^{10}$ cm^{-2}	$<9.7\times10^{23}$ s^{-1}
CS (2576 Å)	15.2 Jan '97	11±1 R	$3.8\pm0.3\times10^{10}$ cm^{-2}	$1.4\pm0.1\times10^{24}$ s^{-1}
CO_2^+ (2890 Å)	22.7 July '96	<2 R	$<7.0\times10^{9}$ cm^{-2}	N/A
CO_2^+ (2890 Å)	25.9 Aug '96	<3 R	$<7.5\times10^{9}$ cm^{-2}	N/A
CO_2^+ (2890 Å)	15.2 Jan '97	10 R	$8.1\pm0.8\times10^{9}$ cm^{-2}	N/A
C_2 (2313 Å)	22.7 July '96	<3.1 R	$<6.5\times10^{10}$ cm^{-2}	$<3.8\times10^{25}$ s^{-1}
C_2 (2313 Å)	25.9 Aug '96	<4.1 R	$<7.0\times10^{10}$ cm^{-2}	$<3.6\times10^{25}$ s^{-1}
C_2 (2313 Å)	15.2 Jan '97	<3.8 R	$<1.8\times10^{10}$ cm^{-2}	$<5.2\times10^{24}$ s^{-1}

Notes:
[a] A band width of 40 Å was used for the OH brightness extraction; a 20 Å width was used for CS, CO_2^+, and C_2.
[b] Upper limits are 3σ values.

unusual, is not unique: it was seen in Halley's approach to the Sun in 1986 over a similar range of heliocentric distance (cf., Feldman et al. 1987).

6. Coma emissions

As one naturally expects, fluorescence emissions from the coma were strongest in the final spectrum we obtained because this spectrum was taken only weeks before Wirtanen reached perihelion. As shown in the bottom panel of Fig. 3, this 15.2 January 1997 HST/FOS spectrum of Wirtanen clearly reveals detections of OH (0-0, 3085 Å; 1-0, 2820 Å; and 1-1, 3140 Å), CS (0-0, 2576 Å), and CO_2^+ (2890 Å) emission; the C_2 (Mulliken, 2313 Å) band was not detected. As Table 2 and Fig. 3 demonstrate, the FOS Wirtanen spectrum obtained on 25.9 Aug 1996 reveals none of these species, except OH, which was weakly detected (at the ∼5.5 level); there is no evidence of detectable emission in the 22.7 July 1996 data.

The destruction (i.e., loss) scale lengths of the species we detected in Wirtanen are more than two orders of magnitude larger than the projected size of the FOS slit during our observations. Therefore, as shown in Table 2, we have converted the measured fluxes into average surface brightnesses (B). For this conversion, we adopted 40 Å spectral windows for the OH bands, and 20 Å spectral windows centered for the other features of interest. The derived brightnesses (or upper limits), calculated on the fluxes remaining after a fitted continuum was subtracted, are shown in Table 2. The $1\,\sigma$ error bars shown for each brightness were computed from the FOS error bars (cf., Fig. 1); calculated upper limits are $3\,sigma$ values, established from the FOS error bars shown in Fig. 1.

We converted the band brightnesses, B, in Table 2, to column densities, N, using the standard formulation, $N = 10^6 B/g$, where g is the resonance fluorescence efficiency of the given emission. For OH we used computed unquenched g-factors (Schleicher & A'Hearn 1988) for Wirtanen's heliocentric distance and velocity at each observation epoch.[8] For CS we adopted $g(1\,\mathrm{AU}) = 5\times10^{-4}\,\mathrm{s}^{-1}$ (Yelle 1994, private communication; also, footnote 9, Noll et al. 1995). For CO_2^+ and the C_2 Mulliken bands we used $g_{\mathrm{CO}_2^+}\,(1\,\mathrm{AU}) = 2.1\times10^{-3}\,\mathrm{s}^{-1}$ (J. Fox 1981, pers. comm.) and $g_{\mathrm{C}_2}\,(1\,\mathrm{AU}) = 3.6\times10^{-4}\,\mathrm{s}^{-1}$ (A'Hearn & Feldman 1980), respectively. The g-factors for CS, CO_2^+, and C_2 were adjusted only for the variation in heliocentric distance.

We derived production rates (Q) for H_2O (the assumed, sole parent of OH) and CS_2 (the assumed, sole parent of CS), using a vectorial model (cf., Festou 1981); production rate upper limits for C_2 were also computed this way. For the $H_2O\longrightarrow OH$ computation, we used $v(\mathrm{H_{2O}}\ ) = 0.85\,R^{-1/2}\,\mathrm{km\,s^{-1}}$ (where R is the heliocentric distance of the comet in AU), 1 AU H_2O photodissociative and total lifetimes of $1.02\times10^5\,R^2$ seconds and $8.6\times10^4\,R^2$ seconds, respectively, an OH excess velocity of dissociation of $1.05\,\mathrm{km\,s^{-1}}$, and a total OH lifetime of $1.59\times10^5\,R^2$ s. For the $CS_2\longrightarrow CS$ computation, we used $v(\mathrm{CS_2}) = 0.85\,R^{-1/2}\,\mathrm{km\,s^{-1}}$, a total lifetime of CS_2 equal to its photodissociative lifetime of $345\,R^2$ second, a small CS excess energy of dissociation of $0.01\,\mathrm{km\,s^{-1}}$ (since it is produced by dissociation within the collisional zone), and a total CS lifetime of $1\times10^5\,R^2$ second. For the C_2 production rate upper lim-

[8] At Wirtanen's heliocentric velocity range during our measurements, the quenched and unquenched OH g-factors are essentially equal.

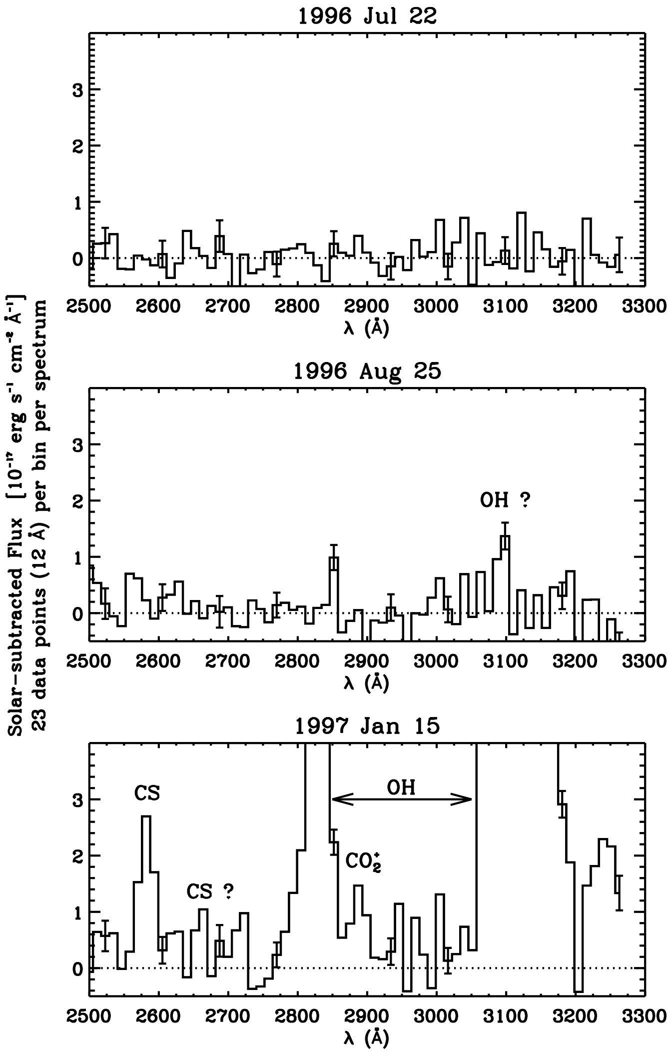

Fig. 3. The mid-UV coma emission features observed in the spectrum of 46P/Wirtanen at each of the three HST/FOS observation epochs. Each of these three spectra has had a fitted solar continuum removed.

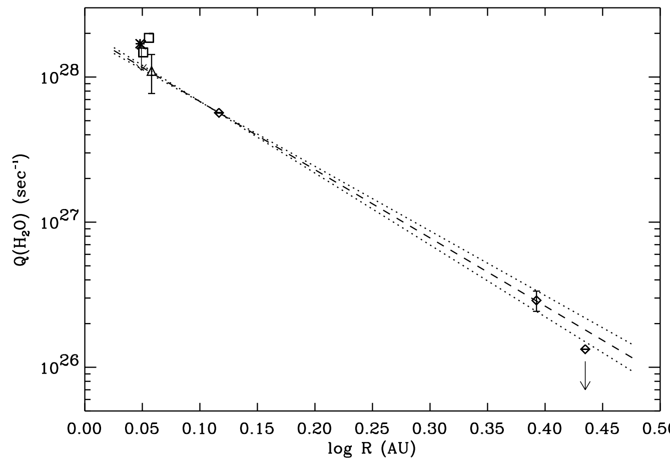

Fig. 4. Comparison of recent water-production rate estimates for 46P/Wirtanen. Symbols: Diamonds (HST/FOS), box (Farnham & Schleicher 1997), asterisk (A'Hearn et al. 1995), triangle (Bertaux 1997), x (Crovisier et al. 1998); error bars are shown only for out HST/FOS data, and Bertaux's SOHO/SWAN data, since the other sources did not quote errors. For the HST data the error bars shown are simply those quoted in Table 2 due to counting statistics. Notice the A'Hearn et al. (1995) groundbased optical measurement/vector model result and the Crovisier et al. (1998) radio upper limit virtually coincide. For the A'Hearn et al., Farnham & Schleicher (OH) and Bertaux (H) brightnesses, we ran our vectoral model to produce the production rate estimates shown here. The dashed line is a simple extrapolation of the HST/FOS measurements using a water production rate that follows the form $Q(R){=}\ Q(R_0)R^{-4.9}$; the dotted lines on either side of this extrapolation represent an envelope of uncertainty, based on the uncertainty in the derived $Q(H_2O)$ values (see text). Note that the H-derived $Q(H_2O)$ is known to be too high by some percentage owing to the fact that we assumed all of the H signal is from H atoms dissociated from H_2O; no allowance was made for H atoms contributed by other H-bearing species.

its we used $v(\mathrm{parent}) = 0.85\,R^{-1/2}\,\mathrm{km\,s^{-1}}$, a total lifetime of the parent equal to its photodissociative lifetime at 1 AU of $2\times10^4\,R^2$ second, an excess energy of dissociation of $1\,\mathrm{km\,s^{-1}}$ (the true values are unknown), and an assumed total C_2 lifetime of $8.64\times10^4\,R^2$ second.

Table 2 gives H_2O and CS_2 production rates derived as we have just described, as well as upper limits on C_2.[9] As noted above, the error bars given in Table 2 are based only on the FOS measurement uncertainties of the derived brightnesses.

To begin, using the 15.2 Jan 1997 and 25.9 August OH detections, we derive a (perhaps oversimplified, but nonetheless valuable) single-valued H_2O power-law production rate exponent of $n = -4.9 \pm 0.25$ between 2.5 AU and 1.3 AU. This $Q(H_2O)$ heliocentric power-law exponent is near the median of water production slopes observed in Jupiter Family comets (cf., A'Hearn et al. 1995).

[9] We did not compute the production rate of CO_2 from CO_2^+ brightness because the quantitative steps involved are not well established.

Fig. 4 illustrates our FOS-derived $Q(H_2O)$ data points and the $Q(H_2O)$ production rate extrapolation just derived, compared to vectoral production rates we derived from the observational parameters and brightness values of three additional, relevent Wirtanen data sets obtained by other groups (A'Hearn et al. 1995; Farnham & Schleicher 1997; Bertaux 1997). The Haser-model H_2O water production upper limit derived by Crovisier et al. (1998) is also shown (see the caption for a symbol legend).

From our power-law solution to $Q(H_2O)$, we can make some simple extrapolations of potential use to *ROSETTA* mission planning, both with regard to the comet's activity level, dust production rate, and the potential for the innermost coma to reach pressures which could cause payload instruments to reach the corona region, endangering exposed high voltage supplies. For example, extrapolating our $Q(H_2O)$ power law inward to Wirtanen's perihelion at 1.06 AU gives an estimated $Q(H_2O)$ $= 1.4\times10^{28}\,\mathrm{s^{-1}}$. Extrapolating the FOS data fit to the 3 AU distance where *ROSETTA* science operations will begin gives an H_2O production rate estimate in the vicinity of $9\times10^{25}\,\mathrm{s^{-1}}$; because the H_2O production rate should fall steeply in this region, this estimate is likely to be a "safe" (i.e., high) upper limit on the water production rate *ROSETTA* will encounter at 3 AU.

Based on the data in Table 2, we can also derive a nominal CS_2/H_2O production rate ratio of 2.7×10^{-4} for Wirtanen on 15.2 Jan 1997. Other comets have been observed to range between 2×10^{-4} and 3×10^{-3}) cf., Azoulay & Festou 1985, Festou et al. 1993; Mumma et al. 1993; Feldman et al. 1987; Meier & A'Hearn 1997). As such, Wirtanen's CS_2/H_2O production ratio is relatively low, but it is not exceptional.

Finally, the UV continuum-derived $Af\rho$ measurements near perihelion on 15 Jan 1997 indicate that Wirtanen is probably dust poor. From Table 2 we quickly find that log $(Af\rho/Q(\mathrm{H_2O})) = -26.52$. If we compare this UV-based $Af\rho/Q(\mathrm{H_2O})$ ratio to the suite of groundbased $Af\rho/Q(\mathrm{H_{2O}})$s given for 85 comets by A'Hearn et al. (1995), we find Wirtanen near the bottom of the range found for Jupiter Family comets (cf., A'Hearn et al. 1995). This remains the case if we derive log $(Af\rho/Q(\mathrm{H_{2O}}))$ using Lamy's 6700 Å $Af\rho$ and our $Q(\mathrm{H_{2O}})$.

7. Conclusions and outlook

HST spectroscopic observations of 46P/Wirtanen in the FOS bandpass between 2220 and 3280 Å have revealed several new facts about the *ROSETTA* mission target comet as it traveled from 2.7 to 1.3 AU during its 1996–1997 approach to perihelion. The comet's UV spectrum appears normal, as does its H_2O production rate curve ($\sim$R$^{-4.9\pm0.25}$). In these respects, Wirtanen appears to be a run-of-the-mill, if small, low dust production, Jupiter Family Comet. However, we have found that Wirtanen's CS_2/H_2O production ratio (2.7×10^{-4}) is near the bottom of the range observed in other comets. Further, we found that (i) Wirtanen's 2600–3200 Å coma color slope ($\approx$25%/1000 Å) is lower than seen in many other comets studied in this wavelength region. Turning to the $Af\rho$ proxy for dust production, we found that Wirtanen's UV-$Af\rho$ remained constant to within a factor of $\sim$2 or less as $Q(\mathrm{H_2O})$ increased by at least a factor of 50. So too, we found that Wirtanen's ratio of dust to H_2O production (i.e., $Af\rho/Q(\mathrm{H_{2O}})$ is smaller than > 90% of the 85 comets in A'Hearn et al.'s (1995) large sample studied in the optical. In these later three respects, the comet is unusual, but not unique.

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