VOLATILE COMPOSITION AND OUTGASSING IN C/2018 Y1 (IWAMOTO): EXTENDING DETECTION LIMITS FOR HIGH-RESOLUTION IR COMETARY SPECTROSCOPY AT THE NASA-IRTF.

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Introduction: We used iSHELL [1,2], the powerful high-resolution ($\lambda/\Delta\lambda$ ~ 40,000) cross-dispersed IR spectrograph at the NASA-IRTF to measure the native ice composition and outgassing of moderately bright, long-period comet C/2018 Y1 (Iwamoto) (hereafter Y1) within weeks of its discovery [3] (Figs. 1 & 2). We measured production rates for H_2O, and production rates and abundance ratios relative to H_2O for eight trace molecules, including the most complete measure of cometary CH_4 achieved to date (Fig. 1b). Compared with mean abundances measured among comets, our study revealed enriched CH_3OH and C_2H_6 yet depleted CO and C_2H_2, perhaps indicating highly efficient H-atom addition on interstellar grains prior to their incorporation into the nucleus. The combined high spectral resolving power and broad spectral coverage of iSHELL allowed characterizing cometary composition using only three instrument settings, and its long-slit coverage allowed comparing the spatial distributions of molecular emissions and dust continuum.

Observations: We recorded spectra of Comet Y1 with iSHELL toward the end of the night on three pre-perihelion dates (Table 1), during scheduled runs that concluded our campaign on Jupiter-family comet 46P/Wirtanen [4]. This allowed a suite of nine parent volatiles (including H_2O) to be measured on the February dates, using just three instrument settings between $\lambda \sim 2.8 - 5.2$ µm. The initial date (13 January) afforded time for one instrument setting only; we used this to assess the hydrocarbon chemistry and to better plan for the February observations near perihelion. For all dates, the geocentric radial velocity of Y1 was unusually large (-58.9 km s^{-1} on 13 January; -48.3 and -45.5 km s^{-1} on 4 and 5 February, respectively), Doppler-shifting lines of cometary CO and CH_4 well away from their opaque telluric counterparts and thereby into regions of highly favorable atmospheric transmittance. This allowed measure of 11 distinct CH_4 lines (Fig.1b).

For all observations of Y1 the slit was oriented along the Sun-comet direction. This permitted direct comparison of outflow of co-measured species and dust in projected Sun/anti-Sun hemispheres (Fig. 2).

Results: When compared with abundances (relative to H_2O) found for a dominant group of comets from the Oort cloud (often referred to as "normal" or "typical" abundances [5]), our study revealed depleted CO, C_2H_2, H_2CO, and NH_3, typical CH_4 and HCN, and enriched C_2H_6 and CH_3OH. A viable pathway for the production of CH_3OH and C_2H_6 is H-atom addition reactions to CO and C_2H_2, respectively, on the surfaces of interstellar grains at very low temperatures (~ 10 – 20 K [6]). Our results also extend the ability to measure spatial emission profiles to considerably weaker comets, particularly from 13 January (Fig. 2a).

Discussion: In this context, our results imply efficient surface chemistry on ice-mantled grains that were assimilated into the nucleus of Y1. Furthermore, among parent volatiles systematically measured in comets, CH_4 is second in volatility (after CO), and therefore its (nearly) "normal" abundance implies that thermal processing (e.g., in the proto-solar nebula) was likely not the dominant consideration in determining volatile abundances in Comet Y1. Our study demonstrates the ability to measure the volatile chemistry of a moderately bright comet with iSHELL; our overall observing efficiency (time on source versus elapsed clock time) was approximately 75%.

We express the brightness of spectral lines through a Figure-of-Merit (FoM) = $10^{-29} Q_R R_h^{-1.5} \Delta^{-1}$, where Q_R is the water production rate at heliocentric distance R_h and geocentric distance Δ, both expressed in AU [7]. For Y1, we estimate FoM ≅ 0.11 on 13 Jan (Fig. 2a), and 0.32 on 04 (Fig. 2b) and 05 Feb (Figs. 2c-2d). This represents a significant advance; the previous (pre-iSHELL) threshold at the IRTF for obtaining meaningful spatial information was FoM ~ 0.7.

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Table 1: Preliminary production rates and molecular abundances in C/2018 Y1 (Iwamoto)

UTDate/Setting/ToS[a]	Species[b]
13 Jan/Lp1/59.8	C_2H_6, CH_3OH, CH_4, H_2CO
04 Feb/M2/38.9	H_2O, CO
05 Feb/Lcust/91.7	H_2O, HCN, C_2H_2, NH_3
05 Feb/Lp1/63.8	C_2H_6, CH_3OH, CH_4, H_2CO

[a] UT date/iSHELL setting/accumulated on-source integration times (minutes) are shown in **bold**.

[b] Co-measured molecules having emissions targeted within each given setting.

References:

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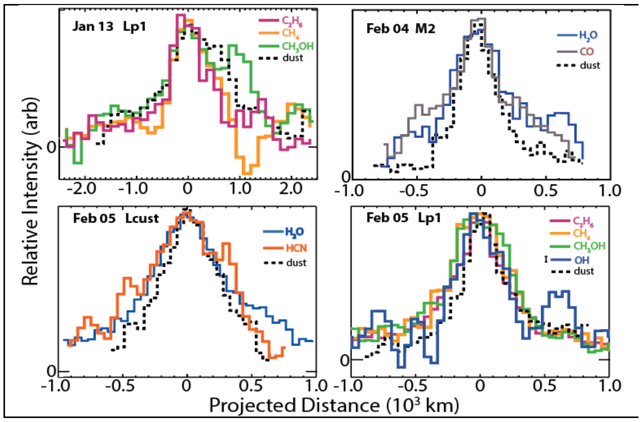
[3] Comet C/2018 Y1 (Iwamoto), CBET 4588, Dec 2018.

[4] Comet 46P/Wirtanen observing campaign website: wirtanen.astro.umd.edu.

[5] Dello Russo, N., et al., Icarus, 278, 301, 2016.

[6] Watanabe, N., et al., ApJ 616, 638, 2004.

[7] Mumma, M. J., et al., Adv Sp Res, 31, 2563, 2003. (Footnote to Table 1.)



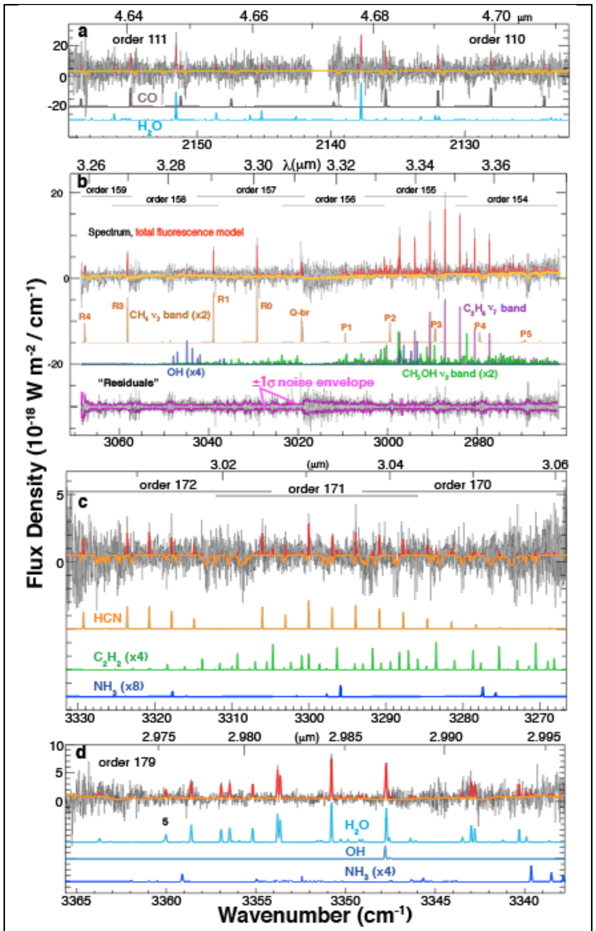


Figure 1. Spectral extracts (black traces) of C/2018 Y1 from selected iSHELL orders (labeled in each panel), with settings and on-source integration times listed in Table 1. In all panels, modeled fluorescence is color-coded by species, and g-factors are multiplied by modeled monochromatic atmospheric transmittance at each Doppler-shifted line position. The modeled continuum (scaled atmospheric transmittance function) is shown in gold overlying each extract, and the total modeled emission is shown in red. (**a**) M2, 04 Feb. (**b**) Lp1, 05 Feb. (**c**) Lcust, 05 Feb. (**d**) Lcust, 05 Feb; order 179 is particularly useful for measuring the rotational temperature of H_2O molecules in the coma.

Figure 2 (at left). Spatial profiles of volatile and dust continuum emissions along the slit, labeled by UT date and iSHELL setting. The projected Sun-facing hemisphere is toward the left in each panel. The 13 January panel in particular demonstrates our ability to obtain meaningful spatial information for a comet with FoM ~ 0.1 (see Discussion above), even given a modest on-source integration time (~ 1 hour; see Table 1).