OUTGASSING BEHAVIOR OF C/2012 S1 (ISON) FROM 2011 SEPTEMBER TO 2013 JUNE

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ABSTRACT

We report photometric observations for comet C/2012 S1 (ISON) obtained during the period time immediately after discovery (r = 6.28 AU) until it moved into solar conjunction in mid-2013 June using the UH2.2 m, and Gemini North 8 m telescopes on Mauna Kea, the Lowell 1.8 m in Flagstaff, the Calar Alto 1.2 m telescope in Spain, the VYSOS-5 telescopes on Mauna Loa Hawaii and data from the CARA network. Additional pre-discovery data from the Pan STARRS1 survey extends the light curve back to 2011 September 30 (r = 9.4 AU). The images showed a similar tail morphology due to small micron sized particles throughout 2013, Observations at submillimeter wavelengths using the James Clerk Maxwell Telescope on 15 nights between 2013 March 9 (r = 4.52 AU) and June 16 (r = 3.35 AU) were used to search for CO and HCN rotation lines. No gas was detected, with upper limits for CO ranging between 3.5–4 × 1027 molecules s−1. Combined with published water production rate estimates we have generated ice sublimation models consistent with the photometric light curve. The inbound light curve is likely controlled by sublimation of CO2. At these distances water is not a strong contributor to the outgassing.

Key words: comets: general – comets: individual (ISON)

Online-only material: machine-readable table

1. INTRODUCTION

On 2012 September 21 a new sungrazing comet was discovered using the 0.4 m International Scientific Optical Network telescope in Russia (Nevski & Novichonok 2012). The comet was designated C/2012 S1 (ISON, hereafter comet ISON) and was bright and active at 6.3 AU pre-perihelion. The current estimate of its orbital eccentricity is 1.00004, thus it is possibly making its first passage through the inner solar system from the Oort Cloud. Perihelion is on 2013 November 28 at a distance of 0.0125 AU (2.7 solar radii), and some predictions suggest it could become exceedingly bright. About a dozen comets in the past ~270 yr have been spectacularly bright (mag < −5), and the hope that comet ISON could be one of these has generated intense scientific interest. However, it is difficult to predict the comet’s behavior while still far from the Sun. Comet ISON was well placed for observation until moving into solar conjunction in 2013 June, and it emerged again in the dawn skies in late 2013 August, near r = 2.4 AU. In this Letter, we report observations of the comet at optical and submillimeter wavelengths from 2011 September through 2013 June. Based on these data and the gas production rates from the literature, we used an ice sublimation model to look at activity scenarios for when the comet emerged from solar conjunction.

2. OBSERVATIONS AND DATA REDUCTION

We initiated both a pre-perihelion imaging campaign and a submillimeter observing campaign to constrain volatile production rates (see Table 1). Imaging data were taken on both photometric nights and nights with some cirrus. Calibrations on photometric nights were accomplished with measurements...
of Landolt (1992) standard stars. Fields on non-photometric nights and for Pan-STARRS1 (PS1) were calibrated against the Sloan Digital Sky Survey (SDSS; York et al. (2000)) or the PS1 2-pi survey (Magnier et al. 2013). Conversion to Kron–Cousins nights and for Pan-STARRS1 (PS1) were calibrated against the

| UT Date      | Telescope | N°  | ρ   | Filter | r°  | Δ°  | α°  | TA | PA−σ | PA+σ | mσ |
|--------------|-----------|-----|-----|--------|-----|-----|-----|----|------|------|-----|
| 2011 Sep 30  | PS1       | 4   | 180 | w_P1  | 9.392 | 9.679 | 5.77 | −175.83 | 284.9 | 299.8 | 20.91 ± 0.12 |
| 2011 Nov 10  | PS1       | 2   | 90  | r_P1  | 9.064 | 8.669 | 5.87 | −175.75 | 278.4 | 294.5 | 20.64 ± 0.11 |
| 2011 Nov 26  | PS1       | 2   | 86  | g_P1  | 8.934 | 8.302 | 5.05 | −175.72 | 274.2 | 293.4 | 20.42 ± 0.10 |
| 2011 Dec 9   | PS1       | 2   | 30  | z_P1  | 8.829 | 8.043 | 4.04 | −175.69 | 268.9 | 293.2 | 19.92 ± 0.12 |
| 2012 Jan 5   | PS1       | 1   | 43  | g_P1  | 8.606 | 7.643 | 1.41 | −175.63 | 226.3 | 302.9 | 19.55 ± 0.09 |
| 2012 Jan 28  | PS1       | 2   | 90  | w_P1  | 8.416 | 7.491 | 2.44 | −175.58 | 125.4 | 61.9  | 19.67 ± 0.02 |
| 2012 Oct 11  | HCT2 m    | 5   | 1500 | R     | 6.089 | 6.212 | 9.26 | −174.80 | 284.9 | 297.2 | 17.49 ± 0.01 |
| 2012 Oct 14  | Calar Alto 1.2 m | 7 | 1800 | R     | 6.067 | 6.155 | 9.32 | −174.79 | 284.7 | 297.0 | 17.49 ± 0.02 |
| 2012 Nov 8   | UH2.2 m   | 2   | 600  | R     | 5.814 | 5.474 | 9.46 | −174.68 | 281.1 | 294.0 | 17.12 ± 0.01 |
| 2012 Nov 22  | Lowell 1.8 m | 3 | 1800 | VR    | 5.672 | 5.114 | 8.68 | −174.70 | 278.0 | 292.5 | 16.87 ± 0.01 |
| 2012 Dec 20  | Lowell 1.8 m | 3 | 1800 | R     | 5.383 | 4.502 | 5.10 | −174.47 | 264.3 | 290.3 | 16.32 ± 0.01 |
| 2012 Dec 23  | PS1       | 4   | 180 | w_P1  | 5.350 | 4.446 | 4.55 | −174.46 | 261.1 | 290.4 | 16.35 ± 0.03 |
| 2013 Jan 3   | PS1       | 1   | 40  | r_P1  | 5.234 | 4.275 | 2.62 | −174.40 | 238.3 | 292.8 | 16.02 ± 0.04 |
| 2013 Jan 6   | Calar Alto 1.2 m | 3 | 900  | R     | 5.199 | 4.231 | 2.15 | −174.37 | 223.3 | 295.5 | 16.08 ± 0.03 |
| 2013 Jan 13  | Lowell 1.8 m | 2 | 1200 | R     | 5.129 | 4.157 | 1.87 | −174.34 | 177.9 | 313.7 | 16.81 ± 0.01 |
| 2013 Feb 4   | Gemini N 8 m | 2 | 150  | r     | 4.891 | 4.019 | 5.95 | −174.20 | 113.2 | 85.6  | 15.88 ± 0.10 |
| 2013 Mar 4   | Gemini N 8 m | 2 | 90   | r     | 4.578 | 4.050 | 11.19 | −174.01 | 99.1  | 84.4  | 15.90 ± 0.10 |
| 2013 Apr 3   | Gemini N 8 m | 4 | 197  | r     | 4.231 | 4.206 | 13.61 | −173.77 | 93.0  | 80.3  | 15.87 ± 0.10 |
| 2013 May 1   | Calar Alto 1.2 m | 4 | 1200 | R     | 3.886 | 4.326 | 12.70 | −173.50 | 90.2  | 75.6  | 15.92 ± 0.02 |
| 2013 May 4   | Gemini N 8 m | 3 | 135  | gri   | 3.857 | 4.331 | 12.50 | −173.48 | 90.0  | 75.1  | 15.61 ± 0.10 |
| 2013 May 17  | UH2.2 m   | 4   | 1200 | R     | 3.693 | 4.341 | 11.13 | −173.42 | 89.6  | 73.6  | 15.85 ± 0.01 |
| 2013 May 30  | Gemini N 8 m | 2 | 90   | r     | 3.528 | 4.318 | 9.34 | −173.18 | 87.6  | 66.2  | 15.65 ± 0.01 |
| 2013 Aug 12  | G95 11-in | R   | 2.487 | 3.418 | 7.88 | −171.89 | 294.2 | 311.3 | 14.73 ± 0.10 |
| 2013 Aug 16  | G95       | R   | 2.425 | 3.332 | 9.07 | −171.79 | 293.1 | 309.1 | 14.71 ± 0.10 |

Table 1: Observations

Notes.

- Number of exposures.
- Total integration time, s.
- Heliocentric distance, AU.
- Geocentric distance, AU.
- Solar phase angle, degrees.
- True anomaly, degrees.
- Position angle of the antisolar vector, degrees east of north.
- Position angle of the negative velocity vector, degrees east of north.
- Mean apparent R-band magnitude.
- Hereford Arizona Observatory.
- Rest Frequency, in GHz.
- Total integration time, s.
- Main beam efficiency.
- 1σ rms noise in unit of the main beam brightness temperature, in mK.
- Kinetic temperature computed based on the formula from Biver et al. (1997), in K.
- 3σ production rates upper limits for CO, in 10^{27} molecules s^{-1},

2.1. Pan STARRSI

Comet ISON was detected in images obtained with PS1 and the Gigapixel Camera 1 (0.256 pixels) between 2011 September and 2013 January during regular survey operations. Exposures were made in the survey grizw_P1 filters. Moving objects are normally automatically detected and measured via difference imaging (Denneau et al. 2013). Before 2012 January the comet was moving too slowly and/or was too faint for this to be successful; these detections were made by manual inspection of the data post-discovery. In all PS1 pre-discovery data the comet has a profile no wider than the point spread function (PSF) of field stars, although we infer it was likely to be active at this time (see Section 3.2). The magnitudes were measured via DAOPHOT PSF-photometry relative to field stars of known magnitudes (Schlafly et al. 2012). The 2012 January 28 detections were reported to the Minor Planet Center within 24 hr. However as its motion was roughly parallel to

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Notes.

- Number of exposures.
- Total integration time, s.
- Heliocentric distance, AU.
- Geocentric distance, AU.
- Solar phase angle, degrees.
- True anomaly, degrees.
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- Position angle of the negative velocity vector, degrees east of north.
- Mean apparent R-band magnitude.
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- Rest Frequency, in GHz.
- Total integration time, s.
- Main beam efficiency.
- 1σ rms noise in unit of the main beam brightness temperature, in mK.
- Kinetic temperature computed based on the formula from Biver et al. (1997), in K.
- 3σ production rates upper limits for CO, in 10^{27} molecules s^{-1},

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18 http://www.sdss.org/
gas returned negative results. HCN is an indicator of sublimated gas, but not expected to play a major role in controlling the brightness of the comet, so we focus only on the analysis of CO. To estimate production rates of CO, we measured the root-mean-square value of the main beam brightness temperature fluctuations within ±10 km s⁻¹ of zero velocity (see Table 1). Given that CO lines are likely to be narrow (Senay & Jewitt 1994; Biver et al. 2002), the 3σ upper limits to the line area were derived within a 1.2 km s⁻¹ or 1.5 km s⁻¹ (for June only) bandwidth. We assume that gas molecules escape from the surface at a constant velocity and follow a Haser density distribution. We adopted an average expansion velocity of 1.12 r⁻⁰.₄₁ km s⁻¹ and the kinetic temperature was estimated using an empirical formula of 116 r⁻¹.₂₄ K, where r is the heliocentric distance (Biver et al. 1997). The derived production rate upper limits, for the CO J(2−1) and J(3−2) transitions, are listed in Table 1.

2.5. The CARA Project

CARA is a consortium of amateur astronomers who have developed a standardized approach to observing comets. Photometry through a Cousins R-filter was obtained on 46 dates (Table 2) beginning shortly after discovery in 2012 September through 2013 May with most of the observations coming from 0.4 m telescopes at the BRIXIIS Observatory in Belgium, the Talmassons Observatory and Stazione Astronomica Descartes in Italy. The photometry was calibrated using the APASS catalog.¹⁹

2.6. VYSOS Telescope

We used the 5.3 inch Variable Young Stellar Objects Survey (VYSOS) program²⁰ robotic refractor at the Mauna Loa Observatory in Hawai‘i, with an Apogee Alta U16M CCD (field of view 2.9 x 2.9 degrees with a plate scale of 2'53 pixel⁻¹) to image the comet. Images were taken nearly nightly from 2013 April to mid-June (Table 2). On most nights, at least three exposures of 100 s each were taken in a Sloan r'-band filter. We used SExtractor²¹ to extract detections from our 165 VYSOS images, using an aperture that contained >95% of the PSF. We corrected for focal plane irregularities with an approximate distortion map, permitting us to match stellar detections between frames in the VYSOS run. We used the first image to perform relative photometric calibrations of subsequent images, and used overlapping stars from frame to frame for calibration—thus establishing a relative zero-point calibration spanning the entire run has a nominal uncertainty of 0.027 mag. For some VYSOS frames, the survey overlapped with SDSS, permitting us to calibrate one selected frame to 0.014 mag using 39 SDSS stars, establishing an absolute magnitude scale for the entire run. ISON’s ephemeris was used to search for it in the SExtractor catalogs and then measure it, finding an object within 4" (<2 pixels) of its predicted location in 129 frames (the others were excluded because of chip gaps and field star proximity).

3. ANALYSIS AND RESULTS

3.1. Finson–Probstein Dust Modeling

Finson–Probstein modeling (Finson & Probstein 1968) was used to analyze the synchrone–syndyne pattern and the optical

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¹⁹ http://www.aavso.org/apass
²⁰ http://www.ifa.hawaii.edu/~reipurth/VYSOS/
²¹ http://www.astromatic.net
appearance of the comet’s dust environment (modeling details are described in Beisser 1987; Vincent 2010). Due to projection, as seen from Earth the synodyne–synchrone pattern converges in the direction of the dust tail, aligning with the central axis of the optical dust tail. The travel time of micron-sized dust through the dust tail in the images is ∼20–30 days. Larger grains of ∼100 μm size may stay much longer (∼100 days) in the immediate (5" radius) neighborhood of the nucleus. The width of the dust tail suggests a dust expansion speed of ∼10 m s⁻¹ assuming micron size dust grains dominate its optical appearance. It is reasonable to assume that larger (100 μm) grains leave the nucleus dust acceleration zone at a speed near one to a few m s⁻¹.

3.2. Conceptual Ice Sublimation Model

We used a simplified ice sublimation model to investigate the level of activity versus heliocentric distance. The model computes the amount of gas sublimating from an icy surface exposed to solar heating (Meech et al. 1986; Meech & Sören 2004). As the ice sublimates, either from the nucleus surface or near-subsurface, the escaping gas entrains dust in the flow which escapes into the coma and tail. The scattered brightness of the comet as measured from Earth has a contribution from the light scattered from the nucleus and the dust. Model free parameters include the ice type, nucleus radius, albedo, emissivity, density, properties of the dust (sizes, density, phase function), and fractional active area.

Our model assumes a nucleus radius of \( R_N \sim 2 \text{ km} \), consistent with the size limit inferred from Hubble Space Telescope (HST) measurements (Li et al. 2013), an albedo of 0.04 for both the nucleus and dust, and a linear phase function of 0.04 mag deg⁻¹ typical of other comets. We assume a nucleus density of 400 kg m⁻³ similar to that seen for comets 9P/Temps 1 and 103P/Hartley 2 (Thomas et al. 2013a, 2013b), a grain density of 1000 kg m⁻³, and micron-sized grains (see Section 3.1 and Yang 2013). Because of the many model free parameters, our conclusions are dependent on how well we can constrain some of the values with observations. The shape of the light curve—i.e., where the curve is steep or shallow—is determined by the sublimating ice composition. With reasonable estimates of nucleus size, albedo, density, and grain properties, the fractional active surface area is adjusted to produce the observed volatile production rates. Note, if the HST nucleus size is much smaller than the upper limit used here, the model will require an increase in the active fractional area, but otherwise the discussion below remains unchanged.

Because the comet was active at discovery (\( r = 6.3 \text{ AU} \)) where it was too cold for significant water-ice sublimation, there must be another volatile besides H₂O responsible for the outgassing. The likely candidates are CO and CO₂. The warm Spitzer measurements on June 13 (Lisse et al. 2013) detected an excess brightness at 4.5 μm due to emission from a neutral gas coma which could either be due to CO₂ or CO (because both have lines in the bandpass). Unfortunately, there have been no definitive spectral detections of either molecule reported yet, however the similarity of the estimated CO₂ production rate to measurements of other comets at large distances (Ootsubo et al. 2012) suggested that CO₂ dominated. We ran two models, assuming the excess seen by Spitzer was either all CO or CO₂ (see Table 3) and the best fit models are shown in Figure 2(a). While both models can fit the inferred Spitzer and water production rates, and match the scattered light data from the dust in 2013 June, neither model alone is a good match to the light curve.

Our June CO production upper limits (which agreed with preliminary estimates from HST; M. A’Hearn 2013, private communication), also suggested that the Spitzer observations were mostly CO₂. With this scenario, however, the only explanation for the light curve between 6–3.5 AU was a long slow outburst, driven most likely by CO (and supported by a possible CO detection; N. Biver 2013, private communication). Such a scenario is physically plausible, as evidenced by the aperiodic CO driven outbursts of Comet 29P/Schwassmann-Wachmann 1 at similar distances (Cochran et al. 1982; Crouzier et al. 1995).

While we were preparing the models, an amateur astronomer, B. Gary²² reported the recovery of the comet as it came out of solar conjunction on 2013 August 12 and 16 at 7 airmasses. These magnitudes are also included in Table 1. At \( r = 2.5 \text{ AU} \), H₂O sublimation should be important and we added this to the model and found that with a fractional active area of 2.5% for water sublimation and 0.54% for CO₂, the model fit both the 2013 August data and the early PS1 data with the comet being largely controlled by CO₂ outgassing as shown in Figure 2(b).

²² brucegary.net/ISON

| UT Date | Tel.⁴ | N | t | Filter | r | Δ | α | TA | PA −⊙ | PA −⊙ | mg |
|---------|------|---|---|-------|---|---|---|-----|------|------|----|
| 2012 Sep 25 | CARA-Net | R | 6.250 | 6.636 | 8.240 | −174.868 | 286.8 | 299.7 | 17.69 ± 0.21 |
| 2012 Oct 4 | CARA-Net | R | 6.161 | 6.405 | 8.830 | −174.831 | 285.8 | 298.3 | 17.05 ± 0.10 |
| 2012 Oct 10 | CARA-Net | R | 6.103 | 6.251 | 9.167 | −174.807 | 285.1 | 297.4 | 17.10 ± 0.20 |
| 2012 Oct 22 | CARA-Net | R | 5.985 | 5.931 | 9.566 | −174.756 | 283.6 | 295.9 | 17.01 ± 0.17 |
| 2012 Oct 23 | CARA-Net | R | 5.978 | 5.912 | 9.579 | −174.753 | 283.5 | 295.8 | 17.07 ± 0.20 |
| 2013 Apr 2 | VYSOS | 3 | 300 | r | 4.242 | 4.201 | 13.589 | −173.78 | 93.2 | 80.4 | 16.10 ± 0.06 |
| 2013 Apr 3 | VYSOS | 6 | 600 | r | 4.232 | 4.205 | 13.608 | −173.77 | 93.0 | 80.3 | 15.68 ± 0.02 |
| 2013 Apr 4 | VYSOS | 3 | 300 | r | 4.220 | 4.211 | 13.627 | −173.76 | 92.9 | 80.1 | 15.89 ± 0.04 |
| 2013 Apr 5 | VYSOS | 3 | 300 | r | 4.208 | 4.216 | 13.642 | −173.75 | 92.8 | 80.0 | 15.90 ± 0.04 |
| 2013 Apr 6 | VYSOS | 3 | 300 | r | 4.196 | 4.222 | 13.653 | −173.75 | 92.7 | 79.9 | 15.89 ± 0.05 |

Note. ⁴ See notes for Table 1.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

Table 2
CARA and VYSOS Observations
The sublimating area of was a period of increased activity reaching a maximum effective starting around the time of the first PS1 observations. The effect (2012 September through 2013 May). As noted in Section 3.1, duration are so large that they stay within the 5\^\text{th} magnitude of large grains from the aperture, grains that would survive for the days at the low temperatures outside \( r = 5.1 \) AU in 2013 January, and linearly dropping off and ceasing activity in mid July. This increase is shown as the dotted line in Figure 2(b). The difference between the observations and the CO\(_2\) plus H\(_2\)O model is shown in Figure 2(c) which represents the CO outburst. The predicted CO production rates during this time are shown in Table 3.

Matching water production estimates from 2013 March 5 and May 4 (Schleicher 2013a, 2013b; see Table 3), required that the effective water-ice sublimating area was \( \sim 6 \times 10^6 \) that of the nucleus surface in March dropping to \( \sim 80\% \) of the surface in May as the heliocentric distance decreased. The model run-out was also consistent with all of the other H\(_2\)O production rate upper limits shown in Table 3. As was seen for 103P/Hartley 2 (A'Hearn et al. 2011), we propose that this outburst ejected large water ice grains into the coma. It has been shown experimentally that sublimation from deeper layers can result in the ejection of large slow-moving grains (Lauffer et al. 2005). A long-lived population of large (\( \sim 100\ \mu m \)) water-ice grains in the near nucleus environment could explain this water production behavior.

If we allow that solar heat from the inbound orbit reached a deeper layer of CO this could trigger additional outgassing starting around the time of the first PS1 observations. The effect was a period of increased activity reaching a maximum effective sublimating area of \( \sim 3.4\% \) at \( r = 5.1 \) AU in 2013 January, and linearly dropping off and ceasing activity in mid July. This increase is shown as the dotted line in Figure 2(b). The difference between the observations and the CO\(_2\) plus H\(_2\)O model is shown in Figure 2(c) which represents the CO outburst. The predicted CO outburst production rate prediction from model CO outburst.

### Table 3

| UT Date 2013 | JD\(^a\) | \( J^b \) | TA\(^c\) | \( Q_{\text{CO}}^d \) | \( Q_{\text{H}_2\text{O}}^d \) | Facility | Ref | Model \( Q_{\text{CO}}^e \) |
|-------------|---------|---------|--------|----------------|-------------------|---------|-----|------------------|
| January 30  | 56232   | 4.94    | -174.23 | <1E28          |      | Swift   | 1   |                  |
| March 5     | 56356   | 4.57    | -174.00 | 3E26           |      | Lowell  | 2   |                  |
| March 11    | 56363   | 4.50    | -173.96 | <1E28          |      | Swift   | 1   |                  |
| March 10–15 | 56365   | 4.52    | -173.97 | <3.9E27        |      | JCMT    | 3   | 1.9E27           |
| March 30–April 1 | 56382 | 4.28    | -173.80 | <3.5E27        |      | JCMT    | 3   | 1.7E27           |
| April 24    | 56407   | 3.98    | -173.58 | <1E28          |      | Swift   | 1   |                  |
| April 27–28 | 56410   | 3.95    | -173.55 | <4.5E27        |      | JCMT    | 3   | 1.5E27           |
| May 4       | 56417   | 3.86    | -173.48 | 6E26           |      | Lowell  | 5   |                  |
| May 9       | 56422   | 3.79    | -173.42 | <1E28          |      | Swift   | 1   |                  |
| June 15     | 56457   | 3.34    | -173.00 | 2.1E27         | 1.9E26 | Spitzer | 6   | 7.0E26           |
| June 14–15  | 56458   | 3.33    | -172.98 | <4.1E27        |      | JCMT    | 3   | 7.0E26           |

Notes.

\( ^a \) Julian Date: 2,400,000.

\( ^b \) Heliocentric distance, AU.

\( ^c \) True anomaly, degrees.

\( ^d \) Production rate, molecules s\(^{-1}\).

\( ^e \) CO production rate prediction from model CO outburst.

### References.

1. Bodewits et al. 2013; 2. Schleicher 2013a; 3. This Letter; 4. M. A’Hearn 2013, private communication; 5. Schleicher 2013b; 6. Lisse et al. 2013.

### 4. DISCUSSION

In formulating the concept of the Oort Cloud (Oort & Schmidt 1951), Oort suggested that the dearth of returning long-period comets at large semi-major axis was due to chemical alteration of their surface layers by cosmic rays, and that this “volatile frosting” was lost on the first passage through the inner solar system. One interpretation of comet IS0N’s heliocentric light curve could be its activity through 2013 January was dominated by the loss of this highly volatile layer, and the activity since then has been decreasing. The implication of this interpretation is that the comet will not brighten as dramatically as hoped near perihelion, and that the apparent brightness coming out of solar conjunction would have remained flat or even decreased. This is similar to the behavior observed for Comet C/1973 E1 (Kohoutek).

In the second scenario for activity where the comet is largely driven by CO\(_2\) outgassing, our models predicted that the apparent brightness within a 5\(^\circ\) radius aperture should be \( \sim R = 14-14.5 \) when the comet came out of solar conjunction in late August/early September matching closely what has occurred. While it is unwise to make predictions about the brightness at perihelion when the comet is still far from the Sun, especially when it will pass so close to the Sun, the run out of these sublimation models show that the comet can still be quite bright at perihelion.

Gemini is operated by AURA under a cooperative agreement with the NSF on behalf of the Gemini partnership. The James Clerk Maxell Telescope is operated by the Joint Astronomy
Figure 2. Conceptual ice sublimation model, showing the best fit for 2013 June 13 (TA = −173.0). The different ice models are for H2O (dot-dash), CO2 (long-short dash), CO (dotted) and total (solid red line). The large telescope photometric measurements are shown as large black squares, the PS1 precovery data as blue squares, the CARA data as cyan triangles, the data from VYSOS as the magenta crosses, and data as reported in the MPECs as black dots (uncorrected for aperture size). The optical data obtained at the time of the Spitzer observations (Lisse et al. 2013) are shown as small red squares. The reported measurements by B. Gary are shown as black triangles. The vertical dotted lines show the dates for which QH2O has been published. The vertical long dashed lines show the dates where we present JCMT QCO upper limits and the short dashed lines indicate when the comet will likely become accessible to large telescopes as it comes out of solar conjunction. (a) Best fit models assuming that all the reported Spitzer outgassing is due to only CO or CO2. (b) Best fit model with baseline CO2 plus H2O sublimation with an additional slow CO outburst. (c) Difference between the data and sublimation model, showing the outburst.