Forbidden Oxygen Lines in Comets C/2006 W3 Christensen and C/2007 Q3 Siding Spring at Large Heliocentric Distance

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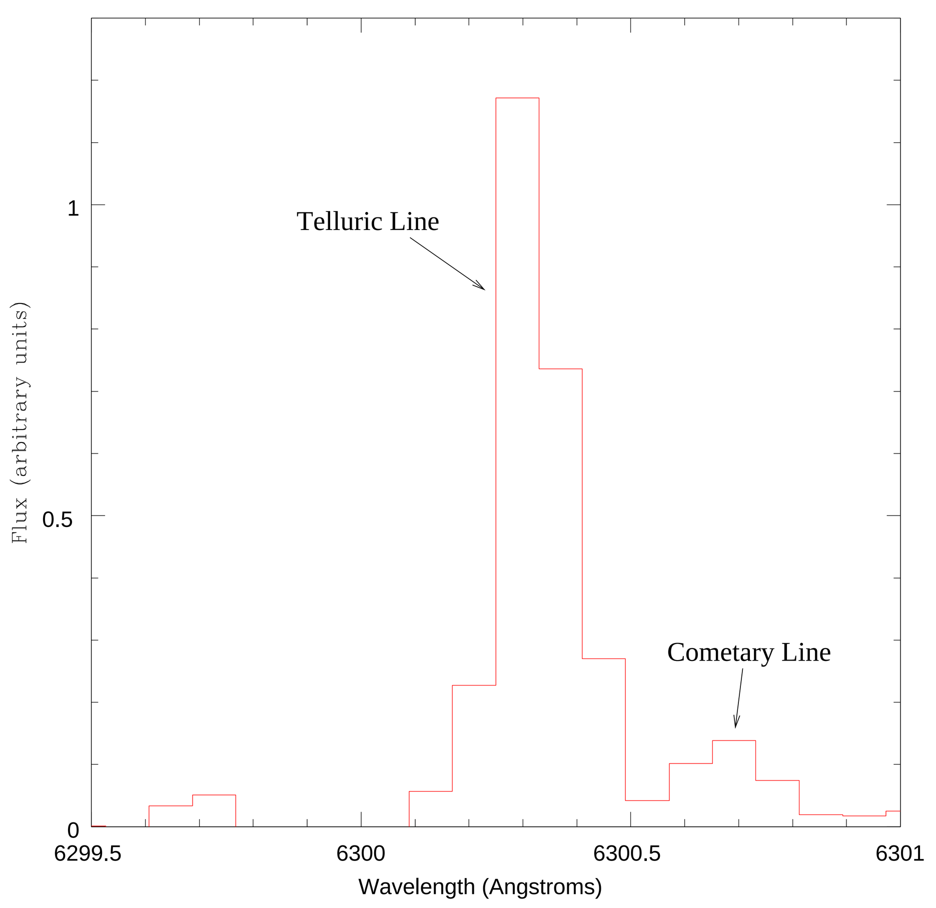
Introduction

- Cometary composition is important in that comets represent pristine material left over from the Solar System's formation. Composition of the nucleus is inferred from the composition of the coma, which is determined by sublimation of the surface ices. Therefore we need to understand the sublimation behavior of the primary ices: H_2O, CO_2, and CO.
- Atomic oxygen is an effective tracer for H_2O, CO_2, and CO in a cometary coma. The intensity ratio of the 5577 $\AA$ line (i.e. ^{1}S atoms) to the sum of the 6300 $\AA$ and 6364 $\AA$ lines (i.e. ^{1}D atoms) can reveal the identity of the dominant parent of the oxygen atoms (Festou and Feldman 1981). If H_2O is the dominant parent, the ratio of the 5577 line to the sum of the 6300 and 6364 line will be around 0.1, while if CO_2 or CO is the dominant parent, this ratio will be ~ 1. The line ratio cannot be greater than unity since every atom that decays through the 5577 line will also decay through either the 6300 or 6364 line.
- All measurements for comets at ~ 1 AU from the Sun suggest that water is the dominant parent (e.g. Cochran and Cochran 2001, Cochran 2008). Measurements by Furusho et al. (2006) and Capria et al. (2010) at ~ 2.5 AU from the Sun suggest CO_2 plays an increased role in supplying the OI population.
- Here we present observations of the forbidden oxygen lines in comets C/2006 W3 Christensen and C/2007 Q3 Siding Spring at heliocentric distances of 3.13 and 2.96 AU, respectively.

Observations

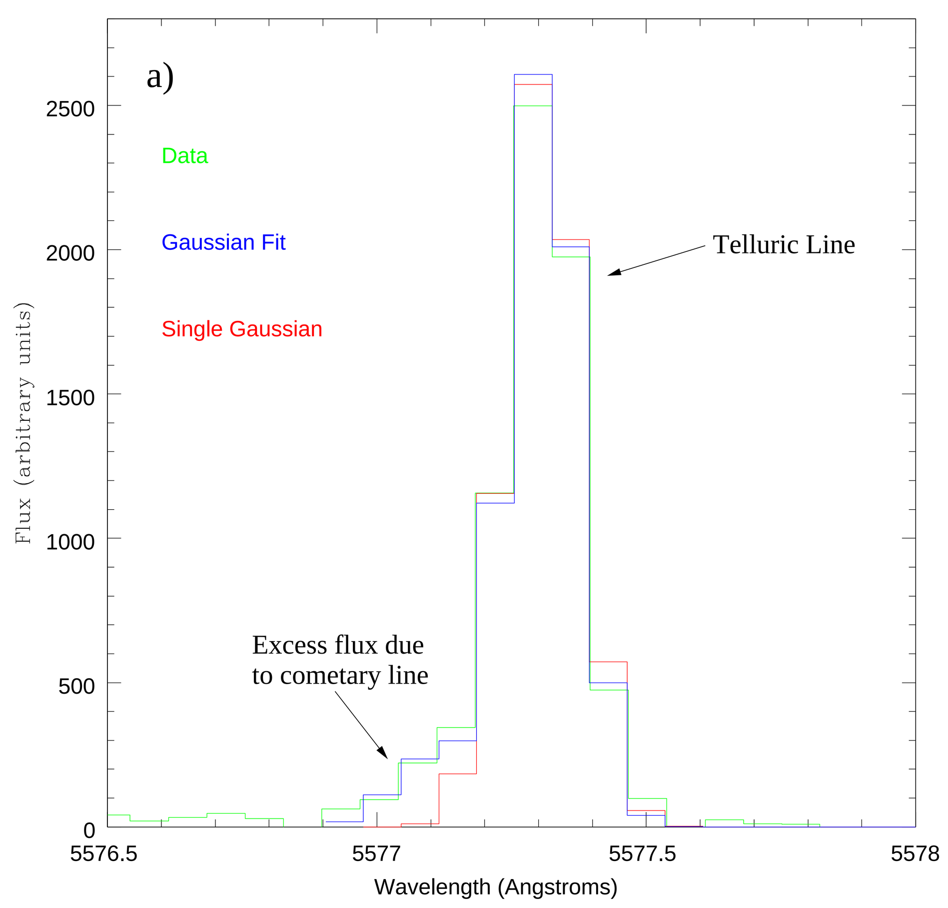
- We obtained observations using the ARCES echelle spectrometer (R $\sim$ 31,500) on the 3.5 meter telescope at Apache Point Observatory.
- We observed C/2006 W3 Christensen on UT August 1, 2009 under non-photometric conditions. We observed C/2007 Q3 Siding Spring on UT March 28 2010 (about 10 days after an observed split of the nucleus) under photometric conditions.
- We centered the 3.2" $\times$ 1.6" slit on the optocenter of the comet in both cases. We observed the 5577, 6300, and 6364 lines simultaneously.

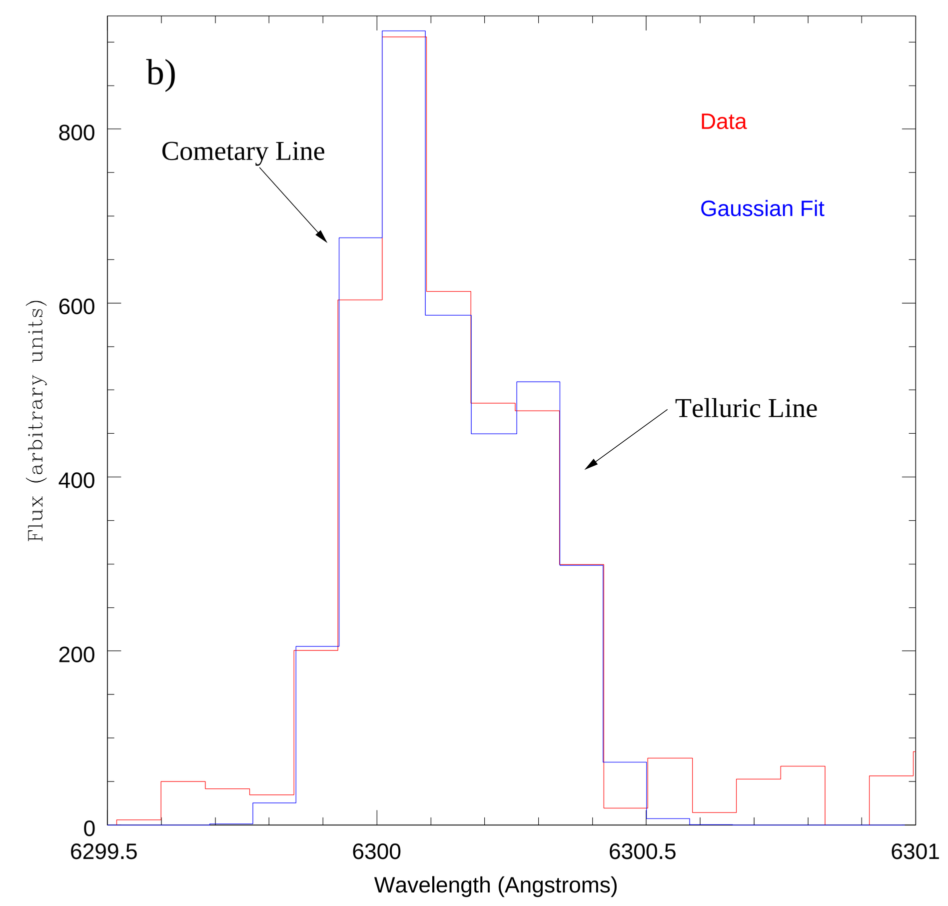
C/2007 Q3 Siding Spring

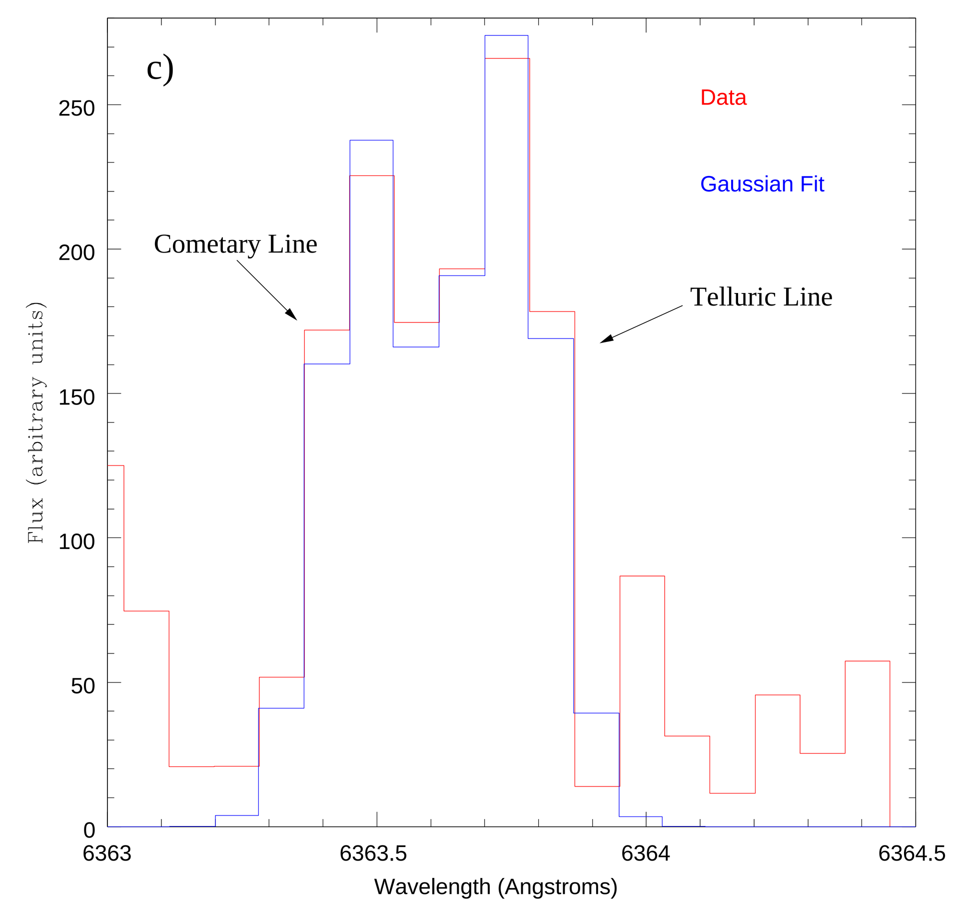


The 6300 line for Comet Siding Spring. We did not detect the 5577 and 6364 lines. Although we are unable to measure the line ratio (5577/(6300+6364)) in this case, we can place an upper limit on its value. We find that this upper limit is 0.32.

C/2006 W3 Christensen







The three oxygen lines for Comet Christensen are shown above. The lines are blended with their telluric counterparts and therefore deblending was neccessary. Gaussian fits to the line profiles which account for both the telluric and cometary lines are overplotted in purple. We derive a line ratio (5577/(6300+6364)) of 0.19 $\pm$ 0.02. a) The 5577 line for Comet Christensen. Note that a single Gaussian (plotted in red) cannot account for the excess flux blueward of the telluric line that is due to the cometary line. b) The 6300 line for Comet Christensen. c) The 6364 line for Comet Christensen.

Results

- The line ratio (5577/(6300+6364)) found for C/2006 W3 Christensen is higher than found in previous studies, suggesting that CO_2 and CO may be playing a more significant role in supplying the OI population. This could be due to a decreased volatility of H_2O relative to CO_2 because of its fairly large heliocentric distance, Christensen being inherently rich in CO_2 relative to H_2O, or a combination of both.
- We have placed an upper limit on the line ratio for C/2007 Q3 Siding Spring of 0.32. This value is consistent with the line ratio found for Christensen and other comets.
- The following equation can be used to determine the ratio $\frac{N_{CO_2}}{N_{H_2O}}$

$$\frac{N_{CO_2}}{N_{H_2O}} = \frac{RA^{1D}_{H_2O} - A^{1S}_{H_2O}}{A^{1S}_{CO_2} - RA^{1D}_{CO_2}} \qquad (1)$$

  where N_x denotes the number density of species x, R is the measured oxygen line ratio and A^x_y represents the excitation rate of molecule y for producing oxygen atoms with excitation state x.
- For Christensen, we find a value of N_{CO_2}/N_{H_2O}= 0.46$\pm$0.07. For Siding Spring, the upper limit on the number density ratio is 1.11.
- We use the 6300 line flux for Siding Spring and aperture corrections derived from Haser Models for H_2O, CO_2, and CO with standard parameters to predict production rates of these molecules under the assumption that each species dominates the OI production. We also consider cases where OI has multiple nonnegligible parents.
- We find that the contribution of CO to the OI population is negligible. Using our upper limit on the line ratio for Siding Spring, we find that the production rate of water is between appoximately 10^{27} and 10^{28} mol/s, while that of CO_2 is less than $\sim 3 \times 10^{27}$ mol/s.

Conclusions

- These oxygen line ratios are not consistent with the vaporization model put forth by Delsemme (1982). According to their model, CO_2 should have a production rate much greater than that of H_2O ($\gg 10$), which is not seen.
- These ratios are consistent with the model put forth by Meech and Svoren (2004), in which a more realistic albedo for the nucleus is used. The lower albedo used by Meech and Svoren results in water sublimation being possible at large heliocentric distances.
- The value of $\frac{N_{CO_2}}{N_{H_2O}}$ we find for Christensen is consistent with the crossing of the CO and OH production rates at 3-4 AU in C/1995 O1 Hale-Bopp observed by Biver et al. (2002). This would imply 3-4 AU from the Sun is a transition region where CO_2 and CO become more important than H_2O for driving cometary activity.

Acknowledgments

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