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Neutral and Plasma Distributions in the Coma of Comet C/2012 S1 ISON: Narrowband Imaging and Integral-Field Spectroscopy

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Abstract

We present concurrent spectra and filtered imaging of the coma of C/2012 S1 ISON at .44 to 0.47 AU from the sun. C_2, NH_2, Na, and H_2O^+ distributions were elongated several thousand km along an axis perpendicular to the comet's motion and the sunward vector. The peak brightness of each species was collocated within 5,000 km of the dusty continuum concentration. ISON's water ion tail appeared distinctly broader than the neutral Na tail and we find no evidence for an extended source of Na by dissociative recombination of a molecular ion. Rather, an extended source of as much as 50% of Na may be attributed to dust, evidenced via Monte Carlo simulations of a distant sodium tail extending beyond 10^6 km. An increase of nearly a factor of four in the Na source rate was found within a 24 hour interval during an outburst, and the relative Na/O abundance is estimated at ~5 x 10^{-7}, well below the ratio known in active comets of comparable geometry.

1. Introduction

Comet C/2012 S1 ISON survived just 14 months between discovery and disintegration just prior to its 2.7 R_{Sun} perihelion. The highly varied water production was monitored using a Lyman α proxy with a source rate as high as 1.1 x 10^{30} s^{-1} during these observations [1]. Fragmentation of the nucleus likely occurred at 0.65 AU from the Sun, with further breakup subsequently and frequent outbursts along its inbound trajectory. A close passage to the Earth (0.86 AU) with near 90° phase angles gave ideal conditions for mapping gas distributions in the coma of this bright, active and pristine Oort cloud comet. We used this opportunity to optimize spatial resolution of the neutral, plasma and dust distribution of the coma.

2. Methods

ISON was observed from McDonald Observatory in Fort Davis, TX, with two small co-aligned optical telescopes on 19.5 and 20.5 Nov 2013. A 40 cm Cassegrain feeding an image-slicer spectrograph (R~20,000) is used here to measure C_2, NH_2, Na, and H_2O^+ emission lines in comet coma within a narrow spectral window spanning 5868Å to 5926Å. The spatial distributions of these species are mapped over a 1.6 x 2.7 arc-minute field made up of 240 individual spectra. Monochromatic images are assembled from individual emission lines, selected to minimize blending in overlapping spectral features. These images are grouped by species, shifted to a common optocenter centroid and co-added to yield distributions in the coma on scales of 10^4 km. At these distances from the nucleus, neutral molecules can be approximately modeled using a Haser analytic formula, while other species demand a more complex treatment.

On larger 10^6 km scales, a small 10 cm refracting telescope with a 7° wide field isolated Na emission by differencing narrowband (14Å) filters centered at 5893Å and 6051Å. In this large field, background spectral standard stars provided an absolute flux calibration through high airmass observing angles. At these distances from the nucleus, the Na tail can be simulated using ballistic atomic trajectories ejected from a collisional radius analogous to a planet's exobase with Monte Carlo seeding. This method integrates the 3D equation of motion of 10^6 particles, considering the effects of gravity, radiation pressure and photo-ionization using a high-resolution solar spectrum interpolated from Earth orbit.

3. Results

ISON's dust distribution fell off less steeply than the canonical inverse with distance from the nucleus and C_2 and NH_2 scale lengths indicate an extended source, possibly due to nucleus fragmentation. No evidence of prompt Triplet or Asundi emissions from CO_2 dissociation into CO is found. The Na tail appears distinctly wider than the ion tail, evidencing dust as the extended source rather than a parent molecular ion (e.g., $NaCl^+$ is known to populate atomic Na clouds from the Io plasma torus). The Na D2/D1 ratio is everywhere 1.38 $\pm$ .10 despite being optically thin.

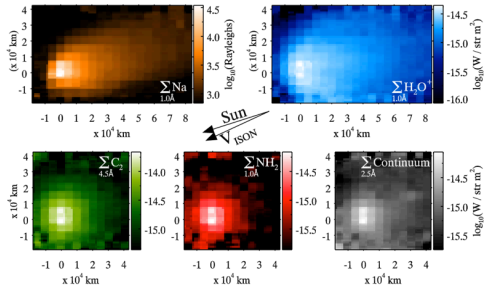

Figure 1: Spatial reconstructions of Na, H_2O^+, C_2, NH_2 and dusty continuum on 20.5 November 2013.

On UT 19.5 Nov 2013, the distant Na tail can be reproduced by 1.6$\pm$0.3 x 10^{23} atoms s^{-1} with nearly half of this production attributed to an extended source such as dust grains. Na production increased to 5.8 $\pm$ 1 x 10^{23} atoms s^{-1} during the following 24 hours, 85% of this within 12,000 km of the nucleus. After this outburst, production became ~5 x 10^{-7} that of water, well below the relative abundance determined in active comets of comparable geometry [2].

4. Summary and Conclusions

We reconstruct the spatial distributions of Na, H_2O^+, C_2, NH_2 and dust in the coma of C/2012 S1 ISON using high-resolution integral-field spectroscopy and differenced narrowband imaging. These data show a very low relative abundance of Na in ISON's coma with a rapidly variable production rate. Consistent with observations of Halley and Hale-Bopp, an extended source is important in the structure of sodium in ISON's coma. These results effectively rule out the possibility of a long-lived ionic parent and strongly suggest dusty origins as an extended source of neutral sodium.

Acknowledgements

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