The Ion Tail of Comet Machholz observed by OSIRIS as a Tracer of the Solar Wind Velocity

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Abstract

During commissioning of OSIRIS, the scientific imaging system onboard Rosetta, the comet C/2004 Q2 (Machholz) was observed on 20th January 2005, close to ist perihelion passage at a distance from Rosetta of 0.443 AU, and from the Earth of 0.405 AU. The Wide Angle Camera (WAC) detected the ion plasma tail of the comet through the Red and Green filters (630 and 537 nm, respectively). By an analysis of ground-based plasma tail observations taken almost during the OSIRIS observation and of the WAC data, we determine the appearance, morphology and orientation of the ion tail. Following this analysis, we estimate the solar wind velocity 3D vector, the first remote determinations of non- radial wind solar velocity components. Furthermore, we compare our observations with the simulations of solar wind condition and relevant coronal observations.

1. Introduction

At comets, neutral atoms and molecules are ionized, mainly by solar radiation. The ions are "picked-up" by the solar wind, and are carried downstream, to form the ion tail.

As first surmised by Biermann [1], the orientation of a comet's ion tail results from the combination of the comet's orbital velocity and the velocity of the solar wind. As a comet's velocity is well-known, its tail orientation indicates the local solar wind velocity, complementing in-situ spacecraft solar wind observations. This information is particularly valuable at high solar latitudes, as only Ulysses has sampled solar wind well outside the ecliptic.

A major problem with deriving the wind velocity from ion tail orientations is that the solar wind is assumed to be flowing radially, i.e. exactly along the local anti-sunward direction, and hence that the ion tail lies in the orbital plane of the comet. However, in-situ observations show that the solar wind deviates from this, typically by a few degrees. Velocities derived from tail orientations are therefore only estimates of solar wind velocity.

To derive the speed and direction of the solar wind, stereo comet observations are required, to obtain the ion tail direction in three dimensions. Observing from Earth alone, this is impossible, however, combined observations from Earth and interplanetary space can provide the necessary information. Here, we report such observations.

2. OSIRIS and Earth-based Observations

Comet C/2004 Q2 (Machholz) was discovered by Donald Machholz on 27 Aug. 2004, and reached a peak brightness of +3.5 mag in January 2005.

During commissioning, **OSIRIS**, the scientific imaging system on Rosetta [2], observed the bright Machholz close to perihelion on 20 January 2005 for around 3 hours in different optical filters (Fig. 1). OSIRIS comprises two cameras: Wide Angle Camera (WAC) and Narrow Angle Camera (NAC), with image scales of 20 and 4 arcsec/pixel, respectively.

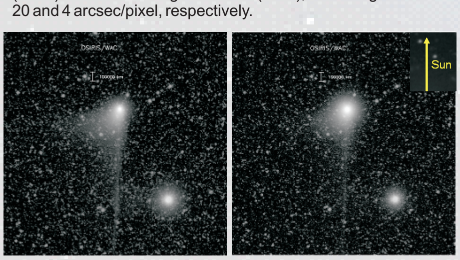

Fig. 1: Observations of Machholz by OSIRIS (left red broadband and right green filter, 630 and 537 nm, respectively). A visible Ion Tail of lenght of > 2000000 km is detected.

OSIRIS observations details:
Pixel Scale at the comet : 1: 1247 km (NAC), 5962 km (WAC)
Filters: 4 medium bandwidth filters at 648 - 980 nm (NAC)
red continuum, green, UV375, CN, CH, CS, and UV245 (WAC)
Time (UT): Start: 19:54, End: 23:01.
Total number of images: 75
Exposure time: 20 and 60 s

No dedicated, ground-based observations of Machholz were made at the exact time of the OSIRIS observations. Western Europe was the best location to have observed the comet concurrent with Rosetta, however, most of the continent was then under extensive cloud cover.

The temporally-closest image clearly showing the ion tail is shown in Fig. 2, obtained by M. Holloway of Arkansas, USA. It is unfortunate that this image was not coincident with those of Rosetta, as the solar wind conditions may have changed significantly between the two times. As this is the best image available, however, we conduct the analysis as if it were obtained at the same time.

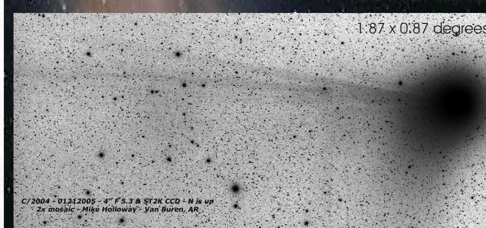

Fig. 2: Image of Machholz taken from USA on January 21 2005, at 2:14 UT (credits: Holloway)

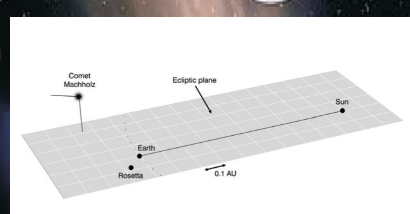

*Fig. 3: **Top-Left:** Relative positions of Sun, Earth, Rosetta and Machholz, with the ecliptic plane, at the time of the OSIRIS observations. **Lower-Right:** 2D plot of the plane containing the Rosetta-Machholz-Earth configuration.*

3.- Solar wind conditions at Machholz around January 20, 2005.

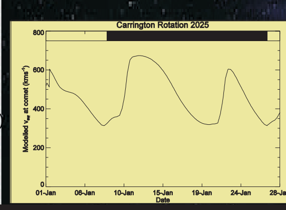

Fig.4: Simulated solar wind velocity and magnetic field polarity at Machholz (black and white bar) following MHD modelling [3]. Changes in polarity cause ion tail disconnections. On 20.1, the velocity was expected to be changing fairly rapidly, from around 320 to >600 km/s in less than a day.

4. Morphology and Orientation of Machholz

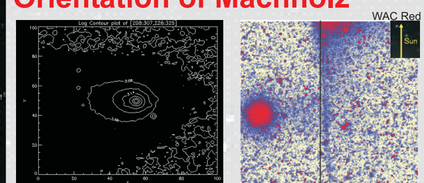

*Fig. 5.- **Left**: OSIRIS contour levels of the comet's coma, demonstrating its elongated shape. **Right**: Plasma tail points very close to the anti-solar direction, suggesting a high wind speed from this single observation.*

5. Retrieval of the 3D Velocity

We assume that the solar wind direction does not change significantly in few hours between the OSIRIS and Holloway observations. Knowing the positions of Rosetta and Earth at January 21.0 UT, the stereo imaging technique yields the ion tail's true direction. However, instead of a unique solar wind speed and direction, combining Machholz's 38.3 km/s orbital velocity and tail direction yields a relationship between solar wind speed and direction.

Using the tail direction at the comet's head in Holloway's image, the tail appears to be directed 5.5 deg. out of Machholz's orbital plane, and 6.4 deg. from the antisunward direction. For a 300 km/s wind speed, the wind flow direction is **12.0 deg**. and for a 600 km/s, **8.9 deg**. from antisunward. Although large, these non-radial wind flow deviations are not unprecedented. As Holloway's image shows tail curvature, calculations are repeated for the orientation further down-tail. The inferred tail direction is then **22.3 deg.** from antisunward, and **20.1 deg**. out of Machholz's orbital plane; the tail being tilted towards the comet's direction of travel, with the wind directed at **20.5 and 21.1 deg**. from antisunward for speeds of 300 and 600 km/s, respectively. These angles are extremely large. Unless the comet was within a coronal mass ejection with large nonradial flows, the tail direction initially calculated is more likely to be correct.

Conclusion

(1) We report the first remote determination of non-radial wind solar velocity components.
(2) The derived solar wind velocity range does overlap with the range of speeds predicted using MHD modelling.
(3) No propagating disturbances were observed in the ion tail, qualitatively consistent with immersion in a fast, steady coronal hole flow.
(4)The imaging sequence demonstrated the excellent performance of the OSIRIS cameras, surpassing the instruments' design requirements.

Acknowledgements

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More information on:
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