Icarus 317 (2019) 610–620

Contents lists available at ScienceDirect

Icarus

journal homepage: www.elsevier.com/locate/icarus

A survey of water production in 61 comets from SOHO/SWAN observations of hydrogen Lyman-alpha: Twenty-one years 1996–2016

M.R. Combi[a,*], T.T. Mäkinen[b], J.-L. Bertaux[c], E. Quémerais[c], S. Ferron[d]

[a] Department of Climate and Space Sciences and Engineering, University of Michigan, 2455 Hayward Street, Ann Arbor, MI 48109-2143, United States
[b] Finnish Meteorological Institute, Box 503, Helsinki SF-00101, Finland
[c] LATMOS/IPSL, Université de Versailles Saint-Quentin, 11, Boulevard d'Alembert, Guyancourt 78280, France
[d] ACRI-ST, Sophia-Antipolis, France

ARTICLE INFO

Keywords:
Comets, coma
Ices
Ultraviolet observations

ABSTRACT

The Solar Wind Anisotropies (SWAN) instrument on the SOlar and Heliospheric Observatory (SOHO) satellite has observed 44 long period and new Oort cloud comets and 36 apparitions of 17 short period comets since its launch in December 1995. Water production rates have been determined from the over 3700 images producing a consistent set of activity variations over large parts of each comet's orbit. This has enabled the calculation of exponential power-law variations with heliocentric distance of these comets both before and after perihelion, as well as the absolute values of the water production rates. These various measures of overall water activity including pre- and post-perihelion exponents, absolute water production rates at 1 AU, active surface areas and their variations have been compared with a number of dynamical quantities for each comet including dynamical class, original semi-major axis, nucleus radius (when available), and compositional taxonomic class. Evidence for evolution of cometary nuclei is seen in both long-period and short-period comets.

1. Introduction

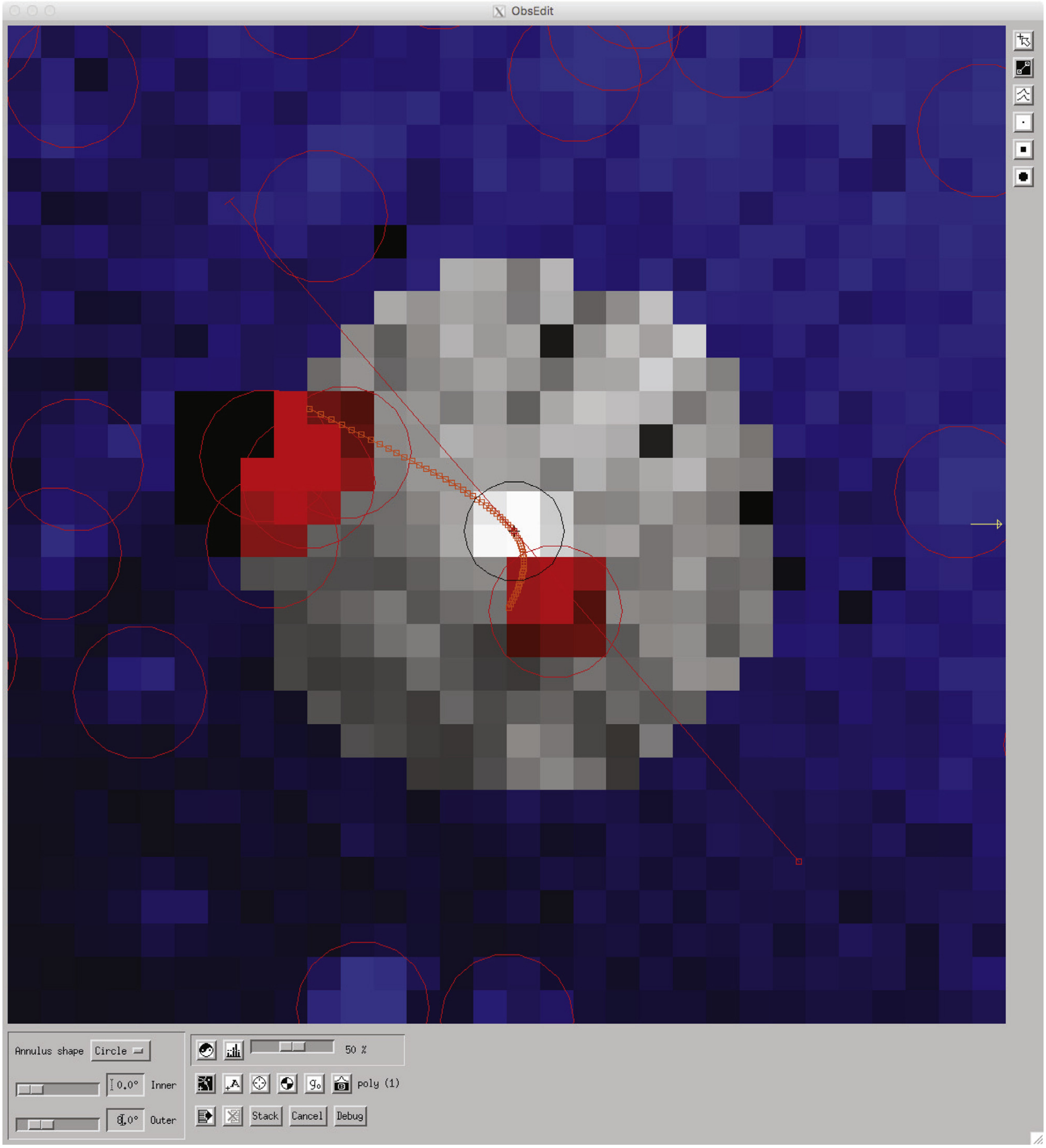
The Solar Wind ANisotropies (SWAN) instrument on board the SOlar and Heliospheric Observatory (SOHO) satellite has been operating in a halo orbit around the Earth-Sun L1 Lagrange point since shortly after its launch on 2 December 1995. Its primary science mission has been to provide continuous monitoring of the whole sky distribution of hydrogen Lyman-alpha emission resulting from interplanetary atomic hydrogen streaming through the solar system and being eaten away by charge exchange, electron impact and ionization by the sun and solar wind and being illuminated by the Sun's Ly-α emission. Because of the required sensitivity and the ability to observe the full sky, SWAN has also been an excellent platform from which to observe the hydrogen Ly-α comae of many comets since the beginning of 1996. After more than 20 years in operation it is still providing excellent measurements of hydrogen in both the interplanetary medium (Bertaux et al., 1995) and comets (Bertaux et al., 1998). SWAN has provided important observations of many individual comets. The SWAN observations allowed to determine that a total of $2.7 \pm 0.4 \times 10^9$ kg of water ice was lost by comet 67P during one perihelion passage in average (Bertaux et al., 2015). Combined with the estimated area of 20 km^2, it yields an equivalent thickness of 15 cm of ice sublimated inside the nucleus and lost to space in one perihelion passage of this comet. SWAN observations also allowed for important coverage of the EPOXI mission target comet 103P/Hartley 2 from previous apparitions (Combi et al., 2011b) and providing coverage throughout the apparition of the flyby (Combi et al., 2011b). Finally, SWAN observations of comet 2012 S1 (ISON) by Combi et al. (2014) allowed for the determination of the water lost by the comet before its total disruption and loss at its very close perihelion passage, which is consistent with pre-perihelion estimates of the size of the nucleus (Lamy et al., 2014).

Most long-term surveys of cometary activity concentrate on composition (Newburn and Spinrad, 1989; A'Hearn et al., 1995; Fink and Hicks 1996; Fink 2009; Langland-Shula and Smith 2011; Cochran et al., 2012; Dello Russo et al. 2016), although A'Hearn et al., (1995) did examine heliocentric distance dependencies of water proxies like OH or even CN. The Nançay radio survey of 18-cm lines of OH in comets (Crovisier et al., 2002), on the other hand, covers OH observations and thus mainly water production rates. Similarly, this survey covers the water production rates of 61 comets each observed over extended periods of time allowing for exponential power-law exponents and production rates at 1 AU to be computed for pre- and post-perihelion legs of the comet orbits. Most of the long period comets included in this survey were observed after most of the comets included most of the

---

[*] Corresponding author.
E-mail address: mcombi@umich.edu (M.R. Combi).

https://doi.org/10.1016/j.icarus.2018.08.031
Received 30 March 2018; Received in revised form 29 August 2018; Accepted 31 August 2018



Annulus shape: Circle

Inner: 0.0°

Outer: 8.0°

50 %

poly (1)

Fig. 1. Lyman-α brightness distribution around comet C/2009 P1 (Garradd) on 1 November 2011. The comet is at the center of the image. The analysis is done on circle of radius 8 degrees shown in gray shades. Each small square corresponds to a 1 degree pixel. The blue shades are the sky background, namely the interplanetary medium emission of hydrogen Lya and background stars. The locations of stars are indicated by red circles. Those stars that would interfere with the comet signal are masked and highlighted in red. The red line from upper left to lower right shows the location of the brightness profile shown in Fig. 2. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

published surveys so detailed comparisons with compositional taxonomic classes do not include many overlapping comets. One exception is the recent infrared survey of Dello Russo et al. (2016), however their IR taxonomy is rather involved providing depleted, typical and enhanced classification for 10 different molecular species compared to H_2O. Unfortunately even for the IR survey there are not enough common comets to make meaningful cross-comparisons. However, Dello Russo et al. looked at the literature for the visual observations of the common carbon radicals and list those taxonomic classes (depleted or typical) for several comets in the SWAN dataset.

2. Observations and basic model analysis

The SWAN all-sky camera consists of two systems one for the north heliographic hemisphere and the other for the south. Each has a 5 × 5 array of detectors of one square degree each that are scanned across the sky every day yielding a full sky map of hydrogen Ly-α emission. Depending on location in the sky with respect to the Sun and the