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Liquid-phase processes and outbursts of comets 1P/Halley, 17P/Holmes and 29P/Schwassmann-Wachmann

R. Miles and G. Faillace
British Astronomical Association, Burlington House, Piccadilly, London, UK, (rmiles@baa.u-net.com / Fax: +44-207-4394629)

Abstract

In a previous paper [1] we showed from detailed considerations of the physical and chemical characteristics of comet nuclei how aqueous and hydrocarbon (HC) liquid phases can form and persist in near-surface regions, the composition of which varies with depth. Here we describe how liquid-phase processes may underlie outbursts of the comets 1P/Halley, 17P/Holmes and 29P/Schwassmann-Wachmann, slow rotations of which promote the formation of consolidated melt zones in the subsurface. In our "wetted-layer model", low-melting reservoirs form near the base of the layer, and these initiate outbursts via explosive release of gases and other volatiles. Several possible mechanisms are mooted dependent on heliocentric distance and composition; (a) supersaturation of liquids leading to the sudden release of dissolved gases and lighter HC fractions, (b) sudden heating of CO-laden amorphous ice through abrupt transport of liquid under capillary forces into the underlying microporous solid, and (c) catalytic decomposition of accumulated hydrogen peroxide in aqueous phase. New observations of 29P shows that outbursts tend to be associated with lateral outflows in directions indicative of material escaping sideways from beneath a localized region having considerable strength and interpreted as a local hydrocarbon-wetted melt zone.

1. Introduction

Cometary outbursts, in which the coma brightens noticeably, generally arise through solar heating increasing gas and volatiles production rates. Fragmentation or disintegration of the nucleus can also result in an apparent outburst in brightness but occasionally comets are seen to brighten dramatically within a matter of hours by several orders of magnitude, the most extreme example being comet 17P/Holmes in 2007. Major outbursts or megabursts of this kind are linked to very energetic, even explosive events taking place within the nucleus. Sekanina interpreted the 17P event to have been triggered by the transformation of gas-laden amorphous water ice into the cubic crystalline form in a reservoir beneath a layer tens of meters thick, which was ejected into space [2]. 17P is just one example of many instances of energetic cometary outburst with perhaps the most enigmatic being the 2-5 mag outbursts of 29P, which have continued every few weeks or months for many years now. We show here that our consolidated "wetted-layer" model described in [1] may explain these phenomena.

2. The wetted-layer model and its role in major cometary outbursts

2.1 Comet 29P/Schwassmann-Wachmann

29P occupies a near-circular orbit at r = 6.2 AU well beyond the distance for significant ice sublimation rates. Observations were made using the 2.0-m Faulkes Telescope North on Haleakala, Maui during 2010 and 2011, some images being taken by schools and amateur groups. Exposures were kept short to avoid significant trailing of the comet and processed by stacking and rotational gradient filtering to reveal details of outflows of material close to the nucleus. A series of Sloan-r' images were obtained covering six outbursts (2010 Feb 2, Feb 9, Feb 16, Apr 15 and 2011 Jan 25, Mar 20). Figures 1 and 2 illustrate

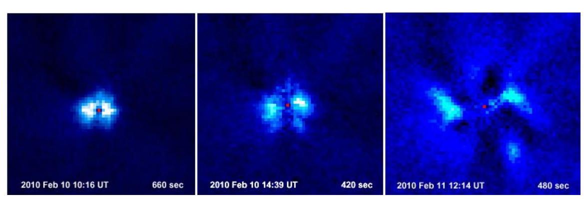

Figure 1: Inner coma of comet 29P (fov ~18" square)

outflows which generally move at 50-100 m s^{-1} projected on the sky and often appear to be moving in relatively opposed directions. No slow-moving outflows were seen which indicates that ejected material moves roughly perpendicular to the line of sight. This characteristic fits a model where material

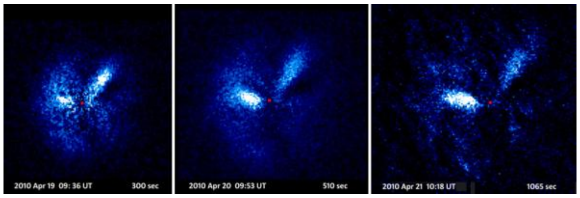

Figure 2: 2010 Apr 15 outburst of comet 29P showing changing intensities (fov ~35" high)

escapes from around the periphery of a strong surface layer able to withstand a sudden pressure increase from beneath. The ejecta contain fine dust as well as large particles which take several days to disintegrate as evidenced by changes in relative intensity of the outflows. Spitzer observations reported by Stansberry et al. [3] have indicated that this comet nucleus rotates with a period of 60 days or more, and has a very low geometric albedo of 0.025. It is therefore a good candidate for the formation of subsurface zones wetted by liquid HCs but the amorphous-to-crystalline ice phase transition releasing gas is not considered a credible energy source for 29P's outbursts given their frequency. Physical trapping of CO, CH_4, N_2 and other volatiles in voids below HC-wetted layers and thermal cycling is expected to generate solutions supersaturated in volatiles, the sudden release of which triggers an outburst.

2.2 Comet 1P/Halley

A remarkable outburst of 1P/Halley took place some 5 years post-perihelion in 1991 whilst 14 AU from the sun where the black-body temperature is calculated to be 75 K. 1P is a relatively slow rotator revolving every several days or so and therefore will be sensitive to diurnal heating effects. Erosion of parts of the surface over several years can uncover regions rich in hydrocarbons having a wide range of composition. If the near-surface is extremely microporous in places and also highly carbonaceous then the formation of a stabilization crust is favoured and a subsurface melt zone can form [1]. Once this happens a compositional gradient builds up and void spaces can form near the base of the relatively strong wetted layer. As with 29P, some of the liquid near the base of the wetted layer can become supersaturated in CO, CH_4 or N_2 such that nucleation and rapid gas release can trigger an outburst.

2.3 Comet 17P/Holmes

The mechanism underlying the megaburst of 17P is likely to be different in that it almost certainly involves water ice. Following the 1892 event, a second outburst occurred two months or so later. Observations have shown that small mini-outbursts also occurred after the 2007 October megaburst possibly at intervals of about 44 days which may be equated with its rotation period [4]. Given such a slow rotation rate, an aqueous wetted layer can form beneath a stabilization crust. Important solutes such as CH_3OH and H_2O_2, the latter formed by exposure of ice in the comet precursor to galactic cosmic rays over billions of years, depress freezing and undergo freeze fractionation through diurnal thermal cycling. If H_2O_2 accumulates such that it reaches a sufficient concentration then catalytic decomposition can ensue as described in [5] liberating heat and large quantities of O_2 gas: hence the megaburst. The exothermicity of this reaction is about 30 times greater weight for weight than that associated with the amorphous-crystalline transition of water ice. Since 17P made many perihelion passages without undergoing a major outburst, it has taken many years for the active material to accumulate. These outbursts may be driven by the amorphous-crystalline transition of gas-laden ice with liquids facilitating heat flow to the interior. However, the long gaps between megabursts and the repeat outburst 'echoes' following each megaburst may negate this mechanism.

Acknowledgements

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