UNIVERSITY OF LJUBLJANA
FACULTY OF MATHEMATICS AND PHYSICS

Seminar

Outburst of Comet 17P/Holmes

Author: Tilen Čadež

Mentor: prof. dr. Tomaž Zwitter

Ljubljana, April 2008

Abstract

In the seminar I present the measured properties of comet's 17P/Holmes' nucleus, mostly its effective radius and rotational period. Then I describe observations of the comet's megaoutburst, that occured on Oct. $23.7 \pm 0.2\,UT$ 2007, and evolution of comet's morphological structure (nucleus, dust cloud center, gaseous and dust coma, dust stripes and tail). Mass ejected during outburst is estimated through differential extinction of coma on background stars. I present four possible mechanisms that could explain ordinary comet outbursts. At the end of seminar the nature of 17P/Holmes' outburst is discussed. Two possible outburst mechanisms are presented, first is based on a pancake-shaped companion nucleus and second on a slow formation and subsequent rapid catalytic decomposition of hydrogen perokside (H_2O_2).

Contents

1 Introduction

Comets are small bodies that orbit the Sun [1]. When far from the Sun (typically more than ~ 4 AU[1]) the activity of comets is very weak or none at all[2] and only their nuclei are seen. Comet nucleus is a conglomerat of frozen gases, ice, dust and rocky particles that are bound together. Nuclei are irregularly shaped and their typical dimension (effective diameter) is a few tenths to a few tens of kilometers [2]. When comet approaches the inner Solar system, solar radiation causes evaporation of ice and frozen gases, which begin to stream from the nucleus together with dust and rocky particles. Material ejected from the nucleus forms sparse atmosphere which is called a coma. At some distance from the nucleus the coma becomes so tenuous that particles in it become unbound and they interact only with solar radiation. Neutral (uncharged) particles experience only pressure from the solar radiation, while charged particles also interact with the Sun's magnetic field and two types of tails can develop. Dust tail forms from uncharged particles that travel away from the Sun. When comet is close to perihelium, dust tails are curved and can be ~ 3 AU long. Ion tail points radialy away from (or towards) the Sun, becouse charged particles are traped in magnetic field lines. Charged particles are mostly excited ions or molecules that emit discreet light and for that reason ion tails are coloured.

The rate of sublimation depends on the comet's distance from the Sun and also on a proportions of different materials on the surface of comet's nuclei. The light from comet is reflected sunlight (from coma and nuclei) and thermal IR light (from nuclei). Globally-averaged albedos[3] for different comets varies [2] from 0.02 to 0.06. Because of low albedo and small effective diameter of nuclei, inactive comets are usually faint and appear starlike. Nuclei brightness is denoted as m_2 and is ussualy obtained via CCD photography. Apparent magnitude m_A is conected to intensity I_A by

$$m_A = m_B + 2.5 \log\left(\frac{I_B}{I_A}\right), \tag{1}$$

where m_B and I_B are some reference apparent magnitude and intensity. Active comets develop coma and the majority of comet's brightness is due to reflected sunlight from coma. Integrated nuclei and coma brightness is denoted as m_1. Comet brightness can also be measured with visual comet photometry [3]. Besides, brighter comets often develop coma that is greater than the field of view of CCD detectors, thus making CCD brightness measurements imposible. Evolution of coma and brightness of a comet is hard to predict and comets often surprise. Such a surpise came on October 24. 2007, when the comet 17P/Holmes underwent an outburst.

[1] Astronomical unit (AU) is the average Sun - Earth distance, 1 AU $\simeq 150 \cdot 10^6 km$.

[2] Although there are some exceptions, that were active even beyond 10 AU, such as 1P/Halley and C/1995 O1 (Hale-Bopp).

[3] One has to be carefull in defining albedo and in seminar I will use the geometric albedo as in [2], which is defined as zero-phase, disk-integrated reflectance relative to that produced by a perfect diffusing disk. In general albedo is a function of wavelenght, but ussualy one approximates nuclei as grey object, meaning that albedo is wavelenght independent. Besides most photometry is obtained at visual and IR (5, 10, 20 μm) wavelengths.

2 Comet 17P/Holmes

2.1 Historical overview

Comet 17P/Holmes was discovered by Edwin Holmes on November 6. 1892 from London [4, 5]. When he tried to find Andromeda galaxy (M31), he saw a bright object in his finder. After seeing the object through a 32 cm reflector telescope, he instantly realized that the object was not the Andromeda galaxy but a comet. The date was Nov. 6.98. He estimated coma diameter as 5 arc minutes across and obtained a rough position at 7.03. The comet was independently discovered by T. D. Anderson (Edinburgh, Scotland) on Nov. 8.9 and by J. E. Davidson (Mackay, Queensland, Australia) on November 9.5. Fig. 1 is a photography of comet 17P/Holmes, taken by E. E. Barnard on Nov. 10. 1892.

Figure 1: 17P/Holmes (marked) and Andromeda galaxy photographed by E. E. Barnard, November 10. 1892 [5].

Comet's elliptical orbit was obtained by the end of November, which revealed the perihelion date as June 13 (1892) and the period as 6.9 years. The orbit shoved that this was a Jupiter-family comet. It was later realized, that when discovered, the comet was in outburst. As reported by many astronomers, comet was visible to the naked eye almoust untill the end of November. By the beginning of January 1893 the comet was barely seen with telescope. Another outburst in brightness occured around Jan. 16 and the comet again became visible to the naked eye. After that the comet steadily faded and it's final observations were reported in the beginning of April. The comet was observed in its next two apparitions in 1899 and 1906, but was faint in both. After 1906 apparition the comet's orbit was perturbed by Jupiter and 17P/Holmes was lost for nearly 60 years. It was recovered in 1964 apparition[4] and was observed at every return since. In 2007 17P/Holmes reached the perihelion on May 4., at the perihelion distance of 2.053 AU [6]. Its orbital elements are shown in Table 1.

[4]The precise integration of comet Holmes' motion between 1899 and 1975 by B. G. Marsden in 1963, shoved that the orbital period increased from 6.86 years to 7.35 years and perihelion distance from 2.121 AU to 2.347 AU after comet's 1906 apparition [4].

Element	Value	Unit
eccentricity	0.43242	
semi-major axis	3.6174	AU
perihelion distance	2.0532	AU
aphelion distance	5.1816	AU
inclination	19.113	deg
longitude of the ascending node	326.87	deg
argument of perihelion	24.259	deg
mean anomaly	359.50	deg
orbital period	6.88	years

Table 1: Orbital elements of comet 17P/Holmes [6].

2.2 Nucleus

Some information [2, 7] about the 17P/Holmes nucleus was measured before its last apparition in 2007. One of the possible methods for determining the shape of cometary nuclei, is to image comet when far from the Sun and thus inactive. Jupiter family comets are typically active when closer than ~ 3 AU from the Sun. For a spherical object the measured R-band[5] magnitude m_R is related to its radius r_N by[6] [7]

$$A_R\, r_N^2 = C\, R_h^2\, \Delta^2\, 10^{0.4(m_\odot - m_R + \beta\,\alpha)}, \tag{2}$$

where $C = 2.238 \cdot 10^{22}\, m^2\, AU^{-4}$ is a constant, A_R is geometric albedo, R_h and Δ are heliocentric (comet-Sun) and geocentric (comet-Earth) distances in AU, $m_\odot = -27.09$ is the apparent magnitude of the Sun in R-band and α and β are the phase angle (Sun-comet-observer angle) in degrees and the phase coefficient in magnitudes per degree. If data over a range of phase angles is not acquired, one must assume a value for phase coefficient. Commonly assumed value [2] is $\beta = 0.035\, mag.\, deg^{-1}$. In the absence of simultaneous IR observations, one must also assume albedo (ussualy a typical value $A_R = 0.04$ is assumed).

For the simplest non spherical nucleus, a two-axial ellipsoid with semi-axes $a > b = c$, a change of nucleus magnitude is due to different cross-section of the rotating elongated nucleus (assuming there is no variation in albedo). As one does not know the orientation of the rotation axes, only a lower limit on a/b can be measured. A time series of snap-shot images can reveal the rotation period of nuclei. Such measurement was taken at European Southern Observatory (La Silla), using 3.6 m New Technology Telescope (NTT) from 5th to 7th March 2005 [7]. During that time 17P/Holmes was 4.66 AU from the Sun and 3.92 AU from the Earth, at phase angle $9.0\, deg$. Becaouse of too short time span of images, four possible rotational periods (P_{rot}) were obtained, $P_{rot} = 7.2, 8.6, 10.3$ and 12.8 hours (Fig. 2). A lower limit on the elongation of the nucleus was obtained $a/b \geq 1.3$ and an effective radius $r_N = 1.62 \pm 0.01$ km for equivalent spherical body (with assumed albedo $A_R = 0.04$ and phase coefficient $\beta = 0.035\, mag.\, deg^{-1}$). This is in agreement with previous measurement

[5] R-band magnitude is obtained using the R-band filter, whoose transmitivity is approximately Gaussian function, with center at 600 nm wavelength and $\sigma \simeq 70$ nm.

[6] Energy density from the Sun at comet's position is $j_\odot = \frac{I_\odot}{R_h^2}$. Reflected intensity from the comet is then $I_c = j_\odot\, A_R\, \sigma$, where $\sigma \propto r_N^2$ is comet's cross section. Detected energy density is $j_d = \frac{I_c}{\Delta^2}$ and detected intensity $I_d \propto j_d$. Using equation (1) radius and apparent magnitude are connected by $A_R\, r_N^2 \propto R_h^2\, \Delta^2\, 10^{0.4(m_\odot - m_R)}$. If one takes phase angle into account then equation (2) is obtained.

of effective radius, which gives [2] $r_N = 1.71$ km. To test the assumption of no large scale variations of albedo, the colour indices[7] $(V-R)$ and $(R-I)$ were measured at least once per night. The indices were consistent within the uncertanties and the average colours were [7]: $(V-R) = 0.41 \pm 0.07$, $(R-I) = 0.44 \pm 0.08$.

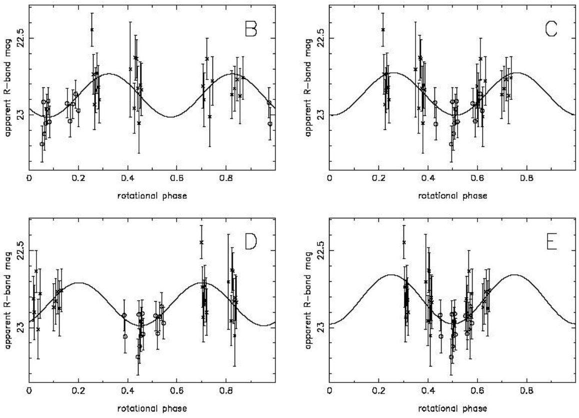

Figure 2: 17P/Holmes photometric data fitted on four possible rotational periods with $P_{rot} = 7.2\,(B)$, $8.6\,(C)$, $10.3(D)$ and $12.8\,(E)$ hours [7].

Using the rotational period and elongation of the nucleus one can put limits on its bulk density D_N. By balancing self gravity with centrifugal force and neglecting nuclei tensile strenght[8] a lower limit on the nuclear density can be found [7]

$$D_N \geq \frac{10.9}{P_{rot}^2} \frac{a}{b}, \tag{3}$$

where rotational period is in hours and bulk density in $g\,cm^{-3}$. For 17P the lower limit of bulk density is $D_N \geq 0.09\,g\,cm^{-3}$ (using $P_{rot} = 12.8$ hours). Measured nuclei parameters are presented in Table 2.

Parameter	Value	Unit
effective radius	1.62 ± 0.01	km
rotational period	7.2, 8.6, 10.3, 12.8	hours
nucleus elongation (a/b)	≥ 1.3	
colour $(V-R)$	0.41 ± 0.07	
colour $(R-I)$	0.44 ± 0.08	
bulk density	≥ 0.09	$g\,cm^{-3}$

Table 2: Measured parameters of comet 17P/Holmes' nucleus [7], assuming albedo $A_R = 0.04$ and phase coefficient $\beta = 0.035\,mag.\,deg^{-1}$.

[7]Difference between magnitudes measured with different filters V, R, I.

[8]A negligible tensile strength was evidenced by the break up of comet D/Shoemaker-Levy 9 under gravitational influence of Jupiter in 1994 and from the results of Deep Impact mission to comet 9P/Tempel 1 in 2005.

3 Measurements of the 2007 outburst

On October 24. 2007 comet underwent a major outburst in brightness and became easily visible to the naked eye. Its position at that time is shown in Fig. 3 and its orbital elements are in Table 1.

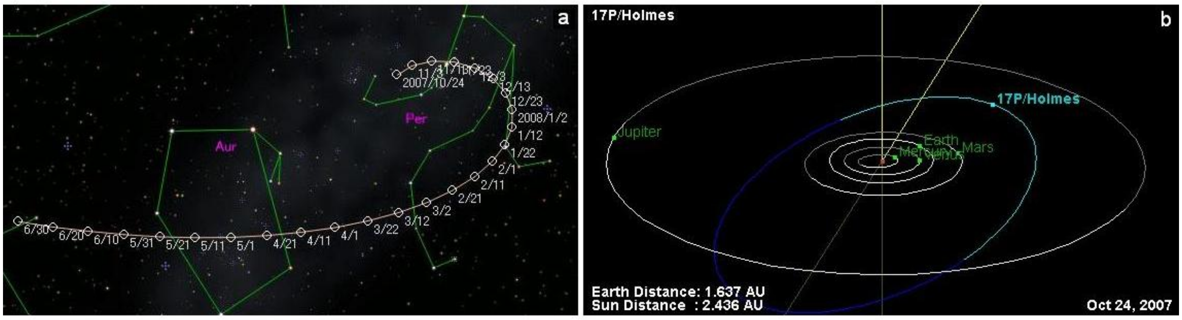

Figure 3: Position of Comet 17P/Holmes: (a) in the night sky [8] and (b) in Solar system [6]. The planets orbits are white lines, and the comets is a blue line. The brighter line indicates the portion of the orbit that is above the ecliptic plane, and the darker portion is below the ecliptic plane.

3.1 Brightness

Comet was observed in spring/summer 2007 at $m_1 \sim 15\,mag$ and in autumn at $m_1 \sim 17\,mag$ (Fig. 4 a), behaving as excpected from its previous apparitions. On Oct. 23 brightness measurements gave [9] magnitude $16.8 - 17.3$, but on Oct. 24.067 UT, J. A. Henriquez Santana (Tenerife, Canary Islands) found comet [9] as a stellar 8.4 magnitude object. Outburst was

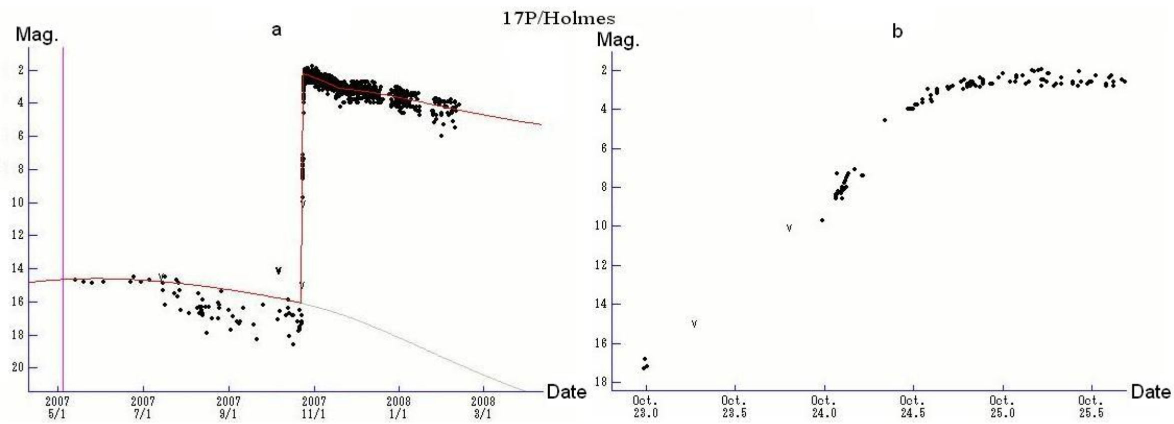

Figure 4: Light curve of integrated apparent magnitude (m_1) of comet 17P/Holmes [8] during 2007 apparition (a) and around the time of outburst (b).

also noticed in all-sky CCD cameras of the Spanish Meteor and Fireball Network [10] and in images taken by superWASP [11]. Also amateur astronomers around the world began to monitor brightness increase [9, 12] (Fig. 4 b), which lasted untill October 25. Comet reached maximum brightness $m_1 \sim 2.5\,mag$ and after approximately one week began to slowly fade.

In the beggining of April 2008, some observers were still able to see the comet with a naked eye.

3.2 Morphological structure

After the outburst the comet nucleus was separated from the center of an expanding dust cloud [13]. Fig. 5 shows evolution of the morphological inner structure of the comet, from Oct. 26. to Nov. 20. 2007. Exposure times of the images were between 40 and 200 s. In order to properly sample surface brightness of the coma, the images are scaled to the same

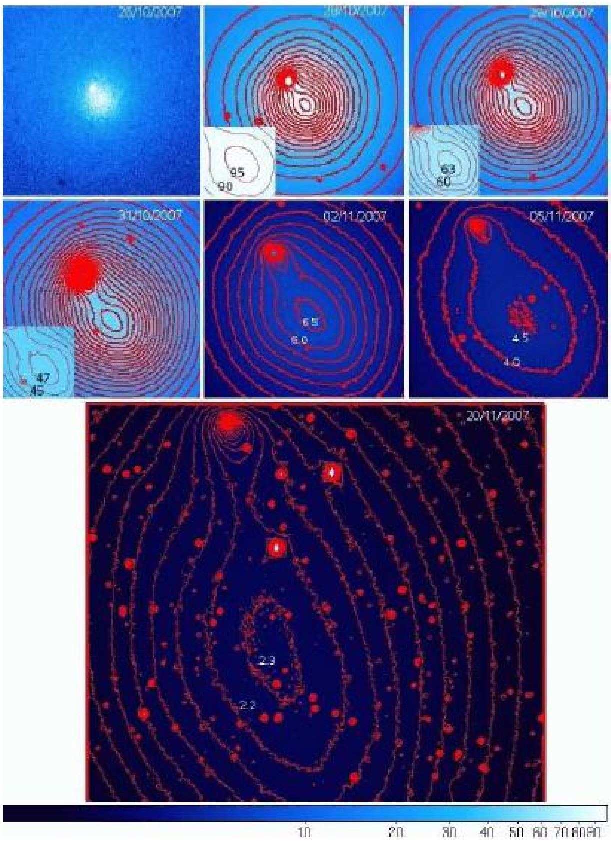

Figure 5: R-band images acquired using 0.8 m Wendelstein telescope [13], showing the evolution of morphological structure of the comet 17P/Holmes. Upper images have a field of view $2.2 \times 2.2\, arcmin^2$ and the lowest one $8 \times 8\, arcmin^2$. The images are codified on a logarithmic color scale and isophotes are added.

exposure time, airmass and intensity range. In images, the comet nuclei appeared as a point-like source and the position of the peak was determined with a gaussian fitting alghorithm, which is also used for stellar objects. The light distribution of dust cloud was extended over a much larger area and the central part was fitted with a bidimensional gaussian. From projected distances between both peaks plotted against the Julian date (JD) the mean separatting velocity was obtained [13], $v_m = (9.87 \pm 0.07)\, arcsec/day = (0.135 \pm 0.001)\, km/s$. Error is mostly due to dust cloud center uncertanty. The mean σ of the dust cloud light distribution against the JD gives the velocity of the expanding material in the inner region,

$v_i = (14.6 \pm 0.3)\, arcsec/day = (0.200 \pm 0.004)\, km/s$. For a set of photometric bands (B, V, R, I), different σ is obtained[9], the biggest in B and smaller in the redder bands. From the images taken on Nov. 2. radial velocity gradient was estimated to be $\nabla_r\, v_i = (0.3 \pm 0.2)\, 10^{-5}\, s^{-1}$.

An evolution of dust stripes in the inner coma was also observed [14] (Fig. 6 b). Dust stripes most likely originated from larger fragments, that were moving away from the comet with velocities $0.05 - 0.10\, km\, s^{-1}$. Comet also developed a tail (Fig. 6 c), which was pointing away from Earth and thus difficult to see. Tail was photographically detected on Oct. 30. and was seen for a few weeks.

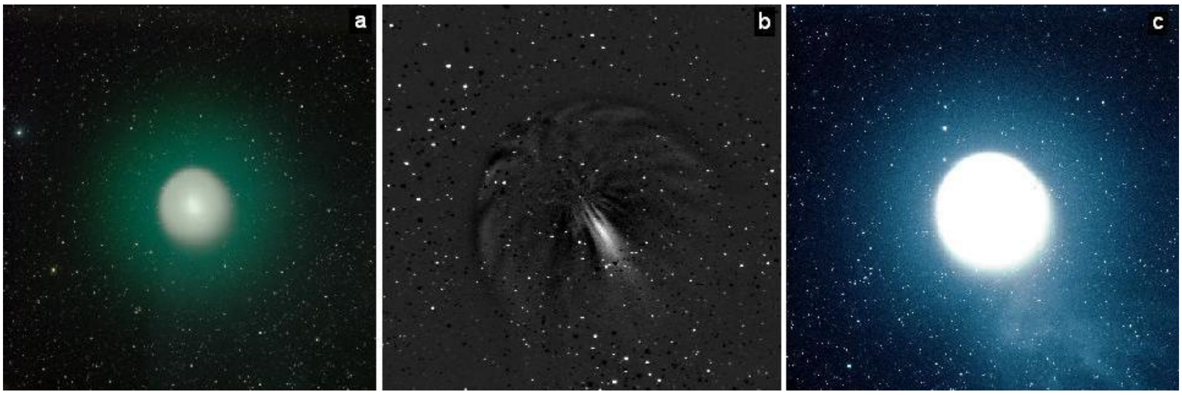

Figure 6: Images of comet 17P/Holmes from Črni Vrh Observatory (MPC code 106) [15]. Field of view is $42 \times 42\, arcmin^2$. a: True color image of comet 17P/Holmes obtained on 2007 Nov. 1 (20h38-20h48UT). Two comae are seen, green is gas coma and grey is dust. Image is a LRGB composite using different filters. b: A series of BVRW images obtained on Nov. 3, processed using Larson-Sekanina filter with a rotation angle of 7.5 degrees, reveal dust stripes. c: False color image of 17P/Holmes' tail obtained on Nov. 5 (19h16UT) with 60-cm, f/3.3 Deltagraph telescope, B filter and CCD. Authors: H. Mikuž (a, b, c), J. Kac (a, b) and J. Zakrajšek (a, b).

Visually and photographically two comae were seen [12] (Fig. 6 a). The outer fainter gaseous coma was visually visible under dark skies untill November 11 [12], when its diameter reached around $50\, arcmin$. Brighter dust coma was expanding slower. Slight elongation of inner coma was seen in November and was obvious later. This was due to interaction with solar wind, which caused sharp NE edge of coma and very diffuse SW part. Visual coma diameter estimates are plotted in Fig. 7. From Fig. 7 (between Oct. 24 and Dec. 20) radial velocity of expanding dust coma was obtained $v_c = 0.57 \pm 0.02\, km\, s^{-1}$. This is consistent with photographically obtained radial velocity [16].

[9]This is because different layers of the expanding cloud are studied.

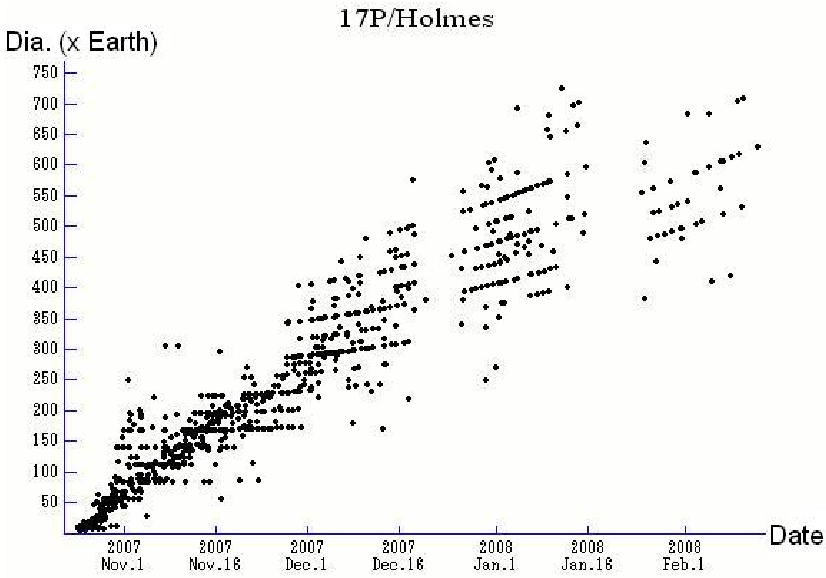

Figure 7: Visual coma diameter estimates [8].

3.3 Ejected dust mass

Dust mass, ejected during the outburst, can be estimated through the exctinction, caused by the dust cloud on the surrounding background stars. Two R-band images (Fig. 8, Top) taken on Oct. 28., were used to estimate the total dust mass. The images were obtained at a 0.8 m Wendelstein telescope [13] and were 2 hours apart. That was enough that apparent motion of dust cloud on the sky plane was obvious and also small enough to avoid significant expansion of the cloud. The stars used, were at the radial distance between 25 $arcsec$ and 3 $arcmin$ from the center of the cloud. Inner limit was set, to avoid the photometry of the stars to be biased by a luminous core of the comet and the outer to avoid detector border effects. There were 20 useful (sharp, unsaturated) stars. The sky background was estimated localy around each star and photometry was extracted in a circular region centered on the stars' centroids with radius 1.3 $arcsec$ (aparture photometry). The derived magnitudes were transformed to the airmass of 1 and exposure time of 1 s.

With the assumption of a uniform and homogenous spherically symmetric mass distribution of dust in coma, optical depth τ of the cloud is

$$\tau(r) = 2\,\sigma_d\, n\,\sqrt{R^2 - r^2}, \tag{4}$$

where r is projected distance of a star from cloud's center, R is radius of the cloud, σ_d is the cross section of the dust grains and n is the number density of the dust particles. Intensity of the light (I) from a background star, passing through coma, changes as

$$I(r) = I_0\, e^{-\tau(r)}, \tag{5}$$

where I_0 is initial star intensity. Considering two different positions r_1 and r_2 of a generic star (see Fig. 8, Top), one can express differential extinction ΔA using equations (1), (4) and

(5) to obtain

$$\Delta A = m_1 - m_2 = -2.5\,\log\left[\frac{e^{-2\,\sigma_d\,n\,\sqrt{R^2-r_1^2}}}{e^{-2\,\sigma_d\,n\,\sqrt{R^2-r_2^2}}}\right] = 5\,\log{(e)}\,\sigma_d\,n\Big(\sqrt{R^2-r_1^2}-\sqrt{R^2-r_2^2}\Big), \quad (6)$$

where m_1 and m_2 are observed apparent magnitudes of the star, at positions r_1 and r_2. Equation (6) can be rewriten into

$$\Delta A = \gamma\,x + \delta, \quad (7)$$

where coefficient $\gamma = 5\,\log{(e)}\,\sigma_d\,n$, parameter $x = \sqrt{R^2-r_1^2}-\sqrt{R^2-r_2^2}$ and coefficient δ is included to account for residual constant zero points between two images. Bottom image in Fig. 8 shows the result of differential extinction after substracting constant zero point. The derived value [13] of γ coefficient is $(0.0006 \pm 0.0002)\,mag/pix$, where a pixel corresponds to approximately $592\,km$ at the distance of the comet. This value for γ was obtained assuming radius of the cloud $R = 3\,arcmin$ ($\sim 3.5\,\sigma$). Increasing the radius to $4\,arcmin$ ($\sim 5\,\sigma$) increases γ to $(0.0012 \pm 0.0004)\,mag/pix$.

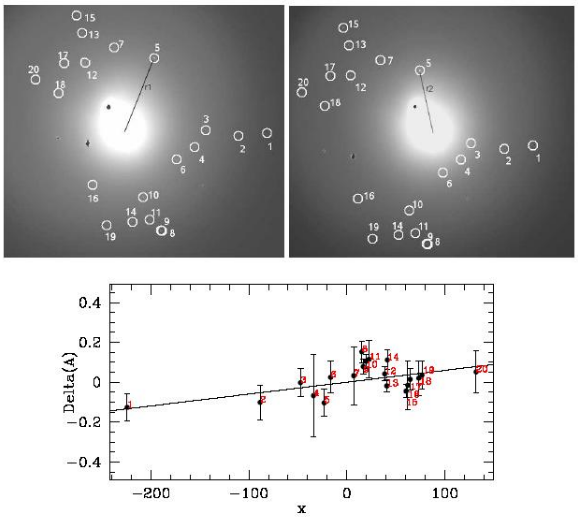

Figure 8: Top: spatial distribution of 20 background stars (indicated by white circles), used for estimation of ejected dust mass. Bottom: measured correlation between the differential R-band extinctions ΔA and the x parameter. [13]

Coma mass (M_c) can be estimated by [13]

$$M_c = \frac{4\pi}{3} R^3\,m_d\,n, \quad (8)$$

where $m_d = \frac{4\pi}{3} r_d^3\,\rho_d$ is mass of a spherical dust particle with a mean density $\rho_d = 2.5\,g\,cm^{-3}$ and a typical radius r_d. As already defined in equation (4) R is radius of the cloud and n is the number density of the dust particles. Exspresing n with γ and taking grain's cross-section $\sigma_d = \pi r_d^2$ the coma mass is

$$M_c = \frac{16\pi}{45\log{(e)}} R^3\,r_d\,\rho_d\,\gamma. \quad (9)$$

By variing charachteristic [13] dust particle radius from 0.005 to 1 μm and radius of the cloud between $3 - 4\,arcmin$, one derives ejected coma's mass to be $M_c \sim 10^{12} - 10^{14}\,kg$.
Assuming a range of possible (see Table 2) nuclear densities $D_N \sim 0.1 - 1.0\,g\,cm^{-3}$ and albedos $A_R \sim 0.01 - 0.1$, a total nuclear mass is $M_N = \frac{4\pi}{3} r_N^3 D_N \sim 10^{12} - 10^{14}\,kg$. Taking the uncertainty range into account, probable ejected dust mass was between $0.01 - 1$ comet's mass.

4 Possible outburst model

During 17P/Holmes' 2007 outburst, its apparent brightness (m_1) increased for $\sim 14\,mag$ (a factor of $\sim 400,000$ in intensity) in roughly 2 days, which is the largest outburst ever observed. Radial velocity of expanding dust cloud (v_c) and projected velocity between nuclei and dust cloud center (v_m), are both in the order of $0.1\,km\,s^{-1}$, which is greater than in observed outbursts of other comets. Estimated ejected dust mass was between $0.01 - 1$ comet's mass. Also observed dust stripes indicate disintegration of fragments, too small to be directly visible. Association of cometary nuclear fragmentation with comet outbursts is well documented, for instance in the case of C/2001 A2 (LINEAR) [17].

From observations obtained in the case of 17P/Holmes' 2007 outburst, one can speculate that some explosive event occured. No fragments were observed, although dust stripes and dust cloud center indicate the presence of fragments that disintegrated. The splitting of the nucleus was nontidal [18] and some of the possible nontidal mechanisms [19] are the impacts with the meteoroids, destruction of cometary grains in the field of strong solar wind, transformation of amorphous water ice into the crystalline ice and the polymerization of hydrogene cyanide (HCN).

4.1 Cometary outburst mechanisms

Cometary outburst is any rapid and unexpected brightness increase, greater than 1 magnitude. During typical outburst comet brightness increases for $2 - 5\,mag$ in a period of a few days. The energy released (on average about $10^{14\pm2}\,J$) is observed as the kinetic energy of

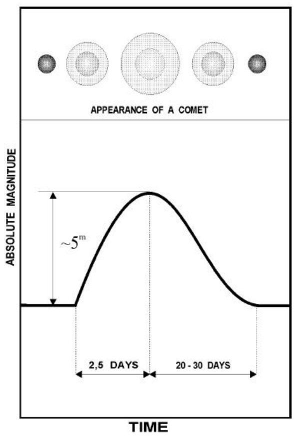

Figure 9: Comet during a typical outburst [19].

the expanding halo. After the outburst the comet's brightness more or less returns to its pre-outburst value in about $20-30$ days. Lightcurve and comet's appearance during an outburst is shown in Fig. 9.

For Jupiter family comets the probability of impact is higher than for other comets, due to proximity of comet's orbit to the main asteroid belt, which is ~ 3 AU from Sun. The consequences of the impact are strongly dependent on relative velocities. The observed cometary outbursts can be generated by [19] impacts of $\sim 1\,m$ sized meteorids with cometary nuclei. Such a collision occurs on average every $100,000$ years, thus an impact mechanism is very unlikely.

Destruction of cometary grains in the field of strong solar wind can be triggered by electrostatical charge of cometary ice-dust grains. But typical change in comet brightness is too small to explain 17P/Holmes' outburst.

The initial cometary ice was probably in amorphous form, due to low temperature and pressure at the time of formation of comets. The amorpous phase is not stable and can undergo phase transition[10] into crystalline cubic form. The process starts slowly at temperature $120\,K$ and becomes rapid at critical temperature $T_{cr} = 137\,K$. The process is caused by solar radiation and begins on nucleus surface. Crystallization latent heat additionally increases temperature and causes heat propagation towards interior. Some of released energy is also used for evaporation of volatile compounds (such as CO and CO_2) and finally a part of energy is absorbed by cometary dust. These processes can continue in comets' next approuch to the Sun, untill the whole amorphous ice is transformed. Density of amorphous water ice is slightly different than crystalline cubic water ice and the crystallization induces numerous strains. Strains lead to cracks and with the help of trapped volatiles an outburst occures.

With respect to water, abundance of HCN inside comets vary [19] from 0.1% to 4%. For 17P/Holmes the observed HCN to water ratio was [20] 0.54%. The polymerization of HCN could begin with the absorption of UV photon or by a free-radical chain reaction. The energy released by reaction is between $10^4 - 10^6\,J\,kg^{-1}$. This energy raises the temperature in an active part of nucleus, which can trigger crystallization of amorphous ice. This reaction provides the main amount of the energy for the outburst. But even polymerization of HCN alone could onset an outburst. In this case around $10^8\,kg$ HCN would have to polymerizate.

4.2 17P/Holmes outburst model

Taking reported information of 17P/Holmes' outburst into account, Z. Sekanina [21] made conclusions on the nature of the observed outburst. Acquired brightness data (Fig. 4 a) suggest that the comet had been active before the outburst. At the event's onset (most probably Oct. $23.7 \pm 0.2\,UT$), the comet's integrated visual magnitude (m_1), normalized to $\Delta = 1AU$ from the Earth was 15.3. This is about 30 times brighter than expected for the nucleus magnitude (m_2), based on measurements discussed in section 2.2. The extremely steeply increasing brightness at the beginning of the outburst (Fig. 4 b) suggests that the rate of dust injection into the coma accelerated with time, or the average particle size was then rapidly decreasing

[10]For thermodynamical description of this mechanism see [19].

with time (perhaps as a result of runaway particle fragmentation), or both. The reported constant rate [9] in mag/hr implies an exponential increase in the cross-sectional area of dust, neglecting the minor contribution from the molecular and atomic species [22].
The maximum brightness plateau was reached ~ 24 hours after the outburst onset, with an integrated normalized magnitude $m_1 = 1.4 \pm 0.2$. The fact that the nucleus was observed after the outburst (see Fig. 5 bottom) implies, that it did not disintegrate completely and thus the lower estimate on ejected dust mass (0.01 comet's mass, see section 2.3) is more likely[11]. This is very similar to the mass that Z. Sekanina found for a typical pancake-shaped[12] companion nucleus of the split comets. Disintegration of such companion would imply nearly symmetrical outer dust cloud, expanding at an average velocity of $0.5\,km\,s^{-1}$, which was observed in case of 17P/Holmes ($v_c = 0.57 \pm 0.02\,km\,s^{-1}$). Complete disintegration probably [14, 16] occured on Oct. $24.40\,UT$. Observed dust stripes (Fig. 6 b) most likely originated from companion's larger fragments.

Another possible outburst model was proposed by R. Milles [23] based on a slow formation and subsequent rapid catalytic decomposition of hydrogen perokside (H_2O_2). Through exposure to UV light, solar-wind particles and cosmic radiation, water near the comet's surface can oxidate and form H_2O_2. Same exposure can cause dissociation of H_2O_2. If comet is close enough to the Sun and the rotation of the nucleus is slow ($<$ 1 revolution/day) some water is liquid and hydrogen perokside can flow towards the interior of the nucleus. In subsurface mantle H_2O_2 concentrates through solid, liquid and gas phase processes (sublimation, evaporation, fractional crystallization, diffusion,...). If high concentration ($\sim 10\%$ or more) of aqueous H_2O_2 comes into interaction with finely dispersed transition metals, metal compounds and minerals (particularly Fe), a rapid exothermic decomposition, liberating oxygen gas, occures. Assumptions of this model are that the comet's nucleus is heterogeneous on a large scale being composed of water-rich areas and loosely-packed agglomerates rich in metals (especially Fe) and that the rotational period is large enough. The second assumption is not met, because measured rotational period of 17P/Holmes is between $7.2 - 12.8$ hours (see section 2.2). On the other hand this model can explain the second outburst some time after the first (as observed in 17P/Holmes' 1892/93 outbursts), because H_2O_2 can concentrate again.

A mechanism that would describe all of the observed characteristics of comet's 17P/Holmes' outburst is not yet known.

References

[1] P. Skale, Comets, Seminar, 2007, http://mafija.fmf.uni-lj.si/seminar/seminar.php (April 2008)

[2] P. L. Lamy, I. Toth, Y. R. Fernández, H. A. Weaver, The Sizes, Shapes, Albedos and Colors of Cometary Nuclei, Comets II (Chapter 15), University of Arizona Press, 2004, 223-264

[11] Another estimate (also based on extinction of background stars) gives similar ejected dust mass estimate. The plateau brightness implies the presence of dust particles in the coma, whose integrated cross-sectional area is $57 \pm 10 \cdot 10^6\,km^2$. For a particle-size distribution with an average radius of $1\,\mu m$, the estimated mass [21] of this dust cloud is $10^{11}\,kg$ at an assumed bulk density of $1.5\,g\,cm^{-3}$.

[12] If surface layers of the nucleus split from the main part, they have a curved pancake shape.

[3] J. Atanackov, J. Kac, Opazovanje in vizualna fotometrija kometov, May 2004, Spika, 224

[4] http://cometography.com/pcomets/017p.html (April 2008)

[5] The Comet's Tale, Newsletter of the Comet Section of the BAA, Nr. 27, December 2007, 1

[6] http://ssd.jpl.nasa.gov/sbdb.cgi?sstr=17p;orb=0;cov=0;log=0 (April 2008)

[7] C. Snodgrass, S. C. Lowry, A. Fitzsimmons, Photometry of cometary nuclei: Rotation rates, colours and a comparison with Kuiper Belt Objects, 2006, MNRAS, 373, 1590

[8] http://www.aerith.net/comet/catalog/0017P/2007.html (April 2008)

[9] D. W. E. Green, IAUC 8886

[10] J. M. Trigo-Rodriguez, B. Davidsson, P. Montañés-Rodriguez, A. Sánchez, B. Troughton, All-Sky cameras detection and telescope follow-up of the 17P/Holmes outburst, Lunar and Planetary Science XXXIX, 2008, LPI Contribution No. 1391., 1627

[11] D. W. E. Green, IAUC 8897

[12] http://kometen.fg-vds.de/fgk_hpe.htm (April 2008)
http://shopplaza.nl/astro/ (April 2008)

[13] M. Montalto, A. Riffeser, U. Hopp, S. Wilke, G. Carraro, The comet 17P/Holmes 2007 outburst: the early motion of the outburst material, 2008, A&A, arXiv:0801.0864v1

[14] D. W. E. Green, CBET 1123

[15] http://www.observatorij.org/ (April 2008)

[16] D. W. E. Green, CBET 1111

[17] Z. Sekanina et. al., Recurring outbursts and nuclear fragmentation of comet C/2001 A2 (LINEAR), 2002, ApJ, 572, 679

[18] Z. Sekanina, The problem of split comets revisited, 1997, A&A, 318, L5

[19] P. Gronkowski, The search for a cometary outbursts mechanism: a comparison of various theories, 2007, AN, 328, No. 2, 126

[20] D. W. E. Green, IAUC 8890

[21] D. W. E. Green, CBET 1118

[22] D. W. E. Green, IAUC 8887

[23] R. Milles, A novel mechanism for outbursts of Comet 17P/Holmes and other short-period comets, 2007, MNRAS