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COMETARY OUTBURSTS AND EVOLUTION OF EJECTED PARTICLES

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RESUMEN

El modelo Dust Trail es un marco robusto desarrollado recientemente para comprender el comportamiento complejo de las colas de polvo cometario resultantes de los estallidos. El modelo tiene en cuenta factores como la presión de radiación solar, las perturbaciones gravitacionales de los cuerpos celestes y las interacciones entre partículas y el cometa progenitor. La precisión del modelo depende de suposiciones sobre las características de las partículas de la erupción, lo que motiva la recopilación oportuna de observaciones de eventos recientes, tal como fue el caso de los estallidos del cometa 12P/Pons-Brooks. Dado que la utilización de observatorios remotos y robóticos resulta crucial para la eficiente recopilación de datos en tiempo real, incorporamos estas observaciones contemporáneas e incluimos una revisión de eventos pasados, como fue el caso de cometas anteriores, el cometa 17P/Holmes por ejemplo. Estos datos sirven para validar el modelo mediante comparaciones con observaciones anteriores y para mejorar las predicciones sobre el comportamiento de las colas de polvo. A través de la comparación de estas predicciones con observaciones recientes, demostramos la eficiencia del modelo para describir la evolución a largo plazo de las colas de polvo cometario.

ABSTRACT

The Dust Trail kit model is a recently developed robust framework for understanding the complex behavior of cometary dust trails resulting from outbursts. The model takes into account factors such as solar radiation pressure, gravitational perturbations from celestial bodies, and interactions between particles and the parent comet. The model accuracy relies on assumptions about outburst particle characteristics, prompting the timely collection of observations from recent events such as the comet 12P/Pons-Brooks outbursts. As the utilization of remote and robotic observatories proves crucial for the efficient collection of real-time data, we incorporate these contemporary observations and include a review of past cases, such as the comet 17P/Holmes. These data serve to validate the model through comparisons with earlier observations and to enchance predictions for dust trail behavior. Through the comparison of these predictions with recent observations, we demonstrate the model efficacy in describing the long-term evolution of cometary dust trails.

Key Words: cometary outbursts — comets — dust trails — dynamical evolution and stability — meteoroid streams — meteors

1. INTRODUCTION

Cometary outbursts, marked by sudden increases in brightness, provide captivating opportunities to observe these relatively small celestial bodies and deduce their characteristics. These outbursts occur among periodic comets and those traversing

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hyperbolic paths, with comet 29P/Schwassmann-Wachmann 1 being a notable example. During outburst events, vast amounts of dust particles and gas are expelled from the cometary nucleus coma, diffusing into elliptical orbits around the Sun. While initially appearing to dissipate, the particle cloud progressively expands. After half a revolution, this meteoroid stream reconverges on the opposite side of the Sun near the mutual node of their orbits, (Lyytinen et al. 2013). Subsequently, a single revolution brings these particles back to their original outburst location, which we refer to as the near-side common node. The hourglass-shaped trail that forms is a result of variations in particle orbits (Lyytinen et al. 2013; Gritsevich et al. 2022). This can be illustrated by considering individual meteoroid orbits with orbital planes differing by up to 3 degrees, a crucial factor contributing to the formation of the apparent hourglass shape (Figure 1). The crossing of these planes results in a distinct contraction and increased brightness at the mutual nodes, and despite the extended duration of meteoroids passing through these regions, the effect remains visible. Figure 1 illustrates how the orbits appear to intersect in the sky, forming a narrow hourglass pattern when observed from inside the orbit near the Sun and close to the plane itself. The brightness distribution exhibits the same hourglass shape, with the center being narrower and having higher surface brightness than the far-side common node.

Fig. 1. Schematic diagram illustrating the intersection of dust trail particle orbits at common nodes when modeling the long-term evolution of the trail (Lyytinen et al. 2013).

Cometary outbursts are complex phenomena with various proposed causes, as detailed in the literature (Wesołowski 2020a, 2021, 2022). The concentration of vapors resulting from the sublimation of volatile compounds beneath the cometary surface is one possible mechanism leading to the destruction of surface layers and intensifying sublimation. Other mechanisms involve impacts with small solar system bodies, shock waves from solar flares, and the polymerization of HCN, initiated by UV or high-energy solar photons, releasing energy and causing surface layer disruption. The presence of cavities in comets, filled with pressurized gas, can also contribute to surface layer destruction, exposing deeper layers and rapidly increasing the sublimation rate. Additionally, the melting of solid CH_4 in cavities, releasing heat, may potentially rupture surface layers, resulting in heightened brightness. These mechanisms often work in combination, with the ejection of surface layers revealing subsurface layers rich in volatile materials as a common factor in sudden comet brightening. The importance of characterizing cometary outbursts is evident, as multiband spectroscopy unveils the ongoing processes occurring in the coma (Trigo-Rodríguez et al. 2008, 2010).

The key physics behind cometary outbursts can be summarized as follows:

i. **Comet Nucleus and Structure:** Comets consist of a nucleus, which is a solid, icy core typically a few kilometers in diameter. The nucleus is composed of a mixture of water ice, frozen gases (like carbon dioxide and carbon monoxide), dust, and other volatile compounds. The nucleus may have a layered structure with subsurface regions and terrain layers on the surface.

ii. **Volatile Sublimation:** As the comet approaches perihelion, the Sun's heat causes the volatile ices on and beneath its surface to sublimate-directly transitioning from solid to gas. This sublimation releases gas and dust into space, forming a temporary atmosphere, or coma, around the nucleus.

iii. **Pressure Build-Up:** Sublimation of ices generates gas pressure beneath the surface, creating stress and tension within the comet's interior. Trapped volatile gases, especially carbon monoxide, play a crucial role in this process.

iv. **Crystallization Process:** Within the comet's nucleus, amorphous (disordered) water ice transforms into a more stable cubic crystalline structure. This crystallization process is exothermic, releasing heat and additional gas.

v. **Exponential Temperature Growth:** As the crystallization progresses, the temperature of the nucleus begins to rise exponentially.

vi. **Self-Feeding Mechanism:** The exponential temperature increase leads to a self-feeding mechanism, where larger quantities of transformed ice release more energy. This results in a rapid jump in temperature within the nucleus.

vii. **Superheated Volatiles:** The rising temperature causes trapped superheated volatile gases to expand explosively, further increasing pressure.

viii. **Terrain Layer Disruption:** Terrain layers on the surface of a comet may not lift as a whole. Instead, they can break up into smaller pieces and get lifted in separate episodes. The level of cohesion

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Fig. 2. Observation of comet 12P/Pons-Brooks on November 20, 2023 (16:50UT), 20min integration time in RGB filters using a QHY600 CCD, taken by Michael Jger.

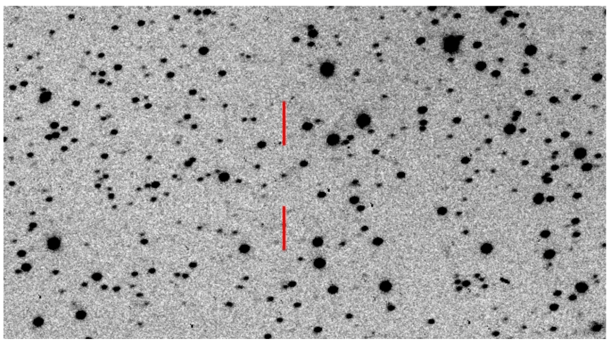

Fig. 3. Early image of comet 12P/Pons-Brooks received remotely on June 13, 2023 using a 0.25-m f/3.4 hyperbolic astrograph (Great Basin Desert, Beryl Junction, Utah, USA). Cometary activity is clearly visible.

within the comet plays a crucial role in determining whether these layers collapse or are ejected.

2. METHODS AND INSTRUMENTS

In our recent publication (Gritsevich et al. 2022), we introduced the Dust Trail kit model, a robust framework capable of elucidating this intricate behavior of cometary dust trails produced by outbursts. The model adeptly considers the influence of solar radiation pressure, gravitational perturbations induced by celestial bodies such as Venus, Earth, Moon, Mars, Jupiter, and Saturn, as well as the gravitational interaction of the particles and the parent comet. By applying the model, we demonstrate the importance of accurately deducing the characteristics of particles released during an outburst to model the subsequent evolution of the dust trail. Therefore, obtaining meticulous observations from the onset of the outburst event is paramount.

To exemplify the model's utility, we took the opportunity to investigate the comet 12P/Pons-

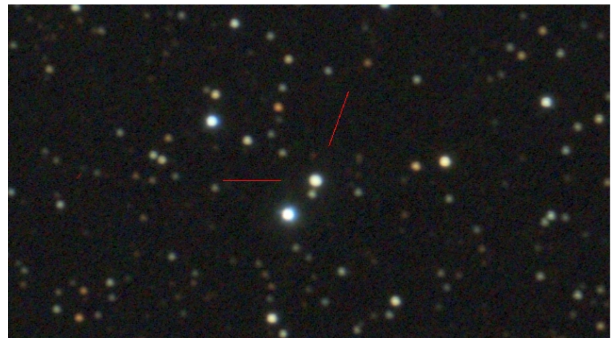

Fig. 4. Coloured image of the comet 12P/Pons-Brooks in the first outburst taken on July 21 with a 0.28−mf/2.2 RASA astrograph (Great Basin Desert, Beryl Junction, Utah, USA). 12P appears very condensed with an increase of ~ 5 mag.

Fig. 5. Appearance of the coma of comet 12P/Pons-Brooks which followed most of the outbursts. 0.61-m f/6.5 astrograph (Auberry, California, USA).

Brooks, a Halley-type comet with a 71-year period, Figure 2. This comet is set to return to perihelion on April, 21, 2024 and during this return it has already experienced a series of notable outbursts (Table 1).

We report findings based on the extensive period of observations conducted on comet 12P/Pons-Brooks, starting from the onset of noticeable activity on June 13, 2023, and continuing until December 17, 2023 (Figures 2-7). The observational span covers heliocentric distances ranging from 4.26 to 2.19 AU. The facilities used in observations include the BOOTES (Burst Observer and Optical Transient Exploring System) a Global Network of Robotic Astronomical Observatories (Castro-Tirado et al. 1999; Castro-Tirado 2023), the 0.3 m Viestikallio remote observatory in Finland, the new remote 0.3 m Makroskooppi observatory in Spain, remote telescopes at the iTelescope observatories in Utah and California (MPC codes U94 and U69, respectively), as well as the 1.3 m and 0.61 m telescopes at the Skalnat Pleso Observatory in Slovakia

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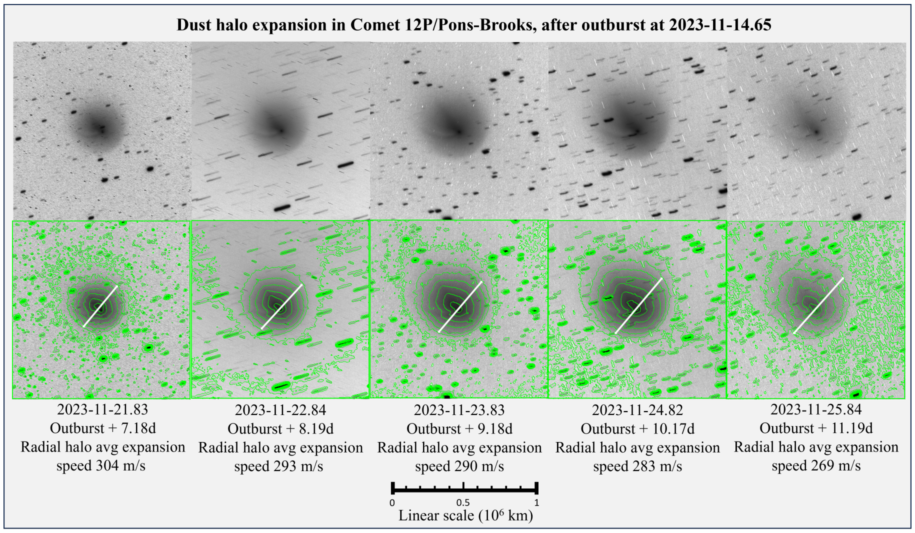

Fig. 6. Dust halo radial expansion speeds of 12P/Pons-Brooks measured and calculated using Viestikallio remote observatory data and the outburst beginning time.

TABLE 1

Date	Brightness change	Amplitude	notes
2023 07 20.37 $\pm$ 0.08 UT	17.18G $\Rightarrow$ 11.68G	5.50	strong outburst
2023 09 04.00 $\pm$ 0.60 UT	16.97G $\Rightarrow$ 16.59G	0.36	mini outburst
2023 09 23.87 $\pm$ 0.02 UT	16.74G $\Rightarrow$ 15.84G	0.90	mini outburst
2023 10 05.16 $\pm$ 0.03 UT	16.37G $\Rightarrow$ 11.37G	5.00	strong outburst
2023 10 22.52 $\pm$ 0.21 UT	16.07G $\Rightarrow$ 15.67G	0.40	mini outburst
2023 10 31.46 $\pm$ 0.20 UT	15.90G $\Rightarrow$ 13.00G	2.90	possibly double event, second outburst on Nov 1.40
2023 11 01.40 $\pm$ 0.15 UT	13.70G $\Rightarrow$ 11.23G	2.50	
2023 11 14.65 $\pm$ 0.05 UT	15.00G $\Rightarrow$ 10.00G	5.00	strong outburst; based on Peter Carson (BAA) observations
2023 11 30.60 $\pm$ 0.02 UT	14.00G $\Rightarrow$ 10.60G	3.40	based on Nick James (BAA) observations
2023 12 14.57 $\pm$ 0.11 UT	14.70R $\Rightarrow$ 13.05R	1.65	

(employing broadband BVR filters). These observations allowed to study the expansion characteristics of the dust halo in comet 12P/Pons-Brooks. The expansion rates triggered by the approximately 5-magnitude outburst on October 05, 2023 (Usher et al. 2023) are presented in Figure 7. Radial expansion speeds of the dust cloud were both measured and calculated based on these observations and the initiation time of the outburst (for additional details, see also Ryske et al. 2023).

In addition to conducting photometric analysis on broadband images, encompassing both nuclear and total magnitudes, we investigated comet 12P/Pons-Brooks for its dust production rate, afrho. Our findings reveal significant variations in comet appearance, estimated magnitude, and dust production activity during outburst periods. Specifically, afrho measured during quiescence on July 01, 2023, was 284$\pm$12 cm, a notably lower value compared to the 17295$\pm$1081 cm recorded during the outburst on November 02, 2023, shortly after another major outburst occurred.

The estimated nucleus radius from these observations is 21 km, aligning well with the findings of Ye et al. (2020). Additional follow-up images of the evolving dust cloud of the comet 12P were obtained from the two observatories in Barcelona: Observatori de Gualba and Observatori de Pujalt (Barcelona) as

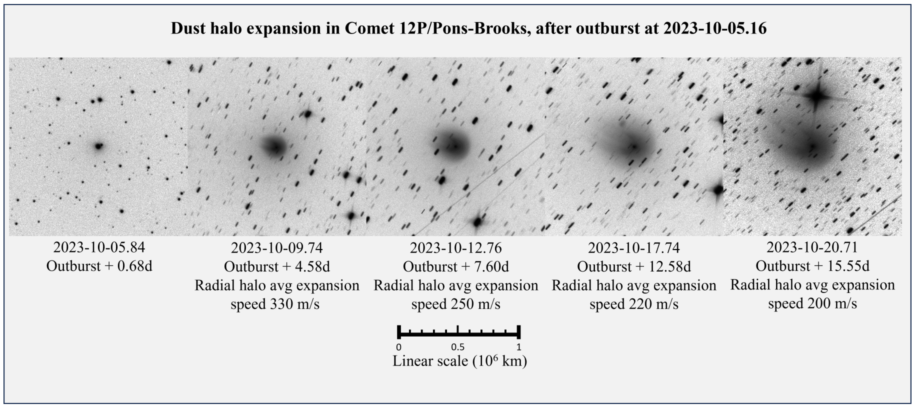

Fig. 7. Dust halo expansion in comet 12P/Pons-Brooks, following a 5 mag outburst on Oct 5, 2023 (Usher et al. 2023), see also Ryske et al. (2023).

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part of an Institut d'Estudis Espacials de Catalunya minor bodies monitoring consortium. These observations facilitated the determination of physical parameters of the dust environment, including dust color and productivity, and allowed for analysis of active structural morphology.

The intersection of Earth with a cometary dust trails gives rise to meteor showers. Notably, certain parent bodies of meteoroid streams, like 12P/Pons-Brooks, have been observed to be linked to more than one observable meteor shower in Earth's atmosphere (Tomko & Neslušan 2016). The dust particle orbits within these dust trails evolve, shifting to locations far from the orbit of their parent body to intersect with Earth's orbit. Conducting a realistic simulation of the dust trail evolution is essential to unveil intricate complex of showers that may be associated with the given parent body. The meteoroid stream associated with 12P/Pons-Brooks includes the December k-Draconids and Northern June Aquilids, providing a unique opportunity to study cometary material within Earth's orbit. Observing these meteor showers offers additional insights into the recent evolutionary history of the parent comet.

3. OTHER NOTABLE EXAMPLES

Not all comets possess the same internal structure or behavior. Some comets may never experience outbursts or fragmentation events due to differences in their composition and thermal properties. Hyperbolic comets contribute to this diversity (Seligman et al. 2023; Peña-Asensio et al. 2024a; Peña-Asensio 2024b). Depending on the degree of cohesion and the specific conditions within the comet, various types of outbursts can occur, ranging from localized outgassing to major fragmentation events. In major fragmentation events, substantial portions of the nucleus may be ejected, forming companions or debris clouds. These fragments may undergo secondary and higher-order fragmentation, leading to a cascading process where progressively smaller fragments are generated.

Notable examples that illustrate various aspects of cometary behavior and their impact on their observable characteristics include:

1. Comet Holmes (17P/Holmes), Montalto et al. (2008); Moreno et al. (2008):

- Experienced a giant explosion in October 2007.
- Brightness shot up $\sim$ 14 magnitudes (or nearly 400,000 times) in a matter of two days.
- Formation of a sharply bounded dust halo and a bright extended feature often referred to as a "blob".
- An estimated 10^{14} grams of dust ejected during the event.
- Intrinsic brightness remained significantly elevated more than a year after the explosion.
- Sustained another giant outburst in 18921893 at the time of its discovery.

2. Halley's Comet (1P/Halley), Gronkowski (2002):

- Underwent a giant explosion in the second half of January 1836, less than 10 weeks after perihelion.
- Accompanied by a sharply bounded, rapidly expanding halo and visible with the naked eye for at least two months after the event.
- Magnitude peak measured at 0.3, indicating a significant brightness increase.

3. Comet C/1996 Q1 (Tabur), Ferrin and Penuelas (2022):

- Suddenly "dissolved" after three months.
- Displayed a physical behavior remarkably similar to that of companions of split comets.

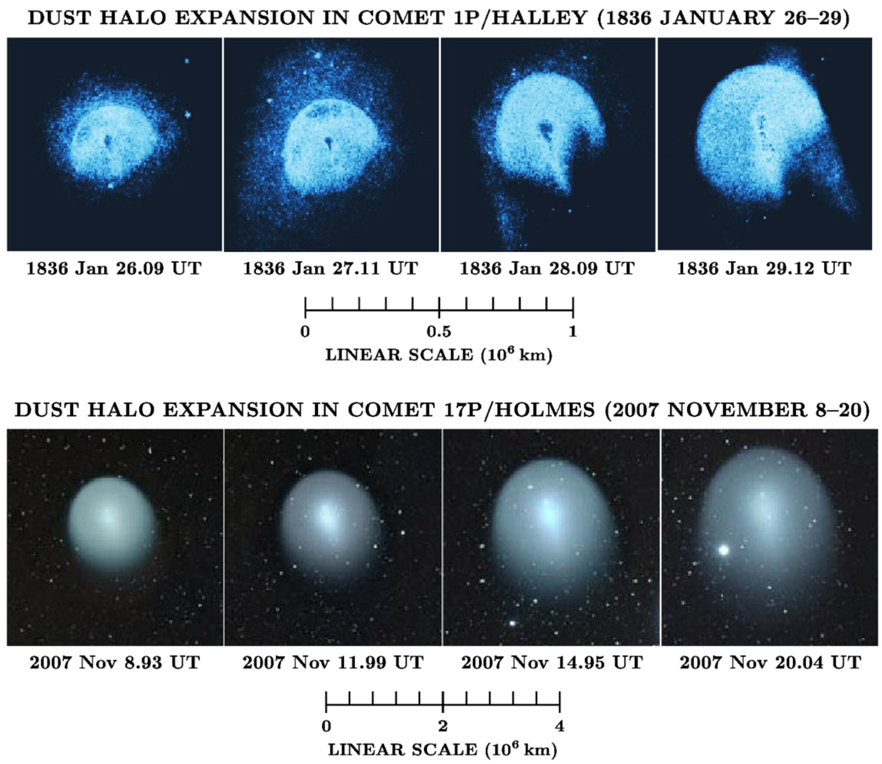

Fig. 8. Dust halo expansion in other cases. Adopted from Sekanina (2008).

- Shared a practically identical orbit with a much brighter comet, C/1988 A1 (Liller).

4. Comet C/1999 S4 (LINEAR), Wolk et al. (2009):

- Disintegrated as it approached the Sun, reaching perihelion on July 26, 2000, at a distance of 0.765 AU. The disintegration was meticulously observed and well-documented.
- Hubble Space Telescope (HST) observations on July 6 revealed a brief outburst and a minor fragmentation event.
- Shortly before perihelion, significant changes in appearance were noted. The comet transformed into a fuzzy, elongated, and faint object.

5. Comet 29P/Schwassmann-Wachmann 1, Gronkowski (2004) & Miles et al. (2016):

- Orbits in a transitional "Gateway" region between the Centaur and Jupiter-family comet (JFC) regions, often referred to as a comet-centaur.
- Estimated nucleus diameter is 60.4 ± 7.4 kilometers.
- Undergoes around seven outbursts per year with a brightness increase of 2-5 magnitudes. Its high level of activity is noteworthy given its nearly circular orbit ($e = 0.04$) and large semi-major axis ($a = 6.05$ AU).
- During outbursts, the coma undergoes a drastic change from being diffuse to very condensed. In the post-outburst periods it exhibits a characteristic horseshoe or spiral shape.
- The last strong outburst occurred on December 23, 2023, with a brightness increase of 2 magnitudes.
- In the 20th century, it experienced two minor approaches to Jupiter. The 21st-century approach on October 11, 2037, will result in an increase in perihelion distance from 5.71 AU to 5.87 AU and an orbital period from 14.37 to 15.87 years.

The timescale for major outburst events is governed by the mean exposure lifespan of terrain layers on the comet surface. The interval between giant outbursts in some comets can be in the order of centuries, providing insights into heat transfer and cometary structure.

4. DUST TRAIL KIT MODELING RESULTS

To illustrate the efficacy of our model in describing long-term dust trail evolution, we studied the comet 17P/Holmes, with an orbital period of close

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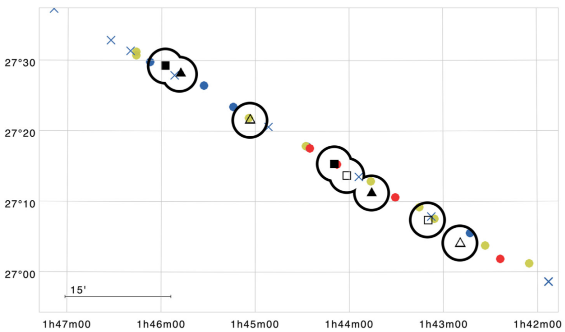

Fig. 9. The positions on the celestial sphere of dust trail resulting from 2007 outburst of the comet 17P/Holmes, depicting color-coded modeled particle population sizes (larger particles (red) with 0.11 mm radius, medium-sized particles (yellow) with 0.010.1 mm radius, and small particles (blue) with 0.0010.01 mm radius). The modeled distribution of particles ejected during the outburst within each of the three groups is uniform. In the first modeling scenario, we assumed spherically symmetric ejection of particles at the start of the outburst. Second scenario for the same particle populations, shown in crosses, only considers particles oriented toward the Sun during the outburst. The modeling results are compared to the observed positions of the trails obtained on dates February 26-28, 2022 and March 01-03, 2022, which are illustrated with black-colored squares and triangle markers. The X-axis denotes Right Ascension (RA), while the Y-axis represents Declination (DEC).

to 7 years, which experienced a massive outburst in October 2007 the largest so far in the documented comet history (Gritsevich et al. 2022). Our simulations encompass various particle populations, ranging in size from 0.001 to 1 mm, with assumptions about ejection speed distributions at the onset of the outburst being subject to variation. The model is implemented in Orekit [17], enabling high computational accuracy through the use of Dormand-Prince numerical integration methods with higher precision. The model's accuracy is validated by comparisons with earlier observations of the trail gathered at common nodes for 0.5 and 1 revolutions. Using this dataset, we formulated predictions concerning the two-revolution dust trail's behavior in proximity to the outburst point and its observability from Earth (Gritsevich et al. 2022).

To enhance practicality, we developed and made available a suite of Python scripts for calculating the dust trail's position based on observatory topographical coordinates (Nissinen & Gritsevich 2022, 2023). Using these predictions, we conducted a series of observations of the 2007 outburst dust trail in February (Ryske et al. 2022), March (Ryske et al. 2022), October, December 2022, and February 2023 (Figure 9). The observability of the dust trail hinges on sunlight scattering by myriad micron-sized particles arising from the outburst phenomenon. Notably, both the brightness of the trail and its spatial coordinates closely align with our earlier published predictions made using the Dust Trail kit model (Gritsevich et al. 2022; Nissinen & Gritsevich 2022).

[17]https://www.orekit.org

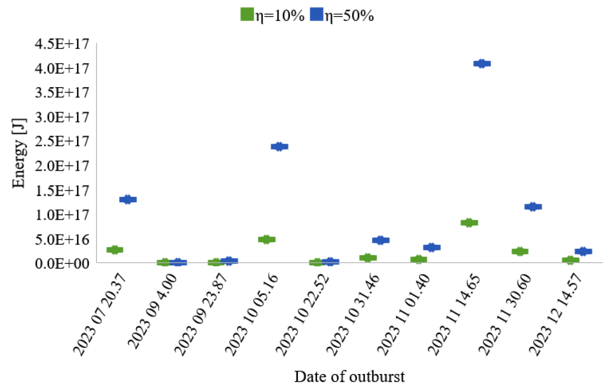

Fig. 10. The energy released during the outbursts of comet 12P/PonsBrooks. The calculations assume two values of the active surface in the quiet sublimation phase (η), which result from observations from comet 1P/Halley to comet 67P/Churyumov-Gerasimenko.

5. ENERGY OUTBURST

The cometary outburst is associated with the destruction of a nucleus fragment, accompanied by the emission of dust and gases into the coma. This causes an increase in the total scattering cross-section, which leads to an increase in the efficiency of scattering incident sunlight (Wesołowski 2022). When analysing individual outburst cases, one of the most important parameters is determining the energy released during the outburst (Figure 10). The amount of energy released means that the outburst is a high-energy process, that may be responsible for the presence of fine particles in the coma (Wesołowski 2024). The obtained energy values depend on the mass ejected, the expansion velocity and the fraction of the active surface (η). The cometary outburst causes local destruction and rejuvenation of the core, which involves the exposure of the original subsurface layer (Wesołowski et al. 2020b).

6. CONCLUSIONS

This study includes an extended synopsis of the physics underlying cometary outbursts, extreme events in the life cycle of comets driven by a complex interplay of physical processes involving the cometary nucleus, dust particles, volatile materials, and solar radiation. The comprehension of cometary outbursts offers insights into the evolution and physical properties of comets and their dust trails as they interact with the surrounding environment. It enhances our current understanding of the diversity of cometary behavior and the fundamental physics shaping the fate of these intriguing celestial objects.

Dedication. This paper is dedicated to the memory of our dear friend and colleague, Esko Lyytinen, a man of extraordinary mind with a lifelong passion for science (Jenniskens et al. 2021; Gritsevich et al. 2021). Remarkably, Esko shares a birthday with the discovery date of comet 17P/Holmes (discovered by the British amateur astronomer Edwin Holmes during the 1892 outburst), separated by a span of 50 years a comet that has greatly captivated his mind and deeply inspired for modeling!

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REFERENCES

Castro-Tirado, A. J., Soldán, J., Bernas, M., et al. 1999, A&A SS, 138, 583
Castro-Tirado, A. J., 2023, Nat Ast, 7, 1136
Ferrin, I. ; Penuelas, G., 2022, The Astronomer's Telegram, 15352
Gritsevich, M., Nissinen, M., Moilanen, J., et al. 2021, WGN, Journal of the International Meteor Organization, 49, 3
Gritsevich, M., Nissinen, M., Oksanen, A., Suomela, J. & Silber, E. A. 2022, MNRAS, 513, 2
Gronkowski, P., 2002, P&SS, 50, 247
Gronkowski, P., 2004, MNRAS, 354, 142
Jenniskens, P., Trigo-Rodríguez, J. M. & Gritsevich, M. 2021, WGN, JIMO, 49, 23
Lyytinen, E., Nissinen, M. & Lehto, H. J. 2013, WGN, JIMO, 41, 77
Miles, R., Faillace, G. A., Mottola, S., et al., 2016, Icar, 272, 327
Montalto, M., Riffeser, A., Hopp, U., Wilke, S., Carraro, G., 2008, A&A, 479, 45
Moreno, F. J. L., Santos-Sanz, P., Morales, N., et al., 2008, ApJ, 677, 63
Nissinen M., & Gritsevich M., 2022, Instructions on where and how to observe the comet 17P/Holmes dust trail. Zenodo. `https://doi.org/10.5281/zenodo.6977358`
Nissinen M., & Gritsevich M., 2023, Instructions for Ongoing Observations of the Dust Trail from the 2007 Outburst of Comet 17P/Holmes. Zenodo. `https://doi.org/10.5281/zenodo.8319474`
Peña-Asensio, E., Visuri, J., Trigo-Rodríguez, J. M., et al. 2024, Icar, 408, 115844
Peña-Asensio, E., Trigo-Rodríguez, J. M., Gritsevich, M., et al. 2025, RMxAC (this issue)
Ryske, J., Gritsevich, M., & Nissinen, M. 2022, EPSC, EPSC2022-60
Ryske, J., Gritsevich, M., Nissinen, M., Pérez-García, I., & Castro-Tirado, A. J. 2023, ATel, 16343
Sekanina, Z. 2008, ICQ, 30, 63
Seligman, D. Z., & Moro-Martín, A. 2023, arXiv e-prints, arXiv:2304.00568
Tomko, D. & Neslušan, L. 2016, A&A, 592, A107
Trigo-Rodríguez, J. M., García-Melendo, E., Davidsson, B. J. R., et al., 2008, A&A, 485, 2
Trigo-Rodríguez, J. M., García-Hernández, D. A., Sánchez, A., et al., 2010, MNRAS, 409, 4
Usher, H., Miles, R., Redondo, J. M. P., et al., 2023, ATel, 16270
Wesołowski, M. 2020a, Icar, 351, 113950
Wesołowski, M., Gronkowski, P., Tralle, I., 2020b, Icar, 352, 114005
Wesołowski, M., 2021, RAA, 21, 69
Wesołowski, M., 2022, Icar, 375, 114847
Wesołowski, M., 2024, Icar, 411, 115937
Wolk, S. J., Lisse, C. M., Bodewits, D., et al., 2009, ApJ, 694, 1293
Ye, Q., Farnham, T. L., Knight, M. M., Holt, C. E. & Feaga, L. M. 2020, RNAAS, 4, 101