

Variations in the volatile-driven activity of comet C/2017 K2 (PanSTARRS) revealed by long-term multiwavelength observations

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C/2017 K2 (PanSTARRS)

Comet C/2017 K2 (PanSTARRS) is a dynamically new Oort cloud comet and one of the most remarkable cases of distant cometary activity ever observed. Discovered at 16.1 au from the Sun (Wainscoat et al., 2017), it was later found to have been active as far as 23.8 au (Jewitt et al., 2017; Meech et al., 2017), making it the second most distant active comet ever detected. Sub-millimeter observations revealed a CO-rich coma (Yang et al., 2021), and its brightness steadily increased as it approached perihelion. Its extraordinary activity at such large heliocentric distances and its pristine, dynamically fresh nature make K2 an ideal laboratory for probing volatile-driven processes across an unprecedented range of solar distances.

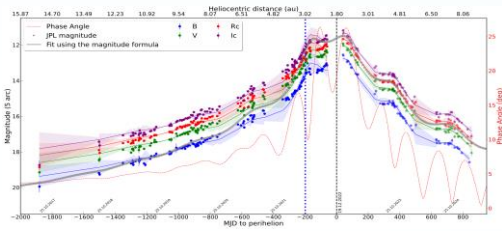
Here, we present a comprehensive analysis of K2's long-term activity and chemical composition, drawing on nearly eight years of photometric observations (15.2 au pre-perihelion to 8.5 au post-perihelion) and spectroscopic data from two instruments at ESO/VLT. Our results shed light on volatile competition, dust coma properties, and the compositional classification of this exceptional comet (Hmoudouch et al., 2025).

TRAPPIST monitoring

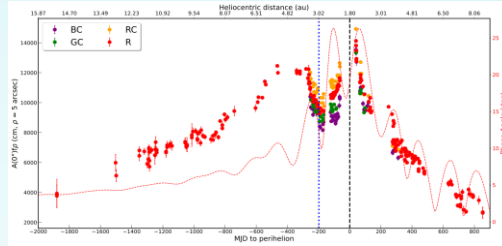
TRAPPIST (TRANSiting Planets and Planetsimals Small Telescope) is a project led by the University of Liège, in Belgium. It is made of two 60-cm robotic telescopes devoted to the detection and characterization of exoplanets using the transit method and to the study of comets and other small bodies in our Solar System (Jehin et al., 2011).



The TRAPPIST monitoring campaign yielded a total of 2204 broadband and 174 narrow-band images across 271 observing nights spanning nearly eight years. Exposure times were adjusted to track the comet's evolving brightness, ranging from 30–240 s in broadband and 300–1500 s in narrow-band filters. Together, this extensive and homogeneous dataset represents one of the most complete long-term optical monitoring programs ever conducted for a dynamically new comet at large heliocentric distances.



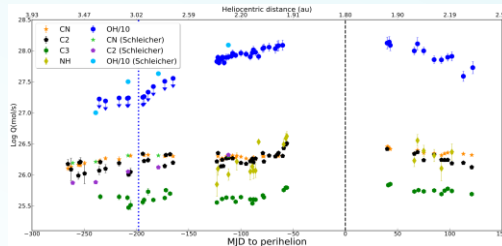
Broadband light curve of comet C/2017 K2 obtained with TRAPPIST, measured within a 5 arcsec radius aperture as a function of time and heliocentric distance relative to perihelion. The vertical dashed line marks the perihelion passage at 179 au on 19 December 2022, while the vertical blue dashed line indicates the approximate water sublimation boundary at ~3 au.



The A(0)fp parameter of comet C/2017 K2 from the broad- and narrow-band filters as a function of the heliocentric distance.

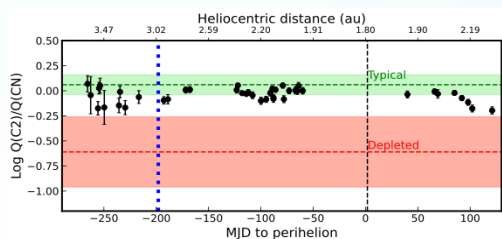
The figure below shows the heliocentric evolution of production rates for five volatile species — OH, NH, CN, C₂, and C₃, in comet K2. OH, production rates are scaled down by a factor of ten for clarity. The logarithmic scale facilitates direct comparison across species with vastly different absolute abundances, while highlighting temporal variations in activity with heliocentric distance.

Production rate ratios relative to CN and OH, along with the dust-to-gas ratio, were derived to characterize the compositional nature of K2. The value log [A(O)fp/Q(OH)] = -24.75 ± 0.43 places K2 in the dust-rich category when compared to the typical cometary values of A'Hearn et al. (1995a).



Logarithmic production rates of OH, NH, CN, C₂, and C₃ of comet C/2017 K2 from TRAPPIST photometry as a function of time and heliocentric distance.

The figure below traces the temporal evolution of the log C₂/CN ratio as a function of both time relative to perihelion and heliocentric distance. Following the taxonomic scheme of A'Hearn et al. (1995a), K2 is classified as a "typical" comet, exhibiting standard relative abundances of C₂ and C₃ with respect to CN and OH.



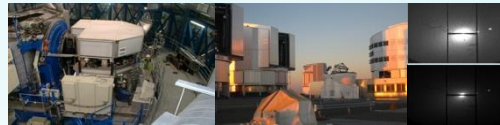
UVES UT2 VLT

To investigate the volatile composition of comet K2 in the optical domain and track its evolution through perihelion, we conducted a dedicated spectroscopic program using the Ultraviolet-Visible Echelle Spectrograph (UVES) on Unit Telescope 2 (Kueyen) of the ESO/VLT at Paranal Observatory. High-resolution optical spectra were acquired at three distinct epochs (Table), sampling heliocentric distances both inside and outside the water sublimation zone (~3 au). This strategy was designed to capture potential shifts in the relative abundances of gaseous species linked to the transition from hypervolatile-driven to water-driven activity.

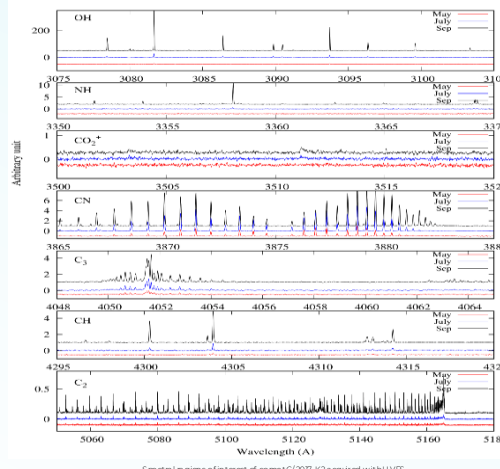
At the first epoch (May 9, 2022; r_h = 3.23 au), only CN, C₂, and C₃ emission bands were detected, consistent with TRAPPIST imaging.

Date 2022	r _h (au)	r _Δ (au)	r _Δ (km/s)
May 9	3.23	2.66	-37.7
July 5	2.73	1.82	-6.65
Sept 21	2.12	2.32	15.98
Sept 22	2.11	2.35	15.6

At the third epoch (September 20, 2022; r_h = 2.12 au), all emission features had intensified substantially, reflecting a marked increase in overall activity (see figure below).



UVES high-resolution spectrograph at VLT, with Red and Blue Sit. We view images 3 July 05.



Spectral regions of interest of comet C/2017 K2 acquired with UVES.

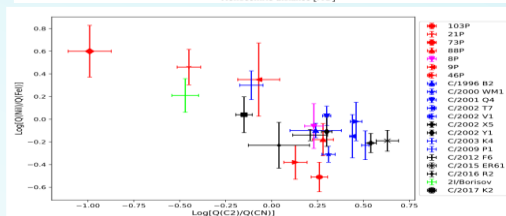
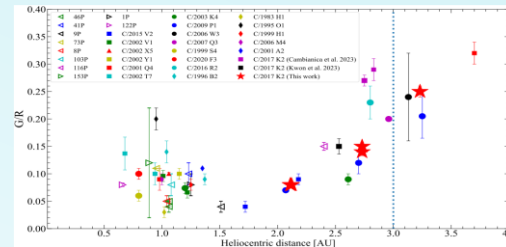
For more details about this work



Table: Gas production rates of comet C/2017 K2 from UVES observations

Date (2022)	OH	CN	C ₂
May 09	3.96 ± 0.79 × 10 ²⁷	7.57 ± 1.51 × 10 ²⁶	2.88 ± 0.58 × 10 ²⁶
Jul 05 (a)	1.23 ± 0.12 × 10 ²⁸	1.07 ± 0.11 × 10 ²⁸	7.03 ± 1.41 × 10 ²⁶
Jul 05 (b)	1.51 ± 0.16 × 10 ²⁸	1.15 ± 0.12 × 10 ²⁸	5.86 ± 1.17 × 10 ²⁶
Sept 21	5.23 ± 0.51 × 10 ²⁸	1.15 ± 0.12 × 10 ²⁸	1.01 ± 0.20 × 10 ²⁶
Sept 22	5.59 ± 0.57 × 10 ²⁸	1.18 ± 0.11 × 10 ²⁸	9.59 ± 1.92 × 10 ²⁵

Integrated fluxes and the green-to-red [O] ratio (G/R; Cochran & Cochran, 2001) were measured at each epoch. The G/R ratio shows a clear heliocentric dependence, declining from ~0.25 beyond the water sublimation boundary (~3 au; Crovisier & Encrenaz, 2000) to ~0.1 near 2 au, in excellent agreement with values reported for a wide range of comets by Decock et al. (2013), Opticom et al. (2019), Cambianica et al. (2021, 2023), Kwon et al. (2023), and Aravind et al. (2024) (see figure below).



Ni/Fe abundance ratios against the C₂/CN adapted from Hutsemekers et al. (2023). The colors in the plot represent different dynamical classes: Jupiter-family comets (red), Halley-family comets (pink), long-period comets (blue), and dynamically new comets (black); the square symbol corresponds to C/2017 K2.

CRIRES+ UT3 VLT

High-resolution NIR spectra were acquired using CRIRES+ (ESO/VLT), upgraded now to a cross-dispersed spectrometer. Two settings, L3377 and M4308, were sufficient to sample the majority of primary volatiles (e.g., H₂O, CO, C₂H₆, CH₄, HCN, NH₃, ...) and to study their evolution as the comet is approaching the Sun.

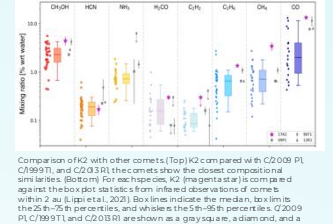


The Cryogenic high-resolution Infrared Echelle Spectrograph (CRIRES+) mounted on the VLT UT3.

Despite K2's pronounced activity at large heliocentric distances, infrared observations reveal a contrasting picture: a weak dust continuum and faint emission from parent species. The infrared dust signal combines reflected solar radiation and the mal emission. Key species detected optically, including H₂O, C₂H₂, and HCN, were only marginally detected even during periods of heightened optical activity. Rotational temperatures, production rates, mixing ratios, and upper limits from CRIRES+ observations are summarized in the following table.

Date	Molecule	Q _{rot} [10 ²⁶ mol/s]	Q _{rot} ² [10 ⁵² mol ² /s]	MR [%, w/w]
5 July 2022	H ₂ O	203 ± 53	332 ± 96	100
	HCN	< 0.8	< 1.3	< 0.4
	C ₂ H ₂	< 0.9	< 1.5	< 0.5
	C ₂ H ₄	1.57 ± 0.34	2.59 ± 0.64	0.77 ± 0.32
	CH ₄	7.8 ± 1.7	12.9 ± 3.2	3.8 ± 0.8
21 Sep 2022	CO	21.8 ± 5.5	36 ± 10	10.7 ± 2.7
	H ₂ O	252 ± 29	446 ± 62	100
	CH ₃ OH	10.5 ± 3.5	19 ± 7	4.2 ± 1.4
	HCN	0.37 ± 0.12	0.66 ± 0.23	0.15 ± 0.05
	C ₂ H ₂	< 0.8	< 1.4	< 0.3
22 Sep 2022	C ₂ H ₄	3.36 ± 0.22	5.95 ± 0.92	1.33 ± 0.09
	CH ₃ OH	6.5 ± 3	11 ± 5	2.6 ± 1.2
	CO	25 ± 3	60 ± 10	13.9 ± 1.2
	H ₂ O	252 ± 29	446 ± 62	100
	CH ₃ OH	11.5 ± 3.5	20 ± 6	4.6 ± 1.2
HCN	0.58 ± 0.24	1.02 ± 0.44	0.23 ± 0.10	
C ₂ H ₂	< 1.2	< 2.2	< 0.5	
C ₂ H ₄	3.64 ± 0.26	6.45 ± 1.02	1.44 ± 0.10	
CH ₃ OH	6.5 ± 3	11 ± 5	2.6 ± 1.2	

Compared to other comets, K2 appears enriched in most volatile species, with compositional similarities to C/1999 T1, C/2009 P1, and C/2013 R1 (see figure below). This enrichment may reflect formation in a cold, organic-rich environment where high CO abundances and efficient hydrogenation on icy grains enhanced molecules such as methanol, ethane, and methane. As a dynamically new comet, K2 has likely preserved much of its primordial composition during its long residence in the Oort cloud, consistent with the strong hypervolatile-driven activity observed beyond 20 au.



Comparison of K2 with other comets. (Top) K2 compared with the C/2009 P1, C/1999 T1, and C/2013 R1 comets shows the closest compositional similarities. (Bottom) For each species, K2 fragments are compared against the boxplot statistics from infrared observations of comets within 2 au (Lippi et al., 2023). Boxes indicate the median, box limits the 25th–75th percentiles, and whiskers the 5th–95th percentiles. C/2009 P1, C/1999 T1, and C/2013 R1 are shown as a grey square, a diamond and, and a triangle, respectively.