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Antonio Armeni

`antonio.armeni@inaf.it`

Istituto Nazionale di Astrofisica - Osservatorio Astronomico di Capodimonte <https://orcid.org/0000-0002-8533-168X>

Alessio Caratti o Garatti

INAF - Osservatorio Astronomico di Capodimonte <https://orcid.org/0000-0001-8876-6614>

Claudia Cyganowski

University of St Andrews

Crystal Brogan

National Radio Astronomy Observatory

Todd Hunter

National Radio Astronomy Observatory <https://orcid.org/0000-0001-6492-0090>

David Taylor

Scottish Universities Physics Alliance (SUPA), School of Physics and Astronomy, University of St Andrews

Rodrigo Álvarez-Gutiérrez

Scottish Universities Physics Alliance (SUPA), School of Physics and Astronomy, University of St Andrews

Zsófia Marianna Szabó

Scottish Universities Physics Alliance (SUPA), School of Physics and Astronomy, University of St Andrews

Andrej M. Sobolev

<https://orcid.org/0000-0001-7575-5254>

Sergey Parfenov

Ural Federal University

Maria Gabriela Navarro

Istituto Nazionale di Astrofisica - Osservatorio Astronomico di Roma

Juan Manuel Alcalà

Istituto Nazionale di Astrofisica - Osservatorio Astronomico di Capodimonte <https://orcid.org/0000-0001-8657-095X>

Olga Bayandina

SKA Observatory

Henrik Beuther

Max-Planck-Institute for Astronomy <https://orcid.org/0000-0002-1700-090X>

Ross Burns

RIKEN Pioneering Research Institute

Jochen Eislöffel

Thüringer Landessternwarte <https://orcid.org/0000-0001-6496-0252>

Hendrik Linz

Max-Planck-Institut für Astronomie <https://orcid.org/0000-0002-8115-8437>

Thomas Megeath

Ritter Astrophysical Research Center, Department of Physics and Astronomy, University of Toledo

Alberto Sanna

INAF-Osservatorio Astronomico di Cagliari

Bringfried Stecklum

Thüringer Landessternwarte Tautenburg <https://orcid.org/0000-0001-6091-163X>

Physical Sciences - Article

Keywords:

Posted Date: August 27th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10433491/v1>

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Additional Declarations: There is **NO** Competing Interest.

JWST reveals a low-mass protostellar outburst driving a methanol maser flare

A. Armeni¹, A. Caratti o Garatti¹, C. J. Cyganowski², C. L. Brogan³, T. R. Hunter³, D. J. Taylor², R. H. Álvarez-Gutiérrez², Z. M. Szabo², A. M. Sobolev^{4,5}, S. Y. Parfenov⁵, M. G. Navarro⁶, J. M. Alcalà¹, O. Bayandina⁷, H. Beuther⁸, R. Burns^{9,10}, J. Eislöffel¹¹, H. Linz⁸, S. T. Megeath¹², A. Sanna¹³, and B. Stecklum¹¹

¹INAF - Osservatorio Astronomico di Capodimonte, Salita Moiariello 16, 80131 Naples, Italy

²Scottish Universities Physics Alliance (SUPA), School of Physics and Astronomy, University of St Andrews, North Haugh, St Andrews KY16 9SS, UK

³National Radio Astronomy Observatory, 520 Edgemont Road, Charlottesville VA 22903, USA

⁴State Key Laboratory of Radio Astronomy and Technology, Xinjiang Astronomical Observatory, CAS, Urumqi 830011, China

⁵Astronomical Observatory, Institute of Natural Sciences and Mathematics, Ural Federal University, 19 Mira Street, 620002 Ekaterinburg, Russia

⁶INAF — Osservatorio Astronomico di Roma, Via di Frascati 33, 00078 Monte Porzio Catone, Italy

⁷SKA Observatory, 2 Fir Street, Observatory 7925, Cape Town, South Africa

⁸Max Planck Institute for Astronomy, Königstuhl 17, 69117 Heidelberg, Germany

⁹RIKEN Pioneering Research Institute, 2-1 Hirosawa, Wako-shi, Saitama 351-0198, Japan

¹⁰Center for Astronomy, Ibaraki University, 2-1-1 Bunkyo, Mito, Ibaraki 310-8512, Japan

¹¹Thüringer Landessternwarte, Sternwarte 5, D-07778 Tautenburg, Germany

¹²Ritter Astrophysical Research Center, Department of Physics and Astronomy, University of Toledo, Toledo, OH 43606, USA

¹³INAF - Osservatorio Astronomico di Cagliari, via della Scienza 5, 09047, Selargius, Italy

Accretion-driven outbursts are a fundamental process in star formation, determining the final masses of stars and the chemistry of protoplanetary disks^{1–4}, yet their detection in the youngest, deeply embedded protostars remains challenging. Radiatively pumped methanol masers⁵, to date associated exclusively with high-mass young stellar objects^{6–11}, exhibit flares that are interpreted as signatures of accretion bursts and serve as beacons to identify massive protostellar outbursts^{12–15}. Indeed, for all such methanol maser flares studied thus far, the driving source has been identified as the associated high mass protostar. By combining *James Webb Space Telescope* (JWST) and *Atacama Large Millimeter/submillimeter Array* (ALMA) observations, we prove that the recent methanol maser flare in the massive star-forming region IRAS 18134-1942¹⁶ was driven by a nearby lower-mass protostar undergoing a strong accretion outburst, rather than the central massive object. Our infrared spectroscopy captures the physical and chemical response of the protostellar core to the accretion burst. Our results demonstrate that methanol masers flares can uncover the hidden population of embedded low-mass bursting protostars in massive clusters, and challenge the standard paradigm where such maser activity is exclusively attributed to massive protostars, demonstrating that cavities opened by low-mass companions can provide a radiative path for triggering flares of pre-existing masers excited by massive protostars.

The IRAS 18134-1942 star-forming region, located at a distance of 1.25 ± 0.05 kpc¹⁷, hosts a cluster of young stellar objects embedded in a dusty environment. The environment is characterized by a hierarchical structure of spiral arms and gas streamers that funnel material toward the central high mass protostar¹⁸. Figure 1 presents a multi-wavelength view of the inner region ($\sim 5'' \times 7''$), revealing a highly complex and clustered environment, with a bright massive source at the center (known as G11.497-1.485; hereafter, MM-main) and several fainter sources around it. The ALMA mm-continuum reveals that MM-main is not isolated. It appears anchored to a dense dusty filament that extends for $\sim 5''$ (6250 AU) and shows

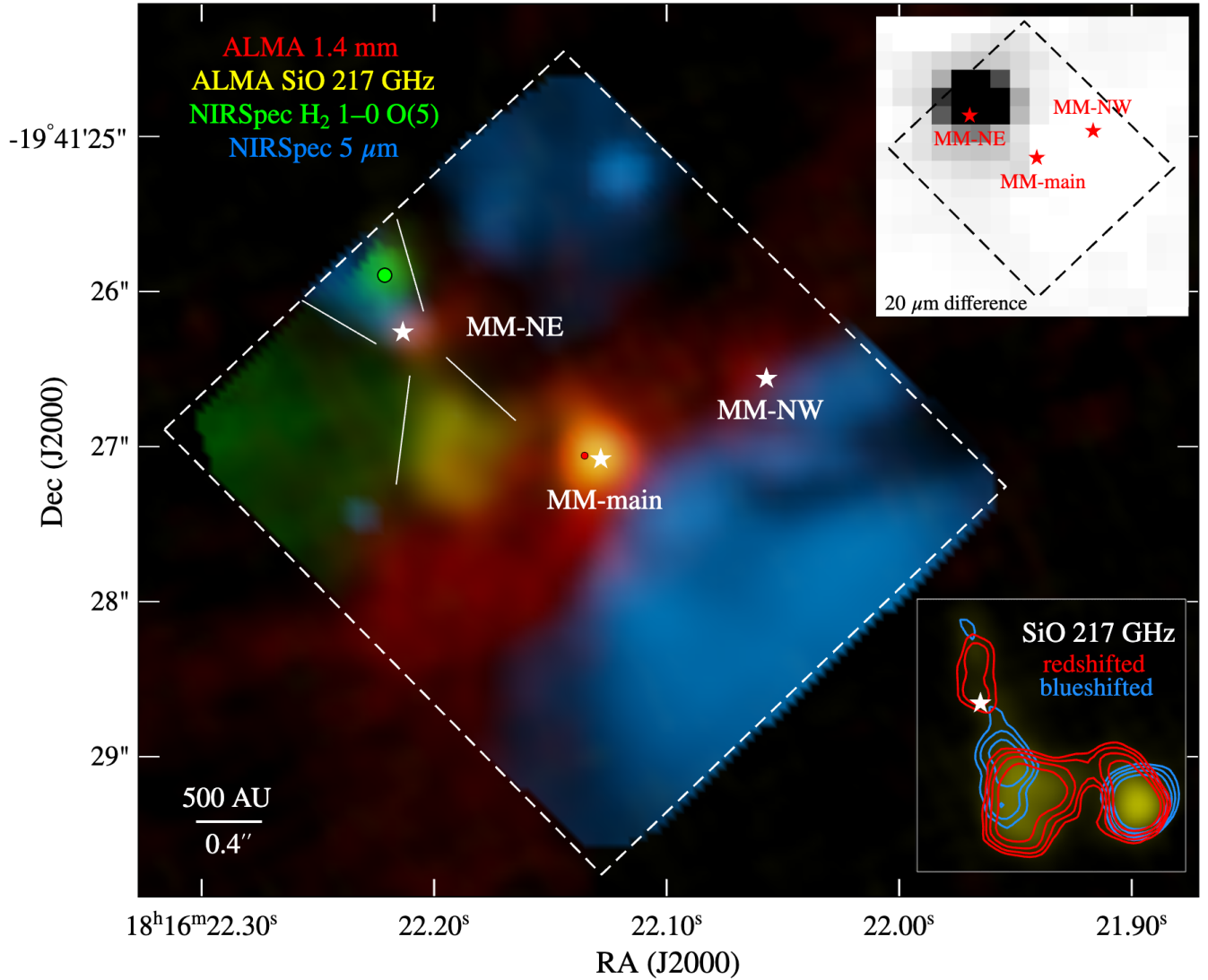


Figure 1. Overview of the IRAS 18134-1942 star-forming region from ALMA and JWST. ALMA dust continuum emission is shown in red. MM-main drives a wide-angle outflow traced by continuum emission at $5\mu\text{m}$ (light blue). MM-NE drives a separate outflow, also visible at $5\mu\text{m}$ and traced by SiO emission (yellow), with white lines indicating its approximate opening angle. A shock knot associated with MM-NE’s outflow is detected in H_2 (green dot). Extended H_2 emission traces the surrounding PDR (green). The red dot indicates the position of the flaring CH_3OH maser cluster¹⁶. The upper inset presents a $20\mu\text{m}$ continuum difference image between the two JWST epochs, showing that MM-NE is the only variable source in the field of view (FoV). The lower inset shows SiO blue- and redshifted emission around MM-NE in contours. The dashed rectangles outline the NIRSpect FoV.

evidence of fragmentation, with another mm condensation identified within the filament (MM-NW). To the northeast of MM-main, at a projected distance of $1.45''$ (~ 1800 AU), we identify a lower-mass object (hereafter MM-NE) embedded in a dust condensation that appears distinct from the main filament hosting the primary source.

The datasets provided by the JWST near infrared spectrograph (NIRSpect) and mid infrared instrument (MIRI) and by ALMA allow us to distinguish the outflow activity in the cluster (see Methods). MM-main excites cm-wavelength continuum emission from an ionized jet or HII region¹⁶ and drives a wide-angle outflow, traced by the emission at $5\mu\text{m}$. ALMA imaging of the silicon monoxide (SiO) transition at 217.1 GHz reveals that MM-NE drives a collimated bipolar outflow, roughly aligned and physically

separated from the outflow of MM-main (in yellow in Fig. 1). A knot in this jet is observed as a bright emission spot in the molecular hydrogen (H_2) 1-0 O(5) line (in green). The complexity of the region is further enhanced by the presence of a photodissociation region (PDR), traced in Fig. 1 by the H_2 1-0 O(5) transition. This PDR is likely powered by a nearby, evolved massive star. Its strong ultraviolet radiation field excites emission in Polycyclic Aromatic Hydrocarbons (PAHs) and pumps the H_2 lines via fluorescence. This creates a diffuse component that overlaps with the shock-excited emission from the protostellar outflows.

Our investigation was triggered by the discovery of a methanol (CH_3OH) maser flare in the star-forming region. Monitoring the region with the single-dish Irbene 32-m radio telescope¹⁹ revealed that the 6.7 GHz CH_3OH maser began a rapid brightening in April 2023, reaching a peak flux density of ~ 200 Jy on 7 July 2023¹⁶. This monitoring showed that the flare was mostly confined to a spectral feature at a local standard of rest velocity of $v_{\text{LSR}} \approx 16.8 \text{ km s}^{-1}$, while other velocity components remained relatively quiescent (Extended Data Fig. 1). This selective excitation is inconsistent with the isotropic heating expected from a central accretion outburst, suggesting instead a directional radiative event or an external driver, such as a nearby companion²⁰. The maser activity provided a clear signature of an energetic event in the protostellar environment. Such flares are typically driven by an increase in the mid-infrared radiation field (20–30 μm) following an episodic accretion burst²¹.

Given the magnitude and rapid rise of the flare, we triggered Target of Opportunity programs with JWST, ALMA, and the *Very Large Array* (VLA) to pinpoint the driving source and investigate the impact of the radiation on the surrounding cluster. The JWST observations were executed in two epochs separated by 11 days: the first on 26 April 2023 and the second on 7 May 2023. ALMA observations were taken on 20 April 2023, 6 days before the first JWST epoch.

The high-resolution radio follow-up with VLA showed that the flaring maser spot is located $0.3''$ to the northeast of MM-main¹⁶, and we find that the outflow cavity of MM-NE is roughly oriented toward this location (Fig. 1). The JWST two-epoch dataset reveals that MM-NE is the only mid-infrared-variable source within the entire region (Fig. 1, inset). The JWST spectra of MM-main (Extended Data Fig. 2) do not show any flux change in either continuum or emission lines, and there is no significant change in MM-main’s mm line or continuum emission compared to pre-burst ALMA observations (Extended Data Table 1 and Extended Data Fig. 3).

In contrast, the JWST spectrum of MM-NE reveals the unmistakable signature of an accretion outburst, characterized by a flux increase in both continuum and emission lines (Fig. 2), all in concert with the brightening of the CH_3OH maser near MM-main. We measure an increase in the mid-infrared continuum ($16 \mu\text{m} < \lambda < 27.5 \mu\text{m}$) of $\sim 30\%$ between the two epochs. Superimposed on the continuum, we detect emission lines probing distinct physical components of the system. We identify emission from the CO fundamental band ($v=1-0$), H_2 transitions, including both pure rotational lines (e.g., 0-0 S(1)–S(8) in MIRI) and rovibrational (1-0 and 2-1) transitions, and molecules such as water (H_2O), sulfur dioxide (SO_2), and methane (CH_4). The detection of the Pf γ and Br α lines of atomic hydrogen (H I) at 3.74 and 4.05 μm (see Methods) confirms the presence of hot gas in the accretion flows close to the protostar. No other strong H I lines at longer wavelengths (e.g. Pf α at 7.47 μm or Hu α at 12.37 μm) are detected in the spectrum, suggesting that the observed lines are seen in scattered light and that the disk geometry is almost edge-on (see Methods).

The jet knot observed in the H_2 1-0 O(5) line, located at a projected distance of ~ 500 AU from MM-NE, can be regarded as a record of the mass-loss history, reflecting the ejection properties of the protostar during a previous phase of activity. From the analysis of the JWST spectra of this knot and ALMA sulfur monoxide (SO) data, we estimate that MM-NE drives an outflow with a mass ejection rate of $\sim 0.3\text{--}7.1) \times 10^{-7} M_{\odot} \text{ yr}^{-1}$ (see Methods). Based on a stellar mass of 0.45–1.45 $M_{\odot}$ (see Methods)

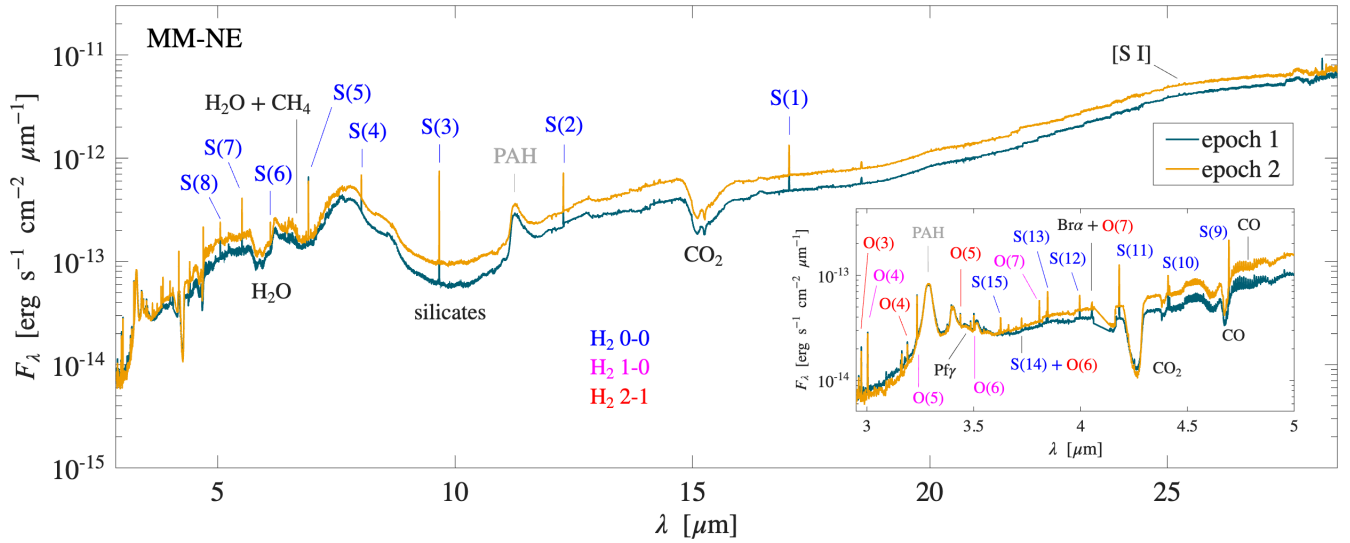


Figure 2. Spectral evolution of the outbursting source. The JWST/NIRspec+MIRI spectra of MM-NE exhibit a pronounced continuum variation between the two epochs. The mid infrared spectrum displays a rich set of emission lines associated with accretion, most notably a huge number of transitions from H₂O and CH₄ at $\sim 6.2 - 8 \mu\text{m}$. The inset zoom shows the region between ~ 3 and $5 \mu\text{m}$, highlighting emission in the H I P γ and Br α lines, CO fundamental band, and high-excitation H₂ transitions.

and a typical protostellar radius of $R_\star \sim 3-5 R_\odot$, we derive an accretion luminosity (L_{acc}) of $\sim 1-100 L_\odot$ before the outburst, compatible with a typical quiescent state²².

By integrating the de-reddened spectral energy distribution from near-infrared to millimeter wavelengths, we quantify the energetics of the accretion burst (see Methods). We measure an accretion luminosity of $L_{\text{acc}} \approx 730 L_\odot$ in the first epoch, which increases to $L_{\text{acc}} \approx 920 L_\odot$ in the second epoch. These values are nearly one order of magnitude higher than the estimated L_{acc} in quiescence, and correspond to a mass accretion rate of $\dot{M}_{\text{acc}} \approx (0.5-3.2) \times 10^{-4} M_\odot \text{ yr}^{-1}$. Notably, the JWST observations were taken ~ 2 months before the burst maximum (Extended Data Fig. 1, inset), suggesting that $\dot{M}_{\text{acc}}$ should be significantly higher at the peak of the flare.

Our two-epoch JWST spectra reconstruct, with unprecedented detail, the complex physical and chemical response of the protostellar system to the accretion burst, revealing a dynamic environment where different structural components are processed by the radiation pulse.

The most immediate evidence of this response is found in the $6.2-7.8 \mu\text{m}$ spectral region, which displays a dense forest of rovibrational emission lines from the H₂O ν_2 bending mode, the SO₂ ν_3 asymmetric stretching mode, and the CH₄ ν_4 asymmetric bending mode (Fig. 3). Given the high upper levels of these transitions ($E_{\text{up}} \approx 2000 - 3000 \text{ K}$), these lines are likely formed in the inner gaseous disk, within the dust sublimation radius ($r_{\text{sub}} \approx 0.7-1 \text{ AU}$, see Methods)²³⁻²⁶. Comparison of the continuum-subtracted spectra reveals a significant variability in the line fluxes over the 11-day baseline (Fig. 3). This rapid response, which follows the increase in luminosity, suggests that the inner gaseous disk is heated during the outburst.

While H₂O traces the rapid thermal evolution of the inner disk during the burst, the CO and H₂ lines, which trace the outflowing gas²⁷, remain remarkably constant in flux between the two epochs (Extended Data Fig. 5). Consistently, we detect no variability in the [S I] line at $25.2 \mu\text{m}$, another diagnostic of outflow activity. This discrepancy suggests that the impact of the burst has not yet propagated to the larger-scale outflow. In the high-mass protostellar outburst of S255IR NIR3¹², a significant time-lag (~ 1 year) was observed between the peak of the accretion burst and the subsequent ejection event²⁸. Similarly, the stability of the molecular and atomic emission in MM-NE indicates that our JWST observations capture

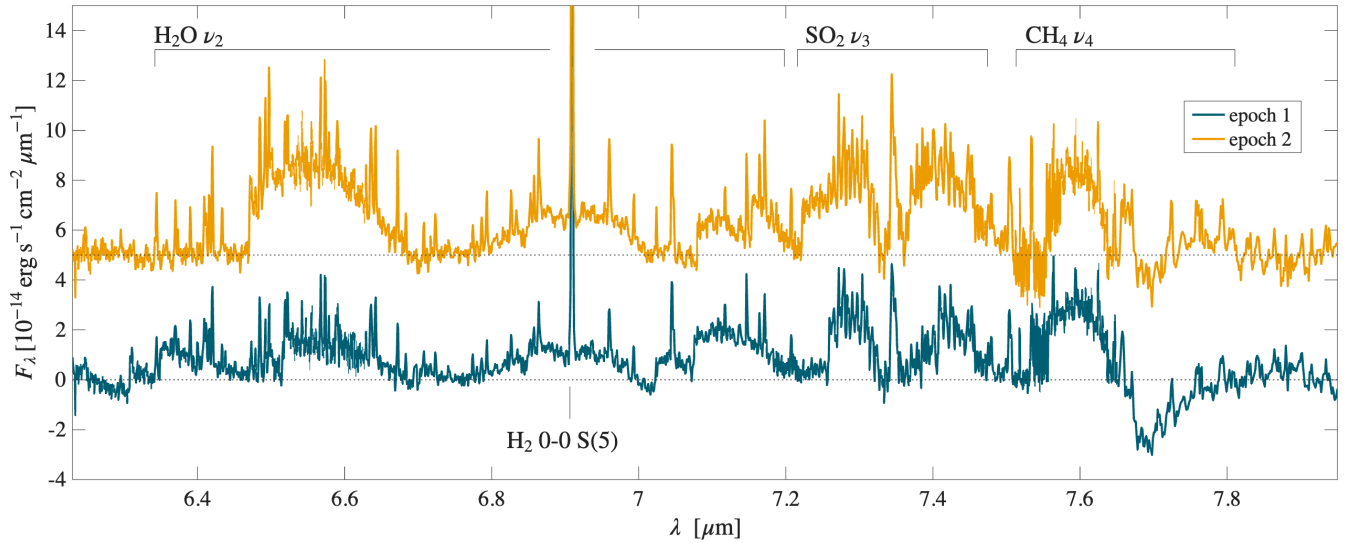


Figure 3. Variability of the hot molecular gas in the outburst. Continuum-subtracted JWST/MIRI spectra of MM-NE in the 6.3–7.9 μm region. The spectrum is dominated by a forest of rovibrational water (H_2O), sulfur dioxide (SO_2), and methane (CH_4) emission lines, originating from hot, dense gas in the innermost disk regions.

the system in the very early stages of the outburst, before the enhanced mass-loss rate has had sufficient time to re-collimate into a coherent outflow.

The burst impact also extends to the silicates and ices, tracing the thermal response of the circumstellar material across different spatial scales. The dereddened spectra (see Methods) reveal a prominent silicate emission feature in the $\sim 8 - 12 \mu\text{m}$ range, whose intensity increases between the two epochs (Fig. 4, left). While a large fraction of the dust resides in the extended and cold envelope, silicates can survive up to sublimation temperatures of $\sim 1500 \text{ K}$ ²⁹, meaning that a significant component is located in the inner dusty disk close to the star. As the outburst proceeds, the heating of this dust leads to enhanced emission. The profile of the flux difference between the two epochs is indicative of the crystallization of amorphous silicates, a phenomenon triggered by the thermal annealing of the inner disk and previously reported in other bursting young stars^{30;31}. In particular, the spectral shape is characteristic of a contribution from forsterite, the magnesium-rich form of olivine, showing two peaks at $\sim 10 \mu\text{m}$ and $11.2 \mu\text{m}$ ^{32;33}.

In contrast to the rapidly varying silicates, the ice features originating in the envelope exhibit a less pronounced evolution. This is traced by the splitting of the $15.2 \mu\text{m}$ CO_2 ν_2 bending mode (Fig. 4, right), a signature arising from resonant dipole-dipole coupling within pure crystalline CO_2 ³⁴. Its detection confirms that the outburst heated the CO_2 ice above the segregation temperature ($T \sim 30 - 50 \text{ K}$), forcing CO_2 molecules to separate from the amorphous H_2O matrix and organize into a crystalline lattice^{35;36}. The CO_2 crystallization radius (r_{cryst}) is expected to expand as the outburst evolves. Since $r_{\text{cryst}} \propto \sqrt{L_{\text{acc}}}$ (see Methods), this radius moves outward by approximately 12% between the two epochs. The subtle strengthening of the splitting substructure indicates an active CO_2 segregation at this expanding front, implying that the envelope has already received the luminosity pulse and is responding to the thermal wave. Since this phase transition is irreversible, the observed splitting constitutes a “thermal fossil” that records the energy released during the outburst.

This accretion outburst presents a consistent framework to explain the CH_3OH flare near MM-main. Our analysis of the radiative pumping conditions demonstrates that while MM-main provides the baseline radiation necessary to bring the existing maser cluster¹⁶ into a highly non-linear regime, it is the accretion burst of MM-NE that supplies the additional flux required to drive the flare (see Methods). The alignment of the outflow cavities of MM-main and MM-NE likely favors the escape of the mid-infrared radiation

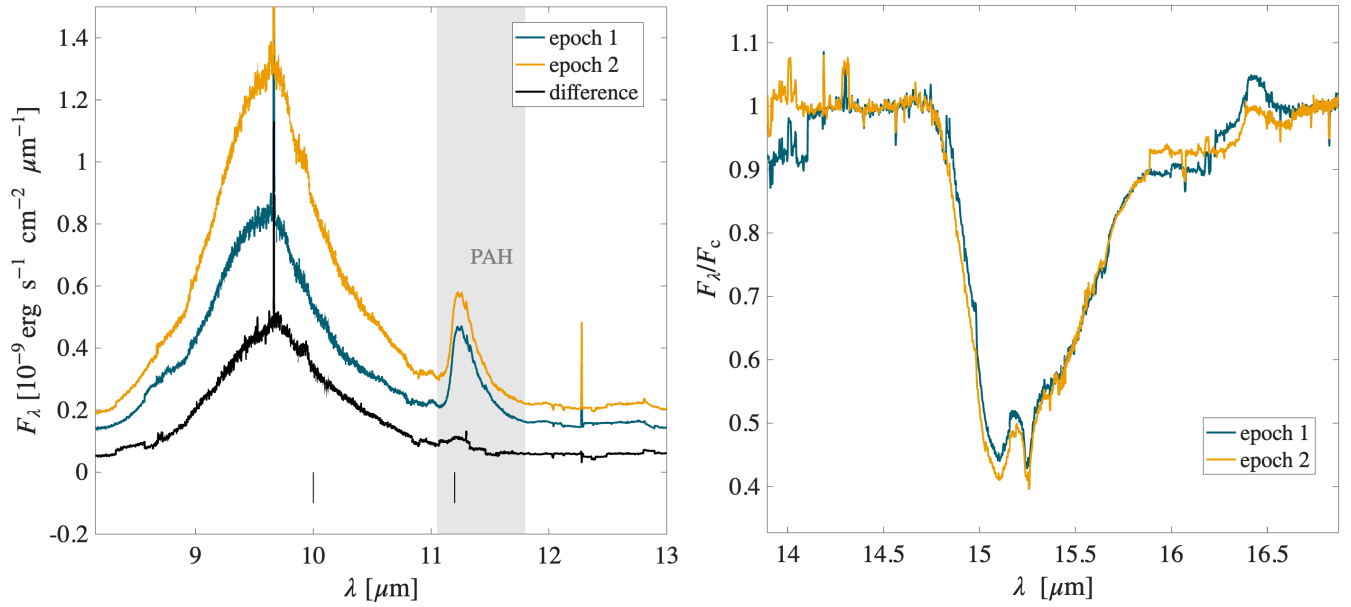


Figure 4. Evolution of the silicate emission and CO_2 ice absorption features. **Left:** dereddened spectra in the region between 8 and 13 μm , with the flux difference between the two epochs shown in black. The gray shaded area highlights the region contaminated by PAH emission, and the vertical ticks mark the expected peak positions for forsterite. **Right:** normalized flux (F_λ/F_c) covering the CO_2 ice absorption band ($\sim 14\text{--}16.5 \mu\text{m}$).

from MM-NE toward the flaring maser cluster located near MM-main. Most importantly, this geometric configuration provides a natural explanation for the selective triggering of an individual flaring maser cluster in crowded, complex environments around massive protostars³⁷.

Methods

Data reduction

The two-epoch JWST observations of IRAS 18134-1942 were obtained on 26 April 2023 and 7 May 2023 with the Near-Infrared Spectrograph (NIRSpec)³⁸ and the Mid-Infrared Instrument (MIRI) in Medium Resolution Spectroscopy (MRS) mode³⁹ (PID 1906, PI A. Caratti o Garatti). These instruments provide integral field spectroscopy with a combined wavelength coverage from 2.87 to 28.1 μm .

The NIRSpec observations were performed using the G395H/F290LP configuration, offering a field of view (FOV) of $3'' \times 3''$ and a spectral resolution of $R \approx 2700$ ($\Delta v \approx 110 \text{ km s}^{-1}$). At these wavelengths, NIRSpec achieves a spatial resolution of approximately $0.1''$. The MIRI/MRS observations consist of four simultaneous channels (Ch1–Ch4) with FOVs increasing from $3.2'' \times 3.7''$ to $6.6'' \times 7.7''$ as a function of wavelength. The MIRI spectral resolution varies between $R \approx 3500$ and 1500, while the spatial resolution scales from $\sim 0.25''$ at 5 μm to $\sim 0.8''$ at 28 μm .

The MIRI and NIRSpec data cubes were reduced using the JWST calibration pipeline with CRDS contexts `jwst_1298.pmap` (CRDS v11.18.4) and `jwst_1303.pmap` (CRDS v12.0.5), respectively. In both cases, all three pipeline stages were executed and complemented by additional custom processing to improve the data quality. These steps included exposure-level background subtraction (MIRI), correction of detector artifacts (warm pixels, cosmic rays, and NIRSpec detector noise), optimized outlier rejection during cube construction, and additional fringe corrections for the MIRI data. The resulting cubes are significantly cleaner and achieve higher signal-to-noise ratios than the standard MAST products.

ALMA observations of IRAS 18134-1942 were obtained on 20 April 2023 (PID 2021.1.00455.T, PI T. Hunter, “epoch 1”) using configuration C-6 with 45 antennas and an integration time of 33.3 min. Archival pre-burst data from 14 August 2022 (PID 2021.1.00095.S, PI L. Zhu, “epoch 0”) were taken in configuration C-5 with 46 antennas and an integration time of 3.5 min. Both datasets were calibrated using the standard ALMA pipeline in CASA⁴⁰.

For each epoch, a pseudo-continuum dataset was constructed using the line-free frequency ranges identified in the epoch 1 data, which are more sensitive to line emission. Manual phase and amplitude self-calibration was performed on each continuum dataset and applied to the respective line data. In addition to native-resolution and sensitivity epoch 1 images, we created epoch 0 and epoch 1 images closely matched in uv -coverage, angular resolution, and sensitivity to enable accurate quantitative comparison.

For these matched images, we restricted the imaging to a subset of epoch 1 visibilities that match the hour-angle coverage and short on-source integration time of epoch 0, using only visibilities from antenna pad baselines common to both configurations. A small alignment offset between epochs ($\sim 0.05''$ in RA, $\sim 0.01''$ in Dec) was corrected by fitting the positions of compact mm continuum sources in the field. Continuum images were convolved to a common $0.35''$ circular beam (rms noise ≈ 0.31 – $0.32 \text{ mJy beam}^{-1}$); line cubes were imaged with a channel width of 1.35 km s^{-1} , the epoch 0 spectral resolution, and convolved to a common $0.40''$ circular beam. All measurements were performed on primary-beam-corrected images and we assume a standard 10% absolute flux calibration uncertainty.

ALMA 1.4 mm continuum sources

To characterize the positions and deconvolved spatial extents of compact mm-emission sources within the NIRSpec field of view, we performed two-dimensional Gaussian fitting on the native-resolution epoch 1 ALMA continuum image (Figure 1; Extended Data Table 1). For MM-NE and MM-NW, a simultaneous two-component fit was used to represent more extended emission and the compact source.

To search for flux variations associated with the outburst, we compared the matched epoch 0 and epoch 1 continuum images. We measured the integrated flux densities of MM-main and MM-NE using

three independent approaches: two-dimensional Gaussian fitting (Extended Data Table 1), and integration within the respective 5σ (MM-NE) and 20σ (MM-main) contours defined in both epochs. All methods confirm that no significant change in the mm flux density occurred for either source. Given that the mid-infrared flux increase of MM-NE between the two JWST epochs is modest (30%), the lack of a detectable millimeter counterpart is expected, as mid-infrared emission responds more strongly and steeply to an accretion burst than the millimeter continuum, which is on the Rayleigh-Jeans portion of the SED.

Integrated Intensity Maps

Figure 1 presents a multi-wavelength composite view of the region, combining ALMA high-resolution millimeter data with JWST infrared integral field spectroscopy. To trace the shocked structures of the system at high spatial and spectral resolution ($\Delta v = 0.35 \text{ km s}^{-1}$), integrated intensity (moment 0) maps of the silicon monoxide (SiO) $J = 5 \rightarrow 4$ transition at 217.105 GHz were computed for the blue- and redshifted emission at $6.25 - 8.35 \text{ km s}^{-1}$ and $11.85 - 17.45 \text{ km s}^{-1}$, respectively. Figure 1 contour levels are 5, 7, 10, and 15 times the rms. Similar moment maps were constructed for the 219.949 GHz transition of SO $J = 6 \rightarrow 5$ which shows similar extended spatial morphology. The spatial coincidence of red and blue shifted outflow components SE of MM-NE (Fig. 1, inset) is suggestive of an outflow that lies nearly in the plane of the sky.

The infrared moment 0 maps were extracted from the JWST NIRSpec spectral cubes of epoch 1 (26 April 2023). The emission in the H_2 1–0 O(5) line at $3.23 \mu\text{m}$ (green) was extracted by performing a pixel-by-pixel continuum subtraction. The NIR continuum emission (light blue) was extracted by averaging the spectrum between 5 and $5.1 \mu\text{m}$. The continuum difference image shown in the inset was constructed by subtracting the MIRI Channel 4 Short cube of epoch 1 from epoch 2, after averaging the spectrum between 19 and $20 \mu\text{m}$.

Properties of MM-NE from ALMA millimeter line emission

The ALMA CH_3CN ($J = 12 \rightarrow 11$) emission from the positions of MM-main and MM-NE (Extended Data Table 2) was inspected for time variability between epochs 0 and 1 using the cubes with matched uv-coverage and resolution. Spectral comparisons (Extended Data Fig. 3) show no variations toward MM-main, but reveal tentative variability in the $K=3$ component toward MM-NE. However, low line sensitivity in epoch 0 precluded quantitative constraints.

From the more sensitive ALMA epoch 1 data with its full uv-coverage and spatial resolution ($0.23''$), we find eight molecular transitions that are sufficiently strong (and unblended) for independent spectral fitting and show compact emission toward MM-NE (3 transitions of CH_3OH , 2 transitions of H_2CO , 1 transition of HC_3N , and the $K=2$ and 3 transitions of CH_3CN). These transitions, with E_{up} ranging from 30 to 374 K, reveal three distinct velocity components centered at 8.4 ± 0.2 (blue-shifted), 10.7 ± 0.2 (systemic), and $13.0 \pm 0.3 \text{ km s}^{-1}$ (red-shifted), with line widths of 2.5 ± 0.4 , 2.2 ± 0.4 , and $2.1 \pm 0.8 \text{ km s}^{-1}$, respectively (Extended Data Fig. 4).

The lack of clear spatial velocity gradients leaves two interpretations open. To constrain both scenarios, we performed 2D Gaussian fits to the moment-0 maps integrated over the full velocity range of the eight transitions, bounding the emission size to a major axis of $0.25''$ (4σ , similar to the beam size) and a minor axis of $0.13''$ (2σ). In the first scenario, the red- and blue-shifted components arise from spatially unresolved, entrained gas near the base of MM-NE's outflow, while the underlying disk emission remains kinematically unresolved. From the line width of the systemic component and using the fitted size⁴¹, we estimate a virial mass of $0.6 \pm 0.2 M_{\odot}$. In the second scenario, the red and blue velocity components could trace the peak rotation velocity of gas in both the disk and base of the outflow. Keplerian rotation yields an enclosed mass of $1.3 \pm 0.4 M_{\odot}$. Both mass estimates incorporate a correction factor for a 60°

inclination, which is consistent with the observed ratio of the mean fitted major to mean minor axes. We adopt the simple average of these two estimates ($0.95 \pm 0.50 M_{\odot}$, where the uncertainty represents the standard deviation) as our final mass for MM-NE.

JWST spectral extraction

Due to the deeply embedded nature of the sources, the mid-infrared emission partly arises from stellar light scattered within the outflow cavities, causing wavelength-dependent spatial offsets relative to the ALMA millimeter cores. To account for this, the JWST continuum extraction was centered on the $15 \mu\text{m}$ continuum peak for both MM-main and MM-NE, using a circular aperture that scales with the telescope diffraction limit to maximize the collection of scattered light. The resulting spectra are presented in Extended Data Fig. 2 and Fig. 2 for MM-main and MM-NE, respectively.

For the quantitative analysis of the accretion tracers, spectra were extracted using fixed circular apertures centered on the 1.4 mm ALMA protostellar positions ($r = 0.25''$ for MM-main and $r = 0.15''$ for MM-NE) to avoid cavity contamination and account for the higher extinction towards the protostar. A separate spectrum was extracted for the jet knot located northeast of MM-NE, using a fixed aperture with $r = 0.25''$ centered on the H_2 1–0 O(5) emission peak.

Foreground diffuse PDR emission was subtracted line-by-line using reference spectra extracted from adjacent regions with matching background brightness contours in the H_2 1–0 O(5) line, using $r = 0.25''$ for MM-main and the knot, and $r = 0.15''$ for MM-NE. All extraction coordinates and radii are summarized in Extended Data Table 2.

Jet and outflow of MM-NE

To constrain the nature of the driving source, we analyzed the H_2 emission from the jet knot at a projected distance of ~ 500 AU from MM-NE. To isolate the intrinsic knot emission, we extracted a PDR reference spectrum from an adjacent region and performed a line-by-line background subtraction; transitions dominated by the PDR (the low-energy 0–0 S(1)–S(4) lines and all $v = 2$ transitions) yielded negative residuals and were excluded.

The resulting Boltzmann diagram^{42;43} exhibits a systematic offset between the 0–0 and 1–0 transitions, a signature of differential extinction. Using an infrared extinction law⁴⁴ and assuming LTE with a fixed ortho-to-para ratio (OPR = 3), a single-temperature fit yields $T = 2860 \pm 50$ K and $A_K = 8.9 \pm 0.3$ mag (Extended Data Fig. 6). From the fit we derived a hot gas column density $N_h = 1.3 \times 10^{19} \text{ cm}^{-2}$. The total mass of the knot was computed as $M_{\text{knot}} = \mu m_{\text{H}} N_h \pi R^2 = 2 \times 10^{-6} M_{\odot}$, where m_{H} is the atomic hydrogen mass and R is the radius of the knot, and we assumed a mean molecular weight $\mu = 2.8$ and an angular radius of $0.25''$ at a distance of 1.25 kpc.

The dynamical timescale was estimated as $\tau_{\text{dyn}} = R/v_{\text{jet}}$, assuming that the knot length is equal its radius. Since the radial velocities observed in the H_2 and SiO 217 GHz lines are only $\sim 10 \text{ km s}^{-1}$, the outflow likely lies nearly in the plane of the sky. Typical jet velocities in such systems are, indeed, an order of magnitude higher^{22;45;46}. Using $v_{\text{jet}} = 10 \text{ km s}^{-1}$ we obtained $\tau_{\text{dyn}} \approx 148 \text{ yr}$ and $\dot{M}_{\text{out}} = M_{\text{knot}}/\tau_{\text{dyn}} = 1.4 \times 10^{-8} M_{\odot} \text{ yr}^{-1}$. Accounting for the unconstrained jet velocity and a cooler dominant column density component ($T < 1000$ K, $N_h/N_w \sim 1\text{--}10\%$), we adopt a conservative range of $\dot{M}_{\text{out}} \approx 10^{-8}\text{--}10^{-7} M_{\odot} \text{ yr}^{-1}$.

We also estimated $\dot{M}_{\text{out}}$ from the ALMA SO $6_5 \rightarrow 5_4$ ($E_{\text{up}} \approx 35$ K) emission, assuming optically thin emission and LTE⁴⁷ at $T = 25$ K⁴⁸, and an SO abundance of $(1.2\text{--}5.2) \times 10^{-7}$ ^{49;50}. We use SO rather than SiO due to the large uncertainty in the SiO fractional abundance⁵¹. The northern and southern outflow lobes each include both blue- and redshifted SO emission, integrated respectively over $6.15 - 9.65 \text{ km s}^{-1}$ and $11.75 - 17.35 \text{ km s}^{-1}$. The northern lobe yields $\dot{M}_{\text{out}} \approx (0.2\text{--}1.0) \times 10^{-4} M_{\odot}$, $\tau_{\text{dyn}} \approx 750 \text{ yr}$, and $\dot{M}_{\text{out}} \approx (0.3\text{--}1.4) \times 10^{-7} M_{\odot} \text{ yr}^{-1}$; the southern lobe yields $\dot{M}_{\text{out}} \approx (0.2\text{--}1.1) \times 10^{-3} M_{\odot}$, $\tau_{\text{dyn}} \approx 1500 \text{ yr}$,

and $\dot{M}_{\text{out}} \approx (1.6\text{--}7.1) \times 10^{-7} M_{\odot} \text{ yr}^{-1}$. The different timescales reflect two outflow components: a fast compact shock (H_2 knot) and a slower, possibly entrained component (SO). Given the large uncertainties associated with column density corrections for the H_2 gas, the SO emission provides a more robust tracer of the total mass in the outflow.

Assuming a mass accretion-to-ejection ratio of $\sim 10^{52;53}$, the SO outflow rates yield $L_{\text{acc}} = GM_{\star}\dot{M}_{\text{acc}}/R_{\star} \sim 1\text{--}100 L_{\odot}$ for a protostar with our estimated mass and $R_{\star} = 3\text{--}5 R_{\odot}$, which marks the typical quiescent state of MM-NE. Notably, similar $\dot{M}_{\text{acc}}$ and L_{acc} values are found in low-mass protostars^{22;43}.

Extinction determination

We determined the K -band extinction (A_K) toward both the MM-NE outflow cavity and the protostellar core using H_2 Boltzmann diagrams, after subtraction of the PDR emission (see subsection Jet and outflow of MM-NE). For the cavity, a single-temperature fit with fixed OPR = 3 yielded $A_K = 14.3 \pm 0.5$ mag. The protostellar core required a two-temperature fit that yielded $A_K = 18.9 \pm 0.7$ mag.

MM-main displays a similarly high degree of obscuration. In its extended cavity, the PDR-subtracted H_2 Boltzmann diagram yielded $A_K = 18.7 \pm 0.5$ mag ($A_V \approx 146$ mag). On-source, the much higher dust column density heavily suppresses the intrinsic H_2 emission below the residual background fluctuations, preventing a reliable Boltzmann diagram construction. This non-detection confirms that the protostellar core is significantly more embedded than its surrounding cavity.

Accretion luminosity from emission lines

To quantify L_{acc} , we analyzed the $\text{H I Pf}\gamma$ ($3.74 \mu\text{m}$) and $\text{Br}\alpha$ ($4.05 \mu\text{m}$) recombination lines from the spectra extracted at the positions of the protostellar cores. Line fluxes were derived via Gaussian fitting; where the signal-to-noise ratio was sufficient to resolve the blending with the H_2 2–1 O(7) transition, a double-Gaussian fit was applied to isolate the $\text{Br}\alpha$ component.

Line luminosities ($L_{\text{Pf}\gamma}$ and $L_{\text{Br}\alpha}$) were computed adopting a distance of 1.25 ± 0.05 kpc and correcting the observed fluxes using the extinction law⁴⁴ and the values of A_K derived from the H_2 diagrams ($A_K = 18.9$ mag for MM-NE and $A_K = 18.7$ mag for MM-main's cavity as a proxy). The estimated values of A_K likely represent lower limits, as the H_2 emission originates from the outflow cavity further away from the heavily obscured protostars. L_{acc} was calculated using its empirical relation with $L_{\text{Pf}\gamma}$ and $L_{\text{Br}\alpha}$ ⁵⁴. As the H I lines are likely seen in scattered light, the estimated L_{acc} values likely represent lower limits. The resulting accretion parameters, including L_{acc} , are summarized in Extended Data Table 3.

Accretion luminosity from spectral energy distribution

To independently estimate L_{acc} during the outburst of MM-NE, we reconstructed its spectral energy distribution (SED) using the JWST spectra in scattered light and the ALMA 1.4 mm continuum flux density from Extended Data Table 1. Integrating the SED yields the bolometric luminosity (L_{bol}) which, for a protostar in outburst, is approximately equal to L_{acc} . The JWST spectra were dereddened using $A_K = 14.3$ mag and directly integrated to compute the mid-infrared contribution ($\sim 390 L_{\odot}$ in epoch 1). As no far-infrared (FIR) high-resolution archival data exist for MM-NE, to account for the unobserved FIR-to-mm emission, we extrapolated the SED using a single-component modified blackbody model, $F_{\lambda} = CB_{\lambda}(T)(1 - e^{-\tau_{\lambda}})$, where the optical depth is $\tau_{\lambda} = (\lambda_0/\lambda)^{\beta}$ and the dust emissivity index was fixed to a typical value of $\beta = 1.5$ ^{55;56}. The model was anchored to the ALMA data point, leaving the temperature (T) and transition wavelength (λ_0) as free parameters. The best-fit model for the epoch 1 spectrum is shown in Extended Data Fig. 7, and has $T = 106 \pm 6$ K and $\lambda_0 = 26 \pm 10 \mu\text{m}$. By summing the integrated JWST emission and the synthetic extrapolation, we obtained $L_{\text{bol}} \approx 730 L_{\odot}$ in epoch 1 and

$L_{\text{bol}} \approx 920 L_{\odot}$ in epoch 2. As epoch 2 data were taken during the rise of the accretion burst (i.e., ~ 2 months before its peak), we expect L_{bol} at maximum to be higher than $1000 L_{\odot}$.

These values likely represent lower limits, as a single-component model may not accurately reproduce the SED peak in the FIR, where the bulk of the emission is expected to emerge. This result introduces a significant discrepancy with the accretion luminosities derived from the HI lines, confirming that the HI lines are seen in scattered light and that the extinction measured toward MM-NE is likely a lower limit. Consequently, these more robust bolometric measurements are adopted as our definitive estimates for L_{acc} in the main text.

For MM-main, the same fit to the JWST spectrum dereddened with $A_K = 18.7$ mag resulted in $T = 121 \pm 2$ K and $\lambda_0 = 43 \pm 3 \mu\text{m}$, yielding $L_{\text{bol}} \approx 8500 L_{\odot}$, compatible with previous estimates⁵⁷.

Physics of the outburst

To reconstruct the physical response of the environment to the outburst, we investigated the different components of the system by analyzing specific molecular tracers.

Inner gaseous disk – H₂O and CH₄. We performed a continuum subtraction in the spectral region between 6.2 and 8 μm by selecting 16 anchor points across the 6.2–8 μm range, and fitting a 15th-order polynomial to these anchor points. The resulting continuum-subtracted spectra are presented in Fig. 3.

We analyzed a selection of unblended H₂O lines²⁶, which exhibit an average FWHM of $82 \pm 18 \text{ km s}^{-1}$ that remains consistent across both epochs. This value is below the MIRI instrumental resolving power (FWHM $\sim 93 \text{ km s}^{-1}$)²⁶, indicating that the lines are spectroscopically unresolved. Notably, these transitions have upper-level energies ranging from ~ 2300 to 3000 K, requiring high kinetic temperatures ($T \gtrsim 1000$ K) to be collisionally excited. This suggests that the water emission originates from hot gas in the innermost region of the disk.

Assuming that dust grains behave as blackbodies in thermal equilibrium with the central radiation, the sublimation radius during the outburst is given by $r_{\text{sub}} = [L_{\text{acc}} / (16\pi\sigma T_{\text{sub}}^4)]^{1/2}$. For an average $L_{\text{acc}} \approx 825 L_{\odot}$ and typical silicate sublimation temperatures of $T_{\text{sub}} \approx 1500$ – 1800 K, we derive $r_{\text{sub}} \approx 0.7$ – 1 AU. This spatial scale defines the dust-free inner disk and matches the typical radius where such highly excited, hot gaseous water lines are expected to form.

Inner dusty disk – silicates. The emission profile of the silicate feature (Fig. 4, left) was derived by dereddening the scattered-light spectra using $A_K = 14.3$ mag. The flux difference between the two epochs isolates the net emission produced during the outburst, and suggests the formation of forsterite (see main text). However, the potential simultaneous sublimation of the overlapping H₂O ice libration band (~ 11 – $16 \mu\text{m}$) and blending with the PAH emission at $11.2 \mu\text{m}$ complicate the isolation of the silicate profile and the precise determination of the dust composition.

Outflow – CO and H₂. To study the response of the outflow to the outburst, we analyzed the CO ro-vibrational spectrum and the H₂ line emission in the scattered-light spectrum of MM-NE. The spectra for both epochs were continuum-subtracted following a standard procedure²⁵, resulting in the non-variability observed in Extended Data Fig. 5.

Envelope – CO₂ ice. The profile of the CO₂ ice ν_2 bending mode (Fig. 4, right) was derived by normalizing the flux to the local continuum (F_c), which was estimated as a third-order polynomial fitted to four anchor points at 14.3, 14.5, 16.8, and 17.3 μm .

We estimated the radius where the dust temperature exceeds the segregation threshold for CO₂ ice by adopting a segregation temperature of $T_{\text{cryst}} = 50$ K, consistent with laboratory studies of pure CO₂ ice formation^{34;58}. Assuming that heating is dominated by the accretion luminosity, the crystallization radius can be approximated as $r_{\text{cryst}} \approx (L_{\text{acc}} / 16\pi\sigma T_{\text{cryst}}^4)^{1/2}$. Using the accretion luminosities derived from the SED, we obtain $r_{\text{cryst}} \approx 840$ AU and $r_{\text{cryst}} \approx 940$ AU for epoch 1 and epoch 2, respectively. The

light-travel time to this crystallization front is ~ 5 days, which is well within the 11-day temporal baseline of our JWST observations.

Maser excitation mechanisms

To identify the driving mechanism of the maser flare, we evaluate the radiative pumping conditions at the maser cluster site, located at RA = 18^h16^m22.15^s, Dec = −19°41′27.06″¹⁶.

The main CH₃OH maser flaring is concentrated within a localized velocity feature at $v_{\text{LSR}} = 16.8 \text{ km s}^{-1}$, which exhibits a complex light curve characterized by multiple secondary brightness peaks. Crucially, identical secondary peaks are detected in other maser features (specifically at $v_{\text{LSR}} = 7.4$ and 8.3 km s^{-1} , Extended Data Fig. 1) located in regions spatially distinct from the main flaring cluster. This spatial dissociation coupled with temporal coincidence rules out localized, small-scale density or temperature fluctuations, which would lack global coordination. Similarly, a collisional origin triggered by an ejection event from MM-main is excluded, as the propagation of a physical shock through the diverse maser sites would introduce measurable time delays. The absence of such delays confirms that the driving mechanism must be radiative. Given that MM-NE is identified by our two-epoch JWST observations as the only variable mid-infrared source in the field, its accretion outburst represents the only radiative trigger capable of synchronously pumping the different maser components.

The flux density of the 6.7 GHz flaring maser feature ($\sim 100 \text{ Jy}$, Extended Data Fig. 1) implies a brightness temperature $> 10^6 \text{ K}$, which requires pumping by dust heated to $T > 115 \text{ K}$ with dilution factors $W > 0.02$ ^{59;60}. Our SED fits confirm that MM-main provides the baseline radiation to sustain this excitation ($T = 121 \pm 2 \text{ K}$), placing the maser in a highly non-linear regime where a $\sim 2 \text{ K}$ dust temperature increase, corresponding to a $\sim 10\%$ increase in the flux at $20 \mu\text{m}$, drives an order-of-magnitude growth in maser brightness^{60;61}. Such a variation would be easily detectable in the JWST spectrum of MM-main, given that the absolute spectrophotometric calibration of MIRI/MRS is accurate to 3–5% and its epoch-to-epoch repeatability is stable to $\lesssim 1\%$ ⁶².

We propose that MM-NE acts as the radiative trigger for this 10% flux increment. To evaluate whether the contributions from MM-main and MM-NE can balance at this threshold, we model the flux density received at the maser site as $F = W \cdot I_{20\mu\text{m}}$, adopting $T = 121 \text{ K}$ for MM-main and $T = 115 \text{ K}$ for MM-NE to ensure optimal maser excitation conditions. The triggering condition is:

$$W_{\text{MM-NE}} \cdot I_{\text{MM-NE}} = 0.10 \cdot (W_{\text{MM-main}} \cdot I_{\text{MM-main}}). \quad (1)$$

From the accretion luminosity of MM-NE ($L_{\text{acc}} \sim 730 L_{\odot}$), its heated dust region extends to $r \approx (L_{\text{acc}}/4\pi\sigma T^4)^{1/2} \approx 316 \text{ AU}$. Adopting a conservative emitting radius of $R_{\text{MM-NE}} \approx 100 \text{ AU}$, the dilution factor at the maser cluster distance (1500 AU) is $W_{\text{MM-NE}} \approx 4.4\%$. Substituting this and the intensity ratio derived from the SED ($I_{\text{MM-main}}/I_{\text{MM-NE}} \approx 2.62$) into Eq. 1 yields $W_{\text{MM-main}} \approx 17\%$, consistent with the geometry once differential extinction in the outflow cavity of MM-main is taken into account. The observed flare can therefore be explained as driven by additional photons arriving less attenuated from the MM-NE outburst.

Data Availability

The JWST data used in this study are publicly available from the Mikulski Archive for Space Telescopes (MAST; <https://mast.stsci.edu>) under Proposal ID 1906. The ALMA interferometric data are accessible through the ALMA Science Archive (<https://almascience.org/asax/>) under Proposal IDs 2021.1.00095.S and 2021.1.00455.T. All other datasets generated or analyzed during the current study, including the JVN monitoring data, are available from AA upon request.

Code Availability

The data reduction and analysis of the JWST dataset were performed using MATLAB (MathWorks, Inc.) routines and processing scripts, and can be obtained from AA upon request. The data reduction and analysis of the ALMA dataset were performed using CASA and Python routines, and can be obtained from CC, RAG, CB, TH, DT, and ZsMS upon request.

Acknowledgments

This paper makes use of the following ALMA data: ADS/JAO.ALMA#2021.1.00455.T and ADS/JAO.ALMA#2021.1.00095.S. ALMA is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada), NSTC and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

This work is partially supported by the Inter-university collaborative project “Japanese VLBI Network (JVN)” of NAOJ and by the Japan Society for the Promotion of Science (JSPS) KAKENHI Grant Numbers JP21H01120 and JP21H00032. The JVN is led by the National Astronomical Observatory of Japan (NAOJ), which is a branch of the National Institutes of Natural Sciences (NINS), (Hokkaido University), the University of Tsukuba, Ibaraki University, Gifu University, Osaka Prefecture University, Yamaguchi University, and Kagoshima University, in cooperation with the Geospatial Information Authority of Japan (GSI), the Japan Aerospace Exploration Agency (JAXA), and the National Institute of Information and Communications Technology (NICT). We thank all staff members and students participating in the operation of JVN.

AA and ACG acknowledge support from PRIN-MUR 2022 20228JPA3A “The path to star and planet formation in the JWST era (PATH)” funded by NextGeneration EU and by INAF-GoG 2022 “NIR-dark Accretion Outbursts in Massive Young stellar objects (NAOMY)”, and by Large Grant INAF-2024 “Spectral Key features of Young stellar objects: Wind-Accretion LinKs Explored in the infraRed (SKYWALKER)”, and from the project “Space Observations of Proto-planetary Accretion Disc Evolution (SPADE)” in the framework of the “PROgramma di Ricerca Spaziale di base (PRORIS)”, financed by the Italian Ministry of University and Research (Ministero dell’Università e della Ricerca; MUR).

CJC and RAG acknowledge support from the STFC (grant ST/Y002229/1). DJT acknowledges financial support from STFC studentship ST/V507088/1 and Zs.M. S. acknowledges funding from a St. Leonards scholarship from the University of St. Andrews.

MGN acknowledges support from the European Union – NextGenerationEU, Mission 4, Component 2, Investment 1.2 (CUP C83C25000450006). MGN also acknowledges financial support from the project “Space Observations of Proto-planetary Accretion Disc Evolution (SPADE)” in the framework of the “PROgramma di Ricerca Spaziale di base (PRORIS)”, financed by the Italian Ministry of University and Research (Ministero dell’Università e della Ricerca; MUR).

Author contributions

AA, ACG, CC, and CB wrote the manuscript. MGN carried out the reduction of JWST/MIRI and NIRSpec datasets. AA and ACG carried out the analysis of the JWST data. CC, CB, TH, DT, RAG and ZsMS carried out the reduction and analysis of the ALMA data. AS and SP developed a model for the maser excitation mechanism. All authors participated in the discussion of the results and commented on the manuscript.

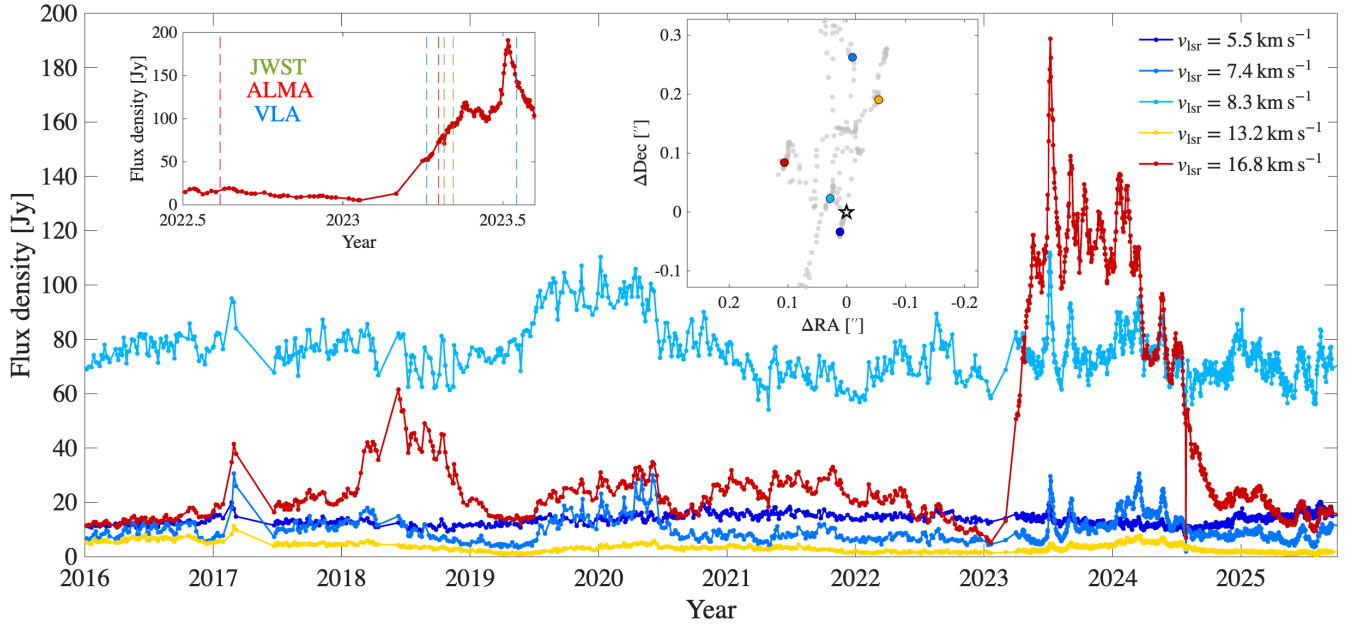
Competing Interests

The authors declare no competing financial interests.

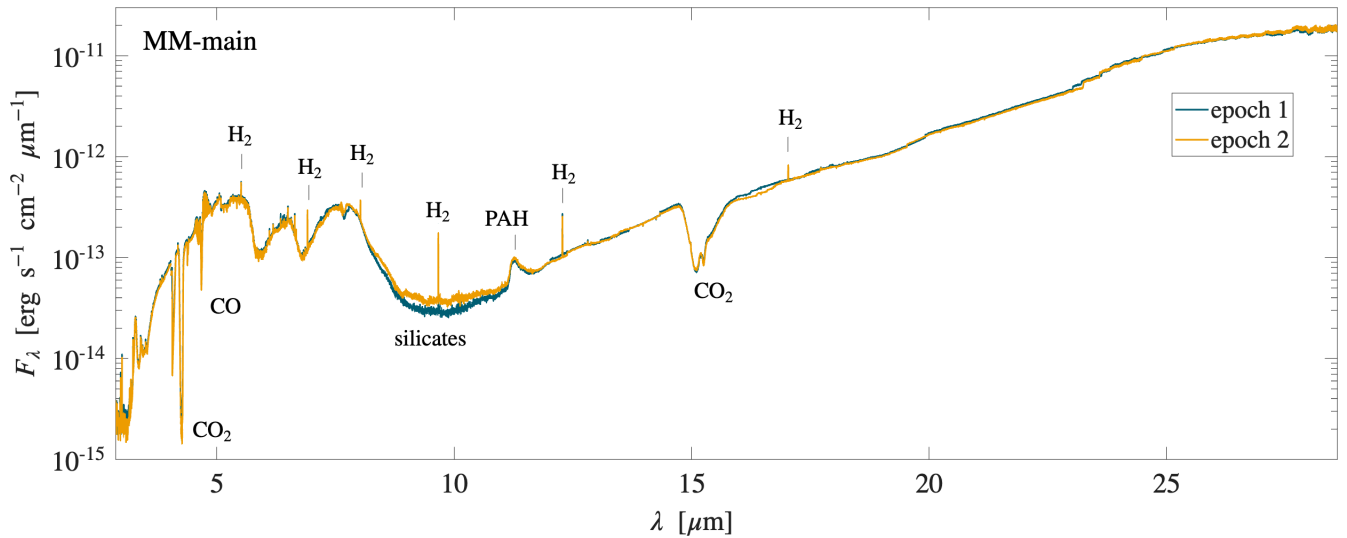
Additional Information

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Extended Data



Extended Data Figure 1. Light curve of the CH_3OH maser flare. The different colored lines show five distinct velocity components (v_{LSR}), with the 16.8 km s^{-1} component (red) exhibiting a flare starting in early 2023 and peaking at $\sim 200 \text{ Jy}$. Vertical lines in the left inset mark coordinated JWST, ALMA, and VLA triggered observations. The central inset displays the spatial distribution of epoch 2 VLA maser spots¹⁶, where the five components are highlighted using the color-coding of the main panel, with the other components in gray. These data were obtained as part of the iMet2 monitoring program using the Japanese VLBI Network (JVN).

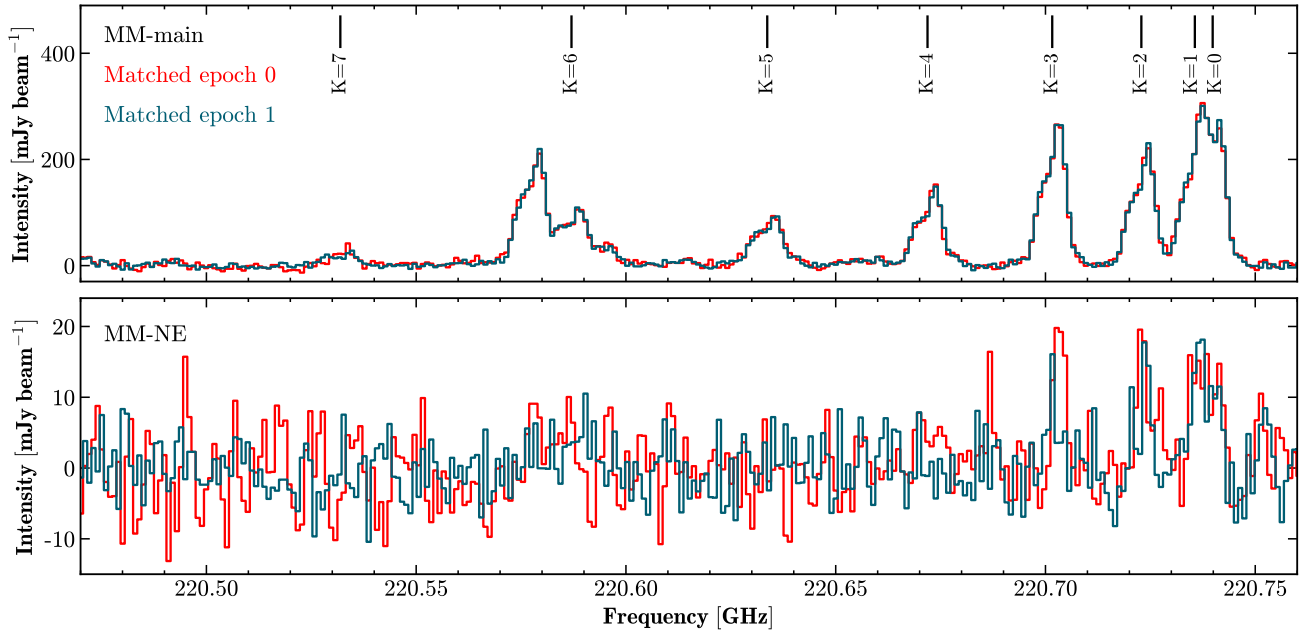


Extended Data Figure 2. Quiescent spectrum of the massive protostar. The JWST spectra of MM-main are characteristic of a deeply embedded source, dominated by deep silicate absorption at $9.7 \mu\text{m}$ and prominent ice absorption features.

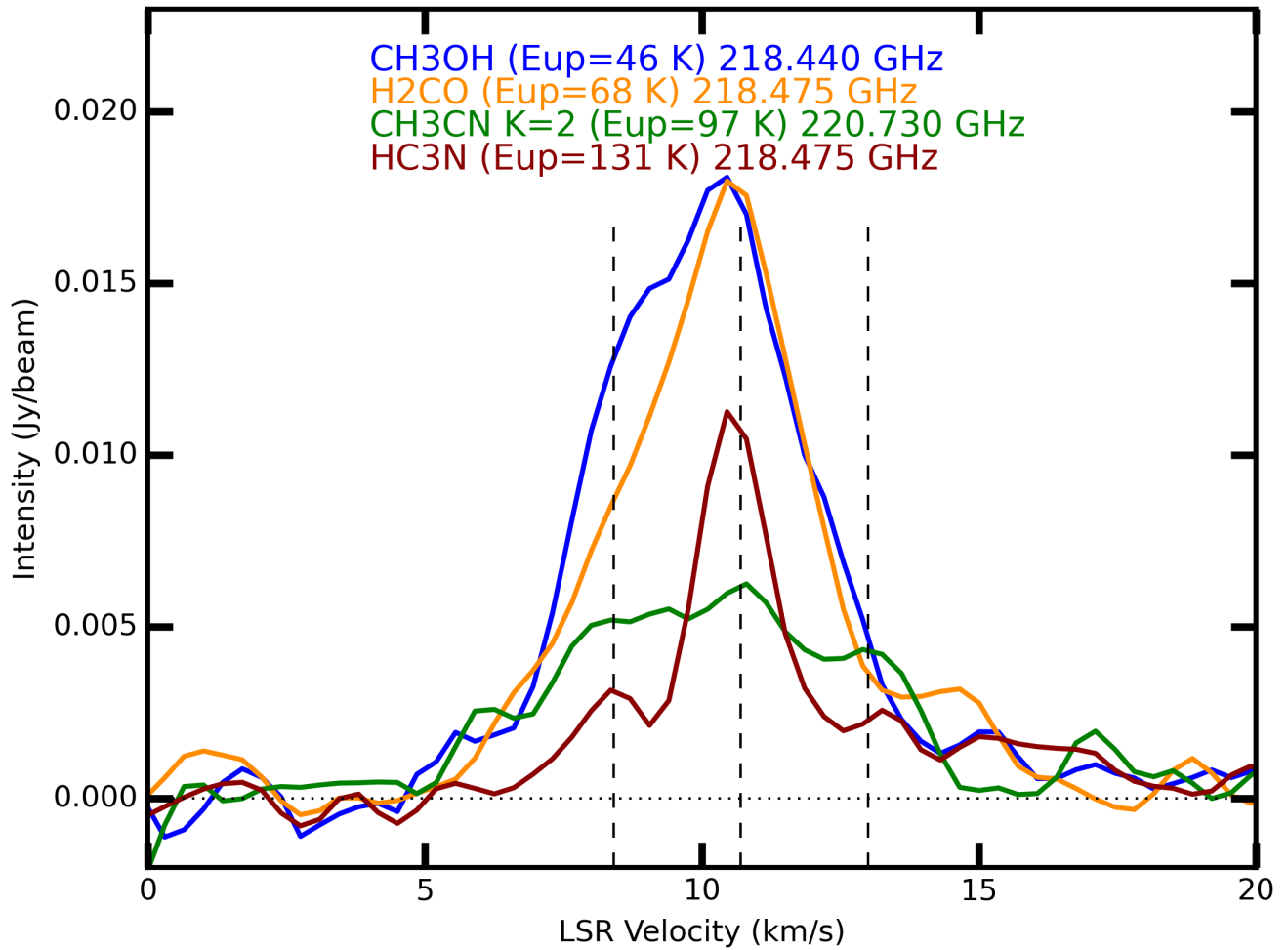
Extended Data Table 1. Positions, sizes, and millimeter flux densities of the compact 1.4 mm sources.

Source	Fitted Centroid (J2000)		Size "×" (PA °)	$F_{1.4\text{mm}}$ (mJy)	
	RA	Dec		epoch 0	epoch 1
MM-main	18 ^h 16 ^m 22.12844 ^s	−19°41′27.0782″	0.217 × 0.171 (173)	71 ± 7	68 ± 7
MM-NE	18 ^h 16 ^m 22.2135 ^s	−19°41′26.261″	< 0.23	6 ± 1	5.6 ± 0.9
MM-NW	18 ^h 16 ^m 22.057 ^s	−19°41′26.56″	0.56 × 0.28 (157)	—	—

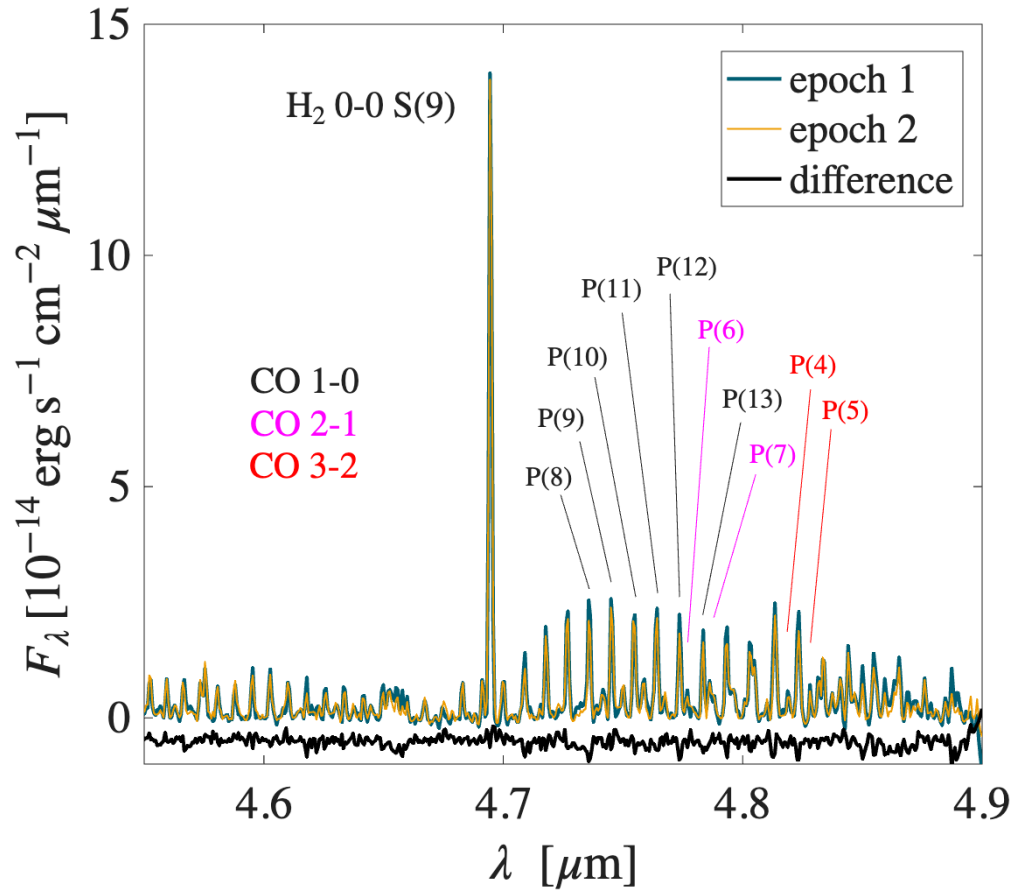
Positions and deconvolved spatial sizes are derived from the native-resolution epoch 1 ALMA continuum image. For MM-NE and MM-NW, parameters are characterized using a simultaneous two-component Gaussian fit to isolate the compact cores from surrounding extended emission. MM-NE was fitted as a point source, and the quoted size represents an upper limit corresponding to the geometric mean of the synthesized beam. Integrated flux densities ($F_{1.4\text{mm}}$) are measured from two-dimensional Gaussian fitting to the matched-resolution images; uncertainties are the formal fitting errors added in quadrature with a 10% absolute flux calibration uncertainty.



Extended Data Figure 3. ALMA $\text{CH}_3\text{CN } J = 12 \rightarrow 11$ spectra of MM-main and MM-NE. MM-main exhibits the strong hot-core line emission characteristic of embedded massive protostars, showing no significant temporal variations between epochs. MM-NE displays much weaker CH_3CN emission but tentative evidence of changes in the line profiles, most evident in the $k = 3$ component.



Extended Data Figure 4. ALMA epoch 1 MM-NE native resolution spectra for four molecular line tracers. The energy E_{up} and rest frequency for each molecular transition are shown in the legend. Three vertical dashed lines indicate the fitted velocities of the blue, systemic, and red spectral components.

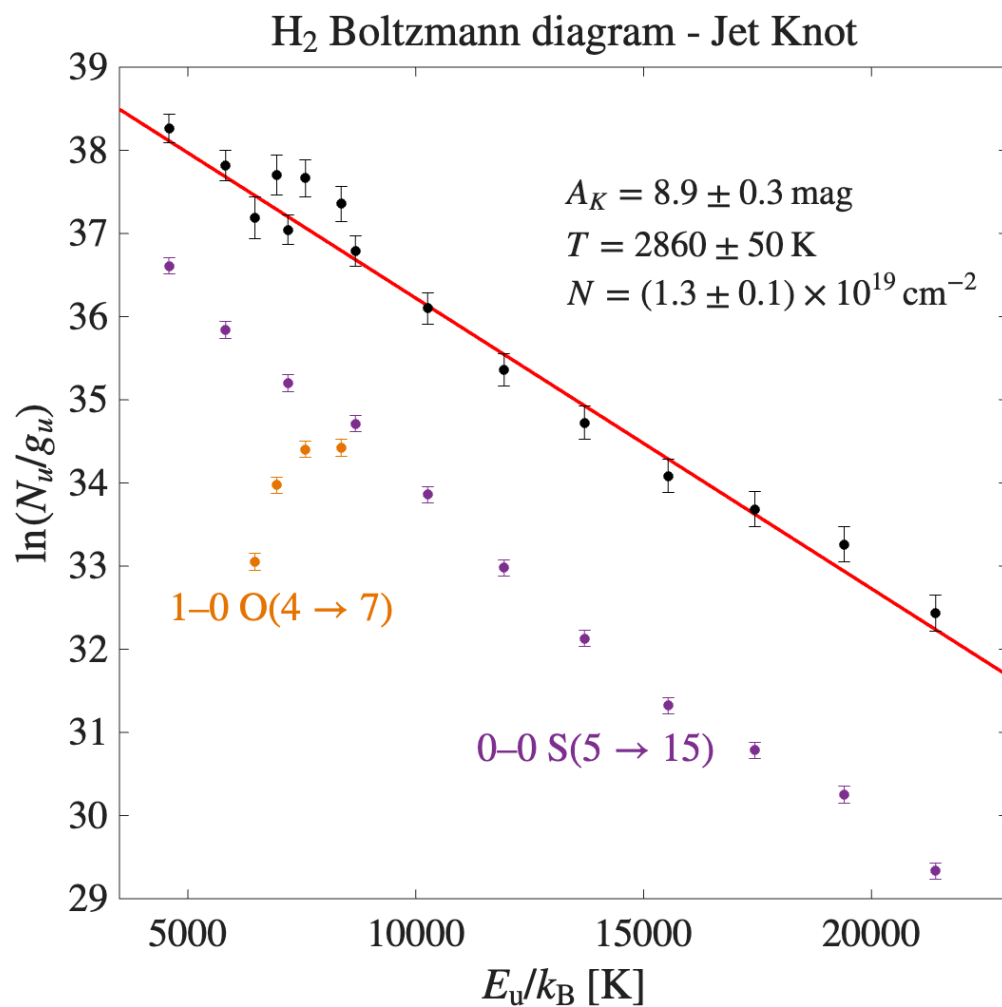


Extended Data Figure 5. Stability of the CO and H₂ emission. Continuum-subtracted spectra of the spectral region at $\sim 4.6\text{--}4.9 \mu\text{m}$ (see Methods). Unblended CO lines are marked, color-coded by vibrational transition. The difference spectrum is shown in black, shifted downwards by -0.5.

Extended Data Table 2. Coordinates and aperture radii for JWST spectral extractions.

Source/Component	RA (J2000)	Dec (J2000)	r	Reference
<i>Scattered-light spectra</i>				
MM-main	18 ^h 16 ^m 22.09 ^s	−19°41′27.47″	$r(\lambda)$	MIRI 15 μm peak
MM-NE	18 ^h 16 ^m 22.21 ^s	−19°41′26.07″	$r(\lambda)$	
<i>On-source spectra</i>				
MM-main	18 ^h 16 ^m 22.128 ^s	−19°41′27.078″	0.25″	ALMA continuum
MM-NE	18 ^h 16 ^m 22.214 ^s	−19°41′26.261″	0.15″	
Jet knot	18 ^h 16 ^m 22.221 ^s	−19°41′25.892″	0.25″	H ₂ 1–0 O(5) peak
<i>PDR spectra</i>				
PDR (MM-main ref.)	18 ^h 16 ^m 22.159 ^s	−19°41′27.704″	0.25″	H ₂ 1–0 O(5) contours
PDR (MM-NE ref.)	18 ^h 16 ^m 22.208 ^s	−19°41′27.117″	0.15″	
PDR (jet knot ref.)	18 ^h 16 ^m 22.215 ^s	−19°41′26.892″	0.25″	

The extraction strategies are detailed in the Methods. The aperture radius r (in ″) for the scattered-light spectra is defined as a function of wavelength λ (in μm) as $r(\lambda) = r_0 + \alpha(\lambda - \lambda_0)$, where $r_0 = 0.167''$, $\alpha = 0.027'' \mu\text{m}^{-1}$, and $\lambda_0 = 2.87 \mu\text{m}$.

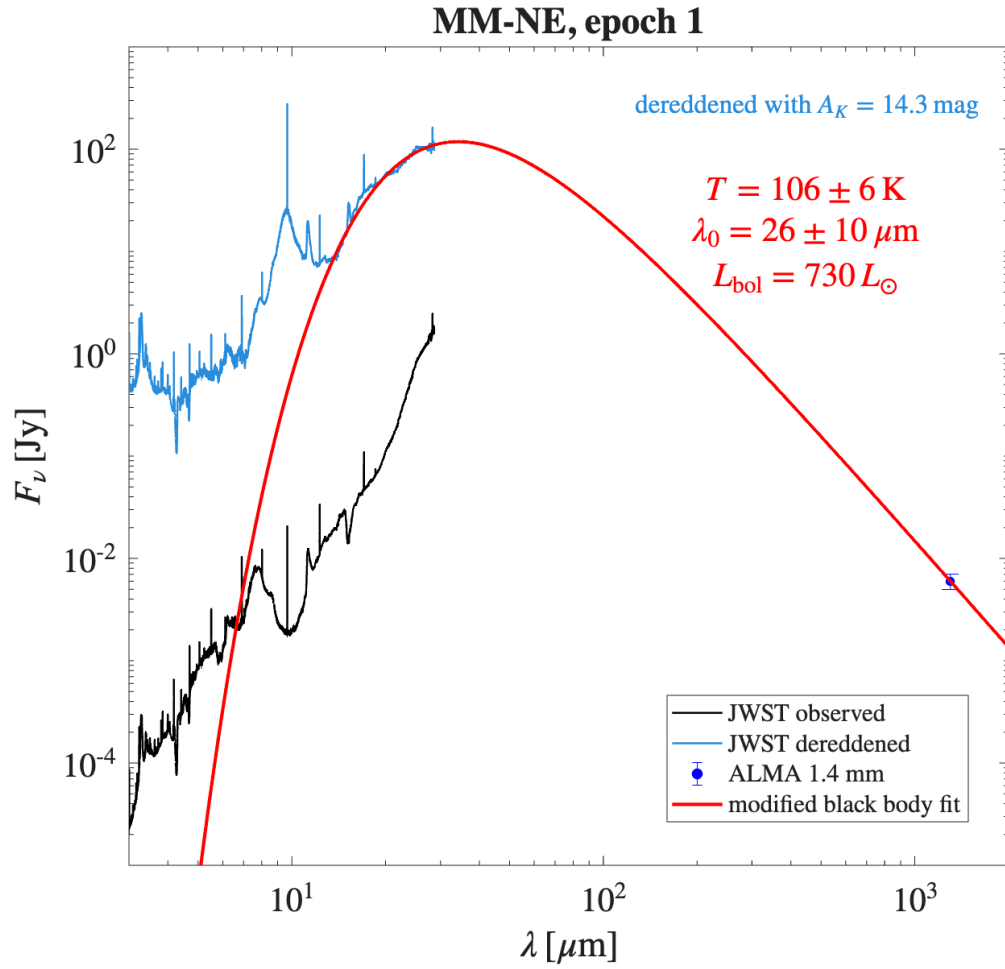


Extended Data Figure 6. H₂ Boltzmann diagram of the jet knot. The diagram was obtained by subtracting the contribution of the PDR. The red line represents the best-fit LTE model. The colored points are the observed values of $\ln(N_u/g_u)$, arbitrarily offset by +2, with the 0-0 lines in violet and the 1-0 (more extinguished) lines in orange.

Extended Data Table 3. Accretion properties derived from the H I P γ and Br α lines.

Line	F_{obs} (10^{-17} erg s $^{-1}$ cm $^{-2}$)	A_{λ}/A_K (mag)	L_{line} ($10^{-3} L_{\odot}$)	L_{acc} ($L_{\odot}$)
MM-main				
<i>epoch 1</i>				
Pf γ	<i>undetected</i>	11.4 ± 0.3	—	—
Br α	0.98 ± 0.21	10.6 ± 0.3	8.1 ± 2.2	69 ± 32
<i>epoch 2</i>				
Pf γ	0.28 ± 0.12	11.4 ± 0.3	4.9 ± 2.3	180 ± 120
Br α	1.23 ± 0.24	10.6 ± 0.3	10.2 ± 2.7	92 ± 41
MM-NE				
<i>epoch 1</i>				
Pf γ	0.48 ± 0.05	11.5 ± 0.3	9.4 ± 2.0	400 ± 170
Br $\alpha^{\dagger}$	1.45 ± 0.34	10.7 ± 0.3	13.4 ± 3.9	127 ± 60
<i>epoch 2</i>				
Pf γ	0.39 ± 0.07	11.5 ± 0.3	7.6 ± 2.0	310 ± 140
Br $\alpha^{\dagger}$	1.51 ± 0.08	10.7 ± 0.3	13.9 ± 2.6	134 ± 51

Uncertainties on L_{acc} propagate measurement errors on line fluxes, source distance, and empirical calibration coefficients. Values for MM-main represent lower limits due to the lack of a direct on-source extinction value. A_{λ}/A_K defines the relative extinction coefficient based on the extinction law. $\dagger$: Line flux derived via double-Gaussian profile fitting to deblend the Br α emission from the H $_2$ 2–1 O(7) line.



Extended Data Figure 7. Spectral energy distribution of MM-NE. The long-wavelength tail of the de-reddened JWST spectrum from epoch 1 and the ALMA Band 6 photometry are fitted with a modified black body, yielding a bolometric luminosity $L_{\text{bol}} = 730 L_{\odot}$.

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