C₂H, HC₃N and HNC observations in OMC–2/3 *

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Abstract For the first time, the OMC-2/3 region was mapped in C₂H (1–0), HC₃N (10–9) and HNC (1–0) lines. In general, the emissions from all the three molecular species reveal an extended filamentary structure. The distribution of C₂H cores almost follows that of the 1300 µm condensations, which might suggest that C₂H is a good tracer to study the core structure of molecular clouds. The core masses traced by HNC are rather flat, ranging from 18.8 to 49.5 M☉, while also presenting a large span for those from C₂H, ranging from 6.4 to 36.0 M☉. The line widths of both HNC and C₂H look very similar, and both are wider than that of HC₃N. The line widths of the three lines are all wider than those from dark clouds, implying that the former is more active than the latter, and has larger turbulence caused by winds and UV radiation from the surrounding massive stars.

Key words: ISM: abundances — ISM: individual (Orion Molecular Clouds) — ISM: molecules — stars: formation

1 INTRODUCTION

The Orion A molecular cloud, at a heliocentric distance of 450 pc (Genzel & Stutzki 1989; it is worth noting that Menten et al. 2007 recently measured the parallax distance and gave a value of 420 pc), is one of the nearest active high mass star-forming regions. To the northern end of Orion A, the f-shaped OMC-2/3 region is regarded as one of the best sites to study both “clustered” and triggered star formation due to its near proximity. Therefore, OMC-2/3 aroused great interest since its discovery and was comprehensively studied recently at a variety of wavelengths and with a variety of molecular species.

Chini et al. (1997) identified at least 21 compact 1300 µm dust continuum condensations in OMC-2/3, with 16 of them embedded in OMC-2 and the others in OMC-3. They suggested that the condensations in OMC-3 with L_{bol}/L_{smm} < 70 are Class 0 objects and thus represent an earlier stage of evolution. The 3.6 cm free-free emission revealed 14 sources, of which seven sources coincide well with the 1300 µm condensations, yet no relation was found between the 3.6 cm radio continuum and 1300 µm (Reipurth et al. 1999). Williams et al. (2003) observed CO(1–0) toward this region and identified nine protostellar outflows.

Dense cores in this region were well studied in many molecular species, e.g. CS and C¹⁸O (Castets & Langer 1995), NH₃ (Cesaroni & Wilson 1994), HCO⁺ and CO (Aso et al. 2000). The

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chemical evolution of OMC-2/3 was also widely studied in a variety of molecular species, in particular the complex molecule species, such as CH$_3$OH, HC$_3$N, and CCS. Johnstone et al. (2003) studied the astrochemistry of OMC-2/3 in H$_2$CO, CH$_3$OH, etc., and found a trend that hotter cores are more likely to have higher CO, H$_2$CO, CH$_3$OH, and CS abundance. Tatematsu et al. (2008) observed N$_2$H$^+$, HC$_3$N and CCS toward Orion A and found that the N-bearing molecules seem to be more intense in OMC-2. Tatematsu et al. (2010) investigated Orion A in CCS, HC$_3$N, DNC, and HN$^{13}$C and detected CCS emission in OMC-3 for the first time. They also proposed that star formation activity seems to be responsible for the enhancement of HC$_3$N intensity.

We mapped the OMC-2/3 region in C$_2$H, HC$_3$N, and HNC. These molecular lines were widely studied in dark clouds and were commonly accepted as good tracers of the physical condition and chemical evolution of dense cores. C$_2$H was first detected in the interstellar medium by Tucker et al. (1974). It has since been detected in a variety of interstellar environments (Wootten et al. 1980, Huggins et al. 1984). Recently, Beuther et al. (2008) further revealed that C$_2$H can be found in cases from the earliest infrared dark clouds (IRDCs) to the later evolutionary stage of ultra-compact HII regions and explained that it was replenished at the core edges by elemental carbon from CO being dissociated by the interstellar UV photons. Due to its small rotation constant, HC$_3$N creates many transitions that are easily detectable in molecular clouds (Vanden Bout et al. 1983). Moreover, the transitions are likely to be optically thin, so it was also an excellent dense gas indicator. However, its mechanism of formation is still not very clear. Woon & Herbst (1997) proposed that it originated from the reaction between CN and C$_2$H. Szczepanski et al. (2005) gave a pathway of formation for HC$_3$N from a C$_3$ carbon cluster and ammonia. Observations of these molecular lines can help us understand the chemistry of HC$_3$N. HNC molecules are considered to be relevant for the formation mechanism of cyanopolyynes (HC$_{2n+1}$N) in future work.

## 2 OBSERVATIONS

The observations were made during 2010 March and July with the PMO 13.7 m millimeter-wave telescope at Delingha, China. The observation center ($\alpha = 05^h35^m26.71^s$, $\delta = -05^\circ10^\prime04^\prime\prime$, equinox=2000.0) was adopted from Chini et al. (1997), the location of FIR 4, which is associated with the strongest 3.6 cm emission (Reipurth et al. 1999). The HNC(1–0), HC$_3$N(10–9) and C$_2$H(1–0) were mapped over a 10$^\prime$ by 23$^\prime$ region with a grid spacing of 60$^\prime\prime$. The detailed observation log is listed in Table 1 (Tucker et al. 1974).

| Molecule | Transition | $\nu$ (MHz) | Relative intensity | $B_0$ (MHz) | $\mu$ (D) |
|----------|------------|-------------|-------------------|-------------|----------|
| C$_2$H   | $J = 3/2 \rightarrow 1/2$ $F = 1 \rightarrow 1$ | 87 284.38 | 4.25 | 43 474.0 | 0.8 |
|          | $J = 3/2 \rightarrow 1/2$ $F = 2 \rightarrow 1$ | 87 317.05 | 41.67 |          |         |
|          | $J = 3/2 \rightarrow 1/2$ $F = 1 \rightarrow 0$ | 87 328.70 | 20.75 |          |         |
|          | $J = 1/2 \rightarrow 1/2$ $F = 1 \rightarrow 1$ | 87 402.10 | 20.75 |          |         |
|          | $J = 1/2 \rightarrow 1/2$ $F = 0 \rightarrow 1$ | 87 407.23 | 8.33  |          |         |
|          | $J = 1/2 \rightarrow 1/2$ $F = 1 \rightarrow 0$ | 87 446.42 | 4.25  |          |         |
| HC$_3$N  | $J = 10 \rightarrow 9$ | 90 978.99 | 4.549 | 3.72      |
| HNC     | $J = 1 \rightarrow 0$ | 90 663.59 | 45 332.0 | 3.05     |

An SIS receiver with a noise temperature of 75–145 K (DSB) was used. The back end was a Fast Fourier Transform Spectrometer (FFTS) having 16 384 channels with a bandwidth of 1000 MHz and effective spectral resolution of 61.0 kHz (0.20 km s$^{-1}$). With the 1000 MHz bandwidth, HNC(1–0) and HC$_3$N(10–9) were received simultaneously. The position-switch mode was used. The system temperatures were about 200–300 K during the observations. The pointing accuracy was checked by regular observations of point sources and was estimated to be better than 9$^\prime\prime$. The main beam size...
was about 60′′ at 115 GHz. The typical on-source time for each position was about 5 min. The main-beam efficiency $\theta_{mb}$ was estimated by comparing the radiation temperatures of calibration sources S140, NGC2264 and Orion A with the NRAO 11 m results (e.g. Huggins et al. 1984; Morris et al. 1976).

All the data were reduced by using the GILDAS software. We performed linear baseline subtractions to most spectra. At the velocity resolution of 0.2 km s$^{-1}$ the typical rms noise level was about 0.2 K in $T_A^*$.  

3 RESULTS AND DISCUSSION

3.1 Spectra and Maps

Figure 1 shows the spectra of the observation center. The intensity scale is given in $T_R^*$ in all figures from this study. Here all six hyperfine components of $C_2H,N = 1 \rightarrow 0$ are presented. The line profiles of both HNC and HC$_3$N show a very symmetric Gaussian profile at this position.

Figure 2 shows the velocity integrated intensity contour and grey-scale maps for the strongest components $J = 3/2 \rightarrow 1/2 F = 2 \rightarrow 1$ of $C_2H$, HC$_3$N and HNC. The integrated velocity ranges from 8 to 14 km s$^{-1}$ for all observed lines. The 1300 µm cores identified by Chini et al. (1997) are marked by pluses in Panel a. It is evident that the distribution of 1300 µm cores shows the most resemblance to that of our $C_2H$ cores. In general, the emissions from all the three molecular species revealed an extended filamentary structure. More than one condensation was detected in both OMC-2 and OMC-3. One exception is the HC$_3$N emission in OMC-3, which is almost negligible and shows very marginal detection ($\sim 3\sigma$). The location of each core was derived from the channel maps.

Fig. 1 Top: spectra towards (0″, 0″); Bottom: six hyperfine components of $C_2H,N = 1 \rightarrow 0$. 

Fig. 2  (a) velocity integrated intensity contour map of the C$_2$H $J = 3/2 \rightarrow 1/2$ $F = 2 \rightarrow 1$. The contour levels are 4.367 K km s$^{-1}$ × (2, 3, 4, 5, 6, 7, 8, 9). Pluses represent the 1300 µm condensations identified by Chini et al. (1997). (b)–(d) velocity integrated intensity contour and grey-scale maps of the C$_2$H $J = 3/2 \rightarrow 1/2$ $F = 2 \rightarrow 1$, HC$_3$N(10–9) and HNC(1–0). The contour levels are 4.367 K km s$^{-1}$ × (2, 3, 4, 5, 6, 7, 8, 9), 1.785 K km s$^{-1}$ × (3, 4, 5, 6, 7, 8, 9), and 11.2 K km s$^{-1}$ × (2, 3, 4, 5, 6, 7, 8, 9), respectively. Pluses mark the positions of all cores identified in this study.

by eye and by applying a threshold of 5σ in two adjacent channels. To improve the signal-to-noise ratio, the channel width was resampled to be 0.5 km s$^{-1}$. Finally, we identified at least eight C$_2$H $J = 3/2 \rightarrow 1/2$ $F = 2 \rightarrow 1$ cores indicated by A1–A8, two HC$_3$N(10–9) cores indicated by B1 and B2, and seven HNC(1–0) cores indicated by (C1–C7) in OMC-2/3. The location of each core is marked by a plus sign in Figure 2. The size of the core is characterized by the nominal core radius $R$ after beam deconvolution, which was calculated by

$$R = \left[ \frac{A}{\pi} - \left( \frac{HPBW}{2} \right)^2 \right]^{1/2},$$

where $A$ is the measured area within the contour of half peak intensity. The derived location and size of each core is summarized in Table 2, which also lists the corresponding Gaussian fitting results for the main components of C$_2$H, HC$_3$N and HNC, including the line center velocity, the line widths and the bright temperature. The shape of most cores is elongated due to the compression from the surrounding medium. The radii of C$_2$H cores range from 0.12 to 0.17 pc with a mean value of 0.14 pc, while HNC cores range from 0.15 to 0.21 pc with a mean value of 0.17 pc. The size of the two HC$_3$N(10–9) cores is much smaller, only 0.08 and 0.09 pc, about half the value of radius for both HNC and C$_2$H cores. In OMC-2, the radius of the C$^{32}$S (2–1) core was found to be about 0.1 pc with a resolution of 53″ (Castets & Langer 1995), and that of the CS(1–0) core was found to be 0.18 pc with a resolution of 35″ (Tatematsu et al. 1993). The discrepancy in radius traced by different molecular species might reflect that HC$_3$N(10–9) and C$^{32}$S (2–1), and perhaps C$_2$H(1–0), trace a much denser region than HNC(1–0) and CS(1–0).
Table 2  Cores’ Parameters

| No | offset (arcmin) | offset (arcmin) | R (arcmin) | R (pc) | \( V_{\text{LSR}} \) (km s\(^{-1}\)) | \( \Delta V \) (km s\(^{-1}\)) | \( T_{\text{mb}} \) (K) |
|----|----------------|----------------|------------|--------|---------------------------------|----------------------|----------------|
| A1 | –2             | 10             | 1.34       | 0.17   | 10.9±0.04                       | 1.8±0.08             | 1.4           |
| A2 | 0              | 7              | 0.95       | 0.12   | 10.9±0.04                       | 1.2±0.10             | 1.2           |
| A3 | 0              | 4              | 1.18       | 0.15   | 11.6±0.04                       | 1.4±0.12             | 1.1           |
| A4 | –1             | 3              | 0.92       | 0.12   | 11.3±0.06                       | 1.7±0.15             | 1.0           |
| A5 | 0              | 0              | 1.32       | 0.17   | 11.3±0.02                       | 1.4±0.04             | 2.8           |
| A6 | –1             | –3             | 0.94       | 0.12   | 10.7±0.03                       | 1.5±0.08             | 1.6           |
| A7 | –2             | –5             | 1.00       | 0.13   | 10.6±0.04                       | 1.5±0.11             | 1.5           |
| A8 | –3             | –6             | 1.01       | 0.13   | 10.4±0.02                       | 0.85±0.07            | 1.8           |
| B1 | 0              | 0              | 0.62       | 0.08   | 11.2±0.01                       | 1.3±0.02             | 2.3           |
| B2 | –1             | –2             | 0.86       | 0.11   | 11.0±0.02                       | 1.1±0.06             | 1.4           |
| C1 | –2             | 10             | 1.17       | 0.15   | 10.7±0.02                       | 1.9±0.04             | 2.9           |
| C2 | –1             | 9              | 1.35       | 0.18   | 10.9±0.01                       | 1.5±0.03             | 3.3           |
| C3 | 0              | 5              | 1.63       | 0.21   | 11.2±0.01                       | 1.1±0.02             | 5.1           |
| C4 | 0              | 2              | 1.27       | 0.17   | 11.2±0.01                       | 1.5±0.02             | 4.2           |
| C5 | 0              | 0              | 1.17       | 0.15   | 11.0±0.01                       | 1.7±0.01             | 6.4           |
| C6 | –1             | –2             | 1.35       | 0.18   | 10.8±0.01                       | 1.3±0.02             | 6.3           |
| C7 | –2             | –5             | 1.14       | 0.15   | 10.4±0.01                       | 1.6±0.03             | 3.3           |

3.2 Radial Velocity and Line Width

The velocities along the line of sight listed in Table 2 show good agreement among \( \text{C}_2\text{H} \), \( \text{HC}_3\text{N} \) and HNC cores. The \( V_{\text{LSR}} \) ranges from 10.4 to 11.6 km s\(^{-1}\) for \( \text{C}_2\text{H} \) (1–0) cores, and 10.4 to 11.2 km s\(^{-1}\) for HNC(1–0) cores. The \( V_{\text{LSR}} \) values of the two \( \text{HC}_3\text{N} \)(10–9) cores are all around 11.0 km s\(^{-1}\). By comparing with the \( V_{\text{LSR}} \) derived from \( \text{C}^{18}\text{O} \) (2–1) and \( \text{C}^{32}\text{S} \) (2–1) observations (Castetsa et al. 1995), we found that the \( V_{\text{LSR}} \) derived from different molecular species are very coherent.

In the north-south direction, a velocity gradient across OMC-2 is apparent in both HNC and \( \text{C}_2\text{H} \), however, that is not the case for OMC-3 (see Table 2). Figure 3 shows the position-velocity diagram, for the HNC (left) and \( \text{C}_2\text{H} \) (middle) along \( \Delta \text{R.A.} = -1 \), and for \( \text{HC}_3\text{N} \) (right) along \( \Delta \text{R.A.} = 0 \). The velocity gradient in OMC-2 was obvious. The previous study also found that the \( V_{\text{LSR}} \) increased gradually from south to north along the Orion A filaments (e.g. Bally et al. 1987). One reasonable explanation for its origin was the compression and acceleration from the adjacent Orion OB I associations (Bally et al. 1987).

![Fig. 3 Position-velocity diagram for the HNC (left) and \( \text{C}_2\text{H} \) (middle) along \( \Delta \text{R.A.} = -1 \) and for \( \text{HC}_3\text{N} \) (right) along \( \Delta \text{R.A.} = 0 \).](image-url)
The line widths of C$_2$H (1−0), HNC (1−0), and HC$_3$N (10−9) range from 0.85 to 1.8 km s$^{-1}$, 1.1 to 1.9 km s$^{-1}$ and 1.1 to 1.3 km s$^{-1}$, respectively. The line widths of both HNC and C$_2$H look very similar, and both are wider than those of HC$_3$N. This indicates that HC$_3$N traces a cooler region. As previously mentioned, HC$_3$N can trace a much denser and more central region of a cloud than HNC and C$_2$H, which might be the reason why HC$_3$N shows the narrowest line width.

Many factors contribute to the line width of a specific molecular species. Among them, the contribution from thermal broadening is about 0.2 km s$^{-1}$, so in our case non-thermal broadening is mainly attributed to the line width. In dark clouds, the typical line width is about 0.4−1.0 km s$^{-1}$ for C$_2$H (1−0) (Wootten et al. 1980), 0.1−0.4 km s$^{-1}$ for HC$_3$N (10−9), and 0.5−0.7 km s$^{-1}$ for HNC (1−0) (e.g. in TMC-1; Churchwell et al. 1984), which are all much narrower than those of the OMC-2/3 region. This suggests that OMC-2/3 is more active than dark clouds, and has a larger turbulence caused by winds and UV radiation from the surrounding massive stars.

3.3 Column Density and Cores’ Masses

We perform hyperfine structure (HFS) fitting to C$_2$H (1−0), to estimate the excitation temperature $T_{ex}$, which was given as $T_{ex}=T_{ant}+T_{bg}$, and optical depth $\tau_{TOT}$, which was given as $\tau_{TOT}=\tau_{main}/0.4167$ (Padovani et al. 2009).

The total gas column density along the line of sight was calculated under the assumption that each tracer is optically thin, in Local Thermodynamic Equilibrium (LTE), and can be expressed as (Scoville et al. 1986),

$$N = \frac{3k}{8\pi^3B\mu^2} \frac{e^{hB(J_l+1)/kT_{ex}}}{J_l+1} \frac{T_{ex}+hB/3k}{1-e^{-h\nu/kT_{ex}}} \int \tau_v d\nu,$$

where $B$ is the rotational constant, $\mu$ is a permanent dipole moment, and $J_l$ is the rotational quantum number of the lower state in the observed transition (Table 1). The excitation temperatures of HC$_3$N and HNC were assumed to be 20 K in OMC-2 and 15 K in OMC-3, which were taken from NH$_3$ observations of Wilson et al. (1999).

The H$_2$ column density N(H$_2$) was estimated by assuming N(C$_2$H)/N(H$_2$)=5.3 × 10$^{-9}$, N(HC$_3$N)/N(H$_2$)=1.3 × 10$^{-10}$, and N(HNC)/N(H$_2$)=5.3 × 10$^{-10}$ (Blake et al. 1987).

| No | $T_{ex}$ (K) | $\tau_{TOT}$ | $N$ (cm$^{-2}$) | N (H$_2$) (cm$^{-2}$) | n (H$_2$) (cm$^{-3}$) | M ($M_\odot$) | $M_{\text{vir}}$ ($M_\odot$) | $M_{\text{vir}}/M$ |
|----|---------------|---------------|-----------------|---------------------|-----------------|-------------|----------------|----------------|
| A1 | 5.1           | 1.2±0.33      | 1.2 × 10$^{14}$ | 2.3 × 10$^{22}$     | 2.2 × 10$^{4}$  | 31.6        | 64.0          | 2.0            |
| A2 | 4.8           | 1.2±0.54      | 7.5 × 10$^{14}$ | 1.4 × 10$^{22}$     | 1.9 × 10$^{4}$  | 9.6         | 30.1          | 2.7            |
| A3 | 7.0           | 0.4±0.42      | 4.8 × 10$^{14}$ | 9.1 × 10$^{21}$     | 1.0 × 10$^{4}$  | 9.9         | 43.9          | 4.0            |
| A4 | 8.9           | 0.2±0.12      | 4.2 × 10$^{14}$ | 7.9 × 10$^{21}$     | 1.1 × 10$^{4}$  | 5.6         | 42.6          | 7.1            |
| A5 | 13.9          | 0.4±0.15      | 1.4 × 10$^{14}$ | 2.6 × 10$^{22}$     | 2.5 × 10$^{4}$  | 36.0        | 49.7          | 1.2            |
| A6 | 8.8           | 0.4±0.28      | 7.2 × 10$^{13}$ | 1.4 × 10$^{22}$     | 1.9 × 10$^{4}$  | 9.6         | 37.6          | 3.7            |
| A7 | 11.7          | 0.2±0.60      | 5.7 × 10$^{13}$ | 1.1 × 10$^{22}$     | 1.4 × 10$^{4}$  | 9.0         | 40.8          | 4.2            |
| A8 | 13.5          | 0.2±0.46      | 4.1 × 10$^{13}$ | 7.7 × 10$^{21}$     | 1.0 × 10$^{4}$  | 6.4         | 23.1          | 3.5            |
| B1 |               |               | 1.2 × 10$^{14}$ | 9.2 × 10$^{22}$     | 18.6 × 10$^{4}$ | 27.9        | 21.8          | 0.8            |
| B2 |               |               | 6.1 × 10$^{14}$ | 4.7 × 10$^{22}$     | 6.9 × 10$^{4}$  | 26.9        | 25.4          | 0.9            |
| C1 |               |               | 1.3 × 10$^{14}$ | 2.5 × 10$^{22}$     | 2.7 × 10$^{4}$  | 26.7        | 59.6          | 2.2            |
| C2 |               |               | 1.2 × 10$^{14}$ | 2.3 × 10$^{22}$     | 2.1 × 10$^{4}$  | 35.8        | 56.4          | 1.6            |
| C3 |               |               | 1.1 × 10$^{14}$ | 2.1 × 10$^{22}$     | 1.6 × 10$^{4}$  | 43.4        | 48.3          | 1.1            |
| C4 |               |               | 1.2 × 10$^{14}$ | 2.3 × 10$^{22}$     | 2.2 × 10$^{4}$  | 31.6        | 53.3          | 1.7            |
| C5 |               |               | 2.2 × 10$^{14}$ | 4.2 × 10$^{22}$     | 4.5 × 10$^{4}$  | 44.4        | 53.3          | 1.2            |
| C6 |               |               | 1.7 × 10$^{14}$ | 3.2 × 10$^{22}$     | 2.9 × 10$^{4}$  | 49.5        | 48.9          | 1.0            |
| C7 |               |               | 9.8 × 10$^{14}$ | 1.8 × 10$^{22}$     | 1.9 × 10$^{4}$  | 18.8        | 50.2          | 2.7            |
were calculated by equation $M = m H X \times N(H_2) \times (\pi R^2)$ where $X$ is the ratio of total gas mass to hydrogen mass, which is about 1.36. The virial mass $M_{\text{vir}}$ was calculated by equation $M_{\text{vir}}(M_\odot) = 210 R (\text{pc}) \delta v (\text{km s}^{-1})$. All derived physical parameters are tabulated in Table 3.

An interesting result is that the core masses traced by HNC are rather flat, ranging from 18.8 to 49.5 $M_\odot$. By contrast, those traced by C$_2$H are steep, ranging from 6.4 to 36.0 $M_\odot$. On the whole, OMC-2 is more massive than OMC-3. The average masses for C$_2$H, HC$_3$N and HNC cores are 14.7, 35.7 and 23.6 $M_\odot$, respectively. The core masses we derived here were strongly dependent on the adopted abundance values and therefore likely have a large uncertainty. The average virial masses of C$_2$H, HC$_3$N and HNC cores are 41.5, 23.6 and 52.7 $M_\odot$, respectively. $M_{\text{vir}}/M$ listed in Table 3 is inversely proportional to the $M$ term, which is consistent with the conclusion of Loren (1989) that low mass clumps are more likely to deviate from virial equilibrium.

4 SUMMARY

We first mapped the OMC-2/3 region in C$_2$H(1–0), HC$_3$N (10–9) and HNC (1–0) by using the PMO 13.7 m telescope. Our main results are summarized as follows:

1. The distribution of C$_2$H cores shows the most resemblance to that of the 1300 µm condensations, which might suggest that C$_2$H is a good tracer to study the structure of molecular clouds.
2. HC$_3$N shows the narrowest line width, while the widths of both HNC and C$_2$H share a very similar distribution. In general, the line width of the three observed lines presented here is wider than that of the dark cloud. This might imply that OMC-2/3 is more active than the dark cloud, and has larger turbulence caused by winds and UV radiation from the surrounding massive stars.
3. The core masses traced by HNC are rather flat, ranging from 18.8 to 49.5 $M_\odot$, while, by contrast, those traced by C$_2$H are steep, ranging from 6.4 to 36.0 $M_\odot$.

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