Trans-ethyl methyl ether in space

A new look at a complex molecule in selected hot core regions

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Abstract. An extensive search for the complex molecule trans-ethyl methyl ether towards several hot core regions has been performed. Using the IRAM 30m telescope and the SEST 15m we looked at several frequencies where trans-ethyl methyl ether has strong transitions, as well as lines which are particularly sensitive to the physical conditions in which the molecule can be found. We included G34.26, NGC6334(I), Orion KL, and W51e2 which have previously been proven to have a rich chemistry of complex molecules. Our observations cannot confirm the tentative Orion KL detection made by Charnley et al.(2001) within their stated column density limits, but we confirm the existence of the trans-ethyl methyl ether towards W51e2 with a column density of $2 \times 10^{14}$ cm$^{-2}$. The dimethyl ether/methanol ratio of 0.6 as well as the newly found ethyl methyl ether/ethanol ratio of 0.13 indicate relative high abundances of ethers toward W51e2. Furthermore, the observation of ethyl methyl ether also confirms the importance of ethanol as a grain mantle constituent. We present new upper limits of around $8 \times 10^{13}$ cm$^{-2}$ for the column densities of the molecule toward Orion KL, G34.26, NGC6334(I) and estimate the column density towards SgrB2(N) to be of the same order. The W51e2 observations are discussed in more detail.

Key words. trans-Ethyl Methyl Ether – hot cores – radio lines – interstellar molecule

1. Introduction

Various large and complex molecules of prebiotic importance have been found as constituents of dense interstellar clouds but their detection remains difficult and some of them doubtful [Snyder et al.(2005)]. Fortunately, space offers many places with a rich chemistry and hot molecular cores (HMCs) are prime targets for such investigations. However, the spectra towards hot cores often reveal a high line density and thus proper line assignments are difficult and have to be viewed with a critical eye. The ethyl methyl ether (CH$_3$OC$_2$H$_5$) is an asymmetric top molecule with two methyl groups acting as internal rotors. Ethyl methyl ether (EME) has two conformers where the trans-EME is lower in energy than the gauche-EME by 550 cm$^{-1}$ [Durig et al.(2002)] and thus favored as an astrophysically detectable species. We searched for several transitions of trans-EME to confirm the tentative detection of this molecule by Charnley et al.(2001). A positive result means the detection of one of the biggest molecules in the interstellar medium (ISM). Charnley et al.(2001) observed a single line in W51 e1/e2 and Orion KL at 160.1 GHz and another line in SgrB2(N) at 79.6 GHz which they assigned to trans-ethyl methyl ether. Based on these isolated measurements, Charnley et al.(2001) estimate the column density of EME to be in the range of $10^{14}$ - $10^{15}$ cm$^{-2}$ in Sgr B2(N). Thus, assuming a hydrogen column density of $10^{24}$ cm$^{-2}$ gives a fractional abundance of $10^{-10}$ - $10^{-9}$. For W51, they estimate EME to have an abundance of a few times $10^{-10}$. Furthermore, they conclude that the emission of EME closely follows that of methanol, as expected if these molecules are chemically linked. Charnley et al.(1995) suggest the following production mechanism for EME in hot cores where temperatures can rise to 100-300 K. Icy mantles which are thought to contain alcohols (e.g. methanol, ethanol) evaporate from dusty grains, e.g. Millar & Hatchell(1998) the
alcohols themselves are thought to be produced via surface reactions starting from the precursor CO. Once the man-
tacles evaporate the alcohols can be converted into ethers and other species. The production of ethers is thought to
happen via ion-molecule reactions\(^1\) (i), methylation of the protonated species\(^2\) (ii) and dissociative recombina-
tion with electrons (iii):

i) \(\text{C}_2\text{H}_5\text{OH} \xrightarrow{\text{H}_2\text{O}^+ \text{HCO}^+} \text{C}_2\text{H}_5\text{OH}^+\)

ii) \(\text{C}_2\text{H}_5\text{OH}^+ \xrightarrow{\text{CH}_3\text{OH}} \text{CH}_3\text{OC}_2\text{H}_6^+\)

iii) \(\text{CH}_3\text{OC}_2\text{H}_6^+ \xrightarrow{\text{e}^-} \text{CH}_3\text{OC}_2\text{H}_5\)

In hot cores saturated species are the dominant con-
stituents. For instance, methanol CH\(_3\)OH is highly
abundant and dimethyl ether (CH\(_3\))\(_2\)O and ethanol
C\(_2\)H\(_5\)OH are seen only in hot cores Herbst(2001).
Charnley et al.(1995) mention in their work that dimethyl
ether, diethyl ether (C\(_2\)H\(_5\))\(_2\)O, and trans-EME should
be present in detectable quantities within cores rich in
ethanol and methanol. Furthermore, a detection of either
EME or diethyl ether would confirm the importance of
ethanol as a grain mantle constituent.

2. EME Spectrum and Observations

Only two investigations on the laboratory rotational spec-
trum of EME have been reported in the literature. The
more recent measurements by Fuchs et al.(2003) from 55
GHz to 350 GHz also include the previously published
data below 40 GHz by Hayashi & Kuwada(1975) in their
analysis. Reliable frequency predictions up to 400 GHz are
now available. Since EME consists of two methyl groups
designated as internal rotors, the laboratory spectra re-
veal extra line splittings which are not necessarily seen
in space due to larger line widths in the HMC environ-
ment. The spectroscopic aspects of ethyl methyl ether in
the mm-wave range are described in our earlier publica-
tions (see Fuchs et al.(2003) Fuchs(2003) and references
therein). EME is an asymmetric top molecule which has
weak a-type transitions and fairly strong b-type transi-
tions above 100 GHz which in theory split into quintets
caused by internal torsion. Laboratory measurements can
resolve only doublets and quartets with splittings mostly
between 0.8 and 2 MHz in our examined frequency ranges.
However, none of the astronomically observed lines is tor-
sionally resolved. Fig. 4 shows the complexity of the EME
spectrum up to 400 GHz with its characteristic features.

The IRAM 30m telescope at Pico Veleta, Spain, has
been used during several days in Sept 2002 and July 2003
and the SEST 15m telescope at La Silla, Chile, in March
2003. The hot core regions of G34.26, NGC6334I, Orion
KL and W51e2 were observed, see Table 4. Rotational
transitions of EME have been searched in the 1mm-, 2mm-
, and 3mm-range. Depending on the source, between 5

1 see Mackay et al.(1979) Bohme et al.(1979)
2 see Karpas & Meot-Ner (1989)

and 11 frequency settings have been used, see Table 4 for
observational details. Typical frequency resolutions were
0.3, 1 and 1.25 MHz, typical bandwidths between 490 and
1020 MHz and rms noise levels between 0.01 K at 81 GHz
and 0.02 - 0.05 K at 245 GHz. The bands were chosen to
allow for the observation of CH\(_3\)OH (a-type), C\(_2\)H\(_5\)OH
and CH\(_3\)OCH\(_3\) transitions as well. At least 5 strong lines
have been measured from each of these species, except for
CH\(_3\)OH in Orion KL where only three transitions have been
observed.

The intensities are measured in \(T_a^*\) the effective an-
tenna temperature corrected for spillover losses and at-
mospheric attenuation, and are then converted to \(T_{mb} = \frac{T_a^*}{\rho}\) using the beam efficiencies \(\rho\) of the telescopes at the
given frequencies.

All sources were examined using long integration times
up to 220 minutes on+off time, elevations greater 40°
and under good atmospheric weather conditions.

3. Source selection

A selection of previous work on the sources is given below.
The authors do not intend to give a review of these sources
but rather focus on contributions relevant for the EME
analysis.

G34.3+0.15 has been surveyed by
MacDonald et al.(1996) and Thompson et al.(1999)
in the 330-360 GHz region. Nomura & Millar(2004)
examined the chemical structure of this region and gave
an overview of the observed species and their abundances
along with some comparisons to their model predictions.
Single molecule investigations like ethanol have been
performed by Millar et al.(1995) Nummelin et al.(1998b)
examined CH\(_3\)CHO and c-C\(_2\)H\(_4\)O but also gave abund-
ances for methanol, ethanol and dimethyl ether (DME).
Heaton et al.(1989) mapped the G34.3 region using the
NH\(_3\)(3,3) emission and determined a size of 3′′ \(\times\) 2′′.
The column density of H\(_2\) towards G34.26 has been
examined by Millar et al.(1995) to be \(N(H_2) = 5.3 \times\)
10\(^{23}\) cm\(^{-2}\). Nummelin et al.(1998b) published a similar
result of \(N(H_2) = 3.0 \times 10^{23}\) cm\(^{-2}\) for a 20′′ source size.

NGC6334I (NGC6334F, G351.41+0.64) has been mapped
in the continuum by Sandell(2000). McCutcheon et al.(2000)
took several spectra in the range between 334 and 348 GHz
using the JCMT. They also mapped the region in CH\(_3\)OCH\(_3\)
emission. Nummelin et al.(1998b) estimated the abundances
of ethanol, methanol and DME in NGC6334I and a hydrogen
column density of \(N(H_2) = 2.0 \times 10^{23}\) cm\(^{-2}\) within
20′′. Cheung et al.(1978) estimate \(N(H_2) \approx 10^{24}\) cm\(^{-2}\).

Orion KL is a well studied object in the sky. Turner(1989) Turner(1991) performed a line sur-
vey between 70 and 115 GHz, Lee & Cho(2002) pre-
sented line spectra between 159.7 to 164.7 GHz and
Sutton et al.(1985) scanned the spectral region between
215 and 247 GHz. Blake et al.(1987) studied the chem-
ical composition of OMC-1 in the 230 GHz atmos-
pheric window. They estimate the hydrogen column den-
sity to be $N_{H_2} = 1.0 \times 10^{23} \text{ cm}^{-2}$ for the hot core. The region between 330 to 355 GHz was examined by Sutton et al. (1991) and Schilke et al. (1997) performed a survey from 325 GHz to 360 GHz (see also references therein). The distribution of some key molecules for the EME analysis has been presented by Sutton et al. (1995). Caselli et al. (1993) applied a dynamical-chemical model which included abundances of many observed species.

The W51 molecular cloud is described in Carpenter & Sanders (1998). The chemistry of the W51e2 region has been investigated by several groups. For example, Zhang et al. (1998) has done CH$_3$CN and CS (3-2) observations, Remijan et al. (2004), Remijan et al. (2002) investigated CH$_3$CN and CH$_3$COOH, Liu et al. (2001) looked for HCOOH in this source and Kuan et al. (2004) searched for several molecules of potential prebiotic importance. The hydrogen column density $3.6 \times 10^{23} \text{ cm}^{-2}$ is based on C$^{18}$O data from Schloerb et al. (1987).

Also the SgrB2 region has been investigated by many groups. It is not part of our own observations but since Charnley et al. (2001) detected one line at an EME transition frequency we use the published data to estimate the column density of EME in Section 6. A spectral line survey from 70 and 150 GHz has been performed by Cummins et al. (1986) and from 70 to 115 GHz by Turner (1989) Turner (1991). A further 3mm spectral line survey has been carried out by Friedel et al. (2004) using the NRAO12m and the BIMA array telescopes. Nummelin et al. (1998a) extended these observations to frequencies between 218 and 263 GHz. Selected molecules, like the oxygen bearing CH$_3$COOH, have been studied by Remijan et al. (2002) and NH$_3$ by Hüttemeister et al. (1993) with comparisons between several sources including those studied here. Martín-Pintado et al. (1990) estimated $N_{H_2} = 5.0 \times 10^{24} \text{ cm}^{-2}$ to be the hydrogen column density. Iked et al. (2001) gave temperatures and abundances of methanol, ethanol and in most cases also for DME for all above mentioned sources. Table 2 summarizes the CH$_3$OH, C$_2$H$_5$OH, CH$_3$OCH$_3$ and C$_2$H$_5$CH$_3$ abundances including our latest results.

### 4. Data Analysis method

For the analysis of the observed lines we used the Grenoble Image and Line Data Analysis Software GILDAS$^4$ and in addition the myXCLASS code written by Peter Schilke which is backed by a database of astrophysically important molecules, including the EME data. myXCLASS can simulate the spectra of many molecules at a time, including their line profiles within the GILDAS environment and has restricted fitting capabilities. Fig. 2 shows the observed spectrum of W51e2 at 151 GHz and the synthetic spectrum calculated by myXCLASS assuming optically thin lines where for each molecule the excitation is characterized by a rotational thermal equilibrium temperature. For each source a simulated spectrum has been created which covered all measured frequency bands. This enables an estimate of the abundances and temperatures of the molecules in these sources and can help to reveal blendings of several lines at a given frequency position. myXCLASS is specially suited to deal with many convoluting line profiles with different line widths and intensities as can regularly be observed in hot core regions where lines of different molecules blend with each other.

The spatial extent of the molecule can influence the value of the inferred column density. This is because the circular Gaussian beam size diameter $\theta_B$ of the telescope varies with frequency $\nu$, i.e. $\theta_B \sim 1/\nu$ (see telescope beam HPBW in Table 4). If the telescope beam points towards a source of circular Gaussian type with size $\theta_S$ the resulting convolution beam filling factor $b$ is given by $b = \theta_S^2/(\theta_B^2 + \theta_S^2)$, see Snyder et al. (2005) and the work by Ulich & Haas (1976). In the case of $\theta_S \gg \theta_B$ the beam filling factor is close to unity, for $\theta_S \sim \theta_B$ the beam dilution is 0.5 and for $\theta_S \ll \theta_B$ it follows $b \approx \theta_S^2/\theta_B^2$. Thus, assuming that the intrinsic intensity distribution $T_3$ of a source is Gaussian, a beam filling factor can be introduced to calculate the measured intensity $T_{mb} = b \cdot T_3$. HMCs are compact objects with diameters < $10''$. Using the IRAM 30m telescope with HPBW around 30'' at 80 and 250 GHz respectively and assuming a 10'' source size the beam filling factor is $b(\nu=80GHz)=0.1$ and $b(\nu=250GHz)=0.5$. Hence, an intensity difference of a factor 5 can occur by not correcting for beam dilution. The program myXCLASS has the source size as an input parameter and can thus simulate the effect of the assumed source size on the line intensities.

For the EME lines we can expect small optical depths so that the rotational temperature $T_{rot}$ and the total molecular column density $N_T$ [cm$^{-2}$] can be determined by a least-squares fit of

$$
\log_{10} \left( \frac{3k_B}{8\pi^3} \frac{\int T_{mb}dv}{\nu \mu^2 S} \right) = \log_{10} \left( \frac{N_T}{Q(T_{rot})} \right) - \frac{\log_{10}(e) E_u}{T_{rot}}
$$

with $\int T_{mb}dv$ the observed line integral, $\mu^2 S$ the dipole and line strength value derived from Pickett et al. (1998) (see their Eq.(2)), $Q$ the partition function, and $E_u$ the energy of the upper level. The resulting fit can be plotted in a rotational-temperature-diagram (RTD) or Boltzmann plot. For detections at the confusion limit Snyder et al. (2005) has shown that Boltzmann plots cannot necessarily be used as independent tools to verify interstellar spectral line identifications. Any false assignment does not automatically reveal itself in the RTD by large displacements from the fitted line and thus can only be avoided by careful line check in catalogs and the literature. As a standard procedure any candidate line of EME has to be checked against competing lines, i.e. the

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$^3$ Note, Charnley et al. (2001) assume $N_{H_2} = 1.0 \times 10^{24} \text{ cm}^{-2}$

$^4$ see http://www.iram.fr/IRAMFR/GILDAS
expected or known intensities of these other lines at the EME frequencies have to be determined. Therefore, a consistent and comprehensive list of molecule abundances in the source is important. Line surveys are invaluable aids in determining the chemical composition of a source.

5. Results

5.1. W51e2

Several lines at EME transitions have been observed towards W51e2, see Fig. [4]. We looked for strong EME b-type lines and at the same time tried to exclude as many blendings with other molecules. By using myXCLASS we first estimated a column density of $\sim 10^{14}$ cm$^{-2}$ and a rotational temperature of roughly 100K. We checked every frequency band for consistency by comparing a simulated spectrum of EME and other known molecules with the observed spectrum. Fig. [4] shows an observed line with simulated EME lines superimposed. The laboratory measurements of the EME line positions are at a precision level unmatched by any astronomical observations. The figure illustrates the effect of the linewidth on the total observations of the EME line positions at a precision level have been observed at lower frequencies. Hot cores reveal a great richness and density in molecular emission lines, see Fig. [5] and it is not astonishing that 77% of the EME lines in the observed bands are blended by strong lines of other known molecules. In our case by far the most blendings occur in the 215 GHz band which is therefore not further detailed in Table 5. 12% of the blendings are at line positions of yet unidentified species. However, from intensity considerations it is clear that these latter lines cannot be dominated by EME because in this case EME should have also strong lines at other frequencies where we have not observed any strong feature. Note that many transition labels in Table 5 have labels with possible blendings. By carefully checking the databases and literature but also by fitting many other species to our spectra we could estimate the abundances of several species which could be potential competitors to the EME lines. To further clarify our detection we made two Boltzmann fits, as shown in Fig. [5]. Here, every line in Table 5 which is marked with an (●) or (□) is depicted. If we use all these 14 lines in the Boltzmann fit (I) we get $T_{\text{rot}} = 126\pm115$ K and $N_i = 7.9^{+32}_{-6} \times 10^{14}$ cm$^{-2}$ as the beam averaged column density. Since we have many weak lines (i.e. around 1σ level) the reliability of the fit can be checked by excluding the weaker or doubtful lines marked with (□=noisy-like). Fit (II) only includes lines (●) with intensities larger than 2σ. As a result we obtain $T_{\text{rot}} = 54\pm38$ K and $N_i = 6.3^{+25}_{-5} \times 10^{14}$ cm$^{-2}$. This fit II should be regarded as more reliable than fit I. Furthermore, it has been shown that the excluded weak and noisy lines (□) are not in contradiction to fit II. Due to the large errors of the weak lines in the Boltzmann plot this is indeed not the case, but we would still expect slightly higher intensities at the (□) frequency positions.

W51e2 is known to have a size $< 10''$ so that the effect of beam dilution should be considered. For each fit (I and II) the above mentioned temperatures and abundances of EME can be recalculated by assuming an 5'' source size. This result in source averaged column densities and temperatures: fit I gives $T_{\text{rot}} = 74\pm50$ K and $N_i = 2^{+8}_{-1.5} \times 10^{14}$ cm$^{-2}$, fit II $T_{\text{rot}} = 69\pm94$ K and $N_i = 2^{+29}_{-1.9} \times 10^{14}$ cm$^{-2}$. Hence, the column densities and temperatures of the diluted and non-diluted beam yield comparable results within their error limits and we will use the source averaged value of fit (II) for further investigations. As has already been stated, RTDs cannot necessarily be used as reliable independent evidence to support the detection of a molecule close to the confusion limit, as was shown by [Snyder et al. (2005)] in the case of glycone. Our estimated column density is also consistent with observations in less favored frequency regions. As can be seen in Fig. [5] where an EME line is expected. For our fitted $2 \times 10^{14}$ cm$^{-2}$ column density no contradiction within the 1σ level can be found, but for a $N_i = 4 - 8 \times 10^{14}$ cm$^{-2}$ the simulated spectrum is in clear conflict with observation.

It is commonly believed that most complex molecules exist within a small area around the forming star, e.g. around 5'' for W51e2. On the other hand, [Hollis et al. (2001)] have shown that complex molecules such as glycolaldehyde can be found on spatial scales of $\geq 60''$ in the case of SgrB2. With our data it is not possible to determine the size of the emitting region. The source size has surely an influence on the detected signal strength which we tried to estimate using the myXCLASS program. Table 4 lists the result of possible column densities consistent with the observations if we assume certain temperatures between 30 K and 150 K. [Charnley et al. (2001)] presented a map of a line at an EME transition frequency towards SgrB2 of the order of 20''. If we assume W51e2 to have this same source size the column density would have to be corrected to lower values by nearly an order of magnitude. More realistic, our best fit value (fit II) assumes an 5'' size of W51e2.

Furthermore, it can be seen from Fig. [6] (see simulated spectrum for $N = 1 \times 10^{15}$ cm$^{-2}$) that in some frequency regions strong EME lines, i.e. lines well above 3σ level, should reveal their internal line splitting. Due to the weakness of the observed lines no line was detected where the torsional splitting could be resolved so that there is no unique proof that these lines indeed belong to EME.

\[ T_{\text{rot}} = 74\pm50 \text{ K}, \quad N_i = 2^{+8}_{-1.5} \times 10^{14} \text{ cm}^{-2} \]

\[ T_{\text{rot}} = 69\pm94 \text{ K}, \quad N_i = 2^{+29}_{-1.9} \times 10^{14} \text{ cm}^{-2} \]
5.2. The other sources

Sample spectra showing all examined sources at 245 GHz are shown in Fig. 8. At this frequency one of the strongest observed EME candidate lines appears in W51e2. However, no line above 1σ appears in these spectra for any other examined source. Also for the other frequency bands we get similar results. For example, the well pronounced feature at 150.845 MHz in W51e2 is only at the 1-2σ level in Orion KL and is completely invisible in G34.26 and NGC6334I. An upper limit for the column density of G34.26, NGC6334I and Orion KL has been estimated by the use of myXCLASS and independently by RTDs using integrated noise at EME transition frequencies and assuming an appropriate line width. Fig. 4 compares the 215 GHz region of W51e2 with Orion KL and also shows simulated spectra of EME for $N=2 \times 10^{14}$ cm$^{-2}$ and $N=1 \times 10^{15}$ cm$^{-2}$ at 70 K (assuming an 5" source size). It is immediately clear that the column densities of these sources must be of the order of $10^{14}$ cm$^{-2}$ or less rather than $10^{15}$ cm$^{-2}$ as estimated by Charnley et al.(2001).

Our results are summarized in Table 2. The previously published line at the EME $3_3-2_{2,3}$ transition frequency at 160.1 GHz in Orion KL by Charnley et al.(2001) has not been considered in the fit.

6. Discussion

Charnley et al.(2001) estimate the column density of EME in Orion KL and SgrB2(N) to be between $10^{14}$ - $10^{15}$ cm$^{-2}$ and in W51 to be a few times $10^{14}$ cm$^{-2}$. EME column densities at around $10^{14}$ cm$^{-2}$ correspond to signal strengths which are already close to the confusion limit in the HMC spectra. Nevertheless, long integration times and the availability of spectra at many frequencies enable us to estimate the column density of Orion KL to be below $1 \times 10^{14}$ cm$^{-2}$ and those of G34.26 and NGC6334I to be of the same order.

We can now use our values in Table 2 of W51e2 to draw some conclusions using the model of Charnley et al.(1995) According to Fig. 2 and Fig. 3a in their paper, which assumes a $10^{-6}$ fractional abundance $X_{Eth}$ of ethanol as a starting value for the chemical evolution in their model, the age of W51e2 should be dance at 0 yr must be $10^{-12}$ and $X_{Eth}$ $\sim 3 \times 10^{-9}$ for EME. On the other hand, if we use Fig. 4a of Charnley et al.(1995) with ethanol starting at $X_{Eth}=10^{-15}$ this translates to $X_{EME} \lesssim 10^{-12}$ and $X_{EME} \sim 4 \times 10^{-10}$. Assuming $C_2H_5OH$ to be the best molecule to determine the chemical age of the HMC it appears that in both cases, i.e. with ethanol starting values or $X_{Eth}$ $= 10^{-6}$ and $X_{Eth}=10^{-7}$, the fractional abundance of EME is nearly the same, namely $X_{EME} \sim 2 \times 10^{-10}$. This value is close to our estimated abundance $5.6 \times 10^{-10}$ for EME in W51e2. According to Table 2 and the model by Charnley et al.(1995) Orion KL and NGC6334I should be roughly of the same age as W51e2. Although we have only upper limits on the EME abundance in these sources it is clear that as a consequence the $C_2H_5OH$ fractional abundance at 0 yr must be $10^{-7}$ rather than $10^{-6}$. G34.26 is slightly older and SgrB2 is the oldest of the here discussed sources and should have an EME abundance $X_{EME}$ of less than $10^{-10}$ (corresponding to less than $10^{14}$ cm$^{-2}$ column density as we see it for Orion KL, G34.26 and NGC6334I). This however is in contradiction to the claimed observations of EME towards SgrB2 by Charnley et al.(2001) when they estimate an abundance of $10^{-10} - 10^{-9}$.

Looking at the observed values only, we notice that Orion KL has the highest fractional abundance of ethanol relative to H$_2$ followed by NGC6334I, G34.26, W51e2 and then SgrB2(N). However, no EME has been detected in Orion KL. The relative abundances of DME with respect to methanol and ethanol are shown in Fig. 7 Here, W51e2 shows a relative high dimethyl ether content relative to methanol and ethanol compared to the other sources, which may be a general indication of a higher ether abundance relative to the alcohols. Assuming that we indeed have detected EME in W51e2 the ratio between EME and ethanol is 0.13 which is 5 times less than the ratio of DME and methanol. If all sources would have a 0.13 EME/ethanol ratio the theoretical column densities would be around $2 \times 10^{14}$ cm$^{-2}$ or higher 6 which at least for G34.26, NGC6334I and Orion KL has been shown to be not the case. Thus, W51e2 is indeed particularly rich in EME.

We conclude that only the tentative detection of EME by Charnley et al.(2001) towards W51e2 can be confirmed within the following caveats 1) the EME Boltzmann fits include a few lines close to the noise level, 2) the obtained temperature of 70 K for EME is lower than that of other observed molecules ($\gtrsim 140$ K), 3) no torsional splitting of the EME lines could be observed and also other characteristic spectral fingerprints have not been observed. However, there are lines at EME transition frequencies which until now can best be explained by the existence of EME in W51e2.

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| Source     | RA    | Dec   | Eq. | LSR  (km s\(^{-1}\)) | telescope |
|------------|-------|-------|-----|---------------------|-----------|
| G34.26     | 18 53 18.496 | 01 14 58.66 | 2000 | +60.0 | IRAM 30m   |
| NGC 6334 I | 17 17 32.300 | -35 44 04.00 | 1950 | -8.0  | SEST 15m  |
| Orion KL   | 05 35 14.171  | -05 22 23.10 | 2000 | +8.8  | IRAM 30m  |
| W51 e2     | 19 23 43.959  | 14 30 34.55 | 2000 | +55.0 | IRAM 30m  |
### Table 2. Rotational temperatures, column densities and fractional abundances X relative to H₂ of CH₃OH, C₂H₅OH, CH₃OCH₃ and C₂H₅OCH₃ (EME) from our and other selected works.

| Source          | Molecules | $T_{rot}$ [K] | $N_v$ [cm⁻²] | $X^a$ | Reference               |
|-----------------|-----------|---------------|--------------|-------|-------------------------|
| **G34.26**      |           |               |              |       |                         |
| CH₃OH           | a-type    | 368 ± 16      | (1.8 ± 0.2) × 10¹⁶ | 4.5 × 10⁻⁸ | MacDonald et al. (1996) |
|                 | b-type    | 368 ± 16      | (1.6 ± 0.2) × 10¹⁶ | 4 × 10⁻⁸  | Thompson et al. (1999)  |
| CH₃OCH₃         | a+b type  | 96 ± 17       | (2.6 ± 1.4) × 10¹⁶ | 6.5 × 10⁻⁸ | Ikeda et al. (2002)     |
|                 | a-type    | 140 ± 14      | 2.2 ± 0.7 × 10¹⁶  | 5.5 × 10⁻⁸ | this work               |
| C₂H₅OH          | 94 ± 27   | (3.5 ± 2.0) × 10¹⁵ | 8.8 × 10⁻⁹  | MacDonald et al. (1996) |
| CH₃OCH₃         | 75 ± 37   | (1.7 ± 2.1) × 10¹⁵ | 4.3 × 10⁻⁹  | Ikeda et al. (2002)     |
|                 | 152 ± 66  | 6.0 ± 3.5 × 10¹⁴ | 1.5 × 10⁻⁹  | this work               |
| CH₃OCH₃         | 137 ± 32  | (3.7 ± 1.8) × 10¹⁵ | 9.3 × 10⁻⁹  | Ikeda et al. (2002)     |
|                 | 146 ± 38  | 3.5 ± 1.8 × 10¹⁵ | 8.8 × 10⁻⁹  | this work               |
| **NGC 6334 I**  |           |               |              |       |                         |
| CH₃OH           | 79 ± 21   | 3.1 ± 0.8 × 10¹⁶ | 1.6 × 10⁻⁷  | Nummelin et al. (1998b) |
|                 | 66 ± 11   | 1.2 ± 1.3 × 10¹⁶ | 6.0 × 10⁻⁸  | this work               |
| C₂H₅OH          | 94 ± 20   | 1.4 ± 0.3 × 10¹⁵ | 7.0 × 10⁻⁹  | Nummelin et al. (1998b) |
| CH₃OCH₃         | 20/440    | 3.5 ± 10¹⁵/1.1 × 10¹⁶ | 4.1 × 10⁻⁸  | Nummelin et al. (1998b) |
|                 | 119 ± 39  | 2.3 ± 1.8 × 10¹⁵ | 1.2 × 10⁻⁸  | this work               |
| C₂H₅OCH₃        | 50 - 150  | < 8 × 10¹³    | < 1 × 10⁻¹⁰ | this work               |
| **Orion KL**    |           |               |              |       |                         |
| CH₃OH           | 120 - 140 | 5 × 10¹⁶      | 5 × 10⁻⁷    | Sutton et al. (1985)    |
|                 | 140       | 4.5 × 10¹⁶    | 4.5 × 10⁻⁷  | Turner (1991) (Onsala)  |
|                 | 192 ± 18  | (1.6 ± 0.2) × 10¹⁶ | 1.6 × 10⁻⁷  | Turner (1991) (NRAO)    |
|                 | > 200     | 2.5 - 30 × 10¹⁶ | 1.6 × 10⁻⁶  | Sutton et al. (1995)    |
| C₂H₅OH          | 120 - 200 | 4.8 ± 16     | 6 × 10⁻⁷    | this work               |
| CH₃OCH₃         | 216 ± 100 | 6.6 ± 12.5 × 10¹⁵ | 6.6 × 10⁻⁸  | Turner (1991)           |
|                 | 289 ± 330 | 4.8 ± 10¹⁴    | 4.8 × 10⁻⁹  | this work               |
| C₂H₅OCH₃        | 75        | 2.5 × 10¹⁵    | 2.5 × 10⁻⁸  | Johansson et al. (1984) |
|                 | 63        | 3.0 × 10¹⁵    | 3.0 × 10⁻⁸  | Blake et al. (1986)     |
|                 | 91 ± 34   | 1.3 ± 0.1 × 10¹⁵ | 1.3 × 10⁻⁸  | Turner (1991)           |
|                 | 125       | ~ 3 × 10¹⁵    | 3.0 ± 10⁻⁸  | Sutton et al. (1995)    |
|                 | 197 ± 42  | 1.1 ± 0.6 × 10¹⁶ | 1.1 × 10⁻⁷  | Lee & Cho (2002)        |
|                 | 126 ± 43  | 4.6 ± 3.1 × 10¹⁵ | 4.6 × 10⁻⁸  | this work               |
| **SgrB2(N)**    |           |               |              |       |                         |
| CH₃OH           | I         | 49 ± 1        | (2.8 ± 0.7) × 10¹⁶ | 5.6 × 10⁻⁹ | Cummins et al. (1986)   |
|                 | II        | 26 ± 138      | 8.4 ± 18 × 10¹⁵ | 1.6 × 10⁻⁹ | Cummins et al. (1986)   |
|                 |           | 120 ± 20      | (3.5 ± 0.5) × 10¹⁵ | 7 × 10⁻¹⁰ | Cummins et al. (1986)   |
| C₂H₅OH          | 204 ± 392 | 6.9 ± 5.6 × 10¹⁵ | 1.4 × 10⁻⁹ | Turner (1991)           |
| CH₃OCH₃         | 24        | 5.2 ± 10¹⁴    | 1 × 10⁻¹⁰  | Cummins et al. (1986)   |
| CH₃OCH₃         | 80 ± 351  | 2.3 ± 0.9 × 10¹⁵ | 4.6 × 10⁻¹⁰ | Turner (1991)           |
| **W51e2**       |           |               |              |       |                         |
| CH₃OH           |           |               |              |       |                         |
|                 | a-type    | 208           | 1.0 × 10¹⁷    | 2.7 × 10⁻⁷ | Ikeda et al. (2002)     |
| C₂H₅OH          | 101 ± 4   | 2.5 ± 0.3 × 10¹⁶ | 6.9 × 10⁻⁸  | this work               |
| CH₃OCH₃         | 169 ± 28  | (3.1 ± 1.1) × 10¹⁵ | 8.6 × 10⁻⁹  | Ikeda et al. (2002)     |
| C₂H₅OCH₃        | 143 ± 20  | 1.6 ± 0.2 × 10¹⁶ | 4.4 × 10⁻⁸  | this work               |
| CH₃OCH₃         | 145 ± 5   | 1.6 ± 0.2 × 10¹⁶ | 4.4 × 10⁻⁸  | this work               |

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*a* We used N(H₂)(G34.26) = 4 × 10²³ cm⁻², N(H₂)(NGC6334) = 2 × 10²³ cm⁻², N(H₂)(Orion KL) = 1 × 10²³ cm⁻², N(H₂)(SgrB2(N)) = 5 × 10²⁴ cm⁻² and N(H₂)(W51e2) = 3.6 × 10²³ cm⁻², see section 4.  

*b* Observed at center of G34.26, as opposed to the halo.  

*c* The Onsala and CTT survey (see Turner (1991)) did not find any ethanol towards Orion KL and estimated an upper limit between 1.5 and 4 × 10¹⁴ cm⁻².  

Cummins et al. (1986)  

and Turner (1991) used two rotational temperature diagrams (I and II) to fit the observed CH₃OH lines. Cummins et al. (1986) uses the transitions with $E_u$ below 70 K for the fit I whereas Turner (1991) splits the two components I and II at $E_u = 40$ K.  

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For Cummins et al. (1986)
Table 3. EME transitions observed in W51e2

| Transition       | Observed frequency\(^a\) (MHz) | Theor. frequency\(^c\) (MHz) | Obs-calc line components | \(E_{\text{upper}}\) (K) | \(\int T_{mb}dv\) (K km s\(^{-1}\)) |
|------------------|-------------------------------|-------------------------------|--------------------------|-----------------|----------------------------------|
| 112₁₀⁻¹₁₁₁₁     | 80 882.3(5) \(^b\)           | 80 882.7(10) \(^d\)         | -0.4                     | 5               | 30.1                             |
| 241₂₃⁻₂₄₀₂₄⁴     | 81 198.4(1)                  | 81 198.7(5)                 | -0.3                     | 5               | 118.5                            |
| 35₂₃⁻₃₅₂₃₂₃     | 91 439.6(5)                  | 91 440.4(10)                | -0.8                     | 5               | 255.2                            |
| 38₁₃⁻₃₈₂₃₆₄     | 91 475.6(9)                  | 91 475.6(9)                 | -0.4                     | 5               | 269.3                            |
| 34₂₃⁻₃₄₂₃₃      | 91 630.1\(^e\)              | 91 630.8(5)                 | -0.7                     | 5               | 237.1                            |
| 34₃₁⁻₃₄₂₃₂      | -                            | 91 688.3(10)                | -                        | 5               | 241.5                            |
| 37₃₃⁻₃₇₂₃₅      | 91 812.7(4)                  | 91 812.6(9)                 | 0.1                      | 5               | 283.7                            |
| 35₂₃⁻₃₅₁₃₄      | -                            | 96 207.0(9)                 | -                        | 5               | 250.8                            |
| 29₂₋₉⁻₂₉₂₇      | 96 390.8(3)                  | 96 391.4(12)                | -0.6                     | 5               | 179.1                            |
| 3₂₋₁\(₂₁\)      | 96 464.1\(^f\)              | 96 464.3(6)                 | -0.2                     | 5               | 6.9                              |
| 2₂₋₁\(₂₂\)      | 107 654.8\(^f\)             | 107 656.8(14)               | -2.0                     | 5               | 108.3                            |
| 7₂₋₅⁻₆₁₆       | 131 350.2(10)                | 131 350.7(8)                | -0.5                     | 5               | 15.4                             |
| 1₅₁₅⁻₁₄₀₁₄      | 131 372.68(80)               | 131 372.8(5)                | -0.12                    | 5               | 46.7                             |
| 3₆₋₃₆⁻₃₆₀₃₆     | -                            | 150 502.4(19)               | 5                        | 260.0           | -                                |
| 3₄₋₃₃⁻₃₄₀₃₃     | 150 661.3(6)                 | 150 662.9(16)               | -1.6                     | 5               | 248.7                            |
| 1₃ₓ⁻₁₄₅₉₋₉yü     | 150 794.1\(^e\)             | 150 794.1(18)               | 0.0                      | 10              | 76.6                             |
| 2₀₋₂₀⁻₁₉₁₁₉      | 150 845.52(30)               | 150 845.5(2)                | 0.02                     | 5               | 80.4                             |
| [...]\(^f\)      | 215 325.4\(^e\)             | 215 326.3(13)               | -0.9                     | 6               | 102.2                            |
| 1₉ₓ⁻₁₉₁₁₉₋₉yü     | 217 939.6(3)                 | 217 940.7(1)                | -1.1                     | 5               | 154.7                            |
| 1₆₋₁₄⁻₁₅₂₁₃      | 245 104.6(32)                | 245 104.7(29)               | 1.43                     | 5               | 62.9                             |
| 3₁₋₃₀⁻₃₀₀₃₀      | 245 275.0(13)                | 245 274.1(1)                | 0.86                     | 5               | 188.8                            |
| 1₇₋₁₅⁻₁₆₂₁₄      | 252 190.7(11)                | 252 189.4(29)               | 1.3                      | 5               | 69.5                             |
| 2₈₋₂₇⁻₂₇₁₂₆      | 253 309.3(3)                 | 253 308.2(12)               | 1.09                     | 5               | 161.0                            |

\(^a\) Rest frequencies (assuming a source LSR velocity of +55 km s\(^{-1}\)) in W51e2.
\(^b\) The numbers in parenthesis are the estimated uncertainties (1\(\sigma\)).
\(^c\) Frequencies are taken from Fuchs et al.(2003)
\(^d\) The deviation from the mean frequency of the transitions to its extreme values, e.g. due to rotational and internal rotational splitting the transition 112₁₀⁻¹₁₁₁₁ is split in 5 transitions which occur between 80 881.7 - 80 883.6 GHz, thus the frequency denoted in the table is 80 882.7(10).
\(^e\) Manually determined (or in case of noise the closest peak). Here the transition 13ₓ⁻₁₄₅₉₋₉yü are with \(k_{c}= 7-9, 7-10, 8-9, 8-10\) and the x in 1₉ₓ⁻₁₉₁₁₉ denotes either 14 or 15.
\(^f\) Region with many blends of EME with other (dominating) molecules.
• Lines included in the Boltzmann fit II, see Fig. 5
□ Lines included in the Boltzmann fit I and II, see Fig. 5

\(n\) "Noisy" line, i.e. a line which has either less than 2\(\sigma\) intensity or where the intensity is difficult to obtain due to baseline variations.

\(b\) Denotes a blend with another molecular line where the other line contributes most to the total intensity.

\(c_{i}\) Denotes a contribution of another molecule to the total intensity where the blended line is estimated to contribute less than 20% (if not otherwise mentioned) compared to EME. Assuming \(T_{rot} \sim 100\ K:\)

\(c_{1}\) C₂H₂OOCCH with \(N \leq 5 \times 10^{15}\ \text{cm}^{-2}\) (could be up to 50%), \(c_{2}\) HOONO₂ with \(N \leq 5 \times 10^{14}\ \text{cm}^{-2}\), \(c_{3}\) c-H₂C₃O with \(N \leq 2 \times 10^{12}\ \text{cm}^{-2}\), \(c_{4}\) C₂H₂NH₂ with \(N \leq 8 \times 10^{15}\ \text{cm}^{-2}\), \(c_{5}\) C₂H₂CN with \(N \leq 2 \times 10^{14}\ \text{cm}^{-2}\), \(c_{6}\) C₂H₂C₁₅N with \(N \leq 3 \times 10^{13}\ \text{cm}^{-2}\) based on our observation that C₂H₂CN has \(N \sim 3 \times 10^{14}\ \text{cm}^{-2}\), \(c_{7}\) CH₂(OH)CHO with \(N \leq 8 \times 10^{14}\ \text{cm}^{-2}\), \(c_{8}\) a-H₂C=CHOH with \(N \leq 2 \times 10^{14}\ \text{cm}^{-2}\).
Table 4. Estimated column density for various source sizes and rotational temperatures for W51e2.

| source size [arc sec] | $T_{rot}$ [K] | column density [cm$^{-2}$] |
|------------------------|---------------|---------------------------|
| 20”                    | 30            | $\sim 5 \times 10^{13}$   |
|                        | 50            | $\sim 4 \times 10^{13}$   |
|                        | 70            | $\sim 4 \times 10^{13}$   |
| 10”                    | 50            | $\sim 8 \times 10^{13}$   |
|                        | 70            | $\sim 9 \times 10^{13}$   |
|                        | 150           | $1.3 \times 10^{14}$      |
| 5”                     | 70            | $2.0 \times 10^{14}$      |
|                        | 150           | $4.5 \times 10^{14}$      |
### Table 5. Observational parameters

| Receiver | $T_{\text{sys}}^{(a)}$ (K) | $\tau$ (min) | Tot. integr. time (on+off) (min) | $\rho^{(b)}$ | Telescope beam HPBW (°) | $1\sigma$ (rms) noise level (K as $T_A^*$) (MHz) | Band width (MHz) | Frequency resolution (MHz) |
|----------|------------------|-------------|-------------------------------|-------------|-----------------|---------------------------------|-----------------|-------------------------|
| **G34.26** | | | | | | | | |
| G34.26 | 81 041 | 144 | 0.03 | 85 | 0.79 | 30 | 0.012 | 490 | 0.3125 |
| | 91 626 | 122 | 0.03 | 115 | 0.77 | 26 | 0.010 | 490 | 0.3125 |
| | 96 371 | 137 | 0.02 | 145 | 0.77 | 25 | 0.014 | 490 | 0.3125 |
| | 131 372 | 200 | 0.06 | 115 | 0.71 | 18 | 0.018 | 490 | 0.3125 |
| | 150 750 | 307 | 0.04 | 220 | 0.68 | 16 | 0.017 | 490 | 0.3125 |
| | 215 500 | 388 | 0.22 | 196 | 0.56 | 11 | 0.032 | 1020 | 1.0 |
| | 217 900 | 350 | 0.14 | 147 | 0.55 | 11 | 0.023 | 1020 | 1.0 |
| | 245 260 | 511 | 1.90 | 160 | 0.50 | 10 | 0.034 | 510 | 1.25 |
| | 252 227 | 848 | 0.37 | 85 | 0.48 | 10 | 0.059 | 510 | 1.25 |
| **NGC 6334 I** | | | | | | | | |
| G34.26 | 81 041 | 327 | 0.41 | 38 | 0.76 | 59 | 0.009 | 994 | 0.6911 |
| | 91 450 | 195 | 0.26 | 37 | 0.74 | 55 | 0.007 | 994 | 0.6911 |
| | 91 630.7 | 185 | — | 87 | 0.74 | 55 | 0.005 | 994 | 0.6911 |
| | 91 811.7 | 212 | 0.06 | 57 | 0.74 | 55 | 0.007 | 994 | 0.6911 |
| | 96 380 | 252 | 0.21 | 55 | 0.73 | 53 | 0.009 | 994 | 0.6914 |
| | 150 662 | 263 | 0.34 | 95 | 0.65 | 33 | 0.012 | 994 | 0.6989 |
| | 245 105 | 513 | 0.96 | 77 | 0.47 | 22 | 0.024 | 994 | 0.6989 |
| | 245 274 | 534 | 0.50 | 127 | 0.47 | 22 | 0.017 | 994 | 0.6989 |
| **Orion KL** | | | | | | | | |
| G34.26 | 81 041 | 138 | 0.03 | 125 | 0.79 | 30 | 0.012 | 490 | 0.3125 |
| | 91 626 | 182 | 0.07 | 95 | 0.77 | 26 | 0.014 | 490 | 0.3125 |
| | 150 750 | 316 | 0.14 | 220 | 0.68 | 16 | 0.029 | 490 | 0.3125 |
| | 215 500 | 539 | 0.33 | 160 | 0.56 | 11 | 0.078 | 1020 | 1.0 |
| | 245 275 | 740 | 0.39 | 190 | 0.50 | 10 | 0.053 | 510 | 1.25 |
| **W51e2** | | | | | | | | |
| G34.26 | 81 041 | 113 | 0.04 | 95 | 0.79 | 30 | 0.012 | 490 | 0.3125 |
| | 91 626 | 116 | — | 60 | 0.77 | 26 | 0.012 | 490 | 0.3125 |
| | 96 371 | 119 | 0.07 | 95 | 0.77 | 25 | 0.013 | 490 | 0.3125 |
| | 107 650 | 223 | 0.14 | 52 | 0.75 | 22 | 0.018 | 490 | 0.3125 |
| | 131 372 | 179 | — | 60 | 0.71 | 18 | 0.019 | 490 | 0.3125 |
| | 150 750 | 249 | 0.26 | 215 | 0.68 | 16 | 0.020 | 490 | 0.3125 |
| | 215 500 | 221 | 0.415 | 195 | 0.56 | 11 | 0.063 | 1020 | 1.0 |
| | 217 900 | 301 | 0.634 | 112 | 0.55 | 11 | 0.044 | 1020 | 1.0 |
| | 245 260 | 371 | 0.75 | 75 | 0.50 | 10 | 0.051 | 510 | 1.25 |
| | 252 227 | 384 | 0.51 | 95 | 0.48 | 10 | 0.062 | 510 | 1.25 |
| | 253 300 | 330 | — | 85 | 0.48 | 10 | 0.045 | 510 | 1.25 |

(a) average system temperature

(b) $T_A^* = \rho T_{mb}$
Fig. 1. Stick spectrum of EME at a rotational temperature of 130 K which is typical for complex molecules in hot core regions. EME has a dense spectrum with many characteristic features. The frequencies are taken from Fuchs et al. (2003). The (⋆) indicate our chosen frequency regions for the W51e2 observations. The intense line at 237 GHz was not selected because of a blending line at the same frequency.

Fig. 2. Observed spectrum of W51e2 at 151 GHz (upper) and simulated spectrum using myXCLASS (lower) including C2H5OCH3, C2H5OOCH, CH3CH3CO, a-(CH2OH)2, c-C2H4O, C2H5OH, CH3OCH3, CH3CHO-e, CH3OH, C2H5OH, CH3OCHO-e, and CH3OCHO-a.
Fig. 3. Spectra recorded towards W51e2. The EME transitions $^{20}_0-^{19}_1$ at 150 845.5 MHz, $^{19}_{5,x}-^{19}_{4,15}$ at 215 325.4 MHz, $^{16}_{3,14}-^{15}_{2,13}$ at 245 106.4 MHz, and $^{17}_{3,15}-^{16}_{2,14}$ at 245 190.7 MHz are indicated.
Fig. 4. The $20_{0,20}-19_{1,19}$ transition of EME at 150 845.5 MHz. The line profile observed towards W51e2 (bold) is compared to three simulated line profiles (dashed) of 0.2, 0.7, and 1.4 MHz line widths (FWHM). For a line width of 0.2 MHz (FWHM) the splitting due to internal torsional motion of the molecule is partly resolved. The stick diagram indicates the position and relative intensities of the split lines based on our recent high resolution laboratory measurements [Fuchs et al. (2003)]. For comparison with the observed spectrum all simulated spectra are normalized to have the same peak intensity.

Fig. 5. Boltzmann plot for the EME transitions found towards W51e2 based on 14 observed lines, assuming no beam dilution. Due to difficulties in assigning the lines to EME two fits have been been performed. I) Fit including all lines marked with □ and • in Table 3. Here $T_{\text{rot}} = 126 \pm 115$ K and $\log(N_t) = 14.9 \pm 0.7$. II) Fit using only lines with intensities $\geq 2\sigma$ (•) resulting in $T_{\text{rot}} = 54 \pm 38$ K and $\log(N_t) = 14.3 \pm 1.2$. Lines which are less than $2\sigma$ intense are marked with an □.
Fig. 6. Observed spectrum at W51e2 (top, dashed) and calculated spectra for different column densities of EME at 70K.

Fig. 7. Observed spectra of Orion KL and W51e2 at 215 GHz. This frequency region has the highest line density of all our observed bands but even here gaps can be found where the presence of EME can be checked. Two simulated spectra of EME are plotted, i.e. $N=2 \times 10^{14}$ cm$^{-2}$ (blue) and $N=1 \times 10^{15}$ cm$^{-2}$ (red) with $T_{\text{rot}}=70$ K. The splitting of the lines which can best be seen above 215600 MHz is mainly due to the internal rotation of the methyl groups of EME with an additional small asymmetry contribution. a) For Orion KL the previously estimated limits of $10^{14}$ - $10^{15}$ cm$^{-2}$ by Charnley et al. (2001) seem questionable as can be seen from the superimposed simulated spectra on the observed spectra. b) In the case of W51e2 the simulated spectrum is in agreement with the observation.
Fig. 8. Spectra of the observed sources at 245 GHz. Only W51e2 reveals a line at an EME transition frequency, whereas all other sources do not show any significant feature above 1σ level. However, W51e2, G34.26 and NGC6334I have similar spectra indicating the same chemical composition and equivalent dynamics.

Fig. 9. Relative abundances of CH$_3$OH, C$_2$H$_5$OH, CH$_3$OCH$_3$ derived from Table 2 by using the values from Turner(1991) for Orion KL, Turner(1991) for SgrB2(N), Thompson et al.(1999) and Ikeda et al.(2002) for G34.26, this work for W51e2 and Nummelin et al.(1998b) for NGC6334I. The ratio of EME/C$_2$H$_5$OH in W51e2 is 0.13 which is 5 times smaller than the ratio of CH$_3$OCH$_3$/CH$_3$OH.