Brief overview of periodic methanol masers

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19 March 2015
Collaborators

- Sharmila Goedhart
- Fanie van den Heever (see poster)
- Jabulani Maswanganye (talk)
- Ruby van Rooyen
Numerous observational studies indicate that the bright 6.7 GHz and 12.2 GHz masers are exclusively associated with very young high mass stars. (Eg. Ellingsen 2006; Breen et al. 2013; de Villiers et al. 2014)

Methanol Multibeam Survey detected 972 6.7 GHz methanol maser sources in the Galaxy (Shari Breen). All high mass star forming regions.

Methanol masers may be very useful indicators of the evolutionary state of the associated system:

- Strong association between presence of 6.7 GHz masers and outflows (de Villiers et al. 2014)
- Relatively small percentage of UCHII regions show associated 6.7 GHz maser emission. Pre-UCHII phase? (Codella & Moscadelli 2004)

Most 6.7 GHz and 12.2 GHz masers show some degree of variability. Some show periodic “flaring” behaviour.
Reported periodic/regular varying masers: 16 known

<table>
<thead>
<tr>
<th>Name</th>
<th>Methanol</th>
<th>OH</th>
<th>Other</th>
<th>Period (days)</th>
<th>Authors</th>
</tr>
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<tbody>
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<td>G9.62+0.20E</td>
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<td>Maswanganye et al.</td>
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</table>

- Periodic masers probe “something” on the AU scale. (Similar to Gabriele Surcis’s use of masers to probe magnetic fields)
- Ask different questions within the context of high mass star formation
Examples of methanol maser light curves

- G9.62+0.20E (12.2 GHz)
- G338.93-0.06 (6.7 GHz)
- G358.460-0.391 (6.7 GHz)
- G339.98-0.425 (6.7 and 12.2 GHz)

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Brief overview of periodic methanol masers
Some questions about the periodic masers:

- What is the underlying driving mechanism for the periodicity? Stellar pulsations, binary system, etc?
- What is affected by the driving mechanism, the masing region or background?
- Are there different “types” of periodic/regular varying masers - flare profiles?
- What can we learn about the star formation environment from these masers?
- Can we see the same behaviour in other masing species and what does it mean?
Variability of masers

Basic relation:

\[ I_m(t) = I_0(t) e^{-\tau_m(t)} \]

<table>
<thead>
<tr>
<th>Proposed Mechanism</th>
<th>( \tau_m(t) )</th>
<th>( I_0(t) )</th>
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<tbody>
<tr>
<td>Orbiting circumstellar dust features</td>
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<tr>
<td>Spiral density waves</td>
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<td>Stellar pulsations</td>
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<tr>
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<tr>
<td>Precessing jet</td>
<td>✓</td>
<td>?</td>
</tr>
<tr>
<td>Colliding-wind Binary</td>
<td>✓</td>
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</tbody>
</table>

- The Polish group concludes that the periodic masers are indicative of massive binary systems.
- No consensus on whether periodicity is due to changes in amplification or background.
- We need to understand what’s driving the periodicity and what is affected in order to learn what the periodic masers tell us.
Two reasonable statements can be made:

- Flare profile **must** carry information about underlying physical mechanism - think of optical light curves for pulsating stars or of binary systems.
- The same mechanism must be at work in sources with similar flare profiles

Make sense to first consider sources with similar flare profiles.
At least four sources with similar flare profiles:

- G9.62+0.20E: 6.7 (A-methanol) & 12.2 (E-methanol), OH
- G22.357+0.066: 6.7 GHz
- G37.55+0.20: 6.7 GHz + H$_2$CO
- G45.473+0.134: 6.7 GHz (new)
Two masers are 2000 AU apart in projection (Araya et al. 2010)

CH$_3$OH and H$_2$CO masers show the same flare profile!

Should the flaring be due to pumping $\Rightarrow$

$$\left[ \frac{g_u}{g_l} x_l(t) - x_u(t) \right]_{\text{CH}_3\text{OH}} - \left[ \frac{g_u}{g_l} x_l(t) - x_u(t) \right]_{\text{H}_2\text{CO}} = \text{constant}$$

Different molecules with different pump cycles should behave in a very specific way. **Very strict requirement.**

Even if both masers are radiatively pumped, how should $T_d(t)$ as well as the IR spectra be tuned to achieve such behaviour?
G9.62+0.20E and similar sources

- Similar conclusion can be reached for G9.62+0.20E: Three transitions (6.7, 12.2 & 107 GHz) for two types of molecules (A- and E-methanol) show the same flare profile.

Same behaviour seen in 12.2 GHz masers in G188.95+0.89. Again two different masing molecules with the same time dependence.
Recent monitoring results on OH in G9.62+0.20E using KAT-7

Common characteristic in all these sources is the shape of the decay.
Proposed explanation (see poster by Fanie van den Heever)

\[
dn_e/dt = -\alpha n_e^2 + \Gamma_\star + \Gamma_p(t) n_H
\]

\[
dn_e/dt = -\alpha n_e^2 + \alpha n_{e,*}^2
\]

\[
I_\nu(t) \propto n_{e,*}^2 \left[ \frac{1 + u_0 \tanh(\alpha n_{e,*}t)}{u_0 + \tanh(\alpha n_{e,*}t)} \right]^{-2}
\]
Fitting the decay of the flares

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Brief overview of periodic methanol masers
Fitting the decay of the most recent flares in G9.62+0.20E

\[ n_e,\star = 1.54 \times 10^5 \text{ cm}^{-3} \]
\[ u_0 = 1.07 \]

\[ \text{Start 12 GHz} \]

\[ \text{G9.62+0.20E (OH 1665 MHz, 1.63 km/s)} \]

\[ n_e,\star = 3.1 \times 10^5 \text{ cm}^{-3} \]
\[ u_0 = 1.07 \]

\[ \text{Start 12 GHz} \]

\[ \text{G9.62+0.20E (OH 1667 MHz, 1.78 km/s)} \]

\[ n_e,\star = 5.7 \times 10^5 \text{ cm}^{-3} \]
\[ u_0 = 1.85 \]

\[ \text{Start 12.2 GHz} \]

\[ \text{G9.62+0.20E (CH_3OH 12.2 GHz, 1.25 km/s)} \]

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Brief overview of periodic methanol masers
The known number of periodic methanol masers has more than doubled over the last couple of years.

The periodic masers reveal the presence of time dependent phenomena associated with very young massive stars that would not have been detected otherwise.

Some masers definitely have the same type of flare profile which implies the same underlying mechanism.

The decay part of the flares for four sources plus the long term decay seen in G188.95+0.89 can be described very well in terms of the recombination of a thermal hydrogen plasma. **Single simple mechanism and requires NO fine tuning.**

It is not clear yet to what extent the periodic behaviour in some of the sources can be ascribed to changes in the pumping of the masers.