Thoughts on the origin and mechanisms of periodic masers

Johan van der Walt

Centre for Space Research, North-West University, Potchefstroom Campus, Potchefstroom, South Africa

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The problem and questions

Less than two hands full of methanol maser sources that show periodic-like or regular changes in observed maser flux density.

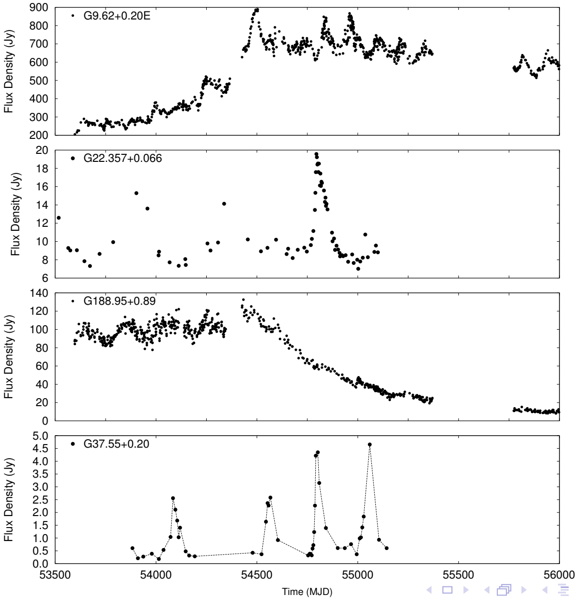
Some questions about the periodic masers:

- What drives the periodicity? Stellar pulsations, binary system?
- What is affected by the driving mechanism, the masing region or background?
- Are there different "types" of periodic/regular varying masers?
- 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?

Periodic/regular varying masers: 9 known

Name	Methanol	OH	Other	Period (days)	Authors
G9.62+0.20E	✓			243	Goedhart et al.
G12.89+0.49	✓			29.5	Goedhart et al.
G22.357+0.066	✓			179	Szymczak et al
G37.55+0.20	✓		H_2CO	237	Araya et al
		6.035		?	Al-Marzouk et al
G188.95+0.89	✓			404	Goedhart et al.
G328.24-0.55	✓			220	Goedhart et al.
G331.13-0.24	✓			504	Goedhart et al.
G338.93-0.06	✓			133	Goedhart et al.
G339.62-0.12	✓			201	Goedhart et al.

Examples of 6.7 GHz light curves



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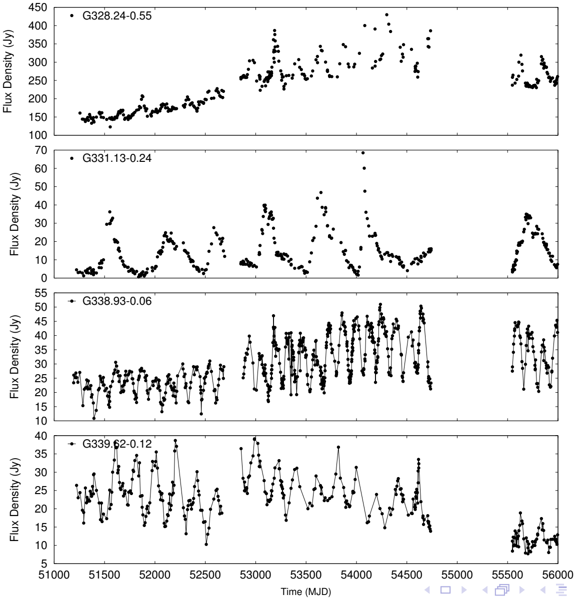

Variability of masers

Basic relation:

$$I_m(t) = I_0(t)\, e^{-\tau(t)}$$

Sobolev et al (1998) to study effect of turbulence on maser spectra:

$$T_m(y, z) = T_{bg} e^{\tau_0 f_m(y,z)}$$

Some Proposed mechanisms

Mechanism	$\tau_m(t)$	$I_0(t)$
Orbiting circumstellar dust features	✓	
Spiral density waves	✓	
Stellar pulsations	✓	✓
Circumstellar matter in accreting binary	✓	
Precessing jet	✓	?
CWB	✓	✓

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- What properties of the flaring can be used to perhaps distinguish whether the origin of the periodic/regular flaring/variability lies in $I_0(t)$ or in $\tau_m(t)$?

Time dependent calculation of level populations

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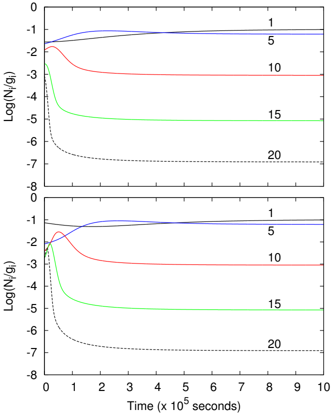
The Rate Equations

$$
\begin{aligned}
\frac{dN_i}{dt} = & \sum_{j<i}[(-N_i + (\frac{g_i}{g_j}N_j - N_i)W\mathcal{N}_{ij})\beta_{ij}A_{ij} \\
& + C_{ij}(N_j\frac{g_i}{g_j}e^{-E_{ij}/kT} - N_i)] \\
& + \sum_{j>i}(N_j + (N_j - \frac{g_j}{g_i}N_i)W\mathcal{N}_{ji})\beta_{ji}A_{ji} \\
& + C_{ji}(N_j - N_i\frac{g_j}{g_i}e^{-E_{ji}/kT})]
\end{aligned} \quad (1)
$$

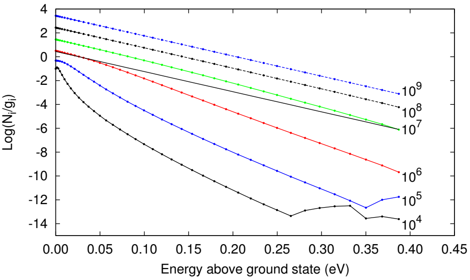
$$
I_d(\nu) = \left(\frac{\nu}{\nu_0}\right)^p B_\nu(T); \quad \beta_{ji} = \frac{1 - e^{\tau_{ji}}}{\tau_{ji}}
$$

$$
\tau_{ji} = \frac{A_{ji}}{8\pi}\left(\frac{c}{\nu_{ji}}\right)^3 \left(\frac{g_j}{g_i}x_i - x_j\right)\frac{N_{mol}}{\Delta v}
$$

Testing on CO



- $T_g = T_d = 300$ K
- $N_{CO}/\Delta v = 10^5$ cm^{-3} s
- $n_{H_2} = 10^4$ cm^{-3}



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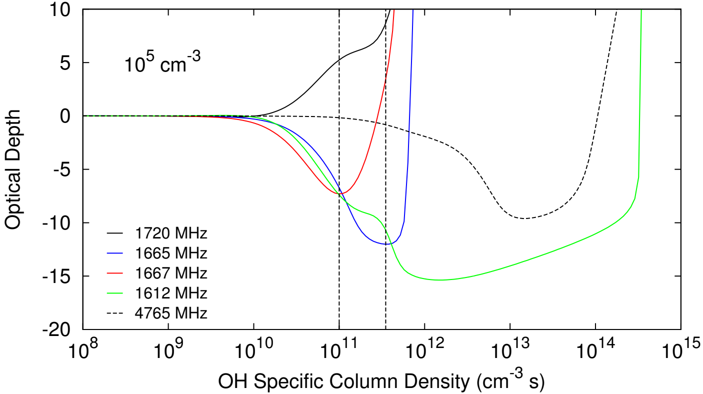
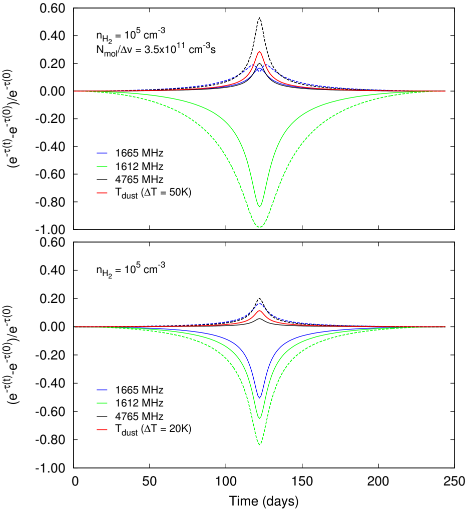
Example of pumping calculation for OH



Only 24 levels taken from the LAMDA
Collisions with ortho- and para-H_2
Line overlap following Elitzur & Netzer.
At present only for the 53 μm line

$T_g = 50$ K
$T_d = 175$ K
$W = 0.1$
$p = 2$

Time dependent T_d



Top panel:

Solid: $\Delta T_d = 20$ K

Dashed: $\Delta T_d = 50$ K

$T_d(0) = 175$ K

$T_g = 50$ K

$W = 0.1$

$p = 2$

Bottom panel:

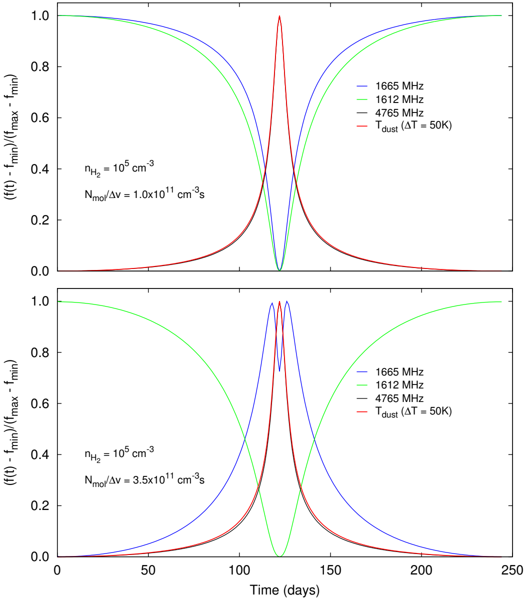
$\Delta T_d = 20$ K.

Solid: $N/\Delta v = 10^{11}$

Dashed: $N/\Delta v = 3.5 \times 10^{11}$

Note small values of relative amplitudes!

Normalized profiles



- For OH: Flare profiles for different transitions do not necessarily reflect $T_d(t)$
- For OH: The masing transitions respond in different ways to changes in pumping radiation field. ie. flare profiles are not the same.
- Would require extreme fine tuning to have the same flare profiles for the different transitions

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- Masers from different transitions and/or different molecules having the same flare profile seems not to be the rule but the exception ("fine tuning") and *may* point to changes in I_o rather than in τ_m.

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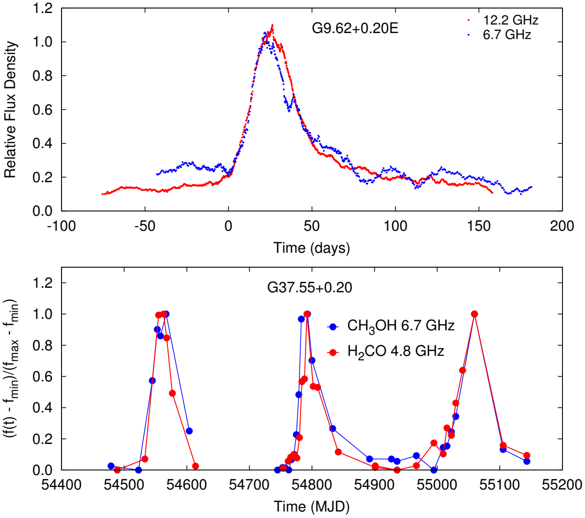
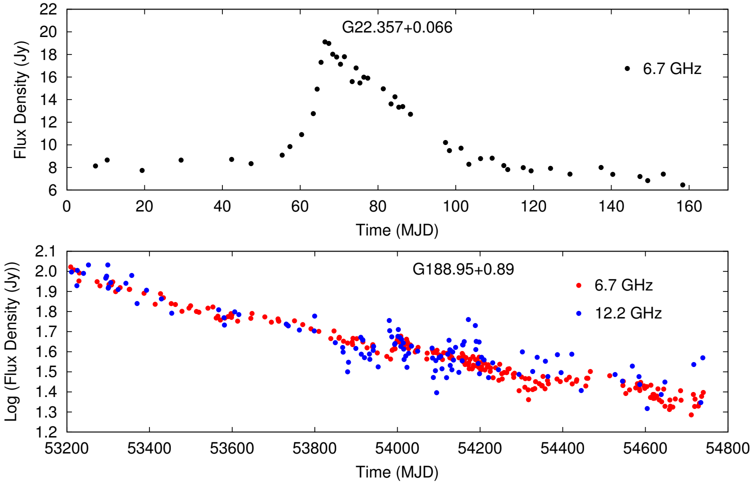
- Masers from different transitions and/or different molecules having the same flare profile seems not to be the rule but the exception ("fine tuning") and *may* point to changes in I_o rather than in τ_m.
- Masers with the same type of flare profile are *most likely* driven by the same underlying process (Szymczak et al., 2010)

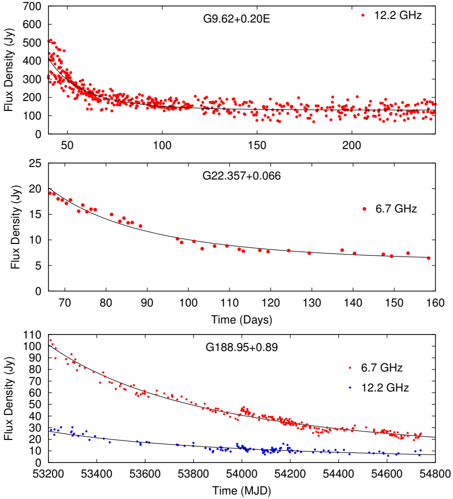
G9.62+0.20E & G37.55+0.20



G22.357+0.066 & G188.95+0.89



G9.62+0.20E, G22.357+0.066 & G188.95+0.89



$$I_\nu(t) \propto n_{e,\star}^2 \left[\frac{1 + u_0 \tanh(\alpha n_{e,\star} t)}{u_0 + \tanh(\alpha n_{e,\star} t)}\right]^{-2}$$

Is the periodic flaring due to changes T_d only? Conclusions

- G9.62+0.20E, G22.357+0.066 and G37.55+0.20 have similar flaring characteristics suggesting the same mechanism underlies the flaring.
- The decays of the 6.7 and 12.2 GHz maser flares in G9.62+0.20E and the 6.7 GHz maser in G22.357+0.066, as well as the 1600 day decay of the 6.7 and 12.2 GHz masers in G188.95+0.89 can be explained in terms of the recombination of a thermal hydrogen plasma. G37.55+0.20 need more data.
- G9.62+0.20E, G22.357+0.066 (see poster) as well as periodicity in G188.95+0.89 (van der Walt, 2011) *can* be explained within the framework of a CWB. G37.55+0.20 need more data.
- G338.93-0.06, G339.62-0.12 are complex while G12.89+0.49 has a very short period. Would be very difficult to explain with a CWB scenario. Uncertain about G328.24-0.55 and G331.13-0.24.
- Multi-transition monitoring necessary!

Some take away thoughts

- Whether you prefer $I_0(t)$ or $\tau_m(t)$, there must be a plausible physical mechanism.
- Whether you prefer $I_0(t)$ or $\tau_m(t)$, you must be able to explain the flare profile – not only the period.
- Whether you prefer $I_0(t)$ or $\tau_m(t)$, you have to consider the energetics of the system. For example, in the case of the CWB model: can the shocked gas produce enough ionizing photons to explain required changes in the electron density at the ionization front. Can it produce the required changes in T_d? But where are the masers located?? $\mathrm{L_{star}} \gg \mathrm{L_{wind}} \gg \mathrm{L_{shock}}$

daimontribe.deviantart.com