Brief overview of periodic methanol masers

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Collaborators

- Sharmila Goedhart
- Fanie van den Heever (see poster)
- Jabulani Maswanganye (talk)
- Ruby van Rooyen

The broader context: High mass star formation and methanol masers

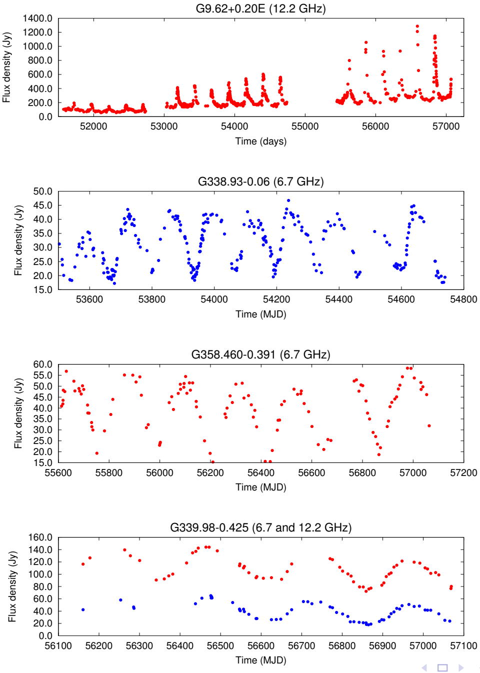
- Numerous observational studies indicate that the bright 6.7 GHz and 12.2 GHz masers are exclusively associated with very young high mass stars. (Eg. Ellingsen 2006; Breen et al. 2013; de Villiers et al. 2014)
- Methanol Multibeam Survey detected 972 6.7 GHz methanol maser sources in the Galaxy (Shari 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

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.
G22.411+0.105	✓			245	Szymczak et al.
G37.55+0.20	✓		H_2CO	237	Araya et al.
		6.035		?	Al-Marzouk et al
G45.473+0.134	✓			195.7	Szymczak et al.
G73.060+1.80	✓			160	Szymczak et al.
G75.76+0.34	✓			119.9	Szymczak et al.
IRAS22198+6336	✓			34.6	Fujisawa 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.
G339.986-0.425	✓			249	Maswanganye et al.
G358.460-0.391	✓			220	Maswanganye et al.

- 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



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:

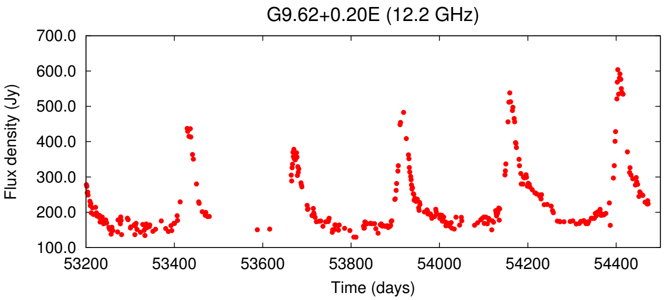
$$I_m(t) = I_0(t)\, e^{-\tau_m(t)}$$

Proposed Mechanism	$\tau_m(t)$	$I_0(t)$
Orbiting circumstellar dust features	✓	
Spiral density waves	✓	
Stellar pulsations	✓	✓
Circumstellar matter in accreting binary	✓	
Precessing jet	✓	?
Colliding-wind Binary	✓ ?!	✓

- 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.

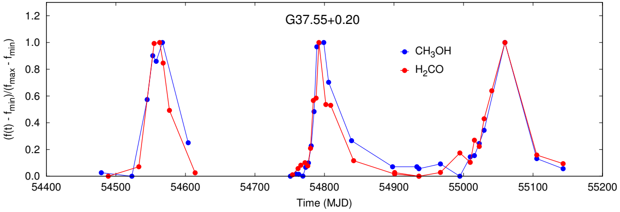
Periodic variability of masers

- 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.



- <u>At least</u> 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_2CO
  - G45.473+0.134: 6.7 GHz (new)

G9.62+0.20E and similar sources: G37.55+0.20



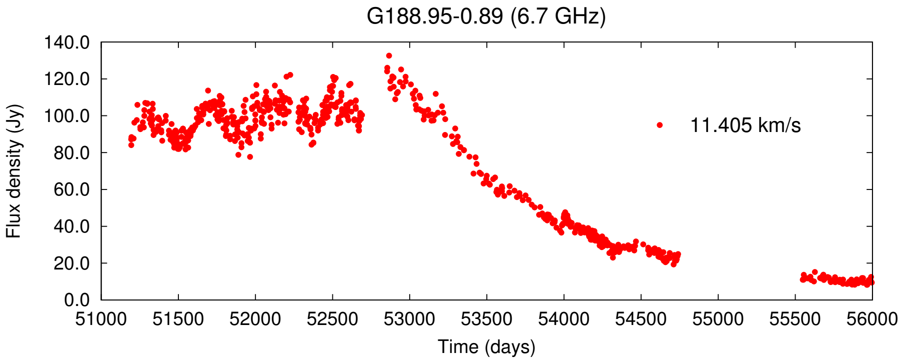
- Two masers are 2000 AU apart in projection (Araya et al. 2010)
- CH_3OH and H_2CO masers show the same flare profile!
- Should the flaring be due to pumping ⇒

$$\left[\frac{g_u}{g_l}x_l(t) - x_u(t)\right]_{\mathrm{CH_3OH}} - \left[\frac{g_u}{g_l}x_l(t) - x_u(t)\right]_{\mathrm{H_2CO}} = \mathrm{constant}$$

- 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 $\mathrm{T_d(t)}$ as well as the IR spectra be tuned to achieve such behaviour?

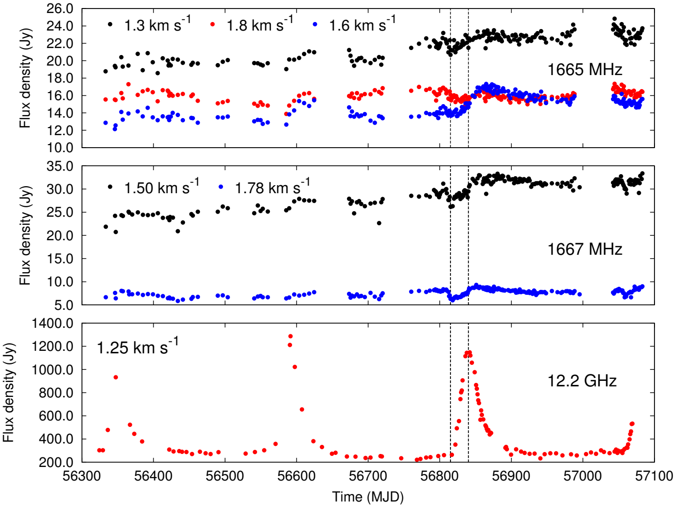
G9.62+0.20E and similar sources

- 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.



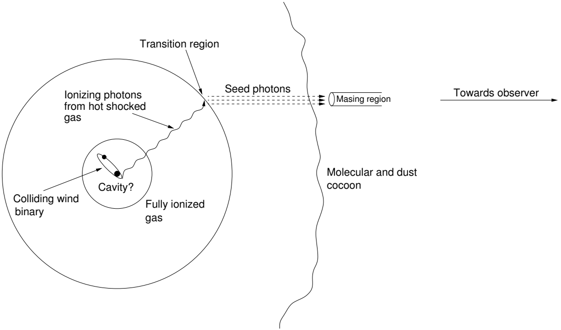
Same behaviour seen in 12.2 GHz masers in G188.95+0.89. Again two different masing molecules with the same time dependence.

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)

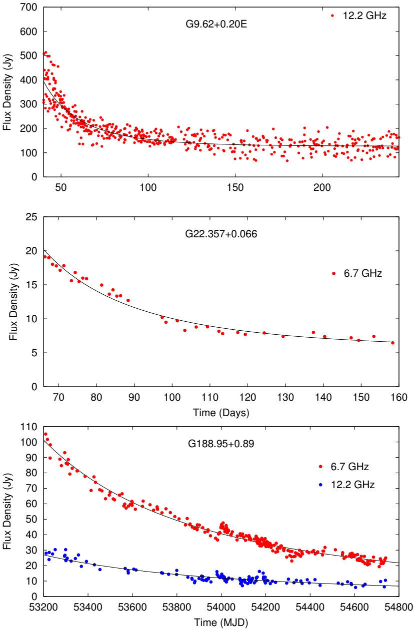


$$dn_e/dt = -\alpha n_e^2 + [\Gamma_\star + \Gamma_p(t)]n_H$$

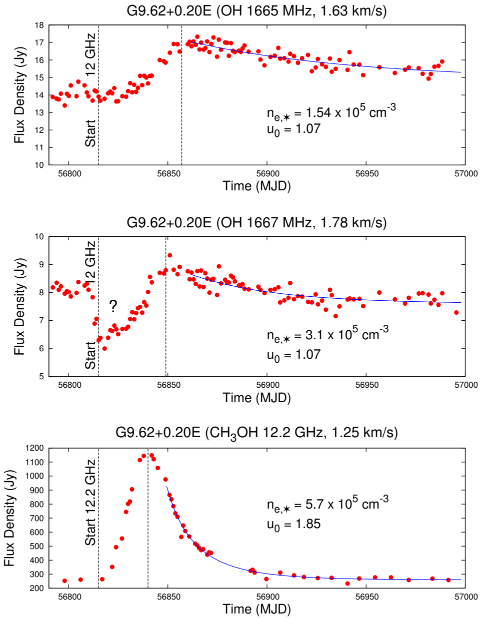
$$dn_e/dt = -\alpha n_e^2 + \alpha n_{e,\star}^2$$

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

Fitting the decay of the flares



Fitting the decay of the most recent flares in G9.62+0.20E



Summary

- 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.