Masers and High-mass Star Formation

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Introduction

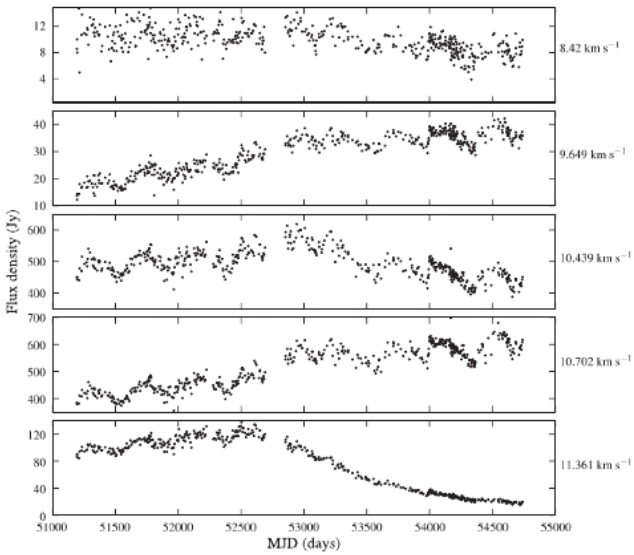
- Association of masers with star forming regions is well known.
- Common maser molecules:
  $SiO, OH, NH_3, H_2O, H_2CO, CH_3OH$
- Numerous surveys have been done in the past to catalog Galactic masers (see eg. work by Jim Caswell and co-workers).
- Main use of masers: diagnostic of physical conditions, kinematics (proper motion studies), magnetic fields, Galactic structure.
- Advantages: Masers "probe" small regions of molecular gas; are bright and can easily be detected/monitored with single dish telescopes.
- Difficulties: Non-LTE physics involved. Population inversion possible over a range of physical conditions.

Time domain study of masers

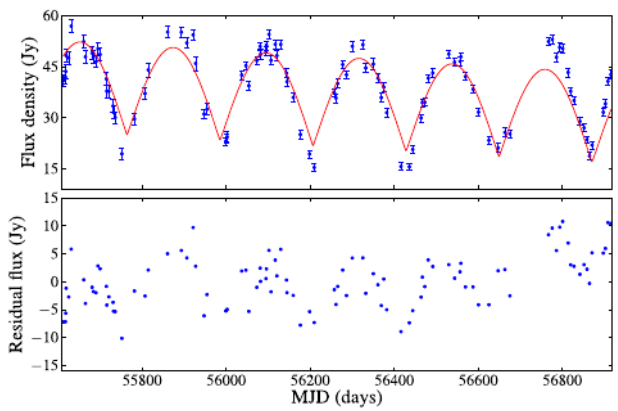
- Has been known that masers associated with high-mass star forming regions are variable.
- Discovery of periodic varying CH_3OH masers in G9.62+0.20E (Goedhart et al, 2003).
- Currently $\sim$ 25 periodic methanol maser sources out of a total of $\sim$ 950 detected methanol masers
- Periods range from 29 days to more than 500 days
- A variety of light curves suggests more than one underlying periodic mechanism (orbital motion, stellar pulsation)
- Recently also periodic OH masers discovered (Goedhart et al, 2019, Seidu et al, 2019, in preparation). One periodic $CH_3OH + H_2CO$ source also known.
- Class II methanol masers: Lifetime $\sim$ (25 - 40) kyr

Periodic methanol masers: Examples of time series

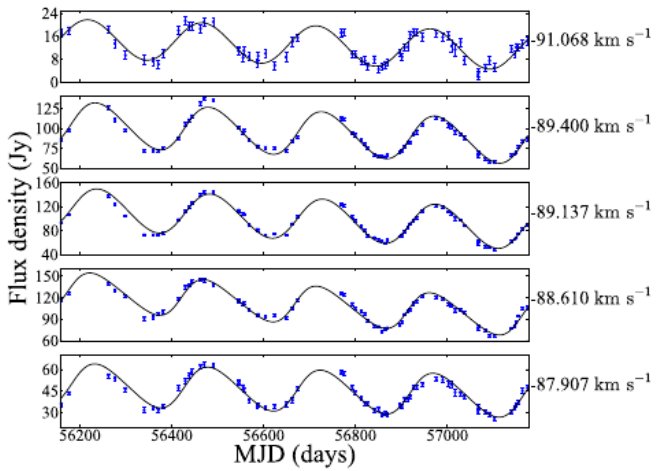
G188.95+0.89 (Goedhart et al. 2014)



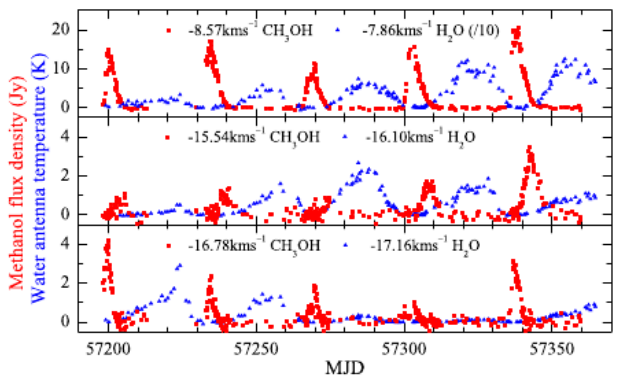
G358.460-0.391 (Maswanganye et al. 2014)



G339.986-0.425 (Maswanganye et al. 2016)

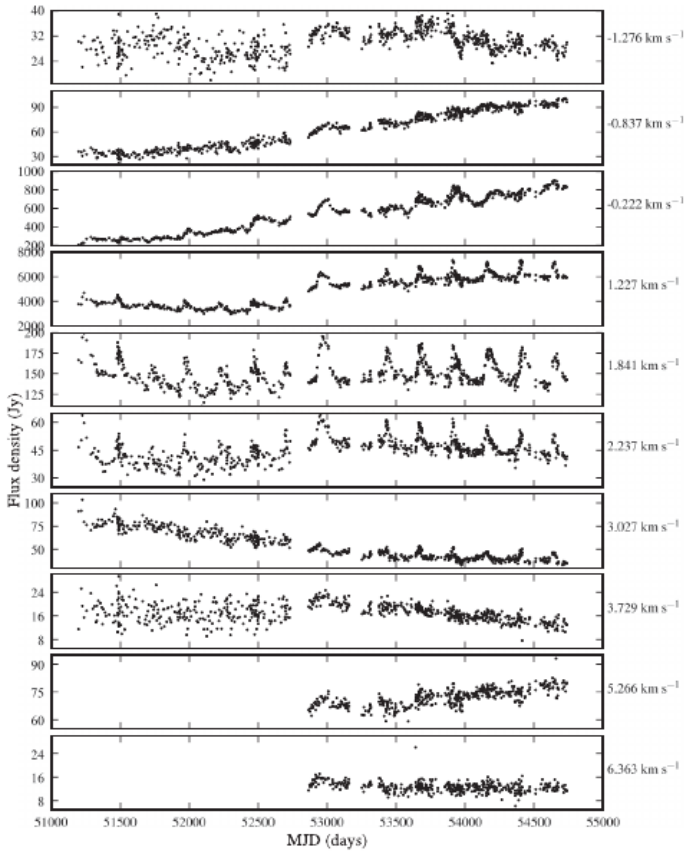


G107.298+5.369 (Szymczak et al. 2016)



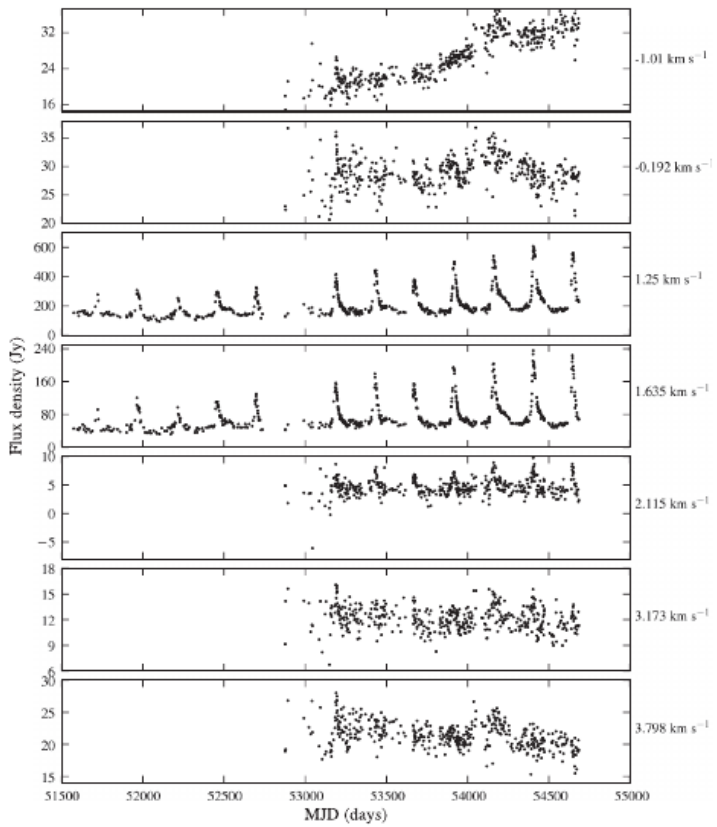
Periodic methanol masers: G9.62+0.20E (P = 243 days)

6.7 GHz A-methanol



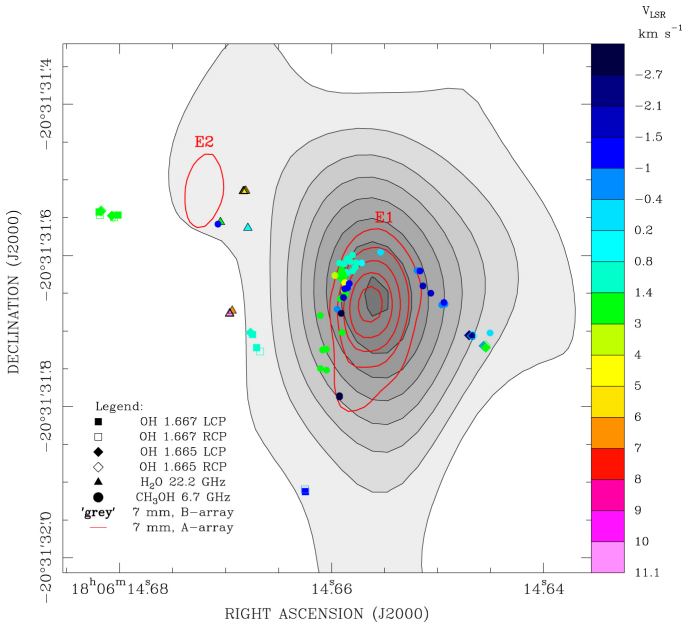
(Goedhart et al., 2014).

12.2 GHz E-methanol

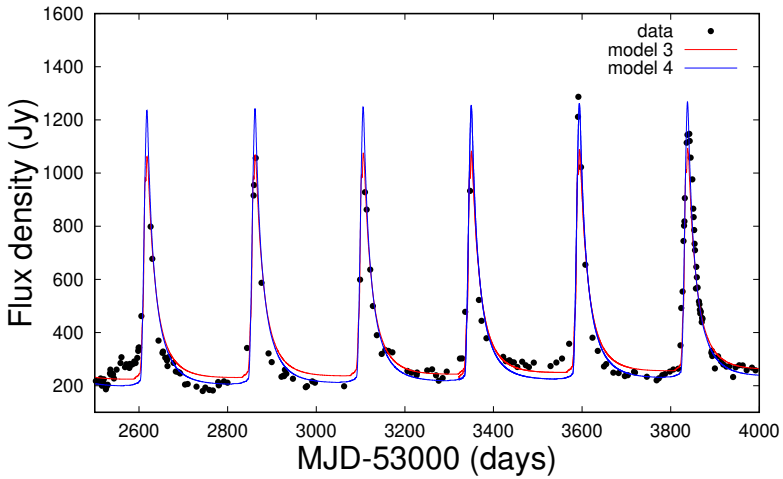


(Goedhart et al., 2014)

Periodic methanol masers: G9.62+0.20E



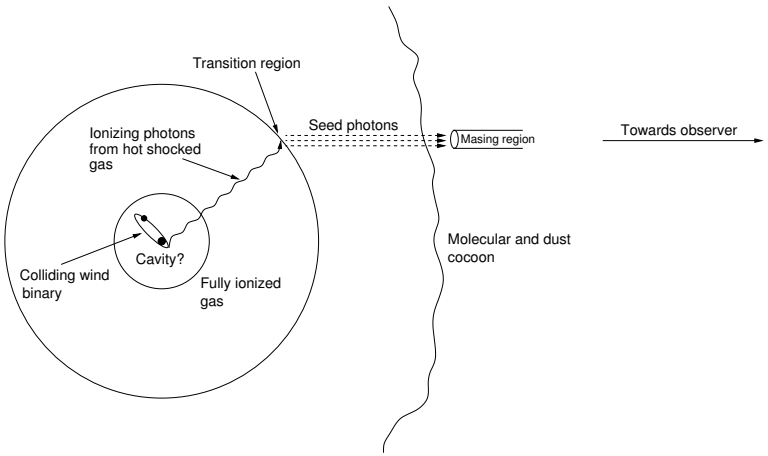
(From Sanna et al, 2015).



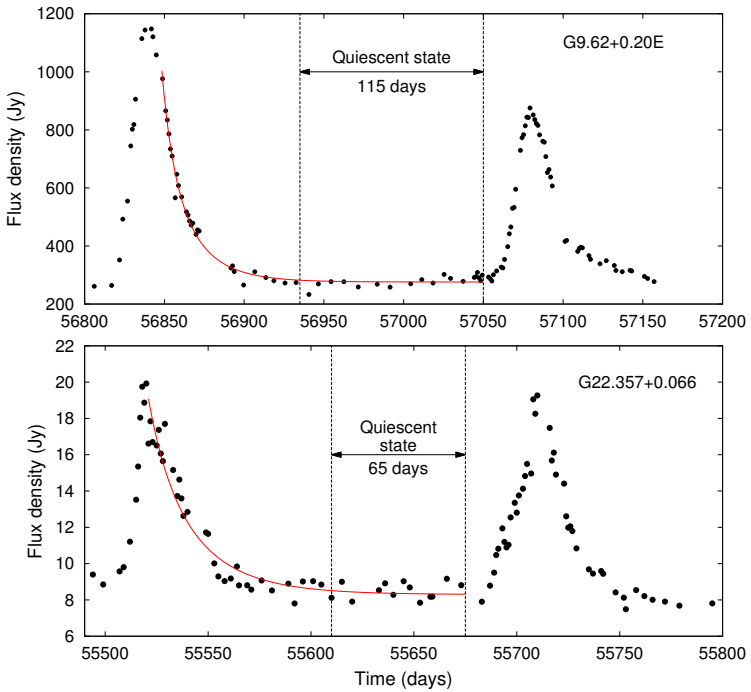
(From van den Heever et al, 2019)

- Decay of flares is very well described in terms of free-free emission from recombining hydrogen plasma.
- Postulate the presence of a young colliding-wind binary system as the periodic source of ionizing photons. (Multiplicity of young high-mass stars - Sarah Sadavoy's talk)

Periodic methanol masers



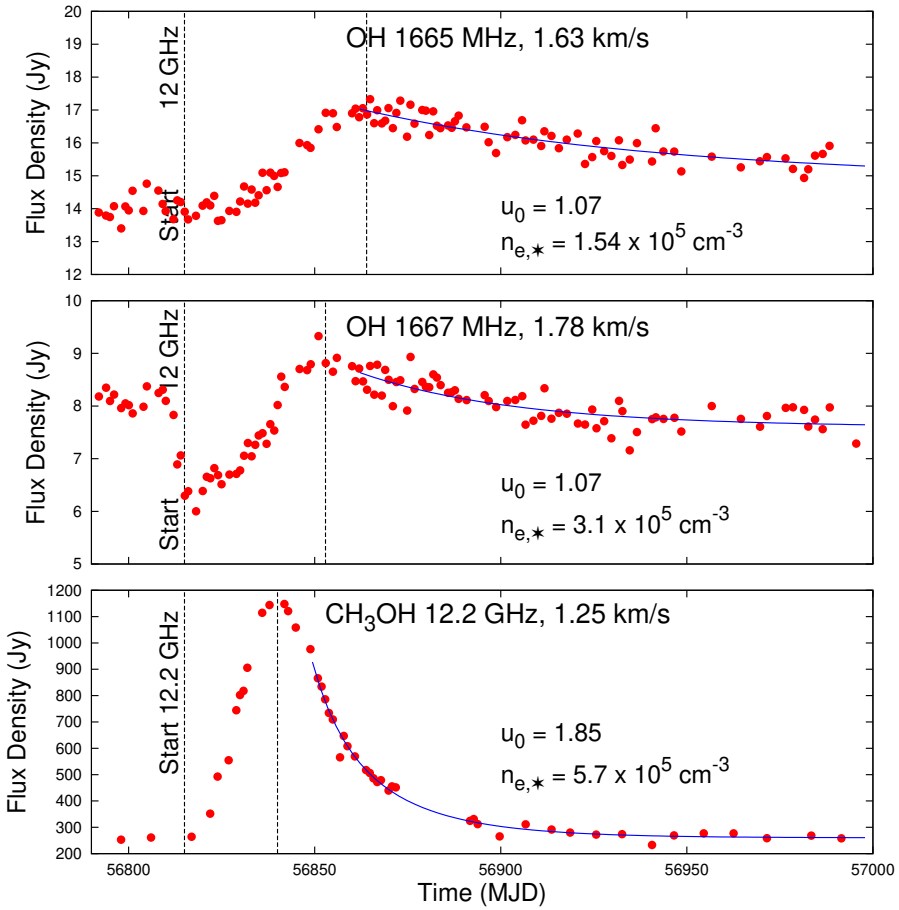
(From van der Walt, 2011)



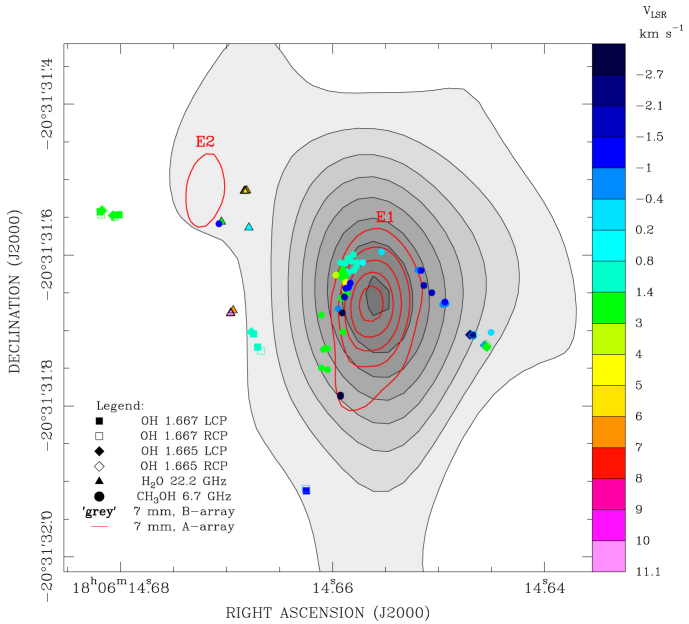
(From van der Walt et al, 2016)

- $I_\nu(t) \propto n_{e,\star}^2 \left[\frac{1+u_0 \tanh(\alpha n_{e,\star} t)}{u_0+\tanh(\alpha n_{e,\star} t)}\right]^{-2}$, $u_0 = n_{e,0}/n_{e,\star}$, $\alpha =$ recomb. coefficient

Periodic methanol and OH masers (G9.62+0.20E)

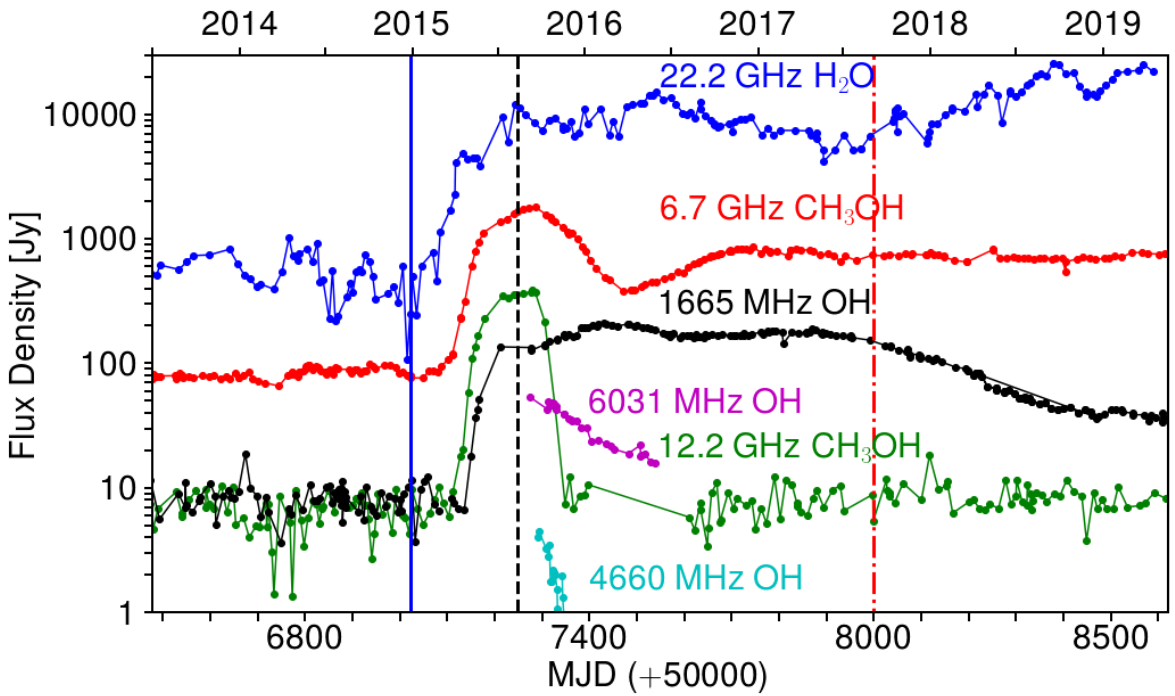


(Goedhart et al., 2019)



(Sanna et al, 2015).

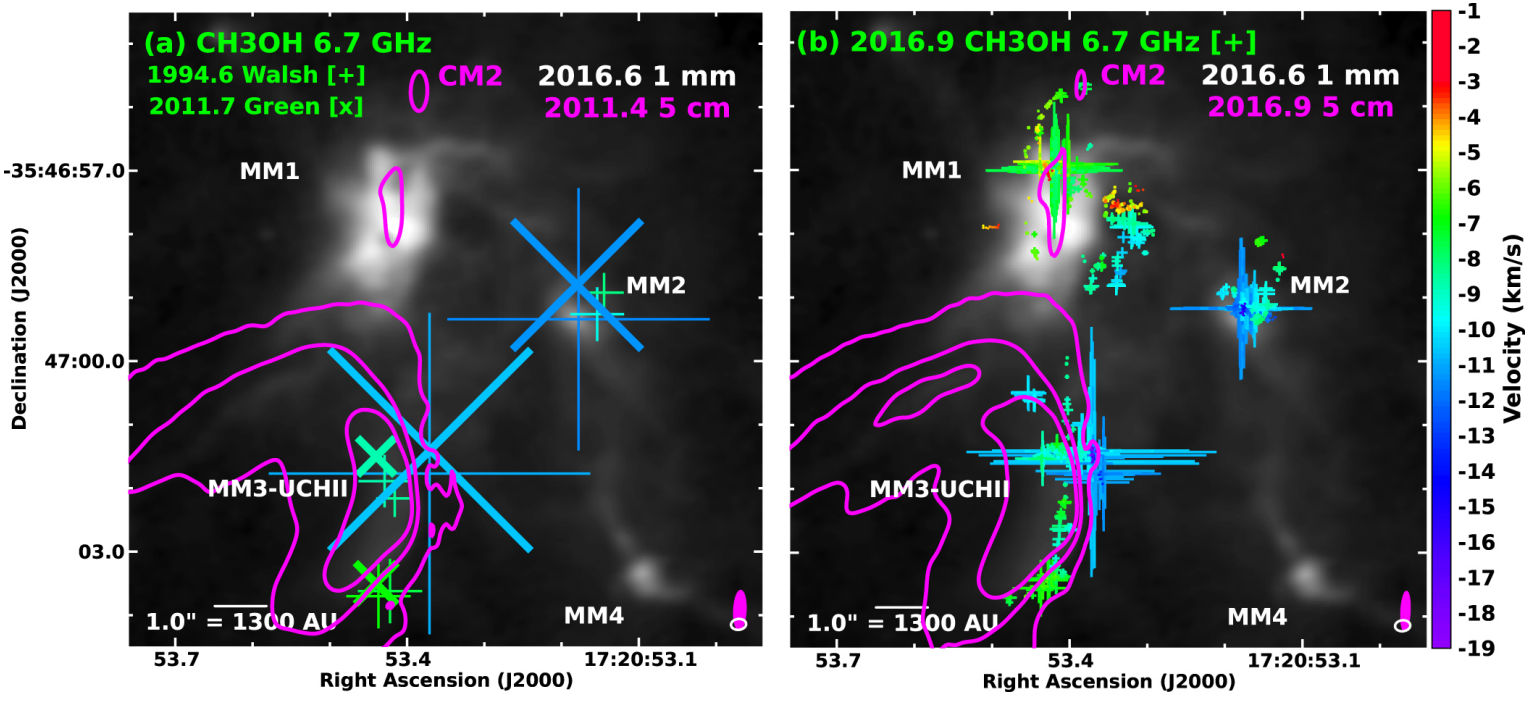
Maser flaring events: NGC 6334I - an episodic accretion event?



(For details see MacLeod et al., 2019)

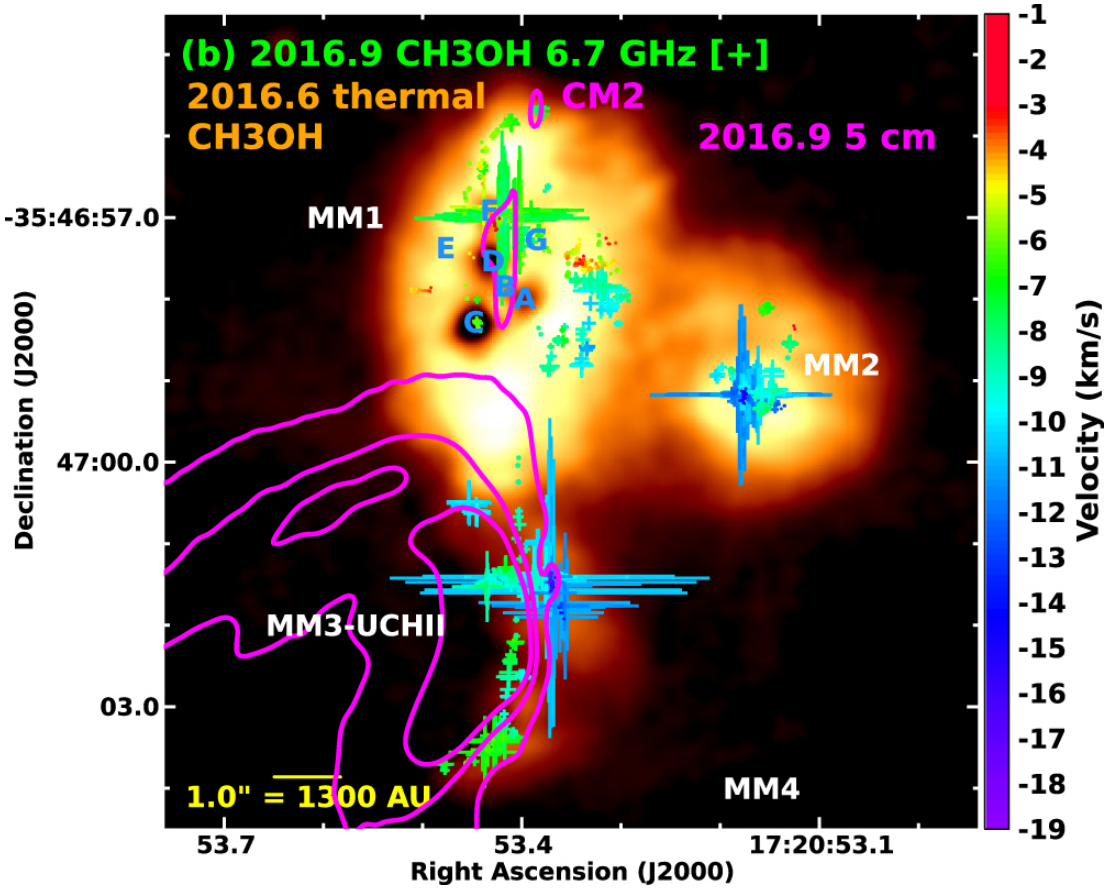
- Flaring of 10 masing transitions of CH_3OH, OH, H_2O

Maser flaring events: NGC 6334I - an episodic accretion event?



(For details see Hunter et al., 2018)

Maser flaring events: NGC 6334I - an episodic accretion event?



(For details see Hunter et al., 2018)

The case of G358.93-0.03

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Sub-arcsecond (sub)millimeter imaging of the massive protocluster G358.93−0.03:
Discovery of 14 new methanol maser transitions associated with a hot core

C. L. Brogan,[1] T. R. Hunter,[1] and Many Others

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ABSTRACT

We present (sub)millimeter imaging at 0.″5 resolution of the massive star-forming region G358.93−0.03 acquired in multiple epochs at 2 and 3 months following the recent flaring of its 6.7 GHz CH_3OH maser emission. Using SMA and ALMA, we have discovered 14 new Class II CH_3OH maser lines ranging in frequency from 199 to 361 GHz, which originate mostly from v_t=1 torsionally-excited transitions. The masers are associated with the brightest continuum source (MM1), which also hosts a line-rich hot core. The masers present a consistent curvilinear spatial velocity pattern that wraps around MM1, suggestive of a coherent physical structure. In contrast, the thermal lines exhibit a linear velocity gradient that bisects MM1 but at progressive position angles that appear to be a function of either increasing temperature or decreasing optical depth. The maser spectral profiles have evolved significantly over a one month period, and the intensities have all dropped by factors of 3.0 to 7.2, with the sole v_t=2 transition showing the largest change. A small area of maser emission from only the highest excitation lines closest to MM1 has completely disappeared. There are seven additional dust continuum sources found in the protocluster, including another hot molecular core (MM3). We

Take home message

- Although interpreting maser emission might be difficult, masers do reveal important physical activity in high-mass star forming regions that otherwise would not be detected.
- Dedicated maser monitoring necessary to catch such events.

So ... if you want to zoom in on star formation ...

Take home message

Collaborators

- Fanie van den Heever (SARAO)
- Sharmila Goedhart (SARAO)
- James Chibueze (NWU)
- Mavis Seidu (NWU)
- Jean-Marie Morgan (NWU)