

NEW PERIODIC VARIABLE METHANOL MASERS IN MASSIVE STAR-FORMING REGIONS

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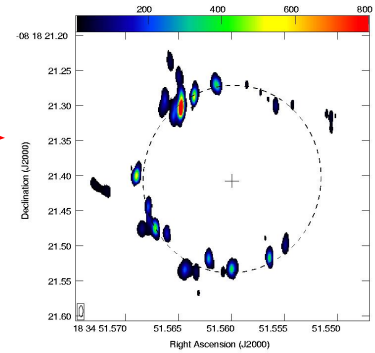
NORTH-WEST UNIVERSITY
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NOORDWES-UNIVERSITEIT

The soul of high mass star formation conference
15-20 March, Puerto Varas, Chile



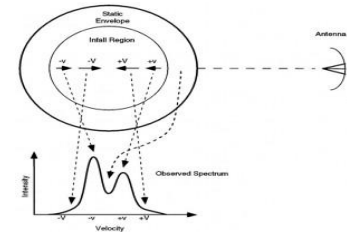
Why are Masers Important?

- Their presence suggest that specific conditions such as density of the environment, temperature in the region, etc.
Since they are sensitive species.
- Masers **distribution** and spectra profiles could suggest possible structure in the region in which they reside.
- Monitoring masers is an indirect way to probe possible changes in the masing region and/or background source.
- The 6.7 and 12.2 GHz methanol masers have one of the rare view of the high mass star forming region
- NB: Astronomical molecular Maser Amplification by Stimulated Emission of Radiation (MASER) is a natural occurring phenomena.



Total intensity (zero moment map) of G23.657-0.127.

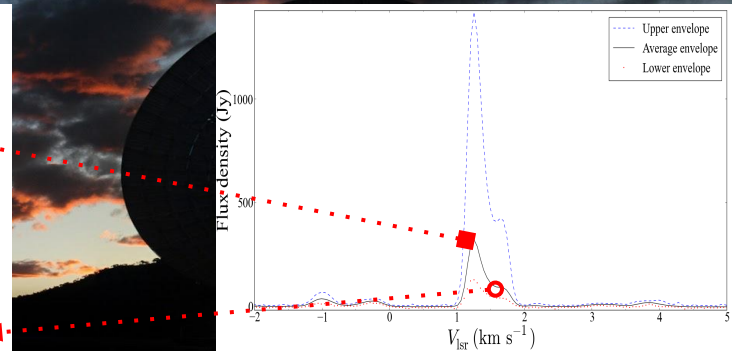
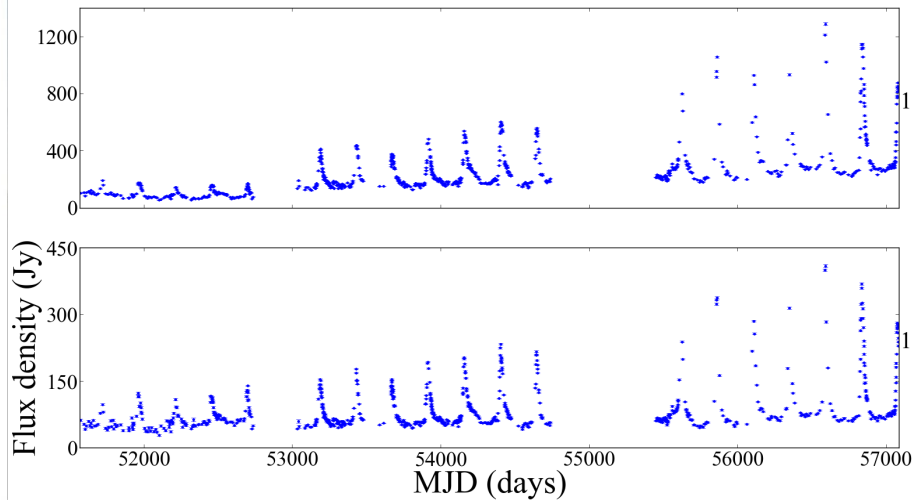
Bartkiewicz et al., 2005



Evans, 1999

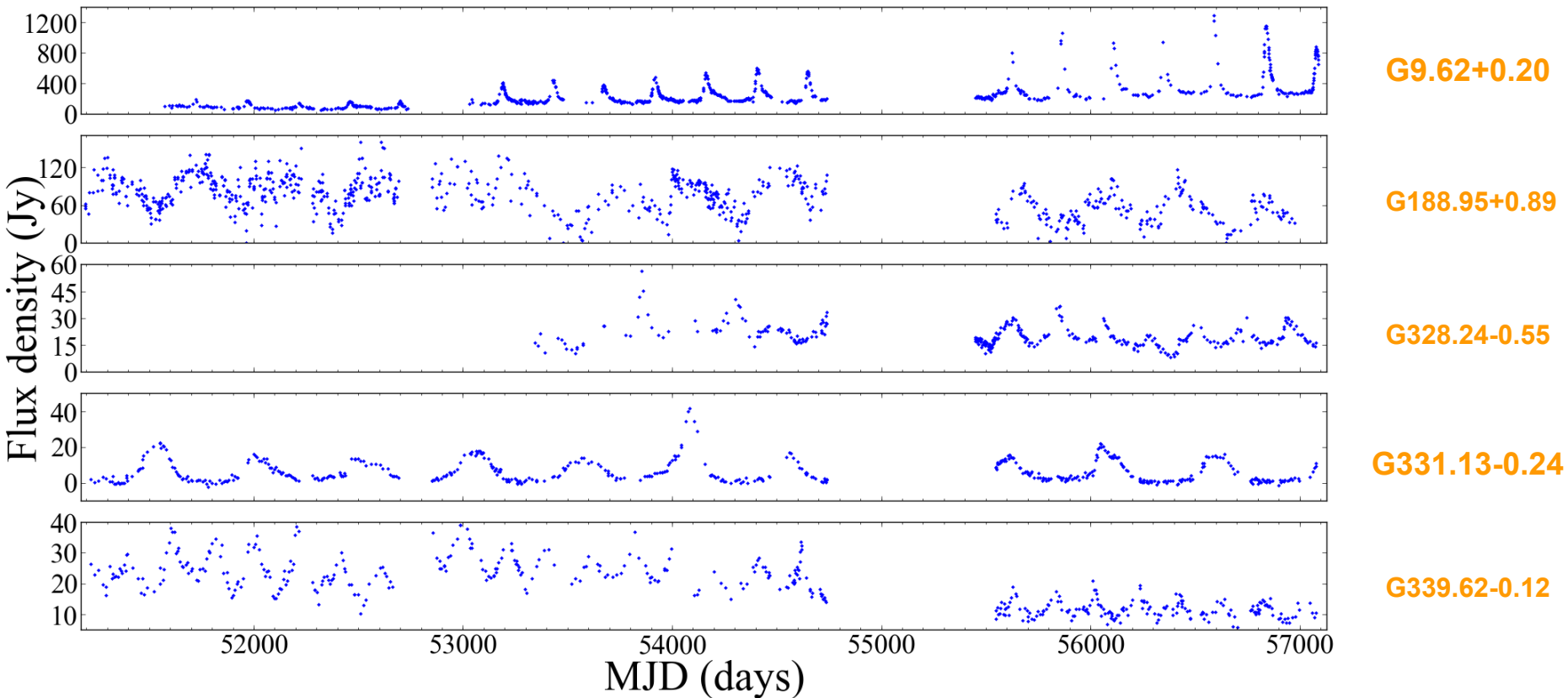
Monitoring Programme for the Methanol masers

- Goedhart et al. (2003,2004) reported periodic variability in seven of 54 monitored at 6.7 GHz.
- Since then, seven more sources were reported by Araya et al. (2010), Szymczak et al. (2011,2015) and Fujisawa et al. (2014) to show periodic variations.



Periodicity was first noted in G9.62-0.20

SOME OF PERIODIC VARIABLE METHANOL MASER SOURCES



What is the origin of the observed periodicity?

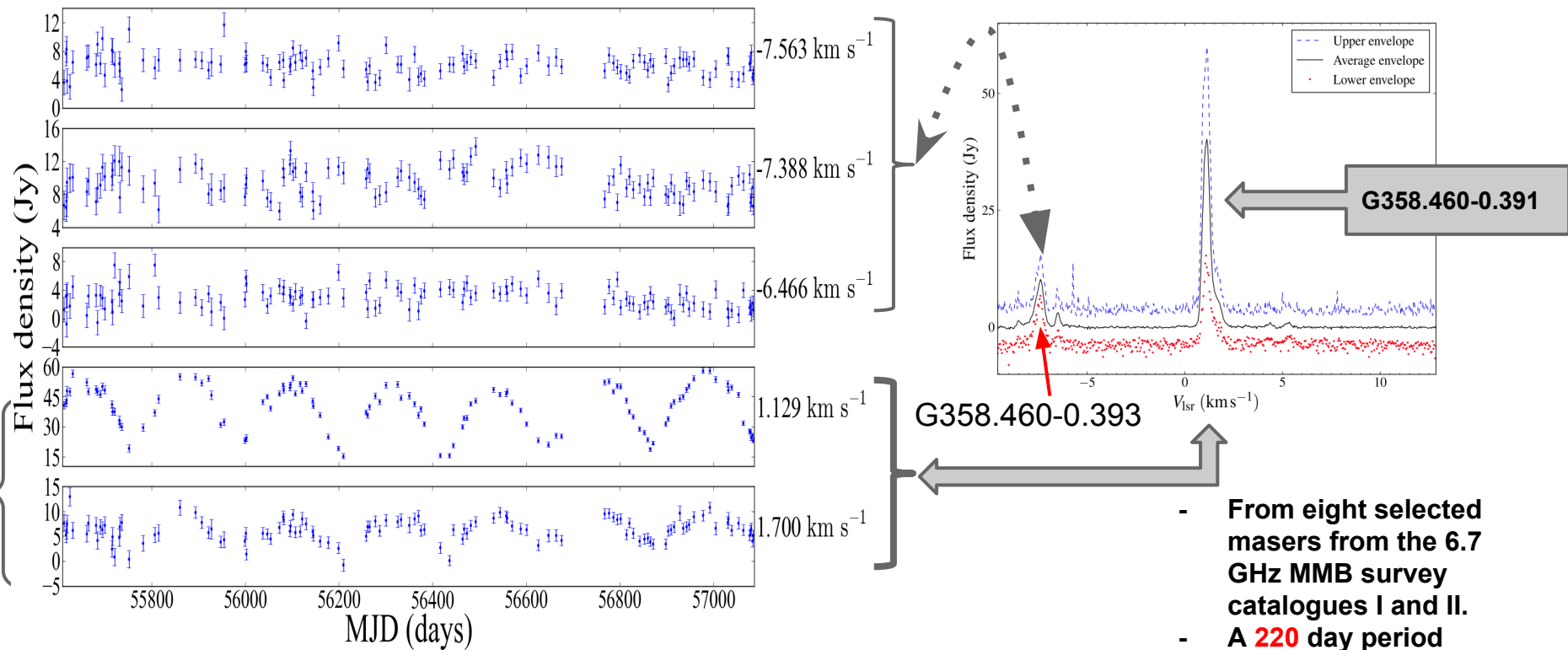
- Sobolev et al. (2007) and Parfenov & Sobolev (2014) proposed variations of dust temperature due to the filaments formed around the young massive stellar object.
- van der Walt, Goedhart & Gaylard (2009) and van der Walt (2011) proposed Colliding Winding Binary (CWB) as the origin of periodicity (Further detail check S.P. van den Heer Poster).
- Araya et al. (2010) proposed periodic circumbinary disc accretion
- Inayoshi et al. (2013) proposed protostellar pulsation.
- There is no observation which confirms any of the above proposal.

The search for the new periodic methanol masers

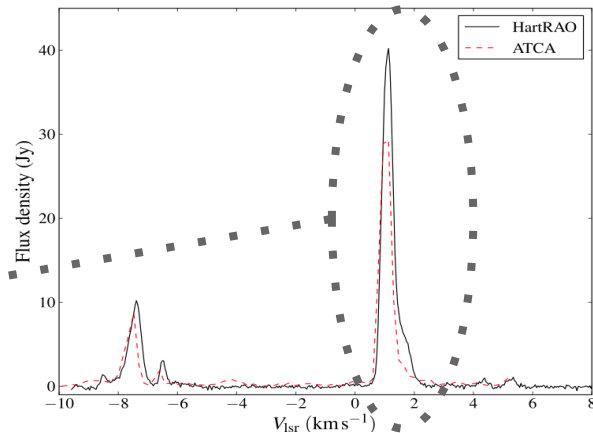
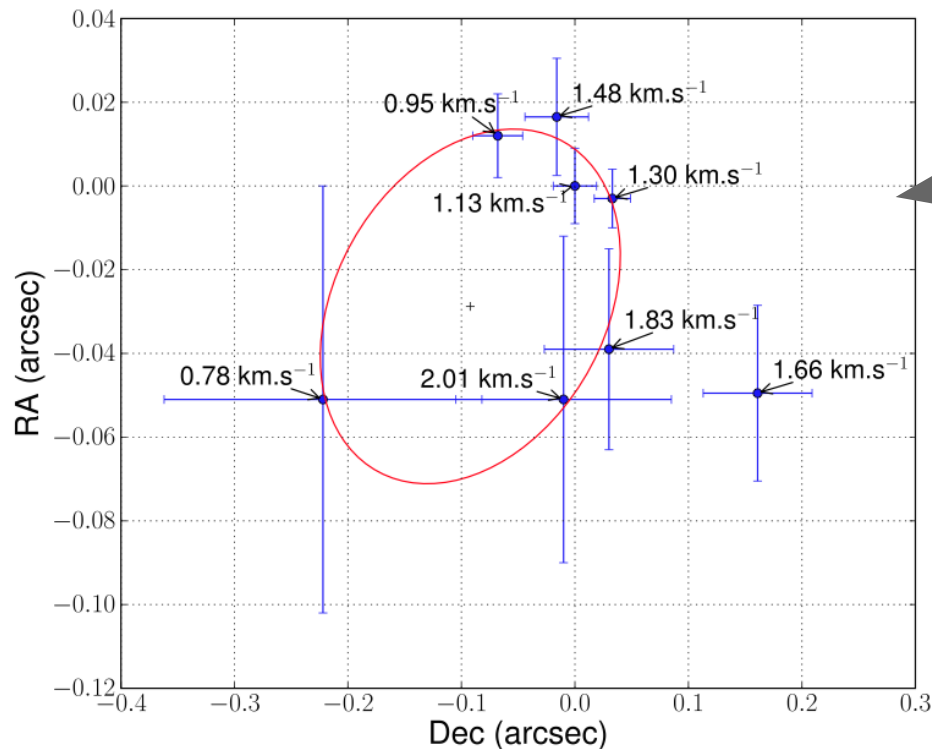
- Eight sources from the 6.7 GHz Methanol Multibeam Survey Catalogues I and II were selected for monitoring at both 6.7 and 12.2 GHz.



NEW PERIODIC METHANOL MASERS ASSOCIATED WITH G358.460-0.391

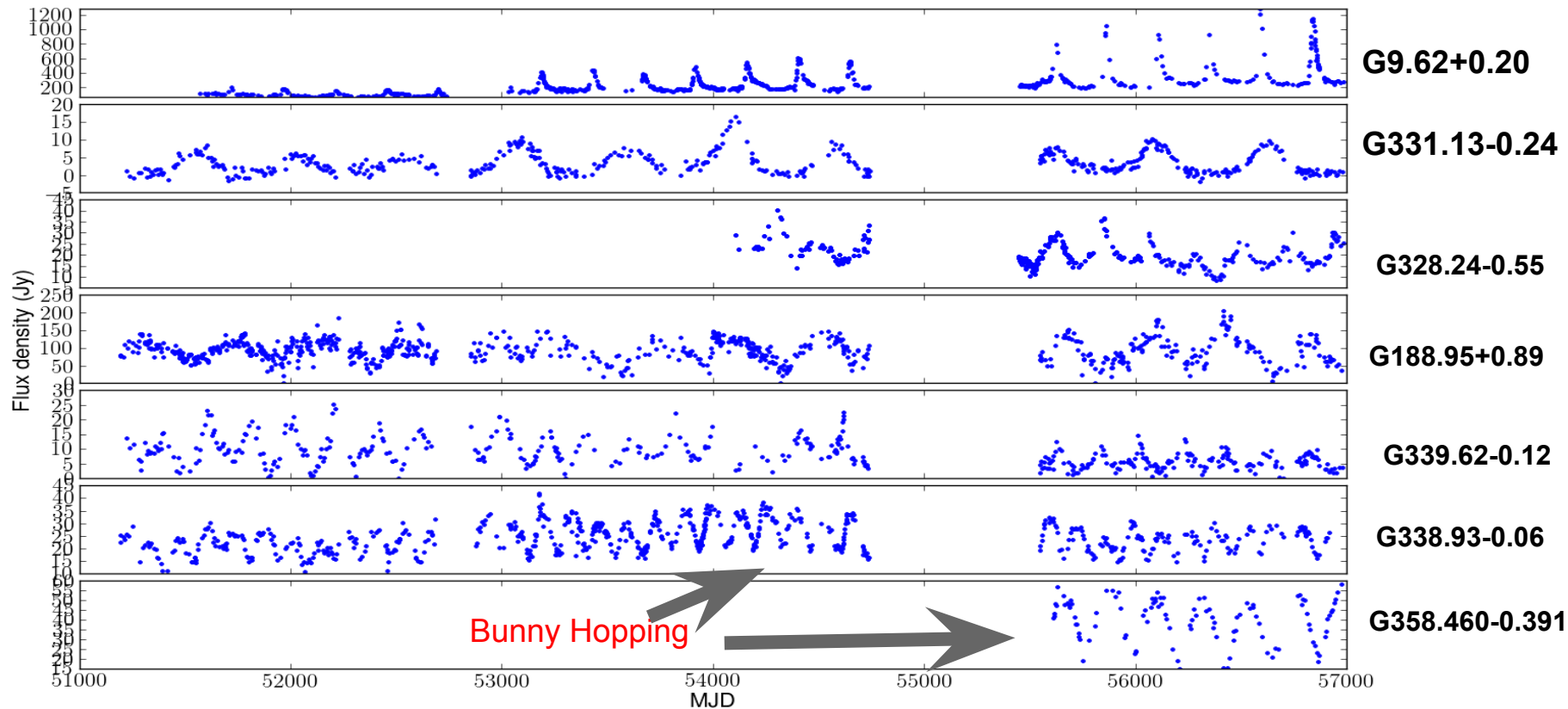


G358.460-0.391 maser SPOTS MORPHOLOGY



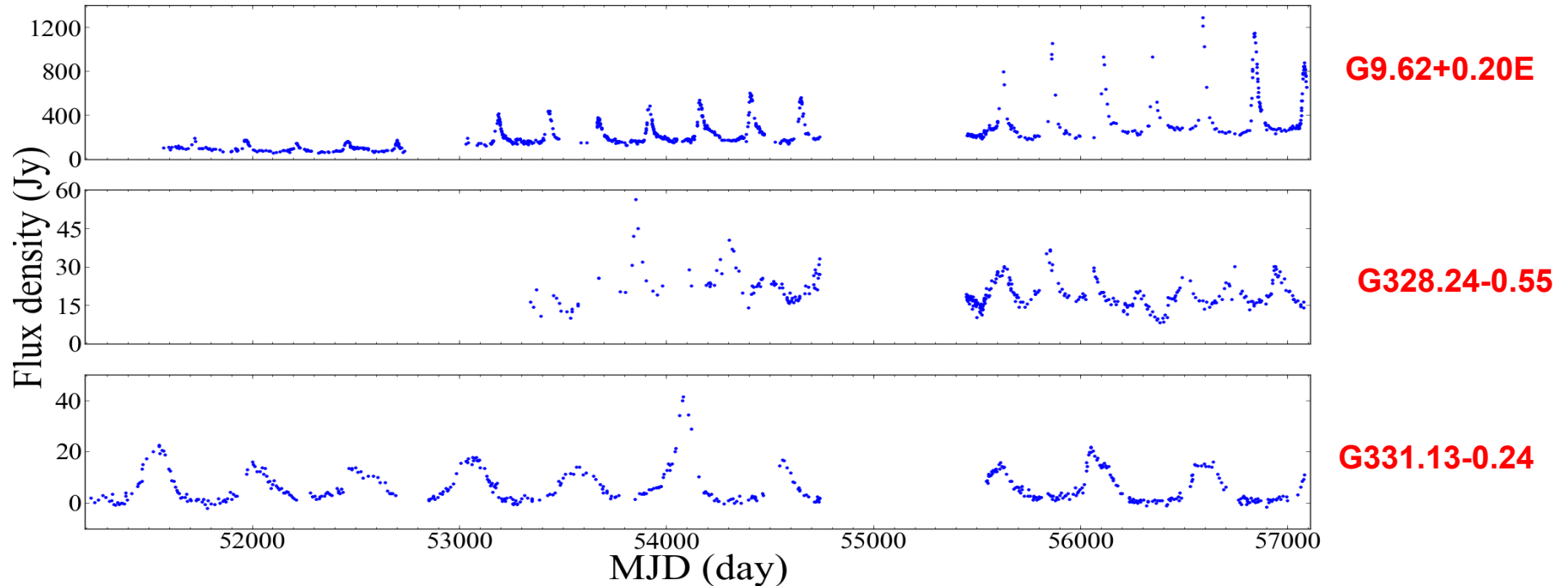
- Five snapshot observations were made with six 22m Australia Telescope Compact Array (ATCA) antennas.
- The maser morphology is elliptical.
- The major diameter of the fitted ellipse is about 0.26 arcsec.
- With 220 day period and, assuming a total stellar mass of 20 solar mass, the semi-major axes for the two systems will be 1.94 au.

compare waveforms



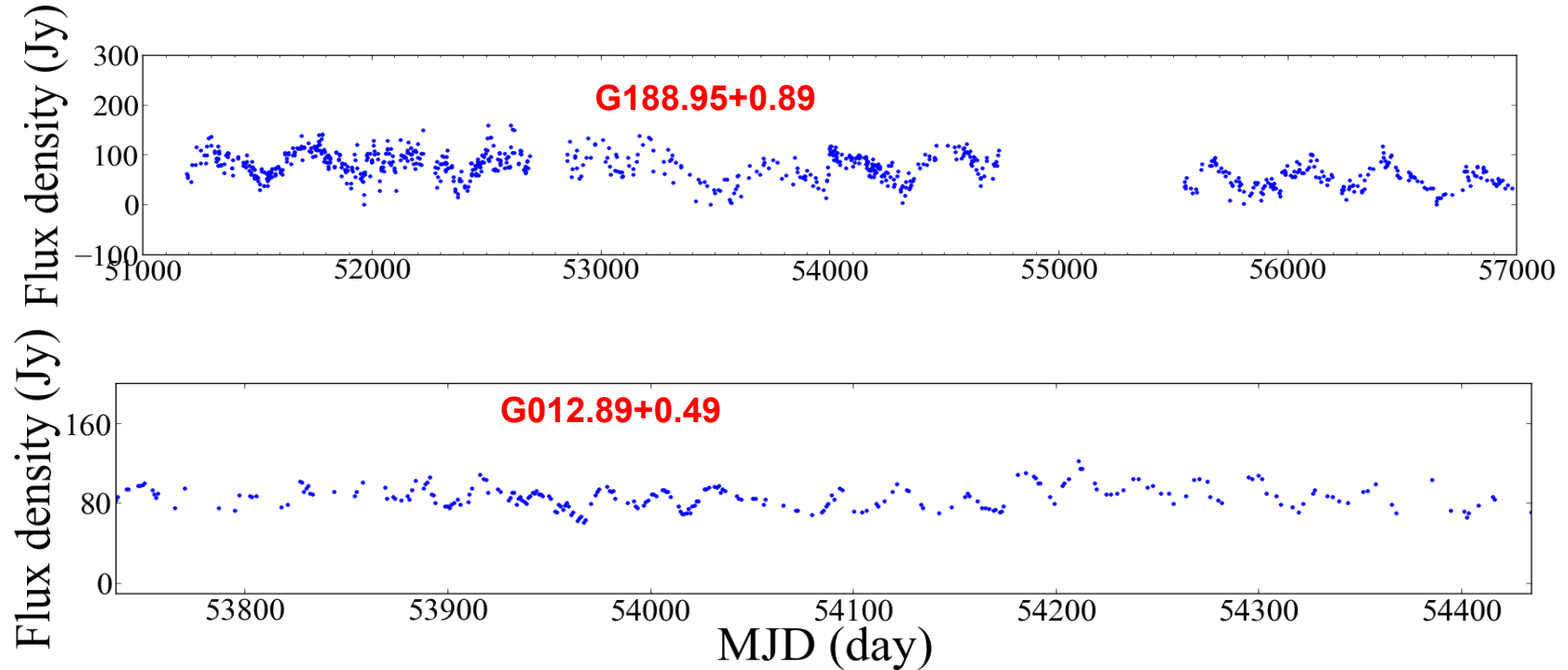
waveFORMS cAtEGORISAtION

- **Group one:** the masers show a fairly rapid rise followed by an exponential-like decay to a minimum value {(G9.621+0.196E, G328.24-0.55, G331.13-0.24, from Goedhart et al. (2003, 2004, 2013), G22.357+0.066 (Szymczak et al. 2011), G37.55+0.20 (Araya et al. 2010) and IRAS 22198+6336 (Fujiswa et al. 2014)}



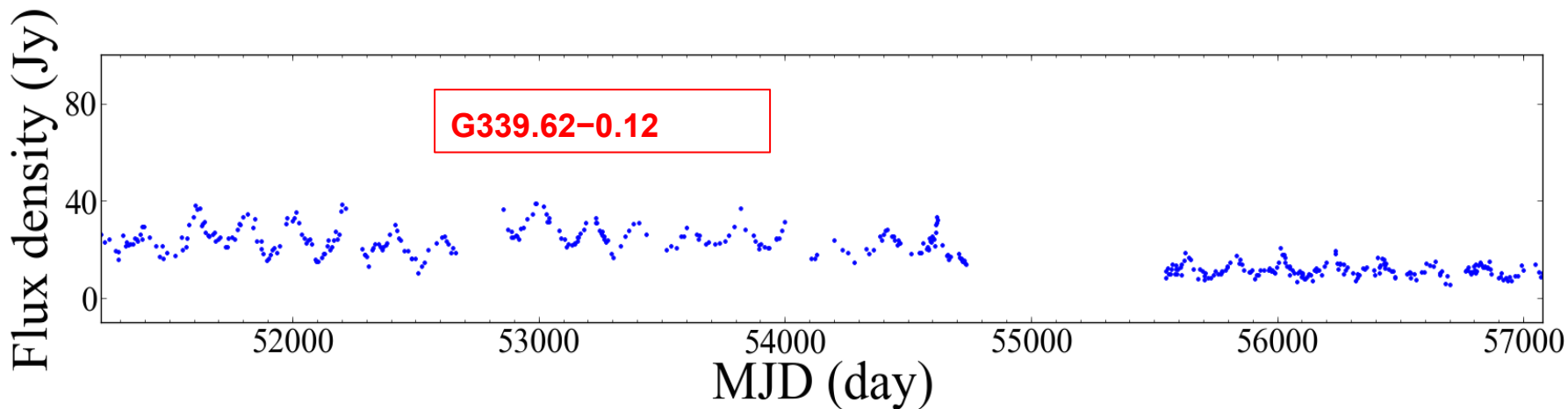
waveFORMS cAtegORISATION

- **Group two:** The masers show semi sinusoidal type variations {G12.89+0.49 and G188.95+0.89, from Goedhart et al. (2003, 2004, 2013)}



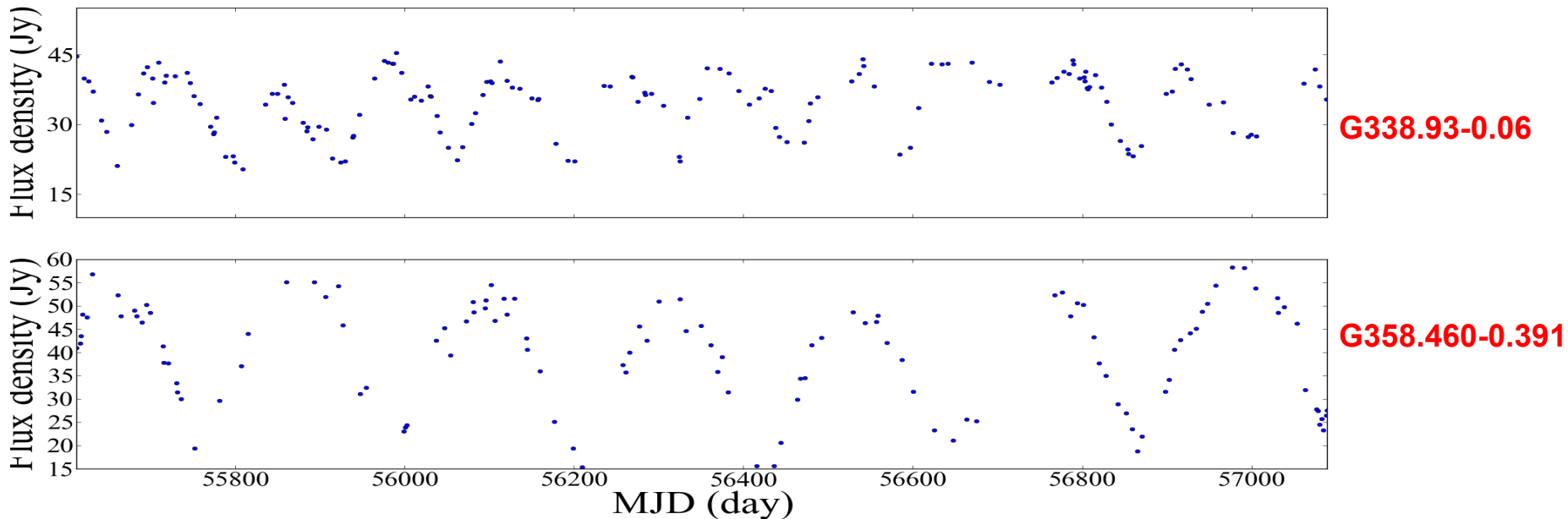
waveFORMS cAtegORISATION

- **Group three:** triangular shaped periodic variations (G339.62-0.12 , from Goedhart et al. (2003, 2004, 2013))

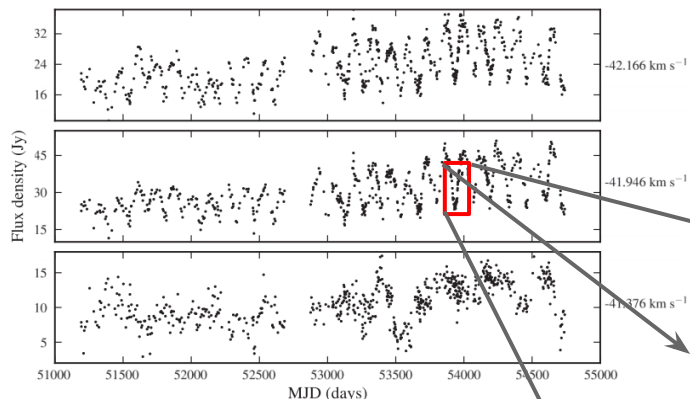


waveFORMS cAtegORisAtion

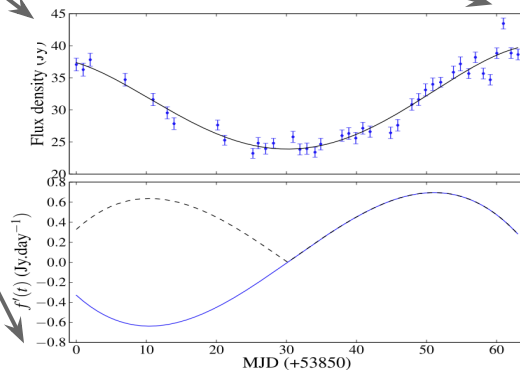
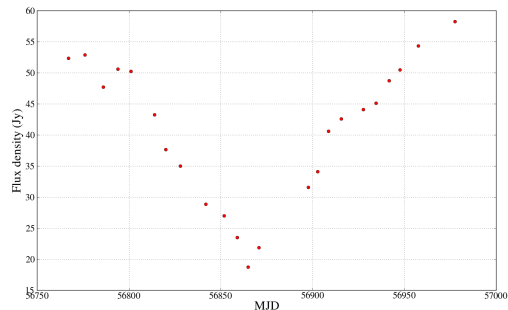
- **Group four:** absolute cosine periodic variations (G338.93-0.06, from Goedhart et al. (2003, 2004, 2007, 2013) and G358.460-0.391, from Maswanganye et al. (2015)).



G338.93-0.06 AND G358-460-0.391 MINIMUM ANALYSIS



Goedhart et al. (2014)

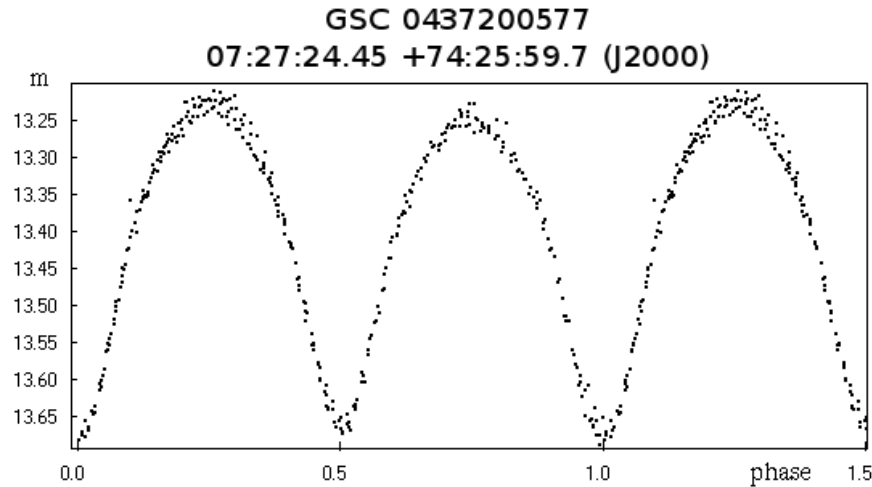


- G338.93-0.06 minimum with good sampling interval.
- The symmetry could around the minimum could be a suggestions that the origin is a symmetric mechanisms.
- The minimum appears to be not as sharp as expected from the absolute cosine.

- The minimum of G358.460-0.391 looks sharp though it had smaller sampling interval..

Maswanganye et al.(2015)

VARIATIONS IN G338.93-0.06 AND G358.460-0.391 COULD BE DUE TO AN ECLIPSING BINARY



$$\text{HJDmin} = 2454479.5727 + 0.32539 \times E$$

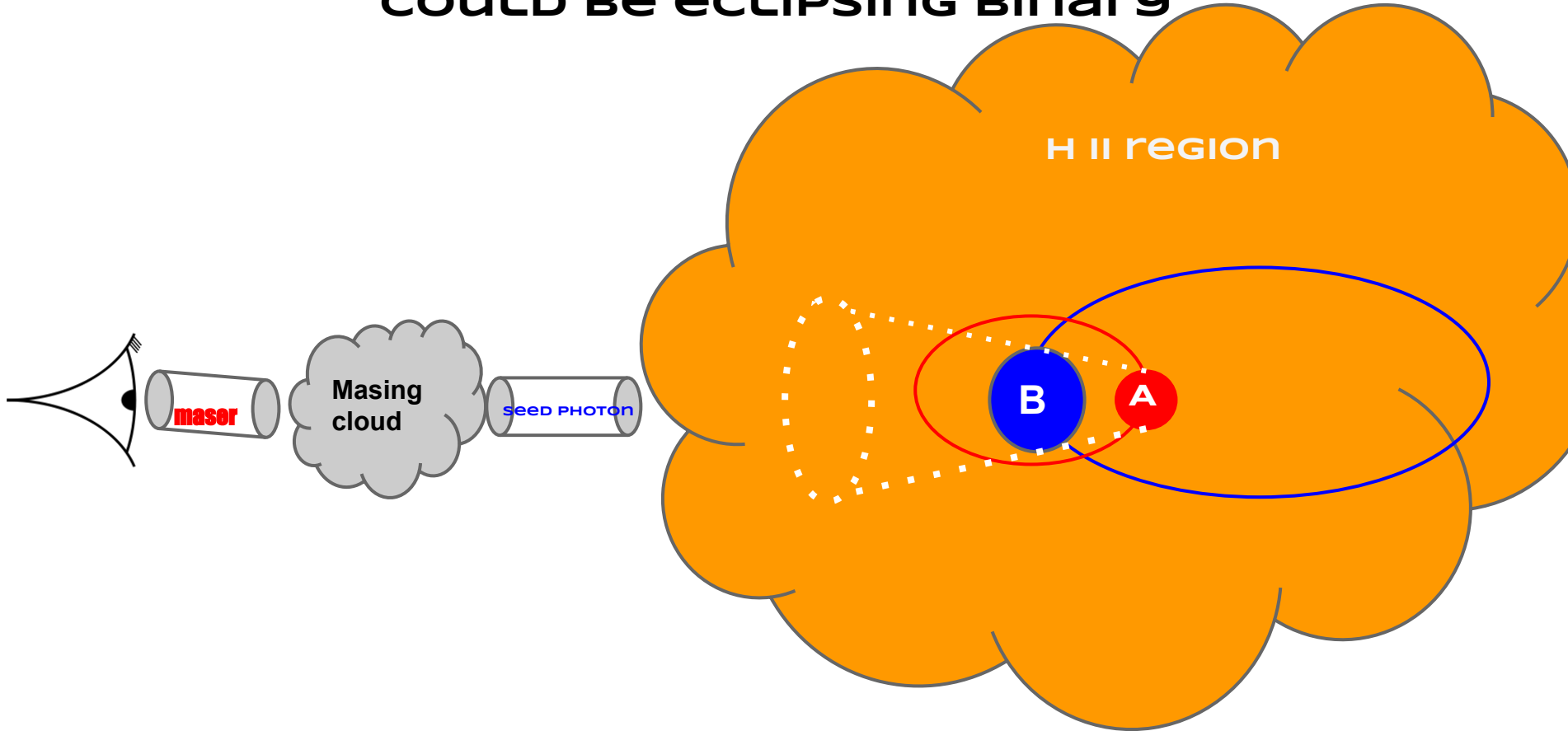
Kryachico et al., (2008)

Hopping Bunny



- Eclipsing binary line curves are similar to that of an absolute cosine (**Hopping Bunny**).

VARIATIONS IN G338.93-0.06 AND G358.460-0.391 COULD BE ECLIPSING BINARY



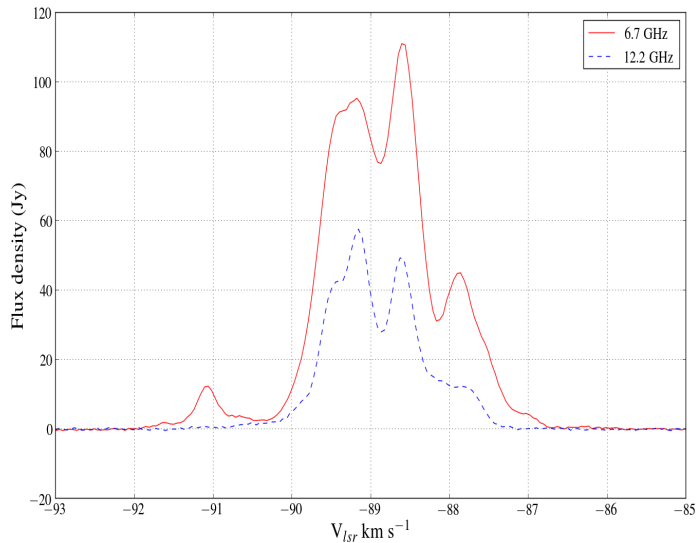
Could there be more periodic methanol masers?

- Maswanganye et al., (2015) estimate of the probability of a finding a periodic maser in a given sample as 0.13 ± 0.04 .
- It translates into possible 34 ± 10 possible periodic masers in the 6.7 GHz MMB survey catalogues I, II, III, and IV.
- In the 6.7 GHz MMB survey Catalogues, **262** sources met the selection criteria, **62** had be monitored before, eight were found to be periodic, which suggests **26** or more from the remaining 200 could be periodic.

Ten sources from the 6.7 GHz Methanol Multibeam Survey Catalogues III and IV were selected for monitoring at both 6.7 and 12.2 GHz.



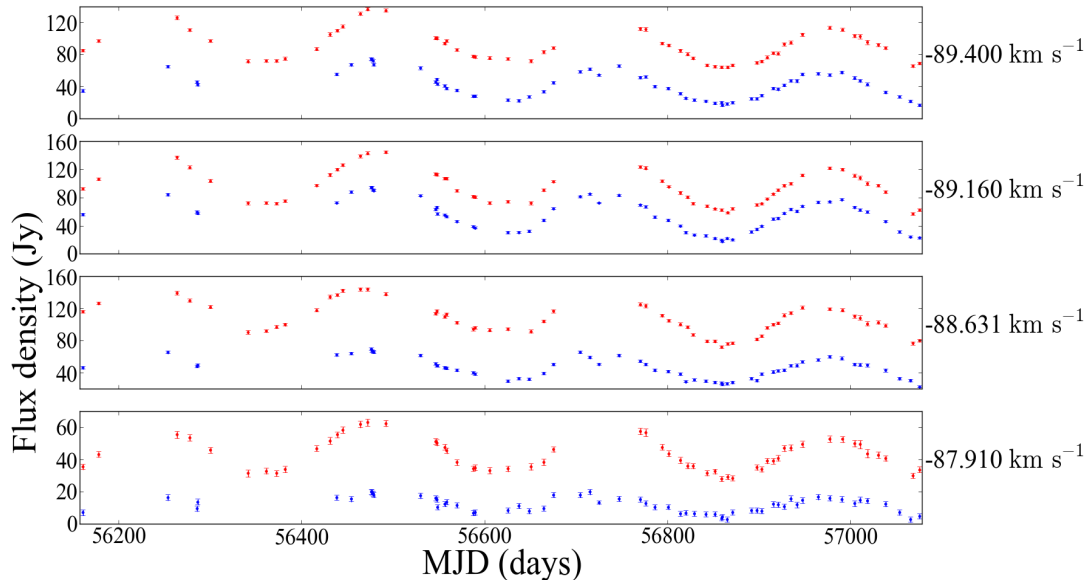
ANOTHER new PERIODIC maser



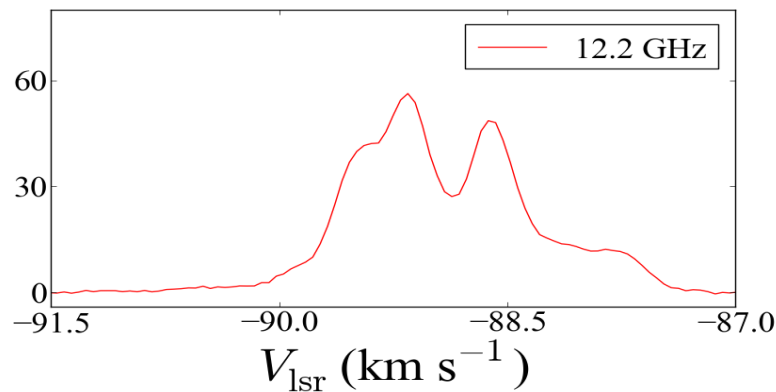
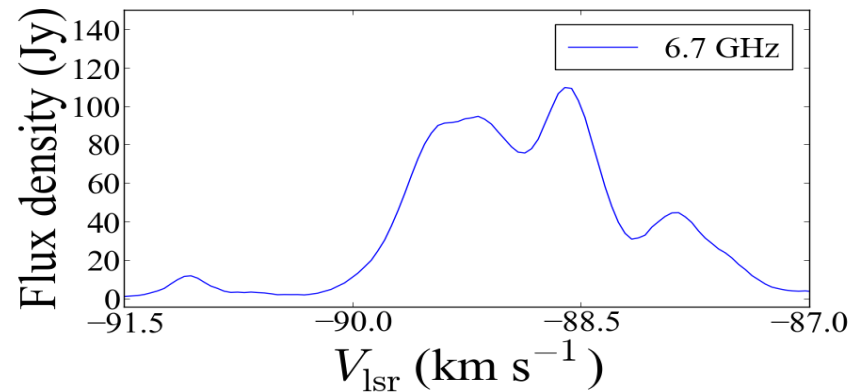
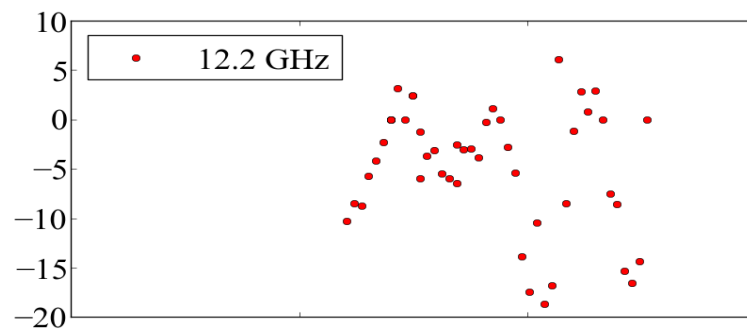
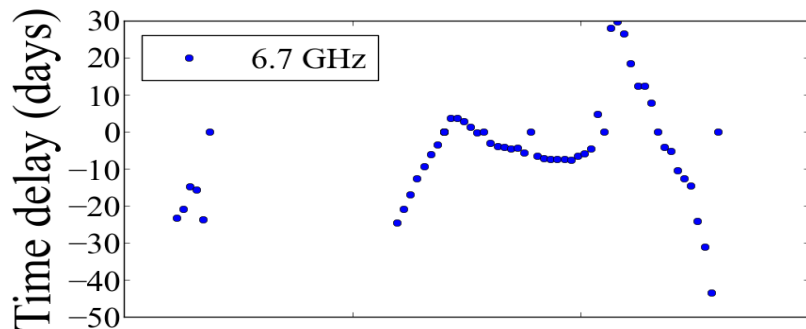
Maswanganye et al. (in Prep)

- The period derived from Lomb-Scargle and epoch-folding was **250 days**.
- It falls into group two.

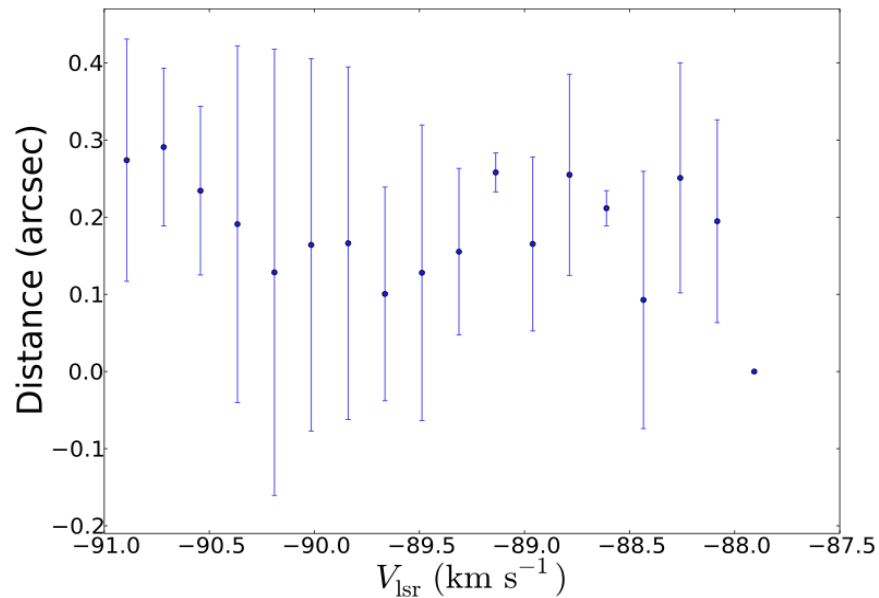
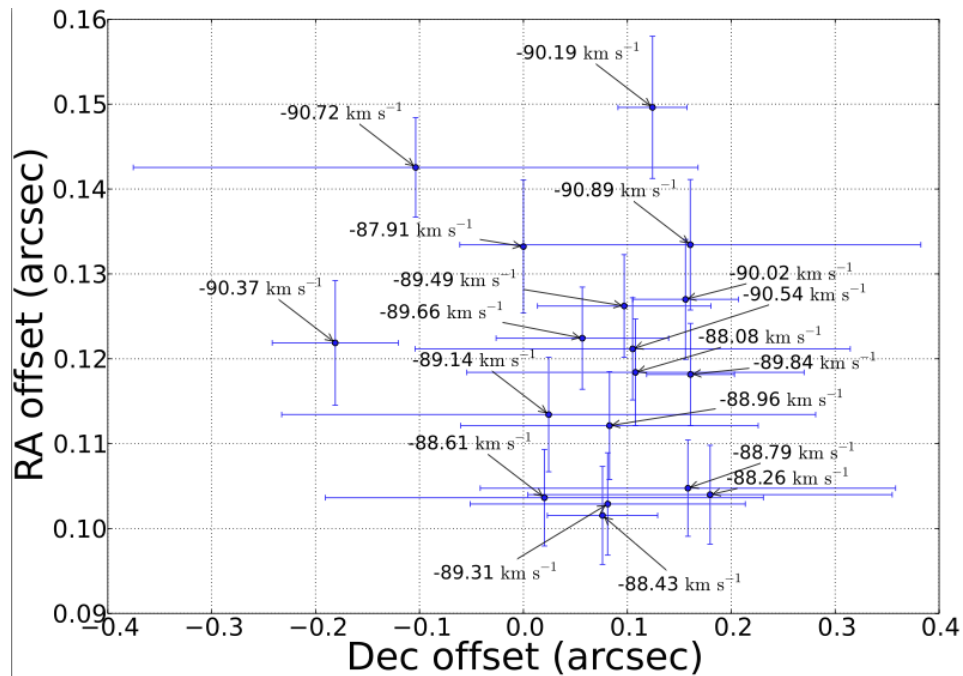
- **G339.986-0.425** shows strong variability at **6.7** and **12.2** GHz.
- The **6.7** and **12.2** GHz lines show similar spectra and time series.



Time delays across the channels



Trying to explain time lags with maser spots distribution



Maswanganye et al., (in Prep)

Summary

- Origin of the periodicity in class II methanol masers is real and complex to explain (**Period range: 29 to 510 days**).
- The Waveforms could be a trace of the origin of periodicity.
- There could be **25** or more periodic sources (from 190) in the 6.7 GHz MMB survey catalogues I, II, III, and IV.
- Could there be more waveforms and why are they different ?
- Any mechanism which explain the origin of the periodicity should also explain the diversity of waveforms, unless it is proposed for a particular of methanol masers.