Astrophysical Masers:
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Variability of water masers in evolved stars on timescales of decades

Jan Brand[1], Dieter Engels[2] and Anders Winnberg[3]

[1]INAF-Istituto di Radioastronomia & Italian ALMA Regional Centre, Bologna, Italy
email: brand@ira.inaf.it
[2]Hamburger Sternwarte, Hamburg, Germany; [3]Onsala Rymdobservatorium, Onsala, Sweden

Abstract. For several decades (1987-2015) we have been carrying out observations of water masers in the circumstellar envelopes (CSE's) of Mira variables, Red Supergiants (RSG's) and Semi-Regular Variables (SRV's) with the Medicina 32-m and Effelsberg 100-m antennas. The single-dish monitoring observations provide evidence for strong H_2O maser profile variations, which likely are connected to structural changes in the maser shells. Such variations include strong flares in intensity lasting several (tens of) months and systemic velocity gradients of maser components developing over years, as well as other secular variations which are superimposed on periodic variations following the stellar light variations.

When complemented with interferometric observations, it is possible to derive the 3-D distribution of the maser spots, and their lifetime, as we have done for RX Boo (Winnberg *et al.* 2008) and U Her (Winnberg *et al.* 2011; Brand *et al. in prep.*).

Keywords. stars: AGB and post-AGB; stars: variables: other; masers; flare

1. Observations

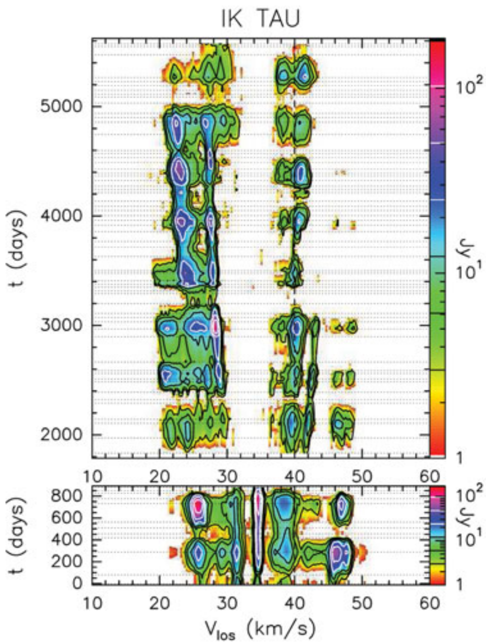
Observations were carried out with the Medicina 32-m antenna between 1987 and 2015, of a representative sample of late-type stars (see Fig.1b), at 1-4 month intervals. The resolution was typically 0.13 km/s (9.8 kHz); the sensitivity improved over the years, and was around $0.5 - 1.5$ Jy for most of the time. With the Effelsberg 100-m dish occasional observations were made between 1987 and 1999; typical resolution and sensitivity were 0.08 km/s and $0.2 - 0.4$ Jy, respectively.

2. Variability; periodic and not

Plots such as shown in Fig.1a are an efficient way to capture the results of the monitoring observations. Virtually all Mira's show periodicity in their maser emission, with the same periods as in the optical. The maser emission lags behind by about 0.2 ± 0.1 in phase. Also the maser emission from some RSG's shows periodicity, but irregularly and not always with a constant period. Individual velocity components may exhibit secular variations in flux density on top of periodic variations.

3. Bursts of maser emission: flares

Long-term monitoring also enabled the detection of infrequent, irregular outbursts or flares (see Fig.1c). Flares occur in all the types of stars we monitored, with an average of once every 5.6 years, and average duration of 18 ± 7 months and an increase in integrated flux by factors of $2 - 20$. Often outbursts occur in individual components, rather than in all components together, and if they do, there may be a delay between the flares in different components. Mira's have the most intense flares in terms of increase in flux.



Star	Type	Star	Type
o Cet	Mira	R Crt	SRV
IK Tau	"	RT Vir	"
R Leo	"	RX Boo	"
U Her	"	SV Peg	"
χ Cyg	"		
RR Aql	"	S Per	RSG
R Cas	"	VX Sgr	"
		NML Cyg	"
OH231.8+4.2	PPN		

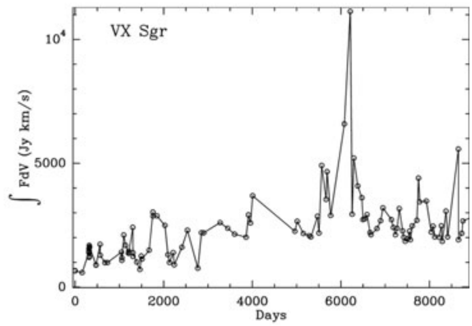


Figure 1. a (left). Flux density versus velocity, as a function of time, for IK Tau. Each horizontal dotted line indicates an observation (spectra within 4 days from each other were averaged). Data are resampled to 0.3 km/s and only emission at levels $\geqslant 3\sigma$ is shown. Day 0 = 12/12/95. **b (top right).** Observed targets. **c (bottom right).** A flare in VX Sgr; the integrated flux increased by a factor of $4-5$, and declined, in a period of about 2.4 yrs (2003-05). Note the general increase of integrated emission over time (by a factor of $\geqslant 2$). Day 0 = 28/3/87.

4. Velocity drifts

Not only the intensity of the maser emission, also the velocities of the emission components change with time. See for example Fig.1a. In this, and similar cases we measure gradients of $0.05 - 0.25$ km/s/yr, about an order of magnitude smaller than gradients observed in star-forming regions (see Brand *et al.* 2007). This can be interpreted as a maser region moving outwards in the shell, and would imply lifetimes of several decades.

5. Conclusions

Long-term single-dish monitoring of water masers in the CSE's of late-type stars unveils both periodic and erratic behaviour of the emission. Whereas single-epoch observations are snapshots of the maser activity and are not necessarily representative for the general behaviour, long-term monitoring can reveal (persistent) profile changes, velocity gradients and maser outbursts. The observed phenomena point to reconfiguration of emission regions; regular interferometric observations are required to study these structural changes. The use of multiple transitions to constrain the physical conditions in the CSE's requires the near-simultaneous (within months) observations of all transitions involved.

References

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