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Revealing the kinematics and origin of ionized winds using RRL masers

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Abstract. The detection of hydrogen radio-recombination maser lines (RRLs) toward MWC349A in the year 1989 opened the chance to place constraints on the kinematics of an ionized circumstellar disk around a massive star. Since then, a significant number of observations have allowed improving our understanding of this source to the point that we have established that its ionized wind launching occurs at a distance of ∼24 au as claimed by disk wind models. On the other hand, this field of study has undergone considerable development over the last six years with the detection of new RRL maser sources. Here, we present a brief summary of all these recent advances and the promising future prospects.

Keywords. masers, stars: winds, outflows, HII regions, accretion, accretion disks

1. Historical background

Since the first detection of hydrogen radio-recombination lines (RRLs), they have allowed us to study the physical conditions and kinematics of ionized (HII) regions which are highly extincted by dust. This is the case of some post-main sequence stars (e.g. pre-planetary nebulae) and pre-main sequence massive stars. Thus, it was found that while many of these stars have low-velocity ionized winds moving at the thermal speed, ~ 20 km s^{-1}, those with the most compact and densest HII regions reach higher velocities (Jaffe & Martín-Pintado 1999). However, the weak intensity of the detected RRLs did not allow to study key issues such as where and how their ionized winds are launched.

In the year 1989, the detection of the first RRLs affected by maser amplification toward MWC349A, a high-mass B[e] star with an edge-on circumstellar disk (Danchi *et al.* 2001), opened a new panorama. The huge intensity of its double-peak mm RRL profiles allowed to study, for the first time, not only the kinematics of its ionized wind but also its ionized circumstellar disk (Planesas *et al.* 1992). Thus at the time of the previous maser conference, after 13 years of the first RRL maser detection, it had already been well established that the ionized layers of its circumstellar disk rotate, apparently following a Keplerian law, like its ionized wind (Martín-Pintado *et al.* 2011). Further detailed constraints on the kinematics and physical conditions were obtained comparing observations with the predictions of a 3D radiative transfer model (Báez-Rubio *et al.* 2013).

As mentioned, MWC349A has been extensively studied after finding that it emits RRL masers. However, with the exception of the detection of these lines toward Eta Carinae (Cox *et al.* 1995), it was not until more than twenty years later when new RRL maser sources were revealed. In particular, the detection of these RRL masers toward Cepheus A HW2 (Jiménez-Serra *et al.* 2011) and Monoceros R2-IRS2 (Jiménez-Serra *et al.* 2013) showed the need for performing observations with high spatial resolution or broad wideband respectively for detecting a larger sample of these objects.

2. Progress in the last five years

Constraint of the launching point of the ionized wind around MWC349A

Herschel/HIFI observations revealed the abrupt appear of two spectral components, blueshited with respect to the maser spikes, when the principal quantum number of the Hnα RRL changes from n = 22 to n = 21 (Báez-Rubio *et al.* 2014). These components are observed in all the RRLs with $17 \leqslant n \leqslant 21$. Since RRLs with lower principal quantum number trace inner regions, it might indicate that these RRLs trace the region where the wind is launched from the circumstellar disk. In fact, the predictions of the MORELI radiative transfer model confirmed that they might be tracing the ejection of the ionized wind at a distance of $\sim$ 24 au. This is also consistent with recent SMA observations (see Zhang *et al.* 2017 or the contribution by J. Moran in this book).

Discovery of new RRL maser sources

Since the last maser conference, RRL masers have been discovered toward G5.89-0.39A and MWC922, making a total of five known RRL maser sources. In the case of G5.89-0.39A, ALMA observations revealed that the H26α RRL emission is masering. Even if its kinematical structure has not been constrained yet, this finding is really interesting because it is the first pre-main sequence massive star where RRL masers have been revealed exclusively based on the measured Hmβ-to-Hnα flux ratio, in particular with spectroscopic measurements of the H32β and H26α RRLs.

On the other hand, the detection toward MWC922 using the IRAM-30m is quite interesting (Sánchez-Contreras *et al.* 2017). This source is thought to be a pre-planetary nebula, although an evolved nature has not been ruled out. Both MWC922 and MWC349A have the same spectral type, B[e] (Lamers *et al.* 1998), and their RRL profiles are strongly similar. These RRL change from a single peak for the H41α to a double peak for the H30α, which is clearly masering. The profiles of MWC922 can be reproduced if this source is modelled as an ionized wind and an edge-on rotating ionized circumstellar disk like in the case of MWC349A. Thus, MWC922 is a very promising source for understanding how the wind is launched from its disk. This, together with the possible future detection of new RRL maser sources, as done in the last few years, will allow us statistically claim if disk wind models explain how winds are launched or if other models are also valid.

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