RRLs as a tool to study ionized outflows and disks around massive stars

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Motivation

- Low-mass star formation: \( \Rightarrow \) accretion of material through circumstellar disks
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- High-mass star formation: $\Rightarrow$ ?
  - Evidence of circumstellar disks around massive stars

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Understanding the kinematics of circumstellar disks and their associated outflows
Motivation

- Radio-recombination lines

\[ E_{n+1} \]
\[ E_{n+2} \]
\[ E_{n+3} \]
\[ E_n \]

\[ \text{hv} = E_{n+1} - E_n \]
\[ \text{hv} = E_{n+2} - E_n \]
\[ \text{hv} = E_{n+3} - E_n \]
\[ \text{hv} = E_{n+4} - E_n \]
\[ \text{hv} = E_{n+5} - E_n \]

\[ H_\alpha \]
\[ H_\beta \]
\[ H_\delta \]
\[ H_\gamma \]
\[ H_\varepsilon \]
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- Radio-recombination lines
- Stellar winds.
  UC-HII regions: $\Delta \nu > 10$ km/s
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- UC-HII regions: $\Delta v > 10$ km/s
- MWC349A
  - Dense circumstellar neutral disk

![Diagram of MWC 349A with labels for VLA Map, 22 GHz continuum, Keck aperture masking, and maser spot.](image)

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  - Maser and laser emission at Hydrogen recombination lines
  - Their high intensity makes possible to have a high spectral and angular resolution

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3D non-LTE radiative-transfer model

MORELI (MOdel for REcombination LInes)

Physical parameters derived from radio-continuum emission

$$N_e(r=6.7 \text{ AU}, \theta=\theta_a)=3.85 \cdot 10^9 \text{ cm}^{-3} \quad \theta_a = 57^\circ \quad T_{\text{wind}}=12000 \text{ K}$$
H30α (231.9 GHz) radio-recombination line

Martín-Pintado et al. 2011, A&A, 530, L15
Kinematic model

- Neutral rotating disk
- Ionized wind
- Keplerian ionized layer

θ_i, θ, θ_a, θ_d
Constraining the kinematics

\[
M \quad 40M_{\text{sun}} \\
\theta_i \quad 8^\circ \\
\theta_k \quad 6.5^\circ \\
r_{\text{min}} \quad 0.05 \text{ AU} \\
\nu_{\text{exp}} \quad 60 \text{ km/s}
\]
Integrated-line fluxes
Other RRL maser sources: Cep A HW2


Other RRL maser sources: MonR2-IRS2

Conclusions

MWC349A

- Radio-recombination lines are an excellent tool to study the kinematics of UC-HII regions.
- Stellar ionized wind is rotating
- Stellar ionized wind acceleration happens in short distances and from very inner radii
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General

- A new field in the study of massive star formation is emerging with the new instrument capabilities
Thank you for your attention! :-)

Gracias!