The potential of the IR to constrain mass-loss rates in massive stars

Paco Najarro
Centro de Astrobiología (CAB)

Margaret Hanson, Cincinnati
Jo Puls, Munich

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Motivation

Address two fundamental problems related to mass-loss in massive stars:
- Clumping
- Weak-winds

Mass-loss diagnostics: Multiwavelength view
- UV (PV, OIV-V, CIV)
- Optical (e.s.), Halpha
- IR + Radio continua

+ IR L+K Band spectroscopy

Potential of IR spectroscopy for Mdot estimates:
- Dense winds $\rightarrow$ Mdot + clumping
- Weak winds $\rightarrow$ Mdot
Mdot from UV: Clumping?

CygOB2#7 O3 If

Obs
fl=2.5
fl=40.

X-Rays?
Mdot from UV: Clumping

DENSE WINDS

<q> Mdot

Unsaturated PV: Mdot $\downarrow$ factor 10!!

BUT

Macroclumping

(Oskinova et al 07, Sundqvist 2010, 11)

Fullerton et al 2006
Mdot from UV

WEAK WINDS

Very low Mdot for Log $L/L_{\odot} < 5.3$

BUT

X-Rays

Mdot - Xray degeneracy

Puls, Vink & Najarro 2008

10 Lac
WEAK WINDS

X-Rays - Mdot degeneracy over 2 dex!!

Mdot from UV

10 Lac

Wavelength (Å) Puls, Vink & Najarro 2008
Mdot from OPTICAL

WEAK WINDS

Hα not optimal diagnostic !!!
Mdot from IR – RADIO : CLUMPING

CygOB2 # 11

Vanishing Clumping !!!

Outer Clumping

Non-thermal emission

Najarro et al 2008
Potential of IR Lines to constrain Mdot


NLTE- effects amplified in the IR in hot stars ($h\nu/kT < 1$)

$$\frac{S_L}{B_\nu} \approx (1 + \frac{\delta}{(h\nu/kT)})^{-1}, \quad \delta = \frac{b_l}{b_u} - 1$$

E.g. $T=30000$ K  $h\nu/kT \approx 0.24$ at $\gamma_B$ and $0.11$ at $\alpha_B$

- $\alpha_B$  $bl/bu=0.95$  $SL/B\nu =1.83$

- $\alpha_B$  $bl/bu=0.90$  $SL/B\nu =11$

Thin winds $\Rightarrow$ $n=4$ depopulation at line core.

Very high sensitivity $\Rightarrow$ valuable diagnostics for Mdot
Potential of IR Lines to constrain $M_{\text{dot}}$

WEAK WINDS

![Diagram showing Hα and Brα lines with labels indicating core and wings.](image-url)
Potential of IR Lines to constrain Mdot

WEAK WINDS

L-Band lines provide reliable constraints on Mdot
Potential of IR Lines to constrain $\dot{M}$

$\sigma$ Ori O9.5V

$\dot{M}=2\times10^{-10}$ $\text{Msun/yr}$!
Potential of IR Lines to constrain Mdot

DENSE WINDS

Najarro, Hanson & Puls 2011
Potential of IR Lines to constrain Mdot

DENSE WINDS

CLUMPING

Najarro, Hanson & Puls 2011
Multi-wavelength study: CygOB2 #7

CygOB2#7 O3 If

Obs
fl=2.5
fl=40.
Multi-wavelength study: CygOB2 #7
Multi-wavelength study: CygOB2 #7

CONSTANT CLUMPING !!!
Constant Clumping?

![Graph showing Log F_ν (Jy) vs Log λ (μm) with a question mark indicating possible clumping.]

CygOB2 7

CONSTANT CLUMPING ???
Multi-wavelength results: Clumping structure of Zeta Puppis

Najarro, Hanson & Puls 2011
Conclusions

Potential of L-Band spectroscopy for $\dot{M}$ estimates:

- **Dense Winds:**
  - $\text{B}\alpha \rightarrow$ intermediate wind
  - $\text{Pf} \gamma \rightarrow$ inner wind
  - When combined with other indicators (multiwavelength studies) $\rightarrow$ wind clumping structure

- **Weak Winds:**
  - $\text{B}\alpha \rightarrow$ reliable diagnostic tool to constrain $\dot{M}$
  - Strong reaction of the emission core to low $\dot{M}$ values
  - Wings behavior similar to H$\alpha$ core

$\text{B}\alpha \rightarrow$ primary diagnostic tool to measure very low mass-loss rates