Hot-star wind mass-loss rates from Hα and IR lines

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OUTLINE

Aim → Obtain the "True" Mass loss rates

Find best contraints for stellar wind properties:
$\dot{M}$, V(r), clumping → Wind density parameters.

Pros and Cons of individual wavebands:

- **UV**
- **Optical**
- **IR**

JWST.....

The “True” mass-loss rates

Equation of continuity $\dot{M} = 4\pi r^2 v(r) \rho(r)$

$v(r) = f(r, V_\infty, \beta) \rightarrow V_\infty [1 - b R_*/r]^\beta$

$\rho(r)$ smooth or clumped (Osterbrock+59,Sundqvist+10)

clumping $\rightarrow$ discriminant between ρ vs ρ^2 proceses

$$<\rho> = [\rho^+ f^+_v + (1- f^+_v) \rho^-]$$

let $x= \rho^- /\rho^+$ then

$$<\rho> = \rho^+ [f^+_v + (1- f^+_v) x]$$

If x=0 (void interclump) $\rightarrow D = \rho^+ /<\rho> = 1/f^+_v = f_{cl}$

$$D = <\rho^2> / <\rho>^2 =$$

$$[f^+_v + (1- f^+_v) x^2] / [f^+_v + (1- f^+_v) x]^2$$

$\dot{M} = f(V_\infty, \beta, R_*, f_{cl})$

Wind density parameters

Line and continuum processes:

ρ : e.s. wings, resonance lines

ρ^2 : recombination lines, bound-free, free-free

To preserve line EWs:

- WRs "Transformed radius": R_t (Schmutz+ 89)

  $$R_t = R_* \left[V_\infty / 2500 \right] / \left[10^4 \dot{M} / \sqrt{f_{cl}} \right]^{2/3}$$

  or inverse of the density parameter

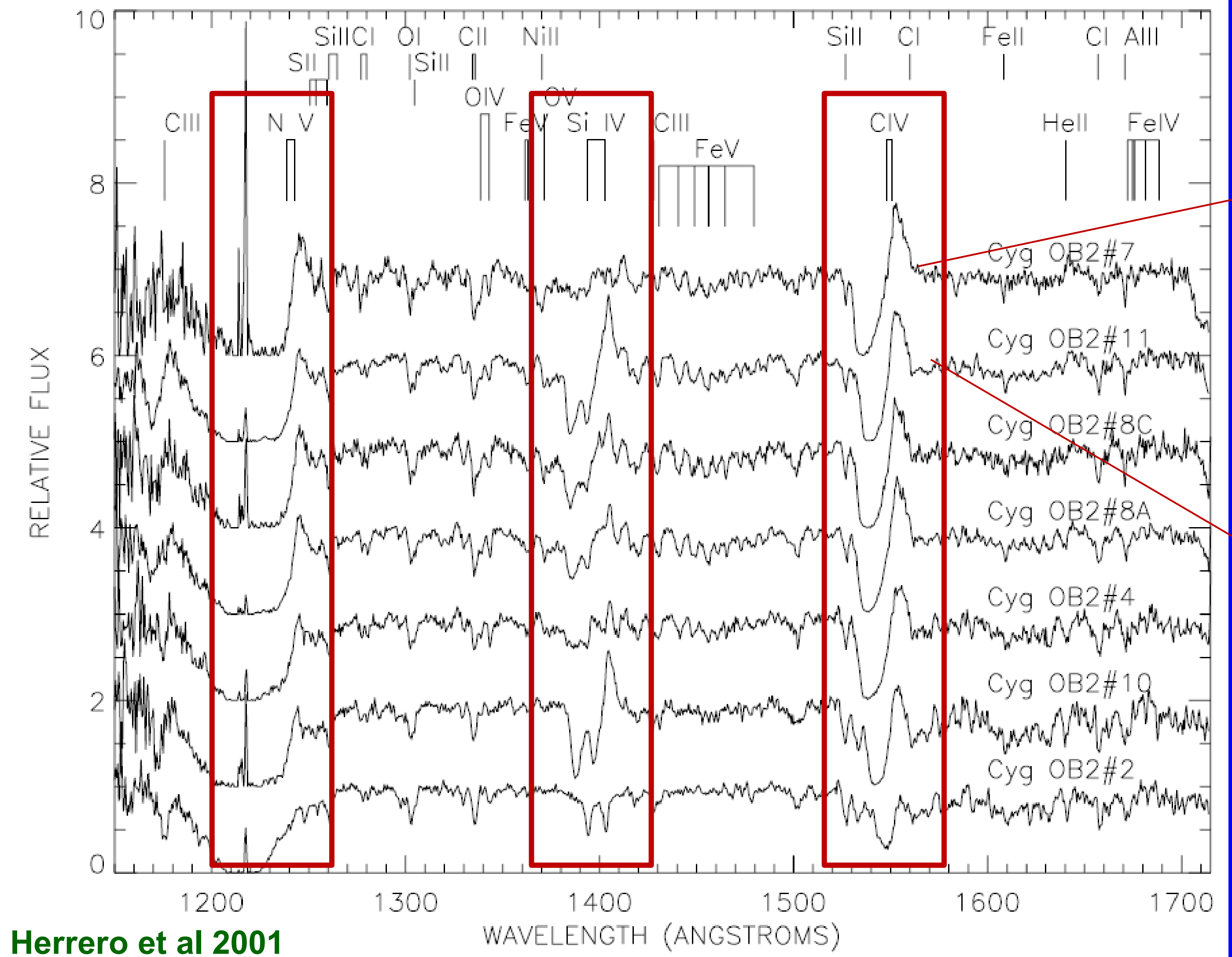
  $$\dot{M} / (\sqrt{f_{cl}}\, V_\infty\, R_*^{3/2})$$

- O stars (H_α) optical depth invariant (Puls+96)

  $$Q = \dot{M}\, f_{cl}^{-0.5} / (V_\infty R_*)^{3/2}$$

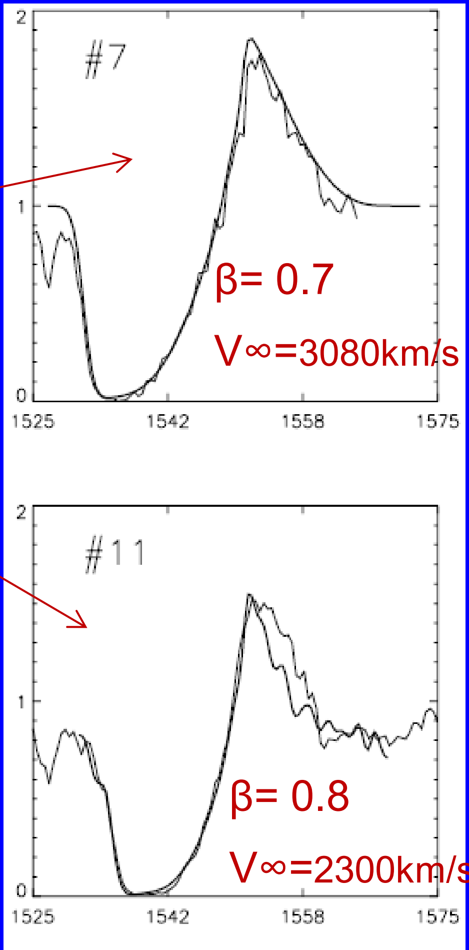
UV

CygOB2 HST



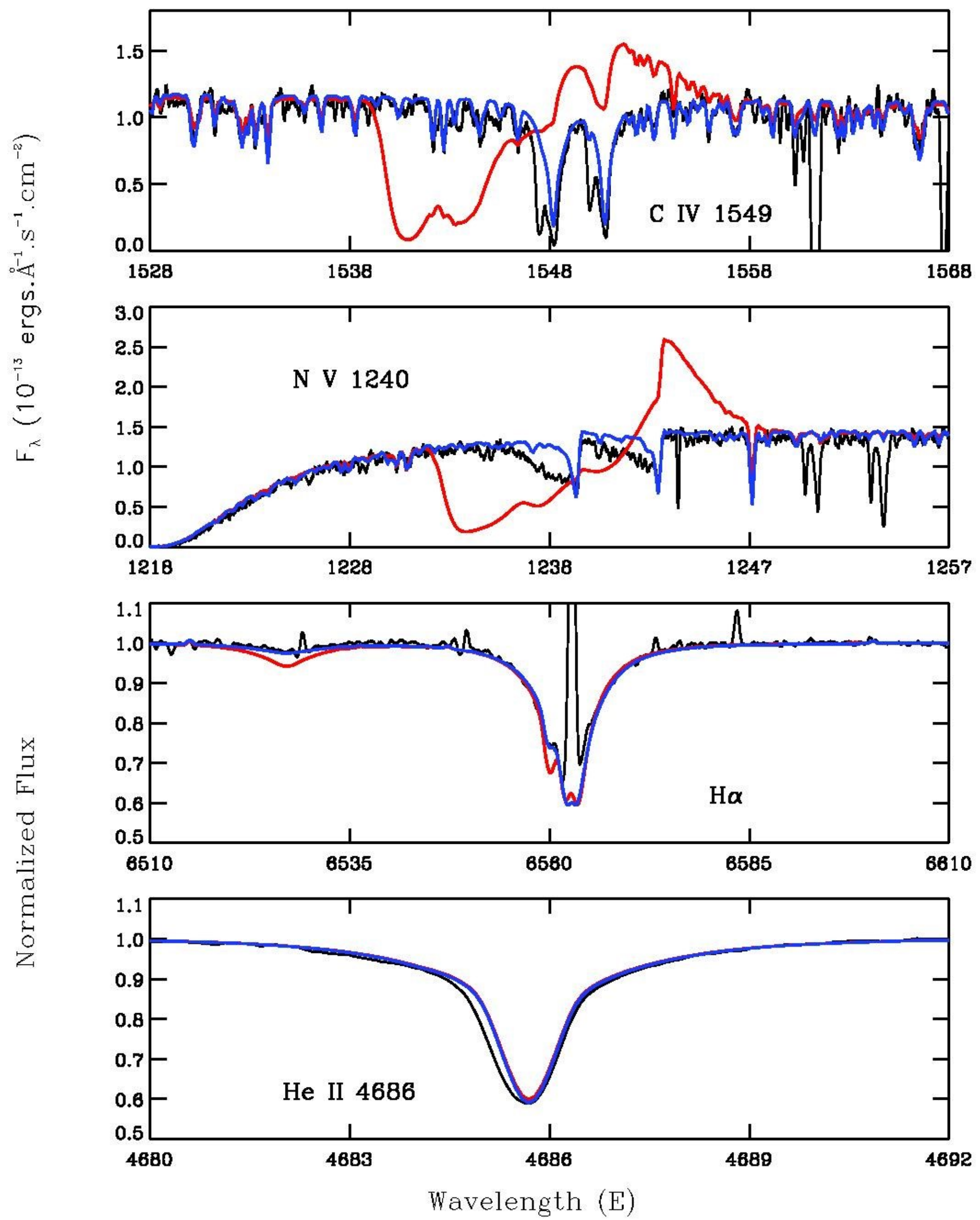
Herrero et al 2001

V(r) from UV



Vturb~ 20%V∞

UV



Mdot from UV

HOWEVER…

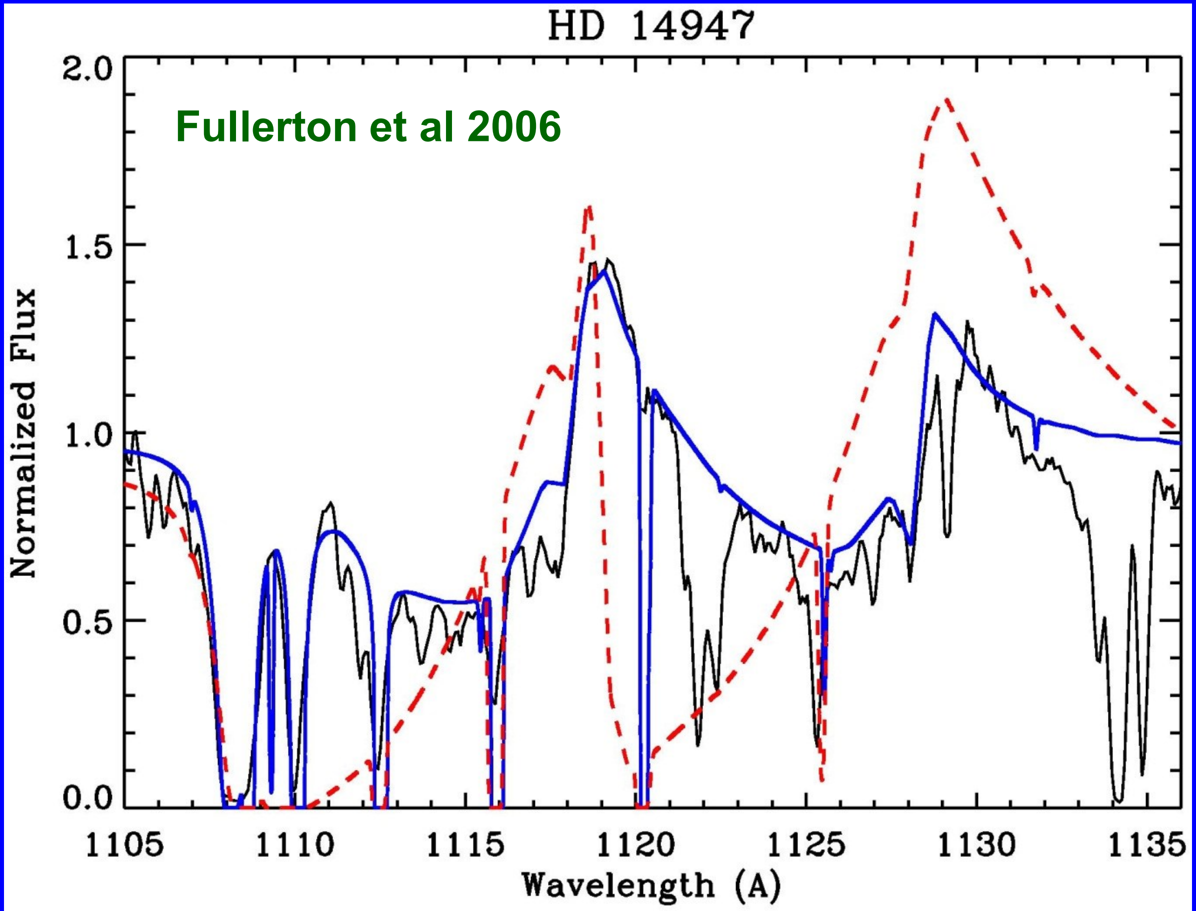
NGC346 031

***Optical* vs UV Mdot**

(Bouret et al 2013)

Mdot from UV: Clumping

DENSE WINDS



<q> Mdot

Unsaturated PV:

Mdot ⬇ factor 10!!

BUT

Macroclumping

(Oskinova et al 07, Sundqvist 2010,11)

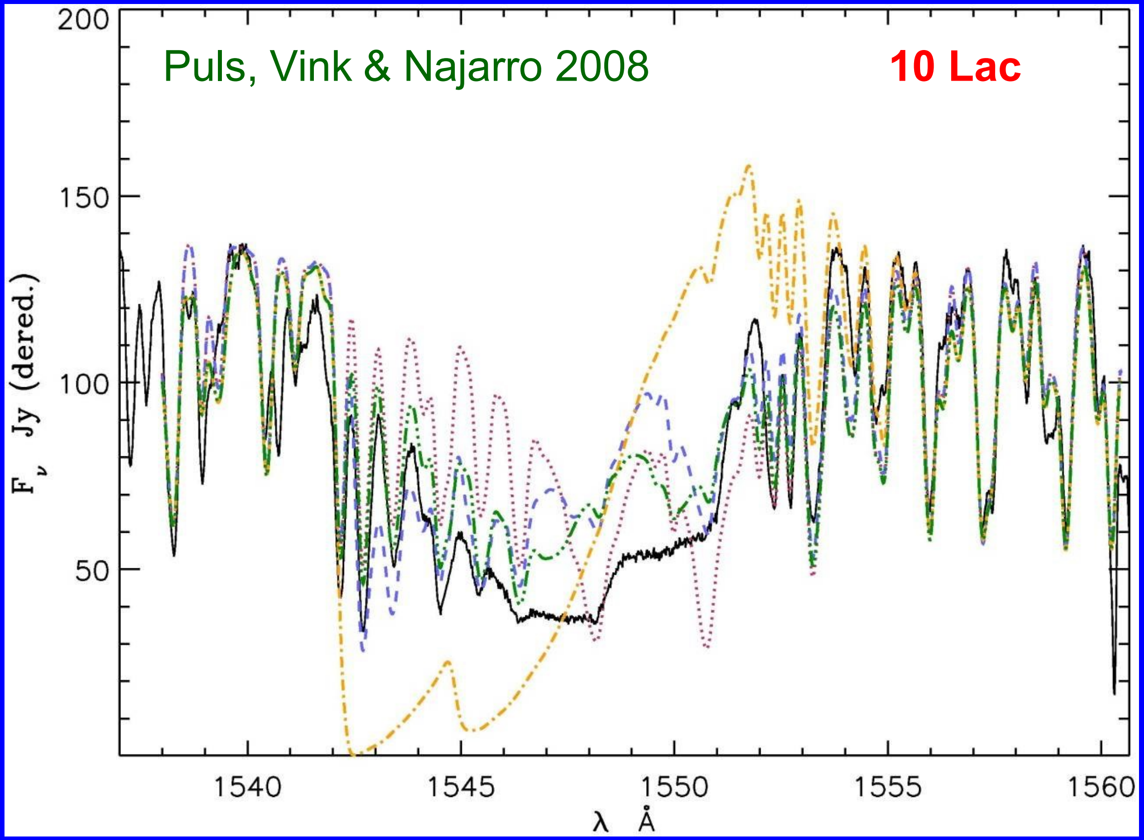
Porosity +

Vorosity =

Perversity

Mdot from UV

WEAK WINDS



Mdot: 1e-10, 2.5e-10, 1.e-9 no X-rays, 1e-9 Xrays Msun/yr

Very low Mdot for

Log L/Lsun < 5.3

BUT

X-Rays

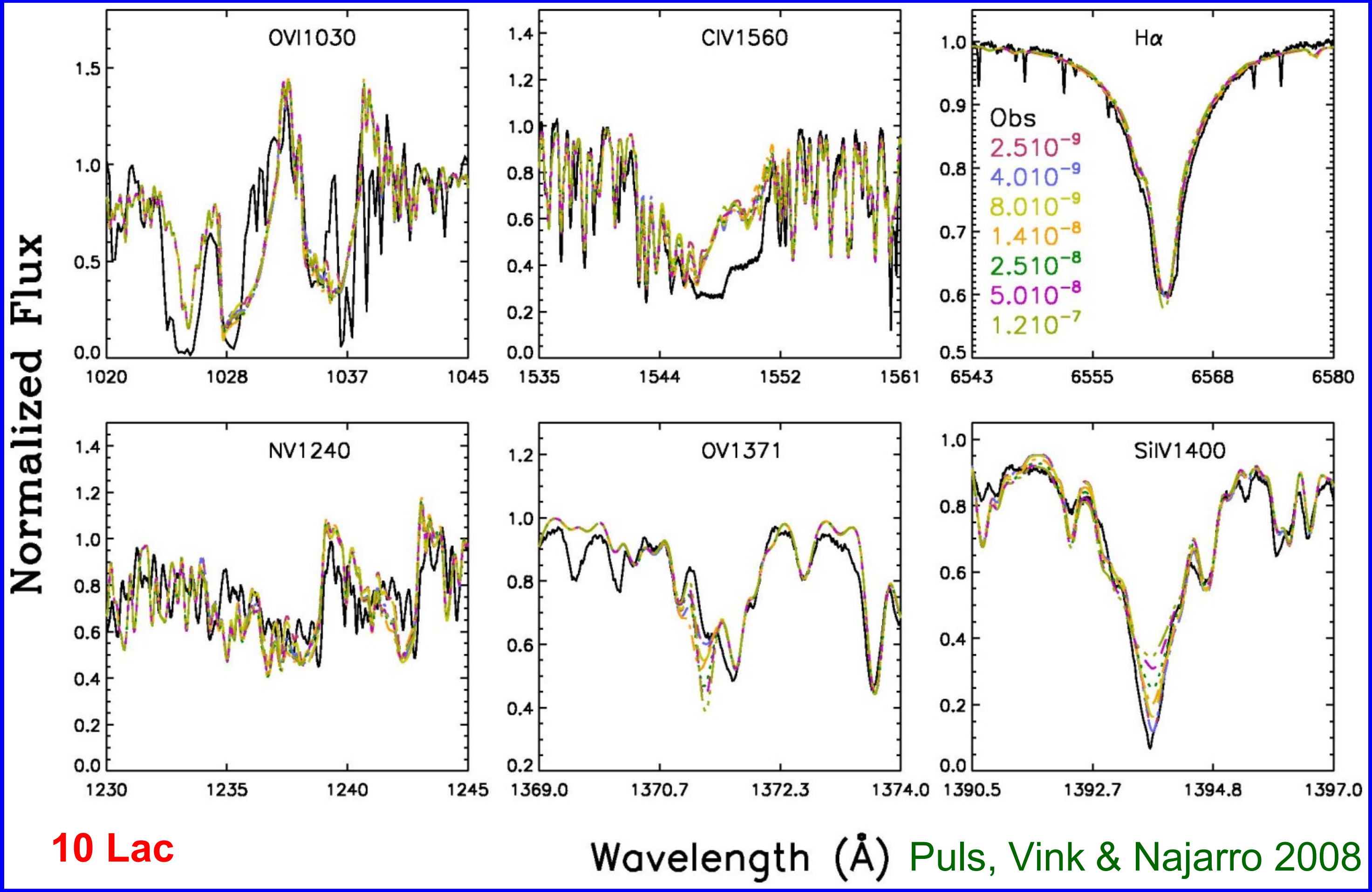
Mdot - Xray

degeneracy

Mdot from UV

WEAK WINDS

X-Rays - Mdot degeneracy over 2 dex!!



Puls, Vink & Najarro 2008

UV Studies

In principle good for
- V_∞
- Mdot, β
- Clumping

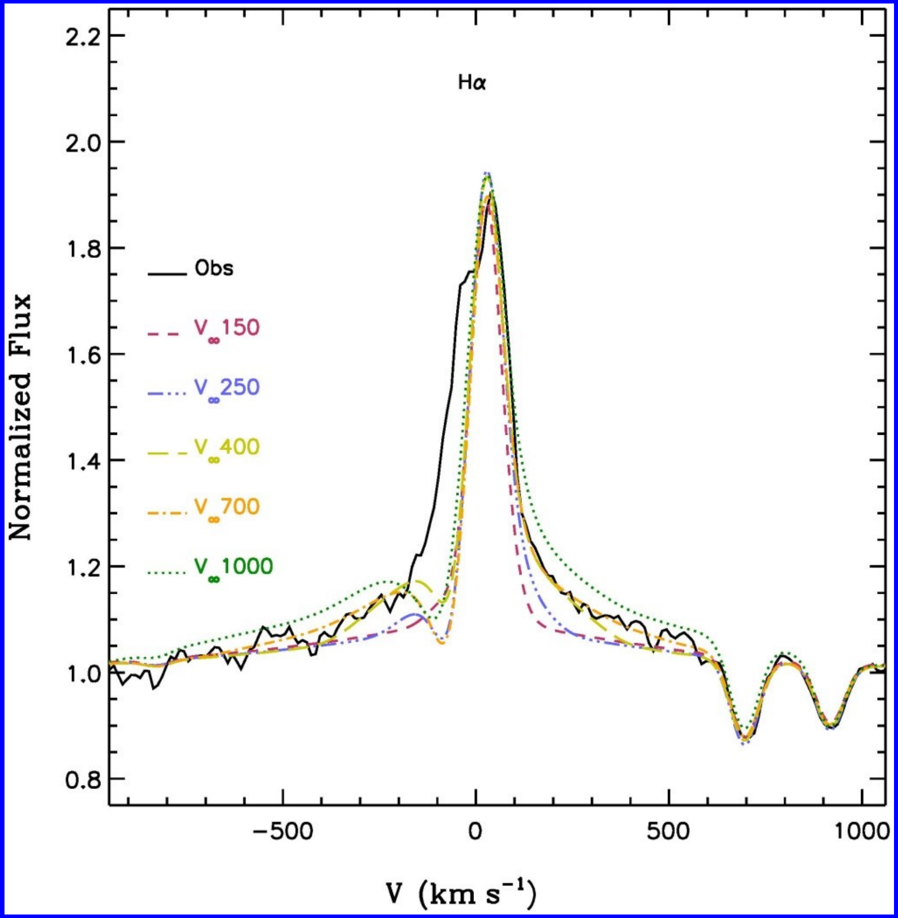
BUT:

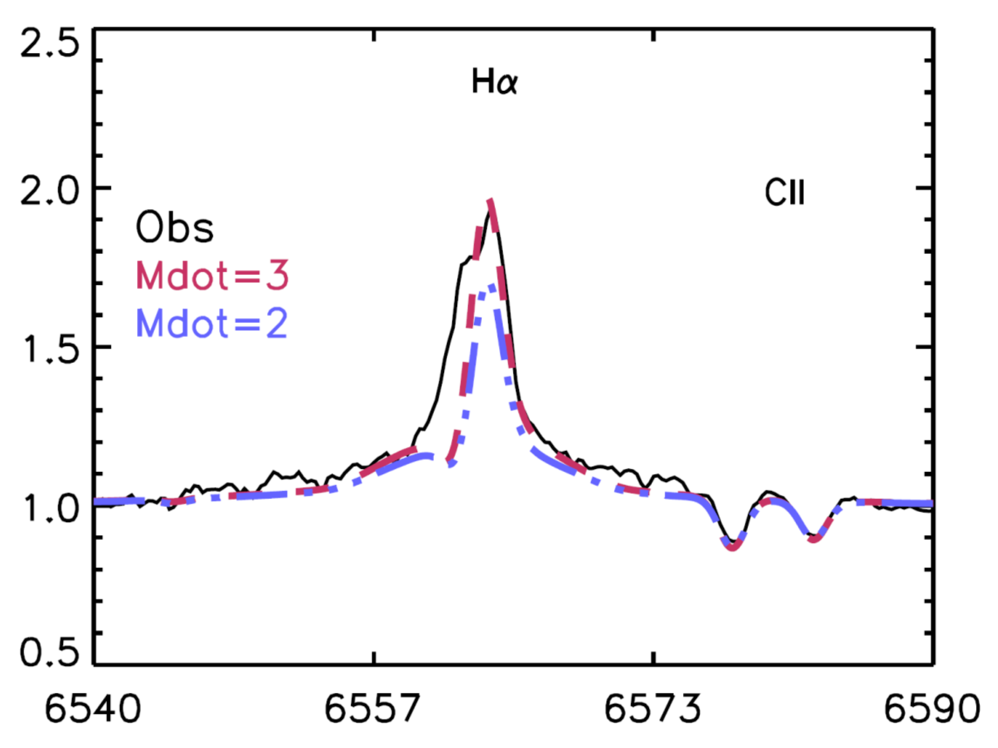
X-RAYS!!

Macroclumping

Mdot from OPTICAL

DENSE WINDS: Hα

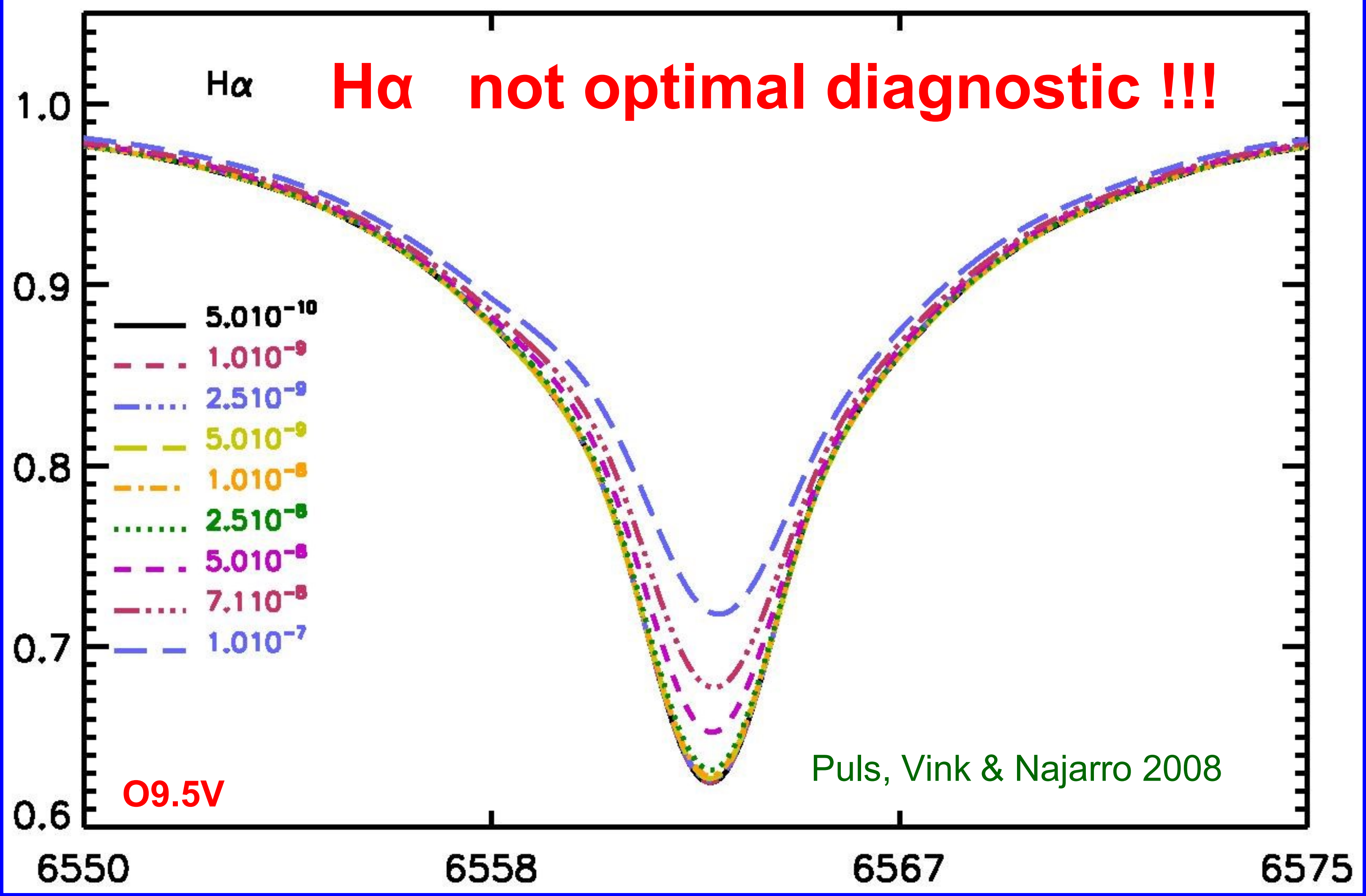




CygOB2 #12 Clark+12

Mdot from OPTICAL

WEAK WINDS



Optical

Hα in dense winds

Good for
- Mdot, β
- Clumping

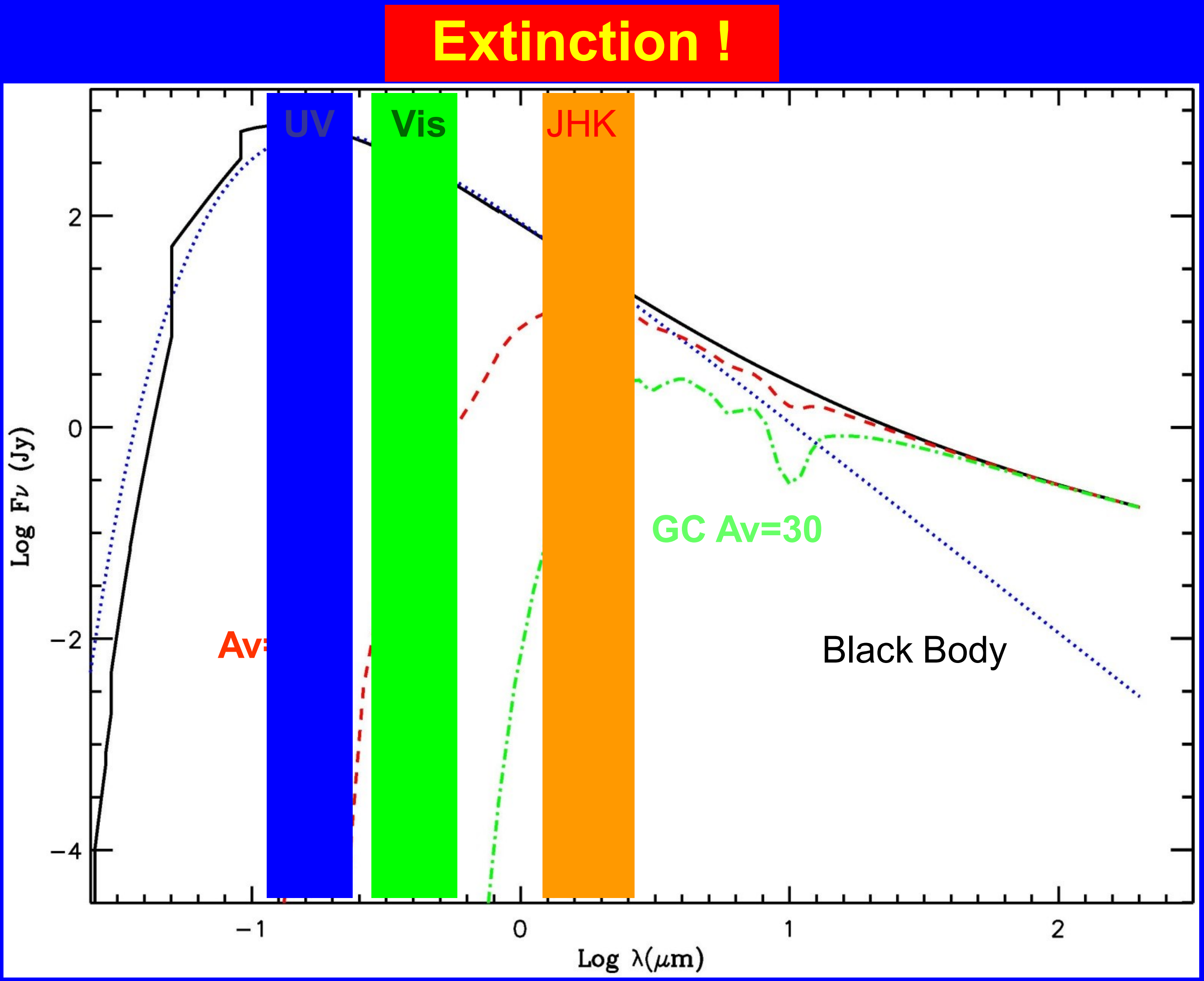
Not so good for
- V_∞

Hα in weak winds

Bad for
- Mdot, β
- Clumping
- V_∞

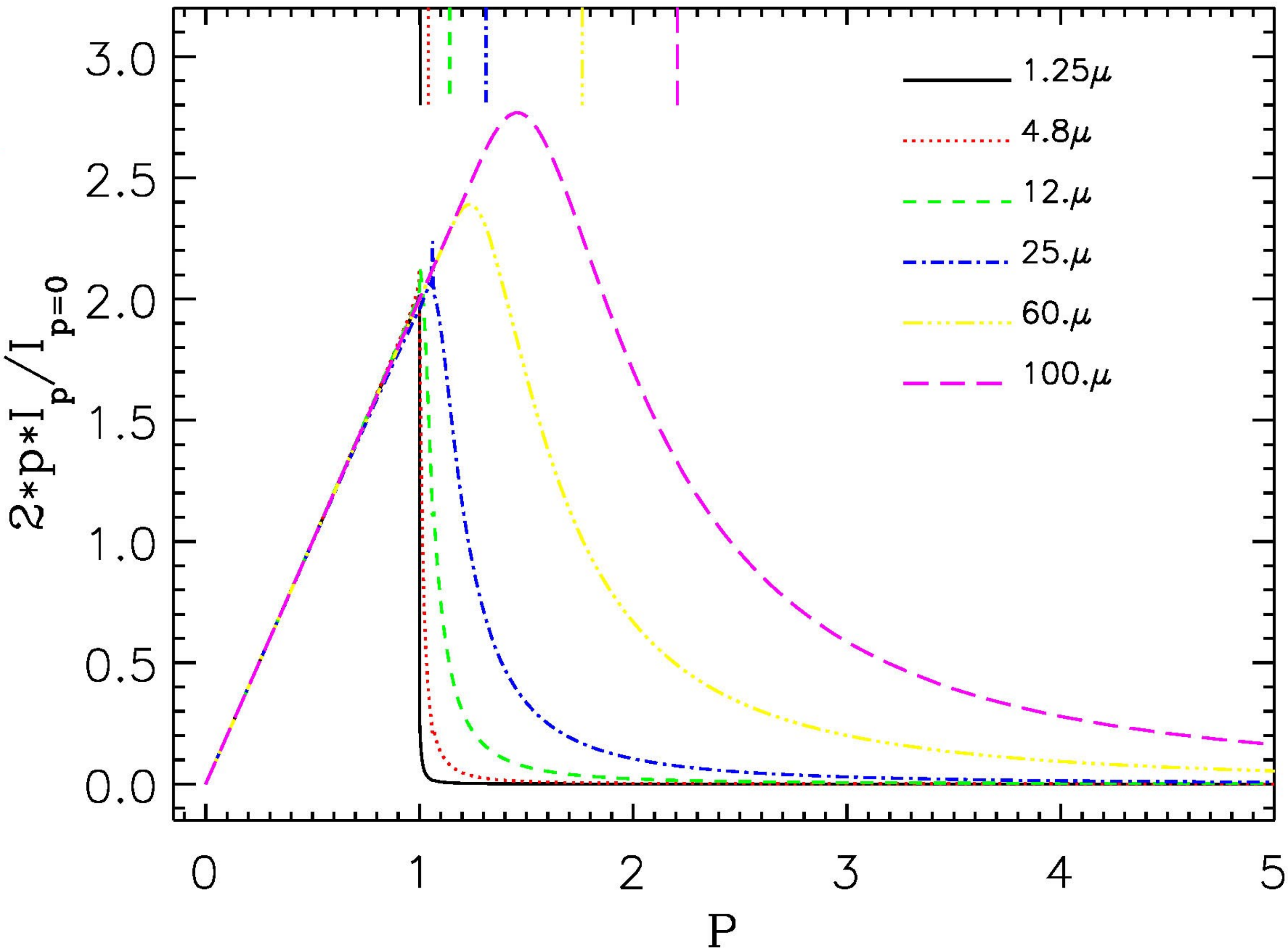
Going Infrared: Sometimes the only way!!

O8If



Bound-Free and Free-Free IR Emission

B1Ia



Stellar Radius increases with $\lambda \Longrightarrow$ Maps different wind regions!!

Potential of IR Lines to constrain Mdot

Auer & Mihalas (1969), Mihalas (1978):

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

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

E.g. T=30000 K hv/kT =0.24 at Bγ and 0.11 at Bα

Bα bl/bu=0.95 SL/Bv =1.83

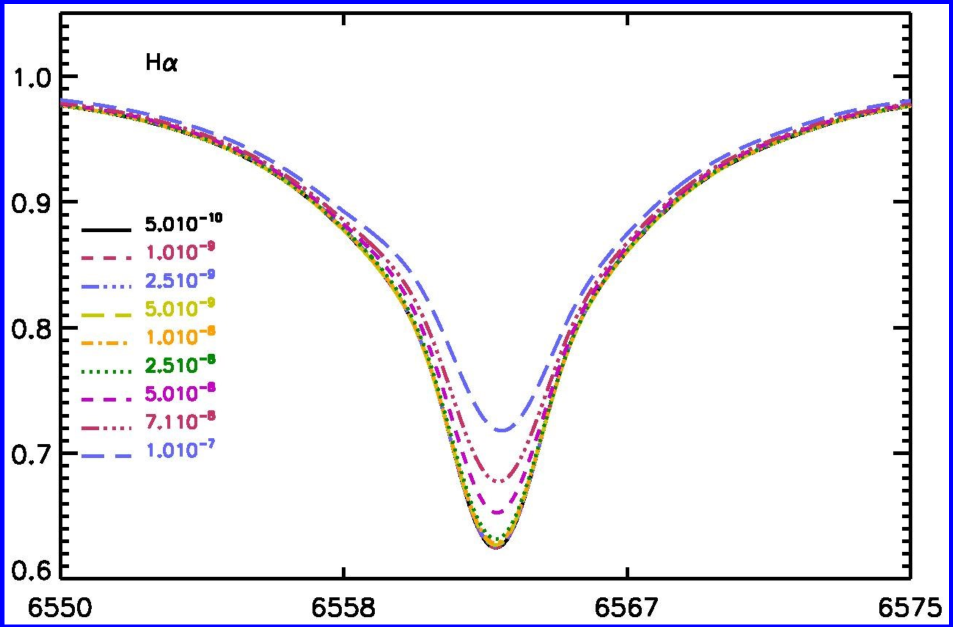
Bα bl/bu=0.90 SL/Bv =11

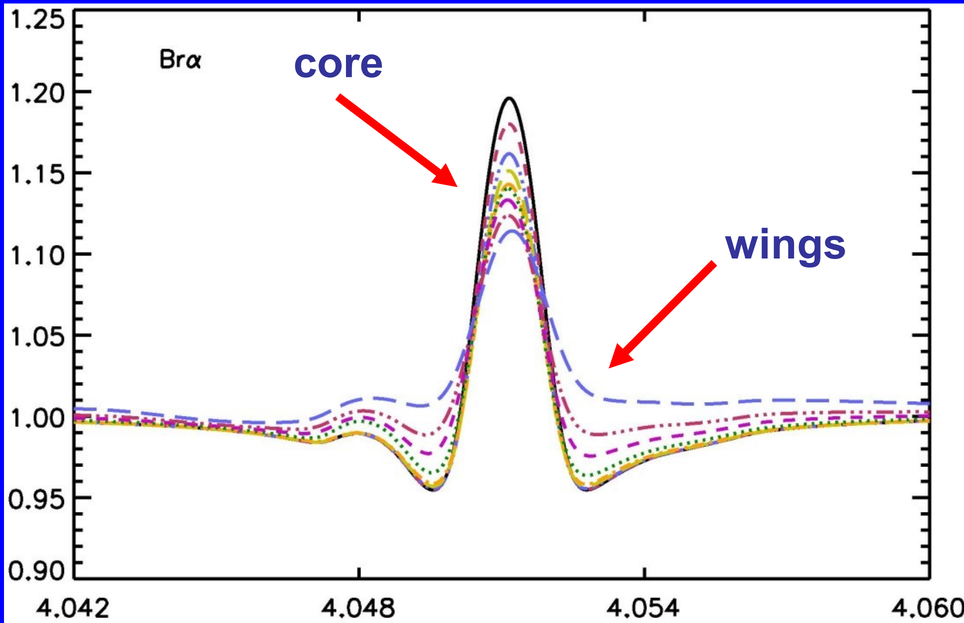
Thin winds ➔ n=4 depopulation at line core.

Very high sensitivity ➔ valuable diagnostics for Mdot

Potential of IR Lines to constrain Mdot

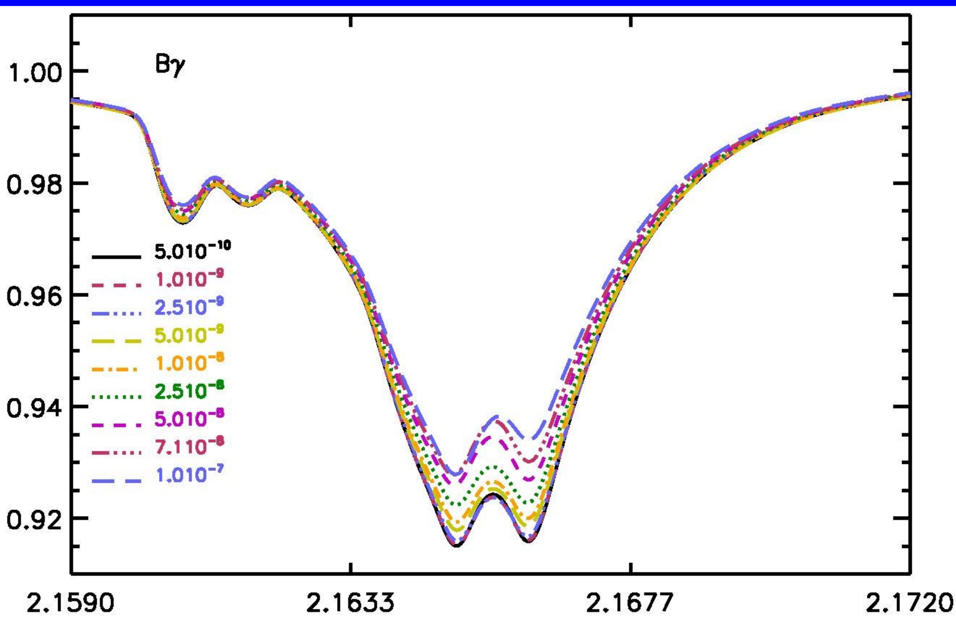
WEAK WINDS

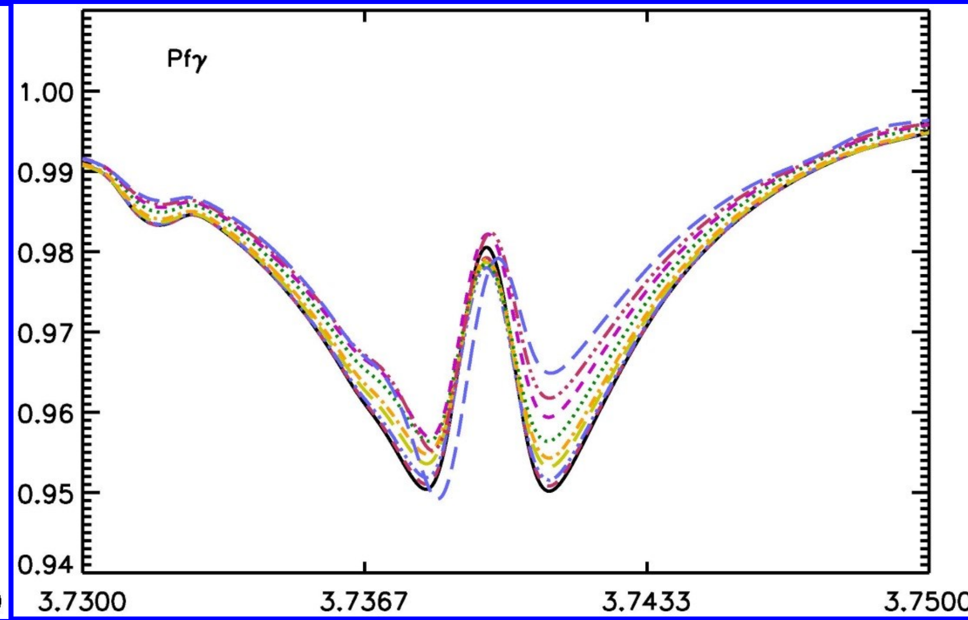




Potential of IR Lines to constrain Mdot

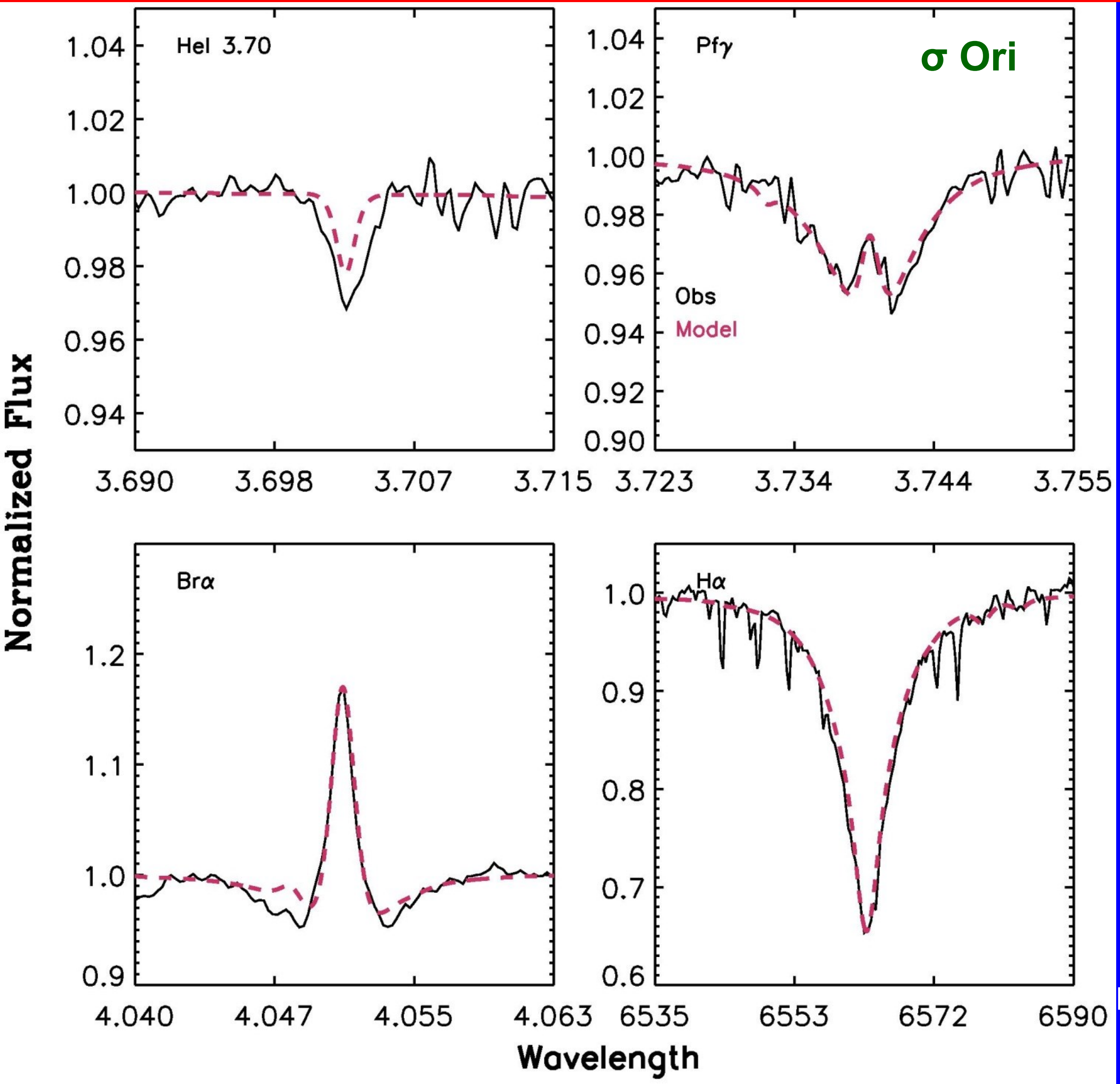
WEAK WINDS





L-Band lines provide reliable constraints on Mdot

Potential of IR Lines to constrain Mdot



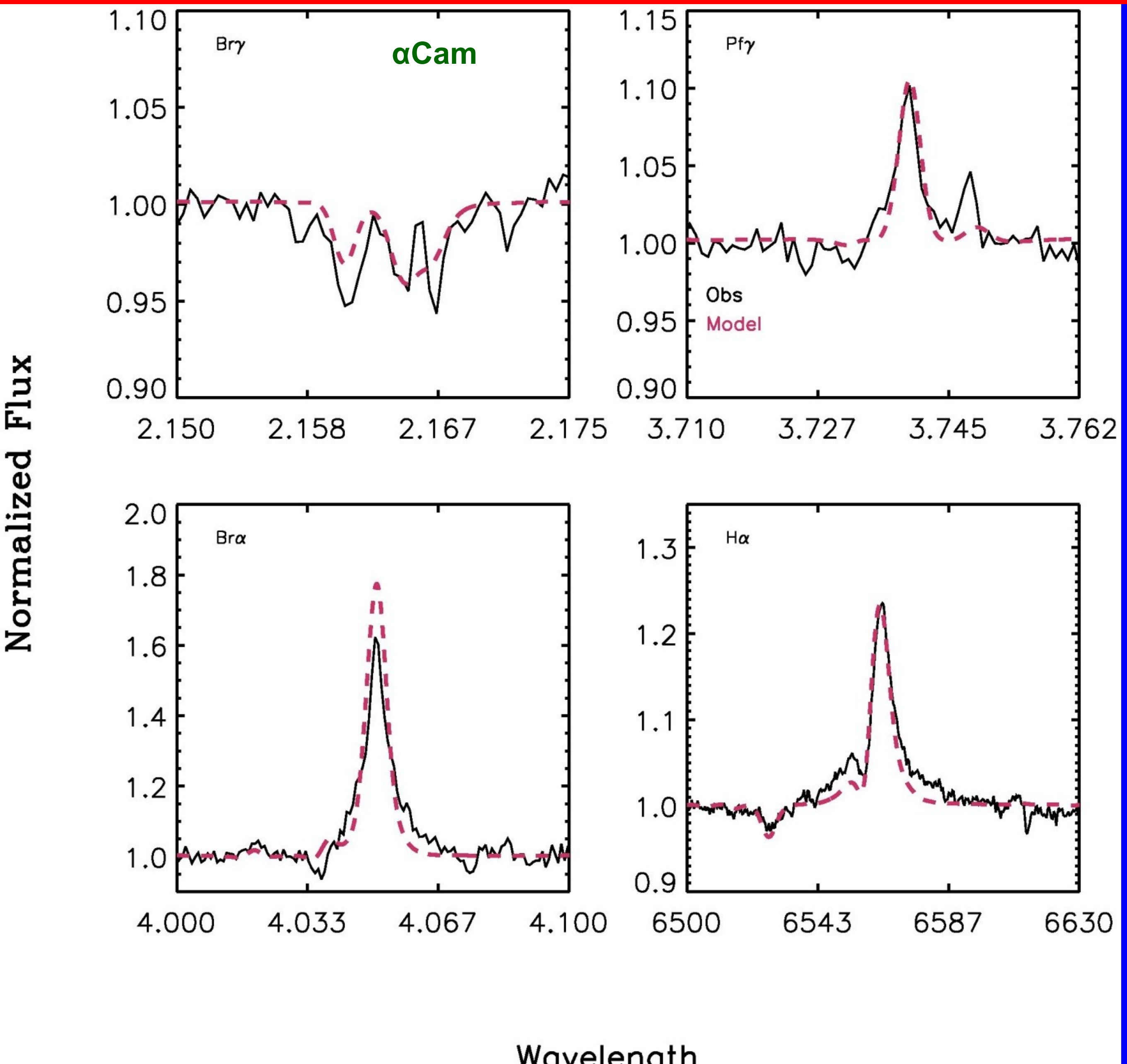
σ Ori O9.5V

$\dot{M}$=2d-10 Msun/yr !

Najarro, Hanson & Puls 2011

Prague June-28-2017

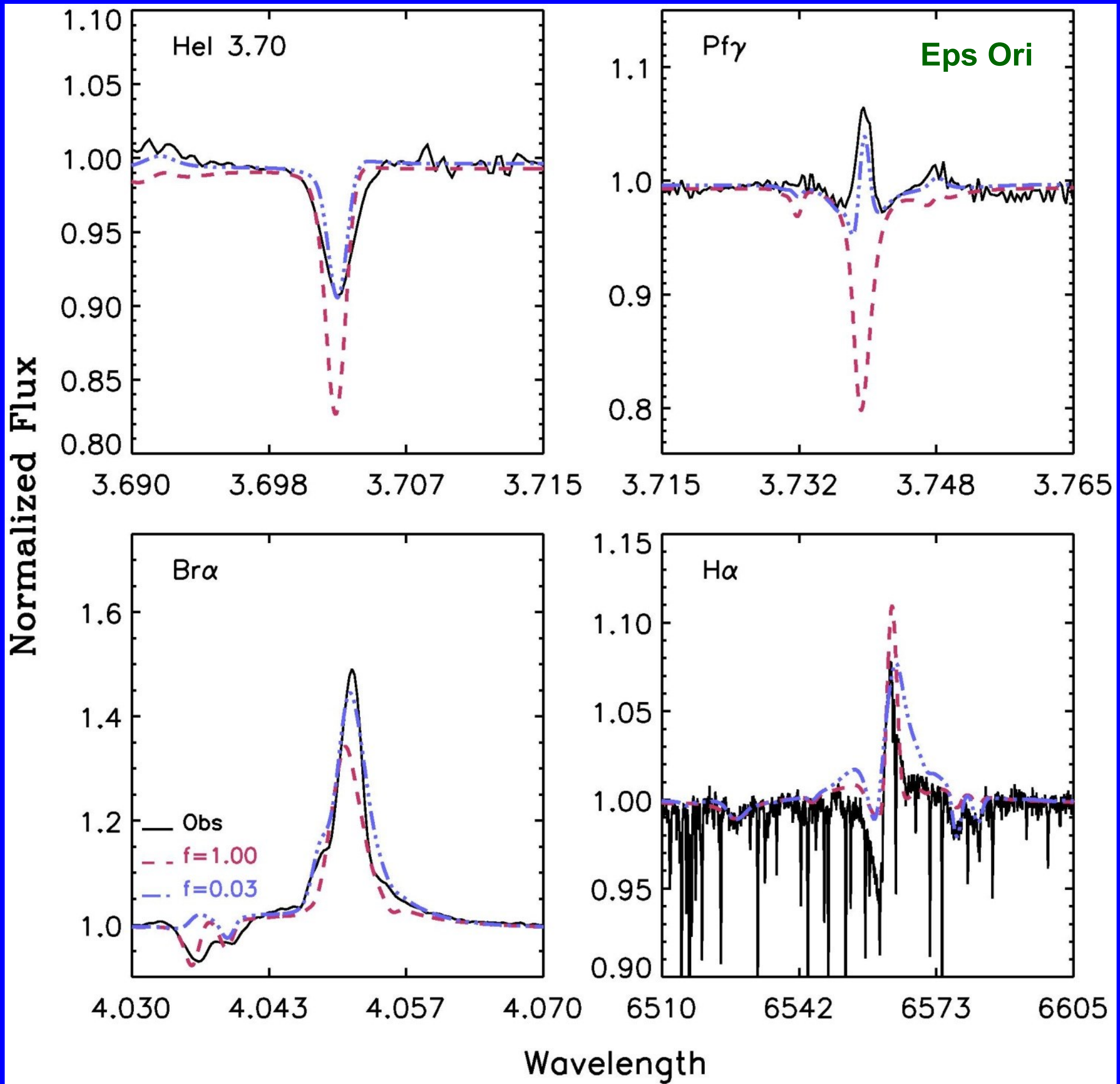
Potential of IR Lines to constrain Mdot



DENSE WINDS

Najarro, Hanson & Puls 2011

Potential of IR Lines to constrain Mdot



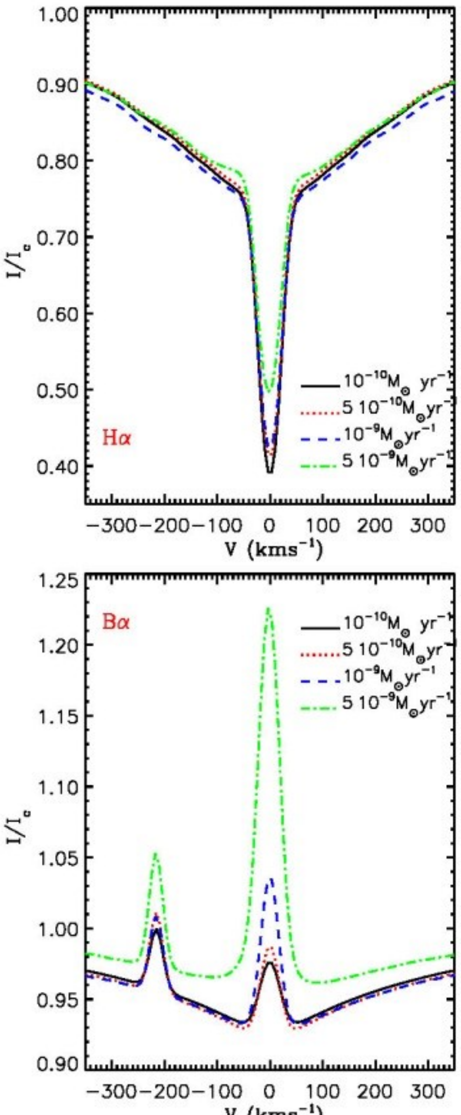
DENSE WINDS

CLUMPING

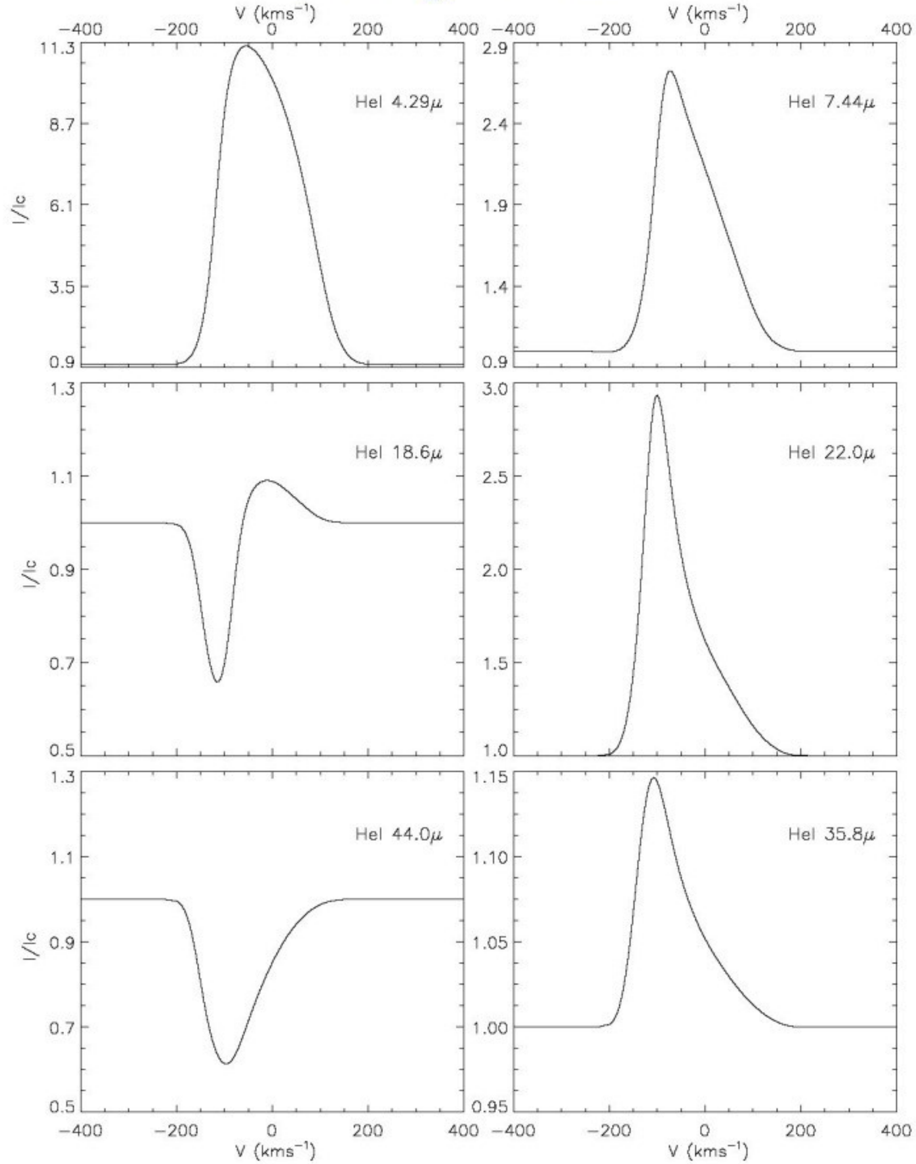
Najarro, Hanson & Puls 2011

IR Lines as diagnostic tools

Weak Winds



Strong Winds



Infrared

IR lines in dense winds

Good for

- Mdot, β
- Clumping
- V_∞

IR lines in weak winds

Good for

- Mdot

Not so good for

- V_∞, β
- Clumping

Potential of IR Lines to constrain Mdot

DENSE WINDS

Bα samples intermediate wind

Bγ and Pfγ sample lower wind as Hα

L band continuum also sensitive to Mdot

Multiwavelength studies (UV, Opt, IR & Radio)

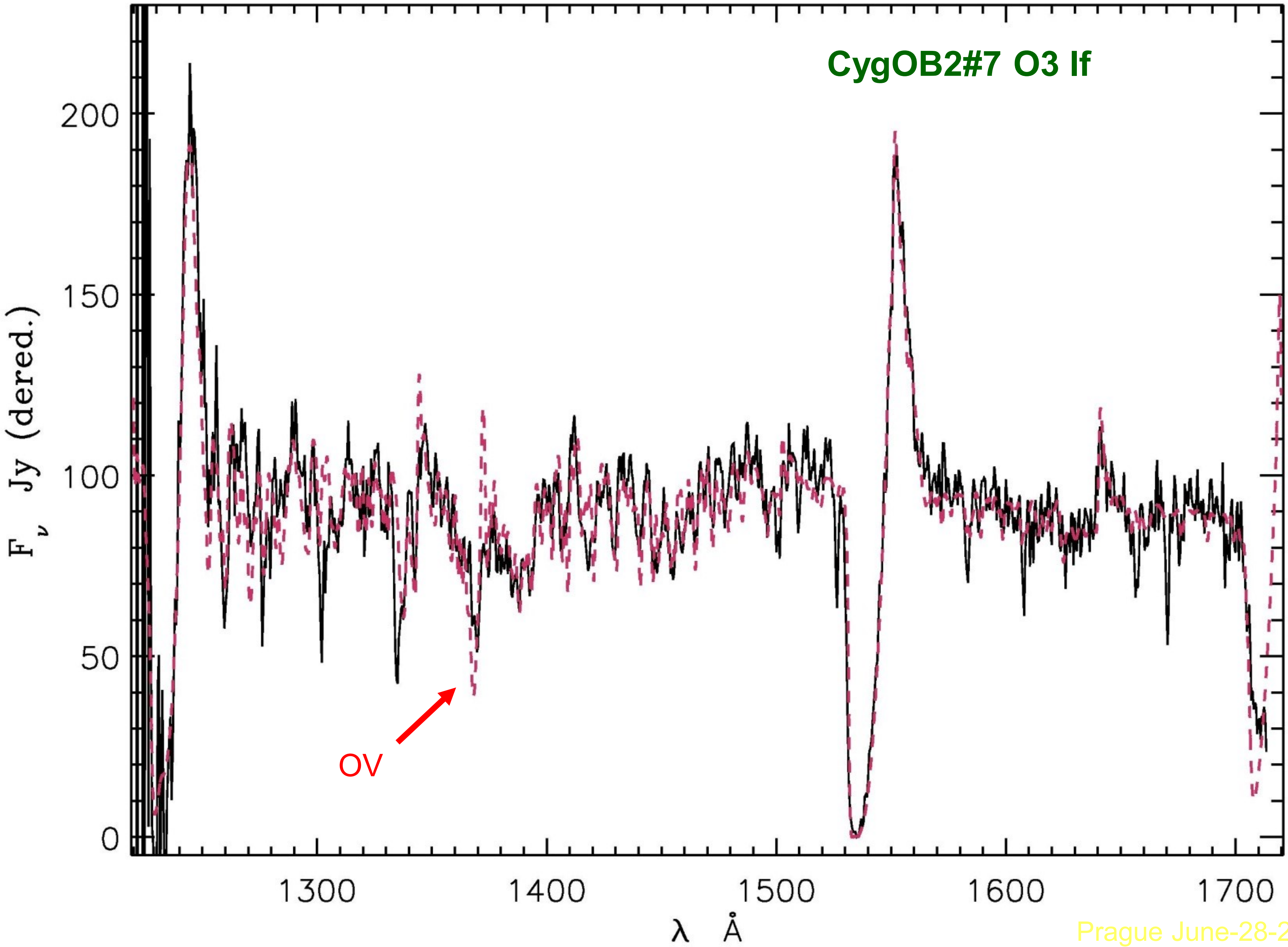
Derive "true" Mdot values

Constrain clumping factor and stellar properties.

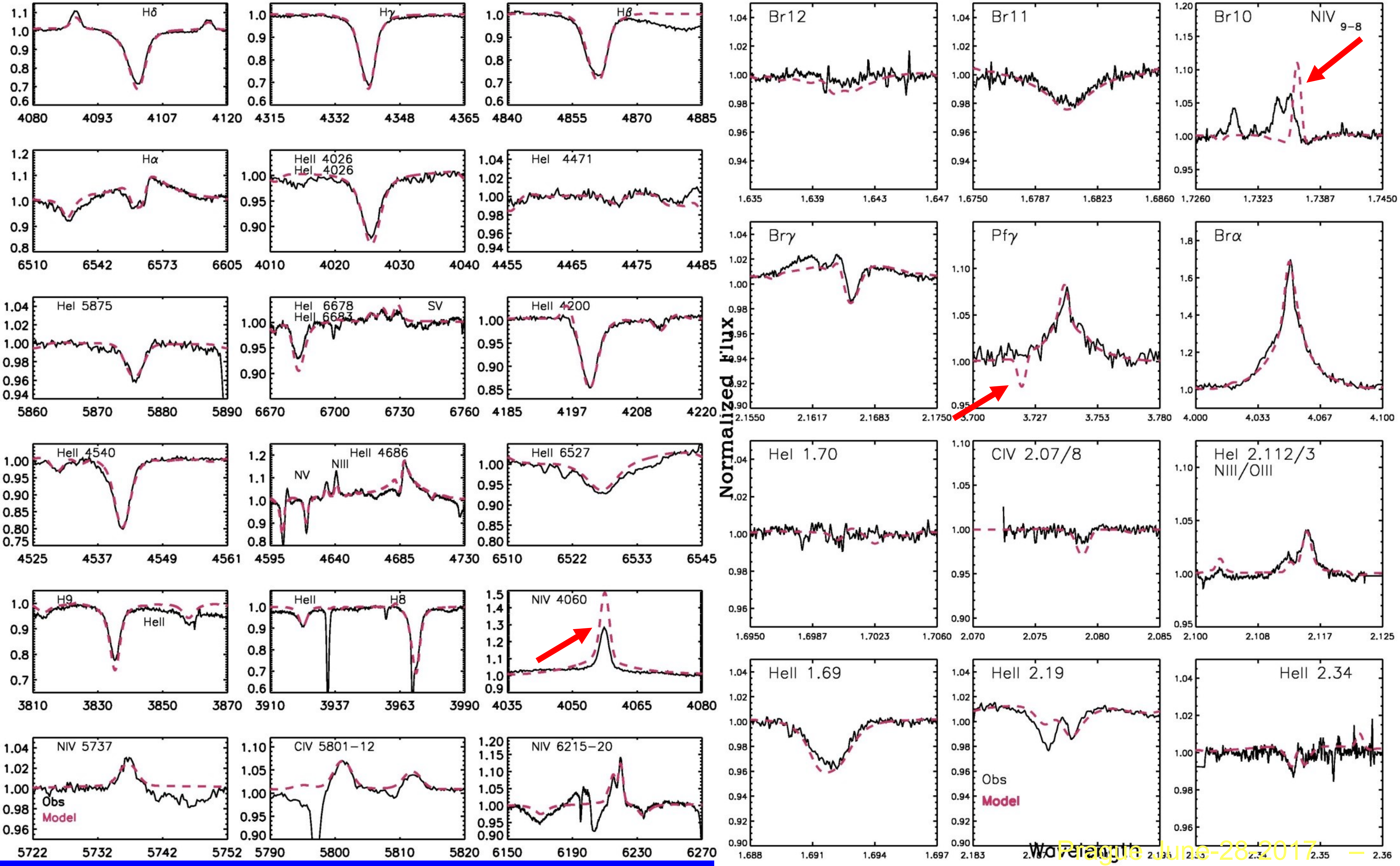
Let's go multi-λ

Najarro, Hanson & Puls 2011

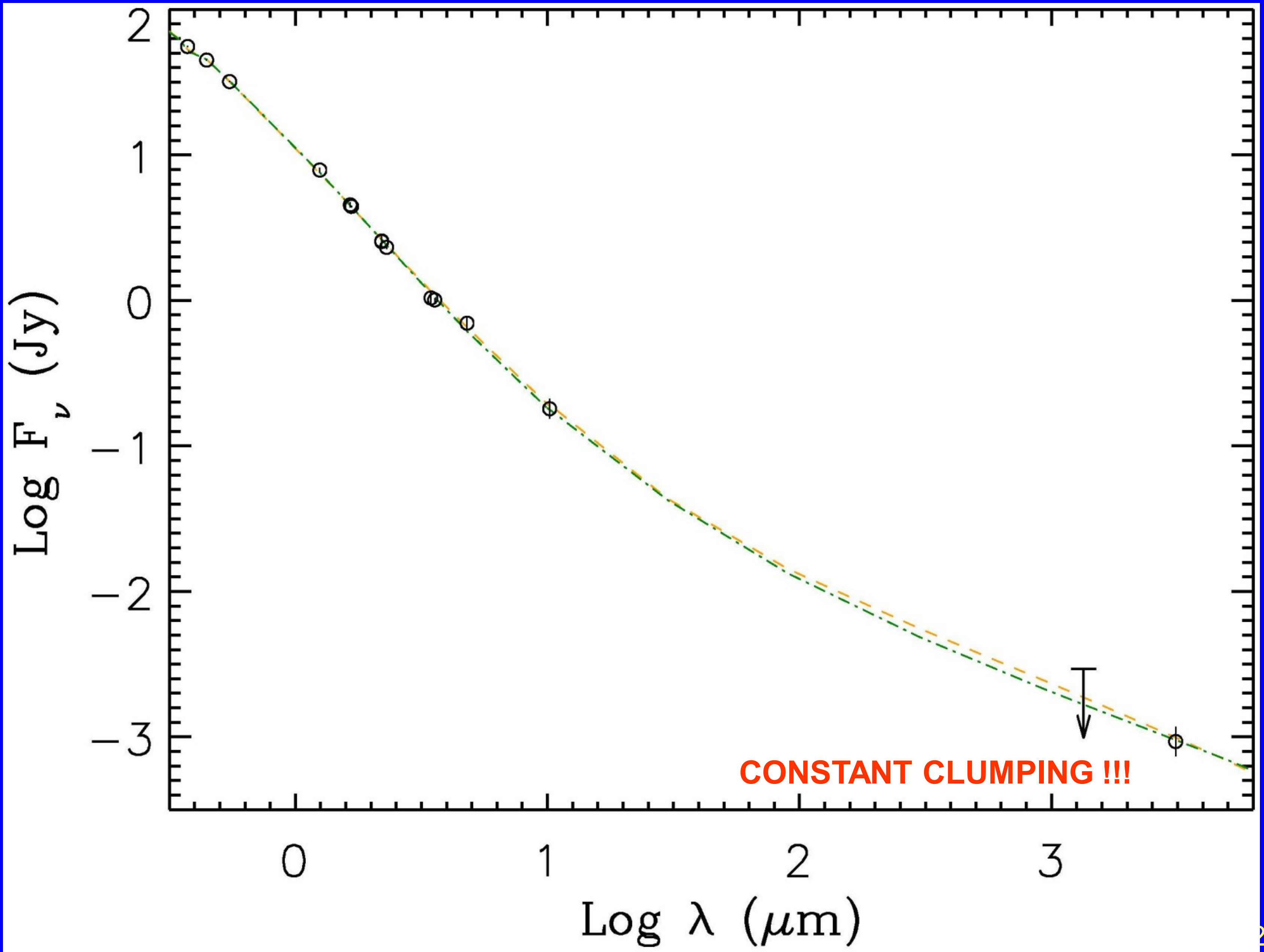
Multi-wavelength study: CygOB2 #7



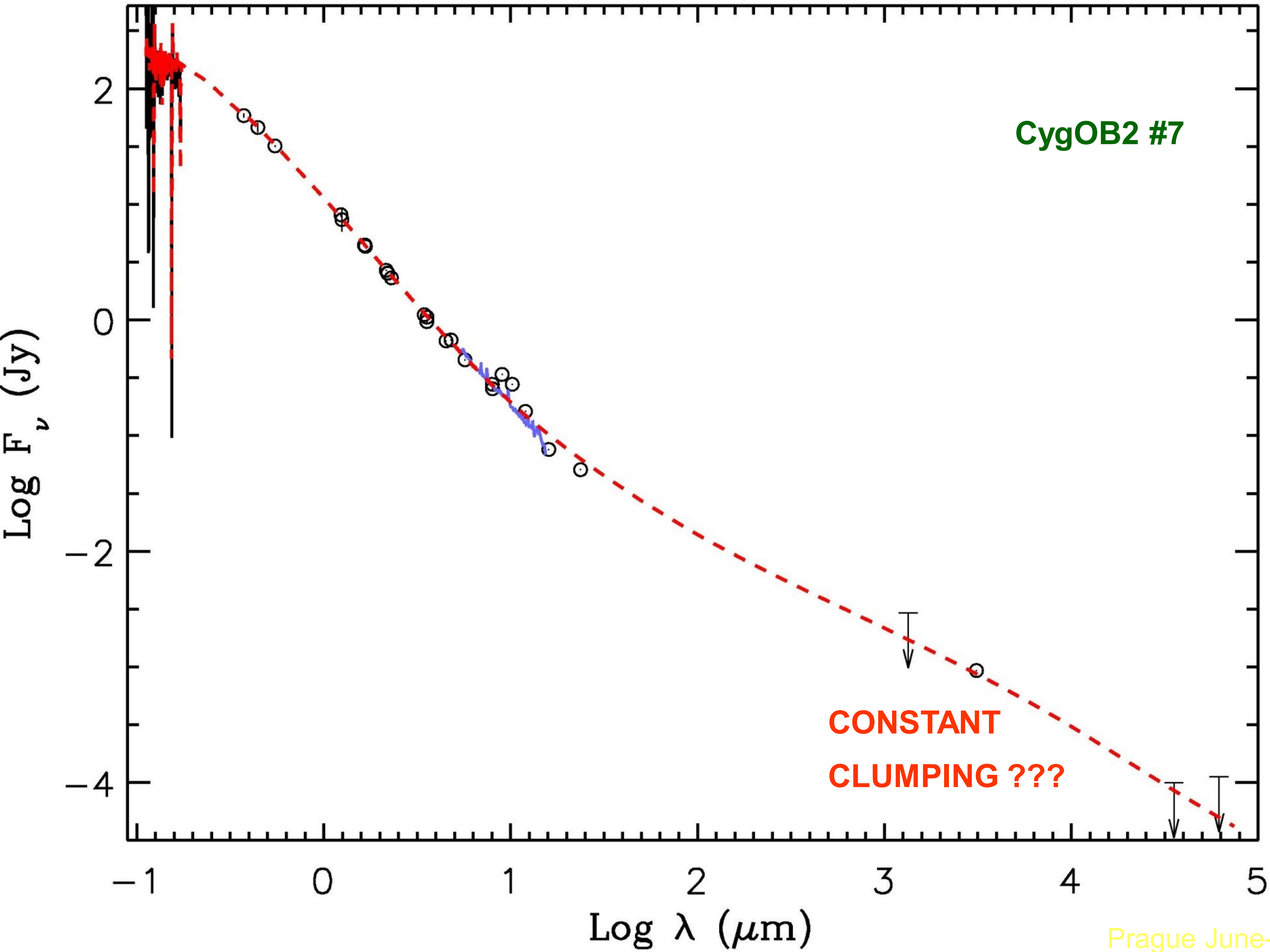
Multiwavelength Study: CygOB2 #7



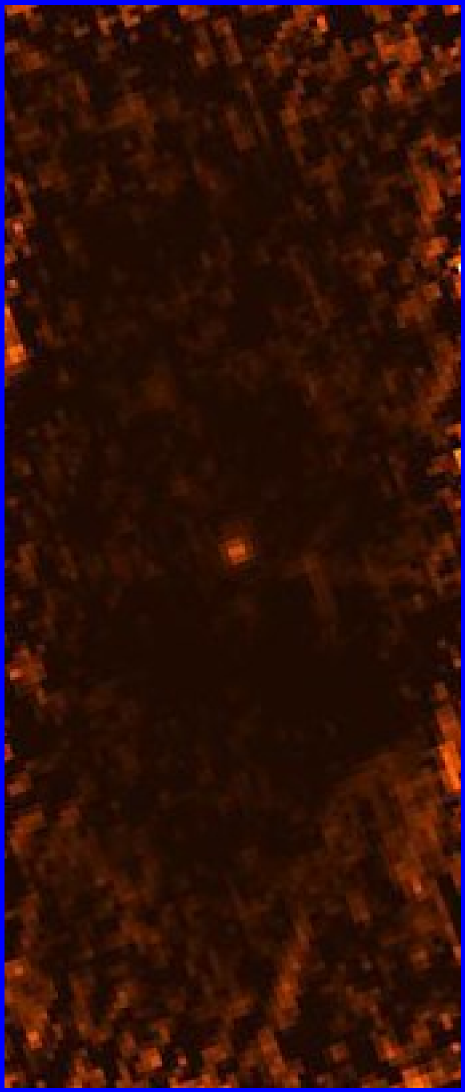
Multiwavelength study: CygOB2 #7

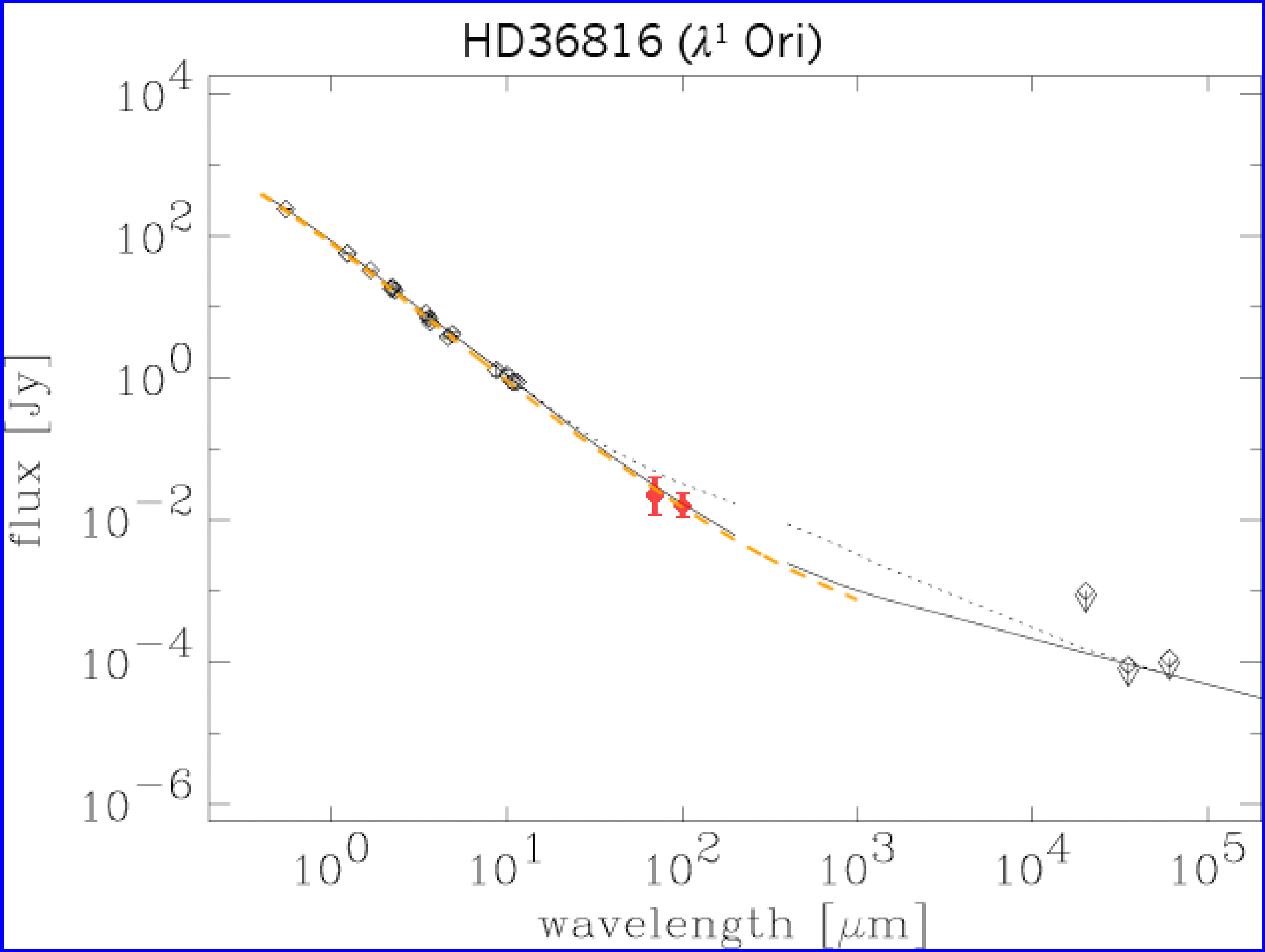


Constant Clumping?



What's next? FIR and Radio
Herschel PACS 70 & 100µm Obs of OB stars

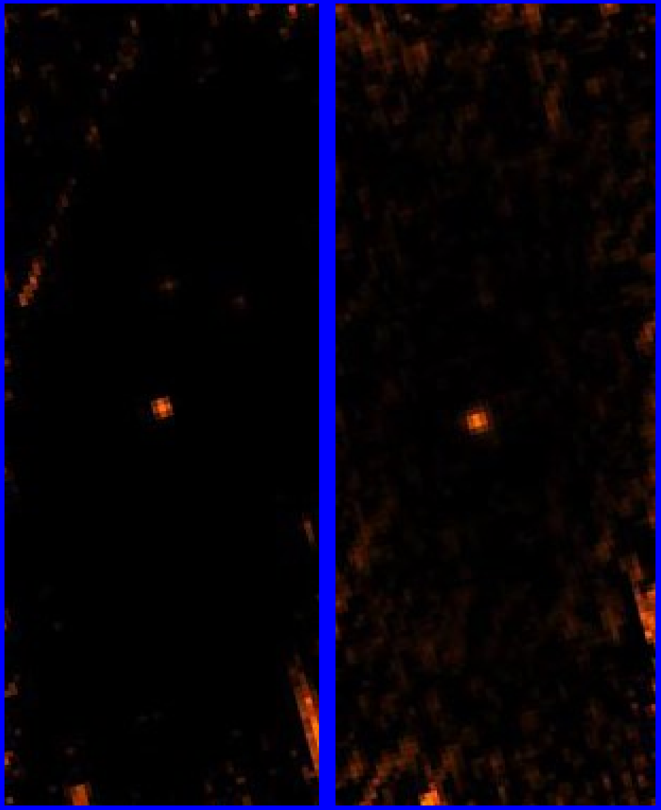


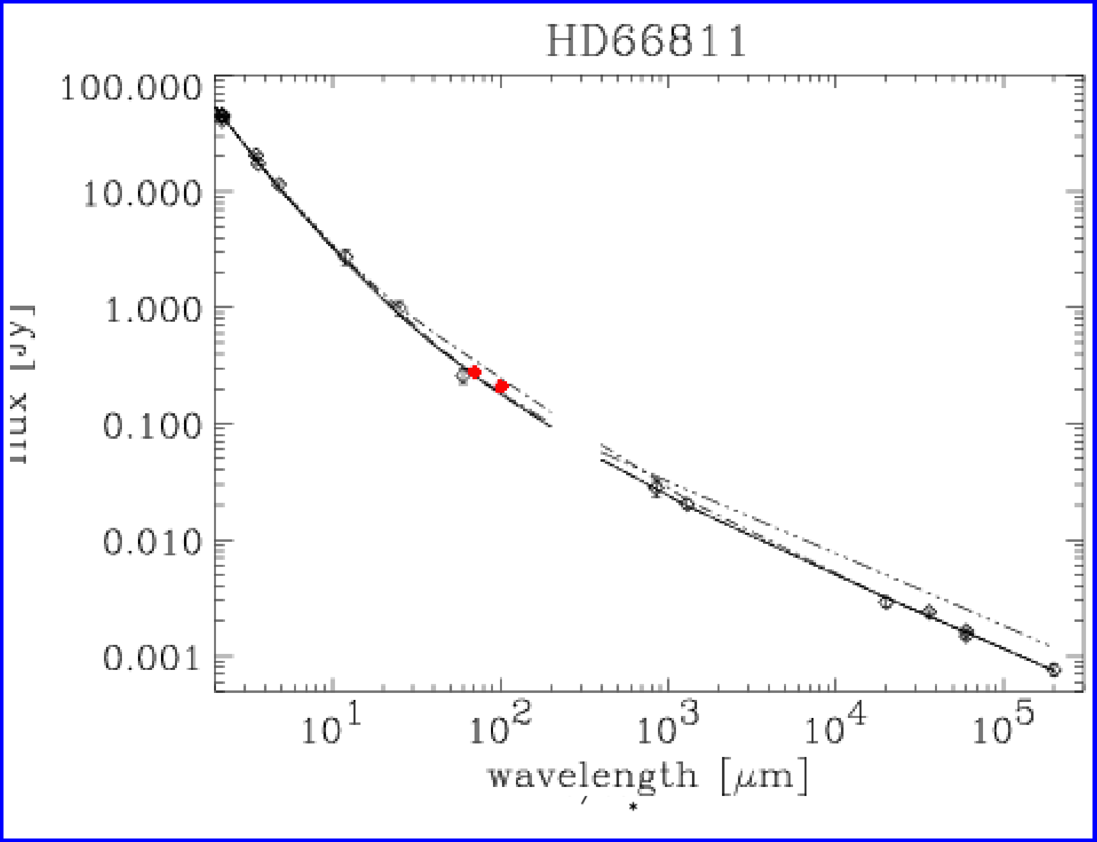


Poster by M. Rubio-Díez, Rhodes

What's next? FIR and Radio
Herschel PACS 70 & 100µm Obs of OB stars

Are you missing ζ Puppis ?

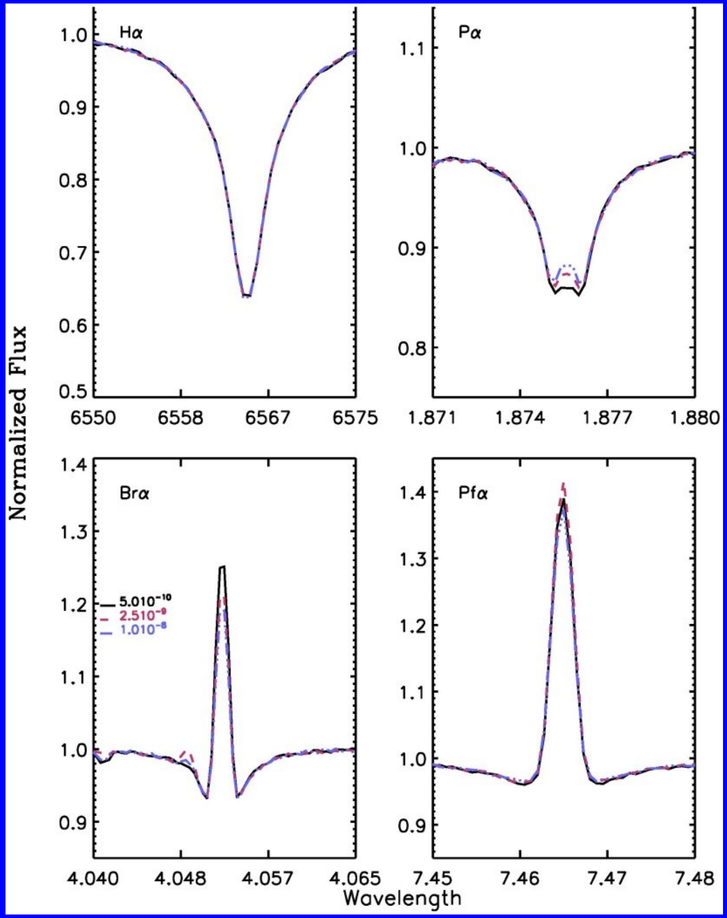




Poster by M. Rubio-Díez et al, Rhodes

Future: JWST and the real Mdots
Weak winds at the SMC

- L Band spectroscopy from earth for high S/N ratio limited to L < 8
- JWST NIRSPEC MIRI major step →L~15 (SMC OV…)



← R~10000

O8V

R~2700 →