Massive stars in metal-poor environments: One step forward from the SMC

A multiwavelength UV+optical project:

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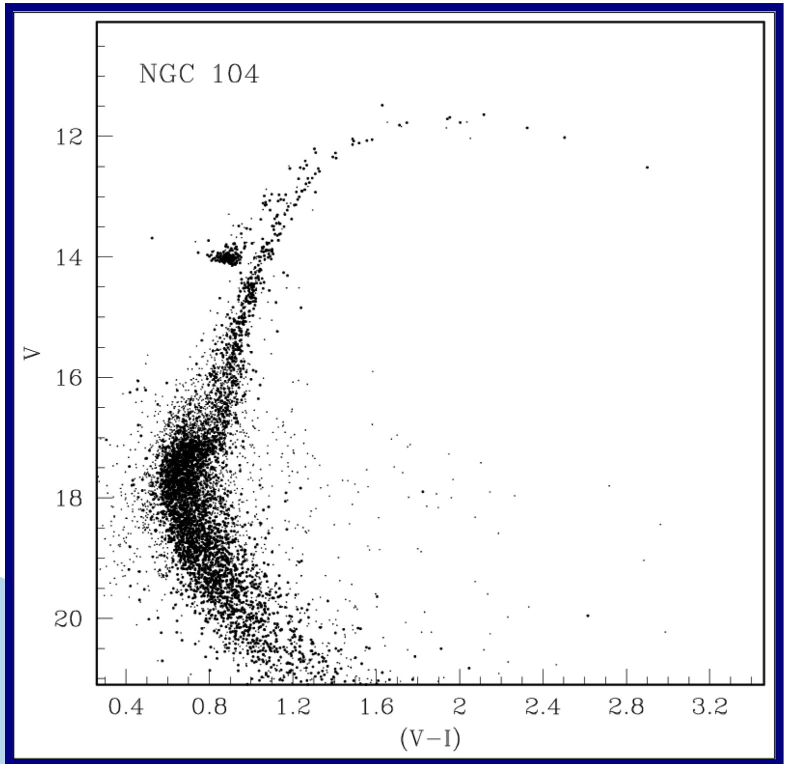
Galaxies meet GRBs
SEPTEMBER/24th/2013

What the Galaxies+GRBs communities need from the massive star people:

- Well-defined evolutionary channels at different metallicity…
  - Time spent at each stage
  - Post-main sequence stages
  - Nucleosynthesized material
- … to quantiy feedback at each stage
  - Ionizing flux
  - Mechanical energy (stellar winds and SN explosion)
  - Yields
- … and to predict the stellar properties at the end of the FeNi-burning stage
- Spectral libraries for the population synthesis codes to confront predictions against the observations.

The life of massive stars is not as straight-forward as those of low-mass stars

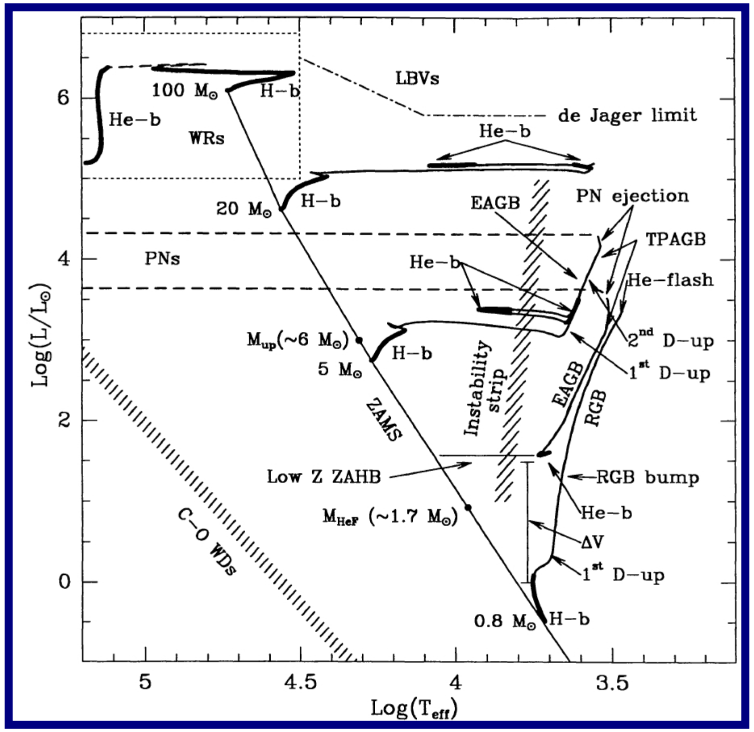
LOW MASS STARS



47 Tucanae

Rosenberg et al. 2000

HIGH MASS STARS



Chiosi, 1998

One of the main problems is that massive star mass loss is yet unknown.

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Blue massive star's radiation-driven winds. Strong metallicity dependence…

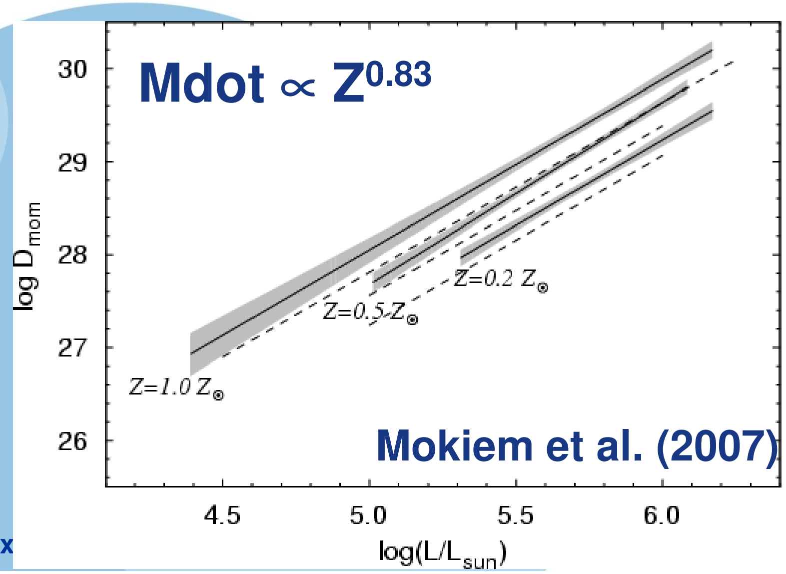
- Powered by photon scattering by metallic lines.
- Main parameters:

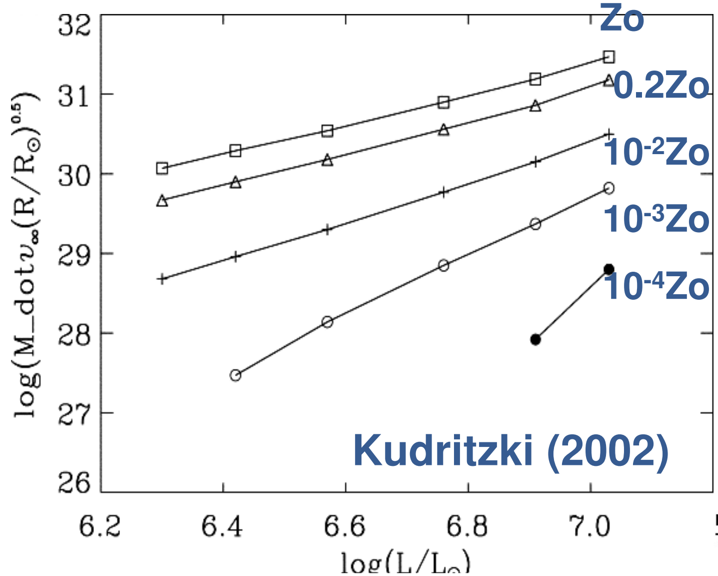
  Mass loss rate ($\dot{M}$) and terminal velocity (v_∞)
- WLR, our main diagnostic tool:

Wind momentum–Luminosity Relation

$$\log D_{mom} = \log D_0 + x \log(L/L_\odot)$$
$$D_{mom} = \dot{M}\, v_\infty (R_*/R_\odot)^{1/2}$$

- **Mdot ∝ $Z^{0.83}$** (Mokiem et al. 2007); **v_∞ ∝ $Z^{0.13}$** (Leitherer et al. 1992)





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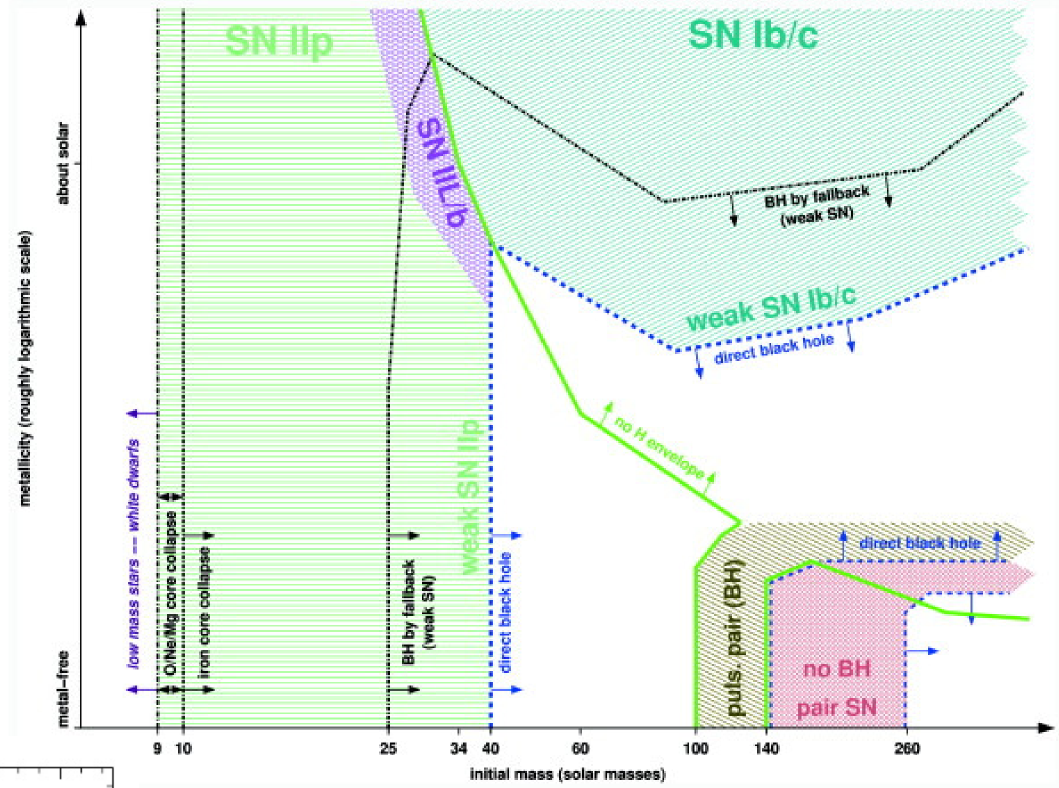
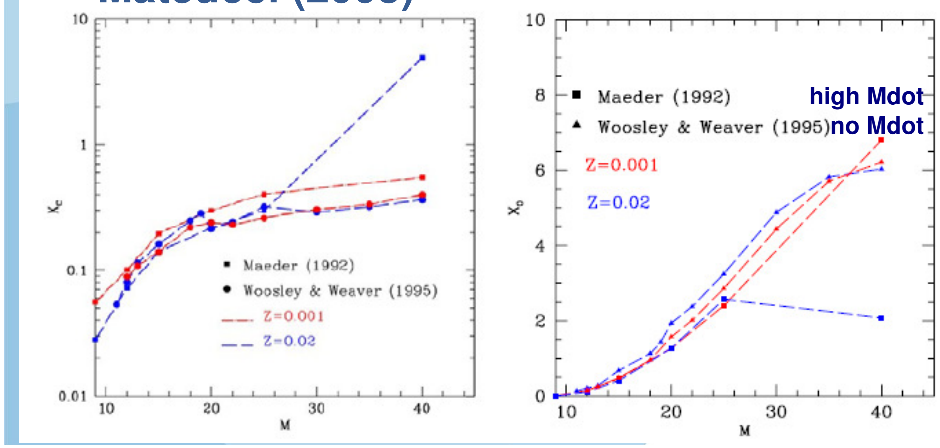
… with great impact on the evolution and death of massive stars

- Evolutionary tracks change
  - The life-average production of ionizing photons change
- The total mass and angular momentum lost decide the CO core mass and the fate of the star
  - **The SN explosion (if any)**
  - **The kind of remnant (if any)**
  - **The stellar yields**



Heger et al. (2003)

Mateucci (2008)



- The wind removes precious angular momentum, needed to form long-GRBs

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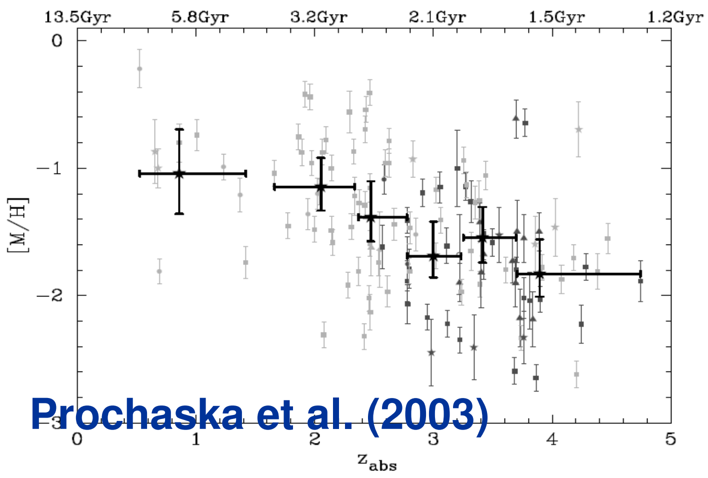
Renewed interest on low-metallicity massive stars:

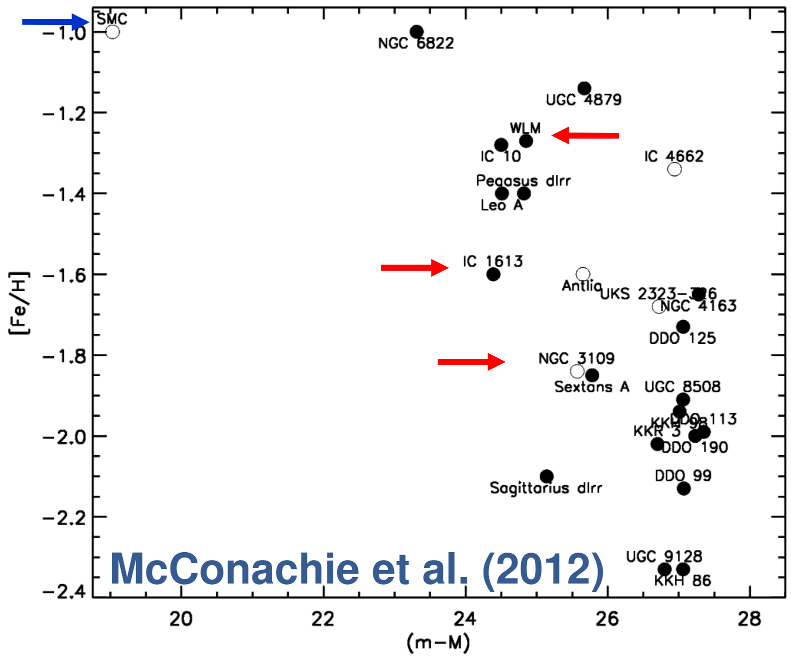
- The metal-poorer Universe as we go back in time
- The ocurrence of long-GRBs mostly in metal-poor environments (Modjaz et al. 2008, Levesque et al. 2010)



Prochaska et al. (2003)

- Population synthesis codes for massive stars feed from SMC observations/models to simulate the low-Z regime.
- There is a reason for this:
  - SMC is nearby. The closer the galaxy the easier the observations:
    - Lower exposure times
    - Less Crowding problems
  - It can be easily accessed from ground-based telescopes
    - e.g. FLAMES survey of massive stars (sumarry at Evans et al. 2008, The Messenger, 131, 25)

We are ready (VLT, Keck & GTC; HST-COS) to look further into the LG for more metal poor galaxies

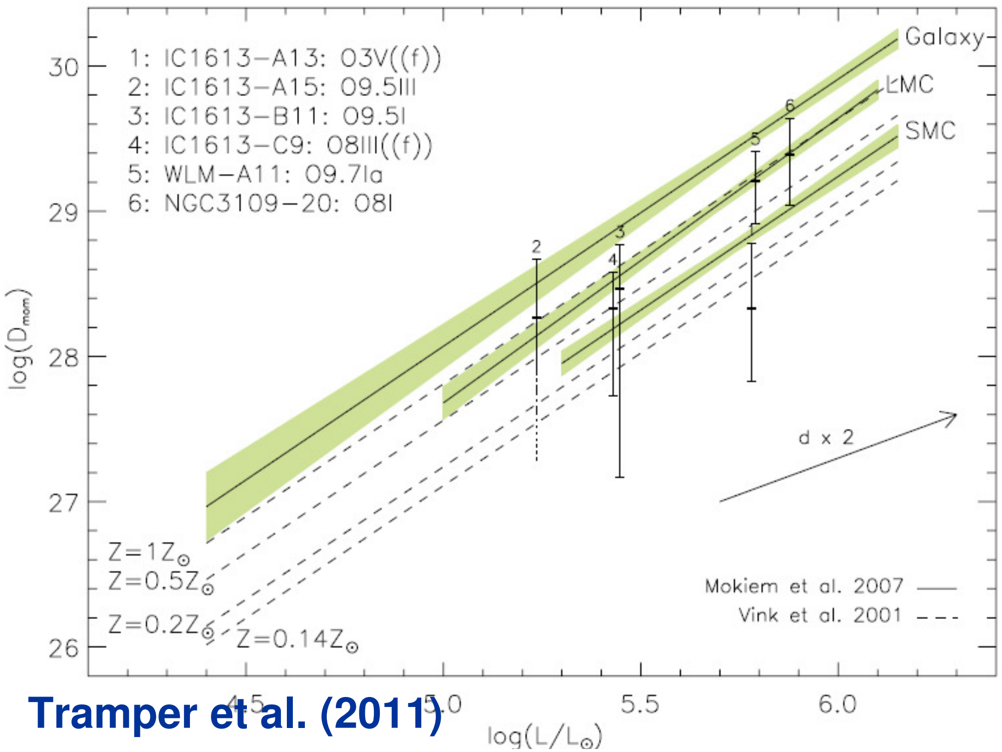


	Z/Zo	DM E(B-V)	V (O9.5Iab) Mv=-6.6
SMC	0.2	18.85[a] 0.06[b]	12.59[d] (EBV=0.12[d])
IC 1613	0.09	24.27[a] 0.03[b]	17.73 (fg EBV)
WLM	0.15	24.5[b] 0.02[b]	17.93 (fg EBV)
NGC3109	0.08	25.51 0.04	19.00 (fg EBV)

Z from Lee et al. (2006)'s oxygen abundances, using 12+log(O/H)=8.66 for the Sun (Asplund et al. 2004). Refs: (a) Dolphin et al.(2003); (b) van den Bergh(2000); (c) Dohm-Palmer et al.(2003); (d) Evans et al.(2004)

We expect low-Z massive stars to have weak winds, BUT!!

There is indication that the winds of IC1613's metal poor O stars are stronger than predicted by the theory



Tramper et al. (2011)

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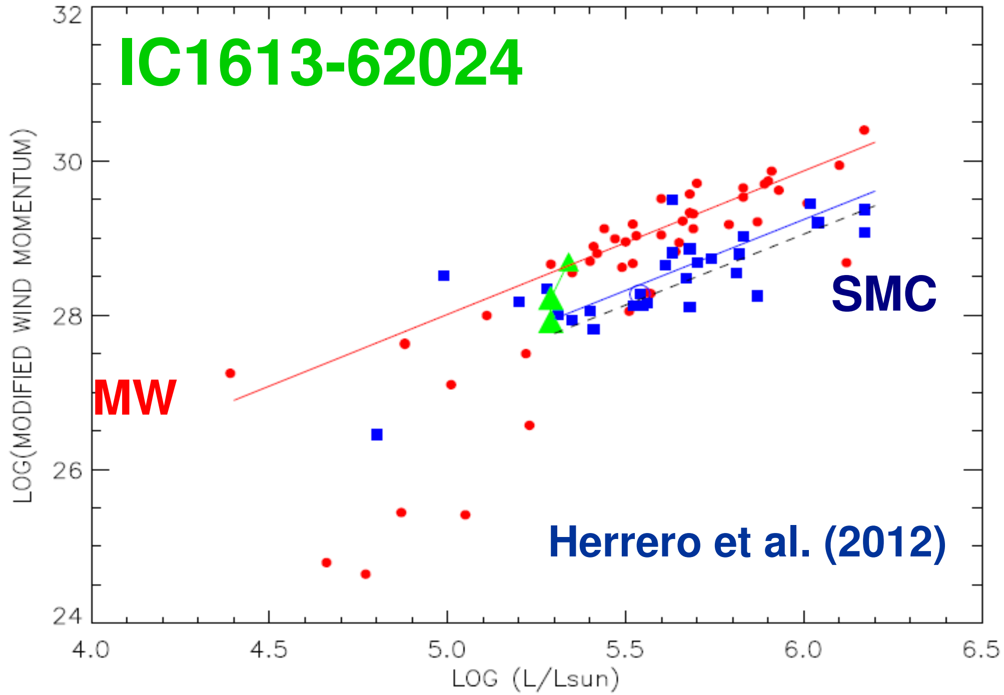
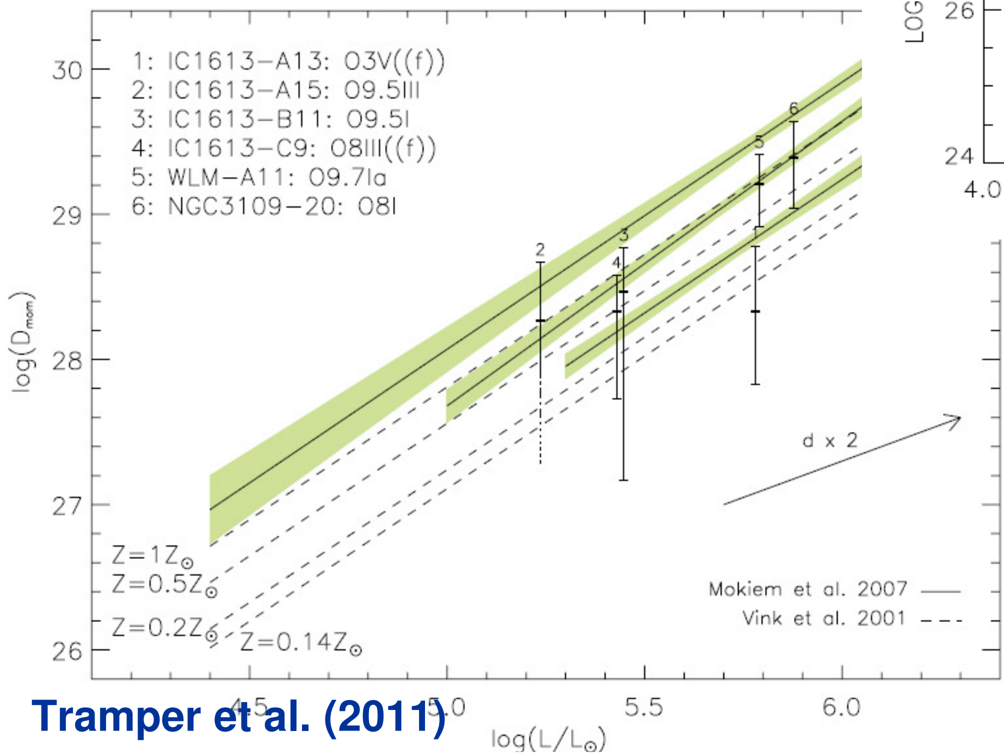


… or is there?



Tramper et al. (2011)

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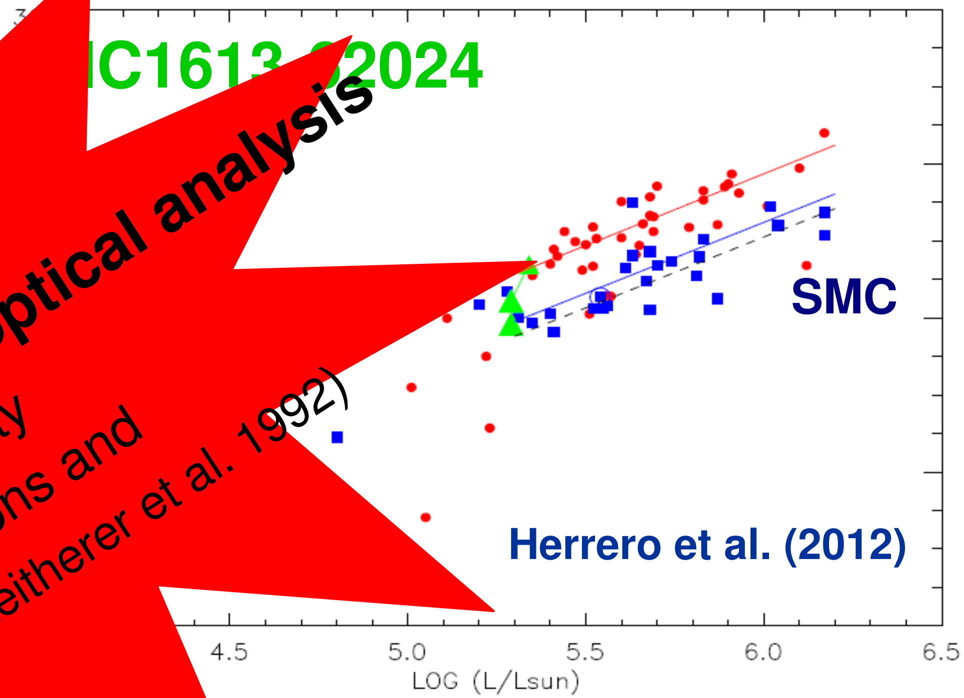
There is indication that th… winds of IC1613's metal p… O stars are stro…r tha… predicted by the…

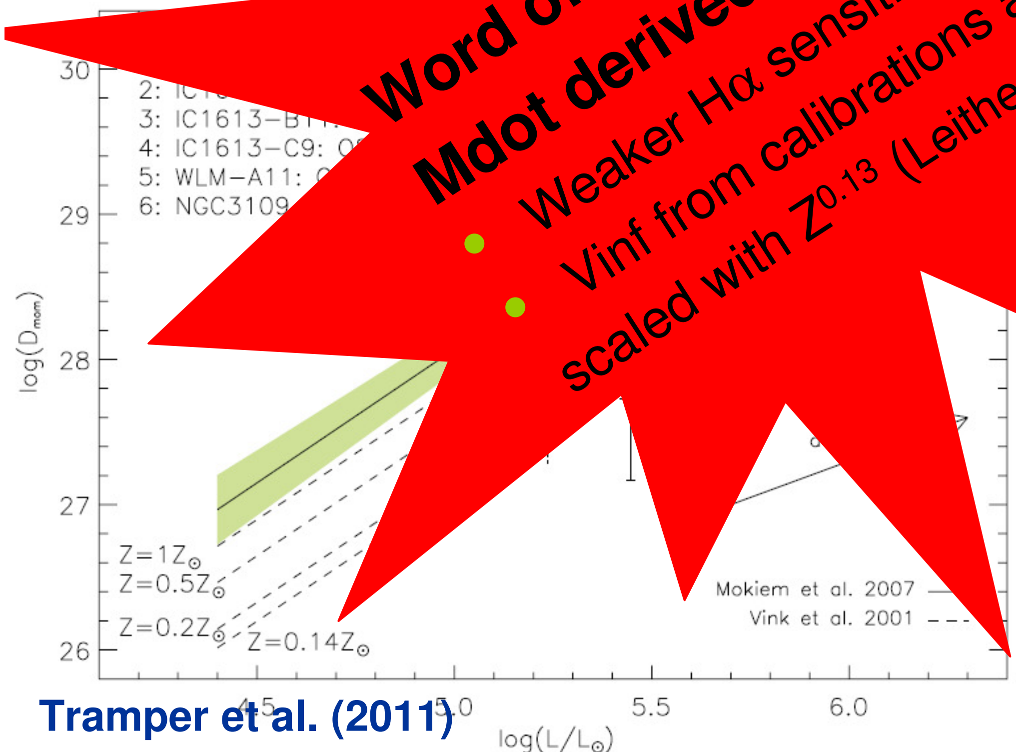


Herrero et al. (2012)

Word of Caution:
Mdot derived from optical analysis
- Weaker Hα sensitivity
- Vinf from calibrations and scaled with $Z^{0.13}$ (Leitherer et al. 1992)

…r is there?

Mdot from Hα and HeII4686 with FASTWIND (Puls et al. 1995) which determines $Q = \dot{M}/(v_\infty R_*)^{1.5}$



Tramper et al. (2011)

Possible explanations
(e.g. Lucy et al. 2012, Herrero et al. 2012)

- The mass loss rates are wrong:
  - Clumping is neglected in the analysis
  - Slower wind acceleration in the low metallicity regime
  - Wrong terminal velocities used for the analysis
- There is an additional wind-driven mechanism undetected in stronger-wind Galactic counterparts
- There is a different wind-driven mechanism that works only on certain parts of the [Teff, logg, Z] parameter space

This may have enormous implications for calculations of

- Low-Z massive star evolution
- Low-Z massive star feedback
- SN and LGRBs expected rates

Our project to study low-Z OB-type stars

Our project on IC1613:

- We are thoroughly studying IC1613's blue massive stars
- Two fronts of project development:
  - Discovery of OB-type stars, and serendipitous blue advanced stages
  - Quantitative spectroscopic analysis

- Battery of optical and UV observations:
  - GTC-OSIRIS (R2000B, 5h): 4000-5500A, R~1000

    PI M. Garcia

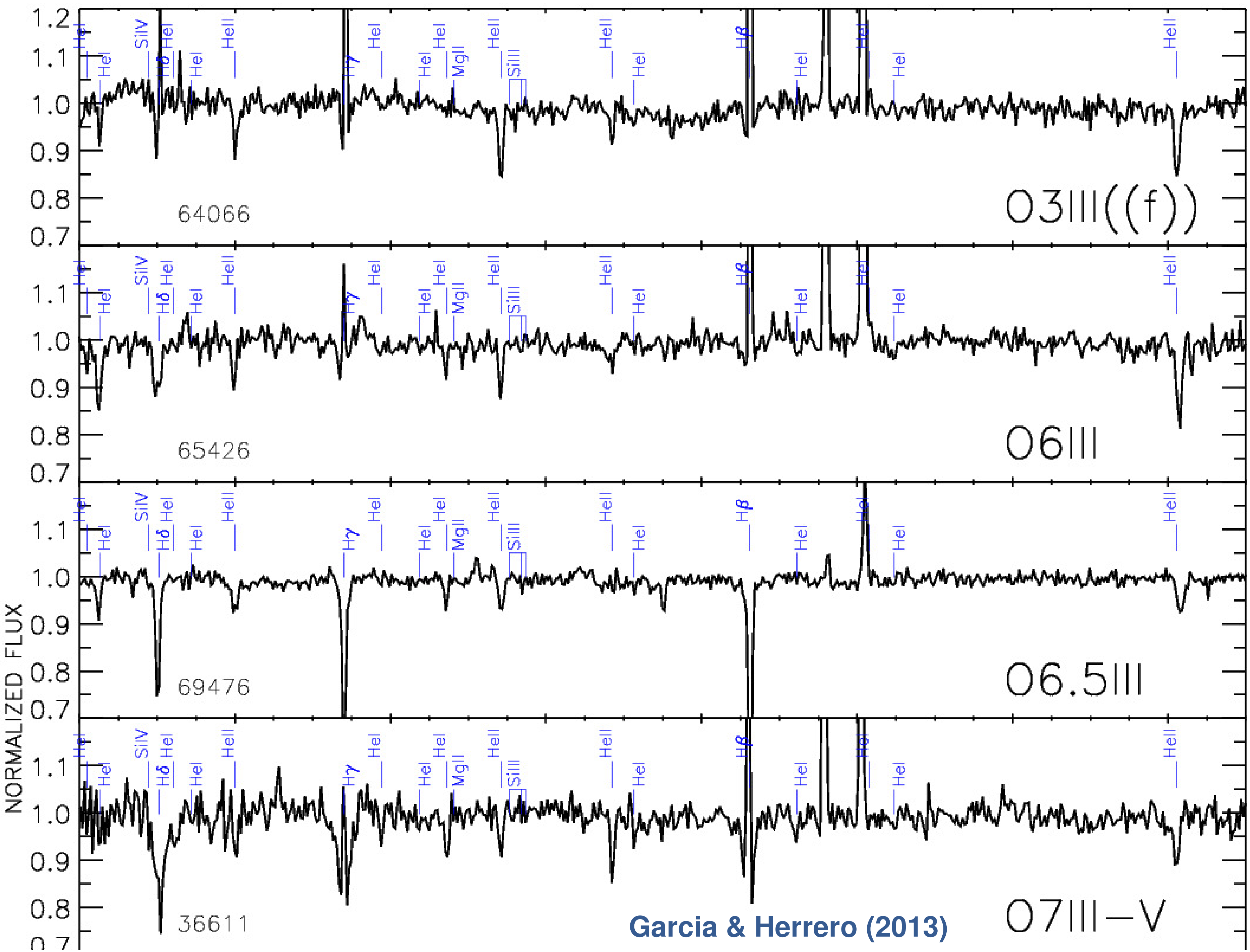
    Garcia & Herrero 2013, A&A, 551, 74
  - **HST-COS (G140L, λ_c=1105A, 23 orbits): 1150-1800A, R~2500**

    PI M. Garcia

    Garcia et al. 2013a, in prep.
  - VLT-VIMOS (HR-Blue+HR-Orange, 36h): 4000-7000A, R~2500

    PI A. Herrero

    Garcia et al. 2013b, in prep.; Herrero et al. 2012, A&A, 543, 85; Herrero et al. 2010, A&A, 513, 70


NORMALIZED FLUX
64066
O3III((f))
65426
O6III
69476
O6.5III
36611
O7III–V
HeI
HeII
SiIV
SiIII
MgII
Hδ
Hγ
Hβ
Garcia & Herrero (2013)

First UV spectroscopic atlas of IC1613 OB-stars

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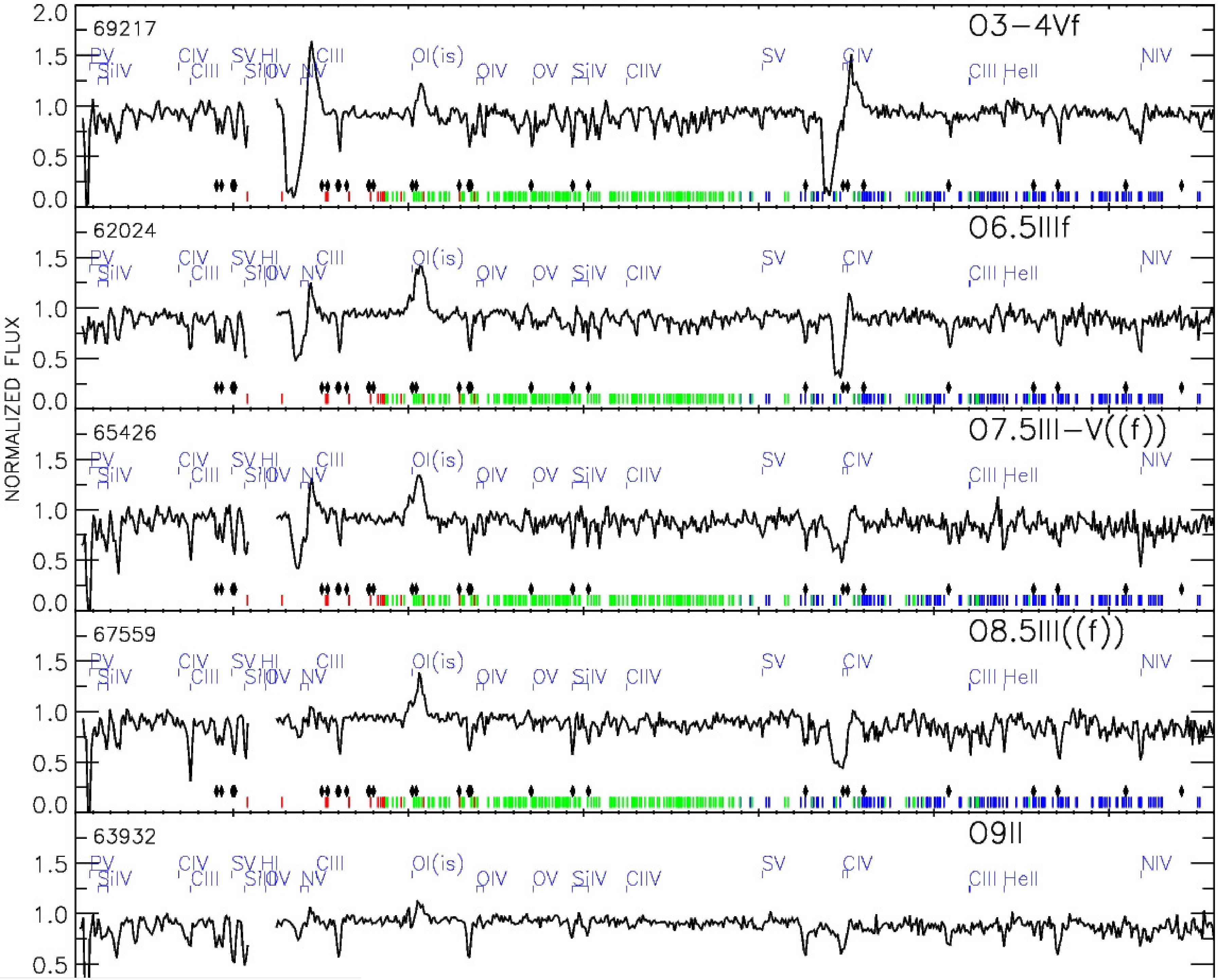
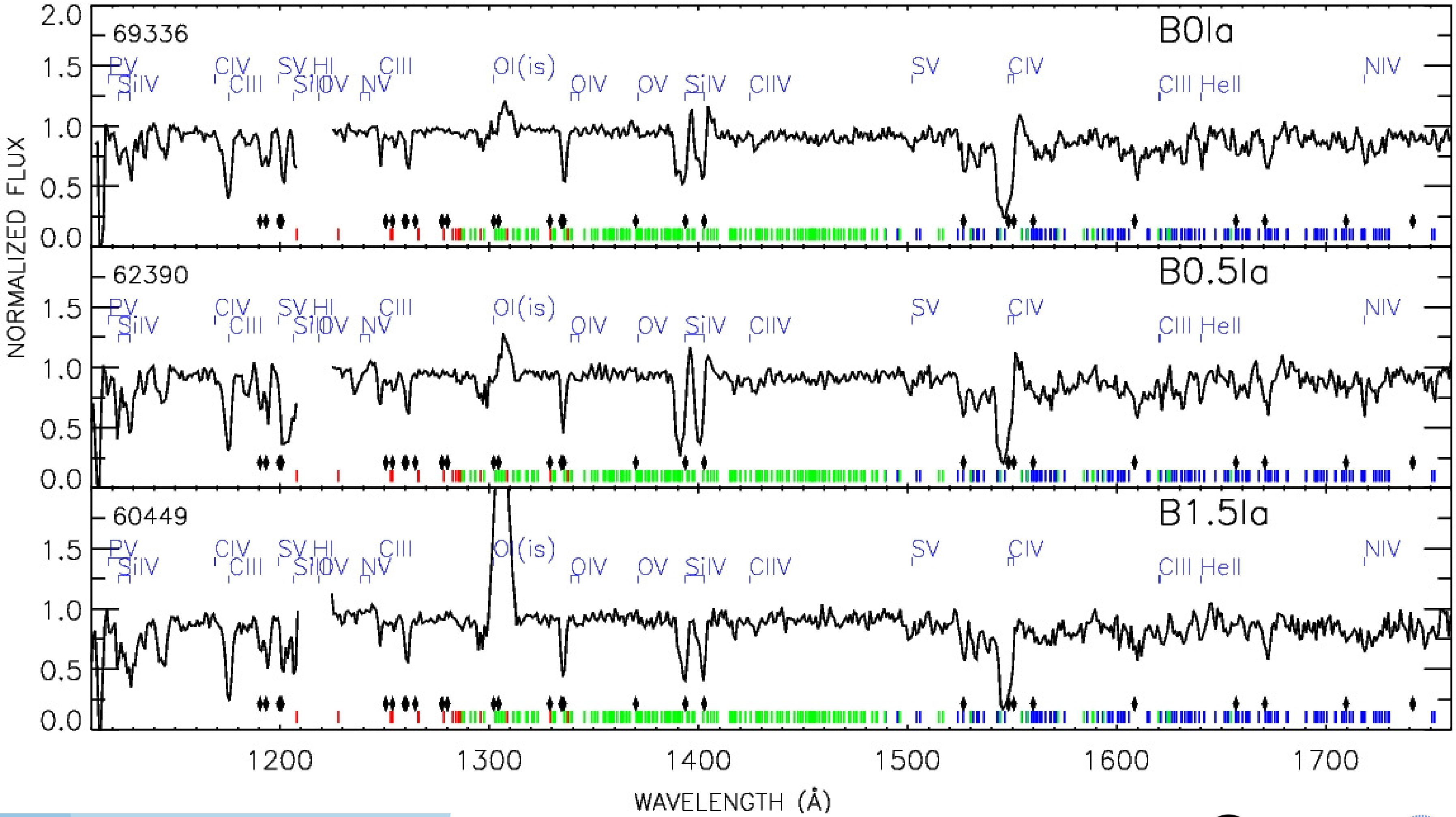
HST-COS spectra of O-stars in IC1613

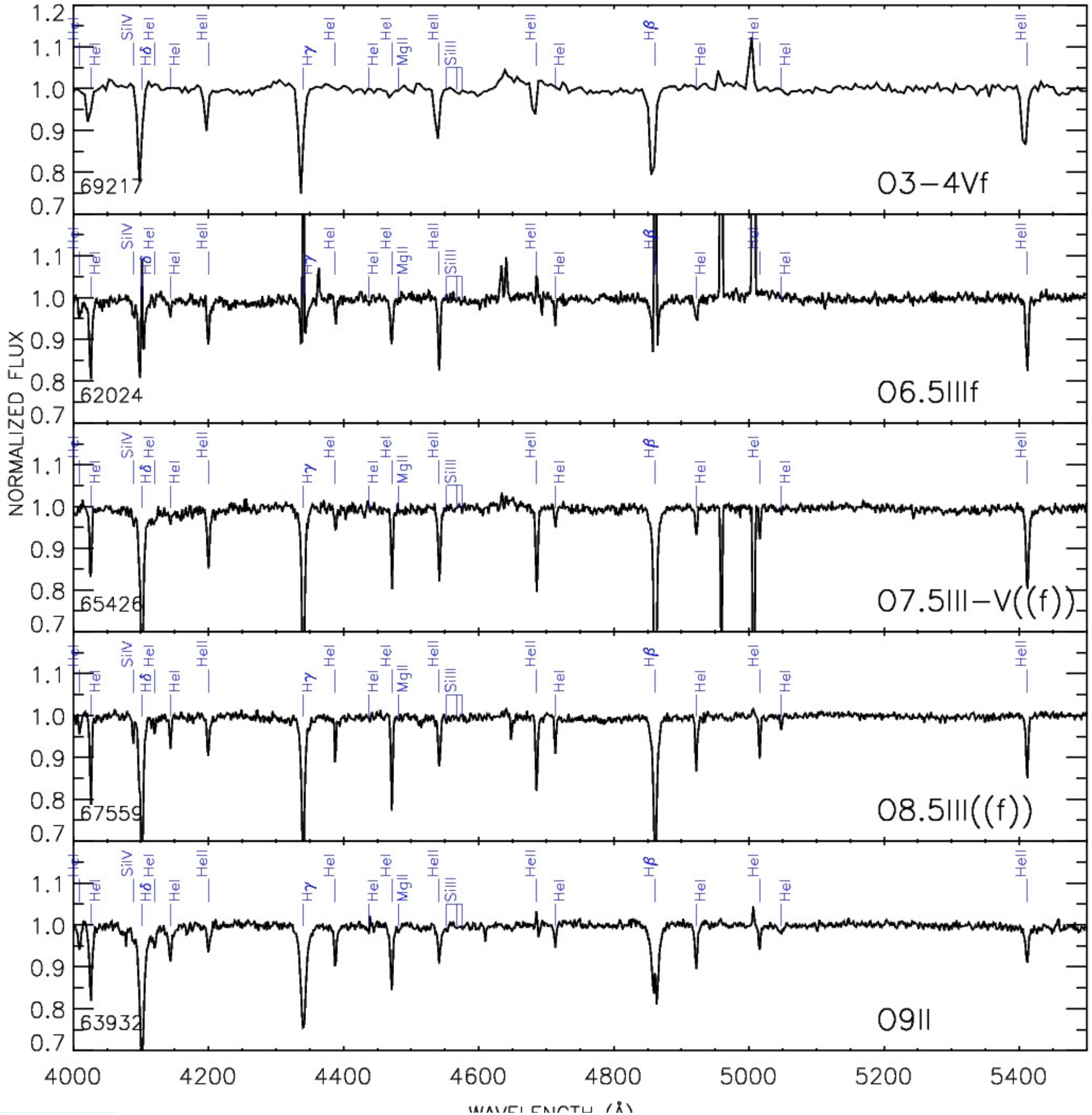


HST-COS spectra of B-supergiants in IC1613

Garcia et al. (2013a)

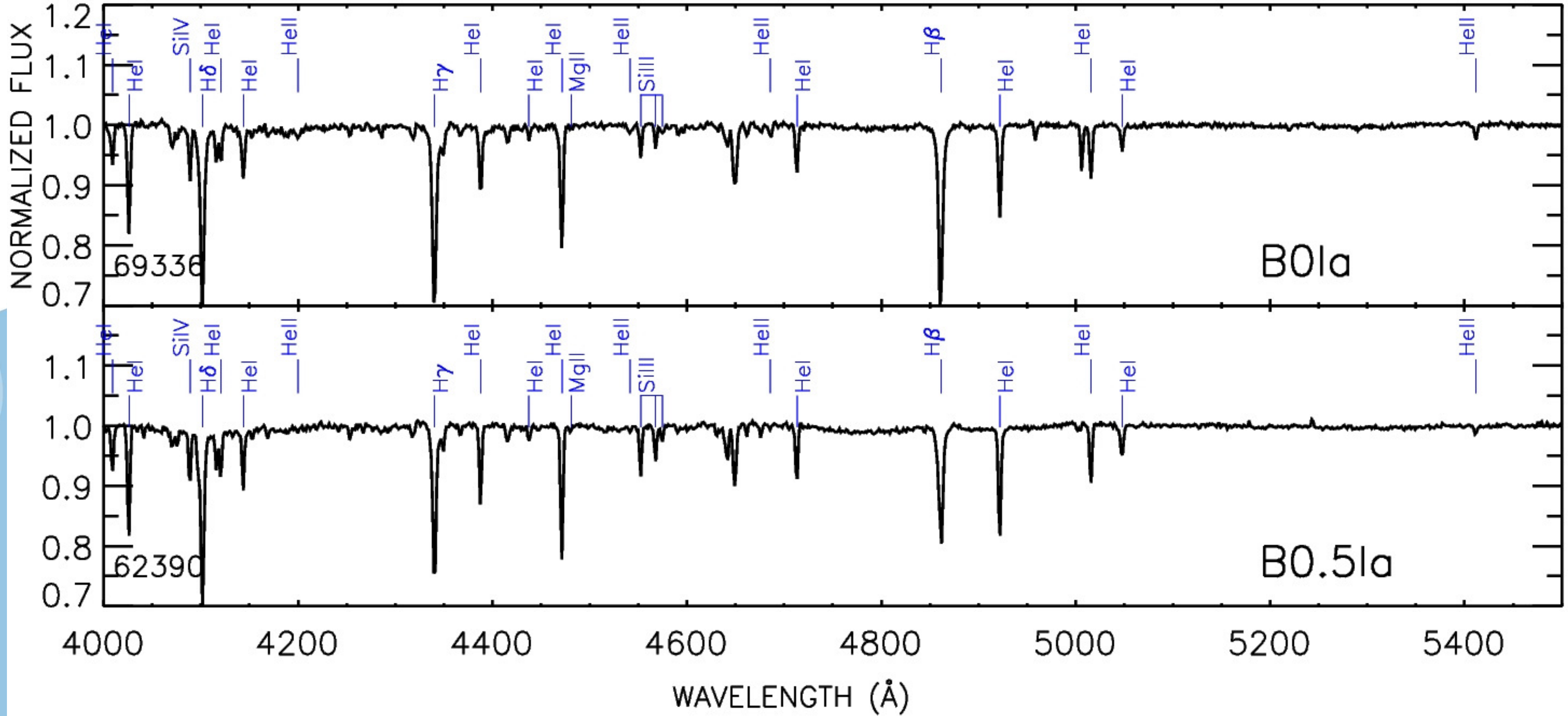


VLT-VIMOS spectra of O-stars in IC1613



VLT-VIMOS spectra of B-supergiants in IC1613

Garcia et al. (2013b)



Metallicity effects on the UV spectra of OB-stars

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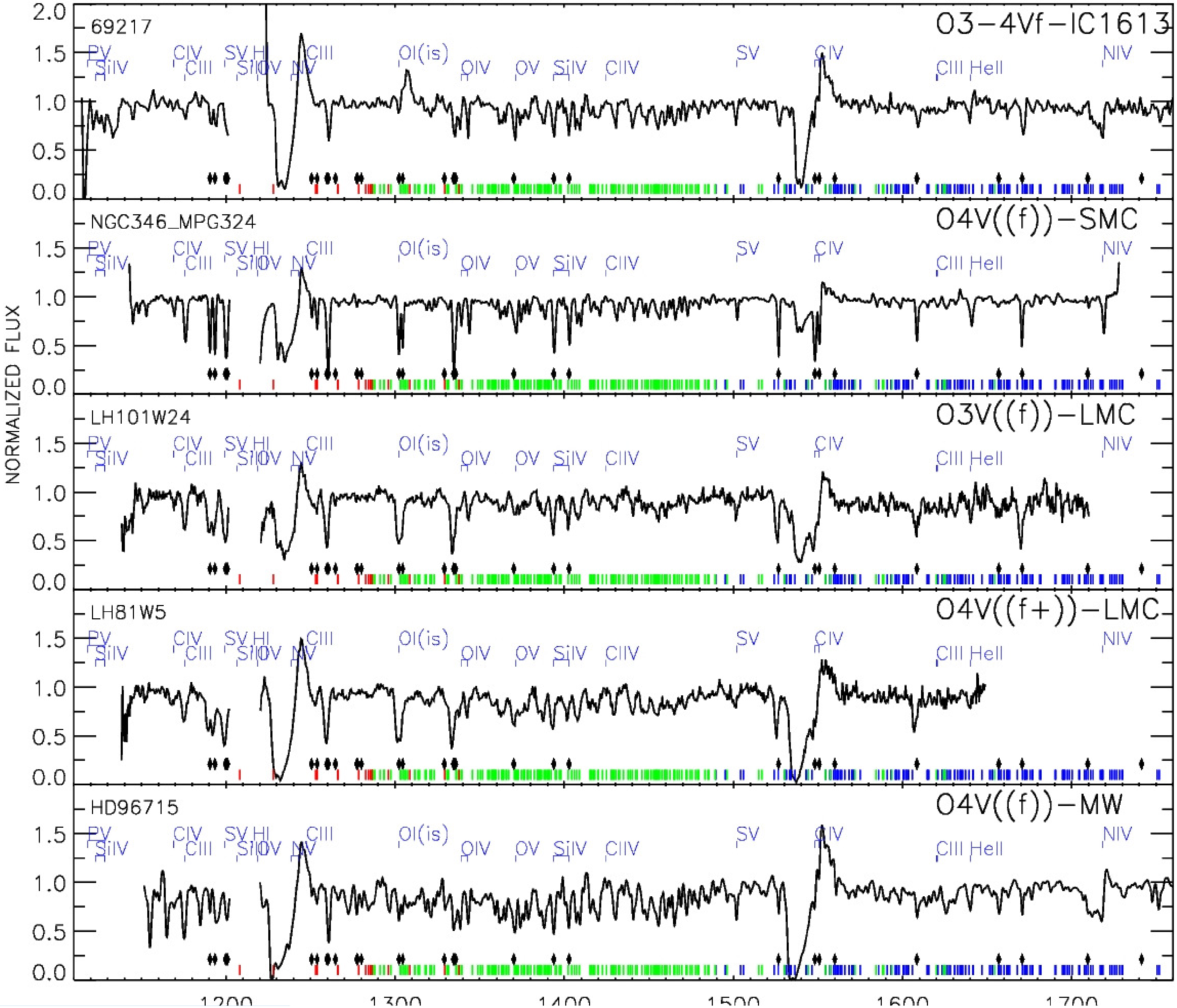
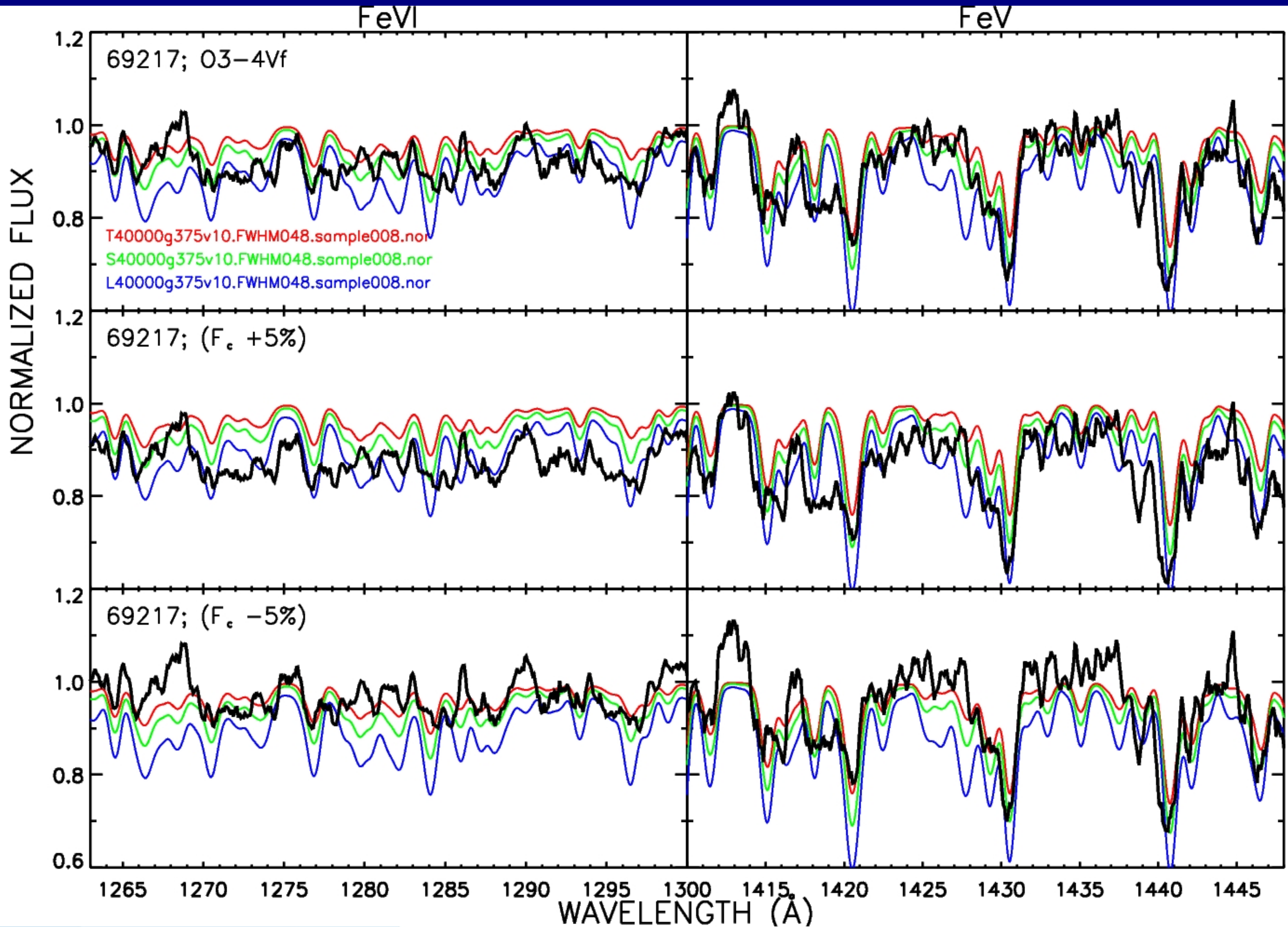
Early-O dwarfs in Local Group galaxies



So… what's #69217's metallicity?



Garcia et al. (2013a)

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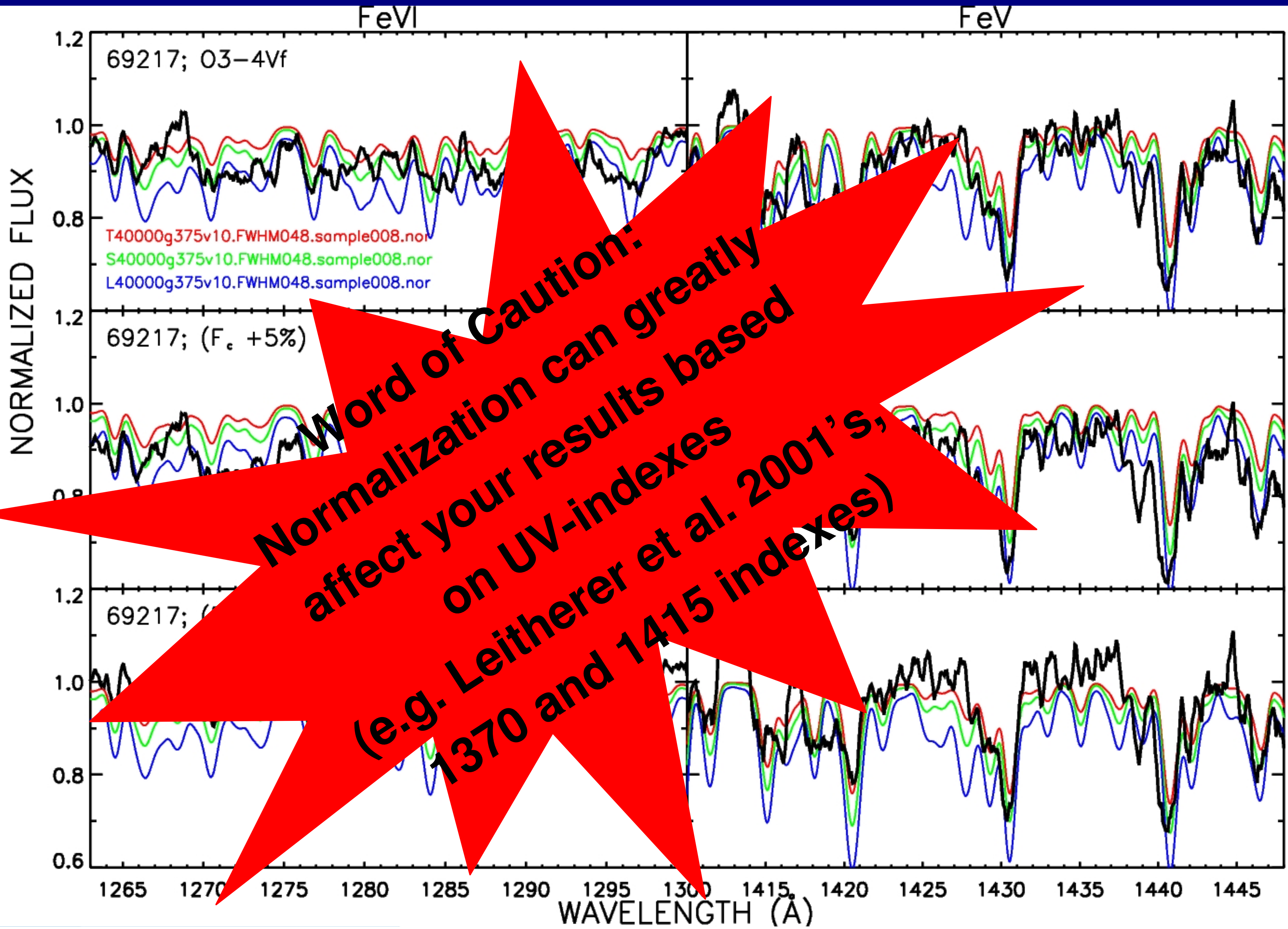


Word of Caution:
Normalization can greatly affect your results based on UV-indexes (e.g. Leitherer et al. 2001's, 1370 and 1415 indexes)

Garcia et al. (2013a)

Terminal velocities for IC1613 stars

Direct measurements of the terminal velocity, key to constrain the winds of OB-stars

- The UV resonance lines provide the only direct diagnostics for the wind terminal velocity.
- v_∞ is needed to compute the wind momentum, our main diagnostic tool to evaluate the winds of blue massive stars.
- Optical studies can only determine $\boldsymbol{Q = \mathrm{Mdot}/(v_\infty \cdot R_*)^{1.5}}$

- v_∞ usually determined from relations, and then scaled with metallicity (using Leitherer's et al. relation).
- But Leitherer et al. (1992) warned us:
  - The v_∞ -- Z relation may not be monotonic in some T_{eff} regimes.

Direct measurements of the terminal velocity, key to constrain the winds of OB-stars

- The UV resonance lines p… vide the … nly dir… t diagnostics for the wind terminal velo…
- v_∞ is needed to compute … um … main diagnostic tool t… evalua… massive stars.
- Optical studies … ot/($v_\infty \cdot R_*$)$^{1.5}$
- v_∞ usu… and then scaled with metallicity (… on).
- But Le… ned us:
  - Th… onotonic in some T_{eff} regimes.

Word of Caution:
Without direct measurements optical studies may misestimate v_∞ and also Mdot, Dmom

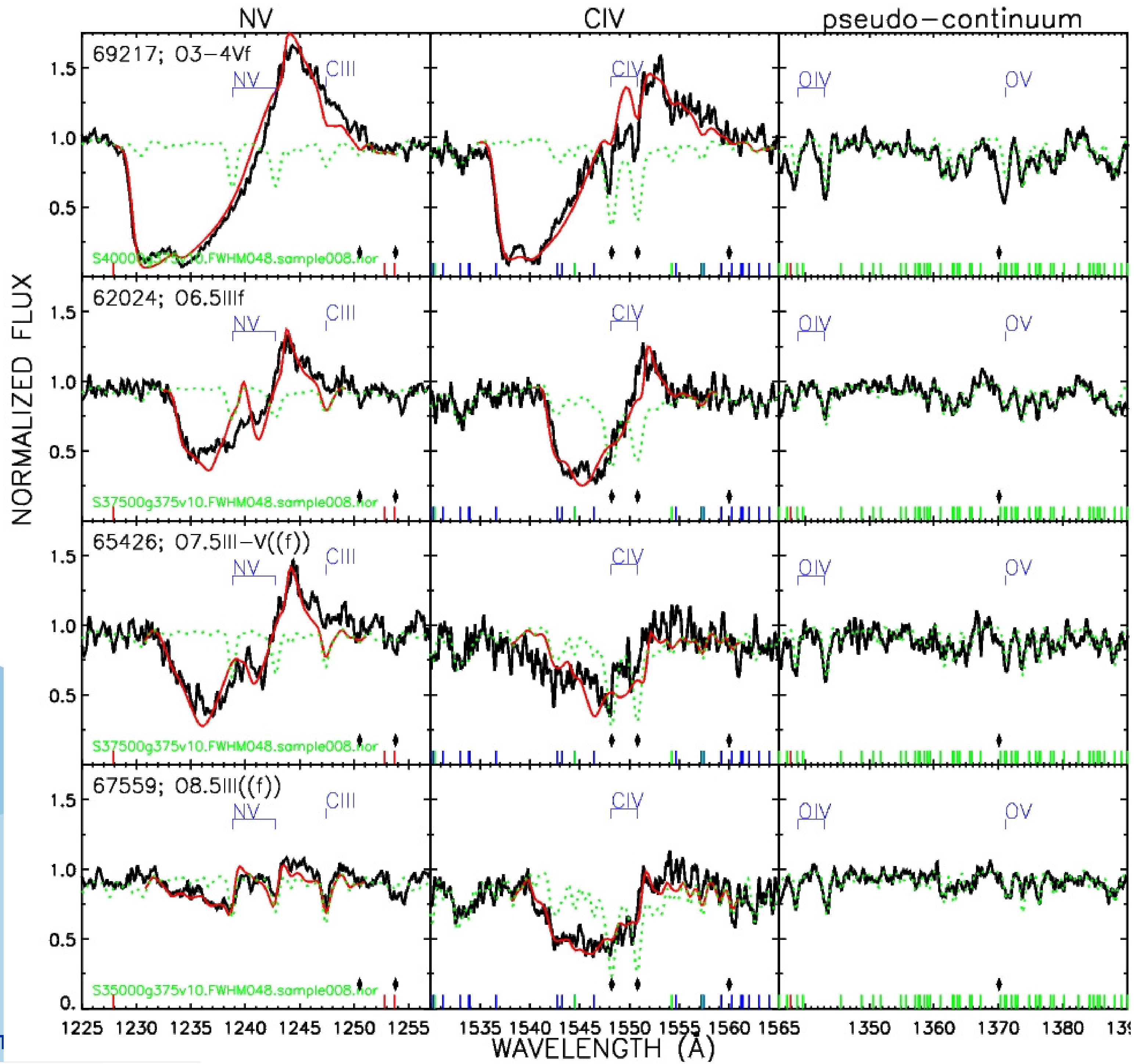
Terminal velocities for IC1613 stars

- SEI method
  - Haser et al. (1995)'s implementation of Hamann (1981)'s idea
- We find robust terminal velocities for sample stars
- No constrains on v_{turb} and β .

ID	SpT	TLUSTY model	v sin i [km/s]	v_{rad} [km/s]	v_∞ [km/s]	v_{turb} [km/s]	β
69217	O3-4Vf	S40000g375v10	94	-240	2200^{+150}_{-100}	150	0.8
62024	O6.5IIIf	S37500g375v10	130	-234	1250^{+150}_{-200}	100	1.2
65426	O7.5III-V((f))	S37500g375v10	65	-206	1500^{+250}_{-250}	160	1.4
67559	O8.5III((f))	S35000g375v10	50	-234	1500^{+300}_{-200}	130	0.7
63932	O9II	T35000g400v10	150	-234	1000^{+500}_{-400}	90	0.8
69336	B0Ia	BS25000g275v2	100	-100	1300^{+100}_{-100}	130	0.8
62390	B0.5Ia	BS25000g275v2	50	-255	1075^{+75}_{-75}	90	0.8
60449	B1.5Ia	BS22000g250v2	50	-243	875^{+75}_{-75}	90	0.8

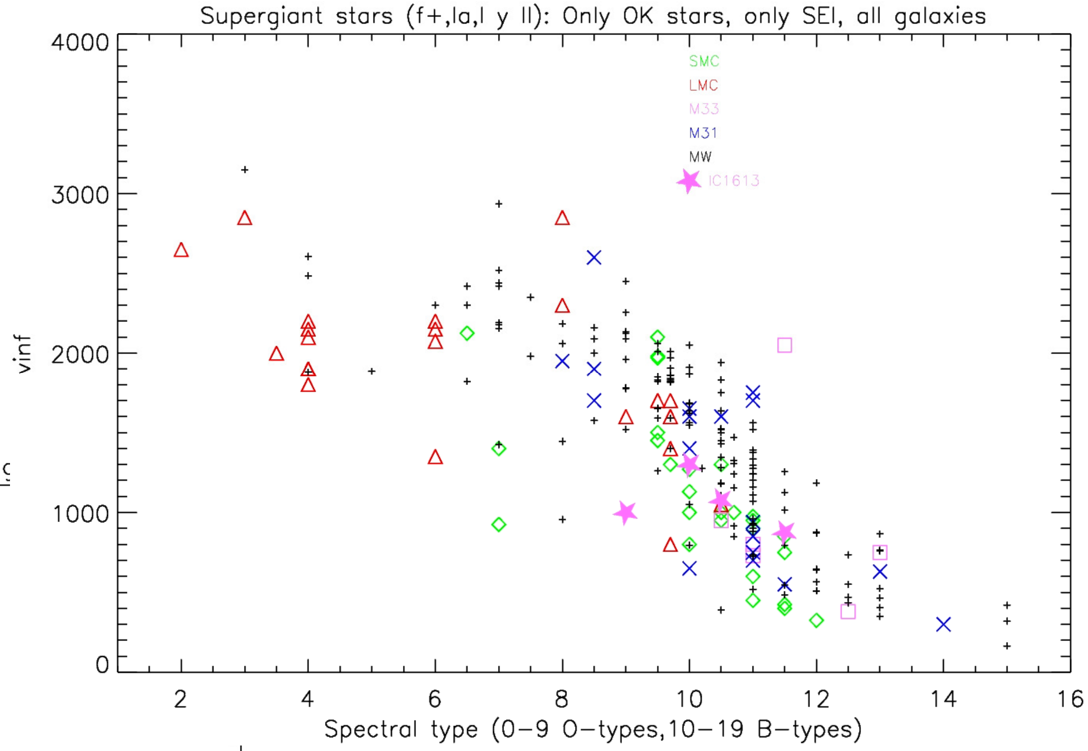
Garcia et al. (2013a)

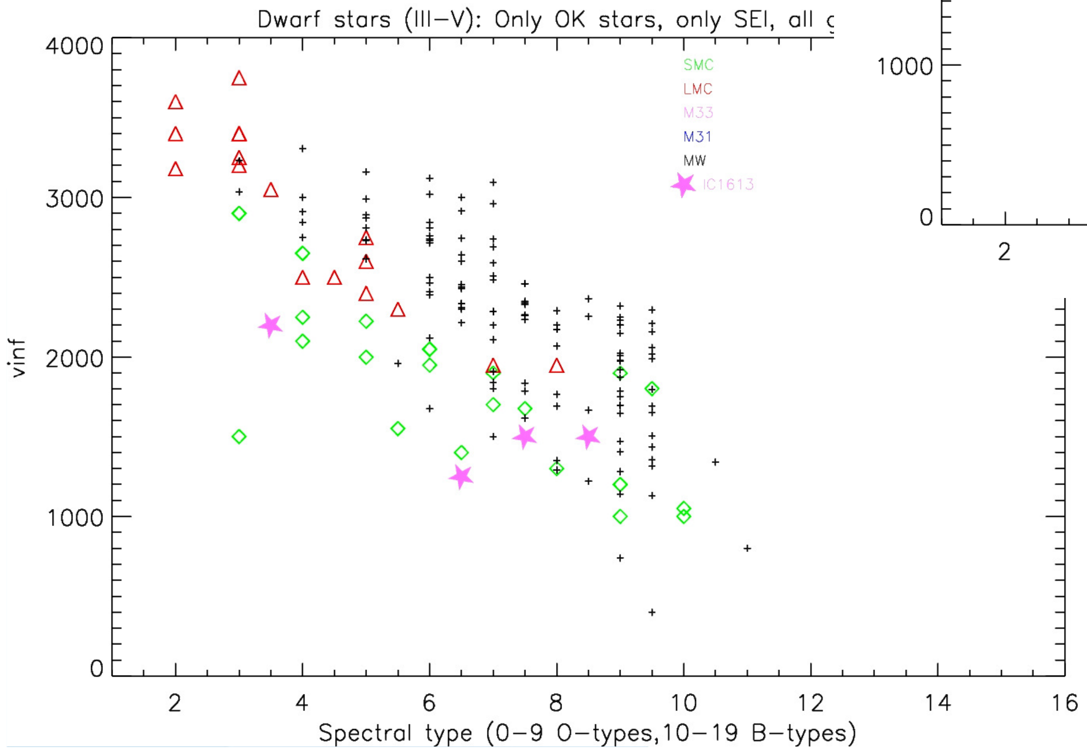
Terminal velocities for O-stars in IC1613



Garcia et al. (2013a)

The metallicity dependence of the terminal velocity





Garcia et al. (2013a)

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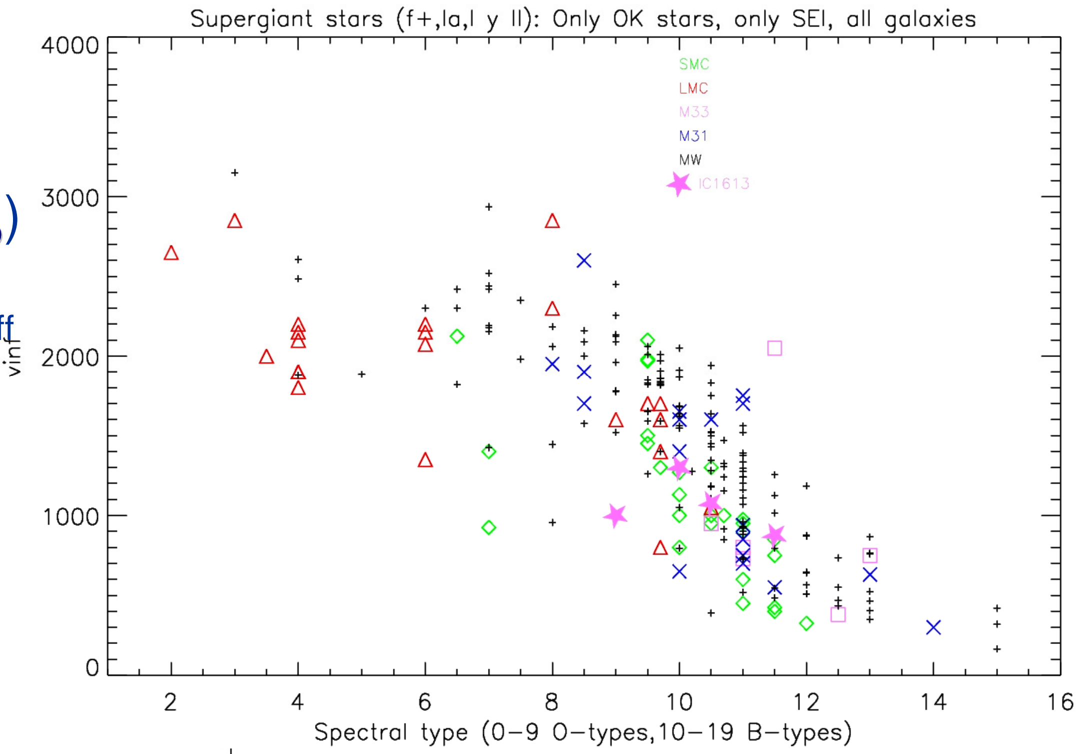
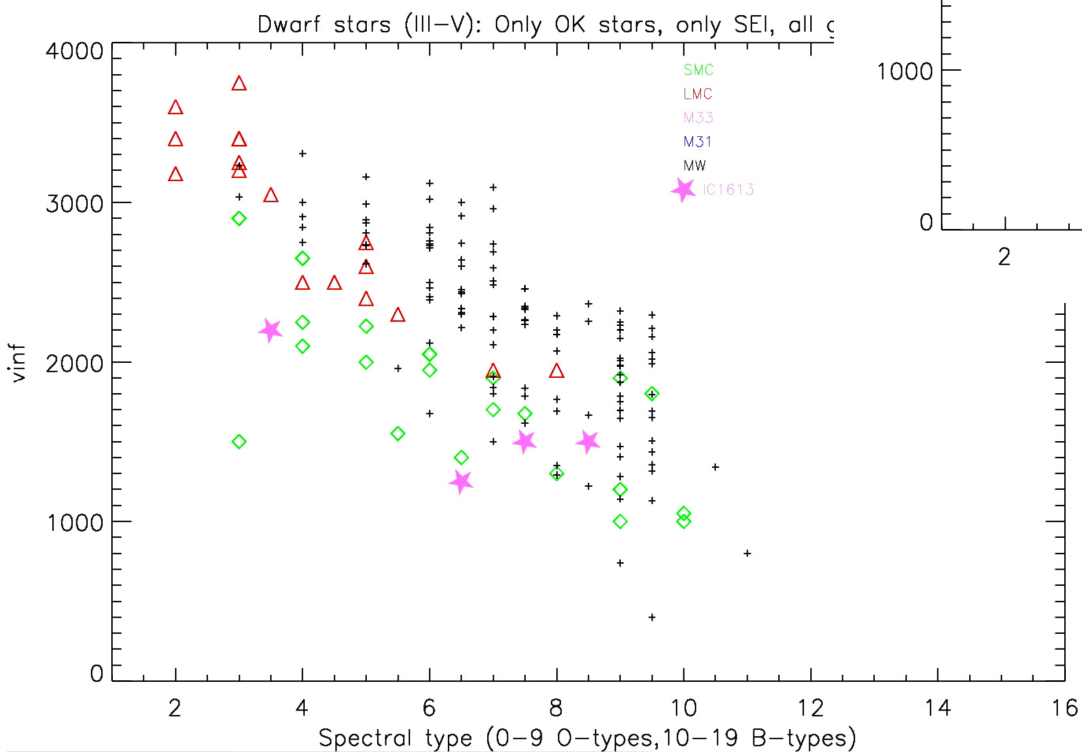
The metallicity dependence of the terminal velocity

Leitherer et al. 1992:

$$\log(v_\infty) = 1.23 - 0.30 \log(L/L_\odot) + 0.55 \log(M/M_\odot) + 0.64 \log T_{eff} + 0.13 \log(Z/Z_\odot)$$





Garcia et al. (2013a)

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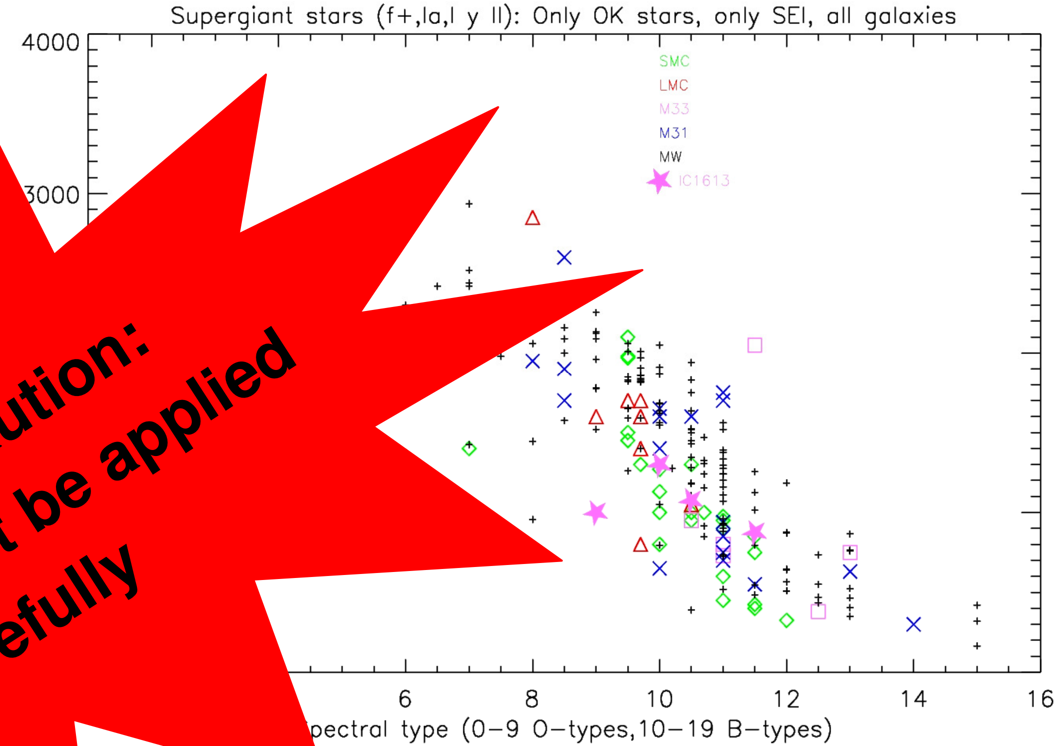

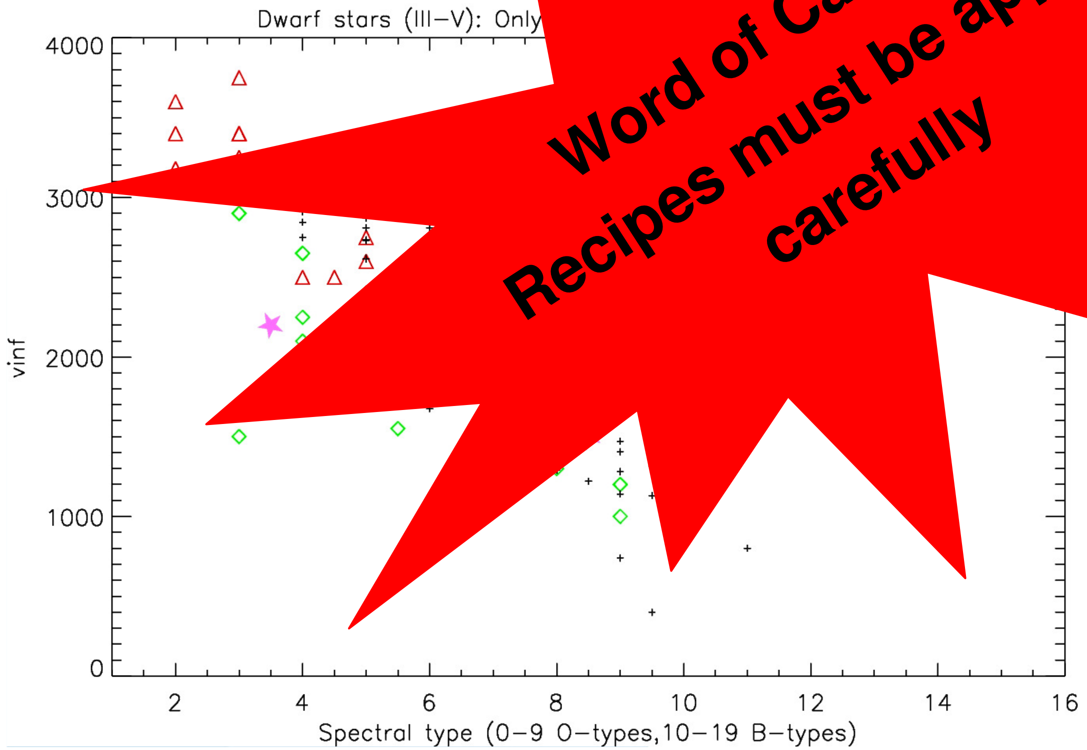

Word of Caution:
Recipes must be applied carefully

Garcia et al. (2013a)

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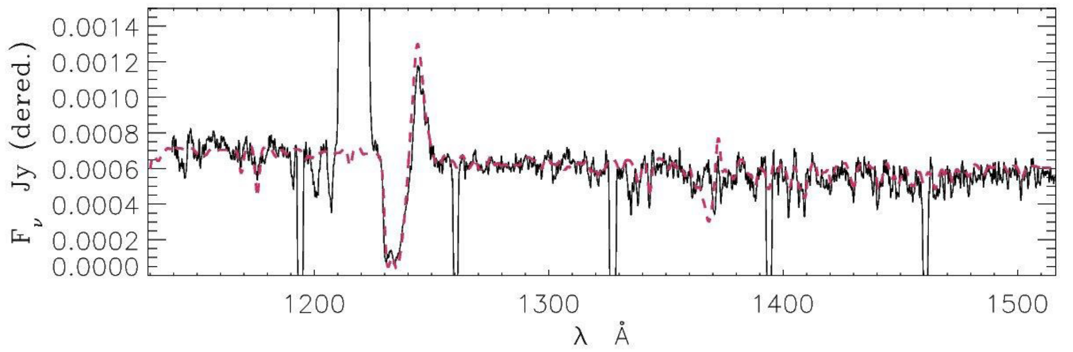
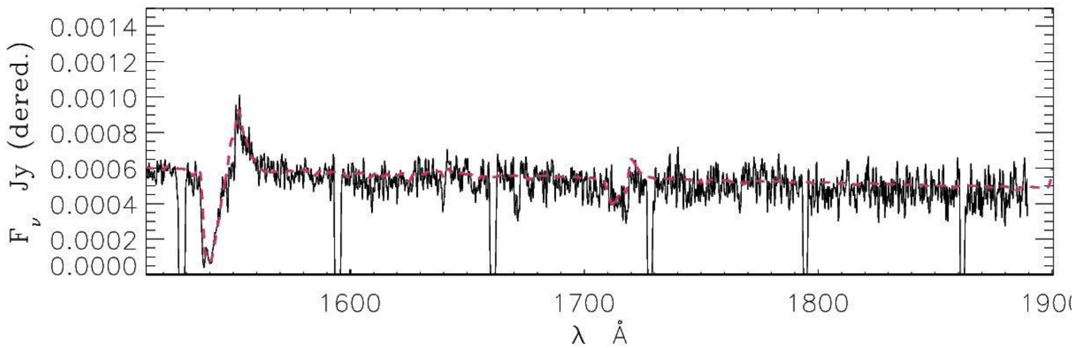
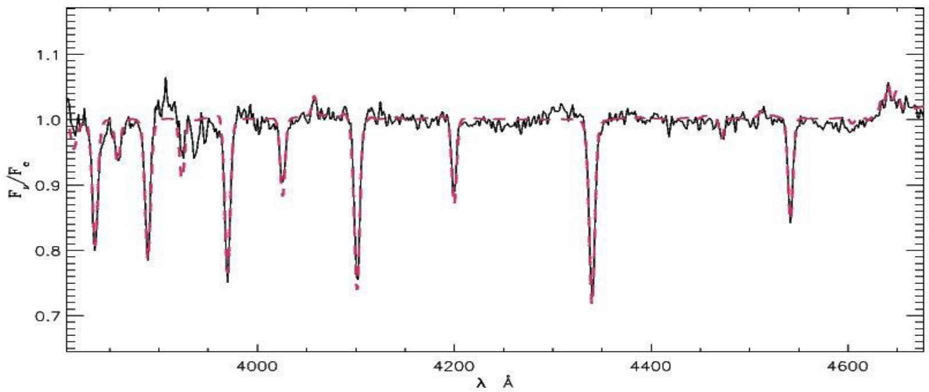
First quantitative optical+UV analysis

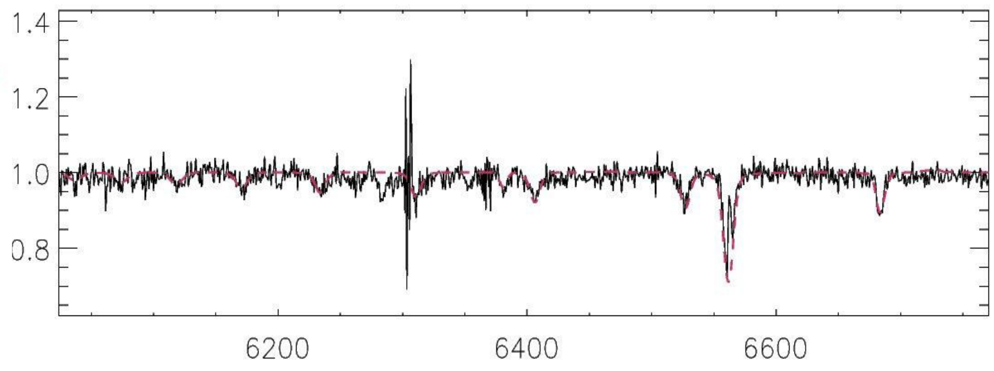
CMFGEN analysis of #69217 optical+UV data





Garcia et al. (2013c) in Massive Stars from α to Ω





CMFGEN analysis of #69217 optical+UV data

T_{eff} [kK]	log *g*	Mdot[$M_\odot$/yr]	v_∞	$R/R_\odot$	Y_{He}	$Z/Z_\odot$	Referencia
47.6	3.73	5.5E-7	1869	11.4	0.32	0.14	Tramper et al.
42.8	3.6	7.0E-7	2150	13.5	0.25	0.2	This work

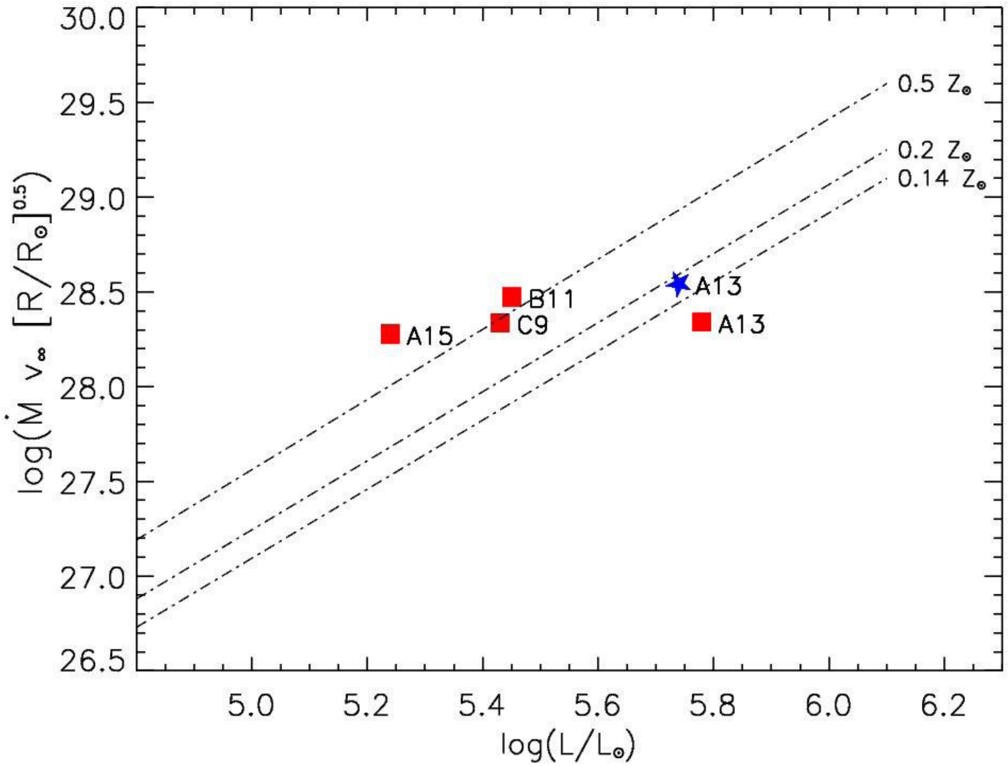


FIGURE 6. IC1613's WLR (wind-momentum luminosity relation). Red squares mark results from Tramper et al. (2011), and the blue star our results for 69217 (A13). Dashed lines represent Vink et al. (2001)'s predictions for different metallicities. A13 was the only target Tramper et al found to be under the theoretical relation. **Our results place the star between IC1613's and the SMC's WLR** due to 1) A better estimate to the stellar luminosity from improved photometry and extinction and 2) Improved determination of the wind parameters from UV diagnostics.

Garcia et al. (2013c)

Conclusions

- The Cosmic Origins Spectrograph has opened the window to study the UV spectra of low-Z OB-stars beyond the SMC
  - It will be crucial for accurate constraints on OB-star winds, and stellar metallicity
- Do not feed “just anything” into your codes
  - Mdot, vinf properties/recipes: better if derived from UV
  - Massive stars’s metallicity: better if derived from joint UV+optical analysis
- Stay tuned for an UV+optical atlas of IC1613 OB stars
- Coming-up soon:
  - Quantitative analysis of the optical and UV spectra to provide T*eff*, log*g*, ξ, and metallicity of IC1613 stars
  - Updated estimates for their ionizing flux and kinetic energy feedback

Gracias