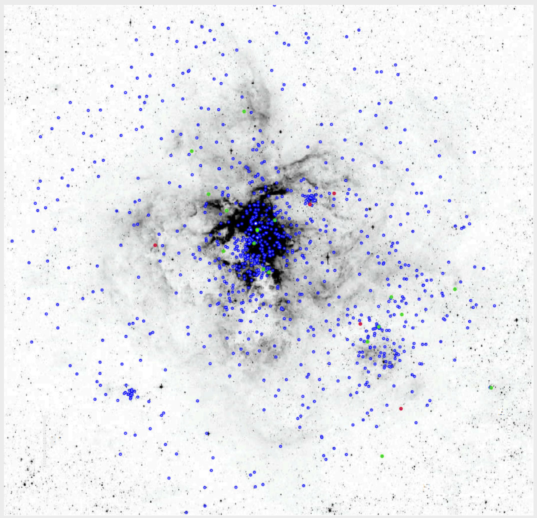
VLT FLAMES Tarantula Survey



Alex de Koter

Evans (PI), Bagnoli, Bastian, Beletsky, Bestenlehner, Bonanos, Bressert, Brott, Campbell, Cantiello, Clark, Costa, Carraro, Crowther, de Koter, de Mink, Doran, Dufton, Dunstall, Friedrich, Garcia, Gieles, Gräfener, Hénault-Brunet, Herrero, Howarth, Izzard, Kunz, Langer, Lennon, Maiz Apellániz, Markova, Najarro, Puls, Ramirez, Sabín-Sanjulían, Sana, Simón-Diaz, Smartt, Stroud, Taylor, Trundle, van Loon, Vink, Walborn

New stellar populations [..] will be discovered, and fundamental questions such as the basic scenarios of stellar evolution will be addressed with Gaia data. Contemporary theoretical models of high-resolution stellar spectra are however seriously hampered by systematic uncertainties due to inadequate input physics and inaccurate or incomplete atomic data.

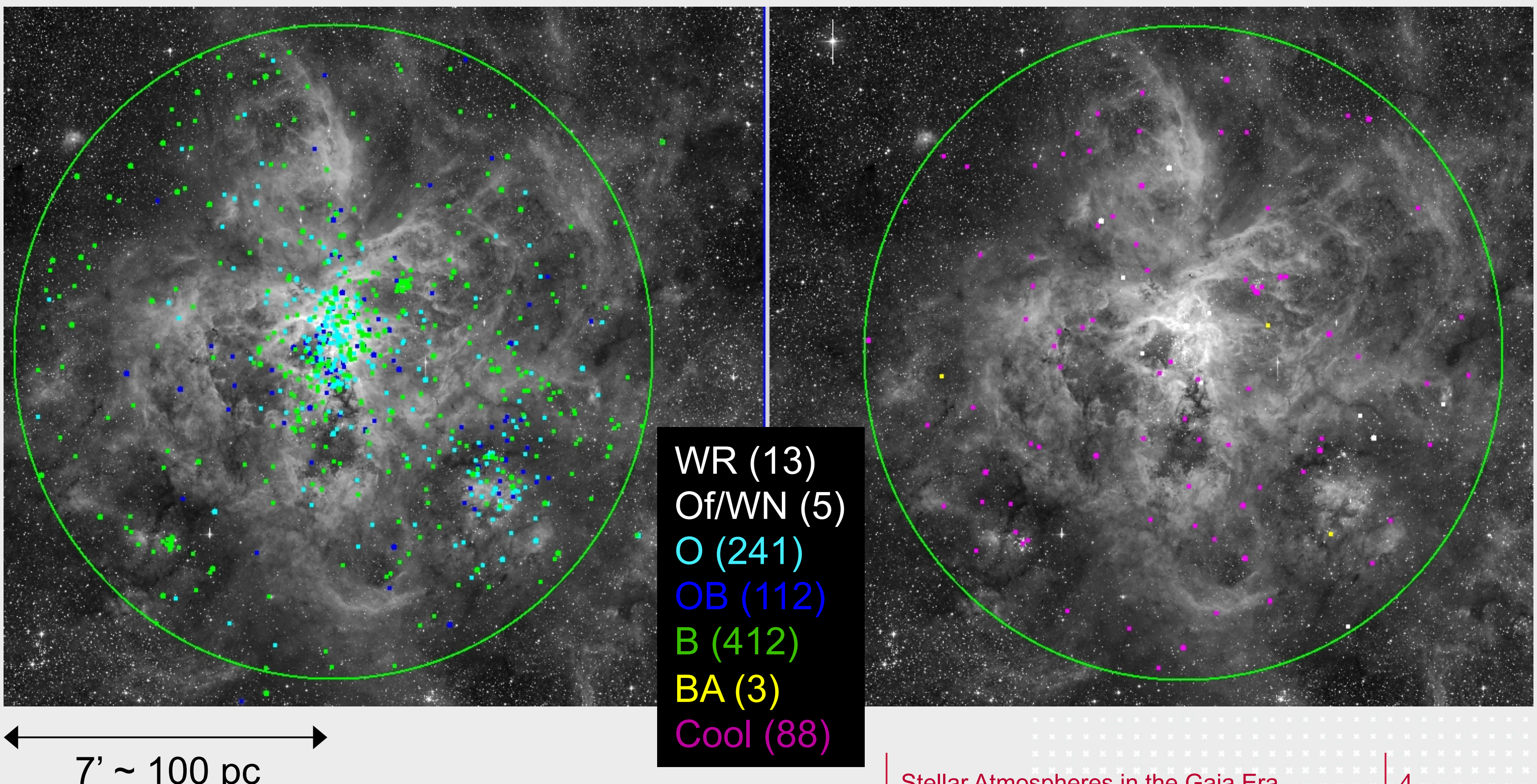
- The VLT/FLAMES Tarantula Survey
- Model atmospheres & fitting techniques
- Predictions of massive star evolution
- First results

VLT FLAMES Tarantula Survey

Evans et al. (2011)

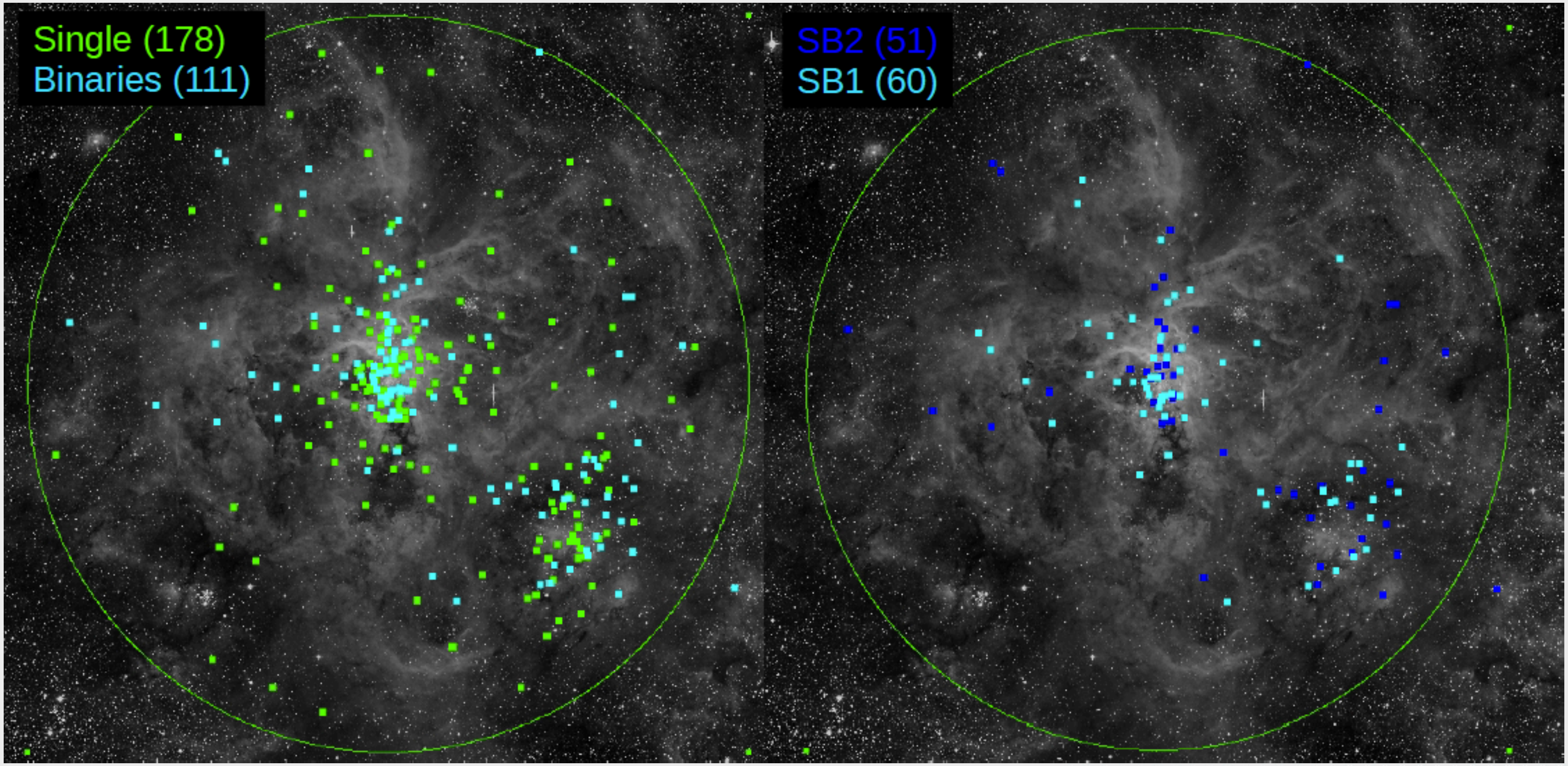
- Multi-epoch spectroscopy of 1,000 most massive stars in 30 Dor
- Testing stellar and cluster evolution
  - Census of nearest “mini-starburst”
  - Binary fraction & period distribution
  - Test of single and binary evolution, including effects of mass-loss and rotation
  - Cluster dynamics, mass segregation and infant mortality
- ESO Large Programme (160hrs) & HST Programmes (110hrs)

Spatial distribution of Spectral Types



UNIVERSITY OF AMSTERDAM

Spatial distribution of O-type binaries



Multi epochs for binary detection

Giraffe setting	λ-coverage	R	Epocs	Exposures
LR2*	3980-4550	7,000	6	2x1815s
LR3	4505-5050	8,000	3	2x1815s
HR15N	6470-6790	17,000	2	2x2265s

- binary detection: 5 epochs < 4 months, 1 one yr later
- P < 100d 90% complete; P~1yr 50%; P<1000d ~20%

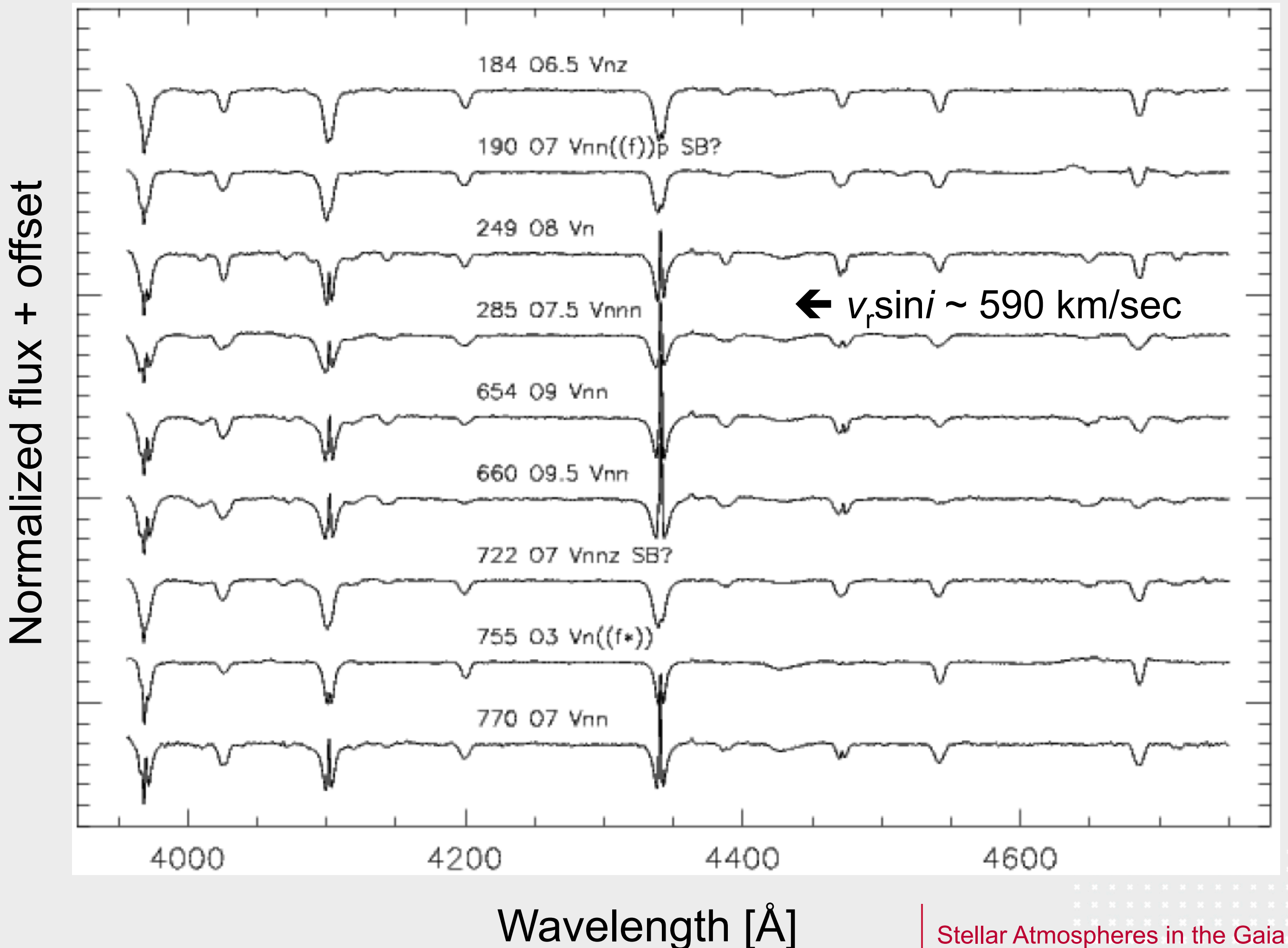
O stars, S/N >70-100, up to 500 for brightest targets

Interesting O-star categories

Category	#
O2	3
O3	6
Ofnp	4
IIIn/nn	7
Vn/nn/nnn	17
Vz	35! + 10?
O3.5-7 V((fc))	10! + 3?
O3.5-7 V((f))	8
O3.5-7 V high SNR No N III, C III emission lines	6
O8-O9.5 with He II broader than He I	5

← *More frequent in runaways*

Interesting O-star categories



O-star binaries

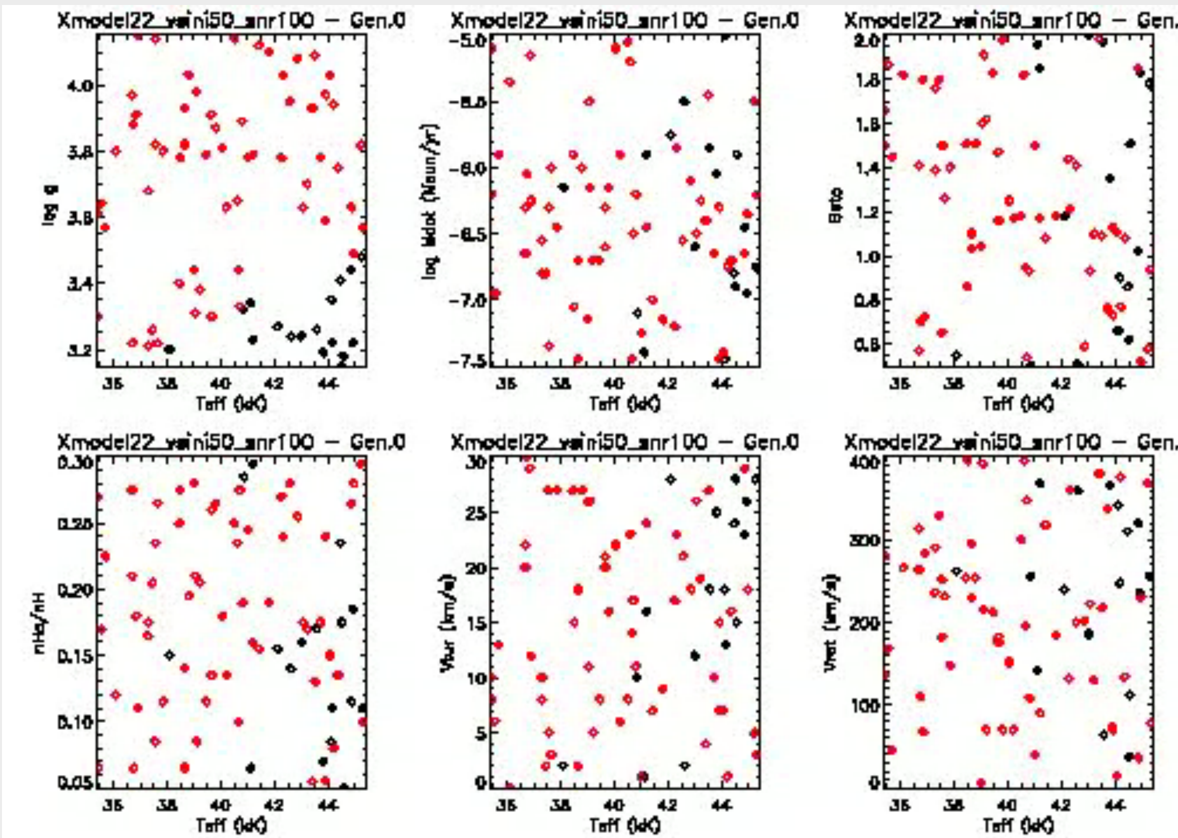
Category	ΔRV	#	fraction f
SB1+SB2	>30	60+51	0.34
Good cand.	20-30	11	0.03
Weak cand.	10-20	22	0.07
Single	<10	178	0.55
Total		322	1
Rejected		24	

Obs. biases	true f
+0.12	0.46

Most missing systems have P > 1 yr

Sana et al. in prep.

Spectral analysis: genetic algorithm fitting technique

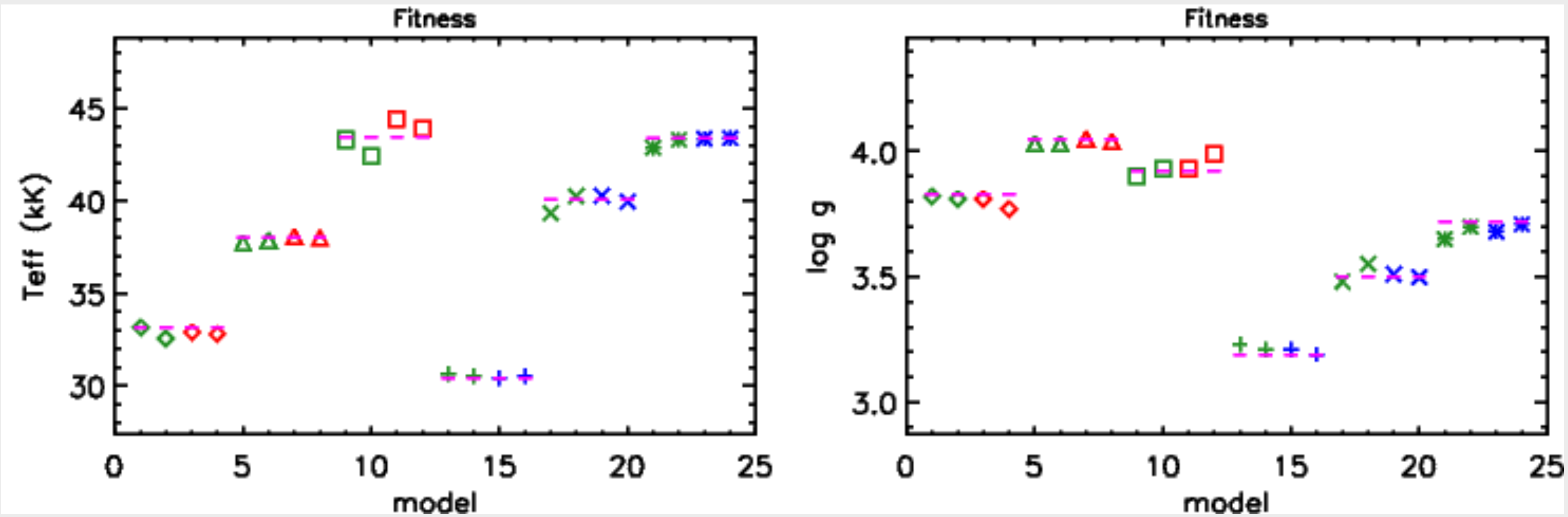


T_{eff}
g
L
Y_{He}
v_{turb}
dM/dt
β
v_{∞}
v_{rot}

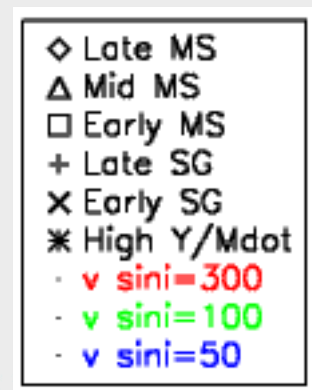
N

Mokiem et al. 2005, Charbonneau 1995

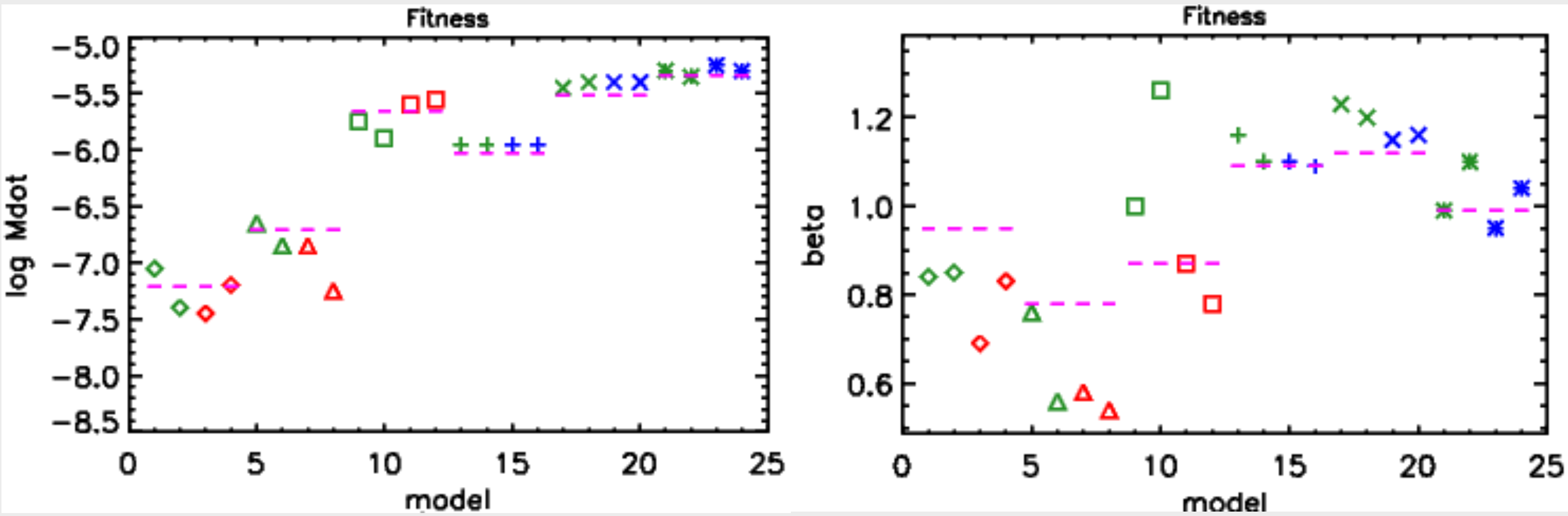
Spectral analysis: test of GA method using synthetic data



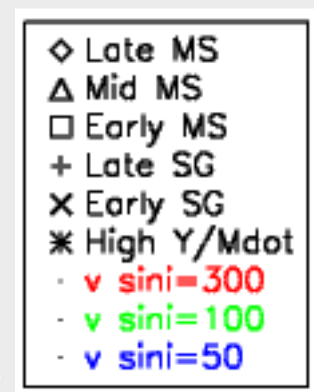
Parameter	<Obs-Comp>	dispersion
Teff	-0.09	0.40 kK
log *g*	-0.00	0.03
log d*M*/d*t*	0.05	0.09
β	0.04	0.05
Y	0.00	0.01
v_{turb}	0.0	2.2 km/sec



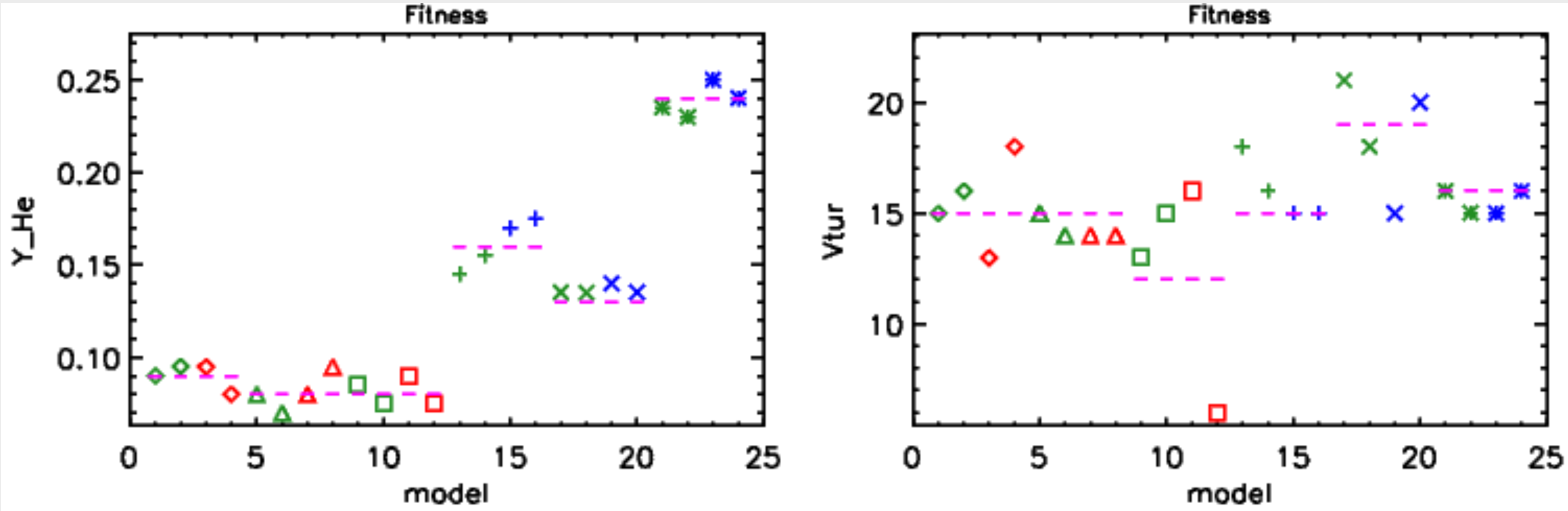
Spectral analysis: test of GA method using synthetic data

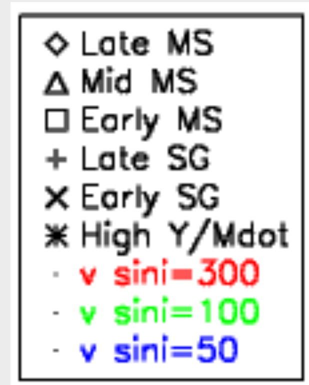


Parameter	<Obs-Comp>	dispersion
Teff	-0.09	0.40 kK
log *g*	-0.00	0.03
log d*M*/d*t*	0.05	0.09
β	0.04	0.05
Y	0.00	0.01
v_{turb}	0.0	2.2 km/sec



Spectral analysis: test of GA method using synthetic data





Parameter	<Obs-Comp>	dispersion
Teff	-0.09	0.40 kK
log *g*	-0.00	0.03
log d*M*/d*t*	0.05	0.09
β	0.04	0.05
Y	0.00	0.01
v_{turb}	0.0	2.2 km/sec

Spectral analysis: problems in O star analysis

- Rapidly rotating stars
- Abundances of N, C, O (fastwind)
- Macro- or “extra” broadening
- Clumping & porosity

- “Binarity”
- Extinction, nebular contamination

Spectral analysis: problems in O star analysis

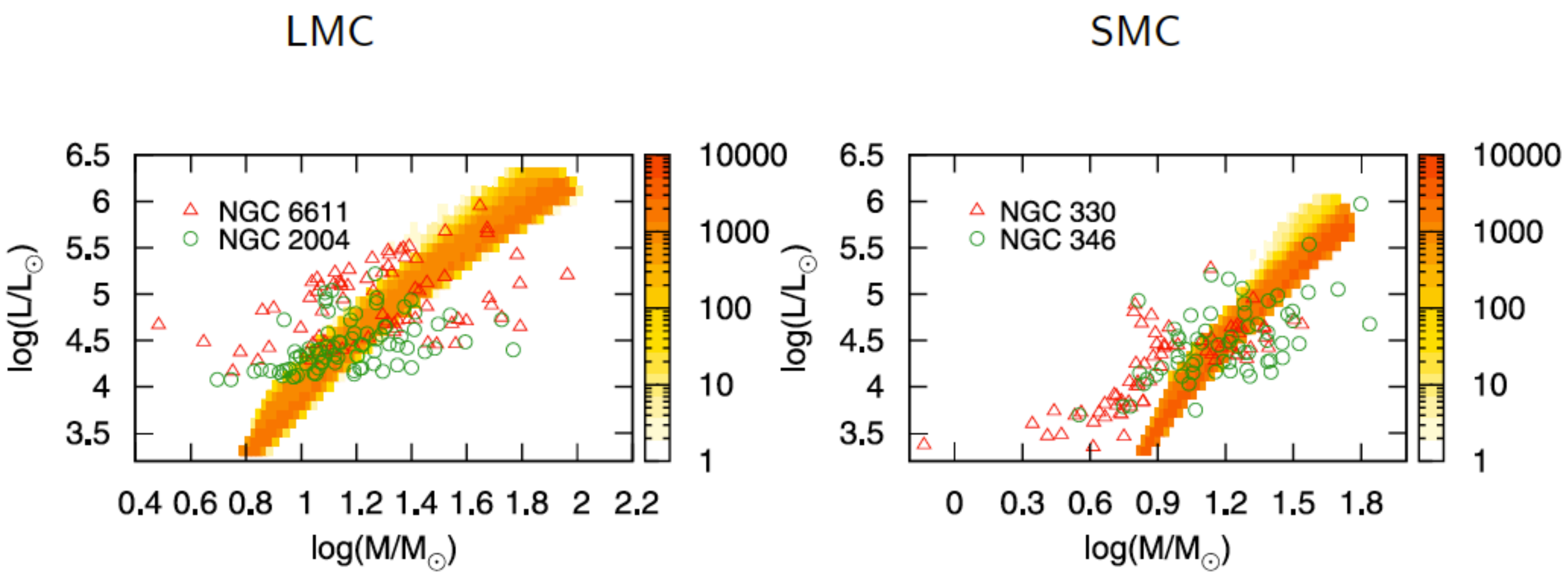
- ☐ Rapidly rotating stars
- ☐ Abundances of N, C, O (fastwind)
- ☐ Macro- or “extra” broadening
- ☐ Clumping & porosity

- ☐ “Binarity” – SB1, SB2
- ☐ Extinction, nebular contamination

Spectral analysis: problems in O star analysis

Mass discrepancy

Herrero et al. 1992

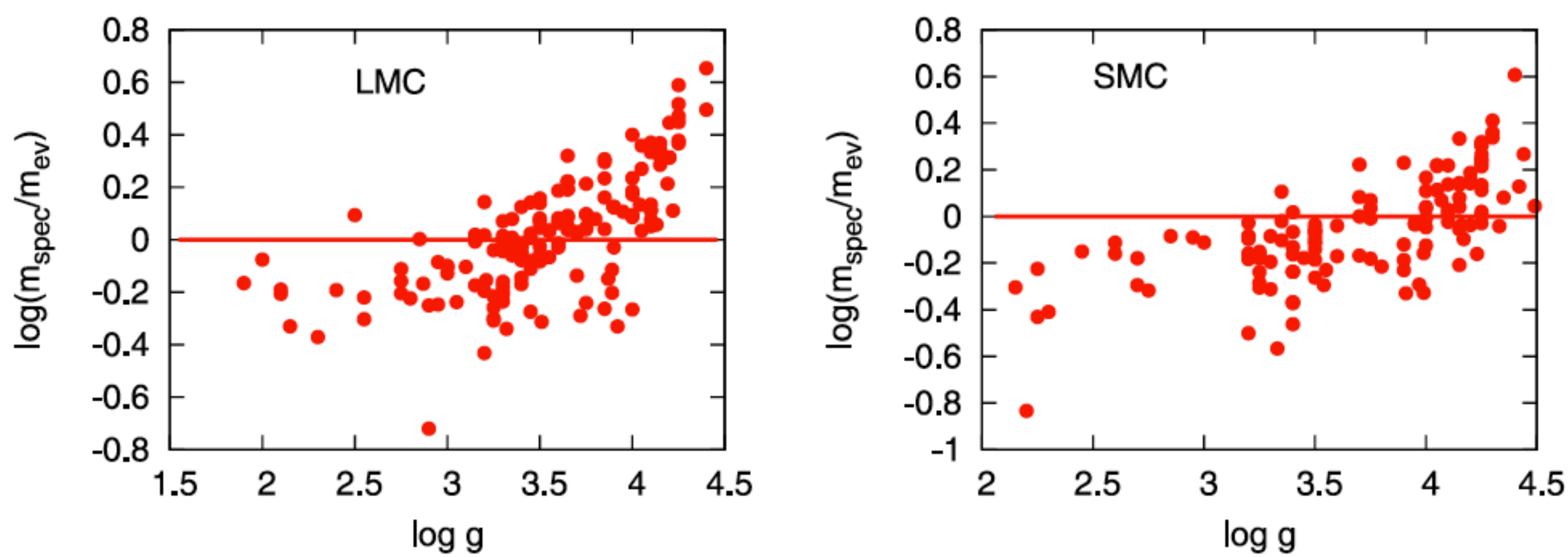


UNIVERSITY OF AMSTERDAM

Spectral analysis: problems in O star analysis

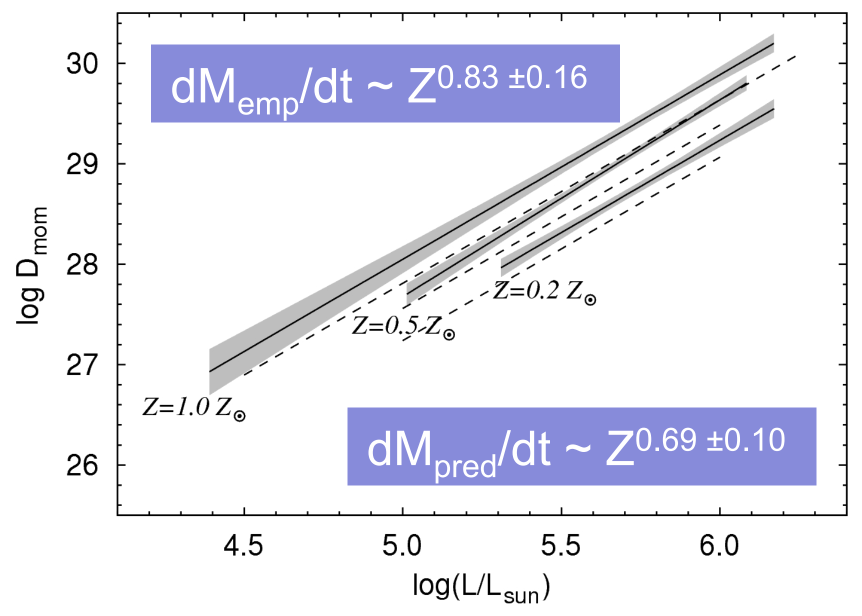
Mass discrepancy

Herrero et al. 1992



Main sequence evolution of rotating massive stars in GAL, LMC, SMC environments

- 5-60 $M_{\odot}$ Brott et al. (2011a)
- 60-300 $M_{\odot}$ Friedrich et al. (in preparation)

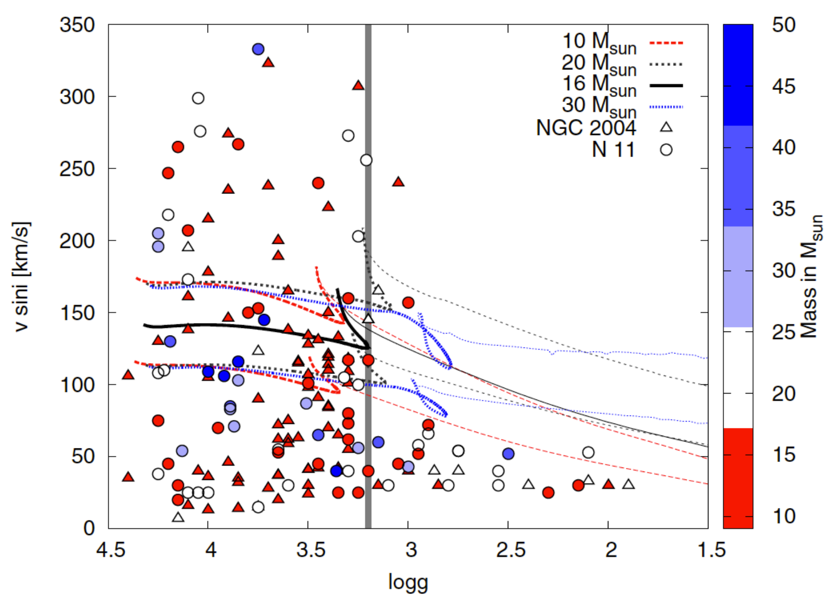


Vink et al. 2001, Mokiem et al. 2007

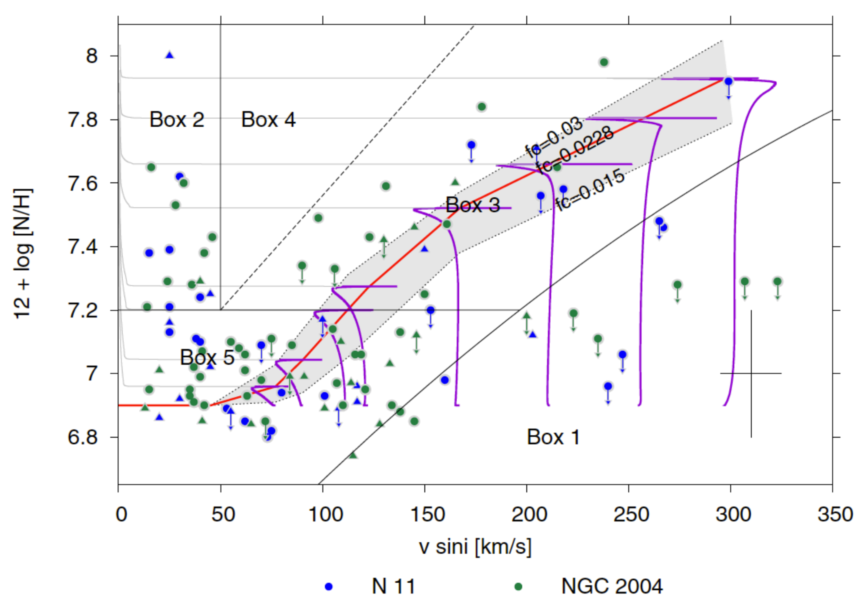
Mass loss prescription

Main sequence evolution of rotating massive stars in GAL, LMC, SMC environments

- 5-60 $M_\odot$ Brott et al. (2011a)
- 60-300 $M_\odot$ Friedrich et al. (in preparation)

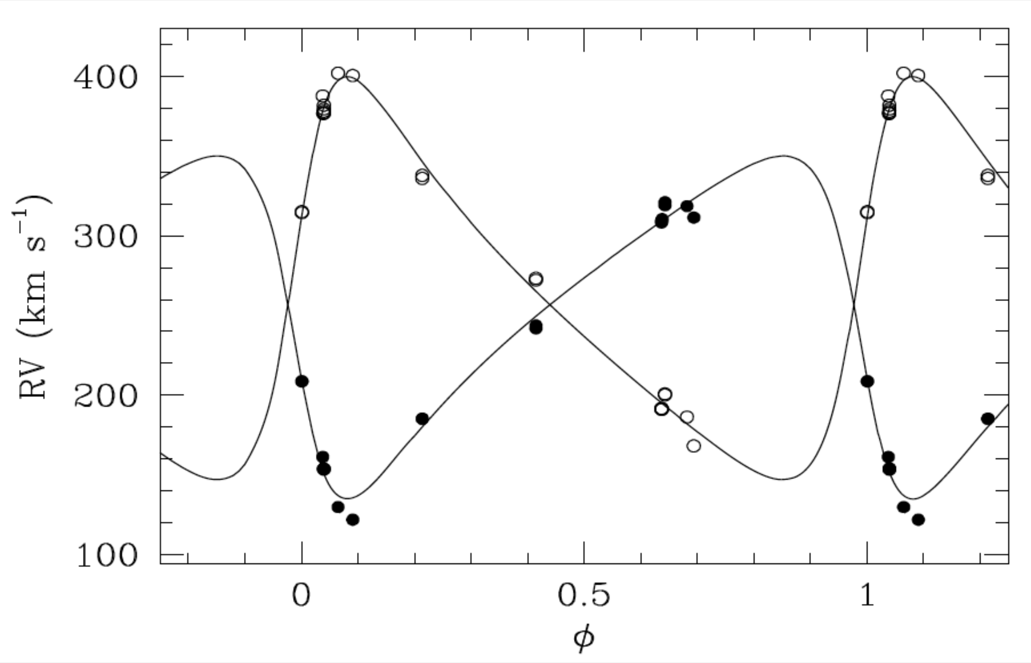


Overshooting calibration



Mixing par. & baseline N abund. calibration

Serendipitous discoveries: R139

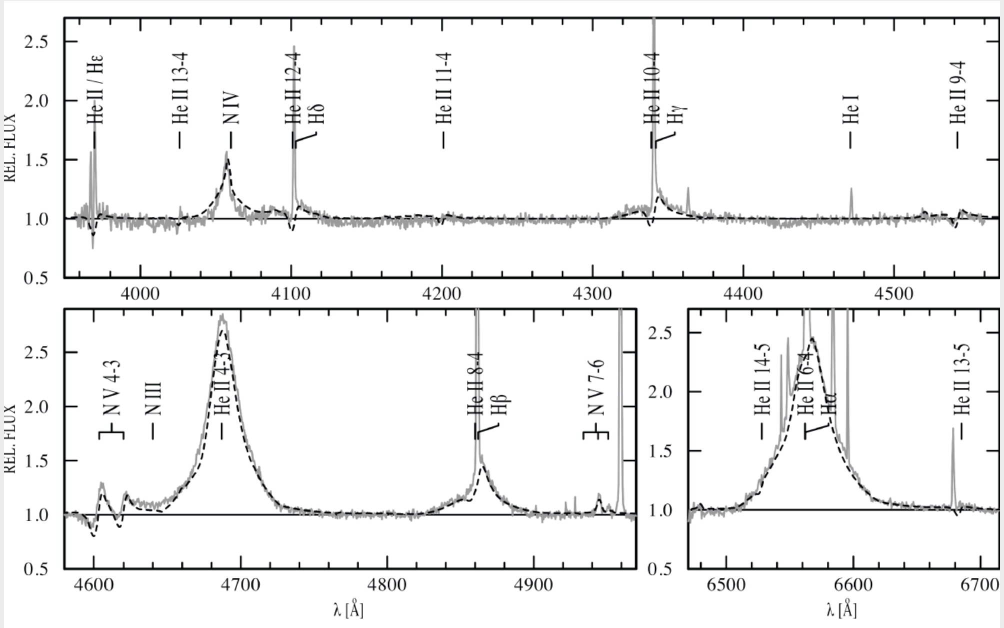


Taylor et al. 2011

- The most massive double-”normal” O binary (O6.5 Iafc + Of Iaf) known, with $M\sin^3 i$ = 78 ± 8 $M_\odot$ and $M\sin^3 i$ = 66 +/- 7 $M_\odot$
- Providing an excellent test for atmospheric and evolutionary models

UNIVERSITY OF AMSTERDAM

Serendipitous discoveries: WN5h star 682

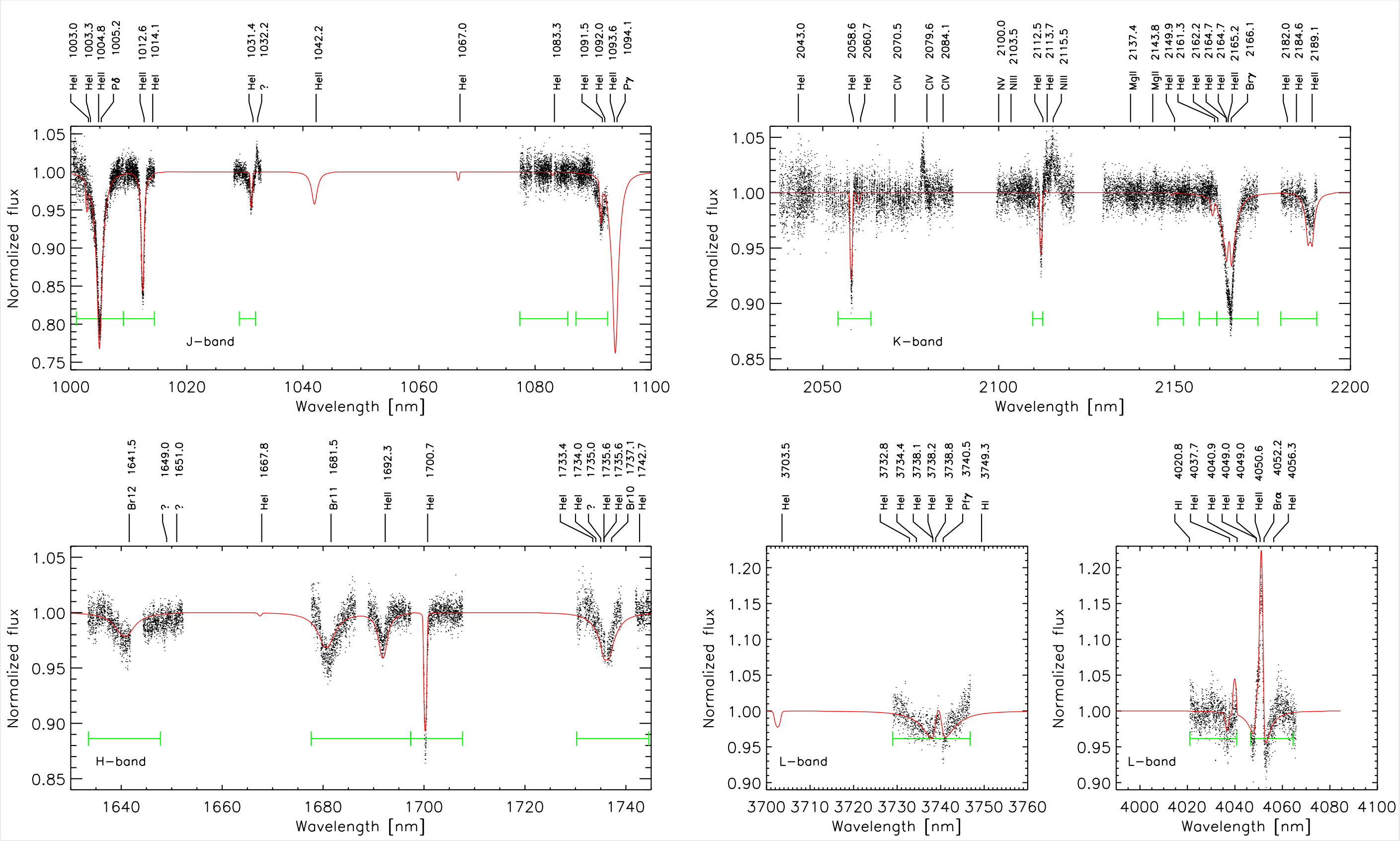


Bestenlehner et al. 2011

- Exceptionally massive WN5h star (M_{init} ~ 200 $M_{\odot}$); the first one of this type to be found outside of a massive young cluster
- Spectroscopic “twin” of R136a3 (M_{init} ~ 320 $M_{\odot}$), the most massive star known

Quantitative IR spectral analysis of O V stars

Arjen Stap (masterstudent UvA) - see poster

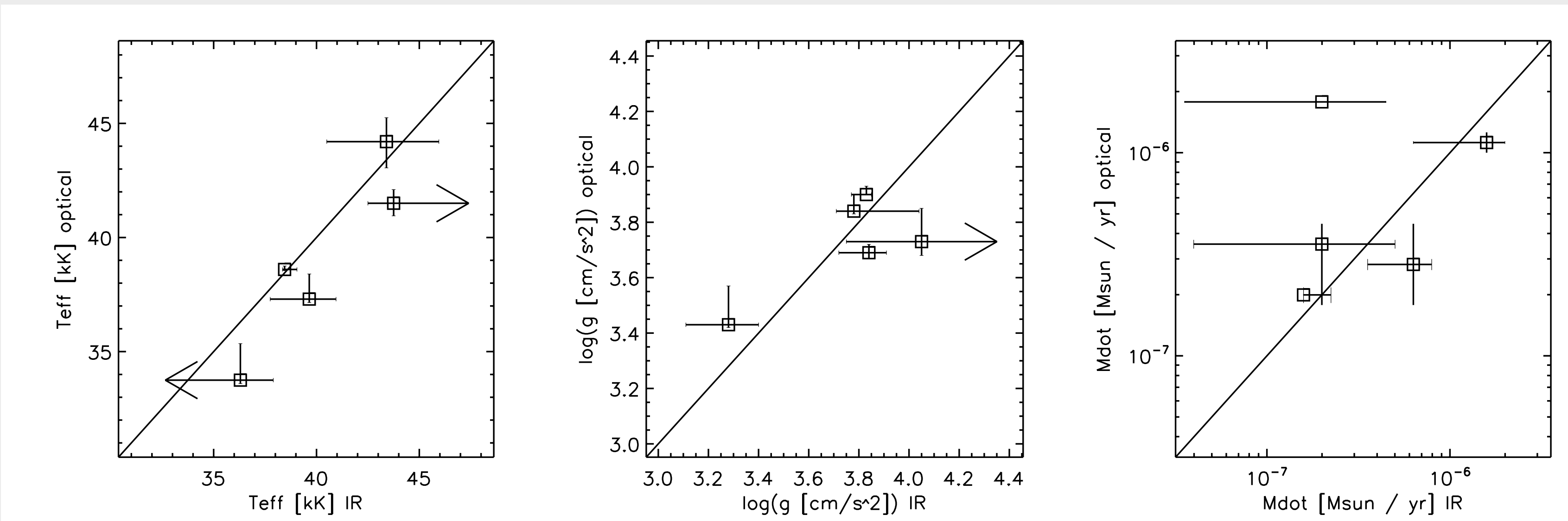


15 Mon (O6 V)

Quantitative IR spectral analysis of O V stars

Object	Spect. region	Spect. type	T_{eff} [K]	log(g) [cm/s^2]	$\dot{M}$ [$M_{\odot}yr^{-1}$]	n_{He}/n_H	V_{rot} [km/s]
HD93250	IR	O4V	43400^{+2550}_{-2900}	$3.84^{+0.07}_{-0.12}$	$-6.70^{+0.35}_{-0.75}$	$0.09^{+0.02}_{-0.04}$	126^{+58}_{-46}
	optical	O3V	44200^{+1050}_{-1150}	$3.69^{+0.03}_{-0.02}$	$-5.75^{+0.00}_{-0.00}$	$0.07^{+0.00}_{-0.01}$	138^{+6}_{-10}
HD46150*	IR	O4V	$43750^{...}_{-1250}$	$3.78^{+0.26}_{-0.07}$	$-5.80^{+0.10}_{-0.40}$	$0.10^{+0.17}_{...}$	70^{+94}_{-46}
	optical	O5V	41500^{+600}_{-550}	$3.84^{+0.06}_{-0.01}$	$-5.95^{+0.05}_{-0.05}$	$0.07^{+0.01}_{-0.00}$	120^{+4}_{-8}
HD54662*	IR	O5.5V	39650^{+1300}_{-1900}	$4.05^{...}_{-0.30}$	$-6.70^{+0.40}_{-0.70}$	$0.07^{+0.12}_{...}$	78^{+78}_{-22}
	optical	O7V	37300^{+1100}_{-150}	$3.73^{+0.12}_{-0.05}$	$-6.45^{+0.10}_{-0.30}$	$0.08^{+0.02}_{-0.02}$	126^{+14}_{-16}
15Mon*	IR	O6V	38450^{+600}_{-100}	$3.83^{+0.02}_{-0.06}$	$-6.80^{+0.15}_{-0.00}$	$0.08^{+0.01}_{-0.02}$	76^{+18}_{-8}
	optical	O6V	38600^{+150}_{-100}	$3.90^{+0.03}_{-0.00}$	$-6.70^{+0.00}_{-0.00}$	$0.05^{+0.00}_{...}$	60^{+6}_{-8}
HD73882	IR	O7.5V	$36300^{+1600}_{...}$	$3.28^{+0.12}_{-0.17}$	$-6.20^{+0.10}_{-0.25}$	$0.06^{+0.09}_{...}$	232^{+98}_{-102}
	optical	O8.5V	33750^{+1600}_{-150}	$3.43^{+0.14}_{-0.01}$	$-6.55^{+0.20}_{-0.20}$	$0.09^{+0.02}_{-0.03}$	202^{+4}_{-16}

Quantitative IR spectral analysis of O V stars



$\Delta T_{\mathrm{eff}} \leq 2{,}000$ K

$\Delta \log g \leq 0.15$ dex

$\Delta \log \mathrm{d}M/\mathrm{d}t \leq 0.3$ dex

Conclusions

- VLT FLAMES Tarantulara Survey largest homogeneous study of O & early-B stars to date ➔ serendipitous discoveries
- Improvements in model atmospheres & fitting methods allow for comprehensive test of theory of massive star evolution, though serious problems remain (including mass discrepancy)

- GA fitting method used to analyse IR spectra of OV stars yields promising results