SPECTRA AND FEEDBACK FROM YOUNG STELLAR CLUSTERS

Varsha Ramachandran[1], R. Hainich[1] , W.-R. Hamann[1], L. M. Oskinova[1], A. Sander[1], T. Shenar[1], H. Todt[1], Leah Fulmer[2], Jay Gallagher[2]

([1] Institut für Physik und Astronomie, Universität Potsdam, Department of Astronomy, [2] University of Wisconsin - Madison, WI, USA)

Introduction

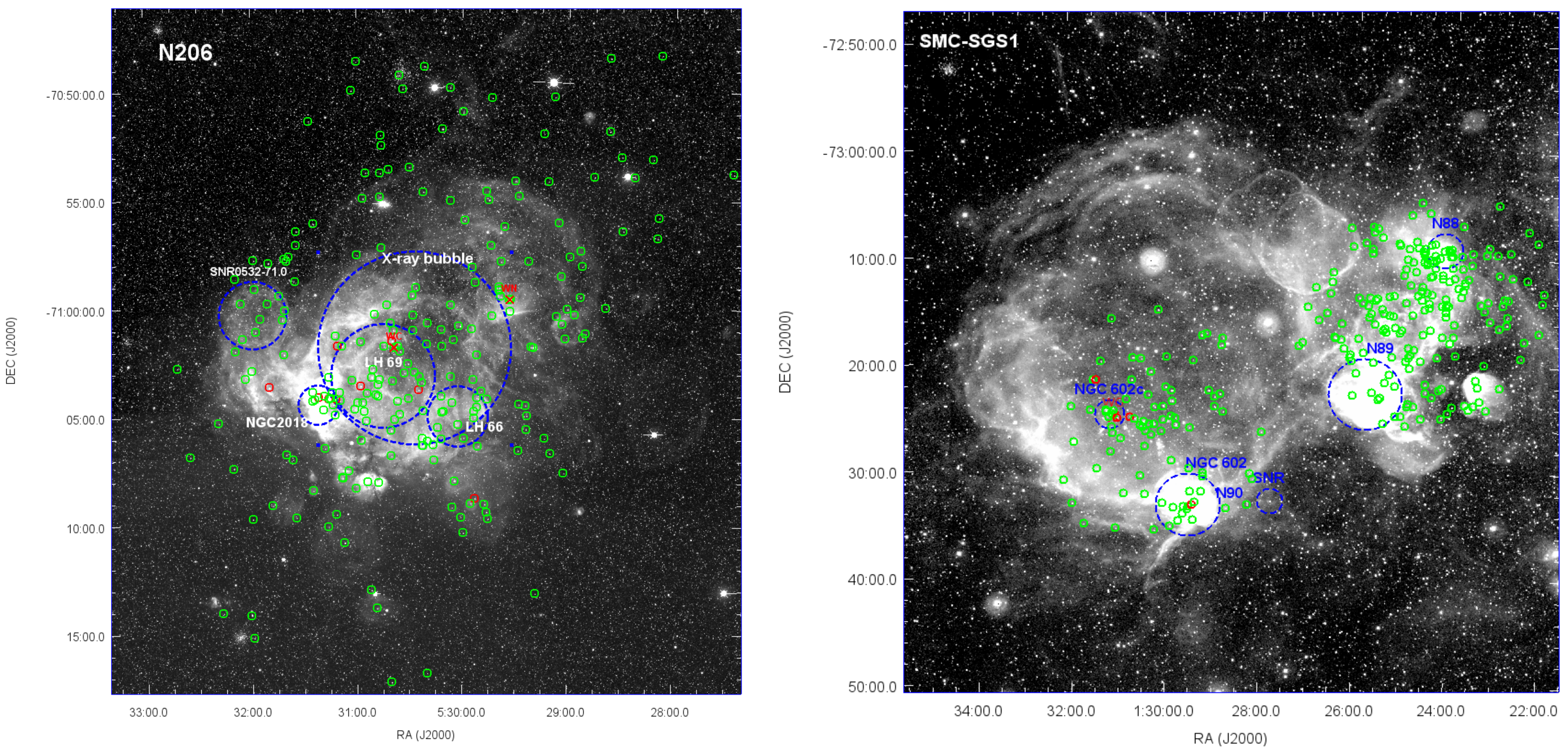
We present the quantitative analysis of massive stars in young clusters. This is required to understand how the feedback of these objects shapes the large scale structures of the ISM. The quantitative spectroscopic analysis, energy feedback, and chemical yields of young stellar populations in two low-metallicity environments are discussed here (superbubble N206 in the LMC and the supergiant shell SMC-SGS1).

Observations and available data

- **VLT-FLAMES**

Grating setup	Wavelength range (Å)
LR02	3964-4567
LR03	4501-5078
HR15N	6470-6790

- HST/STIS (1150-1700 Å)
- IUE (1150-2000 Å)
- FUSE (905-1187 Å)
- UV, optical (U, B, V, I), and infrared (JHK and Spitzer-IRAC) photometry.



Hα image from Magellanic Cloud Emission-Line Survey in the background. Wolf-Rayet stars (cross), Of stars (red circle), OB stars (green circle) are marked

N206 superbubble

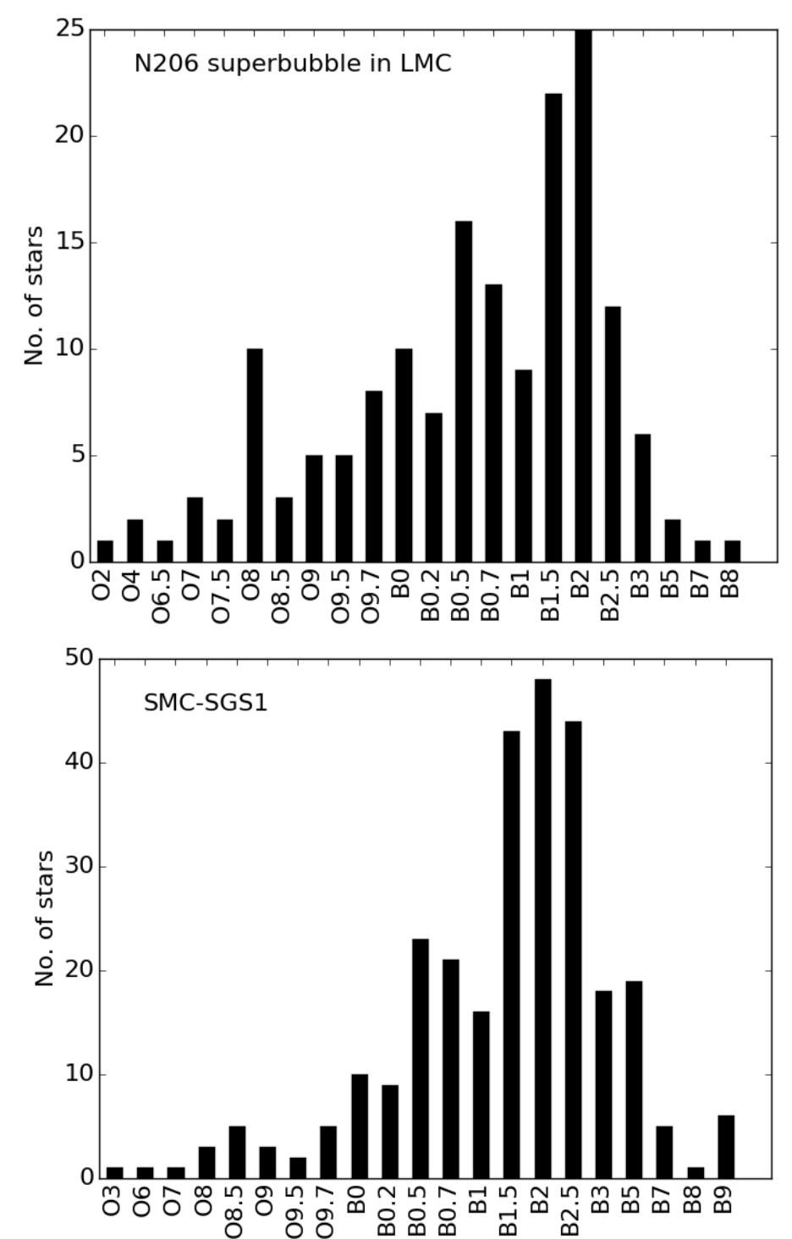
- N206 (LHA 120-N206) in the outskirts of the LMC
- Distance ∼48 kpc
- Metallicity $Z=0.5\,Z_\odot$
- Excited by the winds of the massive stars in the young cluster NGC 2018 and the LH 66 and LH 69 OB associations.
- Harbours a X-ray superbubble and a supernova remnant SNR B0532-71.0
- 164 OB stars analyzed

SMC-SGS1

- Located in the wing of the SMC
- Distance ∼60 kpc
- Metallicity $Z=0.14\,Z_\odot$
- Associated with NGC602 cluster and the N88, N89, and N90 emission nebula
- Harbours a supernova remnant MCSNR J0127-7332
- 284 OB stars analyzed

Stellar population

	N206 superbubble	SMC-SGS1
O stars	40 (9 Of)	21 (4 Of)
B stars	124 (19 Be)	263 (34 Be)
total	164	284



Spectral classification

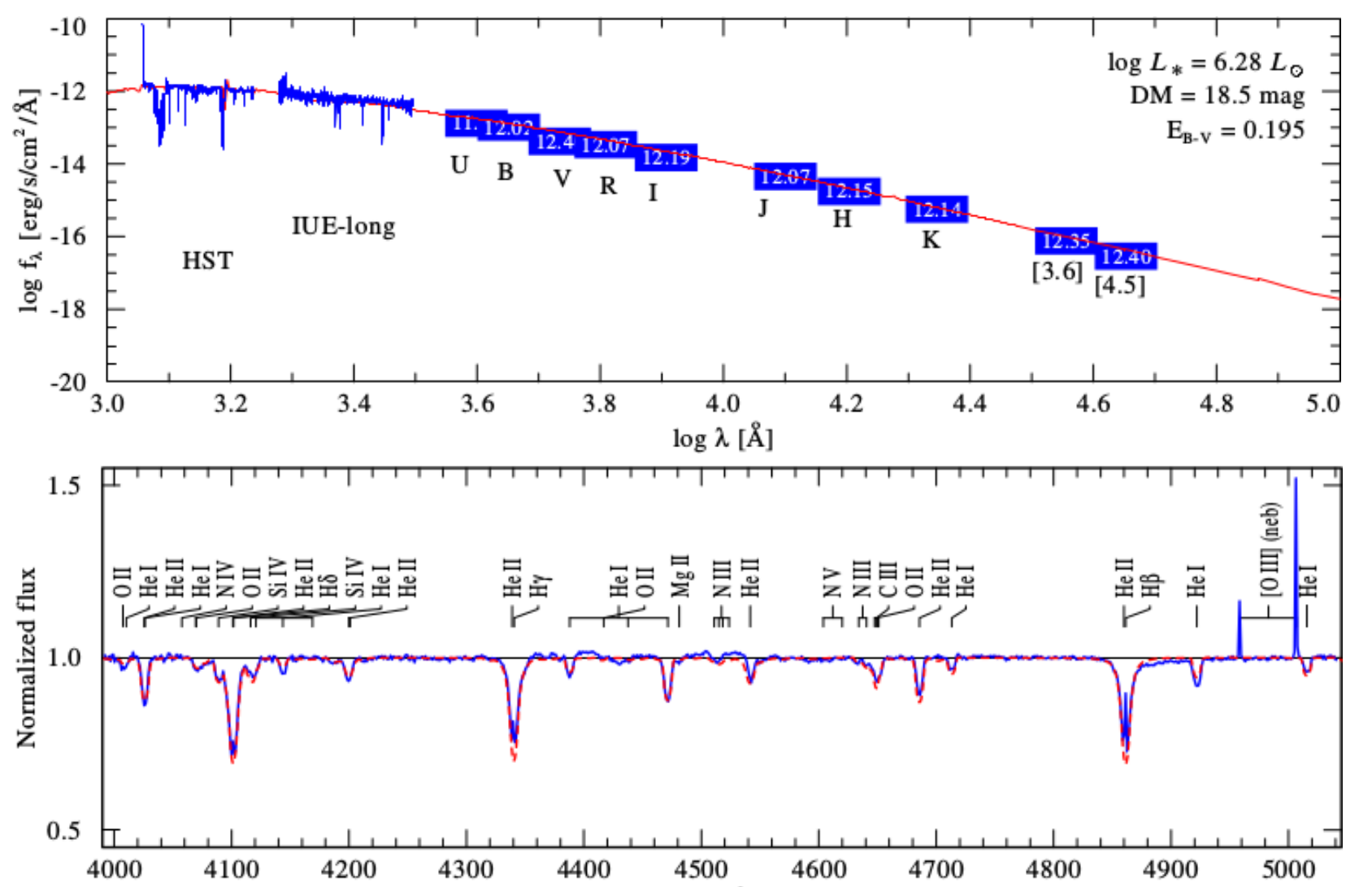
- Based on the spectral lines in the range 3960–5071 Å
- Mainly followed the classification schemes in Sota et al. (2011,2014) and Walborn et al. (2014)
- Main criteria:
  - He I / He II ionization equilibrium
  - N III / N IV ratio in Of stars
  - Si III / Si IV ratio in B stars
  - Si II, Mg II lines in late B stars

The Potsdam Wolf-Rayet (PoWR) model atmosphere code

- PoWR[*] is a state-of-the-art code for expanding stellar atmospheres[6], accounts for non-LTE, wind inhomogeneities, and iron line blanketing[12]
- Main parameters: luminosity L_*, stellar temperature T_* , surface gravity g_*, and mass-loss rate $\dot{M}$
- Spectral analysis: iterartively fitting observed spectra with synthetic spectra (see figure)
- Based on OB-star grids for LMC & SMC metallicity

(T_* = 10 kK to 54 kK , and log g_* = 2.0 to 4.4)

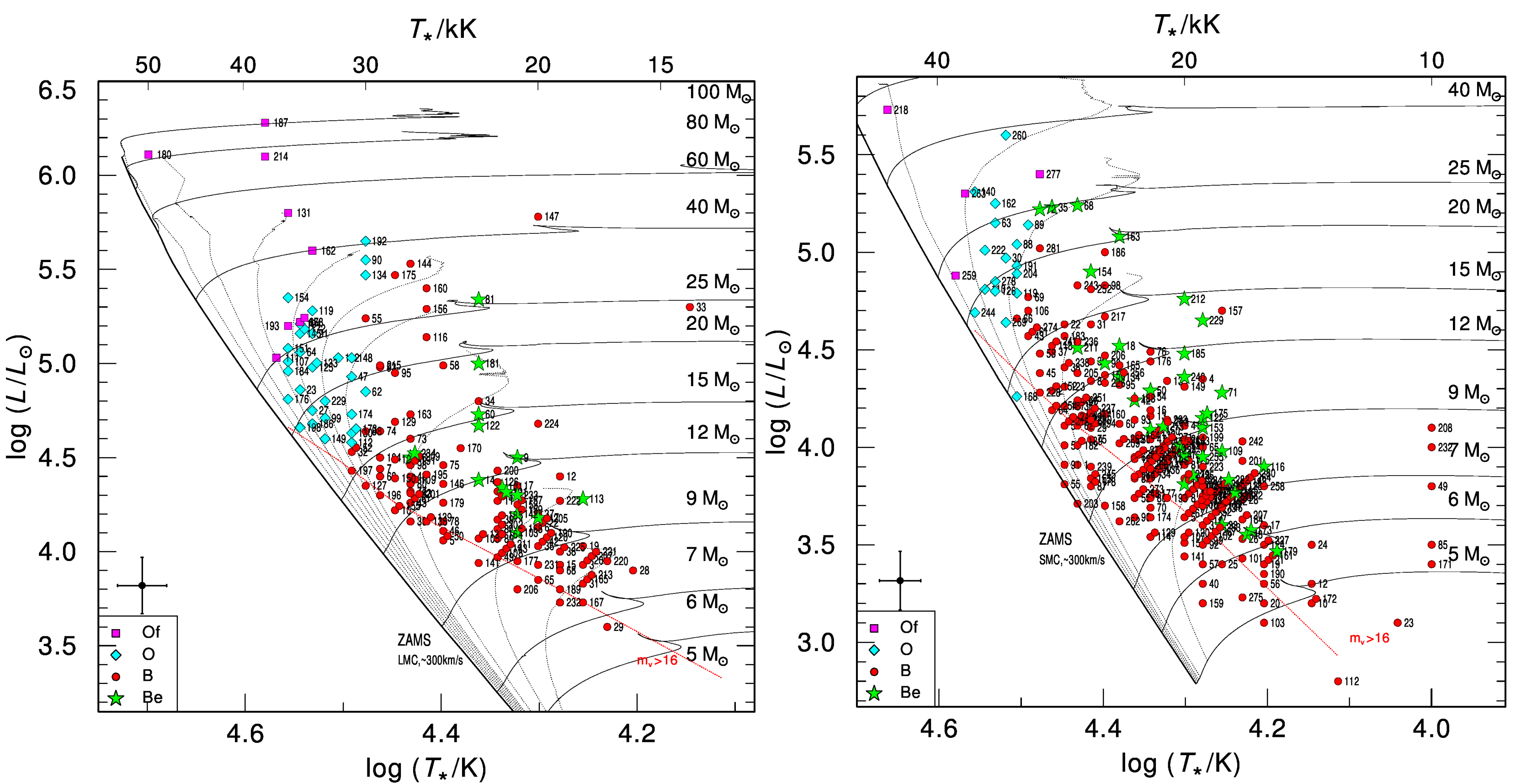
[*] www.astro.physik.uni-potsdam.de/PoWR.html



An example fit for O star. Upper panel: Model SED (red) fitteted tp photometry and UV spectra (blue).
Lower panel: PoWR model spectrum (red) fitted to the normalized VLT- FLAMES spectrum (blue)

The Hertzsprung-Russell diagram

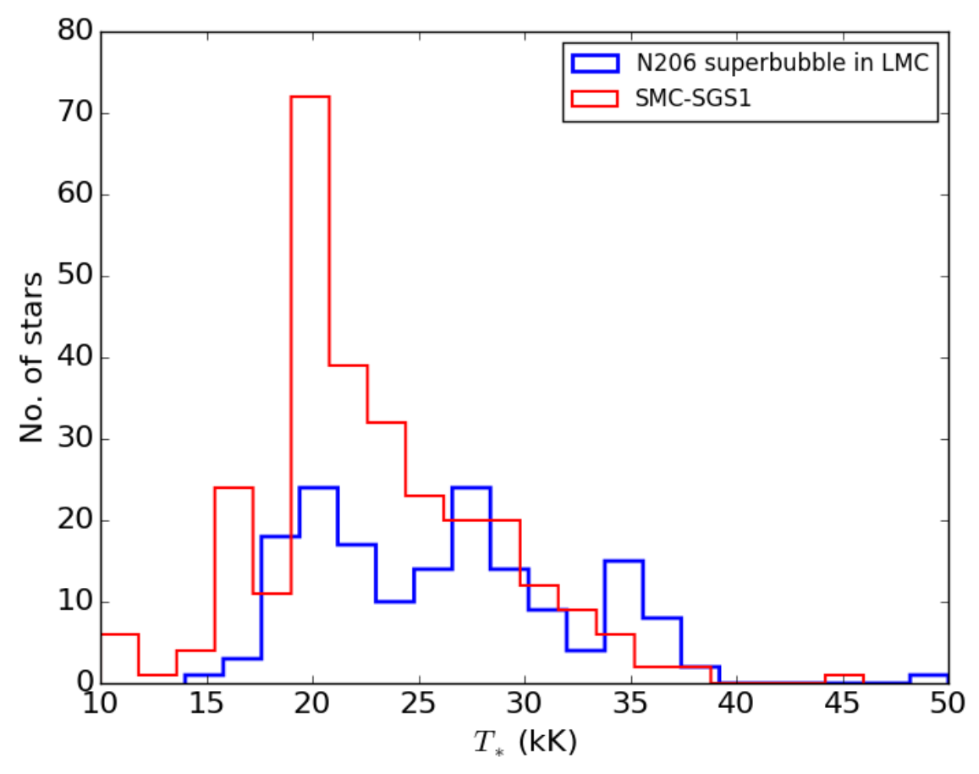
- Multiple populations with a broad age range
- Most of the Be stars are evolved or close to the main sequence turn off

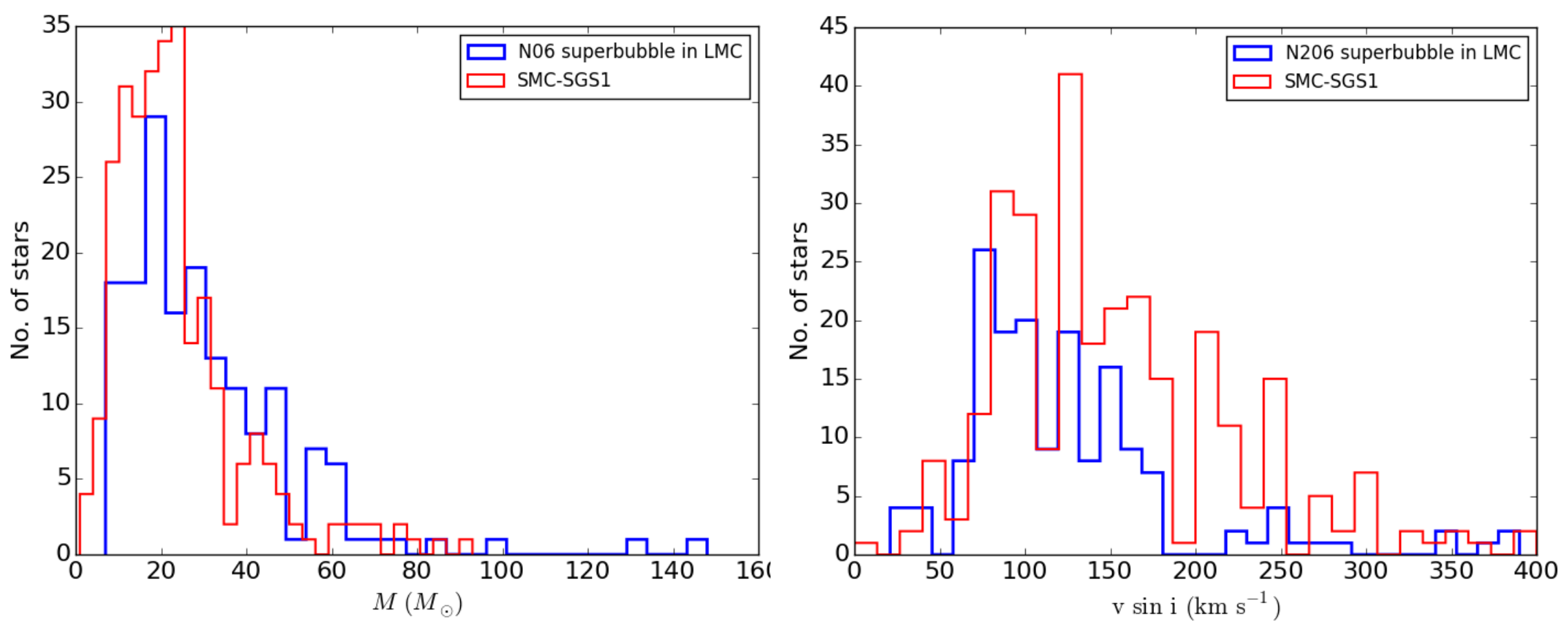


Hertzsprung-Russell diagram for all the OB stars in the N206 superbubble in the LMC (left) and in the SMC-SGS1 (right). The evolutionary tracks & isochrones are based on rotating ($V_{rot,init}$ ∼300 km s $^{-1}$) evolutionary models presented in Brott et al. (2011) and Kohler et al. (2015). The isochrones span from the zero age main sequence (ZAMS) to 30 Myr. The completeness limit is shown (dotted red line) for m_v brighter than 16 mag.

Stellar & wind parameters

- Majority of the massive stars in SMC-SGS1 are of spectral type B, whose temperature peaks at ~20 kK
- Few very massive stars (>100 $M_\odot$) in N206. Most of the stars have spectroscopic mass $M \leq 20\,M_\odot$
- υ sin i higher in SMC-SGS1 → metallicity effect



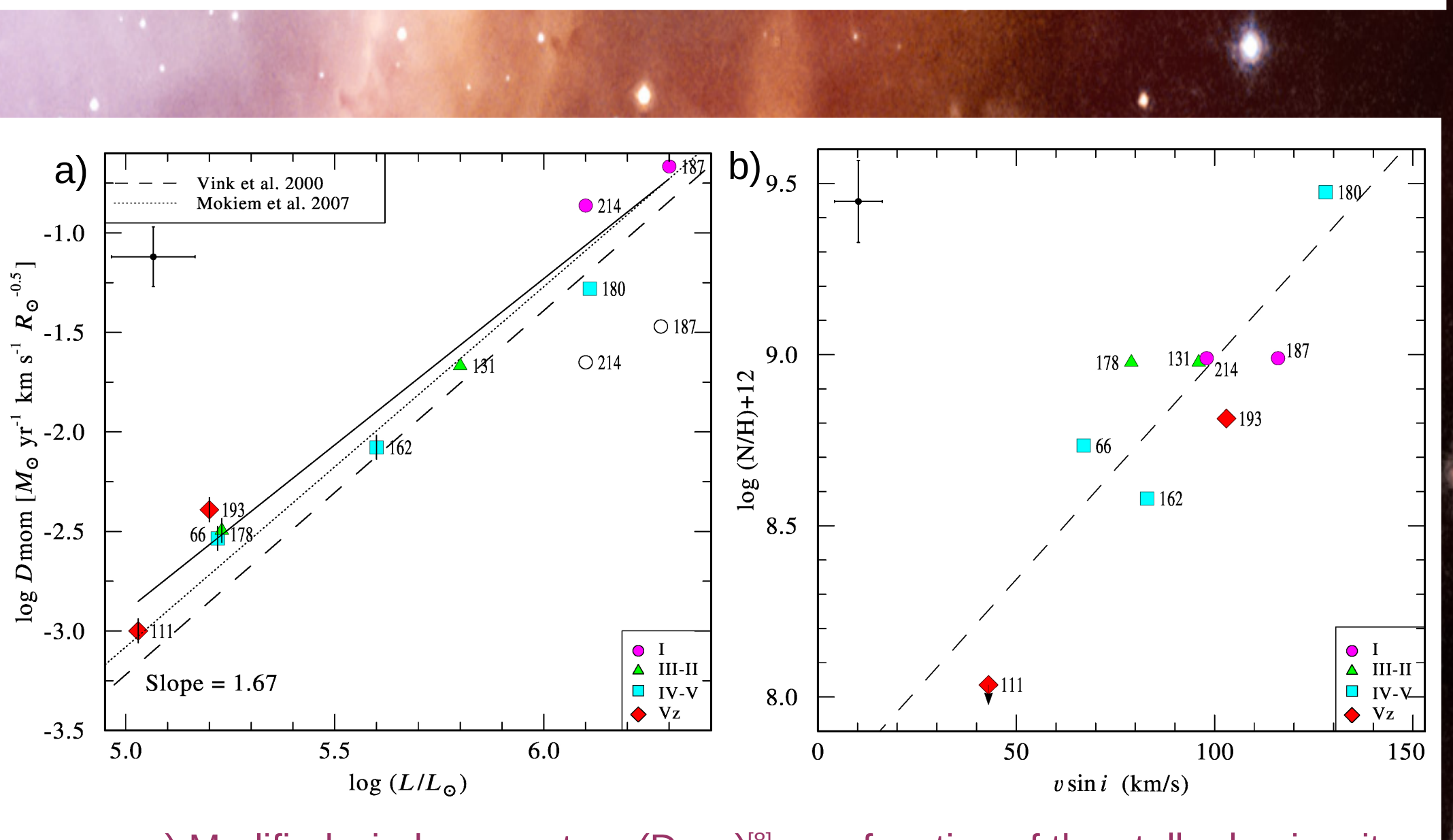


Range of parameters T_*, M_*, and v sin i of all OB stars in the N206 superbubble in t LMC (blue) and in the SMC-SGS1 (red)

'Of-type' stellar population

- Early O type stars with nitrogen emission lines
- Comprises hottest and very masssive stars, age <4 Myr
- Precisely constrained wind parameters and abundances
- Main feedback contributors
- Nine Of stars in the N206[*],including
  - Two suspected binaries (Of + late O subtype)
  - One supergiant (N206-FS187) with very high L and $\dot{M}$ that exhibits very high X-ray luminosity
- Four Of stars in the SMC-SGS1, including
  - One binary (O3+B)
  - One very fast rotating Of supergiant

[*] Ramachandran et al. (sub)



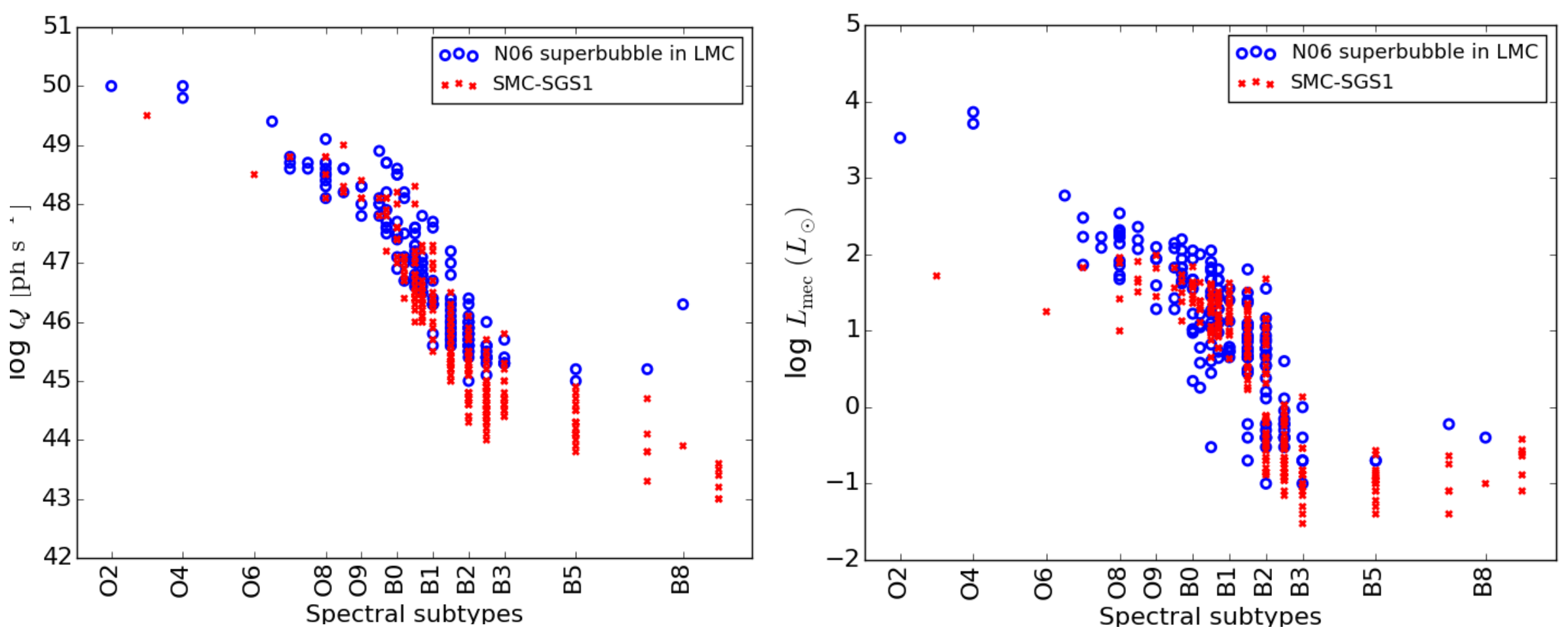
a) Modified wind momentum (D_{mom})[8] as a function of the stellar luminosity and b) Surface nitrogen abundances as a function of the projected rotation velocity v sin i for the Of stars in N206 superbubble.

Of stars in N206:

- Wind momentum-luminosity relation: follows a less steep power-law than theoretically predicted[7]
- Most of the Of stars are nitrogen enriched
  - A clear correlation with rotaion velocity is observable
  - Binaries and evolved stars show more nitrogen enrichment
- The O2 star N206-FS 180: shows a very high nitrogen mass fraction, strongly depleted oxygen abundance

Stellar feedback

Rate of hydrogen ionizing photons (log Q) & mechanical luminosity of the stellar winds ($0.5\,\dot{M} v_\infty^2$) for all OB stars in N206 and SMC-SGS1



The number of ionizing photons and the mechanical luminosity of the stellar winds as a function of spectral subtypes.

Of stars in N 206:

- Contribute more than 70% of total ionizing photon flux and mechanical luminosity, 50 % of the total mass-loss
- Mechanical energy input is comparable to the energy stored in the superbubble

(X-ray and Hα emission[9])

Of stars in SMC-SGS1:

- Dominate the total ionizing photon flux but not the mechanical luminosity

Complete population:

- Radiative & mechanical feedback from OB stars in SMC-SGS1 is an order of magnitude lower than that of the N206 superbubble

	N206 superbubble	SMC-SGS1
Total ionizing photon flux Q_0 (s^{-1})	4.2×10^{50}	9.6×10^{49}
Total mechanical luminosity Lmec ($L_\odot$)	2.2×10^4	3.3×10^3
Total mass-loss rate ($M_\odot$ yr^{-1})	3.1×10^{-5}	8.8×10^{-6}

References

[1]Sota et al. (2011)
[2]Sota et al. (2014)
[3]Walborn et al. (2014)
[4]Madore & Freedman (1998)
[5]Rolleston et al. (2002)
[6]Hamann & Gräfener (2004)
[7]Vink et al. (2001)
[8]Kudritzki & Puls (2000)
[9]Kavanagh et al. (2012)
[10]Mokiem et al. (2007)
[11]Trundle et al.(2007)
[12]Sander et al. (2015)
[13]Brott et al. (2011)
[14]Simon-Dıaz & Herrero (2014)
[15]Kohler et al. (2015)