EWASS 2017 | European Week of Astronomy and Space Science
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# The metallicity dependence of WR winds

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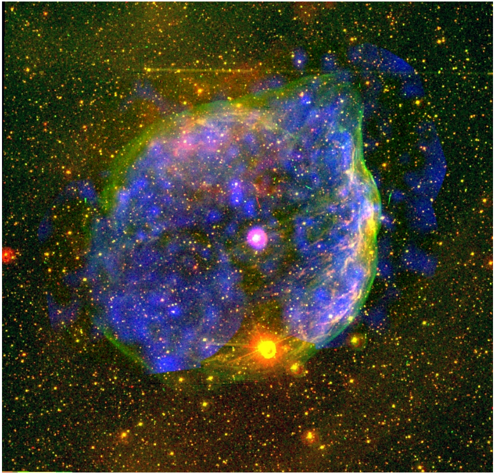
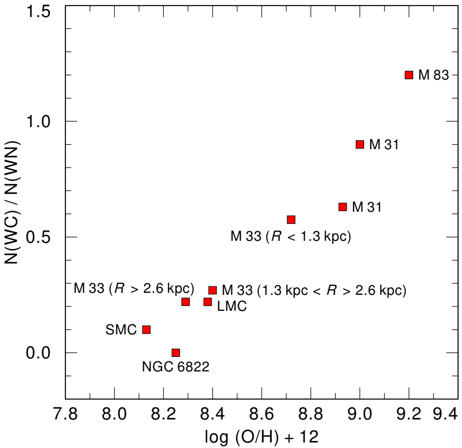
# Wolf Rayet Stars (WR)

- evolved massive stars
  $\rightarrow$ initial masses $> 20 M_\odot$
- dense and fast stellar winds (up to $\approx 5000\,\mathrm{km/s}$)
- strong mass loss
  $(10^{-5} M_\odot/\mathrm{yr} \mathrel{\widehat{=}} 10^9 \dot{M}_\odot)$
- spectra with strong broad emission lines
  - helium and nitrogen
    $\Rightarrow$ WN sequence
  - carbon and helium
    $\Rightarrow$ WC sequence



WR 6 – Credit: J. Toala et al. (2012)

# WR populations: the effect of the metallicity

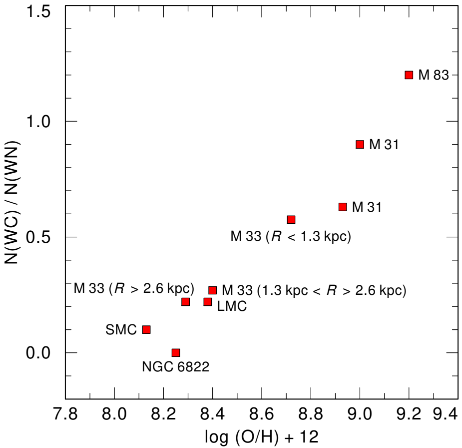



Crowther et al. (2007), Neugent et al. (2012)

**WR populations:**

- properties change depending on the environment
  - WC/WN ratio
  - sub-type distribution
  - spectral characteristic

# WR populations: the effect of the metallicity

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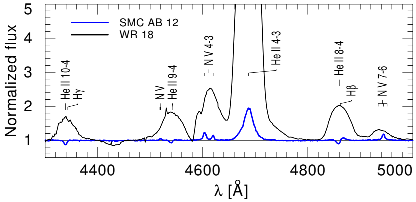
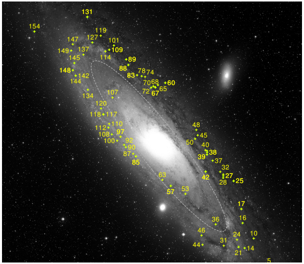


## Andromeda Galaxy

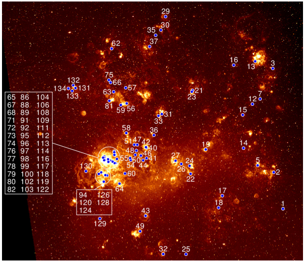


Palomar STScI DSS

- $Z \approx Z_\odot$
- 92 WN stars known
- WNL stars analyzed
- analysis of the WNE is under way

Sander et al. (2013); Hainich et al. (in prep.)

## Large Magellanic Cloud

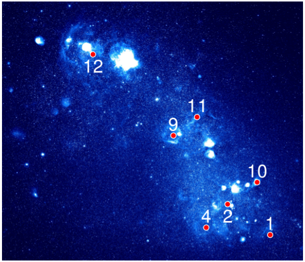


Magellanic Cloud Emission-Line Survey (Smith et al. 2005)

- $Z \approx 1/2\, Z_\odot$
- nearly complete WN population
- single stars analyzed
- analysis of the binaries is under way

Hainich et al. (2014); Shenar et al. (in prep.)

## Small Magellanic Cloud




Magellanic Cloud Emission-Line Survey (Smith et al. 2005)

- $Z \approx 1/4 - 1/7\, Z_\odot$
- complete WN population
  - 7 single WN stars
  - 4 binary systems

Hainich et al. (2015); Shenar et al. (2016)

# PoWR

**Potsdam Wolf-Rayet model code for expanding stellar atmospheres**

- non-LTE population numbers
- radiative transfer in co-moving frame
- complex model atoms
  (H, He, C, N, O, Ne, Mg, Al, Si, P, S, Ar, ...)
- self-consistent treatment of the quasi-hydrostatic regime
- iron-line blanketing (super-level approach)
- wind inhomogeneities (micro-clumping)
- usable for any hot star (WR, O, B, LBV, CSPN, ...)

**PoWR models: www.astro.physik.uni-potsdam.de/PoWR**

# PoWR - The Potsdam Wolf-Rayet Models

This WEB interface allows to inspect and download synthetic spectra for Wolf-Rayet and OB stars. The spectra are calculated from PoWR model atmospheres which account for Non-LTE, spherical expansion and metal line blanketing.

## Model atmospheres and synthetic spectra

The following data is available for each model:

- Spectral Energy Distribution
  (emergent flux received at 10pc distance, low spectral resolution)
- Line spectrum in high resolution for different wavelength bands
  (optionally normalized or flux-calibrated)
- Atmosphere stratification
  (incl. electron temperature, density, optical depth, etc.)
- Colors and ionizing photons

## Model parameters and organisation

The models are arranged in different *Model Grids*. Each model grid is characterized by a set of common parameters, such as stellar luminosity, terminal wind velocity, clumping contrast, and chemical composition. For Wolf-Rayet stars of the nitrogen subclass (WN) there are grids of hydrogen-free models (WNE) and of models with a specified mass fraction of hydrogen (WNL). The iron-group and total CNO mass fractions correspond to the metallicity of the Galaxy, the Large Magellanic Cloud (LMC), or the Small Magellanic Cloud (SMC), respectively.

# Wolf-Rayet model grids

| | | log L | $v_{final}$ | $D_{max}$ | $X_H$ | $X_{He}$ | $X_C$ | $X_N$ | $X_O$ | $X_{Ne}$ | $X_{Fe}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | [$L_{sun}$] | [km/s] | | | | mass fractions | | | | |
| Galactic Metallicity | | | | | | | | | | | |
| WNE | Details | 5.3 | 1600 | 4 | - | 0.98 | 1.0E-4 | 0.015 | - | - | 1.4E-3 |
| WNL-H20 | Details | 5.3 | 1000 | 4 | 0.2 | 0.78 | 1.0E-4 | 0.015 | - | - | 1.4E-3 |
| WNL-H50 | Details | 5.3 | 1000 | 4 | 0.5 | 0.48 | 1.0E-4 | 0.015 | - | - | 1.4E-3 |
| WC | Details | 5.3 | 2000 | 10 | - | 0.55 | 0.4 | - | 0.05 | - | 1.6E-3 |
| LMC Metallicity | | | | | | | | | | | |
| WNE | Details | 5.3 | 1600 | 10 | - | 0.995 | 7.0E-5 | 4.0E-3 | - | - | 7.0E-4 |
| WNL-H20 | Details | 5.3 | 1600 | 10 | 0.2 | 0.795 | 7.0E-5 | 4.0E-3 | - | - | 7.0E-4 |

**WR model grids**

**OB model grids**

### How to cite the grids and models

*PoWR code descriptions*

- Gräfener, Koesterke, & Hamann: 2002, A&A 387, 244 (ADS)
- Hamann & Gräfener: 2003, A&A 410, 993 (ADS)
- Sander, Shenar, Hainich, Gímenez-García, Todt, & Hamann: 2015, A&A 577, A13 (ADS)

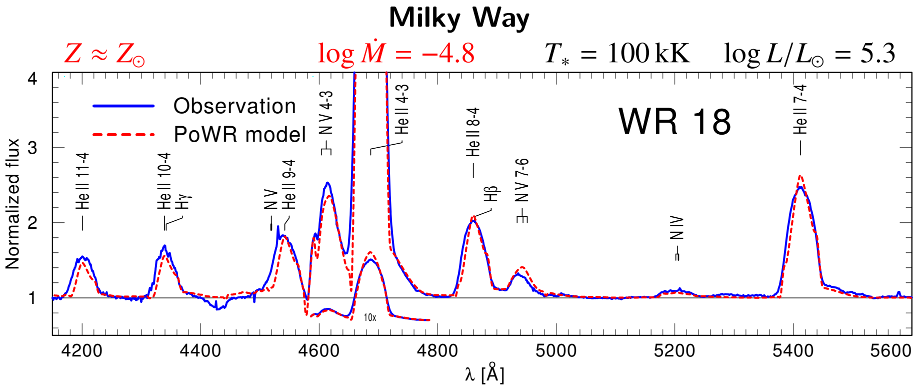
*WN model grids*

- Hamann & Gräfener: 2004, A&A 427, 697 (ADS)
- Todt, Sander, Hainich, Hamann, Quade, & Shenar: 2015, A&A 579, A75 (ADS)

*WC model grid*

- Sander, Hamann, & Todt: 2012, A&A 540, A144 (ADS)

# WN stars: Spectral characteristics at different $Z$




## Spectral analysis

**For each individual star find one model atmosphere which:**

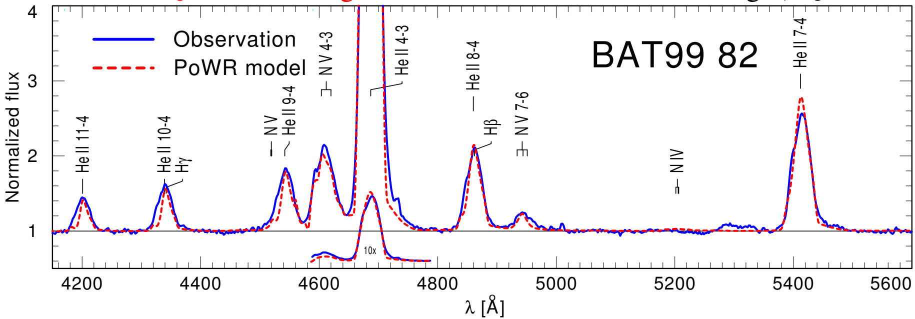
- reproduces the whole line spectrum & spectral energy distribution

⇒ comprehensive set of stellar parameters – $T_*$, $L$, $\dot{M}$, $v_\infty$, ...

# WN stars: Spectral characteristics at different $Z$

**Large Magellanic Cloud**

$Z \approx 0.5\,Z_\odot$   $\log \dot{M} = -5.2$   $T_* = 100\,\mathrm{kK}$   $\log L/L_\odot = 5.5$

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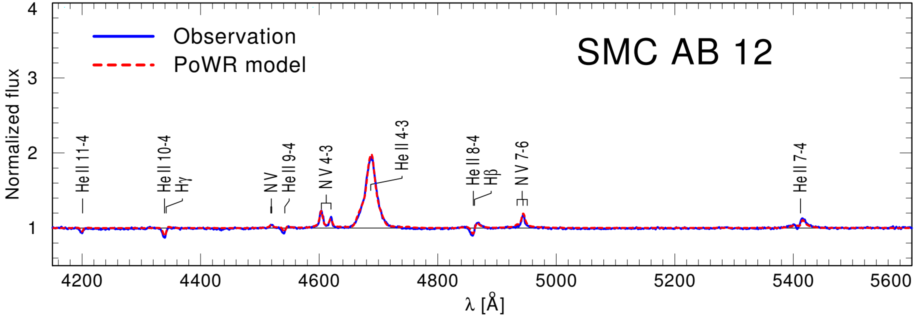
# WN stars: Spectral characteristics at different $Z$

**Small Magellanic Cloud**

$Z \approx 1/4 - 1/7\,Z_\odot$   $\log \dot{M} = -5.8$   $T_* = 112\,\mathrm{kK}$   $\log L/L_\odot = 5.9$

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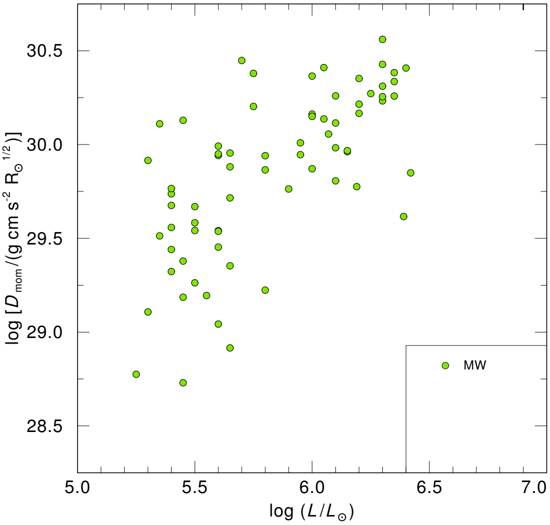
# Wind momentum luminosity relation

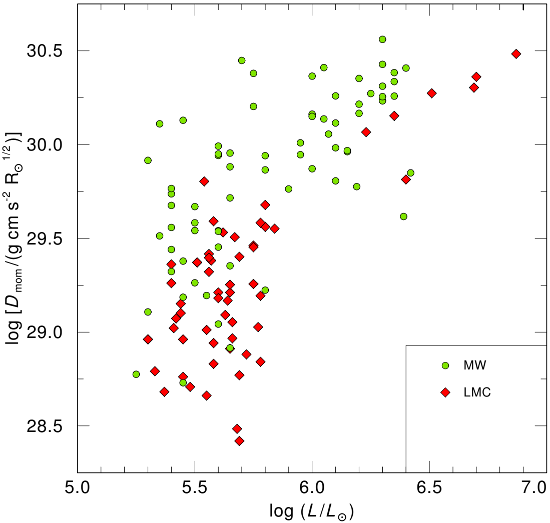



MW: Hamann et al. (2006), Martins et al. (2008), Liermann et al. (2010), Oskinova et al. (2013)

**Modified wind momentum:**

- $D_{\mathrm{mom}} = \dot{M} v_\infty R_*^{1/2}$
- $\dot{M} \propto Z^\alpha \Rightarrow D_{\mathrm{mom}} \propto Z^\alpha$

# Wind momentum luminosity relation

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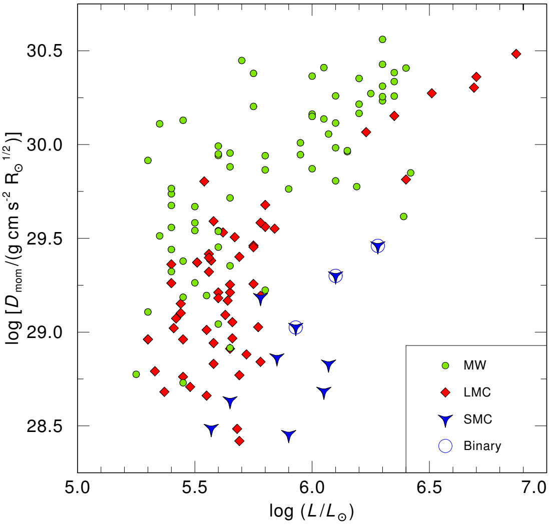


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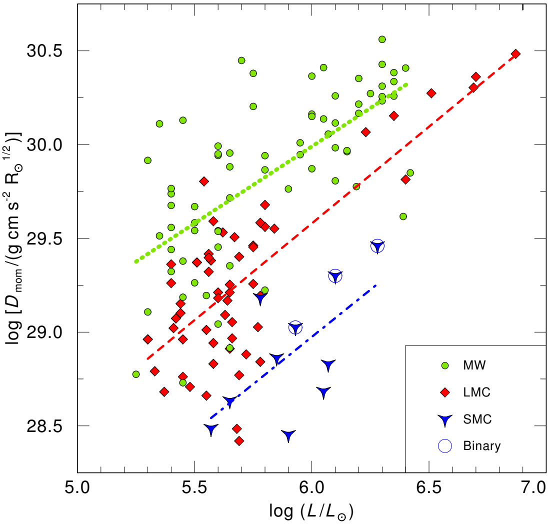


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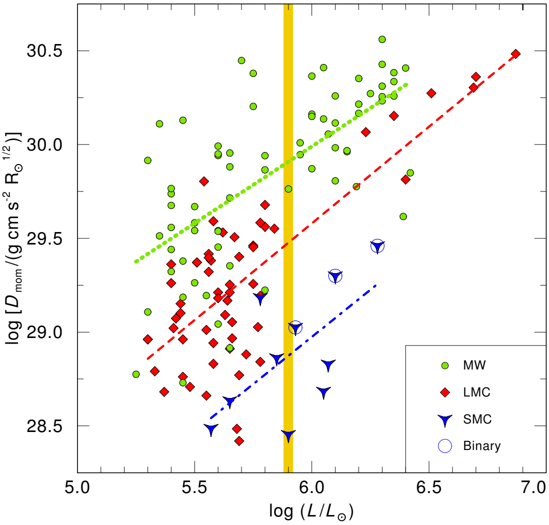
**Wind-momentum luminosity relations:** $D_{\text{mom}} = D_0 \cdot L^m$

- MW: $D_{\text{mom}} = 25.1 \cdot L^{0.8}$
- LMC: $D_{\text{mom}} = 23.4 \cdot L^{1.0}$
- SMC: $D_{\text{mom}} = 22.9 \cdot L^{1.0}$

$$\Rightarrow \alpha = \frac{\log D_0 + m \log(L/L_\odot)}{\log Z} + C$$

# Wind momentum luminosity relation

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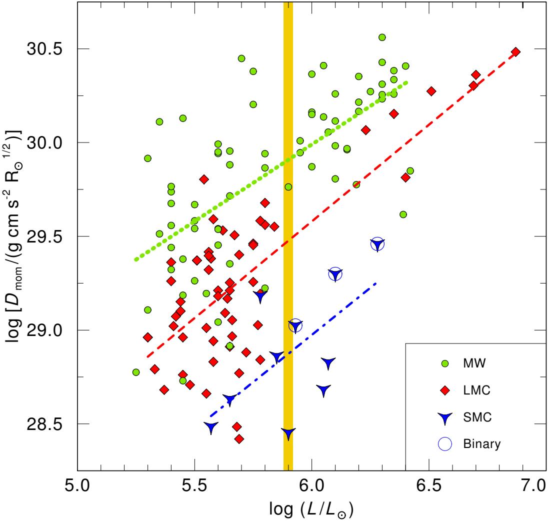


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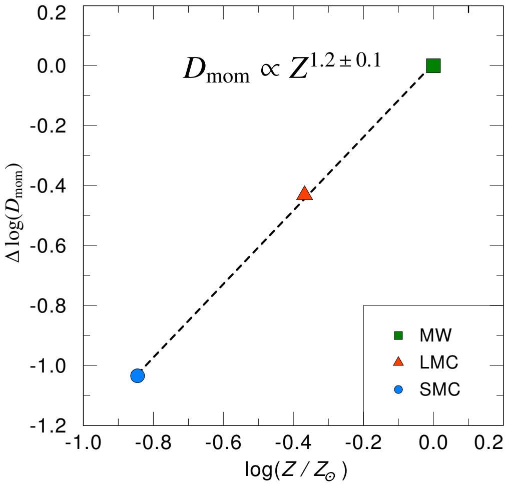
- evaluate at: $\log(L/L_\odot) = 5.9$
- or assume: $D_{mom} \propto L^{1.0}$

# $\dot{M}$-$Z$ relation for WN stars




**Mass-loss rate metallicity relation:**

$$\dot{M} \propto Z^{\alpha}$$

$$\alpha = 1.2 \pm 0.1$$

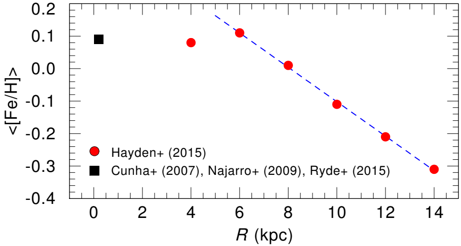
Hainich et al. (2015)

**Low $Z$ environments:**

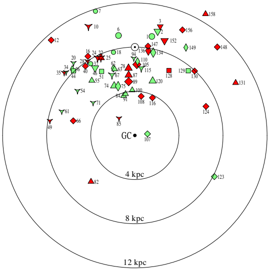
- less angular momentum loss
- higher SN progenitor masses
  $\Rightarrow$ larger black holes

# Galactic metallicity gradient

**Gradient of the $X_{\mathrm{Fe}}$ abundance:**




**Position of the MW WN stars:**




Hamann et al. (2006)
Rosslowe et al. (2014)

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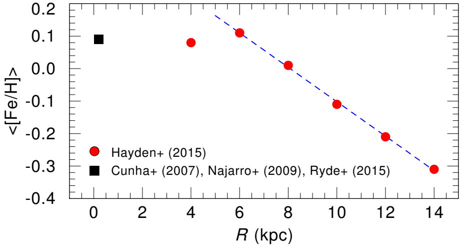
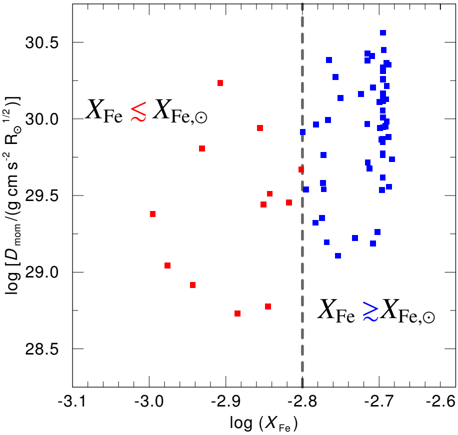



**Separate MW stars in two groups:**

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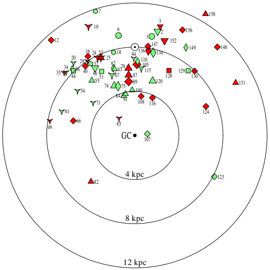


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# $\dot{M}$-$X_{\rm Fe}$ relation

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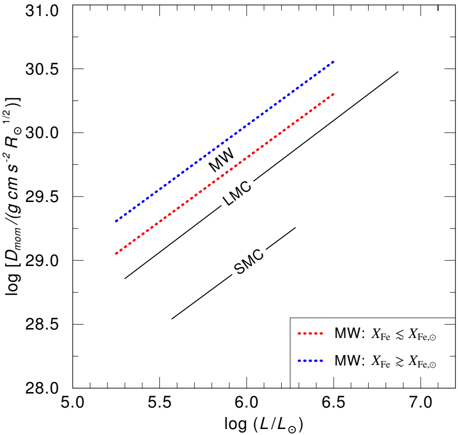


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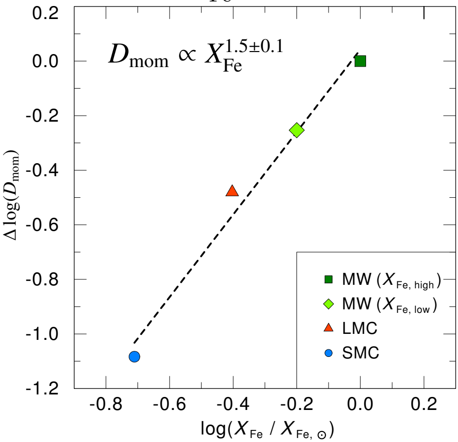
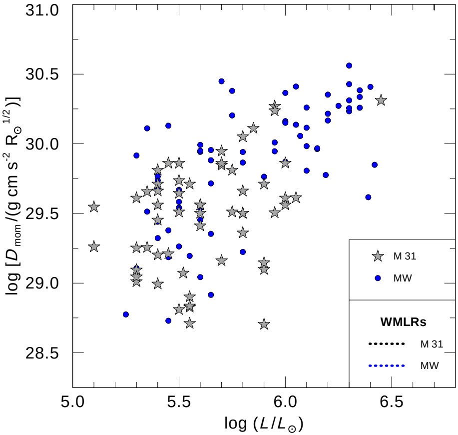



$$\dot{M} \propto X_{\rm Fe}^{1.5\pm0.1}$$

# M 31: Preliminary results



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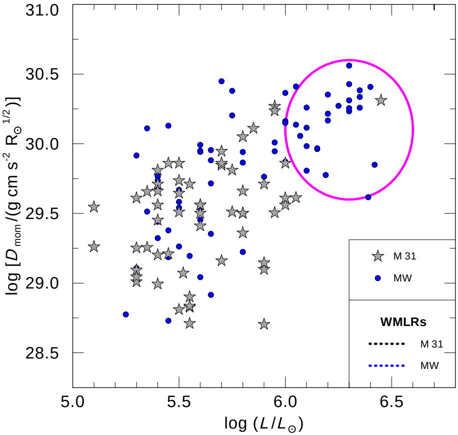


**Andromeda Galaxy:**

- very luminous WN stars are missing in M 31

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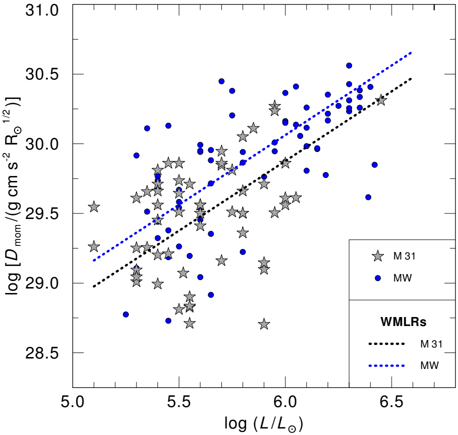


**Andromeda Galaxy:**

- very luminous WN stars are missing in M 31
- $\langle D_{\mathrm{mom}} \rangle$ lower than in the MW

- H II regions: super-solar $X_{\mathrm{O}}$
  - $X_{\mathrm{O}}/X_{\mathrm{O},\odot} \approx 1 \ldots 2$ (Sanders+ 2012, Zurita+ 2012)
- $X_{\mathrm{Fe}}/X_{\mathrm{Fe},\odot} \approx 1$ (Venn+ 2000, Chen+ 2016)

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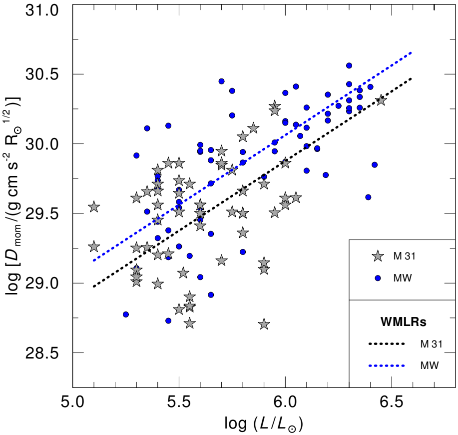


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- $X_{Fe} / X_{Fe,\odot} \approx 1$ (Venn+ 2000, Chen+ 2016)

**Spectral analysis reveals characteristic differences between the WN populations in M 31 and the MW**

# Summary:

## Sample

- WN populations in M 31, SMC, & LMC analyzed
  - all together more than 200 objects

## Metallicity dependence of the WN winds

- stronger dependence on metallicity and iron abundance than expected:
  - $\dot{M} \propto Z^{1.2}$ & $\dot{M} \propto X_{\mathrm{Fe}}^{1.5}$
- implications: less angular momentum loss and potentially higher BH masses at low metallicities

## Outlook

- corroboration by atmosphere models that account for hydrodynamics $\rightarrow$ talk by Andreas Sander