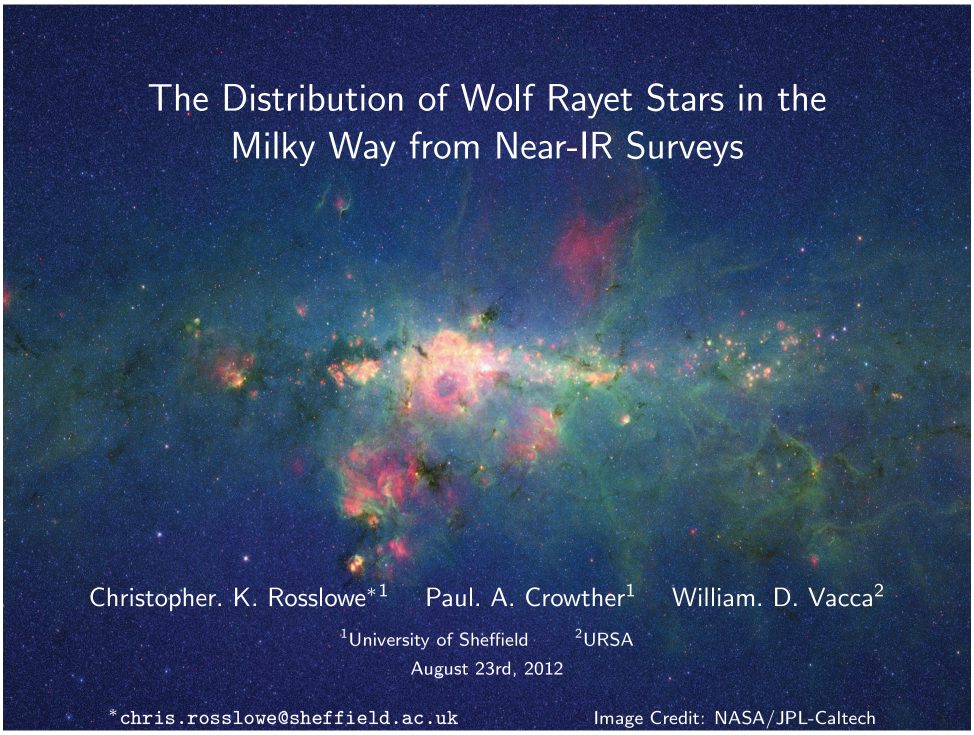

The Distribution of Wolf Rayet Stars in the Milky Way from Near-IR Surveys

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Image Credit: NASA/JPL-Caltech

Galactic Wolf-Rayet stars

1. Basic Properties

What are Wolf-Rayet stars?

- Evolved O-stars,
- Dense stellar winds
  →Strong emission line spectra,
- $log(T_{eff}/K) \gtrsim 4.5$,
  $log(L/L_{\odot}) \gtrsim 5$.

Why are they important?

- Tests of stellar evolution,
- Suspected pre-supernova Ib/c objects,
- Excellent tracers of star formation.

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Estimated ∼**6400** in the Milky Way
(Shara et al. 2009)

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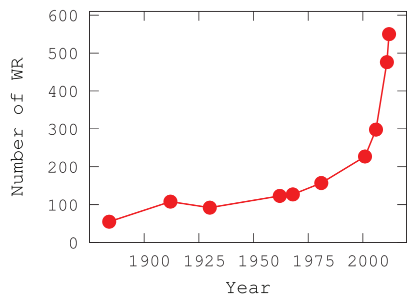
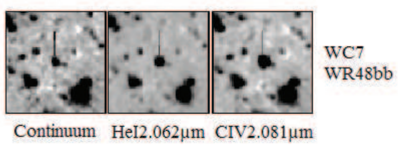


Galactic Wolf-Rayet stars

2. Discovery Methods

1. Narrow-band On/Off method



Homeier et al. (2003) → 4 new WR
Shara et al. (2009) → 41 new WR
Shara et al. (2012) → 71 new WR

Galactic Wolf-Rayet stars

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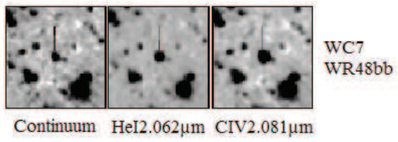

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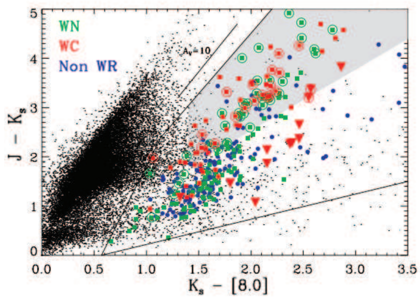
2. Broad-band colour method

Free-free e^- scattering in outer-wind.
→ Distinctive near-IR colours.

Hadfield et al. (2007) → 15 new WR
Mauerhan et al. (2009) → 12 new WR
Mauerhan et al. (2011) → 60 new WR



Galactic Wolf-Rayet stars

2. Discovery Methods

3. SERENDIPITOUS!

Counterparts to bright Radio or X-ray sources, Cluster census.

Clark & Negueruela (2002)
→ 11 WR in Westerlund 1
Mauerhan et al. (2010)
→ 15 WR Toward GC

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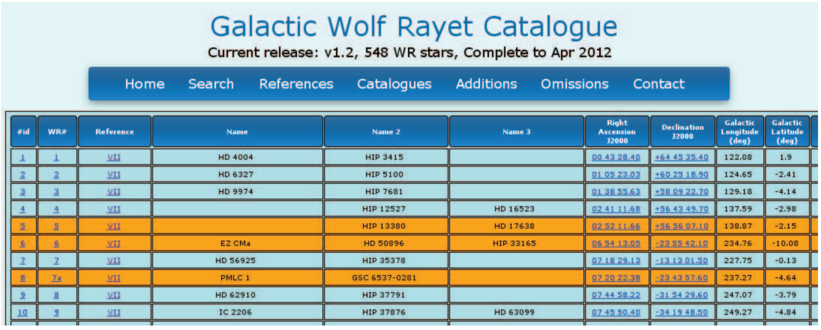
Updated Wolf-Rayet catalog:
`pacrowther.staff.shef.ac.uk/WRcat/`

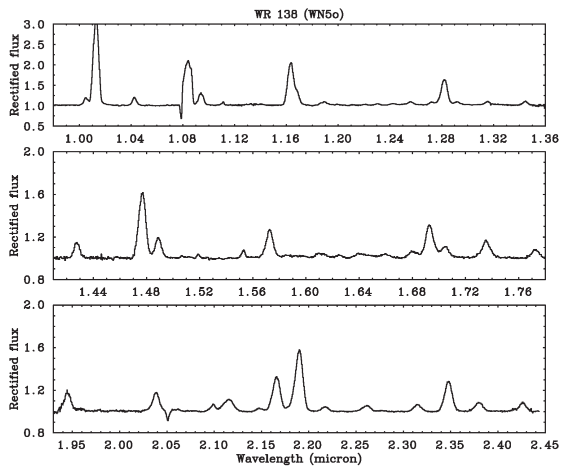


#id	WR#	Reference	Name	Name 2	Name 3	Right Ascension J2000	Declination J2000	Galactic Longitude (deg)	Galactic Latitude (deg)
1	1	VII	HD 4004	HIP 3415		00 43 28.40	+64 45 35.40	122.08	1.9
2	2	VII	HD 6327	HIP 5100		01 05 23.03	+60 25 18.90	124.65	-2.41
3	3	VII	HD 9974	HIP 7681		01 38 55.63	+58 09 22.70	129.18	-4.14
4	4	VII		HIP 12527	HD 16523	02 41 11.68	+56 43 49.70	137.59	-2.98
5	5	VII		HIP 13380	HD 17638	02 52 11.66	+56 56 07.10	138.87	-2.15
6	6	VII	EZ CMa	HD 50896	HIP 33165	06 54 13.05	-23 55 42.10	234.76	-10.08
7	7	VII	HD 56925	HIP 35378		07 18 29.13	-13 13 01.50	227.75	-0.13
8	7a	VII	PMLC 1	GSC 6537-0281		07 20 22.38	-23 43 57.60	237.27	-4.64
9	8	VII	HD 62910	HIP 37791		07 44 58.22	-31 54 29.60	247.07	-3.79
10	9	VII	IC 2206	HIP 37876	HD 63099	07 45 50.40	-34 19 48.50	249.27	-4.84

Wolf-Rayet Classification

Near-IR Wolf-Rayet Spectra

IRTF SpeX, 0.8-5.5μm, $R \sim$ 1000-2000 spectra of 29 Wolf-Rayets (WN, WC, WN/C, WO)



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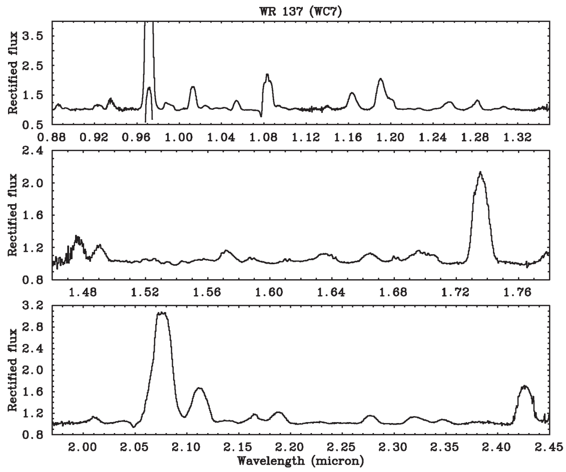

Wolf-Rayet Classification

A new quantitative near-IR scheme

WN

- Mapping to 3D optical classification of *Smith, Shara & Moffat (1996)*,
- Primary: HeII/HeI,
- Secondary: NIII, NIV, NV,
- JHKL
  → Exact 3D spectral type,
- Single band
  → JK:±1 H:±2
  L:WNE/WNL,
- Need J-band to identify presence of Hydrogen.

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WC

- Mapping to optical classifications of *Smith, Shara & Moffat (1990)* and *Crowther, De Marco & Barlow (1998)*,
- Primary: CIV/CIII, HeII/HeI,
- Secondary: CII, OIV, OV,
- JHKL
  → Exact spectral type,
- Single band
  → J:exact, K:±1,
  HL:WCE/WCL.

Absolute Magnitude Calibration

1. The Sample and Methods

- Revised spectral types for 83 and 22 Galactic WN and WC stars with measured distances,
  - 74 Cluster members,
  - 25 Association members,
  - 6 Field stars.

  Previously only 14 and 4 used by *Crowther et al. (2006)*
- J, H and K_s photometry taken mostly from 2*MASS* catalog,
- K_s-band extinction calculated from $(J - K_s)$ and $(H - K_s)$ colour excess, using intrinsic WR colours of *Crowther et al. (2006)*,
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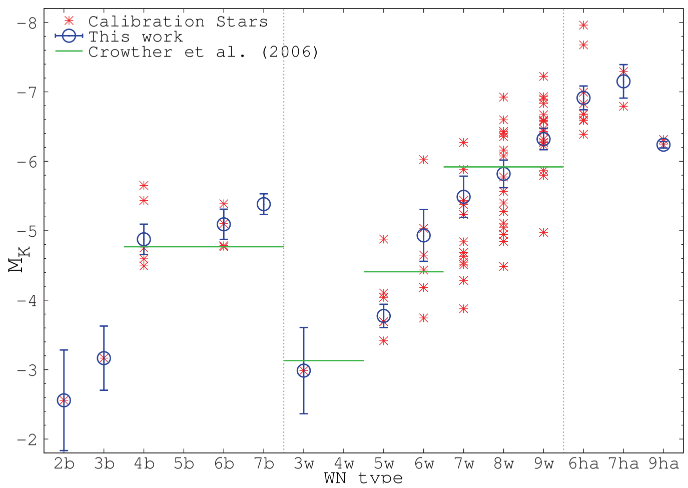
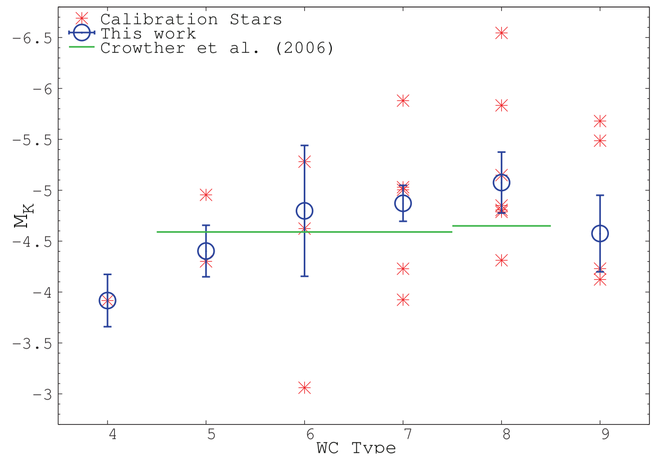
Absolute Magnitude Calibration

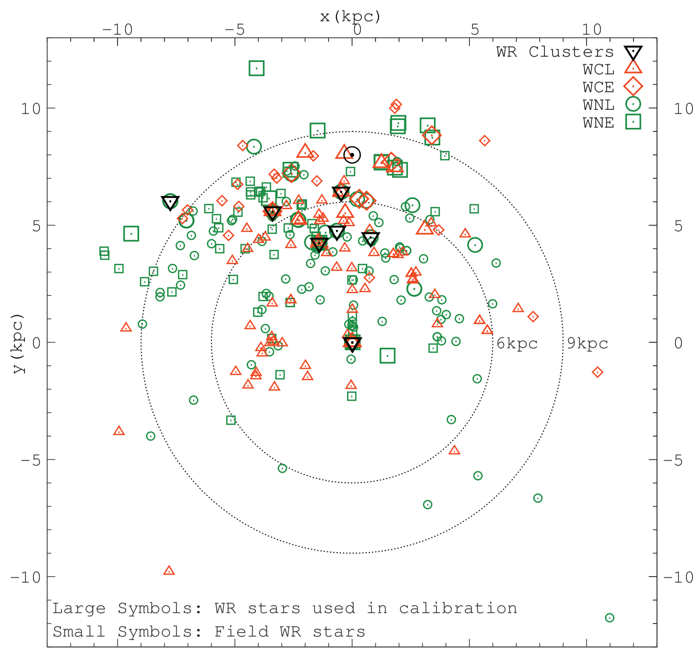
2. The Results: WN Stars

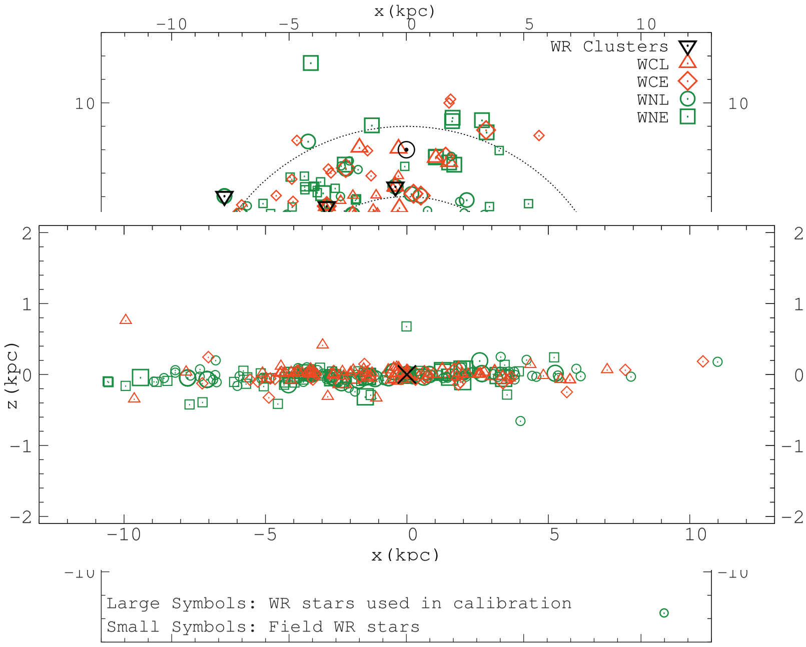


Absolute Magnitude Calibration

3. The Results: WC Stars







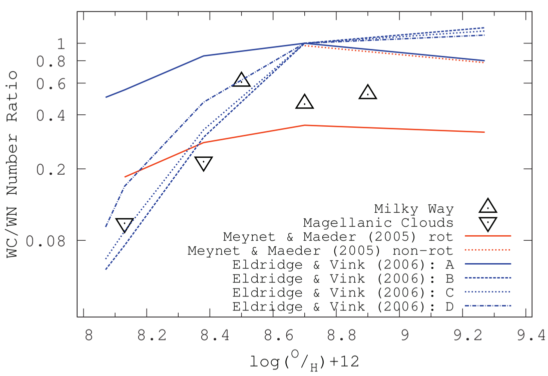
Wolf-Rayet Populations at Different Metallicities

Comparison to Stellar Evolution Models

Inner Galaxy,
$R_G < 6kpc$,
$\log(^O/_H) + 12 \simeq 8.9$
$N_{WC}{:}N_{WN} = 66{:}126$.

Solar neighbourhood,
$6kpc < R_G < 9kpc$,
$\log(^O/_H) + 12 \simeq 8.7$
$N_{WC}{:}N_{WN} = 35{:}76$.

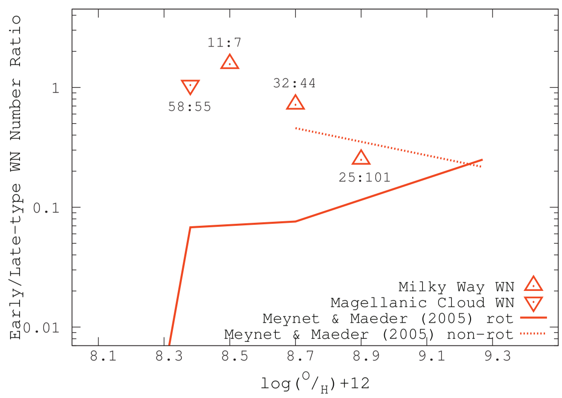
Outer Galaxy,
$R_G > 9kpc$,
$\log(^O/_H) + 12 \simeq 8.5$
$N_{WC}{:}N_{WN} = 11{:}18$.



Wolf-Rayet Populations at Different Metallicities

Comparison to Stellar Evolution Models

Early-type WN: H-free + WN2–6(s),
Late-type WN: H-rich or WN6(w)–9.

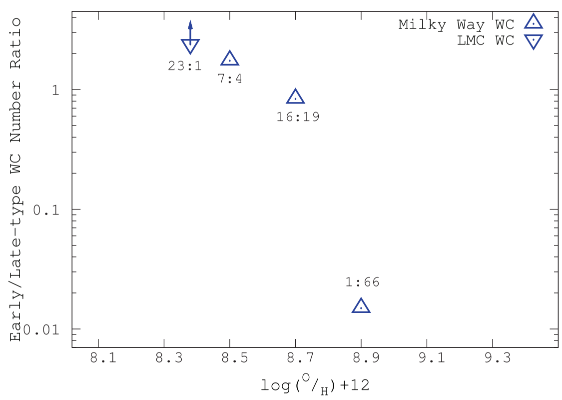


Wolf-Rayet Populations at Different Metallicities

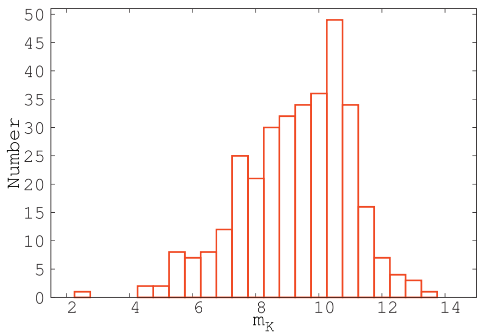
Comparison to Stellar Evolution Models

Early-type WN: H-free + WN2–6(s),
Late-type WN: H-rich or WN6(w)–9.

Early-type WC: 4–6,
Late-type WC: 7–9.



Hidden Galactic Wolf-Rayet Population



m_K distribution of 332 Galactic WR stars

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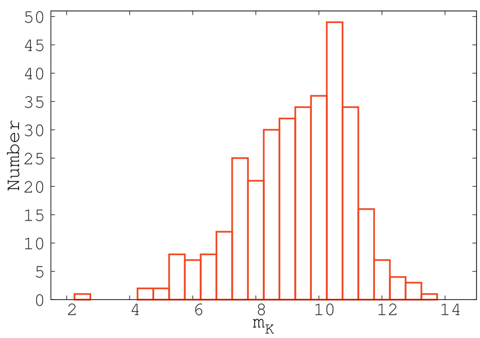
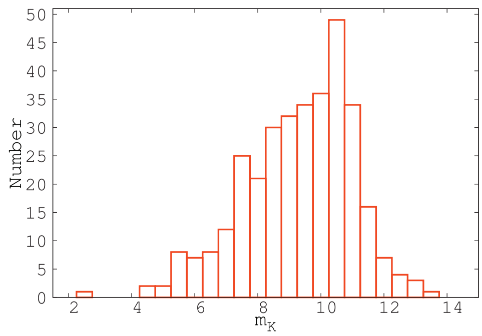


m_K distribution of 332 Galactic WR stars

Far side of the Galaxy:
$\rightarrow$ $D \sim 18kpc$,
$|l| < 10^\circ$ & $b \sim 0^\circ$,
$A_K \sim 3mag$

Hidden Galactic Wolf-Rayet Population



m_K distribution of 332 Galactic WR stars

Far side of the Galaxy:
$\rightarrow$ $D \sim 18 kpc$,
$|l| < 10^\circ$ & $b \sim 0^\circ$,
$A_K \sim 3 mag$

WNE($M_K \simeq -3$): $m_K \simeq 16$.
WC($M_K \simeq -5$): $m_K \simeq 14$.
WNL($M_K \simeq -6$): $m_K \simeq 13$.

Need spectroscopic follow-up of candidates down to 16th K-magnitude

Summary & Conclusions

- Improved near-IR classification scheme based on 0.8–5.5μm IRTF SpeX spectra,
- Revision of obscured WR spectral types $\rightarrow$ M_{JHK}–Subtype calibration (5× more stars than *Crowther et al. (2006)*),
- Distribution throughout Milky Way $\rightarrow$ reasonably well sampled over range of metallicities,
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