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SpS 5: The IR view of Massive Stars

The spectra of Wolf-Rayet stars in the IR

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The Galactic Center region

HST + *Spitzer* color composite

Arches Cluster (

Quintuplet Cluster

30 p

- Many massive stars
- Distance 8 kpc
- Visually obscured
 - $A_V = 27 \text{ mag}$
- Near-IR extinction
 A_k = 3 mag

The Galactic Center region

HST + *Spitzer* color composite





- Many massive stars
- Distance 8 kpc
- Visually obscured A_v = 27 mag
 Near-IR extinction

 $A_{K} = 3 \text{ mag}$

The Potsdam Wolf-Rayet (PoWR) model atmosphere code

- Non-LTE with complex model atoms
- Spherical stellar winds
- Full comoving-frame radiative transfer
- Transition to static photospheres
- Pressure broadening
- Iron line blanketing
- Microclumping
- Applicable for any hot stars (WR, O, B, CSPN ...)
- Non-standard options:
 - Macro-clumping
 - Consistent hydrodynamic solution

Comparable codes:

- CMFGEN (Hillier)
- Fastwind (Puls et al,)



Models can be downloaded from the PoWR web interface: http://www.astro.physik.uni-potsdam.de/PoWR

Potsdam Wolf-Rayet (PoWR) models WEB interface

http://www.astro.physik.uni-potsdam.de/PoWR

WNE grid: • = existing models select grid 03-04 04-04 05-04 06-04 07-04 08-04 09-04 10-04 11-04 12-04 13-04 14-04 15-04 16-04 17-04 18-04 19-04 select model 03_05 04_05 05_05 06_05 07_05 08_05 09_05 10_05 11_05 12_05 13_05 14_05 15_05 16_05 17_05 18_05 19_05 03_06 04_06 05_06 06_06 07_06 08_06 09_06 10_06 11_06 12_06 13_06 14_06 15_06 16_06 17_06 18_06 19_06 1.5 03_07 04_07 05_07 06_07 07_07 08_07 09_07 10_07 11_07 12_07 13_07 14_07 15_07 16_07 17_07 18_07 19_07 (sensitive map) 03-08 04-08 05-08 06-08 07-08 08-08 09-08 10-08 11-08 12-08 13-08 14-08 15-08 16-08 17-08 18-08 19-08 03_09 04_09 05_09 06_09 07_09 08_09 09_09 10_09 11_09 12_09 13_09 14_09 15_09 16_09 17_09 18_09 19_09 03-10 04-10 05-10 06-10 07-10 08-10 09-10 10-10 11-10 12-10 13-10 14-10 15-10 16-10 17-10 18-10 19-10 view model 03-11 04-11 05-11 06-11 07-11 08-11 09-11 10-11 11-11 12-11 13-11 14-11 15-11 16-11 17-11 18-11 19-11 _ ℃ 1.0 03-12 04_12 05_12 06_12 07_12 08_12 09_12 10_12 11_12 12_12 13_12 14_12 15_12 16_12 17_12 18-12 19-12 റ് 03-13 04_13 05_13 06_13 07_13 08_13 09_13 10_13 11_13 12_13 13_13 14_13 15_13 16_13 17_13 18_13 19-13 parameters log 03-14 04_14 05_14 06_14 07_14 08_14 09_14 10_14 11_14 12_14 13_14 14_14 15_14 16_14 17_14 18_14 19-14 03-15 04-15 05-15 06-15 07-15 08-15 09-15 10-15 11-15 12-15 13-15 14-15 15-15 16-15 17-15 18-15 19-15 16 07-16 08-16 09-16 10-16 11-16 12-16 13-16 14-16 15-16 16-16 17-16 18-16 19-16 FUNDAMENTAL PARAMETERS 17 07-17 08-17 09-17 10-17 11-17 12-17 13-17 14-17 15-17 16-17 17-17 18-17 19-17 _____ 18 07_18 08_18 09_18 10_18 11_18 12_18 13_18 14_18 15_18 16_18 17_18 18_18 19-18 MODEL START 04/04/03 13:52:12 63096/1.0D/1600 L=5.3 N=1.5% C=1E-4 Fe=1.4E-3 D4 WN-NODIEL 09-11 19 07-19 08-19 09-19 10-19 11-19 12-19 13-19 14-19 15-19 16-19 17-19 18-19 19-19 19-19 20 07-20 08-20 09-20 10-20 11-20 12-20 13-20 14-20 15-20 16-20 17-20 18-20 19-20 TEFF 63096 K LOG L 5.300 L_SUN (INPUT) 21 07-21 08-21 09-21 10-21 11-21 12-21 13-21 14-21 15-21 16-21 17-21 18-21 19-21 (CALCULATED FROM LUMINOSITY) RSTAR 3.748 R SUN M-DOT = -5.134 DEX, IN M SUN/YR (CALCULATED FROM RTRANS) RTRANS = 10.000= 1.000 DEX(INPUT) 4.7 4.8 4.9 5.05.1 5.2 5.3VFINAL = 1600 KM/S 100 KM/S VDOP $\log T_{*}$ [K] * DENSCON = 4.00 **FILLFAC** =0.2500 LOG G 4.40 [CGS] CALCULATED FROM: MASS-LUMINOSITY RELATION FOR TYPE = WN MASS = 13.02 M SUN* RMAX = 266.78 RSTAR = 1000.00 R SUN

PoWR models on the WEB (continued)

Model data (for preview or download):

Spectral Energy Distribution

- line spectrum (normalized)
- line spectrum (calibrated)
 - select spectral range
 - with line identification?

New models (Aug. 2012): model atoms extended for better coverage of near-IR bands



Analyzing WR stars from their K-band spectra

Example: WR 120bb, a new WN star in the Scutum-Crux arm (Burgemeister et al., to be submitted)

- Subtype WN9, T_{*} = 63 kK, dense wind
- Problem: no pronounced He II lines in the K-band \rightarrow T_{*} ?



... but there a a couple of Hell lines in the J and H band



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Quintuplet: K-band integral-field spectroscopy (SINFONI)



Colliding stellar winds

- Close binary systems
- Both stars with stellar wind, e.g. WR + O

from P. Tuthill

- Formation of a shock cone
- Emission of (relatively hard) X-rays
- Non-thermal radio emission
- Only in WC9: formation of dust



Interacting Binary Wind Model





Colliding stellar winde

- Close binary syst
- Both stars with st
- Formation of a sh ightarrow
- Emission of (rela
- Non-thermal radi
- Only in WC-late: ightarrow

Interacting Binary Wind Mo

of Spiral Outflow Around WI

Rotation Axis

WR Star

OB Star

Shock Fro



from P. Tuthill

Outflow primarily in plane of binary orbit

To Observer

Shock

WR star spectra in the mid-IR: Spitzer observations

Example: our observational program on Spitzer spectroscopy of 2 WN stars near the GC





Infrared Space Observatory SPITZER

Galactic Center region(false color image from IR)

WRstars in mid-IR: stellar spectra, or circumstellar dust



WR 6 (WN4): Model SED (red) predicts perfectly the *Spitzer* measurement



WR102ka (WN10) near GC:
Circumstellar dust emission;
Compact, dusty H II region due to dense environment,
or previous mass ejection ?
Extremely high luminosity!
→ initial mass 150 ... 200 M_☉
(Barniske et al. 2008)

The Peony Nebula around WR 102ka



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Mid-IR nebular spectrum

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Warm dust (100...200K) → Continuum, SiC, PAH (?)

H II region

→ forbidden lines, HI

Photodissociation region (PDR): \rightarrow molecular hydrogen (H₂)

| | WR 102ka | WR 102c |
|---------------------------------|--------------------|-------------------|
| H II region: | | |
| lonized gas | $> 5 M_{\odot}$ | $> 10 M_{\odot}$ |
| Radius | 0.66pc | 0.66pc |
| Photodissociation Region (PDR): | | |
| H_2 mass | $> 0.8 M_{\odot}$ | $> 0.7~M_{\odot}$ |
| Dust shell: | | |
| Warm dust mass | $0.005M_{\odot}$ | $0.08M_{\odot}$ |
| Inner radius | 0.06 pc | 0.07 pc |
| Outer radius | 0.4 pc | 0.4 pc |

Dusty Nebulae around WR stars

- an efficient method to discover new WN stars
 e.g. Gvaramadze et al. (2010), Wachter et al. (2010)
- brightest at 24 μ m, invisible at 3.4 μ m and radio
- often nearly spherical
- *Fig.:* Two interacting circumstellar shells (Burgemeister et al., to be submitted)

Circles: WR 102bb and WR 102bc (both WN9); squares: WC8, O-type



Dusty nebulae around LBV stars

- Circular shells are also found around LBVs
- Are such shells around WN stars indicating a former LBV phase?

Fig.: LBV candidate WS2 and its circular shell Gvaramadze et al. (2012)





Summary

- IR observations revealed many new Galactic WR stars
 - 398 in 2006 (van der Hucht 2006)
 - 476 in 2011 (Mauerhan et al. 2011)
- Strongly absorbed WR stars (A $_{\rm V}$ ~ 30 mag) are observable best in the K-band
- K-band spectra are sufficient for an analysis, but J and H bands are desirable for precision
- For a few stars, even the K-band spectra are dustdominated (all WC9+O pinwheels?)
- Mid-IR spectra of many WR stars are dominated by emission from circumstellar warm dust