SpS 5: The IR view of Massive Stars

The spectra of Wolf-Rayet stars in the IR

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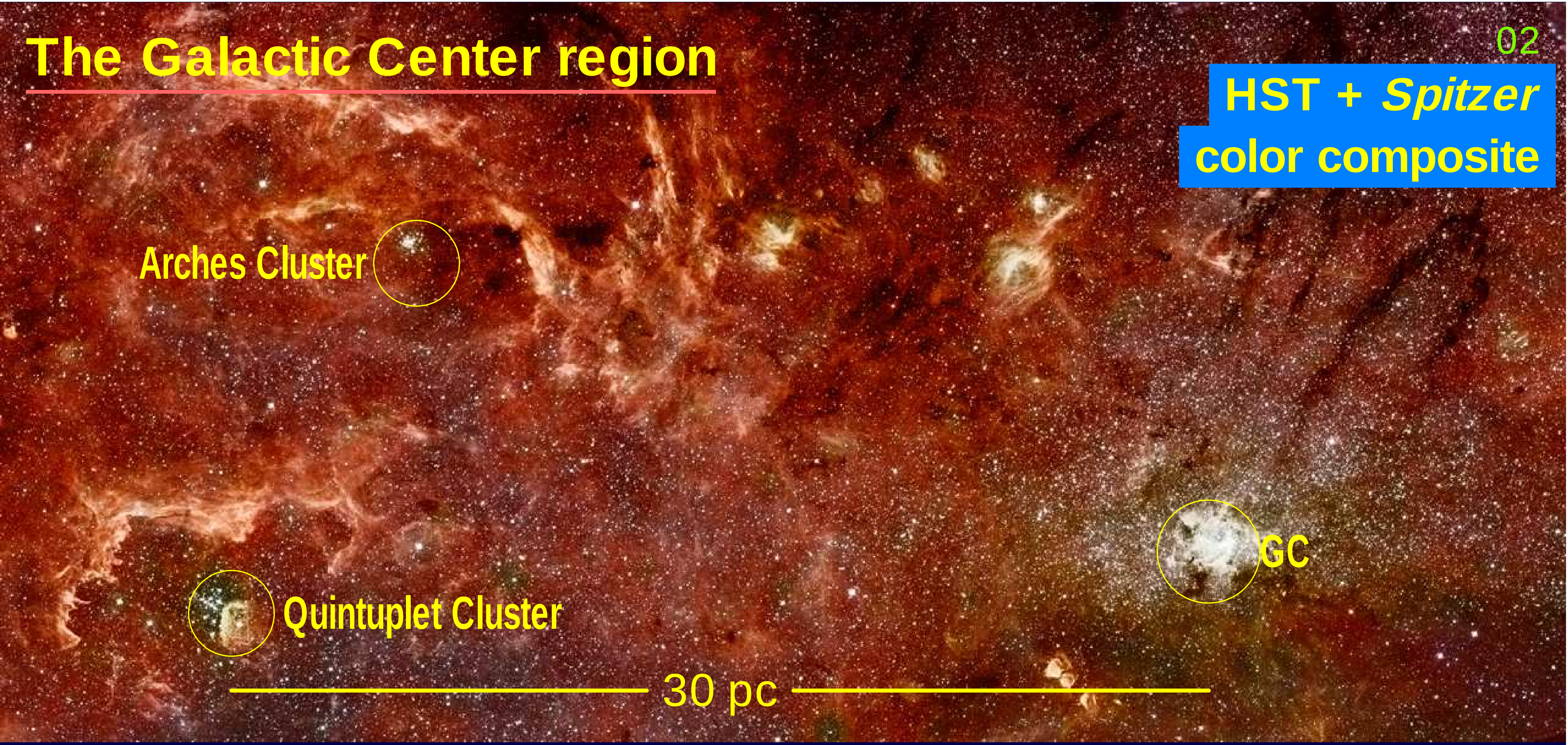
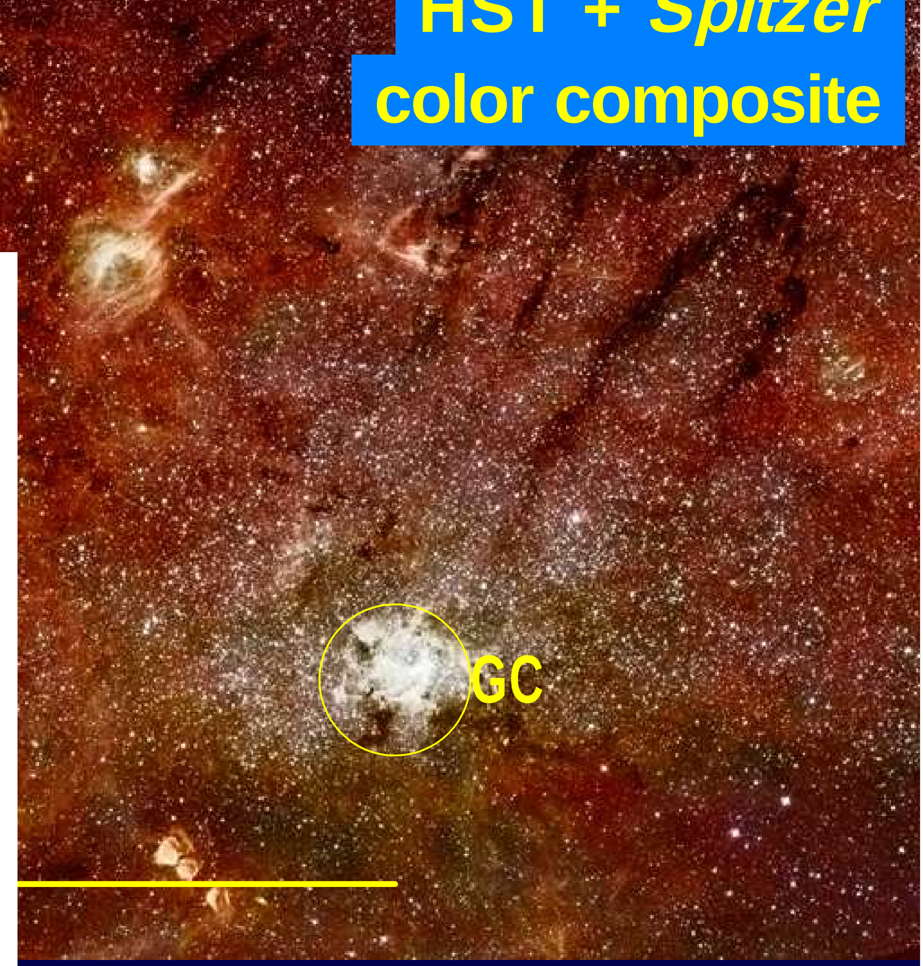
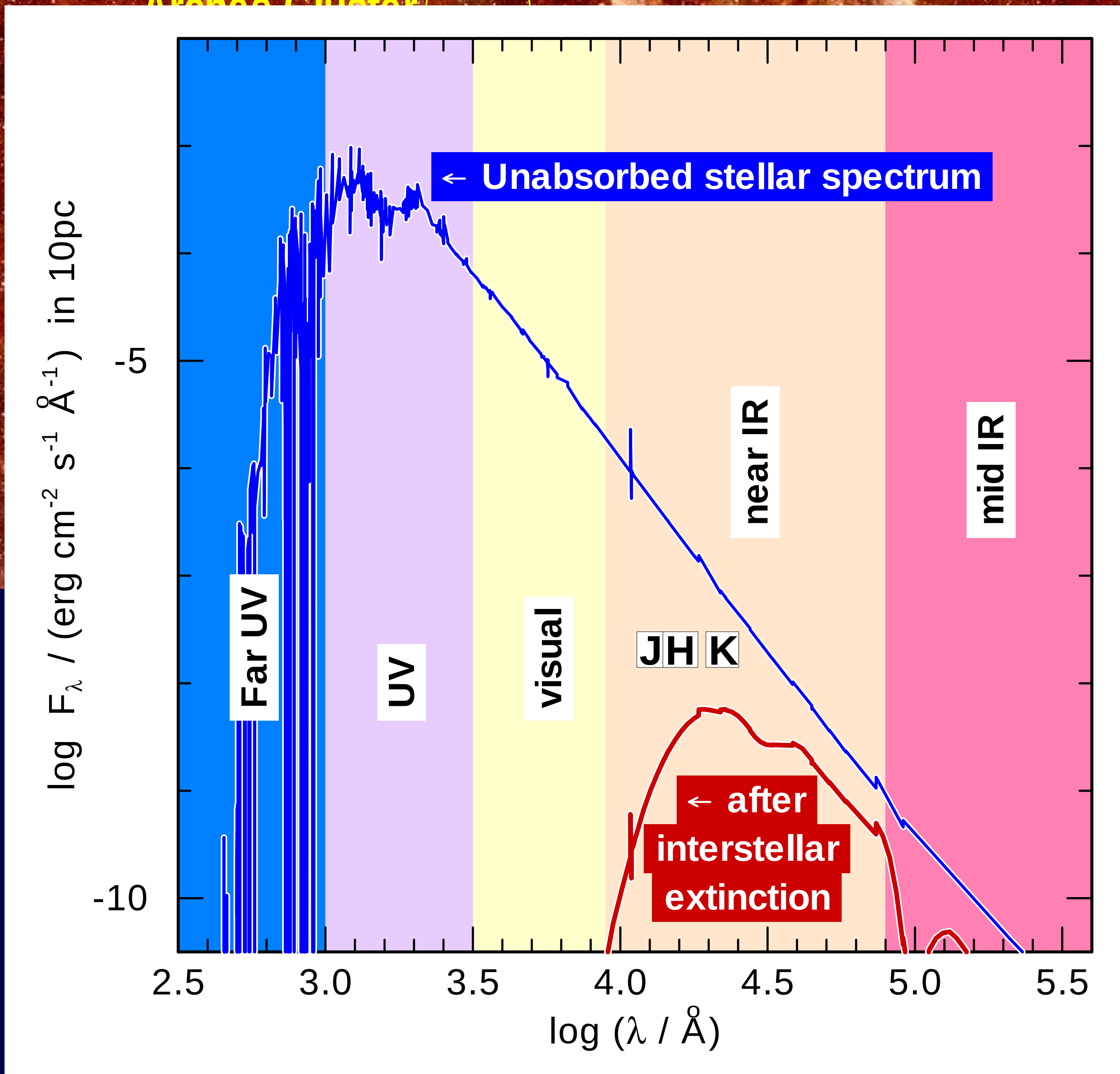
The Galactic Center region



- Many massive stars
- Distance 8 kpc
- Visually obscured
  $A_V = 27$ mag
- Near-IR extinction
  $A_K = 3$ mag

The Galactic Center region





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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:

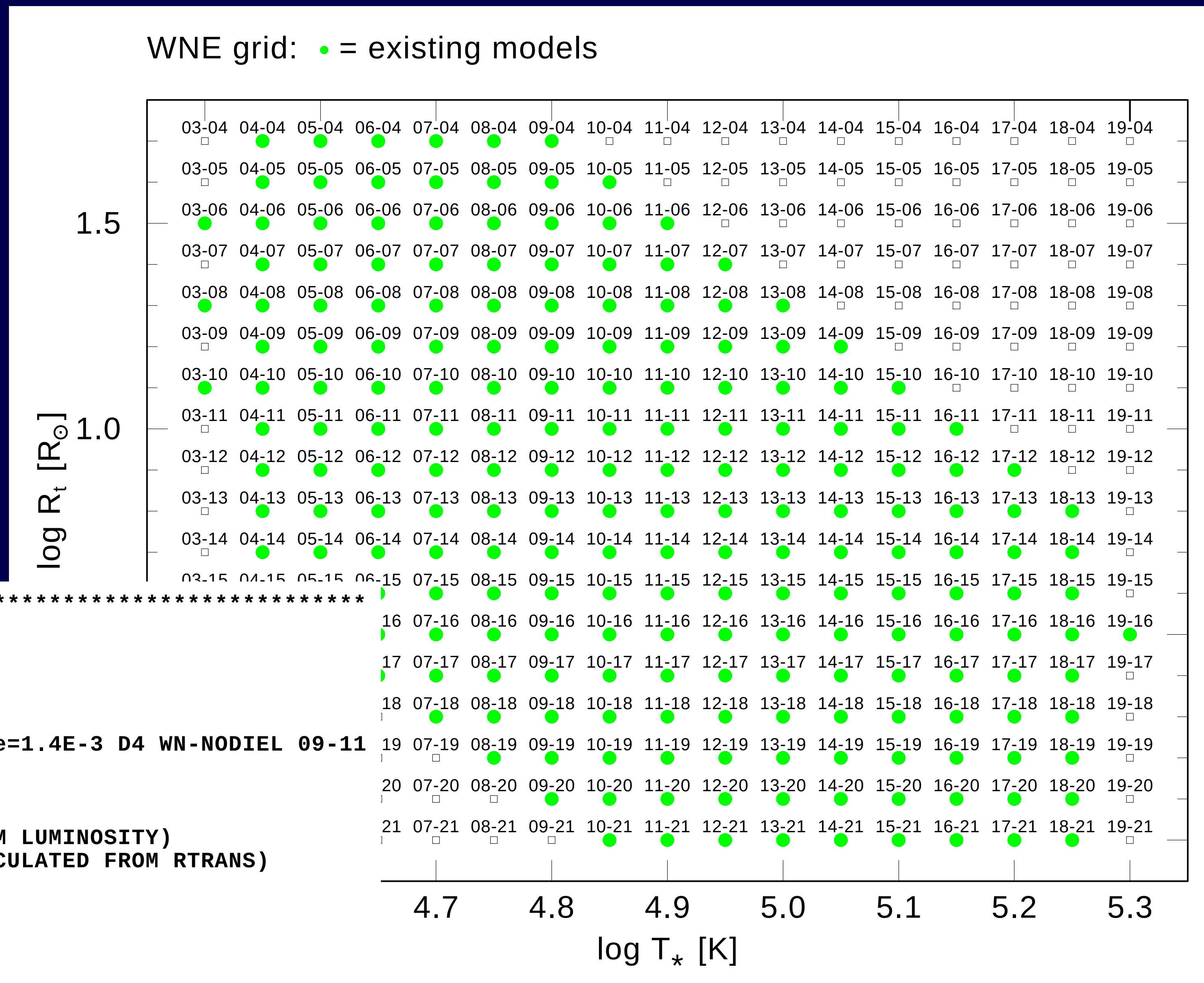
`http://www.astro.physik.uni-potsdam.de/PoWR`

Potsdam Wolf-Rayet (PoWR) models WEB interface

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

- select grid
- select model
  (sensitive map)

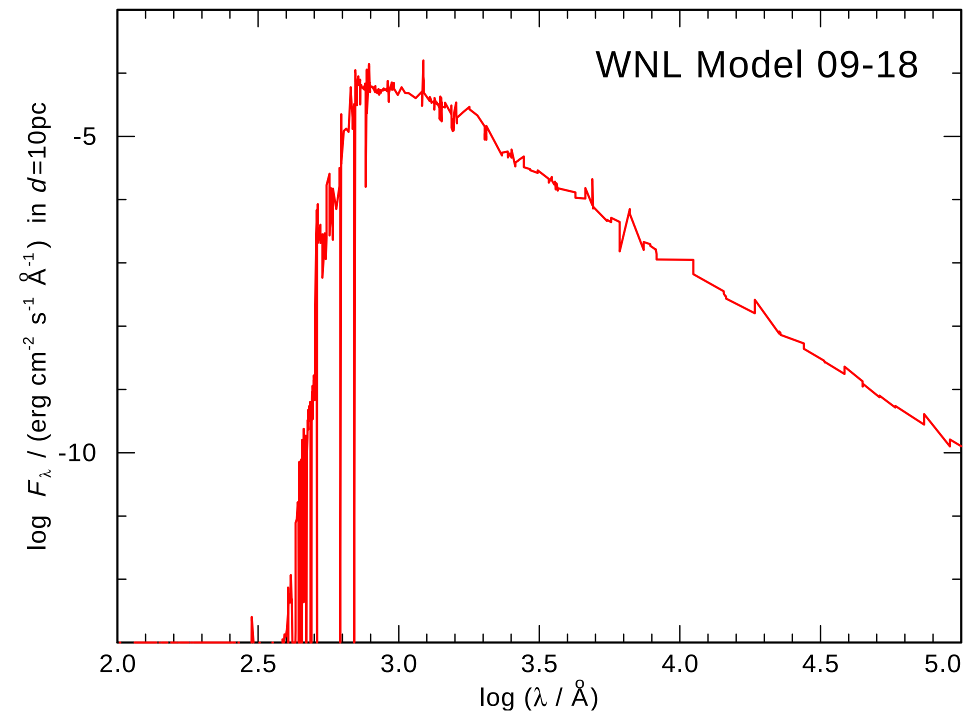
- view model
  parameters



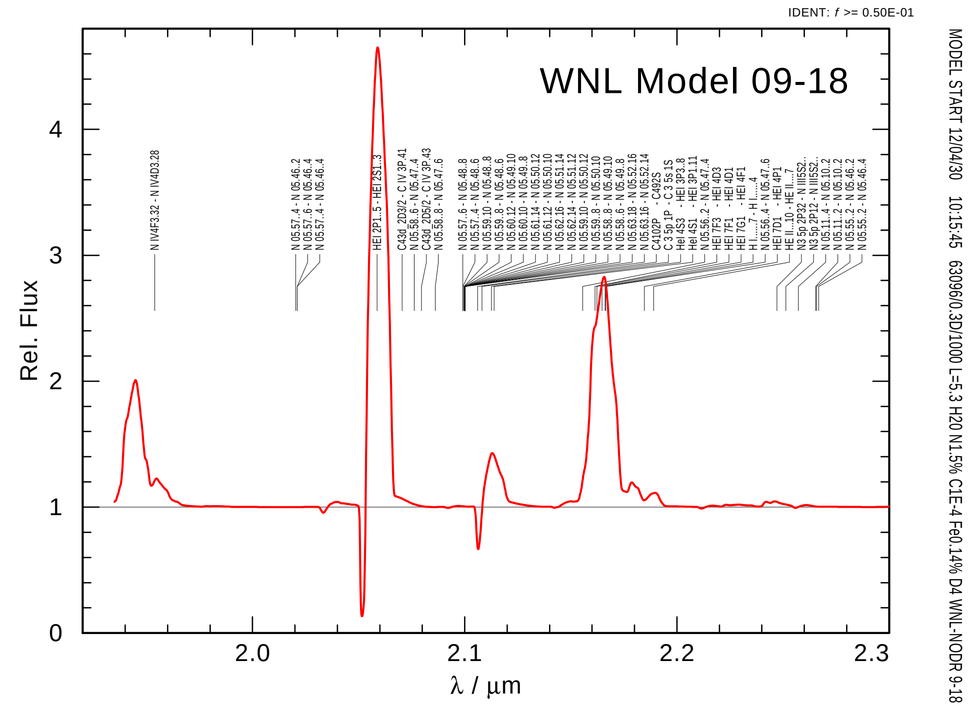

```
**********************************************************************
*
* FUNDAMENTAL PARAMETERS
* ======================
*
* MODEL START   04/04/03  13:52:12
*    63096/1.0D/1600 L=5.3 N=1.5% C=1E-4 Fe=1.4E-3 D4 WN-NODIEL 09-11
*
* TEFF     =  63096 K
* LOG L    =  5.300 L_SUN   (INPUT)
* RSTAR    =  3.748 R_SUN   (CALCULATED FROM LUMINOSITY)
* M-DOT    = -5.134 DEX, IN M_SUN/YR   (CALCULATED FROM RTRANS)
* RTRANS   = 10.000  = 1.000 DEX   (INPUT)
* VFINAL   =   1600 KM/S
* VDOP     =    100 KM/S
* 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



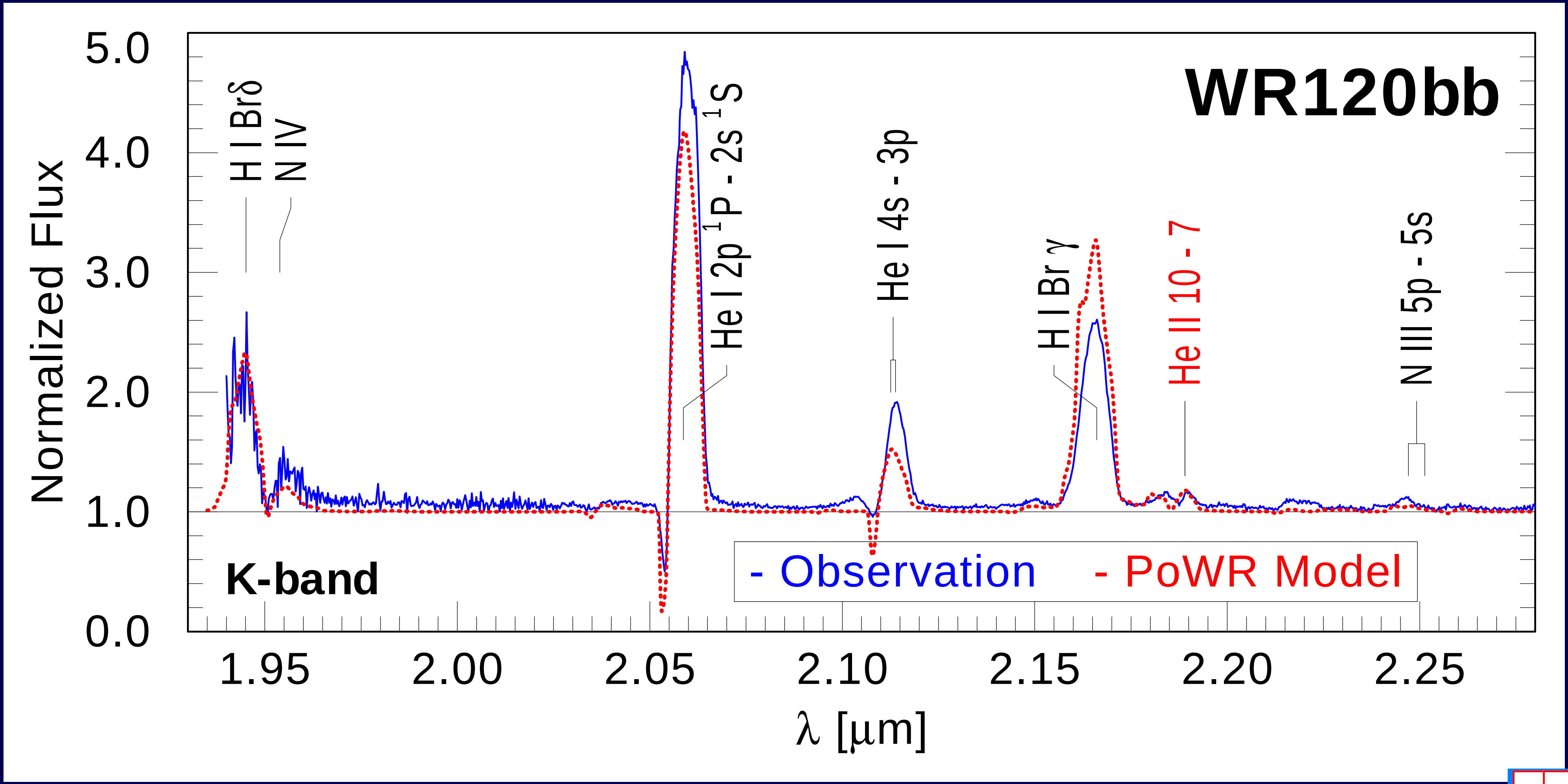
- line spectrum (normalized)
- line spectrum (calibrated)
  - select spectral range
  - with line identification?

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

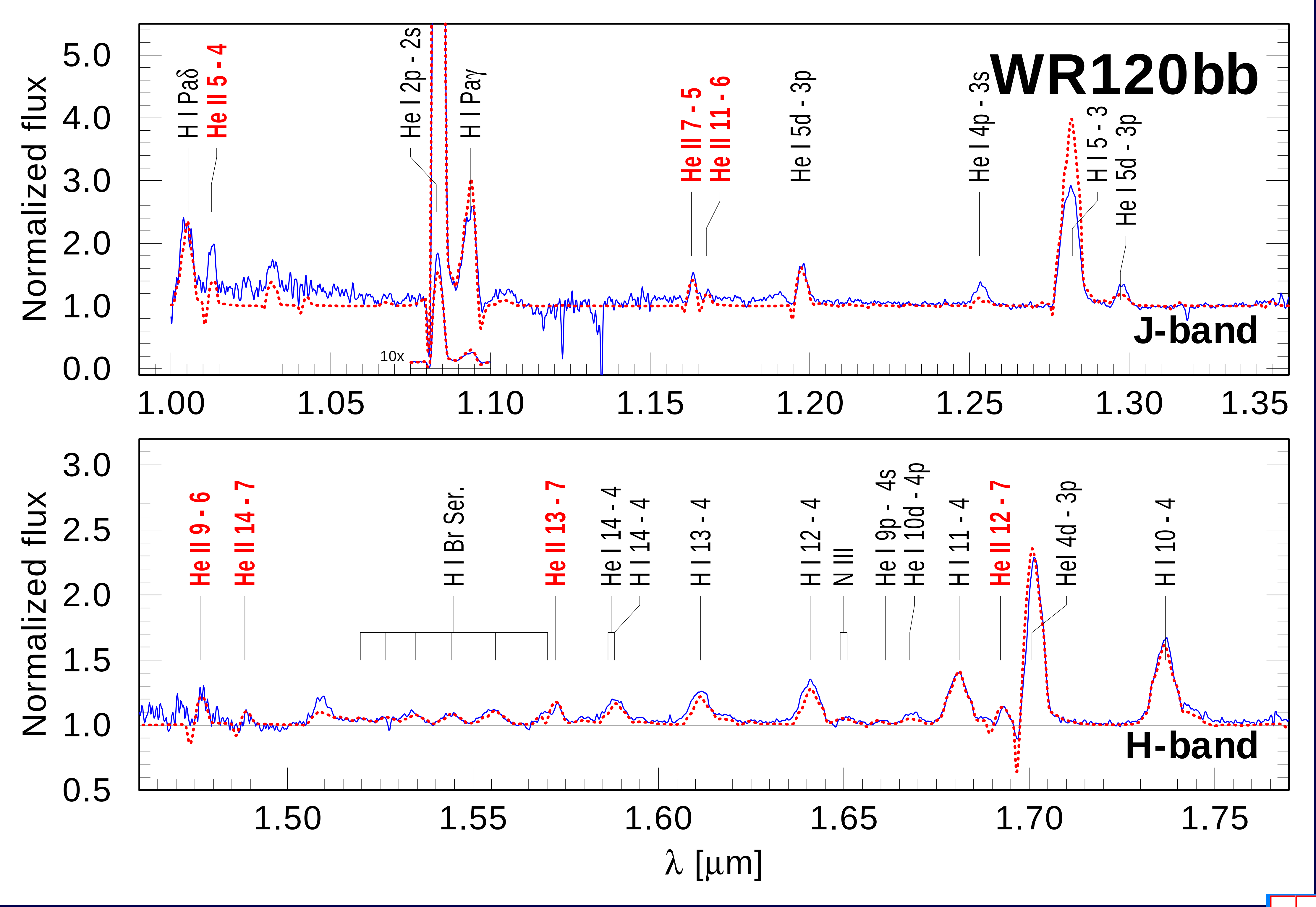
Analyzing WR stars from their K-band spectra

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

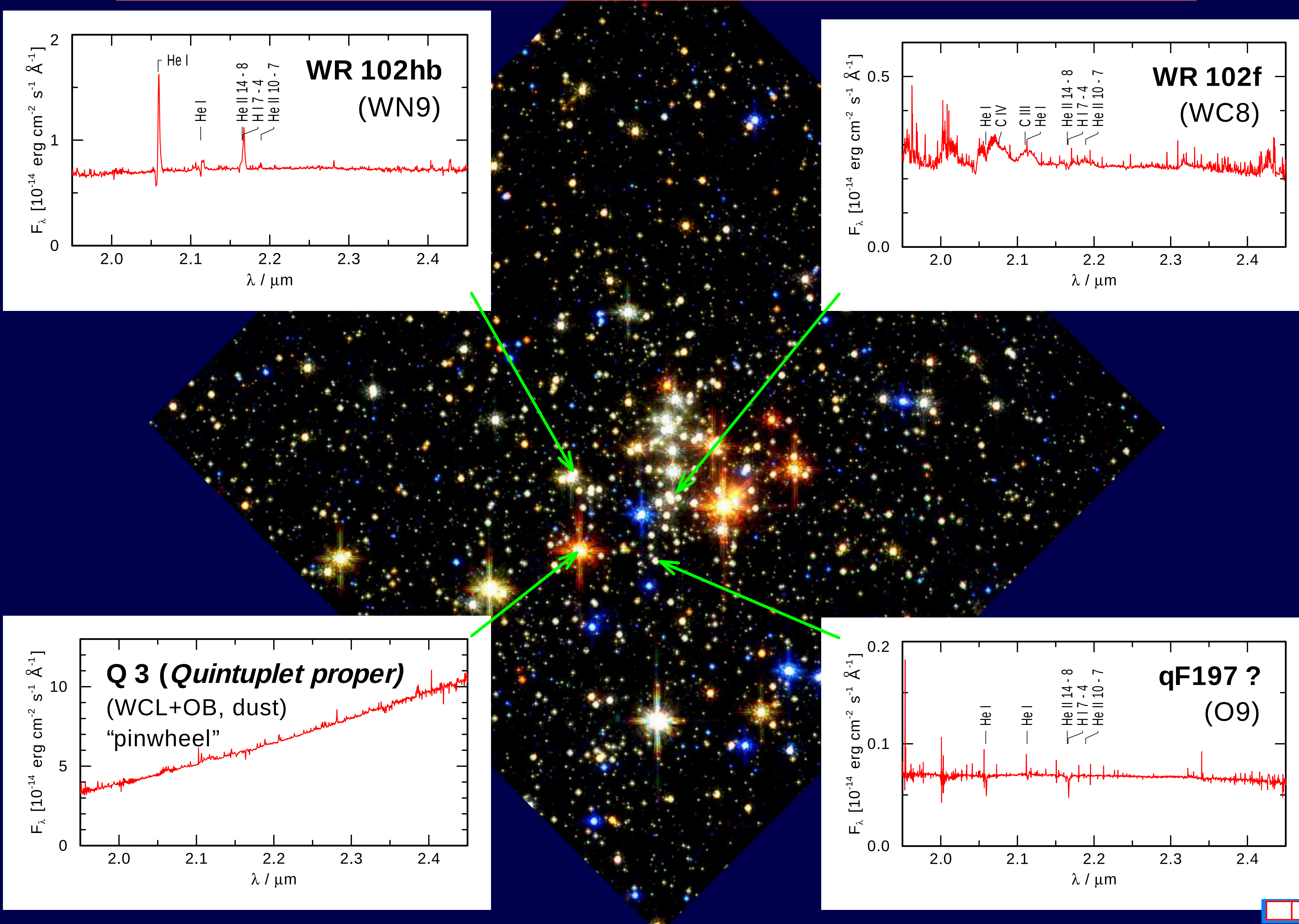
- Subtype WN9, $T_* = 63$ kK, dense wind
- Problem: no pronounced He II lines in the K-band → T_* ?



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

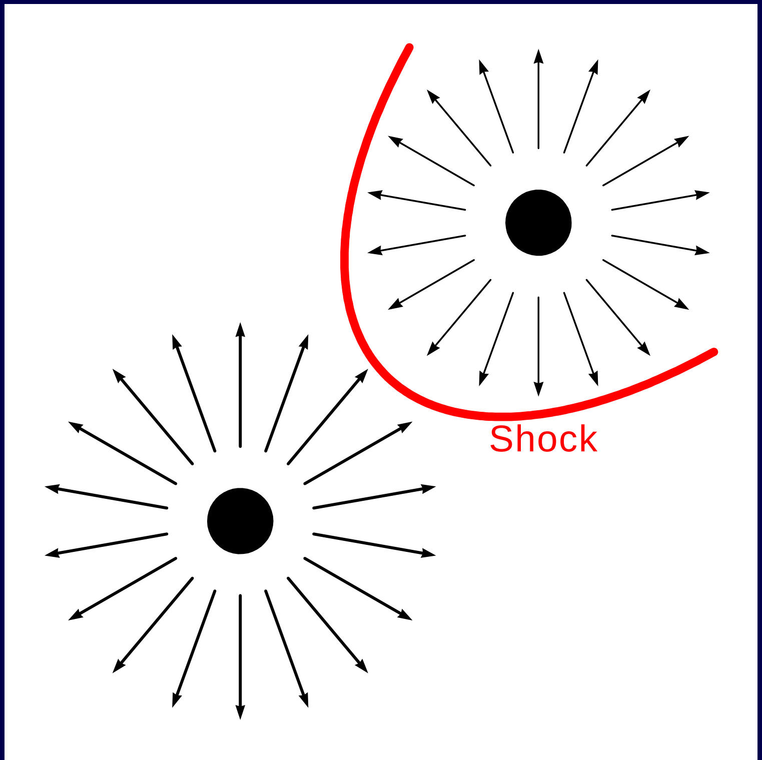


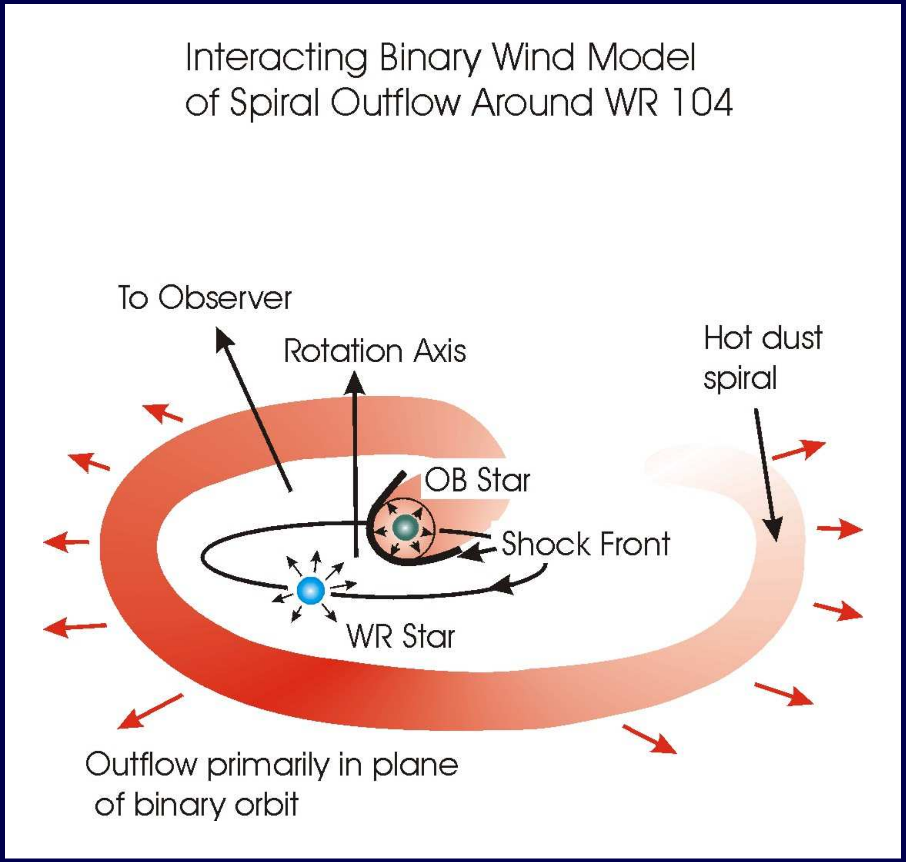
Quintuplet: K-band integral-field spectroscopy (SINFONI)



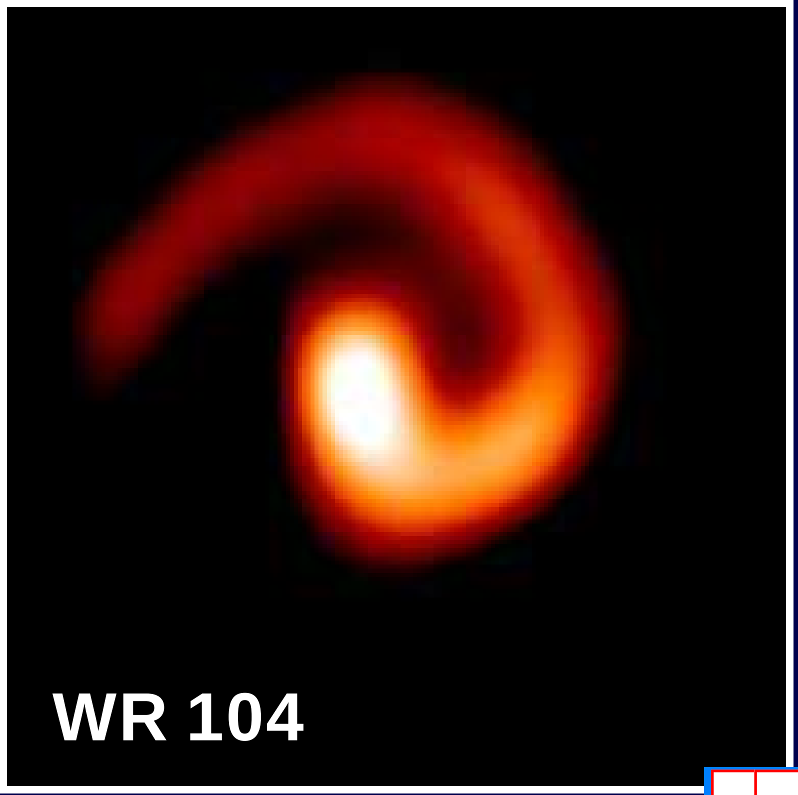
Colliding stellar winds

- Close binary systems
- Both stars with stellar wind, e.g. WR + O
- Formation of a shock cone
- Emission of (relatively hard) X-rays
- Non-thermal radio emission
- *Only in WC9*: formation of dust





from P. Tuthill



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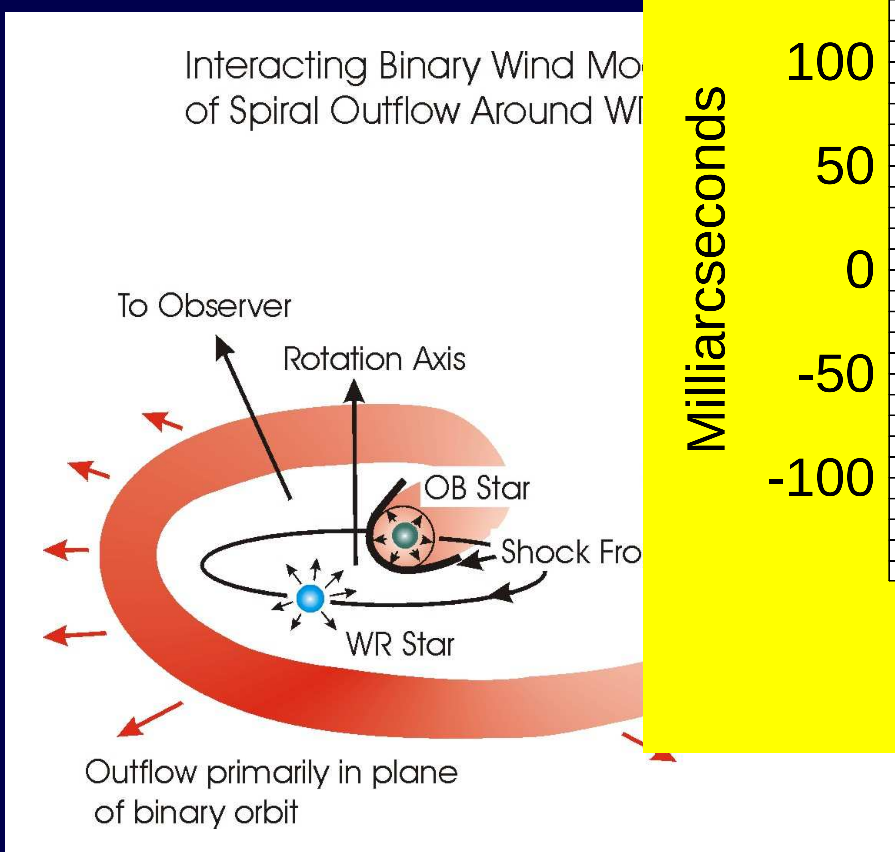

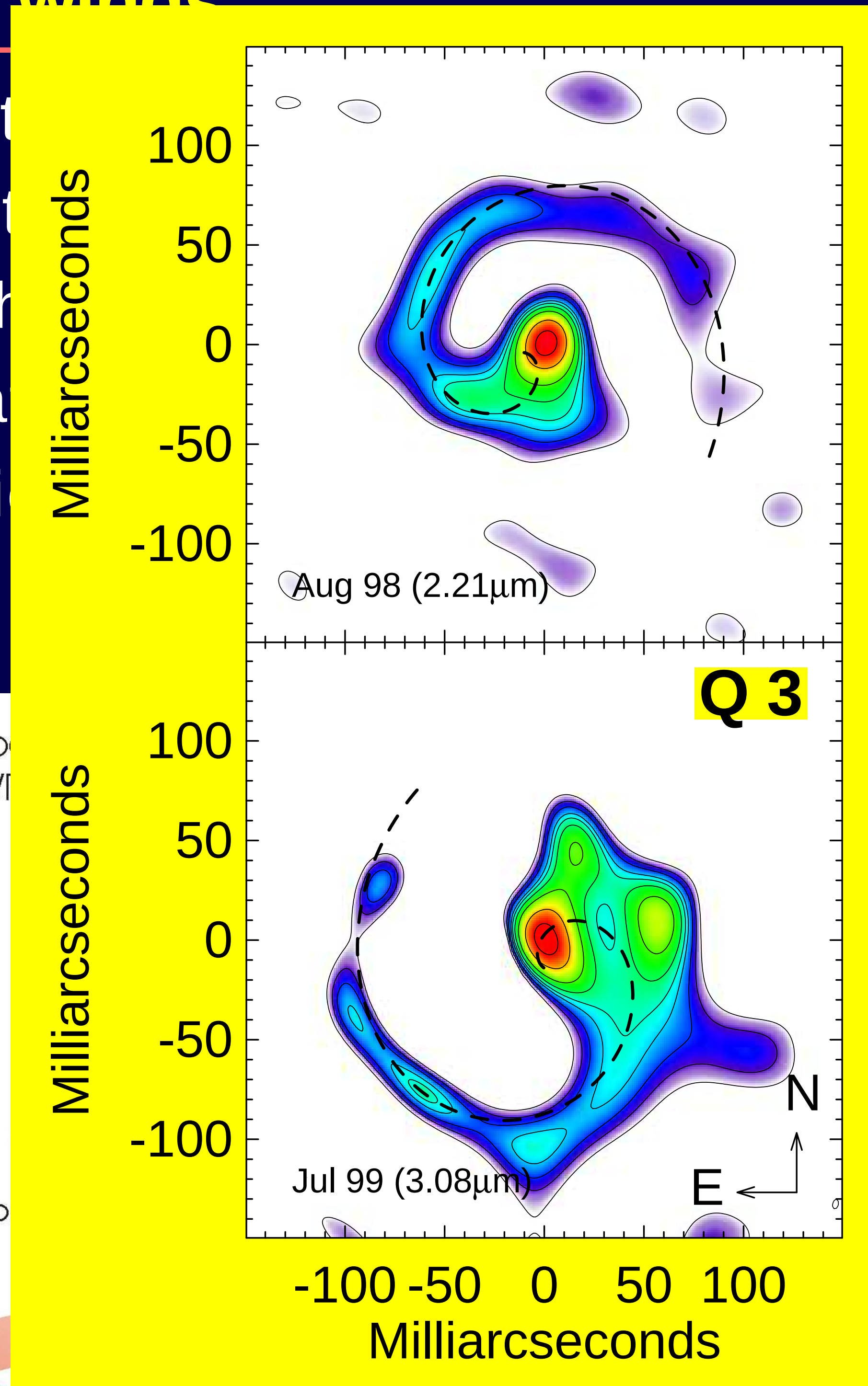

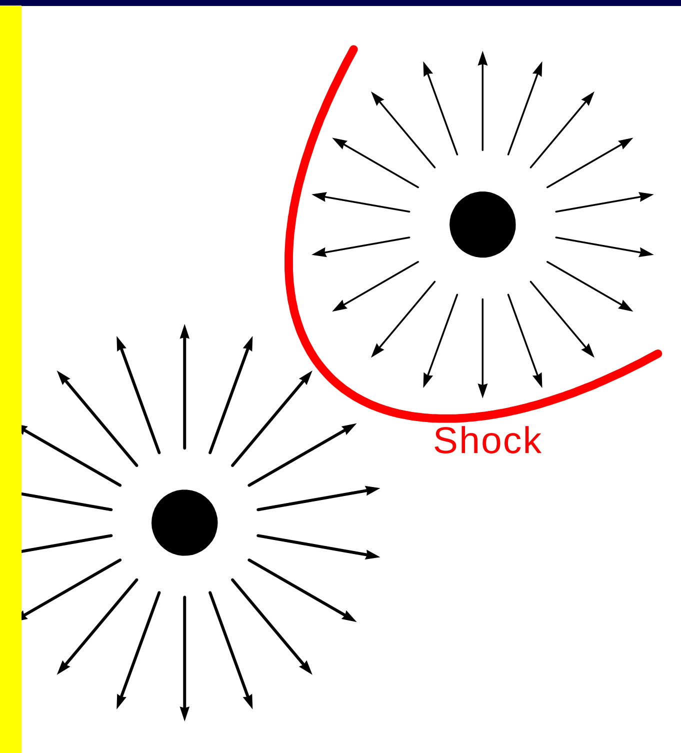

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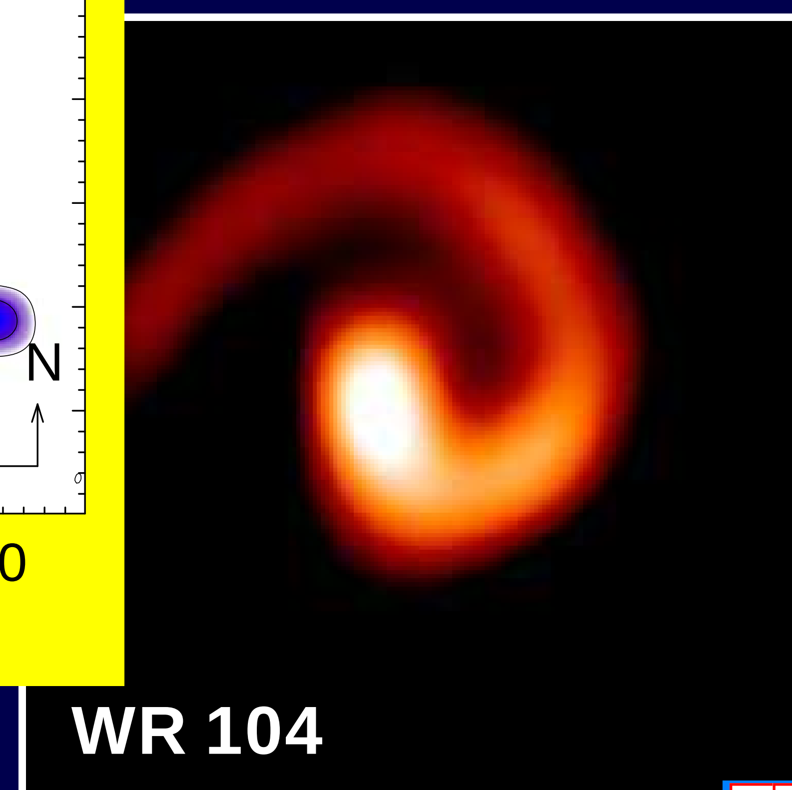
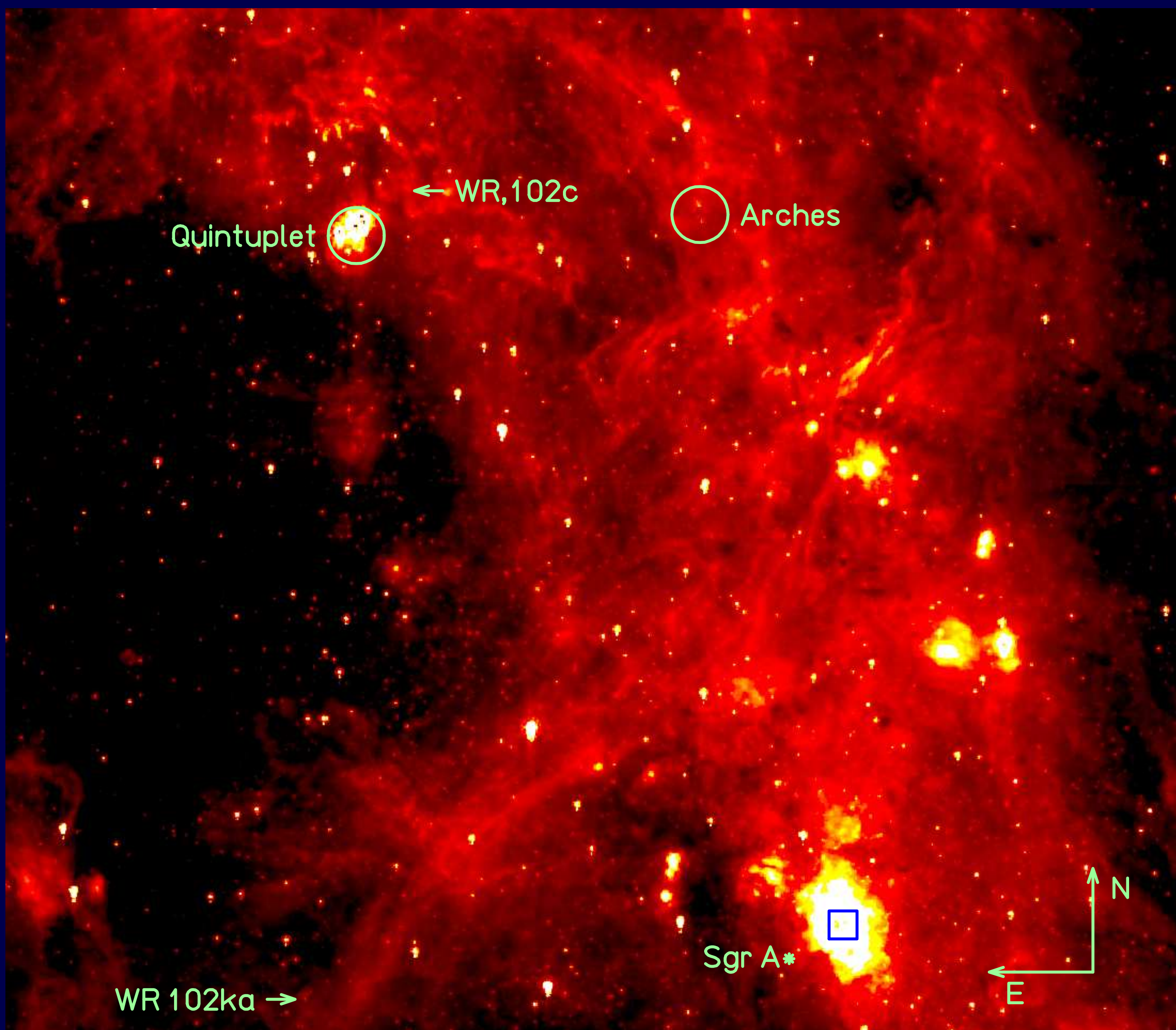
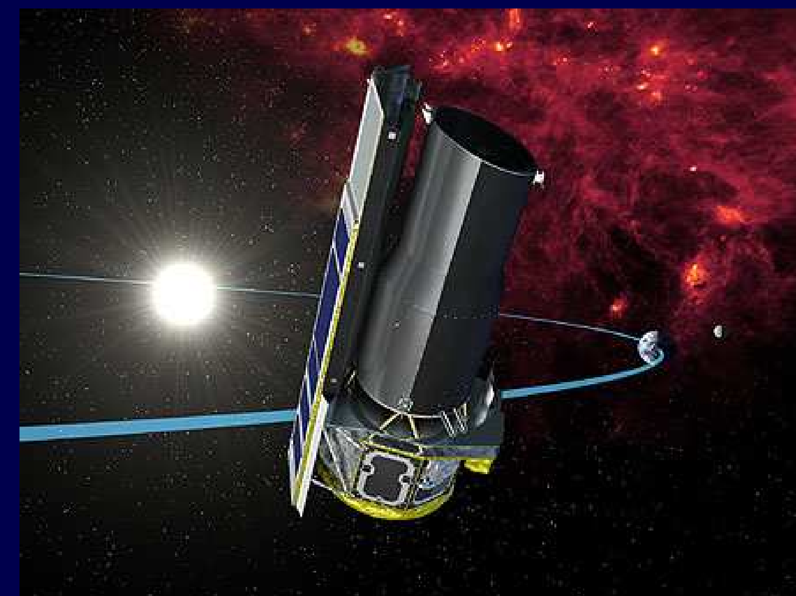


WR star spectra in the mid-IR: *Spitzer* observations

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

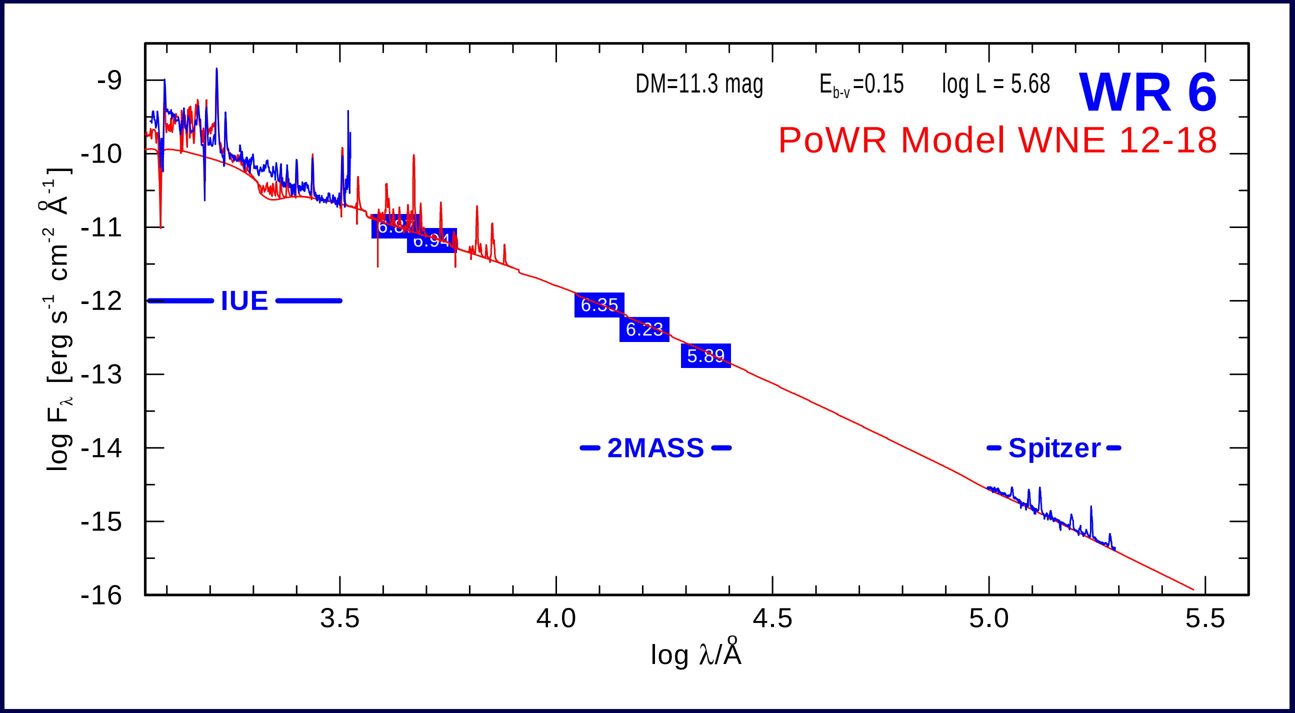




Infrared Space Observatory
SPITZER

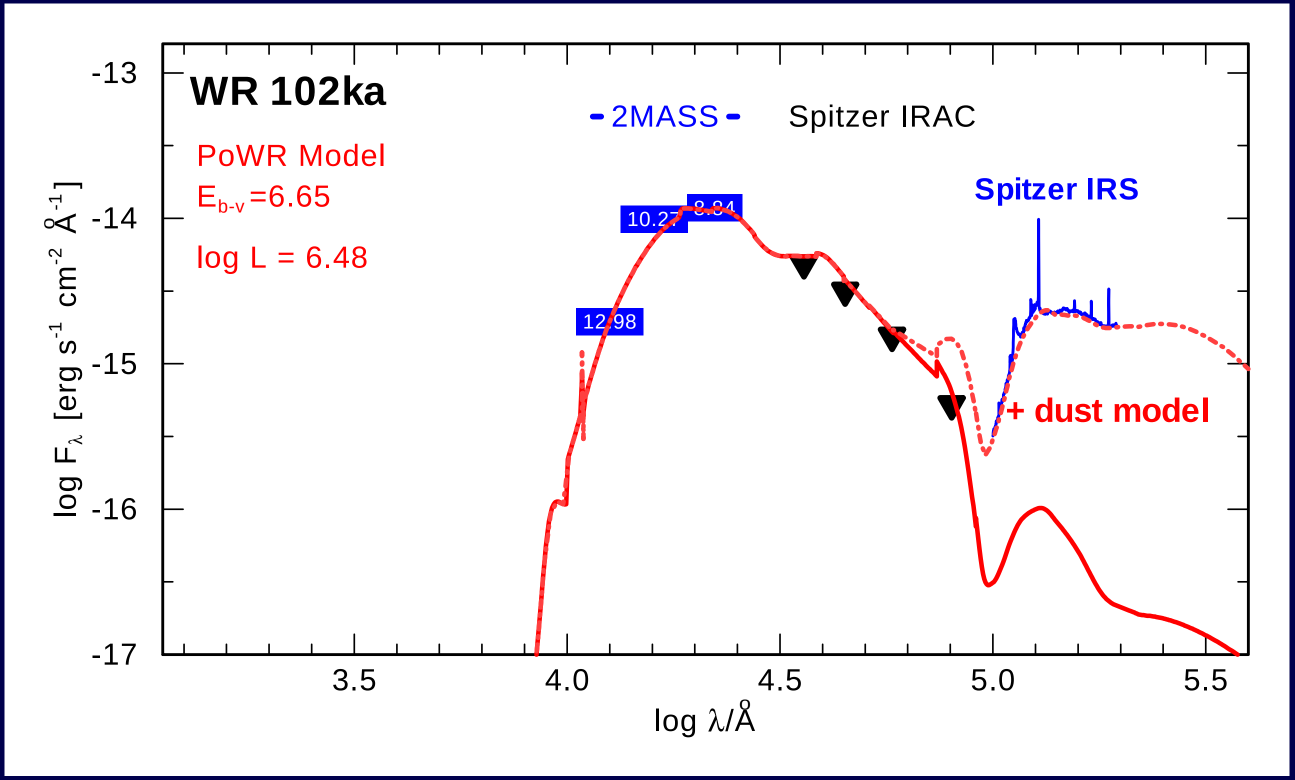
← Galactic Center region
(false color image from IR)

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



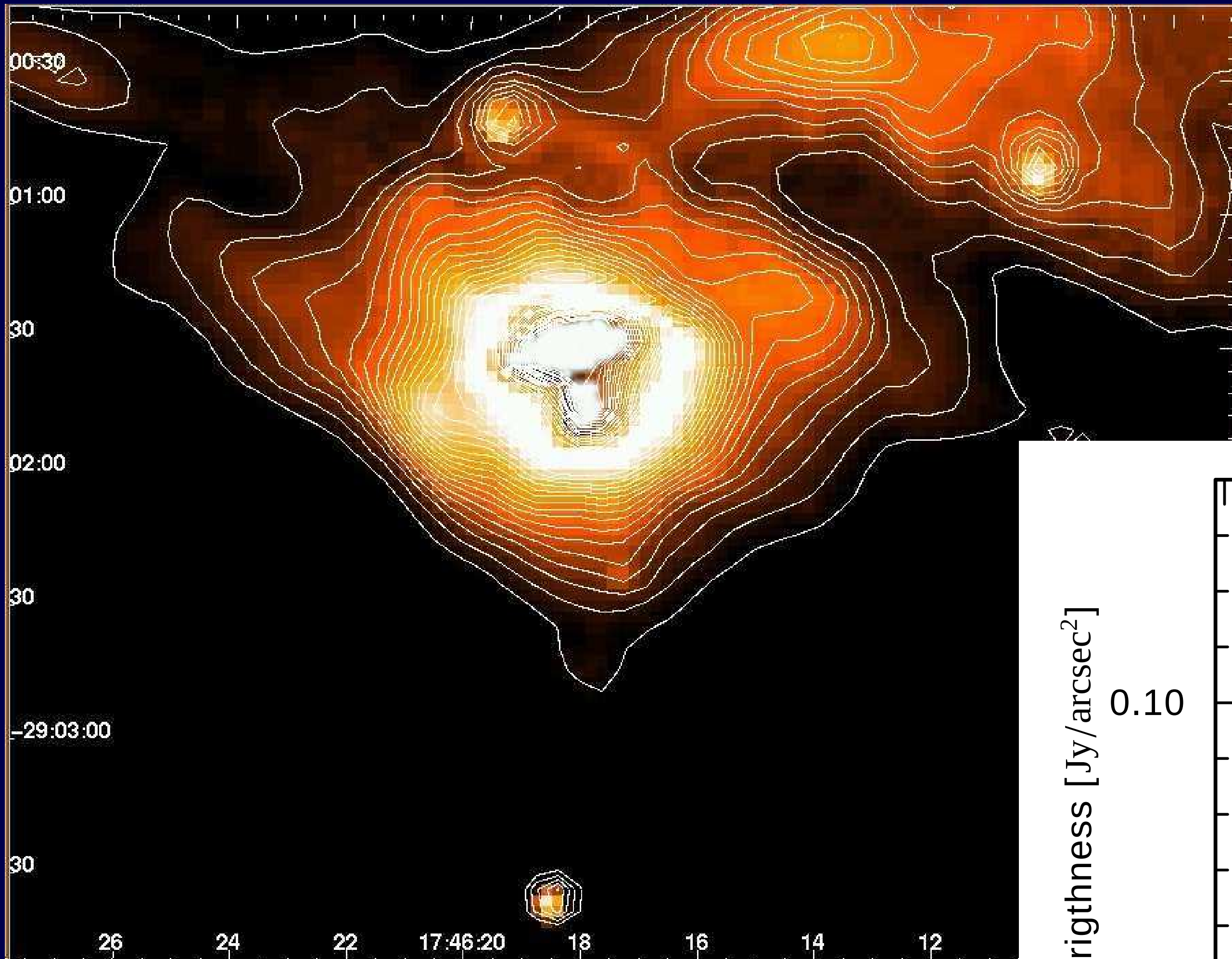
WR 6 (WN4):

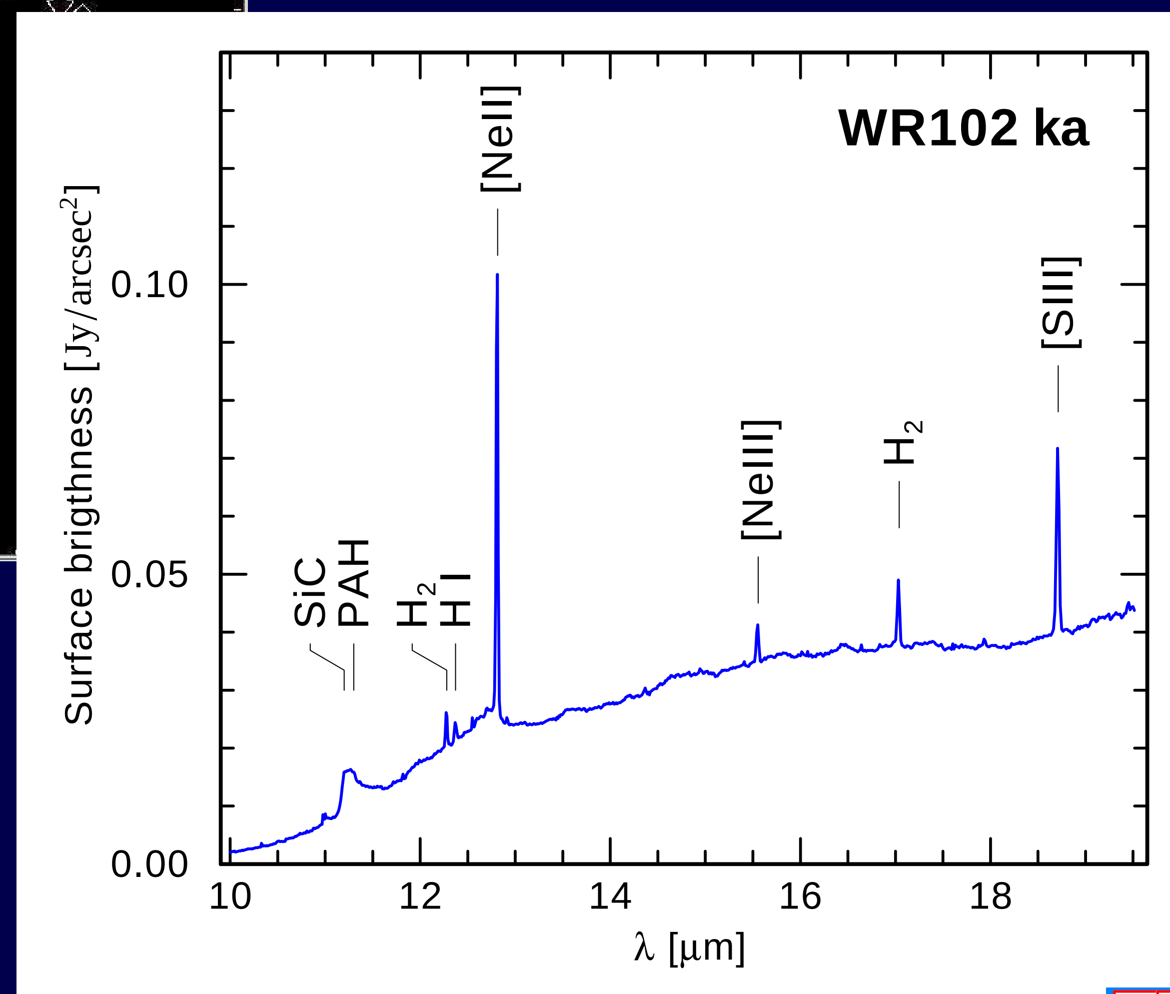
Model SED (red) predicts perfectly the *Spitzer* measurement



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 $M_\odot$
(Barniske et al. 2008)

The *Peony Nebula* around WR 102ka

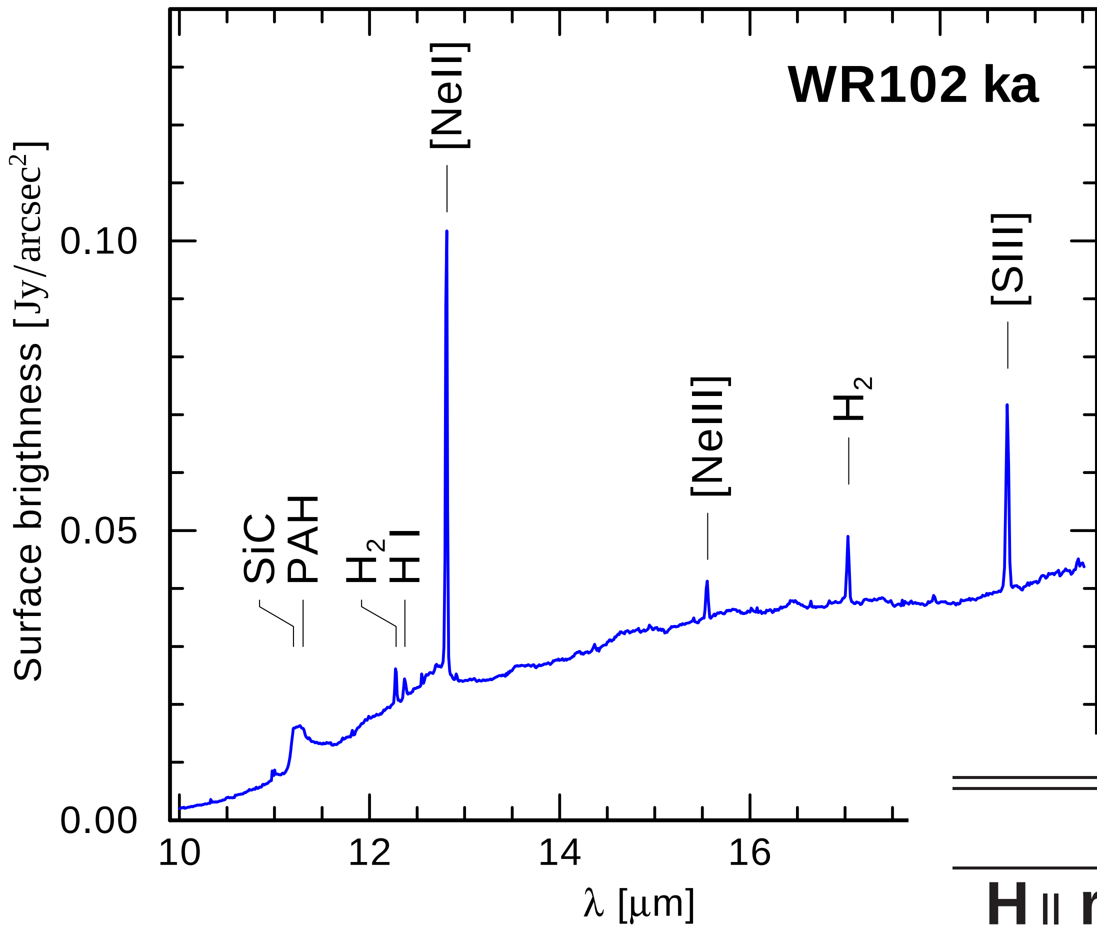




Spitzer at 24 μm (mid-IR)
(central part over-exposed)

Warm dust + H II region + PDR

Mid-IR nebular spectrum



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

H II region
→ forbidden lines, H I

Photodissociation region (PDR):
→ molecular hydrogen (H_2)

	WR 102ka	WR 102c
H II region:		
Ionized gas	$> 5\ M_\odot$	$> 10\ M_\odot$
Radius	0.6 ... 6 pc	0.6 ... 6 pc
Photodissociation Region (PDR):		
H_2 mass	$> 0.8\ M_\odot$	$> 0.7\ M_\odot$
Dust shell:		
Warm dust mass	$0.005\ M_\odot$	$0.08\ M_\odot$
Inner radius	0.06 pc	0.07 pc
Outer radius	0.4 pc	0.4 pc

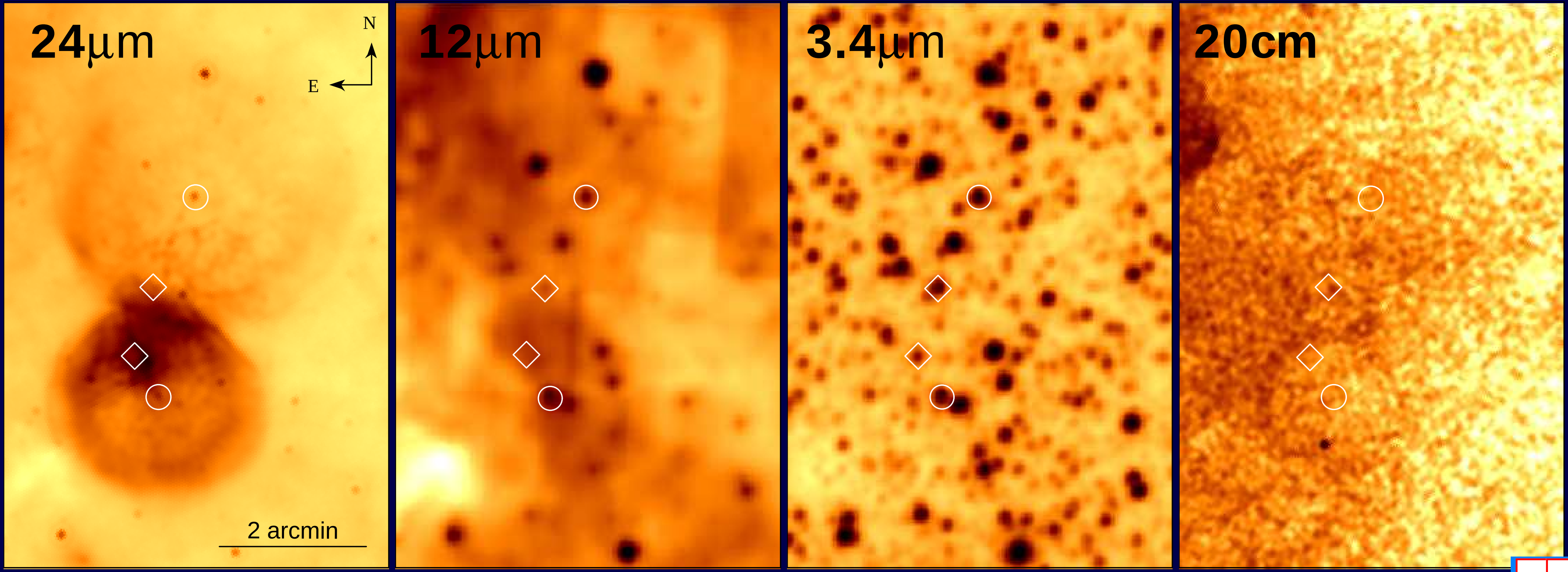
From Barniske et al. (2008)

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 24μm, invisible at 3.4μm and radio
- often nearly spherical

Fig.: Two interacting circumstellar shells
(Burgemeister et al., to be submitted)

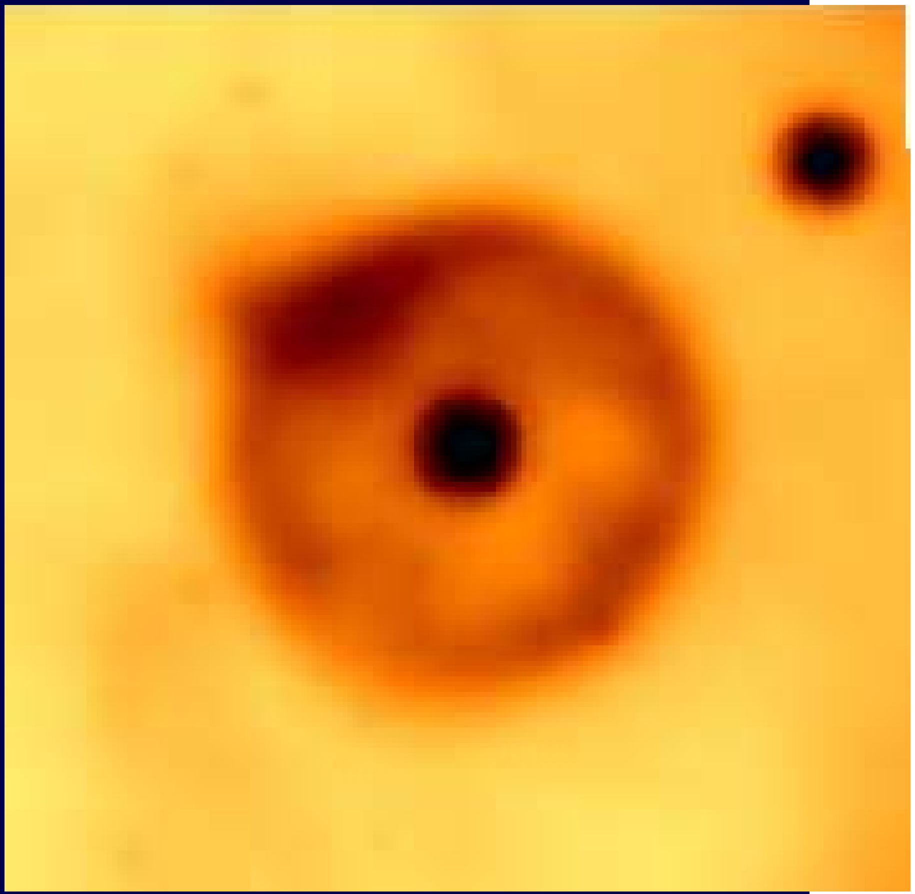
Circles: WR 102bb and WR 102bc (both WN9); squares: WC8, O-type

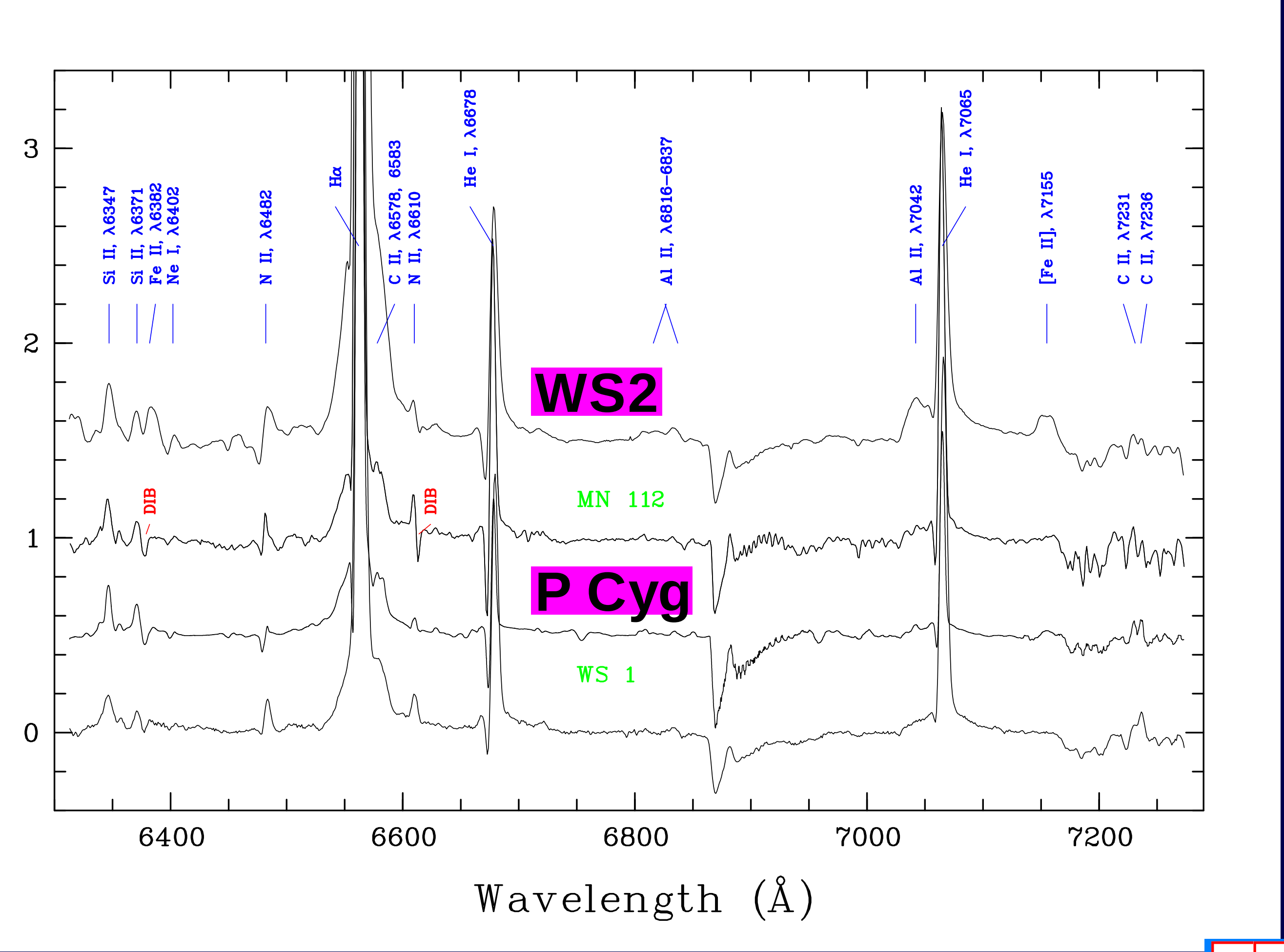


Dusty nebulae around LBV stars

- 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_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 dust-dominated (all WC9+O pinwheels?)
- Mid-IR spectra of many WR stars are dominated by emission from circumstellar warm dust