Unveiling the Evolutionary Journey of J040901.83+323955.6

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Physics of Extreme Massive Stars
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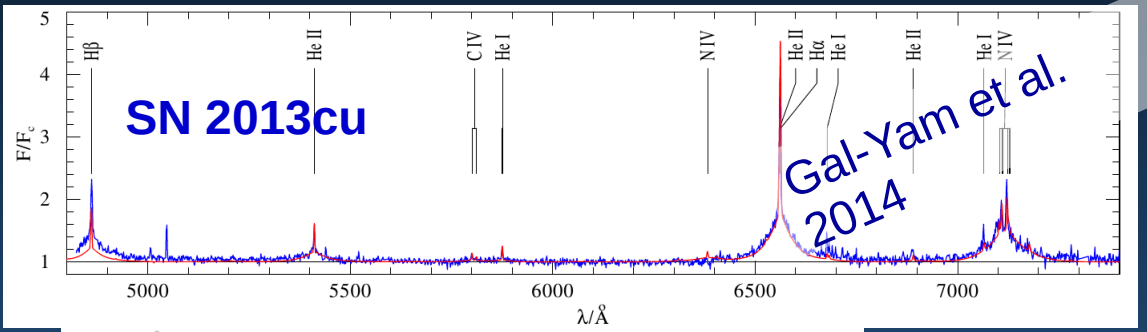
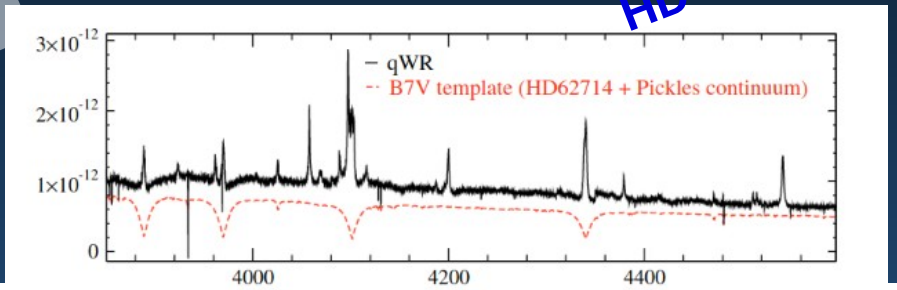
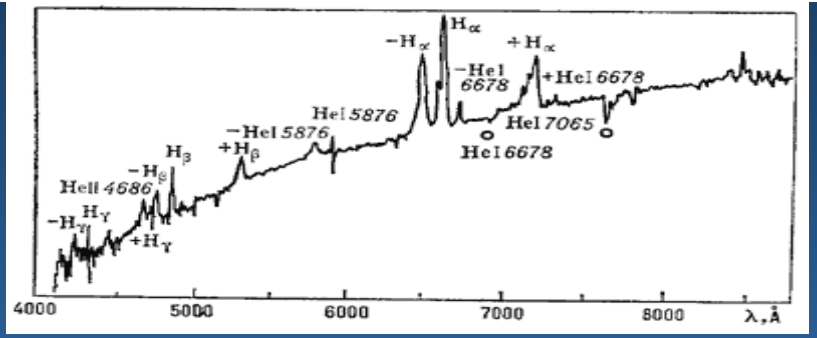
Abstract: *The resemblance in wind conditions between low-mass post-asymptotic giant branch stars and evolved massive stars gives rise to the phenomenon of spectral mimicry. LAMOST J040901.83+323955.6 (J0409+3239) was identified as a WR star in the LAMOST spectroscopic database through machine learning methods. The various spectral type classifications of this object have created the initiative for a detailed investigation. The position of J040901.83+323955.6 's in the Galaxy and its placement on the color-magnitude diagram, let us conclude that it is a low-mass object with WR phenomenon, i.e. [WR], or a central star of planetary nebula (CSPN). The star shows the irregular variability with an amplitude of up to ≈ 0.2 mag, as revealed by new and archival photometric data. Moreover, a spectra obtained in 2022 and 2014 illustrates evidence of spectral variability. Estimations of J0409+3239's mass based on evolutionary tracks indicate that it is less than 0.9 $M_{\odot}$, with a luminosity of L_{*}= 1000 $L_{\odot}$ and an effective temperature of Teff =40,000 K.The star, a low-mass star in a rare transitional phase towards becoming a central star of a planetary nebula.*

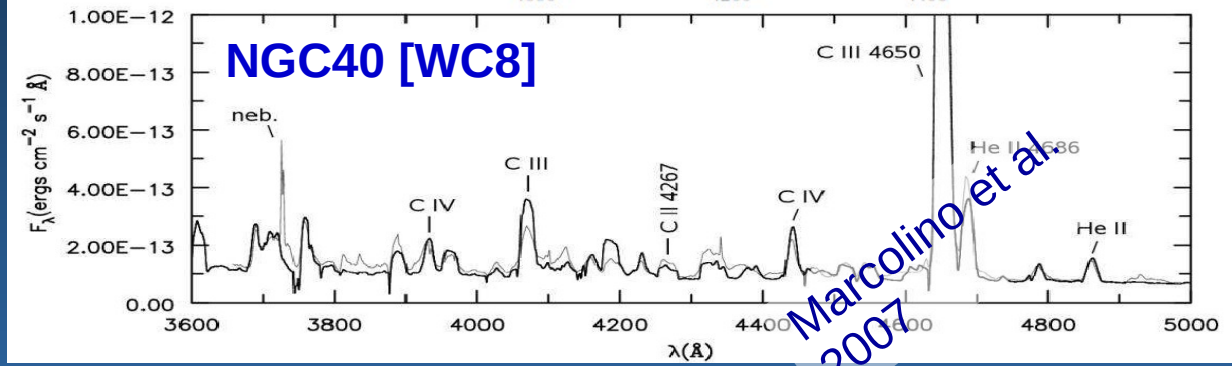
Wolf-Rayet Phenomenon

- “classical” WR stars – descendants of massive (M>25$M_\odot$) O-type stars
- very massive stars (VMS) with M > 100$M_\odot$
- [WR] central stars of planetary nebula
- young supernovae (SNe), which reveal WR-like spectra









Galactic Wolf Rayet Catalogue

v1.28 (Gaia DR3), 669 WR stars, Jun 2023

Home Refs History Additions Omissions IDs Description

ID	WR#	Reference	HD	Alias1	Alias2	Alias3	Right Ascension J2000	Declination J2000	Galactic Longitude (deg)	Galactic Latitude (deg)	Spectral Type	Spectral Type Reference
1	1	VII	HD 4004	HIP 3415			00 43 28.39	+64 45 35.4	122.0825	1.9012	WN4b	SSM96
2	2	VII	HD 6327	HIP 5100			01 05 23.03	+60 25 18.9	124.65	-2.41	WN2b	SSM96
3	3	VII	HD 9974	HIP 7681			01 38 55.62	+58 09 22.6	129.1797	-4.1382	WN3ha	MMC04
4	4	VII	HD 16523	HIP 12527			02 41 11.67	+56 43 49.8	137.5948	-2.9839	WC5+?	VI
5	5	VII	HD 17638	HIP 13380			02 52 11.66	+56 56 07.1	138.8668	-2.1530	WC6	VI

669 WR – stars discovered in the Milky Way Galaxy

Galactic Wolf-Rayet Stars - http://pacrowther.staff.shef.ac.uk/WRcat/index.php

The predicted number of WR's ~1200 (Rosslowe & Crowther 2015)

The object: LAMOST J040901.83+323955.6 (J040901) properties

RA (J2000)	$04^{h}09^{m}01^{s}.8343$	
Dec. (J2000)	$+32^{\circ}39'55''.7627$	
l	$164.^{\circ}12944$	
b	$-13.^{\circ}9698$	
Dist (pc)	$2499.47^{+151.41}_{-162.44}$	*Gaia* DR3 [1]
V (mag)	14.678 ± 0.148	APASS-9 [2]
B (mag)	15.006 ± 0.218	APASS-9 [2]
$B_P - R_P$	0.468 ± 0.036	*Gaia* eDR3 [3]
$E(B-V)$	$0.226^{0.02}_{-0.01}$	3D Dust Mapping [4]

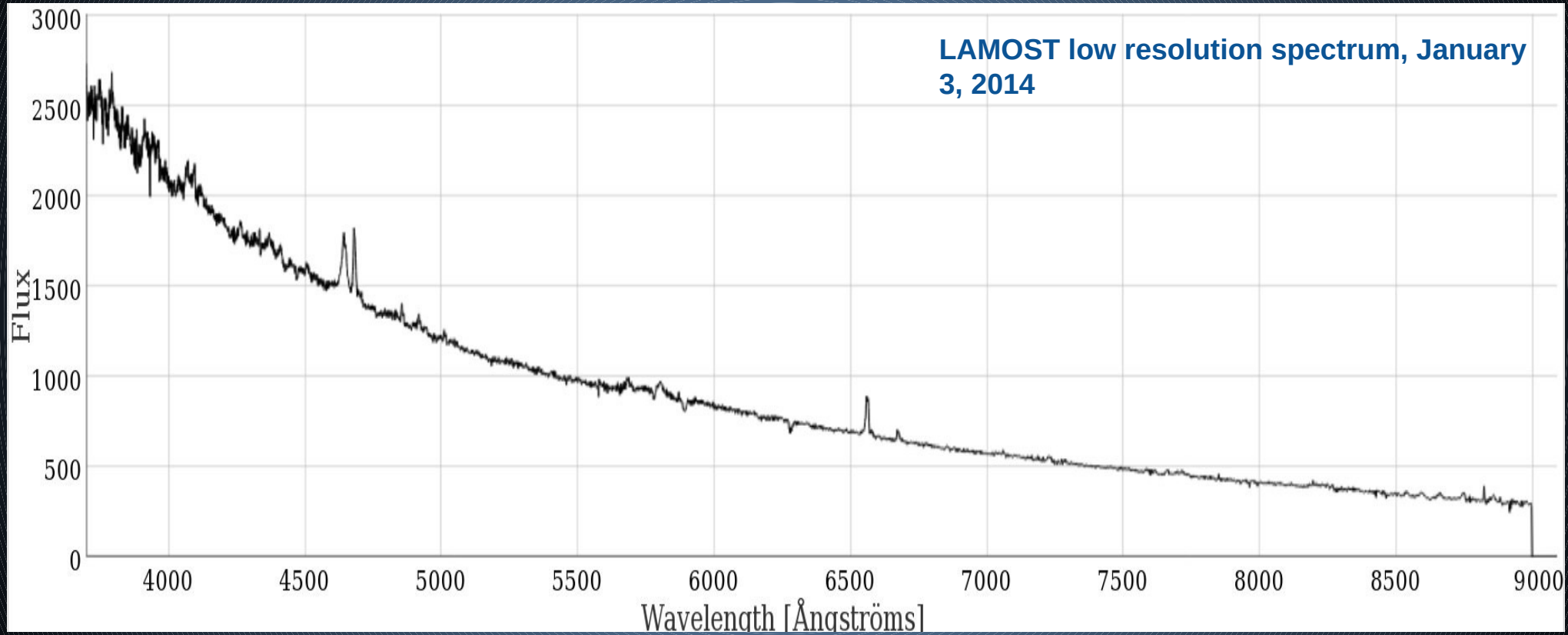
Previous classifications

- Yuan H. B. et al., 2015 - The first spectral observation / LAMOST Spectroscopic Survey of the Galactic Anticentre
- Škoda P., Podsztavek O., Tvrdík P., 2020 - classified as a WN star
- Sesar B. et al., 2017, AJ, 153, 204 - RR Lyrae stars using a machine-learning identification method

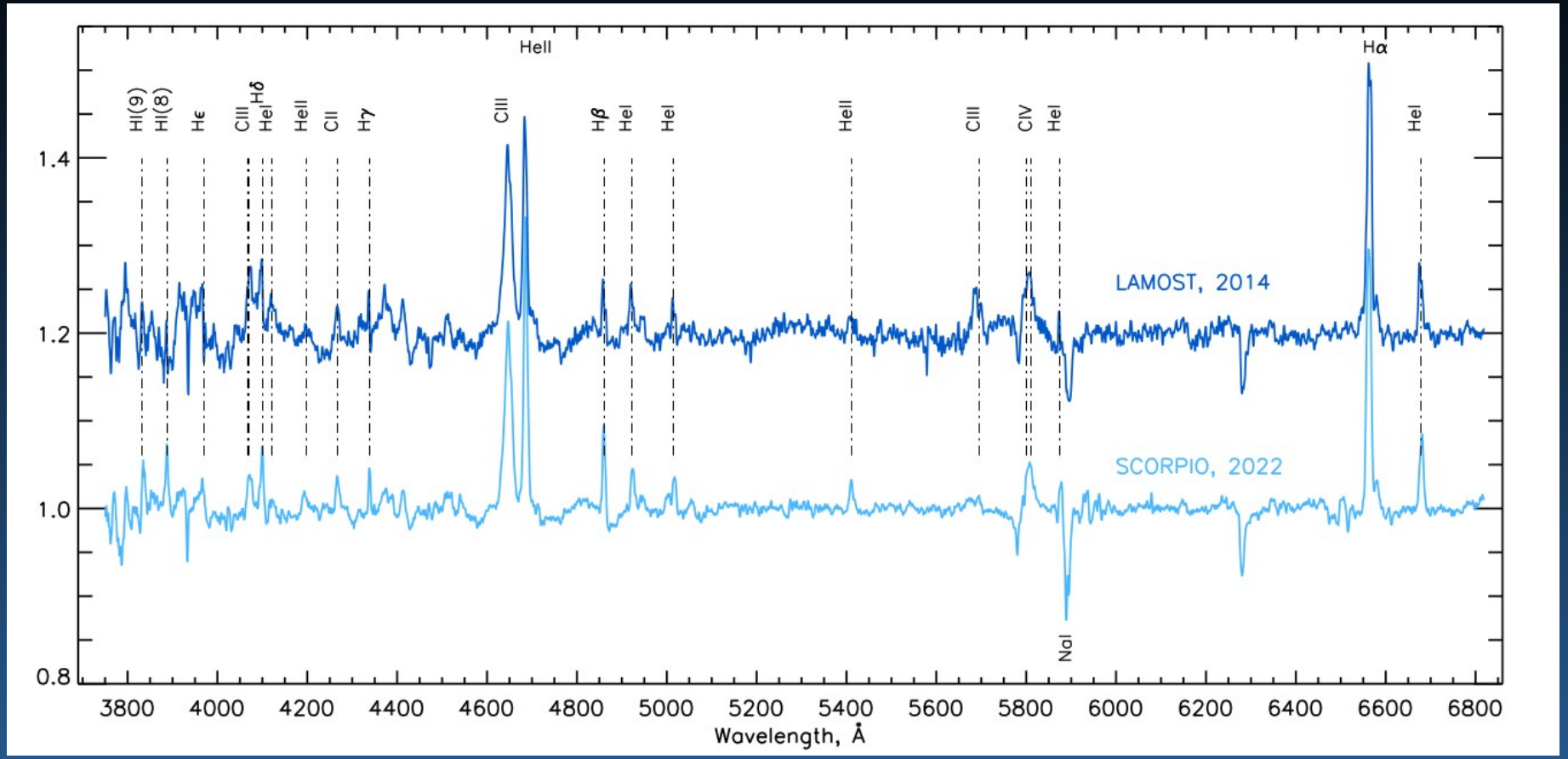
  Have found the period P = 0.2847409137d

- Jayasinghe et al. 2018 ASAS-SN – as a non-periodic object with V = 14.48 mag & Δ ~0.39 mag.

The spectra from LAMOST



The second spectra obtained in 2022



Identification lines and object type

Lines		Lines	
Hγ λ4340	Emission	C IV λ5806	Broad emission
He I λ4471	–	C IV λ4650	–
C III λ4649	Emission	N V λ4603	–
C III λ5696	Broad emission	N V λ4945	–
He II λ4686	Emission	O VI λ3822	–
He II λ5412	Emission	O VI λ5290	–

Crowther,De Marco & Barlow (1998)

criteria of Weidmann et al. (2020)

strong emission lines of
C II λ 4267
C III λ4647, 4650, 4652

Identified

as N III by Škoda, Podsztavek & Tvrdík (2020) and
as C III + N III by Sun et al. (2021)

Teff ~ C III λ4647,
C IV λ5801, 5812, He I and He II.

Teff = 37 000−41 000 K

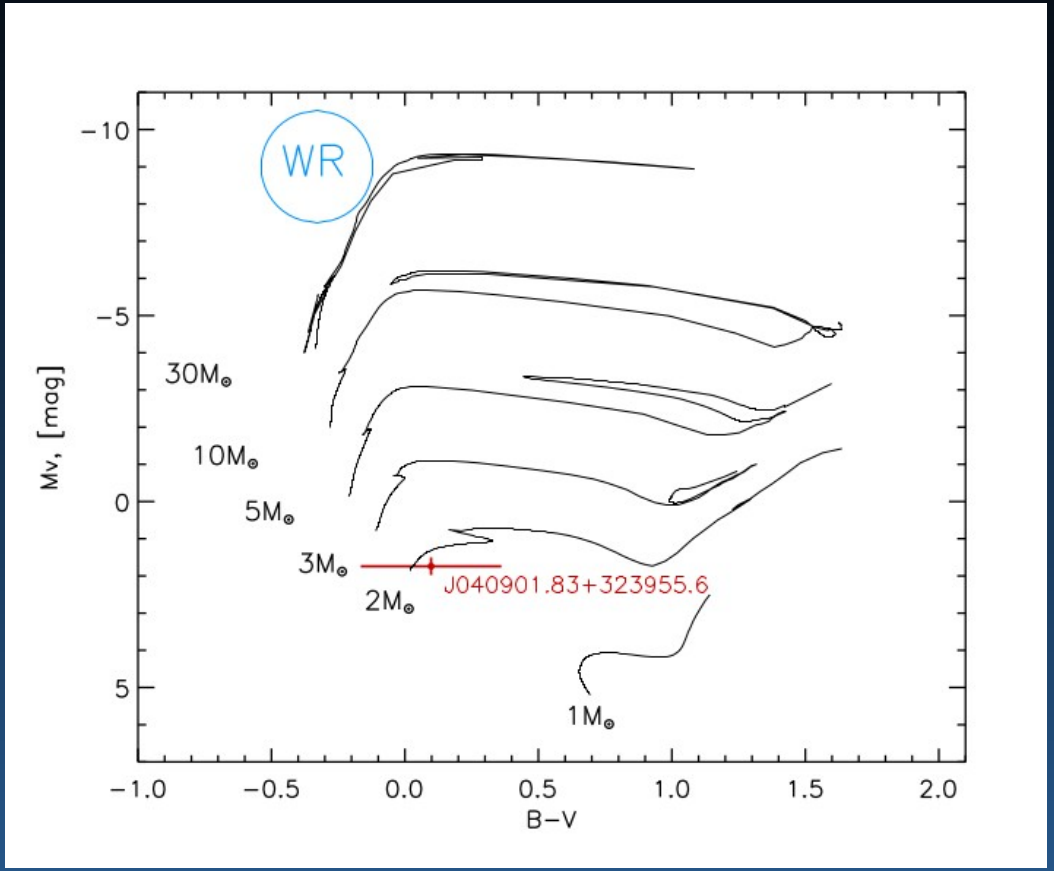
$L_* = 900 - 1000\ L_\odot$

$M_* = 0.9 M_\odot$

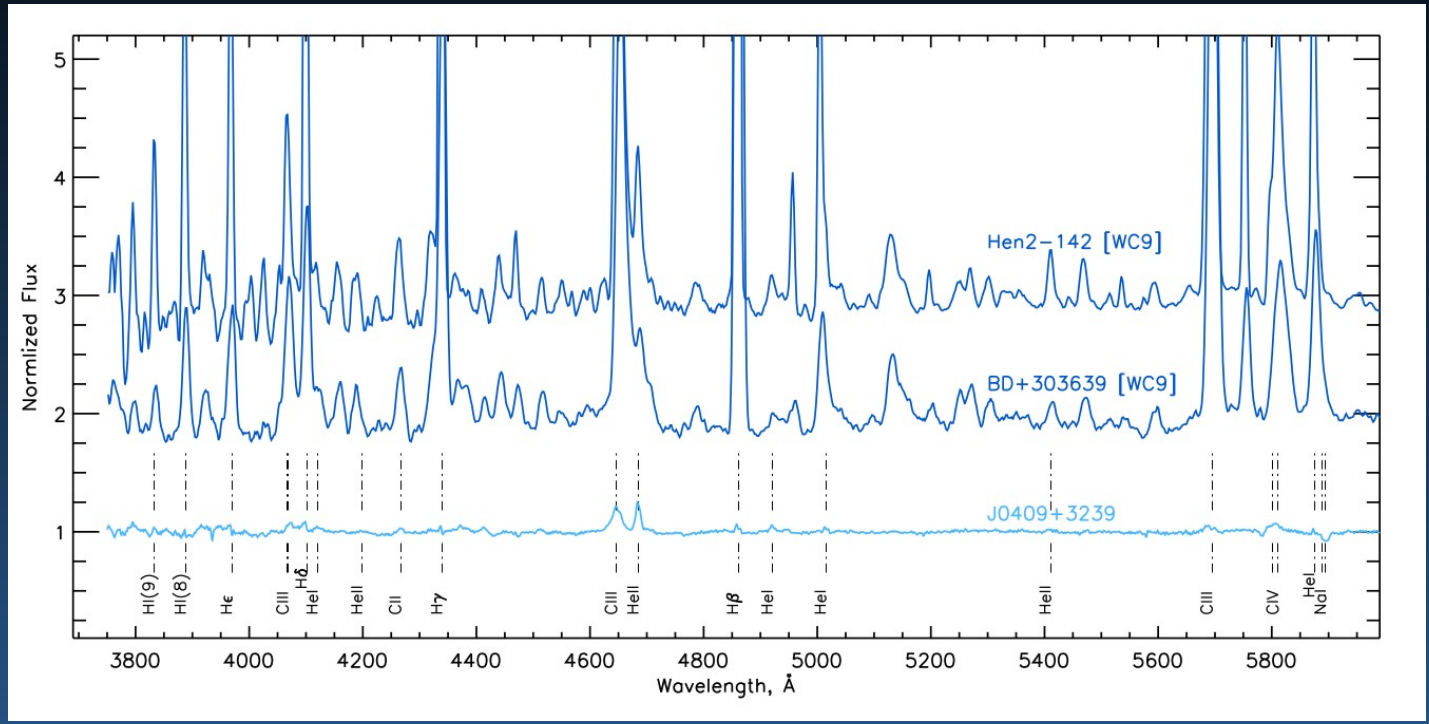
C IV λ5801, 5812/C III λ5696
C IV λ5801, 5812/C II λ4267

According equivalent width ratios, J0409+3239 is a [WC8-9]

Location in the HR diagram
and the evolutionary status of J0409+323



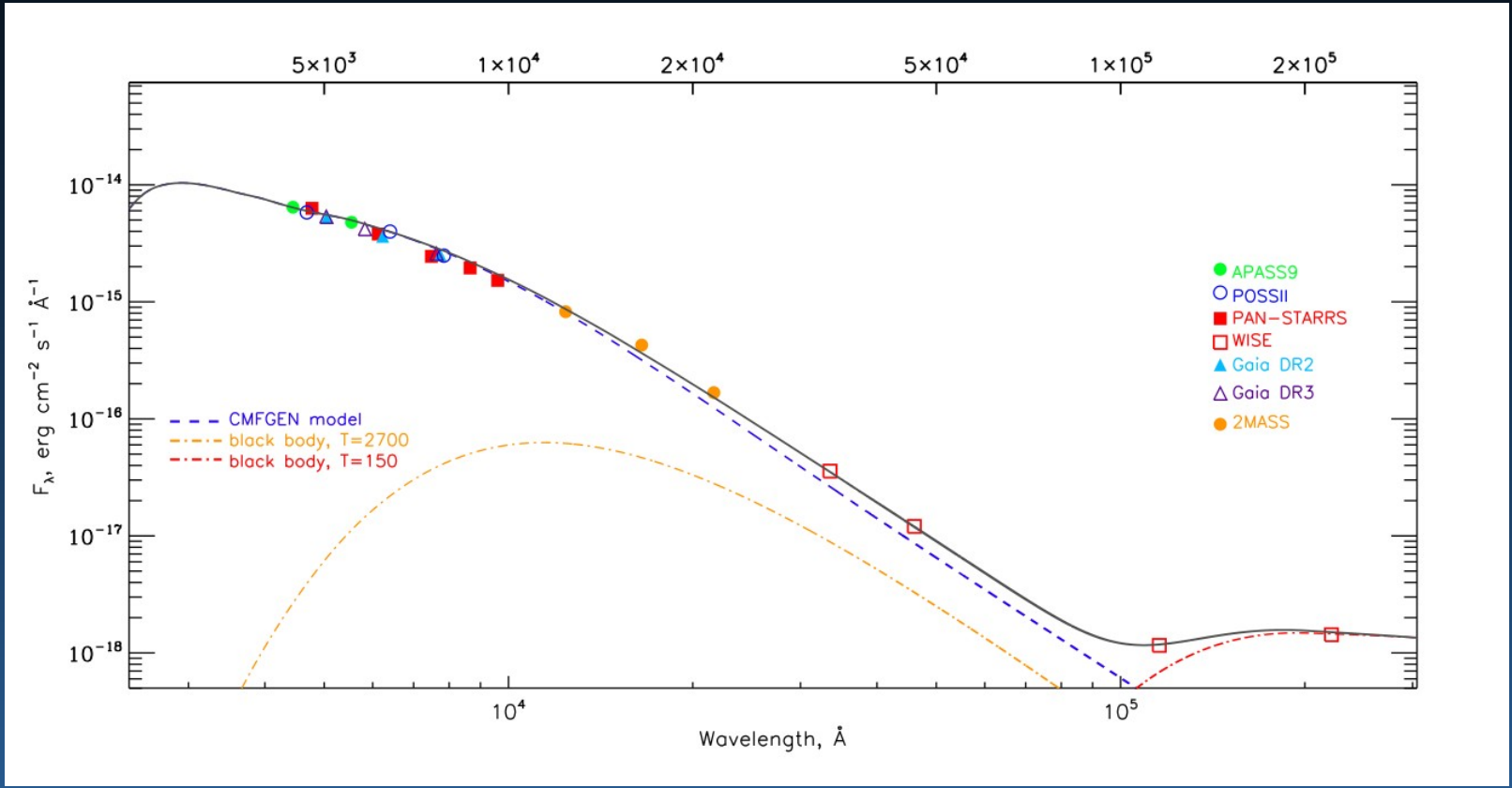
Comparison of normalized spectra of J0409+3239 and [WC9] type stars



Reddening J0409+3239 ~ E(B − V) = 0.6.

SED

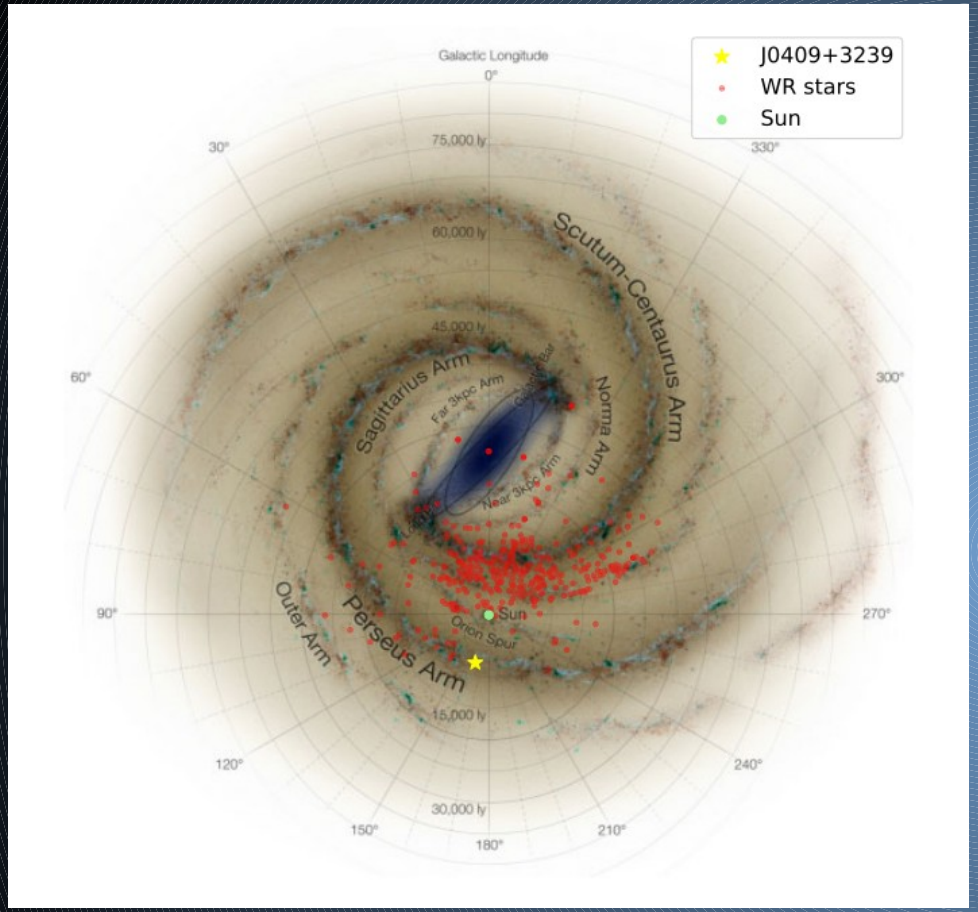
This is 2.6 times larger than the total Galactic reddening in this direction

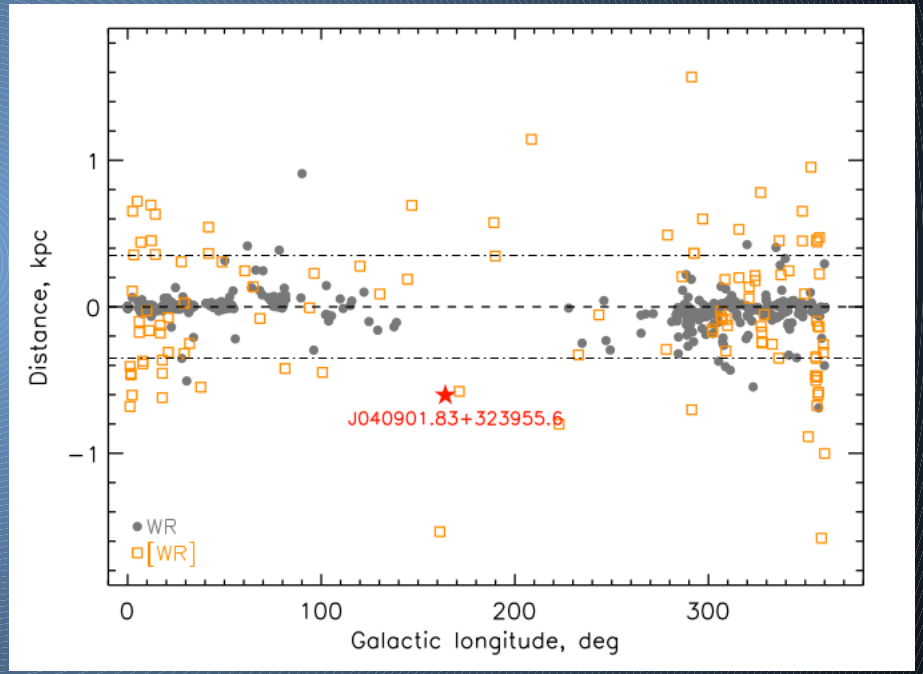


Forbidden nebular lines [O III] λ4959, 5007 and [N II] λ5755

Position in the Galaxy

member of the Galactic halo





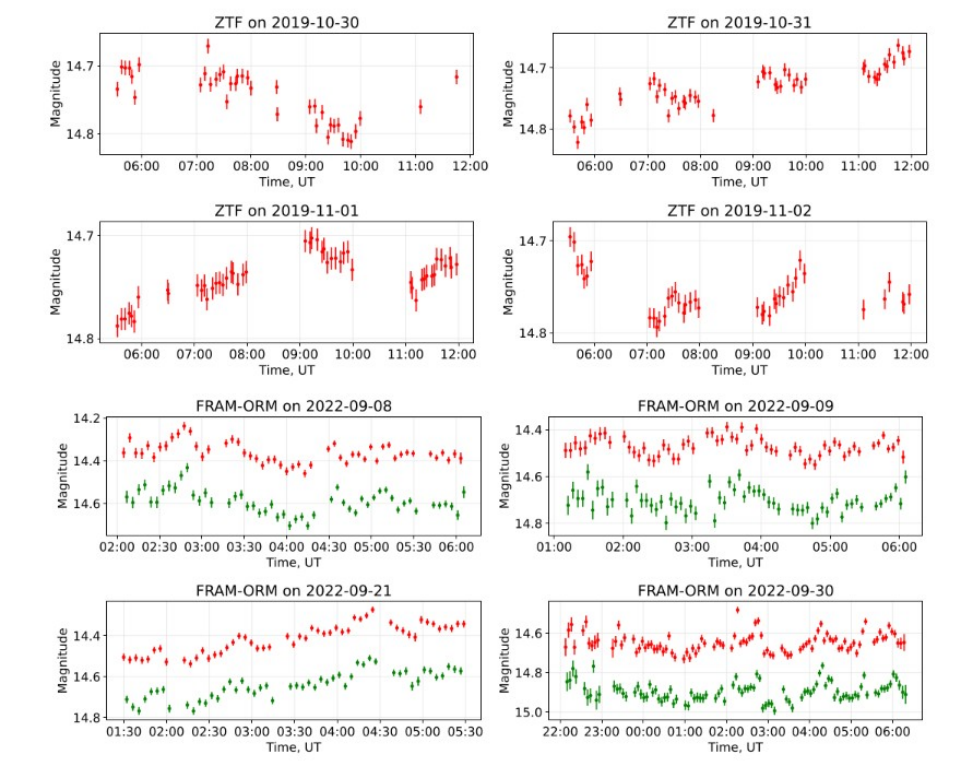
// 138.9 - 227.8 – WR free zone

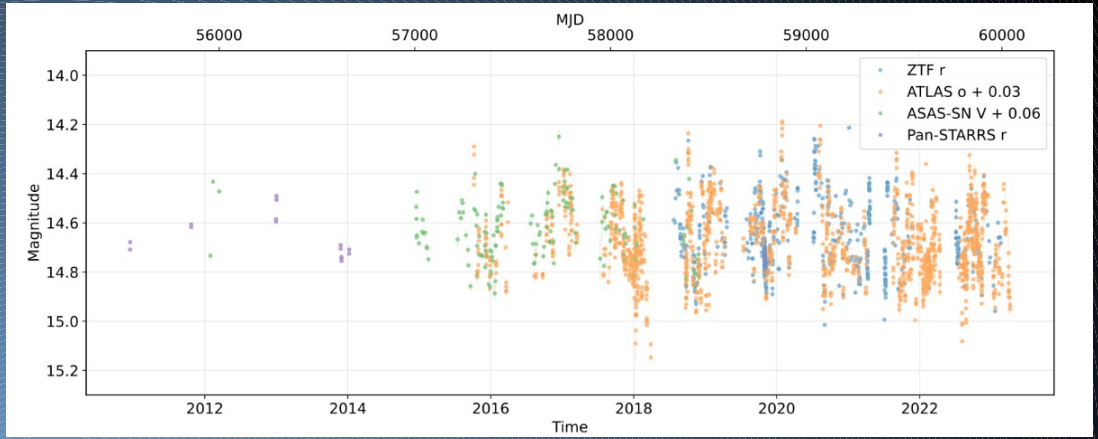
d=2.5 kpc Gaiadr3
z= -0.725 kpc

Photometry

Zwicky Transient Facility (ZTF)

27 March 2018 - 19 February 2023





ZTF data,
Pan-STARRS1,
ATLAS and ASAS-SN

irregular variability

CONCLUSION

J040901.83+323955.6 is a low-mass star in a rare transitional phase towards becoming a central star of a planetary nebula.

Thank you for attention!