BINA/BIPASS MEETING

"EVALUATION AND FUTURE PROSPECTS OF THE INDO-BELGIAN COLLABORATION"

OCTOBER 10TH 2023

The investigation of particle accelerators among massive stars using radio observations

LIÈGE université

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Belgo-indian researchers

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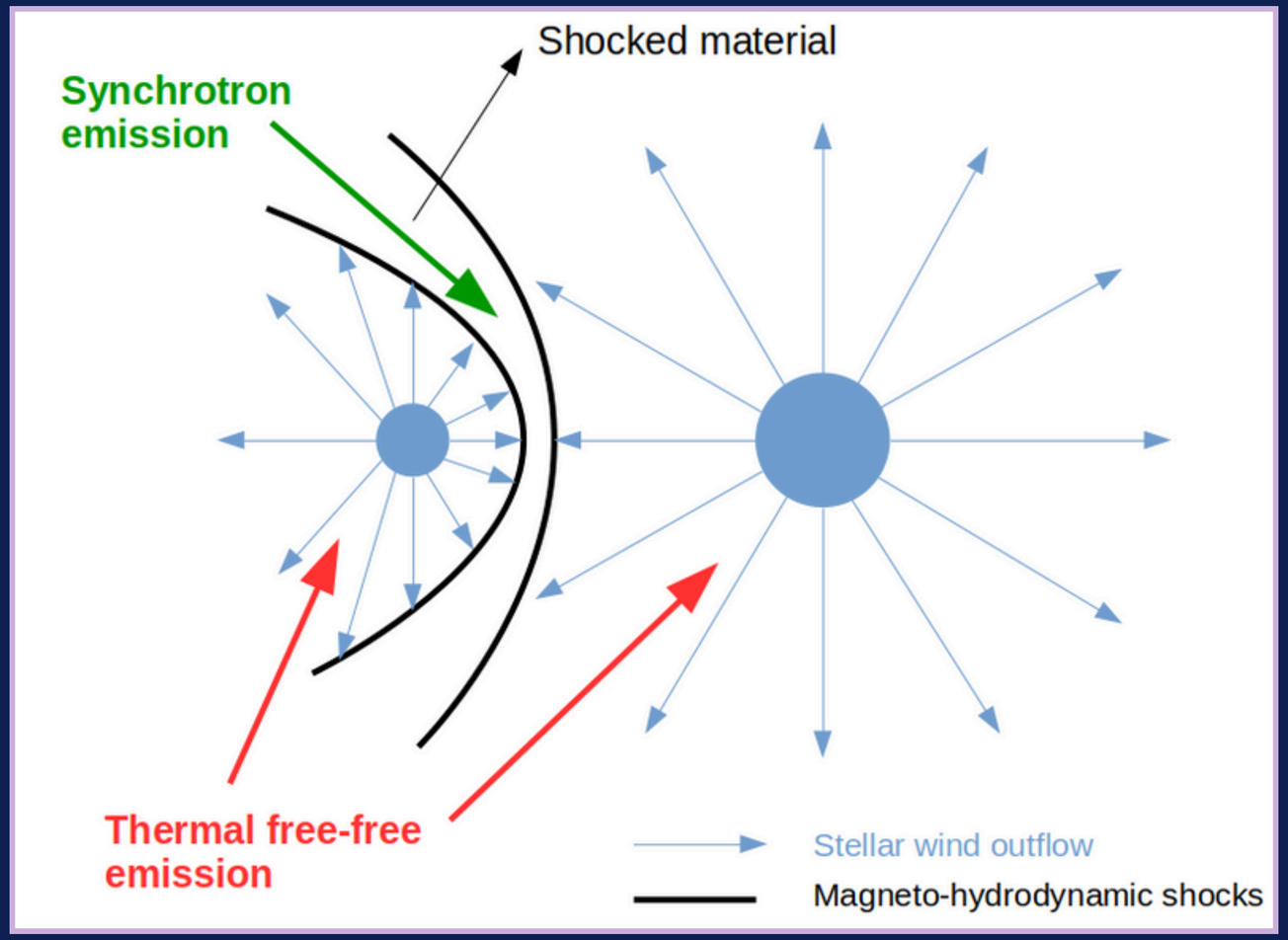
Particle-Accelerating Colliding-Wind Binaries (PACWBs)

- **O and early B-type stars, and WR stars**
- **Powerful winds & Multiplicity**
- **Particle acceleration in the WCR** ⇄ **Non-thermal emission**
- **~ 50 PACWBs cataloged (De Becker, M. & Raucq, F. 2013; De Becker, M. et al. 2017)**


Shocked material
Synchrotron emission
Thermal free-free emission
Stellar wind outflow
Magneto-hydrodynamic shocks

Radio emission of PACWBs

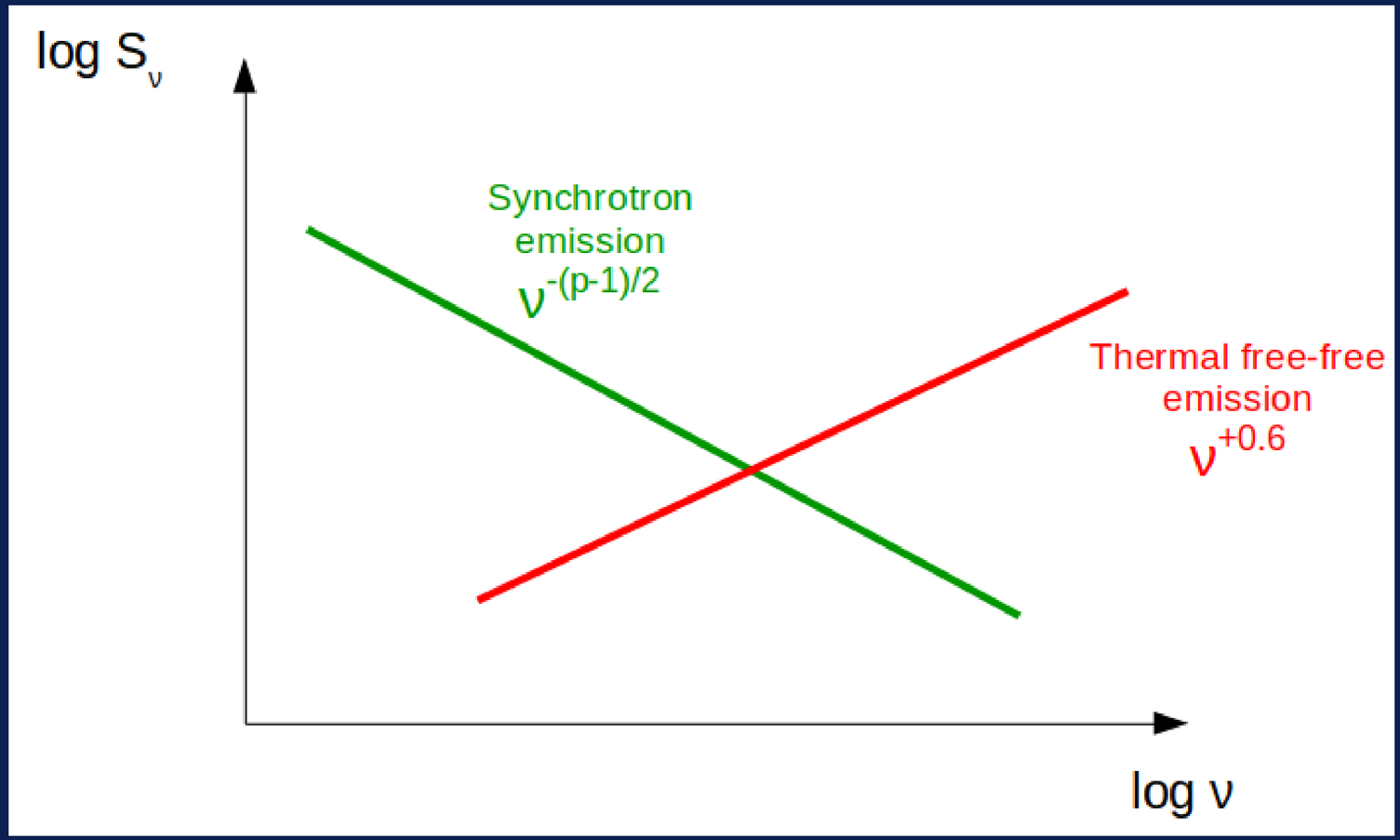
- **Free-free (thermal) radiation from the ionized winds**

$$S_\nu \propto \nu^\alpha$$

$\alpha = 0.6$

$\alpha = -0.5$

- **Synchrotron (non-thermal) radiation from the wind-collision region**


log S_ν
Synchrotron
emission
$\nu^{-(p-1)/2}$
Thermal free-free
emission
$\nu^{+0.6}$
log ν

The question of their population

- **Particle acceleration → relativistic particles (e-, p, He nuclei...) → CRs**
- **Synchrotron signature diluted in the thermal emission or absorbed through FFA**

Low frequency measurements

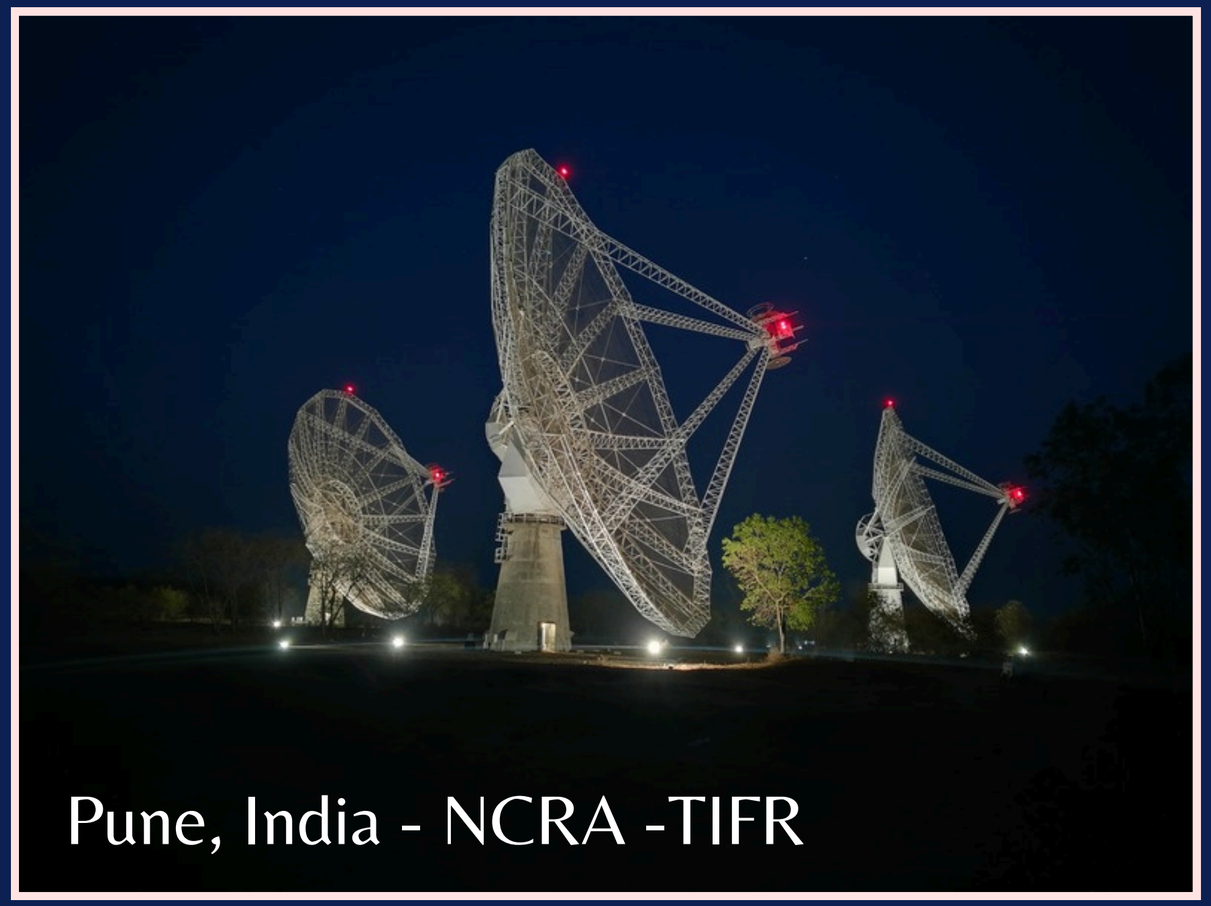
The Synchrotron/Binarity correlation

Search for the signature of synchrotron radio emission → Population of relativistic e-

→ Accelerated in Colliding-Wind Regions → Binary (or >) system

- **Identify new members of the PACWB subcategory**
- **Confirm the binarity of the selected targets**

The uGMRT Observatory



Pune, India - NCRA -TIFR

- Y-shaped array of 30 antennas, 45-m diameter
- Largest baseline of 25 km
  Smallest baseline of 100 m
- Band 2 (120-250 MHz)
  Band 3 (250-500 MHz)
  Band 4 (550-950 MHz)
  Band 5 (1050-1450 MHz)

The CAPTURE Pipeline

- CAsa Pipeline-cum-Toolkit for Upgraded GMRT data REduction
- Kale and Ishwara-Chandra, 2021
- Compatibility with CASA 6 and later versions
- Primary beam correction is separately available

GMRT Observations

Source	Spectral Type	Distance (pc)
WR 87	WN7ha + ?	3000
WR 93	WC7 + ?	1760
WR 98a	WC7d + ?	1960
WR 106	WC9d + ?	2320
WR 110	WN5 + ?	1800

- **Total requested time:**

  14 h 11 m 30 s (Band 4)
  09 h 56 m 31 s (Band 5)

- **Observed in June 2023**

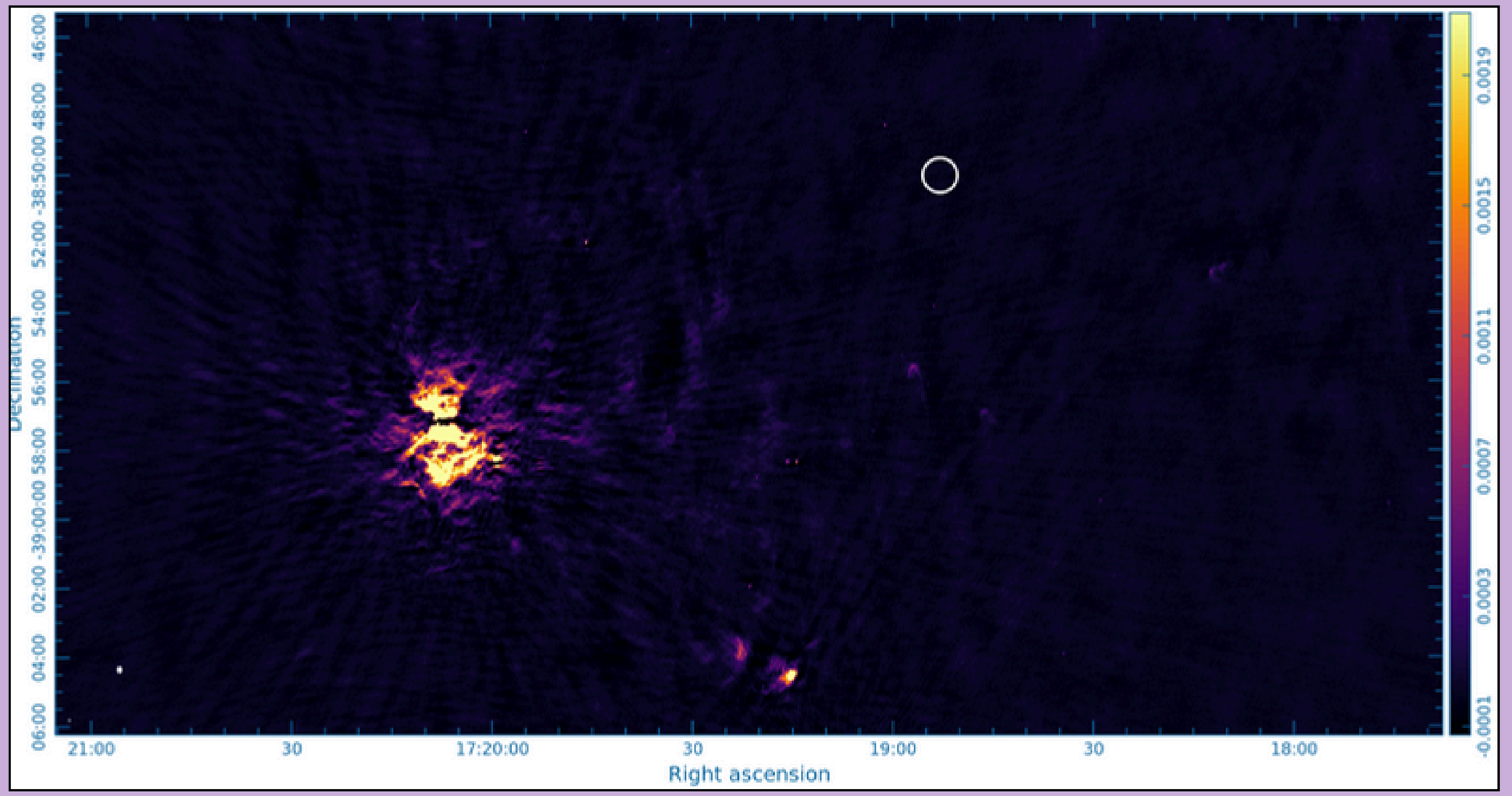
- **Michaël de Becker, Anandmayee Tej, Agustina Blanco and Paula Benaglia**

Band 4 (735 MHz)

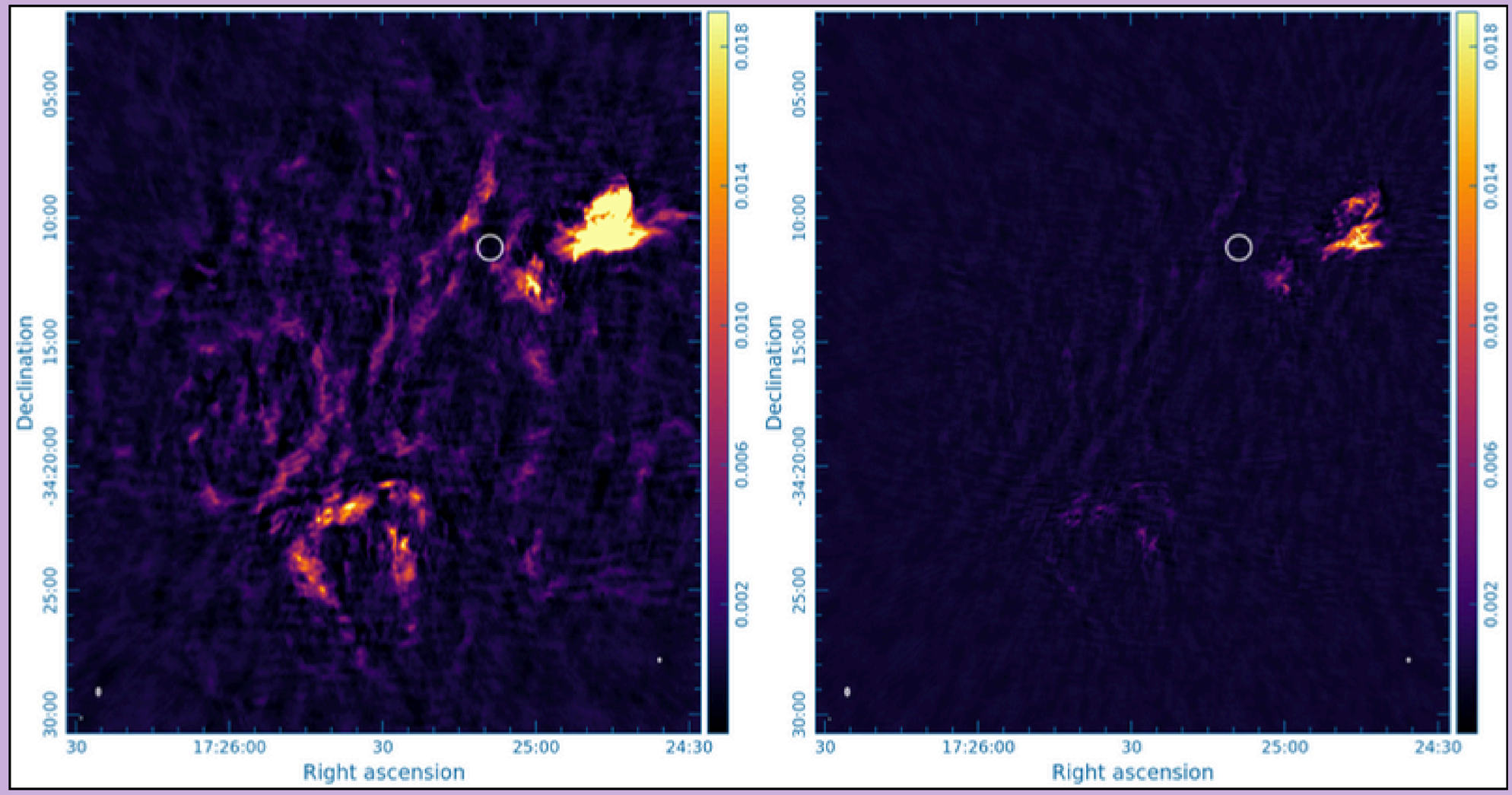
Band 5 (1260 MHz)

Source	Angular resolution	rms [μJy/beam]	Angular resolution	rms [μJy/beam]
WR 87	-	-	3.8" x 1.8"	25
WR 93	8.2" x 3.5"	200	3.5" x 1.9"	97
WR 98a	5.9" x 3.4"	73	4.0" x 1.7"	23
WR 106	5.7" x 3.7"	46	2.9" x 2.0"	23
WR 110	5.6" x 3.6"	40	2.6" x 2.1"	21

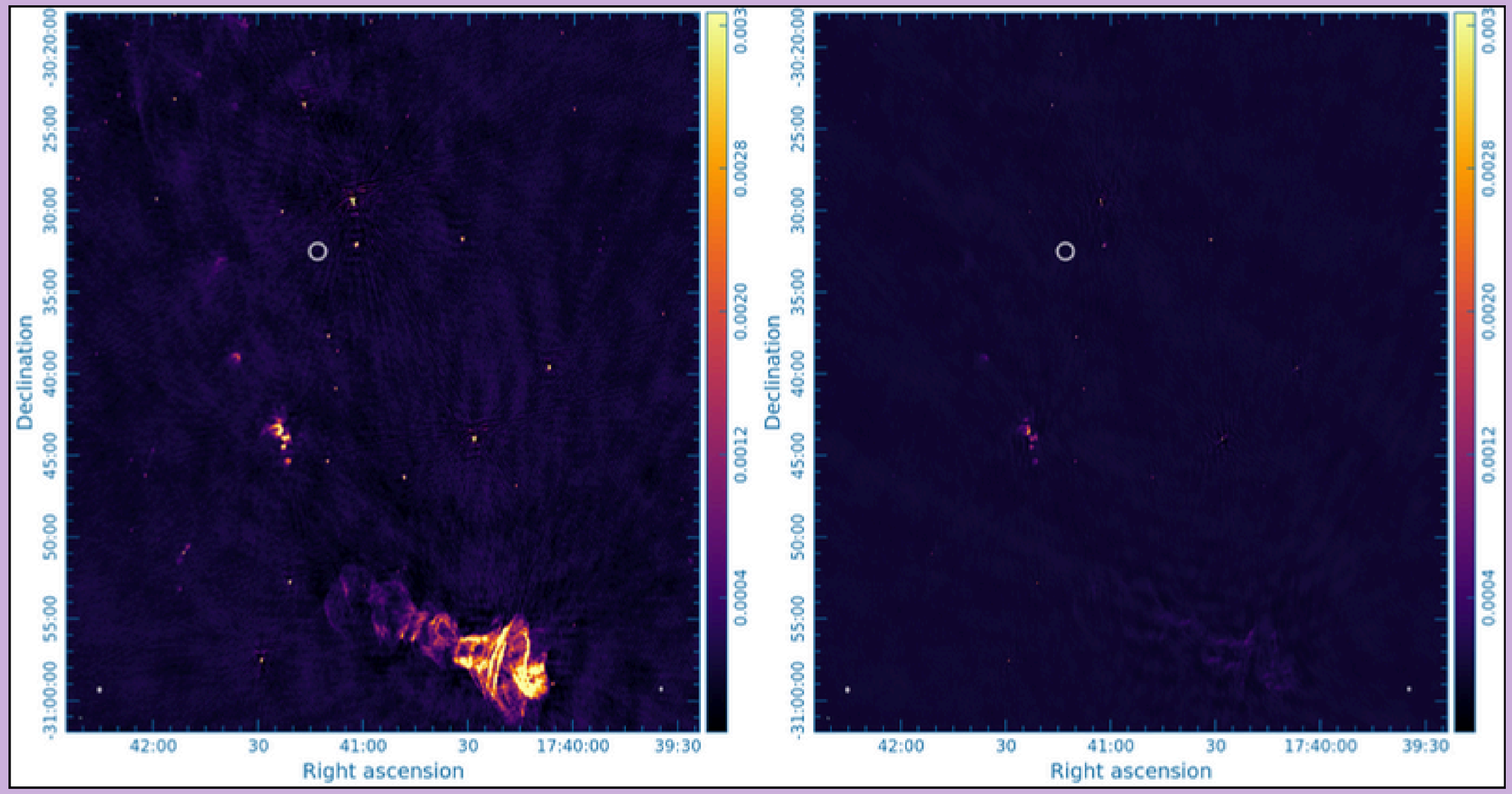
WR 87 - Band 5


Declination
06:00
04:00
02:00
-39:00:00
58:00
56:00
54:00
52:00
-38:50:00
48:00
46:00
21:00
30
17:20:00
30
19:00
30
18:00
Right ascension
0.0019
0.0015
0.0011
0.0007
0.0003
-0.0001

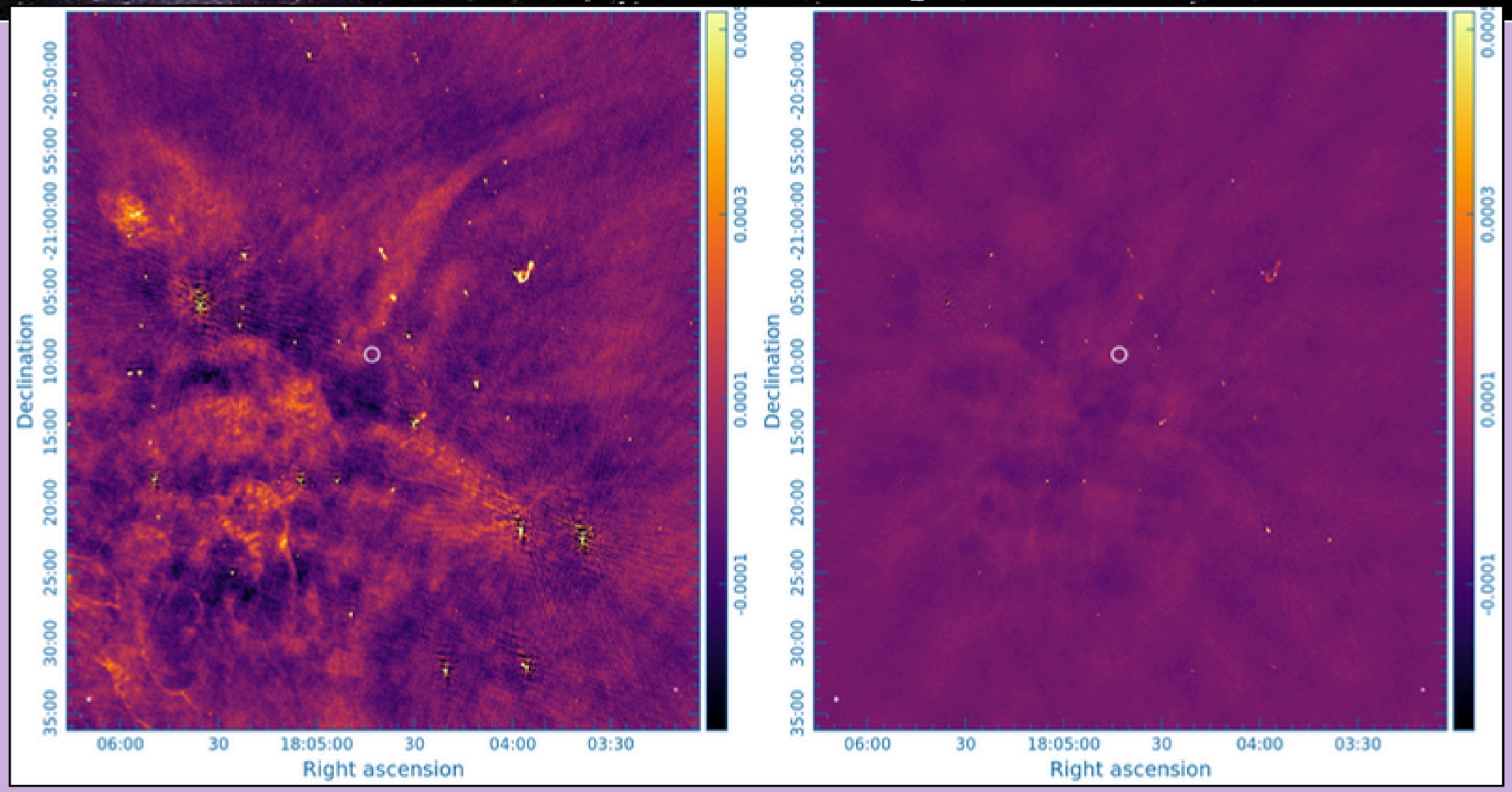
WR 93 – Band 4 / Band 5



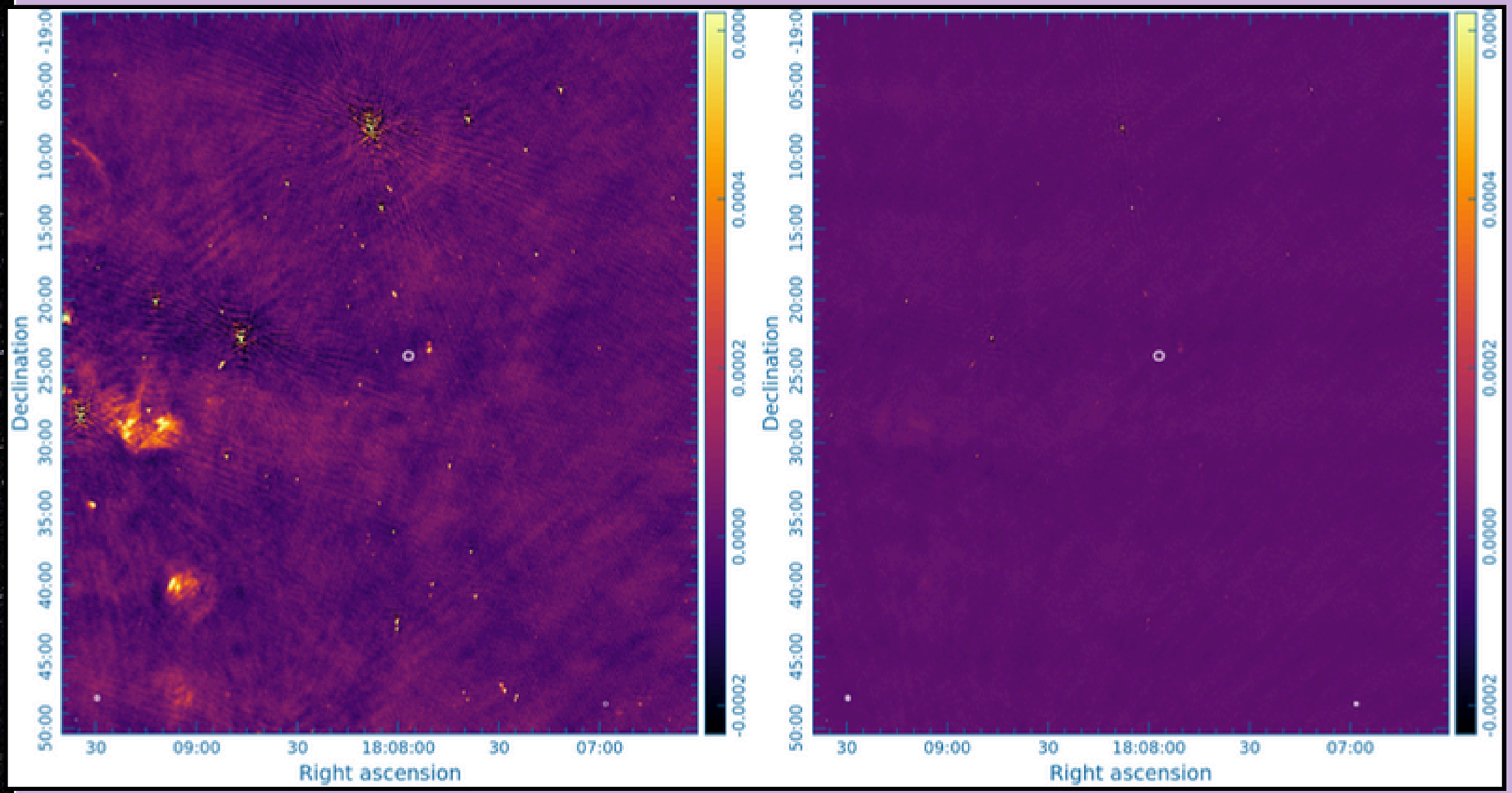
WR 98a – Band 4 / Band 5



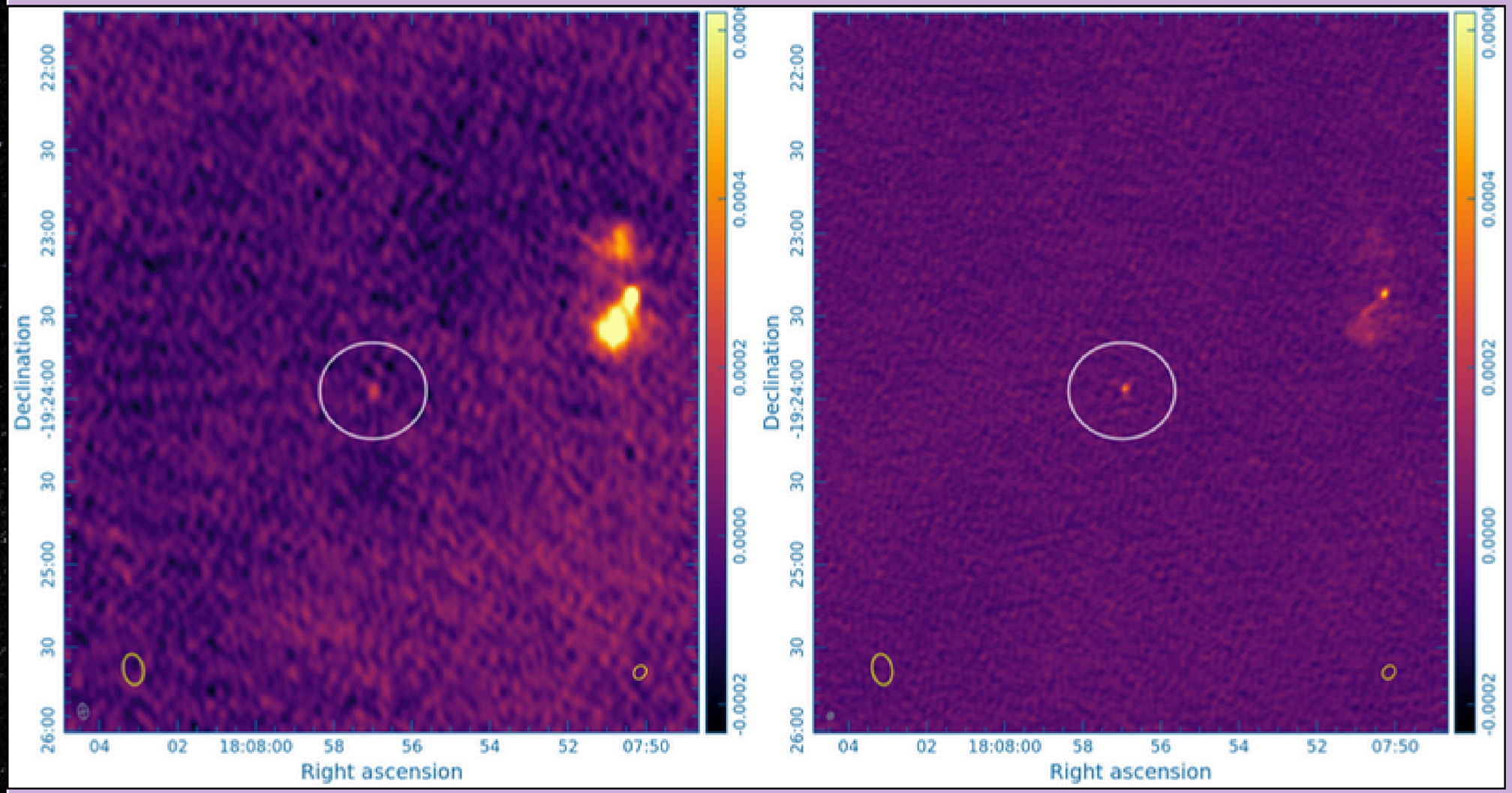
WR 106 – Band 4 / Band 5



WR 110 – Band 4 / Band 5



WR 110 – Band 4 / Band 5



GMRT Observations - Preliminary

Source	Sv [mJy] - Band 4	Sv [mJy] - Band 5
WR 87	-	< 0.075
WR 93	< 0.6	< 0.291
WR 98a	< 0.219	< 0.069
WR 106	< 0.138	< 0.069
WR 110	< 0.12	0.49 +/- 0.05

Other observations

This work

Source	Sv [mJy] - Band 5	Sv [mJy] - 1.4 GHz	Sv [mJy] - 4.9 GHz	Sv [mJy] - 8.4 GHz	Sv [mJy] - 15 GHz
WR 87	< 0.075	< 1.26	< 0.48	< 0.24	
WR 93	< 0.291		0.9 +/- 0.2		
WR 98a	< 0.069	< 0.36	0.37 +/- 0.07, < 0.39	0.47 +/- 0.05, 0.60 +/-0.05	0.64 +/- 0.11
WR 106	< 0.069			< 0.17	
WR 110	0.49 +/- 0.05		1.17 +/- 0.04		

Non-detection of NT emission

- The WR stars are not in binary systems
- The WR stars are in a long-period system and far from periastron
- The WR stars are in a close binary system and the synchrotron emission is affected by FFA

Saha, A. et al. 2023, MNRAS

Non-detection of thermal emission

Estimation of the expected thermal Flux density of the winds (due to Free-Free emission) → predicted flux density values

Source	Sv(ff) [mJy] - Band 4	Sv(ff) [mJy] - Band 5
WR 87	0.4	0.54
WR 93	0.42	0.58
WR 98a	0.18	0.24
WR 106	0.09	0.12
WR 110	1.28	1.75

Non-detection of thermal emission

- For WR93, WR98a and WR 106, in Band 4:

  $S\nu(ff) < S\nu(3\sigma)$ → agreement with a non-detection

- For WR93, WR98a and WR 106 and WR87 in Band 5:

  $S\nu(ff) > S\nu(3\sigma)$ → we should have had a detection, overestimation of mass-loss rate?

- For WR 110 in Band 5:

  $S\nu(ff) \sim 3 * S\nu(measure)$ → pure ff emission, overestimation of mass-loss rate?

Conclusions

- No observational evidence of synchrotron radiation/ binarity
- Upper limits in the cases of non-detection, Flux Density for WR110 B5
- First ever observations in B4, for some targets in B5

What is next?

- Re-run CAPTURE, consolidate the results
- Target selection: new sample of (known) binary systems

Thank you!

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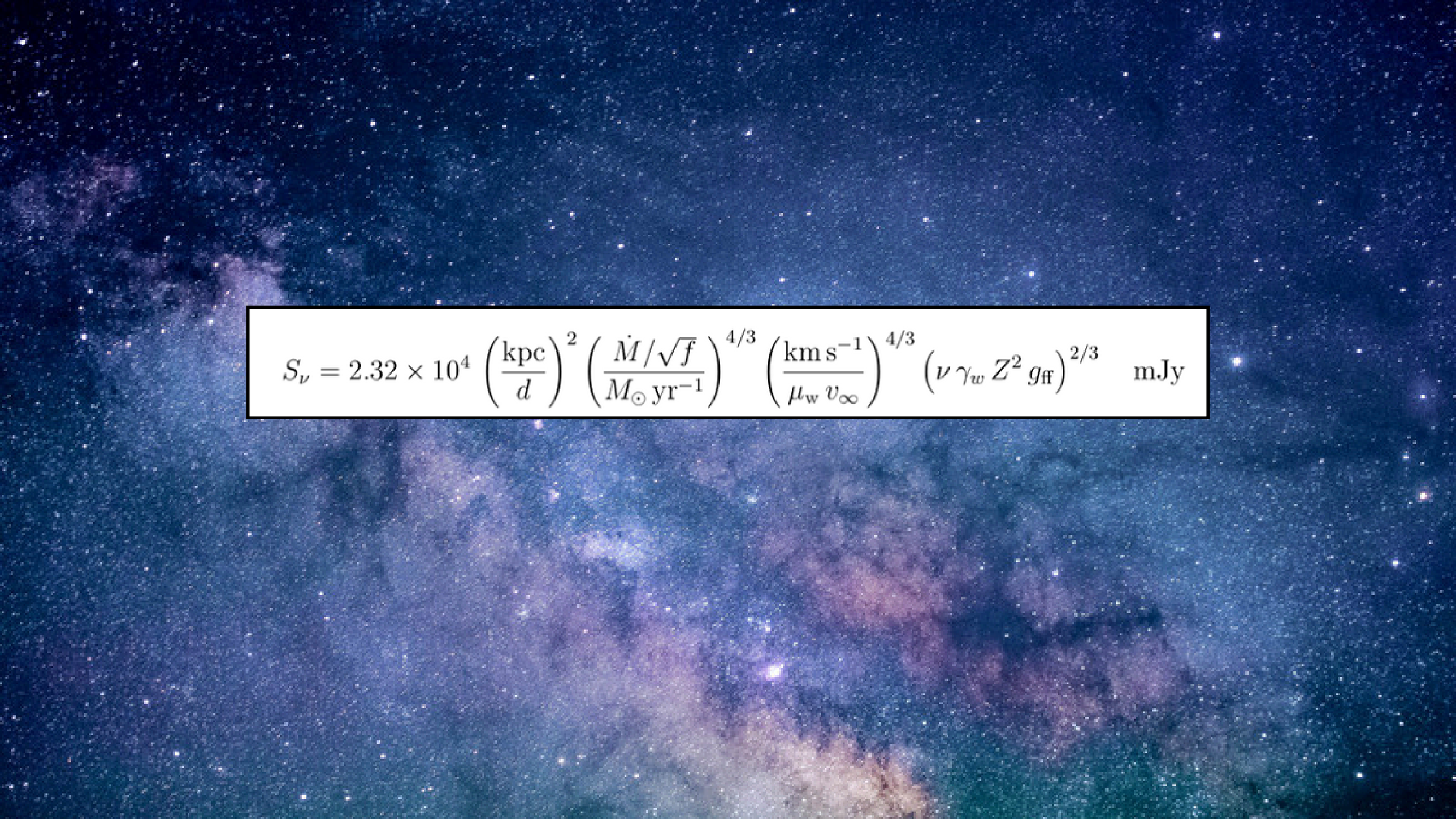

$$S_\nu = 2.32 \times 10^4 \left(\frac{\mathrm{kpc}}{d}\right)^2 \left(\frac{\dot{M}/\sqrt{f}}{M_\odot\,\mathrm{yr}^{-1}}\right)^{4/3} \left(\frac{\mathrm{km\,s}^{-1}}{\mu_\mathrm{w}\,v_\infty}\right)^{4/3} \left(\nu\,\gamma_w\,Z^2\,g_\mathrm{ff}\right)^{2/3} \quad \mathrm{mJy}$$