STAR
Space sciences, Technologies and Astrophysics Research

LIÈGE université

Prospects for radio observations of Particle-Accelerating Colliding-Wind Binaries with the GMRT

Michaël De Becker
Space sciences, Technologies, and Astrophysics Research (STAR) Institute, University of Liège, Belgium

Ishwara Chandra C. H.
National Center for Radio Astronomy (NCRA) – TIFR, Pune, India

Paula Benaglia
Universidad Nacionale de La Plata and Instituto Argentino des Radioastronomia, Argentina

Outline

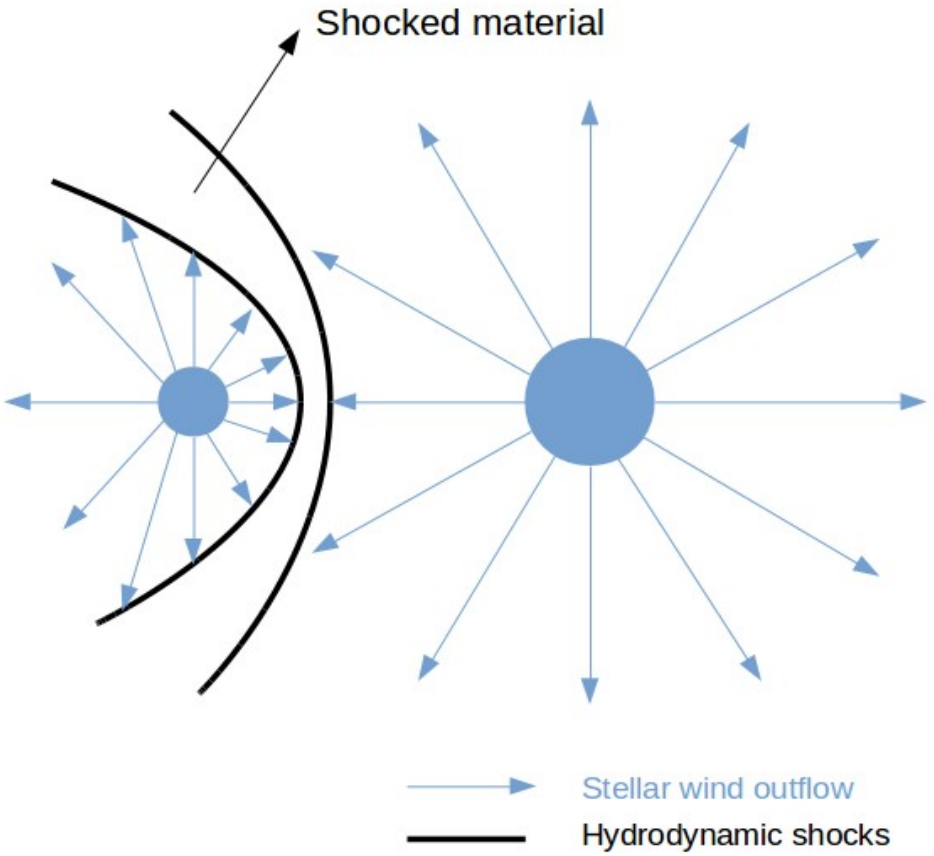
A few words on PACWBs

Synchrotron emission from PACWBs

Expectations from GMRT observations

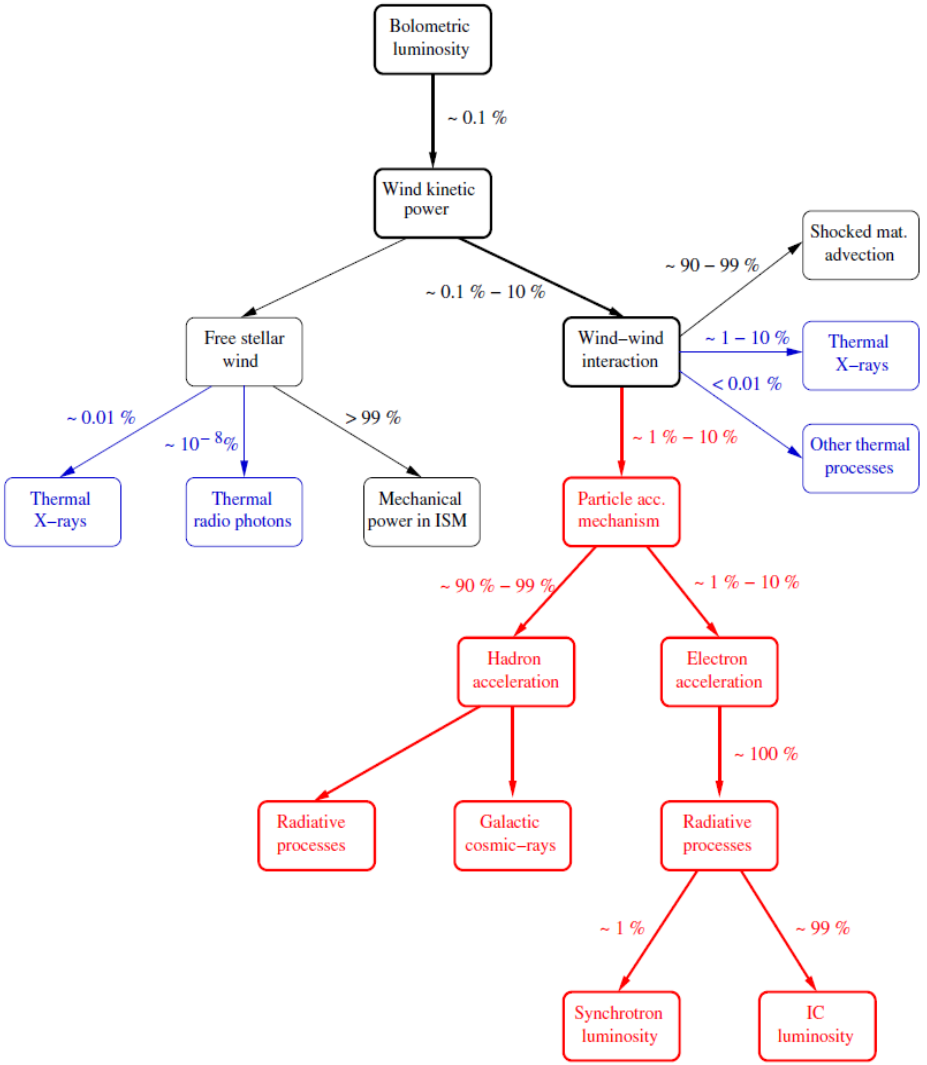
Concluding remarks

A few words on PACWBs



- Systems made of massive stars (O, B, WR…)
- Multiplicity is a crucial feature (binaries, triple and higher multiplicity…)
- Variability on the orbital time-scale is very important !
- Strong stellar winds collide and create strong shocks
- Shock physics is important in these systems, including particle acceleration (Diffusive Shock Acceleration, DSA)
- The existence of relativistic particles allows for non-thermal emission processes to operate

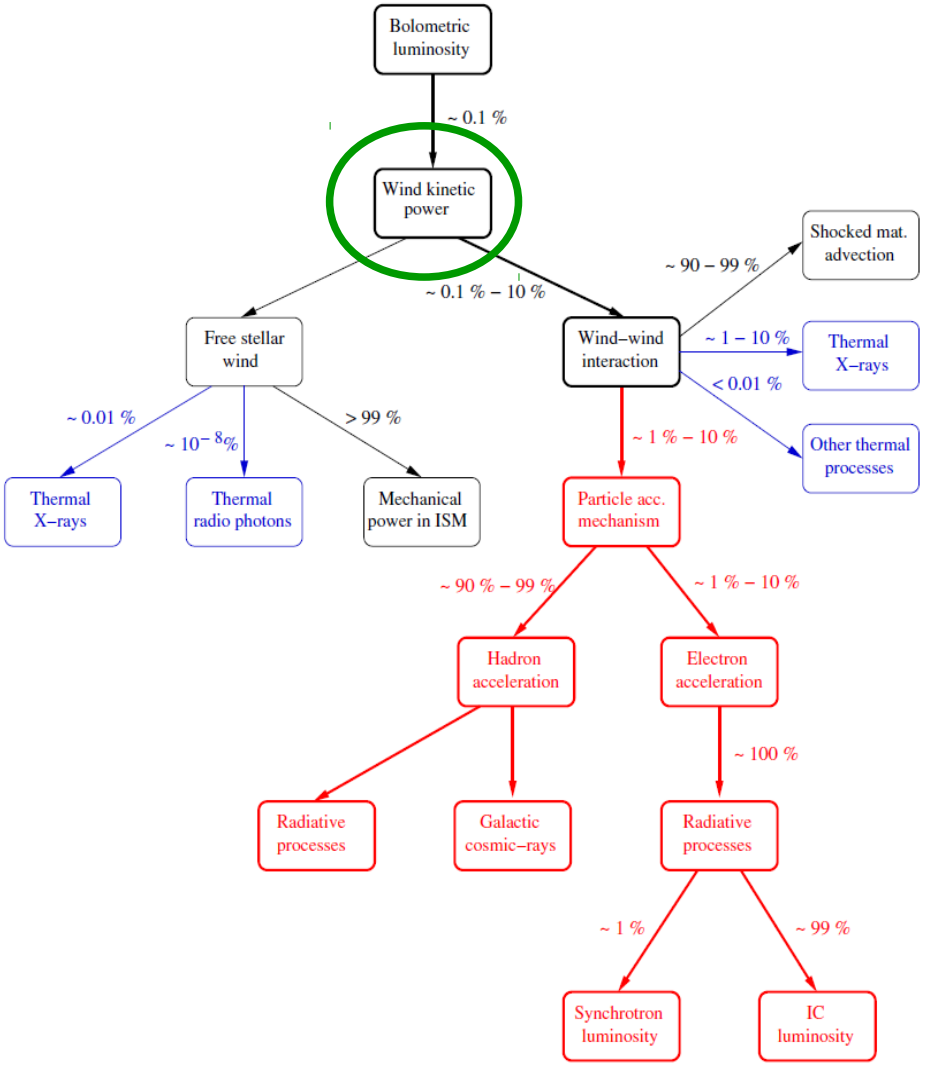
A few words on PACWBs



Energy budget of PACWBs

De Becker & Raucq 2013, A&A, 558, A28

A few words on PACWBs

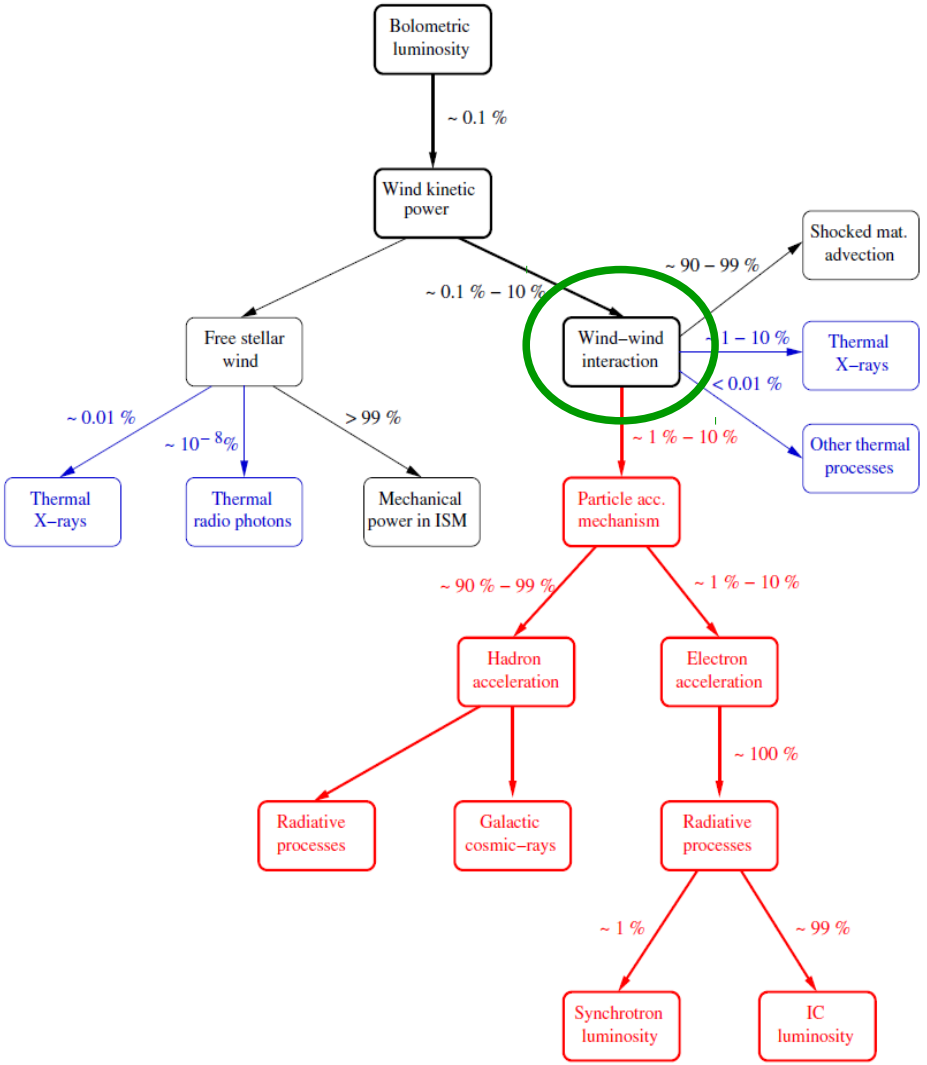


Energy budget of PACWBs

De Becker & Raucq 2013, A&A, 558, A28

- Mechanical energy from the stellar winds, driven by the huge luminosity

A few words on PACWBs

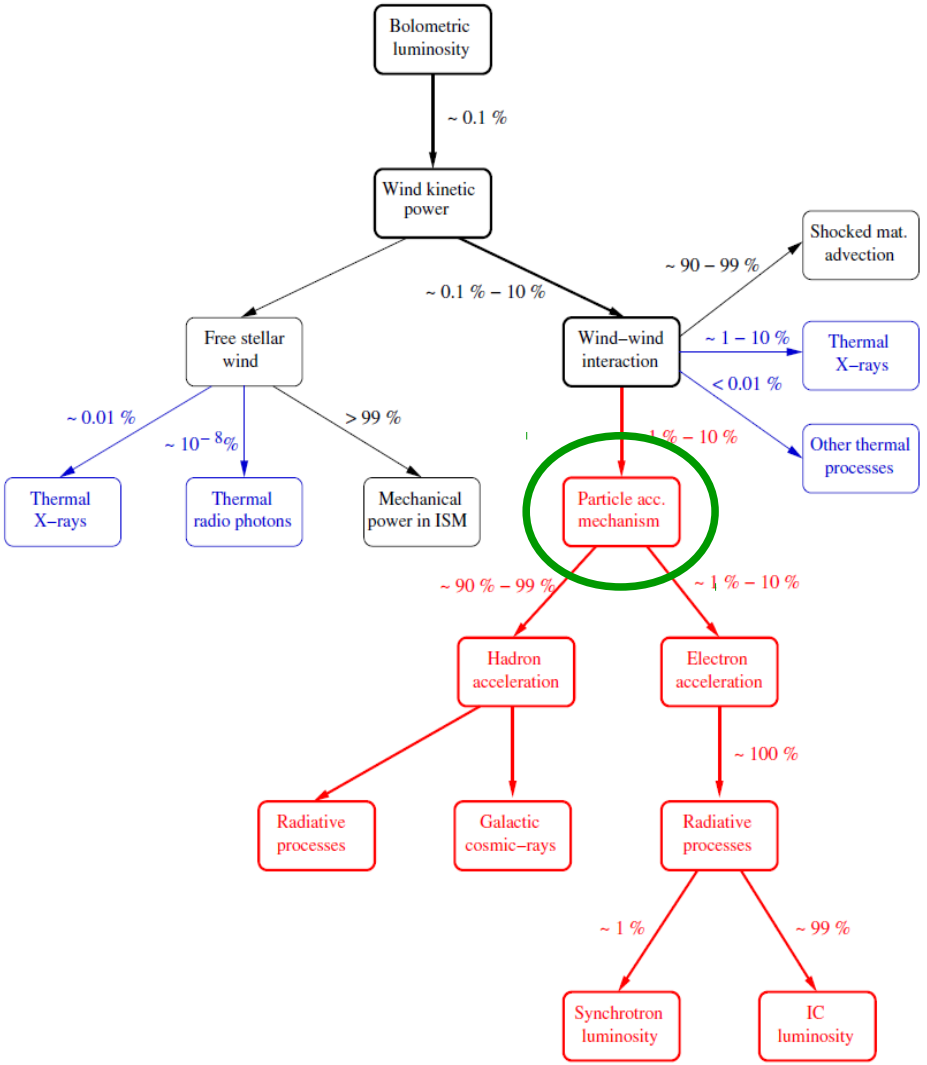


Energy budget of PACWBs

De Becker & Raucq 2013, A&A, 558, A28

- Mechanical energy from the stellar winds, driven by the huge luminosity
- Some kinetic power injected into the interaction region

A few words on PACWBs

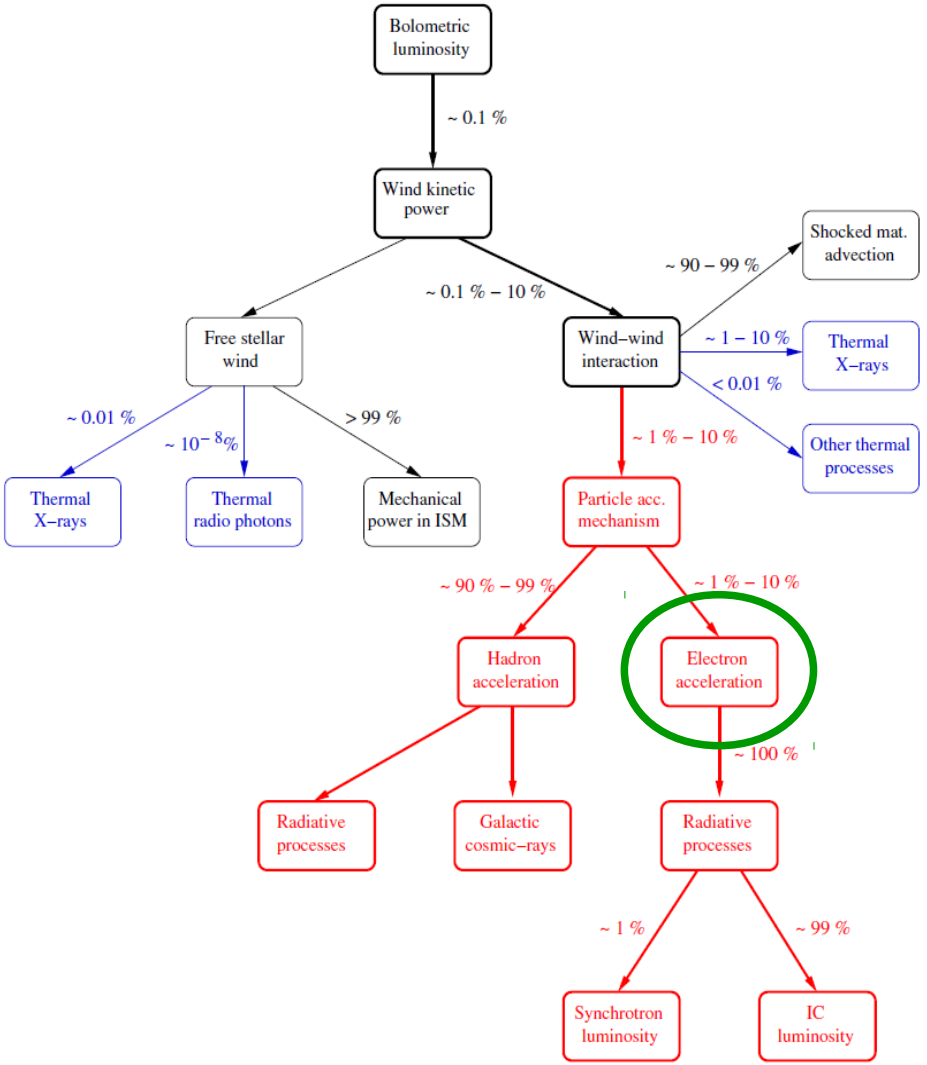


Energy budget of PACWBs

De Becker & Raucq 2013, A&A, 558, A28

- Mechanical energy from the stellar winds, driven by the huge luminosity
- Some kinetic power injected into the interaction region
- A fraction of that energy is used for particle acceleration (Diffusive Shock Acceleration)

A few words on PACWBs

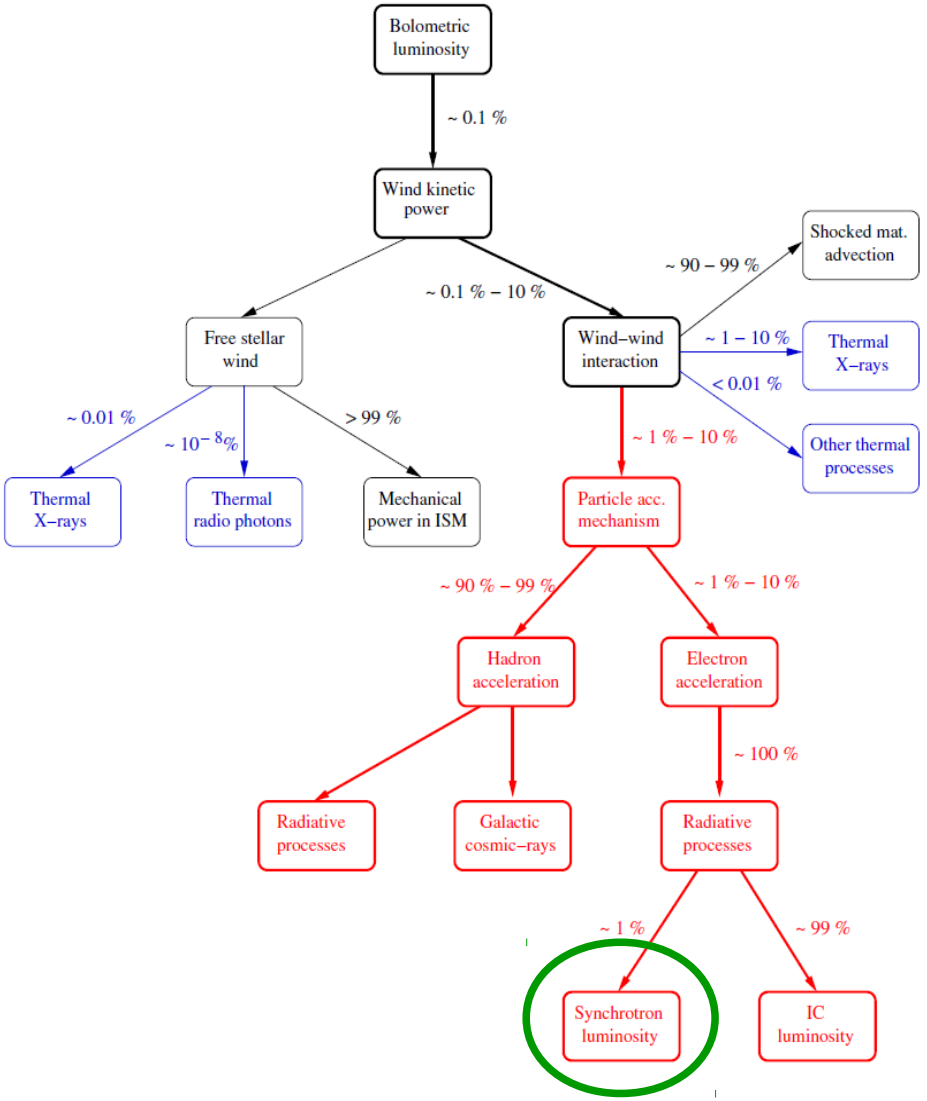


Energy budget of PACWBs

De Becker & Raucq 2013, A&A, 558, A28

- Mechanical energy from the stellar winds, driven by the huge luminosity
- Some kinetic power injected into the interaction region
- A fraction of that energy is used for particle acceleration (Diffusive Shock Acceleration)
- Some of that energy in injected into relativistic electrons

A few words on PACWBs

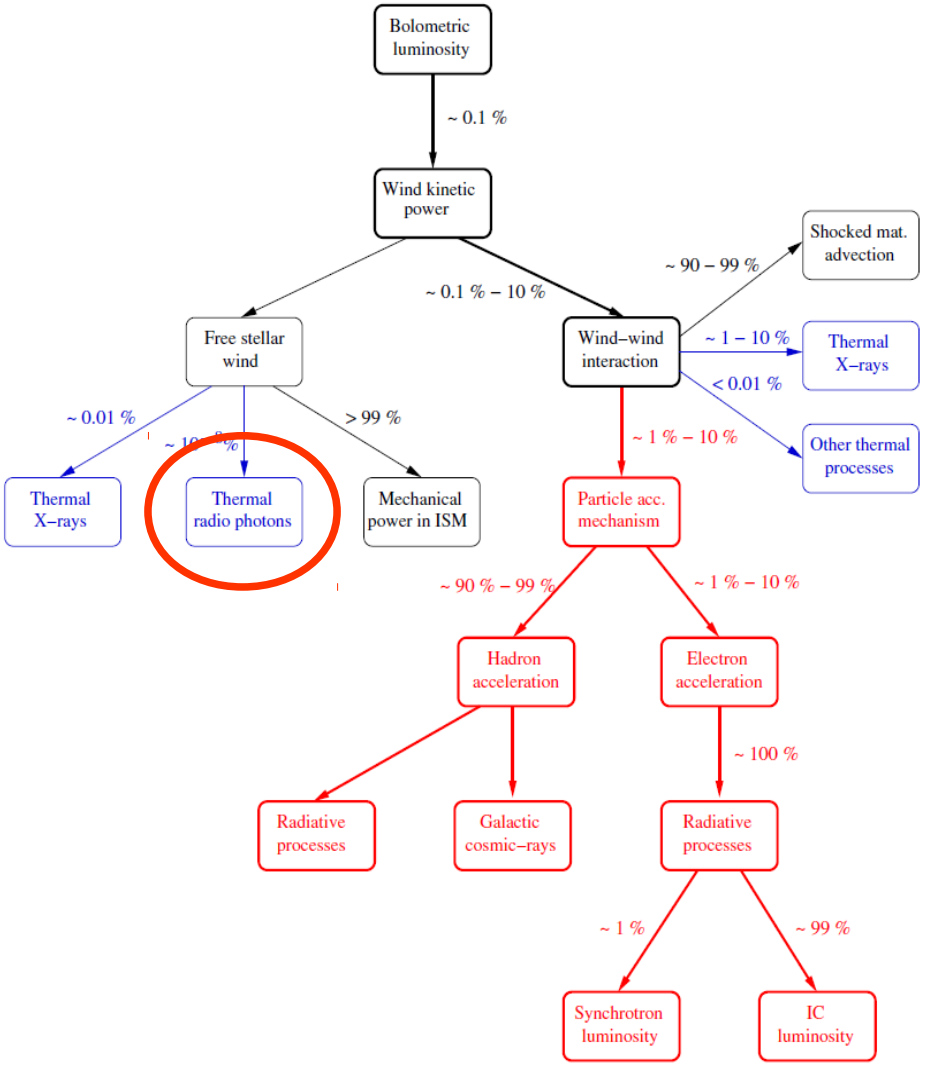


Energy budget of PACWBs

De Becker & Raucq 2013, A&A, 558, A28

- Mechanical energy from the stellar winds, driven by the huge luminosity
- Some kinetic power injected into the interaction region
- A fraction of that energy is used for particle acceleration (Diffusive Shock Acceleration)
- Some of that energy in injected into relativistic electrons
- A fraction of the energy in non-thermal electrons is converted into synchrotron radiation

A few words on PACWBs



Energy budget of PACWBs

De Becker & Raucq 2013, A&A, 558, A28

- Mechanical energy from the stellar winds, driven by the huge luminosity
- Some kinetic power injected into the interaction region
- A fraction of that energy is used for particle acceleration (Diffusive Shock Acceleration)
- Some of that energy in injected into relativistic electrons
- A fraction of the energy in non-thermal electrons is converted into synchrotron radiation
- Thermal radio emission is also present !

Outline

A few words on PACWBs

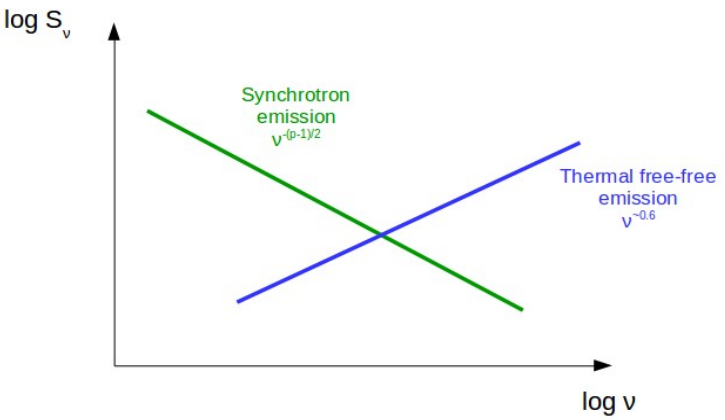
Synchrotron emission from PACWBs

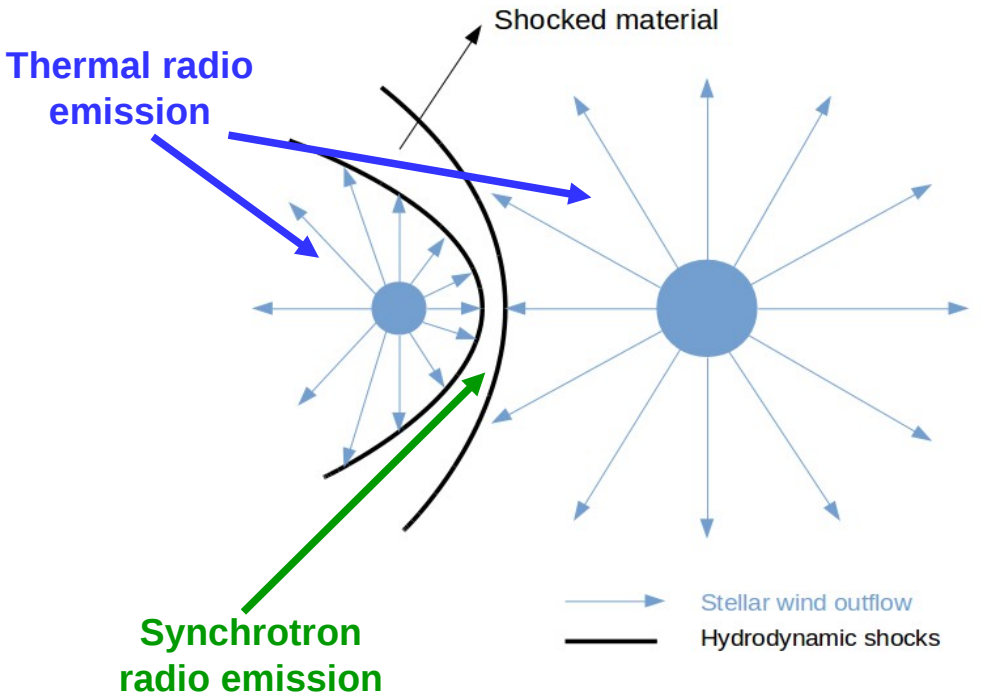
Expectations from GMRT observations

Concluding remarks

Synchrotron emission from PACWBs

$$S_\nu^{obs} = S_\nu^{th} + S_\nu^{syn} e^{-\tau_\nu^{ff}}$$





The radio spectrum is a combination of thermal (optically thick) emission from the stellar winds, and synchrotron emission produced in the colliding wind region (composite spectrum!) → spectral index can be neither typical of pure NT or T emission

$$\alpha = \frac{\ln\left(\frac{S_{\nu,1}}{S_{\nu,2}}\right)}{\ln\left(\frac{\nu_1}{\nu_2}\right)}$$

Synchrotron emission from PACWBs

Synchrotron emission is the most efficient tracer of particle acceleration in massive binaries !
→ valuable probe for non-thermal physics in massive binaries

- Spectral index
- Brightness temp.
- Variability

$\alpha < 0.6$ (for S_ν prop. to ν^α)
→ deviation w.r.t. pure thermal emission

Component with $T_B \sim 10^6 - 10^7$ K

Emission related to the colliding-wind region
- physical conditions are phase dependent
- orientation effect due to free-free absorption

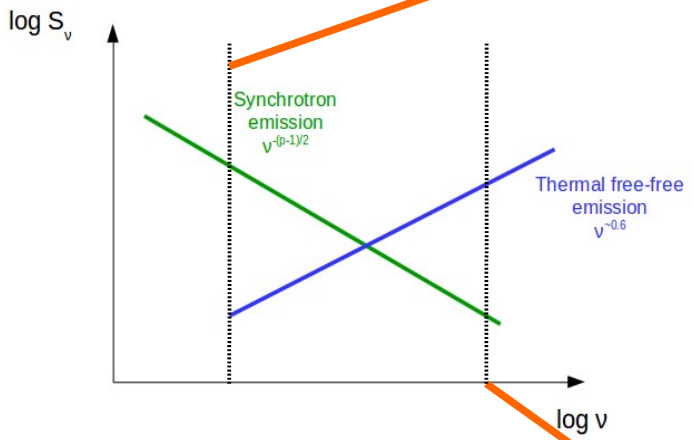
→ Catalogue of ~40 systems **(De Becker & Raucq 2013, A&A, 558, A28)**

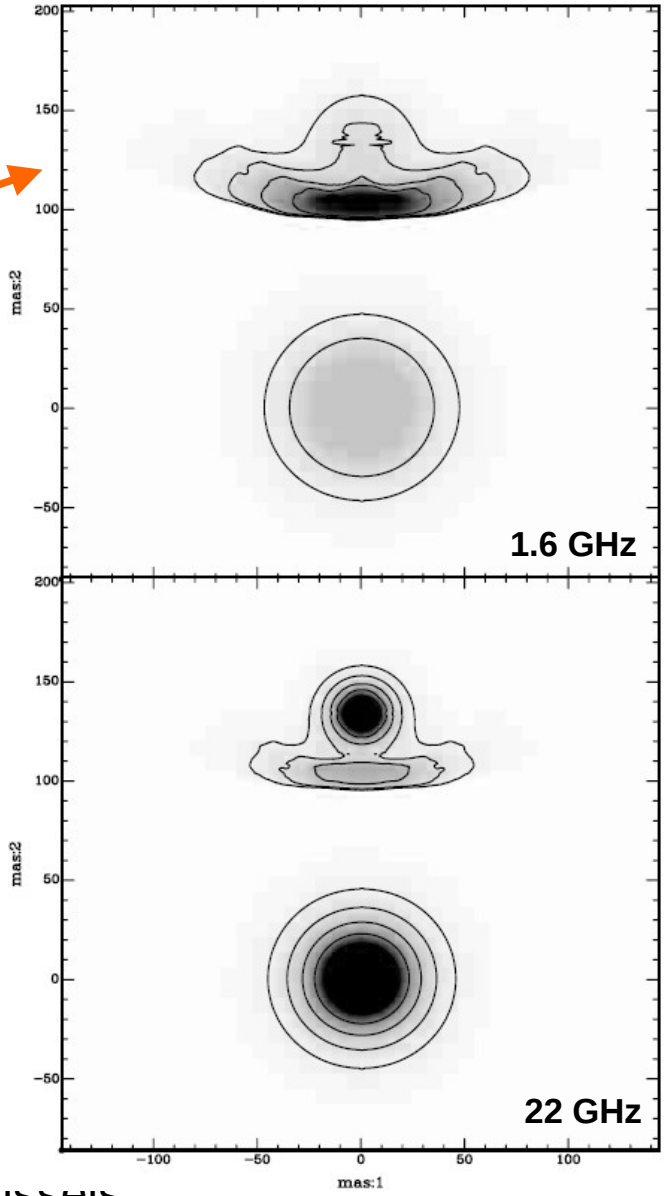
http://www.astro.ulg.ac.be/~debecker/pacwb/

Synchrotron emission from PACWBs

Simulations of radio emission from colliding-wind binaries **(Dougherty et al. 2003, A&A, 409, 217)**

Typical case of a WR + O system





Very relevant science case for GMRT !

→ **Anandmayee Tej's talk (on behalf of I. Chandra) on Thursday morning**

Outline

A few words on PACWBs

Synchrotron emission from PACWBs

Expectations from GMRT observations

Concluding remarks

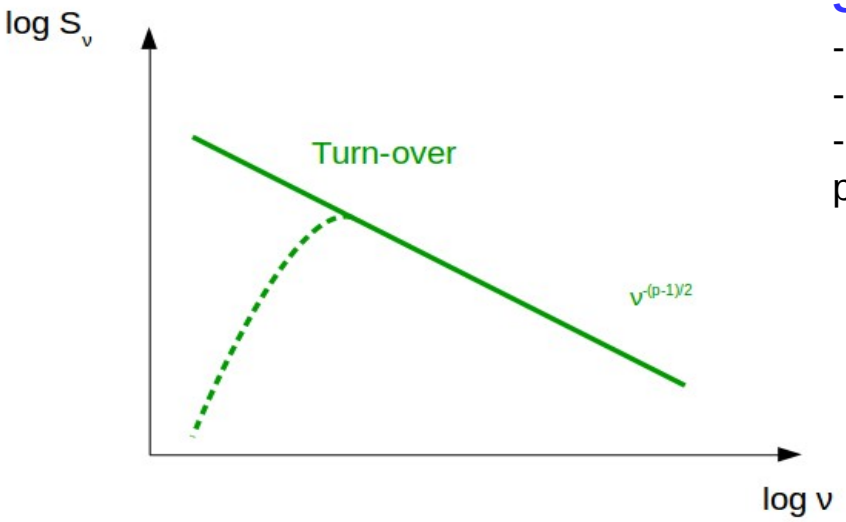
Expectations from GMRT observations

One has to consider...

- The optically thin synchrotron spectrum should cover a range of several orders of magnitude in frequency
- The optically thin synchrotron emission is increasing toward lower frequencies
- Most measurements to date were made at frequencies of 1 … 10 GHz, with flux densities in the 0.1 … 10 mJy range (Benaglia+2001, 2003, 2007, 2006; Blomme+2005, 2006, 2007, 2010, Setia Gunawan+2000, 2003 ; Scuderi+1998; Williams+1994, 1990 …...)
- The spectrum at lower frequencies (< 1 Ghz) can be extrapolated from the knowledge of the synchrotron spectrum measured at 1 … 10 GHz
- At low frequencies, turn-over processes have to be anticipated

Expectations from GMRT observations

- Turn-over processes



Synchrotron Self-Absorption (SSA)
- optically thick spectrum with $\alpha = 5/2$
- active if the number density of NT e is high enough
- not dominant for PACWBs (may contribute for shorter period systems : De Becker 2018, A&A, accepted on 8 Oct. 2018)

Razin-Tsytovitch effect
- suppression of the effect of beaming for NT electrons embedded in a thermal plasma
- strong suppression of synchrotron emission below a cut-off frequency
- may contribute for PACWBs

Free-free absorption (FFA)
- absorption of radio photons by thermal electrons very abundant in the wind plasma
- highly dependent on stellar separation, system orientation, wind properties…
(e.g. Williams et al. 1990, MNRAS, 243, 662 ; Dougherty et al. 2003, A&A, 409, 217)
- very important for PACWBs, origin of a strong phase-locked variability

Expectations from GMRT observations

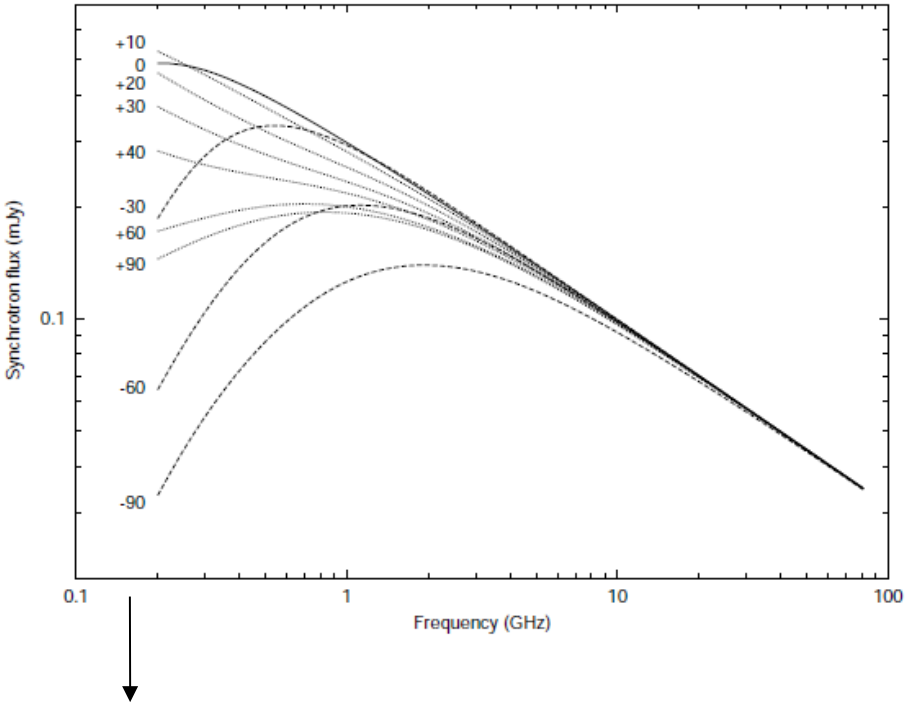
Simulations of radio emission from colliding-wind binaries **(Dougherty et al. 2003, A&A, 409, 217)**

Effect of FFA on the spectrum, as a function of the inclination of the system

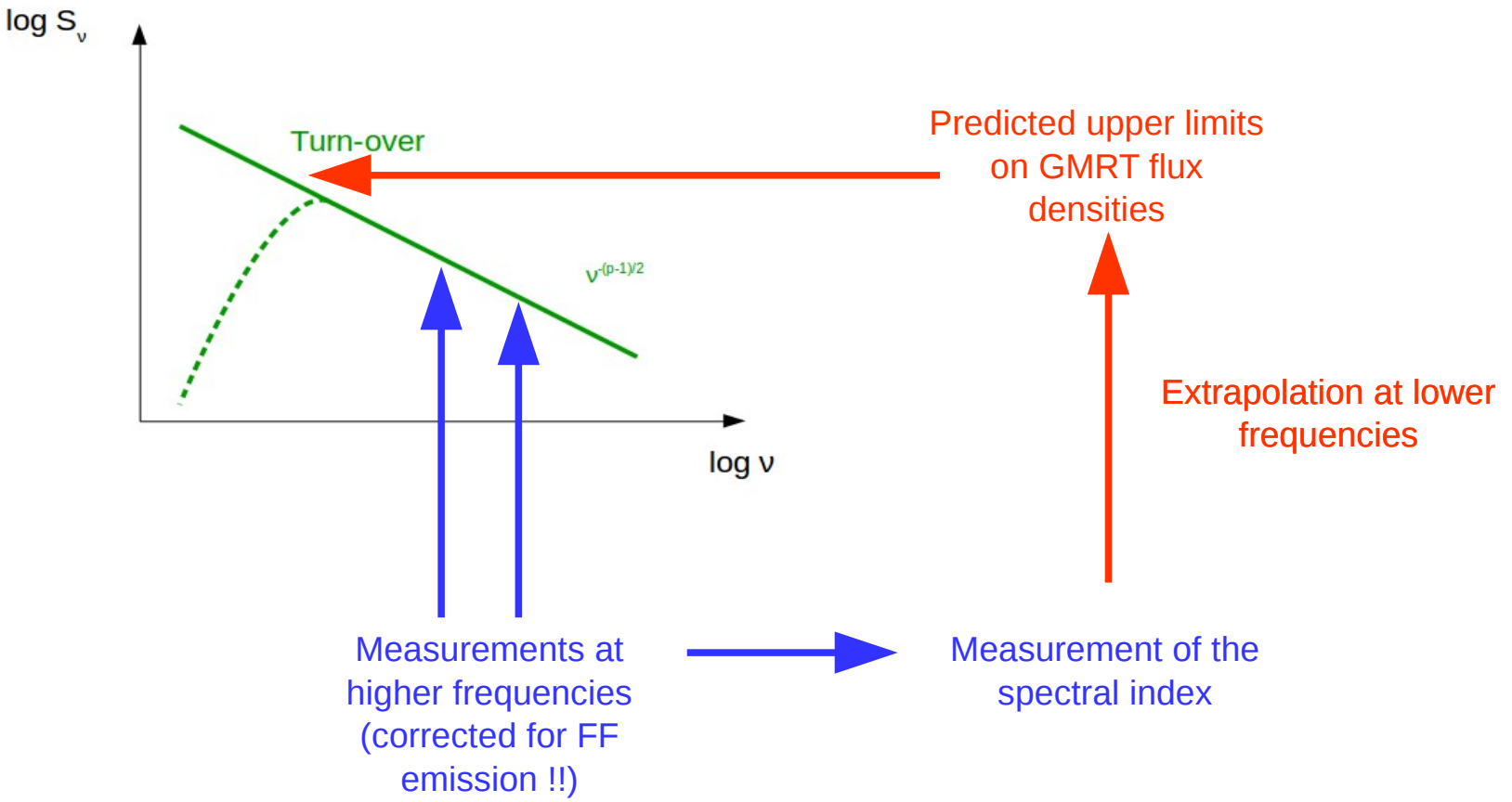
- i < 0° : WR wind in front
- i > 0° : O wind in front

→ orientation effects are very important !

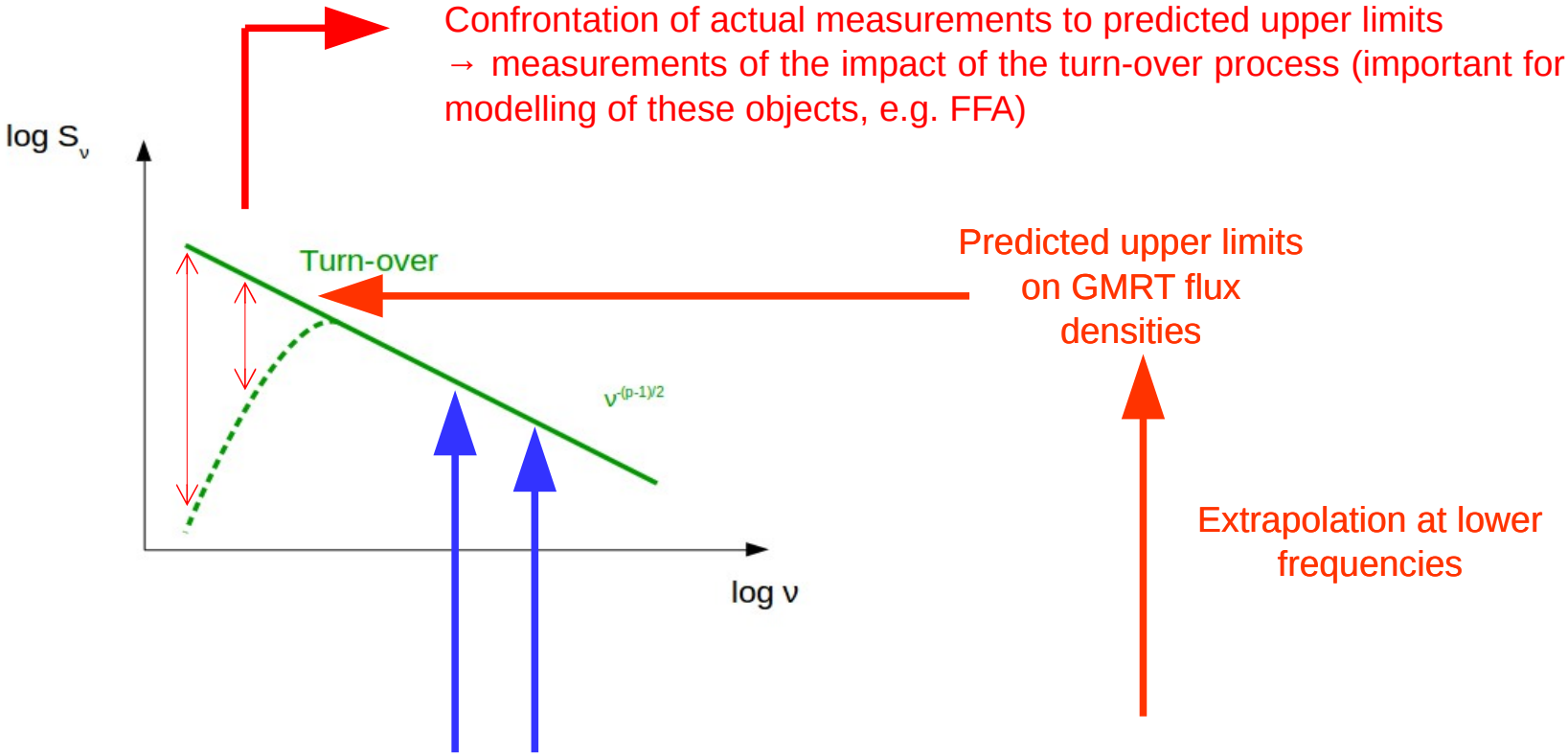
At some lower frequencies, the intrinsic synchrotron emission may be high, but severely attenuated by FFA



Expectations from GMRT observations



Expectations from GMRT observations



Expectations from GMRT observations

High sensitivity observations are important …

… for the study of known PACWBs

- Measurement of rather faint sources, even below the 0.1 mJy level (remember the energy budget discussion !)

- Measurement of synchrotron emission below the turn-over frequency (whatever the process responsible for the turn-over)
  → measure the slope/trend of the inverted spectrum

Expectations from GMRT observations

High sensitivity observations are important …

… for the study of known PACWBs

- Measurement of rather faint sources, even below the 0.1 mJy level (remember the energy budget discussion !)
- Measurement of synchrotron emission below the turn-over frequency (whatever the process responsible for the turn-over)
  → measure the slope/trend of the inverted spectrum

… for the identification of additional PACWBs

- Measurement of rather faint sources, even below the 0.1 mJy level (remember the energy budget discussion !)
- Exploration of a spectral domain dominated by synchrotron emission
  → expectation to improve our knowledge of the fraction of PACWBs among CWBs
  (De Becker, Benaglia, Romero & Peri 2017, A&A, 600, A47)

Outline

A few words on PACWBs

Synchrotron emission from PACWBs

Expectations from GMRT observations

Concluding remarks

Concluding remarks

- GMRT constitutes a relevant, powerful tool to study non-thermal physics in PACWBs
- Observations at 1...10 GHz frequencies can be used to constrain expected emission at GMRT frequencies
- Turn-over processes must be considered in any analysis of low frequency emission from PACWBs, in particular FFA
- The high sensitivity of GMRT (in particular after upgrading) is essential to detect PACWBs even below the 0.1 mJy level
- Such measurements are very important for the modelling of the physics of PACWBs
- Wide field observations with GMRT should lead to the identification of additional members of the catalogue of PACWBs

Concluding remarks

- GMRT constitutes a relevant, powerful tool to study non-thermal physics in PACWBs
- Observations at 1...10 GHz frequencies can be used to constrain expected emission at GMRT frequencies
- Turn-over processes must be considered in any analysis of low frequency emission from PACWBs, in particular FFA
- The high sensitivity of GMRT (in particular after upgrading) is essential to detect PACWBs even below the 0.1 mJy level
- Such measurements are very important for the modelling of the physics of PACWBs
- Wide field observations with GMRT should lead to the identification of additional members of the catalogue of PACWBs

One personal comment about BINA...

One personal comment about BINA...

Thank you !