Investigating the role of pre-supernova massive stars in the acceleration of galactic cosmic rays

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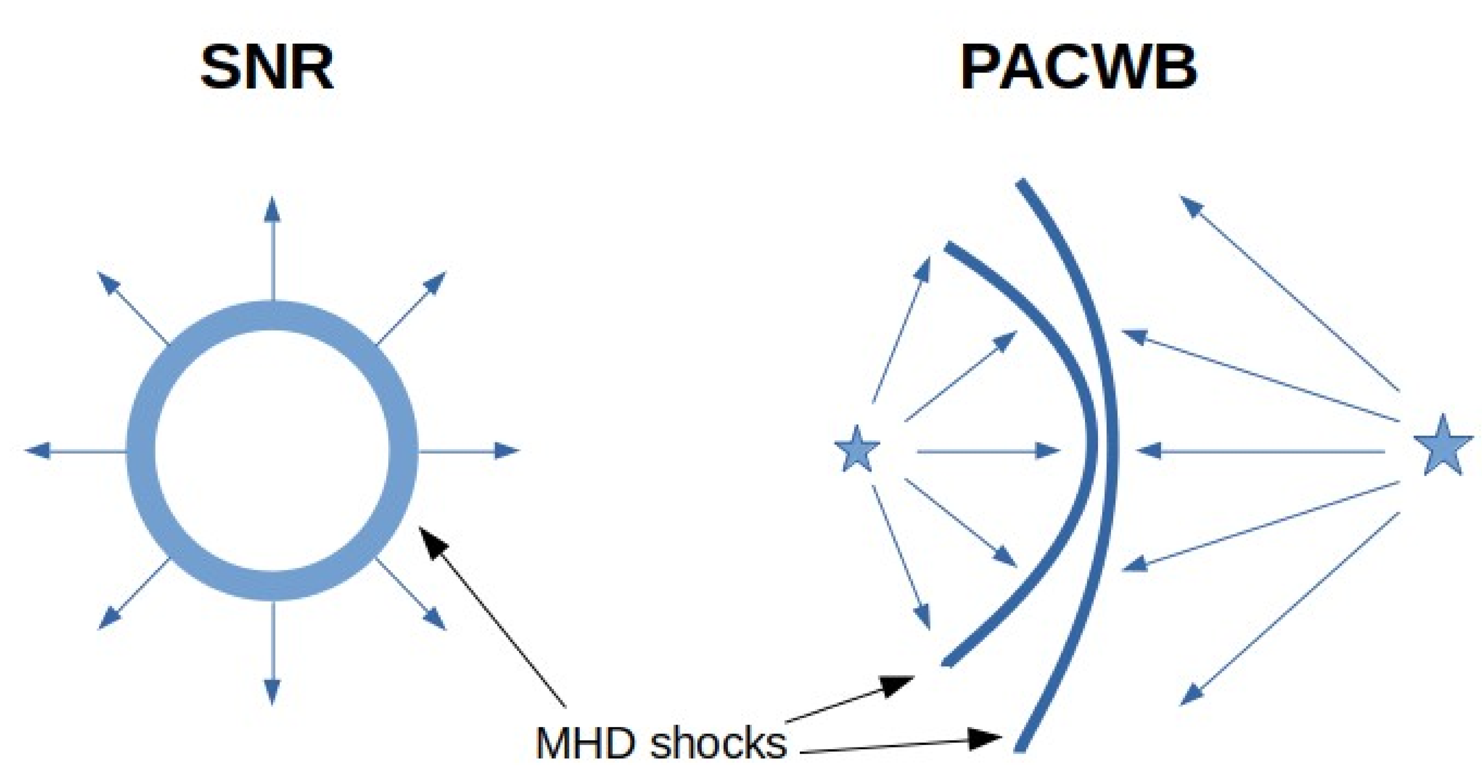
Abstract: ***Galactic cosmic rays (GCRs) constitute a significant part of the energy budget of our galaxy, and the study of their accelerators is of high importance in modern astrophysics. Their main sources are likely supernova remnants (SNR), consisting in an sudden outflow of large amounts of material at speeds of several thousands of km/s. These objects are capable to convert a part of their mechanical energy into charged particle acceleration. However, even though the mechanical energy reservoir of SNRs is promising, a conversion rate into particle energy of 10 to 20% is necessary to feed the population of GCRs. Such an efficiency is however not guaranteed. Complementary sources deserve thus to be investigated. This communication aims at addressing the question of the contribution to the acceleration of GCRs by pre-supernova massive stars.***

Supernova remnants (SNRs)

- Supernovae of any type (core collapse or runaway fusion) inject a substantial amount of mechanical energy in the ISM → prominent laboratories for shock physics!
- Conditions are fulfilled for Diffusive Shock Acceleration (DSA, **[1]**) to operate efficiently → privileged environments to accelerate GCRs
- SNRs are very likely significantly contributing to the population of GCRs. They may be the only significant contributor provided 10 to 20% of the mechanical energy is injected into DSA **[2]**.
- **Such an efficiency is however not warranted, questioning the idea they constitute the only source of GCRs**



	SNR	PACWB
Total mechanical energy:	10^{51} erg (released by the SN)	10^{50} – 4 10^{51} erg (integrated over the pre-SN evolution)
Energy injected in shocks:	10^{51} erg	10^{49} – 4 10^{50} erg (~ 10% of wind energy)
Energy injection in CRs:	Decreasing as the SNR evolves; not very well determined	Steady over most of the pre-SN evolution. Up to 30% depending on conditions

Complementary sources of GCRs are worth investigating, and some requirements are identified:

1. The energy reservoir needs to be significant as compared to SNRs: *a valid energy budget must be made*

2. The complementary sources must be confirmed particle accelerators: *indicators of relativistic particles must be identified*

Particle-Accelerating Colliding-Wind Binaries (PACWBs)

- Binary or higher multiplicity systems made of hot, massive stars (O-type, early B-type, and their evolved counterparts such as Luminous Blue Variable and Wolf-Rayet stars): strong stellar winds with terminal velocities of 2000-3000 km/s, and high mass loss rates (10^{-7} – 10^{-5} solar mass/year)
  → high wind kinetic power feeding many physical processes!
- In multiple systems, their winds collide and produce strong shocks: shock physics is important!
- Diffusive Shock Acceleration is also likely responsible for the acceleration of particles up to relativistic velocities, as evidenced in about 50 systems, hence the Particle-Accelerating Colliding-Wind Binary status (De Becker & Raucq 2013, catalogue of PACWBs **[3], www.astro.uliege.be/~debecker/pacwb**).
- Most particle accelerators among massive binaries are identified through the detection of synchrotron radio emission **[e.g. 4,5,6,7,8,9]**.
- The integration of their wind kinetic power over their evolution time scale **[10]** leads to total energy of the same of order as SNRs.
- As a rough guess, the fraction of wind kinetic power injected into the wind collision is of the order of 10%.
- A key question is that of the injection rate into DSA. Recent models suggest it can amount up to 30% in some conditions **[11]**.

General strategy

- *The identification of PACWBs can be made through the detection of synchrotron radiation. This requires the observation of a large number of targets → better evaluation of the population* ***[12]***
- *Another requirement is to achieve a good census of binaries among massive stars. This is done notably through spectroscopic techniques, or high angular resolution imaging* ***[13,14]****.*

→ *The combination of multiplicity studies of massive stars, with intensive radio observations, is the key to address this question.*

Concluding remarks

Stellar wind collisions in binary systems are known to accelerate particles, thanks to their synchrotron emission in the radio domain. Their stellar winds are energy reservoirs less abundant than SNRs, but they are capable to sustain a high acceleration efficiency for millions of years (to be compared to a few thousand years for SNRs). Many radio observations are needed to identify a significant number of particle accelerators among massive stars, and make a decisive leap forward in our understanding of their contribution to the production of GCRs. The relevant approach includes observations at various frequencies and various angular scales, to optimize the identification efficiency. The exploration of this scientific question is meant to achieve a more global view of the origin of GCRs.

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