Particle acceleration in core-collapse supernova remnant expanding inside the wind bubble

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Results

Overview

Introduction Wind-bubble Diffusive Shock Acceleration Numerical Methods Results Conclusions



The bubble nebula, NGC 7635, HST 2016 bubble created by BD+60°2522 (\approx 44 M_{\odot})

[Credit:NASA, ESA, Hubble Heritage Team]

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| Introduction ●○ | Numerical Methods | Results 0000 | Conclusions |
|---------------------|-------------------|------------------------|-------------|
| Stellar wind bubble | | | |



Schematic diagram of wind bubble Weaver et al. [1977]

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 Mass loss during different evolutionary stages of massive star leads to create wind bubble

$$ho_{wind}(r) = rac{\dot{M}_{\star}(t)}{4\pi r^2 v_{wind}(t)}$$

- Massive star explodes as core-collapse supernova which evolves through the modified circumstellar medium (CSM) before the Interstellar medium (ISM)
- The complex environment of CSM, hydrodynamics and magnetic field should have impact on generated particle spectra and emission.





Applied Codes- Radiation Acceleration Transport Parallel Code (**RATPaC**) to study particle acceleration, **PLUTO** for hydrodynamics

Solve the equations

- in one dimensional spherical symmetry
- on a co-moving grid for CR transport equation, and turbulence

| Introduction | Numerical Methods | Results | Conclusions |
|------------------------------|-------------------|---------|-------------|
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| Diffusive Shock Acceleration | | | |



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| Introduction | Numerical Methods | Results | Conclusions |
|------------------------------|-------------------|---------|-------------|
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| Diffusive Shock Acceleration | | | |



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| Introduction | Numerical Methods | Results | Conclusions |
|-------------------------|--------------------------|---------|-------------|
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| Diffusive Shock Acceler | ation Model descriptions | | |

Hydrodynamics

- Evolution of wind bubbles created by progenitor stars with 20M_☉, 60M_☉ ZAMS mass using pre-calculated stellar evolutionary tracks (Groh et al. [2014] and Geneva grids of stellar evolution models).
 - ► Post Main-sequence evolution 20M_☉-Red Supergiant phase 60M_☉-Luminous Blue Variable +Wolf Rayet phases
- Introduced supernova explosion in pre-supernova CSM.

Diffusion coefficient prescriptions

- Bohm-like diffusion(D_r)= $\zeta \frac{v}{3}r_g(r, p)$; $\zeta = 10$ [time-independent]
- Alfvenic diffusion- $D_r = \frac{4v}{3\pi} r_g \frac{U_m}{E_w}$ [time-dependent]
 - U_m \Rightarrow energy density of ambient magnetic field

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| Introduction | Numerical Methods ○○○○○● | Results 0000 | Conclusions |
|-----------------------|-----------------------------|------------------------|-------------|
| CSM magnetic field (B |) | | |



| Introduction | Numerical Methods | Results ●000 | Conclusions |
|---------------|-------------------|-----------------|-------------|
| FS Parameters | | | |



| Introduction 00 | Numerical Methods | Results ○●○○ | Conclusions |
|------------------------|--------------------|-----------------|-------------|
| Spectra-Volume-average | ed FS downstream [| 60 <i>M</i> ⊙ | |

Bohm – like diffusion

Alfvenic diffusion



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| Introduction 00 | Numerical Methods | Results ००●० | Conclusions |
|------------------------|-------------------|-----------------|-------------|
| Cosmic-ray escape [60/ | M_{\odot} | | |

Alfvenic diffusion-The diffusion

coefficient increases at later times, hence particles at higher energies diffused in the upstream region would not participate in the shock acceleration mechanism.

Downstream spectra-Spectra become rapidly softer at later times around above 1-10GeV, **signature of particle** "escape" from downstream to upstream

The spectral index of obtained total production spectra is harder than the downstream particle spectra

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Proton number – spectra





Alfvenic diffusion



Proton number – spectra

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| Introduction | Numerical Methods | Results 0000 | Conclusions ●○ |
|--------------|-------------------|-----------------|-------------------|
| Conclusions | | | |

- The stellar evolutionary stages, ZAMS mass, rotation, and metallicity of progenitor stars have significant roles in spectral modification.
- The spectral shape depends on the temperature of bubble, and FS interactions. Although, the considered diffusion models have extensive effects on spectral index, softer spectra are prominent during the FS evolution inside hot bubble for $60M_{\odot}$.
- In Alfvenic diffusion, rapid particle escape from downstream above 1-10GeV at later times produces the softer downstream spectra at higher energies.
- CSM magnetic field as well as diffusion play significant role in emissions from the spectra and in remnant morphology.

For more details regarding this study, please go through

"Leptonic non-thermal emission from supernova remnants evolving in the circumstellar magnetic field"-Sushch et al. 2022, ApJ, 926,140 -Impact of CSM magnetic field on SNR emission

"Spectral softening in core-collapse supernova remnant expanding inside wind-blown bubble"- Das et al. 2022, AA, 661, A128 - Extensive study of particle acceleration with Bohm diffusion for SNR with $60M_{\odot}$ progenitor

| Introduction | Numerical Methods | Results | Conclusions |
|--------------|-------------------|---------|-------------|
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Thank You for your attention!