Relativistic particles in space

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Astrophysics
- cosmology
- stellar astrophysics
- spectroscopy of the intergalactic medium

Astroparticle physics
- observational (HESS & CTA)
- theoretical

New: M.Sc. program in astrophysics (fully in English)
Introduction

What is a relativistic particle?

Any elementary particle, e.g., electrons and atomic nuclei

How high can the energy be?

Larger than a billion times the restmass energy, $E=mc^2$
Long history of cooperation

Energy distribution
over 12 decades
or 40 octaves
Long history of cooperation
The physics

Collisions between cosmic particles are very rare:
→ collisionless!

Cosmic magnetic field is necessary for particle acceleration

Turbulent magnetic field determines scattering and confinement
The physics

Dynamics of field provides accelerating electric field
The physics

Turbulent magnetic field

→ Ensemble of waves

A wave at rest

→ No electric field

Moving waves

→ Particle acceleration
Supernova remnants
Supernova remnants

Tycho’s Supernova remnant in the Optical
Supernova remnants

Tycho’s SNR in X rays

Red: Hot gas

Blue: Energetic electrons
Supernova remnants

RX J1713-3946 in TeV-band gamma rays
Large and small

Supernova remnants are particle accelerators

They are a few lightyears in size

Particle scattering and acceleration operate on small scales down to lightmilliseconds

The range of scales is 100 billion
Large-scale evolution

We can model outflows on large scales

Supernova explosion of massive star
Large-scale evolution

Shock acceleration:

Significant energy gain by multiple shock crossing

How does that look under the microscope?
Small scale: shock structure

- Ion density
- Electric field
- Magnetic field

1 light-millisecond
Small scale: shock structure

Electron density and Magnetic field

Kinetic energy
Relativistic particles

Many processes operate in parallel

Their nonlinear interplay determines particle acceleration

The large spread in temporal and spatial scales is a challenge

Is there a global structure, such as weather vs. climate?
Armenia, Germany, and Brandenburg

A long history of cooperation in measuring relativistic particles in space.

Can we extend that to understanding their acceleration and interactions?