Propagation of Solitons in an Obliquely Magnetized Electron-Positron-Ion Plasma with Non-thermal Electrons and Positrons

Lukiya Nazziwa

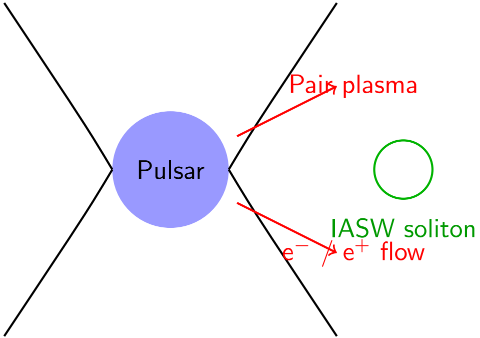
Department of Physics
Mbarara University of Science and Technology
Mbarara-Uganda

African Astronomical Society Conference 2026

Motivation

- In many Astronomical environments such as pulsar magnetospheres, solar wind flows, and planetary magnetic tails, charged particles move under extremely strong magnetic fields and highly dynamic.
- In such disturbances do not simply dissipate instead, nonlinear effects can lead to the formation of-**solitary waves, or solitons**.
- Solitons are special kind of waves that don't fade away or change shape as they move; they are stable and strong over long distances. This is unique behavioir has inspired scientists to use mathematics to solve real world problems. For example **In internet cables** (optical fibres), **Medicine and technology**, & **Energy and plasma research**,
- Understanding these waves helps interpret observed fluctuations in space plasma environments

Pulsar Magnetosphere Plasma Environment



- Pulsar magnetospheres contain dense **electron–positron plasmas**.
- Nonlinear waves can evolve into **localized ion-acoustic solitons**.
- Nonlinear theories of IASWs in magnetized e-p-i plasmas have demonstrated the existence of stable localized structures, (Halmi 2003, Phys Rev Lett. **46** (1)).
- These structures may influence plasma transport and radio emission.

Problem Statement

Although ion acoustic solitary waves have been studied, there are still gaps in existing models. In particular;

- Many previous studies of IASWs assume Maxwellian distributions (Mustaq & Shah, 2005; Mehdipour & Kazemipour 2012; Alinejad, 2013) in pulsar magnetosphere.
- However, observations of space plasmas exhibit superthermal particles which are better described using the kappa distribution (Vasyliunas,1968).
- Effects of positrons and magnetic field obliqueness often neglected.
- Need for realistic plasma modeling with κ-distrubuted particles.

Plasma Model & Method

- Cold ions
- Superthermal electrons and positrons that follow κ-distrubution
- Magnetic field is assumed to be oblique, lying in the x-z plane $\mathbf{B} = (B_0 \cos\theta, 0, B_0 \sin\theta)$
- Wave propaagtion is along the x-direction, allowing us to investigate the propagation angle relative to the magnetic field influences the nonlinear dynamics. The Governing equations include:
- ion continuity equation
- momentum equations
- ion pressure equation

Using the reductive perturbation theory, we derive the the Korteweg-de-Vries Equation which describes the evolution of small amplitude nonlinear waves

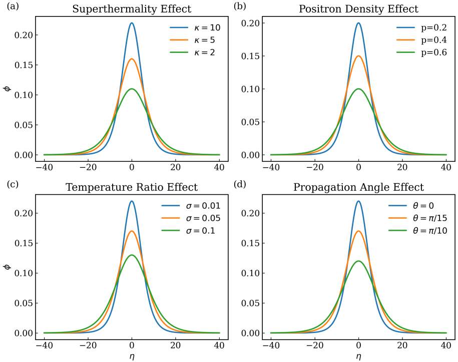
Method: KdV Equation

The nonlinear equation takes the form:

$$\frac{\partial \phi}{\partial \tau} + P\phi\frac{\partial \phi}{\partial \xi} + Q\frac{\partial^3 \phi}{\partial \xi^3} = 0 \tag{1}$$

- Nonlinearity effects (P)
- Dispersion effects (Q)
- Balance produces solitons

Results & Discussions

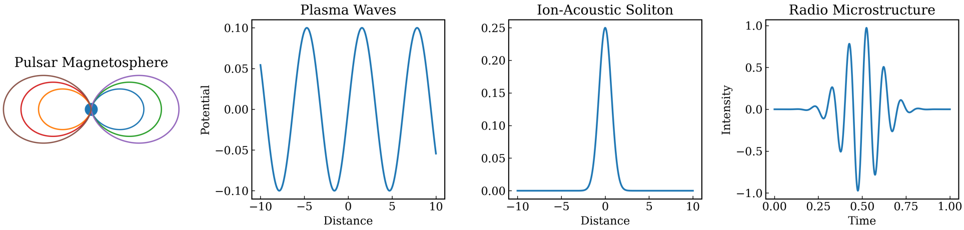


- **Effect of superthermality (κ):** Lower κ (stronger high-energy particle populations) leads to broader and lower-amplitude solitary structures.
- **Role of positron density:** Increasing positron concentration enhances charge neutrality, reducing the electrostatic potential amplitude.
- **Temperature ratio effects:** The electron-to-ion (or pair-to-ion) temperature ratio governs the balance between nonlinear steepening and dispersion.
- **Oblique magnetic field propagation:** Increasing obliqueness enhances dispersion, producing wider and weaker solitary waves.

Astrophysical Interpretation

- *Effect of superthermality (κ):* In pulsar magnetospheres, this suggests that non-Maxwellian pair plasmas suppress strong electrostatic localization, resulting in more diffuse wave structures that can modulate radio emission over wider spatial scales.
- *Role of positron density:* In pair-dominated pulsar plasmas, efficient charge screening weakens localized electric fields, which may reduce particle trapping and limit the formation of sharp emission spikes observed in pulsar microstructures.
- *Temperature ratio effects:* Variations in plasma temperature across magnetospheric regions can control the stability and width of solitary waves, potentially explaining the diversity in observed pulsar radio pulse shapes and fine structures.
- *Oblique magnetic field propagation:* Since wave propagation in pulsar magnetospheres is rarely parallel to magnetic field lines, oblique effects naturally lead to broadened electrostatic structures, influencing radio emission coherence and beam morphology.

Take-Home Message



Pulsar Magnetosphere → Pair Plasma → Nonlinear Waves
→ Solitons → Radio Microstructures

Thank You Very Much For Your Attention