RELATIVISTIC MHD WINDS FROM ROTATING NEUTRON STARS

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ABSTRACT: We present simulations of axisymmetric, general relativistic MHD winds from rotating neutron stars. The mass loss rate is obtained self consistently subject to a finite thermal pressure at the stellar surface, chosen to be representative of the neutrino driven phase in newly born Magnetars, which have been considered as a possible engine for GRBs. We compute the angular momentum and energy losses as a function of σ and compare them with the analytic expectations from the classical theory of pulsar winds. Results also show that a dipolar magnetic field and the presence of a close zone do not modify significantly the acceleration and collimation properties of the wind.

INTRO: It is known that in the simple 1D radial geometry acceleration of a relativistic wind from a highly magnetized neutron star, is inefficient. The terminal Lorentz factor is ~ $\sigma^{1/3}$.

$$\sigma = \Phi^2\,\Omega^2 / F$$

Φ = Magnetic flux
Ω= Rotation rate
F = Mass flux

However Pulsar Wind Nebulae are clear evidence that magnetic energy is converted to kinetic energy, and high Lorentz factor are achieved

A possible solution comes from considering a 2D axisymmetric rotator. If magnetic collimation is efficient then acceleration to ultrarelativistic speed can be achieved. An intrinsically multidimensional problem that can properly be solved only by using numerical simulations.

PROBLEM: In a newly born Magnetar neutrino heating can support a dense atmosphere against the gravity of the neutron star. A wind is injected from the base of the star with characteristic pressure $p \sim 0.1\rho c^2$. This wind can be magneto-centrifugally accelerated by the strong magnetic field of the neutron star (10^{15}G). At the base $\sigma \sim 10^{2\text{-}3}$, so if collimation and acceleration are efficient , a Magnetar can trigger a GRB. The question is under what conditions the resulting wind does have the right properties for a GRB?

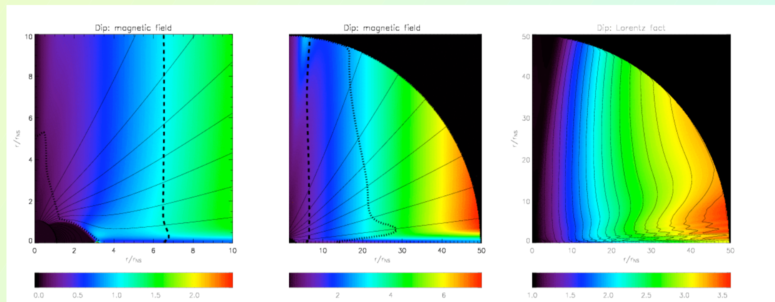

Fig 2: Flow structure for a dipolar magnetic filed (σ=20). Left: poloidal magnetic field and ratio B_ϕ / B_r; slow and alfvenic surfaces. Center: flow structure at larger distances, poloidal magnetic field and ratio B_ϕ / B_r; alfvenic and fast surfaces. Right: Lorentz factor.

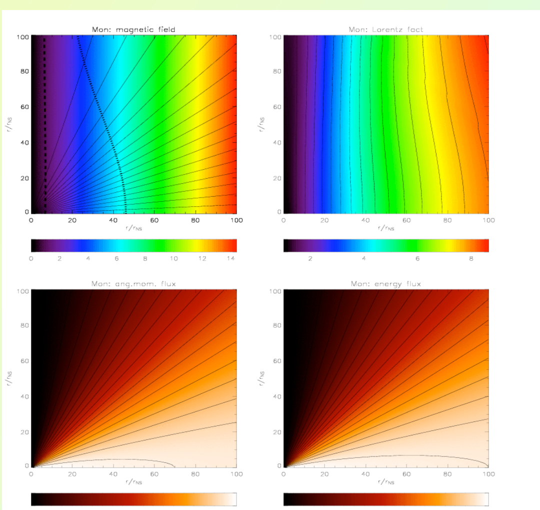

Fig 1: Flow structure for a monopolar magnetic filed (σ=200, Ω=0.14). Upper-Left: poloidal magnetic field and ratio B_ϕ / B_r; alfvenic and fast surfaces. Upper-Right: Lorentz factor ~ $\sin(\theta)$. Lower-Left: angular momentum flux in normalized units. Lower-Right: energy flux in normalized units ~ $\sin^2(\theta)$

RESULTS: Simulations show that as soon as $\sigma > 1$, the flow structure rapidly approaches the force-free limits. Outside the Light Cylinder the magnetic field remains radial, and there is no evidence for a collimated energetic jet. The Alfvenic surface approaches the Light Cylinder and the toroidal magnetic field

$$B_\Phi \sim \sin(\theta)$$

Energy and angular momentum losses are a function of σ and do not depend singularly on the magnetic field or the rotation rate. As $\sigma > 1$ they rapidly converge to the force-free values. In the high σ limit the energy flux goes like

$$H \sim \sin^2(\theta)$$

Higher on the equatorial plane. Acceleration appears to be inefficient with terminal Lorentz factor <10 for σ = 200. Dipolar magnetic field gives results coincident with monopolar field provided σ is the same. This suggest that the presence of a closed zone does not affect acceleration and collimation of the flow. The closed zone appears smaller that the Light Cylinder, because of the high thermal pressure at the base, thus giving higher losses, than the standard dipole formula would predict.

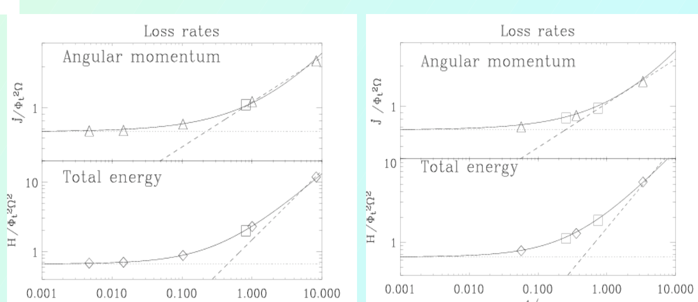

Fig 3: Energy and angular momentum losses for a monopolar (left) and dipolar (right) magnetic field as a function of σ. Squares indicated cases with different rotation rate. Dashed line represent the low-sigma analytic theory, dotted line is the force free limits. The continuous curve is a power-law fit for the monopolar field: the results of the dipole follow the same curve of the monopole.

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REFERENCE: N. Bucciantini et al.., 2006, "Relativistic magnetohydrodynamics winds from neutron stars" , to be published in MNRAS, astro-ph/0602475