Stability of strong waves and its implications for pulsar wind shocks

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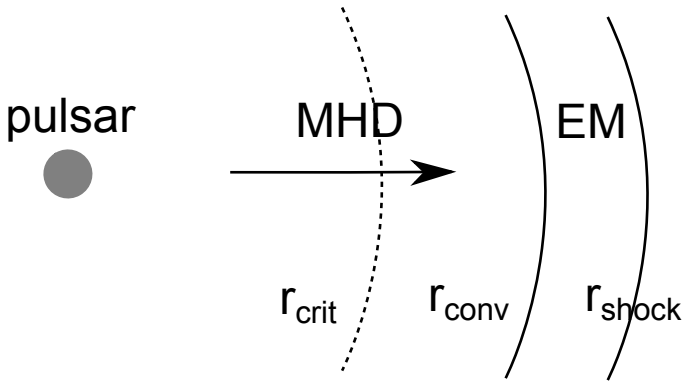
Madrid, 22/05/2013

Pulsar winds and strong waves

- dense plasma $\kappa \gg 1$, pulsar wind described in the MHD framework (striped wind – Jérôme's talk)
- when the density drops $\rightarrow$ propagation of strong EM waves possible $r > r_{\rm crit} \approx 4\kappa\, r_{\rm L}$



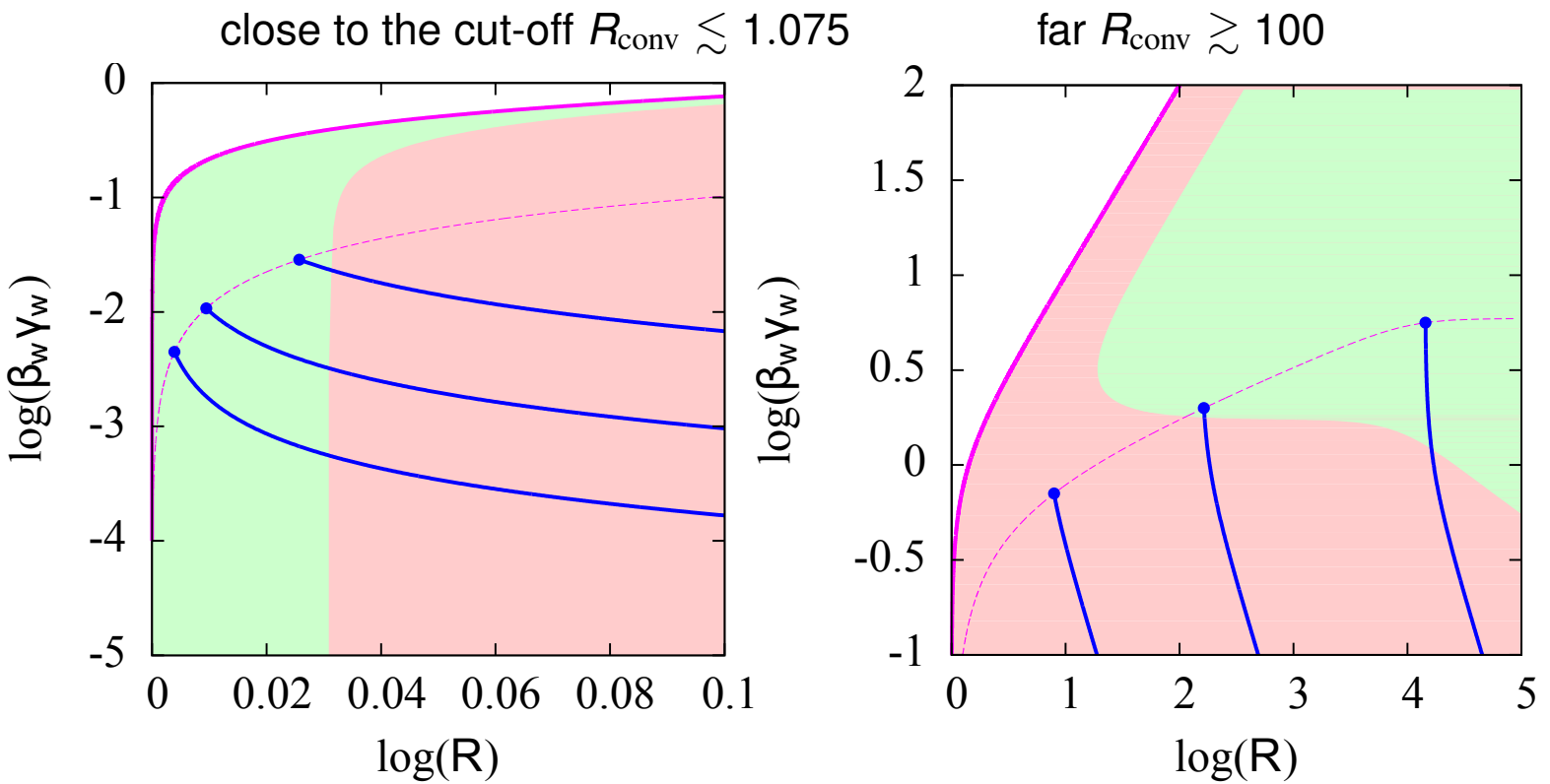
- EM mode carries the same particle, energy and radial momentum fluxes as the MHD wave $\Rightarrow$ solve the jump conditions Kirk 2010, Arka & Kirk 2012

Strong waves

- exact solutions of two-fluid ($e^{\pm}$) and Maxwell eqs Max & Perkins, Clemmow, Kennel & Pellat,...
- large-amplitude = able to drive particles relativistic in one wave period
- phase speed $\beta > 1$, group speed $\beta_* = 1/\beta < 1$
- two modes:
  - free-escape (vacuum)
  - **confined** that slows down with the distance and stagnates at a finite pressure (**shock precursor**)
- $\langle\gamma\rangle$ is an integral of motion for arbitrary polarization (adiabatic invariant!) IM & JK 2013

Stability of strong waves

- unstable against parametric instabilities Max, Perkins, Romeiras, Lee & Lerche stabilized by transverse field component Asseo et al.'80 and relativistic streaming Romeiras'78, Skjæraasen et al.'05
- circularly pol. waves only in two regions are launched as stable precursors that become unstable after $\sim 10^3$ wavelengths

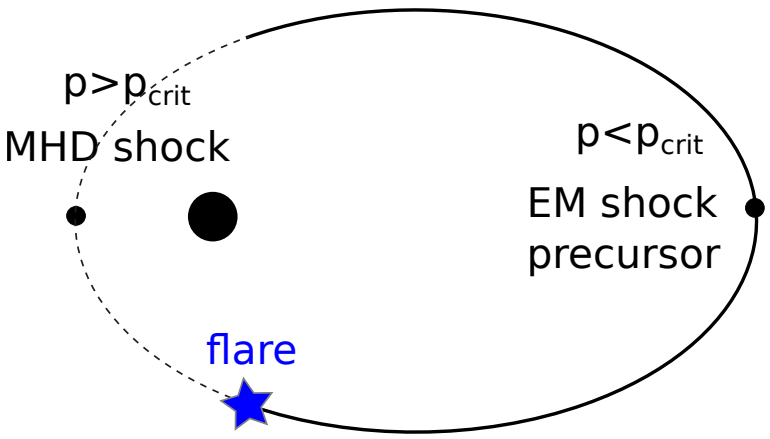


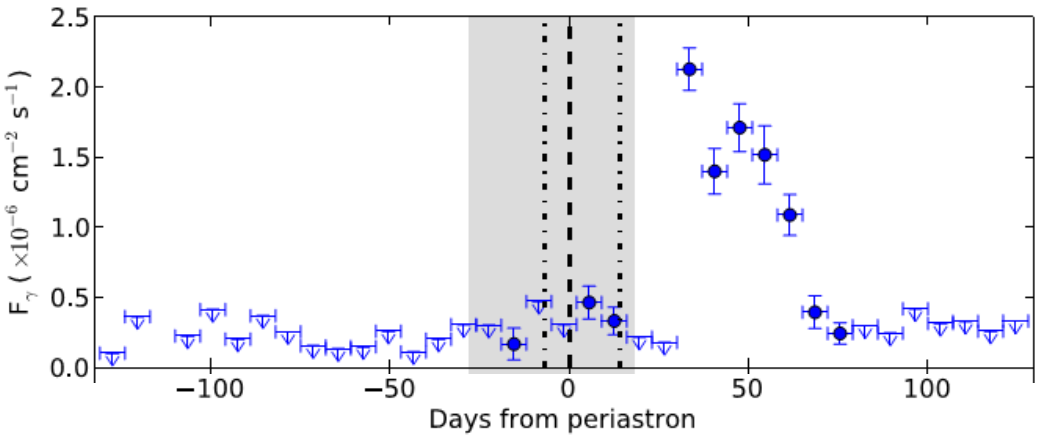
Stability of strong waves

zone	pressure of confining medium	system
inner	high	binaries
outer	low	PWNe of isolated pulsars

- plasma dynamics in precursor determined by $E > B$ field
- resulting shock is essentially unmagnetized (efficient particle acceleration?) Amano & Kirk 2013
- PIC sim. of shock-driven reconnection show the field annihilates Pétri & Lyubarsky '07, Sironi & Spitkovsky '11 but power-law component in particle spectra vanishes for $r/r_{\mathrm{L}} > \kappa$ – strong waves?

B1259-63 – shock regime switch?



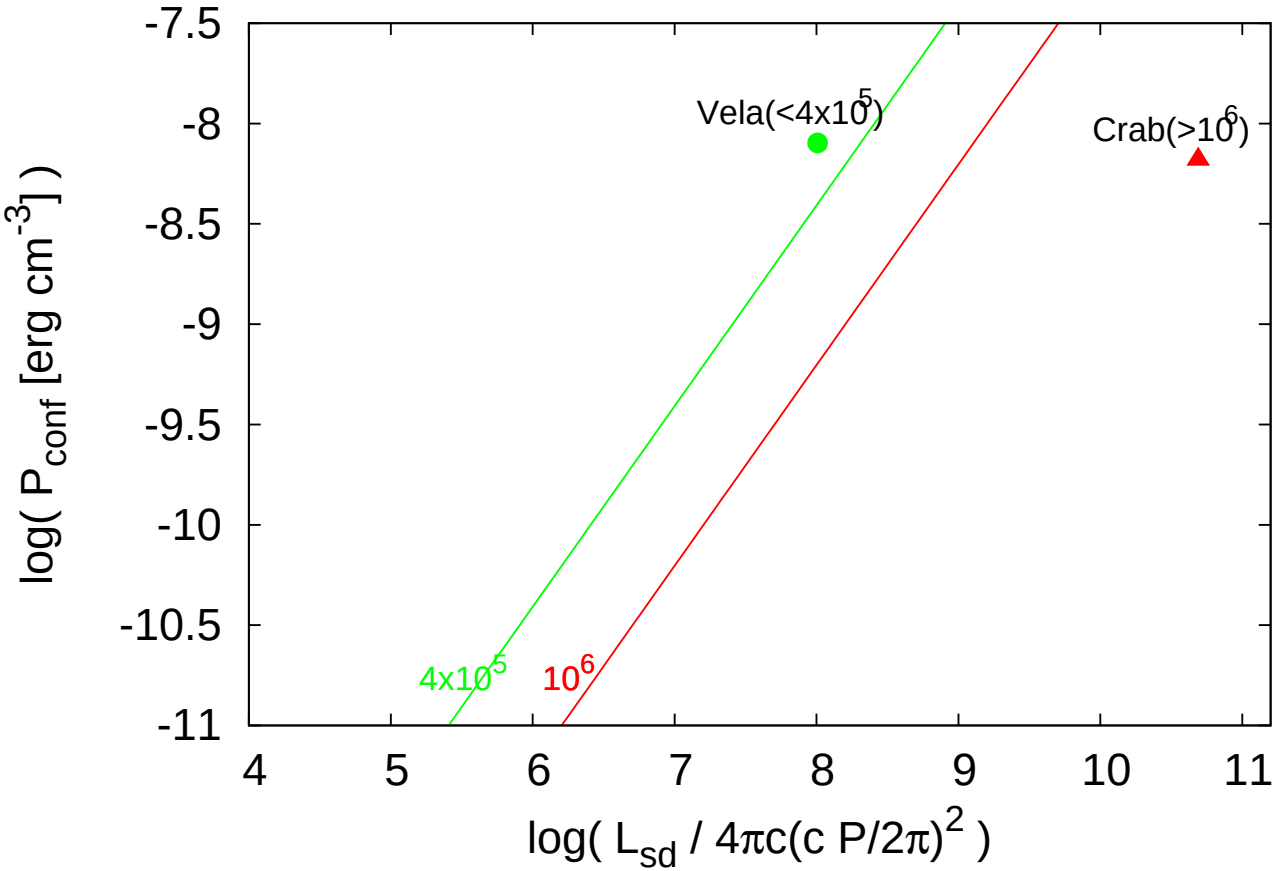


Abdo et al.'11

- if external pressure high – MHD shock (dissip. by driven reconnection); EM precursor possible at larger separation
- regime switch accompanied by synchrotron-like and IC emission from the precursor
- if switch 30 days after periastron, i.e., $r_{\rm crit} = 3.7 \times 10^{13}$ cm, then $\kappa \sim 4 \times 10^4$ and en. per particle $\gamma_{\rm max} \sim 2 \times 10^4 \rightarrow$ synchr. component $\nu \sim \gamma^3 \omega \sim 10^{15}$ Hz, and IC $\epsilon \sim \gamma^2 \epsilon_* \sim 2$ GeV IM & JK, to be submitted

X-ray efficiency?

objects with /without extended precursors occupy right /left region from the limiting line $R \approx 100$



triangle:
$L_{\rm pwn}/L_{\rm sd} > 0.001$

Chandra data:
Kargaltsev &
Pavlov 2008

κ from Bucciantini et al. '11, Tanaka & Takahara '11, de Jager '07

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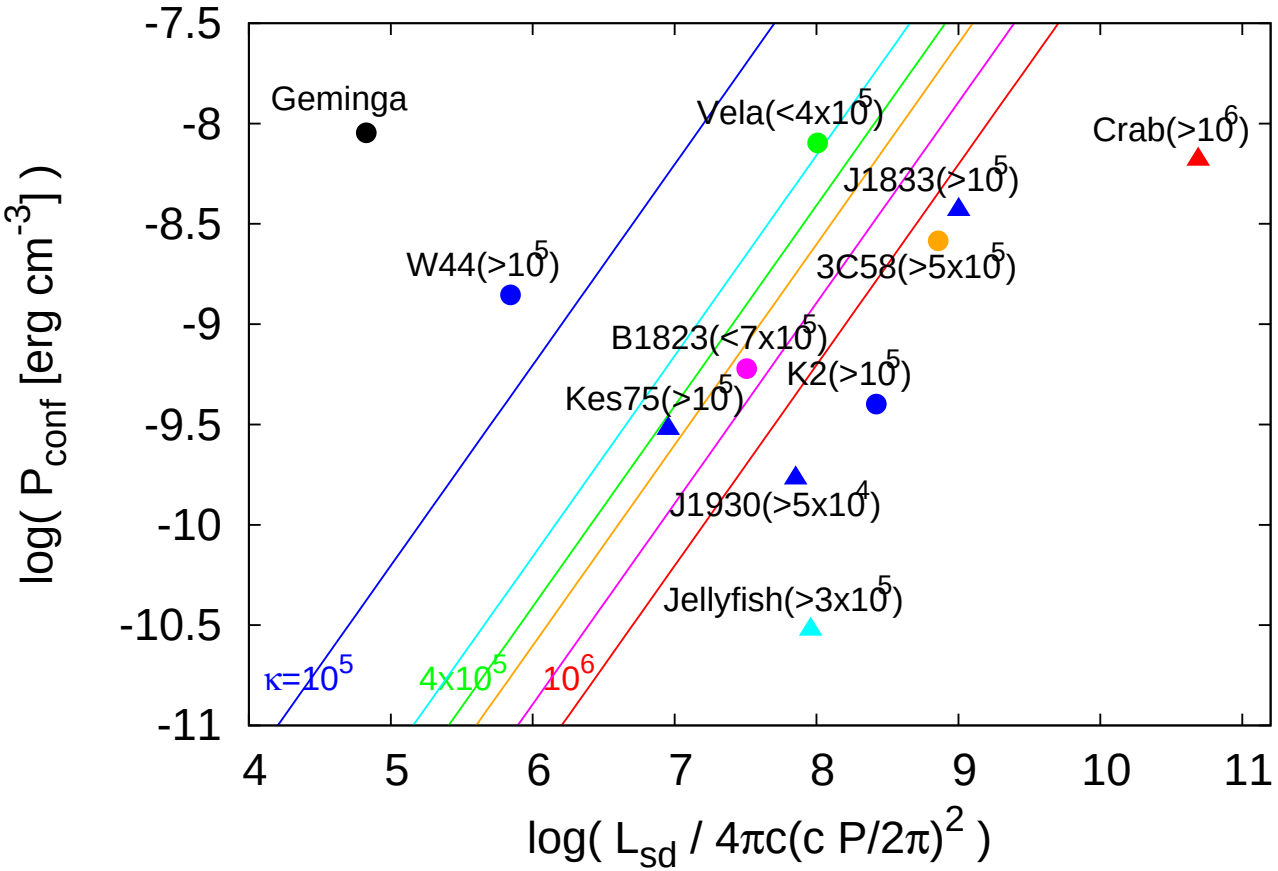

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Summary

- strong modes important for structure of shocks at larger stand-off distance $r/r_{\rm L} > \kappa$ (binaries)
- extended precursors in most isolated pulsars; not possible if the pressure is high (e.g., Vela-like pulsars)
- an electromagnetically modified shock is potentially an efficient particle accelerator