The role of electron beam pitch angles and density gradients in solar type III radio bursts via PIC simulations

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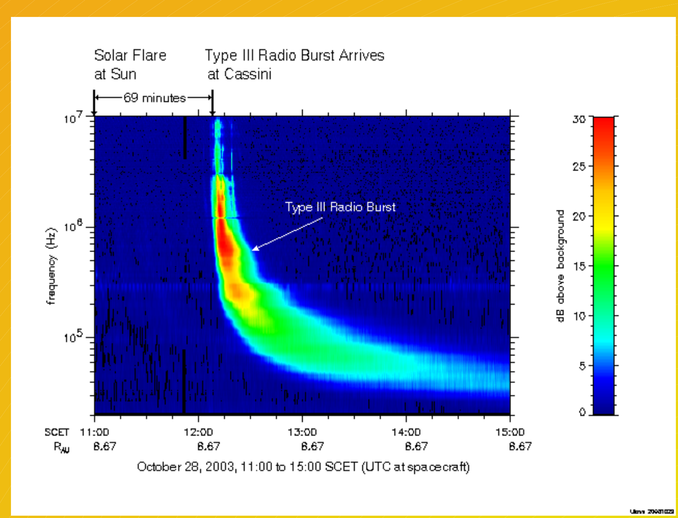
Introduction

The type III solar radio bursts are known to be generated by the super-thermal beams of electrons that travel away from the Sun on open magnetic field lines. The beams are likely to be manifestations of magnetic reconnection which, in turn, is driven by solar flares. However, flares can also drive dispersive Alfvén waves which also can serve as a source of super-thermal beams.
In this work we do not focus on a question what is an actual source of a beam. Instead, we consider a situation when a hot 6×10^6K, super-thermal (v_b=0.5γc) beam is injected into a cool 3×10^5K, Maxwellian plasma with a decreasing density gradient, along an open magnetic field line with B=3G. The latter mimics a magnetic field line that connects Sun to Earth. We base this study on previous work by Tsiklauri (2011) and continue by studying 90° pitch angle runs to explore the exact mechanism of EM radiation generation and its properties.

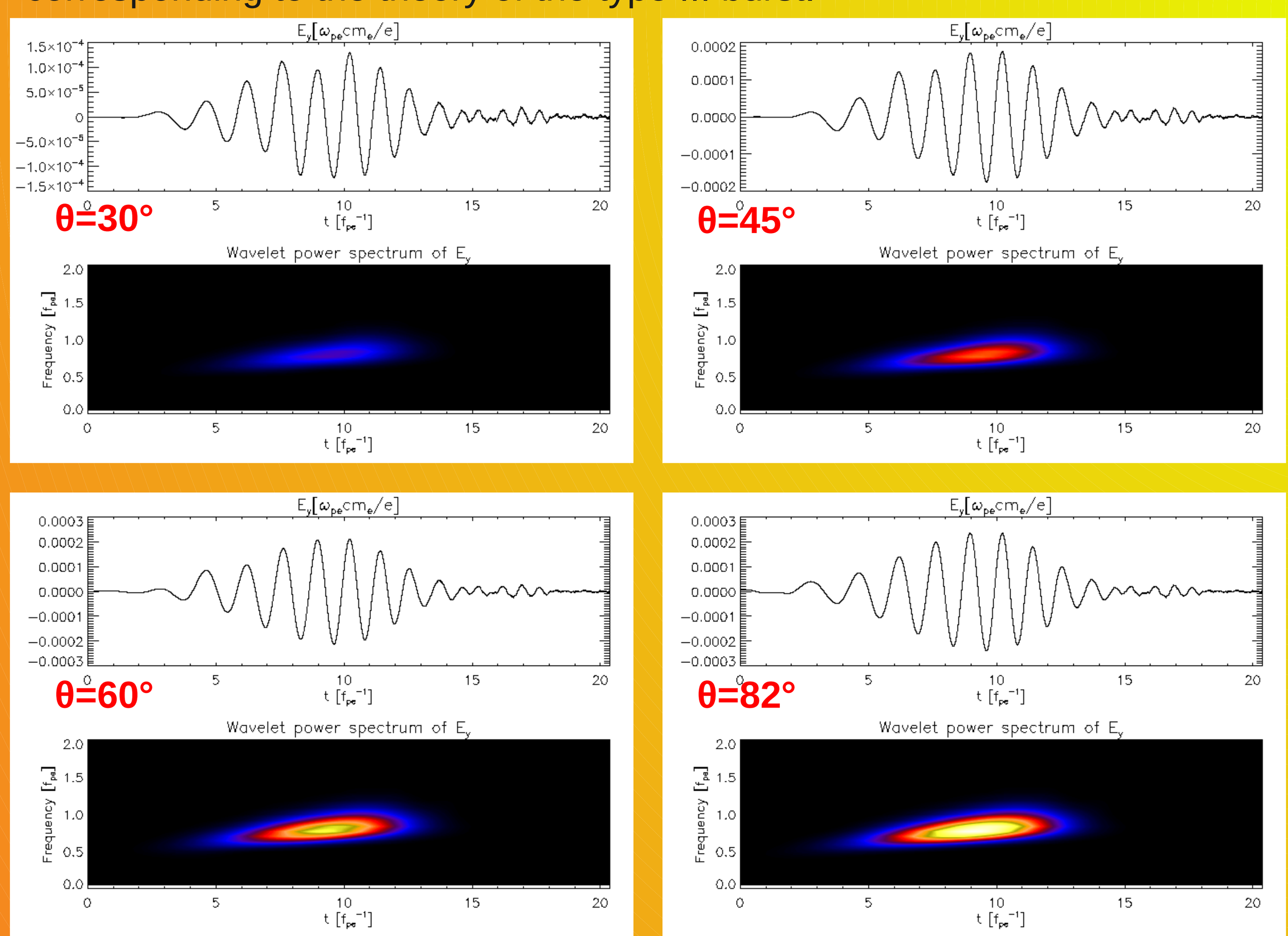
Dynamical Spectrum

The dynamical spectrum shows the emission intensity as a function of frequency and time. Electron beams travel away from the sun, while causing emission at the local plasma frequency and its second harmonic. Due to the decrease in density along the path of the beam, the emission frequency drops as well, causing the characteristic shape in the dynamical spectrum.



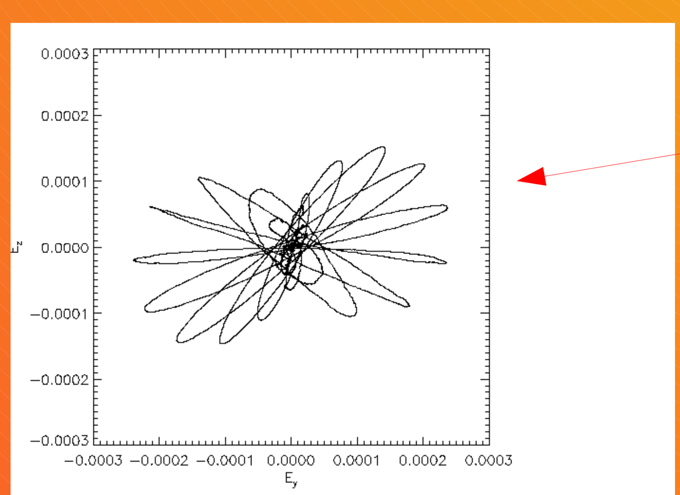
Varying The Injection Angle

We take a snapshot of E_y at t = $100\omega_{pe}$ and transform space into time via t = x/c . We then perform a wavelet analysis to obtain the dynamical spectrum of the signal. Due to the way we transform space into time, the further right we observe a signal, the earlier it occurs. The dynamical spectrum shows a decrease of frequency with increasing time, corresponding to the theory of the type III burst.

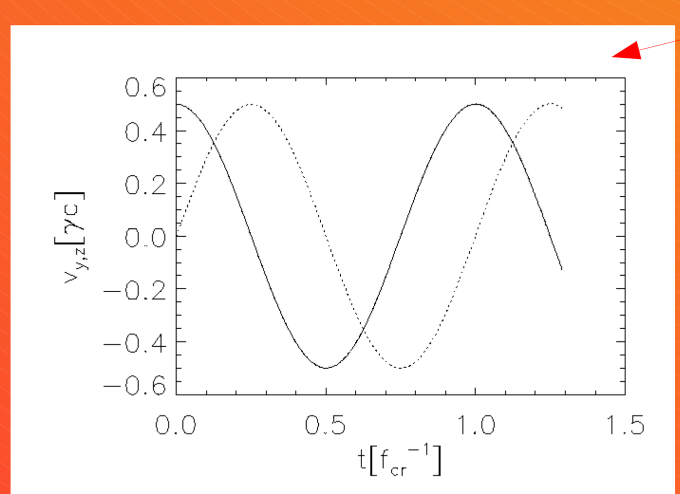


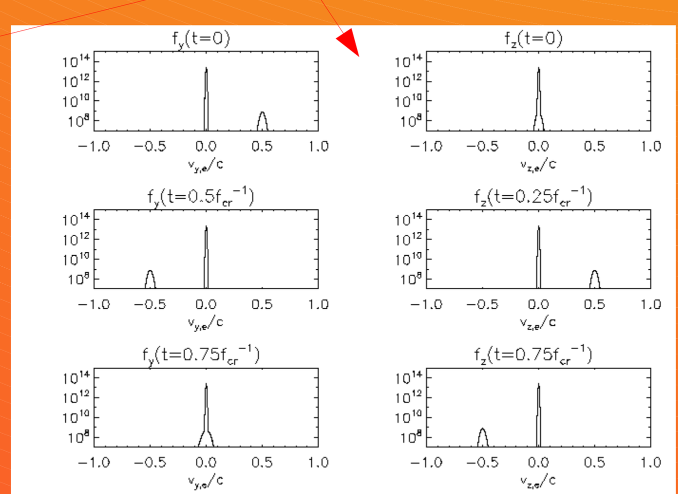
- does not change shape of dynamical spectrum
- changes emission intensity, maximum emission for θ=90°

Polarization, Gyration, Distribution Functions



A plot of the time evolution of the signal in the $E_y E_z$-plane shows that the emission is elliptically polarized. The time evolution of the perpendicular components of the distribution function shows gyration in the y,z-plane with the relativistic gyro-frequency.



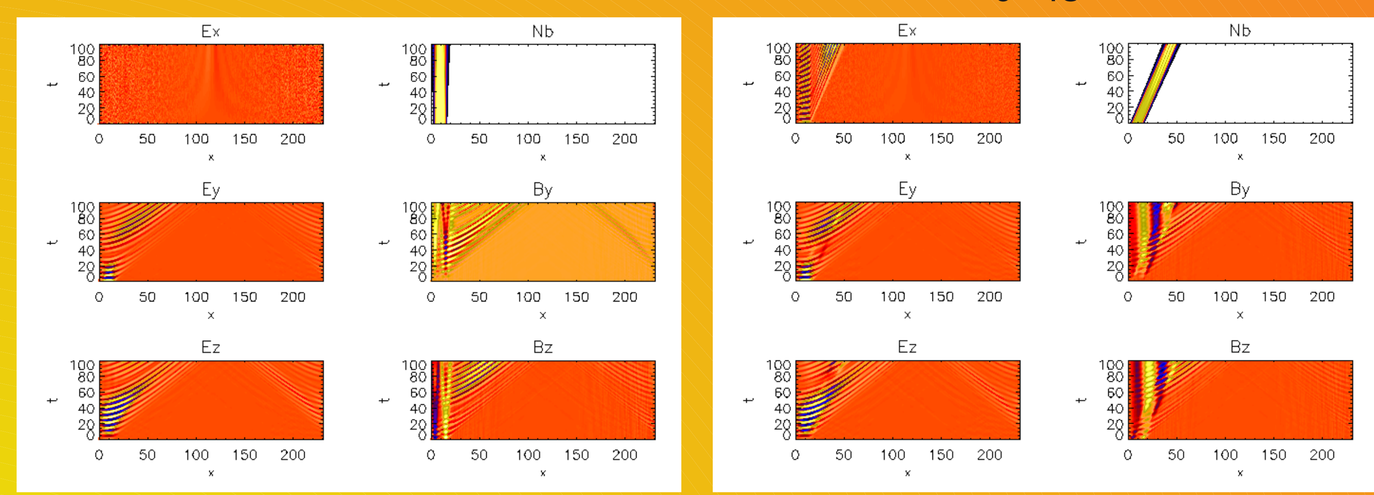


Simulation Parameters

Simulations were carried out with EPOCH, a fully electromagnetic, relativistic particle-in-cell code developed by CCPP (Collaborative Computational Plasma Physics) consortium of 30 UK researchers.
We simulate a 1-dimensional straight line of 65000 grid points and grid size $\lambda_D/2$ with the background density dropping from the initial $n_0=10^{14}m^{-3}$.
The beam density is $n_b=10^{11}m^{-3}$, giving $n_b/n_0=10^{-3}$ and ω_{ce}/ω_{pe}=0.094 at the injection point. The background magnetic field is along the x axis, as is the density variation.
The aim of our simulations is to identify tendencies in the dynamical spectra of plasma emission with respect to changes in the beam injection angle and density gradient. One run typically takes 20 hours on 256 cores with 4Tb of RAM.

Time-Distance Plots

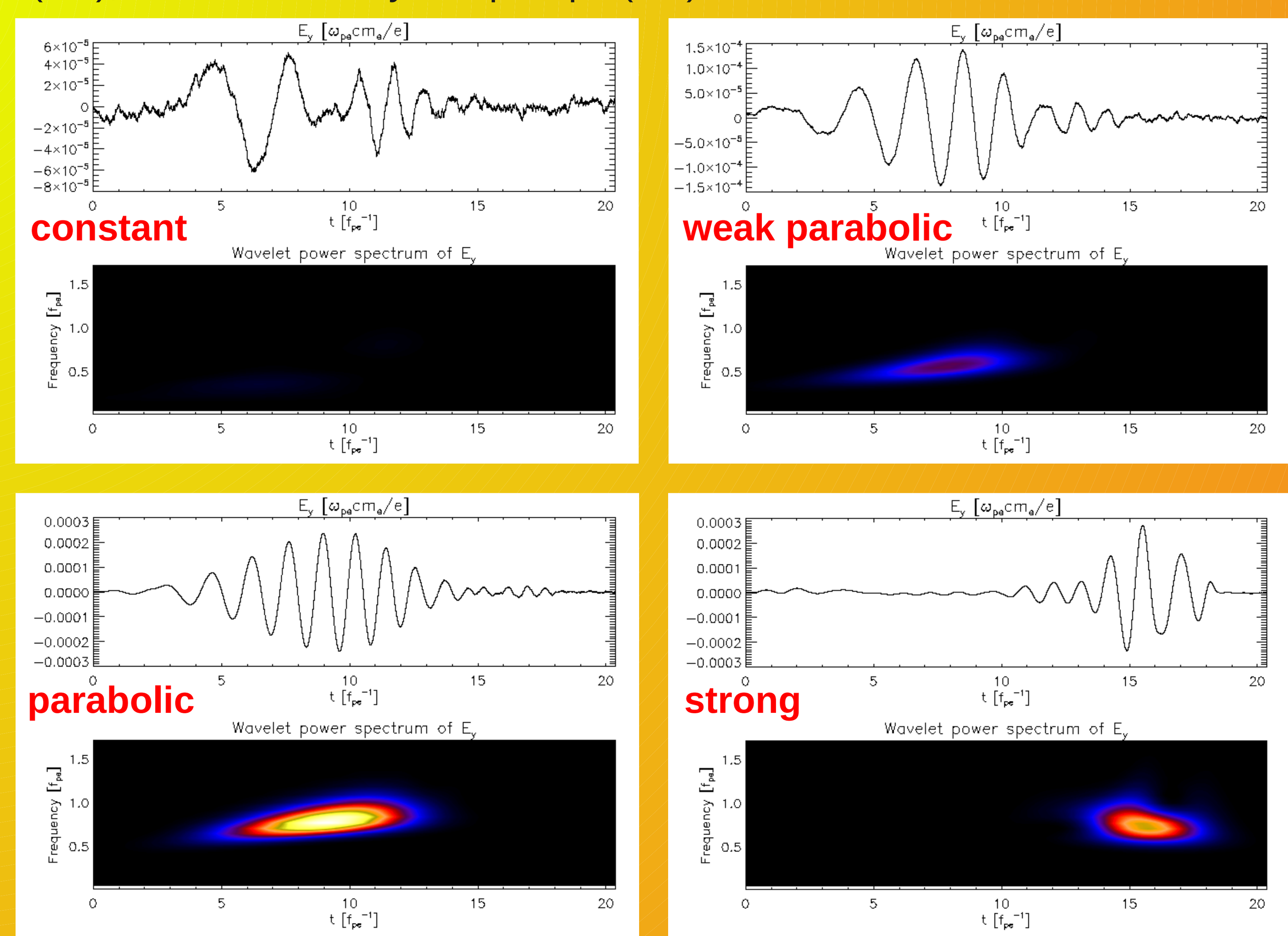
θ=90° θ=45°



Units are chosen such that a slope of unity corresponds to a propagation at the speed of light. The electromagnetic y,z-components, therefore, show waves propagating with roughly c in both above cases, which has to be interpreted as electromagnetic emission. Additionally, we notice that there is a parallel component of electrostatic emission in the θ=45° case. Both these simulations were run with a parabolic density profile.

Varying Density Profiles

In order to study the effect of the gradient on the emission, we set the beam injection angle to θ=90° and vary the background density profile. We investigate runs with constant density, a weakly and a strongly parabolic ($\sim x^2$), as well as a very steep slope ($\sim x^8$)



- leaves emission frequency unaltered
- affects emission intensity
- stronger gradients cause earlier emission

Conclusions

- pitch angle changes intensity of emission
- highest intensity for θ=90°
- presence of a density gradient means emission
- emission is elliptically polarized
- gyration with relativistic gyro-frequency clearly visible in distribution function

Future Work

- mode identification, dispersion relations
- determination of the emission mechanism
- why does the emission damp?
- forward modelling of the LOFAR single station data

References

D. Tsiklauri, Physics of Plasmas, 'An alternative to the plasma emission model: Particle-in-cell self consistent electromagnetic wave emission simulations of solar type III radio bursts', 2011
The wavelet software was provided by C. Torrence and G. Compo, and is available at URL: http://paos.colorado.edu/research/wavelets/

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