(ω,k)-space drift due to the density variation as a cause of electromagnetic emission generation of type III solar radio bursts by a non-gyrotropic electron beam

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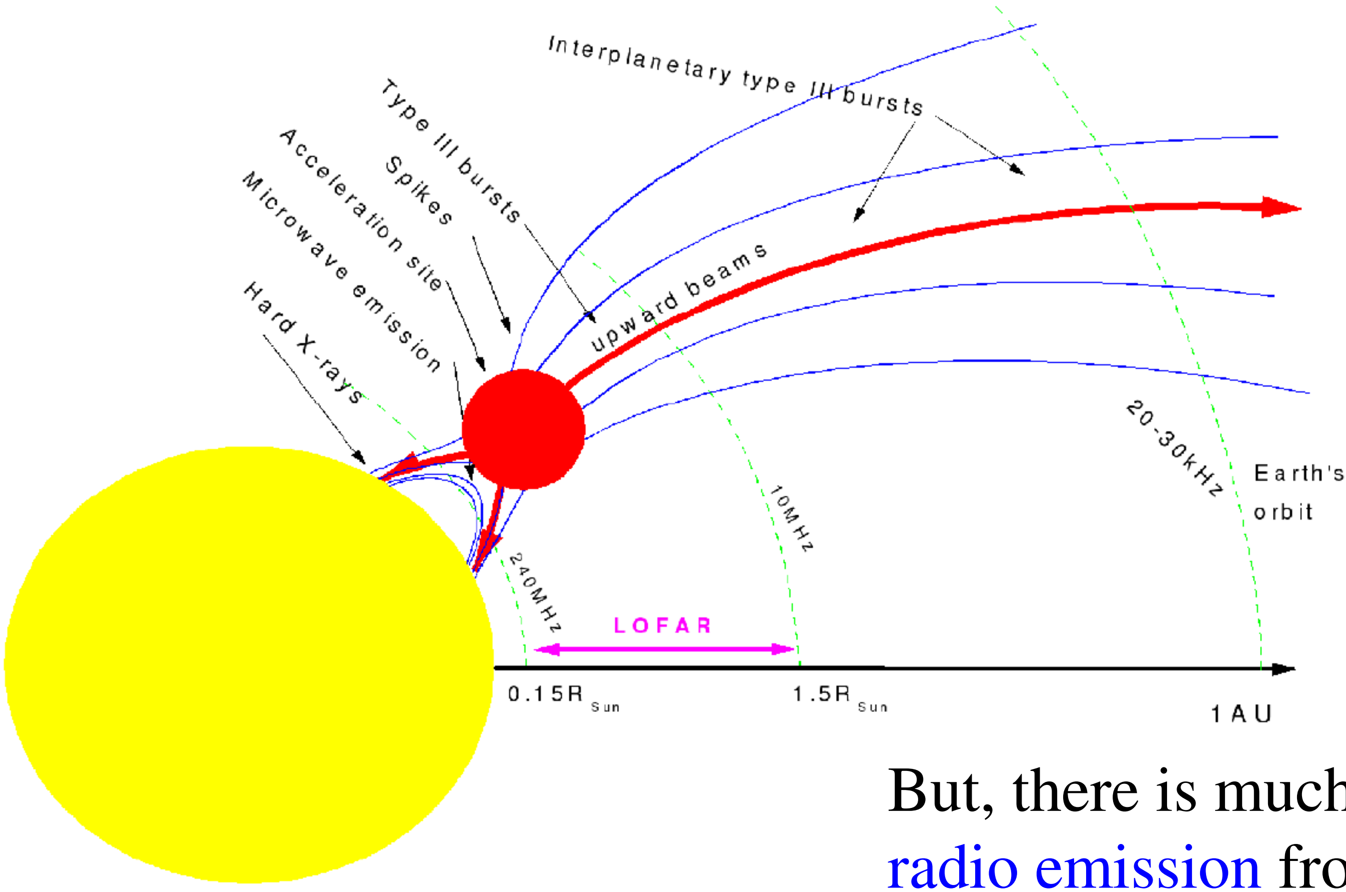
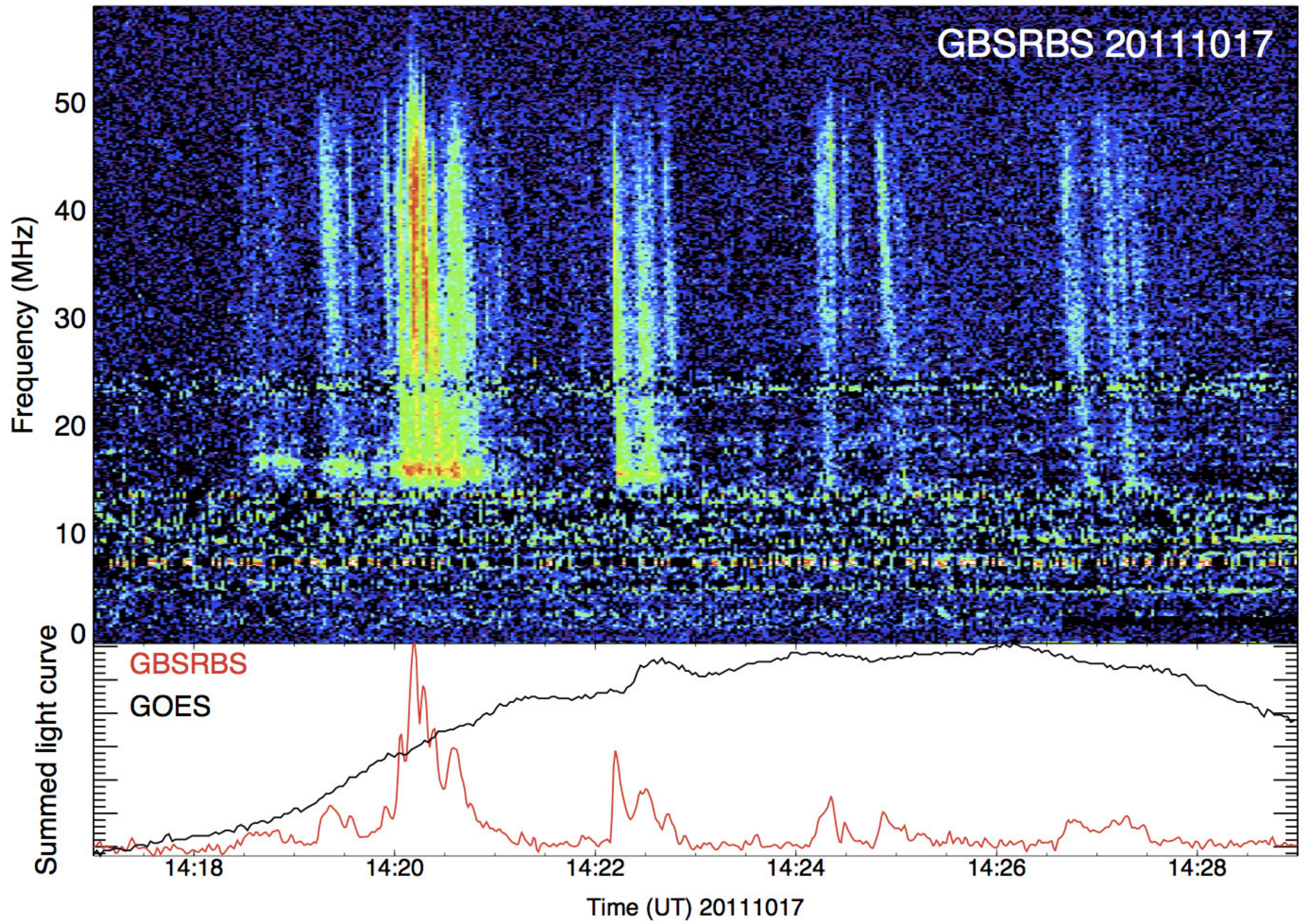


In solar physics research main focus has been on X-rays (RHESSI), which are produced by (collisions) bremsstrahlung of Sun-wards moving particles.

But, there is much less explored radio emission from upwards moving, collisionless electrons (to be studied by LOFAR, currently explored by e.g. Nancay Radio-heliograph, Owens Valley Solar Interferometer two 27-m telescopes).

Type III burst Dynamical spectrum -- frequency vs time.



Type III solar radio burst, Green Bank SRB Spectrometer 17/10/2011. The rapid drift of the structures with time is clear, as is their occurrence during the impulsive phase of a solar flare (GOES X-ray flux increasing; bottom panel), http://www.transientskp.org/science/flarestars/

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Basic physics of the radio emission mechanism (*plasma emission*):

*solar flares (i.e. reconnection) induce an electron beam;

*This generates Langmuir waves via bump-on-tail instability;

*Lamgmuir waves ($\approx \omega_{pe}$ and $2\omega_{pe}$) scatter off thermal ions or couple to ion-acoustic waves and produce EM emission at $\approx \omega_{pe}$ & $2\omega_{pe}$.

Good intro to mechanisms Malaspina et al. 2010 JGR, 115,A01101
cf. "antenna mechanism" and linear mode coupling on density gradient.

(i) Plasma emission proposed by Ginzburg & Zheleznyakov 1958;

(ii) large, 1 AU-scale, phenomenological models based on Quasi-linear theory; Stochastic growth theory, Cairns & Robinson 1998, Li & Cairns, 2008, Reid & Kontar 2010.

(iii) small-scale, few 1000s Debye length = 10^{-10} AU, fully kinetic, Particle-In-Cell (PIC) simulation with self-consistent EM fields: Sakai et al (2005)+others, still based on plasma emission however.

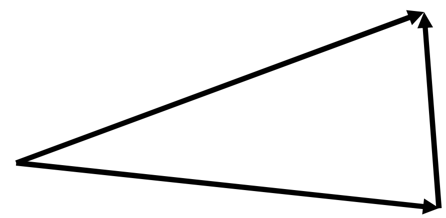
Motivation (for <u>alternatives</u> to the *plasma emission* mechanism)

* In the plasma emission mechanism, non-linear wave-wave interaction between Langmuir, ion-acoustic and EM waves requires the beat conditions to be satisfied. The emission formula (i.e. the three wave interaction probability) includes a cross vector product factor $\left| \vec{k}_L \times \vec{k}_T \right|^2$

The beat conditions for the three-wave interaction process

$$\omega_1 + \omega_2 = \omega_3$$

$$\vec{k}_1 + \vec{k}_2 = \vec{k}_3$$

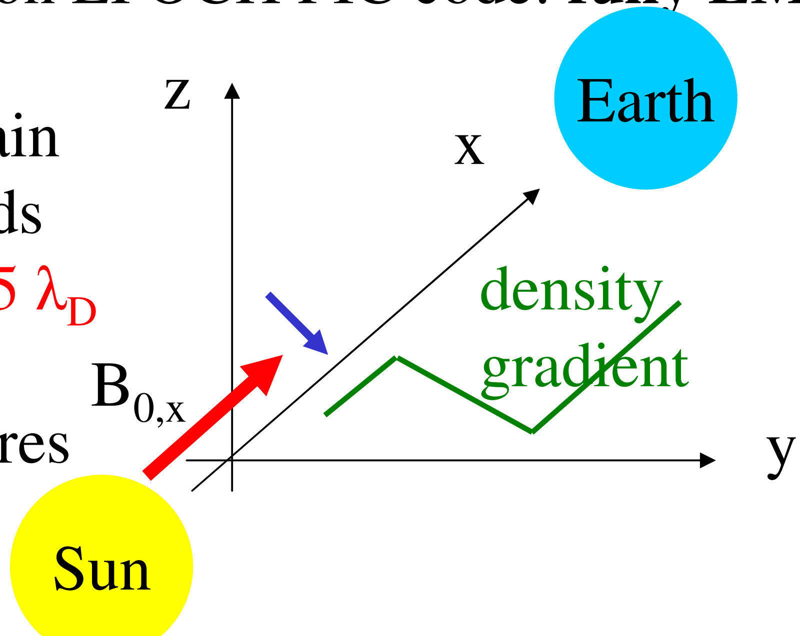


* This implies that the correct treatment of the act of EM emission needs 2D spatial dimensions. This poses serious computation limitation. Our aim is to find an EM emission mechanism that can do the job in 1.5D, since we know that EM emission of type III bursts have mostly $k_{\|}$ and nearly zero $k_{\perp}$.

Model is based on EPOCH PIC code: **fully EM, relativistic PIC code.**

Simulation domain size = 65000 grids
grid size 0.25-0.5 λ_D

each run: 512 cores 40 h, few x10^9 particles



strongly magnetized case $\beta=1\times10^{-2}$.

k_{perp} is non-zero by setting 45^o beam pitch angle.

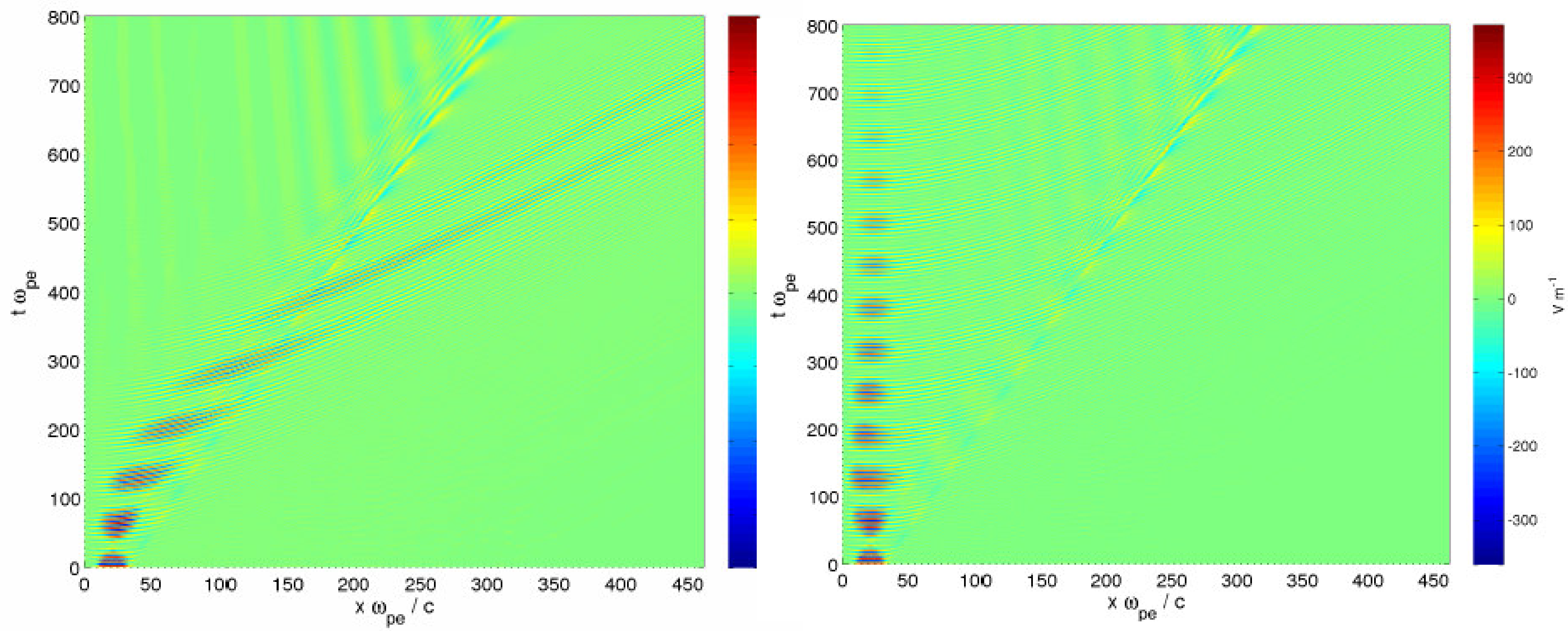
$$n_b(x) = n_0 \exp\left[-\left(\frac{x - L/25}{L/40.0}\right)^8\right] \qquad n_e(x) = n_E + (n_S - n_E)(x/L - 1)^2$$

$$f_b(x, v_x, v_y, v_z) = \frac{n(x)}{2\pi m_e k T_b} e^{-\frac{(v_x - v_b/\sqrt{2})^2 - (v_y - v_b/\sqrt{2})^2}{2 m_e k T_e}}$$ **Reference run**

Ring distribution run

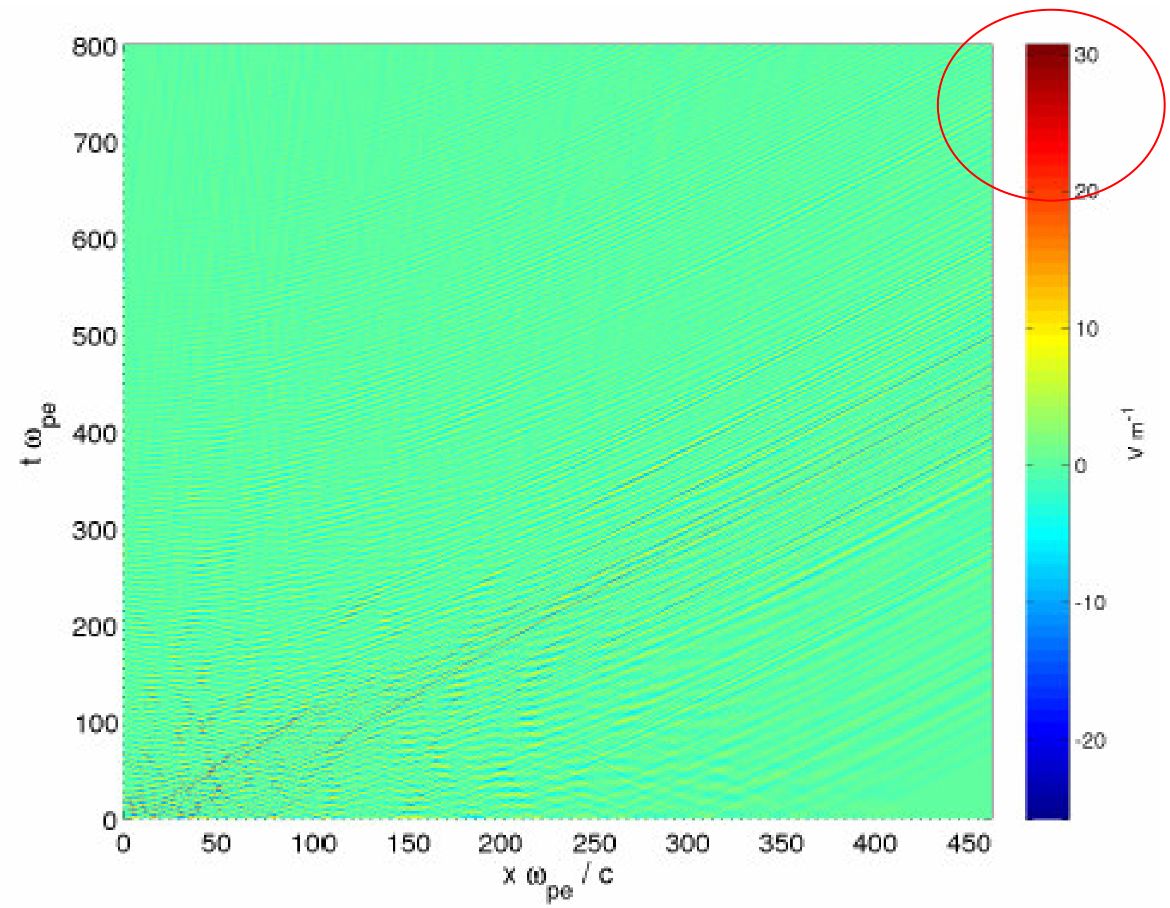
$$f_b(x, v_x, v_y, v_z) = \frac{n(x)}{2\pi m_e k T_b} e^{-\frac{(v_x - v_b/\sqrt{2})^2 - (\sqrt{v_y^2 + v_z^2} - v_b/\sqrt{2})^2}{2 m_e k T_e}}$$

PIC numerical simulation results



Transverse electric field component E_y time-distance plots for the reference run (left panel) and with a density plateau (right panel).

PIC numerical simulation results



Transverse electric field component E_y time-distance plot for the ring distribution.

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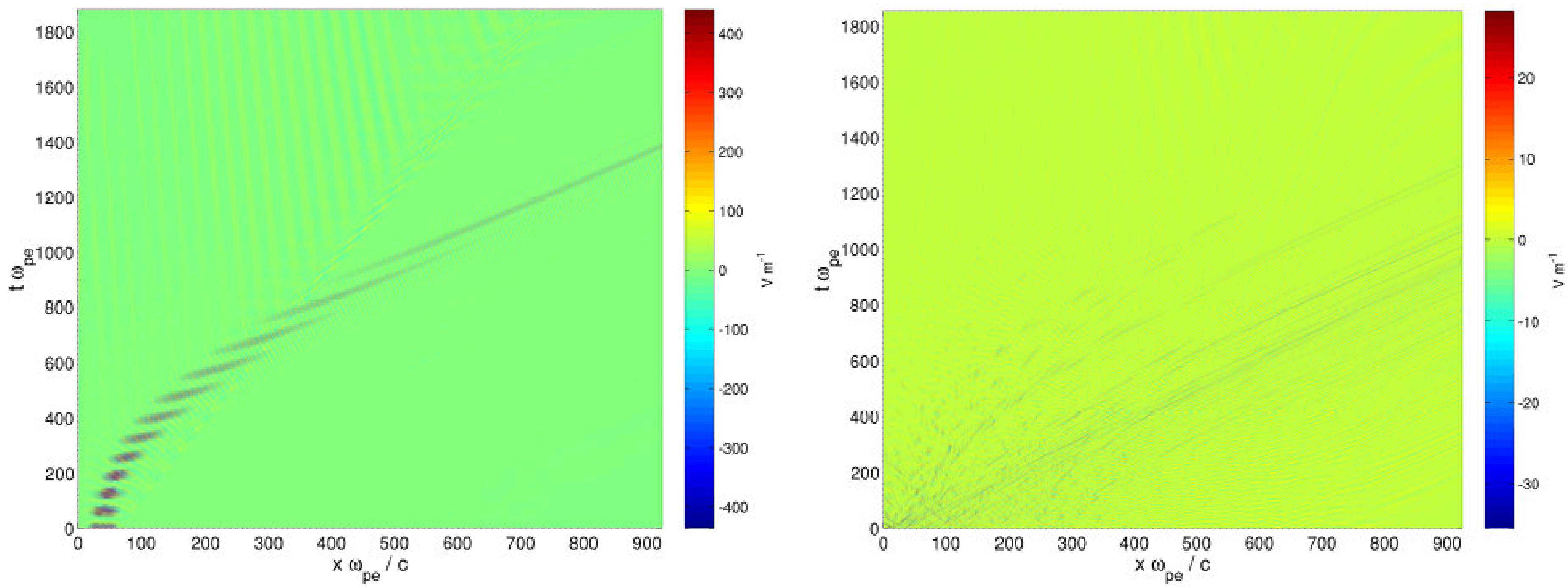
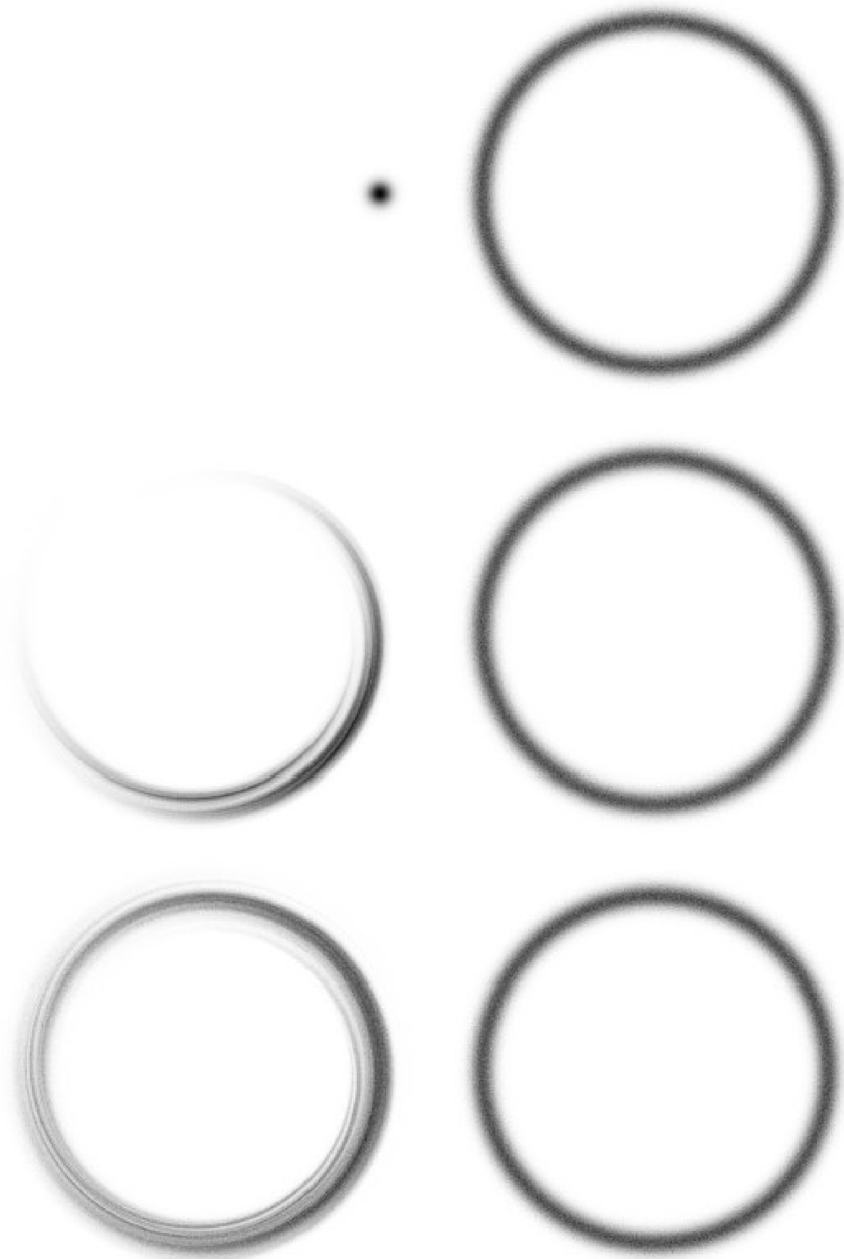
PIC numerical simulation results

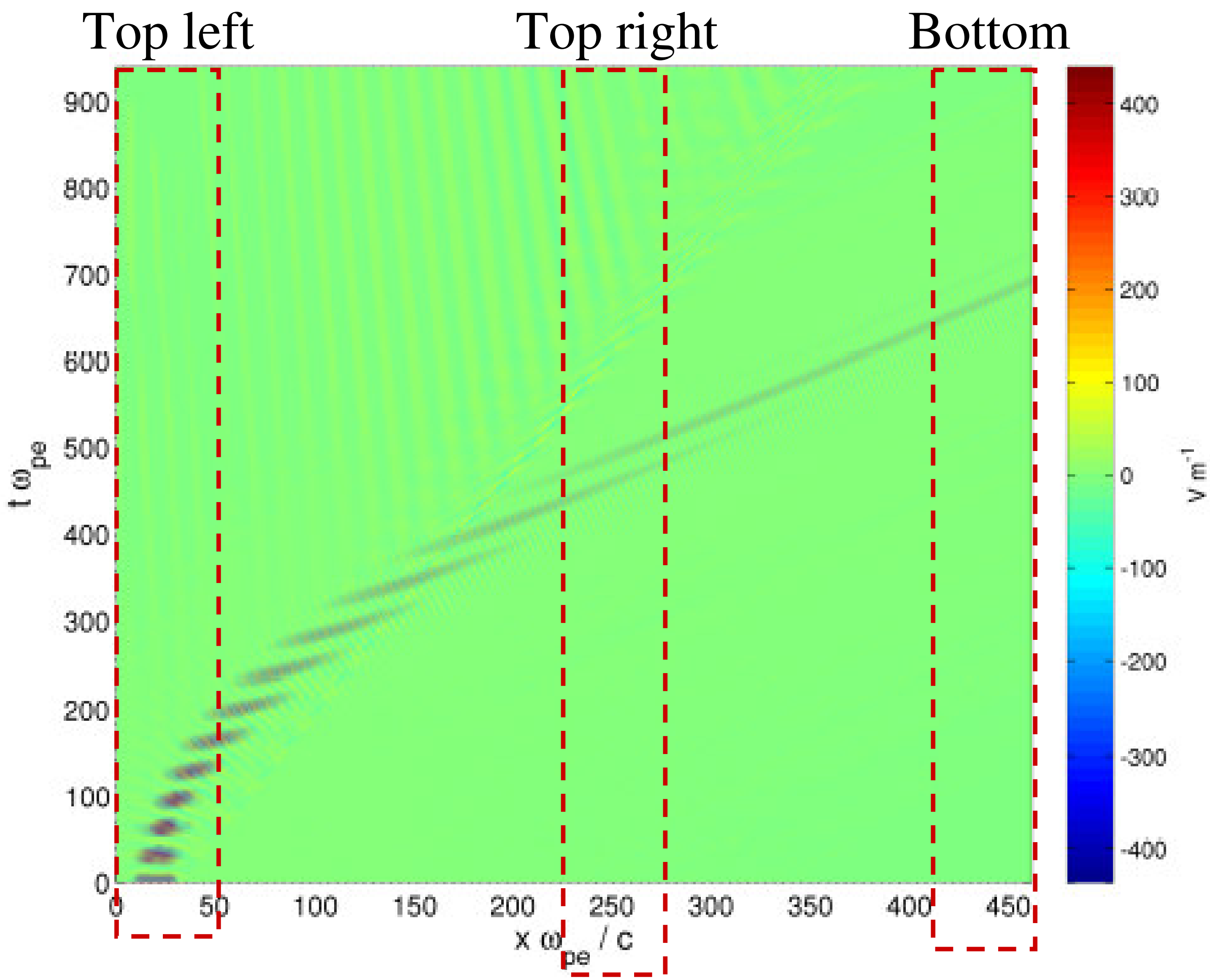


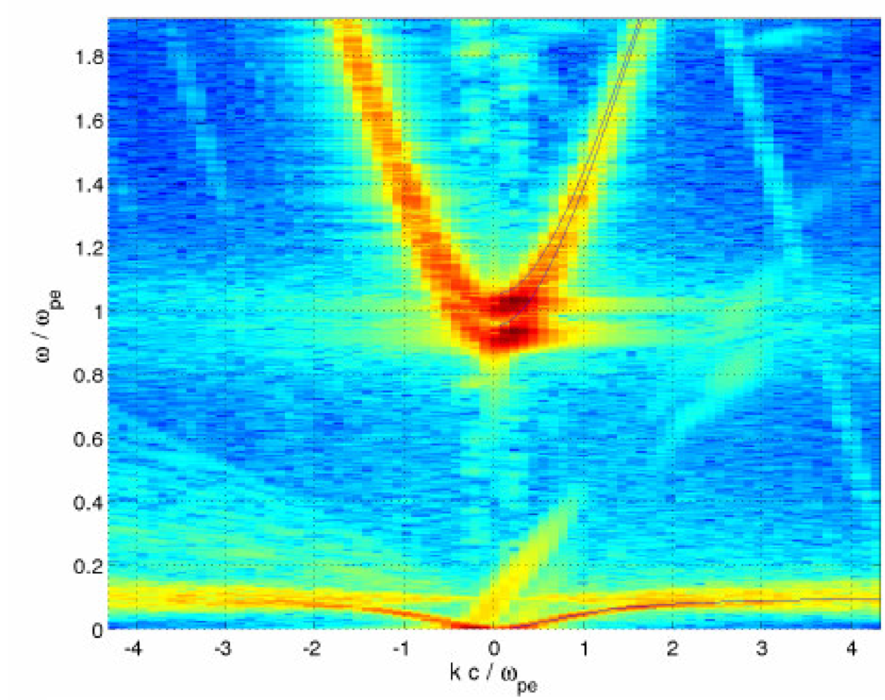
Transverse electric field component E_y time-distance plots for the two long runs reference run (left panel) and with a ring distribution (right panel).

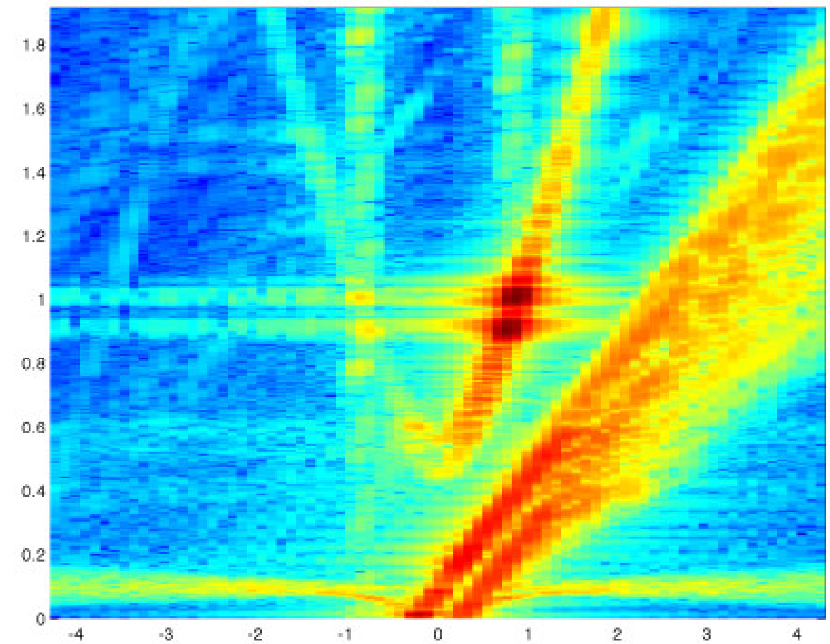


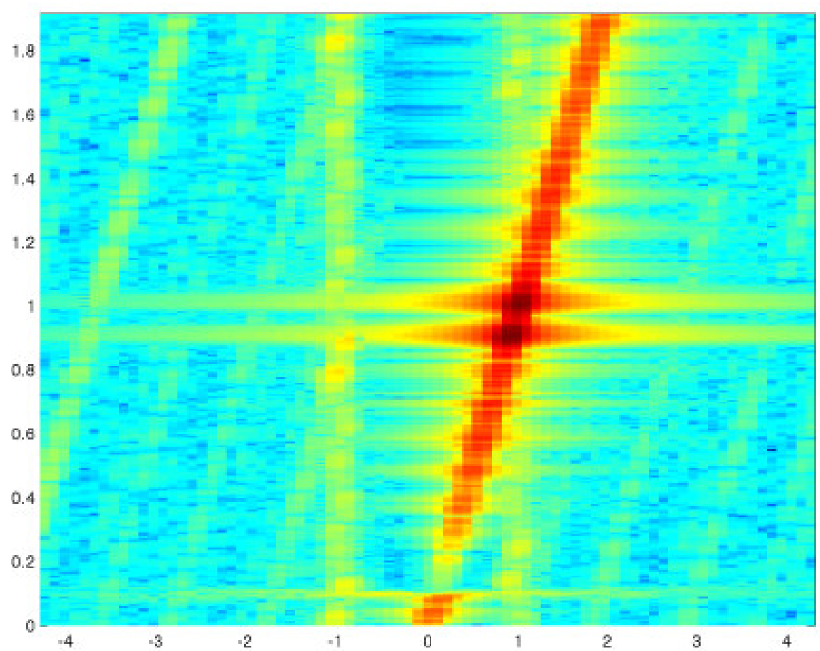
v_y-v_z phase space densities for the long reference run (left column) and ring distributed beam (right column) at
$t=0$ (top),
$t=900\ \omega_{pe}^{-1}$, (middle) and
$t=1800\ \omega_{pe}^{-1}$, (bottom).

Input for 2D Fourier transform of E_y on next slide









2D Fourier transform of E_y.
Top left -- beam injection region
Top right -- middle simulation box
Bottom -- the right edge of the box
for the reference run.

Conclusions: When non-gyrotropic beam is injected on a density gradient, escaping EM radiation is generated;

When the electron beam is injected
(i) on a plateau which is followed by a density gradient or
(ii) ring distribution is imposed,
NO EM emission is generated.

This means that existence of
(i) the density gradient in the beam injection location and
(ii) transverse to the magnetic filed current is needed for EM emission.

The EM emission occurs due to (ω,k)-space drift facilitated by the density gradient and the transverse electron beam current.

Further details in:

H. Schmitz, D. Tsiklauri, Phys. Plasmas, (2013), submitted for publ.
R. Pechhacker, D. Tsiklauri, Phys. Plasmas 19, 110702 & 112903 (2012)
D. Tsiklauri, Physics of Plasmas 18, 052903 (2011)

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