# Realistic mass ratio simulations of Lower Hybrid Drift Instability turbulence in the terrestrial magnetotail with the fully kinetic semi-implicit adaptive Multi-Level Multi-Domain (MLMD) method

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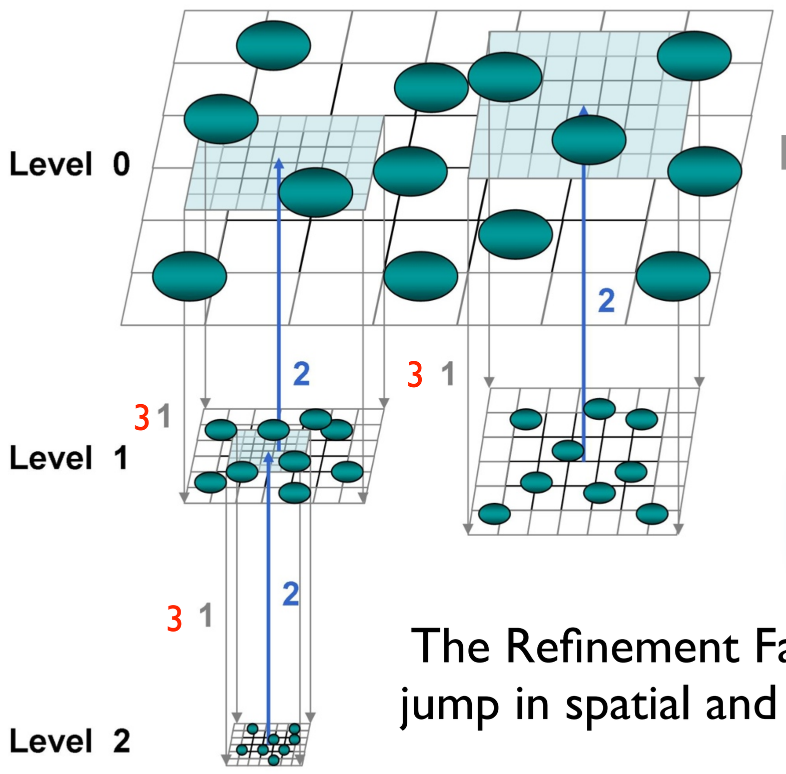
## The Multi Level Multi Domain (MLMD) method




MLMD system:

1: Boundary Condition (BC) interpolation Coarse (C) to Refined (R)

2: updated field projection R2C

3: particle repopulation C2R

Fig 1: sketch of a MLMD system

The Refinement Factor RF and the Time Ratio TR are the jump in spatial and temporal resolution between the levels

The MLMD method is a *semi-implicit* (Implicit Moment Method) and *adaptive* method for Particle-In-Cell simulations of plasmas

Computational resources are saved by simulating the domain at *different levels* with *different spatial* and *temporal resolution* between the levels

Performances are evaluated by comparing the execution times of single level simulations with those of MLMD simulations with same coarse domain sizes and refined grid resolutions equal to the resolution of the single level simulations

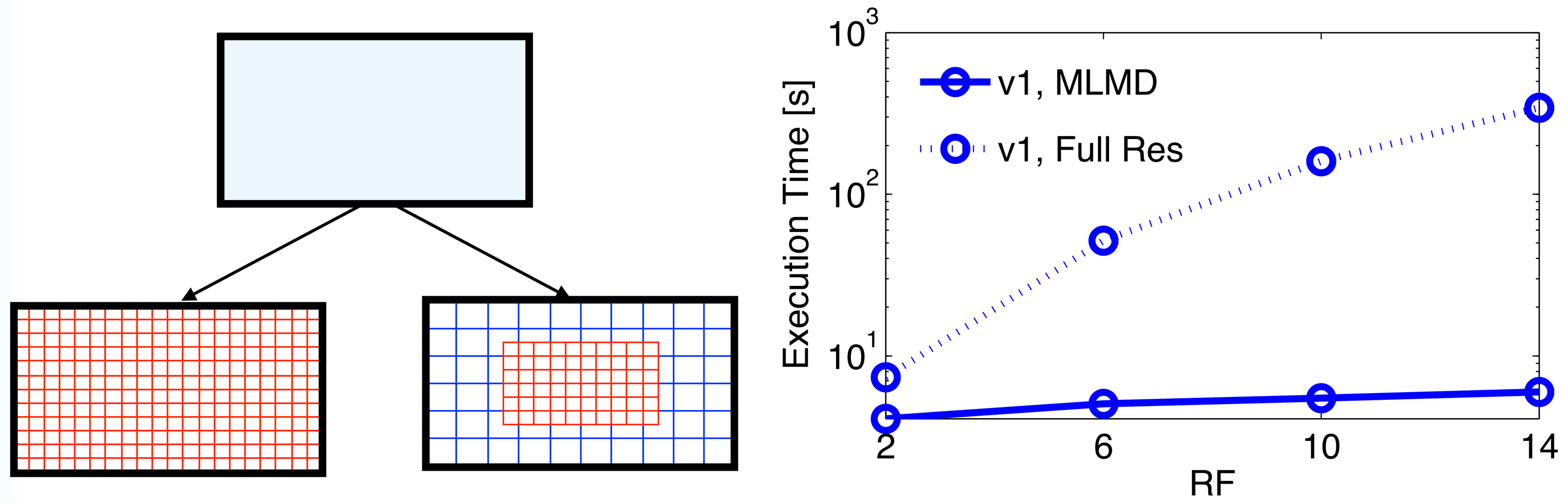



Fig 2: evaluation of performances of MLMD systems: evaluation method (left) and measures as a function of the Refinement Factor (RF) between the grids (right)

With RF= 14, TR=1, MLMD simulations of magnetic reconnection are *70 times faster* than their traditional counterparts

The MLMD has been used to simulate *electrostatic and electromagnetic kinetic instabilities* [Innocenti13], *plasma expansion in vacuum* [Beck14] and *realistic mass ratio magnetic reconnection* [Innocenti15]

We study here *Lower Hybrid Drift Instability turbulence* in the terrestrial magnetotail at realistic mass ratio

*Symbols*: $\gamma$ growth rate; $\Omega_{LH}$ lower hybrid frequency; k perpendicular wavenumber; $\rho_{e/i}$ electron/ ion gyroradius; $d_i$ ion skin depth; $L_H$ half width of the Harris sheet; $\Omega_{ci}$ ion cyclotron frequency; $\delta$ fluctuations

## The Lower Hybrid Drift Instability (LHDI)

The Lower Hybrid Drift Instability (LHDI):

1) is driven by a density gradient in presence of a perpendicular field

2) is *unstable over a large range of wavenumber and frequencies*: fast branch with $\gamma \sim \Omega_{LH}$, $k \sim 1/\rho_e$, ES, slow branch at $k \sim 1/\sqrt{\rho_e \rho_i}$, EM

3) breaks large scale fields in smaller and smaller structures → acts as a "*turbulence generator*"

4) has been long *connected to magnetic reconnection,* through different process, e.g.. anomalous resistivity [Brackbill84, Ozaki96, Horiuchi99, Silin05, Buchner07, Innocenti07], to enhance the growth rate of tearing modes [Lapenta02, Daughton04], as a reconnection front instability [Divin15]

5) *fluctuations of LHDI origin are observed* in the terrestrial magnetotail [Shinohara98, Oieroset02, Norgren12] and -pause [Bale02, Vaivads04] and in laboratory plasmas [Carter01]

## MLMD simulations of LHDI with realistic mass ratio and RF=8

The LHDI is simulated at *realistic mass ratio* with a MLMD system with RF=8

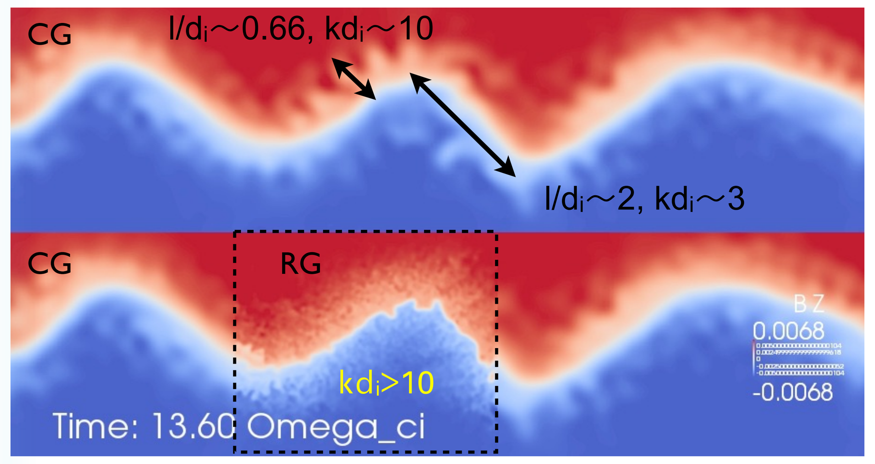



Fig 3: zoom of the out-of-plane field component Bz in a MLMD simulation of LHDI with RF=8; different wavelengths are visible in the Coarse (CG) and Refined (RG) Grid, superimposed in the bottom panel

[Norgren 2012] observes *coupling between the perpendicular electric field and magnetic field oscillations in the magnetotail* in presence of LHDI waves at wavenumbers corresponding to the electrostatic LHDI branch with the perpendicular electron current (J) as mediator. We confirm their observations and extend the study to lower wavenumber (electromagnetic LHDI branch, kink instability)

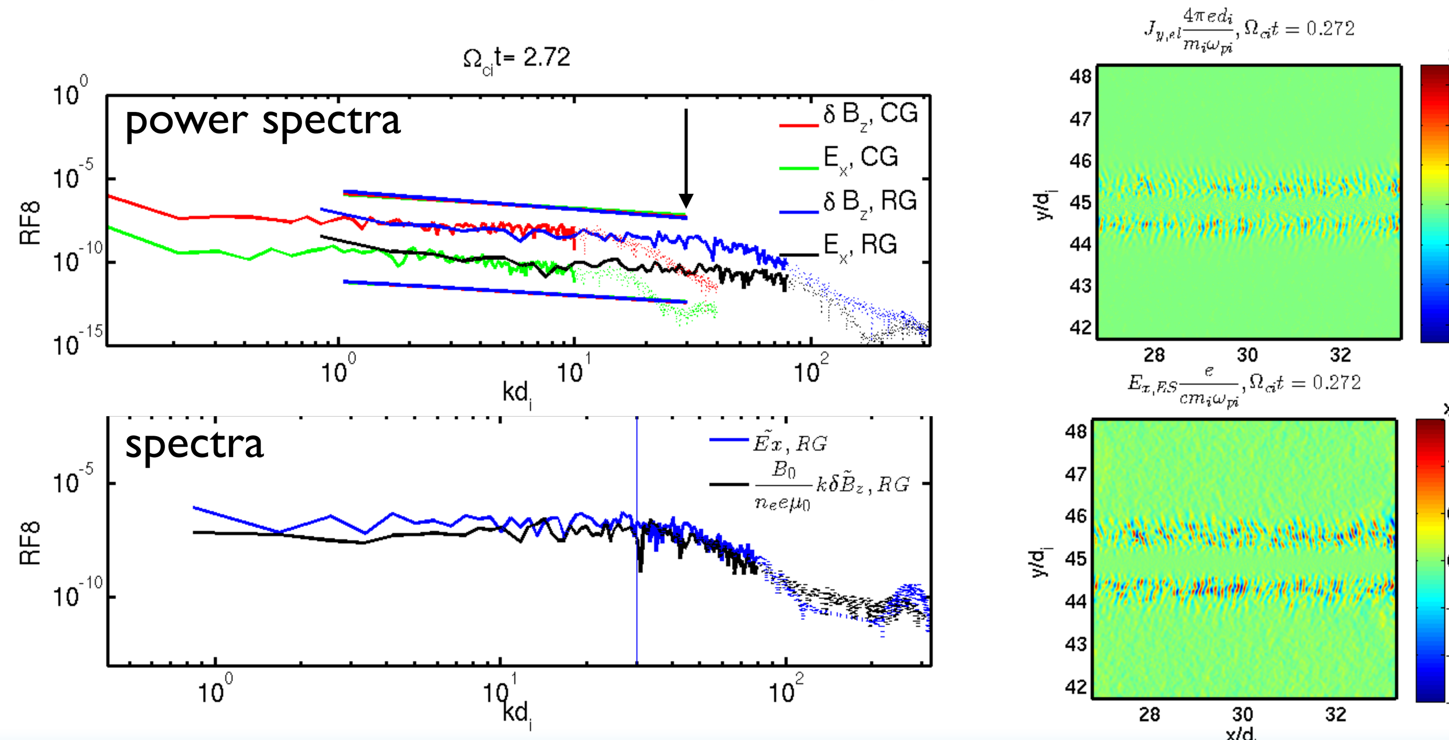



Fig 4: electrostatic (ES) LHDI branch time scales and wavenumbers: Ex δBz coupling observed, electron current as mediator → break in the δBz power spectra at lower, non coupled (k di ~30) wavenumbers

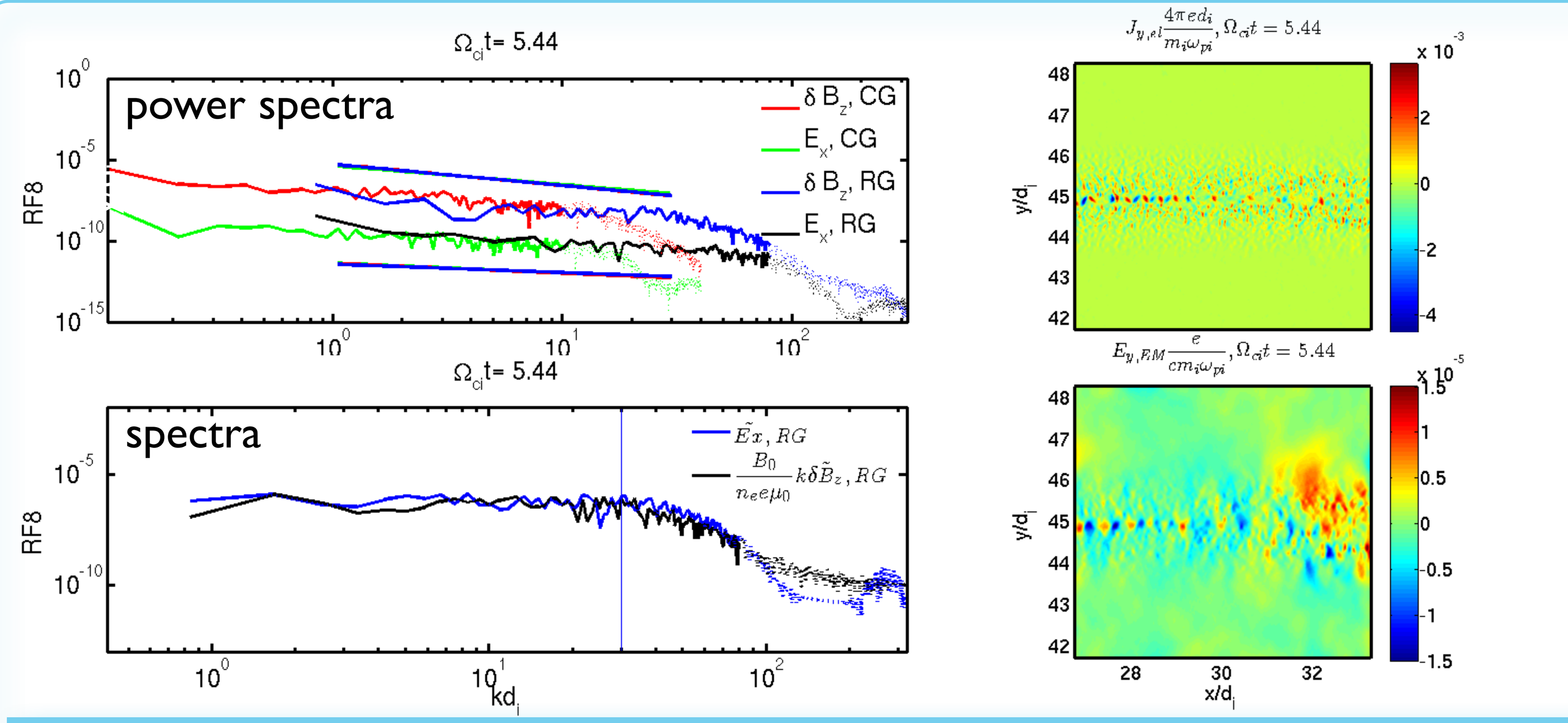



Fig 5: coupling extends to LHDI electromagnetic (EM) wavenumbers with the onset of LHDI EM branch ($1/\sqrt{\rho_e \rho_i} \sim 20/d_i$); mediator is still the electron current, but structures are at the centre of the current sheet and of EM origin

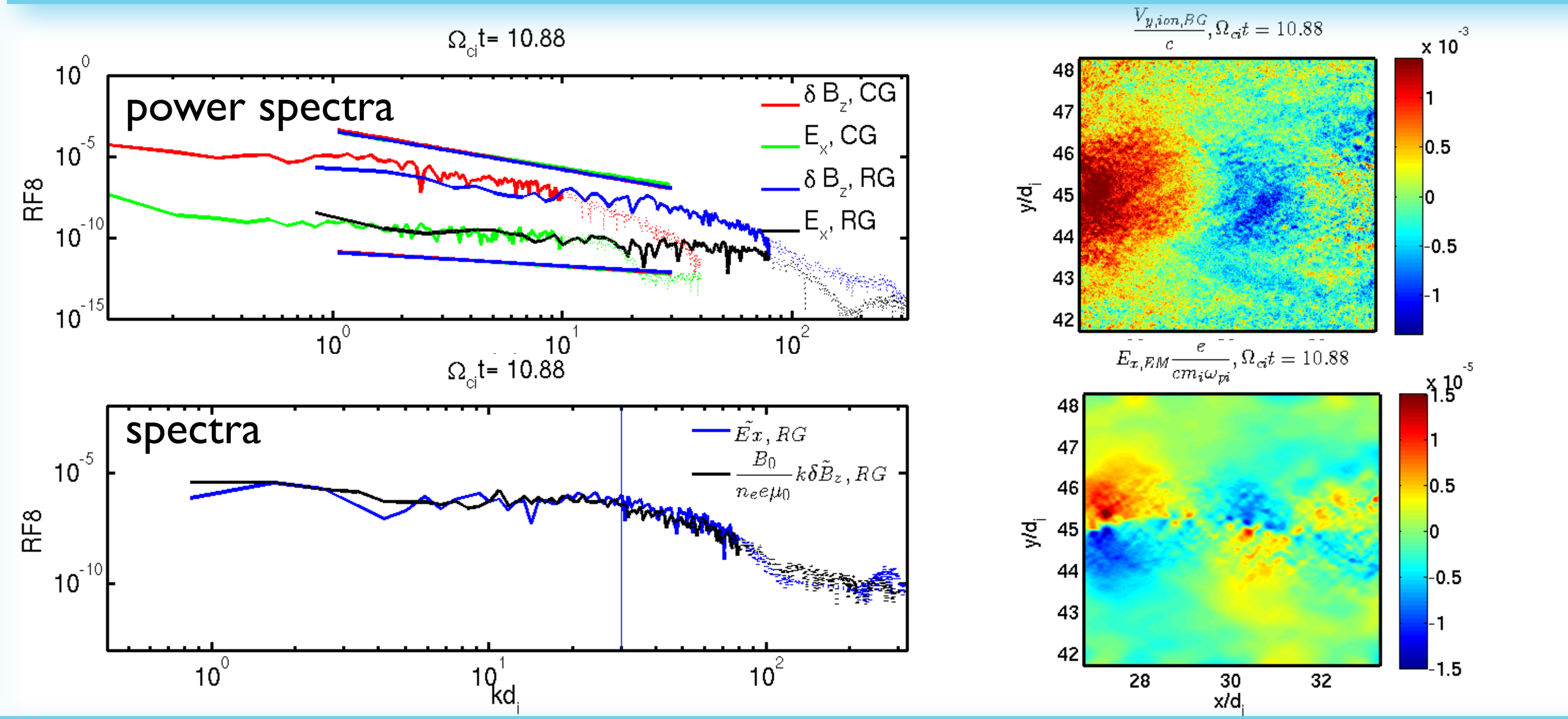



Fig 6: at kink mode time scales and wavenumbers ($kL_H \sim 2$, $kd_i \sim 4$), background ions [Karimabadi 2003] act as mediators

## Conclusions

We have used the MLMD method to simulate, at moderate computational cost, LHDI turbulence in the terrestrial magnetotail with realistic mass ratio. We have observed the coupling between magnetic field and perpendicular electric field fluctuations described in [Norgren12] at ES LHDI wavenumber and extended the study of the coupling to lower (EM LHDI, ion-ion kink instability) wavenumbers

References: M.E. Innocenti, G. Lapenta, S. Markidis, A. Beck, and A. Vapirev. *A MLMD method for Particle In Cell Plasma Simulations*. JCP, 2013; A. Beck, M.E. Innocenti, G. Lapenta, and S. Markidis. *MLMD algorithm implementation for 2D multiscale PIC simulations*. JCP, 2014.; M.E. Innocenti, A. Beck, T. Ponweiser, S. Markidis and G. Lapenta. *Introduction of temporal sub-stepping in the Multi Level Multi Domain semi-implicit Particle In Cell code Parsek2D-MLMD*, CPC, 2015; M.E. Innocenti, D. Newman, S. Markidis and G. Lapenta. *Study of electric and magnetic field fluctuations from LHDI waves in the terrestrial magnetotail with the fully kinetic, semi-implicit, adaptive Multi Level Multi Domain method*, in preparation

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