

Un projet de code MHD pour les sciences de l'Univers: rêve ou réalité ?

ASSNA Décembre 2003

Equipe d'origine :

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- Stéphane COLOMBI I.A.P.
- Sébastien FROMANG I.A.P.

Accord de principe :

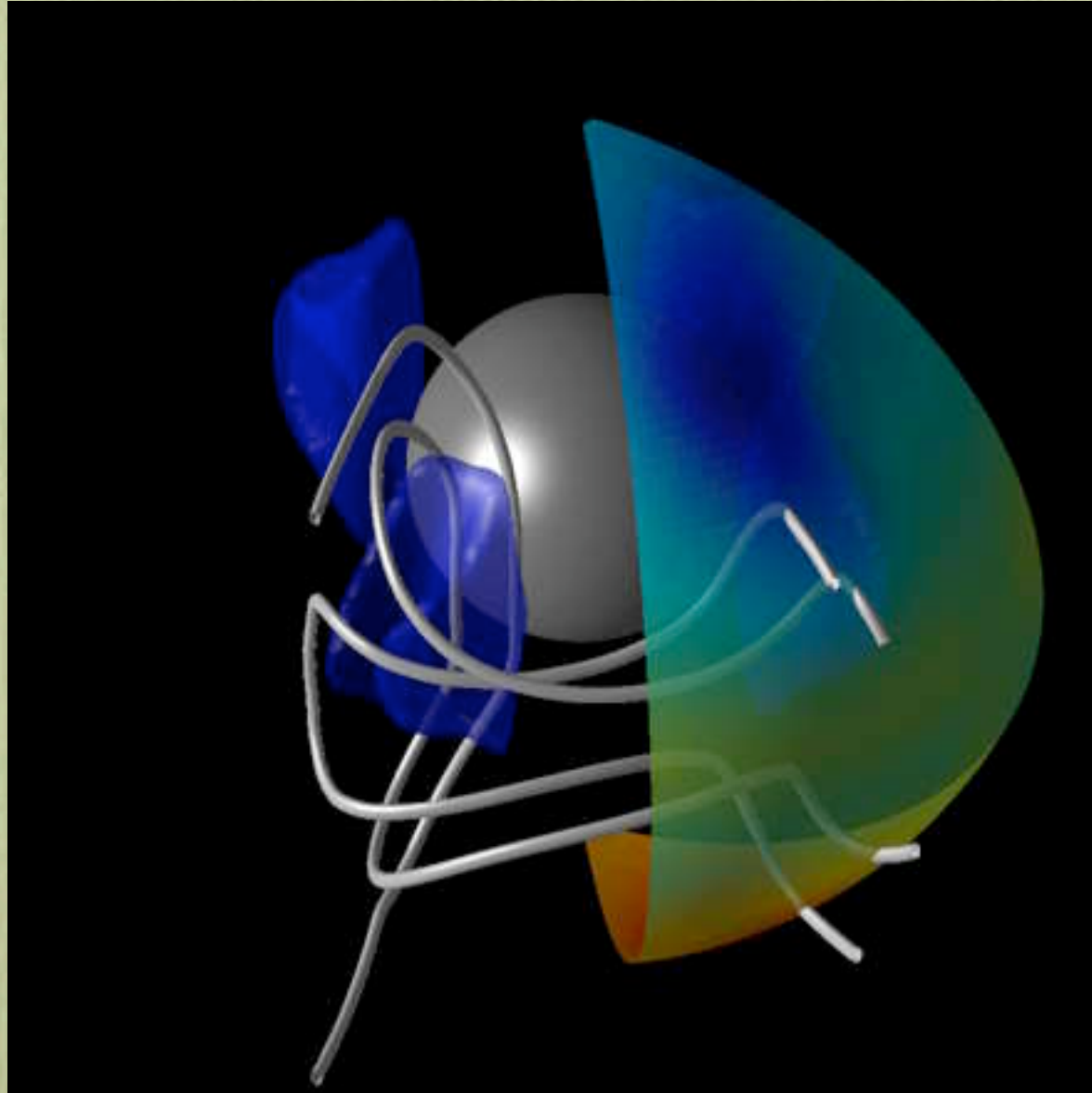
- François BOUCHUT D.M.A. E.N.S.
- Allan Sacha BRUN SAp C.E.A.
- Patrick HENNEBELLE L.R.A. E.N.S.
- Frédéric MASSET SAp C.E.A.
- Yannick PONTY O.C.A.
- ...

Les codes existant au sein du groupe

- Méthodes Spectrales
- Volumes Finis

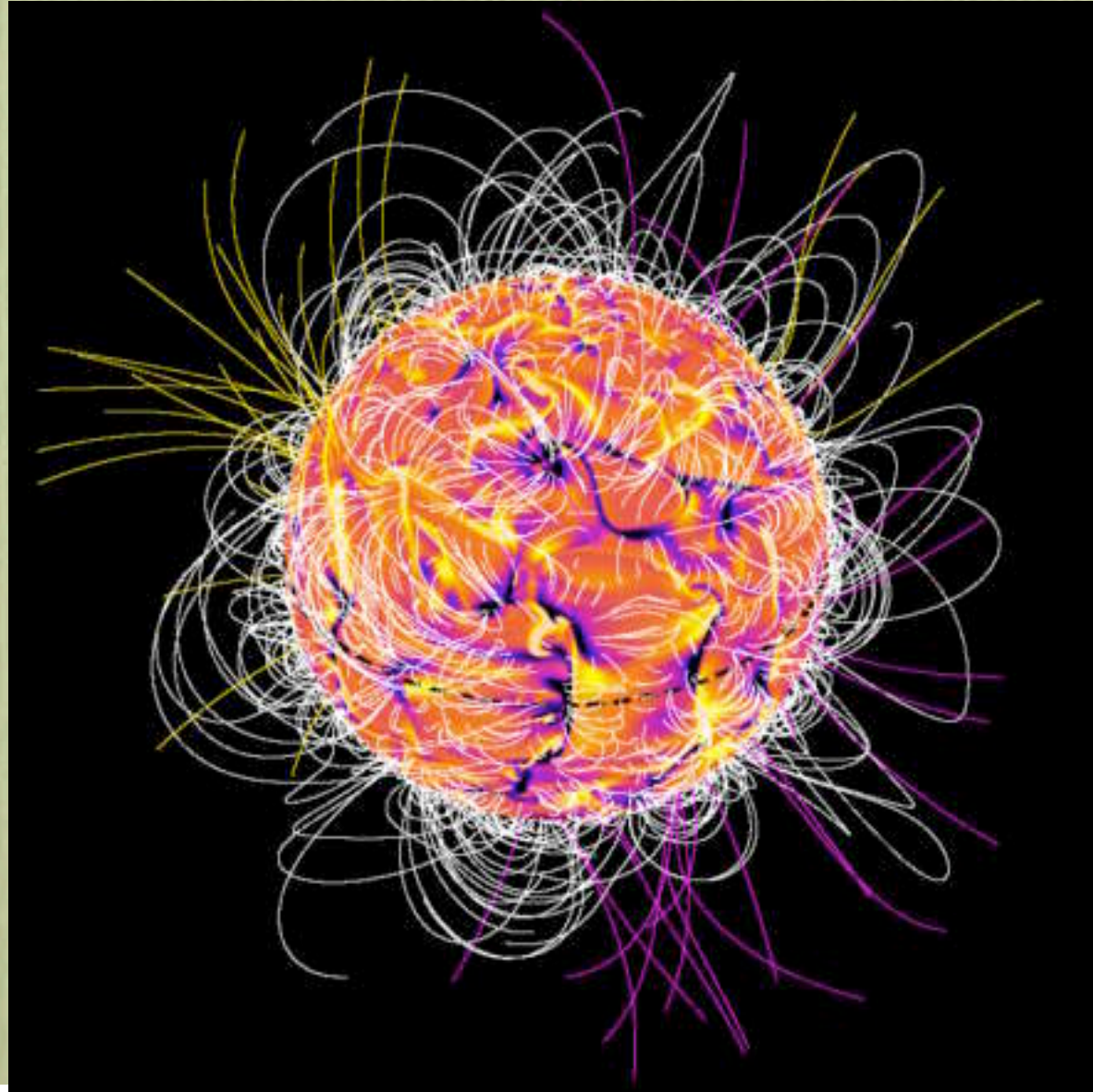
Code spectral Boussinesq

Benchmark international 2000

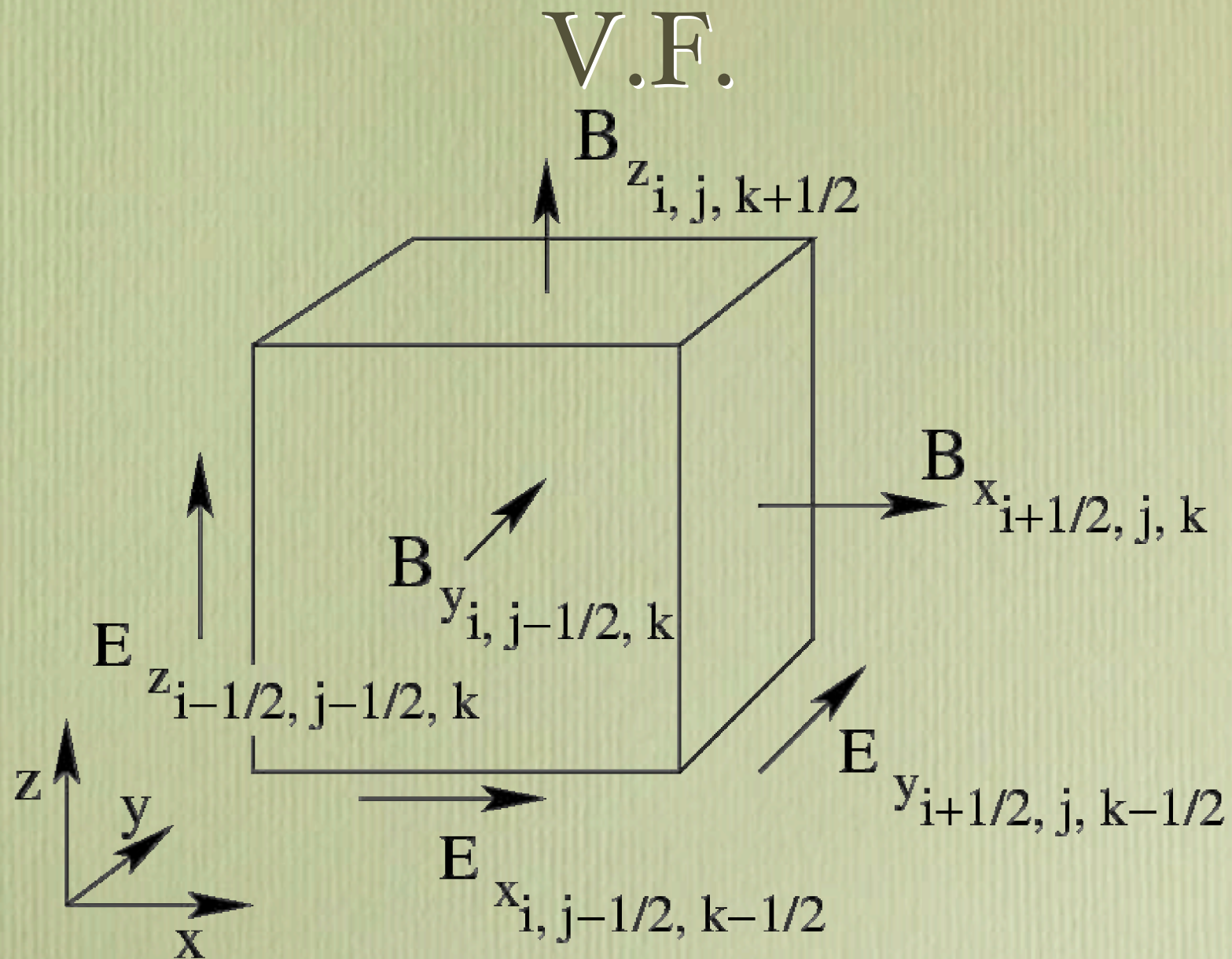


Aubert, Cardin, Dormy.

Code spectral anélastique ASH

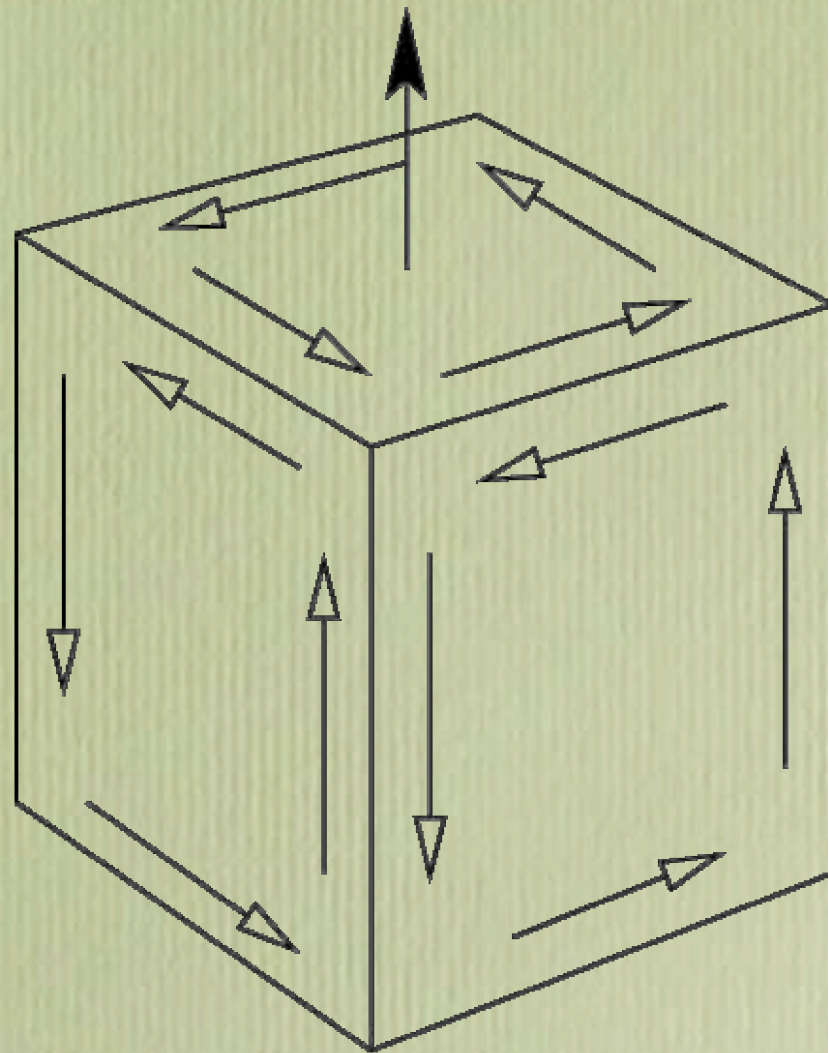


A.S. Brun



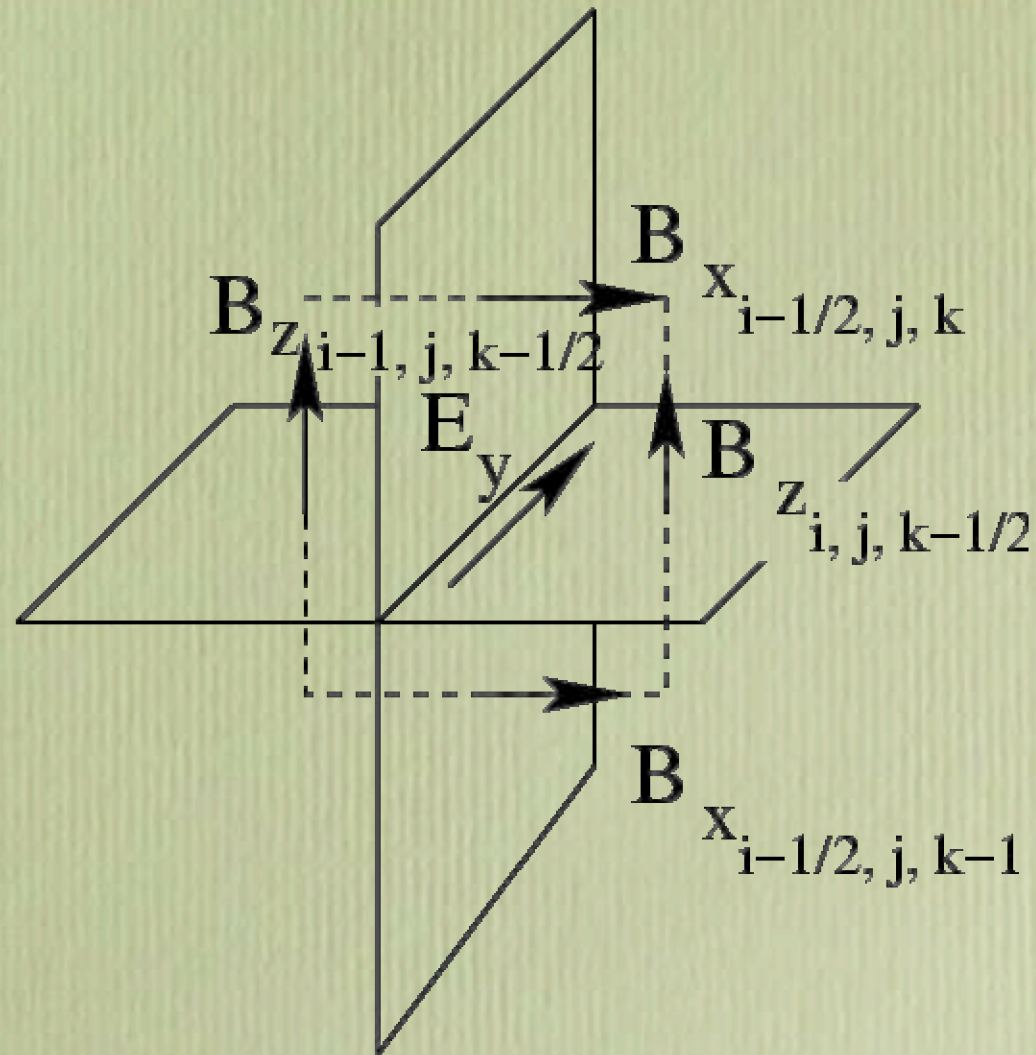
$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}, \quad \mathbf{E} = -\mathbf{u} \times \mathbf{B} + \eta \nabla \times \mathbf{B}$$

V.F.



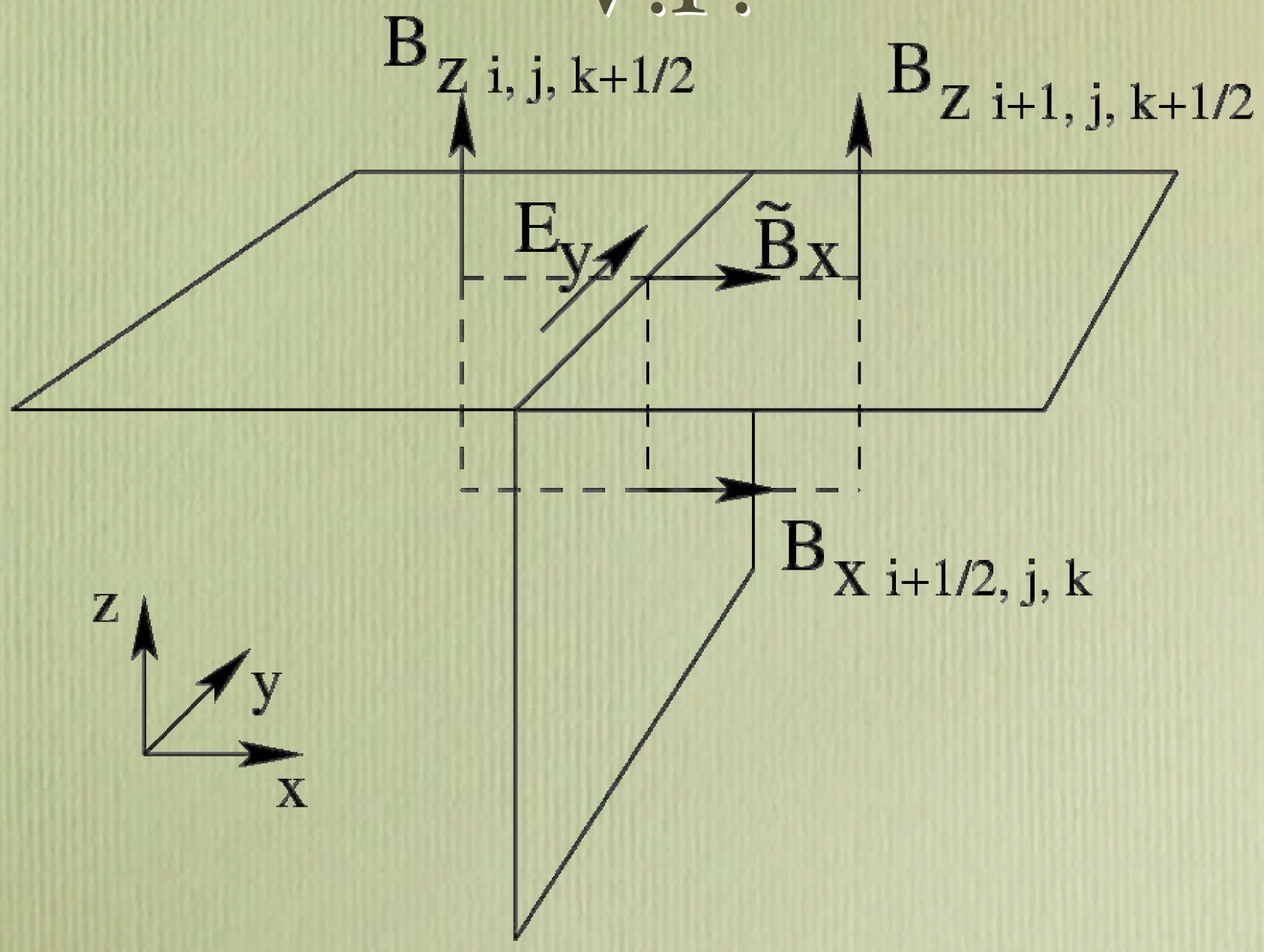
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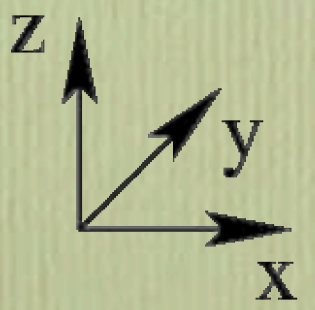
$B_{z i, j, k+1/2}$

$B_{z i+1, j, k+1/2}$

E_y

\tilde{B}_x

$B_{x i+1/2, j, k}$



V.F.

Domaine fini

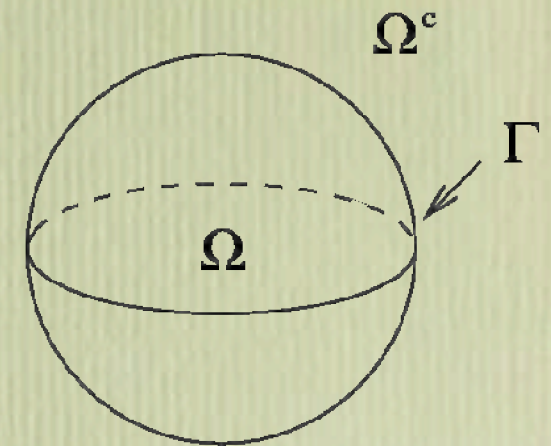
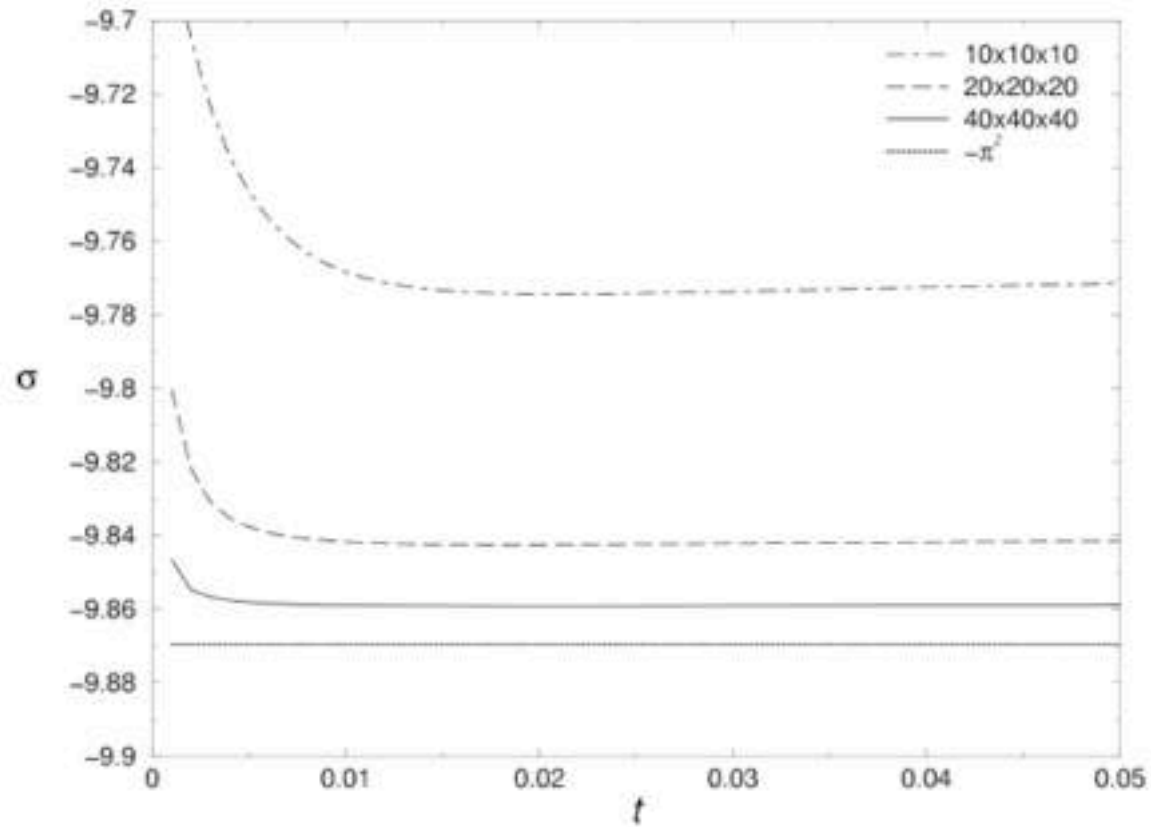
$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}, \quad \mathbf{E} = -\mathbf{u} \times \mathbf{B} + \eta \nabla \times \mathbf{B}$$

$$\phi(\mathbf{x}) = -2 \int_{\Gamma} \left(\phi(\mathbf{y}) \frac{\partial G(\mathbf{x}, \mathbf{y})}{\partial n} + B_n(\mathbf{y}) G(\mathbf{x}, \mathbf{y}) \right) ds(\mathbf{y}).$$

Couplage V.F. et B.E.M.

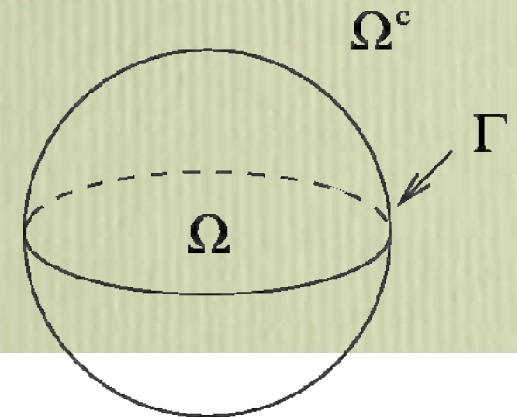
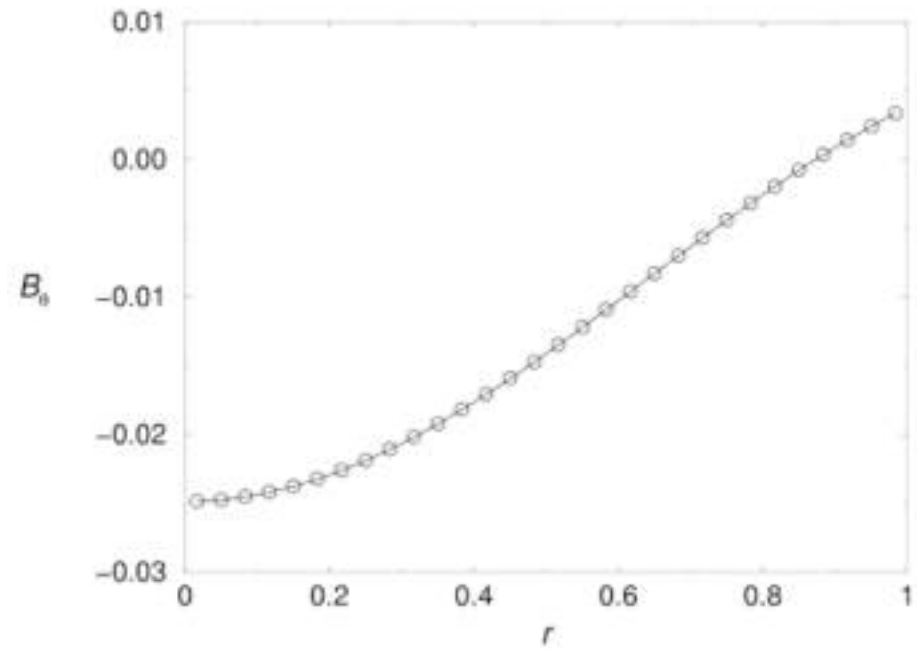
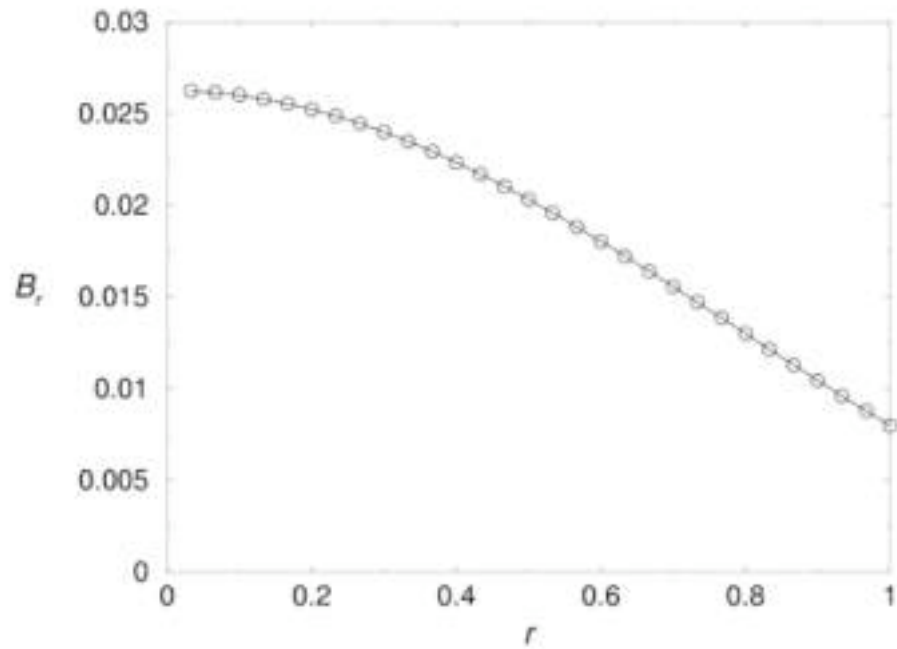
A. Iskakov, S.Descombes, E. Dormy

V.F.



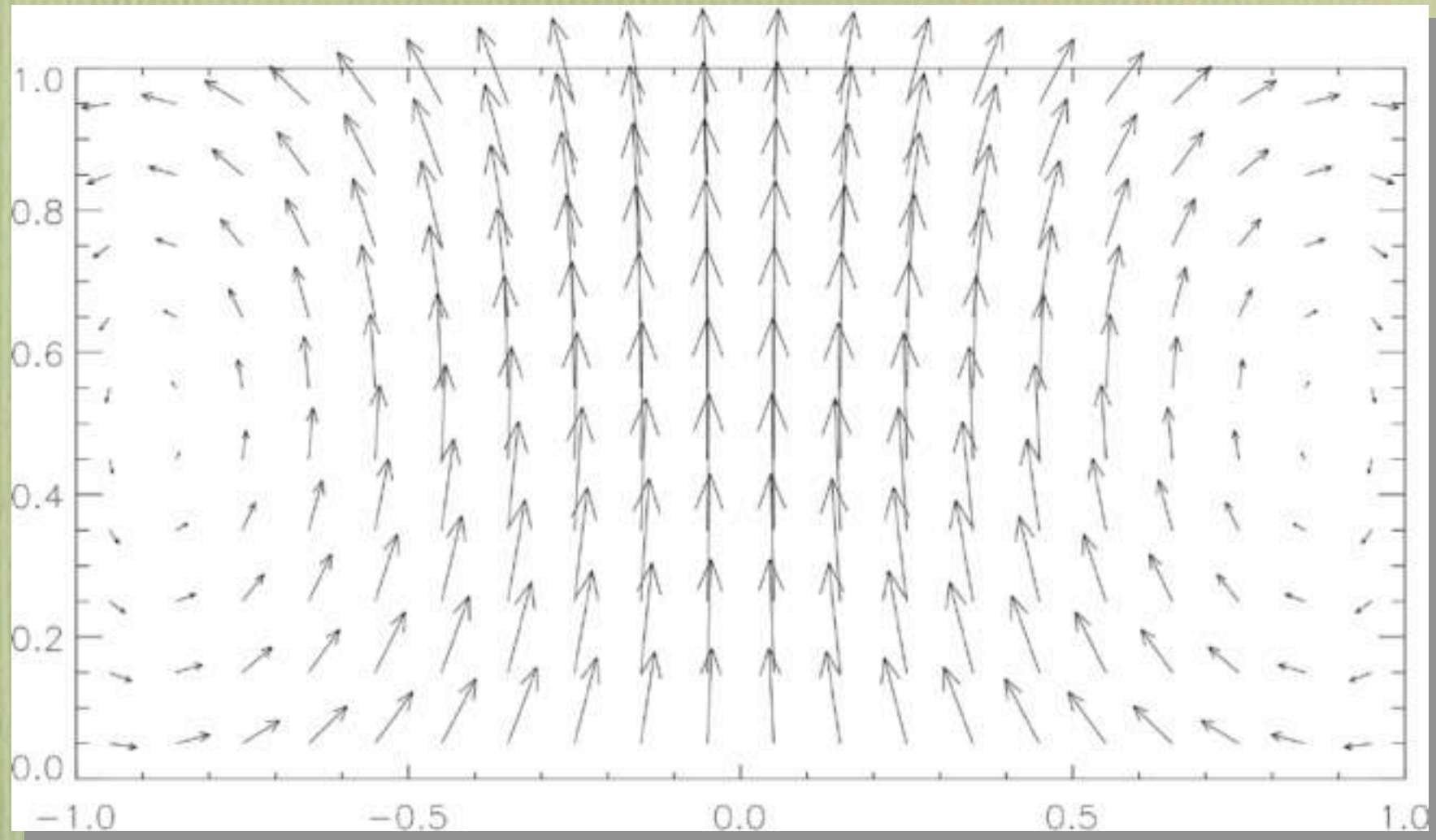
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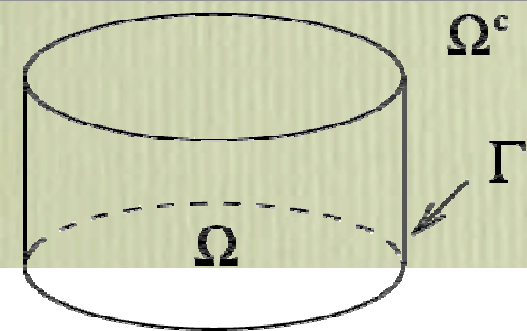


A. Iskakov, S.Descombes, E. Dormy

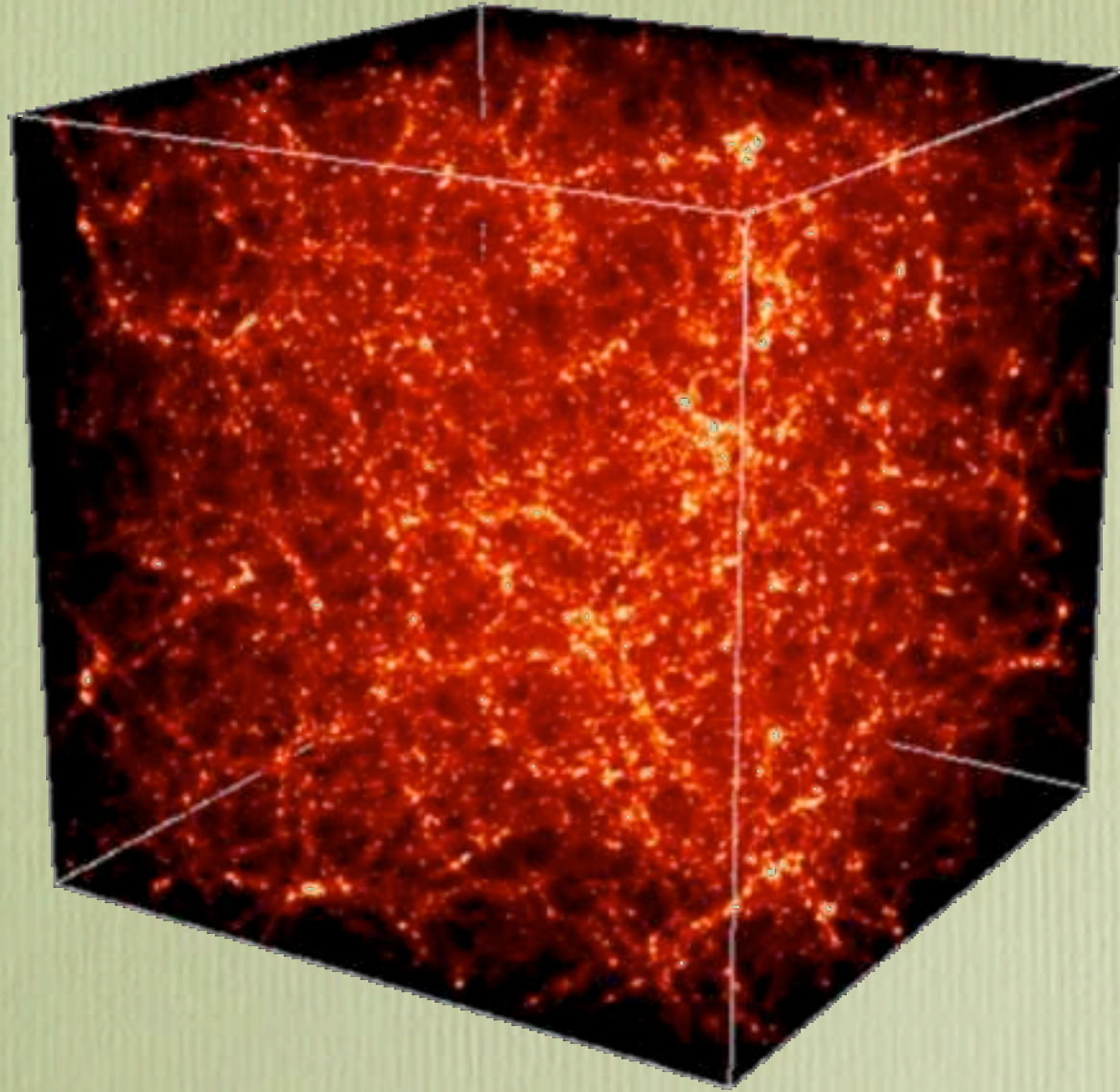
V.F.



A. Iskakov, S.Descombes, E. Dormy
J.Comp.Phys., sous presse

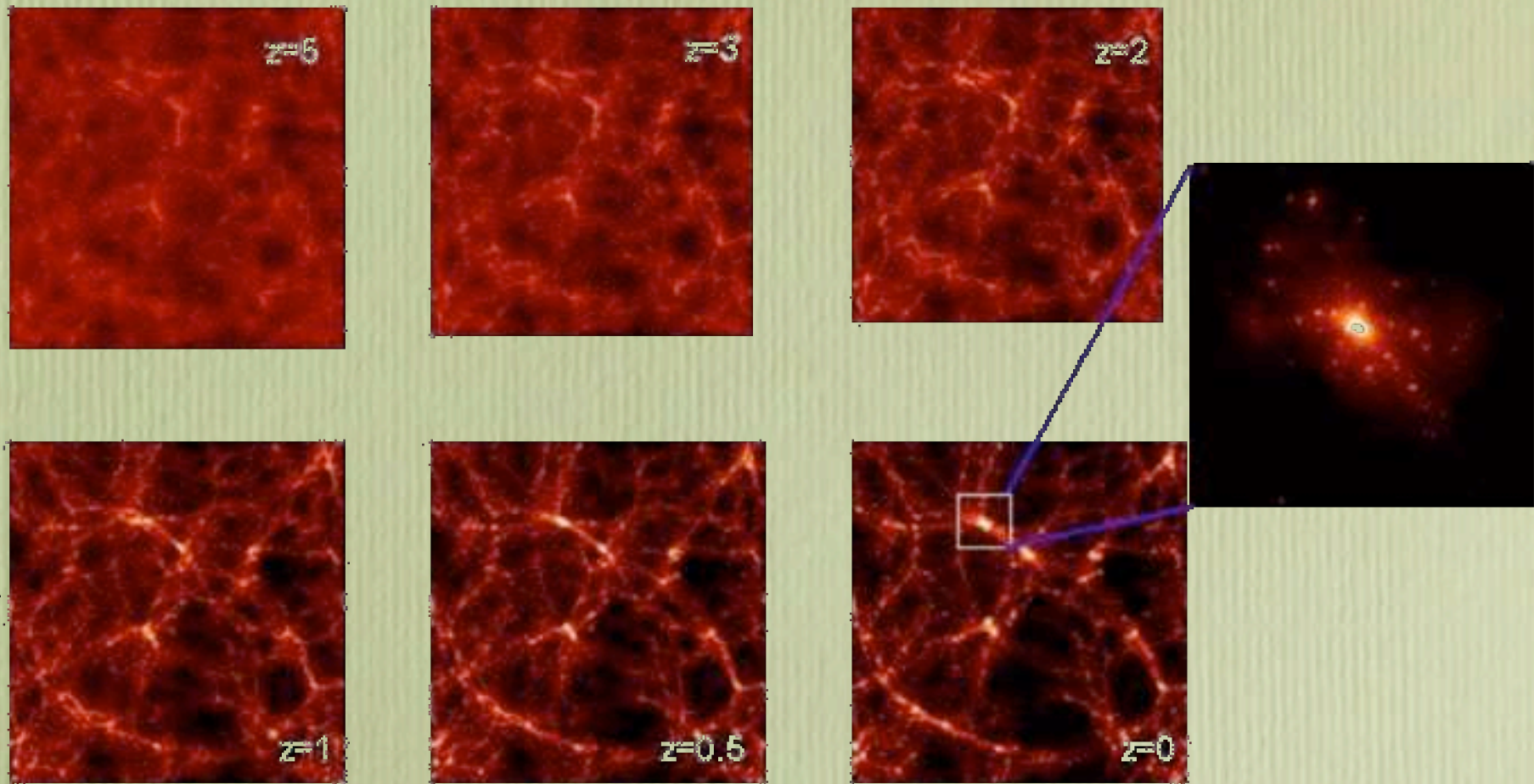


AMR RAMSES



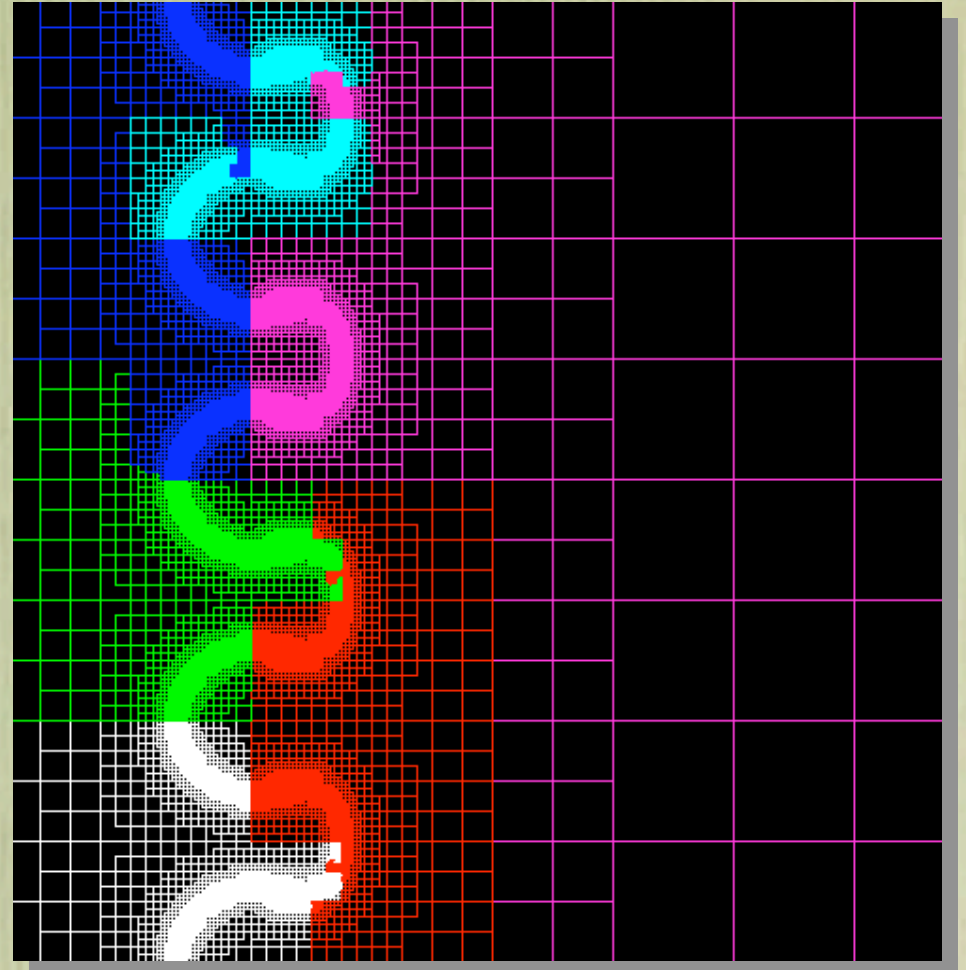
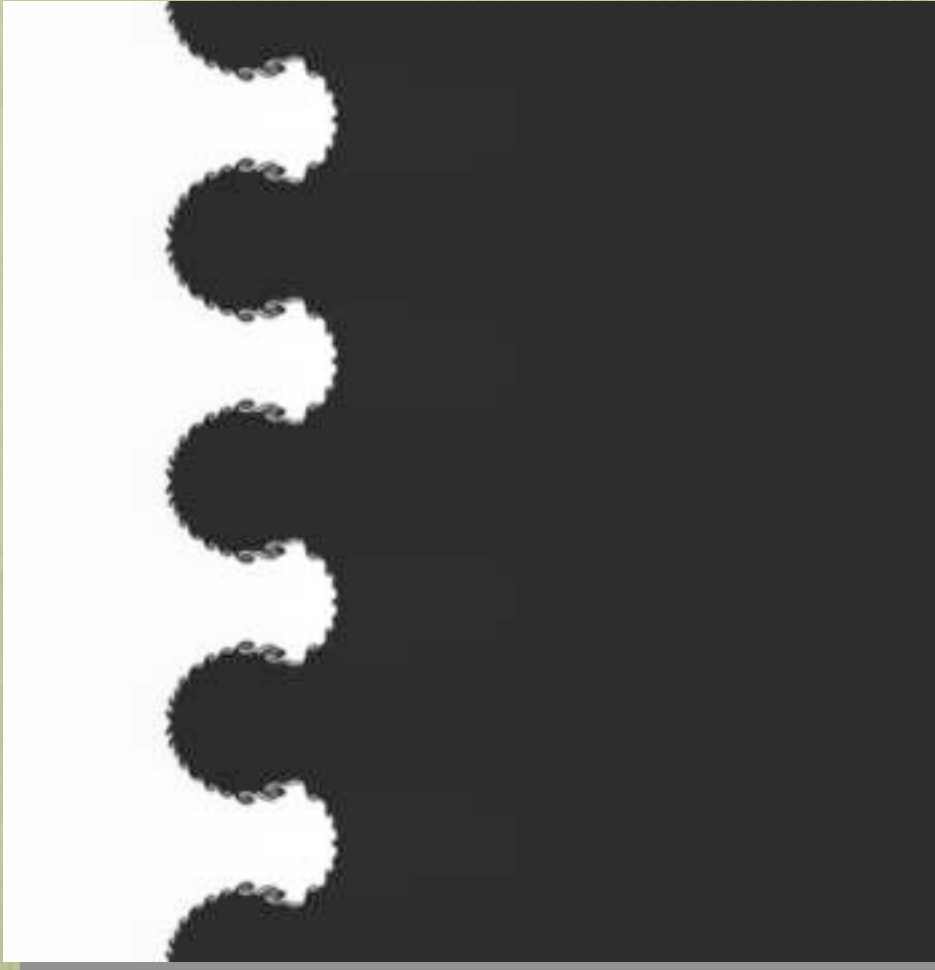
Romain Teyssier

AMR RAMSES



Romain Teyssier

AMR RAMSES



Romain Teyssier

VF Godunov

$$\partial_t \mathbf{U} + \partial_x \mathbf{F}(\mathbf{U}) = \mathbf{0}$$

Méthode de Godunov d'ordre 1:

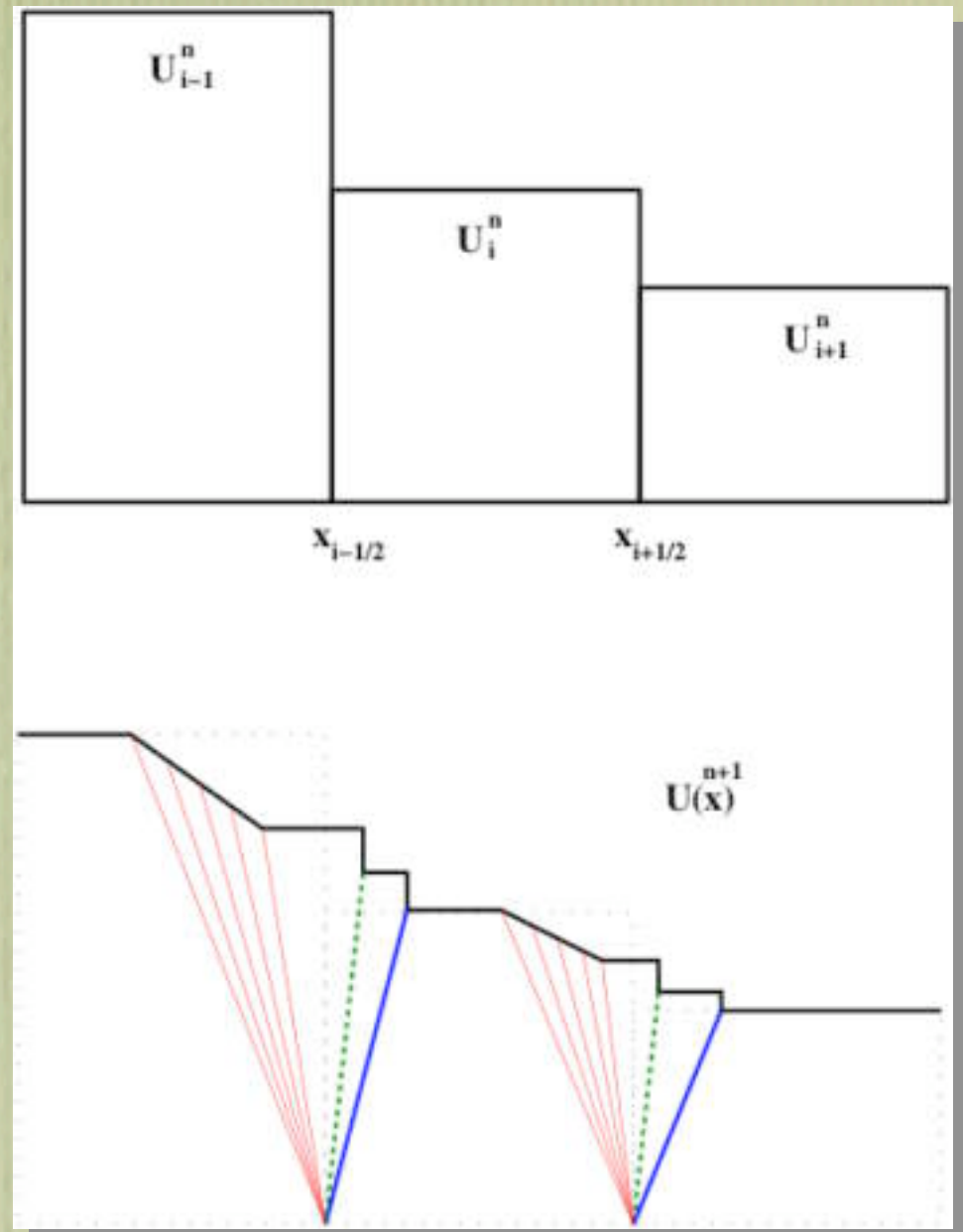
Solution constante par morceaux

Le flux est obtenu par la résolution d'un problème de Riemann 1D à l'interface entre deux cellules.

$$\mathbf{U}_i^{n+1} = \mathbf{U}_i^n - \frac{\Delta t}{\Delta x} (\mathbf{F}_{i+1/2}^{n+1/2} - \mathbf{F}_{i-1/2}^{n+1/2})$$

Schémas d'ordres élevés :

Reconstruction linéaire par morceaux ou parabolique, avec des contraintes de monotonicité (TVD).

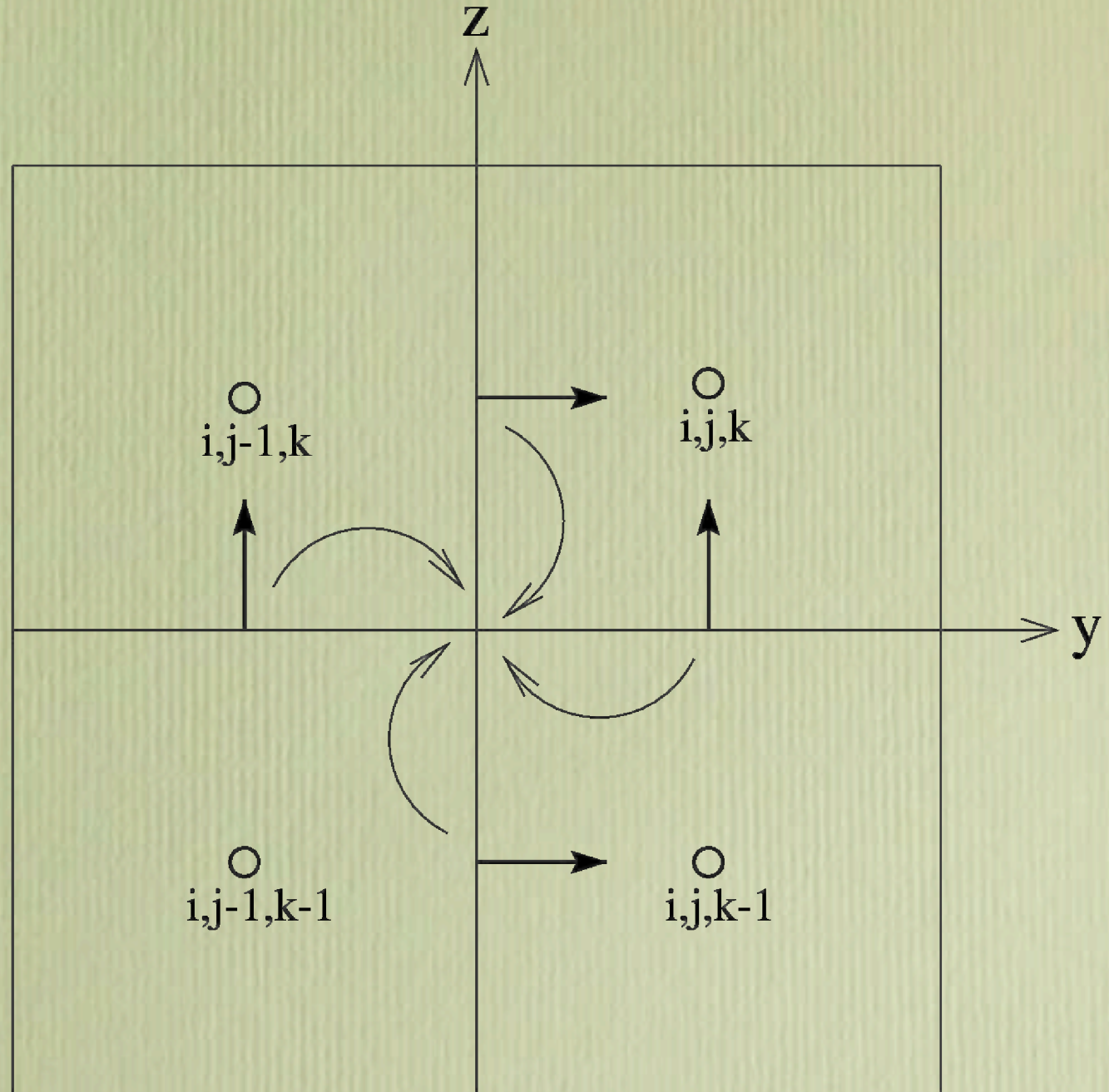


VF Godunov

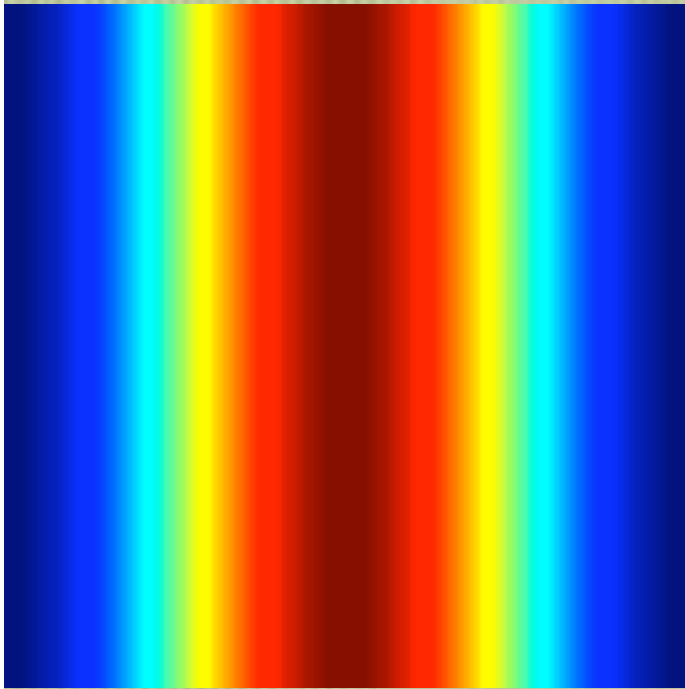
Equation d'induction seule:

Grille « staggered »,

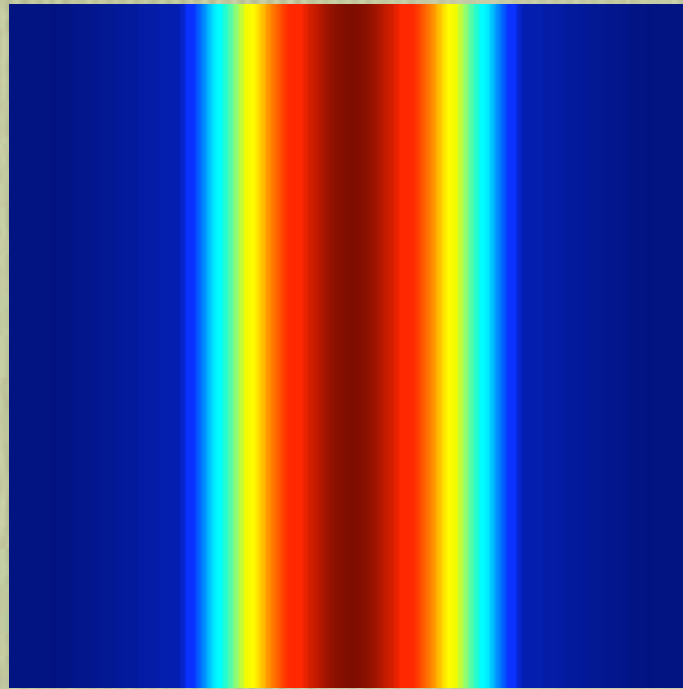
« solveur de Riemann » à 2D.



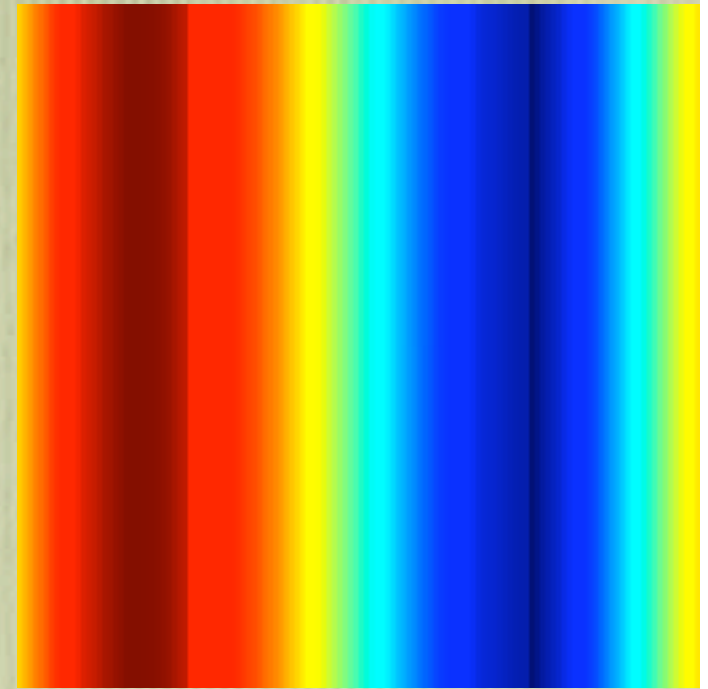
Equation d'induction avec un champ de vitesse analytique dynamo rapide



B_x x, y



B_y x, y



B_z x, y

Coupe, à z fixé, dans une simulation numérique 3D

Evolution : induction avec
champ de vitesse d'une
simulation hydrodynamique.

MHD complète

- MHD idéale ou très grand R_m
- V.F. Godunov, deuxième ordre explicite
- Grille structurée

Powell 8 ondes

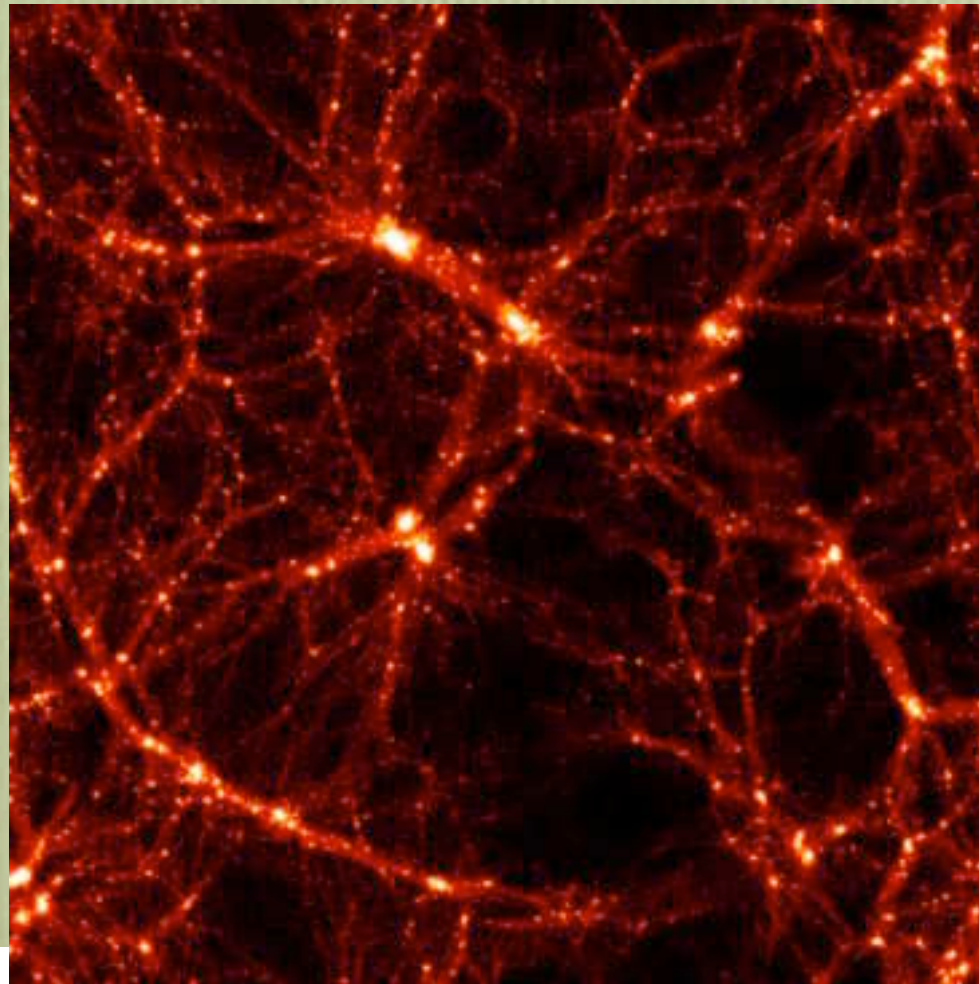
Modification des équations de Maxwell...

$$\frac{\partial \rho \mathbf{v}}{\partial t} + \nabla \cdot (\mathbf{v} \rho \mathbf{v} - \mathbf{B} \mathbf{B}) + \nabla p_{tot} = -(\nabla \cdot \mathbf{B}) \mathbf{B}$$
$$\frac{\partial \mathbf{e}}{\partial t} + \nabla \cdot (\mathbf{v} \mathbf{e} + \mathbf{v} p_{tot} - \mathbf{B} \mathbf{B} \cdot \mathbf{v} - \mathbf{B} \times \eta \mathbf{J}) = -(\nabla \cdot \mathbf{B}) \mathbf{B} \cdot \mathbf{v}$$
$$\frac{\partial \mathbf{B}}{\partial t} + \nabla \cdot (\mathbf{v} \mathbf{B} - \mathbf{B} \mathbf{v}) + \nabla \times (\eta \mathbf{J}) = -(\nabla \cdot \mathbf{B}) \mathbf{v}$$

voir Toth, J. Comput. Phys, **161**, 605, 2000

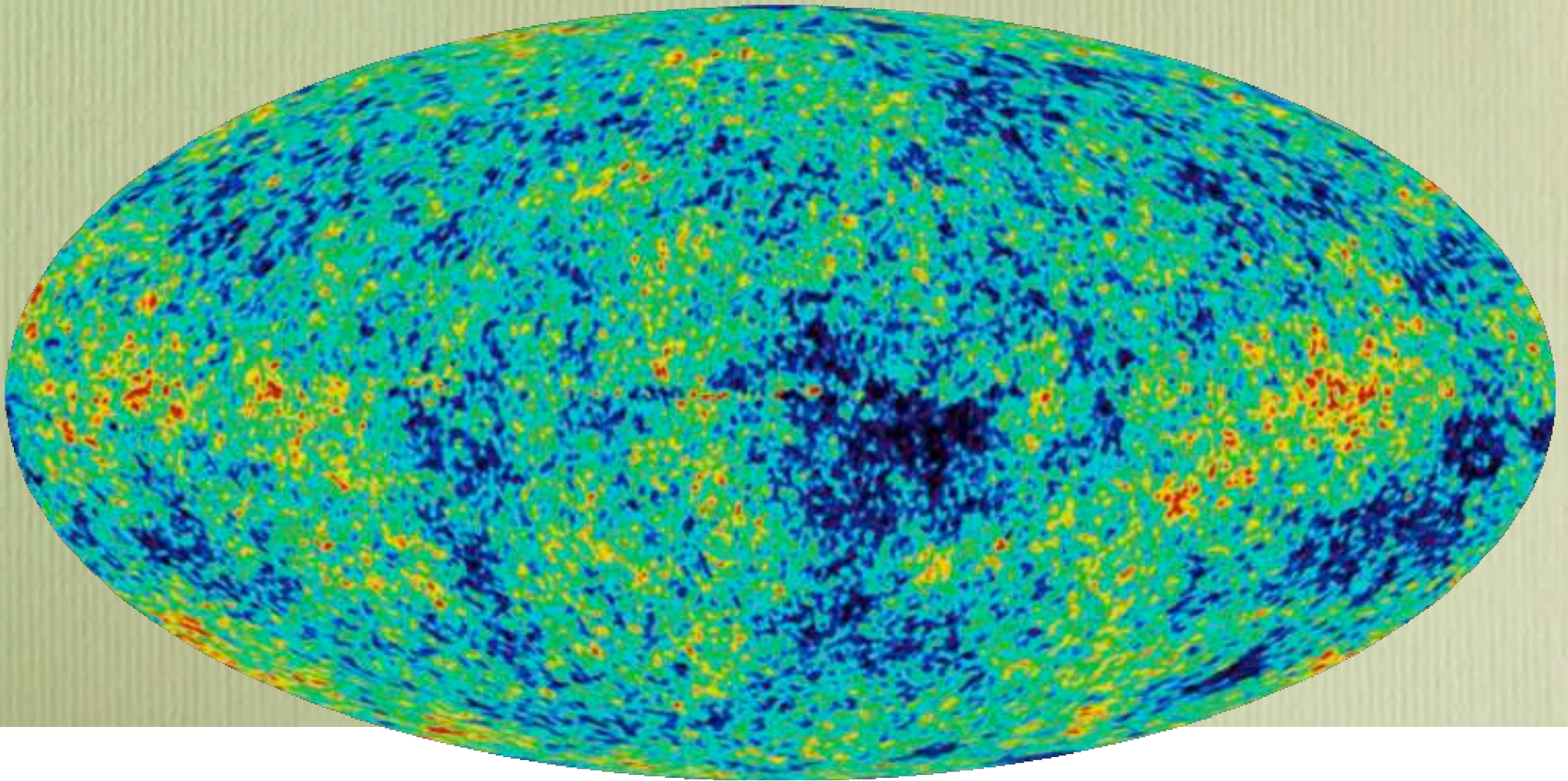
Applications physiques : MHD & Cosmologie

Dynamique du champ magnétique
dans la formation des grandes structures



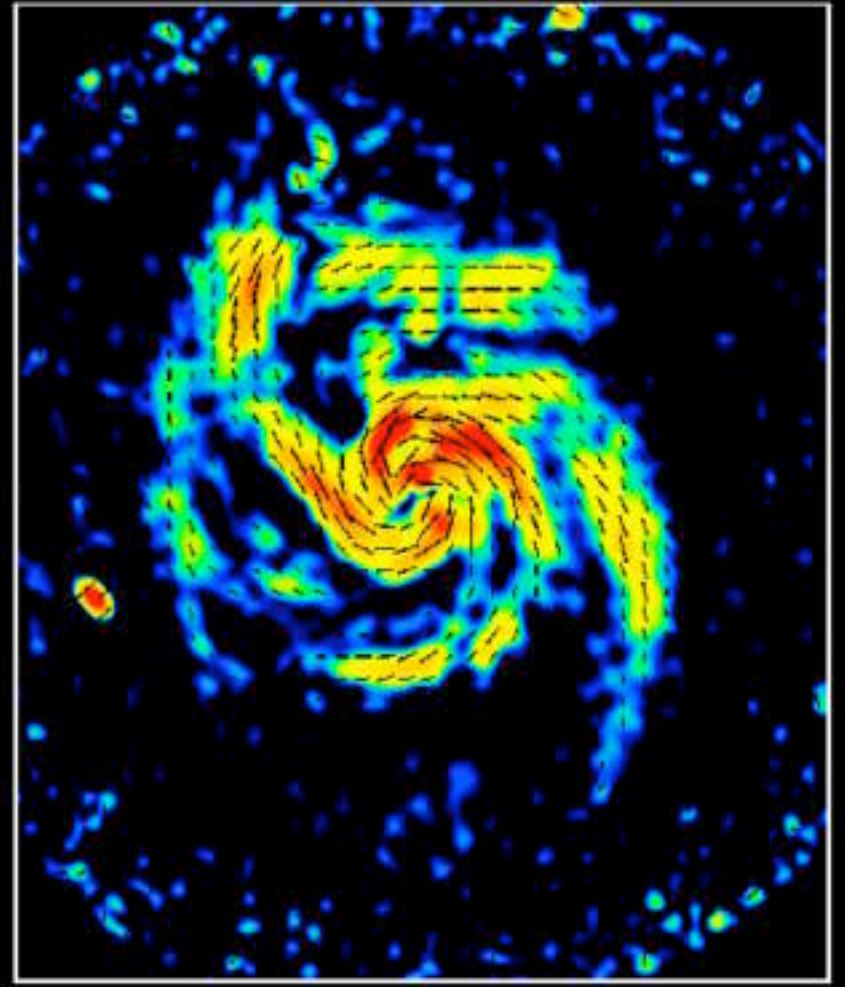
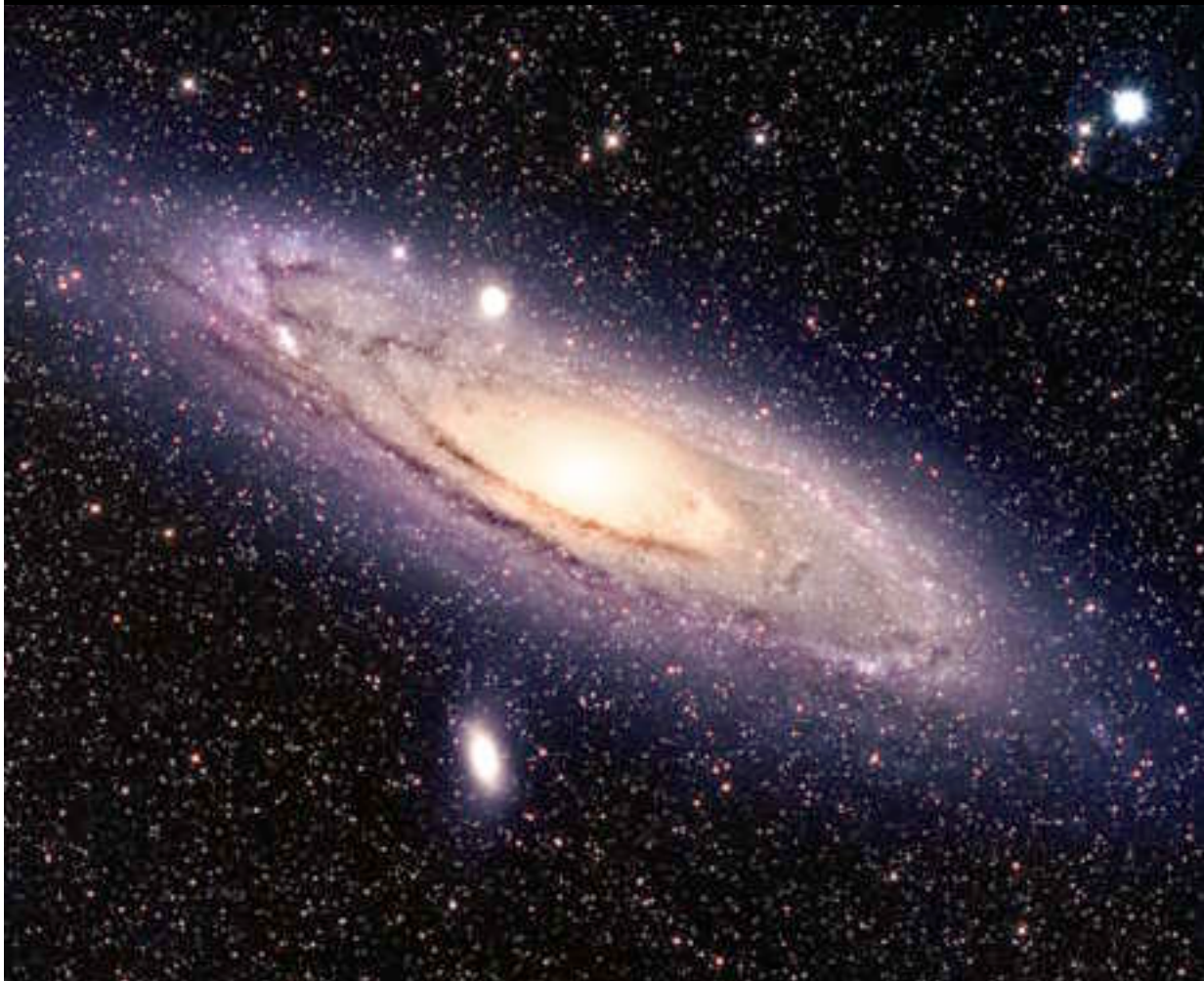
Applications physiques : MHD & Cosmologie

Structure du champ magnétique,
effet sur la polarisation du CMB



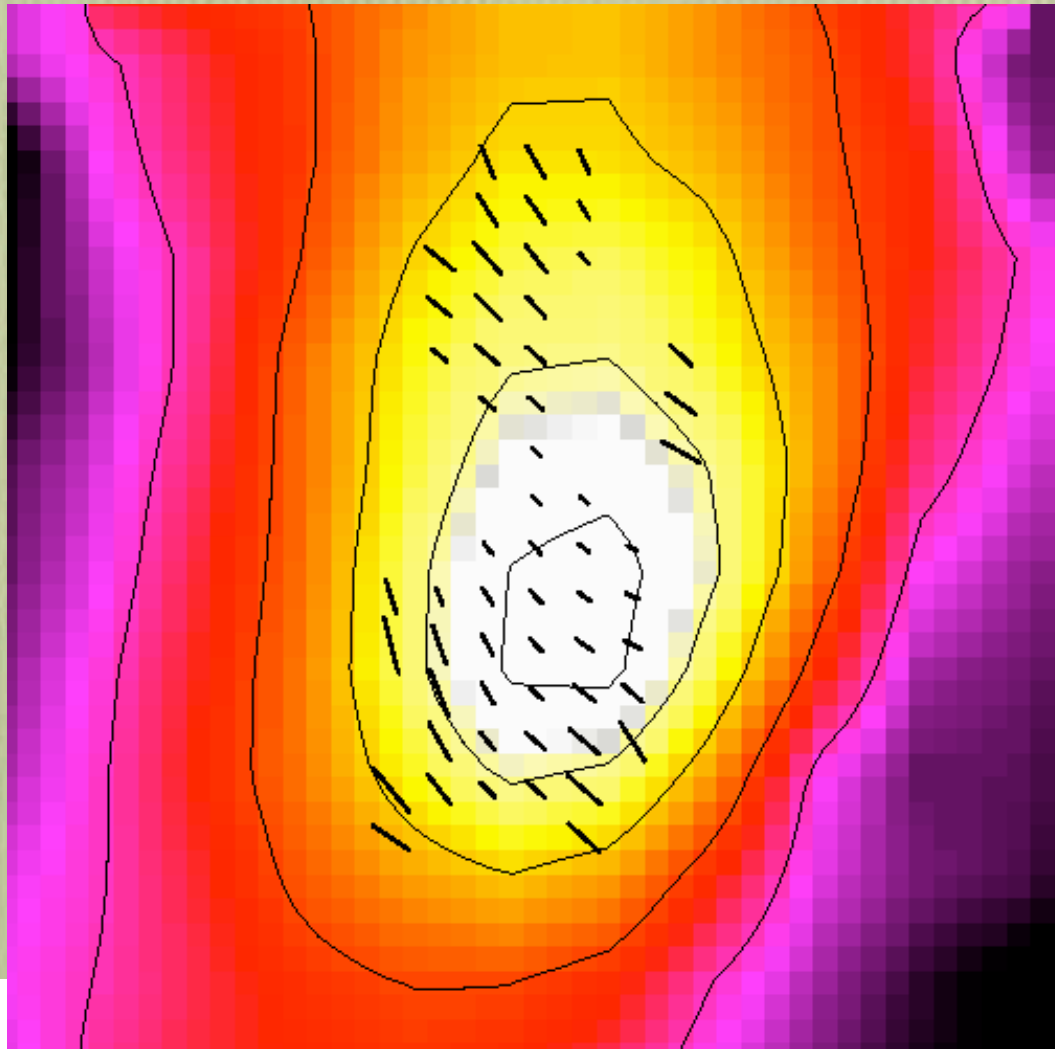
Applications physiques : Effet dynamo

Galaxies, étoiles, planètes



Applications physiques : MHD & ISM

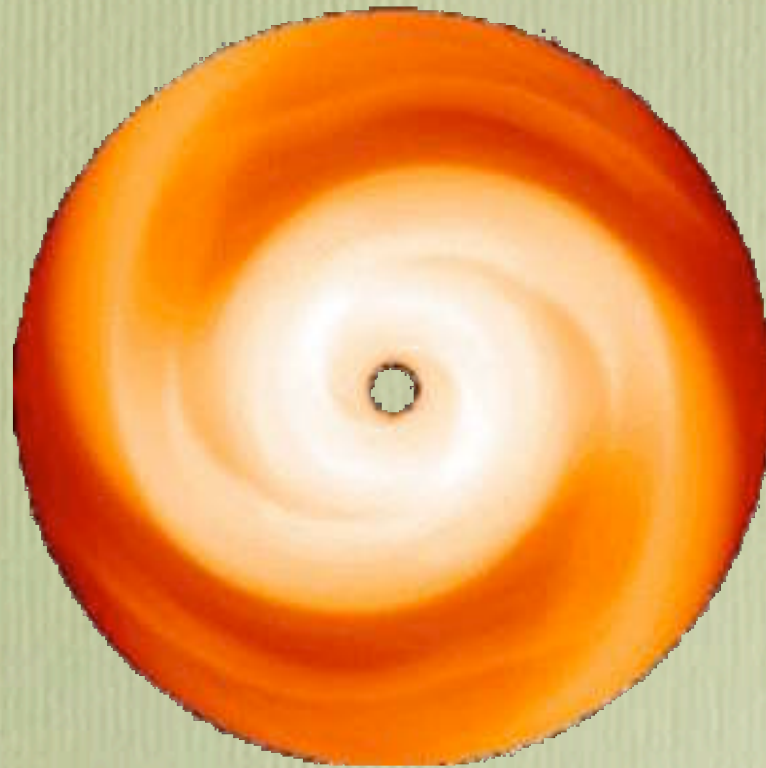
Rôle du champ magnétique



Applications physiques : MHD & ISM



Applications physiques : disques d'accrétion



Sebastien Fromang I.A.P.

Un projet de code MHD pour
les sciences de l'Univers:
rêve ou réalité ?
