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On our way to a full GR n-body code, gevolution and LATfield2

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Gevolution: Julian Adamek, Ruth Durrer and Martin Kunz
Nature Phys. 12 (2016) 346-349: 1509.01699 ; 1604.06065
LATfield2: Mark Hindmarsh, Neil Bevis 1508.05610
Numerical relativity: Ermis Mitsou, Yves Dirian

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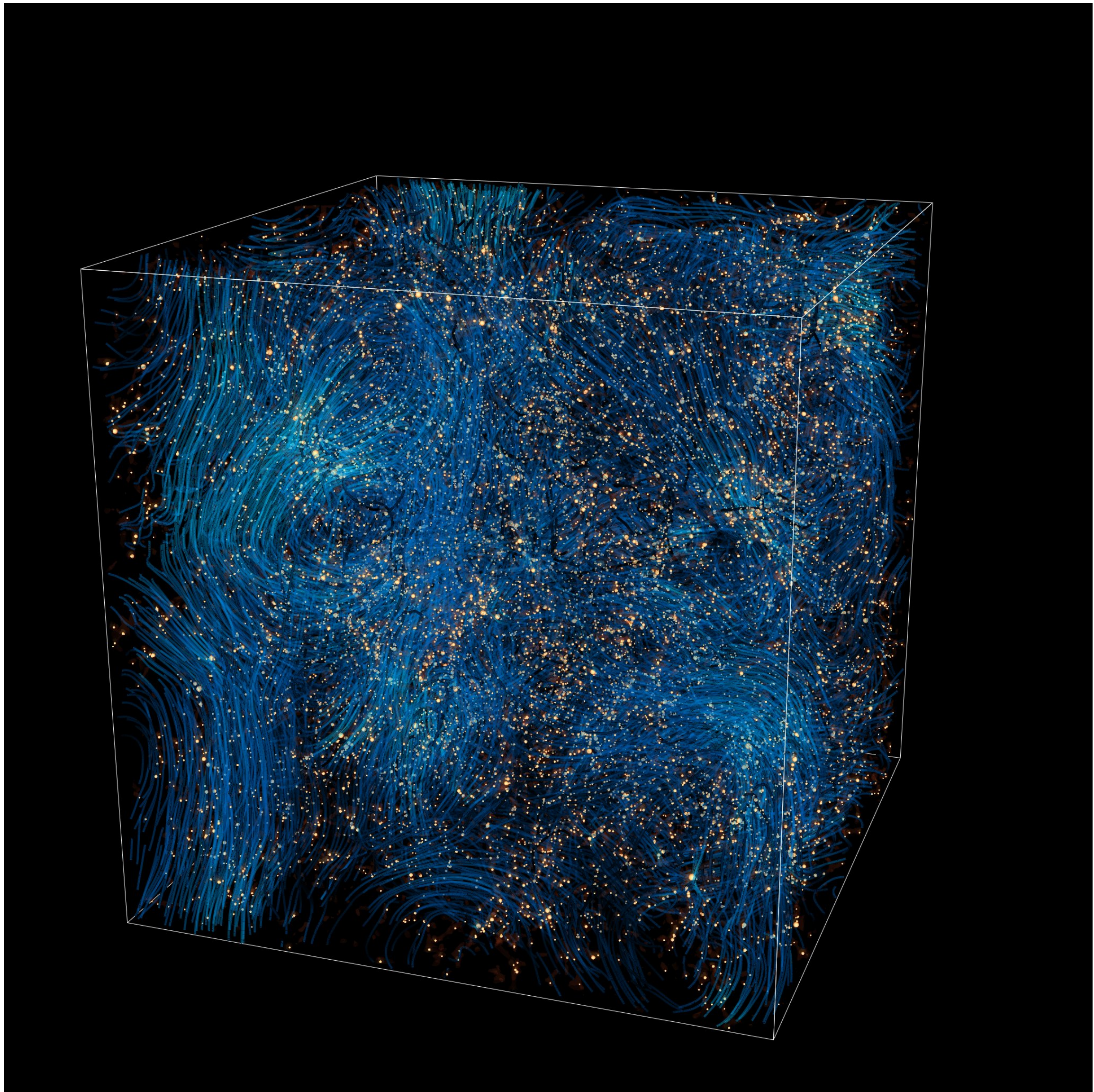
Motivation

- relativistic effect are relevant for next generation of surveys.
- Can we believe ray-tracing results without vectors, tensors and gravitational slip?
- Some effects (e.g. backreaction) need GR simulation.
- Including relativistic particles (i.e. neutrinos) & fields (Dark Energy/Modified Gravity) appears also more natural with a relativistic framework.

gevolution

- Pure particles-mesh code.
- Solves Einstein equation in the weak field limit.
- Solves the geodesic equation to evolve particles.
- Uses a staggered leapfrog.
- Reduce equations to modified Poisson equations.
- Solvers in Fourier Space
- Developed on top of LATfield2



LATfield2, the gevolution C++ framework

Gevolution is written in C++ on top of the LAtfield2 library. (www.LATfield.org)

LATfield2:

- Cartesian static mesh.
- parallelization (pure MPI).
- Field operations.
- Ghost cells management.
- Fourier transforms.
- Particles handler.
- Output management (using HDF5).

Advantages:

- Extreme versatility: fields of C++ classes, arbitrary particles properties.
- Easy and intuitive.
- Very good scalability: scale up to 100,000 MPI processes.
- Outputs readable by Matlab, Python, Mathematica, VisIt & Paraview.

Disadvantage:

- No adaptive mesh methods (moving mesh under development).

gevolution weak field approximation

- Beyond linear order vector and tensor coupled to scalar:

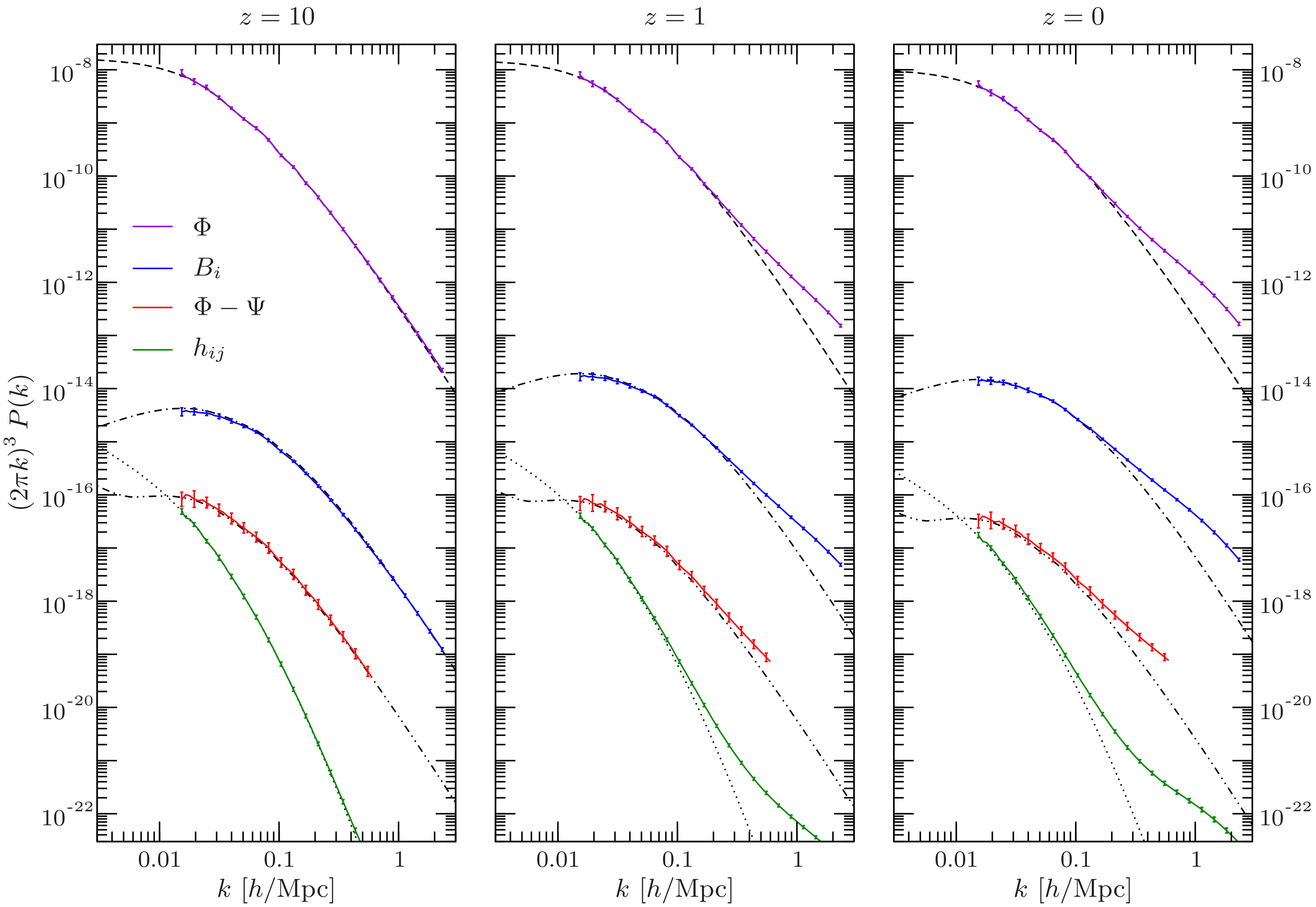
$$ds^2 = a^2(\tau)\left[-(1+2\Psi)d\tau^2 - 2B_i dx^i d\tau + (1-2\Phi)\delta_{ij}dx^i dx^j + h_{ij}dx^i dx^j\right].$$

- **metric perturbations** are supposed to remain small: keep them only to **linear order**
- **density perturbations** will become large: keep to **all orders**
- **gradients** of the metric perturbations are intermediate: keep to **second order**

gevolution weak field approximation

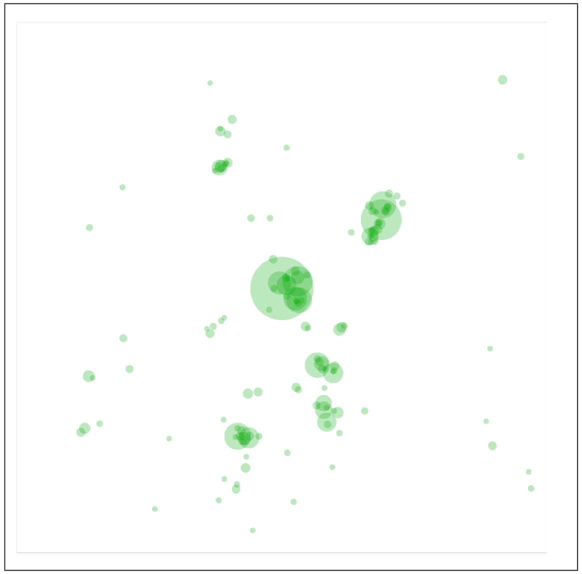
variable	order
$\Phi,\ \Psi,\ \Phi',\ \Psi',\ \Phi'',\ \Psi''$	ϵ
$\Phi_{,i},\ \Psi_{,i},\ \Phi'_{,i},\ \Psi'_{,i}$	$\epsilon^{1/2}$
$\Phi_{,ij},\ \Psi_{,ij}$	1
$\chi,\ \chi',\ \chi'',\ \chi_{,i},\ \chi'_{,i},\ \chi_{,ij}$	ϵ
$B_i,\ B'_i,\ B''_i,\ B_{i,j}\ B'_{i,j}\ B_{i,jk}$	ϵ
$h_{ij},\ h'_{ij},\ h''_{ij},\ h_{ij,k},\ h'_{ij,k},\ h_{ij,kl}$	ϵ
$\delta T^0_0/\bar{T}^0_0$	1
$T^0_i/\bar{T}^0_0$	$\epsilon^{1/2}$
$\Pi_{ij}/\bar{T}^0_0$	ϵ
$v^i,\ q_i$	1

First result with CDM, power spectrums

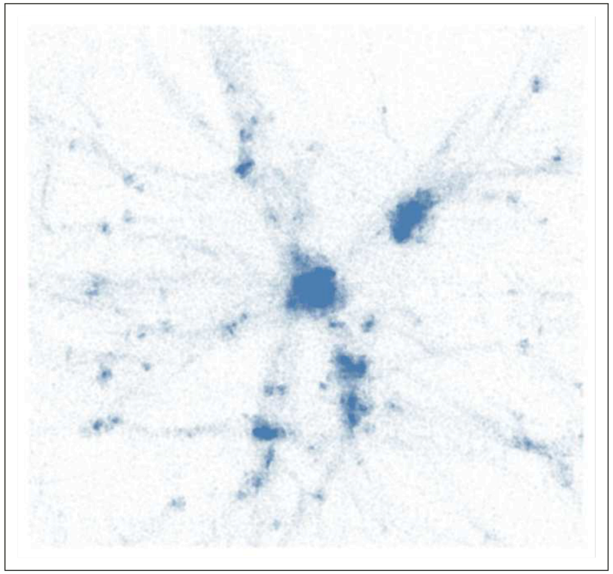


Scalar Vector Split Tensor

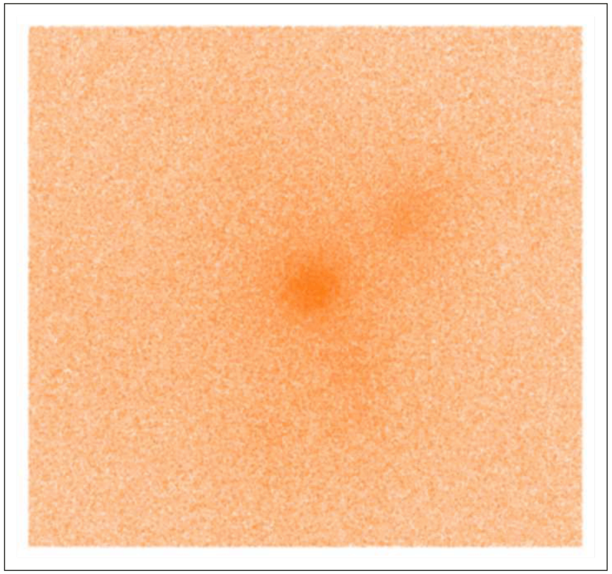
First result with Neutrino, z=0.



Halos



Cold dark matter density



Neutrino density

Moving to a full GR n-body/fluid code

Work in collaboration with Yves Dirian & Ermis Mitsou

- Presence of growing mode in the matter side (already present at the linear level):
    - can enhance numerical instability and/or contaminate other modes.
    - Spoils the robustness test on a FRLW background.
- Presence of constraint equations involving the matter sector.
    - Forbid to add effective physics:
        - Usage of particle-mesh methods
        - Additional astrophysical effects (active galactic nuclei, supernovae and radiation feedbacks, etc.)

We need a NR scheme which solves both of those issues:
an unconstrained scheme which does not evolve the matter content and is valid in arbitrary gauge, is it possible?

Work in progress, first "results" coming soon.

Conclusion

- Gevolution solves the Einstein equation in the weak field limit.
- Its approximation scheme is well suited for cosmology, but still works at astrophysical scales.
- Code available at:

gevolution: https://github.com/gevolution-code/gevolution-1.0
LATfield2: https://github.com/daverio/LATfield2

Outlooks

gevolution: f(R) under development.
LATfield2: Moving mesh, hybrid MPI-openMP, accelerators.
Full GR: theory and testbed papers under preparation.

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