Weak Field Newtonian Motion Gauges

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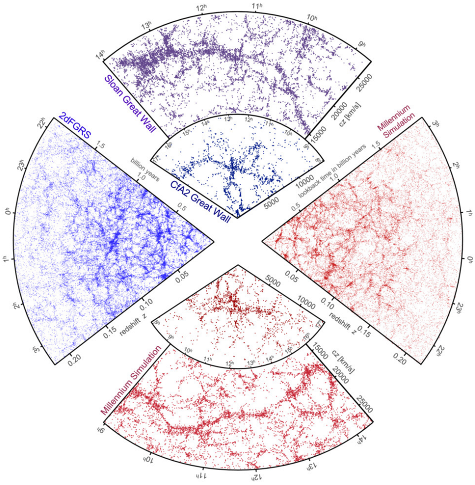
Today

The Large Scale Structure

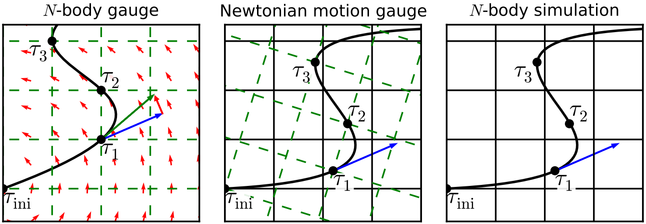


The Newtonian Motion Gauge Idea

Gauge Freedom of General Relativity

- The gauge defines the coordinates
- The gauge specifies the dynamical equations

Can we find a gauge that has a Newtonian dynamics?



The Newtonian Motion Gauge Idea

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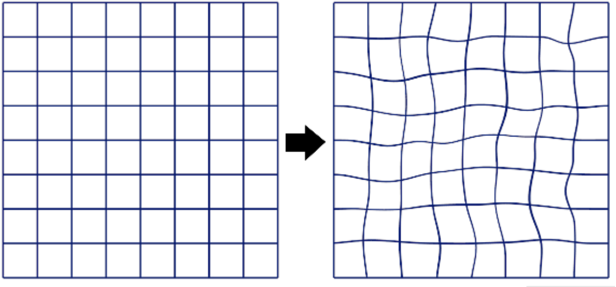
The post Newtonian forces in the N-body gauge act only on large scales



Instead of separating pairs of particles, relativistic corrections move them together. This may be used to define a novel gauge, the Newtonian motion gauge.

The Newtonian Motion Gauge

$$\mathrm{d}s^2 = -a^2(1+2A)\,\mathrm{d}\eta^2 - 2a^2\hat{\boldsymbol{\nabla}}_i B\,\mathrm{d}\eta\,\mathrm{d}x^i + a^2\left[\delta_{ij}(1+2H_{\mathrm{L}}) + 2\left(\hat{\boldsymbol{\nabla}}_i\hat{\boldsymbol{\nabla}}_j + \frac{\delta_{ij}}{3}\right)H_{\mathrm{T}}\right]\mathrm{d}x^i\mathrm{d}x^j$$

Gauge Condition

- We want Newtonian trajectories: $v_{\mathrm{cdm}} = v_{\mathrm{N}}$
  - ➔ $A + (\partial_\tau + \mathcal{H})\,\mathfrak{K}^{-2}\dot{H}_{\mathrm{T}} = -\Phi^{\mathrm{N}}$
- The relativistic density is related to the coordinate density via the volume perturbation: $\rho = (1-3H_{\mathrm{L}})\rho_{\mathrm{N}}$
  - ➔ $4\pi G a^2 \delta\rho_{\mathrm{N}} = \mathfrak{K}^2\Phi^{\mathrm{N}}$
- Combined the gauge condition becomes $(\partial_\tau + \mathcal{H})\dot{H}_{\mathrm{T}} = 4\pi G a^2(\delta\rho_\gamma + 3\mathcal{H}(\rho_\gamma + p_\gamma)\mathfrak{K}^{-1}(v - \mathfrak{K}^{-1}\dot{H}_{\mathrm{T}}) - \rho_{\mathrm{cdm}}(3\zeta - H_{\mathrm{T}})) + 8\pi G a^2\Sigma$

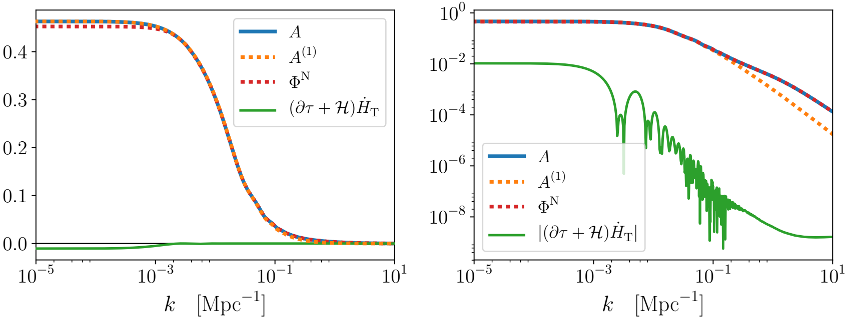
The Newtonian Motion Gauge

- The scheme is self-consistent: All metric perturbations remain small in the weak field sense
- The evolution of H_{T} decouples from the non-linear matter perturbations and may be solved in SPT

The Newtonian motion gauge decouples the full relativistic evolution

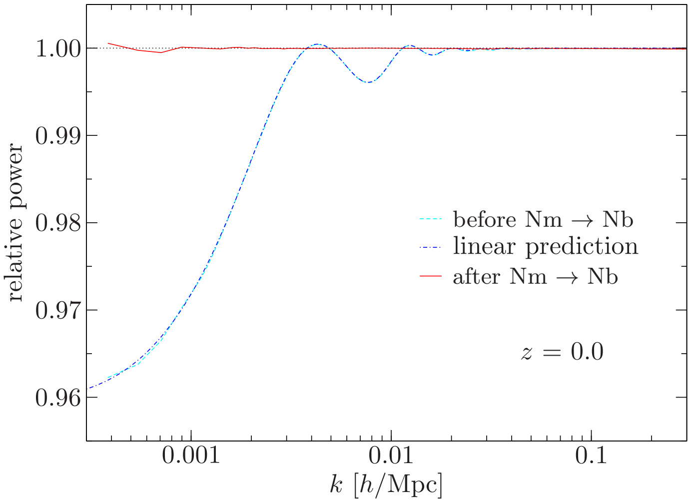
- Into the non-linear but Newtonian collapse of matter
  - ➔ Can be simulated by existing N-body codes
- And the relativistic but linear analysis of the underlying space-time
  - ➔ Can be implemented in existing linear Boltzmann codes

The Metric



0.4
0.3
0.2
0.1
0.0
10^{-5}
10^{-3}
10^{-1}
10^{1}
$k \quad [\mathrm{Mpc}^{-1}]$
A
$A^{(1)}$
Φ^{N}
$(\partial\tau + \mathcal{H})\dot{H}_{\mathrm{T}}$
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-5}
10^{-3}
10^{-1}
10^{1}
$k \quad [\mathrm{Mpc}^{-1}]$
A
$A^{(1)}$
Φ^{N}
$|(\partial\tau + \mathcal{H})\dot{H}_{\mathrm{T}}|$

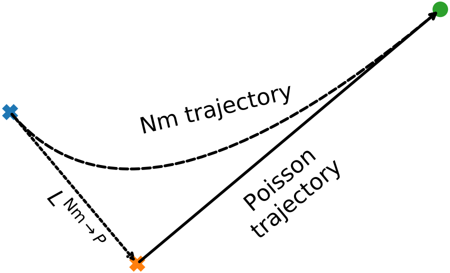
Comparison to gevolution



The ICS Effect

Light Transport on a Non-Trivial Metric

- The simulation potential Φ^N bends light rays: Lensing
- Corrections from H_T introduce a rotation in the photon direction
  - ➔ The effect is integrated along a trajectory comparable to the ISW
  - ➔ ICS = Integrated coordinate shift



Conclusions

- Newtonian motion gauges allow a consistent embedding of Newtonian simulations in general relativity, from the large to the small scales
- Numerically efficient and simple to use
- Caution is needed in the interpretation of the data, a Newtonian simulation lives on a NM gauge

`Thank You For Your Attention`