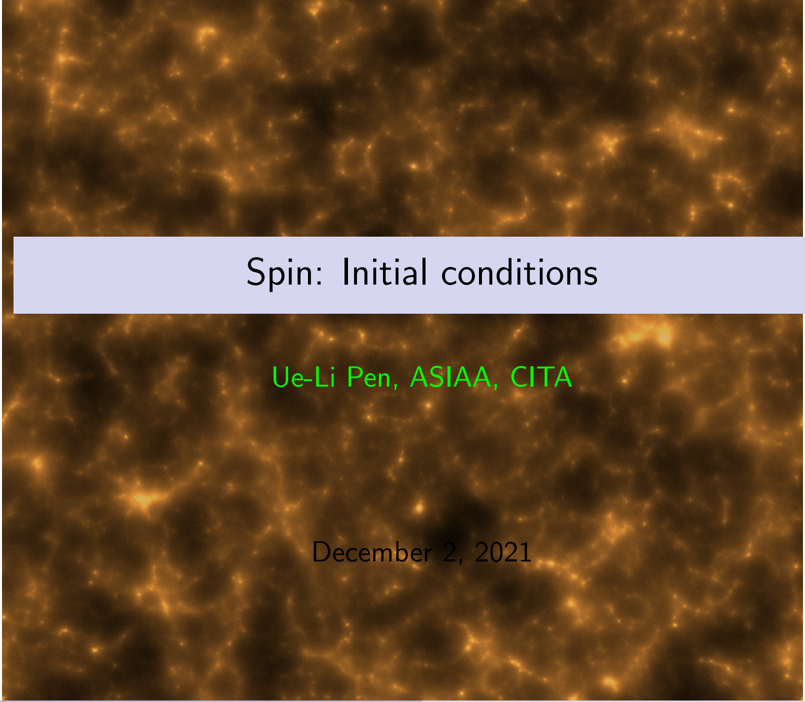


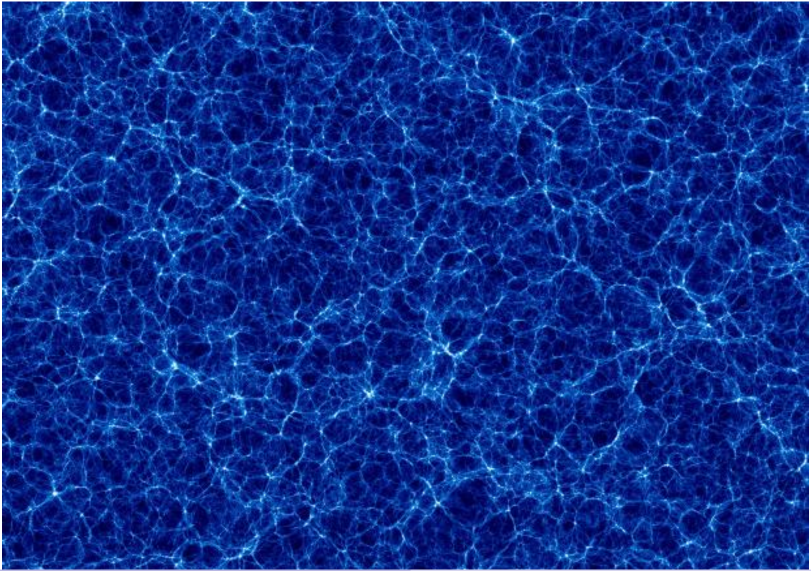
Spin: Initial conditions

Ue-Li Pen, ASIAA, CITA

December 2, 2021

Movie

http://cita.utoronto.ca/~haoran/thnu/movie.html



Galaxy Spins

- most galaxies are rotating disks of stars and gas
- dust lanes, trailing spiral arms, HI velocity (rotation) field
- readily identifyable spin axis in 3-D (see Motloch talk)
- potentially vast reservoir of fossils from initial conditions ($\gtrsim 10^8$ modes)

Observable

(M51, from Wikipedia)

Angular momentum

- 1st order effect from misalignment of moment of inertia and tidal tensor
- torque: $\tau \equiv \int \rho \mathbf{r} \times \nabla\phi$
- Taylor expand: $\tau_i = \epsilon_{ijk} \int \rho x^j x^l \partial_l \partial_k \phi \equiv \epsilon_{ijk} I_{il} T_{lk}$
- Tensor form $\tau = *I \cdot T$
- first realized by S. White (1984), see also LP00

Origin of Angular Momentum

- Tidal Torque Theory (TTT): relates spin to initial Inertia and Tide
- Inertia tensor not easily identified, requires running N-body simulation.
- approximate Inertia by Tide (Zeldovich), torqued by external tide.
- IC-TTT: $j_\alpha = \epsilon_{\alpha\beta\gamma}\mathcal{T}_{\beta\kappa}\mathcal{T}^+_{\kappa\gamma}$
- $\mathcal{T} = \bar{\phi}_{,\beta\kappa}$ smoothed tidal field
- $\mathcal{T}^+_{\beta,kappa} = \bar{\phi}^+_{,\beta\kappa}$ tidal field smoothed on slightly larger scale, Taylor approximated by $\mathcal{T}^+_{\beta,kappa} = \bar{\rho}_{\beta\kappa}$
- ~ 0.5 correlation with actual eulerian spin at optimal mass filter
- "best one can hope for" in data reconstruction

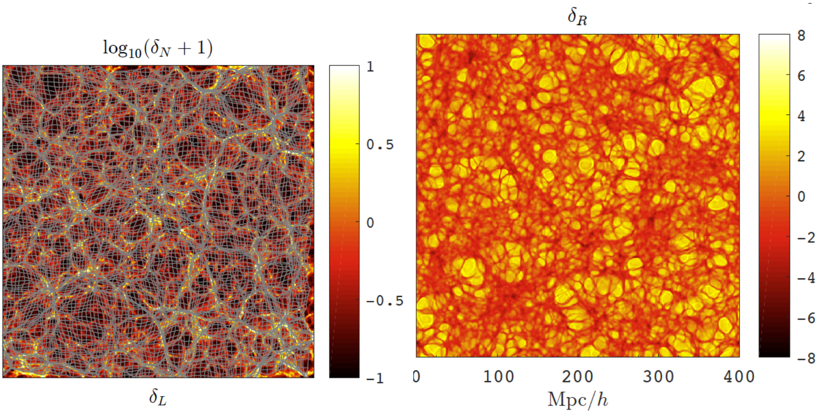
E-mode Coordinate

reduce 3-D Lagrangian map to 1-D potential (*max Zeldovich*):

$$
\begin{aligned}
\text{potential deformation} \qquad x^i &= \xi^\mu \delta^i_\mu + \frac{\partial \phi}{\partial \xi^\mu}\delta^{i\mu} \\
\text{dreibein} \qquad e^i_\mu &\equiv \partial x^i / \partial \xi^\mu \\
\text{volume element} \qquad \sqrt{g} &\equiv \det \left| e^i_\mu \right| \\
\text{mass coordinate} \qquad \rho\sqrt{g} &= \text{Const.} \\
\partial_\mu(\rho\sqrt{g} e^\mu_i \delta^{i\nu}\partial_\nu \dot{\phi}) &= \langle\rho\rangle - \rho\sqrt{g} \qquad (1)
\end{aligned}
$$

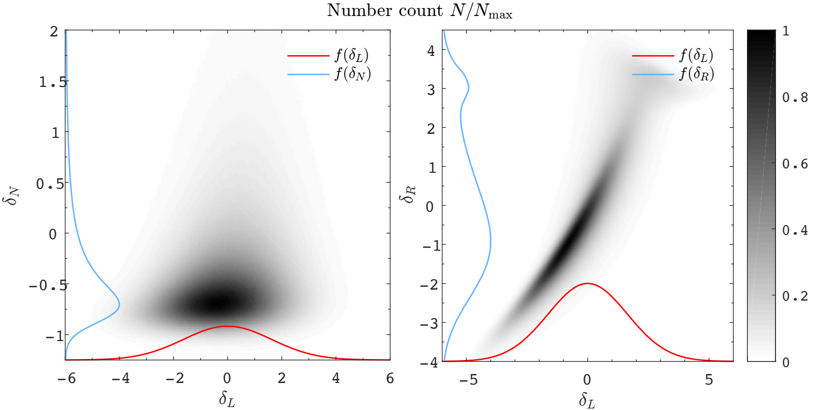
Solve Monge-Ampére eqn (1) using multigrid (Pen 1995): unique bijective mass coordinate. See also Tully/Peebles, Mohayaee+, Goldberg, Schmidtfull, Wang+, Seljak, Zaldarriaga, Hada/Eisenstein, Shi/Brikin/Li+, Jasche+, Sarpa+

3-D: E-mode Lagrangian



Eulerian (L) vs Lagrangian (R) (from Yu et al 2016, 1610.7112)

Lagrangian coordinates



Multigrid solution

Figures/map0512-0128_i1500_xz222.pdf

Redshift space

Zhu et al 1610.09638

Figures/map0512-0128_i0900_xz222_rsd3.pdf

Low noise limit

Figures/rk.pdf

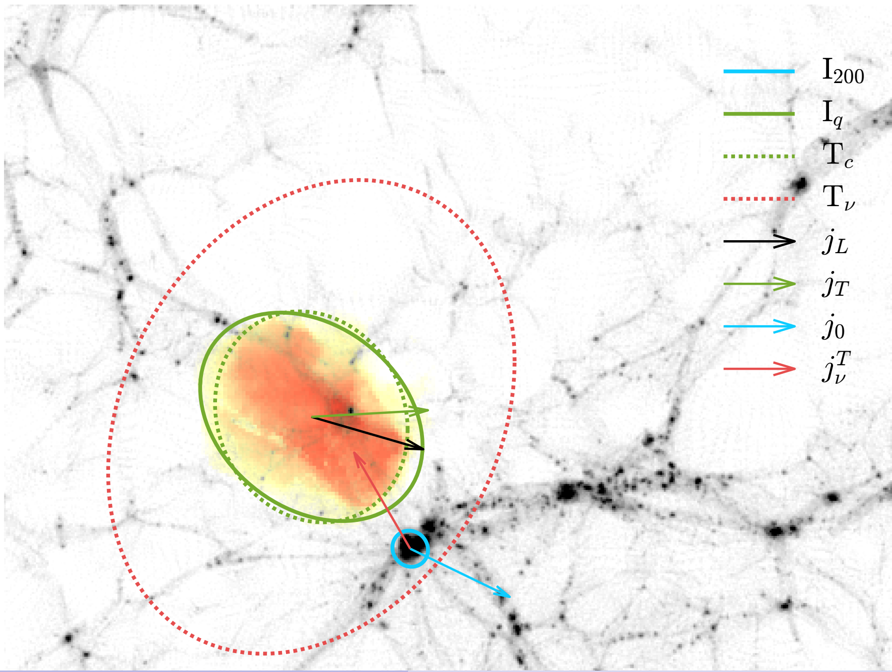
Halos

es/halocc.pdf

Predicting Neutrino Torques

- $\Delta x(q) = q^j \partial_i \partial_j \psi$
- $I_c \sim T_c$: both describe particle displacement
- $j_\nu = \epsilon T_c T_\nu$
- Neutrino tidal torque is predictable observable from displacement potential

Illu



Size estimate

- $|j_\nu/j_c| \sim 10^{-4}(f_\nu/0.003)[\sqrt{P(k_{\rm FS})/P(k_{\rm vir})}/0.03]$
- agrees with simulation measurement
- need $n > 10^8$ galaxy spins
- accessible in next generation 21cm surveys

Future 21cm Surveys

- expand on HSHS (Peterson et al 2006), CHIME
- build on economy of scale, map 10^{11} galaxies

More cosmological applications

- map initial (linear) tidal field
- BAO, standard ruler (Alcock-Paczynski effect)
- modified gravity, time evolving neutrino mass

Conclusions

- galaxy spins: new probe of initial conditions
- predictable from observable displacement field using non-linear reconstruction
- computationally straightforward, mass coordinate similar to Lagrangian
- already observable, scalable to much larger surveys
- parity odd field, less likely to be contaminated
- enables measurement of 2 cosmic scalar fields: potential beat cosmic variance limits, etc