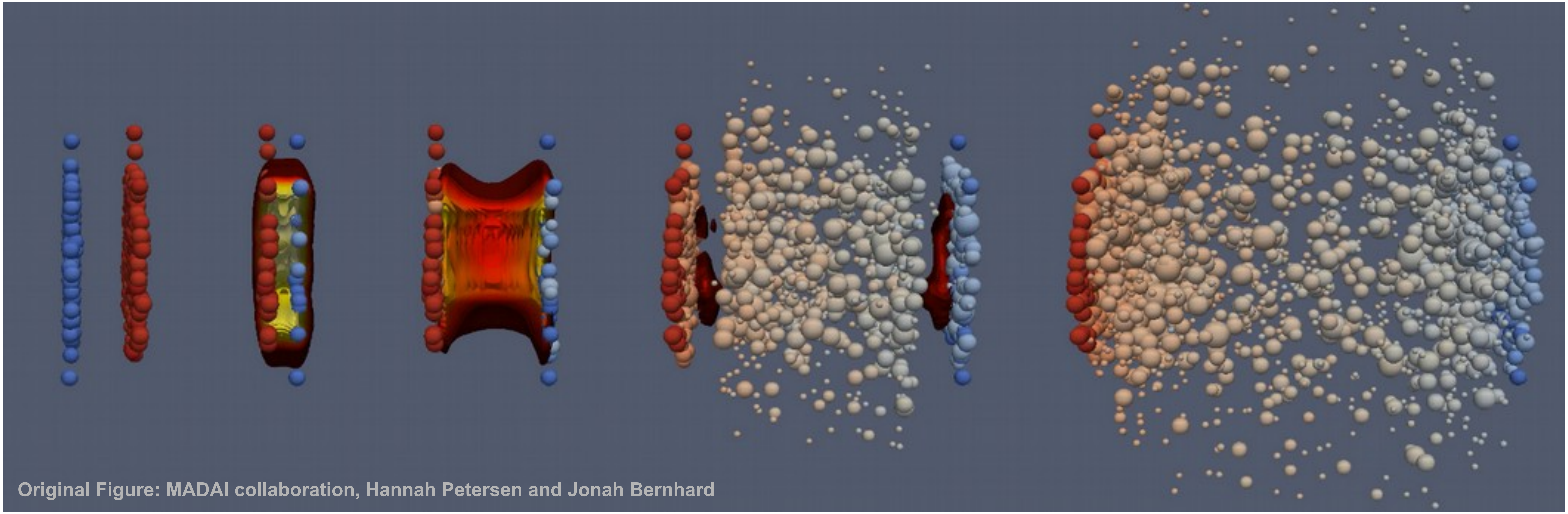
Extreme hydro workshop 2021

T. NUNES - UNIVERSIDADE FEDERAL DE SANTA CATARINA (UFSC)

THE INITIAL CONDITION – TRENTO AND KOMPOST

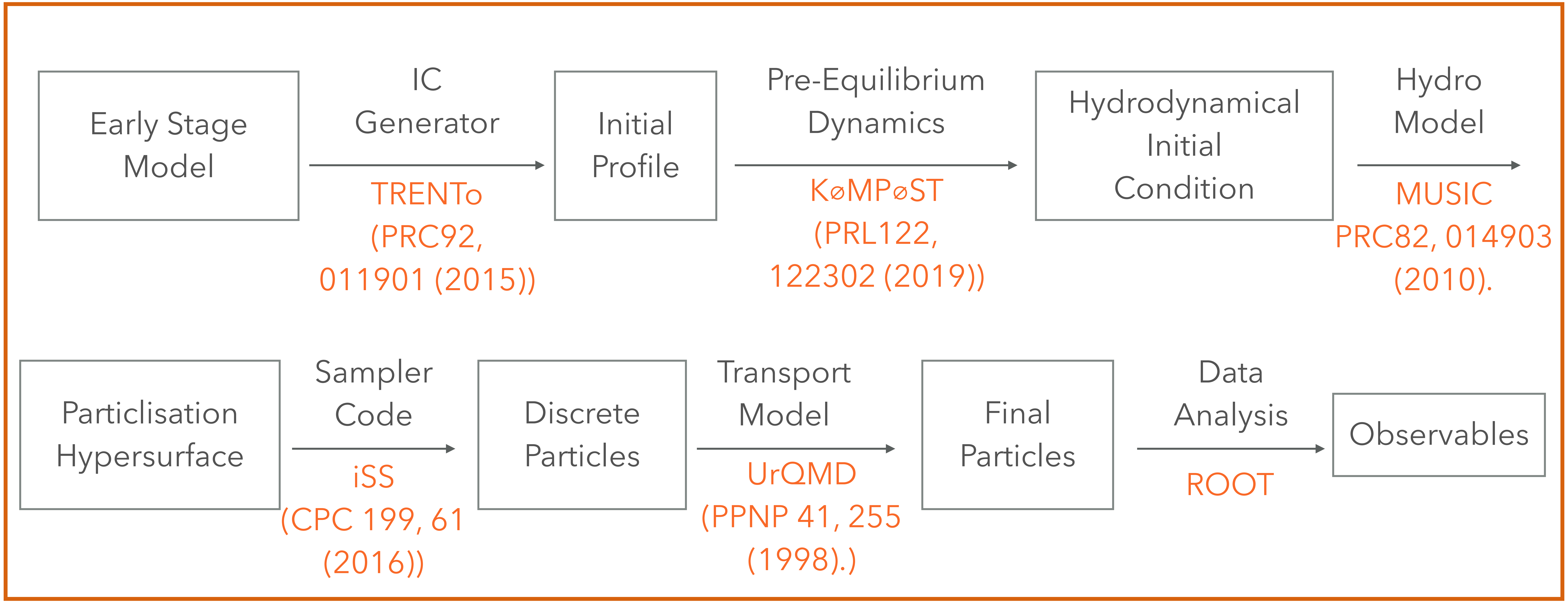
HOW DO WE UNDERSTAND HEAVY-ION COLLISIONS?



Pre-Equilibrium Dynamics | Hydrodynamical Evolution | Hadronization | Hadronic Cascade

HOW DO WE SIMULATE HEAVY ION COLLISIONS?

ExTrEMe Hybrid Model



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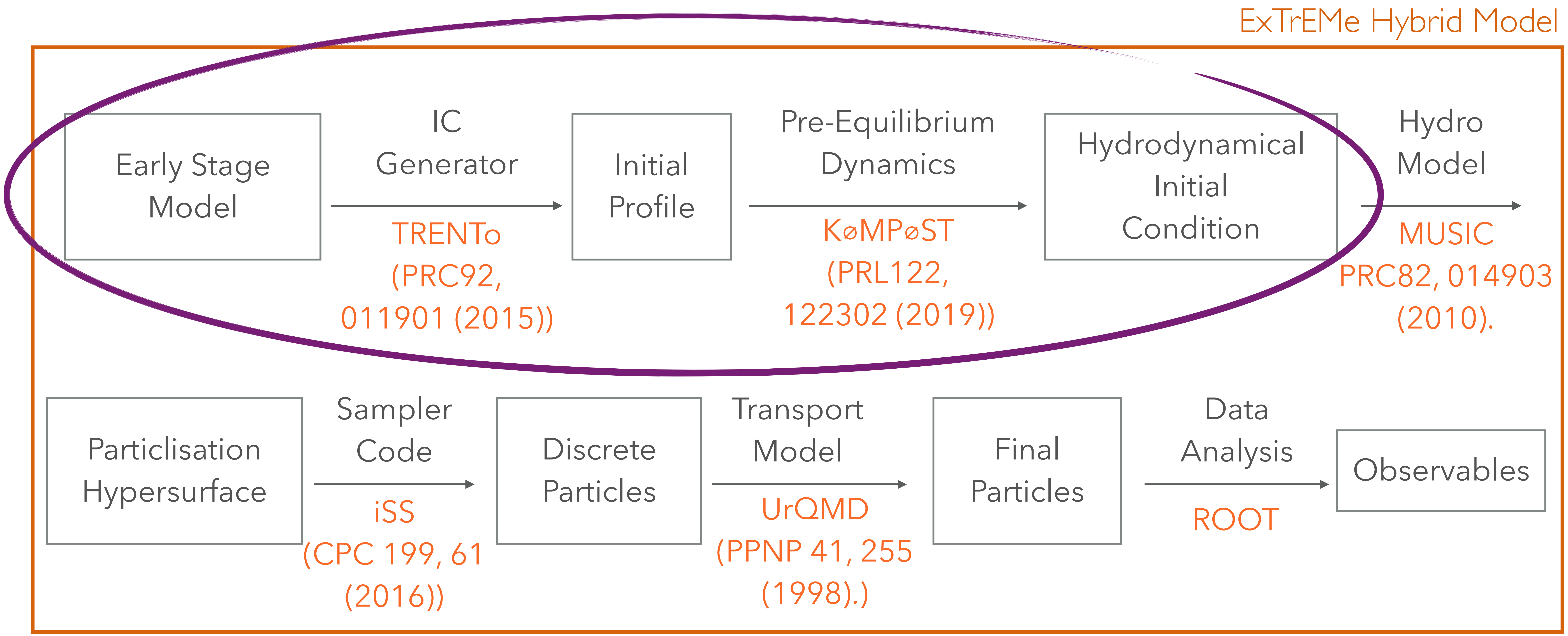
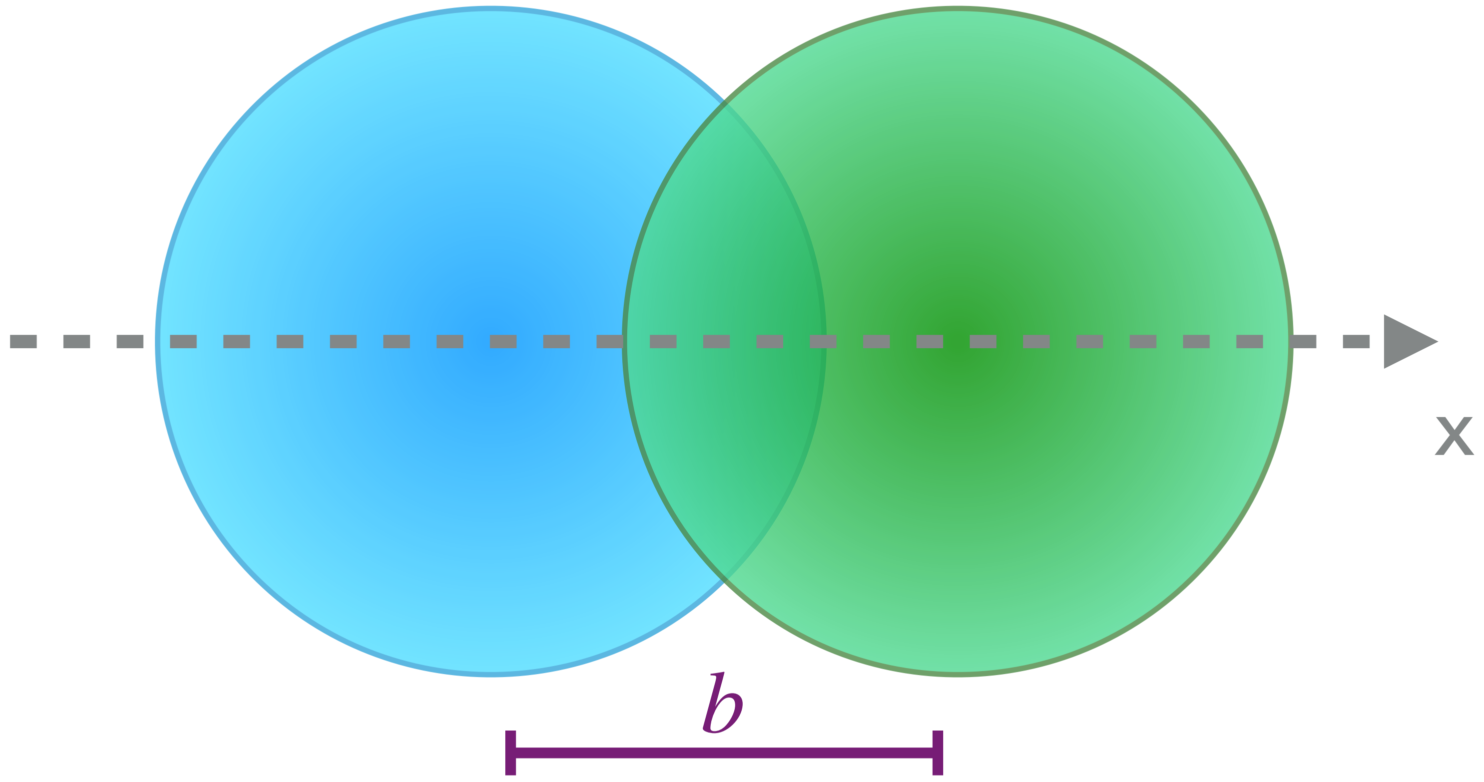
HOW DO WE SIMULATE HEAVY ION COLLISIONS?



TRENTO

- TRENTo is a model used for generating and energy or entropy density profile immediately after a collision;
- TRENTo is an effective model:
  - It assumes no specific physical mechanisms for entropy production, pre-equilibrium dynamics or thermalization;
  - It parametrizes entropy (or energy) deposition within a discretized grid
- Source and manual : http://qcd.phy.duke.edu/trento/

TRENTO: HOW IT WORKS



- Protons A and B collide with impact parameter b;
- Their matter densities are: $\rho_{A,B} = \rho_{\text{proton}} \left(x \pm \frac{b}{2}, y, z \right)$;
- Assume $\int dz\, \rho_{\text{proton}}$ either has a closed form or can be computed numerically.

This is typically a gaussian!

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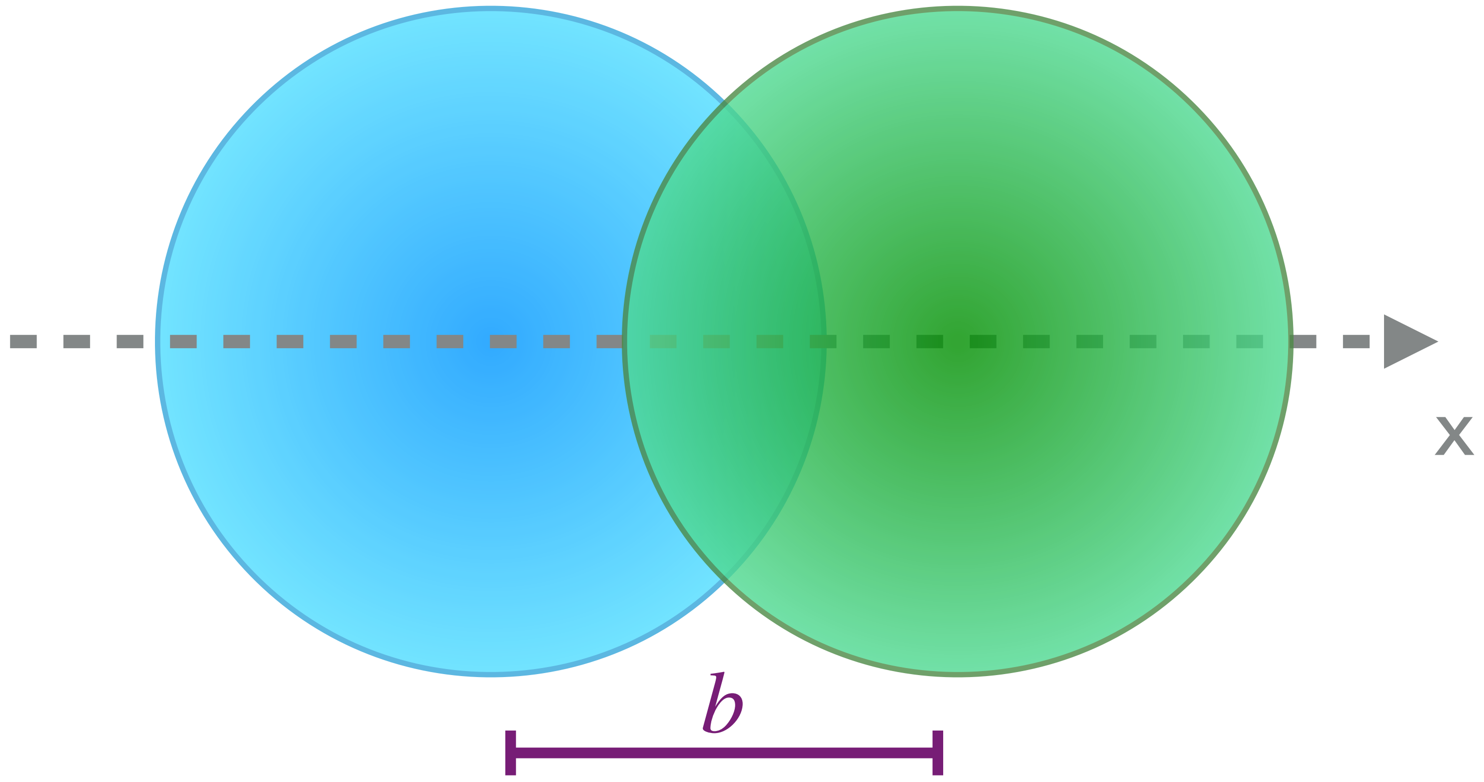
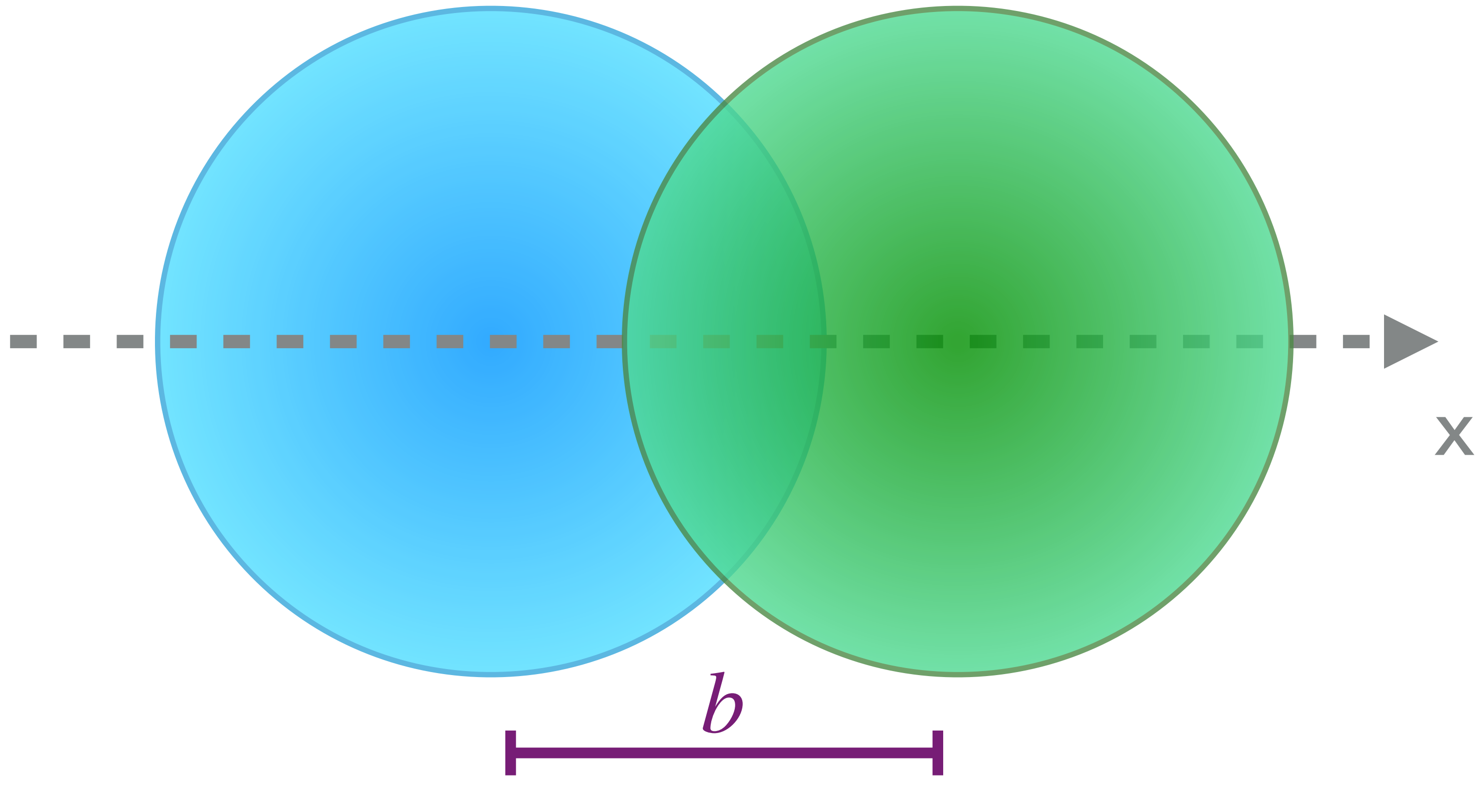
TRENTO: HOW IT WORKS



- Collision probability is given by $P_{\text{coll}} = 1 - \exp\left[\sigma_{gg} \int dx\, dy \int dz\, \rho_A \int dz\, \rho_B\right]$
- σ_{gg} is an effective parton-parton cross section tuned so that $\int 2\pi\, b\, db\, P_{\text{coll}}(b) = \sigma_{NN}^{inel.}$
- The above probability is sampled in order to determine whether protons collide.

TRENTO: HOW IT WORKS

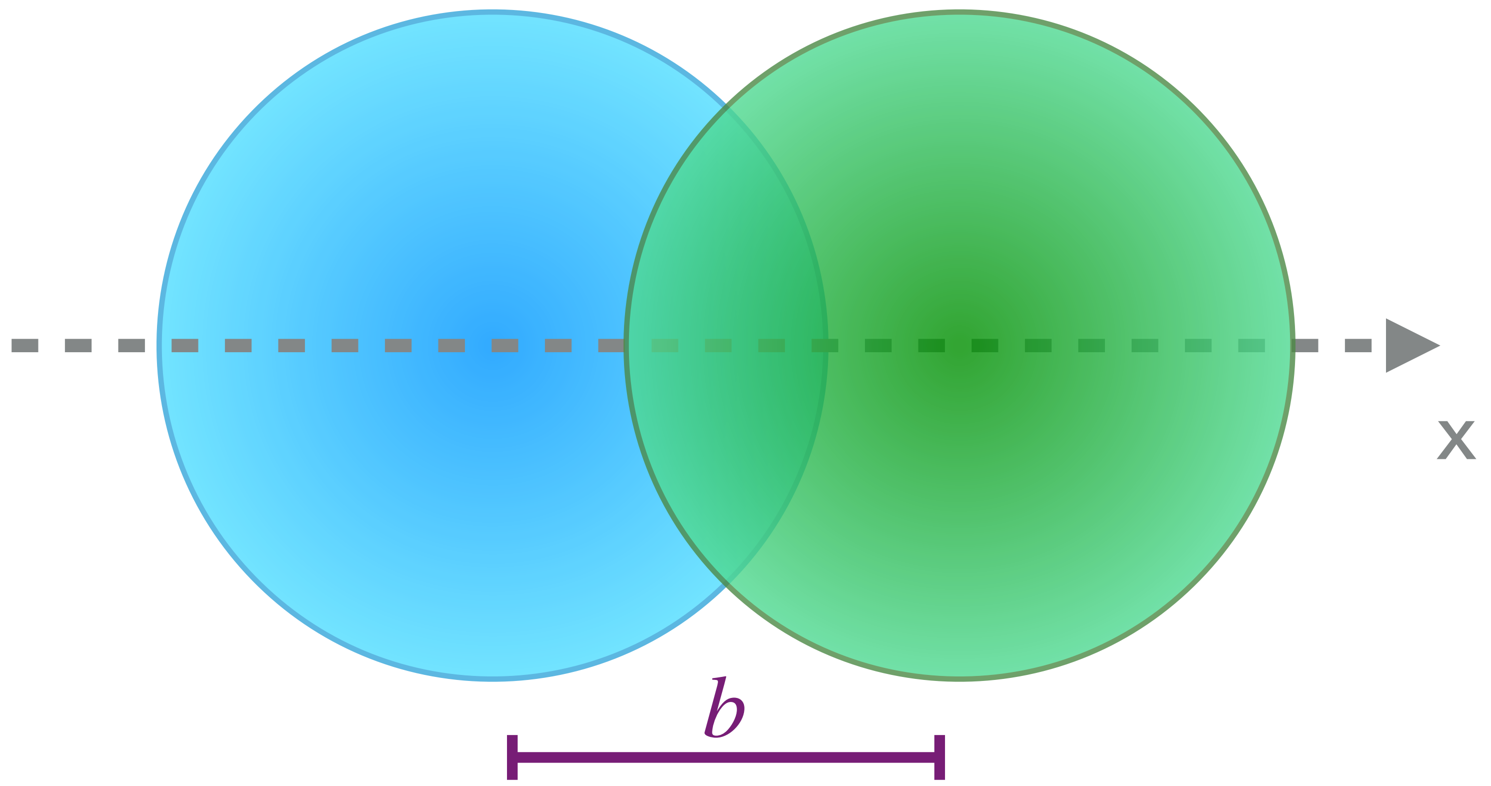


- If protons collide, assign each proton a fluctuated thickness $\tilde{T}_{A,B}(x,y) = w_{A,B} \int dz\, \rho_{A,B}(x,y,z)$
- The random weights $w_{A,B}$ are sampled from a gamma distribution with unit mean:

$$P_k(w) = \frac{k^k}{\Gamma(k)} w^{k-1} e^{-kw} \;;$$

- These weights are meant to introduce additional multiplicity fluctuations as observed experimentally in p-p collisions.

TRENTO: HOW IT WORKS



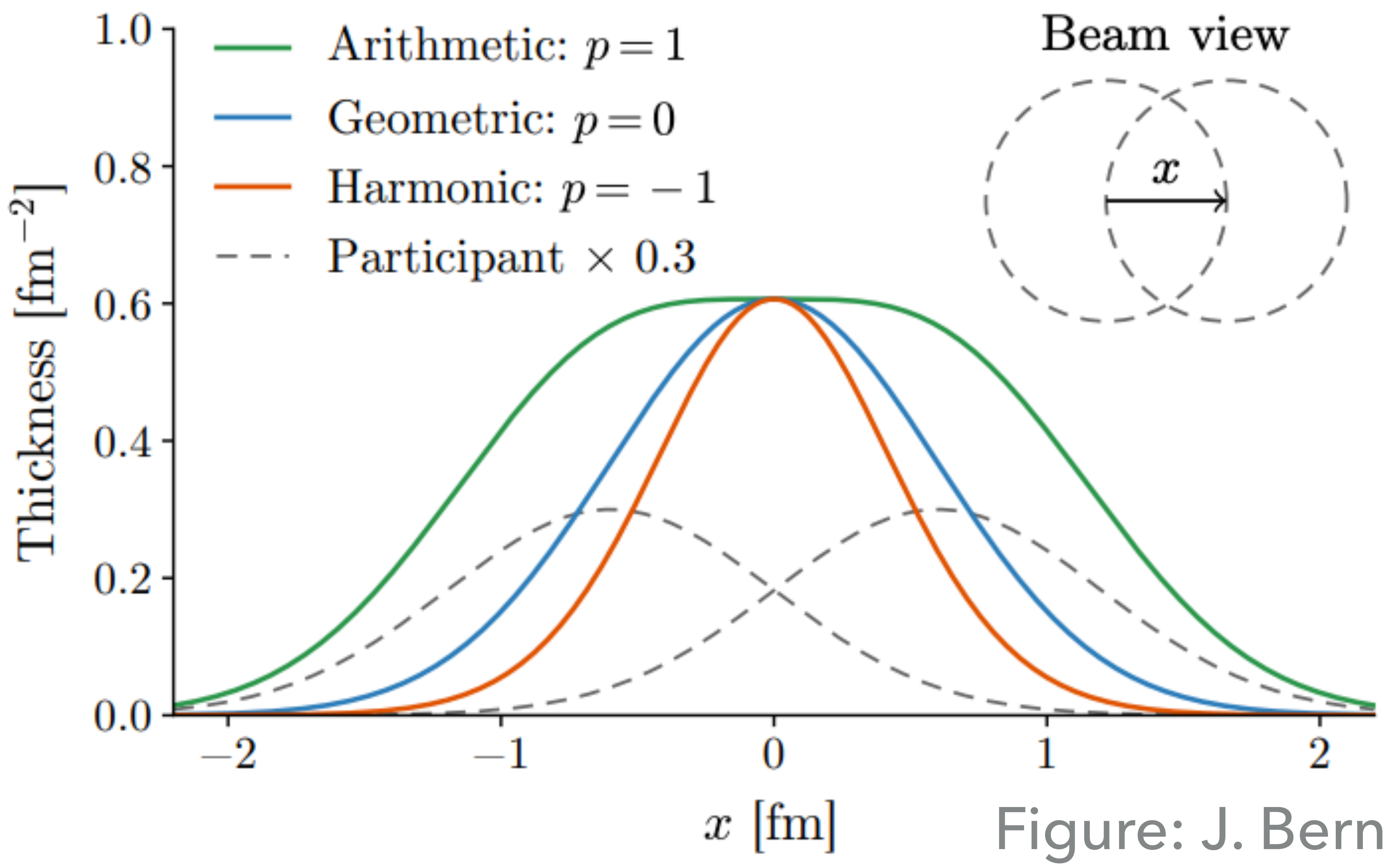


Figure: J. Bernhard

- TRENTo assumes that there is a function $f(\tilde{T}_A, \tilde{T}_B)$ that converts projectile thickness intro entropy deposition, such that $s\big|_{\tau=\tau_0} \propto f$
- Proposal: *reduced* thickness $f \equiv \left(\frac{\tilde{T}_A^p + \tilde{T}_B^p}{2}\right)^{1/p}$

TRENTO – STEP BY STEP

- Composite collisions are treated as superpositions of p-p collisions:
- 1. Sample a set of nucleon positions for each projectile from an uncorrelated Woods-Saxon distribution;
- 2. Sample collision probability for each pairwise interaction and label participant nucleons (others are discarded);

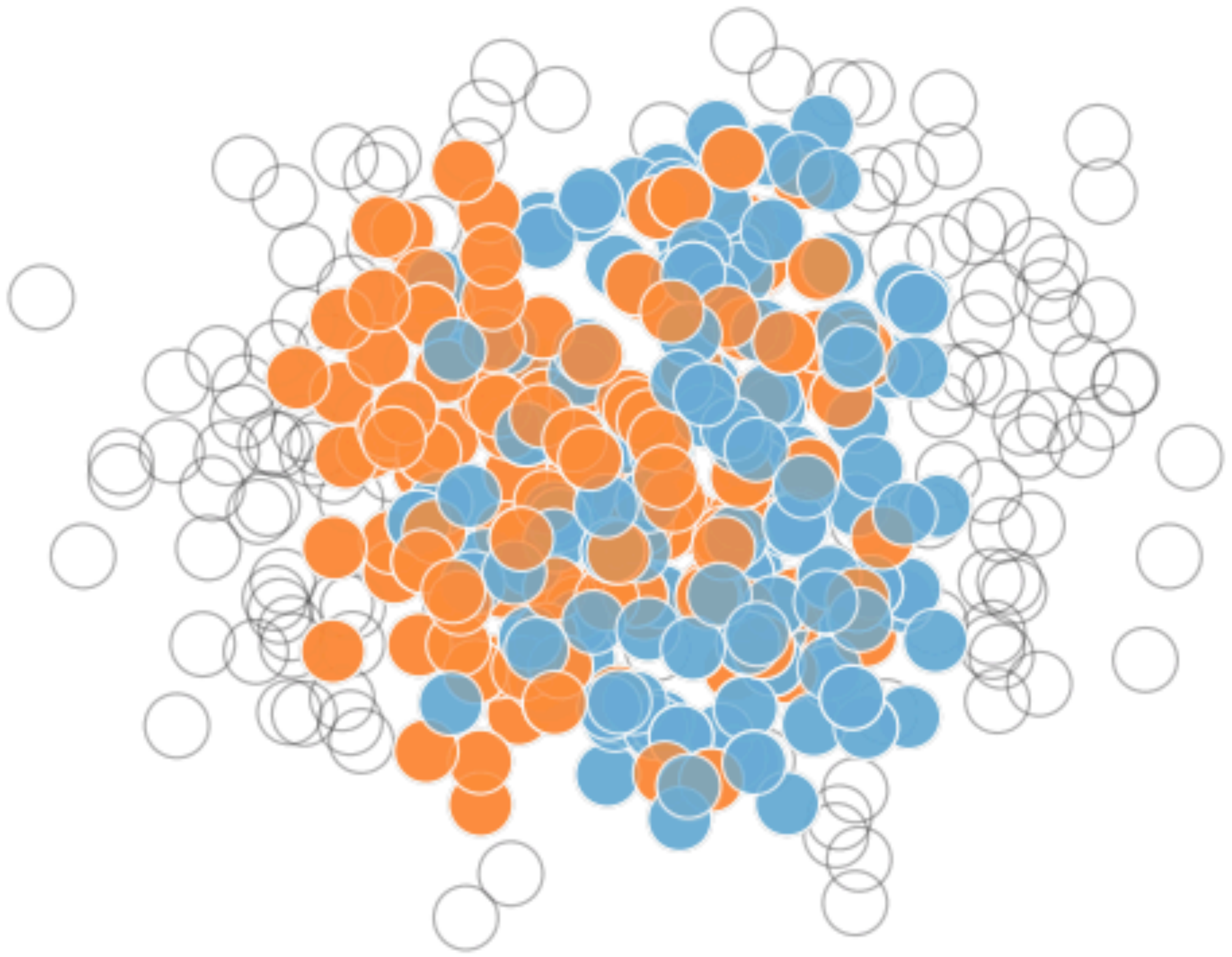


Figure: J. Bernhard

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TRENTO – STEP BY STEP

- 3. Calculate the fluctuated thickness function for each nucleus:

- $$\tilde{T}_{A,B} = \sum_{i=1}^{N_{\text{part}}} w_i \int dz\, \rho_{\text{proton}}(x - x_i, y - y_i, z - z_i)$$

- 4. Parametrize entropy deposition:

- $$s(x,y) \propto \left(\frac{\tilde{T}_A^p + \tilde{T}_B^p}{2} \right)^{1/p}$$

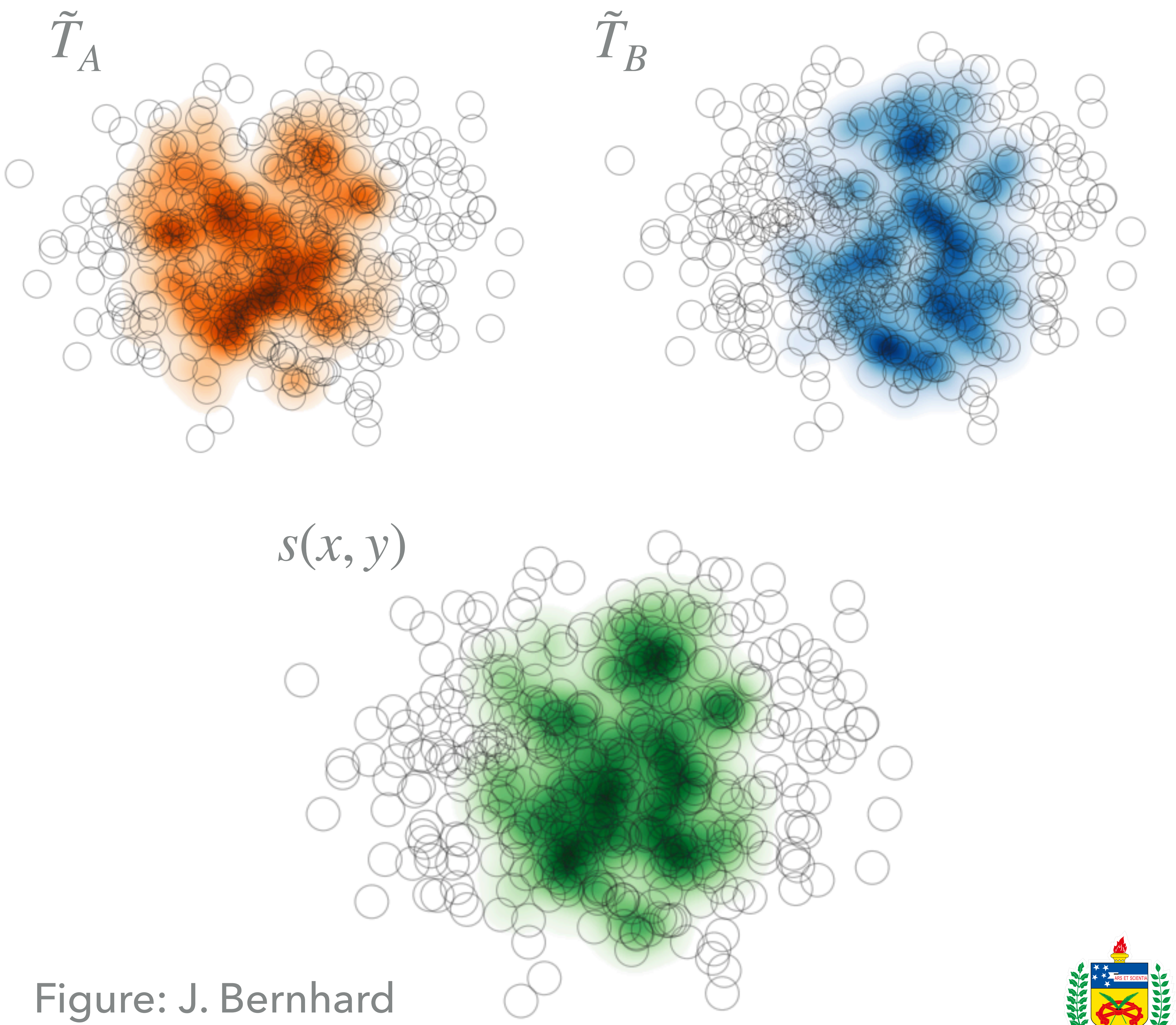
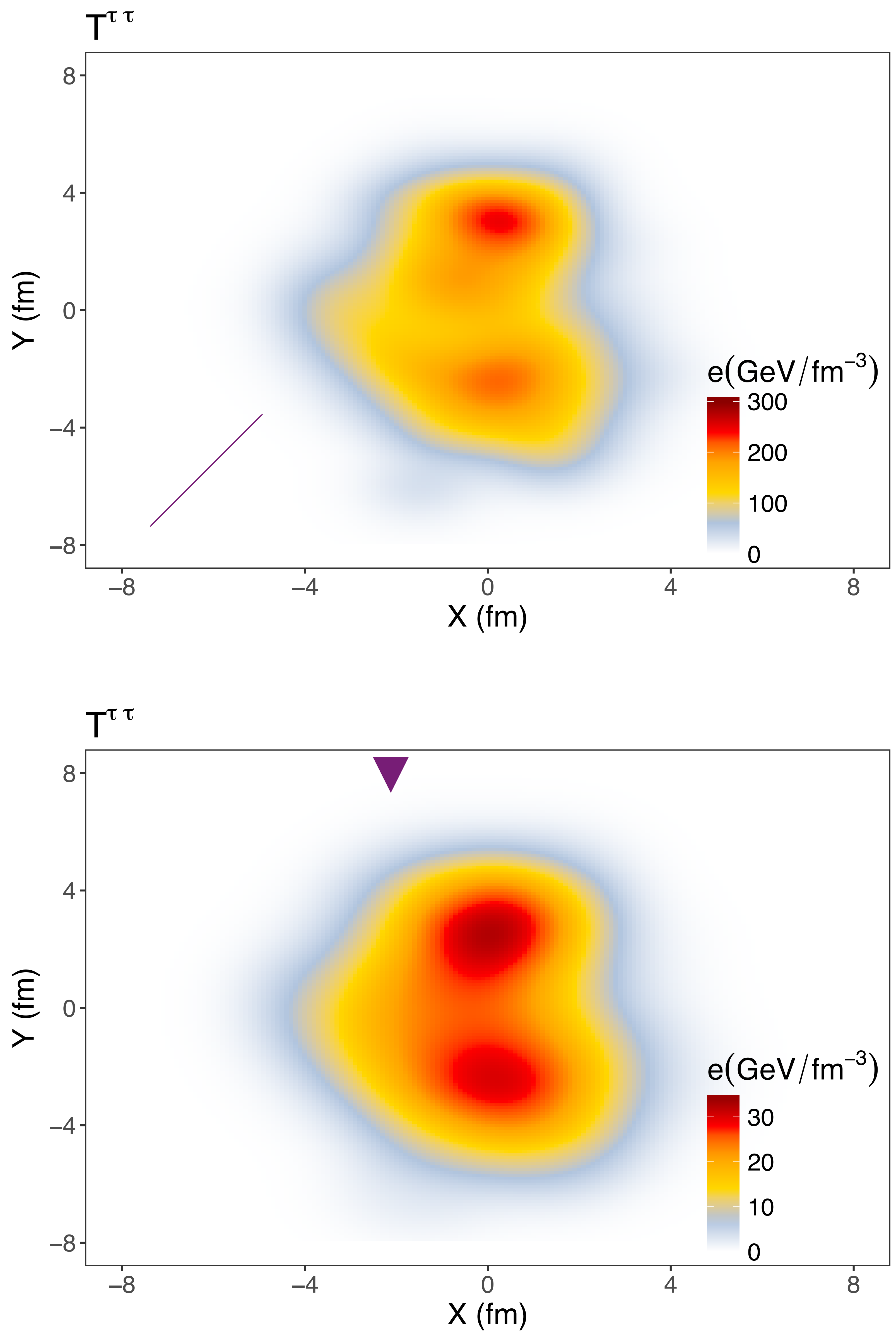


Figure: J. Bernhard

PRE-HYDRODYNAMICS

- Hydrodynamics usually assumes (approximate) local thermodynamic equilibrium;
- The system that emerges immediately after the collision is not in equilibrium and must be driven to equilibrium by some early dynamical;
- Two stage approach:
    1. Deposition model describes the system around $\tau = 0^+$
    2. Pre-equilibrium model brings the system (close) to equilibrium



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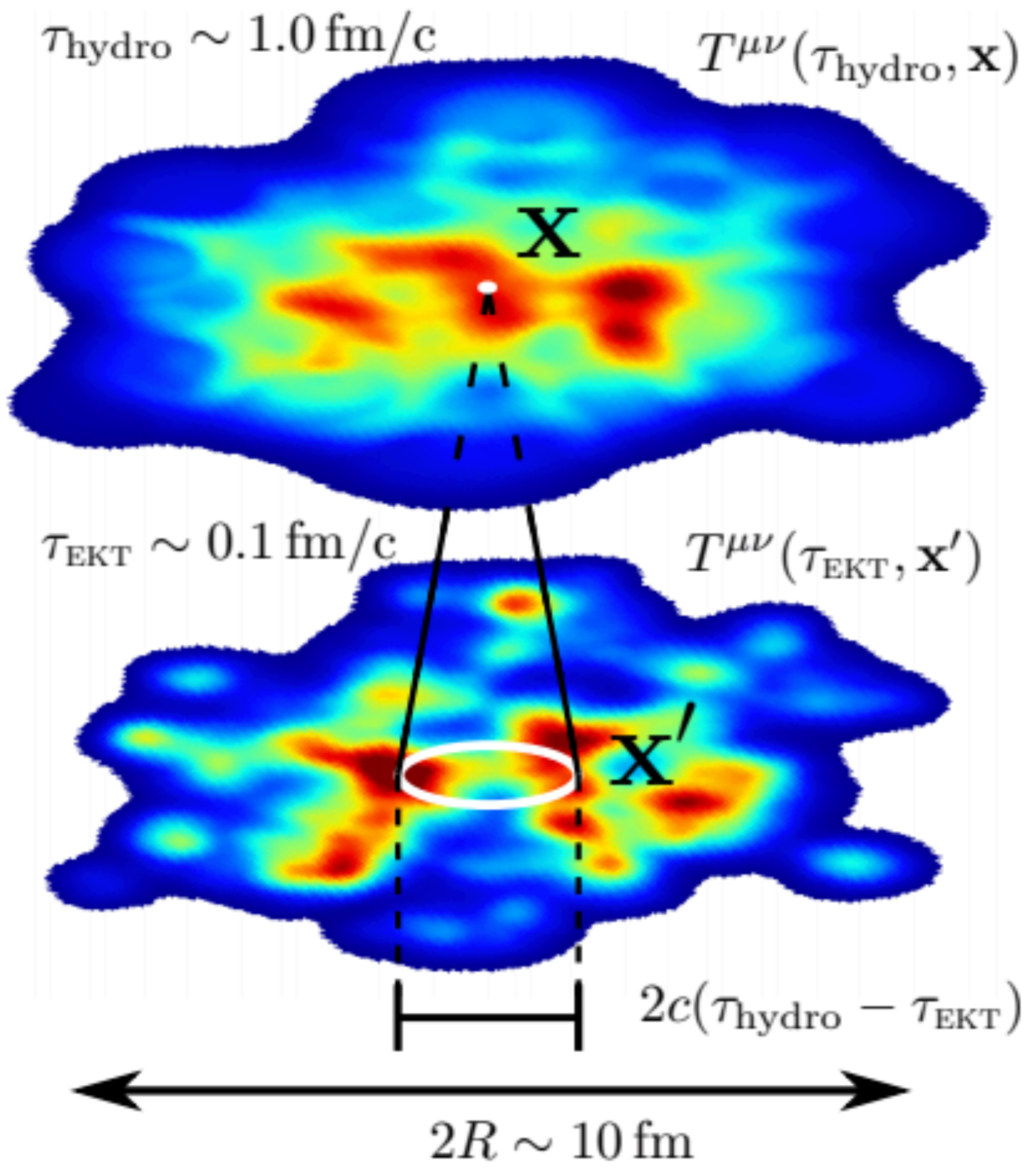
KOMPOST

- Start from a energy density profile at τ_{EKT} (e.g., from TRENTo);
- Decompose the corresponding $T^{\mu\nu}$:

$$T^{\mu\nu}(\tau, \mathbf{x}) = \underbrace{\bar{T}^{\mu\nu}_{\mathbf{x}_0}(\tau)}_{\text{background}} + \underbrace{T^{\mu\nu}(\tau, \mathbf{x}) - \bar{T}^{\mu\nu}_{\mathbf{x}_0}(\tau)}_{\equiv \delta T^{\mu\nu}_{\mathbf{x}_0}(\tau, \mathbf{x})},$$

- Background is given by a spatial average of $T^{\mu\nu}(\tau_{EKT}, \mathbf{x})$ over the causal circle
- Once $\bar{T}^{\mu\nu}_{\mathbf{x}_0}$ is known around $\mathbf{x}_0$, calculate $\delta T^{\mu\nu}_{\mathbf{x}_0}$;



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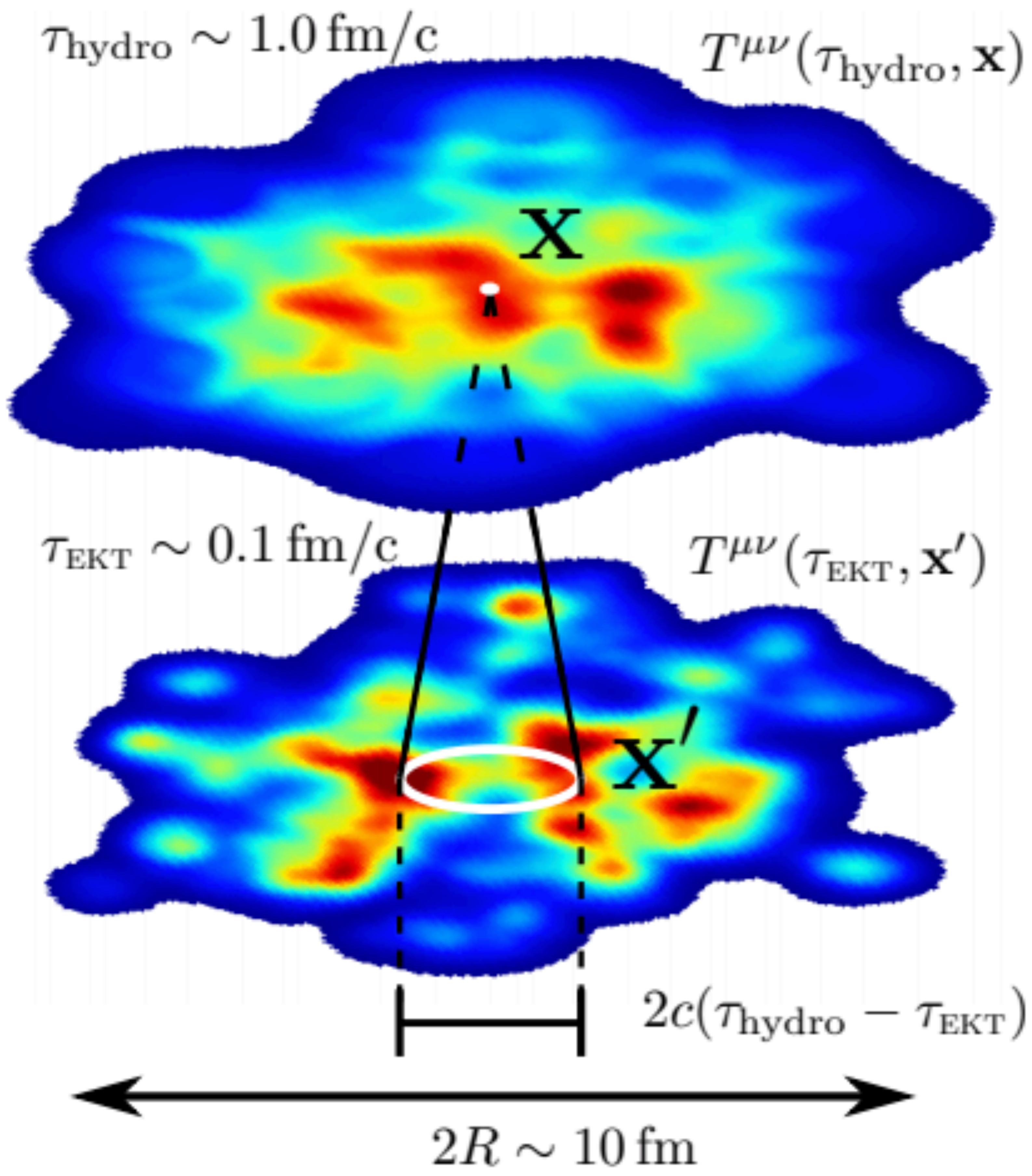
KOMPOST

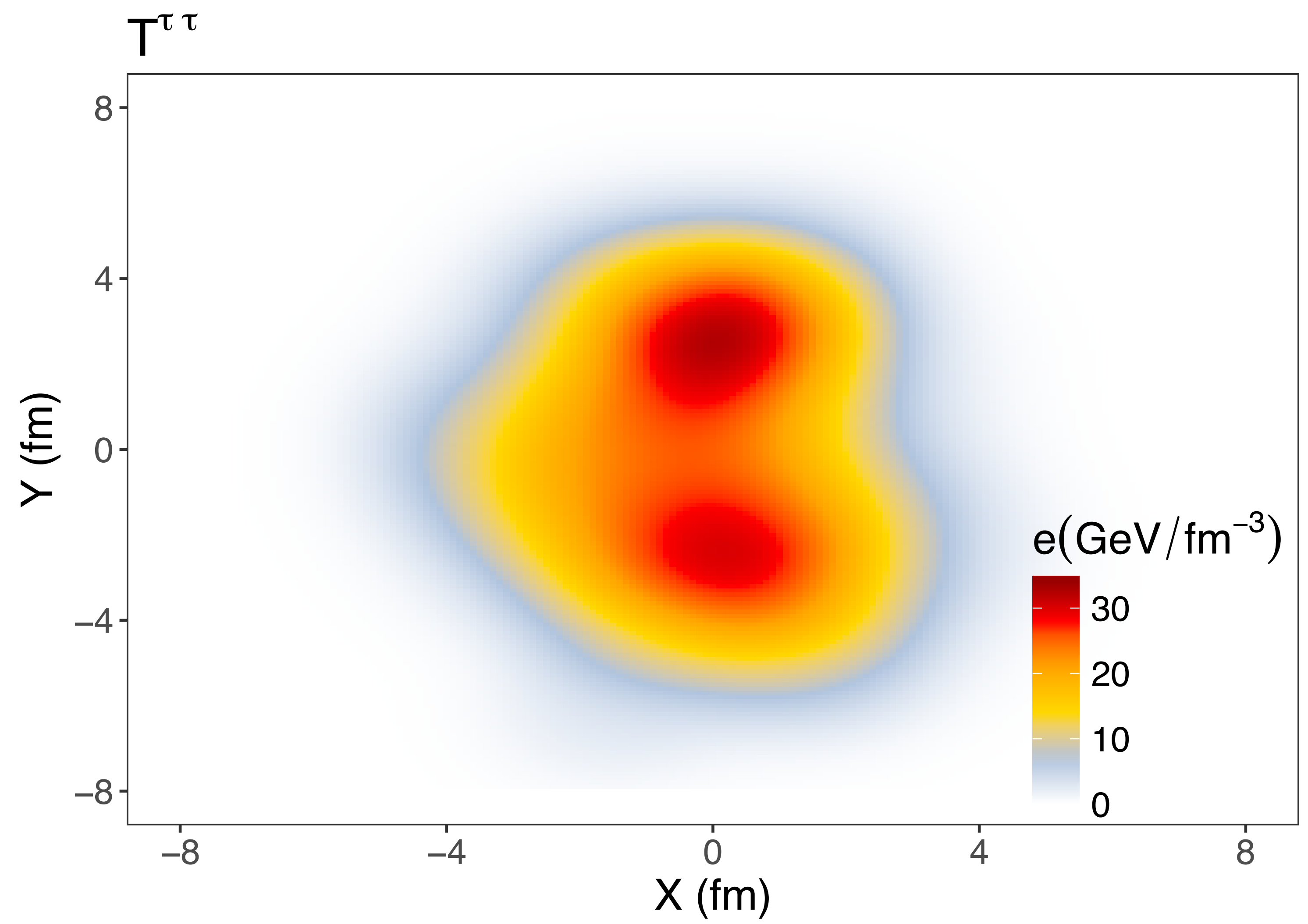
- Background components $\overline{T}^{\mu\nu}_{\mathbf{x}_0}$ at τ_{hydro} are calculated from a universal scaling curve.
- The initial energy and momentum perturbations $\delta T^{\tau\tau}_{\mathbf{x}_0}(\tau_{EKT}, \mathbf{x})$ and $\delta T^{\tau i}_{\mathbf{x}_0}(\tau_{EKT}, \mathbf{x})$ are propagated using linear kinetic response functions:

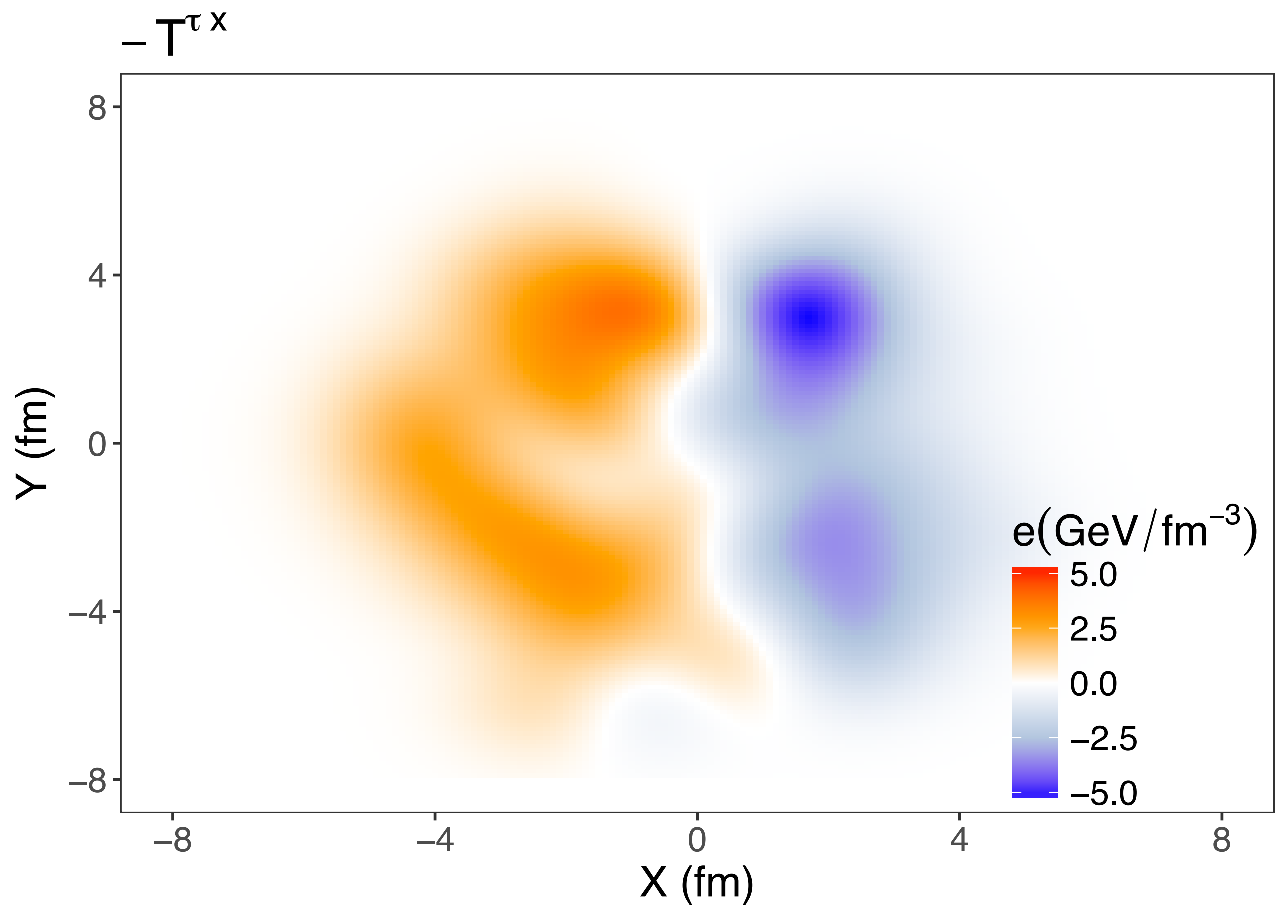
$$\delta T^{\mu\nu}_{\mathbf{x}}\left(\tau_{\text{hydro}}, \mathbf{x}\right) = \int d^2\mathbf{x}' G^{\mu\nu}_{\alpha\beta}\left(\mathbf{x}, \mathbf{x}', \tau_{\text{hydro}}, \tau_{\text{EKT}}\right) \times \delta T^{\alpha\beta}_{\mathbf{x}}\left(\tau_{\text{EKT}}, \mathbf{x}'\right) \frac{\bar{T}^{\tau\tau}_{\mathbf{x}}\left(\tau_{\text{hydro}}\right)}{\bar{T}^{\tau\tau}_{\mathbf{x}}\left(\tau_{\text{EKT}}\right)}$$

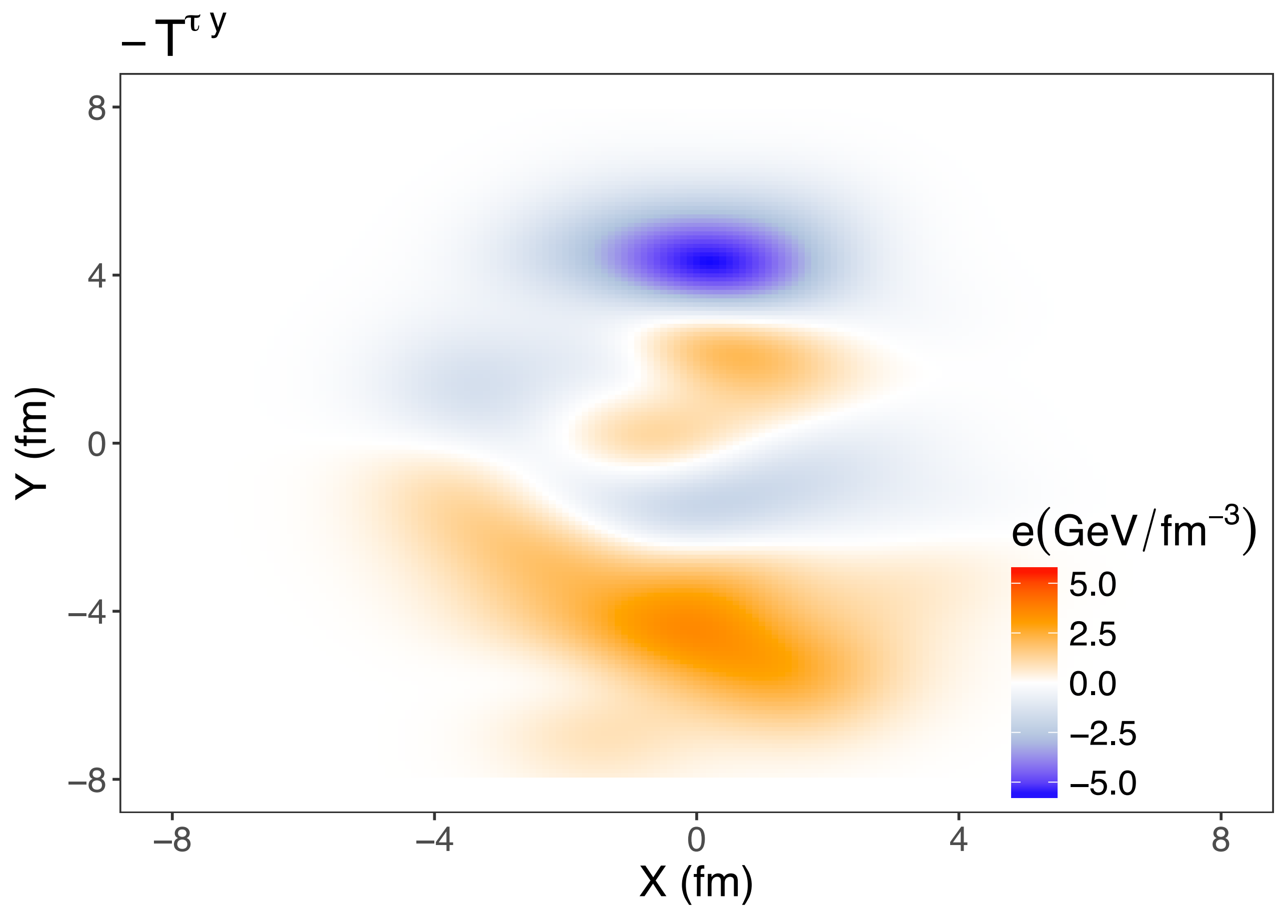


KOMPOST

- The full $T^{\mu\nu}$ is built by adding:
- $T^{\mu\nu}\left(\tau_{\text{hydro}}, \mathbf{x}_0\right) = \bar{T}^{\mu\nu}_{\mathbf{x}_0}\left(\tau_{\text{hydro}}\right) + \delta T^{\mu\nu}_{\mathbf{x}_0}\left(\tau_{\text{hydro}}, \mathbf{x}_0\right)$
- Decomposition in hydro variables (all components):
- $T^{\mu\nu} = e u^\mu u^\nu + p(e)\Delta^{\mu\nu} + \pi^{\mu\nu}$
- The result can be used as an initial condition for hydrodynamical simulations.







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