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Maps of the Little Bangs through Energy Density and Temperature Fluctuations

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Abstract: We propose for the first time to map the heavy-ion collisions at ultra-relativistic energies, similar to the maps of cosmic microwave background radiation, using fluctuations of energy density and temperature in small phase space bins. We study the evolution of fluctuations at each stage of the collision using event-by-event hydrodynamic framework. We demonstrate the feasibility of making fluctuation maps from experimental data and its usefulness in extracting considerable information regarding the early stages of the collision and its evolution.

Introduction:

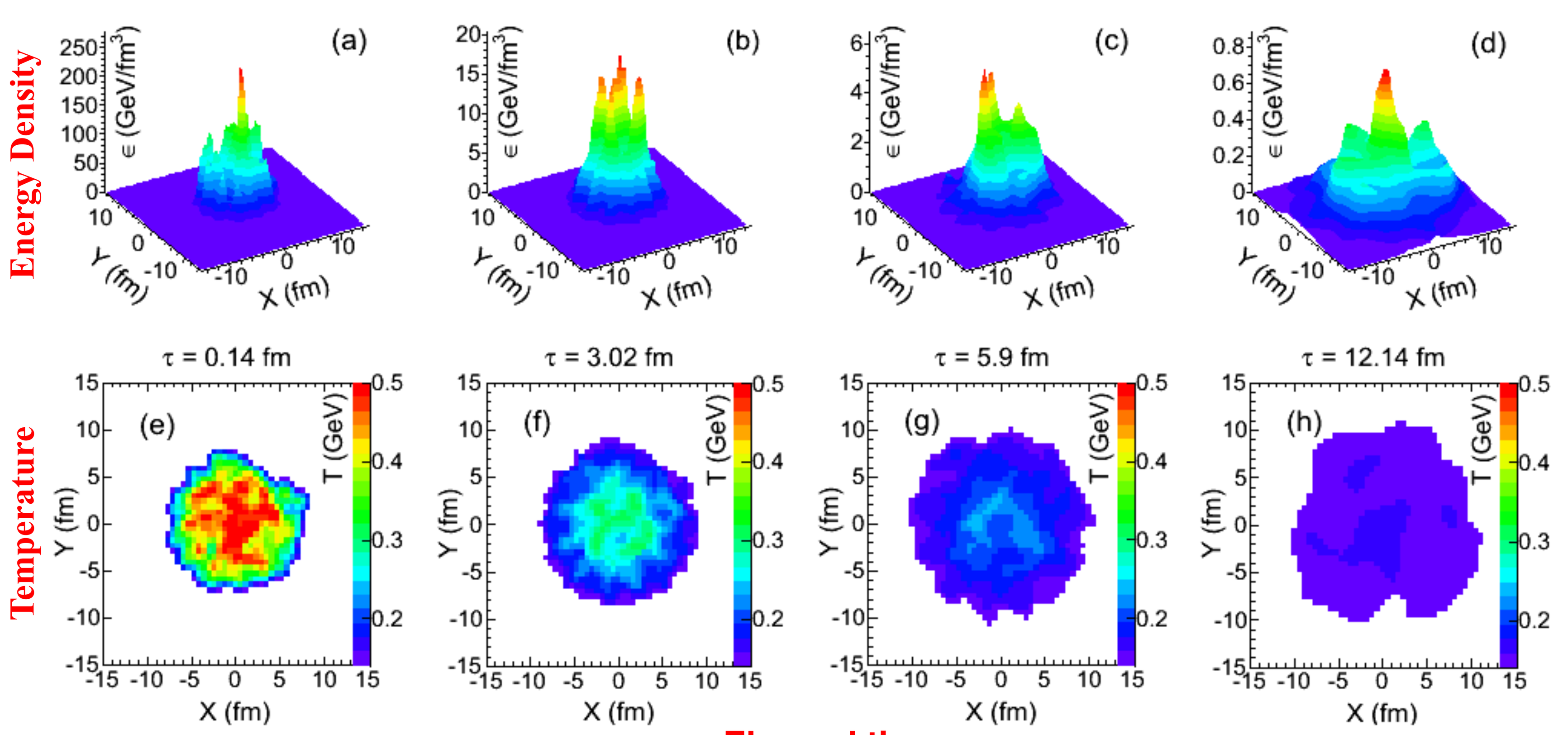
=> The physics of heavy-ion collisions at ultra-relativistic energies, popularly known as little bangs, has often been compared to the early Universe Big Bang phenomenon. We propose to make maps of the little bang, analogous to the CMBR maps, and use fluctuation measures to quantitatively probe the early stages of the heavy-ion collisions.

=> Fluctuation maps in bins of rapidity (y) and azimuthal angle (ϕ) are made from AMPT event generator which can be a proxy for experimental data.

=> A (2+1)-dimensional event-by-event ideal hydrodynamical framework to model the evolution of the produced system and make maps of ε and T from initial time to freeze-out, and estimate their relative fluctuations.

=> By making a correspondence of measured fluctuations with the time evolution profiles of the fluctuations from hydrodynamic calculations, we show that it is possible to visualize the thermodynamic conditions which presumably existed at different stages of evolution.

Energy density and Temperature:



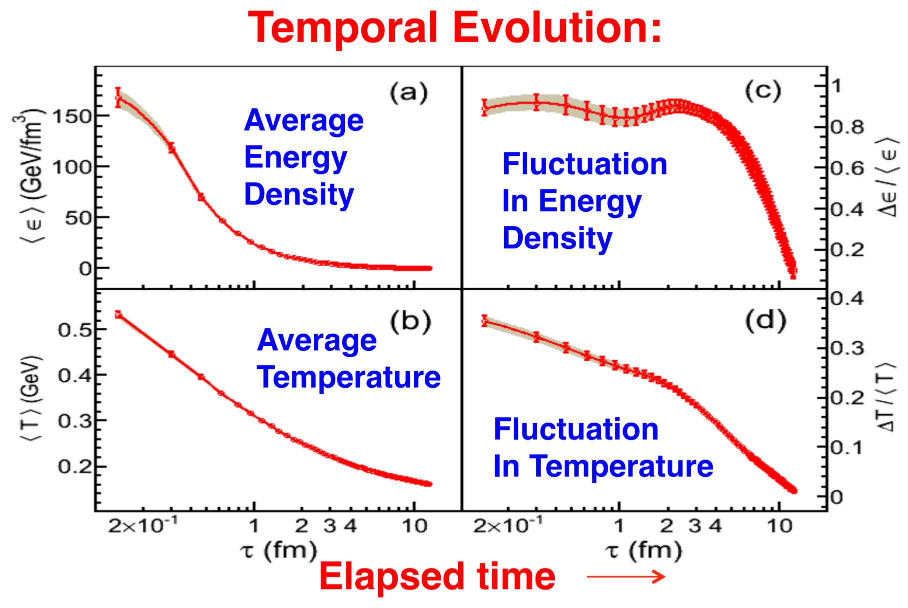
Observations from hydrodynamic calculations:

- At early times system is inhomogeneous and quite violent:
  - sharp and pronounced peaks in energy densit & hotspots in temperature
  - Extremely large fluctuations (~90%) in energy density
- With time, the system cools, expands and bin-to-bin variations smoothens
- Energy density drops fast, the fluctuation in energy density remains almost constant up to τ~2.5 fm, then falls rapidly.
- A kink in fluctuation of temperature observed around same time

Hydrodynamics Framework:

- (2+1)dimensional event-by-event ideal hydrodynamical framework is used in the present work to model the space-time evolution
- Lattice Equation of State with Transition temperature 170 MeV
- An wounded nucleon (WN) profile is considered where the initial entropy density is distributed around the WN using a 2-dimensional Gaussian distribution function.

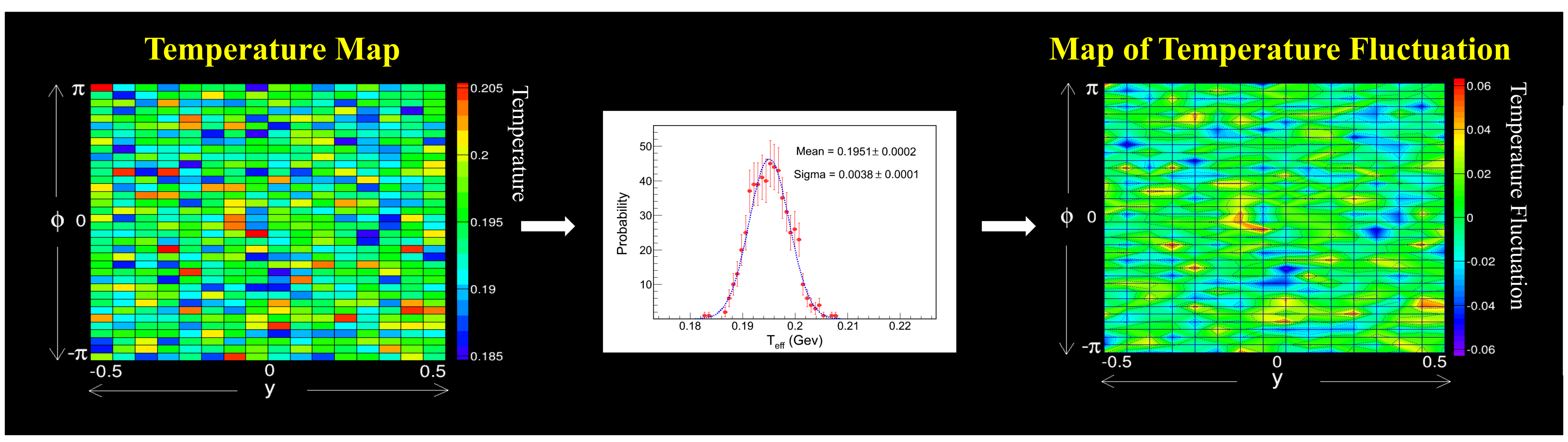
Temporal Evolution:



Temperature Map:

- AMPT (String Melting)
- Phase space in rapidity: -0.5<y<0.5 and full azimuth
- Phase space is divided to a grid of 16x36 bins
- p_T spectra of pions are constructed for each y−ϕ bin by combining large number of events.
- Each p_T spectrum is fitted by a Maxwell-Boltzmann function within p_T window of 0.5 to 1 GeV.
- T_{eff} obtained for each bin and plotted in the temperature map.

Central Pb-Pb Collisions at $\sqrt{S_{NN}}$ = 2.76 TeV



Construction of Fluctuation Map:

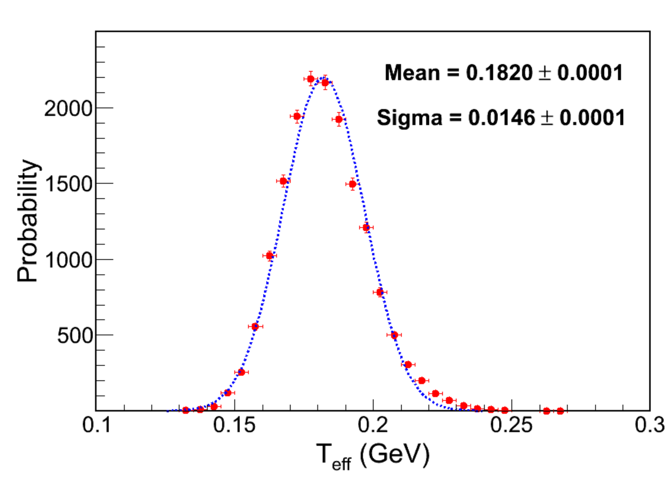
- Distribution of Teff for all bins are made (shown in middle panel)
- Calculate Temperature Fluctuation: $(\langle T_{eff}\rangle - T_{eff}) / \langle T_{eff}\rangle$
- Make a temperature fluctuation map in y−ϕ

Observations from Fluctuation maps:

- Temperature Fluctuation map is a novel way of representing data from the Little Bang.
- For majority of the bins – the fluctuations are close to zero
- Map shows several hot spots (red) and cold zone (blue)
- Observed fluctuations may be remnants of the initial energy density fluctuations and are not washed out even till freeze-out.

Temperature Fluctuations: Event-by-Event

- Event-by-event temperature fluctuations can be studied only at LHC, due to large number ($dN_{ch}/d\eta$ ~1600) of particle production in each event.
- The inverse slope parameters (T_{eff}^{ebye}) are obtained from p_T distribution in each event by fitting with Maxwell Boltzmann distribution function.

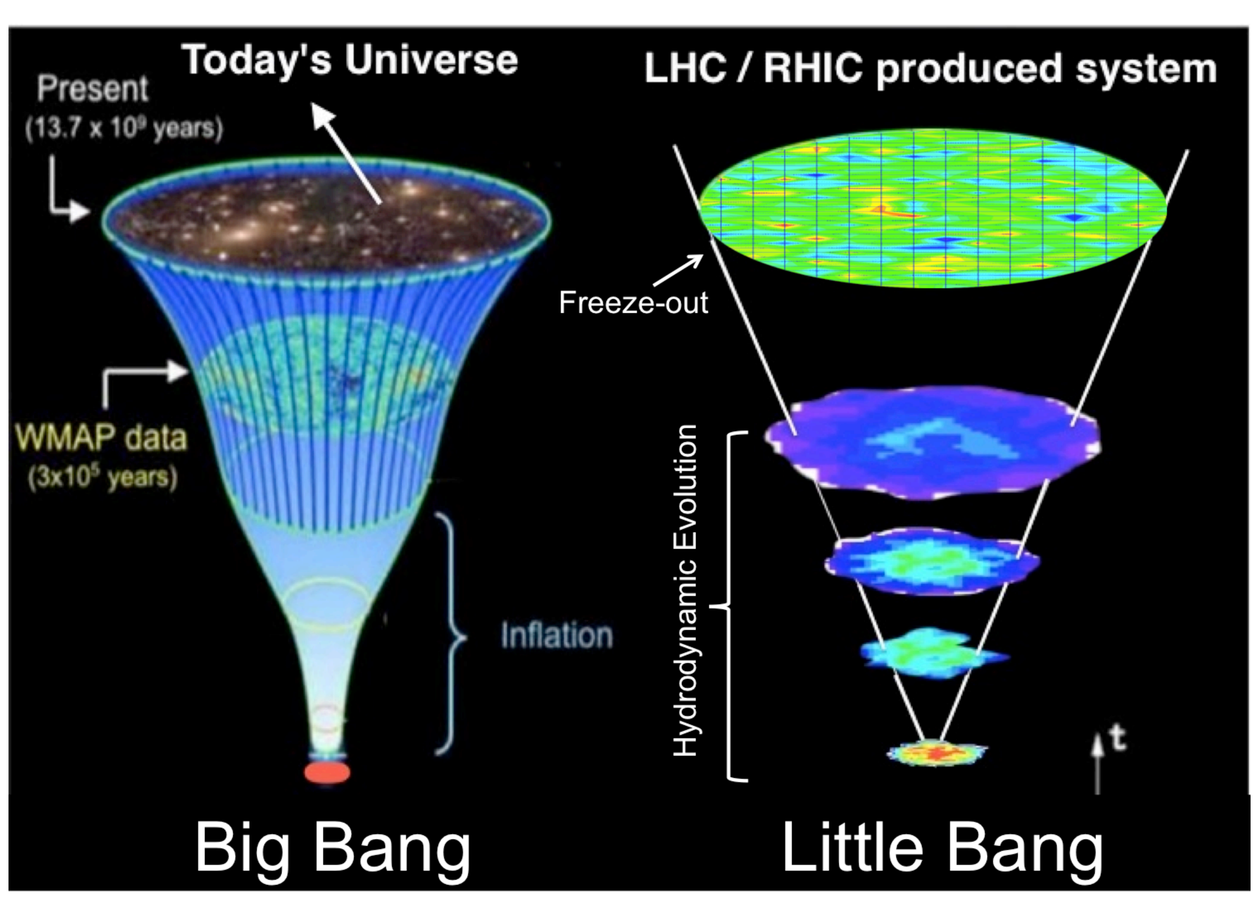


- Event-by-event temperature fluctuations are related to the heat capacity of the system:

$$\frac{1}{C_V} = \left(\Delta T_{eff}^{ebye} / \left\langle T_{eff}^{ebye} \right\rangle\right)^2$$

- We obtain, C_V = 155.3 for Pb-Pb system at LHC energies.

Big Bang *vs.* Little Bang:



Summary and Outlook:

- Temperature fluctuation maps, similar to those in CMBR experiments, offer a novel way of representing data in heavy-ion collisions.
- Bin to bin fluctuations in temperature has been found to be1.9% over bins in y-ϕ.
- This may indicate that the observed fluctuations are remnants of the initial energy density fluctuations and are not washed out even till the freeze-out.
- Making the connections of similar fluctuation at freeze-out from data and hydro, one can look back to the early stages of the collisions.
- Important information like speed of sound(c_s), C_V, etc., can be extracted from event-by-event temperature fluctuations.
- This novel way of studying temperature fluctuations will open up new avenues of studying the heavy-ion collisions and QGP.

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