After a search spanning 20 years, Kent State scientists report a significant advance in the study of excited subatomic matter and its possible states

Results from the dissertation of KSU physics PhD graduate Yadav Pandit, published in the April 25, 2014 issue of the American Physical Society's flagship journal *Physical Review Letters*, are considered promising indications of a phase transition never previously observed in this branch of physics, in the same mathematical category as the familiar phase changes between ice, liquid water, and water vapor.

Former KSU PhD student Yadav Pandit working on the STAR experiment at Brookhaven National Lab, Long Island, NY. Dr. Pandit is currently a postdoctoral researcher at U. of Illinois, Chicago.

It is known that nuclear matter, when sufficiently excited, changes its state, or phase. The nuclei at the center of all atoms in their normal state contain basic indivisible constituents called quarks. In normal atoms, the quarks are so tightly bound in place that even their presence is not normally apparent. Only under conditions of very extreme excitation, in collisions at accelerators, can a phase change happen. These collisions result in a new phase where the quarks become liberated ("deconfined") and are able to move around freely, at least for a brief time before the matter returns to its normal state. This deconfined phase of matter is usually called Quark Gluon Plasma (QGP). The importance and ubiquity of nuclear matter is underlined by the fact that it makes up 99.973% (by weight) of our everyday world.

The group at KSU is headed by Prof. Declan Keane (Dr. Pandit's PhD adviser) and Prof. Spiros Margetis. The KSU group works in collaboration with a large international team, representing more than 50 institutions, and conducts experiments using the Relativistic Heavy Ion Collider (RHIC) accelerator at Brookhaven National Laboratory, New York. Their large house-sized detector for measurement of the particles that emerge when nuclei collide at RHIC is called the Solenoidal Tracker At RHIC (STAR). Dr. Jonathan Bouchet and PhD students Jeremy Alford, Michael Lomnitz, Amilkar Quintero and Prashanth Shanmuganathan are KSU researchers who are co-authors of the new paper by virtue of their vital contributions to constructing and operating the various interdependent subsystems of the STAR detector.

Evidence for the QGP phase was discovered at RHIC during its first decade of operation, beginning in the year 2000. However, the phase change originally observed at RHIC was always a smooth transition, quite unlike the familiar discontinuous changes of phase when ice turns to liquid water, or when liquid water turns to vapor. Changes of phase like in water are called first-order phase transitions. Theoretical physicists had anticipated that the normal energy of the RHIC accelerator is too high to observe a first-order phase transition, and they predicted that if nuclear matter exhibits this phenomenon, it might be seen at a lower energy. In particular, Prof. Horst Stoecker and his group at the University of Frankfurt in Germany, based on fluid models, predicted a first-order phase transition phenomenon called 'softest point collapse', where the pressure of the excited nuclear matter would show a sharp drop and then increase again as nuclei were collided over just the right range of energies.

In the 1990s, experiments at lower-energy accelerators at Brookhaven and in Europe carried out many searches for the softest point collapse. Prof. Declan Keane was spokesperson for an experiment initiated in 1993, with such a search as one of its goals. Indeed, had the 1^{st}-order phase transition occurred at the predicted energy, KSU graduate Heng Liu (PhD, 1998) would have been the first to observe it.

Beginning around 2010, accelerator physicists at Brookhaven developed ways to run their machine at lower energies than it was designed for, but still higher than the energies explored in the 1990s. For the first time, this opened up the 'sweet spot' in energy where the new measurements suggest that the elusive first-order phase transition can be found.

The best way for experiments to measure the pressure of the excited matter created in nuclear collisions is to measure a particular type of collective motion, called directed flow, which is a measure of the extent to which the emitted particles deviate from spreading out uniformly in all directions. The softest point collapse was predicted to show up as a drop in the pressure, and hence a drop in the flow, as the energy of the accelerator was scanned across the right region.

A special technique pioneered by Yadav Pandit in his PhD research, which involved a creative re-purposing of a detector subsystem originally developed for an unrelated project, allowed directed flow to be measured in the new energy region opened up for study at Brookhaven in 2010 and subsequent years. In the April 2014 paper in *Physical Review Letters,* Dr. Pandit's PhD work is combined with earlier directed flow measurements at higher energies from an analysis by Dr. Gang Wang, a 2006 PhD graduate of Kent State, and currently a staff researcher at UCLA. These measurements allow the STAR collaboration to report a drop in flow that shows a remarkable qualitative similarity to the predicted 'softest point collapse'. The Media Office at Brookhaven has issued a press release to coincide with publication of the new flow measurements. This release has in turn been summarized and discussed in the online magazine of other US National Laboratories, has been translated into Italian and featured on an Italian website devoted to scientific news, and has been taken up by news outlets in Dr. Pandit's home country, by his present institution as well as by Kent State.

In spite of this recent progress, many questions remain unresolved. In an effort to better understand these experimental results from the STAR collaboration, new state-of-the-art model calculations were published in mid-2014. The improved models deviate further from experiment than the older models, and raise doubts about which type of phase transition might be involved. It is clear that further work remains to be done. The accelerator at Brookhaven is being upgraded to allow much enhanced energy scan data to be acquired, and more detailed and comprehensive experiments are planned for 2018-2019.