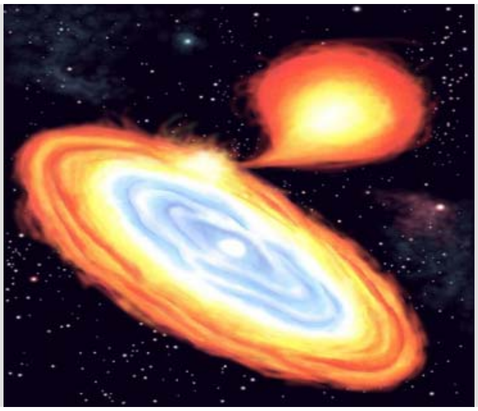
The Joint Institute for Nuclear Astrophysics

Ejecting nuclear ashes in X-ray bursts

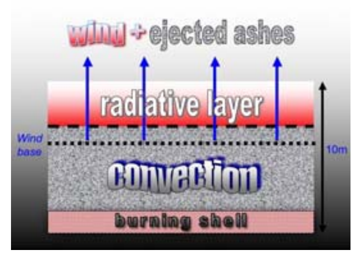


Artist's view of a stellar binary system where material is streaming from a regular star (upper right) onto a neutron star (bright dot below the center) via an accretion disk. X-ray bursts occur on the surface of the neutron star burning the nuclear fuel obtained from the companion star. Credit: Tony Piro

X-ray bursts are thermonuclear explosions that occur on the surface of neutron stars accreting matter from a nearby companion star. They last about 10-100 seconds. With over 70 known systems just in our Galaxy, and with many of them bursting several times a day, these are the most frequent thermonuclear explosions in our universe.

During the explosion, nuclear reactions fuse accreted hydrogen and helium into heavier nuclei. As the gravitational binding of a nucleus on the surface of a neutron star exceeds the nuclear energy release by about a factor of 40, it is clear that most of the produced ashes remain on the neutron star surface. However, a long standing question has been whether a small fraction of the freshly synthesized nuclei are ejected into space. In that case, astronomers might have a chance to detect these nuclei, and in addition, X-ray bursts could actually contribute to the synthesis of the elements in the cosmos.

JINA scientists at UC Santa Barbara and Michigan State University showed, that a small fraction of nuclear ashes could indeed escape under certain conditions. This became possible by combining theoretical models with detailed nuclear reaction networks. They found that convection can transport freshly synthesized nuclei to sufficiently shallow surface layers that the nuclei can be ejected by the radiation pressure driven wind of a "Photospheric Radius Expansion burst". Their calculations of the freshly ejected composition yielded expected signatures in the emitted X-rays that will now be searched for with the current generation of X-ray telescopes. The most promising targets are neutron stars that accrete helium rich material at low rates. In fact, anomalous oxygen to neon ratios observed in the direction of some X-ray bursters might be a first indication of this ejection process, though other explanations cannot be excluded at this point.



Schematic view of the layers on the surface of an accreting neutron star. It is shown that during the thermo-nuclear explosion of the surface layers that is observed as an X-ray burst a convection zone transports matter from the burning shell upwards close enough to the surface so that it can be ejected in a wind.

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With ejection of nuclear ashes being likely, it is possible that X-ray bursts contribute to the synthesis of heavier elements in the cosmos. These calculations showed that the ejected nuclei are produced during the beginning of the burst and are therefore in the mass range that is readily produced in much larger quantities in supernova explosions. However, the more interesting heavier nuclei produced late in the burst might be ejected in subsequent bursts, for example during the recently discovered superbursts that occur every year or so.

Finally, the nuclear reaction sequence responsible for the production of the ejected nuclei was investigated in detail and discussions for experiments at radioactive beam facilities within the JINA collaboration are underway to address some of the nuclear physics uncertainties.