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IceCube Sensitivity for Low-Energy Neutrinos from Nearby Supernovae

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ABSTRACT

This paper describes the response of the IceCube neutrino telescope located at the geographic South Pole to outbursts of MeV neutrinos from the core collapse of nearby massive stars. IceCube was completed in December 2010 forming a lattice of 5160 photomultiplier tubes that monitor a volume of $\sim 1\,\text{km}^3$ in the deep Antarctic ice for particle induced photons. The telescope was designed to detect neutrinos with energies greater than 100 GeV. Owing to subfreezing ice temperatures, the photomultiplier dark noise rates are particularly low. Hence IceCube can also detect large numbers of MeV neutrinos by observing a collective rise in all photomultiplier rates on top of the dark noise. With 2 ms timing resolution, IceCube can detect subtle features in the temporal development of the supernova neutrino burst. For a supernova at the galactic center, its sensitivity matches that of a background-free megaton-scale supernova search experiment. The sensitivity decreases to 20 standard deviations at the galactic edge (30 kpc) and 6 standard deviations at the Large Magellanic Cloud (50 kpc). IceCube is sending triggers from potential supernovae to the Supernova Early Warning System. The sensitivity to neutrino properties such as the neutrino hierarchy is discussed, as well as the possibility to detect the neutronization burst, a short outbreak of ν_e's released by electron capture on protons soon after collapse. Tantalizing signatures, such as the formation of a quark star or a black hole as well as the characteristics of shock waves, are investigated to illustrate IceCube's capability for supernova detection.

Key words. neutrinos – supernovae: general – telescope