Supernova Pointing by Neutrino Matter Oscillation

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Basic idea

In a core-collapse supernova about 99% of the energy is released as neutrinos. They arrive in pure mass eigenstates at the Earth, but for allowed oscillation parameters they undergo additional oscillations when travelling through Earth matter before reaching a detector (MSW effect). The oscillations can be seen in the energy spectrum and are equidistant in inverse energy $y = 12.5/E$. A Fourier transformation in $y$ yields a peak. [1,2]

Resolving ambiguities

The position of the highest peak is clearly correlated with the pathlength $L$. There is also information in the height of that peak which especially helps to differentiate between regions of different matter density.

Given a detector location we can map pathlengths allowed by the Neyman construction to allowed areas in the sky within which the supernova is likely to have occurred. Here we see example skymaps in equatorial coordinates for a detector in Finland and a supernova at RA=20°, dec=60° at 0:00 GMST showing allowed regions (red) at 90% C.L. The L=0 bin makes up half the sky. The ambiguity can be resolved using peak height information.

Combining multiple detectors

With a single detector only the allowed region can be restricted to a ring in the sky in the best case. With two detectors we can reduce it to two distinct areas, and three detectors can bring it down to one spot. In practice there are still ambiguities because of finite statistics and energy resolution. Technically data of multiple detectors can be combined by doing the Neyman construction in a higher-dimensional space with tuples of pathlengths $L$, and tuples of peak positions and heights $(k, h)$.

Detector effects

Real detectors do have finite energy resolution; that is they do not reconstruct the energy of each event perfectly. This smears out the measured spectrum, making peaks harder to identify. For each event we assume the measured energy is given by a Gaussian around the real energy, with its width heavily depending on the detector type.

With many simulated finite statistics spectra we can check the distributions of peak $k$ for a given pathlength $L$. In this Neyman construction one can read off the allowed regions for a measured $k$ by drawing a horizontal line. Especially for low pathlengths, when no oscillation occurs, random noise can easily be misidentified as a peak.

Summary

- Need high statistics, O(60,000) events
- Need good energy resolution
- Inferior to water Cherenkov elastic scattering
- Feasible for scintillator detectors
- Combination of multiple detectors improves pointing
- Relative timing can resolve remaining ambiguities
- Good knowledge of oscillation parameters desired