Fast-time variations of supernova neutrino fluxes and detection perspectives

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Xmas Workshop 2013
Bari, December 23, 2013
Outline

- Supernova explosion mechanism
- Neutrino signatures of the SN hydrodynamical instabilities
- Detection perspectives adopting first full-scale 3D SN simulations
- Conclusions

This talk is based on:
Neutrinos in Supernovae

**Core-collapse supernovae:** Terminal phase of massive stars \([M \geq 8M_☉]\). Stars collapse ejecting the outer mantle by means of shock-wave driven explosions. **Expected rate:** 1-3 SN/century in our galaxy (~ 10 kpc).

**Neutrino typical energies:** ~ 15 MeV.
**Neutrino emission time:** ~ 10 s.

Neutrinos carry 99% of the released energy (~ \(10^{53}\) erg).
Neutrinos and SN Explosion Mechanism

★ Shock wave forms within the iron core. It dissipates energy dissociating iron layer.

★ Stalled shock wave receives energy from neutrinos to start re-expansion against ram pressure of in-falling stellar matter. (Delayed Neutrino-Driven Explosion.)

★ Convective overturn and shock oscillations (standing accretion shock instability, SASI) enhance efficiency of neutrino heating and revive the shock.

Directional Neutrino Signal

First full-scale 3D SN simulations with detailed neutrino transport being performed!* SASI and convective motions leave an imprint on the neutrino signal.

Close to the SASI plane (optimistic observer direction)

Perpendicularly to the SASI plane (pessimistic observer direction)

Large amplitude modulations close to the plane where spiral SASI mode develops. Are such modulations detectable?

* For details see also: F. Hanke et al., arXiv: 1303.6269.
Detection Perspectives

In IceCube and Hyper-Kamiokande, neutrinos are primarily detected by inverse beta decay

$$\bar{\nu}_e + p \rightarrow n + e^+$$

IceCube
- 1 km antarctic ice with 5160 PMT
- $R_{\text{bkgd}} = 1480 \text{ ms}^{-1}$

Hyper-Kamiokande
- Fiducial mass: 740 kton
- Background free signal + event-by-event energy information

* For details see: Abbasi et al., arXiv: 1108.0171 (IceCube), K. Abe et al., arXiv: 1109.3262 (Hyper-K).
SASI Detection Perspectives (27 $M_{\odot}$)

Our 3D 27 $M_{\odot}$ SN progenitor shows pronounced SASI. SASI sinusoidal modulation of the neutrino signal will be detectable by IceCube and Hyper-K.

Strong signal modulation
(optimistic observer direction)

Weak signal modulation
(pessimistic observer direction)

Expected rate above IceCube background

Hyper-K rate = 1/3 IceCube rate
SASI still detectable
**SASI Detection Perspectives (27 M_{\odot})**

Time evolution of the IceCube detection rate on a sky-plot of observer directions.

![Time evolution of the IceCube detection rate on a sky-plot of observer directions.](image)

On average, the fraction of sky where good observation chances apply is significant (> 50%).

\[
\sigma \equiv \left( \int_{t_1}^{t_2} dt \left[ R - \langle R \rangle \right]^2 \right)^{1/2}
\]

\[ [t_1, t_2] = [120, 250] \text{ ms} \]
SASI Detection Perspectives (20 $M_{\text{sun}}$)

For the 27 $M_{\text{sun}}$ SN progenitor, two SASI episodes occur with a convective phase in between. For the 20 $M_{\text{sun}}$ SN progenitor, only one SASI episode occurs.
SASI Detection Perspectives (20 $M_{\odot}$)

On average, the fraction of sky where good observation chances apply is significant (> 50%). The SASI plane of the 20 $M_{\odot}$ SN progenitor is not the same as the 27 $M_{\odot}$ one.
SASI detection perspectives \((11.2 \, M_{\text{sun}})\)

SASI does not occur for any progenitor.

Large scale convection is the dominant hydrodynamic instability in the \(11.2 \, M_{\text{sun}}\) progenitor.
A peak appears at the SASI frequency of \( \sim 80 \text{ Hz} \) for the 20 and 27 \( M_{\odot} \) SN progenitors.
Conclusions

★★ World-wide first 3D SN simulations with detailed neutrino transport available.

★★ Neutrinos carry imprints of the explosion dynamics.

★★ The SN neutrino signal can diagnose the nature of the hydrodynamical instability.

★★ SASI modulations of the neutrino signal will be clearly detectable in IceCube and Hyper-K.

★★ Detection chances depend on progenitor properties, distance and observer location relative to the main sloshing direction.
Buone Feste!