Neutrino Signatures of Supernovae SASI

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Neutrino Signatures of Supernovae SASI

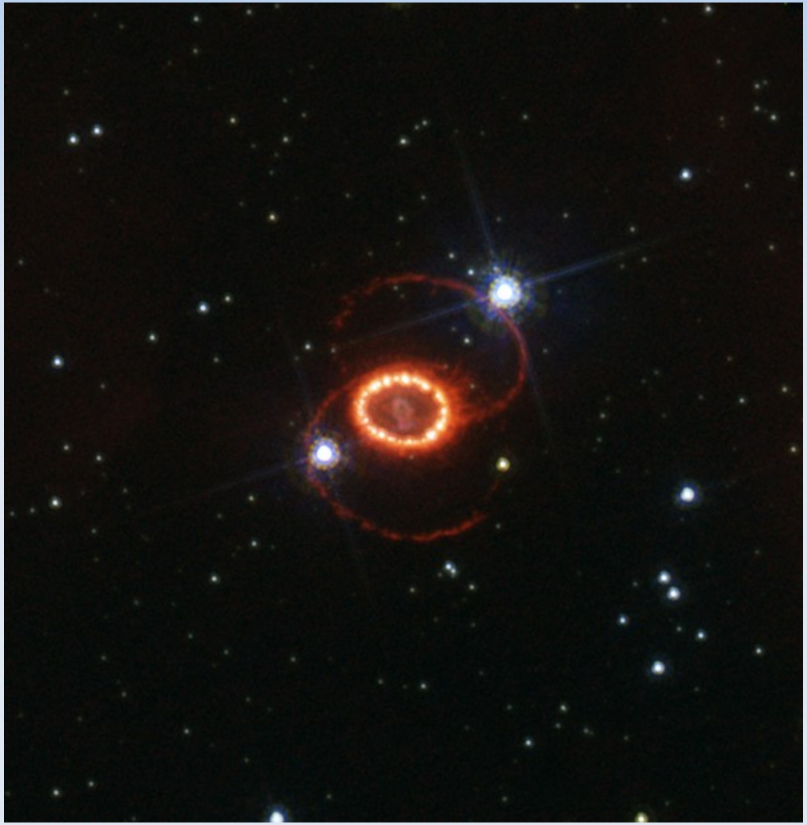
Motivation

Standing Accretion Shock Instability - SASI

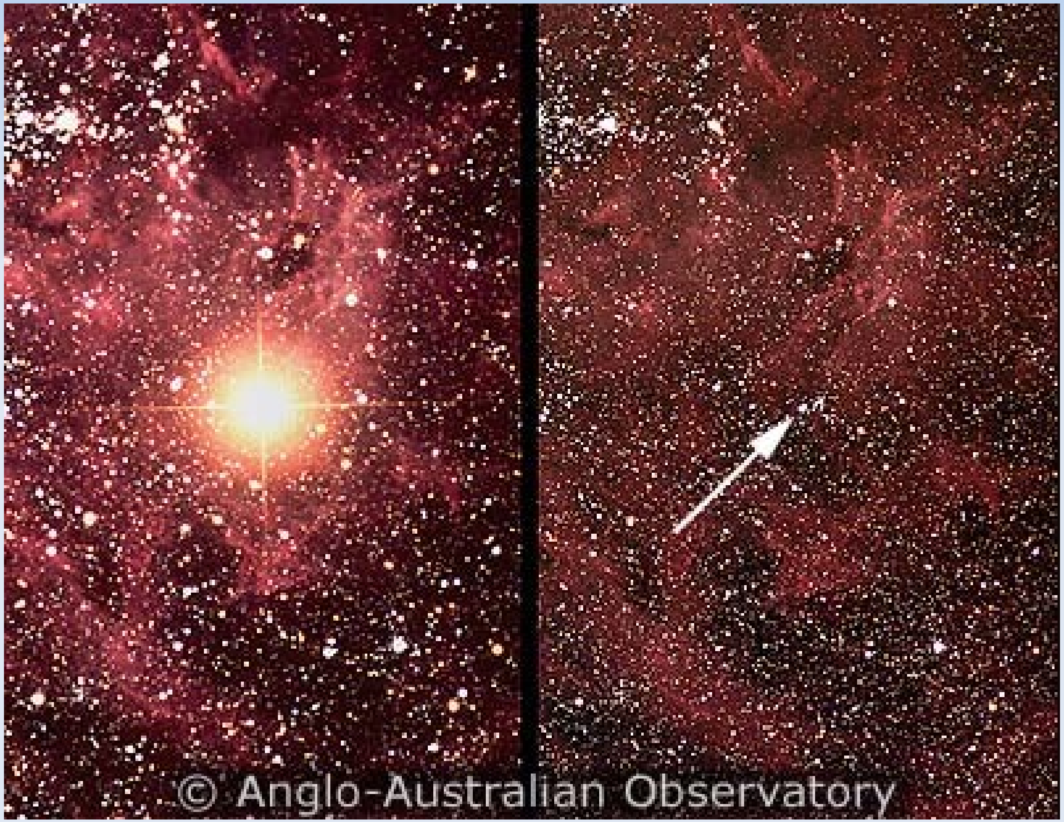
IceCube

Our work - results

Conclusions



Neutrinos to understand Supernova physics



SN1987A:

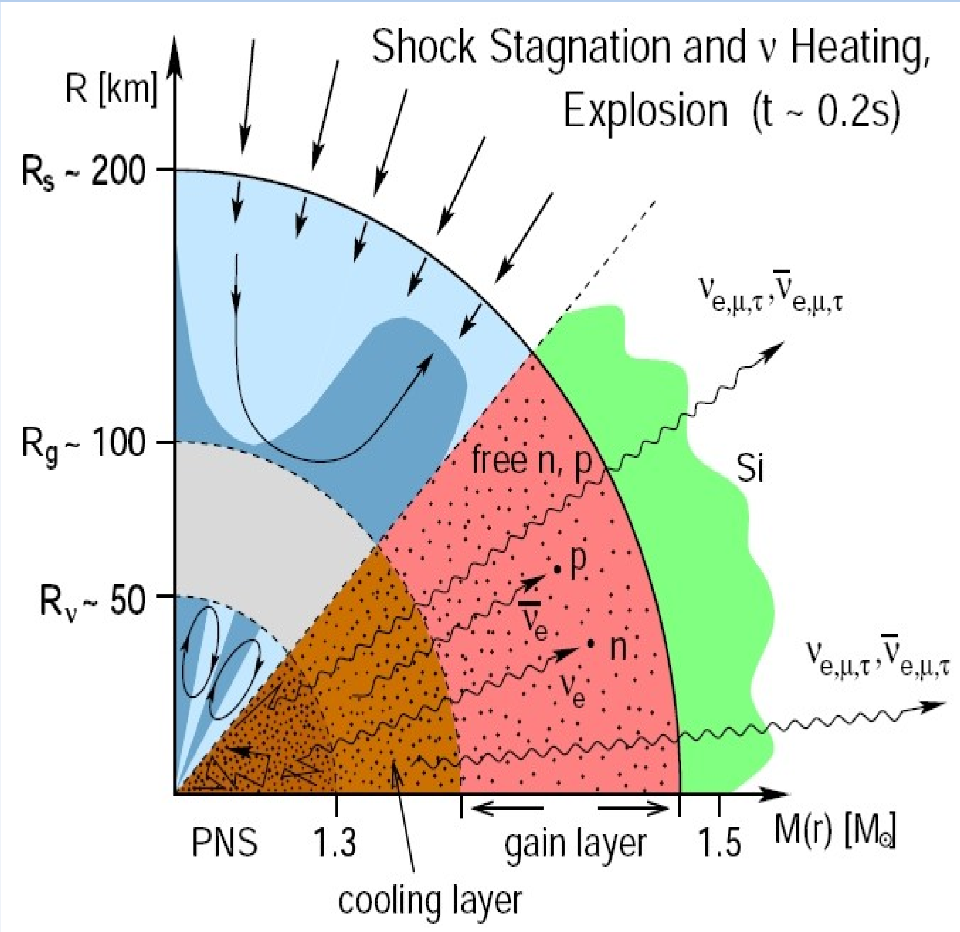
First observed supernova neutrinos → looking inside.

In LMC, D = 50 kpc.

Confirmed overall SN understanding.

Explosion picture incomplete.

Standing Accretion Shock Instability



[H.-Th. Janka et al.]

Energy loss halts shock wave → Standing Accretion Shock.

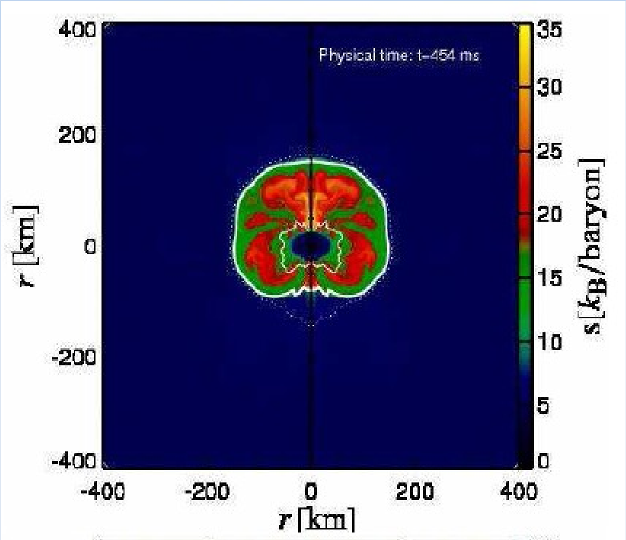
How to revive?

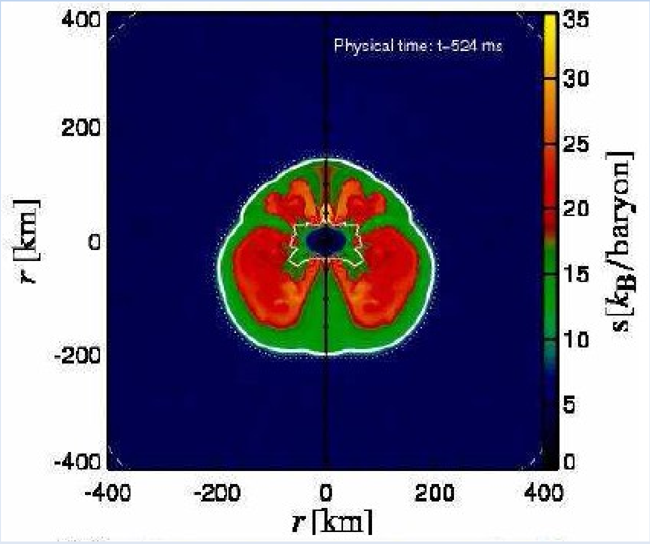
SASI : instability → perturbs shock front → R_{shock} increases and pulsates.

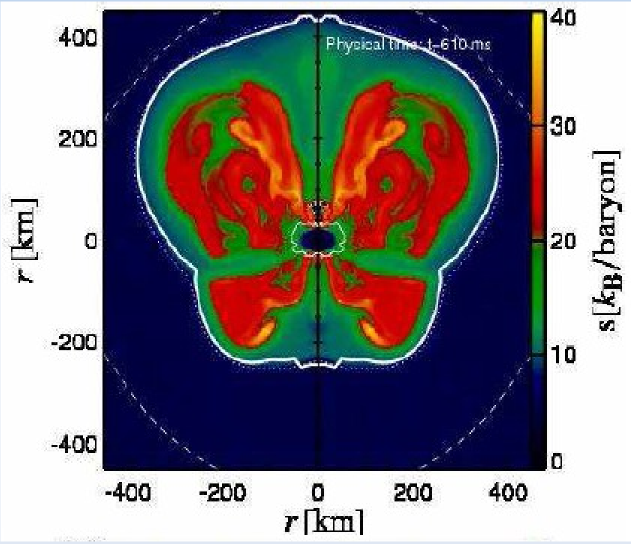
Large R_{shock} → infalling material longer time in heating area.

More energy → shock wave revived → final explosion.

SASI – how does it look?

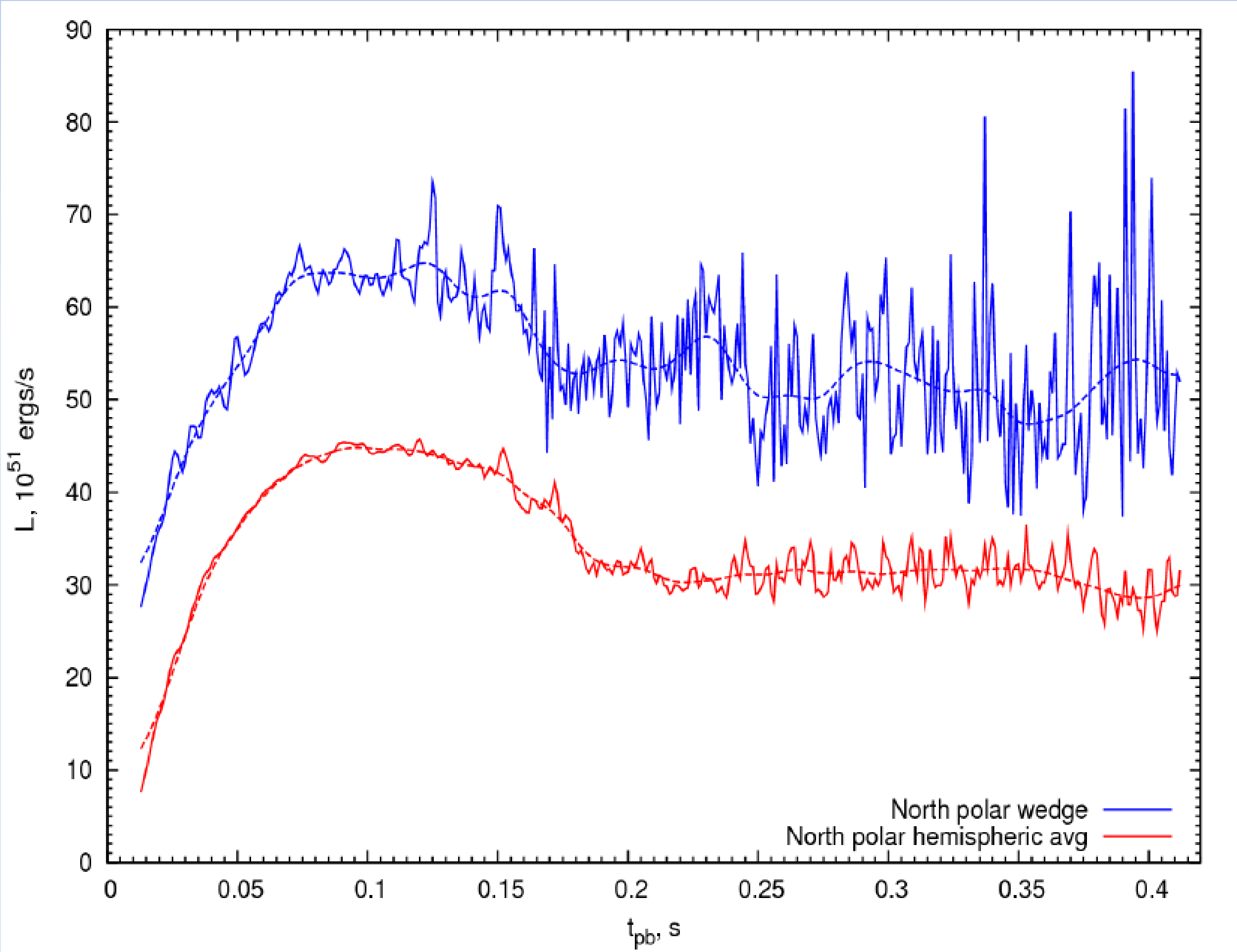






[A. Marek & H.-Th. Janka]

Effect of SASI



SASI induced fluctuations clearly visible:

- ~ 10 % for hemi-spheric average and ~ 40 % for ray.

Similar effect in energy spectra.

IceCube – Cherenkov telescope

Digital Optical Modules with photo-multiplier tubes.

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

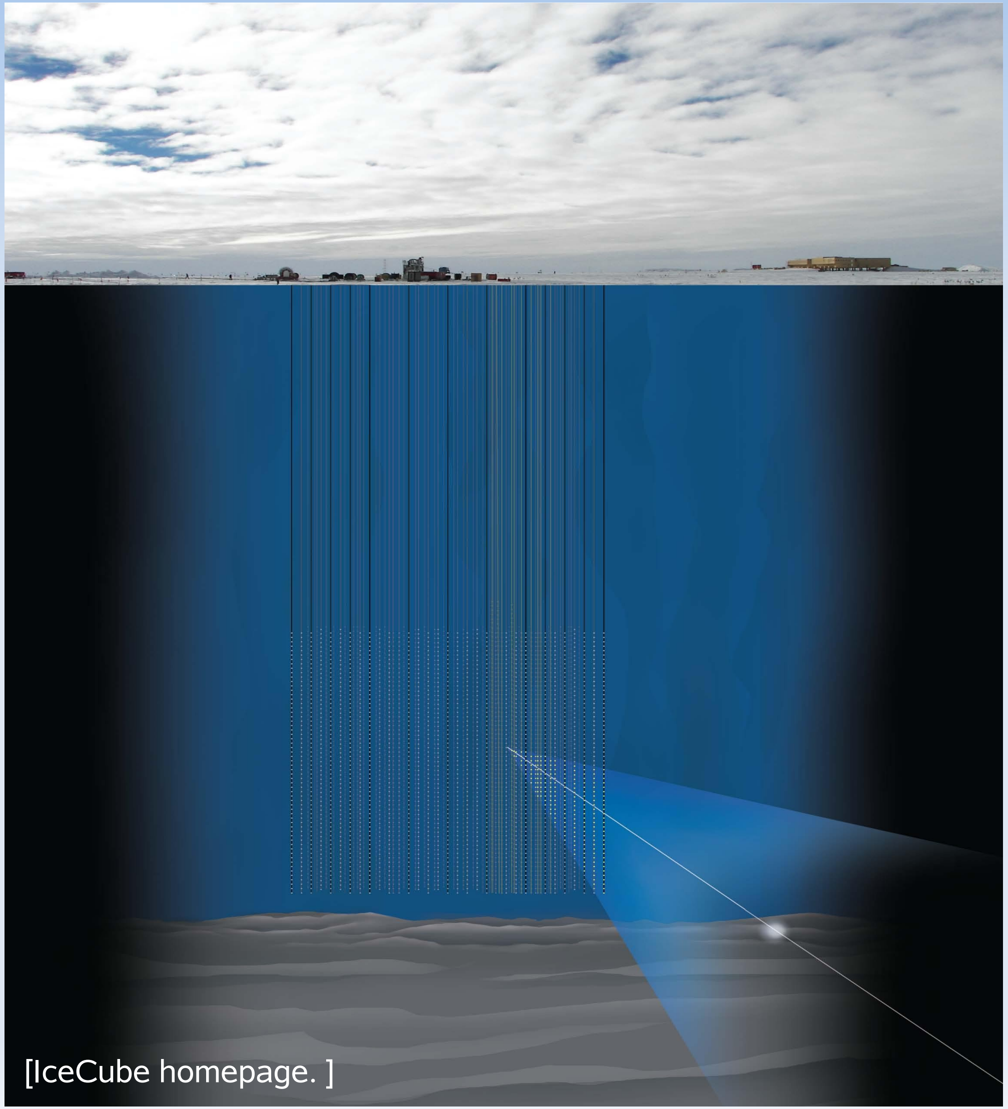
Optimized for energy range:

1 TeV ≤ E ≤ 1 PeV

SN anti-ν_e energy:

E ~ 12 – 18 MeV

So not entire Cherenkov cone only one photon per interaction → diffuse blue glow of the ice.



IceCube – superiority

For entire duration (t~10 s) of SN we expect ~10^6 events.

Factor of 100 more than expected in SuperKamiokande.

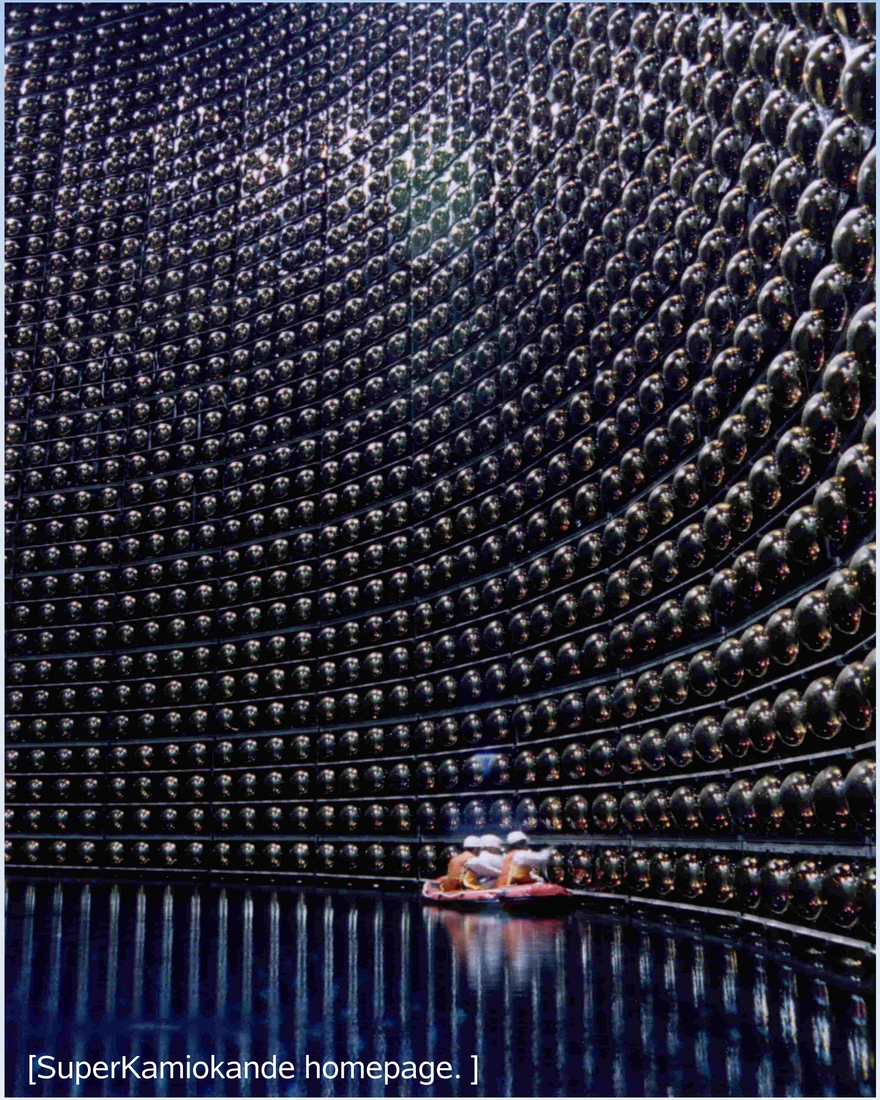
Instantaneous rate:

$$\Gamma_{SN} \sim 900\ ms^{-1}$$

Dark Current noise in IceCube:

$$\Gamma_{noise} = 1340\ ms^{-1}$$

Looking at time structure of the increased noise.



Calculations

Expected eventrate in IceCube:

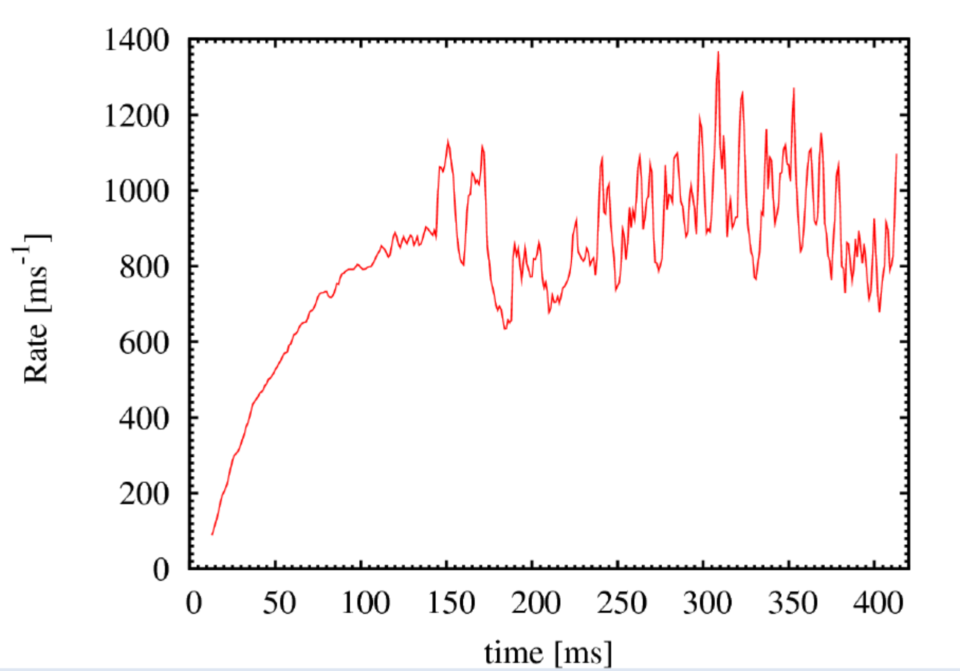
$$R_{\bar{\nu}_e} = 114 \text{ ms}^{-1} \frac{L_{\bar{\nu}_e}}{10^{52} \text{ erg s}^{-1}} \left(\frac{10 \text{ kpc}}{D}\right)^2 \left(\frac{E_{\text{rms}}}{15 \text{ MeV}}\right)^2$$

$$E_{\text{rms}}^2 = \frac{\langle E^3 \rangle}{\langle E \rangle}$$

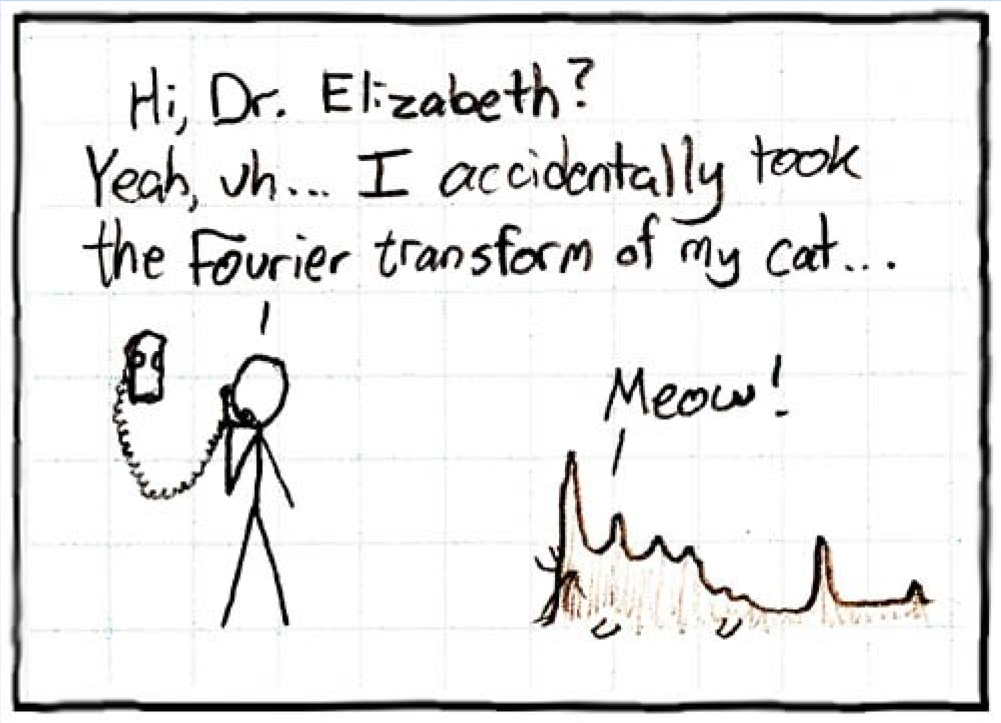
Energy and luminosity data from numerical simulations by A. Marek and H.-Th. Janka.

Progenitor star; 15 $M_\odot$, non-rotating, soft equation of state.

Data on angular rays, and spanning post bounce time of 10 - 416 ms.



Power spectrum



[xkcd.com]

Fourier transform to investigate features in the time signal.

Nyquist frequency is 250 Hz due to IceCube binning.

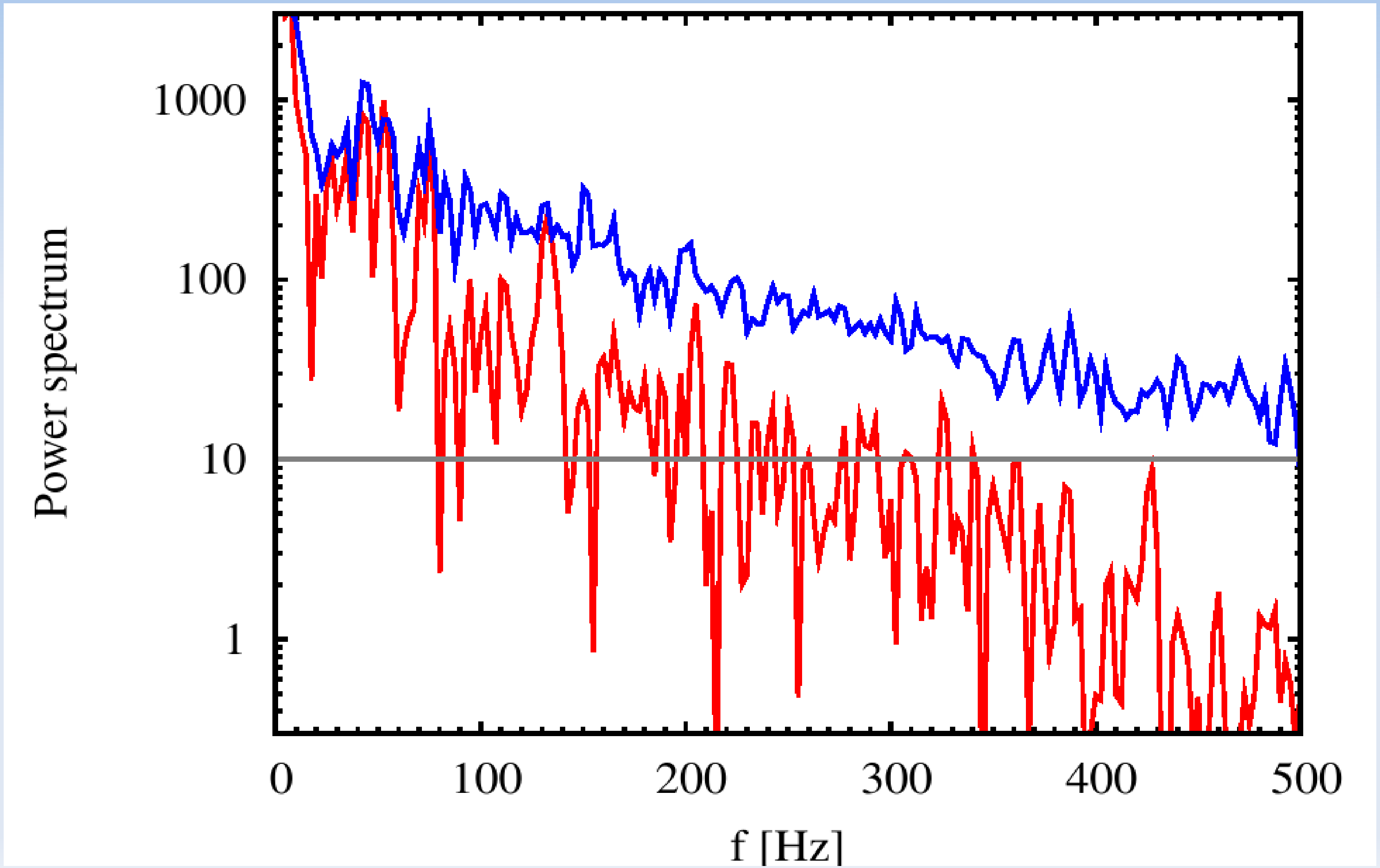
Reduced to 400 ms to get frequency spacing of 2.5 Hz.

Used Hanning window to avoid edge effects.

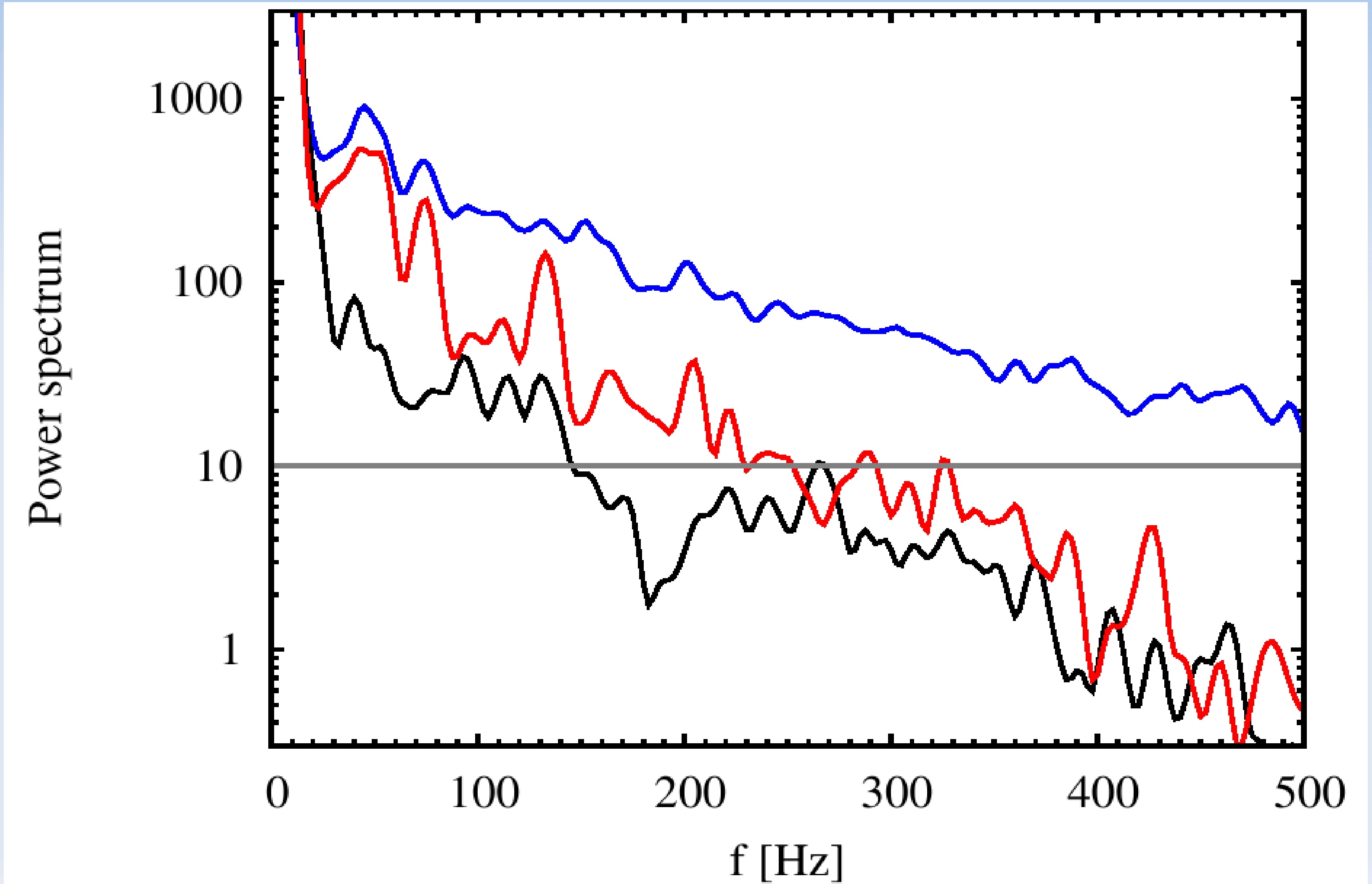
Restating our question before we answer it:

Is the SASI observable in IceCube?

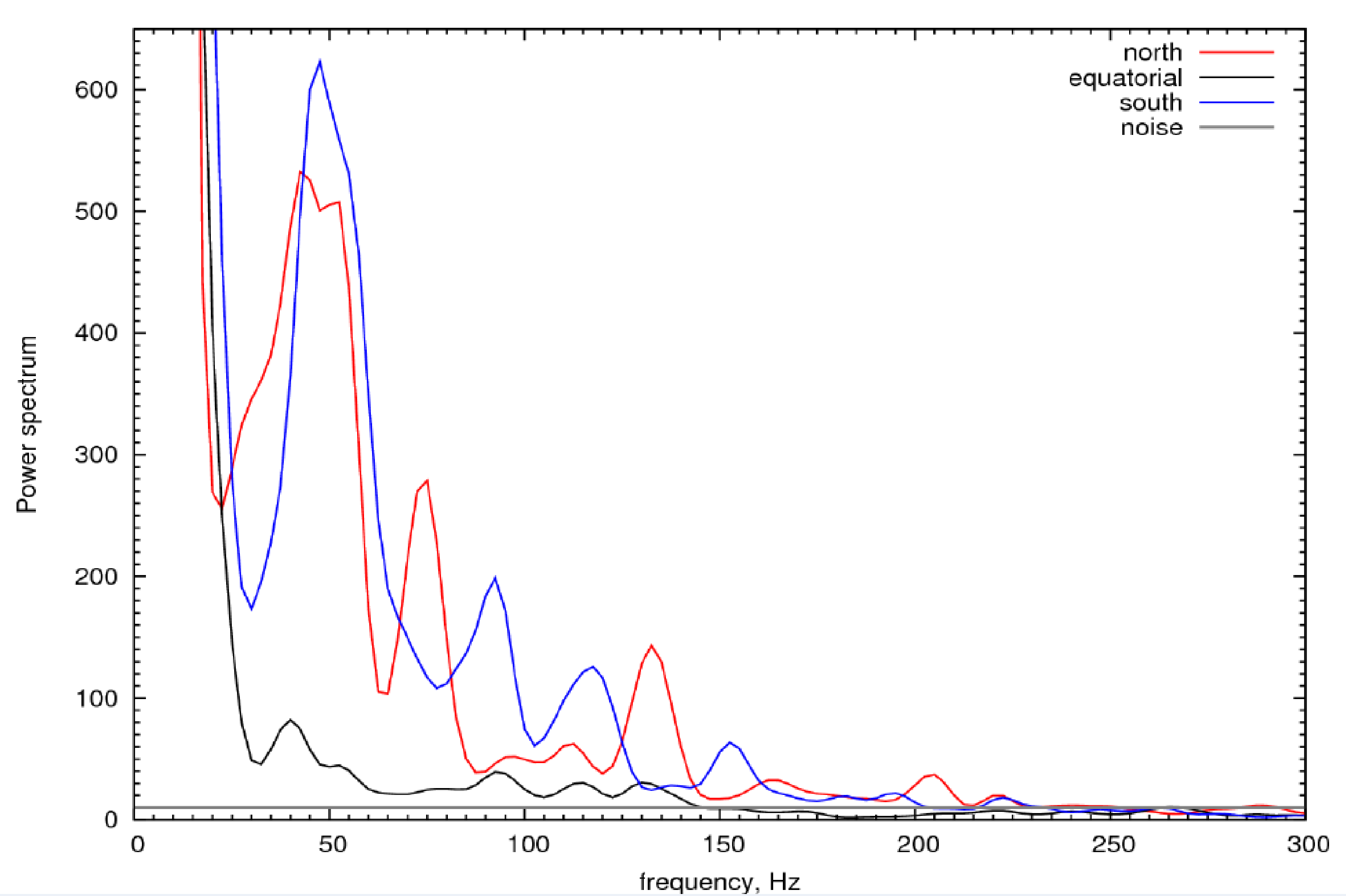
Power spectrum



Smoothed power spectrum

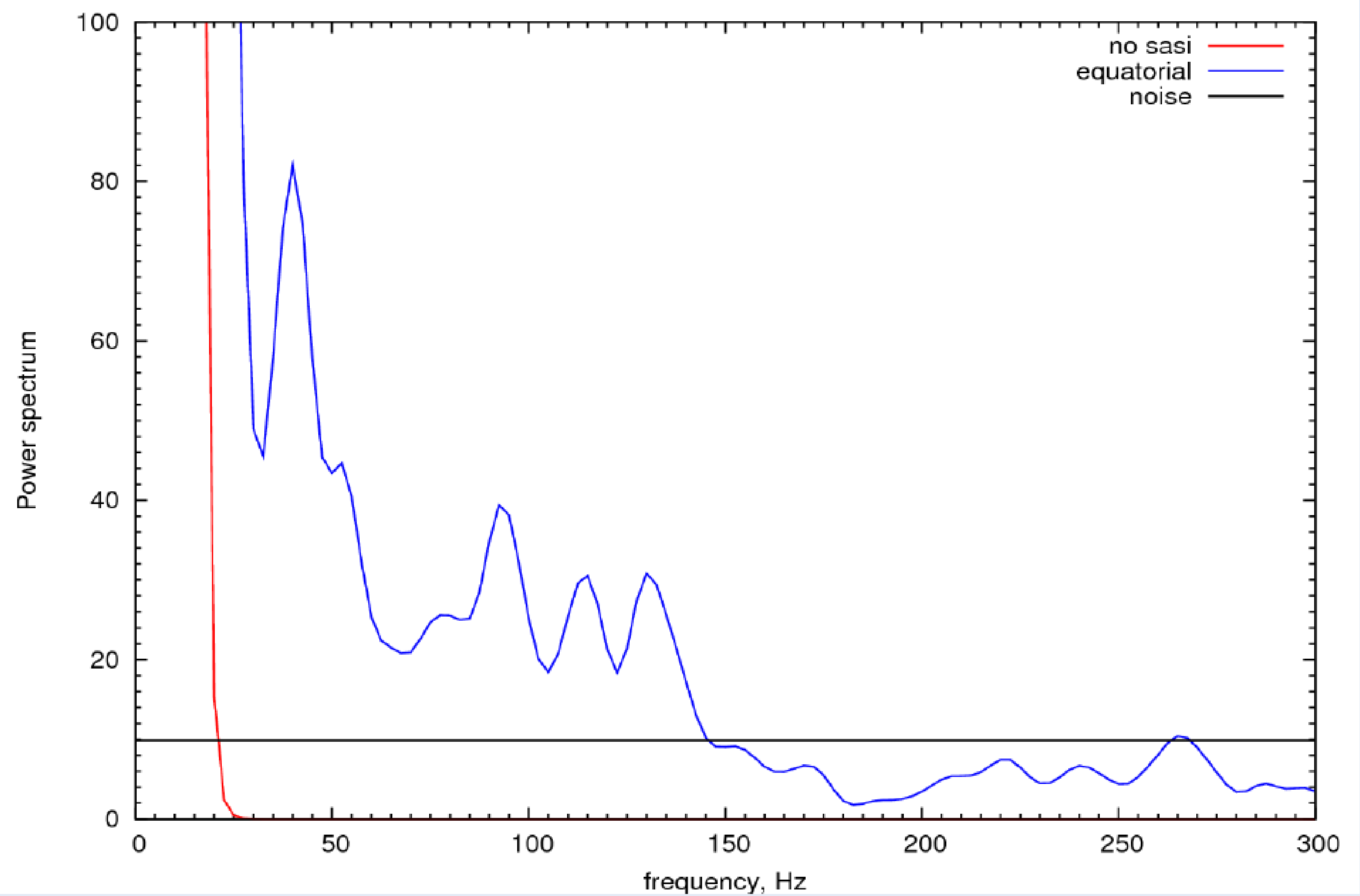


Results



north
equatorial
south
noise
Power spectrum
frequency, Hz
0
100
200
300
400
500
600
0
50
100
150
200
250
300

Results



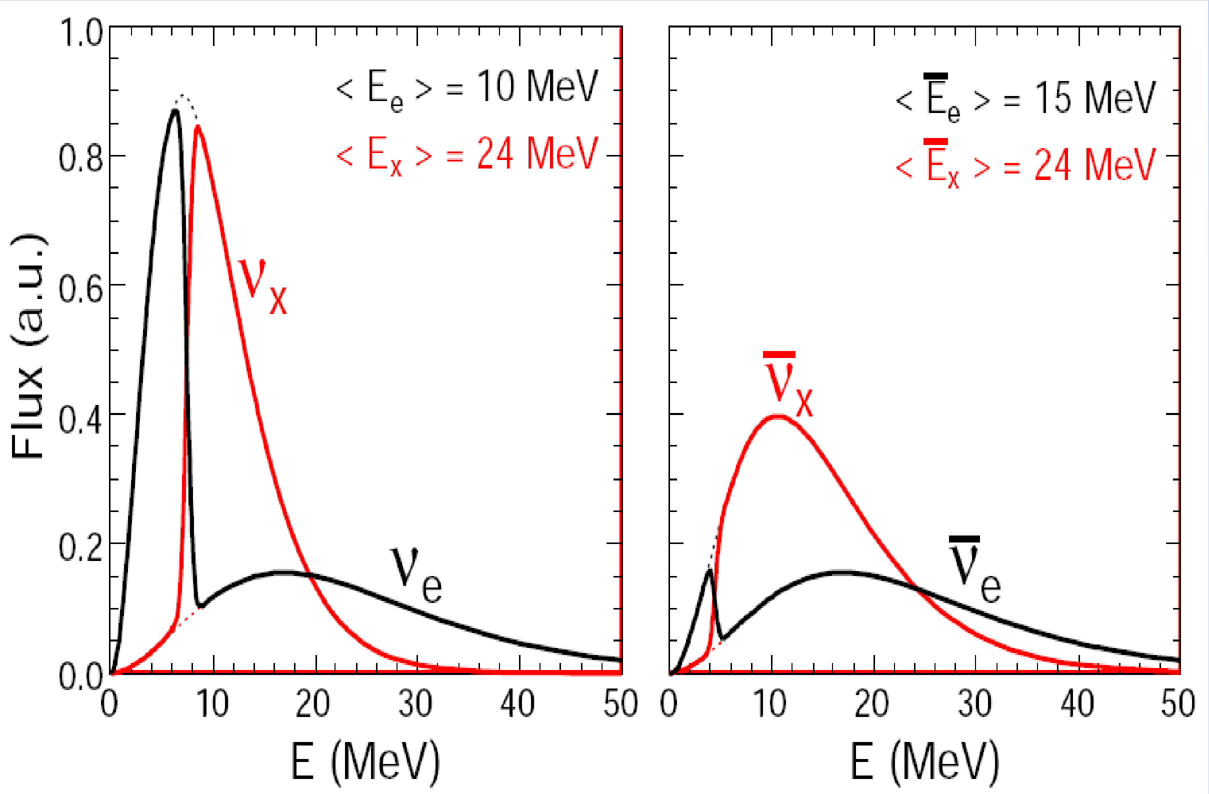
no sasi
equatorial
noise
Power spectrum
frequency, Hz
0
20
40
60
80
100
0
50
100
150
200
250
300

Caveat

MSW oscillations not included.

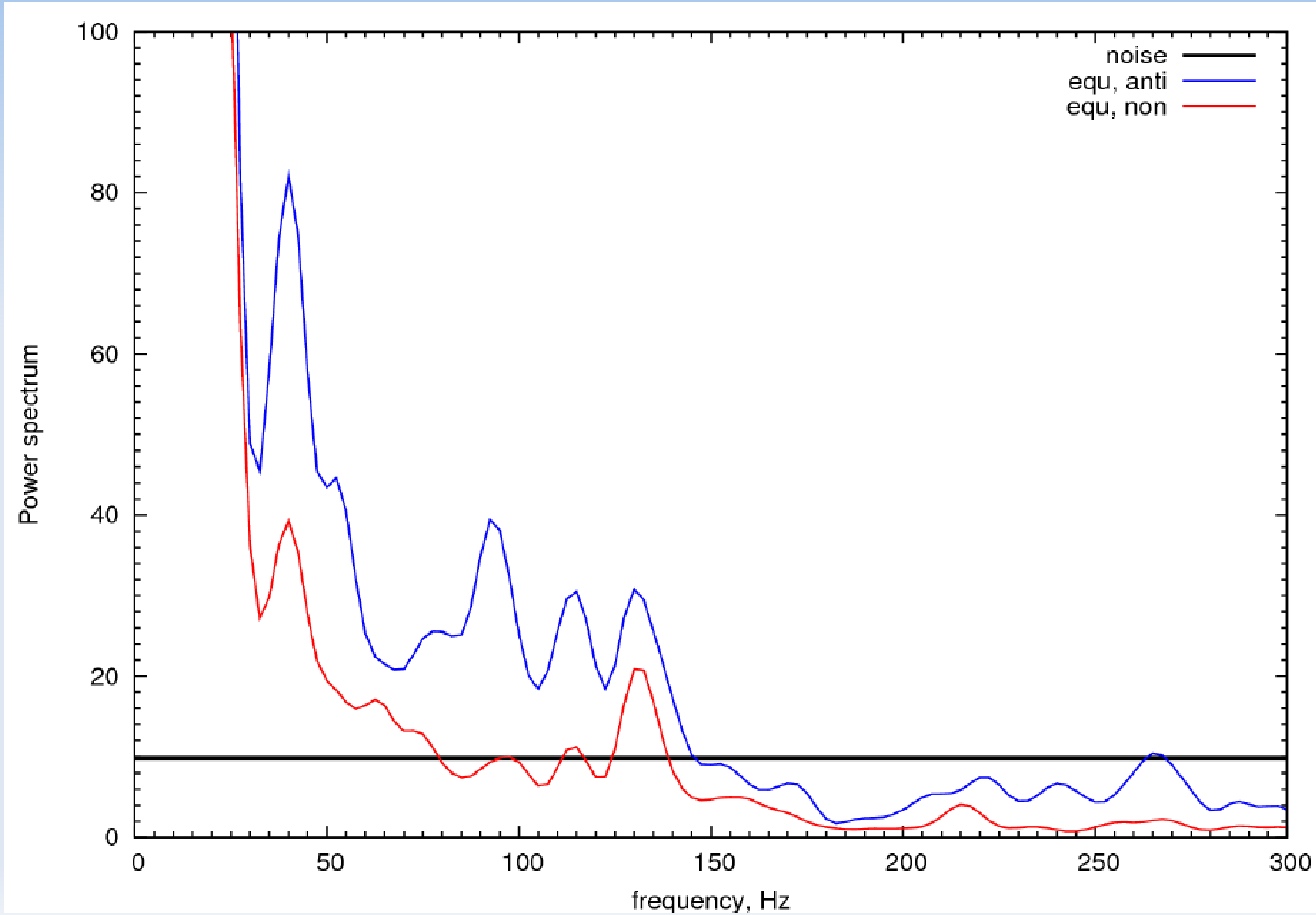
Collective flavor oscillations not included.

May swap the energy spectra of anti-ν_e and anti-ν_x flavors.

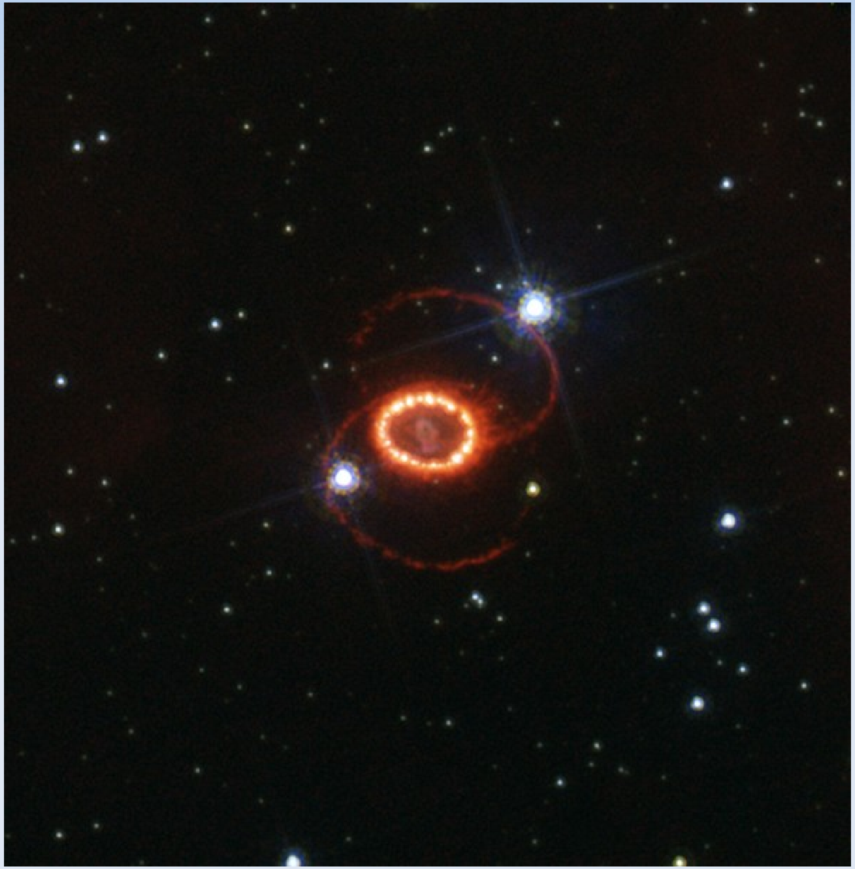


[Fogli et al.]

Flavor comparison



Conclusion



SASI effects can be observed $\longrightarrow$ better understanding of SN.

IceCube usefull despite lacking energy information.

Flavor caution.

Need Milky Way SN.


Thank you!

References

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A. Marek & H.-Th. Janka, ”Delayed neutrino-driven supernova explosions aided by the standing accretion-shock instability”, [arXiv: 0708.3372v2.]

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F. Halzen & G. G. Raffelt “Reconstructing the super-nova bounce time with neutrinos in IceCube”, Phys. Rev. D 80, 087301 (2009) [arXiv:0908.2317v1 [astro-ph.HE]].

G. L. Fogli et al., ”Low-energy spectral features of supernova (anti)neutrinos in inverted hierarchy”, [arXiv: 0808.0807v1]

IceCube webpages: http://icecube.wisc.edu/ and http://gallery.icecube.wisc.edu/external/icecube-concept/