Exploring the neutrino emission of 3D core-collapse supernovae models

SNEWS Meeting @ Neutrino 2020

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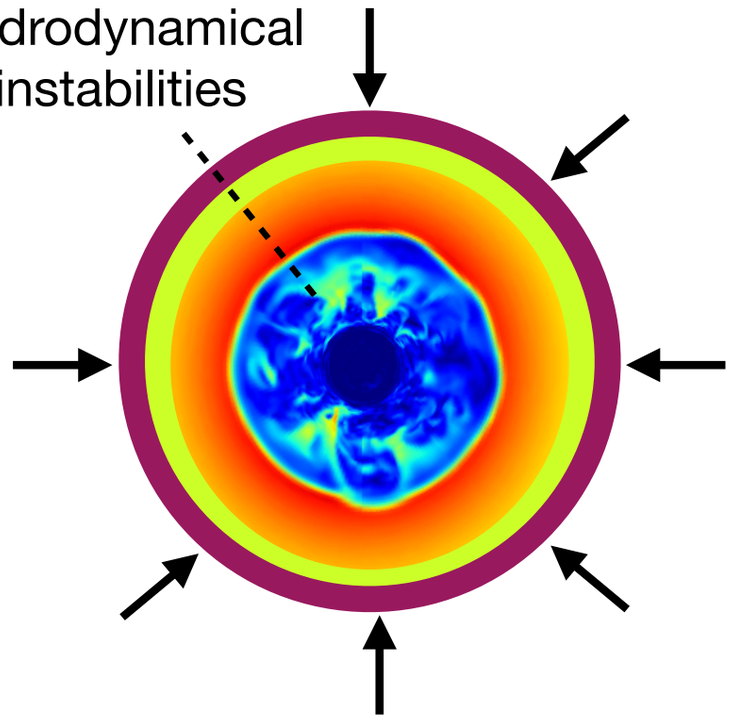
June 19, 2020

Neutrinos from supernovae

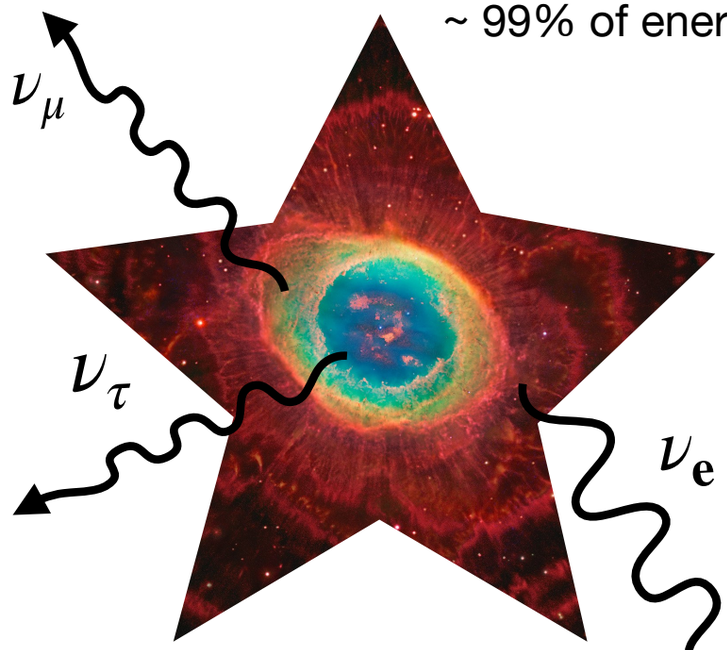
Hydrodynamical instabilities



Stellar core-collapse

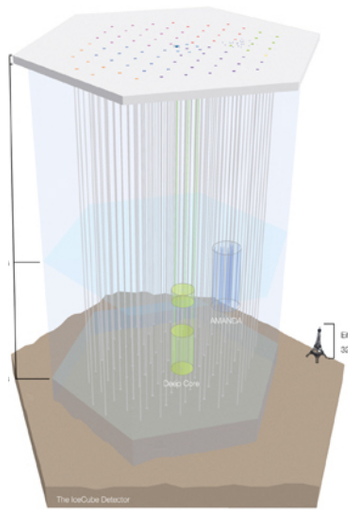
Supernova explosion!

~ 99% of energy released as neutrinos!

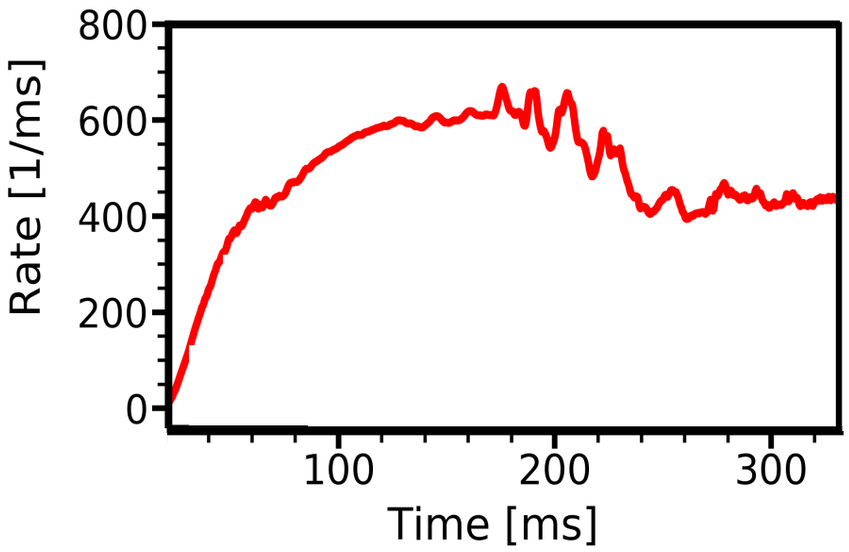


Neutrinos propagate

Neutrinos Detected



IceCube Observatory



Neutrino signal probes SN dynamics!

Neutrinos as probes

1. Hydrodynamical instabilities
2. Progenitor rotation
3. Black-hole formation

Based on:

Walk, Tamborra, Janka, Summa. *Phys. Rev. D. 98 (2018)*

Walk, Tamborra, Janka, Summa. *Phys. Rev. D. 100 (2019)*

Walk, Tamborra, Janka, Summa, Kresse. *Phys. Rev. D. 101 (2020)*

Neutrinos as probes : Hydrodynamical instabilities

What hydrodynamical instabilities can form during the core-collapse?

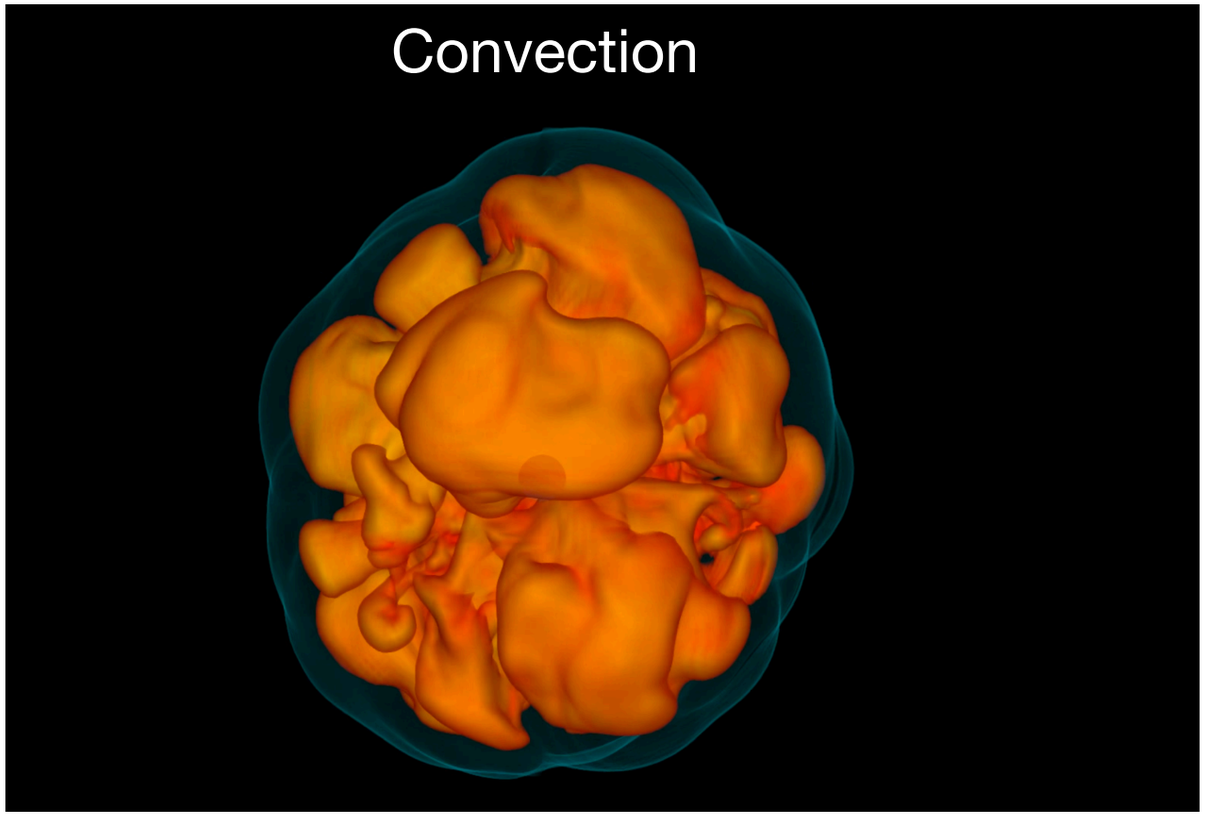
How are the hydrodynamics reflected in the neutrino emission?

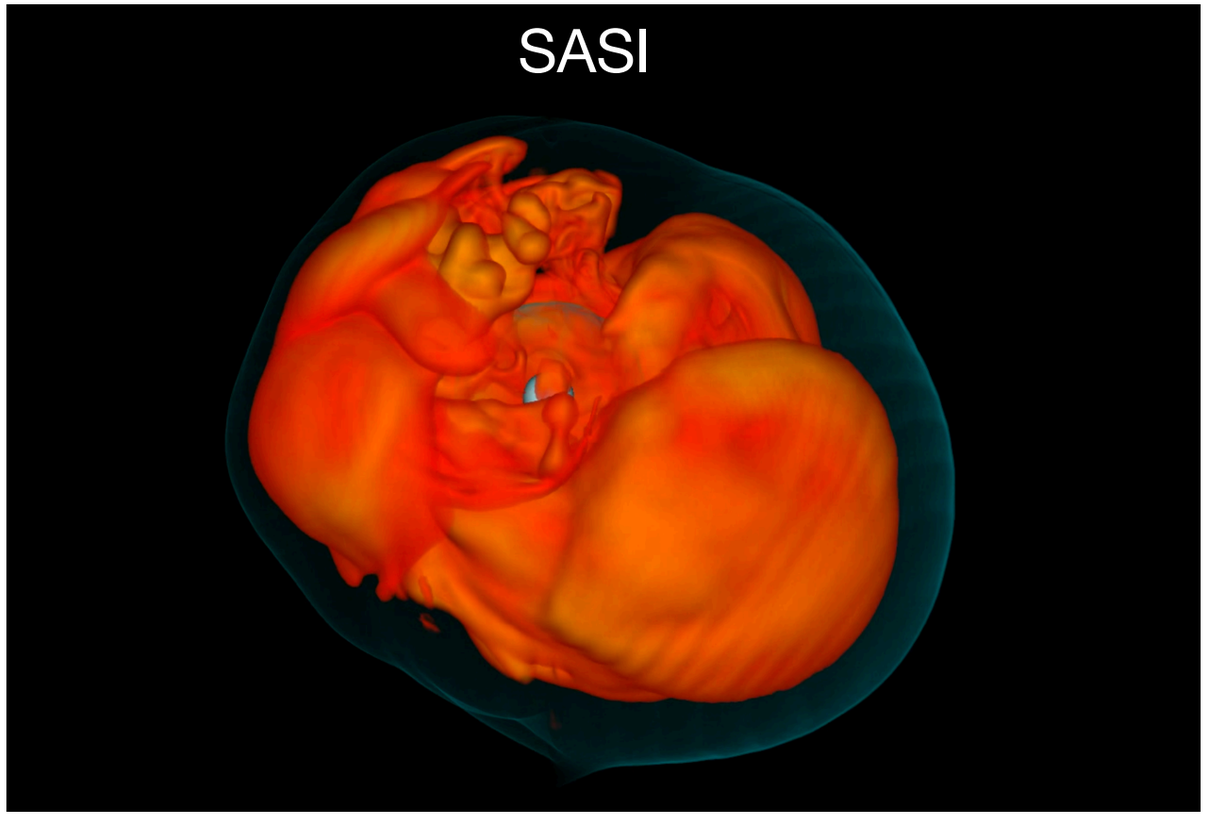
⟶ Based on 3D model of 27 $\mathrm{M}_{\odot}$ progenitor

For details please see: Tamborra, Raffelt, Hanke, Janka, Müller, Phys. Rev. D 90 (2014)

Neutrinos as probes - Hydrodynamics

What hydrodynamical instabilities can form during the core-collapse?



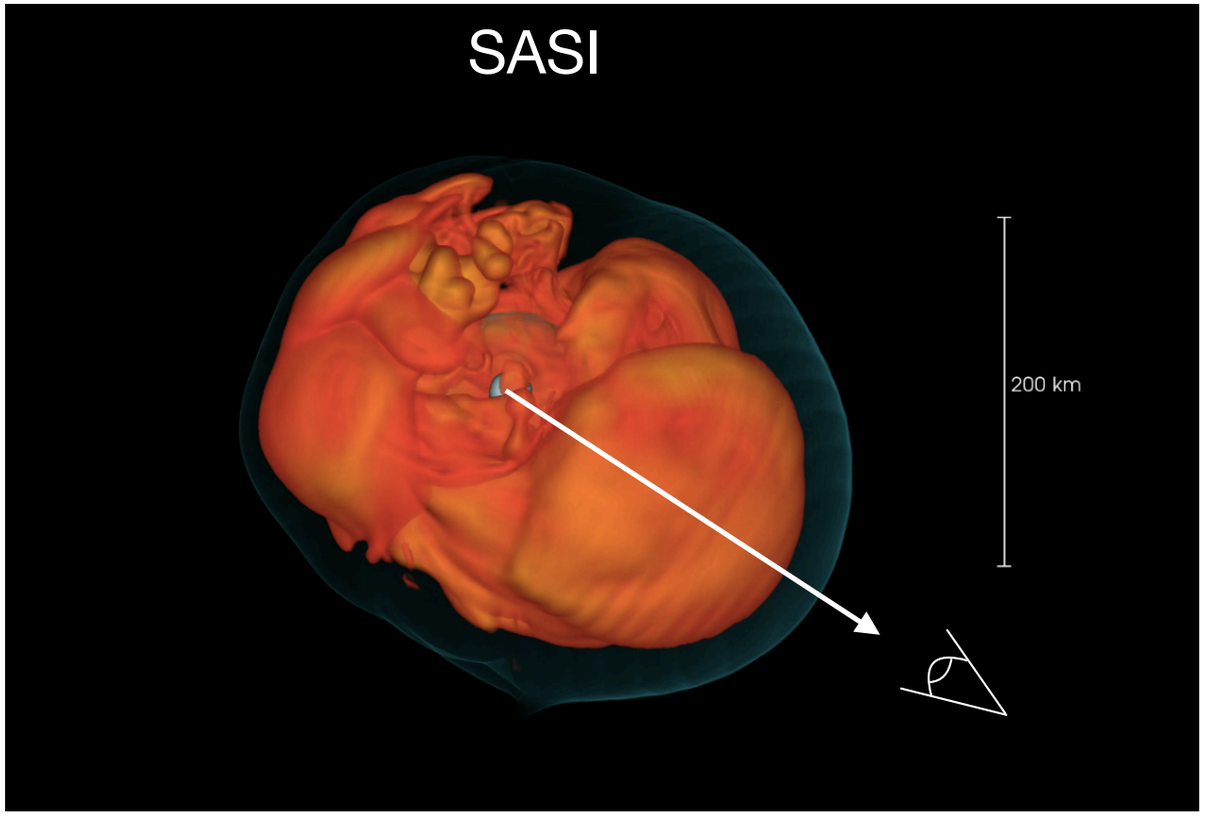


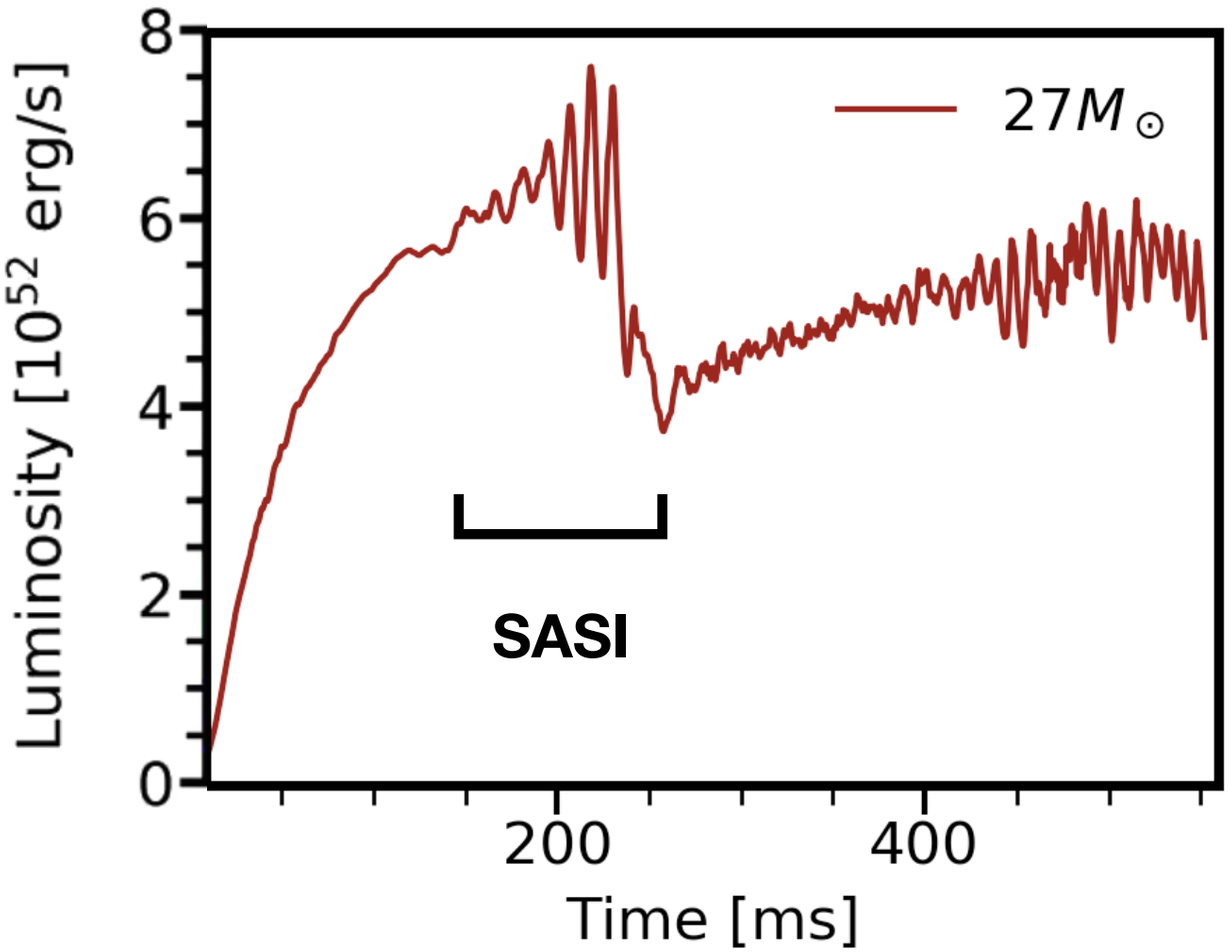
SASI ⟶ dipolar oscillating deformation of the shockwave along a plane

Convection ⟶ higher order/frequency deformations of the shockwave

Neutrinos as probes - Hydrodynamics (SASI)

How are the hydrodynamics reflected in the neutrino emission?





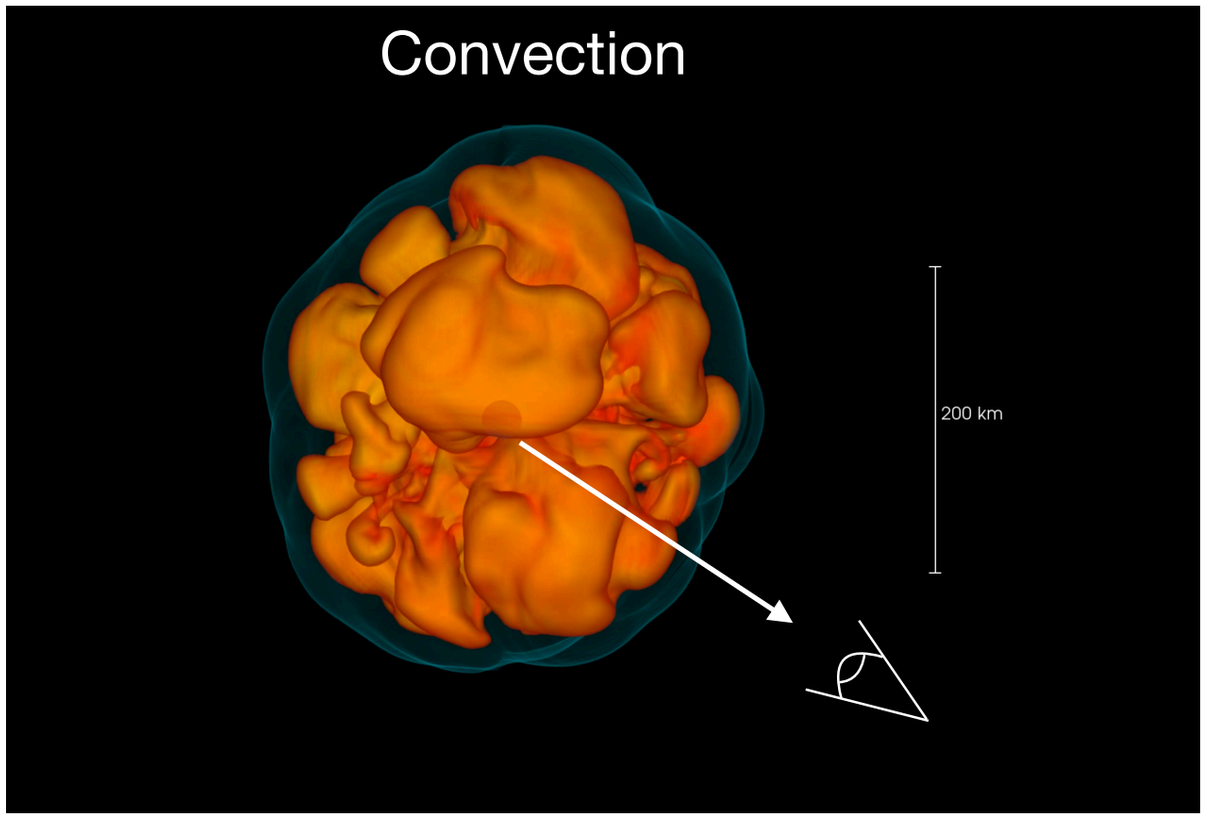
- SASI presents as sinusoidal modulations of the neutrino luminosity

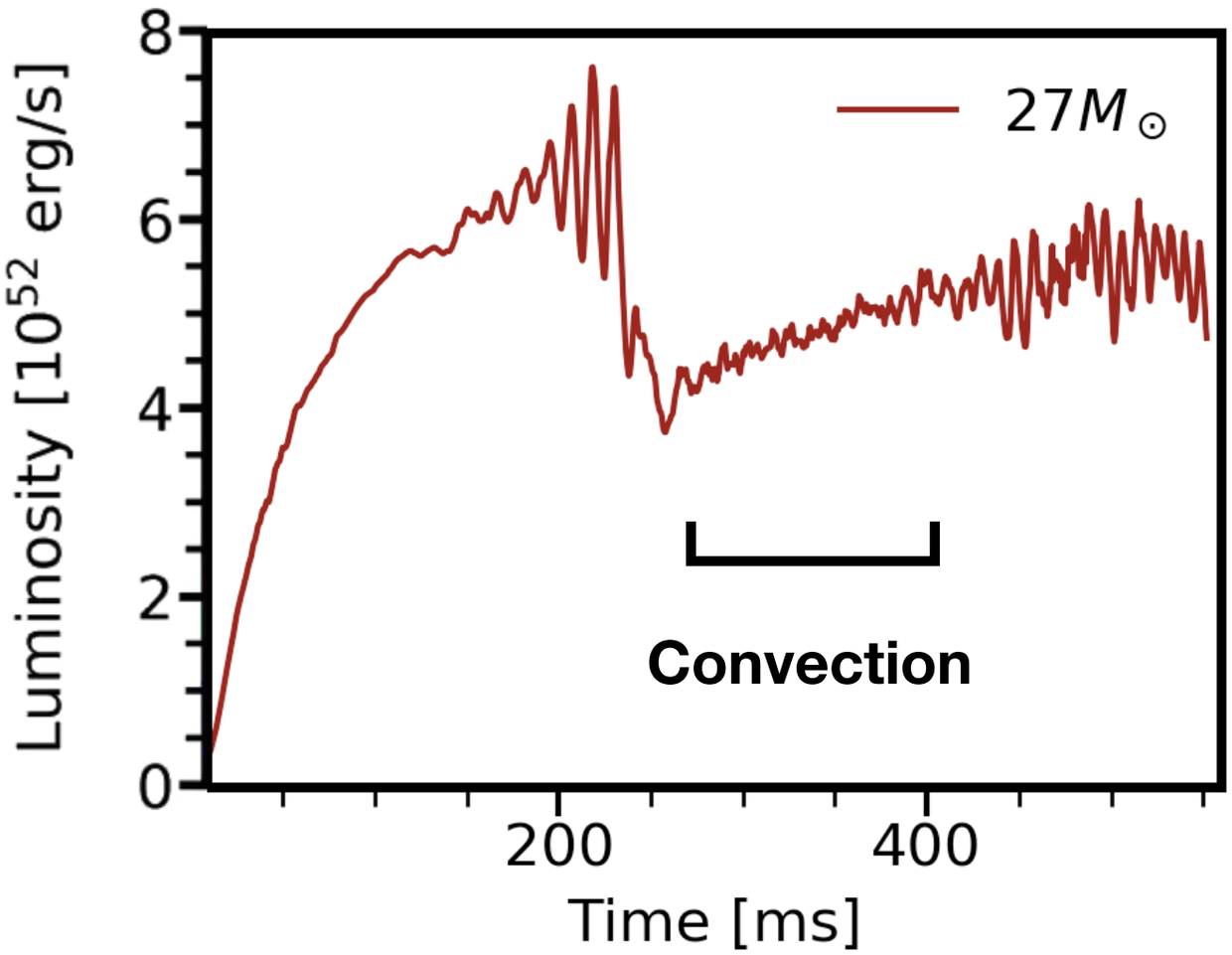
$$f_{\mathrm{SASI}} \propto R_{\mathrm{s}}^{-3/4}$$

See also: *Tamborra, Raffelt, Hanke, Janka, Müller, Phys. Rev. D 90 (2014)*

Neutrinos as probes - Hydrodynamics (Convection)

How are the hydrodynamics reflected in the neutrino emission?





- Convection presents as small-scale fluctuations of the neutrino luminosity

See also: *Tamborra, Raffelt, Hanke, Janka, Müller, Phys. Rev. D 90 (2014)*

Neutrinos as probes :
Progenitor rotation

What are the effects of rotation on hydrodynamical instabilities?

Can we constrain rotational velocity through neutrinos?

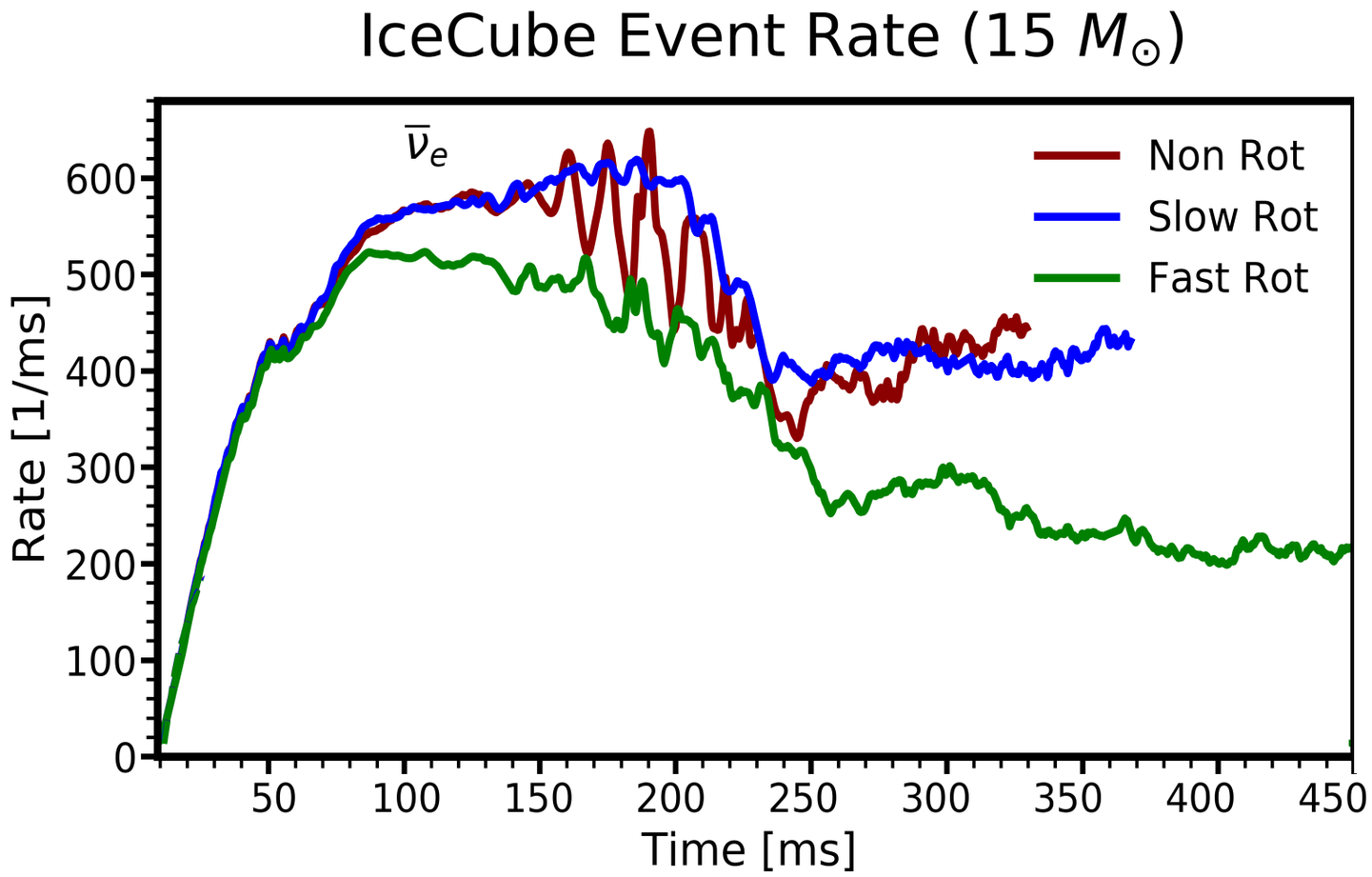
Based on three self-consistent $15\,\mathrm{M}_{\odot}$ models:

1. Non-rotating model
2. Slow rotating (spin period of 6000 s)
3. Fast rotating model (spin period of 20 s)

For details please see: Summa, Janka, Melson, Marek, *Astrophys. J. 852, 28 (2018)*

Neutrinos as probes - Progenitor rotation

What are the effects of rotation on hydrodynamical instabilities?



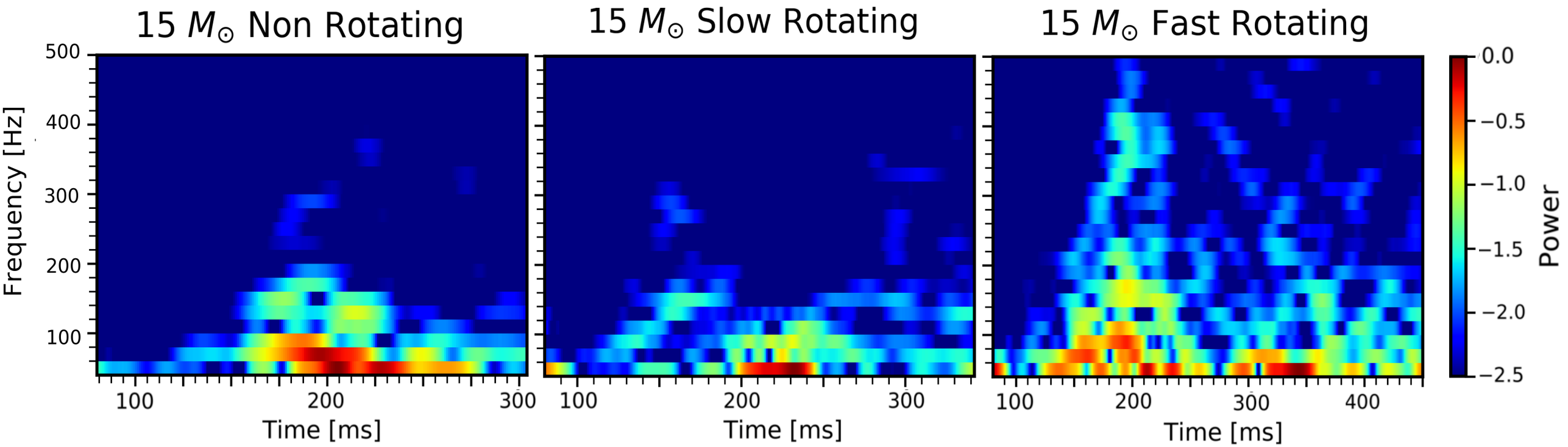
- Sinusoidal SASI modulations present in non-rotating model

- Amplitude decreased in the slow rotating model

- Small-scale fluctuations present in fast rotating model

Neutrinos as probes - Progenitor rotation

Can we constrain rotational velocity through detectable neutrinos?



- Rotation weakens the SASI peak

- Less dominant SASI region, wider spread in high frequencies

- i.e. Small-scale fluctuations are resolved by spectrograms

- Suggests again an interplay between SASI and convection, brought on by rotation

Neutrinos as probes :
Black-hole formation

Can we see black-hole forming stellar collapses through neutrinos?

Are there unique signatures in the neutrino emission?

⟶ Based on two 3D progenitor models of 40 and 75 $\mathrm{M}_{\odot}$

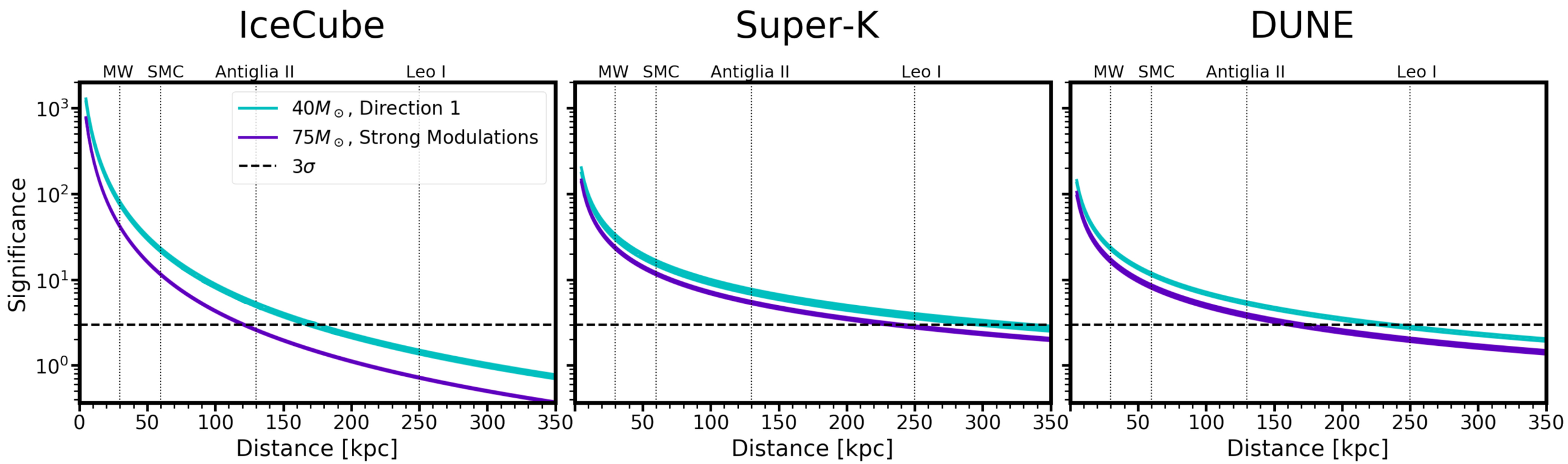
For details please see: Walk, Tamborra, Janka, Summa, Kresse. *Phys. Rev. D. 101 (2020)*

Neutrinos as probes - Black-hole formation

Can we see black-hole-forming stellar collapses through neutrinos?

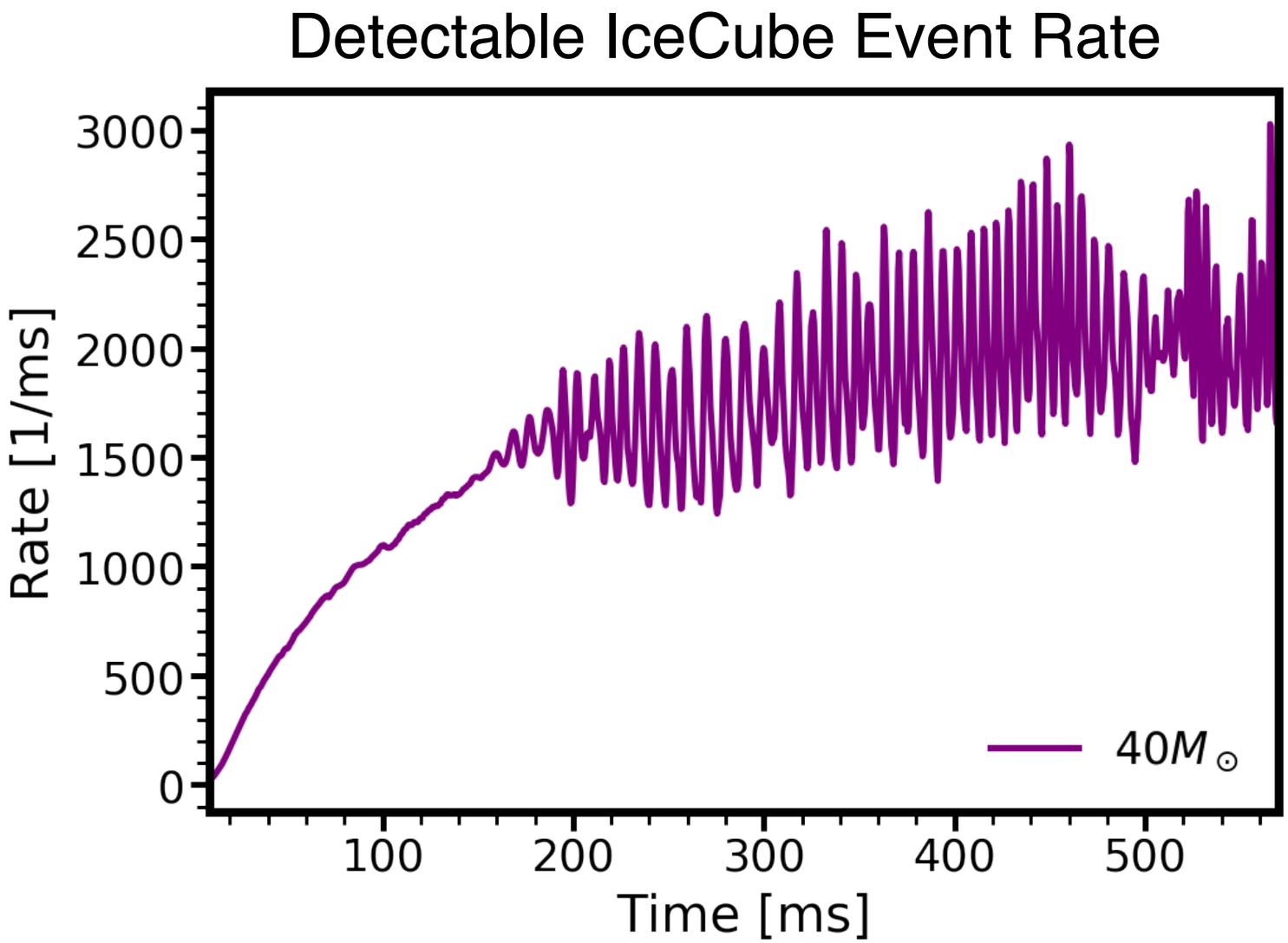
- Neutrinos are amongst the only probes of BH-forming collapses

- High event statistics makes BH-forming collapses detectable up to great distances



Neutrinos as probes - Black-hole formation

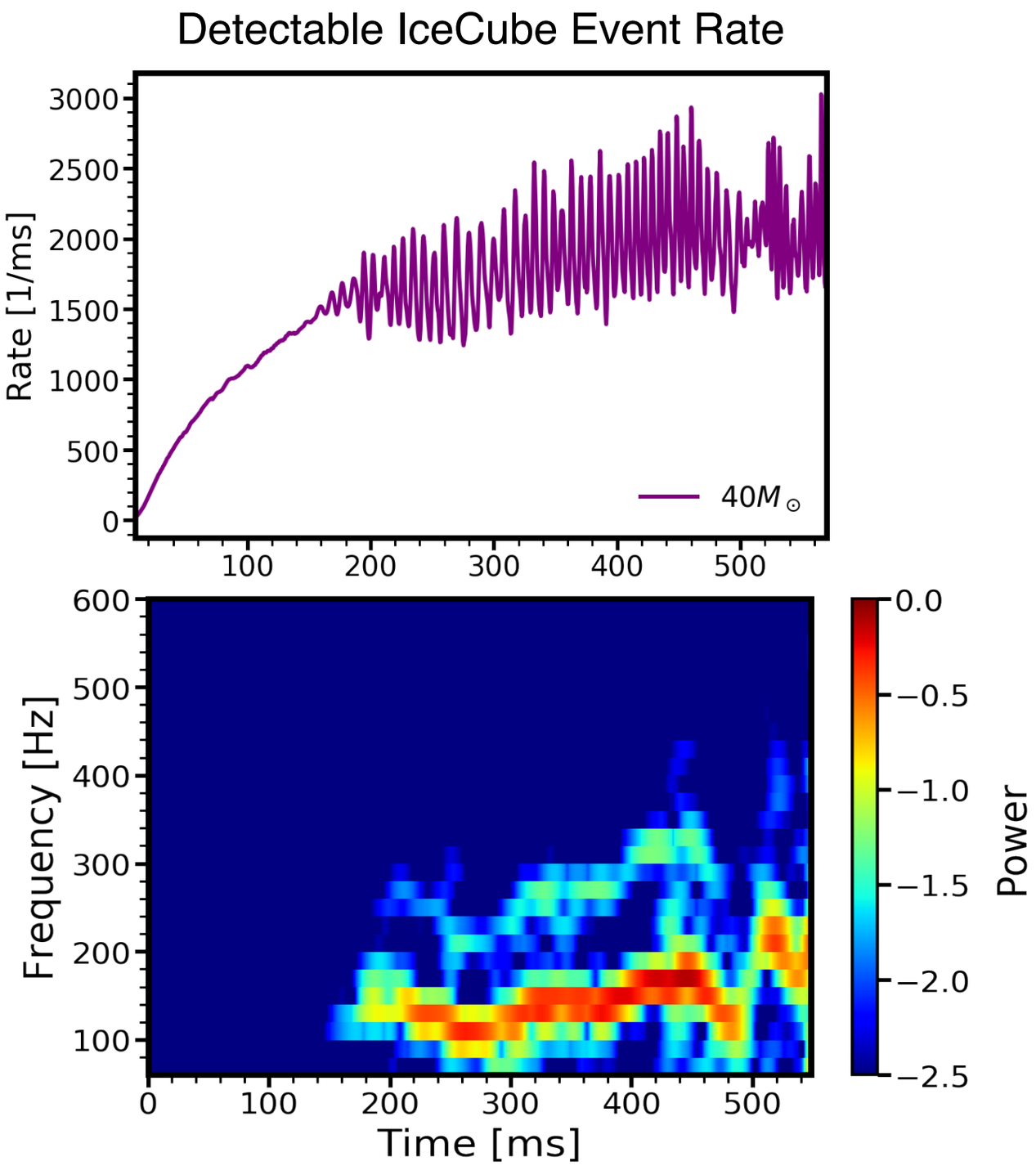
Are there unique signatures in the neutrino emission?



- Two long, strong SASI episodes detectable for the $40M_\odot$ BH-forming progenitor

Neutrinos as probes - Black-hole formation

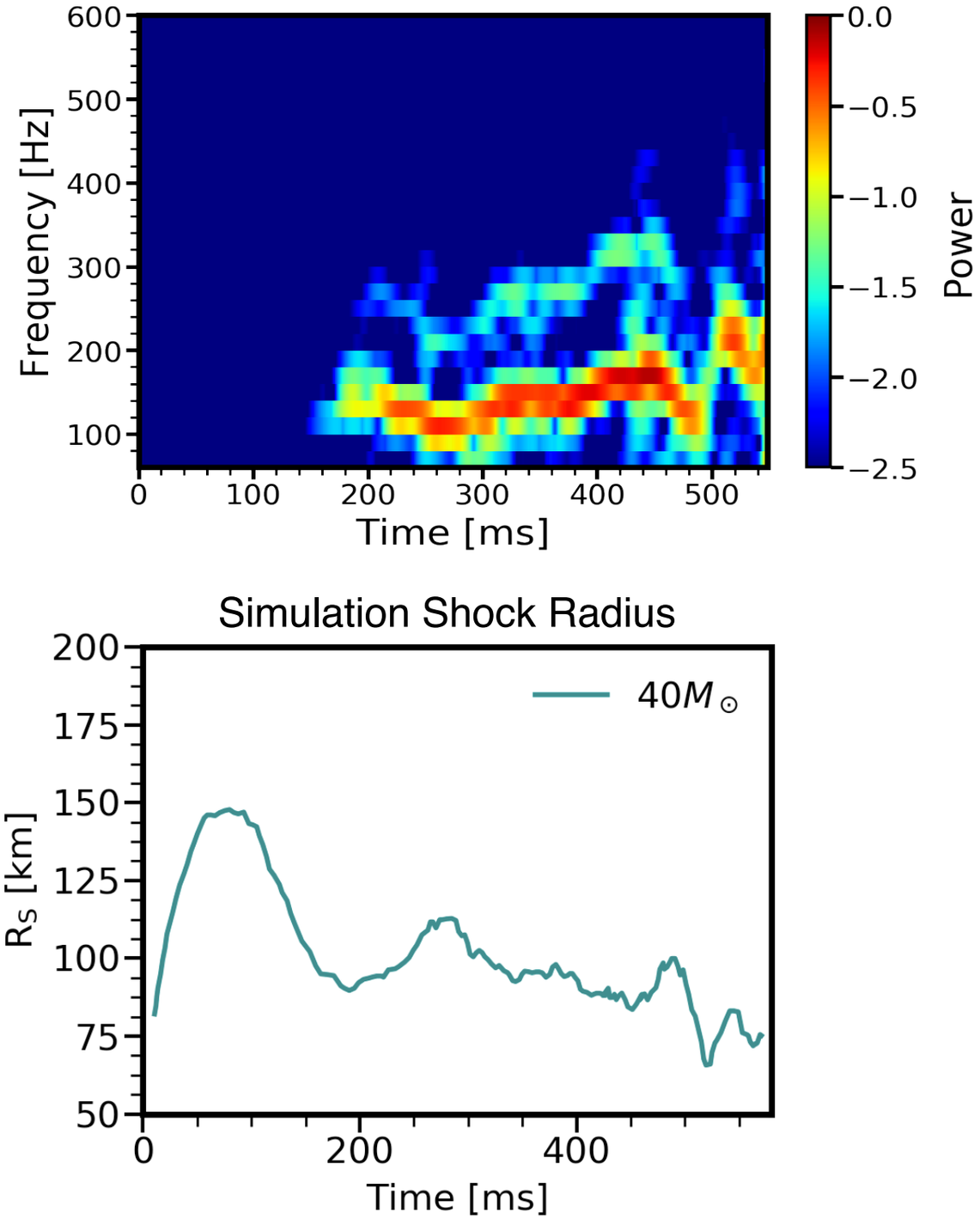
Are there unique signatures in the neutrino emission?



- Model shows two SASI episodes
- SASI frequency clearly traceable
- i.e. evolves (oscillates) with time
- Second SASI episode has a higher frequency than the first

Neutrinos as probes - Black-hole formation

Are there unique signatures in the neutrino emission?



$$f_{\mathrm{SASI}} \propto R_{\mathrm{s}}^{-3/4}$$

- SASI frequency and shock radius inversely proportional
- Tracks the contraction and expansion of the shock-front
- Clear, detectable imprints of the explosion physics through neutrinos!

Conclusions

- Neutrino signal reflects hydrodynamics of the core-collapse

- Rotation destroys large-scale global deformations of the shockwave

- Induces small-scale fluctuations instead

- Signatures of rotation may be visible in the detectable signal

- Neutrinos are key probes of BH formation

- Neutrino emission prior to BH formation reflects interesting physics

- Due to their large mass, BH-forming SNe have excellent detection prospects

Neutrinos are essential for exploring core-collapse supernovae!

Thank you!