Neutrino Gyroscopes!

Using neutrinos to probe rotation in core-collapse supernovae

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Outline

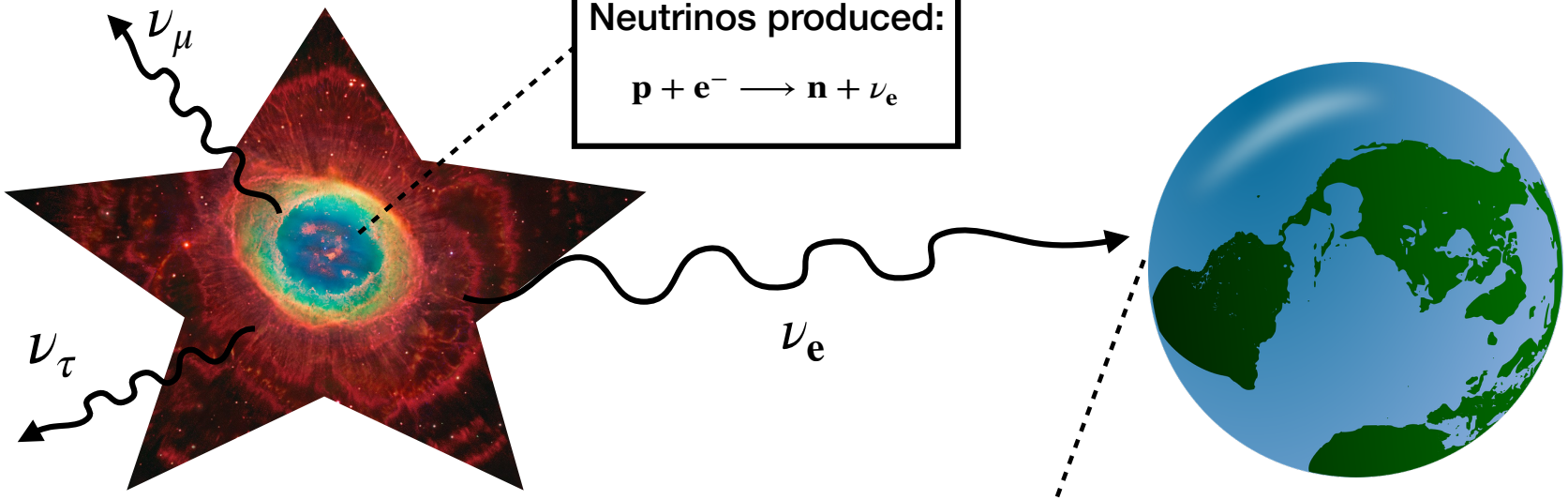
1. Neutrinos from Supernovae
2. The Supernova Explosion Mechanism
3. Rotating Supernovae in 3D
4. Detectable Neutrino Features
5. Conclusions

Based on:

Identifying rotation in SASI-dominated core-collapse supernovae with a neutrino gyroscope

Walk, Tamborra, Janka, and Summa
Phys. Rev. D 98, 123001 Published 5 December 2018

Neutrinos from Supernovae

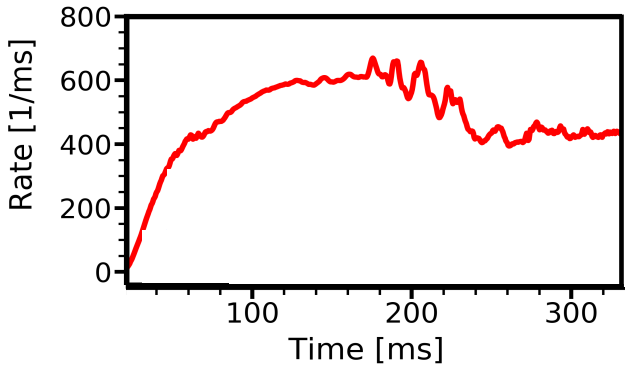


Neutrinos produced:

$$p + e^- \longrightarrow n + \nu_e$$

Supernova explosion!

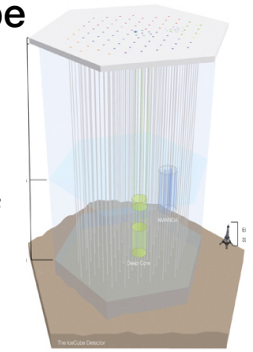
~ 99% of energy released as neutrinos!



Neutrino signal probes SN dynamics!

Neutrinos Detected: IceCube

- Inverse beta decay: $(\overline{\nu}_e + p \rightarrow n + e^+)$
- detects Cherenkov radiation of positron
- largest event statistics (~10^6 events)



Neutrinos from Supernovae

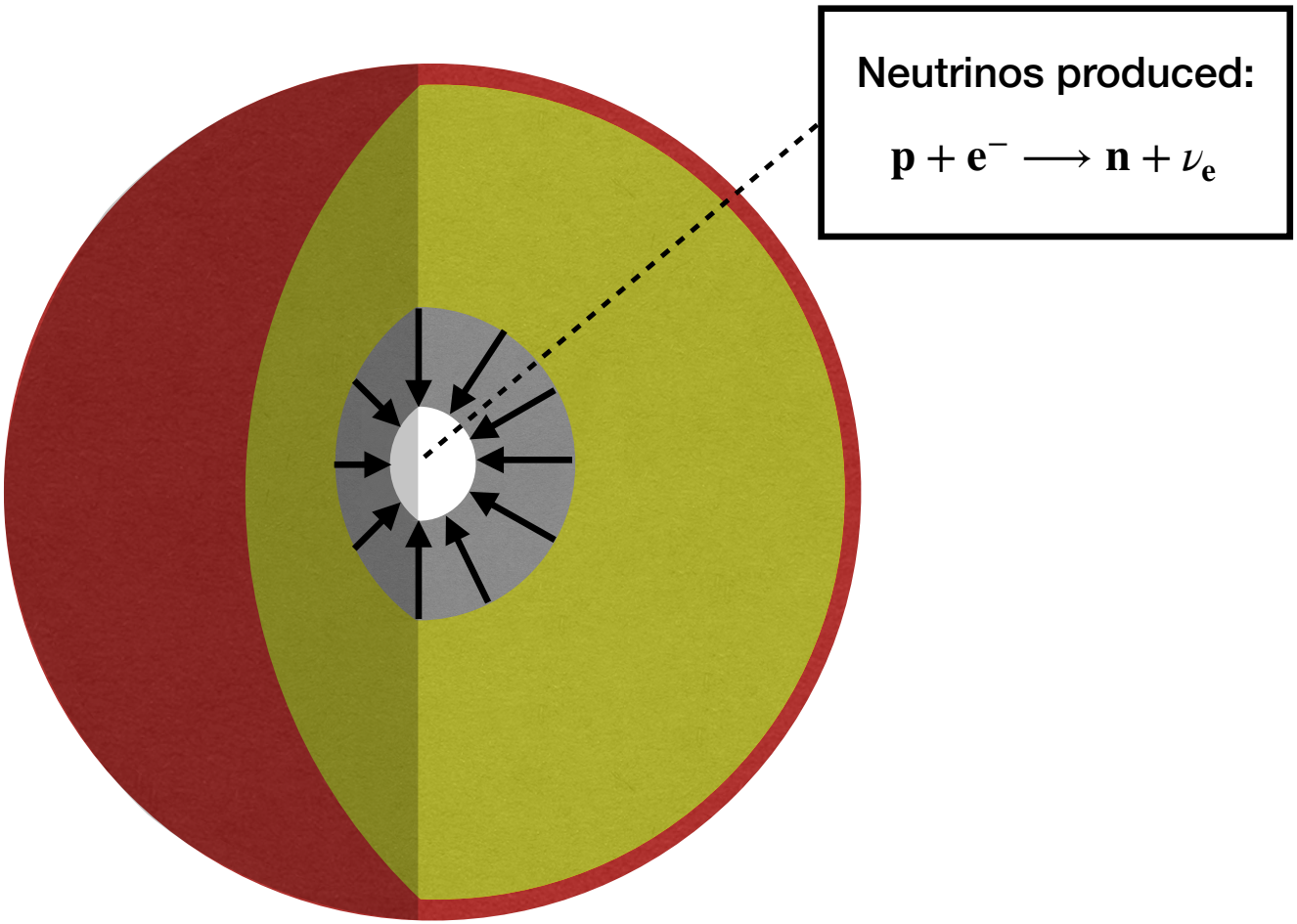
Neutrinos are essential because:

- $\longrightarrow$ abundantly produced deep inside the core
- $\longrightarrow$ essential role in supernova explosion mechanism
- $\longrightarrow$ affect nucleosynthesis
- $\longrightarrow$ probe hydrodynamics of supernova
- $\longrightarrow$ **probe progenitor rotation**

Aim of this work:

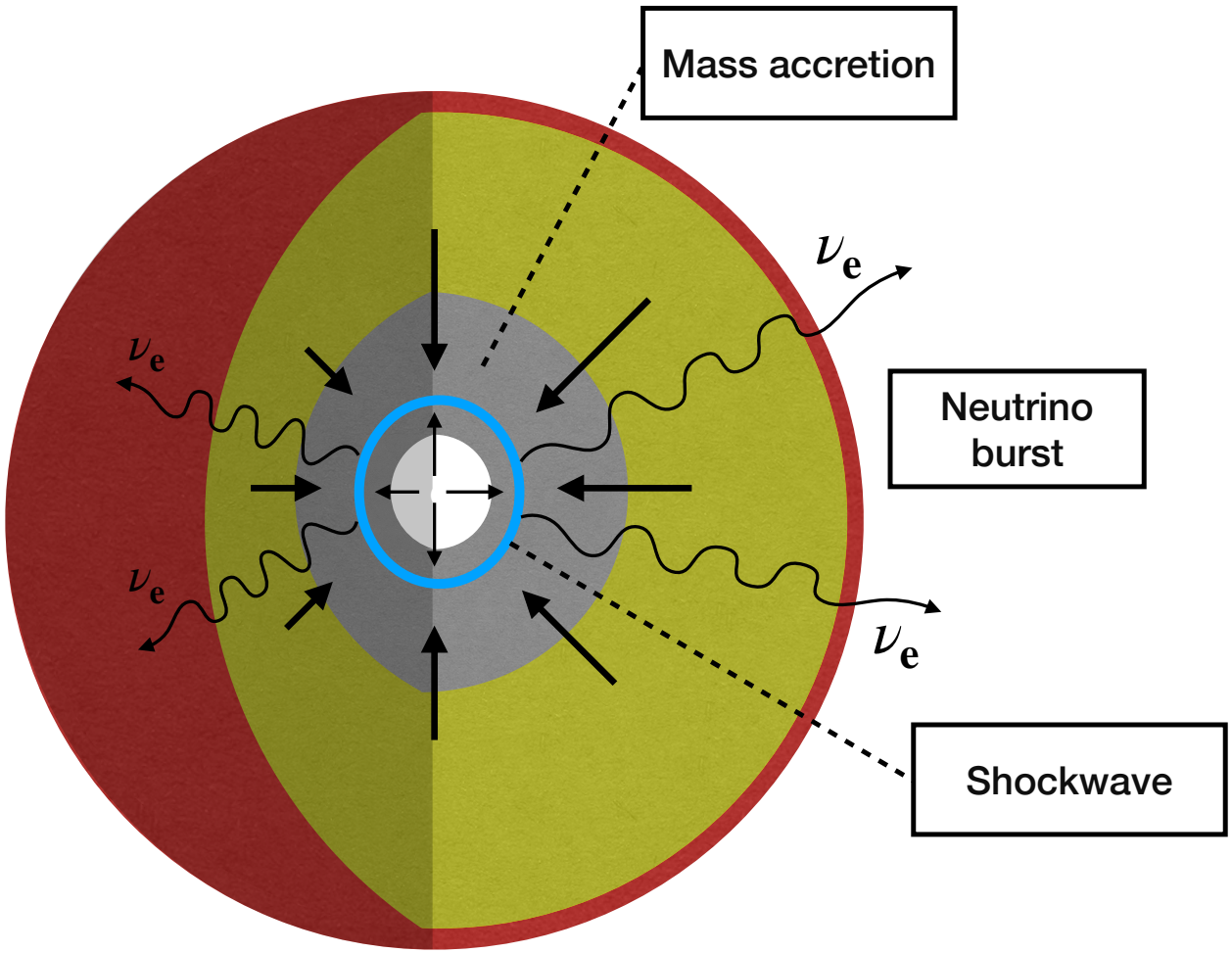
Indentifying the angular momentum of core-collapse supernovae through rotational imprints in the detectable neutrino signal.

The Supernova Explosion Mechanism



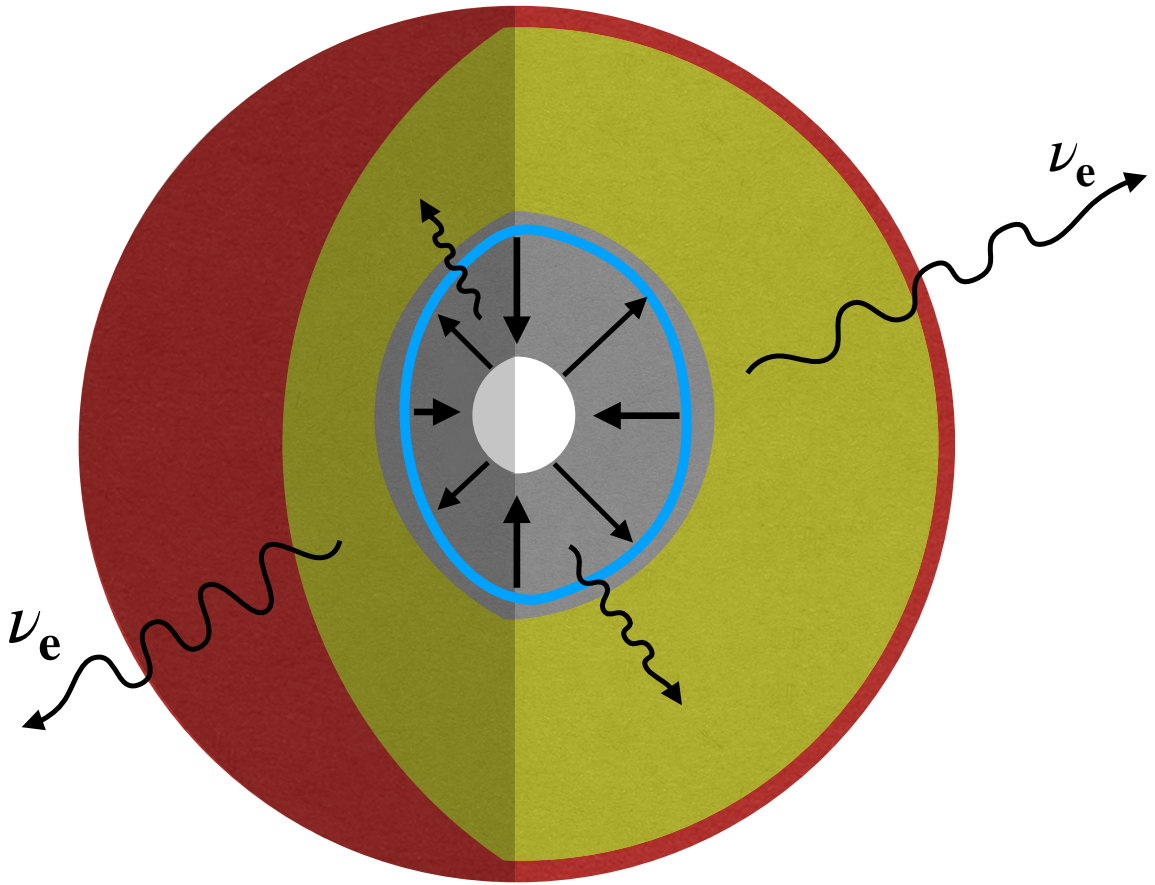
Onset of core collapse

The Supernova Explosion Mechanism



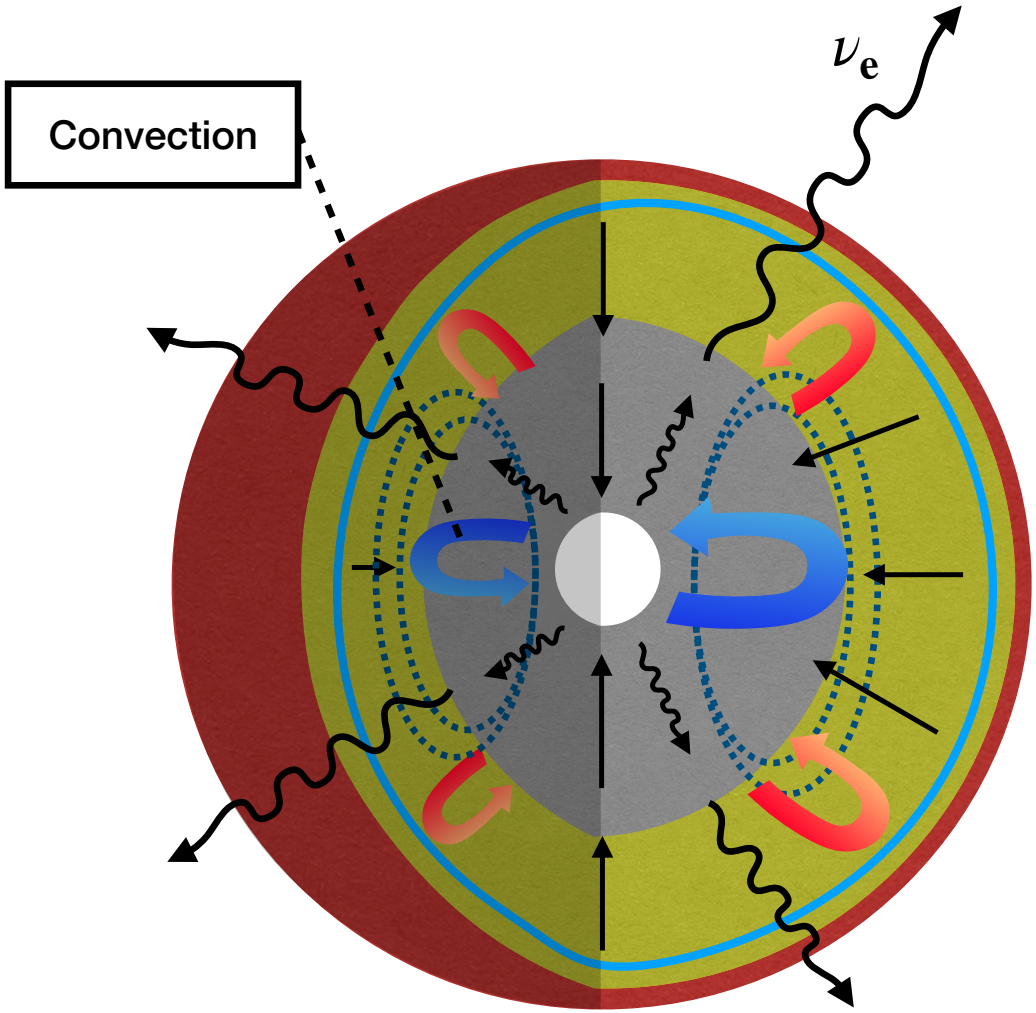
Core bounce

The Supernova Explosion Mechanism



Shockwave stalls

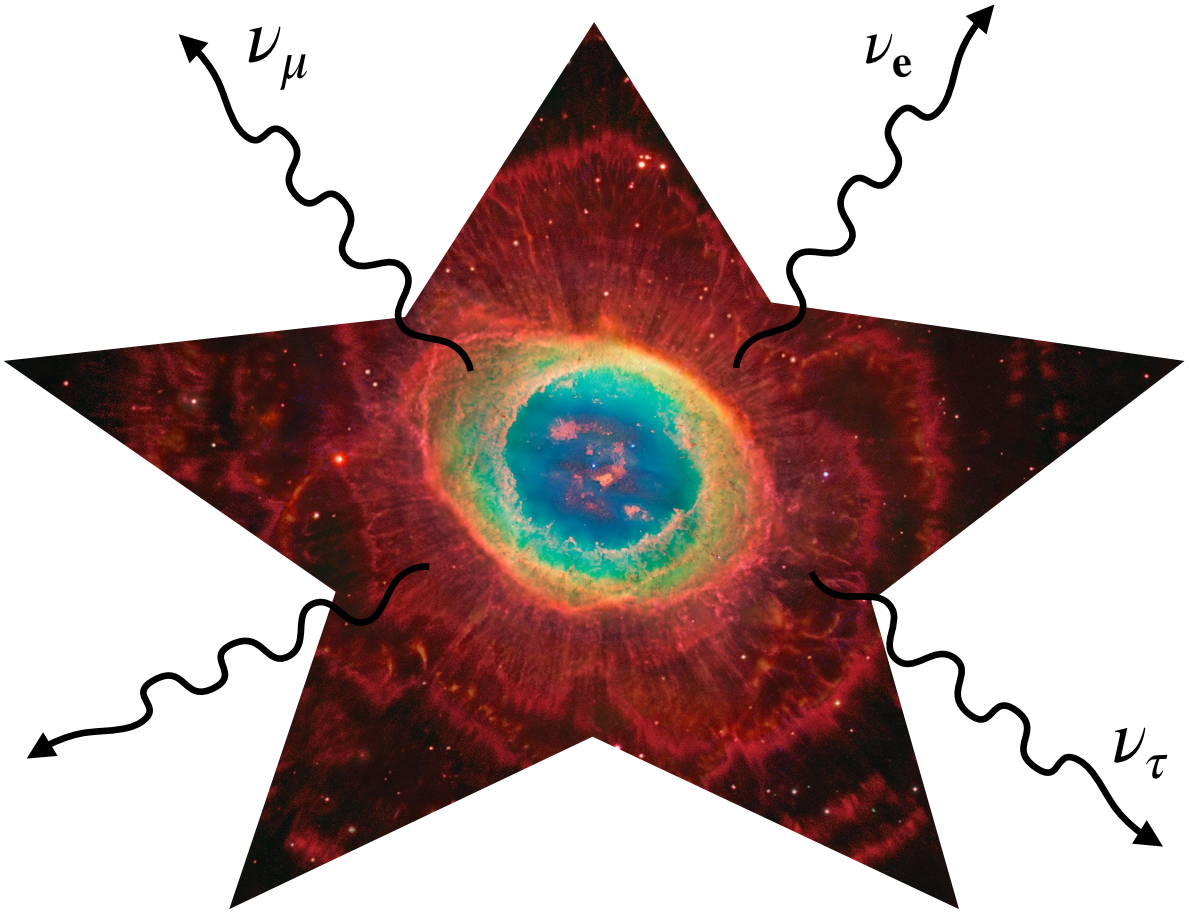
The Supernova Explosion Mechanism



Shockwave revival

→ shockwave bounces as it acquires energy

The Supernova Explosion Mechanism



Supernova explosion!

~ 99% of energy released as neutrinos!

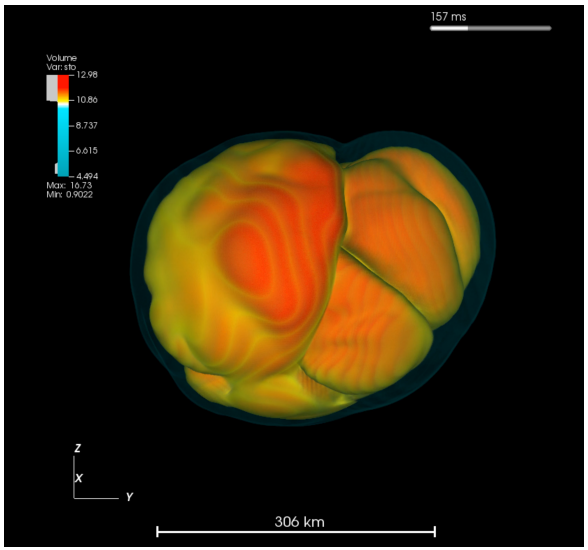
3D Simulations

Study supernovae at the hands of:

$\longrightarrow$ 3D hydrodynamical simulations

$\longrightarrow$ three self-consistent 15 $M_\odot$ progenitors :

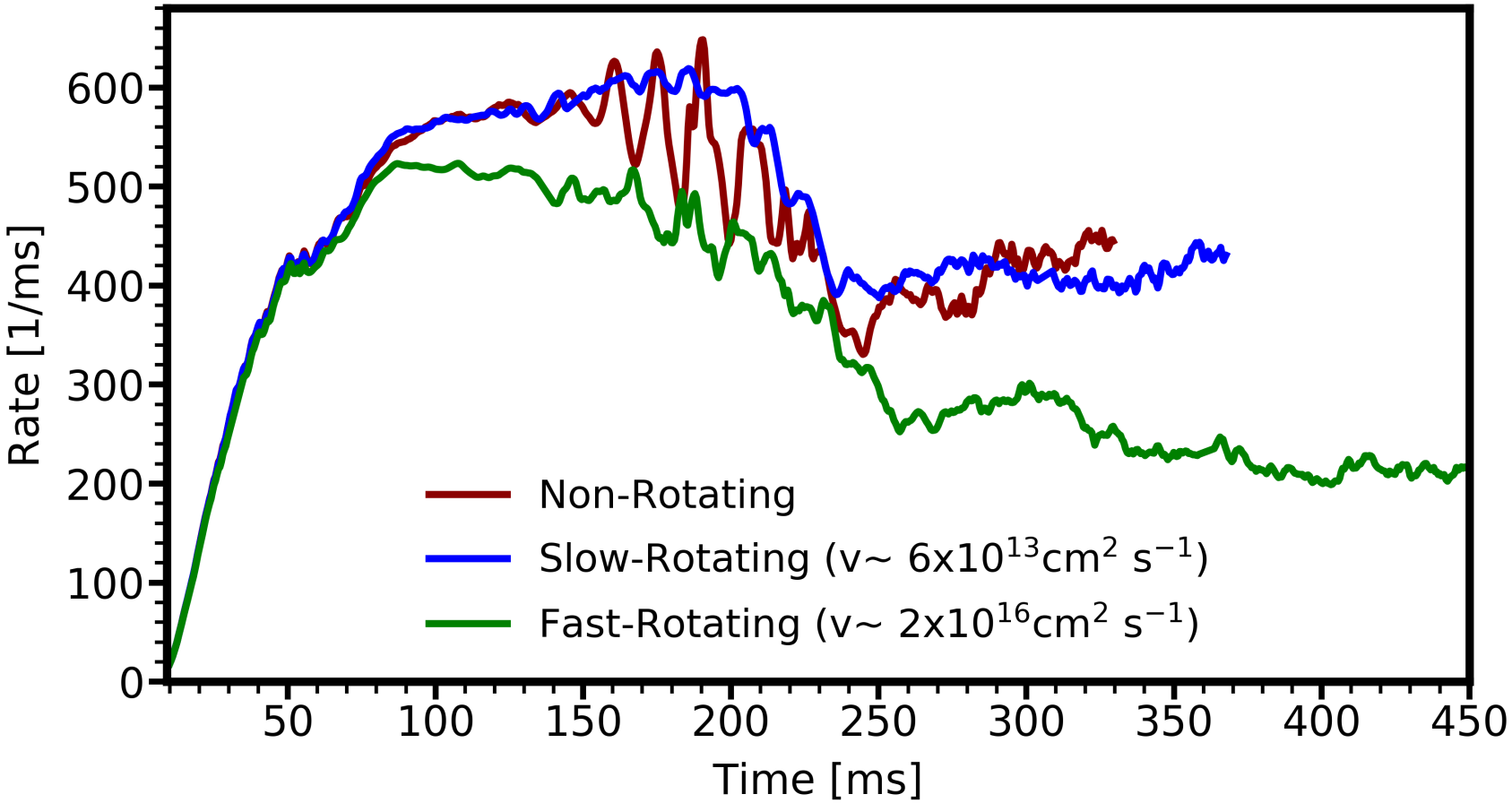
1. Non-rotating
2. Slow-rotating $\left(\text{spin period of } 6000 \text{ s}\right)$
3. Fast-rotating $\left(\text{spin period of } 20 \text{ s}\right)$



Animation by:

Alexander Summa, Hans-Thomas Janka,
Tobias Melson, Andreas Marek

Detectable Features - Event Rate in Strong SASI Direction (15 $M_\odot$, 10 kpc)

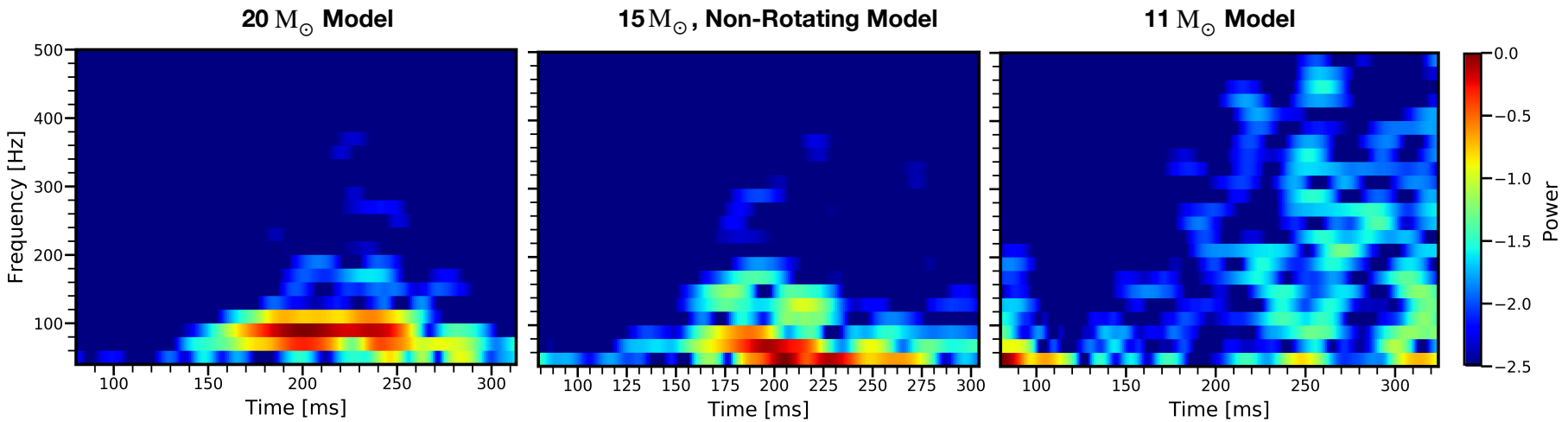


$\longrightarrow$ SASI modulation dominant in non-rotating model

$\longrightarrow$ Modulations weakened by rotation

$\longrightarrow$ Fast-rotating model exhibits small-scale fluctuations

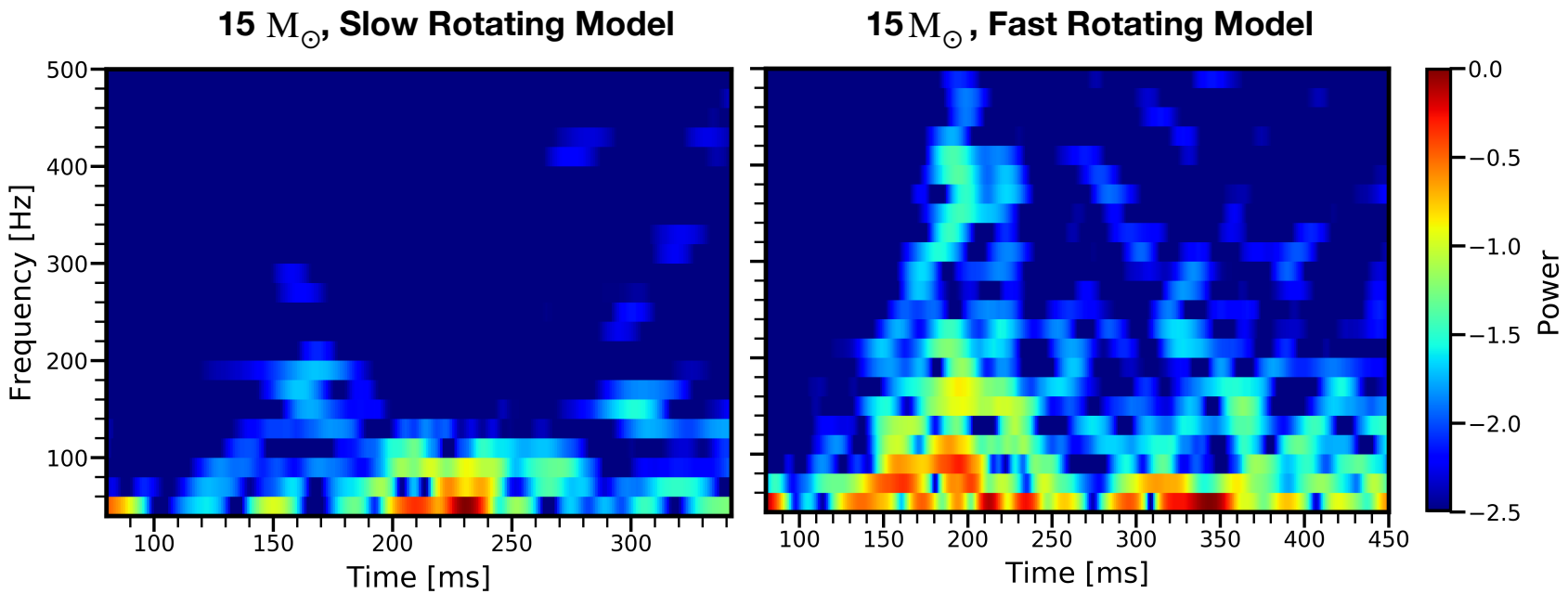
Detectable Features -Spectrograms Non-Rotating Models



⟶ Strong SASI represented as well-defined peak in correspondence of the SASI frequency

⟶ Convection represented by peaks uniformly distributed at various frequencies

Detectable Features -Spectrograms Rotating Models



⟶ Rotation weakens the SASI peak

⟶ Creates broader stacks with a hot, low frequency region and a spread in higher frequencies

⟶ Suggests an interplay between SASI and convection brought on by rotation

Conclusions

We propose a strategy for detecting progenitor rotation using neutrinos as gyroscopes!

$\longrightarrow$ Rotation destroys signatures of large-scale global deformations of the shockwave, and induces small scale fluctuations in the neutrino signal.

$\longrightarrow$ Rotation may be constrained by relative order of SASI frequency to other frequency peaks in the spectrogram of the event rates, given the SN occurs at a favorable observer direction.


End