Introduction

- A core-collapse supernova occurs when an extremely massive star runs out of fuel and collapses in on itself.
- The resulting shock wave expands rapidly before stalling at a radius of about 100-200 km.
- The shock is unstable—called the Standing Accretion Shock Instability (SASI), or the SASI (Fig. 1).

Our goal is to characterize the turbulence caused by the SASI to get a better understanding of core-collapse supernovae.

Background

As the SASI evolves from a linear to a nonlinear phase (Fig. 2), it produces turbulence.

Turbulence could power the supernova explosion!

Characterizing turbulence

Energy cascades: vortices move towards smaller length scales (direct cascades) or larger length scales (inverse cascades, see Fig. 3).

Cascades identified by scaling of power spectra (Fig. 4).

Results

Two-Dimensional Turbulence

Fig 7. Normalized power spectra of various resolutions compared to $k^{-5/3}$ (red, top) and $k^{-3}$ (green, bottom).

At low resolutions, the 2-D power spectrum appears to fit best with $E(k) = k^{-3}$ (inverse cascade); however, at higher resolutions, the 2-D power spectrum appears to drop off to a scaling of $-5/3$.

Three-Dimensional Turbulence

Fig 8. Normalized power spectra of various resolutions compared to $k^{-5/3}$ (red, top) and $k^{-3}$ (green, bottom).

The 3-D power spectrum appears to fit best with $E(k) = k^{-3}$.

Goals

In order to investigate turbulence, we aim to:

- Empirically determine the scaling law for the energy cascade
- Compare and contrast 2- and 3-D turbulence.

Methods

1. Use VH-1 code\(^{1,2}\) to simulate the SASI on 2-D (Fig. 5a) and 3-D (Fig. 5b) grids
2. Determine time that nonlinear SASI begins and angular kinetic energy saturates
3. Record angular kinetic energy, averaged over a range of radii (Fig. 6)
4. Create spherical harmonic power spectra and average over time
5. Analyze slopes of power spectra to determine if a scaling law (Fig. 4) exists

Conclusions

The 2-D SASI produces turbulence whose scaling appears to vary depending on resolution. It is worth noting that a similar “kink” in atmospheric energy spectra has been observed. Further investigation of the effect of resolution is needed to confirm the existence of a “kink” effect.

The 3-D SASI produces turbulence that is consistent at larger length scales with a scaling of $k^{-3}$, suggesting an enstrophy (not an energy) cascade.

The 3-D SASI creates turbulence that does not conserve enstrophy.

Future Work

Time dependence and Resolution

- Confirm scaling laws by checking if the peak of the power spectra moves toward larger or smaller wavenumbers (smaller or larger length scales, respectively)
- Continued investigation of 2-D resolution

Intermittency

- Turbulence scaling laws assume self-similarity
  - i.e. Vortices behave the same on all length scales
- Intermittency = non-self-similarity
  - Probability distribution functions of velocity components are slightly different from Gaussian distributions (Fig. 9) as a result of intermittency

- Problem: separating global SASI from local turbulent motion

Selected References


Acknowledgments

National Science Foundation
Undergraduate Research for Computational Astrophysics
Kraken XT5 – National Institute for Computing Sciences