A hydrodynamic mechanism for hot spot formation in SN1987A

Michael Wadas¹, Heath LeFevre², Aaron Towne¹, Carolyn Kuranz², and Eric JOHNSEN¹
¹Mechanical Engineering, University of Michigan, Ann Arbor, MI.
²Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI.

Introduction

SN1987A is a crucial system for supernova research due to its proximity to Earth in the Large Magellanic Cloud (LMC) and recency. About 20,000 years prior to the supernova blast, the progenitor star emitted a toroidal puff of heavy gas that may have encountered velocity gradients conducive to the formation of an expanding vortex dipole. Such a system is subject to the Crow instability [1].

Figure 1: The LMC where SN1987A resides (left), an image showing the 28 hotspots (top center), a schematic showing the section of a gaseous torus (top right), a schematic showing a cross section of the torus (bottom center), and the formation of a vortex dipole from an analogous fluid experiment (bottom right).

Our objective is to assess the viability of the Crow instability as the mechanism causing the formation of the observed 28 mass accumulations along the circumstellar torus. The Crow instability was initially explored in the context of the dissipation of wingtip vortices shed from large aircraft. Symmetric perturbations along the vortex cores grow until they touch, resulting in a series of vortex rings.

Figure 2: A schematic showing wingtip vortex formation (top), and wingtip vortex breakup (bottom).

Model

The linear stability analysis considers perturbations along neighboring vortex cores governed by the Biot-Savart law and the condition that perturbations move at the local flow velocity. Both symmetric and anti-symmetric perturbations experience growth.

\[ \psi = \sum \left( R_0 \psi_{n+1} + \psi_{n-1} \right) \]

\[ \psi = \psi_{n+1} + \psi_{n-1} \]

\[ \psi_{n+1} = \psi_{n-1} \]

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Results

Our analysis predicts three separate wavenumber bands that experience perturbation growth. The fastest growth rates are those associated with the high-frequency symmetric band and the anti-symmetric band. However, these bands constantly migrate to larger wavenumbers while the low-frequency symmetric band consistently excites lower wavenumbers. The dominant wavenumber is 28, which is consistent with the number of observed hotspots in SN1987A.

Figure 3: A schematic showing the relevant parameters in the stability analysis: (left), the governing equations, (top right), and a schematic showing symmetric and anti-symmetric perturbations (bottom right).

Conclusions and Acknowledgement

The dominant mode predicted by our stability analysis is consistent with the number of observable hot spots along the circumstellar torus of SN1987A. The Crow instability may therefore be a viable mechanism facilitating the accumulation of mass along radial tori ejected by some star systems.


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