# Influence of Differential Rotation and Precollapse Angular Momentum on Stellar Collapse and Its Gravitational Wave Signature

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# Introduction

# Core-Collapse Supernovae (CCSN)

1. Iron core
2. Chandrasekhar mass
3. Rapid collapse
4. Bounce
5. Energy loss
6. Shock revival
7. Explosion

# Questions

- Shock revival?
- How is angular momentum distributed?
- Remnant?

**How do stars rotate?**

# Why Gravitational Waves?

- Traditional methods are insufficient
- Gravitational waves produced by accelerated mass quadrupole moments in the inner core

# How Do We Study Gravitational Waves?

- Analytical approach? No.
- Numerical approach? Yes.
- Parameter study of core collapse, bounce, and ring-down
  - **Differential rotation**
  - **Total rotation**
  - **EoS**

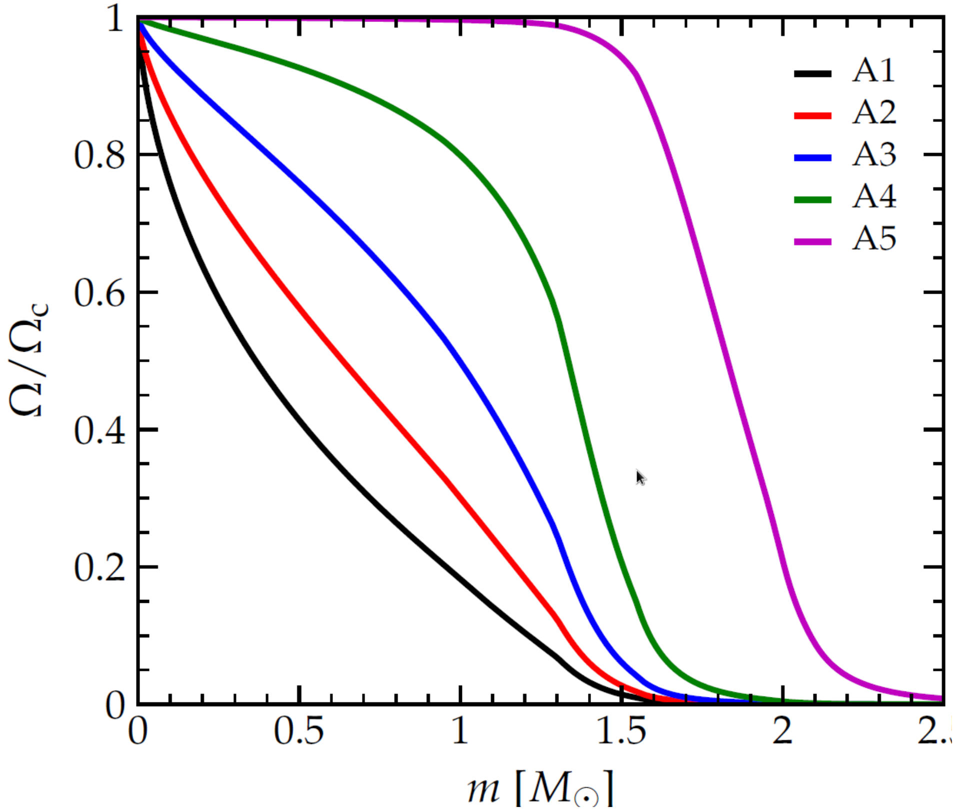
# Model

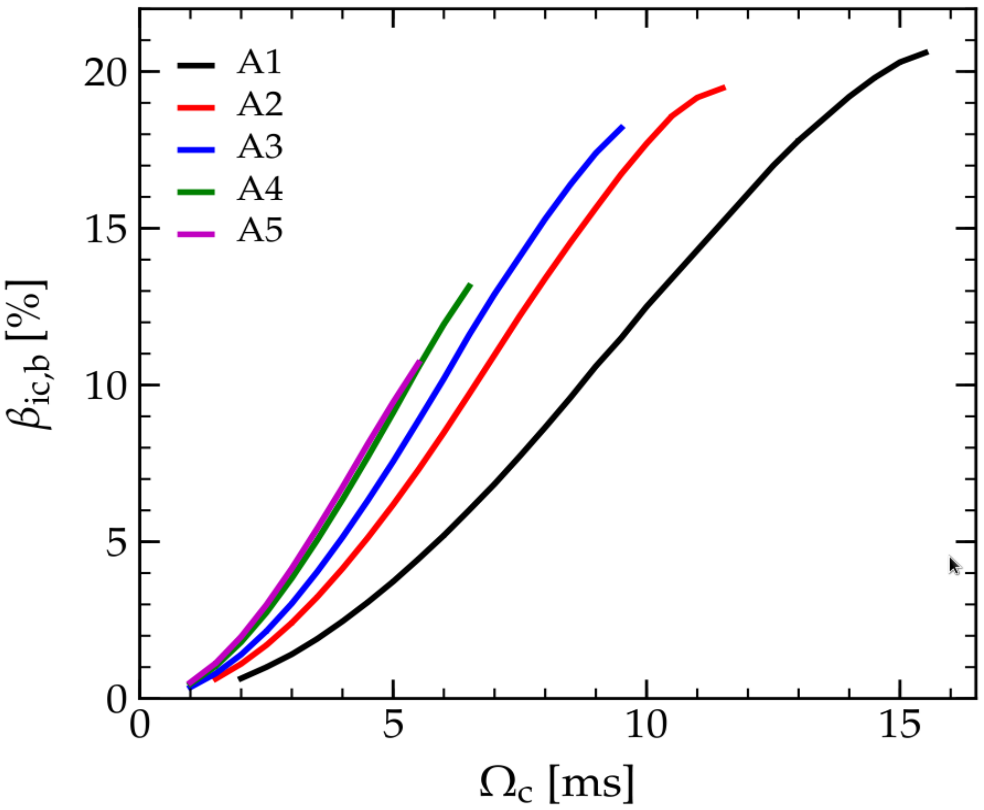
**Central angular velocity**

$$\Omega(\varpi) = \frac{\Omega_c}{1 + (\frac{\varpi}{A})^2}$$

**Differential rotation**

# Differential and Total Rotation



# Criteria

1. Convective stability

$$\rho\frac{\partial^2\xi}{\partial t^2} = \mathrm{L}\xi\ , \quad \int_V \xi\cdot\mathrm{L}\xi\mathrm{dx} > 0$$ *(Fjørtoft-Lebovitz Criterion)*

$$\int_V \xi\cdot\mathrm{L}\xi\mathrm{dx} = -\int_V \xi\mathrm{M}\xi\ dm - \int_V [\frac{(\delta p)^2}{\Gamma_1 p\rho} + \xi\cdot(\nabla\delta V)]\ dm$$

$$\mathrm{trace}\ \mathbf{M} > 0\,, \quad \det\ \mathbf{M} > 0$$ *(assuming no p-modes, many nodes)*

$$\frac{1}{\varpi^3}\frac{\partial j^2}{\partial\varpi} + \frac{1}{c_p}\frac{\gamma-1}{\Gamma_3-1}(-\mathbf{g})\cdot(\nabla S) > 0\ , \quad -g_z(\frac{\partial j^2}{\partial\varpi}\frac{\partial S}{\partial z} - \frac{\partial j^2}{\partial z}\frac{\partial S}{\partial\varpi}) > 0$$ *(assuming no p-modes, many nodes)*

$$(-\mathbf{g})\cdot(\nabla S) > 0\,, \quad \frac{d}{d\varpi}(\Omega^2\varpi^4) > 0$$ *(in the limits of no rotation and homentropic conditions)*

2. Build on previous trials

3. Simple and easy to use!

# Methods

# Code

- Axisymmetry (2D), equatorial symmetry
- Conformally flat GR
- GR hydrodynamics

Dimmelmeier *et al.* (2001, 2005)

# Microphysics

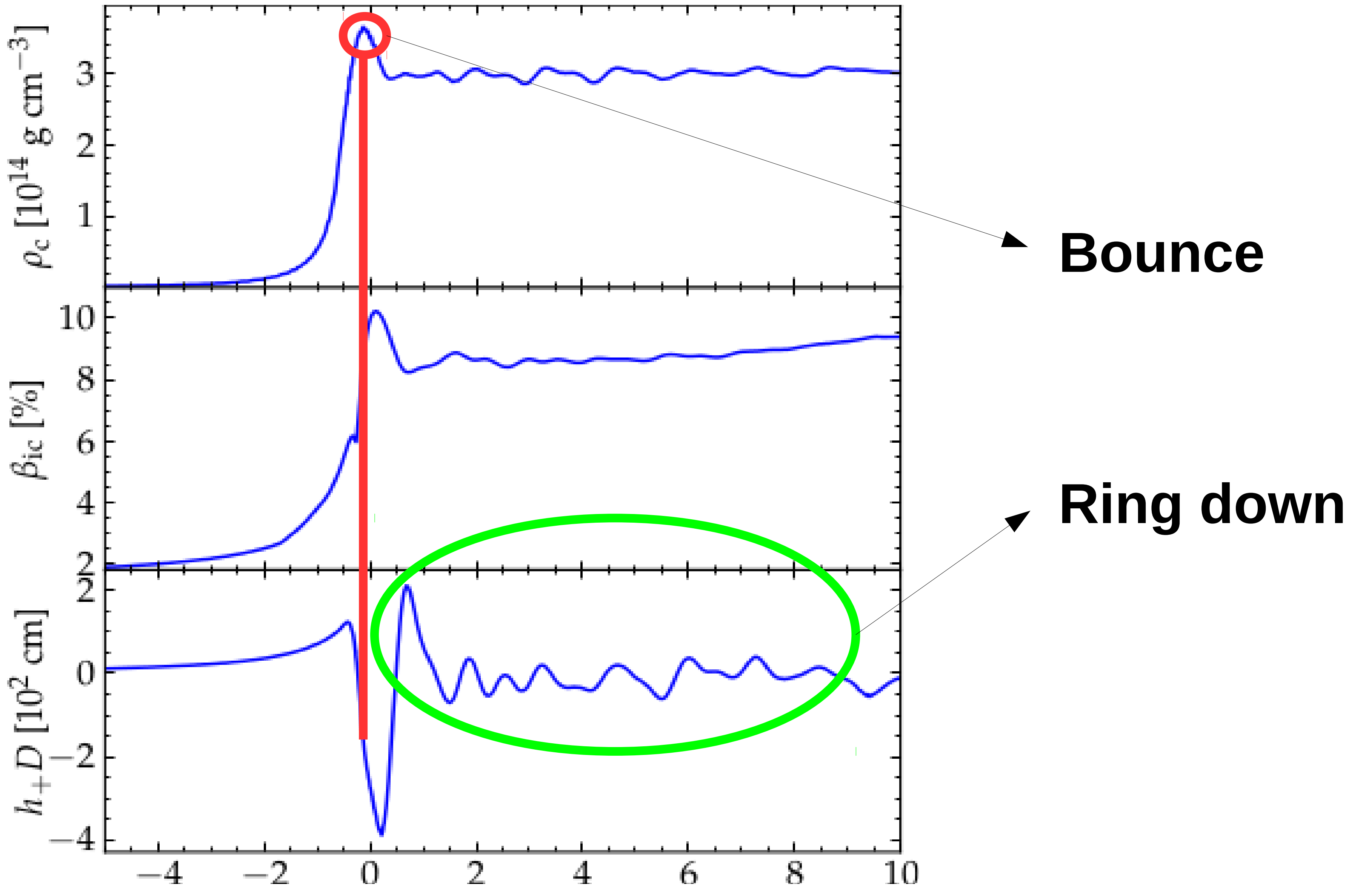
- Equation of state
  - **Lattimer & Swesty**, $K = 220$ MeV
  - **Shen *et al.***
- Parametrized deleptonization (collapse)
- Neutrino heating/leakage (post-bounce)

# Spherical Grid

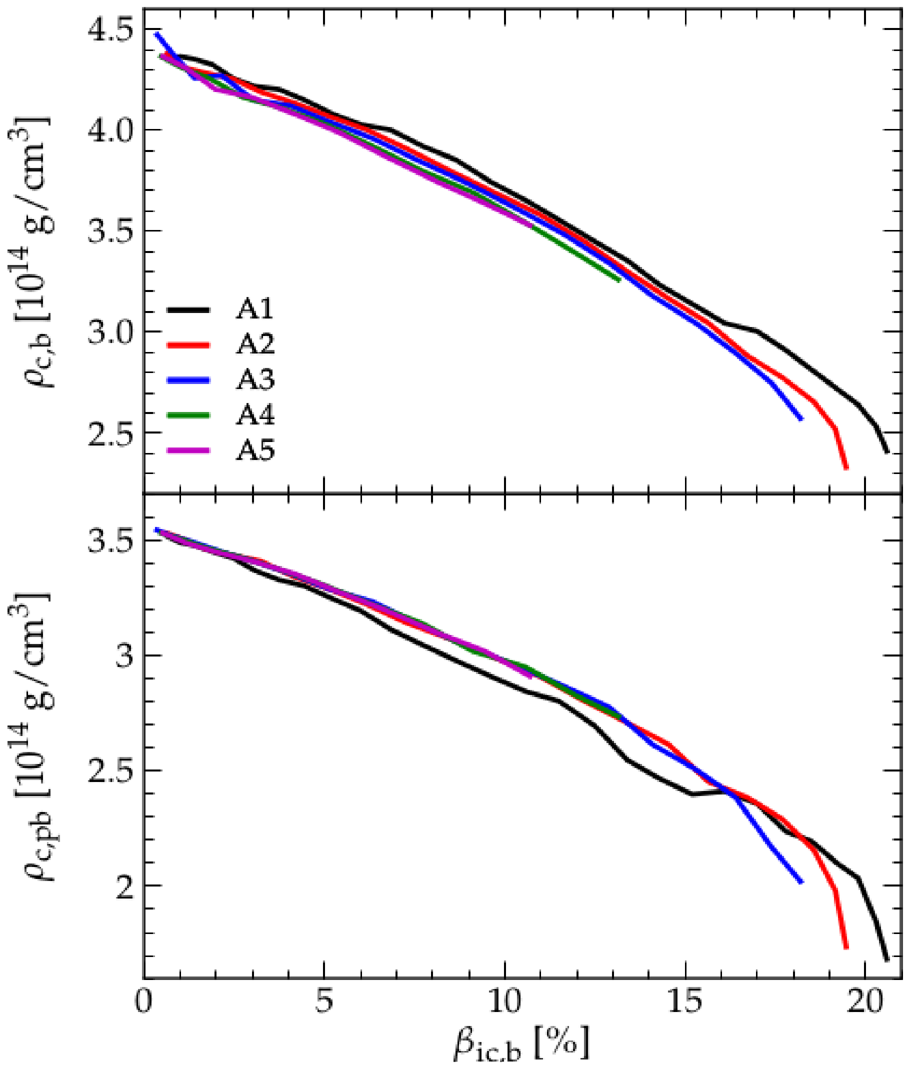
- $R$ = 3,000 km
- 250 radial points (log spaced)
- 40 angular grids
- Central resolution of 250 m

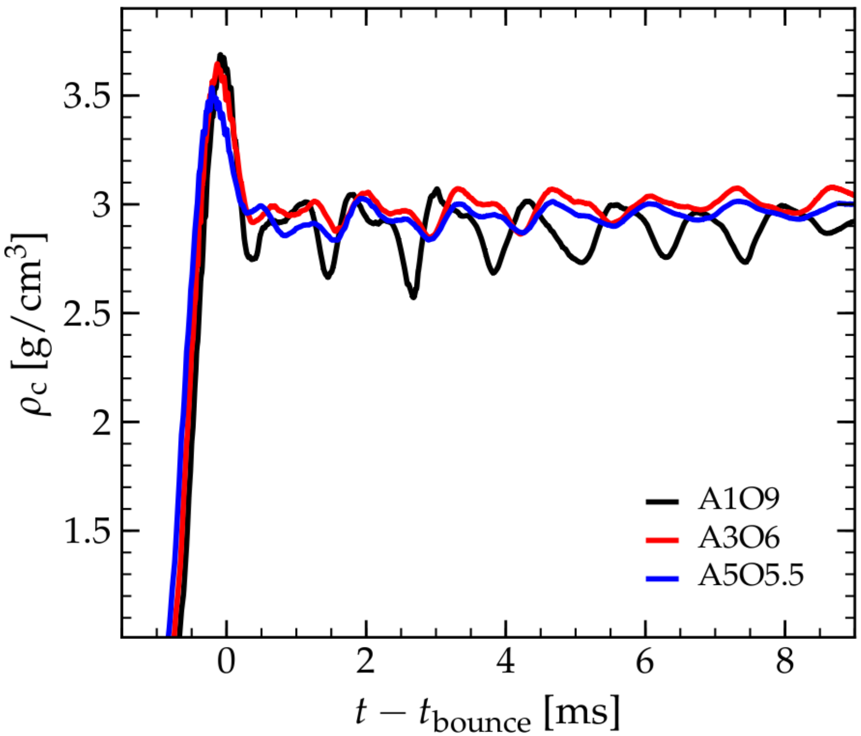
# Results

# Dynamics



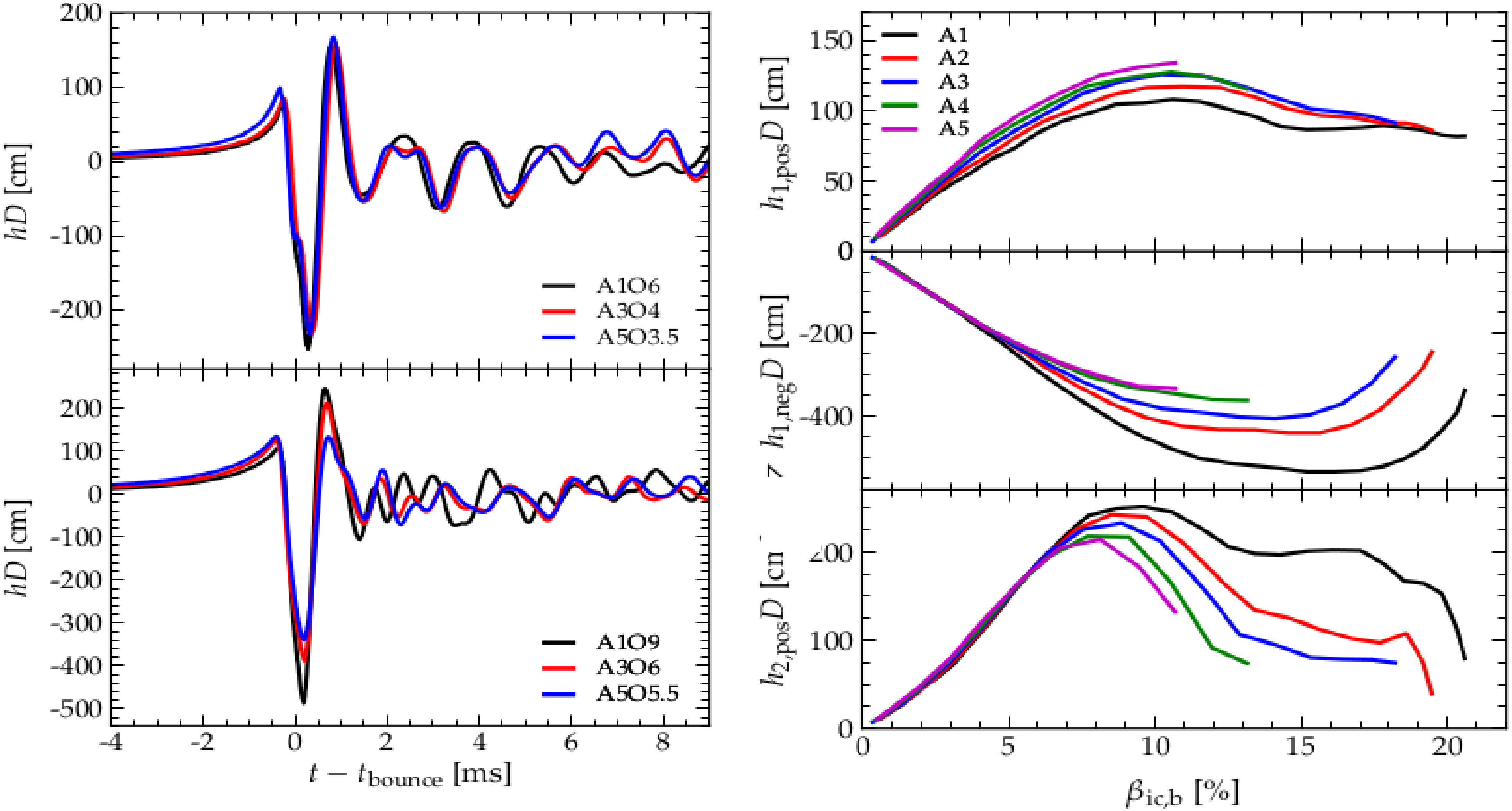
# Dynamics Cont.



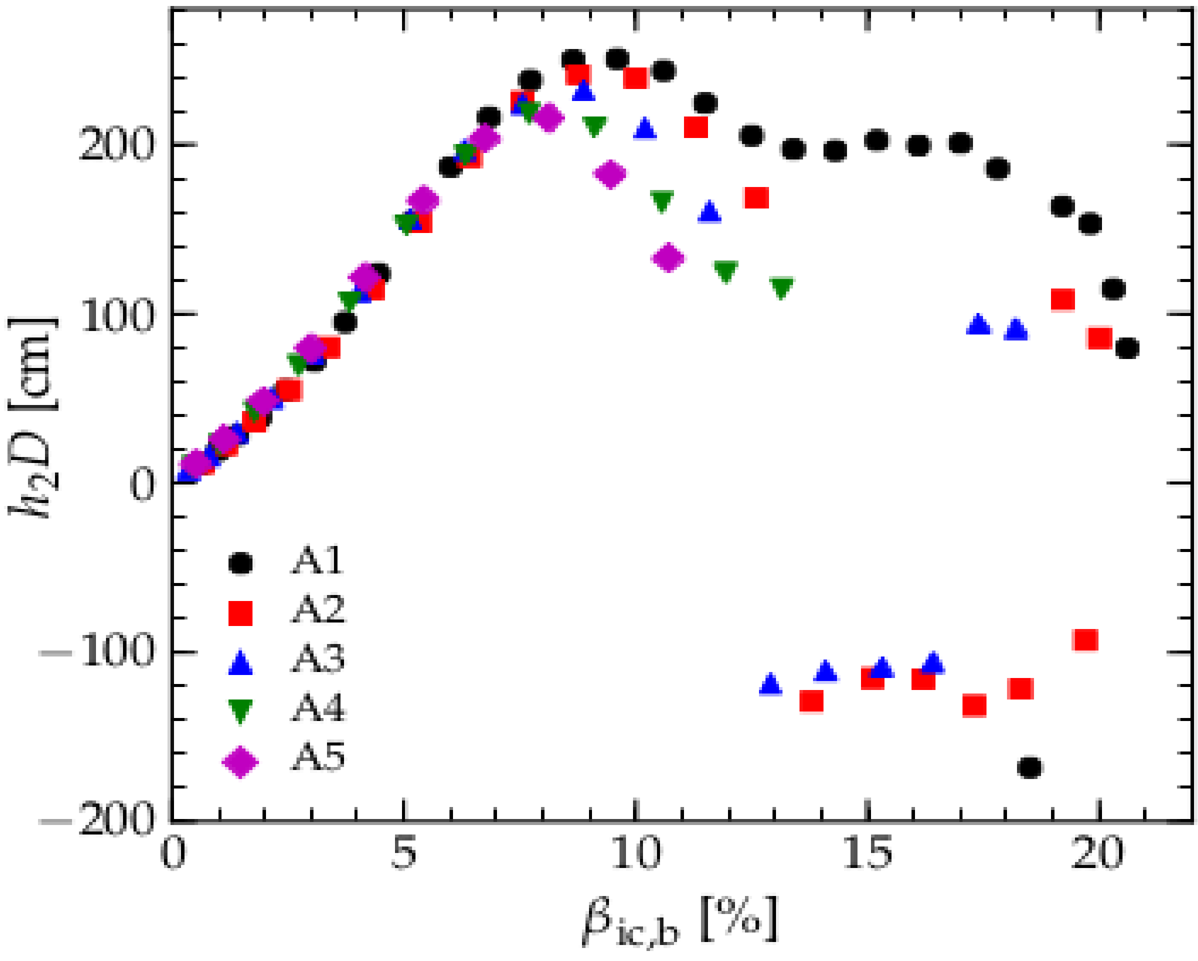

**Density decreases with total rotation, increases with differential rotation.**

# Gravitational Waves




**With differential rotation, magnitude of first peak decreases, but that of second and third peaks increase. All effects more pronounced with total rotation.**

# Gravitational Waves Cont.

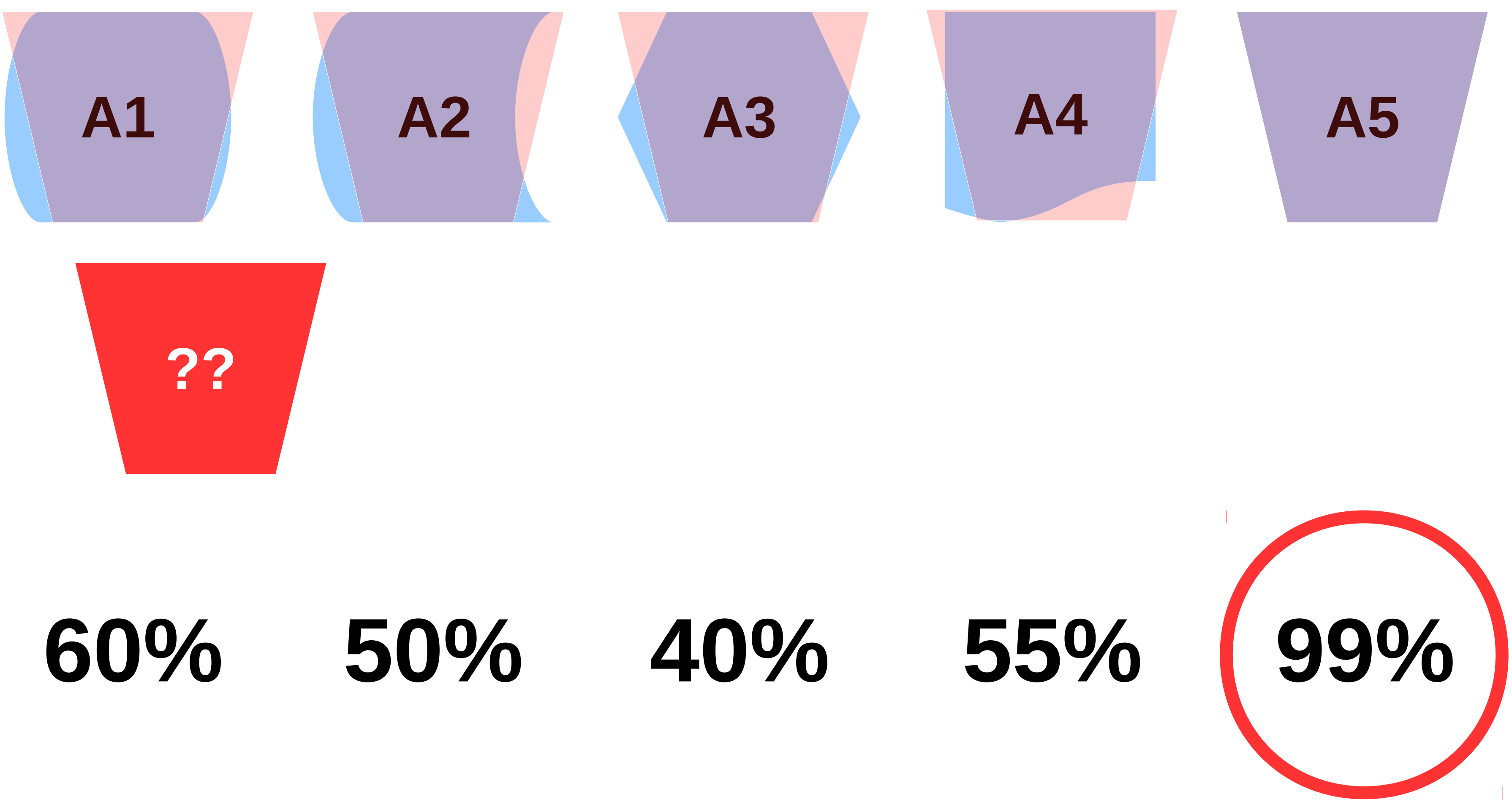



**Hayama *et al.* (2008) incorrect!**

# Bayesian Analysis

# Bayesian Techniques

Same *A* → shared characteristics?



# Principal Component Analysis

$$\mathbf{W_{i,j}} = h(A1\Omega_j, t_i)$$

$$\mathbf{W}{=}\mathbf{U\Sigma V^T}$$

$$\mathbf{U} = [\mathbf{x_1} \quad \mathbf{x_2} \quad \mathbf{x_3} \quad \ldots \quad \mathbf{x_m}]$$

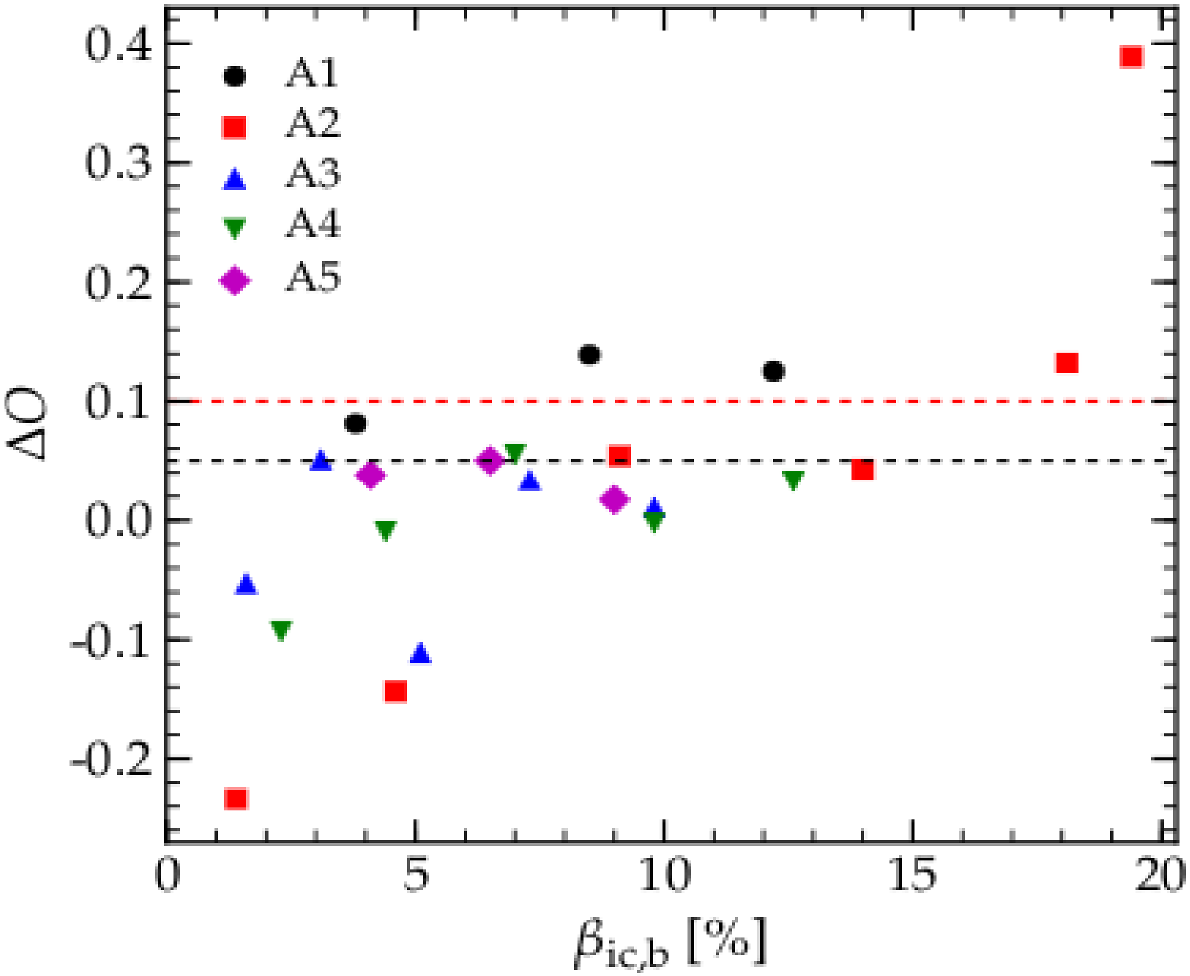
$$\epsilon_i = \beta_1 x_{1,i} + \beta_2 x_{2,i} + \beta_3 x_{3,i} \ldots + \beta_7 x_{7,i}$$

Nested sampling...

*(Repeat for all five differential rotation categories...)*

Overlap...

# Detectability




**Detectability increases with total rotation.**

# Summary

Q Is the angular momentum distribution detectable?

A Yes, at rapid rotation.

# Acknowledgements

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