Accretion Induced Collapse of White Dwarfs

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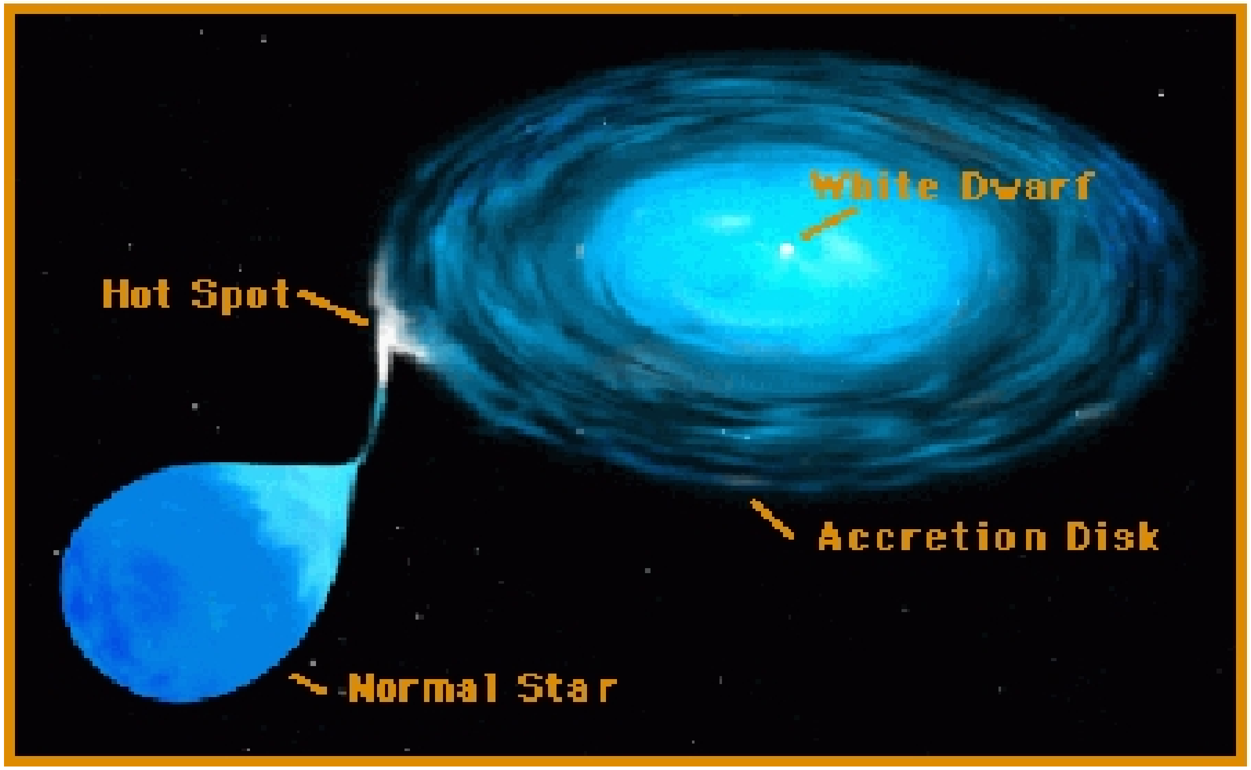

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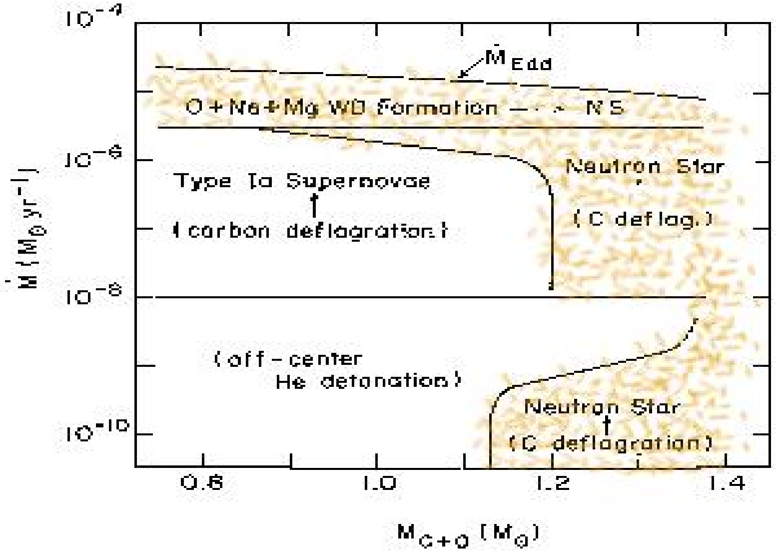
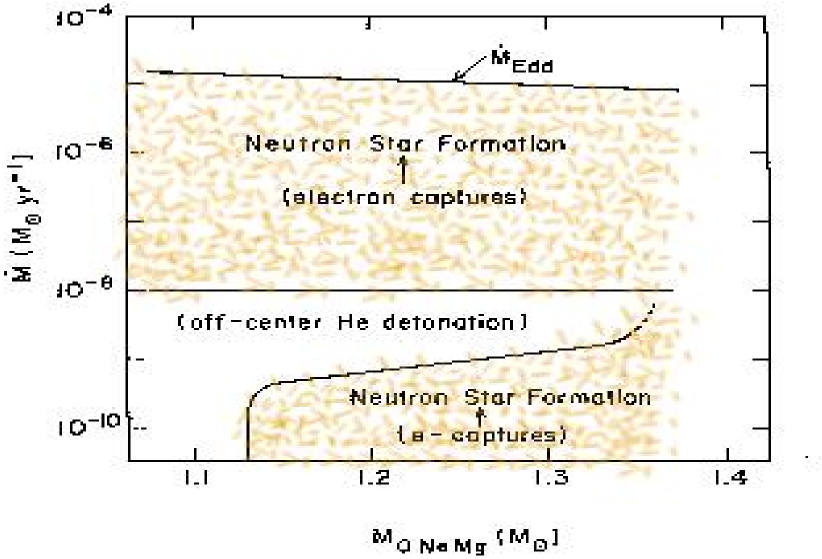
- The Accretion Induced Collapse of a White Dwarf star can lead to the formation of neutron stars with large angular momenta. These rapidly rotating neutron stars may be subject to non-axisymmetric instabilities which could provide an interesting source of gravitational radiation.

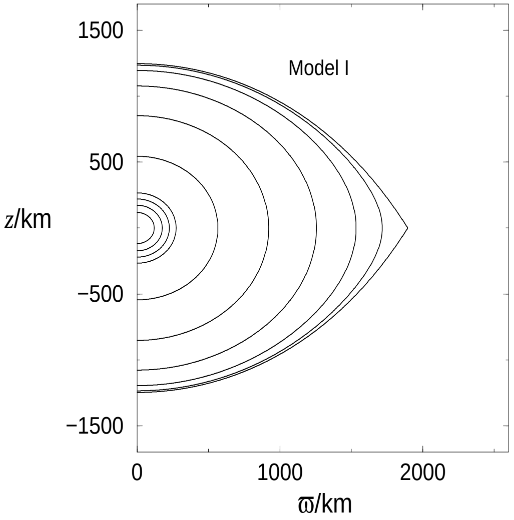
- I will describe the models of these objects (including their stability and the properties of the graviational radiation emitted) developed by Yuk-Tung Liu and L^2.
  - Compute pre-collapse white dwarf models.
  - Compute post-collapse nascent neutron star models.
  - Determine the stability of these models by solving the time dependent perturbed self-gravitating fluid equations.
  - Estimate the properties of the gravitational radiation emitted by the dynamically unstable fluid modes.

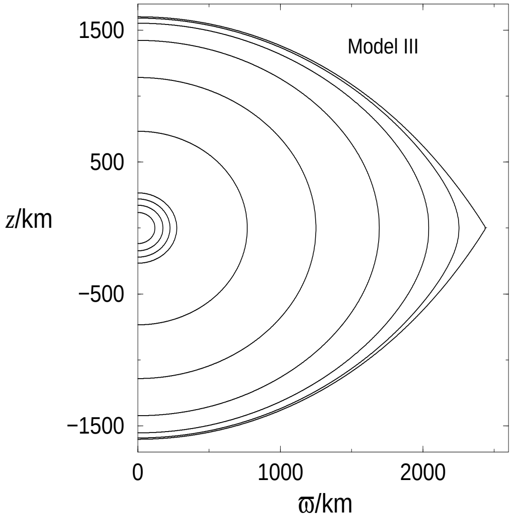
- White dwarfs in binary systems can be driven beyond the stable mass range by accretion: When the central density of the star crosses a certain threshold, nuclear reactions are triggered, which result in electron captures, that reduce the pressure, which leads to collapse.
  - When Carbon ignition in C-O white dwarfs occurs in the range $6 \times 10^9 < \rho_c < 10^{10}$ gm/cm^3), then electron captures behind the burning front significantly reduce the pressure, and the white dwarf collapses to a neutron star.
  - When the central density exceeds 4×10^9 gm/cm^3 in an O-Ne-Mg white dwarf, electron captures by Neon and Magnesium reduce the pressure which leads to collapse to a neutron star.

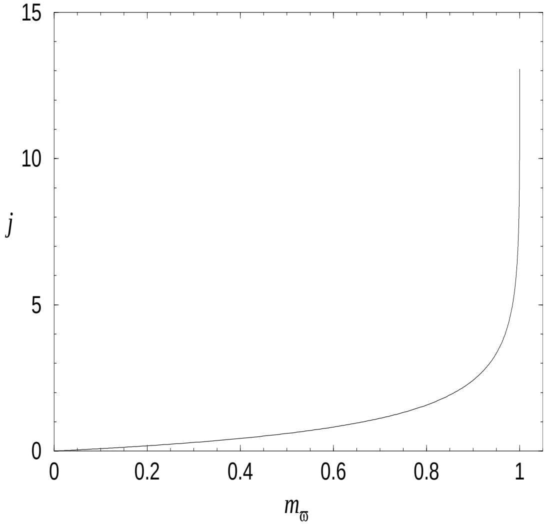




- Compute sequences of rigidly rotating white dwarf models with central densities equal to the critical AIC values. The maximum angular velocity models have masses in the range $1.47 - 1.43 M_\odot$, which are slightly above the Chandrasekhar mass.

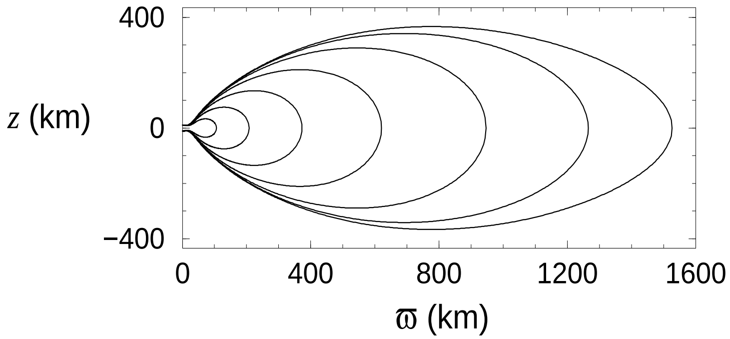


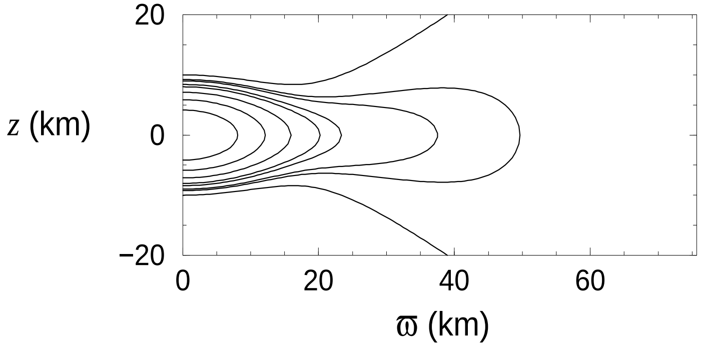




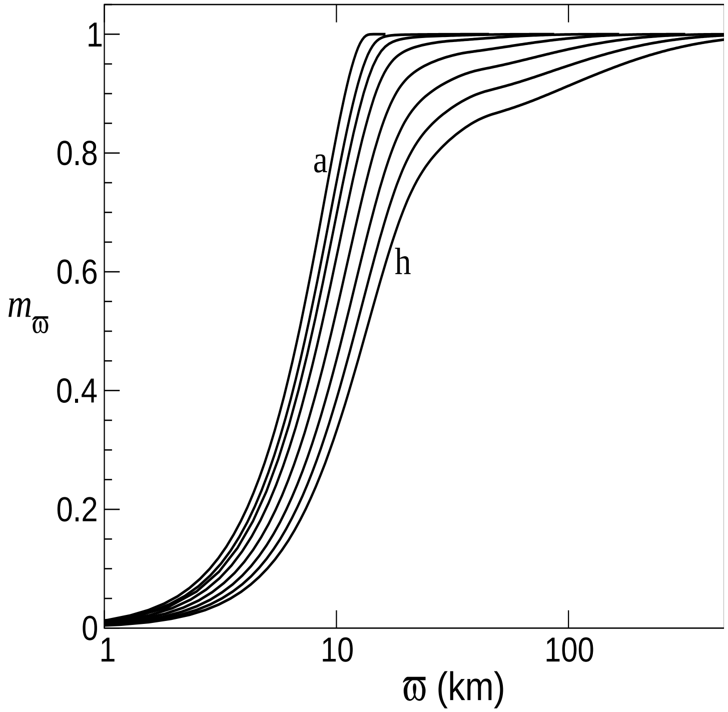
- Determine the angular momentum distribution $j(m)$ for each stellar model in these sequences.

- Compute nascent neutron star models having the WD angular momentum distributions but with realistic NS equations of state. These models have central densities comparable to nuclear density for cold models and about 1/10 nuclear density for hot models.

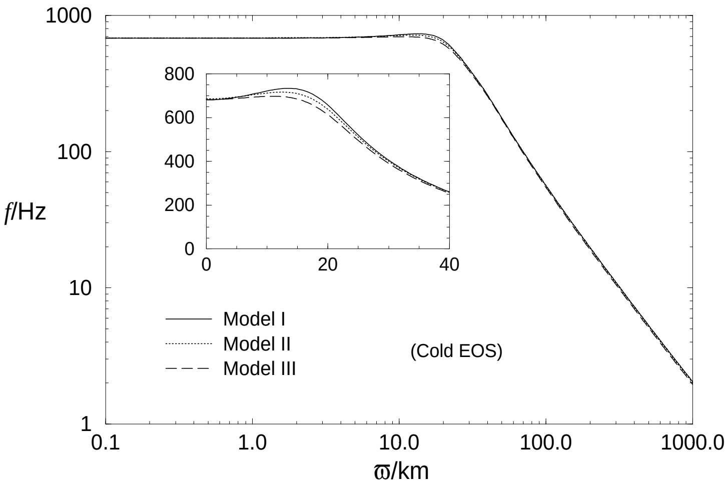


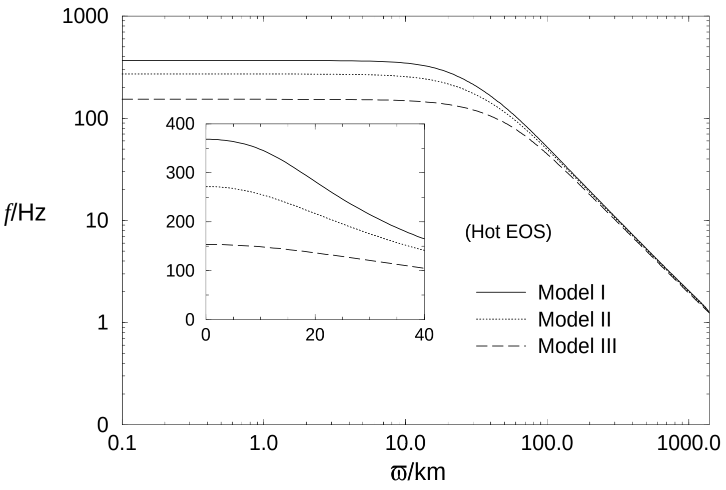


- These nascent neutron stars contain 90% of their mass within 10-100 km of the rotation axis (depending on the star's angular momentum).

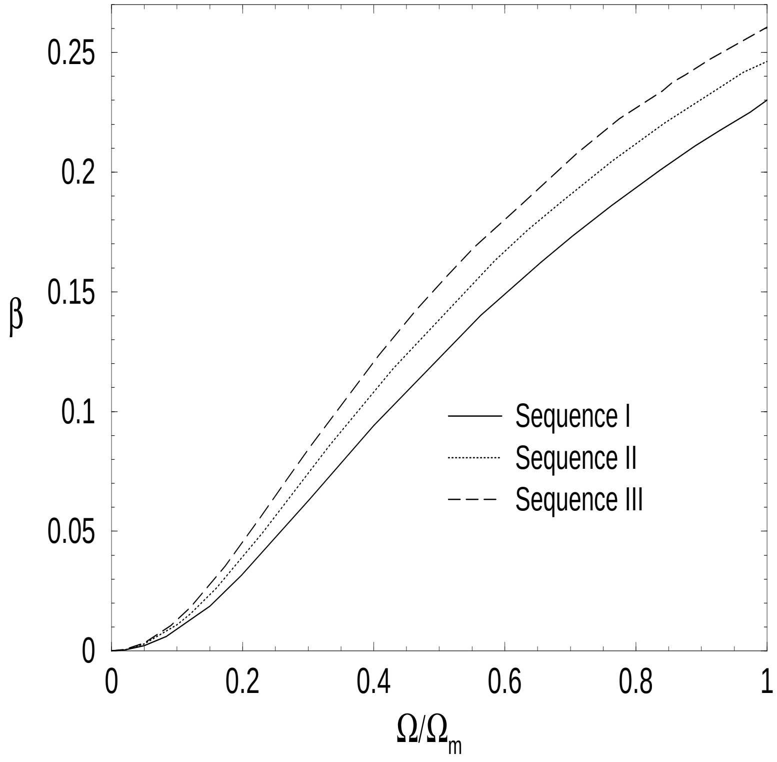


- The inner cores of the most rapidly rotating models have fairly uniform angular velocities, while the outer regions have almost Keplerian angular velocity profiles.





- The parameter, $\beta = T/|W|$ which measures the angular momentum of the neutron star, as a function of the initial WD angular velocity Ω for two C+O sequences (solid curves) and one O+Ne+Mg (dashed curve), based on a realistic (cold) NS equation-of-state.

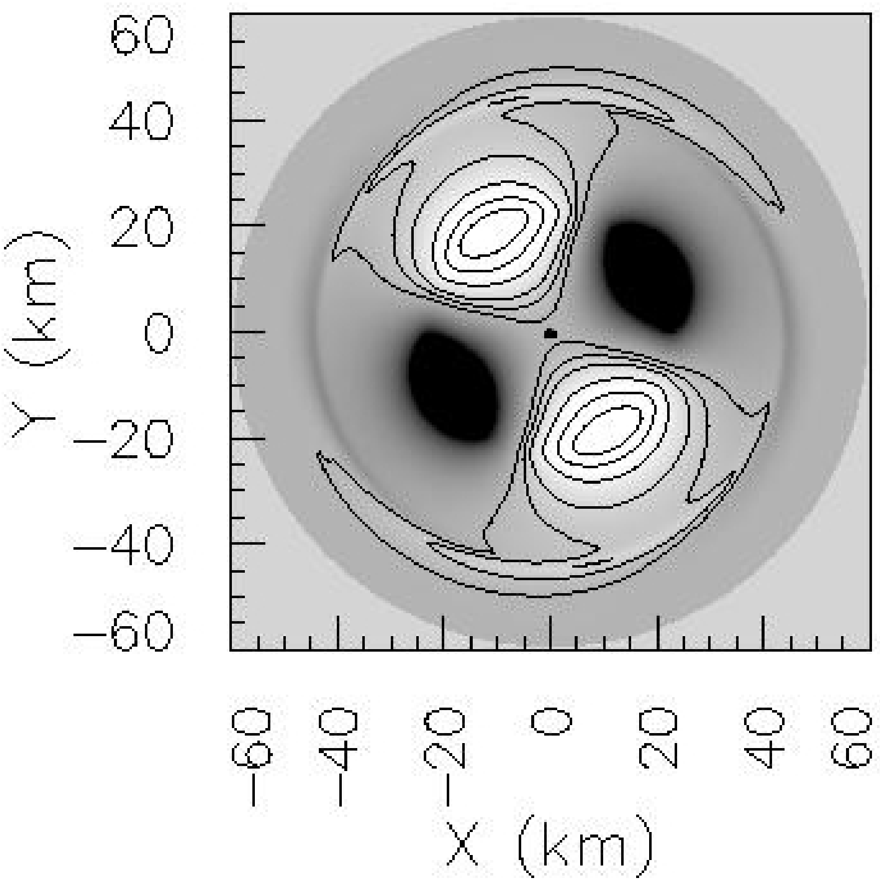


- Evaluate the stability of the proto-neutron star models by solving the linearized self-gravitating fluid equations numerically:

$$\begin{aligned}\delta\rho &= \delta\rho(\varpi, z, t)\ e^{im\varphi}\\ \delta\vec{v} &= \delta\vec{v}(\varpi, z, t)\ e^{im\varphi}\\ \delta\Phi &= \delta\Phi(\varpi, z, t)\ e^{im\varphi}\end{aligned}$$

- Liu searched for exponentially growing solutions to the linearized equations with $m = 1$ and $m = 2$. Models were considered unstable if a well defined exponentially growing solution was found, stable if no exponentially growing solution was evident within 40 (on axis) rotation periods of the equilibrium model.

- Dynamical instabilities were found for solutions only for $m = 2$, the "bar" modes, and only for models with $\beta > 0.24$. Thus only the most rapidly rotating O+Ne+Mg WDs are subject to this instability.



Properties of the Emitted Gravitational Radiation

- The GR from these dynamical instabilities is emitted in a fairly monochromatic burst with frequencies near $f = 450$ Hz.
- Only the most rapidly rotating nascent neutron stars, with $\beta > 0.24$, are subject to this dynamical instability, and so the maximum angular momentum that can be radiated as GR is about $\Delta J < 5 \times 10^{48}$ cgs.
- The timescale for the GR emission can be estimated from

$$\tau_{GR} \approx \Delta J \left(\frac{dJ}{dt}\right)^{-1} \approx 7\mathrm{s}\left(\frac{\alpha_S}{0.1}\right)^{-2}\left(\frac{\Delta J}{5 \times 10^{48}\mathrm{cgs}}\right)$$

where α_S is the dimensionless amplitude of the mode when saturation occurs, and ΔJ is the total amount of angular momentum radiated.

- No dynamical instability is found in any model constructed from a realistic (hot) equation-of-state. The NS must cool before this dynamical instability can play any role. Thus the GR signal would lag the collapse event in these objects by a time of order 20 s.

- The maximum optimal signal-to-noise ratio for detecting GR signals from sources whose angular momentum evolution is driven by GR is given by a simple expression (Blandford; Owen & L^2):

$$\frac{S}{N} = 15\left(\frac{20\,\mathrm{Mpc}}{D}\right)\sqrt{\frac{\Delta J}{5\times 10^{48}\mathrm{cgs}}}\sqrt{\frac{450\,\mathrm{Hz}}{f}}\left(\frac{2\times 10^{-24}\mathrm{Hz}^{-1/2}}{\sqrt{S_h(f)}}\right)$$

- Observation of such sources by LIGO II with $S/N \approx 5$ require the event rate of these very rapidly rotating dynamically unstable AIC systems to exceed 10^{-6}/galaxy/year.
- Estimates of the total event rates for all AIC vary widely (Fryer, et al; Kalogera; Wasserburg):
  - Binary population synthesis techniques give expected AIC event rates in the range $10^{-6} \sim 10^{-4}$/galaxy/year.
  - Observed abundances of the heavy elements expected to be injected into the interstellar medium give AIC event rates in the range $10^{-7} \sim 10^{-4}$/galaxy/year.
  - A very recent estimate based on heavy r-process element abundances gives an extremely high rate: 10^{-1}/galaxy/year.
- In summary: the detection of GR from AIC by LIGO II seems unlikely at this point, but is not completely ruled out.