Multi-messenger Signals of Dark Matter Admixed Accretion-Induced Collapse of White Dwarfs

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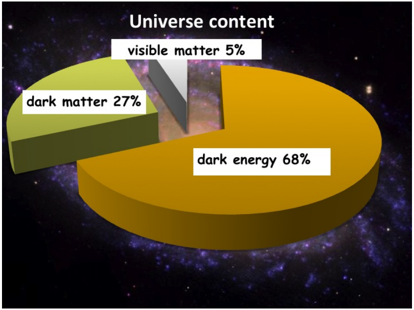
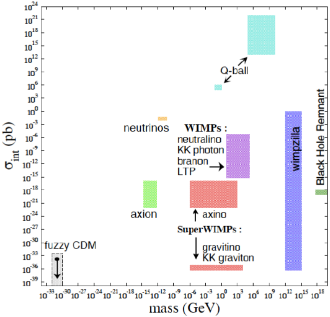
Plan of this talk

1. Background
2. Spherically symmetrical case: ν and low NS mass
3. Rotating collapse case: gravitational-wave (g-wave)
4. Summary & Outlook

Dark matter (DM) mysteries



(a) Credit: *Quantum diaries*

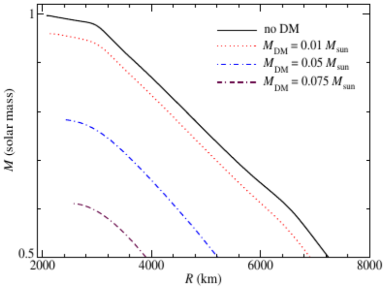


(b) Park *DMSAG*, 2007

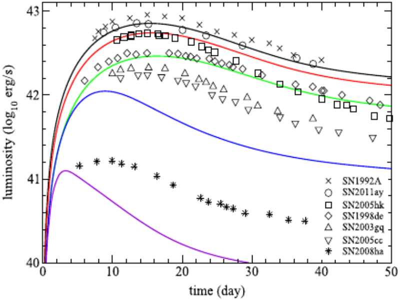
- Dominant roles for large scale structure formation, CMB ...
- Any impact on stars?
  - Extra gravity; heating or cooling; energy transport ...

DM admixed white dwarf (WD) and Type Ia supernovae

DM model: 1 GeV non-self-interacting Fermions



(c) M-R relations (Leung + 2013).



(d) SN Ia light curves (Leung + 2015).

- DM admixture reduces the effective Chandrasekhar mass limit ($M_{Chan,\mathrm{eff}}$);
- DM admixture reduces the mass of $^{56}\mathrm{Ni}$ synthesized which may explain some sub-luminous type Ia SNe.

Accretion-induced collapse (AIC) of WD from 8 – 10 $M_\odot$ stars

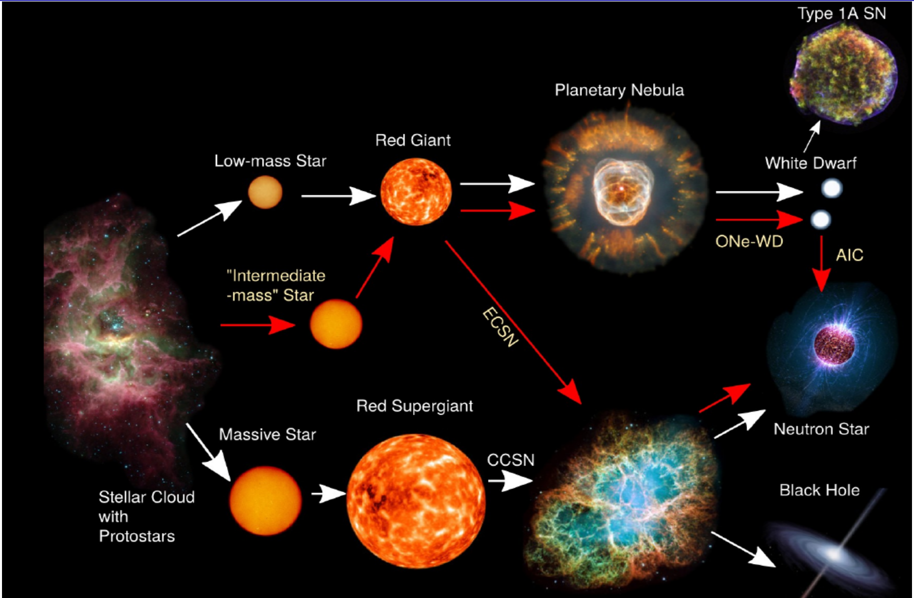
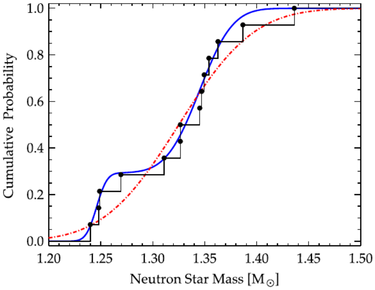


Image credit: Unknown/Jones/Möller

Why study AIC?

Less well-studied case of stellar death, with potential importances:

- Nucleosynthesis:
  - Production of Ag and Pd (Hansen+ 2012)
  - Possible r-process (Au, Eu) site (Fryer+ 1999)
- 'Bimodal' NS mass distibution, origin of low-mass pulsars
- Short, less luminous transients in electromagnetic observations.



NS mass distribution(Schwab+ 2010)

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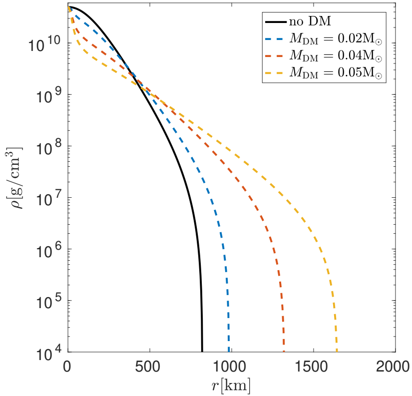
Spherically symmetrical AIC simulation: *GR1D*

GR1D: an open-source GR code with M1 neutrino-transport for realistic CCSNe simulations developed by **Evan P. O'Connor** (O'Connor 2015).
— STOS equation of state.

Production	
Charged-current Interactions	Thermal Processes
$\nu_e + n \to p + e^-$	$e^- + e^+ \to \nu_x + \bar{\nu}_x$
$\bar{\nu}_e + p \to n + e^+$	$N + N \to N + N + \nu_x + \bar{\nu}_x$
$\nu_e + (A, Z) \to (A, Z + 1) + e^-$	
Scattering	
Isoenergetic Scattering	Inelastic Scattering
$\nu + \alpha \to \nu + \alpha$	$\nu_i + e^- \to \nu_i' + e^{-\,\prime}$
$\nu_i + p \to \nu_i + p$	
$\nu_i + n \to \nu_i + n$	
$\nu + (A, Z) \to \nu + (A, Z)$	

Figure: Neutrinointeractions included

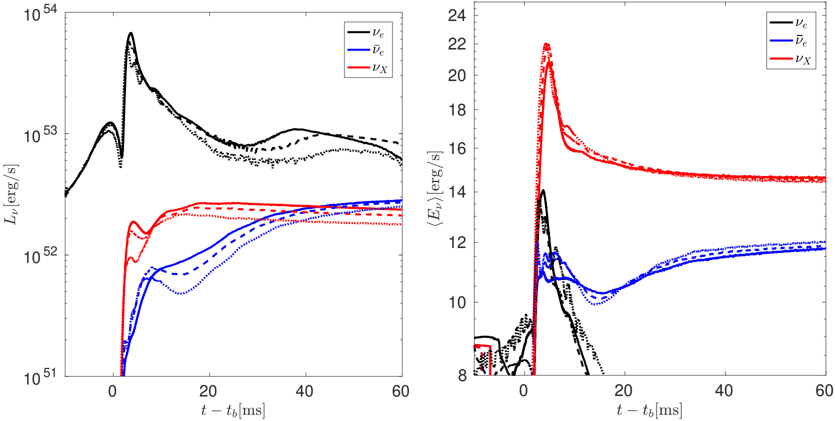
DM effects on collapsing dynamics



DM admixture effectively softens the core, accelerates the contraction intially but delays the collapse, and results in the low PNS central density.

DM effects on neutrino luminosity

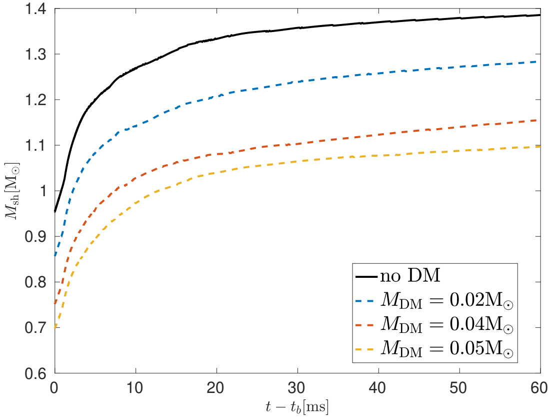
— $M_{\rm DM} = 0.00 M_\odot$, - - $M_{\rm DM} = 0.02 M_\odot$, $\cdots$ $M_{\rm DM} = 0.04 M_\odot$



- Less luminous in neutrino with inclusion of DM.
- Slightly higher energy as neutrino sphere is deeper.

DM effects on proto neutron star (PNS) mass

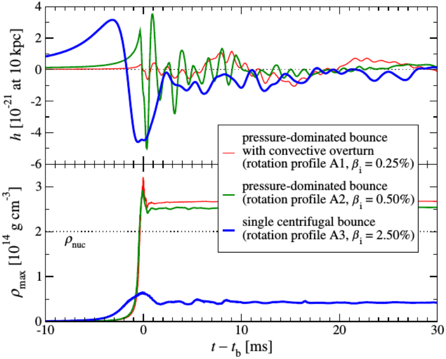
PNS defined at $\rho \geq 10^{11}\ \mathrm{g/cm^3}$



PNS mass (baryonic mass) decreased from $1.39 M_\odot$ to $1.10 M_\odot$.

Plan of this talk

G-waves from rotating core collapse



Generic waveforms from Dimmelmeier+ 2007

- Measuring the angular momentum of the SN core (Abdikamalov+ 2014).
- Constrain nuclear equations of state (Richers+2017).

Simulations of rotating AICs: Methods

- Initial condition: constructed by solving hydrostatic eq. with self consistent (SCF) method (Hachisu 1986)

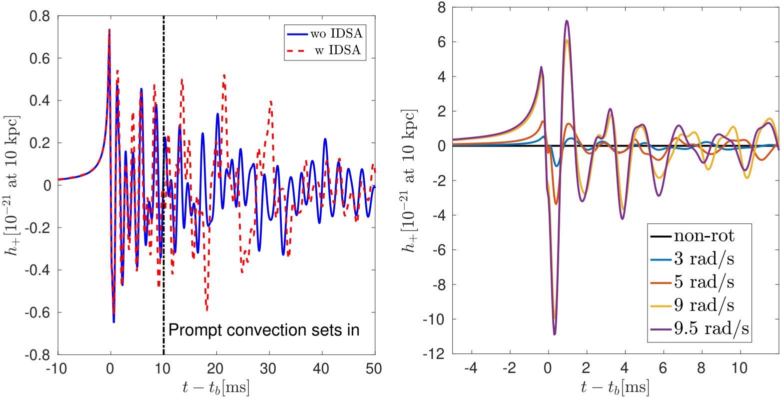
$$\text{Integrate} \quad -\rho\nabla\Phi - \nabla P = -\rho\Omega^2 r\hat{e}_r \rightarrow$$
$$H(\rho) = \int \rho^{-1}\mathrm{d}P = C - \Phi + \int \Omega^2 r\mathrm{d}r \tag{1}$$

  Assume uniform rotation in current study.

- 2.5D hydrodynamic simulation: home-built hydro code (Leung+ 2015) with 5th order shock capture scheme – Weighted Essentially Non-Oscillatory (WENO, Jiang&Shu 1996), together with parametrized electron capture scheme ($Y_e = Y_e(\rho)$ Libendörfer 2005).
- Standard quadrupole formula for g-wave extraction

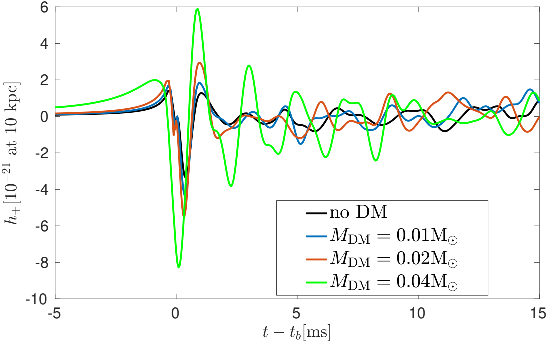
$$h_+ = \frac{3}{2}\frac{G}{Dc^4}\ddot{\mathbf{I}}_{zz}\sin^2\theta \tag{2}$$

G-waves from normal rotating AICs



(e) $\Omega = 5$ rad/s

- Neutrino transport affects the g-wave signal majorly after 10 ms postbounce.
- Generic g-wave waveforms for normal uniformly rotating AICs.

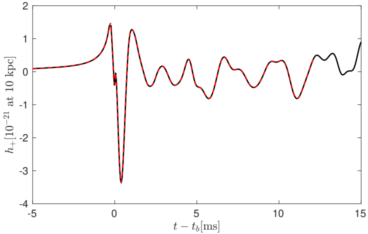


$\Omega_{\rm ini} = 5$ rad/s

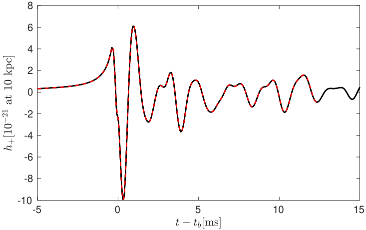
- DM admixture enhances the amplitude of g-wave signal for same $\Omega_{\rm inid}$.
- Large amount of DM admixture could lead to centrifugal bounce like shape.

Convergence of resolution

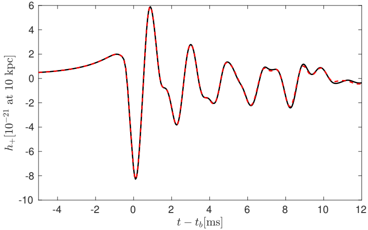
— low resolution 2^{o} - - high resolution 1.5^{o}



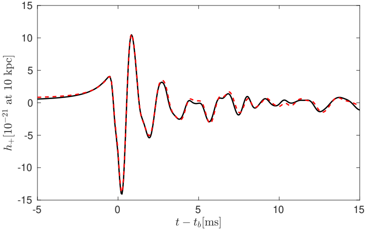
(g) $\Omega_{\rm ini} = 5{\rm rad/s}$, no DM



(h) $\Omega_{\rm ini} = 9{\rm rad/s}$, no DM



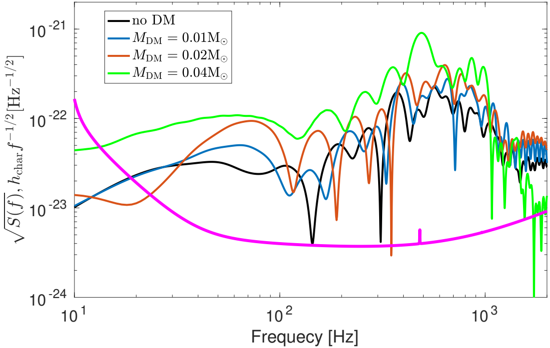
(i) $5{\rm rad/s}$, $M_{\rm DM} = 0.04{\rm M}_\odot$



(j) $9{\rm rad/s}$, $M_{\rm DM} = 0.02{\rm M}_\odot$

Detection prospect

Assume source at 10 kpc;
compared with Adv-LIGO noise spectrum.



Just for illustration, might be to optimistic due to the complication of real g-wave search.

Summary & Outlook

- DM admixture inside WDs delays the accretion-induced collapse process, resulting in less luminous neutrino signals and less massive neutron stars.
- DM admixture enhances the amplitude of g-waves from rotating AICs and changes the waveform shape, which might be distinguishable in future g-wave detection.
- Work on fitting the waveforms to yield a few-parameter template bank for realistic g-wave search and comparison to iron-core-collapse signals is on the way.

Thank you!!

Q&A