Arthur B. McDonald
Canadian Astroparticle Physics Research Institute

Queen's University

Dark Matter-Induced Baryonic Feedback in Galaxies

Yilda Boukhtouchen

PHENO 2023 • May 9th, 2023

Work in preparation by: An, Acevedo, Bramante, Boukhtouchen, Richardson, Sansom

Overview

How does baryonic feedback due to dark matter ignition of Type Ia supernovae influence galaxy structure?

I. Type Ia Supernovae Induced By Heavy Dark Matter

II. Baryonic Feedback Processes in Galaxy Structure

III. Dark Matter-Induced Baryonic Feedback in GIZMO Simulation

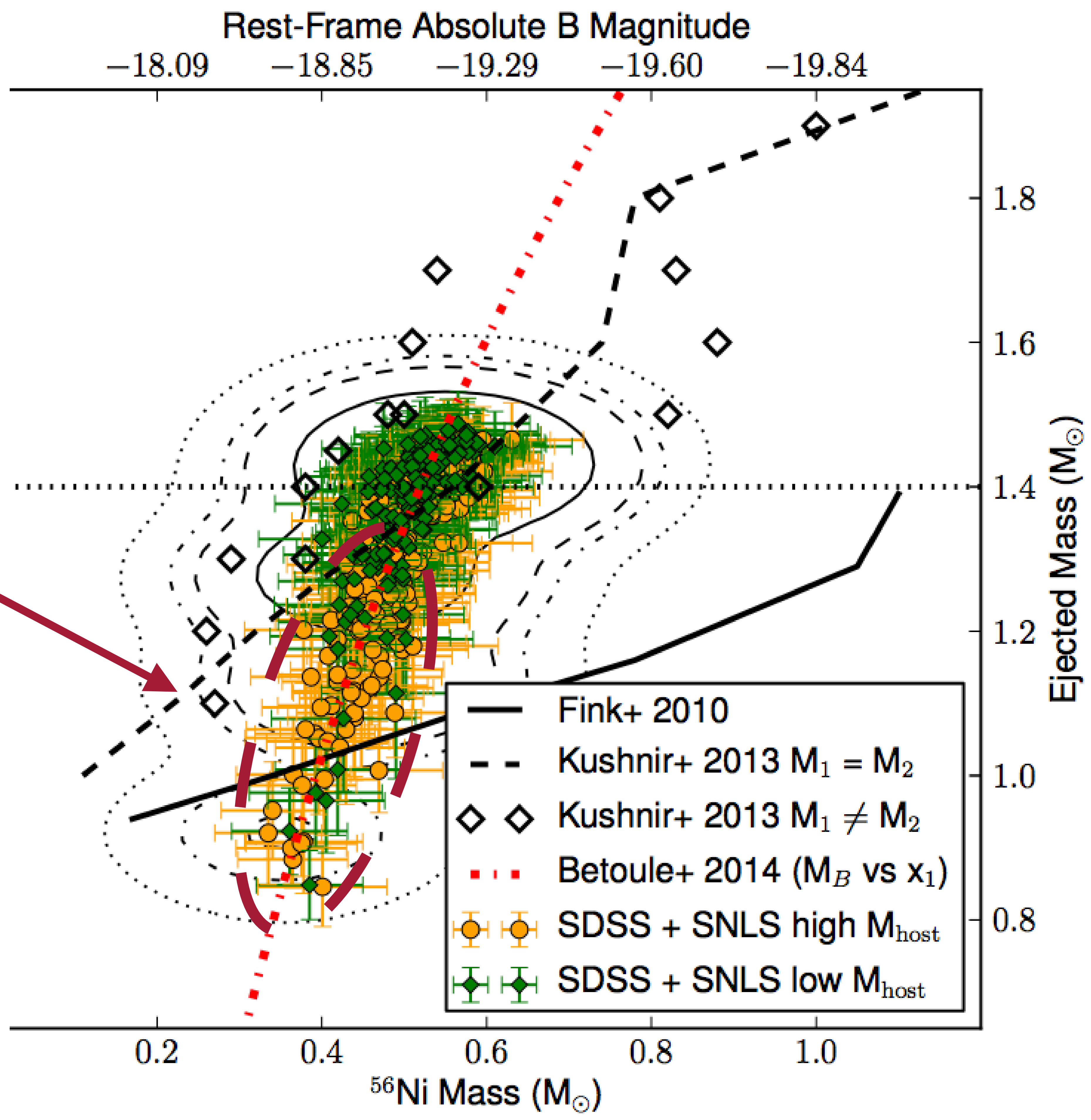
Sub-Chandrasekhar Type Ia Supernovae?

Expect Type Ia supernovae due to gravitational collapse of > $1.4\ M_\odot$ white dwarfs

Observe a long tail of sub-Chandrasekhar mass SNIa

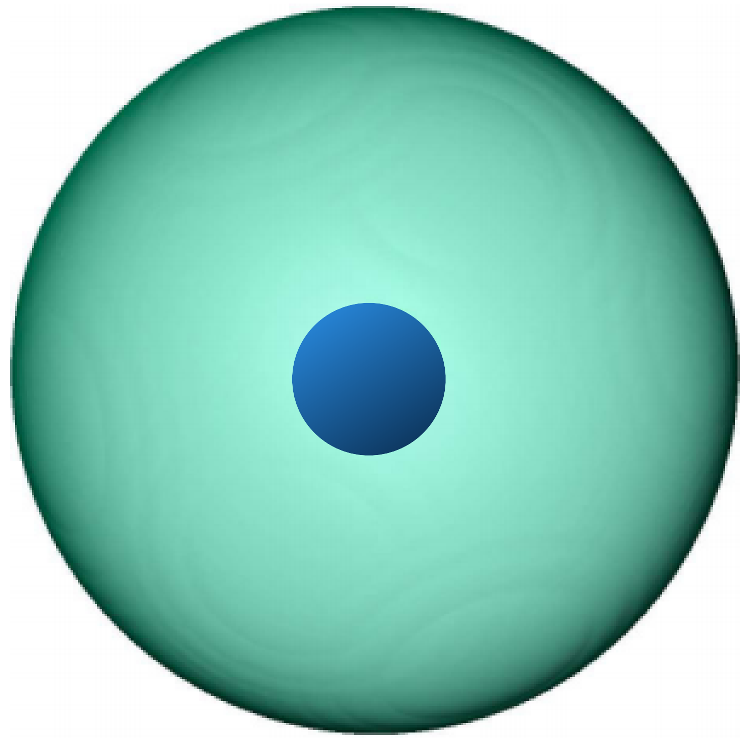
- White dwarf binary mergers?
- Matter accretion from binary systems?

How can lone sub-Chandrasekhar white dwarfs lead to Type Ia supernovae?



Scalzo et al. 1408.6601

Dark Matter Igniting White Dwarfs


Ignition region inside WD

Incoming DM particles

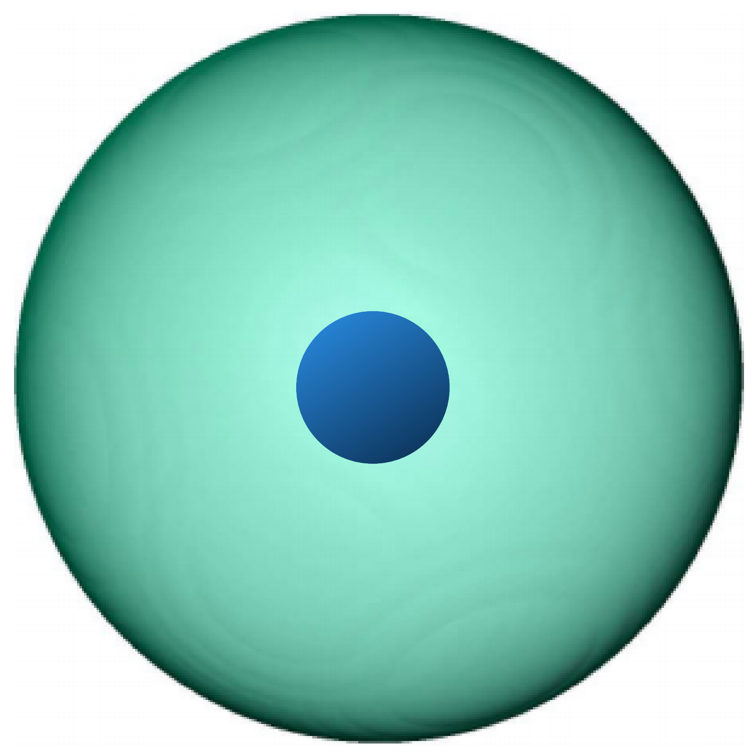
$$\dot{M}_X \propto \sigma_{nX}, \quad \rho_X, \quad m_X^{-1}, \quad v_X^{-1}$$

↓ Energy loss from DM-nucleus collisions

Become gravitationally bound and accumulate in the core

J.F. Acevedo, J. Bramante, 1904.11993

Dark Matter Igniting White Dwarfs



Ignition region inside WD

Incoming DM particles

$$\dot{M}_X \propto \ \sigma_{nX}, \ \ \rho_X, \ \ m_X^{-1}, \ \ v_X^{-1}$$

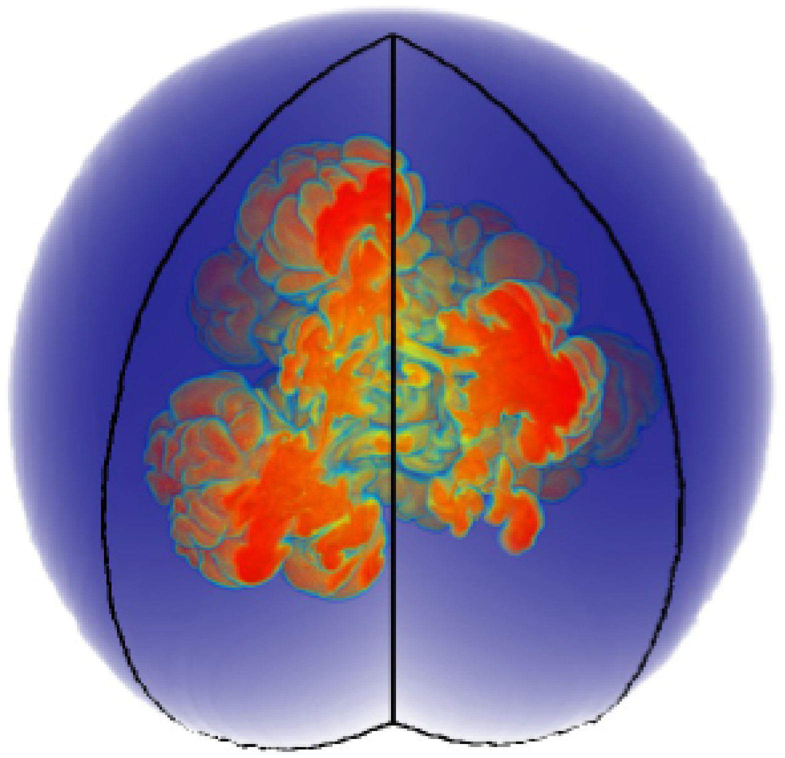
Energy loss from DM-nucleus collisions

Become gravitationally bound and accumulate in the core

$$\rho_{X,\ sphere} \geq \rho_{wd}$$

$$M_{crit} \propto \ m_X^{-1}, \ \rho_{wd}^{-1}, \ T_{core}$$

Dark matter sphere reaches critical mass for self-gravitation



Gravitational collapse heats white dwarf core via scattering with nuclei, sparking a supernova

J.F. Acevedo, J. Bramante, 1904.11993

Ignition by Heavy Asymmetric Dark Matter

Asymmetric: no self-annihilation interactions, allows dark matter core to grow

Heavy: thermalizes within a smaller volume

shorter capture time for collapse

$$t_{cap} \propto \; v_X,\, m_X^{-1},\, \rho_{wd}^{-1},\, \rho_X^{-1},\, \sigma_{nX}^{-1}$$

Vector Portal Model

Higgs Portal Model

Baryonic Feedback and Galaxy Structure

Gas blowout from supernovae

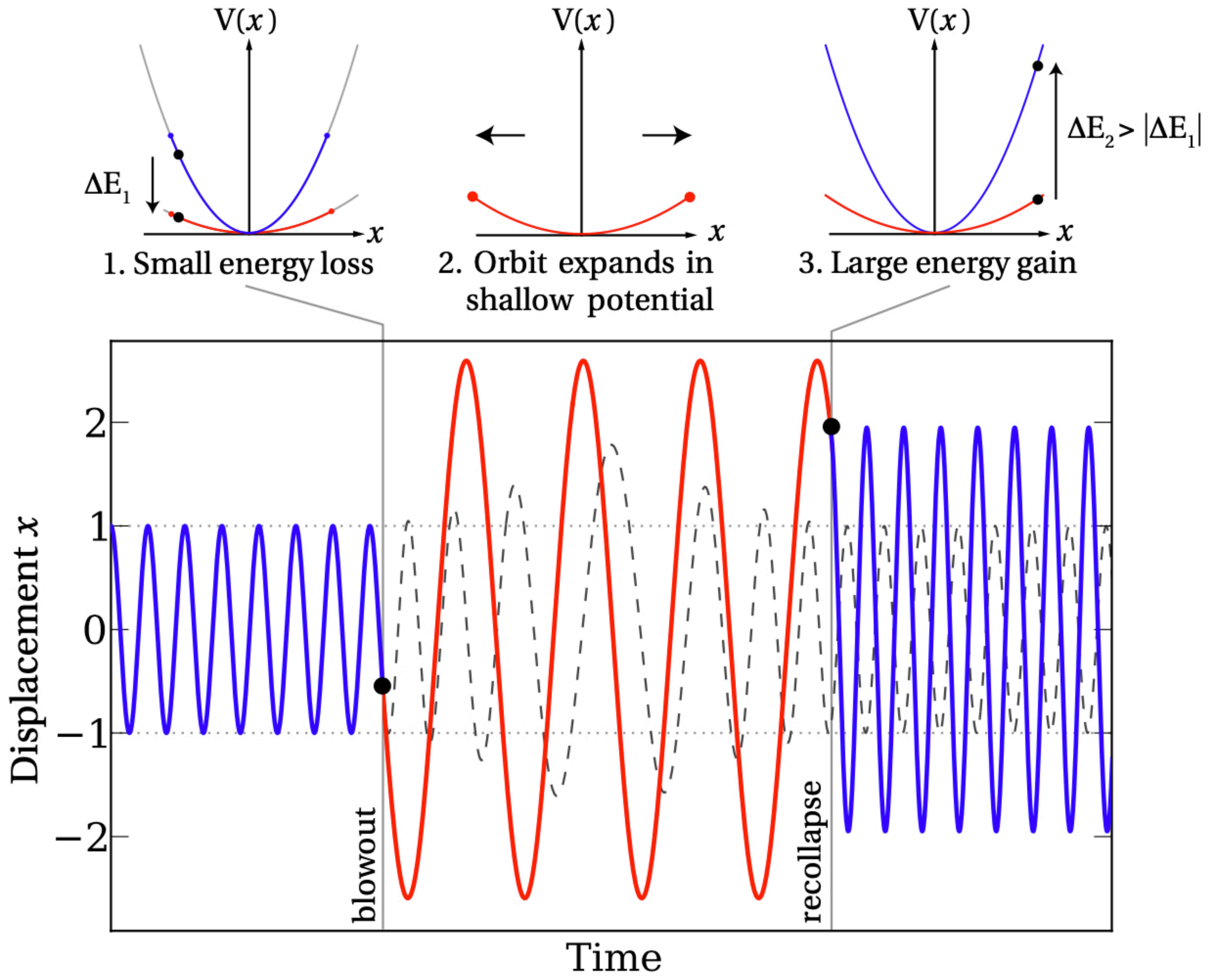
→ Suppress star formation, affecting galaxy luminosity

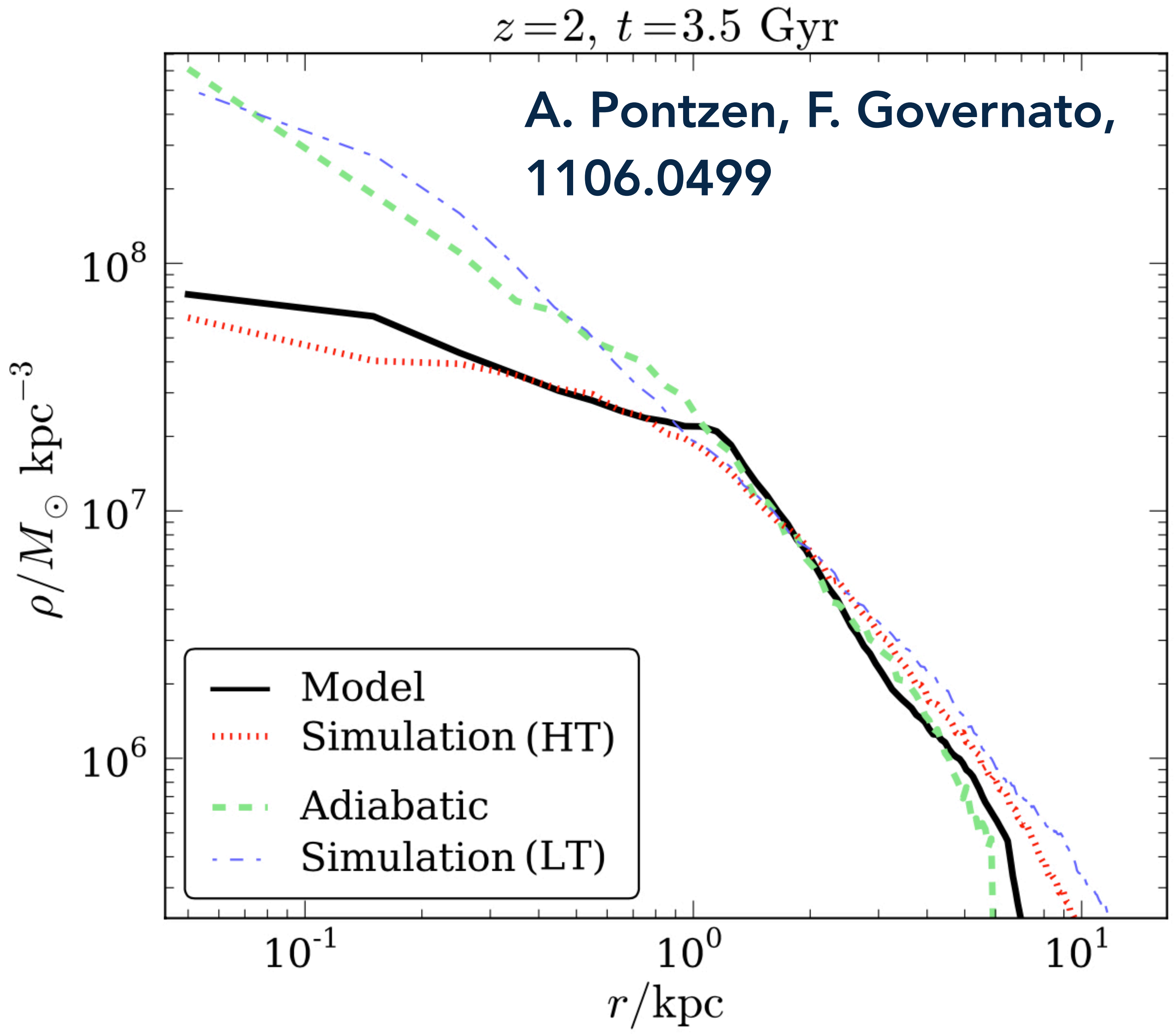
Baryonic Feedback and Galaxy Structure

Gas blowout from supernovae

→ Suppress star formation, affecting galaxy luminosity

→ Lead to fluctuations in dwarf galaxies' gravitational potential, flattening central density profile





Baryonic Feedback and Galaxy Structure

Gas blowout from supernovae

→ **Suppress star formation, affecting galaxy luminosity**

→ **Lead to fluctuations in dwarf galaxies' gravitational potential, flattening central density profile**

If dark matter induces feedback:

Explosion time depends on local dark matter distribution

and dark matter density is affected by feedback

Heavier white dwarfs explode sooner

Compare these effects in different simulations of an isolated dwarf galaxy

DM-Driven Baryonic Feedback Simulation

Initial Conditions: MakeNewDisk

Galaxy Simulation: GIZMO

Isolated Dwarf Galaxy 1.86 x 10^9 solar masses		
Galaxy Component	**Mass Fraction**	**Number of Particles**
Dark matter halo	0.9615	480750
Gas disk	0.0175	8750
Stellar disk	0.0175	8750
Stellar bulge	0.0035	1750
Particle mass: 3721 solar masses		

M. Smith et al 1709.03515

$t = 0$ **star particle formed**

stellar population calculated from Chabrier IMF

$t = 5\ Myr$ **core-collapse supernovae**

AGORA model, J. Kim et al. 1610.03066

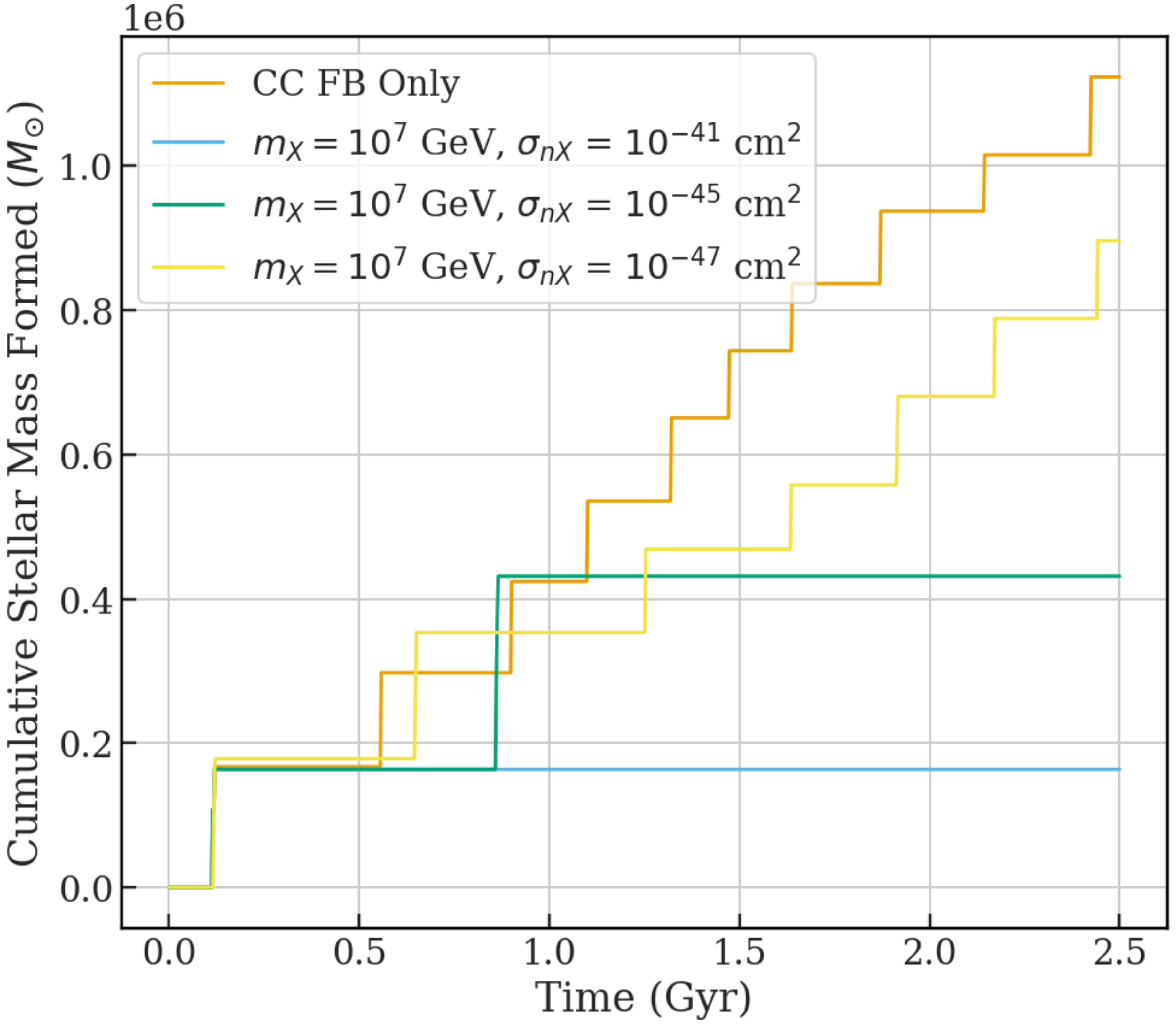
$t = t_{MS}$ **white dwarf formation**, $0.8 - 1.4\ M_\odot$

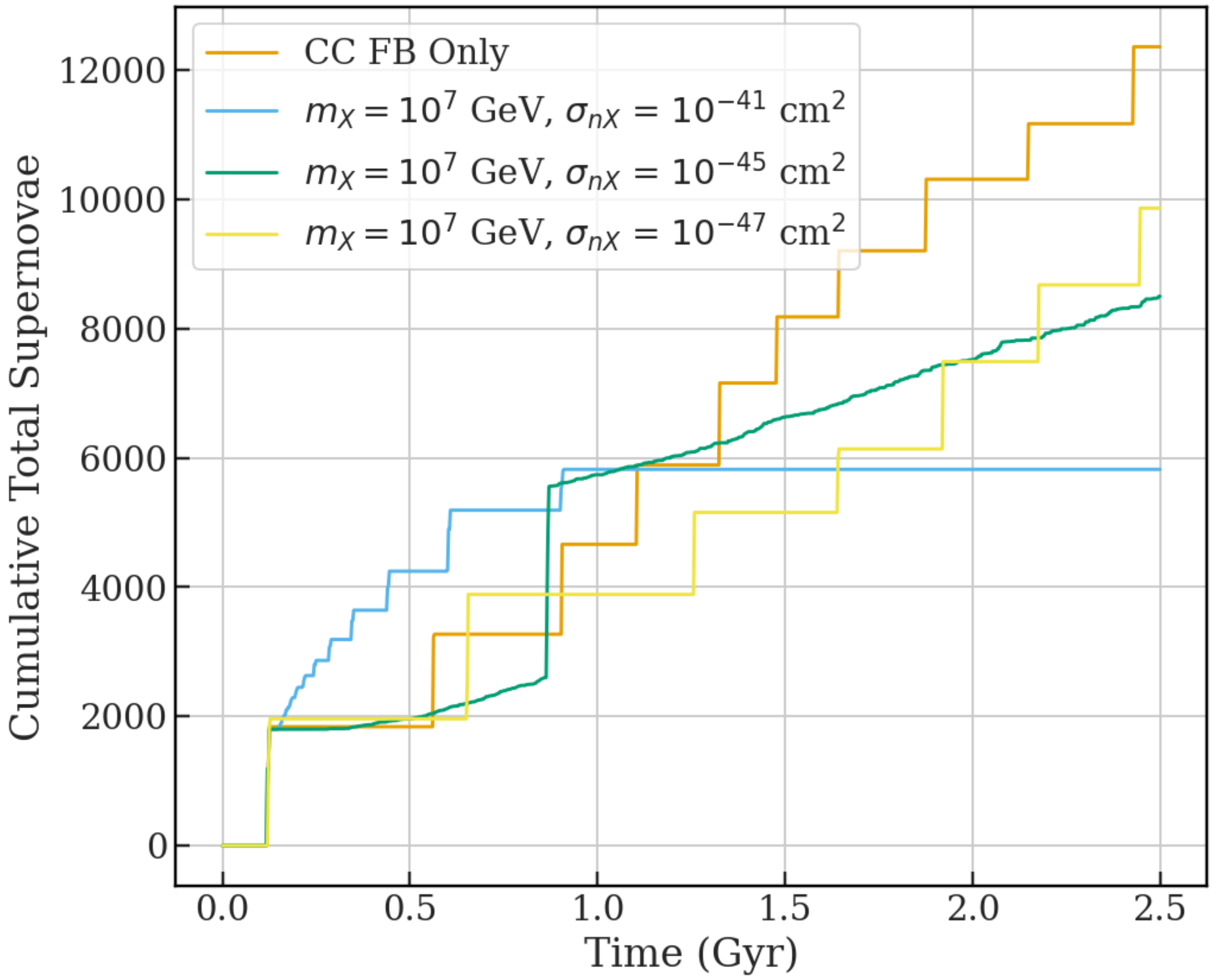
explosion time calculated using local v_X, ρ_X

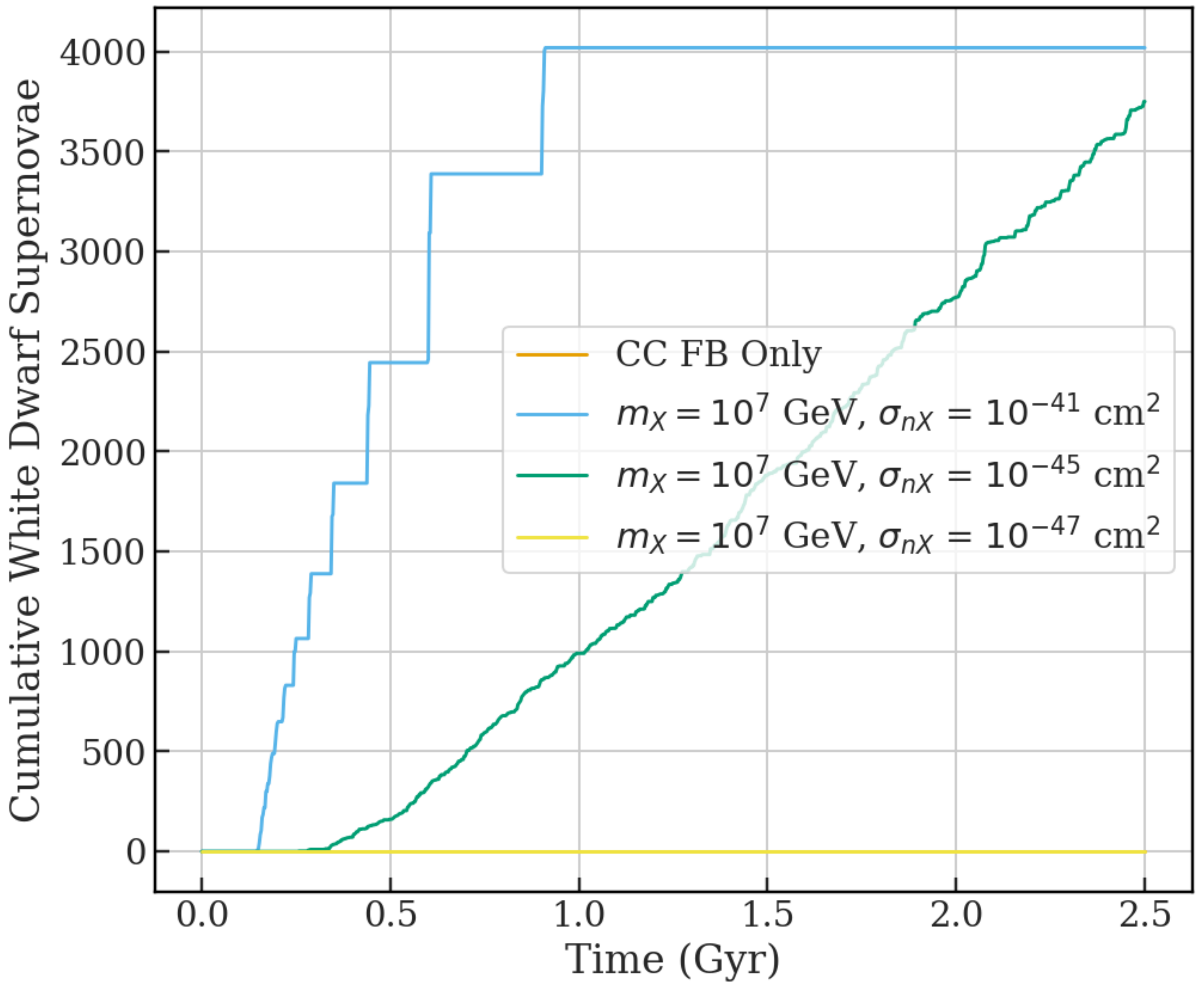
$$t_{cap} \propto \ v_X,\ m_X^{-1},\ \rho_{wd}^{-1},\ \rho_X^{-1},\ \sigma_{nX}^{-1}$$

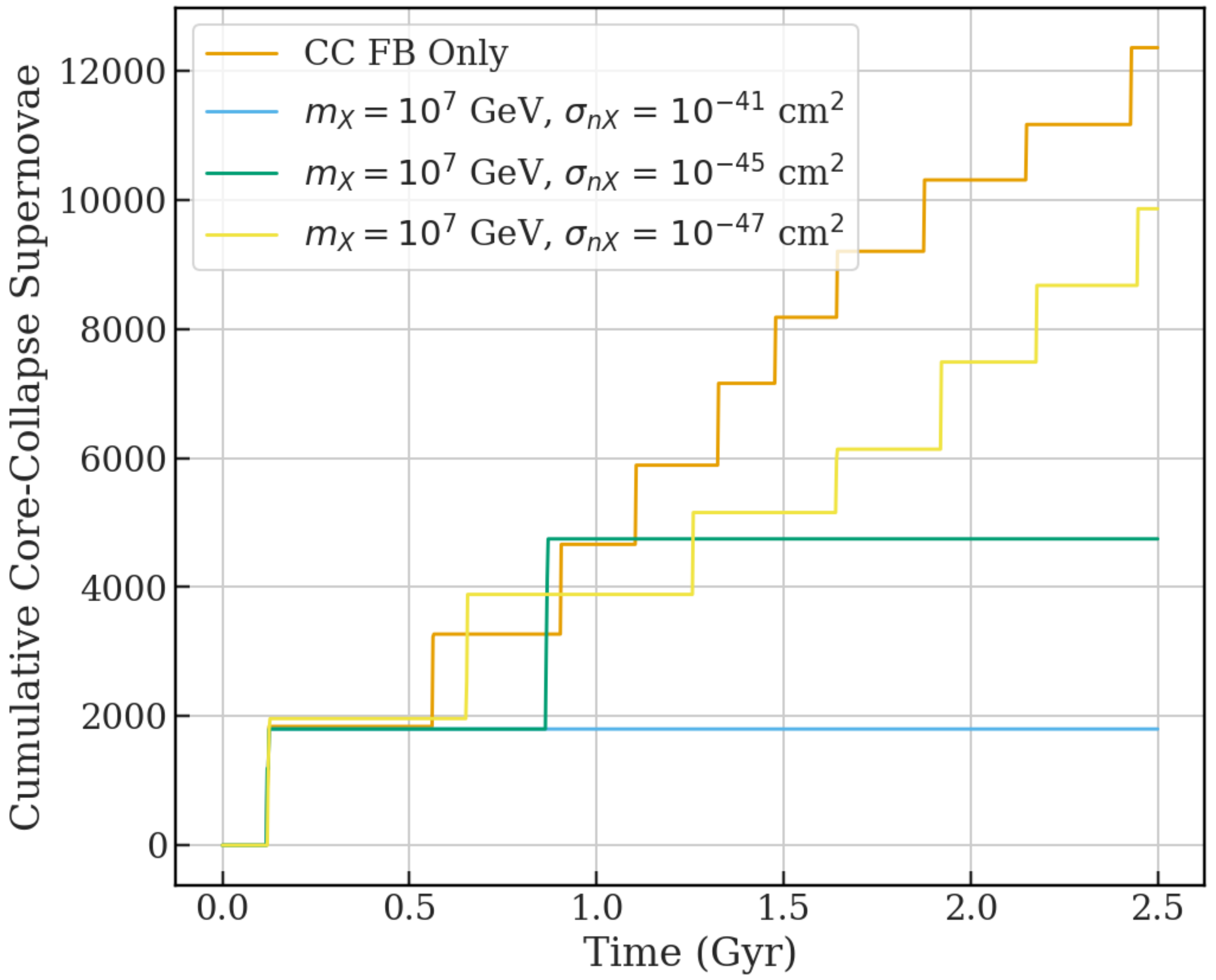
$t = t_{cap}$ **type Ia supernovae**

Star Formation Suppression







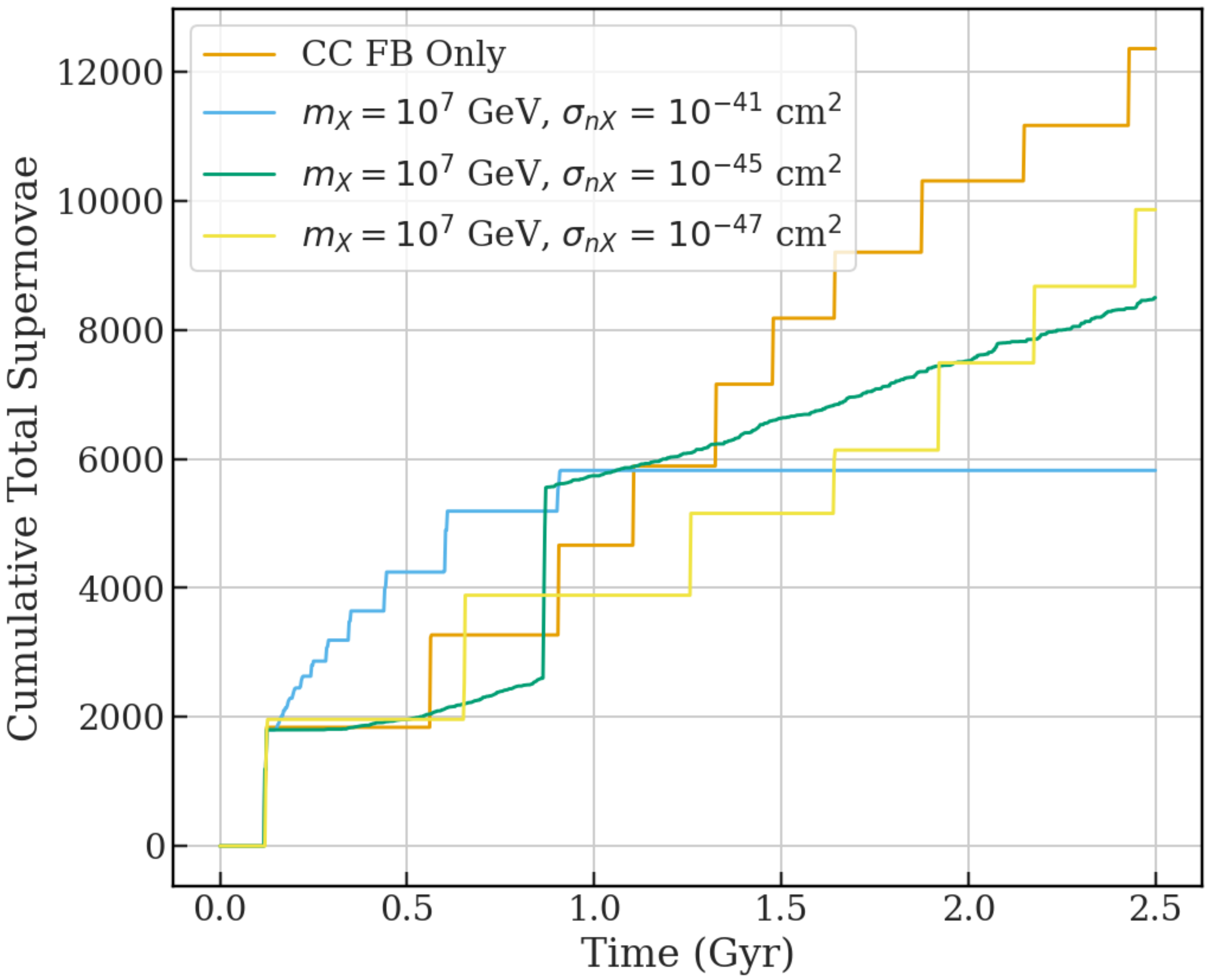


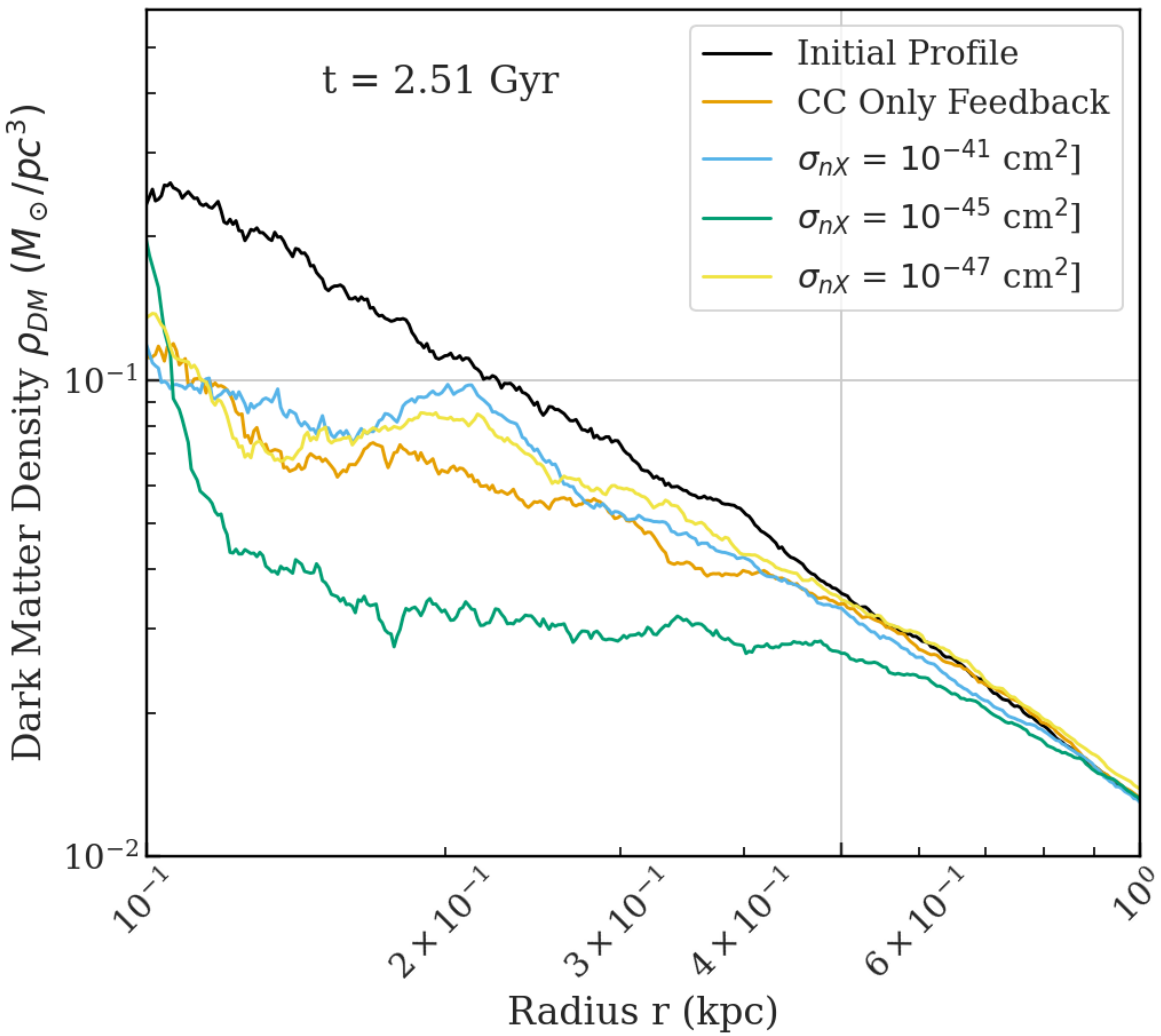
High cross-sections: complete gas blowout, suppressing star formation and subsequent supernovae

Intermediate cross-sections: star formation epochs slowed

Preliminary Results

Baryonic Feedback Creating Cored Halo Profiles





High cross-section: baryonic feedback effects shut off by suppressed star formation

Intermediate cross-section: long period of sustained supernova explosions allows more efficient flattening

Preliminary Results

Conclusions and Next Steps

Dark baryonic feedback in a small dwarf galaxy can affect star formation and dark matter profiles

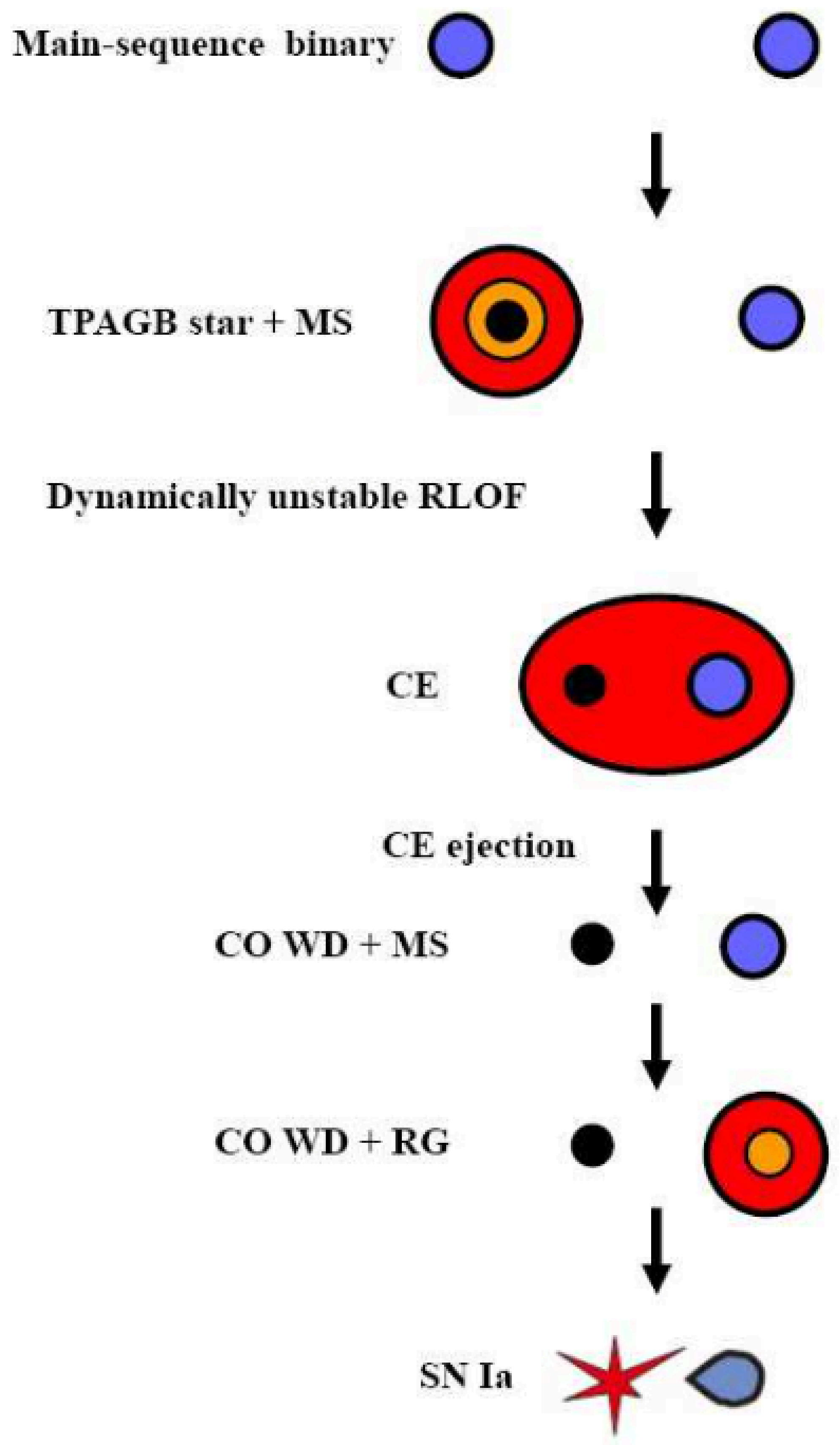
Sufficient dark baryonic feedback could "shut itself off", decreasing long-term feedback effects

Next steps:

- Simulation of larger galaxy
  - greater difference in ρ_X : more explosions in the central region
- Improve modelling of energy ejection for type Ia supernovae
- Incorporate dark baryonic feedback during galaxy formation

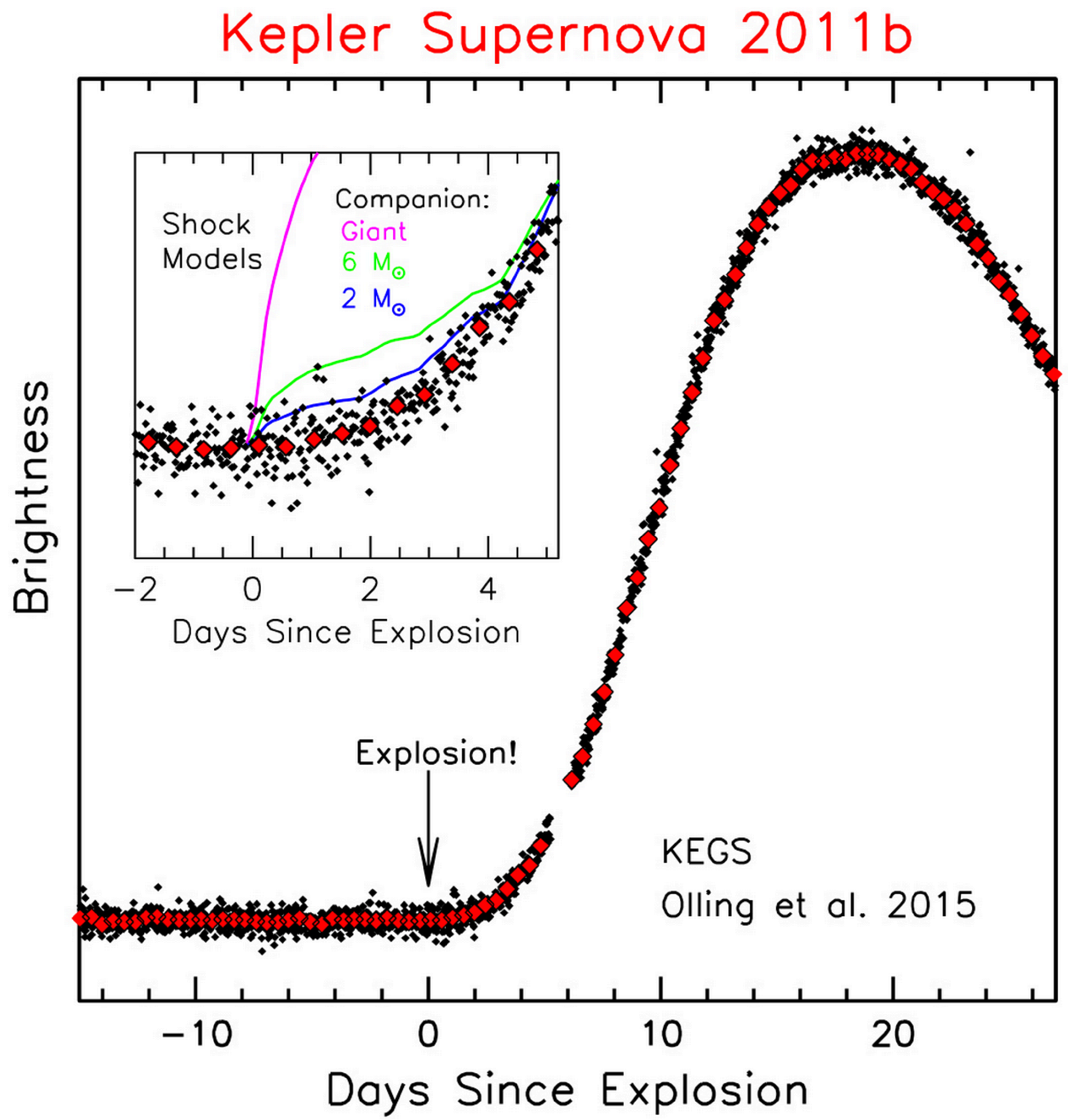
Thank you!

Main Sequence Binary Ignition



Main Sequence Binary Evolution
B. Wang, Z. Han 1204.1155

SNe ejecta collide with companion star: expect a "shock" spike in the light curve



Capture, Thermalization and Collapse Timescales

Capture: $\dot{m}_X \approx \text{Min}\left[3\times 10^{27}\,\frac{\text{GeV}}{\text{s}}, 6\times 10^{24}\,\frac{\text{GeV}}{\text{s}}\left(\frac{10^8\ \text{GeV}}{m_X}\right)\left(\frac{\sigma_{nX}}{10^{-42}\ \text{cm}^2}\right)\right]\times\left(\frac{\rho_X}{0.3\ \text{GeV/cm}^3}\right)\left(\frac{10^{-3}}{\bar{v}}\right)$

First Thermalization: $t_1^{th} \lesssim 10^{-4}\ \text{yrs}\left(\frac{10^{-40}\ \text{cm}^2}{\sigma_{nX}}\right)\left(\frac{m_X}{10^6\ \text{GeV}}\right)\left(\frac{1.4 M_\odot}{M}\right)^{\frac{3}{2}}\left(\frac{R}{2500\ \text{km}}\right)^{\frac{7}{2}}$

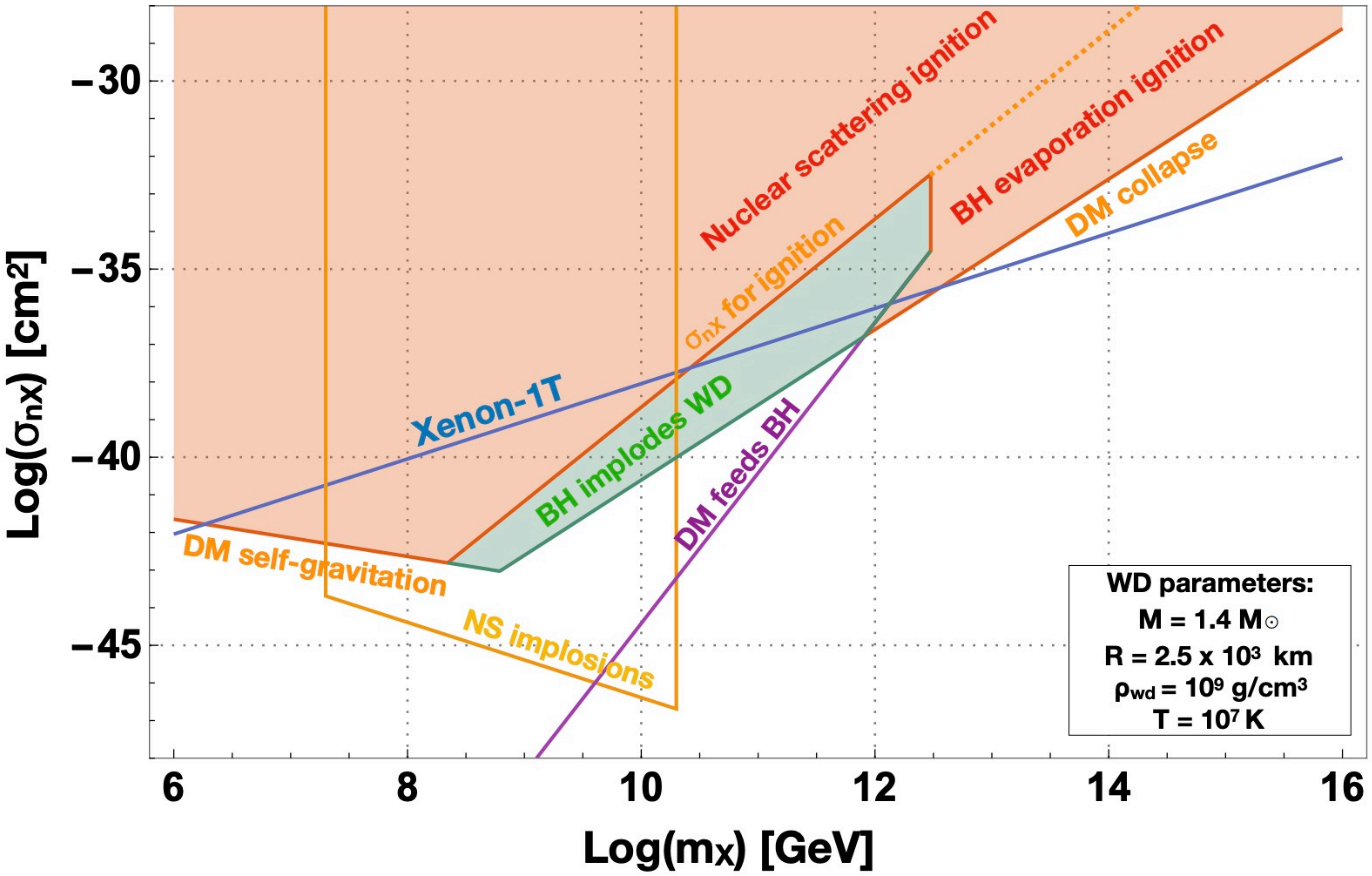
Second Thermalization: $t_2^{th} \approx 20\ \text{yrs}\left(\frac{10^{-40}\ \text{cm}^2}{\sigma_{nX}}\right)\left(\frac{m_X}{10^6\ \text{GeV}}\right)^2\left(\frac{10^7\ \text{K}}{T}\right)^{\frac{5}{2}}$

Collapse: $r_{th} = \sqrt{\frac{9T}{4\pi G\rho_{wd} m_X}} \approx 30\ \text{m}\left(\frac{10^6\ \text{GeV}}{m_X}\right)^{\frac{1}{2}}\left(\frac{10^9\ \frac{\text{g}}{\text{cm}^3}}{\rho_{wd}}\right)^{\frac{1}{2}}\left(\frac{T}{10^7\ \text{K}}\right)^{\frac{1}{2}}$

$$N_{sg} = \frac{M_{crit}}{m_X} \approx 6\times 10^{37}\left(\frac{10^6\ \text{GeV}}{m_X}\right)^{\frac{5}{2}}\left(\frac{10^9\ \frac{\text{g}}{\text{cm}^3}}{\rho_{wd}}\right)^{\frac{1}{2}}\left(\frac{T}{10^7\ \text{K}}\right)^{\frac{3}{2}}$$

J.F. Acevedo, J. Bramante, 1904.11993

Bounds from an Old GAIA White Dwarf



J.F. Acevedo, J. Bramante, 1904.11993