ASYMMETRIC DARK MATTER & NEUTRON STARS

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Compact stars in the QCD phase diagram 2026
Barcelona, 18-23 May 2026

based on

NonPrimordial Solar Mass Black Holes

with C. Kouvaris & P. Tinyakov, PRL 121 (2018) 22, 221102

Condensed dark matter with Yukawa interactions

with R. Garani & J. Vandecasteele, *PRD* 106 (2022) 11, 116003

Compact stars as portals to extra-dimensional Dark Matter

with R. Garani, C. Kouvaris & J. Vandecasteele, arXiv:2512.14837

Weakly interacting massive particles and neutron stars

Itzhak Goldman and Shmuel Nussinov
School of Physics and Astronomy, Raymond and Beverley Sackler Faculty of Exact Sciences, Tel Aviv University, Tel Aviv 69978, Israel
(Received 21 April 1989)

Neutron stars are used to set constraints on the characteristics of weakly interacting massive particles (WIMP's) suggested as dark-matter candidates. Some special classes of WIMP's are ruled out because they would be trapped in neutron stars, concentrate towards the star center, and become self-gravitating. This results in the formation of a mini black hole that consumes the neutron star, transforming it into a black hole, on a time scale shorter than observed ages of neutron stars in various astrophysical systems.

dark matter particle

$v_\chi \sim 10^{-3}$

$\rho_\chi \sim \mathrm{GeV/cm^3}$

$\rho_n \sim 10^{38}\,\mathrm{GeV/cm^3}$

$3 \cdot 10^{14}\,\mathrm{g/cm^3}$

$10^{-3}\,\mathrm{GeV^4}$

I. DM capture $\sigma_{\chi n}$?

↓

II. DM thermalisation

↓

III. DM self-gravitating

↓

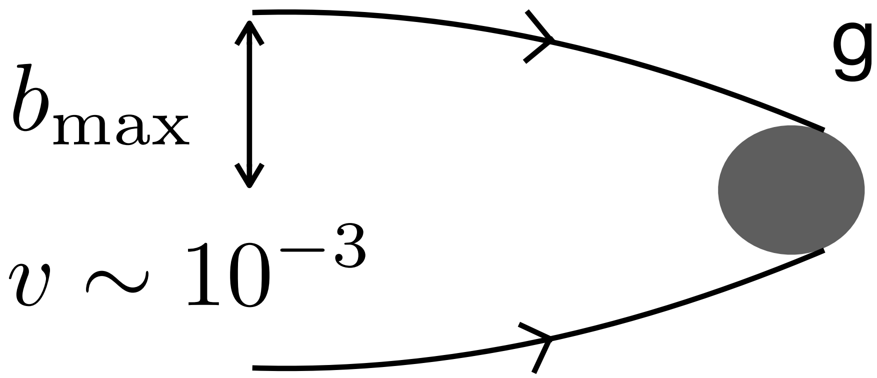
IV. DM gravitational collapse

↓

V. NS turned into solar-mass BH

Goldman & Nussinov, 1989

I. DM capture



grav. focusing

$$b_{\max} = R\sqrt{1 + \frac{2GM}{Rv^2}}$$

$$\sigma_{\text{geom}} = \pi R^2 \longrightarrow \sigma = \pi b_{\max}^2 \approx 2\pi \frac{GMR}{v^2}$$

capt. rate $$C_{\text{capt}} \sim \left(\frac{\rho_\chi}{m_\chi} \frac{GMR}{v} \right) \times \min\left(1, n_n \sigma_{n\chi} R\right)$$

saturation if $$\sigma_{\chi n} \gtrsim \sigma_c \sim \frac{1}{n_n R} \sim 10^{-45}\,\text{cm}^2$$

$$N_{\text{capt}} \sim 10^{42} \frac{\text{GeV}}{m_\chi} \sim 10^{-15} M_\odot$$

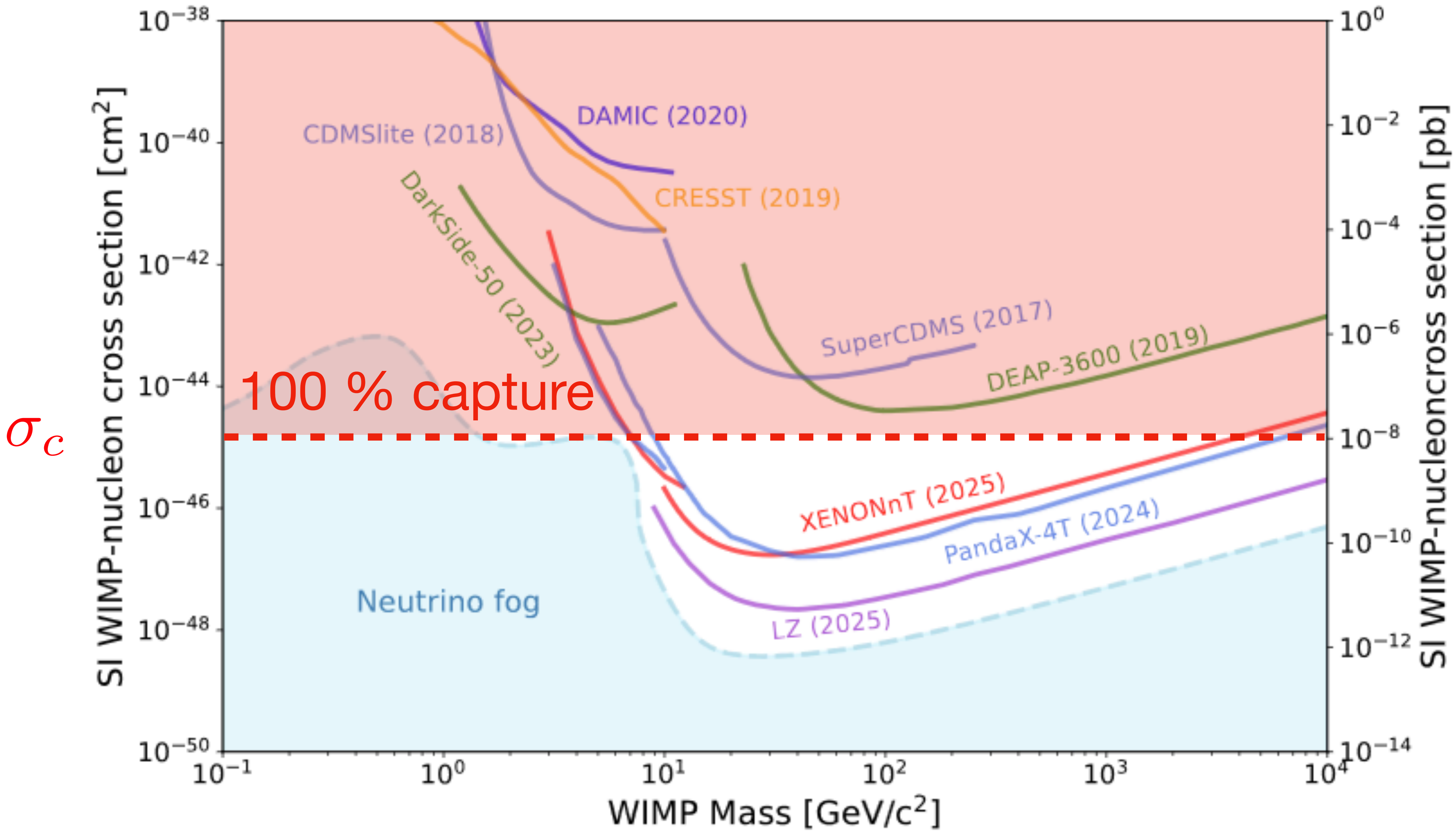


Figure 27.1: Upper limits on the SI DM-nucleon cross section as a function of DM mass.

PDG 2025

WIMP ⟶ ASYMMETRIC DM

By construction, WIMP annihilate — difficult to accumulate

$$\dot{N} = C - AN^2 \longrightarrow N_{\max} = \sqrt{C/A}$$

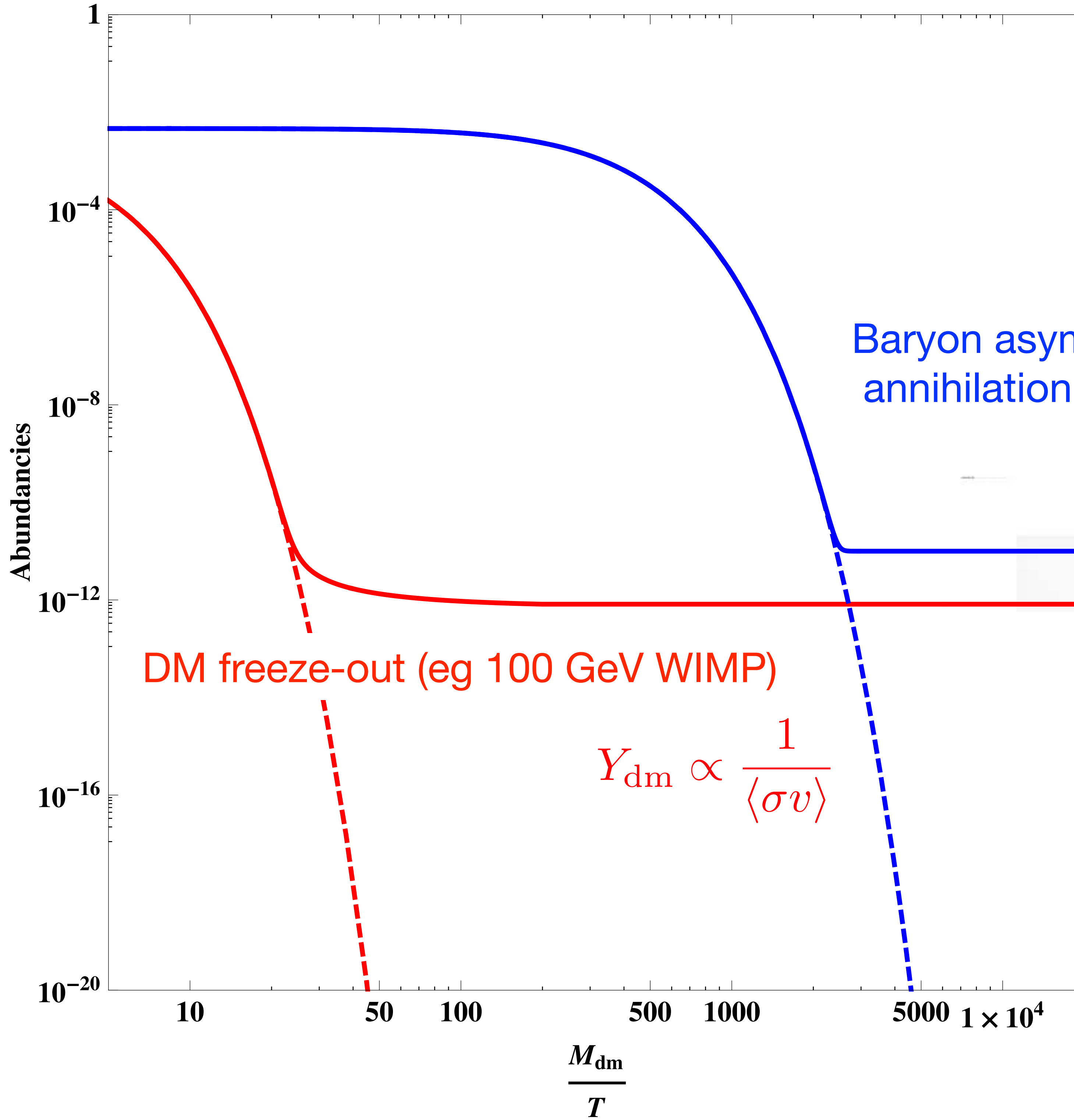
Asymmetric DM ~ Baryon asymmetry

$$\dot{N} = C \longrightarrow N \sim C \times t$$

Chris Kouvaris & Peter Tinyakov,
"Constraining Asymmetric Dark Matter through observations of compact stars",
Phys. Rev. D 83 083512

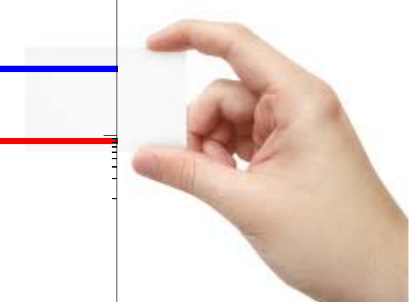
Samuel D. McDermott, Hai-Bo Yu & Kathryn M. Zurek *"Constraints on Scalar Asymmetric Dark Matter from Black Hole Formation in Neutron Stars"*
arXiv:1103.5472; PRD 85 023519

ASYMMETRIC DM



Baryon asymmetry (avoiding annihilation catastrophe)

$Y_B \propto \mu_B$



?

$$\frac{\Omega_{\rm dm}}{\Omega_{\rm b}} \approx 5$$

SIGNATURES OF ASYMMETRIC DM ?

By construction, asymmetric DM does not annihilate « today »

→ no indirect detection (ie gamma-rays)

Destruction of NS may be a possible signature

Mere lack/absence of old NS in dense DM regions

GW from solar-mass BH

C. Kouvaris, P. Tinyakov, MHGT, PRL 121 (2018) 22, 221102
NonPrimordial Solar Mass Black Holes

GW FROM SOLAR-MASS BH

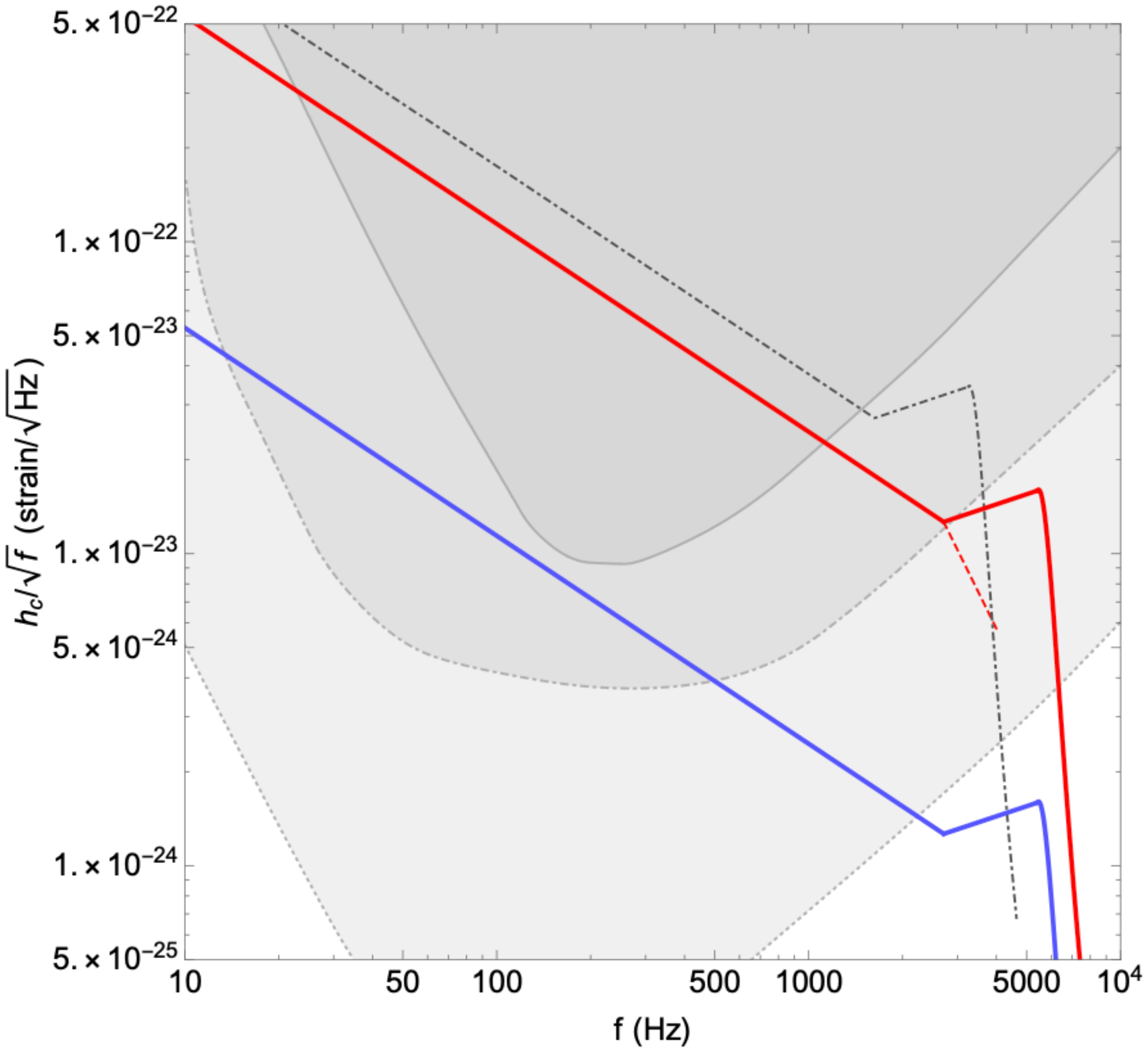


FIG. 2. Spectrum of GW from a $(1.5+1.5)M_\odot$ BBH at 40 Mpc (red solid). The spectrum of a corresponding BNS is schematically depicted by the break (red dashed). Also shown are a $(1.5+1.5)M_\odot$ BBH at 400 Mpc (blue solid) and a $(2+2)M_\odot$ BBH at 40 Mpc (grey dot-dashed). The sensitivity curves are for to LIGO2017 (black solid), LIGO design (black dot-dashed) and ET design (black dotted).

C. Kouvaris, P. Tinyakov, MHGT, PRL 121 (2018) 22, 221102
NonPrimordial Solar Mass Black Holes

I. Asymmetric DM capture

$$N_{\rm capt} \sim 10^{42}\,\frac{\rm GeV}{m_\chi} \sim 10^{-15} M_\odot$$

$\rho_\chi \sim {\rm GeV/cm^3}$ (could be much larger)

$\sigma_{\chi n} \gtrsim \sigma_c$ (could be much smaller)

II. DM thermalisation

$$r_{\rm th} \sim \sqrt{\frac{T}{G \rho_n m_\chi}} \sim \text{few meters} \left(\frac{\rm GeV}{m_\chi}\right)^{1/2}$$

(timescale ~ mins to yrs)

III. DM self-gravitating

?

IV. DM gravitational collapse

V. NS turned into solar-mass BH

III. SELF-GRAVITATING DM

DM cloud thermalized & confined within the thermal radius

DM self-gravitating when $M_\chi \gtrsim M_n(r_{\rm th})$

$$\longrightarrow \quad N_\chi \sim 10^{44} \left(\frac{\rm GeV}{m_\chi}\right) \quad \text{for} \quad \begin{array}{l} \rho_\chi \sim {\rm GeV/cm^3} \\ \text{t} \sim \text{Gyr} \\ T \sim 10^5\, K \end{array}$$

but (typically) $N_\chi \gtrsim N_{\rm capt} \sim 10^{42} {\rm GeV}/m_\chi$

$\longrightarrow$ old & cold NS in dense DM regions

I. Asymmetric DM capture

$$N_{\rm capt} \sim 10^{42} \frac{\rm GeV}{m_\chi} \sim 10^{-15} M_\odot$$

$\rho_\chi \sim {\rm GeV/cm^3}$ (could be much larger)

$\sigma_{\chi n} \gtrsim \sigma_c$ (could be much smaller…)

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(timescale ~ mins to yrs)

III. DM self-gravitating

$$N_\chi \sim 10^{44} \left(\frac{\rm GeV}{m_\chi}\right)$$

(old/cold NS, dense DM regions)

IV. DM gravitational collapse

? $R_{\rm Sch} \sim {\rm fm}$

V. NS turned into solar-mass BH

III. DM self-gravitating

↓

IV. DM gravitational collapse

So far, it did not matter if DM is bosonic or fermionic

My story is essentially about **fermions**

IV. DM GRAVITATIONAL COLLAPSE

degenerate DM cloud $n_\chi \sim k_F^3 \sim N_\chi / R^3$

non-relativistic Fermi pressure

$$E_\chi \sim \frac{N_\chi^{2/3}}{m_\chi R^2} - \frac{G N_\chi m_\chi^2}{R} \longrightarrow R_{\min} \sim \frac{M_{\rm Pl}^2}{m_\chi^3 N_\chi^{1/3}}$$

Chandrasekhar condition

$$k_F \sim \frac{N_\chi^{1/3}}{R} \sim \frac{m_\chi^3 N_\chi^{2/3}}{M_{\rm Pl}^2} \sim m_\chi \longrightarrow N_{\rm Ch} \sim \left(\frac{M_{\rm Pl}}{m_\chi}\right)^3$$

relativistic : collapse

IV. DM GRAVITATIONAL COLLAPSE

Fermi pressure fails to support the cloud if

$$N_{\rm Ch} \sim \left(\frac{M_{\rm Pl}}{m_\chi}\right)^3 \sim 10^{57} \left(\frac{\rm GeV}{m_\chi}\right)^3$$

e.g. $M_{\rm Ch} \sim M_\odot$ for $m_\chi \sim {\rm GeV}$

$$N_{\rm capt} \sim 10^{42} \left(\frac{\rm GeV}{m_\chi}\right) \gtrsim M_{\rm Ch} \longrightarrow m_\chi \gtrsim 10\,{\rm PeV}$$

ultra-heavy
asymmetric
fermionic DM

I. Asymmetric DM capture

$$N_{\text{capt}} \sim 10^{42}\,\frac{\text{GeV}}{m_\chi} \sim 10^{-15} M_\odot$$

$\rho_\chi \sim \text{GeV}/\text{cm}^3$ (could be much larger)

$\sigma_{\chi n} \gtrsim \sigma_c$ (could be much smaller…)

II. DM thermalisation

$$r_{\text{th}} \sim \sqrt{\frac{T}{G\rho_n m_\chi}} \sim \text{few meters}\left(\frac{\text{GeV}}{m_\chi}\right)^{1/2}$$

(timescale ~ mins to yrs)

III. DM self-gravitating

$$N_\chi \sim 10^{44}\left(\frac{\text{GeV}}{m_\chi}\right)$$

(old, cold NS,

dense DM regions)

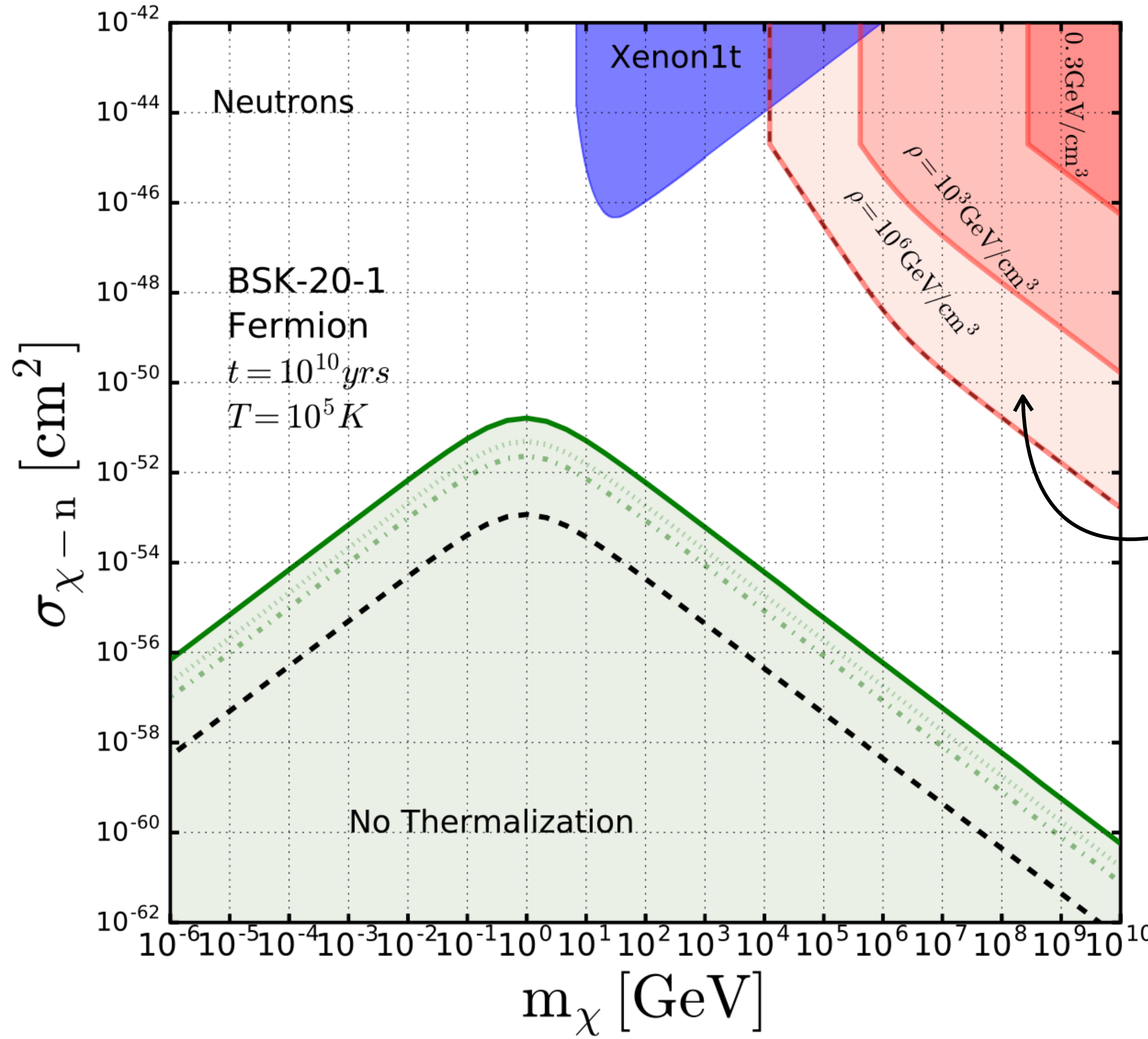
IV. DM black hole

$$N_{\text{Ch}} \sim \left(\frac{M_{\text{Pl}}}{m_\chi}\right)^3 \sim 10^{57}\left(\frac{\text{GeV}}{m_\chi}\right)^3$$

$$m_\chi \gtrsim 10\,\text{PeV}$$

V. NS turned into solar-mass BH

Bondi accretion vs Hawking radiation



DM rich regions

Garani, Genolini & Hambye (2019)

The trouble (among others things) with Asymmetric DM

Typically, DM initially in thermal equilibrium.

One of the **complications** is to suppress the symmetric part, which requires a **large annihilation cross section**.

This is bounded by **unitarity** $$\langle \sigma v \rangle \lesssim \frac{4\pi}{m_\chi^2 v}$$

Griest & Kamionkowski (1990)

$$\langle \sigma v \rangle \gtrsim 10^{-36} \mathrm{cm}^2/s \longrightarrow m_\chi \lesssim 100\,\mathrm{TeV} \ll 10\,\mathrm{PeV}$$

suppress symmetric part	unitarity bound	gravitational collapse

Q: HOW TO BEAT FERMI PRESSURE ?

Models of ultra-heavy asymmetric DM ?

DM self-interactions ?

Softer Equation of State ?

DM SELF-INTERACTIONS ?

Cold Dark Matter (CDM) works perfect on large scales

But there are issues on galactic and sub-galactic scales

A **cusp or a core** at the center of (dwarf) galaxies ?

collisionless DM

self-interacting DM ?

$$\sigma/m_{\rm dm} \sim {\rm barn/GeV}$$

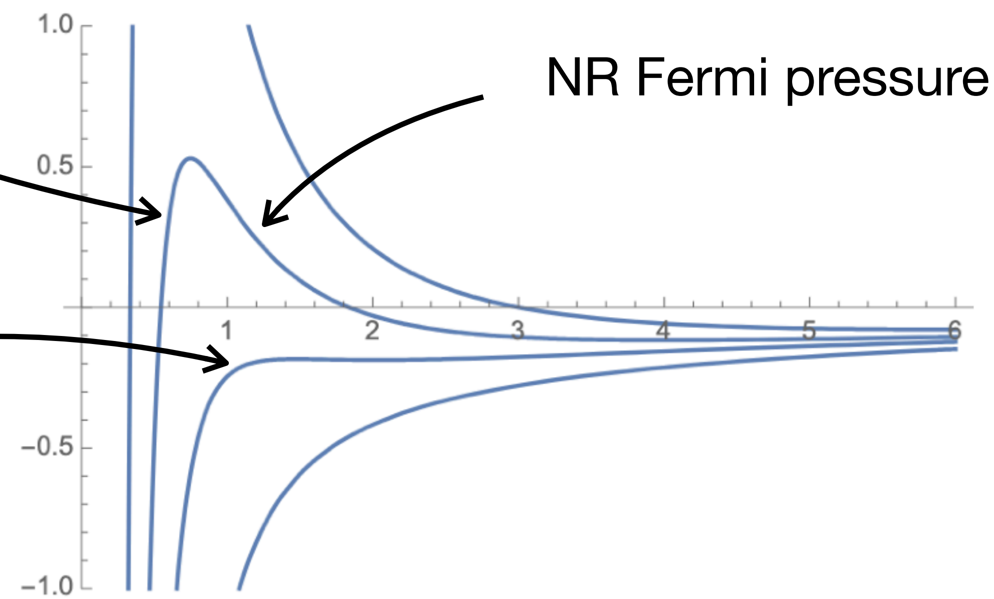
Spergel & Steinhardt (1999)

Homogeneous DM sphere, N particles, Yukawa potential

$$E_\chi \sim \frac{N^{2/3}}{m_\chi R^2} - \frac{\alpha N}{m_\phi R^3} - \frac{G N m_\chi^2}{R}$$

attractive $\alpha > 0$

range ~ $1/m_\phi$



$$N_{\rm Ch} \sim \left(\frac{m_\phi}{\sqrt{\alpha} m_\chi}\right)^3 \left(\frac{M_{\rm Pl}}{m_\chi}\right)^3$$

C. Kouvaris, P. Tinyakov, MHG, PRL 121 (2018) 22, 221102

#	α	mediator mass m_ϕ	dark matter mass m_χ	$N_{\rm cr}$	$N_{\rm Ch}$	$M_{\rm Ch}$
1	10^{-4}	1 MeV	1 TeV	$3 \cdot 10^{33}$	$6 \cdot 10^{35}$	$5 \cdot 10^{-19} M_\odot$
2	10^{-3}	10 MeV	1 TeV	$5 \cdot 10^{35}$	$2 \cdot 10^{37}$	$2 \cdot 10^{-17} M_\odot$
3	10^{-3}	1 MeV	200 GeV	$1.3 \cdot 10^{34}$	$3 \cdot 10^{38}$	$5 \cdot 10^{-17} M_\odot$
4	10^{-4}	1 MeV	200 GeV	$3.7 \cdot 10^{34}$	$8 \cdot 10^{39}$	$2 \cdot 10^{-15} M_\odot$

TABLE I. Benchmark values of Yukawa self-attraction parameters, corresponding critical numbers $N_{\rm cr}$ and $N_{\rm Ch}$, and resulting mass of the mini-BH.

$$N_{\rm Ch} \sim \left(\frac{m_\phi}{\sqrt{\alpha} m_\chi}\right)^3 \left(\frac{M_{\rm Pl}}{m_\chi}\right)^3$$

$10^{-10} - 10^{-12}$

(solutions to core/cusp problem)

C. Kouvaris, P. Tinyakov, MHG, PRL 121 (2018) 22, 221102

WHICH SELF-INTERACTIONS ?

Spin 1 repulsive (not useful for our purpose)

Spin 0 attractive ~ Yukawa interaction

Spin 2 attractive ~ massive graviton

Spin 0 mediator ~ Yukawa interaction

DM — mediator

$$\mathcal{L} = i\bar{\psi}\partial\psi - m\bar{\psi}\psi + \tilde{\mu}\,\bar{\psi}\gamma^0\psi + \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m_\phi^2\phi^2 - g\,\bar{\psi}\psi\phi$$

Waleka model

$$m_* = m + g\langle\phi\rangle \rightarrow m_* = m - \frac{g^2}{m_\phi^2}n_s(m_*)$$ (modifies DM mass)

$$n_s = \langle\bar{\psi}\psi\rangle \sim \int_0^{k_F} dk\,k^2\frac{m_*}{\sqrt{k^2+m_*^2}}$$ (scalar density ≠ number density)

Low densities

$$n_s \approx \langle\psi^\dagger\psi\rangle = n \qquad \rho \approx mn + \frac{n^{5/3}}{m} - \frac{g^2n_s^2}{m_\phi^2}$$ (same as estimate)

High densities

$$n_s \rightarrow \text{const} \quad \& \quad m_* \rightarrow 0 \longrightarrow N_{\rm Ch} \sim \left(\frac{M_{\rm Pl}}{m_\chi}\right)^3$$

Gresham & Zurek (2018)

Which DM self-interactions ?

Spin 1 repulsive (not useful for our purpose)

Spin 0 attractive ~ Yukawa interaction (at the end, not useful)

Spin 2 attractive ~ massive graviton ?

MASSIVE SPIN-2

$$\mathcal{L} = \quad \bar{u}(p)\left[\not{p} + \mu\gamma^0 - m + \frac{2c_\chi}{4\Lambda} G_{\mu\nu}(\gamma^\mu p^\nu + \gamma^\nu p^\mu - 2g^{\mu\nu}(\not{p} - m))\right] u(p) - \frac{1}{2} M^2 G^2$$

DM mediator

$$\longrightarrow \qquad \rho \sim m_\chi n + \frac{n^{5/3}}{m_\chi} - \frac{c_\chi^2}{\Lambda^2}\frac{m_\chi^2 n^2}{M^2}$$

Unlike spin 0, $G_{\mu\nu}$ couples to the **number of particles** (ie conserved number)

Like gravity, massive spin 2 leads to collapse,

$$N_{\rm Ch} \sim \left(\frac{\Lambda M}{c_\chi m_\chi^2}\right)^3 \left(\frac{M_{\rm Pl}}{m_\chi}\right)^3 \ll \left(\frac{M_{\rm Pl}}{m_\chi}\right)^3$$

TOWER

OF

MASSIVE SPIN-2

???

1. Gravity stronger

$$V(r) = -\frac{G_4 m^2}{r}\sum_{n=0}^{\infty} e^{-nr/R_*} \underset{r \lesssim R_*}{\sim} -\frac{G_4 R_* m^2}{r^2} \sim -\frac{G_5 m^2}{r^2}$$

Braneworld, dark dimensions (new twist), … ~ ordinary matter confined to 3D

current constraints $R_* \lesssim \mu m$

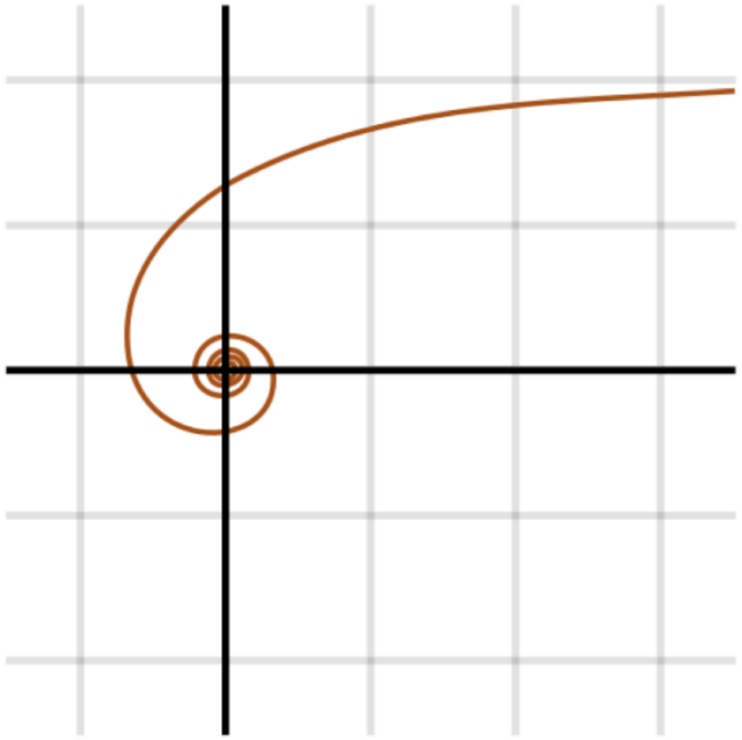
gravity strong at a (much) lower scale than M_{Pl}

Antoniadis, Arkani-Hamed, Dimopoulos, Dvali (1998)

2. Kepler orbits unstable

Inverse cube force law ~ d=1 extra-dimension

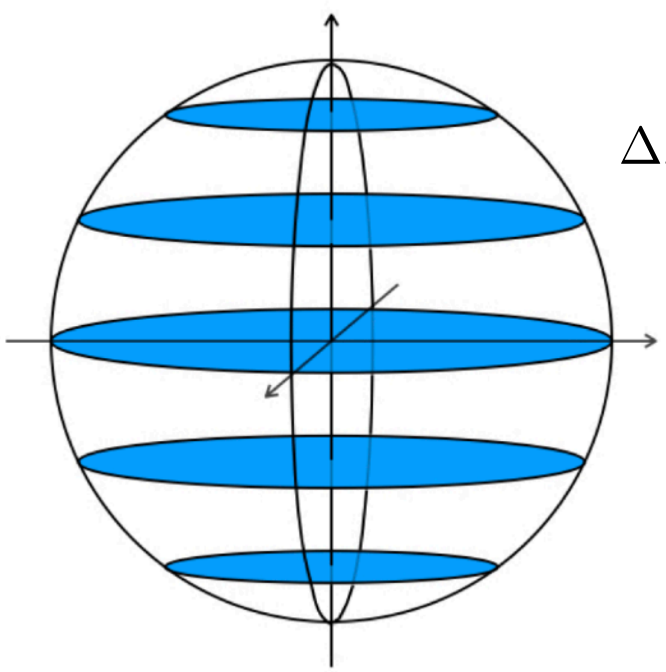
$$m\ddot{r} = -\frac{c}{r^3} + \frac{L^2}{mr^3}$$



cf Newton's *Principia*

more generally, **no stable Kepler orbits for d ≥ 2** extra dimensions

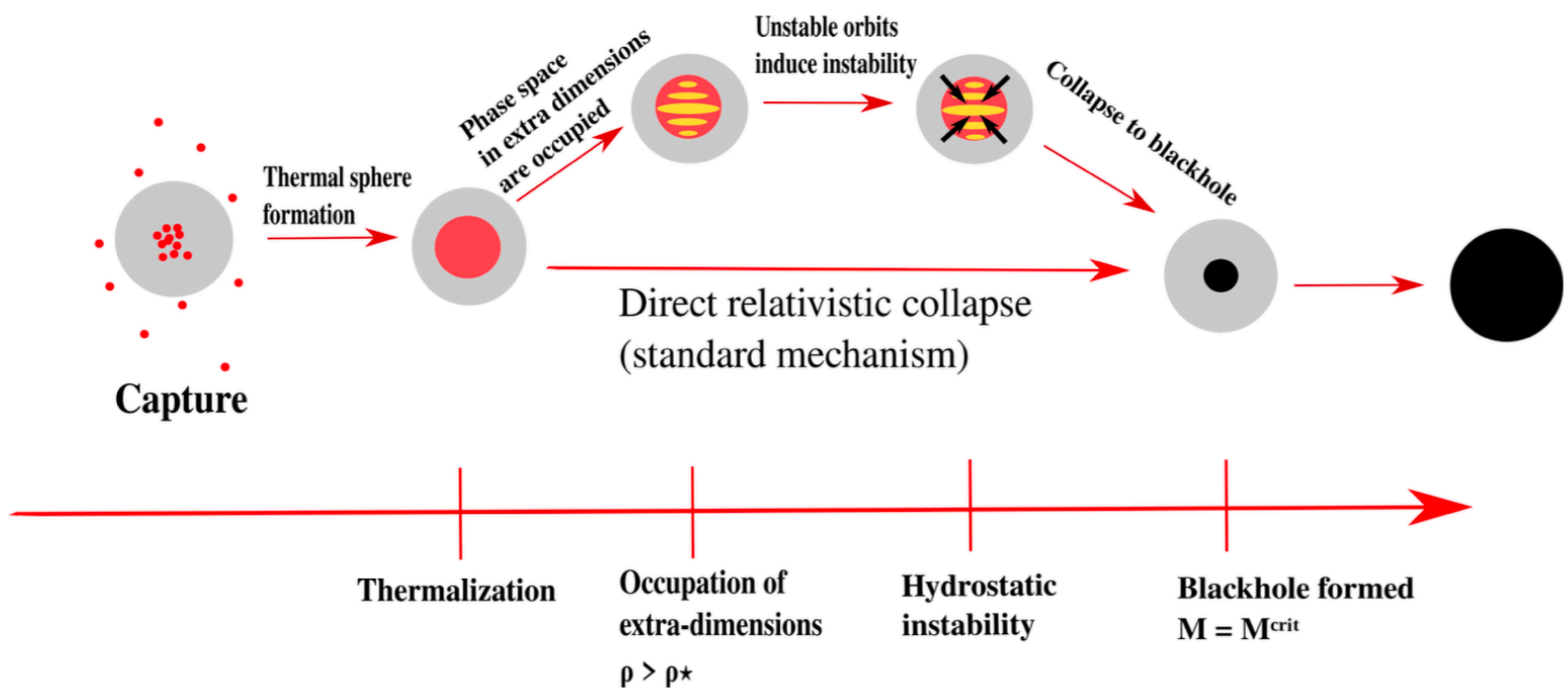
3. Softer equation of state



$$\rho = g \sum_{k_\perp} \int \frac{d^3k}{(2\pi)^3} \frac{E}{e^{\beta(E-\mu)}+1},$$

$$P = g \sum_{k_\perp} \int \frac{d^3k}{(2\pi)^3} \frac{p^2}{3E} \frac{1}{e^{\beta(E-\mu)}+1}$$

A DARK DIMENSIONS SCENARIO



- stronger gravity (lower effective Planck scale)
- no Kepler stable orbits

] helps but complicated

- **softer equation of state**

Our claim: EoS sufficient to make robust conclusions for d > 2

Garani, Kouvaris, Vandecasteele, MHGT (2025)

Polytropic index : $P = K\rho^{\gamma}$

$$\gamma_d = \frac{5+d}{3+d}$$

degenerate fermion gas

Standard lore : **no stable star-like configuration for**

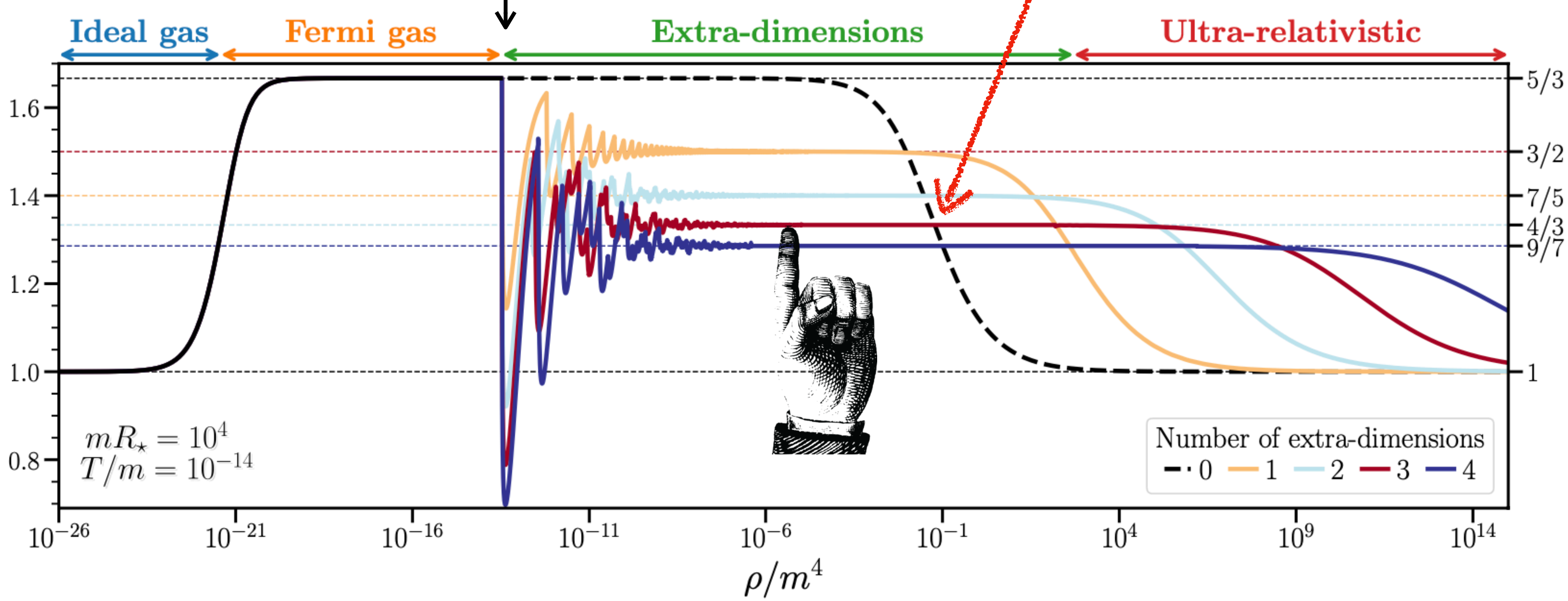
$$\gamma \leq \frac{4}{3} \qquad (d \geq 3)$$

cf Shapiro & Teukolsky

$k_F \gtrsim 1/R_*$

$3D\ N_{\mathrm{Ch}}$

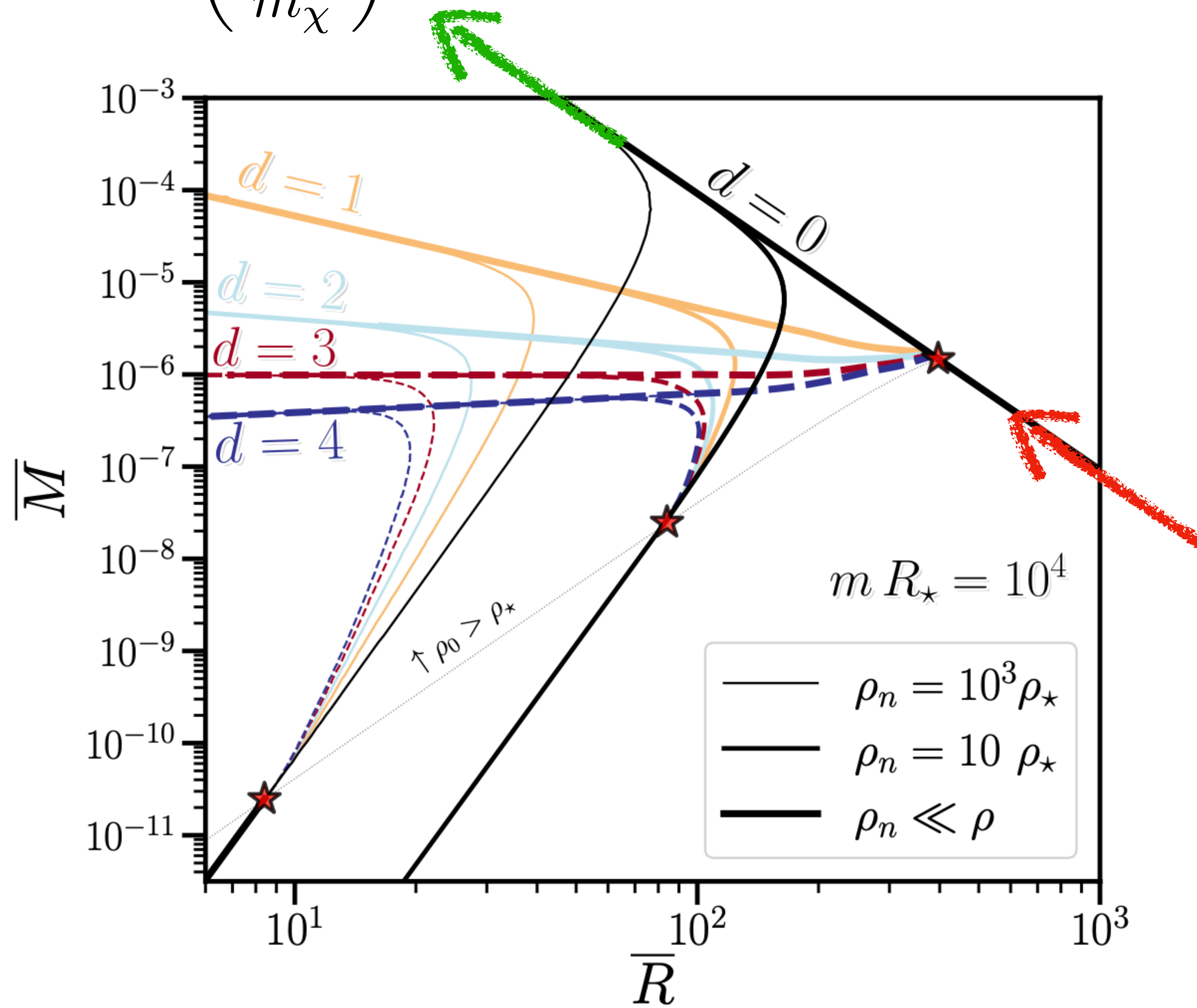
$$\gamma = \frac{d\ln P}{d\ln \rho}$$



Garani, Kouvaris, Vandecasteele, MHGT (2025)

STANDARD SCENARIO (d=0)

toward $N \gtrsim \left(\frac{M_{\rm Pl}}{m_\chi}\right)^3$

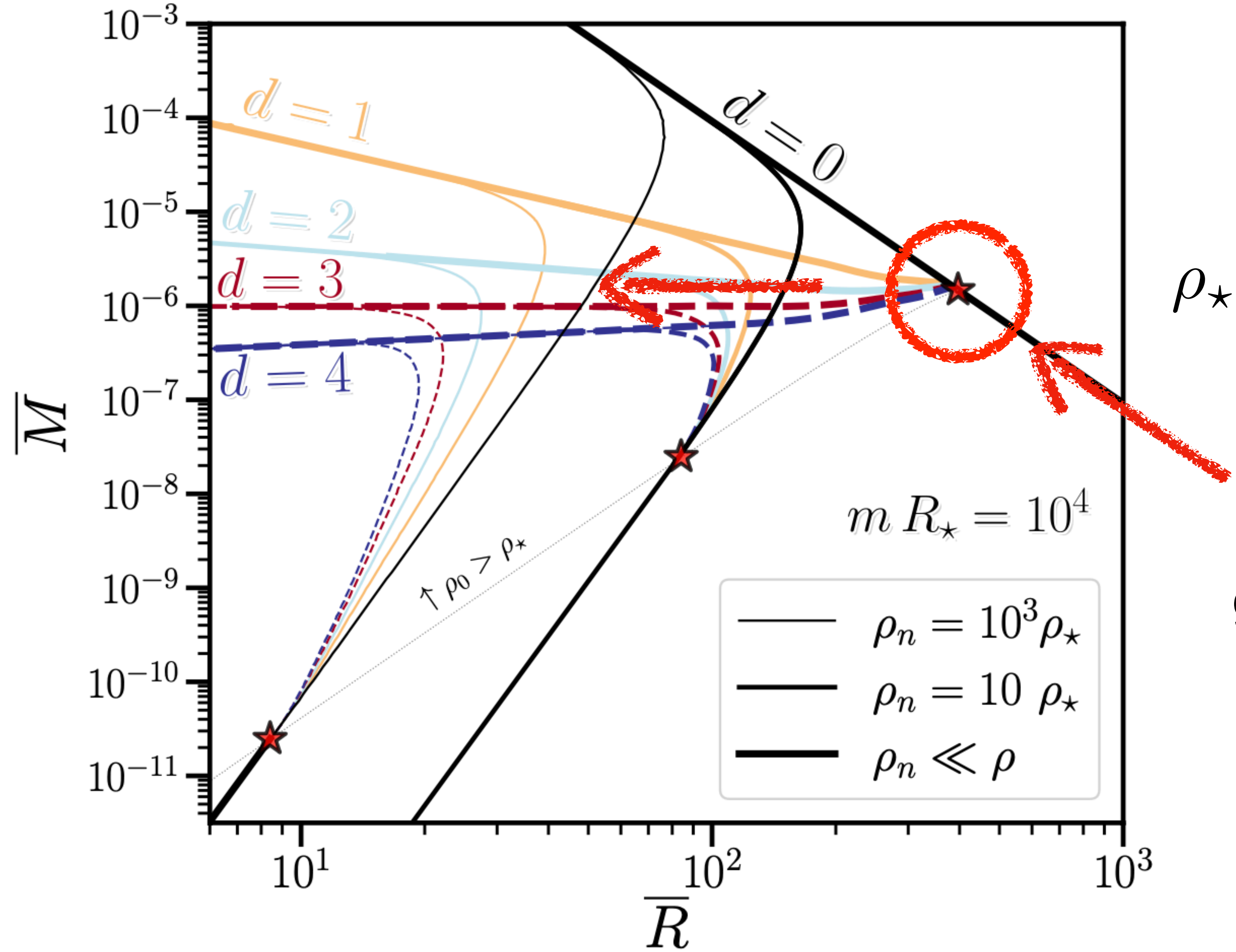


self-gravitating cloud

Lane-Emden equation, spherical D=3 DM cloud, D=3+d EoS

Garani, Kouvaris, Vandecasteele, MHGT (2025)

DARK DIMENSIONS

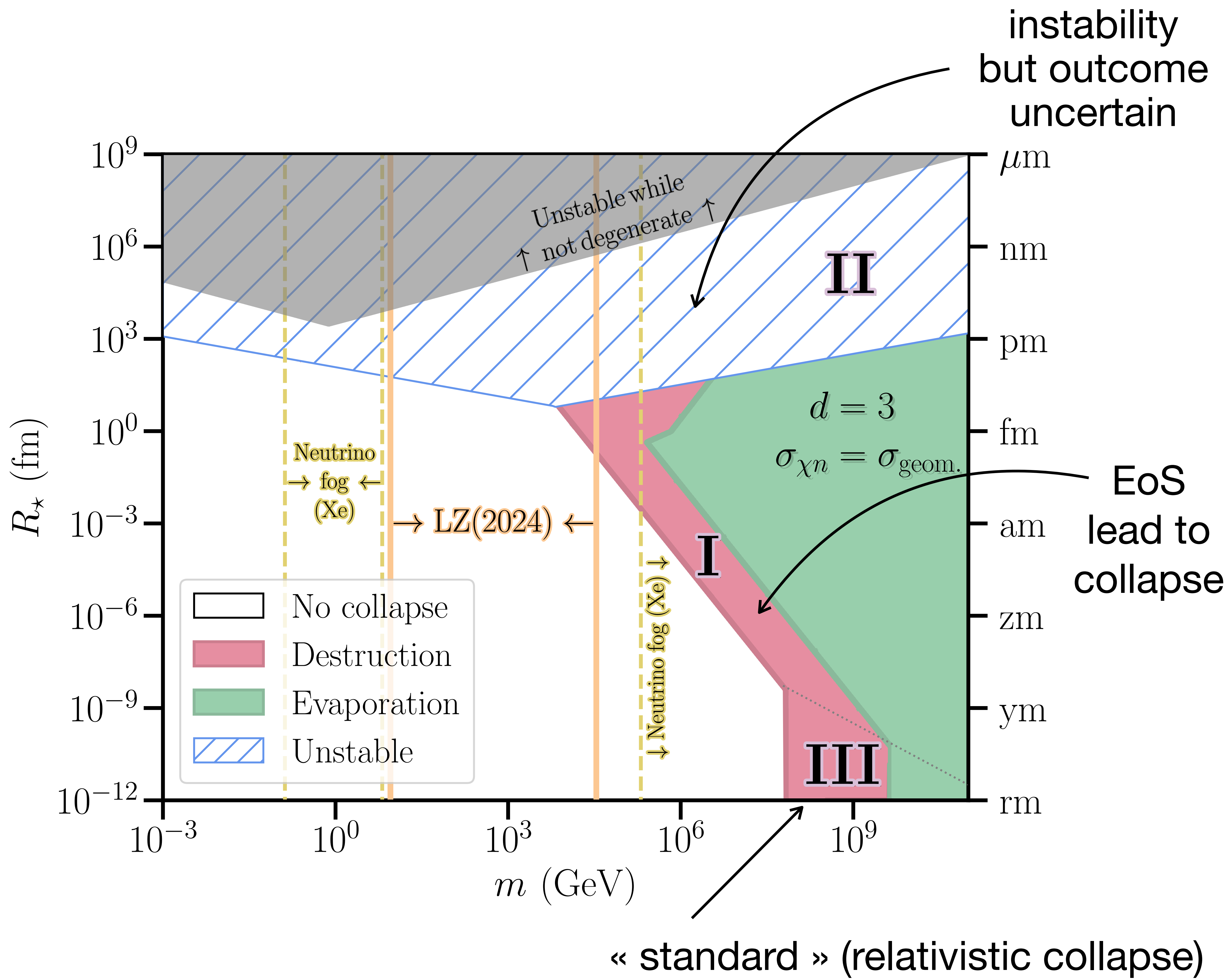


$$\rho_\star \sim \frac{m_\chi}{R_*^3}$$

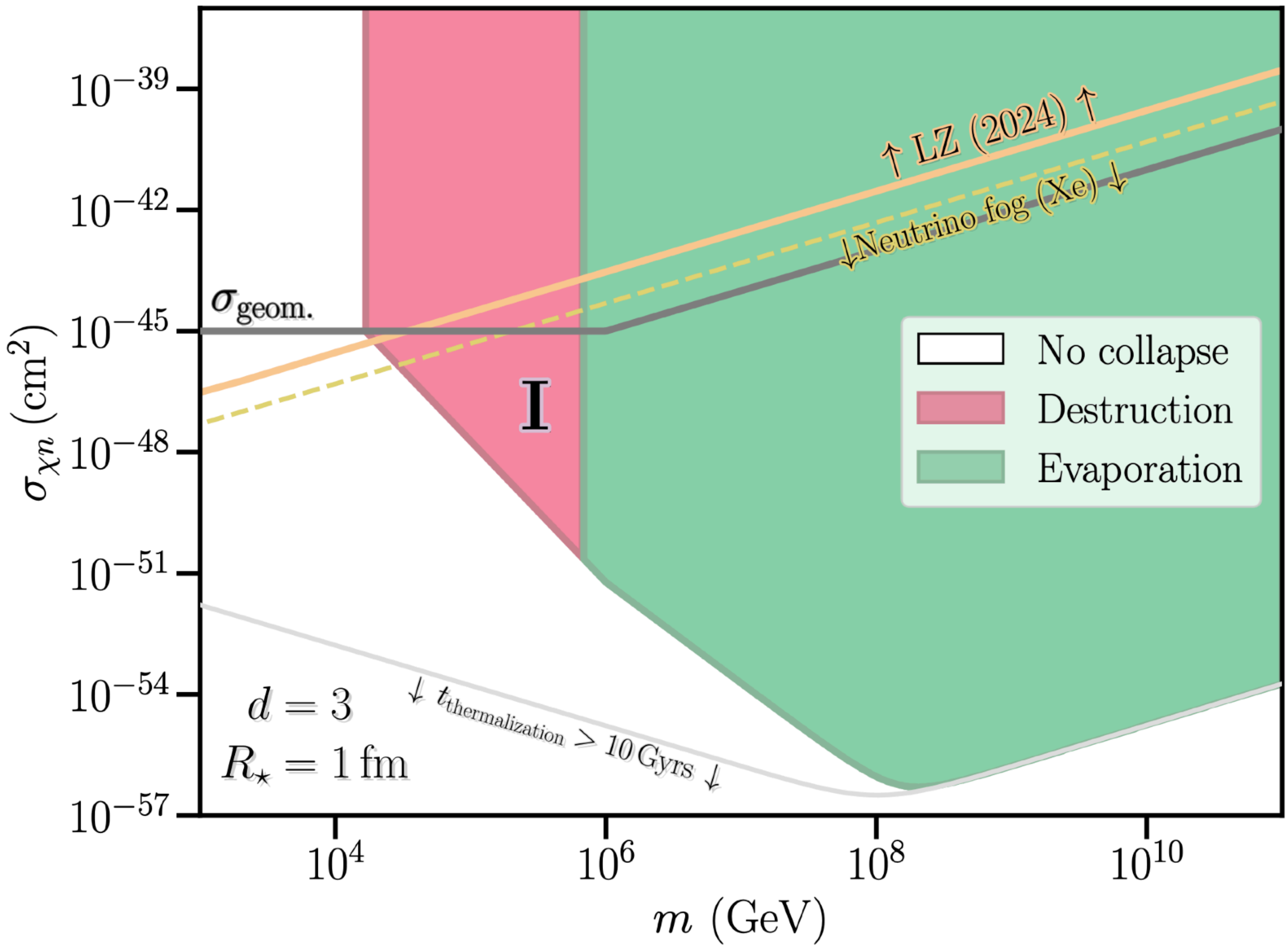
self-gravitating cloud

no stable solution for d ≥ 3 (inconclusive for d=1,2)

Garani, Kouvaris, Vandecasteele, MHGT (2025)

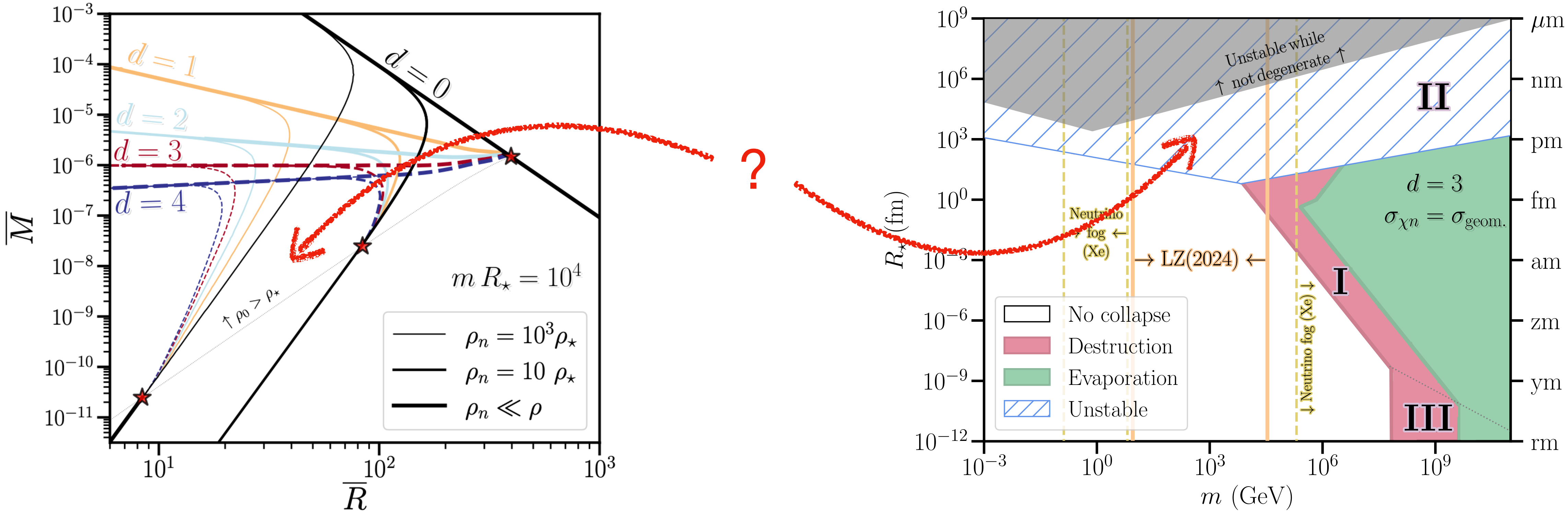


Garani, Kouvaris, Vandecasteele, MHGT (2025)



10^{-39}
10^{-42}
10^{-45}
10^{-48}
10^{-51}
10^{-54}
10^{-57}
$\sigma_{\chi n}$ (cm^2)
10^4
10^6
10^8
10^{10}
m (GeV)
↑ LZ (2024) ↑
↓Neutrino fog (Xe) ↓
$\sigma_{\rm geom.}$
I
No collapse
Destruction
Evaporation
$d = 3$
$R_\star = 1$ fm
↓ $t_{\rm thermalization} > 10$ Gyrs ↓

Prospects ?



All this is based on using the D=3+d EoS

Enough to claim instability for d > 2

Next step would be take into account (somehow) the fact that the core feels D=3+d gravity

This should further destabilise the DM cloud, and so the NS star

Thank you !

Supplementary material

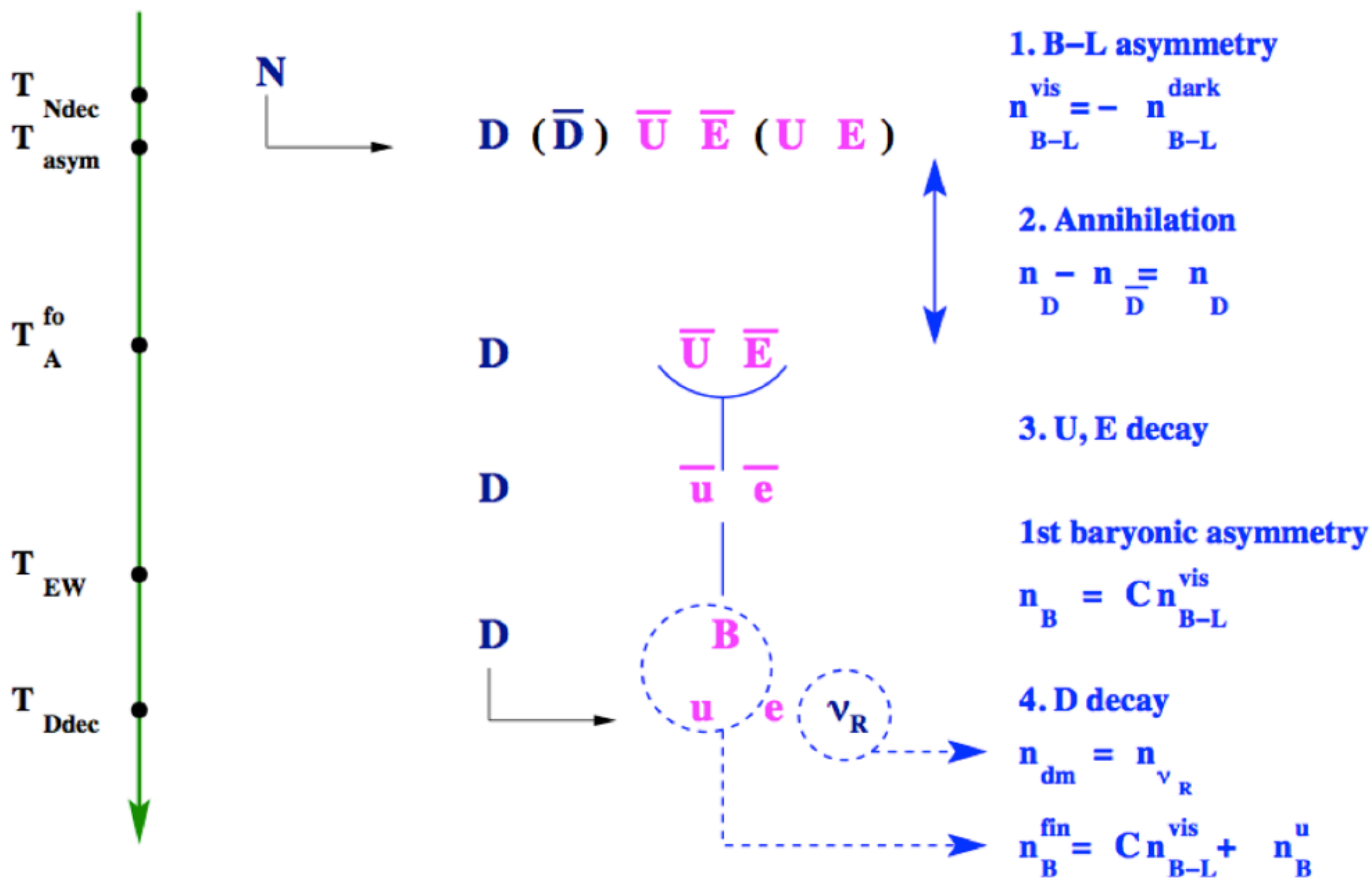
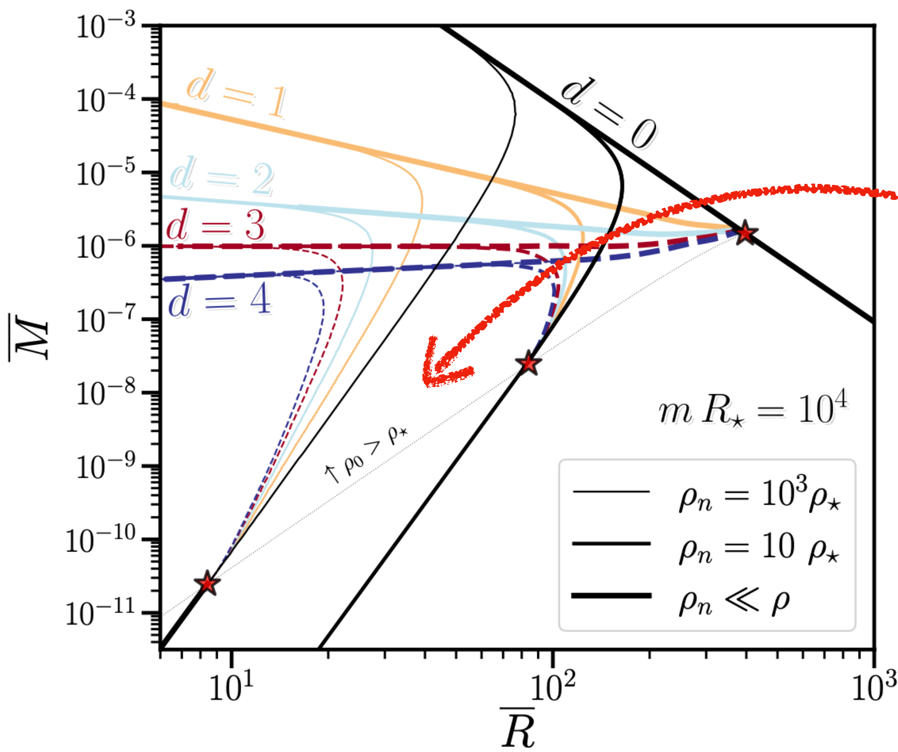


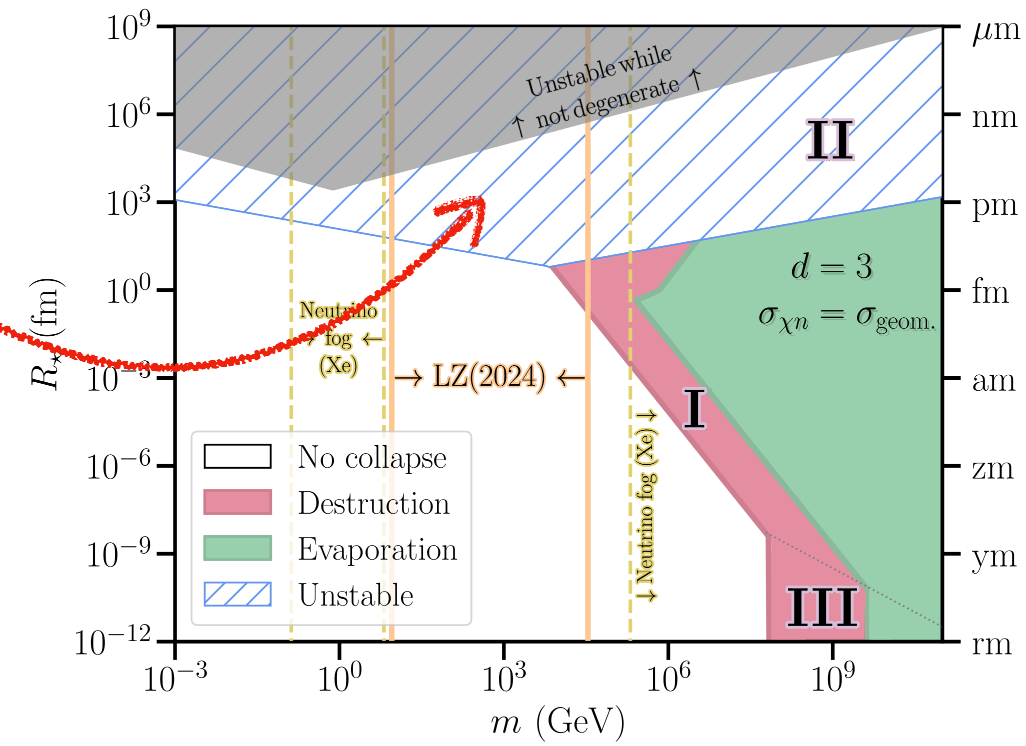
Figure 1: Steps of Matter Genesis

Figure from Lopez Honorez, Cosme and M.T. (2005)

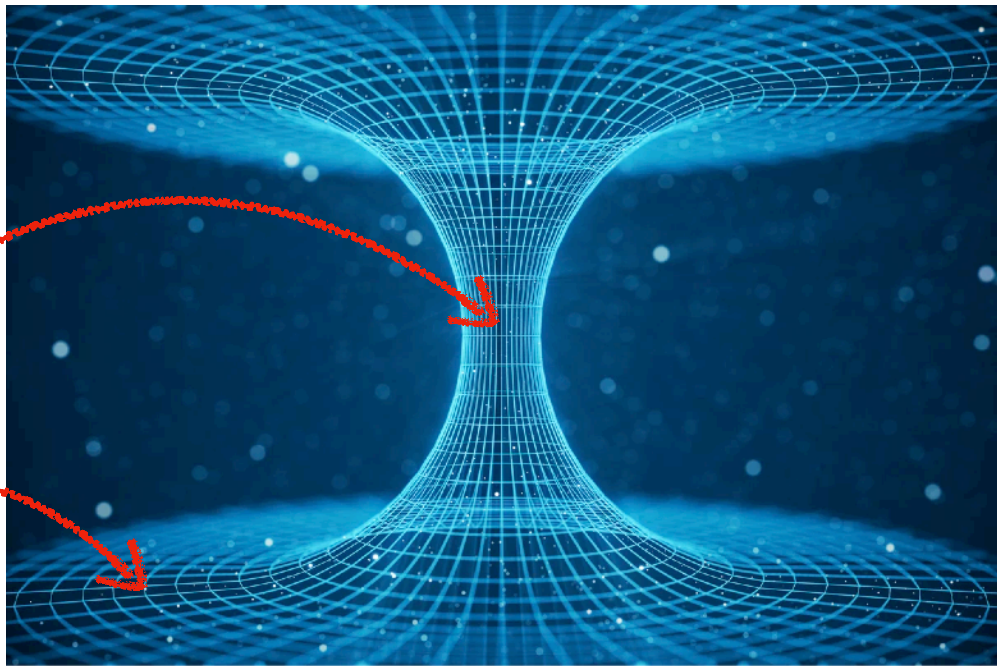
Prospects ?



?



D=3+d



D=3

$\sim R_\star$ periodic

~ Gregory-Laflamme instability for black strings

V. Bondi accretion vs Hawking radiation

growth or evaporation?

Bondi radius $$\frac{GM}{r_B} \sim v_s^2 \longrightarrow r_B \sim \frac{GM}{v_s^2}$$ accretion if $r \lesssim r_B$

gravity vs pressure

neutrons accretion rate $$\dot{M}_B \sim 4\pi r_B^2 \rho_{\rm far} v_s \longrightarrow \dot{M}_B \sim 4\pi \frac{GM^2 \rho_{\rm far}}{v_s^3}$$

Hawking radiation $$\dot{M}_H \sim -\frac{g_* M_{\rm Pl}^4}{5 \cdot 10^4 \, M^2}$$

$$\dot{M}_B \gtrsim |\dot{M}_H| \longrightarrow \boxed{M_{\rm crit} \sim 10^{37}\,{\rm GeV}}$$

NS becomes BH if $M_\chi \gtrsim M_{\rm crit}$

Bosonic DM *a priori* better

degenerate bosonic cloud

$$E_\phi \sim \frac{1}{m_\phi R^2} - G\frac{M m_\phi}{R}$$

$p \sim 1/R$ **Non Rel. pressure**

$$\frac{1}{R} \sim N \frac{m_\phi^3}{M_{\rm Pl}^2} \xrightarrow{N \nearrow} \frac{1}{R} \sim m_\phi$$

Rel. pressure

gravitational collapse if

$$N \gtrsim N_{\rm Ch} \sim \left(\frac{M_{\rm Pl}}{m_\phi}\right)^2$$

instead of $N \gtrsim \left(\frac{M_{\rm Pl}}{m_\chi}\right)^3$

for fermions

Homogeneous DM sphere, N particles, Yukawa potential

$$\mathcal{E} = -\frac{1}{2}\alpha N^2 \int d^3\mathbf{r_1} \int d^3\mathbf{r_2}\, \frac{e^{-\mu r}}{r}$$ (cloud self-energy)

$$= -\frac{4\pi^2 \alpha N^2}{3\mu^5}\left(2\mu^3R^3 - 3\mu^2R^2 + 3 - 3e^{-2\mu R}(1+\mu R)^2\right)$$

$\mu R \ll 1 \longrightarrow \mathcal{E} = -\frac{3\alpha N^2}{5R}$ (long range, eg $\alpha = Gm^2$)

$\mu R \gg 1 \longrightarrow \mathcal{E} \approx -\frac{3}{2}\frac{\alpha N^2}{\mu^2 R^3}$ **(short range)**

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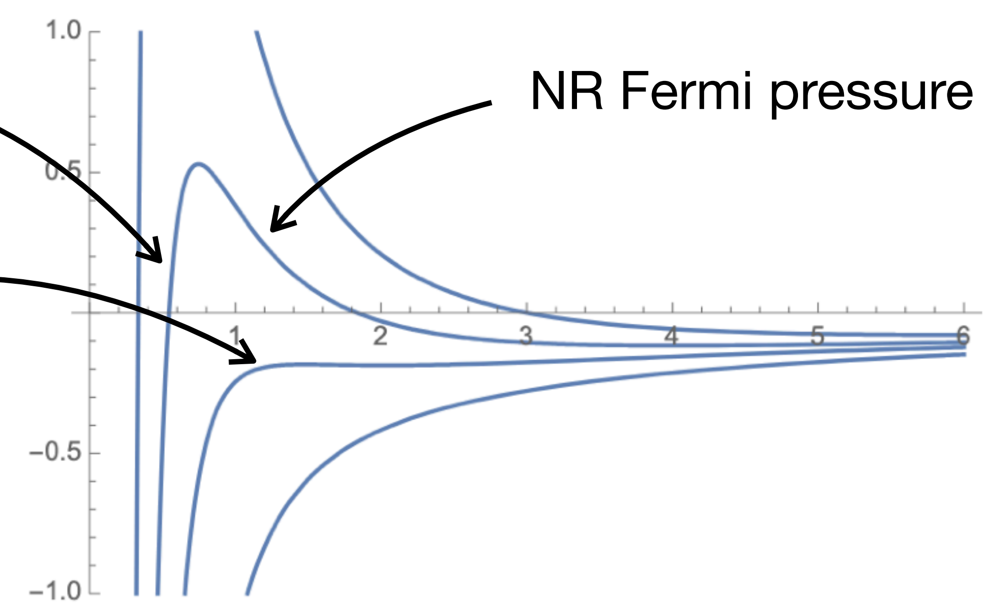
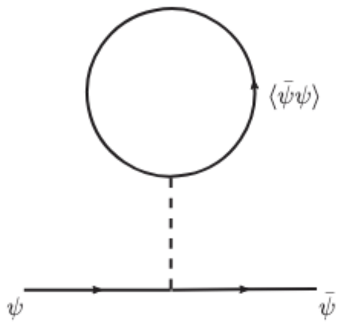
$$\mathcal{E}_{\rm tot}/N \sim \frac{N^{2/3}}{m_\chi R^2} - \frac{GNm^2}{R} - \frac{\alpha N}{\mu^2 R^3}$$



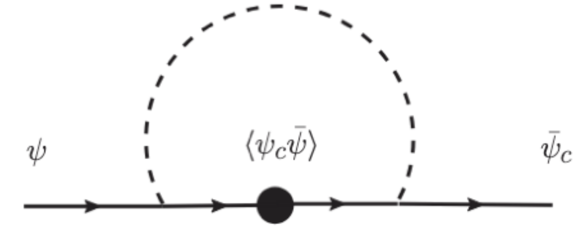
$$\longrightarrow \quad N_{\rm Ch} \sim \left(\frac{\mu}{\sqrt{\alpha}m_\chi}\right)^3 \left(\frac{M_{\rm Pl}}{m_\chi}\right)^3$$

A digression - superfluid DM

$\langle \bar{\psi}\psi \rangle \sim$

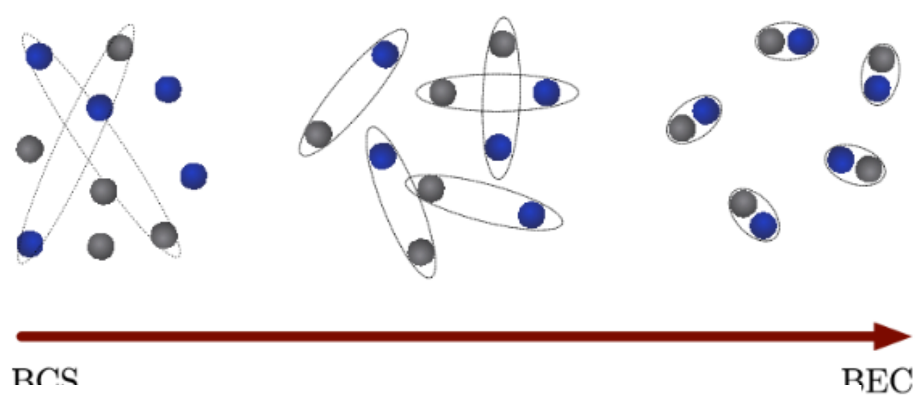


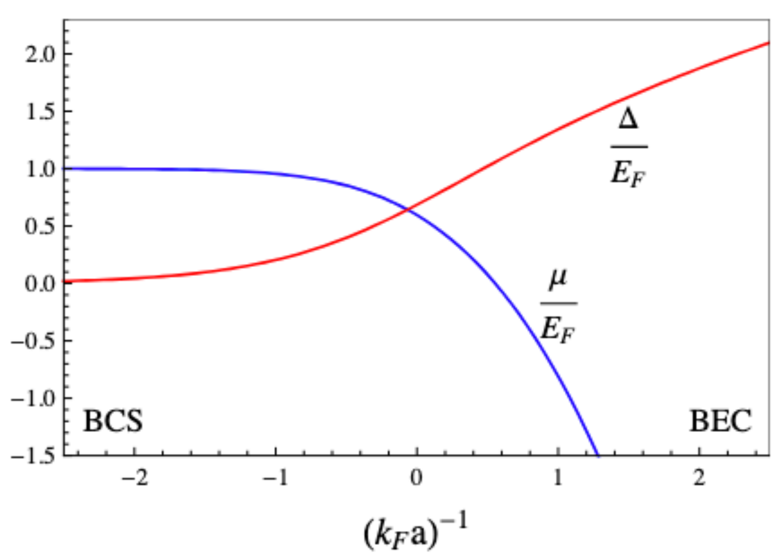
$\langle \psi_c \bar{\psi} \rangle \sim$



$$m_* = m \to m_* = 0$$

Rischke & Pisarski (1999)





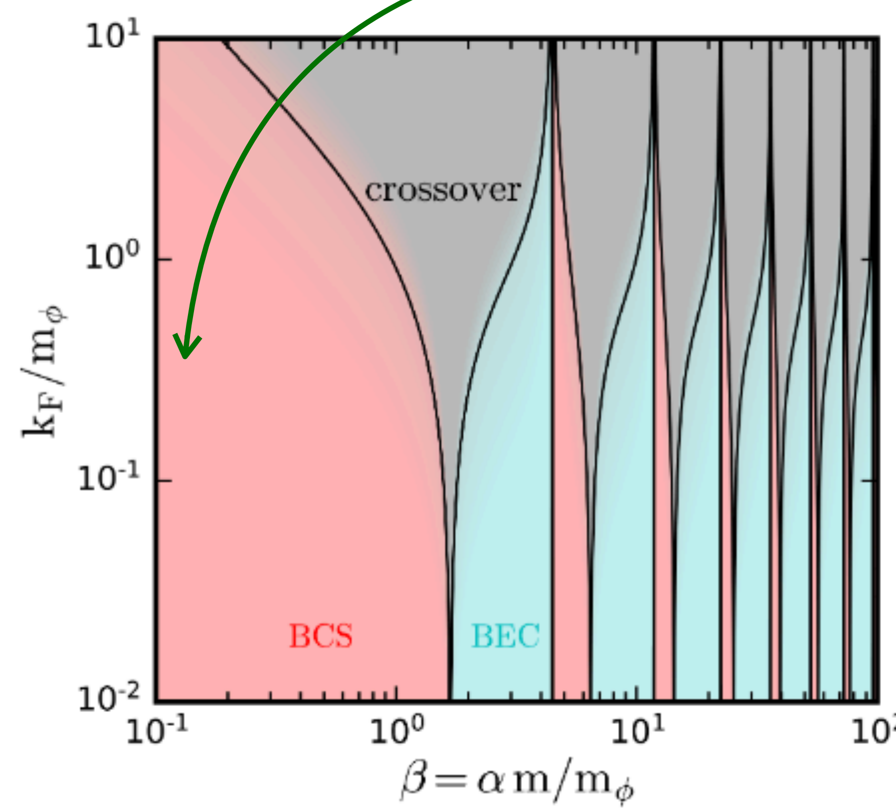


Figure 2: Contours of $(k_F a)^{-1}$. Red shaded regions are characterized by $(k_F a)^{-1} < -1$ indicating BCS regime. In the cyan shaded regions $(k_F a)^{-1} > 1$ indicating BEC regime, and the gray regions correspond to possible BEC-BCS crossover with $-1 < (k_F a)^{-1} < 1$.

cf Massimo Mannarelli's lectures

Garani, Vandecasteele, MHGT (2022)

Bosonic DM *a priori* better

Fermions Cloud	Bosons Cloud
$E_\chi \sim \frac{N_\chi^{2/3}}{m_\chi R^2} - \frac{G N_\chi m_\chi^2}{R}$	$E_\phi \sim \frac{1}{m_\phi R^2} - G\frac{N_\phi m_\phi^2}{R}$
$p_F \sim N_\chi^{1/3}/R$	$p \sim 1/R$
$N_\chi \gtrsim \left(\frac{M_{\rm Pl}}{m_\chi}\right)^3$	$N_\phi \gtrsim \left(\frac{M_{\rm Pl}}{m_\phi}\right)^2$

Bosonic DM *a priori* better

1. Too good at making BH — tend to **evaporate** instead of accreting

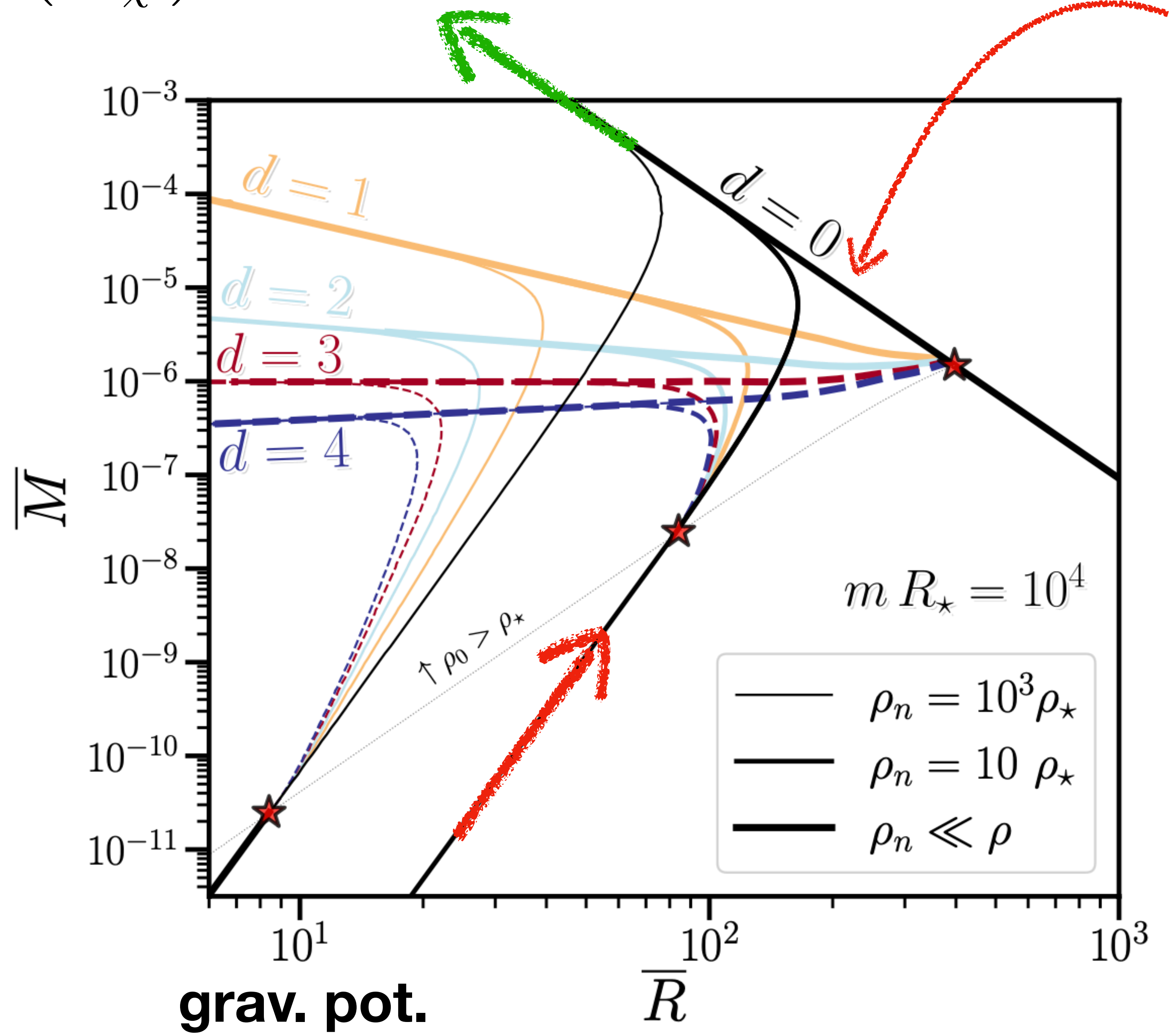
$$M_{\rm Ch} \sim 10^{38} \left(\frac{\rm GeV^2}{m_\phi}\right) \qquad \text{vs} \qquad M_{\rm Bondi} \gtrsim 10^{37}\,\rm GeV$$

2. Spoiled by self-interactions ~ $\lambda\phi^4$

$$N_\phi \gtrsim \left(\frac{M_{\rm Pl}}{m_\phi}\right)^2 \xrightarrow{\lambda \gtrsim 10^{-38}} N_\phi \gtrsim \sqrt{\lambda}\left(\frac{M_{\rm Pl}}{m_\phi}\right)^3$$

at the end, similar to Fermi pressure $N \gtrsim \left(\frac{M_{\rm Pl}}{m_\chi}\right)^3$

toward $N \gtrsim \left(\frac{M_{\rm Pl}}{m_\chi}\right)^3$



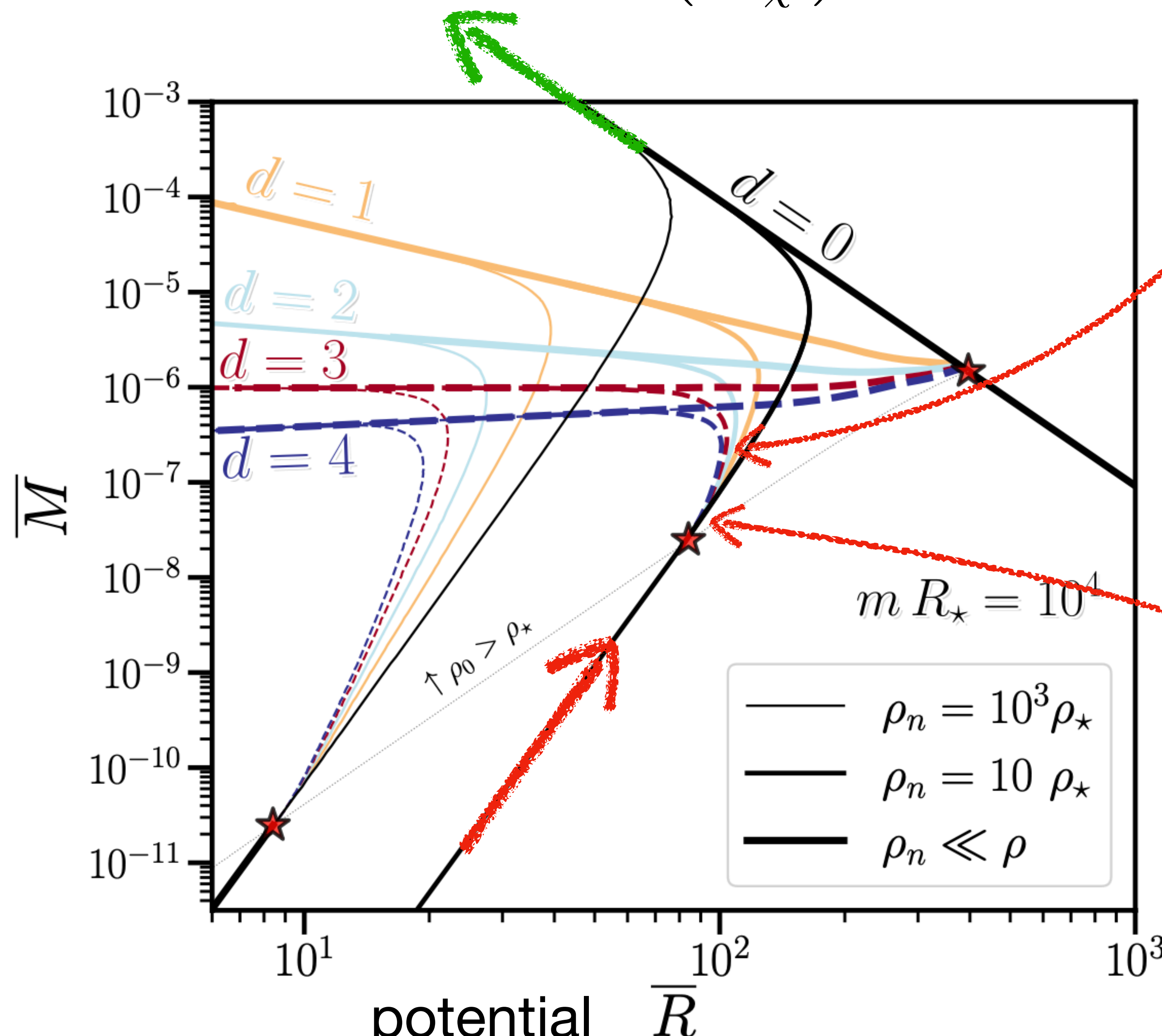
grav. pot. dominated by neutrons

Standard Scenario - Fermions

Garani, Kouvaris, Vandecasteele, MHGT (2025)

toward $N \gtrsim \left(\frac{M_{\rm Pl}}{m_\chi}\right)^3$

self-gravitating cloud



unstable mode

(but outcome unclear)

potential dominated by neutrons

Garani, Kouvaris, Vandecasteele, MHGT (2025)

Summary of « constraints »