DIAS
Danish Institute for Advanced Study

University of Southern Denmark

The Dark Side of Stars

Chris Kouvaris

CP3 - Origins

Particle Physics & Origin of Mass

Mass 2012

What is the nature of Dark Matter?

WIMP-nucleus cross section:
- Spin-Independent
- Spin-dependent
- Inelastic cross section

WIMP-WIMP cross section:
- Self-Interacting dark matter

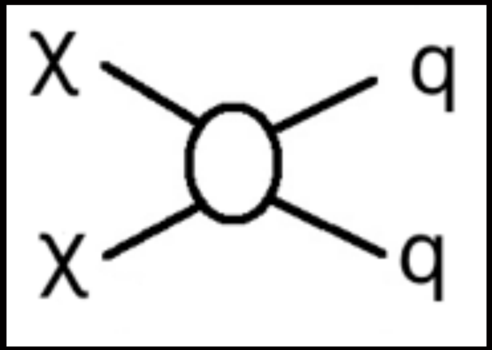
WIMP-WIMP annihilation:
- Thermally produced WIMPs
- Nonthermally, asymmetric dark matter

Decaying WIMPs:
possible explanation of PAMELA results

Detection of Dark Matter

Detection of Dark Matter

Direct detection

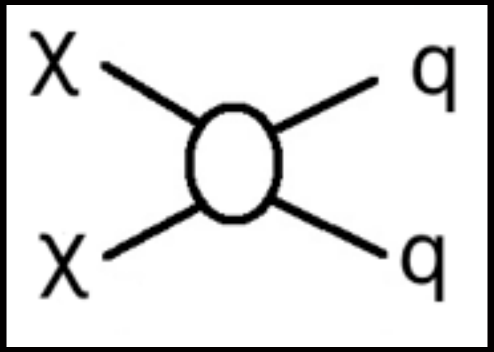


Inconclusive!
DAMA. CoGeNT, CRESST have signals compatible with dark matter.
Xenon, CDMS, Picasso null results.

DIAS
Danish Institute for Advanced Study

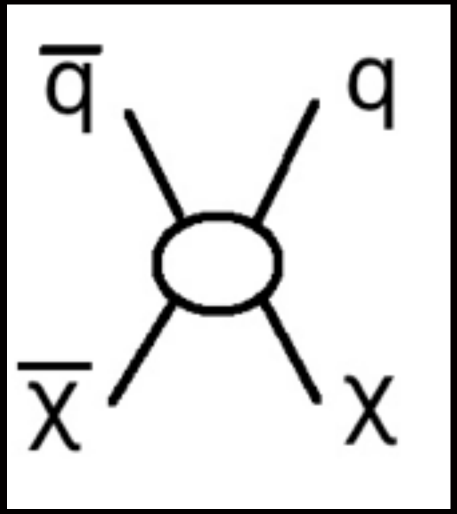
Detection of Dark Matter

Direct detection



Inconclusive!
DAMA. CoGeNT, CRESST have signals compatible with dark matter.
Xenon, CDMS, Picasso null results.

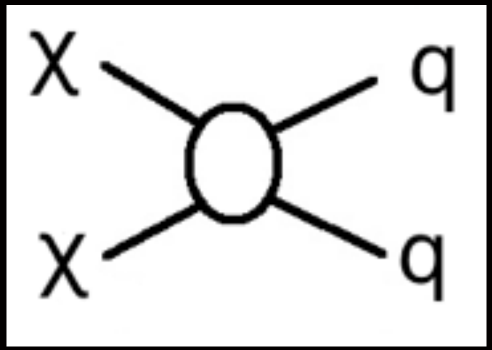
Indirect detection



Inconclusive!
PAMELA positron excess, FERMI 130 GeV line?

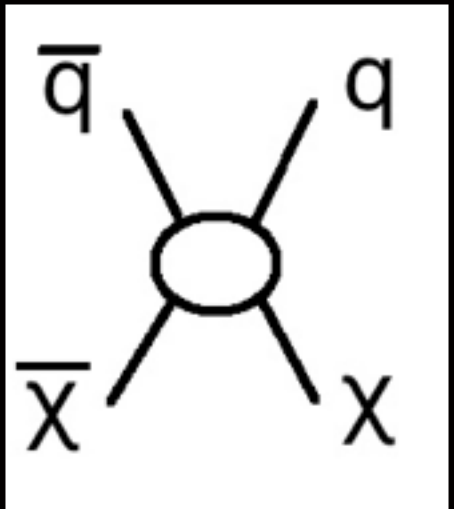
Detection of Dark Matter

Direct detection



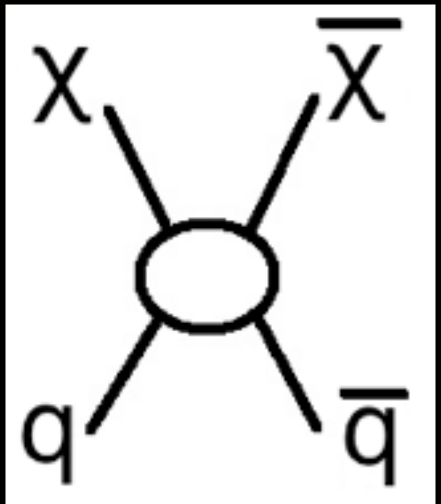
Inconclusive!
DAMA. CoGeNT, CRESST have signals compatible with dark matter.
Xenon, CDMS, Picasso null results.

Indirect detection



Inconclusive!
PAMELA positron excess, FERMI 130 GeV line?

Production



Inconclusive!
LHC monophoton, monojet production and missing energy signal... nothing yet

Astrophysical Observations

Astrophysical Observations

WIMP annihilation and Cooling of Stars

WIMP annihilation as a heating mechanism for

- neutron stars (CK '07, CK Tinyakov '10, Lavallaz Fairbairn '10)
- white dwarfs (Bertone Fairbairn '07, McCullough '10)

Astrophysical Observations

WIMP annihilation and Cooling of Stars

WIMP annihilation as a heating mechanism for
•neutron stars (CK ’07, CK Tinyakov ’10, Lavallaz Fairbairn ’10)
•white dwarfs (Bertone Fairbairn ’07, McCullough ’10)

WIMP collapse to a Black Hole

WIMPs can be trapped inside stars and later collapse forming a black hole that destroys the star (Goldman Nussinov ’89, CK Tinyakov ’10, ’11, McDermott Yu Zurek ’11, CK’11, Guver Erkoca Reno Sarcevic ’12, Fan Yang Chang ‘12)

WIMP capture in Stars

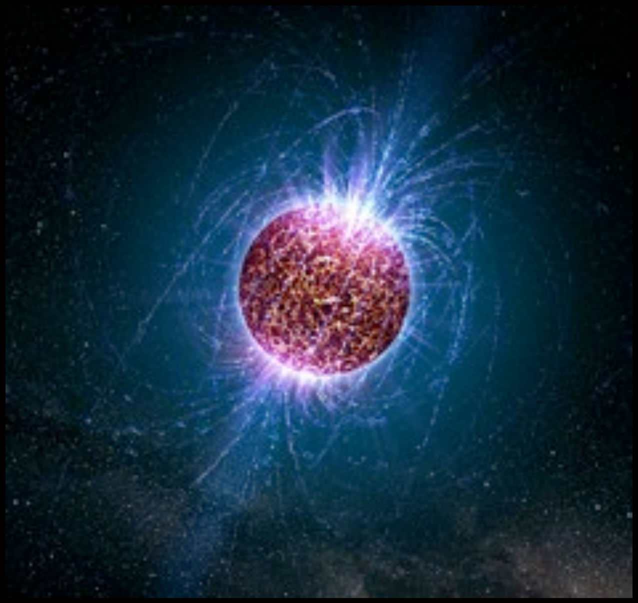
Condition: The energy loss in the collision should be larger than the asymptotic kinetic energy of the WIMP far out of the star.

Example: Sun

WIMP mean free path inside the sun $\xi \approx \frac{1}{n\sigma}, \quad n \approx \frac{M_{solar}}{(4/3)\pi R_{solar}^3 m_n} \approx 8 \cdot 10^{23} \quad particles/cm^3$

Even if current limit of CDMS $\sigma < 10^{-41} cm^2, \quad \xi \approx 10^{17} cm, \quad \frac{R_{solar}}{\xi} \approx 10^{-6}$

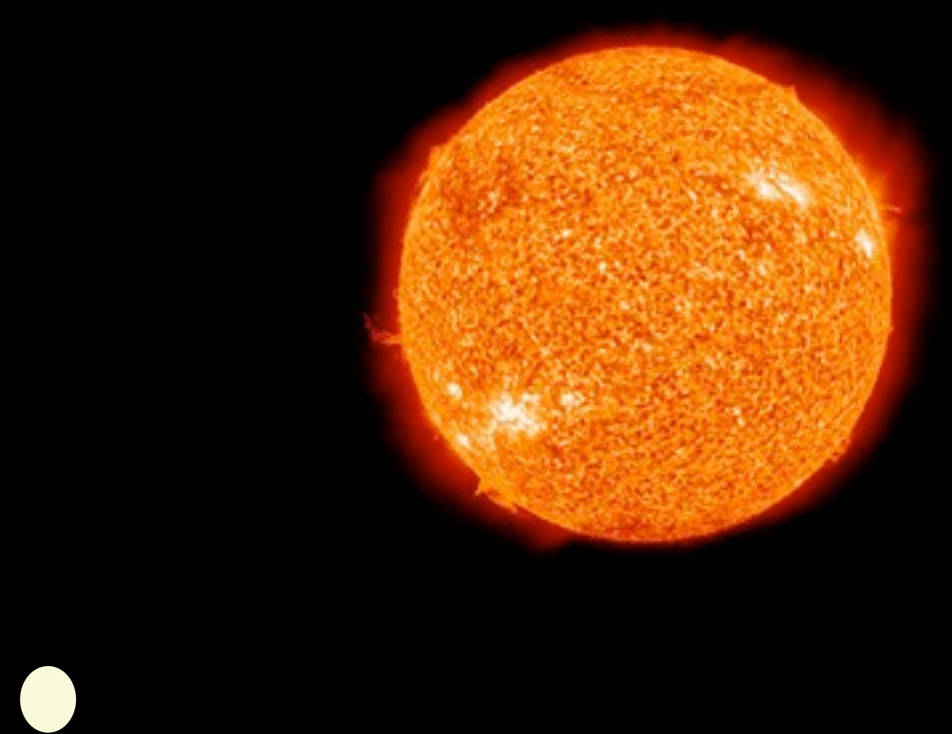
Only one out of a million WIMPs scatters!



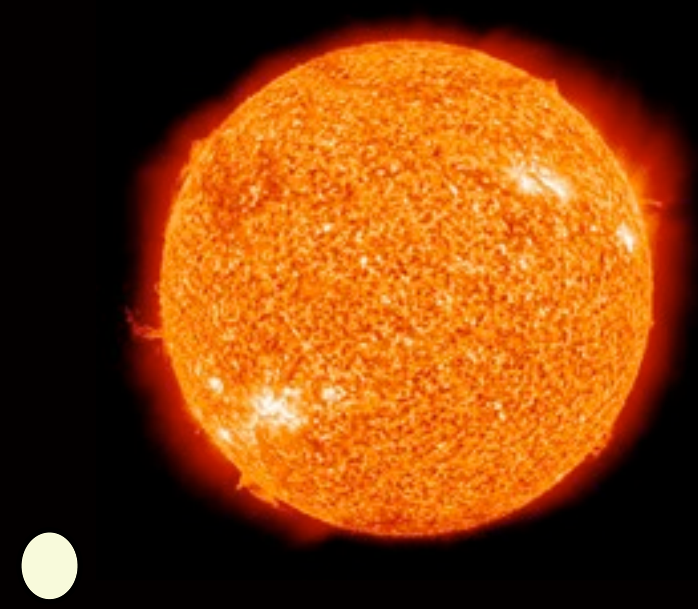
For a typical neutron star $M_{NS} \approx 1.4 M_{solar}, \quad R \approx 10 km$

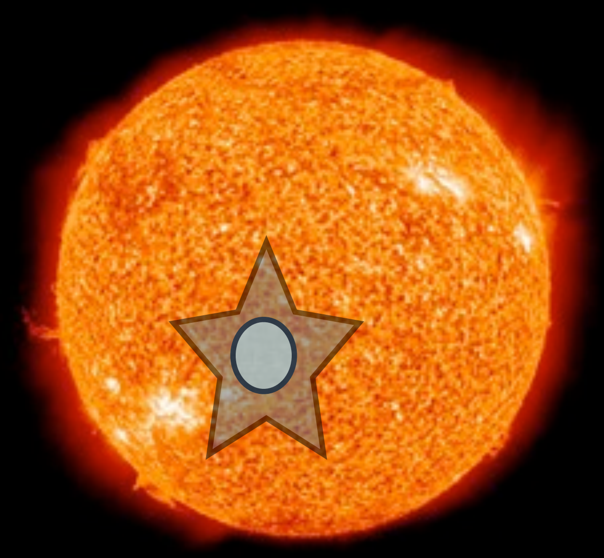
$\sigma > \sigma_{critical} \approx 5 \cdot 10^{-46} cm^2$ CK'07

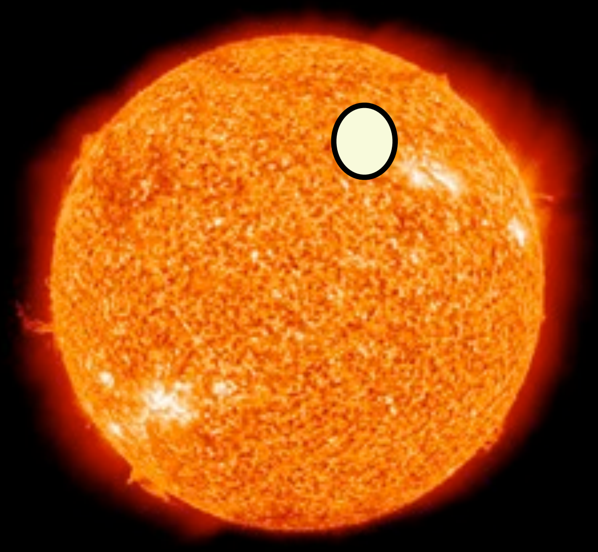
For cross section larger than the critical one, every WIMP passing through the neutron star will be on average interact inside the star.



DIAS
Danish Institute
for Advanced Study

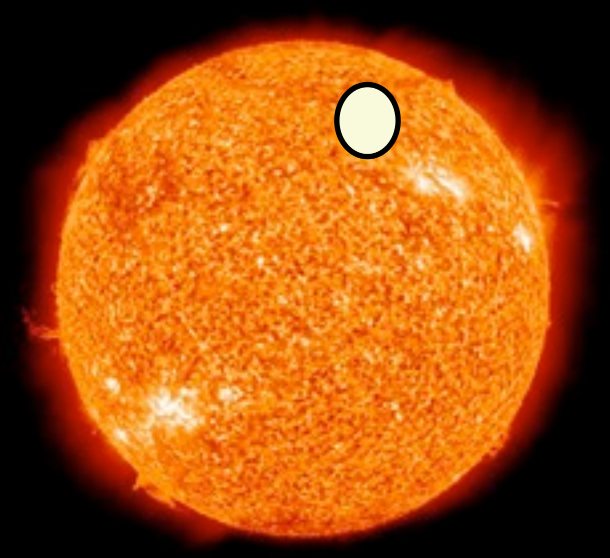


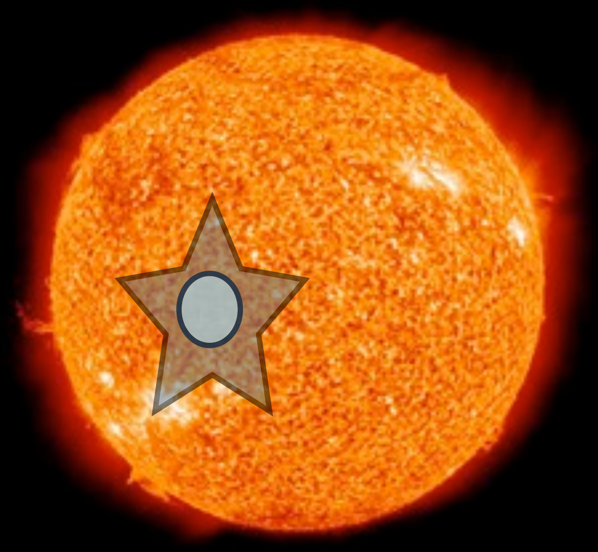




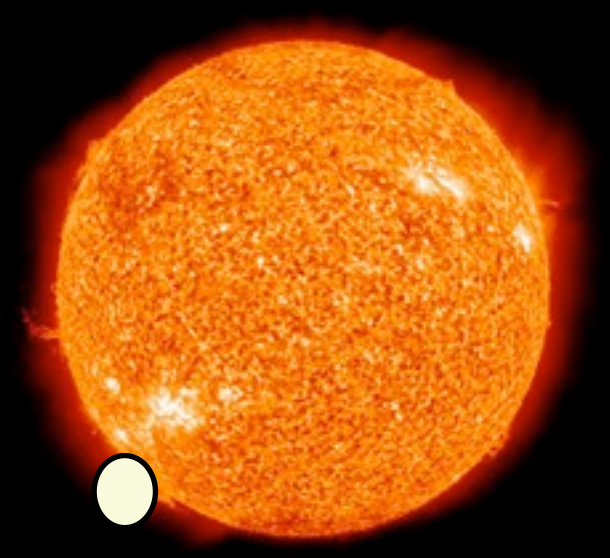
DIAS
Danish Institute
for Advanced Study

Danish Institute for Advanced Study

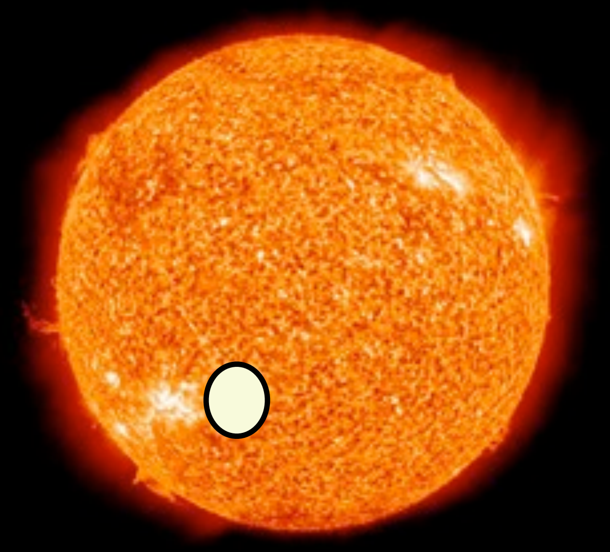


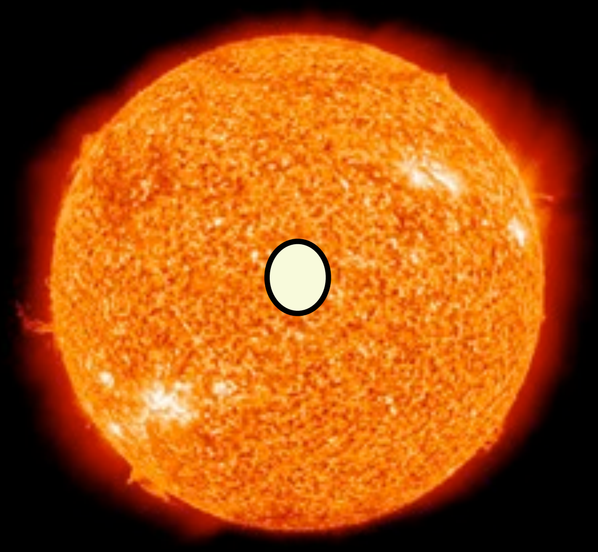


Danish Institute for Advanced Study

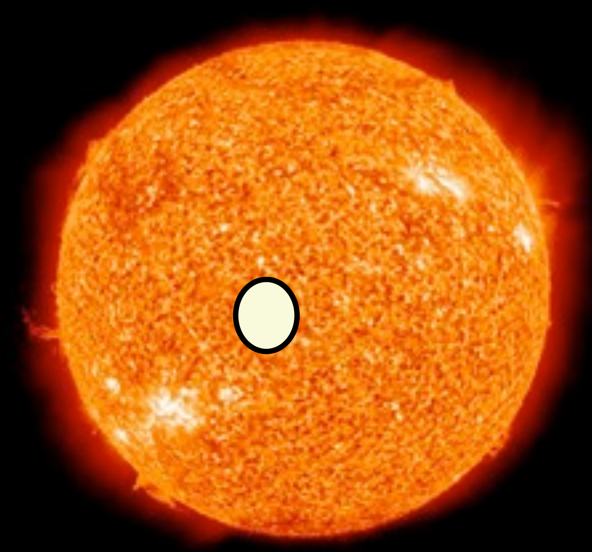


DIAS
Danish Institute
for Advanced Study

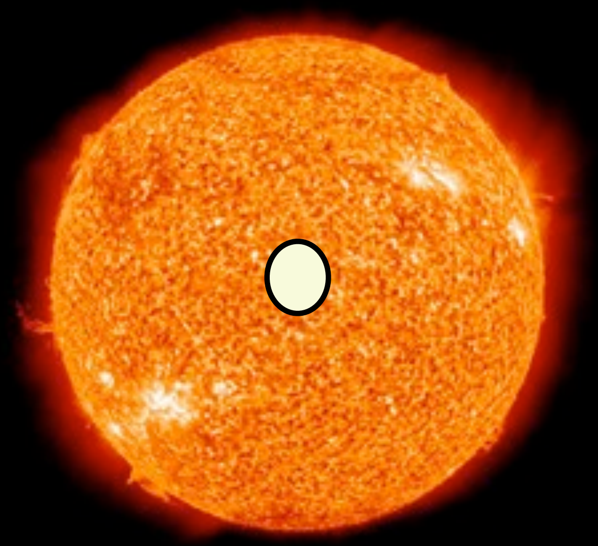


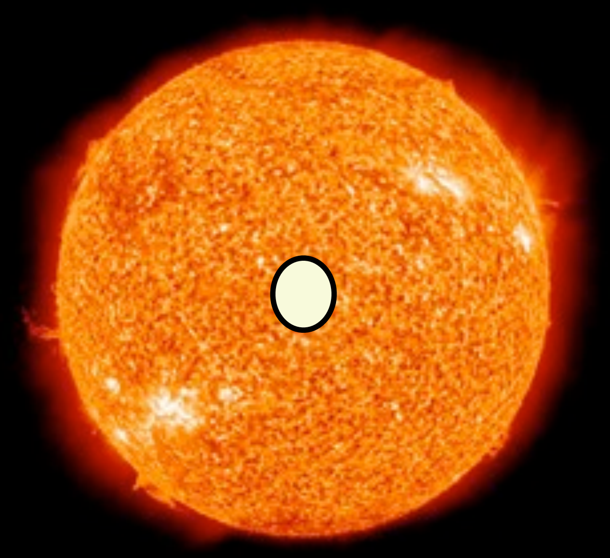


DIAS
Danish Institute
for Advanced Study



DIAS
Danish Institute
for Advanced Study





WIMP capture in Stars

$$F = \frac{8}{3}\pi^2 \frac{\rho_{\rm dm}}{m} \left(\frac{3}{2\pi v^2}\right)^{3/2} \frac{GMR}{1-\frac{2GM}{R}} v^2 (1 - e^{-3E_0/v^2}) f$$

Press Spergel ’85, Gould ’86, Nussinov Goldman ’89, CK’07, CK Tinyakov ’10

WIMP capture in Stars

$$F = \frac{8}{3}\pi^4 \frac{\rho_{\rm dm}}{m}\left(\frac{3}{2\pi v^2}\right)^{3/2} \frac{GMR}{1-\frac{2GM}{R}} v^2 (1 - e^{-3E_0/v^2}) f$$

Press Spergel '85, Gould '86, Nussinov Goldman '89, CK'07, CK Tinyakov '10

higher local DM density gives higher accretion

WIMP capture in Stars

$$F = \frac{8}{3}\pi^2 \frac{\rho_{\rm dm}}{m}\left(\frac{3}{2\pi v^2}\right)^{3/2} \frac{GMR}{1-\frac{2GM}{R}} v^2 \left(1 - e^{-3E_0/v^2}\right) f$$

Press Spergel ’85, Gould ’86, Nussinov Goldman ’89, CK’07, CK Tinyakov ’10

higher local DM density gives higher accretion

smaller velocities enhance capture

WIMP capture in Stars

$$F = \frac{8}{3}\pi^2 \frac{\rho_{\rm dm}}{m}\left(\frac{3}{2\pi v^2}\right)^{3/2} \frac{GMR}{1-\frac{2GM}{R}} v^2 \left(1 - e^{-3E_0/v^2}\right) f$$

Press Spergel ’85, Gould ’86, Nussinov Goldman ’89, CK’07, CK Tinyakov ’10

higher local DM density gives higher accretion

smaller velocities enhance capture

minimum initial energy leading to capture

DIAS
Danish Institute for Advanced Study

WIMP capture in Stars

$$F = \frac{8}{3}\pi \frac{\rho_{\mathrm{dm}}}{m}\left(\frac{3}{2\pi \bar{v}^2}\right)^{3/2} \frac{GMR}{1-\frac{2GM}{R}}\bar{v}^2\left(1-e^{-\frac{3E_0}{\bar{v}^2}}\right) f$$

Press Spergel ’85, Gould ’86, Nussinov Goldman ’89, CK’07, CK Tinyakov ’10

higher local DM density gives higher accretion

smaller velocities enhance capture

minimum initial energy leading to capture

$f=1$ if $\sigma>\sigma_{crit}$
$f=0.45\sigma/\sigma_{crit}$ if $\sigma<\sigma_{crit}$

DIAS
Danish Institute
for Advanced Study

WIMP capture in Stars

$$F = \frac{8}{3}\pi^{1/2}\frac{\rho_{\mathrm{dm}}}{m}\left(\frac{3}{2\pi \bar{v}^2}\right)^{3/2}\frac{GMR}{1-\frac{2GM}{R}}\bar{v}^2\left(1-e^{-\frac{3E_0}{\bar{v}^2}}\right)f$$

Press Spergel ’85, Gould ’86,
Nussinov Goldman ’89,
CK’07, CK Tinyakov ’10

higher local DM density
gives higher accretion

smaller velocities enhance capture

minimum initial energy
leading to capture

$f=1$ if $\sigma>\sigma_{\mathrm{crit}}$
$f=0.45\sigma/\sigma_{\mathrm{crit}}$ if $\sigma<\sigma_{\mathrm{crit}}$

$$f \simeq \frac{\sigma_\chi}{\sigma_{\mathrm{crit}}}\left\langle \int \frac{\rho}{M/R^3}\frac{dl}{R}\right\rangle$$

WIMP capture in Stars

$$F = \frac{8}{3}\pi^2 \frac{\rho_{\rm dm}}{m}\left(\frac{3}{2\pi \bar{v}^2}\right)^{3/2} \frac{GMR}{1-\frac{2GM}{R}} \bar{v}^2 \left(1 - e^{-\frac{3E_0}{\bar{v}^2}}\right) f$$

Press Spergel ’85, Gould ’86, Nussinov Goldman ’89, CK’07, CK Tinyakov ’10

higher local DM density gives higher accretion

smaller velocities enhance capture

minimum initial energy leading to capture

$f=1$ if $\sigma>\sigma_{crit}$

$f=0.45\sigma/\sigma_{crit}$ if $\sigma<\sigma_{crit}$

$$f \simeq \frac{\sigma_\chi}{\sigma_{\rm crit}} \left\langle \int \frac{\rho}{M/R^3} \frac{dl}{R} \right\rangle$$

For typical NS

$$F = 1.25 \times 10^{24} {\rm s}^{-1} \left(\frac{\rho_{\rm dm}}{{\rm GeV/cm^3}}\right) \left(\frac{100{\rm GeV}}{m}\right) f$$

Danish Institute for Advanced Study

Thermalization

$$t_{\rm th} = 0.2{\rm yr} \left(\frac{m}{\rm TeV}\right)^2 \left(\frac{\sigma}{10^{-43}{\rm cm}^2}\right)^{-1} \left(\frac{T}{10^5{\rm K}}\right)^{-1}$$

Goldman Nussinov'89, CK Tinyakov '10

$$r_{\rm th} = \left(\frac{9T}{8\pi G \rho_c m}\right)^{1/2} \simeq 22{\rm cm} \left(\frac{T}{10^5{\rm K}}\right)^{1/2} \left(\frac{100{\rm GeV}}{m}\right)^{1/2}$$

Evaporation

$$F = n_s \left(\frac{T}{2\pi m}\right)^{1/2} \left(1 + \frac{GMm}{RT}\right) \exp\left(-\frac{GMm}{RT}\right)$$

Krauss Srednicki Wilczek '86

for WIMPs with mass larger than ~2 keV evaporation can be ignored

DIAS Danish Institute for Advanced Study

WIMP Annihilation in Neutron Stars

$$C_A = \langle \sigma_A v \rangle / V$$

$$\tau = 1/\sqrt{F C_A}$$

$$\tau = 3.4 \times 10^{-5}\mathrm{yr} \left(\frac{100}{m}\right)^{1/4} \left(\frac{\mathrm{GeV/cm^3}}{\rho_{\mathrm{dm}}}\right)^{1/2} \left(\frac{10^{-36}\mathrm{cm}^2}{\langle \sigma v \rangle}\right)^{1/2} \left(\frac{T}{10^5\mathrm{K}}\right)^{3/4} f^{-1/2}$$

Energy Release $W(t) = F m \,\mathrm{Tanh}^2 \frac{t+c}{\tau}$

we have to compare with other heating/cooling mechanisms

Basics of Neutron Star Cooling

Urca process

Direct Urca

$$n \rightarrow p + e + \bar{\nu}_e$$
$$p + e \rightarrow n + \nu_e$$

However for nuclear matter triangle inequalities are not satisfied

For quark matter it holds!

Emissivity: $\propto T^6$

Modified Urca presence of bystander

$$n + n \rightarrow n + p + e + \bar{\nu}_e$$
$$p + e + n \rightarrow n + n + \nu_e$$

Emissivity: $\propto T^8$

Photon Emission Emissivity: $\propto T^4$

$$T_{\text{surface}} = (0.87 \times 10^6 \text{ K}) \left(\frac{g_s}{10^{14} \text{cm/s}^2} \right)^{1/4} \left(\frac{T}{10^8 \text{K}} \right)^{0.55}$$

... more cooling mechanisms

- Nucleon Pair Bremsstrahlung

$$n + n \rightarrow n + n + \nu + \bar{\nu}$$

$$n + p \rightarrow n + p + \nu + \bar{\nu}$$

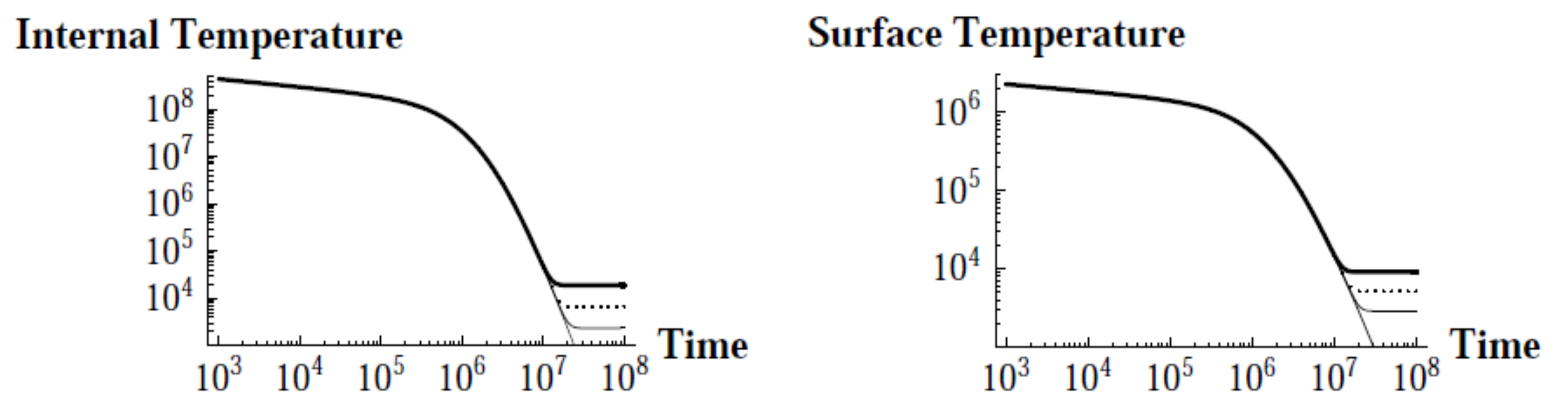
- Neutrino Pair Bremsstrahlung

$$e + (A, Z) \rightarrow e + (A, Z) + \nu + \bar{\nu}$$

- Pionic Reactions
- Superfluidity
- Color Superconductivity

Cooling of Neutron Stars

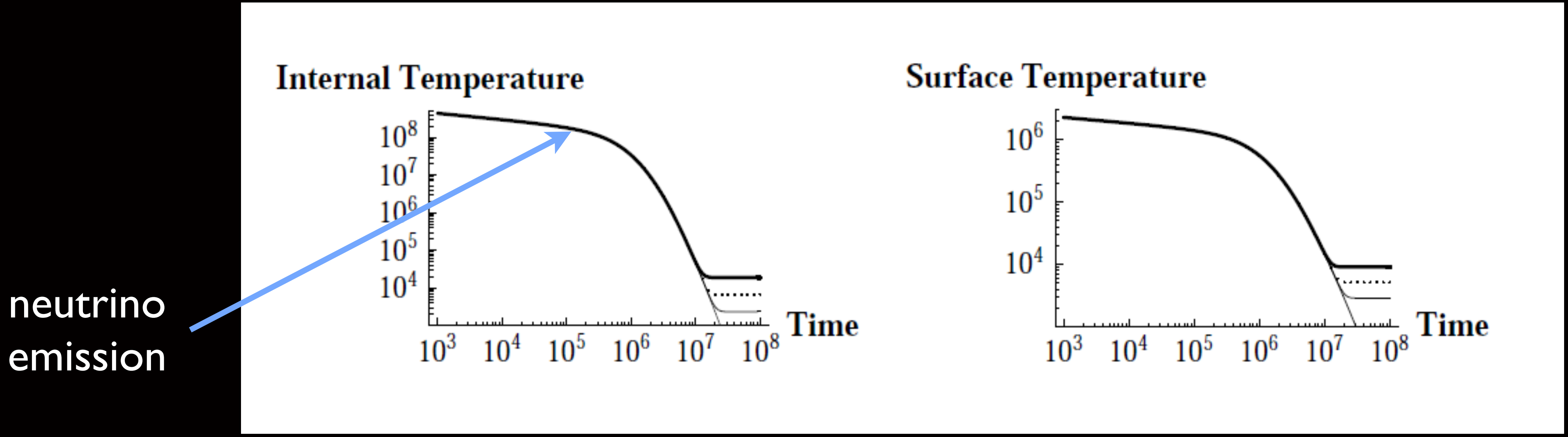
$$\frac{dT}{dt} = \frac{-L_\nu - L_\gamma + L_{\rm dm}}{V c_V} = \frac{V(-\epsilon_\nu - \epsilon_\gamma + \epsilon_{\rm dm})}{V c_V} = \frac{-\epsilon_\nu - \epsilon_\gamma + \epsilon_{\rm dm}}{c_V}$$



CK'07

Cooling of Neutron Stars

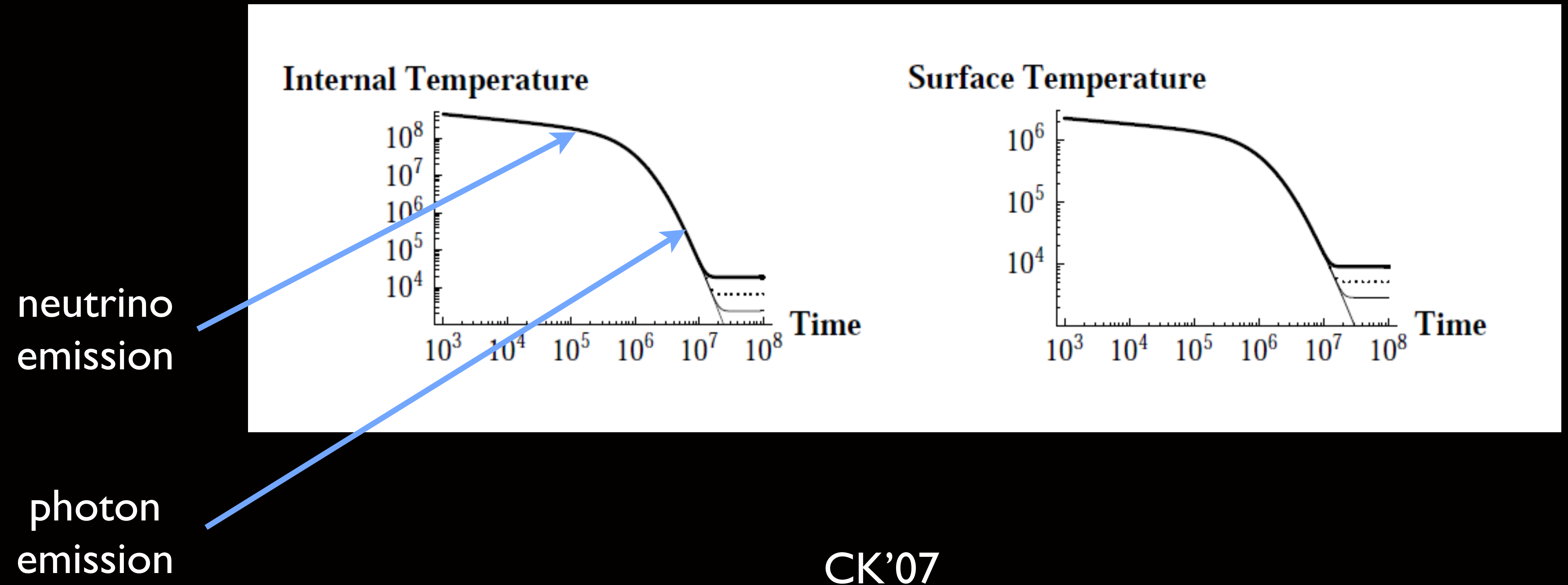
$$\frac{dT}{dt} = \frac{-L_\nu - L_\gamma + L_{\rm dm}}{V c_V} = \frac{V(-\epsilon_\nu - \epsilon_\gamma + \epsilon_{\rm dm})}{V c_V} = \frac{-\epsilon_\nu - \epsilon_\gamma + \epsilon_{\rm dm}}{c_V}$$



CK'07

Cooling of Neutron Stars

$$\frac{dT}{dt} = \frac{-L_\nu - L_\gamma + L_{\rm dm}}{V c_V} = \frac{V(-\epsilon_\nu - \epsilon_\gamma + \epsilon_{\rm dm})}{V c_V} = \frac{-\epsilon_\nu - \epsilon_\gamma + \epsilon_{\rm dm}}{c_V}$$

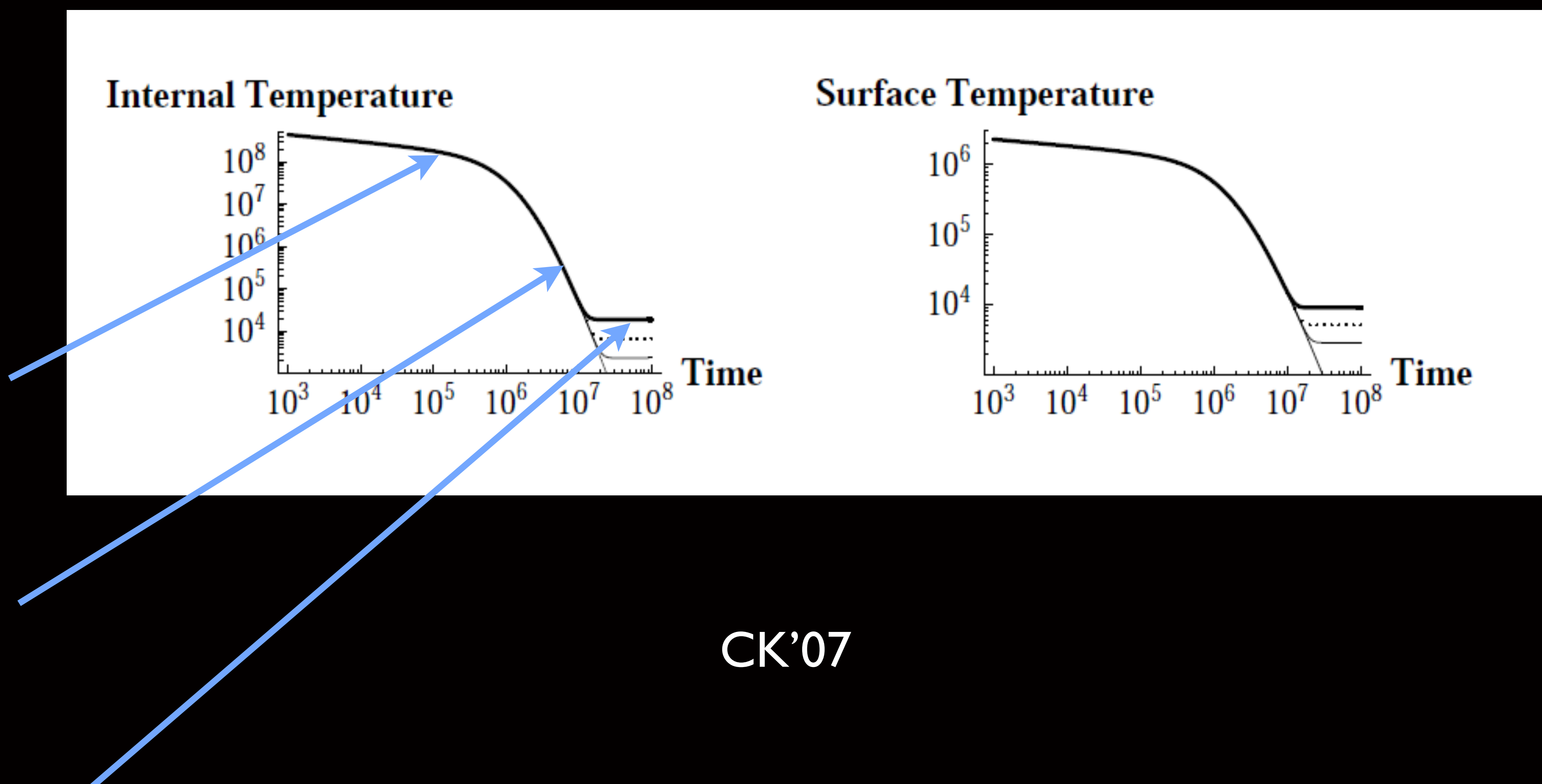


CK'07

DIAS Danish Institute for Advanced Study

Cooling of Neutron Stars

$$\frac{dT}{dt} = \frac{-L_\nu - L_\gamma + L_{\rm dm}}{V c_V} = \frac{V(-\epsilon_\nu - \epsilon_\gamma + \epsilon_{\rm dm})}{V c_V} = \frac{-\epsilon_\nu - \epsilon_\gamma + \epsilon_{\rm dm}}{c_V}$$



neutrino emission

photon emission

dark matter heating

CK’07

Cooling of Neutron Stars

Galactic Center

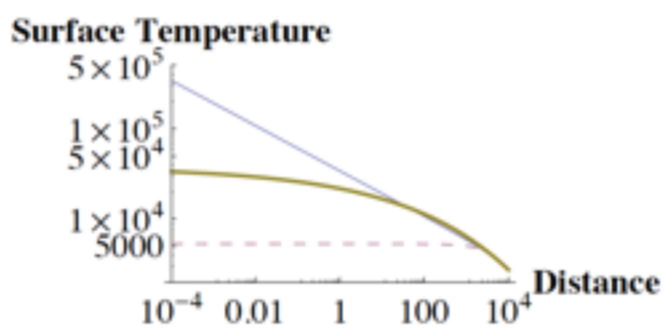


FIG. 3: The surface temperature of a typical old neutron star in units of K as a function of the distance of the star from the galactic center in pc, with the dark matter annihilation taken into account. The three curves correspond to three different dark matter profiles: NFW (thin solid line), Einasto (thick solid line), and Burkert (dashed line).

Globular Cluster

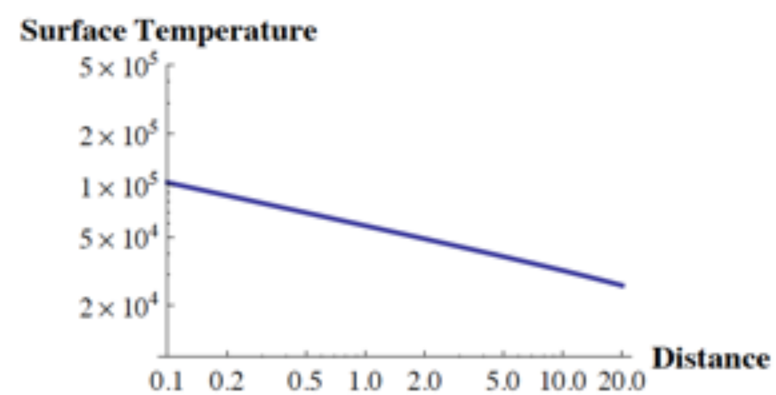


FIG. 5: The surface temperature of a typical old neutron star in units of K as a function of the distance in pc for a NFW profile of the globular cluster $M4$.

$$\rho_{\rm NFW} = \frac{\rho_s}{\frac{r}{r_s}\left(1+\frac{r}{r_s}\right)^2}$$

$$\rho_{\rm Ein} = \rho_s \exp\left[-\frac{2}{\alpha}\left[\left(\frac{r}{r_s}\right)^{\alpha} - 1\right]\right]$$

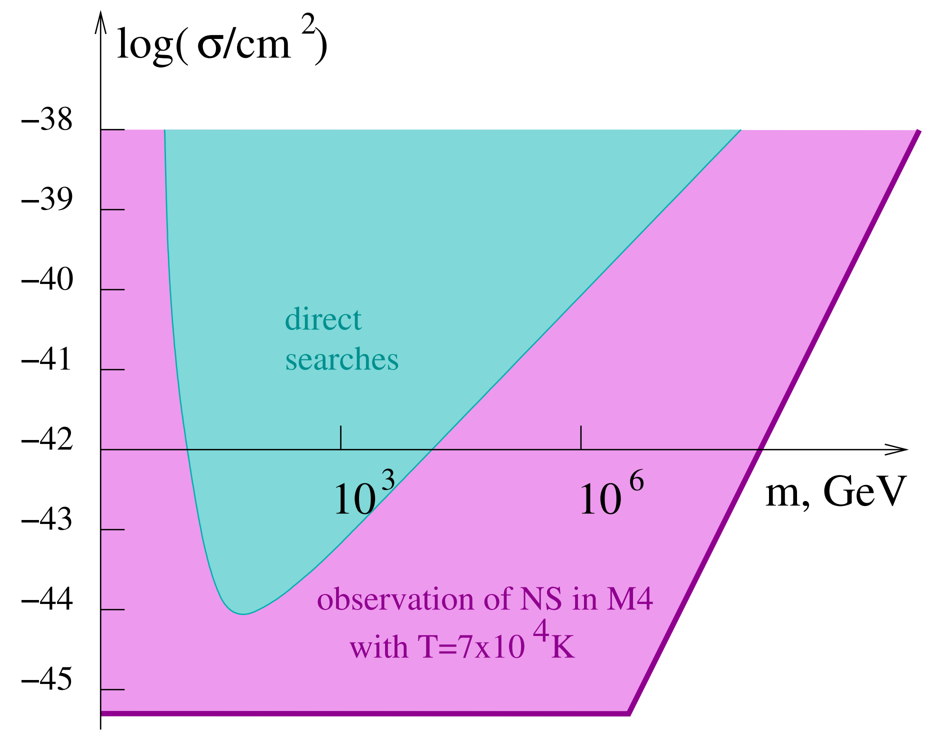
$$\rho_{\rm Bur} = \frac{\rho_s}{\left(1+\frac{r}{r_s}\right)\left[1+\left(\frac{r}{r_s}\right)^2\right]}$$

CK, Tinyakov ’10
Fairbairn Lavallaz’10

Nearby old neutron stars

J0437-4715 temperature ~10^5 K
J2124-3358 temperature ~10^5 K
130-140 pc away

Cooling of Neutron Stars



Old neutron stars in Globular Clusters

X7 in 47 Tuc
1620-26 in M4

both have temperatures roughly 10^6 K

Danish Institute for Advanced Study

Asymmetric Dark Matter

- Asymmetric DM can emerge naturally in theories beyond the SM
- Alternative to thermal production
- Possible link between baryogenesis and DM relic density

Nussinov '85, Barr Chivukula Farhi '90, Gudnason CK Sannino '06
Khlopov CK '07, CK '08, Ryttov Sannino '08, Kaplan Luty Zurek '09, Buckley Randall '10
Dutta Kumar '10, Taoso '10, Falkowski Ruderman Volansky '11

TeV WIMP

$$\frac{\Omega_{TB}}{\Omega_B} = \frac{n_{TB}}{n_B}\frac{M_{TB}}{M_p}$$

$$\frac{n_{TB}}{n_B} \sim e^{-M_{TB}/T_*}$$

$$e^{-4}10^3 \simeq 18 \sim 5$$

Light WIMP ~GeV

$$\frac{\Omega_{TB}}{\Omega_B} = \frac{n_{TB}}{n_B}\frac{M_{TB}}{M_p}$$

$$n_{TB} = n_B$$

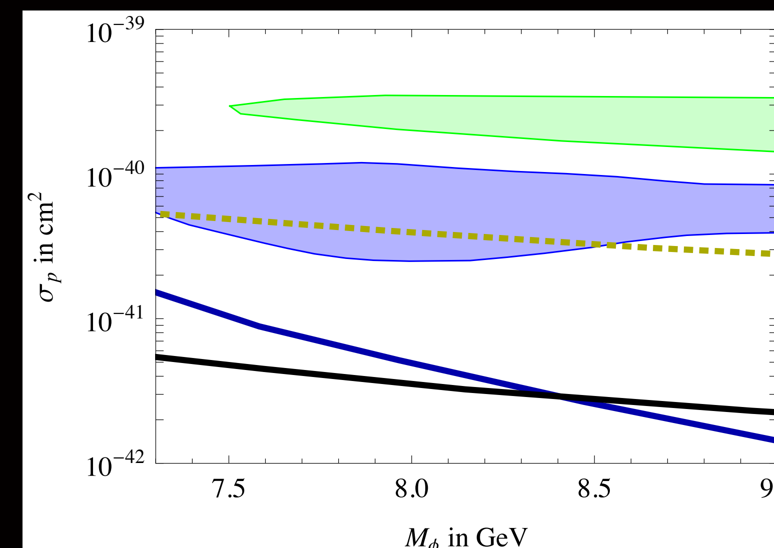
$$M_{TB} = 5\text{GeV}$$

$$1 \times 5 = 5$$

DIAS
Danish Institute for Advanced Study

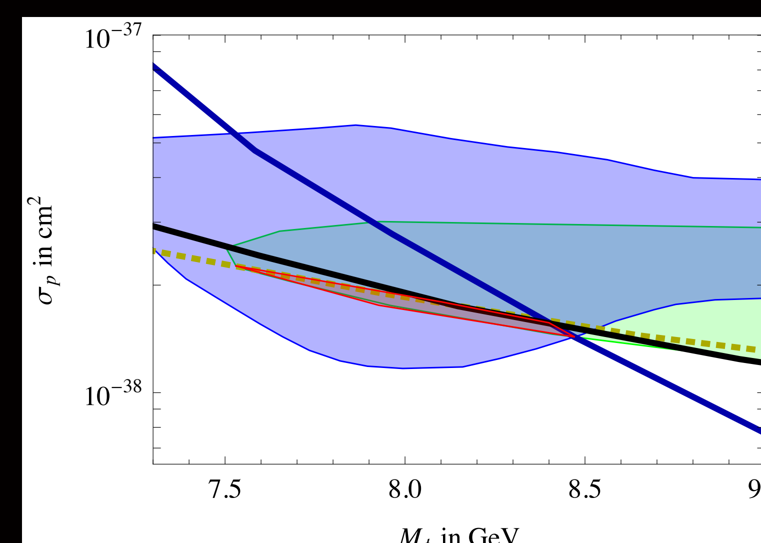
Interfering Dark Matter

- Dama and CoGeNT detect signal with annual modulation
- Xenon and CDMS exclude them if



However if

Chang Liu Pierce Weiner Yavin '10, Feng Kumar Marfatia Sanford '11, Del Nobile CK Sannino '11

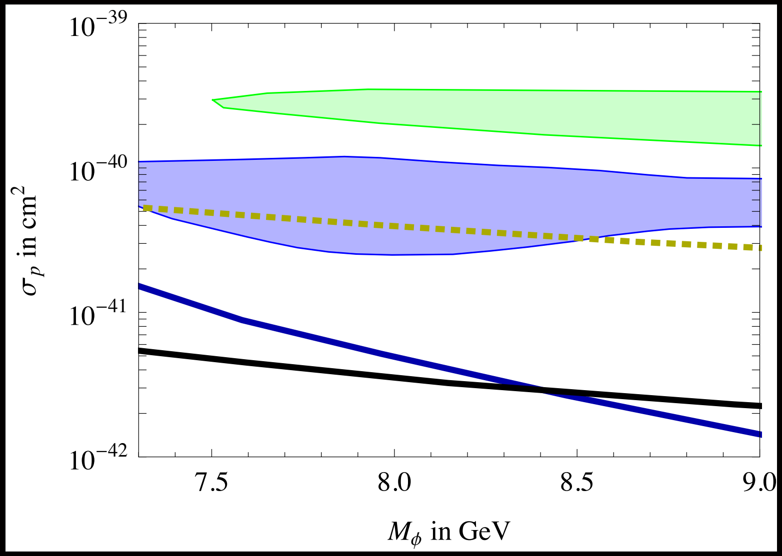


Need for isospin violation!

Interfering Dark Matter

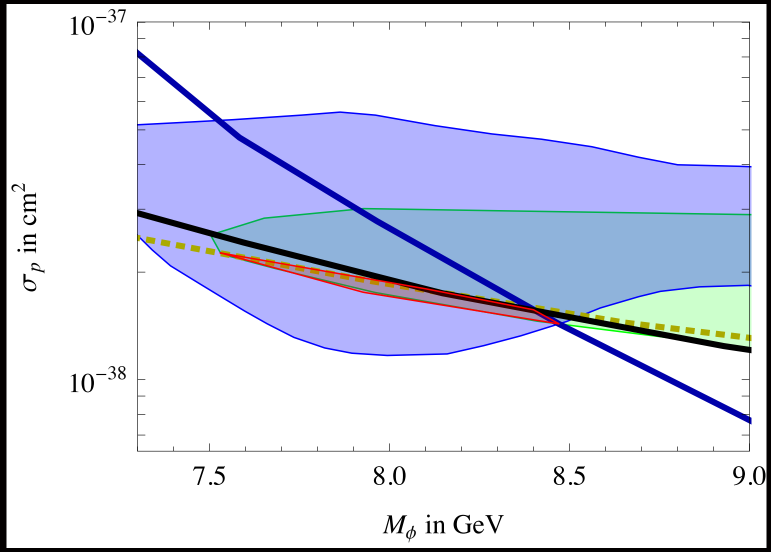
- Dama and CoGeNT detect signal with annual modulation
- Xenon and CDMS exclude them if

$$\sigma_A = \frac{\mu_A^2}{4\pi}\left|Zf_p + (A-Z)f_n\right|^2 \qquad f_n = f_p$$



However if $f_n/f_p \simeq -0.7$

Chang Liu Pierce Weiner Yavin '10, Feng Kumar Marfatia Sanford '11, Del Nobile CK Sannino '11



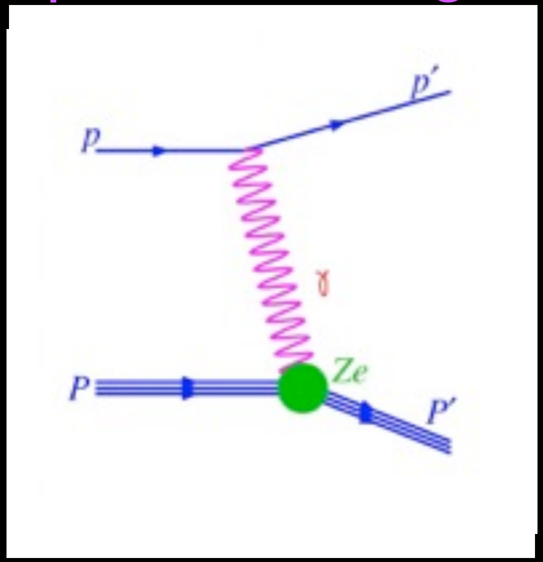
Need for isospin violation!

Interfering Dark Matter

Interference of Asymmetric Composite DM can resolve the experimental puzzle

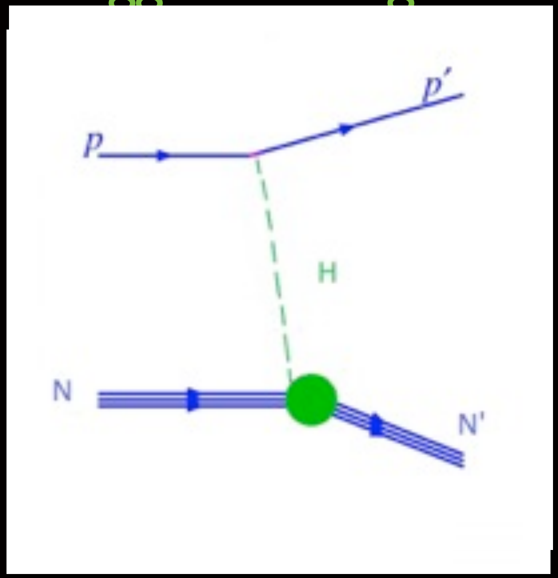
Say UD is the WIMP, U and D are oppositely charged

photon exchange



+

Higgs exchange



$\frac{d_B}{\Lambda^2} e J_\mu \partial_\nu F^{\mu\nu}$ $\quad J_\mu = i\phi^* \overleftrightarrow{\partial_\mu} \phi$ $\quad d_H H^\dagger H \phi^* \phi$

$$\frac{d_B}{\Lambda^2} \sim 3 \times 10^{-4}\ \mathrm{GeV}^{-2}\ , \quad \frac{d_H}{m_H^2} \sim 5 \times 10^{-4}\ \mathrm{GeV}^{-2}$$

Del Nobile CK Sannino '11

Bosonic Asymmetric Dark Matter

Bosonic Asymmetric Dark Matter

No Fermi pressure but Heisenberg uncertainty keeps bosons from collapse

Bosonic Asymmetric Dark Matter

No Fermi pressure but Heisenberg uncertainty keeps bosons from collapse

$$\frac{GNm^2}{r} \simeq \frac{\hbar}{r} \longrightarrow M_{crit} = \frac{2M_{\rm Pl}^2}{\pi m}\sqrt{1 + \frac{M_{\rm Pl}^2}{4\sqrt{\pi} m}\sigma^{1/2}}$$

$$\sigma = \lambda^2/(64\pi m^2)$$

Bosonic Asymmetric Dark Matter

No Fermi pressure but Heisenberg uncertainty keeps bosons from collapse

$$\frac{GNm^2}{r} \simeq \frac{\hbar}{r} \longrightarrow M_{crit} = \frac{2M_{\mathrm{Pl}}^2}{\pi m}\sqrt{1 + \frac{M_{\mathrm{Pl}}^2}{4\sqrt{\pi}m}\sigma^{1/2}} \qquad \sigma = \lambda^2/(64\pi m^2)$$

repulsive interactions

Bosonic Asymmetric Dark Matter

No Fermi pressure but Heisenberg uncertainty keeps bosons from collapse

$$\frac{GNm^2}{r} \simeq \frac{\hbar}{r} \longrightarrow M_{crit} = \frac{2M_{\rm Pl}^2}{\pi m}\sqrt{1 + \frac{M_{\rm Pl}^2}{4\sqrt{\pi}m}\sigma^{1/2}}$$

$$\sigma = \lambda^2/(64\pi m^2)$$

repulsive interactions

BEC accelerates collapse

$$T_c = \left(\frac{n}{\zeta(3/2)}\right)^{2/3} \frac{2\pi\hbar^2}{mk_B} \approx 3.31\,\frac{\hbar^2 n^{2/3}}{mk_B}$$

$$N_{\rm BEC} \simeq 2 \times 10^{36}$$

$$r_{\rm th} \simeq 2\ {\rm m}\left(\frac{T_c}{10^5{\rm K}}\right)^{1/2}\left(\frac{m}{\rm GeV}\right)^{-1/2} \longrightarrow r_c = \left(\frac{8\pi}{3}G\rho_c m^2\right)^{-1/4} \simeq 1.6\times 10^{-4}\left(\frac{\rm GeV}{m}\right)^{1/2}\ {\rm cm}$$

Bosonic Asymmetric Dark Matter

No Fermi pressure but Heisenberg uncertainty keeps bosons from collapse

$$\frac{GNm^2}{r} \simeq \frac{\hbar}{r} \longrightarrow M_{crit} = \frac{2M_{\rm Pl}^2}{\pi m}\sqrt{1 + \frac{M_{\rm Pl}^2}{4\sqrt{\pi}m}\sigma^{1/2}}$$

$$\sigma = \lambda^2/(64\pi m^2)$$

repulsive interactions

BEC accelerates collapse

$$T_c = \left(\frac{n}{\zeta(3/2)}\right)^{2/3}\frac{2\pi\hbar^2}{mk_B} \approx 3.31\,\frac{\hbar^2 n^{2/3}}{mk_B}$$

$$N_{\rm BEC} \simeq 2\times 10^{36}$$

$$r_{\rm th} \simeq 2\ {\rm m}\left(\frac{T_c}{10^5{\rm K}}\right)^{1/2}\left(\frac{m}{\rm GeV}\right)^{-1/2} \longrightarrow r_c = \left(\frac{8\pi}{3}G\rho_c m^2\right)^{-1/4} \simeq 1.6\times 10^{-4}\left(\frac{\rm GeV}{m}\right)^{1/2}{\rm cm}$$

Evolution of the Black Hole

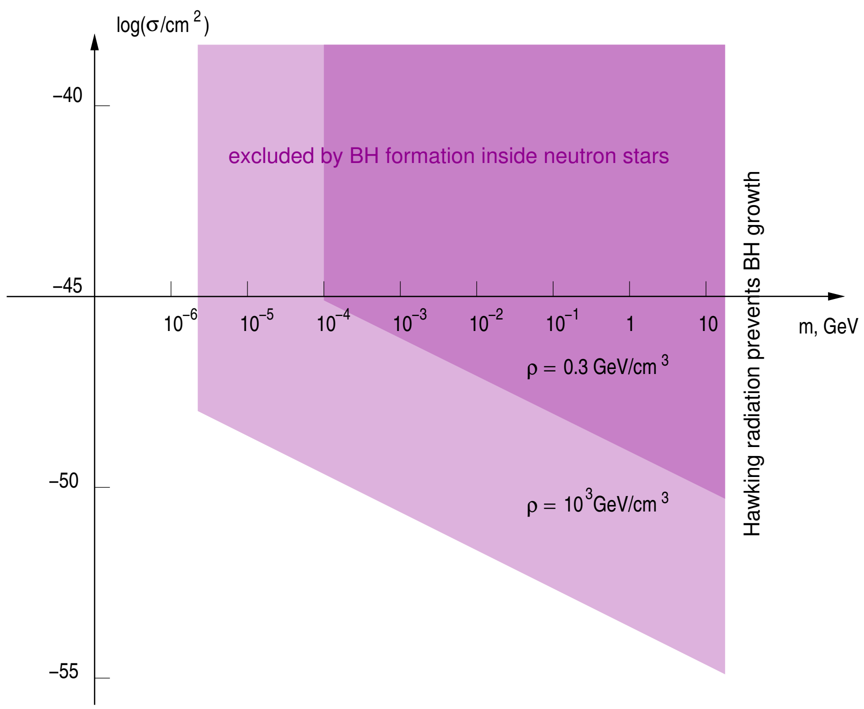
$$\frac{dM}{dt} = \frac{4\pi\rho_c G^2 M^2}{c_s^3} - \frac{1}{15360\pi G^2 M^2}$$

Bondi accretion

Hawking Radiation

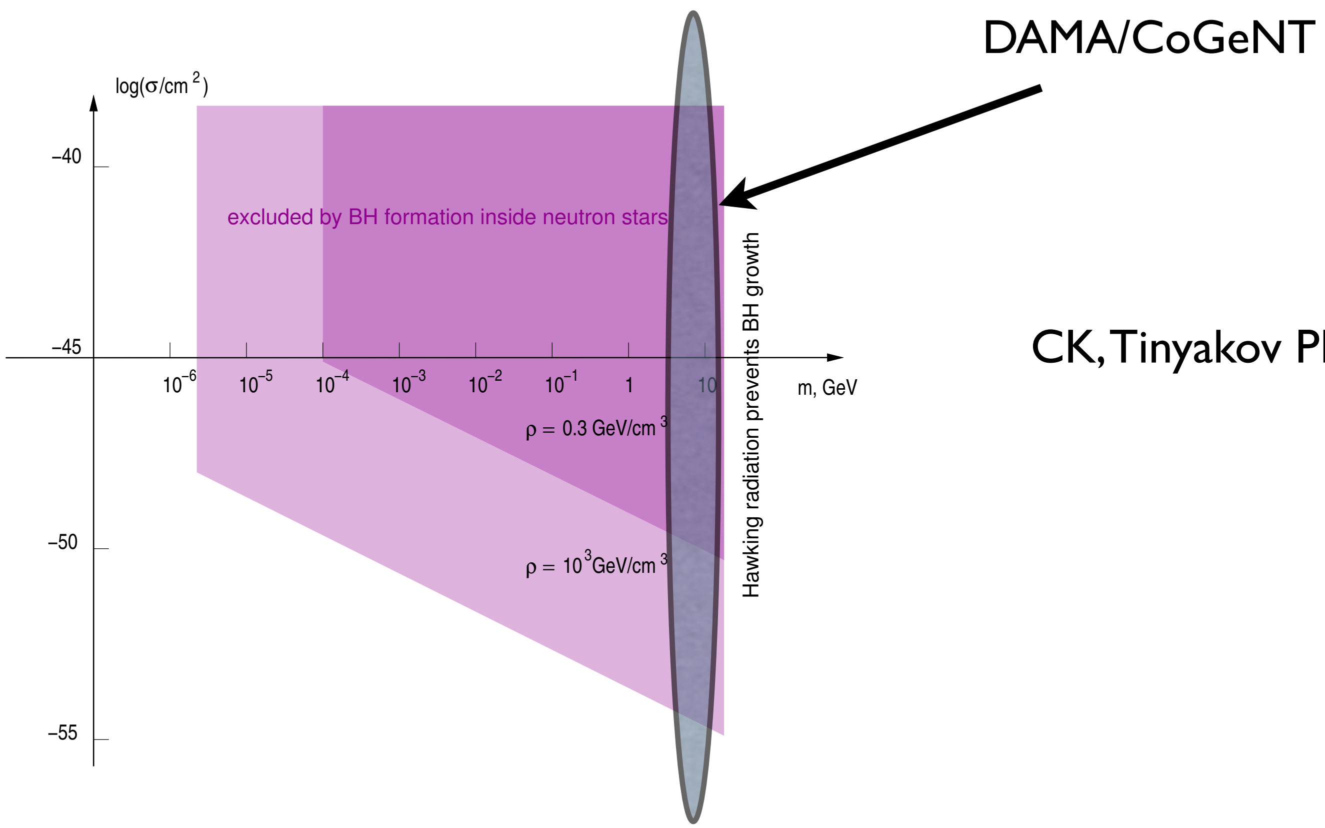
Bosonic Asymmetric Dark Matter

Bosonic Asymmetric Dark Matter



CK, Tinyakov PRL '11

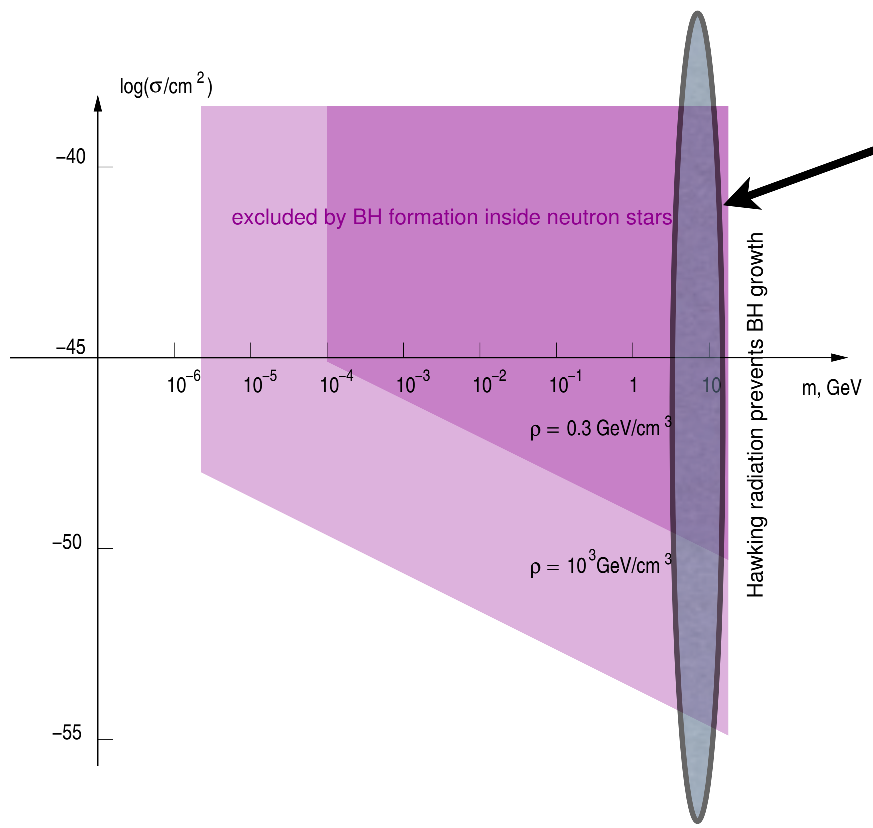
Bosonic Asymmetric Dark Matter



CK, Tinyakov PRL '11

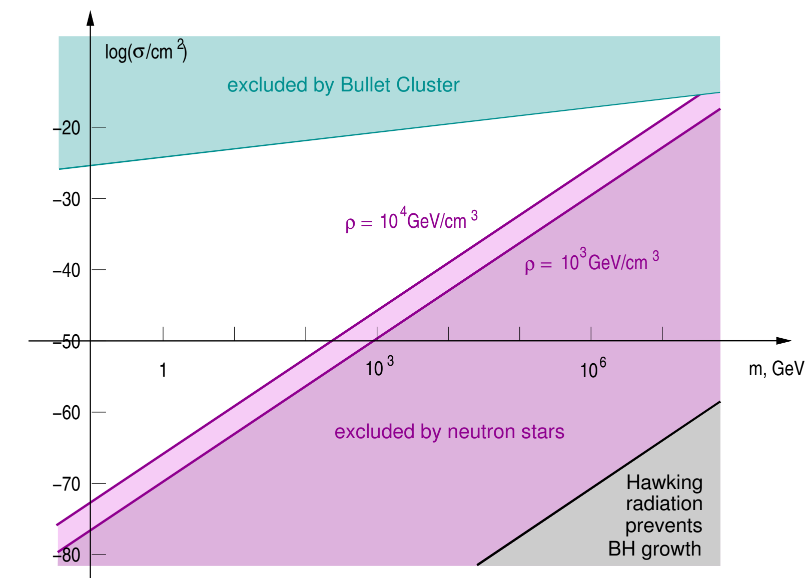
Danish Institute for Advanced Study

Bosonic Asymmetric Dark Matter



DAMA/CoGeNT

CK, Tinyakov PRL '11

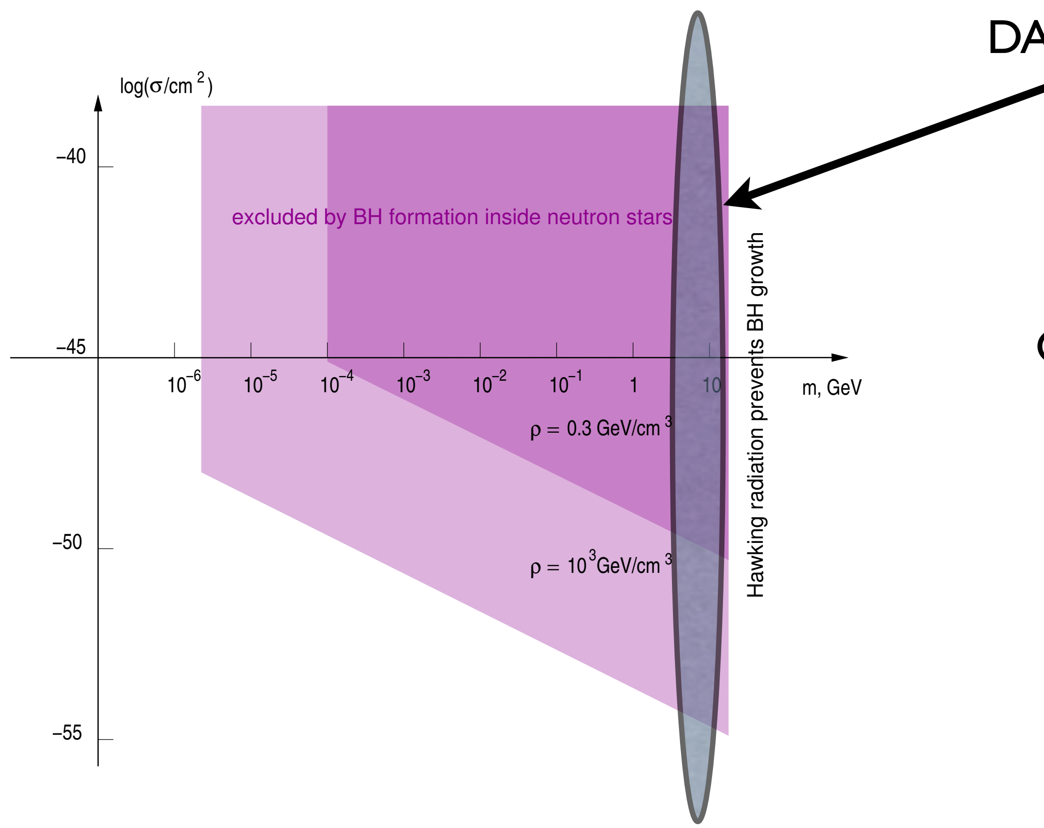


Self-Interacting DM

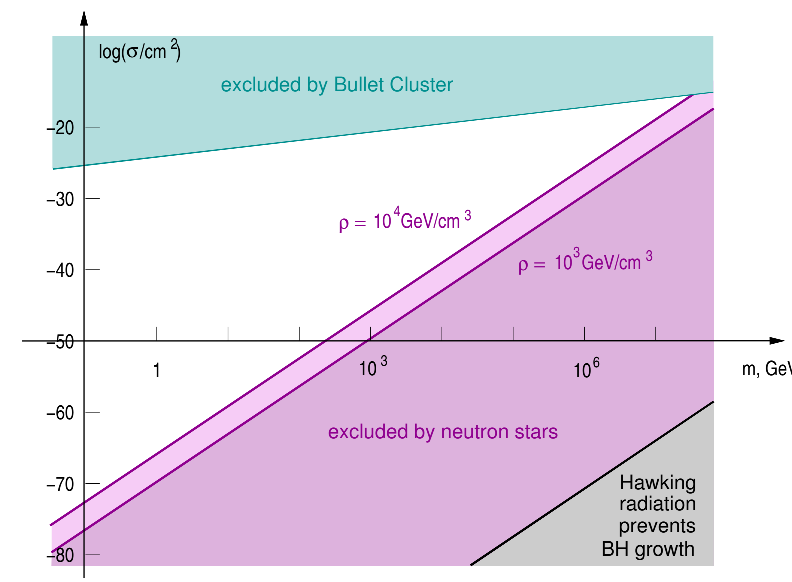
Danish Institute for Advanced Study

Bosonic Asymmetric Dark Matter

DAMA/CoGeNT



CK, Tinyakov PRL '11



Self-Interacting DM

If WIMP is a composite of fermions

$$\Lambda_{crit} = m^{1/3} M_{\rm Pl}^{2/3} \left(1 + \frac{\lambda m_{pl}^2}{32\pi m^2}\right)^{-1/3}$$

If WIMP is a composite of fermions above that scale, the bosonic constraints still hold

Danish Institute for Advanced Study

Self-Interacting Dark Matter

“Chandrashekhar Limit for WIMPs”

$$\frac{GNm^2}{r} > k_F = \left(\frac{3\pi^2 N}{V}\right) = \left(\frac{9\pi}{4}\right)^{1/3}\frac{N^{1/3}}{r}$$

N=10^57/m^3!!!

Yukawa-type WIMP self-interactions can explain the flatness of dwarf galaxies Spergel-Steinhardt ’99, Loeb-Weiner ’11

$$\alpha\phi\bar{\psi}\psi$$

$$V(r) = -\alpha\exp[-\mu r]/r$$

Yukawa self-interactions can alleviate the effect of the Fermi pressure, leading to a gravitational collapse with dramatically lower amount of captured WIMPs

Self-Interacting Dark Matter

Virial Theorem

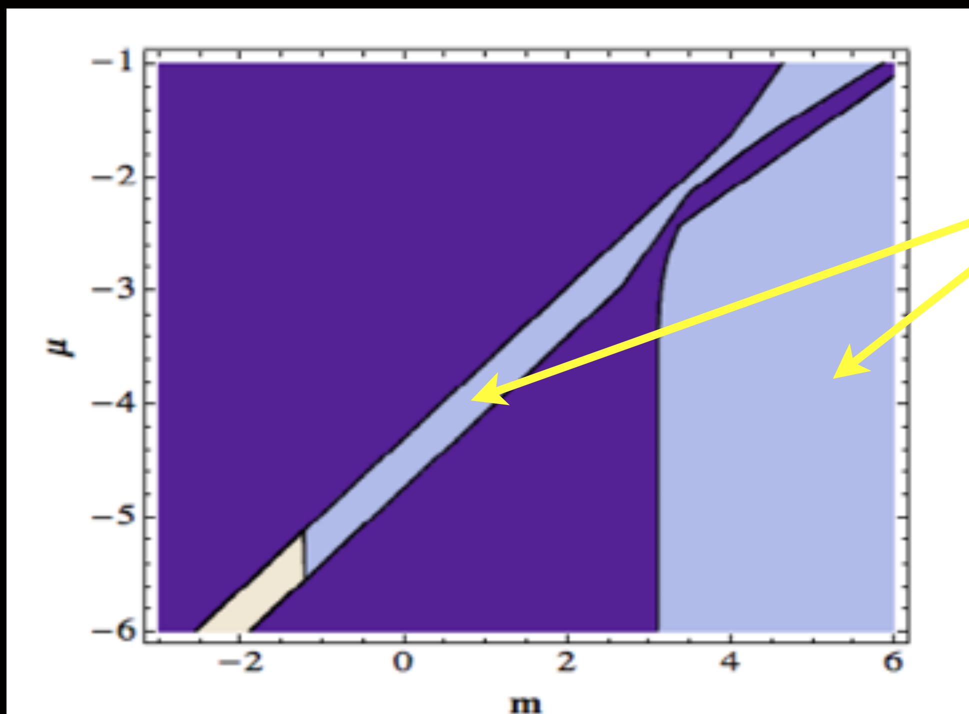
$$2\langle E_k \rangle = \frac{8}{3}\pi G \rho m r^2 + \frac{GNm^2}{r} + \left\langle \sum_j \alpha \frac{e^{-\mu r_{ij}}}{r_{ij}} + \alpha \mu e^{-\mu r_{ij}} \right\rangle$$

- Self-attraction before degeneracy
- Self-attraction after degeneracy

Yukawa potential energy once saturated it scales as 1/r^3

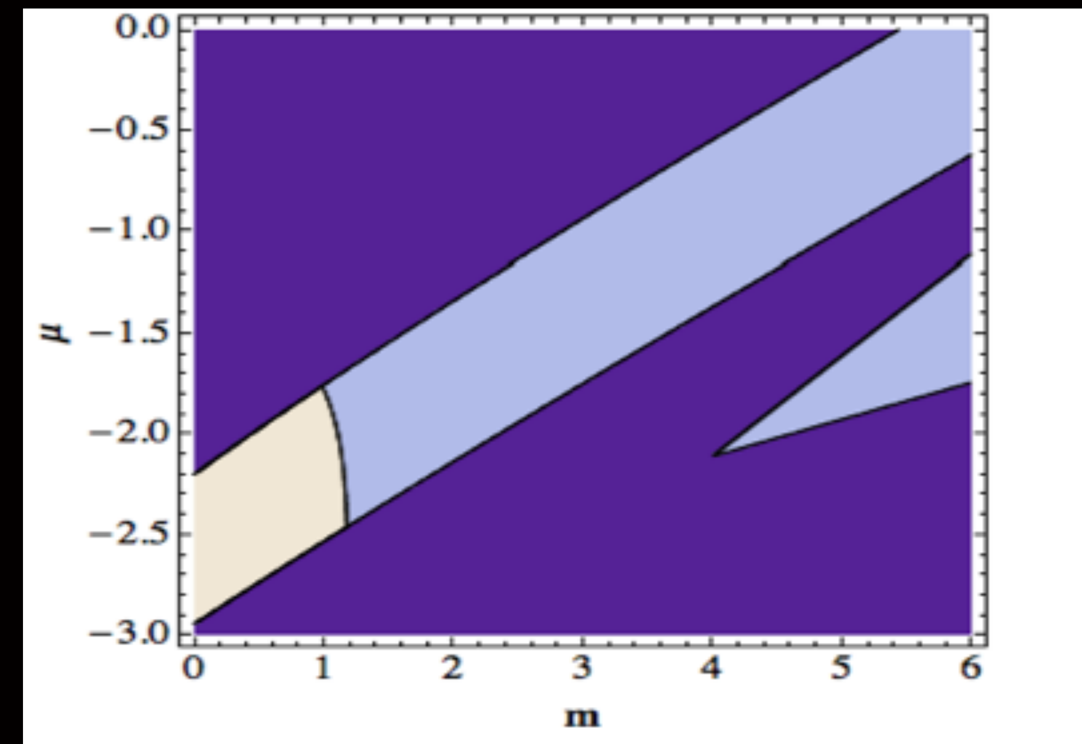
DIAS
Danish Institute for Advanced Study

Self-Interacting Dark Matter



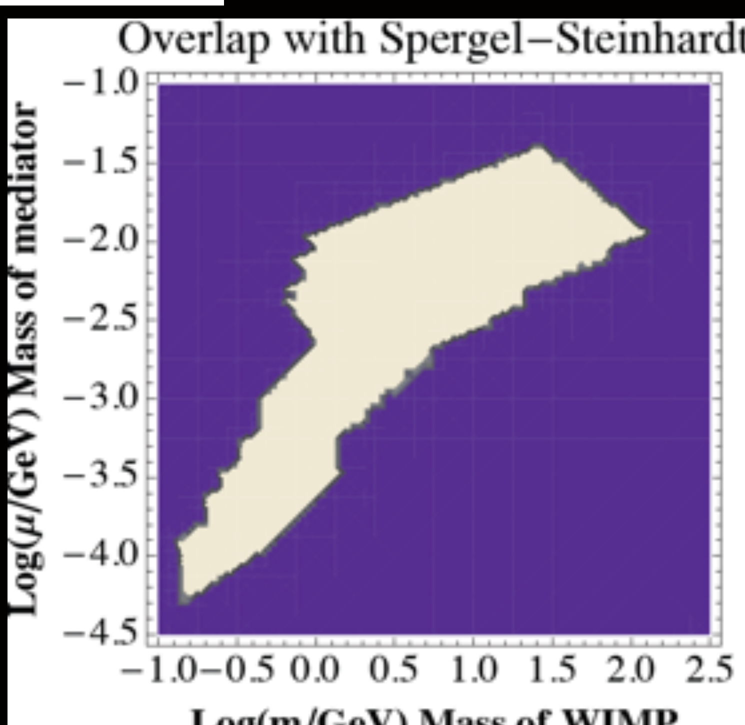
Exclusion regions

CK PRL'12



$\alpha = 10^{-5}$

$\alpha = 0.1$



Loeb-Weiner

$$(m_\chi/10\mathrm{GeV})(m_\phi/100\mathrm{MeV})^2 \sim 1$$

Spin-Dependent Asymmetric Dark Matter

Spin-Dependent Asymmetric Dark Matter

A regular star accumulates WIMPs with spin-dependent WIMP-nucleon interactions and collapses to a white dwarf after the hydrogen and helium burning stages

Spin-Dependent Asymmetric Dark Matter

A regular star accumulates WIMPs with spin-dependent WIMP-nucleon interactions and collapses to a white dwarf after the hydrogen and helium burning stages

The WIMP population is inherited by the white dwarf and gets thermalized inside it due to the presence of C13-WIMP spin-dependent interactions

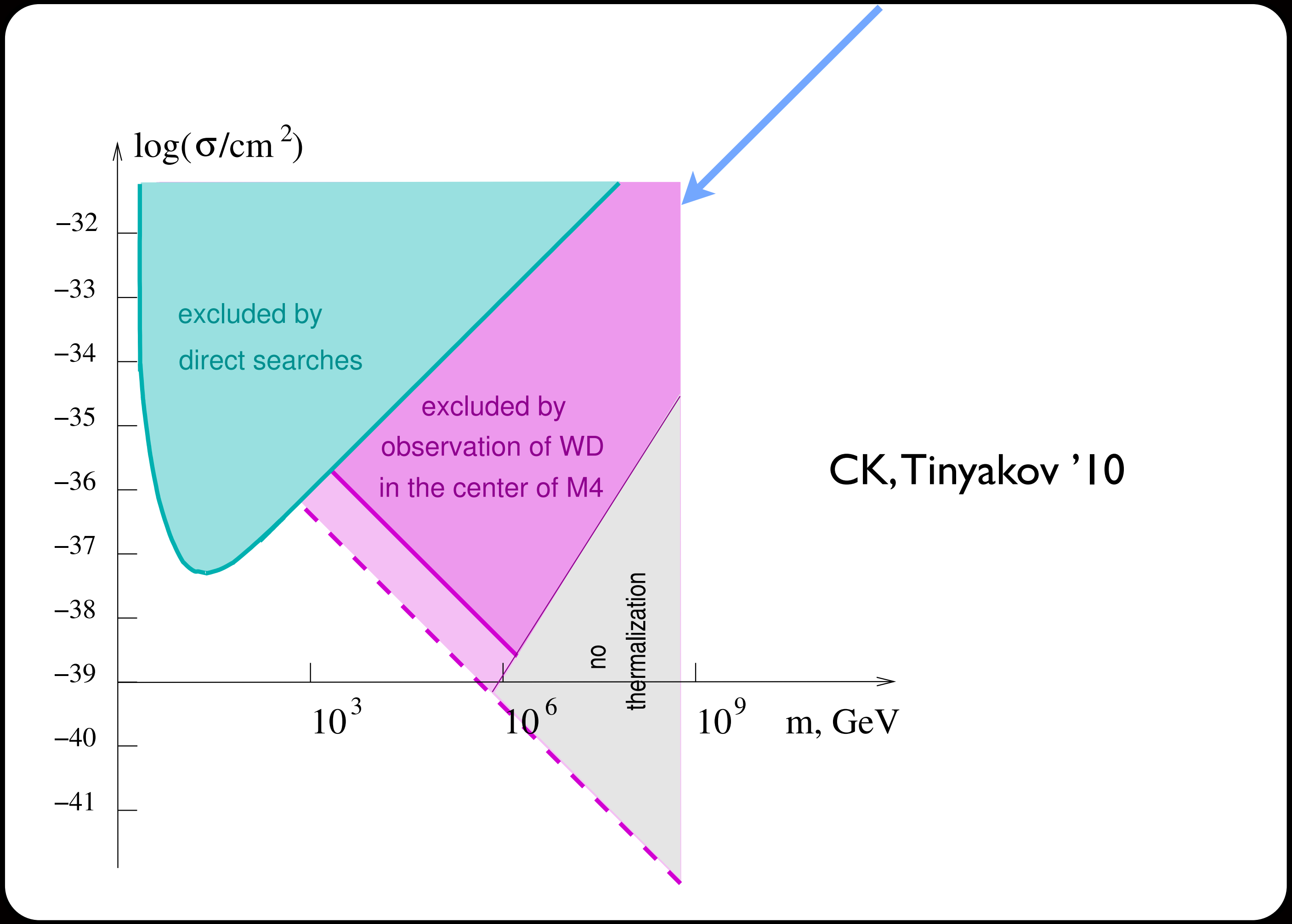
DIAS
Danish Institute
for Advanced Study

Spin-Dependent Asymmetric Dark Matter

A regular star accumulates WIMPs with spin-dependent WIMP-nucleon interactions and collapses to a white dwarf after the hydrogen and helium burning stages

The WIMP population is inherited by the white dwarf and gets thermalized inside it due to the presence of C13-WIMP spin-dependent interactions

Formation of a Black Hole



The Dark Side of the Stars

Compact stars can reveal a lot of information about the nature of DM putting constraints on its properties complementary to direct searches.

• Observation of cold neutron stars can exclude thermally produced dark matter.

• Asymmetric dark matter:

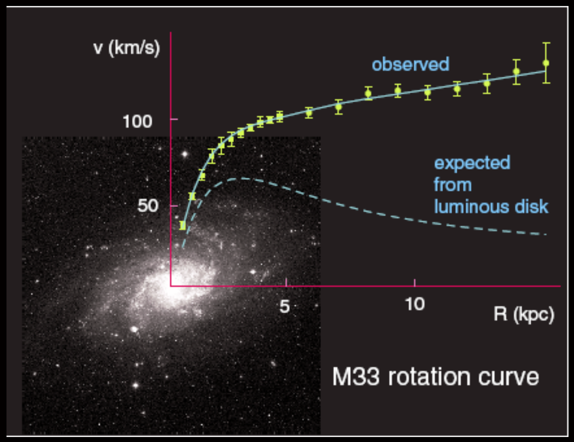
1. keV to ~16GeV bosonic dark matter is excluded.
2. Part of fermionic WIMP self-interactions excluded.
3. Constraints on WIMP-nucleon spin-dependent interactions.

DIAS
Danish Institute
for Advanced Study

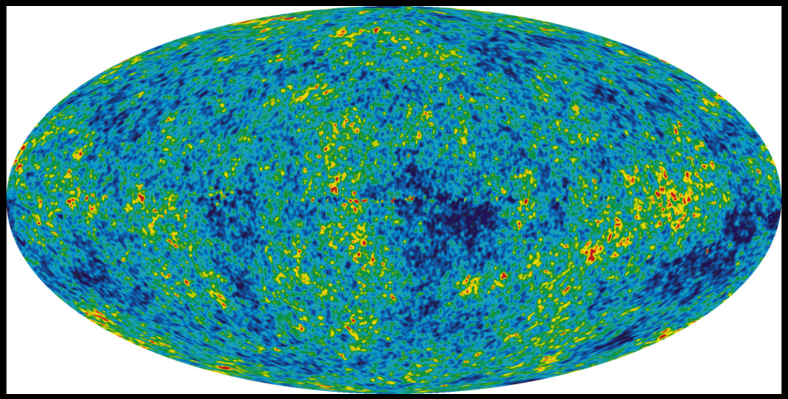
The Missing Mass of the Universe

A Mystery for 80 years!

Zwicky 1933:
Virial Theorem on Coma cluster

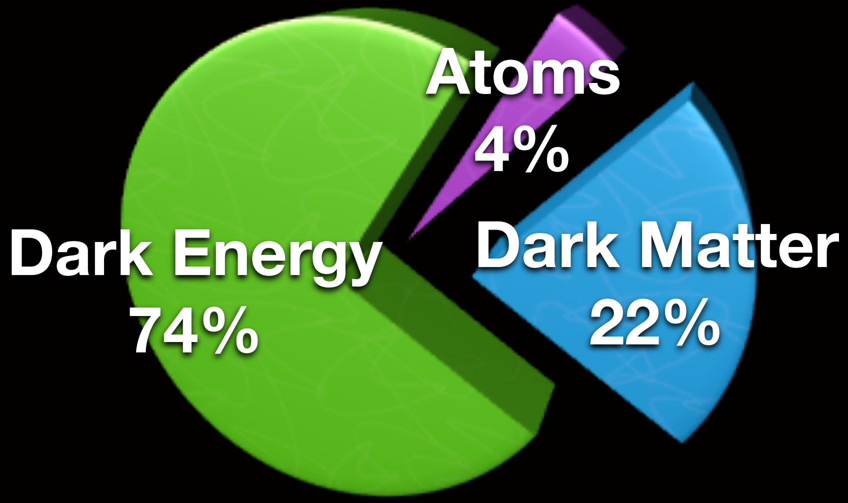


Vera Rubin 70's
Rotation curves of Andromeda are not falling according to Newton's law!



Microwave Background Radiation

Bullet Cluster



What is the nature of Dark Matter?

Hidden Sector

Supersymmetry

???

Technicolor

Unparticle

Axions

Kaluza-Klein