



On the effect of
Bose-Einstein condensed *dark matter*
for the magnetic field
in *neutron stars*

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Sep. 29, QM2015@Kobe Fashion Mart





Messages of this presentation

1. Physics of dark matter
in stars

2. Magnetar

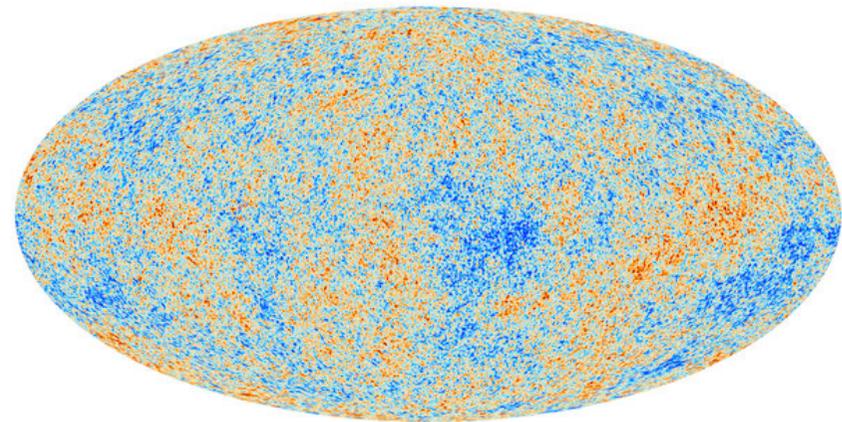
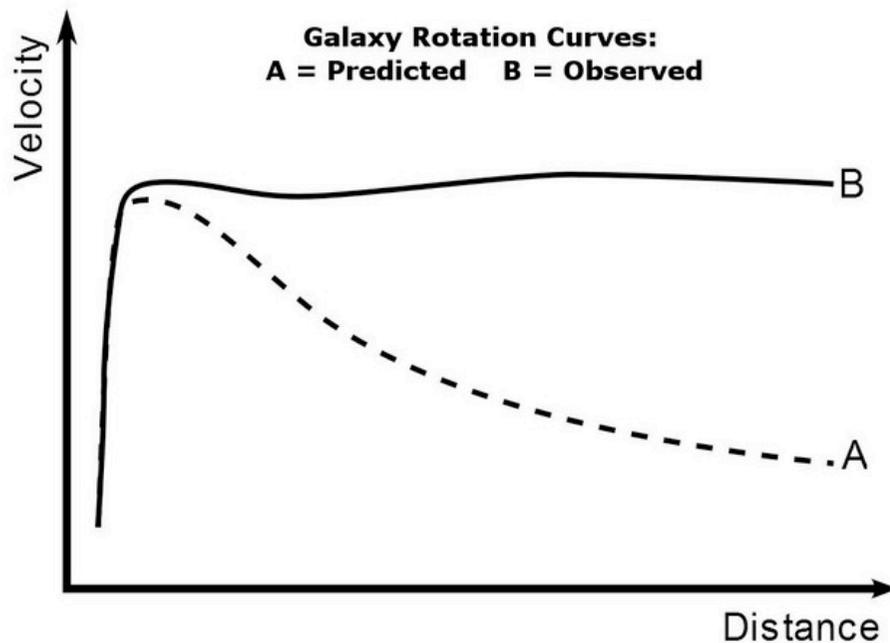
-the strongest magnet in the universe-

3. BEC of DM in NS

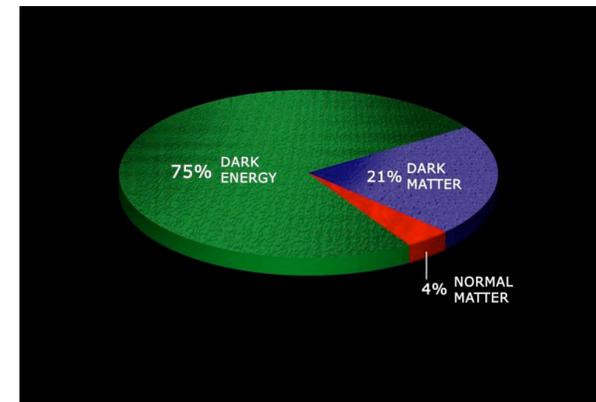


What is dark matter (DM) ?

Undoubtedly exists, but properties unknown
Interacting with other particles very weakly



European Space Agency; Planck Collaboration



What is neutron star (NS) ?

Landau's gigantic nucleus

Good market selling ultimate environments



$$R_{NS} \sim 10km$$

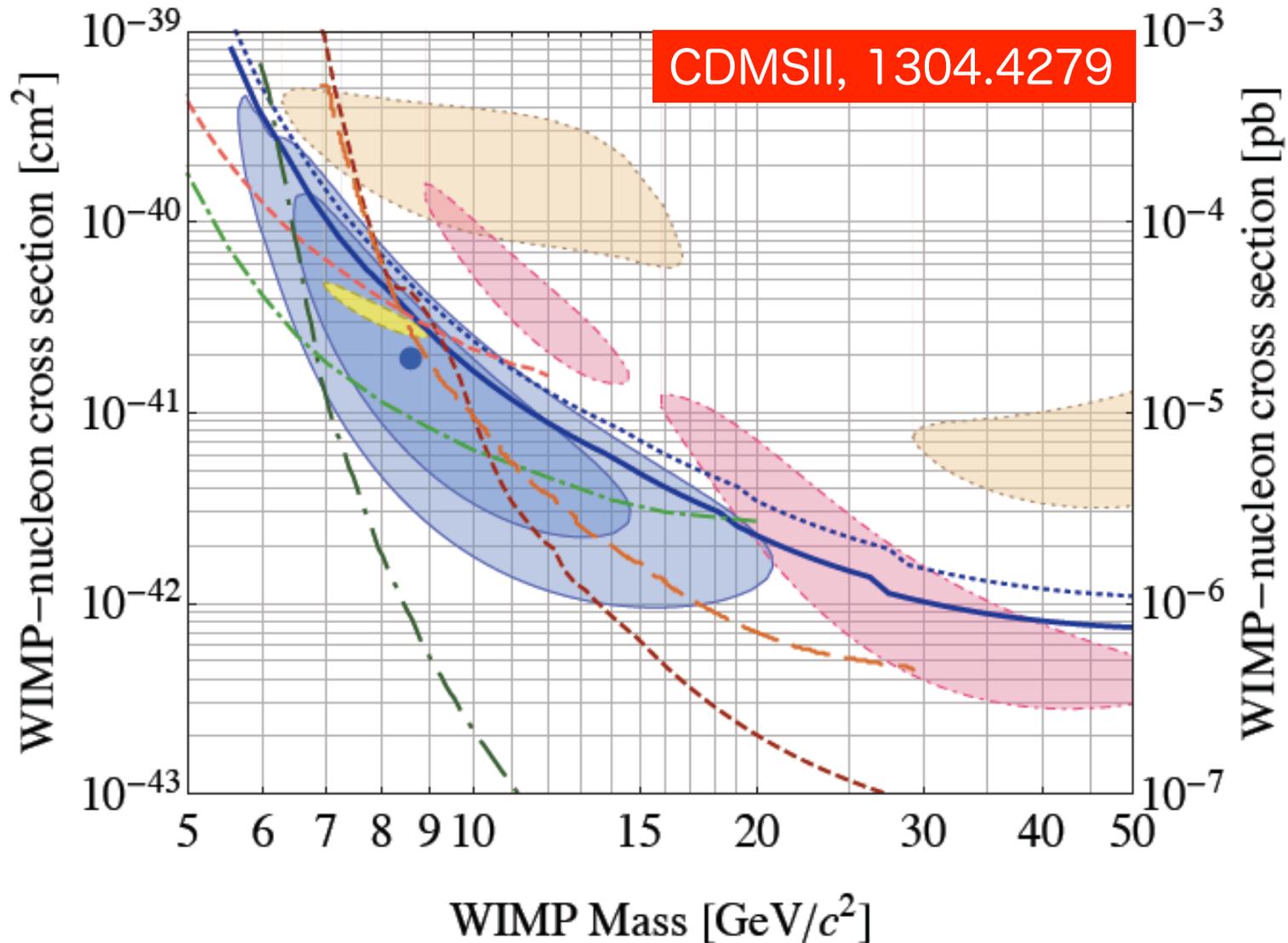
$$M_{NS} \sim 1.4M_{SUN}$$

$$T_{NS} < 10MeV$$

$$B_{NS} \sim 10^8 - 10^{11} T$$

$$P_{NS} \sim 2 - 3ms$$

Possibly constraining DM properties via NS?





A naive consideration

$$\sigma = \frac{1}{n\lambda} \quad \lambda : \text{mean free path}$$

$$n \approx \frac{M}{(4/3)\pi R^3 m_N}$$

For a typical NS, $M \approx 1.4M_{SUN}$, $R \approx 10\text{km}$



$$\sigma_{NS} \approx 5 \times 10^{-46} \text{cm}^2$$

Way below
the CDMS limit!





Impacts of dark matter on NS

- NS mass-radius relation with dark matter EOS
- NS heating via dark matter annihilation
- NS seismology
- Dark matter capture in NS and formation of black-hole to collapse host neutron stars

cf) This is not a new idea. People have considered the DM capture by Sun/Earth since 80's.

cosmion

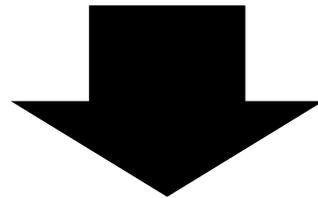
Press and Spergel (1984)





Question

Another impact of dark matter
on physics of neutron stars?



Some peculiar magnetic property

Magnetar





Magnetar hypothesis

Duncan-Thompson(1992)

Large magnetic field : $10^{10} - 10^{11} T$

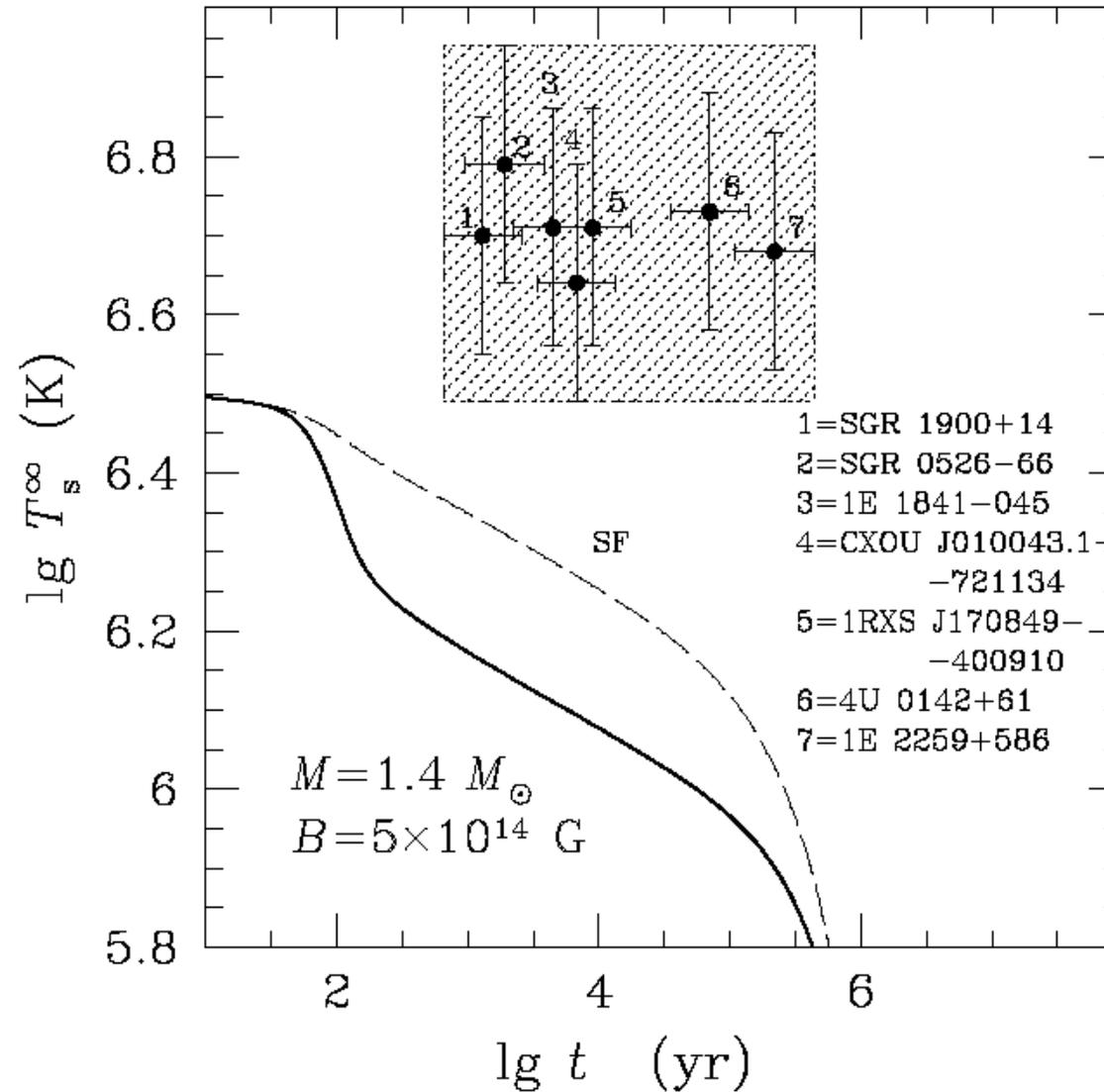
(Relatively) young : $10^3 - 10^6 yrs$

(Relatively) hot : → **Next Slide**

Isolated stars? (no companion stars)



Cooling of neutron stars



Kaminker et al., MNRAS(2006)



Light dipolar DM (LDDDM) model

-light scalar boson w/ magnetic moment-

Properties

1. Massive boson with $m_X \sim 100 - 1000 eV$
2. “weak” or magnetic interaction
with ordinary particles
3. Possible magnetic moment μ_X

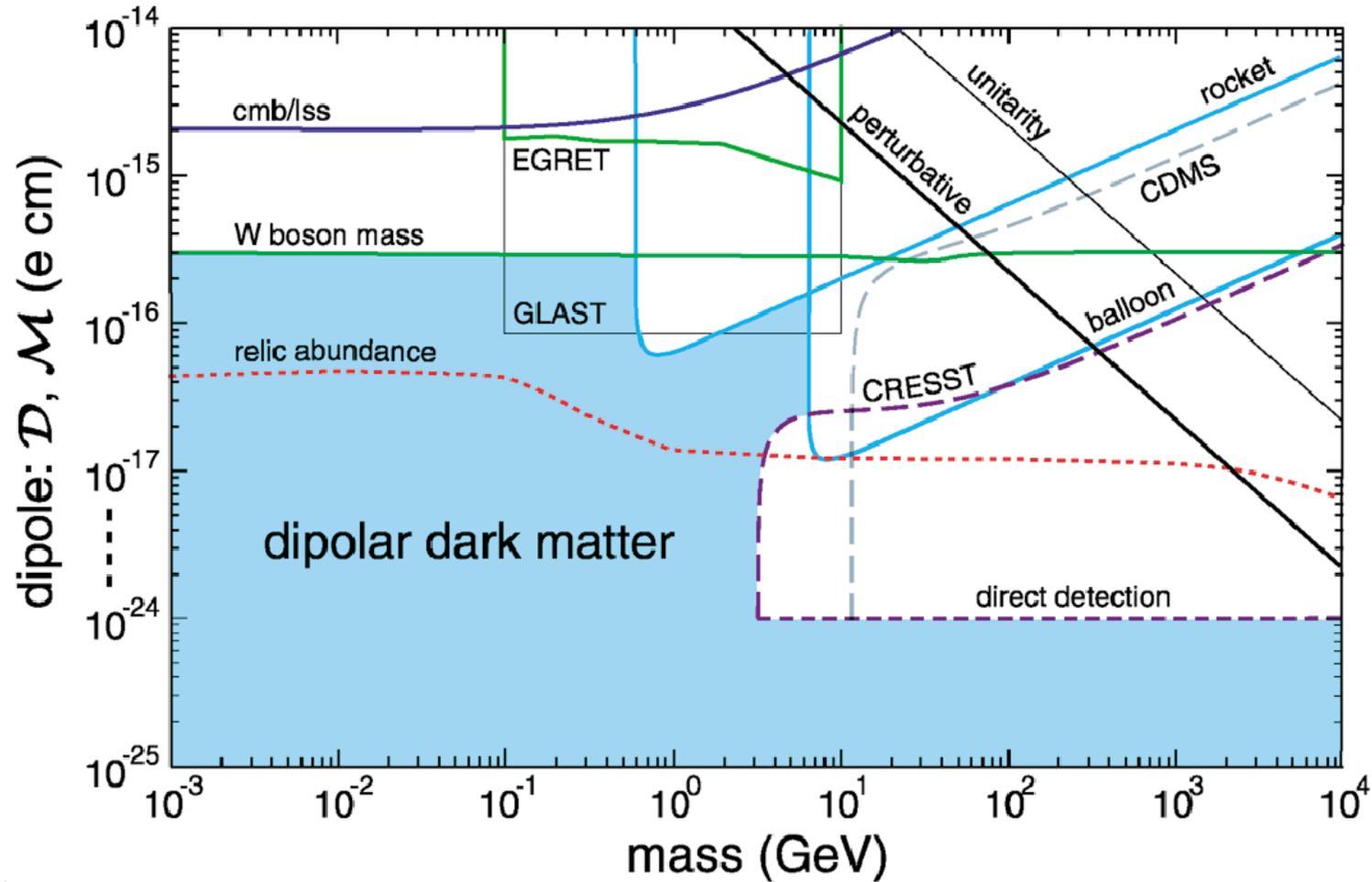
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Constraints on dipolar DM

KRIS SIGURDSON *et al.*

PHYSICAL REVIEW D **70** 083501



K. Sigurdson et al., PRD70(2004)

Star as a gravitational harmonic oscillator

DM equilibrium condition

$$T \cong Gm_X \frac{\rho_B(r)}{r} \sim Gm_X m_N n_B r^2$$

➔ $r \sim 20 \sqrt{\frac{T}{m_X}} [km]$ Thermal radius

So the mass of DM is comparable to NS temperature, it can be trapped inside of NS



If DM is uniformly distributed in NS,
the surface magnetic field made by DM is

$$B \sim \frac{\mu_X N_X}{4\pi R^3} \sim \frac{1}{4\pi} \left(\frac{\mu_X}{\mu_B} \right) \times 10^{-42} N_X [T]$$

If we impose the amount of accreted DMs
does not exceed the mass of NS, then

$$\mu_X > 10^{-22} (e \cdot cm)$$




Bose-Einstein condensed DM

When NS cools down and the temperature gets to the critical value, Bose-Einstein condensate of DM (**WIMP-BEC**) is formed

“BEC radius”

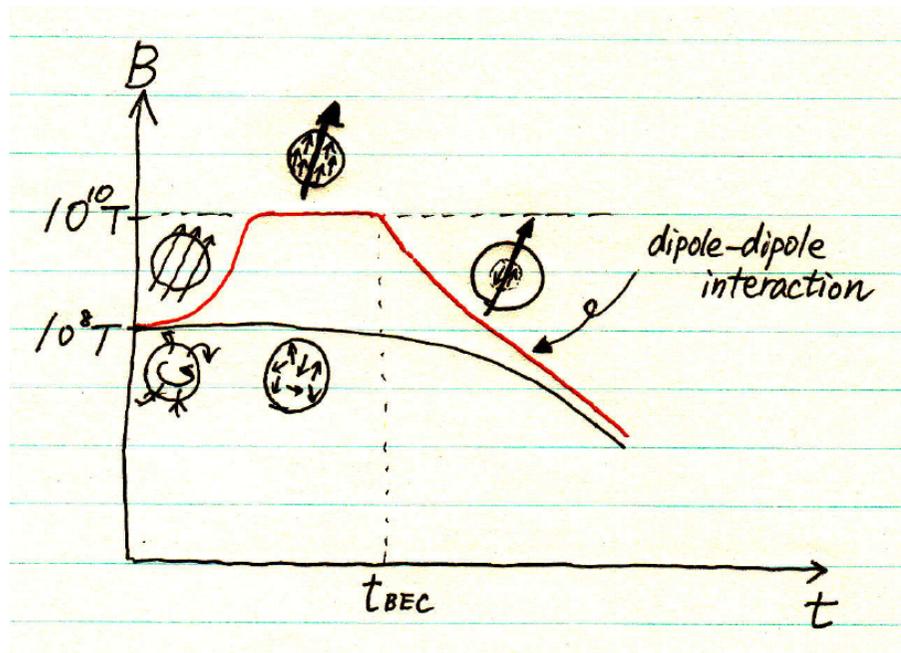
$$r_{BEC} \sim 1.5 \times 10^{-1} \sqrt{\frac{10^3 eV}{m_X}} [cm]$$

Dipole int. between DMs gets dominant and mag. fields by DMs are mutually canceled !

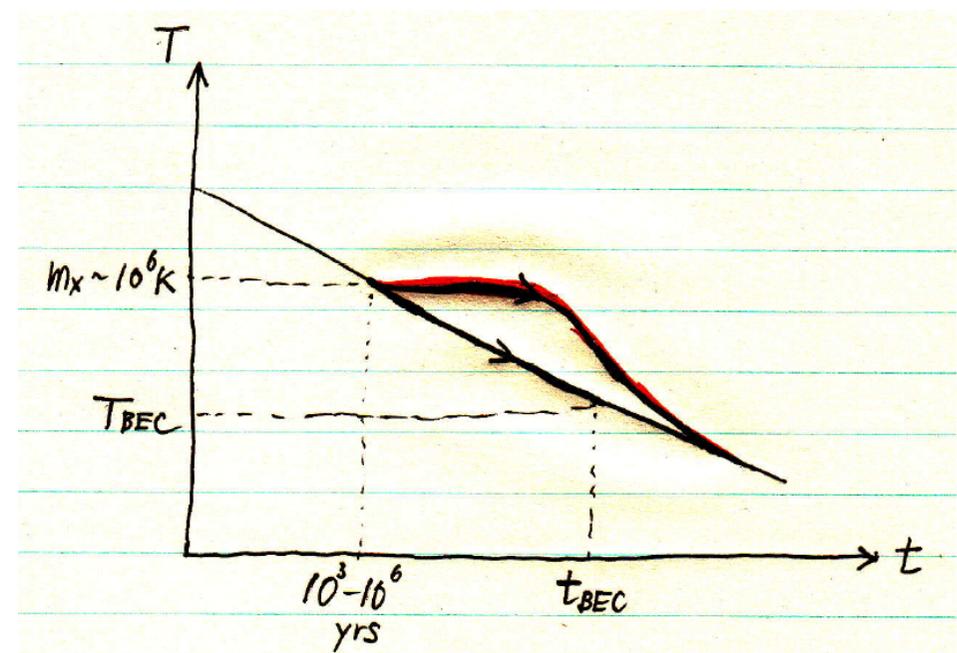


A possible scenario

Enhancement by DM
Reduction by BEC



Magnetic field vs. time



Temperature vs. time