Sterile Neutrino Dark Matter

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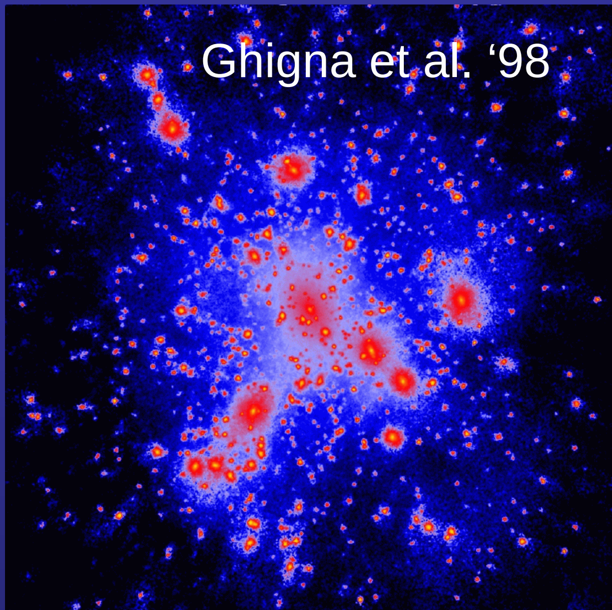
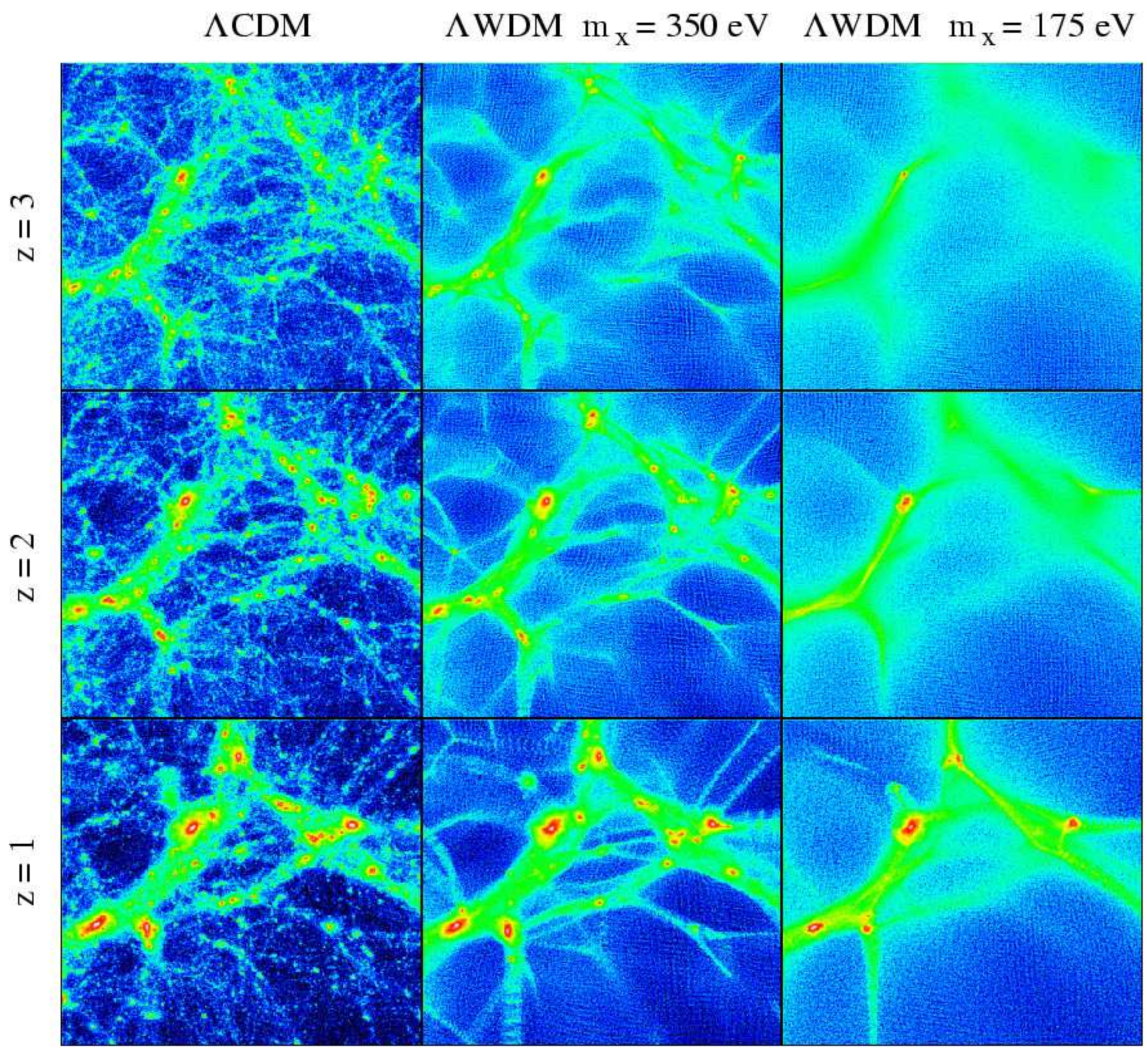
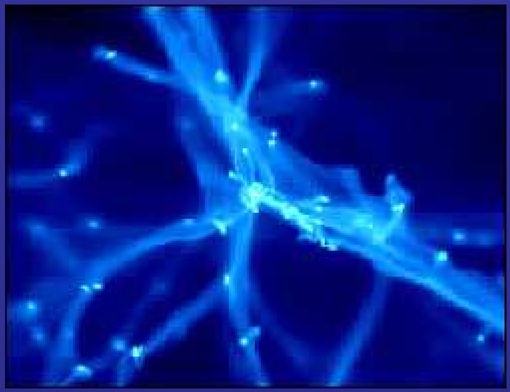
Theoretical Astrophysics



Small Scale Structure

Bode Ostriker & Turok 2001

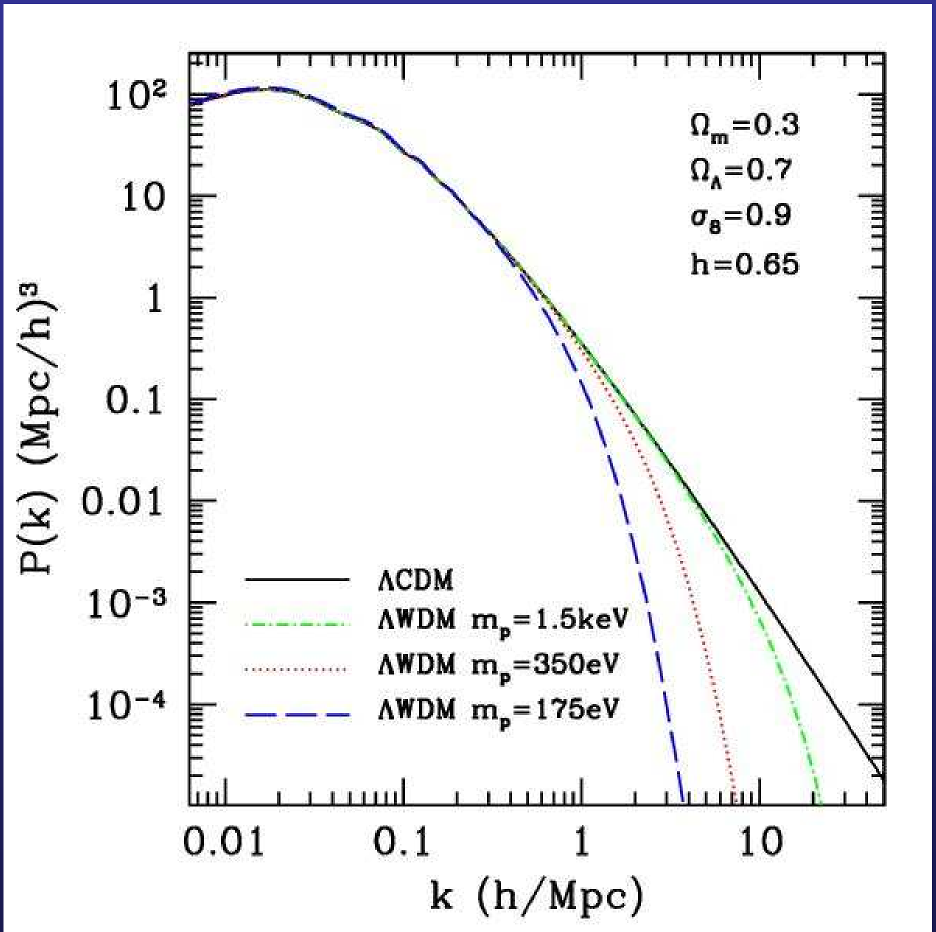




Is there a dwarf halo problem?

- Suppression of gas infall into dwarf halos after reionization, and tidal disruption of halos (Bullock, Kravtsov & Weinberg 2001)
- Disruption of gas infall due to winds from star formation and supernovae in small potential wells (Binney et al 2001)
- Breaking the power spectrum produced by inflation at the proper scale (Kamionkowski & Liddle 2001)
- Warm dark matter: thermal suppression of small scale power

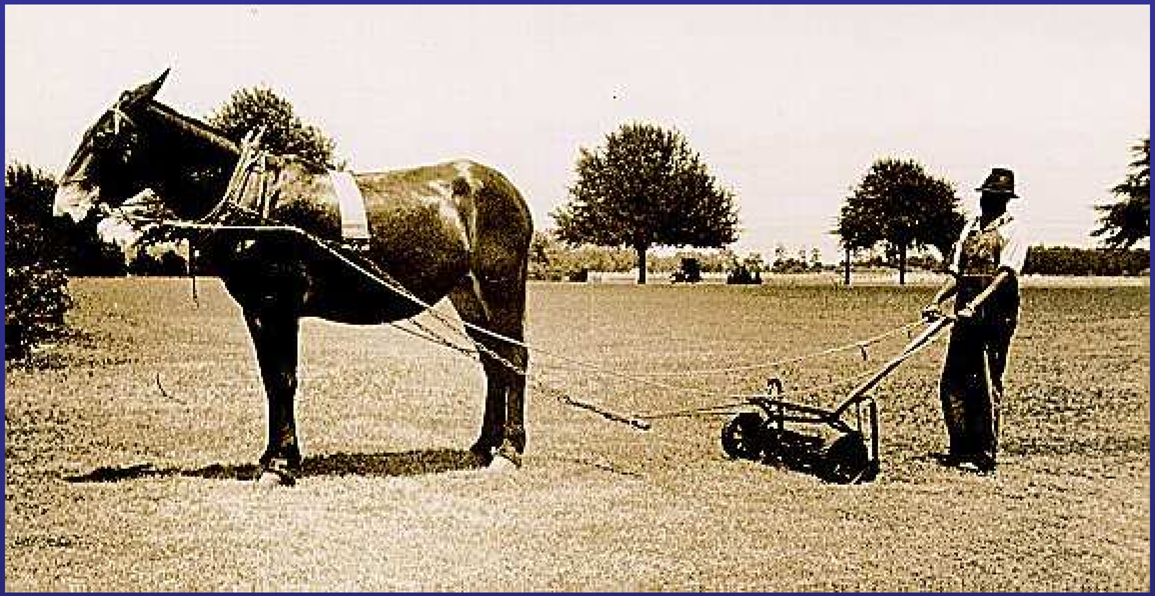
Power Spectrum Suppression with Warm Dark Matter



WDM/CDM Candidates…

- ***Sterile Neutrinos*** (Dodelson & Widrow 1993)
- Gravitinos (Kawasaki, Sugiyama & Yanagida 1997)
- Active Neutrinos (Giudice, Kolb, Riotto, Semikoz & Tkachev 2000)

Sterile Neutrinos?



active/sterile mass matrix:

$$-L = \frac{1}{2}(\,\nu_L \;\; N_L^c\,)\begin{pmatrix} m_T & m_D \\ m_D^T & m_M \end{pmatrix}\begin{pmatrix} \nu_R^c \\ N_R \end{pmatrix} + h.c.,$$

ν_L: active neutrino

N_L: sterile neutrino

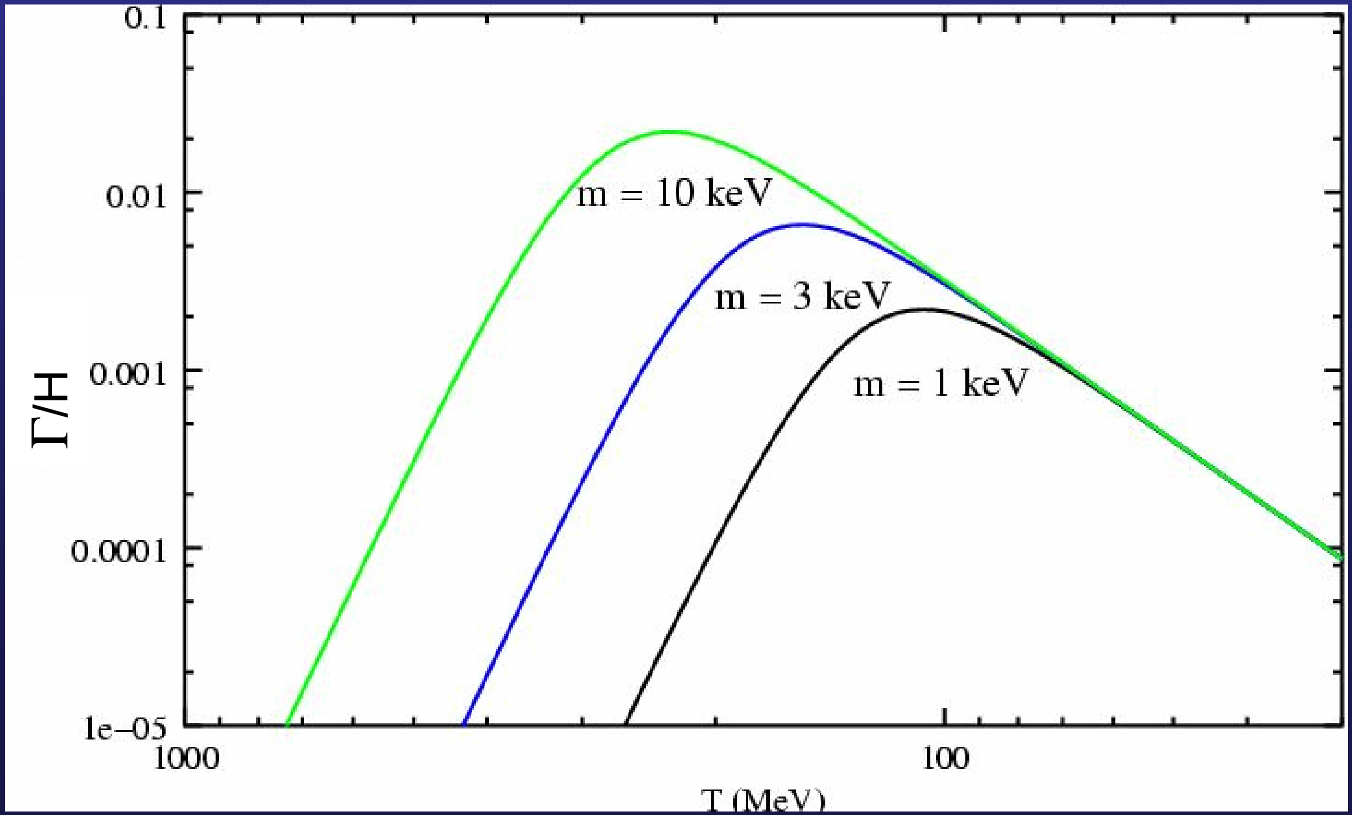
for appreciable mixing, $m_T \sim m_M \sim m_D$

Arise in several extensions to the Standard Model [e.g. SO(10), E_6]

Sterile Neutrino Dark Matter Production

Boltzmann equation for production:

$$\frac{\partial}{\partial t} f_s(p,t) - H\, p\, \frac{\partial}{\partial p} f_s(p,t)$$
$$\approx \Gamma(\nu_\alpha \to \nu_s; p, t)\, [f_\alpha(p,t) - f_s(p,t)] \, .$$



QCD Thermodynamics

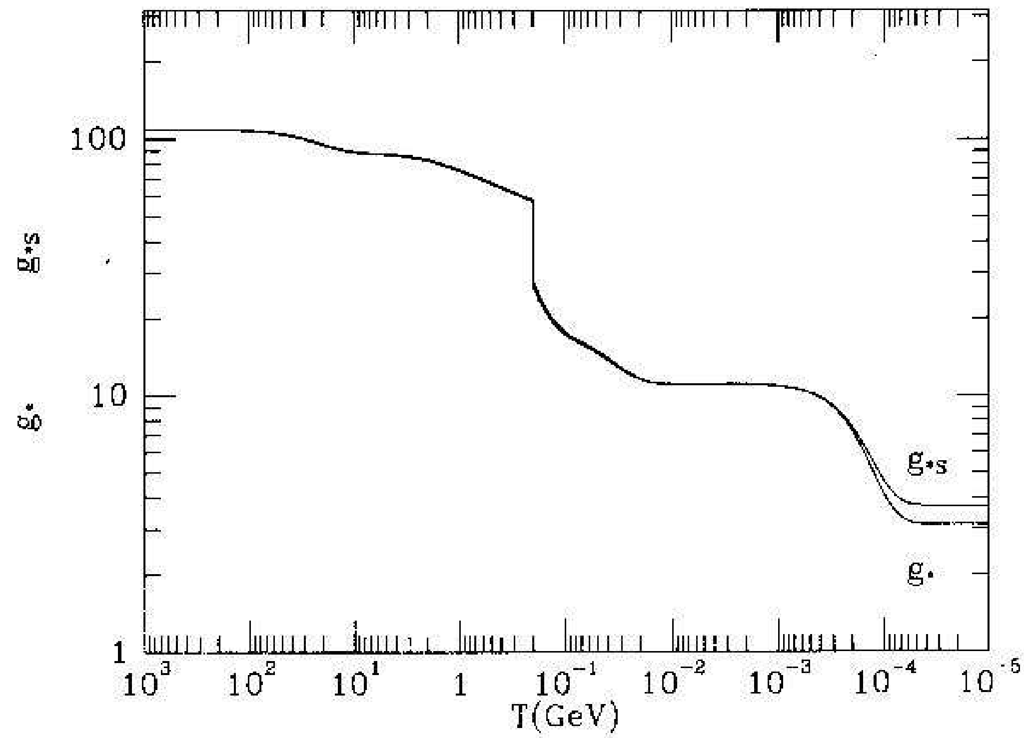
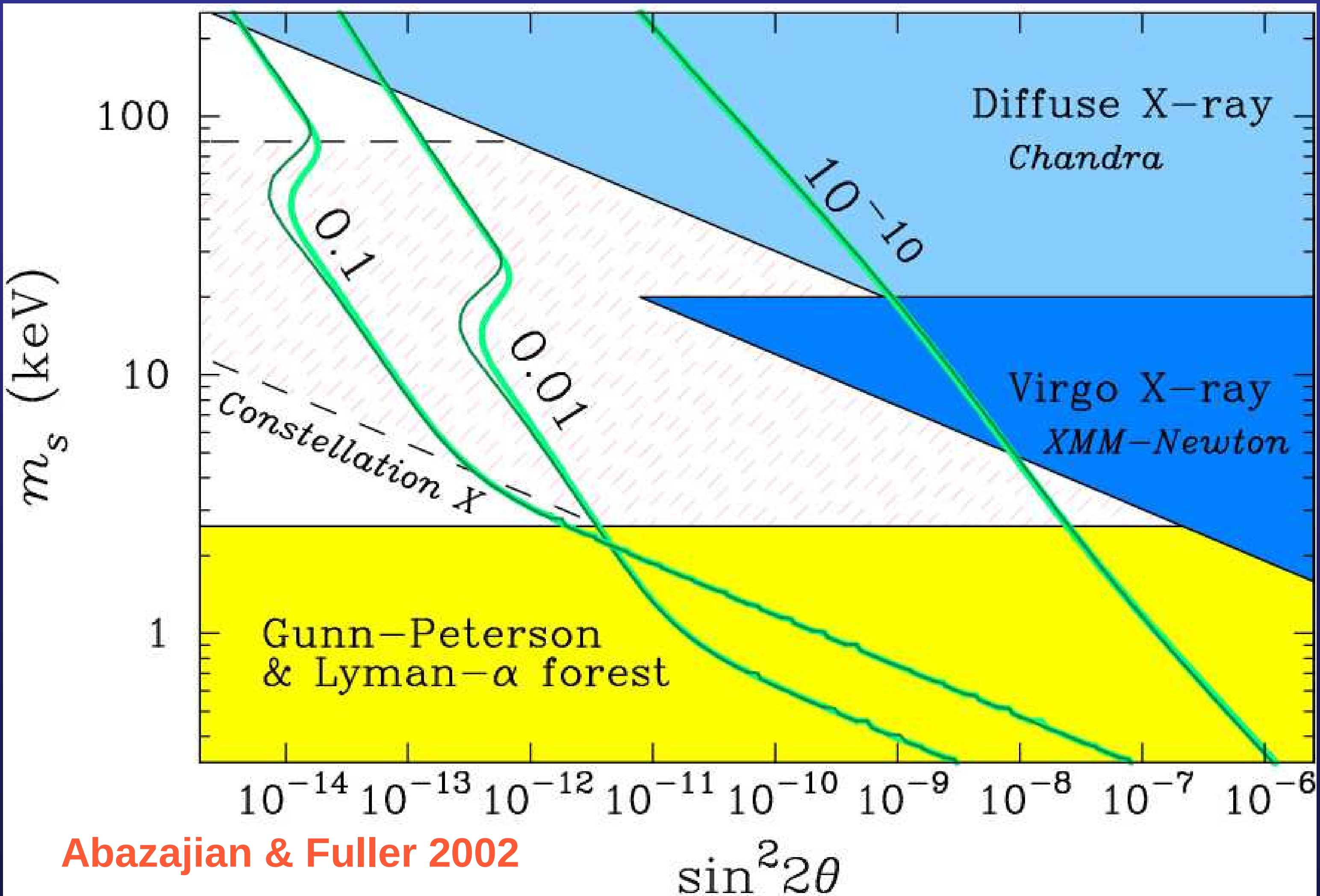


Fig. 3.5: The evolution of $g_*(T)$ as a function of temperature in the $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$ theory.

Kolb & Turner 1990

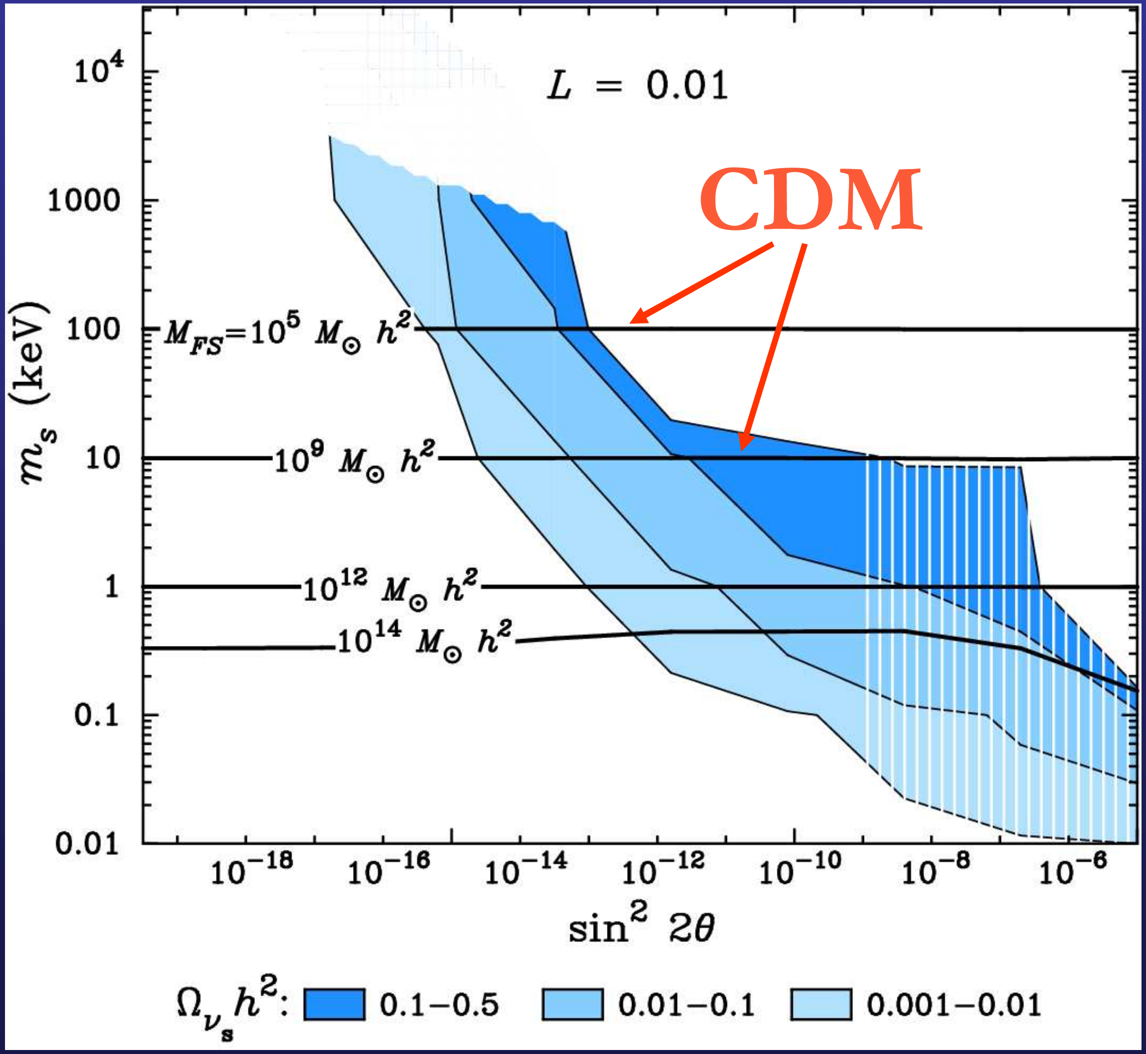
Sterile Neutrino Dark Matter: Production & Prediction

Dodelson & Widrow (1993), Shi & Fuller (1998), Abazajian, Fuller & Patel (2001), Dolgov & Hansen (2001)



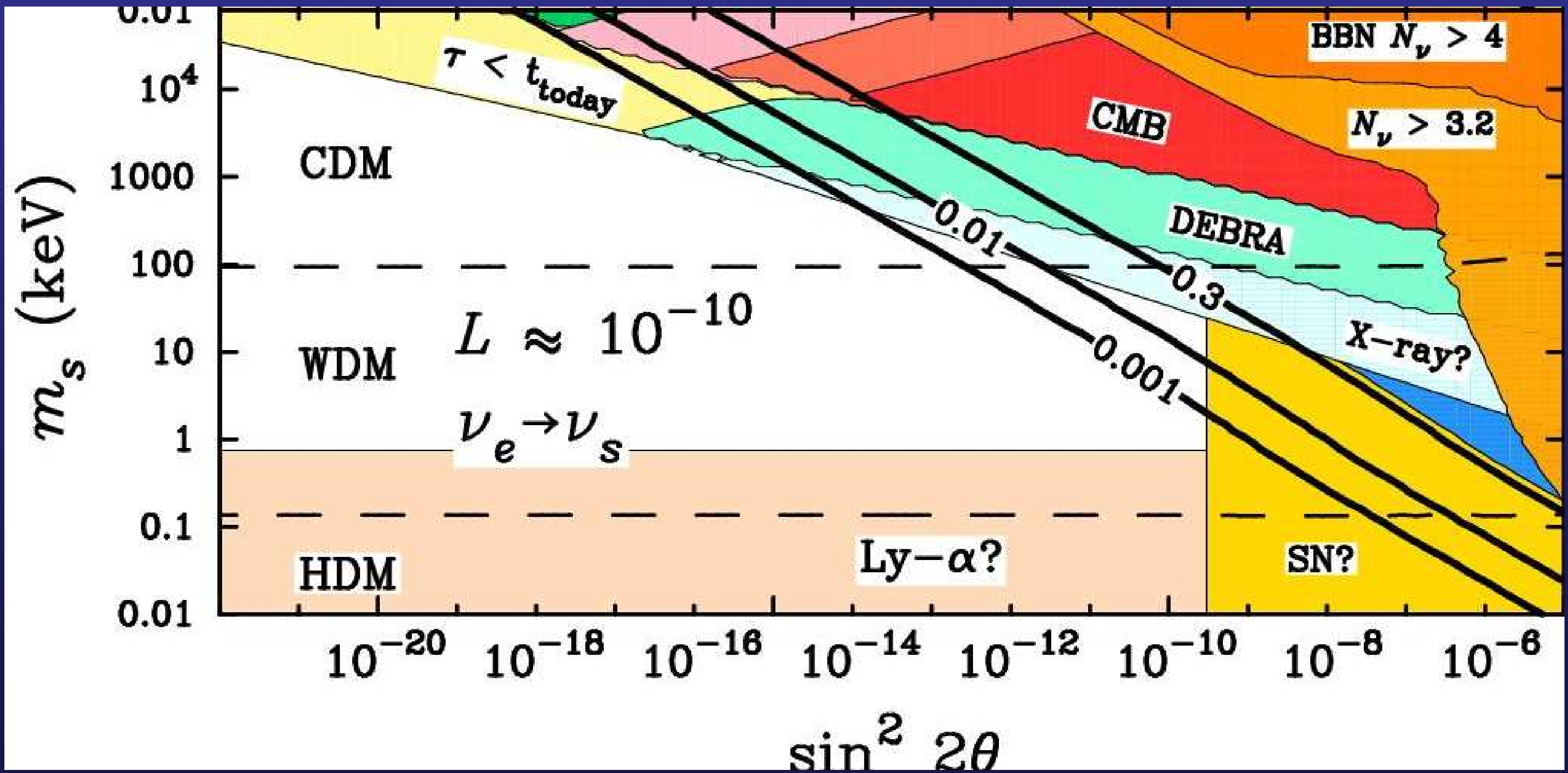
Abazajian & Fuller 2002

Mass Suppression Scale for Non-zero Lepton Number Cosmologies



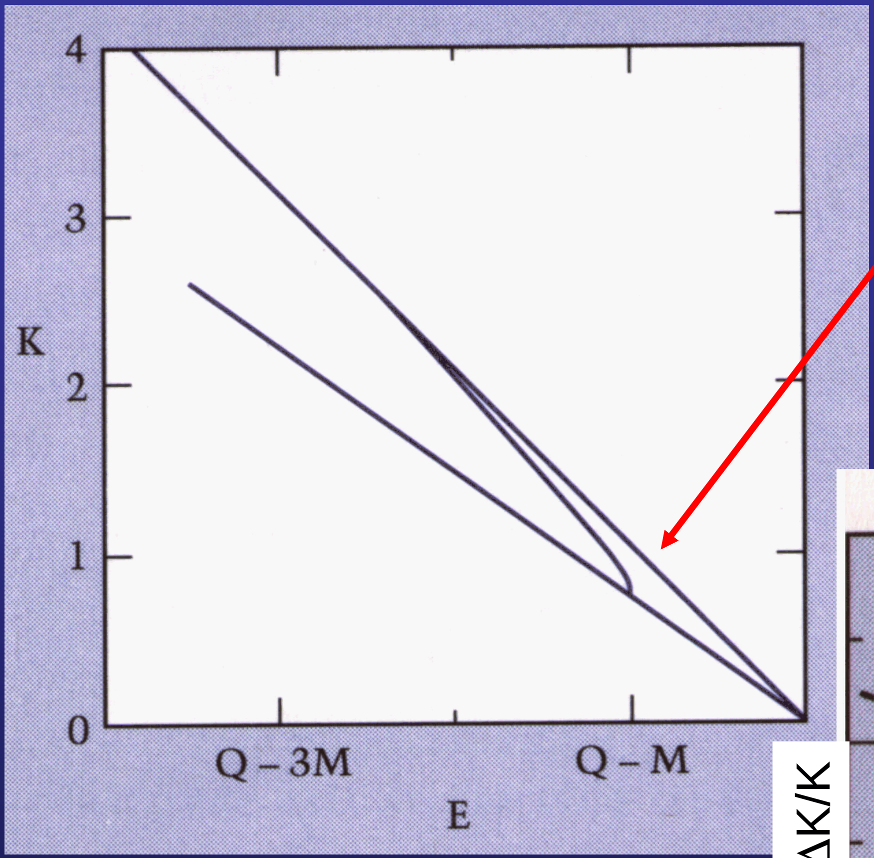
Constraints: *CMB, Diffuse Photon Background, BBN, Type II Supernovae, Small Scale Structure, X-Ray…*

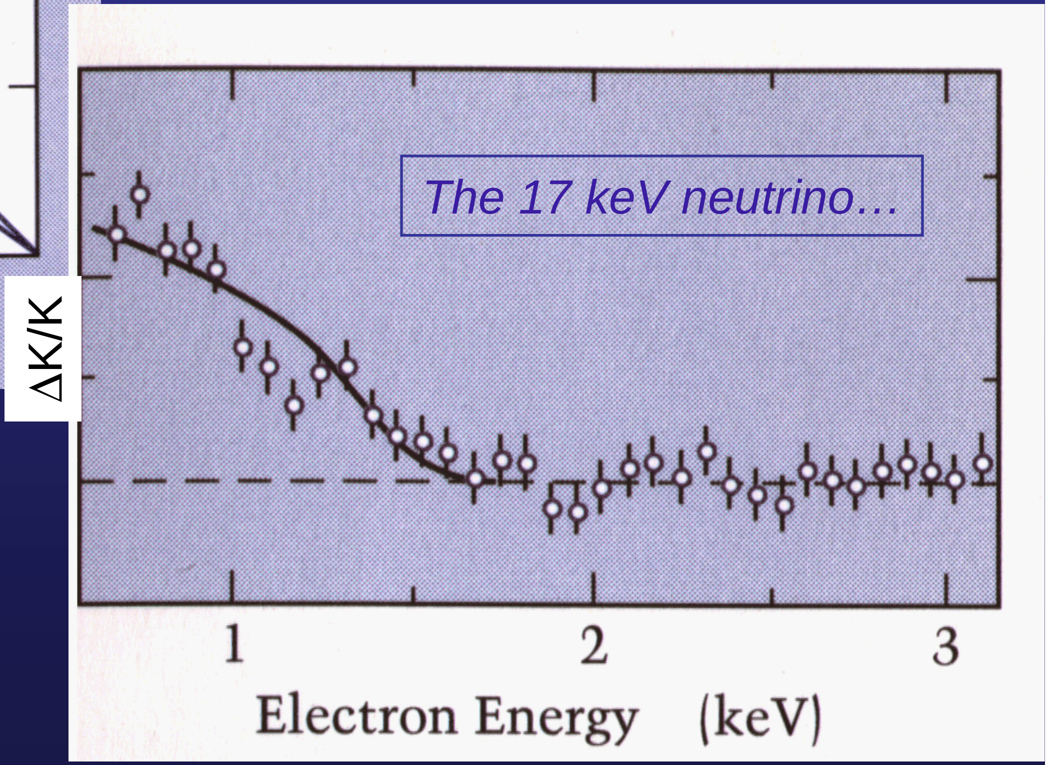
Abazajian, Fuller & Patel 2001

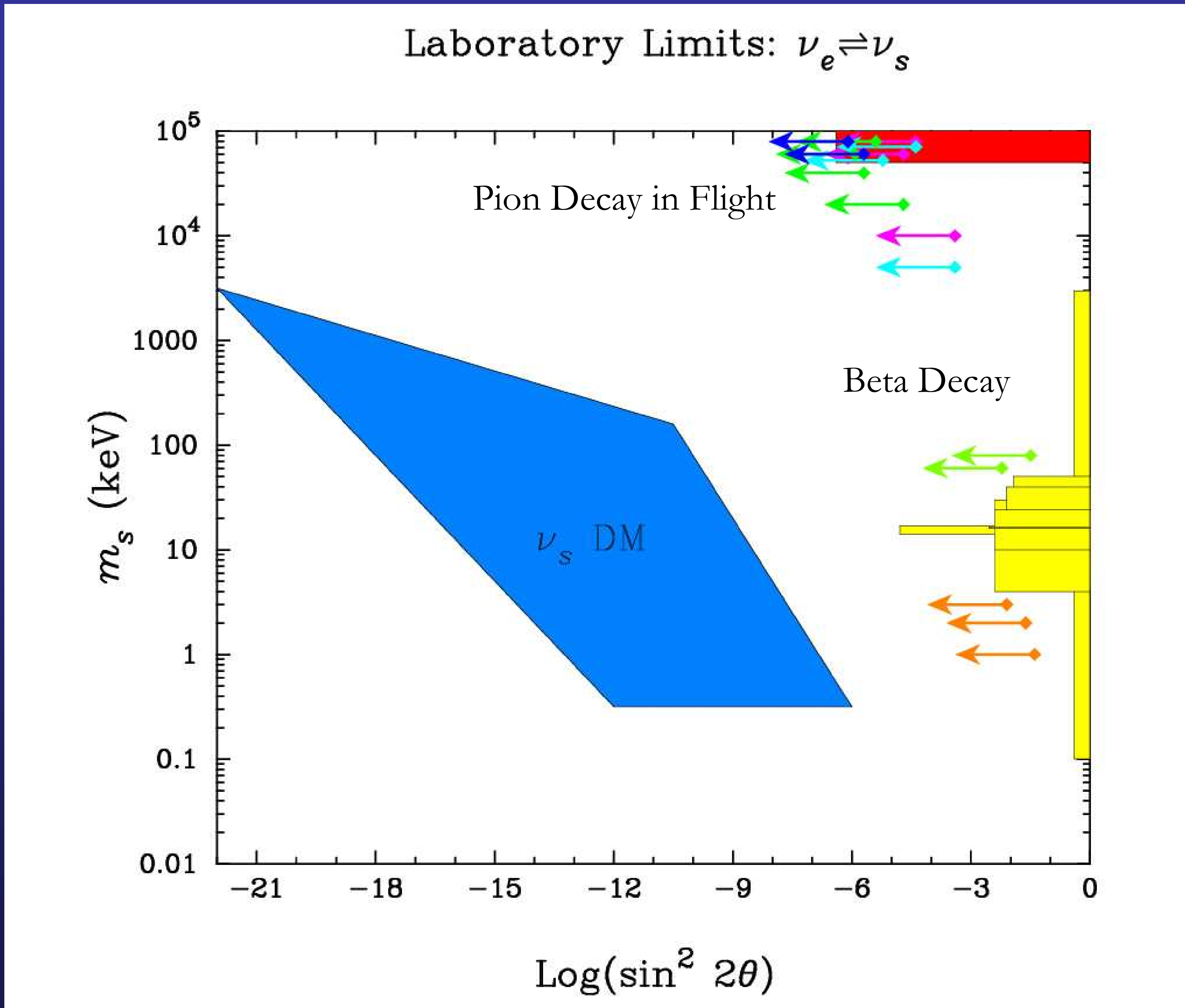


Laboratory Methods for detection of massive sterile neutrinos

kink-searches in nuclear beta-decay

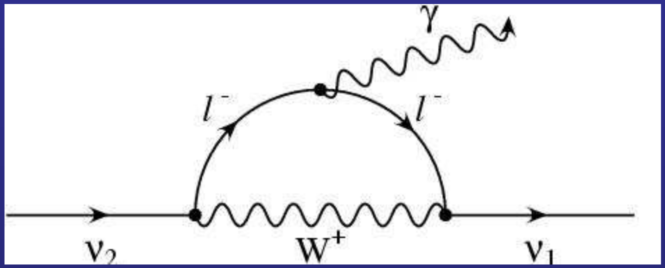






Laboratory Limits: $\nu_e \rightleftharpoons \nu_s$
Pion Decay in Flight
Beta Decay
ν_s DM
m_s (keV)
10^5
10^4
1000
100
10
1
0.1
0.01
−21
−18
−15
−12
−9
−6
−3
0
Log($\sin^2 2\theta$)

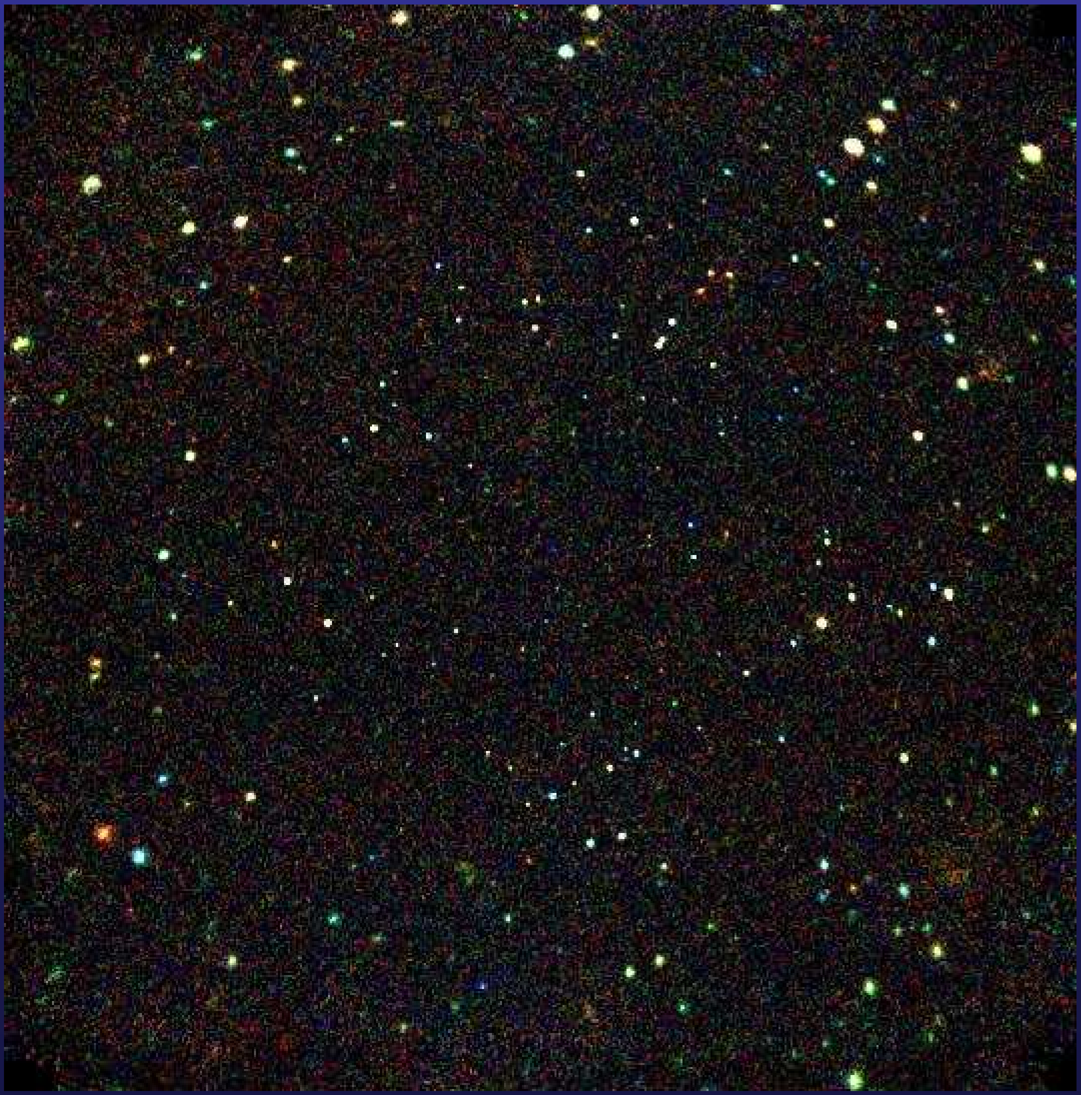
Radiative decay



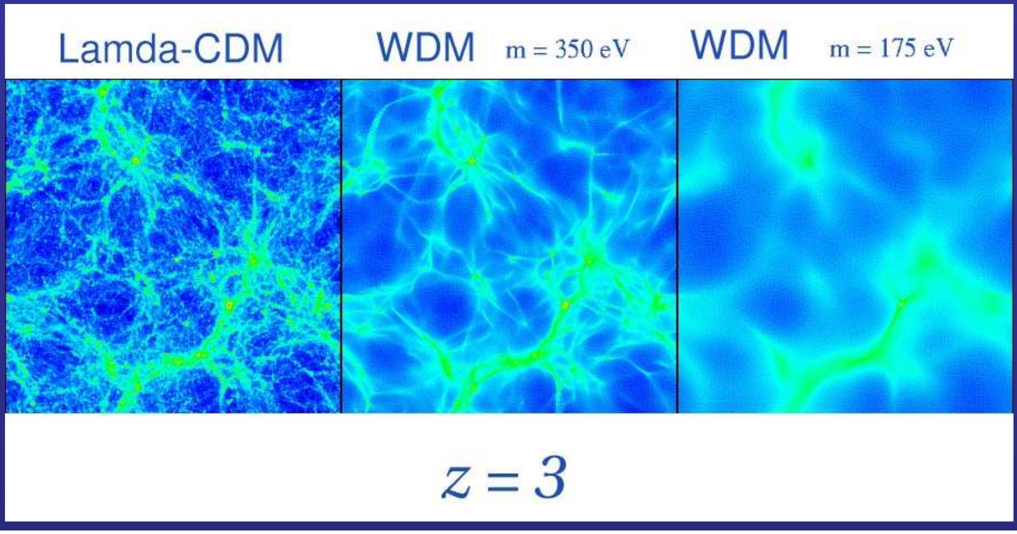
$$\nu_s \rightarrow \nu_\alpha + \gamma$$

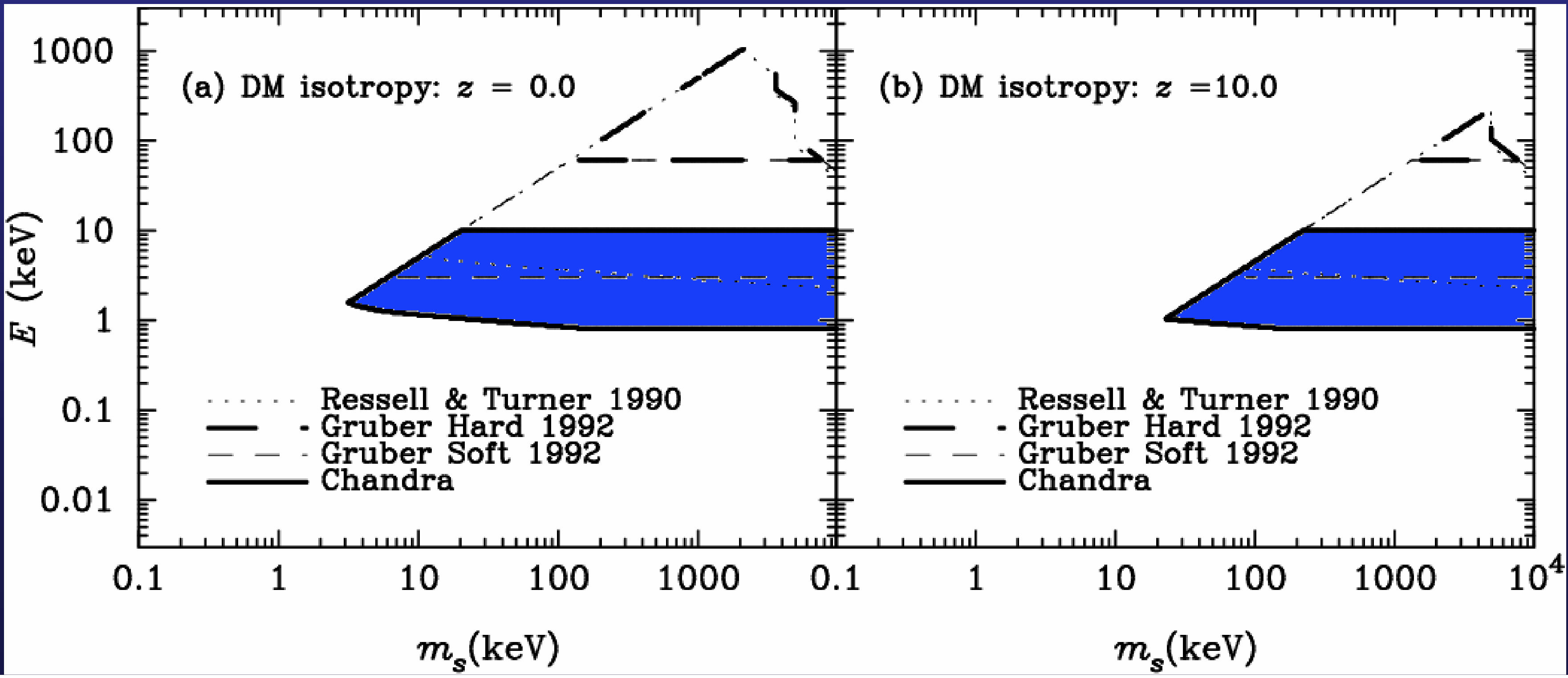
$$\Gamma_\gamma = 6.8 \times 10^{-33}\ \mathrm{s}^{-1} \left(\frac{\sin^2 2\theta}{10^{-10}}\right)\left(\frac{m_s}{1\ \mathrm{keV}}\right)^5$$

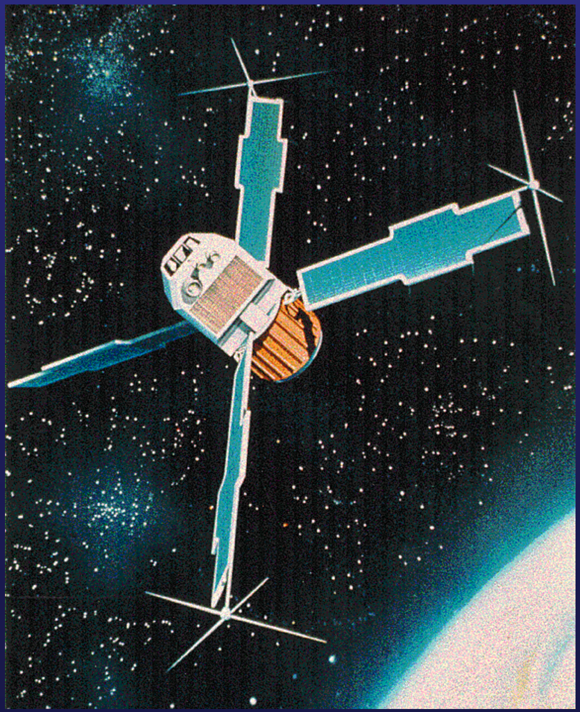
Resolving the Diffuse X-ray Background…



The Diffuse X-ray Background



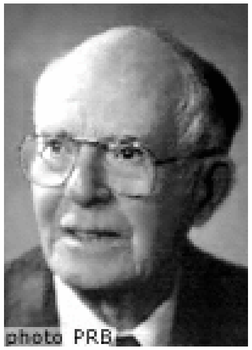




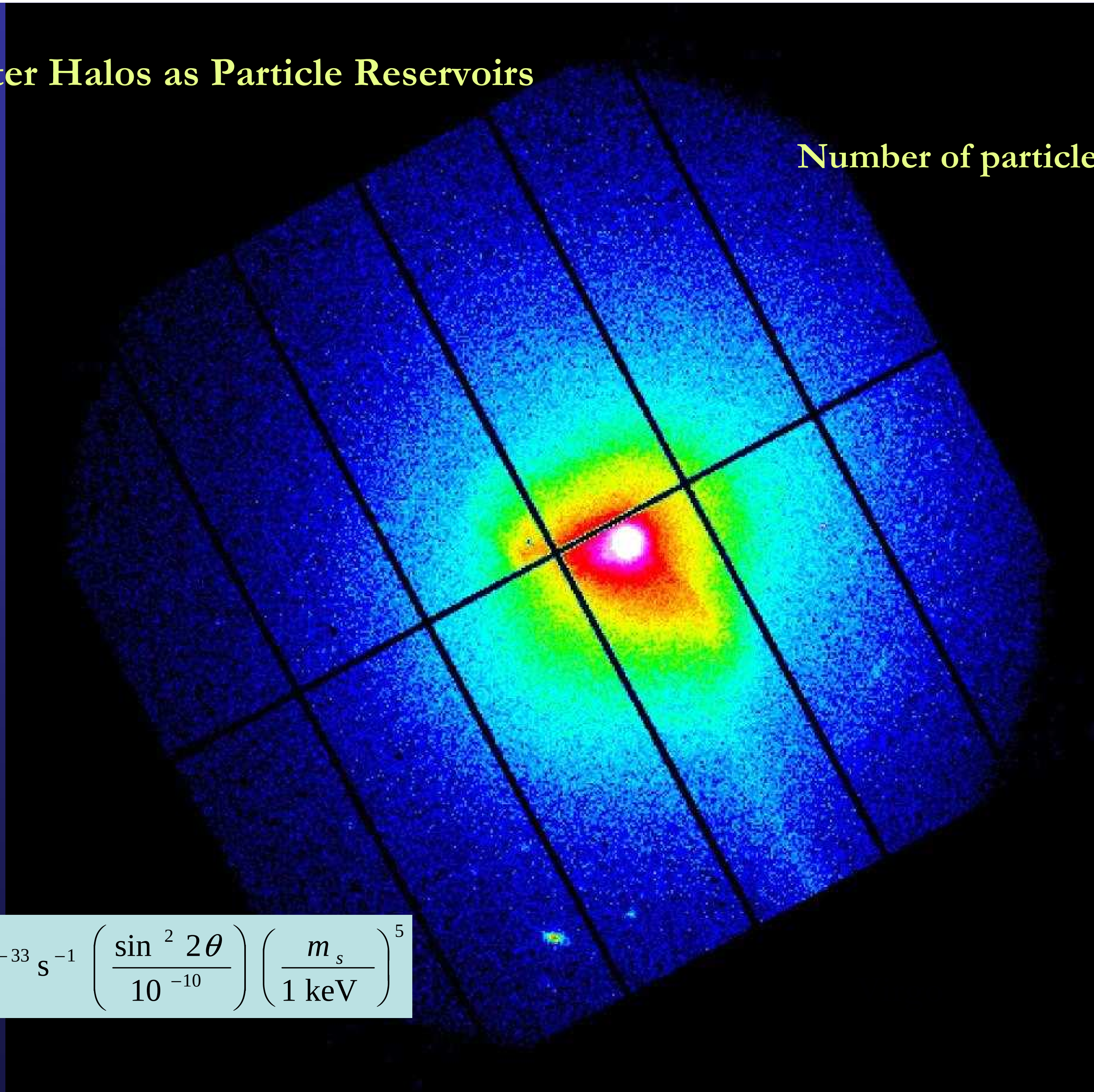
The Nobel Prize in Physics 2002

"for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos"

"for pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources"

 photo PRB	 photo PRB	 photo NASA/CXC/SAO
Raymond Davis Jr.	**Masatoshi Koshiba**	**Riccardo Giacconi**
1/4 of the prize	1/4 of the prize	1/2 of the prize
USA	Japan	USA
University of Pennsylvania Philadelphia, PA, USA	University of Tokyo Tokyo, Japan	Associated Universities Inc. Washington, DC, USA
b. 1914	b. 1926	b. 1931 (in Genoa, Italy)

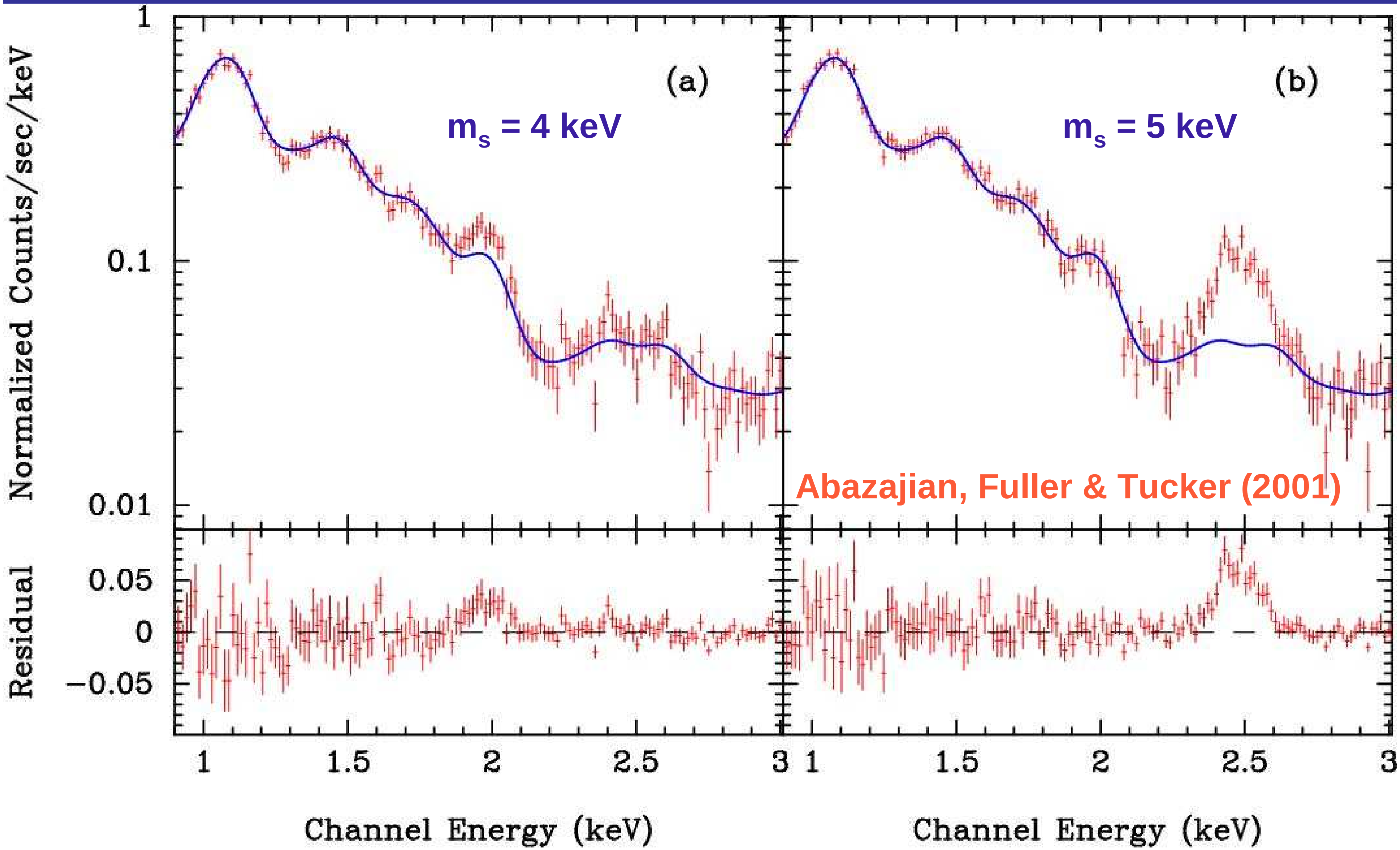
Dark Matter Halos as Particle Reservoirs



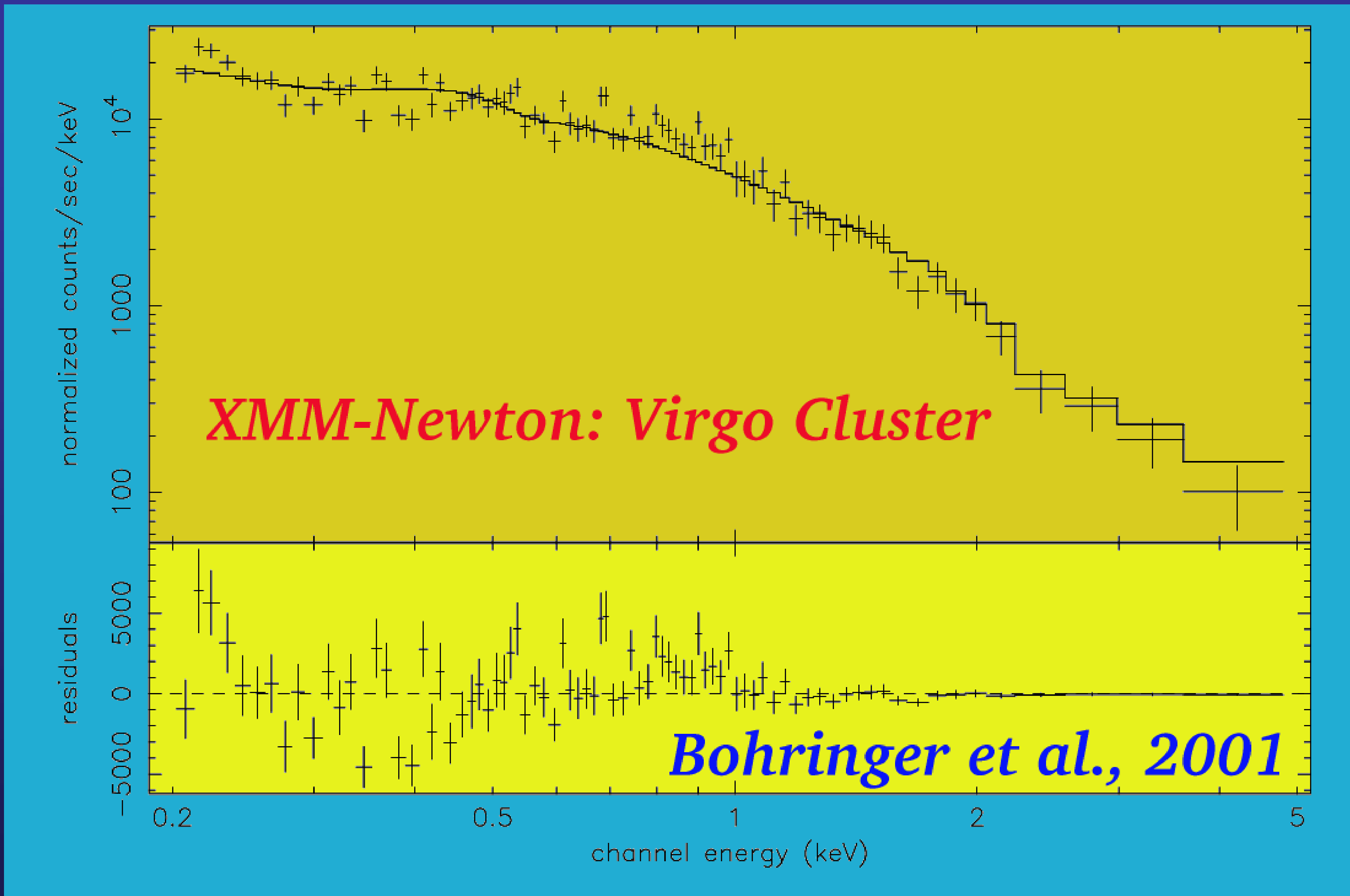
Number of particles ~ 10^{70}

$$\Gamma_\gamma = 6.8\times10^{-33}\,\mathrm{s}^{-1}\left(\frac{\sin^2 2\theta}{10^{-10}}\right)\left(\frac{m_s}{1\ \mathrm{keV}}\right)^5$$

X-ray Telescopes as dark matter particle detectors…

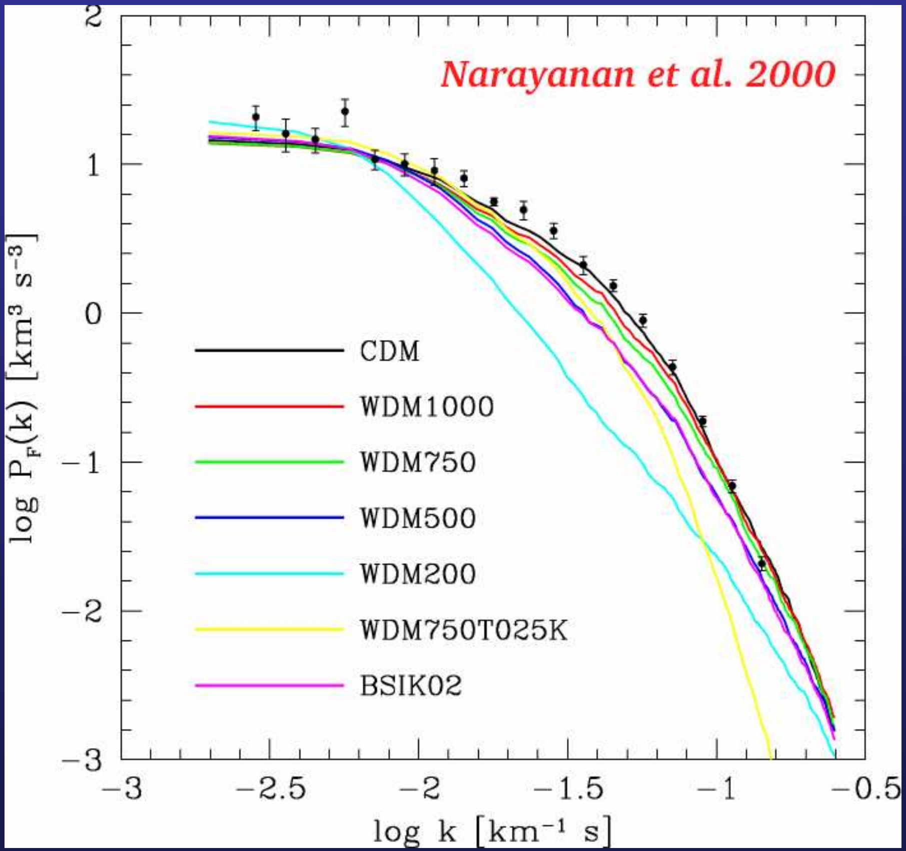


$$\Gamma_\gamma = 6.8\times 10^{-33}\,\mathrm{s}^{-1}\left(\frac{\sin^2 2\theta}{10^{-10}}\right)\left(\frac{m_s}{1\,\mathrm{keV}}\right)^5$$



$$\Rightarrow m_s < 5\,\mathrm{keV}$$

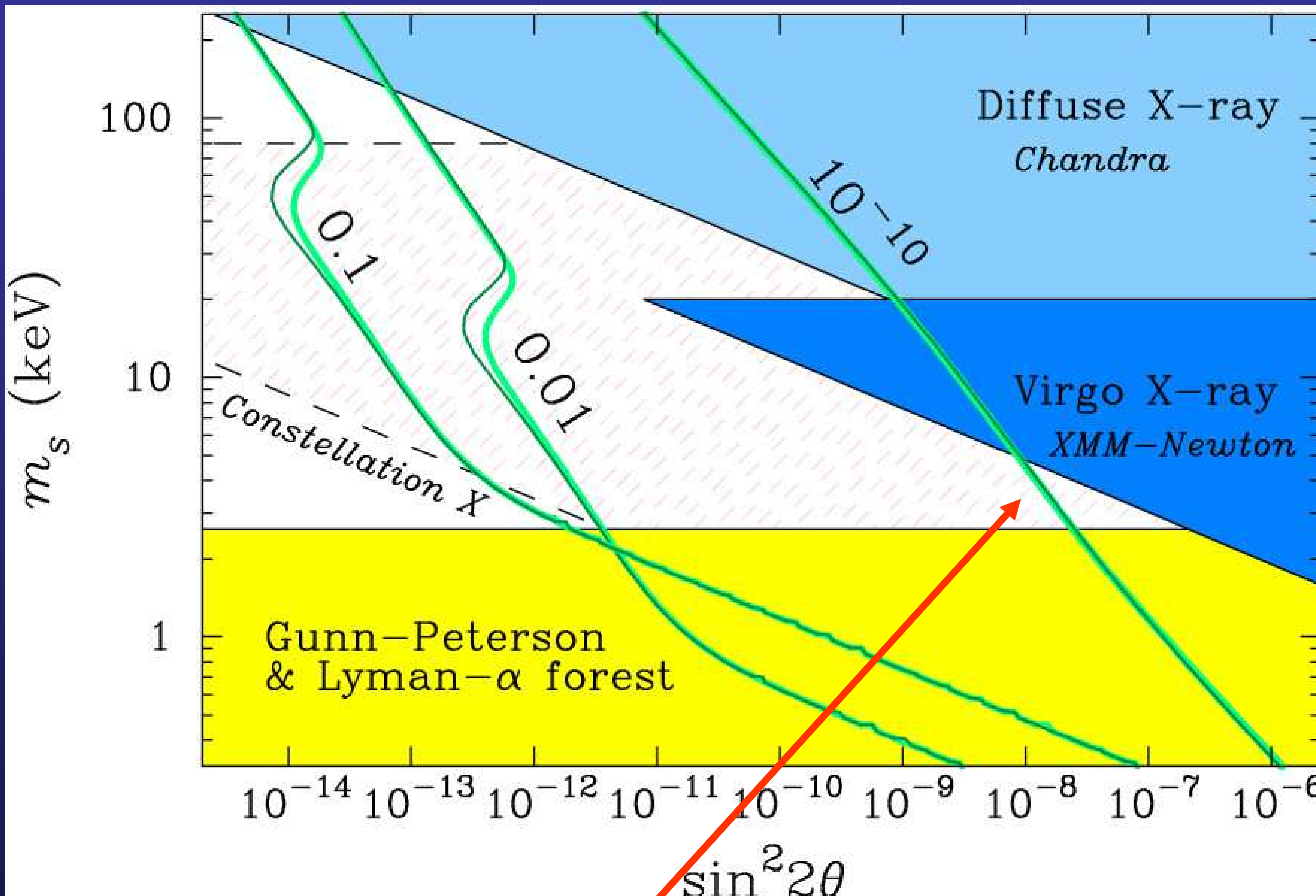
Lower bounds on mass…



- Suppression of the observed Lyman-alpha power spectrum
- Reionization (Barkana, Haiman & Ostriker 2001)

- m > 0.75 keV for gravitino WDM
- m > 2.6 keV for warmer sterile neutrino WDM
- for m > 1 (3) keV, no difference in the nonlinear power spectrum from CDM

Eminent Exclusion or *Detection*…



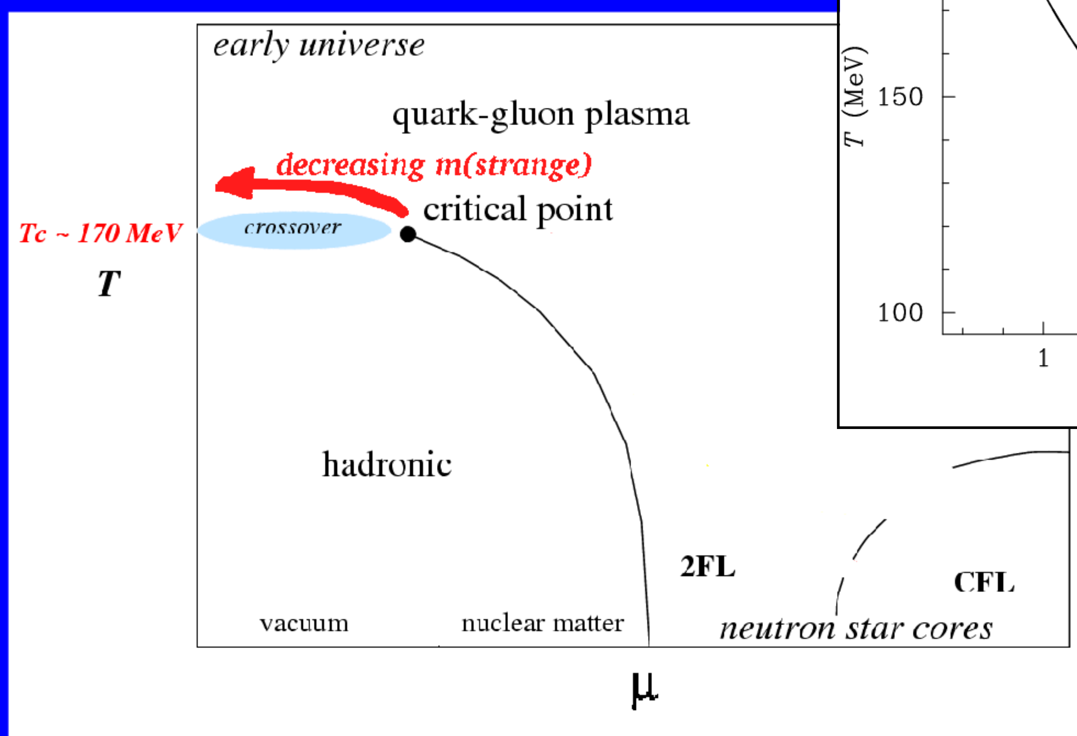
$$2.5\,\mathrm{keV} < m_s < 5\,\mathrm{keV}$$

AFTER

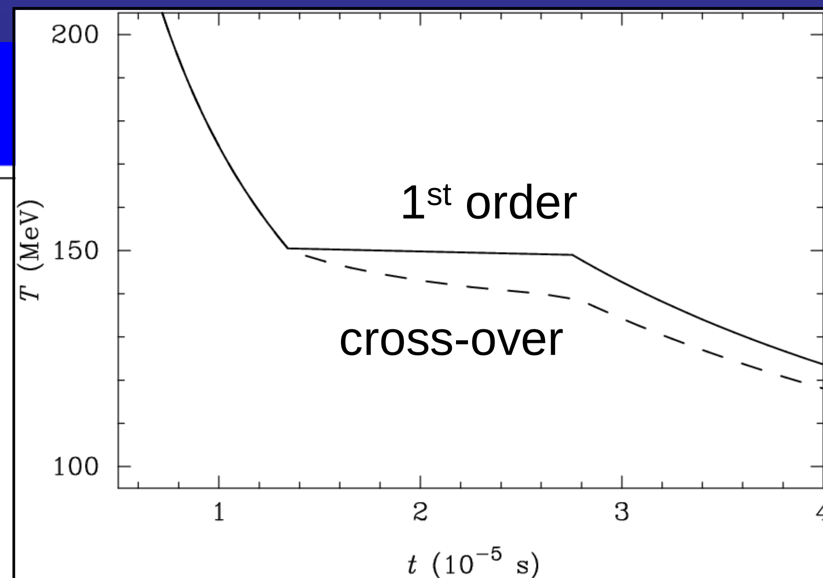
Detection of the Dark Matter…

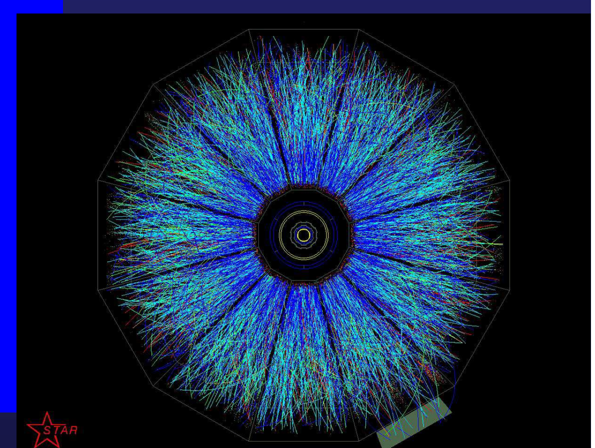
Probe the QCD transition

The QCD Phase Diagram

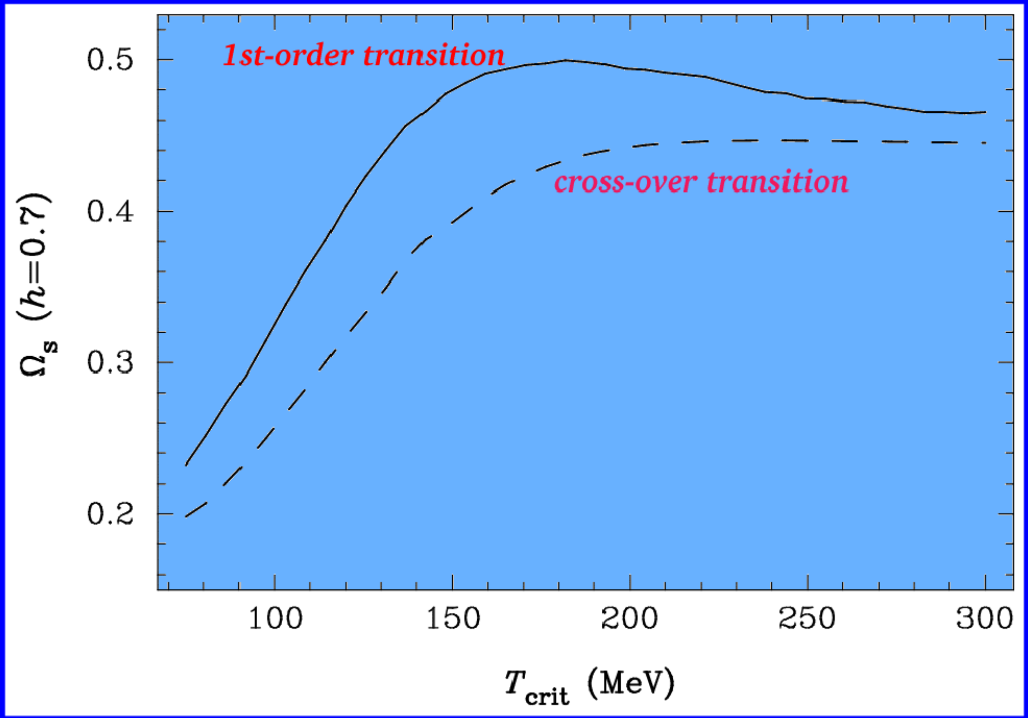


(From Simon Hands, 2001)





Probing bulk QCD thermodynamics with dark matter...



Abazajian & Fuller (2002)

- Dark Matter Density
- Strength and Energy of X-ray Line
- Probes critical behavior of QCD at high T

Summary…

- Sterile neutrinos arise in several extensions to the SM
- The need for a slight suppression of small scale structure may indicate the presence of WDM
- Sterile neutrino dark matter may be *detected* with X-ray observations
- Such detections may probe the physics of the early universe beyond the epoch of nucleosynthesis to the QCD transition