Sterile neutrinos

What have they done for us lately?

Steen Hansen
OXFORD
Les Houches 2001

- solve ~~atmospheric √~~ problem
- solve ~~solar √~~ problem
- are perfect Warm Dark Matter candidates !!!

A. Dolgov
J. Lesgourgues, S. Pastor, J. Silk

Overview

What do we know about Dark Matter ?

Why ν_s with $m \simeq 4$ keV is such a good DM candidate

Observational constraints (very strong)

Where we stand

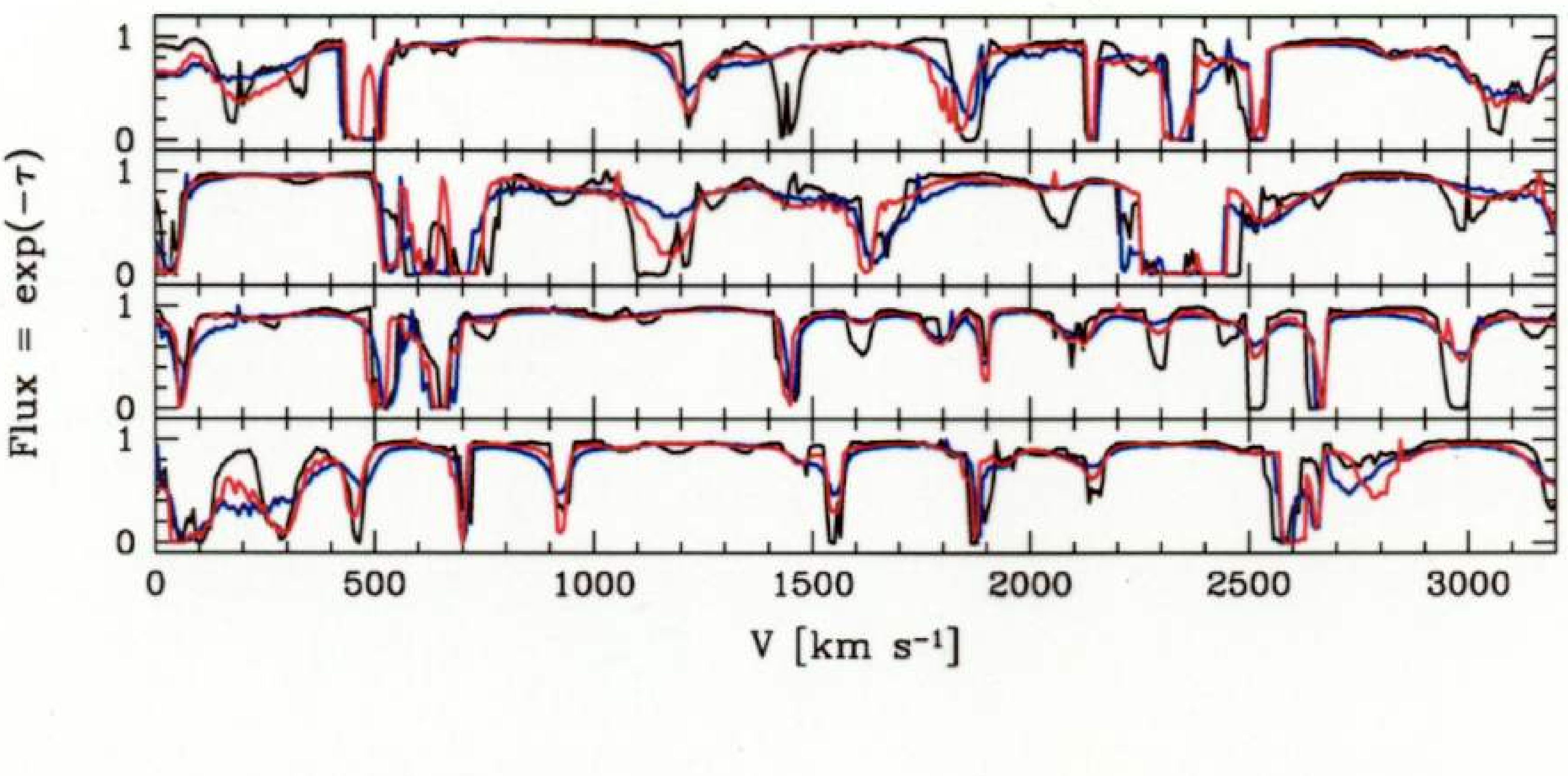


Fig. 2.— Examples of artificial spectra at $z = 3$ along four random lines of sight in the simulations. All simulations have identical phases for the Fourier components of the initial density fields. In each panel, black line shows results for CDM, blue line shows WDM500, and red line shows WDM750.

Narayanan et al astro-ph/0005095

What is the mass of the Dark Matter particle?

a) satellite galaxies $m \approx 1$ keV

b) disk formation $m \approx 1$ keV

Both indications!

Real bounds ....

c) reproduce Ly-α $m > 0.75$ keV

d) existence of massive BH at large redshift $m > 0.75$ keV

Only one candidate ??

$$\nu_s$$

$$\Omega_x h^2 = \frac{115}{g_{dec}} \cdot \frac{g^*}{1.5} \frac{m}{\text{keV}}$$

The technical page

$$\nu_\tau = \cos\vartheta \cdot \nu_1 + \sin\vartheta \cdot \nu_2$$
$$\nu_s = -\sin\vartheta \cdot \nu_1 + \cos\vartheta \cdot \nu_2$$

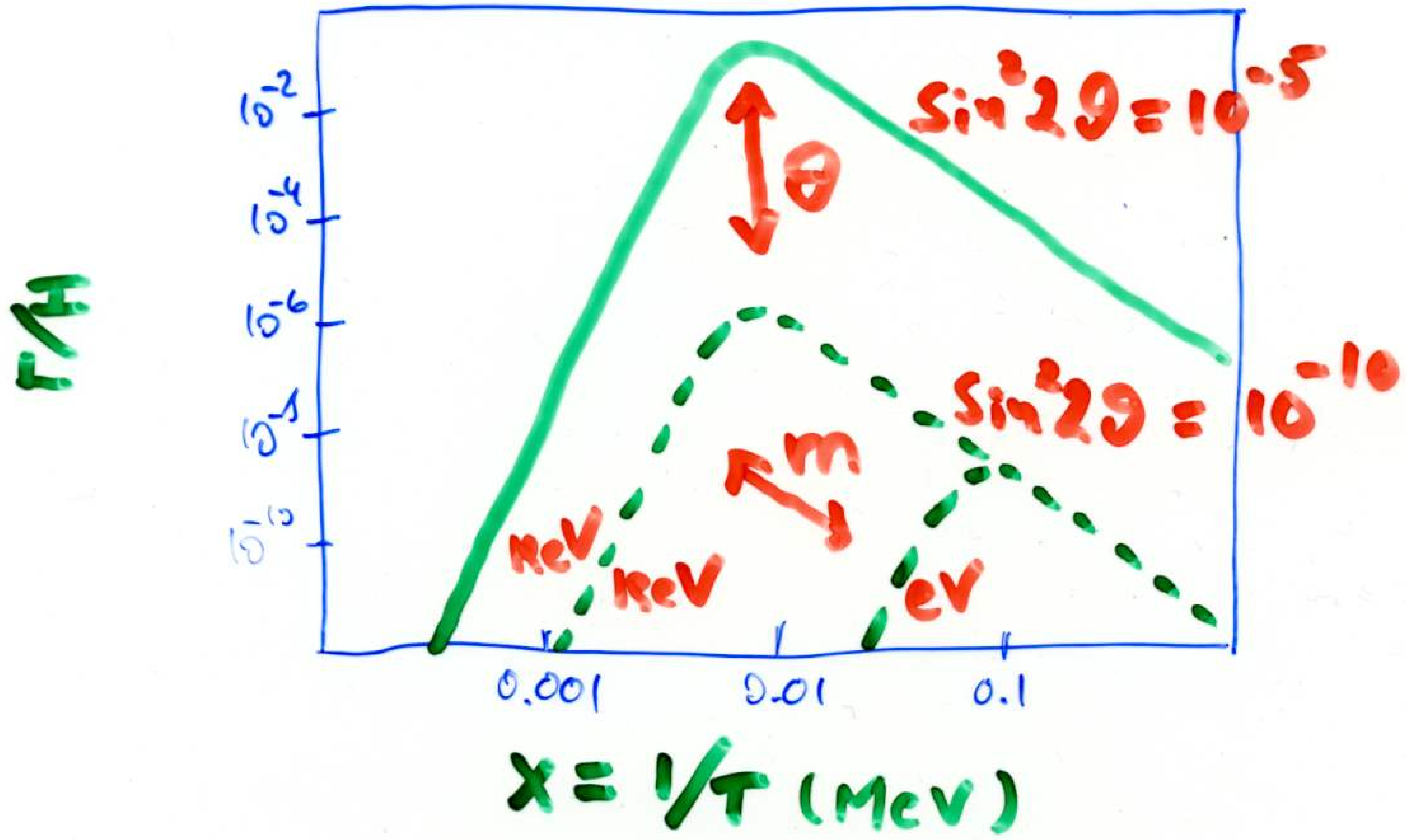
ν_s = sterile neutrino

ν_1, ν_2 = mass eigenstates

$\delta m^2 = m_1^2 - m_2^2$

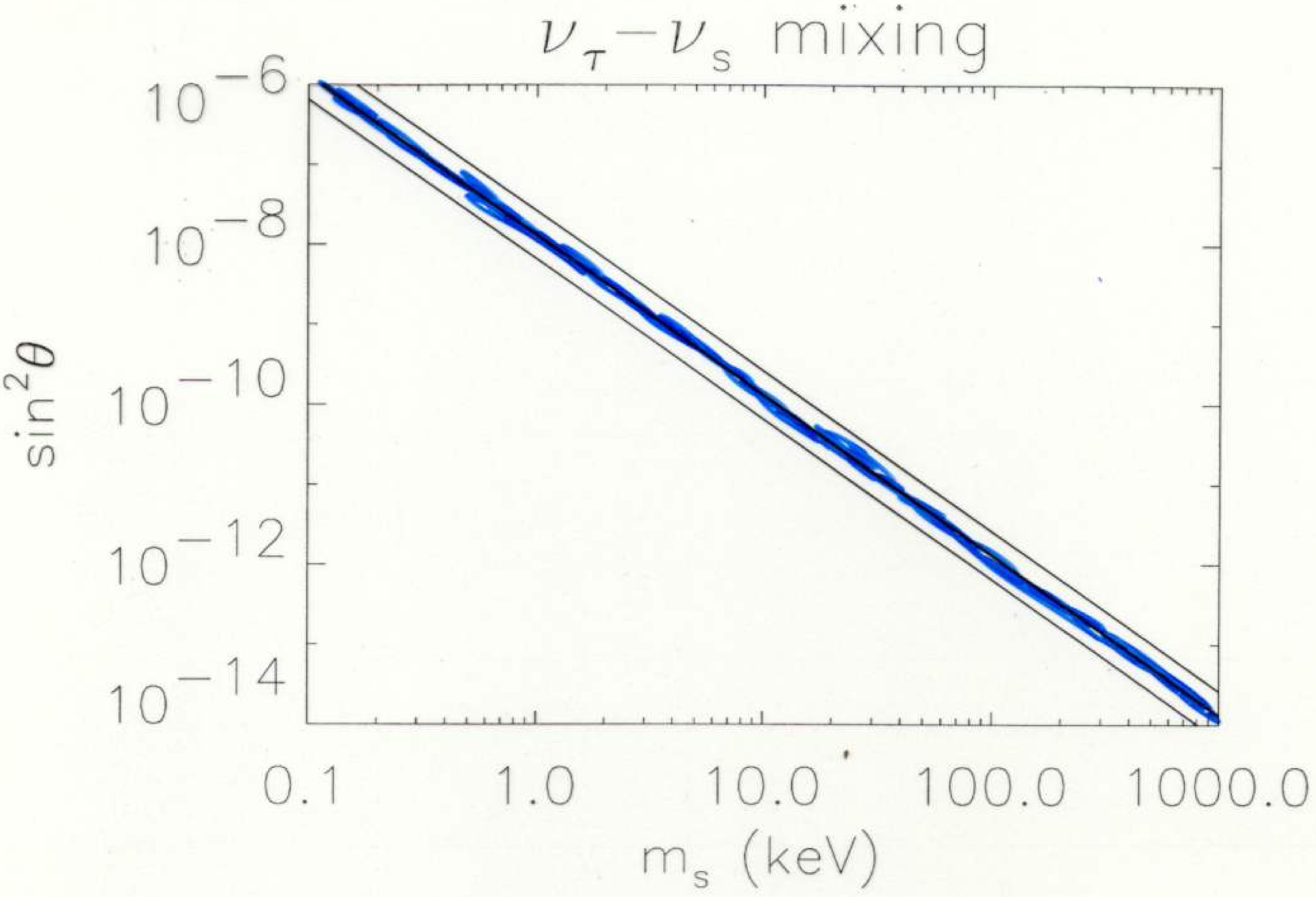
ϑ = mixing angle

2, 7, 15, ... for n = 2, 3, 4, ...



$$\sin 2\theta_M = \frac{\sin 2\theta}{1 + c\, T^6 m^{-2}}$$

$$\frac{n_s}{n_\alpha} \approx 10^{-2} \frac{\sin^2 2\theta}{10^{-7}} \frac{m}{\mathrm{keV}} \left(\frac{10.75}{g^*}\right)^{3/2}$$



If sterile ν is Dark Matter:

$$n_s = 1.27 \cdot 10^{-5} \cdot n_a \cdot \left(\frac{\text{MeV}}{m}\right)\left(\frac{\Omega_{DM}}{0.3}\right)\left(\frac{h}{0.65}\right)^2$$

Compare with produced

$$n_s(m, \theta)$$

Dodelson, Widrow '94, Kainulainen 1990, Cline 1992, Shi, Schramm, Fields 1993, Langacker '89, Barbieri, Dolgov '90, Enqvist, Kainulainen, Thomson '92, Shi, Fuller 1997, Abazajian, Fuller, Patel 2001

A. Dolgov, S.H. hep-ph/0009083

Kinetic equations for density matrix

$$\rho = \begin{pmatrix} \rho_{aa} & \rho_{as} \\ \rho_{sa} & \rho_{ss} \end{pmatrix}$$

$\rho_{ss} \sim f_s$

$$\dot{\rho}_{aa} = -F \cdot I - \int |A_{el}|^2 \ldots - \int |A_{am}|^2 \ldots$$

$$\dot{\rho}_{ss} = F \cdot I$$

$$\dot{R} = W I - \int |A_{el}|^2 \ldots - \int |A_{am}|^2 \ldots$$

$$\dot{I} = -W R - \frac{F}{2}(\rho_{ss} - \rho_{aa}) - \int |A_{el}|^2 \ldots - \int |A_{am}|^2 \ldots$$

$$\Rightarrow \frac{n_s}{n_e} \simeq 4.0 \cdot 10^{-3} \left(\frac{\sin^2 2\theta}{10^{-7}}\right)\left(\frac{m}{keV}\right)\left(\frac{10.75}{g^*_{prod}}\right)^{3/2}$$

about a factor 6 different

Observational Constraints

Lower limit: Remember prod at $T \sim 150$ MeV

$\Rightarrow$ $m > 2.5$ keV

(Hansen, Lesgourgues, Pastor, Silk)

Preferred mass: from cosm.

$m \approx 4$ keV

(Colin, Avila-Reese, Valenzuela)

(Sommer-Larsen, Dolgov)

Upper limit: $\nu_s \to \nu_\alpha + \gamma$

γ with $E = \frac{m}{2}$

Diffuse Gamma background

$m < 20$ keV

(Dolgov, Hansen)

Observe nearby galaxies

$m < 5$ keV

(Abazajian, Fuller, Tucker)

Where do we stand ?

ν_s a perfect WDM candidate

(only one ?)

Easy to produce right amount

(still many open questions)

Easy to falsify

1 year (one month?)
- yes → discover DM particle
- no → work harder