The neutrino reactor anomaly and cosmological bounds [1]

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[1] Based on EC, J Evslin, H Li and XM Zhang, "The Reactor Anomaly and Mass Varying Neutrinos"; in preparation

Neutrino Anomalies

Gallium Anomaly

- Neutrinos from radioactive sources inside the detector: baseline $\simeq$ 0-4 m
- Neutrino flux: $14 \pm 5\%$ lower than the predicted one

Reactor Anomaly

- Global fit from several very short-baseline reactor experiments (10-100 m)
- Neutrino flux: $5.7 \pm 2.3\%$ lower than the predicted one

Neutrino Anomalies

In experiments with baseline greater than 100 m the value of θ_{13} affects the anomaly

(smaller reactor anomaly $\Leftrightarrow$ greater θ_{13})

Daya Bay collaboration measured the value of θ_{13} in a flux-independent way, using two near and one far detectors.

$\Downarrow$

We can extend the analysis of the reactor anomaly also to the short baseline experiments (100-1000 m)

Our goal is to analyze the Daya Bay, RENO and Double Chooz results to obtain an estimation of θ_{13} and the reactor anomaly simultaneously.

Oscillation Probability

$$N_i^{ex} = (1+a) \sum_{j=1}^{n_{reactor}} N_{ij}^{th} \left(1 - \sin^2(2\theta_{13}) \int \sin^2\left[\frac{1.27\Delta m_{13}^2 d_{ij}}{E}\right] \rho_j(E)\mathrm{d}E\right)$$

- The index i indicates the detector, the index j the reactor
- N_{ij}^{th} is the expected number of neutrinos in the case of no-oscillation.

$$N_{ij}^{th} = \frac{\epsilon_i P_j}{d_{ij}^2}$$

- ϵ_i = detector efficiency, P_j = reactor power,
  d_{ij} = detector-reactor distance,
  $\rho_j(E)$ = energy spectrum of the neutrinos from the detector j.

RENO

$\rho(E)$

- We can use the prompt spectrum (energy of the positron from the inverse beta decay): $E_{\bar{\nu}} \simeq E_{\rm pr} + 780 {\rm keV}$ However, the statistical errors are large and the quality of the energy calibration is unknown
- We found that using the sample neutrino energy spectrum from DayaBay 07 we can obtain good results (difference less than 1%)

Version 1

The theoretical flux is used

Version 2

Flux-independent analysis

Comparing the two versions we can obtain the theoretical prediction for the flux. However, for completeness, we perform also an analysis based only on N_{far}/N_{near} (information only on $\sin^2 2\theta_{13}$, not on a)

Double Chooz

The experiment consist in a detector at 1050 m from two reactor cores ($\Rightarrow$ ONE experimental point)
We perform a rate analysis using the ratio between the measured events and the number of predicted interactions.

$$R = (1 + a)\left(1 - \sin^2(2\theta_{13}) \int \sin^2\left[\frac{1.267\Delta m^2_{13} d}{E}\right] \rho(E)\mathrm{d}E\right)$$

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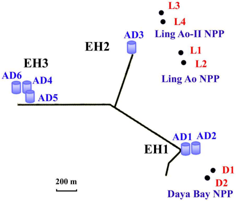
$n\sigma$ region

$$\left(1 - \frac{R + n\sigma}{1 + a}\right)/\sin^2\Theta_D < \sin^2(2\theta_{13}) < \left(1 - \frac{R - n\sigma}{1 + a}\right)/\sin^2\Theta_D$$

In the future Double Chooz will be provided of a near and a far detector $\Rightarrow$ precision should be significantly increased

Daya Bay Results



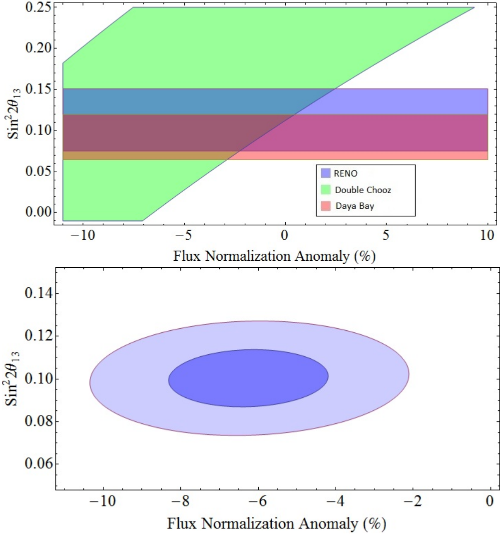
6 reactors and 6 detectors ⇒ it is possible to perform a anomaly-independent analysis, finding only θ_{13} without using the theoretical flux.

$$\sin^2 2\theta_{13} = 0.092 \pm 0.016\ (\mathrm{stat.})\ \ \pm 0.005\ (\mathrm{syst.})$$

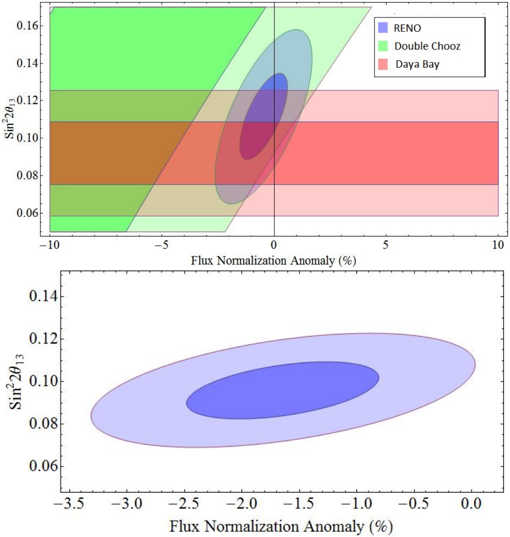
No information on the power of the reactors are released yet ⇒ we cannot evaluate the reactor anomaly from Daya Bay results.

When the informations on reactors will be release we can evaluate the theoretical flux and compare it with the best-fit prediction

Data Analysis



Data Analysis



Possible explanations

Possible explanations of the anomaly

- Wrong theoretical model
- Absorption ⇒ Neutrino flux should decrease with distance ⇒ No such effect is detected (Ex: KamLAND)
- Sterile neutrino ⇒ Cosmological bounds? ➥Additional hypothesis can reduce the tension with cosmological bounds (environmental dependence, cosmic strings, giant monopoles...)

Sterile Neutrino mass:

- VSB Reactor Anomaly: baseline >10 meters
- Gallium anomaly: baseline $\leq$ 3-4 m

$$m_\nu \simeq 1eV$$

($m_\nu \simeq$ 0.5 eV: OK for Reactor Anomaly, NOT for Gallium Anomaly)

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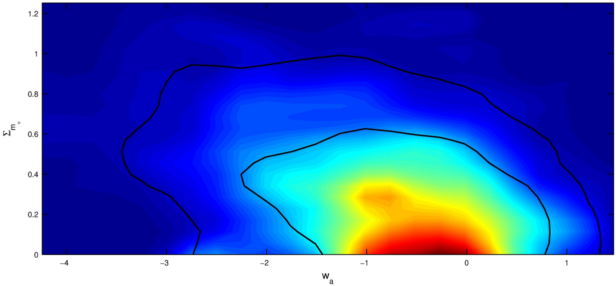
Sterile Neutrino solution: Cosmological Constraints

Qualitative picture

LSS	$\Rightarrow$	$\Omega_m \nearrow$
CMB	$\Rightarrow$	$N_{eff} = 4$ compensate $\Omega_m \nearrow$
Supernova Ia	$\Rightarrow$	$w \searrow$, to compensate $\Omega_m \nearrow$
BAO	$\Rightarrow$	Absolute size of BAO $\nearrow$ $\Rightarrow$ $w \nearrow$ to keep the angular size fixed

Strong bounds from the tension between SN Ia and BAO constraints.
This tension can be reduced allowing w to depend on z $\Rightarrow$ Quintom scenario

Numerical simulations



$$w = w_0 + (1 - a)w_a$$

$$m_\nu = 1 \text{ eV compatible at } 2\sigma$$

Numerical simulations

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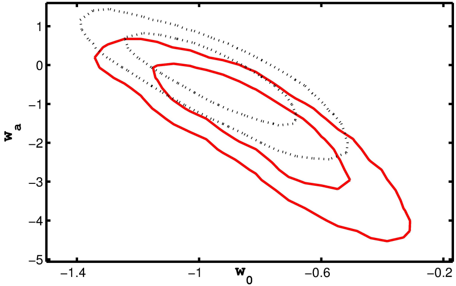

Red curve: with the massive sterile neutrino
Dotted curve: without the massive sterile neutrino

Summary

- If we use the theoretical flux for RENO the reactor anomaly is around 1.7%; otherwise the best fit value is around 6.7%
- The presence of a massive sterile neutrino ($m_\nu = 1$ eV) is at 2 σ from the present cosmological bounds in a quintom scenario
- The knowledge of the theoretical flux of the experiments is crucial; $\Rightarrow$ the theoretical flux in Daya Bay experiment can significantly change this scenario
- BAO data are from region with a lower z than Supernova Ia $\Rightarrow$ new BAO data with higher z could rule out this hypothesis

Thank You!