Нейтринная астрофизика. Космологические Нейтрино.

Иванчик

Александр Владимирович

ФТИ им. А.Ф. Иоффе

Академический университет им. Ж.И. Алферова

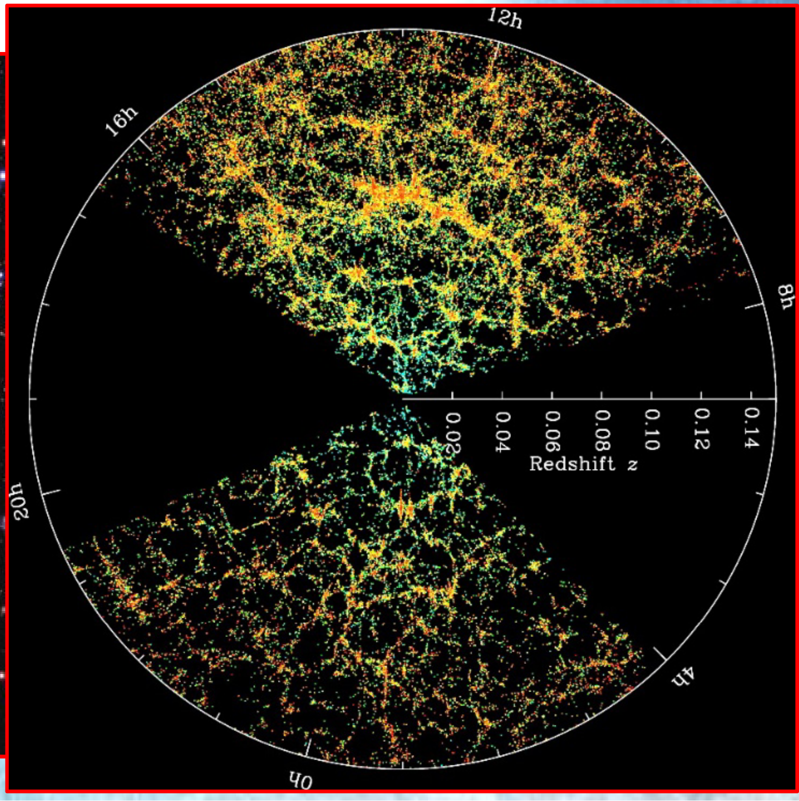
СПбПУ Петра Великого

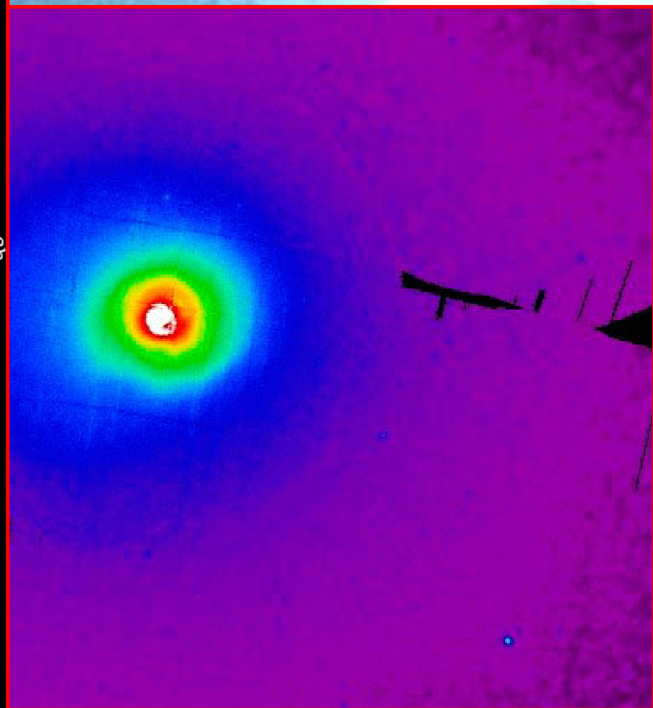
С.-Петербург 2022

Достижения ЭМВ Астрономии

1. Радиоволны: Центр и спиральные рукава Галактики,
Радиогалактики, Пульсары 
Пульсар X-T  CMBR 

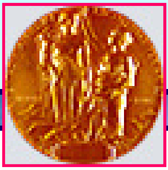
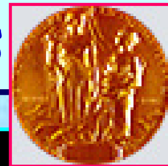
2. Рентген , Гамма: Точечные источники – ЧД
Скопления Галактик

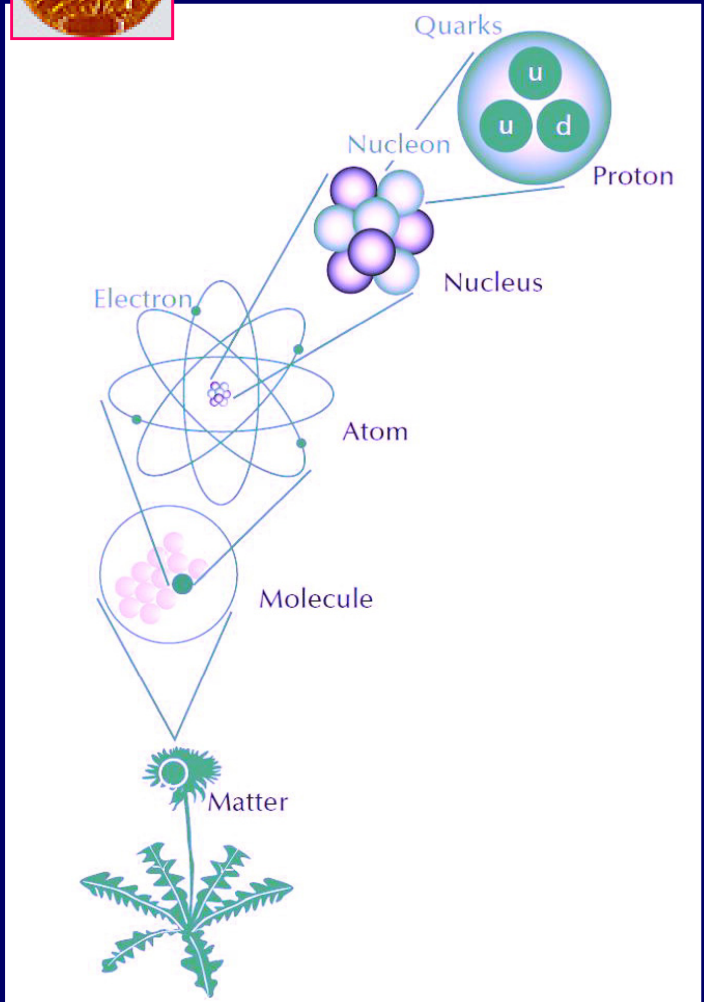


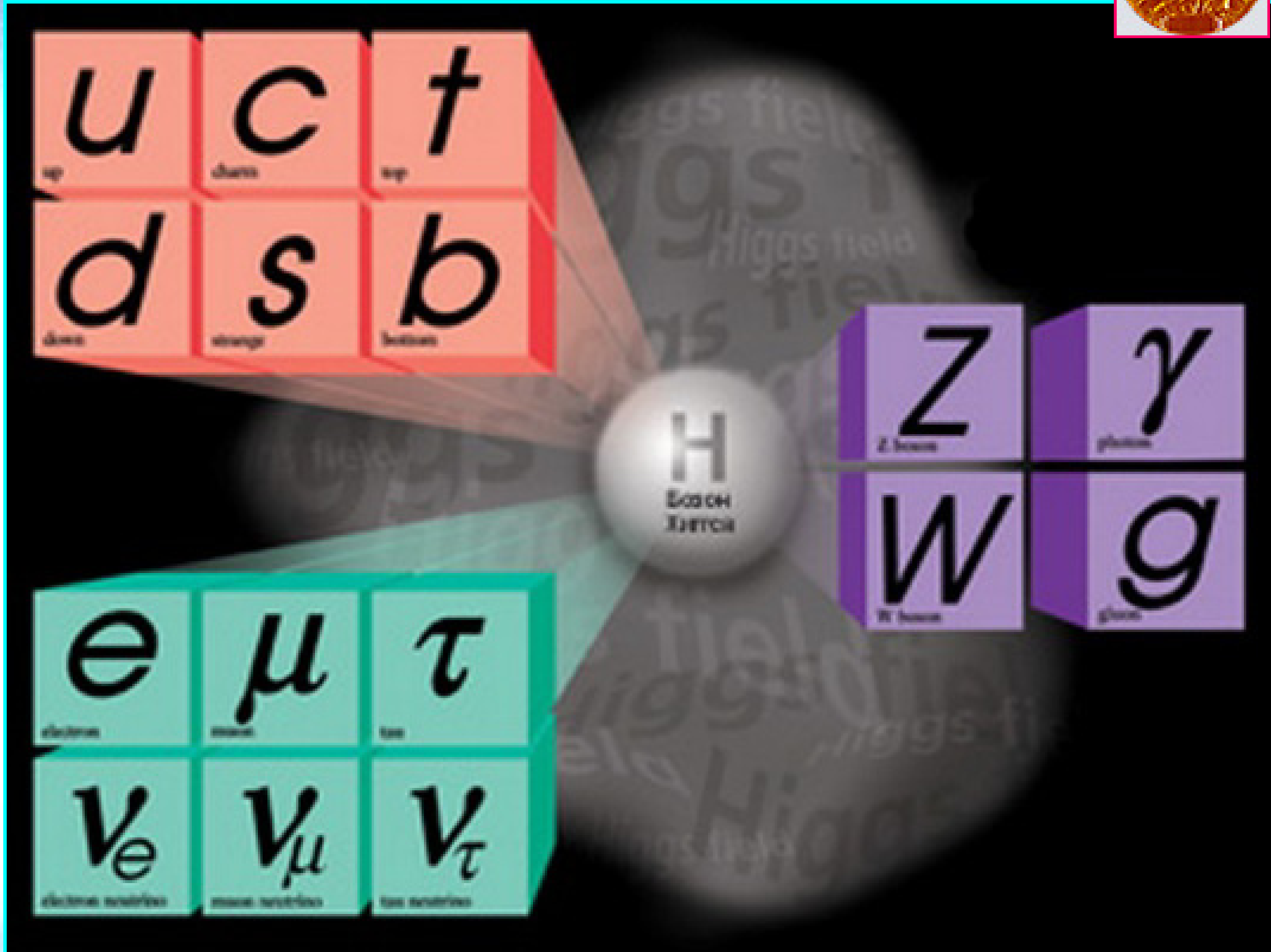


Стандартная Модель
(Кварк-лептонная структура материи)

1897 … **5%** … **2012**


J.J.Thompson (NP 1906) — (NP2013) F. Englert & P. Higgs






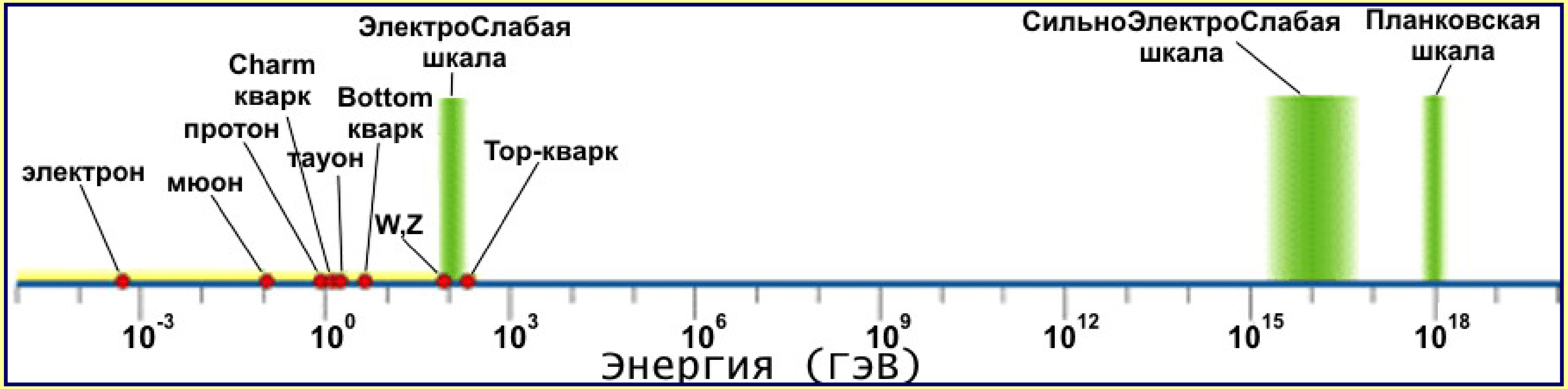
НО

Стандартная Модель

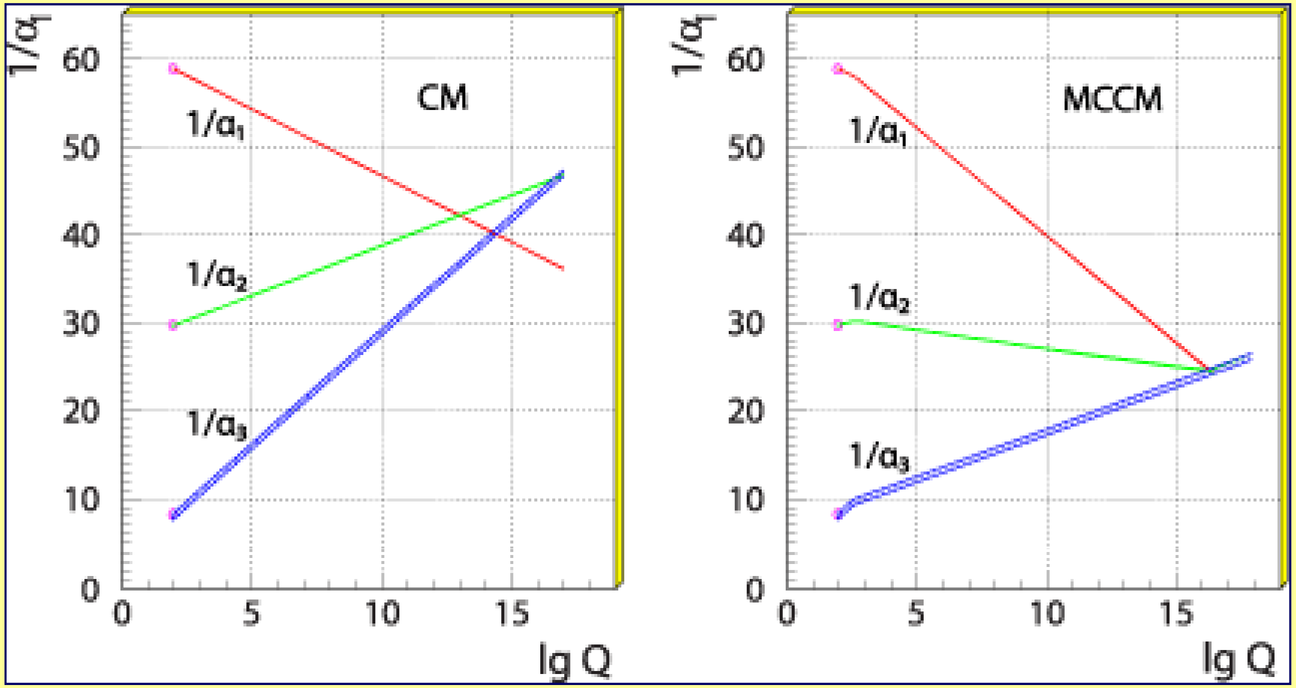
НЕПОЛНА !!!

Необъясненные проблемы Стандартной Модели

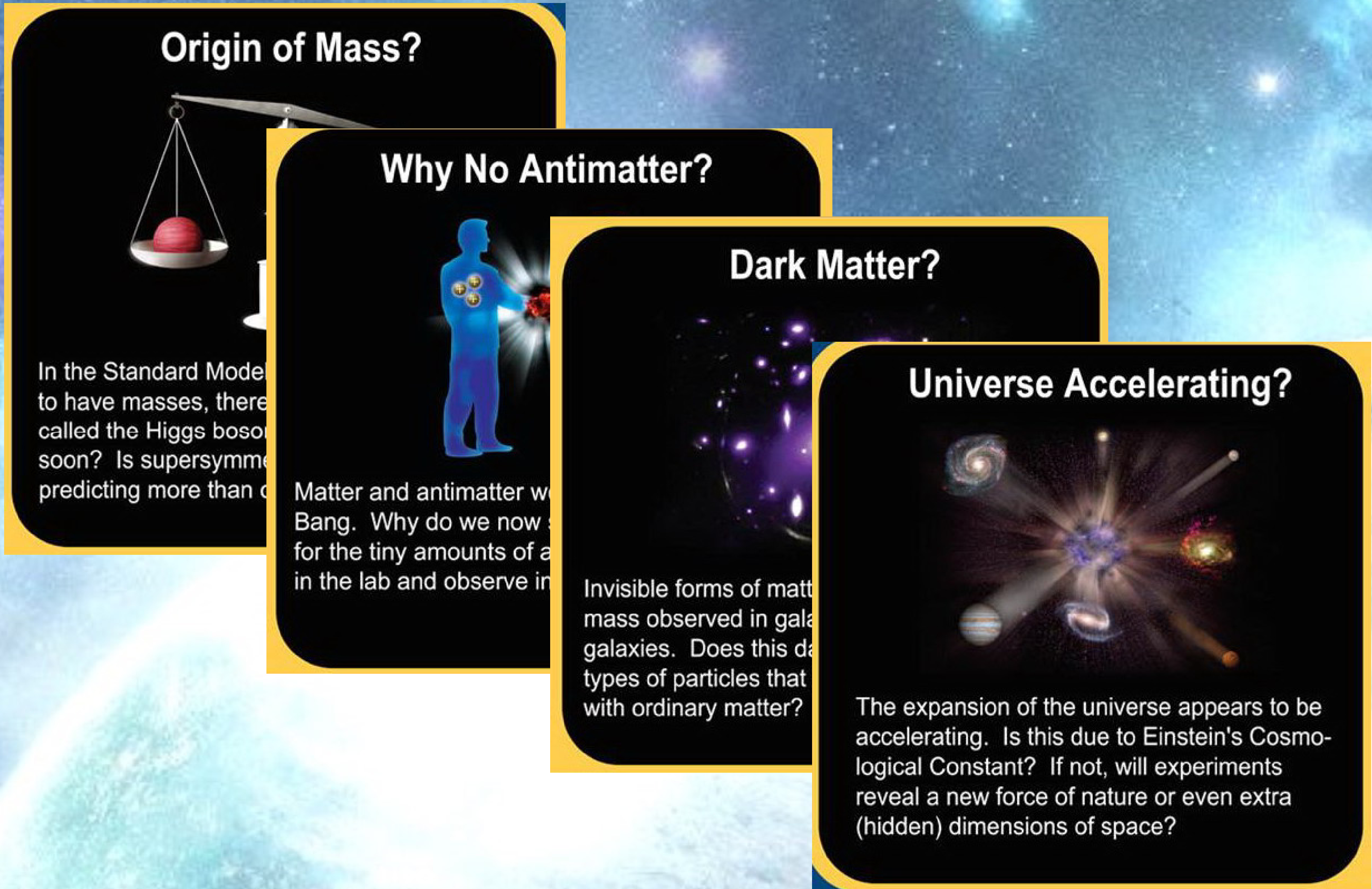
Проблема иерархии масс, энергетическая пустыня



Бегущие константы



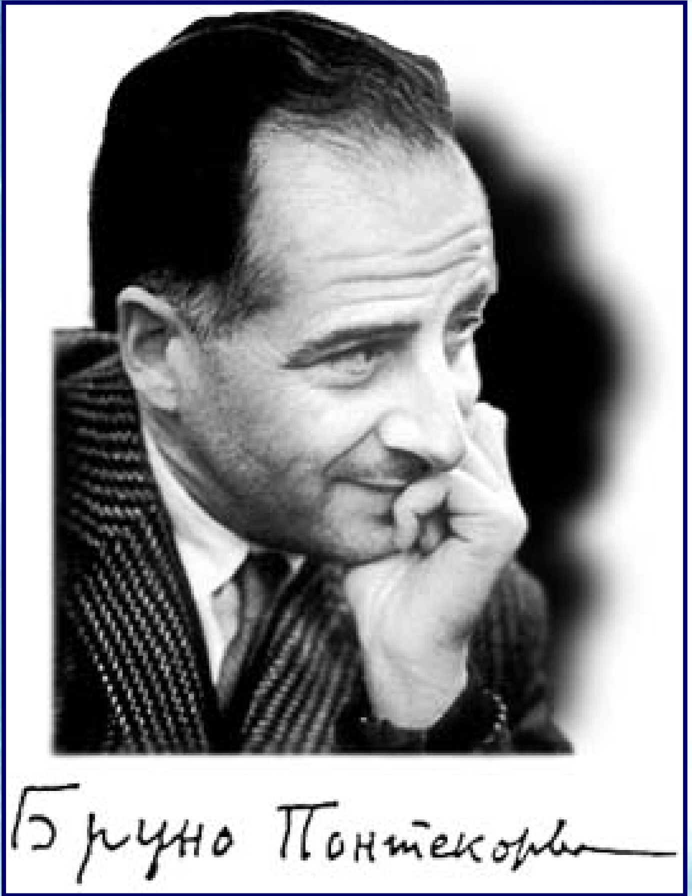
Косвенные аргументы неполноты СМ

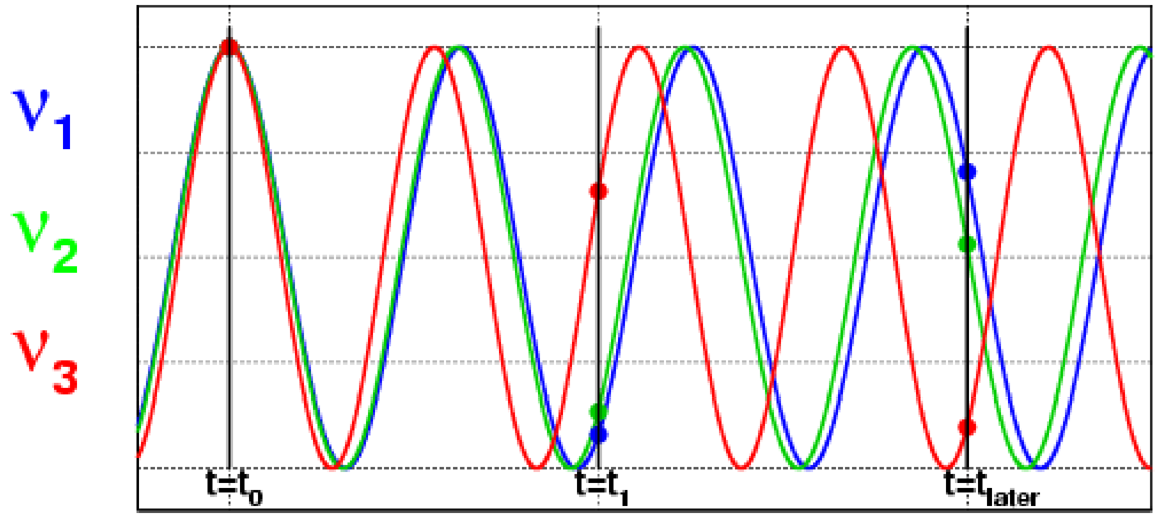


Стандартная Модель НЕПОЛНА !!!

Нейтринные осцилляции – массы нейтрино

1957



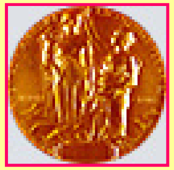


Осцилляции нейтрино

⇔

Массы нейтрино

4 Нобелевские Премии
за исследования,
связанные непосредственно с нейтрино



1. L.M. Lederman, M. Schwartz, J. Steinberger – 1988
   (два поколения лептонов посредством открытия мюонного нейтрино)

2. Frederic Reines – 1995
   (за открытие нейтрино)

3. R. Davis Jr. & M. Koshiba – 2002
   (за открытие космических нейтрино «cosmic neutrinos»)

4. T. Kajita & A.B. McDonald – 2015
   (за открытие осцилляций нейтрино = существование массы)

Особенности нейтрино

1. Нейтрино – ВТОРАЯ по распространенности частица во Вселенной.

2. Нейтрино – самая легкая из известных массивных частиц !

3. **Нейтрино – нарушает симметрию правого и левого !!!**
(как и живая природа)

4. Осцилляции нейтрино, выходящие за рамки СМ
($\Delta Le=0$, $\Delta L\mu=0$, $\Delta L\tau=0$)
Лептогенезис => Бариогинезис => Темная Материя

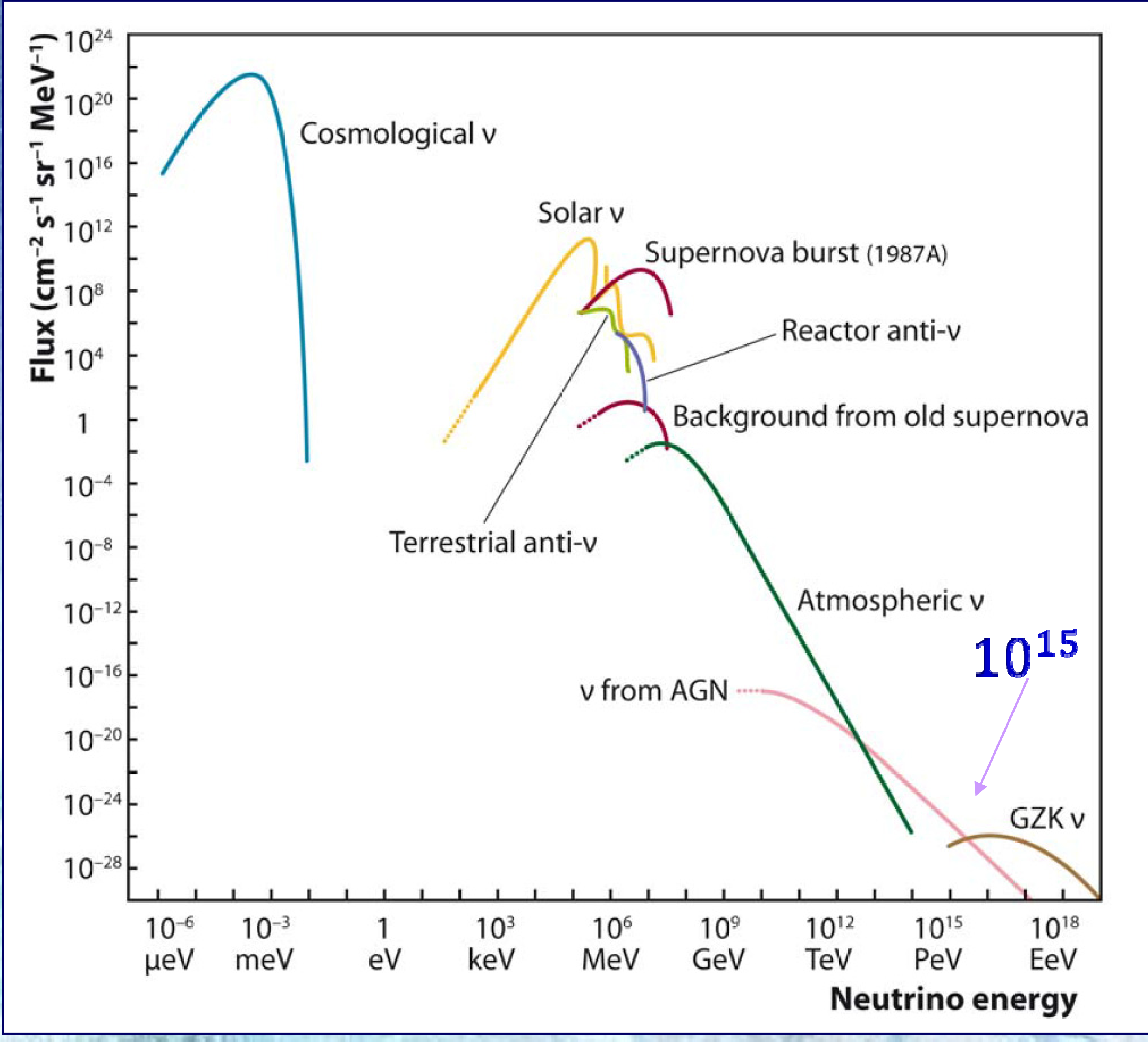
5. Нейтрино – одна из компонент Темной Материи ($0.01\% < \rho_\nu < 0.1\%$)

6. Вносит определяющий вклад в скорость расширения Вселенной на РД-стадии, тем самым определяет He/H и ход звездной эволюции.

7. Проникающая способность нейтрино столь высока, что позволит заглянуть в первые секунды рождения Вселенной.

...

Комплексный спектр нейтрино
«Grand Unified Neutrino Spectrum»



Нейтрино (итал. нейтрончик)

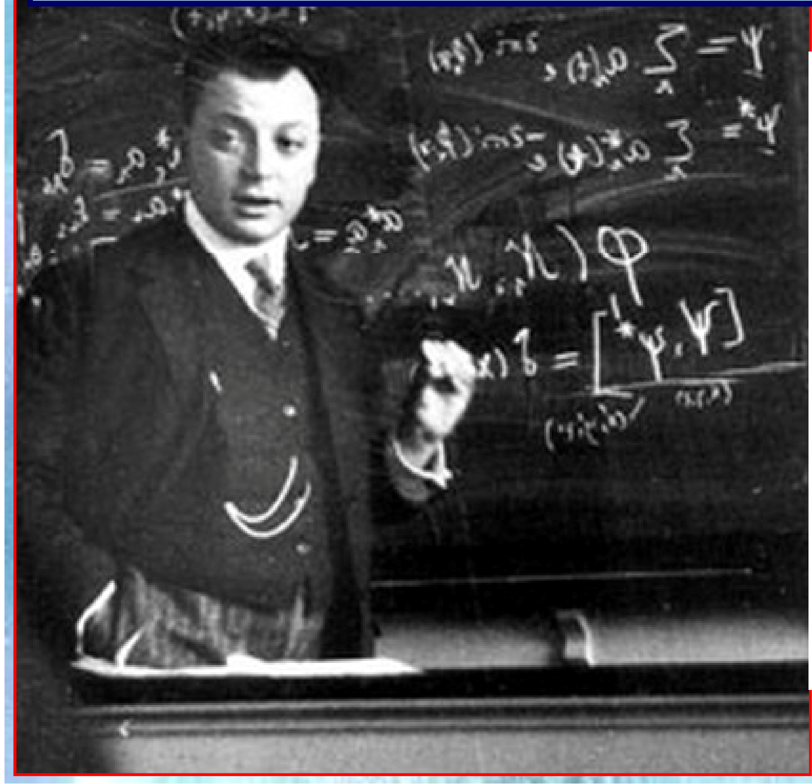
1930 1934

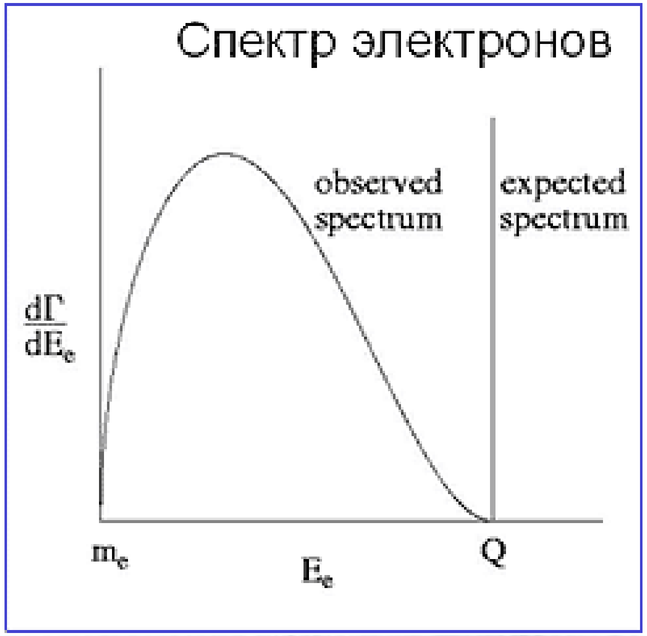
на основе теории Ферми в 1934 Х. Бете и Р. Пайерлс

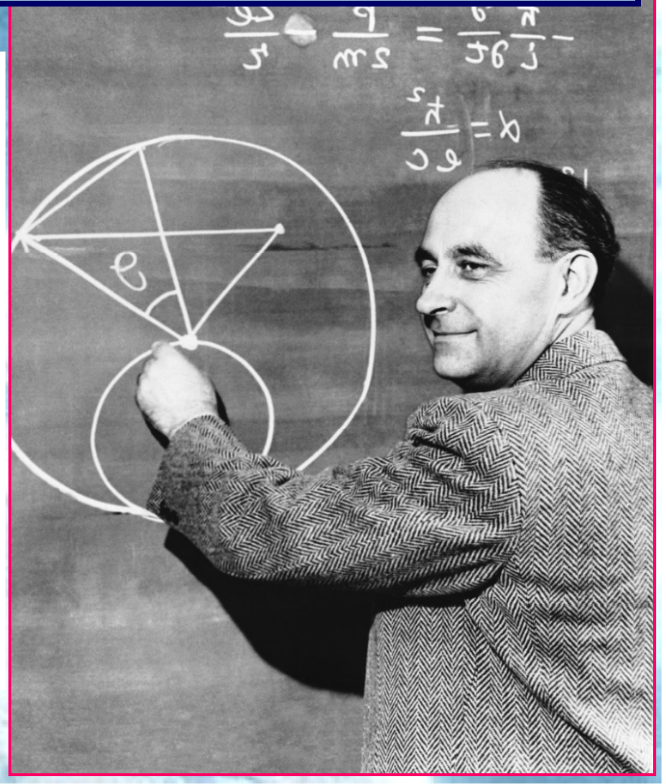
σ ≈ 10^-44 см^-2, ~ 1000 световых лет

"… я совершил ужасную вещь - предсказал частицу, которую никогда не удастся обнаружить …"

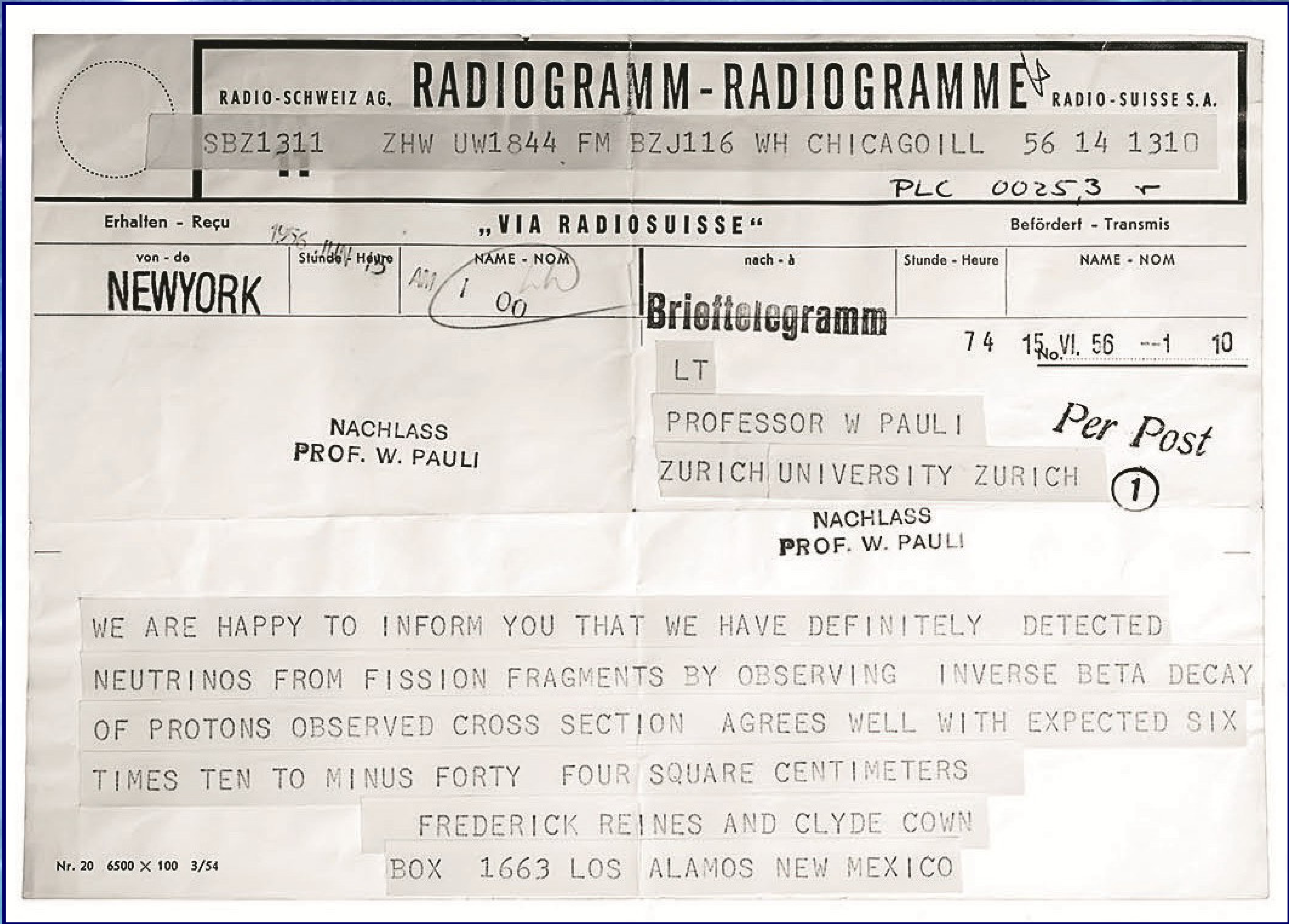
(… никогда не говори "никогда" …)







1956 Jun 15 AM 1 00



RADIO-SCHWEIZ AG. RADIOGRAMM - RADIOGRAMME RADIO-SUISSE S.A.

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von - de: NEWYORK | Stunde - Heure: 1956 | NAME - NOM: AM 1 00 | nach - à: Briefftelegramm | Stunde - Heure | NAME - NOM

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LT

PROFESSOR W PAULI

ZURICH UNIVERSITY ZURICH

Per Post ①

NACHLASS PROF. W. PAULI

NACHLASS PROF. W. PAULI

WE ARE HAPPY TO INFORM YOU THAT WE HAVE DEFINITELY DETECTED NEUTRINOS FROM FISSION FRAGMENTS BY OBSERVING INVERSE BETA DECAY OF PROTONS OBSERVED CROSS SECTION AGREES WELL WITH EXPECTED SIX TIMES TEN TO MINUS FORTY FOUR SQUARE CENTIMETERS

FREDERICK REINES AND CLYDE COWN

BOX 1663 LOS ALAMOS NEW MEXICO

Nr. 20 6500 × 100 3/54

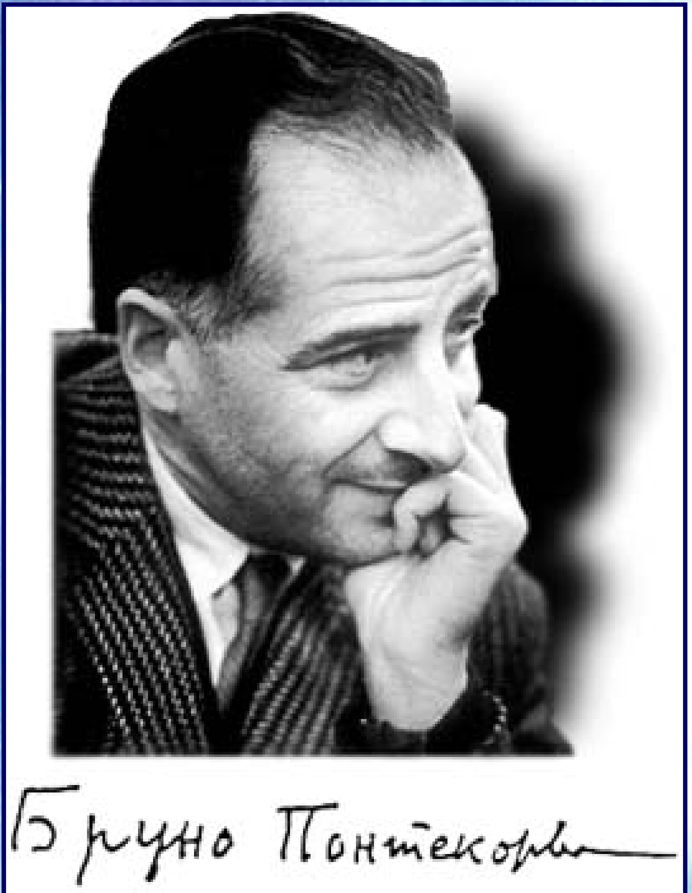
$$\sigma \approx 6 \cdot 10^{-44}\ \mathrm{cm}^2$$

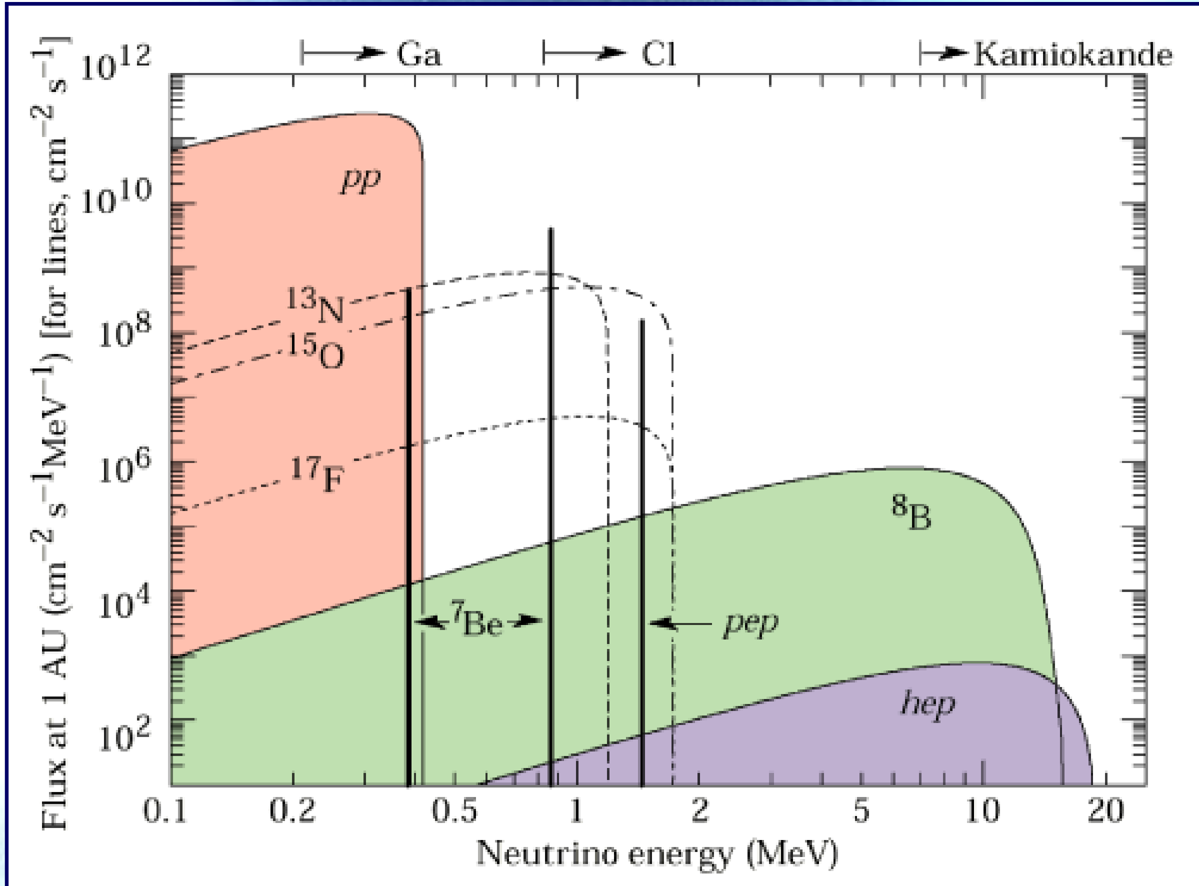
1995 "for the detection of the neutrino"

Метод для экспериментального обнаружения нейтрино

1946

$$\nu_e + {}^{37}\mathrm{Cl} \longrightarrow {}^{37}\mathrm{Ar} + e^-$$



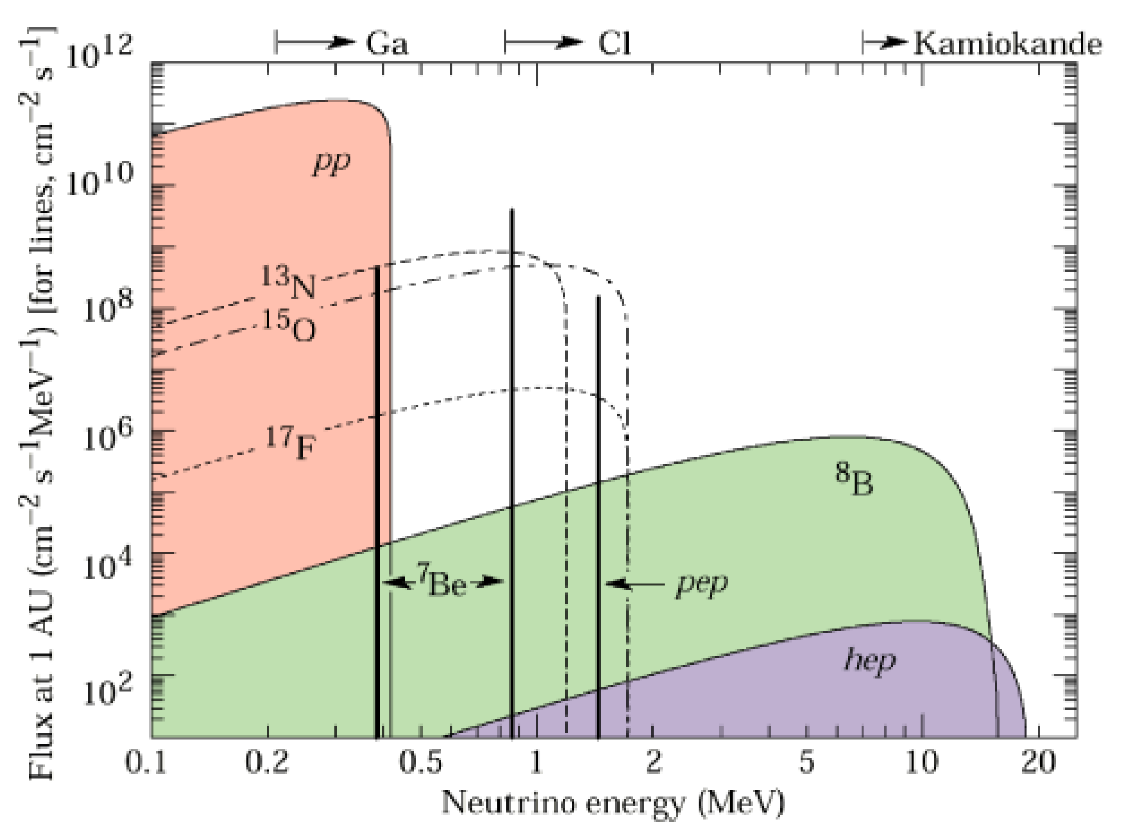


Начало нейтринной астрономии

1964 (предложен) **- 1967** (начат) **- 1994** (окончание)

Эксперимент Дэвиса - Солнечные нейтрино

$$\nu_e + {}^{37}\mathrm{Cl} \longrightarrow {}^{37}\mathrm{Ar} + e^-$$



Поток < 2 раза

1. Неверна
   Солнечная модель

2. 1957, 1969 г.
Понтекорво и Грибов
(осцилляции)

(2.6 ± 0.3)SNU – Davis_Exp1998

(8.6 ± 1.2)SNU – Bahcall2002

1 нейтрино в 4 суток

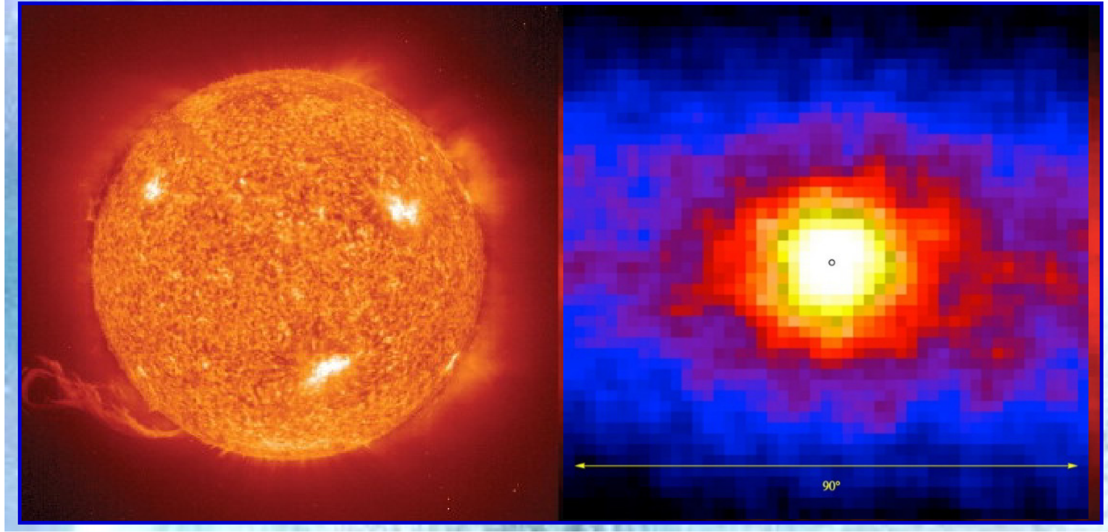
Эксперимент Kamiokande

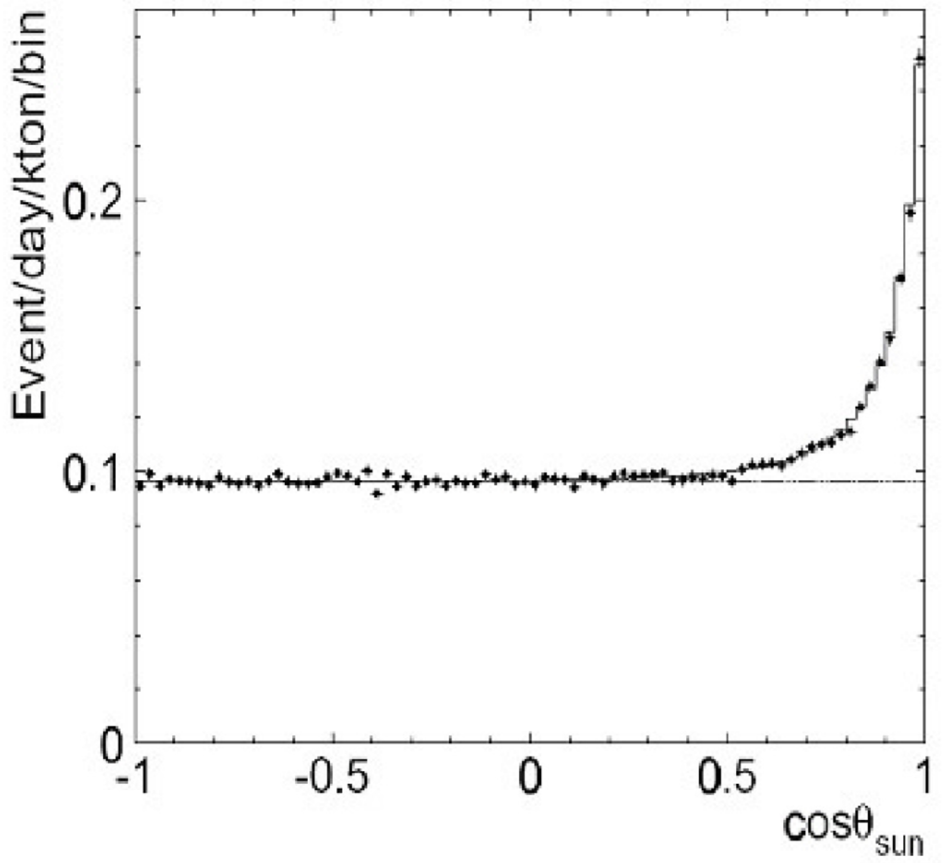
~1980 – 1986(II) - 1987(SN1987) – 1996 (Super) -

$$p \rightarrow \pi^0 + e^+$$

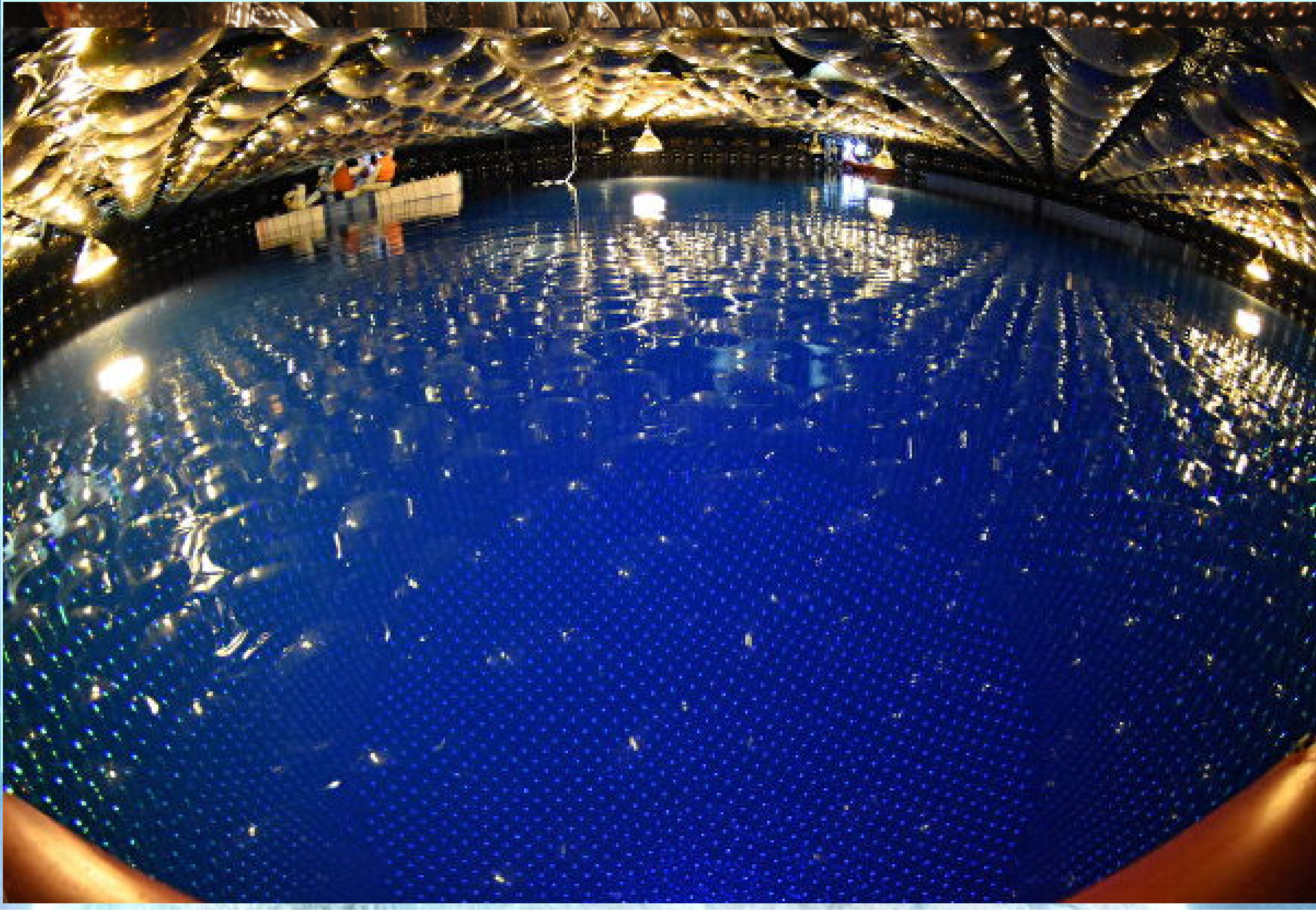
Регистрация солнечных нейтрино,
подтверждение рез. Дэвиса
Регистрация атм. нейтрино

Солнце
в
Оптике и Нейтрино



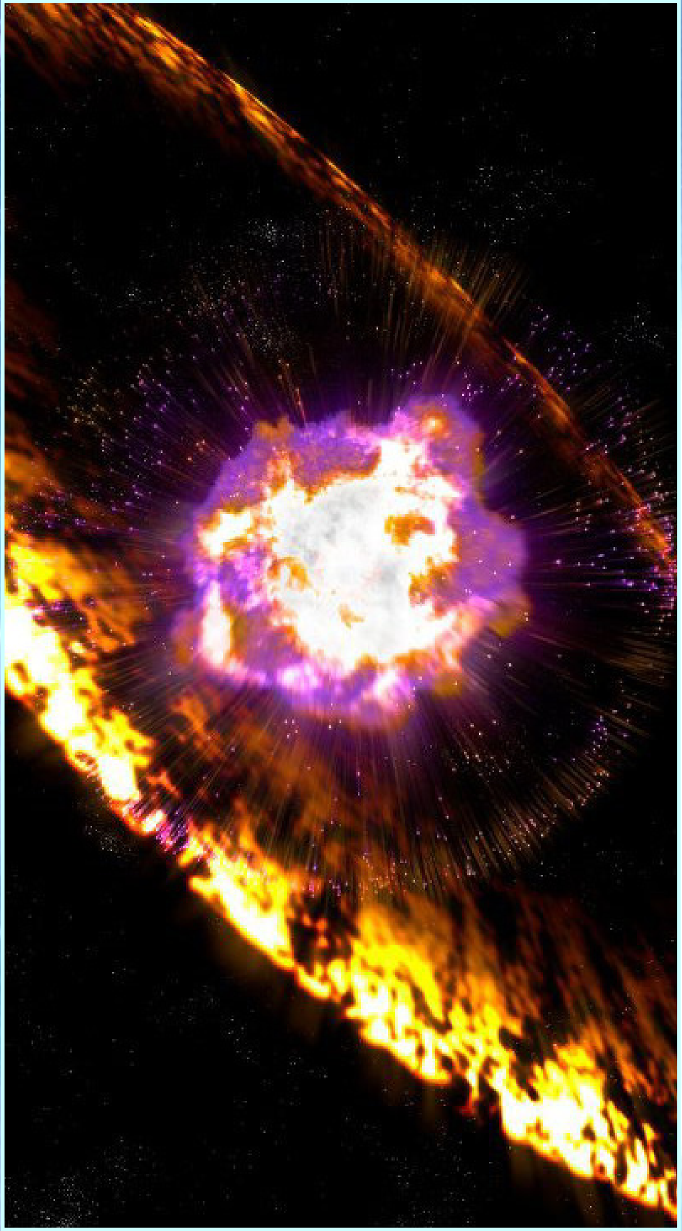


SuperKamiokande (1996)



Сверхновая 1987А

(10:35, 23 февраля 1987)

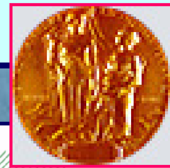


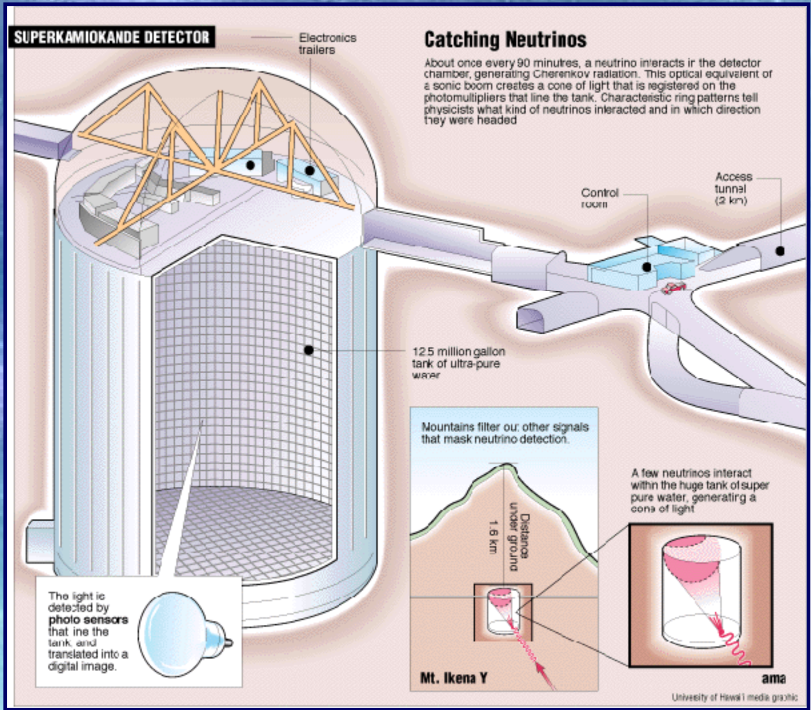
7:35 – KamiokandeII, IBM и БАКСАН, регистрирую вспышку нейтрино длительностью < 13 мин (в направлении на БМО 20град, Kamiokande)

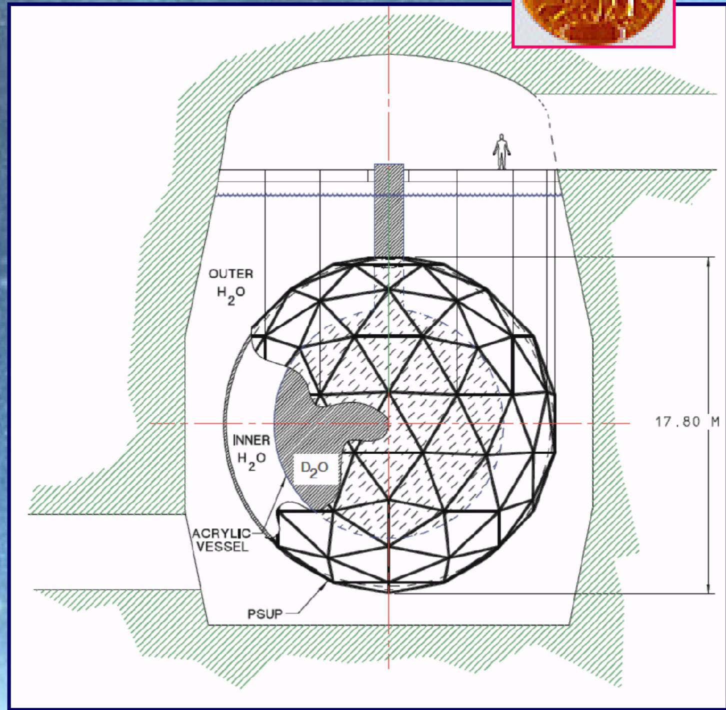
24 нейтрино и антинейтрино

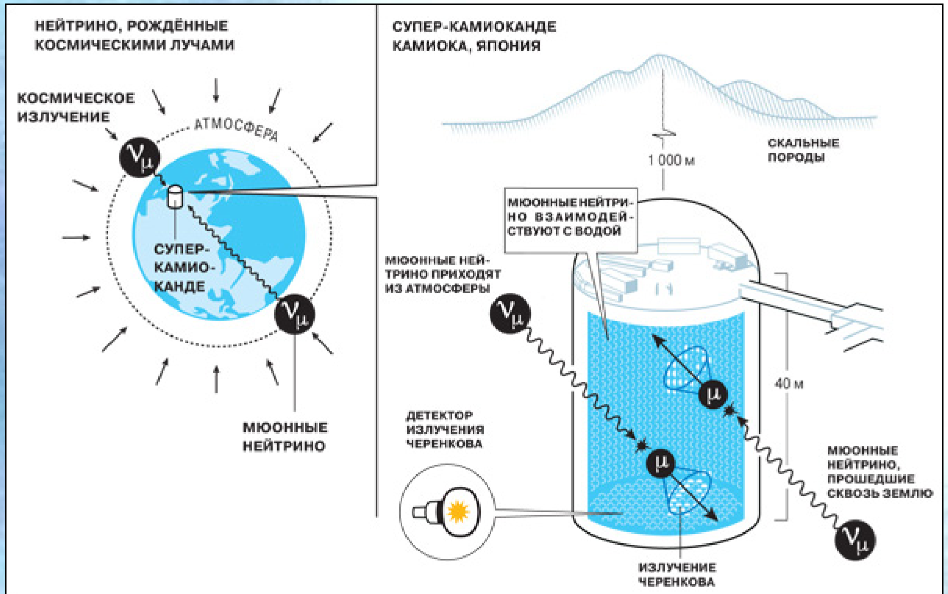
T. Kajita & A.B. McDonald 2015

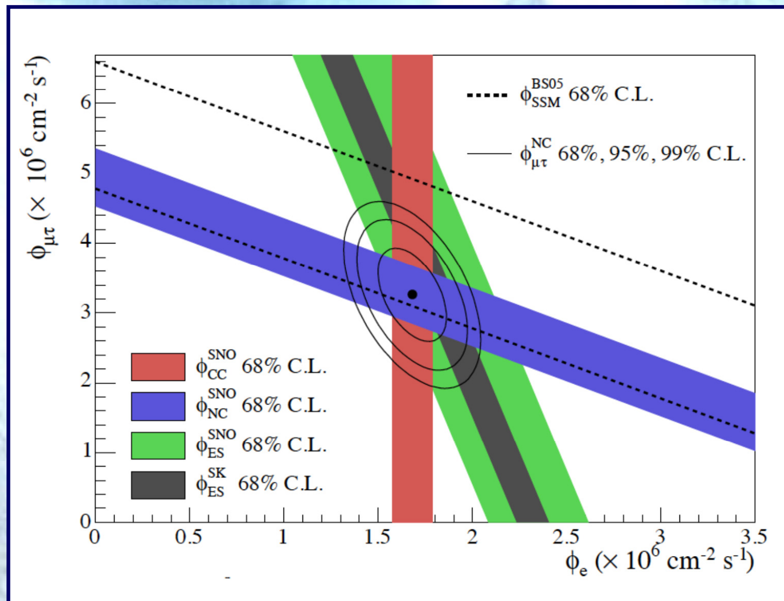
(за открытие осцилляций нейтрино = существование массы)



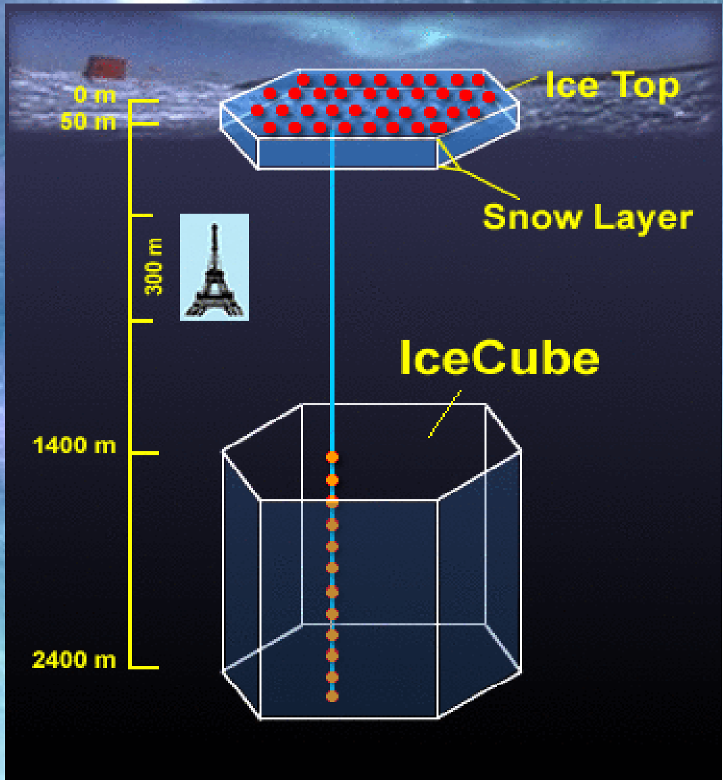


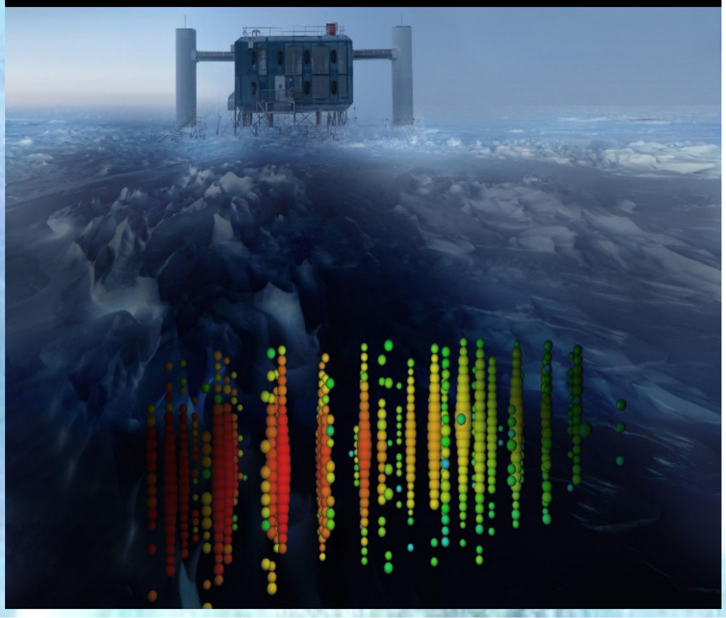


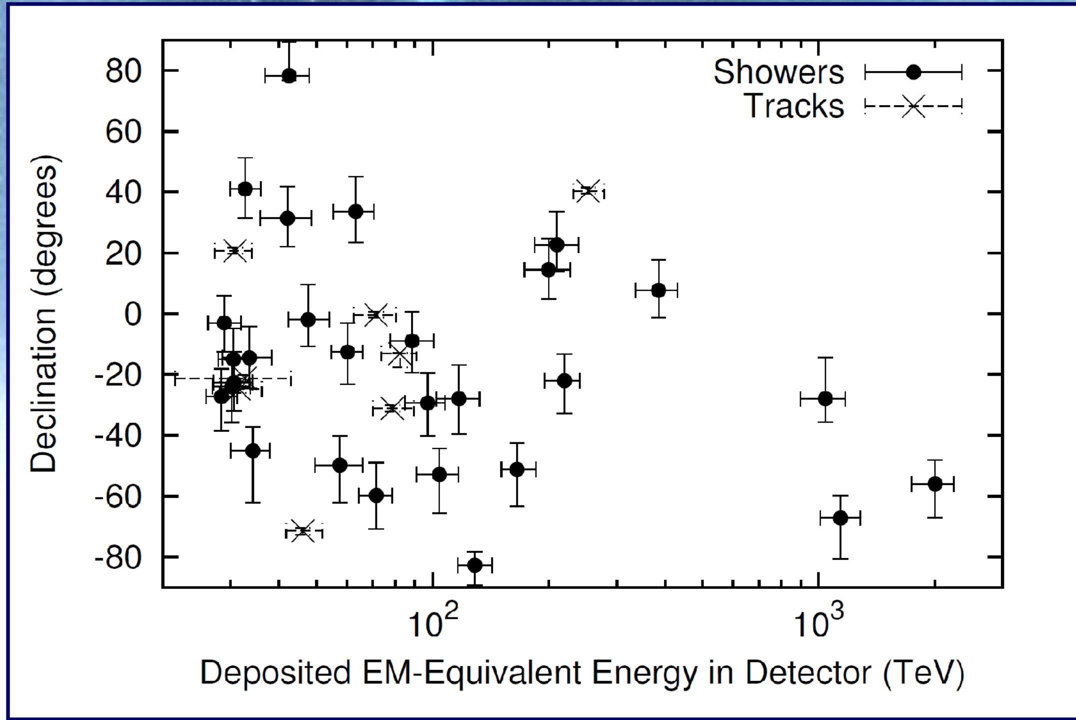


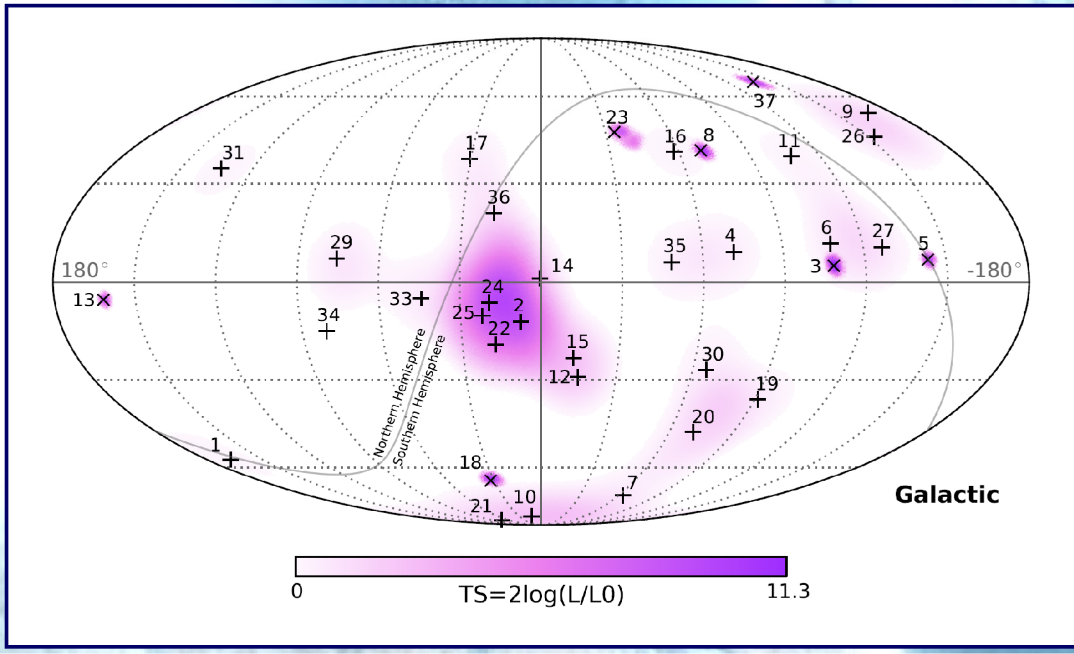


IceCube - 2014 - космос в нейтринных лучах



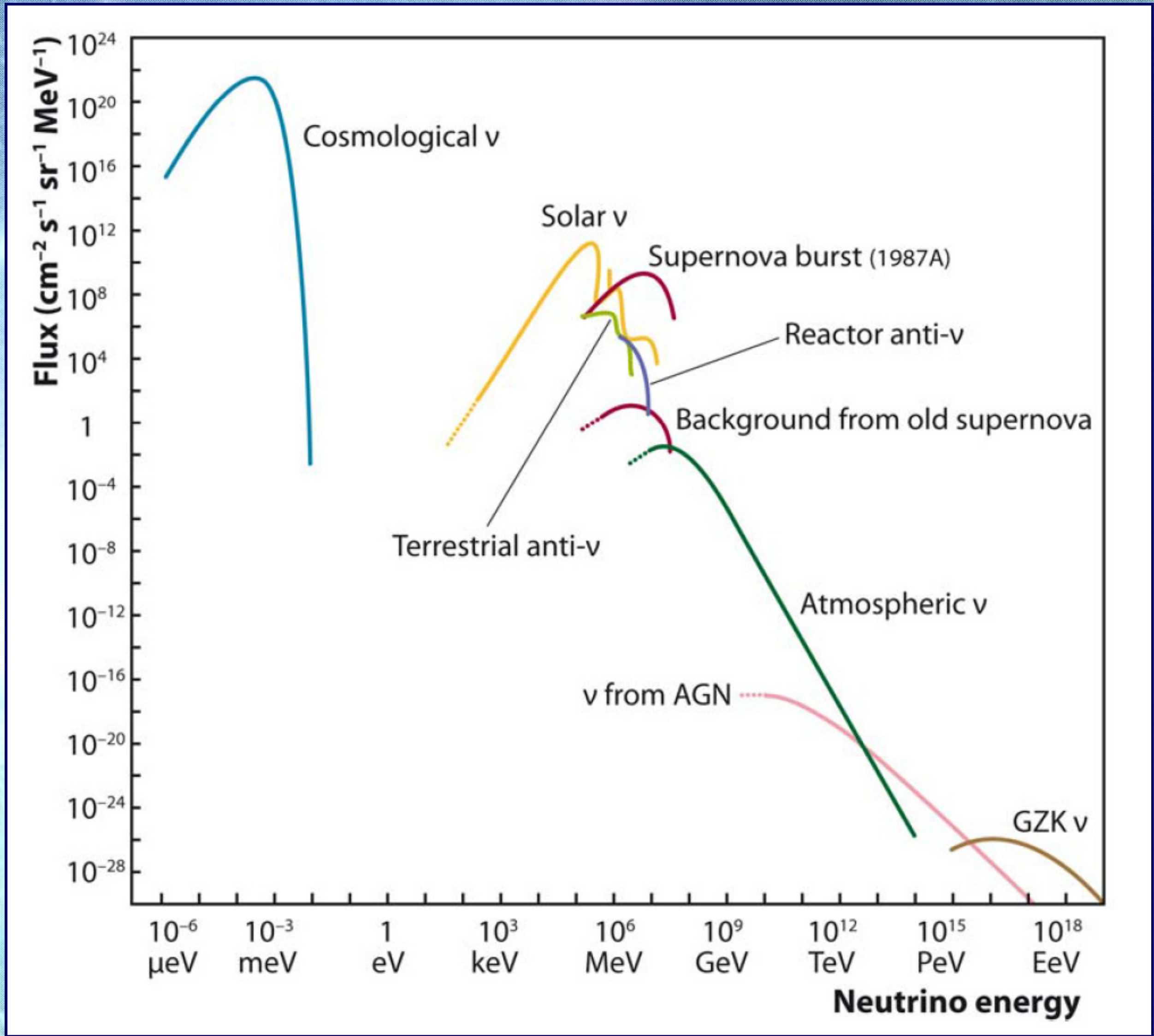






Космологические Нейтрино

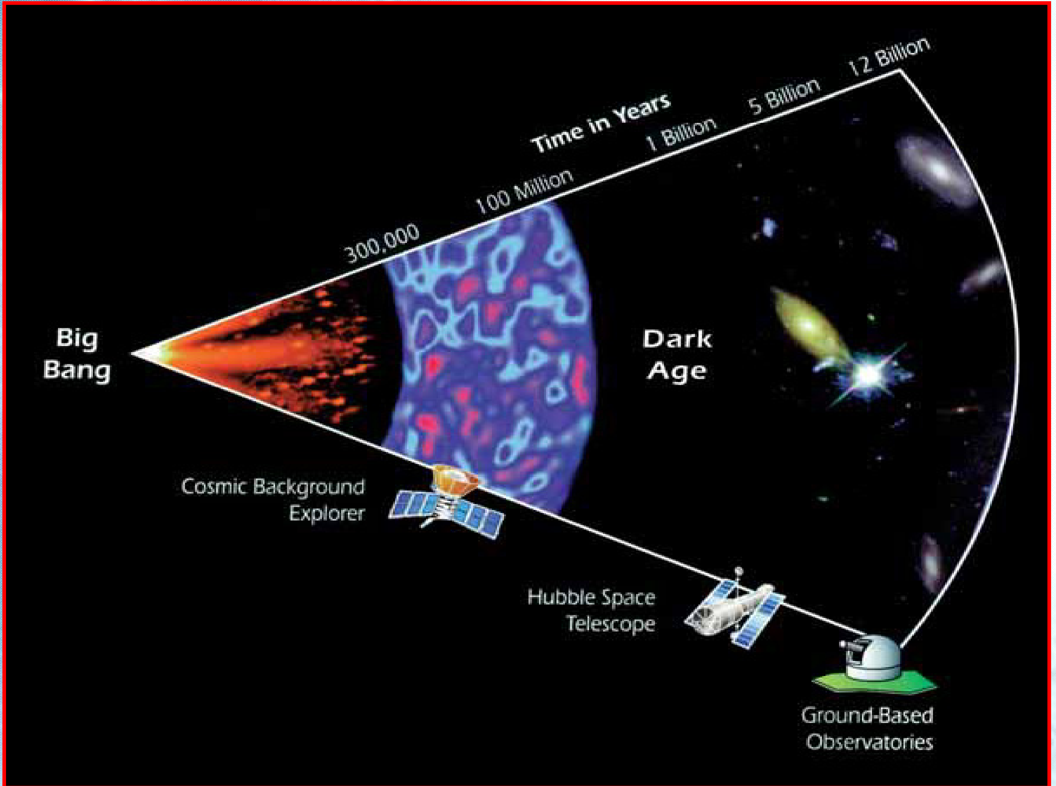
CνB

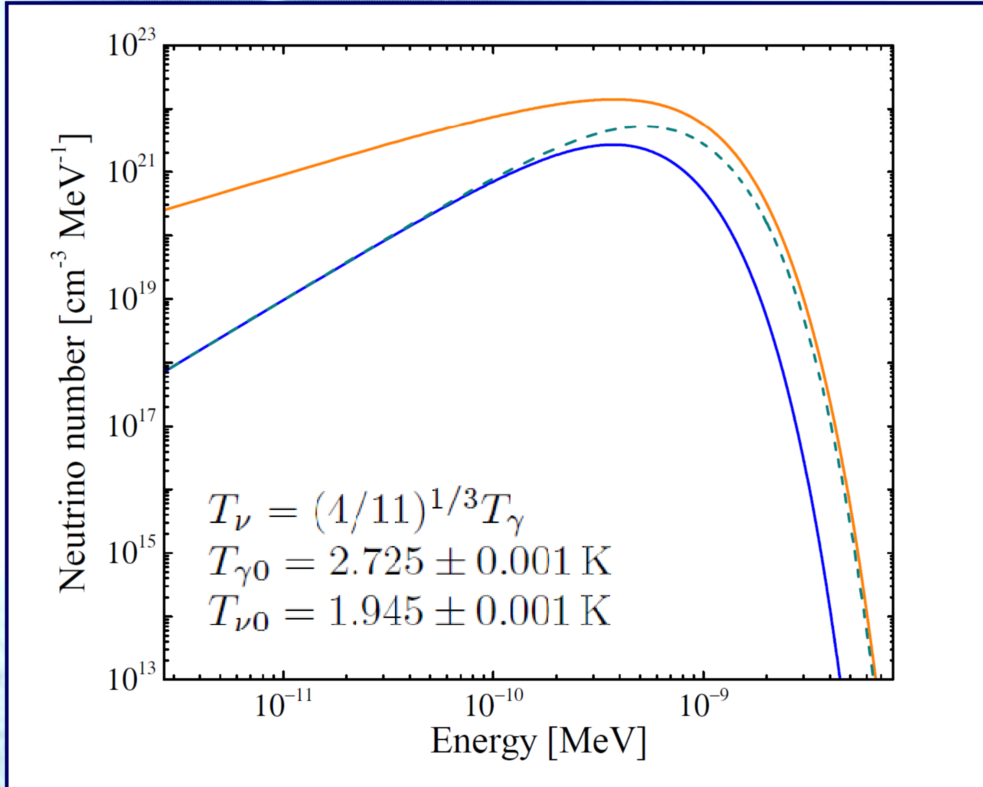


Космологические Нейтрино

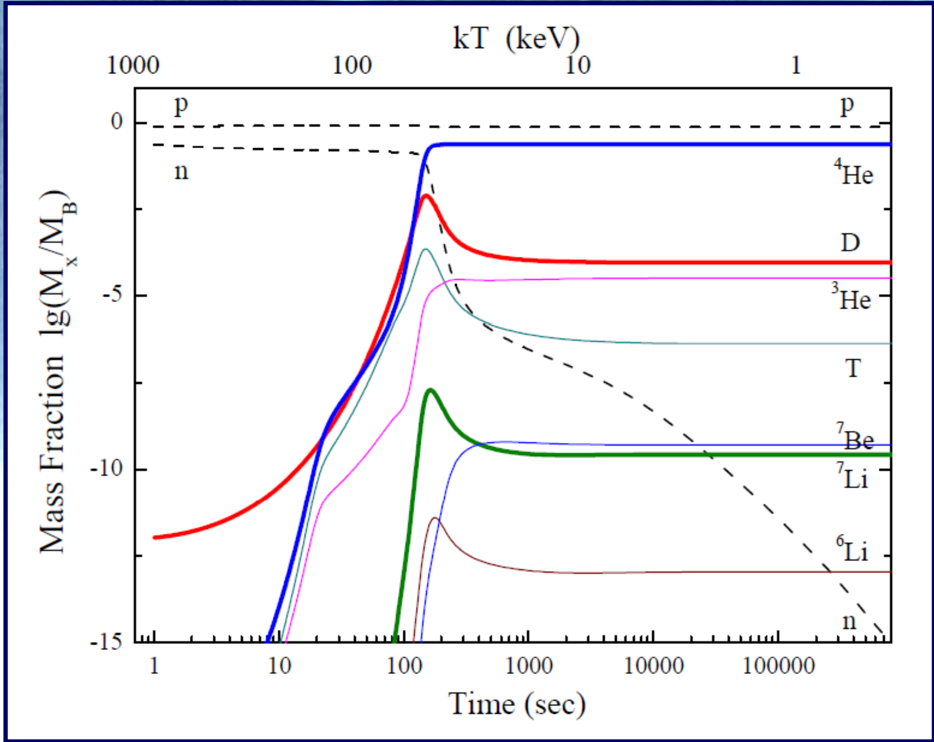
CνB

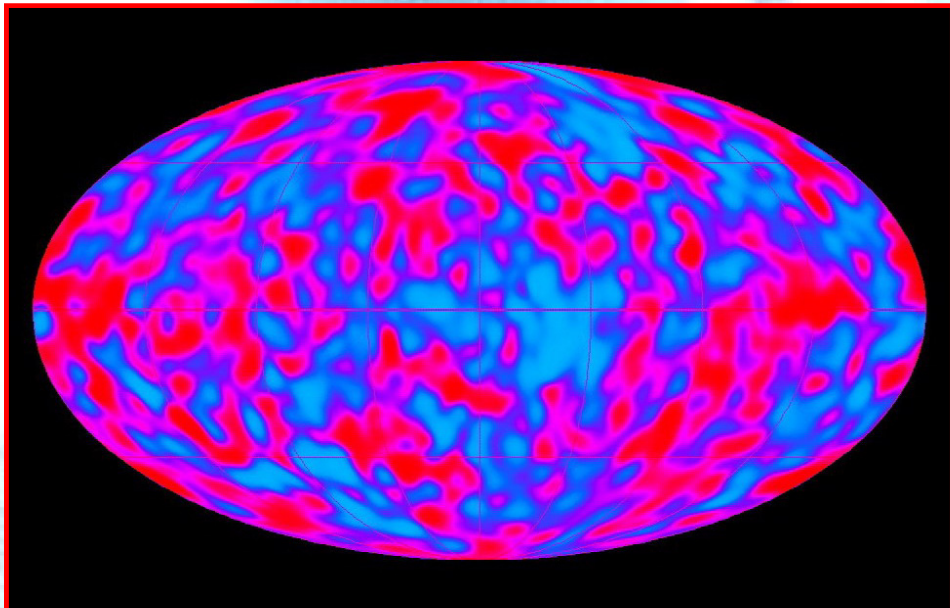
$$dn(\varepsilon, T) = \frac{4\pi g}{(2\pi\hbar)^3 c^3} \frac{\varepsilon^2 d\varepsilon}{\exp\left(\frac{\varepsilon}{kT}\right) \pm 1}$$





Химический состав Вселенной



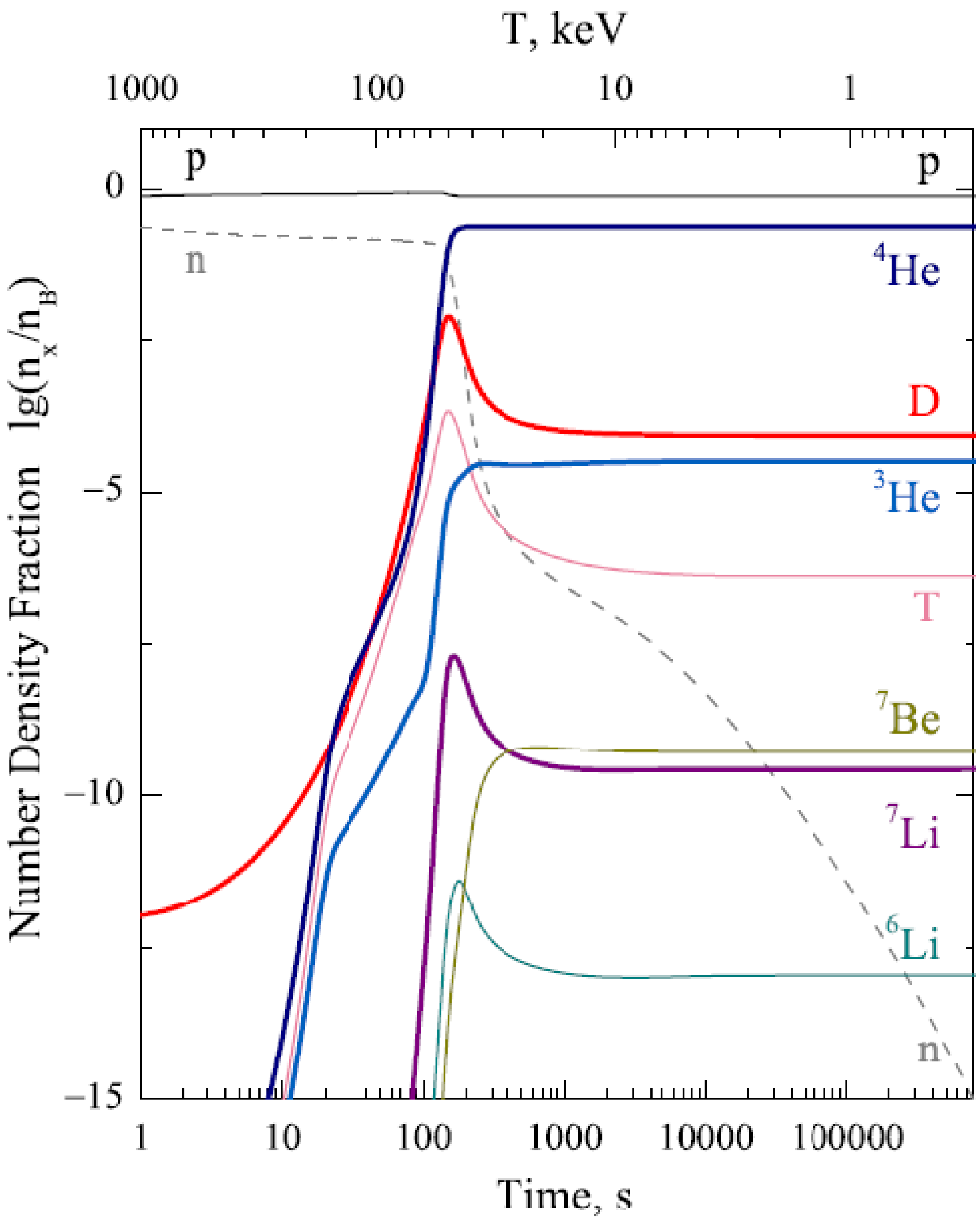


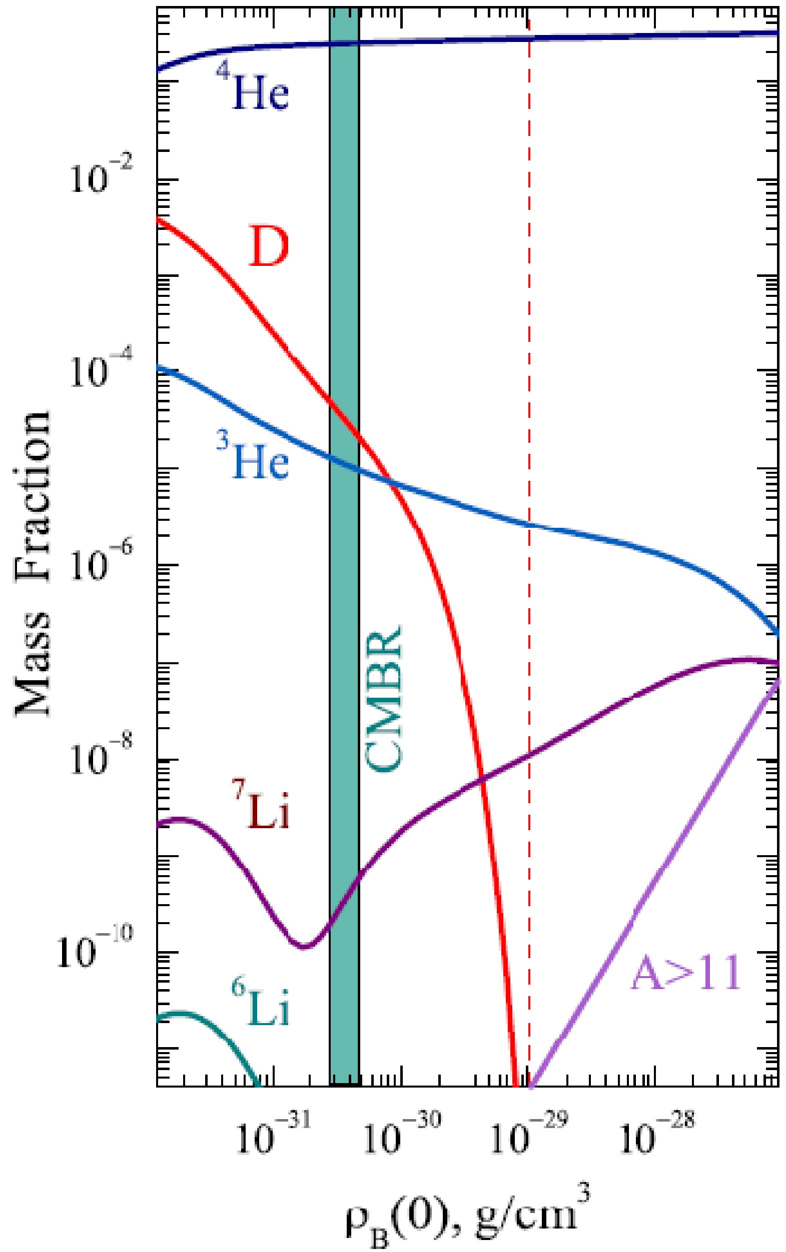
Георгий Гамов

Горячая Вселенная

1948

Первичный нуклеосинтез, роль нейтрино





Факторы определяющие конечные распространенности D, He, Li

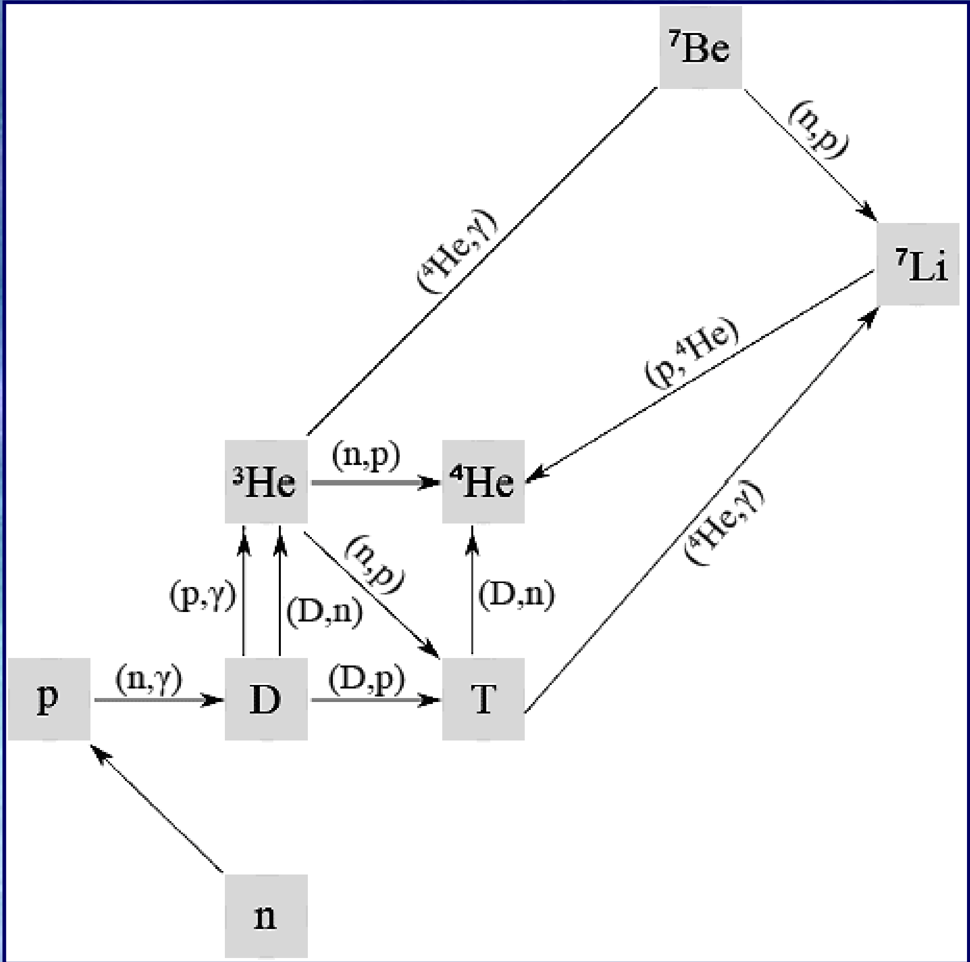
$$\Omega_B \approx 4\%$$

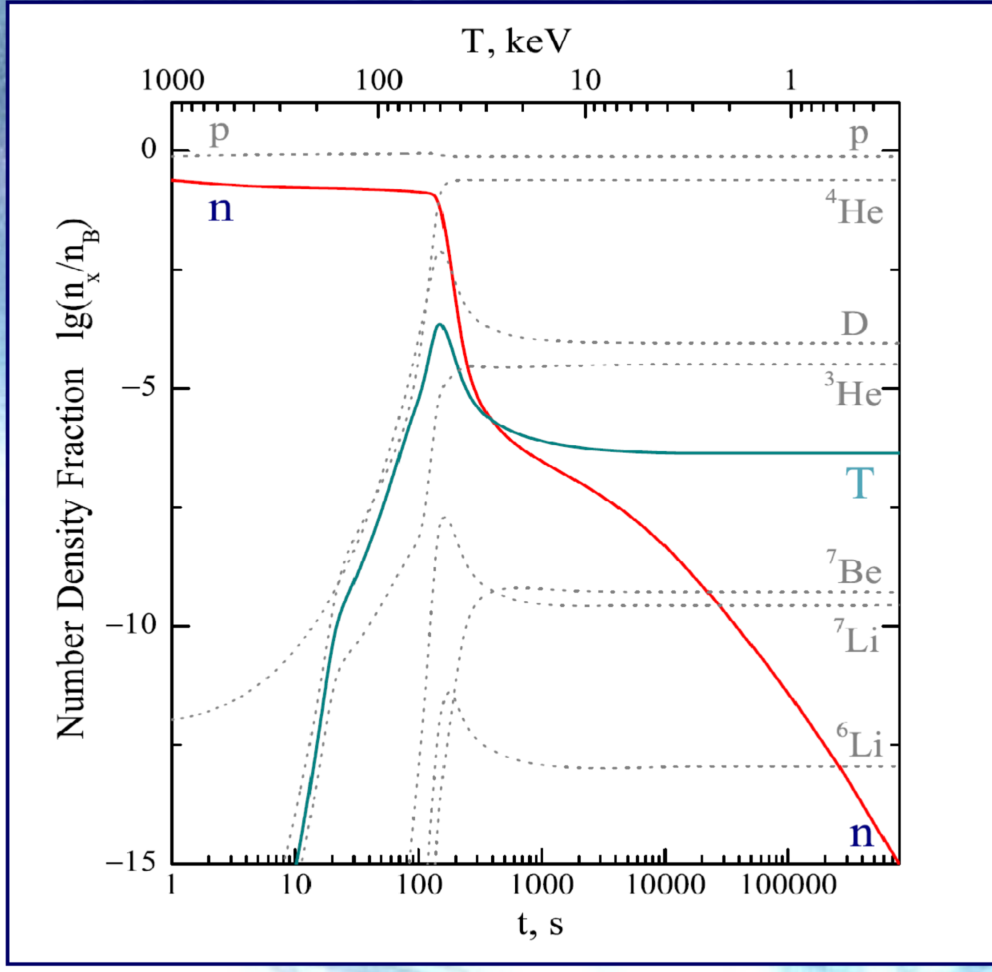
$$H(t) = \sqrt{\frac{8\pi G}{3}\rho(t)}, \qquad \rho(T) = \frac{\mathcal{N} a_B T^4}{2}$$

$$\mathcal{N} = 2_\gamma + \tfrac{7}{8}(3 \cdot 2_\nu + 4_{e^+e^-}) \qquad \mathcal{N} = 2_\gamma + \tfrac{7}{8} \cdot 3 \cdot 2_\nu \cdot \left(\tfrac{4}{11}\right)^{4/3}$$

$$2_\gamma + 5.25_\nu + 3.5_{e^+e^-} \quad (\approx 50\%) \qquad 2_\gamma + 1.363_\nu \quad (\approx 40\%)$$

Нетепловые (анти)нейтрино Первичного нуклеосинтеза

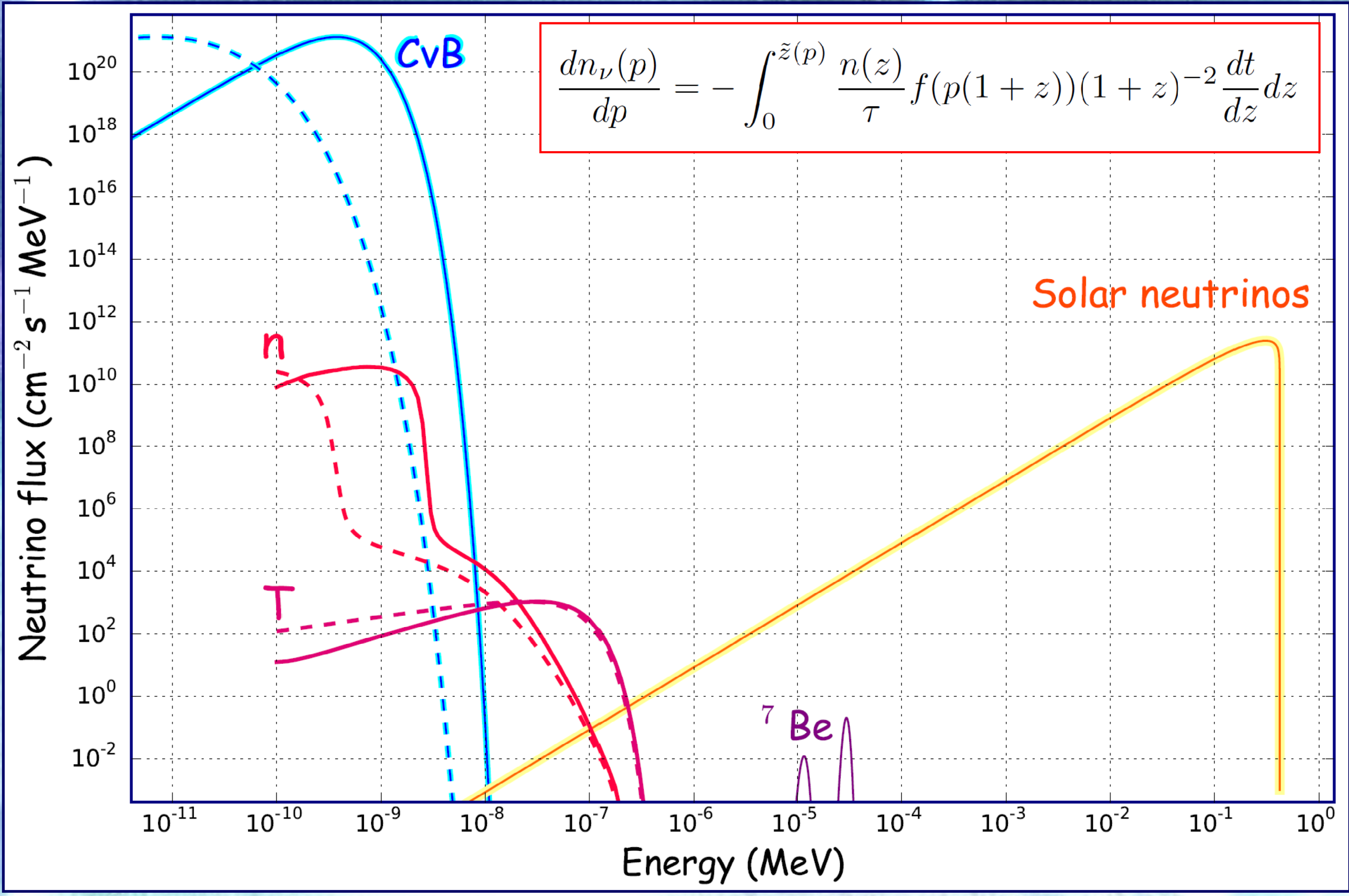




$$dn_\nu(p) = \lambda n(t) f(p) dp dt$$

$$f_\nu(p)dp = \mathcal{C}\sqrt{(1-\tilde{p})\left(1-\tilde{p}+\frac{2m_e c^2}{Q}\right)}\left(1-\tilde{p}+\frac{m_e c^2}{Q}\right)\tilde{p}^2 d\tilde{p}$$

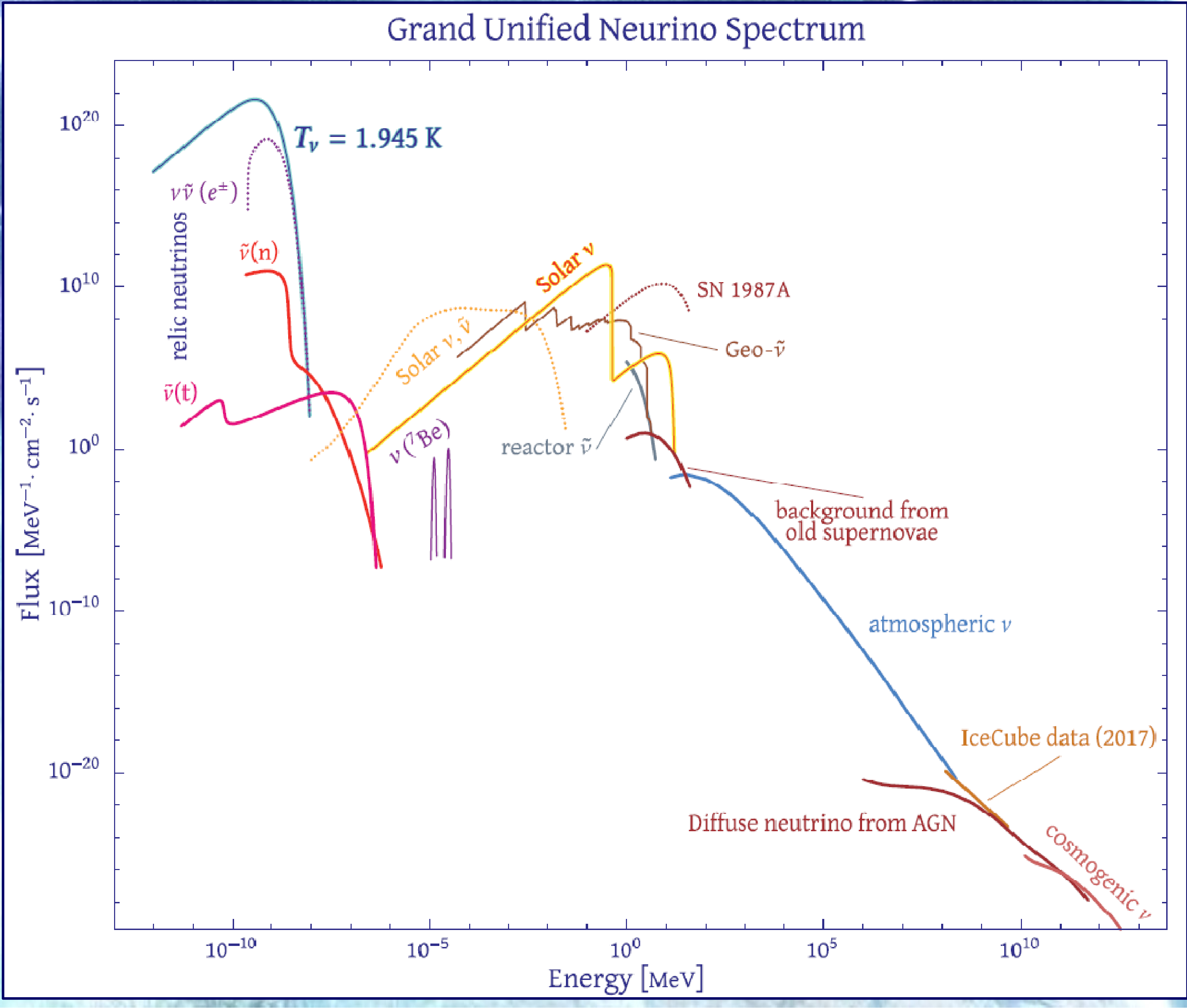
Нетепловые (анти)нейтрино Первичного нуклеосинтеза.



$$\frac{dn_\nu(p)}{dp} = -\int_0^{\tilde{z}(p)} \frac{n(z)}{\tau} f(p(1+z))(1+z)^{-2}\frac{dt}{dz}dz$$

CMB и CvB и их искажения, что о чем говорит ???

Комплексный спектр нейтрино



PHYSICAL REVIEW D

covering particles, fields, gravitation, and cosmology

research highlights

FLUID DYNAMICS

Flight of the dandelion

Nature https://doi.org/10.1038/s41586-018-0604-2 (2018)

Credit: Brian Jackson/Alamy Stock Photo

Weed though it may be, the common dandelion is savvy when it comes to dispersing its seeds (pictured). Once separated from the head, the seeds remain airborne with the help of a bundle of drag-enhancing bristles known as a pappus. This structure itself isn't an obvious bet for enabling the formidable distances the seeds cover: other species adopt wing-like structures in dispersal. But now, Cathal Cummins and colleagues have found that the bristly pappus induces a vortex of recirculating fluid that offers the requisite lift.

By visualizing the flow around the seeds, Cummins et al. found that for low Reynolds number, neighbouring bristles interact strongly due to the boundary layer around each filament. This in turn reduces airflow through the pappus, conferring a high drag coefficient. The team showed that a structure with a similar porosity could reproduce this flow behaviour, suggesting that pappus porosity is tuned to simultaneously stabilize the vortex and optimize aerodynamic loading. *AK*

https://doi.org/10.1038/s41567-018-0350-2

ACADEMIC CAREERS

On the move

J. R. Soc. Interface **15**, 20180580 (2018)

Changing countries seems to be an unspoken rule for making a career in academia — but what is the actual impact of academic mobility? Alexander M. Petersen looked into this question by analysing the publication record of 26,170 physicists between 1980 and 2009.

Each physicist who relocated in that period of time — roughly 60% of the total — was paired with a non-mobile colleague who had a similar output prior to the move. On average, the comparison between these pairs showed that in the ten years after their move, researchers tend to accrue up to 17% more citations than their immobile counterparts. Additionally, the data revealed the crucial role of mobility in rewiring the global collaboration network, as moves lead to curtailing of old collaborations and the creation of new ones. This positive effect applies at all academic levels, and is not only to the benefit of the elite — making a case for better support of international travel for young researchers. *FL*

https://doi.org/10.1038/s41567-018-0351-1

FREE-ELECTRON LASERS

The fast and the luminous

Nat. Commun. **9**, 4025 (2018)

Serial femtosecond crystallography with ultra intense X ray pulses is one of the most promising analytical methods provided by large scale free electron lasers. The microsecond interpulse separation afforded by the recently launched European X-ray Free-Electron Laser was anticipated to offer new opportunities by reducing the beamtime and sample volumes required — but its viability was not clear. Now, Anton Barty and colleagues have realized a setup capable of efficiently collecting high-quality diffraction patterns from small sample volumes.

Barty et al. exploited a custom-made version of a rapid full-frame detector and devised a novel high-speed jet to deliver and replenish the irradiated sample volume in the focal spot. They collected diffraction data from two different samples to benchmark their experiment at ångström resolution, demonstrating the ability to amass data from any member of the available megahertz X-ray pulse train. The unique method provides a key step toward future investigations of the temporal evolution of complex molecular structures. *JPK*

https://doi.org/10.1038/s41567-018-0352-0

QUANTUM METROLOGY

Be no exception

Nat. Commun. https://doi.org/10.1038/s41467-018-06477-7 (2018)

Dispersive measurement is the central idea behind modern sensor devices: the presence of a perturbation changes the original resonant frequency of the electromagnetic mode, which can be detected at very high precision. Recent investigations have suggested that the sensitivity could be further improved in a non-Hermitian system, making use of spectral degeneracies known as exceptional points. Now Hoi-Kwan Lau and Aashish Clerk have identified the fundamental limit of this approach.

For a system to be non-Hermitian, coupling with an external reservoir is an essential ingredient. The dissipative dynamics is inevitably accompanied by noise, which was neglected in previous studies. By mapping the non-Hermitian sensing set-up to an open quantum system, Lau et al. were able to fully account for the noise effect, and derive the limit that constrains sensing protocols based on non-Hermitian Hamiltonians. Within their model, the improvement arising from exceptional points can be achieved by simply adding gain to conventional set-up without any such points in the system. *YL*

https://doi.org/10.1038/s41567-018-0354-y

ASTROPARTICLE PHYSICS

Greetings from the past Universe

Phys. Rev. D **98**, 081301(R) (2018)

When the Universe was still in its infancy, nuclei such as helium or hydrogen isotopes began to form. Our current knowledge about this process — the so-called primordial nucleosynthesis — is limited, as the scattering off this particle 'soup' meant that the Universe was opaque to electromagnetic radiation. By comparing theoretical predictions with the measured abundance of the nuclei created, we can challenge our understanding of the early Universe. But are there no other ways to look back into the past?

Alexandre Ivanchik and Vlad Yurchenko think that we might be able to learn something from the contribution of neutron and tritium nuclear decays to the neutrino cosmic microwave background. They have predicted that these decays are the only source contributing to the spectrum for antineutrinos within a certain energy range. And as the neutrino cosmic microwave background was formed prior to the nucleosynthesis, an experimental observation of these antineutrinos would allow us to witness the creation of the first heavier elements. *SR*

https://doi.org/10.1038/s41567-018-0353-z

Abigail Klopper, Jan Philip Kraack, Federico Levi, Yun Li and Stefanie Reichert

nature physics

Research Highlight | Published: 01 November 2018

ASTROPARTICLE PHYSICS

Greetings from the past Universe

Stefanie Reichert

Nature Physics **14**, 1071 (2018) | Download Citation

Phys. Rev. D **98**, 081301(R) (2018)

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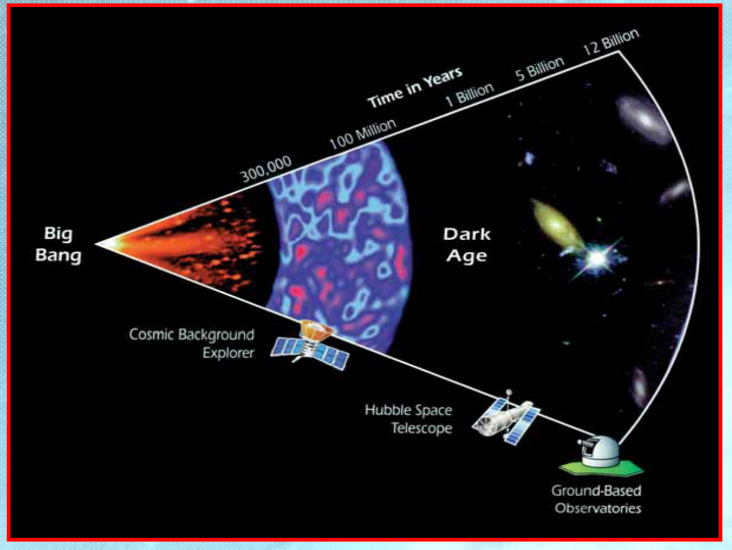
Способы получения информации в современной Астрономии



1. Практически весь спектр эм волн – радиоволны – гамма-излучение (400 тыс. лет после Большого Взрыва)

2. Космические лучи (до 10^{21} эВ)

3. Нейтринная астрономия (до 10^{15} эВ) (первые секунды, минуты, часы после Большого Взрыва)

4. Гравитационные волны (10^{-16} с после БВ и, возможно, до Большого взрыва)

Дальнейшие перспективы развития нейтринофизики

Галактическая и Внегалактическая нейтринная астрофизика, развитие нейтринных телескопов – дальнейший набор статистики, увеличение объема детекторов …

Космологические нейтрино – некоторые знаменитые физики, выразили уверенность, что детекторы для CνB не появятся в нынешнем столетии …

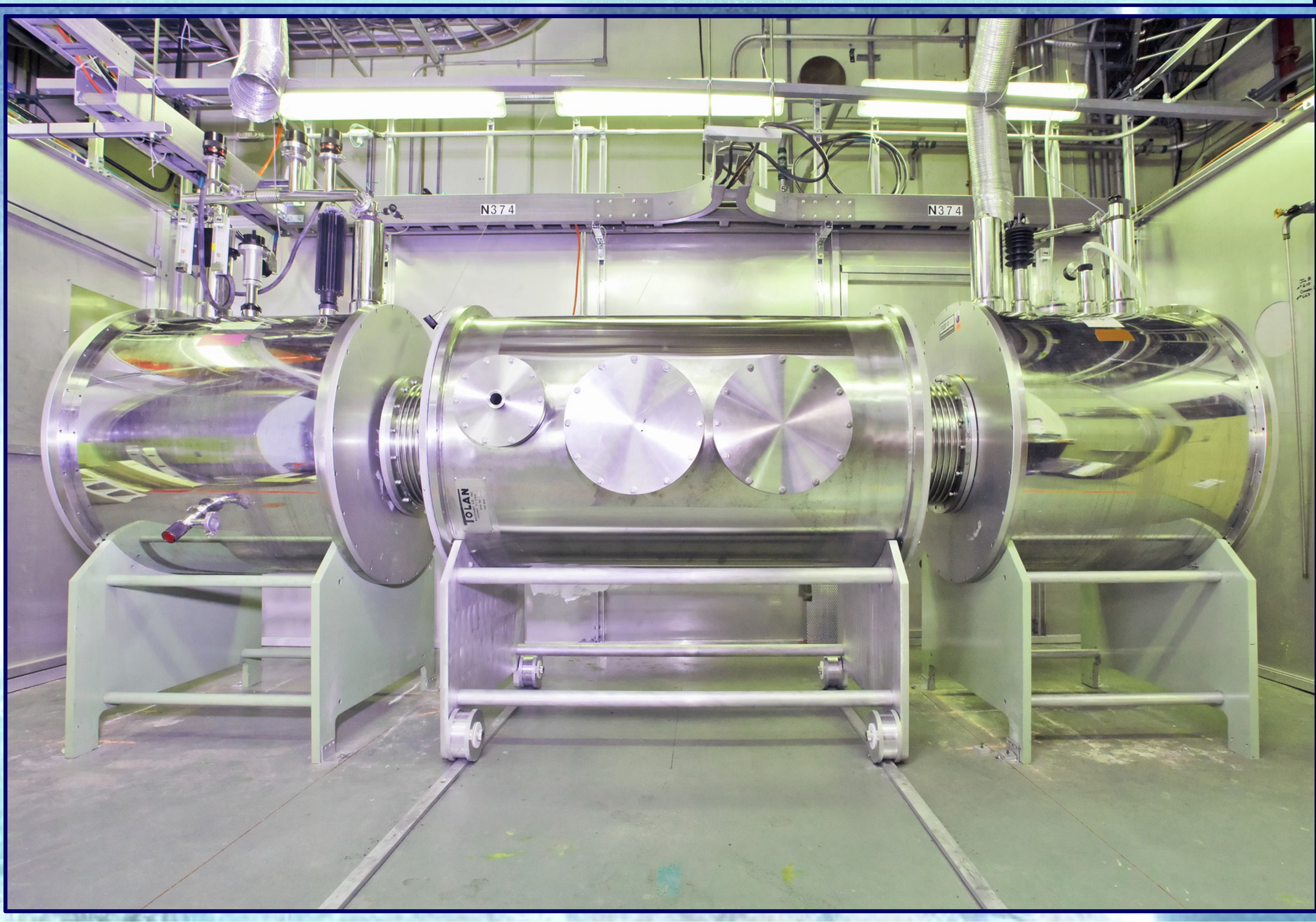
… это оптимистичнее, чем "никогда" … но вспомним опыт Паули …

В 1962 Вайнберг предложил использовать $\nu_e + \mathrm{T} \longrightarrow {}^3\mathrm{He} + e^-$
и сейчас несколько независимых групп работают над проектами по регистрации CνB …

…

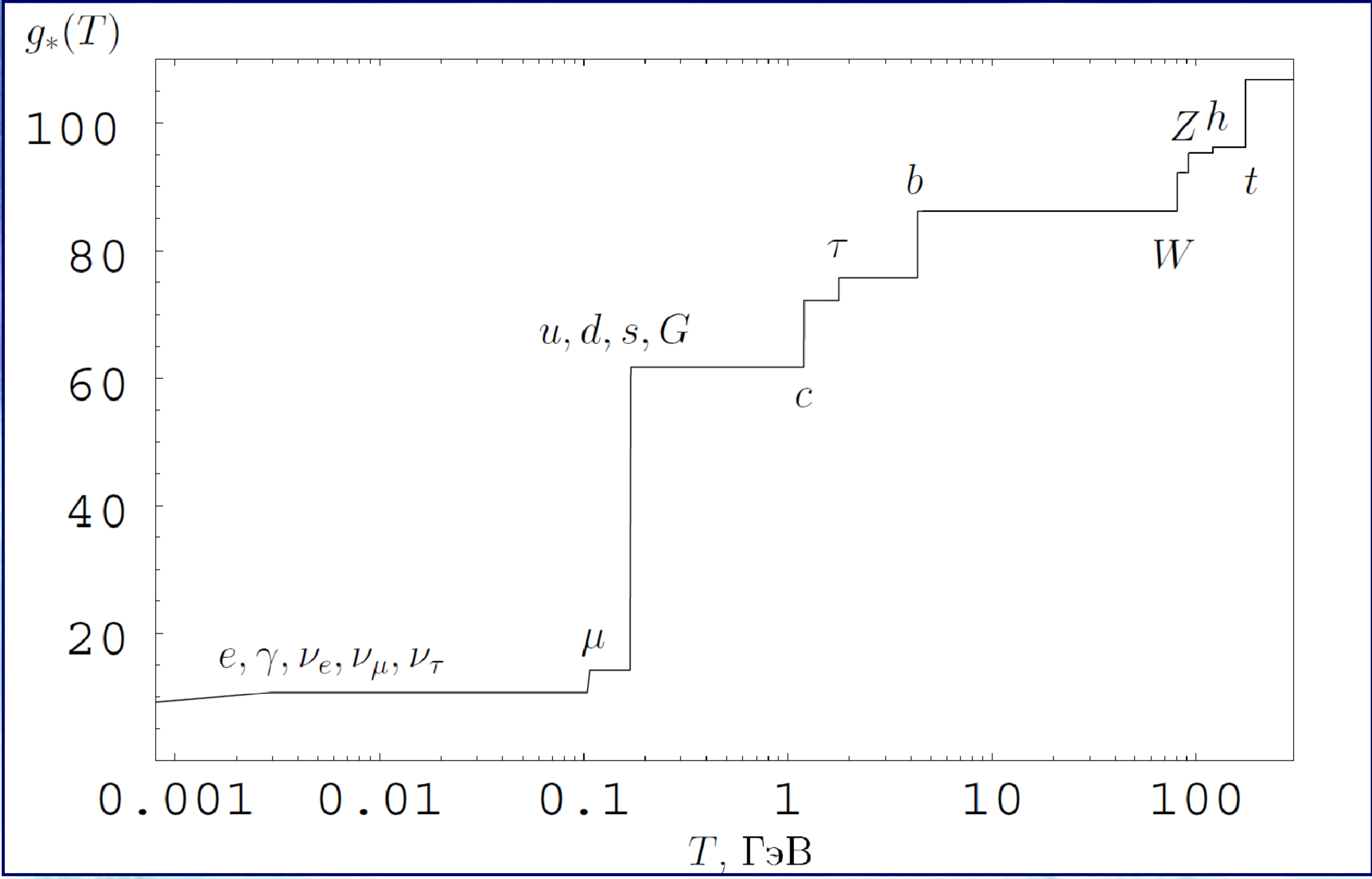
Проект *PTOLEMY*

(Princeton Tritium Observatory for Light, Early-Universe, Massive-Neutrino Yield)



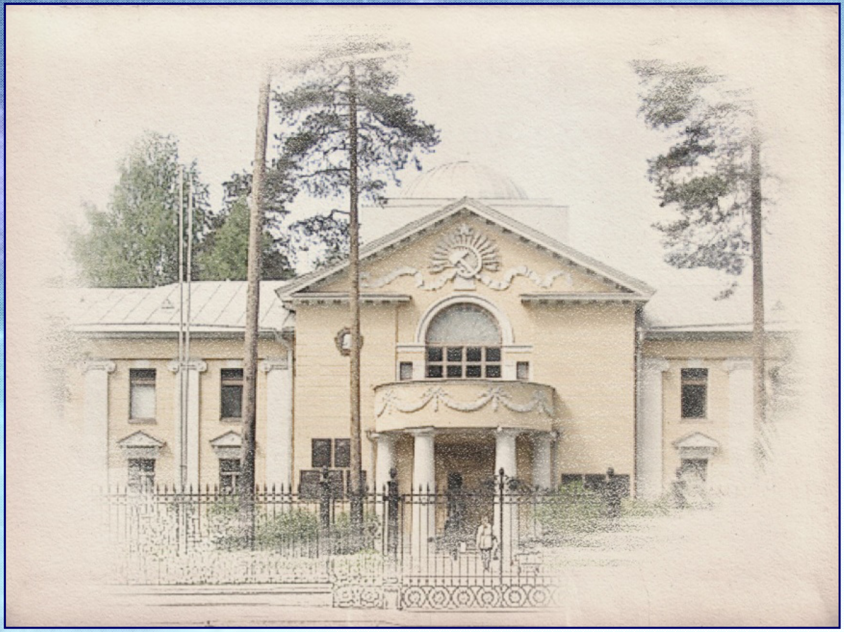
Благодарю за внимание ☺

История до и после Первичного нуклеосинтеза



$$\mathcal{N} = 2_\gamma + \frac{7}{8} \cdot 3 \cdot 2_\nu \cdot \left(\frac{4}{11}\right)^{4/3}$$

Физико-технический институт
Российской академии наук

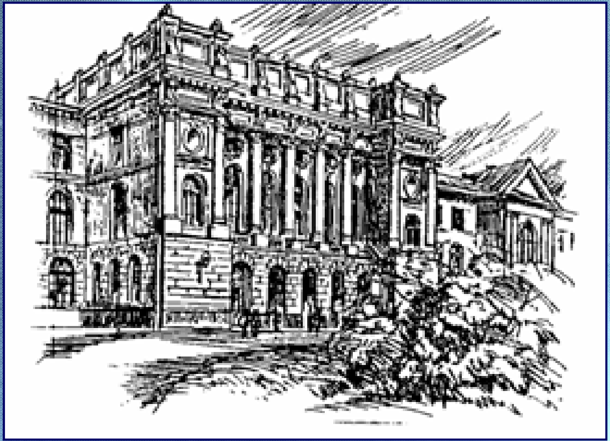


Сектор теоретической астрофизики

Лаборатория
Экспериментальной астрофизики

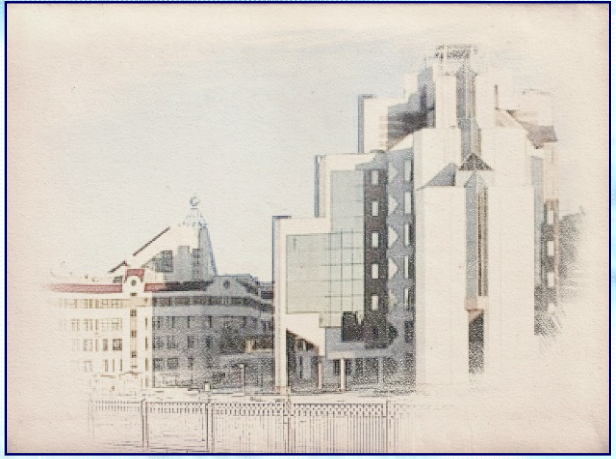
Лаборатория
Астрофизики Высоких Энергий

Санкт-Петербургский государственный политехнический университет



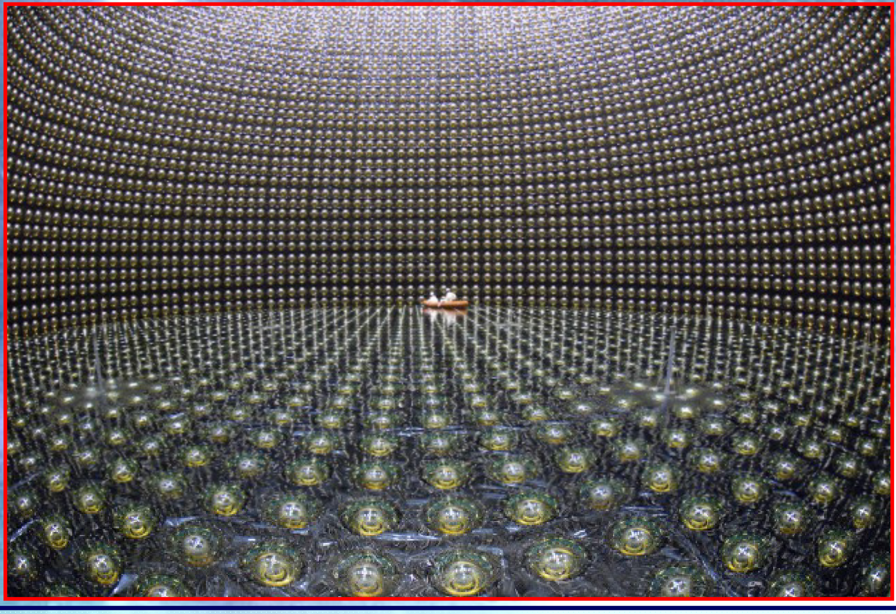
«Космические исследования»
«Теоретическая физика»

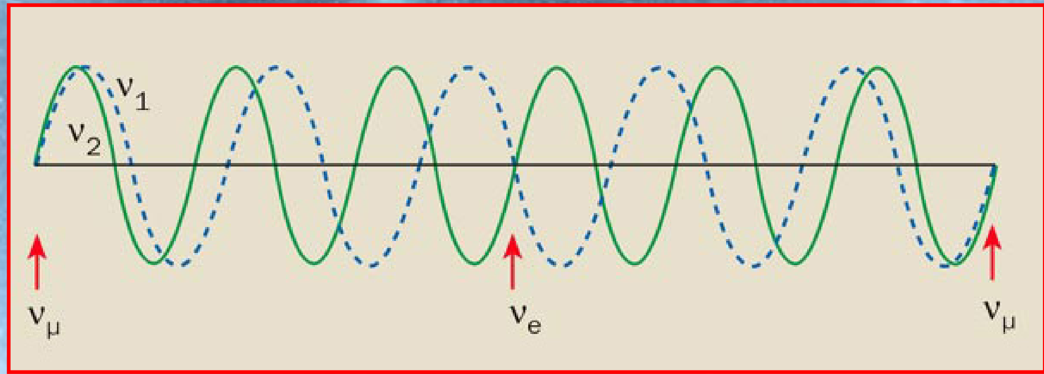
Академический Университет



Кафедра
«Астрофизики»

Эффект Михеева-Смирнова-Вольфенштейна



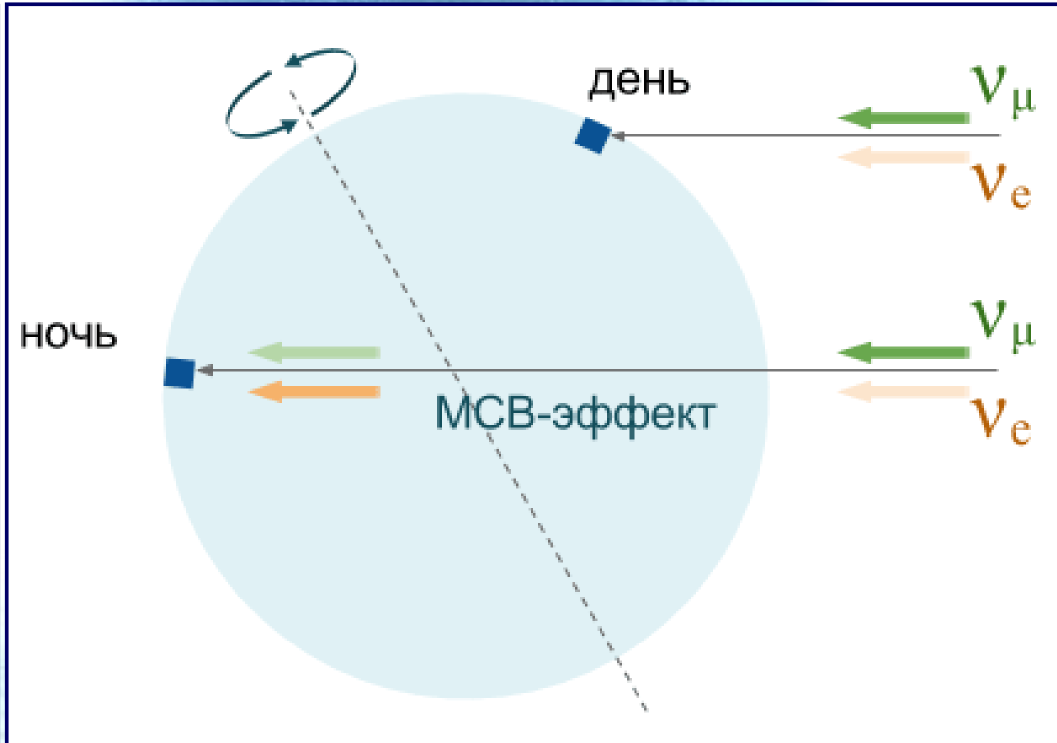


(косвенное подтверждение для Солнца)

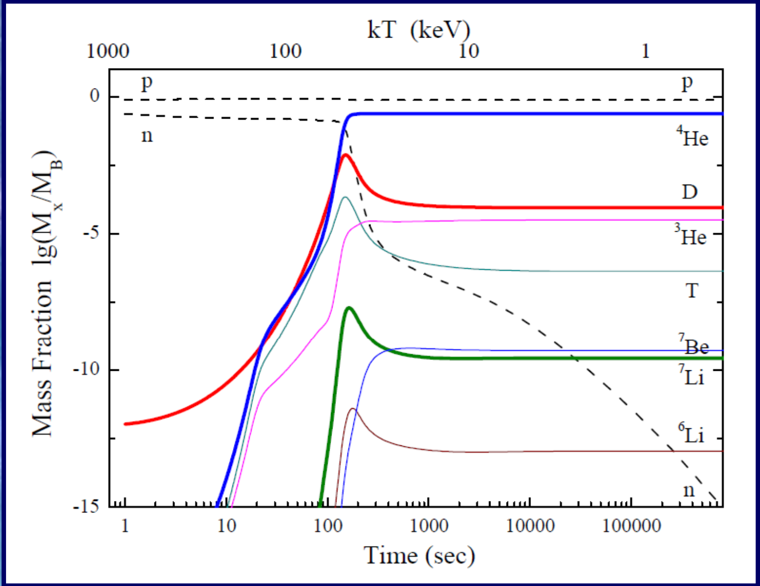
Super-Kamiokande
2014 г.

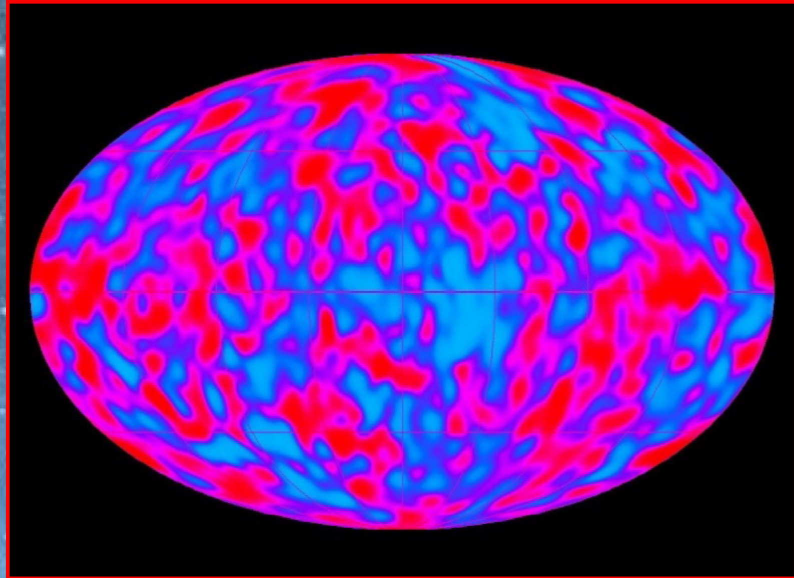
(3,2 ± 1,1 ± 0,5)%

(данные за 18 лет)



Химический состав Вселенной

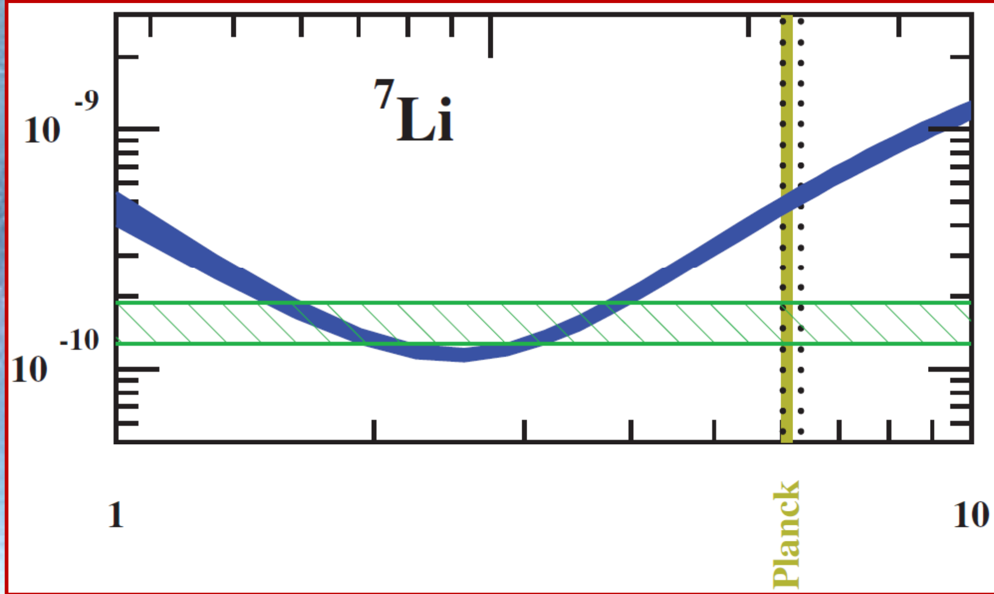




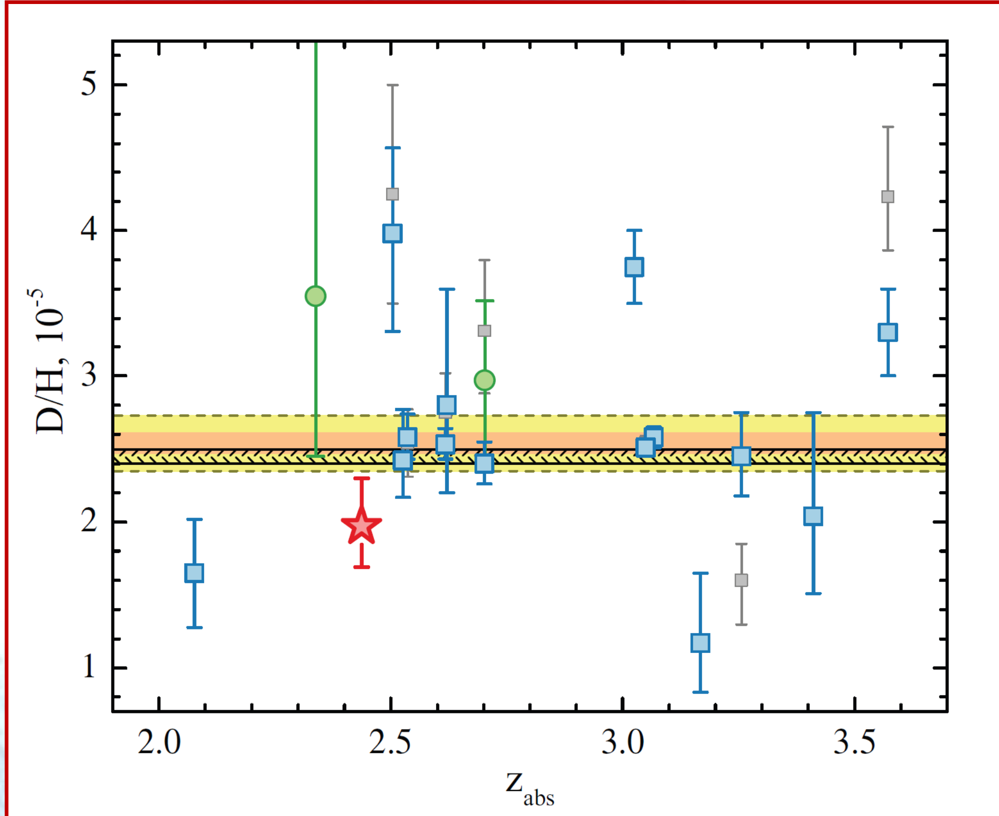
Элемент	Предсказываемое значение	Наблюдаемое значение
^{4}He	0.2471 ± 0.0003 (0.1%)	0.2551 ± 0.0022 (0.9%) 0.2449 ± 0.0040 (1.6%) 0.251 ± 0.014 (5.6%)
D	$(2.58 \pm 0.13) \cdot 10^{-5}$ (5.0%)	$(2.53 \pm 0.04) \cdot 10^{-5}$ (1.6%) $(2.48 \pm 0.13) \cdot 10^{-5}$ (5.2%) $(3.26 \pm 0.29) \cdot 10^{-5}$ (8.9%)
^{7}Li	$(4.68 \pm 0.67) \cdot 10^{-10}$ (14%)	$(1.58^{+0.34}_{-0.28}) \cdot 10^{-10}$ (22%)

(4.79 ± 0,10)% (4.84 ± 0,05)%

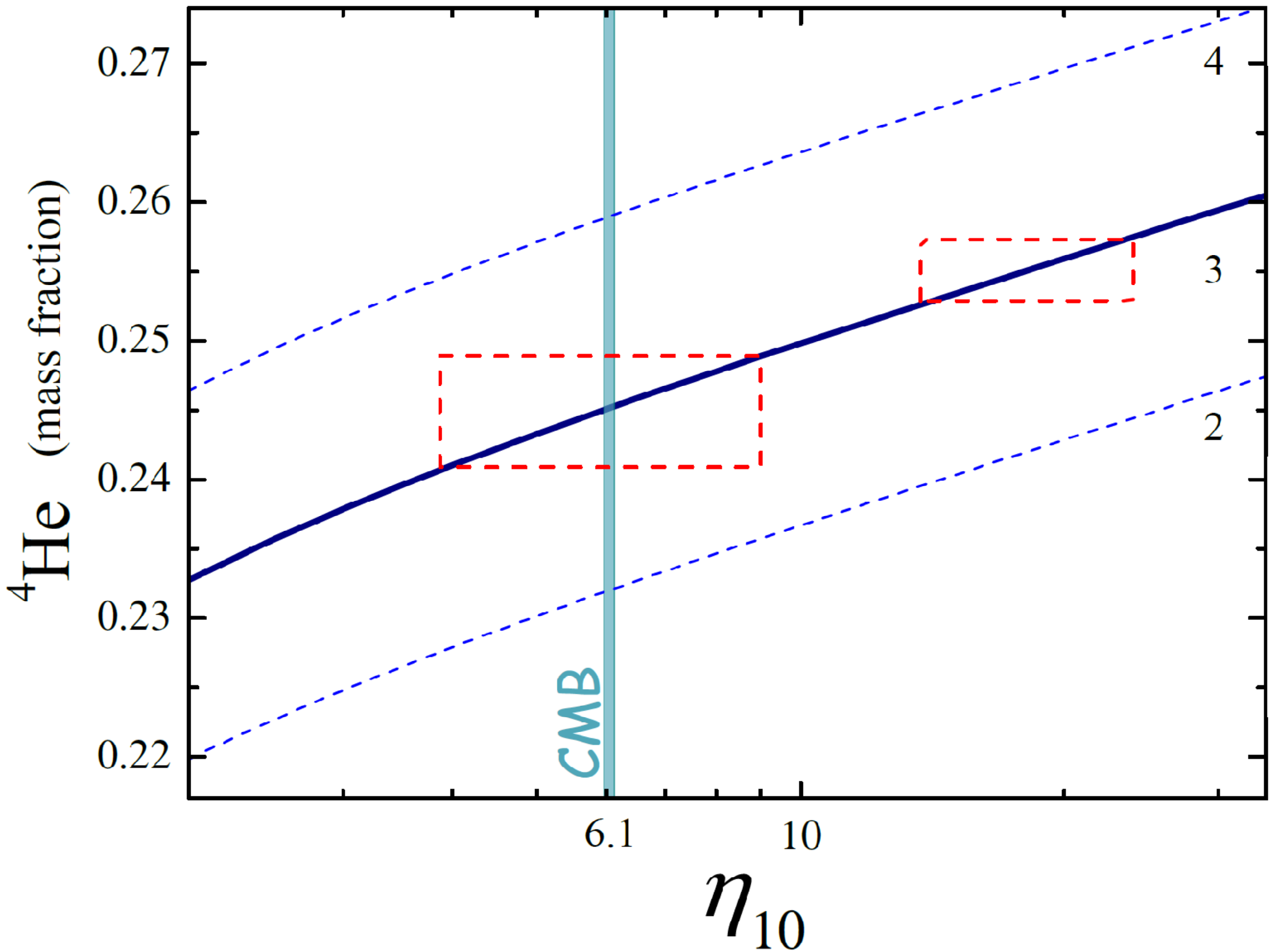
«Литиевая проблема»



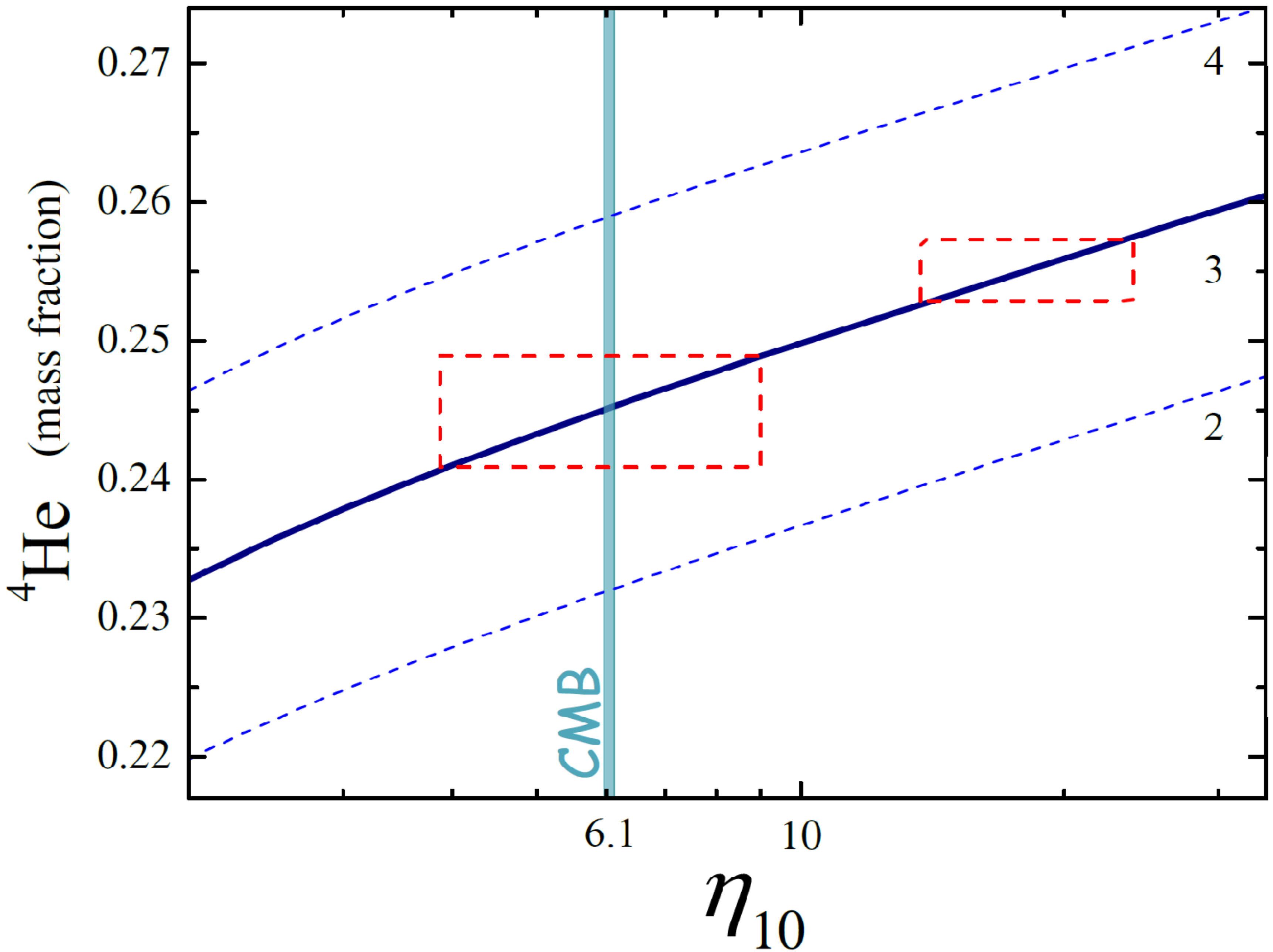
«Дейтеривая проблема»



Гелиевая проблема



Гелиевая проблема



Пути решения указанных проблем:

1. (Самое простое) Завышение точности, не учёт систематических ошибок.

2. При достигнутой точности возникает необходимость учета большего числа параметров и различных тонких эффектов, которыми ранее пренебрегали.

3. Возможность проявления физики за рамками "стандартной модели"