2012 ... 2013 ... IceCube, ... 1973 ... 2013 ... IceCube ... ANTARES, ...

PACS numbers: 13.15.+g, 95.55.Vj, 98.70.Vc DOI: 10.3367/UFNr.0184.201405e.0510

1.

2012 ... 100 ...

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28 ... 2014 г.

IceCube ...

[illegible] 0,1 [illegible]^3. [illegible] 2004 [illegible] [28]. [illegible] [29].

[illegible] ANTARES (Astronomy with a Neutrino Telescope and Abyss Enviromental Research). [illegible] 1990- [illegible] [30] [illegible] 1999 [illegible] ANTARES [illegible] 12 [illegible] 25 [illegible] 0,01 [illegible]^3 [illegible] AMANDA. [illegible] ANTARES, [illegible] 2002 [illegible] 2008 [illegible] [31].

[illegible] NEMO (NEutrino Mediterranean Observatory) [32], [illegible] 1998 [illegible] 1 [illegible]^3, [illegible] 3,5 [illegible] 100 [illegible] [33]. [illegible] 2016 [illegible] KM3NeT (Cubic Kilometer Neutrino Telescope) ([illegible] 6).

4.4. [illegible] IceCube

[illegible] IceCube [34, 35] [illegible] 5160 [illegible] 86 [illegible] 1450 [illegible] 2450 [illegible] 60 [illegible] 10- [illegible] 320 [illegible] IceTop [illegible] 1^). [illegible] AMANDA, [illegible] IceCube, [illegible] 2009 [illegible] DeepCore, [illegible] IceCube. [illegible] DeepCore [illegible] IceCube. [illegible] IceCube [illegible] 10 [illegible] IceCube [illegible] 2005 [illegible] (NSF) [36]. [illegible]

[illegible] 8, 13, 18, 19, 20 [illegible] 7 [illegible] 86 [illegible] 18 [illegible] 2010 [illegible]!

5. [illegible]

[illegible] IceCube [illegible] ≈ 10 [illegible] IceCube, [illegible] (IceTop). [illegible] IceCube [37] [illegible] ANTARES [38], [illegible]-200 [illegible] [39, 40].

5.1. [illegible]

[illegible] 100 [illegible] $E^{-3,7}$ [illegible] $E^{-2,7}$. [illegible] 4 [illegible] 200 [illegible] (ANTARES [41]) [illegible] 400 [illegible] (IceCube-40[1] [42]) [illegible]

[1] IceCube-40 [illegible] IceCube 40 [illegible]

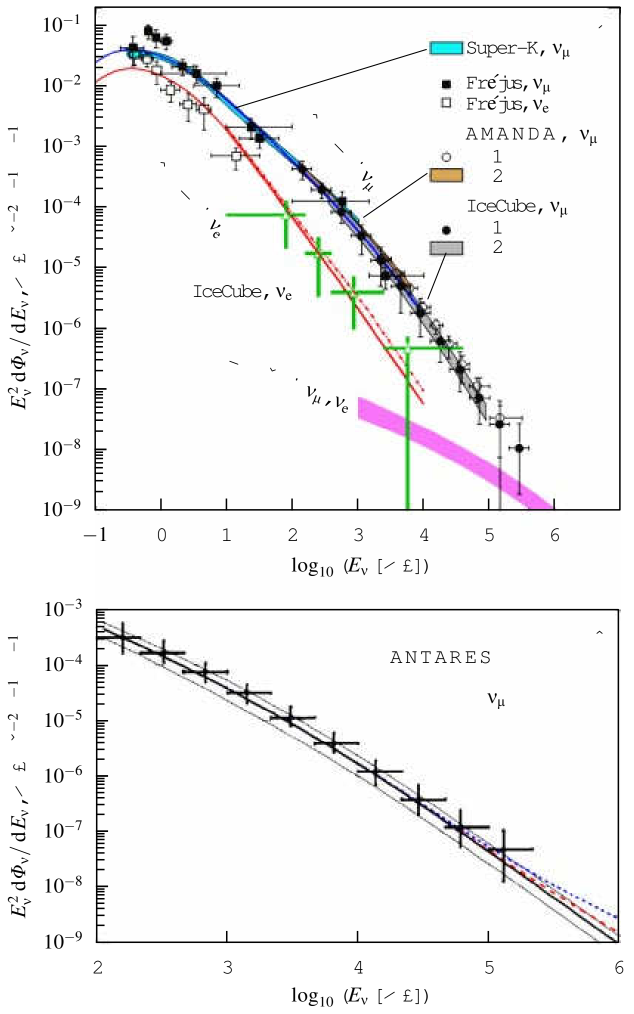


Fig. 4. IceCube-40, [42]. 1 2 ANTARES.

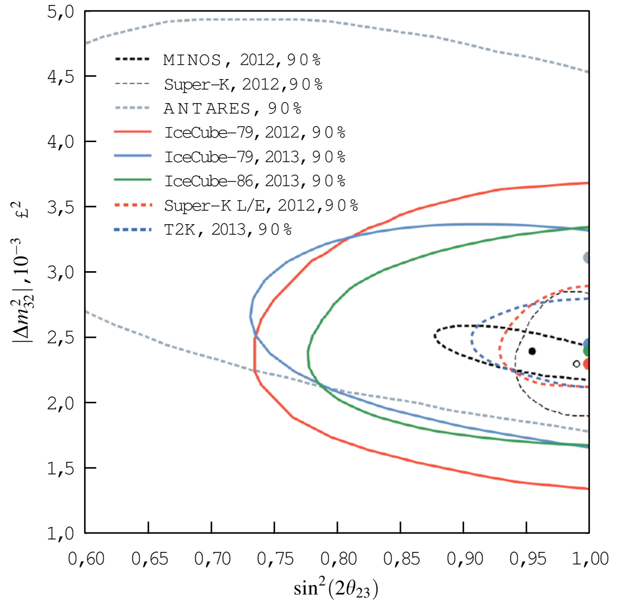


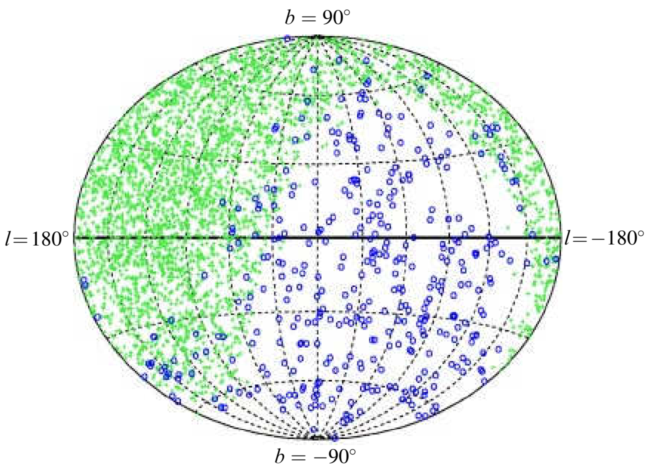
Fig. 5. IceCube IceCube-79 IceCube-86 ( ). ANTARES ( ) MINOS, Super-K, T2K 2013 IceCube. [43].)

IceCube 79 86 100 . dE/dx 10

ν_τ ν_e IceCube E_ν $E_\nu \approx 24$ ν_μ θ_{23} Δm_{23}^2 5 ANTARES IceCube/DeepCore [43]. DeepCore ANTARES MINOS (Main Injector Neutrino Oscillation Search), Super-K, T2K (Tokai to Kamioka) DeepCore IceCube (PINGU (Precision IceCube Next Generation Upgrade)) 6). 2013 5.4.

‡ ˘ ˉ – , –˙ ˇ˙–˙ ˙ ˚–´ ¸ ˙ ˛ – ˘ ˜ ˛ ˙ Super-K Æ

5.2. ﬂ˙ ‹ ("), ( ) Æ Æ Æ– Æ ¿ Æ

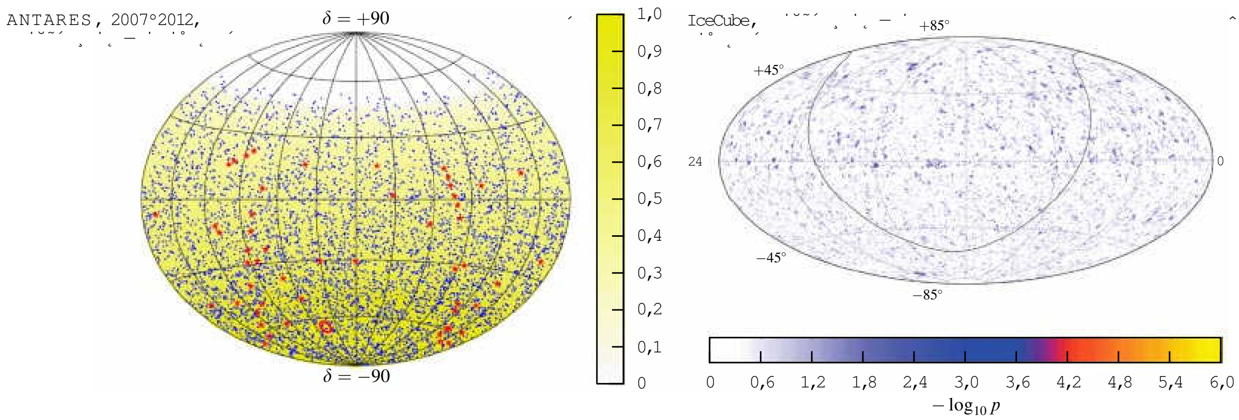


†¸ . 6. (£ ˜˙ ˙ –¸´ –.) ‡ AMANDA fl·-200 (˝ ˘ – ˜˝´ 2005 ˉ.).

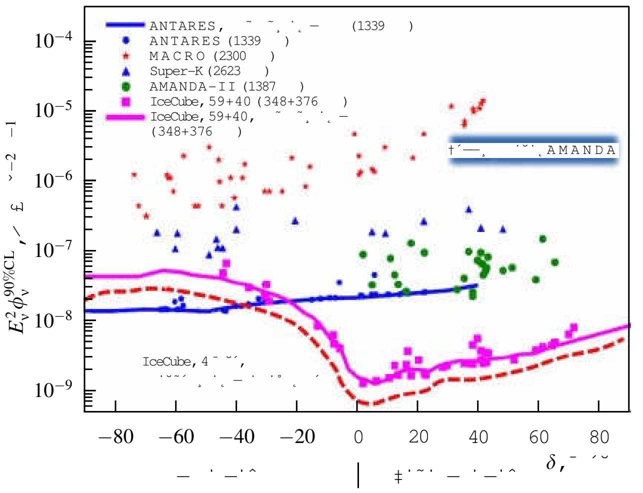
¿˜ ¸Æ ¸Æ AMANDA ¸ IceCube . 3 ¸˚ [44]. £ 17 1999 ˉ. 10[4] 2012 ˉ. 1000–˝ (˘. –¸ . 8)! ﬂ´ 6 2005 ˉ. AMANDA ¸ ﬂ·-200

‡ ANTARES Æ IceCube ( ). ﬂ´ 7 ANTARES ¸ IceCube [38, 45].

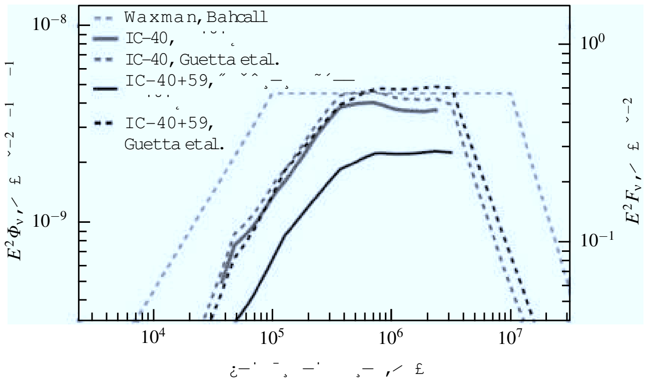
¥ ANTARES Æ ‡ Æ ﬂ´ IceCube Æ Æ Æ Æ 1 – £ . ﬂ´ 8 ‡ AMANDA (˝ 10) IceCube 1000 ´˚! ƒ IceCube E^{-2} E^{-2} ¸˚ ‡ Æ Æ ANTARES, 45°. ¿



†¸ . 7. (£ ˜˙ ˙ –¸´ –.) ﬂ˙ˆ˙ – ˙ ˝´ (´) ANTARES ( ) ¸ (ˆ) IceCube (ANTARES ¸˚ 40, 59, 79 ¸ 86 ˉ¸ ¸ [45]). ANTARES, Æ



8. 90%) Super-Kamiokande, AMANDA, IceCube ANTARES [2]).



9. IceCube (Guetta et al. [47]) (Waxmann, Bahcall [46]). [48].)

IceCube ANTARES $3\cdot10$ IceCube.

5.3.

[46]. (fireball model) [46, 47]. IceCube, ANTARES [48] IceCube, 215 [47] 5,2 (. 9). 90% 3,7

[49]. IceCube. ≈ 300 ANTARES 296 [50] 2007–2011 296 IceCube, 30 IceCube, ANTARES.

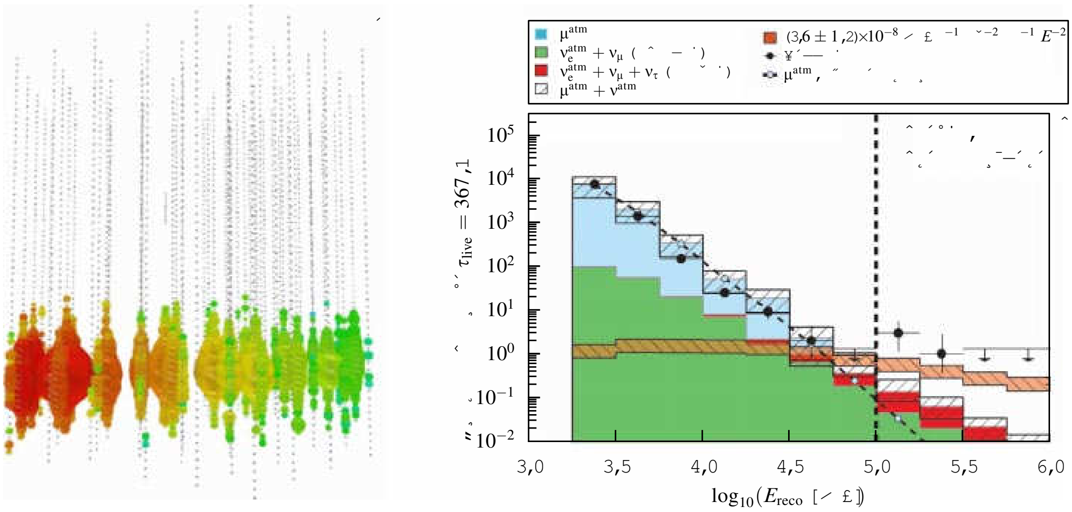
5.4.

[51]

1)

2)

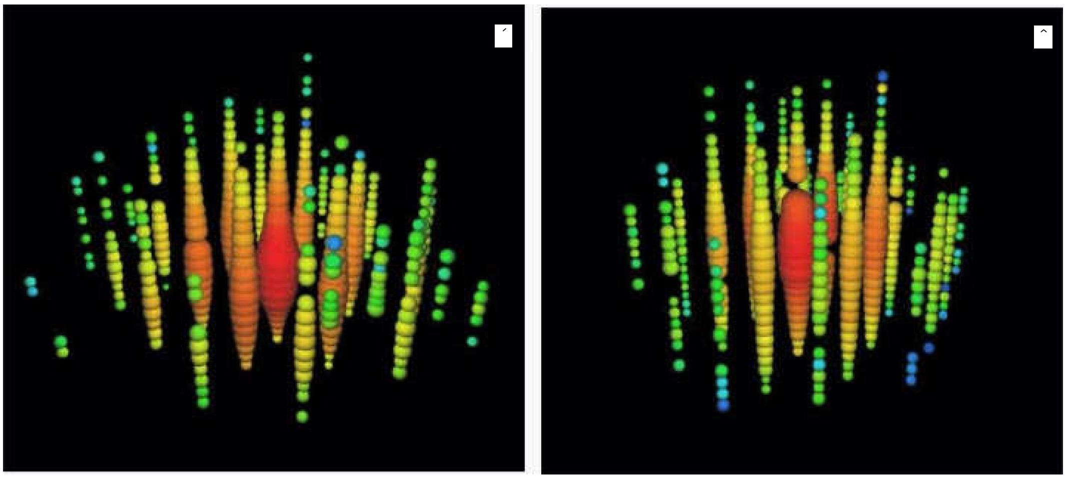
3)



†¸ . 10. (£ ... IceCube-59 ... 400 · £, ... 500 · £ ° 1 – £ [55]. (ˆ) £ ... IC-40 [56]. ¢ ... ¥ ...).

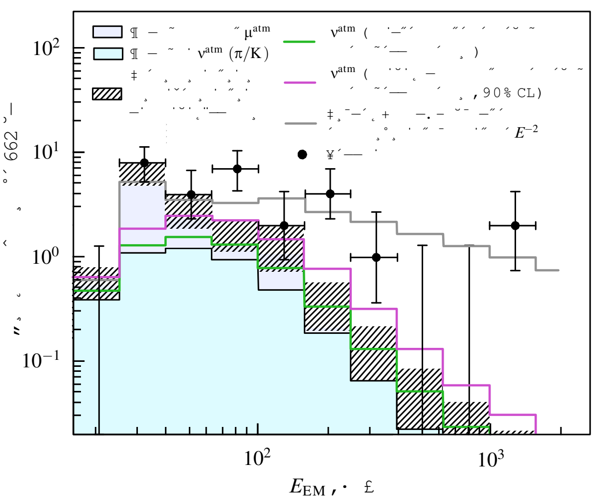
... [52]. ... Æ ... ó ... £ [53] ... Æ ... ‡ ... Æ ... IceCube. ... 2012 ... IceCube-59 ... Æ ... 22000 ... [54]. fl ... 10 ... 1,2°. fiÆ ... 400 · £, ... 0,5 ° 1 – £. ... Æ ... 1,8σ. ... $E^2\Phi < 1{,}4 \times 10^{-8}$ ⁄ £ ˘−2 −1 −1 ... E^2, ... 3,8 ... [57]. ... [55] ... £ ... 2011 ... IceCube-40.

¿ ... Æ ... (140 ° 220 · £) ... [56]. ¿ ... 10ˆ. ... 2,7σ ... 0,25 ... fi ... IceCube-59 ... [58]. ... £ ... [59], ... (⁄ ' ‹) ... [60]. † ... ≈ 500 · £. ¥ ... 2010 ¸ 2011 ... 79 ¸ 86 ... ¥ ... 1,04 ¸ 1,14 – £, ... Ernie ¸ Bert (¸ . 11). ¿ ... Æ 2,8σ ... Ernie ¸ Bert ... ⁄ ' ‹ –



11. 2011 (Ernie) 2012 (Bert).

10 % 1,2 IceCube ( ) 14 2013 [61]. 28 ≈ 30 1,14

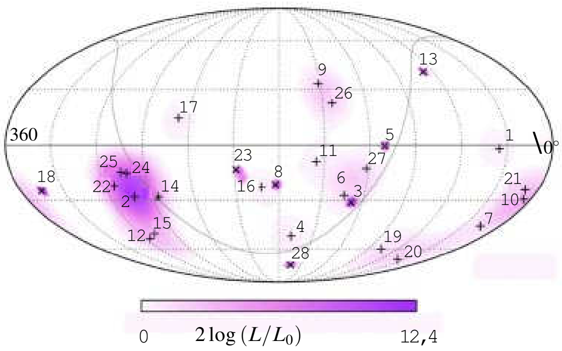


12. 28 (E_{EM}) [61].

12 Ernie Bert (≈ 30 250) 28 $10{,}6^{+5{,}0}_{-3{,}6}$ $4{,}1\sigma$. E^{-2} $E^2\Phi = (1{,}2 \pm 0{,}4) \times 10^{-8}$ $^{-2}$ $^{-1}$ $^{-1}$. 1 1 E^{-2}, $E^{-2{,}2}$. 40 59 59 79/86 [52].

$E^{-2}\exp(E/E_{cut})$. 28 : $E^2\Phi = (1{,}0^{+0{,}8}_{-0{,}5})\times$ $\times 10^{-8}$ $^{-2}$ $^{-1}$ $^{-1}$, E_{cut} 1 6 Φ_{prompt} (2,8 ± 2,0) [57].

13 28 2012 2013 50 [62, 63].



13. (… 28 … 14) … 8%, …

… [64], …

… [52]. … IceCube, …

… 21:7 … 1:1:1.

… (BigBird) … 10% … IceCube-86, … IceCube-59, … 2012 … 400 … 10). … IceCube-79 … IceCube-86, … 2014 … IceCube-40 … IceCube-59 … IceCube.

6.

… IceCube … 1000 … 1990- … IceCube …

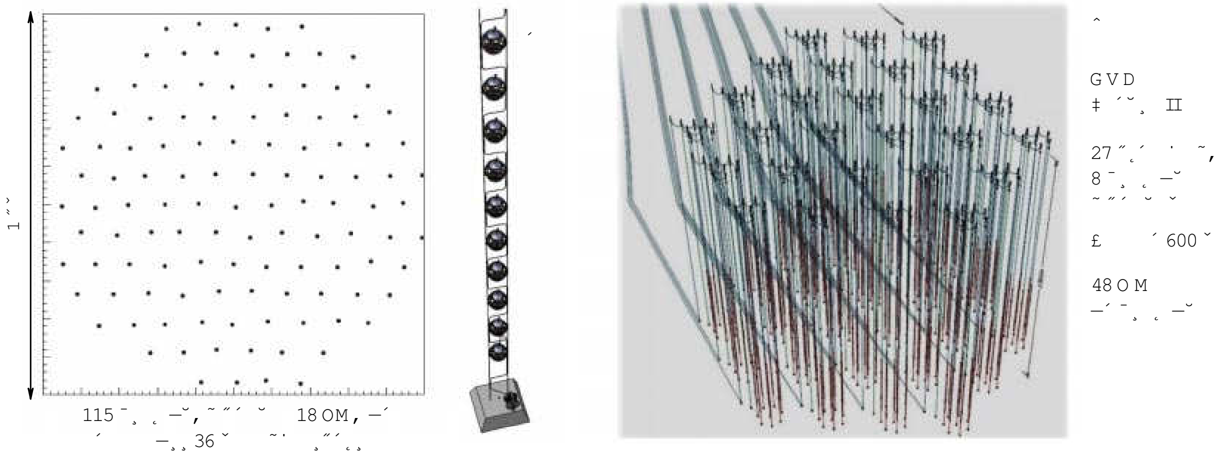
… 1 $км^3$ …

… IceCube, … (… IceCube) …

KM3NeT … GVD (Gigaton Volume Detector, …)

KM3NeT, … 14 … [65]), … KM3NeT … ≈ 5 $км^3$ … 2014 … 225 … 40 …

(KM3NeT, … 1). … KM3NeT, … 1,5, … 1 $км^3$, … IceCube. … 50 ° 70 … 40 …

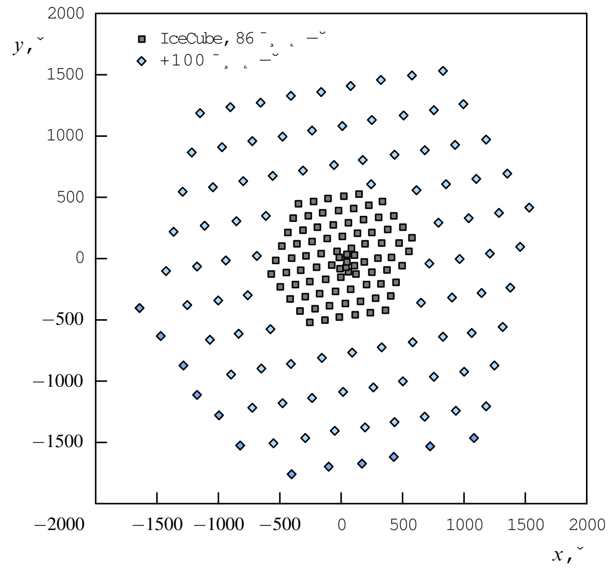


†¸ . 14. (´) £¸˘ ˜· ˘– ¯ ¸˚ · ¸ ·˘ ˛´¯´·˘ ˆ˛ ˝ ˜ KM3NeT. (ˆ) ¿ ˝¸˚– ·¸˚ ˆ ´ ·–¸·˜ ·–¸GVD ˆ ¸˘ ˆ "˘ ˘ ˝ ˛ 1,5 ˝ˇ³.

£ † ¸¸ ¢´ ˝´˛ ˝´ ˝ ˛˛ˆ ´ ´– ¸ ˛´–¸ · – ´ – · ´˚~" ~´–¸·–´ ¢ ˝´ · –´ —– ˘· ·˝– ´ GVD ˝¸˛ ˘· ~ – ˘´ ´ˆ´ [66], ·– ˚ [illegible] 0,5 ˝ˇ³ [illegible] ˆ ˆо˛ ¸ ˘ ˆ "˘ ˘ (¸ . 14ˆ). £ 2008 ° 2013 ¯¯. [illegible] ‹ – · – [67].

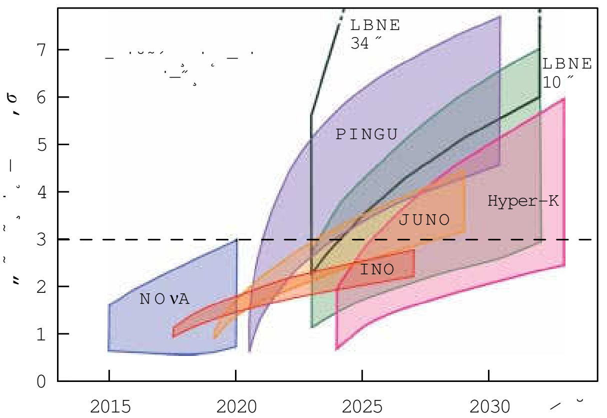
¡ –´ – ˘ ˛Æ ˙? £ [illegible] IceCube [illegible] DecaCube). †˙˚ [illegible] [68]. [illegible] ˚100 [illegible] IceCube, ˝´˚´–´ –´ ¸ . 15. – ¸ ˆ "˘· 7 ˝ˇ³ ¸ –· – [illegible] 10 · £ [illegible] Æ ˝ ˘Æ –– ˘ ·˝´˘ (˝´ ˝´˘´˘) ˜ 3 (7) [illegible] IceCube. ¡–´˛¸˚ [illegible] 5.4, [illegible] 4 ° 8 ´˚ˆ [illegible] IceCube ([illegible]). – [illegible] Æ [illegible] £ [illegible] 50–˝ [illegible] Æ [illegible] IceTop, [illegible] Æ [illegible] IceCube. ·´˝´ [illegible] Æ [illegible] 100 · £.

[illegible] IceCube –´ ˘¸ ·˝ PINGU (˙ ¸˚¸ —´ ˘ ˘·˙– –¸˚´ ¸ IceCube ˛·˘ Æ ˙– ˝ ˛˙–¸) (˘. ¸ ˘



†¸ . 15. £¸˘ ˜· ˜ ˚˘ – ¯ ˝ – ˝ ¸˜– ¯ ˜´ ¸´– ´˘· ·˝ – ´ DecaCube (´ ¸ ·–¸· ˘· ·˝ ´ IceCube –´ ˆ˛´ ˜ ˝¸ –´ ¯¸) 100 ˘ ˛–¸ ·˛ – ˘¸ ¯¸ ˛ –˘´˘, ˛– ˆ "˘ ˝ ˛ 7 ˝ˇ³ [68].

–´˘· ·–¸ ˝ ˛˛´ˆ ´ ¸¸ PINGU ° IceCube [69]). ⁄˛´˜– – ·˛ Æ ·˝ ´ PINGU ˜˛ · [illegible] '·˘˛Æ. – ¸ –· ¯¸ –¸ ˙ 10 ° 15 ⁄ £ [illegible] Æ [illegible] Æ [illegible] Æ PINGU. £ ˆ´˚ ˜ ˜· ¸¸ ˘· ·˝ PINGU – ¸ ¸˚ 40 ˘ –¸ ·˛ – ¯¸ ˛ –ˇ (60 , fi ˜˝´ – ˘), [illegible] DeepCore. ¿–˙ ¯· [illegible] ⁄ £. fl´ ¸ –˝˙ 16 ˝´˚´– ·–˝ [illegible] Æ [illegible] ¡–´˛ [illegible] – ˘ ˝ ¯ ·˝ ´ ORCA (Oscillation Research with Cosmics in Abyss) [71], ˜ ˝ [illegible] ν ¸˛¸ ν̄ ¸˚ ˝ – ¸ ·˛ – ˜¸– –´ ANTARES [72].



†. 16. … [70]. … NOνA (NuMI (Neutrino at the Main Injector) Off-axis electron-neutrino Appearance) LBNE (Long Baseline Neutrino Experiment)), … CP- … δ, … JUNO (Jiangmen Underground Neutrino)) … θ_{23}, … PINGU … [69]; … Æ … [70].

7. …Æ …

… PINGU ORCA … Æ … Æ, … Æ … 100- … Æ … ¢ … 2013 … Æ … 2011 2012 … θ_{13}, 2013 … LBNO (Long-Baseline Neutrino Oscillations)/LBNE, JUNO PINGU/ORCA.

fl … Æ … Æ, … !

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High-energy neutrino astronomy: a glimpse of the Promised Land

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In 2012, physicists and astronomers celebrated the hundredth anniversary of the detection of cosmic rays by Viktor Hess. A year later, in 2013, the first evidence for extraterrestrial high-energy neutrinos emerged, promising fundamental insight into the origin of cosmic rays. The evidence was obtained from the data from the IceCube neutrino telescope at the South Pole. When the idea of this telescope was first discussed at the 1973 International Cosmic Ray Conference, it was beyond anyone's imagination that it would take biblical forty years before the first discoveries would be made and the Promised Land of the high energy neutrino would first be glimpsed. This paper sketches the development towards really sensitive detectors, describes the latest results from the IceCube and ANTARES neutrino telescopes, and takes a look at the future.

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