

IceCube : Een nieuw venster op het Universum

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VRIJE
UNIVERSITEIT
BRUSSEL



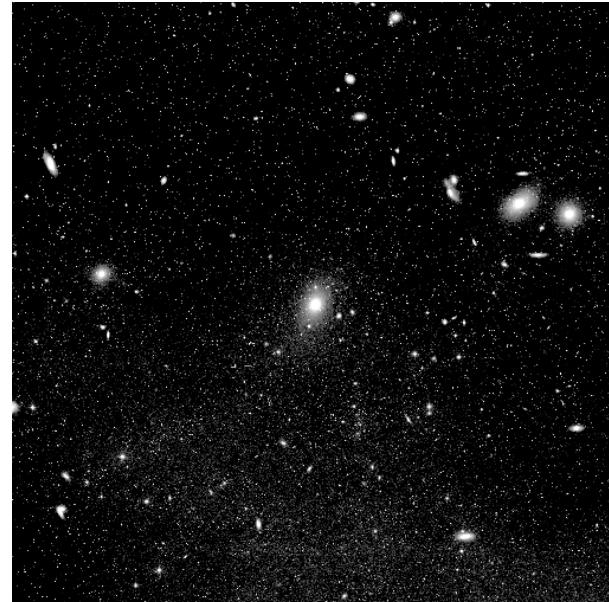
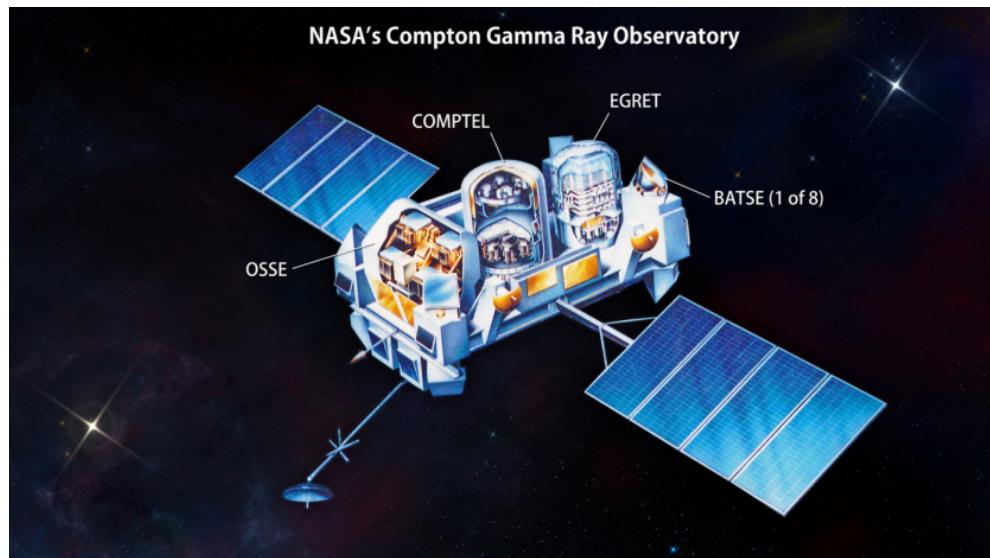
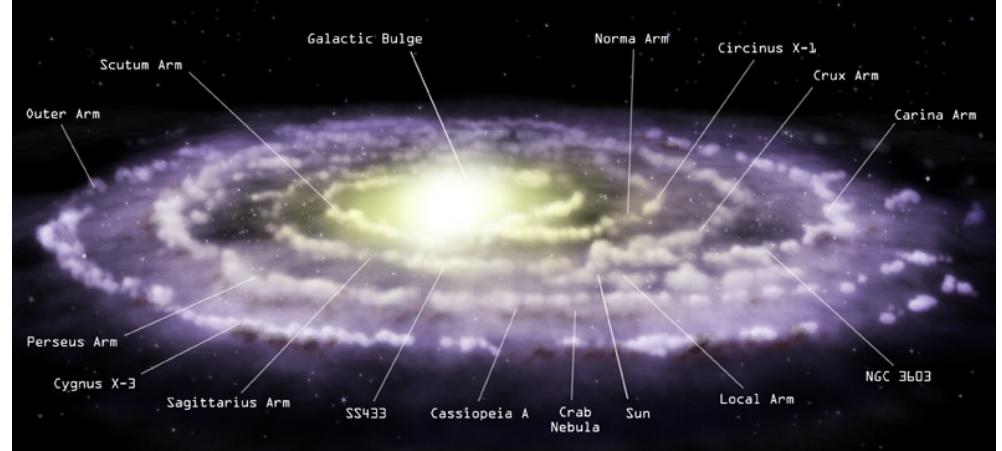
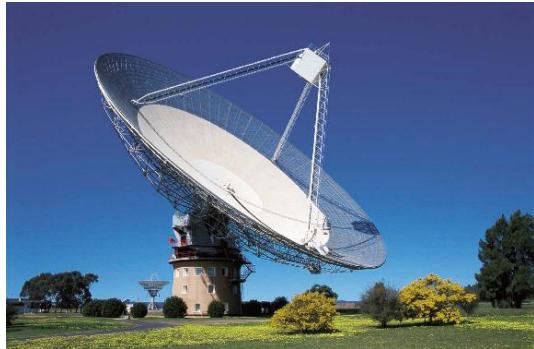
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Overzicht

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Het zichtbare heelal

Electromagnetische straling



Het zichtbare heelal

- Waar komt deze materie vandaan ?



- Waarom zo "klonterig" verdeeld ?

Onderlinge interacties

Mechanica (zwaartekracht)

- Wat laat de sterren stralen ?

Nucleaire processen

Deeltjesfysica

- Emissie- en absorptielijnen ?

Atoomstructuur

Quantumfysica

- Observatie verschoven spectraallijnen

Uitdijend Heelal

Kosmologisch model

Het onzichtbare heelal

La physique des particules étudie la matière dans ses dimensions les plus petites.

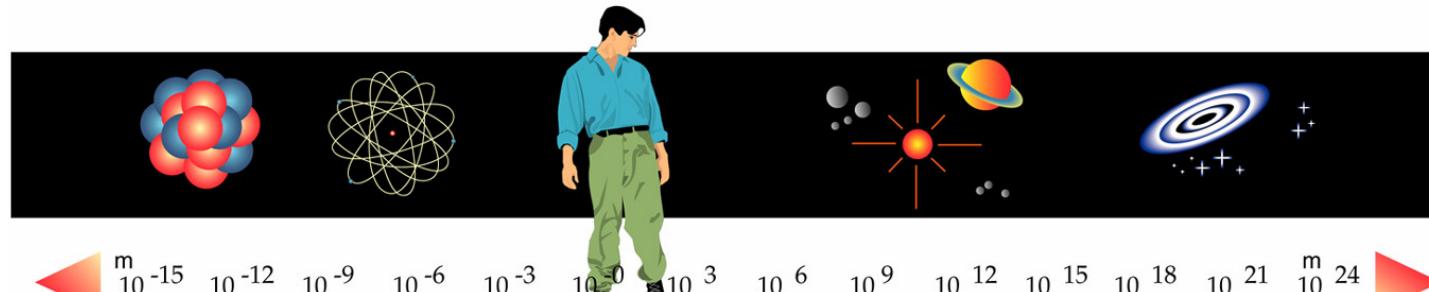


Particle physics looks at matter in its smallest dimensions.

L'astrophysique étudie la matière dans ses dimensions les plus grandes.



Astrophysics looks at matter in its largest dimensions.



Accélérateurs
et détecteurs
Accelerators
and detectors

Microscopes
Microscopes

L'oeil nu.
Naked eye

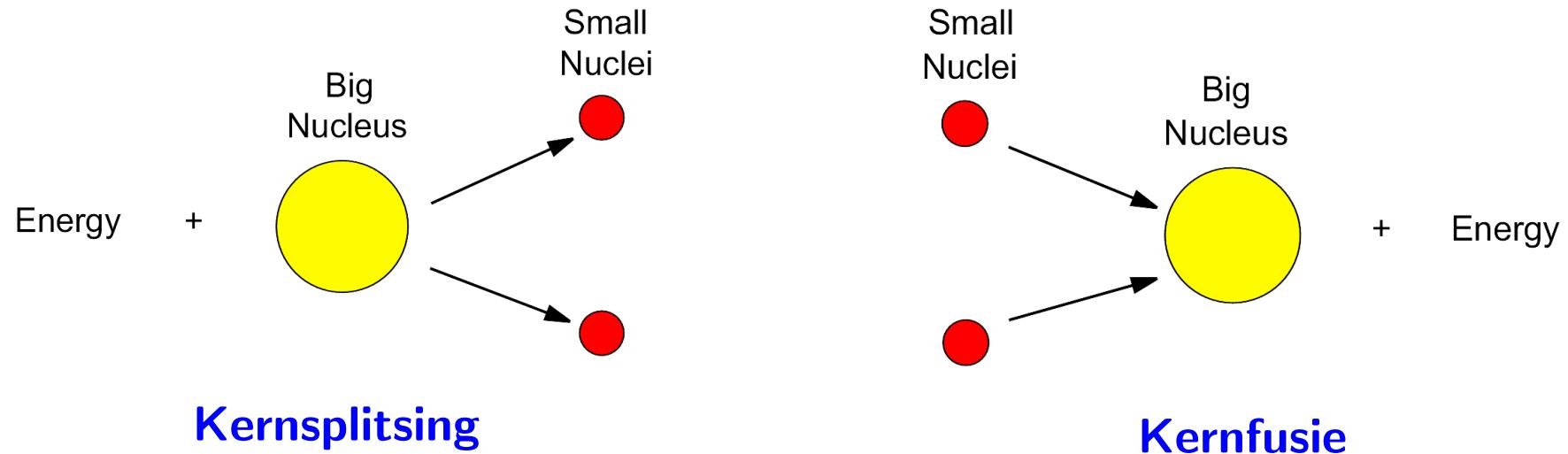
Jumelles
Binoculars

Telescopes optiques & radio
Optical & radio telescopes

THE TWO FRONTIERS OF PHYSICS LES DEUX FRONTIERES DE LA PHYSIQUE

CERN AC - Z11 - V11/5/98

Kernfusie laat sterren stralen



Zwakke kracht produceert neutrinos

(Supernovae, AGN, GRBs)

- Ontstaan van neutronensterren

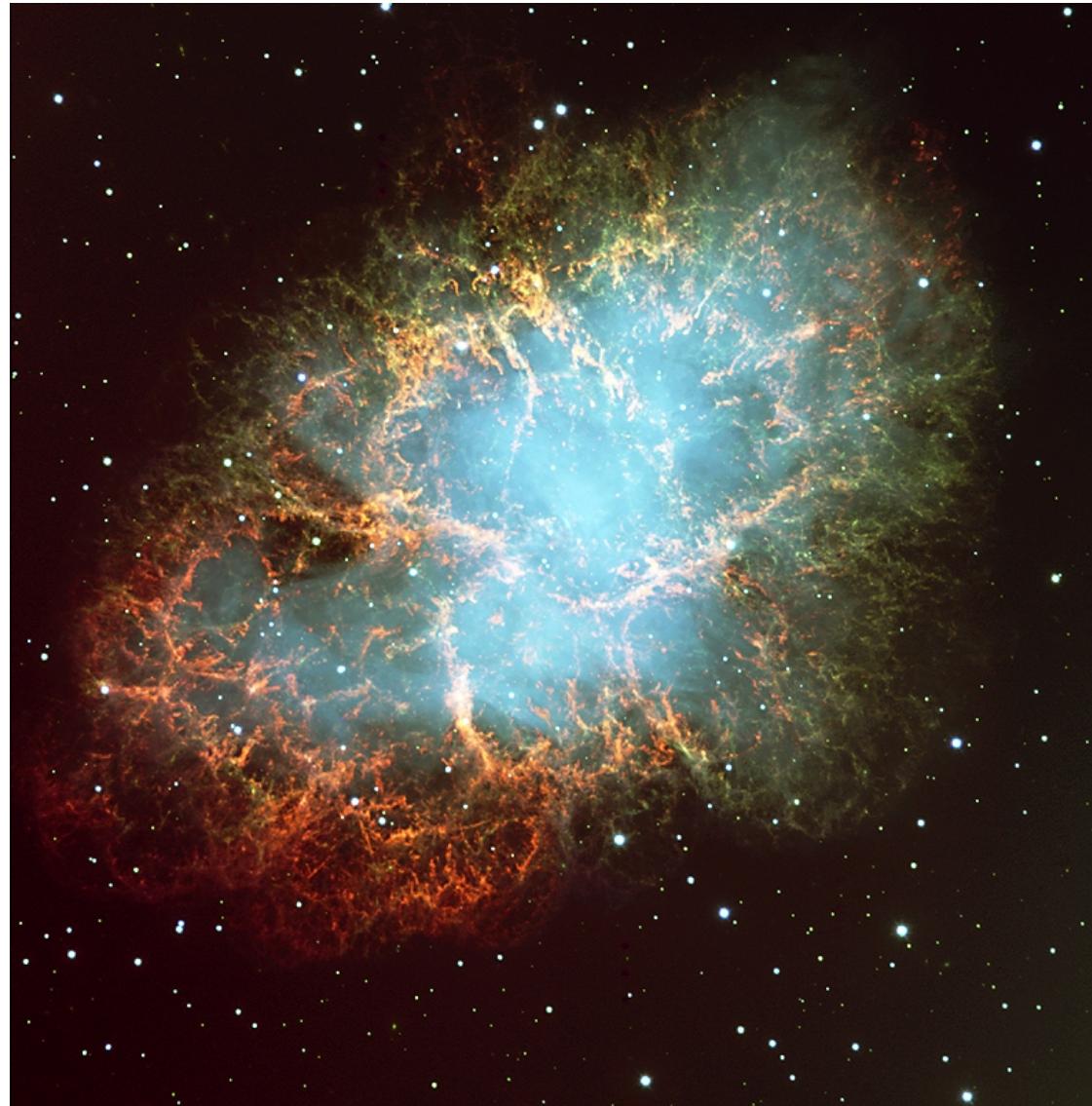
$$n \rightarrow p + e^- + \bar{\nu}_e$$

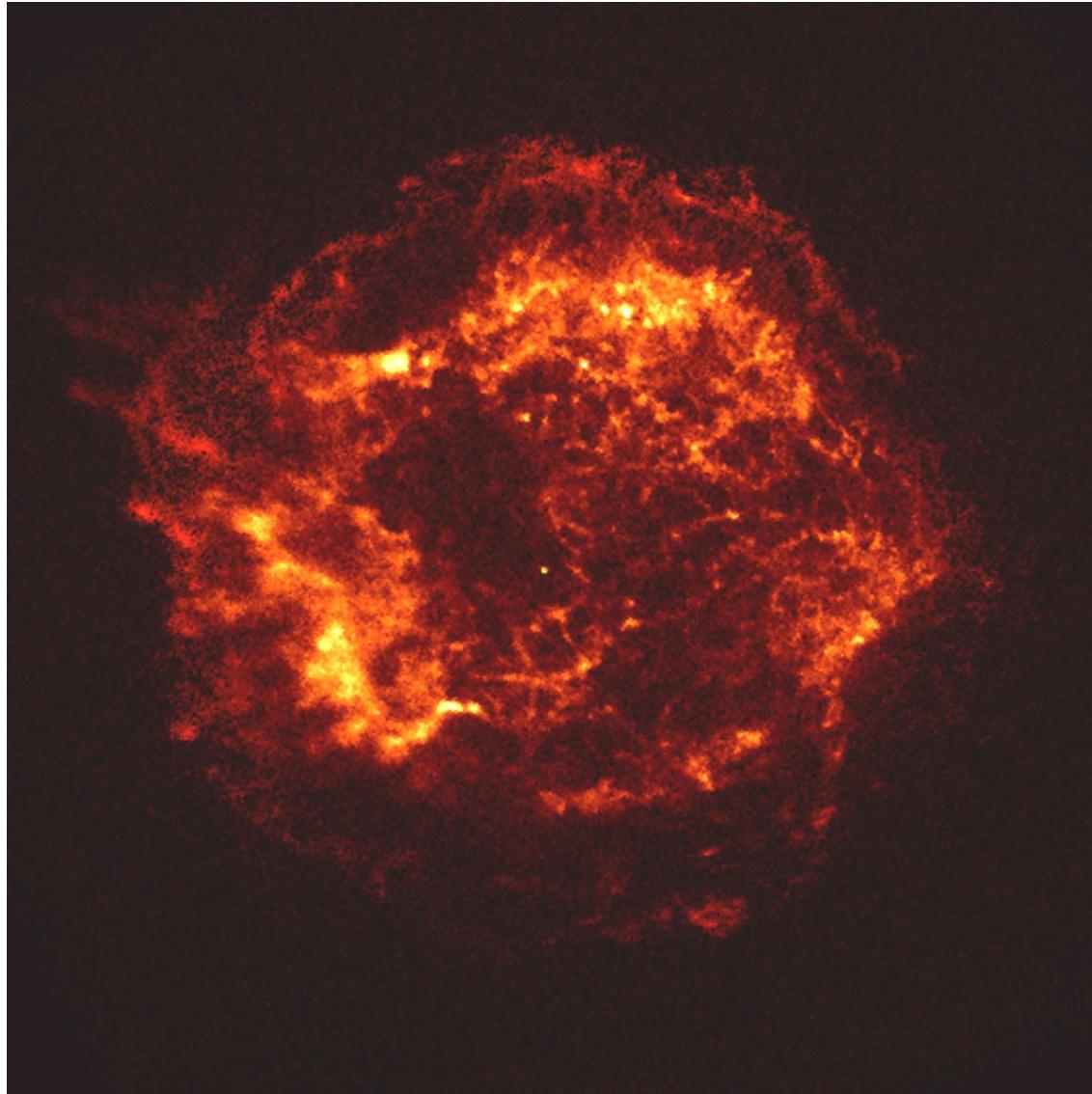
$$p + e^- \rightarrow n + \nu_e$$

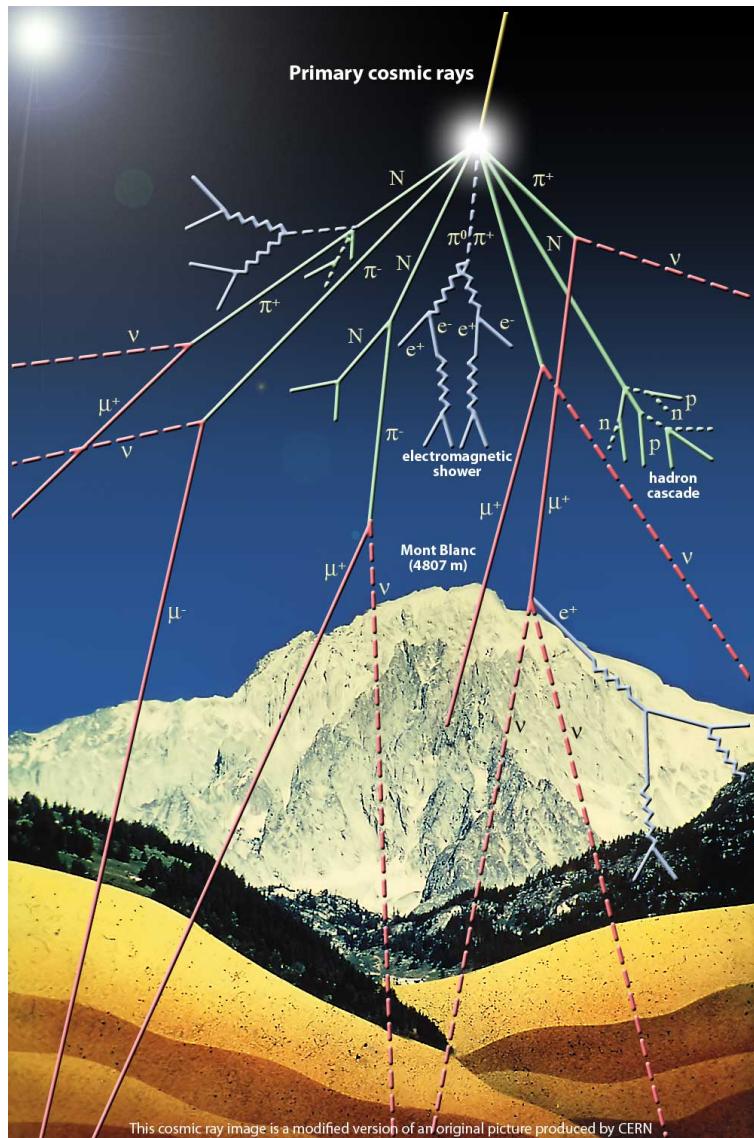
$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$$

$$\mu^- \rightarrow \nu_\mu + e^- + \bar{\nu}_e$$

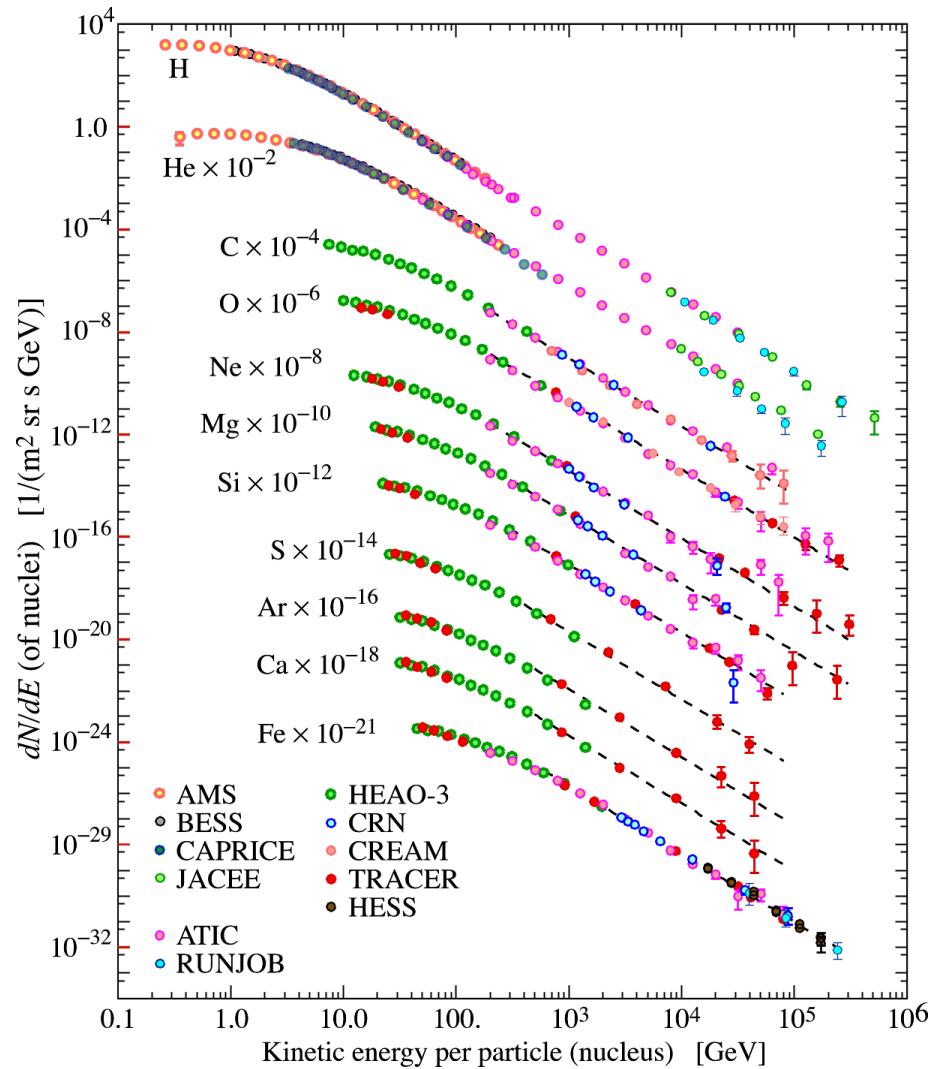
Het onzichtbare heelal



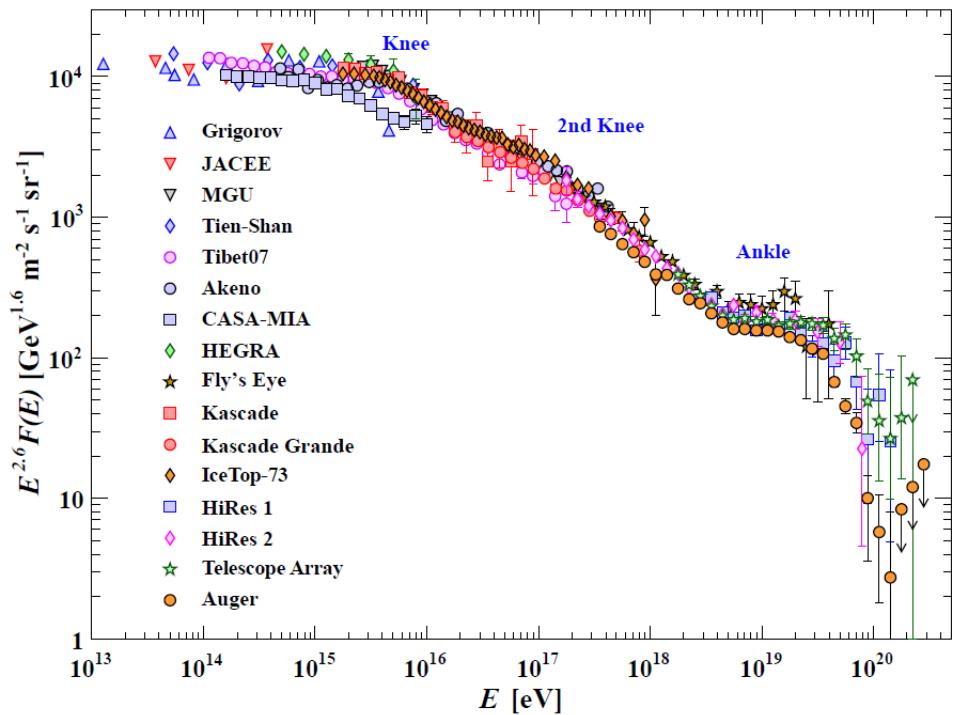




Spectrum van kosmische straling



$E^{2.6}$ geschaalde flux



- Spectrale structuur (knie, enkel)
- Energetische limieten van kosmische versnellers ?
- Wat zijn dit voor versnellers ?
- Heftige explosieve fenomenen
 - Supernova's ?
 - Of iets anders ?

- Supernova schokgolven

Bewegende lading in mag. veld

$$\text{Gyroradius } r = \frac{p}{ZeB} \quad (\vec{p} \perp \vec{B})$$

$$\rightarrow \left(\frac{p}{1 \text{ eV}} \right) = 0.03 \cdot Z \left(\frac{B}{1 \mu\text{G}} \right) \left(\frac{r}{1 \text{ m}} \right)$$

- Versneller van afmeting R

$r > R \rightarrow \text{deeltje ontsnapt} \rightarrow E_{max}$

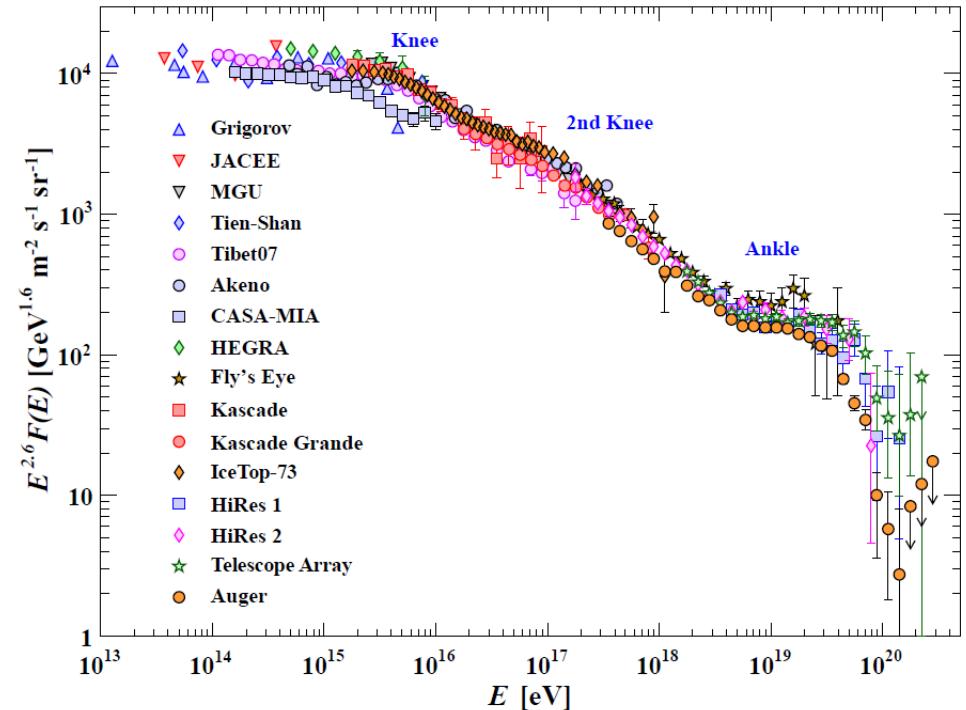
Typisch : $B \approx \mu\text{G}$ $R \approx 3 \cdot 10^{16} \text{ m}$

→ Protonen : $E_{max} \approx 10^{15} \text{ eV}$

* Bij bepaalde $r \rightarrow E_Z = ZE_{proton}$

* $E > 10^{19} \text{ eV} \rightarrow r > R_{melkweg}$

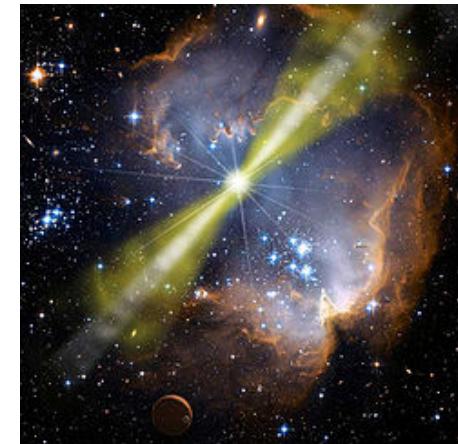
⇒ Extra-galactische oorsprong



Wat veroorzaakt de 'enkel' ?

Nog veel krachtigere explosies
(AGN and GRBs)

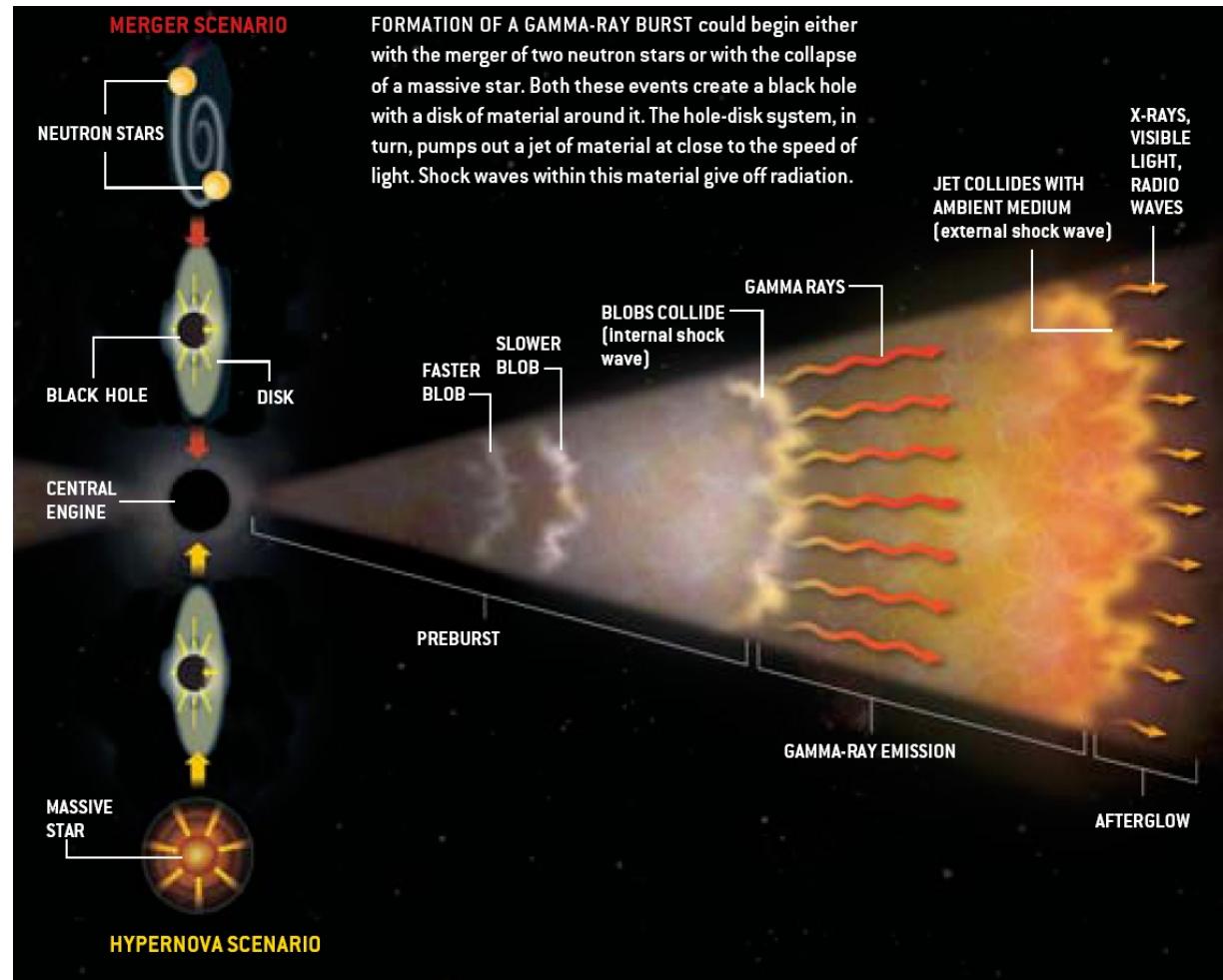
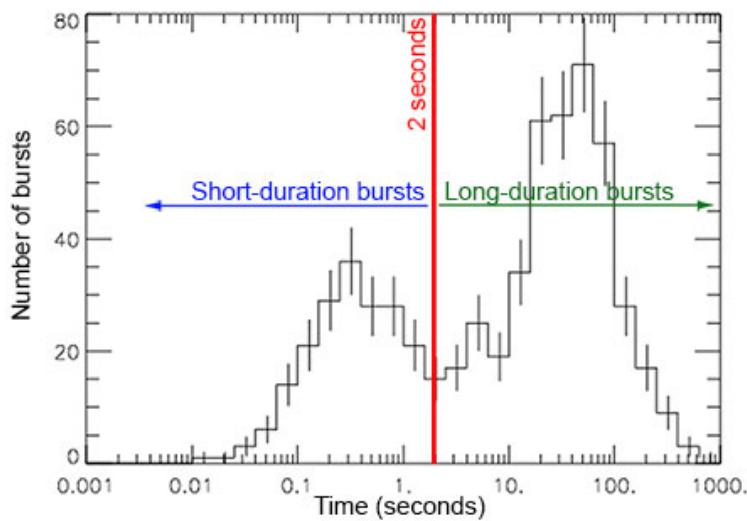
→ Zwarte gaten

Actieve Melkwegkernen (AGN)**Kosmische Gamma Flitsen (GRBs)**

Het onzichtbare heelal

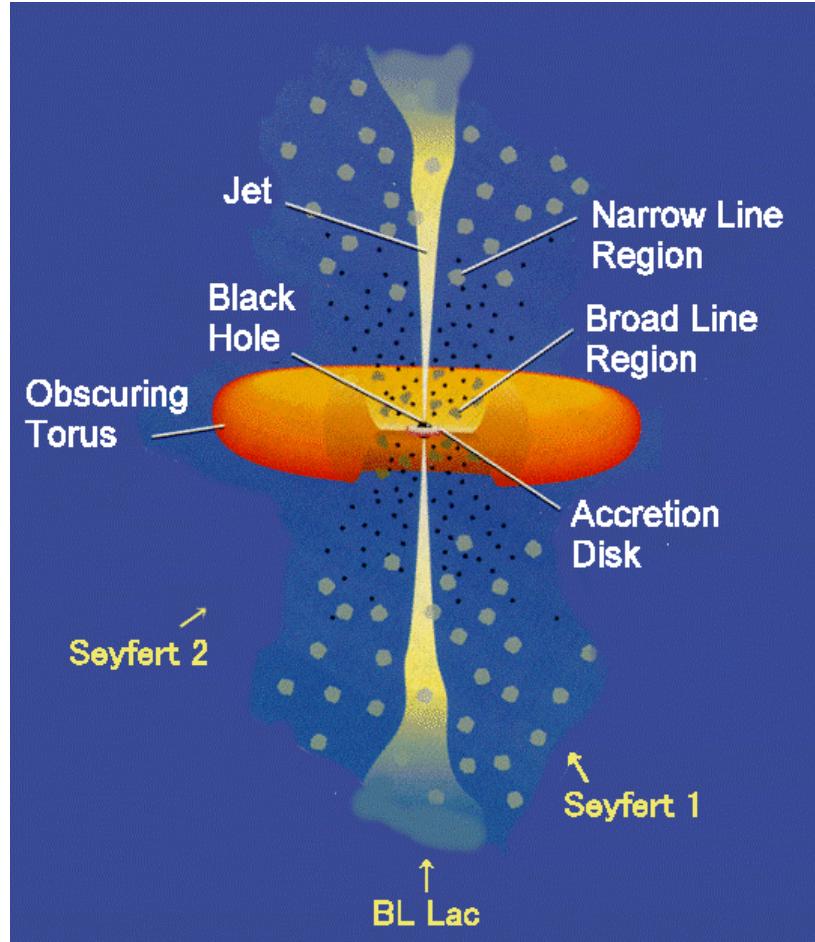
Waargenomen flitsduur distr.

Mogelijke GRB scenarios

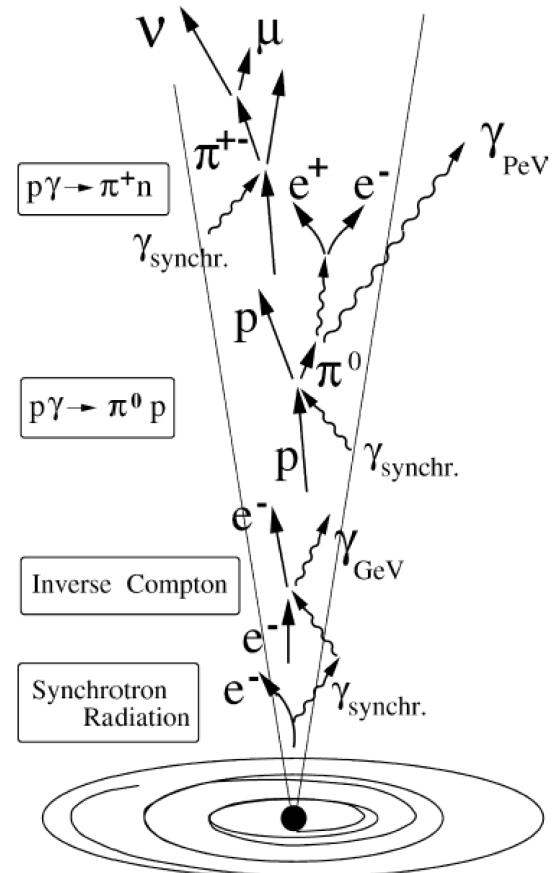


Korte GRBs mogelijk ook bronnen van gravitatiegolven

Algemeen beeld

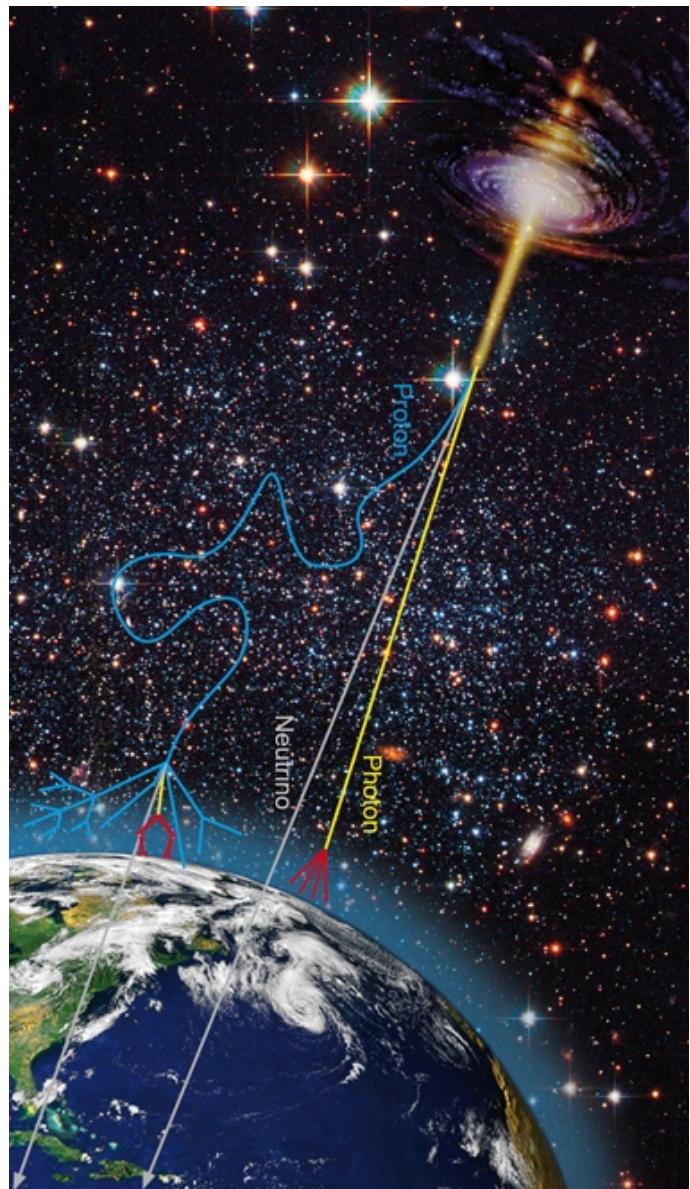


Fysische processen



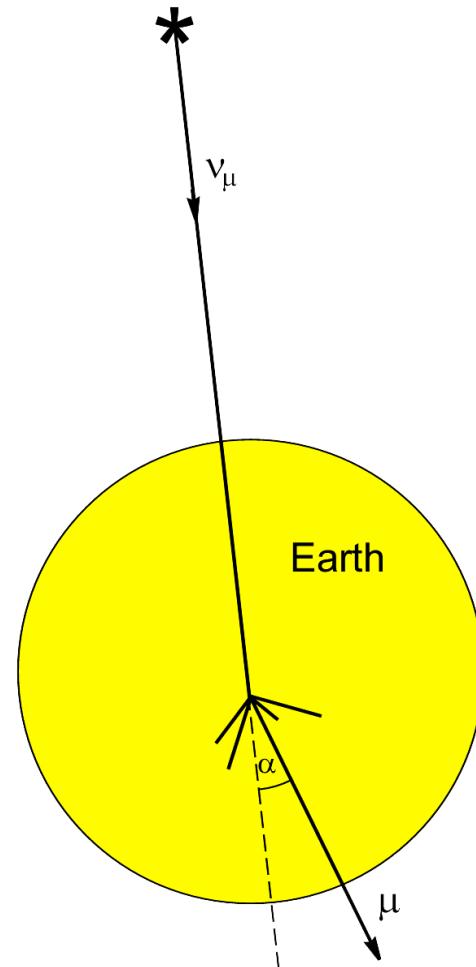
Versnelling in schokgolven

Hoog-energetische fotonen en neutrinos

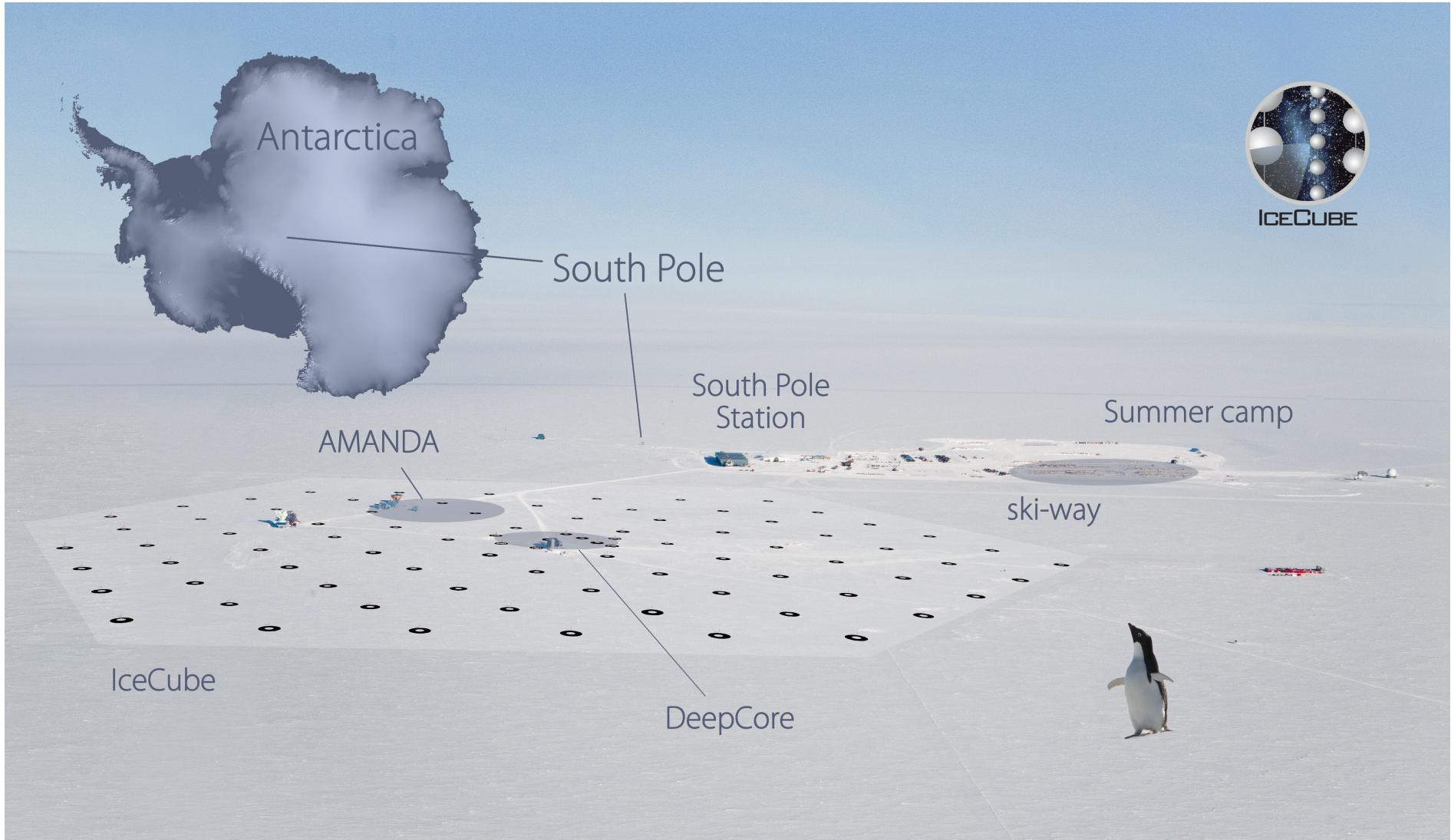


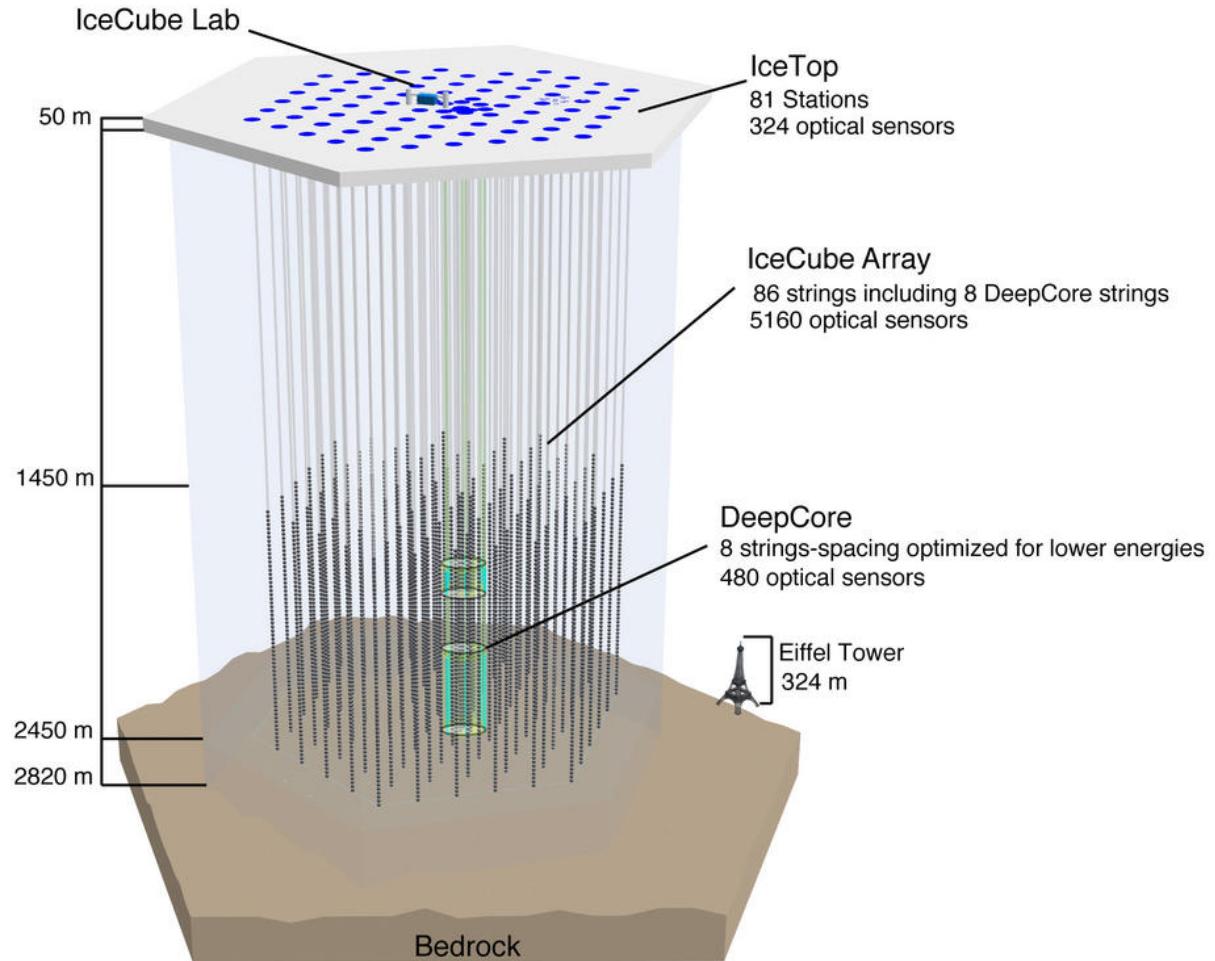
Neutrino detectiemechanisme

Cosmic Event



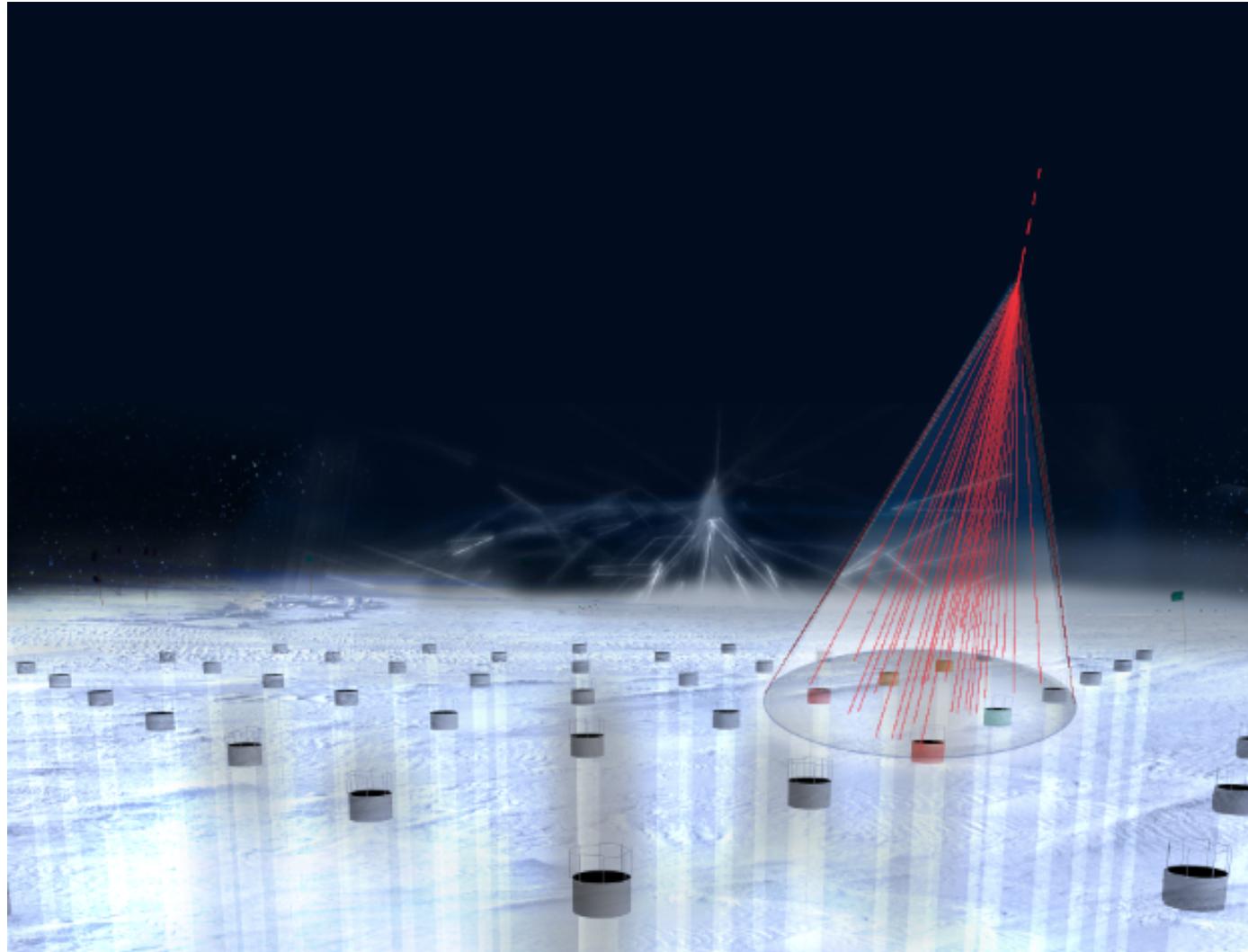


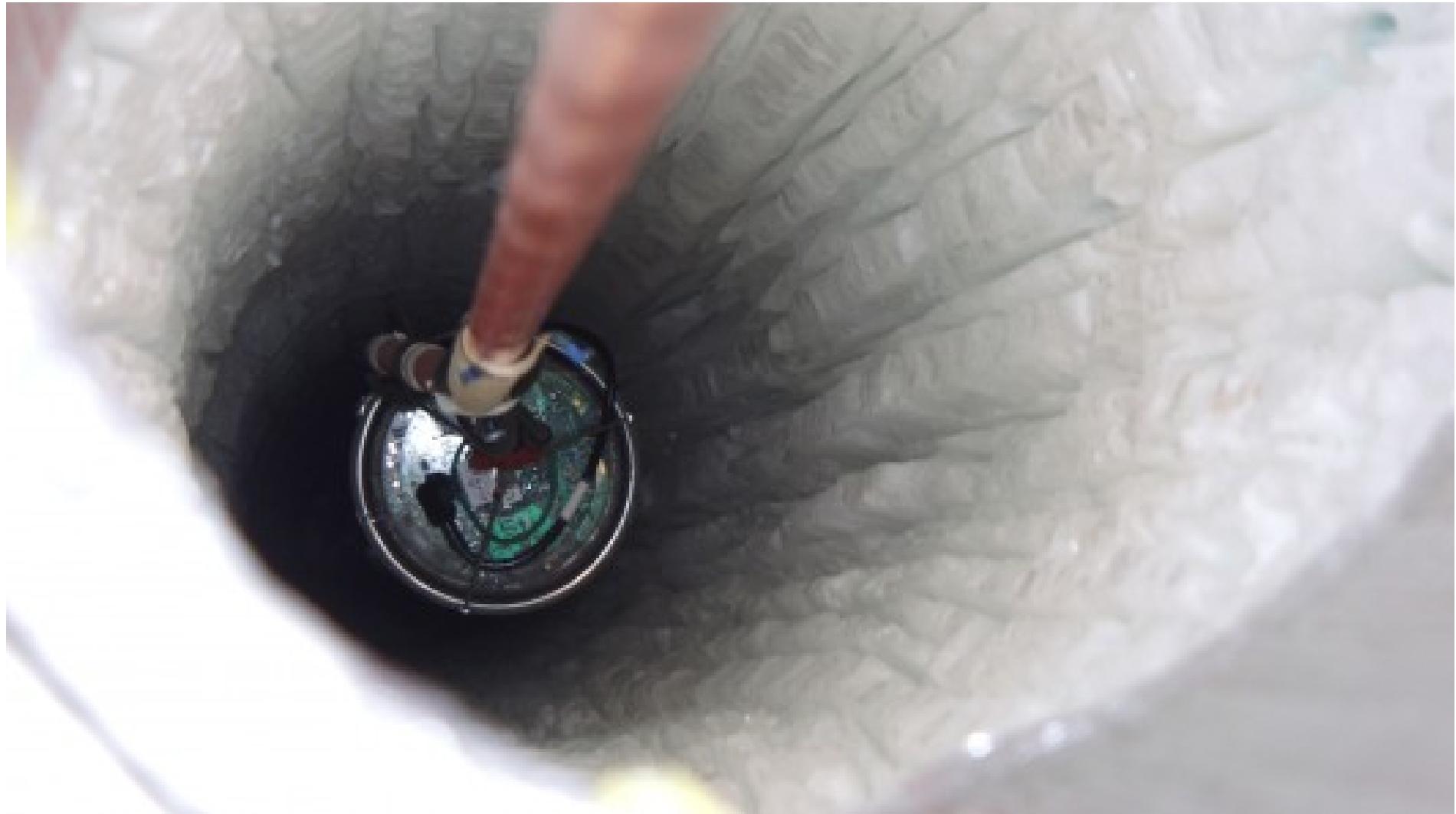




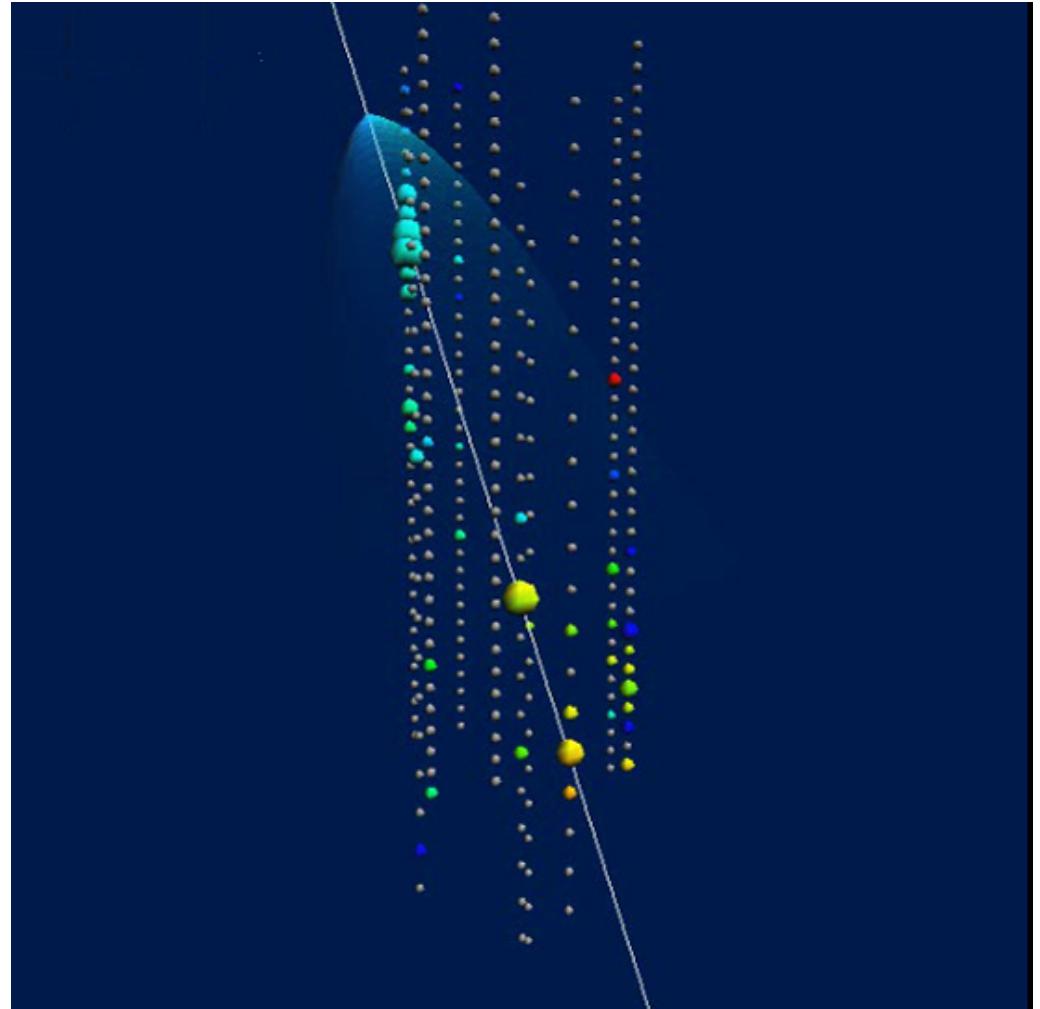
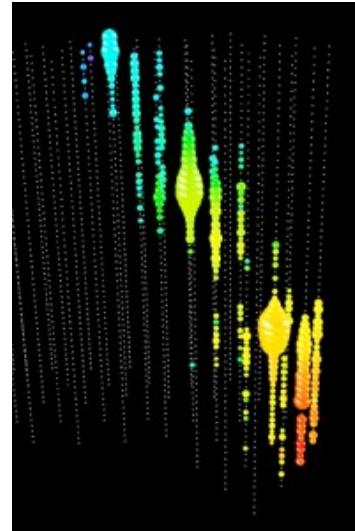


IceTop detectieprincipe





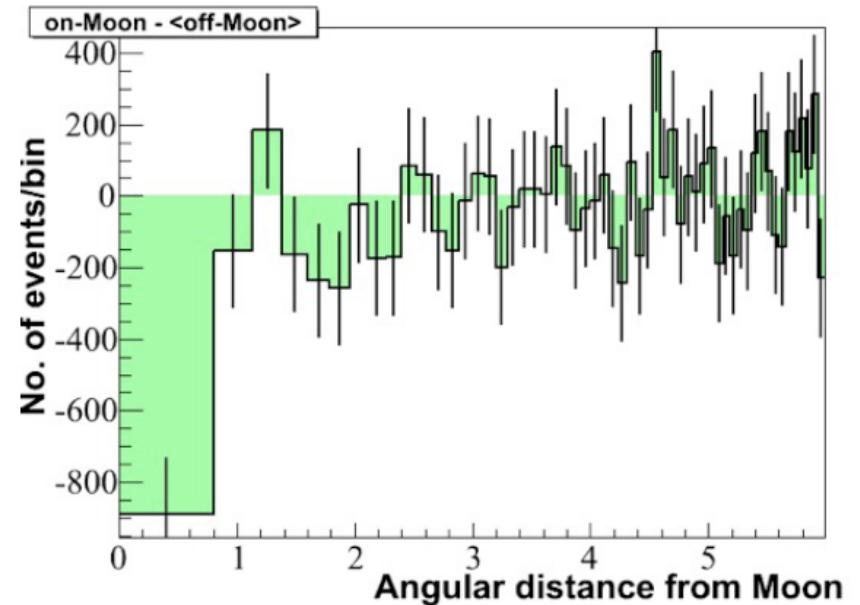
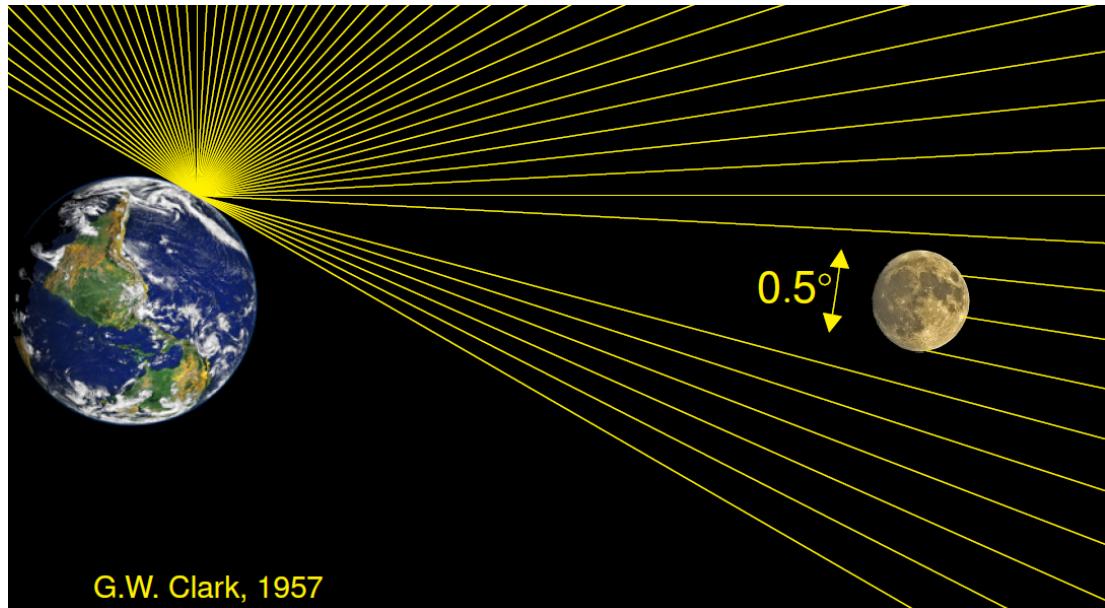
InIce detectieprincipe





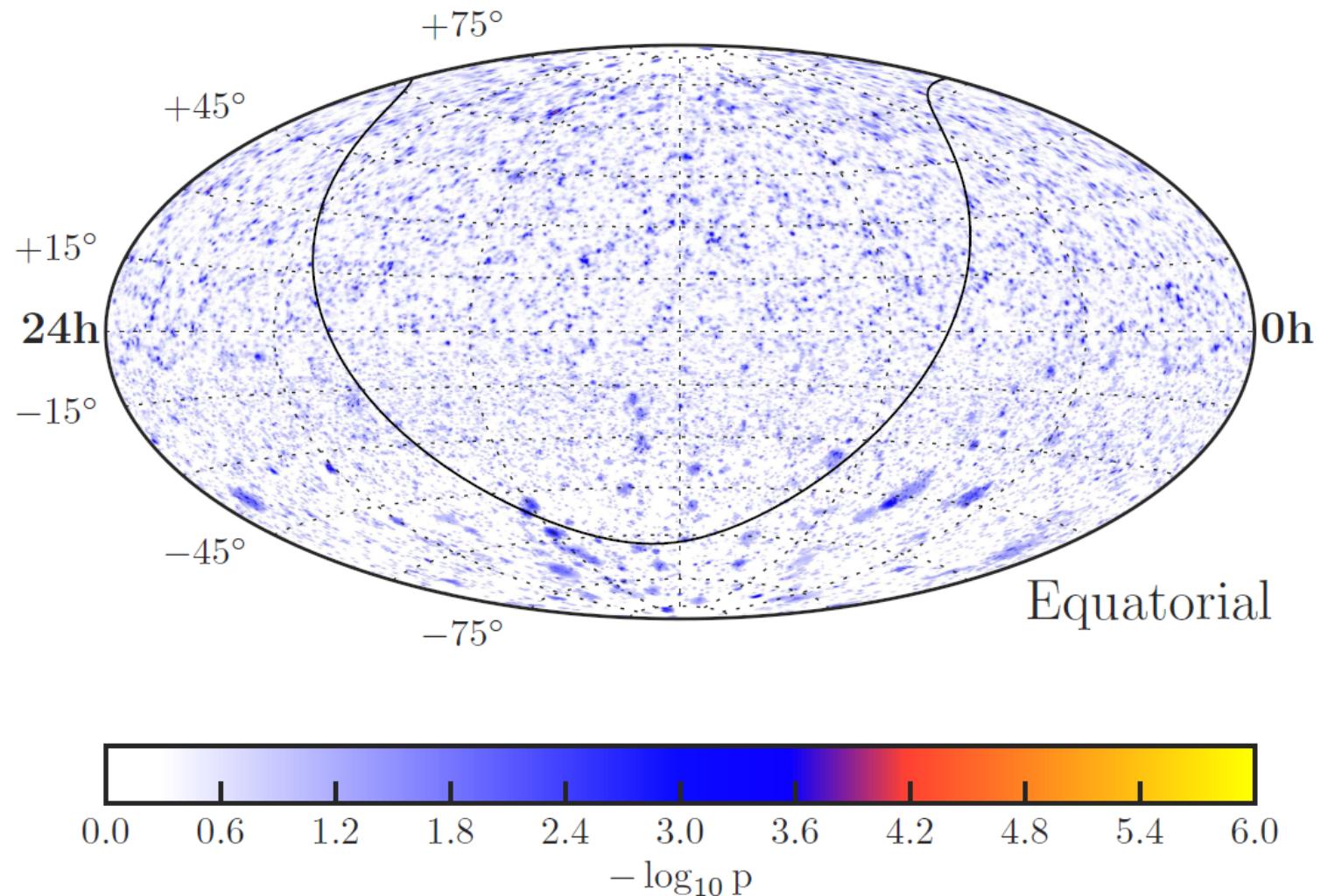
Muonen van atmosferische interacties

De schaduw van de Maan



Hoekresolutie : $\sim 0.8^\circ$

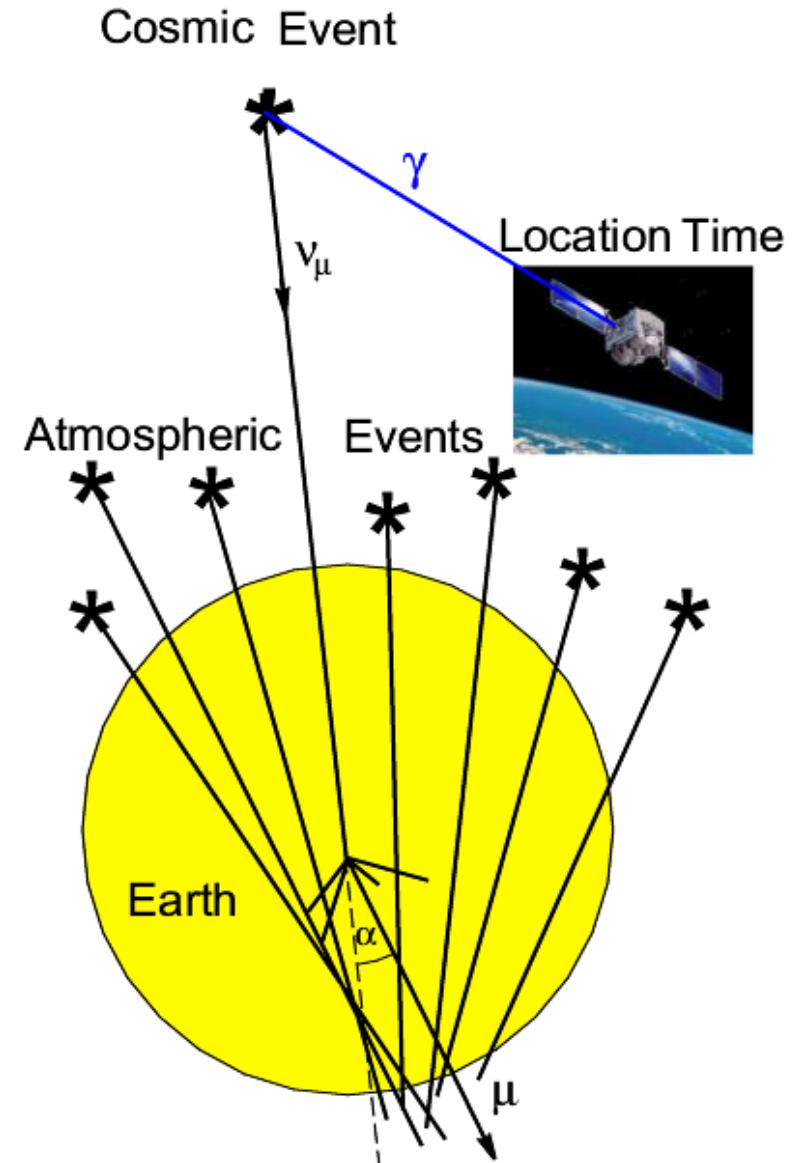
De IceCube hemelkaart (7 jaar data, $\sim 700'000$ events)



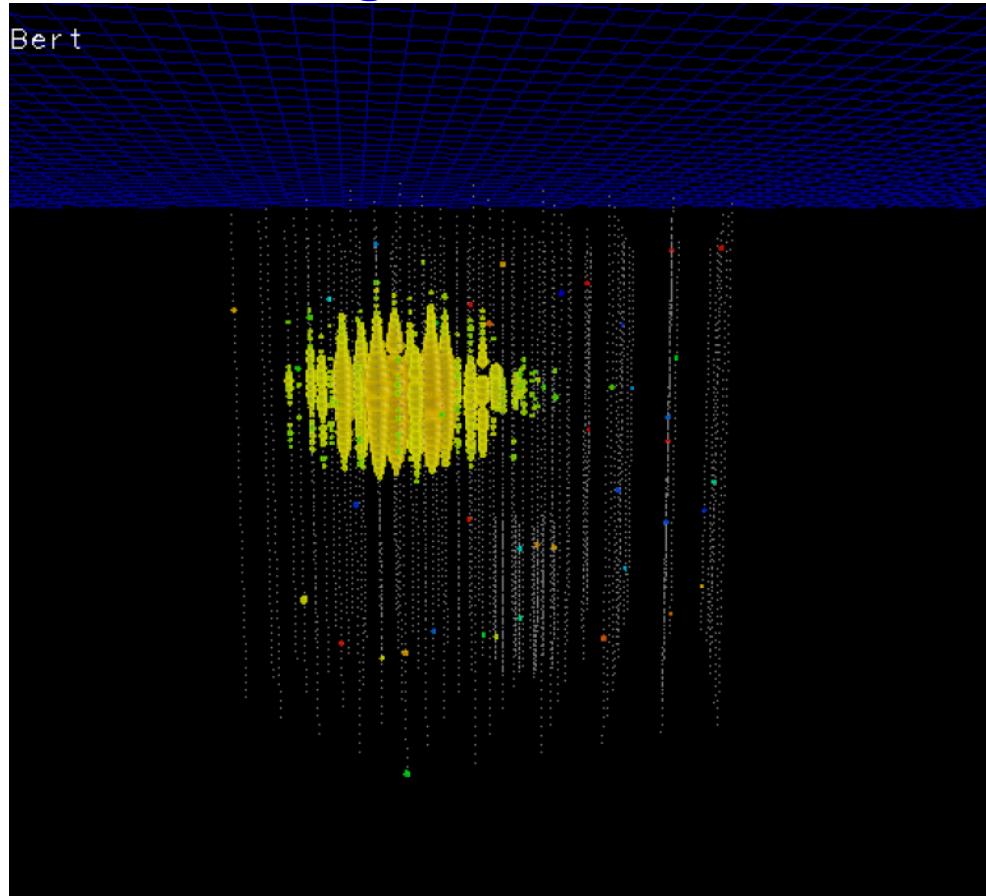
- Signalen zijn atm. achtergrond ν
Niet te onderscheiden van kosm. ν

Kijk naar kortstondige explosies

Specifieke plaats en tijd (satelliet)
 → nagenoeg geen achtergrond
 * IIHE movie



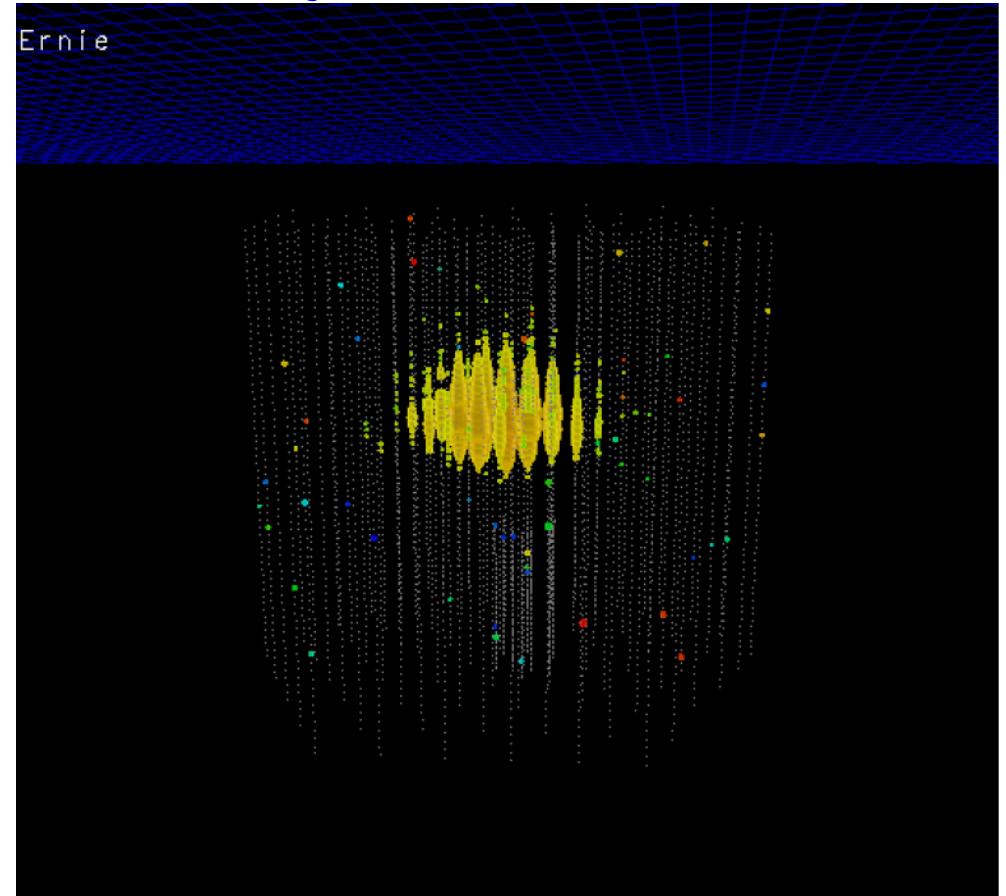
Tue 09-aug-2011 07:23:18 UTC



$1.04 \pm 0.16 \text{ PeV}$

Atmosferische ν achtergrond ?

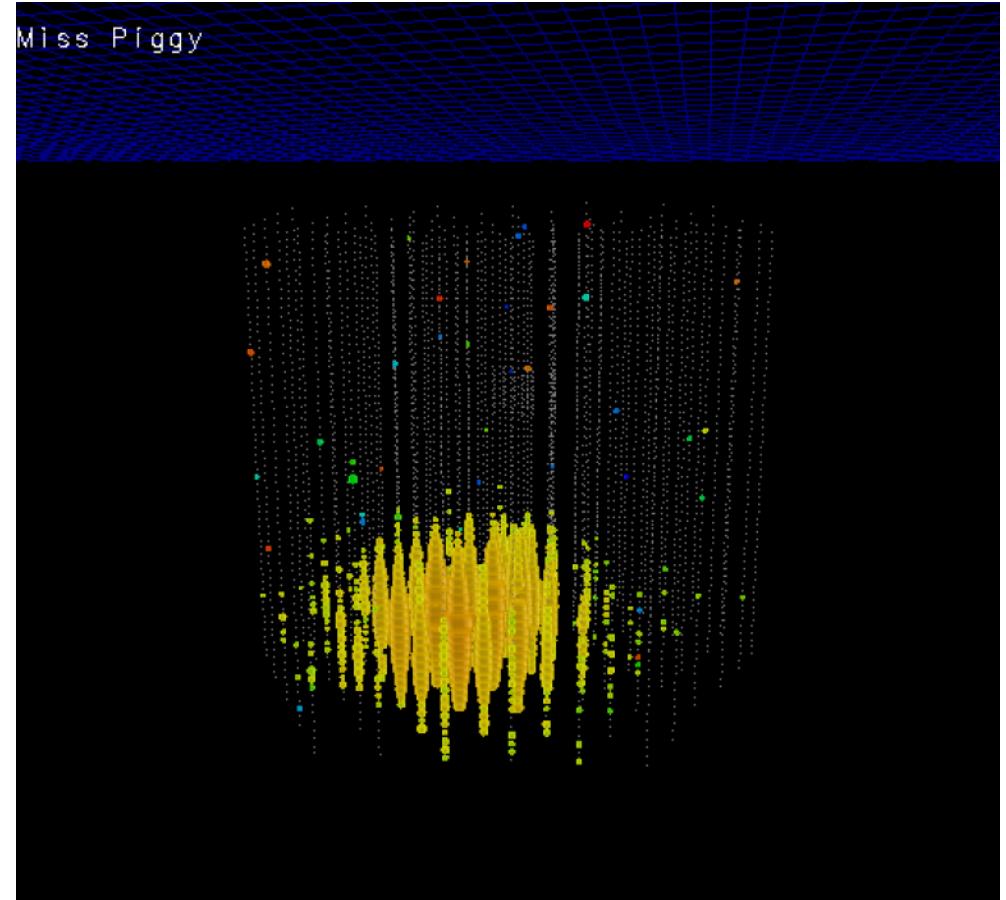
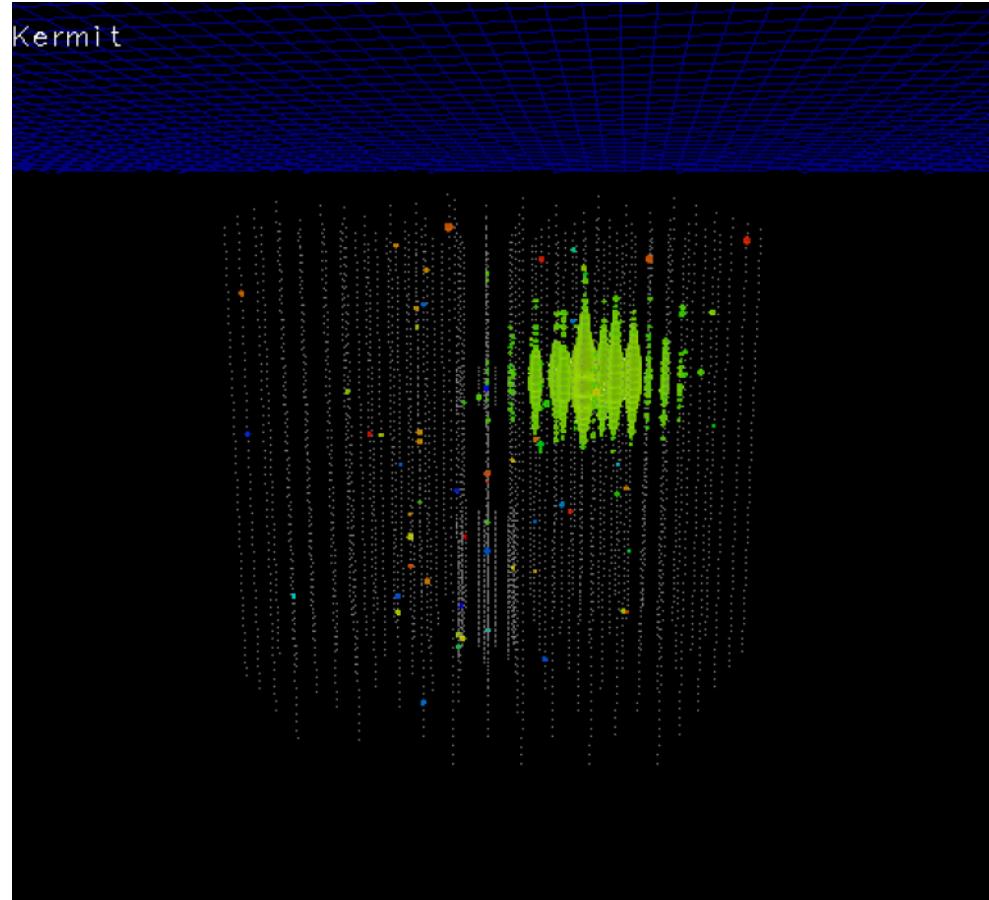
Tue 03-jan-2012 03:34:01 UTC



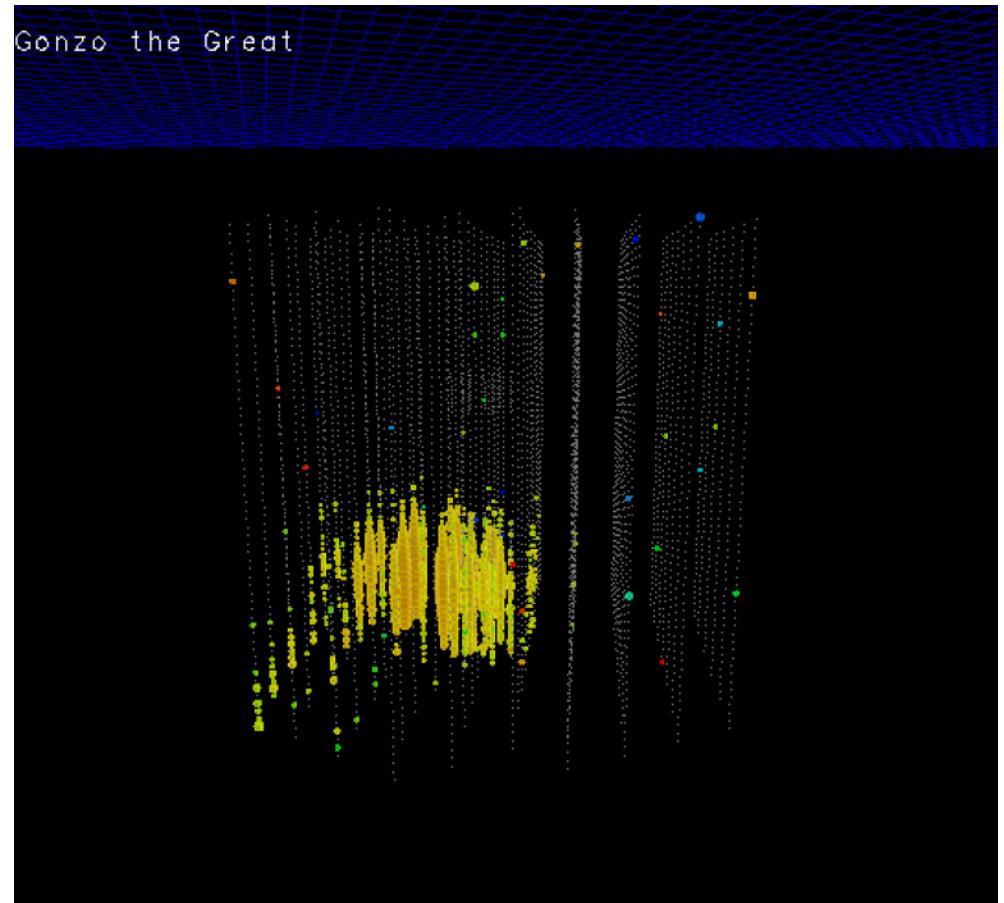
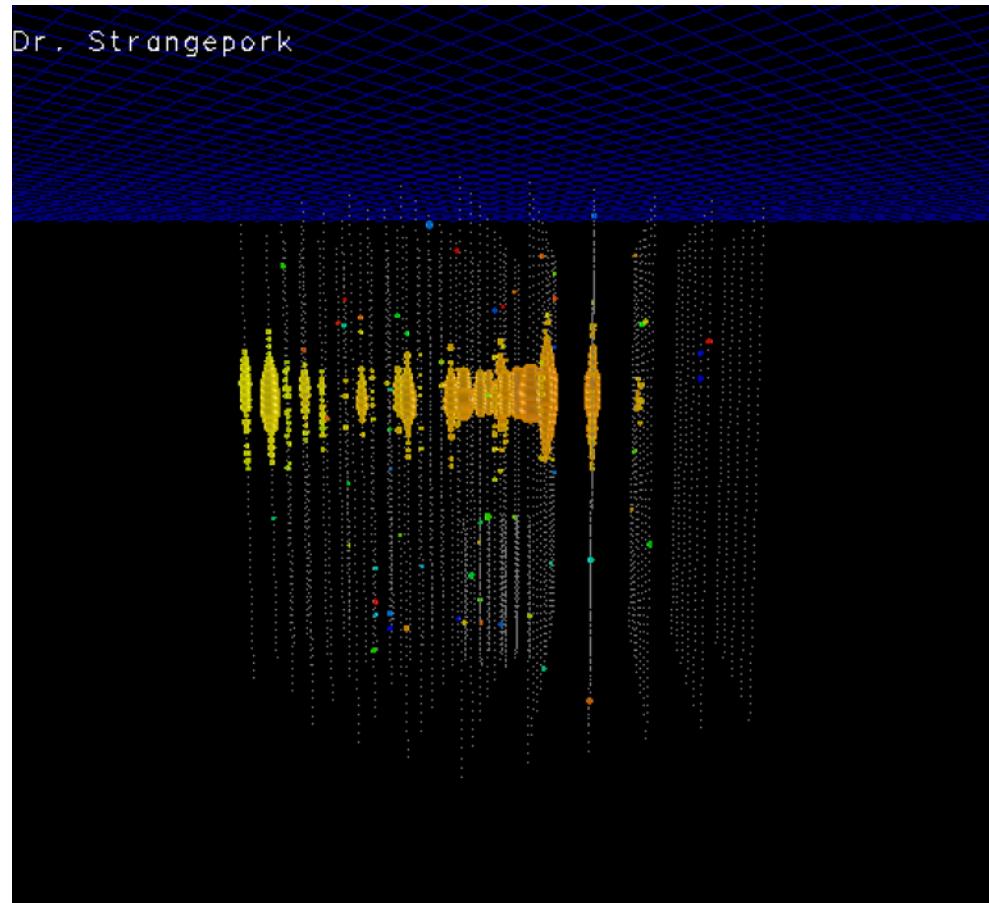
$1.14 \pm 0.17 \text{ PeV}$

Slechts ca. 0.3% kans op achtergrond

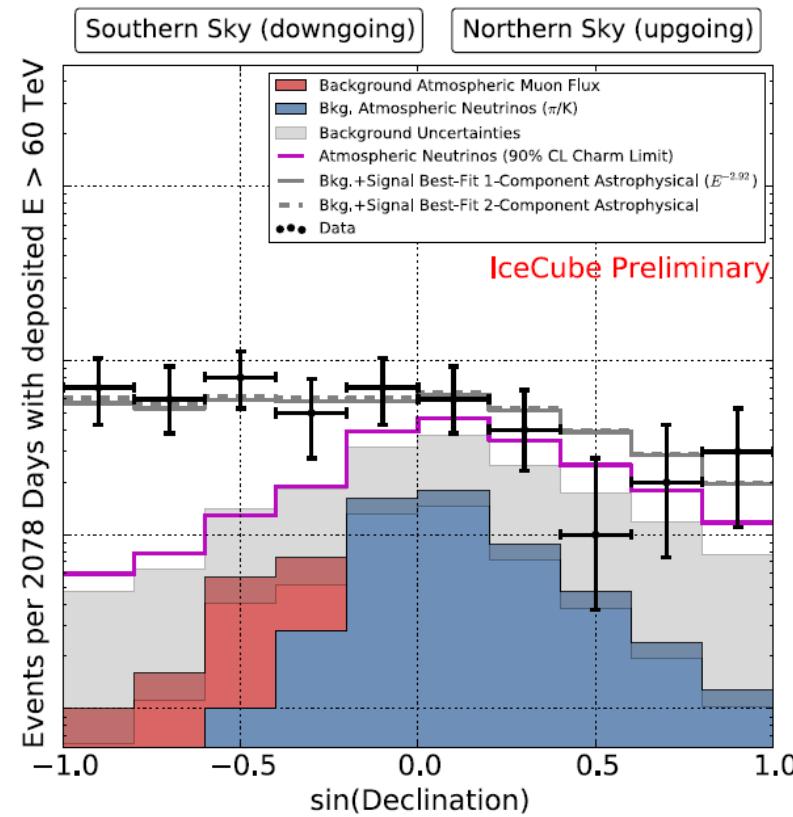
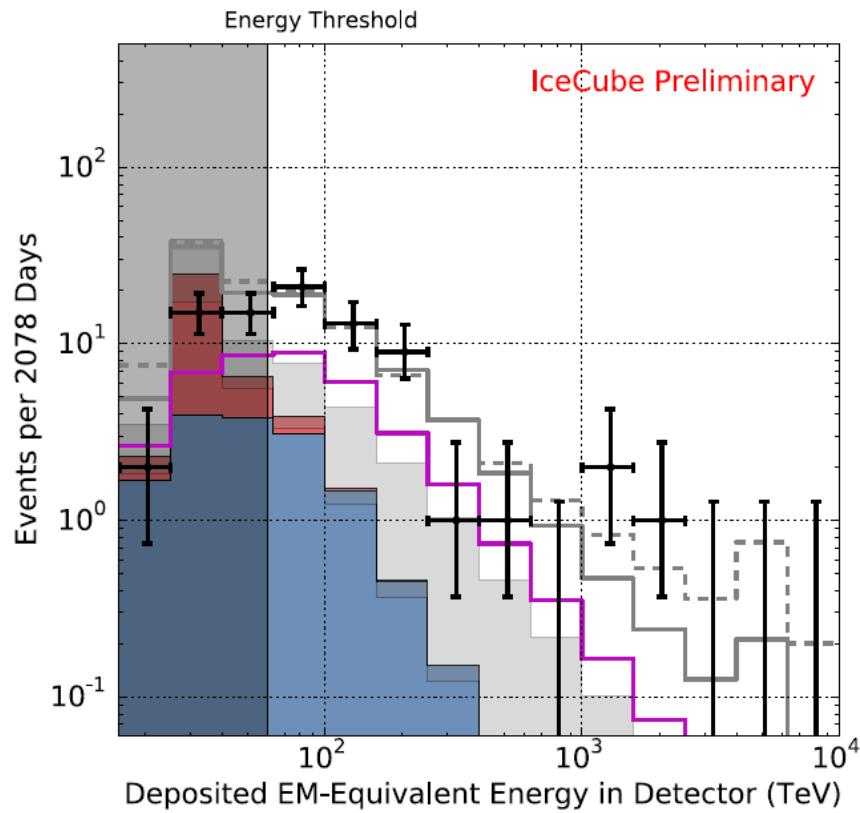
Nog een aantal additionele events gevonden



Ook enkele μ spoorsignaturen



Karakteristieken van 82 events



Aanduiding voor kosmische hoog-energetische neutrino's



Physics World Breakthrough of the Year 2013

The *Physics World* Breakthrough of the Year is awarded for physics research published in 2013 and the decision is based on the following criteria:

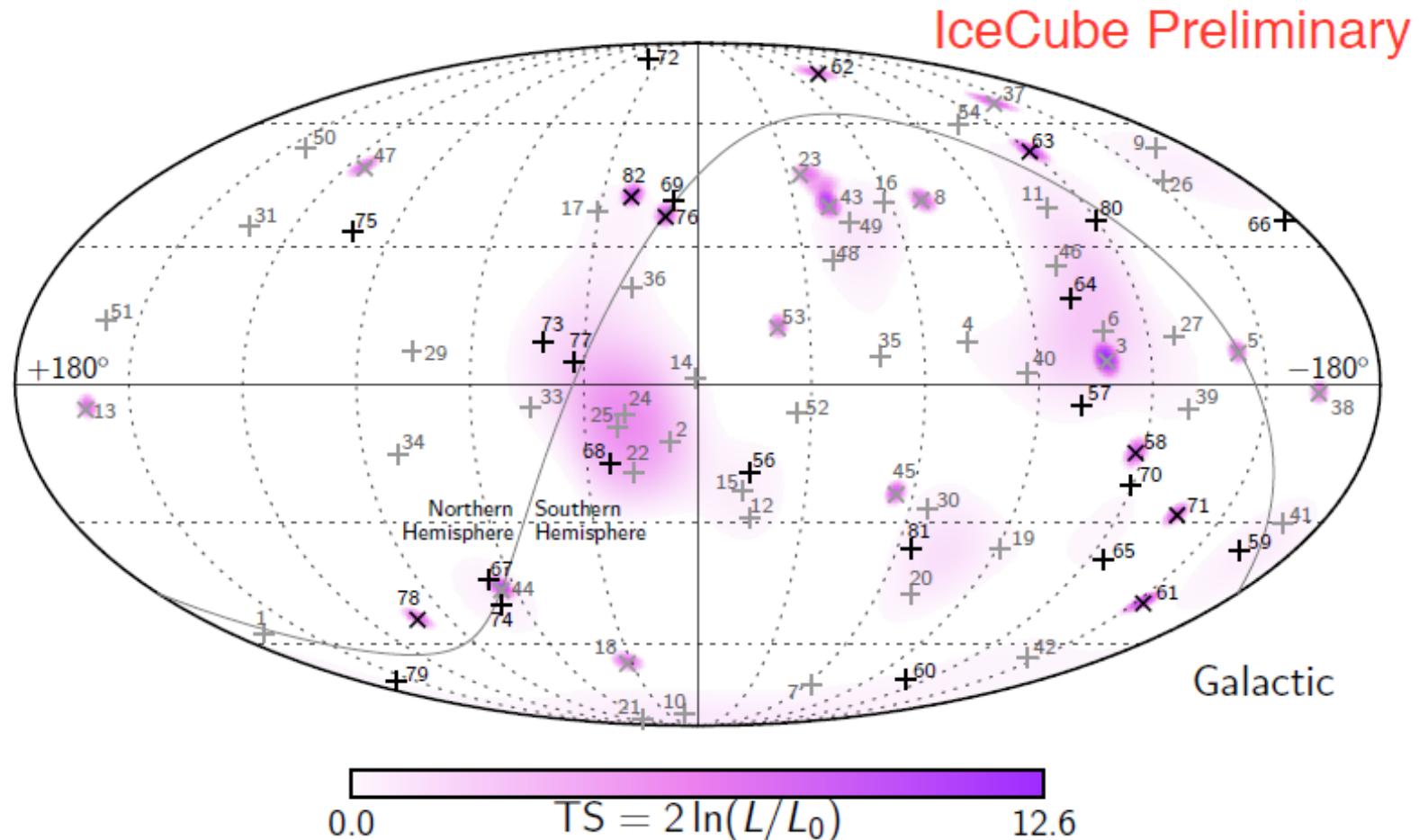
- Fundamental importance of research
- Significant advance in knowledge
- Strong connection between theory and experiment
- General interest to all physicists

This is to certify that the *Physics World* Breakthrough of the Year has been given to

The IceCube South Pole Neutrino Observatory

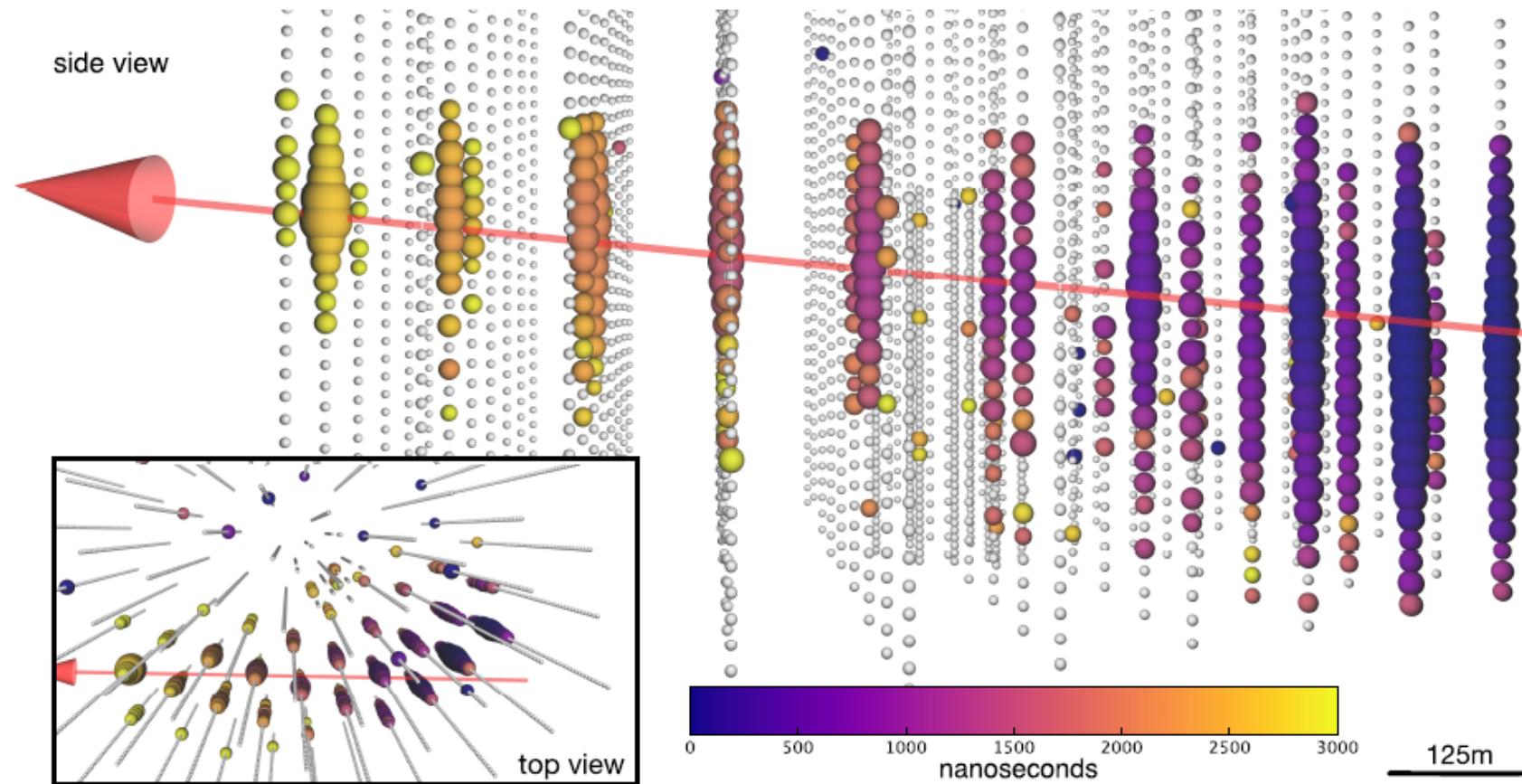
for making the first observations of high-energy cosmic neutrinos

Herkomst van deze 82 events



Geen bewijs voor puntbron(nen)

IceCube: Spoor met $E_{dep} \sim 24$ TeV gezien op 22-sep-2017 20:54:30.43 UTC
→ EHE alarm (IC170922A) uitgezonden (~ 4 per jaar)



IC170922A spoorparameters: $\alpha = 77.43^{\circ+0.95}_{-0.65}$ $\delta = 5.72^{\circ+0.50}_{-0.30}$ $E_\nu = 290 \text{ TeV}$

Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

ATel #10791; *Yasuyuki T. Tanaka (Hiroshima University), Sara Buson (NASA/GSFC), Daniel Kocevski (NASA/MSFC) on behalf of the Fermi-LAT collaboration*
on 28 Sep 2017; 10:10 UT

Credential Certification: David J. Thompson (David.J.Thompson@nasa.gov)

Subjects: Gamma Ray, Neutrinos, AGN

Referred to by ATel #: 10792, 10794, 10799, 10801, 10817, 10830, 10831, 10833, 10838, 10840, 10844, 10845, 10861, 10890, 10942

First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

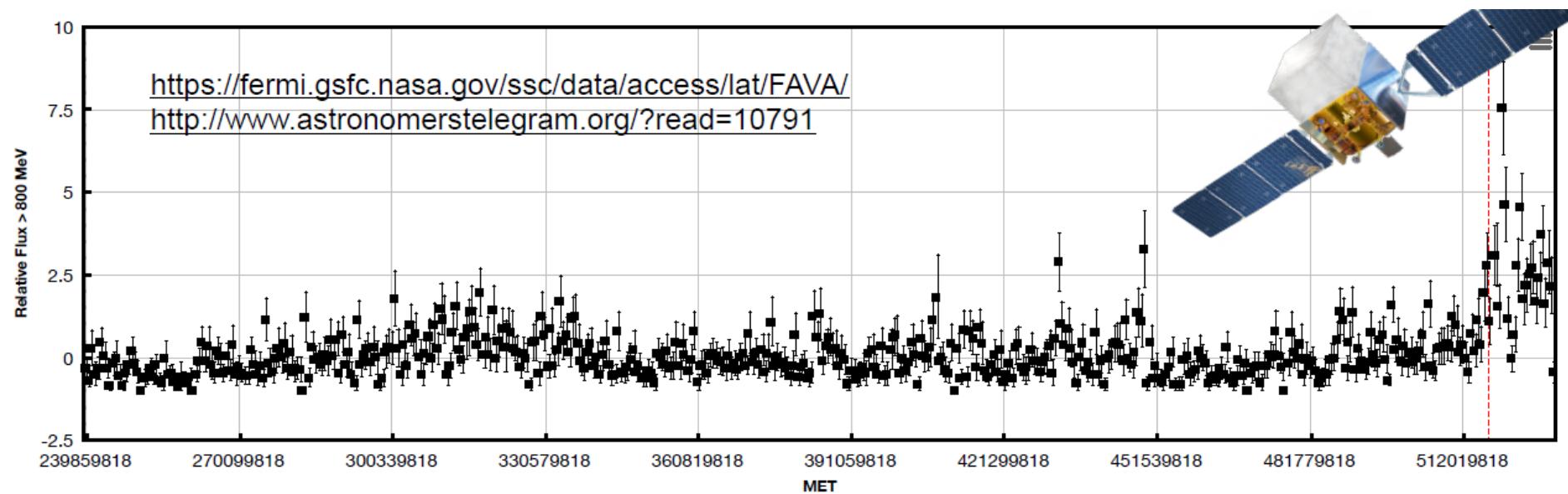
ATel #10817; *Razmik Mirzoyan for the MAGIC Collaboration*
on 4 Oct 2017; 17:17 UT

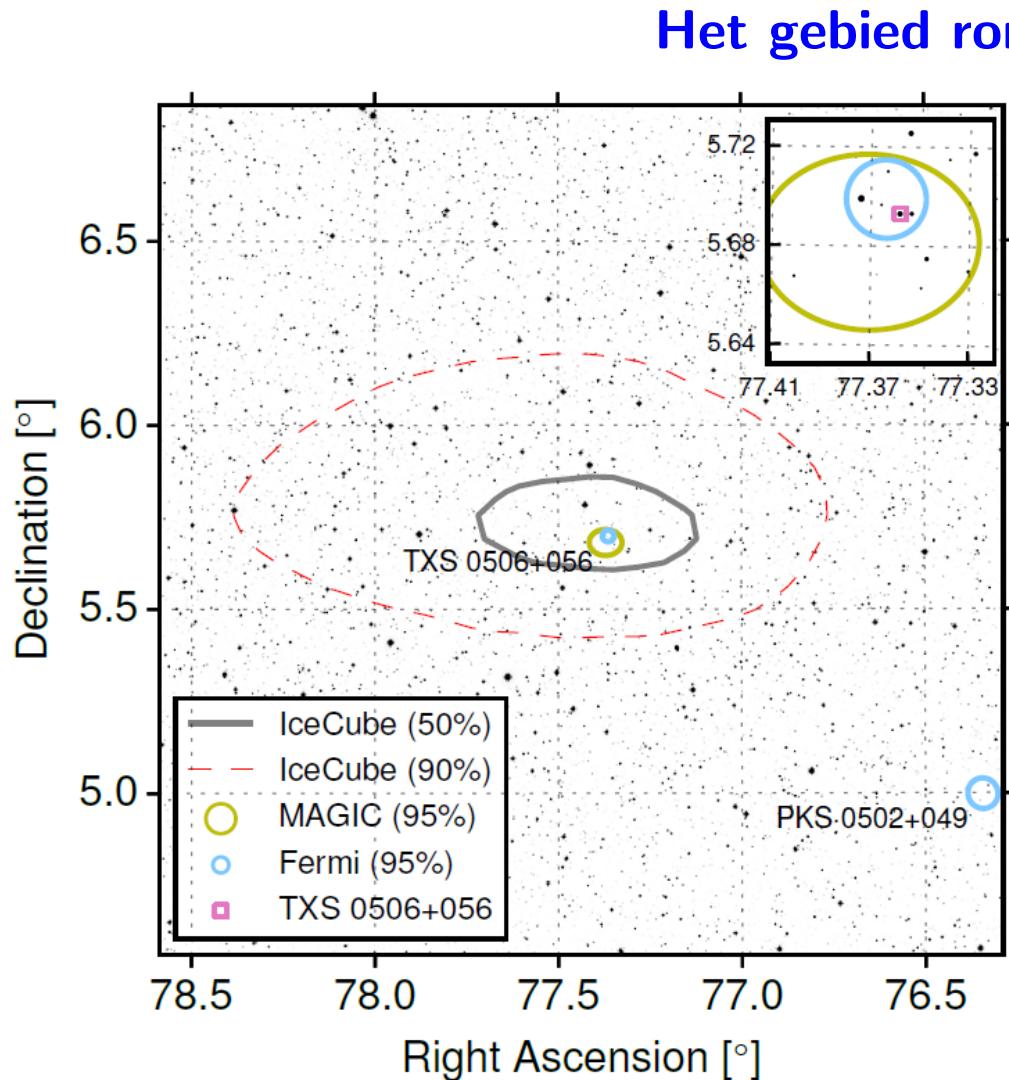
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Optical, Gamma Ray, >GeV, TeV, VHE, UHE, Neutrinos, AGN, Blazar

Referred to by ATel #: 10830, 10833, 10838, 10840, 10844, 10845, 10942

Fermi lichtcurve voor IC170922A

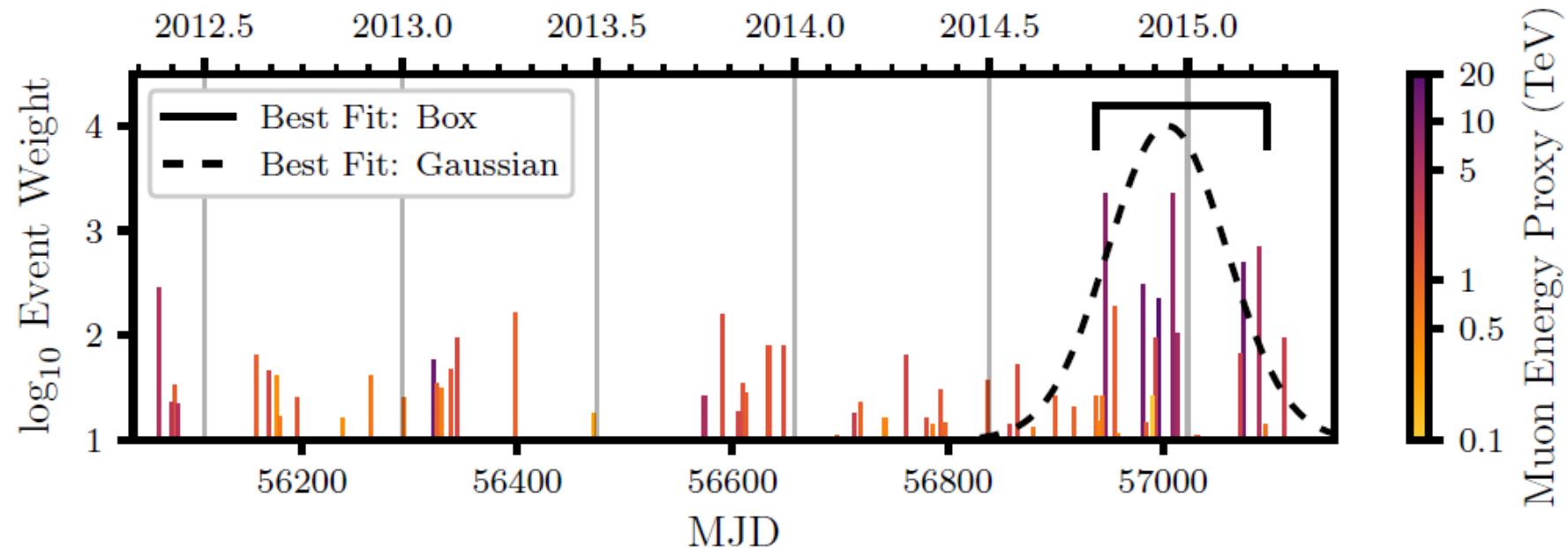




- Veel radio en X-ray bronnen
Meeste zijn erg zwak
- 2 kandidaten blijven over
[Padovani et al. MNRAS 12-jul-2018]
 - * **TXS 0506+056 (Blazar $z = 0.3365$)**
 $D_{phys} = 1.37\text{Gpc}$ ($\sim 4.5 \text{ Gly}$)
 - * **PKS 0502+049 (FSRQ $z = 0.954$)**
 $D_{phys} = 3.29\text{Gpc}$ ($\sim 11 \text{ Gly}$)
- **TXS valt samen met ν positie**
PKS is 1.22° verwijderd

IceCube analyse op basis van archiefdata

- Neem de TXS 0506+056 locatie als referentiepunt
 → Zoek naar neutrino event clustering in positie en tijd
 (elk event krijgt een gewicht op basis van energie en relatieve positie)



- Neutrino activiteit rond 13-dec-2014 (± 21 dagen) gedurende 110^{+35}_{-24} dagen

- **IceCube : 's Werelds grootste neutrino observatorium op de Zuidpool**

De volledige IceCube detector is sinds december 2010 in bedrijf

IceCube sensoren werken naar behoren (Maanschaduw, hemelkaart)

- **Wereldprimeur (2013): Kosmische hoog-energetische neutrino's ontdekt**

De geboorte van Neutrino Astronomie

- **Ligo-Virgo : 's Werelds eerste observatorium voor gravitatiegolven**

Wereldprimeur (2015): Ontdekking van gravitatiegolven

Waargenomen signalen van samensmelende zwarte gaten en neutronensterren

- **Wereldprimeur (2018): Eerste kosmische neutrinobron geïdentificeerd**

Neutrino alarm (IceCube) → Opflakkerende Blazar (Fermi, Magic)

Gecombineerd onderzoek van het "Gamma, Neutrino, GW Universum"

- **Uitbreiding naar hogere neutrino energie (radio detectie)**

Er breken zeer interessante tijden aan voor onze Astrodeeltjes Fysica !

The IceCube Gen2 Facility

