# *Neutrino Astrophysics*

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Instituto de Física Gleb Wataghin
UNICAMP

@

School and Workshop on Dark Matter and Neutrino Detection
ICTP-SAIFR/IFT-UNESP
07/2018

- Outline of the talk
  - Supernova Neutrino Detection
  - Diffuse Supernova Neutrinos
  - High-Energy Neutrinos

# *Supernova Neutrinos*

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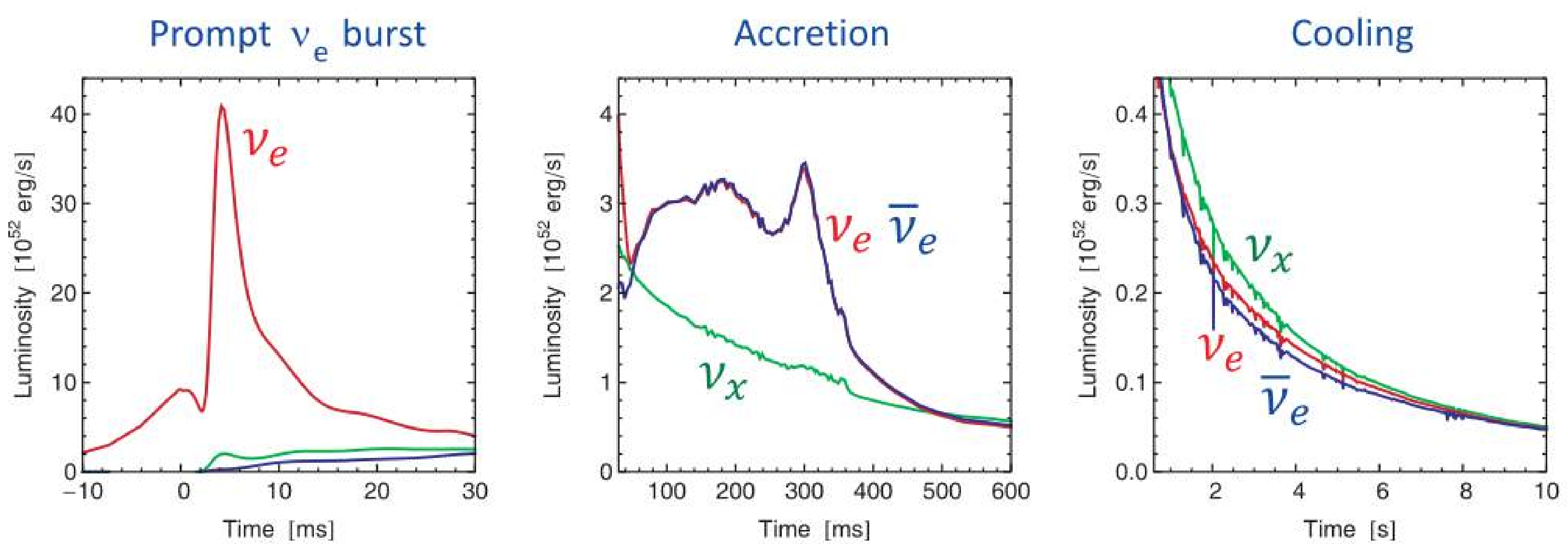
- <u>Supernova Neutrino Emission</u>

  - strong emission of neutrinos from colapsing stars

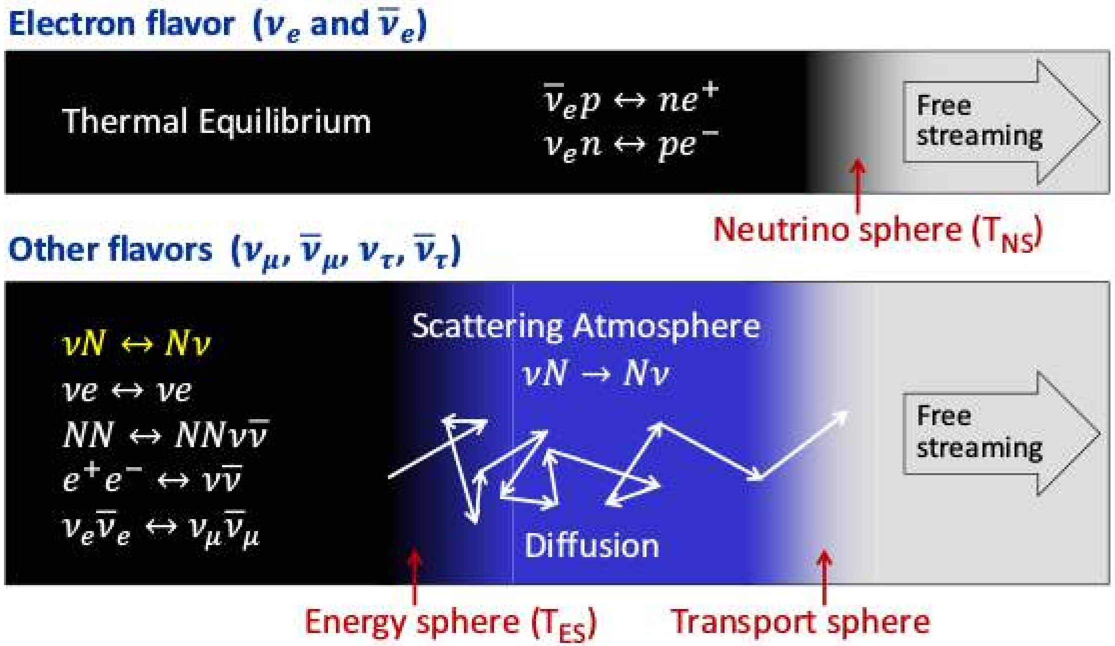



Raffelt, 1201.1637

# *Supernova Neutrinos*

- Supernova Neutrino Emission

  - close to thermal emission, with $\langle E_{\nu_e} \rangle < \langle E_{\bar{\nu}_e} \rangle < \langle E_{\nu_x} \rangle$

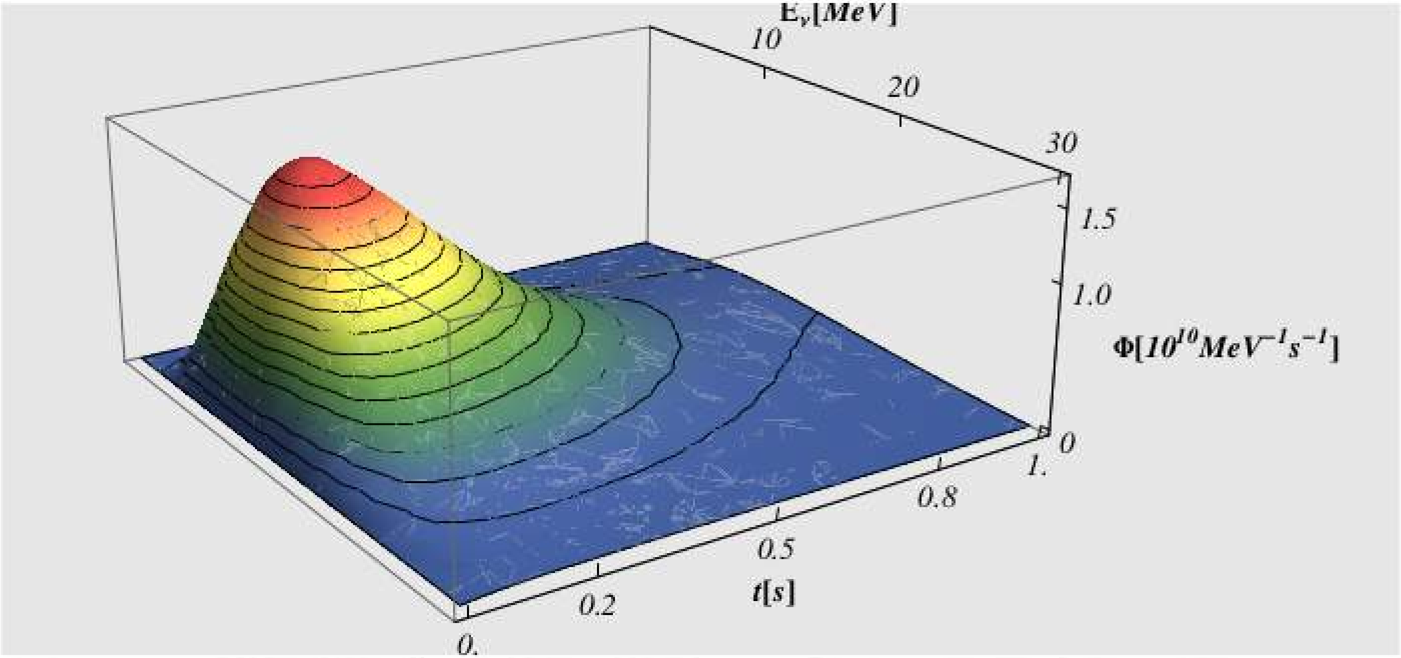



Raffelt, 1201.1637

# Supernova Neutrinos

- <u>Supernova Neutrino Emission</u>

  - importance features on time and energy structure!

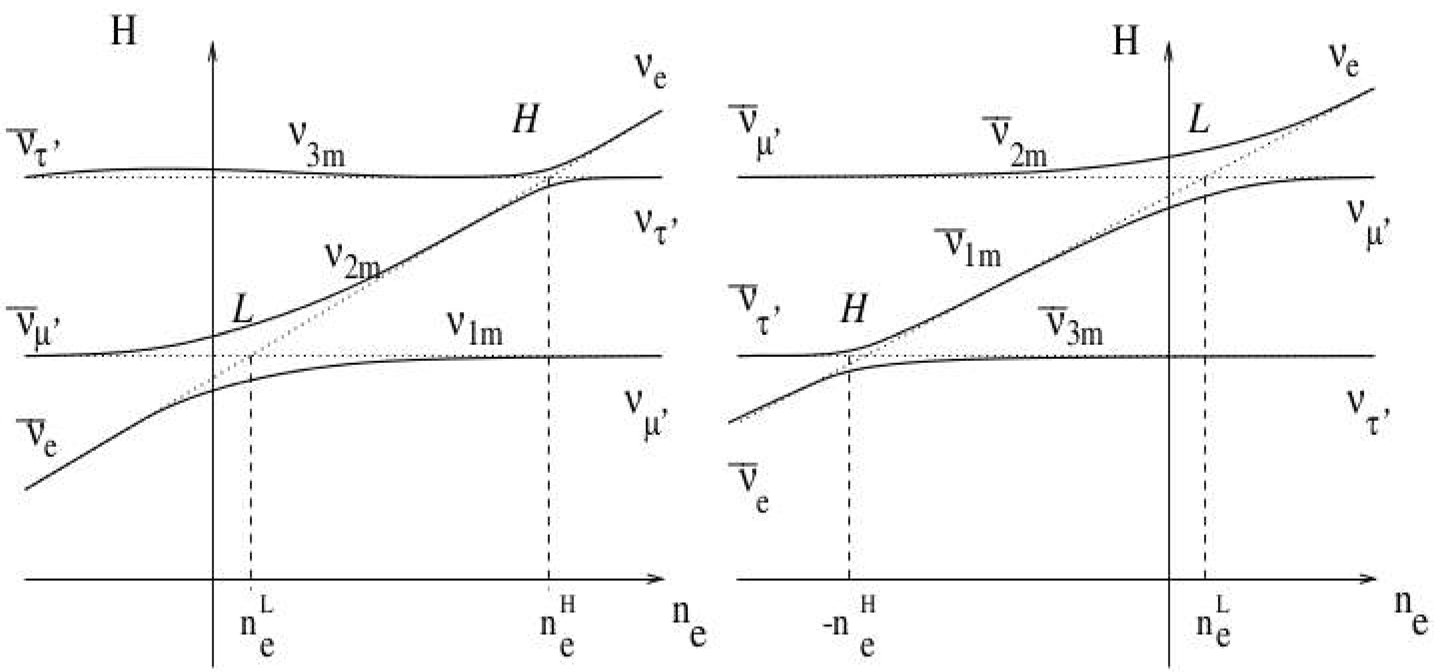



from Vissani's talk, Paris 2011.

# *Supernova Neutrinos*

- <u>Supernova Neutrino Conversion</u>

  - like solar neutrinos, supernova neutrinos are produced in a dense medium, in flavour eigenstates that relates to mass eigenstates through proper diagonalization of the Hamiltonian.




normal inverted

# Supernova Neutrinos

But things are more complicated:

$$i\frac{d\rho_{\vec{p}}}{dt} = [\Omega^0_{\vec{p}}, \rho_{\vec{p}}] + [\Omega^{int}_{\vec{p}}, \rho_{\vec{p}}] + C[\rho_{\vec{p}}, \bar{\rho}_{\vec{p}}]$$

νν interaction

$$\Omega^0_{\vec{p}} = \frac{M^2}{2p}$$

$$\Omega^{int}_{\vec{p}} = \sqrt{2}G_F(N_{e^-} - N_{e^+} - 8pE/3m_W^2)$$

$$C = \sqrt{2}G_F\left[\rho - \bar{\rho} - \frac{8p}{3m_Z^2}(\bar{U} + U)\right]$$

$$\rho = \int \frac{d^3p}{(2\pi)^3}\rho_{\vec{p}} \qquad U = \int \frac{d^3p}{(2\pi)^3}p\rho_{\vec{p}}$$

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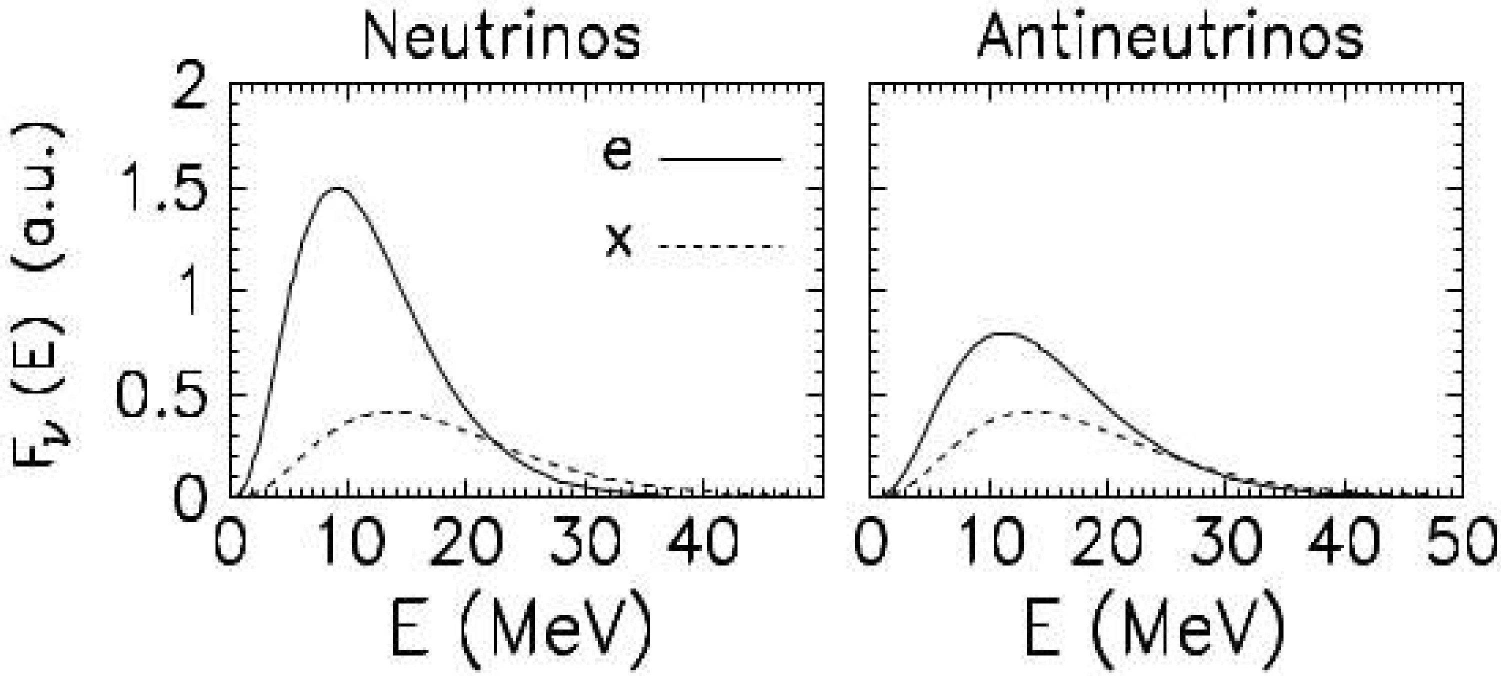

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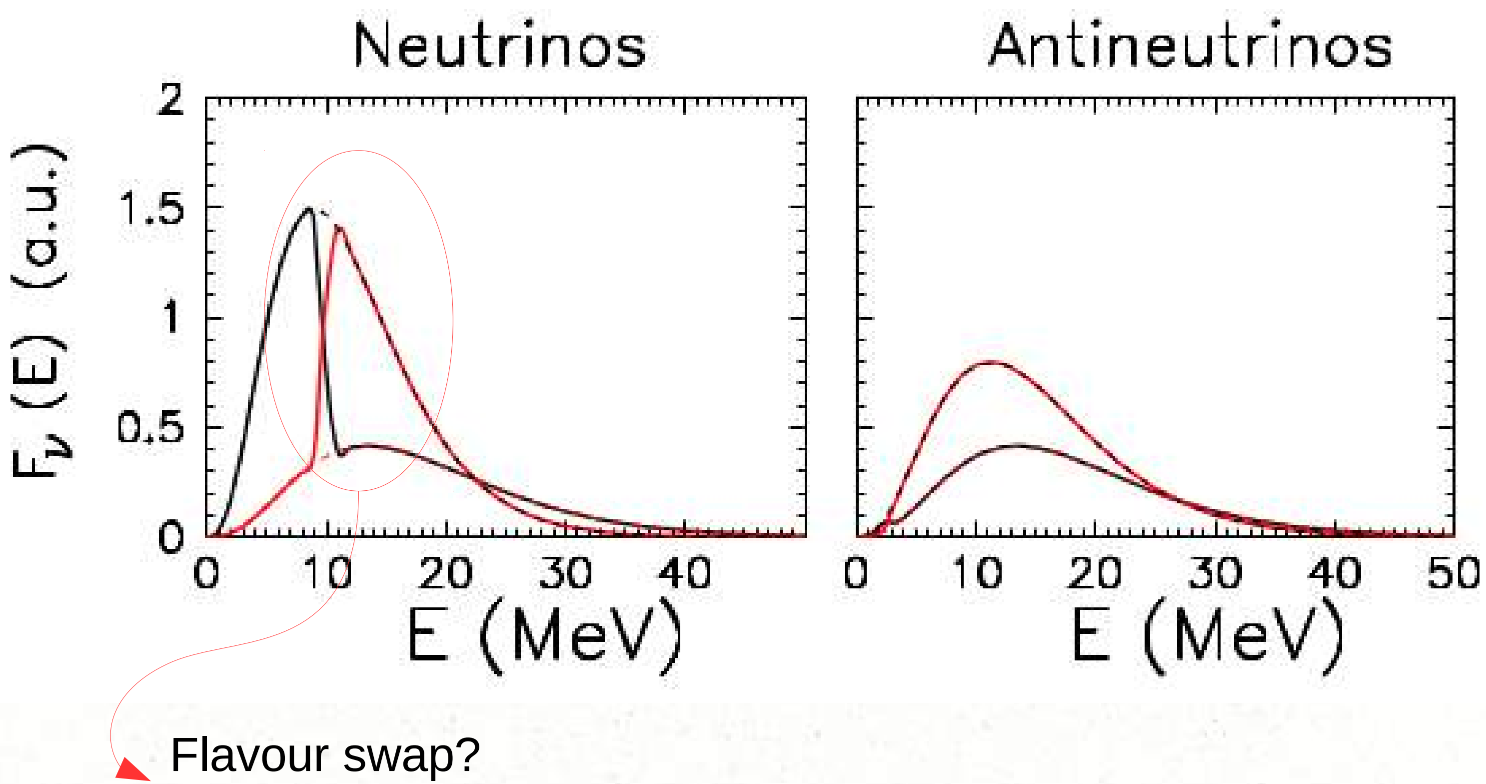
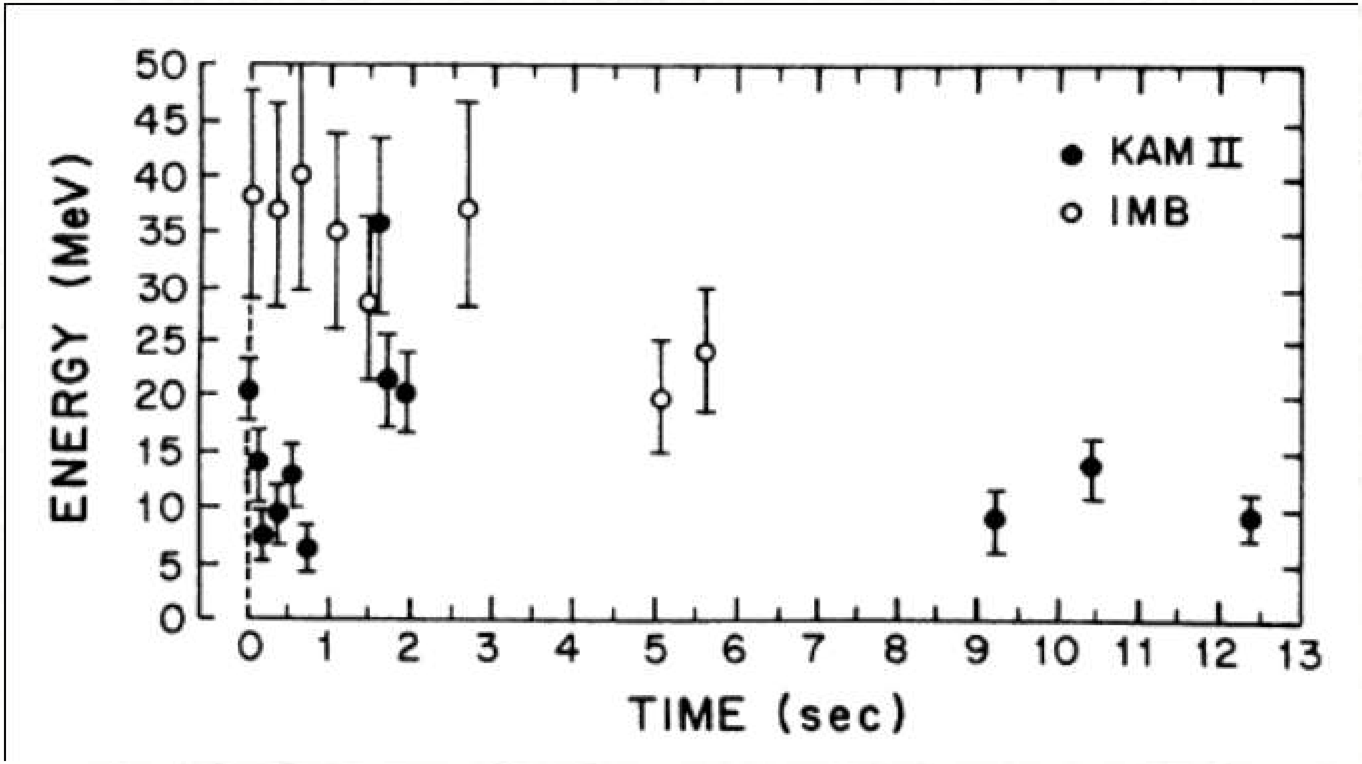



Flavour swap?
Collective oscillations?

To be honest, we don't know the flavour distribution of supernova neutrinos!

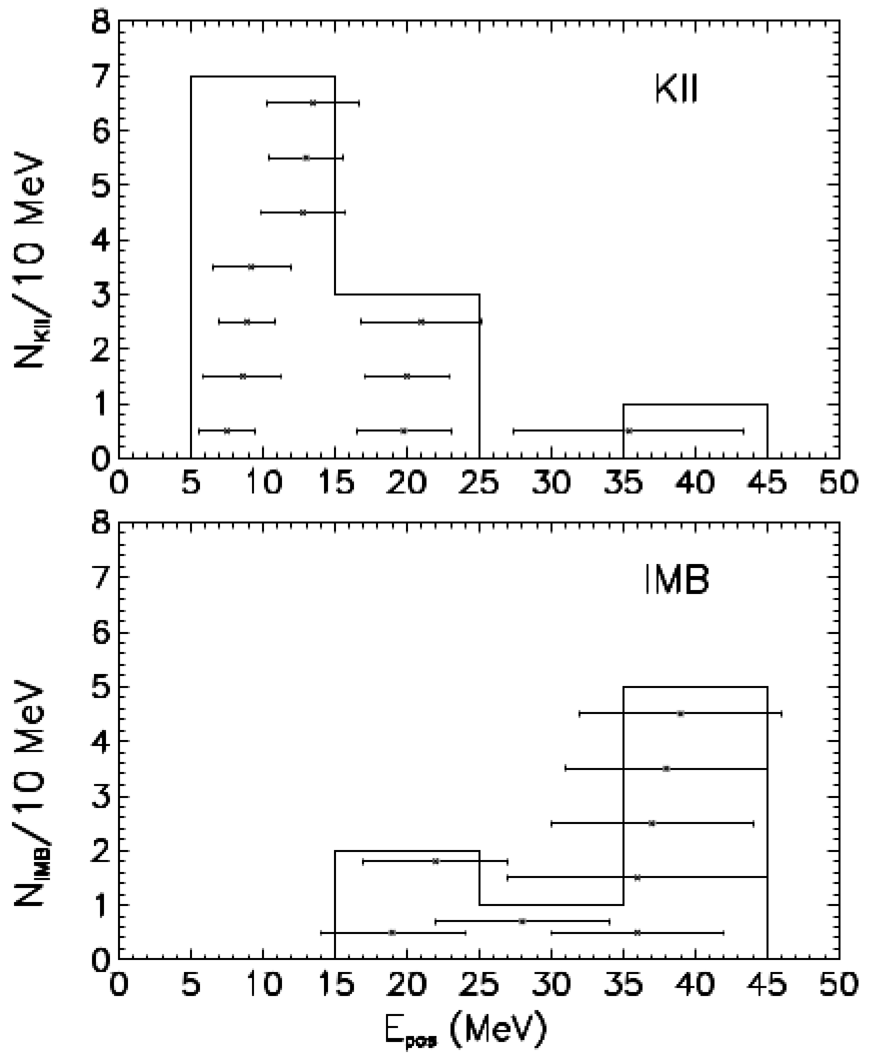
# *Supernova Neutrinos*

**SN 1987A: a succesfull case for Supernova Neutrino detection**



# Supernova Neutrinos

**SN 1987A**



# *Supernova Neutrinos*

- Next Galactic Supernova will provide great statistics;
- Strong conversion of physicist into supernova neutrino specialists;
- > 200 articles in the first month;
- dedicated conferences in nice places;
- a lot of learning opportunities.

**Fortunately, it will happen in our lifetime.**

# *Diffuse Supernova Background DSNB*

# *Diffuse Supernova Background DSNB*

- Why waiting for a gallactic SN, if somewhere else in the Universe a SN is exploding every second?

$$1/r^2$$

worse then that, we have to account redshift and space expansion!

- But what if we integrate the signal of all neutrinos from SN explosions?

# *Diffuse Supernova Background DSNB*

Related question: **Olbers' paradox.**

# *Diffuse Supernova Background DSNB*

Related question: Olbers' paradox.

Why is the night dark?

$$L(t) = \int_0^\infty \frac{L_s(t)}{r^2} 4\pi r^2 dr \rightarrow \infty$$

We should have a bright sky!

# *Diffuse Supernova Background DSNB*

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- Universe is expanding, so photons redshift.

# Diffuse Supernova Background DSNB

- Back to DSNB:

$$\Phi_(\nu_\alpha) = \frac{c}{H_0}\int_{M_0}^{M_{max}}\int_0^{z_{max}} dz \frac{\dot{\rho}_{SN}(z,M)F_{\nu_\alpha}(E(1+z),M)}{\sqrt{\Omega_M(1+z)^3+\Omega_\Lambda}}$$

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► - SN explosion rate

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- SN explosion rate
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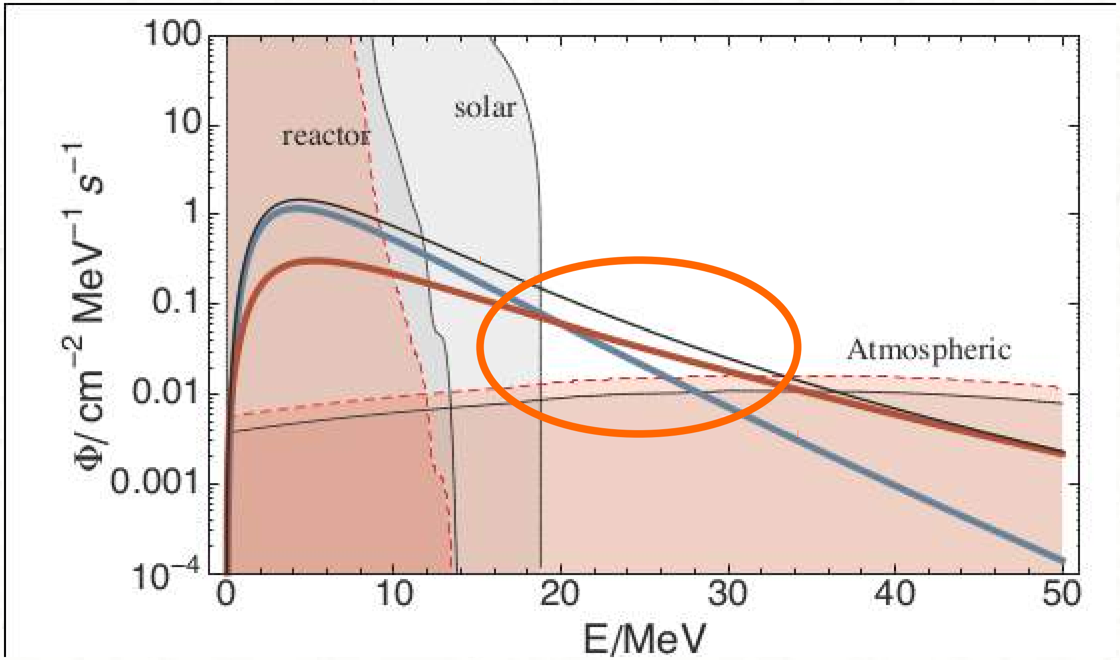
- SN explosion rate
- neutrino energy redshifted
- universe expansion

# *Diffuse Supernova Background DSNB*

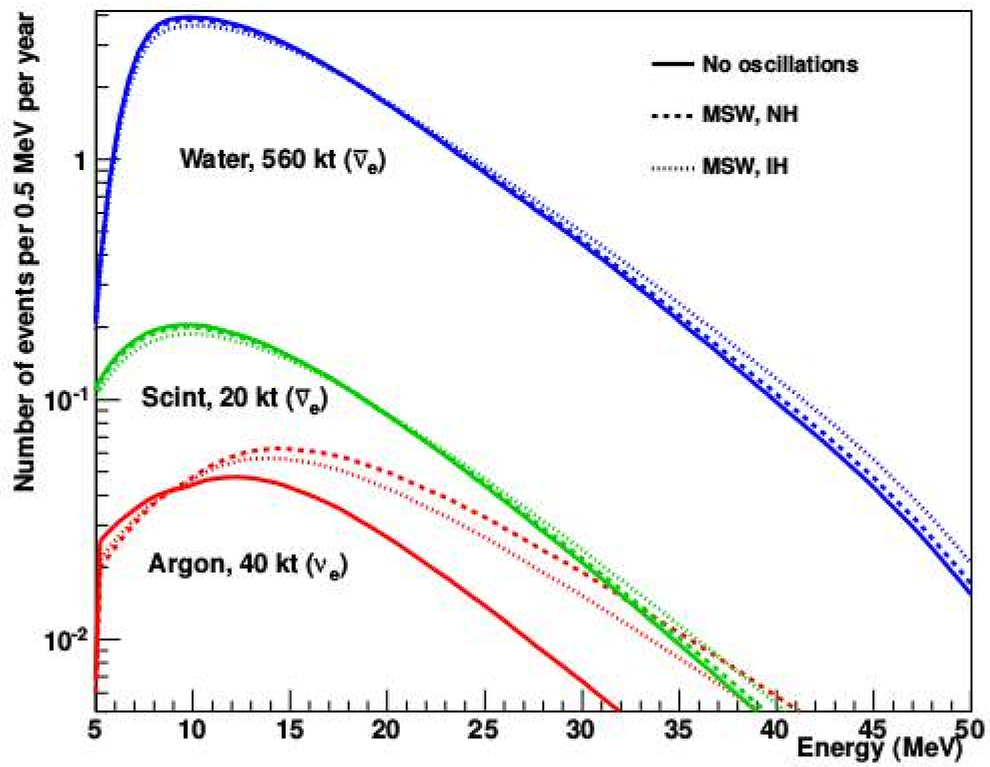
- Small window between solar and atmospheric neutrinos to search for DSNB.




Lunardini et al., ArXiV:1012.1274

# *Diffuse Supernova Background DSNB*

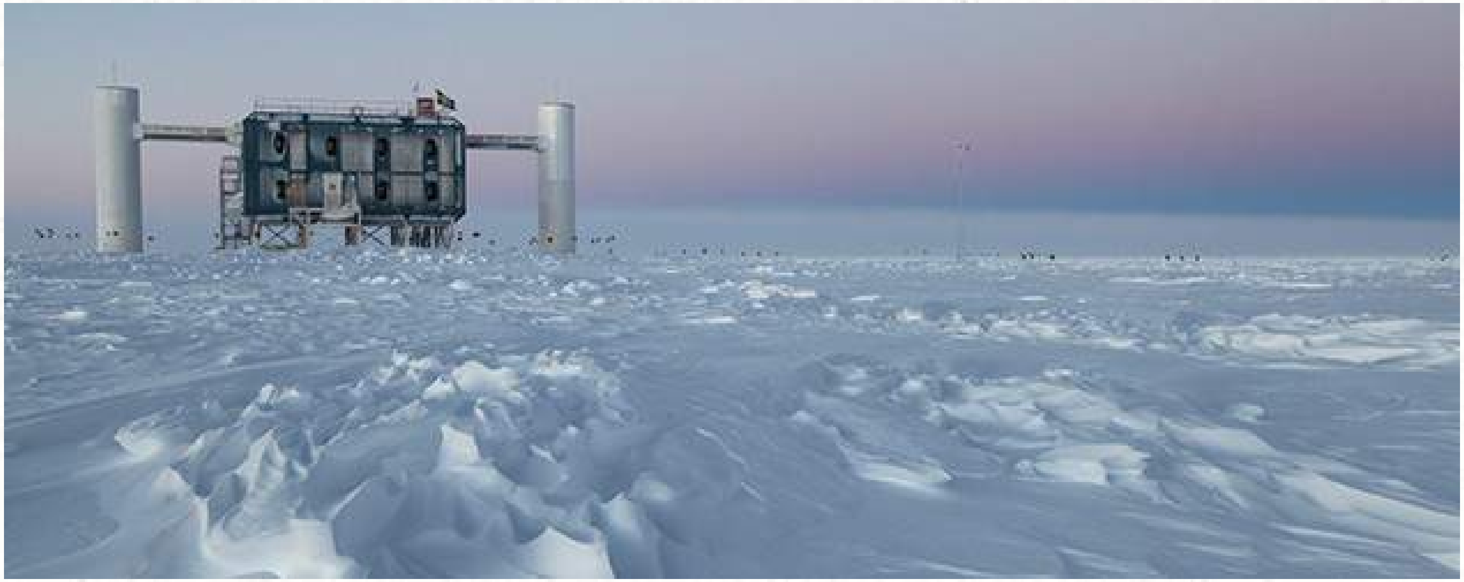
- but with a chalenging event rate...



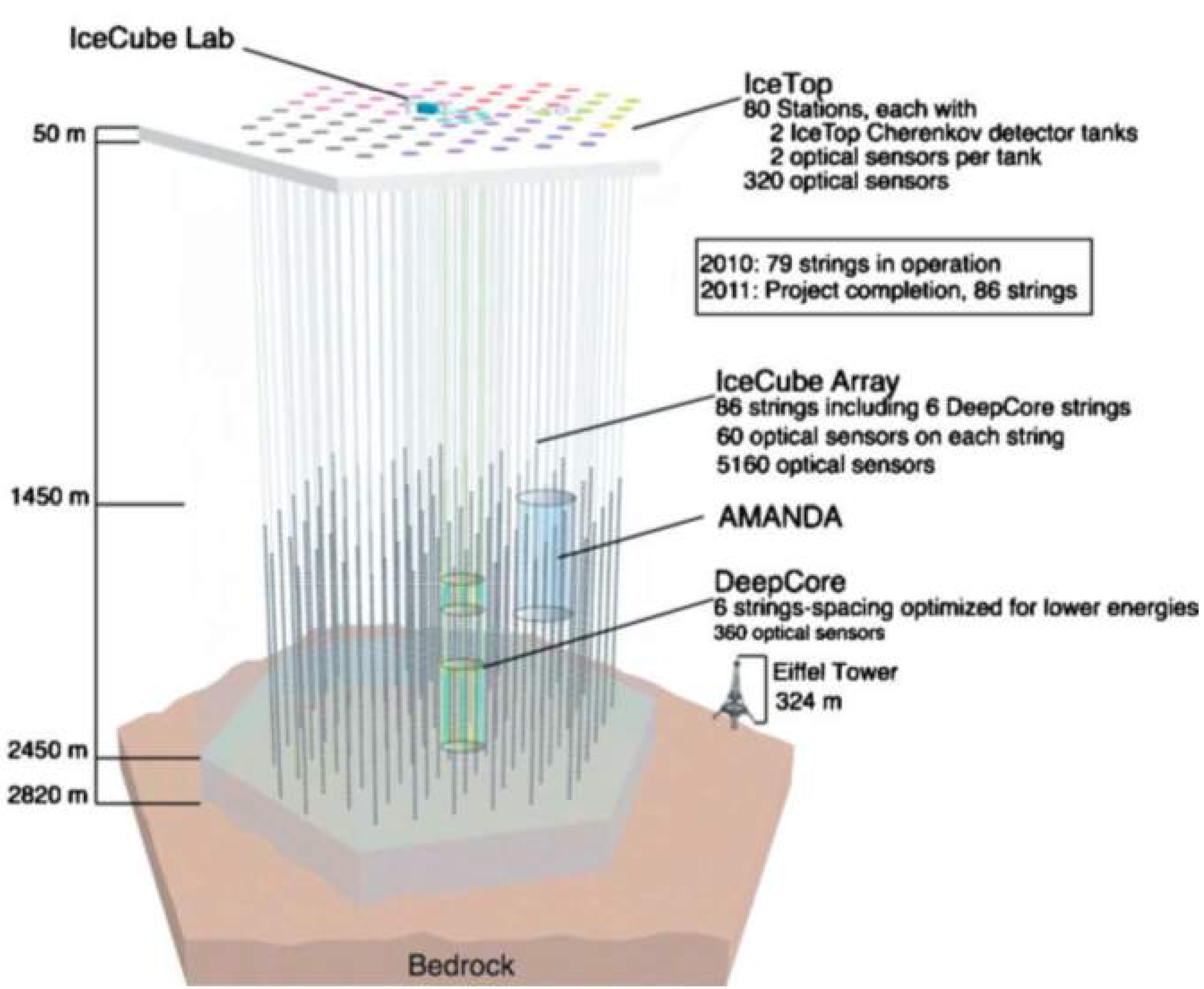

From ArXiV:1508.00785

# *High-Energy Neutrinos*

# *Icecube*



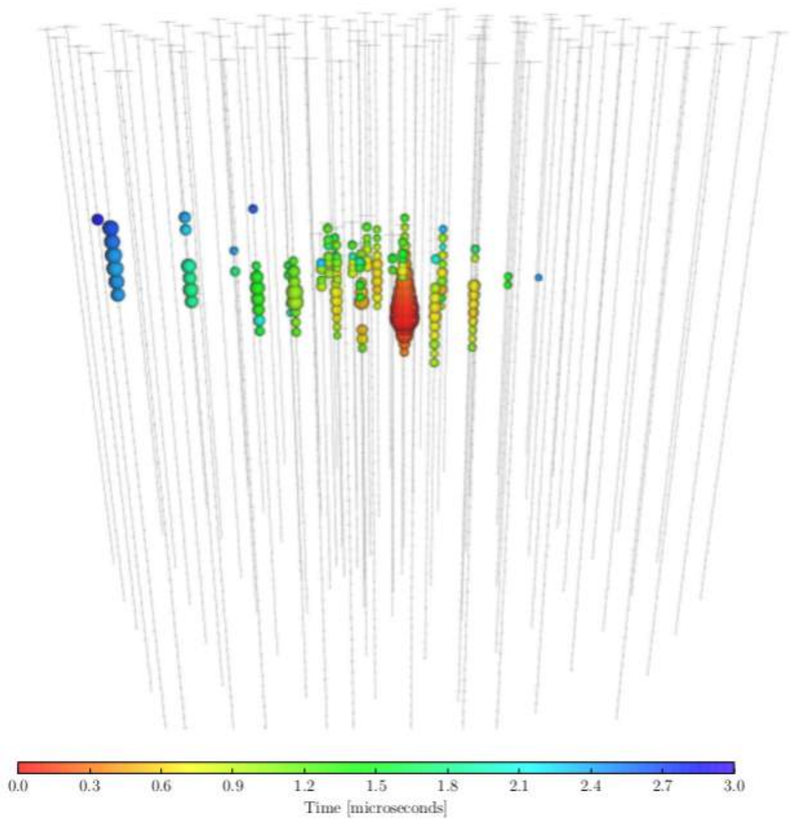
# Icecube



IceCube Lab
IceTop
80 Stations, each with
2 IceTop Cherenkov detector tanks
2 optical sensors per tank
320 optical sensors
50 m
2010: 79 strings in operation
2011: Project completion, 86 strings
IceCube Array
86 strings including 6 DeepCore strings
60 optical sensors on each string
5160 optical sensors
1450 m
AMANDA
DeepCore
6 strings-spacing optimized for lower energies
360 optical sensors
Eiffel Tower
324 m
2450 m
2820 m
Bedrock

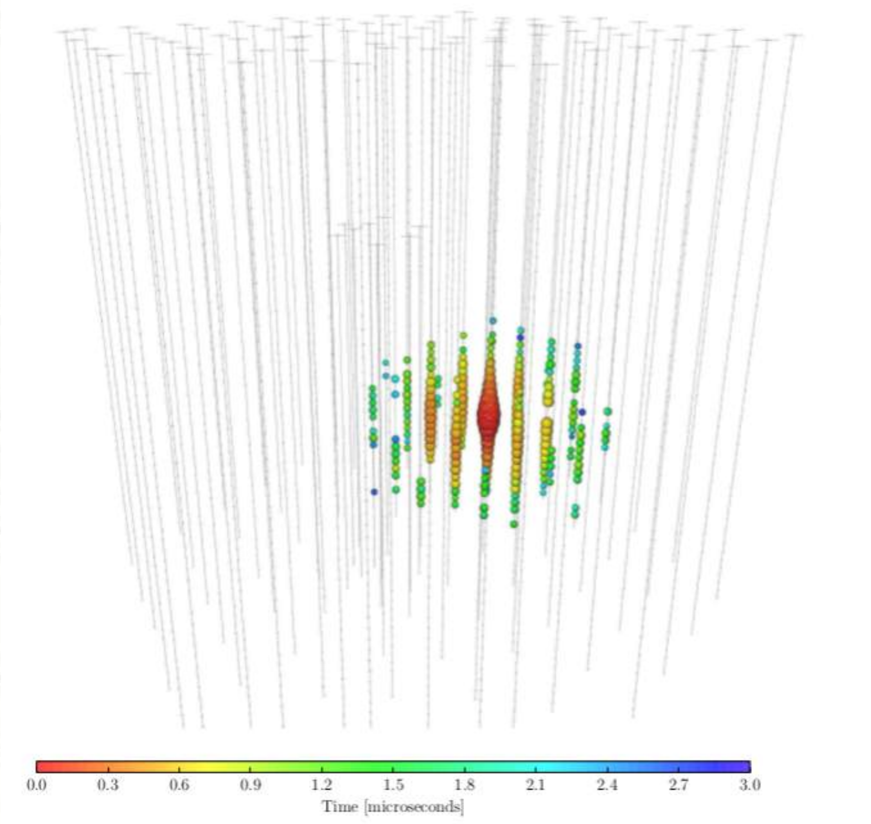
# Icecube

- detect cherenkov light from charged particles.
- incoming neutrino produces the associated charged lepton through charged current.
    - Muon neutrinos leave a track + a hadronic shower.



# *Icecube*

- detect cherenkov light from charged particles.
- incoming neutrino produces the associated charged lepton through charged current.
  - Electron and (low energy) tau neutrinos produce only a shower



# *Icecube*

- events with muon tracks has an excelent angular resolution < $1^o$.

- But events are not contained, so energy leaks out of the detector, making it difficult to find original neutrino energy.
- Huge atmospheric background, difficult (but not impossible) to distinguish non-atmospheric neutrinos.
- At such high energies, neutrino absortion on Earth is relevant, so more sensible to downgoing neutrinos: south hemisphere

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  - At such high energies, neutrino absortion on Earth is relevant, so more sensible to downgoing neutrinos: south hemisphere

- Shower events can do a better job in reconstructing neutrino energy, but with poor direccionality: < 30º

  - Sensible to electronic and tauonic neutrinos, not present in atmospheric neutrino flux for high energies → cleaner background

# IceCube Runs

**Table 1. IceCube neutrino data samples.** Six data-taking periods make up the full 9.5-year data sample. Sample numbers correspond to the number of detector strings that were operational. During the first three periods, the detector was still under construction. The last three periods correspond to different data-taking conditions and/or event selections with the full 86-string detector.

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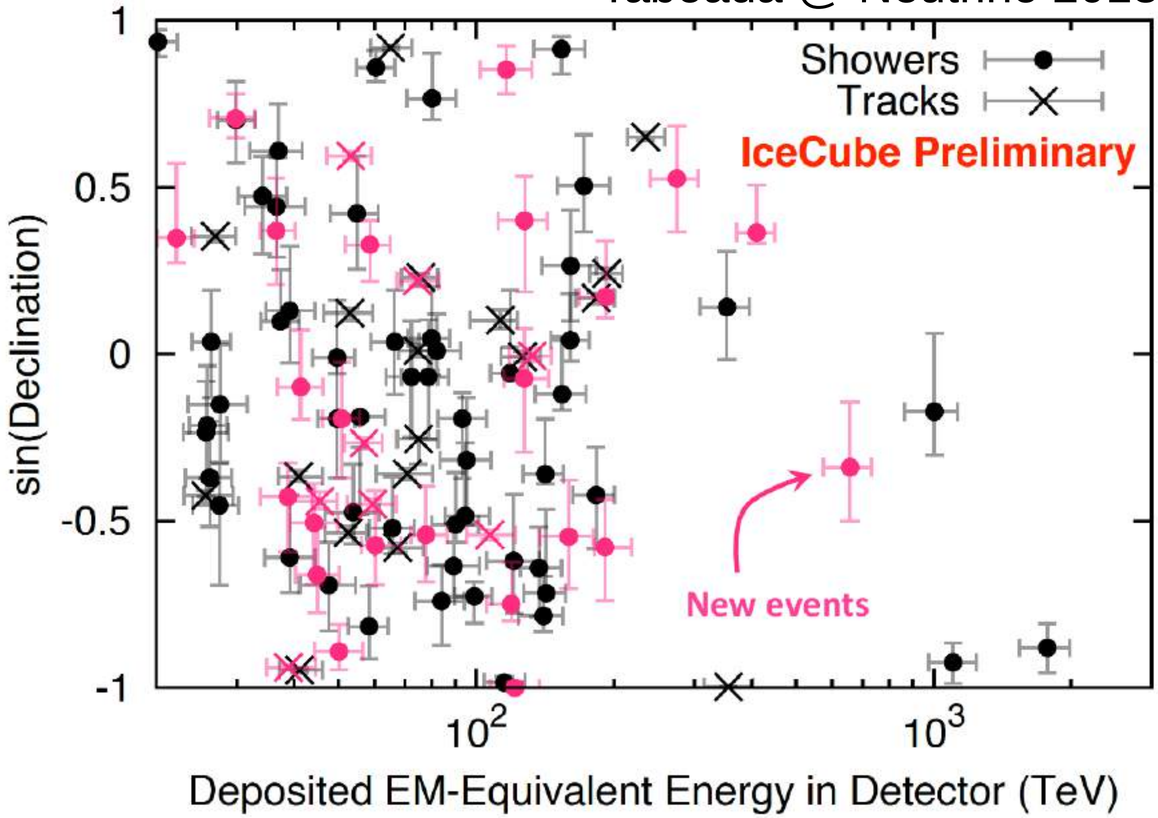
# *Icecube, track x showers*

- 103 events (60 events with energy > 30 TeV)

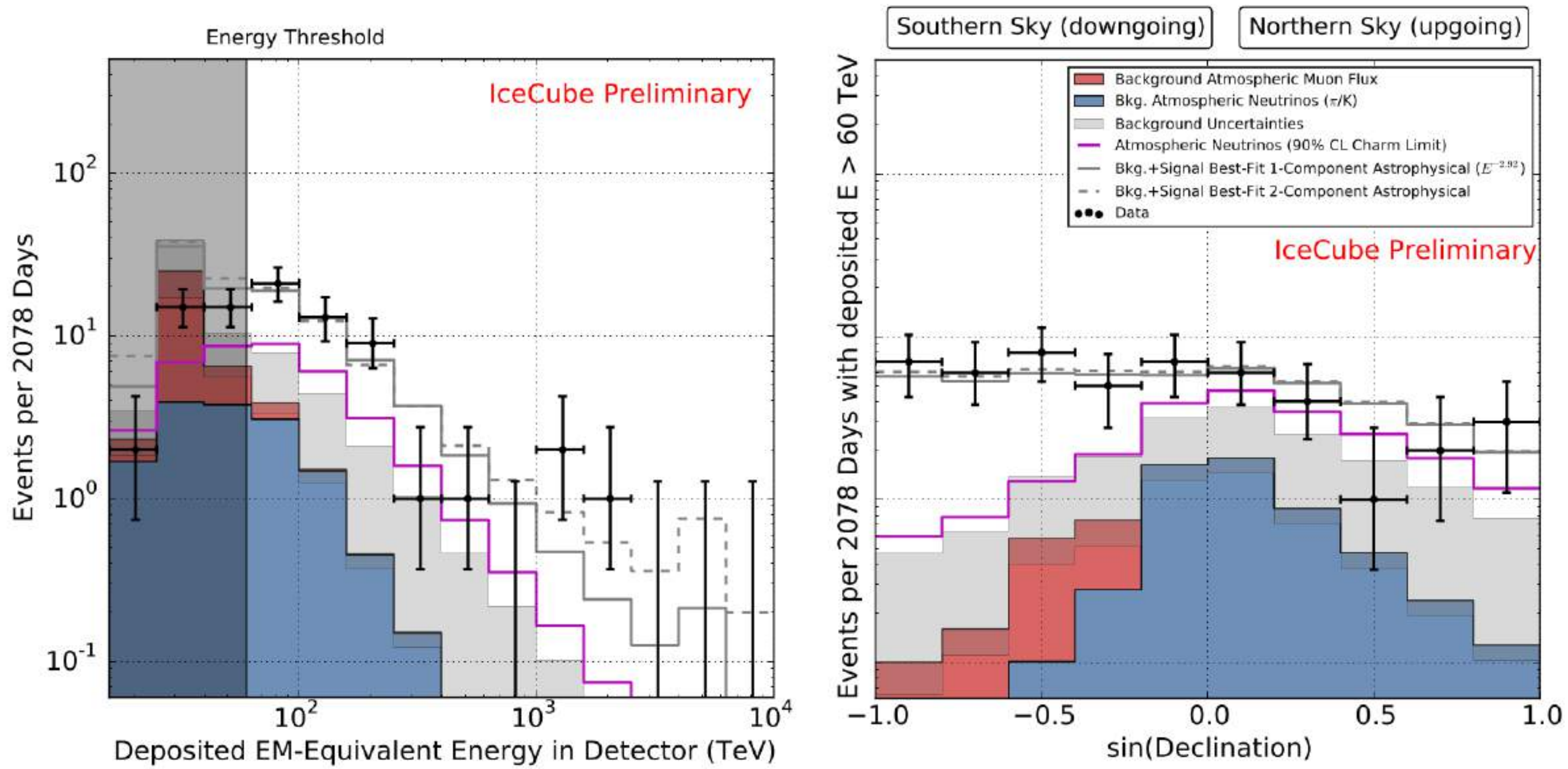
Taboada @ Neutrino 2018



# *Icecube, track x showers*

Event excess in high-energy and downgoing.

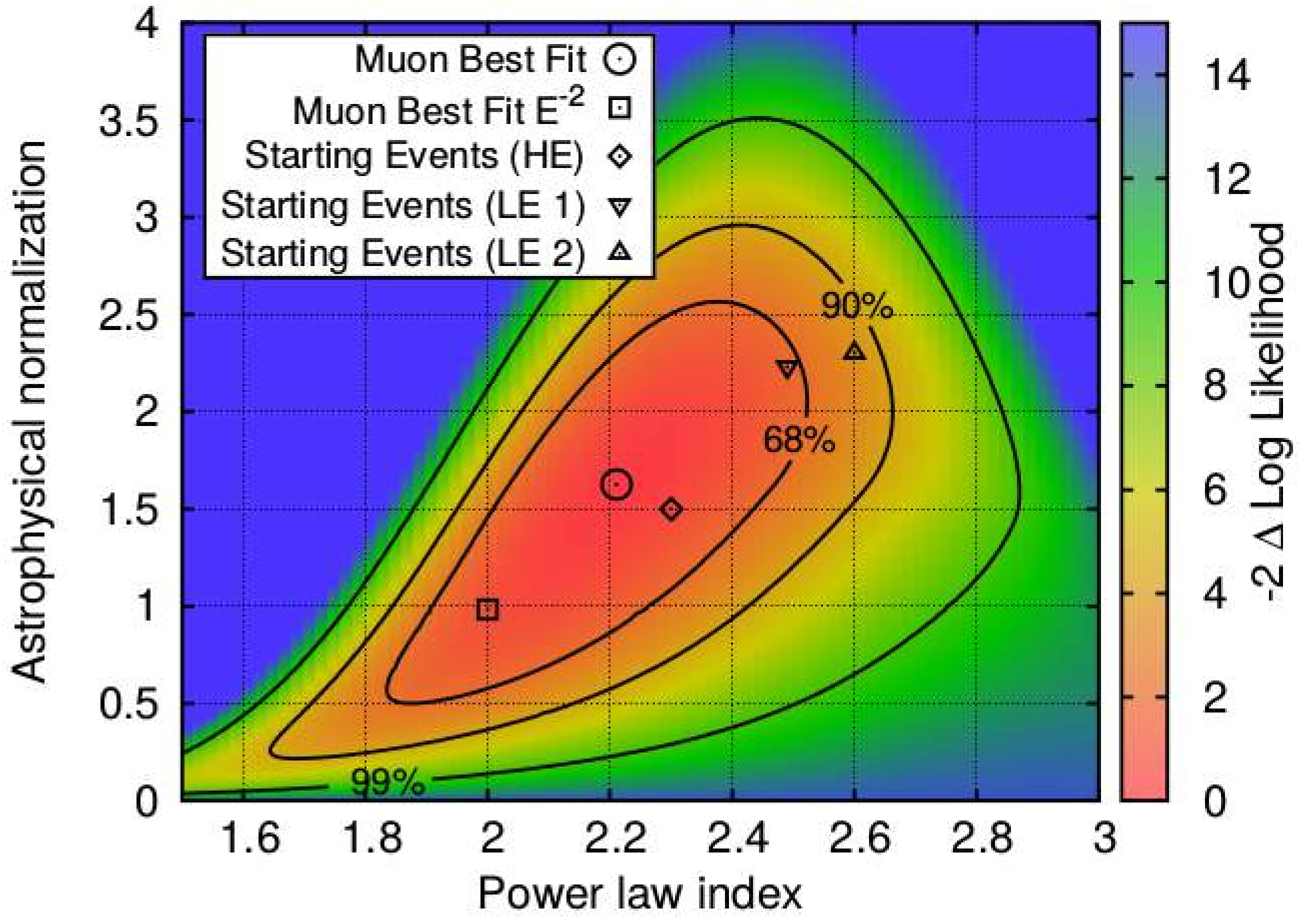
Taboada @ Neutrino 2018




(a) deposited energies

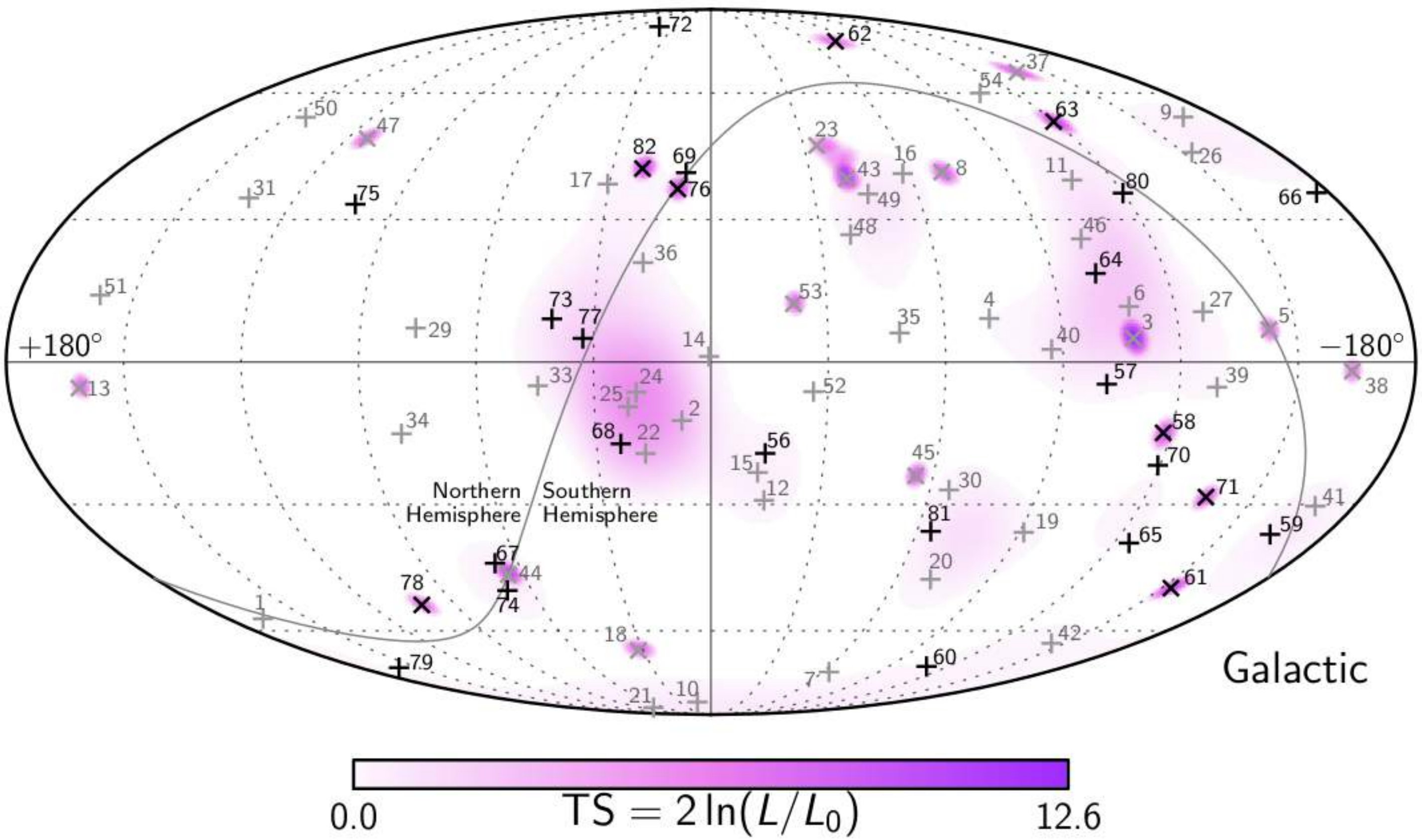
(b) arrival directions

# $\nu_\mu$ from northern hemisphere



# *Icecube, track x showers*

No directionality (!)



# *Flavor composition*

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Due to large mixing angles, flavour distribution in initial neutrino fluxes changes with neutrino evolution.

Píon decay:

$$(\nu_e : \nu_\mu : \nu_\tau) = (1 : 2 : 0) \xrightarrow[\text{evolution}]{\text{neutrino}} (0.93 : 1.05 : 1.02)$$

Muon damped / radioactive decay:

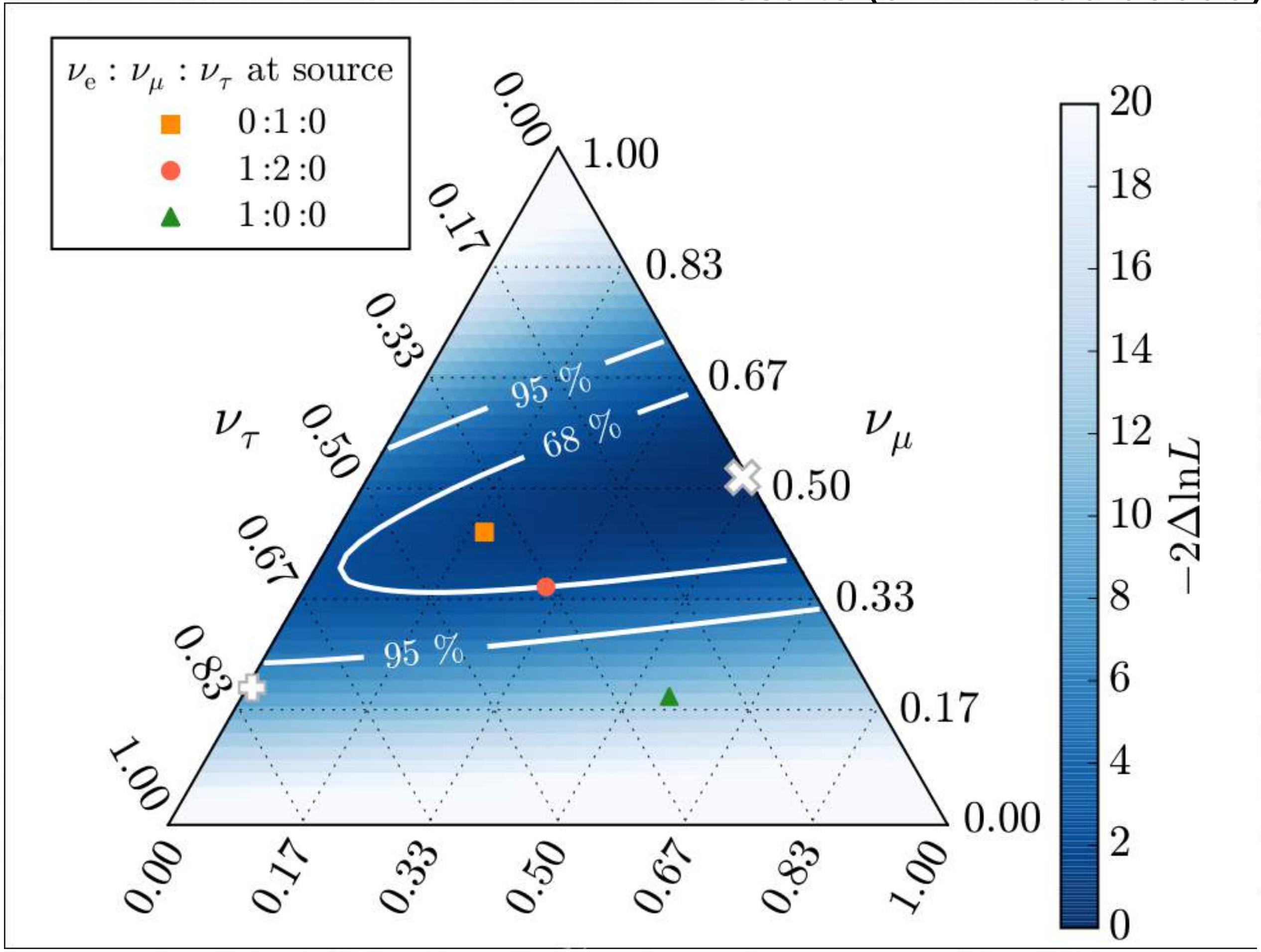
$$(\nu_e : \nu_\mu : \nu_\tau) = (1/0 : 0/1 : 0)$$

$$\xrightarrow[\text{evolution}]{\text{neutrino}} \begin{cases} (1.6 : 0.6 : 0.8) \\ (0.6 : 1.3 : 1.1) \end{cases}$$

It is reasonable to expect something close to (1:1:1) on Earth.

# *Flavor composition*

Results (arxiv:1806.05696)



# But, recently:

RESEARCH ARTICLE

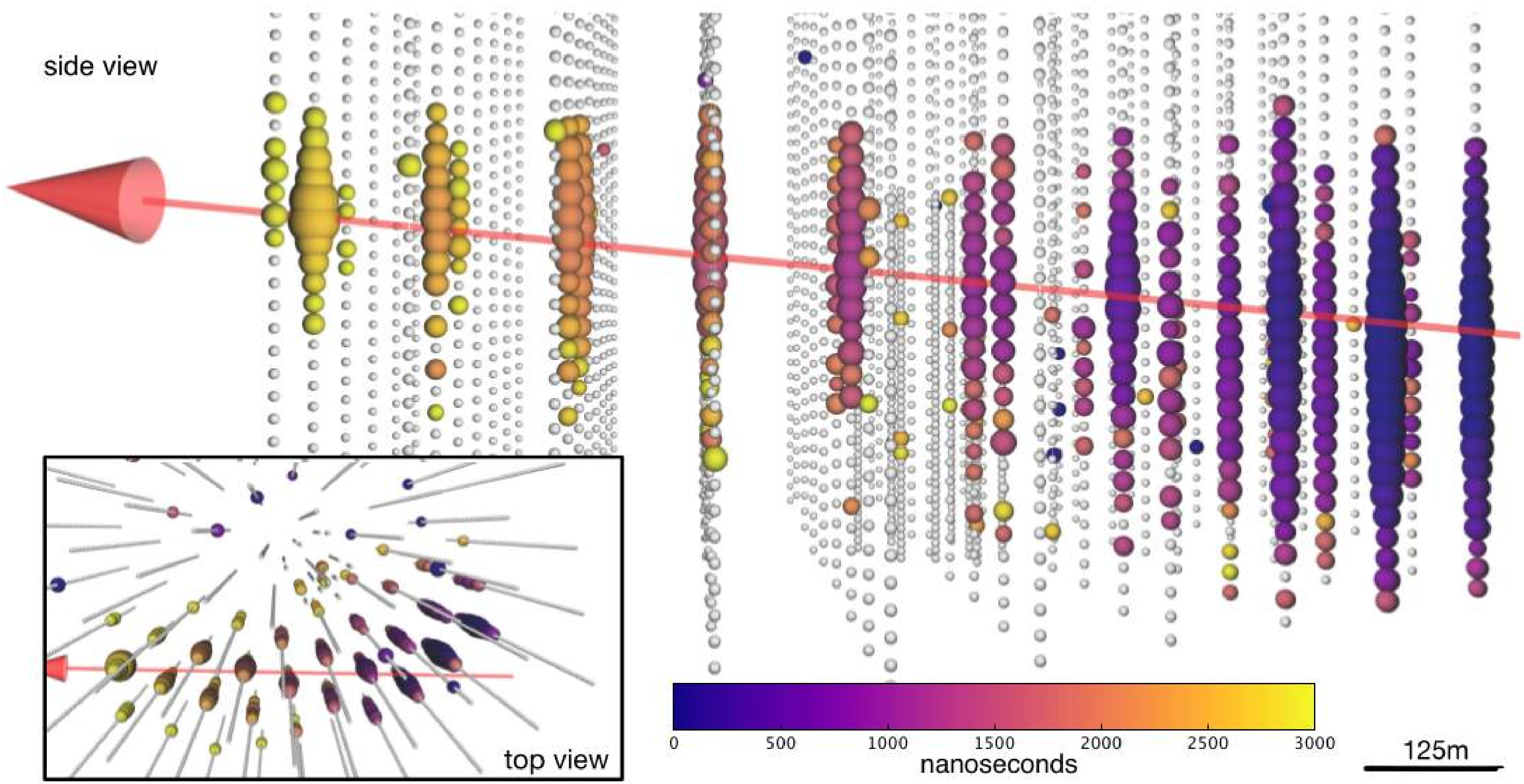
NEUTRINO ASTROPHYSICS

## Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A

The IceCube Collaboration, *Fermi*-LAT, MAGIC, *AGILE*, ASAS-SN, HAWC, H.E.S.S., *INTEGRAL*, Kanata, Kiso, Kapteyn, Liverpool Telescope, Subaru, *Swift/NuSTAR*, VERITAS, and VLA/17B-403 teams*†

Previous detections of individual astrophysical sources of neutrinos are limited to the Sun and the supernova 1987A, whereas the origins of the diffuse flux of high-energy cosmic neutrinos remain unidentified. On 22 September 2017, we detected a high-energy neutrino, IceCube-170922A, with an energy of ~290 tera–electron volts. Its arrival direction was consistent with the location of a known γ-ray blazar, TXS 0506+056, observed to be in a flaring state. An extensive multiwavelength campaign followed, ranging from radio frequencies to γ-rays. These observations characterize the variability and energetics of the blazar and include the detection of TXS 0506+056 in very-high-energy γ-rays. This observation of a neutrino in spatial coincidence with a γ-ray–emitting blazar during an active phase suggests that blazars may be a source of high-energy neutrinos.

# *But, recently:*




Energy = 290 TeV,
Zenith angle = 5.7 degrees below horizon

# *And, then:*

RESEARCH ARTICLE

NEUTRINO ASTROPHYSICS

## Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert

IceCube Collaboration*†

A high-energy neutrino event detected by IceCube on 22 September 2017 was coincident in direction and time with a gamma-ray flare from the blazar TXS 0506+056. Prompted by this association, we investigated 9.5 years of IceCube neutrino observations to search for excess emission at the position of the blazar. We found an excess of high-energy neutrino events, with respect to atmospheric backgrounds, at that position between September 2014 and March 2015. Allowing for time-variable flux, this constitutes 3.5$\sigma$ evidence for neutrino emission from the direction of TXS 0506+056, independent of and prior to the 2017 flaring episode. This suggests that blazars are identifiable sources of the high-energy astrophysical neutrino flux.

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**Table 1. IceCube neutrino data samples.** Six data-taking periods make up the full 9.5-year data sample. Sample numbers correspond to the number of detector strings that were operational. During the first three periods, the detector was still under construction. The last three periods correspond to different data-taking conditions and/or event selections with the full 86-string detector.

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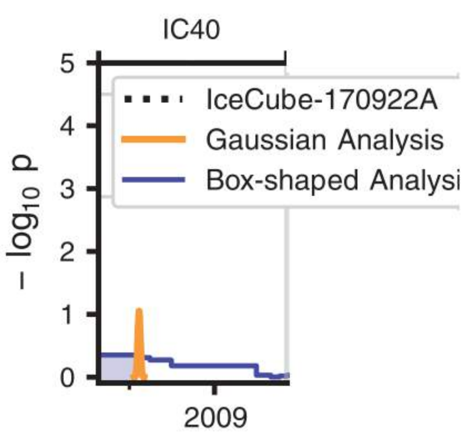

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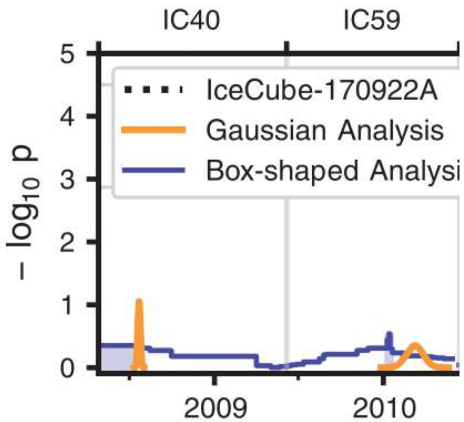

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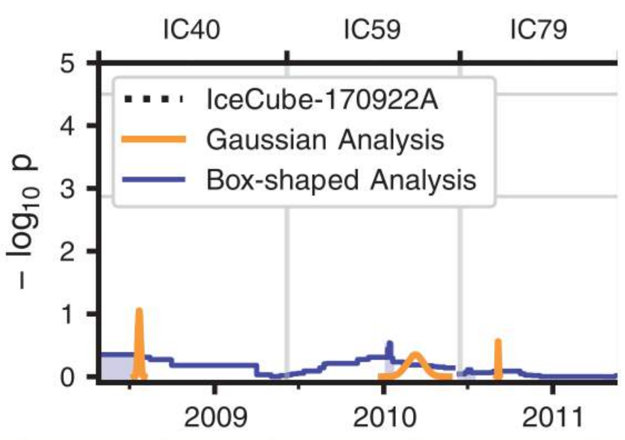

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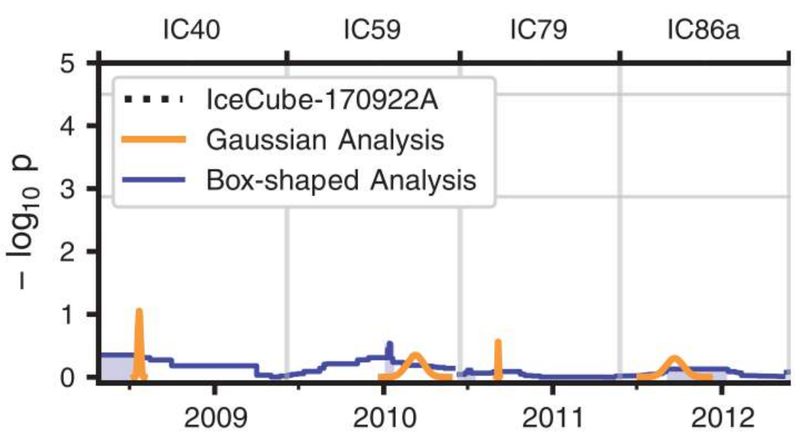

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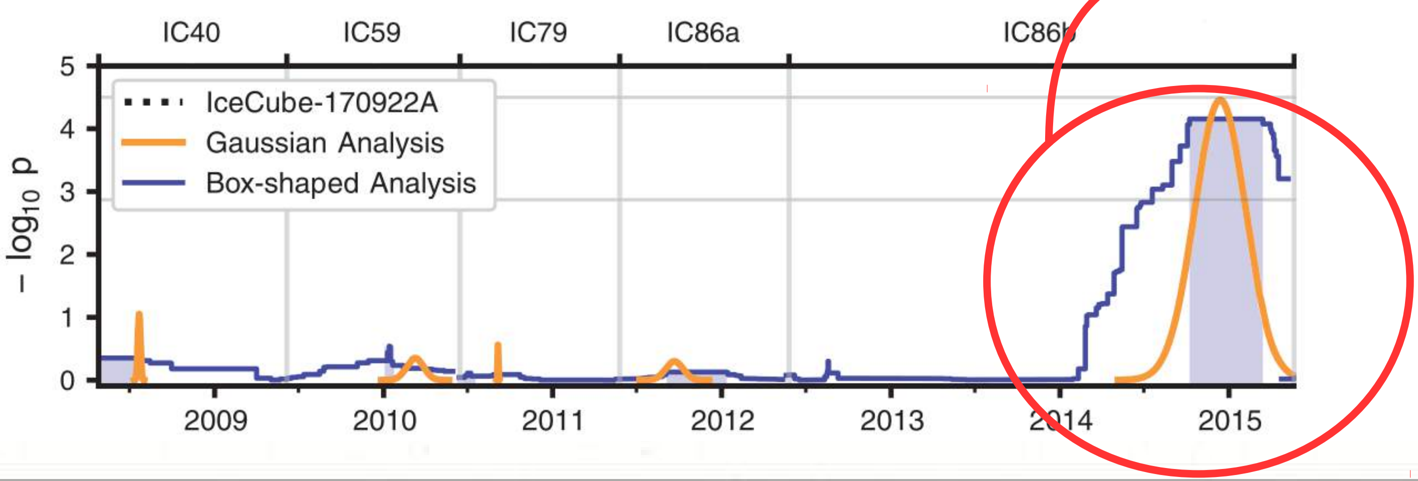
13 events in excess!



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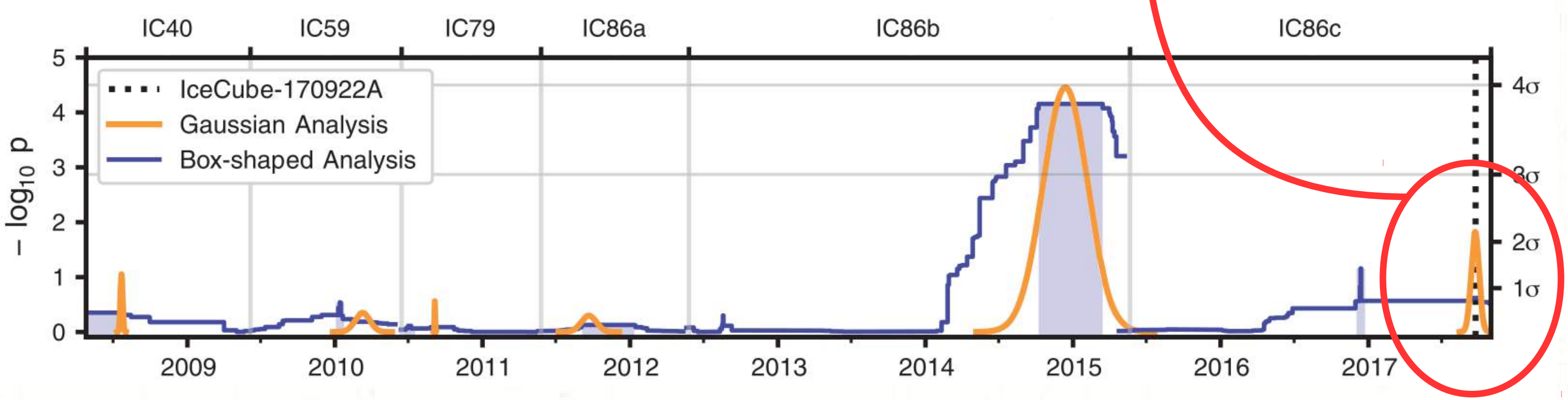
1 event that triggered the analysis



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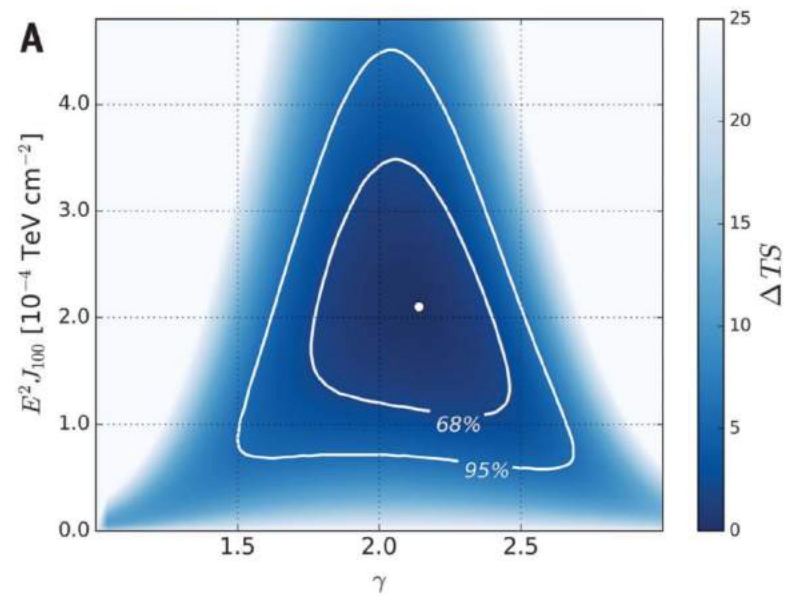


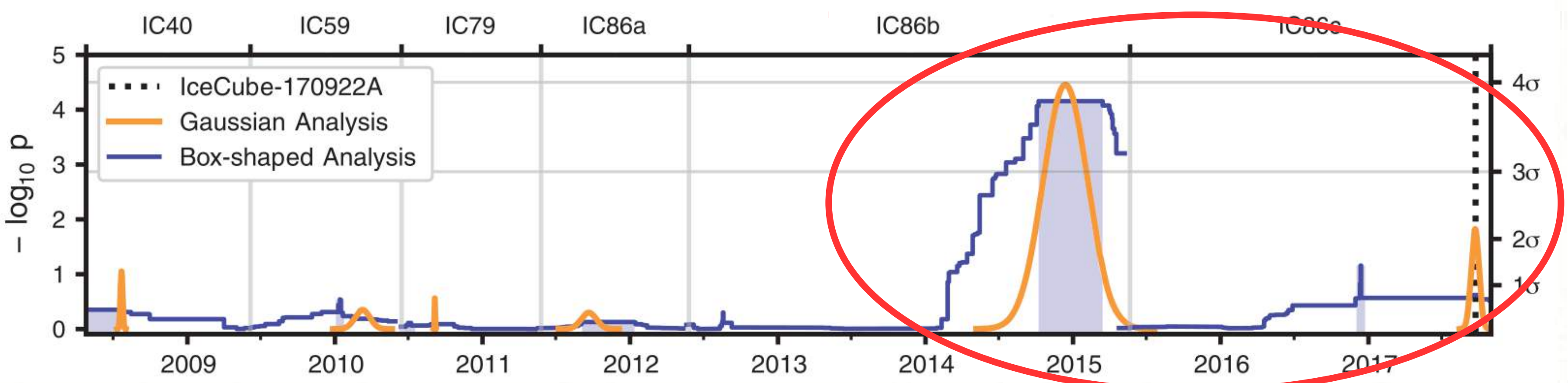

# *Announcement:*


Francis Halzen – IceCube Principal Investigator

Regina Caputo – Fermi-LAT Analysis Coordinator

Razmik Mirzoyan – MAGIC Spokesperson

Olga Botner – Former IceCube Spokesperson

# *Announcement:*


Multi-messenger!!

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# *Conclusions*

- work in progress...