理論研究計劃書 I : 準-狄拉克微中子(Pseudo-Dirac neutrino)震盪現象

idea and concept

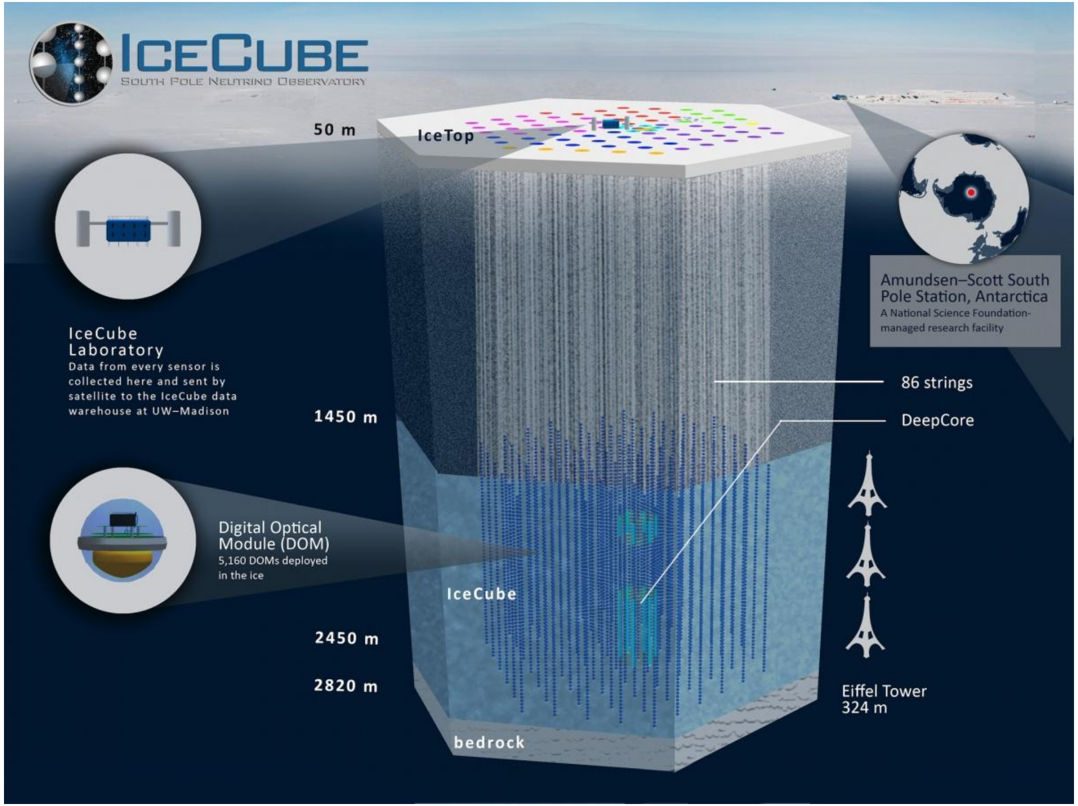
合作對象: 交大林貴林教授, 長庚賴光昶教授

Extra-High-Energy neutrinos with Pseudo-Dirac Neutrinos Mechanism

idea and concept

TsungChe Liu

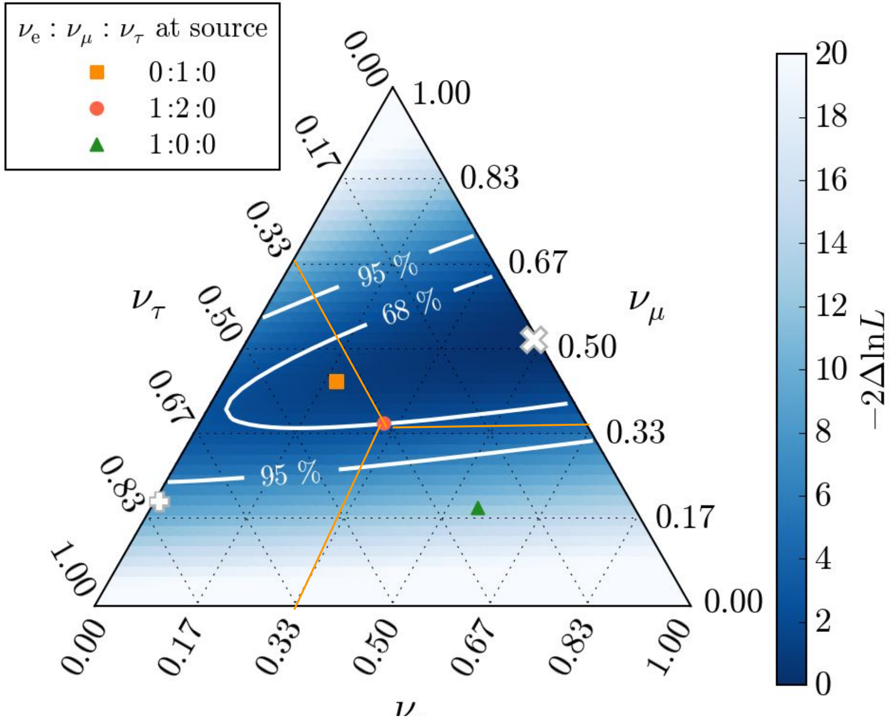
IceCube: The result of IceCube experiment



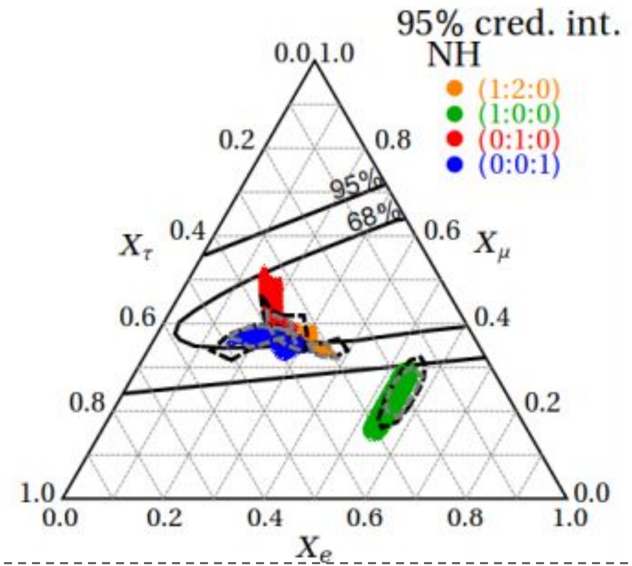
IceCube: 位於南極，於南極極點冰層下方架設佔地一立方公里的觀測站，以光電倍增管，量測微中子所衍生的光學訊號

The result of IceCube experiment

Best fit result from IceCube data (by Jan/16/2019).

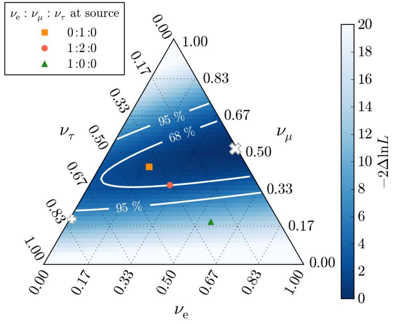


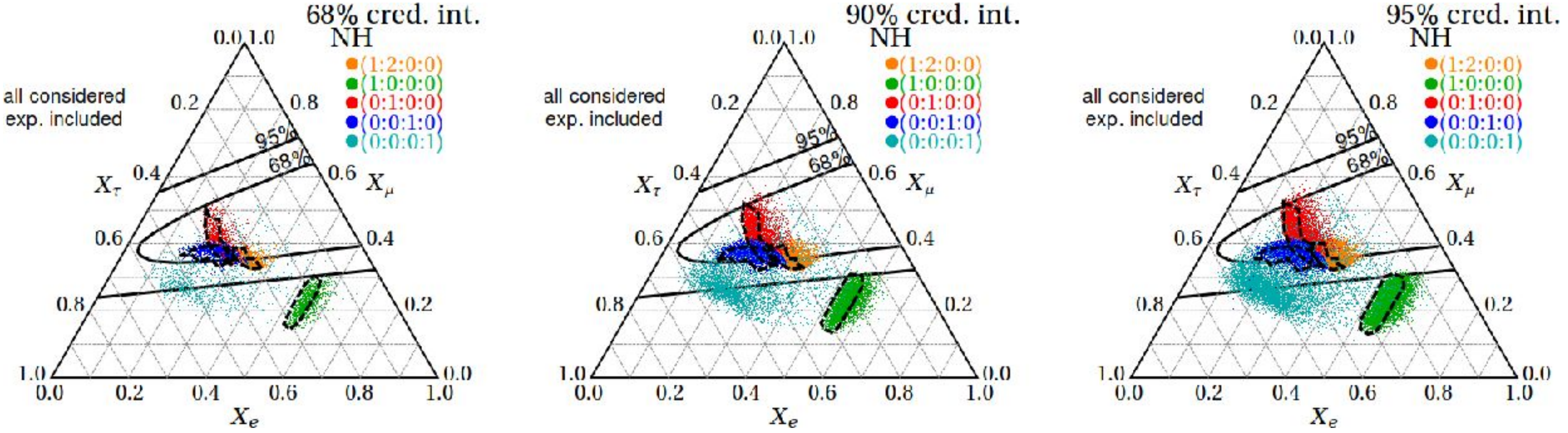
standard oscillation prediction



*The IceCube Collaboration has just performed its first measurement of tau neutrino appearance in oscillations of atmospheric muon neutrinos **arXiv:1901.05366**

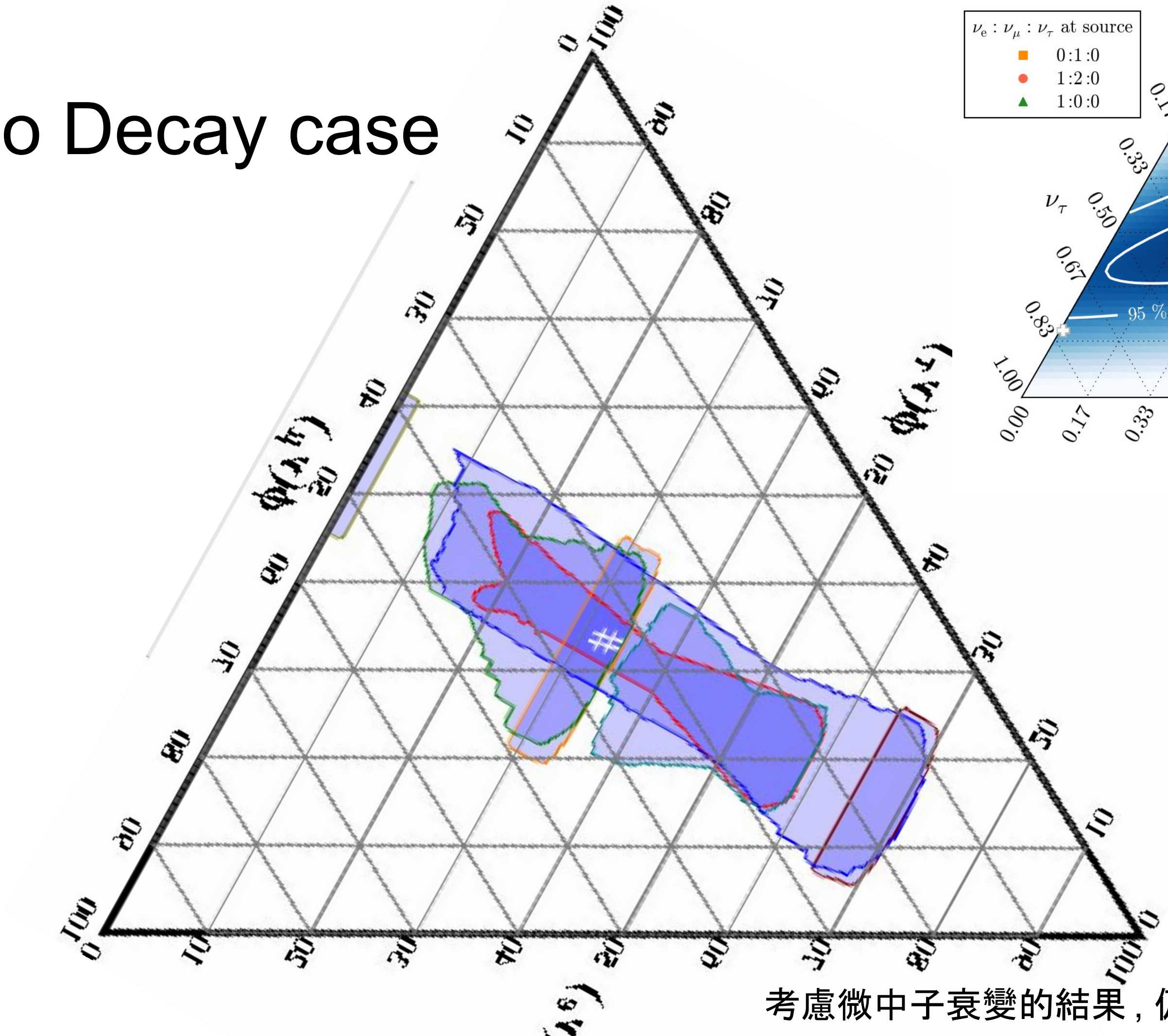
sterile neutrinos involve with the oscillation

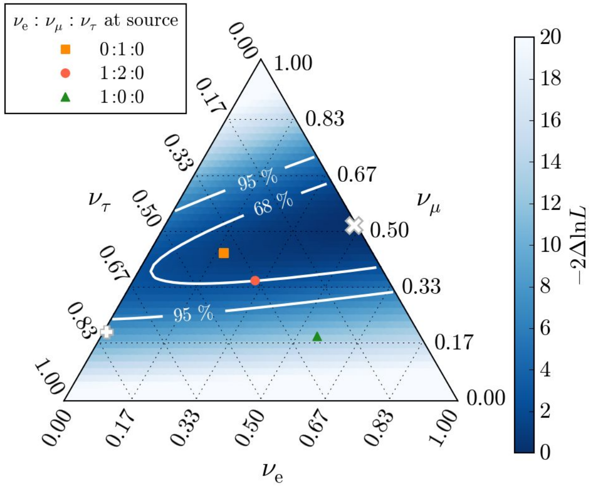




即使考慮惰性微中子模型, 仍無法解釋IceCube現有資料.

Neutrino Decay case





考慮微中子衰變的結果，仍無法解釋現有資料.

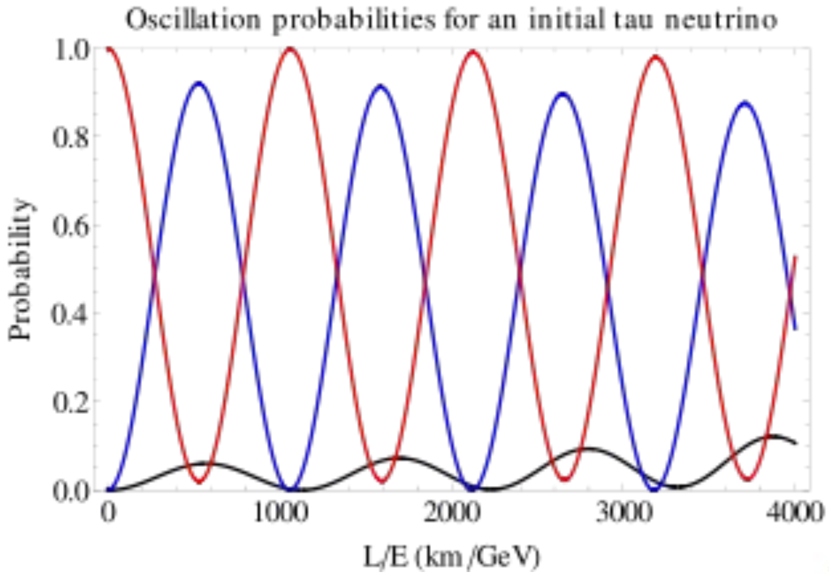
The Neutrinos **fully oscillation** before neutrinos arrive Earth

在標準的微中子震盪模型下, 低能量微中子的三個"味本徵態" 在天文距離下應已充分震盪.

$$P_{\alpha\to\beta} = |\langle\nu_\beta|\nu_\alpha(t)\rangle|^2 = \left|\sum_i U_{\alpha i}^* U_{\beta i} e^{-im_i^2 L/2E}\right|^2.$$

This is more conveniently written as

$$P_{\alpha\to\beta} = \delta_{\alpha\beta} - 4\sum_{i>j} Re(U_{\alpha i}^* U_{\beta i} U_{\alpha j} U_{\beta j}^*) \sin^2(\frac{\Delta m_{ij}^2 L}{4E}) + 2\sum_{i>j} Im(U_{\alpha i}^* U_{\beta i} U_{\alpha j} U_{\beta j}^*) \sin(\frac{\Delta m_{ij}^2 L}{2E}),$$



where $\Delta m_{ij}^2 \equiv m_i^2 - m_j^2$. The phase that is responsible for oscillation is often written as (with c and $\hbar$ restored)[5]

$$\frac{\Delta m^2 c^3 L}{4\hbar E} = \frac{\text{GeV fm}}{4\hbar c} \times \frac{\Delta m^2}{\text{eV}^2} \frac{L}{\text{km}} \frac{\text{GeV}}{E} \approx 1.267 \times \frac{\Delta m^2}{\text{eV}^2} \frac{L}{\text{km}} \frac{\text{GeV}}{E},$$

The distance from the source(Blazar) to Earth

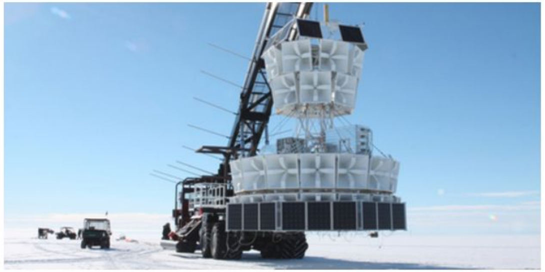
3*10^14 eV

5*10^17 eV

Synopsis: ANITA Spots Another Inverted Cosmic-Ray-Like Event

October 18, 2018

A fountain of high-energy particles that resembles an upside-down cosmic-ray shower is detected for the second time by the Antarctic Impulsive Transient Antenna.

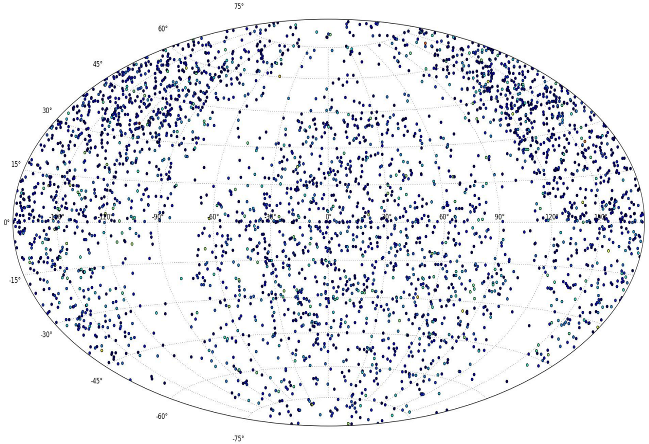


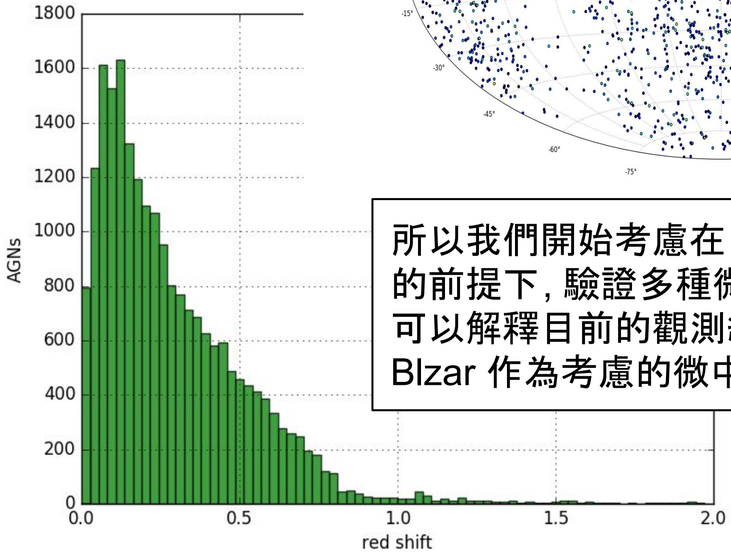
C. Miki/University of Hawaii

雖然IceCube在中高能微中子沒有看到濤微中子．但更高能的ANITA實驗卻看到兩個可能的濤微中子事例

The distance from the source(Blazar) to Earth

3*10^14 eV

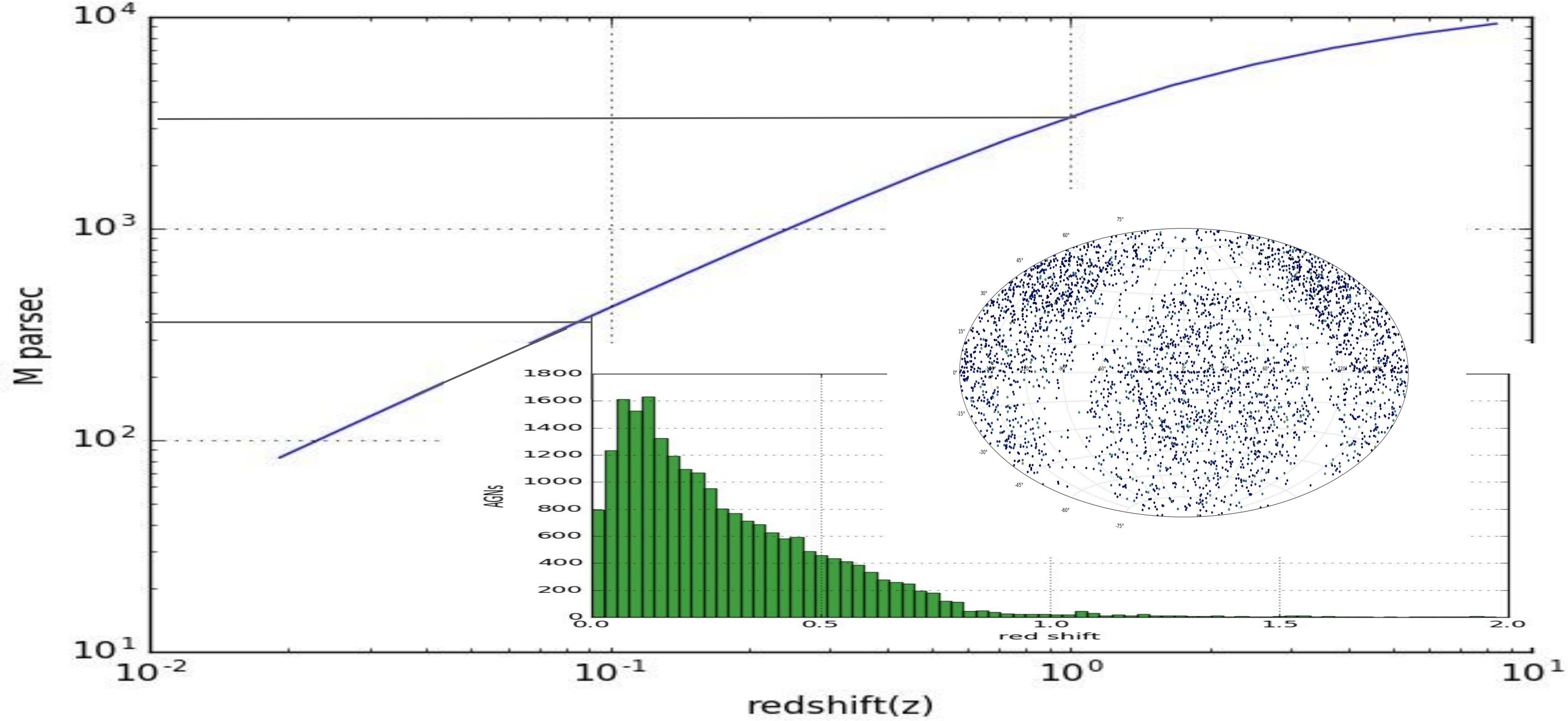




所以我們開始考慮在已知高能微中子源頭的前提下, 驗證多種微中子震盪模型 , 是否可以解釋目前的觀測結果 : 我們先行選取 Blzar 作為考慮的微中子源

The distance from the source(Blazer) to Earth

耀變體的距離分佈約為 300~4000Mparsec, Z<1



Pseudo-Dirac neutrino? (J.F Beacom, Phys Rev Lett. 2004 Jan 9;92(1):011101)

考慮類-狄拉克微中子模型

The generic mass matrix in the $(\nu_L, (\nu_R)^C)$ basis is

$$\begin{pmatrix} m_L & m_D \\ m_D & m_R \end{pmatrix}. \quad (1)$$

A Dirac neutrino corresponds to the case where $m_L = m_R = 0$, and may be thought of as the limit of two degenerate Majorana neutrinos with opposite CP parity. Alternatively, we may form a pseudo-Dirac neutrino [1, 2] by the addition of tiny Majorana mass terms $m_L, m_R \ll m_D$, which have the effect of splitting the Dirac neutrino into a pair of almost degenerate Majorana neutrinos, each with mass $\sim m_D$. The mixing angle between the active and sterile states is very close to maximal, $\tan(2\theta) = 2m_D/(m_R - m_L) \gg 1$, and the mass-squared difference is $\delta m^2 \simeq 2m_D(m_L + m_R)$. For three generations, the mass spectrum is shown in Fig. 1. The mirror model can produce a very similar mass spectrum [3, 4].

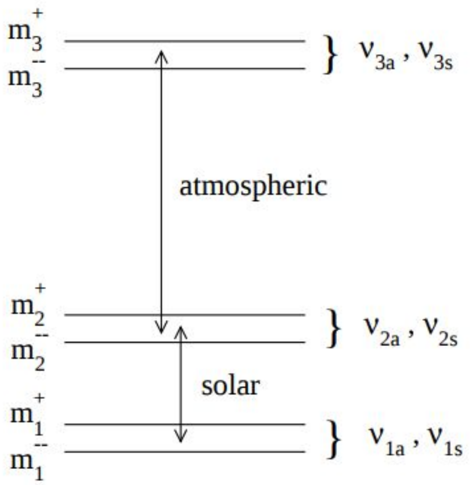


FIG. 1: The neutrino mass spectrum, showing the usual solar and atmospheric mass differences, as well as the pseudo-Dirac splittings in each generation (though shown as equal, we assume they are independent). The active and sterile components of each pseudo-Dirac pair are ν_{ja} and ν_{js}, and are maximal mixtures of the mass eigenstates ν_j^+ and ν_j^-. Neither the ordering of the active neutrino hierarchy, nor the signs of the pseudo-Dirac splittings, has any effect on our discussion.

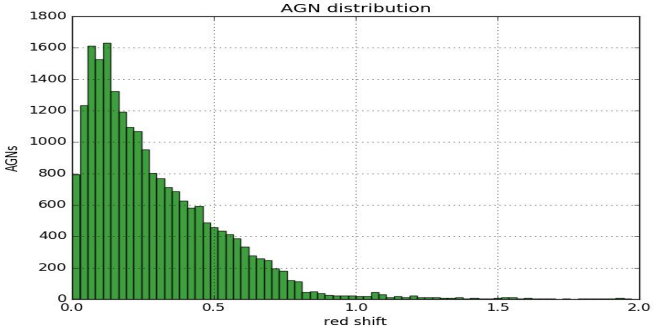
Pseudo-Dirac neutrino: (J.F Beacom, Phys Rev Lett. 2004 Jan 9;92(1):011101)

在選取適當的惰性微中子與作用微中子態的質量差．我們可以有一個分界能量，讓同一種微中子在低能量與高能量的流量不同

$$L^k_{\rm osc} \simeq \left(\frac{0.8\times10^{-16}\,{\rm eV}^2}{\Delta m_k^2}\right)\left(\frac{E}{10^6{\rm GeV}}\right){\rm Gpc} \lesssim {\rm Gpc} \qquad (30)$$

which means that neutrino oscillations can be measurable only when $\delta_k \gtrsim 0.8\times10^{-15}$ eV. From Eq. (30), we see that given the tiny mass splittings $\Delta m_k^2 = 10^{-16\sim-17}{\rm eV}^2$ with the energies around TeV–PeV, a new oscillation curve at neutrino trajectory $\mathcal{O}(1)$ Gpc is naively expected to occur. Since $E/\Delta m_k^2 \sim L(z) \gg E/\Delta m^2_{\rm Atm}$, the probability of the oscillation

E	10^14	10^15	10^16	10^17	10 ^18
delta m^2 =10^-16	100Mpc	1Gpc	10Gpc	100GPc	1Tpc
z	~0.02	~0.2 1	~8		
delta m^2 =10^-17	10Mpc	1ooMpc	1Gpc	10Gpc	100GPc
z=	~0.002	~0.02	~0.2 1	~8	



因此微中子的全天譜,
在高能量與低能量時應有
比例的差異:

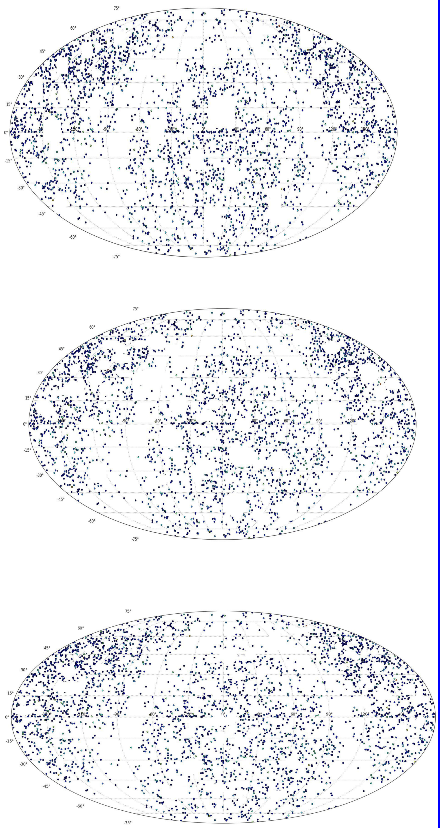
目前我只考慮Balzar的情形.
但極高能neutrino source 仍有
GRB(gamma ray burst) 與其他
AGN source. 而且GRB所分佈的
範圍可以遠到redshidt z=9的狀
況, 我們可以預測出不同微中子
源在地球上的可能觀測結果. 進
而釐清IceCube濤微中子的消失
問題

electron neutrino

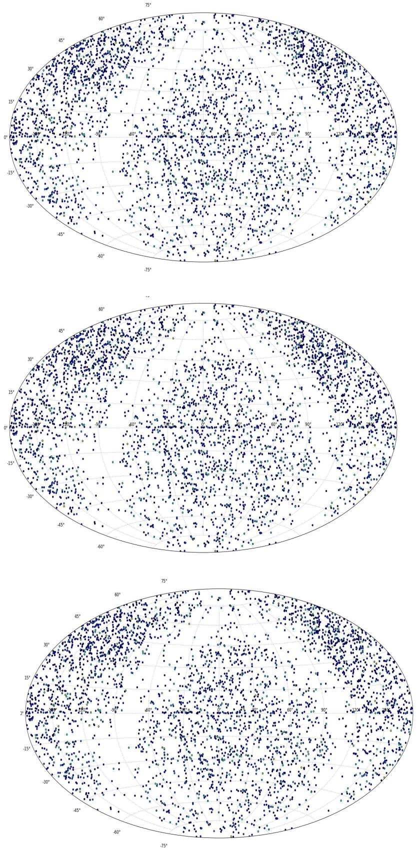
muon neutrino

tau neutrino

Low enwrgy neutrinos



High energy neutrinos



quantum simulation of neutrino flavor oscillations

$$|\nu_e\rangle = U^{2x2\dagger}_{PMNS}|0\rangle$$

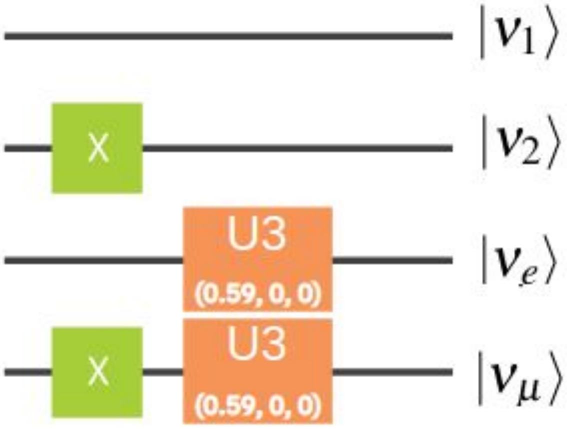
$$|\nu_\mu\rangle = U^{2x2\dagger}_{PMNS}|1\rangle$$

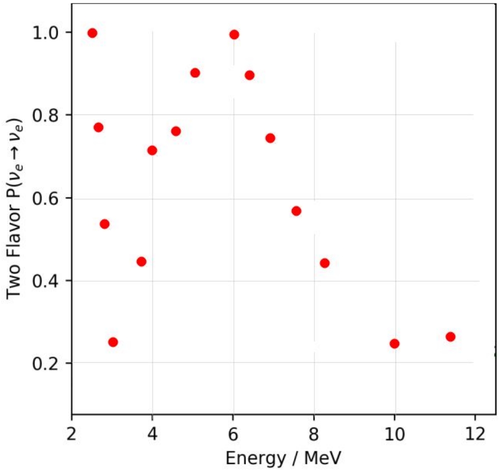
$$U3(\Theta,\phi,\lambda) = \begin{pmatrix} \cos\frac{\Theta}{2} & -\sin\frac{\Theta}{2}e^{i\lambda} \\ \sin\frac{\Theta}{2}e^{i\phi} & \cos\frac{\Theta}{2}e^{i(\lambda+\phi)} \end{pmatrix}$$

$$U^{2x2}_{\text{PMNS}} = U3(2\theta,0,0) = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix}$$

$$U^{2x2\dagger}_{\text{PMNS}} = U3(-2\theta,0,0)$$

$$\mathscr{U}(t) = \begin{pmatrix} 1 & 0 \\ 0 & e^{i\phi} \end{pmatrix}, \text{ where } \phi = \Delta m^2 t/2E\hbar.$$





可以利用量子模擬與量子電腦ibm Q 計算微中子震盪問題

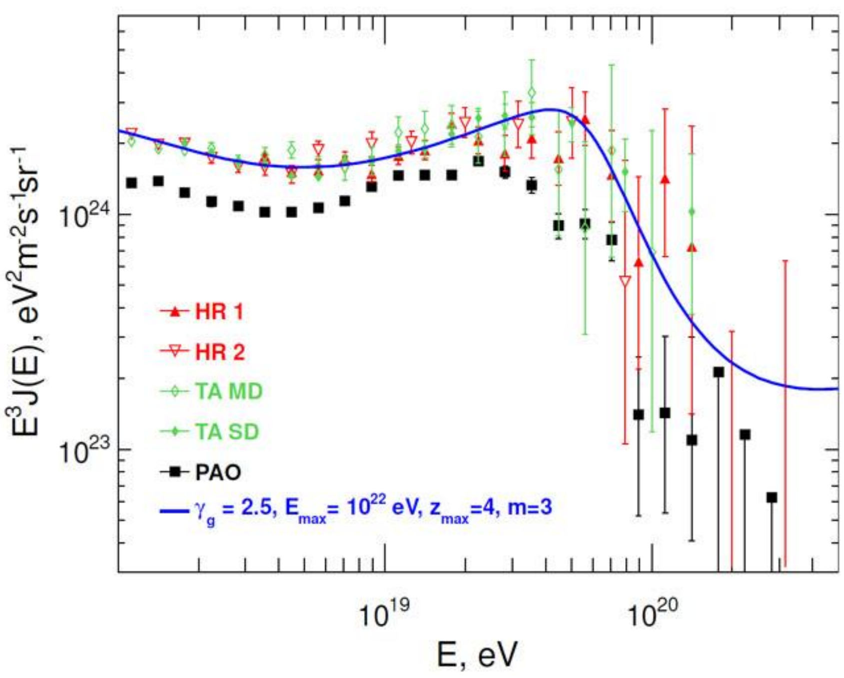
第四代微中子問題 additional generation？

惰性微中子問題 sterile neutrino? 3+1, 3+2, or 3+n

微中子共振問題 neutrino resonance interactions

準狄拉克微中子問題 pseudo-Dirac neutrino 問題.

理論研究計劃書 II :
Extra-High energy neutrino spectrum to test cosmic neutrino background



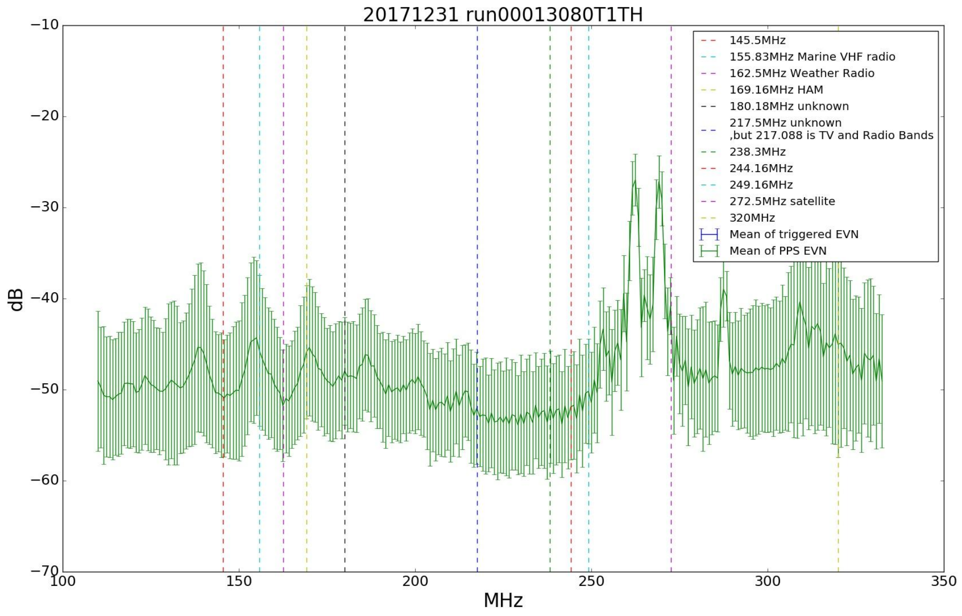
GZK effect: 當極高能宇宙射線能量高於 10^{19}eV時, 質子可以與2.7K宇宙背景輻射起反應 , 宇宙射線的觀測能譜 ,證實了此效應

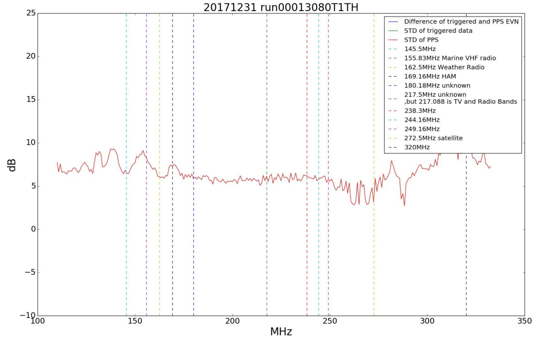
極高能微中子雖然無法與 2.7K的宇宙背景輻射起反應 , 但卻與1.9K的宇宙背景微中子起反應 . 我們目前基於現有的標準模型的反應, 結合極高能微中子源的流量預測 , 我們可以計算微中子能譜的概況 , 預測是否有微中子版本的GZK效應.

合作對象: 中研院吳孟儒, 廣州中山大學王則均

理論研究計劃書 III :

TAROGE, ANITA, ARA, HCR: Data analysis





目前TAROGE 在臺灣運作的三個站, 以10Hz *24 *2的速度紀錄110-400MHz的電波數據.

ANITA 目前尚在分析第三次(2014)與第四次飛行(2017)的資料

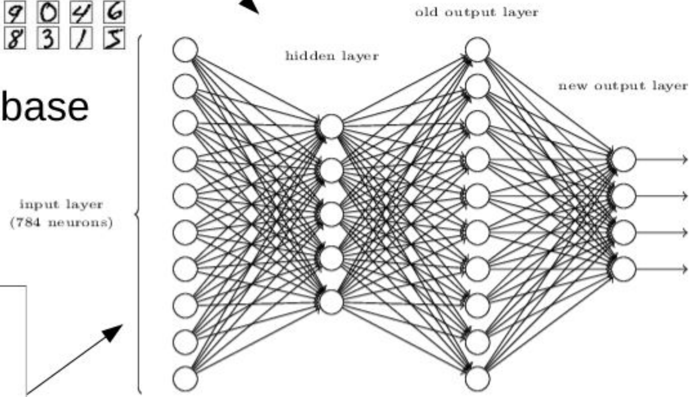
HCR(2018年觀測結果將於明年三月送回), ARA 2010-2018年資料

合作對象: 臺大梁次震中心陳丕燊, 南智祐, 聯合大學黃明輝,& 國際合作群

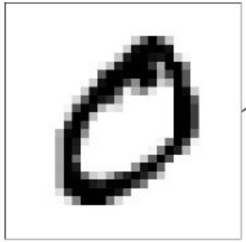
Classifiction wth deep learning

people use the deep learning method to classify handwriting

DATA base



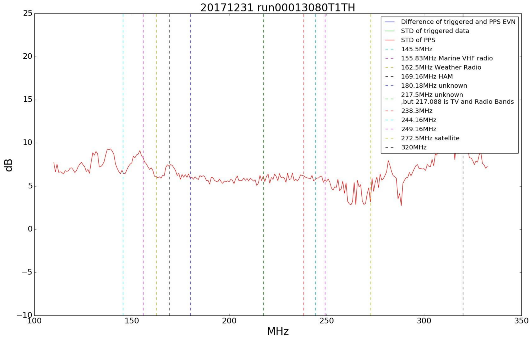
Algorithm



input

0

result



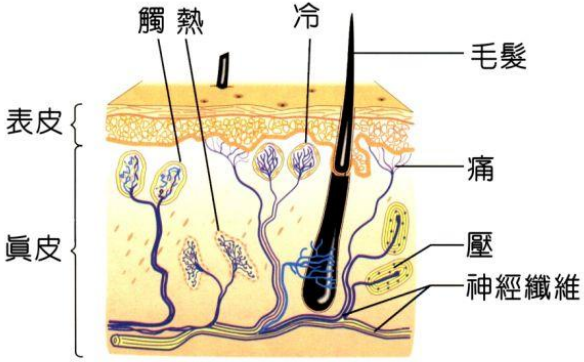
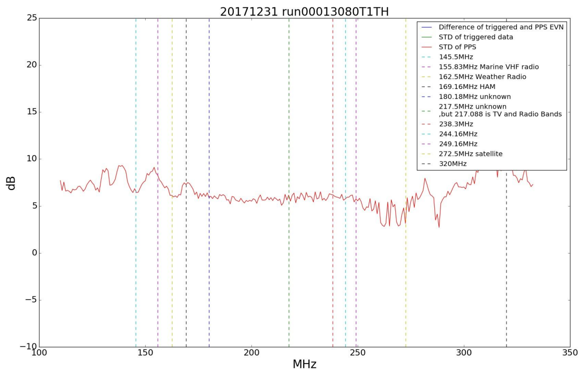
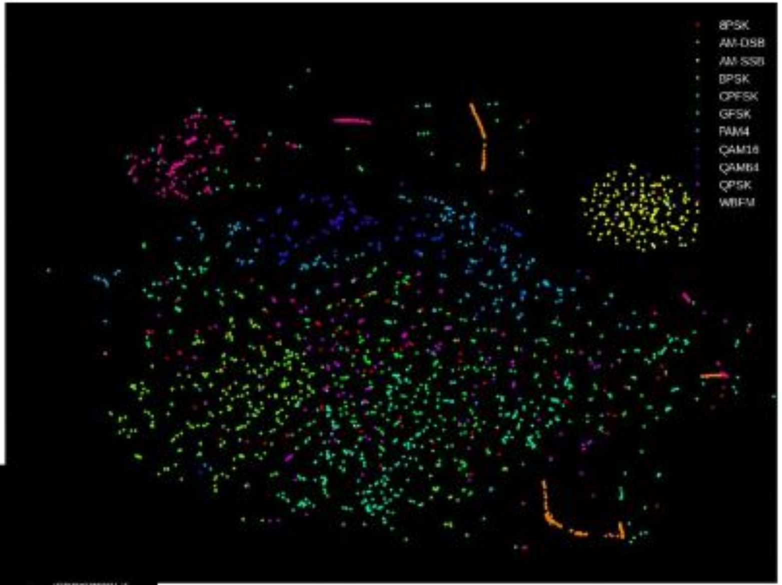
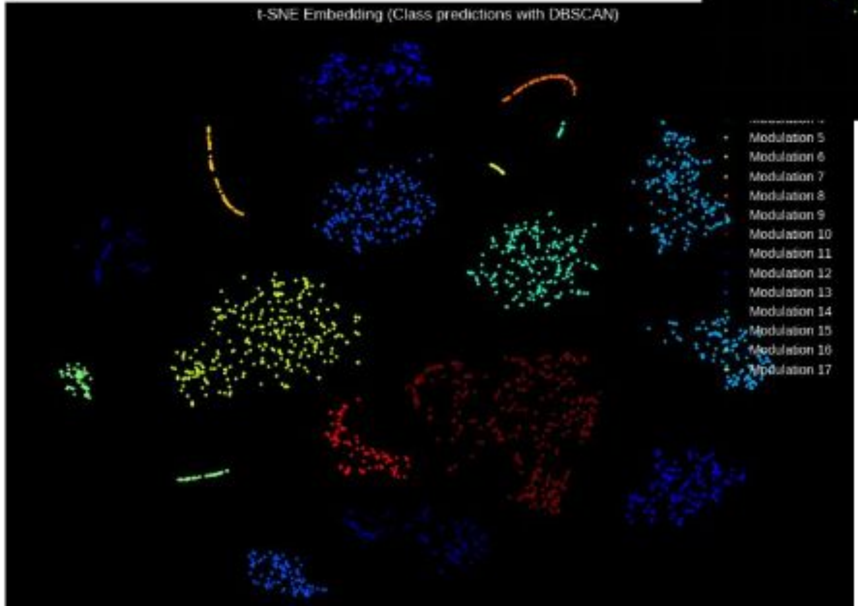


圖5-1人類皮膚中的感覺受器







由於衛星通訊費用過貴，iridium usd1.6/kB，我們目前正在整合演算法到實驗站的資料擷取系統中. 僅將最可能的實驗事例由衛星傳回臺灣，其餘資料將隔年後方取回.