Department of Physics
UNIVERSITY OF OXFORD

John Adams Institute for Accelerator Science

IceCube – Neutrinos from Active Galaxies

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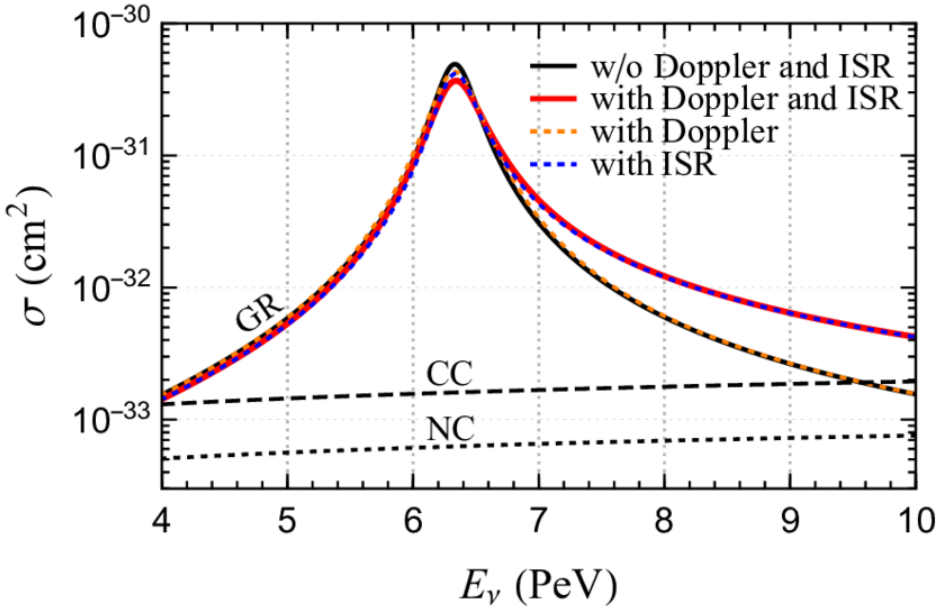
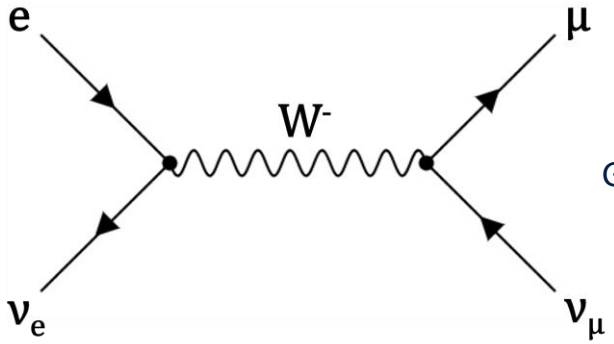
Glashow Resonance



Cross section for s-channel W boson production via CC and NC DIS, and the Glashow Resonance.



Feynman diagram for the Glashow resonance process observed at IceCube.

- Possible neutrino **origins**:
  - **Atmospheric**

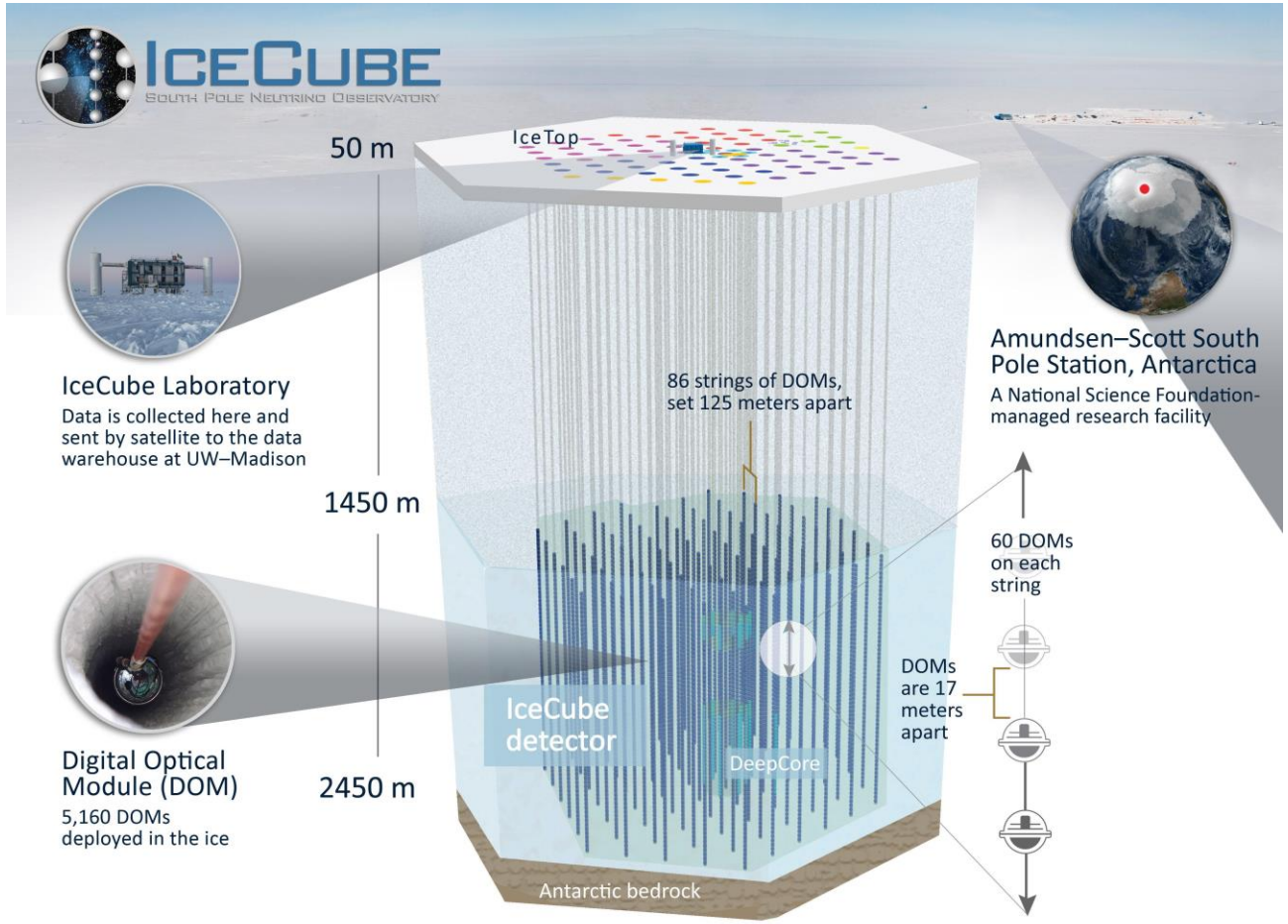
  → Expect $2 \cdot 10^{-7}$ events over 4.6 yrs

  → 1 event in **40 million years** (unlikely)
  - **Cosmic**

  → This event: **5.2σ**

  → More events: **>8σ**

IceCube – The Detector



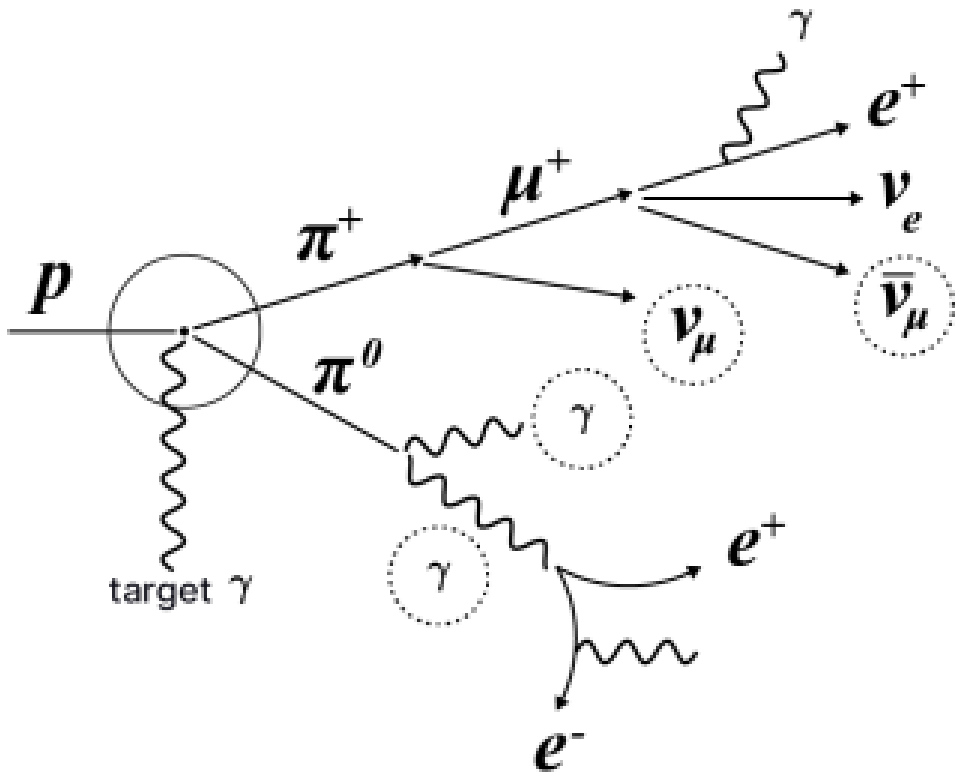
- 1km^3 **Čerenkov** detector
  - 5160 DOMs (optical sensors)
  - 86 strings
- 1500m below the South Pole
- Most sensitive to **muons** and **muon neutrinos**
  - Penetrating
  - No scattering

Where are the neutrinos from?

- **Signatures** of cosmic neutrinos
  - High energy (**TeV/PeV**)
  - Neutrinos + lower energy **EM shower**
  - **No muon** acompanying
  - Energy spectrum of **neutrino flux**:

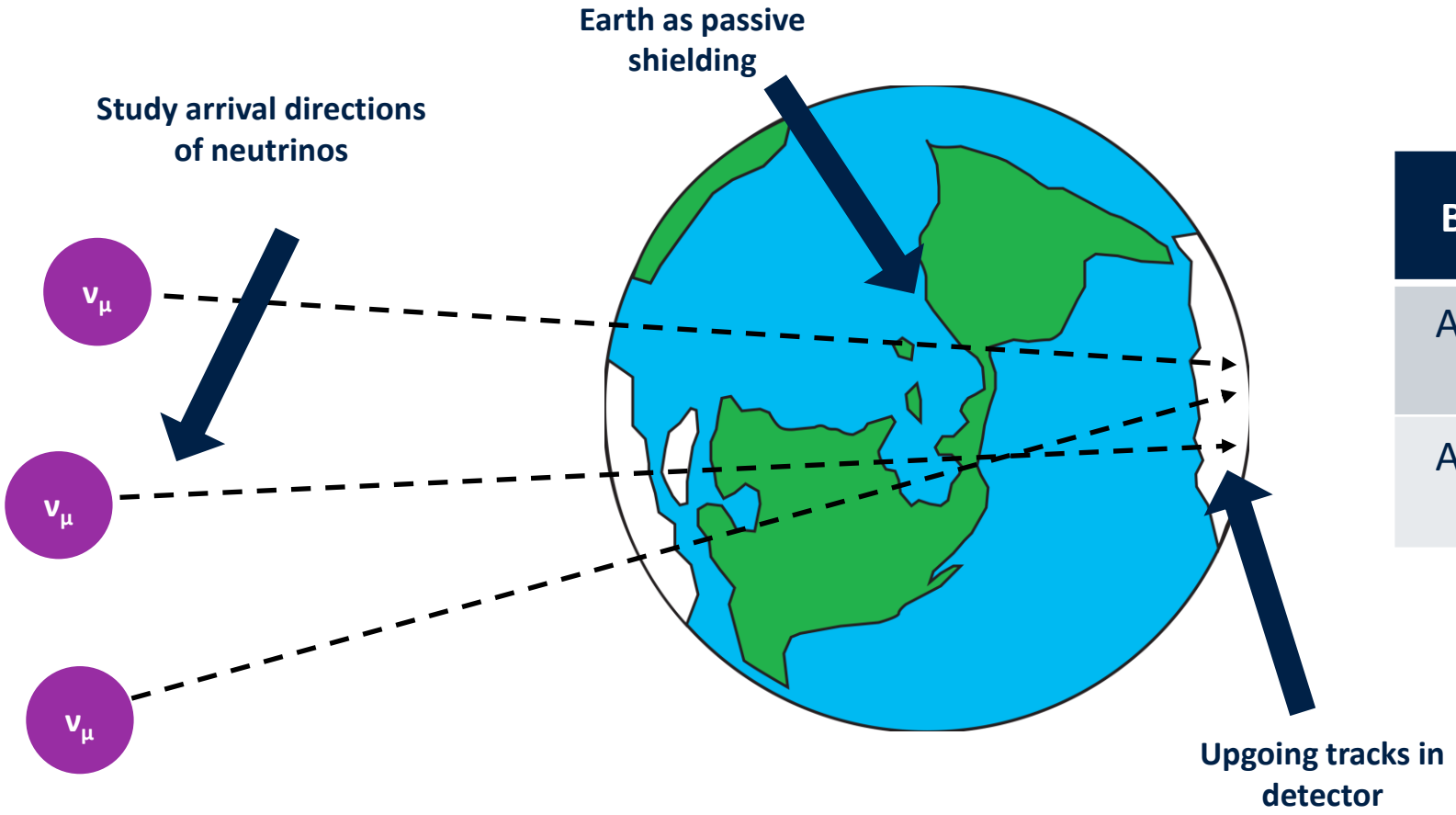
$$\frac{dN}{dE} \sim E^{-\gamma}$$ → Calculate **spectral index** γ

- **Where** are the neutrinos from?
  - GRB?
  - Supernova?
  - Elsewhere?



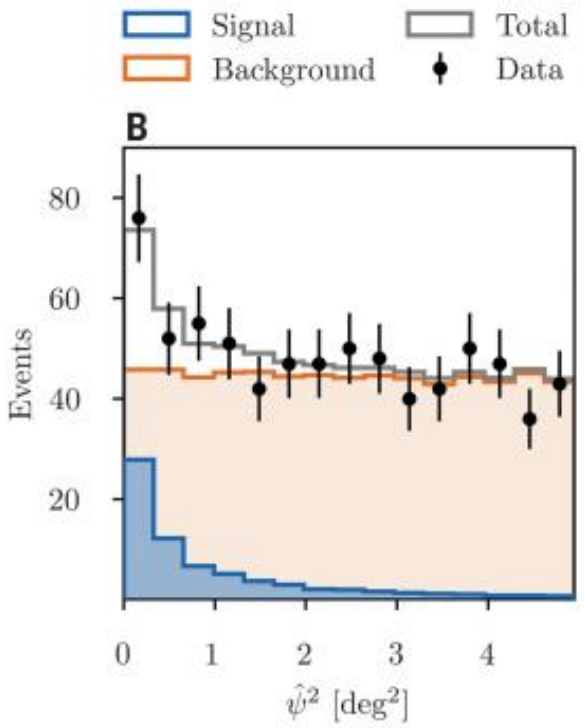
A typical interaction resulting in cosmic ray neutrinos.

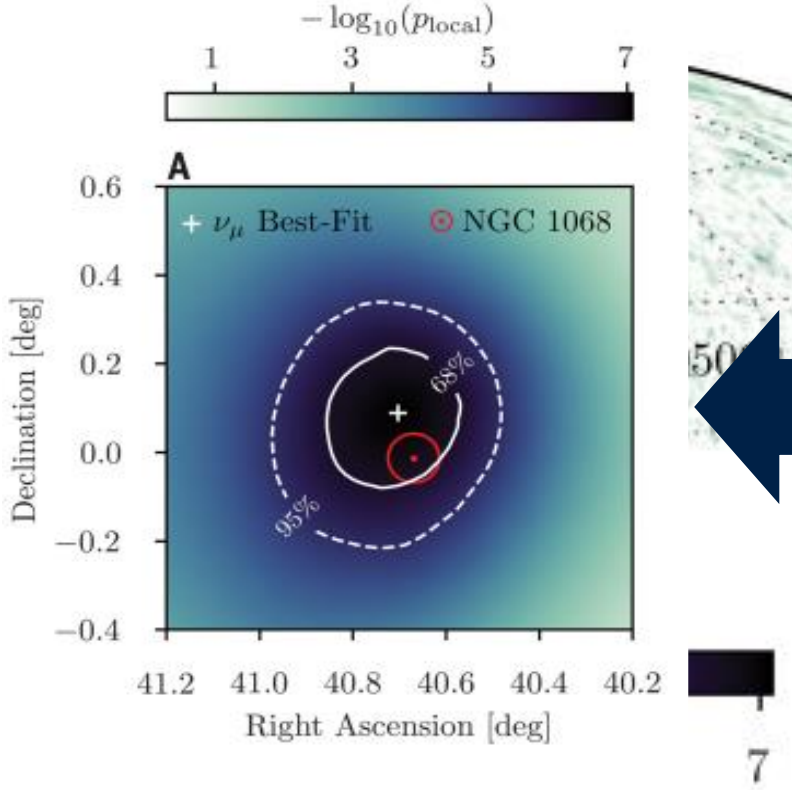
Methodology

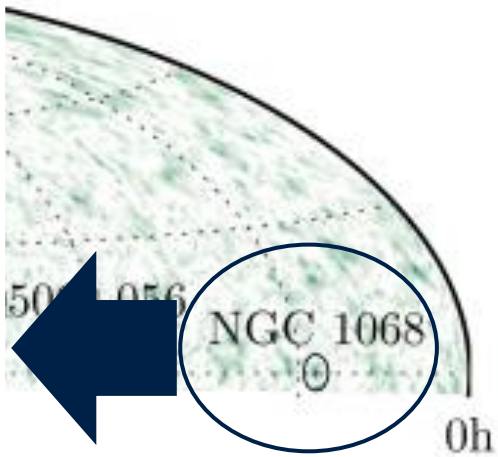


Background	Mitigation
Atmospheric muons	Upgoing tracks – use Earth as shield
Atmospheric neutrinos	Constant background, spectral index (γ)

Results



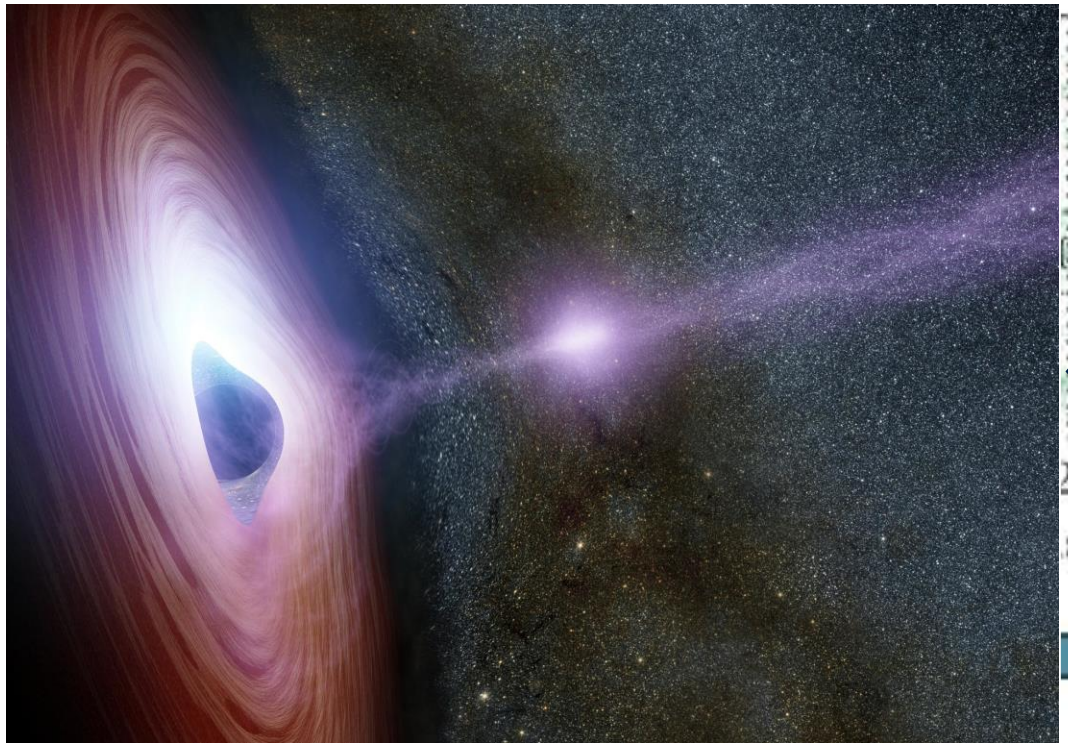


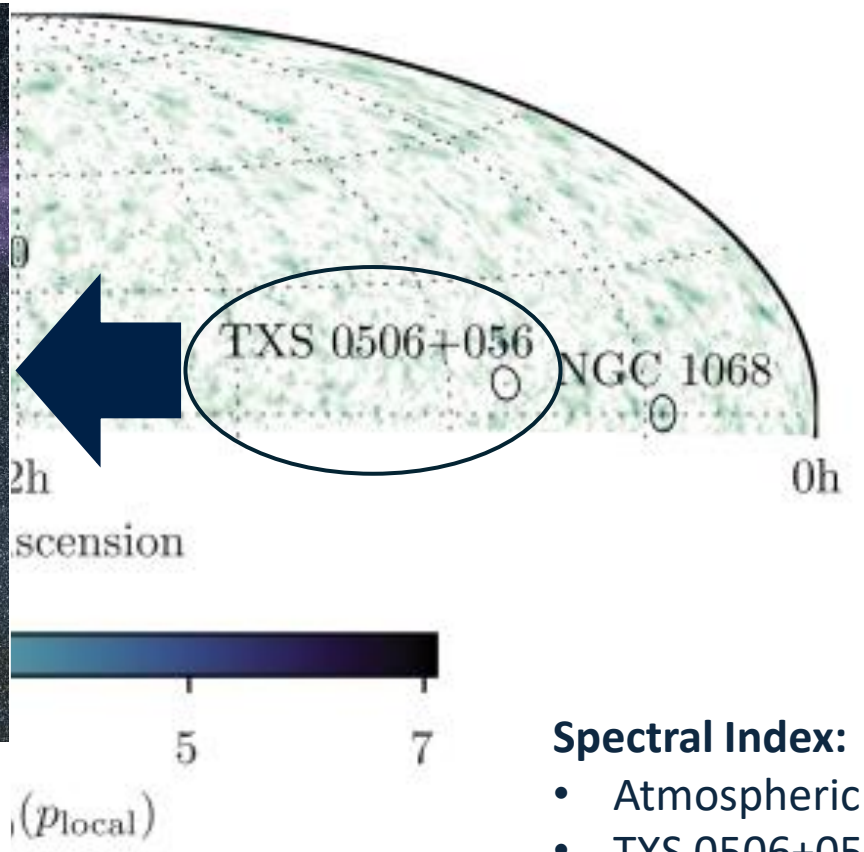


Spectral Index:

- Atmospheric γ : 3.7
- M77 γ : 3.2 ± 0.2

Results





Spectral Index:

- Atmospheric γ : 3.7
- TXS 0506+056 γ : 2.37 ± 0.09

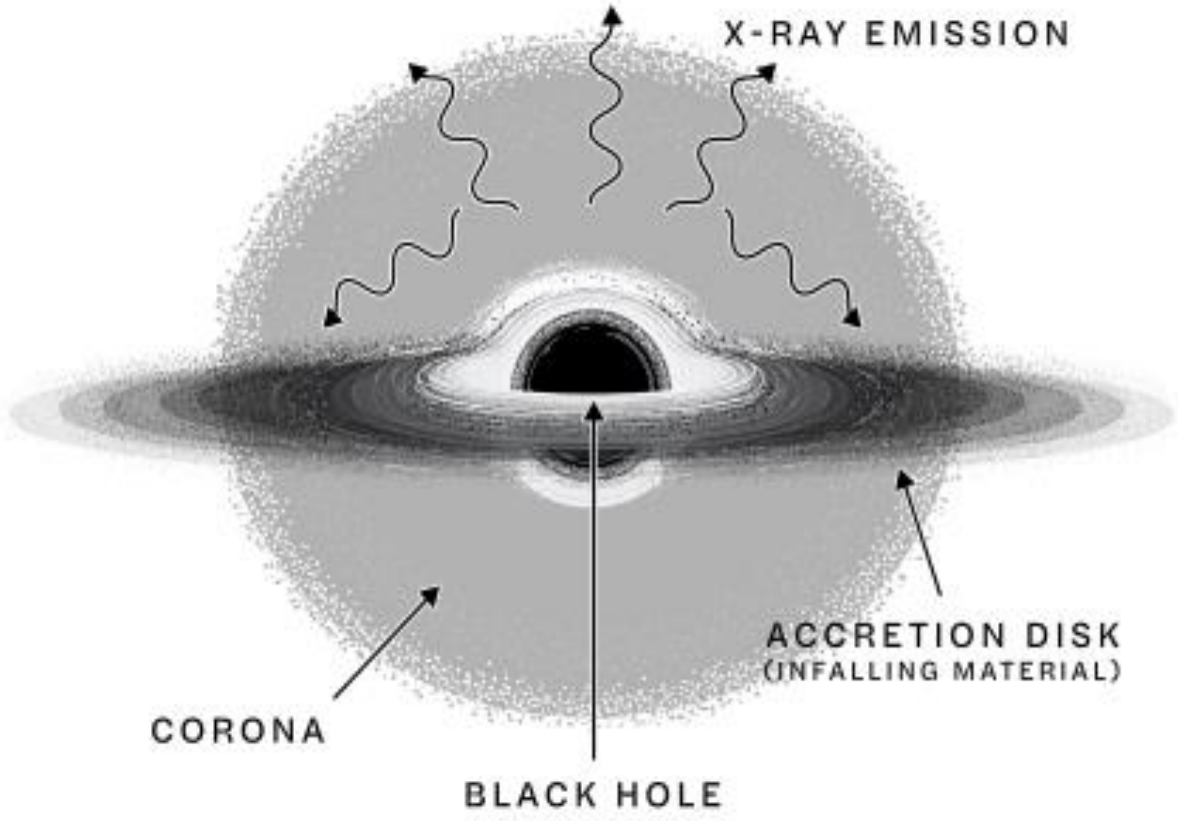
Are neutrinos from galaxy cores?

- Protons **accelerated** in accretion disk
- Interactions with **corona** produce showers
  - Corona has **high density** of X-rays and matter
  - **Different opacity** to protons and photons:

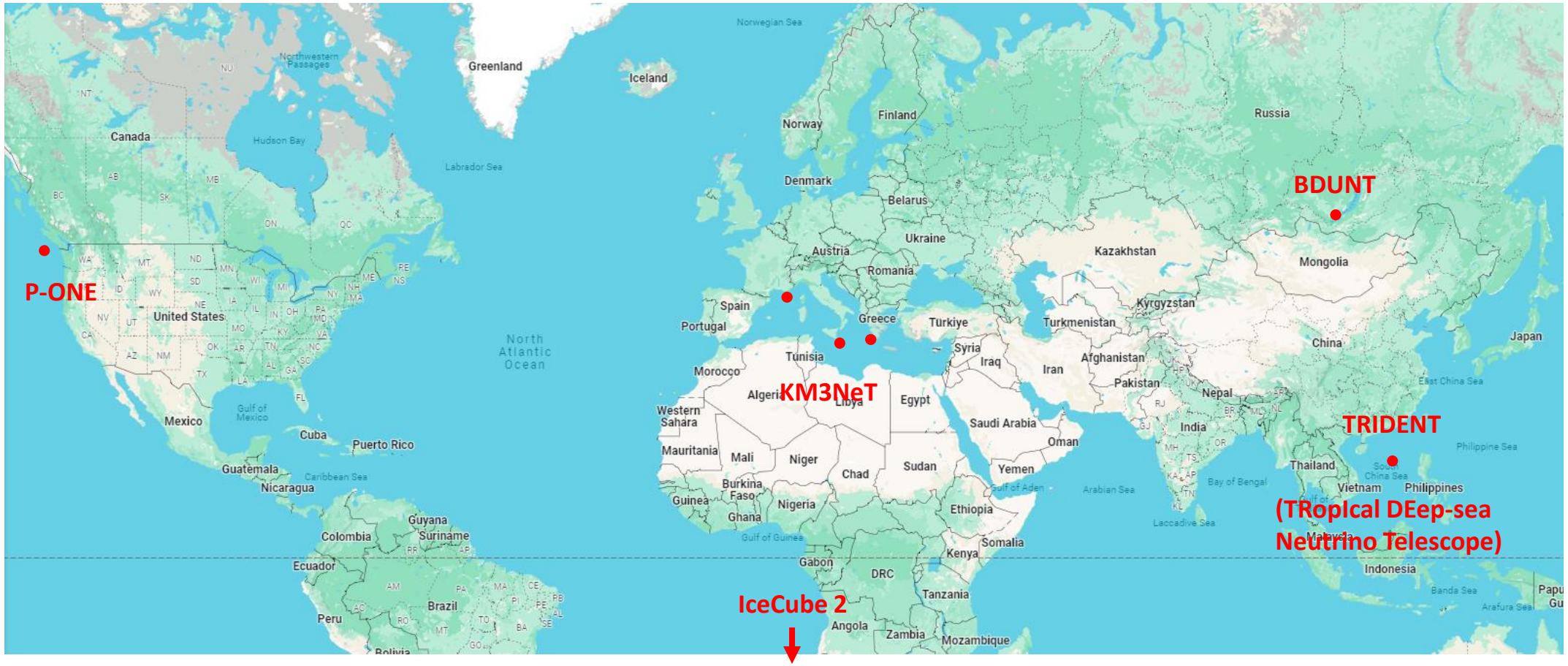
$$\sigma_\gamma \approx 1000\sigma_p$$

- Large opacity required for **neutrino production**
  - **Suppression** of photon flux guaranteed

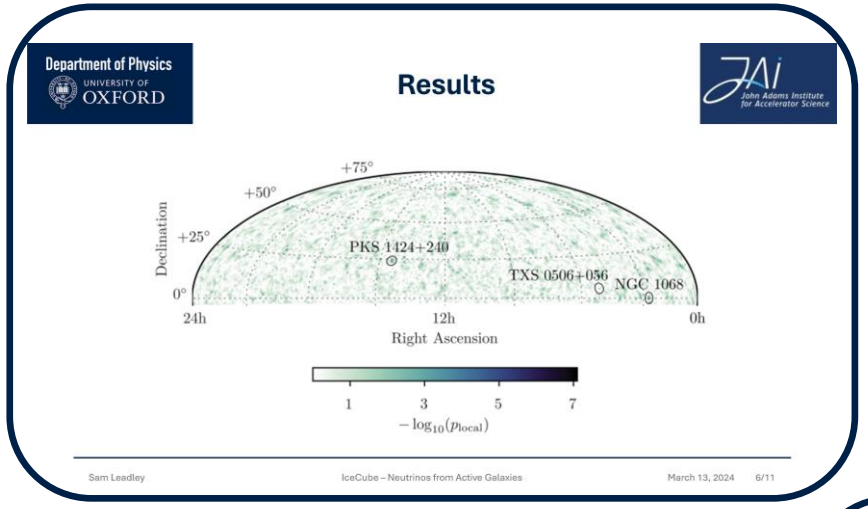
- **Luminosity** of M77 suggests $R \approx 10R_s$



Next steps

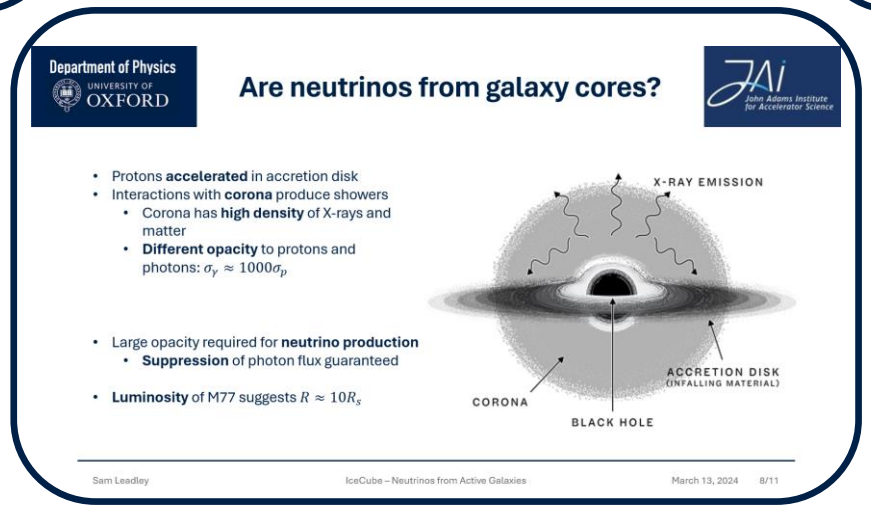

P-ONE
KM3NeT
BDUNT
TRIDENT
(TRopIcal DEep-sea
Neutrino Telescope)
IceCube 2
Greenland
Iceland
Norway
Finland
Russia
Canada
Hudson Bay
Labrador Sea
Denmark
Belarus
Ukraine
Austria
Romania
Kazakhstan
Mongolia
Spain
Portugal
Greece
Turkiye
Turkmenistan
Kyrgyzstan
China
Japan
Tunisia
Syria
Iraq
Iran
Afghanistan
Pakistan
Morocco
Algeria
Libya
Egypt
Nepal
India
Western Sahara
Saudi Arabia
Oman
Mauritania
Mali
Niger
Chad
Sudan
Yemen
Burkina Faso
Guinea
Nigeria
Ethiopia
Ghana
Somalia
Kenya
Gabon
DRC
Tanzania
Angola
Zambia
Mozambique
Thailand
Vietnam
Philippines
Indonesia
United States
Mexico
Gulf of Mexico
Cuba
Puerto Rico
Guatemala
Nicaragua
Caribbean Sea
Guyana
Suriname
Colombia
Ecuador
Peru
Brazil
North Atlantic Ocean
Norwegian Sea
Arabian Sea
Bay of Bengal
Laccadive Sea
Gulf of Aden
Gulf of Guinea
East China Sea
Philippine Sea
Banda Sea

Summary and Conclusion



Proposed mechanisms explain missing high energy neutrino flux

First **high energy source** of cosmic neutrinos discovered



Progress requires better sky **coverage** and angular **resolution**

References

Slide 2
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- IceCube Collaboration, Detection of a particle shower at the Glashow resonance with IceCube (10/03/2021)
- G. Huang & M. Lindner & N. Volmer, Inferring astrophysical neutrino sources from the Glashow resonance (11/2023) (image)

Slide 3
- IceCube/NSF, IceCube detector schematic - https://icecube.wisc.edu/gallery/neutrino-emission-from-ngc-1068/#modulagallery-9811-1995 (04/11/2022) (image)

Slide 4
- R. Abbasi et. al., An Absence of Neutrinos Associated with Cosmic Ray Acceleration in Gamma-Ray Bursts (18/04/2012)
- IceCube Collaboration, Evidence for neutrino emission from the nearby active galaxy NGC 1068 (03/11/2022) (image)

Slide 5
- IceCube Collaboration, Neutrinos from Active Galaxies (11/03/2023)

Slide 6
- IceCube Collaboration, Neutrinos from Active Galaxies (11/03/2023) (images)

Slide 7
- NASA/JPL-Caltech, Shifting Coronas Around Black Holes - https://www.jpl.nasa.gov/images/pia20051-shifting-coronas-around-black-holes-artist-concept (27/10/2015) (image)
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Slide 8
- IceCube Collaboration, Neutrinos from Active Galaxies (11/03/2023) (image)

Slide 9
- Wikipedia, List of Neutrino Experiments (04/03/2024)

Extra Material
- IceCube Collaboration, Evidence for High-Energy Extraterrestrial Neutrinos at the IceCube detector (16/12/2013)
- B. Zhou & J. Beacom, W-boson and trident production in TeV-PeV neutrino observatories (18/02/2020)