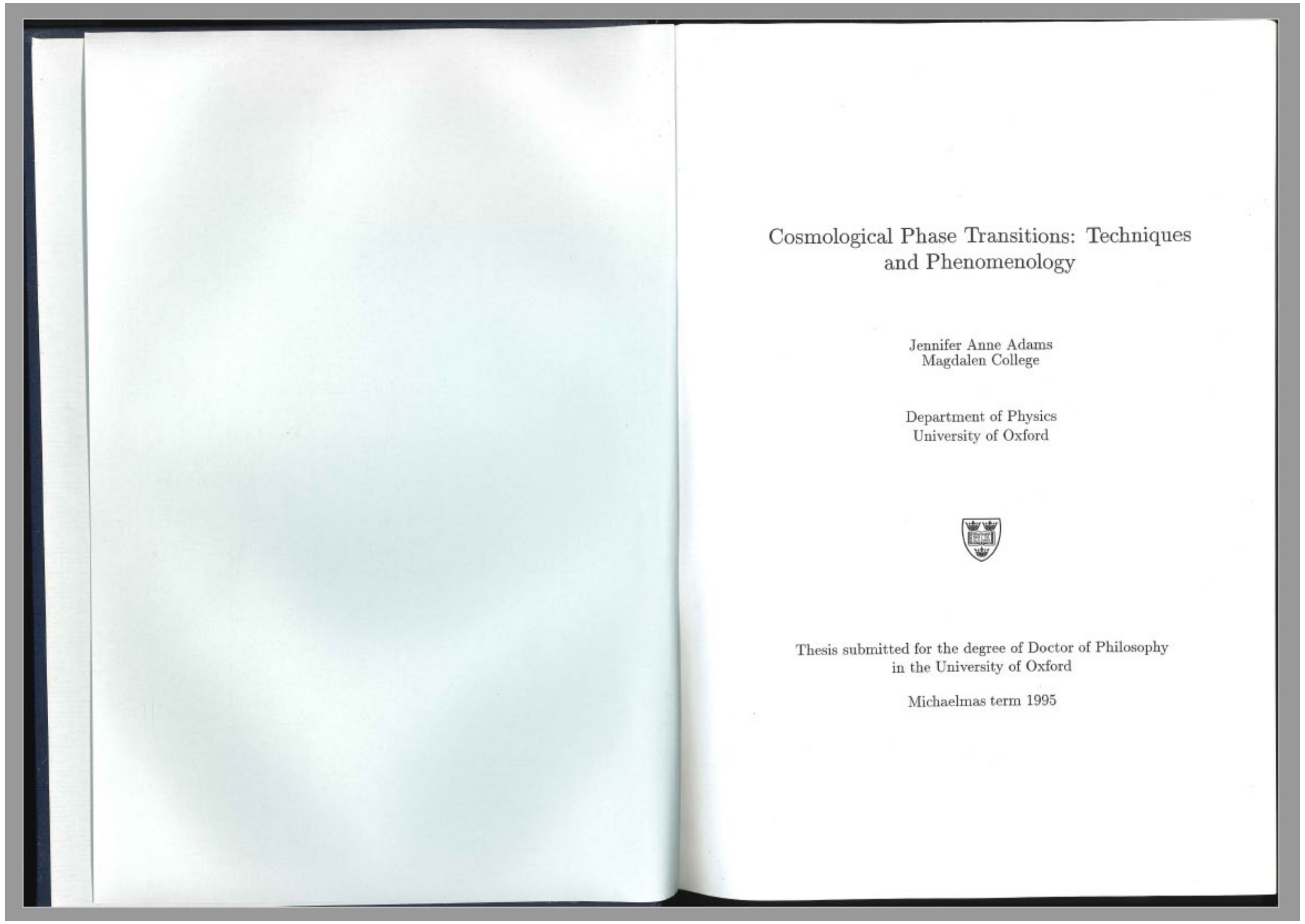
Galactic Birthday Greetings, Subir!

Huge thanks, Subir for your support



Cosmological Phase Transitions: Techniques and Phenomenology

Jennifer Anne Adams
Magdalen College

Department of Physics
University of Oxford

Thesis submitted for the degree of Doctor of Philosophy in the University of Oxford

Michaelmas term 1995

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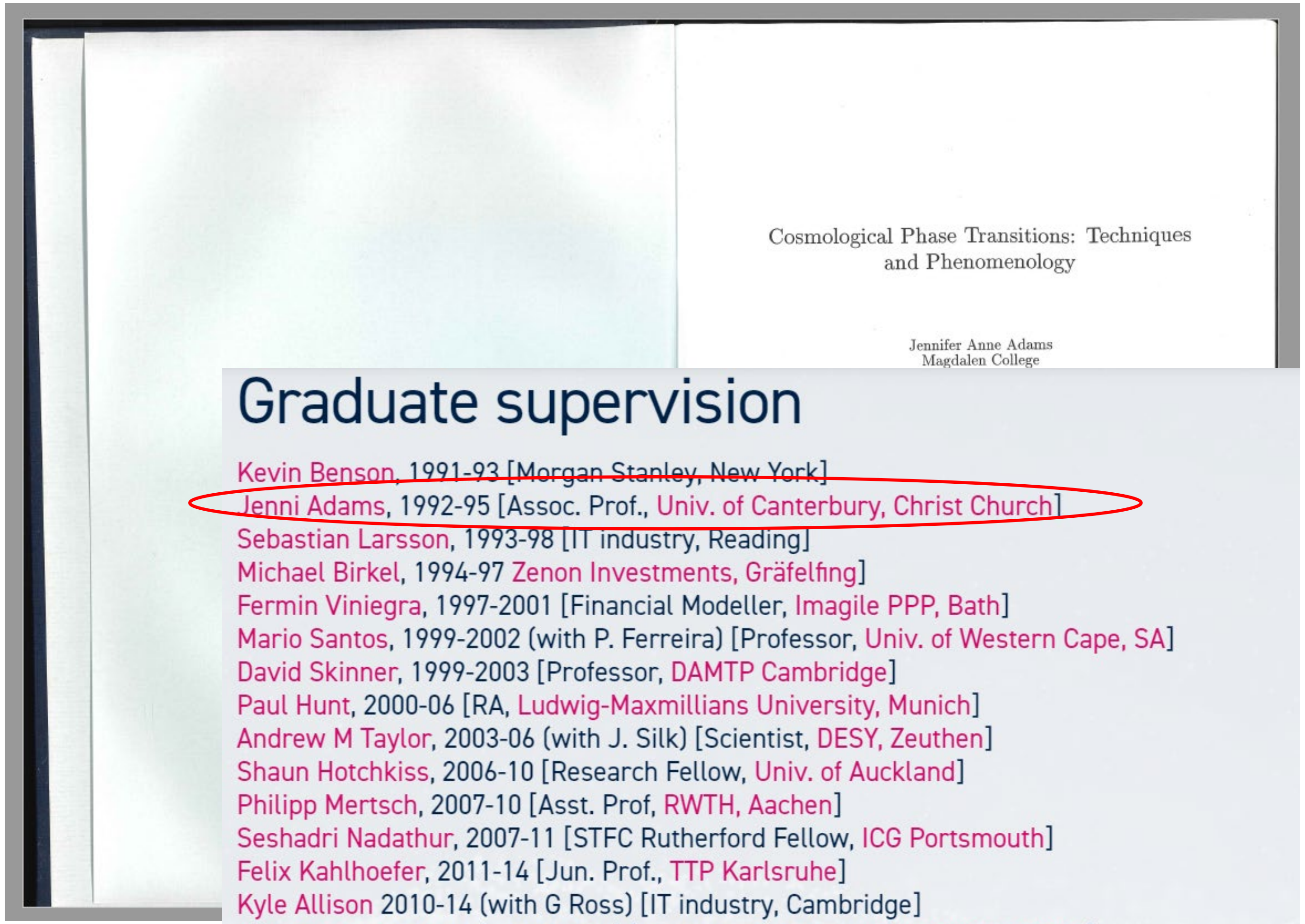
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Graduate supervision

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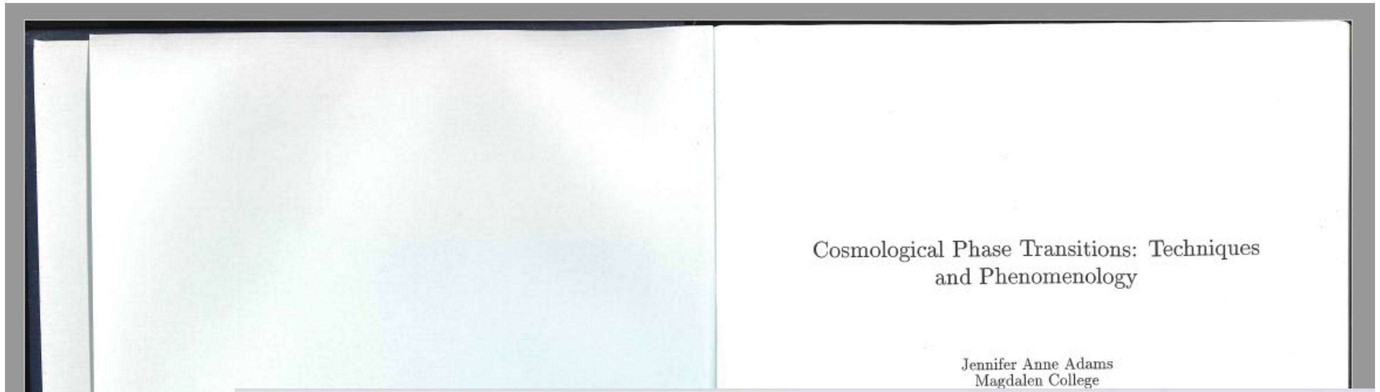

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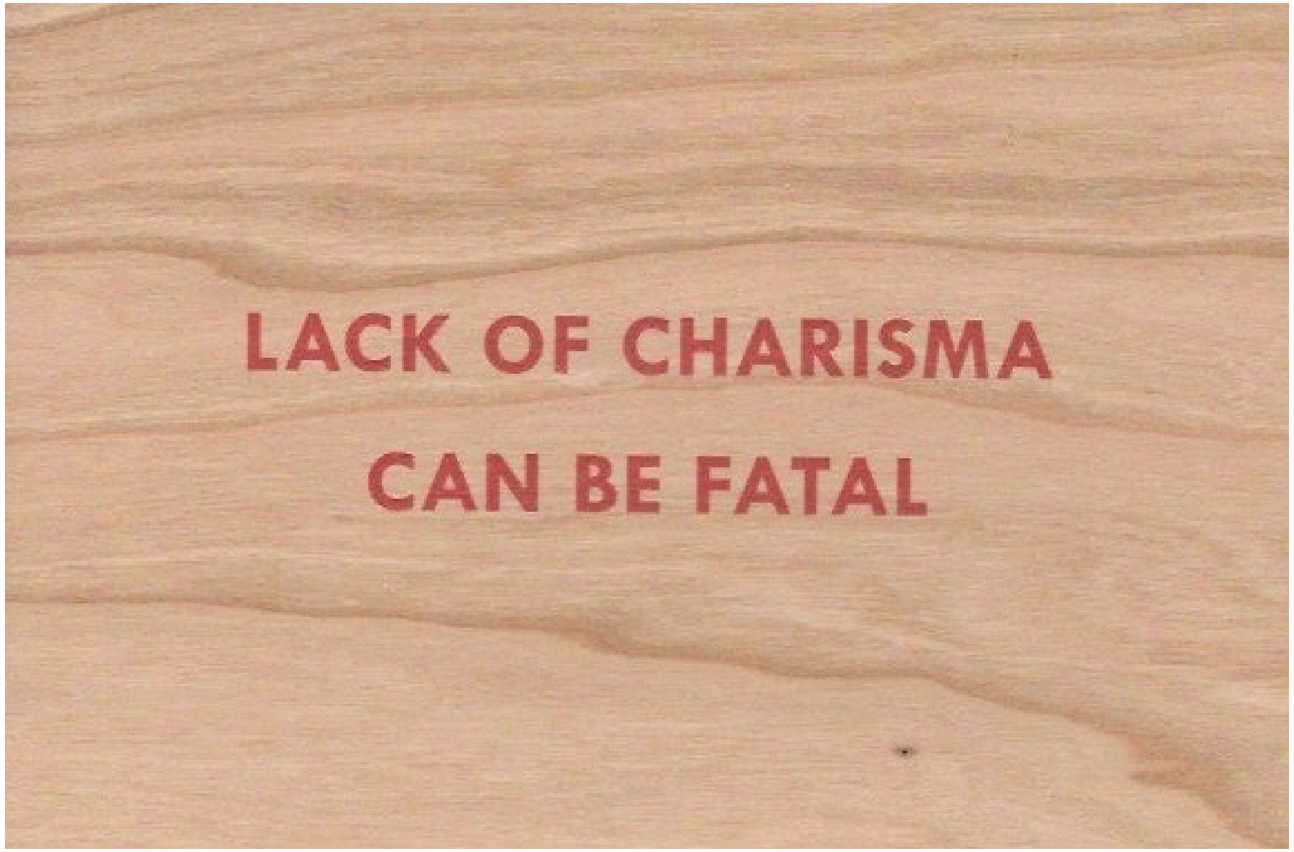

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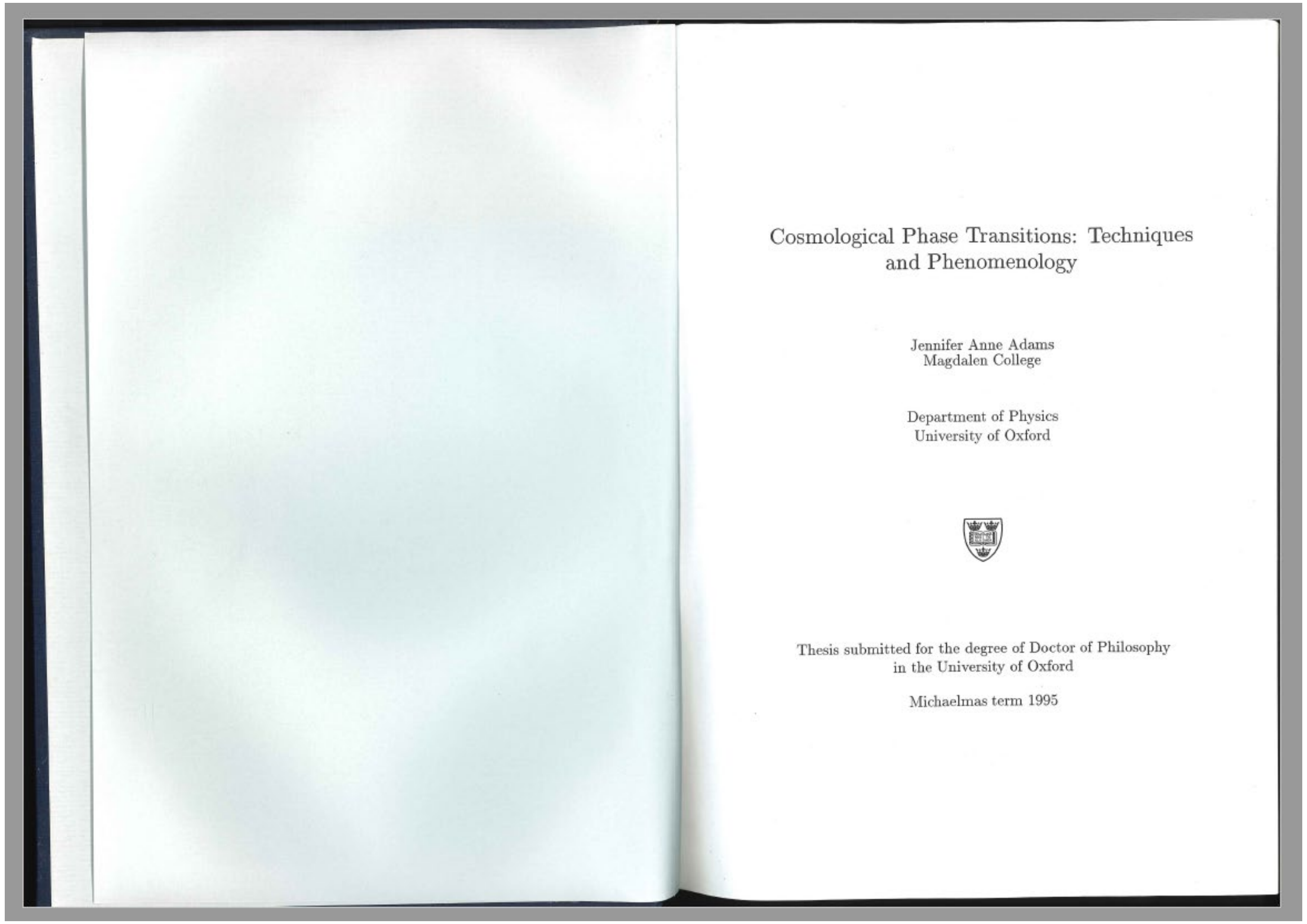

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N·H
ELSEVIER
16 January 1997
PHYSICS LETTERS B
Physics Letters B 391 (1997) 271–280

Natural supergravity inflation

Jennifer A. Adams [a], Graham G. Ross [b], Subir Sarkar [b,1]
[a] *Department of Theoretical Physics, Uppsala University, Box 803, S-75108 Uppsala, Sweden*
[b] *Theoretical Physics, University of Oxford, 1 Keble Road, Oxford OX1 3NP, UK*

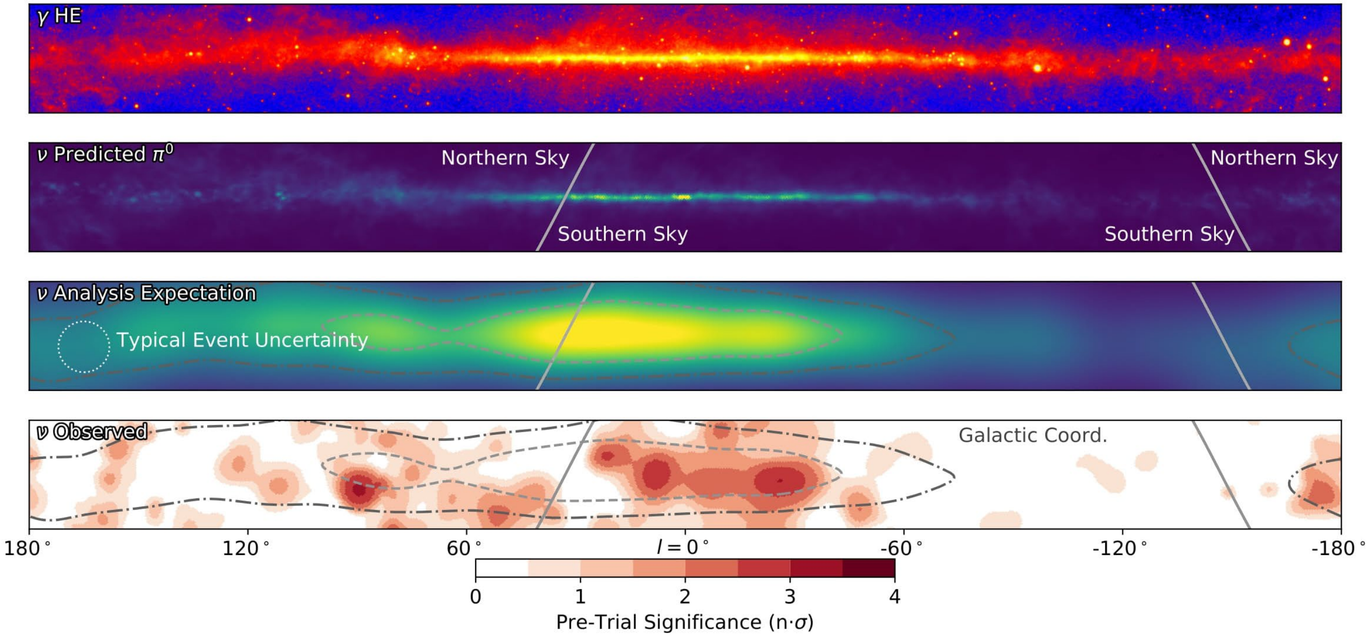
Received 16 August 1996; revised manuscript received 28 October 1996
Editor: P.V. Landshoff

N·H
ELSEVIER
NUCLEAR PHYSICS B
Nuclear Physics B 503 (1997) 405–425

Multiple inflation

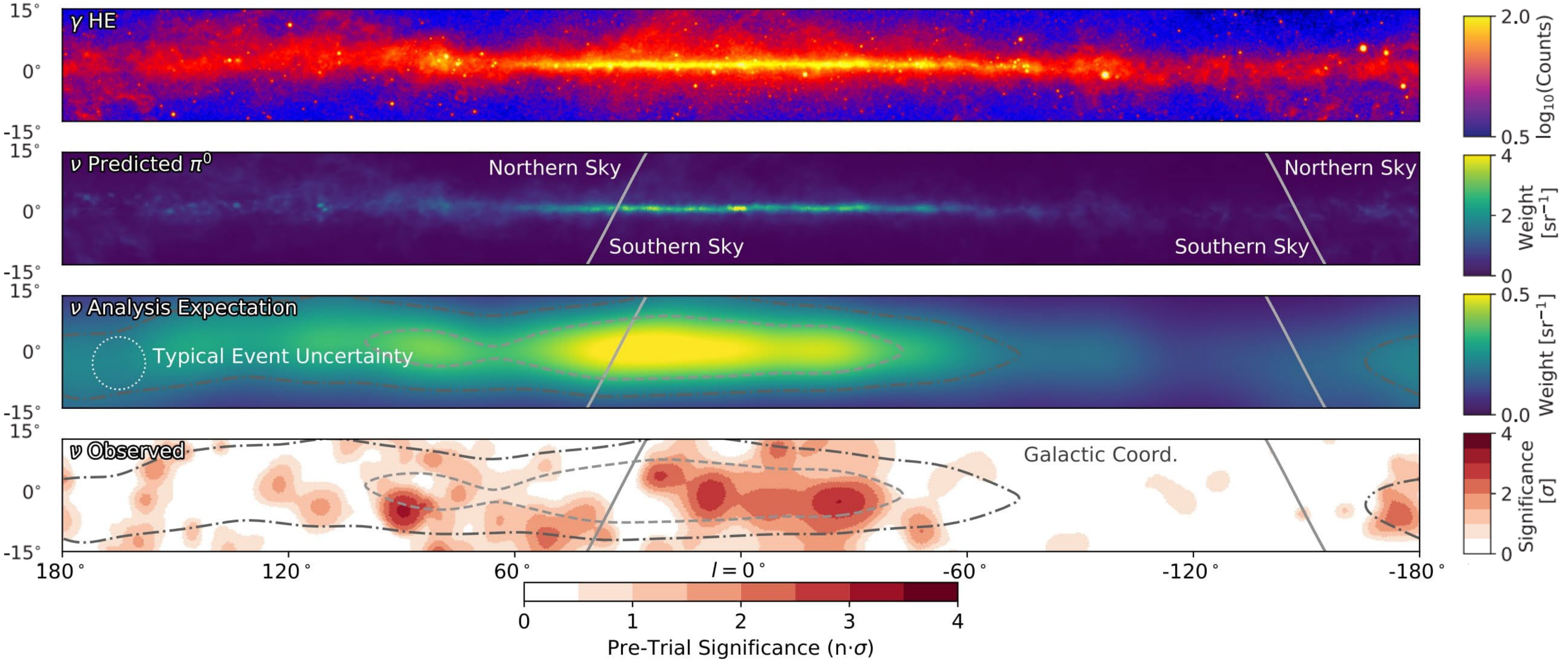
Jennifer A. Adams [a], Graham G. Ross [b], Subir Sarkar [b,1]
[a] *Department of Theoretical Physics, Uppsala University, Box 803, S-75108 Uppsala, Sweden*
[b] *Theoretical Physics, University of Oxford, 1 Keble Road, Oxford OX1 3NP, UK*

Received 15 April 1997; accepted 23 June 1997

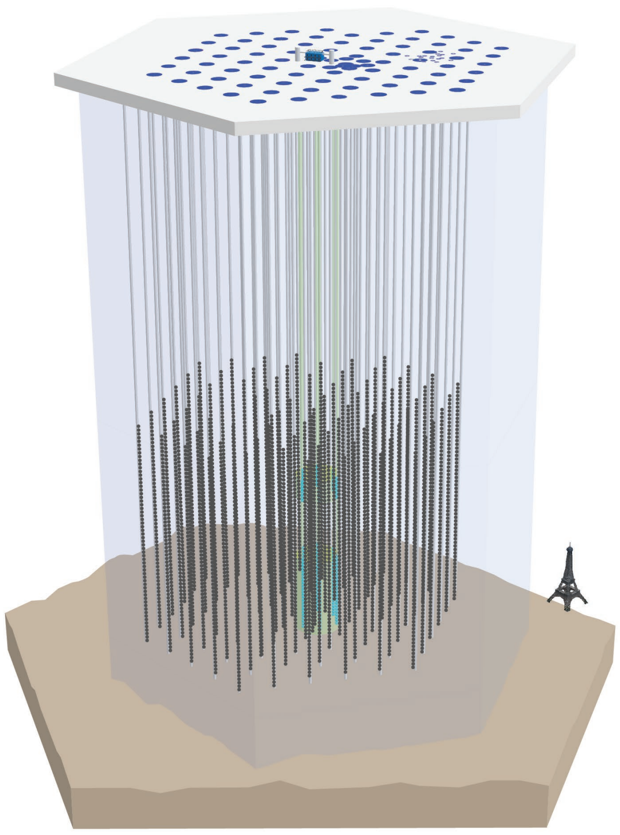


Galactic neutrino – determining the most promising sources associated with supernova remnants

IceCube Observation of Neutrinos from the Galactic Plane

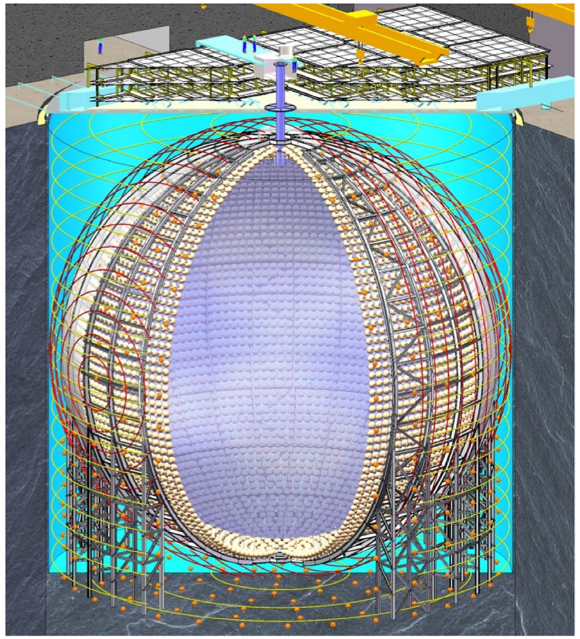


IceCube Neutrino telescope

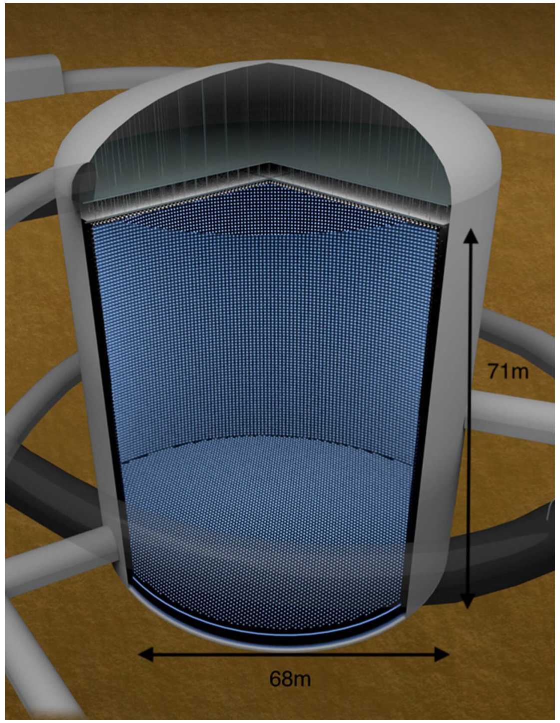


IceCube

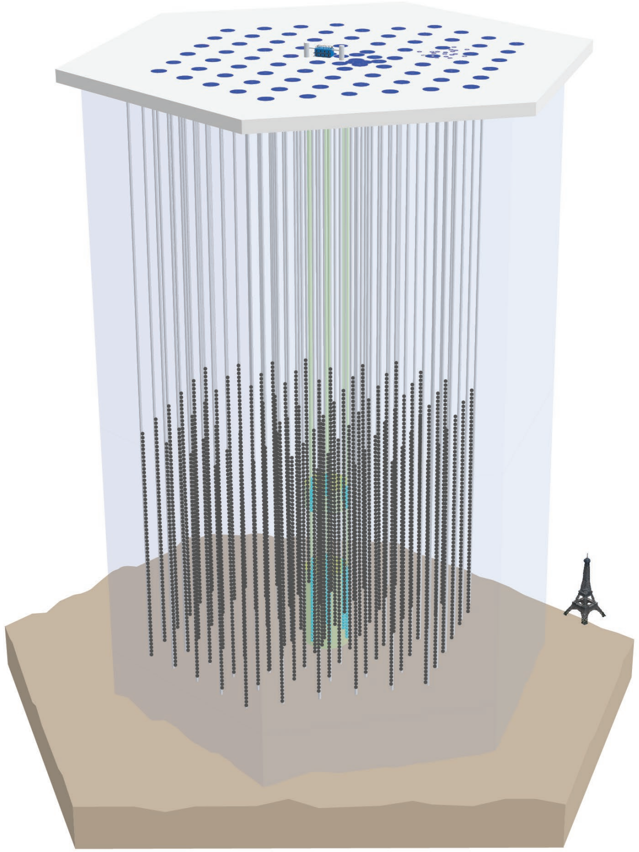
Neutrino telescopes – Big cousins of neutrino detectors



JUNO



Hyper-Kamiokande



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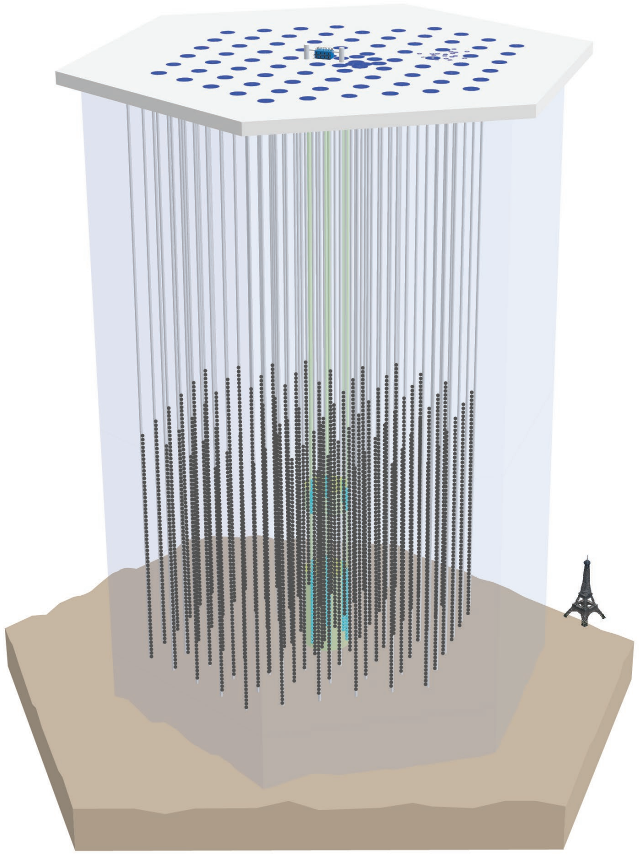
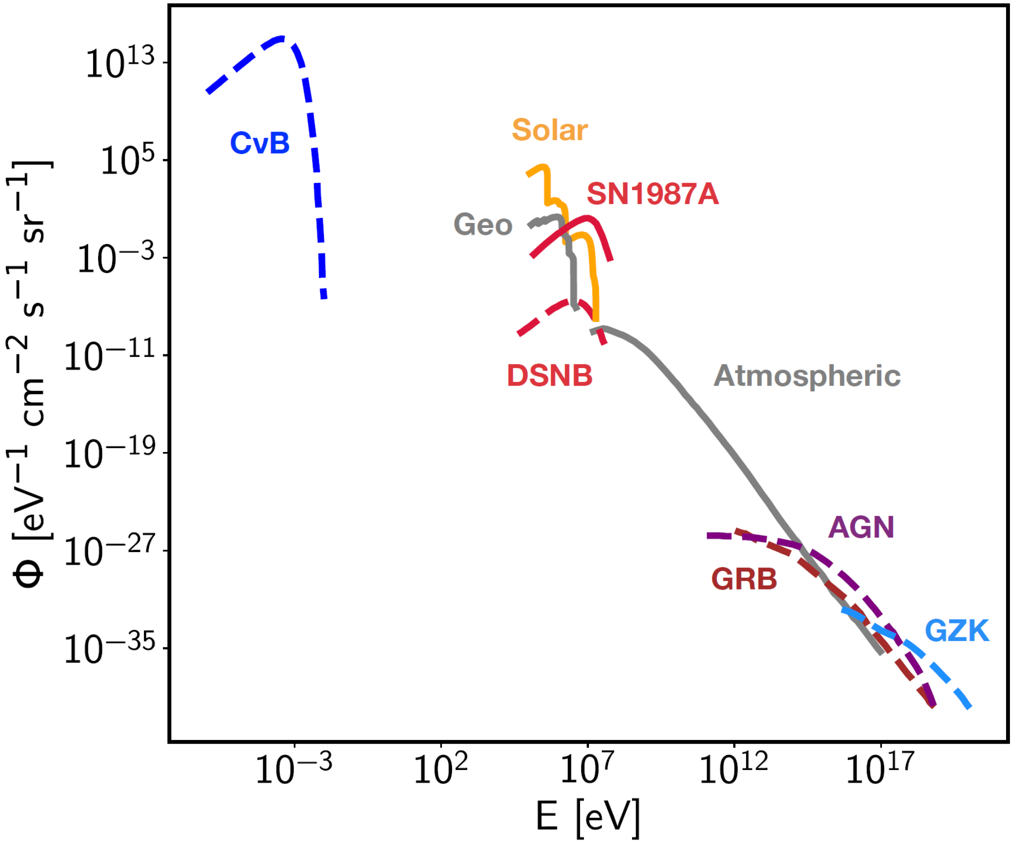


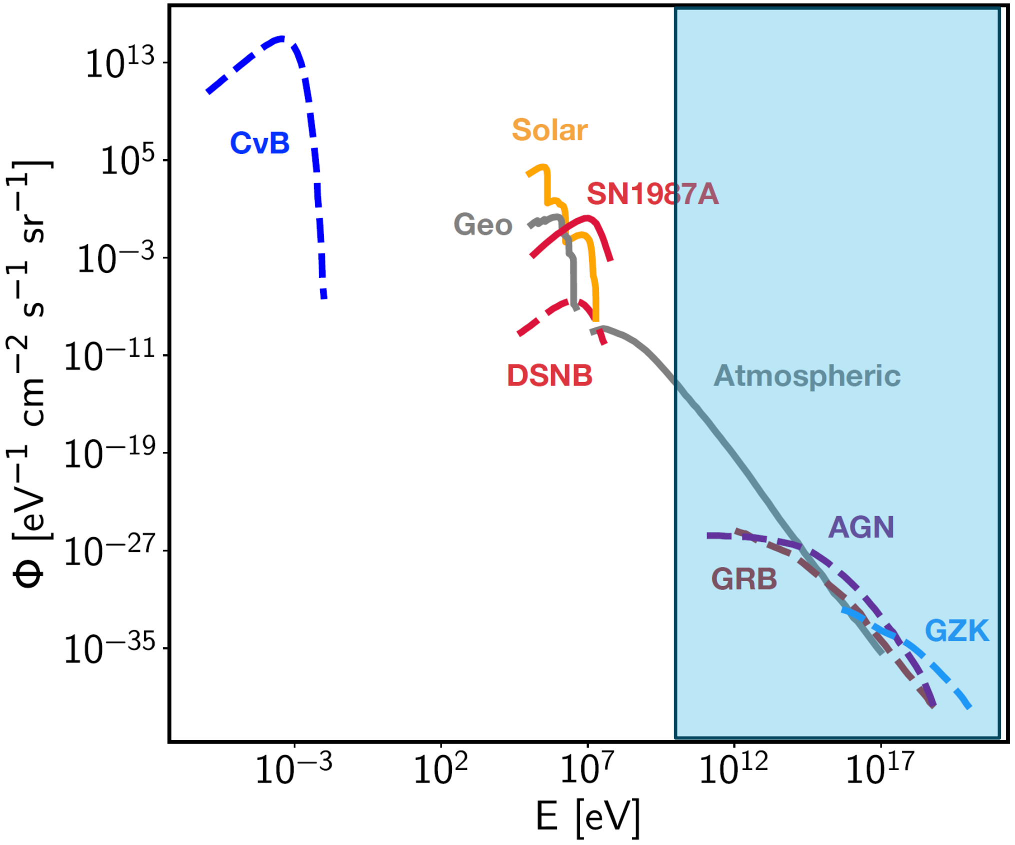
IceCube

Astrophysical neutrino spectra



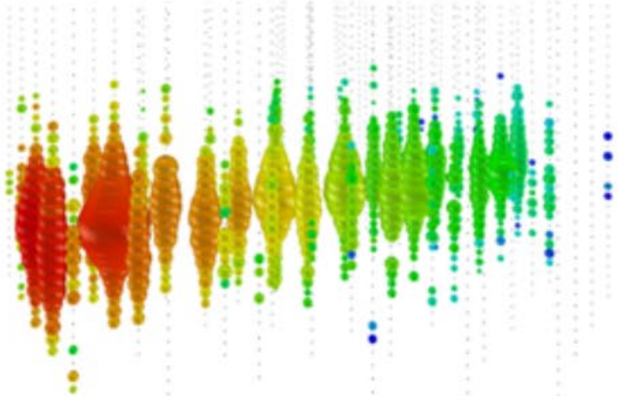
Astrophysical neutrino detection- challenge of small cross-secton AND low fluxes

Astrophysical neutrino spectra



Astrophysical neutrino detection-challenge of small cross-section AND low fluxes

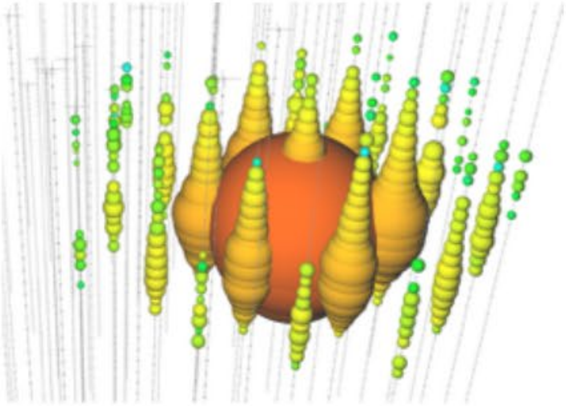
Neutrino event signatures in IceCube



Track
(Data)

CC Muon neutrinos

factor of ≈ 2 energy resolution
(in E_μ rather than E_ν)
< 1º angular resolution



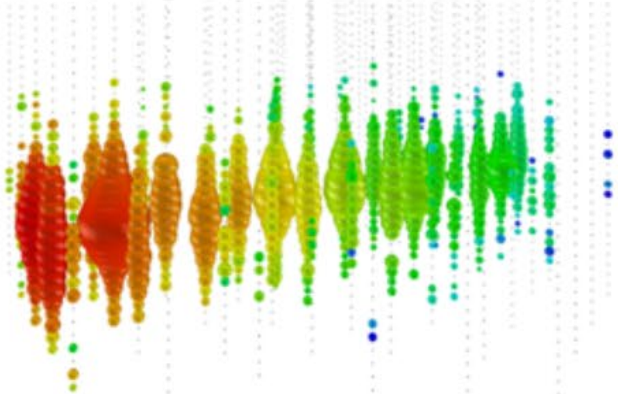
Shower or cascade
(Data)

NC all neutrino flavours
CC Electron and Tau neutrino

15% deposited energy resolution

angular resolution ~10º for >100 TeV

Neutrino event signatures in IceCube



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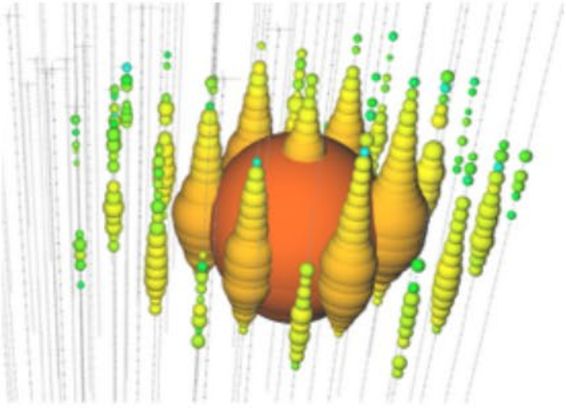

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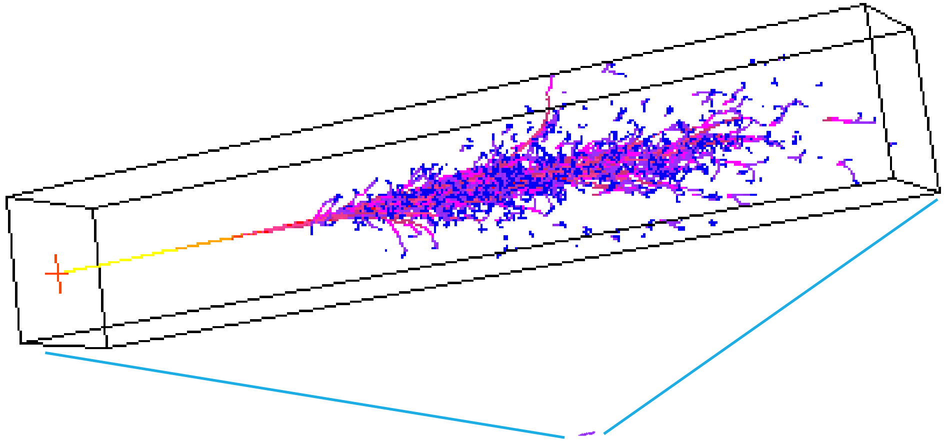
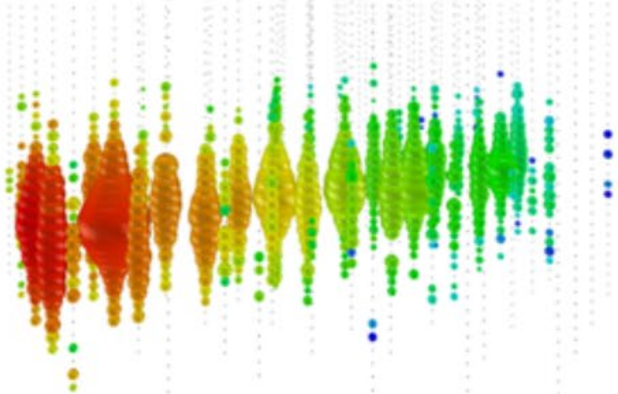


Neutrino event signatures in IceCube

$L_\tau \simeq 50\text{m} \cdot E_\tau \,/\text{PeV}$



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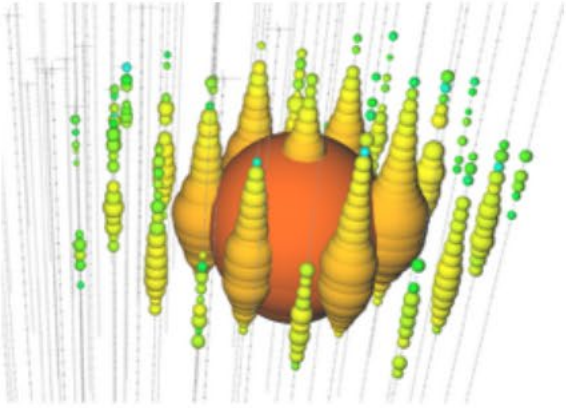

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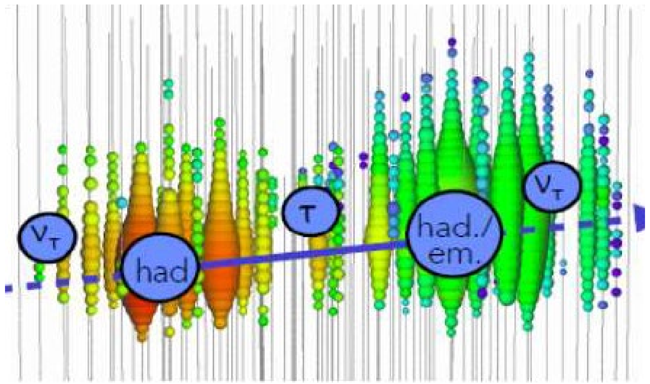
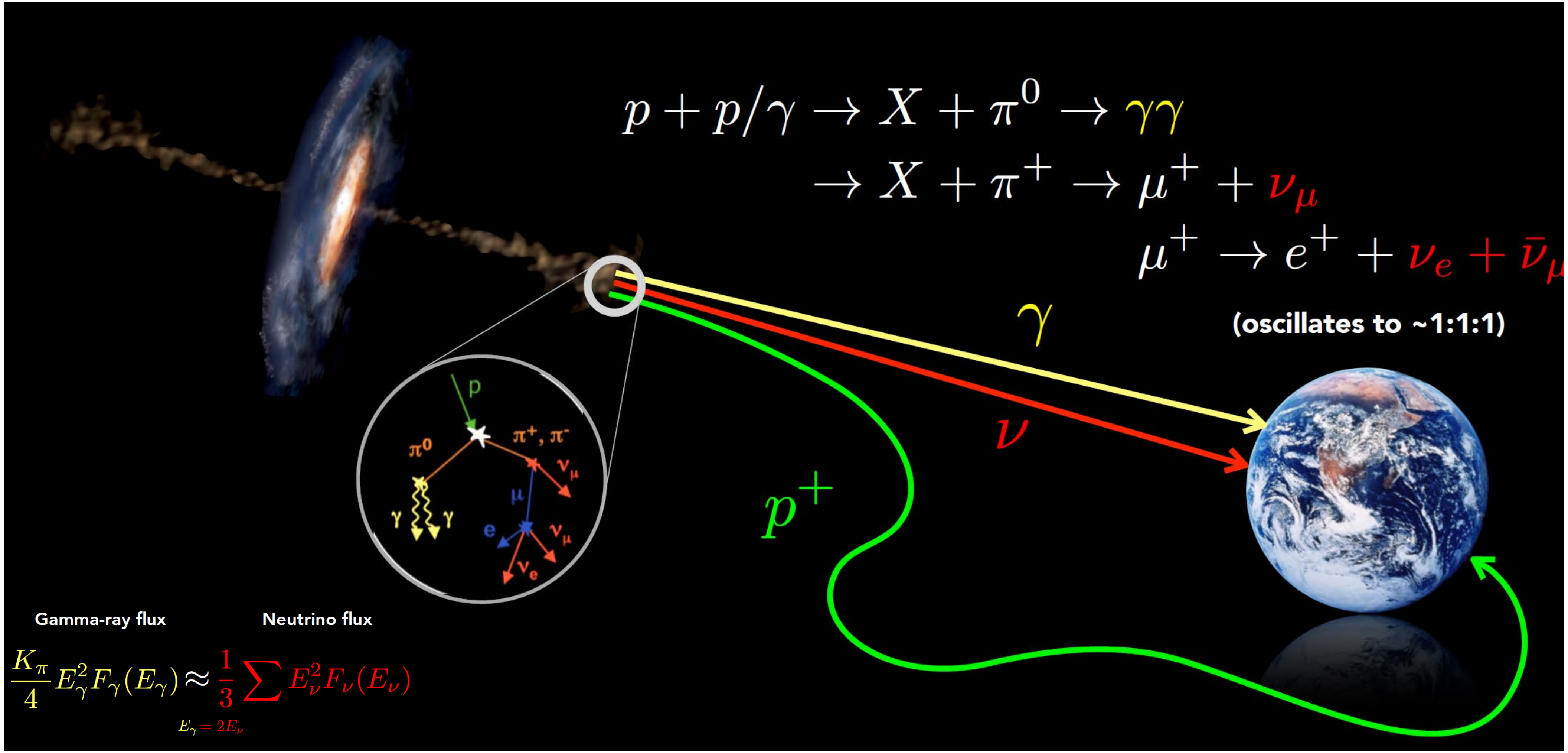
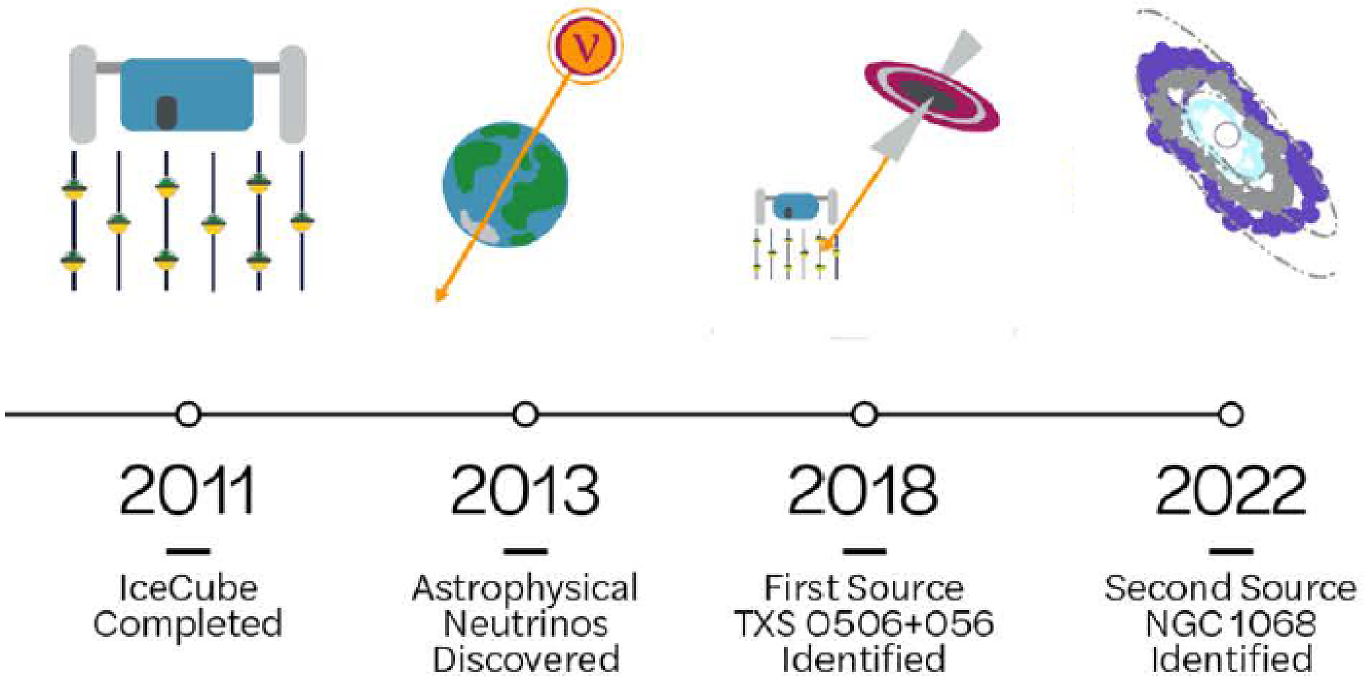


Double Bang
(Simulation ~PeV Tau neutrinos)

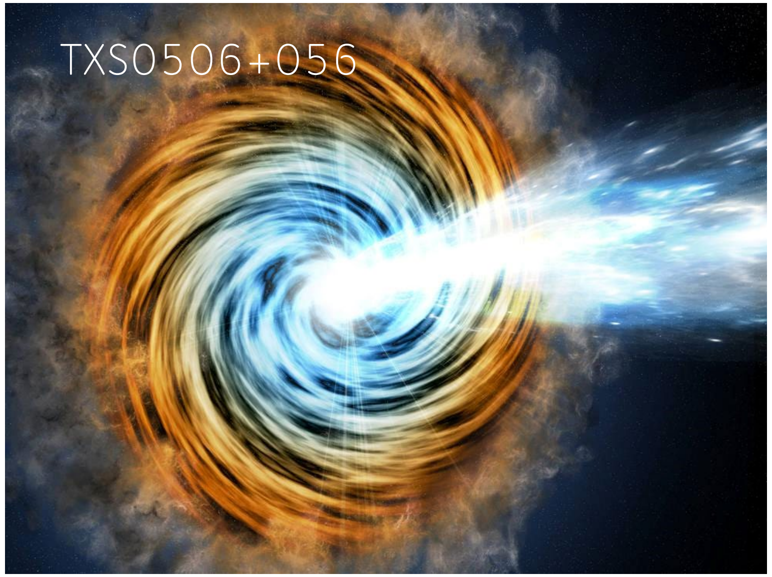
Neutrinos as cosmic-ray tracers



IceCube Astrophysical Neutrino Discoveries



IceCube neutrino source detections



Blazar – AGN with relativistic jets orientated towards line of sight

Transient emission

z = 0.3365 5.7 billion light years

Non-jetted AGN with obscured black hole

Steady state emission

z = 0.00381 47 million light years

Galactic Neutrino Observation Challenges

Galactic neutrinos - challenging background rejection as:

- Lower energy neutrinos
- Galactic centre in the Southern sky

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Galactic neutrinos - challenging background rejection as:

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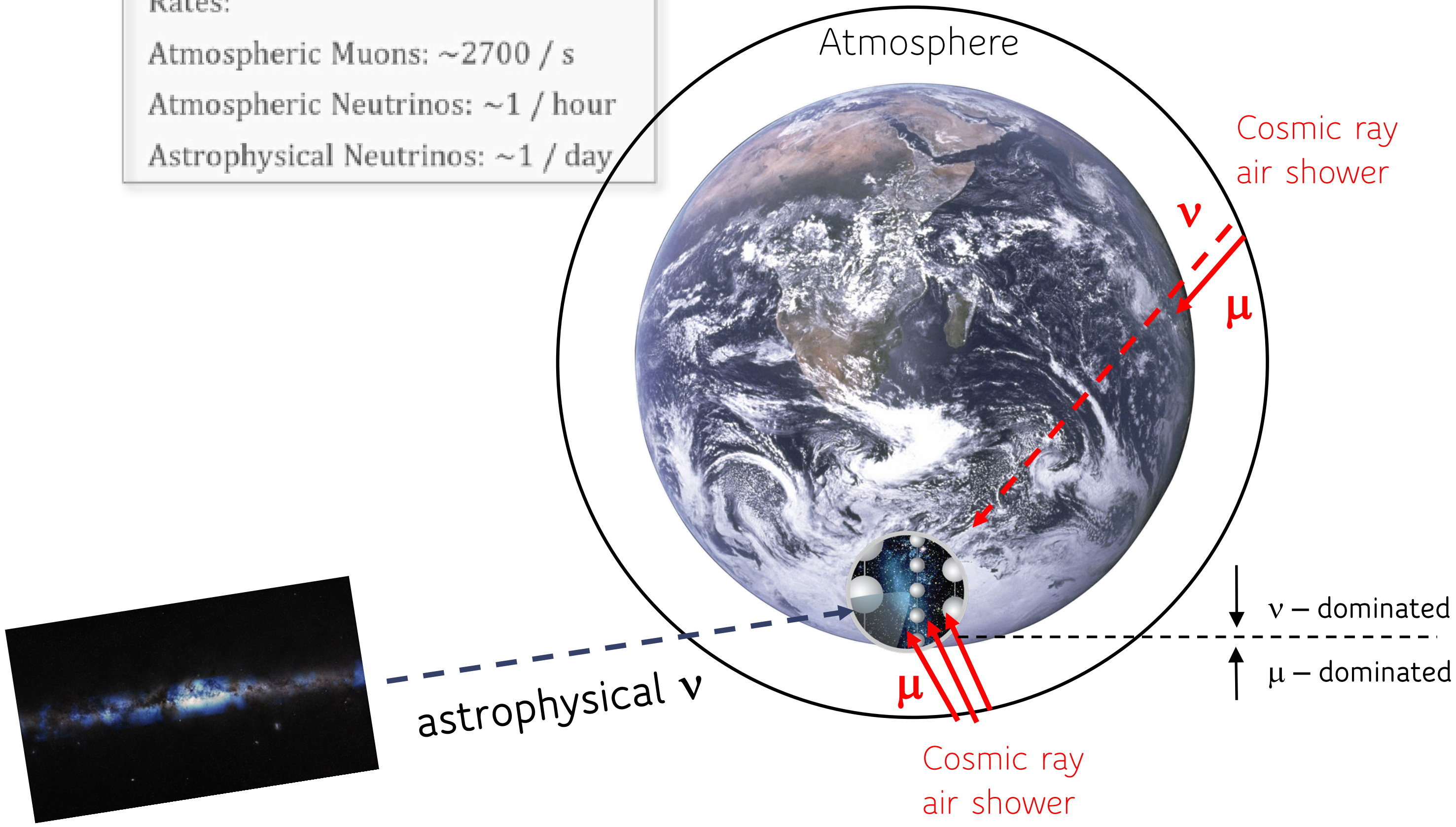
Rates:

Atmospheric Muons: ~2700 / s

Atmospheric Neutrinos: ~1 / hour

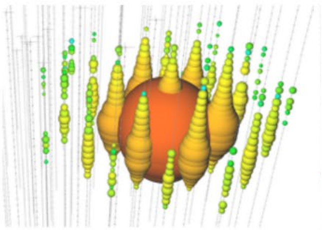
Astrophysical Neutrinos: ~1 / day



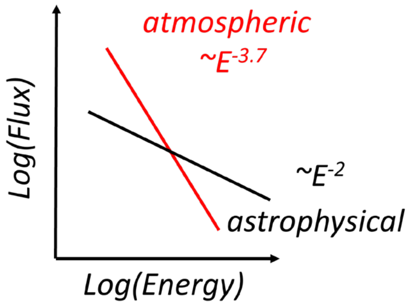
Background rejection tools

Various strategies to reject background…

- Select cascade events to remove atmospheric muon events



- Employ the differing spectral slopes of atmospheric and astrophysical neutrinos



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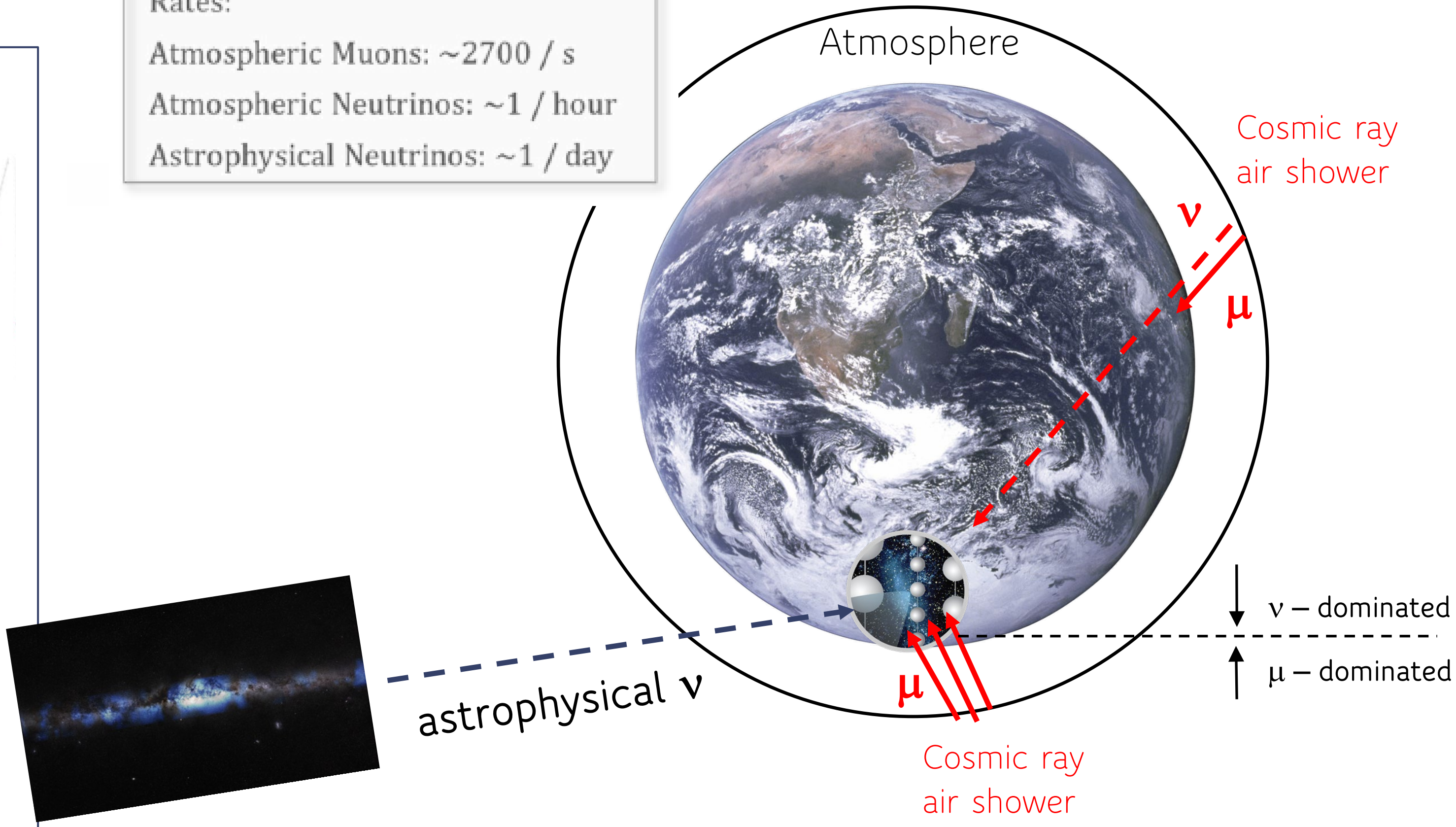
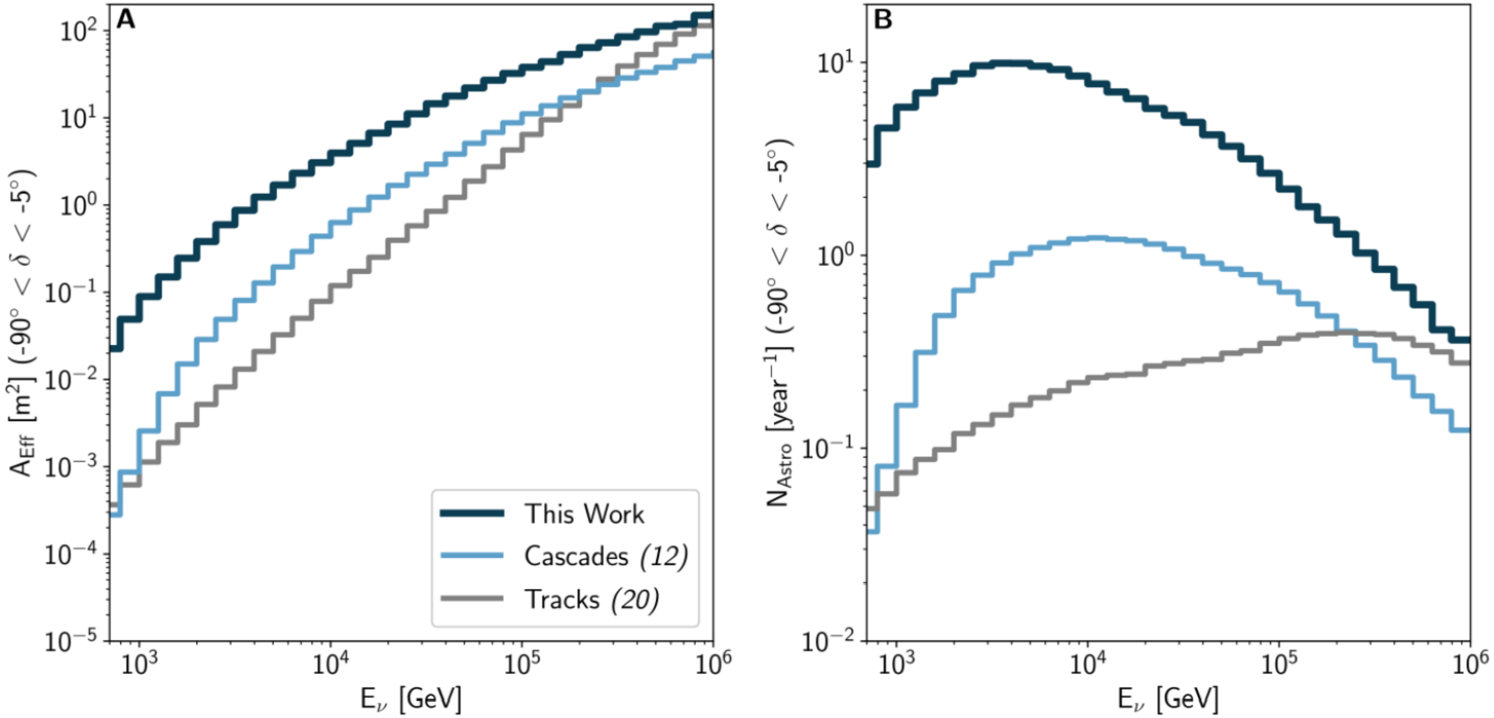


IceCube Observation of Neutrinos from the Galactic Plane

IceCubeCollaboration*† *Science* **380**,1338-1343(2023).DOI:10.1126/science.adc9818

- Ten-year cascade event sample, Convolutional Neural Networks used to select cascade events and reject track events, 60 000 events, 30X more than previous selection




Steve Sclafani


Mirco Hünnefeld

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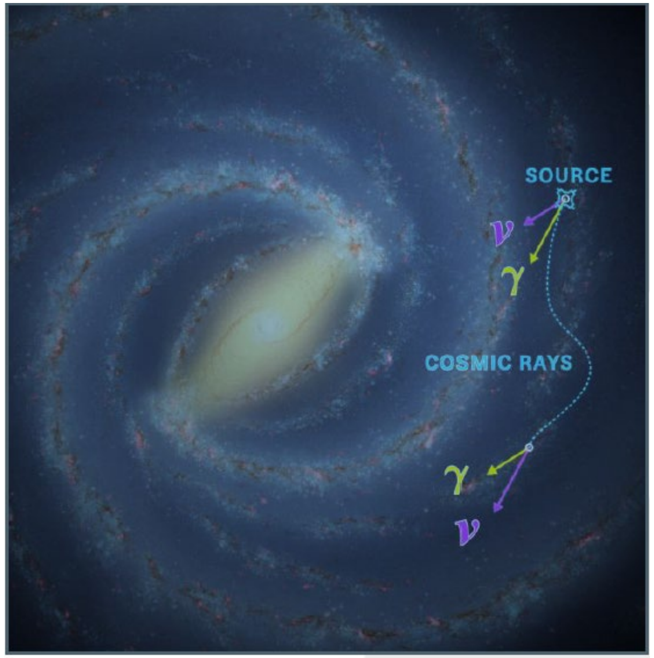
- 3 diffuse model tests



- 3 stacking source catalogue tests

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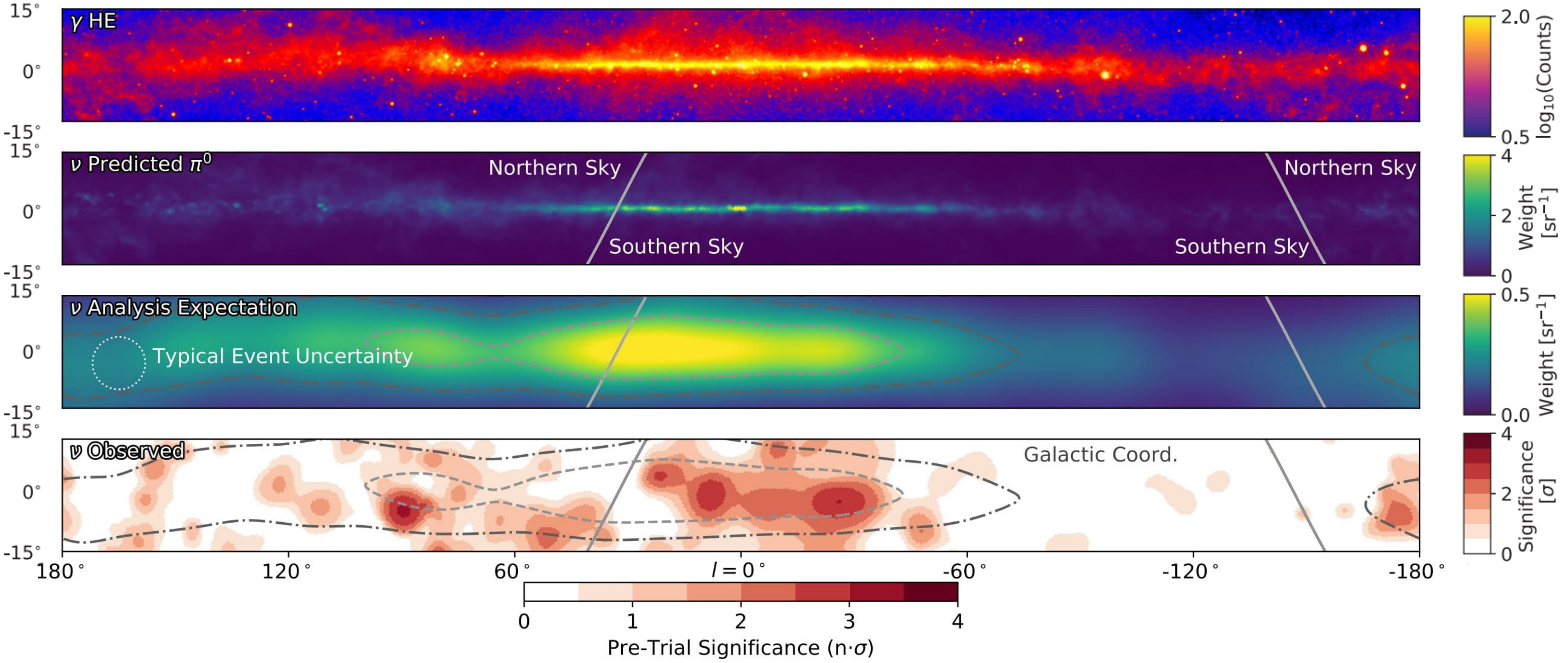

IceCube Observation of Neutrinos from the Galactic Plane

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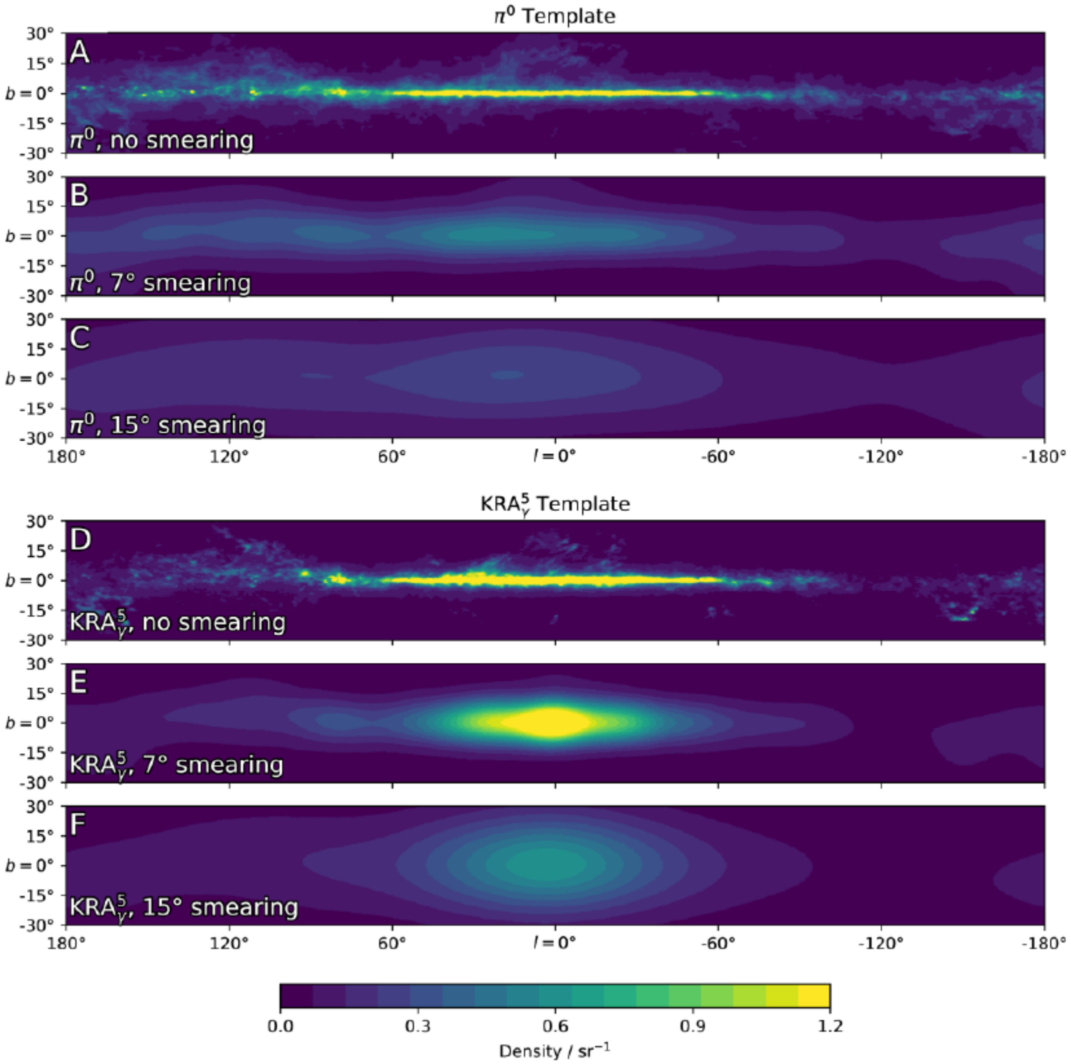
- 3 diffuse model tests
  - Fermi π^0
  - 2 KRA γ models
    - Radially dependent CR diffusion
    - 2 energy cutoffs 5 and 50PeV
  - Fixed Spectrum
  - Fit for flux normalisation

- 3 stacking source catalogue tests
  - Supernova remnants
  - Pulsar Wind Nebulae
  - Other unidentified Galactic Sources



IceCube Observation of Neutrinos from the Galactic Plane

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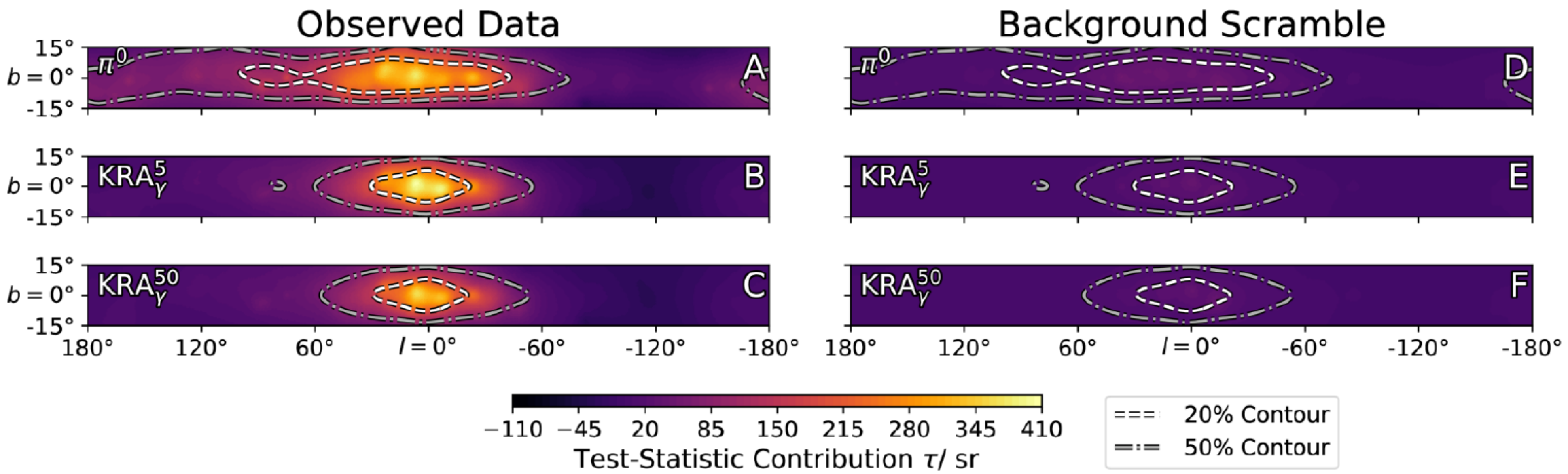
- Evidence for neutrino emission from the galactic plane. Global Significance 4.5 σ
- 3 s significance from the stacking catalogues
- Background estimation with data scrambles

Diffuse Galactic plane analyses	Flux sensitivity Φ	p-value	Best-fitting flux Φ
π^0	5.98	1.26×10^{-6} (4.71σ)	$21.8^{+5.3}_{-4.9}$
KRA_γ^5	0.16×MF	6.13×10^{-6} (4.37σ)	$0.55^{+0.18}_{-0.15}$×MF
KRA_γ^{50}	0.11×MF	3.72×10^{-5} (3.96σ)	$0.37^{+0.13}_{-0.11}$×MF
Catalog stacking analyses		**p-value**	
SNR		5.90×10^{-4} (3.24σ)*	
PWN		5.93×10^{-4} (3.24σ)*	
UNID		3.39×10^{-4} (3.40σ)*	



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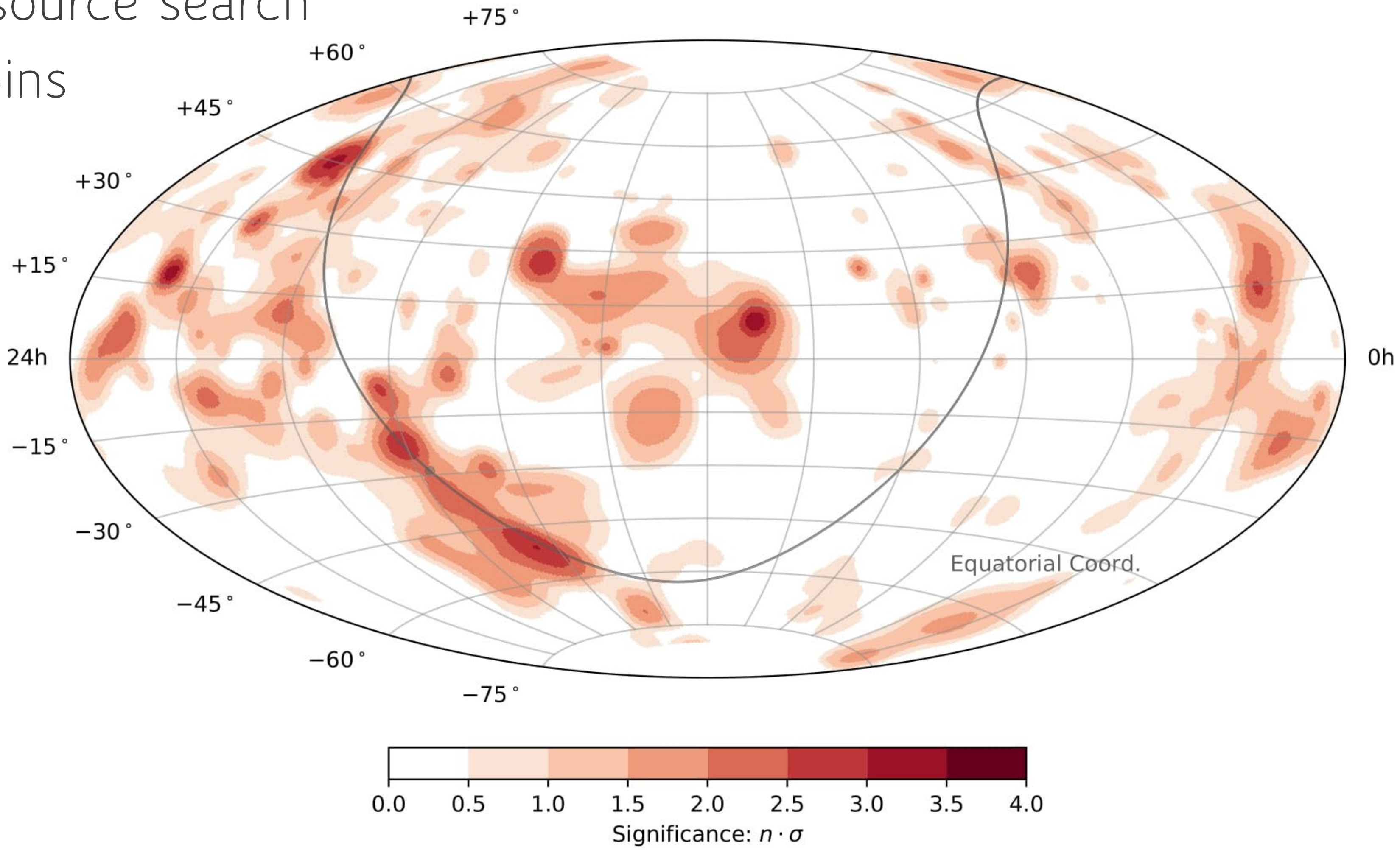
- All sky point source search grid of 0.45° bins



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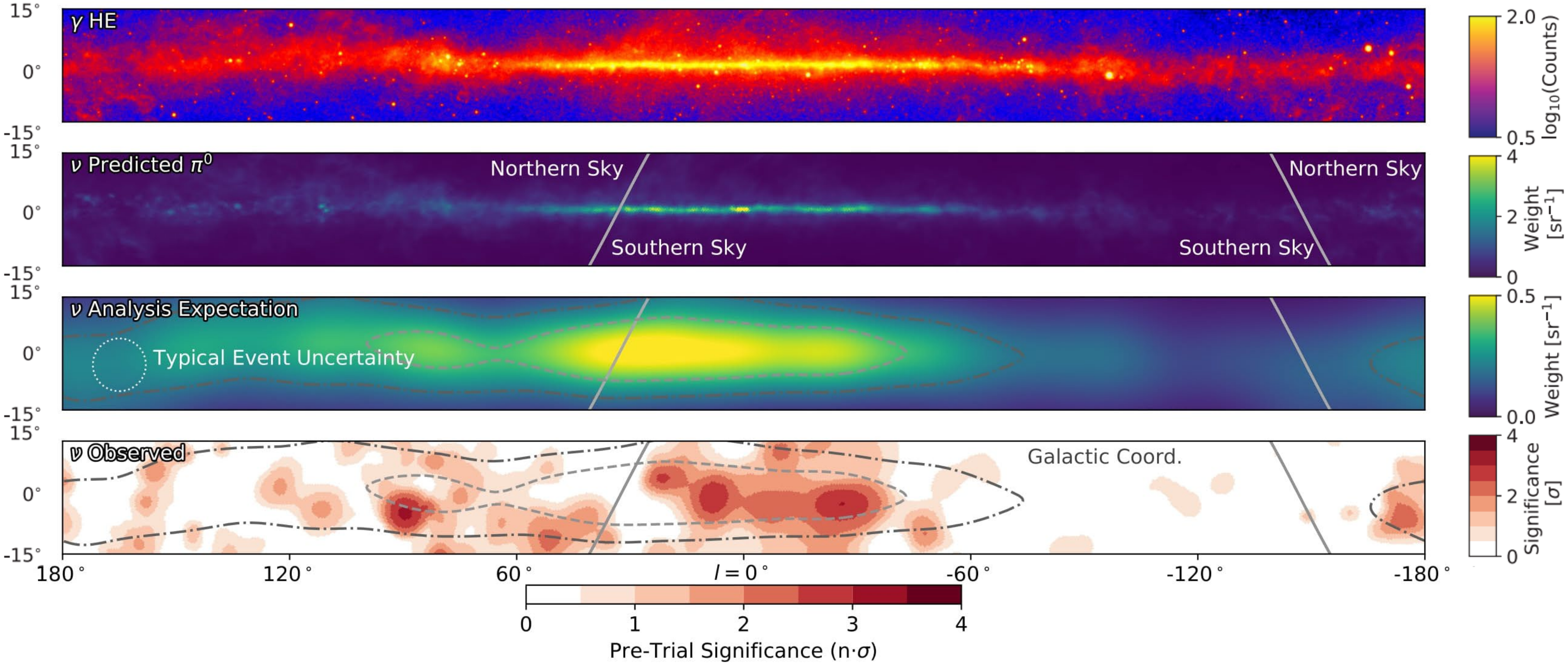
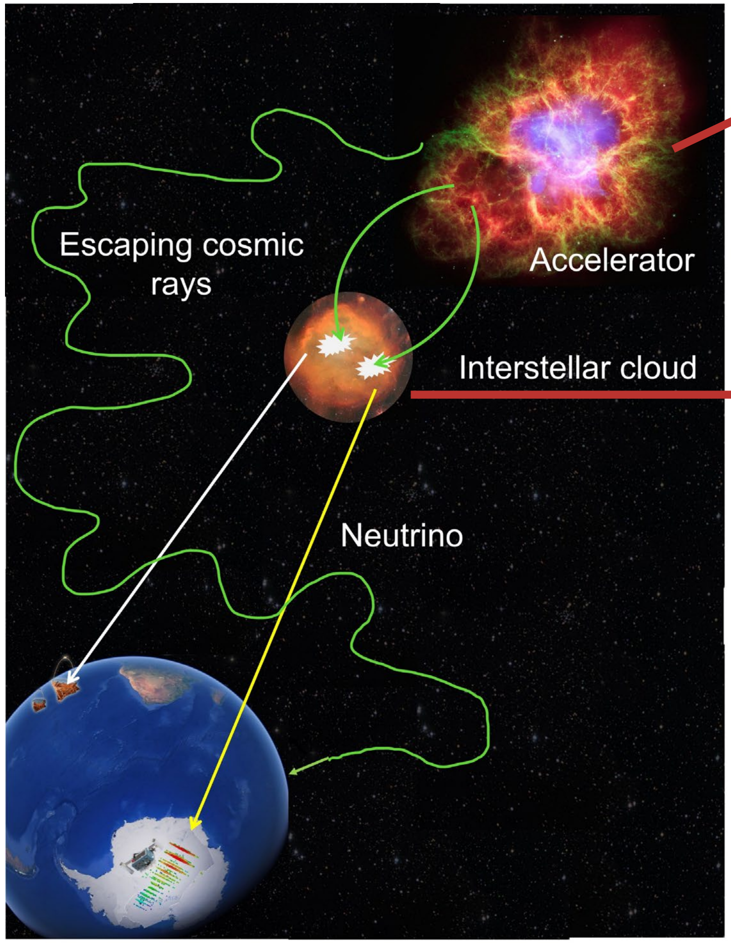


Neutrino/gamma ray fluxes for pairs of Supernova remnant and molecular clouds

Ryan Burley, Sabrina Einecke, Gary Hill, Gavin Rowell (Adelaide), JA and Rhia Hewett (Canterbury)



SNR Catalogue Green, A & A, **40** (2019)

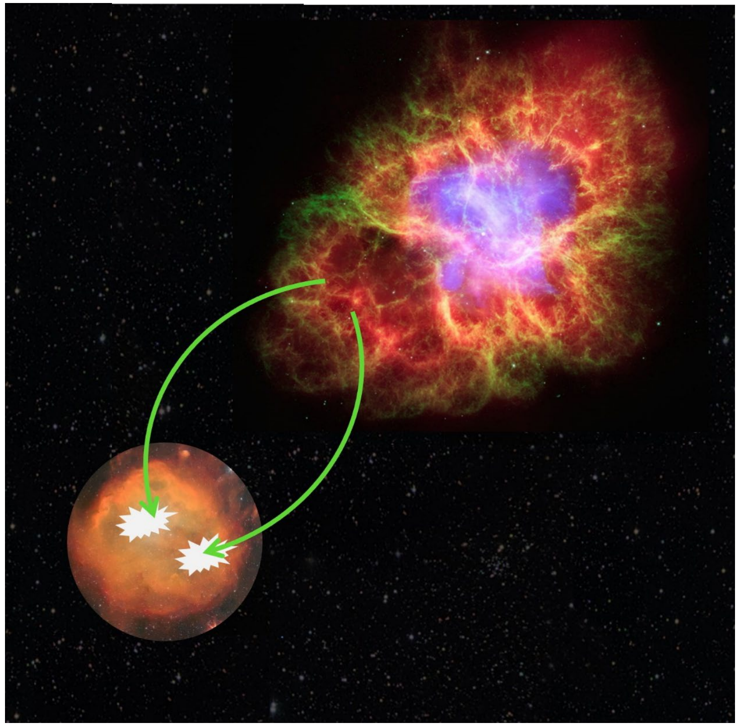
303 SNRs
Type, age, distance

Molecular Cloud Catalogue Rice et al, ApJ, 822 (2016)

1064 Molecular clouds
Distance, Mass, radius, angular size

Consider pairs of SNR and Molecular Clouds with a separation of 100 pc or less

Neutrino/gamma ray fluxes for pairs of Supernova remnant and molecular clouds



Aharonian and Atoyan solution to the transport equation with diffusion and radiative losses:

$$J(E,R,t) \propto \frac{N_0 f_0 E^{-\alpha}}{\pi^{3/2} l_{\mathrm{dif}}^3} \exp\left[-\frac{(R-R_{\mathrm{esc}})^2}{l_{\mathrm{dif}}^2}\right] \exp\left[-\frac{(\alpha-1)(t-t_{\mathrm{esc}})}{\tau_{pp}}\right]$$

*Aharonian & Atoyan, A&A, **309** (1996)*

$t_{\mathrm{esc}}, l_{\mathrm{dif}}, \tau_{pp}$ all energy dependent

Aharonian and Atoyan solution assumed all particles escaped at the same time, here f_0 adjusts for expanding supernova and energy dependent particle release time and radius

$$f_0 = \frac{\sqrt{\pi} l_{\mathrm{dif}}^3}{(\sqrt{\pi} l_{\mathrm{dif}}^2 + 2\sqrt{\pi} R_{\mathrm{SNR}}^2) l_{\mathrm{dif}} + 4 R_{\mathrm{SNR}} l_{\mathrm{dif}}^2}$$

*Mitchell et al., MNRAS, **503** (2021)*

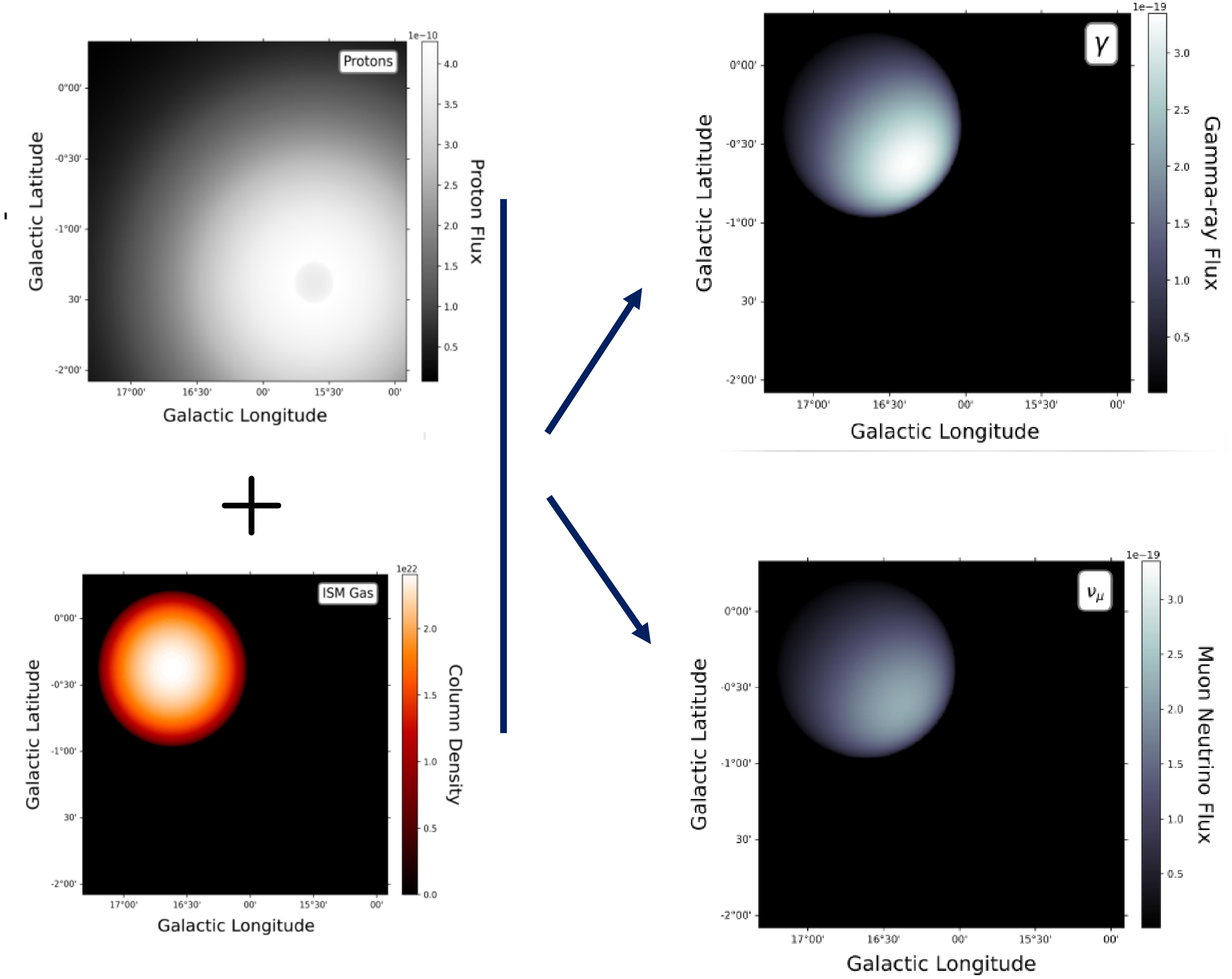
$$R_{\mathrm{SNR}}(t) = 1.15 \left(\frac{E_{\mathrm{SN}}}{n_0}\right)^{1/5} t^{2/5}$$

*Truelove & McKee, ApJSS, **120** (1999)*

$$t_{\mathrm{esc}}(E) = t_{\mathrm{sedov}} \left(\frac{E}{E_{max}}\right)^{-1/\beta}$$

*Gabici et al., MNRAS, **396** (2009)*

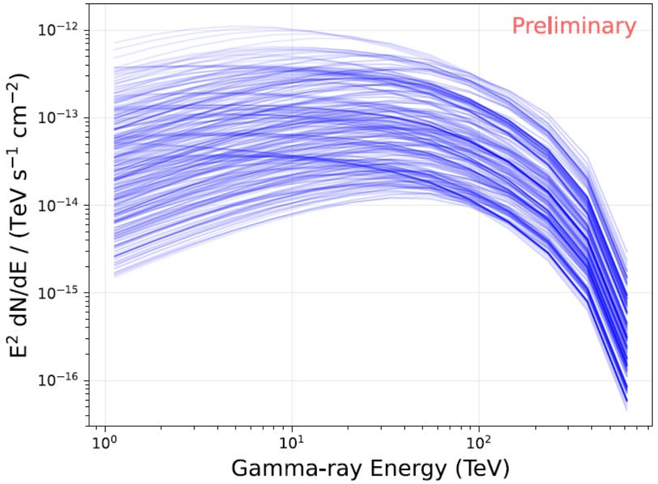
Neutrino/gamma ray fluxes for pairs of Supernova remnant and molecular clouds

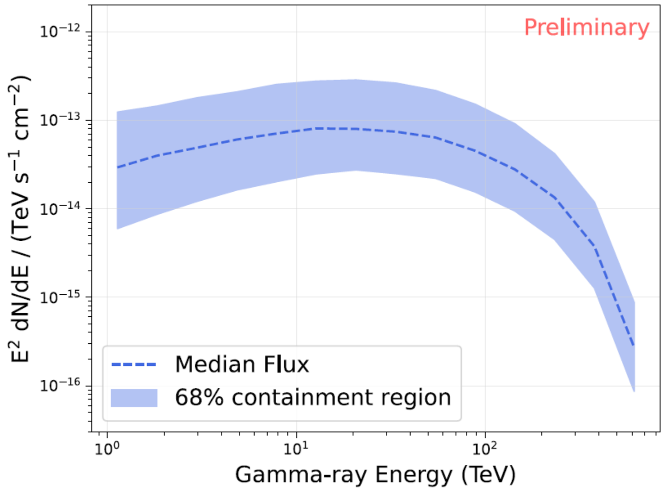


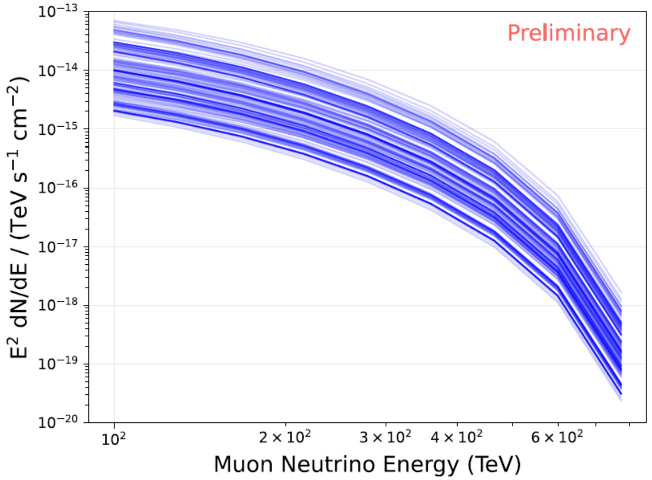
Model Parameter	Values
χ	0.1, 0.01, 0.001
δ	0.3, 0.5
η	0.1, 0.3
$E_{\mathrm{p,max}}$	1 PeV, 5 PeV
α	2, 2.2
$E_{\mathrm{SN}}, M_{\mathrm{ej}}$	$(10^{51}$ erg, $1.4\,M_{\odot})$, $(10^{51}$ erg, $10\,M_{\odot})$, $(10^{52}$ erg, $20\,M_{\odot})$

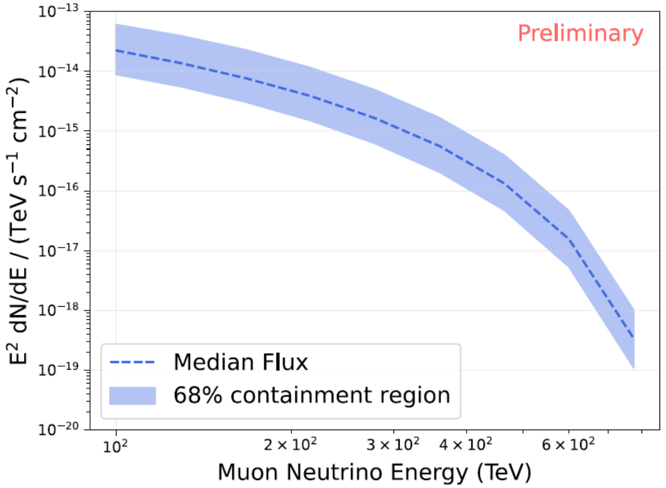
Neutrino/gamma ray fluxes for pairs of Supernova remnant and molecular clouds

Example - a particular combination:





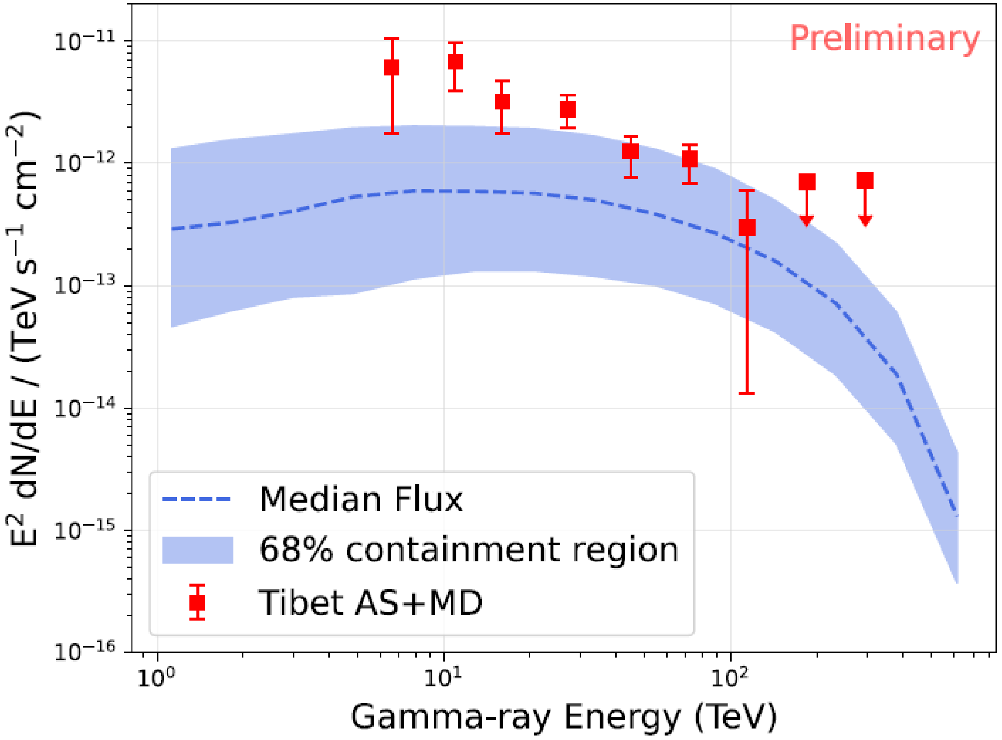


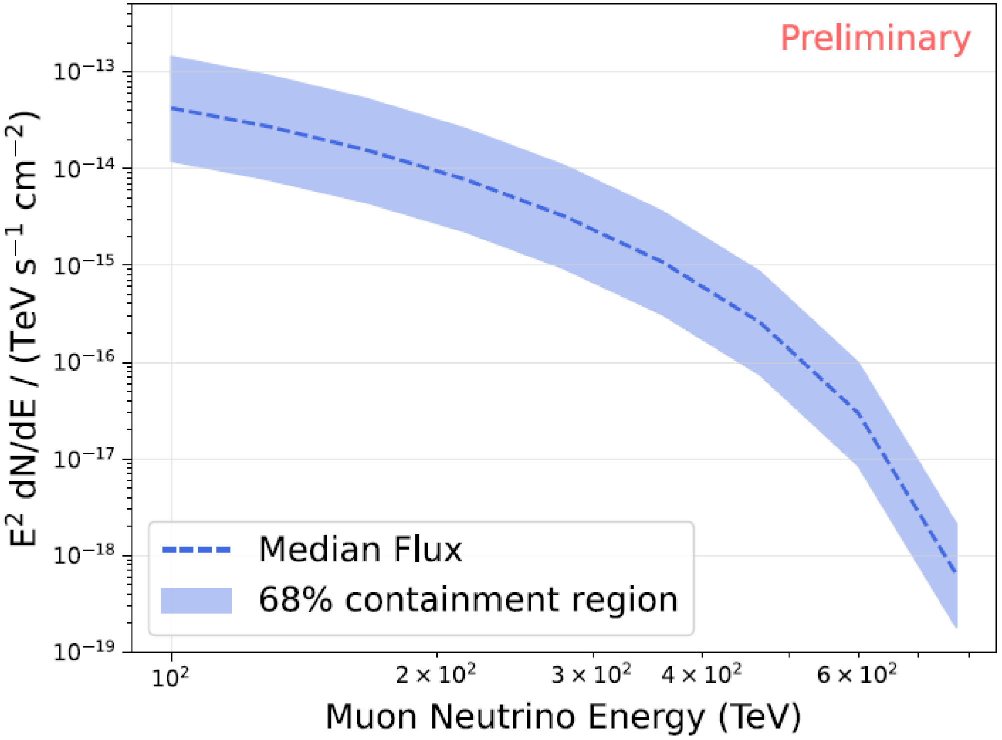


SNR G106.3+2.7 (Boomerang PWN)

Example of SNR G106.3+2.7 and cloud #630 from
Rice et al, ApJ, 822 (2016)

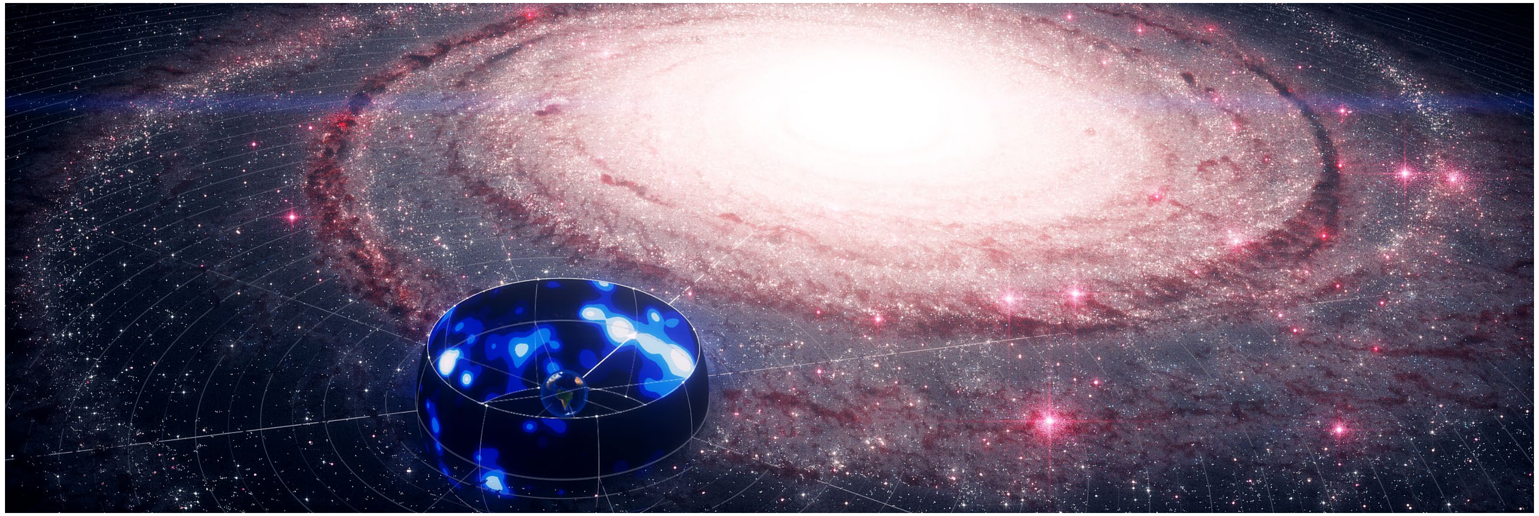
SNR G106.3+2.7 observed in > 10 TeV gamma rays
(Tibet Asγ Collaboration et al, Nat Astron 125 (2021))





Summary

- IceCube evidence of neutrino observation from the Galactic plane
  - Unable to separate the galactic plane diffuse emission scenario from a situation where the emission is from a combination of sources
- We are conducting a systematic study of pairs of Supernova Remnants and Molecular Clouds to estimate neutrino emission



Galactic Birthday Greetings, Subir!