I read the paper up to and including section:

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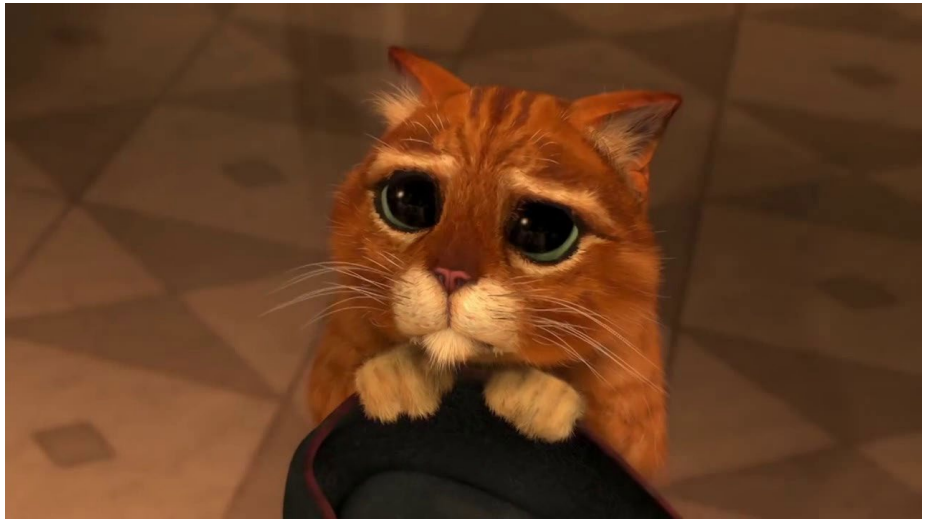

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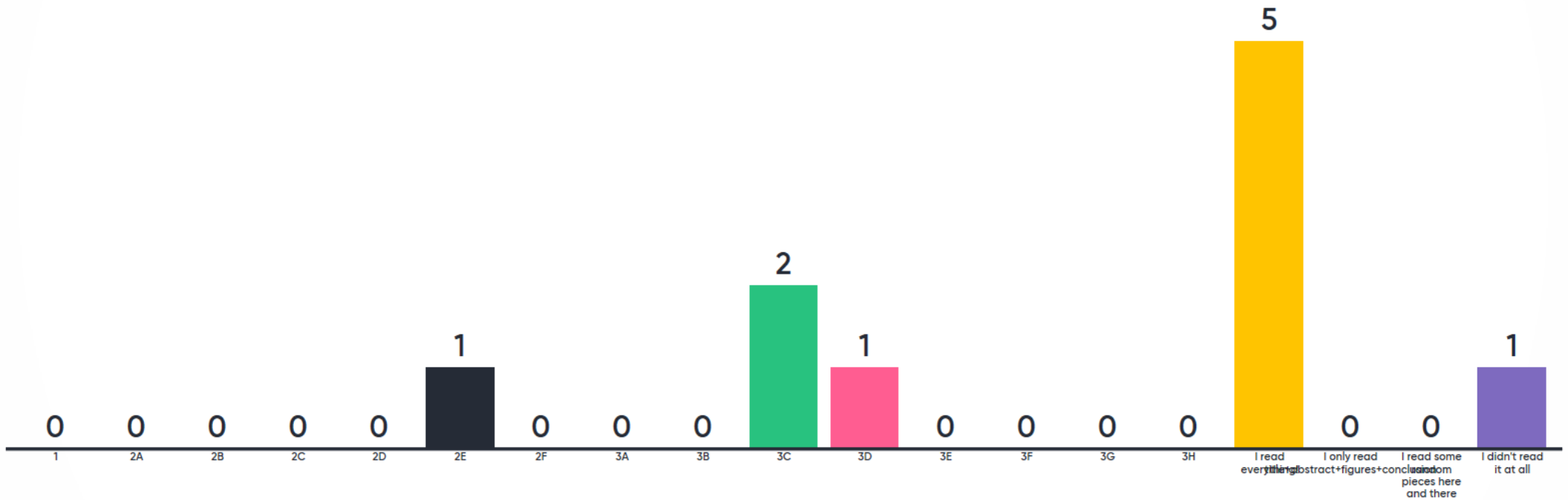

PHYSICAL REVIEW D **96,** 023003 (2017)

Prospects of establishing the origin of cosmic neutrinos using source catalogs

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Paper groupmeeting
November, 2019, Amsterdam

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APS physics

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I. Motivation & Goal

Motivation

- High E neutrinos are tool to learn about astrophysical processes
- Ice Cube detects cosmic neutrino flux
- But sources producing the measured neutrino flux is unknown
- Origin more challenging sources?

Goal

- Devise and evaluate a method

  to find population of distant continuous neutrino sources

  using source catalogs.

I. Theory – "multiple search strategies"

(i) Neutrino-only

Spatial or temporal clustering of neutrinos to identify energetic nearby sources

(ii) Spectral information

Compare the neutrino spectrum with other astrophysical fluxes (CR / γ-ray)

(iii) Multimessenger searches

Neutrinos associated with a source population observed through other messengers

> in contrast to the case of transient sources, the identification of multiplets from a population of continuous sources will be challenging

I. Theory – scale

And here smart asses build detectors to detect neutrino's of which the bulk

Starburst galaxies

AGN

Blazars

Galaxy clusters

we will consider four astrophysical source types, namely starburst galaxies, AGN, blazars, and GCs. These are the primary considered continuous source candidates for the detected cosmic neutrino flux.

ν

ν

ν

ν

II. Search strategy

A. Search distance threshold

B. Only track events will be used

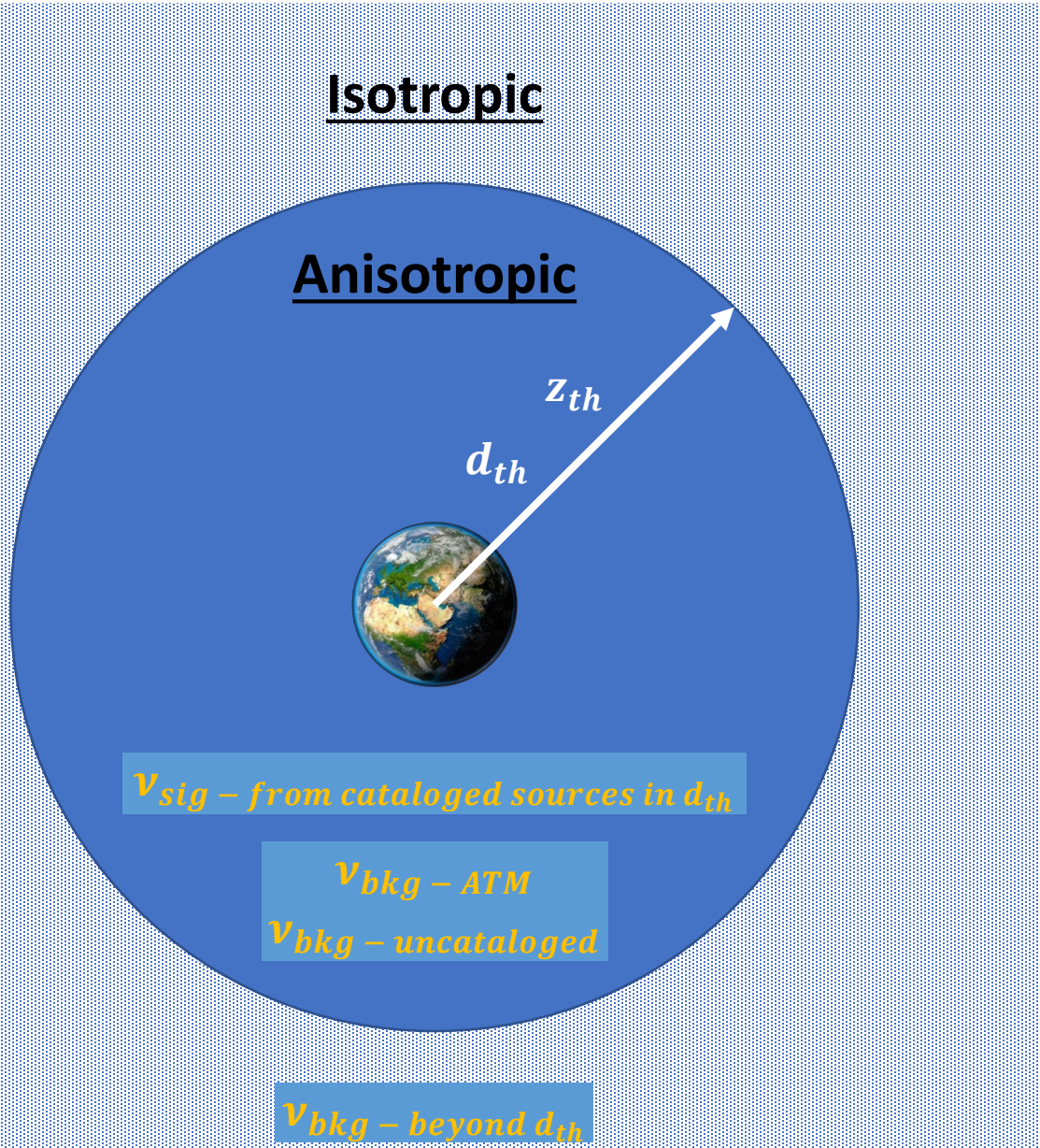
C. Method

D. Astrophysical source types

E. Fraction of neutrinos from within threshold distance

F. Comparison to previous work

Constraining the search to neutrinos emitted from known sources within d_{th} means, in effect, that neutrinos originating in these known sources will be the *signal* neutrinos, while *background* neutrinos will be those (i) originating in the atmosphere, (ii) from sources beyond d_{th}, and (iii) from uncataloged sources within d_{th}.



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F. Comparison to previous work

Tracks

- IceCube < 1*
- KM3NeT/ARCA < 0.3*

Showers

- IceCube < 10*
- KM3NeT < few*

II. Search strategy

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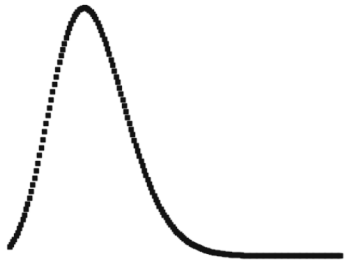
F. Comparison to previous work

- Expected sig & bkg neutrinos:

$$N_s = f_d(N_{total} - N_{atm})$$
$$N_b = N_{total} - N_s.$$



- Fraction of signal nu within dth:

$$f_d(z_{th}) = \Phi_\nu(z_{th})/\Phi_\nu(\infty)$$

II. Search strategy

A. Search distance threshold

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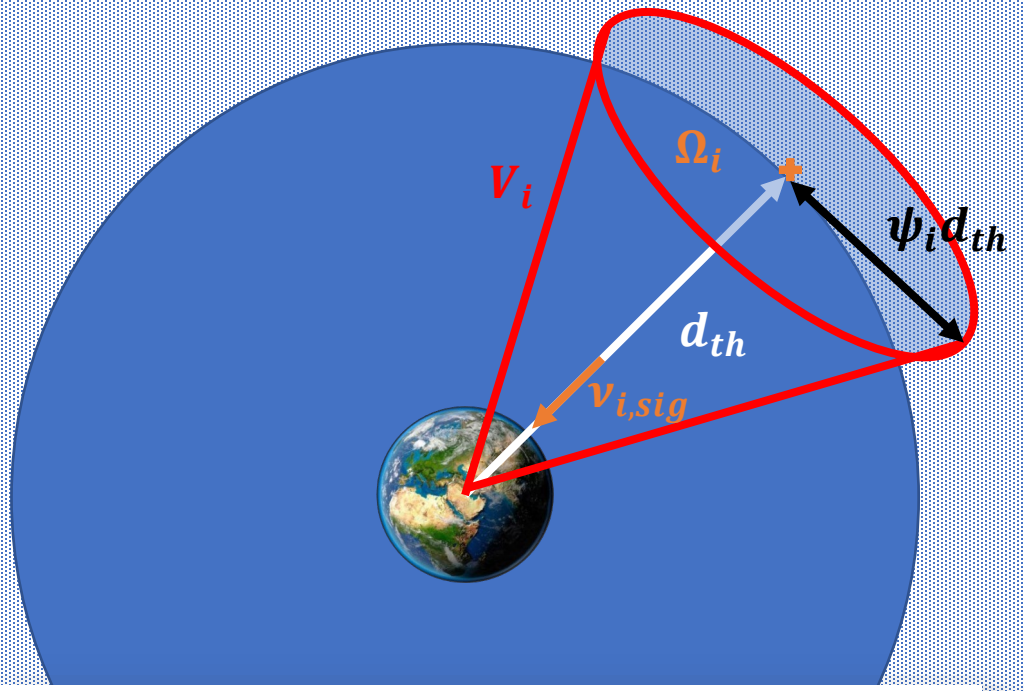
E. Fraction of neutrinos from within threshold distance

F. Comparison to previous work



We calculate the expected total neutrino flux from sources within V_i,

$$\mathcal{F}_{\nu,i} = \frac{1}{4\pi} \sum_j L_{\nu,j} d_j^{-2}, \quad (3)$$

where $L_{\nu,j}$ is the neutrino luminosity of source j and the sum is over the sources within V_i.

II. Search strategy

A. Search distance threshold

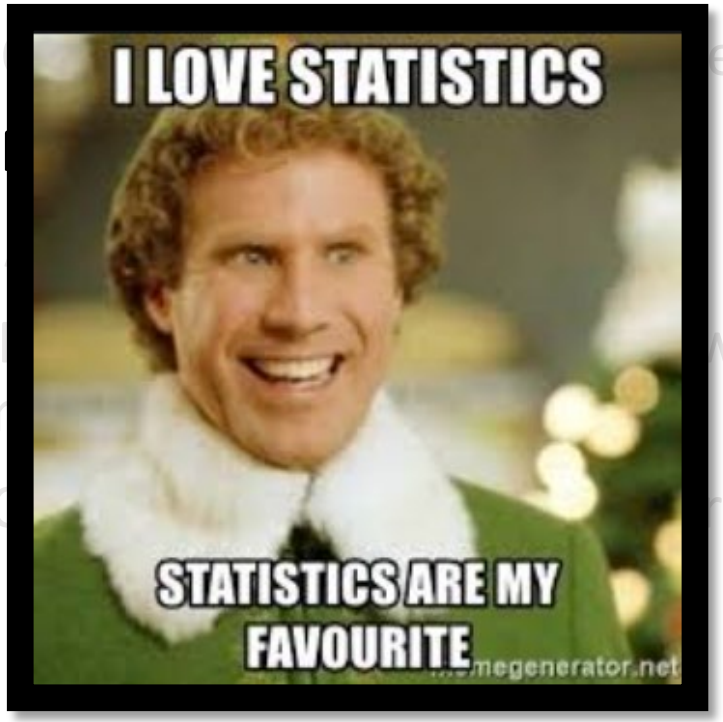
B. [illegible]ed

C. [illegible]

D. [illegible]

E. [illegible]within [illegible]

F. [illegible]rk



- PDF's: $\mathcal{B}_\mathrm{i} = \mathrm{const.}$ $\quad \mathcal{S}_\mathrm{i} \propto \frac{\mathcal{F}_{\nu,\mathrm{i}}}{\sin^2(\psi_\mathrm{i})}$
- Likelihood:

$$\mathcal{L}(N_\mathrm{s}, N_\mathrm{total}) = \prod_i \left(\frac{N_\mathrm{s}}{N_\mathrm{total}} \mathcal{S}_\mathrm{i} + \frac{N_\mathrm{b}}{N_\mathrm{total}} \mathcal{B}_\mathrm{i} \right)$$

$$\mathcal{L}(0, N_\mathrm{total}) = \prod_i \left(\frac{N_\mathrm{b}}{N_\mathrm{total}} \mathcal{B}_\mathrm{i} \right)$$

- Likelihoodratio:

$$\lambda = 2 \log \left[\frac{\mathcal{L}(N_\mathrm{s}, N_\mathrm{total})}{\mathcal{L}(0, N_\mathrm{total})} \right]$$

- P-value:

$$p_\lambda = \int_\lambda^\infty P_\mathrm{bg}(\lambda') d\lambda'$$

II. Search strategy

A. Search distance threshold

B. Only track events will be used

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D. Astrophysical source types

E. Fraction of neutrinos from within threshold distance

F. Comparison to previous work

Local source densities & emission profiles

(i) Starburst galaxies

$\rho_{starburst} = 10^{-4}\ \mathrm{Mpc}^{-3}$

ν emission $\Leftrightarrow$ SFR

(ii) Active Galactic Nuclei

$\rho_{agn} = 10^{-5} - 10^{-4}\ \mathrm{Mpc}^{-3}$

ν emission $\Leftrightarrow$ X-ray emiss. AGN

(iii) Blazars

$\rho_{blazar} = 10^{-9}\ \mathrm{Mpc}^{-3}$

ν emission $\Leftrightarrow$ X-ray emiss. AGN

(iv) Galaxy clusters

$\rho_{gc} = 5 \cdot 10^{-5}\ \mathrm{Mpc}^{-3}$

ν emission $\Leftrightarrow$ $(1+z)^3$

II. Search strategy

A. Search distance threshold

B. Only track events will be used

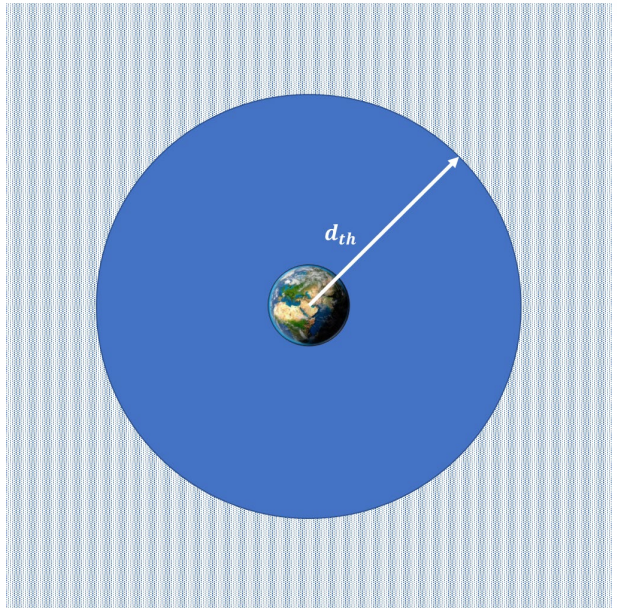
C. Method

D. Astrophysical source types

E. Fraction of neutrinos from within threshold distance

F. Comparison to previous work

$$f_{\mathrm{d}}(z_{\mathrm{th}}) = \Phi_{\nu}(z_{\mathrm{th}})/\Phi_{\nu}(\infty)$$



II. Search strategy

A. Search distance threshold

B. Only track events will be used

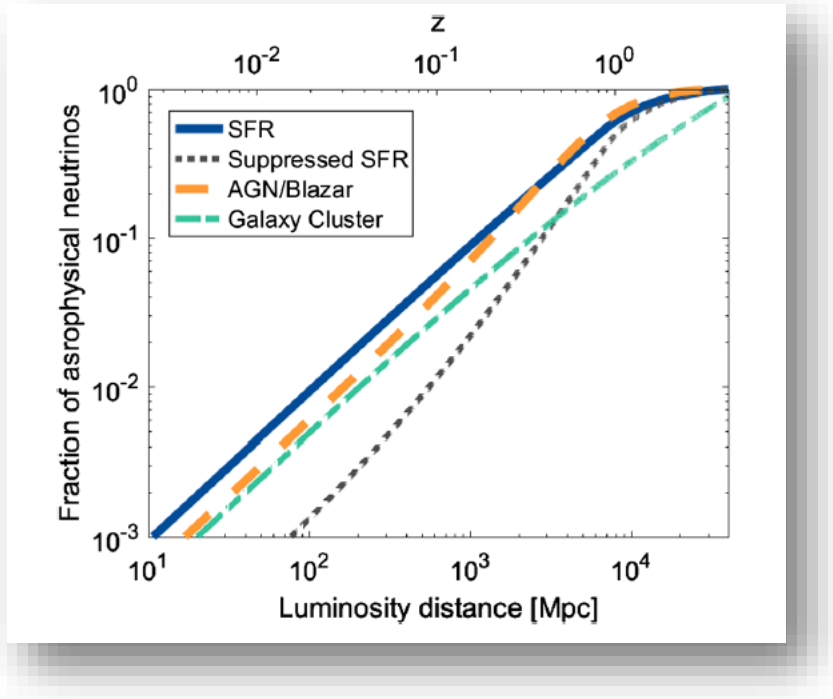
C. Method

D. Astrophysical source types

E. Fraction of neutrinos from within threshold distance

F. Comparison to previous work

Results are shown in Fig. 1. For all cases, to good approximation, we obtain the linear relationship $f_d(d_{th}) = f_0(d_{th}/1\ \text{Mpc})$ for $d_{th} \lesssim 1$ Gpc. This is not surprising, as we expect such a linear relationship for the no-evolution case as well.



II. Search strategy

A. Search distance threshold

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D. Astrophysical source types

E. Fraction of neutrinos from within threshold distance

F. Comparison to previous work

III. Results

III. Results

III. Results

A. Neutrino detection rate

B. Monte Carlo simulation

C. Optimal threshold distance for source catalog

D. Angular uncertainty

E. Comparison to searches at TeV energies

F. Detector size

G. Veto power

H. Locally suppressed starburst contribution

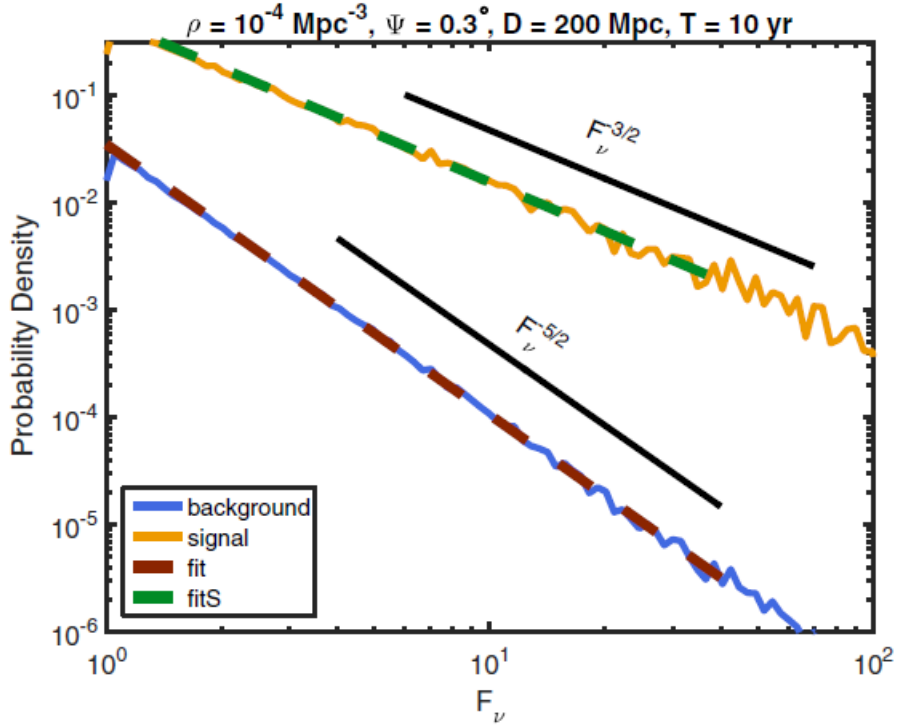

FIG. 2. Simulated distribution of neutrino flux $\mathcal{F}_\nu$ corresponding to signal and background neutrinos. This example shows the densities for $\psi = 0.3°$, $d_{\rm th} = 200$ Mpc, for starburst galaxies. The dashed red line shows a power-law fit on the background density's tail. The black solid lines show power-law slopes with $\mathcal{F}_\nu{}^{-3/2}$ and $\mathcal{F}_\nu{}^{-5/2}$, the theoretical expectations for the signal and neutrino models, respectively, for the case in which the expected number of sources within $d_{\rm th}$ coincident with a neutrino is $\ll 1$.

III. Results

A. Neutrino detection rate

B. Monte Carlo simulation

C. Optimal threshold distance for source catalog

D. Angular uncertainty

E. Comparison to searches at TeV energies

F. Detector size

G. Veto power

H. Locally suppressed starburst contribution

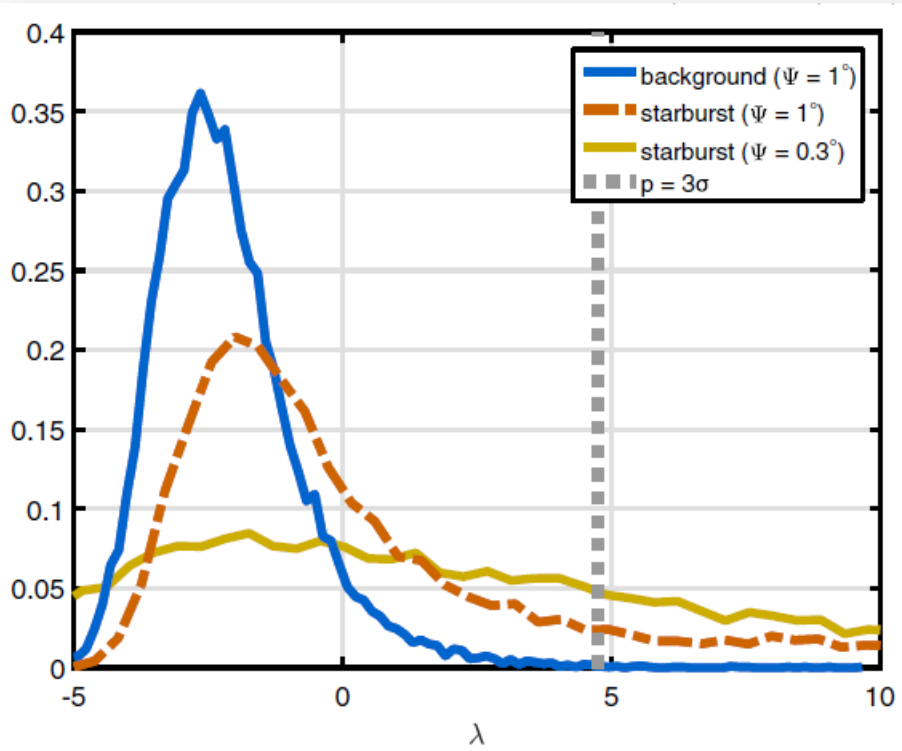

FIG. 3. Simulated distributions of likelihood ratio λ for the signal + background and background-only models. This example shows the distributions for $d_{\text{th}} = 200$ Mpc, $T_{\text{obs}} = 10$ yr, for starburst galaxies, and with angular uncertainties specified in the legend. The vertical dashed line shows the likelihood ratio corresponding to the $p = 3\sigma$ p-value from the background distribution.

III. Results

A. Neutrino detection rate

B. Monte Carlo simulation

C. Optimal threshold distance for source catalog

D. Angular uncertainty

E. Comparison to searches at TeV energies

F. Detector size

G. Veto power

H. Locally suppressed starburst contribution

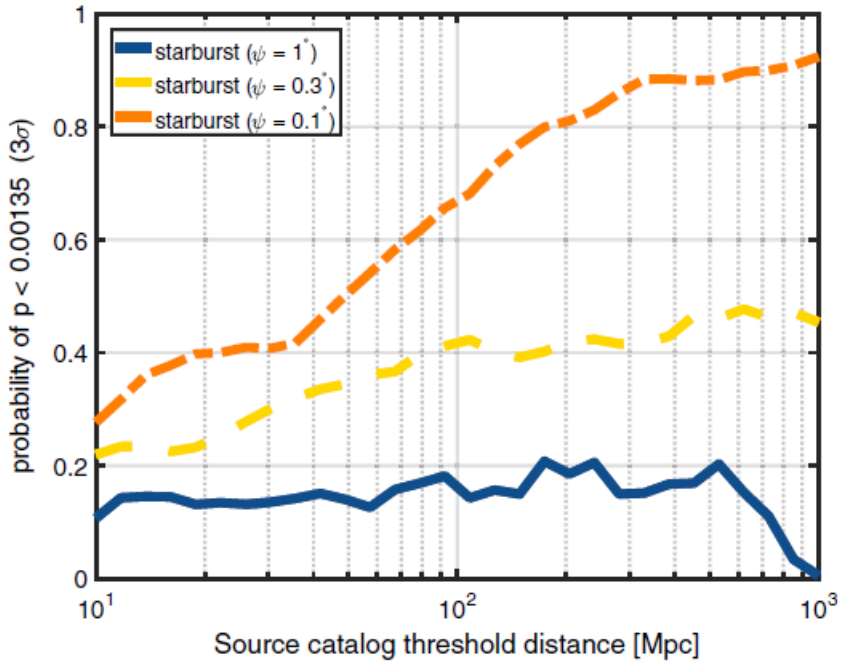

FIG. 4. Probability of a signal + background observation having a p-value $\leq p_0 = 3\sigma = 0.00135$ as a function of threshold distance d_{th}, for different angular uncertainties (see the legend). The results are obtained using the starburst-galaxy model, assuming $T_{\text{obs}} = 10$ yr with IceCube-Gen2 for the highest energy (≥ 30 TeV) neutrinos.

III. Results

A. Neutrino detection rate

B. Monte Carlo simulation

C. Optimal threshold distance for source catalog

D. Angular uncertainty

E. Comparison to searches at TeV energies

F. Detector size

G. Veto power

H. Locally suppressed starburst contribution

- <u>Catalog completeness</u>
  - Starburst galaxy
    - $Z < 0.03$ ➔ close to complete
  - Galaxy catalogs in the local Universe
    - < 100 Mpc ➔ 80% complete
    - < 200 Mpc ➔ 40% complete
  - AGN
    - $Z < 0.1$ ➔ 10% complete
  - Blazars
    - … ➔ 80% complete
  - Galaxy Clusters
    - $Z < 3$ ➔ compelte

III. Results

A. Neutrino detection rate

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H. Locally suppressed starburst contribution

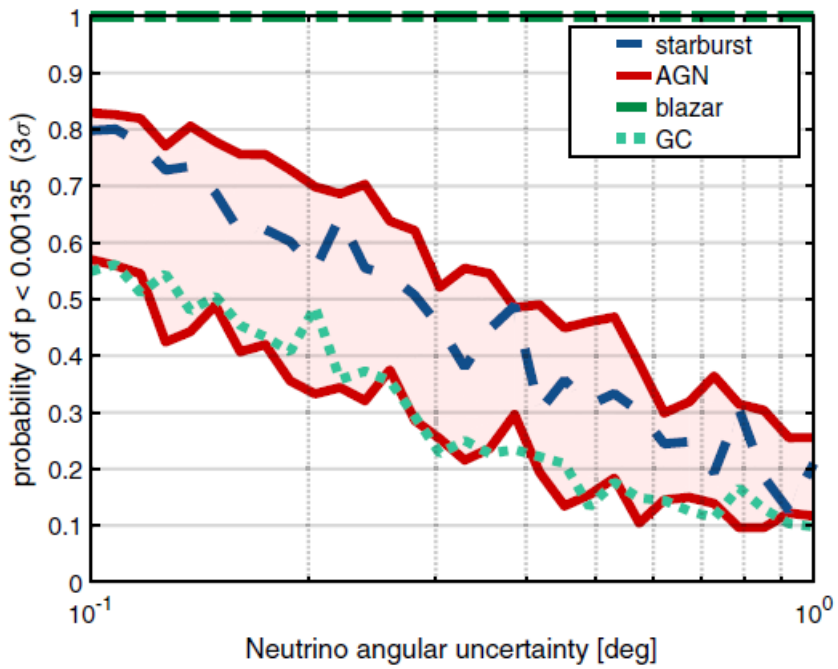


FIG. 5. Probability of a signal + background observation having a p-value $\leq p_0 = 0.00135$ (3σ) as a function of neutrino angular uncertainty, for different source assumptions (see the legend). For AGN, the spread corresponds to the range 10^{-5}–10^{-4} Mpc^{-3} source density. The results are obtained assuming $T_{\mathrm{obs}} = 10$ yr with IceCube-Gen2 in the Sunflower 240 configuration, for the highest energies with >24 TeV neutrinos, corresponding to a detection rate of 36 astrophysical and 36 atmospheric neutrinos per year.

III. Results

A. Neutrino detection rate

B. Monte Carlo simulation

C. Optimal threshold distance for source catalog

D. Angular uncertainty

E. Comparison to searches at TeV energies

F. Detector size

G. Veto power

H. Locally suppressed starburst contribution

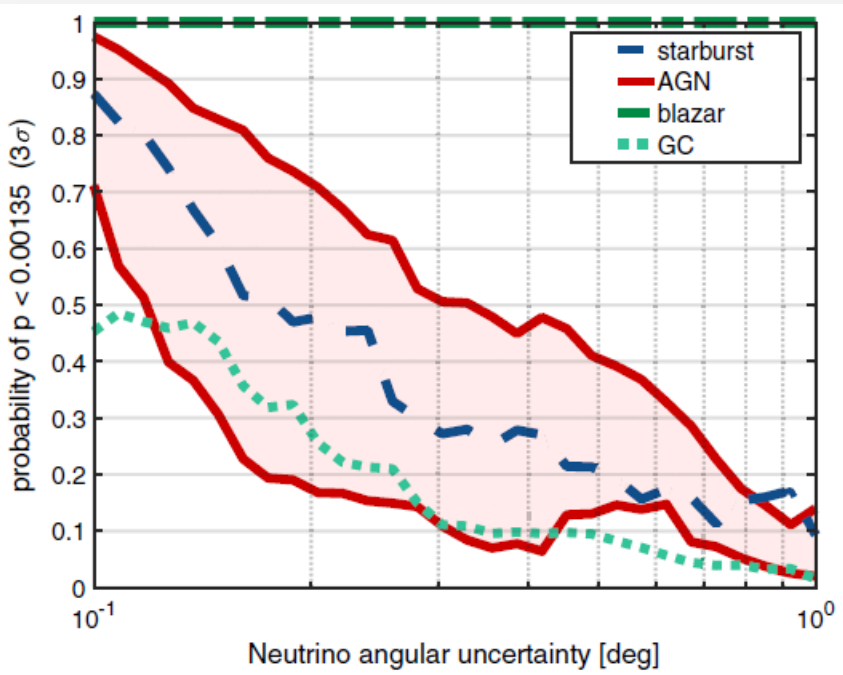


FIG. 6. (Same as Fig. 5, but for the low-threshold neutrino search.) Probability of a signal + background model having a p-value $\leq p_0 = 0.00135$ (3σ) as a function of neutrino angular uncertainty for a low-threshold (> 1 TeV) neutrino search, for different source models (see the legend). The results are obtained assuming $T_{\rm obs} = 10$ yr with IceCube-Gen2.

III. Results

A. Neutrino detection rate

B. Monte Carlo simulation

C. Optimal threshold distance for source catalog

D. Angular uncertainty

E. Comparison to searches at TeV energies

F. Detector size

G. Veto power

H. Locally suppressed starburst contribution

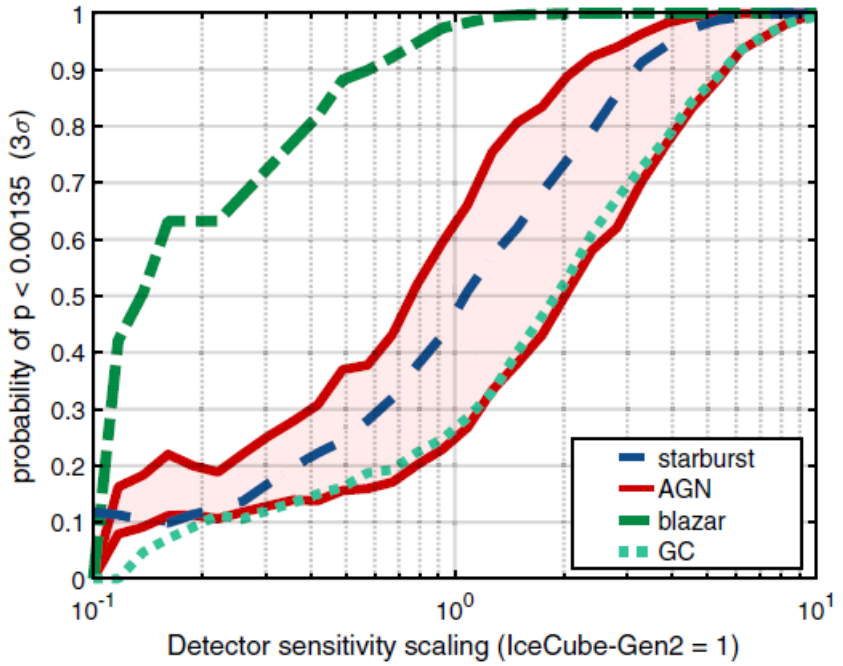


FIG. 7. Probability of a signal + background observation having a p-value $\leq p_0 = 0.00135$ (3σ) as a function of the number of detected neutrinos. The x axis is normalized to the case of IceCube-Gen2 in the Sunflower 240 configuration, for the highest energies with > 24 TeV neutrinos, which corresponds to a detection rate of 36 astrophysical and 36 atmospheric neutrinos per year. We show results for different source assumptions (see the legend). The number of both astrophysical and atmospheric neutrinos is scaled identically. For AGN, the spread corresponds to the range 10^{-5}–10^{-4} Mpc^{-3} source density. The results are obtained assuming an angular uncertainty of 0.3° and $T_{\text{obs}} = 10$ yr.

III. Results

A. Neutrino detection rate

B. Monte Carlo simulation

C. Optimal threshold distance for source catalog

D. Angular uncertainty

E. Comparison to searches at TeV energies

F. Detector size

G. Veto power

H. Locally suppressed starburst contribution

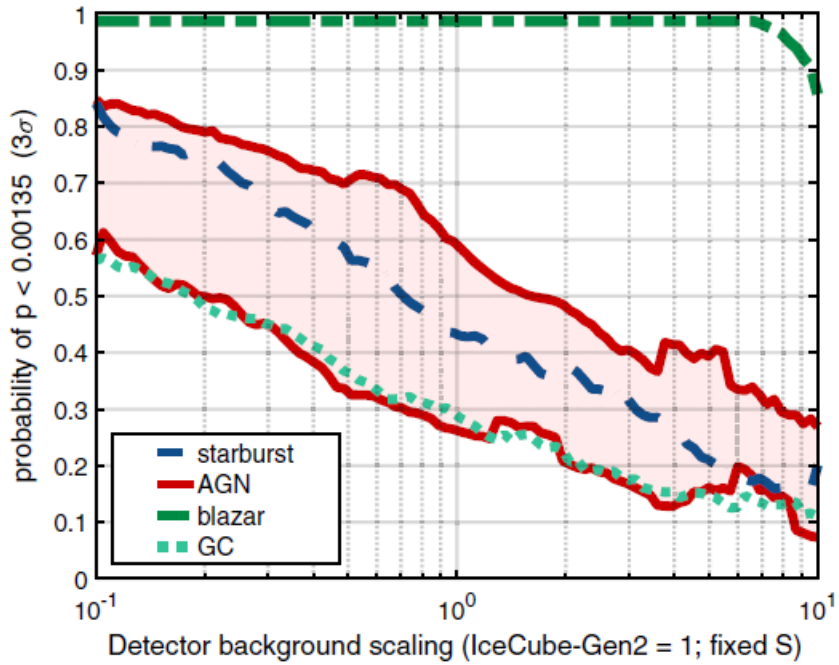


FIG. 8. Probability of a signal + background observation having a p-value $\leq p_0 = 0.00135\,(3\sigma)$ as a function of the number of detected atmospheric neutrinos. The x axis is normalized to the case of IceCube-Gen2 in the Sunflower 240 configuration, for the highest energies with > 24 TeV neutrinos, which corresponds to a detection rate of 36 atmospheric neutrinos per year. The detection rate of astrophysical neutrinos is kept fixed at 36 yr^{-1}. We show results for different source assumptions (see the legend). For AGN, the spread corresponds to the range 10^{-5}–10^{-4} Mpc^{-3} source density. The results are obtained assuming an angular uncertainty of 0.3°, and $T_{\mathrm{obs}} = 10$ yr.

III. Results

A. Neutrino detection rate

B. Monte Carlo simulation

C. Optimal threshold distance for source catalog

D. Angular uncertainty

E. Comparison to searches at TeV energies

F. Detector size

G. Veto power

H. Locally suppressed starburst contribution

- If Starburst galaxies have steeper cosmic evolution than the SFR
- Suppressed fraction of local neutrino emission

IV. Conclusion + Future

(i) *Identification of challenging source types.*—Our main conclusion is that it may be feasible to identify the source population of the origin of high-energy neutrinos even for some of the challenging source types such as starburst galaxies or AGN using next generation high-energy neutrino observatories. Strong cosmic evolution, nevertheless, reduces the probability of source identification.

(ii) *Source catalogs are beneficial.*—Search sensitivity using a source catalog exceeds that of using only the closest sources, and beyond some threshold distance, extending the source catalog further brings only marginal improvement.

Abstract: *IceCube-Gen2 can statistically establish the origin of cosmic neutrinos for starburst galaxies, AGN, or galaxy clusters – if neutrino track directions can be reconstructed with a precision ~0.3°.*

(iii) *Required catalog depth.*—We find that, for typical angular resolutions $\psi \gtrsim 0.3°$, it is viable to have a complete source catalog out to ~100 Mpc. A complete catalog out to this distance cannot be significantly improved by going to higher distances, except if high accuracy direction reconstruction is available ($\psi \lesssim 0.1°$), or for lower number-density source types such as blazars. This is good news, since it is difficult to assemble complete source catalogs for distances much farther than 100 Mpc for most source types.

(iv) *Role of detector characteristics.*—We examined the role of the detector's (i) angular resolution, (ii) size, and (iii) veto capability in source identification. We characterized results in comparison to IceCube-Gen2 in the Sunflower 240 configuration with a search for the highest energies with >24 TeV neutrinos, with typical angular uncertainty of 0.3°. Size was assumed to identically change $R_{\nu,\mathrm{ast}}$ and $R_{\nu,\mathrm{atm}}$, while veto capability changes $R_{\nu,\mathrm{atm}}$ only. We find that, for angular resolution and detector size, a factor of 2 change corresponds to a change in identification probability, P, of roughly 20%. The dependence is somewhat weaker for veto power.

Go to **www.menti.com** and use the code **20 57 60**

I like them a lot. but let's try to keep <1h.

I like them! As long as the papers are relevant/new/interesting. I learnt things I wouldn't usually, as well as reading papers I wouldn'tnot from Brían

I like the paper meetings.

I like it. But people should read it. I found the discussion good. Sometimes we need to followup things.

I like it. More general introduction

Very nice, especially the discussion.

We should read more papers :)

Maybe we could define some goals like proposing an improvement or highlight a good point of it, ...

I like it, we should have them more often! Maybe find some somewhat tangential papers too?

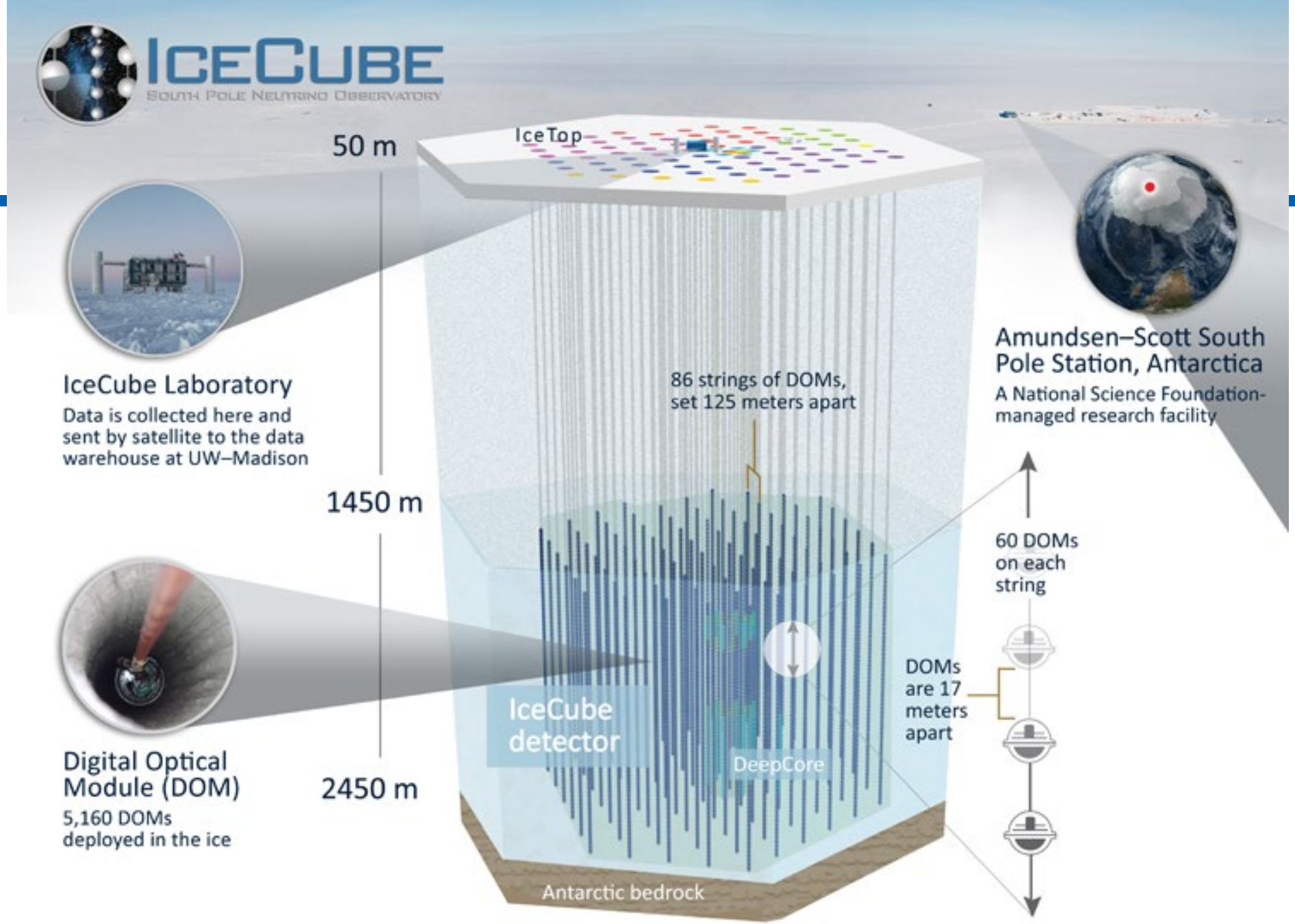
I like them!

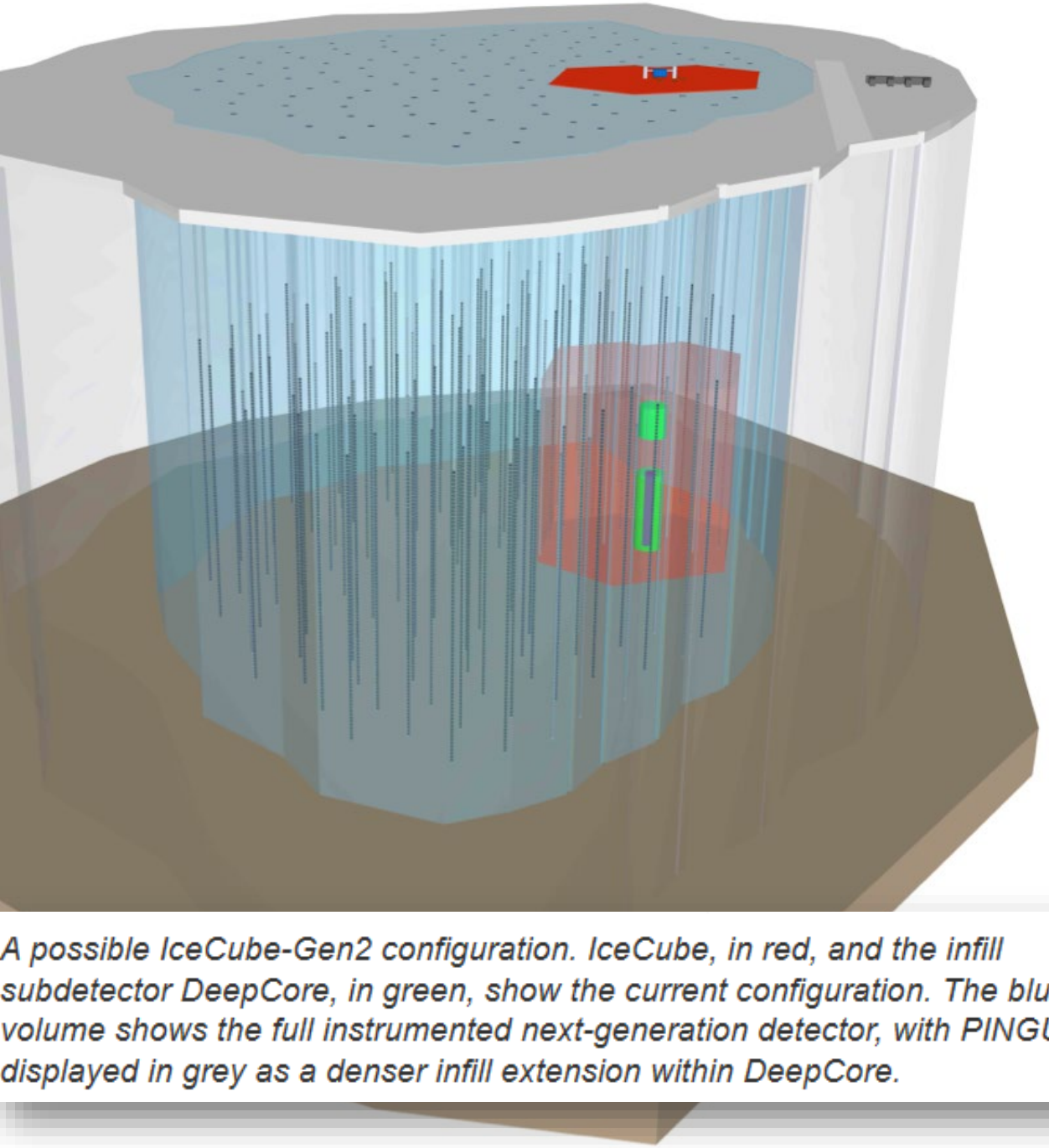
good exercise, side discussions on different topics are also valuable

Mentimeter

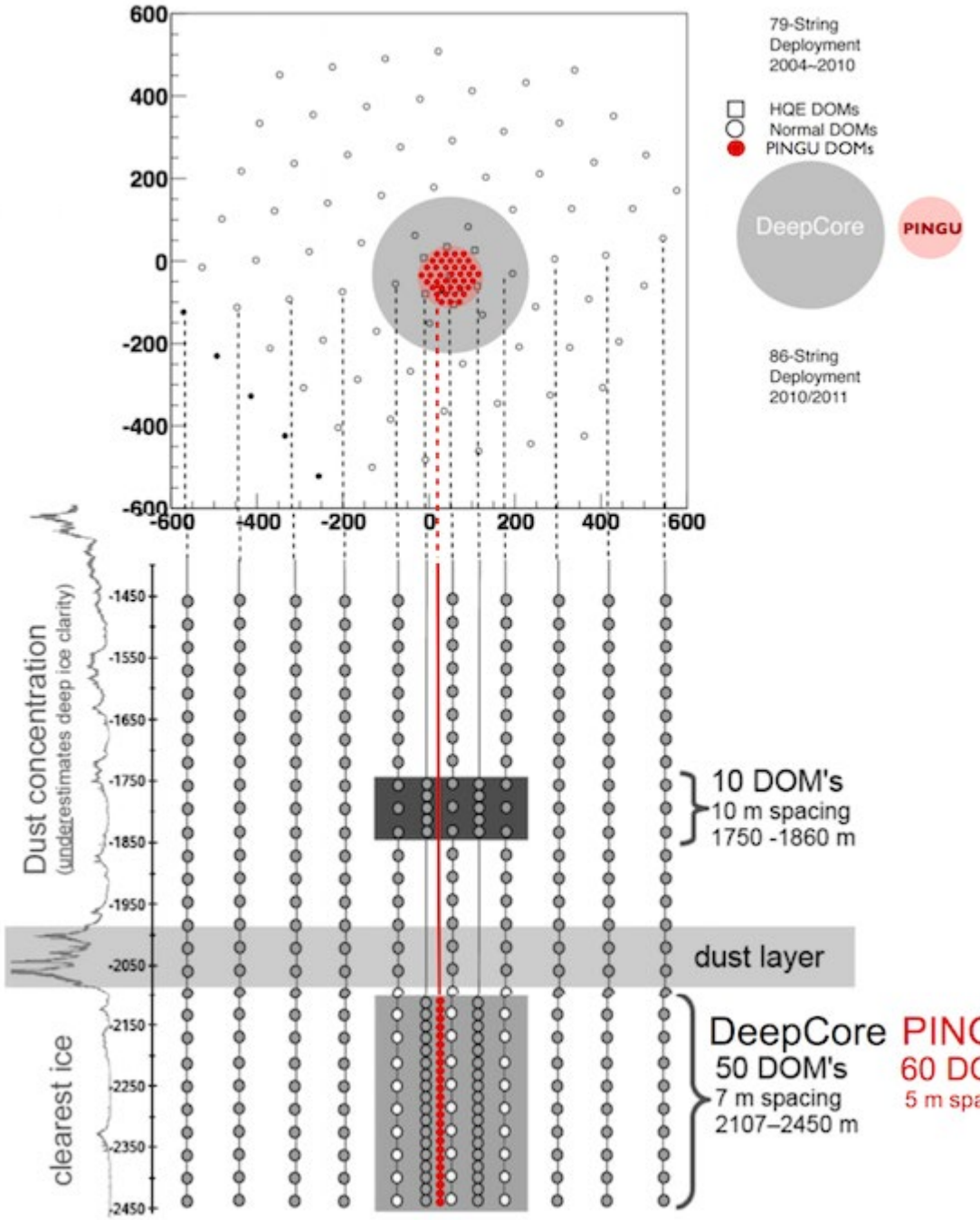
What do you thinik of the paper meetings & what do you like / how to improve?

Back-up Slides


IceCube
South Pole Neutrino Observatory
50 m
IceTop
IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison
86 strings of DOMs, set 125 meters apart
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility
1450 m
60 DOMs on each string
DOMs are 17 meters apart
IceCube detector
DeepCore
Digital Optical Module (DOM)
5,160 DOMs deployed in the ice
2450 m
Antarctic bedrock



A possible IceCube-Gen2 configuration. IceCube, in red, and the infill subdetector DeepCore, in green, show the current configuration. The blue volume shows the full instrumented next-generation detector, with PINGU displayed in grey as a denser infill extension within DeepCore.



Ice cube sunflower layout

flux scales with the rate of cascade events, and thus the instrumented volume. Several geometries are under consideration for the high-energy array, with instrumented volumes ranging from 6.2 to 9.5 km^3. Each detector geometry strikes a different compromise between projected area and contained volume. For the studies described here we focus on the "sunflower" layout shown in Fig. 1.

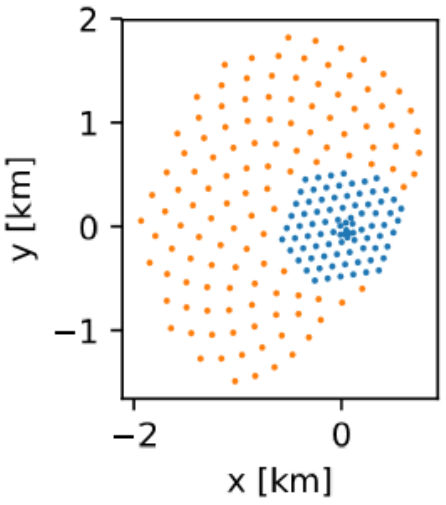


Figure 1: View of IceCube-Gen2 strings from above in the "sunflower" layout. The 120 new strings (shown as orange points) are spaced 240 m apart and instrumented with 80 optical modules over a vertical length of 1.25 km. The total instrumented volume is 7.9 km^3, nearly 10 times larger than IceCube alone (blue points).

https://inspirehep.net/record/1628389/files/arXiv:1710.01207.pdf

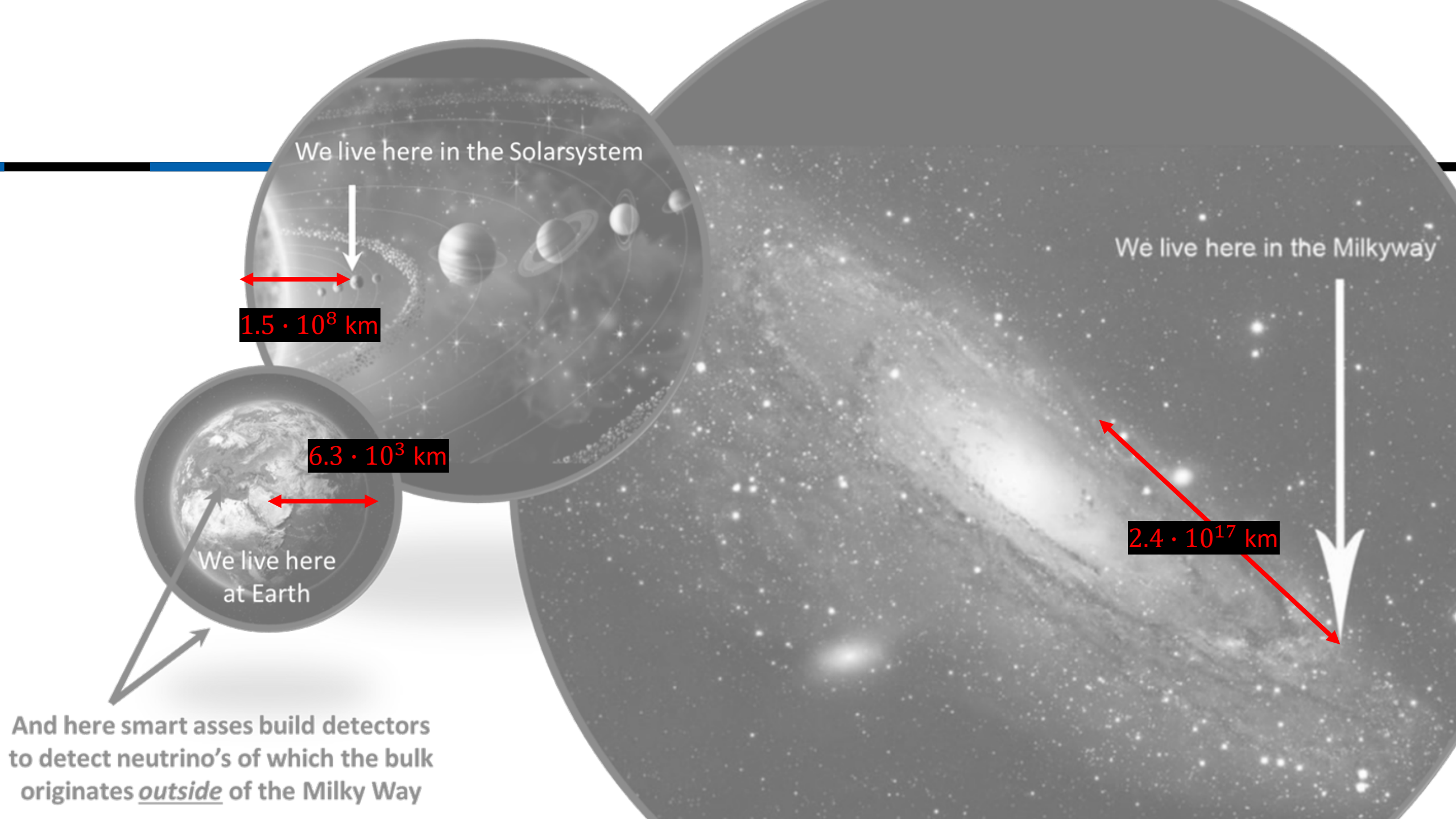
List of Assumptions (probably forgot a few)

1. "Assume that we know the the expected number N_{atm} within the total from atmospheric contribution models" (p.2)
2. "assume that L_ν is identical for all sources within a given source type" (p.2, 4)
3. "for simplicity, we do not make use of the energy of the neutrino" (p.3)
4. "For simplicity, we will omit this maxismization."
5. "assume that all cosmic neutrinos orginate from the same source type" (p.4)
6. "We assume a power-law source spectrum ϵ_ν^γ" (p.4)
7. "For the case of starburst galaxies, we assume that neutrino emission tracks the cosmic SFR" (p.4)
8. "For AGN and blazars, we assume that neutrino emission tracks the hard X-ray emission of AGN" (p.4)
8. "For GC's, we adopt an evolution of $(1+z)^3$" (p.4)
9. "We assume an astrophysical flux of

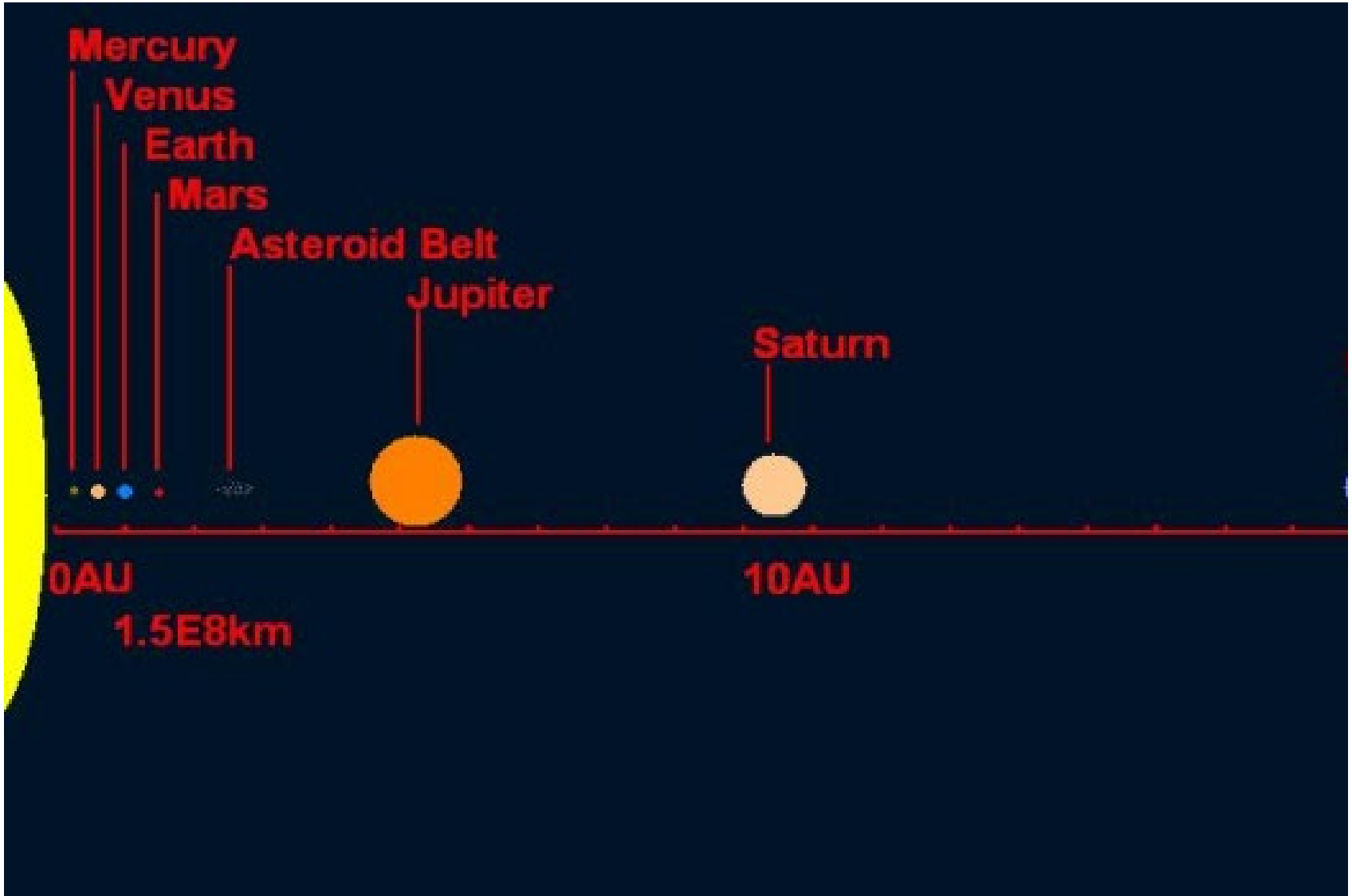
$$0.9 \cdot 10^{-18} \left(\frac{E}{100\mathrm{TeV}}\right)^{-2.13} \mathrm{GeV}^{-1}\mathrm{sr}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}$$

as measured in Ref. [37]. (p.4)

11. We consider all neutrinos having the same angular uncertainty ψ." (p.5)
12. "We assume that the true neutrino direction is uniformly distributed within ψ. (p.5)
13. In the paper they only consider 1 type to be the source of all neutrino's => what about a combination AGN + blazar + stg + gc?


We live here in the Solarsystem
$1.5 \cdot 10^8$ km
$6.3 \cdot 10^3$ km
We live here
at Earth
We live here in the Milkyway
$2.4 \cdot 10^{17}$ km
And here smart asses build detectors
to detect neutrino's of which the bulk
originates *outside* of the Milky Way

Solar system scale



III. Results

A. Neutrino detection rate

B. Monte Carlo simulation

C. Optimal threshold distance for source catalog

D. Angular uncertainty

E. Comparison to searches at TeV energies

F. Detector size

G. Veto power

H. Locally suppressed starburst contribution

- IceCube Sunflower config
  - Flux

We will assume an astrophysical flux of $0.9 \times 10^{-18}(E/100\ \mathrm{TeV})^{-2.13}$ $\mathrm{GeV}^{-1}\ \mathrm{sr}^{-1}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

  - High-threshold search (≥ 30 TeV)
    - $R_{\nu,\,ast} = 36\ \mathrm{yr}^{-1}$
    - $R_{\nu,\,atm} = 36\ \mathrm{yr}^{-1}$
  - Low-threshold search (≥ 1 TeV)
    - $R_{\nu,\,ast} = 200\ \mathrm{yr}^{-1}$
    - $R_{\nu,\,atm} = 15000\ \mathrm{yr}^{-1}$