Dark matter from ZeV to aeV: 3rd IBS-MultiDark-IPPP Workshop
Durham, November 2016

Dark matter searches with neutrinos

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MultiDark
Multimessenger Approach for Dark Matter Detection

Outline

- Introduction
- X-rays and sterile neutrinos
- Neutrino telescopes
- Results
  - Sun
  - Earth
  - Milky Way
  - Extra-galactic
- Future
- Summary

Introduction

Evidence

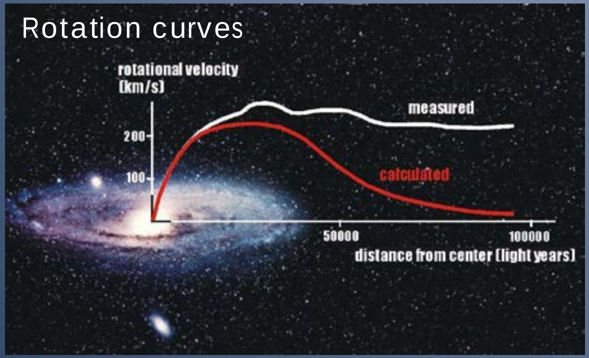
- The evidence for the existence of dark matter is very solid and, which is very important, at many different scales


Comma Cluster

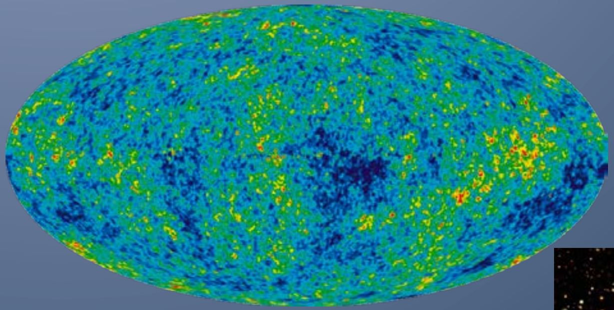
Virial theorem $\langle V \rangle + 2\langle K \rangle = 0$

$$V = -\frac{N^2}{2} G_N \frac{\langle m^2 \rangle}{\langle r \rangle}; \quad K = N \frac{\langle m v^2 \rangle}{2}$$

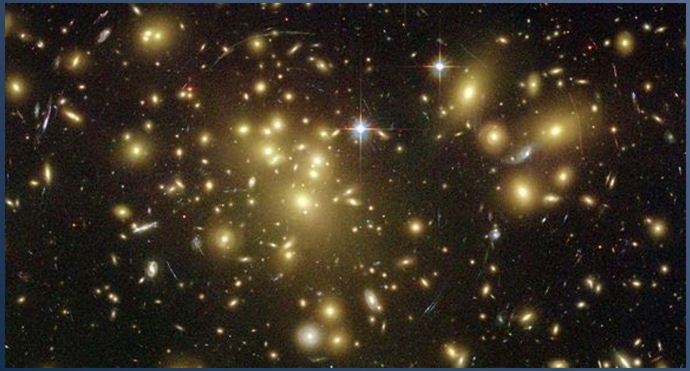
$$M = N\langle m \rangle \sim \frac{2\langle r \rangle \langle v^2 \rangle}{G_N} \gg \sum m_{\mathrm{galaxies}}$$



Rotation curves


Cosmic Microwave Background

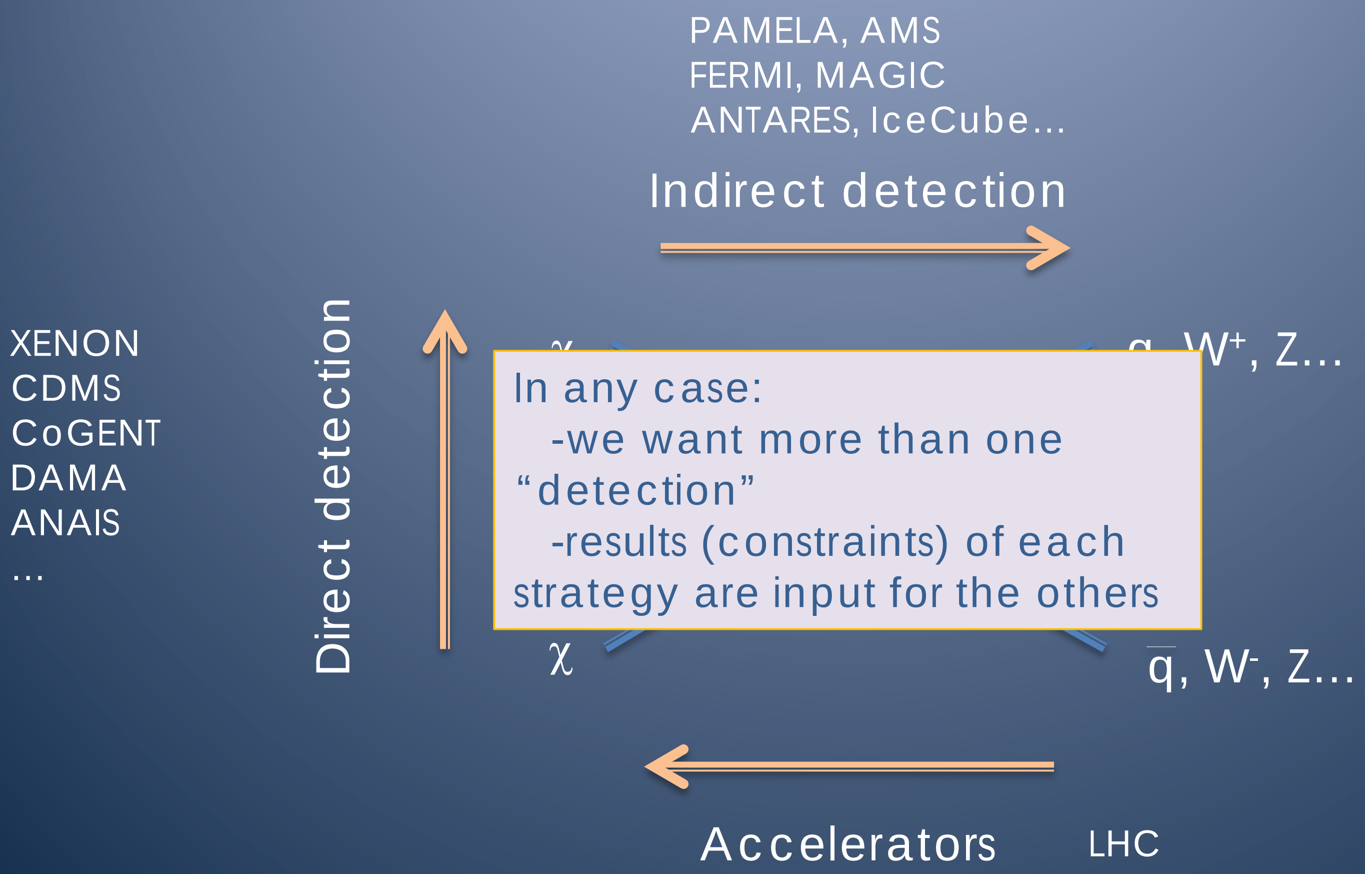

Bullet Cluster


Gravitational Lensing

+ BNN, N-body simulations…

Detection strategies

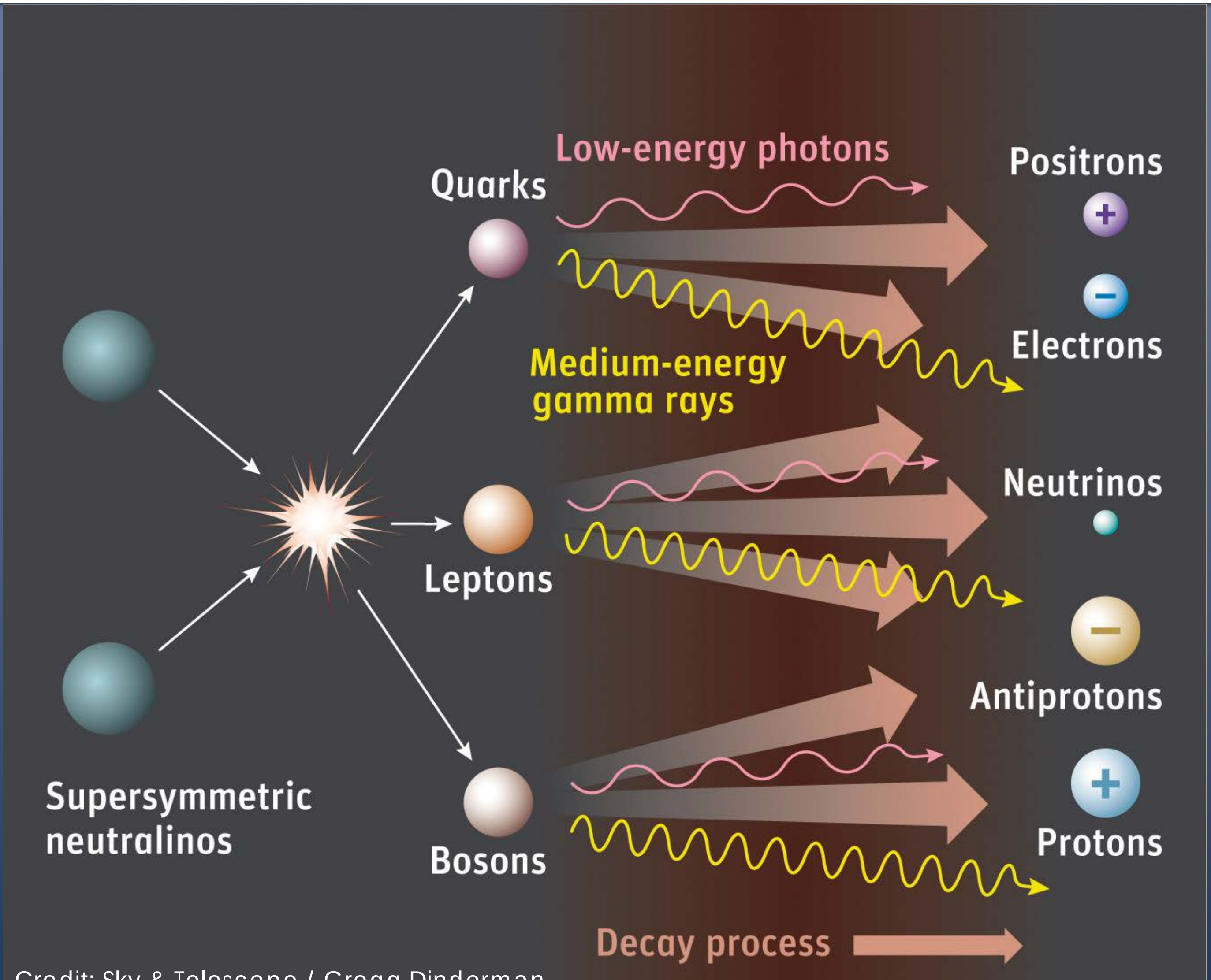
- We do not know what is dark matter, so it is hard to say which is the winning strategy: multi-front attack!



In any case:
-we want more than one "detection"
-results (constraints) of each strategy are input for the others

+astrophysical probes (self-interaction of DM affecting dark matter densities in galaxies…)

Indirect searches

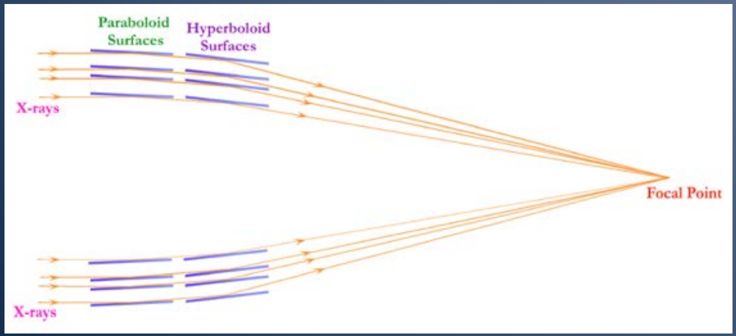


Credit: Sky & Telescope / Gregg Dinderman

X-rays and sterile neutrinos

X-rays

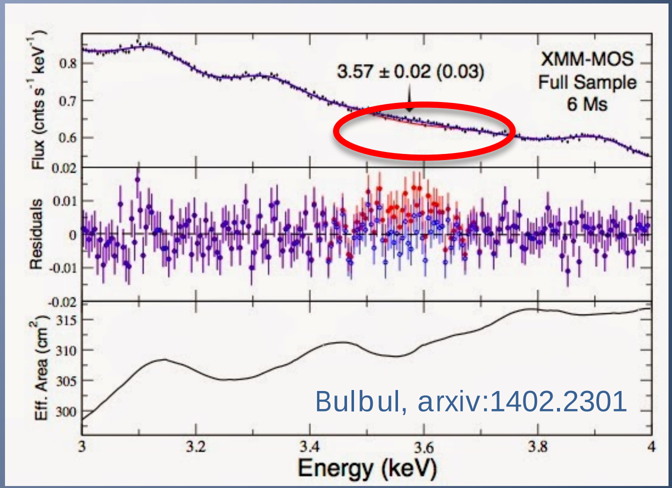
- X-ray astronomy (1-100 keV) differs from gamma ray astronomy in the detection strategy
- Atmosphere absorbs X-rays and fluxes are high, so observation is based on balloons and satellites
- X-rays cannot be focused by lenses, so focusing is based on total reflection (Wolter telescope)
- Projects: Chandra, XMM-Newton, Suzaku



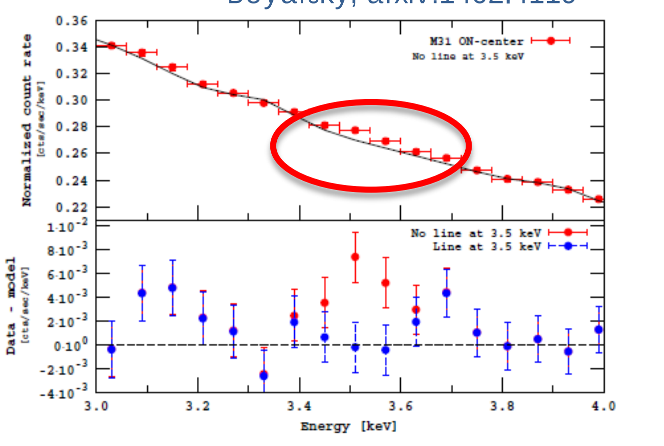
XMM-Newton: Large collecting area
Simultaneous imaging and high resolution spectroscopy

X-rays

- Monochromatic **3.5 keV photon line** observed in data of XMM-Newton from 73 galaxy clusters
- Located within 50-100 eV of several known faint lines
- Interpreted as **decay from sterile neutrinos** with m_s=7.1 keV, which would be **dark matter**
- Also observed in Andromeda and Perseus



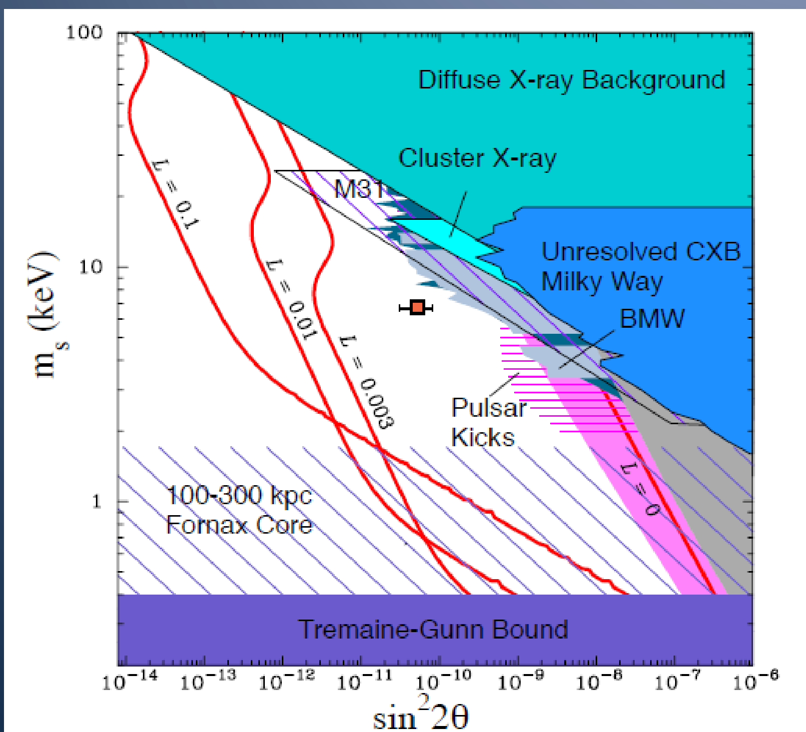
Bulbul, arxiv:1402.2301

Boyarsky, arxiv:1402.4119


X-rays

- Interpretation as sterile neutrino ($\sin^2(2\theta) \sim 7 \times 10^{-11}$) consistent with present constraints
- However, significant astrophysical unknowns involved (for instance, potassium XVIII line)

Bulbul, arxiv:1402.2301



Boyarsky, arxiv:1402.4119

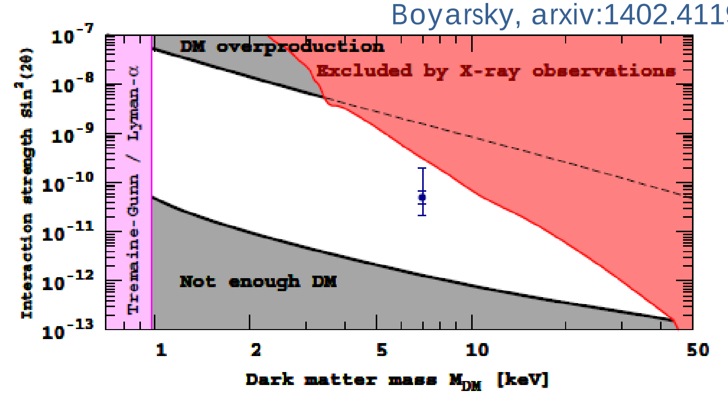
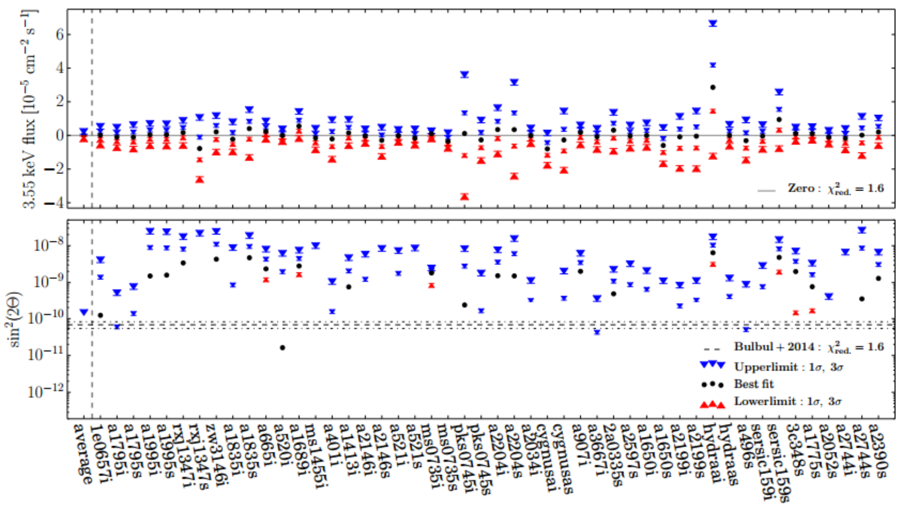


FIG. 4: Constraints on sterile neutrino DM within νMSM [4]. The blue point would corresponds to the best-fit value from M31 if the line comes from DM decay. Thick errorbars are $\pm 1\sigma$ limits on the flux. Thin errorbars correspond to the uncertainty in the DM distribution in the center of M31.

X-rays

Chandra

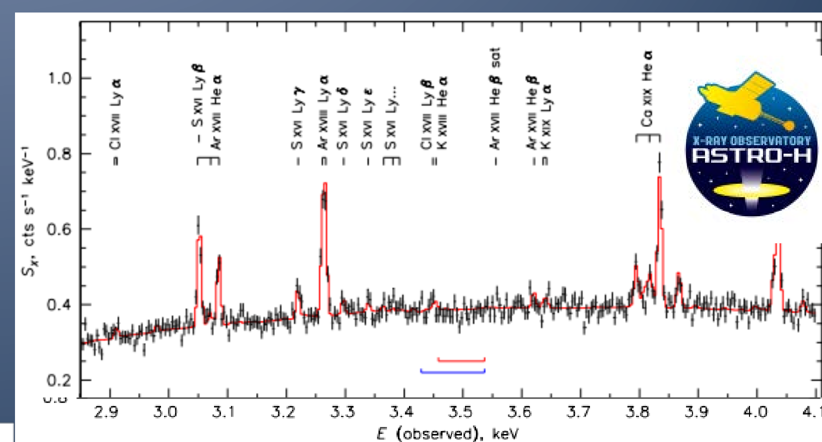
- New analysis by Chandra based on observations of 33 galactic clusters neither finds and excess



Astronomy & Astrophysics 592: A112 (2016)

Astro-H

- Astro-H satellite (aka Hitomi), equipped with a X-ray spectrometer, was launched in Feb 2016.
- It had the capability of accurate spectral measurements of the lines in Perseus
- Unfortunately, on March 2016 the orientation control stopped working and is not operative anymore.
- Some first measurements were done during the calibration phase. No hint of X-ray in the region of interest

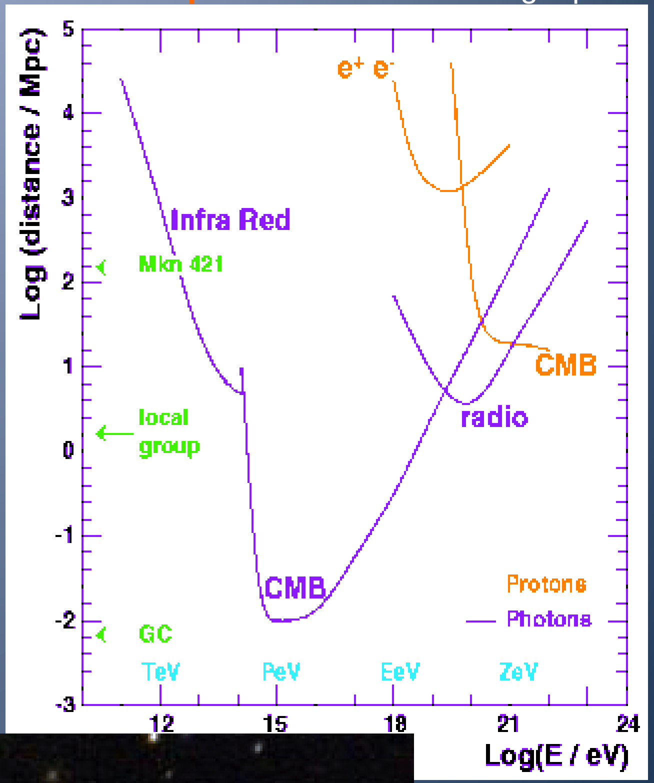


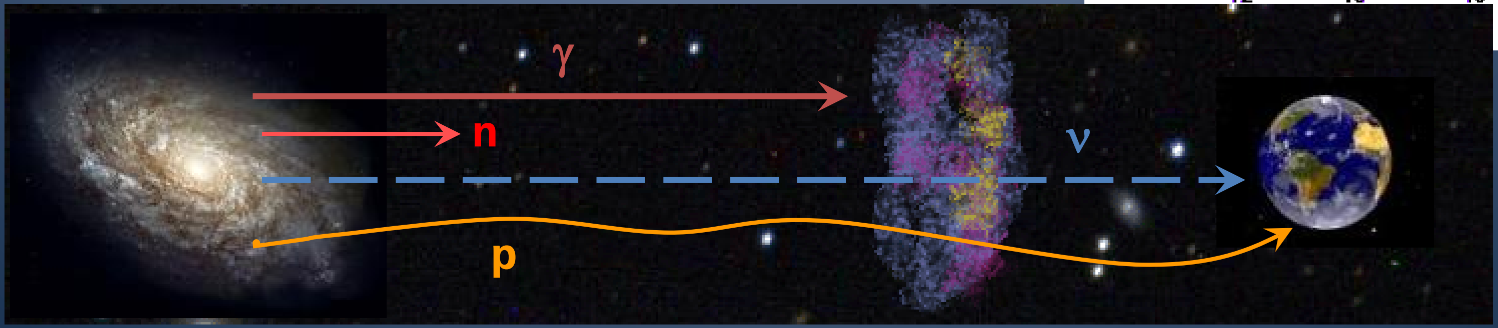
Neutrino telescopes

Neutrino Astronomy

- Advantages:
  - Photons: interact with CMB and matter
  - Protons: interact with CMB and are deflected by magnetic fields
- Drawback: large detectors (~GTon) are neded

Photon and proton mean free range path

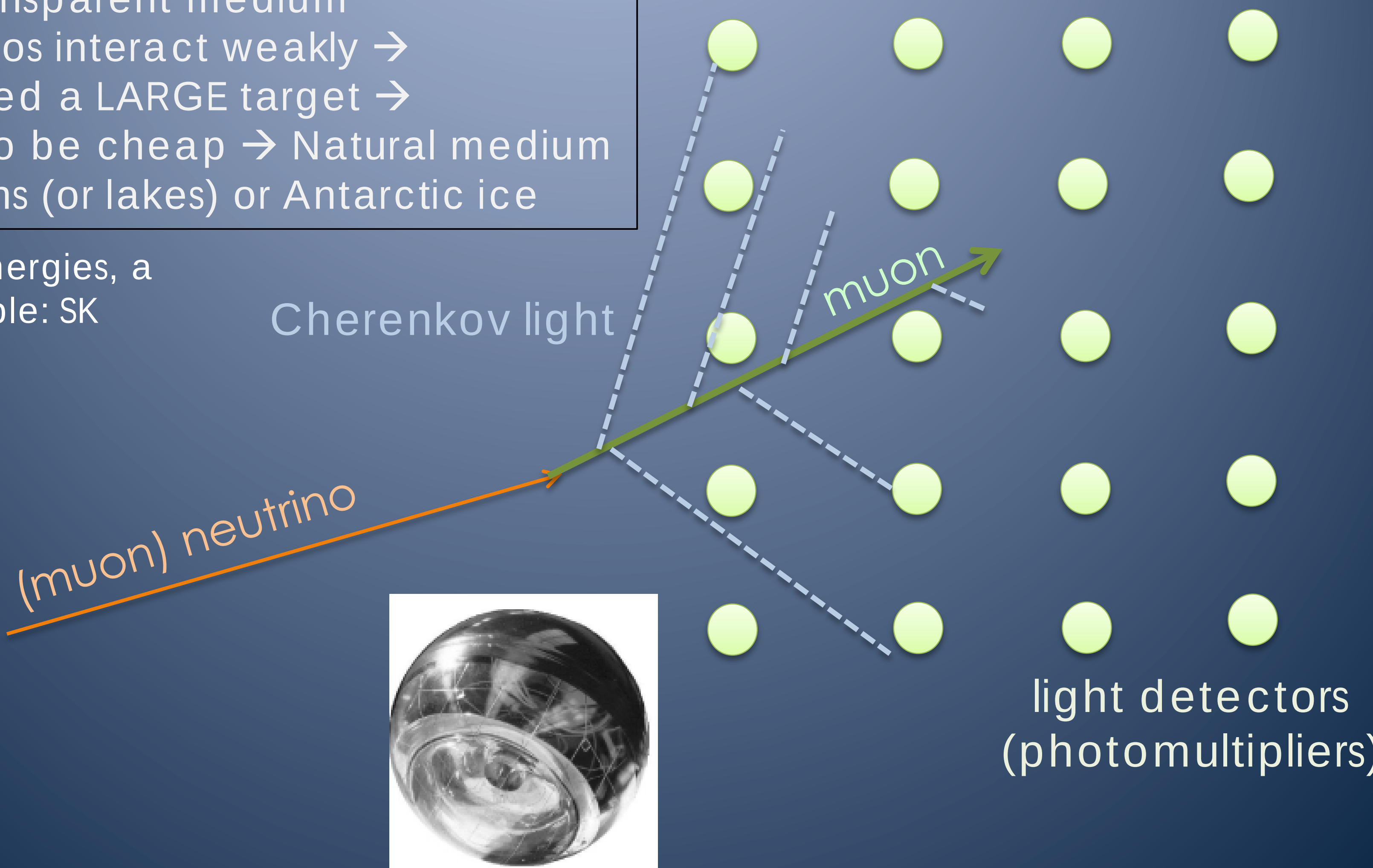




Detection Principle

Where to put the detector?
1) In a transparent medium
2) Neutrinos interact weakly →
→ We need a LARGE target →
→ It has to be cheap → Natural medium
→ Oceans (or lakes) or Antarctic ice

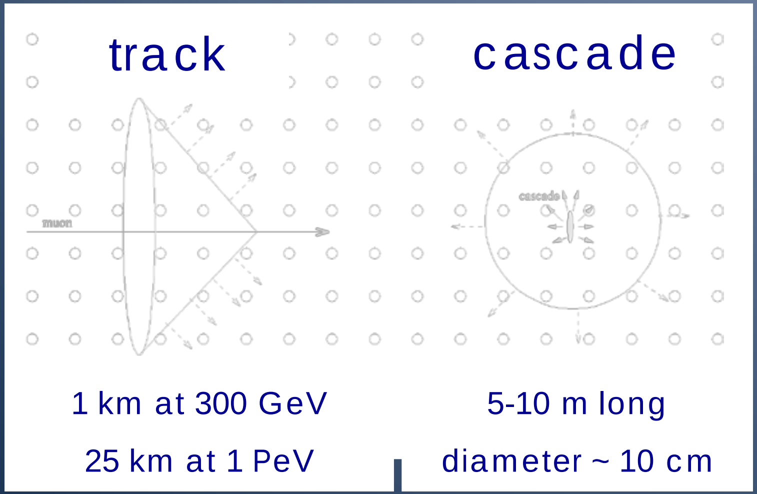
*For low energies, a pool is viable: SK

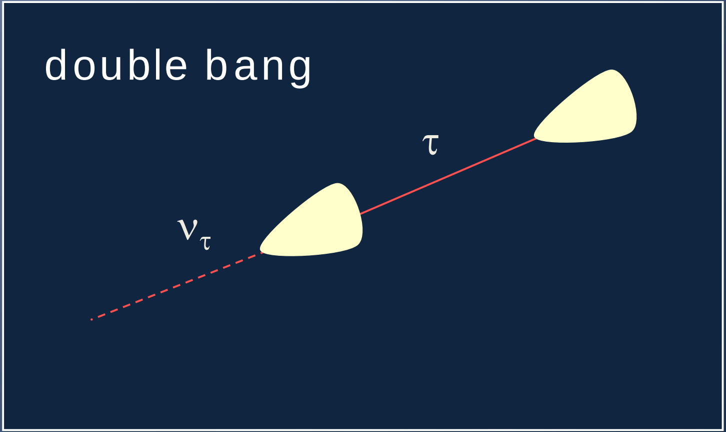


Other signatures

- Cascades are an important alternative signature: detection of electron and tau neutrinos.
- Also neutral interaction contribute (only hadronic cascade)

- Clear signature of oscillations.
- ANTARES is too small to detect double bang signature (they are too rare)
- However, cubic-kilometer telescopes could detect them
- Maximum sensitivity at 1-10 PeV

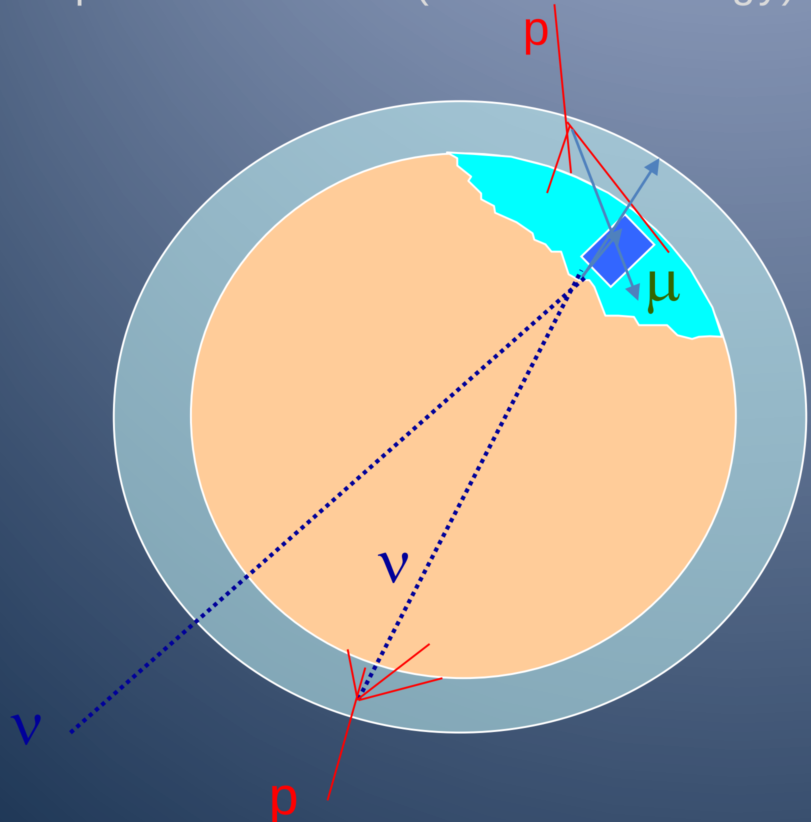


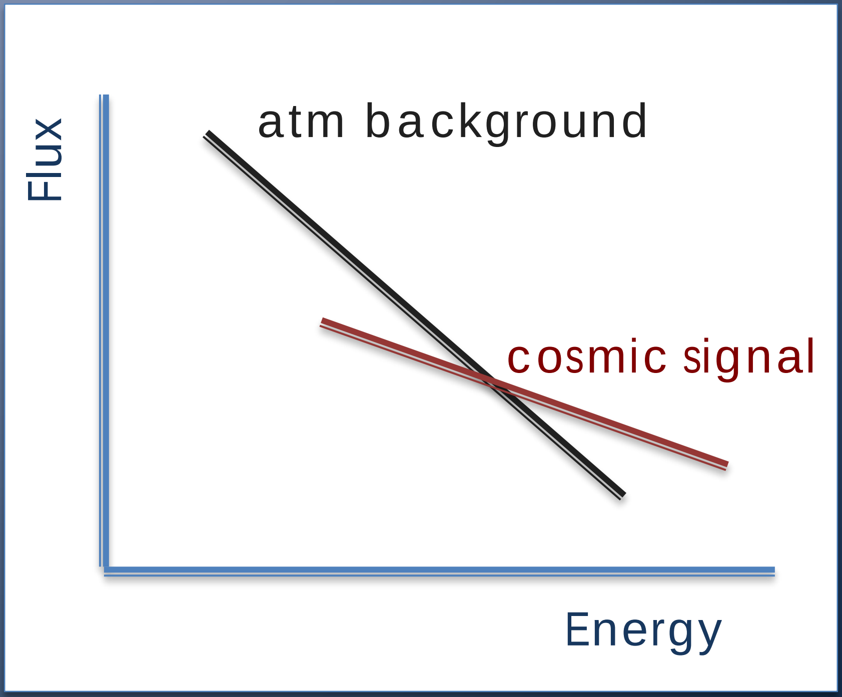


Physical Background

- There are two kinds of background:
  - Muons produced by cosmic rays in the atmosphere (→ detector deep in the sea and selection of up-going events)
  - Atmospheric neutrinos (cut in the energy)

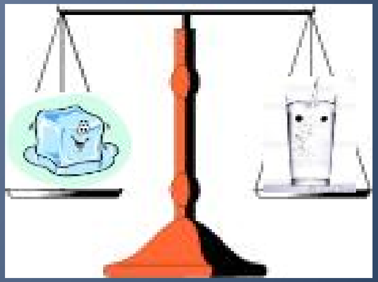
$$p \to \pi^{+}(+K^{+}...) \to \mu^{+} + \nu_{\mu}$$
$$\mapsto e^{+} + \overline{\nu}_{\mu} + \nu_{e}$$





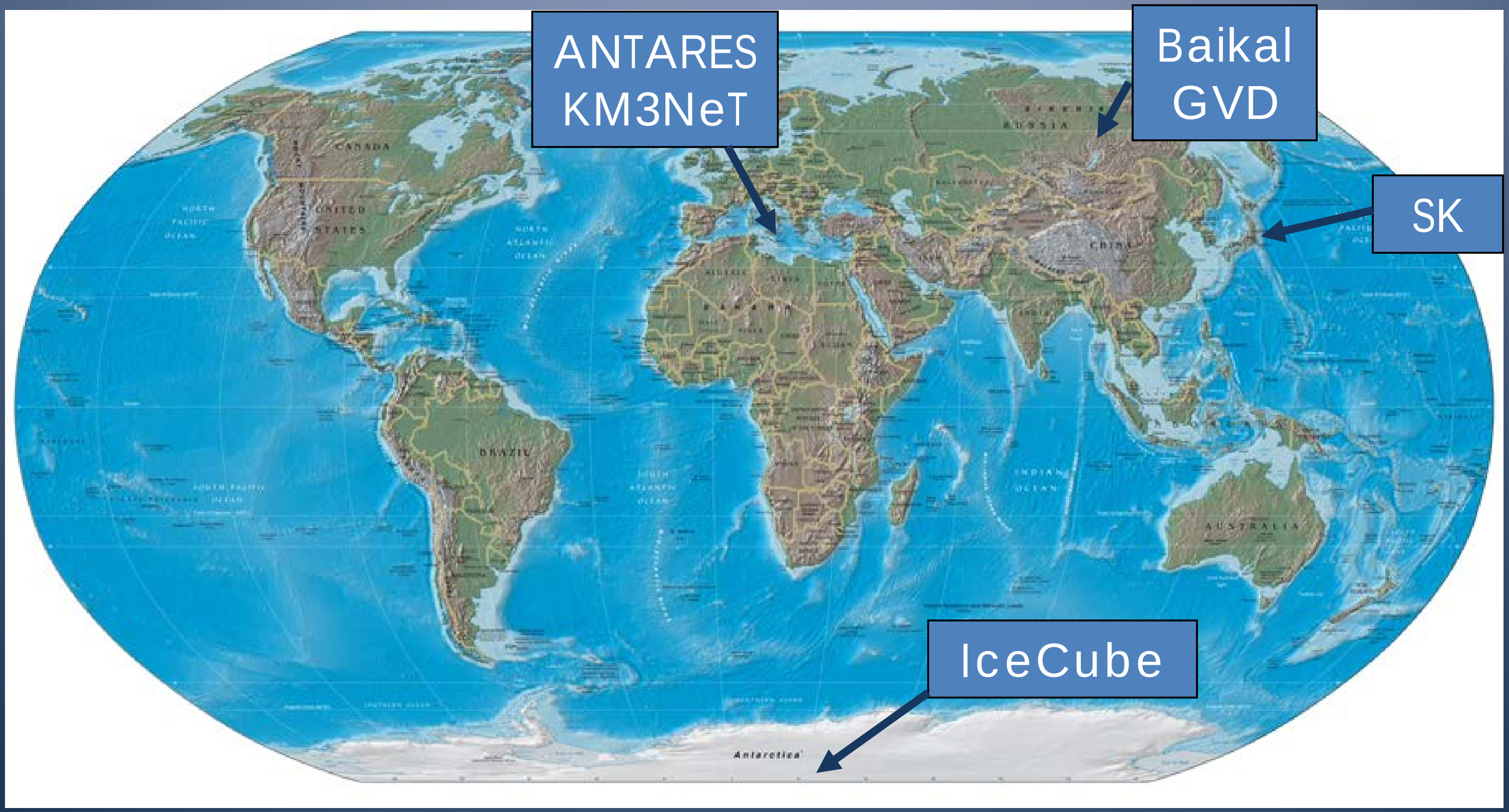
Water vs Ice

- Very large volumes of medium transparent to Cherenkov light are needed:
  - Ocean, lakes…
  - Antarctic ice
- Advantages of oceans:
  - Larger scattering length → better angular resolution
  - Weaker depth-dependence of optical parameters
  - Possibility of recovery
  - Changeable detector geometry
- Advantages of ice:
  - Larger absorption length
  - No bioluminescence, no ^{40}K background, no biofouling
  - Easier deployment
  - Lower risk of point-failure
- Anyway, a detector in the Northern Hemisphere in necessary for complete sky coverage (Galactic Center!), and it is only feasible in the ocean.



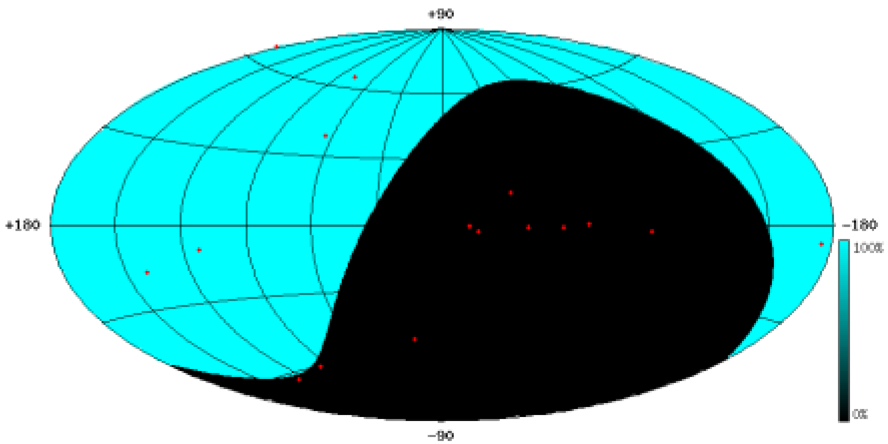
NTs in the world

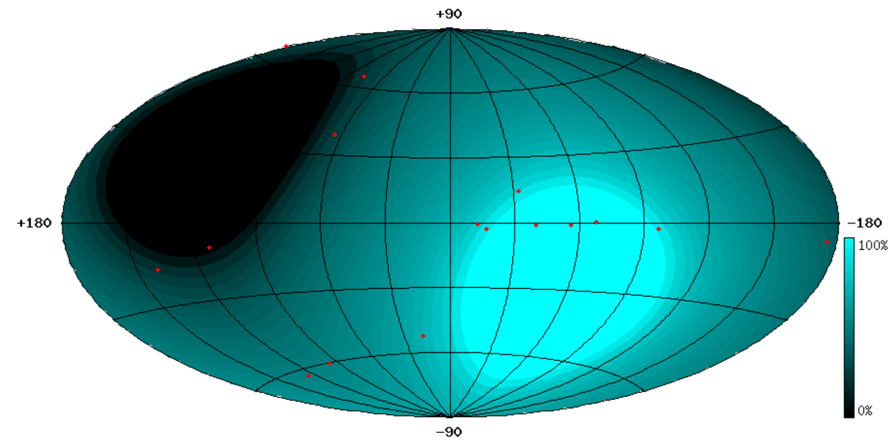
- Several projects are working/planned, both in ice and ocean and lakes.

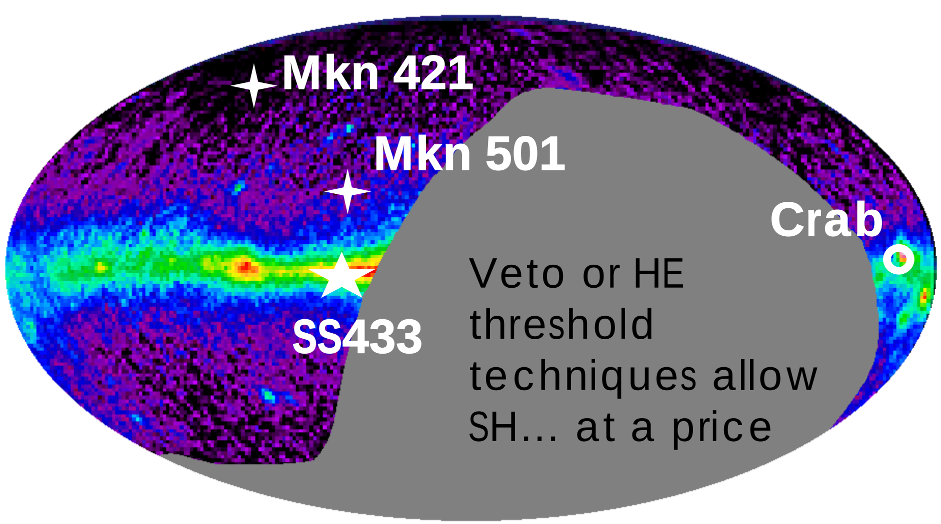


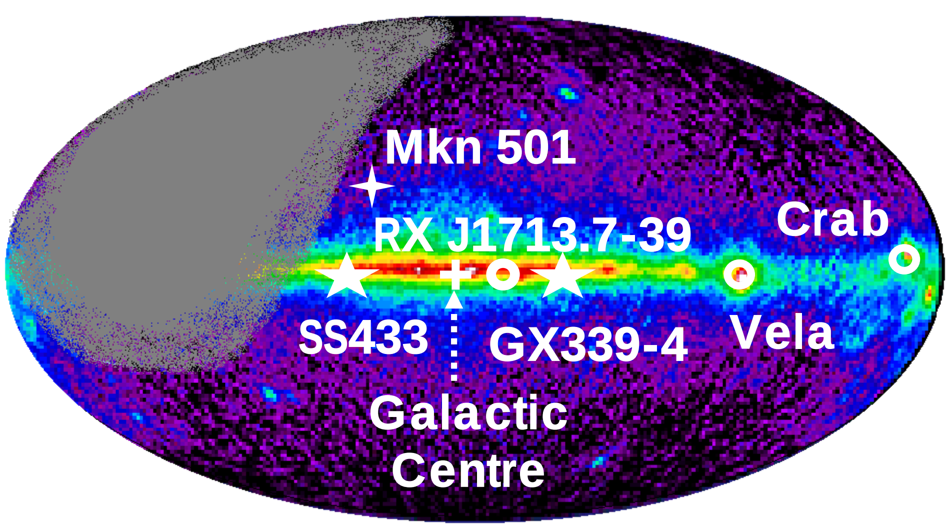
Regions observed by NTs

IceCube (South Pole) (ang. res.: 0.5°)	ANTARES/KM3NeT (43° North) (ang. res.: ~0.3°/0.1°)









Scientific Scope

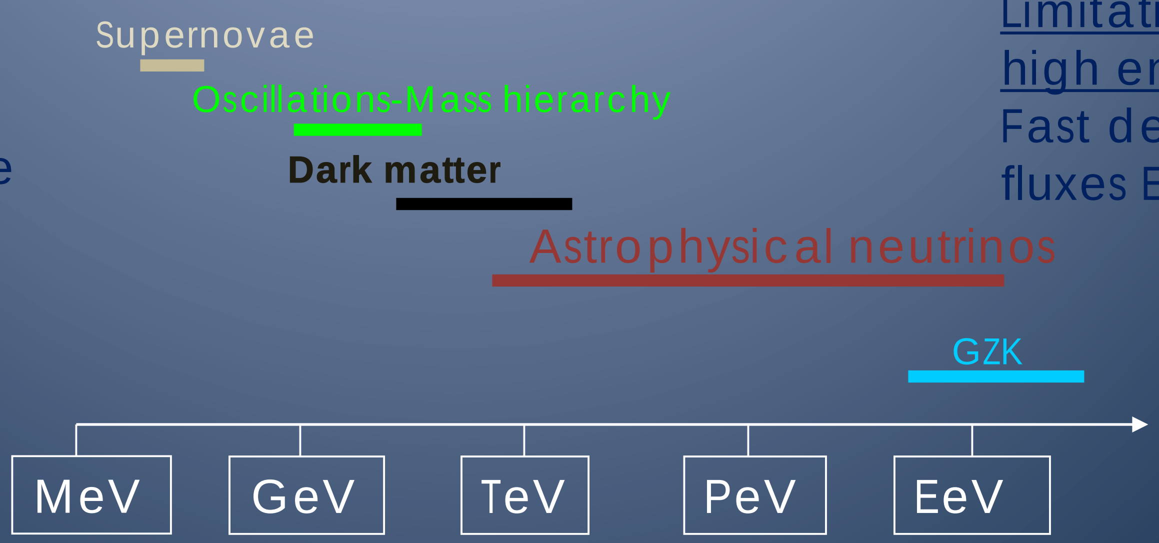
- Origin of cosmic rays
- Hadronic vs. leptonic signatures
- Neutrino mass hierarchy
- Dark matter

Detector size

Limitation at high energies:
Fast decreasing fluxes E^{-2}, E^{-3}

Limitation at low energies:
-Short muon range
-Low light yield
-^{40}K (in water)

Detector density



Other physics: monopoles, nuclearites, Lorentz invariance, etc...

Dark matter detection in NTs

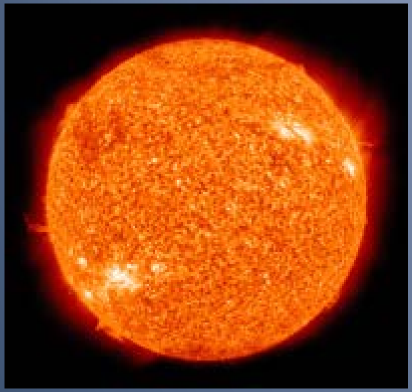
- WIMPs (neutralinos, KK particles) are among the most popular explanations for dark matter
- They would accumulate in massive objects like the Sun, the Earth or the Galactic Center
- The products of such annhiliations would yield “high energy” neutrinos, which can be detected by neutrino telescopes

Specific advantages of neutrinos

- Limits on neutrino channel
- For the Sun analysis:
  - No dependence on stream, structures, subhaloes, etc. or the properties of the Galactic magnetic or radiation fields
  - A signal would be very clean (the astrophysics are well known), compared with other indirect searches (which can be also interpreted as pulsars, etc.)
  - Given a dark matter candidate, the signal can be well predicted. If not observed the model is ruled out

Sources for DM searches

Sun



Galactic Centre

Dwarf galaxies

Earth

Galactic Halo

Galaxy clusters

Sun/Earth: σ_{XN}

Differential neutrino flux is related with the annihilation rate as:

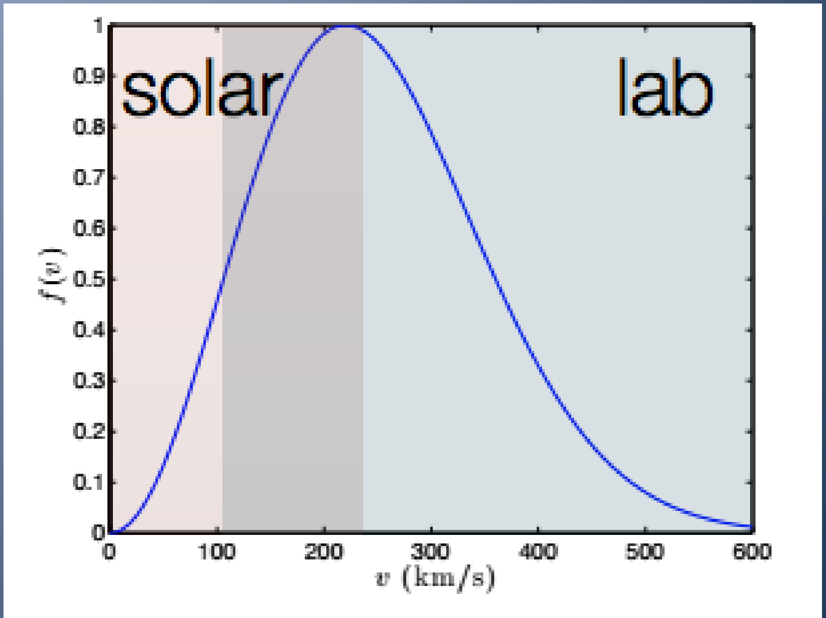
If we assume equilibrium between capture and annihilation in the Sun:

where the capture rate can be expressed as:

Velocity distributions (I)

- Neutrino telescopes (for searches in the Sun) complementary to direct searches
  - low velocity: easier to capture in the Sun
  - high velocity: large recoils easier at high velocities
- Escape velocity:
  - Sun: 620 km/s
  - Earth: 11-15 km/s

$$f(u) = \sqrt{\frac{3}{2\pi}}\frac{u}{v_\odot v_{\rm rms}}\left(\exp\left(-\frac{3(u-v_\odot)^2}{2v_{\rm rms}^2}\right) - \exp\left(-\frac{3(u+v_\odot)^2}{2v_{\rm rms}^2}\right)\right)$$

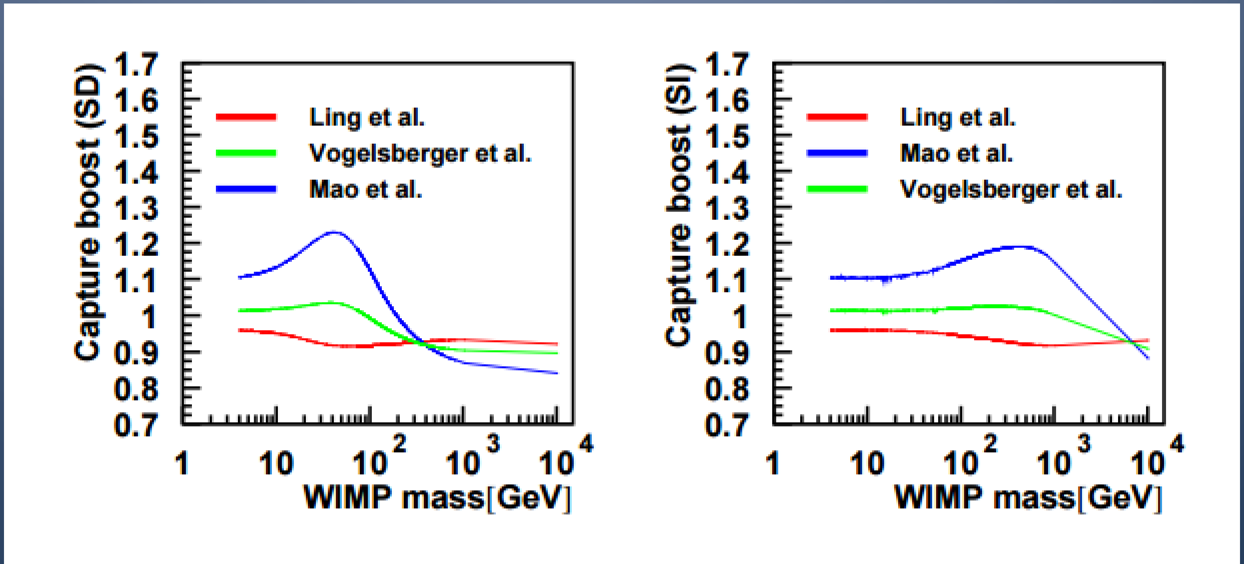


Typically Maxwell distribution of velocities is assumed

Other v distributions: <20% change in C
Choi et al. JCAP 1405 (2014) 049

Velocity distributions (II)

- Effect of uncertainties in velocity distributions for Sun results (Choi et al., arxiv:1312.0273)
  - orbital speed of the Sun
  - escape velocity of dark matter from the halo
  - dark matter velocity distribution functions
  - existence of a dark disc
- Only the existence of dark disk would have a relevant (and very positive) effect)
- Complementary way to deal with direct searches uncertainties



Rate calculation

- Gamma rays, neutrinos (annihilation):

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma, \psi, \theta, \Delta\Omega) = \frac{1}{4\pi}\frac{\langle\sigma_{\rm ann}v\rangle}{2m_\chi^2}\frac{dN_\gamma^i}{dE_\gamma}\int_0^{\Delta\Omega} d\Omega \int_{\rm l.o.s} \rho^2(r(s,\psi,\theta))ds.$$

$(\gamma \rightarrow \gamma, \nu)$

Particle Physics

Dark matter distribution (J-factor)

(for decay: ~ρ)

- Cosmic rays:
  - propagation more complex

$$-\mathcal{K}(E)\cdot\nabla^2 n_f - \frac{\partial}{\partial E}\left(b(E,\vec{x})\,n_f\right) + \frac{\partial}{\partial z}\left(\mathrm{sign}(z)\,V_{\rm conv}\,n_f\right) = Q(E,\vec{x}) - 2h\,\delta(z)\,\Gamma\,n_f$$

Density profiles (I)

- Many profiles available on the market

Cirelli et al., 1012.4515v4

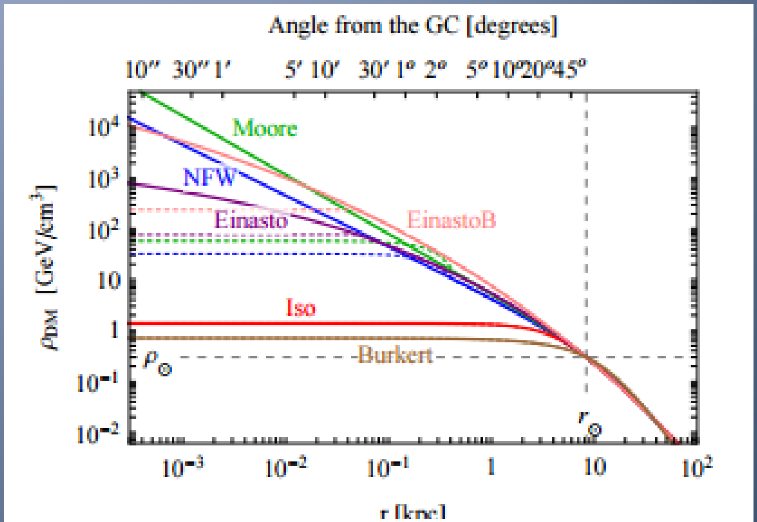
$$\text{NFW}: \quad \rho_{\rm NFW}(r) = \rho_s \frac{r_s}{r}\left(1+\frac{r}{r_s}\right)^{-2}$$

$$\text{Einasto}: \quad \rho_{\rm Ein}(r) = \rho_s \exp\left\{-\frac{2}{\alpha}\left[\left(\frac{r}{r_s}\right)^{\alpha}-1\right]\right\}$$

$$\text{Isothermal}: \quad \rho_{\rm Iso}(r) = \frac{\rho_s}{1+(r/r_s)^2}$$

$$\text{Burkert}: \quad \rho_{\rm Bur}(r) = \frac{\rho_s}{(1+r/r_s)(1+(r/r_s)^2)}$$

$$\text{Moore}: \quad \rho_{\rm Moo}(r) = \rho_s\left(\frac{r_s}{r}\right)^{1.16}\left(1+\frac{r}{r_s}\right)^{-1.84}$$



DM halo	α	r_s [kpc]	ρ_s [GeV/cm^3]
NFW	–	24.42	0.184
Einasto	0.17	28.44	0.033
EinastoB	0.11	35.24	0.021
Isothermal	–	4.38	1.387
Burkert	–	12.67	0.712
Moore	–	30.28	0.105

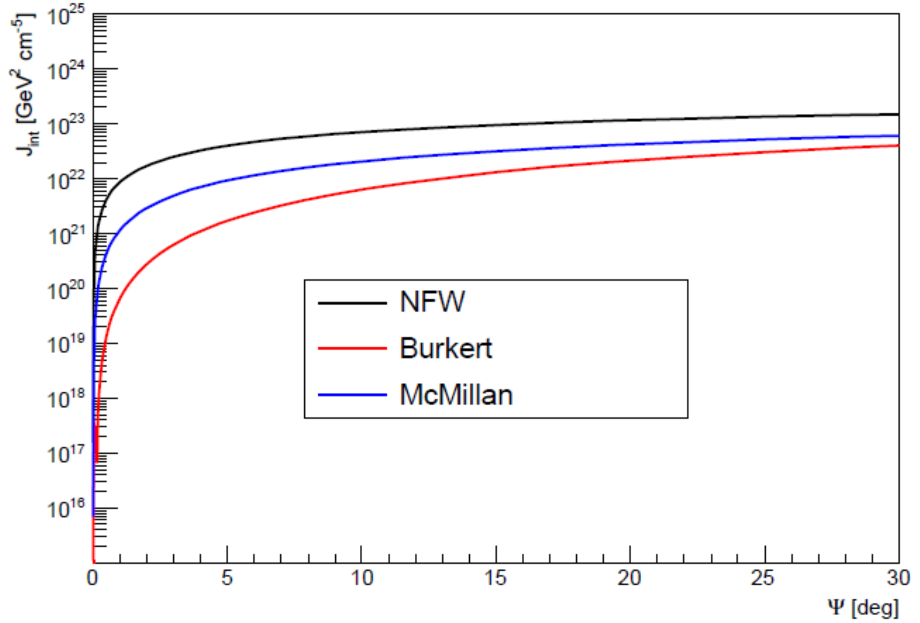
- NFW, Einasto: cuspy, result from simulations
- Isothermal, Burkert: motivated by observations of galactic rotation curves
- Effect of baryons unknown
- Maybe not spherical (triaxial)
- Dark disk: very good for NTs
- Our galaxy very difficult to study!

a new one: McMillan
(MNRAS 414 (2016) 2446.)

Density profiles (II)

- Integrated J-factor (in new ANTARES analysis):

Parameter	NFW	Burkert	McMillan
r_s $[kpc]$	$16.1^{+17.0}_{-7.8}$	$9.26^{+5.6}_{-4.2}$	17.6 ± 7.5
ρ_{local} $[GeV/cm^3]$	$0.471^{+0.048}_{-0.061}$	$0.487^{+0.075}_{-0.088}$	0.39 ± 0.034



*J-factors can be calculated with packages like CLUMPY (A. Chardonnier, C. Com
D. Maurin, Comp. Phys. Comm. 183, 656 (2012))

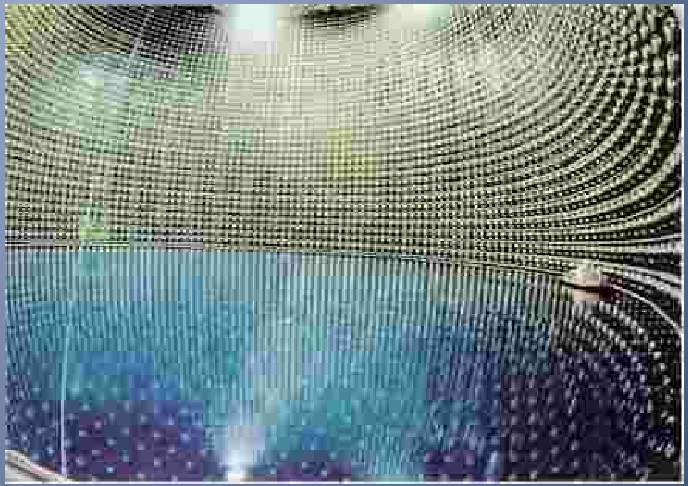
Density profiles (III)

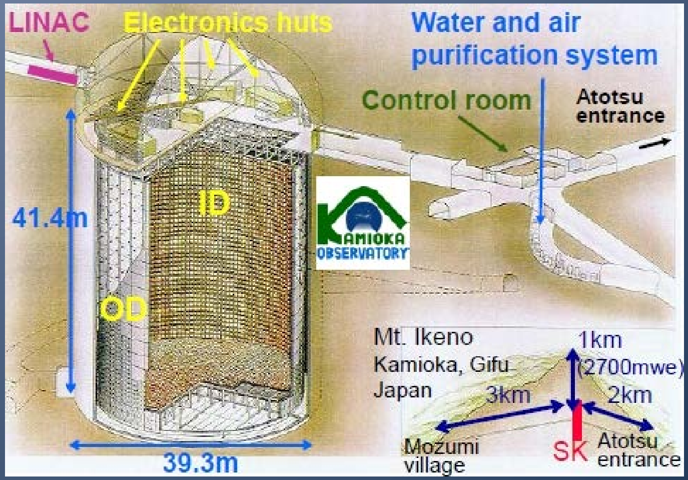
- Simulations favor that the DM collapse give "cuspy" profiles, i.e. more peaked (good for enhancing the signal)
- Observations of rotation curves of galaxies favor "cored" profiles, i.e. constant density cores
- Substructure not well resolved below $\sim 10^5 M_\odot$, which may have an important effect due to the ρ^2 dependency of signal
- Effect of baryons is still unclear:
  - steepening through adiabatic contraction
  - flattening through star bursts

Detectors

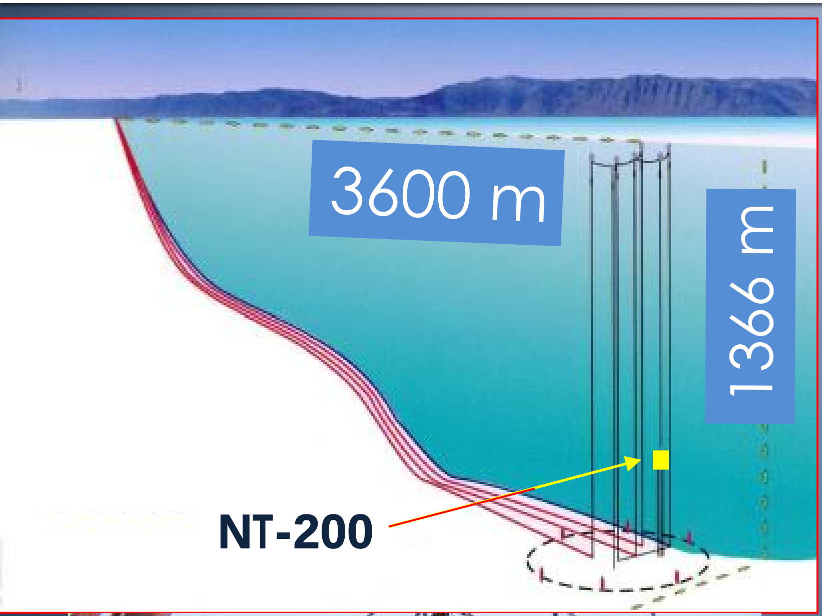
Super-Kamiokande

- 2^{nd} generation of water Cherenkov tank detectors (1996-2016)
- 50 kton detector (22.5 kton fiducial mass)
- For dark matter, competitive at low masses (~10 GeV)





Baikal

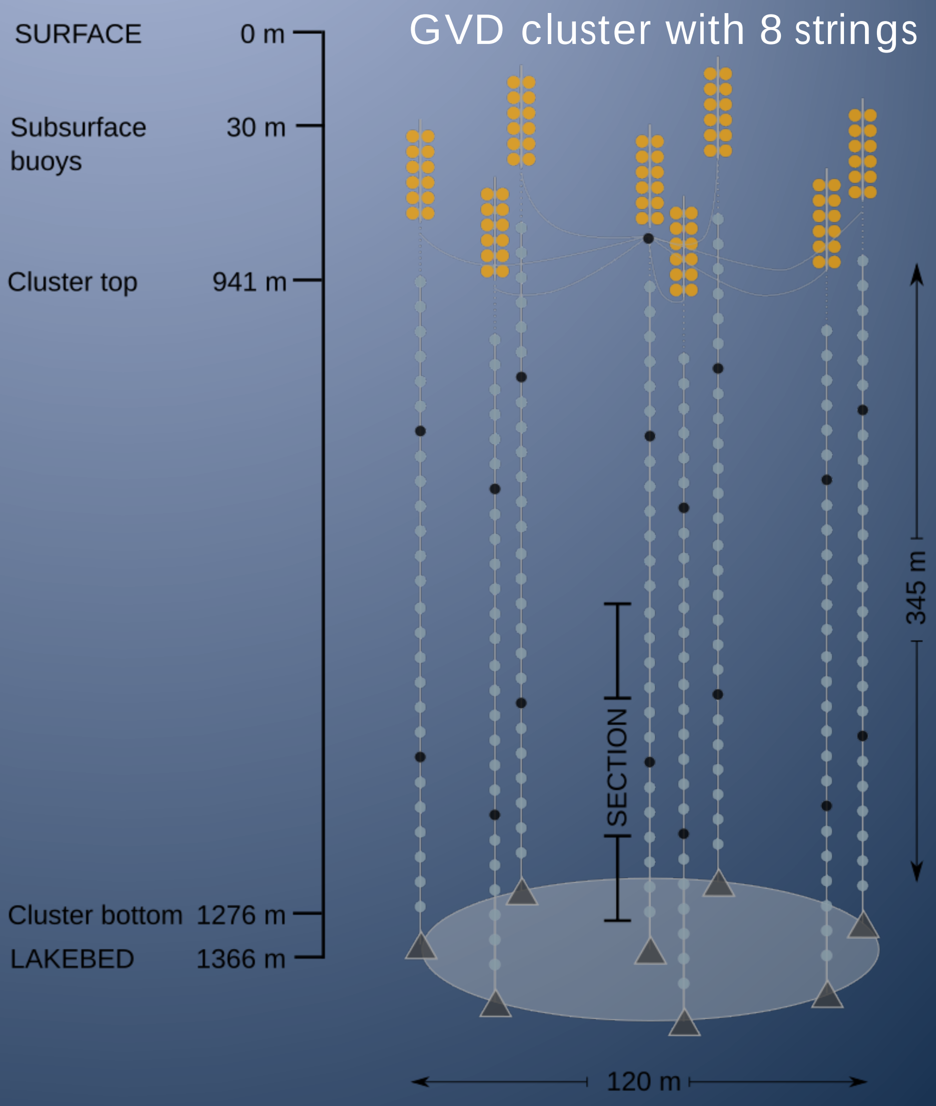


- History of the project
- since 1980: site studies
- 1984 first stationary string
- 1993 NT-36 started
- 1994 first atmospheric neutrino identified
- 1998 NT-200 commissioned
- 2005: NT200+ commissioned

GVD

[Status and plans]

- Prototype line deployed in 2011
- One cluster ("DUBNA") deployed (2015). Upgraded in 2016
- Two more to be installed by 2017
- Eight clusters by 2020 (2304 OMs)



IceCube

IceTop

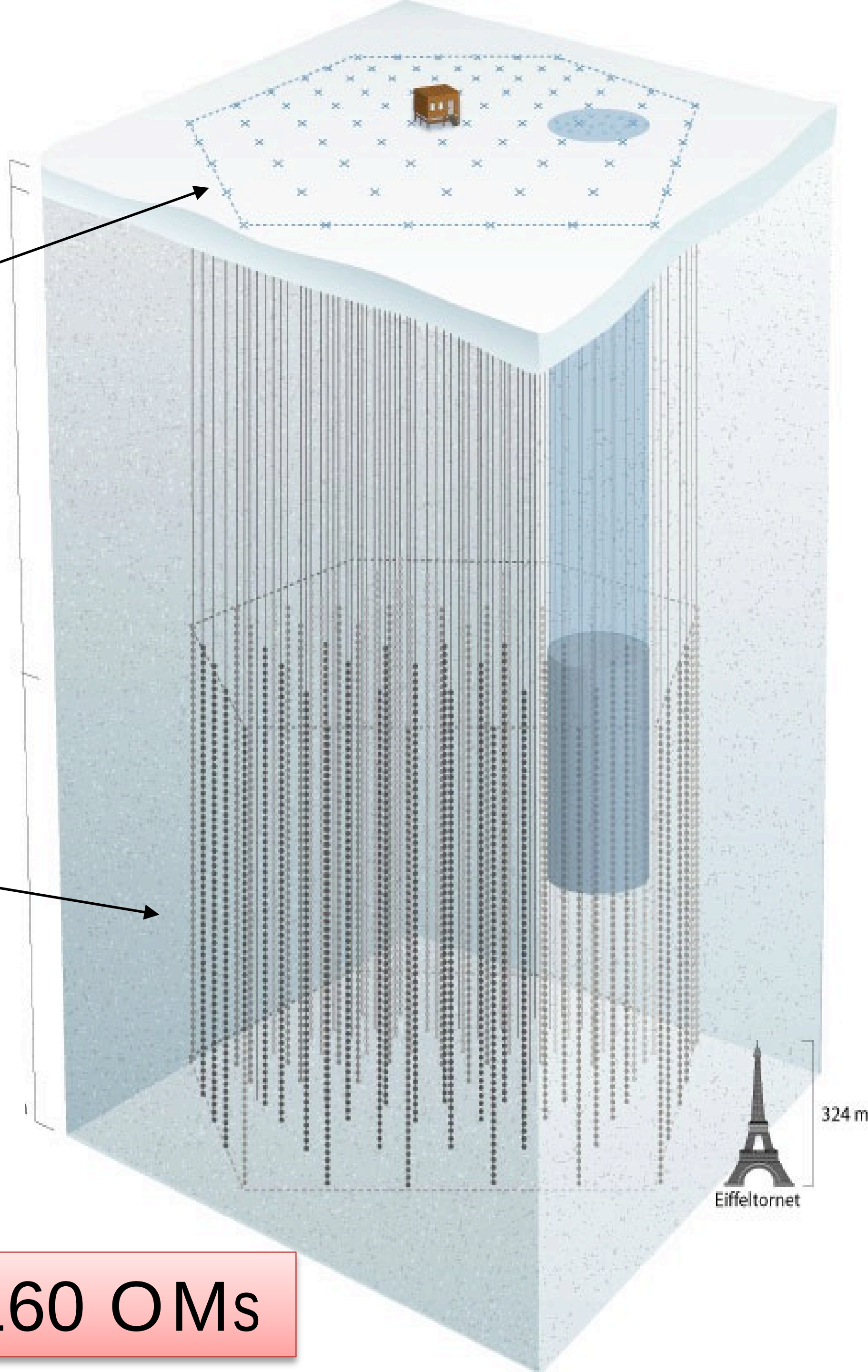
80 pairs of ice Cherenkov tanks
Threshold ~ 300 GeV

IceCube Array

80 strings with 60 OMs
17 m between OMs
125 m between strings
1 km^3. A 1-Gton detector

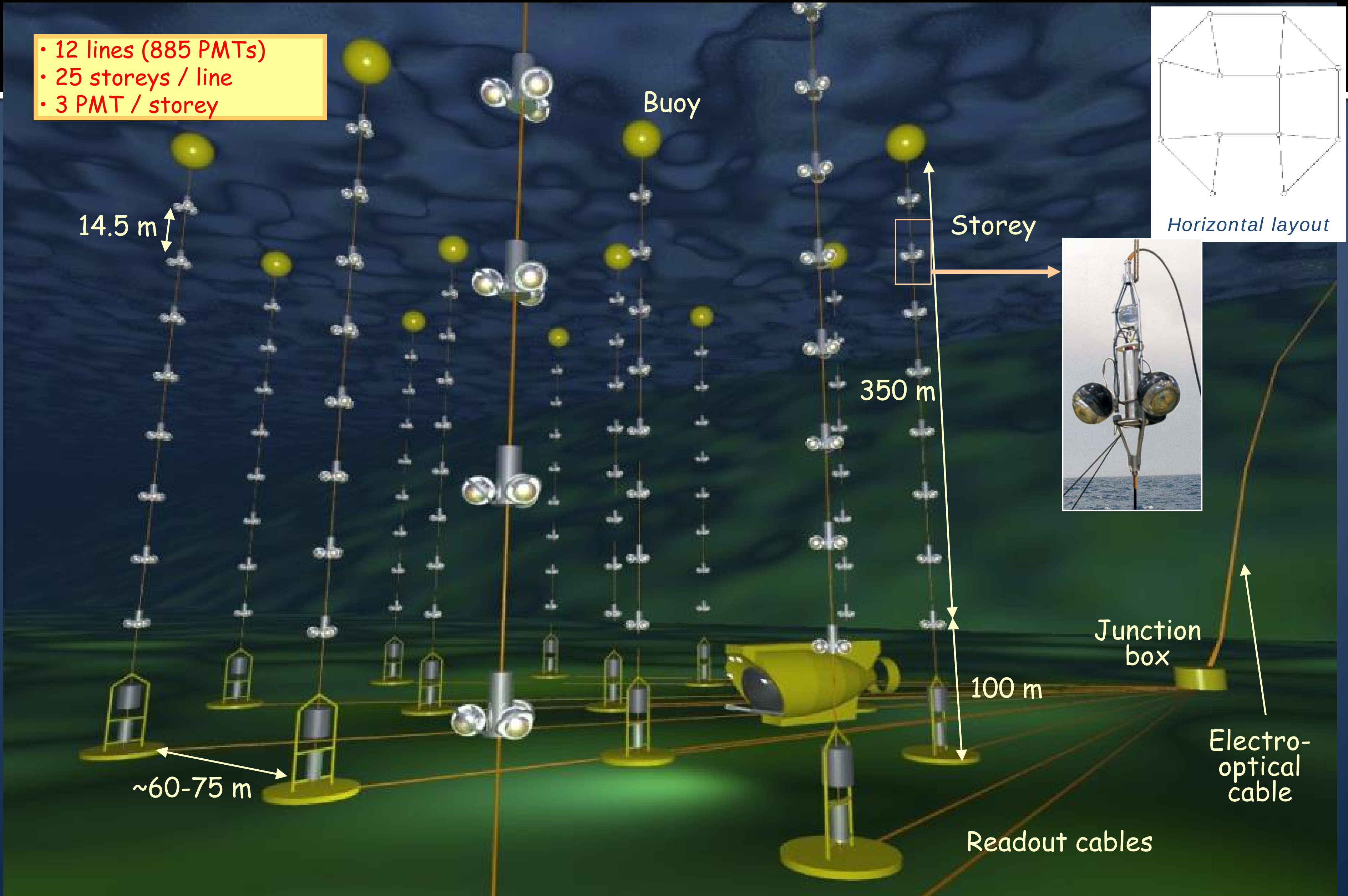
Deep Core

6 strings with 60 HQE OMs
Inner part of the detector



IceCube + Deep Core = 5160 OMs

The ANTARES Detector



Results

Bibliography

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  - IceCube Coll. PRL 110, 131302 (2013)
  - IceCube Coll., JCAP 04 (2016) 022
  - Baikal Coll., Astroparticle Physics (2015), pp. 12-20
  - SuperK, PRL 114, 141301 (2015)
- Earth
  - IceCube Coll., arXiv:1609.01492 (ANTARES paper in preparation)
- Galatic Centre
  - ANTARES Coll. JCAP 1510 (2015) no.10, 068 (new paper for 07-15 in preparation)
  - IceCube Coll. Eur.Phys.J. C75 (2015) no.10, 492
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  - IceCube Coll. Eur. Phys. J. C 76, 531 (2016)
- Dwarf galaxies and galaxy clusters
  - IceCube Coll. Phys.Rev. D88 (2013) 122001

Sun

Tough questions... for others

Indirect Dark Matter Detection
CF2 Working Group Summary

Conveners: J. Buckley, D.F. Cowen, S. Profumo

A. Archer, M. Cahill-Rowley, R. Cotta, S. Digel, A. Drlica-Wagner, F. Ferrer, S. Funk, J. Hewett, J. Holder, B. Humensky, A. Ismail, M. Israel, T. Jeltema, A. Olinto, A. Peter, J. Pretz, T. Rizzo, J. Siegal-Gaskins, A. Smith, D. Staszak, J. Vandenbroucke, M. Wood

6 Tough Questions

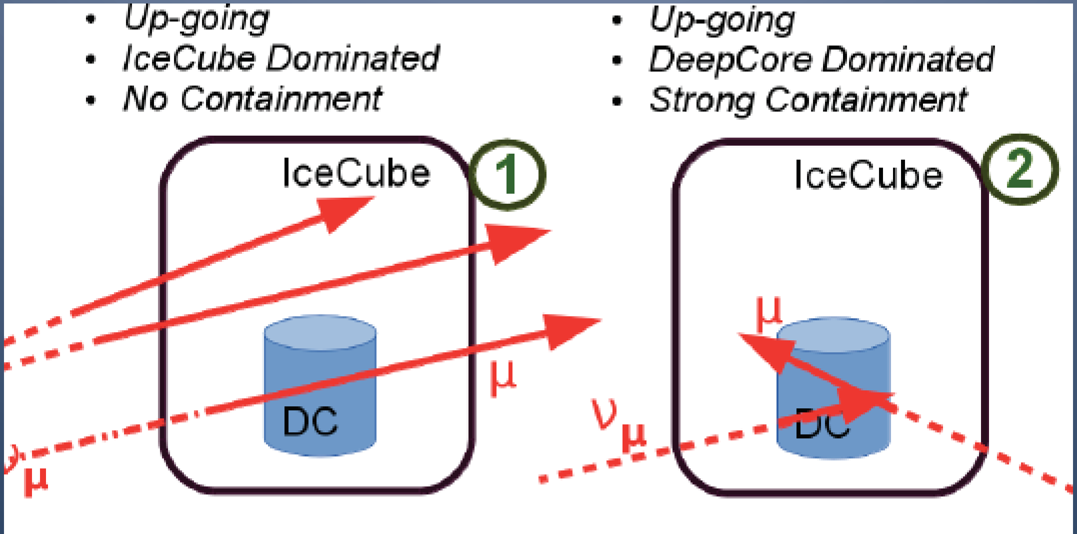
As part of this planning process, tough questions were solicited from the particle physics community, and addressed to the various subgroups. Here, we explicitly answer two tough questions that were addressed to the CF2 subgoup.

(1) Tough question CF11 "*Can dark matter be convincingly discovered by indirect searches given astrophysical and propagation model uncertainties? Do indirect searches only serve a corroborating role?*"

However, the detection of a high energy neutrino signal from the sun, or a narrow gamma-ray line could provide a smoking-gun signal, and more than just a corroborating evidence. Even if the LHC or Direct

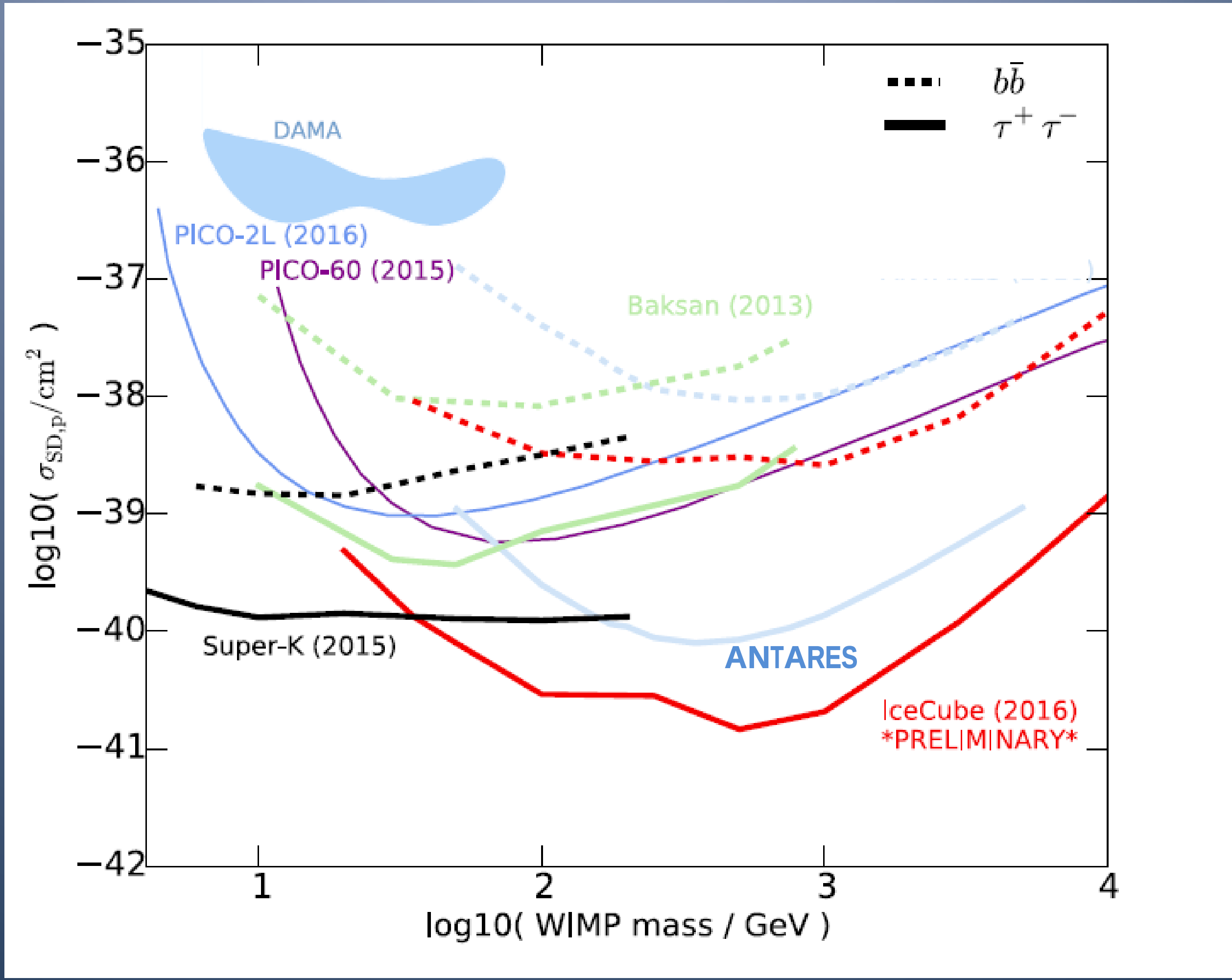
Sun

- IceCube, two analysis:
  - HE (M_{WIMP}>100 GeV), IceCube-dominated
  - LE (M_{WIMP}=30-100 GeV), DeepCore-dominated
- ANTARES is smaller but has a better angular resolution and the Sun is less time close to the horizon, where there is more background
- SK has recently also included cascade events in their analysis



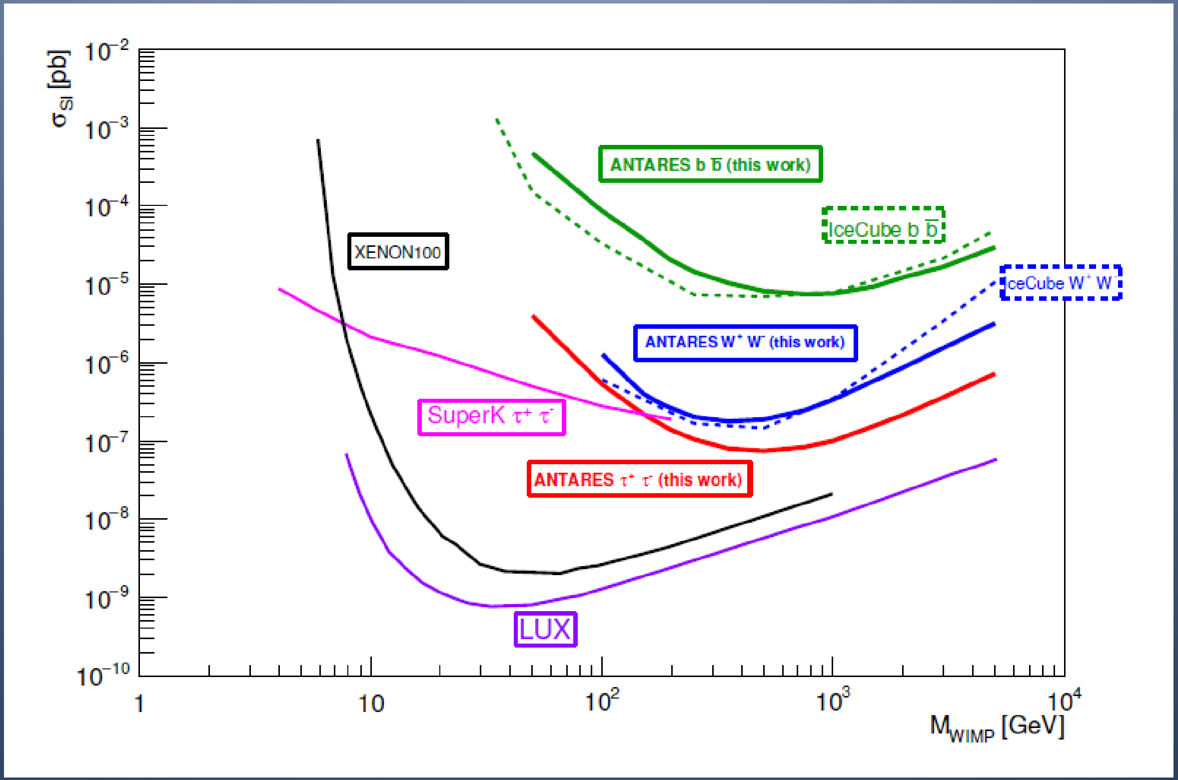
Sun: Spin Dependent σ

M. Danninger, Neutrino 2016



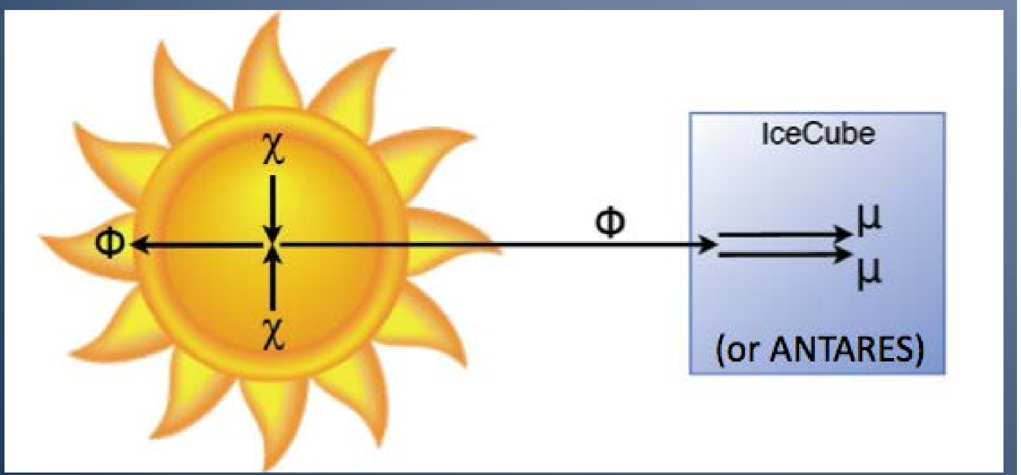
Sun: Spin Independent σ

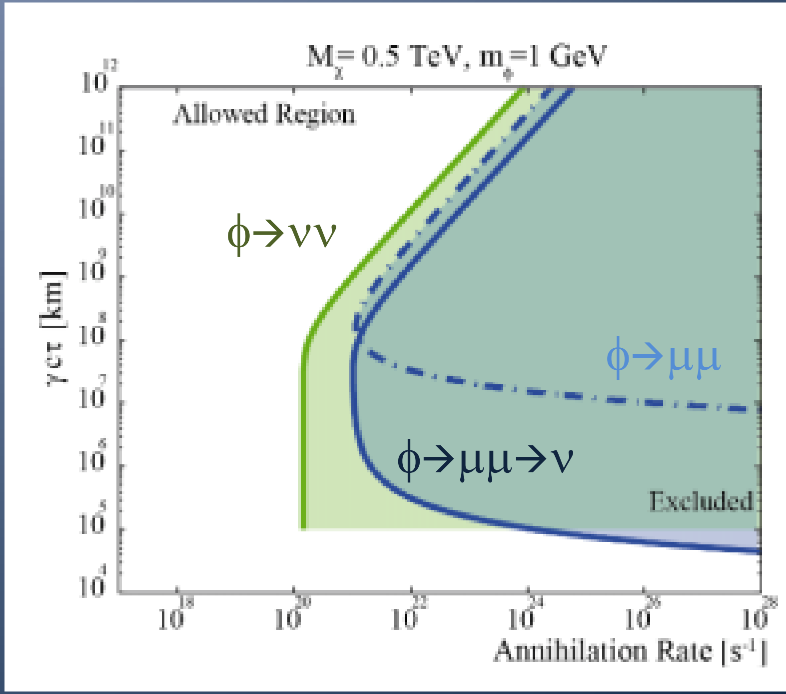
- For spin-independent NTs are not competitive with direct searches



Sun: Secluded DM

- In this model the Dark Matter, is secluded from 'normal' matter by a mediator, Φ, which could be some new gauge boson from the dark sector, or some other candidate.
- In the simplest picture the dark matter annihilates into the mediator. If the mass of the dark matter was greater than the mediator then the dark matter would be leptophilic and might be the explanation of some observations suggesting 'new physics'





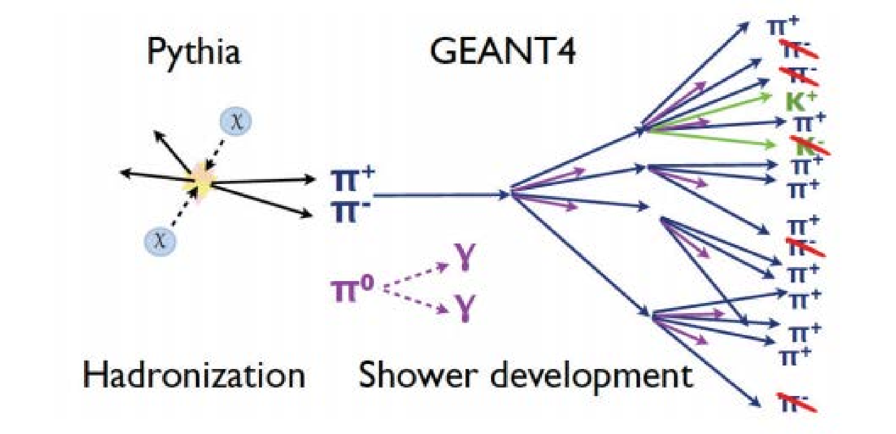
other possibilities:

-mediator → neutrinos

-mediator → di-muon → neutrinos

Sun: Low energy neutrinos

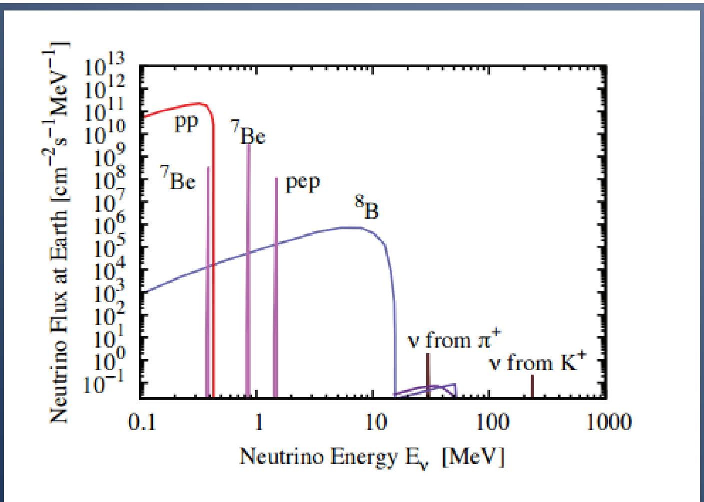
Rott, AIP Conf. Proc 1743, 020010 (2016)

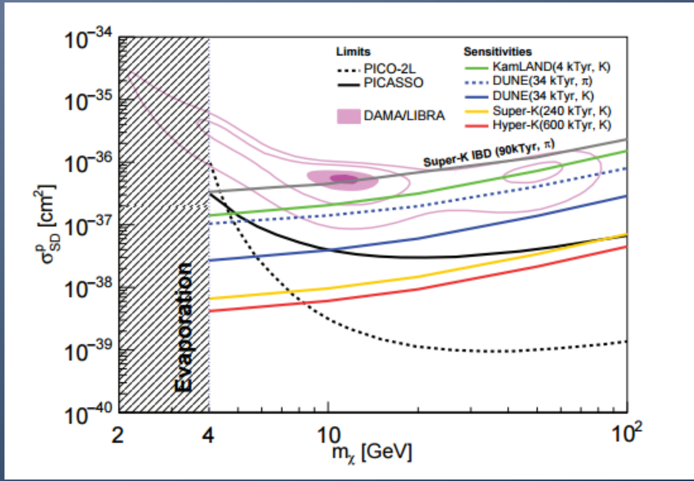


New idea: monoenergetic neutrinos produced in pion and kaon decays (MeV energies)

- $\pi^+ \rightarrow \nu_\mu\, \mu^+$ (29.8 MeV)
- $K^+ \rightarrow \nu_\mu\, \mu^+$ (235.6 MeV)

- $\mu^+ \rightarrow$ anti-$\nu_\mu\, \nu_e$ (cont. ~ few-50 MeV)

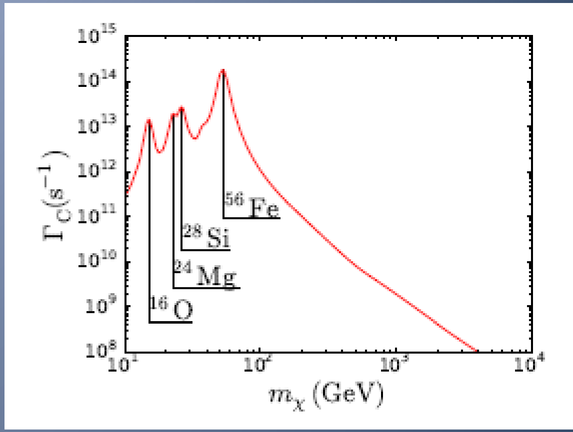


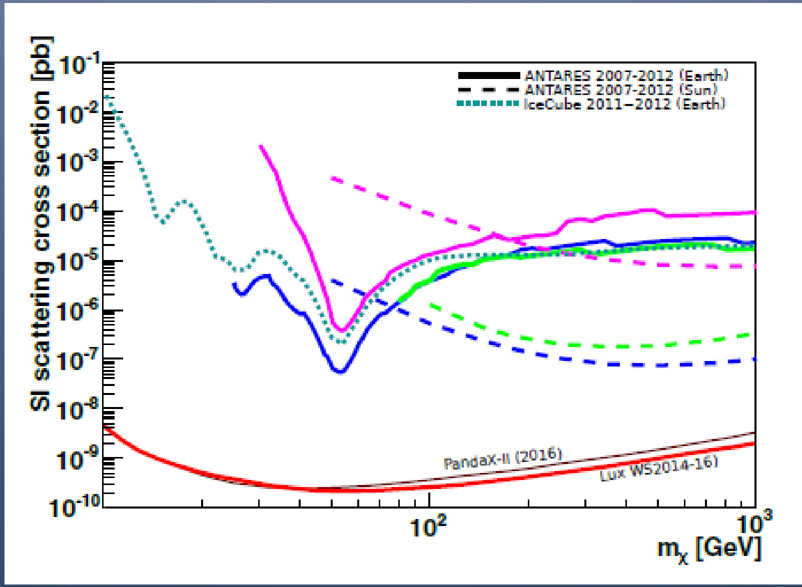


Earth

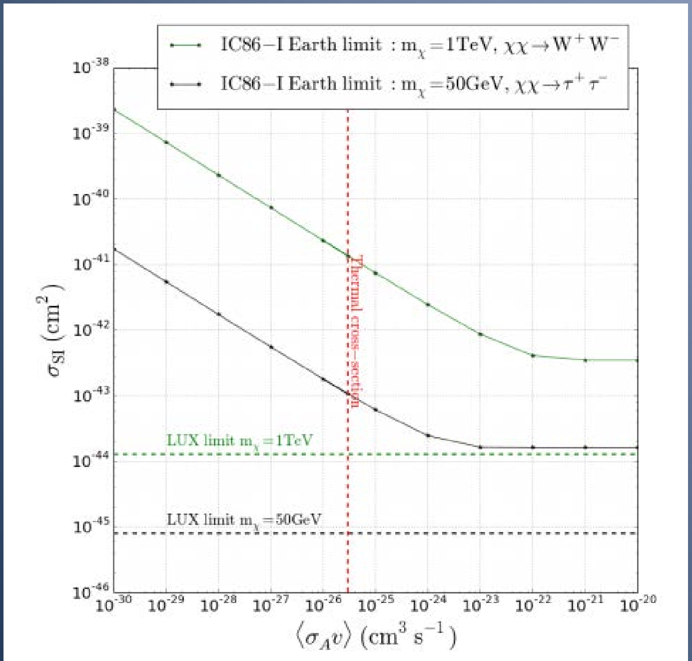
Earth

- Limits on spin independent cross section
- More efficient for masses close to those of Fe and Ni
- Background harder to estimate compared to Sun or GC
- No equilibrium between capture and annihilation can be assumed in general
- Great enhancement if there is a dark disk





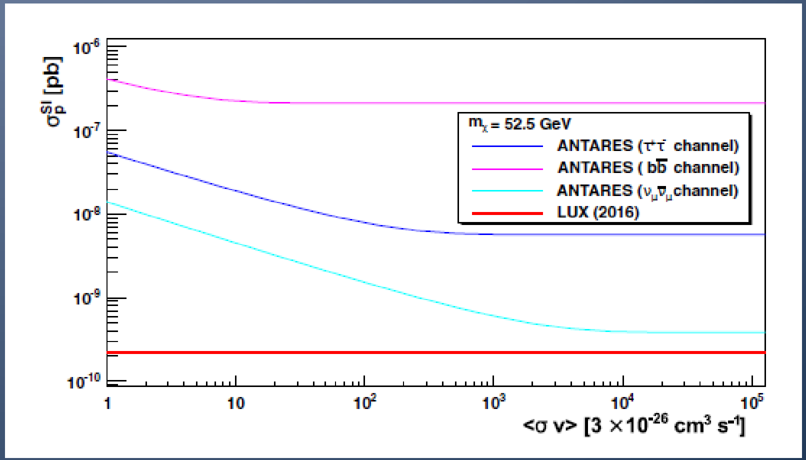
Earth



IceCube

- τ_{Earth}~10^{11} y vs t_o~4.5×10^9 y →
- → no equilibrium between capture and annihilation → $\Gamma_A \propto C^2$
- we derive limits on σ_{SI} as a function of $< \sigma v >$

ANTARES



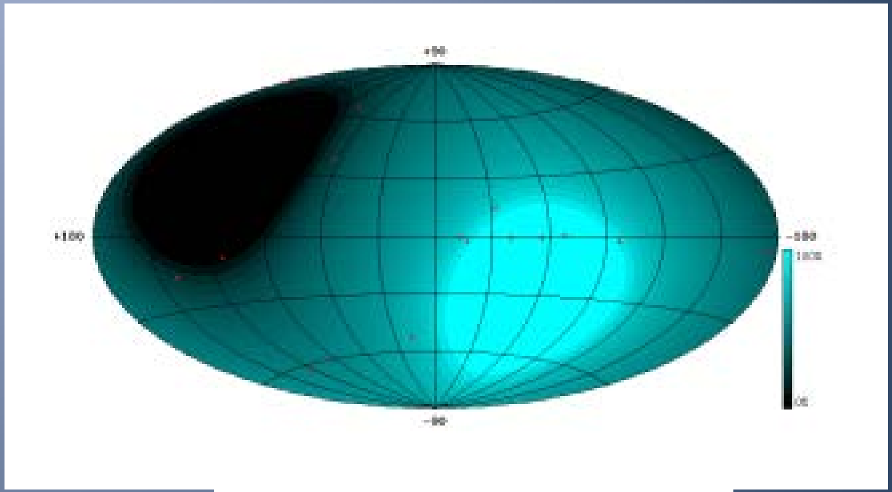
Milky Way

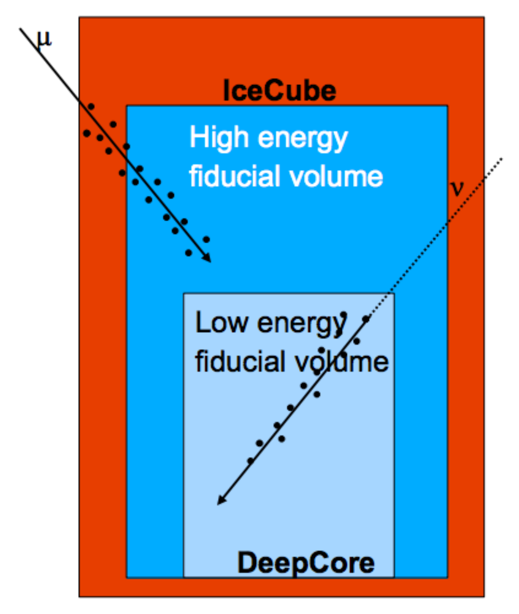
-Galactic Centre

-Galactic Halo

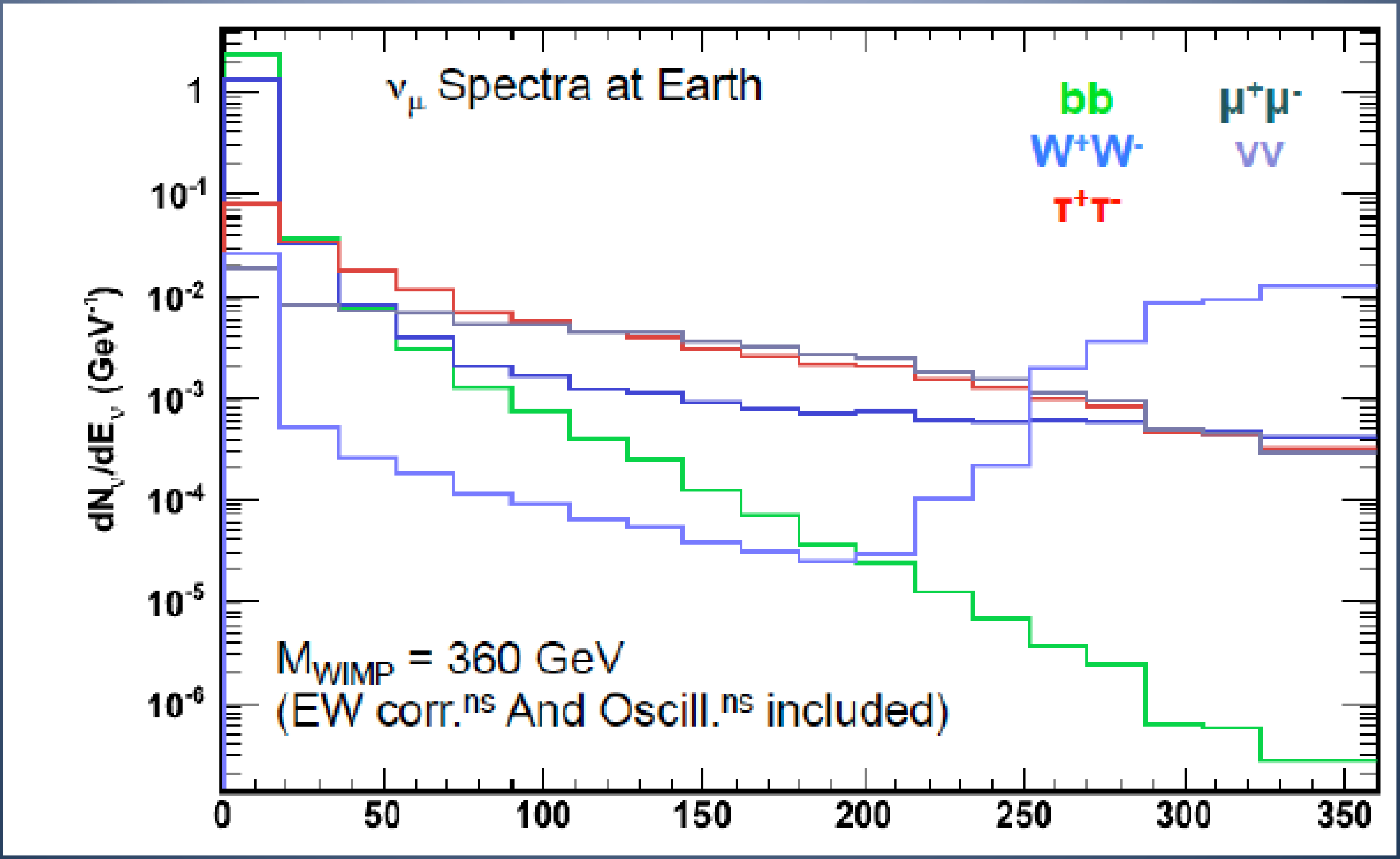
Galactic Center

- Astrophysical background could be important
- High energy component not absorbed (contrary to the case of the Sun)
- ANTARES: GC most of the time below the horizon
- IceCube: GC always above the horizon, veto techniques needed





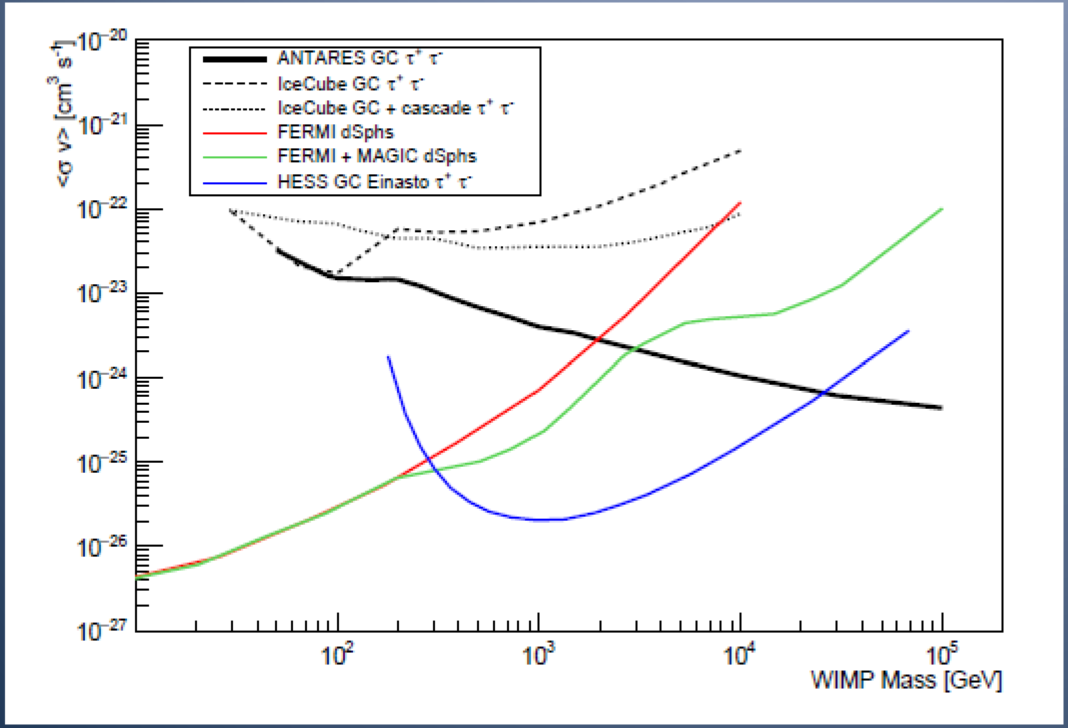
Spectrum (GC)



E (GeV)

GC: Annihilation σ

- Results for 2007-2015 recently unblinded
- Best results at large masses (better visibility of Galactic Centre)
- ANTARES: better than IC (all masses) and best limits for MWIMP>30 TeV)



Although number density decreases with MWIM, V_{eff} and angular resolution improves
For IC, veto kills signal at large M_{WIMP}

- Note: Upper bound on DM mass can be set by unitarity (Griest, PRL, 64, 6) at ~120 TeV (with updated value for $h^2\Omega$) but for some models (non-thermal production) this is avoided

Large mass WIMPs

- Upper bound on DM mass can be set by unitarity (Griest, PRL, 64, 6) at ~120 TeV (with updated value for $h^2\Omega$)

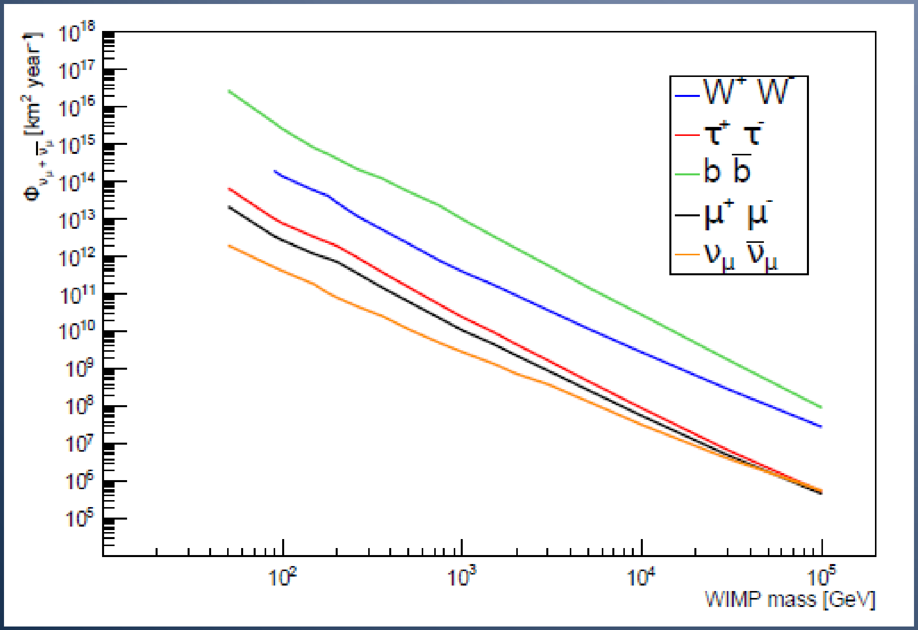
$$\sigma v \lesssim \frac{4\pi}{M^2 v}$$

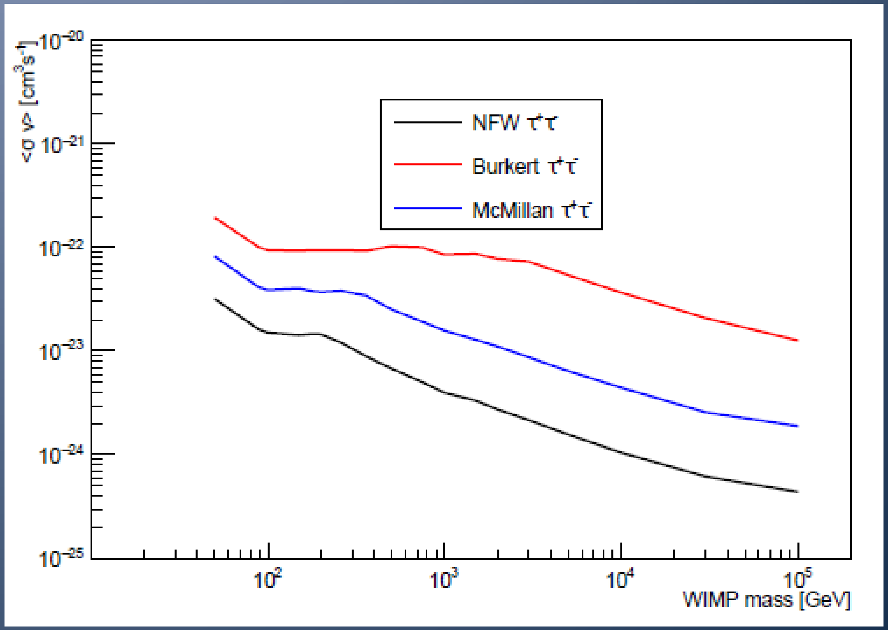
- However, this can be avoided (typically, by non-thermal mechanisms, but not only)
  - Non-thermal: Profumo, Phys. Rev. D 72, 103521 (2005)
  - Thermal: Harigaya et al., arxiv:1606.00159v1 (DM as bound state)

- In any case, reminder: ANTARES beats the rest of the gang already at 30 TeV

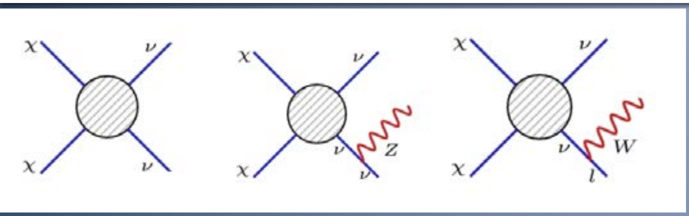
GC: flux limits

- ANTARES: other channels, other profiles

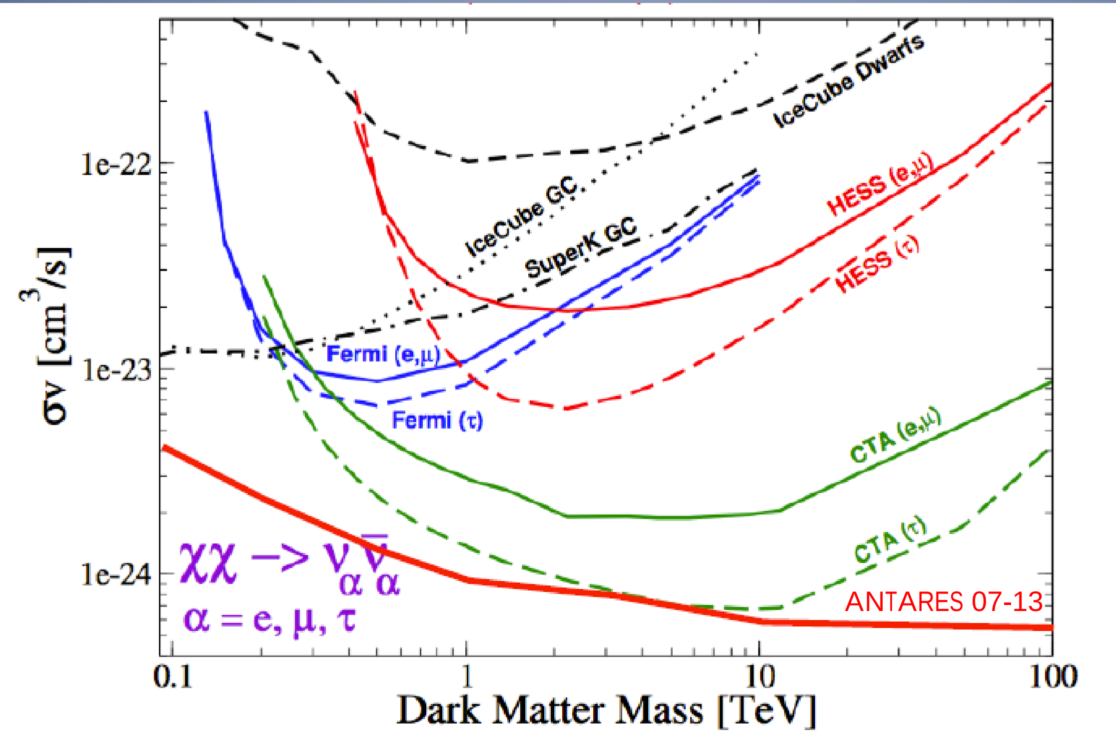




Neutrino channel



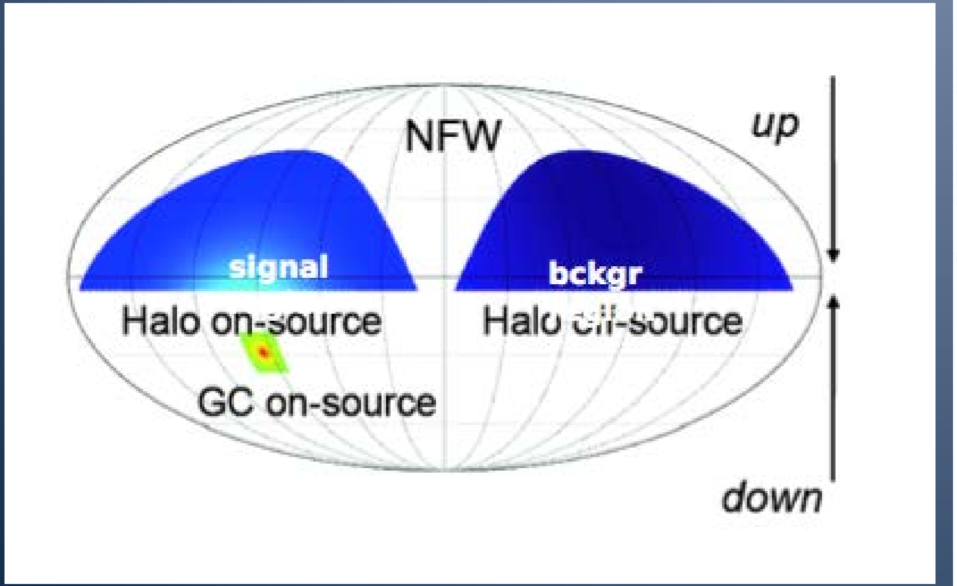
M. Danninger, Neutrino 2016



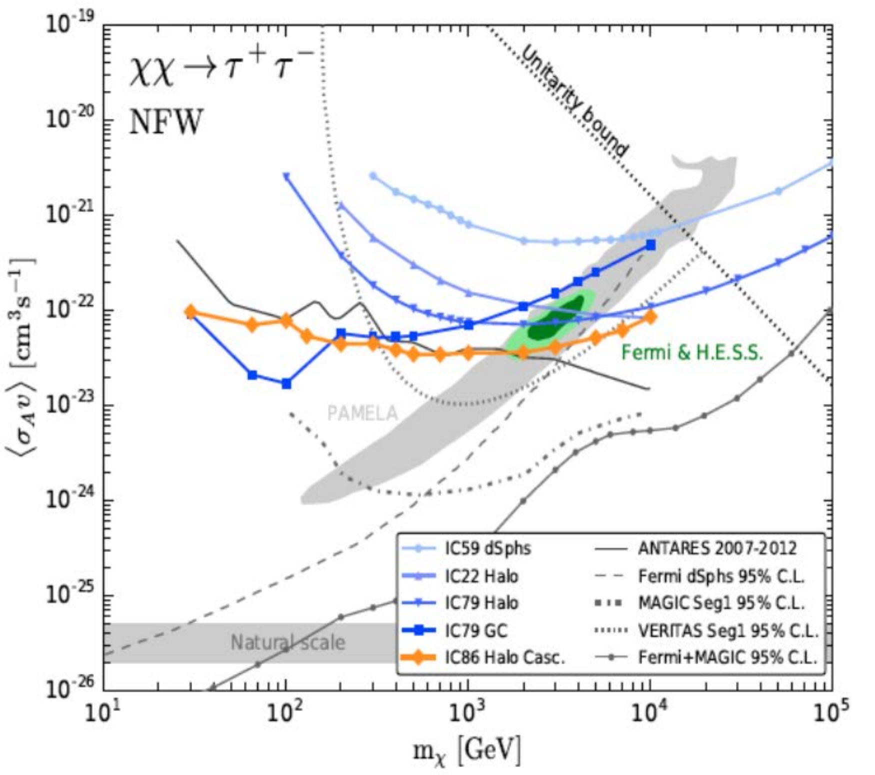
In JCAP 05 (2016) 050: gamma telescopes more sensitive to neutrino lines than NTs? → NO! (with new results from ANTARES)

Galactic Halo

- Three analyses by IceCube:
  - Cut and count (IC22, 275d)
  - Multipoles (IC79, 316d)
  - All-flavor search (inclusion of cascades)



arXiv:1606.00209v1

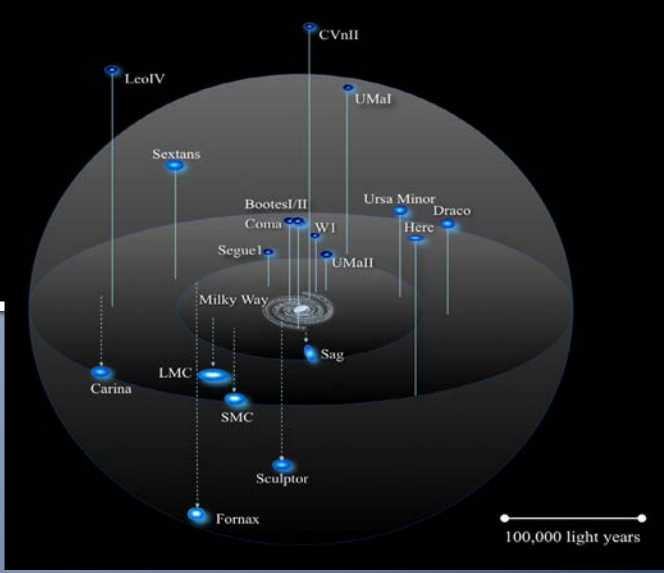


Extra-galactic

-Dwarf galaxies

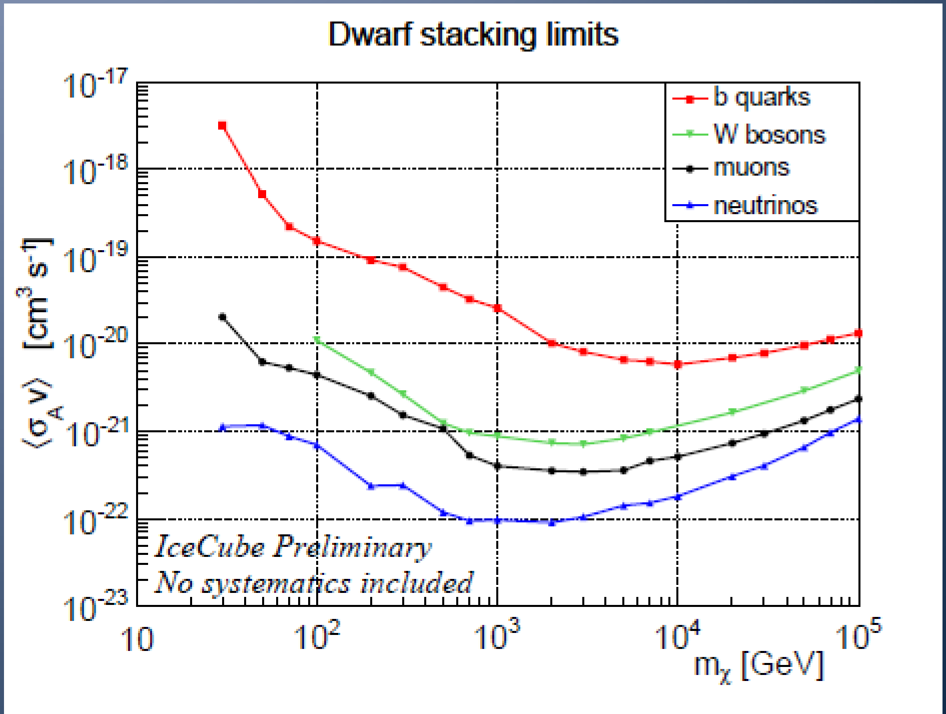
-Galaxy clusters

Dwarf galaxies



Targets	Type	RA [deg]	Dec [deg]	Distance [kpc]	$\log_{10}(J_{NFW}$ / GeV^2 cm^{-5})
Segue 1	Dwarf galaxy	151.767	16.082	23	19.5 ± 0.29
Ursa Major II	Dwarf galaxy	132.875	61.310	32	19.3 ± 0.28
Willman 1	Dwarf galaxy	162.343	51.051	38	19.1 ± 0.31
Coma Berenices	Dwarf galaxy	186.746	23.919	44	19.0 ± 0.25
Draco	Dwarf galaxy	260.052	57.915	76	18.8 ± 0.16
M31	Major galaxy	10.685	41.269	785	19.2 ± 0.1
Virgo	Galaxy cluster	187.704	12.391	16800	18.5

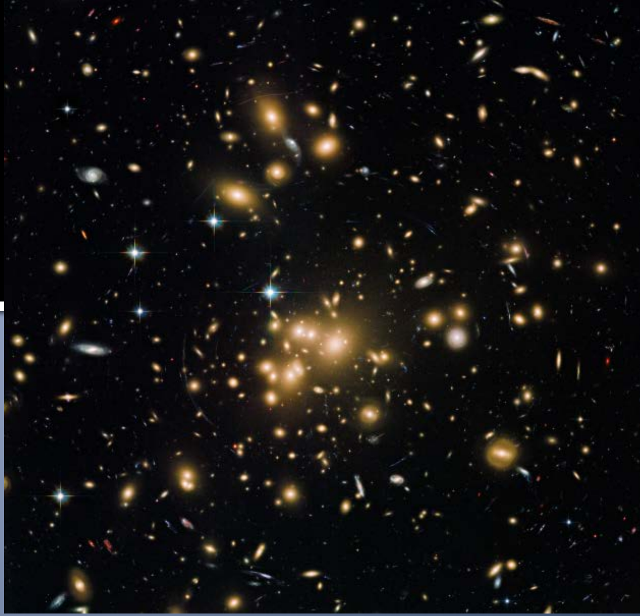
- Dwarf galaxies are satellites of MW
- Large Mass/Luminosity
- Stacking possible (and number increasing)
- Known distances



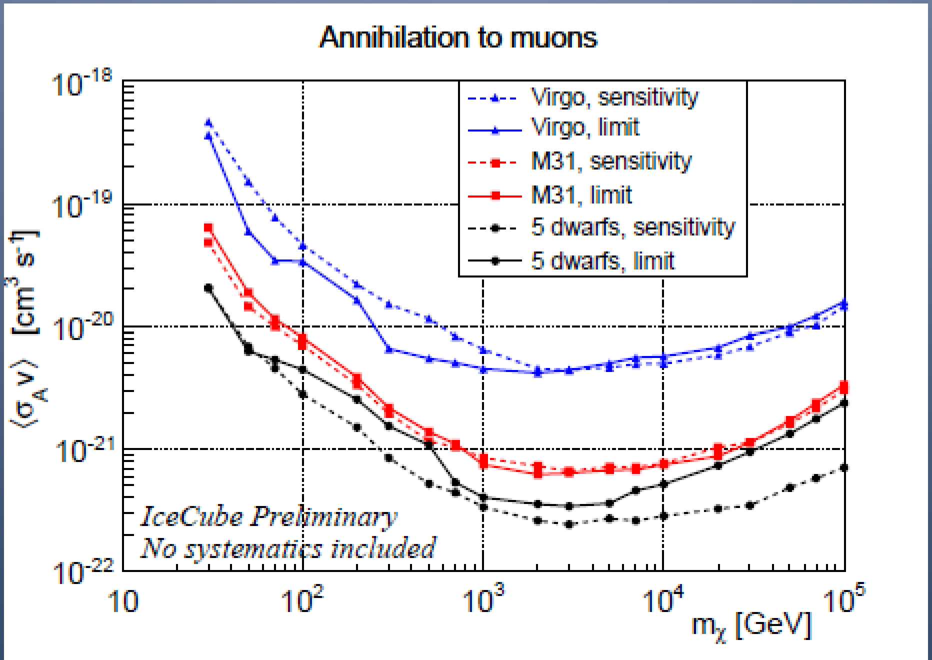
PoS ICRC2015 (2016) 1215

Galaxy clusters

- Largest gravitationally bounded objects in the Universe
- Substructure is quite uncertain
- Boost factors could be large



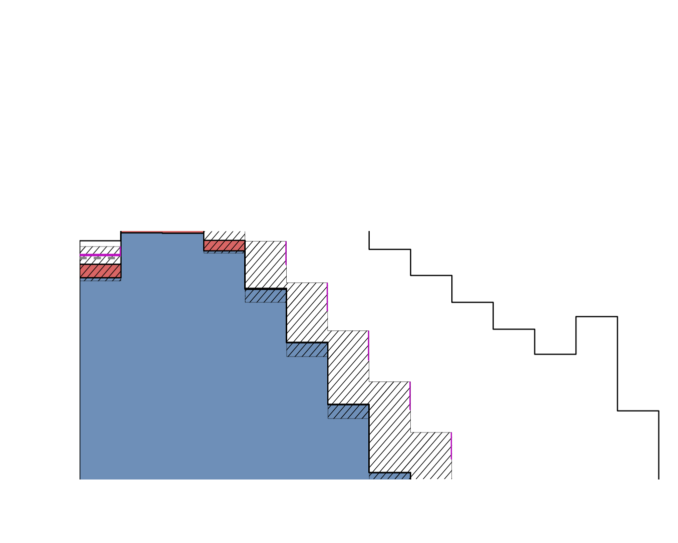
Virgo Galaxy Cluster
credit: ESA



PoS ICRC2015 (2016) 1215

HE events in IC and DM

- 54 high-energy events in the 4 year sample (expected background: 21)
- Interpretation:
  - Diffuse flux?
  - Galactic component?
  - Decaying dark matter?



HE events in IC and DM

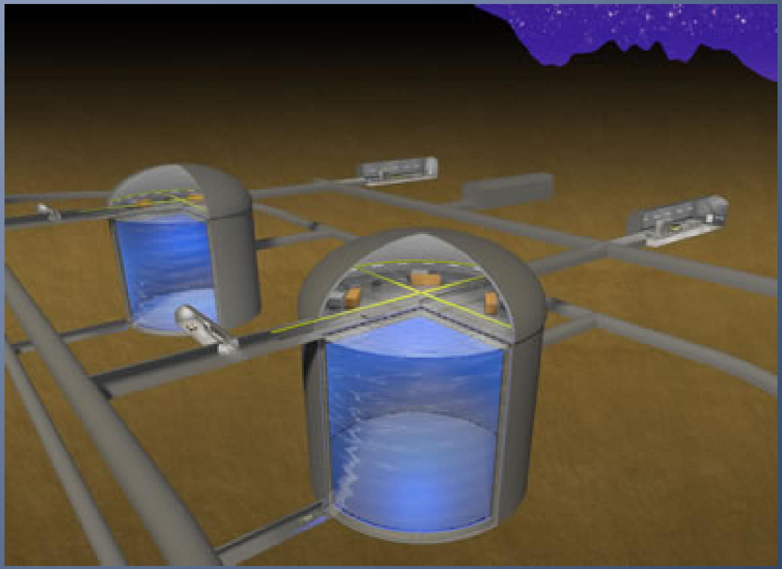
- Decaying DM from halo could explain spatial distribution of HE events
- It could be also compatible with energy spectrum: peak at PeV and continuum from low energy contribution
- Also favoured by the fact that no evidence for SUSY is found in accelerators

Example: C. Rott et al., Phys. Rev. Lett. D92(2) 023529 (2015)

Future (partly present)

Hyper-K

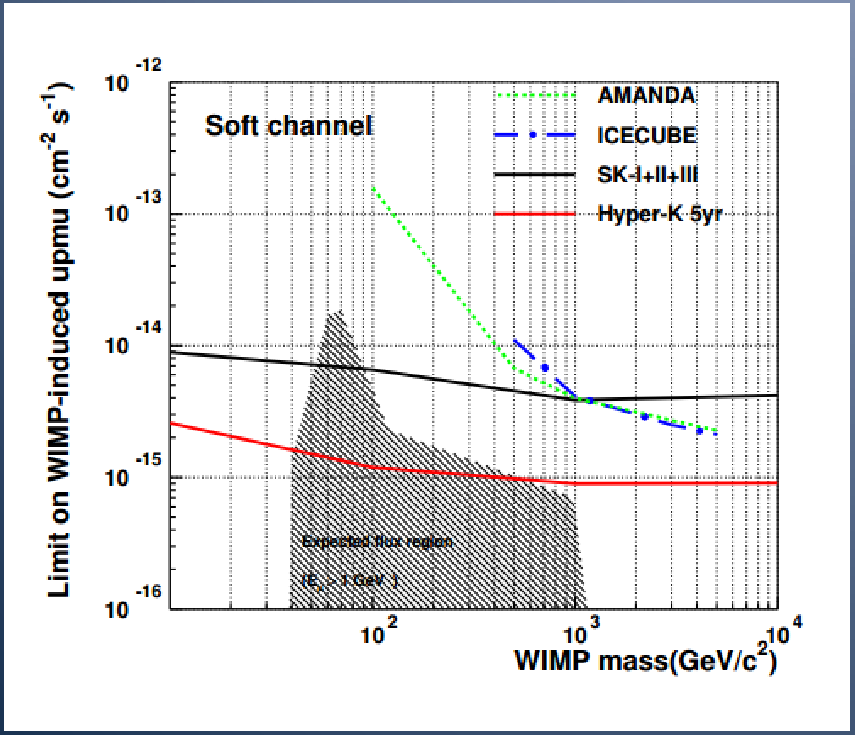
- Third generation of large water Cherenkov detector
- 0.52 Mton (380 kton fiducial). x10/x20 Super-K
- Plan: start >2026 (first tank)



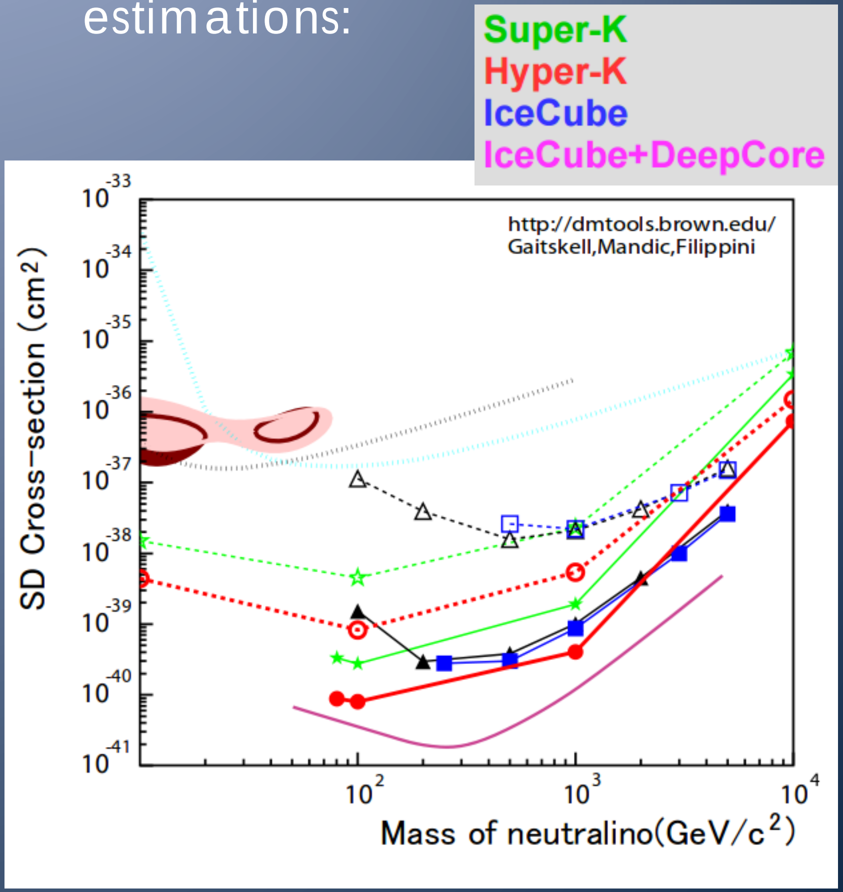
- Sensitivity to WIMPs from Sun, Earth, Galactic Halo
- Expected sensitivity at 10^{-39} cm^2 @ 10 GeV

Hyper-K

- From Hyper-K LoI (arxiv: 1109.3262v1)
- Room from improvement:
  - flavor information
  - Fully contained sample

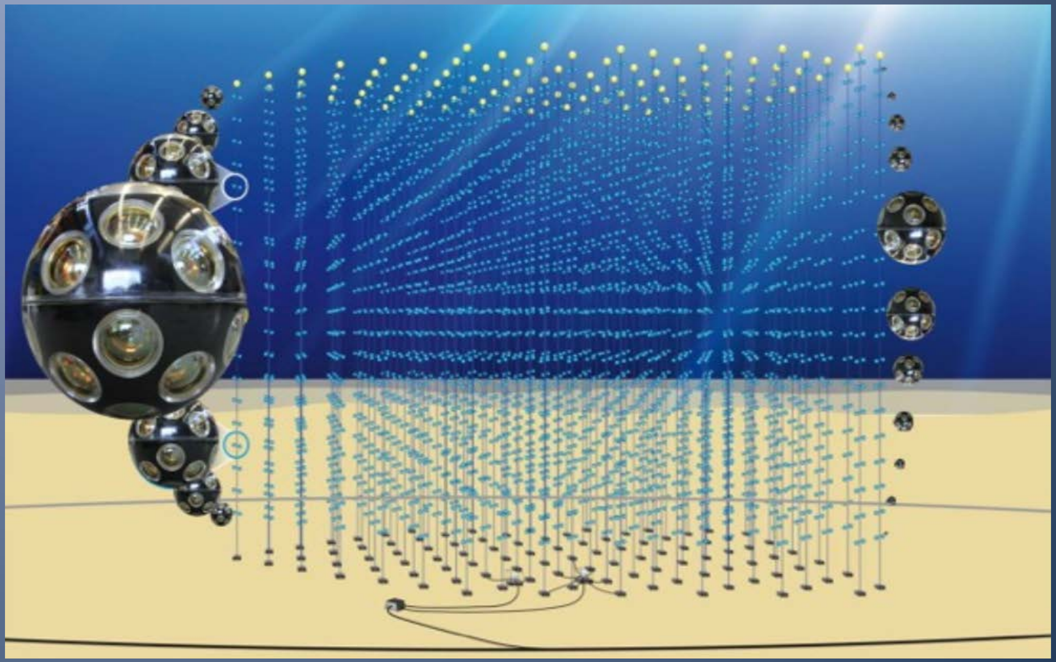


- More recent estimations:



KM3NeT

- KM3NeT is a common project to construct neutrino telescope in the Mediterranean with an instrumented volume of several cubic kilometers
- It will also be a platform for experiments on sea science, oceanography, geophysics, etc.
- 240 groups of Astroparticle Physics and Sea Science from 12 countries are involved
- New groups very welcome! (UGR just joined)



- Prototype lines have already been installed
- The first KM3NeT line has been installed in December 2015 (and two more in May 2016)

Phases

PHASE 1:

- Already funded
- 31 lines (24 in Italy, 7 in France)to be deployed in 2015-2017
- Proof of feasibility and first science results

PHASE 2.0:

- ***ARCA*** (Astroparticle Research with Cosmic Rays)
  - Test IceCube signal
  - Italy
  - 2x115 lines
  - Sparse configuration
- ***ORCA*** (Oscillation Research with Cosmic Rays)
  - Mass ordering (and DM)
  - France
  - 115 lines
  - Dense configuration

PHASE 3: FINAL CONFIGURATION

- 6x115 lines (in total)
- Neutrino astronomy including Galactic sources

ORCA and ARCA

- Same technology

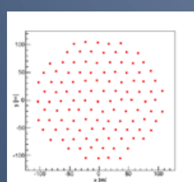
ARCA

ORCA

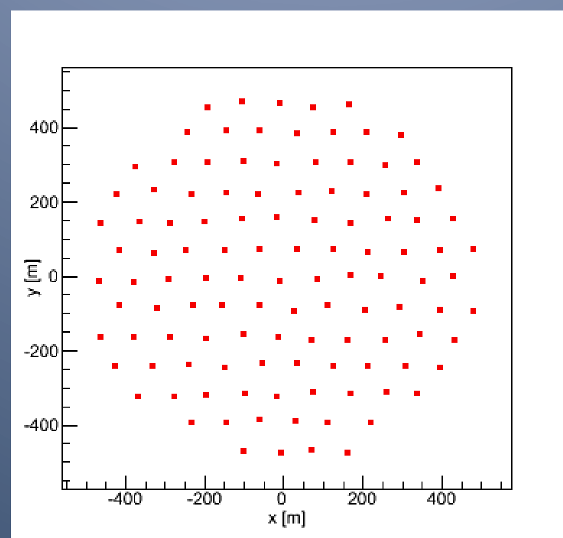
1 km

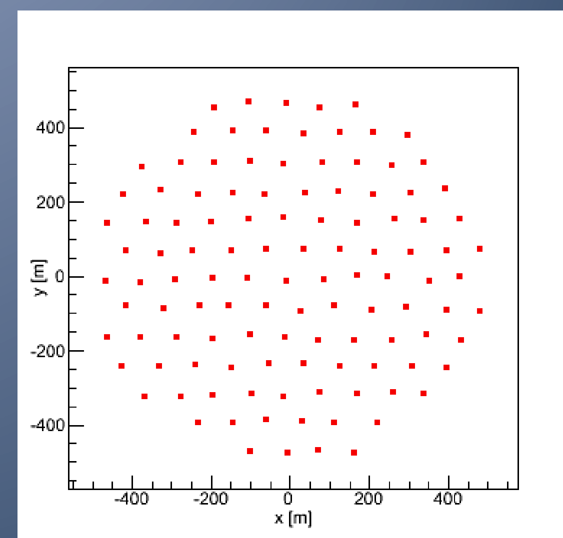
1 km

200 m



France

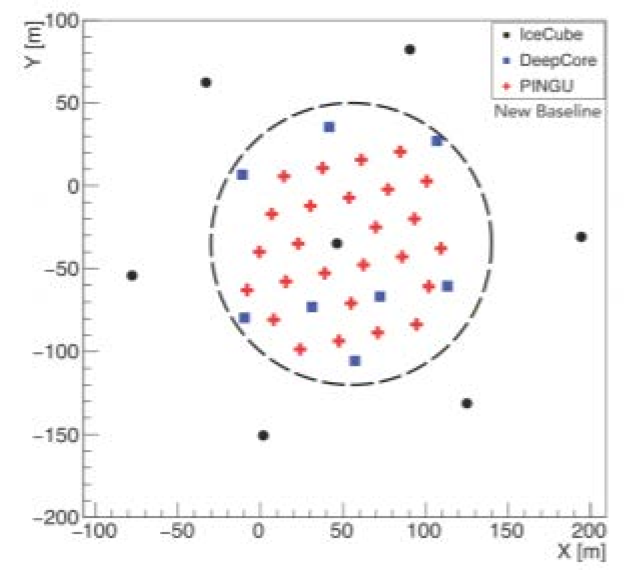




Italy

PINGU

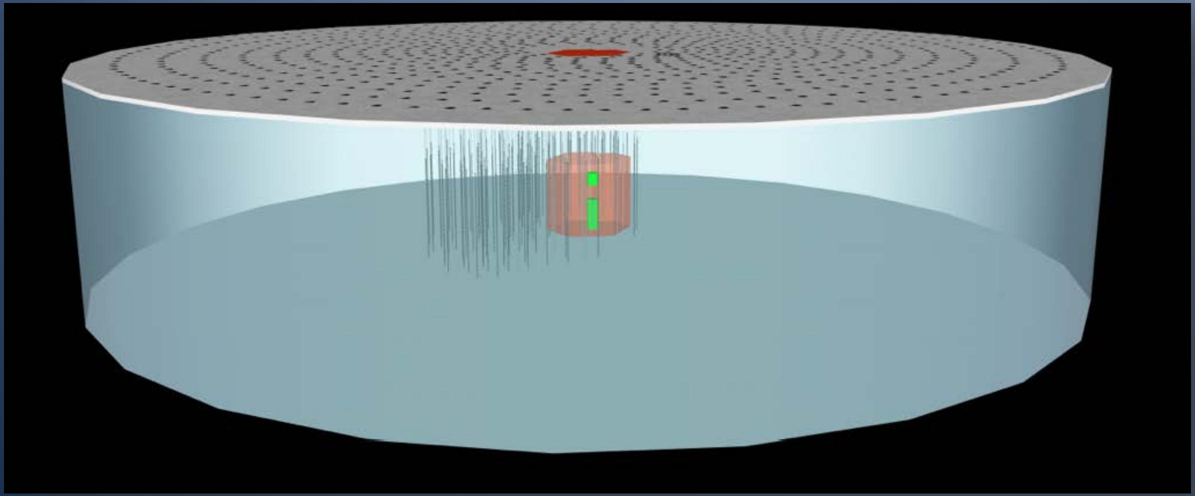
arxiv: 1607.02672

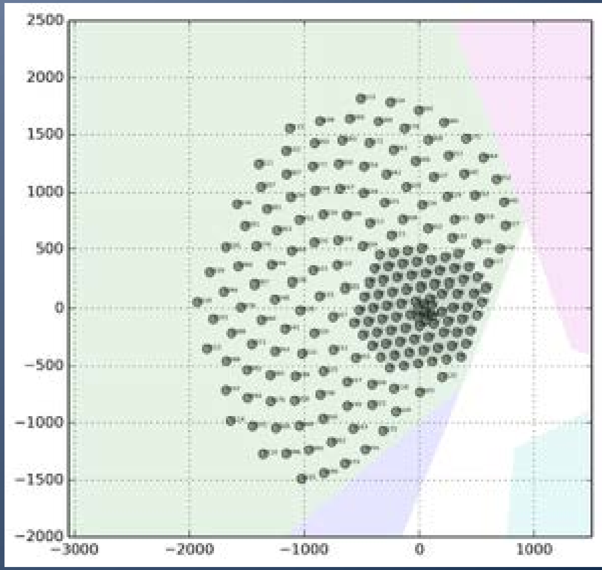


- 26 strings
- 192 DOMs per string
- 24 m horizontal spacing
- 1.5 m floor spacing
- Less holes to drill similar performance than proposal in arxiv:1401.2046
- Five years from construction start to detector completion

IceCube-Gen2

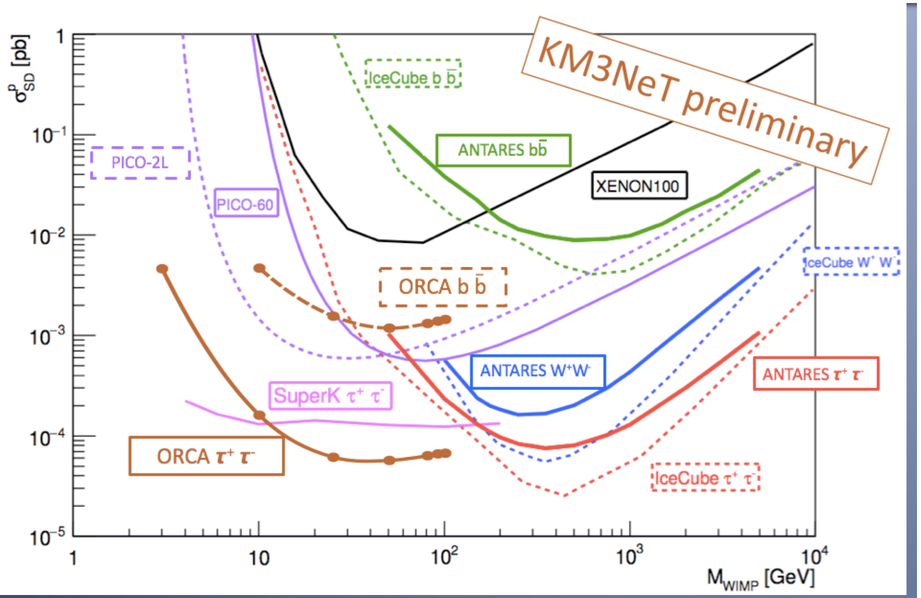
- Interline space: 240 m
- Size: 7 km^3
- End construction by 2031

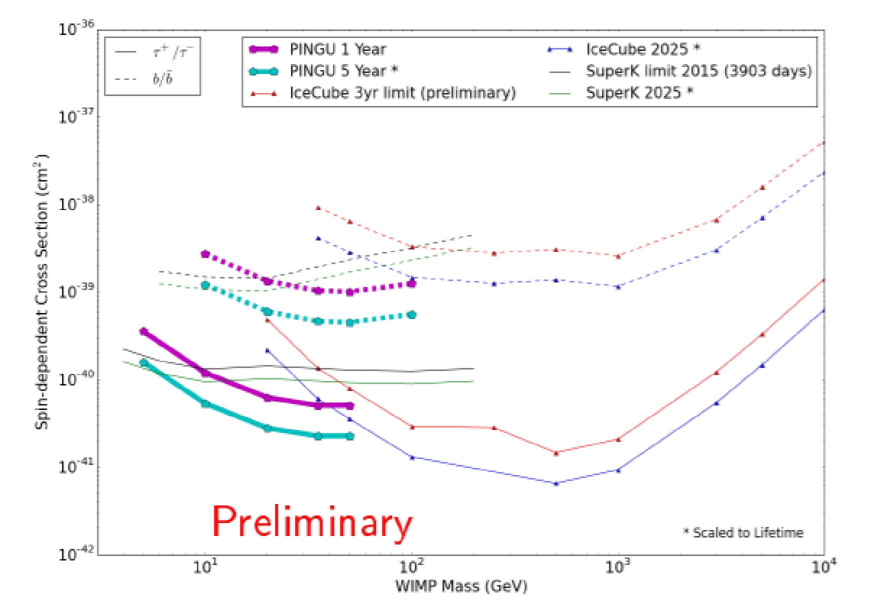




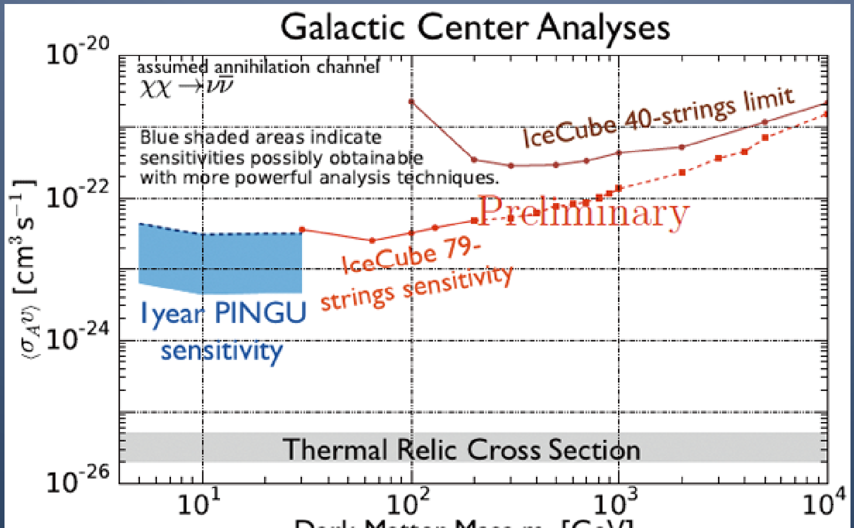
The future

Sun

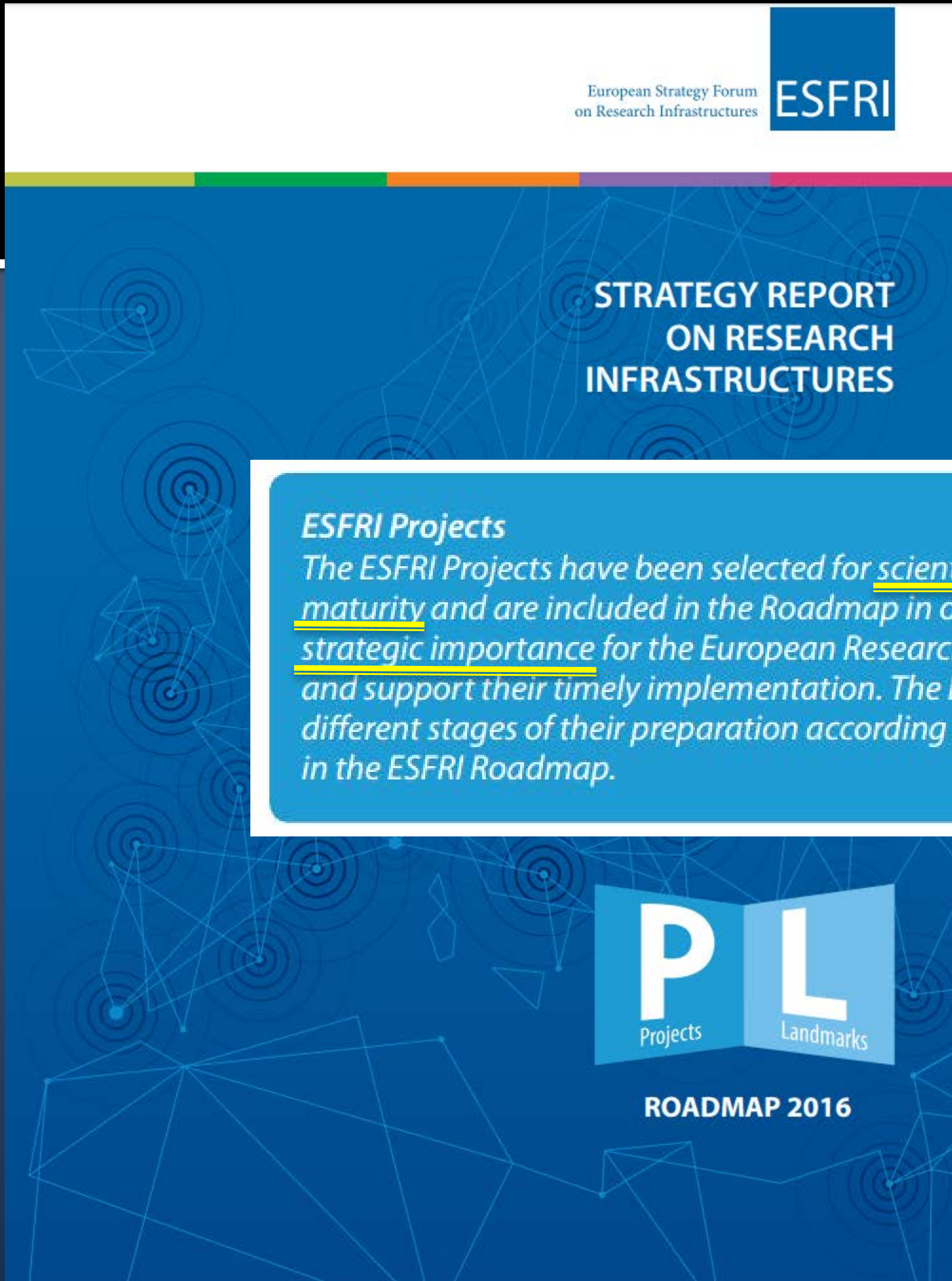




GC



KM3NeT in the ESFRI list



ESFRI Projects

The ESFRI Projects have been selected for scientific excellence and maturity and are included in the Roadmap in order to underline their strategic importance for the European Research Infrastructure system and support their timely implementation. The ESFRI Projects can be at different stages of their preparation according to the date of inclusion in the ESFRI Roadmap.

KM3NeT 2.0

KM3 Neutrino Telescope 2.0: Astroparticle & Oscillations Research with Cosmics in the Abyss

A network of neutrino telescopes in the Mediterranean Sea for astroparticle and oscillations research

Description

typical energies observed in cosmic rays. Neutrinos are ideal for observing the highest-energy phenomena in the Universe and, in particular, pinpointing the hitherto unknown sources of cosmic rays.

The IceCube neutrino telescope at the South Pole has detected a flux of cosmic neutrinos which is assumed to have its origin in extragalactic sources. They might be the same sources that produce the flux of the highest energy gamma rays observed, for instance, by H.E.S.S.

the first time. The phase one of the project has led to the engineering of the modular detector and to construction of the final prototypes. The resubmission of KM3NeT 2.0 redefines the previous project and adopts it to the scientific and technological progress which has been made in the last years. It is effectively under construction as a first set of the new detectors is being deployed at this time.

TYPE: distributed
COORDINATING COUNTRIES: NL
PROSPECTIVE MEMBER COUNTRIES: EL, FR, IT, NL

PARTICIPANTS: CY, DE, ES, IE, PL, RO, UK

TIMELINE
- ESFRI Roadmap entry: 2006, 2016
- Preparation phase: 2008-2014
- Construction phase: 2016-2020
- Operation start: 2020

ESTIMATED COSTS
- Capital value: 137 M€
- Preparation: 45 M€
- Construction: 92 M€
- Operation: 3 M€/year

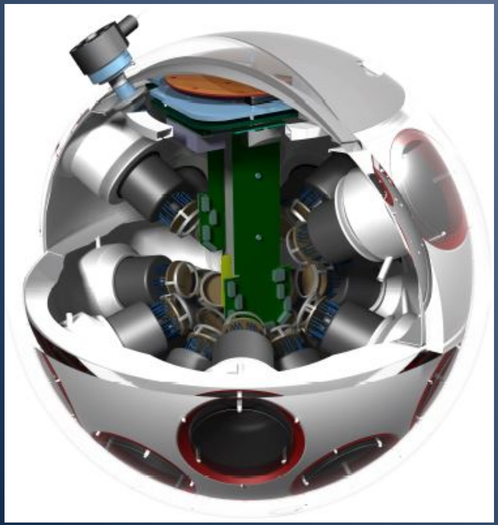
HEADQUARTERS
KM3NeT-HQ
Amsterdam Science Park
Amsterdam
The Netherlands

WEBSITE
http://www.km3net.org/

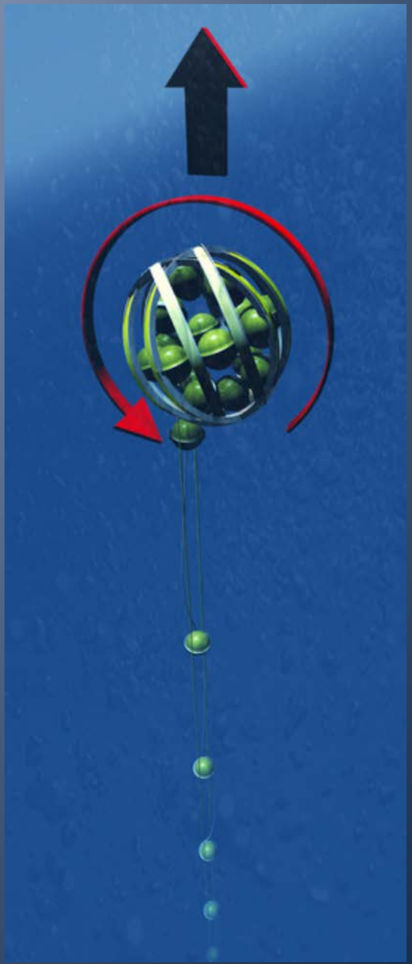
THE NETHERLANDS

51

KM3NeT Optical Modules

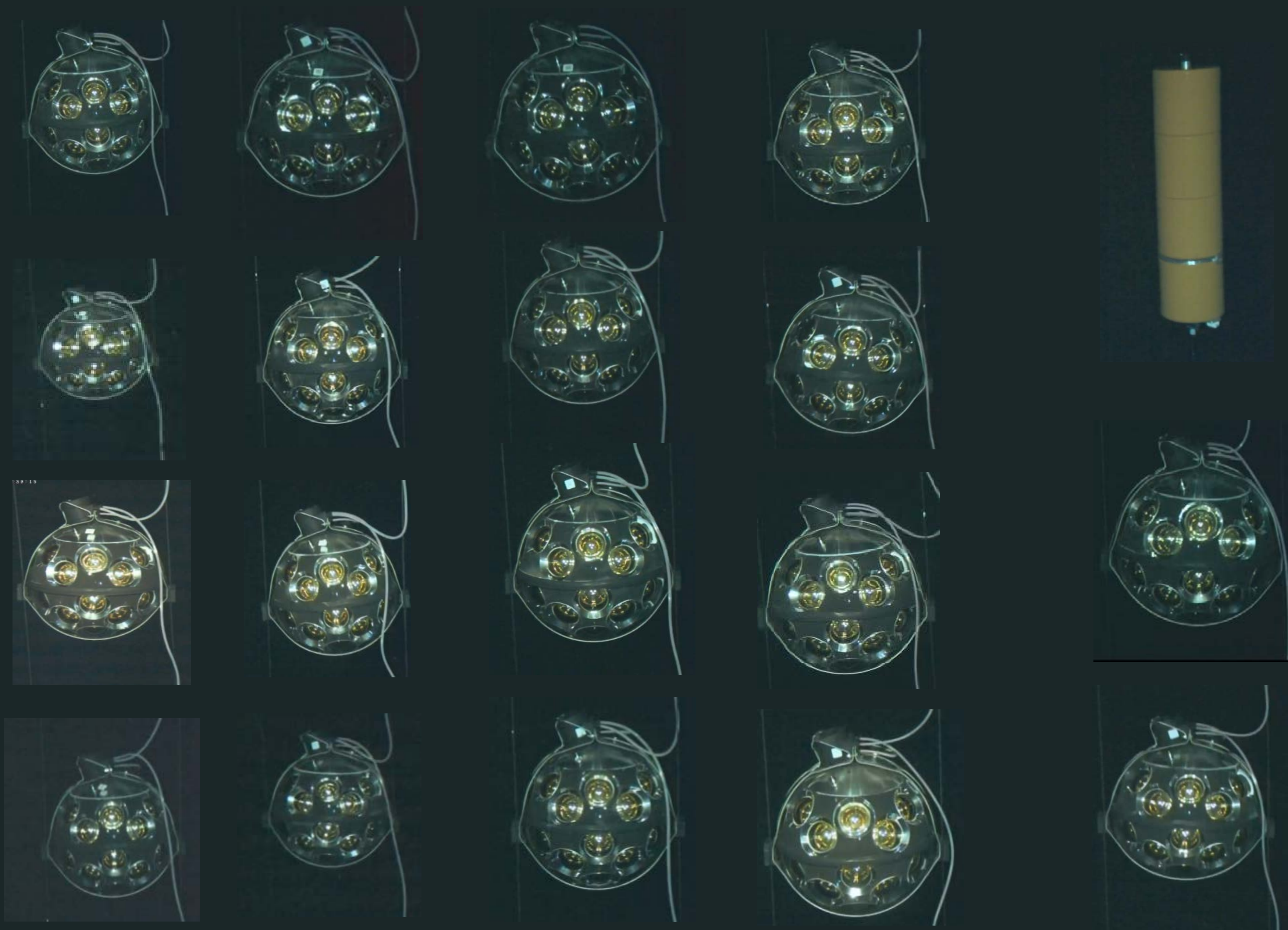


- (Multi-PMT) Optical Module
  - 31 x 3" PMTs
  - diameter: 17''
  - low power requirements
  - "full" module: no additional electronics vessel needed
  - uniform angular coverage
  - information of the arrival direction of photons
  - better rejection of background
- Detector Units (strings)
  - 18 DOMs, separated vertically by: 6 m (ORCA) or 36 m (ARCA)
  - anchored at sea floor by a dead weight
  - kept vertical by buoys
  - 115 DUs = 1 building block

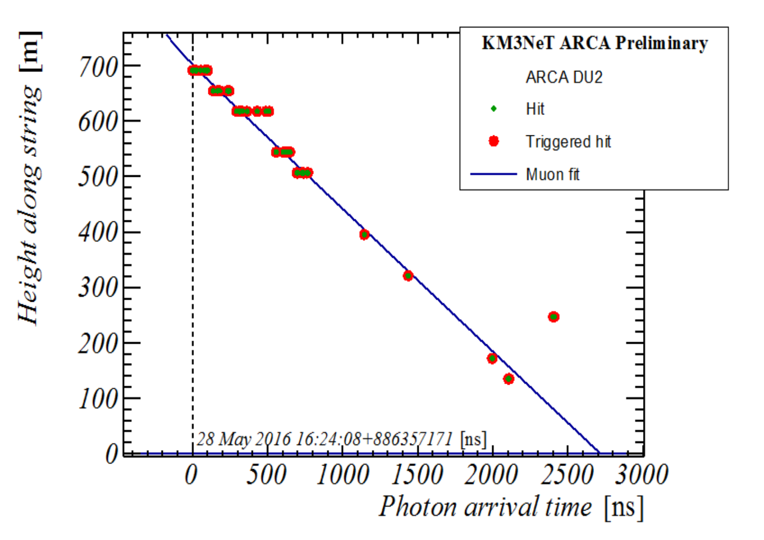


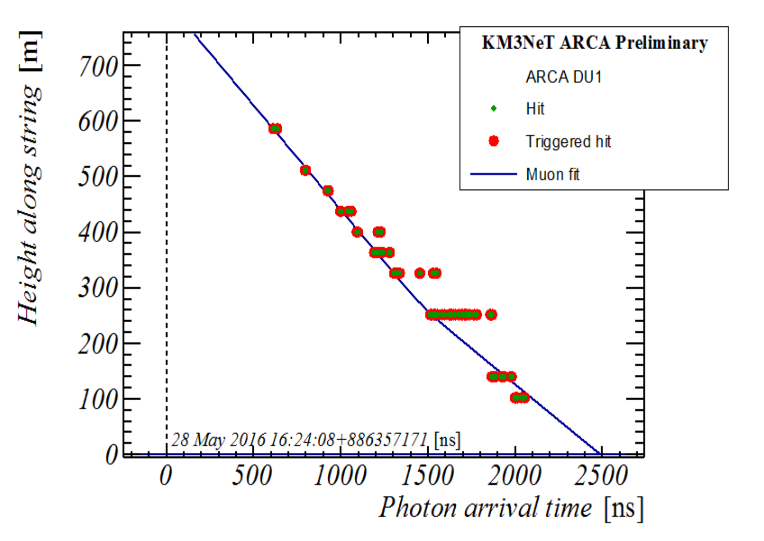
First KM3NeT line in situ

P. Coyle, Neutrino 16



Two-line events





Summary

- Dark matter is one of the major questions in Physics nowadays
- To find unambiguous evidence of its detection requires multi-front attack
- Neutrino telescopes have specific advantages
  - Sun: free of astrophysical background and probe of low velocities
- ANTARES/KM3NeT specific advantages:
  - Better angular resolution
  - Better visibility of the GC
- A promising future is being built (ORCA) or planned (PINGU, Hyper-K)

Backup

Astrophysical uncertainties