2nd “Low-Energy” Neutrino Workshop
(PSU July 1-2, 2010)

DeepCore and Galactic Center Dark Matter

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Overview

- Motivation
- Probing for Dark Matter with Neutrinos
  - What makes neutrinos special ?
  - How big can the dark matter self-annihilation cross section be ?
    - What can IceCube say ?
    - Prospects for Deep Core ?
- Conclusions

Motivation


1E 0657-56 - Bullet Cluster
D. Clowe et al., astro-ph/0608407, AJ 648 (2006) L109-113

Strategies for WIMP Detection

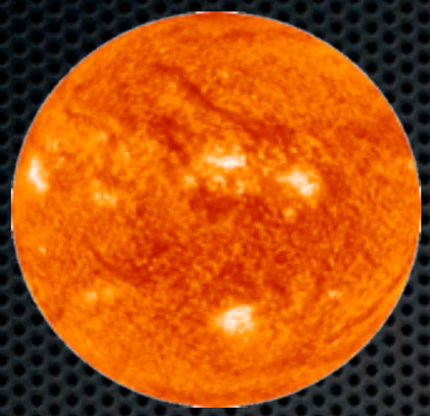
- Direct Detection
  - Recoil effects - WIMP scattering of nucleons
- Indirect Detection
  - Neutrinos – annihilation signals from WIMPs accumulated in the Sun or Earth
  - Photons, Neutrinos – Milky Way Halo, Cosmic Flux, …
  - Anti-matter (e+,D,pbar) – local neighborhood (few kpc)
- Production
  - LHC, Tevatron, ILC, …

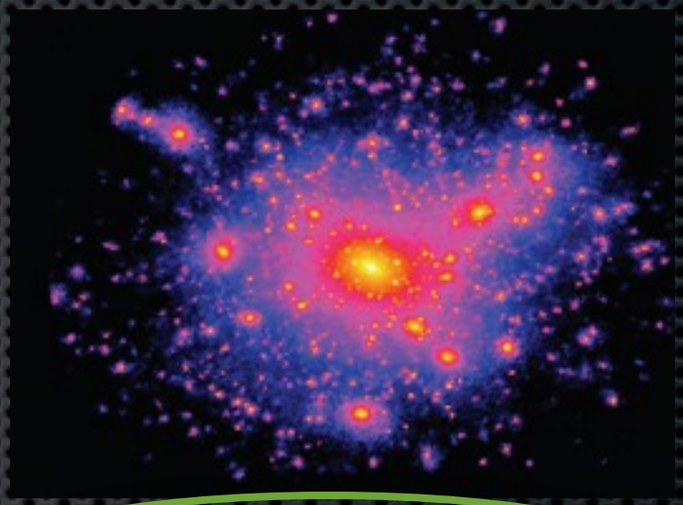
WIMP-Nucleon Scattering cross-section

WIMP Self-annihilation cross-section

see previous talks from Matthias Danniger and Erik Strahler for details on Solar WIMPs

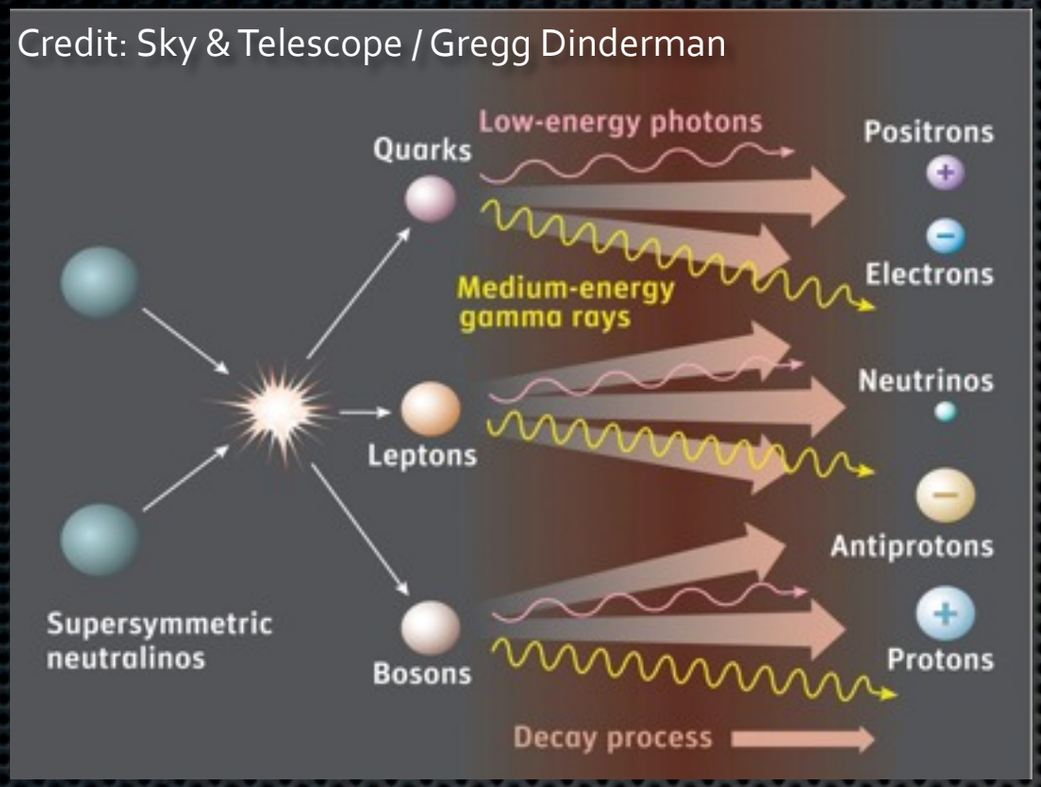
Neutrino Dark Matter Searches

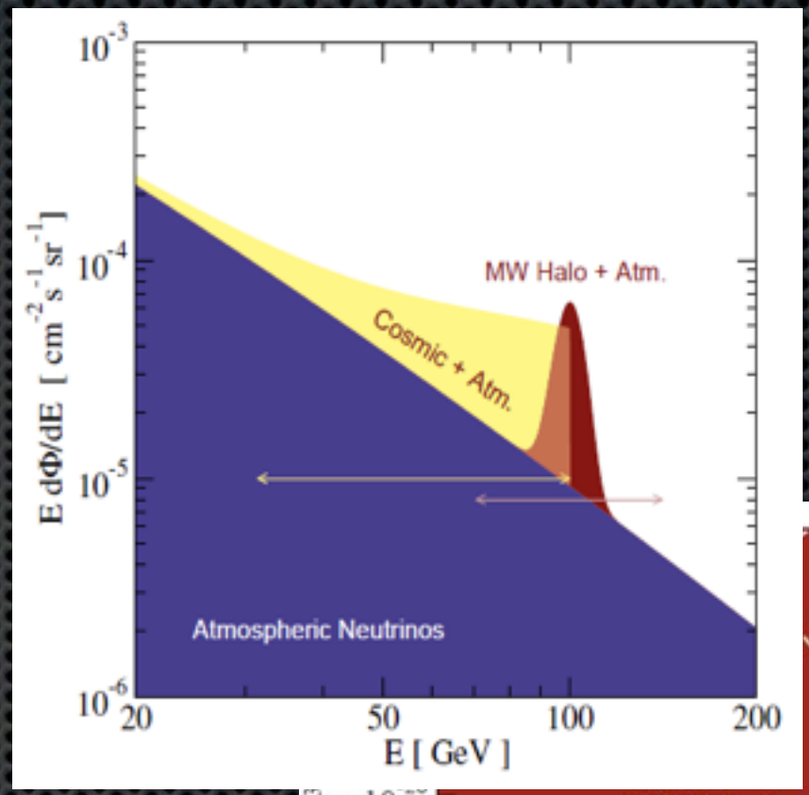


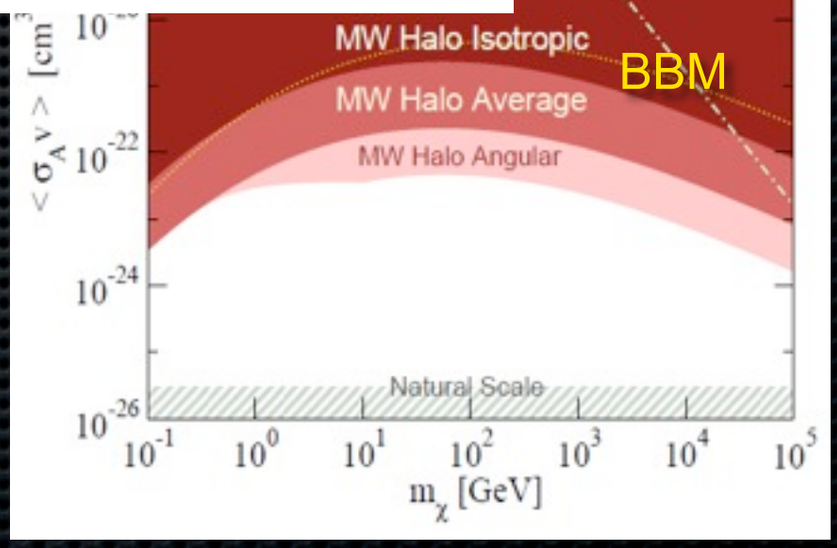


Solar	Earth	Halo
Scattering cross section (Neutrino Flux)		Self-annihilation cross section
Muon neutrinos	Muon neutrinos	All Flavors
Tracks	Tracks	Tracks, Cascades
E_ν<1TeV		
Background on/off-source / simulations	Background simulations	Background on/off source / simulations
M_{WIMP}~<TeV	M_{WIMP}~<100GeVTeV	All M_{WIMP}

Dark Matter self-annihilation products and theoretical constraints



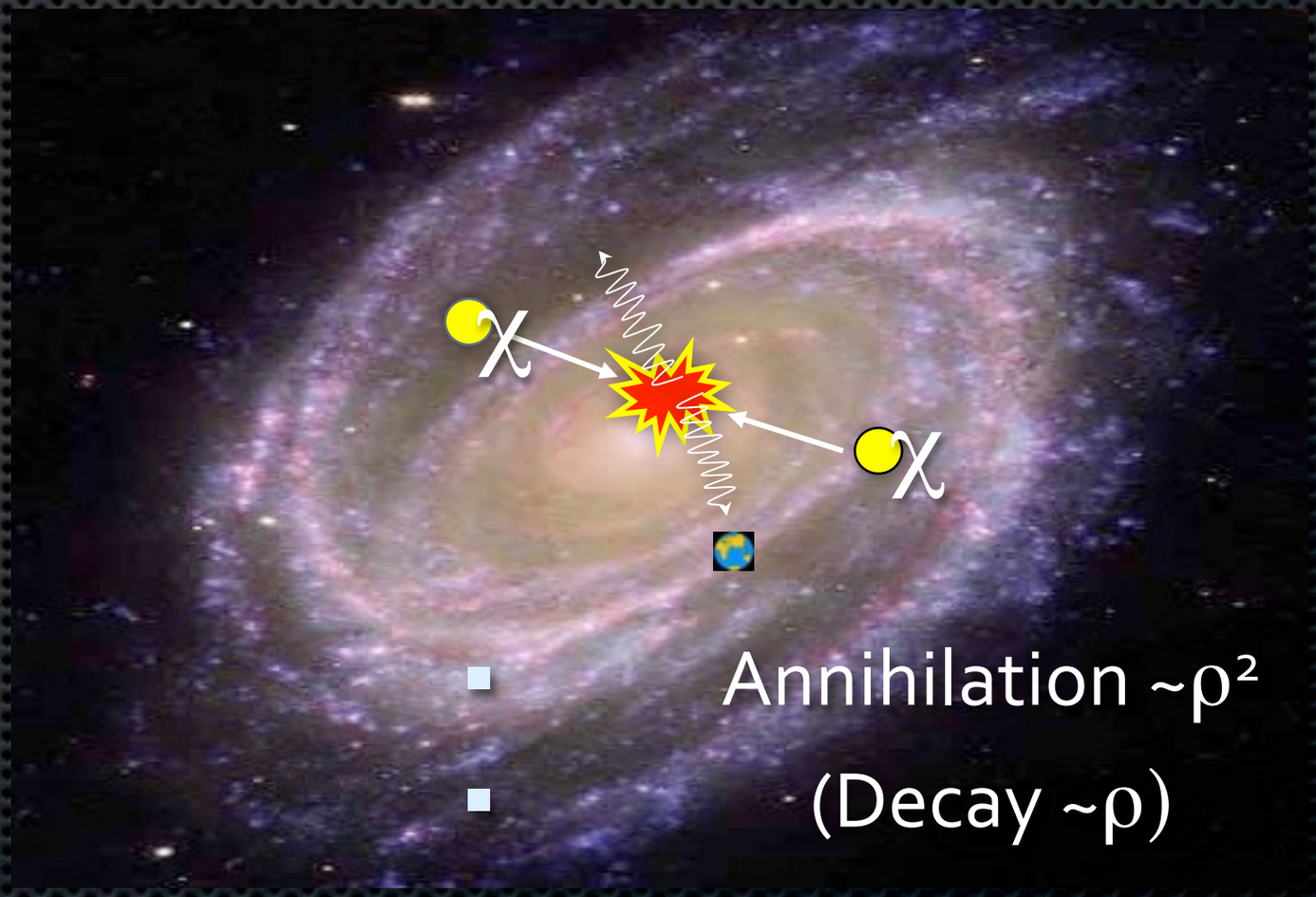




- Variety of particles generated in annihilation process
- Neutrinos are least detectable messenger -> conservative upper limit on total $\langle \sigma_A v \rangle$
- Smoking gun: Observed particle spectra may show feature at $E=M_{WIMP}$
- MilkyWay better than cosmic signal

Yuksel, Horiuchi, Beacom, Ando (2007)
Beacom, Bell, Mack (2008)

Galactic Halo WIMPs



- Annihilation ~ρ^2
- (Decay ~ρ)

Halo Profiles

J. Einasto, Trudy Inst. Astroz. Alma-Ata 5, 87 (1965),
Navarro, Frenk, White, *Astrophys. J.* ***490, 493–508 (1997),***
Moore, et al. Mon. Not. Roy. Astron. Soc. 310, 1147 (1999) [arXiv:astro-ph/9903164],
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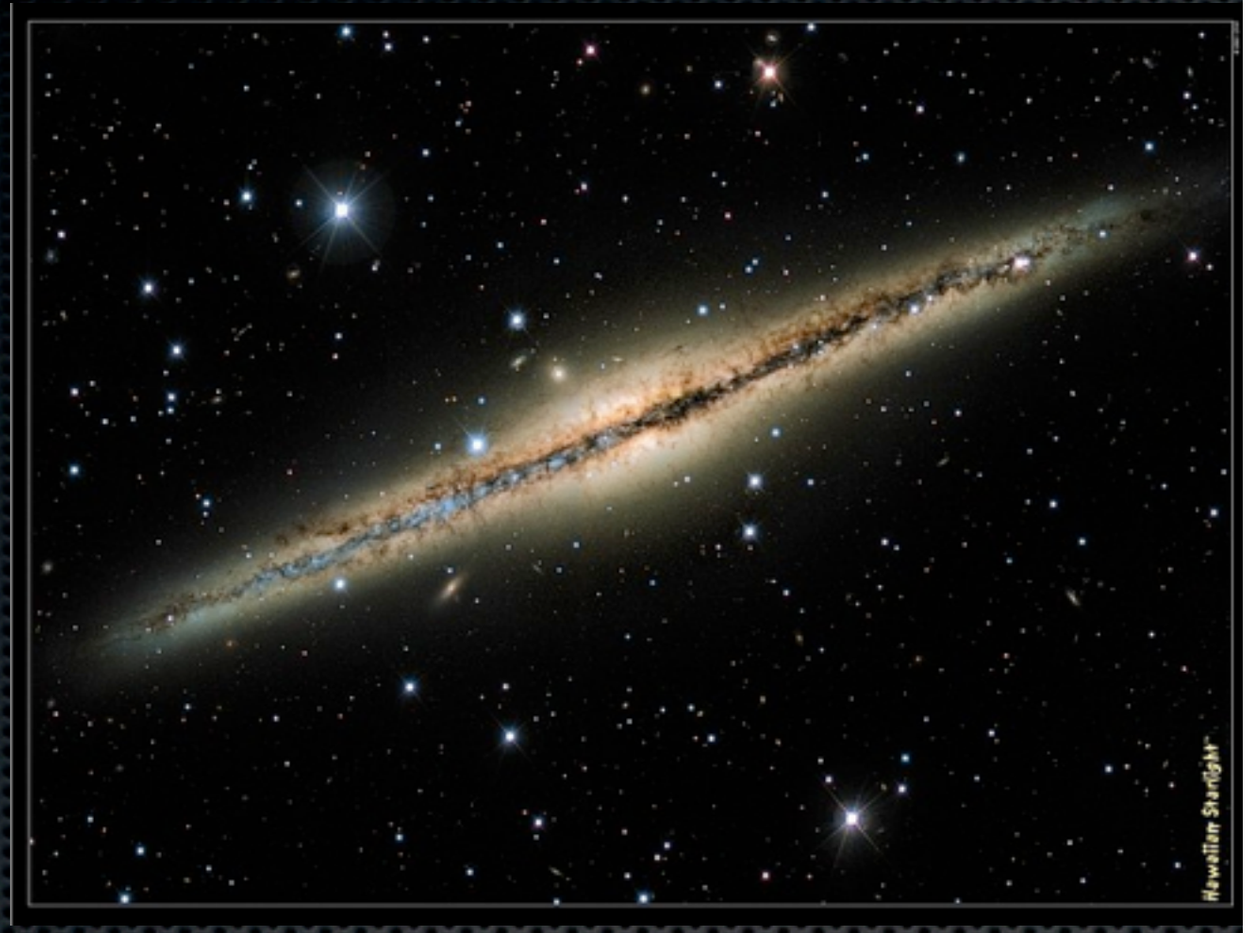

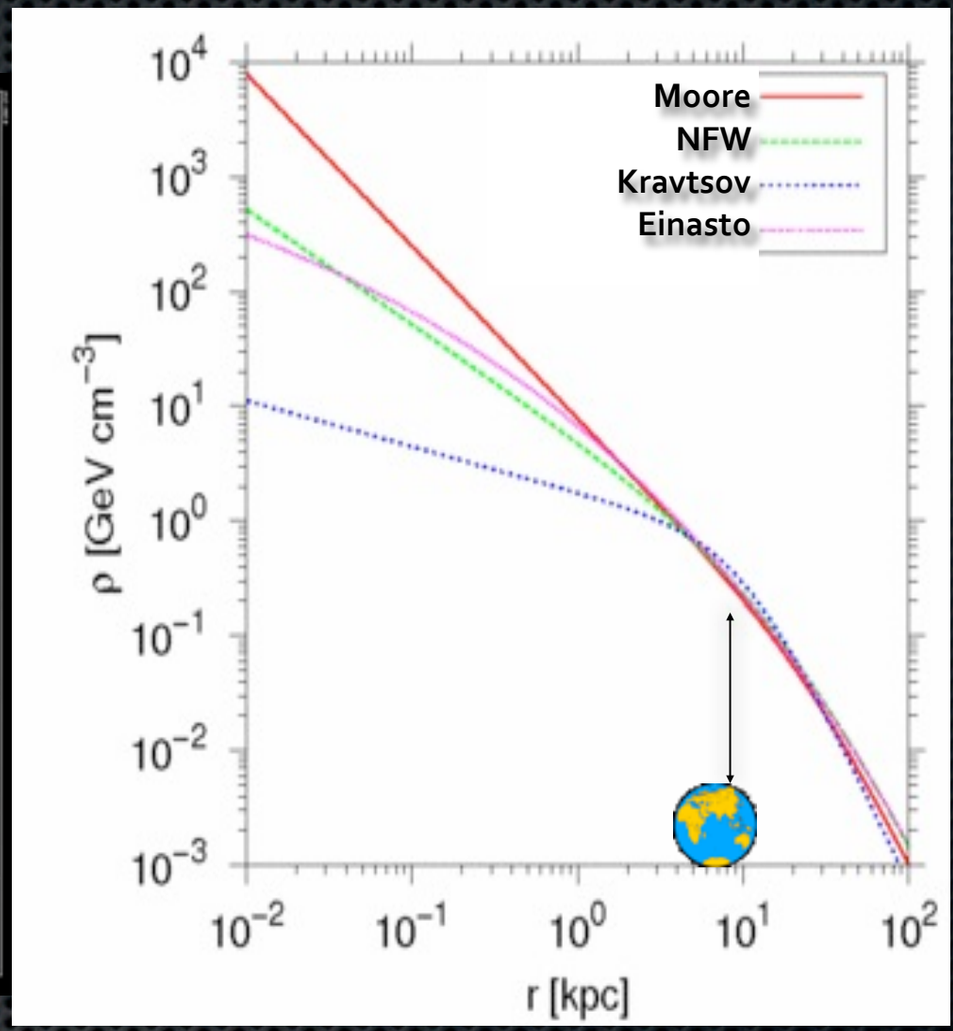

Two IceCube analyses:
1) Search for an anisotropy in the neutrino candidate sample
2) Look at the Galactic Center (down-going events)

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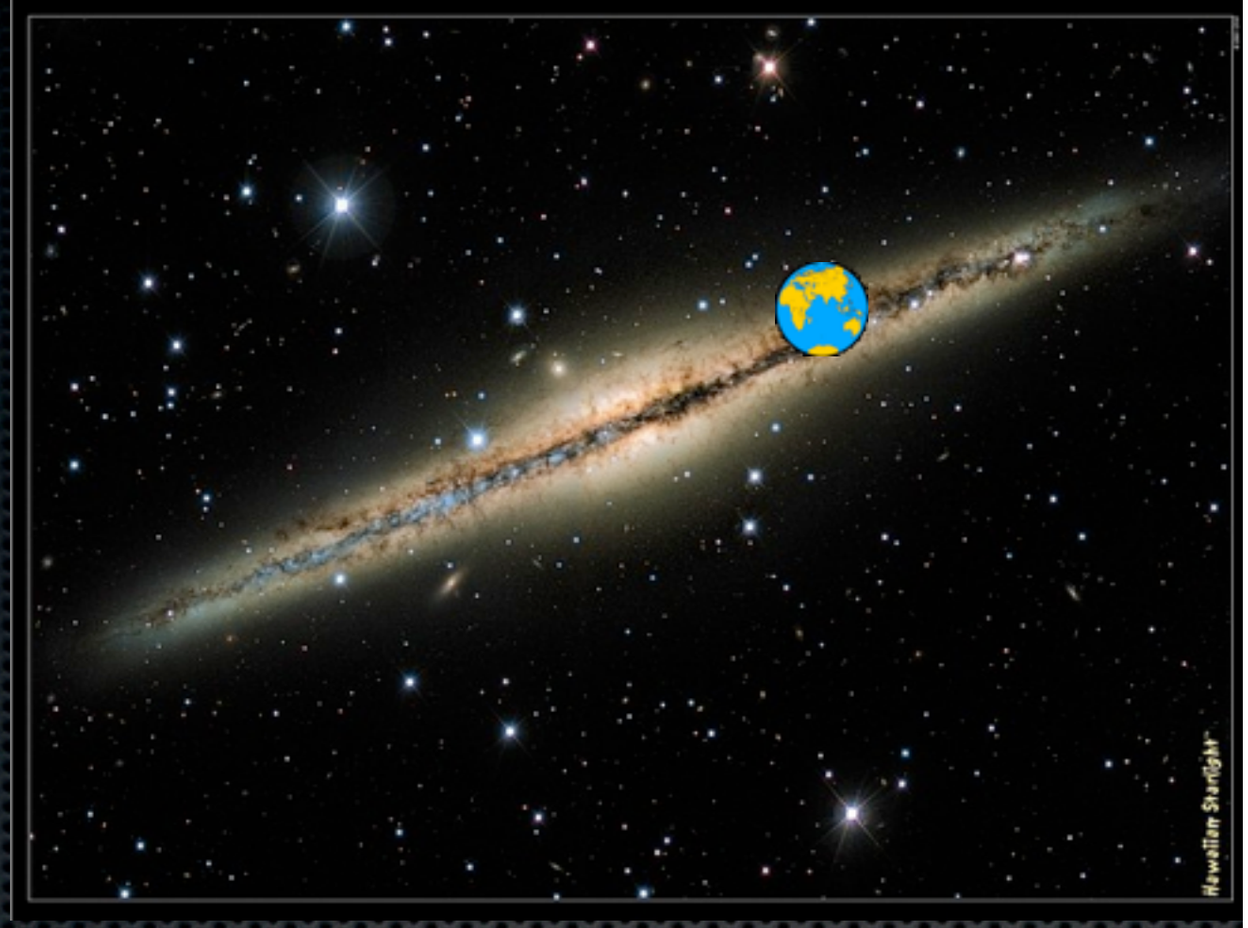

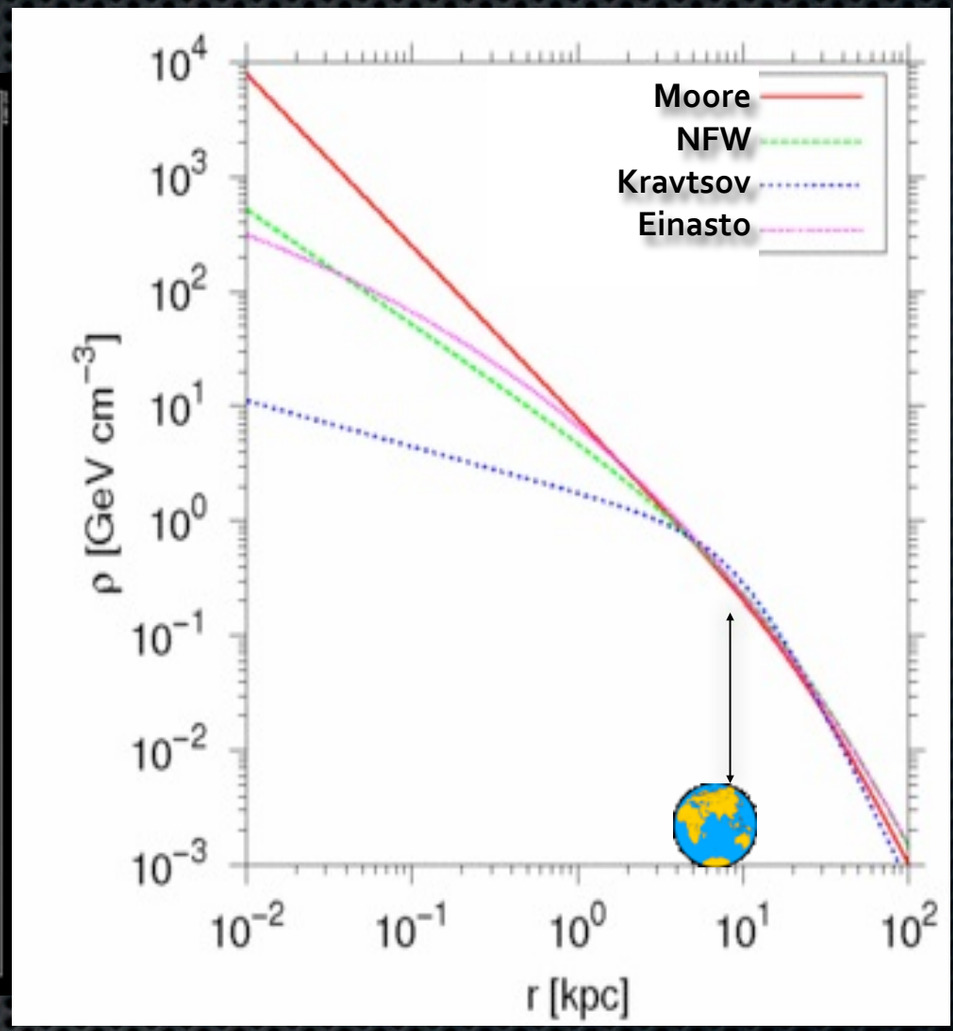

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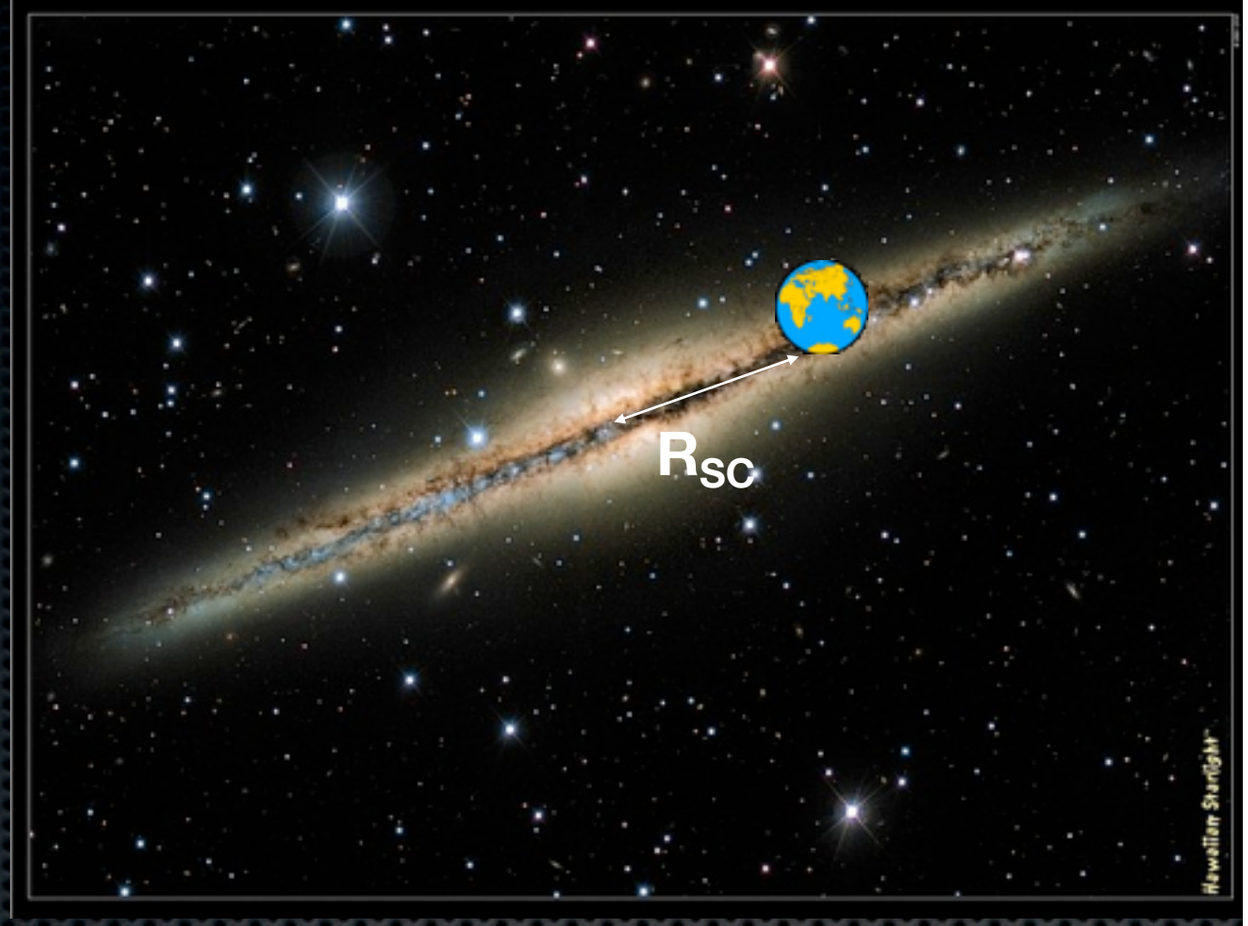

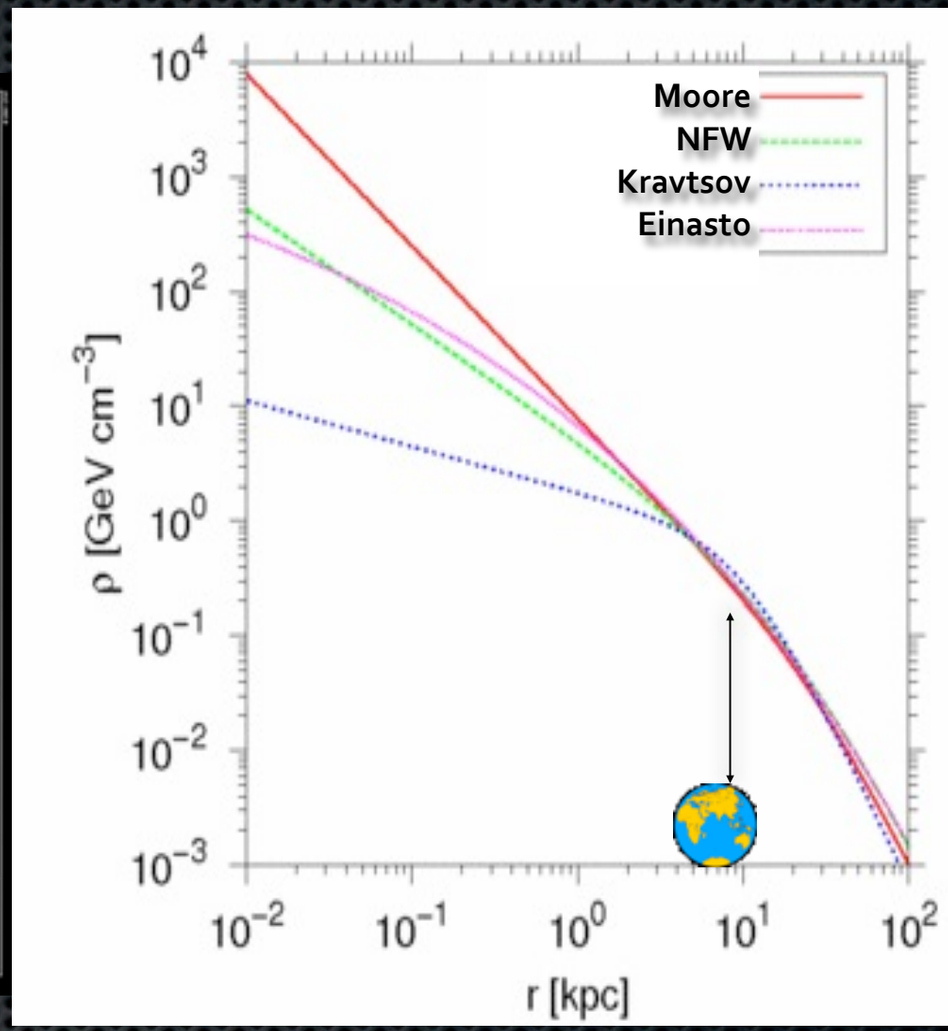

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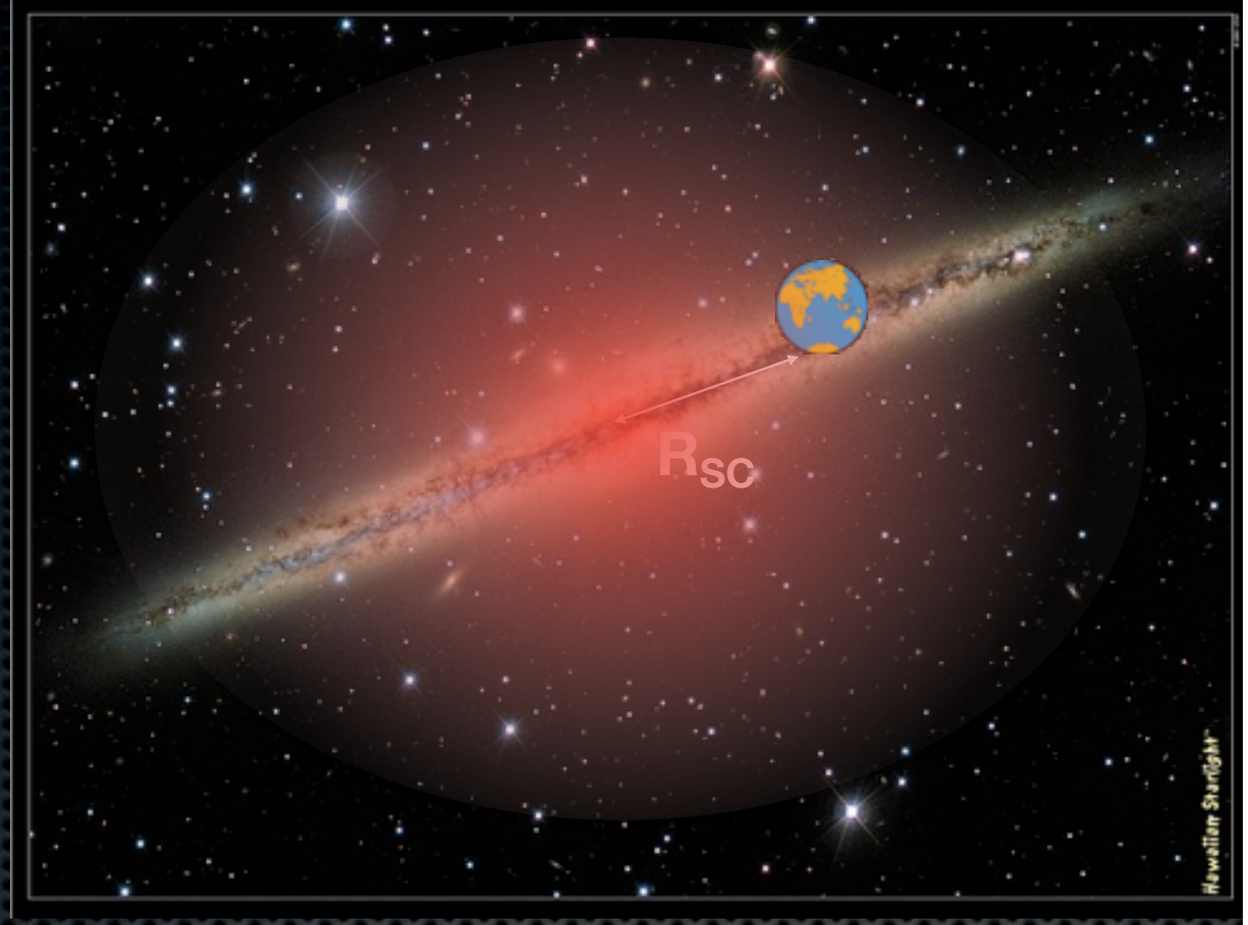

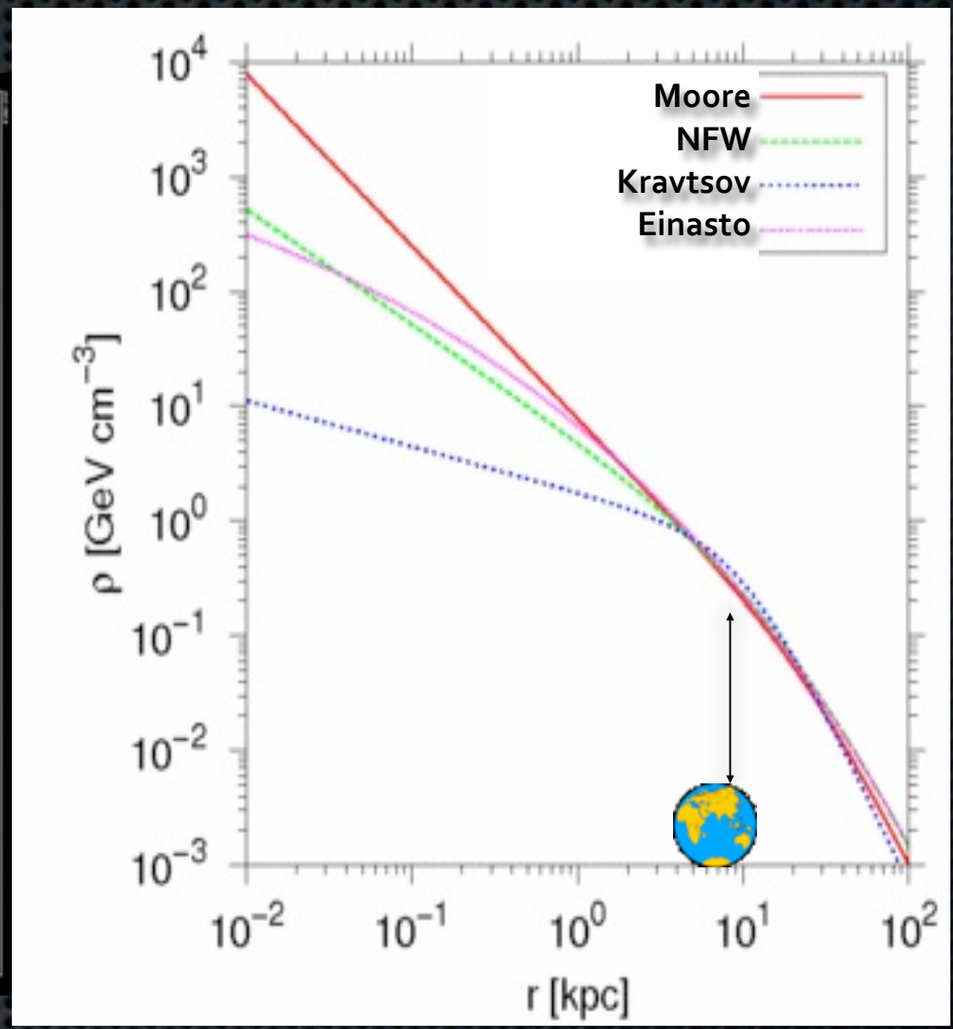

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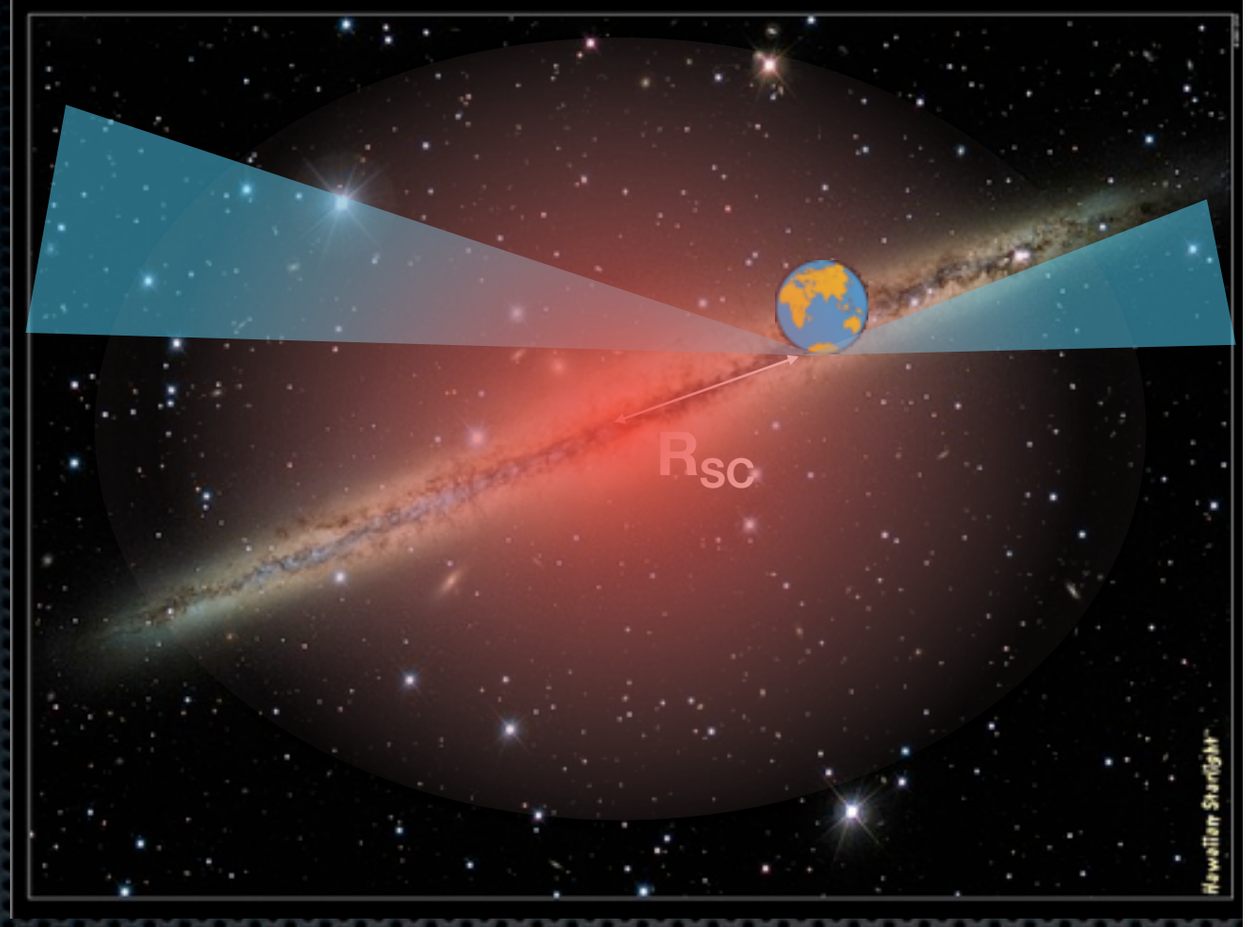

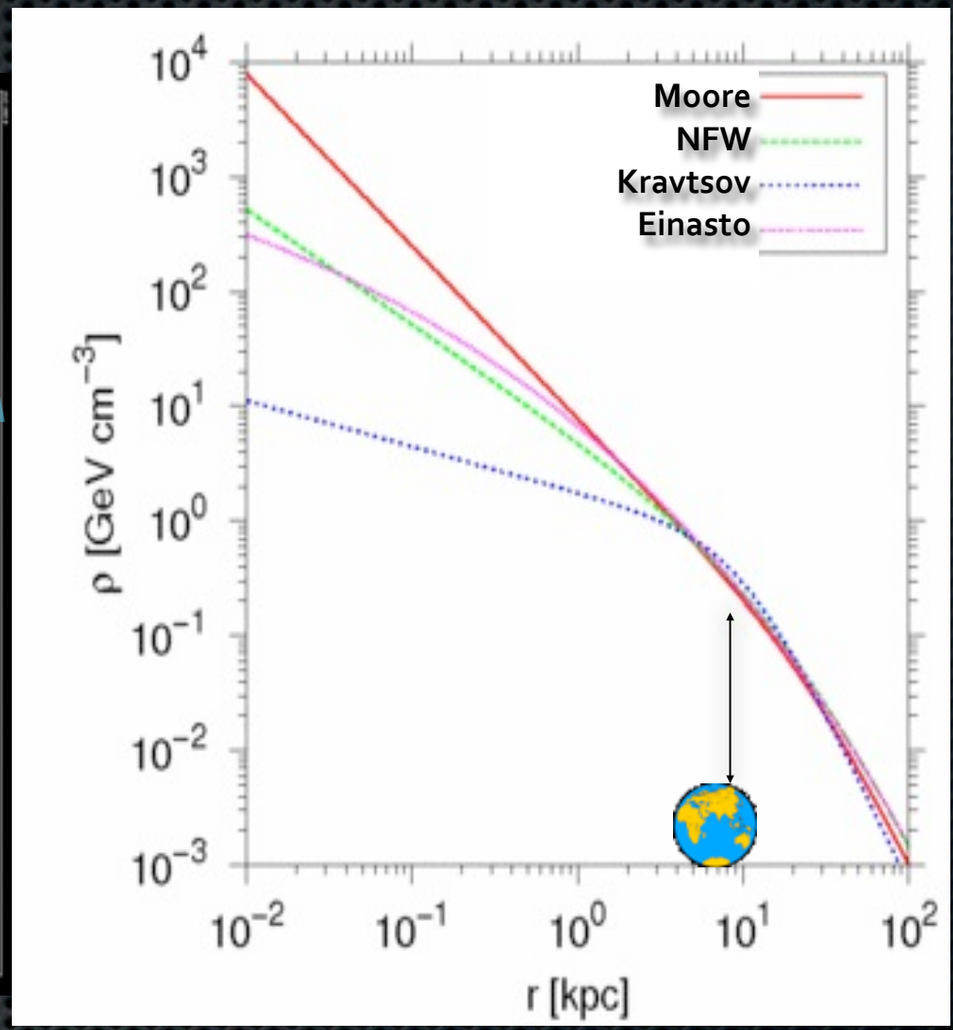

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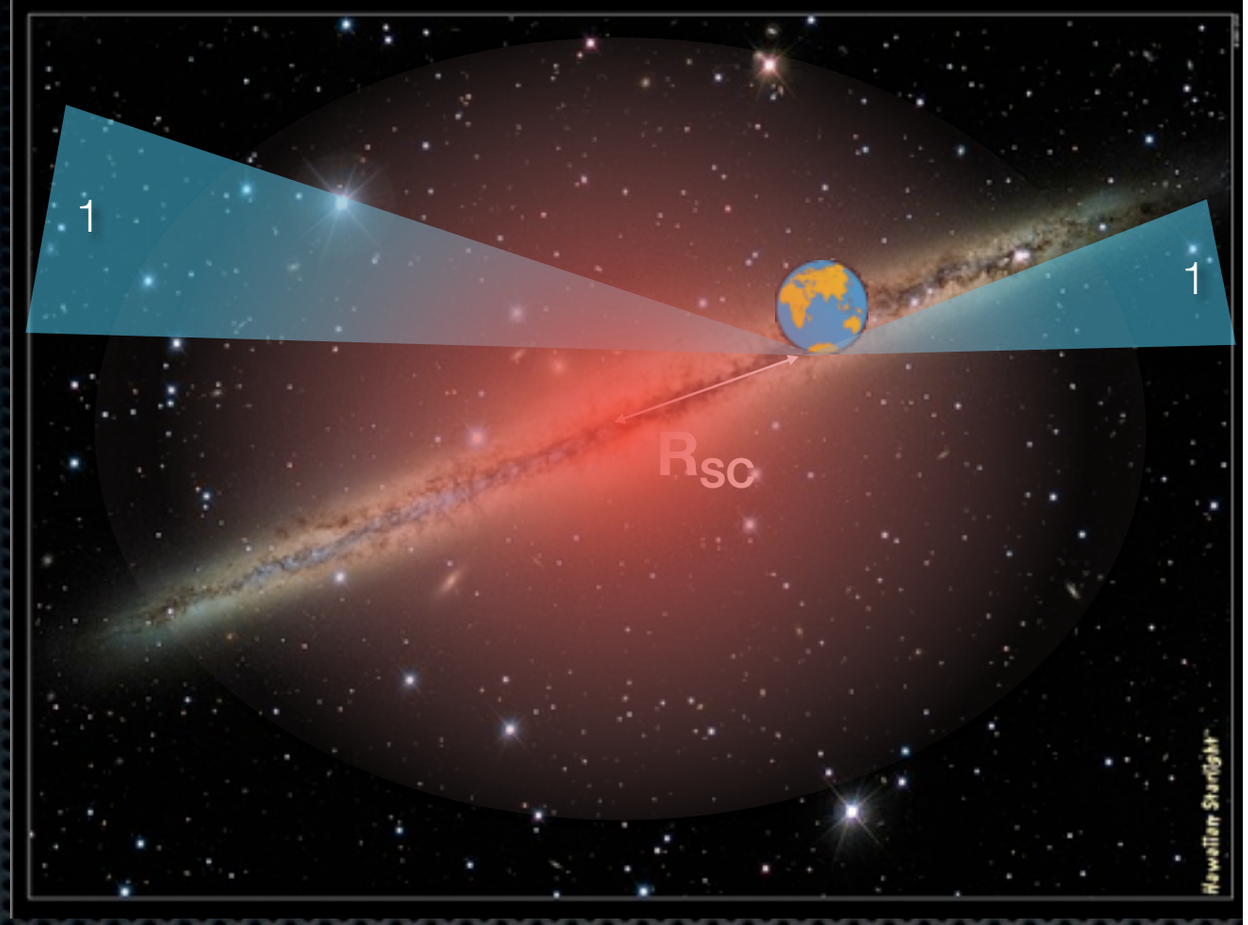

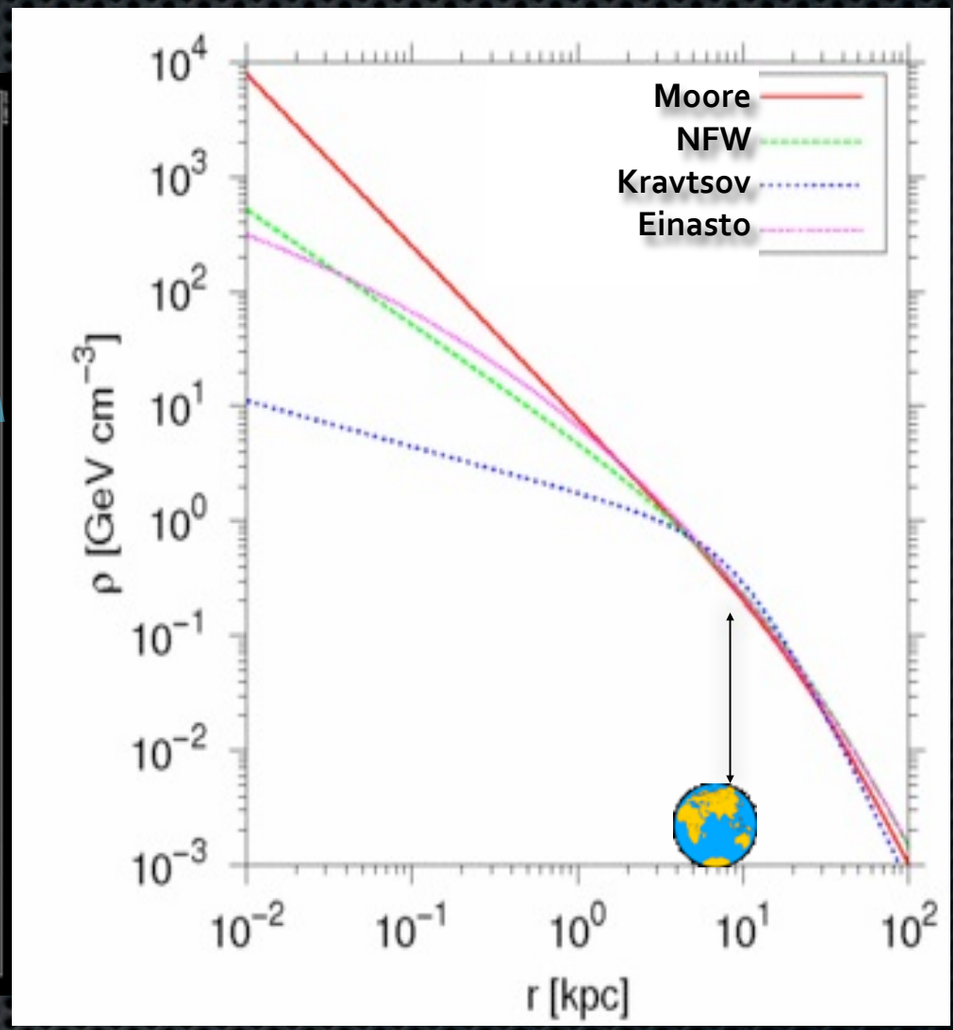

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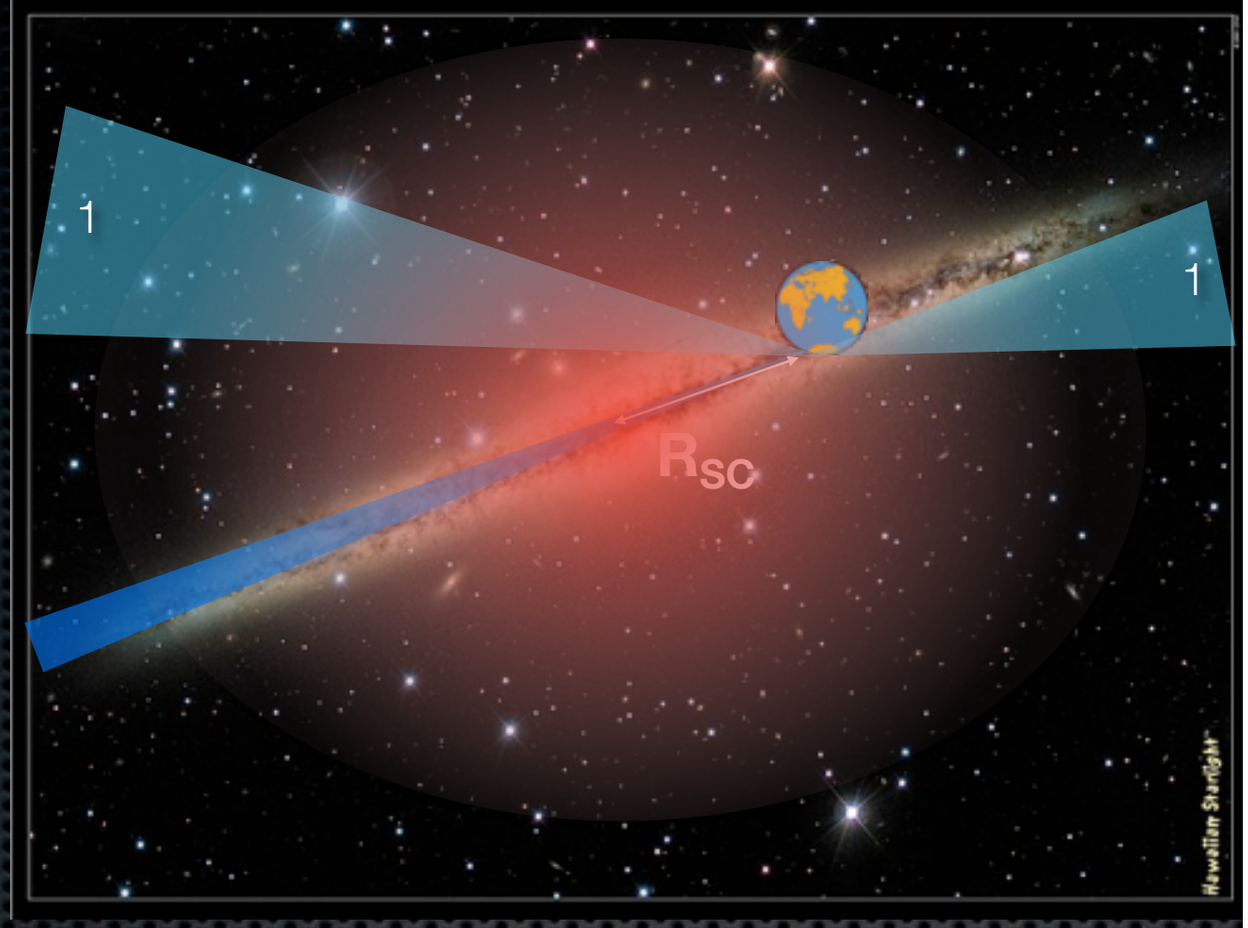

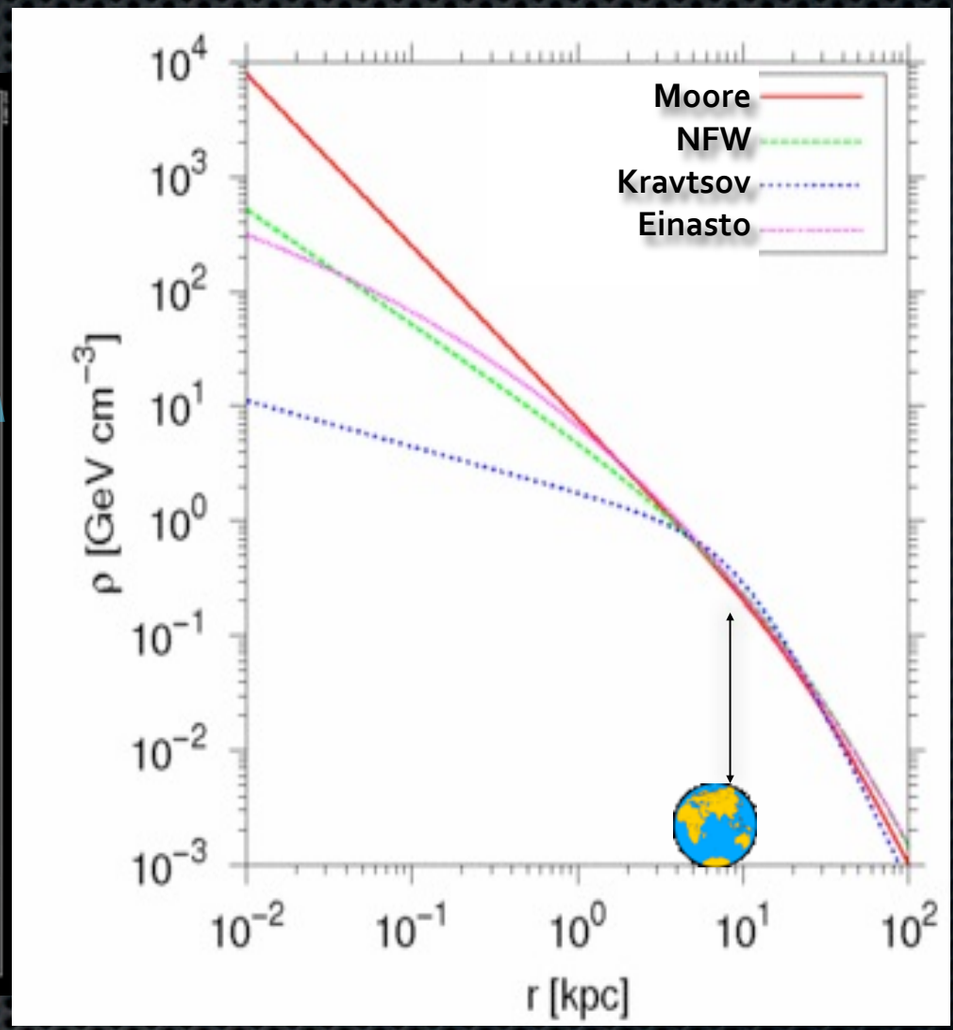

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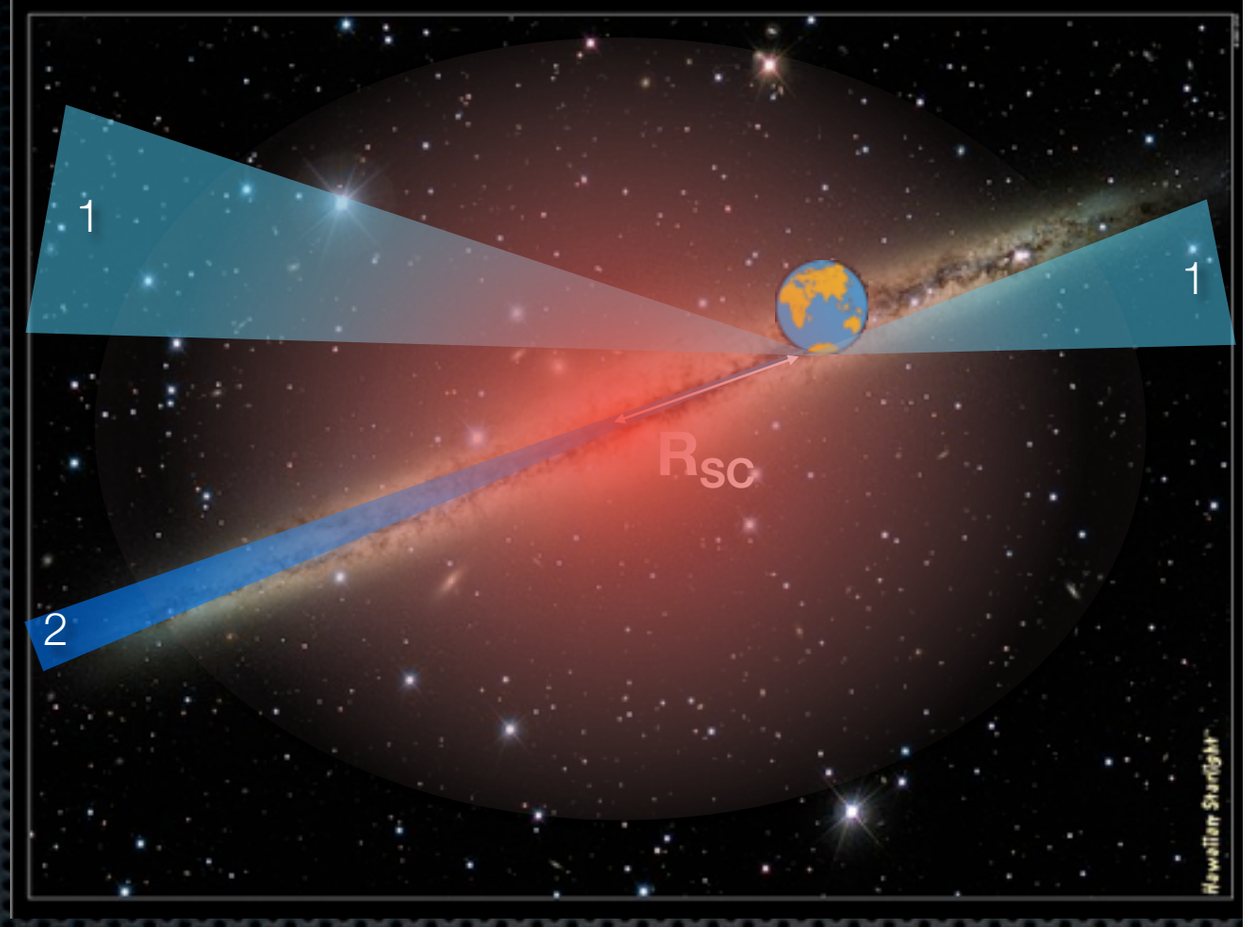

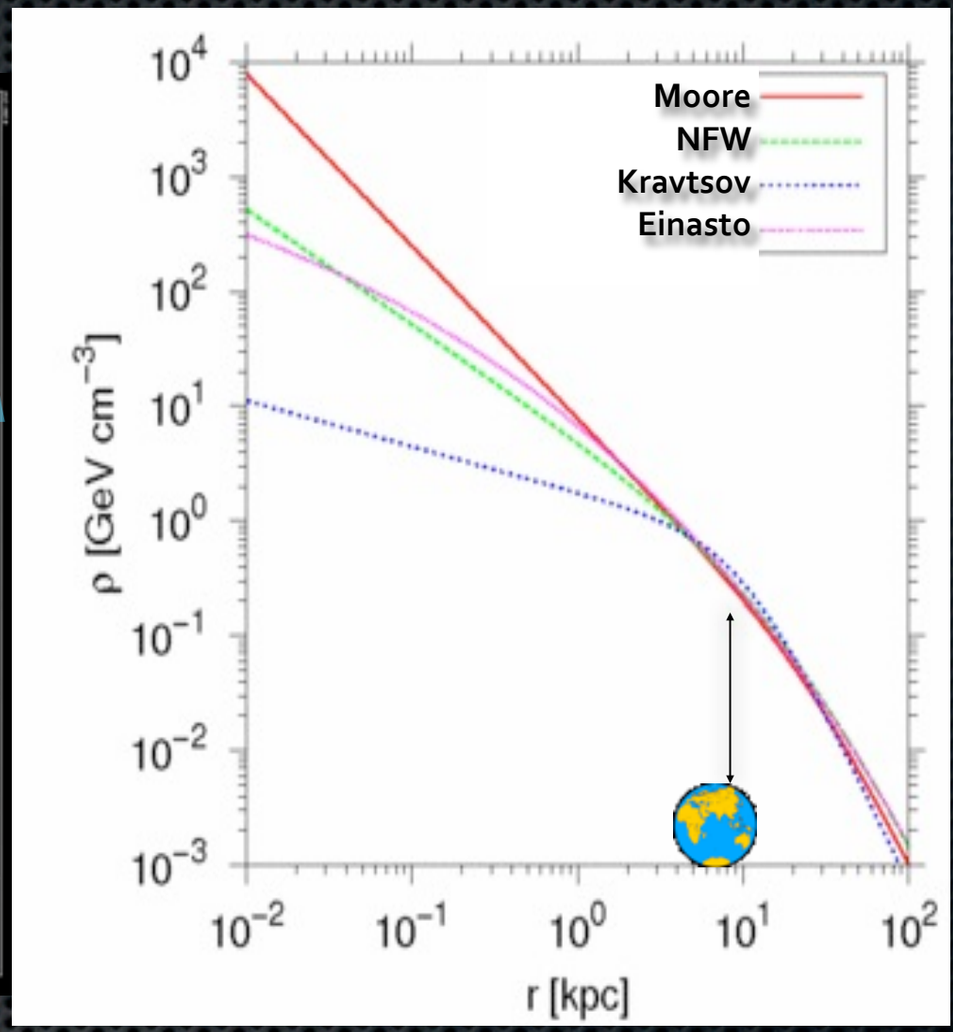

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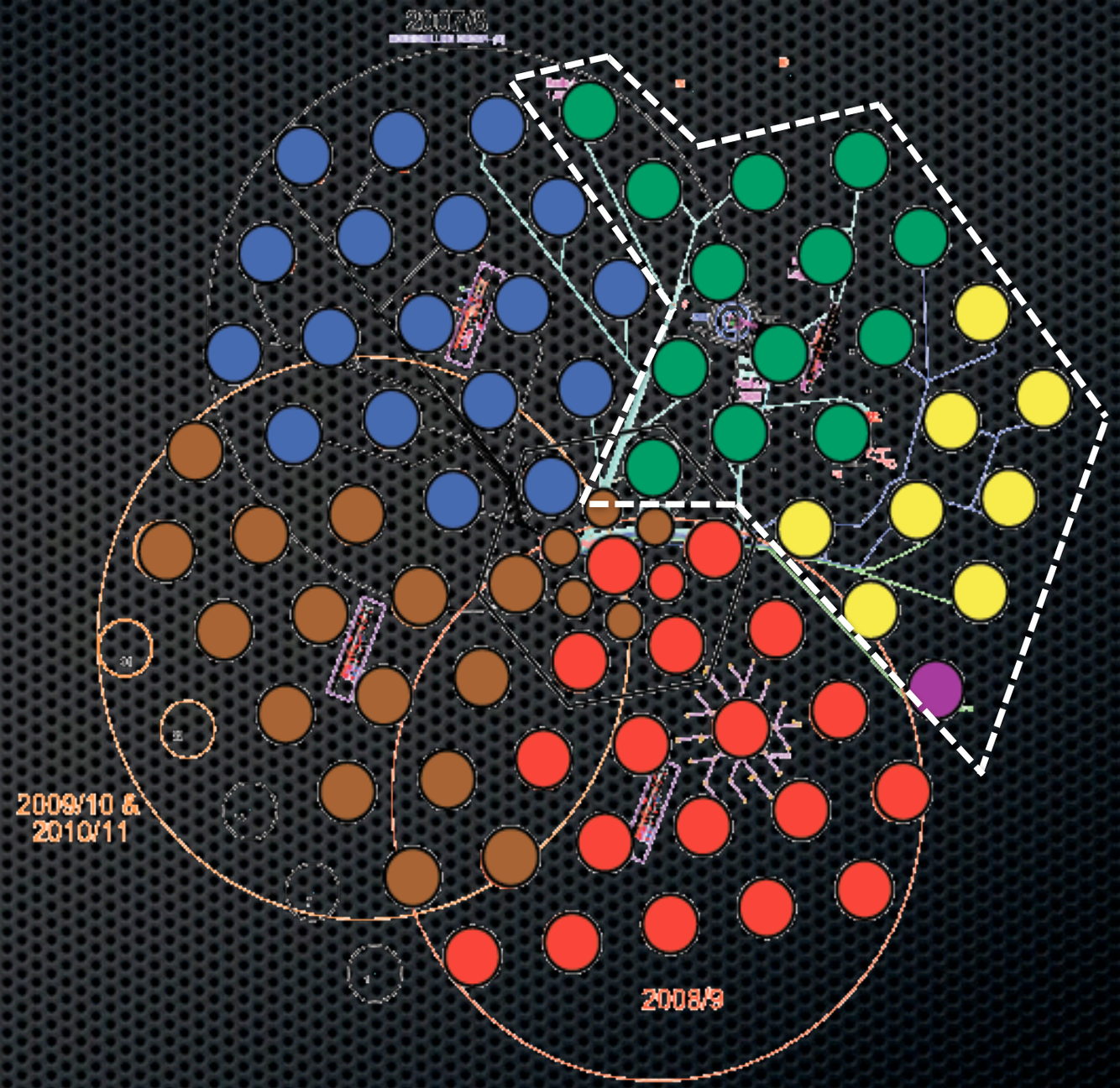
IceCube

Year	Deploy	Total
2004/5	1	1
2005/6	8	9
2006/7	13	22
2007/8	18	40
2008/9	18+1	58+1
2009/10	15+5	73+6



(1) Galactic halo analyses uses the IceCube 22 string detector active 2007-2008

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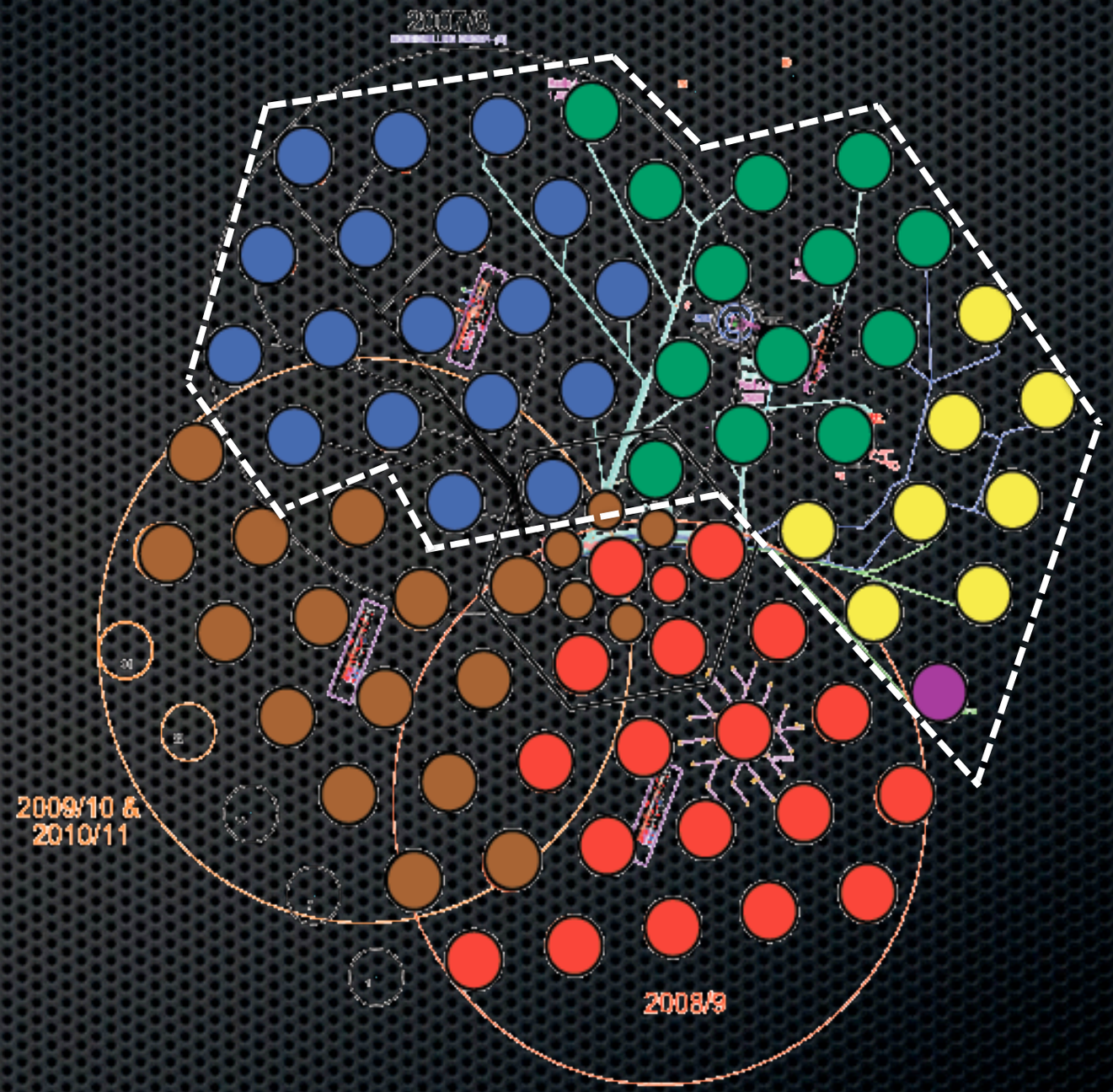


(2) Galactic center analyses uses the IceCube 40 string detector active 2008-2009

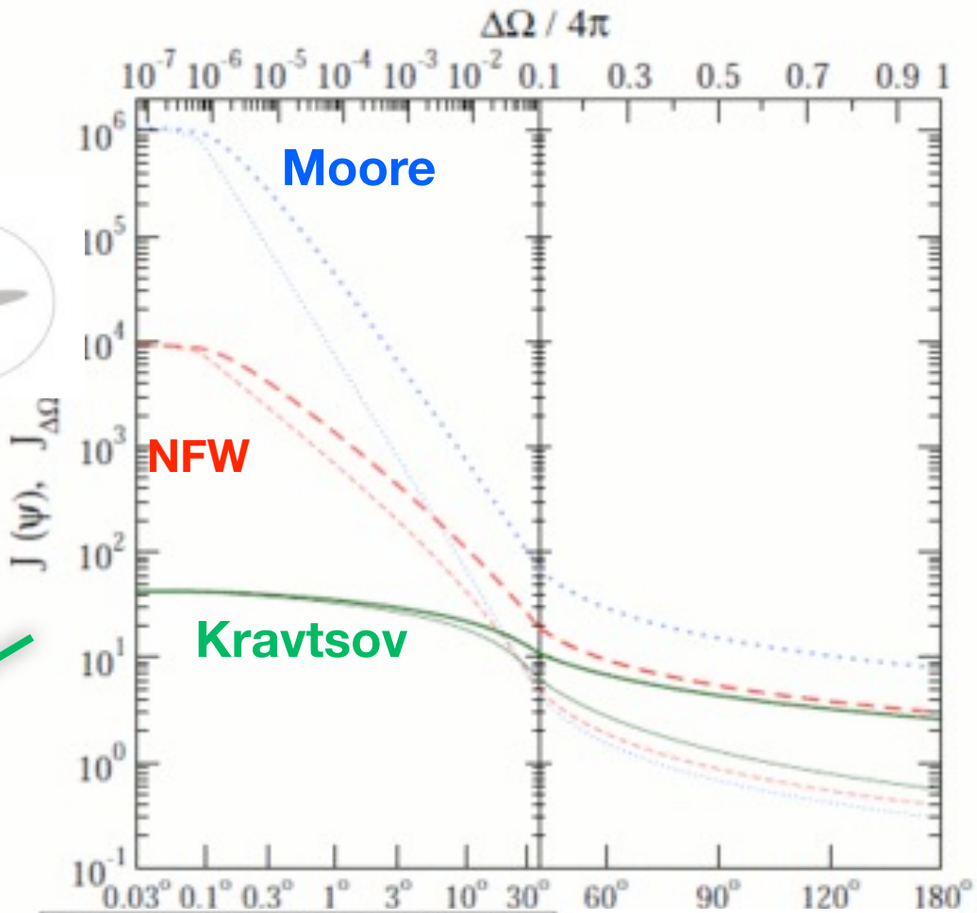
Neutrino Flux from annihilations

Line of sight integral:

$$\ell_{max} = \sqrt{(R_{MW}^2 - \sin^2\psi R_{sc}^2)} + R_{sc}\cos\psi$$

$$\mathcal{J}(\psi) = \frac{1}{R_{sc}\rho_{sc}^2}\int_0^{\ell_{max}} \rho^2(\sqrt{R_{sc}^2 - 2\,l\,R_{sc}\cos\psi + l^2})\,d\ell$$

$$\mathcal{J}_{\Delta\Omega} = \frac{1}{\Delta\Omega}\int_{\cos\psi}^{1} \mathcal{J}(\psi')\,2\pi\,d(\cos\psi')$$

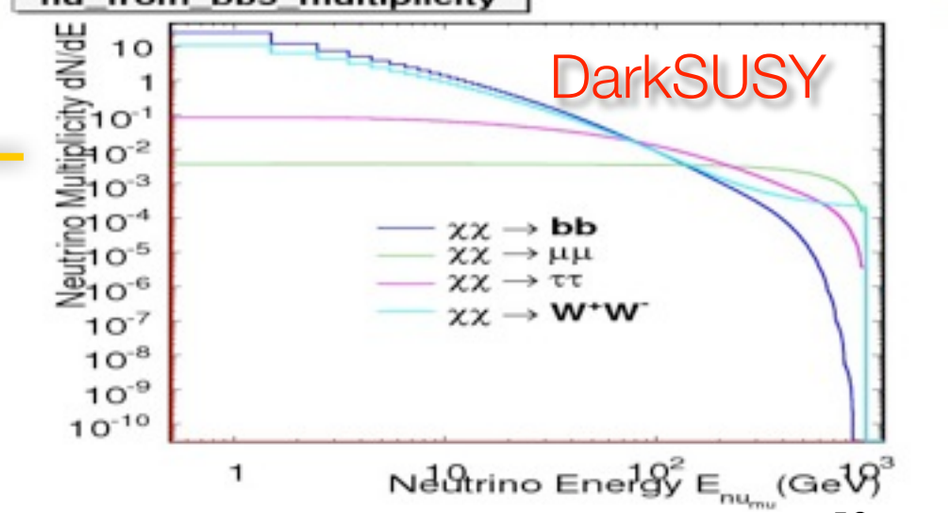


Expected differential neutrino Flux:

$$\frac{d\Phi}{dE} = \frac{<\sigma_A v>}{2} J(\psi)\frac{R_{sc}\rho_{sc}^2}{4\pi m_\chi^2}\frac{dN}{dE}$$

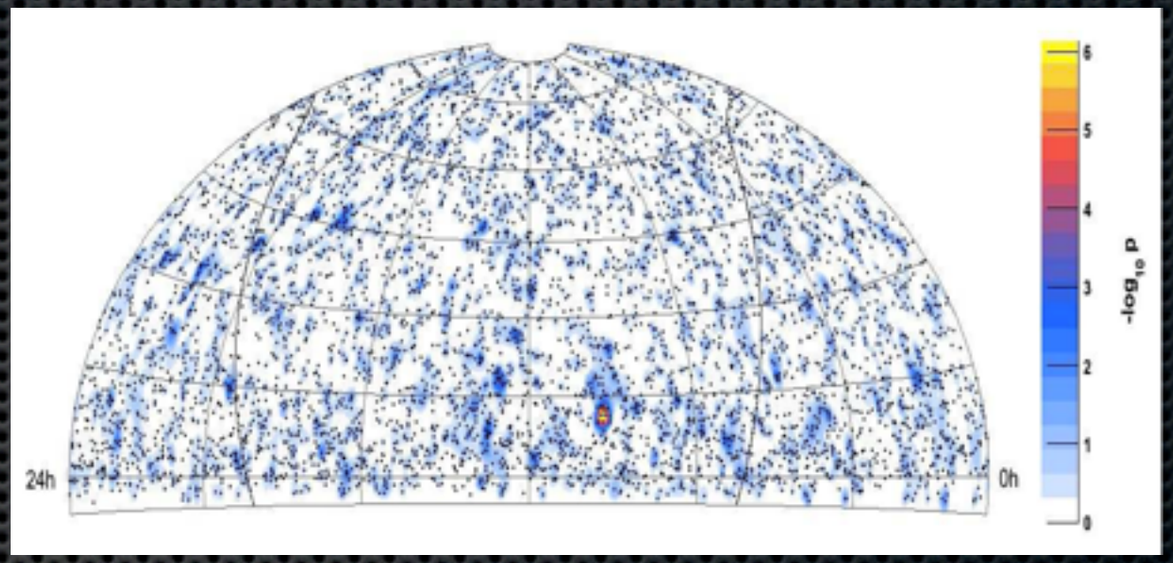
Measure integrated flux

Isotropic emission

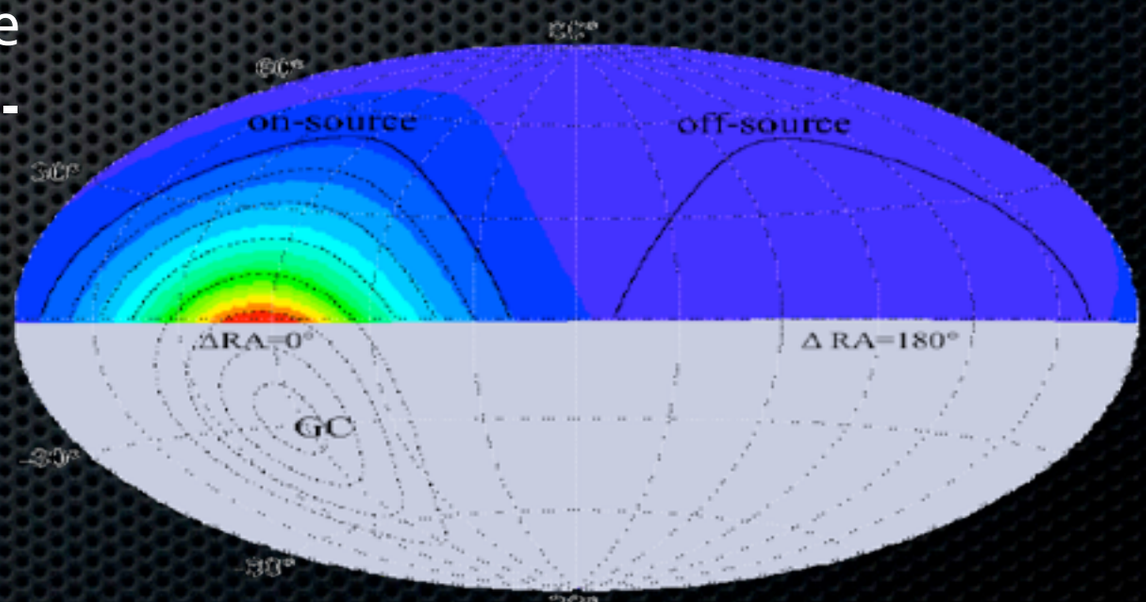


Sky map IceCube (22strings)

- 275.7 days of livetime collected with IceCube operating in the 22-string configuration (2007-2008)
- 5114 Events after selection from -5° to +85° declination
- Track selection criteria have been well established for the IceCube point source search, for simplicity and minimization of systematic effect we apply the same selection criteria (**Astrophys.J.701:L47-L51,2009**.)

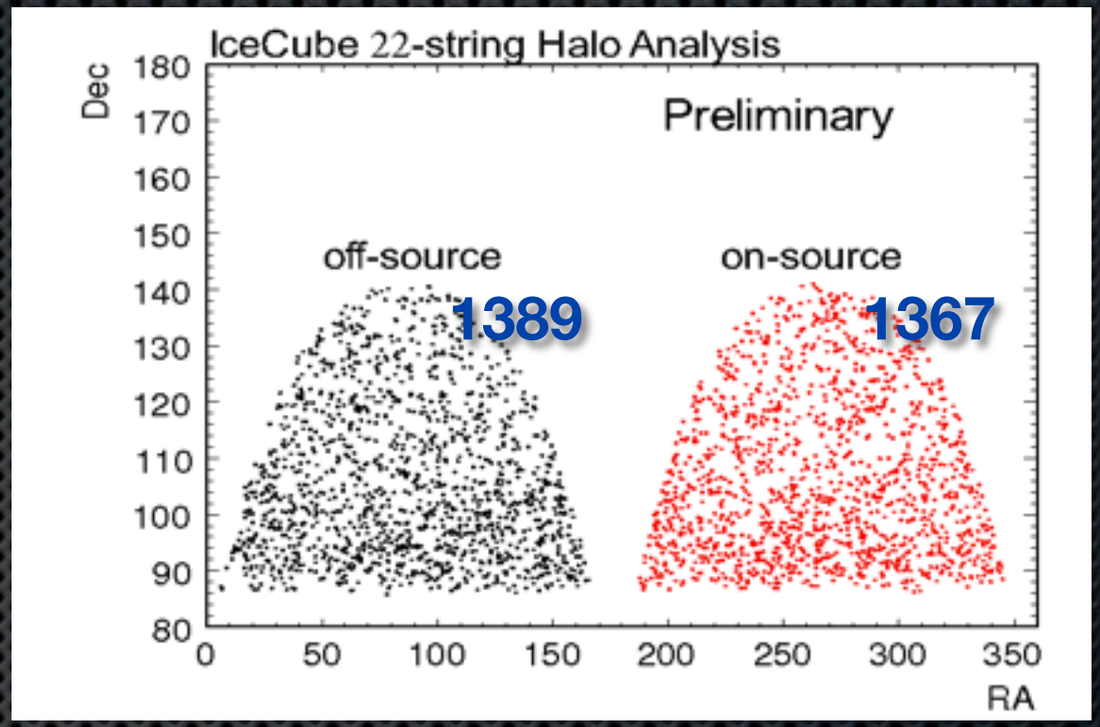


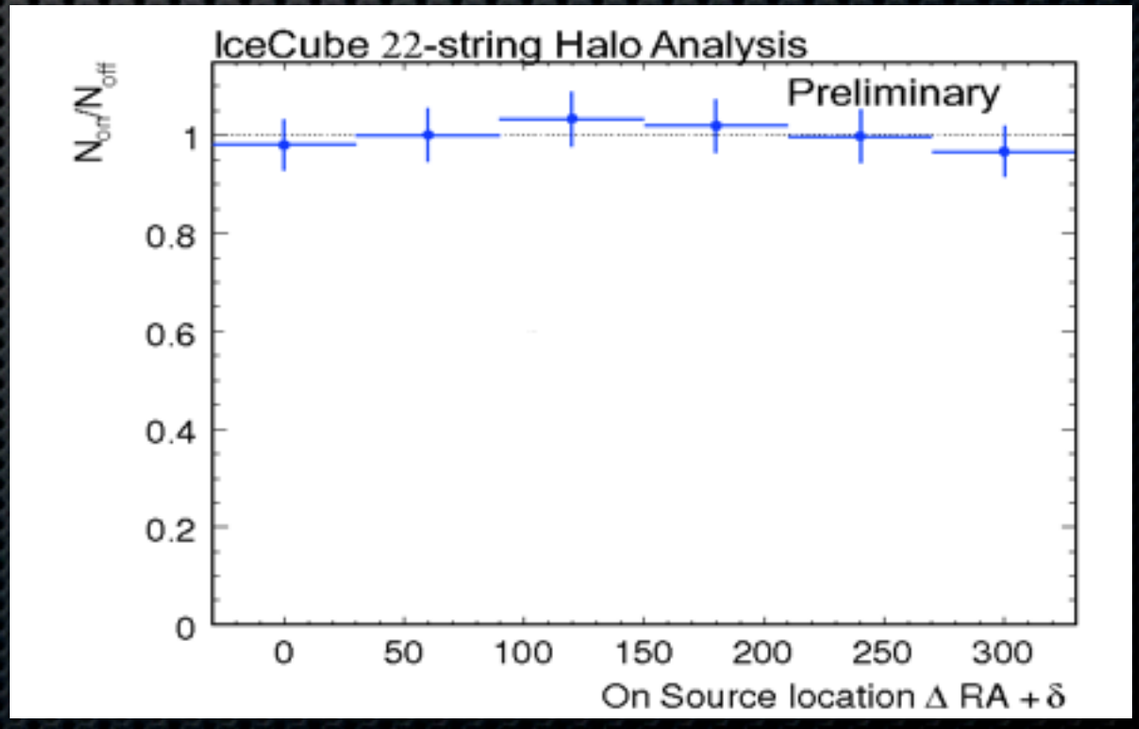
- Do we see any effects on Dark Matter in our neutrino sample ?



Galactic Halo IceCube 22

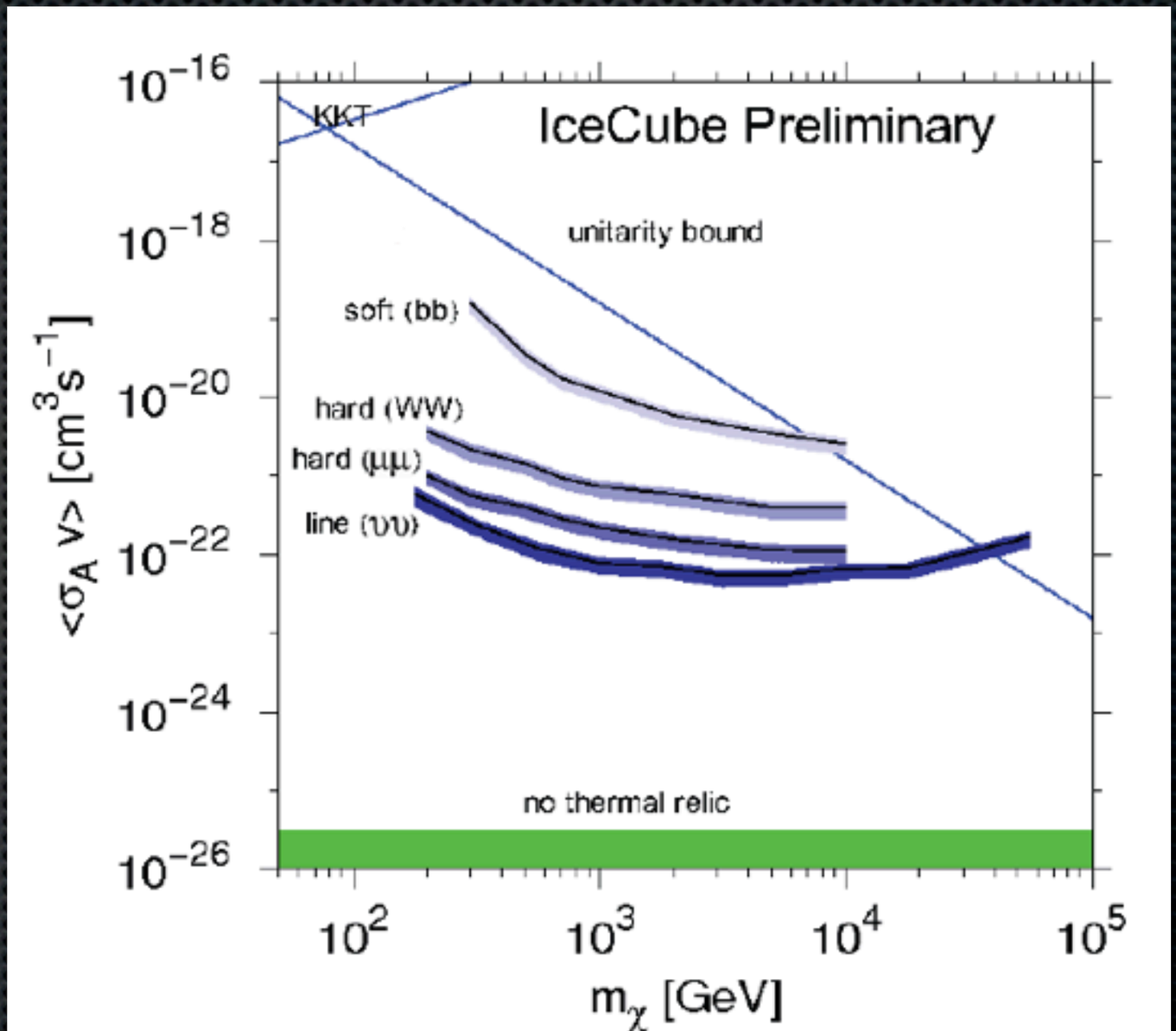
- Compare regions of equal "size" (on vs. off-source)
  - This technique allows to reduce systematic uncertainties
- No excess flux in the region, closer to the galactic center
- Rotate regions in 60° steps as systematic cross check
  - Distribution is flat





Galactic Halo Analysis - IceCube 22

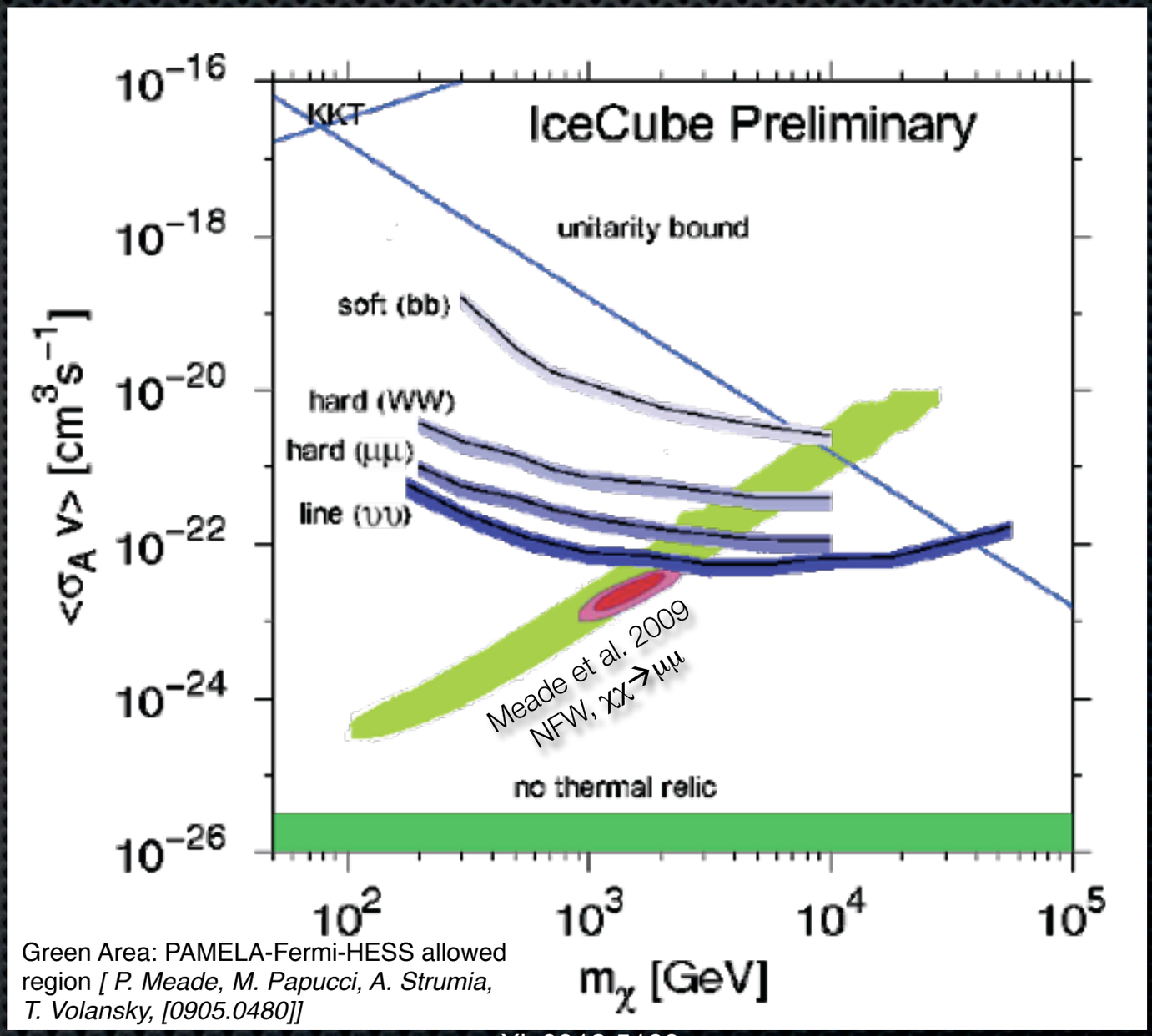
- No anisotropy was observed in IceCube data – constrain the dark matter self-annihilation cross-section
- Limits are at 90% C.L.
- As the outer halo is probed there is only a small dependence on halo profiles
- Annihilation into $\nu\nu$ could also be interpreted as upper limit on total dark matter annihilation cross section (Beacom, Bell, Mack 2008)



arXiv0912.5183

Galactic Halo Analysis - IceCube 22

- Preliminary IceCube constraints using 275 days of data and the 22 string dataset can probe already some of the preferred parameter space
  - No systematic uncertainties included
  - Only small dependence on halo models
- Significantly more data has been collected already

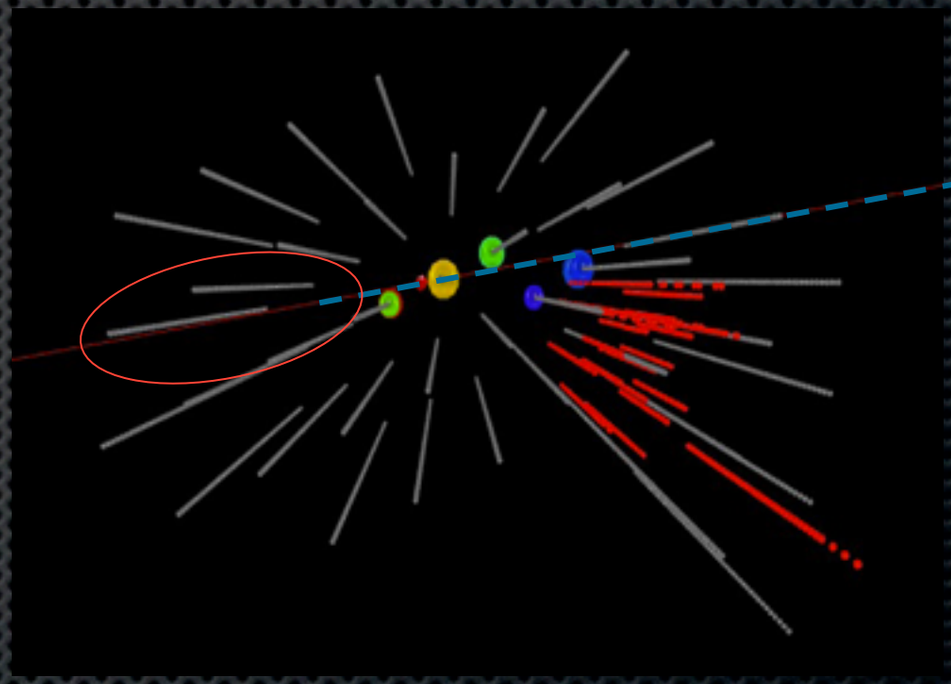


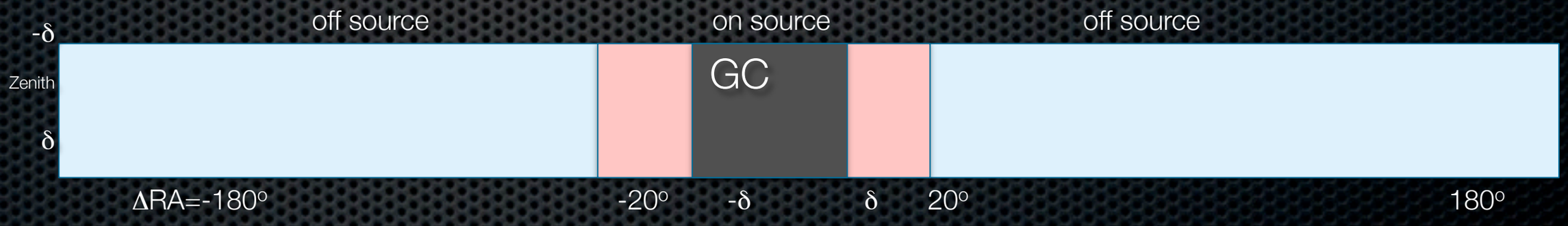
Green Area: PAMELA-Fermi-HESS allowed region *[P. Meade, M. Papucci, A. Strumia, T. Volansky, [0905.0480]]*

arXiv0912.5183

Galactic Center IceCube – 40 strings

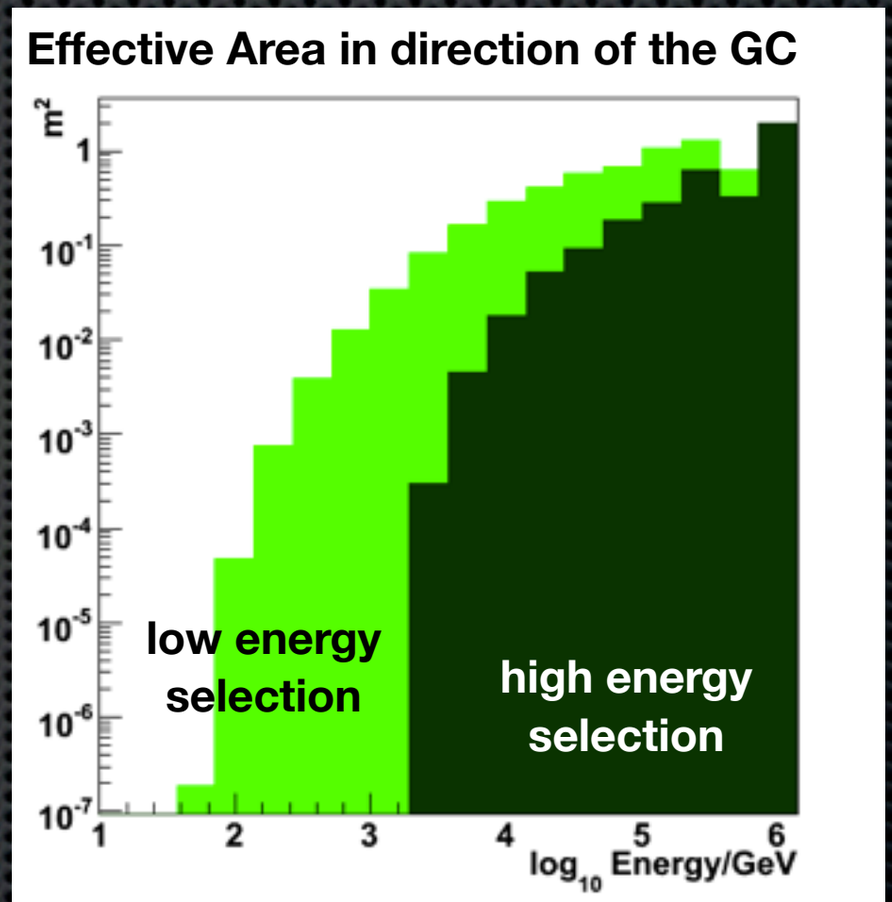
- Dark Matter profiles are peaked at the galactic center
- As the galactic center (GC) is above the horizon these events are down-going in IceCube
  - Use down-going starting events to reduce atmospheric muon background





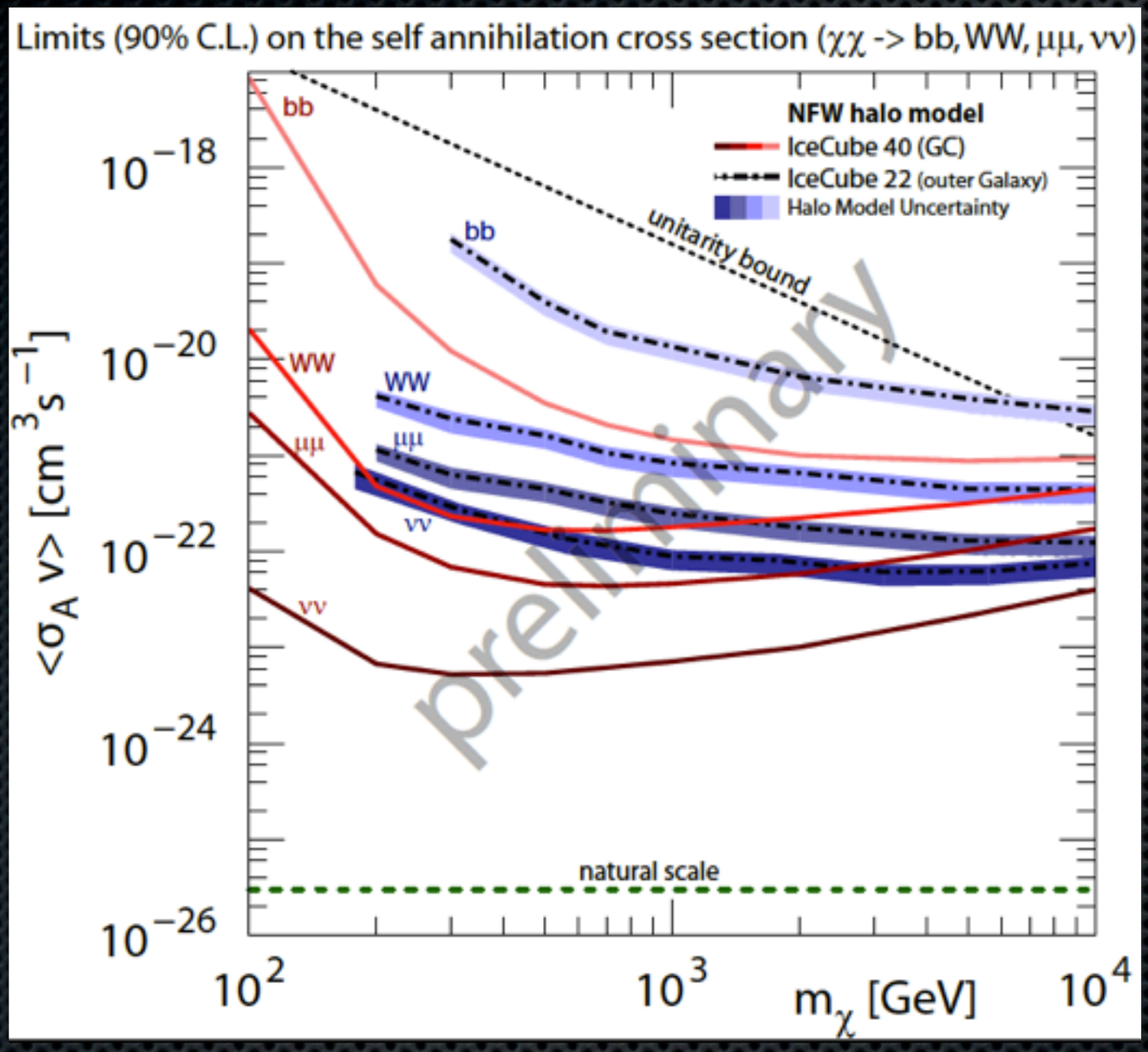
Galactic Center - IceCube 40

- Effective Area for muon neutrinos from Galactic Center 61^{o}
  - This analyses uses low energy selection
  - high energy selection used for point source search (details see talk J-P. Huelss DPG 2010)



Optimize the size of the on-source region
- $\delta = 8^{o}$
- compare the amount of events in the on- and off-source region
  ~800k background events expected (and observed)

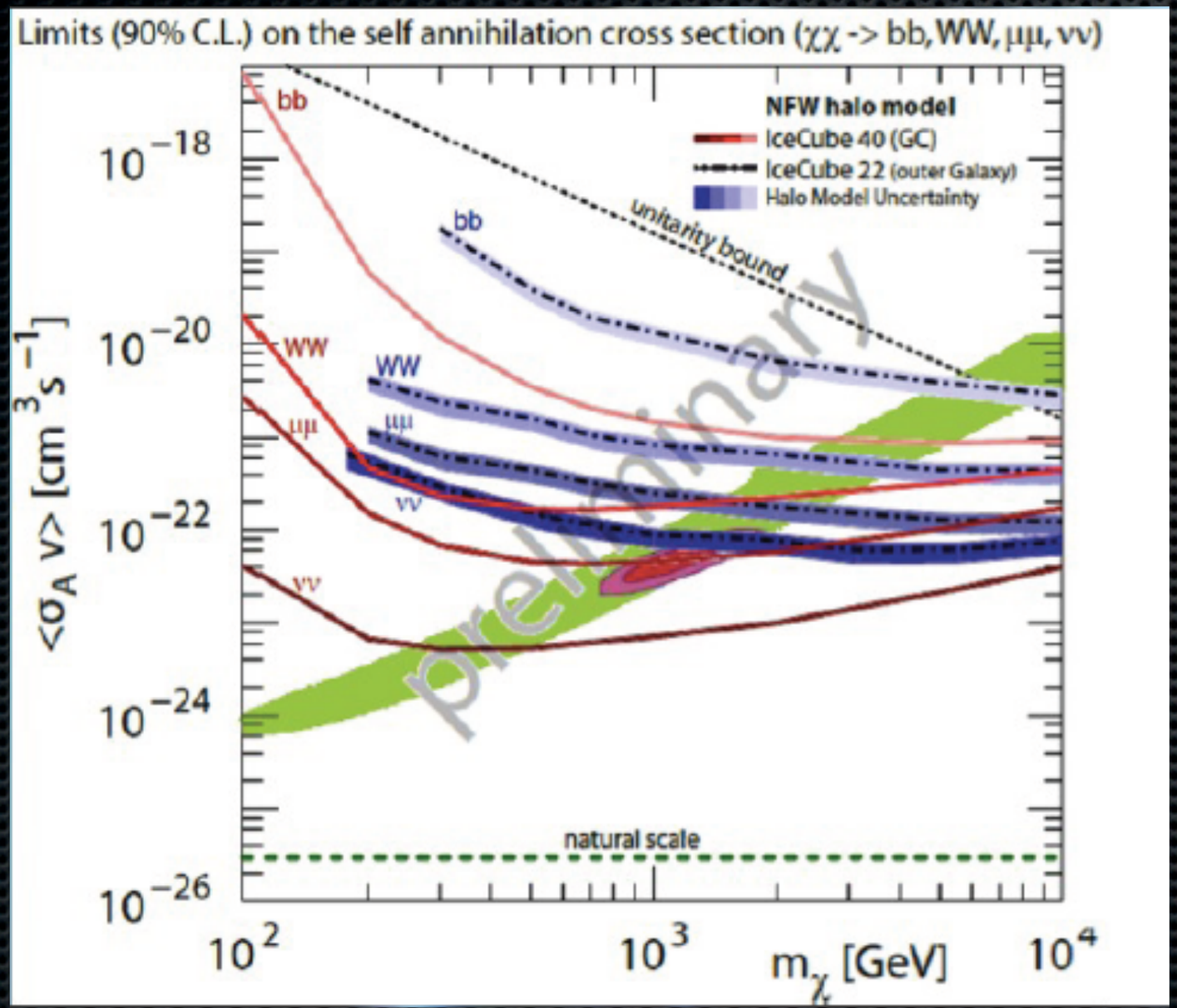
Galactic Center



Arxiv:0912.5183
J.Huelss DPG

- Neutrino constraints from IceCube are very competitive and start to probe preferred regions from the PAMELA positron excess and Fermi
- The IceCube/Deep Core subdetector is designed to obtain a clean neutrino sample of starting events, which will substantially improve our sensitivity for WIMPs in the 100 GeV range

Galactic Center



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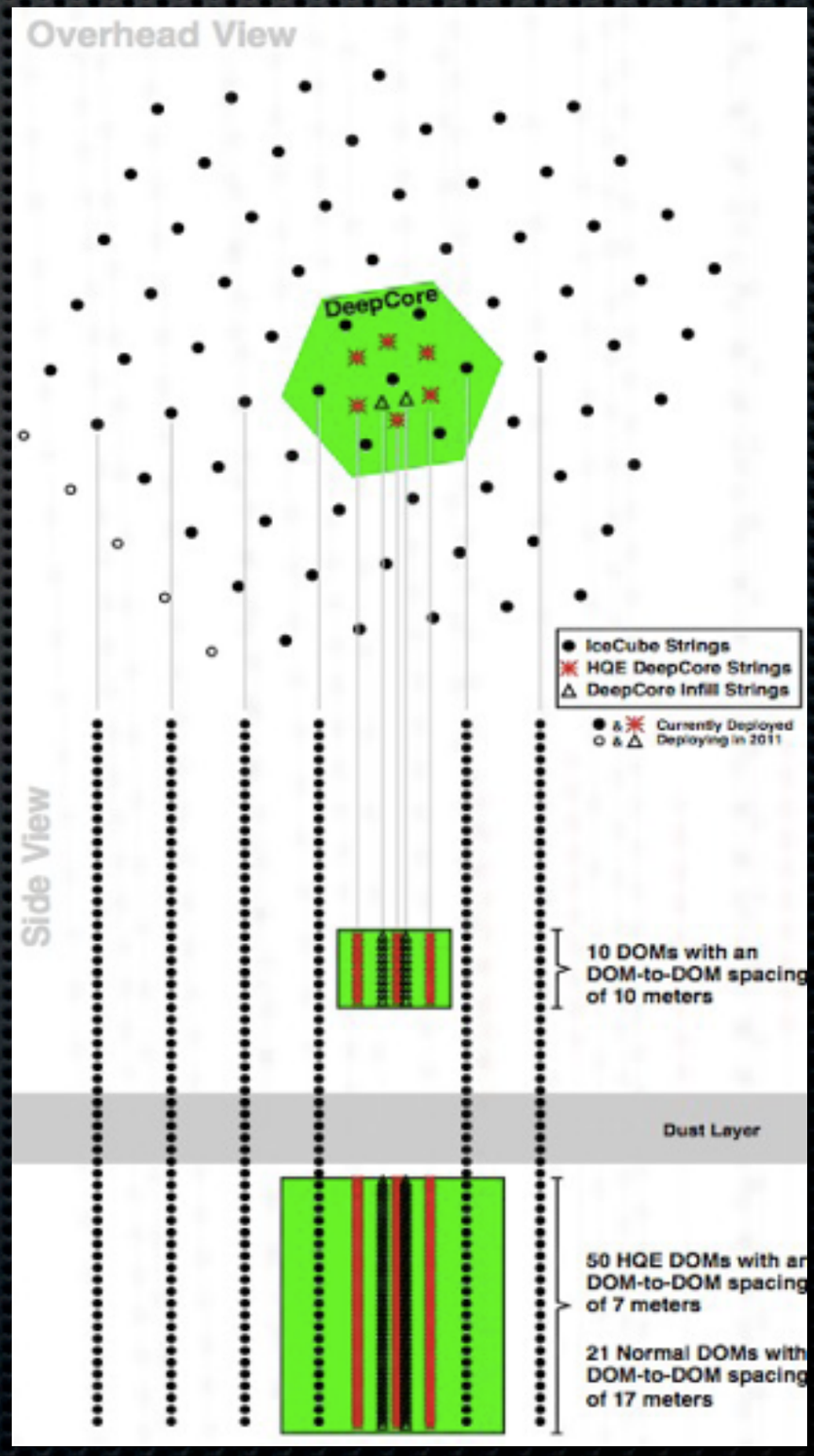
Deep Core

- What's next ?
  - IceCube can perform a variety of Dark Matter Analyses to test the self-annihilation cross-section and lifetime
    - Galactic Center
    - Galactic Halo
    - Stacking (Dwarf Spheroidals)
    - Line Search
  - Deep Core will extend IceCube's reach to lower energies, new neutrino flavors and make the Galactic center more accessible



Conclusions

- Neutrino Searches can be used to constrain both the WIMP-proton scattering cross section (Solar WIMPs) and the self-annihilation cross section (Galactic Halo)
- Observations in lepton channels (if interpreted as DM signals) favor models with high-mass leptophilic WIMPs
  - Neutrinos are powerful to test these models and have a crucial part in obtaining a more complete picture
- Using the partially instrumented detector and one year of data, IceCube can already provide very interesting constrains on the dark matter self-annihilation cross-section
- Stay tuned many new exciting results to come soon
  - IceCube is essentially completed now
  - DeepCore just started taking data