Microwave background and neutrino telescope likelihoods for global fits + implications for the MSSM

Pat Scott

Department of Physics, McGill University

Based on:
PS, Savage, Edsjö & The IceCube Collab. *JCAP* 2013, arXiv:1207.0810
Silverwood, PS, Danninger, et al. *JCAP* 2013, arxiv:1210.0844
Cline & PS *JCAP* 2013, arXiv:1301.5908

Slides available from:
`http://www.physics.mcgill.ca/~patscott`

Why should we care about having full likelihood functions?

1. Gives full info on how consistent a given model is with data (not IN/OUT) $\rightarrow$ allows global fits
2. Allows proper recasting of experimental results to different models
3. Allows uncertainties on m_t, $\Sigma_{\pi N}$, detector efficiency, etc to be accounted for + propagated consistently

Why should we care about having full likelihood functions?

1. Gives full info on how consistent a given model is with data (not IN/OUT) $\rightarrow$ allows global fits
2. Allows proper recasting of experimental results to different models
3. Allows uncertainties on m_t, $\Sigma_{\pi N}$, detector efficiency, etc to be accounted for + propagated consistently

Likelihoods for beyond-the-SM searches to be described:

- CMB angular power spectrum distortions:
  Energy injection from DM annihilation $\chi\chi \rightarrow SM$ at $z \sim 600$
- Neutrino signals from the centre of the Sun:
  Solar WIMP capture and annihilation

Why should we care about having full likelihood functions?

1. Gives full info on how consistent a given model is with data (not IN/OUT) $\rightarrow$ allows global fits
2. Allows proper recasting of experimental results to different models
3. Allows uncertainties on m_t, $\Sigma_{\pi N}$, detector efficiency, etc to be accounted for + propagated consistently

Likelihoods for beyond-the-SM searches to be described:

- CMB angular power spectrum distortions:
  Energy injection from DM annihilation $\chi\chi \rightarrow SM$ at $z \sim 600$
- Neutrino signals from the centre of the Sun:
  Solar WIMP capture and annihilation

Models:

- CMSSM: m_0, $m_{\frac{1}{2}}$, A_0, $\tan\beta$, μ
- MSSM-25: M_1, M_2, M_3, $15 \times m_{\tilde{f}}$, A_t, A_b, A_τ, $A_{e/\mu}$, m_A, $\tan\beta$, μ

Generalised DM CMB likelihood functions

Simple CMB likelihood function, for

- Any combination of annihilation or decay channels
- Any dark matter mass
- Any decay lifetime/annihilation cross-section

→ just requires interpolating one number in a table.

Cline & PS, 1301.5908, using

- CMB energy deposition from Slatyer, 1211.0283 and Finkbeiner et al, 1109.6322
- PYTHIA annihilation/decay spectra of Cirelli et al, 1012.4515.

Generalised DM CMB likelihood functions

Simple CMB likelihood function, for

- Any combination of annihilation or decay channels
- Any dark matter mass
- Any decay lifetime/annihilation cross-section

$\rightarrow$ just requires interpolating one number in a table.

$f_{\rm eff}$ for annihilation:

$$\ln \mathcal{L}(\langle\sigma v\rangle | m_\chi, r_i) = -\frac{1}{2} f_{\rm eff}^2(m_\chi, r_i)\lambda_1 c_1^2 \left(\frac{\langle\sigma v\rangle}{2\times 10^{-27}{\rm cm}^3{\rm s}^{-1}}\right)^2 \left(\frac{\rm GeV}{m_\chi}\right)^2 \quad (1)$$

Generalised DM CMB likelihood functions

Simple CMB likelihood function, for

- Any combination of annihilation or decay channels
- Any dark matter mass
- Any decay lifetime/annihilation cross-section

$\rightarrow$ just requires interpolating one number in a table.

$f_{\rm eff}$ for annihilation:

$$\ln \mathcal{L}(\langle\sigma v\rangle|m_\chi, r_i) = -\frac{1}{2} f_{\rm eff}^2(m_\chi, r_i)\lambda_1 c_1^2 \left(\frac{\langle\sigma v\rangle}{2\times 10^{-27}{\rm cm}^3{\rm s}^{-1}}\right)^2 \left(\frac{\rm GeV}{m_\chi}\right)^2 \quad (1)$$

η for decay:

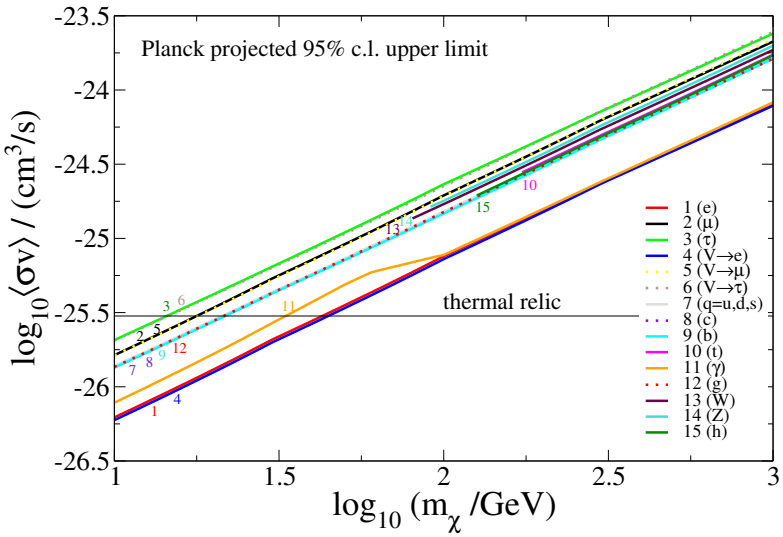
$$\ln \mathcal{L}(\tau|m_\chi, r_i) = -\frac{1}{2}\left(\frac{\delta\Omega}{\Omega_{\rm DM}\tau}\right)^2 \eta^2(\tau, m_\chi, r_i) \quad (2)$$

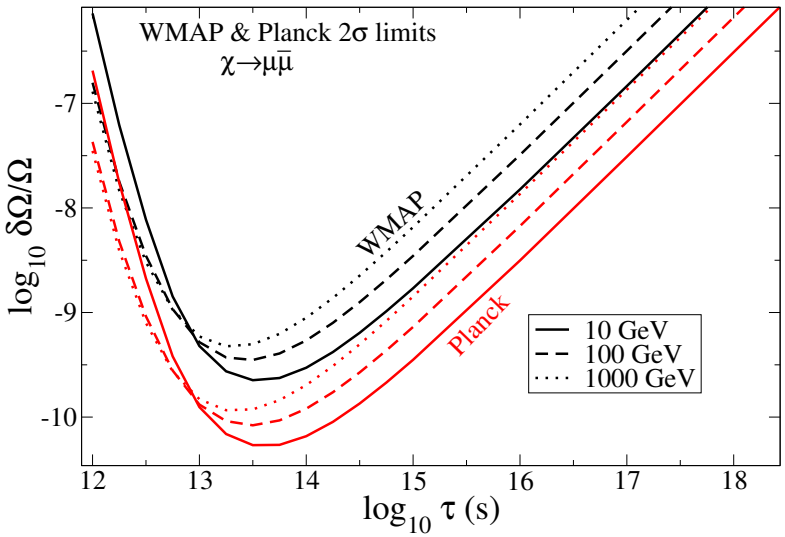
Generalised DM CMB likelihood functions

Simple CMB likelihood function, for

- Any combination of annihilation or decay channels
- Any dark matter mass
- Any decay lifetime/annihilation cross-section

$\longrightarrow$ just requires interpolating one number in a table.

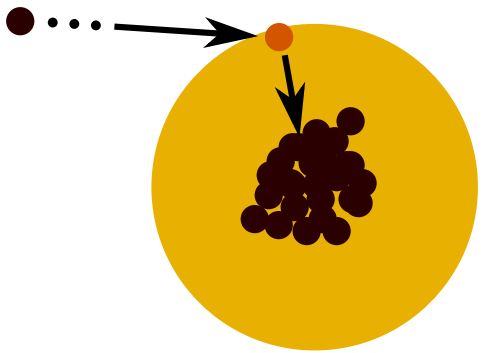




How to find DM with neutrino telescopes

The short version:

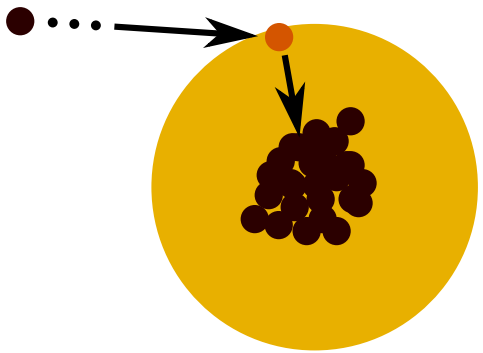
How to find DM with neutrino telescopes



The short version:

1. Halo WIMPs crash into the Sun

How to find DM with neutrino telescopes



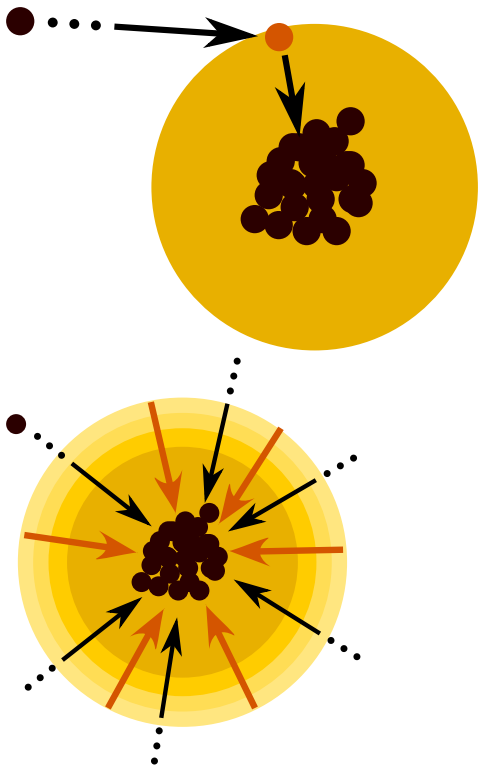
The short version:

1. Halo WIMPs crash into the Sun
2. Some lose enough energy in the scatter to be gravitationally bound

How to find DM with neutrino telescopes

The short version:

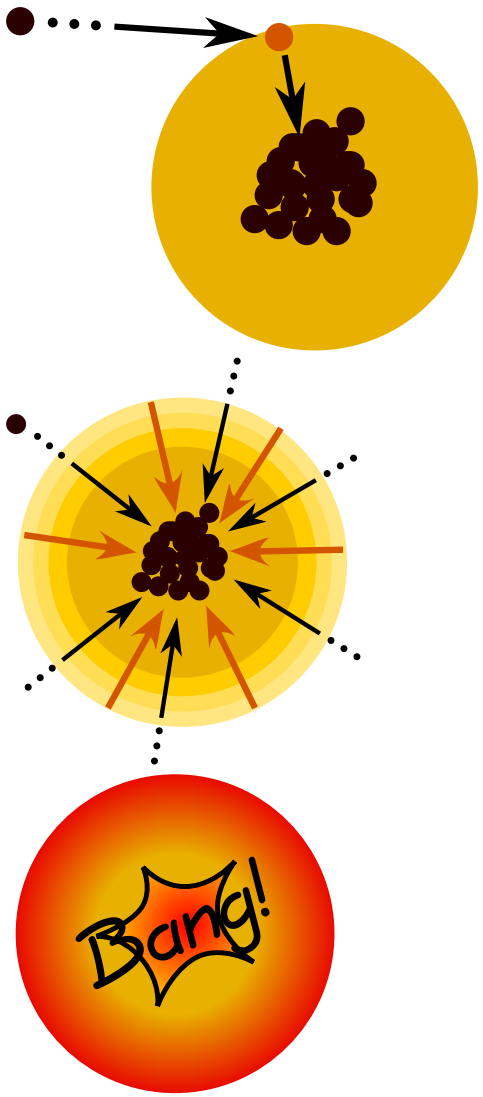
1. Halo WIMPs crash into the Sun
2. Some lose enough energy in the scatter to be gravitationally bound
3. Scatter some more, sink to the core



How to find DM with neutrino telescopes

The short version:

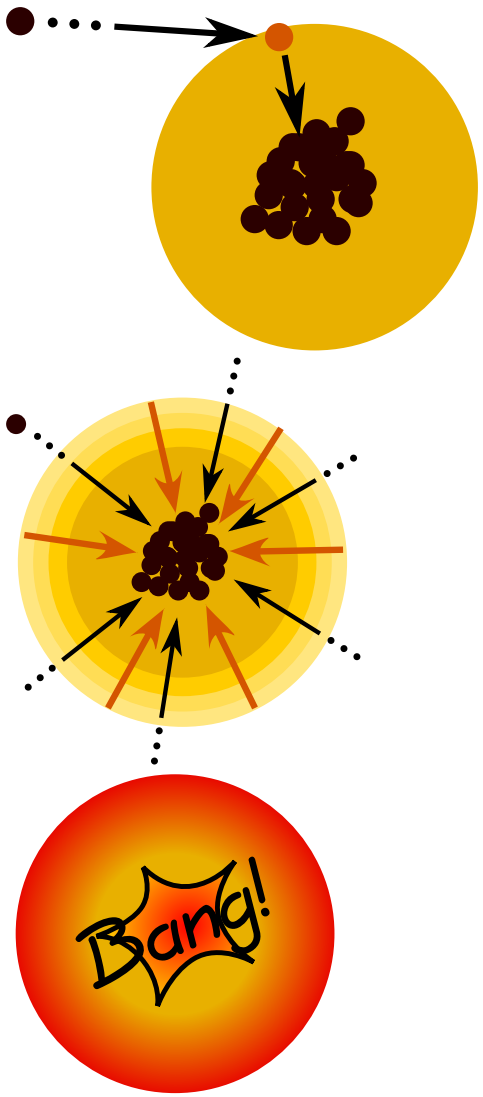
1. Halo WIMPs crash into the Sun
2. Some lose enough energy in the scatter to be gravitationally bound
3. Scatter some more, sink to the core
4. Annihilate with each other, producing neutrinos



How to find DM with neutrino telescopes

The short version:

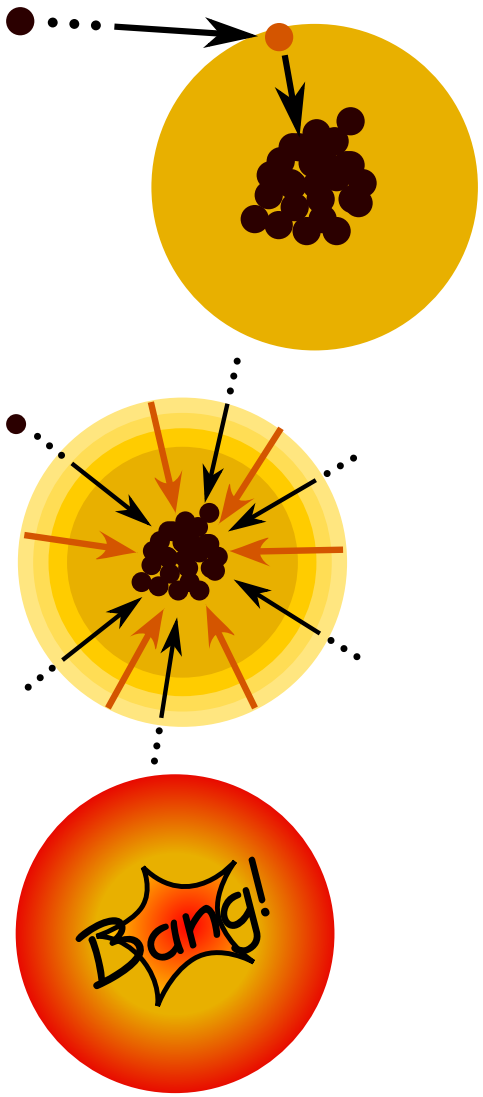
1. Halo WIMPs crash into the Sun
2. Some lose enough energy in the scatter to be gravitationally bound
3. Scatter some more, sink to the core
4. Annihilate with each other, producing neutrinos
5. Propagate+oscillate their way to the Earth, convert into muons in ice/water



How to find DM with neutrino telescopes

The short version:

1. Halo WIMPs crash into the Sun
2. Some lose enough energy in the scatter to be gravitationally bound
3. Scatter some more, sink to the core
4. Annihilate with each other, producing neutrinos
5. Propagate+oscillate their way to the Earth, convert into muons in ice/water
6. Look for Čerenkov radiation from the muons in **IceCube**, ANTARES, etc



Advanced IceCube Likelihood for Model Testing

Simplest way to do anything is to first make it a counting problem...

Compare observed number of events n and predicted number θ for each model, taking into account error σ_ϵ on acceptance:

$$\mathcal{L}_{\rm num}(n|\theta_{\rm BG}+\theta_{\rm sig}) = \frac{1}{\sqrt{2\pi}\sigma_\epsilon}\int_0^\infty \frac{(\theta_{\rm BG}+\epsilon\theta_{\rm sig})^n e^{-(\theta_{\rm BG}+\epsilon\theta_{\rm sig})}}{n!}\frac{1}{\epsilon}\exp\left[-\frac{1}{2}\left(\frac{\ln\epsilon}{\sigma_\epsilon}\right)^2\right]\mathrm{d}\epsilon\,. \tag{3}$$

Nuisance parameter ϵ takes into account systematic errors on effective area, etc. $\sigma_\epsilon \sim 20\%$ for IceCube.

Advanced IceCube Likelihood for Model Testing

Simplest way to do anything is to first make it a counting problem...

Compare observed number of events n and predicted number θ for each model, taking into account error σ_ϵ on acceptance:

$$\mathcal{L}_{\rm num}(n|\theta_{\rm BG}+\theta_{\rm sig}) = \frac{1}{\sqrt{2\pi}\sigma_\epsilon}\int_0^\infty \frac{(\theta_{\rm BG}+\epsilon\theta_{\rm sig})^n e^{-(\theta_{\rm BG}+\epsilon\theta_{\rm sig})}}{n!}\frac{1}{\epsilon}\exp\left[-\frac{1}{2}\left(\frac{\ln\epsilon}{\sigma_\epsilon}\right)^2\right]\mathrm{d}\epsilon\,. \tag{3}$$

Then: upgrade to full unbinned likelihood with number ($\mathcal{L}_{\rm num}$), spectral ($\mathcal{L}_{\rm spec}$) and angular ($\mathcal{L}_{\rm ang}$) bits:

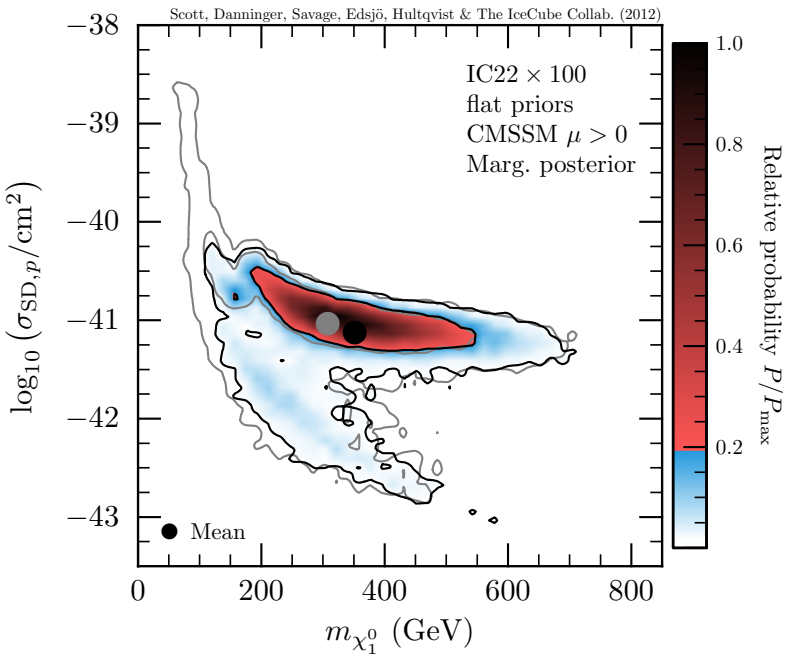
$$\mathcal{L} = \mathcal{L}_{\rm num}(n|\theta_{\rm signal+BG})\prod_{i=1}^{n}\mathcal{L}_{{\rm spec},i}\,\mathcal{L}_{{\rm ang},i} \tag{4}$$

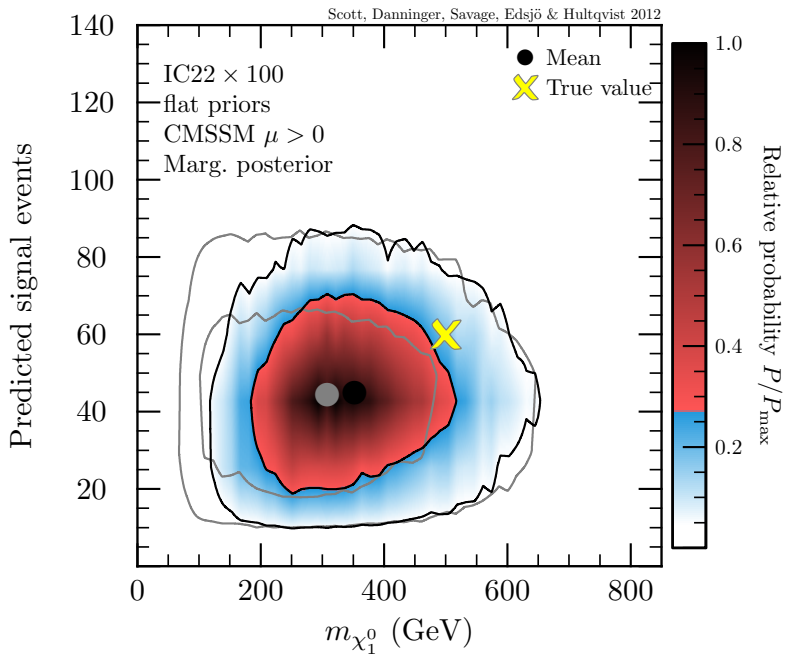
All available in DarkSUSY v5.0.6 and later: www.darksusy.org

CMSSM model reconstruction with IceCube event data

Benchmark recovery with 22-string IceCube WIMP-search neutrino events + full likelihood:

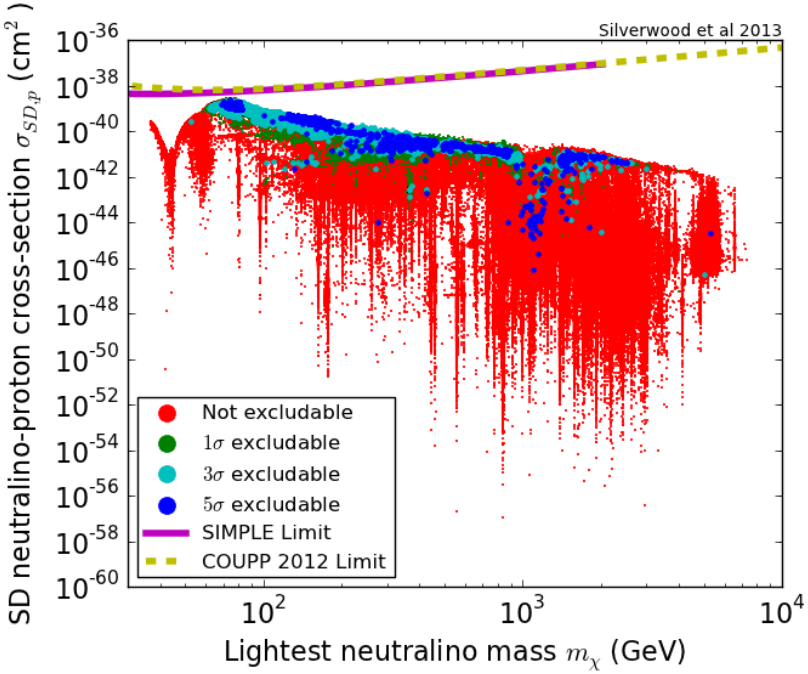
Mock signal: 60 events, $m_\chi = 500\,\text{GeV}$, 100% $\chi\chi \to W^+W^-$

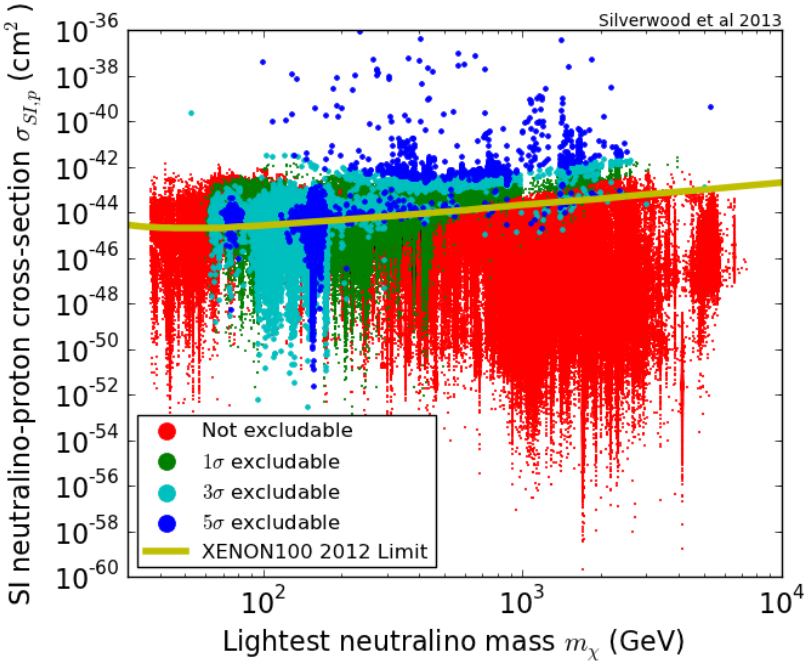




Prospects for detection in the MSSM-25

86-string IceCube vs Direct Detection (points pass $\Omega_\chi h^2$, $b \to s\gamma$, LEP)

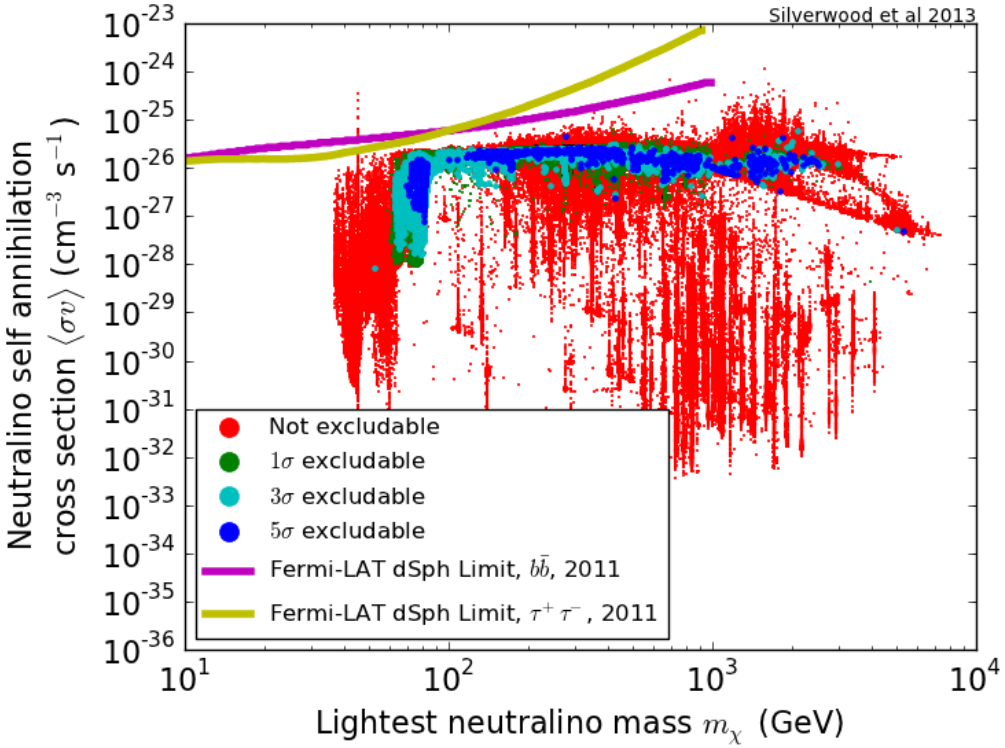




Many models that IceCube-86 can see are not accessible to direct detection…

Prospects for detection in the MSSM-25

86-string IceCube vs Gamma Rays

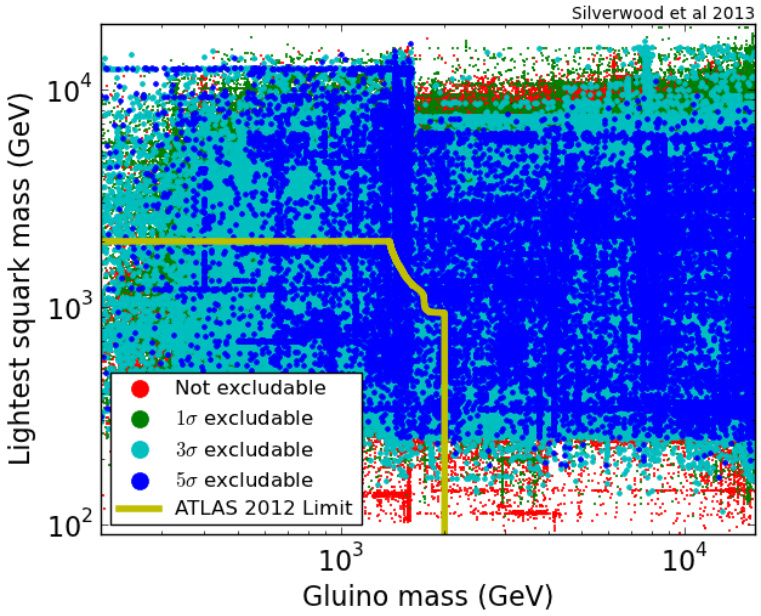


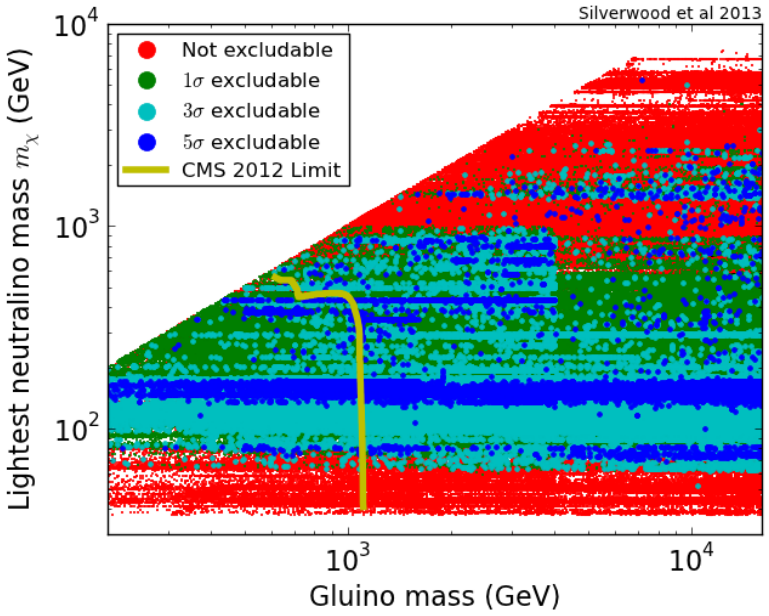
Many models that IceCube-86 can see are not accessible by other indirect probes…

Prospects for detection in the MSSM-25

86-string IceCube vs LHC (very naively)

SMS limits: 7 TeV, 4.7 fb^{-1}, jets + $E_{T,miss}$; 0 leptons (ATLAS), razor + M_{T2} (CMS)





Many models that IceCube-86 can see are also not accessible at colliders.

Summary

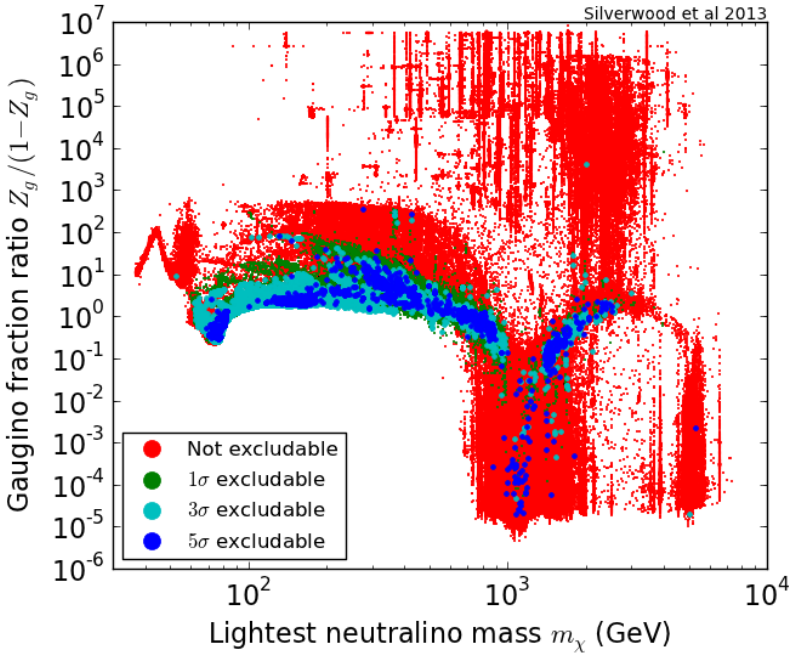
Take-home messages:

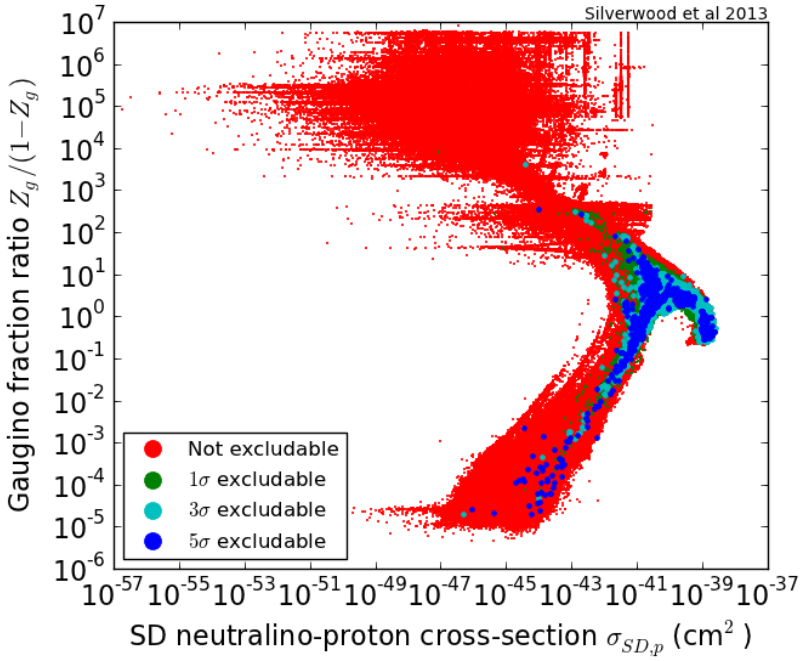
1. Limits are not enough – experiments need to give full likelihood information if phenomenology is to be done properly
2. Neutrino telescopes provide the only access to many MSSM-25 models
3. Energy information in neutrino DM searches can help greatly in model discrimination

Backup Slides

Prospects for detection in the MSSM-25

Gaugino fractions





Mainly mixed models, a few Higgsinos