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

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Based on:
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) → 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
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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
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Models:

- CMSSM: $m_0$, $m_1$, $A_0$, $\tan \beta$, $\mu$
- MSSM-25: $M_1$, $M_2$, $M_3$, $15 \times m_\tau$, $A_t$, $A_b$, $A_{\tau}$, $A_{e/\mu}$, $m_A$, $\tan \beta$, $\mu$
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.
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\[ f_{\text{eff}} \text{ for annihilation:} \]
\[
\ln \mathcal{L}(\langle \sigma v \rangle | m_\chi, r_i) = -\frac{1}{2} f_{\text{eff}}^2 (m_\chi, r_i) \lambda_1 c_1^2 \left( \frac{\langle \sigma v \rangle}{2 \times 10^{-27} \text{cm}^3\text{s}^{-1}} \right)^2 \left( \frac{\text{GeV}}{m_\chi} \right)^2
\] (1)
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\]

\( \eta \) for decay:

\[
\ln \mathcal{L}(\tau | m_\chi, r_i) = -\frac{1}{2} \left( \frac{\delta \Omega}{\Omega_{\text{DM}\tau}} \right)^2 \eta^2(\tau, m_\chi, r_i) (2)
\]
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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
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Simplest way to do anything is to first make it a counting problem. . .

Compare observed number of events $n$ and predicted number $\theta$ for each model, taking into account error $\sigma_\epsilon$ on acceptance:

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

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

(3)

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

\[
\mathcal{L} = \mathcal{L}_{\text{num}}(n|\theta_{\text{signal+BG}}) \prod_{i=1}^{n} \mathcal{L}_{\text{spec},i} \mathcal{L}_{\text{ang},i}
\]

(4)

All available in DarkSUSY v5.0.6 and later: www.darksusy.org
Benchmark recovery with 22-string IceCube WIMP-search neutrino events + full likelihood:

**Mock signal**: 60 events, $m_\chi = 500$ GeV, 100% $\chi\chi \rightarrow W^+ W^-$
Prospects for detection in the MSSM-25

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

Many models that IceCube-86 can see are not accessible to direct detection...
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 + $E_{T,\text{miss}}$; 0 leptons (ATLAS), razor + $M_{T2}$ (CMS)

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