Indirect detection in micrOMEGAs

Details in arXiv:1004.1092
Energy spectra in micrOMEGAs

To store spectra micrOMEGAS uses $NZ=250$ arrays.
  double Tab[NZ];
The first element corresponds to $E=M_{cdm}$, the last one $10^{-7}M_{cdm}$

Energy distribution can be obtained by

$$dN/dE = \text{SpectdNdE}(E, \text{Tab})$$

For spectra visualization use displaySpectrum(Tab, text, Emin, Emax, Units)
If $Units=0$ then $dN/d\log_{10}(E/M_{cdm})$ will be displayed
otherwise you will get $dN/dE$ plot

SigmaV$= \text{calcSpectrum}(key, Sg, Se, Sp, Sne, Snm, Snl, \& \text{err})$
Calculates $\sigma_v$ in cm$^3$/s units and fills $Sg, Se, Sp, Sne, Snm, Snl$ arrays for gamma, positrons, antiprotons, and neutrinos.
  key$= k1 + 2k2 + 4k4$
    $k1=1$ - switch on W,Z polarization effects
    $k2=1$ – switch on effects of gamma radiation
    $K4=1$ - prints partial $\sigma_v$ for each channel.
For each basis annihilation channel like \{ b, b-bar \} micrOMEGAs has spectra tables for hadronization generated by Pythia. You can find them by

\texttt{basicSpectra(PDGnum, outN, spectrumTab)}

\texttt{PDGnum=5} in case of \{ b, b-bar \}

For \textit{transverse} \textit{W} PDG=24+'\text{T}', For \textit{longitudinal} \textit{W} PDG=24+'\text{L}'

outN = 0, 1, 2, 3, 4, 5 for gamma, positrons, antiprotons, neutrinos ....
Loop induced channel for MSSM

In MSSM there are loop induced processes
neutralino, neutralino -> A, A
neutralino, neutralino -> A, Z

It gives point-like spectrum of gamma. Experimental observation of this spectrum will allow to define neutralino mass.

In order to get corresponding cross sections uncomment
#define LoopGAMMA

Long time compilation is expected for first call

Output for SUGRA point ./main 120 500 -350 10 1 173.1

Gamma ray lines:
E=1.96E+02[GeV] vcs(Z,A)= 2.67E-30[cm^3/s], flux=7.04E-15[cm^2 s]^{-1}
E=2.06E+02[GeV] vcs(A,A)= 6.07E-30[cm^3/s], flux=3.20E-14[cm^2 s]^{-1}
**Halo profiles**

MicrOMEGAs can work with any spherically symmetric DM distribution which is defined via DM density at Sun orbit and profile function. Also we foresee that this distribution can have a clump structure.

\[ \rho(r) = \rho_\odot F_{halo}(r) \quad <\rho^2>(r) = \rho_\odot^2 F_{halo}^2(r) F_{clump}(r) \]

`setHaloProfiles(Fhalo,Fclump);` allows user to specify halo profile and clump boost factor.

We assume that \( F_{halo}(R_{\odot})=1 \)

\( R_{\odot} \) is a global parameter with default value 8.5 kpc

\( \rho_\odot \) is defined by parameter \( \rho_{DM} \) with default value 0.3 GeV/cm\(^3\).

MicrOMEGAs have implemented two popular DM profiles:

- \( h\text{ProfileABG}(r) \)
  \[ F_{halo}(r) = \left( \frac{R_{sun}}{r} \right)^\gamma \left( \frac{r_c^\alpha + R_{sun}^\alpha}{r_c^\alpha + r^\alpha} \right)^{-\gamma/\alpha} \]

- \( h\text{ProfileEinasto}(r) \)
  \[ F_{halo}(r) = \exp \left[ -\frac{2}{\alpha} \left( \left( \frac{r}{R_{sun}} \right)^\alpha - 1 \right) \right] \]

To fix parameters:

`setProfileABG(alpha,beta,gamma,rc)`  `setProfileEinasto(alpha)`
By default we use \texttt{hProfileABG} profile with parameters $\alpha = 1$, $\beta = 3$, $\gamma = 1$, $rc = 20 \text{kpc}$ and $\text{noClump}(r) = 1$, clump boost factor.
Gamma signal integrated over the line of sight.

\textbf{GammaFluxTab}( \phi, d\phi, \sigma_v, \text{ Sg, Flux})

\textbf{Sg} – input annihilation spectrum  
\textbf{Flux} – output flux table in \(1/(\text{sec cm}^2)\) units  
\text{Integrated over solid angle } 2\pi(1- \cos(d\phi))

\textbf{\phi} – angle respect to galactic center  
\textbf{d\phi} - half of cone angle

For point like spectrum micrOMEGAs has a function

\textbf{gammaFlux}( \phi, d\phi, \sigma_v)

For the \(\gamma\gamma\) case factor 2 needs.
Propagation of charged particles: positron and antiproton signals

Galactic disk is a source of irregular magnetic field which propagates several kpc from the disk. Because of this field propagation of charged particles is described by diffusion equations. MicrOMEGAs gives solution of simplified equations which can be expressed in terms of integrals.

We assume that propagation parameters are constant in cylinder with radius \( R_{\text{disk}} \) and vertical size +/- \( L_{\text{diff}} \).

Diffusion coefficient depends on particle momentum \( p \)

\[
K = K_{\text{dif}} \times \left( \frac{p}{q/1\text{GeV}} \right)^{\Delta_{\text{dif}}}
\]

There is galactic wind which is described by convective velocity \( V_{\text{c,dif}} \) directed outside of the disk.

There is electron energy lost caused by electron scattering on CMB and stellar light.

\[
\frac{dE}{dt} = b(E) = \frac{E^2}{1\text{GeV/}\tau_{\text{dif}}}
\]

\( L_{\text{dif}}, R_{\text{disk}}, K_{\text{dif}}, \Delta_{\text{dif}}, V_{\text{c,dif}} \tau_{\text{dif}} \) are global parameters in micrOMEGAs.
Boron/Carbon rate in cosmic rays imposes some relation on these parameter

<table>
<thead>
<tr>
<th>Model</th>
<th>$\delta$</th>
<th>$K_0$ (kpc$^2$/Myr)</th>
<th>$L$ (kpc)</th>
<th>$V_c$ (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIN</td>
<td>0.85</td>
<td>0.0016</td>
<td>1</td>
<td>13.5</td>
</tr>
<tr>
<td>MED</td>
<td>0.7</td>
<td>0.0112</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>MAX</td>
<td>0.46</td>
<td>0.0765</td>
<td>15</td>
<td>5</td>
</tr>
</tbody>
</table>

For protons

\[
\left( K(E)\Delta^2 + \frac{\delta}{dz} V_c + 2\Gamma_{tot}\delta(z) - \frac{\delta}{\delta E} b(E) \right) \Psi_x = \frac{\sigma_v}{2} \frac{\rho^2}{M_{cdm}^2} f_x(E)
\]

For positrons
<table>
<thead>
<tr>
<th>Name</th>
<th>Default value</th>
<th>Units</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mcdm</td>
<td></td>
<td>GeV</td>
<td>Mass of Dark Matter particle, $M_x$</td>
</tr>
<tr>
<td>Rsun</td>
<td>8.0</td>
<td>kpc</td>
<td>Distance from the Sun to the Galactic center, $r_\odot$</td>
</tr>
<tr>
<td>rhoDM</td>
<td>0.3</td>
<td>GeV/cm$^3$</td>
<td>Dark Matter density at Rsun, $\rho_\odot$</td>
</tr>
<tr>
<td>Rdisk</td>
<td>20</td>
<td>kpc</td>
<td>Radius of the galactic diffusion disk, $R$</td>
</tr>
<tr>
<td>K_diff</td>
<td>0.0112</td>
<td>kpc$^2$/Myr</td>
<td>Diffusion coefficient $K_0$</td>
</tr>
<tr>
<td>L_diff</td>
<td>4</td>
<td>kpc</td>
<td>Half height of the galactic diffusion zone $L$</td>
</tr>
<tr>
<td>Delta_diff</td>
<td>0.7</td>
<td></td>
<td>Slope of diffusion coefficient, $\delta$</td>
</tr>
<tr>
<td>Tau_diff</td>
<td>$10^{16}$</td>
<td>s</td>
<td>Positron energy loss time scale, $\tau_E$</td>
</tr>
<tr>
<td>Vc_diff</td>
<td>12</td>
<td>km/s</td>
<td>Convective velocity of Galactic wind, $V_C$</td>
</tr>
</tbody>
</table>

Table 3: Global parameters of the indirect detection module
Solution of equations

`posiFluxTab(Emin,sigmav, Se, FluxE)` calculates positron flux

`pbarFluxTab(Emin,sigmav, Sp, FluxP)` calculates antiproton flux

`SpectdNdE(E,Flux)` gives flux for given energy point

`displaySpectrum(Spectrum,message,Emin,Emax,Units)` – shows plot