Predicting dark matter relic densities and direct and indirect detection rates in supersymmetric models

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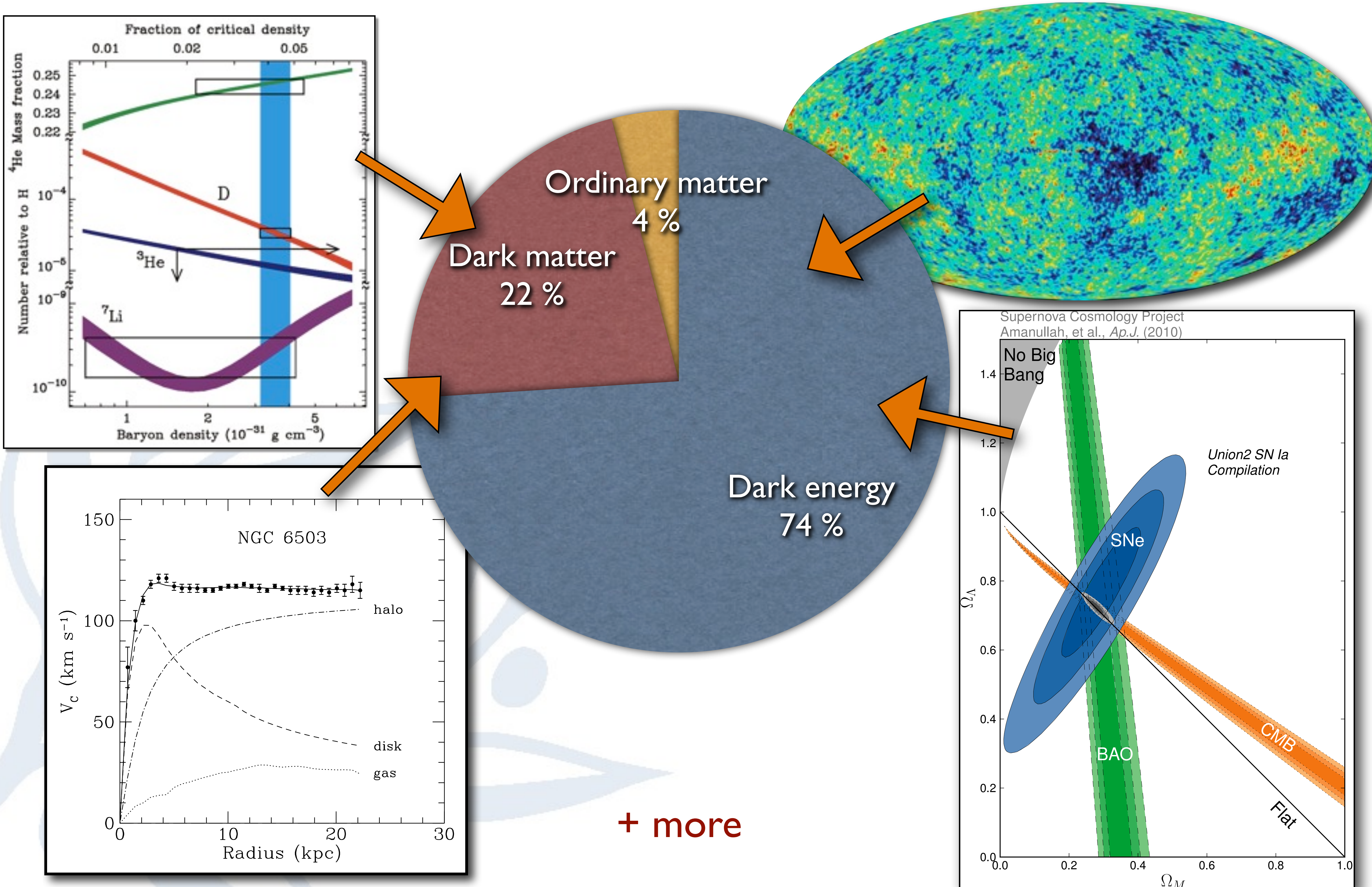
The need for dark matter



+ more

Ways to search for dark matter

Accelerator searches

- LHC
- Rare decays
- ...

Direct searches

- Spin-independent scattering
- Spin-dependent scattering

DarkSUSY

Indirect searches

- Gamma rays from the galaxy
- Neutrinos from the Earth/Sun
- Antiprotons from the galactic halo
- Antideuterons from the galactic halo
- Positrons from the galactic halo
- Dark Stars
- ...

Need to treat all of these in a consistent manner, both regarding particle physics and astrophysics

Will not cover all of these...

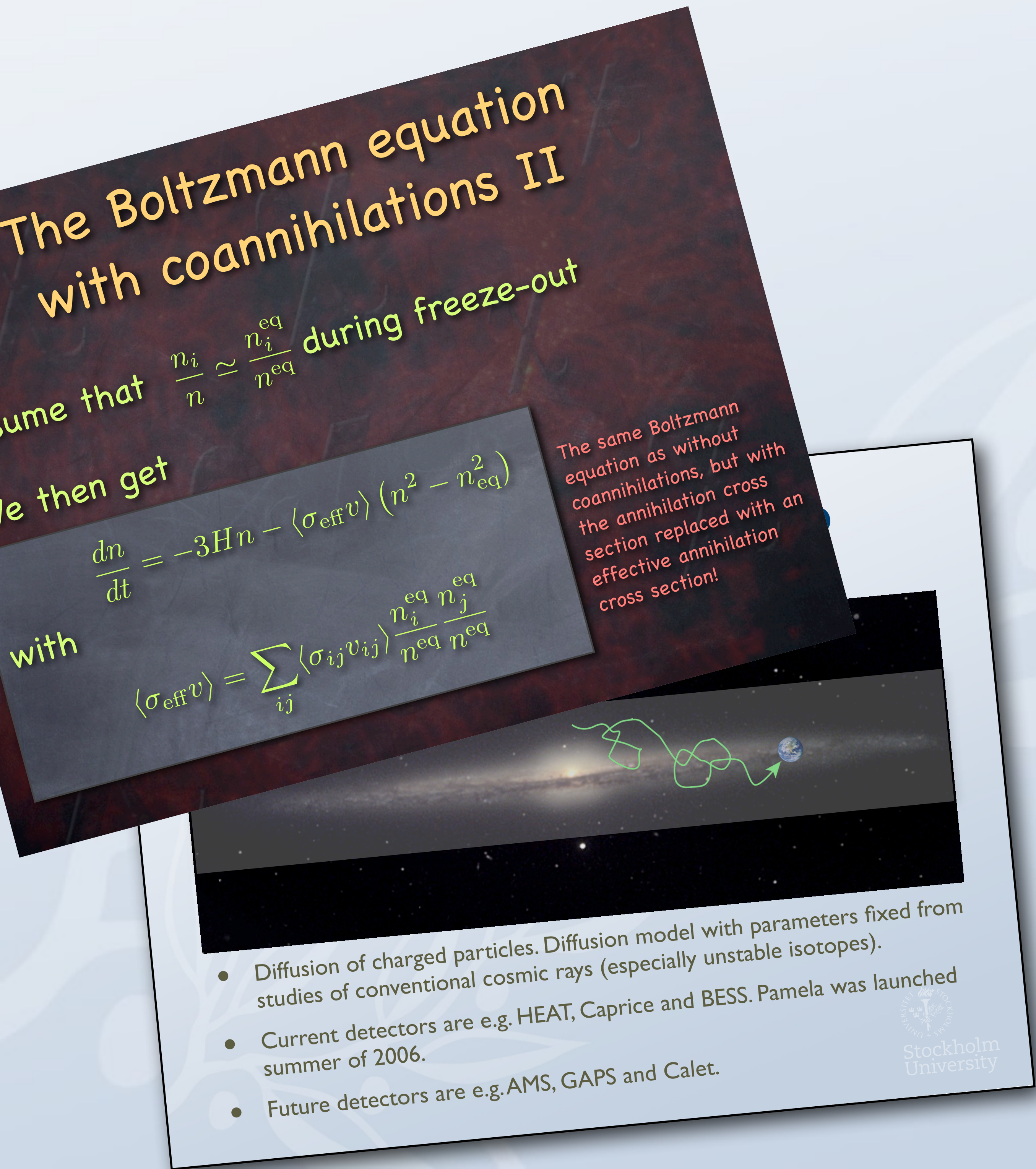
Outline

- Introduction to and layout of DarkSUSY
- SUSY setup
- Accelerator constraints
- Relic density
- Direct detection
- Indirect detection:
  - gamma rays
  - charged cosmic rays
  - neutrinos (from the Sun/Earth)

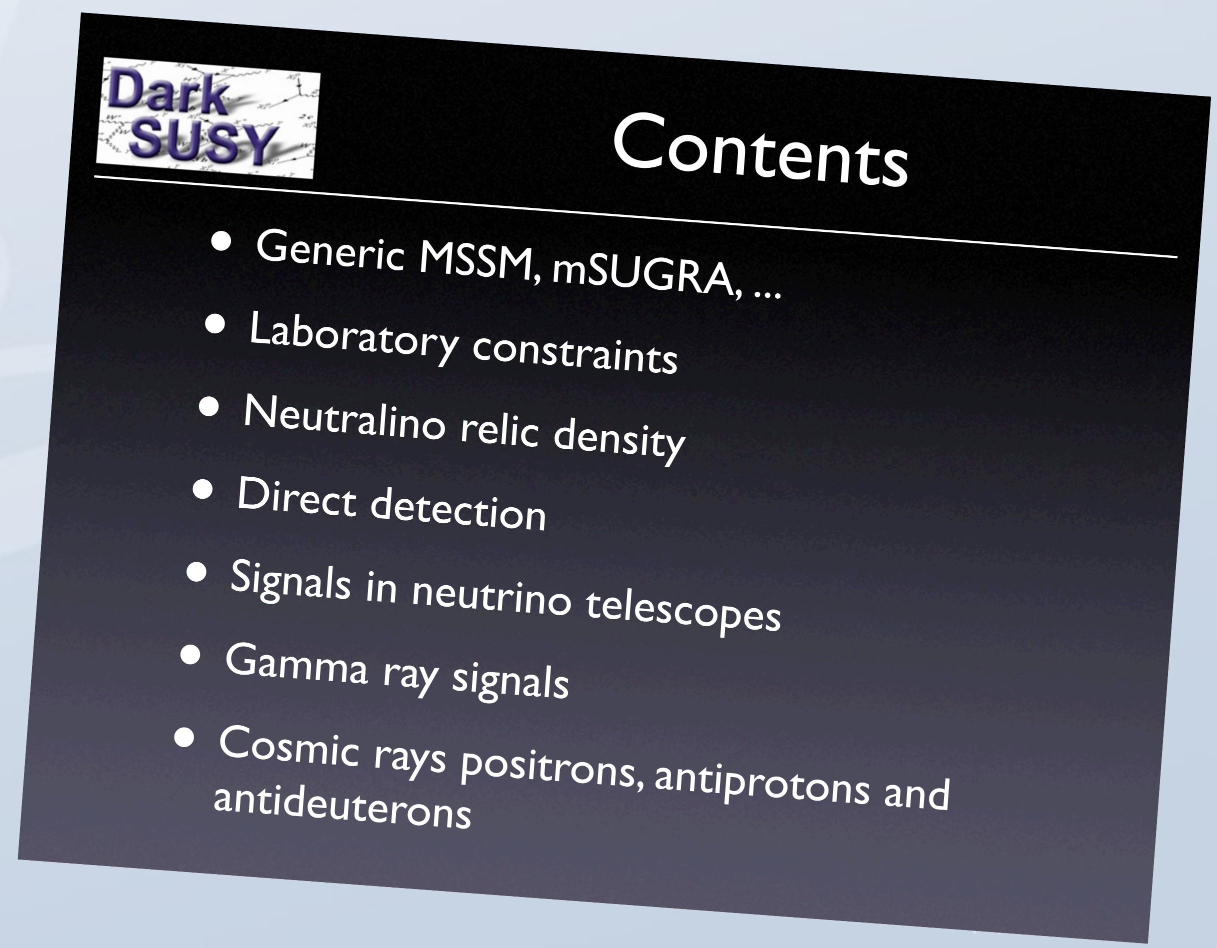
Will focus on supersymmetric neutralinos as dark matter, but most results/ routines are applicable to any WIMP

Slide convention

Physics slides



More technical DarkSUSY slides



Introduction and layout

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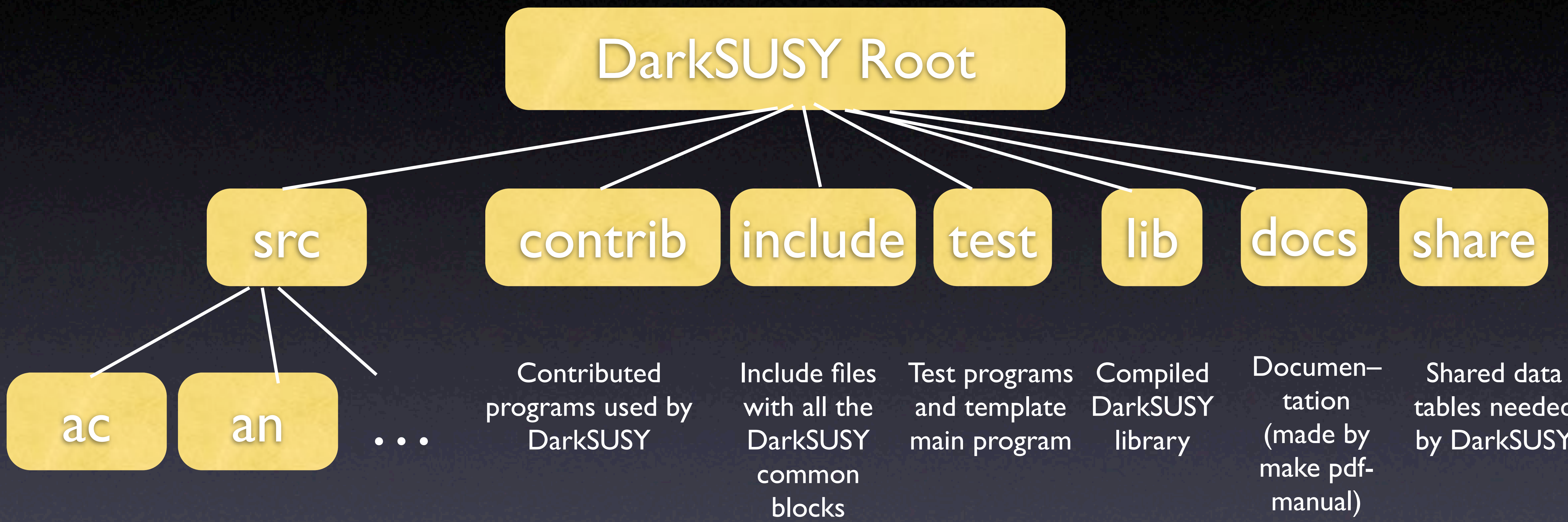
Philosophy

- Modular structure (given the F77 constraints...)
- Library of subroutines and functions
- Fast and accurate
- “Standard” Fortran 77 - works on many platforms
- Flexible
- Version control (subversion) for precise version tagging

Program layout



Here are the main routines of DarkSUSY making up libdarksusy.a

Compile and install

- To compile and install DarkSUSY, do

  ./configure [optional arguments]
  make

- Works on most platforms and with most compilers (gfortran, ifort, ...)

Other options

- Other options can also be given at configure time, e.g. I use

  ./configure F77=ifort FFLAGS= FOPT=-O

  to compile with ifort instead of default Fortran compiler.

Manual

- A manual (not fully up-to date yet and doesn't cover everything) is distributed with DarkSUSY, create with

  make pdf-manual (to make the default manual)

  make pdf-manual-short to make a short version (without subroutine headers).

- Also see the headers of various subroutines for instructions.

[Show manual]

SUSY setup

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SUSY model setup

We work in the framework of the minimal $N = 1$ supersymmetric extension of the standard model defined by, besides the particle content and gauge couplings required by supersymmetry, the superpotential

$$W = \epsilon_{ij}\left(-\hat{\mathbf{e}}_R^*\mathbf{Y}_E\hat{\mathbf{l}}_L^i\hat{H}_1^j - \hat{\mathbf{d}}_R^*\mathbf{Y}_D\hat{\mathbf{q}}_L^i\hat{H}_1^j + \hat{\mathbf{u}}_R^*\mathbf{Y}_U\hat{\mathbf{q}}_L^i\hat{H}_2^j - \mu\hat{H}_1^i\hat{H}_2^j\right) \quad (2)$$

and the soft supersymmetry-breaking potential

$$\begin{aligned} V_{\text{soft}} = \; & \epsilon_{ij}\left(-\tilde{\mathbf{e}}_R^*\mathbf{A}_E\mathbf{Y}_E\tilde{\mathbf{l}}_L^iH_1^j - \tilde{\mathbf{d}}_R^*\mathbf{A}_D\mathbf{Y}_D\tilde{\mathbf{q}}_L^iH_1^j + \tilde{\mathbf{u}}_R^*\mathbf{A}_U\mathbf{Y}_U\tilde{\mathbf{q}}_L^iH_2^j - B\mu H_1^iH_2^j + \text{h.c.}\right) \\ & + H_1^{i*}m_1^2H_1^i + H_2^{i*}m_2^2H_2^i \\ & + \tilde{\mathbf{q}}_L^{i*}\mathbf{M}_Q^2\tilde{\mathbf{q}}_L^i + \tilde{\mathbf{l}}_L^{i*}\mathbf{M}_L^2\tilde{\mathbf{l}}_L^i + \tilde{\mathbf{u}}_R^*\mathbf{M}_U^2\tilde{\mathbf{u}}_R + \tilde{\mathbf{d}}_R^*\mathbf{M}_D^2\tilde{\mathbf{d}}_R + \tilde{\mathbf{e}}_R^*\mathbf{M}_E^2\tilde{\mathbf{e}}_R \\ & + \frac{1}{2}M_1\tilde{B}\tilde{B} + \frac{1}{2}M_2\left(\tilde{W}^3\tilde{W}^3 + 2\tilde{W}^+\tilde{W}^-\right) + \frac{1}{2}M_3\tilde{g}\tilde{g}. \end{aligned} \quad (3)$$

Here i and j are SU(2) indices ($\epsilon_{12} = +1$), $\mathbf{Y}$'s, $\mathbf{A}$'s and $\mathbf{M}$'s are 3×3 matrices in generation space, and the other boldface letter are vectors in generation space.

= 3x3 complex matrices

= complex parameters

How to choose parameters

- The full MSSM-124 has 124 free parameters (including complex phases)
- The goal is to be able to choose all of these arbitrarily
- We are not fully there yet, even if most things can be chosen quite arbitrarily in DarkSUSY
- Currently they have to be real (but not necessarily diagonal)

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Supersymmetric models

- Input parameters at EW scale (MSSM), or
- Input parameters at GUT scale (mSUGRA/CMSSM)
- Higgs sector with FeynHiggs
- Higgs decay widths from literature or from FeynHiggs
- mSUGRA interfaces: ISASUGRA, and other codes via SLHA2 (e.g. softsusy).
- SUSY Les Houches Accord 2 implemented (both read and write)

Routines

- dsgive_model: sets an MSSM-7 model
- dsgive_model13: sets an MSSM-13 model
- dsgive_model_isasugra: sets an mSUGRA model

Typical program

call dsinit

[make general settings]

[determine your model parameters your way]

call dsgive_model [or equivalent]

call dssusy [or equivalent]- to set up DarkSUSY for that model

[then calculate what you want]

*set routines

- Essentially all the packages in DarkSUSY have a corresponding *set routine that determines how those routines are going to be used, which parameter sets to use etc.
- As an example,
  call dshmset('default') chooses the default halo model (NFW)
- All these *set routines are called with the argument 'default' by dsinit, but can be changed later by the user.

Generality of expressions

- We try to be as general as possible when including new physics, but it is hard to be overly general all the time
- Hence, most of our expressions and setups in DarkSUSY are more general than typical use would indicate

General forms

- The sfermion mass parameters can be general 3x3 (real) matrices, even if some other parts of the code (e.g. rare decays) rely on them at least being diagonal
- No GUT relation needs to be assumed for M_1, M_2 and M_3.

Accelerator constraints

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Direct accelerator searches

- Squarks
- Sleptons
- Neutralinos
- Charginos
- Higgs bosons

From PDG (Squarks, Sleptons, Neutralinos, Charginos)

From HiggsBounds (Higgs bosons)

Higher order corrections

- Rare decays, $b \rightarrow s \gamma$, ...
- Magnetic moment of the muon, a_μ
- Invisible width of Z boson

Currently from literature, other tools (SuperIso etc) via SLHA2
Some tools might be interfaced directly with DarkSUSY in the future

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General checks

- Accelerator constraints are most easily checked with a call to

  call dsacbnd(excl)

- excl is non-zero if excluded and the set bits of excl tells why it is excluded.
- For backwards-compatibility, we keep old versions of the accelerator constraints as well, but dsacbnd always points to the latest set of constraints.
- It takes some time for new constraints (or signals!) to make it into the code though.

Meaning of excl

From header of dsacbnd9.f:

```
c      bit set   dec.   oct.   reason
c      -------   ----   ----   ------
c            0      1      1   chargino mass
c            1      2      2   gluino mass
c            2      4      4   squark mass
c            3      8     10   slepton mass
c            4     16     20   invisible z width
c            5     32     40   higgs mass
c            6     64    100   neutralino mass
c            7    128    200   b -> s gamma
c            8    256    400   rho parameter
c            9    512   1000   (g-2)_mu
```

Likelihoods

- We are working on going away from hard cuts to likelihoods when possible
- For example, in the soon to be released DarkSUSY 5.0.6 we will include IceCube likelihoods (see Pat's talk later today).

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Relic density

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DarkSUSY implementation

- We solve the Boltzmann equation,

$$\frac{dn}{dt} = -3Hn - \langle \sigma_{\mathrm{eff}} v \rangle \left(n^2 - n_{\mathrm{eq}}^2 \right)$$

numerically, calculating the thermally averaged annihilation cross section,

$$\langle \sigma_{\mathrm{eff}} v \rangle = \frac{\int_0^\infty dp_{\mathrm{eff}} p_{\mathrm{eff}}^2 W_{\mathrm{eff}} K_1 \left(\frac{\sqrt{s}}{T} \right)}{m_1^4 T \left[\sum_i \frac{g_i}{g_1} \frac{m_i^2}{m_1^2} K_2 \left(\frac{m_i}{T} \right) \right]^2}$$

$$W_{\mathrm{eff}} = \sum_{ij} \frac{p_{ij}}{p_{11}} \frac{g_i g_j}{g_1^2} W_{ij} \quad ; \quad W_{ij} = 4 E_1 E_2 \sigma_{ij} v_{ij}$$

in every step using tabulated $W_{\mathrm{eff}}(p)$.

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Relic density routines

- The main routine for SUSY neutralinos is dsrdomega that calculates the relic density of neutralinos
- However, the relic density routines are more general than that and can be used for any WIMP with a call to dsrdens.

How to call dsrdens for general WIMPs

Call

dsrdens(wrate,npart,mgev,dof,nrs,rm,rw,nt,tm,oh2,tf,ierr,iwar)

where you have to supply

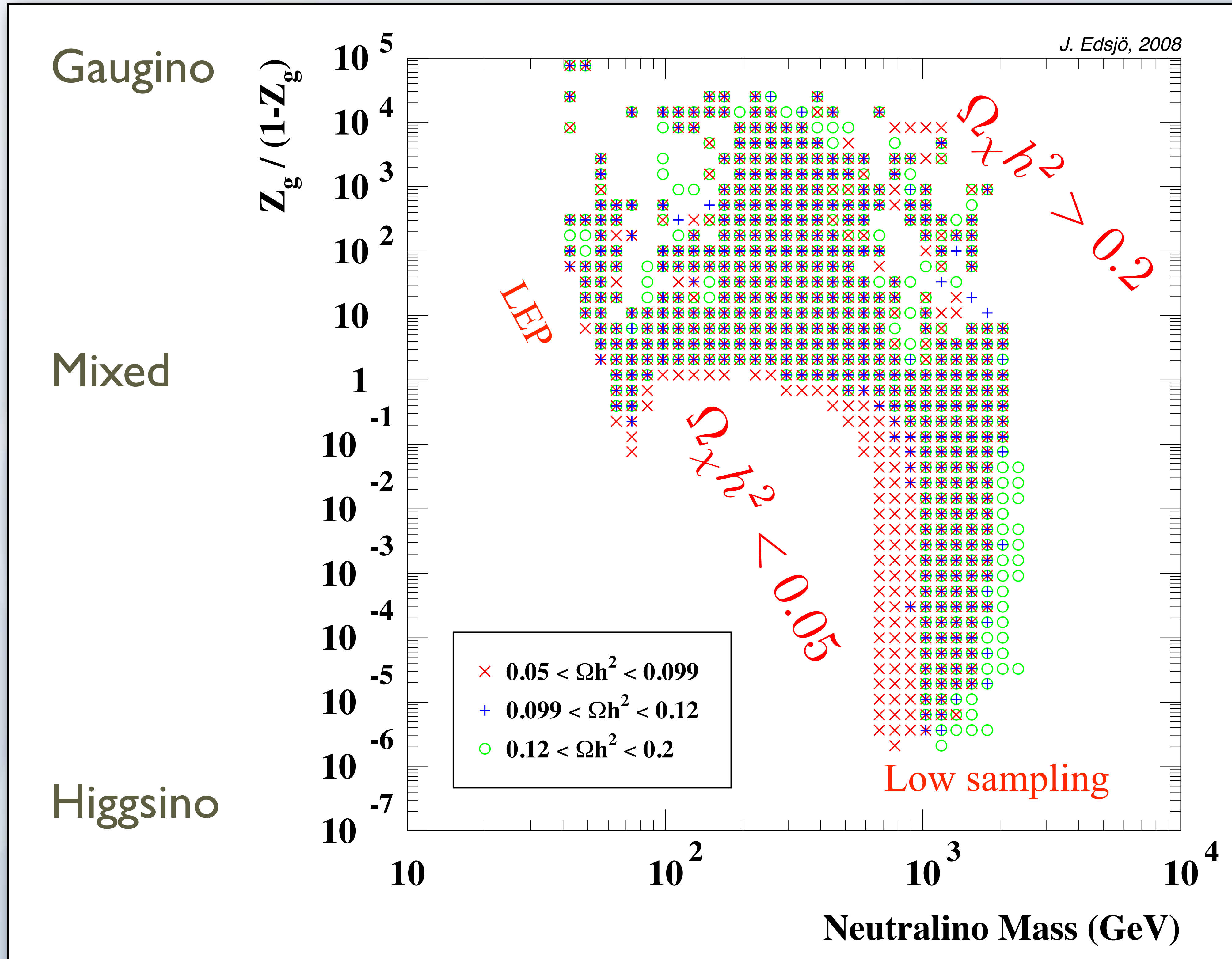
- wrate - invariant effective annihilation rate (function)
- npart - number of coannihilating particles
- mgev - mass of these
- dof - internal degrees of freedom of these
- nrs - number of resonances
- rm - mass of resonances
- rw - width of resonances
- nt - number of thresholds
- tm - equivalent mass of thresholds

The routine then returns

- oh2 - omega h^2
- tf - freeze-out temperature

Note: All this is taken care of for neutralinos in dsrdomega

The $m_\chi - Z_g$ parameter space



Direct detection

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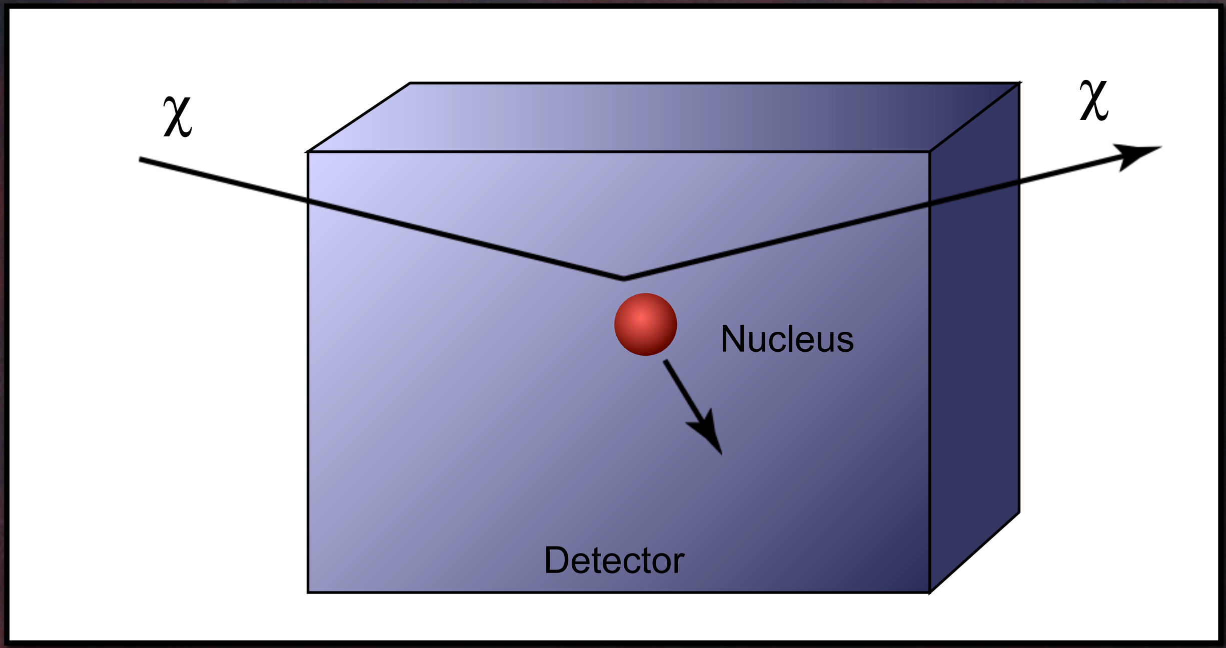
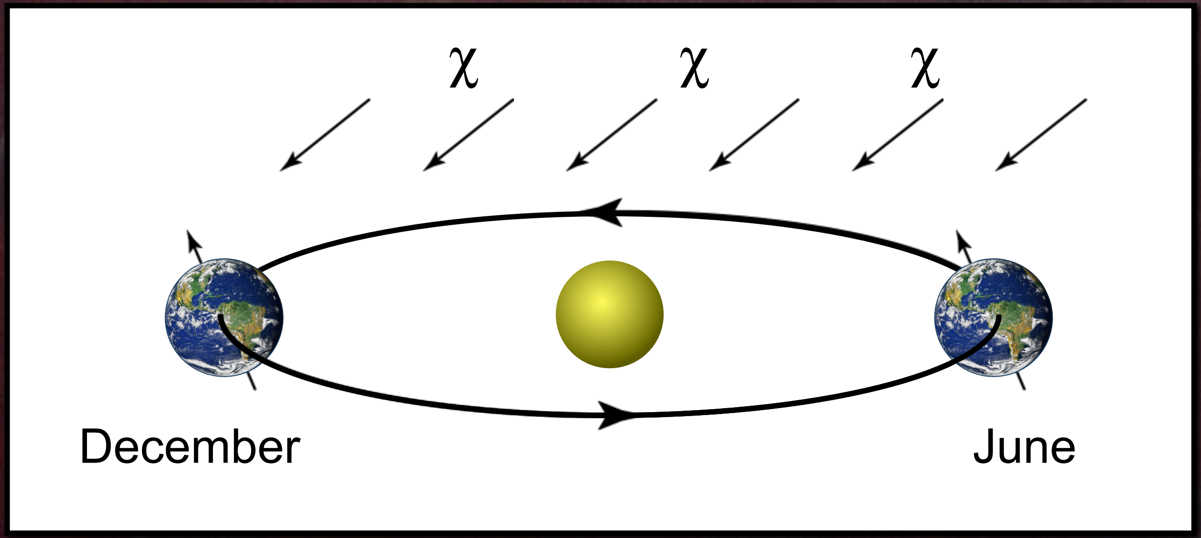
Direct detection

general principles



- WIMP + nucleus → WIMP + nucleus
- Measure recoil energy
- Suppress background enough to be sensitive to a signal, or...



- Search for an annual modulation due to the Earth's motion in the halo

Event rates

$$\frac{dR}{dQ} = \frac{\sigma_0 \rho_0}{2 m_\chi m_r^2} F^2(Q) \int_{v_{\min}}^{\infty} \frac{f(v)}{v} dv$$

with

$$\begin{aligned} Q &= \frac{|\mathbf{q}|^2}{2m_N} = \frac{m_r^2 v^2}{m_N}(1 - \cos\theta_{CM}) \\ v_{\min} &= \sqrt{\frac{Q m_N}{2 m_r^2}} \\ m_r &= \frac{m_\chi m_N}{m_\chi + m_N} \end{aligned}$$

$F(Q)$ – form factor

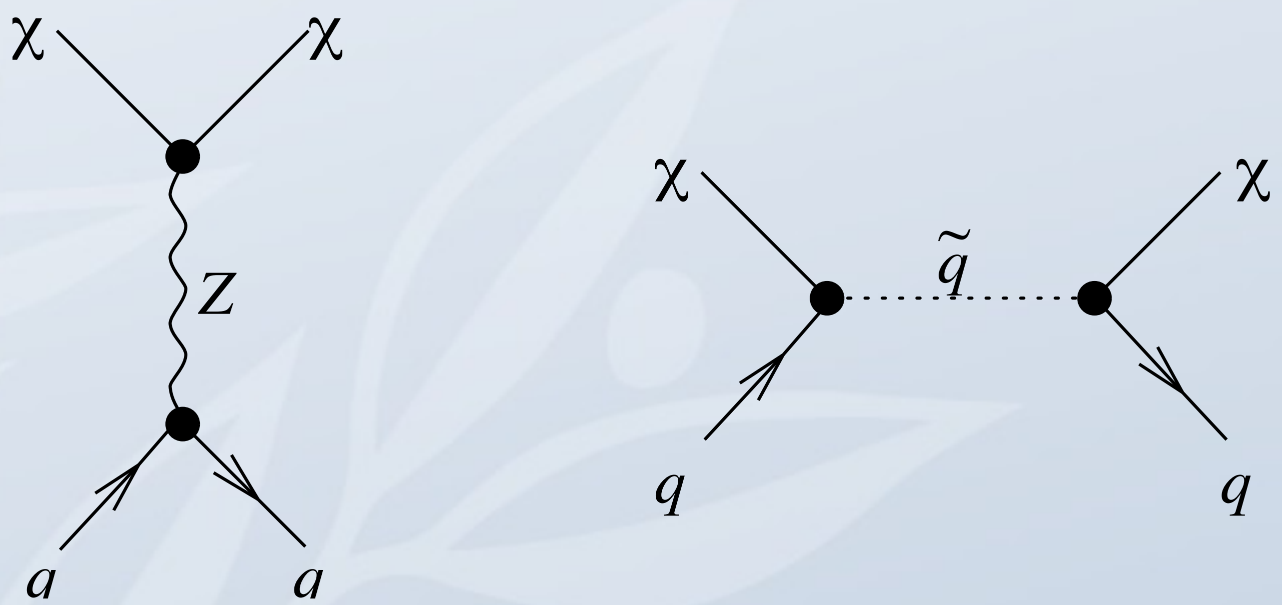
σ_0 – elastic scattering cross section

ρ_0 – local dark matter density (~ 0.3 GeV/cm^3)

$f(v)$ – velocity distribution

Spin-dependent (SD) scattering

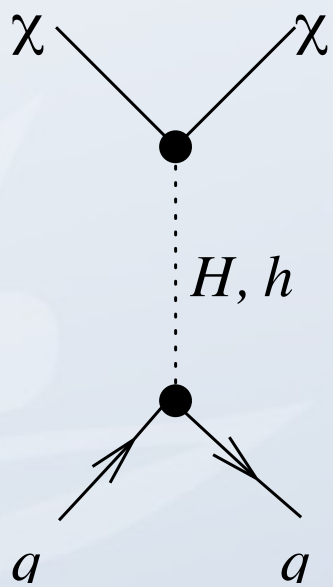
- Spin-dependent scattering, couples to the total spin of the nucleus

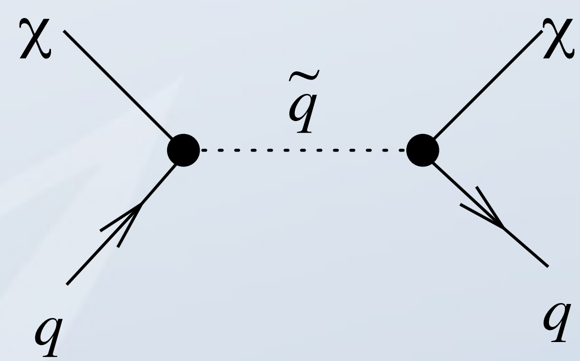


- Not all target nuclei have spin

Spin-independent (SI) scattering

- Couples to all nucleons in the nucleus coherently





$$\sigma = \sigma_p^{\mathrm{SI}} A^2 \left(\frac{M_\chi m_N}{M_\chi + m_N} \right)^2 \left(\frac{M_\chi m_\mathrm{p}}{M_\chi + m_\mathrm{p}} \right)^{-2}$$

~A^4

Differential rate as A^2 / bin

Scattering cross section on proton

Coherence factor

Phase space factor (kinematics)

Form factor suppression (decoherence) adds on top of this though, taking some of the enhancement away.

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Direct detection

- Routines to calculate the spin-independent and spin-dependent scattering cross sections on protons and neutrons. These are most easily used to compare with experimental results.
- Also routines to calculate the differential rates on various targets including both spin-independent and spin-dependent form factors.
- Halo model and velocity distribution can be chosen arbitrarily
- Annual modulation signal can be calculated
- Different sets of form factors available

Direct detection routines

- **dsddneunuc:** calculates the spin-independent and spin-dependent scattering cross sections on neutrons and protons.
- **dsdddrde:** calculates the differential scattering rate on various targets as a function of time (can be used to predict annual modulation signals e.g.)

Indirect detection – gamma rays

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Annihilation channels

- As we are very interested in trying to observe the annihilation products from dark matter annihilation, we need to investigate what they are. Some of the relevant are:

$$\chi\chi \rightarrow \begin{cases} b\bar{b} \\ t\bar{t} \\ \tau^-\tau^+ \\ W^-W^+ \\ Z^0Z^0 \\ \nu_\alpha\bar{\nu}_\alpha \\ H^\pm W^\pm \\ H_i^0 Z^0 \end{cases}$$

Note: ν final states are absent for neutralinos

- These will hadronize/decay and produce electrons, positrons, antiprotons, gamma rays, neutrinos etc
- As the neutralino is a Majorana fermion, the annihilation cross section to fermions go as

$$\sigma_{f\bar{f}} \propto \frac{m_f^2}{m_\chi^2}$$

which means that we will be dominated by the heavy fermions (b and t quarks).

- Yield calculated with Pythia and tabulated for use by DarkSUSY.

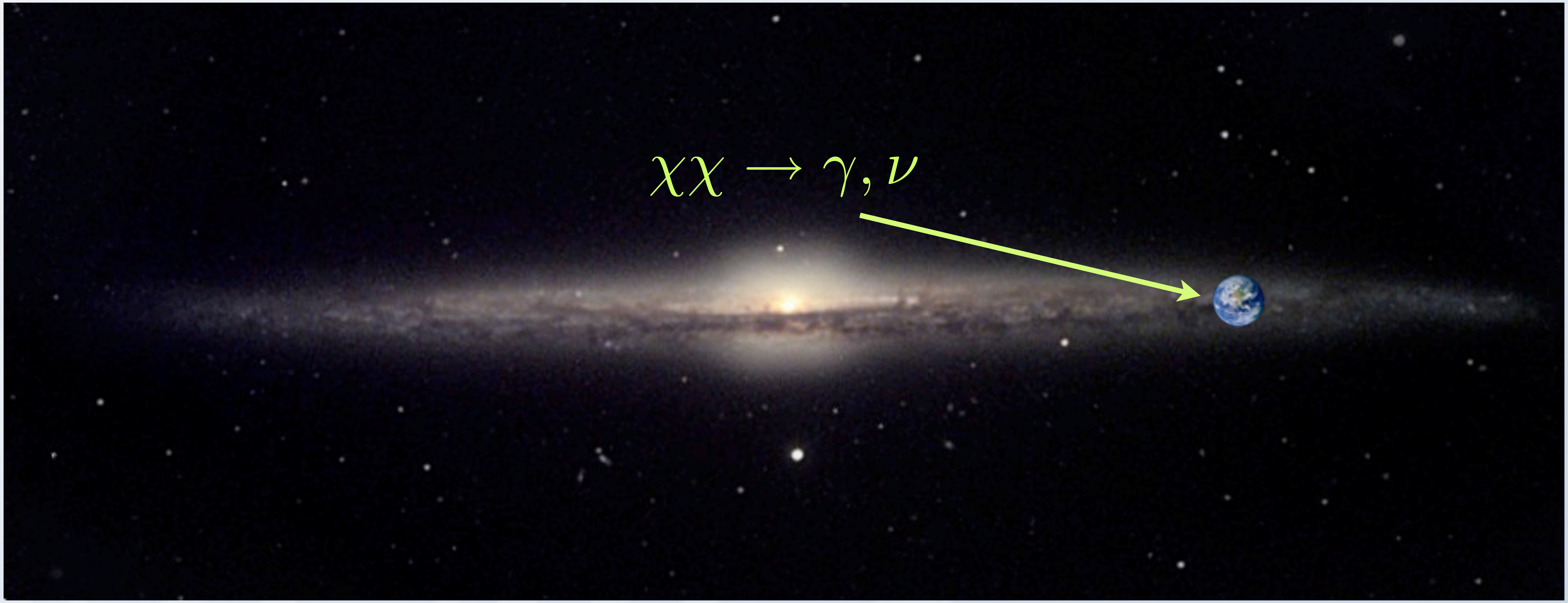
Indirect rates

- Gamma rays from the halo
- Antiprotons from the halo
- Antideuterium from the halo
- Positrons from the halo
- Neutrinos from the Sun/Earth

Gamma rays
spectral components from dark matter

- Continuum emission (from quark jets, π^0's)
- Line emission ($\gamma\gamma$ and $Z\gamma$)
- Internal bremsstrahlung photons
- Inverse Compton Scattering from charged particles (not directly in DS yet)

Annihilation in the halo



- Gamma rays can be searched for with e.g. Air Cherenkov Telescopes (ACTs) or Fermi-LAT (launched June, 2008).
- Signal depends strongly on the halo profile,

$$\Phi \propto \int_{\text{line of sight}} \rho^2 dl$$

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Gamma ray fluxes from the halo

We can write the flux as

$$\Phi_\gamma(\eta, \Delta\Omega) = 9.35 \cdot 10^{-14} S \times \langle J(\eta, \Delta\Omega) \rangle \ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}$$

with

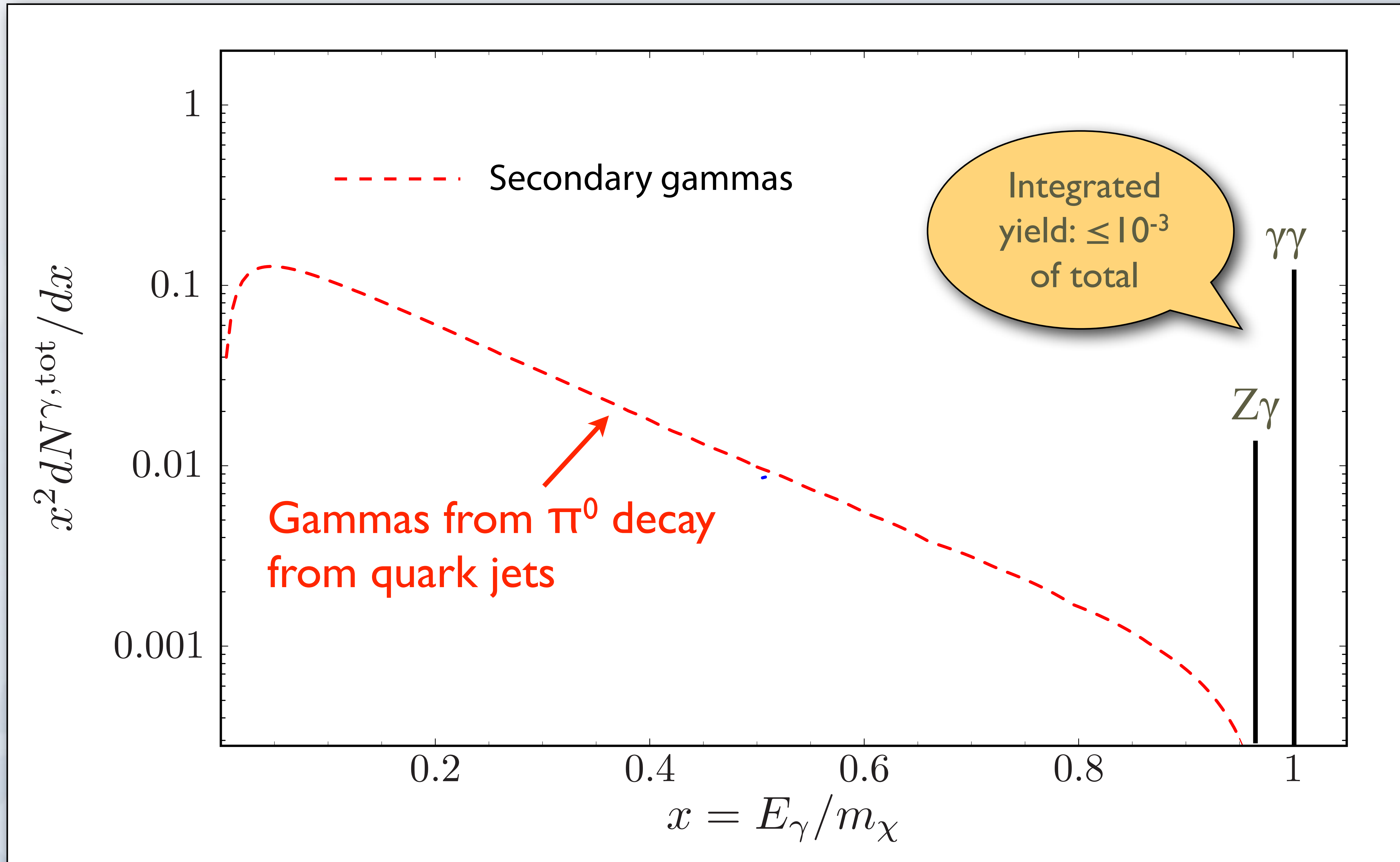
$$S = N_\gamma \frac{\langle \sigma v \rangle}{10^{-29}\ \mathrm{cm}^3\ \mathrm{s}^{-1}} \left(\frac{100\ \mathrm{GeV}}{m_\chi} \right)^2$$

Particle physics (SUSY, ...)

$$\langle J(\eta, \Delta\Omega) \rangle = \frac{1}{8.5\ \mathrm{kpc}} \frac{1}{\Delta\Omega} \int_{\Delta\Omega} \int_{\text{line of sight}} \left(\frac{\rho(l)}{0.3\ \mathrm{GeV/cm}^3} \right)^2 dl(\eta) d\Omega$$

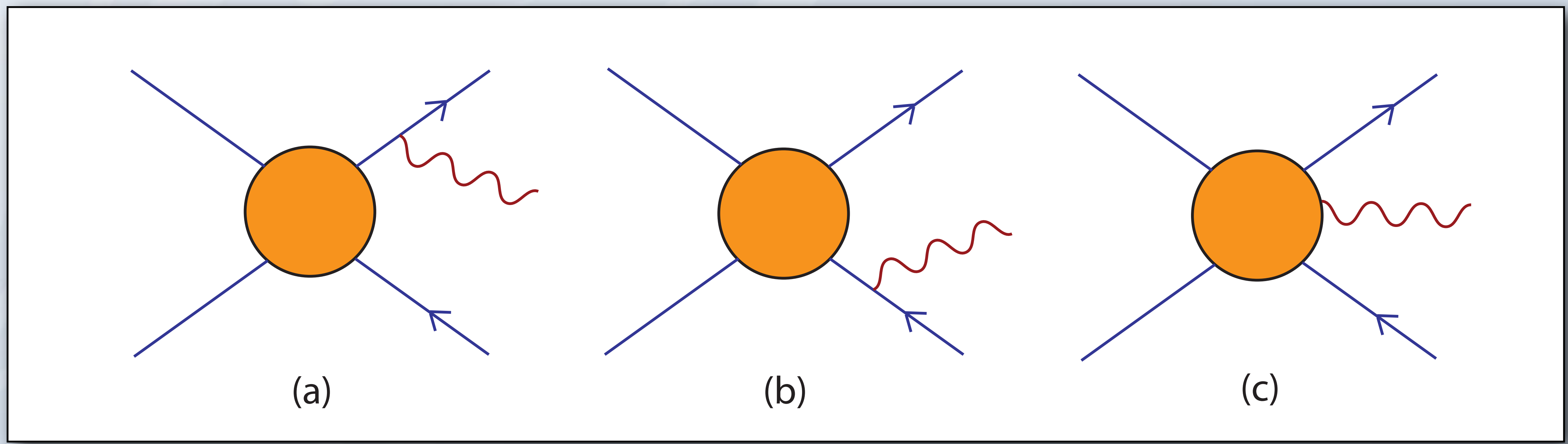
Astrophysics

Typical gamma ray spectrum



Internal Bremsstrahlung

- Whenever charged final states are present, photons can also be produced in internal bremsstrahlung processes



See Bergström, PLB 225 (1989) 372 and later work

Contributions to the gamma flux

- We can write the contributions to the gamma flux as

$$\frac{dN^{\gamma,\mathrm{tot}}}{dx} = \sum_f B_f \left(\frac{dN_f^{\gamma,\mathrm{sec}}}{dx} + \frac{dN_f^{\gamma,\mathrm{IB}}}{dx} + \frac{dN_f^{\gamma,\mathrm{line}}}{dx} \right)$$

- How large are these different contributions?

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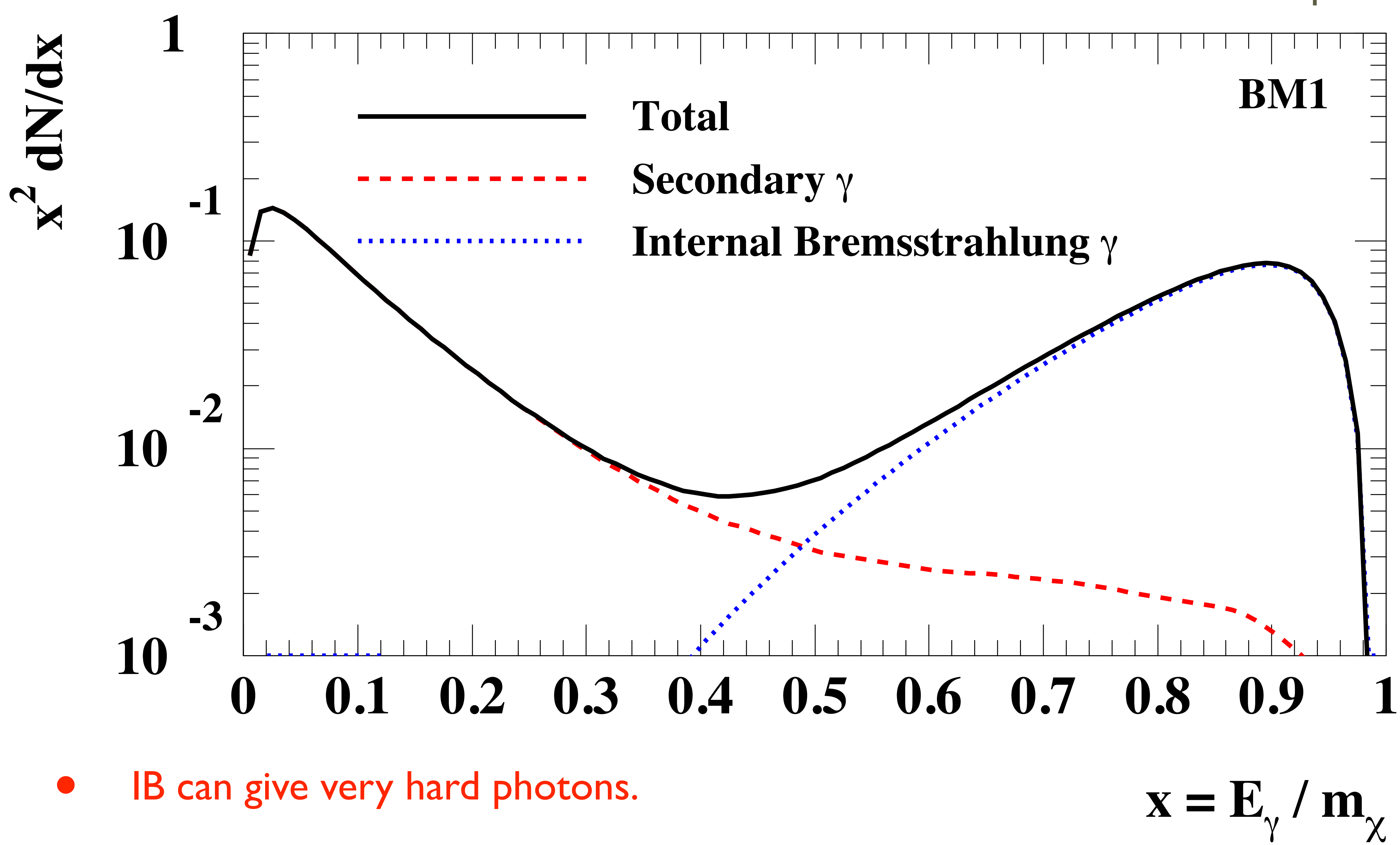
Gamma ray spectrum including IB photons I

Neutralino mass: m_χ = 1396 GeV

IB from stop exchange



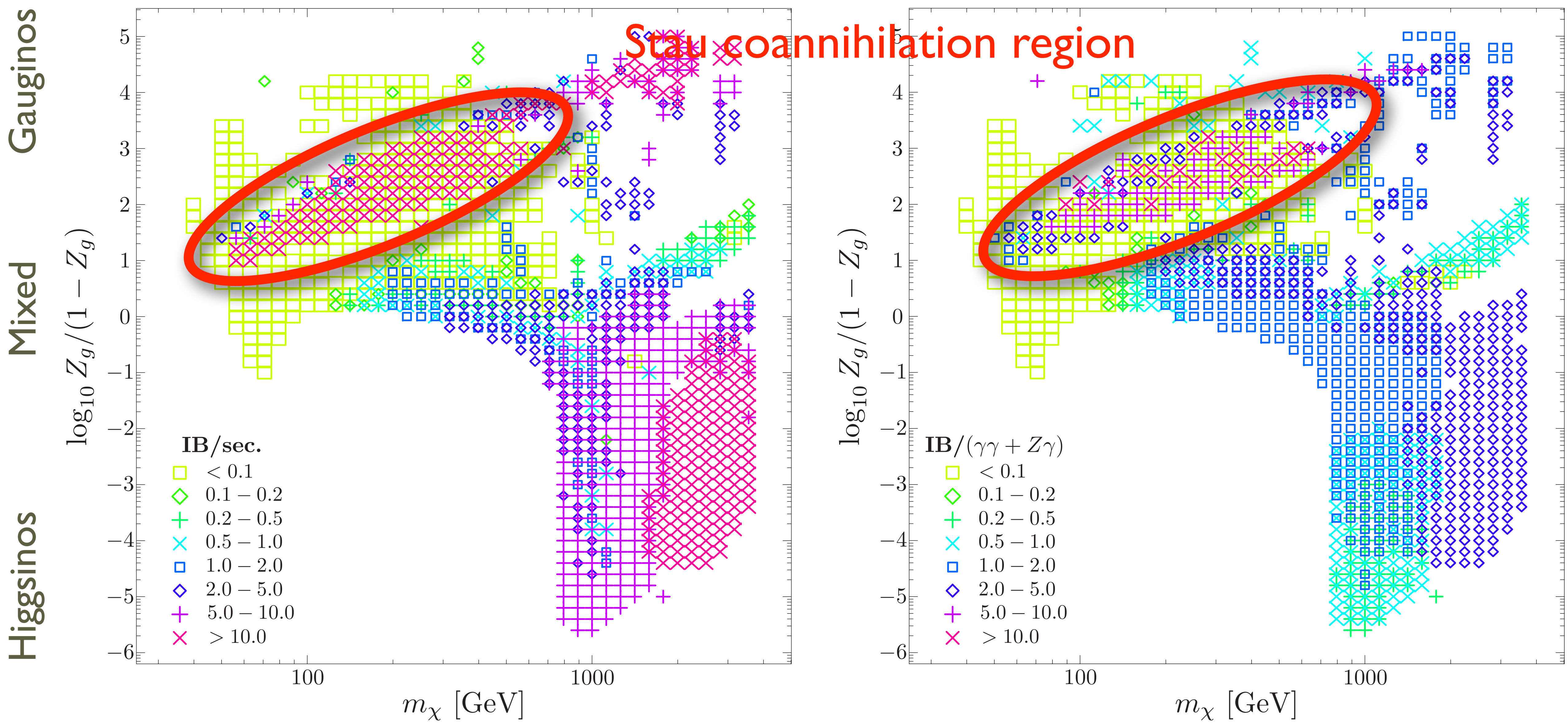
- IB can give very hard photons.
- Dramatic at high energies!

T. Bringmann, L. Bergström and J. Edsjö, arXiv: 0710.3169, JHEP 01 (2008) 049

Internal Bremsstrahlung

When is it important?

MSSM and mSUGRA scans



All models OK with WMAP and accelerator constraints. IB>$0.6m_\chi$

T. Bringmann, L. Bergström and J. Edsjö, arXiv: 0710.3169, JHEP 01 (2008) 049

Halo profiles

- A common spherically symmetric parameterization is

$$\rho(r) = \frac{\rho_s}{(r/a)^\gamma[1 + (r/a)^\alpha]^{(\beta-\gamma)/\alpha}}$$

with e.g.

Profile	**α**	**β**	**γ**
NFW	1	3	1
Isothermal	2	2	0

In principle, any distribution function (like a data file) can be used.

Halo profiles

- Any spherically symmetric profile can be entered into DarkSUSY. Presets are available for
  - NFW
  - Moore
  - Burkert
  - Adiabatically contracted profiles
  - Isothermal sphere
- In principle, a corresponding velocity distribution should be set simultaneously and DarkSUSY is set up to do this.
- Halo profiles are set with dshmset('name')

Indirect detection – charged cosmic rays

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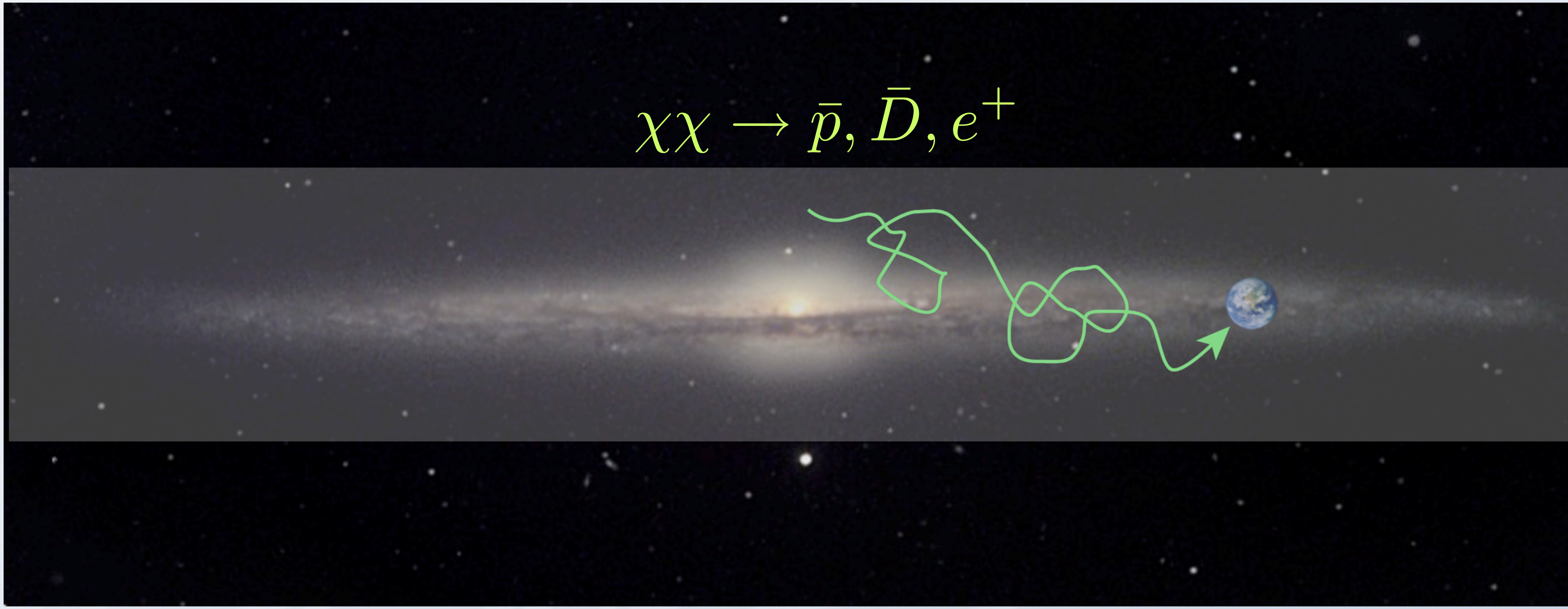
Indirect rates

- Gamma rays from the halo
- Antiprotons from the halo
- Antideuterium from the halo
- Positrons from the halo
- Neutrinos from the Sun/Earth

Diffusion model



- Cylindrical diffusion model with free escape at the boundaries
- Energy losses on the interstellar medium (for antiprotons and antideuterons) or starlight and CMB (for positrons)
- Reacceleration can change the energy of the particles (can partly be mimicked by a break in the diffusion coefficient)

Diffusion equation

$$\partial_z \left(V_C \, \psi\right) - K \, \Delta\psi + \partial_E \left\{ b^{\rm loss}(E) \, \psi - K_{EE}(E) \, \partial_E \psi \right\} = Q\left(\mathbf{x}, E\right)$$

Wind — Spatial diffusion — Energy losses — Energy diffusion (reacceleration) — Source term

$$K(E) = K_0 \, \beta \, \left(\mathcal{R}/1 \, \mathrm{GV}\right)^{\delta}$$

$$K_{EE} = \frac{2}{9} \, V_a^2 \, \frac{E^2 \beta^4}{K(E)}$$

$$Q(\mathbf{x}, E) \propto \rho^2 \langle \sigma v \rangle \frac{dN}{dE}$$

As the source term depends on the DM density squared, we are very sensitive to the halo profile and substructure.

Diffusion parameters

- The most important diffusion parameters are

  K_0 (D_0) – diffusion coefficient

  δ – exponent for energy dependence of diffusion coefficient

  L – diffusion zone half height

- In addition, more parameters are needed for energy losses, galaxy radial extent, etc

Diffusion model solving

- Either one solves the diffusion equation analytically (requires some simplifying assumptions), or
- One solves it numerically, with all possible effects included.

Analytical solution

- Simplified axial symmetry (typically)
- Sometimes infinite radial extent of the diffusion zone
- Simplifying assumptions on reacceleration (diffusion in momentum space) and energy losses

+ Fast
+ Can give better understanding of what is going on

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Numerical solutions

- + Can include all possible effects, different form of the diffusion coefficient, energy losses etc
- + Can include full 3D galaxy
- + "Easy" to include complementary signals, Inverse Compton gammas, synchrotron etc
- - Slow

In both the analytical and numerical solutions, for a given halo model and propagation model, one can solve for the Green's functions once and for all, and just get the energy at Earth via a simple integral

$$\frac{d\Phi}{dE} \propto \int_0^{m_\chi} G(E')\frac{dN}{dE'}dE'$$

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Propagation

- There are at least 2–3 public codes:
  - Galprop (numerical)
  - USINE (semi-analytical), first release 2012?
  - Dragon (numerical)
- All of which should have interfaces to DarkSUSY and other signal codes. Rudimentary galprop interface in place. Usine interface in next DarkSUSY version (if Usine public by then).

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Routines in DarkSUSY

- Analytical expressions to calculate fluxes of
  - antiprotons
  - antideuterons
  - positrons
- Also, an interface to use Galprop (for experts only). More and better interfaces to come (Usine when made public).
- Typically, we produce many antiprotons and some antideuterons compared to background (antideutrons show a clearer signal at low energy). Positron signal usually smaller, but with more features.

Antideuterons

- Compared to antiprotons, the background of antideuterons is essentially zero at low energies.
- Search for a signal at e.g. 0.1-0.4 GeV, either in the solar system, but preferably in interstellar space.

- AMS launched in 2011
- Future: GAPS (Gaseous AntiParticle Spectrometer Mori et al., ApJ 566 (2002) 604).

F. Donato, N. Fornengo and P. Salati,, Phys. Rev. D62 (2000) 043003.

Positron fluxes from neutralinos

- Compared to antiprotons,
  - energy losses are much more important
  - higher energies due to more prompt annihilation channels (ZZ, W^+W^-, etc)
  - propagation uncertainties are higher
  - solar modulation uncertainties are higher

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Indirect detection – neutrinos

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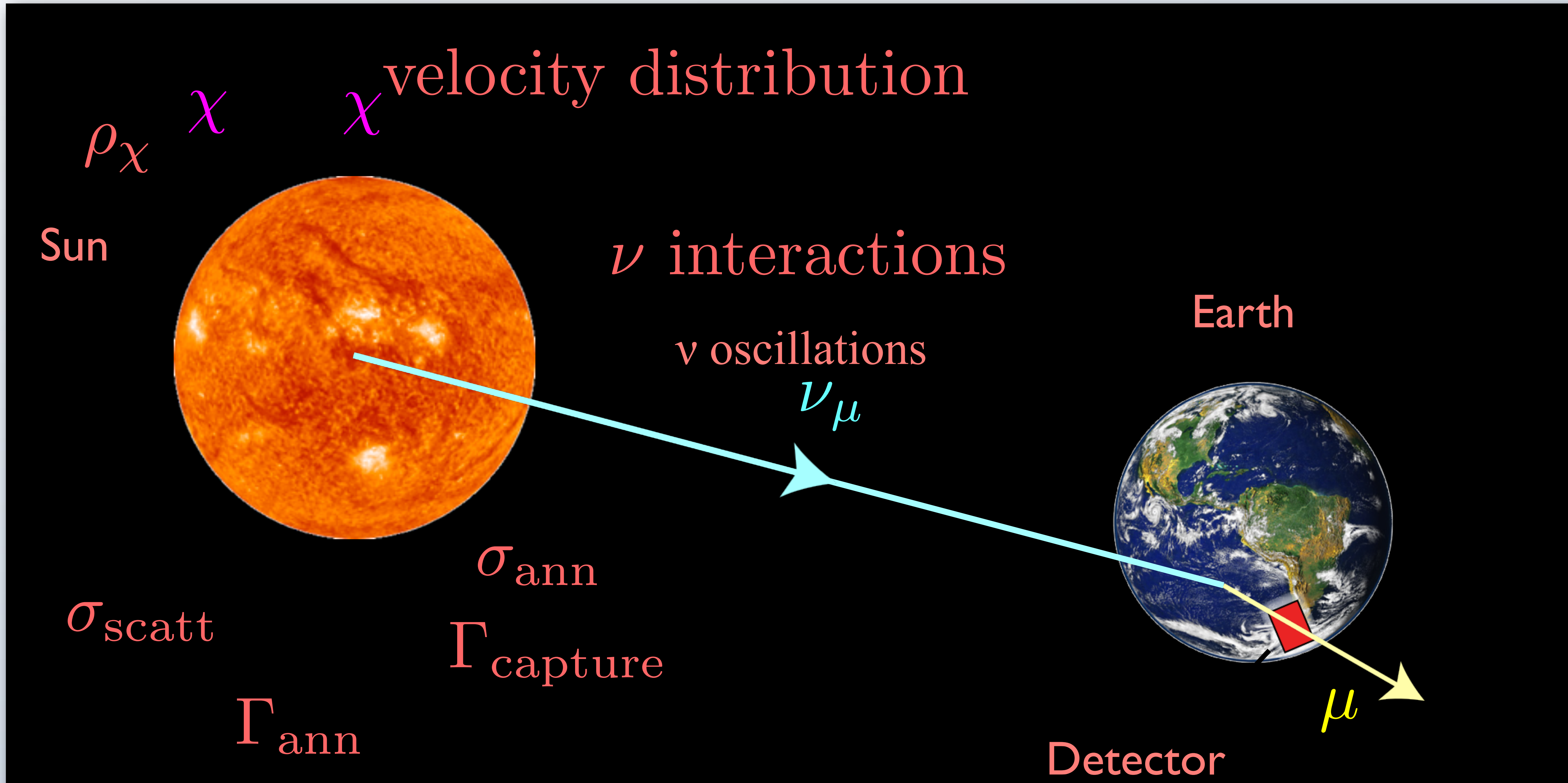
Indirect rates

- Gamma rays from the halo
- Antiprotons from the halo
- Antideuterium from the halo
- Positrons from the halo
- Neutrinos from the Sun/Earth

Neutralino Capture

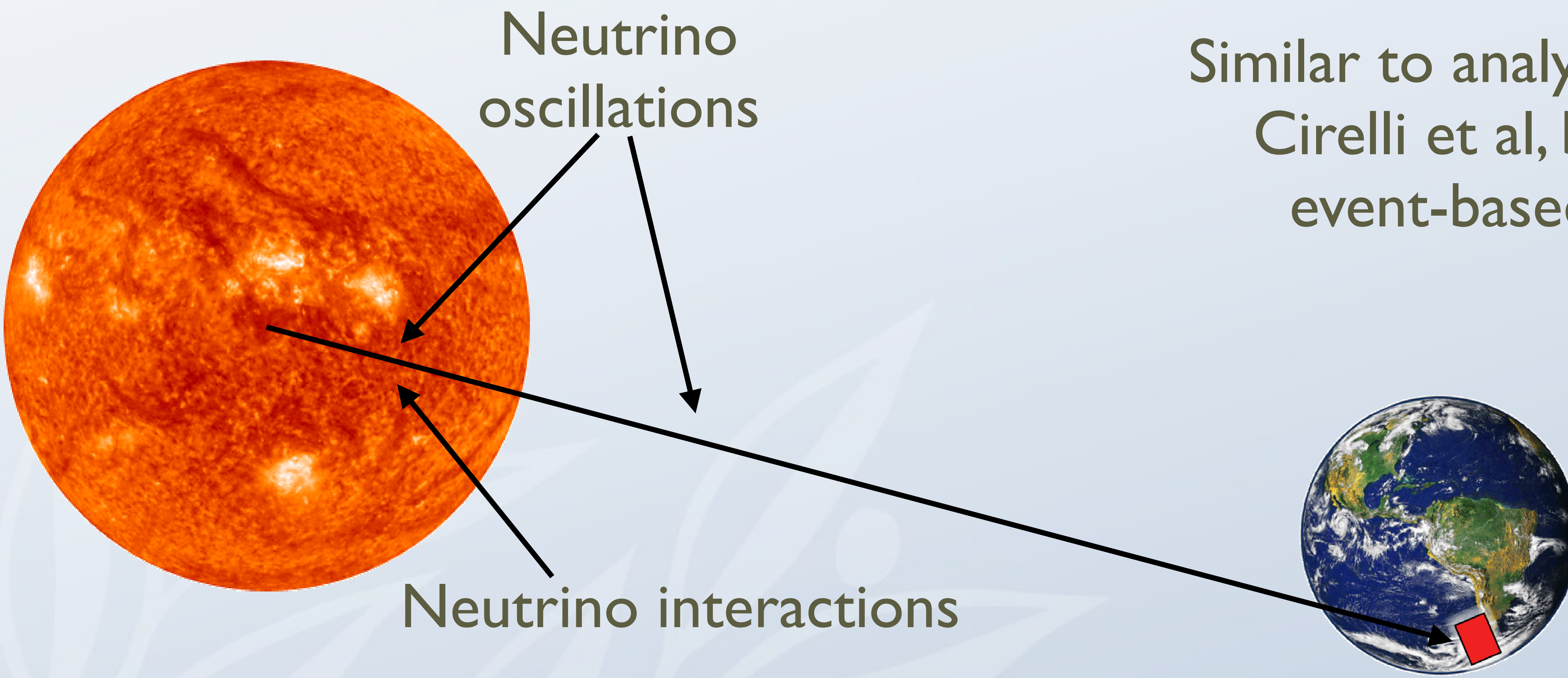


Freese '86
Krauss, Srednicki & Wilczek '86
Gaisser, Steigman & Tilav '86

Silk, Olive and Srednicki '85
Gaisser, Steigman & Tilav '86

M. Blennow, J. Edsjö and
T. Ohlsson, JCAP01 (2008) 021

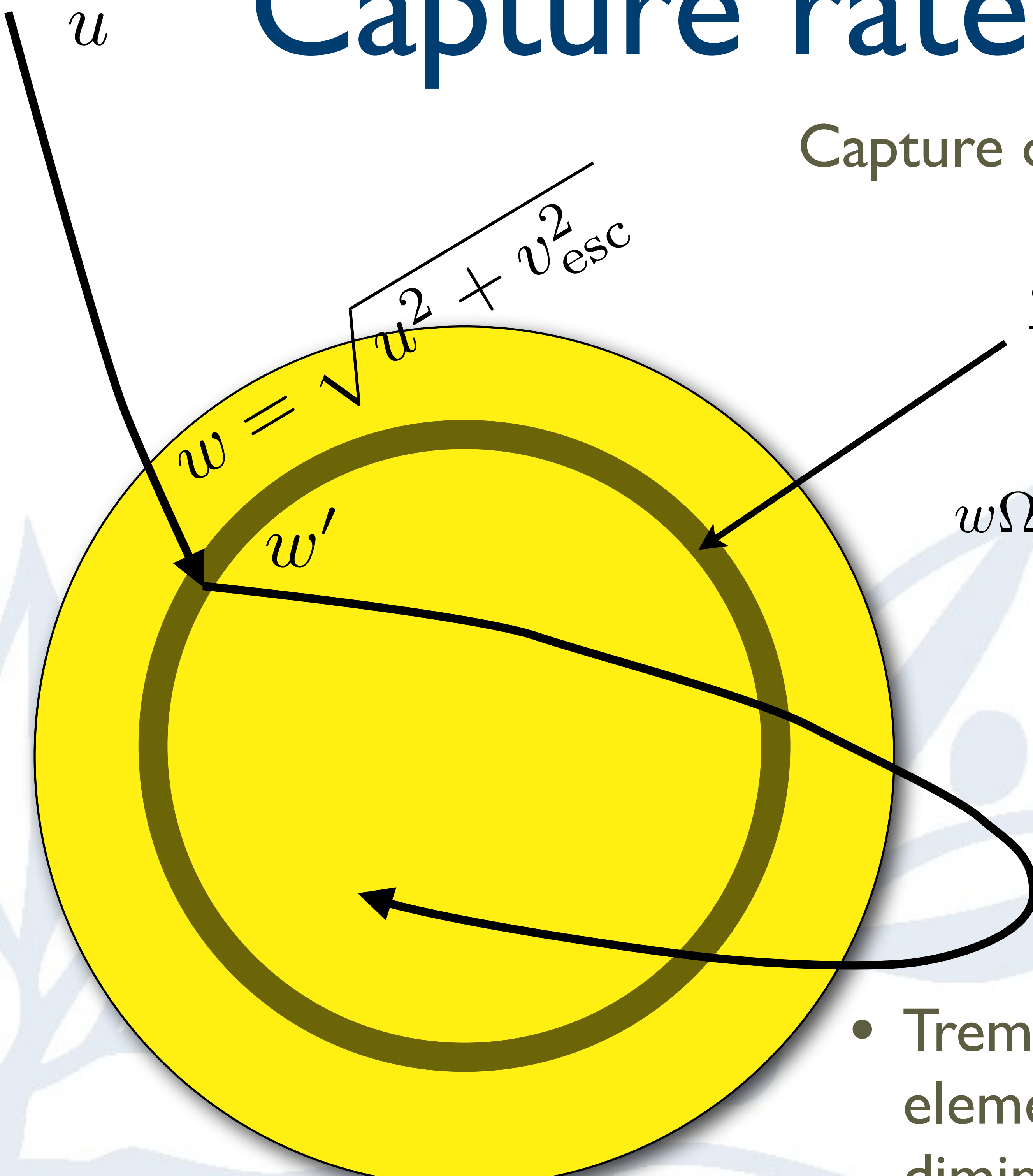
Neutrino oscillations



Similar to analysis of Cirelli et al, but event-based.

- New numerical calculation of interactions and oscillations in a fully three-flavour scenario. Regeneration from tau leptons also included.
- **Publicly available code:** WimpSim: WimpAnn + WimpEvent suitable for event Monte Carlo codes: www.fysik.su.se/~edsjo/wimpsim
- Main results are included in DarkSUSY.

Capture rate calculation



Capture on element i in volume element

$$\frac{dC_i}{dV} = \int_0^{u_{max}} \mathrm{d}u \frac{f(u)}{u} w\Omega_{v,i}(w),$$

$$w\Omega_{v,i} \propto \sigma_{\chi i} n_i(r) P(w' < v_{\text{esc}})[\text{FF suppr.}]$$

~A² ~A²

~A⁴

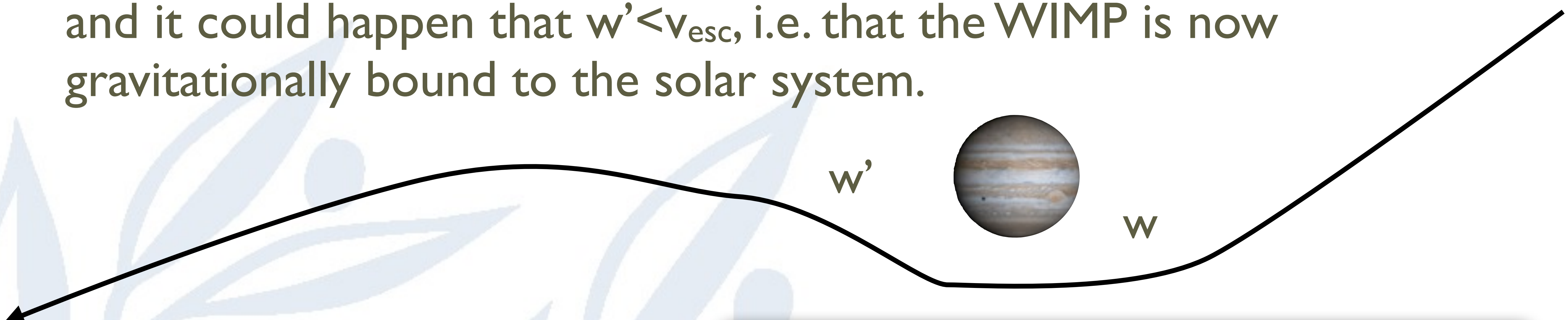
- Tremendous enhancements for heavy elements in the Sun. The form factor diminishes it somewhat though by reducing the first A^2.
- Low velocity WIMPs are easier to capture.

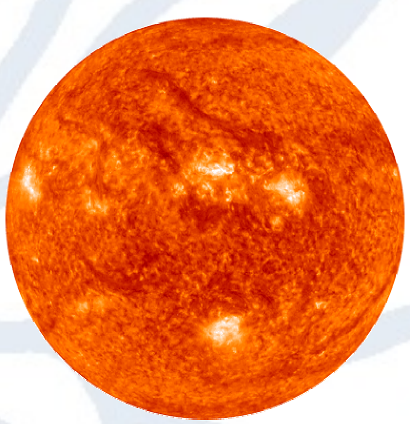
DM diffusion in the solar system

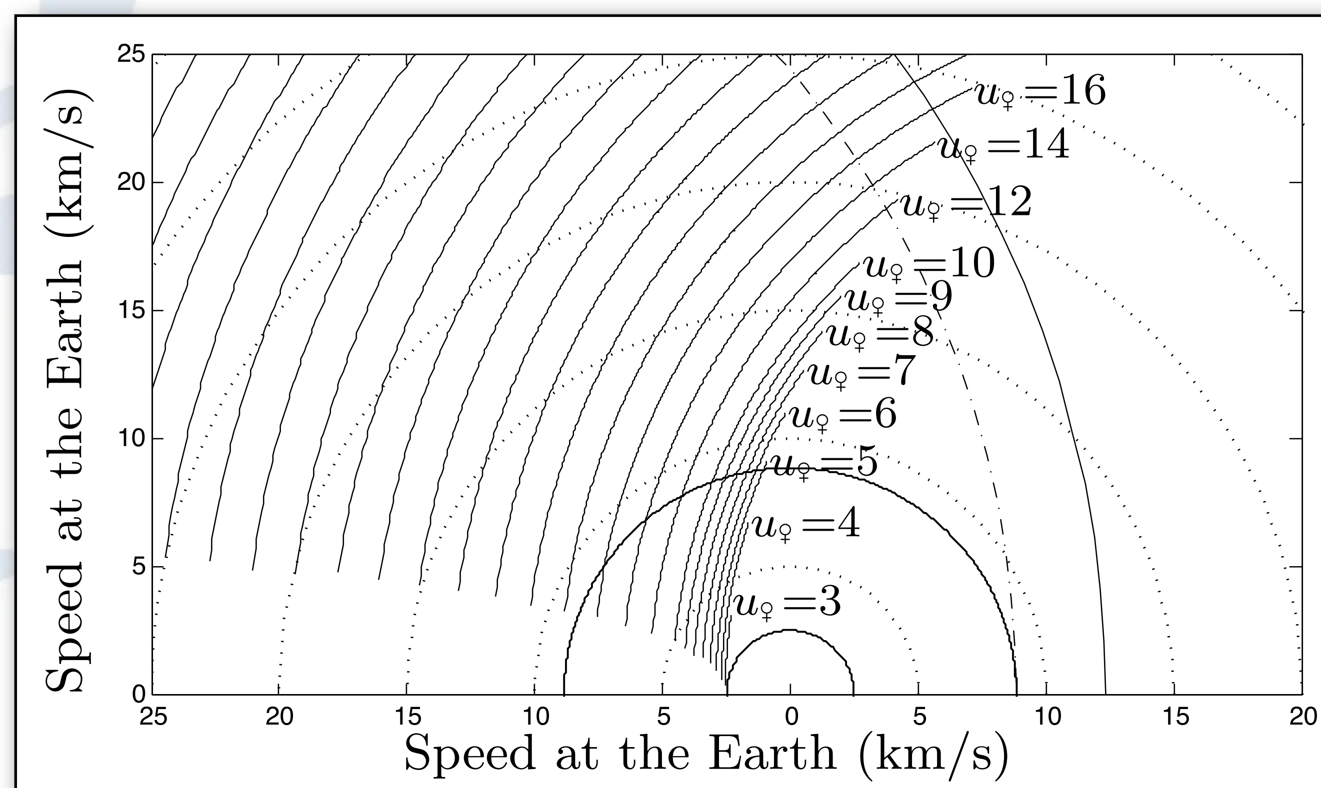
- DM particles are affected by the Sun and the planets (gravitational diffusion) in the course of being captured.
- See Gould '91, Lundberg & Edsjö '04, Peter '09, Sivertsson & Edsjö '12 for more details

Diffusion by planets, e.g. Jupiter

- In **Jupiter**'s frame of reference: w=w'
- In the **Sun**'s frame of reference, w'≠w (since Jupiter is moving) and it could happen that w'<v_{esc}, i.e. that the WIMP is now gravitationally bound to the solar system.



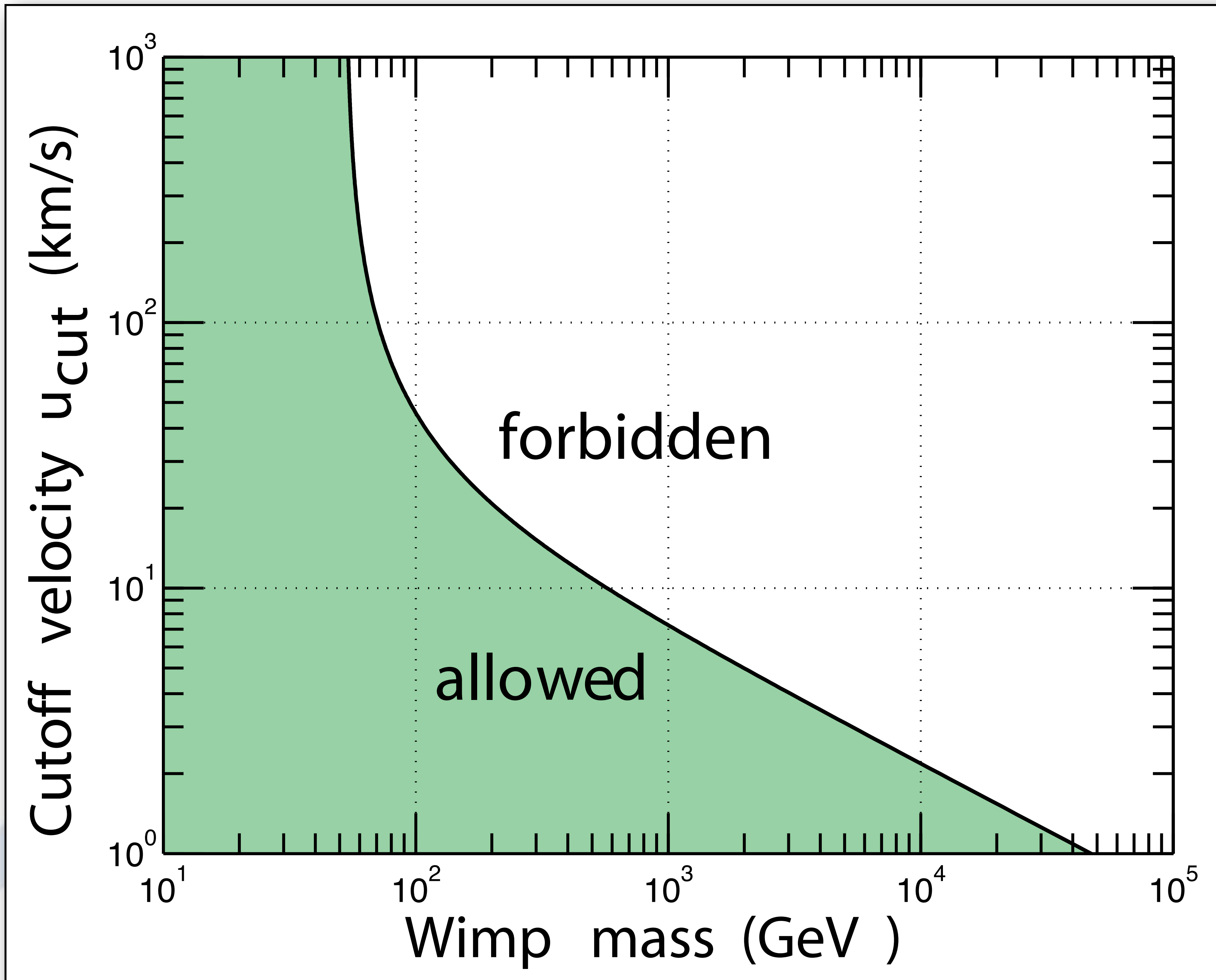




Earth Capture

Why are low velocities needed?

- Capture can only occur when a WIMP scatters off a nucleus to a velocity less than the escape velocity



For capture on Fe, we can only capture WIMPs if the velocity is lower than

$$u_{\rm cut} = 2\frac{\sqrt{M_\chi M_{Fe}}}{M_\chi - M_{Fe}} v_{\rm esc}$$

or, alternatively, for a given lowest velocity, we can only capture WIMPs up to a maximal mass.

WIMP diffusion revisited

- Many processes (solar depletion, Jupiter depletion, ...) can in principle affect the capture rates
- However, if one includes also reverse effects, like repopulation of WIMPs via weak capture in the Sun, these effects are essentially cancelled
- Capture in the Sun and Earth almost as if in free space!

Sivertsson and Edsjö, arXiv:1201.1895, PRD85(2012)123514.

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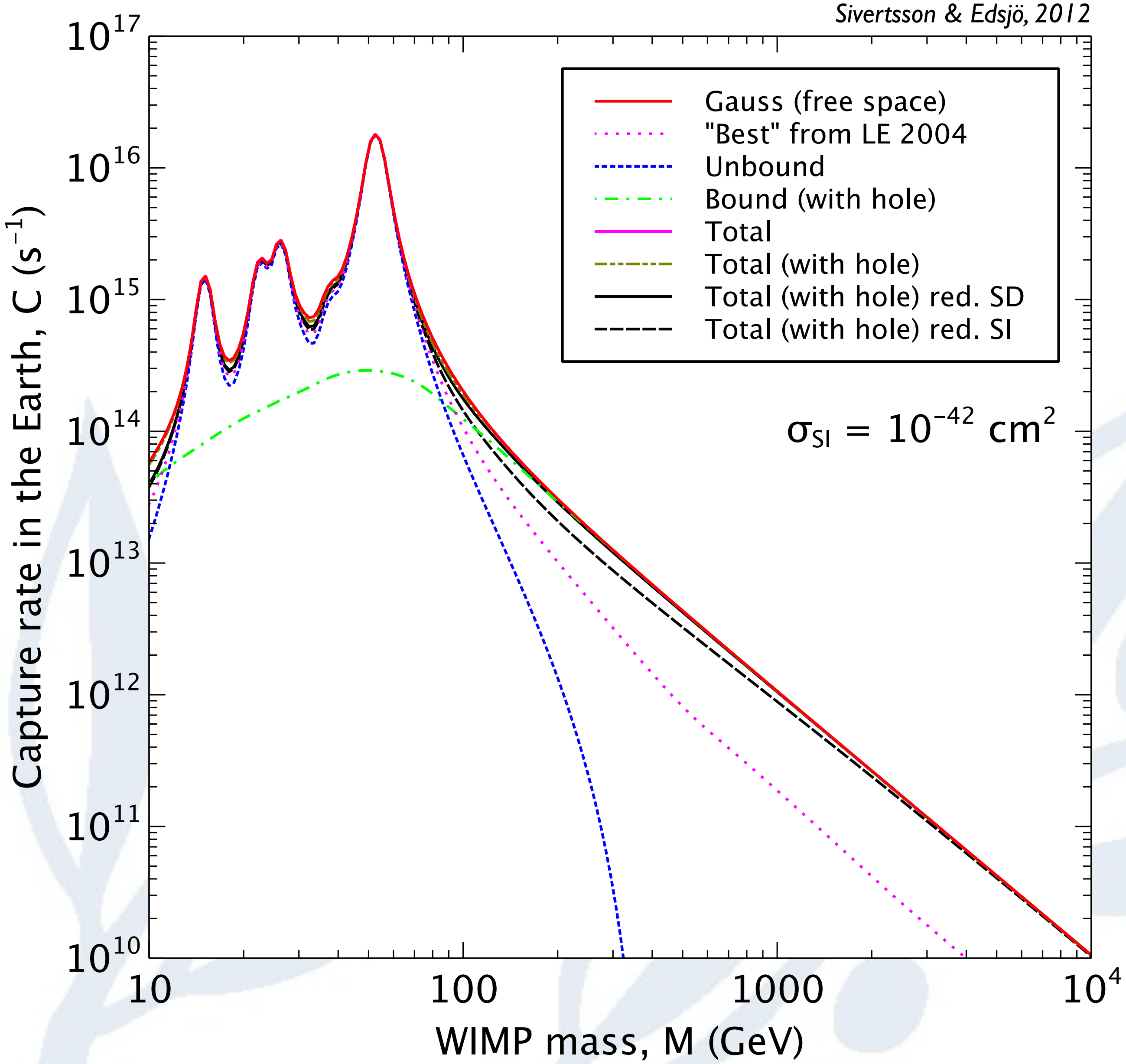
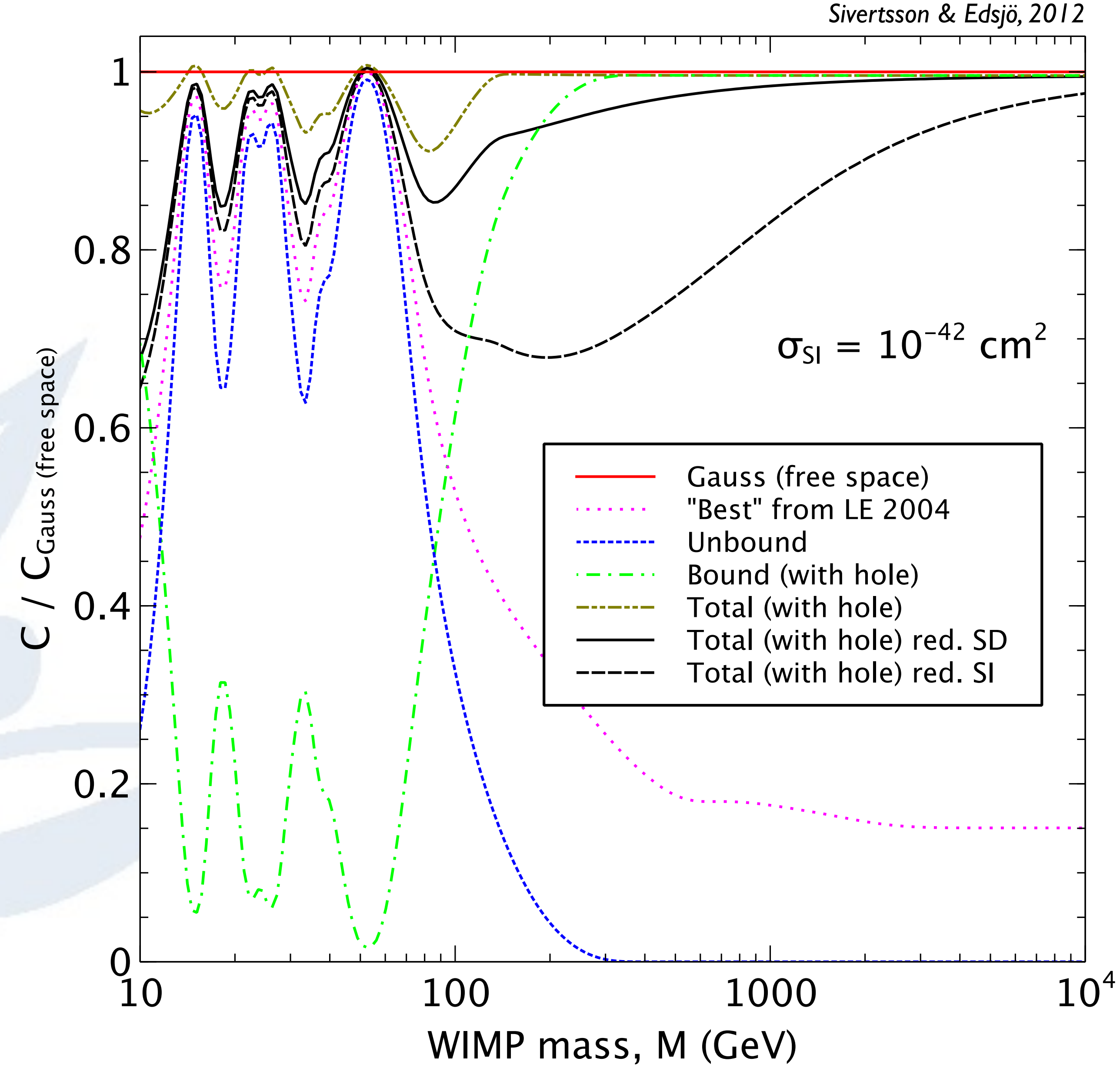
Capture rates in the Earth





The true capture is somewhere in between the free space approximation (red) and the reduced curves (black). Free space approximation is quite good for reasonably kind (smooth) halo profiles.

Neutrinos from Sun/Earth

- Rate of neutrino-induced muons in neutrino telescopes
- Neutrino scattering and absorption in Sun included
- Fully numerical capture calculation with any velocity distribution
- Neutrino oscillations, all flavours and hadronic showers

In the pipeline

- Include more refined solar models and form factors and allow for numerical solution for any form factor (not just Gaussian)
- Implement new solar system diffusion results (Sivertsson & Edsjö), even if free-space approximation works quite well for now

Uncertainties with respect to direct detection

Input	Direct detection	Neutrinos from Sun	Neutrinos from Earth
Velocity distribution, f(u)	"All" velocities, for low-masses, high-velocity tail	Low velocities, some solar diffusion effects, especially for heavy WIMPs	Very low velocities, large solar diffusion effects
Form factor	Velocities ~200 km/s => low momentum transfer	Velocities ~1500 km/s => high momentum transfer	Velocities ~200 km/s => low momentum transfer
Local density	Sensitive to it now	Sensitive to average over last $\sim 10^8$ years	Sensitive to average over last $\sim 10^9$ years

Reference / outlook

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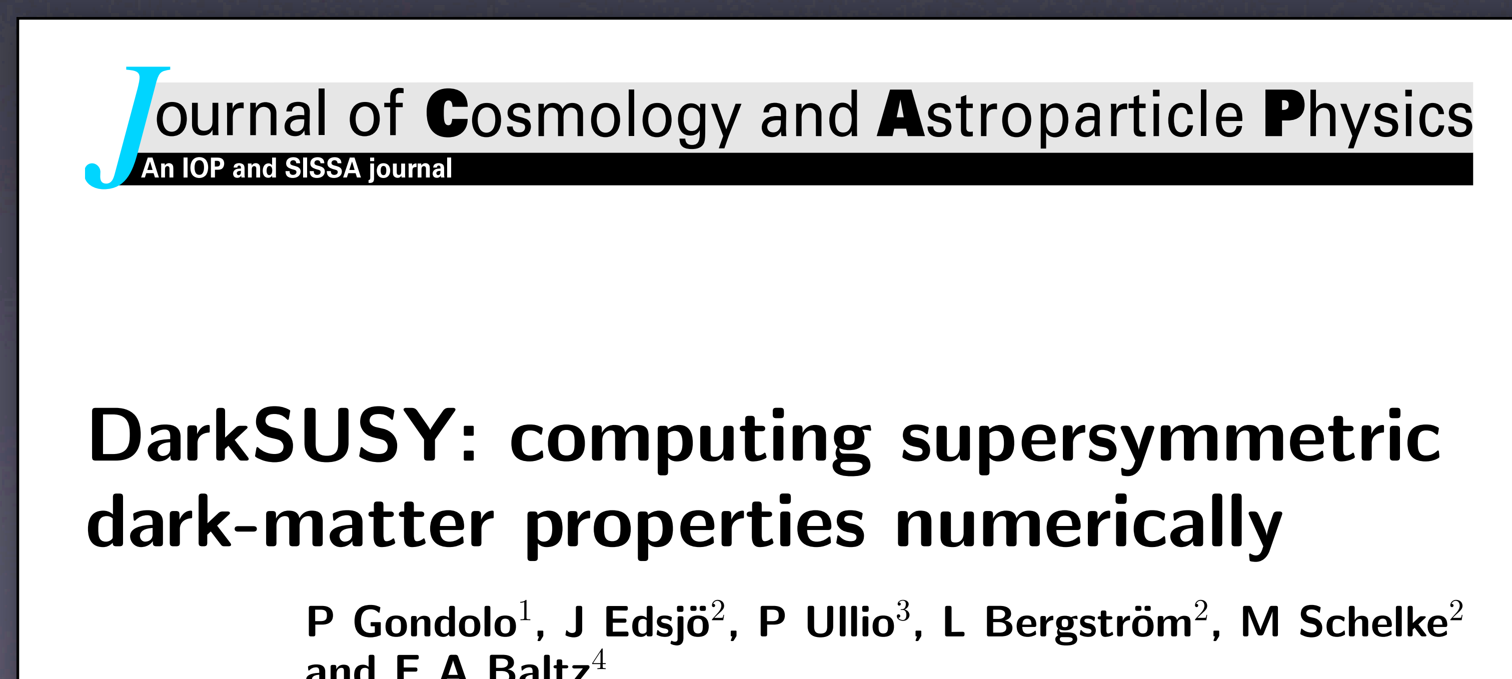
Reference / download

- DarkSUSY 5.0.5 is available at

  www.darksusy.org

- Long paper, describing DarkSUSY available as JCAP 06 (2004) 004 [astro-ph/0406204]
- Manual (pdf and html) available

WimpSim
for WIMP annihilations
in the Sun/Earth also
available.


Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

DarkSUSY: computing supersymmetric dark-matter properties numerically

P Gondolo[1], J Edsjö[2], P Ullio[3], L Bergström[2], M Schelke[2] and E A Baltz[4]

DarkSUSY Homepage

http://www.darksusy.org/

Overview
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Documentation
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DarkSUSY online

Internal pages (password restricted)

DarkSUSY Home Page

Welcome to DarkSUSY's home on the web!

DarkSUSY is a fortran package for supersymmetric dark matter calculations. It is written by Paolo Gondolo, Joakim Edsjö, Lars Bergström, Piero Ullio, Mia Schelke, Ted Baltz, Torsten Bringmann and Gintaras Duda. On these pages you will find information about DarkSUSY and you can also download the package.

If you use DarkSUSY, please refer to the following publication describing DarkSUSY:

> **P. Gondolo, J. Edsjö, P. Ullio, L. Bergström, M. Schelke and E.A. Baltz,**
> **JCAP 07 (2004) 008** [astro-ph/0406204]

Please also cite this web page as

> **P. Gondolo, J. Edsjö, P. Ullio, L. Bergström, M. Schelke, E.A. Baltz, T. Bringmann and G. Duda,**
> **http://www.darksusy.org.**

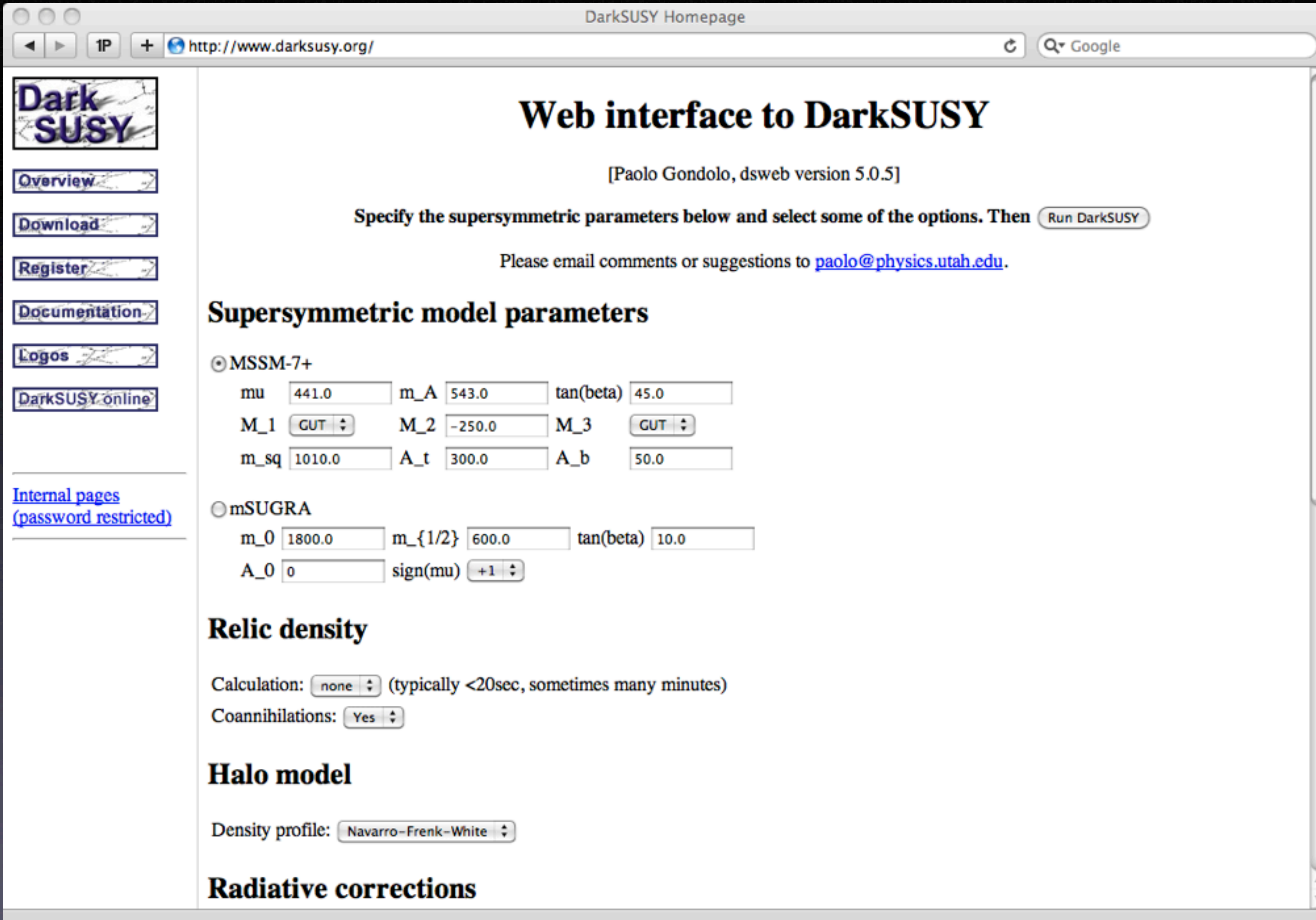
Note. You should also refer to the original physics work on which DarkSUSY is based and which DarkSUSY uses. Most notably, DarkSUSY is interfaced (and uses) the following codes:

- FeynHiggs - for Higgs masses and widths
- HiggsBounds - for Higgs boson constraints from accelerators
- ISAJET/ISASUGRA -for mSUGRA/CMSSM RGE running
- SLHALIB - for reading/writing SLHA2 files

and can (for the experienced user) be configured to run with

- Galprop - for cosmic ray propagation (not used by default).

Current version *New!*


DarkSUSY Homepage
http://www.darksusy.org/
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Logos
DarkSUSY online
Internal pages (password restricted)
Web interface to DarkSUSY
[Paolo Gondolo, dsweb version 5.0.5]
Specify the supersymmetric parameters below and select some of the options. Then Run DarkSUSY
Please email comments or suggestions to paolo@physics.utah.edu.
Supersymmetric model parameters
MSSM-7+
mu 441.0 m_A 543.0 tan(beta) 45.0
M_1 GUT M_2 -250.0 M_3 GUT
m_sq 1010.0 A_t 300.0 A_b 50.0
mSUGRA
m_0 1800.0 m_{1/2} 600.0 tan(beta) 10.0
A_0 0 sign(mu) +1
Relic density
Calculation: none (typically <20sec, sometimes many minutes)
Coannihilations: Yes
Halo model
Density profile: Navarro-Frenk-White
Radiative corrections

Future: what is needed?

- We have been aiming at consistency in calculations, both regarding astrophysics and particle physics.
- Need even more of this and more interfaces to specialized codes,
  e.g. CharginoBounds, SusyBSG,
  SDecay, Galprop, Usine,
  Dragon, ...
- Make it easier to add other than regular SUSY models (BMSSM, IDM already done, but is currently done 'by hand')

DarkSUSY 5.0.6

- Will appear shortly (weeks)
  - will include IceCube likelihood calculations (see Pat's talk)

DarkSUSY 6

- Major update (later this year)
  - restructuring of code (even more modular)
  - New refined halo annihilation and neutrino routines
  - better solar models
  - Interface to Usine, Dragon
  - DLHA = Dark matter Les Houches Accord (see Csaba's talk)

Thanks!

Stockholm University

Announcement

STOCKHOLM UNIVERSITY invites applications for a position as

SENIOR LECTURER (universitetslektor) in Theoretical Particle Physics with focus on Phenomenology
Placed within the Department of Physics
(ref.no. SU 612-1342-12).

Deadline for applications: October 1, 2012

Stockholm University

Will appear on www.fysik.su.se within a week or so