DarkSUSY

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APS Meeting
160830

Oskar Klein centre

Ways to search for dark matter

Accelerator searches

- LHC
- Rare decays
- ...

Direct searches

- Spin-independent scattering
- Spin-dependent scattering

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
- ...

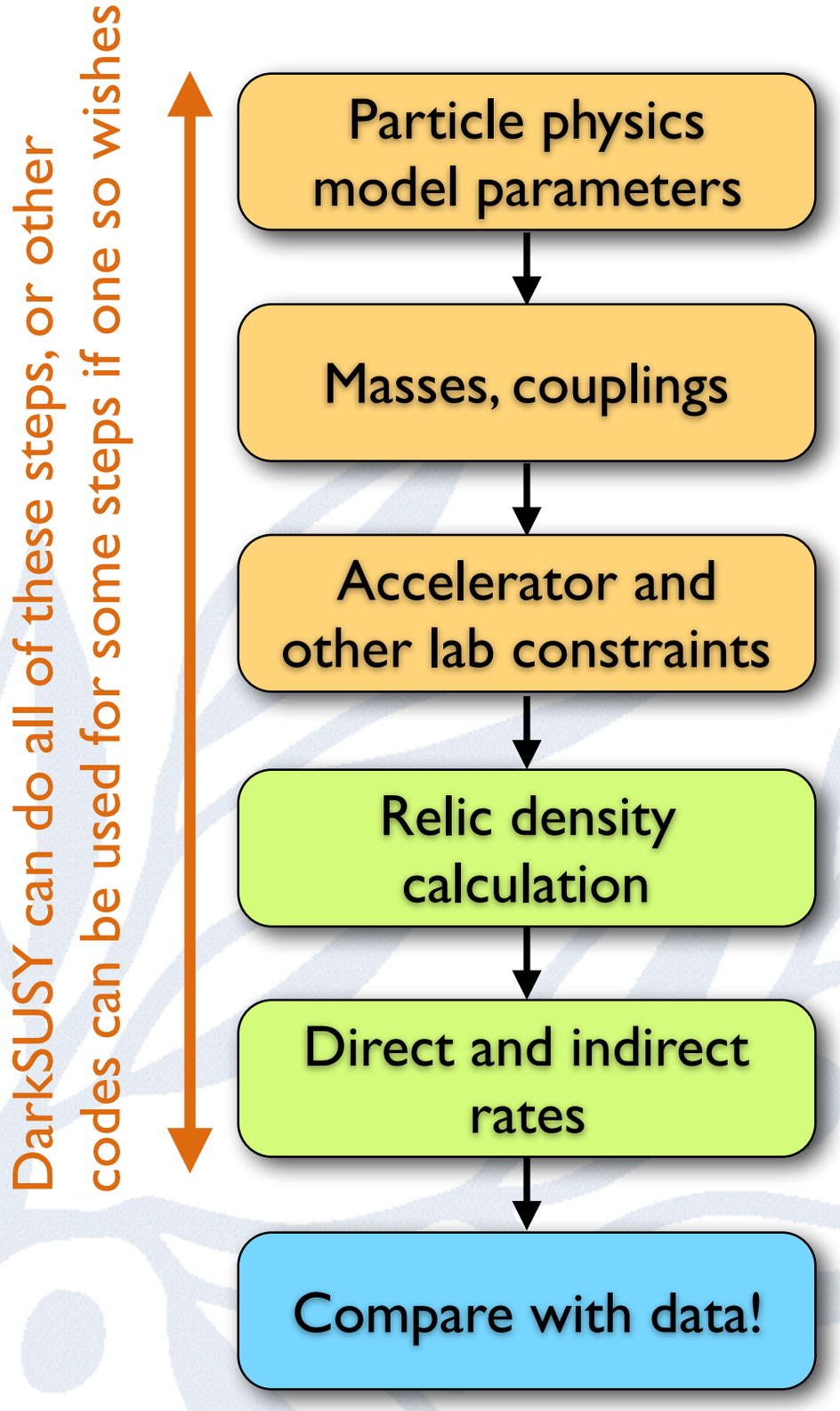
Need to treat all of these in a consistent manner, both regarding particle physics and astrophysics

Current version: 5.1.3

darksusy.org

Will not cover all of these...

Calculation flowchart



Parameters within a model, e.g. pMSSM, CMSSM, KK, scalar singlet, generic Wimp etc

Spectrum calculator (e.g. RGE solver)

Direct searches, rare decays, precision measurements

Annihilation cross section calculator and Boltzmann equation solver

Rate calculator

Compare individual rates or perform global fits

Outline

- Introduction to and layout of DarkSUSY
- Relic density
- Direct detection
- Indirect detection:
  - gamma rays
  - charged cosmic rays
  - neutrinos (from the Sun/Earth)
- DarkSUSY 6 coming soon

Relic density – DarkSUSY implementation

- We solve the Boltzmann equation,

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

numerically, calculating the thermally averaged annihilation cross section,

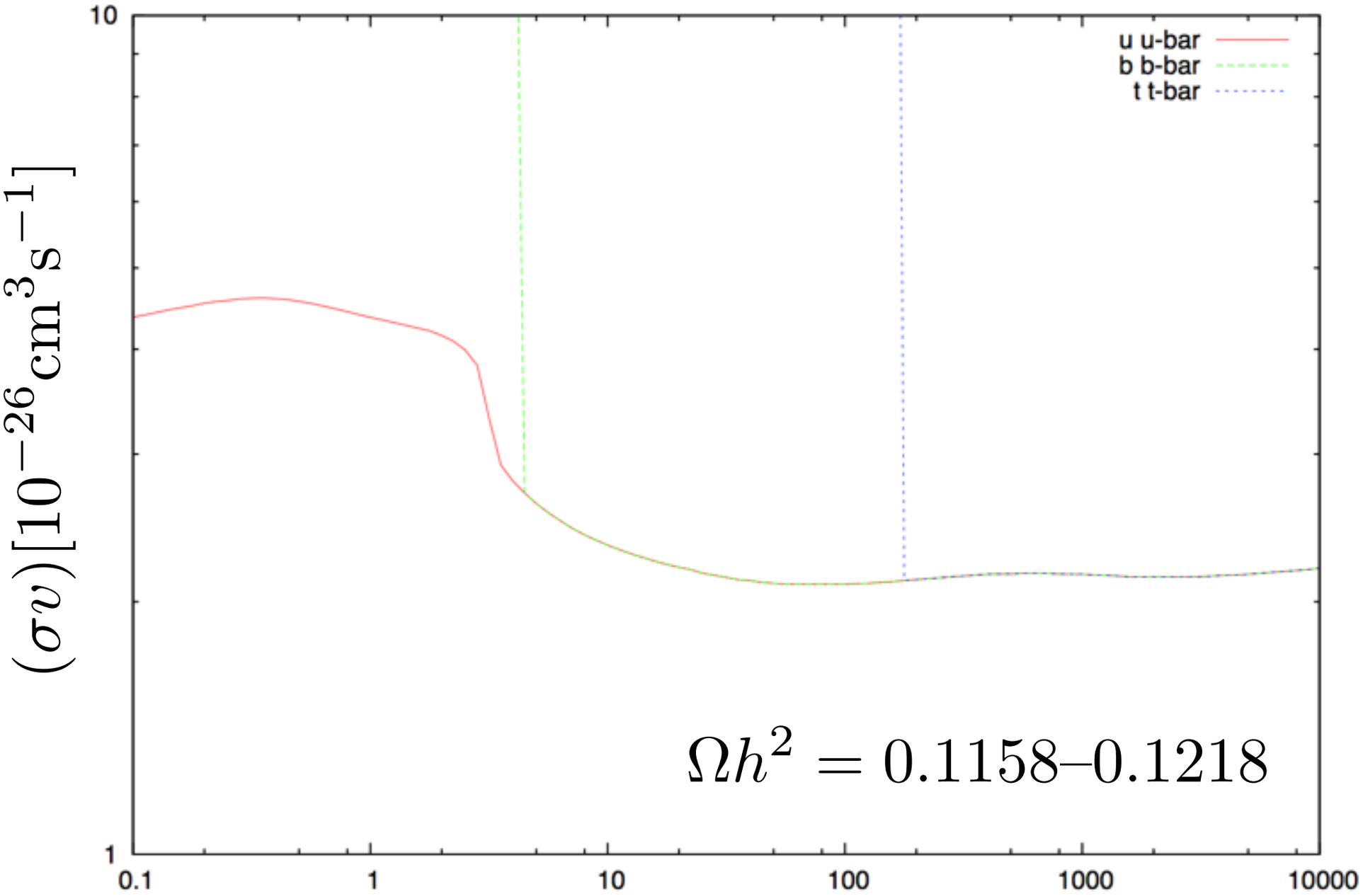
$$\langle \sigma_{\rm eff} v \rangle = \frac{\int_0^\infty dp_{\rm eff} p_{\rm eff}^2 W_{\rm eff} K_1 \left(\frac{\sqrt{s}}{T} \right)}{m_1^4 T \left[\sum_i \frac{g_i}{g_1} \frac{m_i^2}{m_1^2} K_2 \left(\frac{m_i}{T} \right) \right]^2}$$

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

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

DarkSUSY can calculate $W_{\rm eff}$ for SUSY or you can supply your own and use DarkSUSY as a Boltzmann equation solver. Interface to DM@NLO for SUSY coming.

Example, generic WIMP



cf. Steigman, 2012

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

Indirect rates – 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).

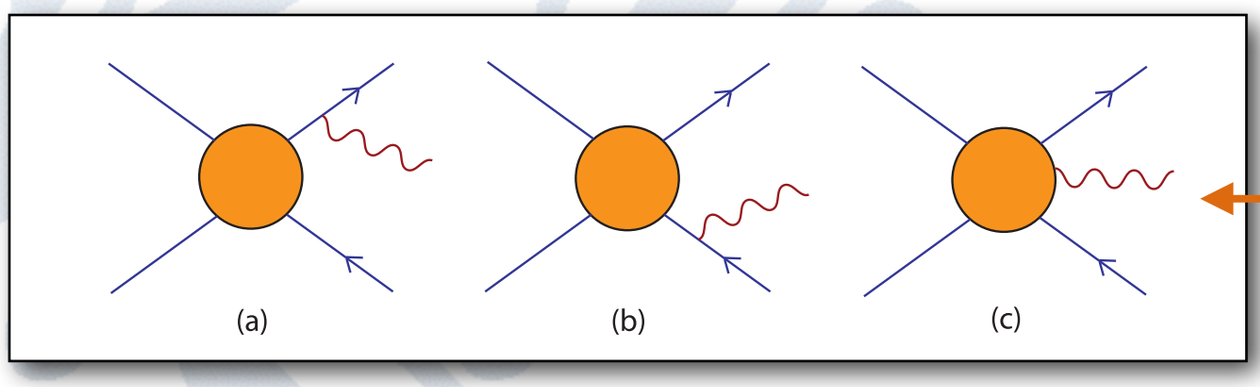
- Yield calculated with Pythia and tabulated for use by DarkSUSY (3 GeV – 20 TeV)
- Higgs bosons are let to decay in flight summing up the yields from the decay products

Gamma rays

- DarkSUSY includes generic WIMP routines to calculate gamma yields from WIMP annihilations
  - Based on Pythia simulations for WIMP masses between 3 GeV and 20 TeV

Works for any WIMP

  - Line signals
  - Internal Bremsstrahlung added separately

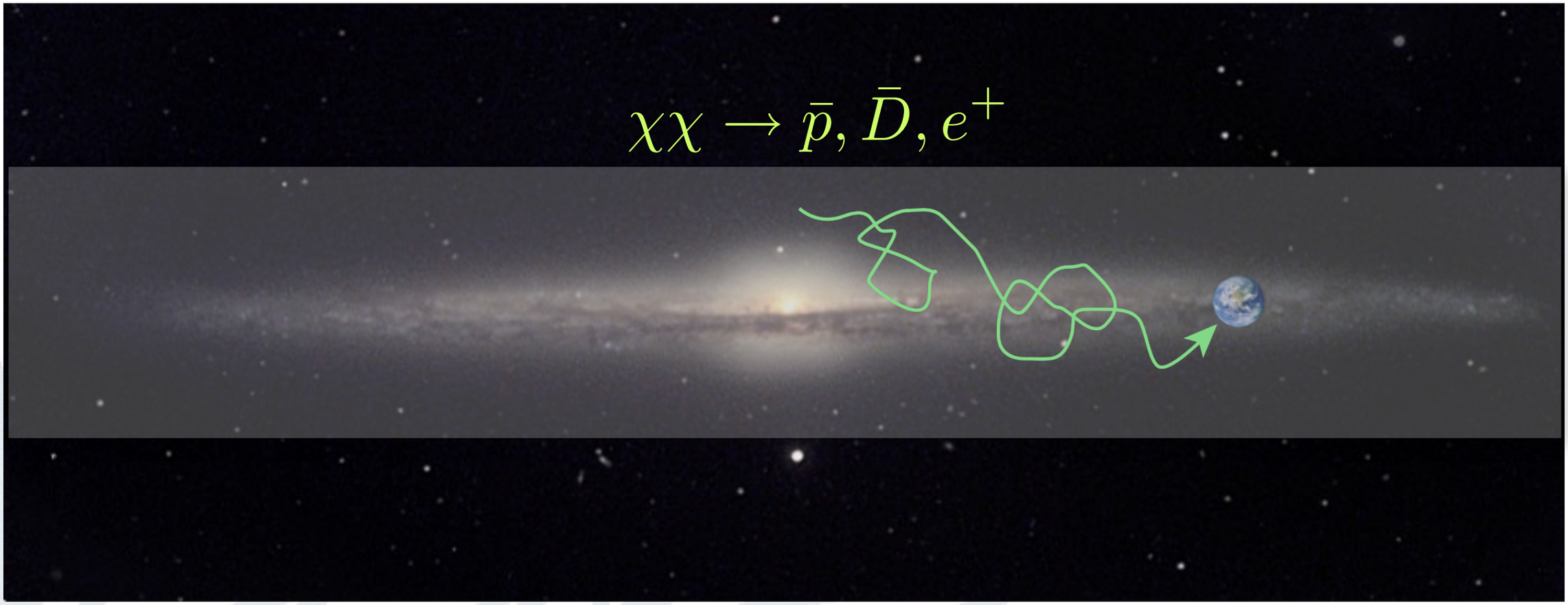


Virtual internal bremsstrahlung is model dependent!
SUSY calculation included.

Halo profiles

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

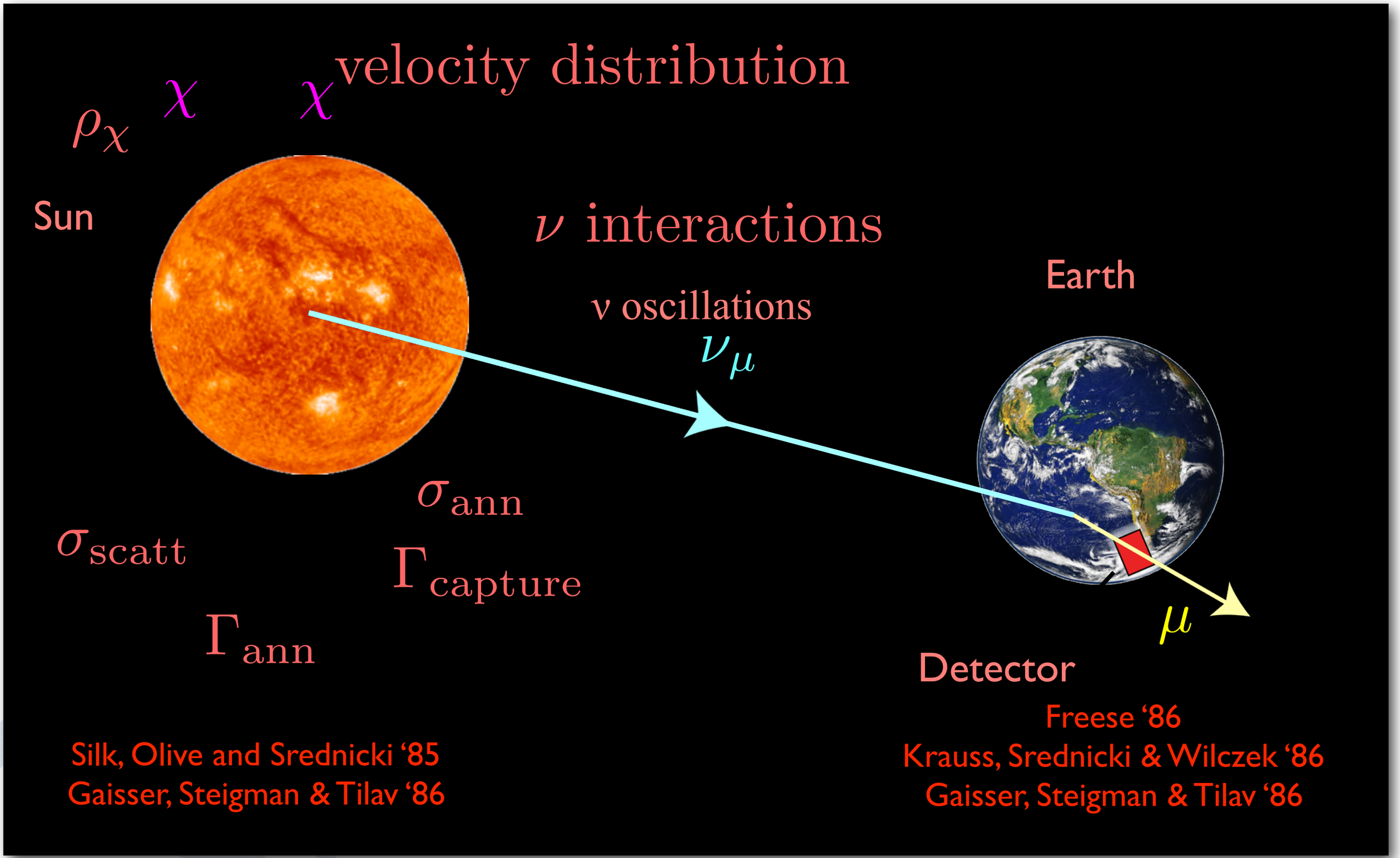
Charged cosmic rays – diffusion model



- 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)

- Analytic expressions in DarkSUSY (new improved ones in coming DS 6)
- New in DS6: new Pythia runs and new anti-deuteron calculations (MC based coalescence)

Neutrinos from the Earth/Sun



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

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

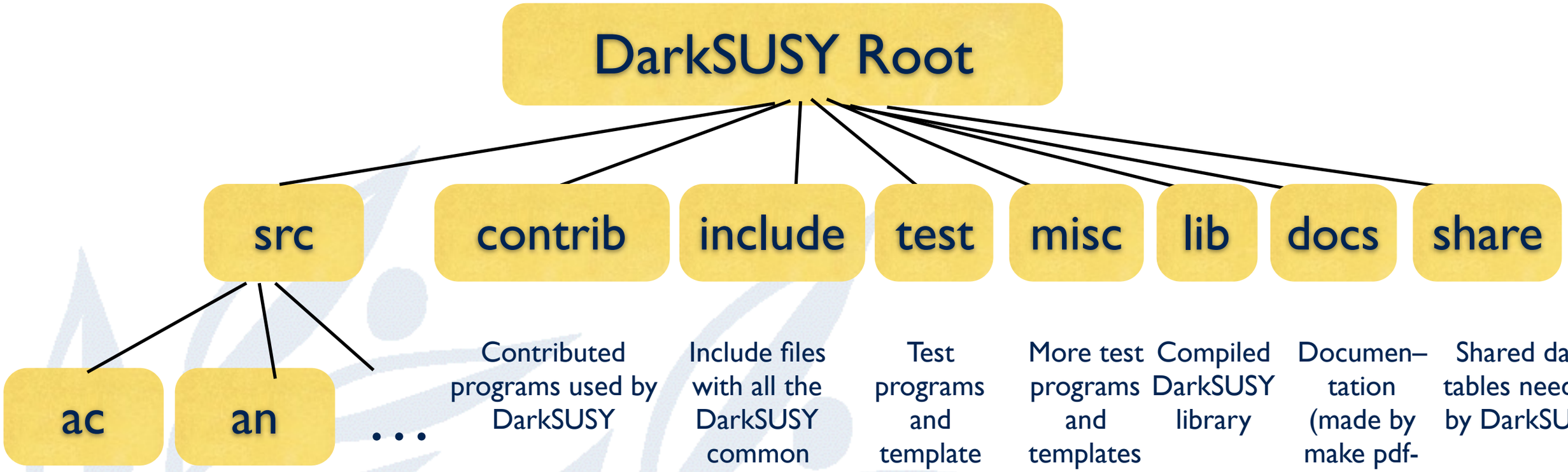
Neutrinos from the Earth/Sun

- Full numerical integration over solar radius, summing most relevant elements ("all" in coming DS 6)
- Full numerical integration over velocity distribution, no need to assume Maxwell-Boltzmann distribution
- In coming DS 6: full numerical integration over momentum transfer: arbitrary form factors can be used (do not need to be exponential). Database of form factors included.
- Interactions and oscillations in the Sun and to the detector simulated with WimpSim, results available as data tables in DarkSUSY.

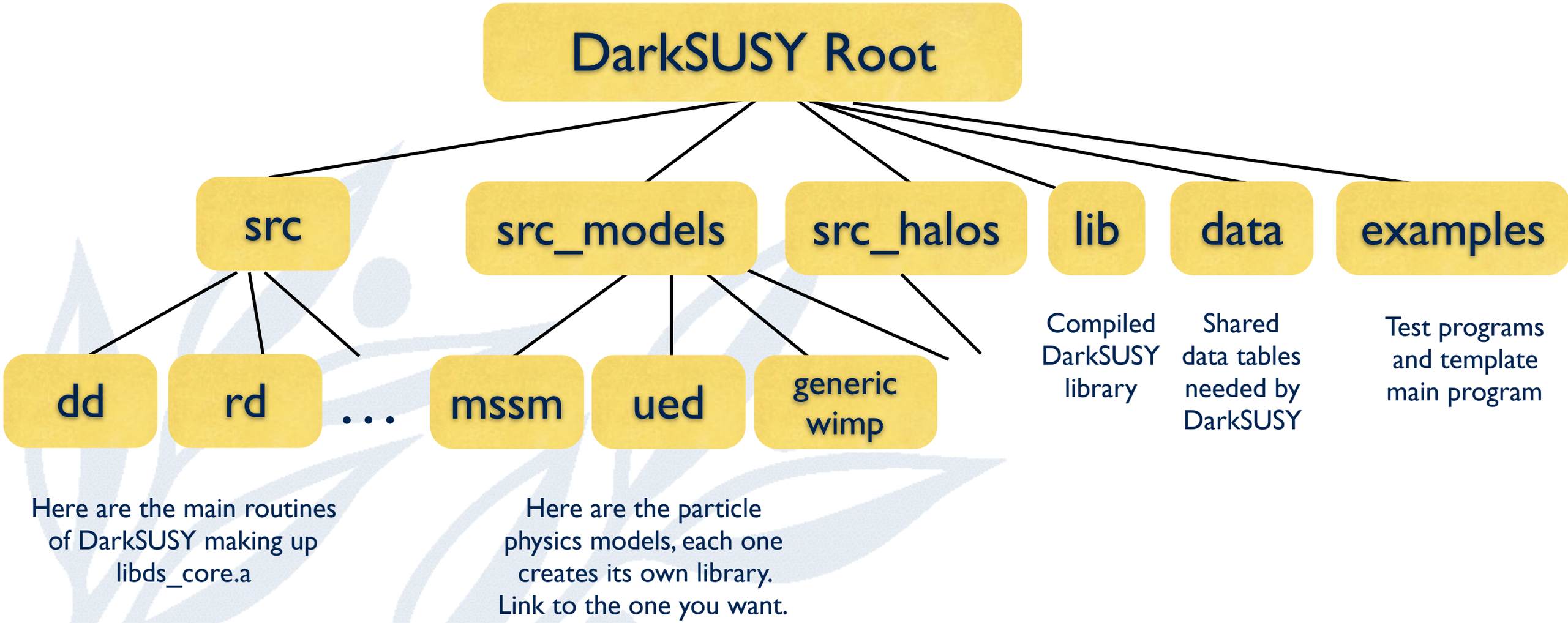
Philosophy

- Modular structure (given the Fortran constraints...)
- Library of subroutines and functions
- Fast and accurate
- “Standard” Fortran - works on many platforms (g77 support dropped though)
- Flexible
- Version control (subversion) for precise version tagging

DarkSUSY 5 layout



DarkSUSY 6 layout

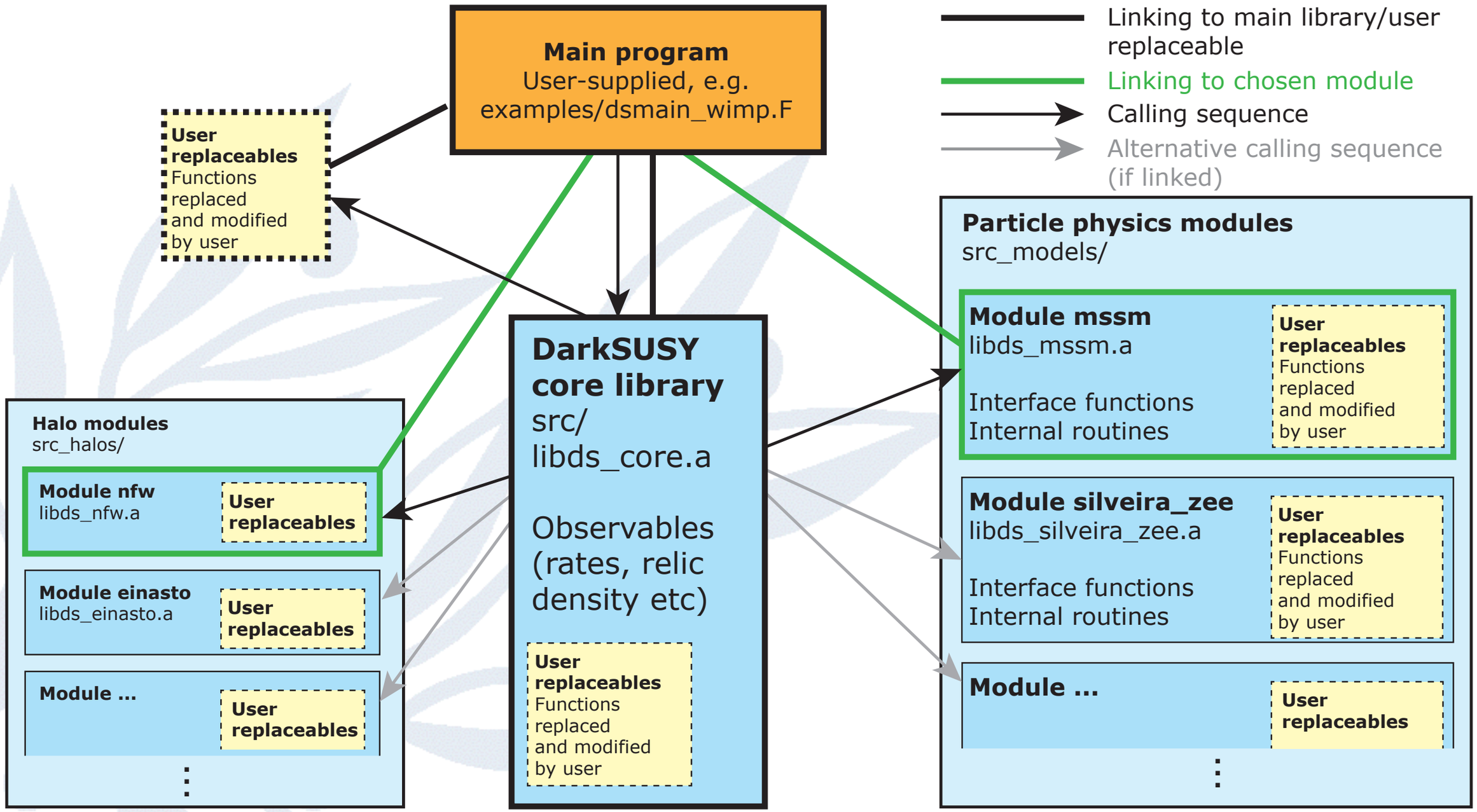


- In DarkSUSY 6 you link to the particle physics model you want to use
- More clear division between particle physics model and general routines
  - General DS routines in src/
  - Particle physics model dependent routines in src_models/

DarkSUSY 6 concepts

- **Interface functions.** Functions/routines that the particle physics module should provide if you want to calculate a given observable
  - e.g. W_{eff} is an interface function and needed by ds_core to calculate the relic density
- **Replaceable functions.** Any function/routine in DarkSUSY can be replaced by a user-supplied version.
  - e.g. you might want to have your own velocity distribution then you can just replace the standard routine

DarkSUSY 6 structure



Compile and install

- To compile and install DarkSUSY, do

  ./configure [optional arguments]
  make

- Works on most platforms and with most compilers (gfortran, ifort, …)
- When you link, you link to ds_core and to the particle physics module of your choice, e.g. ds_mssm, ds_generic_wimp, etc

```
gfortran -o dsmain dsmain.f -lds_core -lds_mssm - for MSSM
gfortran -o dsmain dsmain.f -lds_core -lds_generic_wimp - for generic Wimp
```

And then we have the name…

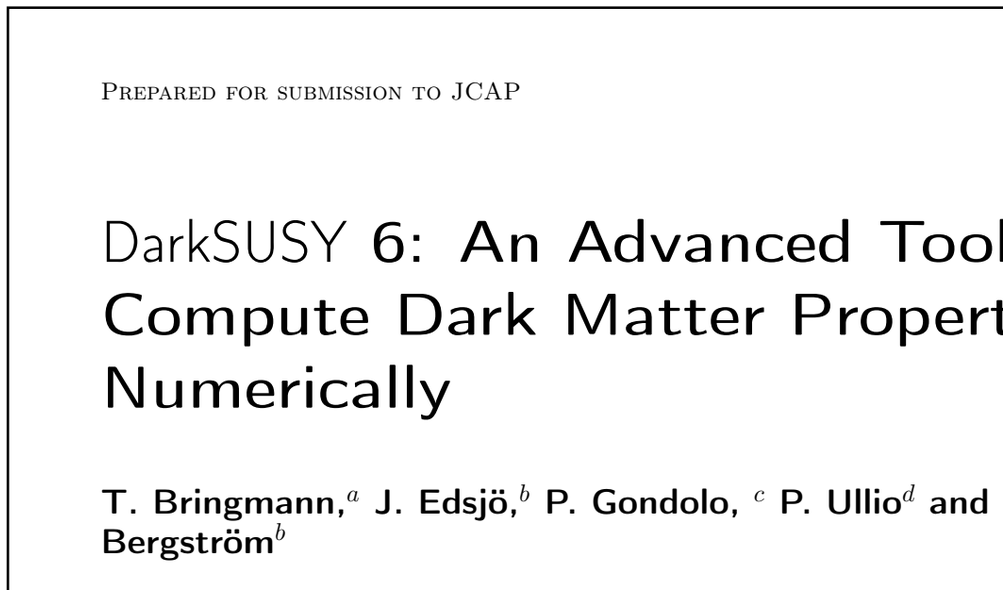
- DarkSUSY does now mean…
- Dark SUsy Samt Ytterligare Modeller

Reference / download

- DarkSUSY 5.1.3 is available at

  www.darksusy.org

- Long paper, describing DarkSUSY available as JCAP 06 (2004) 004 [astro-ph/0406204]
- Manual (pdf and html) available
- DarkSUSY 6 coming soon with new paper



Prepared for submission to JCAP

DarkSUSY 6: An Advanced Tool
Compute Dark Matter Propert
Numerically

T. Bringmann,[a] J. Edsjö,[b] P. Gondolo, [c] P. Ullio[d] and
Bergström[b]

Conclusions

- DarkSUSY 5 publically available
- DarkSUSY 6 will be much more modular and include other improvements. Coming soon…
- When comparing different signals, it is crucial to perform these calculations in a consistent framework, with e.g. a tool like DarkSUSY

Merci!

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