Short review of Dark Matter Tools

VSOP 2024, Quy Nhon

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A bit of history: automation

In the early 2000's, if you wanted to compute the dark matter abundance predicted by your favourite model, you had to:

· Write down your Lagrangian.

· Extract all vertices.

· Figure out which processes are relevant for dark matter production/depletion.

e.g. in the MSSM ~2800 processes

· Compute all the cross-sections.

· Write down the relevant Boltzmann equations.

· Code all these expressions and numerically solve your Boltzmann equations.

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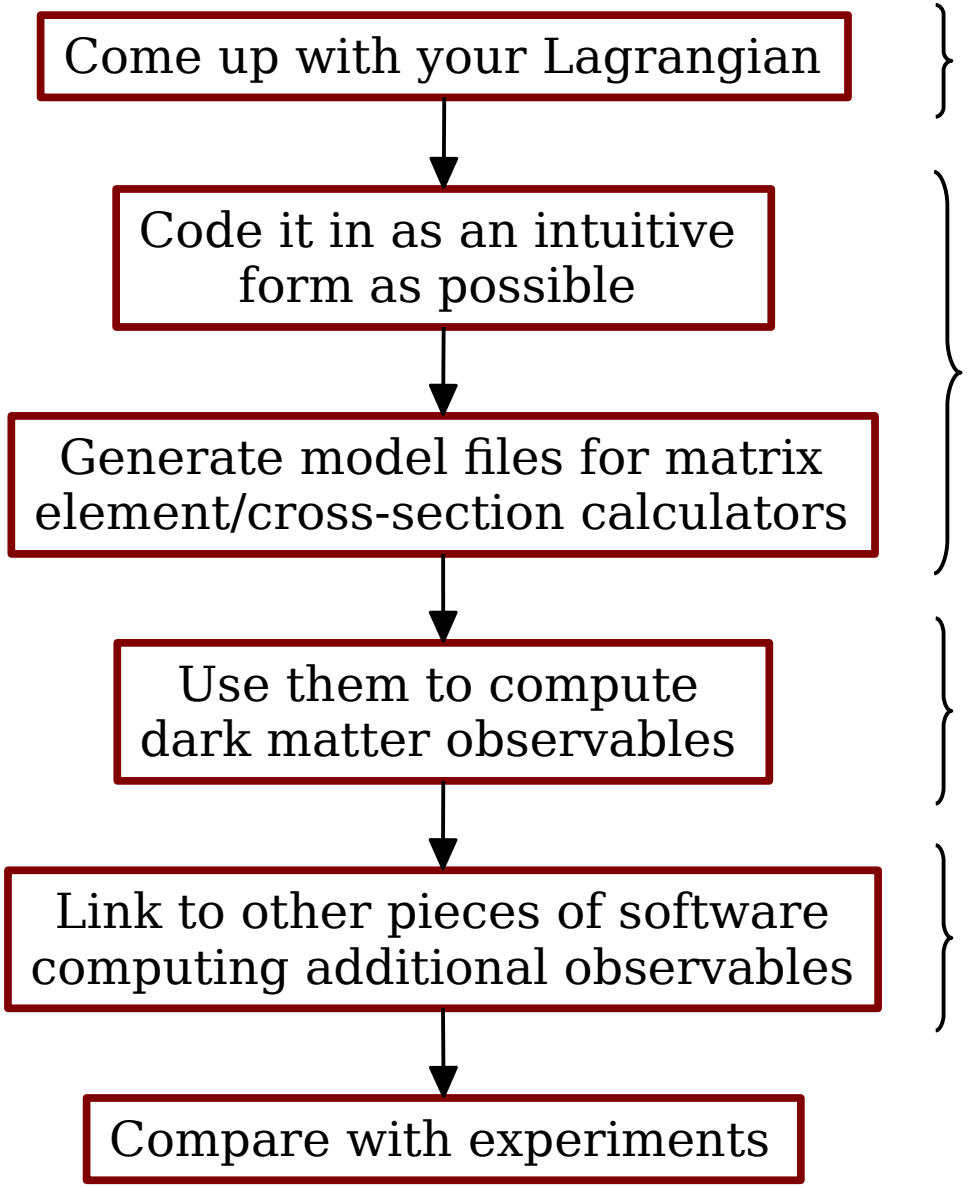
Can we make our lives a bit easier?

A phenomenologist's wishlist



The traditional way (for the moment!).

Model file generators.

e.g. LanHEP, FeynRules, SARAH...

Relic density, direct/indirect detection cross-sections and spectra...

May require additional input (astro etc)

Collider constraints, BBN bounds, flavour observables...

+ Do all of that reasonably fast.

So which are the dark matter tools?

For the sake of the presentation, let's split them into two categories:

Tools that compute
the DM relic abundance

(but which may also serve other purposes!)

· micrOMEGAs: Generic BSM models.

· DarkSUSY: Generic BSM models.

· SuperIso Relic: MSSM/NMSSN.

· MadDM: Generic BSM models.

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Tools that don't compute the DM relic abundance

(and which definitely serve other purposes!)

· Direct detection: DirectDM, RunDM, RAPIDD, DaMaSCUS, DDCalc...

EFT matching, RGE evolution, scattering in the earth...

· Indirect detection: GALPROP, DRAGON, USINE, CLUMPY, PPPC4DMID, HDMSpectra...

Cosmic ray propagation, annihilation spectra...

· Additional functionalities: DarkBit, DarkHistory...

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· SuperIso Relic: MSSM/NMSSM.

· MadDM: Generic BSM models.

NB: All of these codes also perform (at least) the most standard calculations for direct/indirect detection.

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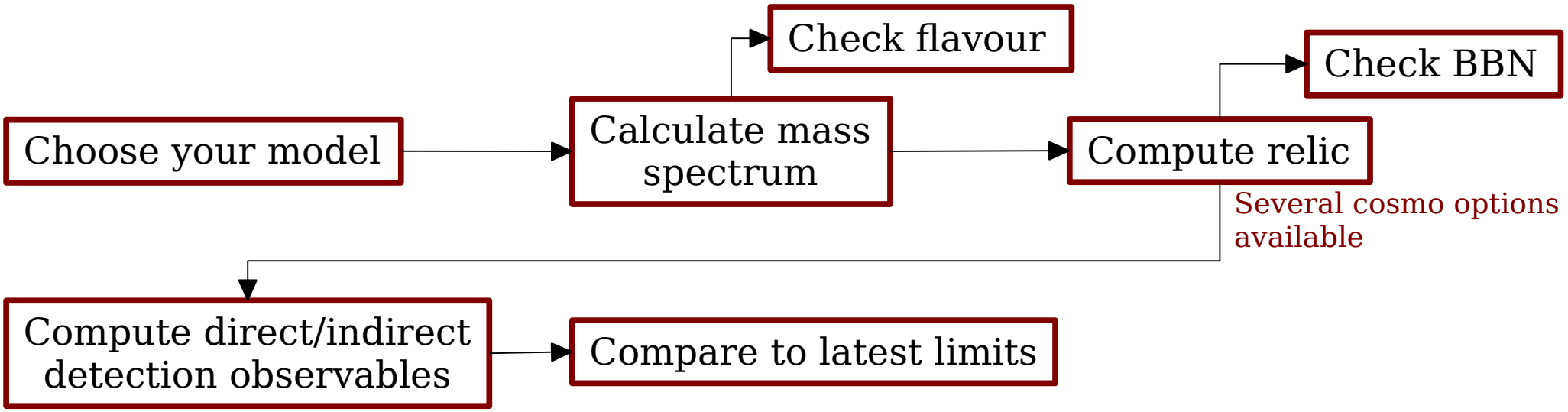
NB: Some of these codes are/can be linked to relic abundance calculation codes.

SuperIso Relic

SuperIso Relic
By Alexandre Arbey, Farvah Nazila Mahmoudi & Glenn Robbins
http://superiso.in2p3.fr/relic/

A mixed C/Fortran code to compute numerous dark matter observables in the MSSM/NMSSM (current version: v4).



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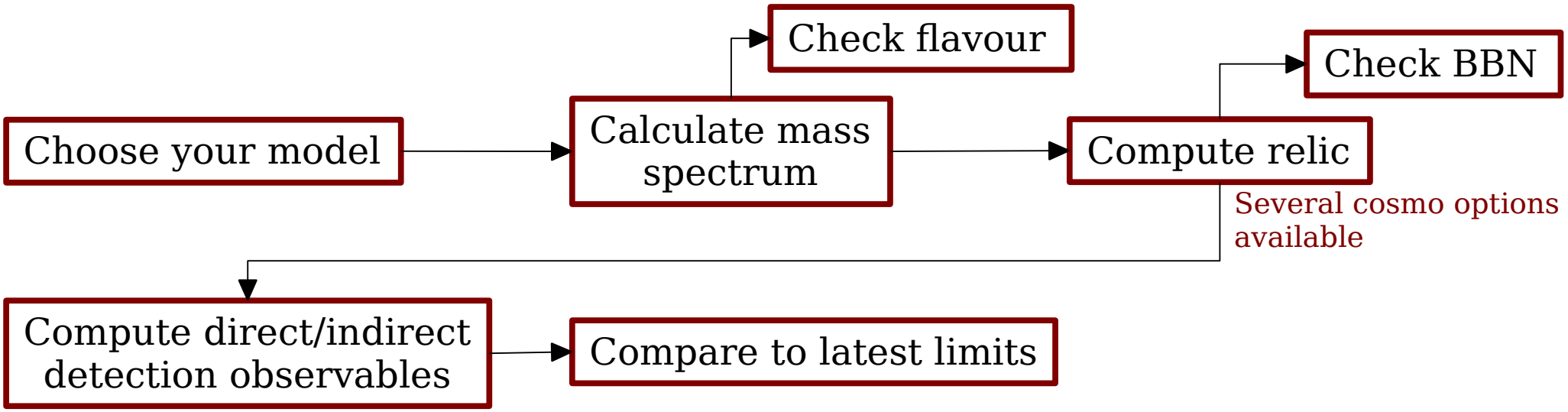


Highlights:

· Comprehensive framework for analysis of neutralino dark matter in (N)MSSM.

· Possibility to modify several cosmological assumptions.

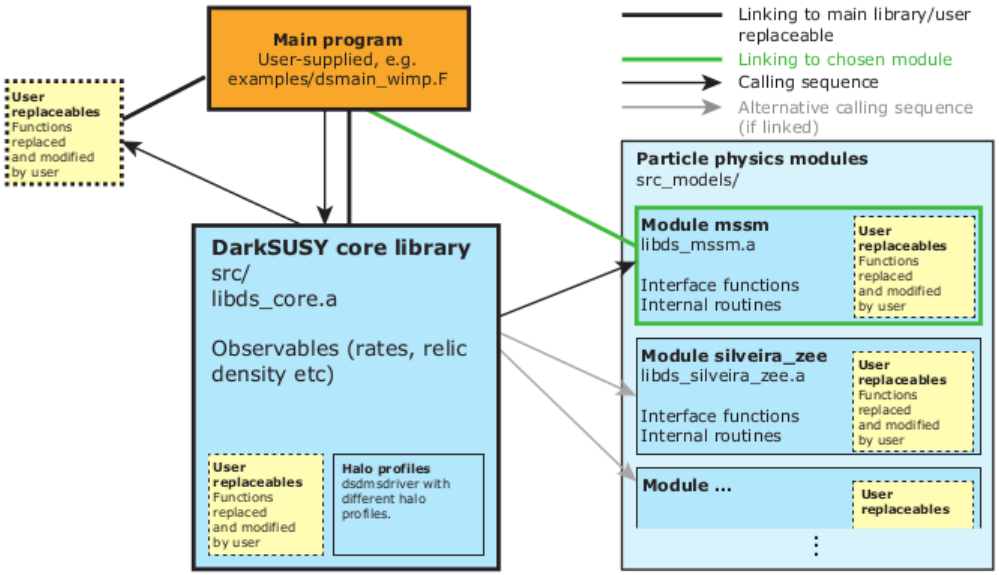
· Readily linked with AlterBBN to compute BBN observables.

· Readily linked with SuperIso to check flavour constraints.

DarkSUSY

https://darksusy.hepforge.org/

A Fortran code to compute numerous dark matter observables for different dark matter candidates (current version: v6).



· Underwent *major* upgrade a few years ago, no longer SUSY-specific.

· Freeze-out, freeze-in, direct detection, indirect detection (under different astro assumptions).

· Possibility to link to other, model-specific packages.

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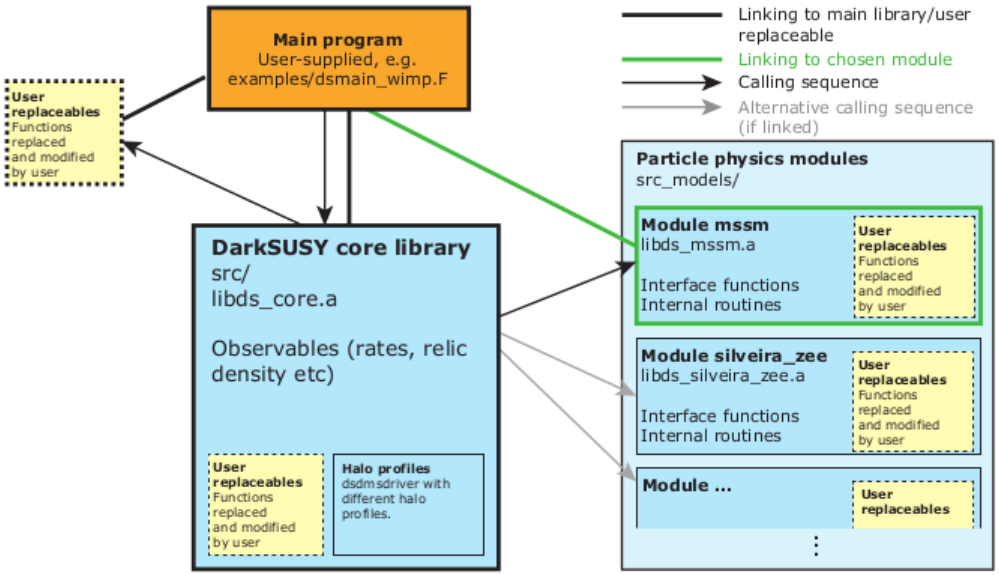

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Highlights:

· Very modular.

· Dark freeze-out computations w/ different sector temperatures.

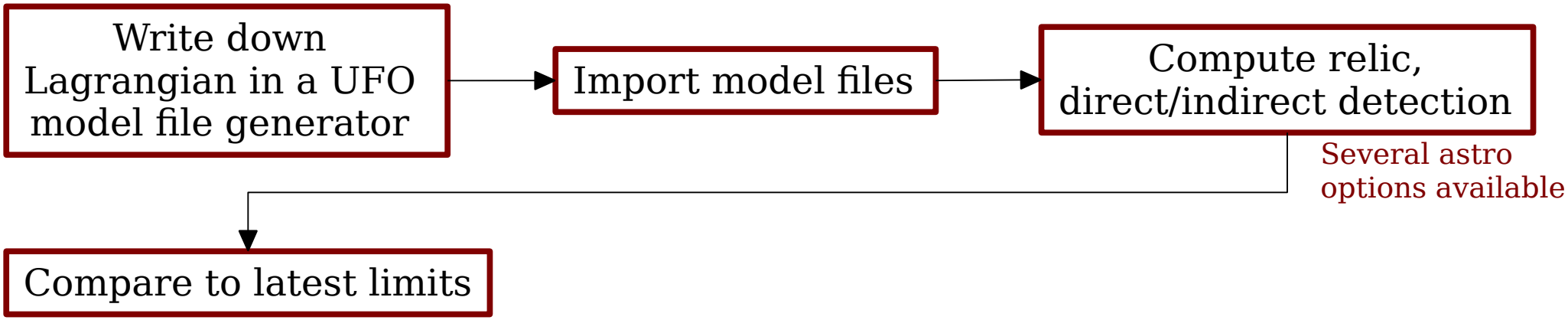
· Possibility to account for late kinetic decoupling, Sommerfeld enhancement.

· Possibility to compute self-interaction effects.

MadDM

https://launchpad.net/maddm/

A Fortran/Python code to compute dark matter observables for generic dark matter candidates (current version: v3).



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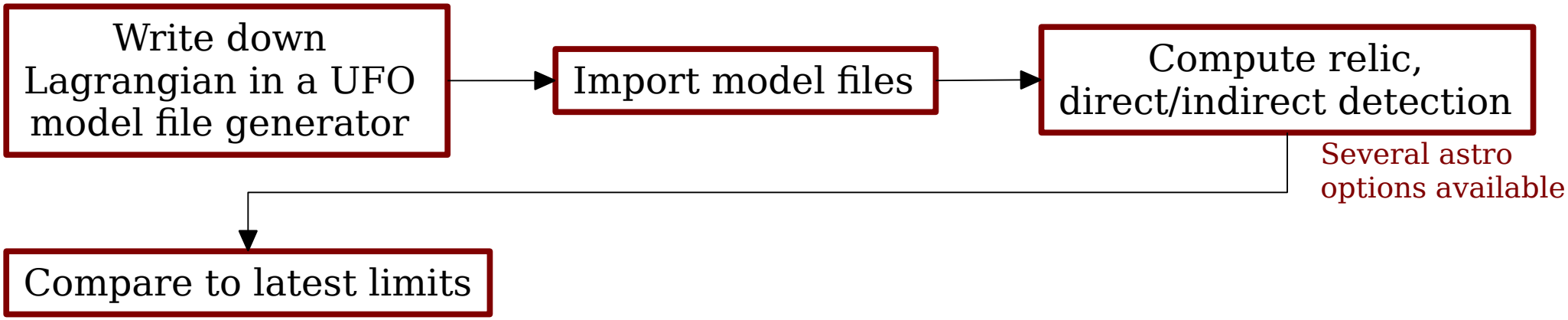

Highlights:

· Handles generic extensions of the SM, no need to compute cross-sections by hand.

· Relies on MG5_aMC, extensively used in collider physics.

· Readily linked with numerous HEP packages.

· Possibility to compute 2 → n/loop-induced processes for ID via MadLoop.

micrOMEGAs

https://lapth.cnrs.fr/micromegas/

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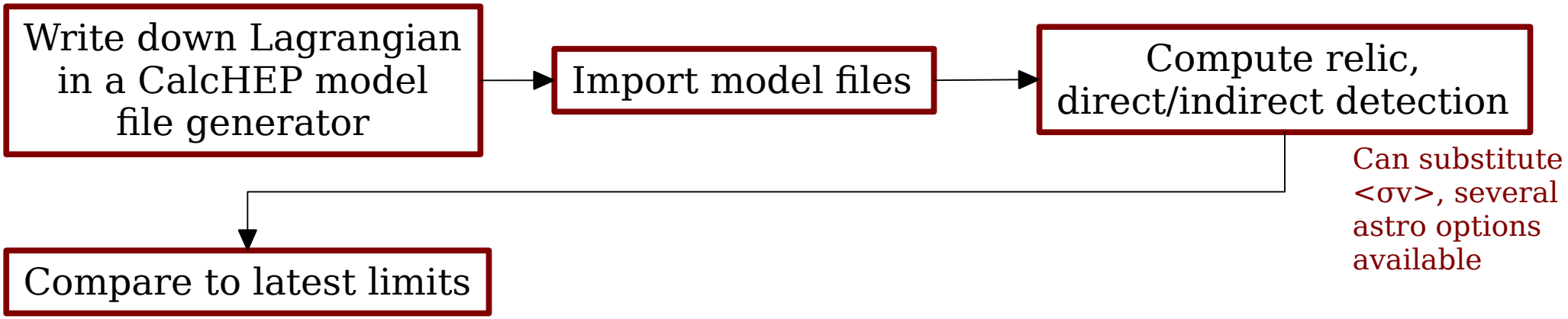

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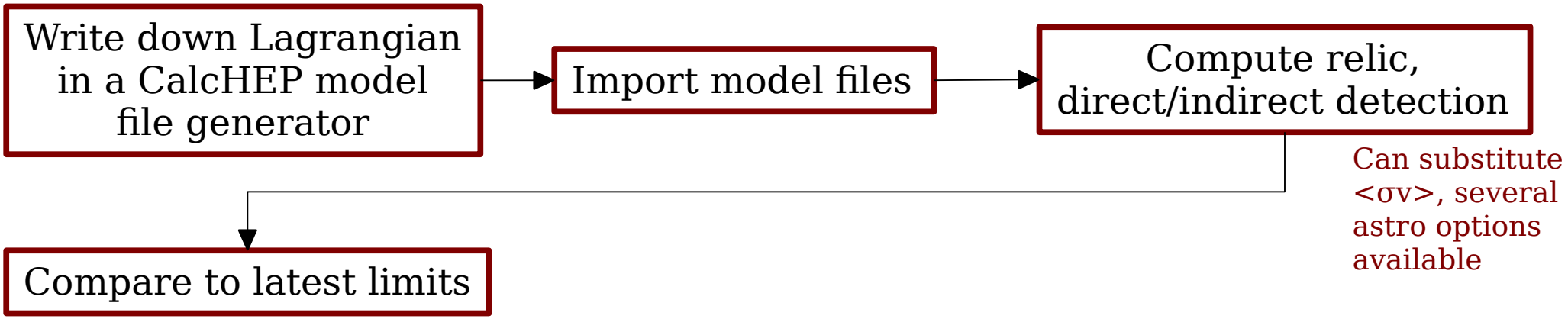

Highlights:

· Can handle multi-component dark matter models.

· Includes semi-annihilations.

· Freeze-in.

· Readily linked with numerous HEP packages.

Summary and outlook

· Dark matter tools have evolved *significantly* during the last few years, and they continue doing so.

· They are now capable of dealing with issues such as: generalized cosmological settings, self-interactions, loop-induced processes, alternative dark matter generations mechanisms, generic dark matter models.

· Which tool you should use really depends on what exactly it is that you're trying to do. Apart from a common core, each code may offer specific functionalities which might be best suited for your purposes.

· Specialized tasks may require specialized codes. Each code has its limitations!

cf codes that don't compute the DM abunance

· All of these tools have been developed by people from *within* our community and they evolve thanks to the feedback *from* the community.

Thank you!