MadDM v.3.0 - Tutorial

Jan Heisig (UCL - CP3)
on behalf of the
MadDM collaboration

Chargé de recherches fnrs

F. Ambrogi, C. Arina, M. Backovic, JH, F. Maltoni, L. Mantani,
O. Mattelaer, G. Mohlabeng, 1804.00044, Phys. Dark Univ. (2019)

Tools 2020

Capabilities

MadDM capabilities

For a generic dark matter model with UFO files

Relic density (MadDM v.1.0) [Backovic, Kong, McCaskey 2013]

- Coannihilation
- Multi-component dark matter

Direct detection (MadDM v.2.0)

- Theoretical elastic spin-independent and spin-dependent cross section dark matter off nucleons
- Directional event rate (double differential event rate)
- LUX likelihood

Indirect detection (MadDM v.3.0)

- Theoretical prediction for the velocity averaged cross section at present time
- Generation of energy spectra from dark matter annihilation
- Computation of fluxes at source and detection
- Fermi-LAT likelihood for dwarf spheroidal galaxies

Model parameter space sampling (MadDM v.3.0)

- Sequential grid scan
- PyMultiNest interface

Experimental constraints module (MadDM v.3.0)

Capabilities

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For a generic dark matter model with UFO files

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- Coannihilation
- Multi-component dark matter

Direct detection (MadDM v.2.0) [Backovic, Kong, Martini, Mattelaer, McCaskey, Mohlabeng 2015]

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- Directional event rate (double differential event rate)
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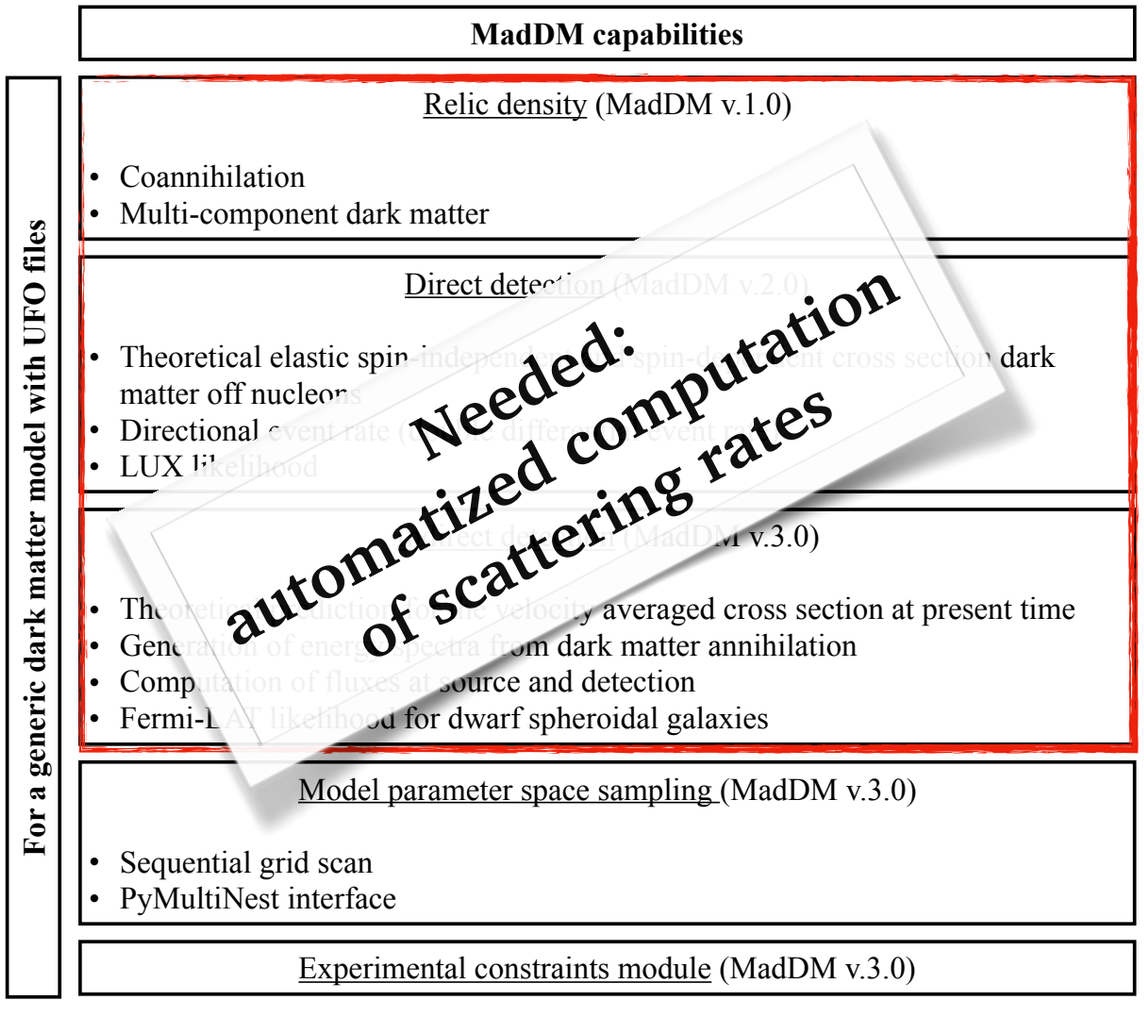
[F. Ambrogi, C. Arina, M. Backovic, JH, F. Maltoni, L. Mantani, O. Mattelaer, G. Mohlabeng, arXiv:1804.00044]

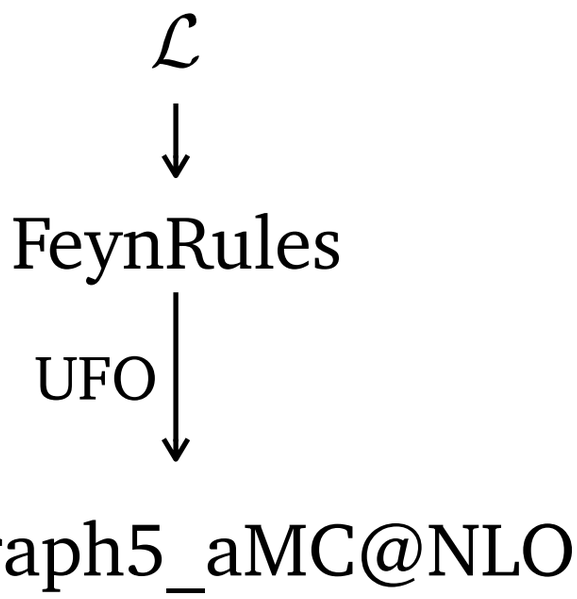
Model parameter space sampling (MadDM v.3.0)

- Sequential grid scan
- PyMultiNest interface

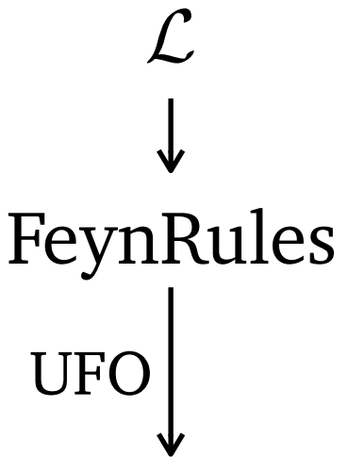
Experimental constraints module (MadDM v.3.0)

Framework


MadDM capabilities
For a generic dark matter model with UFO files
Relic density (MadDM v.1.0)
• Coannihilation
• Multi-component dark matter
Direct detection (MadDM v.2.0)
• Theoretical elastic spin-independent and spin-dependent cross section dark matter off nucleons
• Directional event rate (for the different event rates)
• LUX likelihood
Indirect detection (MadDM v.3.0)
• Theoretical prediction of the velocity averaged cross section at present time
• Generation of energy spectra from dark matter annihilation
• Computation of fluxes at source and detection
• Fermi-LAT likelihood for dwarf spheroidal galaxies
Model parameter space sampling (MadDM v.3.0)
• Sequential grid scan
• PyMultiNest interface
Experimental constraints module (MadDM v.3.0)
Needed:
automatized computation
of scattering rates


$\mathcal{L}$
FeynRules
UFO
MadGraph5_aMC@NLO

Framework



MadDM

Relic density

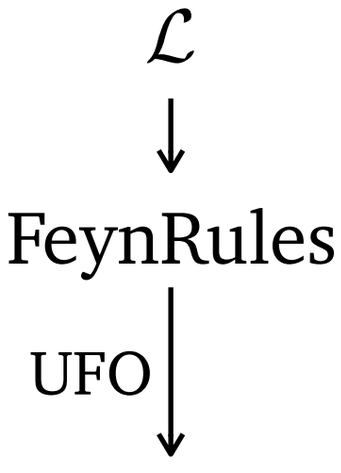
Direct detection

Indirect detection

MadGraph5_aMC@NLO

+ phase-space integrator
+ Boltzmann solver

Framework



MadDM

Relic density

Direct detection

Indirect detection

MadGraph5_aMC@NLO

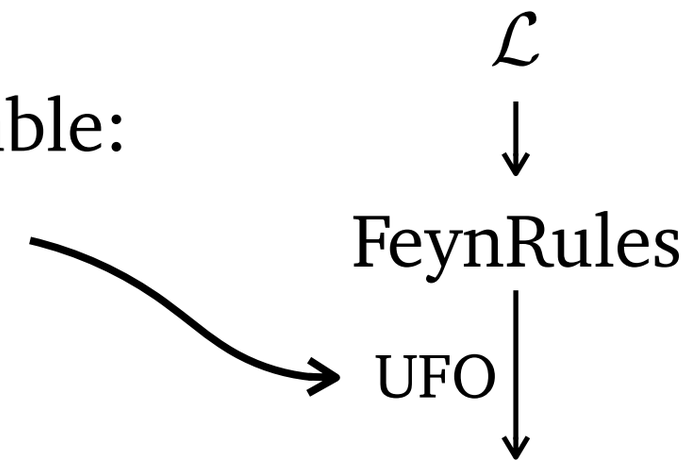
- MadEvent

Pythia8

Dragon2

Framework

Many dark-matter models available:
http://feynrules.irmp.ucl.ac.be/wiki/ModelDatabaseMainPage



MadDM

Relic density

Direct detection

Indirect detection

MadGraph5_aMC@NLO
- MadEvent
Pythia8
Dragon2

Code structure and user interface

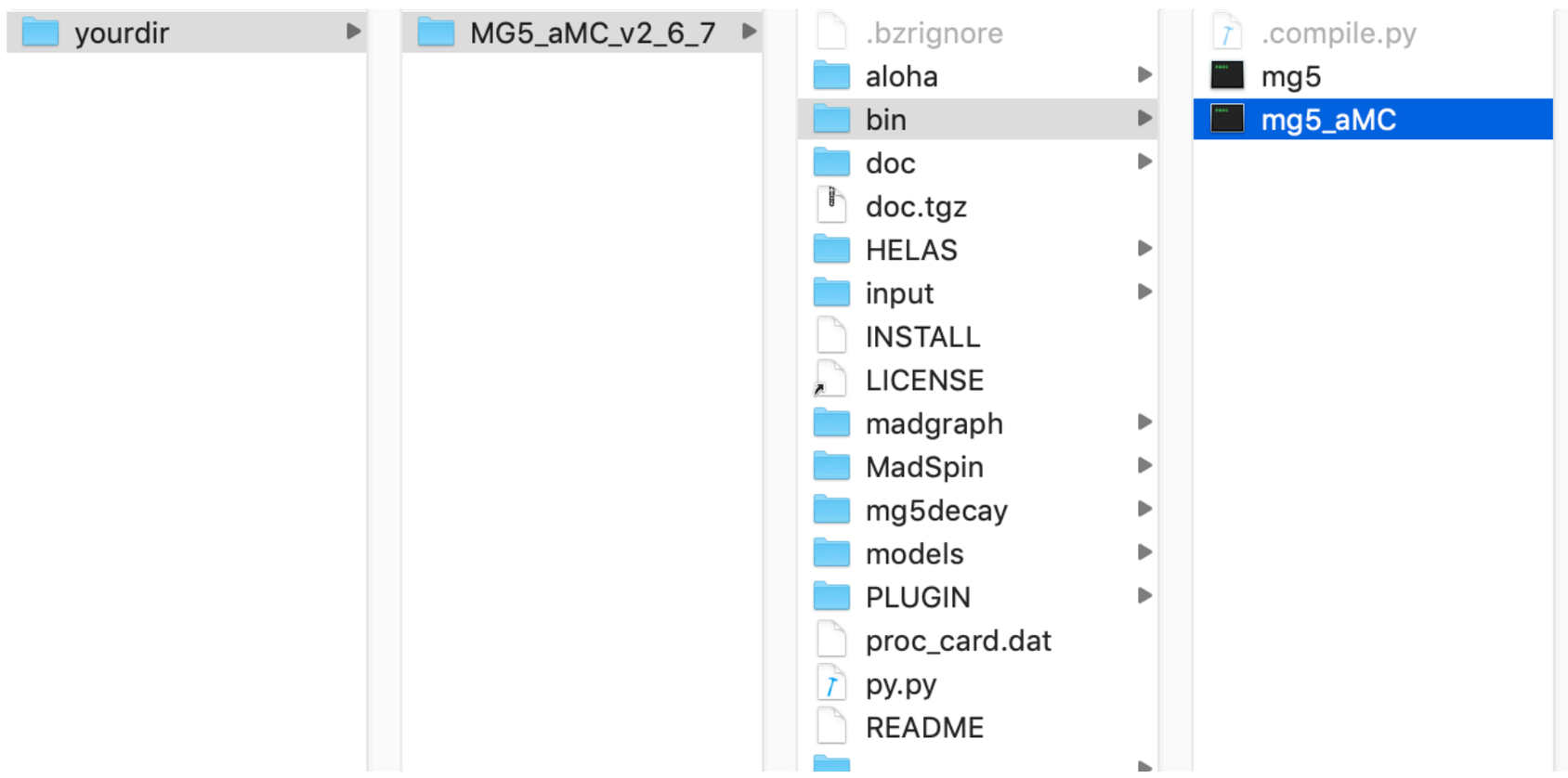
- MadDM is plugin of MadGraph5_aMC@NLO
- Written in Python/Fortran
- Provides command line interface
- Download MadGraph5_aMC@NLO,
  install plugins via MG_aMC command line
  (automatic download and installation)

Installation

```
yourdir$ wget https://launchpad.net/mg5amcnlo/
2.0/2.6.x/+download/MG5_aMC_v2.6.7.tar.gz
```

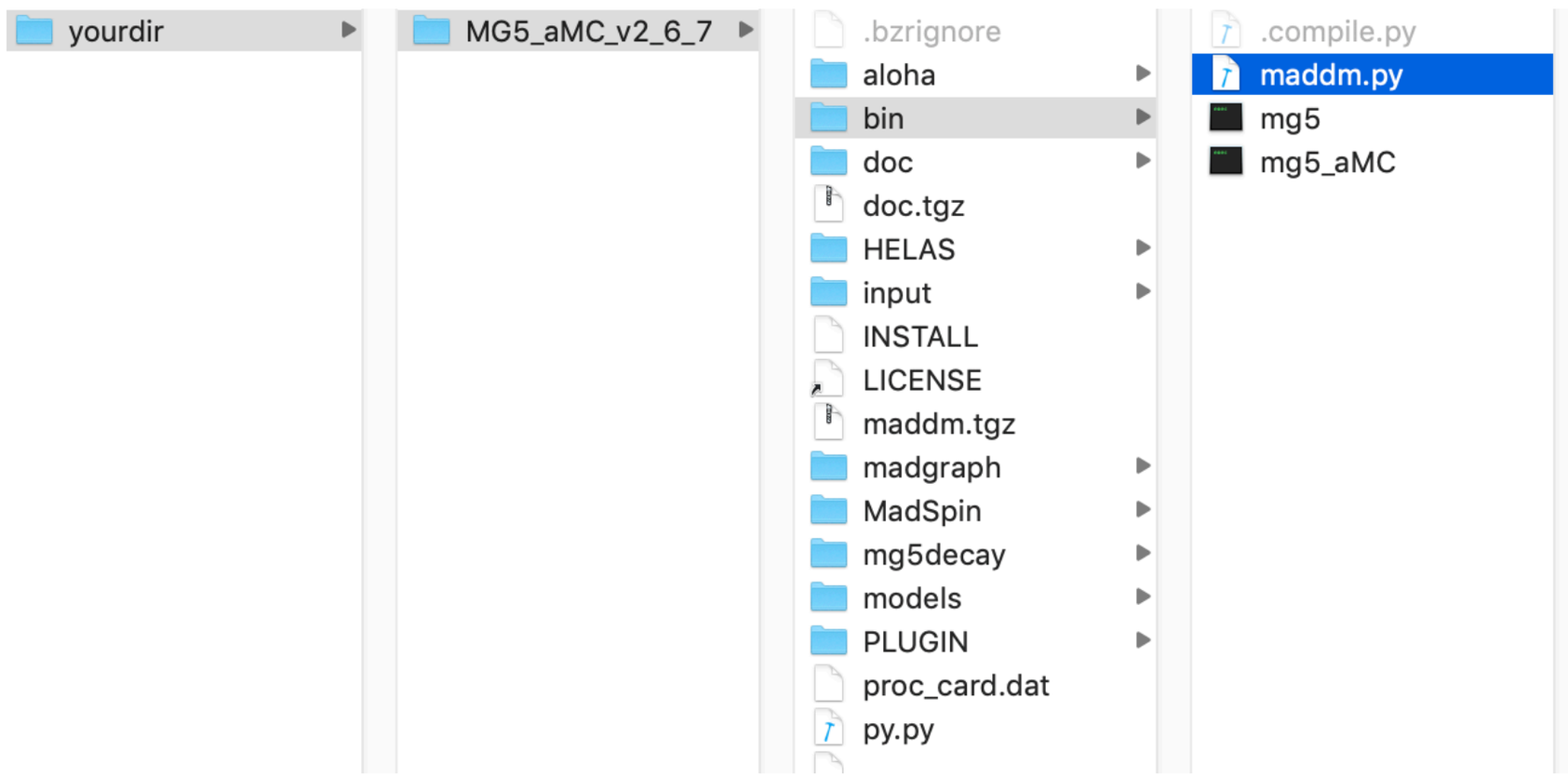
Installation

```
yourdir$ wget https://launchpad.net/mg5amcnlo/
2.0/2.6.x/+download/MG5_aMC_v2.6.7.tar.gz
yourdir$ tar -xzf MG5_aMC_v2.6.7.tar.gz
yourdir$ cd MG5_aMC_v2_6_7/
MG5_aMC_v2_6_7$ bin/mg5_aMC
```



Installation

```
yourdir$ wget https://launchpad.net/mg5amcnlo/
2.0/2.6.x/+download/MG5_aMC_v2.6.7.tar.gz
yourdir$ tar -xzf MG5_aMC_v2.6.7.tar.gz
yourdir$ cd MG5_aMC_v2_6_7/
MG5_aMC_v2_6_7$ bin/mg5_aMC
MG5_aMC> install maddm
MG5_aMC> quit
MG5_aMC_v2_6_7$
```



Installation

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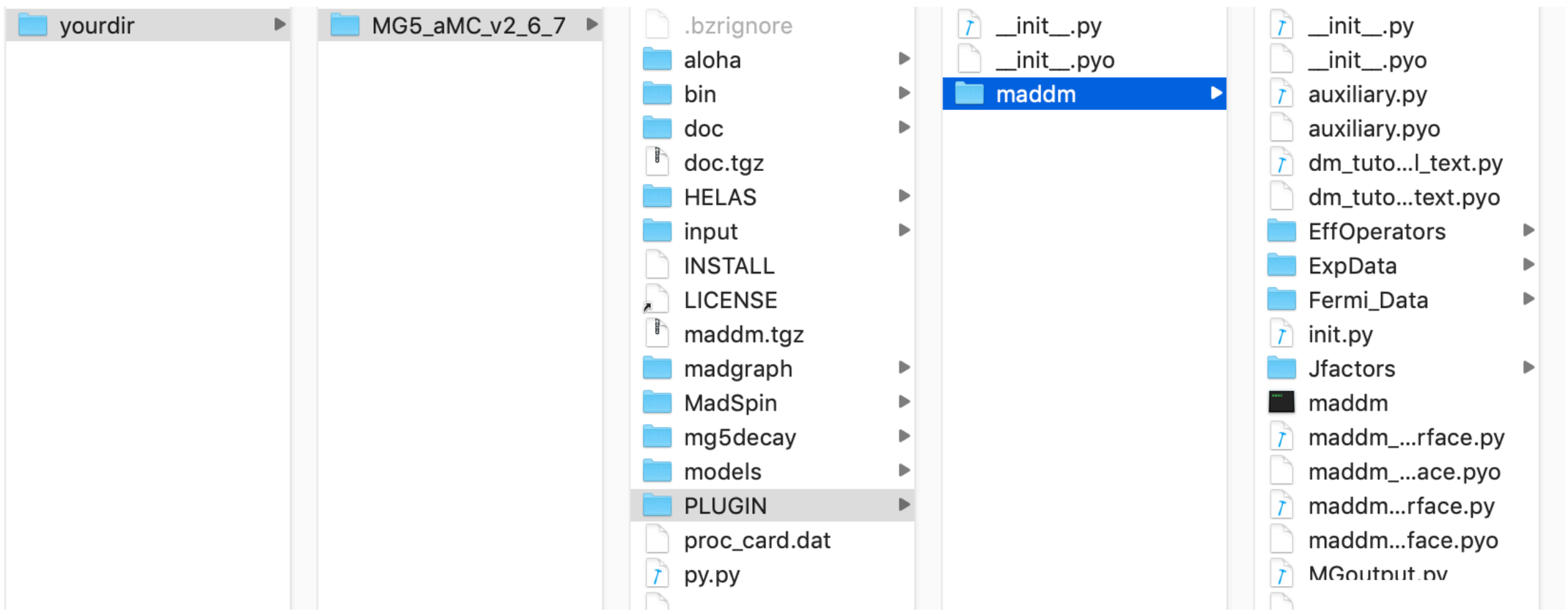
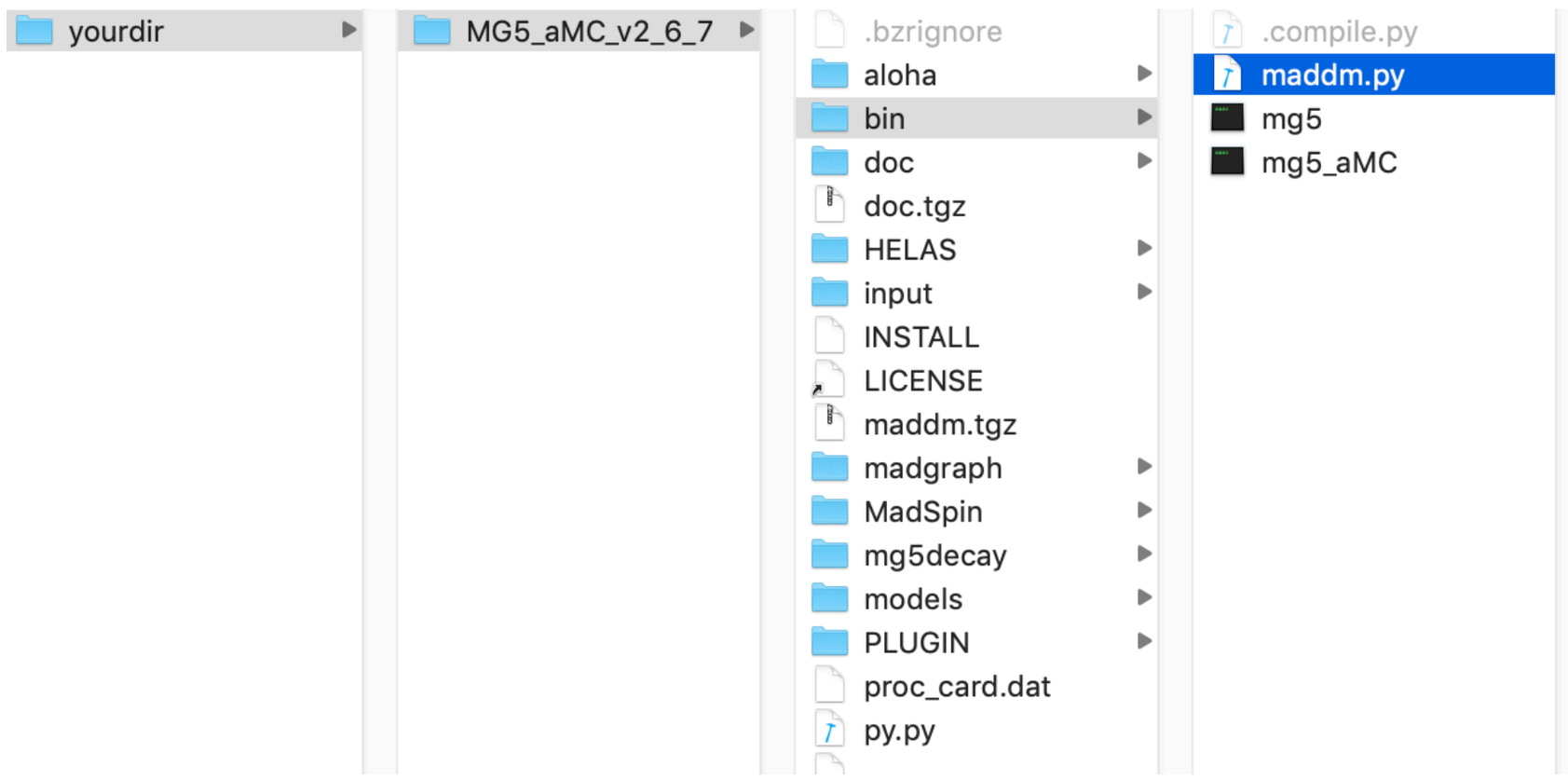
```



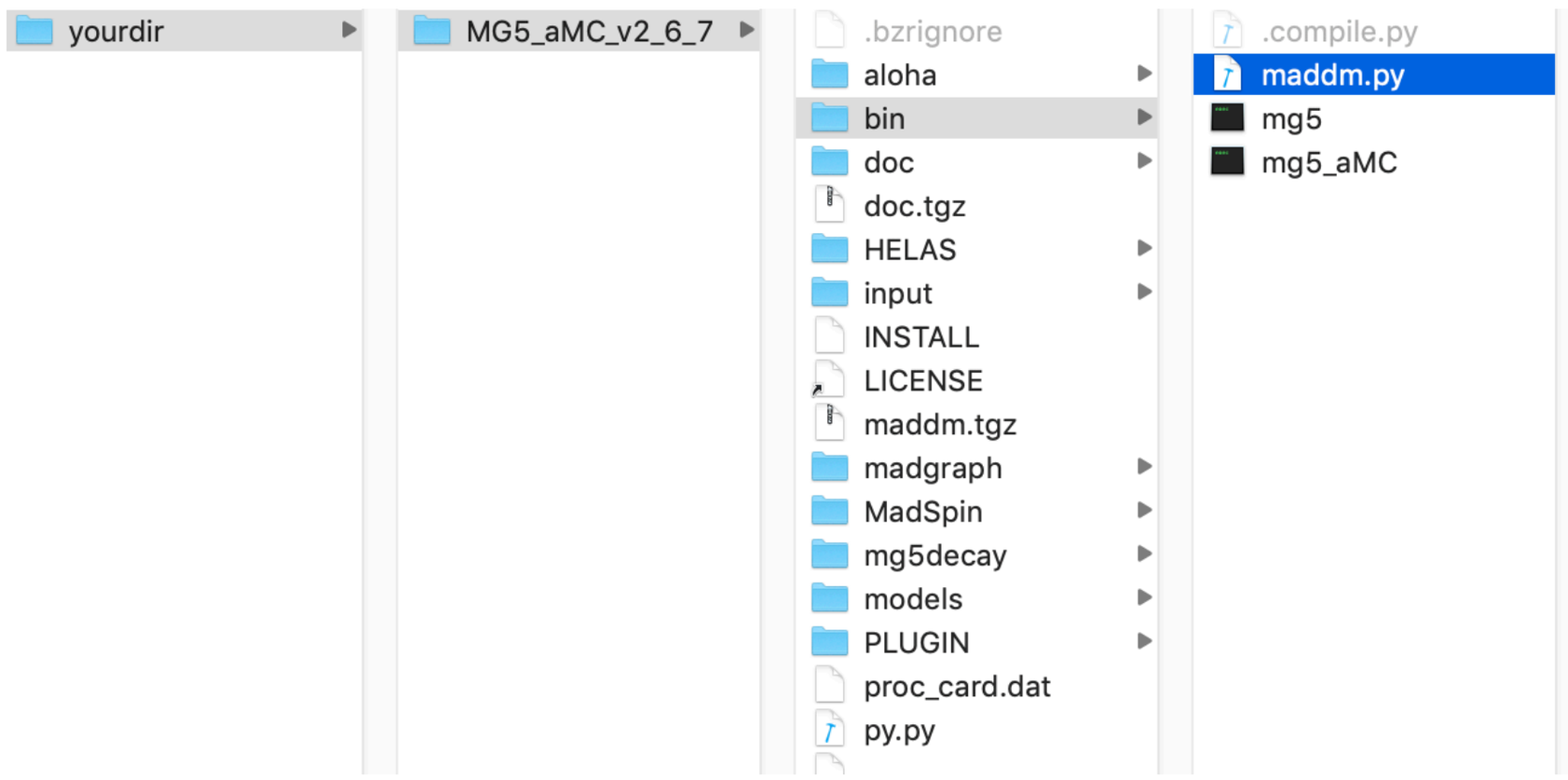
Run MadDM

```
MG5_aMC_v2_6_7$ python bin/maddm.py
MadDM>
```



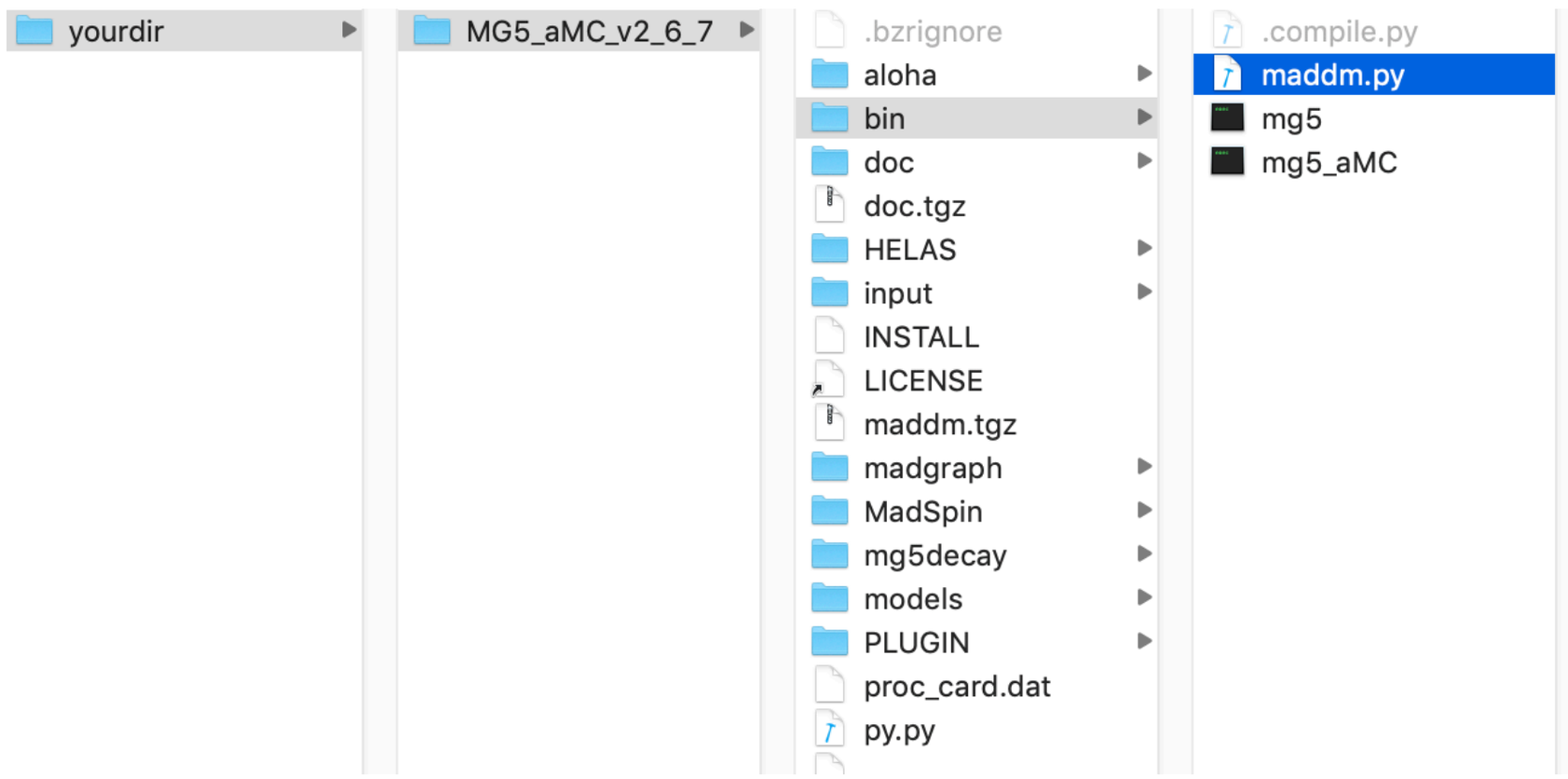
Run MadDM

```
MadDM> import model DMsimp_s_spin0
MadDM>
```



Run MadDM

```
MadDM> import model DMsimp_s_spin0
MadDM> define darkmatter xd
MadDM> generate relic_density
MadDM> add direct_detection
MadDM> add indirect_detection
MadDM>
```



Run MadDM

```
MadDM> import model DMsimp_s_spin0
MadDM> define darkmatter xd
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MadDM> add direct_detection
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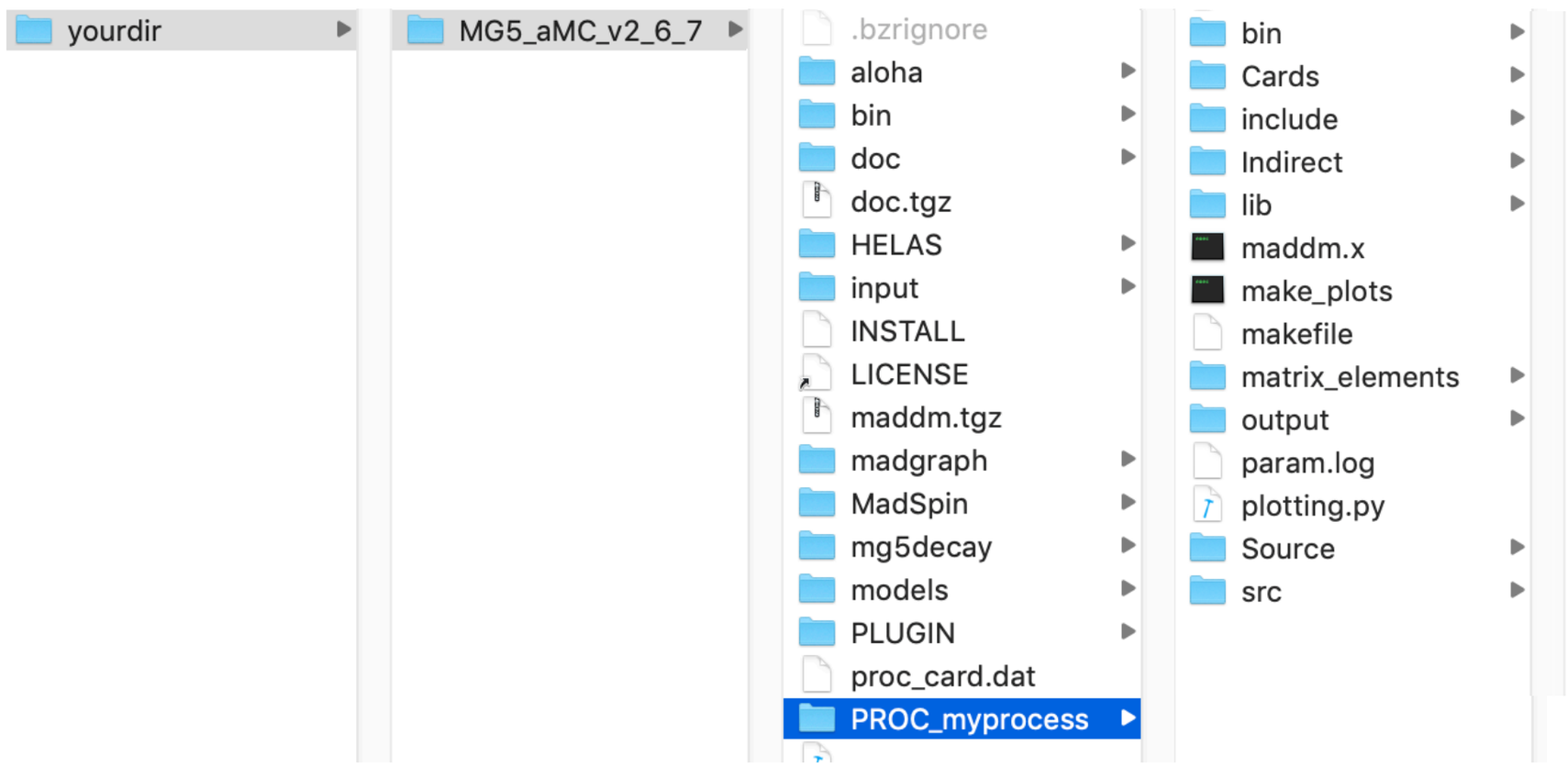
MadDM> output PROC_myprocess
```



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MadDM> output PROC_myprocess
MadDM> launch PROC_myprocess
```
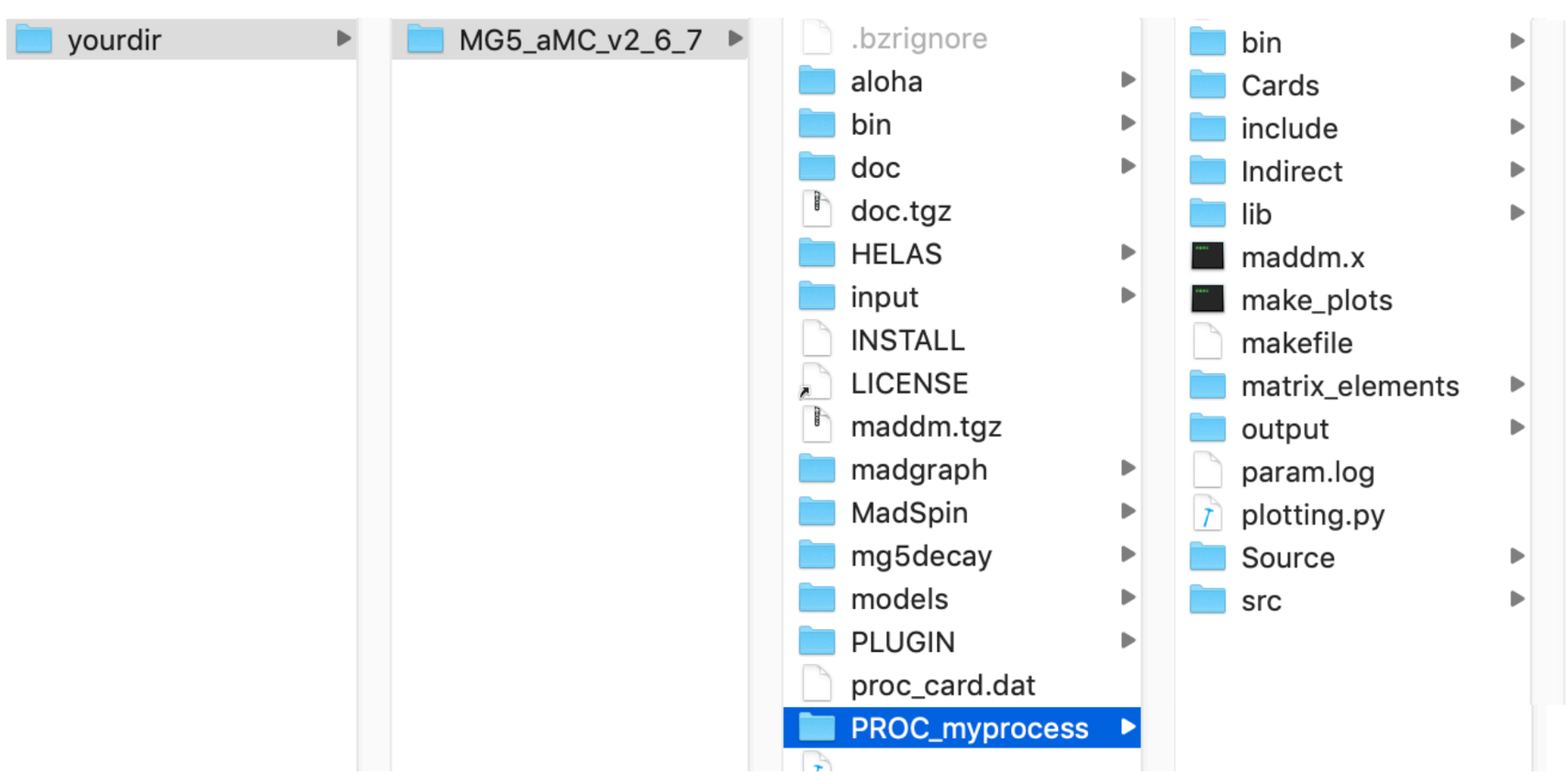
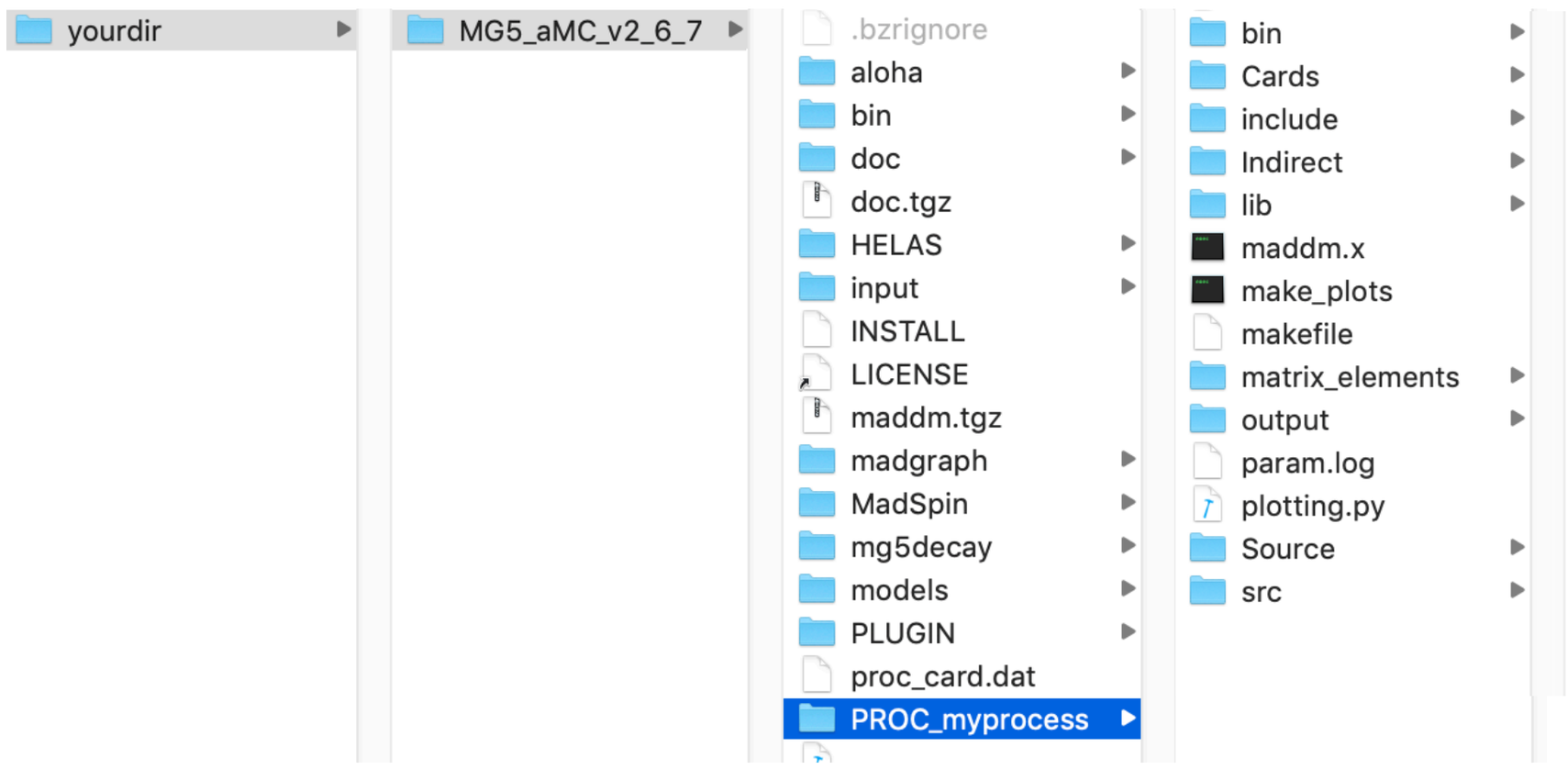



Run MadDM

```
MadDM> launch PROC_myprocess
/============ Description ============|======== values =========|======= other options ========\
| 1. Compute the Relic Density         |     relic = ON           |  OFF                          |
| 2. Compute direct(ional) detection   |    direct = direct       |  OFF|directional              |
| 3. Compute indirect detection/flux   |  indirect = sigmav       |  flux_source|flux_earth|OFF   |
| 4. Run Multinest scan                |  nestscan = OFF          |  Please install module        |
\=============================================================================================/
>
```



Run MadDM

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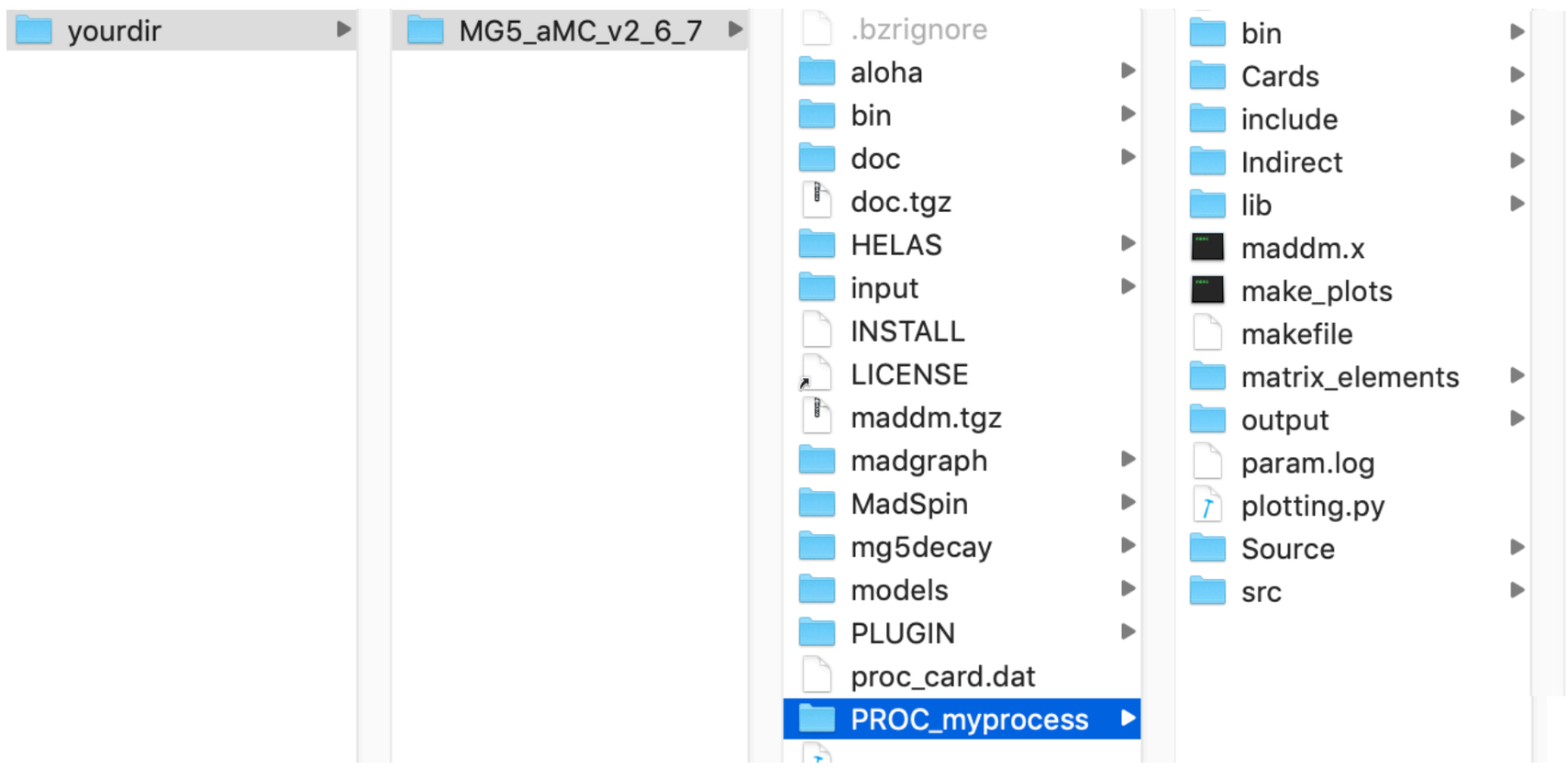
\=====================================================================================/
> 3
```



Run MadDM

```
> 3
/============ Description ============|======== values =========|======= other options ========\
| 1. Compute the Relic Density         |     relic = ON           |  OFF                          |
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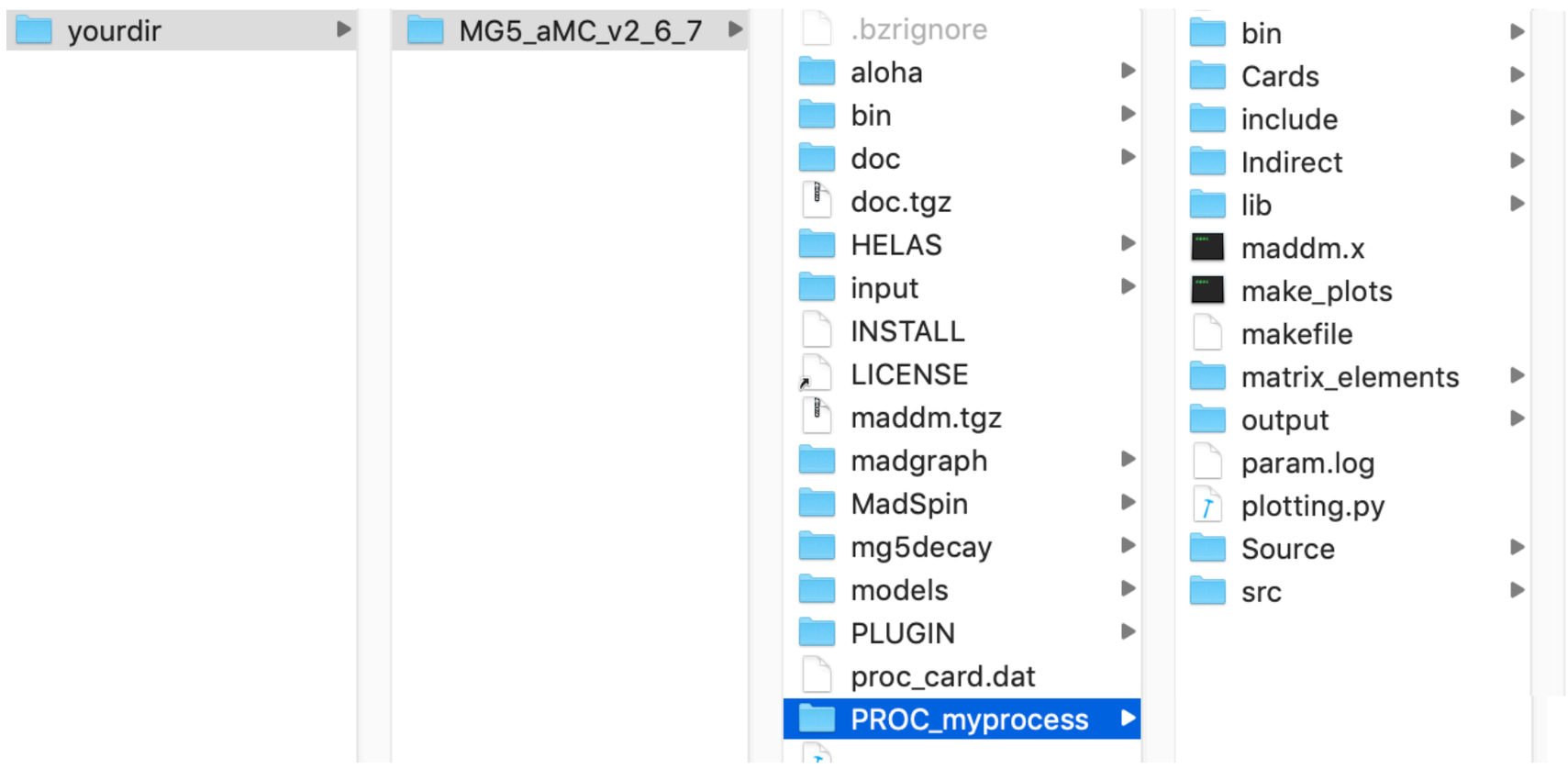
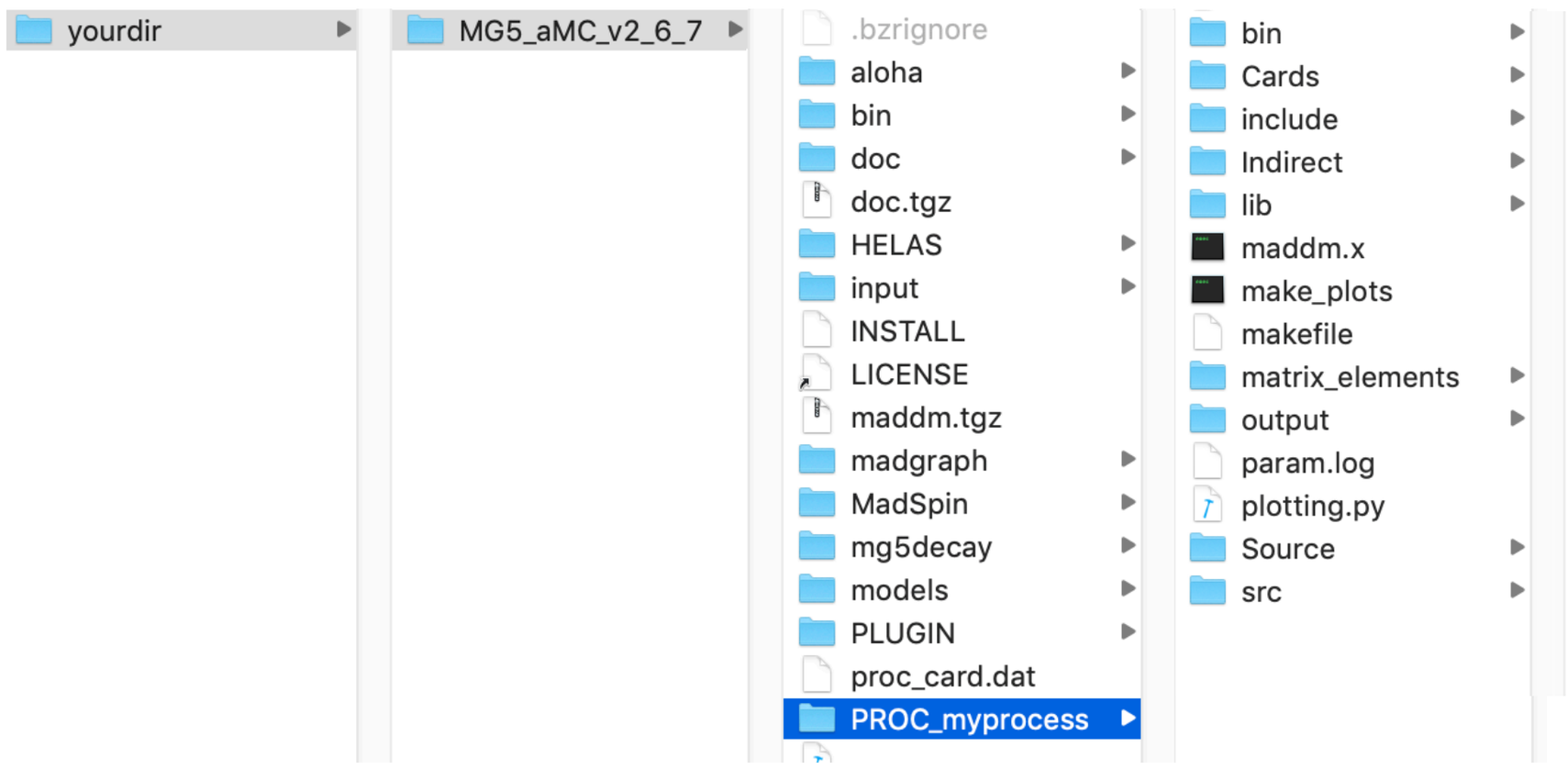
| 3. Compute indirect detection/flux   |  indirect = flux_source  |  flux_earth|OFF|sigmav      |
| 4. Run Multinest scan                |  nestscan = OFF          |  Please install module        |
\=================================================================================================/
>
```



Run MadDM

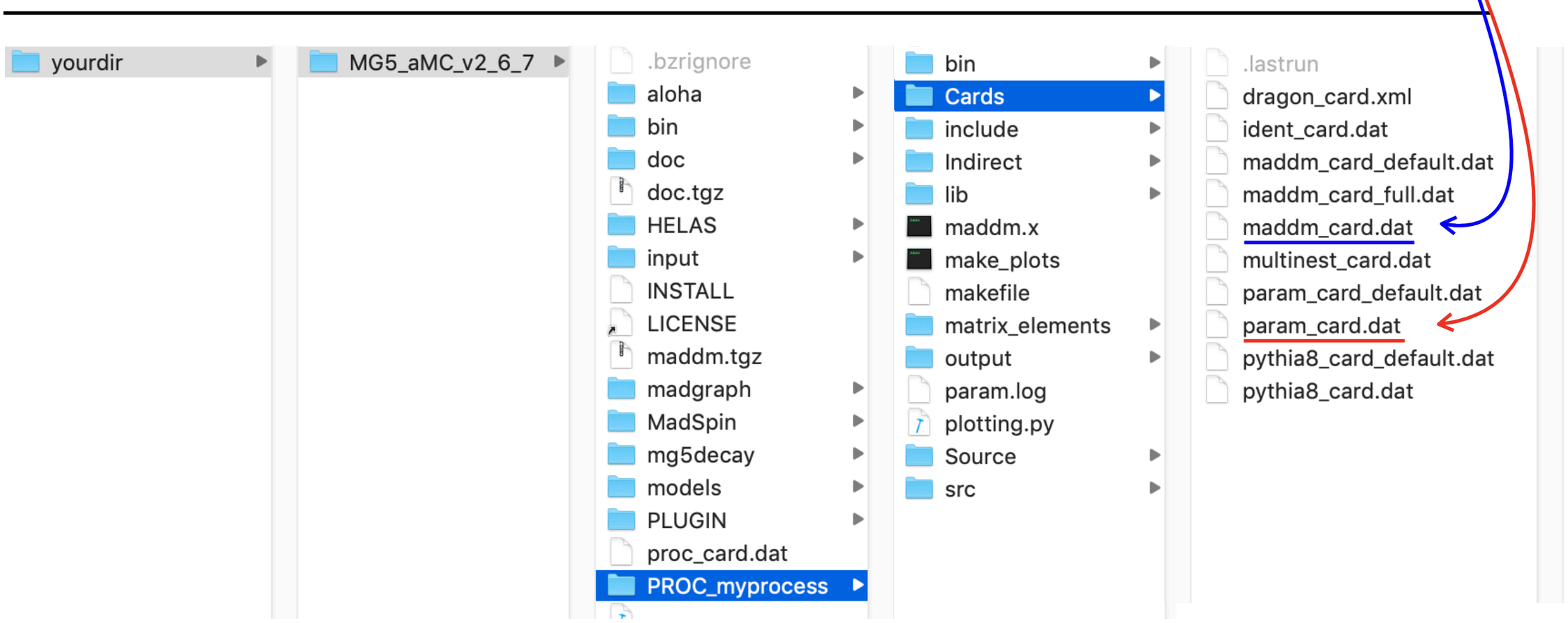
```
| 4. Run Multinest scan                | nestscan = OFF          | Please install module       |
\======================================================================================/
> set MXd 500
> set sigmav_method = madevent
> ...
```



Run MadDM

```
| 4. Run Multinest scan                 |  nestscan = OFF          |  Please install module       |
\=======================================================================================/
> set MXd 500
> set sigmav_method = madevent
>
```

Parameters and settings
either be changed by
set-commands or in config-files ("cards")



Run MadDM

```
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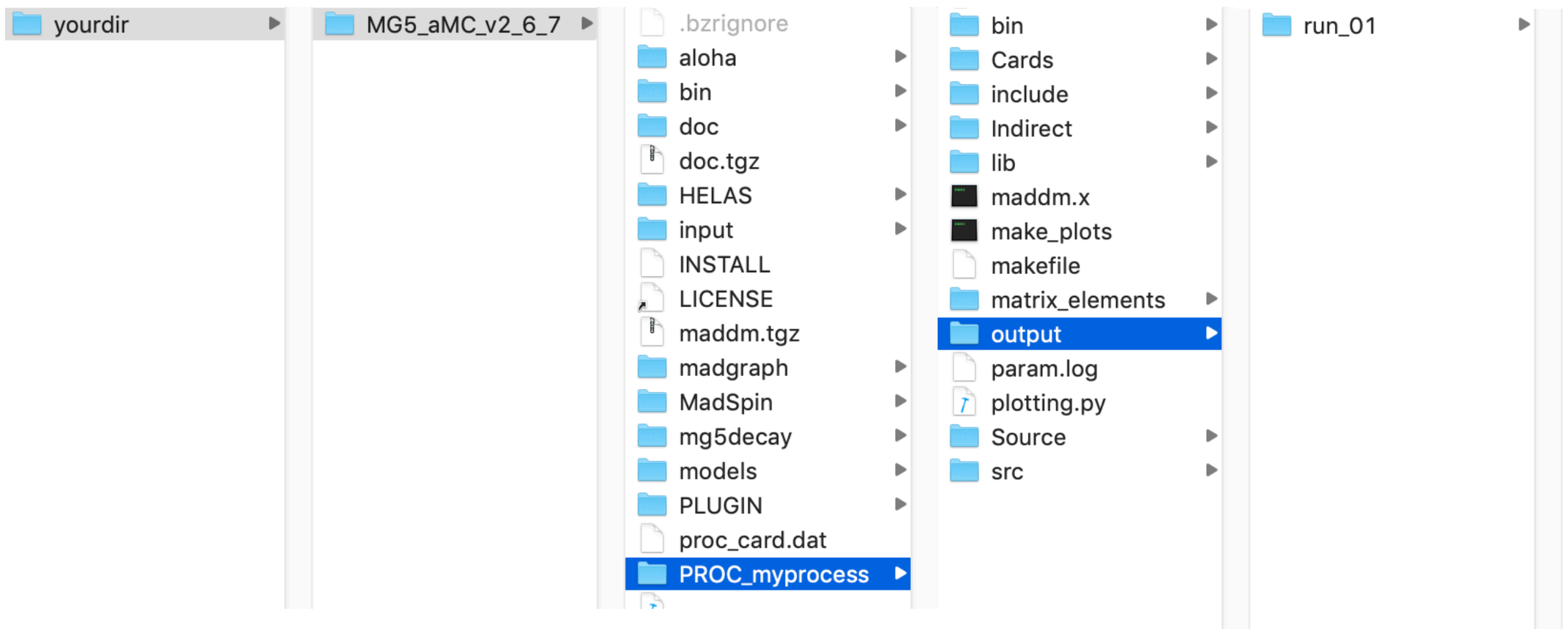
> set MXd 500
> set sigmav_method = madevent
>
MadDM>
```



Run MadDM

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| 4. Run Multinest scan                | nestscan = OFF          | Please install module       |
\=======================================================================================/
> set MXd 500
> set sigmav_method = madevent
>
MadDM>
```
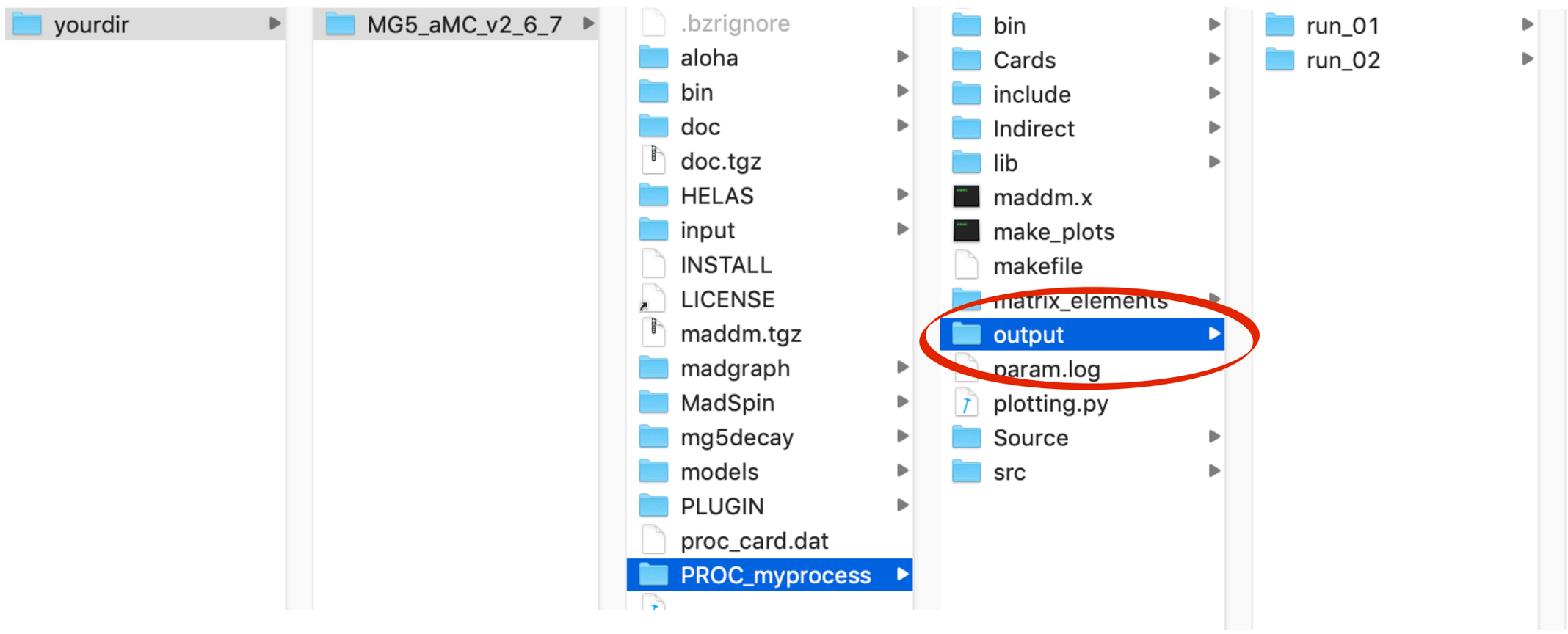



Running a scan

- Passing everything as text file

```
MG5_aMC_v2_6_7$ python bin/maddm.py run.txt
```

```
---------- run.txt ----------
import model DMsimp_s_spin0
define darkmatter xd
generate indirect_detection
output PROC_myprocess
launch PROC_myprocess
3
set sigmav_method = madevent
set MXd 500
```

Running a scan

- Passing everything as text file

```
MG5_aMC_v2_6_7$ python bin/maddm.py run1.txt
MG5_aMC_v2_6_7$ python bin/maddm.py run2.txt
```

```
----------run1.txt ----------
import model DMsimp_s_spin0
define darkmatter xd
generate indirect_detection
output PROC_myprocess

---------- run2.txt ----------
launch PROC_myprocess
3
set sigmav_method = madevent
set MXd 500
```

Running a scan

- Passing everything as text file

```
MG5_aMC_v2_6_7$ python bin/maddm.py run1.txt
MG5_aMC_v2_6_7$ python bin/maddm.py run2.txt
```

- Sequential grid scan in MadDM

```
MadDM> launch PROC_myprocess
> set MXd scan:range(50,700,25)
```

```
----------run1.txt ----------
import model DMsimp_s_spin0
define darkmatter xd
generate indirect_detection
output PROC_myprocess

---------- run2.txt ----------
launch PROC_myprocess
3
set sigmav_method = madevent
set MXd 500
```

```
----------- param_card.dat -----------
...
Block mass
    1 5.040000e-03 # MD
    2 2.550000e-03 # MU
    3 1.010000e-01 # MS
    4 1.270000e+00 # MC
    5 4.700000e+00 # MB
    6 1.720000e+02 # MT
   15 1.777000e+00 # MTA
   23 9.118760e+01 # MZ
   25 1.250000e+02 # MH
  5000521 scan:range(50,700,25)   # MXd
  5000001 1.000000e+03 # MY1
...
```

Running a scan

- Passing everything as text file

```
MG5_aMC_v2_6_7$ python bin/maddm.py run1.txt
MG5_aMC_v2_6_7$ python bin/maddm.py run2.txt
```

- Sequential grid scan in MadDM

```
MadDM> launch PROC_myprocess
> set MXd scan:range(50,700,25)
```

- Employing Multinest scan (Bayesian inference tool)

```
MadDM> launch PROC_myprocess
> nestscan = 0N
```

...and set multinest parameters in multinest_card.dat

```
----------run1.txt ----------
import model DMsimp_s_spin0
define darkmatter xd
generate indirect_detection
output PROC_myprocess

---------- run2.txt ----------
launch PROC_myprocess
3
set sigmav_method = madevent
set MXd 500
```

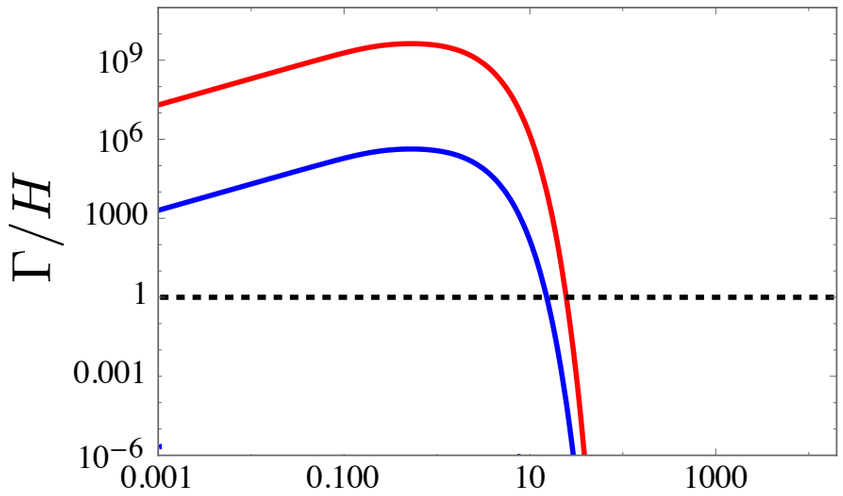
```
---------- param_card.dat ----------
...
Block mass
    1 5.040000e-03 # MD
    2 2.550000e-03 # MU
    3 1.010000e-01 # MS
    4 1.270000e+00 # MC
    5 4.700000e+00 # MB
    6 1.720000e+02 # MT
   15 1.777000e+00 # MTA
   23 9.118760e+01 # MZ
   25 1.250000e+02 # MH
 5000521 scan:range(50,700,25)   # MXd
 5000001 1.000000e+03 # MY1
...
```

More Details

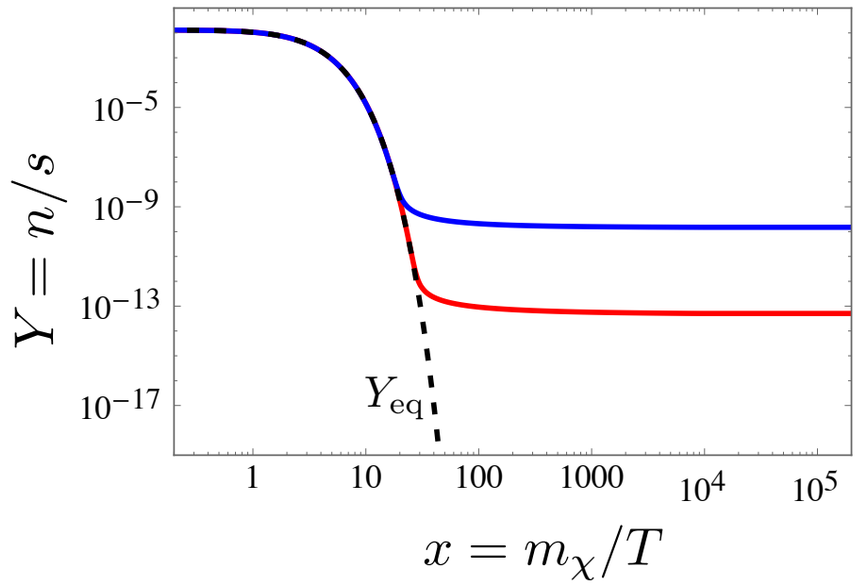
Relic density, Direct detection, Indirect detection

Relic density

- Compute scattering rates

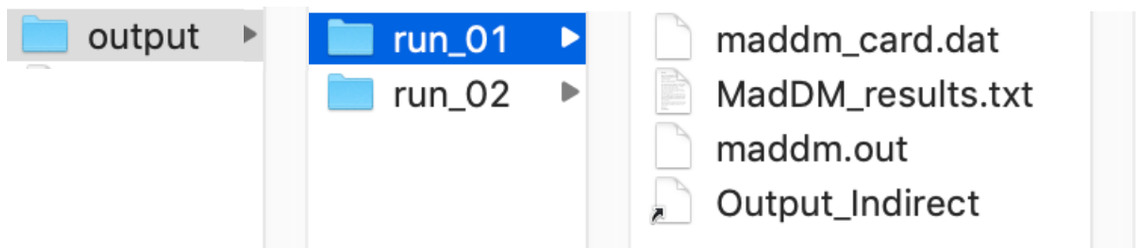


- Solve Boltzmann equation



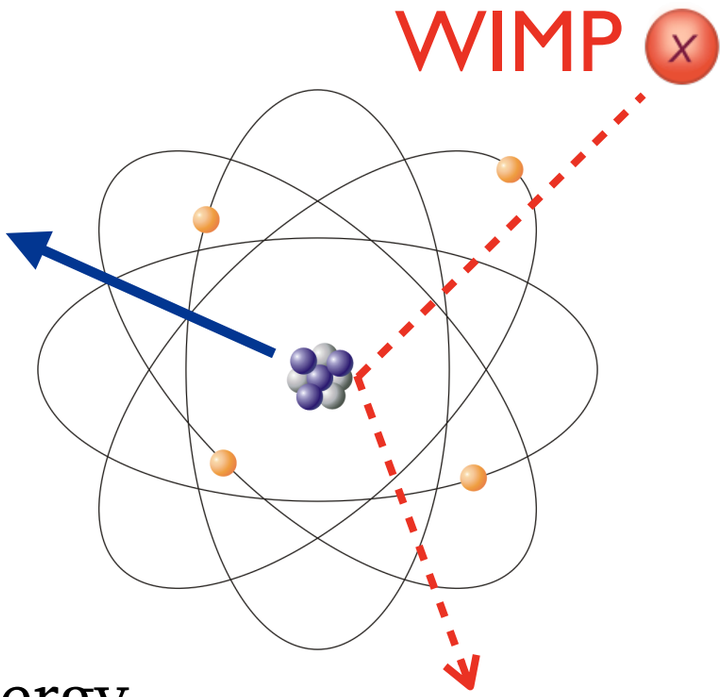

```
MadDM> define darkmatter xd
MadDM> define coannihilator xr
MadDM> gernerate relic_density
```

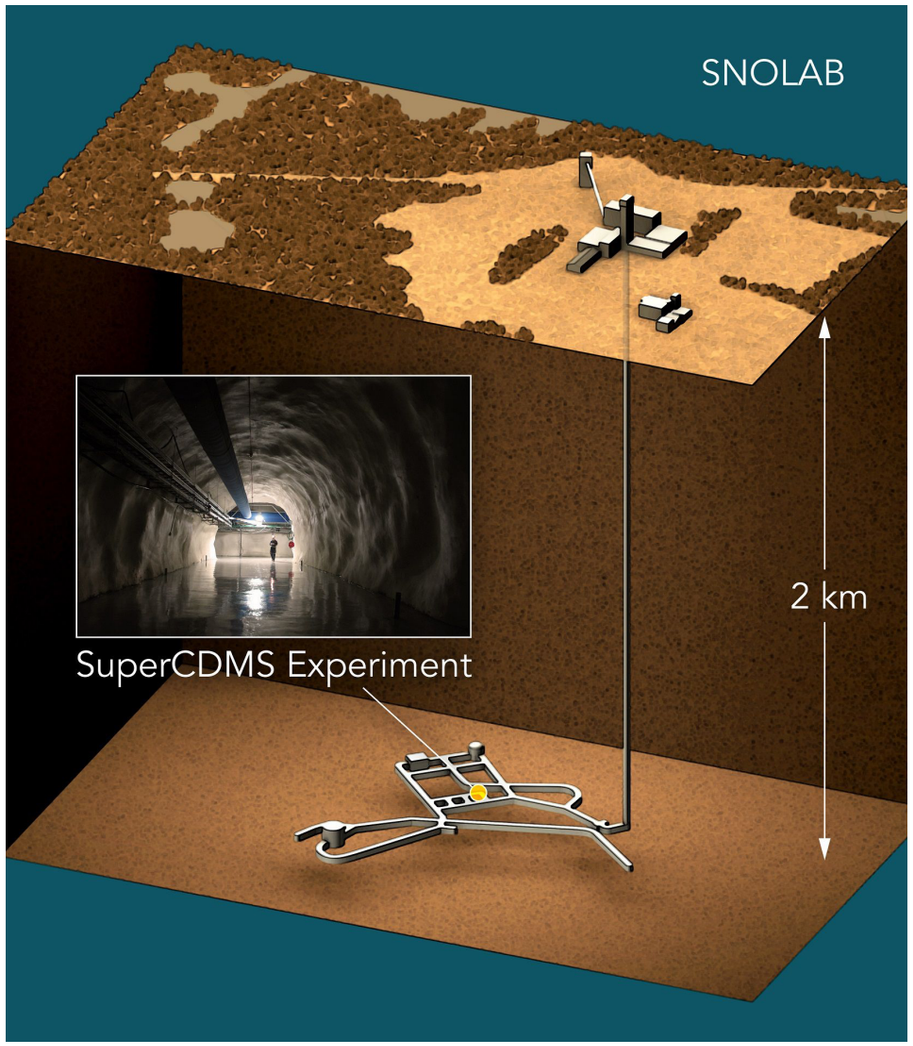
```
***** Relic Density
OMEGA IS  0.000325869586293
INFO: Relic Density = 3.26e-04 ALLOWED
INFO: x_f           = 2.80e+01
INFO: sigmav(xf)    = 2.81e-07
INFO: xsi           = 2.72e-03
```



Direct detection of WIMP dark matter

- Elastic scattering of WIMPs off nuclei:





- Recoil energy threshold $E_{\mathrm{R}} \sim$ few 10 keV

$$E_{\mathrm{R}} = \frac{q^2}{2m_N}\,,\; q_{\mathrm{max}} = 2m_\chi v$$

$$v \sim 10^{-3}$$

Direct(ional) detection

- Two modes:

```
/============ Description ============|======== values =========|======= other options ========\
| 1. Compute the Relic Density         |     relic = ON          |  OFF                          |
| 2. Compute direct(ional) detection   |    direct = direct      |  OFF|directional              |
| 3. Compute indirect detection/flux   |  indirect = sigmav      |  flux_source|flux_earth|OFF  |
| 4. Run Multinest scan                |  nestscan = OFF         |  Please install module        |
\=================================================================================================/
>
```

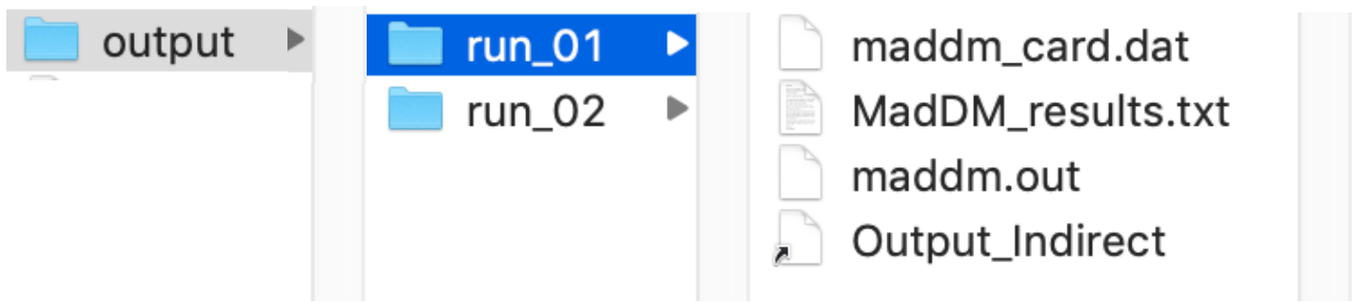
`direct = direct` / `direct = directional`

Direct(ional) detection

i) 'direct' mode:

- Computation of spin-independent and -dependent dark-matter-nucleus cross sections $\sigma_{\chi N}$
- Together with corresponding experimental limits

```
***** Relic Density
OMEGA IS  0.000325869586293
INFO: Relic Density        = 3.26e-04     ALLOWED
INFO: x_f                  = 2.80e+01
INFO: sigmav(xf)           = 2.81e-07
INFO: xsi                  = 2.72e-03
***** Direct detection [cm^2]:
INFO: SigmaN_SI_p   Thermal = 2.01e-50   ALLOWED    All DM = 7.40e-48   ALLOWED   Xenon1ton ul = 6.44e-46
INFO: SigmaN_SI_n   Thermal = 1.98e-50   ALLOWED    All DM = 7.27e-48   ALLOWED   Xenon1ton ul = 6.44e-46
INFO: SigmaN_SD_p   Thermal = 0.00e+00   ALLOWED    All DM = 0.00e+00   ALLOWED   Pico60 ul    = 2.03e-40
INFO: SigmaN_SD_n   Thermal = 0.00e+00   ALLOWED    All DM = 0.00e+00   ALLOWED   Lux2017 ul   = 1.22e-40
```

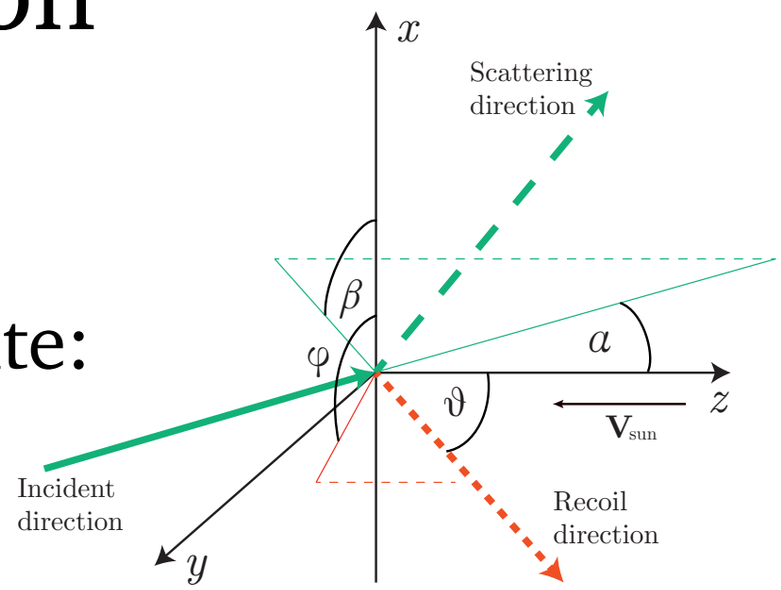


Direct(ional) detection

ii) 'directional' mode:

- Same as 'direct' plus differential recoil rate:

$$\frac{\mathrm{d}^2 R}{\mathrm{d}E_\mathrm{R}\,\mathrm{d}\cos\theta}(E_\mathrm{R},\theta,t)$$



Binned in recoil energy, scattering angle and time

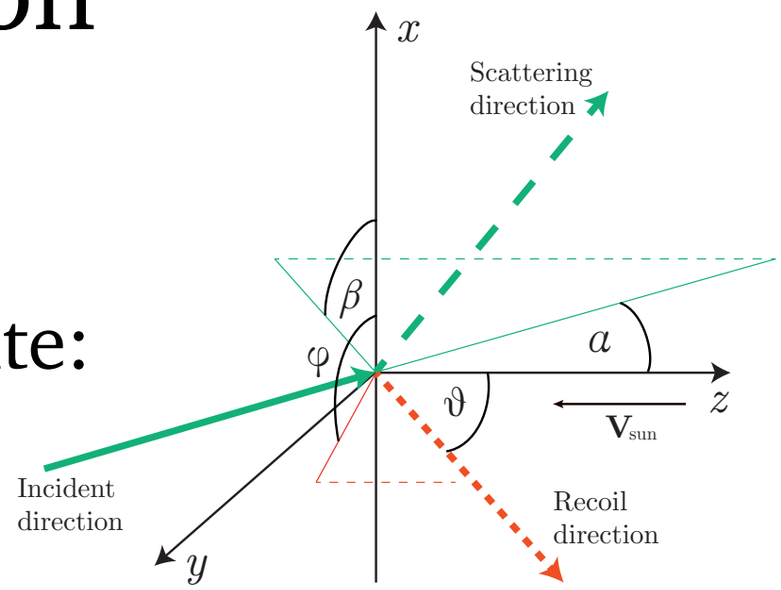
```
# choose the target material (type "help material" for more info)
   1          = material ! 1: Xenon, 2: Germanium, 3: Silicon, ...

# galactic halo DM constants
   220.0      = vMP      ! Most probable WIMP velocity v_0 (km/s)
   650.0      = vescape  ! Escape velocity of WIMPS in Halo (km/s)
   0.3        = rhoDM    ! Local WIMPs density (GeV/c^2/cm^-3)

# choose the size of the detector
   1000.0     = detector_size  ! in kg
   4.0        = En_threshold    ! in keVnr
...
```

Direct(ional) detection

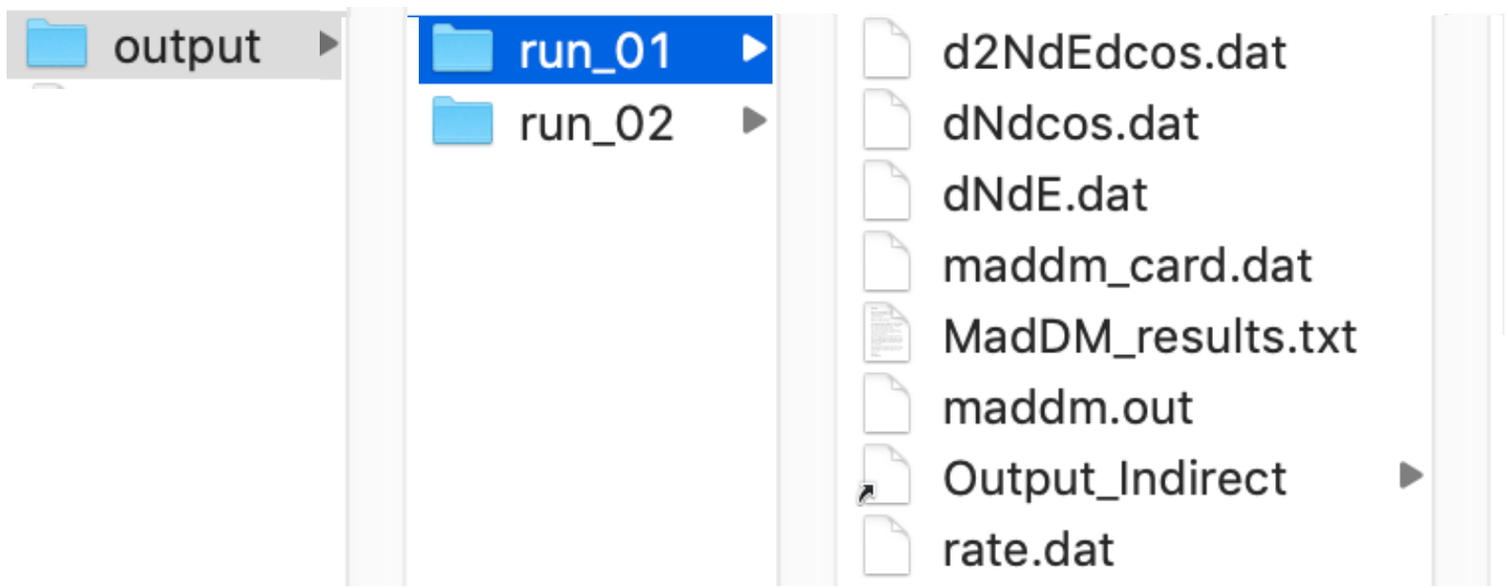
ii) 'directional' mode:

- Same as 'direct' plus differential recoil rate:

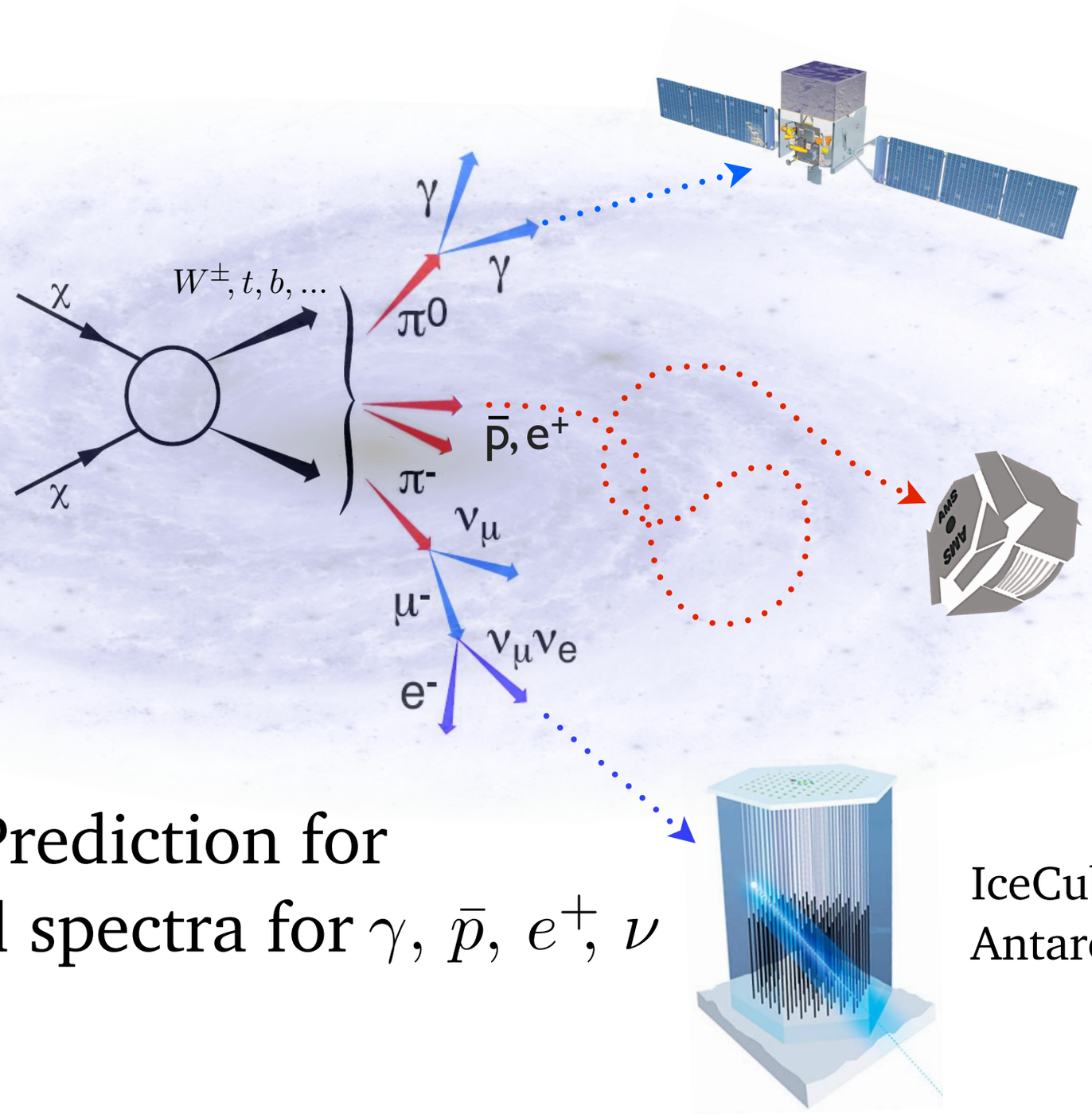
$$\frac{\mathrm{d}^2 R}{\mathrm{d}E_\mathrm{R}\,\mathrm{d}\cos\theta}(E_\mathrm{R},\theta,t)$$



Binned in recoil energy, scattering angle and time



Indirect detection of WIMP dark matter



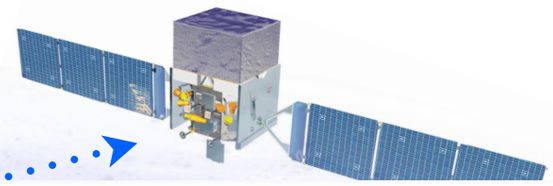
Fermi-LAT, HESS, MAGIC, VERITAS, MAGIC, CHAW, CTA, LHAASO, ...

AMS-02, HERD, ...

IceCube, Antares, ...

Needed: Prediction for fluxes and spectra for γ, $\bar{p}$, e^{+}, ν

Indirect detection of WIMP dark matter



Fermi-LAT, HESS, MAGIC, VERITAS, MAGIC, CHAW, ...

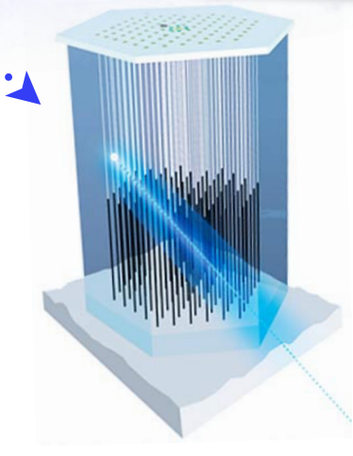
E.g. for gammas:

$$\frac{\mathrm{d}\Phi}{\mathrm{d}E_\gamma}(E_\gamma) = \frac{1}{2m_\chi^2} \sum_i \left(\frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma}\right)_i \langle\sigma v\rangle_i \; \frac{1}{4\pi} \int_\theta \mathrm{d}\Omega \int_{\mathrm{los}} \mathrm{d}l \, \rho^2(\theta, l)$$

Gamma-spectrum per annihilation

Annihilation cross section

Needed: Prediction for fluxes and spectra for γ, $\bar{p}$, e^+, ν

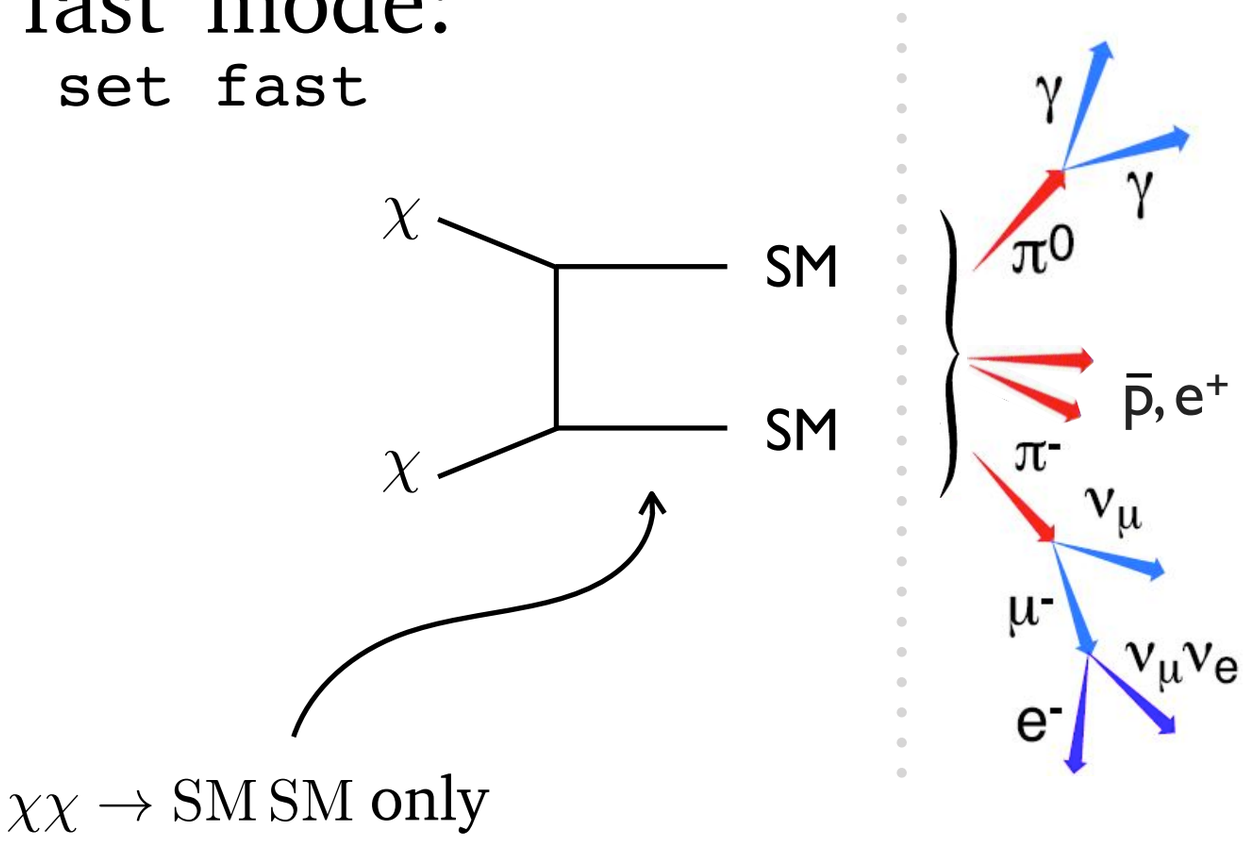


IceCube, Antares , ...

Prediction for indirect detection fluxes and spectra with MadDM

i) 'fast' mode:

```
set fast
```



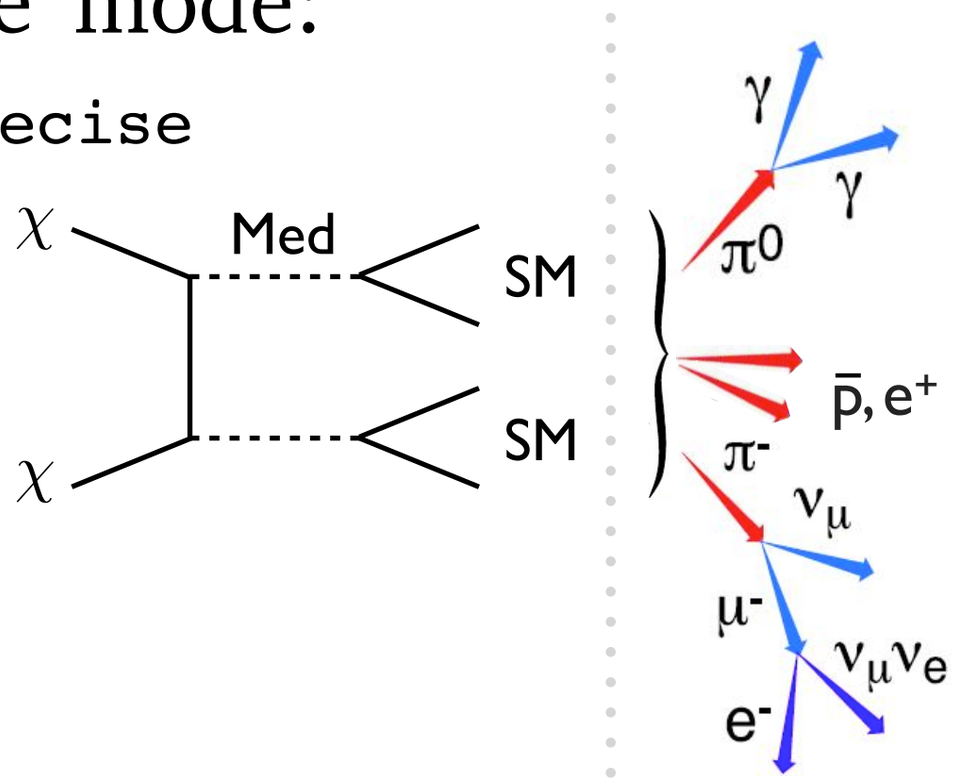
$\chi\chi \to \mathrm{SM}\,\mathrm{SM}$ only

Pre-computed spectra for $\gamma,\ \bar{p},\ e^{+},\ \nu$

Prediction for indirect detection fluxes and spectra with MadDM

ii) 'precise' mode:

```
set precise
```



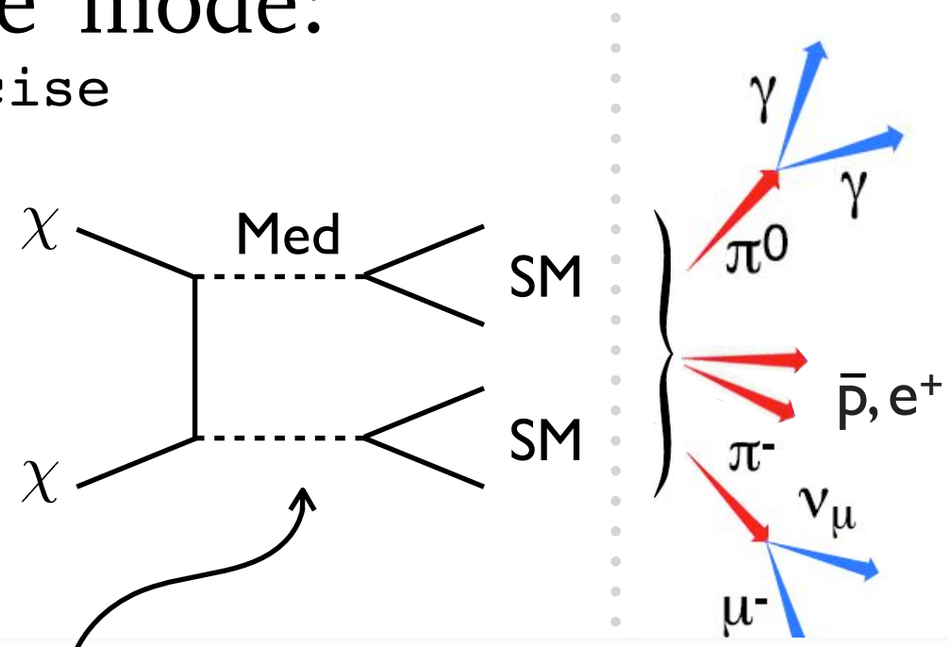
MadEvent $\xrightarrow{\text{lhe}}$ Pythia $\longrightarrow$ Spectra $\frac{\mathrm{d}N_m}{\mathrm{d}E_m}$ for γ, $\bar{p}$, e^+, ν

MadEvent $\searrow$ $\langle\sigma v\rangle$

Prediction for indirect detection fluxes and spectra with MadDM

ii) 'precise' mode:

```
set precise
```



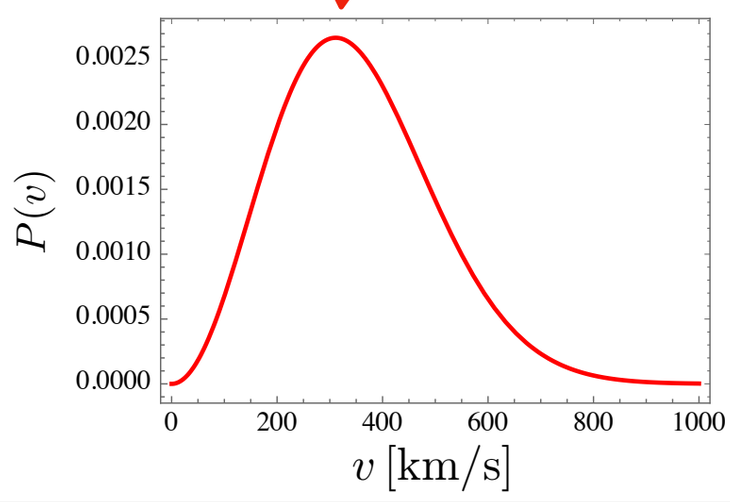

```
set vave_indirect <value>
```

fixed velocity $\sigma v|_{v\sim v_0}$

```
sigmav_method = madevent
```

or Maxwell-Boltzmann distribution

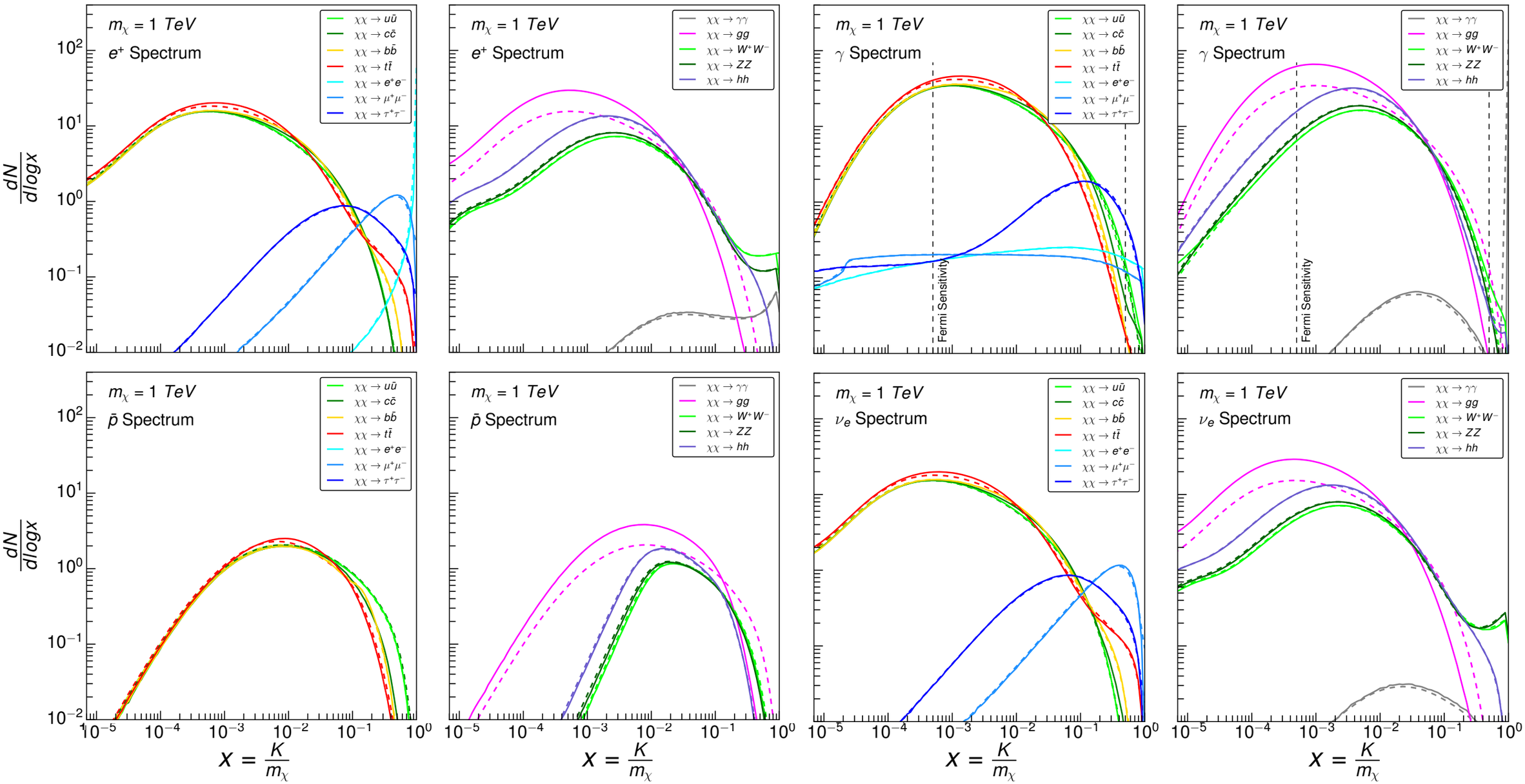
```
sigmav_method = reshuffling
```



Pre-computed spectra ('fast' mode)

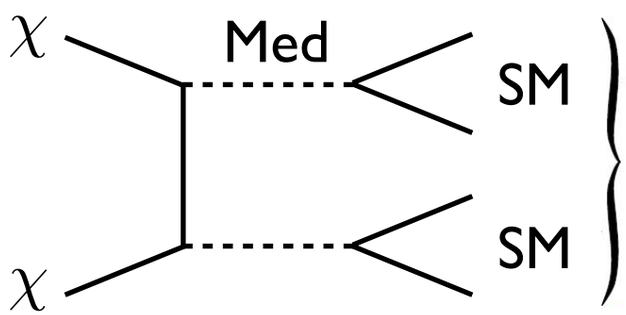
Comparison to PPPC 4 DM ID:

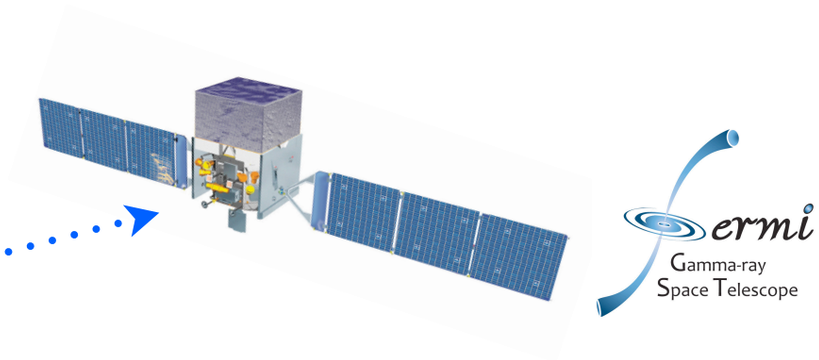
[Cirelli, Corcella, Hektor, Hütsi, Kadastik, Panci, Raidal, Sala, Strumia 2012]



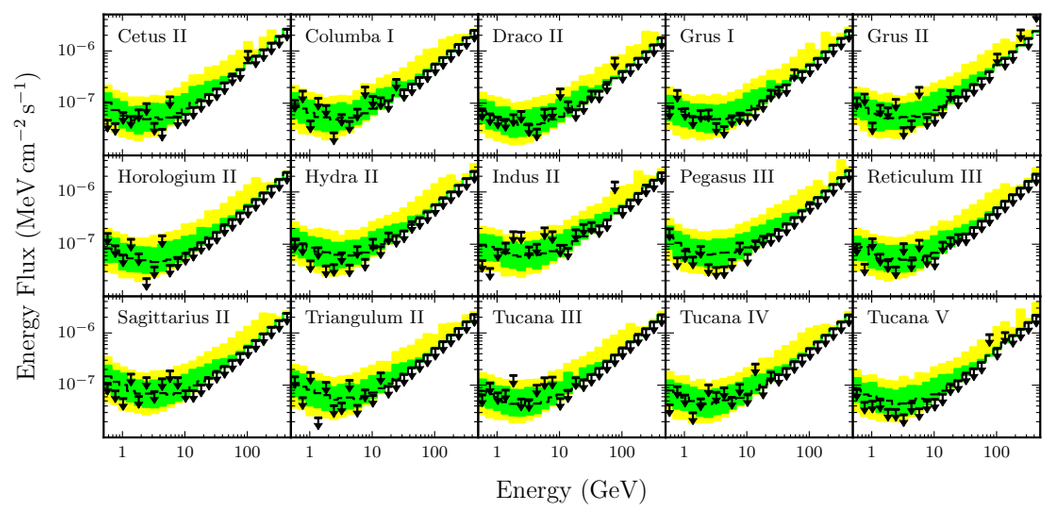
Constraints: Fermi-LAT dwarfs

MadDM:





[Fermi-LAT 2016]



Predicted flux in each energy bin:

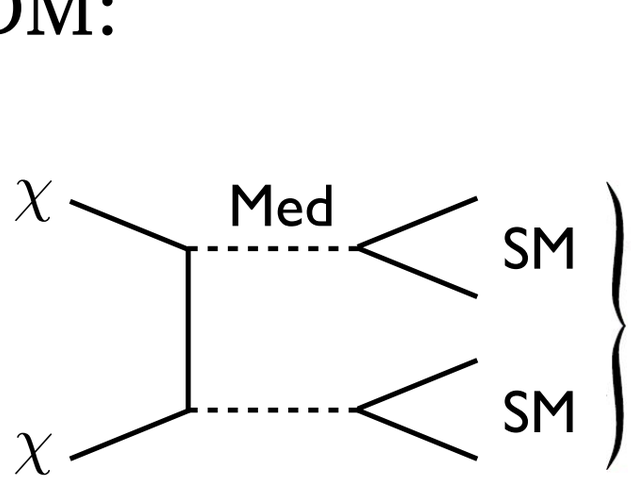
$$E^2 \frac{\mathrm{d}\phi}{\mathrm{d}E} = \frac{J}{4\pi} \frac{1}{2m_\chi^2} \sum_i \langle \sigma v \rangle_i \int_{E_{\min}}^{E_{\max}} \mathrm{d}E_\gamma \, E_\gamma \frac{\mathrm{d}N_\gamma^i}{\mathrm{d}E_\gamma}$$

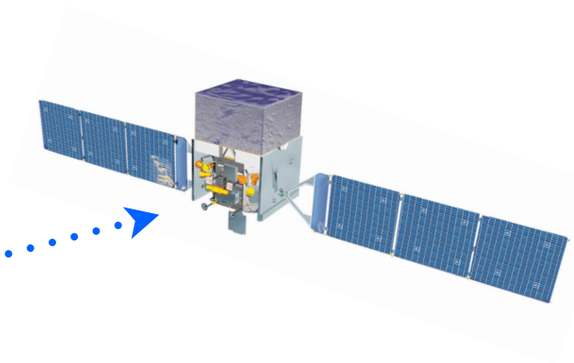
J-factor: $J = \int \mathrm{d}\Omega \int_{\mathrm{l.o.s.}} \mathrm{d}s \, \rho_{\mathrm{DM}}^2$

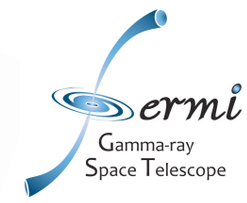
```
set vave_indirect 2e-5
```

Constraints: Fermi-LAT dwarfs

MadDM:







Utilize binned public likelihood
[Fermi-LAT 2016]

Computation of cross section upper limits:

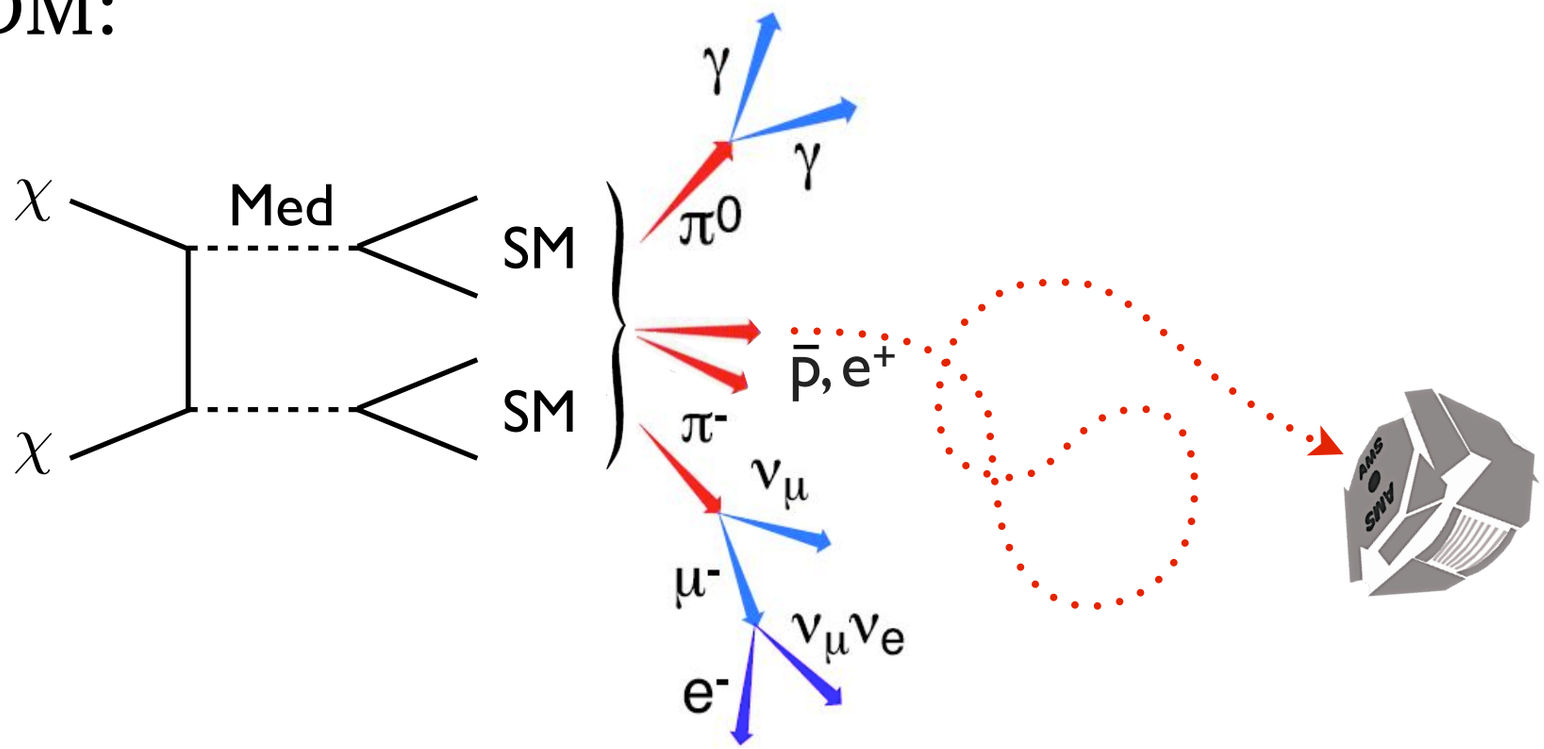
$$TS = -2 \sum_{\text{dwarfs}} \frac{\mathcal{L}\left(\widehat{J}, \sigma v\right)}{\mathcal{L}\left(\widehat{\widehat{J}}, \widehat{\sigma v}\right)}$$

Profiling over *J*-factors

➔ Likelihood, *p*-value and σv_{UL} for given point

Propagation of charged cosmic rays

MadDM:



- Fast mode: pre-computed fluxes at Earth from PPPC 4 DM ID
  `indirect_flux_earth_method = PPPC4DMID_ep`
- User-friendly interface to Dragon [Evoli, Gaggero, Grasso, Maccione 2008]
  `indirect_flux_earth_method = dragon`

Indirect detection overview

		Indirect detection module			Experimental constraints
Running mode		$< \sigma v >$	Energy Spectra	Flux at Earth	Module available:
	Fast	$(\sigma \times v)\|_{v=v_{\rm rel}}$ Allows only DM DM $\rightarrow$ 2 particles	Numerical tables Allows only DM DM $\rightarrow$ SM SM	Prompt photons Neutrinos Positrons (fixed sets of propagation parameters)	Simplified framework based on the ExpConstraint class
	Precise	Full integration over the DM velocity distribution Allows for any DM annihilation process	Pythia 8 computes on the fly the energy spectra Allows for any DM annihilation process DM DM $\rightarrow$ n particles	Prompt photons Neutrinos Positrons Anti-protons (free choice of propagation parameters)	Fermi-LAT likelihood for dSPhs + ExpConstraint class

`indirect =` `sigmav` `flux_source` `flux_earth`

Indirect detection overview

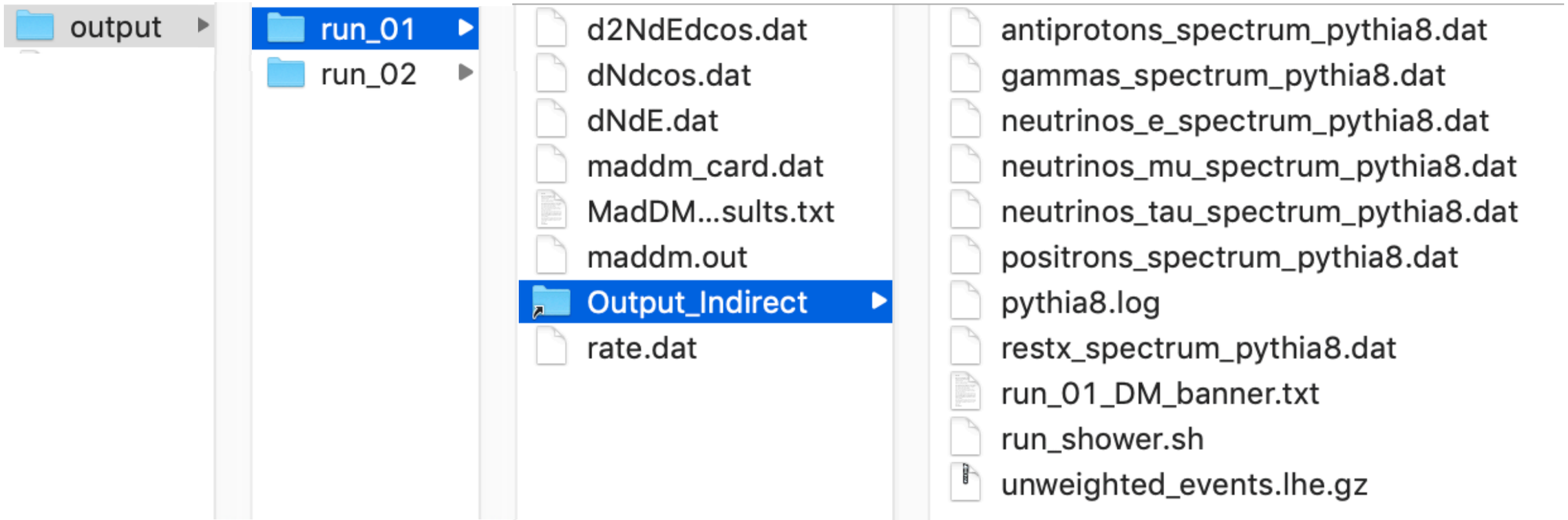
	Indirect detection module			Experimental constraints
Running mode	$< \sigma v >$	Energy Spectra	Flux at Earth	Module available:
Fast	$(\sigma \times v)\|_{v=v_{\rm rel}}$ Allows only DM DM $\to$ 2 particles	Numerical tables Allows only DM DM $\to$ SM SM	Prompt photons Neutrinos Positrons (fixed sets of propagation parameters)	Simplified framework based on the ExpConstraint class
Precise	Full integration over the DM velocity distribution Allows for any DM annihilation process	Pythia 8 computes on the fly the energy spectra Allows for any DM annihilation process DM DM $\to$ n particles	Prompt photons Neutrinos Positrons Anti-protons (free choice of propagation parameters)	Fermi-LAT likelihood for dSPhs + ExpConstraint class

```
indirect =
    sigmav
    flux_source
    flux_earth
```

Indirect detection screen output

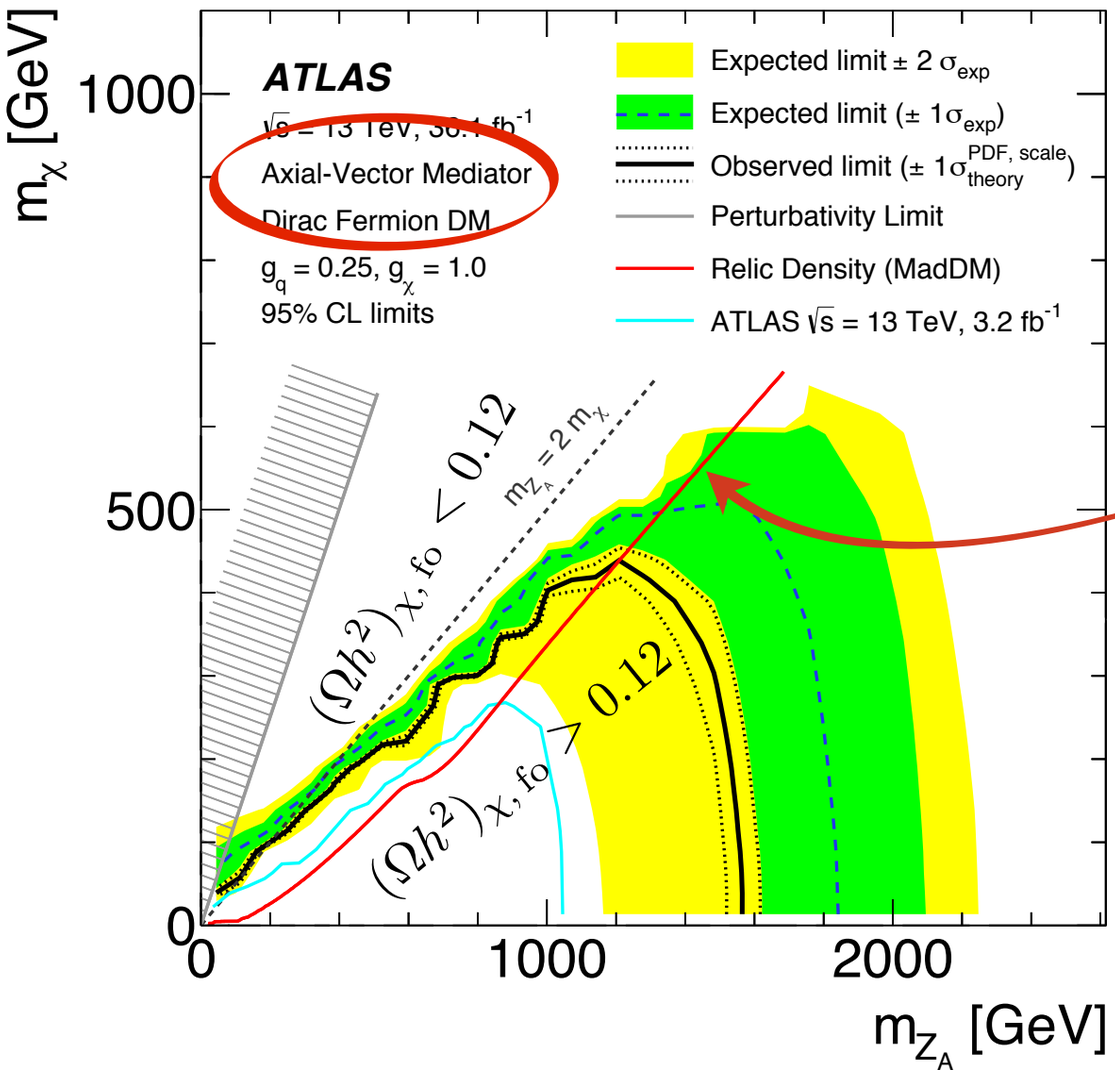
```
***** Relic Density
OMEGA IS  0.000325869586293
INFO: Relic Density     = 3.26e-04         ALLOWED
INFO: x_f               = 2.80e+01
INFO: sigmav(xf)        = 2.81e-07
INFO: xsi               = 2.72e-03
****** Indirect detection [cm^3/s]:
INFO: <sigma v> method: madevent
INFO: DM particle halo velocity: 2e-05/c
INFO: xdxdx_zz          Thermal = 1.67e-38  ALLOWED     All DM = 2.26e-33  ALLOWED   Fermi ul  = 1.16e-25
INFO: xdxdx_aa          Thermal = 1.25e-37  NO LIMIT    All DM = 1.69e-32  NO LIMIT  Fermi ul  = -1.00e+00
INFO: xdxdx_ttx         Thermal = 1.29e-35  ALLOWED     All DM = 1.74e-30  ALLOWED   Fermi ul  = 1.09e-25
INFO: xdxdx_hh          Thermal = 6.03e-39  ALLOWED     All DM = 8.15e-34  ALLOWED   Fermi ul  = 1.03e-25
INFO: xdxdx_wpwm        Thermal = 1.28e-38  ALLOWED     All DM = 1.73e-33  ALLOWED   Fermi ul  = 1.14e-25
INFO: Skipping zero cross section processes for: xrxr, xcxcx, y0y0
INFO: Total limits calculated with Fermi likelihood:
INFO: DM DM > all       Thermal = 1.30e-35  ALLOWED     All DM = 1.76e-30  ALLOWED   Fermi ul  = 2.85e-25
INFO:
INFO: *** Fluxes at earth [particle/(cm^2 sr)]:
INFO: gammas Flux         =   1.22e-14
INFO: neutrinos_e Flux    =   8.92e-18
INFO: neutrinos_mu Flux   =   9.75e-18
INFO: neutrinos_tau Flux =   8.78e-18
```

Indirect detection output files



Scan example: Reproduce relic contour

$$\mathcal{L} = \bar{\chi}\gamma_\mu(g_\chi^V + g_\chi^A\gamma_5)\chi Z_A^\mu + \bar{q}\gamma_\mu(g_q^V + g_q^A\gamma_5)qZ_A^\mu$$



$$(\Omega h^2)_{\chi,\,\mathrm{fo}} = 0.12$$

Scan example: Reproduce relic contour

Load model:

```
MadDM>import model DMsimp_s_spin1
```

Define DM candidate:

```
MadDM>define darkmatter xd
```

Request for computation of relic density:

```
MadDM>generate relic_density
```

Creating output folder and run:

```
MadDM>output PROC_DMsimp_scan
MadDM>launch
```

Example: Simplified dark matter model

```
/============= Description =============|========= values ==========|======= other options =======\
| 1. Compute the Relic Density           |          relic = ON        |    OFF                       |
| 2. Compute direct(ional) detection     |         direct = OFF       |    Please install module     |
| 3. Compute indirect detection/flux     |       indirect = OFF       |    Please install module     |
| 4. Run Multinest scan                  |       nestscan = OFF       |    Please install module     |
\=========================================================================================/
 You can also edit the various input card:
 * Enter the name/number to open the editor
 * Enter a path to a file to replace the card
 * Enter set NAME value to change any parameter to the requested value
 /=================================================================\
 |  5. Edit the model parameters    [param]                        |
 |  6. Edit the MadDM options       [maddm]                        |
 \=================================================================/
[60s to answer]
>5
```

↳ opens yourdir/MG5_aMC_v2_6_7/PROC_DMsimp_scan/Cards/param_card.dat

param_card.dat:

```
...
#####################################
## INFORMATION FOR DMINPUTS
#####################################
Block dminputs
    1 0.000000e+00 # gVXc
    2 0.000000e+00 # gVXd
    3 1.000000e+00 # gAXd
    4 0.000000e-01 # gVd11
    5 0.000000e-01 # gVu11
    6 0.000000e-01 # gVd22
    7 0.000000e-01 # gVu22
    8 0.000000e-01 # gVd33
    9 0.000000e-01 # gVu33
   10 0.000000e+00 # gVl11
   11 0.000000e+00 # gVl22
   12 0.000000e+00 # gVl33
   13 2.500000e-01 # gad11
   14 2.500000e-01 # gau11
   15 2.500000e-01 # gad22
   16 2.500000e-01 # gau22
   17 2.500000e-01 # gad33
   18 2.500000e-01 # gau33
   19 0.000000e+00 # gAl11
   20 0.000000e+00 # gAl22
   21 0.000000e+00 # gAl33
   22 0.000000e+00 # gnu11
   23 0.000000e+00 # gnu22
   24 0.000000e+00 # gnu33
   25 0.000000e+00 # gVu31
   26 0.000000e+00 # gAu31
   27 0.000000e+00 # gVd31
   28 0.000000e+00 # gAd31
   29 0.000000e+00 # gVh
...
```

Run a scan

```
...
#####################################
## INFORMATION FOR MASS
#####################################
Block mass
    1 5.040000e-03 # MD
    2 2.550000e-03 # MU
    3 1.010000e-01 # MS
    4 1.270000e+00 # MC
    5 4.700000e+00 # MB
    6 1.720000e+02 # MT
   15 1.777000e+00 # MTA
   23 9.118760e+01 # MZ
   25 1.250000e+02 # MH
 5000001 scan:range(50,2000,50)  # MY1
 5000511 1.000000e+01 # MXr
 5000512 1.000000e+01 # MXc
 5000521 scan:range(50,700,25)   # MXd
 999000006 7.000000e+01 # sdmm
 999000008 7.000000e+01 # vdmm
## Dependent parameters, given by model restrictions.
...
```

Alternative way to change parameters:

```
> set Mxd scan:range(50,700,25)
> set MY1 scan:range(50,2000,50)
```

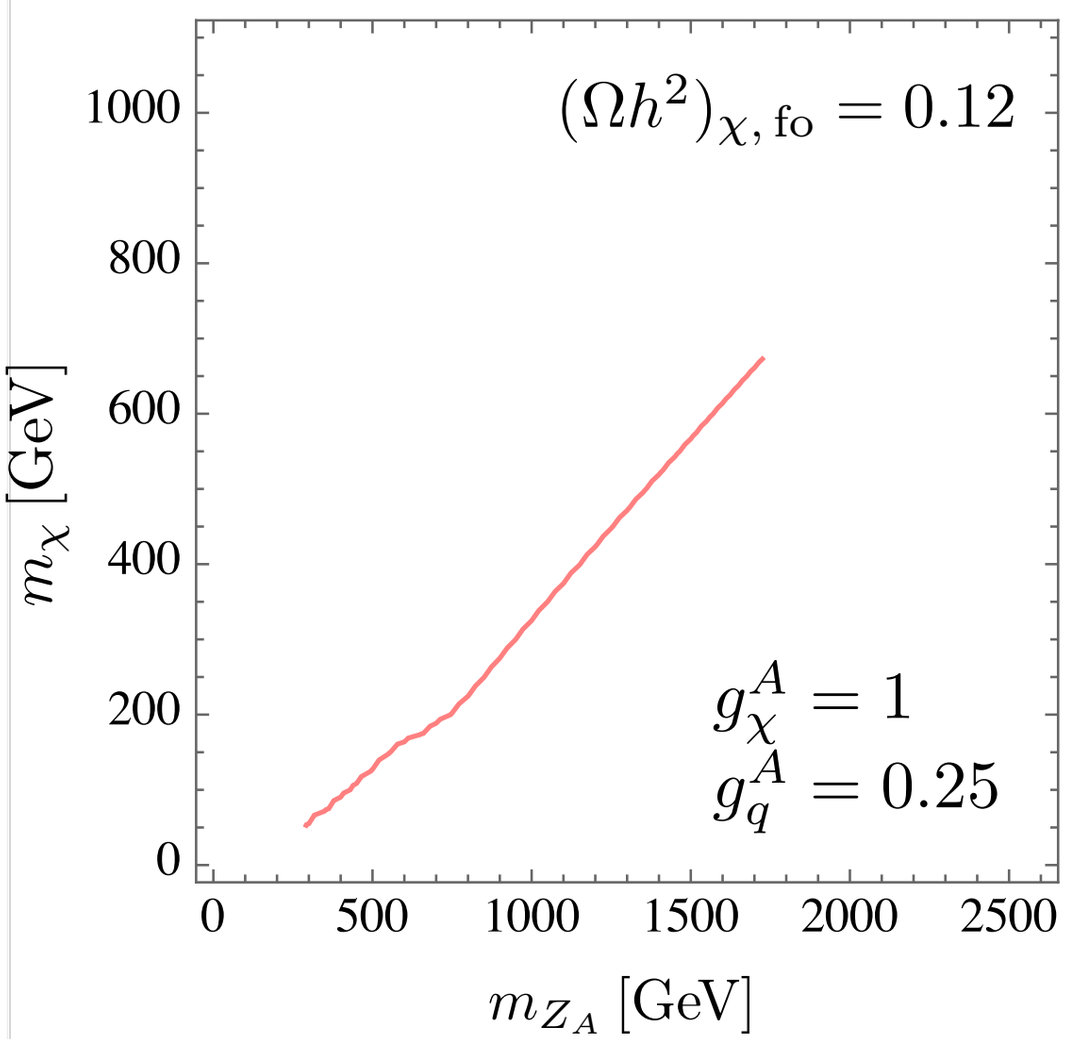
Results of the scan

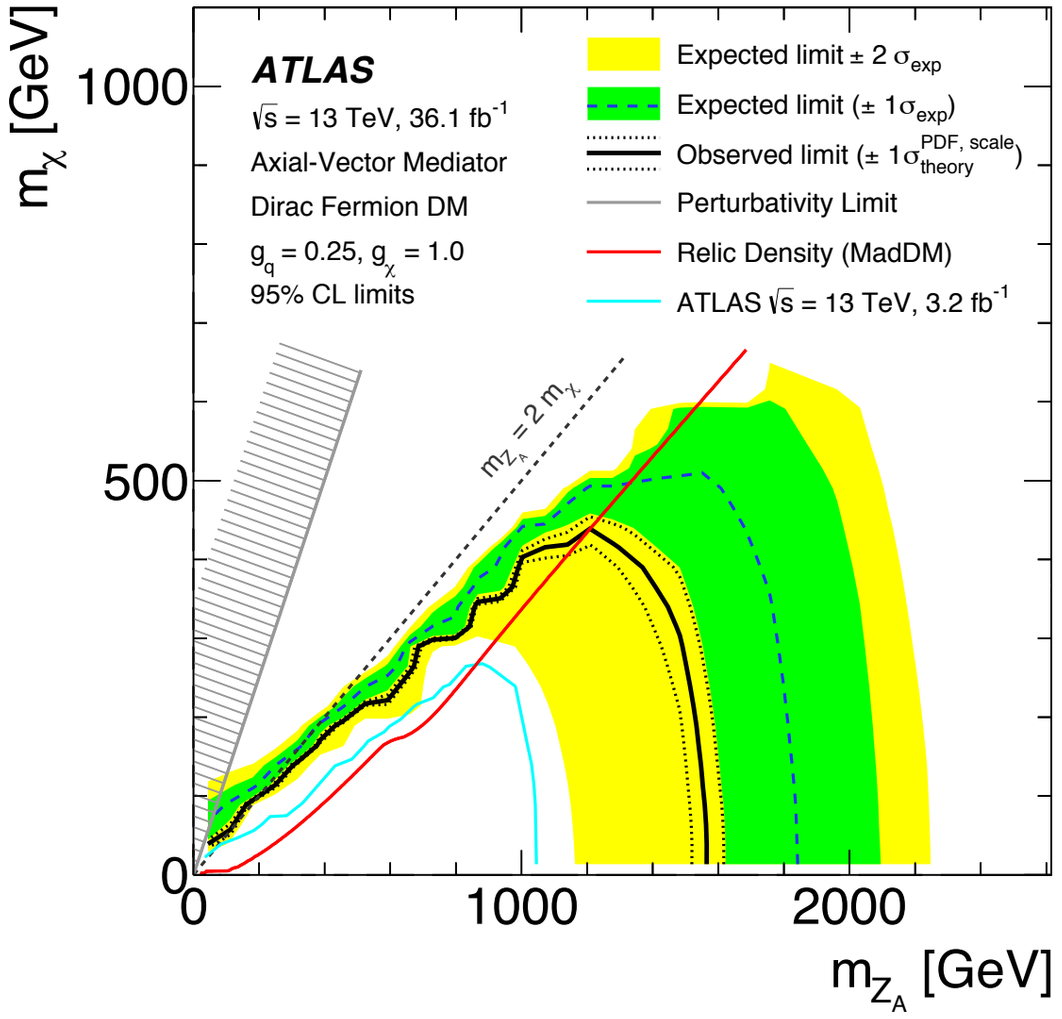
/yourdir/MG5_aMC_v2_6_7/PROC_DMsimp_scan/output/scan_run_01.txt:

```
# [01] : run
# [02] : mass#5000001
# [03] : mass#5000521
# [04] : Omegah^2
# [05] : x_f
# [06] : sigmav(xf)
# [07] : xsi

run_02_01  5.00e+01   5.00e+01   3.75e-04   2.60e+01   7.62e-07   3.13e-03
run_02_02  5.00e+01   7.50e+01   1.08e-04   2.80e+01   1.83e-06   8.99e-04
run_02_03  5.00e+01   1.00e+02   8.91e-05   2.80e+01   2.58e-06   7.44e-04
run_02_04  5.00e+01   1.25e+02   6.92e-05   2.90e+01   3.55e-06   5.78e-04
run_02_05  5.00e+01   1.50e+02   5.31e-05   2.90e+01   4.92e-06   4.43e-04
run_02_06  5.00e+01   1.75e+02   1.27e-05   3.10e+01   1.50e-05   1.06e-04
run_02_07  5.00e+01   2.00e+02   6.57e-06   3.10e+01   2.54e-05   5.48e-05
run_02_08  5.00e+01   2.25e+02   5.31e-06   3.20e+01   3.11e-05   4.43e-05
run_02_09  5.00e+01   2.50e+02   4.68e-06   3.20e+01   3.58e-05   3.91e-05
run_02_10  5.00e+01   2.75e+02   4.28e-06   3.20e+01   3.99e-05   3.57e-05
...
```

Results of the scan

Contour plot:





Questions?

	‘fast’ mode `set fast` ONLY for SM final states ($2 \to 2$)	‘precise’ mode `set precise` ALL possible final states ($2 \to n$)
$\langle\sigma v\rangle$ `Indirect = sigmav`	`sigmav_method = inclusive` NO EVENTS generated output: $\langle\sigma v\rangle$ for each $2 \to 2$ annihilation process (SM and BSM)	`sigmav_method = reshuffling` (default) or can be changed to `sigmav_method = madevent` EVENTS generated (LHE file) $\langle\sigma v\rangle$ for ANY annihilation process

Spectra at source
`Indirect = flux_source`
	`indirect_flux_source_`
	`method = PPPC4DMID_ew` (default)
	or can be changed into
	`indirect_flux_source_`
	`method = PPPC4DMID`
	
	computes $\langle\sigma v\rangle$ with `inclusive`
	
	output: energy spectra
	coming ONLY from SM final states
		`indirect_flux_source_`
		`method = pythia8` (default)
		
		computes $\langle\sigma v\rangle$ with `reshuffling`
		
		output: energy spectra
		coming from ANY final state

Flux at Earth `Indirect = flux_earth`	`indirect_flux_earth_` `method = PPPC4DMID_ep` (default) computes $\langle\sigma v\rangle$ with `inclusive` output: γ and ν_i using `PPPC4DMID` tables at production (ew case) e^+ flux at Earth using `PPPC4DMID` tables or can be changed into e^+ and $\bar{p}$ fluxes at Earth using `DRAGON`	`indirect_flux_earth_` `method = dragon` (default) computes $\langle\sigma v\rangle$ with `reshuffling` output: γ and ν_i using `Pythia 8` for the prompt energy spectra e^+ and $\bar{p}$ fluxes at Earth using `DRAGON`
Experimental constraints	`ExpConstraints` class + full Fermi-LAT likelihood for dSphs ONLY for SM final states	`ExpConstraints` class + full Fermi-LAT likelihood for dSphs