g-𝓛ike : LIKELIHOOD MAXIMISATION AND PROFILING FOR ASTROPHYSICAL (AND BEYOND) APPLICATIONS
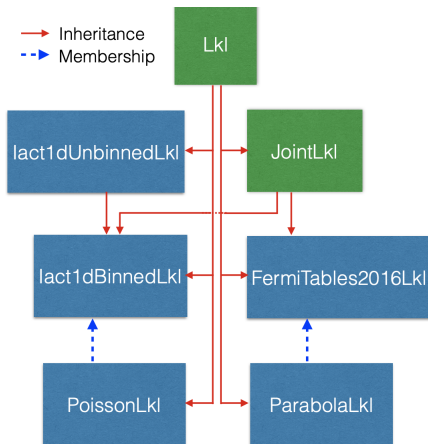
Workshop on Open-Source Software Lifecycles

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What is gLike?

> framework for numerical maximisation of joint (multi-instrument) likelihood functions;

> $\mathcal{L}$: **one free parameter** (g), **as many nuisance parameters as wanted**, profiled over in the maximization process;

> hosted on `GitHub`;

> dependency: `ROOT`;

> bibliography highlights:
> → *Fermi*-LAT + MAGIC combined DM searches in dSphs,
> → `gloryduck` project.

→ structure

`Lkl`: minimises $-2\log\mathcal{L}$ vs g

`JointLkl`: Combine `Lkl` objects into a joint likelihood remaining classes implement a particular $\mathcal{L}$ function
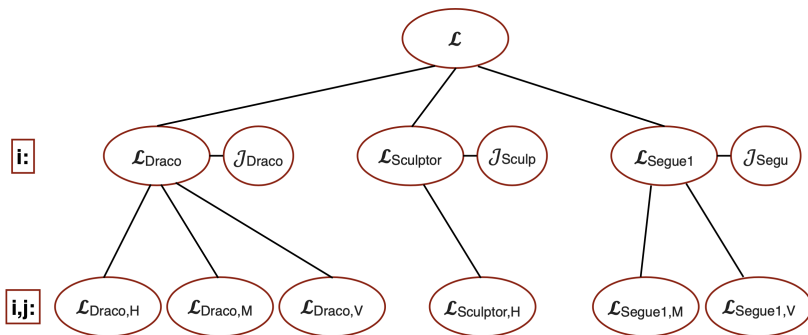
Example: Simple Poisson Likelihood

> **problem**: estimate number of signal events **g** in a dataset with N_{ON} counts from a signal region, N_{OFF} counts from a background control region;

> **minimise**: $\mathcal{L}(g; b, \tau | N_{\mathrm{ON}}, N_{\mathrm{OFF}}) = \frac{(g+b)^{N_{\mathrm{ON}}} e^{-(g+b)}}{N_{\mathrm{ON}}!} \frac{(\tau b)^{N_{\mathrm{OFF}}} e^{-(\tau b)}}{N_{\mathrm{OFF}}!}$,

$\rightarrow \tau$: expsoure ratio background to signal regions (fixed parameter),
$\rightarrow b$: estimated number of background events (nuisance parameter);

> gLike classes can be called from the ROOT terminal:

```
root [0] Int_t Non=130, Noff=90;
root [1] Double_t tau=1;
root [2] PoissonLkl* lkl = new PoissonLkl(Non, Noff, tau);
root [3] lkl->SetErrorDef(4); // 2 sigma error: -2logL falls by 4
root [4] lkl->ComputeLklVsG();

Lkl::ComputeLklVsG (PoissonLkl) Message: Finding minimum of -2logL...
Lkl::MinimizeLkl (PoissonLkl) Message: minimizing -2logL
Lkl::CallMinimization (PoissonLkl) Results: Trial #1,
g: 4.00e+01 +/- 2.97e+01 (4.00e+01 +/- 2.97e+01); b: 9.00e+01 +/- 1.90e+01;
tau: 1.00e+00 +/- 0.00e+00; eff: 1.00e+00 +/- 0.00e+00;
-2logL = 13.0462; iflag = 0 (converged)

Lkl::ComputeLklVsG (PoissonLkl) Message: computing -2logL in 200 points between
g=-1.93973(-1.93973), and g=81.9447(81.9447), this could take a while
.................... Completed 200 points
Lkl::ComputeLklVsG (PoissonLkl) Message:
g_min = 39.7917 +/- 30.242 (39.7917 +/- 30.242), -2logLmin = 13.0464
```
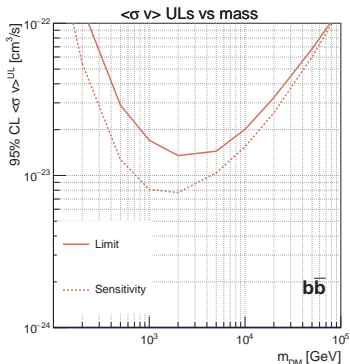
Application: Dark Matter Seraches

> gLike can create complex likelihood functions from simpler likelihood terms;
> nuisance parameters can selectively affect in the same way an arbitrary number of these terms.

Application: Dark Matter Searches

- > **problem**: estimate UL on $\langle \sigma v \rangle$ for annihilating DM using different IACT observations;
- > **minimise**: a joint Poisson $\mathcal{L}$ (a term per each dataset);
- > run `jointLklDM` executable;

- > `jointLklDM` configurable via input card:

```
################
I/O CONFIGURATION
################

# Directory with dN/dE files
jointLklDM.dNdEDir: DM/dNdE/Cirelli

# Directory for output plots
jointLklDM.plotsDir: plots

#####################
ANALYSIS CONFIGURATION
#####################

# channel to be analyzed (bb, cc, tt, tautau, mumu, WW, ZZ, hh, gammagamma, ...)
# linear combination in the form: 'br_1*channel_1+...+br_n*channel_n'!
jointLklDM.Channel: bb

# Process to be analyzed ("ann" or "dec" for annihilation and decay, respectively)
# (remember to change consistently the list of masses and J-factors)
jointLklDM.Process: ann

# list of DM masses to be considered (in GeV)
jointLklDM.MassList: 100 200 500 1000 2000 5000 10000 20000 50000 100000

# Delta(-2logLkl) for limits (2.71 = 95% CL, 4.495 = 5sigma)
jointLklDM.deltaLogLkl: 2.71

#############################
JOINT LIKELIHOOD CONFIGURATION
#############################
#     jointLklDM.lklTerm<XXX>: <termType> <parentTerm> [<options>]
jointLklDM.lklTerm000: JointLkl -    DlogJ=0
jointLklDM.lklTerm001: Iact1dUnbinnedLkl  0    logJ=19.  DlogJ=0  inputfile=...
jointLklDM.lklTerm002: Iact1dBinnedLkl    0    logJ=19.  DlogJ=0  inputfile=...
```

Prospects

> gLike will be **included in the OSSR collection**;

> **interoperability with other ESCAPE softwares**: unbinned $\mathcal{L}$ for IACT osbervations can read FITS data reduced with gammapy;

> gLike can now simultaneously work with ROOT and FITS data;

> encourage new developers to include classes handling other instruments datasets;

> gLike can be a valuable tool in the **ESCAPE DM test science project**.