Overview of ThreeML

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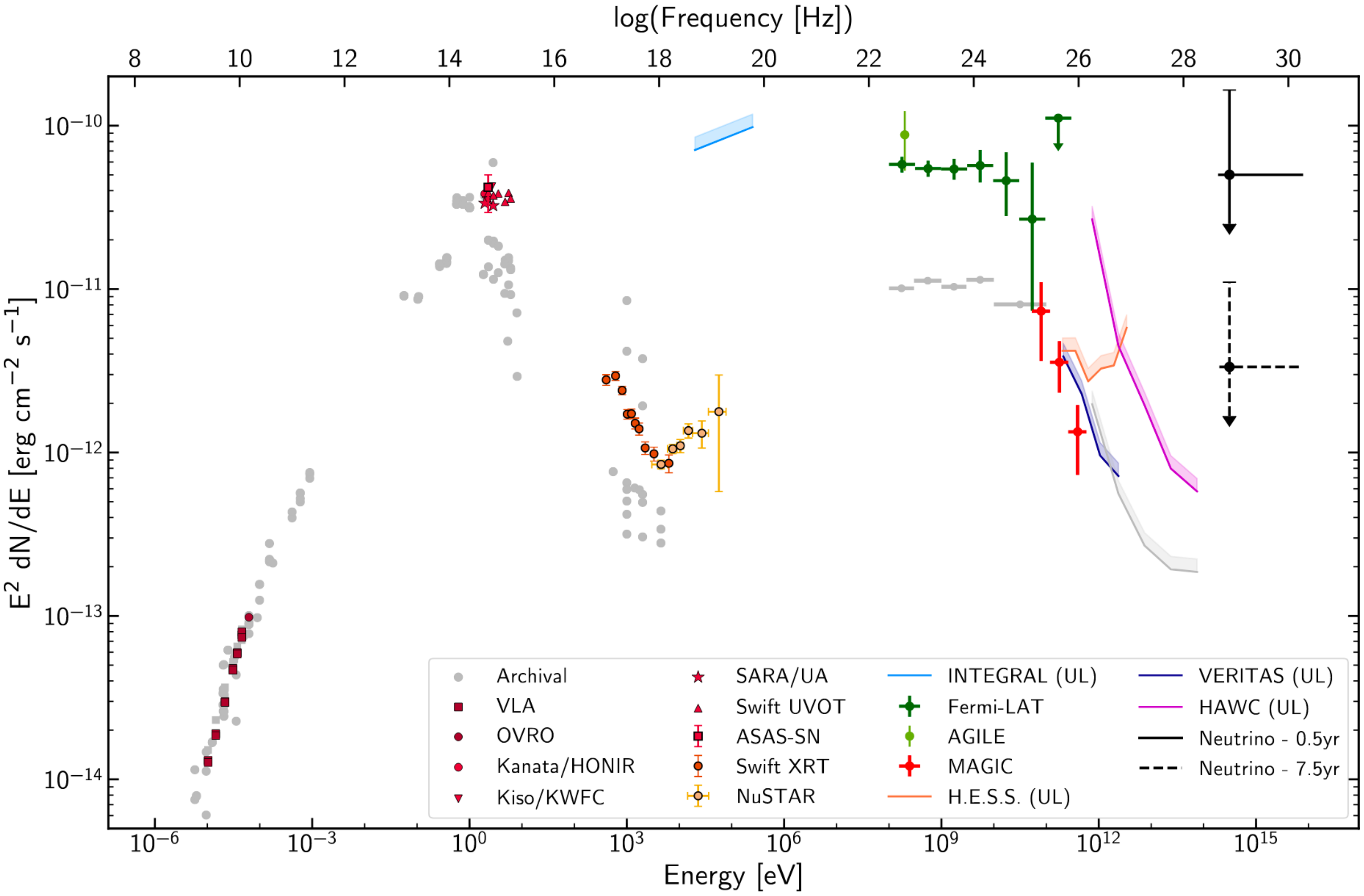
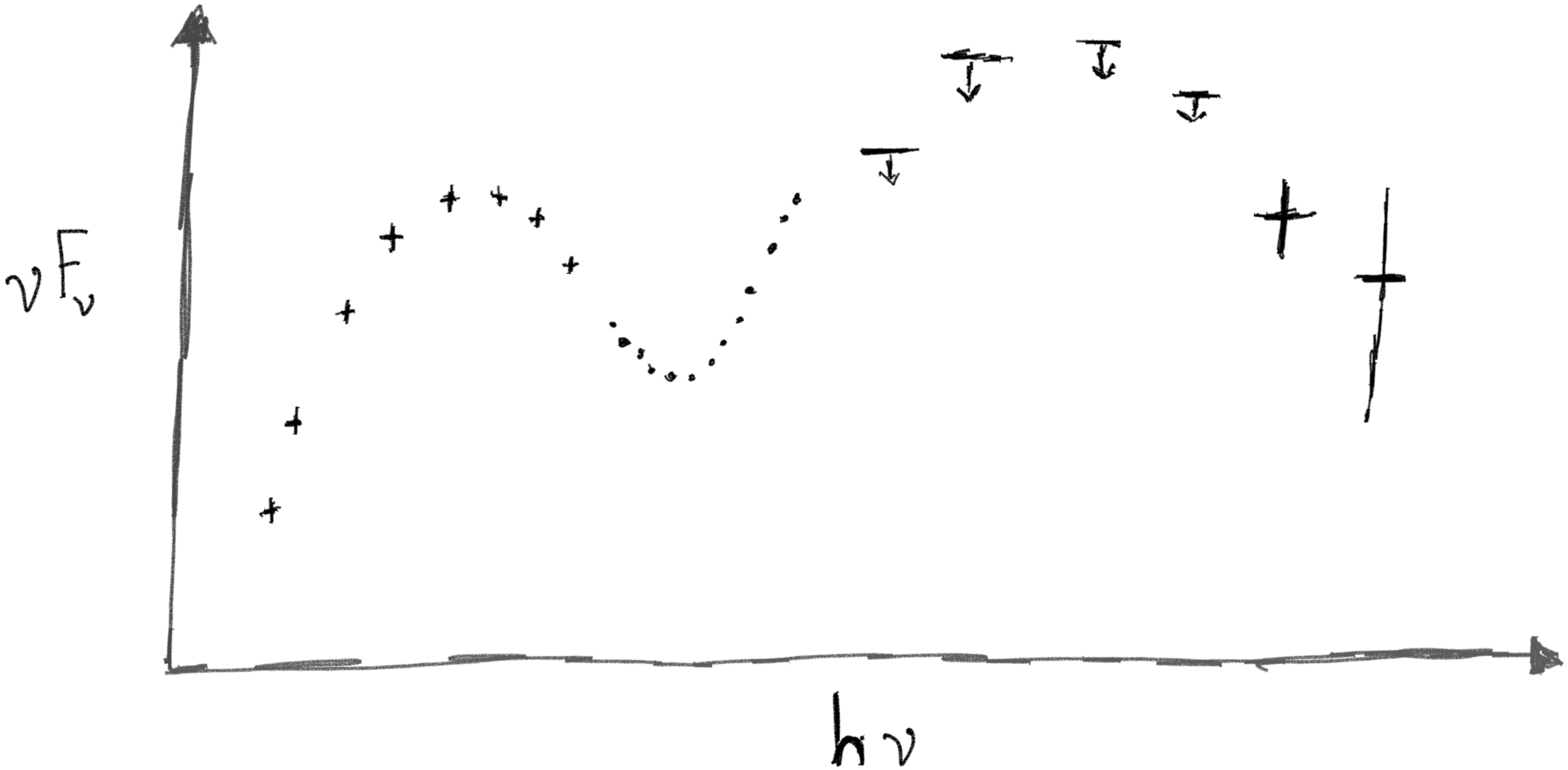
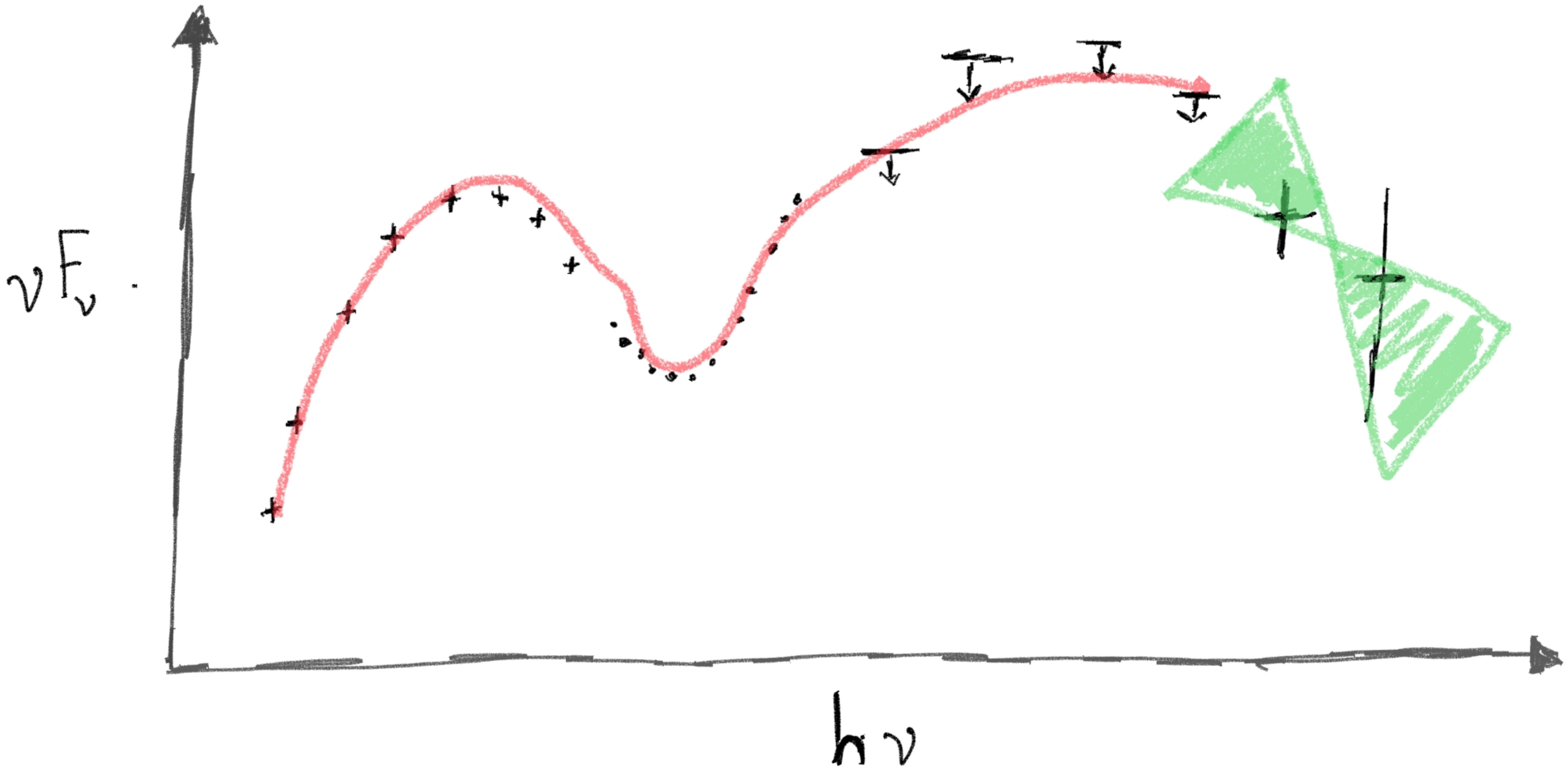
Multi-wavelength Astronomy



Multi-wavelength Astronomy



Multi-wavelength Astronomy



Unfolding vs Forward-folding

Two approaches to compare/fit models to measured data:

👎 **Unfold data**, fit to high-level data (e.g. differential flux measurements)

- Unfolding makes (implicit) assumptions on spectrum, source size/shape etc. (not always consistent).
- Weak sources: deal with upper limits, non-gaussian uncertainties etc.
- Combining information from instruments with different angular/energy resolution can be challenging.

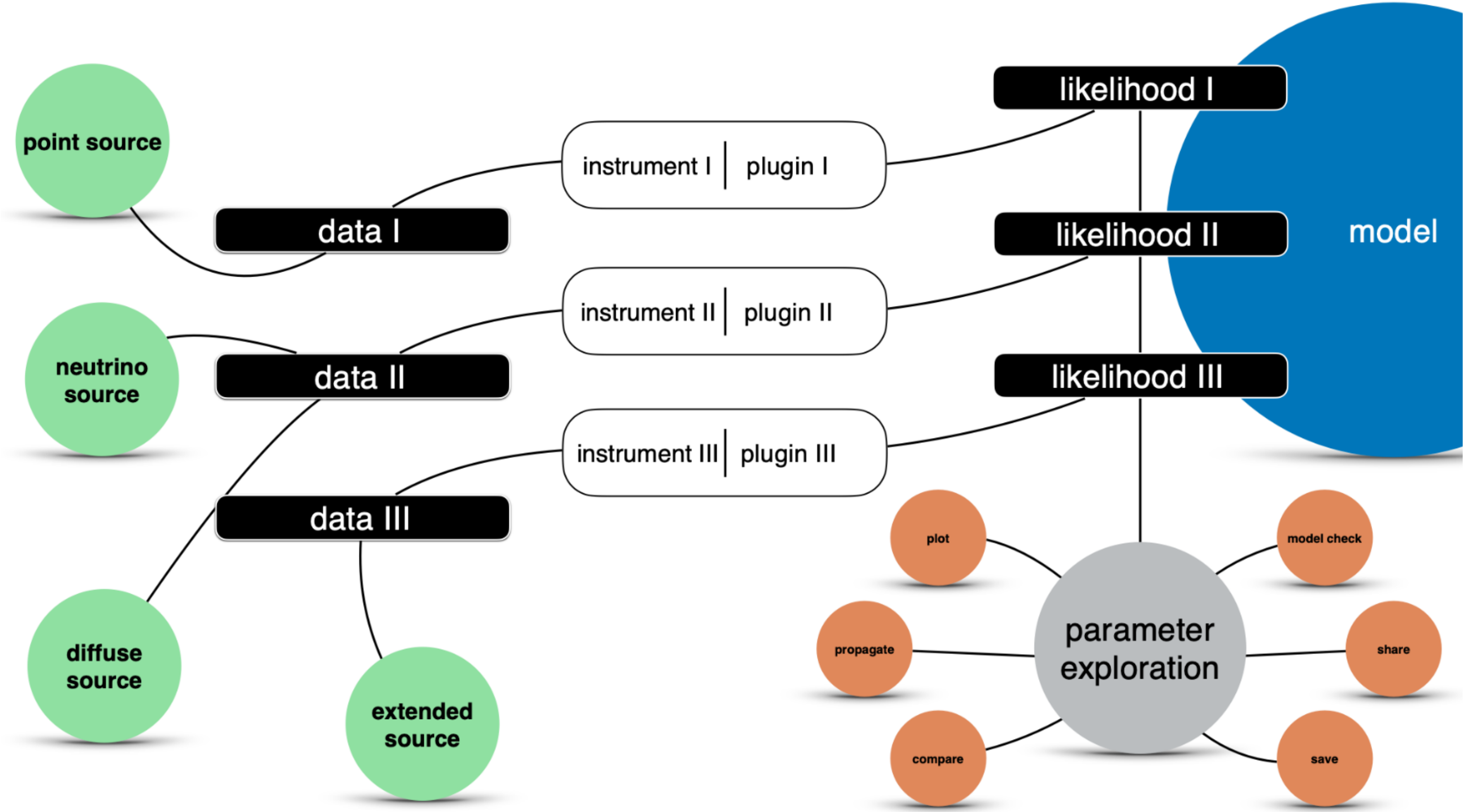
👍 **Forward-fold model**, fit to low-level data (e.g. photon counts)

- Model assumptions are made explicit.
- Need to deal with different formats for data/instrument response.

ThreeML

- Multi-Mission Maximum Likelihood framework (ThreeML):
  - Provides a common, robust high-level interface for **multi-wavelength, multi-instrument likelihood analysis** of astronomical data
  - Allows for an easy, coherent and flexible modeling of sources with *astromodels*
- Architecture based on plug-ins:
  - 3ML uses under the hood the **official software** of each instrument maintained by the collaborations
- Github webpages:
  - https://github.com/threeML/threeML
  - https://github.com/threeML/astromodels
- Documentation:
  - https://threeml.readthedocs.io/en/stable/
  - https://astromodels.readthedocs.io/en/latest/

ThreeML Working Principle



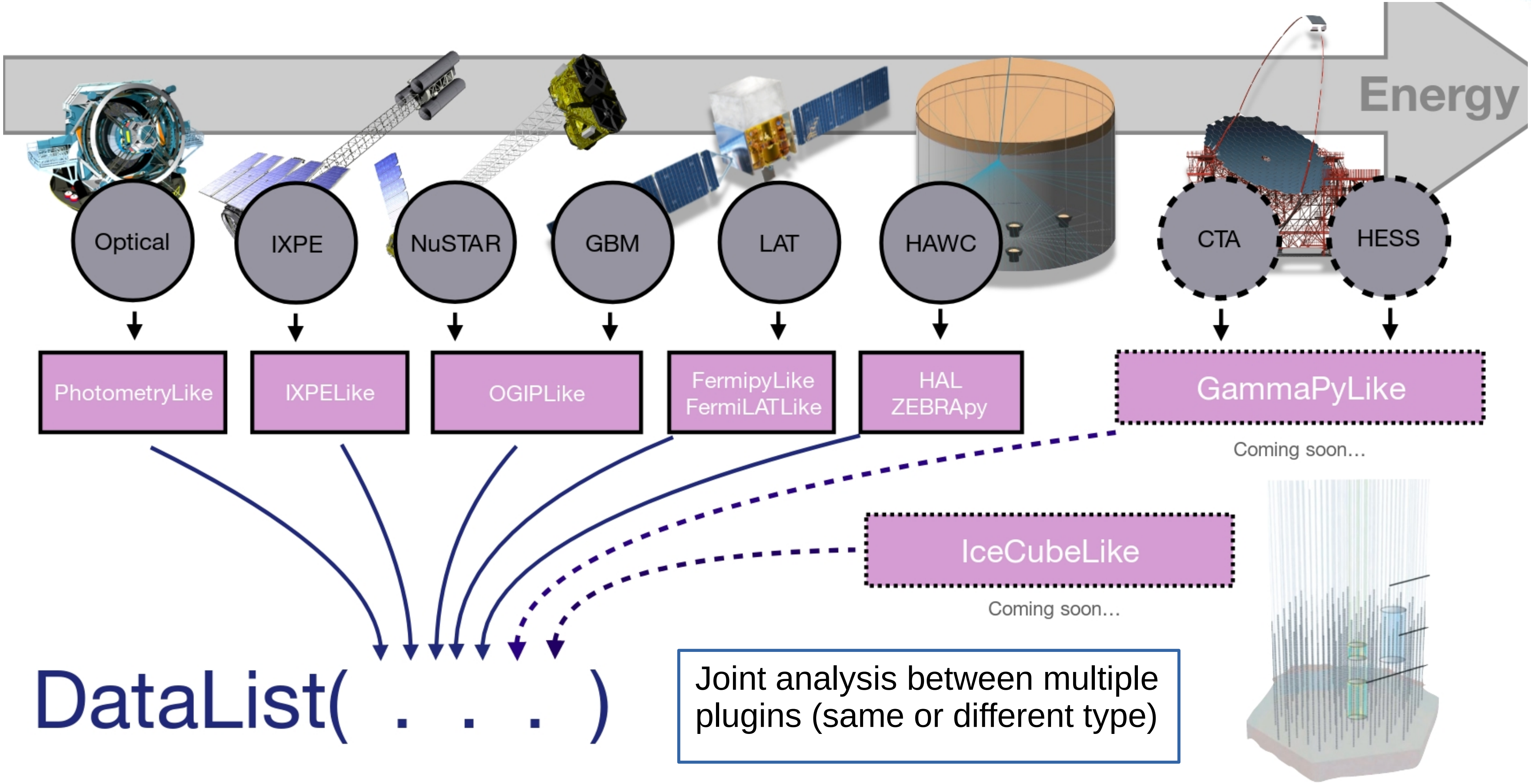
Modeling with astromodels

- A model can contain one or more sources:
  - Can have a spatial morphology (point source/extended), one or more spectral components, with optional polarization. Energy-dependent shape also supported.
- Several spectral models already implemented and supported:
  - Phenomenological models: Powerlaw, log-parabola, broken or cutoff powerlaws, …
  - Physical models: Blackbody, photometric absorption, DM spectra, EBL absorption, …
  - **Access to all XSPEC models** (if *XSPEC* or *xspecmodelsonly* installed)
- Flexible framework:
  - Users can define their own functions at run time, or read in tabulated spectra/fits maps, and **easily combine** (add, multiply, etc) existing functions (e.g. absorption terms)
  - Models and their constituents can be saved to/read from disk in *yml* format
  - **Model parameters** can be time-dependent and may be **linked via arbitrary functions**
  - **Physical units fully supported** and handled to not slow down the computation
- Can generate models from external catalogs (Fermi-LAT 4FGL or GBM catalogs)

The Plugins

- Currently supported:
  - Fermi-LAT (*fermipy*, *gtburts*), all OGIP-compliant instruments (Fermi-GBM, Swift XRT, NuSTAR), HAWC, POLAR, general photometric data
- In the works:
  - INTEGRAL/SPI, KONUS, IXPE, ZEBRApy, gammapy, IceCube, cosipy
- Can be wrappers for external software (*fermipy*) or standalone (*HAL*)
- Interface with instruments able to:
  - Read in data / instrument response files in **“native” format**
  - Convolve model with detector response and calculate model predictions
  - **Calculate the likelihood** taking care of internal “nuisance parameters”
  - Produce (pseudo-) random simulated datasets given a model to assess the goodness of fit.
  - Optional convenience functions for data visualization and download

The Plugins

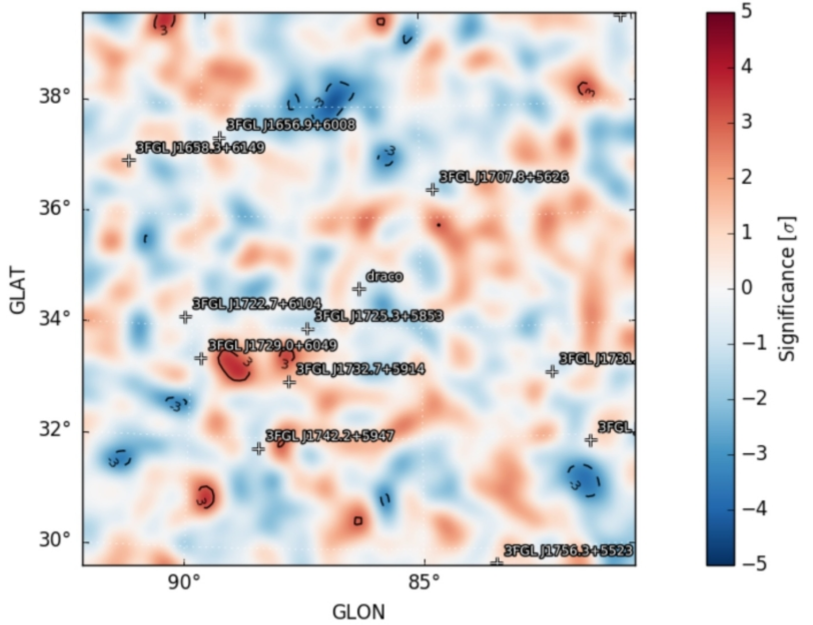


Joint analysis between multiple plugins (same or different type)

Fermi-LAT Plugins

- **FermipyLike:**
  - Wrapper for *fermipy/fermitools*
  - Imaging and spectral analyses (binned)
  - Released version currently supports point sources with arbitrary spectral models
  - Limited subset of extended source morphologies (symmetric gaussian, disk, user-supplied template)
  - Can download LAT data files
- **FermiLATLike:**
  - Optimized for short transient analysis (GRBs and solar flares)
  - Unbinned likelihood analysis (based on *gtburst*)
  - Can download LAT data files
  - It also has a TransientLATDataBuilder method

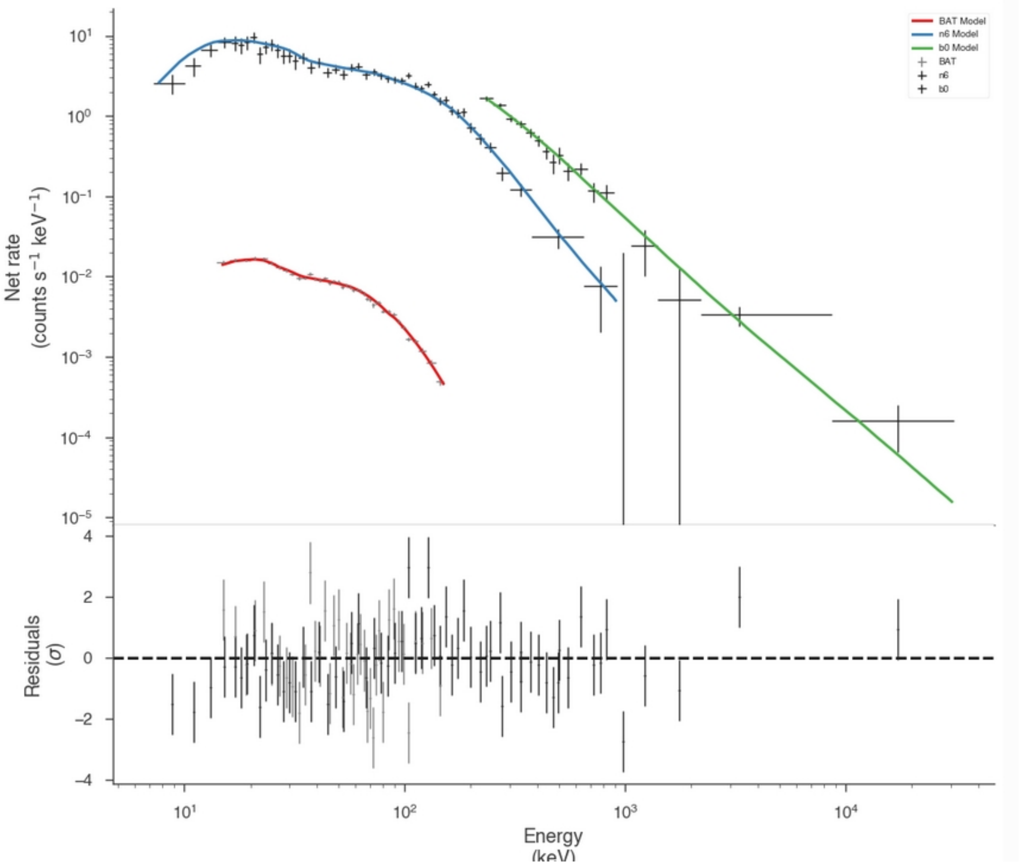
FermipyLike example



FermiLATLike example

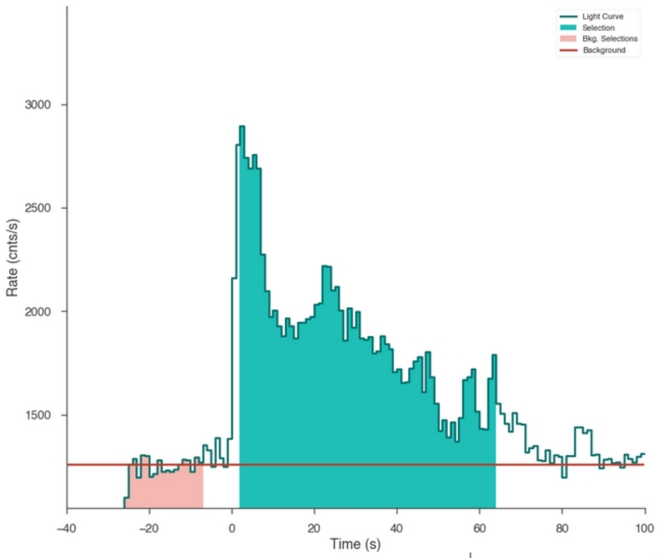
OGIPLike Plugin

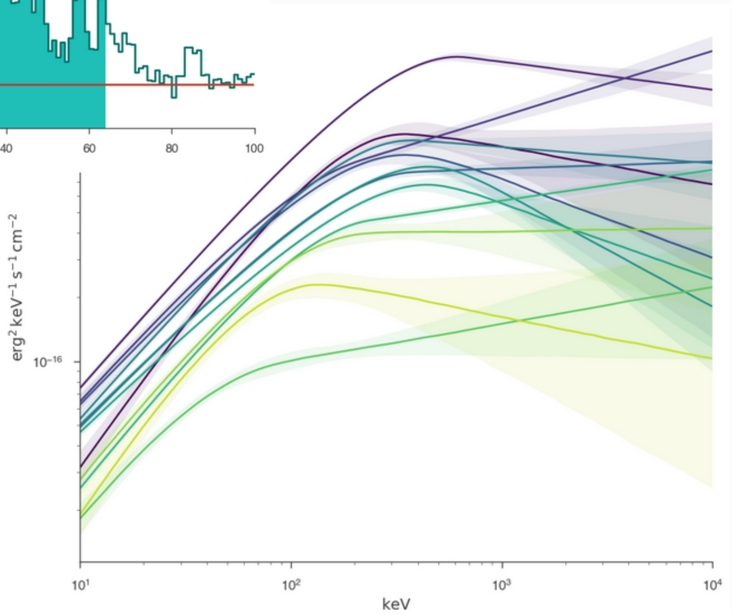
- Supports data and instrument response files following the OGIP standard
  - **Everything that can be fit in XSPEC can be done in 3ML!**
- Spectral analysis only
- Uses appropriate likelihood for each instrument:
  - PGStat (GBM) / Cstat (XRT) / Chi2 (BAT)
- Optional correction factor for effective area as a nuisance parameter to account for systematic offsets.
- Recently extended to support polarimetric data from IXPE:
  - Spectro-polarimetric fitting



GBM/LLE Data Reduction

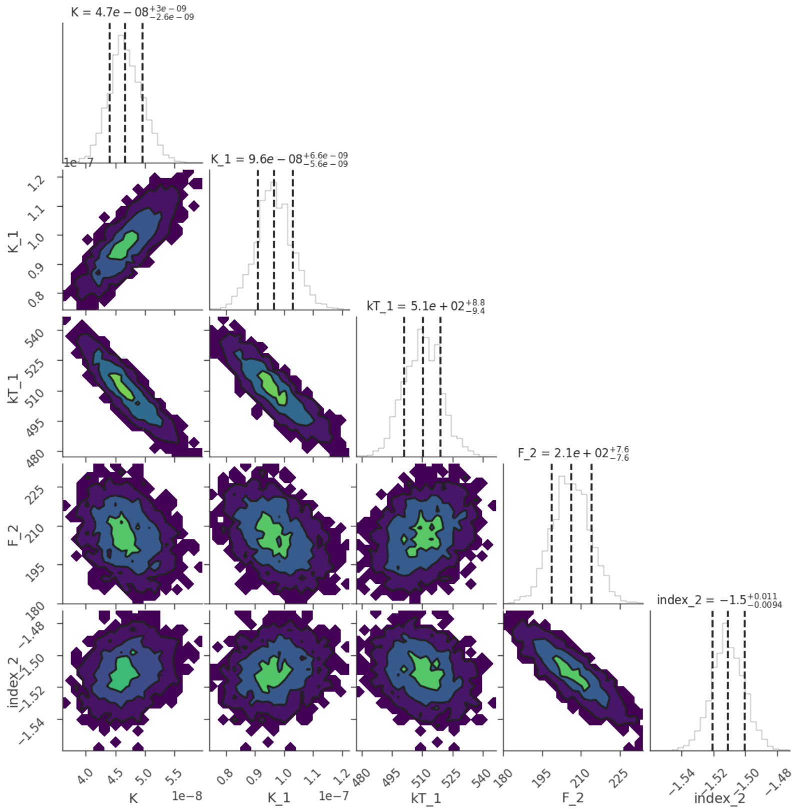
- TimeSeriesBuilder class can be used to set background and source intervals and fit the background rate of GBM observations.
- Source and background selections can be imported from GBM catalog.
- Includes visualization options
- Both time-integrated and time-resolved analyses possible.





Minimizers and Samplers

- Easy to switch between maximum likelihood estimation and Bayesian posterior sampling:
  - Just a few lines of code!
- Supported likelihood minimizers:
  - Local: Minuit2 (via ROOT or iminuit), scipy
  - Global: Pagmo, multinest, grid minimizer
- Supported Bayesian samplers:
  - emcee, multinest, dynesty, ultranest, zeus
- Convenience functions to produce corner plots or likelihood profiles



Conclusions

- 3ML provides a robust and flexible framework for multi-wavelength, multi-instrument likelihood analysis of astronomical data:
  - It is “publication-ready” and being used for analysis of data from Fermi-LAT, Fermi-GBM, Swift-BAT, POLAR, HAWC and others
- Active development is ongoing, more plugins are in the works:
  - Latest stable version **v2.4.2** released a few days ago
- Would you like to start using ThreeML and astromodels? That’s great!
  - Packages available on conda and PyPI
  - See the documentation for installation instructions and tutorials
- Are you already using ThreeML? Become a developer!
  - Found a bug or had an idea to improve the code? Open an issue on the github page or implement your code and open a pull request to merge it!